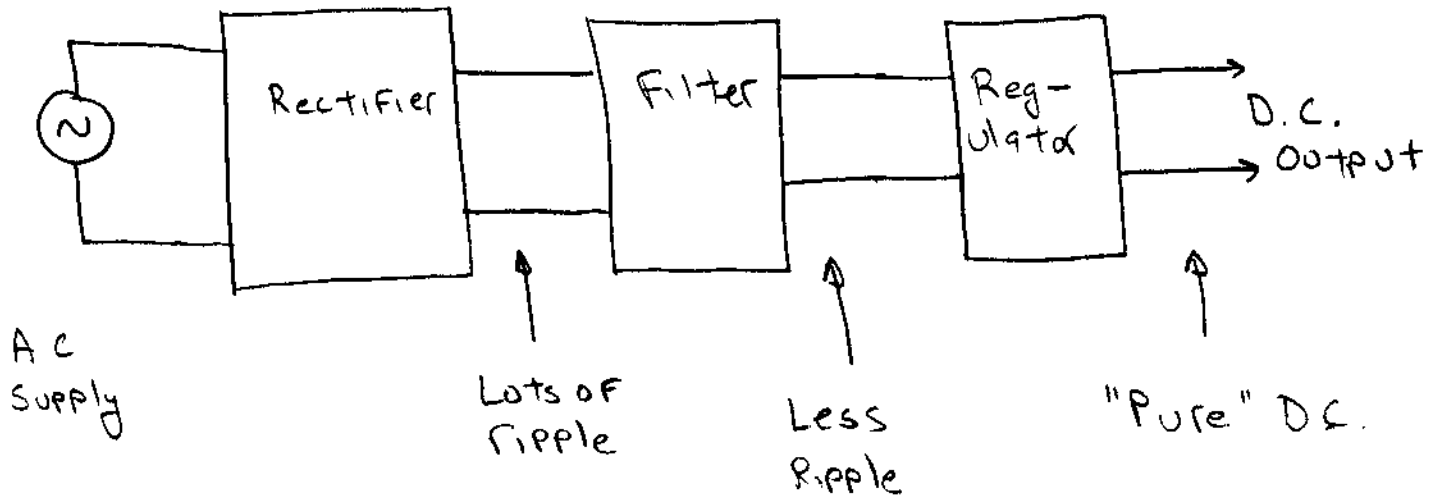
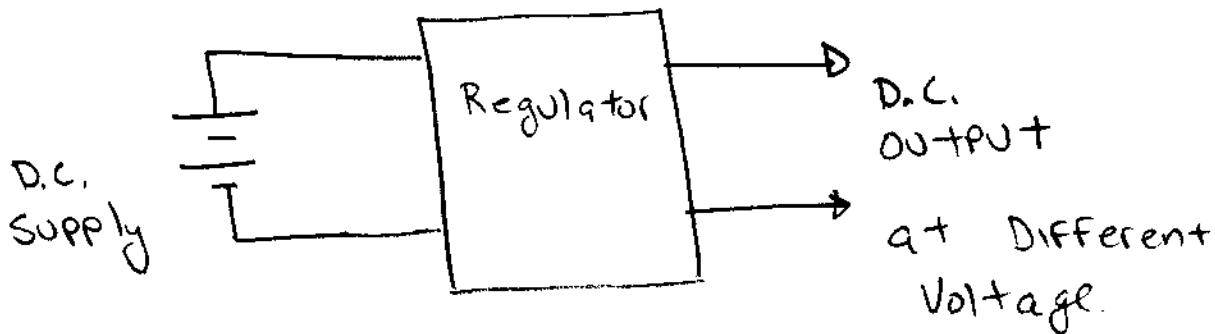


D.C. Power Supply design

AC - DC power supply



DC - DC converter



Regulators:

Linear - Simple but inefficient,
Lower output voltage only

Switching - more complicated,
more efficient, (up to 95%)
more Flexible: Higher output,
Lower output, opposite polarity
out: i.e. $V_{in} = 12V$, $V_o = 5$,
 $V_o = 15$, $V_o = -5$.

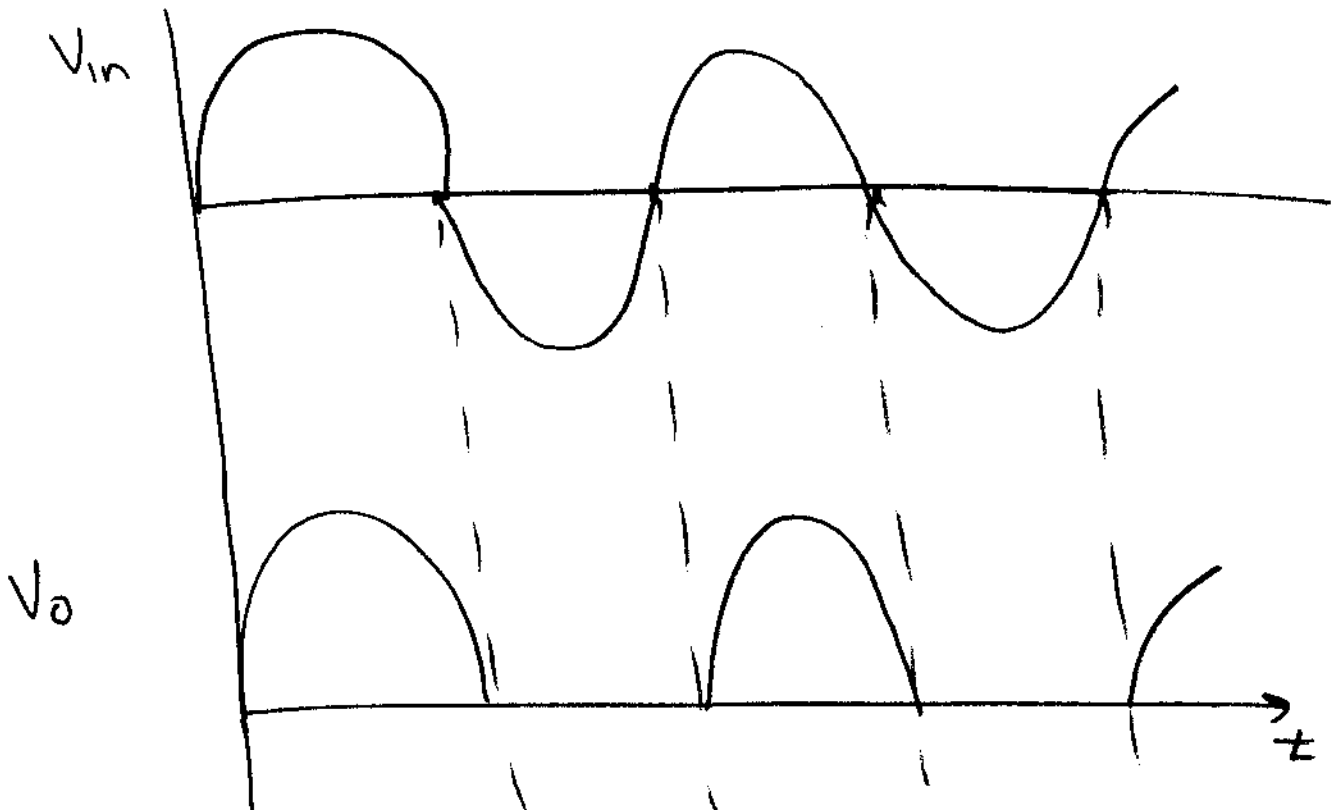
- For DC-DC regulators, input is "pure" DC, output is pure D.C. \Rightarrow Regulator is used to transform the voltage level.

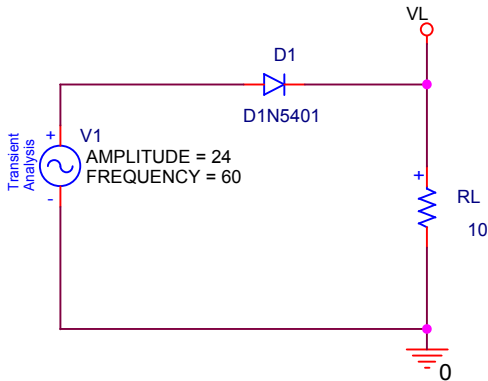
- For AC-DC supply, Regulator is used to take a D.C. voltage with a lot of ripple & provide a "pure" DC output. \Rightarrow used to transform voltage as well as smooth out ripple

Rectifiers

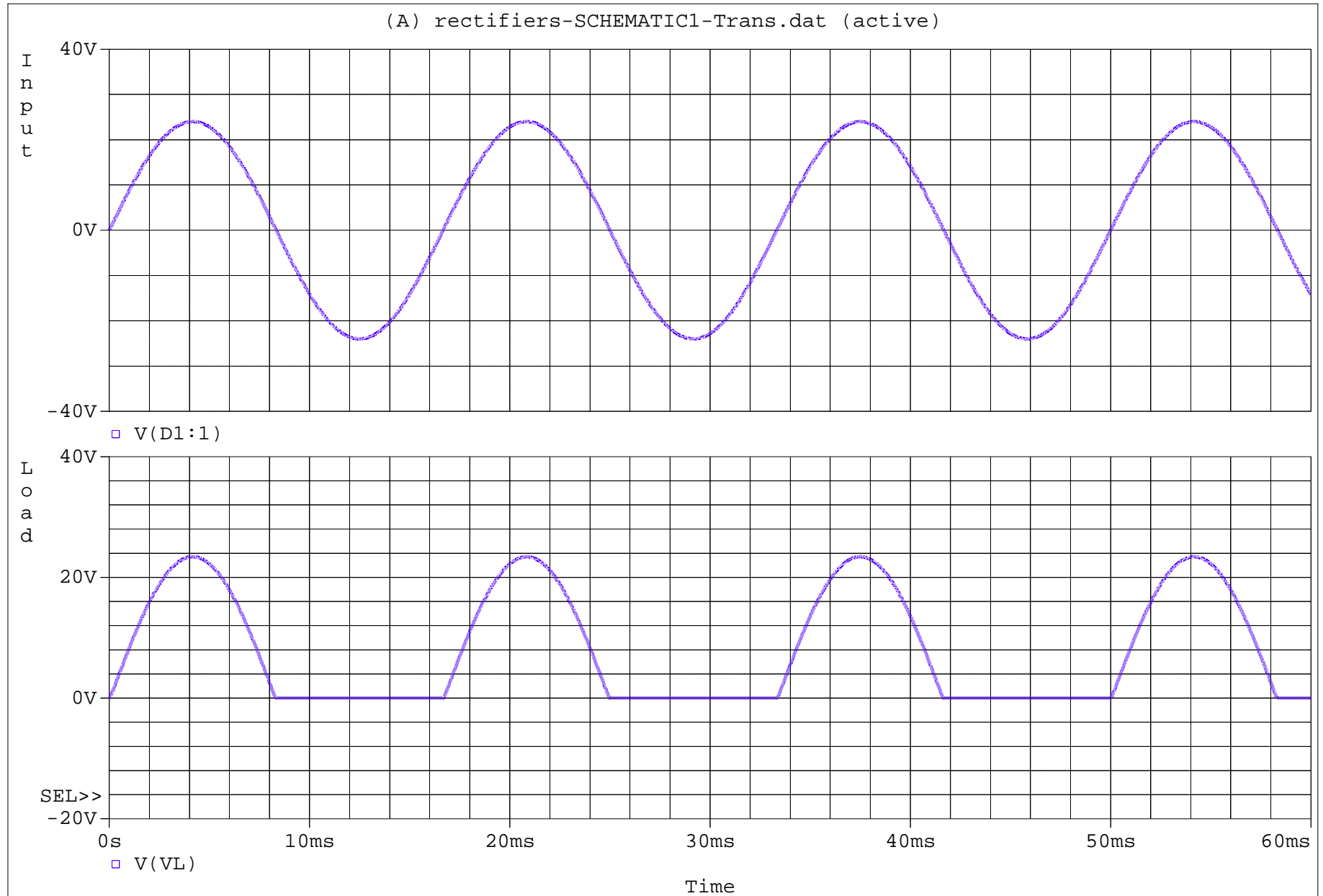
Provide AC to DC conversion.

Half wave Rectifier:





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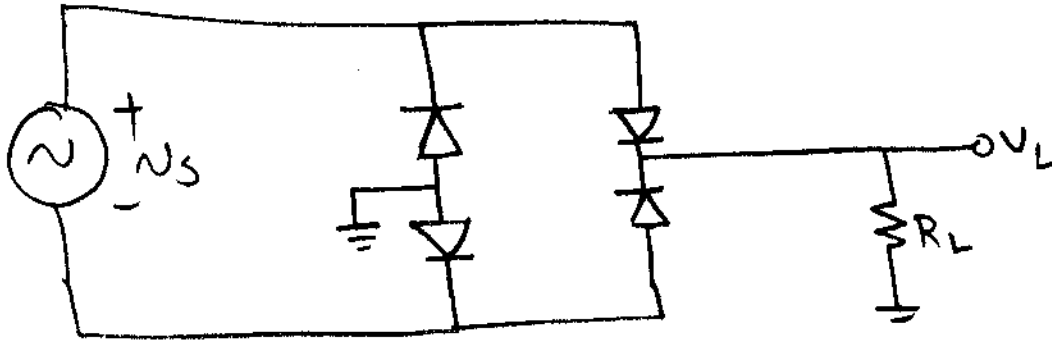


Date: December 12, 2002

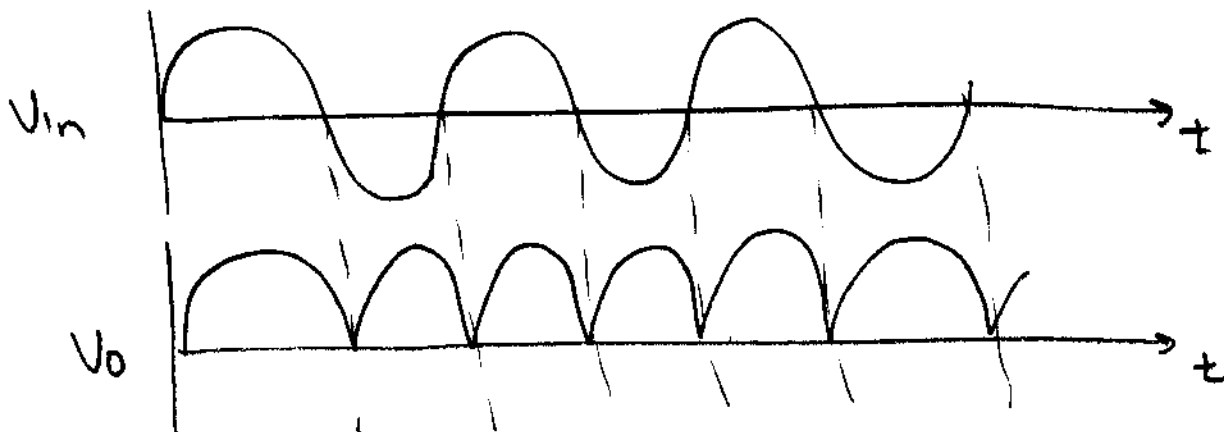
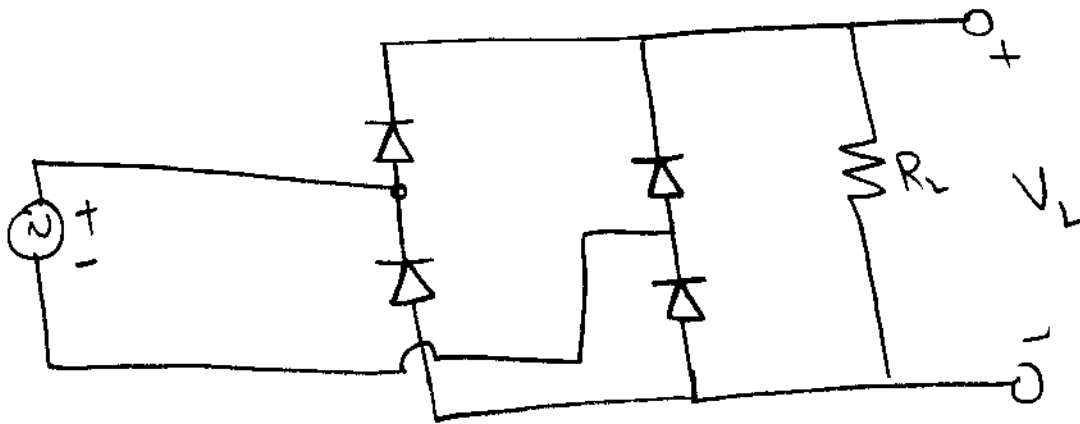
Page 1

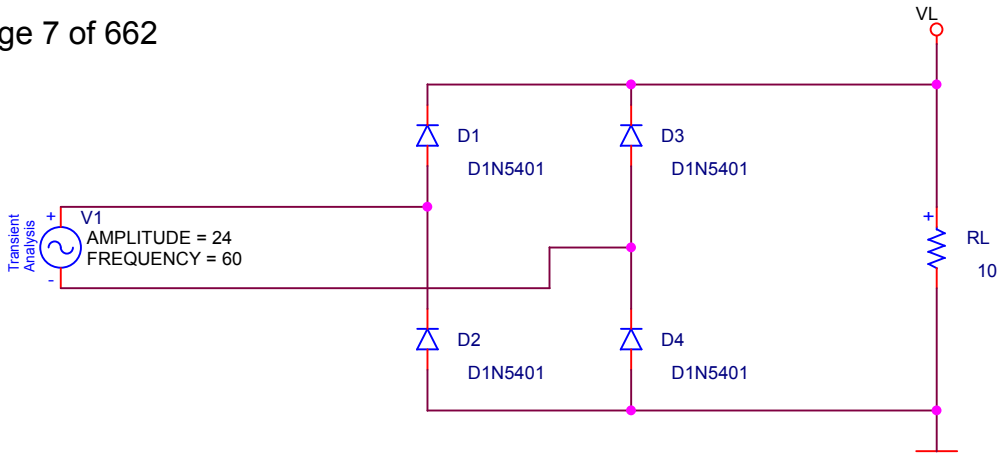
Time: 10:55:24

Full-Wave OR Bridge Rectifier

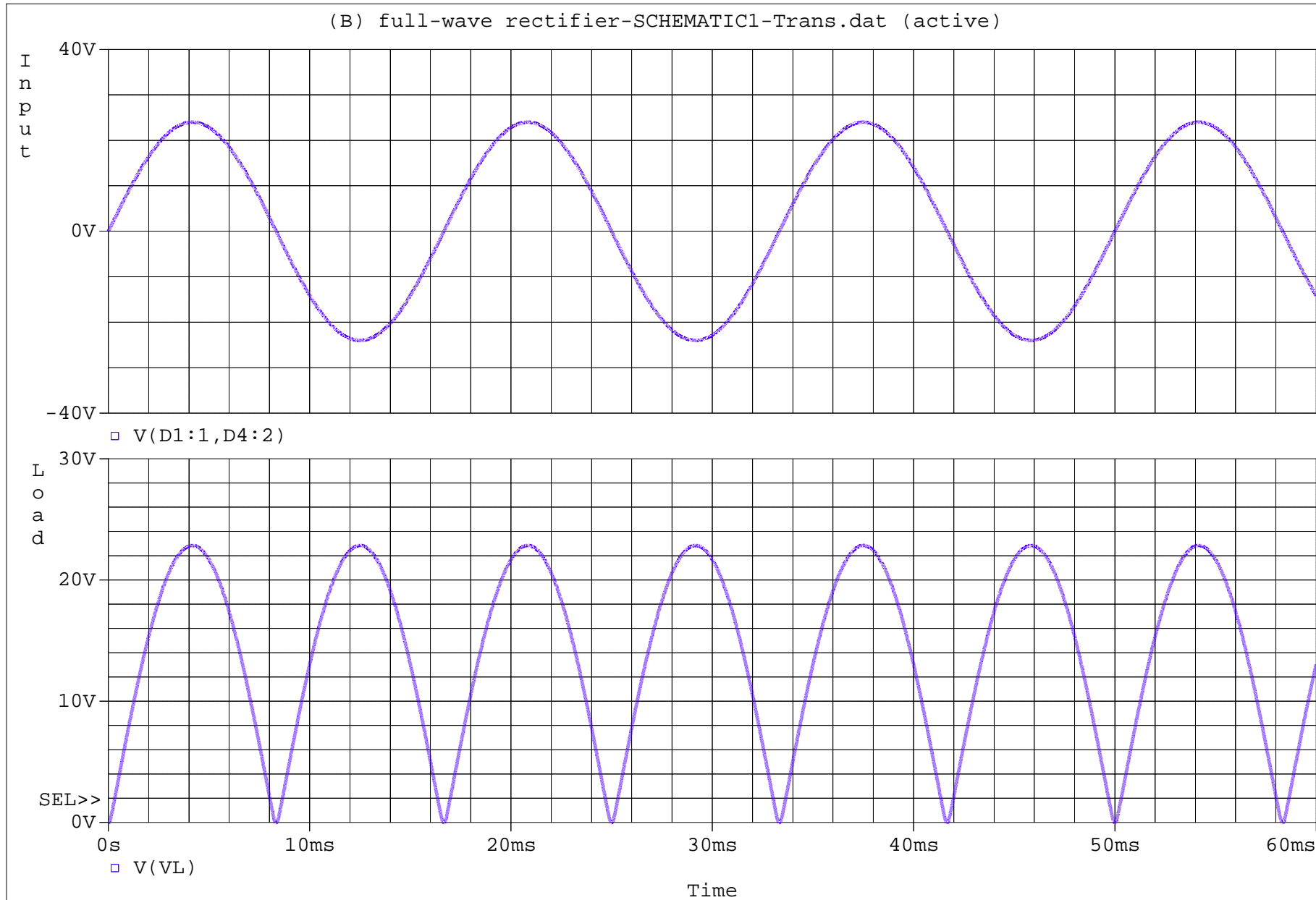


alternate Drawing

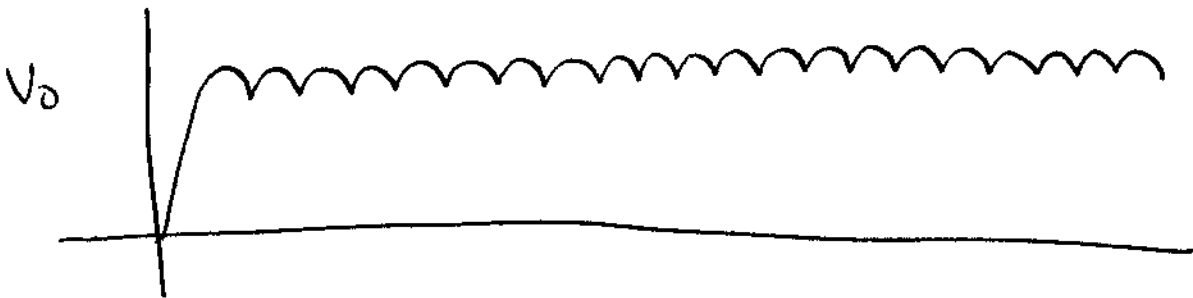
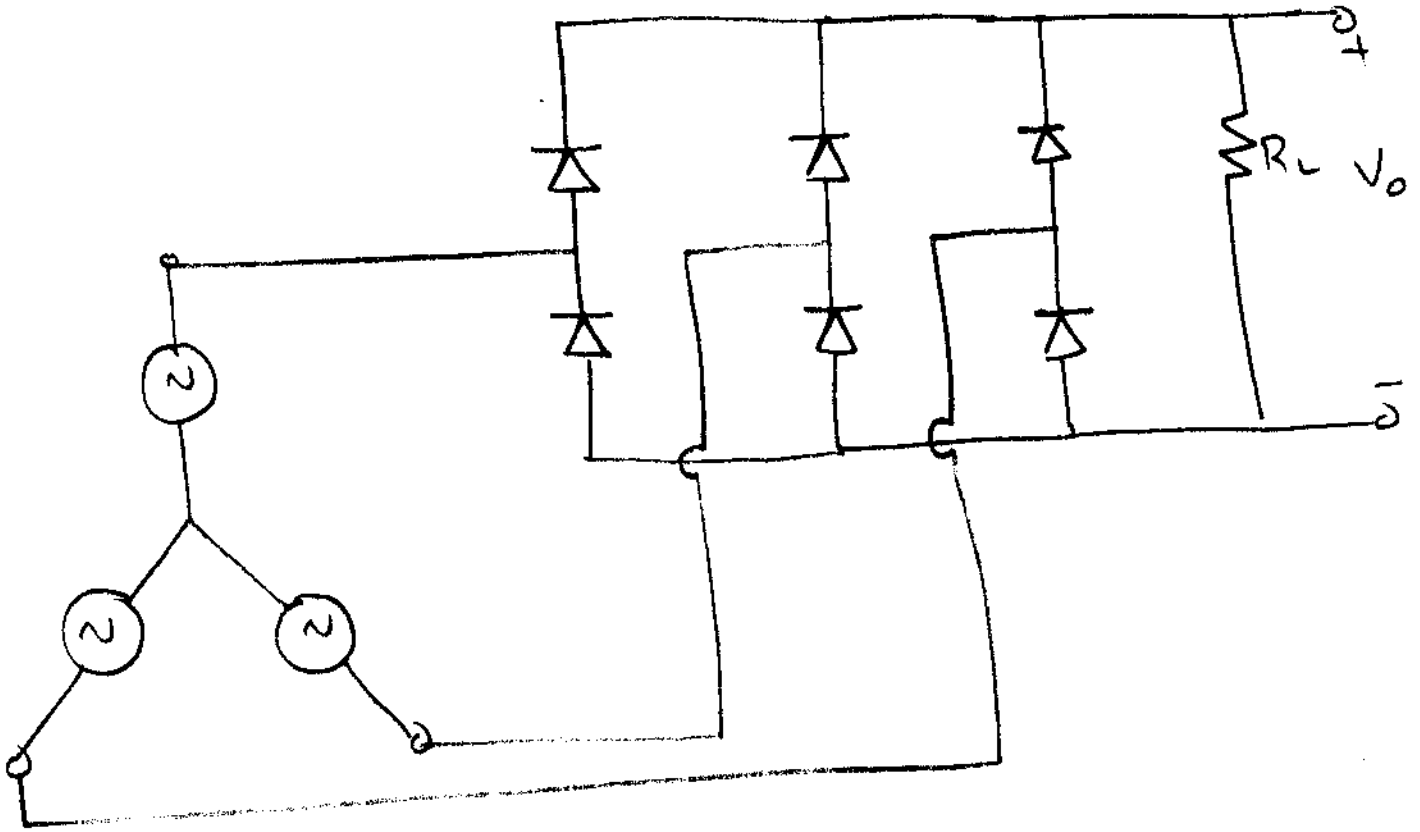


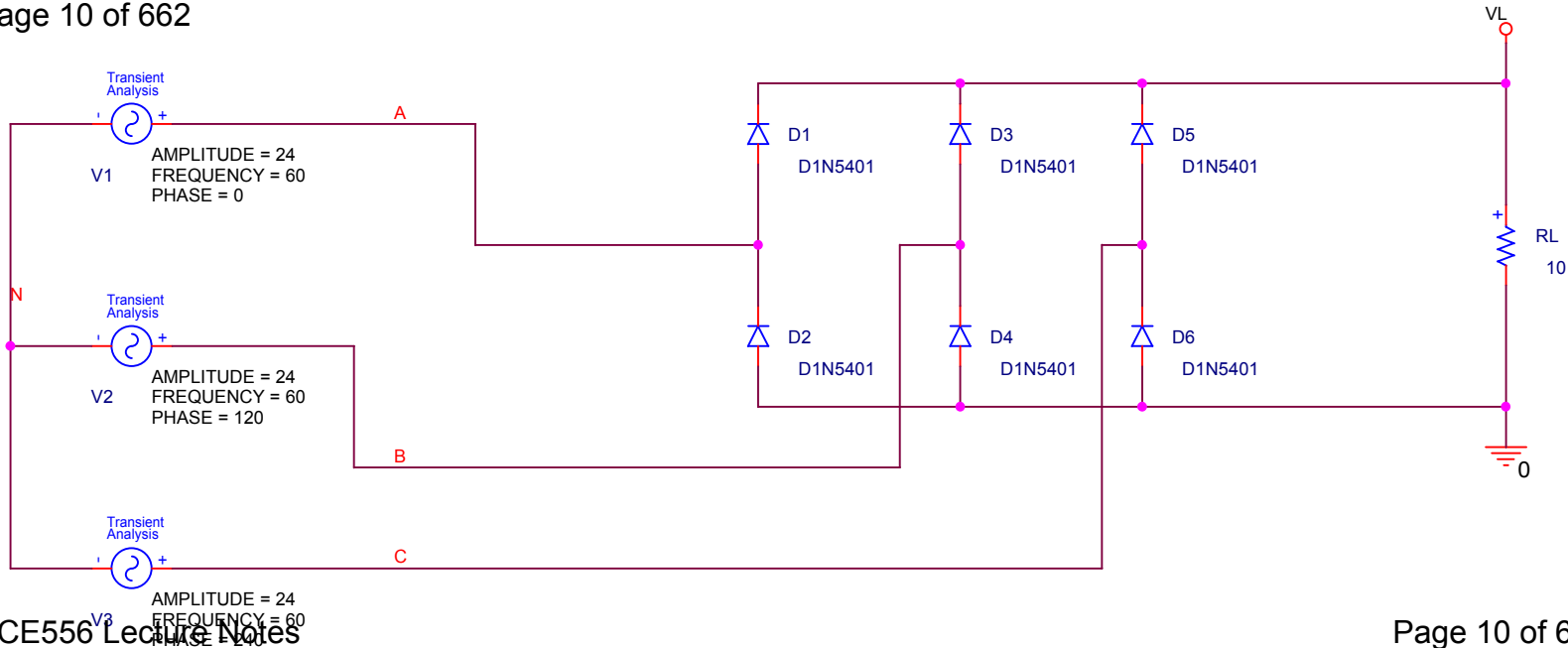


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Date/Time run: 12/12/02 10:57:46 Temperature: 27.0

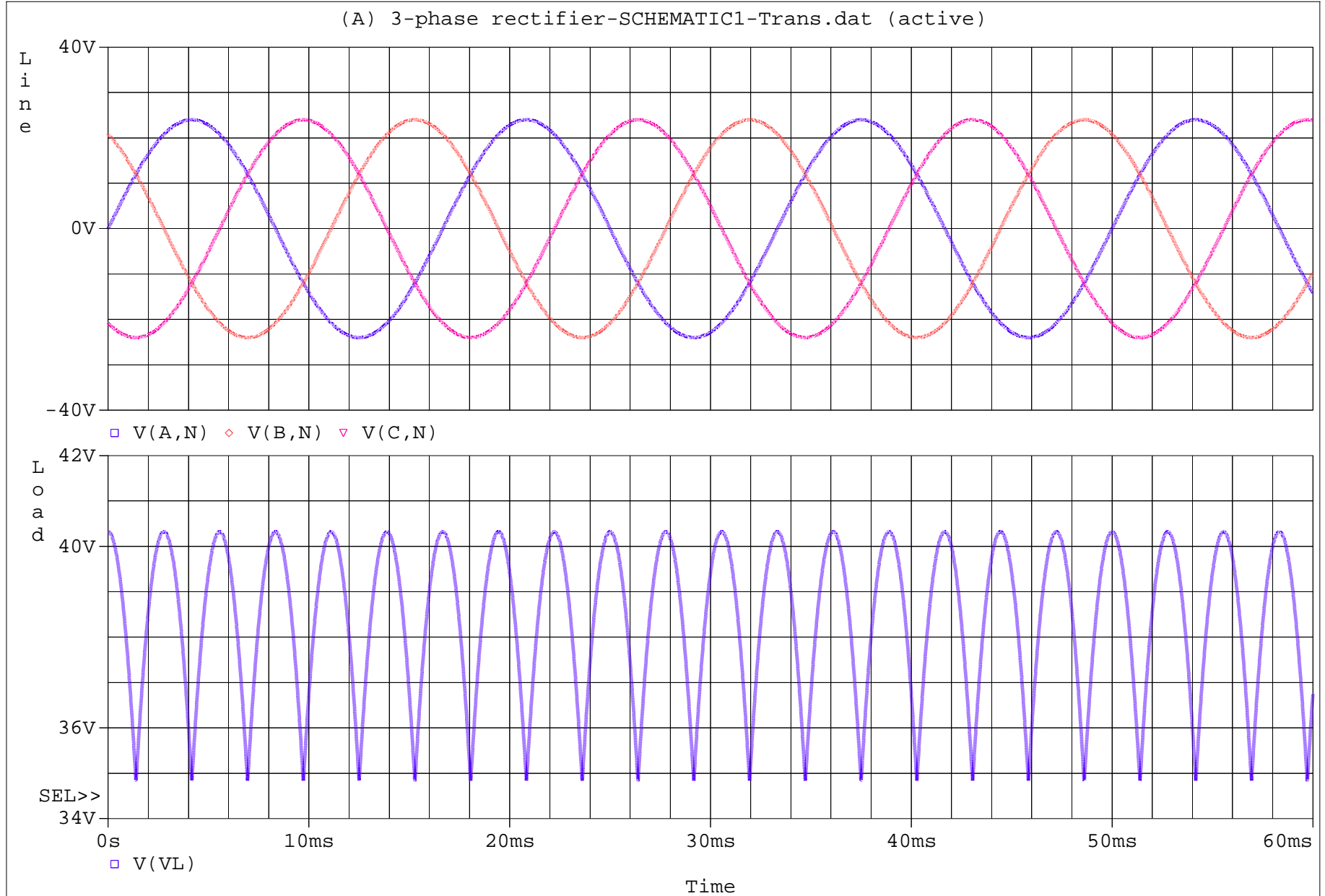


3- ϕ Bridge





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Date/Time run: 12/12/02 11:41:45 Temperature: 27.0



Which is "Better"

Half wave - Most ripple

Full wave -

3- ϕ Bridge - Least ripple

For a source with same voltage output and same current out, and same ripple, the 3 ϕ Bridge will have:

- Smaller diode currents

- Smaller filter capacitor

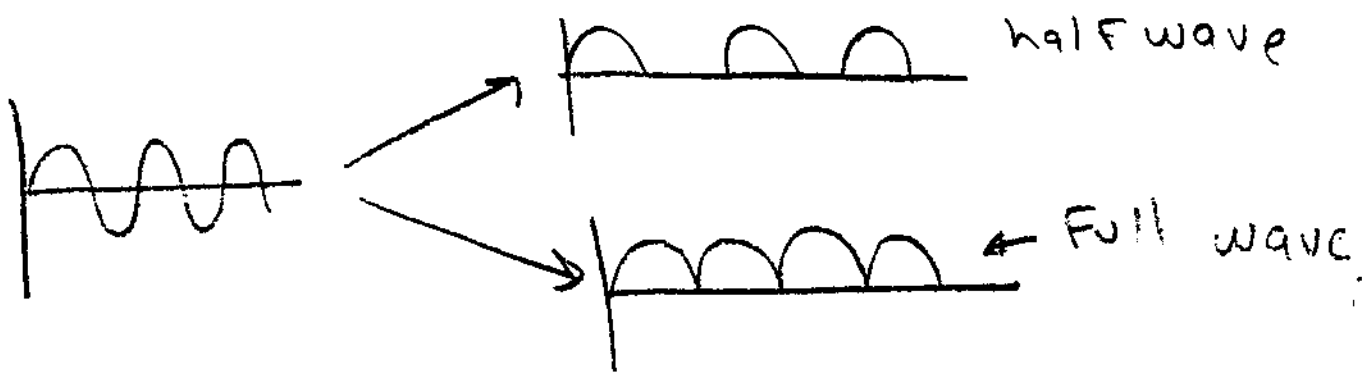
\Rightarrow For High power applications, 3 ϕ Bridge is much nicer

Filter Capacitors

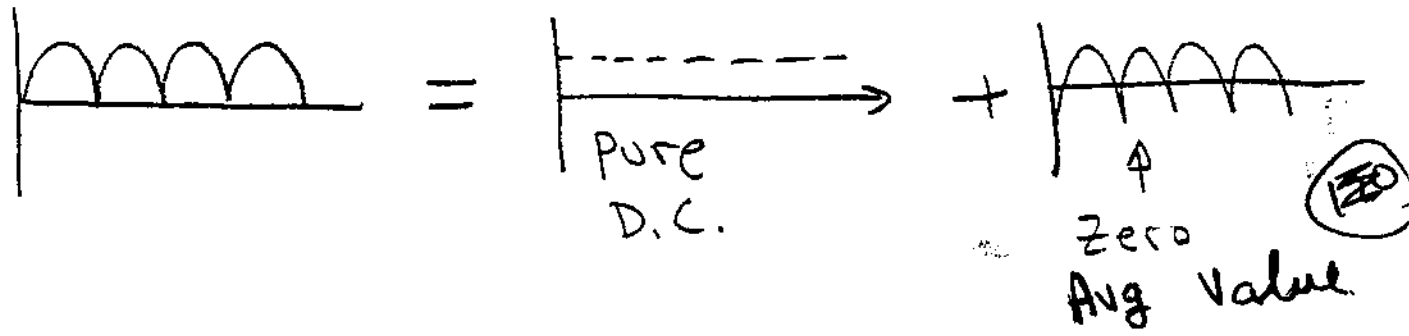
(B)



A Full or Half wave rectifier converts a sinusoidal waveform with no average value to a wave form with an average value

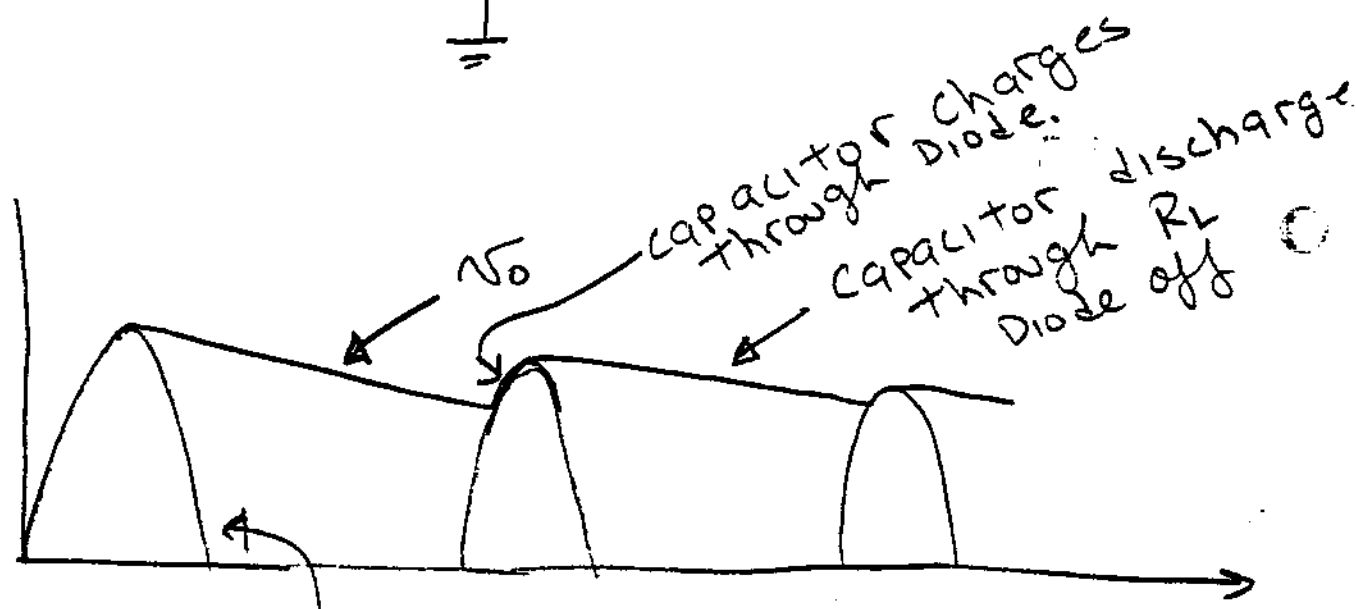
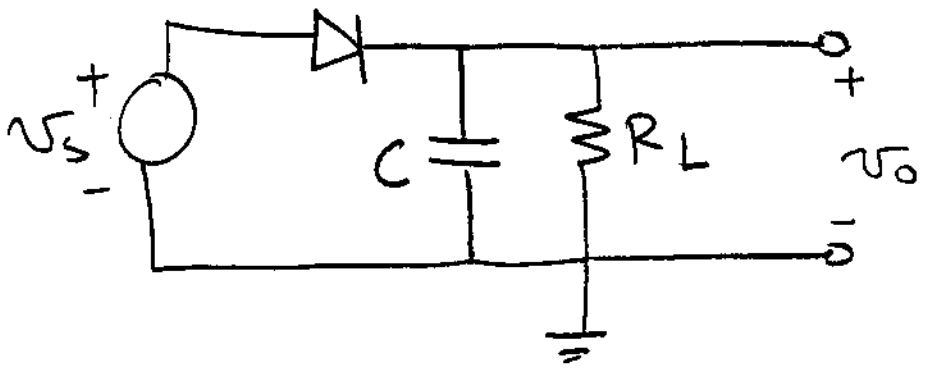


what we desire is a constant voltage. The rectified waveforms have a large amount of ripple superimposed on top of the average value.

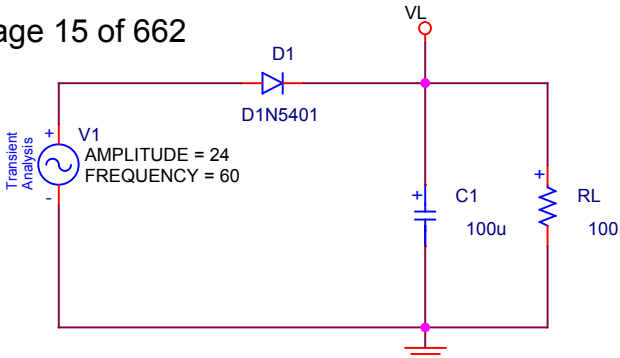


14

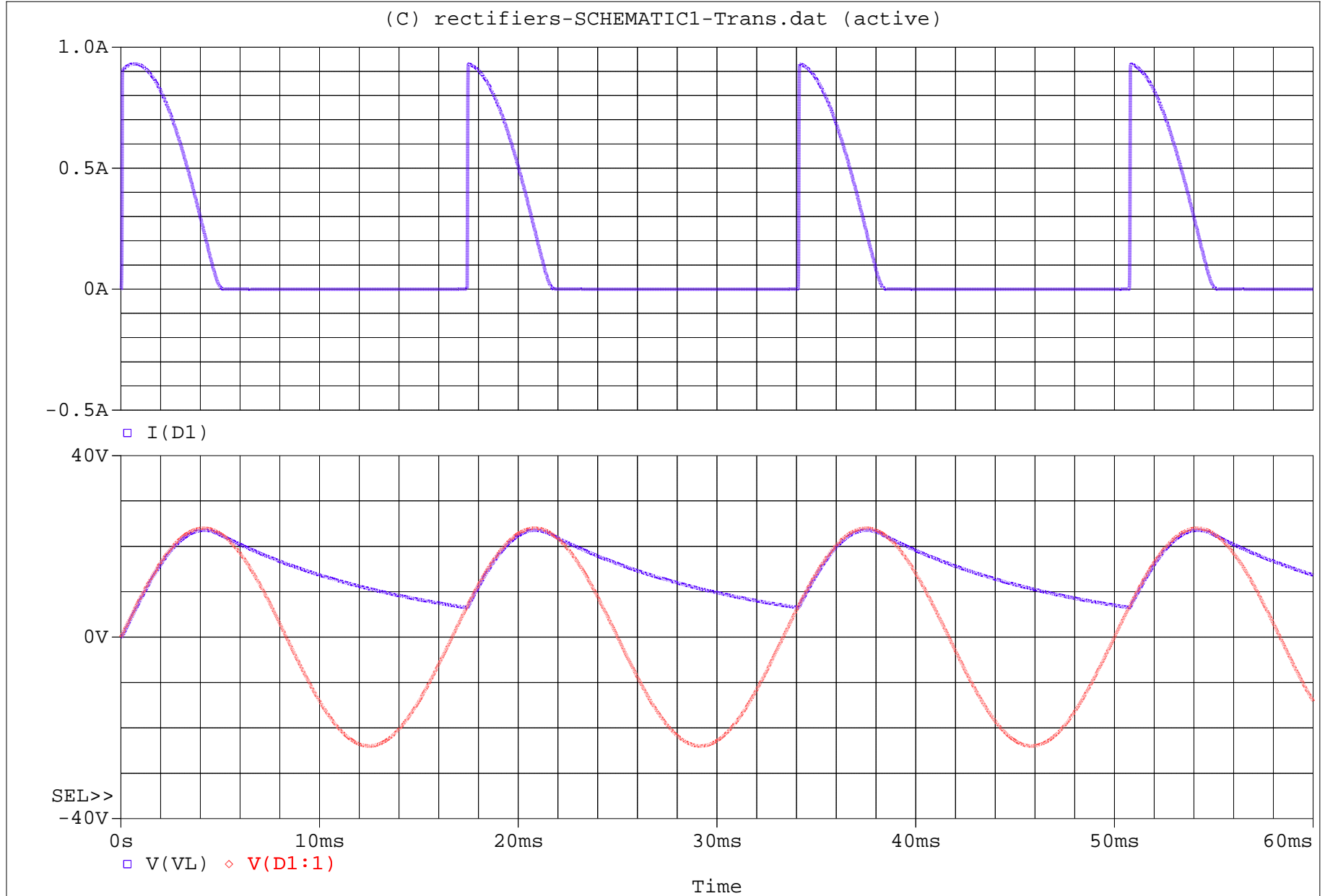
We will add a Filter Capacitor to the circuit to smooth out the ripple.



14



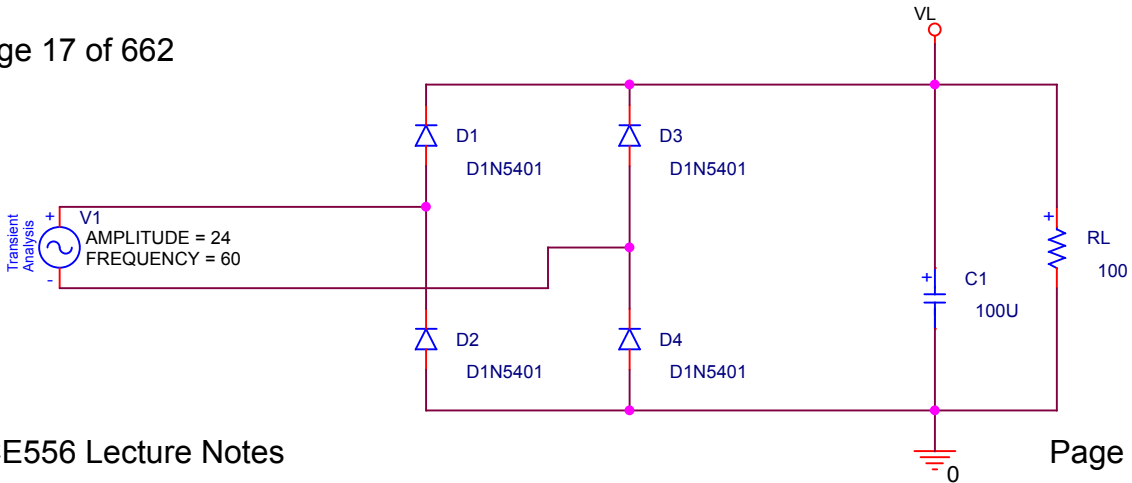
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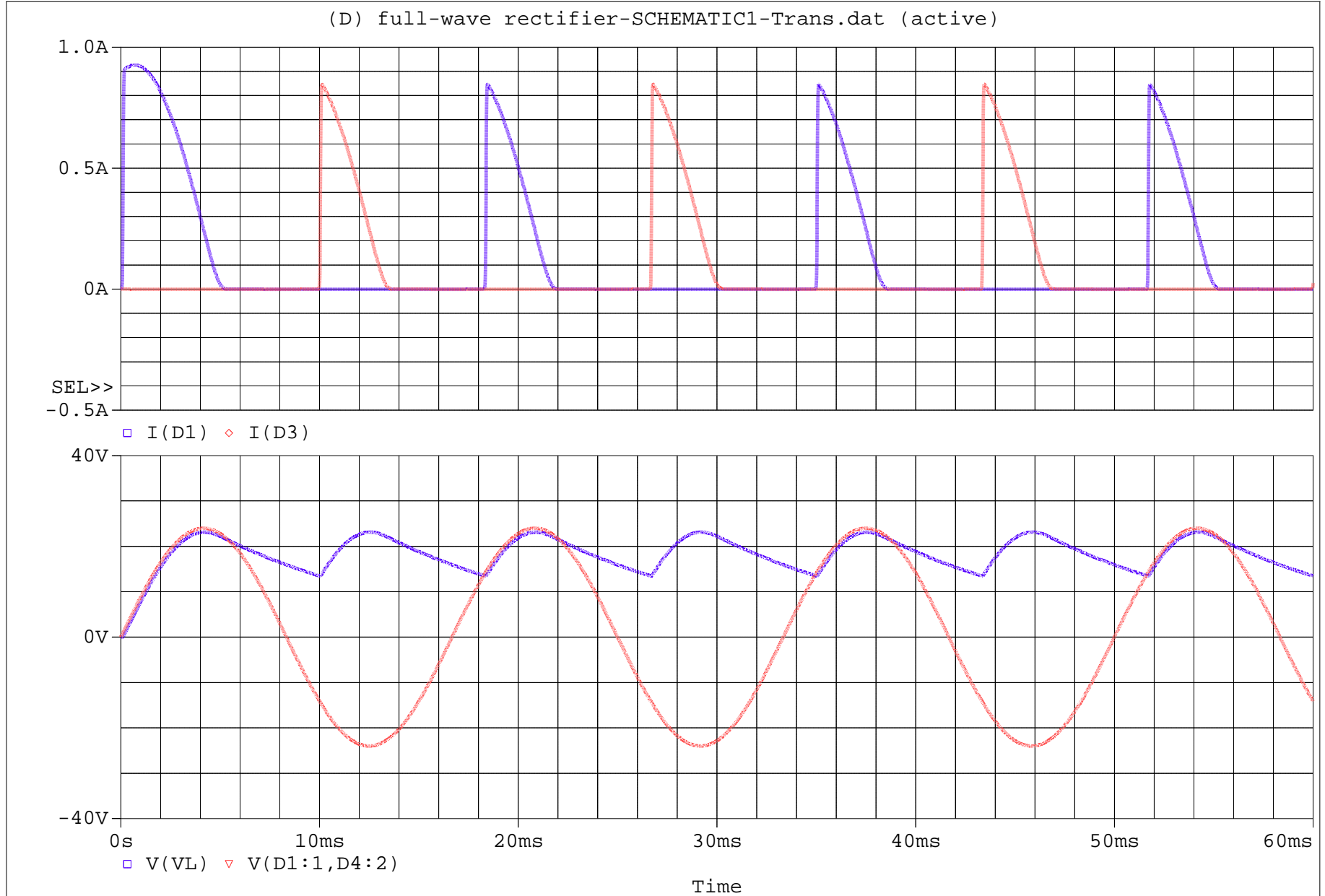
Date: December 12, 2002

Page 1

Time: 11:48:15



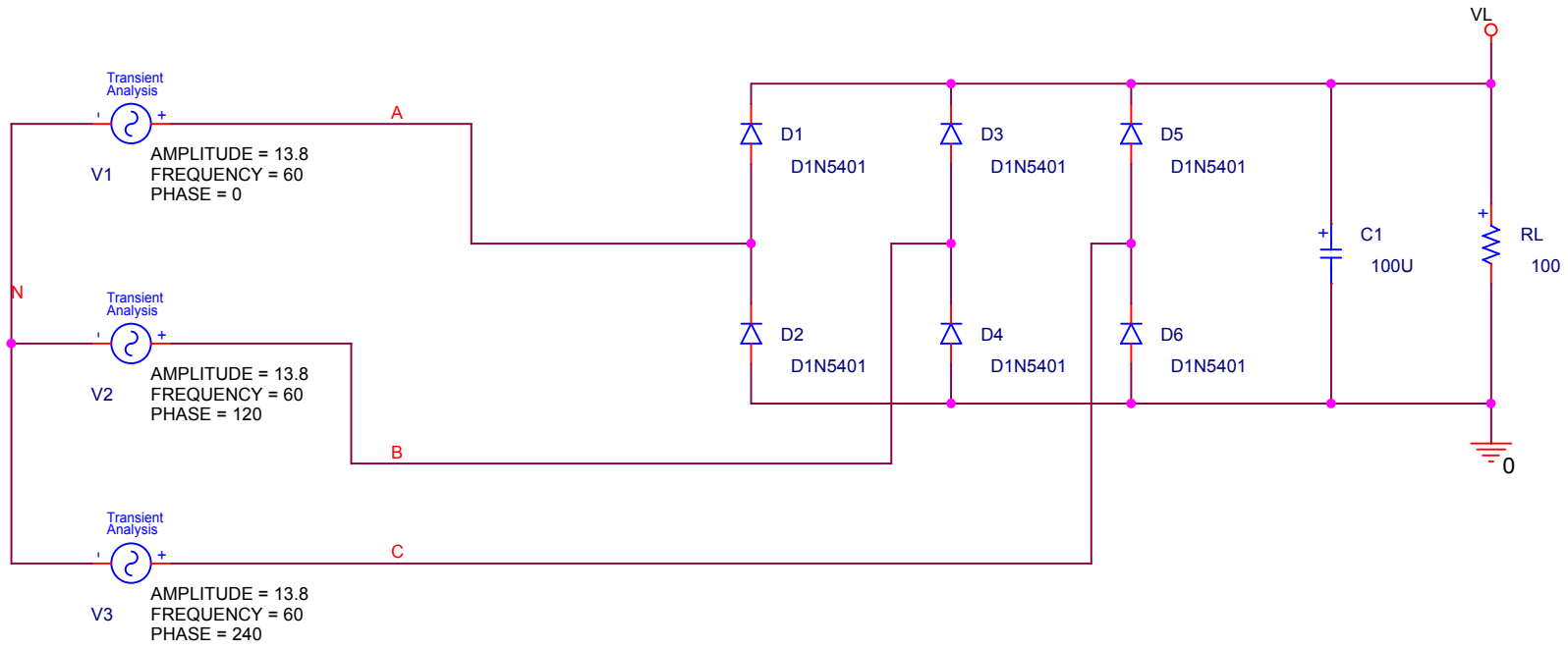
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Date/Time run: 12/12/02 11:49:29 Temperature: 27.0



Date: December 12, 2002

Page 1

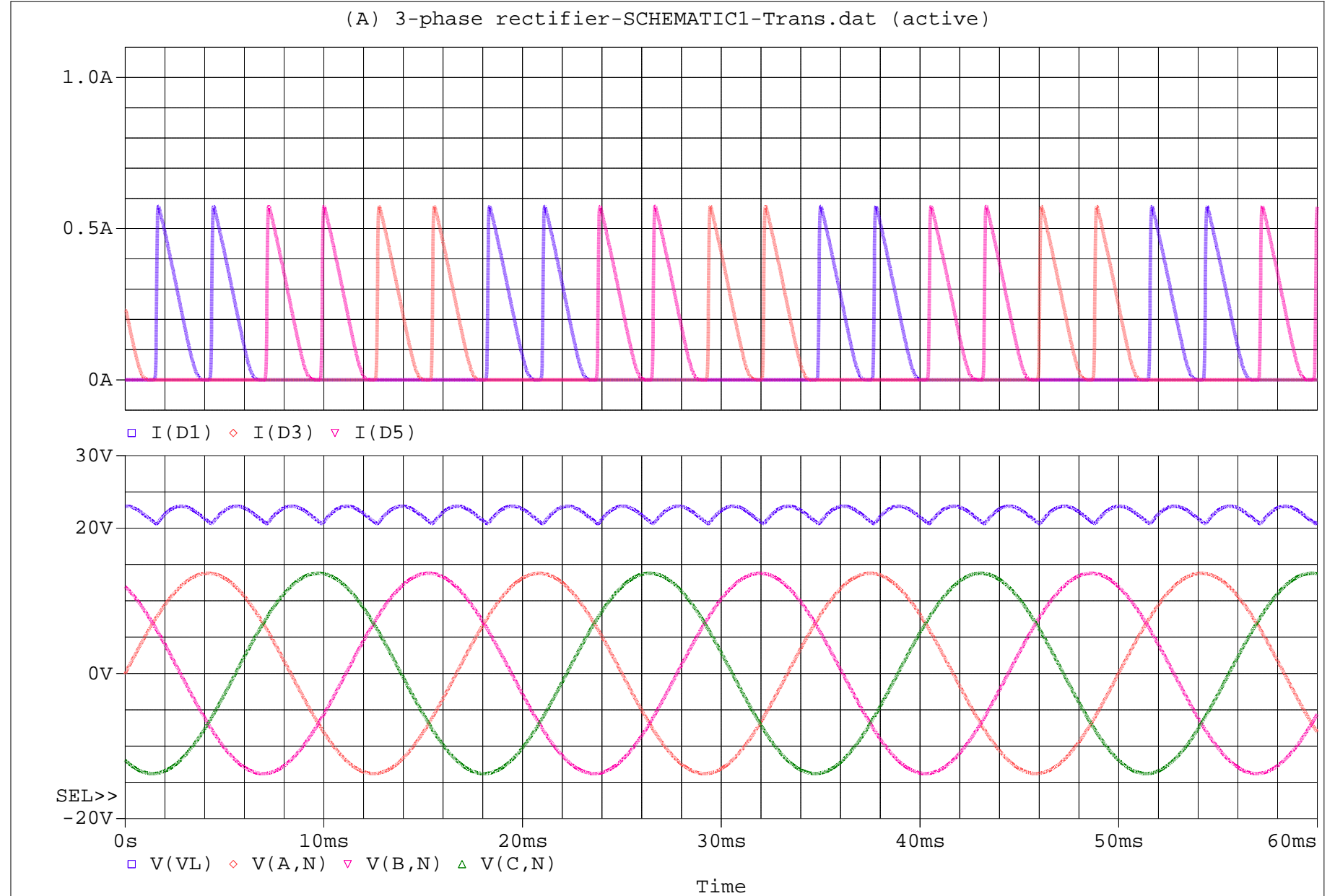
Time: 11:50:35



Note: $24/\sqrt{3} = 13.8$ volts.

		ECE Department 5500 Wabash Avenue Terre Haute, IN 47803 Ph: (812) 877-8512 FAX: (253) 369-9536	
		Name: Marc E. Herniter Class: ECE456	
Size A	Document Name		Rev 1
Date: Thursday, December 12, 2002		Sheet 1	of 1

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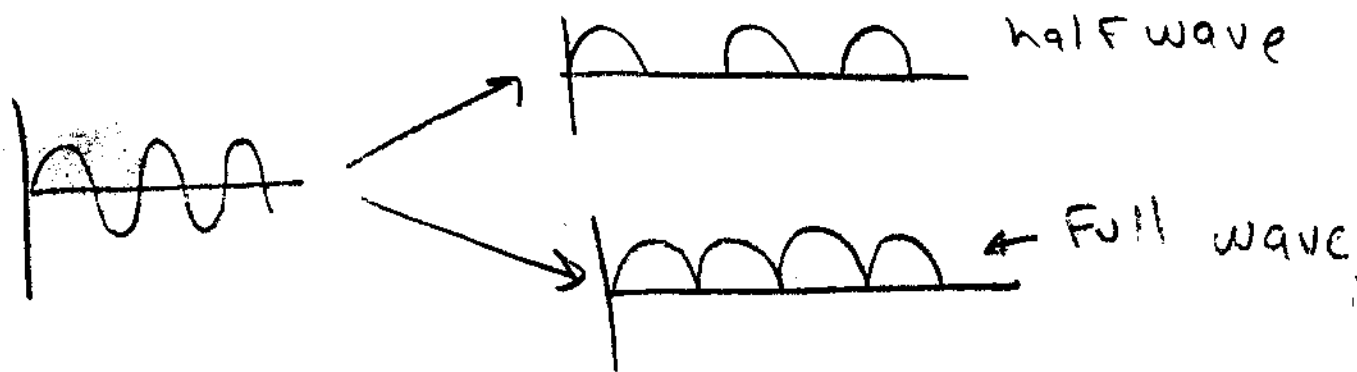
Date: December 12, 2002

Page 1

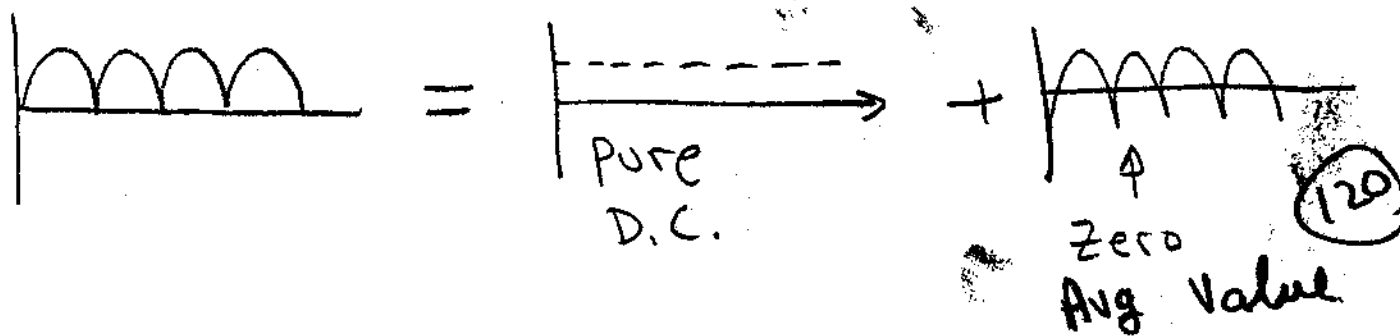
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Filter Capacitors

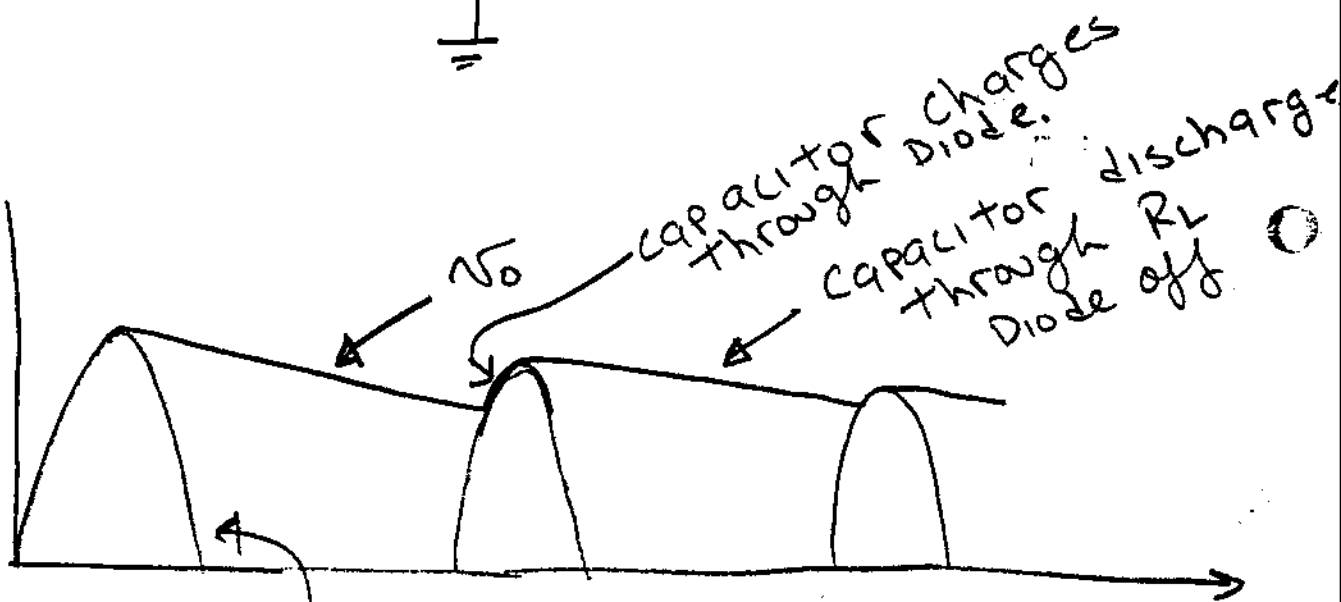
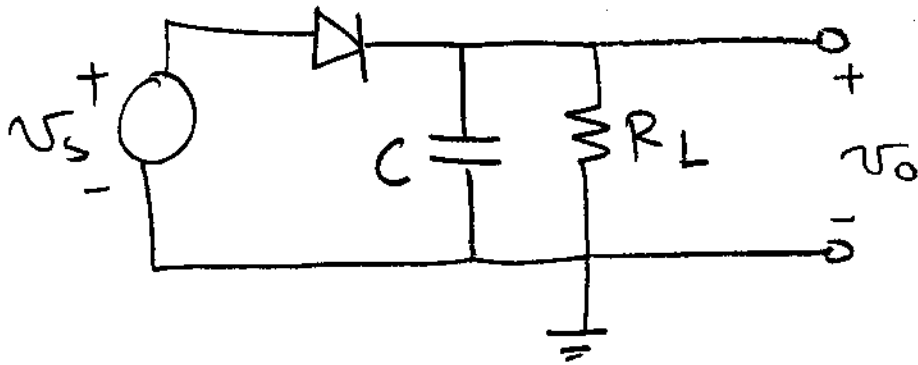
A Full or Half wave rectifier converts a sinusoidal waveform with no average value to a waveform with an average value



- what we desire is a constant voltage. The rectified waveforms have a large amount of ripple superimposed on top of the average value.

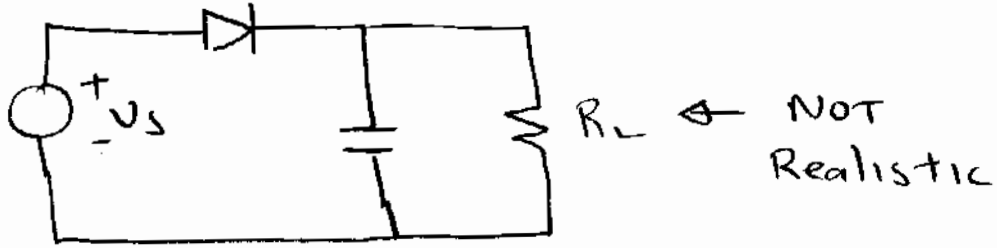


We will add a filter capacitor to the circuit to smooth out the ripple.

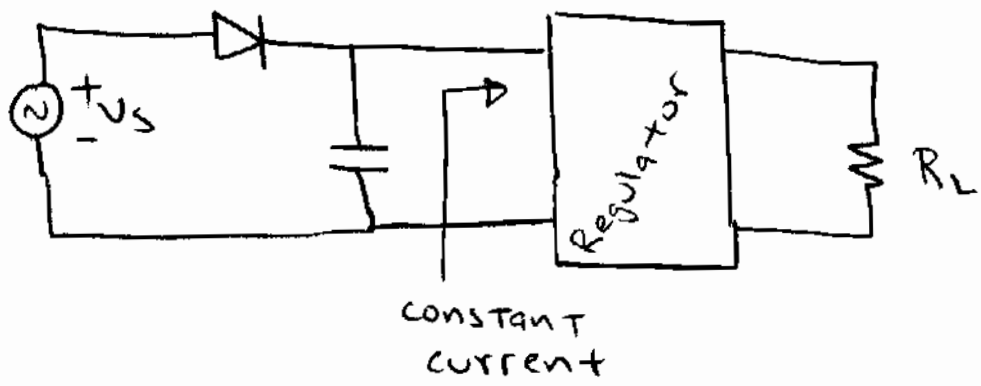


Rectified
Waveform
without
Filter
Capacitor

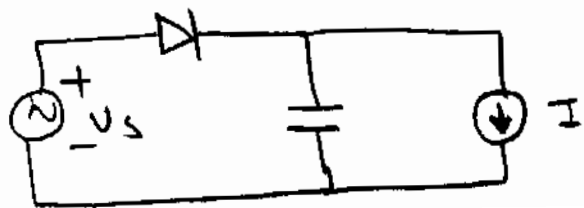
Most of our power supplies will have regulators rather than a resistive load

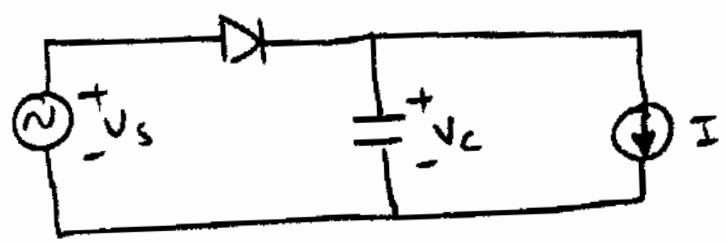


we will have a regulator between our load and the AC/DC converter

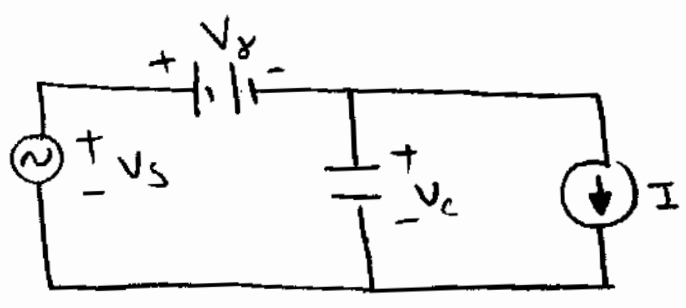


Typically The regulator draws a constant current. when designing our AC/DC converter we will assume a constant current load



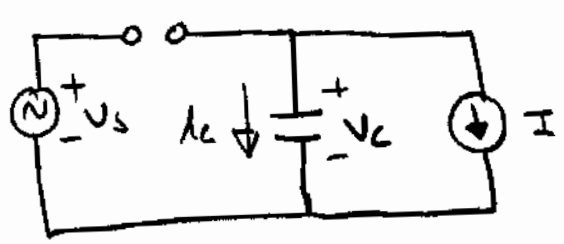


When $V_s > V_s + \text{a diode drop}$, we have



V_c follows V_s minus a diode drop

When $V_s < V_c$, The diode is off, and The current source discharges the cap



$$i_c = C \frac{dV_c}{dt} = -I$$

$$V_c(t) = \frac{1}{C} \int_{t_0}^t i_c(t) dt + V_c(t_0)$$

$$= \frac{1}{C} \int_{t_0}^t -I dt + V_c(t_0)$$

(3)

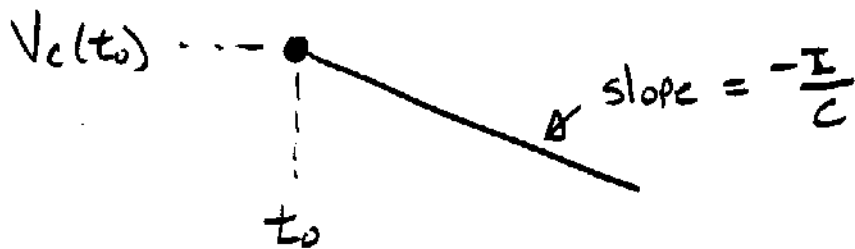
- Since I is a constant, we have

$$V_c(t) = -\frac{I}{C} \int_{t_0}^t dt + V_c(t_0)$$

$$= -\frac{I}{C} (t - t_0) + V_c(t_0)$$

or

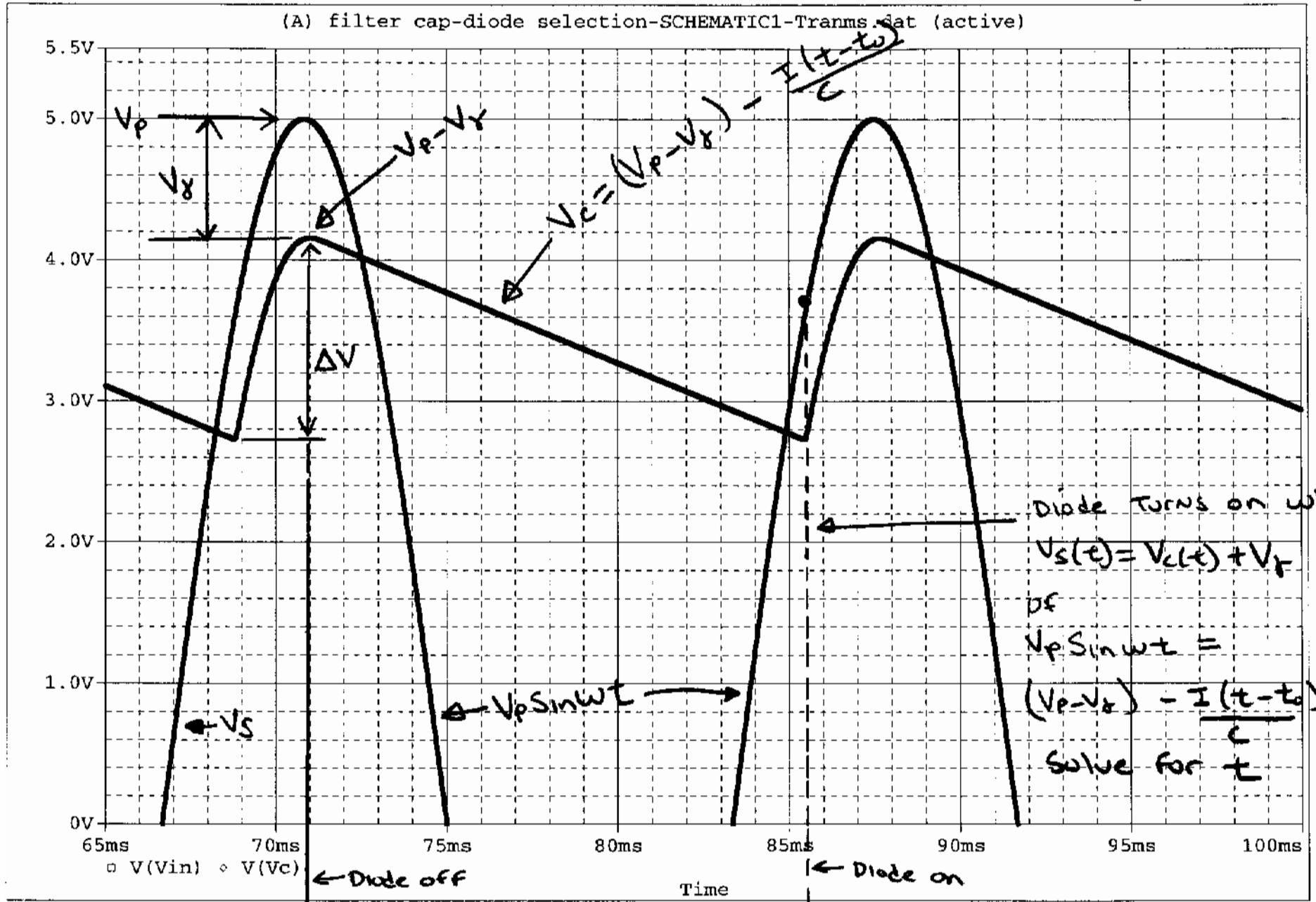
$$V_c(t) = \underbrace{V_c(t_0)}_{\substack{\text{Initial} \\ \text{capacitor} \\ \text{Voltage}}} - \underbrace{\frac{I}{C}}_{\substack{\uparrow \\ \text{slope}}} \underbrace{(t - t_0)}_{\substack{\Delta t \\ \text{OR} \\ \text{discharge} \\ \text{Time}}}$$



Simplified form

$$V_c(t) = V_c(t_0) - \frac{I \Delta t}{C}$$

$$\Delta V = \frac{I \Delta t}{C}$$



t_0 → CAPACITOR DISCHARGES FOR LESS THAN ONE CYCLE

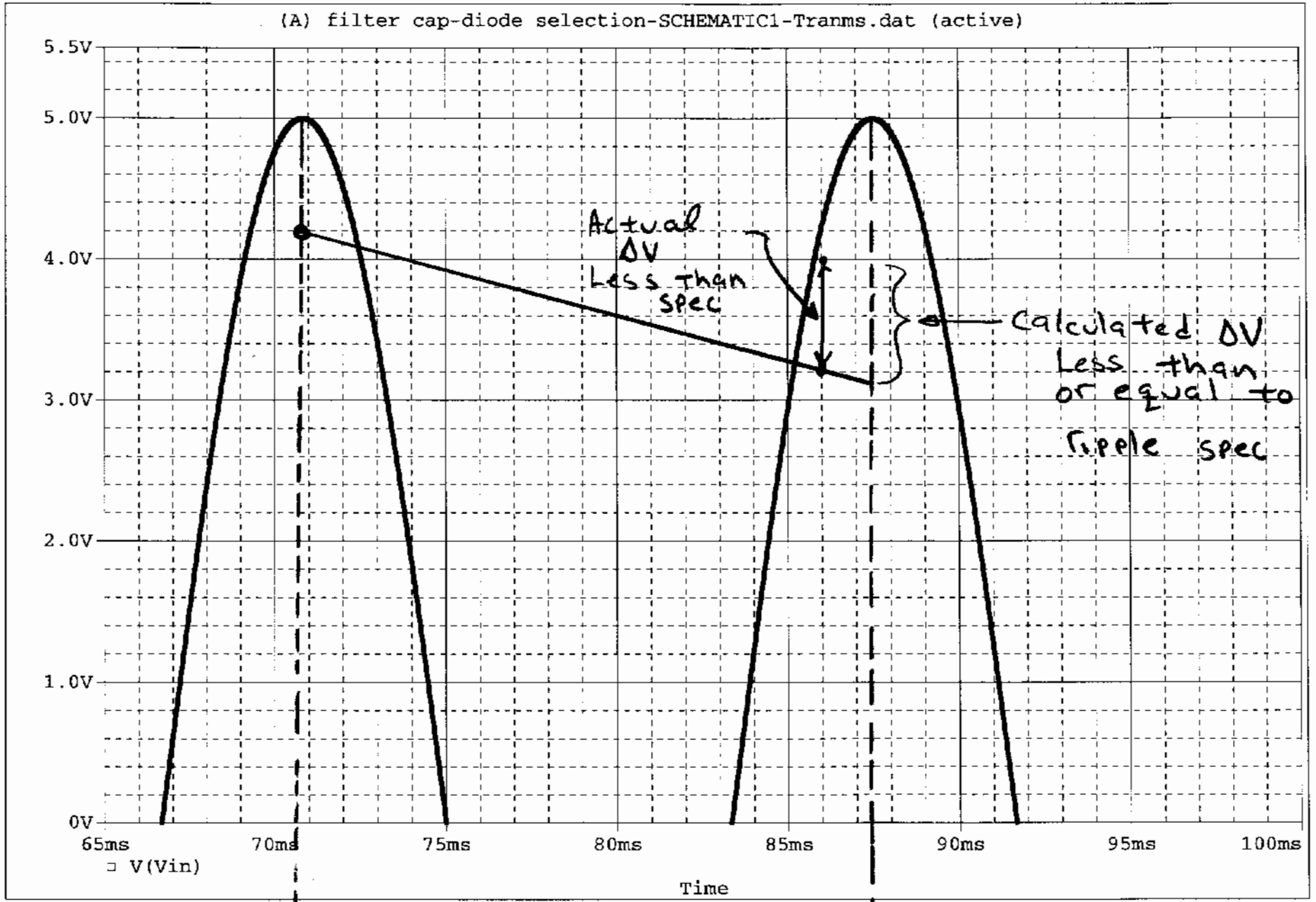
- we could solve this equation with an equation solver, but where is the fun in that? We will make an approximation.

- when we pick our capacitor, we are concerned with keeping ΔV below a specified amount and ΔV will be known.

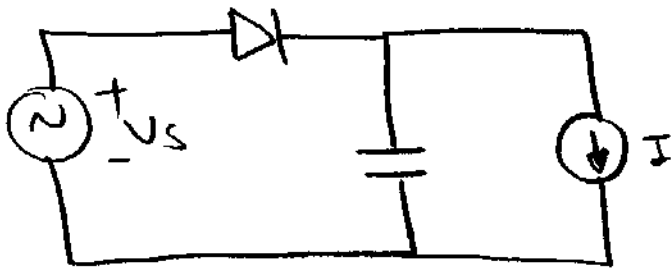
- We will assume that the capacitor discharges for one complete cycle.

This is a longer discharge time than we actually have.

⇒ If we meet ΔV spec with a longer discharge time, then the actual ΔV will be less



$T = 1/60$



- Usually I is specified because you are designing for a certain output current.
- ΔV is specified because that is the amount of ripple on your supply

- from
$$\Delta V = \frac{I \Delta t}{C}$$

$$C = \frac{I \Delta t}{\text{delta-V}}$$
 where $\Delta t = 1/60$ for a half wave Rectifier.

● - The next thing we have to find is the peak current through the diode when it charges the capacitor.

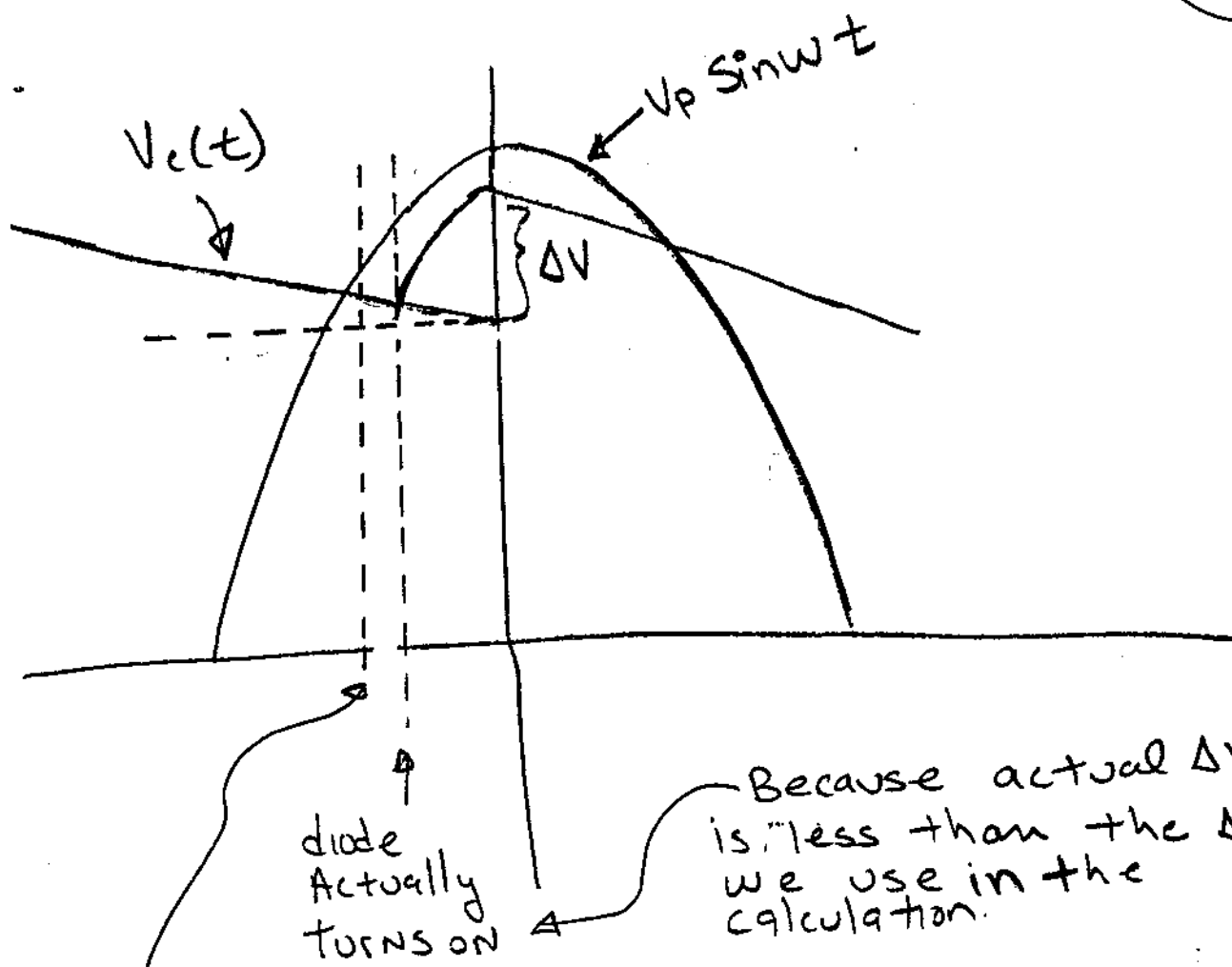
- The diode conducts when
 $(V_p \sin \omega t) - V_f = V_c(t)$

- when the diode conducts the capacitor voltage is the peak capacitor voltage - ΔV

$$(V_p \sin \omega t - V_f) = \underbrace{V_p - V_f}_{\text{Peak Cap Voltage}} - \Delta V$$

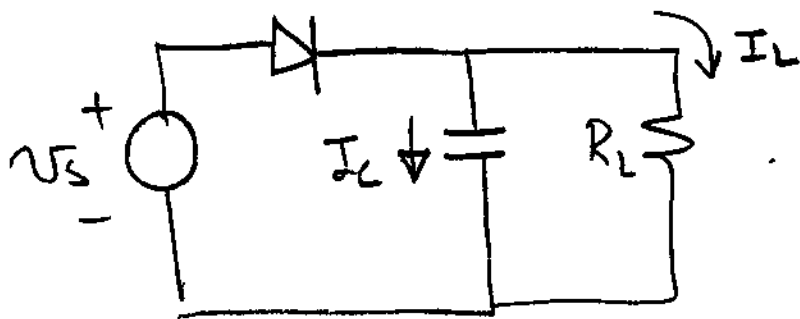
solve for t , call it t_{on}

$$t_{on} = \frac{\sin^{-1} \left[1 - \frac{\Delta V}{V_p} \right]}{\omega}$$



t_{on} - Calculated from ΔV . This will give us a large value for the diode peak current than actually occurs. \Rightarrow We will pick a bigger diode than necessary but this is O.K.

● t_{on} is when the diode turns on. At this time the diode supplies current for the capacitor and the load



● when the diode conducts

$$V_c(t) = V_p \sin \omega t - V_r$$

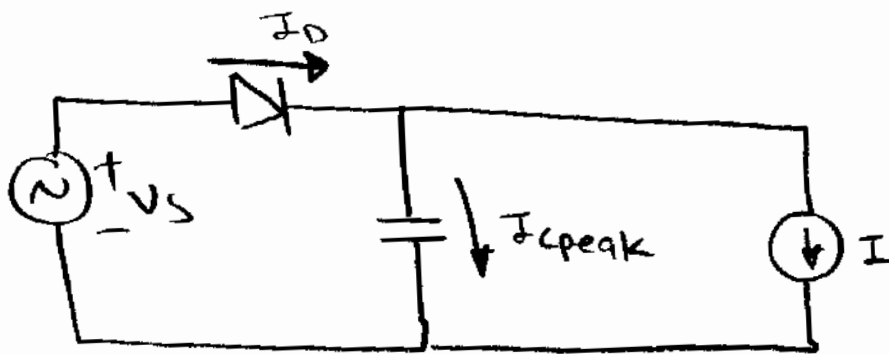
$$I_c = \frac{C dV_c}{dt} = \omega C V_p \cos \omega t$$

at $t = t_{on}$

$$I_c \Big|_{\text{Peak}} = \omega C V_p \cos(\omega t_{on})$$

(11)

When the diode is on, it must supply current to the capacitor and the load

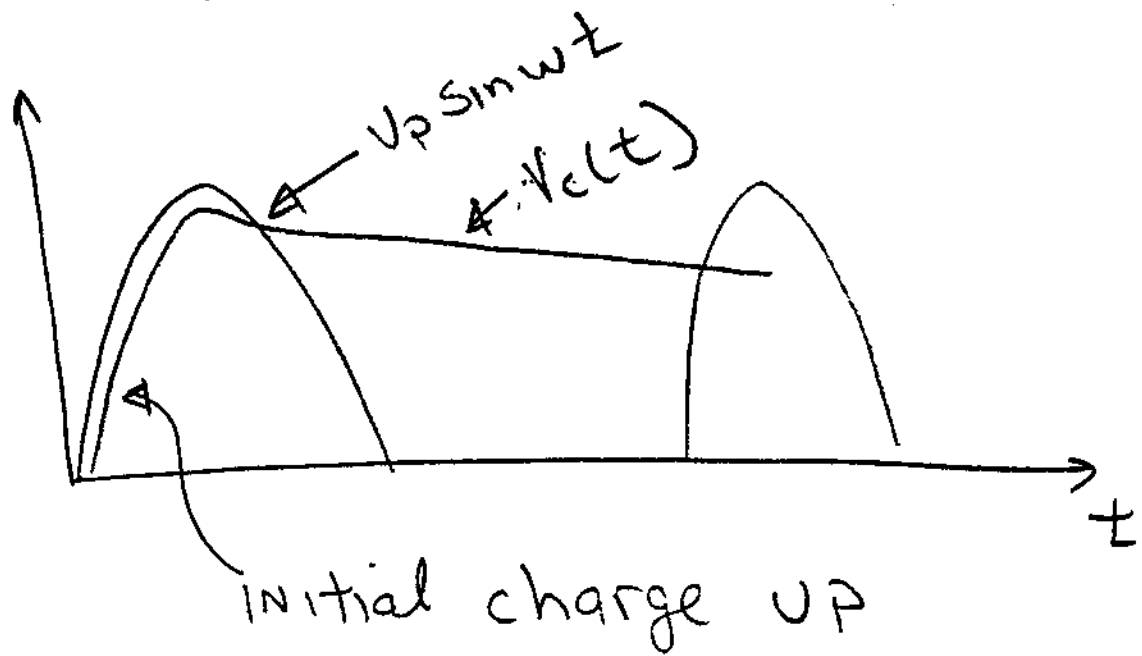


$$I_{D\text{peak}} = I_{C\text{peak}} + I$$

This is the repetitive peak current through the diode. For the diode spec, you must pick the RMS current so

$$I_{\text{RMS}} = \frac{1}{\sqrt{2}} I_{D\text{peak}} \quad \leftarrow \text{Big over Estimate}$$

The next Diode spec we need is the one time surge current through the diode. This occurs when the power supply is first switched on and the capacitor is initially not charged



$$V_c(t) = V_p \sin \omega t - V_r$$

$$I_c(t) = C \frac{dV_c(t)}{dt} = \omega V_p C \cos \omega t$$

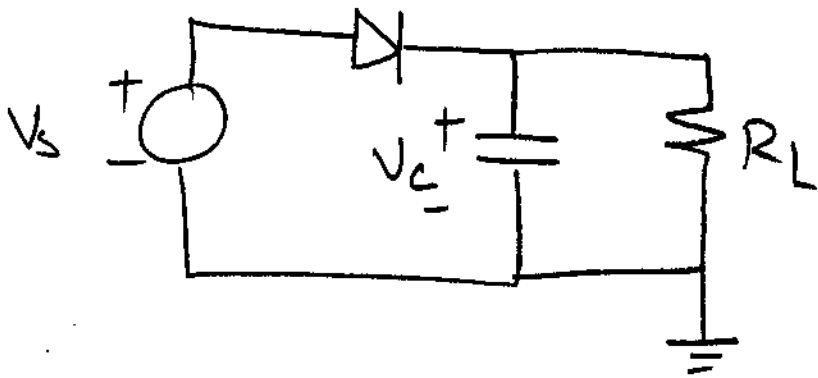
The capacitor current will be a maximum at $t=0$. so

$$I_c \Big|_{\substack{\text{Peak} \\ \text{one} \\ \text{Time}}} = \omega C V_p$$

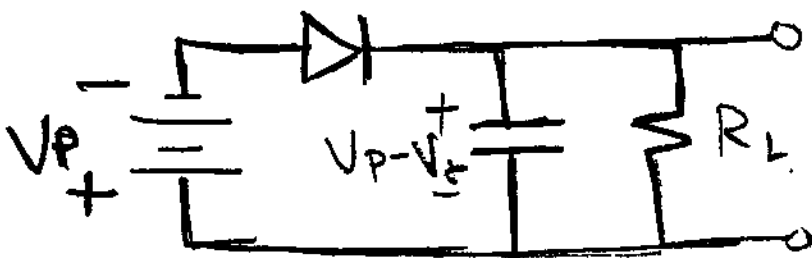
Diode data books call this spec I_{FSM} . so

$$I_{FSM} = \omega C V_p$$

The last diode specification we need is the maximum reverse voltage the diode must withstand when it is reverse biased



The worst possible case would be when V_c is charged to its maximum of $V_c = V_p - V_f$ and when $V_s(t) = -V_p$. In this case we have the CKT



• we see that $ZV_p - V_f$ will appear across the diode. we will find this value up to ZV_p .

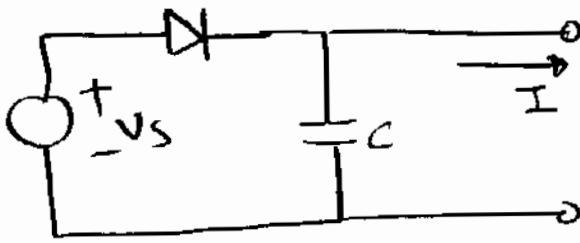
- in data books this spec is called V_{RRM} - some times

• so

$$V_{RRM} = ZV_p$$

Half wave Rectifier Summary

16



Design for specified Load current I

$$v_s = V_p \sin \omega t$$

$$C = \frac{I \Delta t}{\Delta V} \quad \text{where } \Delta t = 1/60 \text{ for HW Rectifier}$$

$$t_{on} = \frac{\sin^{-1} \left[1 - \frac{\Delta V}{V_p} \right]}{\omega} ; \text{ make sure your calculator is using radians}$$

$$I_C |_{peak} = C \omega V_p \cos(\omega t_{on})$$

$$I_D |_{peak} = I_C |_{peak} + I$$

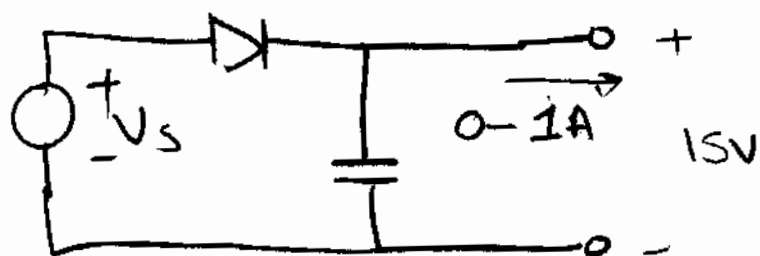
$$I_D |_{RMS} = \frac{I_D |_{peak}}{\sqrt{2}}$$

$$I_{FSM} = C \omega V_p$$

$$V_{RRM} = 2V_p$$

Example : Design a 15V DC Supply that can supply 1 A of current with less than 1% of ripple

$$\Delta V = (0.01)(15V) = 0.15V$$



For 15V output, we need $V_s = 15.7 \sin(\omega t)$

$$C = \frac{I \Delta t}{\Delta V} = \frac{(1A) \left(\frac{1}{60} \text{ sec}\right)}{0.15V} = 0.111111 F$$

Now Find the diode parameters

$$t_{on} = \frac{\sin^{-1}\left[1 - \frac{\Delta V}{V_p}\right]}{\omega} = \frac{\sin^{-1}\left[1 - \frac{0.15}{15.7}\right]}{2\pi 60} = 3.8 \text{ ms}$$

Note: Round down t_{on} to make I_{Cpeak} Larger.

\Rightarrow we will pick a Larger diode than necessary.

$$\begin{aligned}
I_c|_{\text{peak}} &= C \omega V_p \cos(\omega t_{\text{on}}) \\
&= (0.1111)(2\pi 60)(15.7V)(\cos 2\pi 60 \times 3.8\text{ms}) \\
&= 90.6\text{A}
\end{aligned}$$

$$I_o|_{\text{peak}} = I_c|_{\text{peak}} + I = 90.6\text{A} + 1\text{A} = 91.6\text{A}$$

$$I_o|_{\text{rms}} = \frac{I_o|_{\text{peak}}}{\sqrt{2}} = \frac{91.6\text{A}}{\sqrt{2}} = 64.1\text{A rms}$$

$$\begin{aligned}
I_{\text{FSM}} &= \omega C V_p \\
&= (2\pi 60)(0.1111\text{F})(15.7\text{V}) = 658\text{A}
\end{aligned}$$

$$V_{\text{RRM}} = 2V_p = 31.4\text{V}$$

MR2502, MR2504, MR2510

MR2504 and MR2510 are Preferred Devices

Medium-Current Silicon Rectifiers

... compact, highly efficient silicon rectifiers for medium-current applications requiring:

- High Current Surge — 400 Amperes @ $T_J = 175^\circ\text{C}$
- Peak Performance @ Elevated Temperature — 25 Amperes @ $T_C = 150^\circ\text{C}$
- Low Cost
- Compact, Molded Package — For Optimum Efficiency in a Small Case Configuration

Mechanical Characteristics:

- Case: Epoxy, Molded
- Weight: 1.8 grams (approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminals are Readily Solderable
- Lead Temperature for Soldering Purposes: requires a custom temperature soldering profile
- Polarity: Cathode Polarity Band
- Shipped 5000 units per box

MAXIMUM RATINGS

Please See the Table on the Following Page



ON Semiconductor™

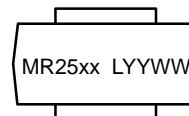
<http://onsemi.com>

**MEDIUM-CURRENT
SILICON RECTIFIERS
25 AMPERES
200-1000 VOLTS
DIFFUSED JUNCTION**



**MICRODE BUTTON
CASE 193**

MARKING DIAGRAM



MR25xx = Device Code
xx = 02, 04 or 10
L = Location Code
YY = Year
WW = Work Week

ORDERING INFORMATION

Device	Package	Shipping
MR2502	Microde Button	5000 Units/Box
MR2504	Microde Button	5000 Units/Box
MR2510	Microde Button	5000 Units/Box

Preferred devices are recommended choices for future use and best overall value.

MR2502, MR2504, MR2510

MAXIMUM RATINGS

Characteristic	Symbol	MR2502	MR2504	MR2510	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	200	400	1000	Volts
Non-Repetitive Peak Reverse Voltage (Halfwave, single phase, 60 Hz peak)	V_{RSM}	240	480	1200	Volts
Average Rectified Forward Current (Single phase, resistive load, 60 Hz, $T_C = 150^\circ\text{C}$)	I_O	25			Amps
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	400 (for 1 cycle)			Amps
Operating and Storage Junction Temperature Range	T_J, T_{stg}	± 65 to $+175$			$^\circ\text{C}$




THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case (Single Side Cooled)	$R_{\theta JC}$	1.0	$^\circ\text{C}/\text{W}$

ELECTRICAL CHARACTERISTICS

Characteristics and Conditions	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage ($i_F = 78.5$ Amps, $T_C = 25^\circ\text{C}$)	v_F	1.18	Volts
Maximum Reverse Current (rated dc voltage) $T_C = 25^\circ\text{C}$ $T_C = 100^\circ\text{C}$	I_R	100 500	μA

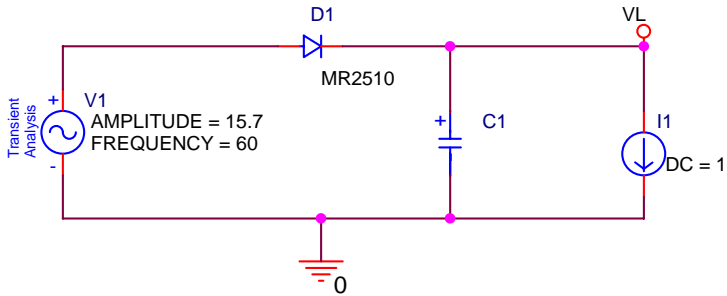
Table 7 — General-Purpose Rectifiers (continued)

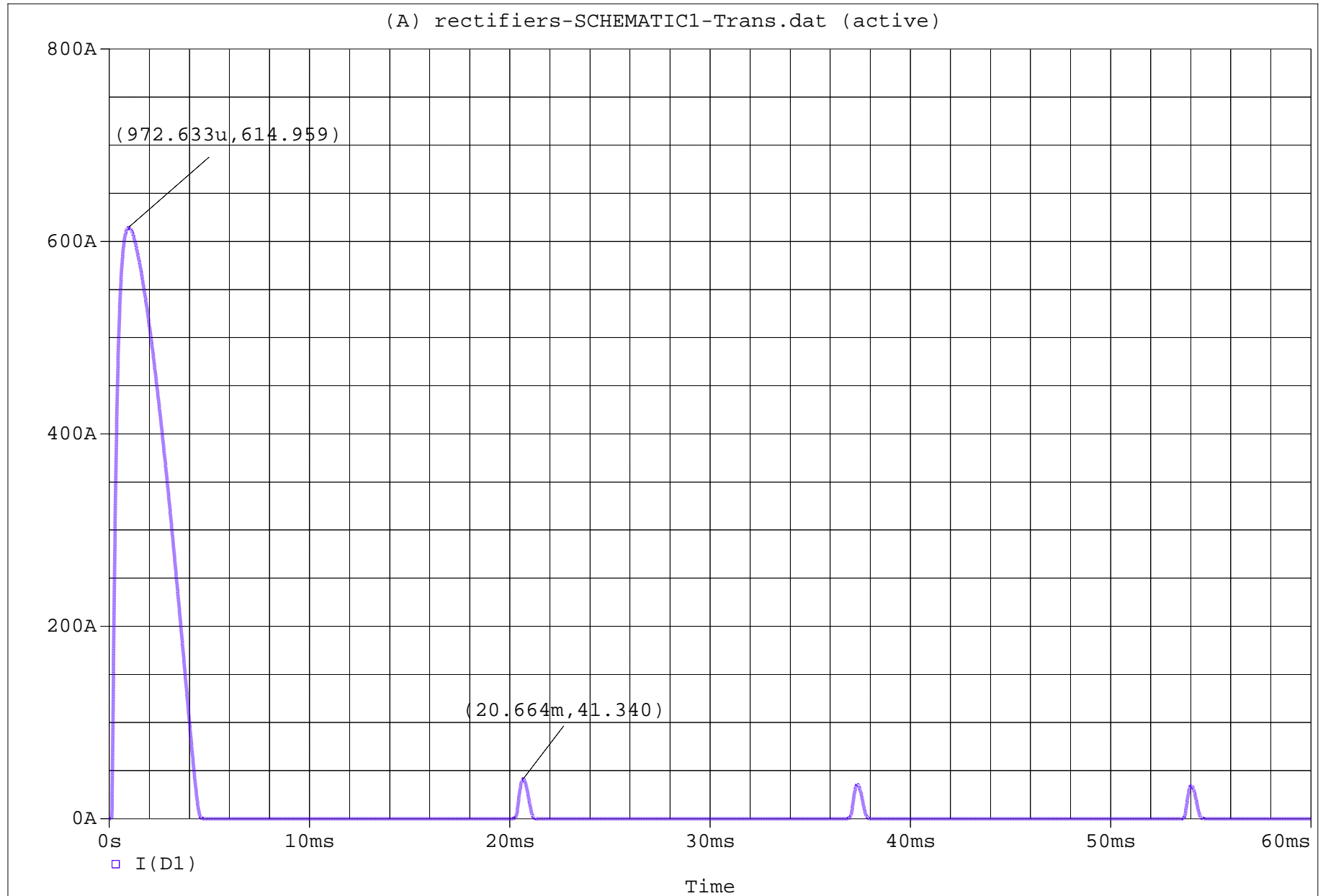
V_{RRM} (Volts)	I_O , AVERAGE RECTIFIED FORWARD CURRENT (Amperes) ⁽¹⁾			
	25	30		40
	193-04 Plastic ⁽¹⁰⁾ Cathode = Polarity Band 	1-07 (TO-204AA) Metal Styles 8 and 9 		42A-01 (DO-203AB) Metal Style 1 
50	MR2500			1N1183A
100	MR2501	MR4422CT	MR4422CTR	1N1184A
200	MR2502			1N1186A
400	MR2504			1N1188A
600	MR2506			1N1190A
800	MR2508			
1000	MR2510			
I_{FSM} (Amps)	400	400	400	800
T_A @ Rated I_O (°C)				
T_C @ Rated I_O (°C)	150			150
T_J (Max) °C	175	150	150	190

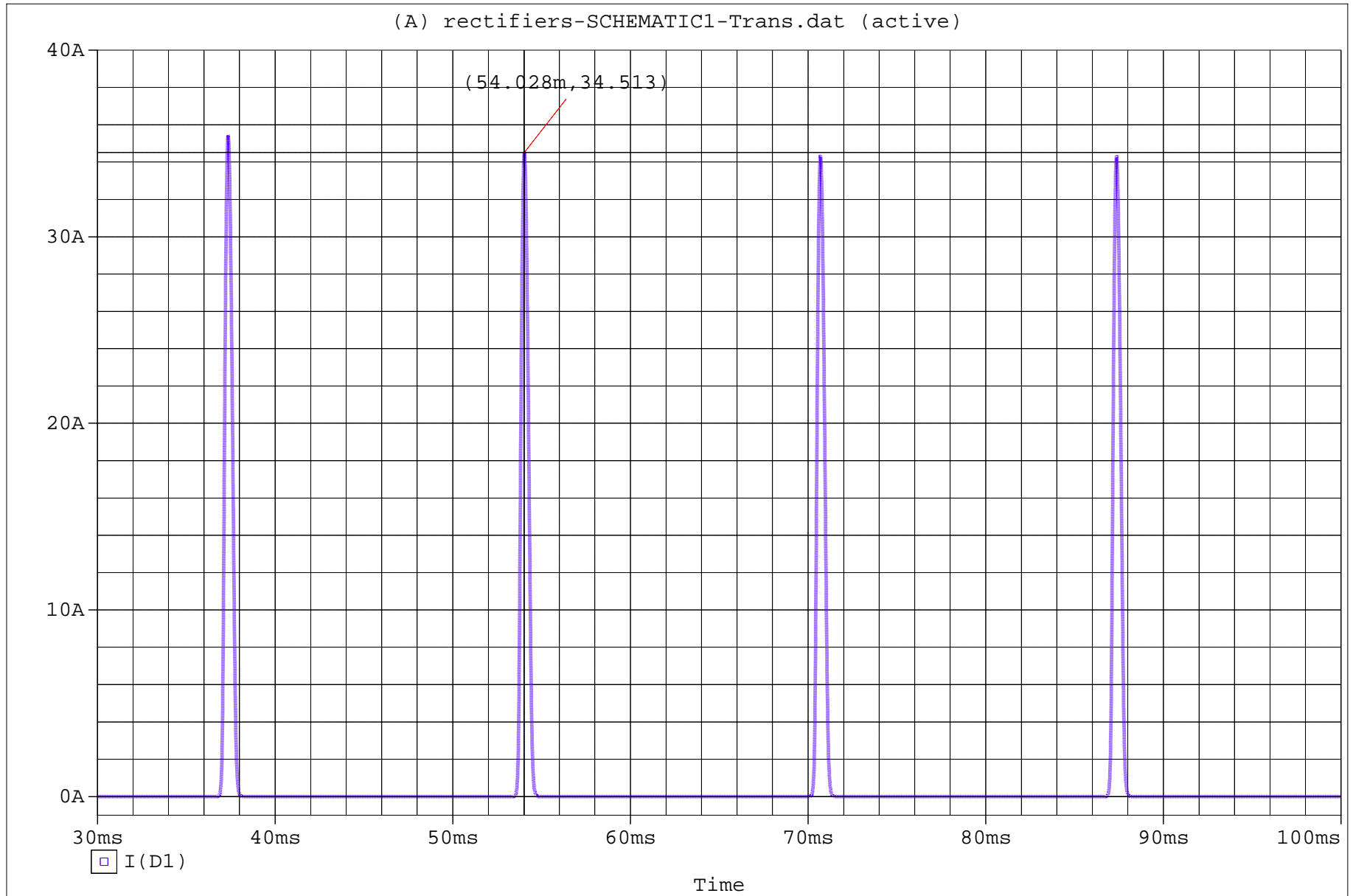
⁽¹⁾ I_O is total device output.

⁽¹⁰⁾ Request data sheet for mounting information.

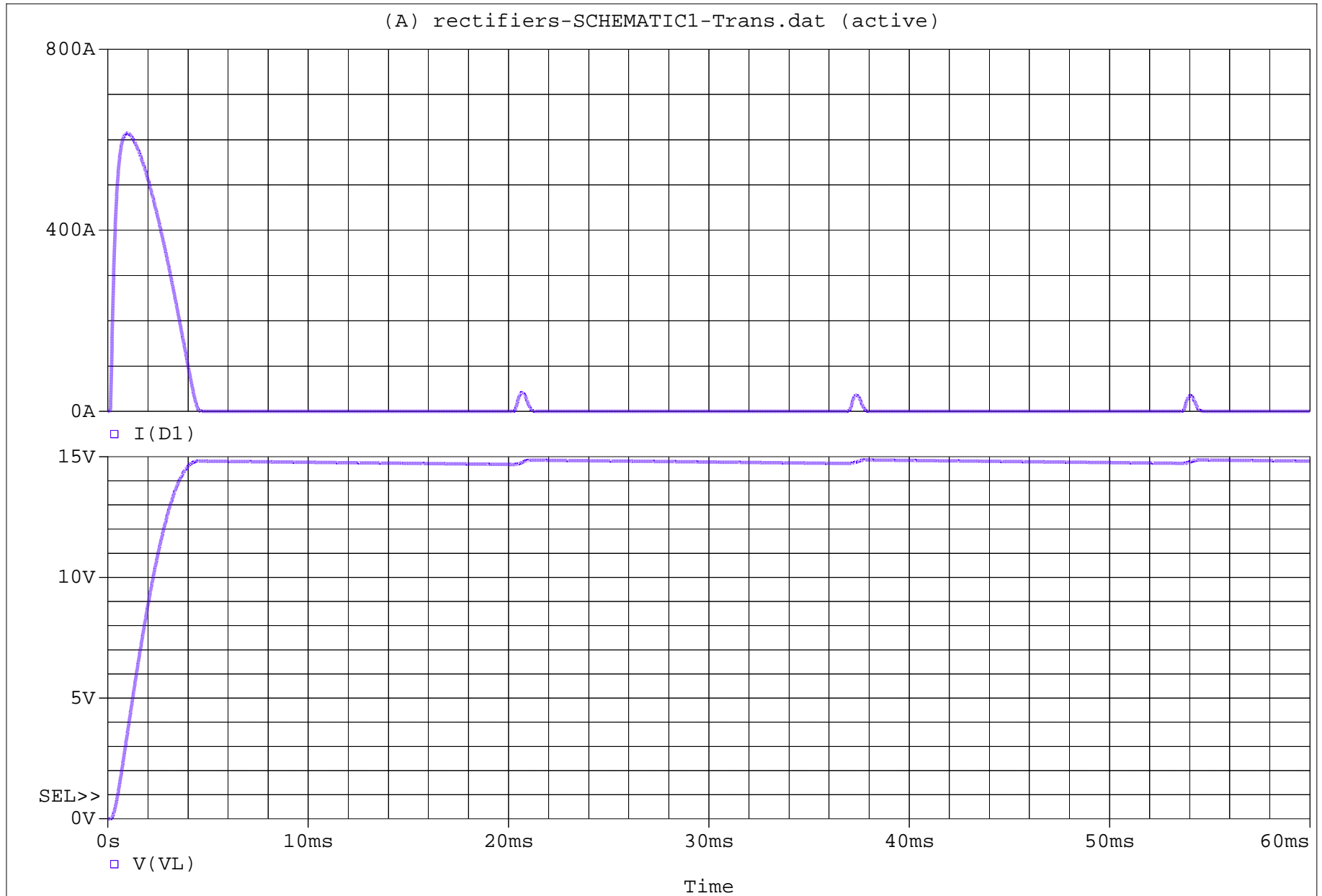
Devices listed in bold, italic are Motorola preferred devices.

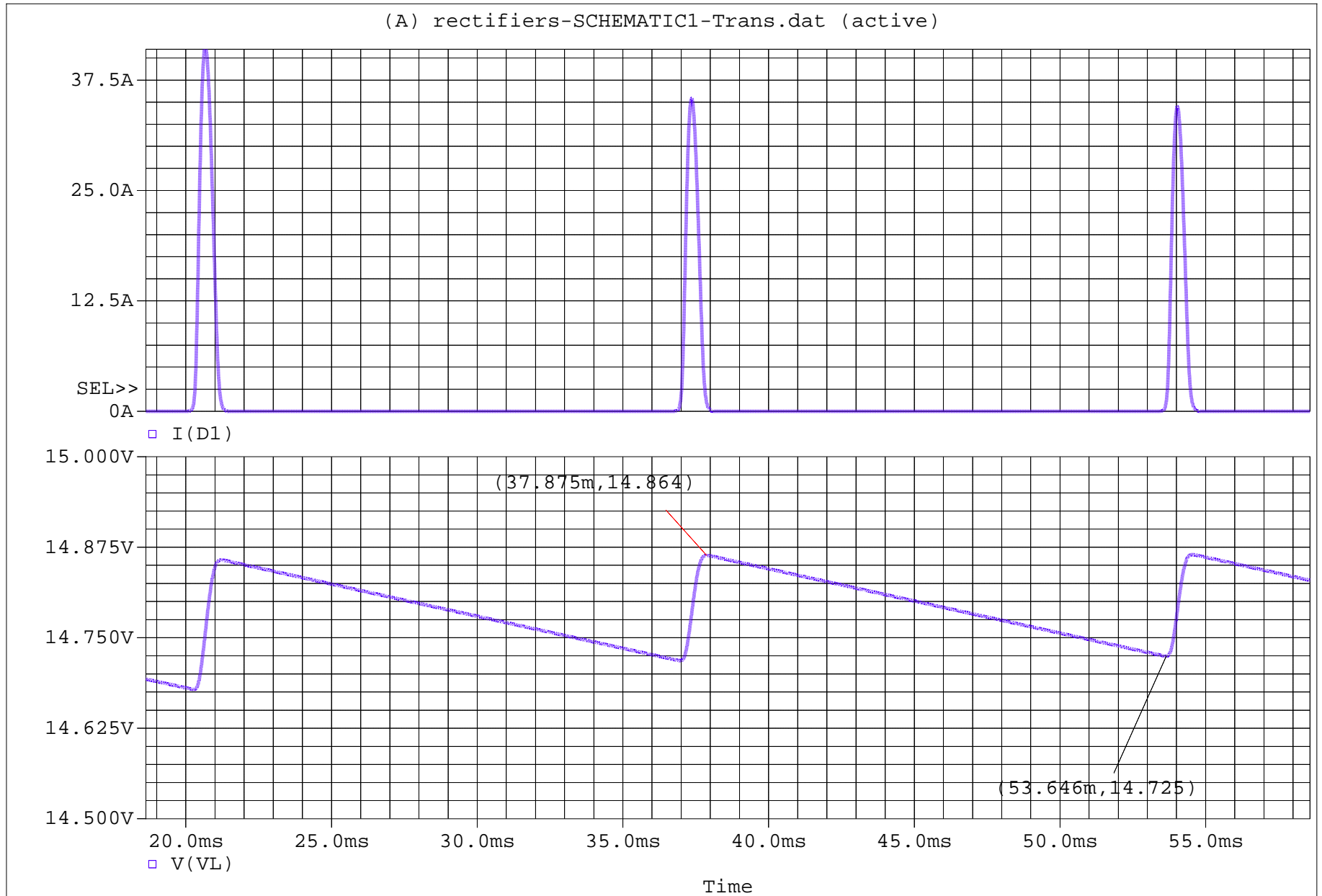






A1: (54.028m, 34.513) A2: (29.996m, -22.343u) DIFF(A): (24.032m, 34.513)





Another way of finding the diode avg current.

We used the method on p 134

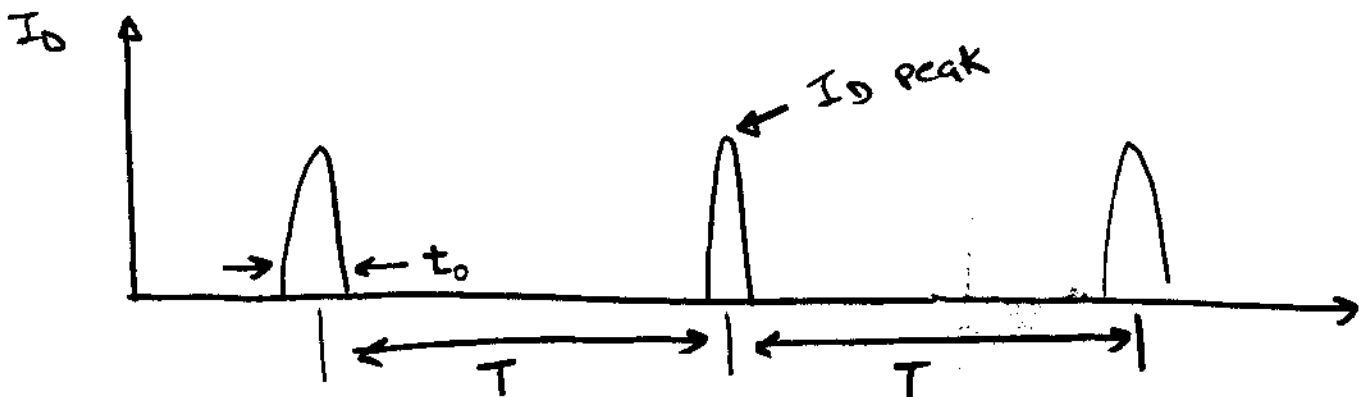
$$I_{cpeak} = C W V_p \cos(\omega t_{on}) \quad - \text{fairly accurate}$$

$$I_{Dpeak} = I_{cpeak} + I_{Rpeak} \quad - \text{Very Accurate}$$

$$I_{D|rms} = \frac{I_{Dpeak}}{\sqrt{2}} \quad - \text{Very conservative over estimate}$$

In Reality $\frac{I_{Dpeak}}{\sqrt{2}} \gg \text{actual value of } I_{D|rms}$

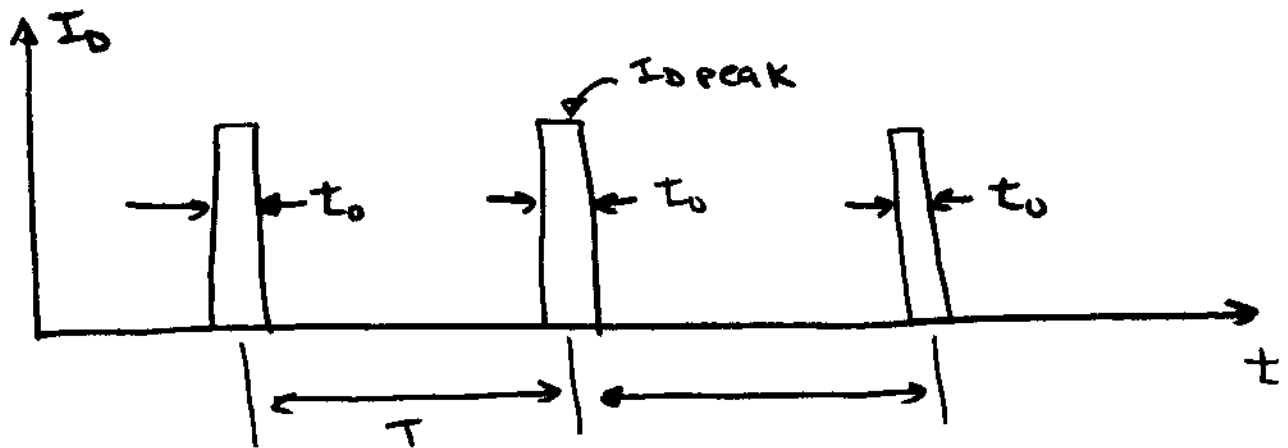
In Steady state, I_D looks like



- Since the pulses are very thin,

$I_0|_{Rms}$ is much smaller than $I_0 peak$

- We will approximate the waveform on the previous page by the waveform below



For this waveform $I_0|_{Rms} = I_0 peak \left(\frac{t_0}{T} \right)$

For the waveform on Page 141, $I_0 peak = 43A$,
 $t_0 \approx 1ms$, $T = 1/60$

$$\Rightarrow I_0|_{Rms} \approx (43) \left[\frac{1ms}{1/60} \right] = 2.6A Rms$$

Compare this value to using

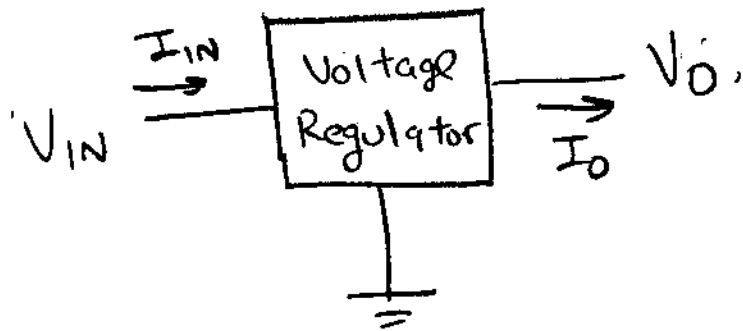
$$I_{D_{RMS}} = \frac{I_{D_{PEAK}}}{\sqrt{2}} = \frac{43}{\sqrt{2}} = 30.4A$$

- guaranteed to work
- expensive

Question: Can a 2.6A Rms diode handle repetitive peak current of 43A?

A 30.4A Rms diode is designed to handle 43A peak currents. A 2.6A Rms diode may not.

Voltage Regulators



Read psice
manual
pages 171-182

V_O is held constant at V_O For

$$0 < I_O < \text{rated maximum}$$

$$\underbrace{V_O + 2}_{\text{approx}} \leq V_{IN} < \text{rated maximum}$$

It is true that $I_O = I_{IN}$

Example

UA7815:

$$V_O = 15V, I_O = 1A \text{ max}$$

$$V_{IN} = 17V \text{ to } 35 \text{ volts}$$

Ripple rejection - The ratio of ripple on V_o as a function of the ripple on V_{in} . Usually specified

$$\text{Ripple Rejection} = 20 \log_{10} \left(\frac{\Delta V_{in}}{\Delta V_o} \right)$$

For the UA 7815

$$\text{Ripple rejection} = 70 \text{ dB}$$

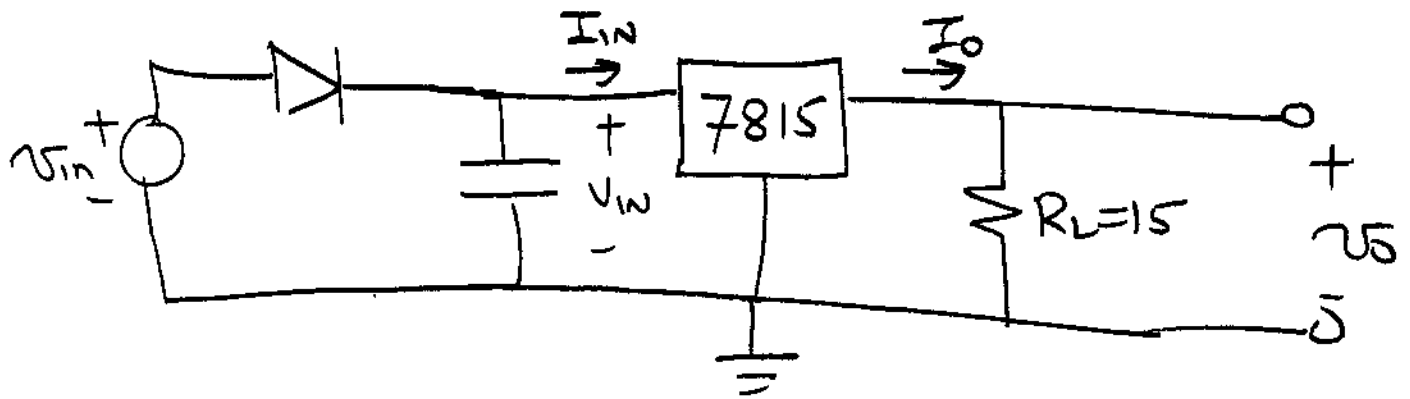
so

$$70 = 20 \log \frac{\Delta V_{in}}{\Delta V_o}$$

$$\Rightarrow \Delta V_o = \frac{\Delta V_{in}}{3162.3}$$

\Rightarrow Large ripple on input produces small ripple at output

15 volt regulated supply



Since V_o is constant at 15 volts
 I_o is constant at $I_o = 1A$. Since
 I_o is constant I_{in} is constant.

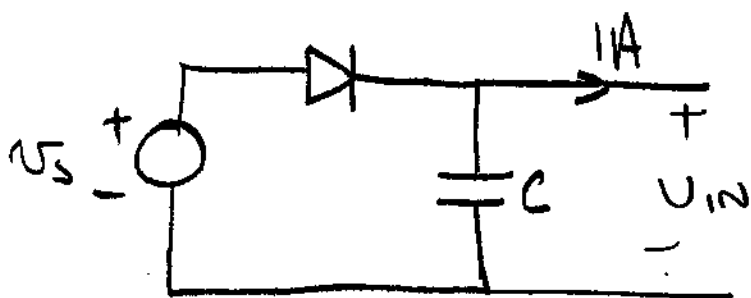
\Rightarrow With a regulator it is true
that the capacitor is being discharged
with a constant current.

\Rightarrow The regulator allows us to
have a very large ΔV_{in} .

For the 7815, V_{IN} can be between 17 and 35 volts and V_o would be constant at 15 volts.

- Let us design a 15 volt supply to supply 1A. We will use the regulator. All we need is to pick the voltage supply, Diode and capacitor.

Use a 24 volt RMS transformer
so $V_s = 24\sqrt{2} \sin \omega t$
 $= 34 \sin \omega t$



$$\begin{aligned} V_{IN \text{ max}} &= V_p - V_f \\ &= 34 - 0.7 \\ &\approx 33 \text{ V} \end{aligned}$$

The minimum input to the regulator is 17 volts. Design for 18 volts

$$\text{So } V_{IN \text{ max}} = 33V$$

$$V_{IN \text{ min}} = 18V$$

$$\Delta V = V_{IN \text{ max}} - V_{IN \text{ min}} = 15 \text{ volts}$$

Since ΔV is so large we can use a much smaller diode and capacitor than before.

- Now find the capacitor. The capacitor is being discharged with a constant current

$$\Delta V = \frac{I T}{C} \Rightarrow C = \frac{I T}{\Delta V} = \frac{(1A)(1/60)}{15}$$
$$= 1111 \mu F$$

$C = 1111 \mu F$ is a reasonable value.

- Now Find the diode parameters.

$$t_{on} = \frac{\sin^{-1} \left[1 - \frac{\Delta V}{V_p} \right]}{\omega} = \frac{\sin^{-1} \left[1 - \frac{15}{34} \right]}{2\pi 60}$$
$$= 1.57 \text{ msec}$$

$$I_c|_{peak} = C \omega V_p \cos(\omega t_{on})$$
$$= (1111 \times 10^{-6}) (2\pi 60) (34) \cos(2\pi 60 \times 0.00157)$$
$$= 11.8 \text{ A}$$

The diode current is the capacitor current plus the regulator current I_W .

$$I_d|_{peak} = I_W + I_c|_{peak} = 12.8 \text{ A peak}$$

- The diode Avg. forward current is

$$I_D \text{ Avg. forward current} = \frac{12.8}{\sqrt{2}} = 9.05 \text{ A rms}$$

$$\begin{aligned} - I_{FSM} &= C \omega V_p = (1111 \times 10^{-6})(2\pi 60)(34) \\ &= 14.24 \end{aligned}$$

$$V_{RRM} = Z V_p = 68 \text{ Volts}$$

- Now find the ripple at the output. From the ripple rejection ratio we know that

$$\Delta V_o = \frac{\Delta V_{IN}}{3162.3} = \frac{15}{3162.3} = 4.75 \text{ mV}$$

$$\% \Delta V_o = 0.0316 \% \text{ ripple}$$

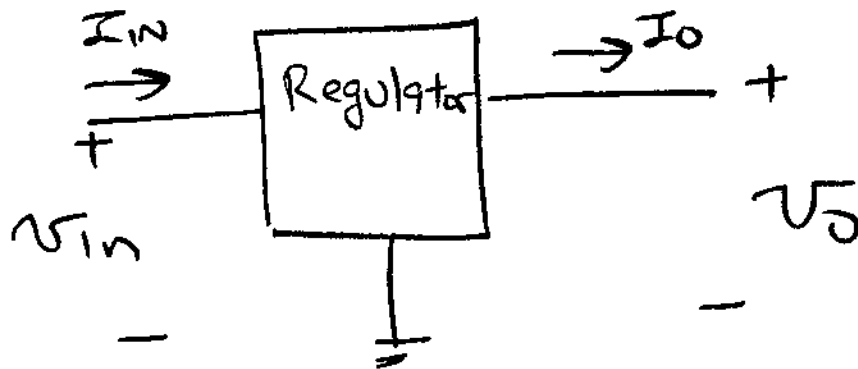
Comparison of Power supplies

	7815 Regulated	Un regulated
Capacitor	1111 μ F	0.1111 F
Avg. Forward diode current	9.05 Arms	64.1 Arms
IFSM	14.2 A	658 A
VRRM	68	31.4
Ripple	0.316%	1%
Diode	1N200 A, B, C MR11Z1	

Not only is the regulated supply a better supply, its components are smaller and cheaper. The 7815 IC costs about \$1.



The last thing we need to calculate is the average power dissipated by the regulator



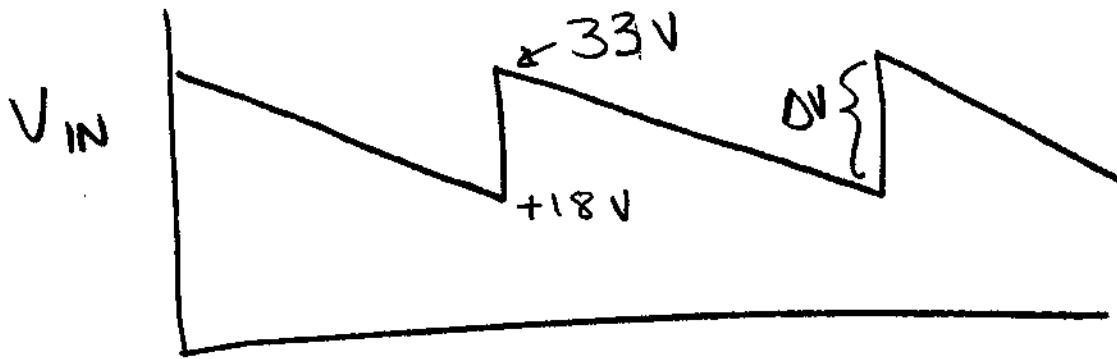
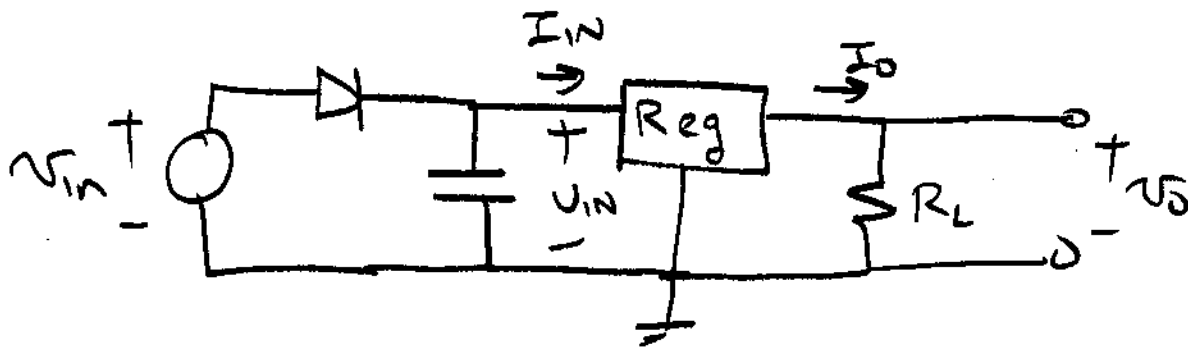
$$P_{in} = V_{in} I_{in}$$

$$P_{out} = V_o I_o$$

Power dissipated by regulator

$$P_{reg} = P_{in} - P_{out}$$

- The voltage input to the regulator is not constant



Note that I_{IN} , I_O and V_o are constant.
For our example

$$I_O = I_{IN} = 1A, \quad V_o = 15V$$

$$\Rightarrow P_o = (1A)(15V) = 15W$$

- The maximum power input to the regulator is

$$P_{in\max} = V_{in\max} I_{in} = (33V)(1A) = 33W$$

- The minimum power input is

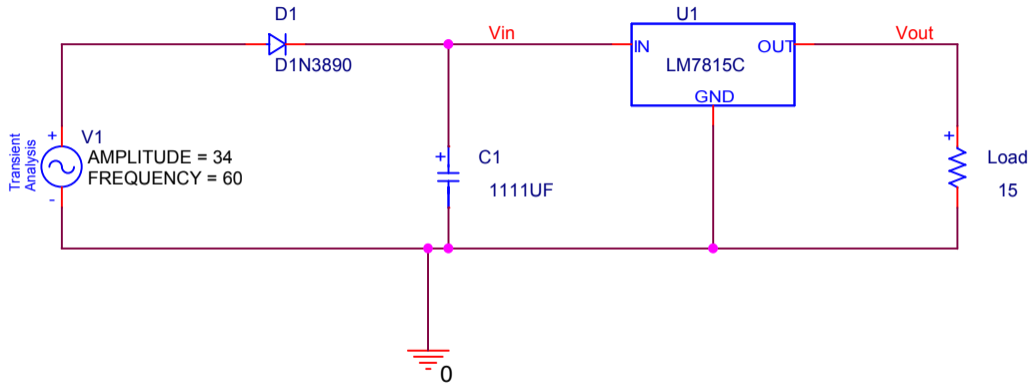
$$P_{in\min} = (V_{in\min})(I_{in}) = (18)(1A) = 18W$$

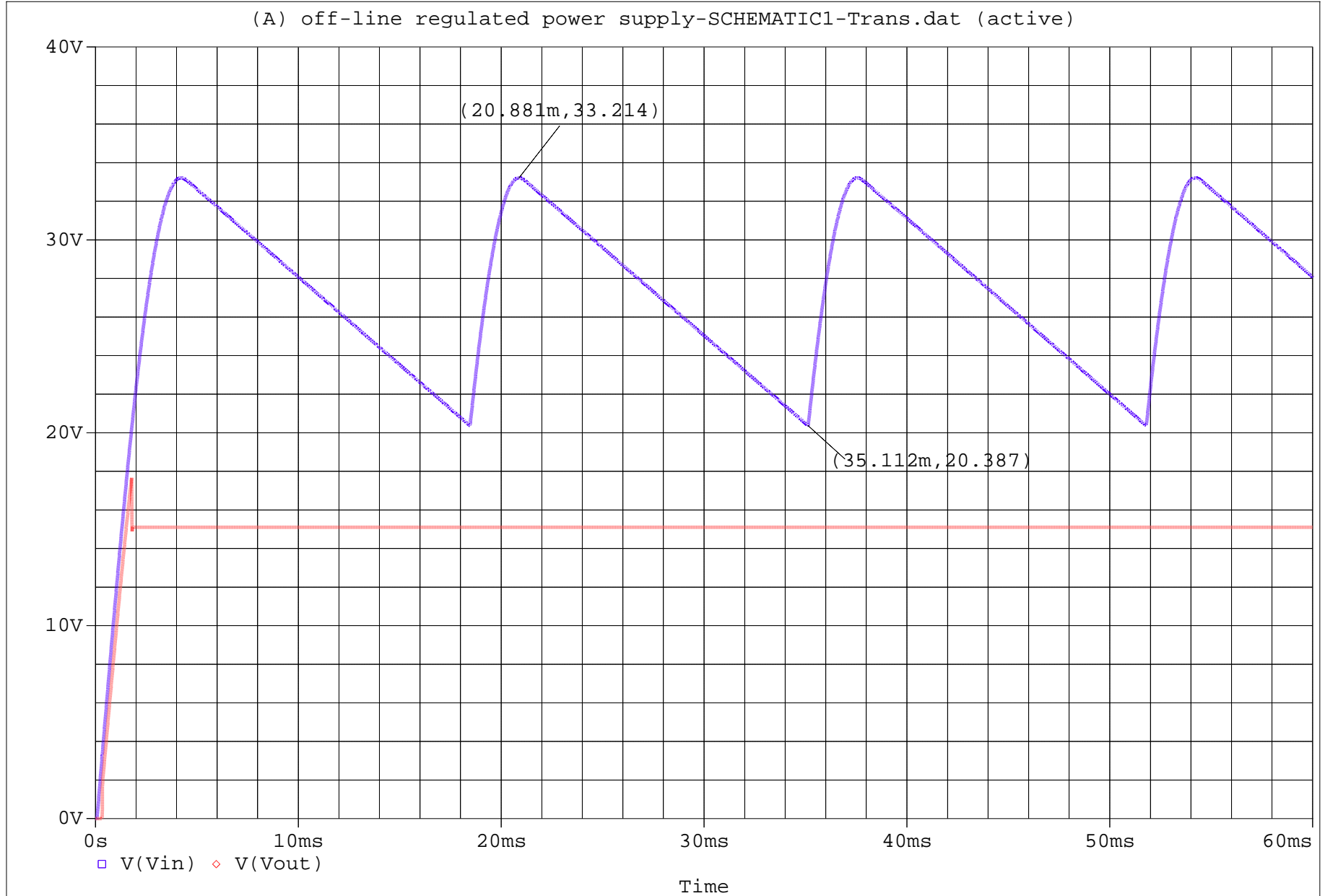
- Due to the shape of V_{in}

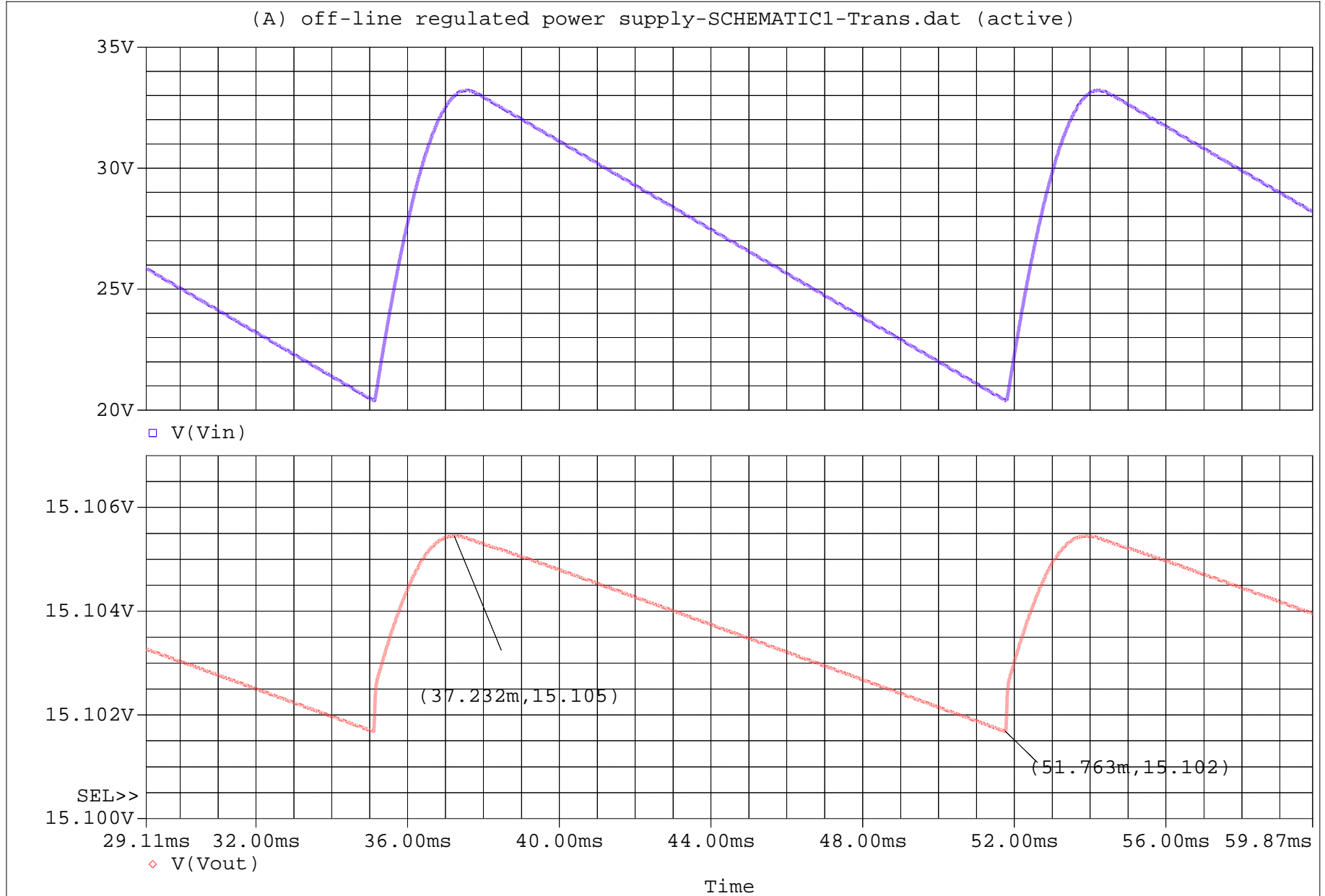
$$\begin{aligned} P_{in\text{avg}} &= \frac{P_{in\max} + P_{in\min}}{2} \\ &= \frac{33W + 18W}{2} = 25.5W \end{aligned}$$

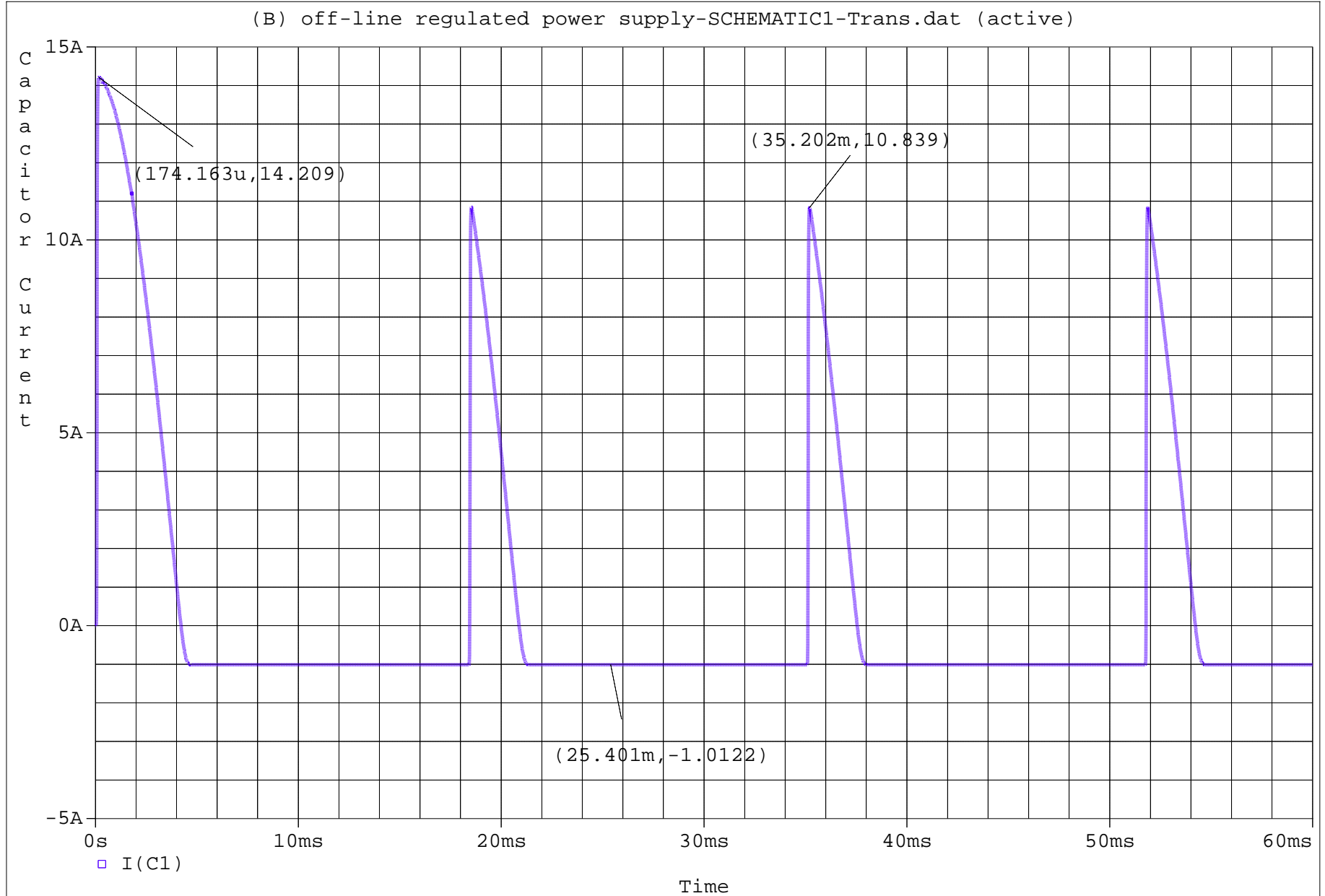
Thus

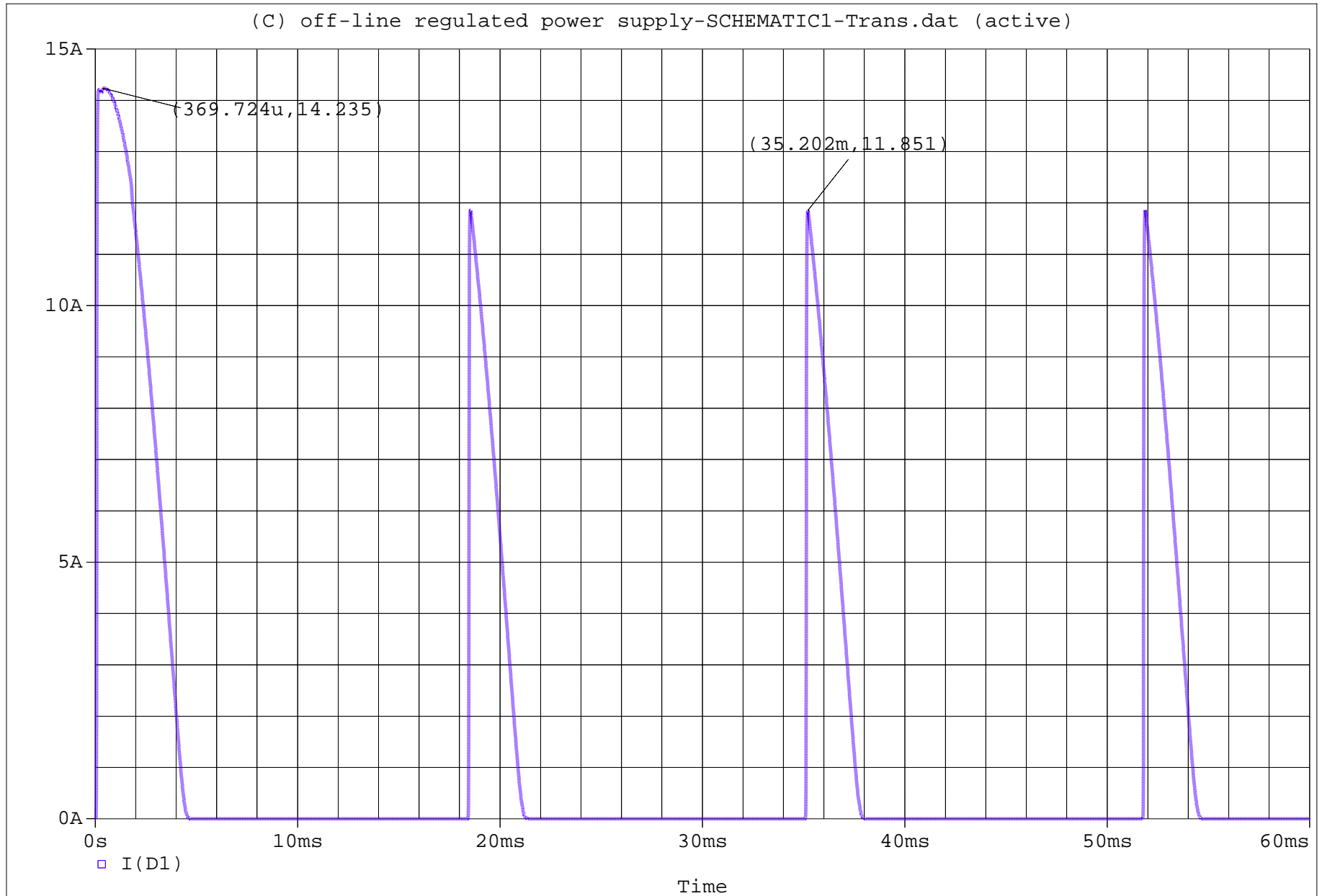
$$\begin{aligned} P_{reg} &= P_{in\text{avg}} - P_{out} \\ &= 25.5W - 15W = 10.5W \end{aligned}$$



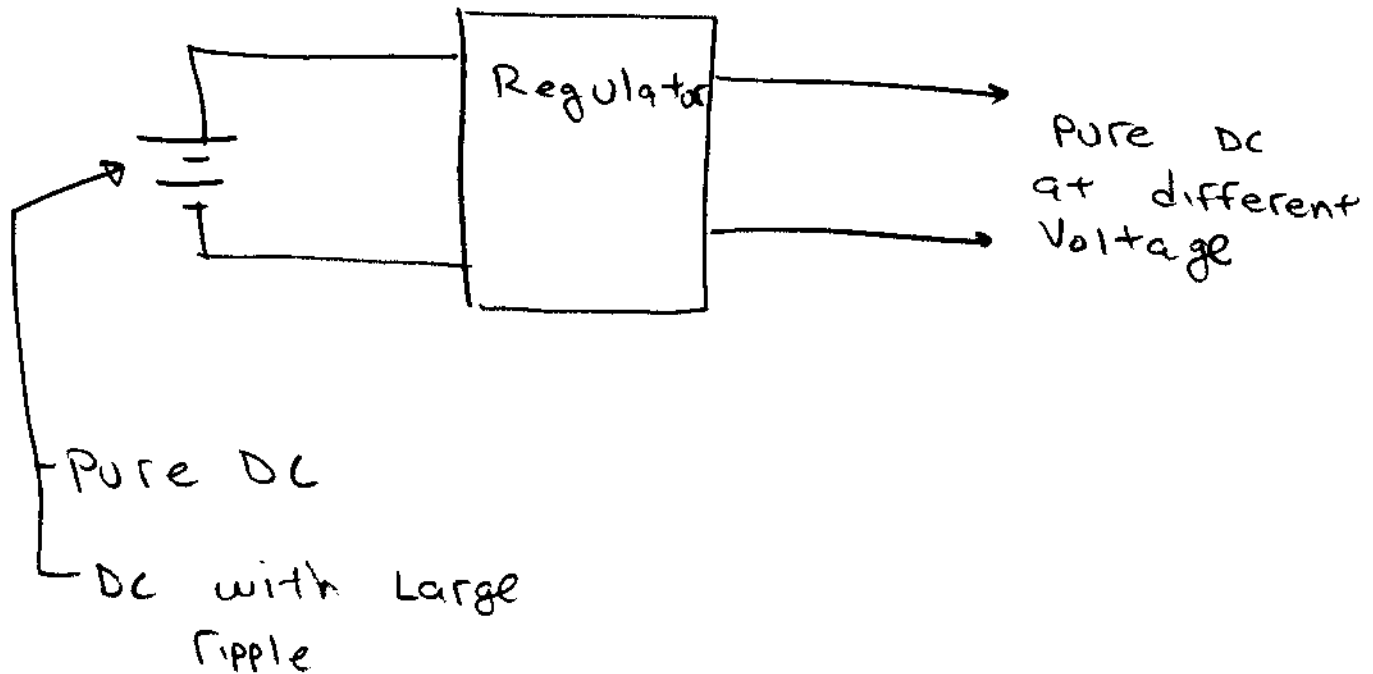








So what we have now is

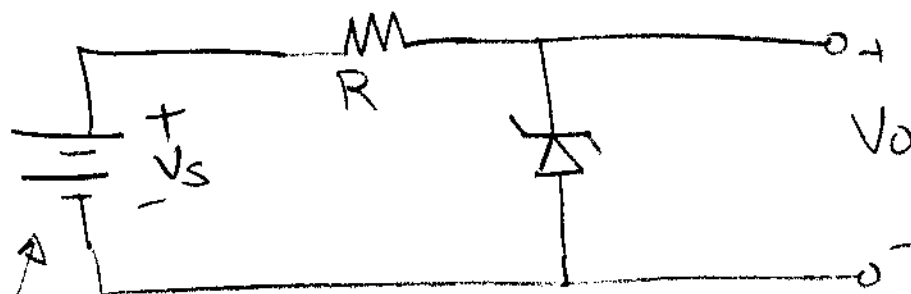


- IF AC - DC then
This is a Rectifier
and filter cap

- IF DC - DC then
this is a DC
Supply

Linear Regulators

Zener Regulator



- D.C. Supply
with Ripple

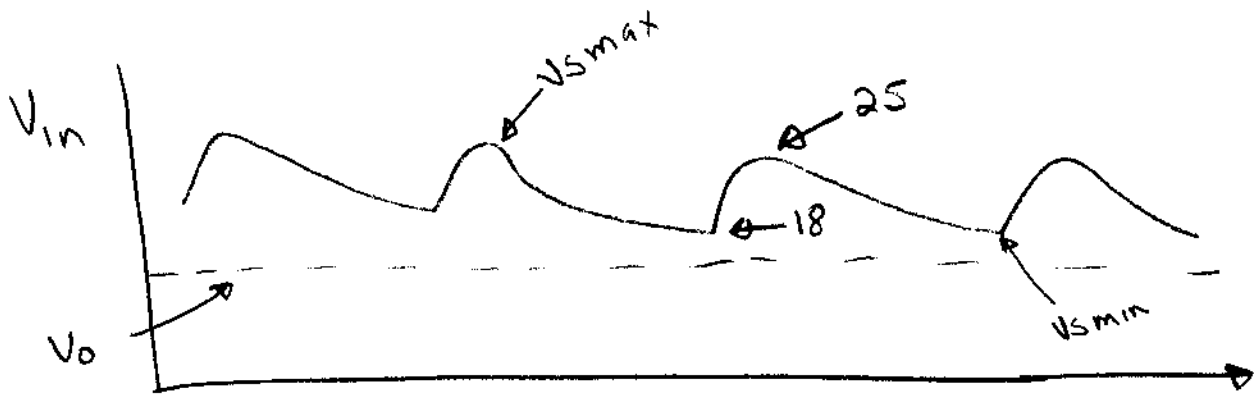
- Waveform From a Rectifier + Filter cap.

Design Problems

- want $V_o = 15V$ @ $1A$

- V_{in} is supplied from a Bridge Rectifier
and Filter Capacitor with

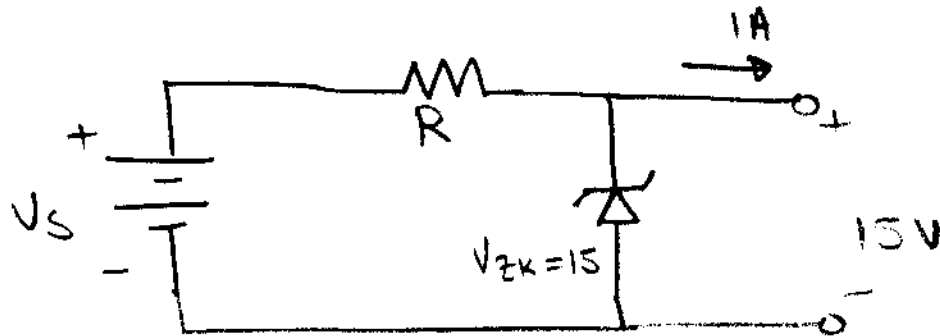
$$18 \leq V_{in} \leq 25$$



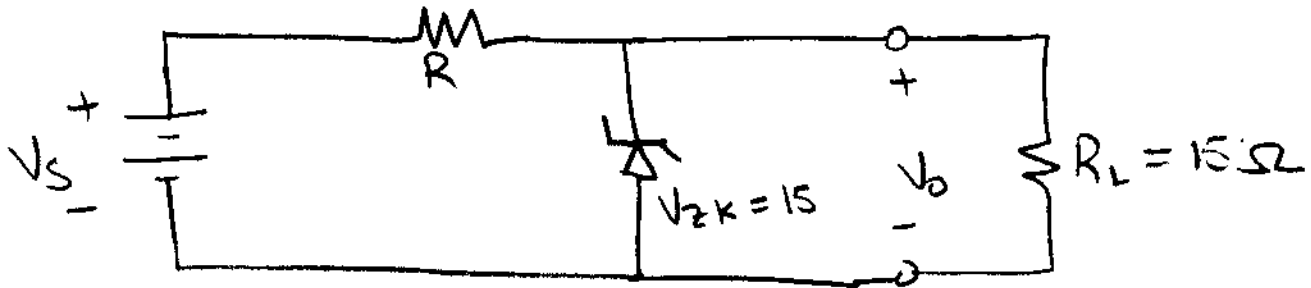
Design:

- Need a 15V Zener
- To have constant V_o , the Zener must always be broken down

Design for maximum load of 1A.

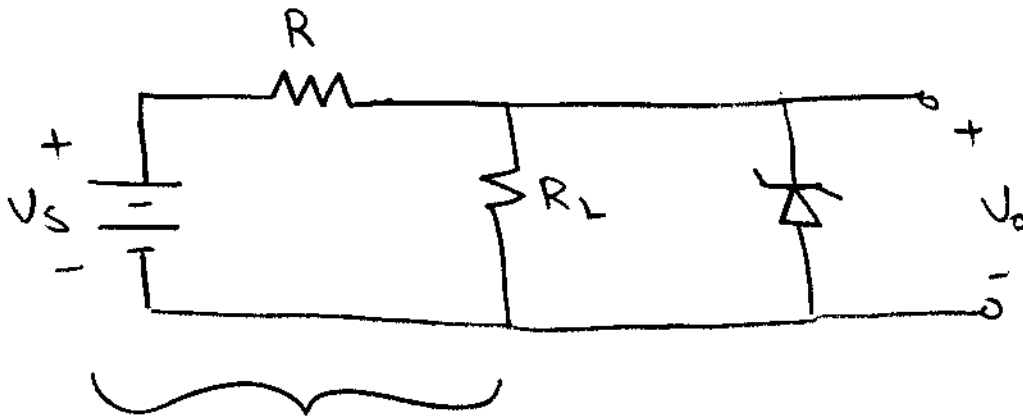


Equivalent circuit at max Load

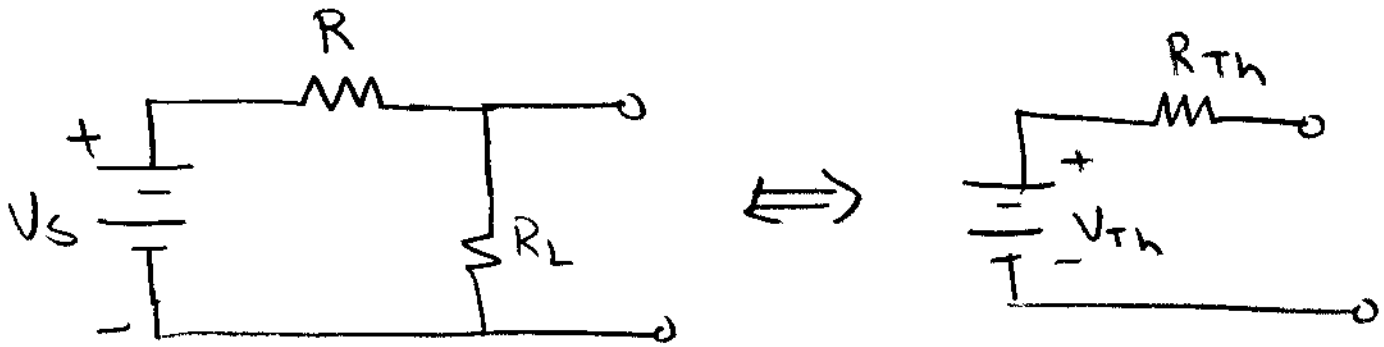


Question: What value should R be if we want the Zener to always be broken down?

Redraw:

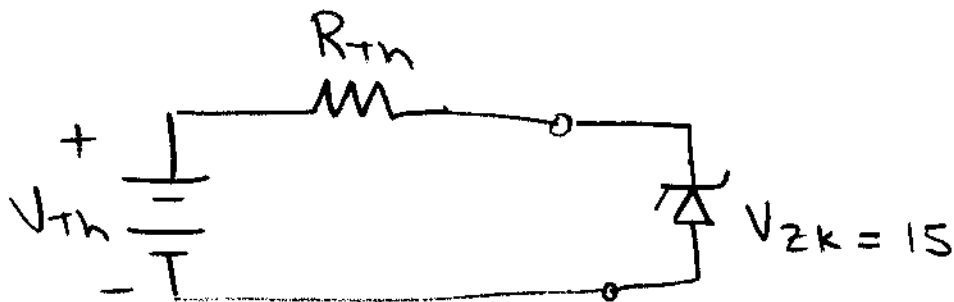


Make a
Thevenin Equivalent



Where $V_{Th} = \frac{V_s R_L}{R + R_L}$, $R_{Th} = R_L \parallel R$

So our circuit becomes:



Question: When is the Zener broken down?

Answer: $V_{Th} > V_{ZK}$

So

$$V_{TH} > V_{ZK} \quad \text{OR}$$

$$\frac{V_S R_L}{R + R_L} > 15 \quad \text{always}$$

Worst case: If this is true for V_{Smin} then the inequality is true for V_{Smax}

So we want

$$\frac{V_{Smin} R_L}{R + R_L} > 15$$

Solve for R

$$R < \frac{V_{Smin} R_L}{15} - R_L$$

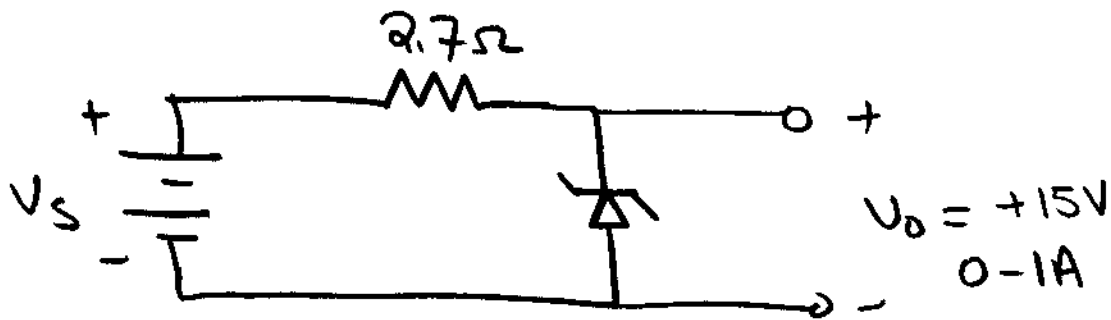
$$\text{OR } R < \frac{(18V)(15\Omega)}{15V} - 15\Omega$$

OR

$$R < 3\Omega$$

choose $R = 2.7\Omega$ - STD 5%

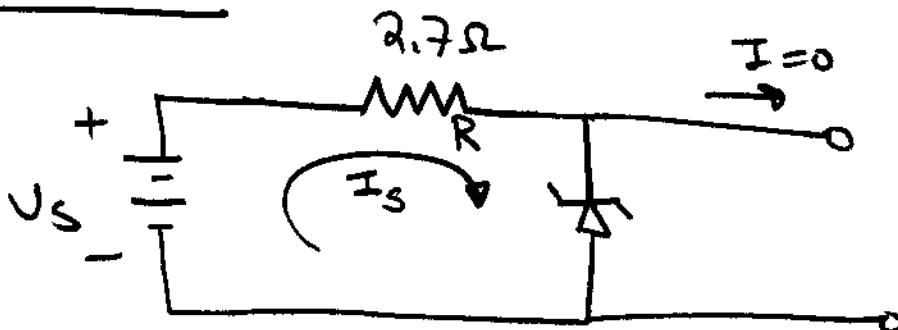
So our Regulator is



$$V_s = 18 - 25V$$

NEXT, Find the Power dissipation

No Load



$$I_s = \frac{V_s - V_{ZK}}{R}$$

- The power dissipated in R and the Zener is $V_s I_s$

$$\text{When } V_s = 18 \text{ V, } I = \frac{V_s - V_{ZK}}{R} = \frac{18 - 15}{2.7} = 1.11 \text{ A}$$

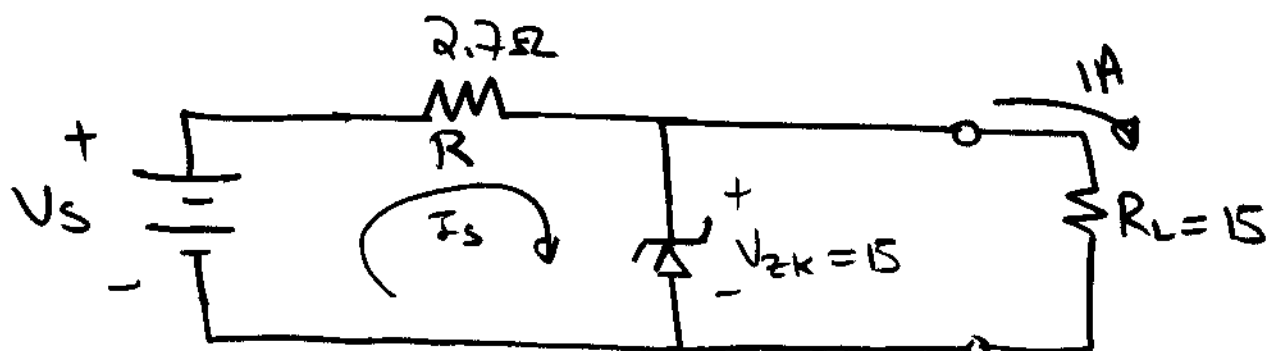
$$P = (18 \text{ V})(1.11 \text{ A}) = 20 \text{ W}$$

$$\text{When } V_s = 25 \text{ V, } I = \frac{V_s - V_{ZK}}{R} = \frac{25 - 15}{2.7} = 3.7 \text{ A}$$

$$P = (25 \text{ V})(3.7 \text{ A}) = 92.5 \text{ W}$$

Since V_s is periodic, the avg power is somewhere between 20W + 92.5W

Note: $P_{in} > 20 \text{ W}$
 $P_{out} = 0$ } Not efficient

Maximum load

Output Power :

$$P_o = (V_o)(I_o) = (15V)(1A) = 15W$$

Input Power

$$P_{in} = (V_s)(I_s)$$

$$I_s = \frac{V_s - V_{zk}}{R}$$

- Since V_{zk} is always 15V, I_s is the same as before

When $V_s = 25V$, $P_{in} = 92.5W$

when $V_s = 18V$, $P_{in} = 20W$

Avg input Power is between $20W + 92.5W$

at Full load

$$P_o = 15W$$

$$P_{in} > 20W$$

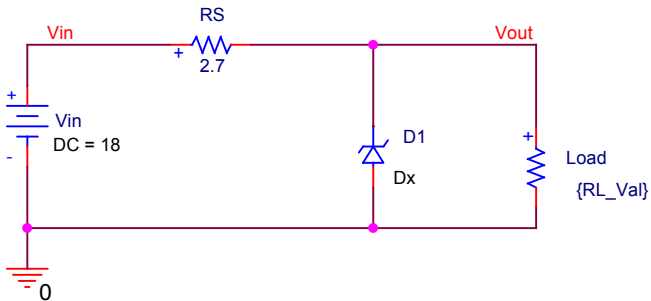
} 75% efficient
at Best

NOTE: P_{IN} is the same independent
of P_{out} .

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PARAMETERS:

$RL_val = 1MEG$



Model = Dx D BV=15 RS=1m IBV=.3

ECE556 Lecture Notes

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Simulation Settings - DC Sweep [X]

General Analysis Include Files Libraries Stimulus Options Data Collection Probe Window

Analysis type:

Options:
 Primary Sweep
 Secondary Sweep
 Monte Carlo/Worst Case
 Parametric Sweep
 Temperature (Sweep)
 Save Bias Point
 Load Bias Point

Sweep variable:
 Voltage source Name:
 Current source Model type:
 Global parameter Model name:
 Model parameter Parameter name:
 Temperature Parameter name:

Sweep type:
 Linear Start value:
 Logarithmic Decade End value:
 Points/Decade:
 Value list

OK Cancel Apply Help

Simulation Settings - DC Sweep [X]

General Analysis Include Files Libraries Stimulus Options Data Collection Probe Window

Analysis type:

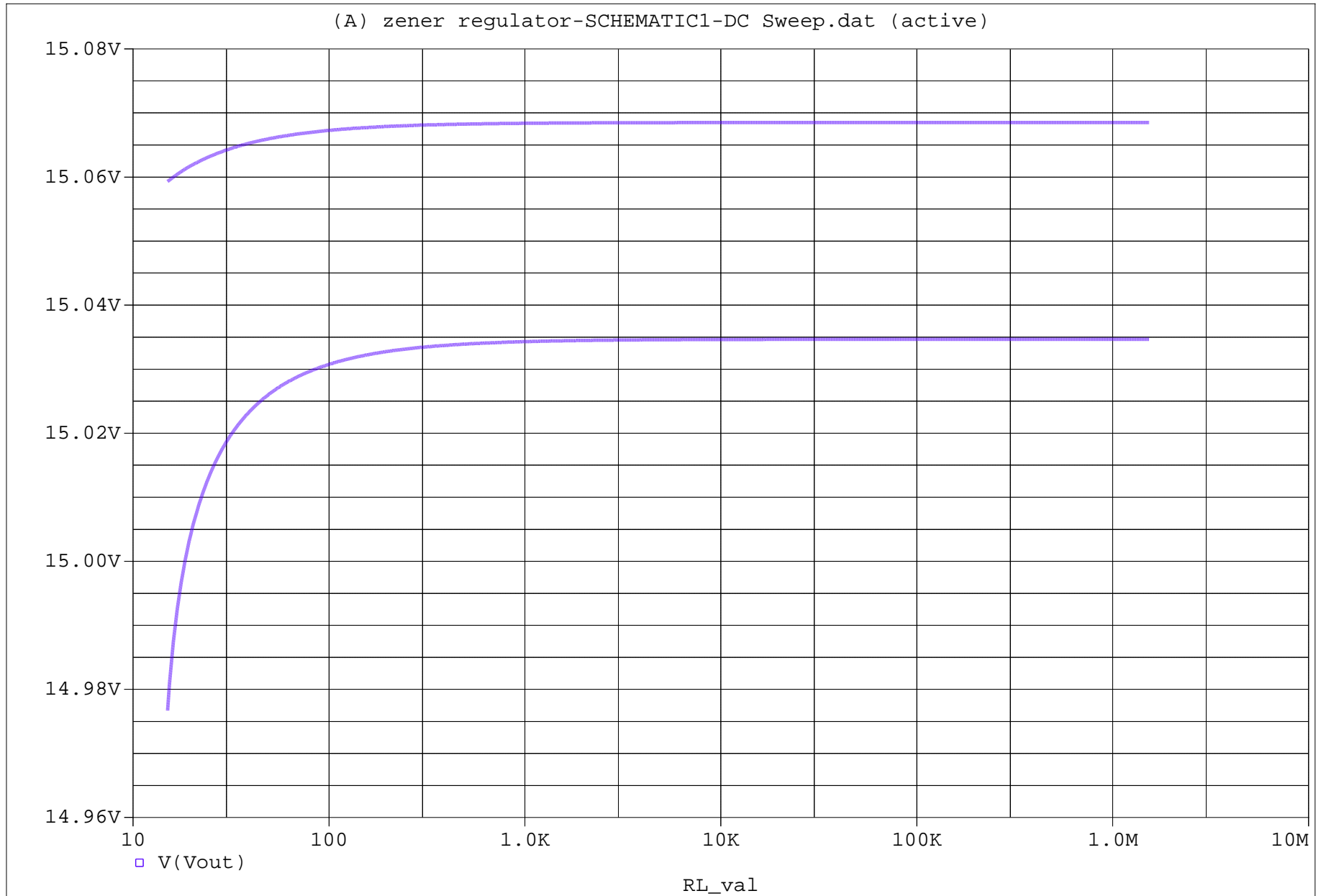
Options:
 Primary Sweep
 Secondary Sweep
 Monte Carlo/Worst Case
 Parametric Sweep
 Temperature (Sweep)
 Save Bias Point
 Load Bias Point

Sweep variable:
 Voltage source Name:
 Current source Model type:
 Global parameter Model name:
 Model parameter Parameter name:
 Temperature Parameter name:

Sweep type:
 Linear Start value:
 Logarithmic Decade End value:
 Increment:
 Value list

OK Cancel Apply Help

** Profile: "SCHEMATIC1-DC Sweep" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Zener Regulator\zen...
Date/Time run: 12/16/02 10:33:48 Temperature: 27.0



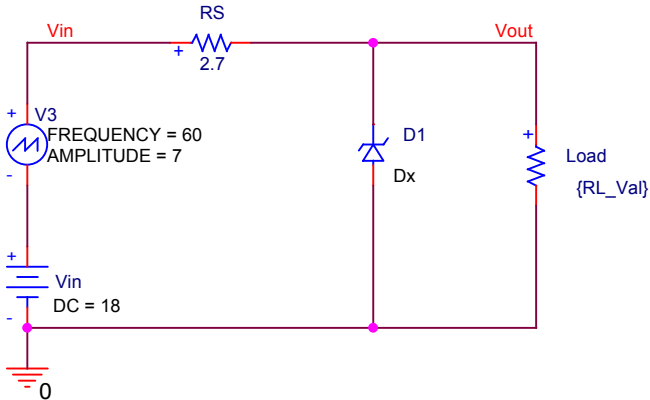
Date: December 16, 2002

Page 1

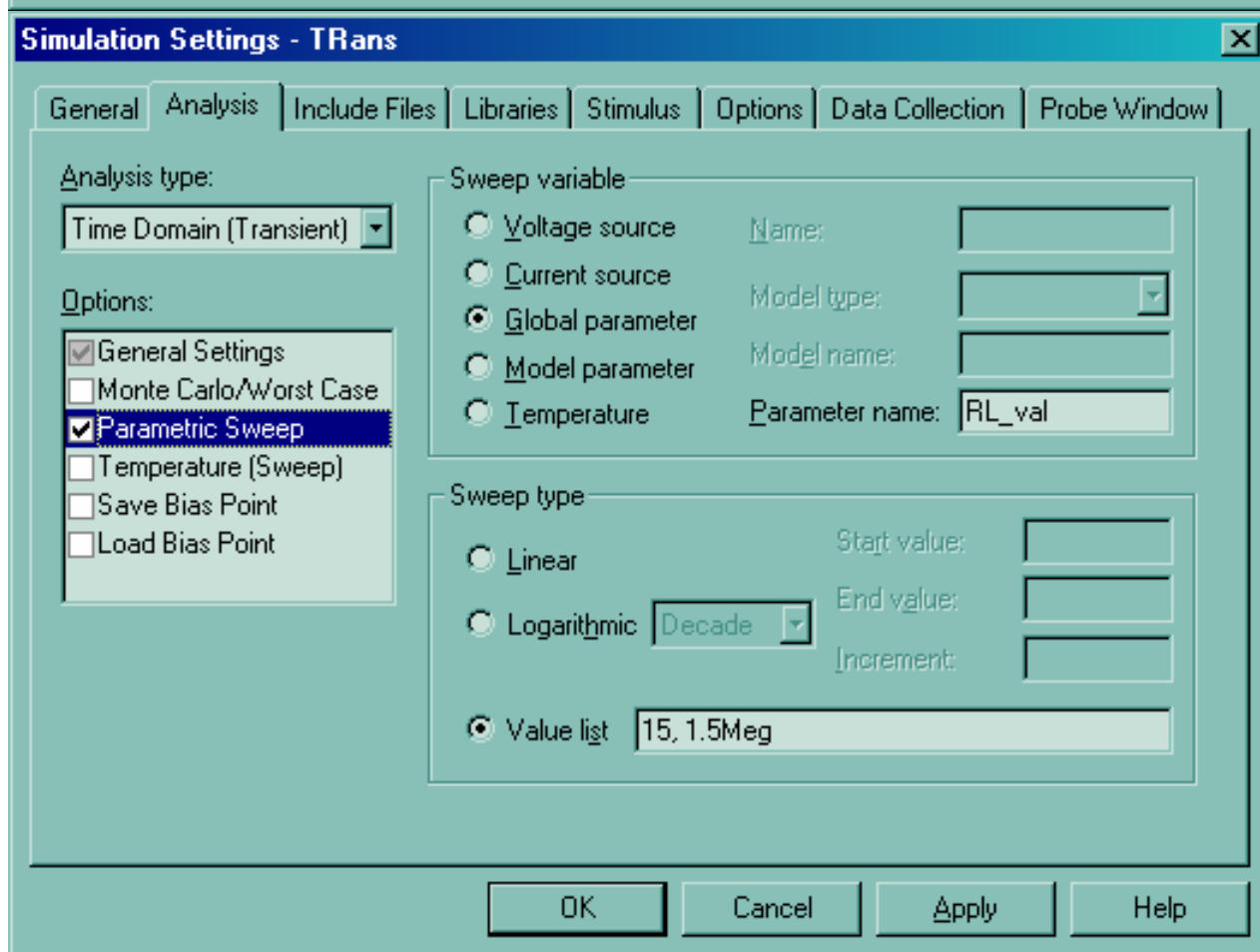
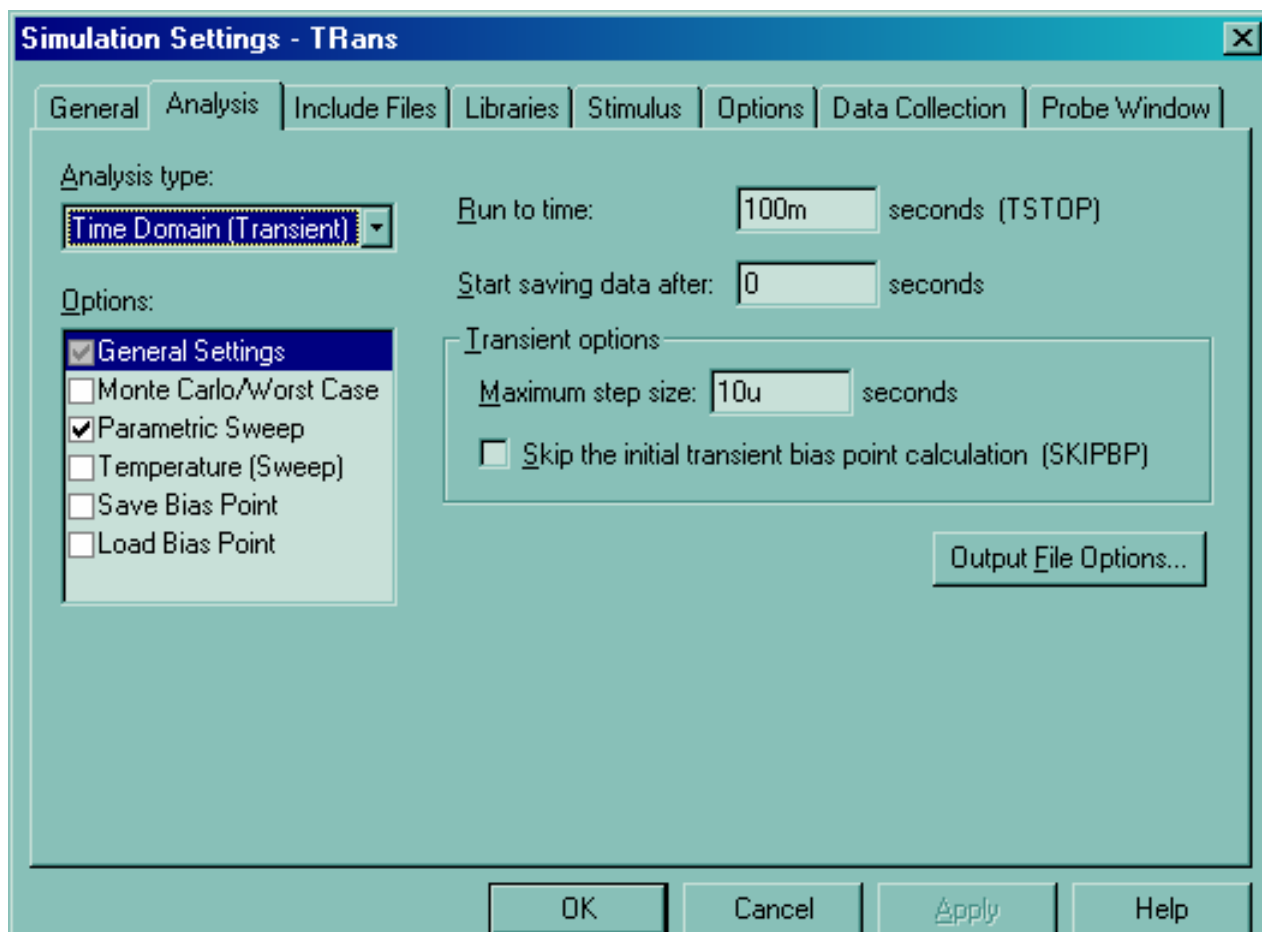
Time: 10:37:40

PARAMETERS:

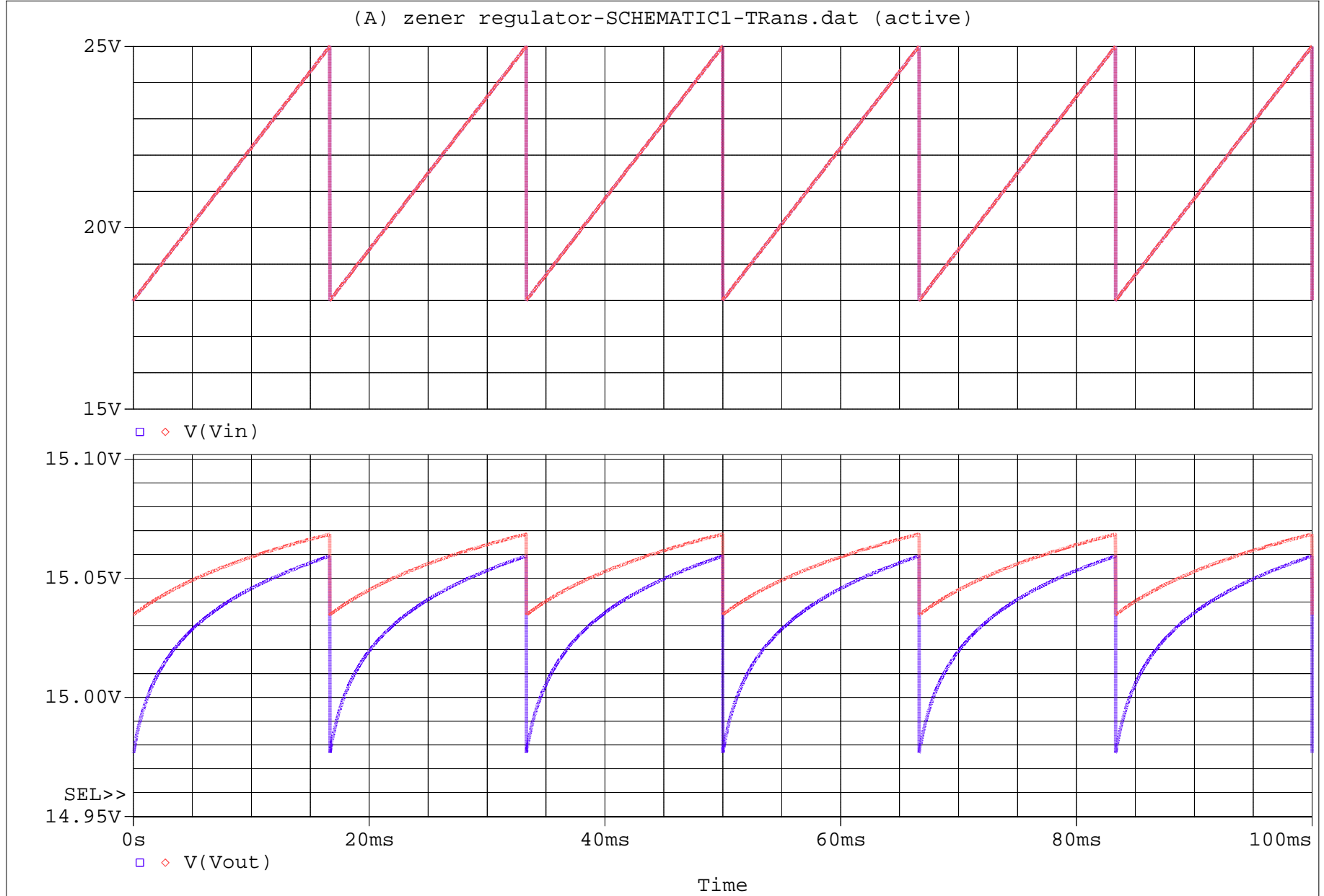
RL_val = 1MEG



Model = Dx D BV=15 RS=1m IBV=.3



** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Zener Regulator\zener ...
Date/Time run: 12/16/02 10:44:41 Temperature: 27.0

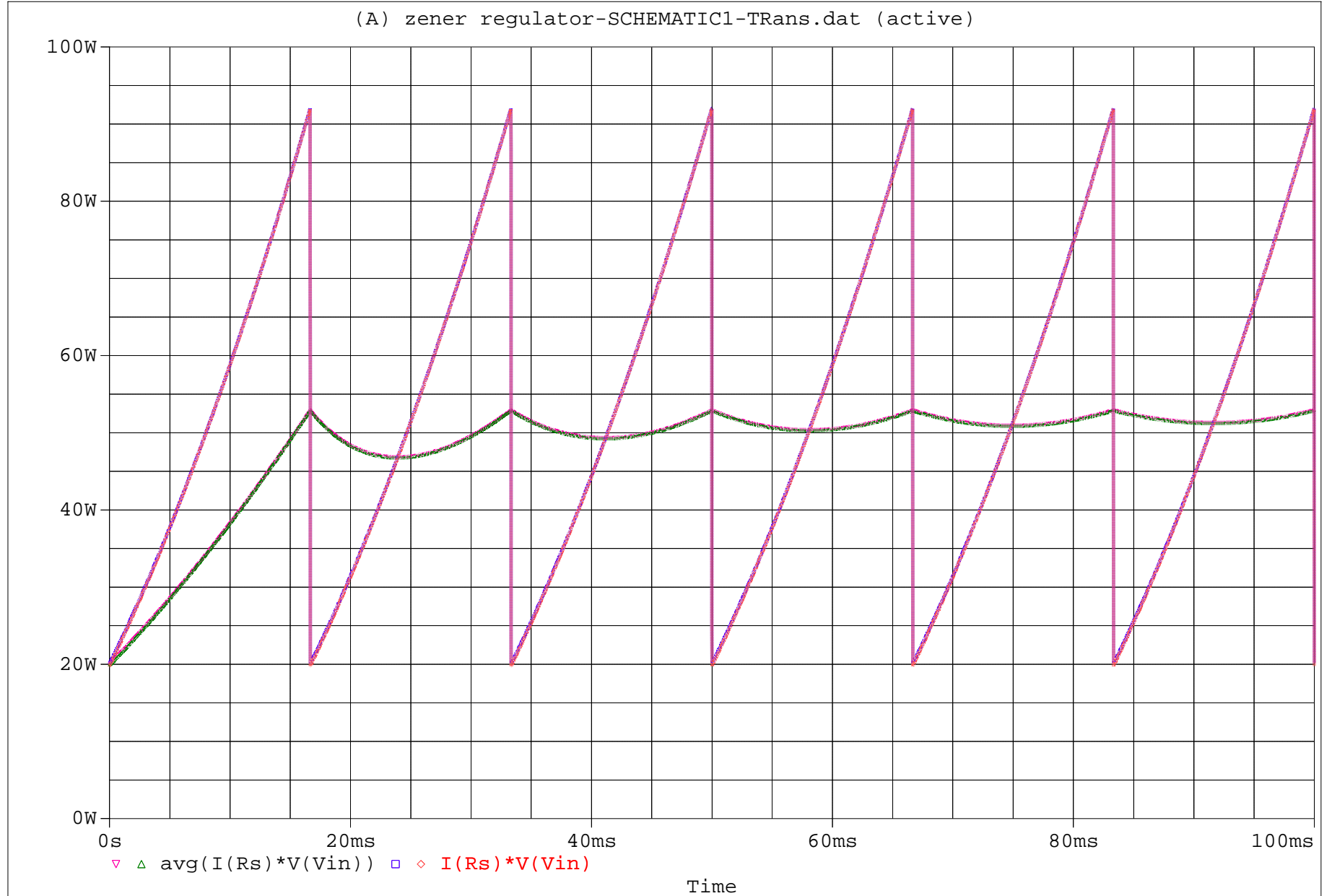


Date: December 16, 2002

Page 1

Time: 10:46:51

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 Date/Time run: 12/16/02 10:44:41 Temperature: 27.0



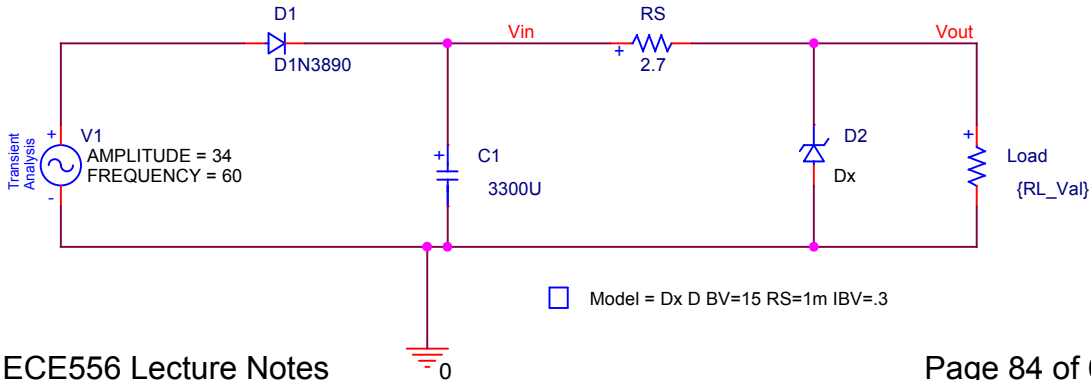
Date: December 16, 2002

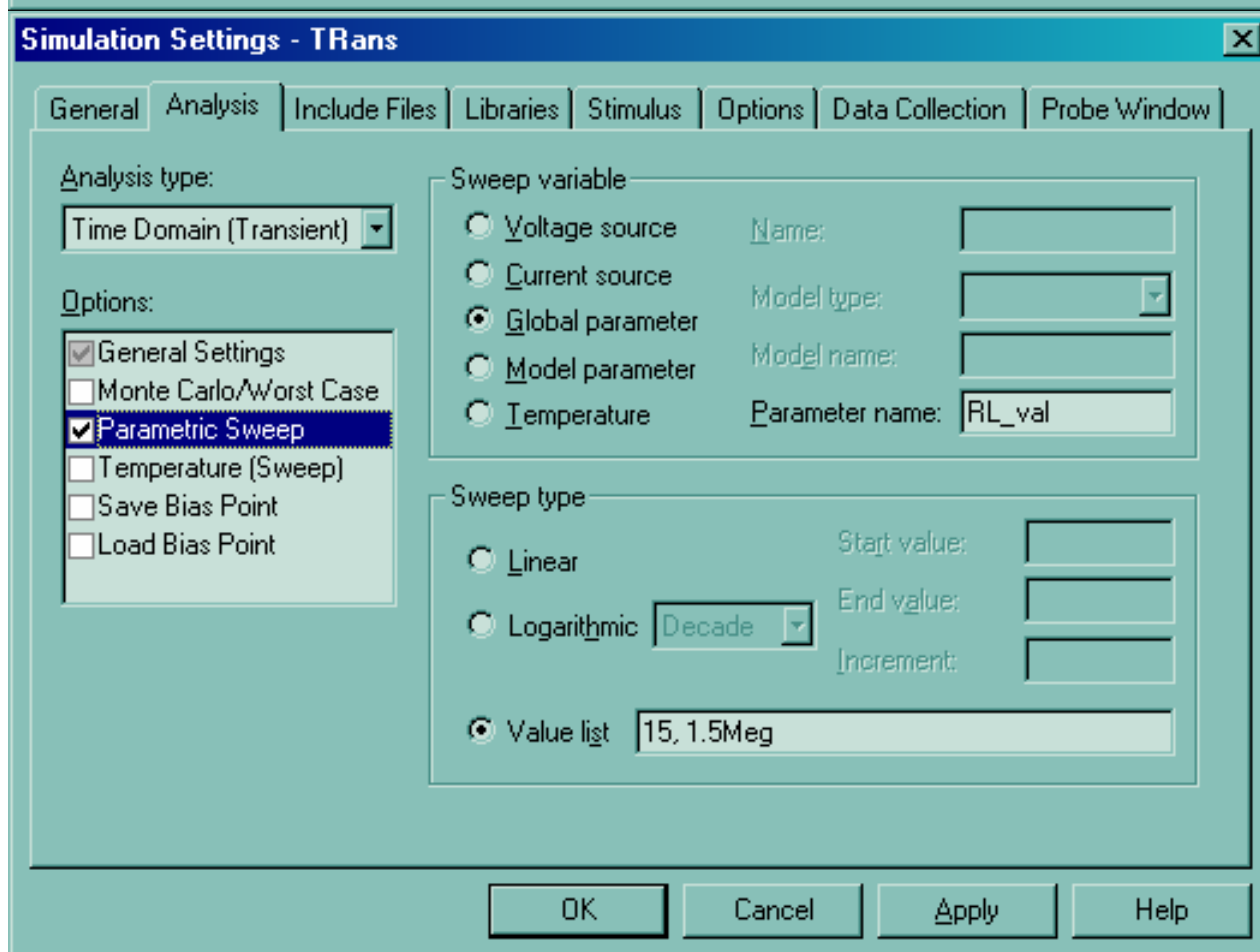
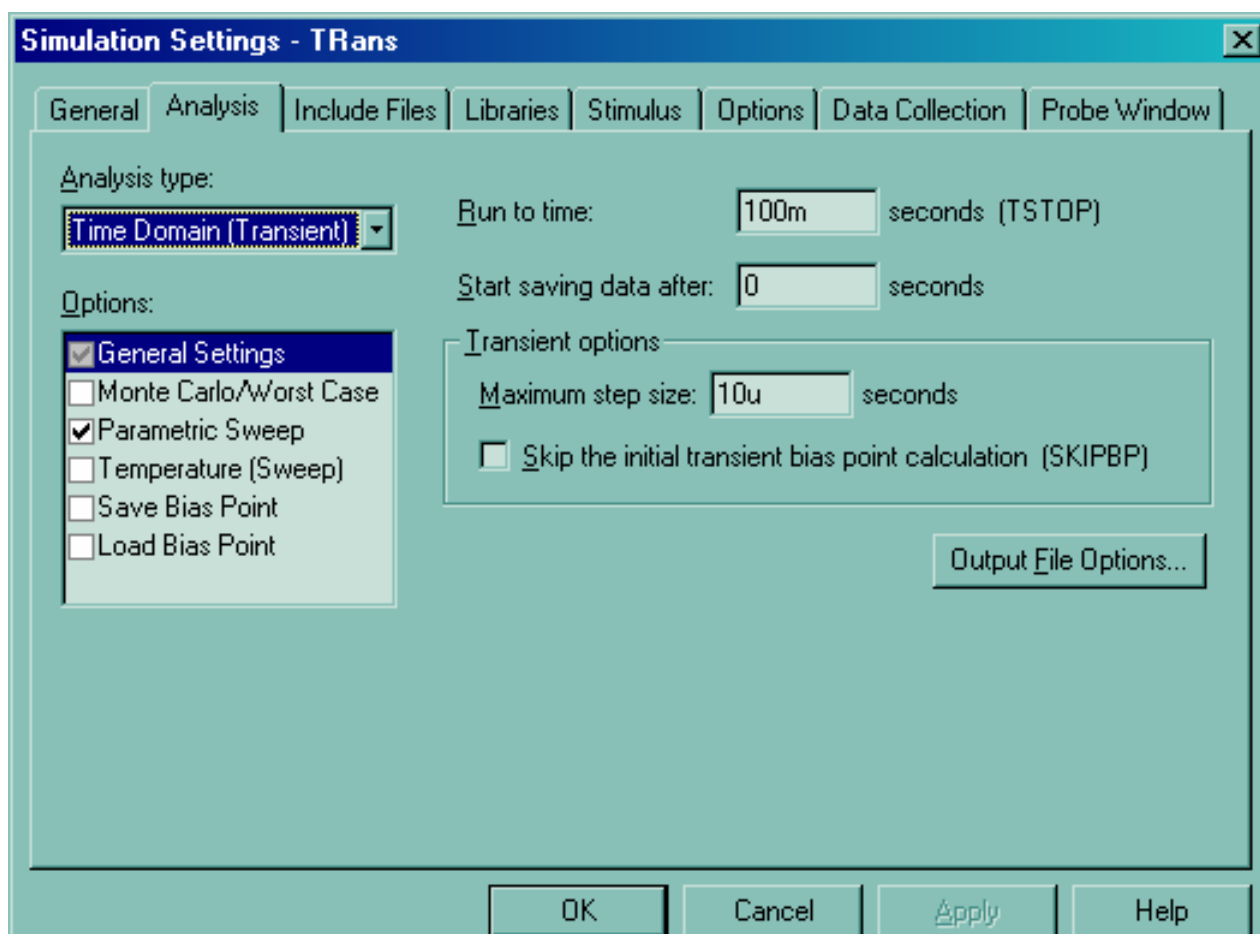
Page 1

Time: 11:02:26

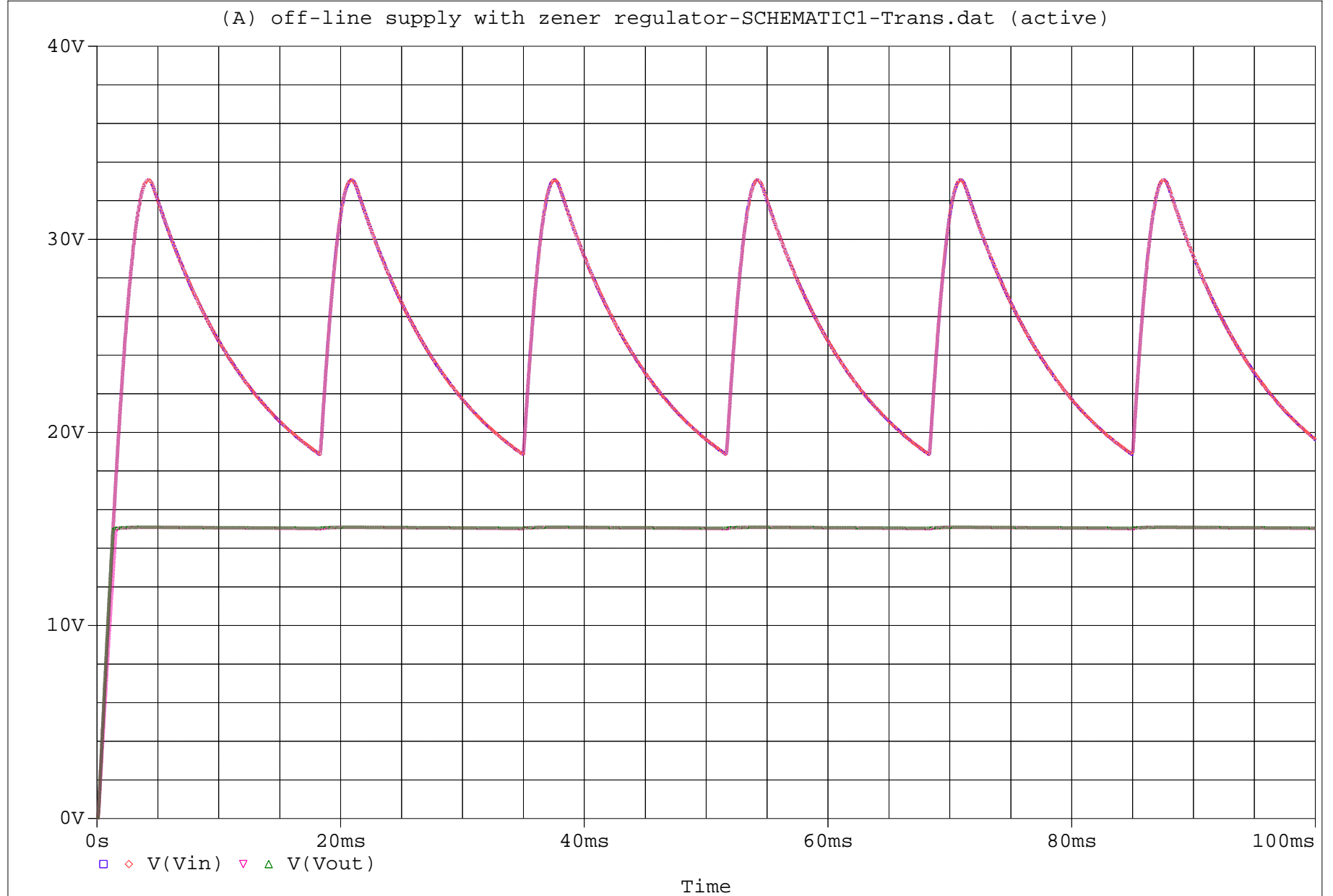
PARAMETERS:

RL_val = 1MEG





** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Zener Regulator\off-li...
Date/Time run: 12/16/02 11:21:32 Temperature: 27.0

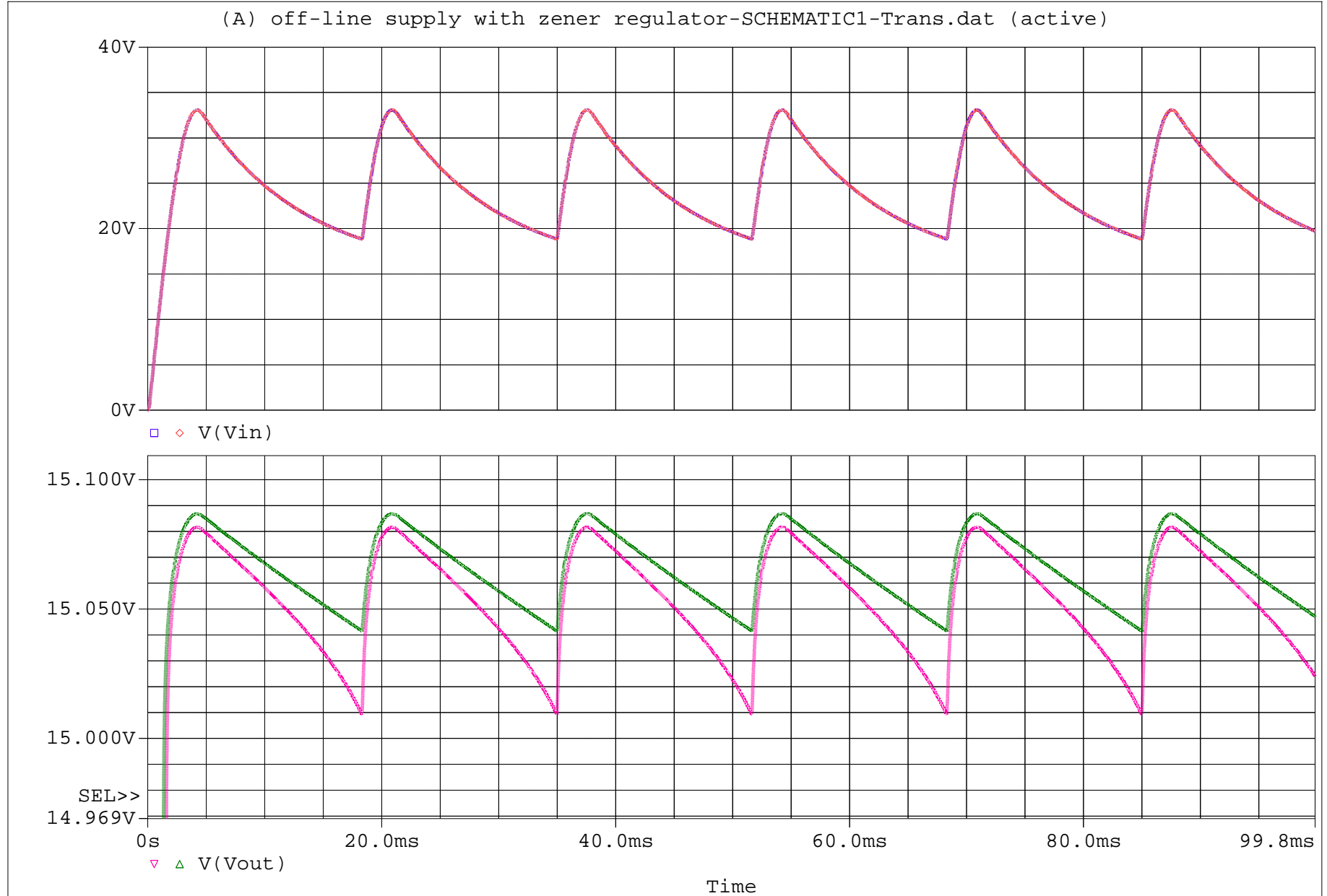


Date: December 16, 2002

Page 1

Time: 11:23:03

** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Zener Regulator\off-li...
Date/Time run: 12/16/02 11:21:32 Temperature: 27.0



Date: December 16, 2002

Page 1

Time: 11:24:27

Zener Linear Regulator Calculations

Specify the Regulator Parameters

$$V_o := 15 \cdot \text{volt} \quad I_o := 1 \cdot \text{amp}$$

$$V_{\text{in_min}} := 18 \cdot \text{volt} \quad V_{\text{in_max}} := 25 \cdot \text{volt} \quad T := 1 \cdot \text{sec}$$

Define the input voltage waveform

$$V_{\text{in}}(t) := V_{\text{in_max}} - \frac{V_{\text{in_max}} - V_{\text{in_min}}}{T} \cdot t$$

Calculate the equivalent load resistance $R_L := \frac{V_o}{I_o} \quad R_L = 15 \Omega$

Choose a Zener Diode $V_{ZK} := 15 \cdot \text{volt}$

Using the Thevenin equivalent voltage, find R_S max. Note that V_{th} must be larger than V_{zk}

$$R_S := 3 \cdot \Omega$$

Given

$$V_{\text{in_min}} \cdot \left(\frac{R_L}{R_S + R_L} \right) = V_{ZK}$$

$$R_S := \text{find}(R_S) \quad R_S = 3 \Omega$$

$$\frac{R_S}{1.05} = 2.857 \Omega$$

Choose the next smallest standard 5% resistor.

$$R_S := 2.7 \cdot \Omega$$

Calculate the average power assuming no load current.

$$P_{in_avg} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T V_{in}(t) \cdot \frac{V_{in}(t) - V_{ZK}}{R_S} dt$$

$$P_{in_avg} = 53.272 \text{ watt}$$

Calculate the Power dissipated in R_S

$$P_{R_avg} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T \frac{(V_{in}(t) - V_{ZK})^2}{R_S} dt$$

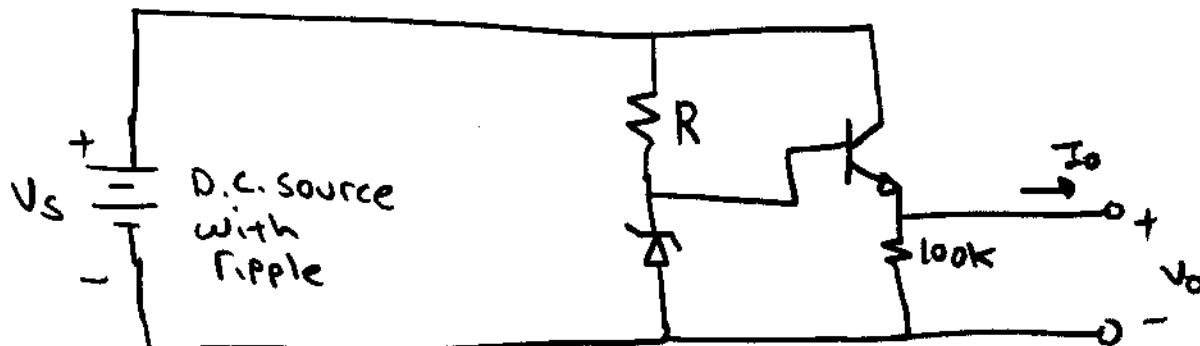
$$P_{R_avg} = 17.16 \text{ watt}$$

Calculate the power dissipated in the zener assuming no load

$$P_{Z_avg} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T \frac{(V_{in}(t) - V_{ZK})}{R_S} \cdot V_{ZK} dt$$

$$P_{Z_avg} = 36.111 \text{ watt}$$

Transistor Voltage Regulator OR Pass Transistor Regulator



Design For $V_o = 15V @ 1A$

$$18V \leq V_s \leq 25V$$

Solution

- Use IN966B 16V Zener
500mW \Rightarrow 31.25 mA capacity.

- Use a TIP31A

$$V_{ce \max} = 60V$$

$$I_{c \max} = 3A$$

$$h_{FE \min} = 25 @ 1A$$

$$h_{FE \max} = 80 @ 3A$$

GENERAL DATA — 500 mW DO-35 GLASS

Low level oxide passivated zener diodes for applications requiring extremely low operating currents, low leakage, and sharp breakdown voltage.

- Zener Voltage Specified @ $I_{ZT} = 50 \mu\text{A}$
- Maximum Delta V_Z Given from 10 to 100 μA

ELECTRICAL CHARACTERISTICS ($T_A = 25^\circ\text{C}$, $V_F = 1.5 \text{ V}$ Max at $I_F = 100 \text{ mA}$ for all types)

Type Number (Note 1)	Zener Voltage V_Z @ $I_{ZT} = 50 \mu\text{A}$ Volts			Maximum Reverse Current $I_R \mu\text{A}$ (Note 3)	Test Voltage V_R Volts	Maximum Zener Current $I_{ZM} \text{ mA}$ (Note 2)	Maximum Voltage Change ΔV_Z Volts (Note 4)
	Nom (Note 1)	Min	Max				
1N4678	1.8	1.71	1.89	7.5	1	120	0.7
1N4679	2	1.9	2.1	5	1	110	0.7
1N4680	2.2	2.09	2.31	4	1	100	0.75
1N4681	2.4	2.28	2.52	2	1	95	0.8
1N4682	2.7	2.565	2.835	1	1	90	0.85
1N4683	3	2.85	3.15	0.8	1	85	0.9
1N4684	3.3	3.135	3.465	7.5	1.5	80	0.95
1N4685	3.6	3.42	3.78	7.5	2	75	0.95
1N4686	3.9	3.705	4.095	5	2	70	0.97
1N4687	4.3	4.085	4.515	4	2	65	0.99
1N4688	4.7	4.465	4.935	10	3	60	0.99
1N4689	5.1	4.845	5.355	10	3	55	0.97
1N4690	5.6	5.32	5.88	10	4	50	0.96
1N4691	6.2	5.89	6.51	10	5	45	0.95
1N4692	6.8	6.46	7.14	10	5.1	35	0.9
1N4693	7.5	7.125	7.875	10	5.7	31.8	0.75
1N4694	8.2	7.79	8.61	1	6.2	29	0.5
1N4695	8.7	8.265	9.135	1	6.6	27.4	0.1
1N4696	9.1	8.645	9.555	1	6.9	26.2	0.08
1N4697	10	9.5	10.5	1	7.6	24.8	0.1
1N4698	11	10.45	11.55	0.05	8.4	21.6	0.11
1N4699	12	11.4	12.6	0.05	9.1	20.4	0.12
1N4700	13	12.35	13.65	0.05	9.8	19	0.13
1N4701	14	13.3	14.7	0.05	10.6	17.5	0.14
1N4702	15	14.25	15.75	0.05	11.4	16.3	0.15
1N4703	16	15.2	16.8	0.05	12.1	15.4	0.16
1N4704	17	16.15	17.85	0.05	12.9	14.5	0.17
1N4705	18	17.1	18.9	0.05	13.6	13.2	0.18
1N4706	19	18.05	19.95	0.05	14.4	12.5	0.19
1N4707	20	19	21	0.01	15.2	11.9	0.2
1N4708	22	20.9	23.1	0.01	16.7	10.8	0.22
1N4709	24	22.8	25.2	0.01	18.2	9.9	0.24
1N4710	25	23.75	26.25	0.01	19	9.5	0.25
1N4711	27	25.65	28.35	0.01	20.4	8.8	0.27
1N4712	28	26.6	29.4	0.01	21.2	8.5	0.28
1N4713	30	28.5	31.5	0.01	22.8	7.9	0.3
1N4714	33	31.35	34.65	0.01	25	7.2	0.33
1N4715	36	34.2	37.8	0.01	27.3	6.6	0.36
1N4716	39	37.05	40.95	0.01	29.6	6.1	0.39
1N4717	43	40.85	45.15	0.01	32.6	5.5	0.43

NOTE 1. TOLERANCE AND VOLTAGE DESIGNATION (V_Z)

The type numbers shown have a standard tolerance of $\pm 5\%$ on the nominal Zener voltage, C for $\pm 2\%$, D for $\pm 1\%$.

NOTE 2. MAXIMUM ZENER CURRENT RATINGS (I_{ZM})

Maximum Zener current ratings are based on maximum Zener voltage of the individual units and JEDEC 250 mW rating.

NOTE 3. REVERSE LEAKAGE CURRENT (I_R)

Reverse leakage currents are guaranteed and measured at V_R as shown on the table.

NOTE 4. MAXIMUM VOLTAGE CHANGE (ΔV_Z)

Voltage change is equal to the difference between V_Z at 100 μA and V_Z at 10 μA .

NOTE 5. ZENER VOLTAGE (V_Z) MEASUREMENT

Nominal Zener voltage is measured with the device junction in thermal equilibrium at the lead temperature at $30^\circ\text{C} \pm 1^\circ\text{C}$ and 3/8" lead length.

Complementary Silicon Plastic Power Transistors

... designed for use in general purpose amplifier and switching applications.

- Collector–Emitter Saturation Voltage —
 $V_{CE(sat)} = 1.2 \text{ Vdc (Max) @ } I_C = 3.0 \text{ Adc}$
- Collector–Emitter Sustaining Voltage —
 $V_{CEO(sus)} = 60 \text{ Vdc (Min) — TIP31A, TIP32A}$
 $= 80 \text{ Vdc (Min) — TIP31B, TIP32B}$
 $= 100 \text{ Vdc (Min) — TIP31C, TIP32C}$
- High Current Gain — Bandwidth Product
 $f_T = 3.0 \text{ MHz (Min) @ } I_C = 500 \text{ mAdc}$
- Compact TO–220 AB Package

*MAXIMUM RATINGS

Rating	Symbol	TIP31A TIP32A	TIP31B TIP32B	TIP31C TIP32C	Unit
Collector–Emitter Voltage	V_{CEO}	60	80	100	Vdc
Collector–Base Voltage	V_{CB}	60	80	100	Vdc
Emitter–Base Voltage	V_{EB}	5.0			Vdc
Collector Current — Continuous Peak	I_C	3.0 5.0			Adc
Base Current	I_B	1.0			Adc
Total Power Dissipation @ $T_C = 25^\circ\text{C}$ Derate above 25°C	P_D	40 0.32			Watts W/ $^\circ\text{C}$
Total Power Dissipation @ $T_A = 25^\circ\text{C}$ Derate above 25°C	P_D	2.0 0.016			Watts W/ $^\circ\text{C}$
Unclamped Inductive Load Energy (1)	E	32			mJ
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–65 to +150			$^\circ\text{C}$

THERMAL CHARACTERISTICS

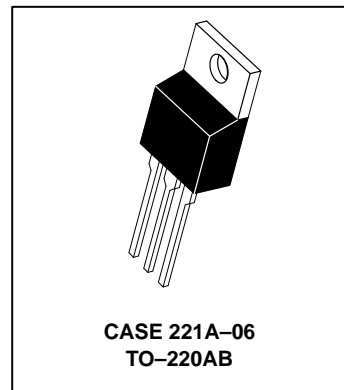
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	62.5	$^\circ\text{C/W}$
Thermal Resistance, Junction to Case	$R_{\theta JC}$	3.125	$^\circ\text{C/W}$

(1) $I_C = 1.8 \text{ A}$, $L = 20 \text{ mH}$, $\text{P.R.F.} = 10 \text{ Hz}$, $V_{CC} = 10 \text{ V}$, $R_{BE} = 100 \Omega$.

NPN
TIP31A
TIP31B*
TIP31C*
PNP
TIP32A
TIP32B*
TIP32C*

*Motorola Preferred Device

3 AMPERE
POWER TRANSISTORS
COMPLEMENTARY
SILICON
60–80–100 VOLTS
40 WATTS



Preferred devices are Motorola recommended choices for future use and best overall value.

REV 1

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TIP31A TIP31B TIP31C TIP32A TIP32B TIP32C

ELECTRICAL CHARACTERISTICS ($T_C = 25^\circ\text{C}$ unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector–Emitter Sustaining Voltage (1) ($I_C = 30\text{ mA}$, $I_B = 0$)	$V_{CE(sus)}$	60 80 100	—	Vdc
Collector Cutoff Current ($V_{CE} = 30\text{ Vdc}$, $I_B = 0$) ($V_{CE} = 60\text{ Vdc}$, $I_B = 0$)	I_{CEO}	— — —	0.3 0.3 0.3	mAdc
Collector Cutoff Current ($V_{CE} = 60\text{ Vdc}$, $V_{EB} = 0$) ($V_{CE} = 80\text{ Vdc}$, $V_{EB} = 0$) ($V_{CE} = 100\text{ Vdc}$, $V_{EB} = 0$)	I_{CES}	— — —	200 200 200	μAdc
Emitter Cutoff Current ($V_{BE} = 5.0\text{ Vdc}$, $I_C = 0$)	I_{EBO}	—	1.0	mAdc
ON CHARACTERISTICS (1)				
DC Current Gain ($I_C = 1.0\text{ Adc}$, $V_{CE} = 4.0\text{ Vdc}$) ($I_C = 3.0\text{ Adc}$, $V_{CE} = 4.0\text{ Vdc}$)	h_{FE}	25 10	— 50	—
Collector–Emitter Saturation Voltage ($I_C = 3.0\text{ Adc}$, $I_B = 375\text{ mAdc}$)	$V_{CE(sat)}$	—	1.2	Vdc
Base–Emitter On Voltage ($I_C = 3.0\text{ Adc}$, $V_{CE} = 4.0\text{ Vdc}$)	$V_{BE(on)}$	—	1.8	Vdc
DYNAMIC CHARACTERISTICS				
Current–Gain — Bandwidth Product ($I_C = 500\text{ mAdc}$, $V_{CE} = 10\text{ Vdc}$, $f_{test} = 1.0\text{ MHz}$)	f_T	3.0	—	MHz
Small–Signal Current Gain ($I_C = 0.5\text{ Adc}$, $V_{CE} = 10\text{ Vdc}$, $f = 1.0\text{ kHz}$)	h_{fe}	20	—	—

(1) Pulse Test: Pulse Width $\leq 300\ \mu\text{s}$, Duty Cycle $\leq 2.0\%$.

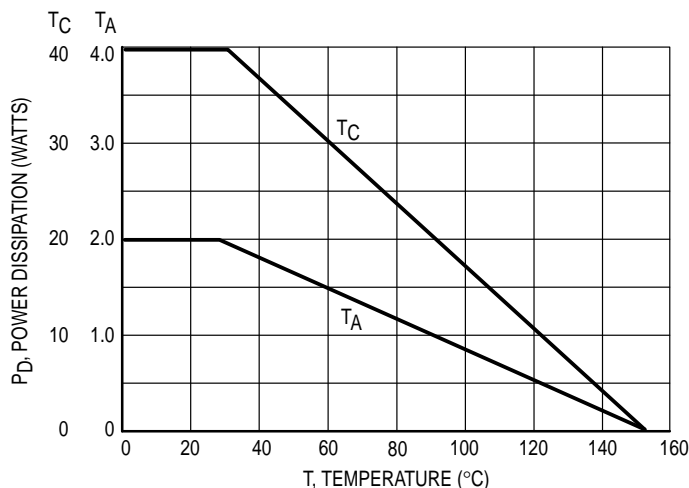


Figure 1. Power Derating

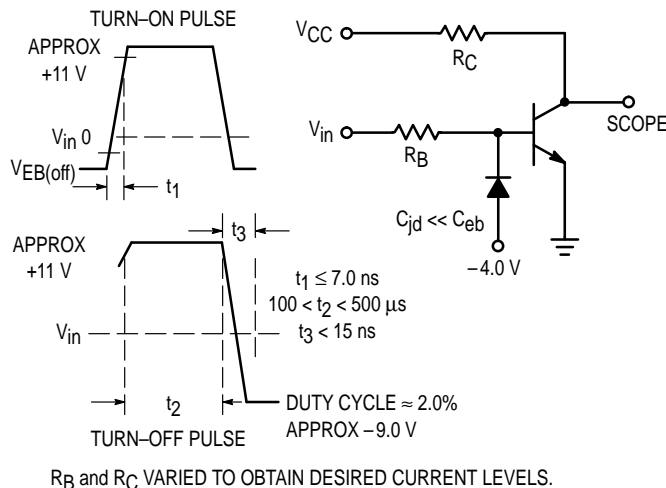


Figure 2. Switching Time Equivalent Circuit

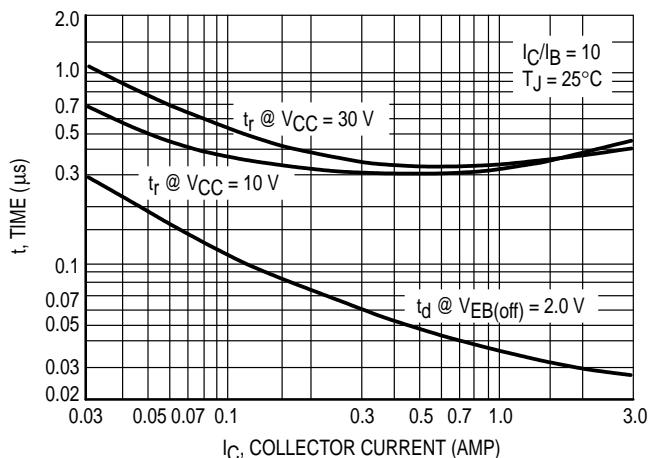
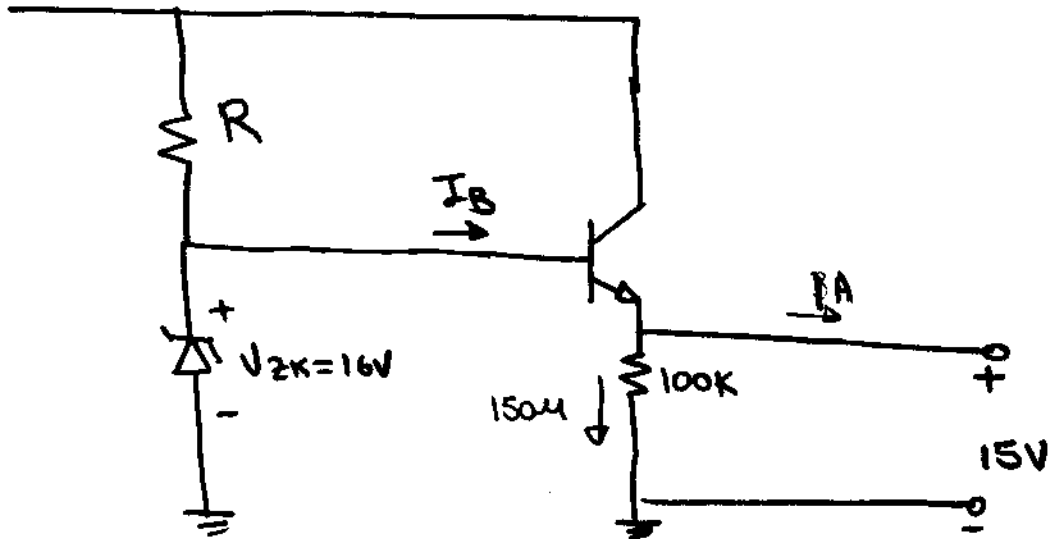


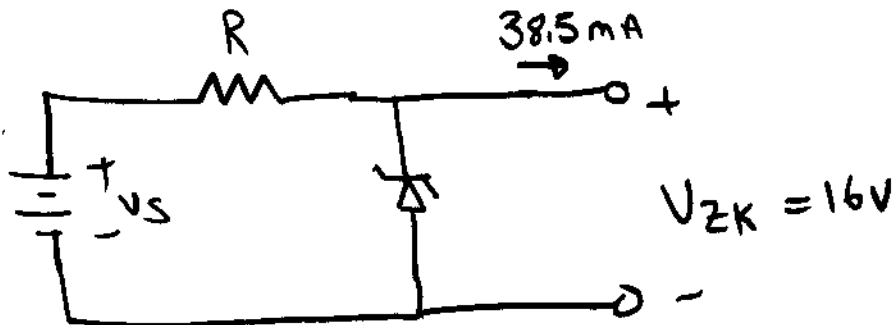
Figure 3. Turn–On Time

Calculations



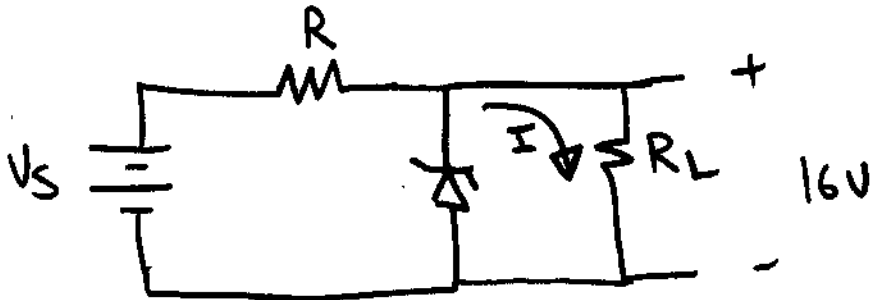
$$I_{B \max} = \frac{I_E}{\beta + 1} = \frac{1.00015A}{26} = 38.5 \text{ mA}$$

Now Find R .



$$18 \leq V_S \leq 25$$

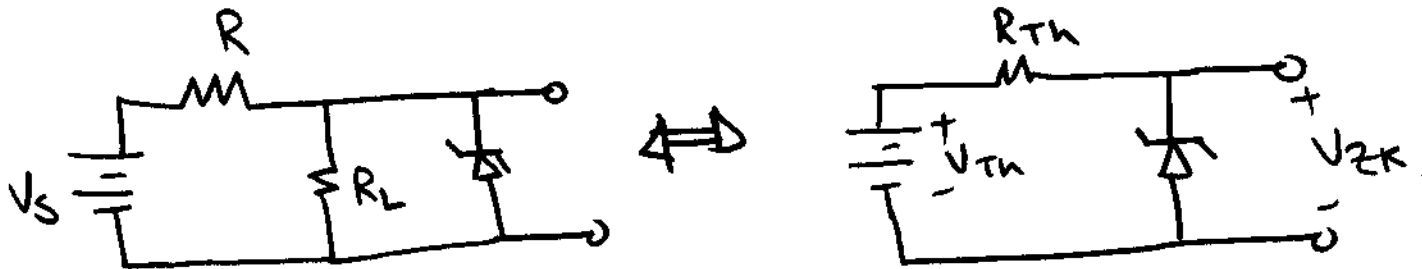
make equivalent ckt



$$I = 385 \text{ mA}$$

$$R_L = \frac{16 \text{ V}}{385 \text{ mA}} = 415.5 \Omega$$

convert to thevenin equivalent



$$V_{TH} = \frac{V_S R_L}{R + R_L}, \quad R_{TH} = R // R_L$$

For Zener to be broken down need

$$V_{TH} \geq V_{ZK} \quad \text{OR} \quad V_{TH_{min}} \geq 16$$

SO

$$\frac{V_s R_L}{R + R_L} \geq 16 \Rightarrow \frac{V_{smin} R_L}{R_{max} + R_L} \geq 16$$

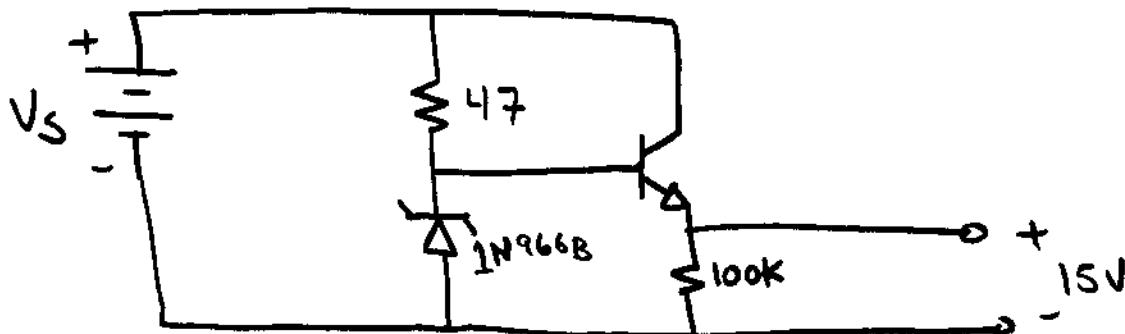
$$R_{max} \leq \frac{V_{smin} R_L}{16} - R_L$$

$$R_{max} \leq \frac{18(415.5)}{16} - 415.5$$

$$R_{max} \leq 51.93 \Omega$$

choose $R = 47 \Omega$ 5%

OUR CKT IS



BJT-Zener Linear Regulator Calculations

Specify the Regulator Parameters

$$V_{\text{out}} := 15 \cdot \text{volt} \quad I_{\text{out}} := 1 \cdot \text{amp}$$

$$V_{\text{in_min}} := 18 \cdot \text{volt} \quad V_{\text{in_max}} := 25 \cdot \text{volt} \quad T := 1 \cdot \text{sec}$$

Define the input voltage waveform

$$V_{\text{in}}(t) := V_{\text{in_max}} - \frac{V_{\text{in_max}} - V_{\text{in_min}}}{T} \cdot t$$

Specify the BJT Parameters

$$\beta_{\text{min}} := 25 \quad V_{\text{BE}} := 1 \cdot \text{volt}$$

Calculate the operation parameters seen by the Zener Regulator

$$V_o := V_{\text{out}} + V_{\text{BE}} \quad I_o := \frac{I_{\text{out}}}{\beta_{\text{min}} + 1}$$

$$V_o = 16 \text{ volt} \quad I_o = 38.462 \text{ mA}$$

The remaining design is just like the Zener regulator

Calculate the equivalent load resistance

$$R_L := \frac{V_o}{I_o} \quad R_L = 416 \Omega$$

Choose a Zener Diode $V_{ZK} := 16 \cdot \text{volt}$

Using the Thevenin equivalent voltage, find R_S max. Note that V_{th} must be larger than V_{zk}

$$R_S := 3 \cdot \Omega$$

Given

$$V_{in_min} \cdot \left(\frac{R_L}{R_S + R_L} \right) = V_{ZK}$$

$$R_S := \text{Find}(R_S) \quad R_S = 52 \Omega$$

$$\frac{R_S}{1.05} = 49.524 \Omega$$

Choose the next smallest standard 5% resistor. $R_S := 47 \cdot \Omega$

Calculate the power dissipated by the Zener portion of the circuit assuming no load.

Calculate the input power to the Zener portion of the circuit.

$$P_{in_avg_Z} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T V_{in}(t) \cdot \frac{V_{in}(t) - V_{ZK}}{R_S} dt$$

$$P_{in_avg_Z} = 2.603 \text{ watt}$$

Calculate the Power dissipated in R_S

$$P_{R_avg} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T \frac{(V_{in}(t) - V_{ZK})^2}{R_S} dt$$

$$P_{R_avg} = 0.73 \text{ watt}$$

Calculate the power dissipated in the zener

$$P_{Z_avg} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T \frac{(V_{in}(t) - V_{ZK})}{R_S} P_{Z_avg} = 1.872 \text{ watt}$$

Calculated the power input to the pass-transistor portion

$$P_{in_avg_pass} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T V_{in}(t) \cdot I_{out} dt$$

$$P_{in_avg_pass} = 21.5 \text{ watt}$$

The power to the output is $P_{\text{out}} := V_{\text{out}} \cdot I_{\text{out}}$

$$P_{\text{out}} = 15 \text{ watt}$$

Calculated the power dissipated by the BJT

$$P_{\text{avg_BJT}} := P_{\text{in_avg_pass}} - P_{\text{out}} \qquad P_{\text{avg_BJT}} = 6.5 \text{ watt}$$

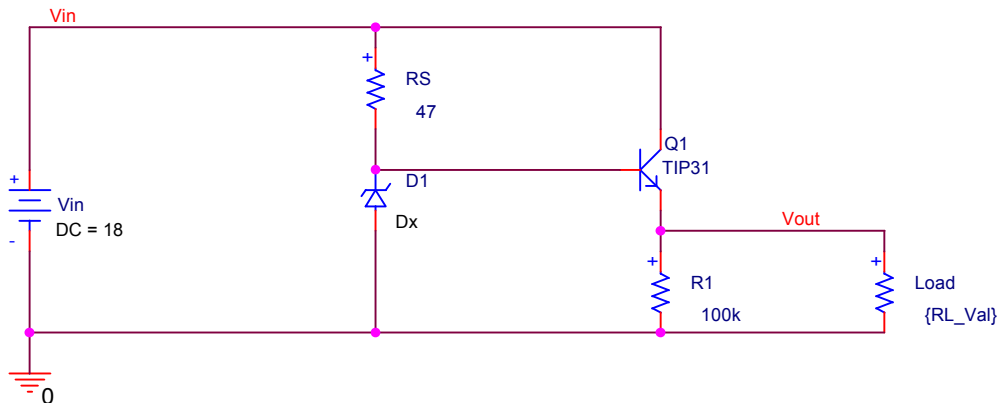
Calculate the efficiency

$$P_{\text{in_total}} := P_{\text{in_avg_pass}} + P_{\text{in_avg_Z}} \qquad P_{\text{in_total}} = 24.103 \text{ watt}$$

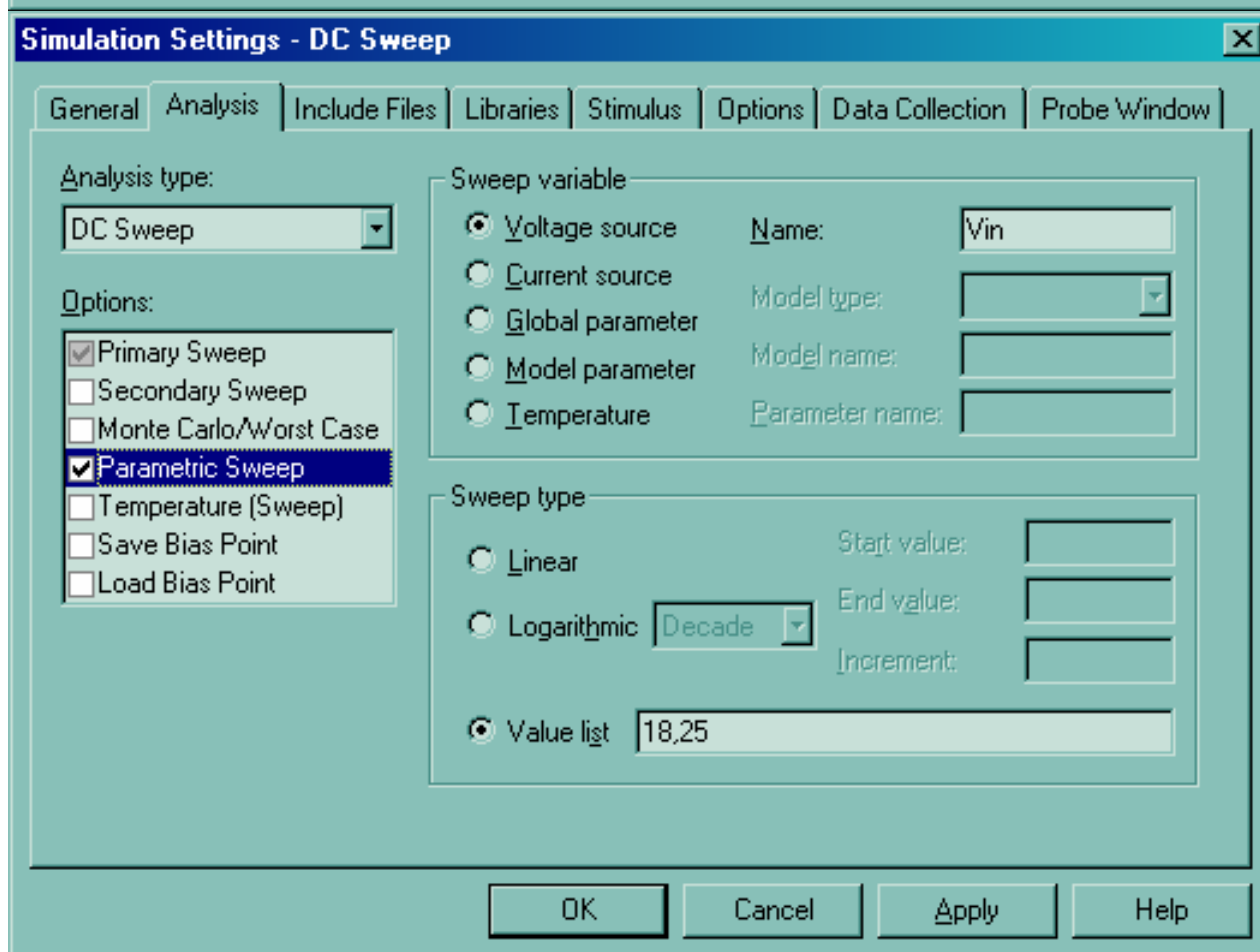
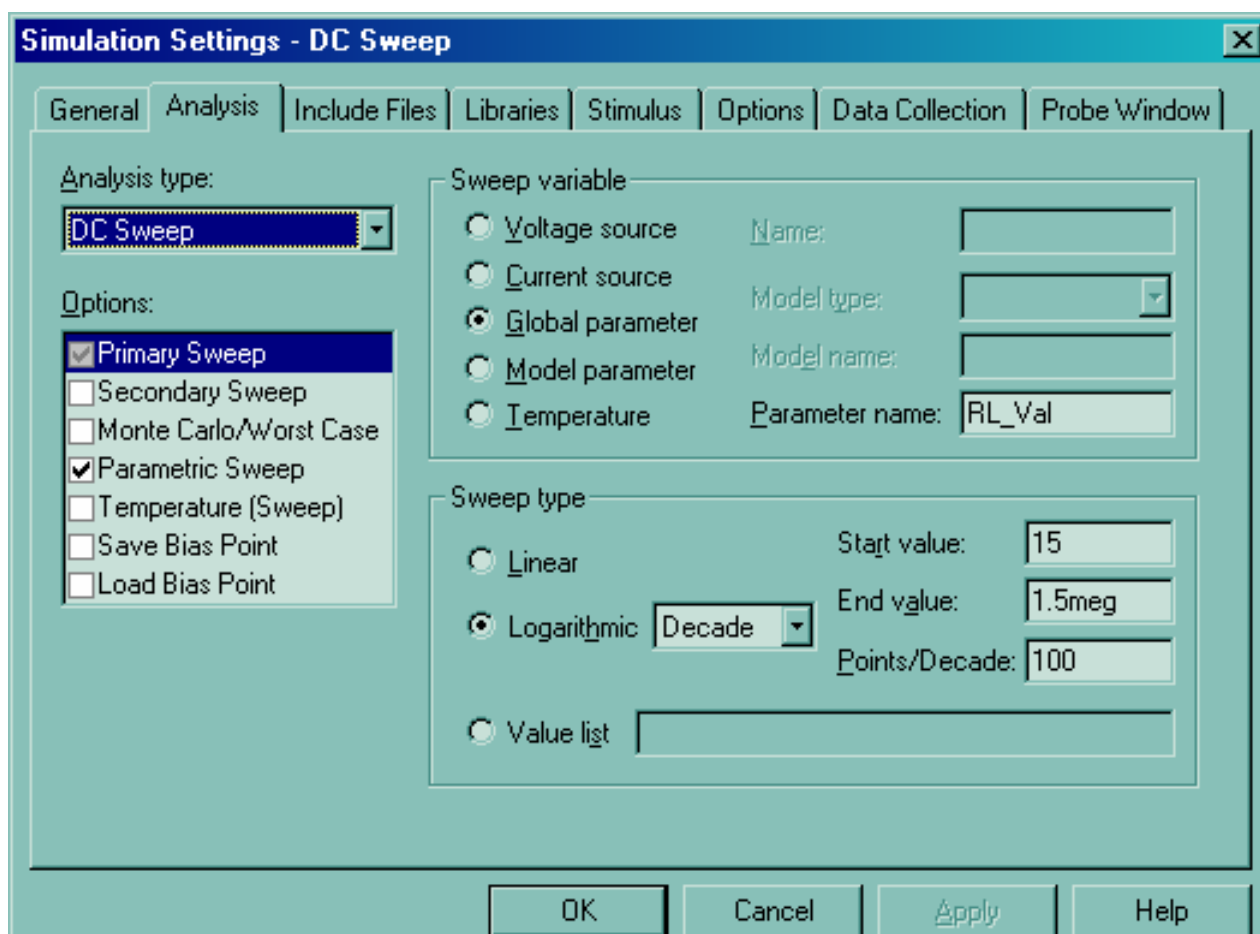
$$\text{Eff} := \frac{P_{\text{out}}}{P_{\text{in_total}}} \qquad \text{Eff} = 62.233 \%$$

PARAMETERS:

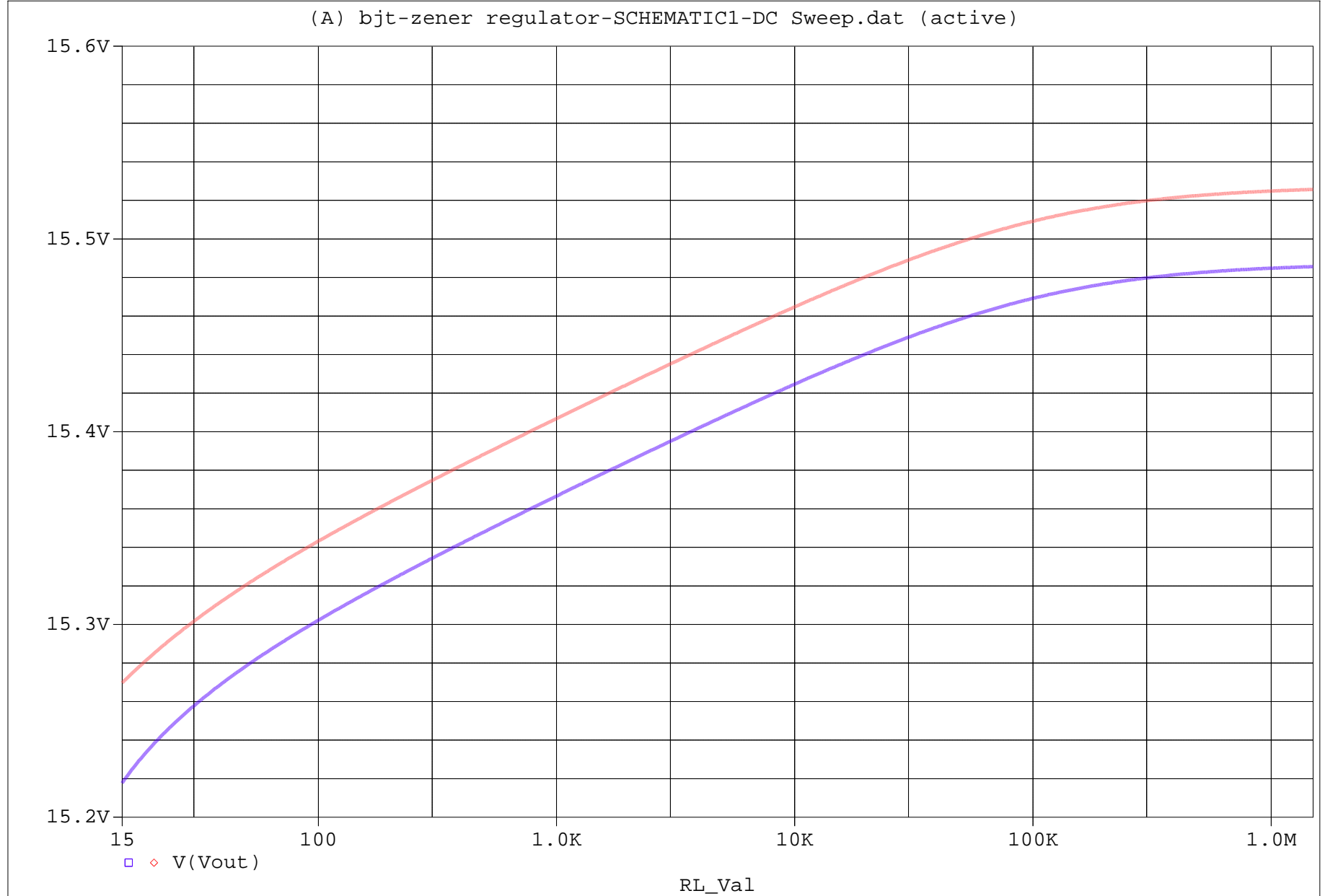
RL_val = 1MEG



Model = Dx D BV=16 RS=1m IBV=.3



** Profile: "SCHEMATIC1-DC Sweep" [C:\WEBSITE\ROSE_CLASSES\ECE456\Notes\Orcad\BJT-Zener Regulator...
 Date/Time run: 12/17/02 12:24:11 Temperature: 27.0

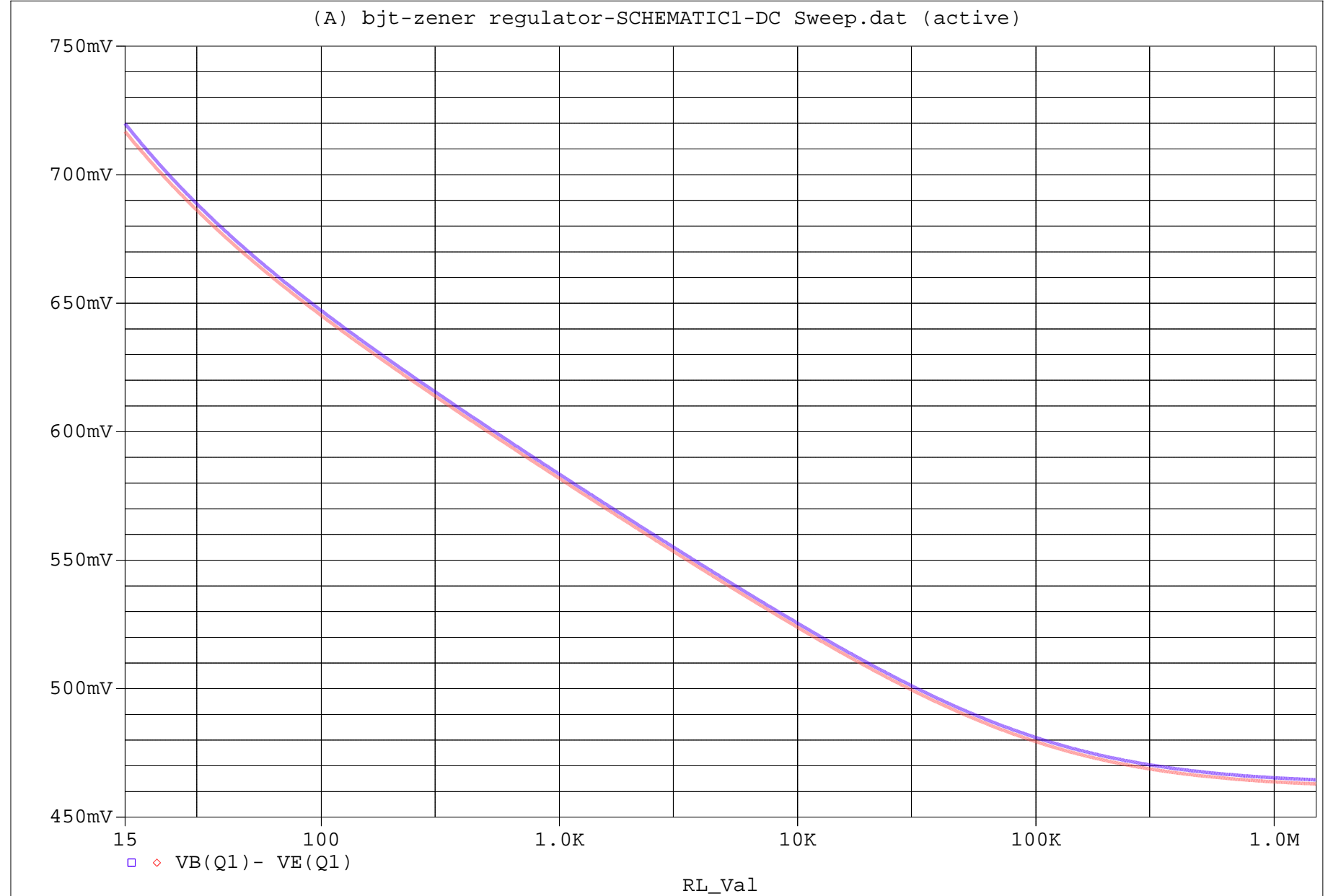


Date: December 17, 2002

Page 1

Time: 12:27:38

** Profile: "SCHEMATIC1-DC Sweep" [C:\WEBSITE\ROSE_CLASSES\ECE456\Notes\Orcad\BJT-Zener Regulator...
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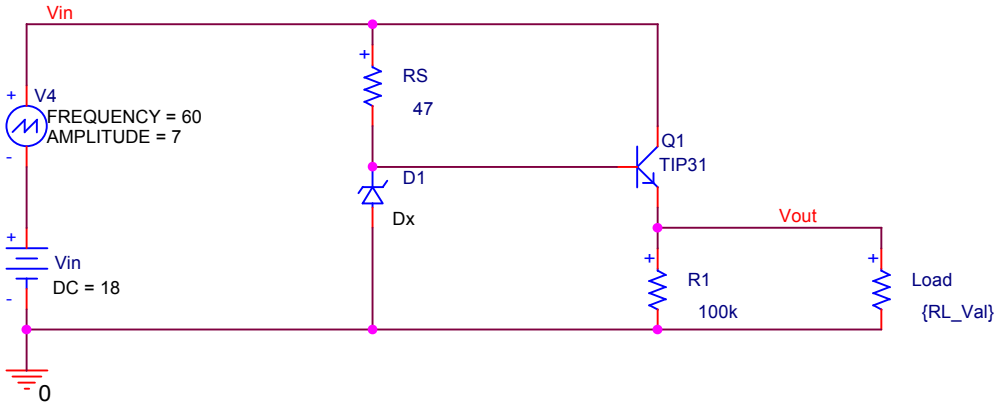


Date: December 17, 2002

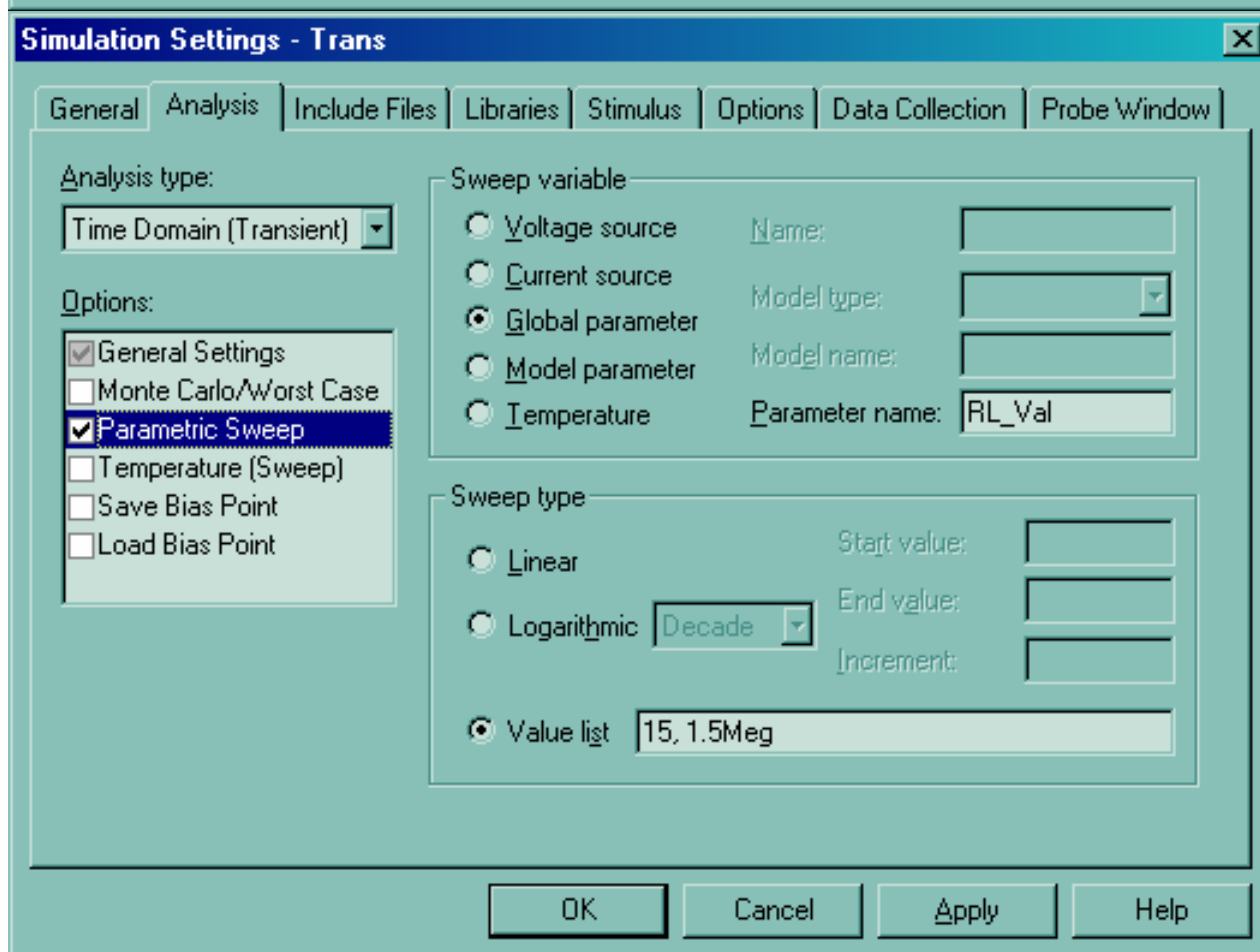
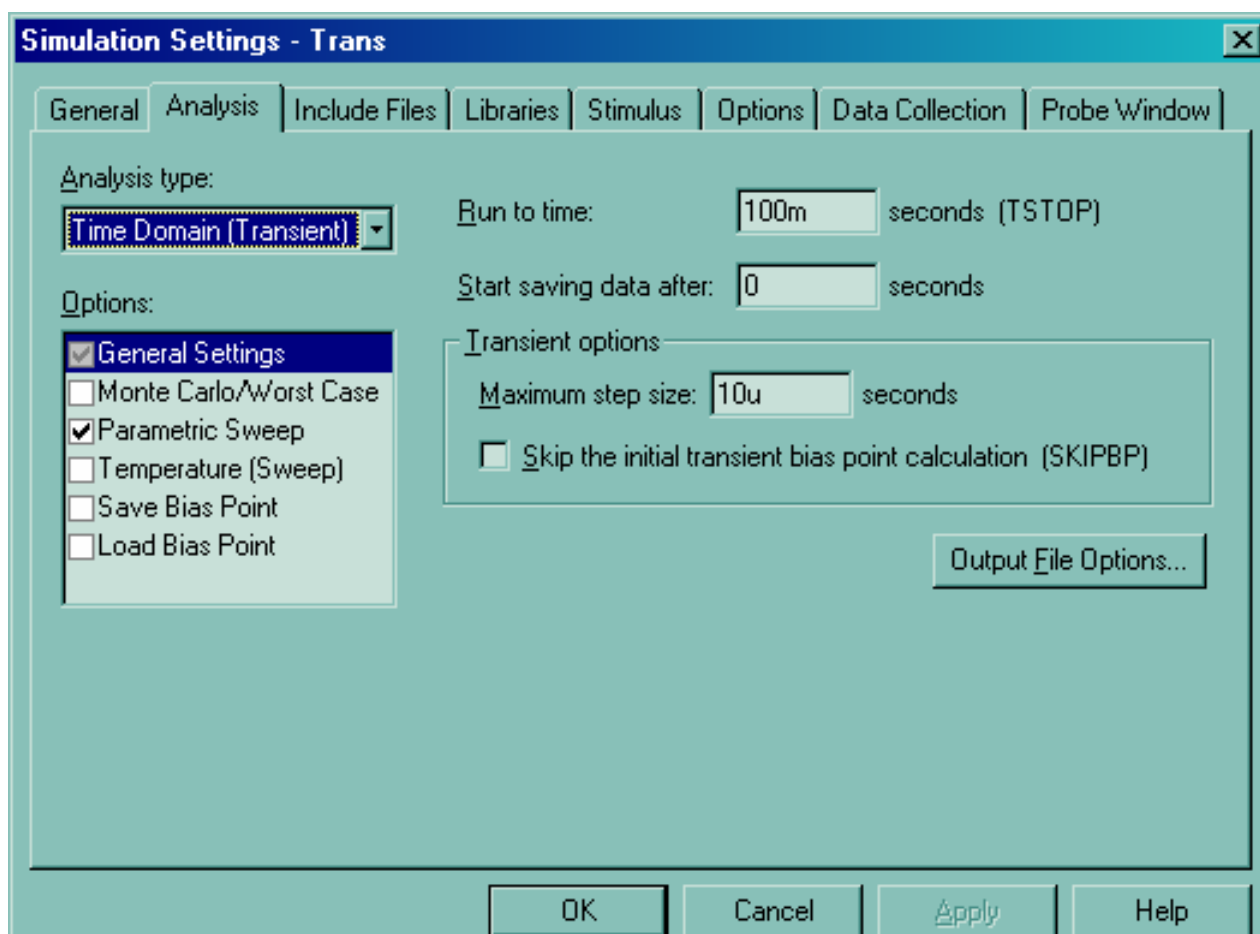
Page 1

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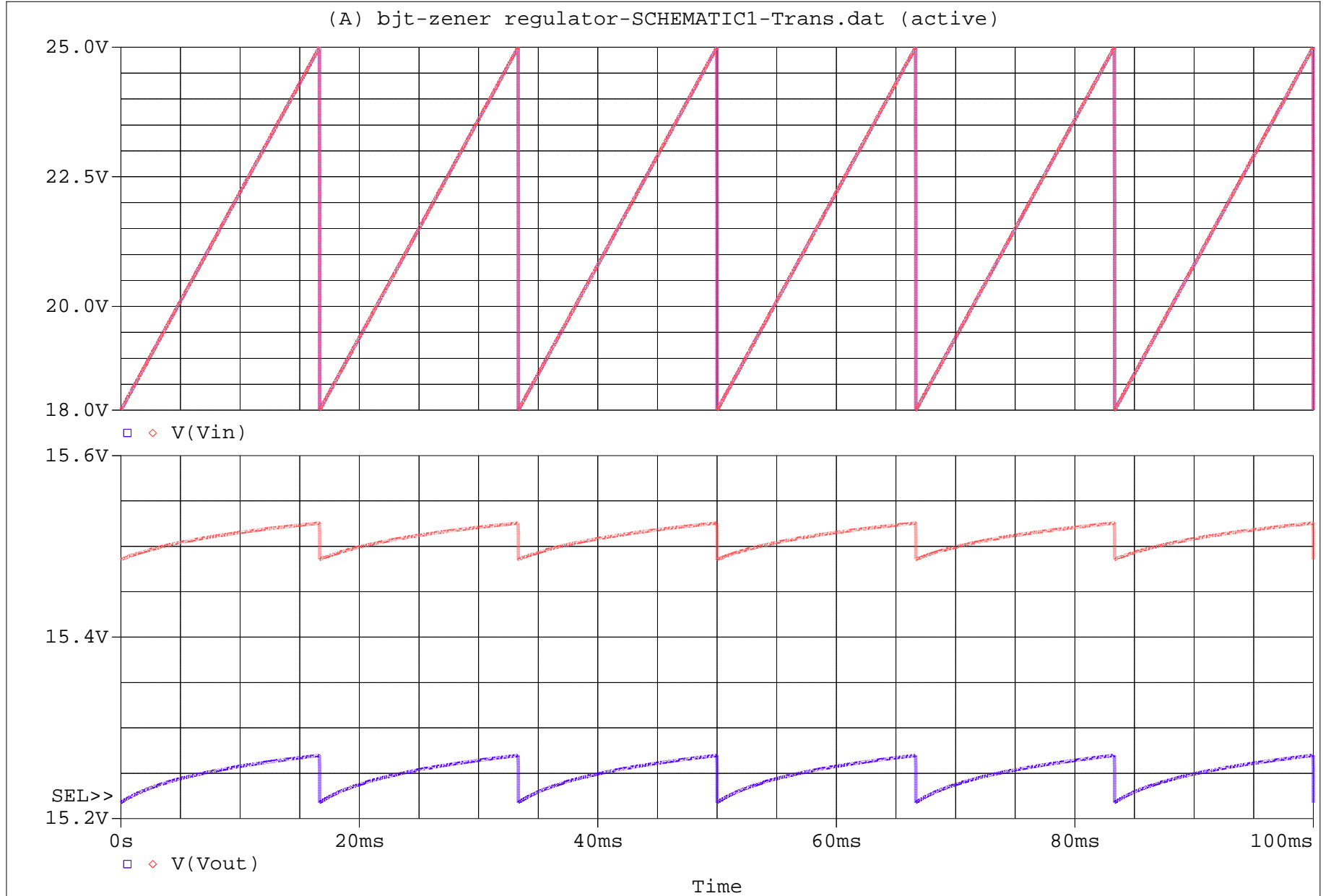
PARAMETERS
RL_val = 1MEG



PARAMETERS
Model = TIP31, $\beta = 100$, $V_{BE} = 0.7$, $V_{CE} = 10$, $V_{IBV} = 0.3$



** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\Notes\Orcad\BJT-Zener Regulator\bj...
Date/Time run: 12/17/02 12:31:53 Temperature: 27.0

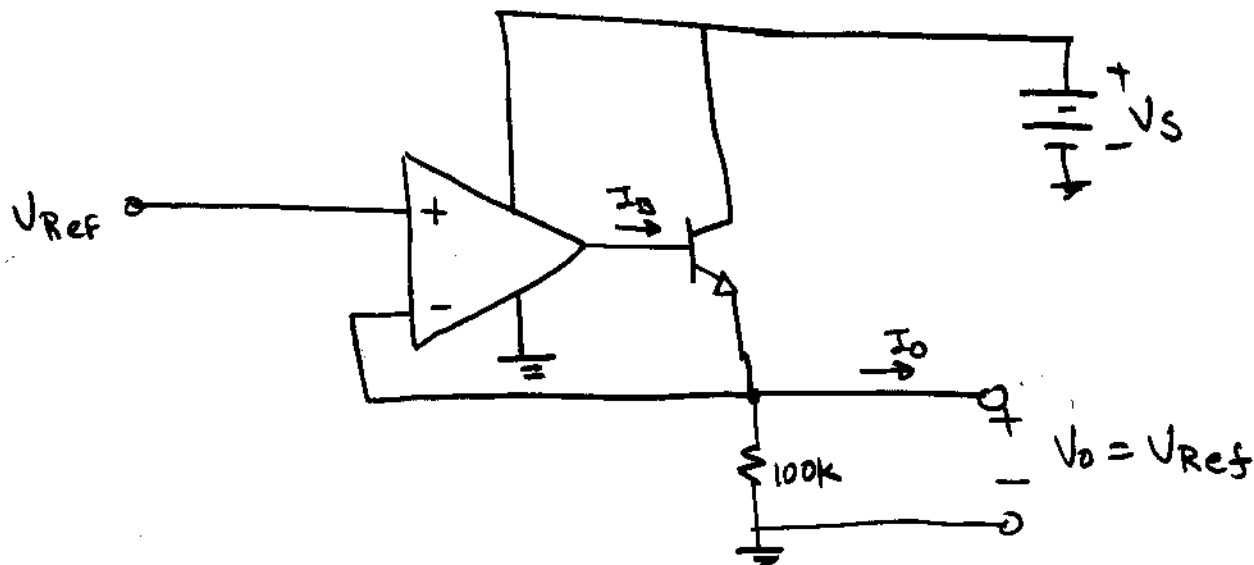


Date: December 17, 2002

Page 1

Time: 12:33:36

OPamp Voltage Regulator



$$18 \leq V_s \leq 25$$

- V_{Ref} is a voltage Reference

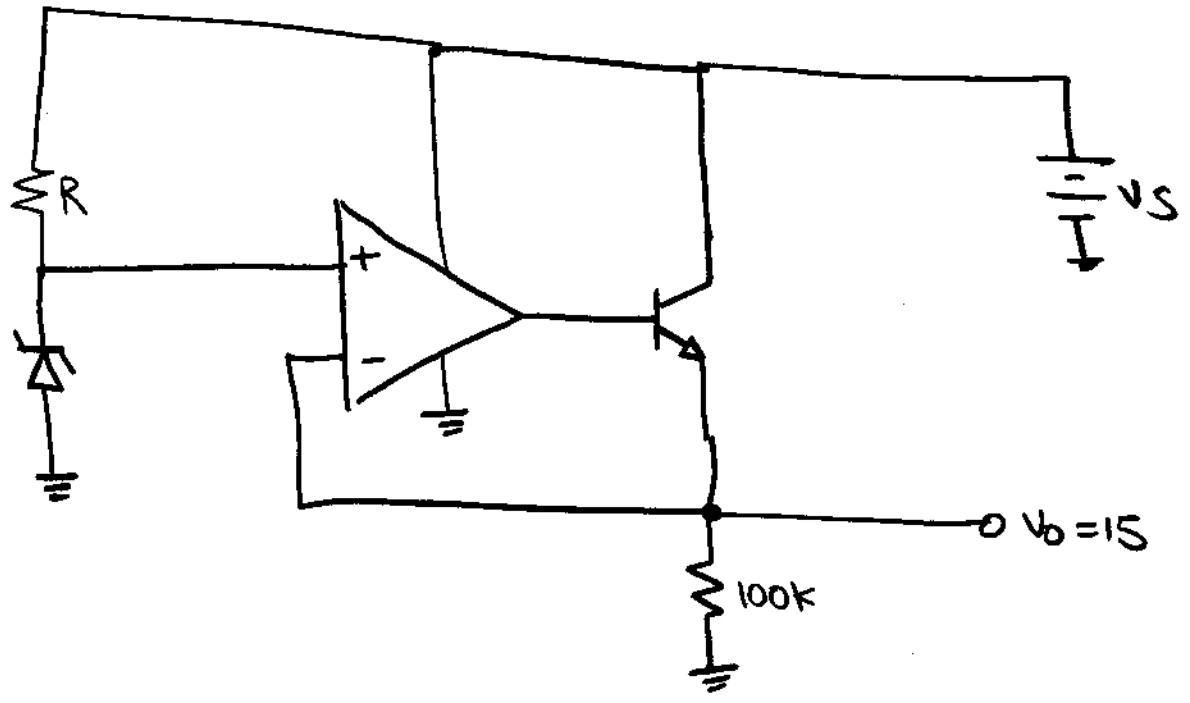
- The OPamp has (-) feedback

$$\Rightarrow V_+ = V_- = V_0$$

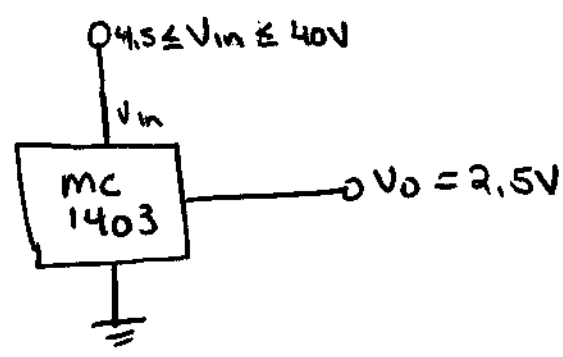
$$\Rightarrow V_0 = V_{Ref}$$

$$- I_B = \frac{I_0}{\beta + 1}$$

could use a Zener for the voltage Ref



- How accurate is the 15V Zener?
- Typically not too accurate.
- Use the MC1403 Precision Voltage Ref



MC1403, B

Low Voltage Reference

A precision band-gap voltage reference designed for critical instrumentation and D/A converter applications. This unit is designed to work with D/A converters, up to 12 bits in accuracy, or as a reference for power supply applications.

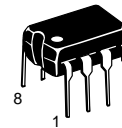
- Output Voltage: 2.5 V \pm 25 mV
- Input Voltage Range: 4.5 V to 40 V
- Quiescent Current: 1.2 mA Typical
- Output Current: 10 mA
- Temperature Coefficient: 10 ppm/°C Typical
- Guaranteed Temperature Drift Specification
- Equivalent to AD580
- Standard 8-Pin DIP, and 8-Pin SOIC Package

Typical Applications

- Voltage Reference for 8 to 12 Bit D/A Converters
- Low T_C Zener Replacement
- High Stability Current Reference
- Voltmeter System Reference

MAXIMUM RATINGS ($T_A = 25^\circ\text{C}$, unless otherwise noted.)

Rating	Symbol	Value	Unit
Input Voltage	V_I	40	V
Storage Temperature	T_{stg}	-65 to 150	°C
Junction Temperature	T_J	+175	°C
Operating Ambient Temperature Range MC1403B MC1403	T_A	-40 to +85 0 to +70	°C °C

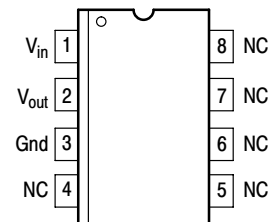
PRECISION LOW VOLTAGE
REFERENCESEMICONDUCTOR
TECHNICAL DATA

P1 SUFFIX
PLASTIC PACKAGE
CASE 626



D SUFFIX
PLASTIC PACKAGE
CASE 751
(SO-8)

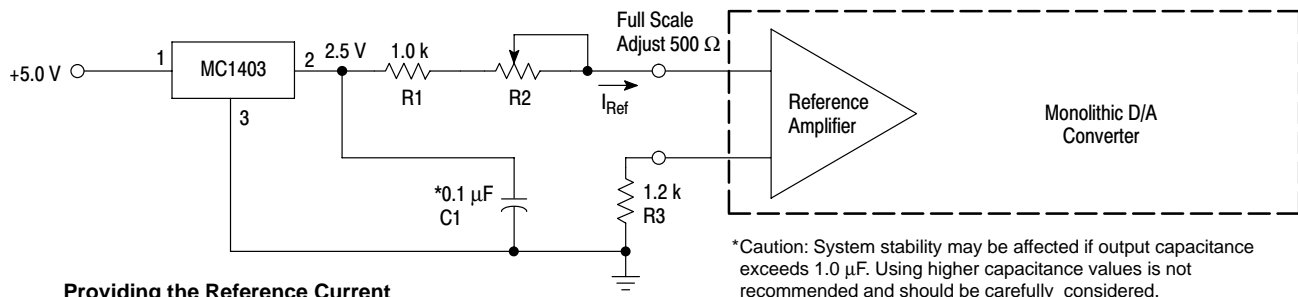
PIN CONNECTIONS



ORDERING INFORMATION

Device	Operating Temperature Range	Package
MC1403D	$T_A = 0^\circ$ to $+70^\circ\text{C}$	SO-8
MC1403P1		Plastic DIP
MC1403BD	$T_A = -40^\circ$ to $+85^\circ\text{C}$	SO-8
MC1403BP1		Plastic DIP

Figure 1. A Reference for Monolithic D/A Converters

Providing the Reference Current
for ON Semiconductor Monolithic D/A Converters

The MC1403 makes an ideal reference for many monolithic D/A converters, requiring a stable current reference of nominally 2.0 mA. This can be easily obtained from the MC1403 with the addition of a series resistor, R1. A variable resistor, R2, is recommended to provide means for full-scale adjust on the D/A converter.

The resistor R3 improves temperature performance by matching the impedance on both inputs of the D/A reference amplifier. The capacitor decouples any noise present on the reference line. It is essential if the D/A converter is located any appreciable distance from the reference.

A single MC1403 reference can provide the required current input for up to five of the monolithic D/A converters.

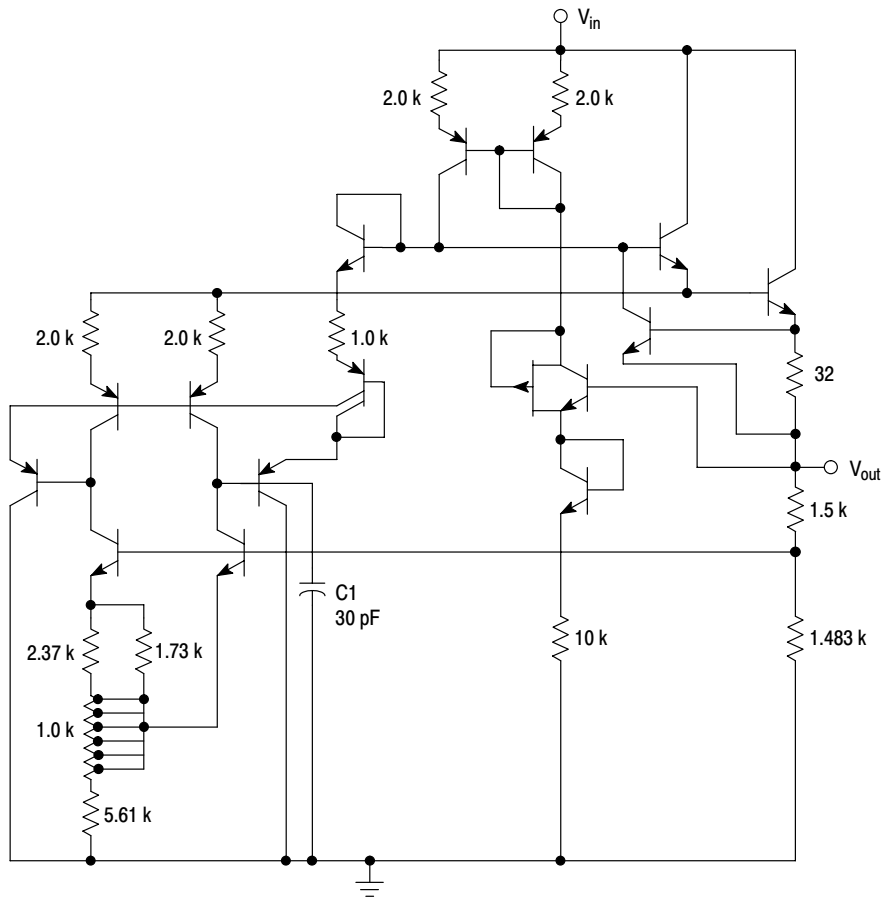
MC1403, B

ELECTRICAL CHARACTERISTICS ($V_{in} = 15\text{ V}$, $T_A = 25^\circ\text{C}$, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Output Voltage ($I_O = 0\text{ mA}$)	V_{out}	2.475	2.5	2.525	V
Temperature Coefficient of Output Voltage* MC1403	$\Delta V_O / \Delta T$	-	10	40	ppm/ $^\circ\text{C}$
Output Voltage Change* (Over specified temperature range) MC1403 0 to $+70^\circ\text{C}$ MC1403B -40 to $+85^\circ\text{C}$	ΔV_O	-	-	7.0 12.5	mV
Line Regulation ($I_O = 0\text{ mA}$) ($15\text{ V} \leq V_I \leq 40\text{ V}$) ($4.5\text{ V} \leq V_I \leq 15\text{ V}$)	Reg_{line}	-	1.2 0.6	4.5 3.0	mV
Load Regulation ($0\text{ mA} < I_O < 10\text{ mA}$)	Reg_{load}	-	-	10	mV
Quiescent Current ($I_O = 0\text{ mA}$)	I_Q	-	1.2	1.5	mA

*Guaranteed but not tested.

Figure 2. MC1403, B Schematic



This device contains 15 active transistors.



Micropower Voltage Reference Diodes

The LM285/LM385 series are micropower two-terminal bandgap voltage regulator diodes. Designed to operate over a wide current range of 10 μ A to 20 mA, these devices feature exceptionally low dynamic impedance, low noise and stable operation over time and temperature. Tight voltage tolerances are achieved by on-chip trimming. The large dynamic operating range enables these devices to be used in applications with widely varying supplies with excellent regulation. Extremely low operating current make these devices ideal for micropower circuitry like portable instrumentation, regulators and other analog circuitry where extended battery life is required.

The LM285/LM385 series are packaged in a low cost TO-226AA plastic case and are available in two voltage versions of 1.235 and 2.500 V as denoted by the device suffix (see Ordering Information table). The LM285 is specified over a -40°C to $+85^{\circ}\text{C}$ temperature range while the LM385 is rated from 0°C to $+70^{\circ}\text{C}$.

The LM385 is also available in a surface mount plastic package in voltages of 1.235 and 2.500 V.

- Operating Current from 10 μ A to 20 mA
- 1.0%, 1.5%, 2.0% and 3.0% Initial Tolerance Grades
- Low Temperature Coefficient
- 1.0 Ω Dynamic Impedance
- Surface Mount Package Available

Order this document by LM285/D

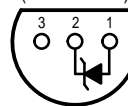
LM285 LM385, B

MICROPOWER VOLTAGE REFERENCE DIODES

SEMICONDUCTOR TECHNICAL DATA

Z SUFFIX
PLASTIC PACKAGE
CASE 29

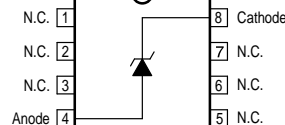
(Bottom View)



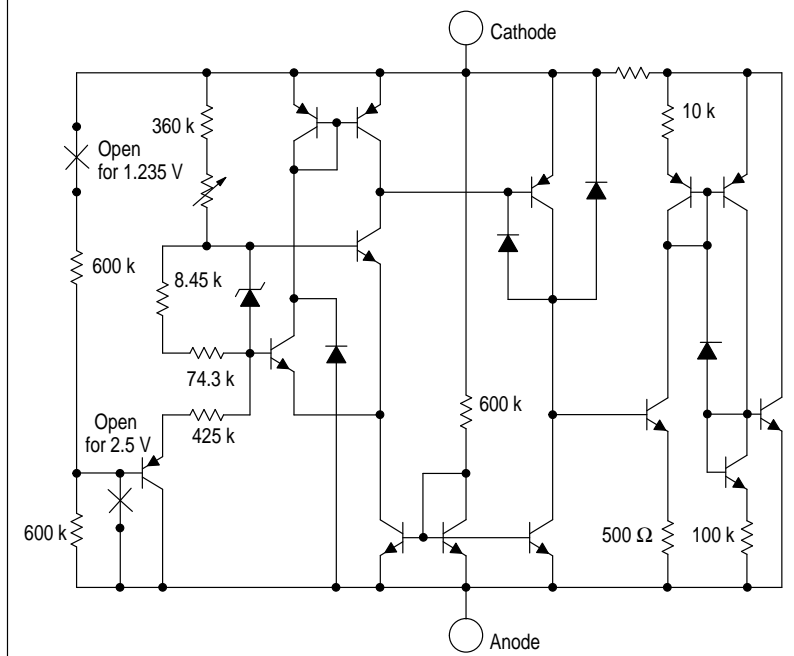
N.C.
Cathode
Anode



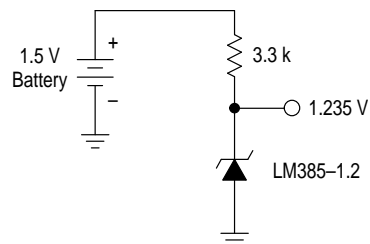
D SUFFIX
PLASTIC PACKAGE
CASE 751
(SO-8)



Representative Schematic Diagram



Standard Application



ORDERING INFORMATION

Device	Operating Temperature Range	Reverse Break-down Voltage	Tolerance
LM285D-1.2 LM285Z-1.2	$T_A = -40^{\circ}$ to $+85^{\circ}\text{C}$	1.235 V	$\pm 1.0\%$
LM285D-2.5 LM285Z-2.5		2.500 V	$\pm 1.5\%$
LM385BD-1.2 LM385BZ-1.2	$T_A = 0^{\circ}$ to $+70^{\circ}\text{C}$	1.235 V	$\pm 1.0\%$
LM385D-1.2 LM385Z-1.2		1.235 V	$\pm 2.0\%$
LM385BD-2.5 LM385BZ-2.5		2.500 V	$\pm 1.5\%$
LM385D-2.5 LM385Z-2.5		2.500 V	$\pm 3.0\%$

LM285 LM385, B

MAXIMUM RATINGS ($T_A = 25^\circ\text{C}$, unless otherwise noted)

Rating	Symbol	Value	Unit
Reverse Current	I_R	30	mA
Forward Current	I_F	10	mA
Operating Ambient Temperature Range LM285 LM385	T_A	- 40 to + 85 0 to +70	$^\circ\text{C}$
Operating Junction Temperature	T_J	+ 150	$^\circ\text{C}$
Storage Temperature Range	T_{stg}	- 65 to + 150	$^\circ\text{C}$

ELECTRICAL CHARACTERISTICS ($T_A = 25^\circ\text{C}$, unless otherwise noted)

Characteristic	Symbol	LM285-1.2			LM385-1.2/LM385B-1.2			Unit
		Min	Typ	Max	Min	Typ	Max	
Reverse Breakdown Voltage ($I_{Rmin} \leq I_R \leq 20 \text{ mA}$) LM285-1.2/LM385B-1.2 $T_A = T_{low}$ to T_{high} (Note 1) LM385-1.2 $T_A = T_{low}$ to T_{high} (Note 1)	$V_{(BR)R}$	1.223 1.200	1.235 -	1.247 1.270	1.223 1.210	1.235 -	1.247 1.260	V
Minimum Operating Current $T_A = 25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1)	I_{Rmin}	- -	8.0 -	10 20	- -	8.0 -	15 20	μA
Reverse Breakdown Voltage Change with Current $I_{Rmin} \leq I_R \leq 1.0 \text{ mA}$, $T_A = +25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1) $1.0 \text{ mA} \leq I_R \leq 20 \text{ mA}$, $T_A = +25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1)	$\Delta V_{(BR)R}$	- - - -	- - - -	1.0 1.5 10 20	- - - -	- - - -	1.0 1.5 20 25	mV
Reverse Dynamic Impedance $I_R = 100 \mu\text{A}$, $T_A = +25^\circ\text{C}$	Z		0.6	-	-	0.6	-	W
Average Temperature Coefficient $10 \mu\text{A} \leq I_R \leq 20 \text{ mA}$, $T_A = T_{low}$ to T_{high} (Note 1)	$\Delta V_{(BR)}/\Delta T$	-	80	-	-	80	-	ppm/ $^\circ\text{C}$
Wideband Noise (RMS) $I_R = 100 \mu\text{A}$, $10 \text{ Hz} \leq f \leq 10 \text{ kHz}$	n	-	60	-	-	60	-	μV
Long Term Stability $I_R = 100 \mu\text{A}$, $T_A = +25^\circ\text{C} \pm 0.1^\circ\text{C}$	S	-	20	-	-	20	-	ppm/ kHR

LM285 LM385, B

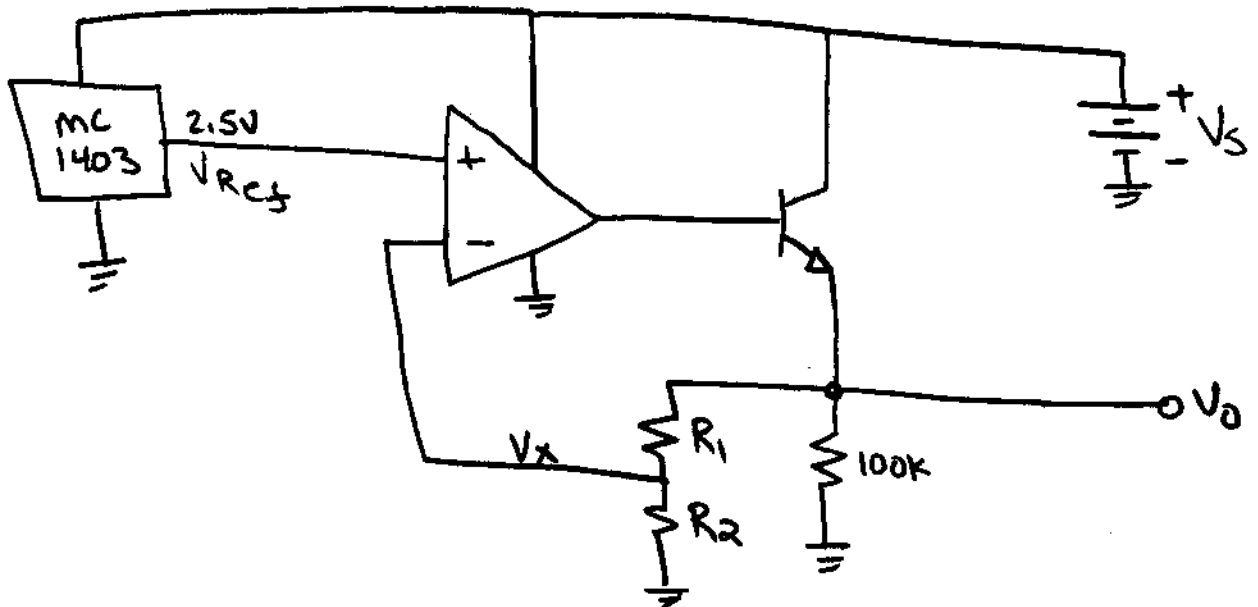
ELECTRICAL CHARACTERISTICS ($T_A = 25^\circ\text{C}$, unless otherwise noted)

Characteristic	Symbol	LM285-2.5			LM385-2.5/LM385B-2.5			Unit
		Min	Typ	Max	Min	Typ	Max	
Reverse Breakdown Voltage ($I_{Rmin} \leq I_R \leq 20 \text{ mA}$) LM285-2.5/LM385B-2.5 $T_A = T_{low}$ to T_{high} (Note 1) LM385-2.5 $T_A = T_{low}$ to T_{high} (Note 1)	$V_{(BR)R}$	2.462 2.415 – –	2.5 – – –	2.538 2.585 – –	2.462 2.436 2.425 2.400	2.5 – 2.5 –	2.538 2.564 2.575 2.600	V
Minimum Operating Current $T_A = 25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1)	I_{Rmin}	– –	13 –	20 30	– –	13 –	20 30	μA
Reverse Breakdown Voltage Change with Current $I_{Rmin} \leq I_R \leq 1.0 \text{ mA}$, $T_A = +25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1) $1.0 \text{ mA} \leq I_R \leq 20 \text{ mA}$, $T_A = +25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1)	$\Delta V_{(BR)R}$	– – – –	– – – –	1.0 1.5 10 20	– – – –	– – – –	2.0 2.5 20 25	mV
Reverse Dynamic Impedance $I_R = 100 \mu\text{A}$, $T_A = +25^\circ\text{C}$	Z	–	0.6	–	–	0.6	–	W
Average Temperature Coefficient $20 \mu\text{A} \leq I_R \leq 20 \text{ mA}$, $T_A = T_{low}$ to T_{high} (Note 1)	$\Delta V_{(BR)R}/\Delta T$	–	80	–	–	80	–	ppm/ $^\circ\text{C}$
Wideband Noise (RMS) $I_R = 100 \mu\text{A}$, $10 \text{ Hz} \leq f \leq 10 \text{ kHz}$	n	–	120	–	–	120	–	μV
Long Term Stability $I_R = 100 \mu\text{A}$, $T_A = +25^\circ\text{C} \pm 0.1^\circ\text{C}$	S	–	20	–	–	20	–	ppm/ kHR

NOTES: 1. $T_{low} = -40^\circ\text{C}$ for LM285-1.2, LM285-2.5
 $= 0^\circ\text{C}$ for LM385-1.2, LM385B-1.2, LM385-2.5, LM385B-2.5

$T_{high} = +85^\circ\text{C}$ for LM285-1.2, LM285-2.5
 $= +70^\circ\text{C}$ for LM385-1.2, LM385B-1.2, LM385-2.5, LM385B-2.5

How do we get 15V out with a 2.5V Reference?



$$\begin{aligned} (-) \text{ Feed back} &\Rightarrow V_+ = V_- \\ &\Rightarrow V_{Ref} = V_x \end{aligned}$$

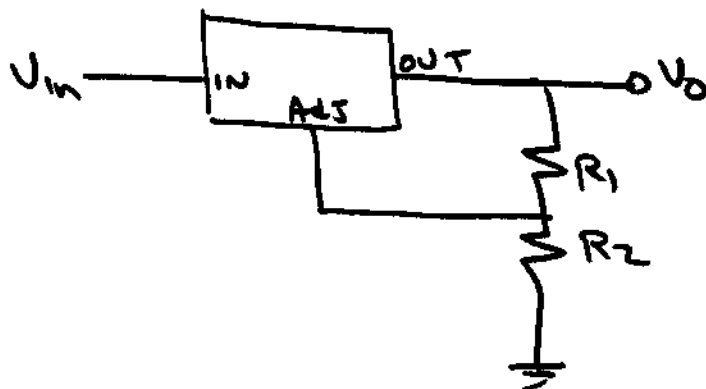
$$\text{But } V_x = \frac{V_o R_2}{R_1 + R_2}$$

$$\Rightarrow V_{Ref} = V_x = \frac{V_o R_2}{R_1 + R_2} \Rightarrow V_o = \left(1 + \frac{R_1}{R_2}\right) V_{Ref}$$

$$\Rightarrow V_o = \left(1 + \frac{R_1}{R_2}\right) V_{ref}$$

$$\text{Want } V_o = 15V \Rightarrow \frac{R_1}{R_2} = 5$$

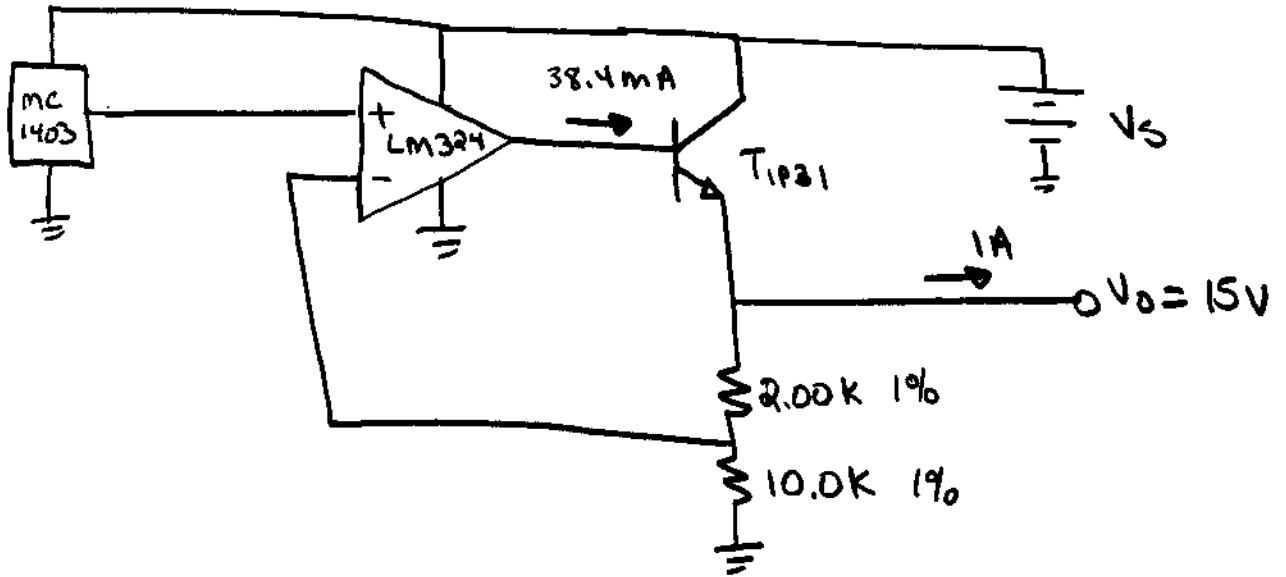
Remember the Lm 317



$$V_o = \left(1 + \frac{R_1}{R_2}\right) 1.25$$

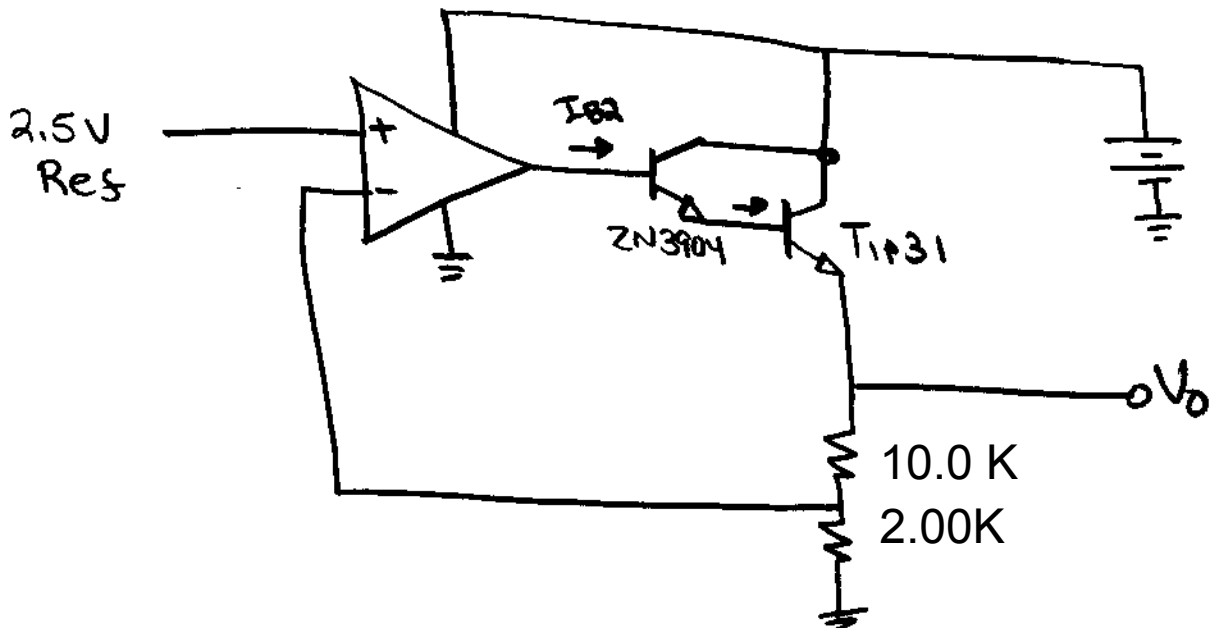
\Rightarrow The Lm317 used a 1.25V Reference.

Design for $V_o = 15V, I_o = 1A$



Problem: LM324 can not supply 38.4 mA

Soln: make a darlington connection



OPAMP-BJT-Zener Linear Regulator Calculations

Specify the Regulator Parameters

$$V_{\text{out}} := 15 \cdot \text{volt} \quad I_{\text{out}} := 1 \cdot \text{amp}$$

$$V_{\text{in_min}} := 18 \cdot \text{volt} \quad V_{\text{in_max}} := 25 \cdot \text{volt} \quad T := 1 \cdot \text{sec}$$

Specify the BJT Parameters. Use a Darlington Connected BJT (TIP 102)

$$\beta_{\text{min}} := 1000 \quad V_{\text{BEmax}} := 2.8 \cdot \text{volt}$$

Calculate the current supplied by the OP-AMP Output

$$I_{\text{B}} := \frac{I_{\text{out}}}{\beta_{\text{min}} + 1} \quad I_{\text{B}} = 0.999 \text{ mA}$$

Specify the Parameters for the Voltage Reference. (LM385-2.5)

$$V_{\text{ZK}} := 1.235 \cdot \text{volt} \quad I_{\text{max}} := 20 \cdot \text{mA} \quad I_{\text{min}} := 22 \cdot \mu\text{A}$$

Choose the Zener series resistor to provide the minimum current at the minimum input voltage.

$$R_{\text{Z}} := \frac{V_{\text{in_min}} - V_{\text{ZK}}}{I_{\text{min}}} \quad R_{\text{Z}} = 0.762 \text{ M}\Omega$$

Choose a smaller standard resistor value.

$$R_Z := 470 \cdot \text{k}\Omega$$

Check the voltage reference maximum and minimum current with this resistor. Assume a 5% resistor

$$I_{Z_max} := \frac{V_{in_max} - V_{ZK}}{R_Z \cdot (0.95)} \quad I_{Z_max} = 53.225 \mu\text{A}$$

$$I_{Z_min} := \frac{V_{in_min} - V_{ZK}}{R_Z \cdot (1.05)} \quad I_{Z_min} = 33.972 \mu\text{A}$$

Next, calculate the voltage divider reference resistor.

Choose a standard value for R2. $R_2 := 0.909 \cdot \text{k}\Omega$

$$R_1 := \frac{R_2 \cdot (V_{out} - V_{ZK})}{V_{ZK}} \quad R_1 = 10.131 \text{ k}\Omega$$

Choose a standard 1% resistor for R1

$$R_1 := 10.0 \cdot \text{k}\Omega$$

Calculate the Power dissipated by the pass transistor

Define a function that models the input voltage.

$$T := \frac{1}{120 \cdot \text{Hz}} \quad V_{\text{in}}(t) := V_{\text{in_max}} - \frac{V_{\text{in_max}} - V_{\text{in_min}}}{T} \cdot t$$

Calculate the average power dissipated by the BJT at max output current.

$$P_{\text{BJT_avg}} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T (V_{\text{in}}(t) - V_{\text{out}}) \cdot I_{\text{out}} dt \quad P_{\text{BJT_avg}} = 6.5 \text{ watt}$$

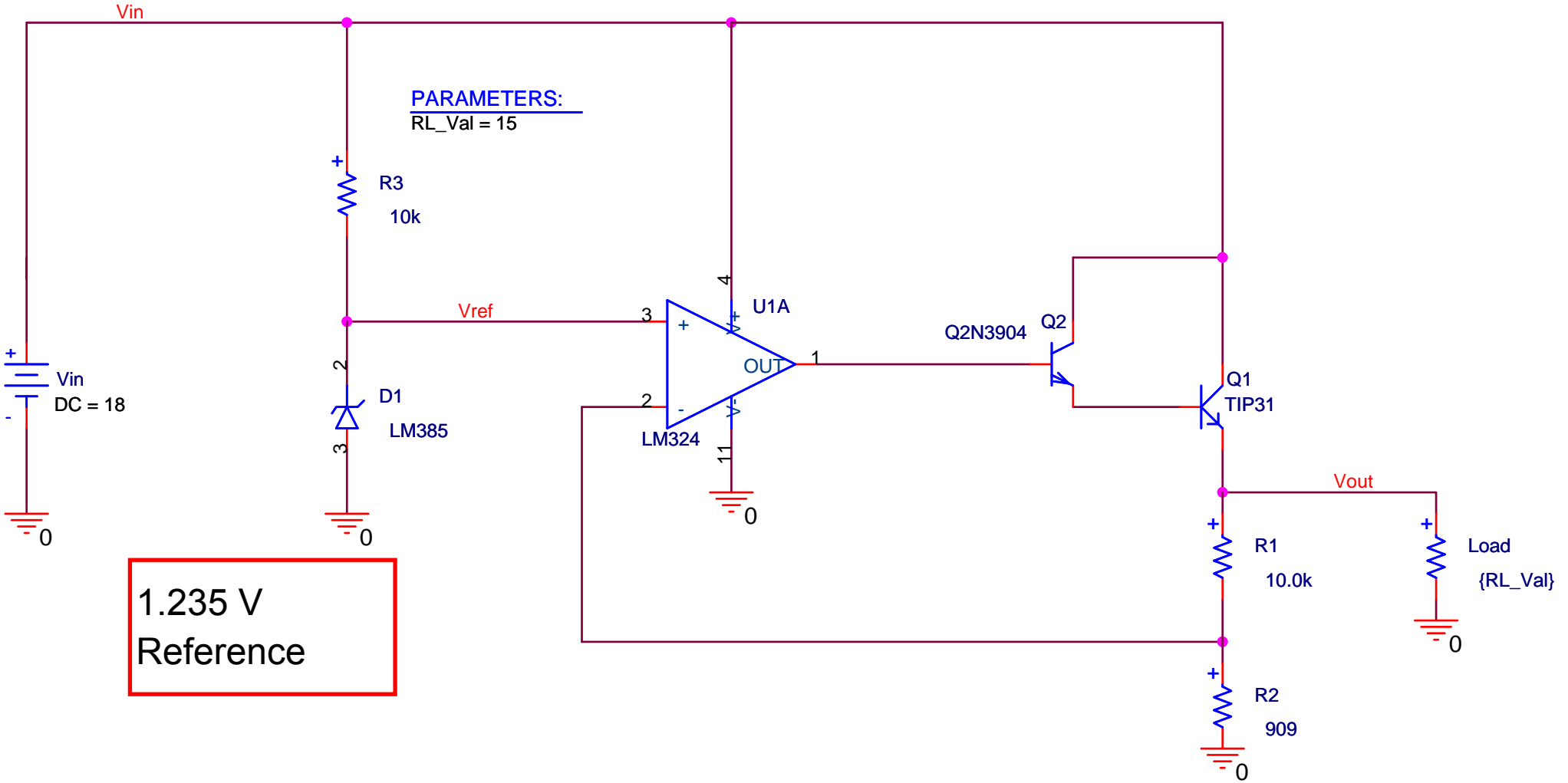
The power to the output is $P_{\text{out}} := V_{\text{out}} \cdot I_{\text{out}} \quad P_{\text{out}} = 15 \text{ watt}$

Calculate the average input power

$$P_{\text{IN_avg}} := \frac{1}{T} \cdot \int_{0 \cdot \text{sec}}^T (V_{\text{in}}(t)) \cdot I_{\text{out}} dt \quad P_{\text{IN_avg}} = 21.5 \text{ watt}$$

Calculate the efficiency at full output power.

$$\text{Eff} := \frac{P_{\text{out}}}{P_{\text{IN_avg}}} \quad \text{Eff} = 69.767 \%$$



Analysis type:

DC Sweep

Options:

- Primary Sweep
- Secondary Sweep
- Monte Carlo/Worst Case
- Parametric Sweep
- Temperature (Sweep)
- Save Bias Point
- Load Bias Point

Sweep variable

- Voltage source
- Current source
- Global parameter
- Model parameter
- Temperature

Name:

Model type:

Model name:

Parameter name:

RL_Val

Sweep type

- Linear
- Logarithmic
- Value list

Decade

Start value:

15

End value:

1.5meg

Points/Decade:

100

Analysis type:

DC Sweep

Options:

- Primary Sweep
- Secondary Sweep
- Monte Carlo/Worst Case
- Parametric Sweep
- Temperature (Sweep)
- Save Bias Point
- Load Bias Point

Sweep variable

- Voltage source
- Current source
- Global parameter
- Model parameter
- Temperature

Name:

Vin

Model type:

Model name:

Parameter name:

Sweep type

- Linear
- Logarithmic
- Value list

Decade

Start value:

End value:

Increment:

18,25

Display Probe window when profile is opened.

Display Probe window:

during simulation.

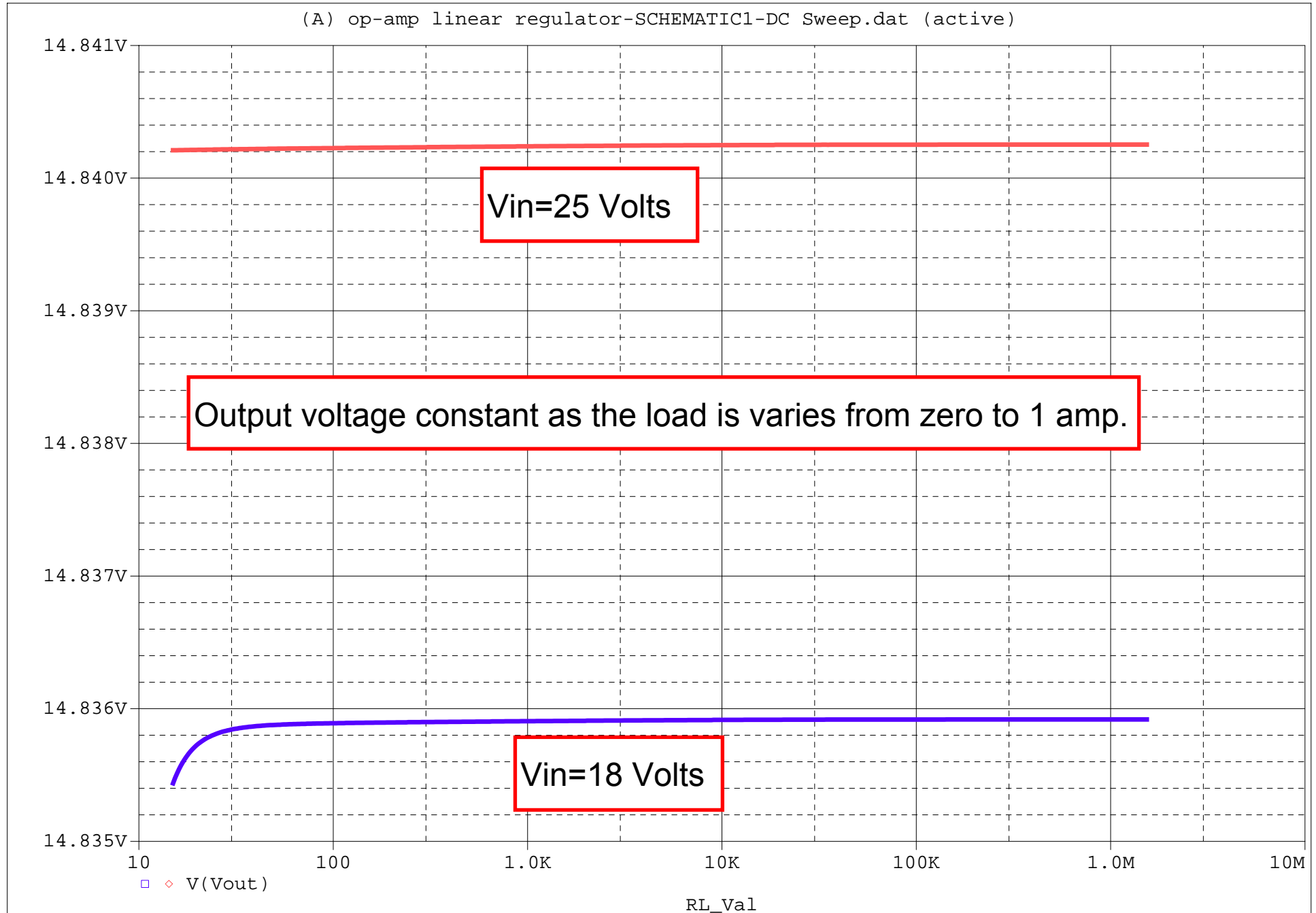
after simulation has completed.

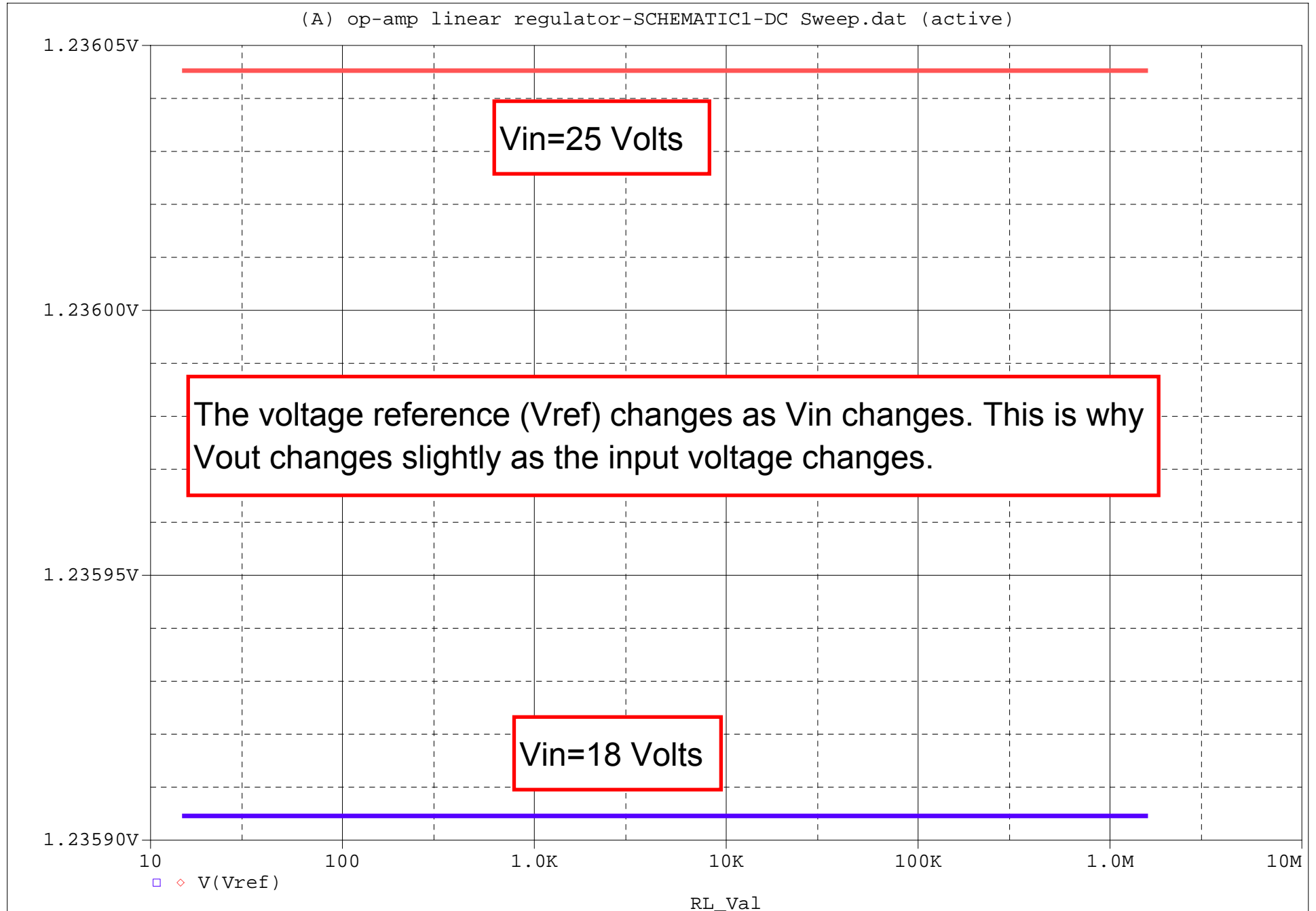
Show

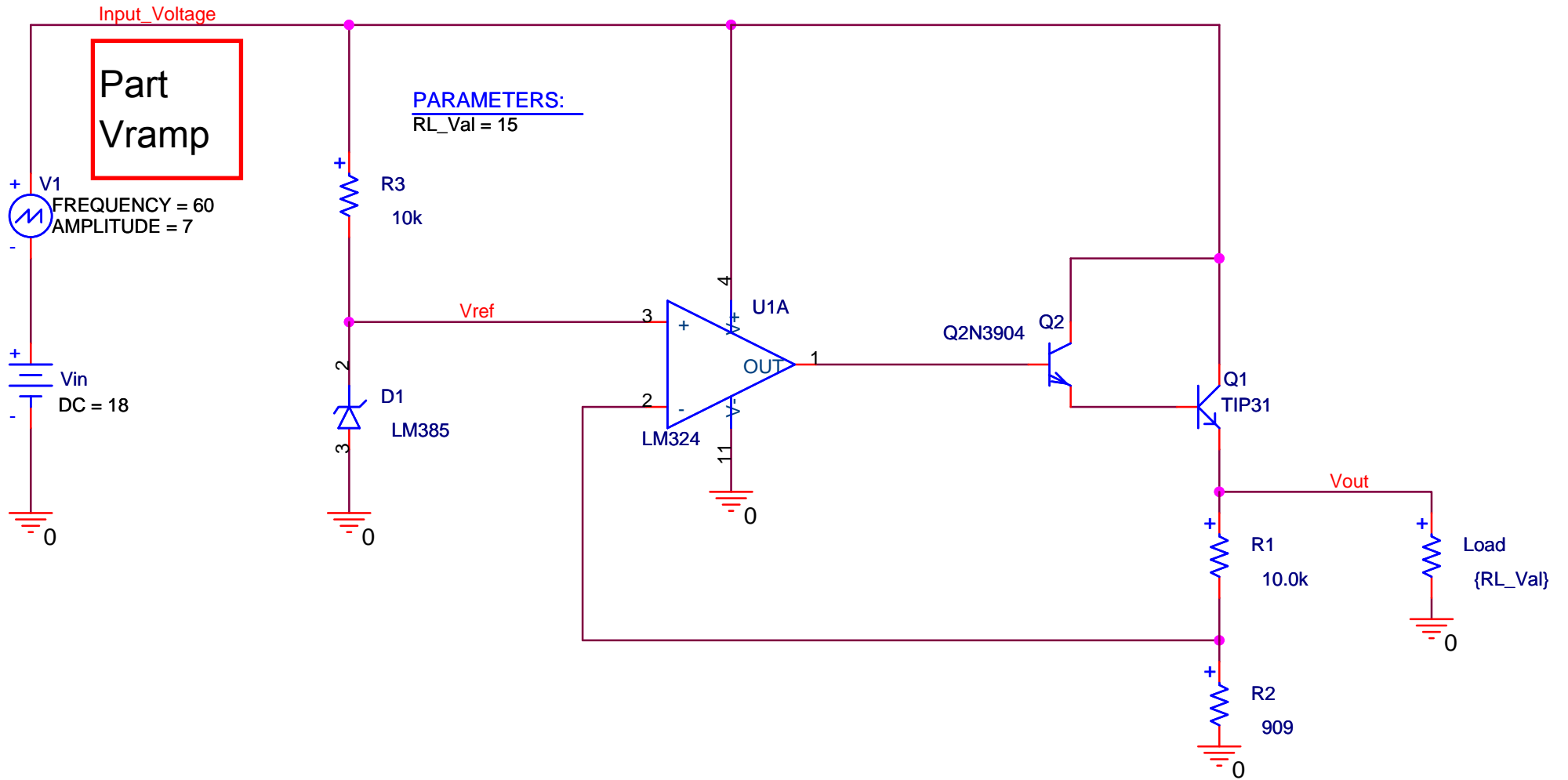
All markers on open schematics.

Last plot.

Nothing.







Analysis type:

Time Domain (Transient)

Run to time: 100m seconds (TSTOP)

Start saving data after: 0 seconds

Options:

 General Settings Monte Carlo/Worst Case Parametric Sweep Temperature (Sweep) Save Bias Point Load Bias Point

Transient options

Maximum step size: 10u seconds

 Skip the initial transient bias point calculation (SKIPBP)

Output File Options...

Analysis type:

Time Domain (Transient)

Options:

- General Settings
- Monte Carlo/Worst Case
- Parametric Sweep
- Temperature (Sweep)
- Save Bias Point
- Load Bias Point

Sweep variable

- Voltage source
- Current source
- Global parameter
- Model parameter
- Temperature

Name:

Model type:

Model name:

Parameter name:

RL_Val

Sweep type

- Linear
- Logarithmic
- Value list

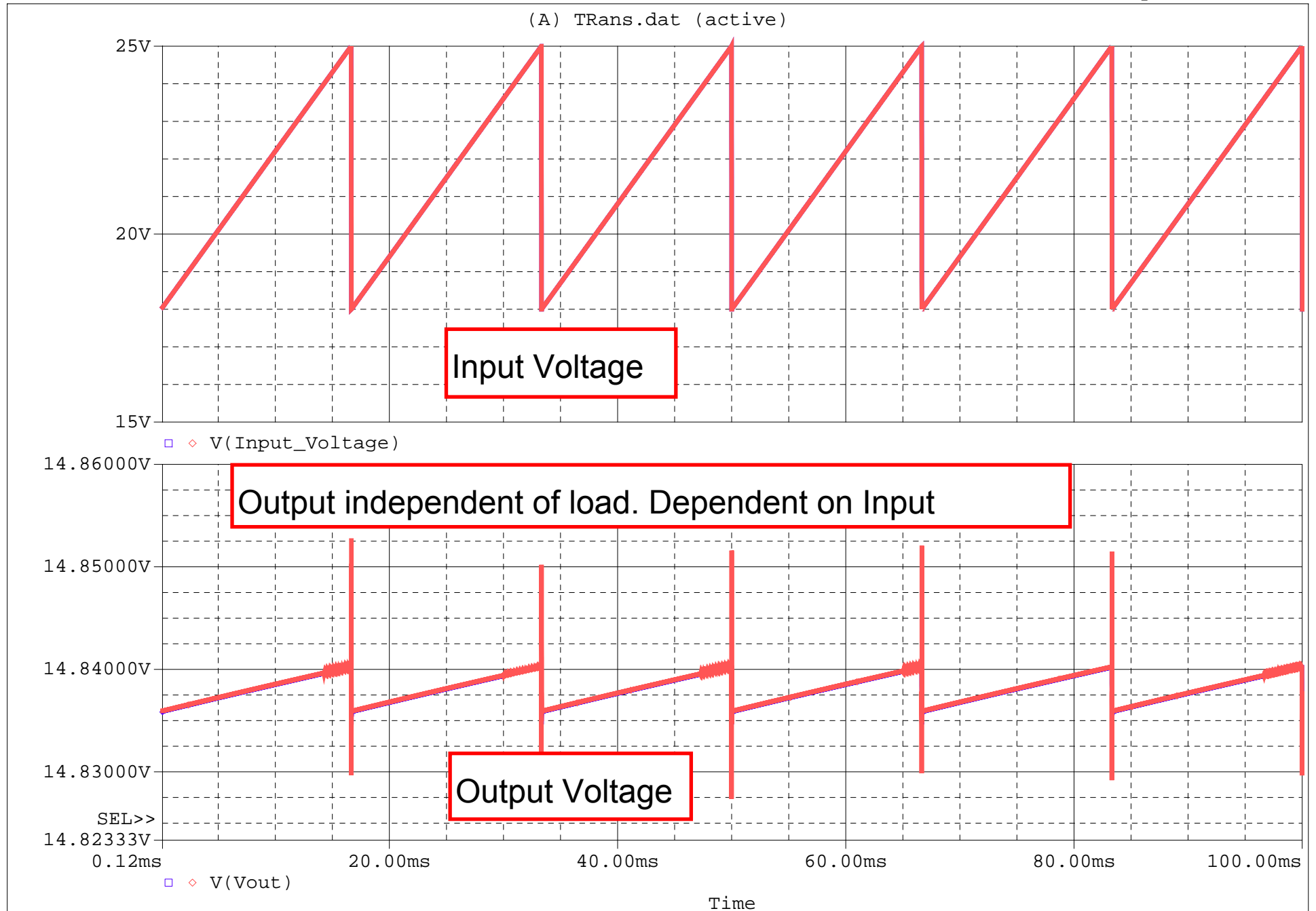
Decade

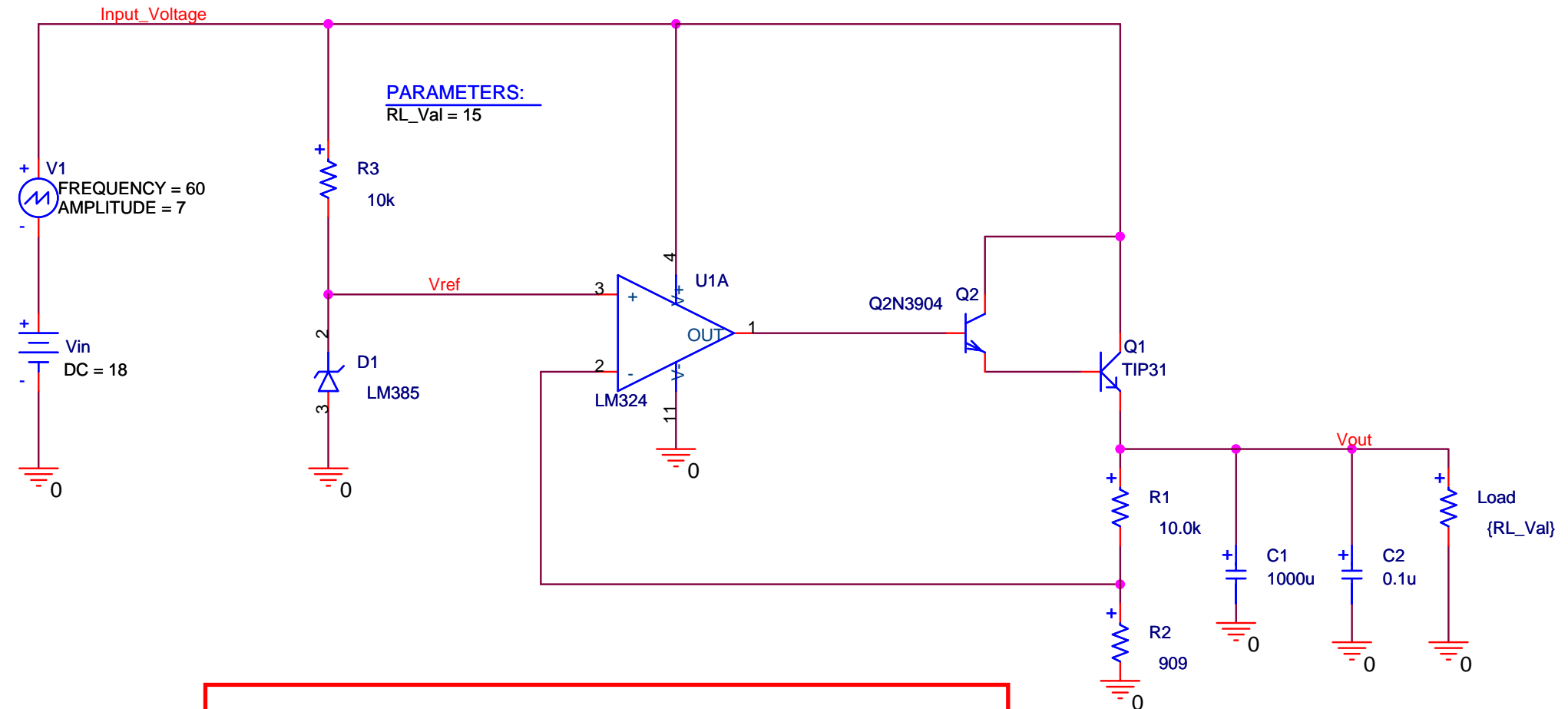
Start value:

End value:

Increment:

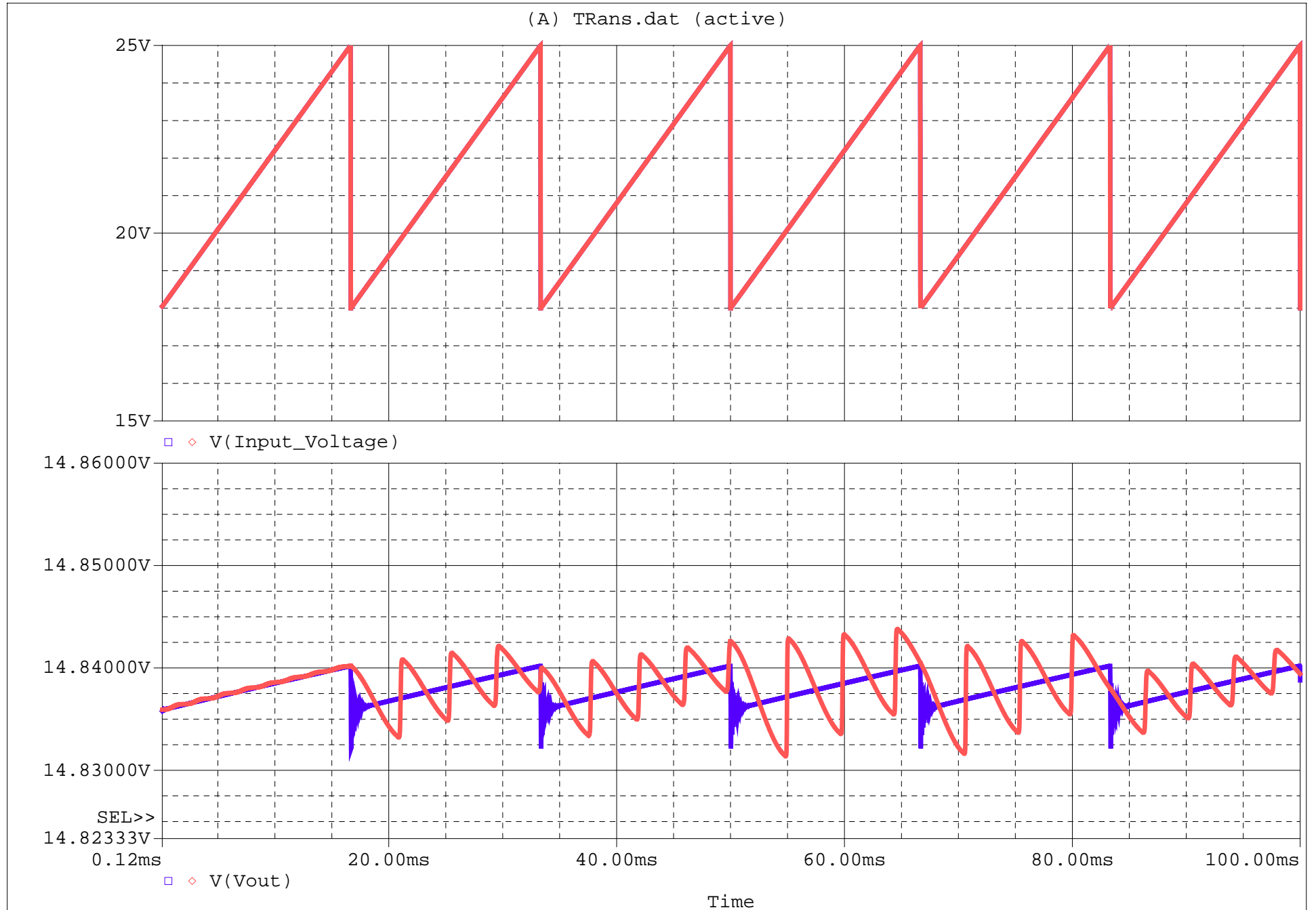
15, 1.5MEG

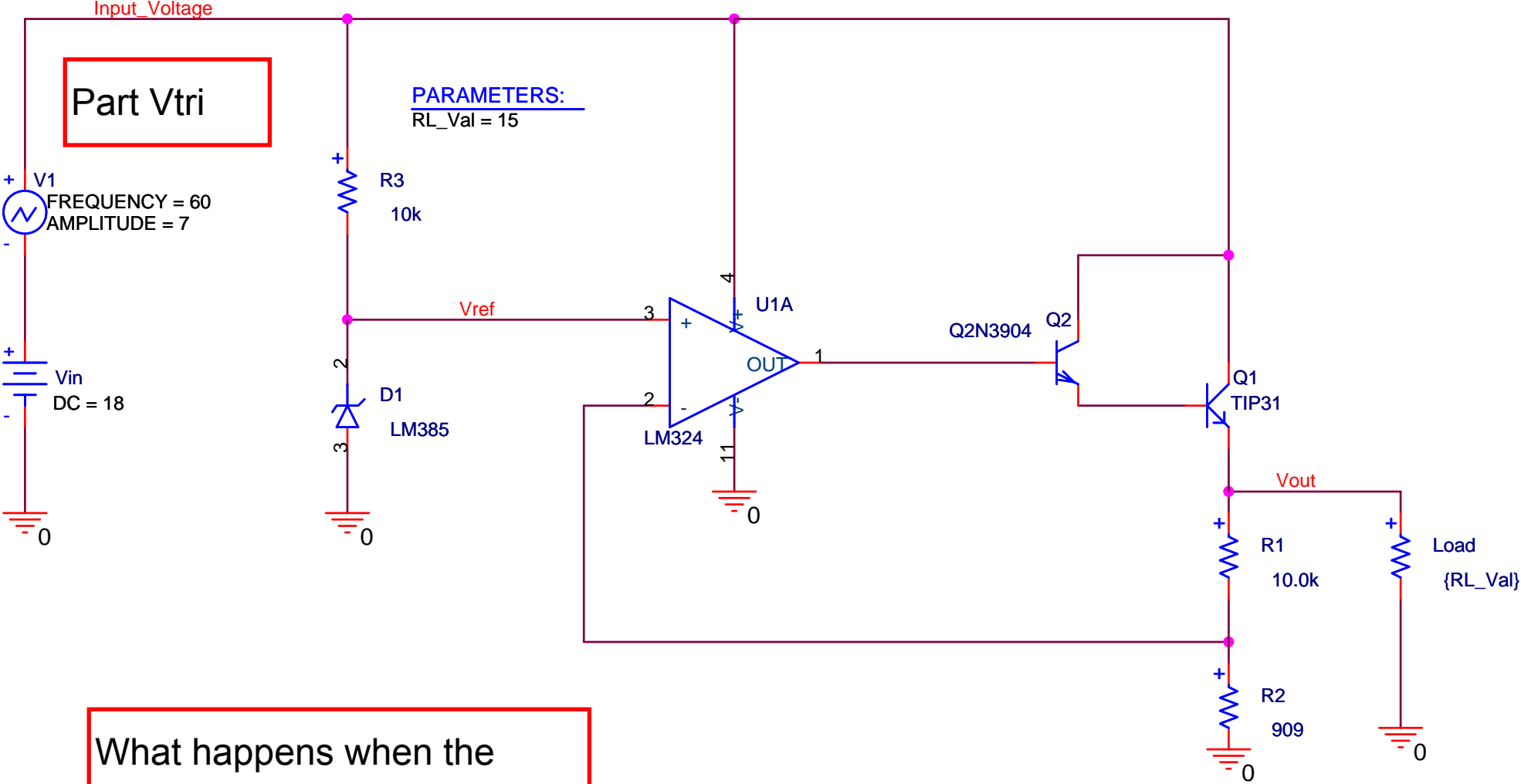




Added filter cap on output. In practice, add a 0.1uF in parallel with an electrolytic because electrolytics have a large series inductance and a high series impedance at high frequency.

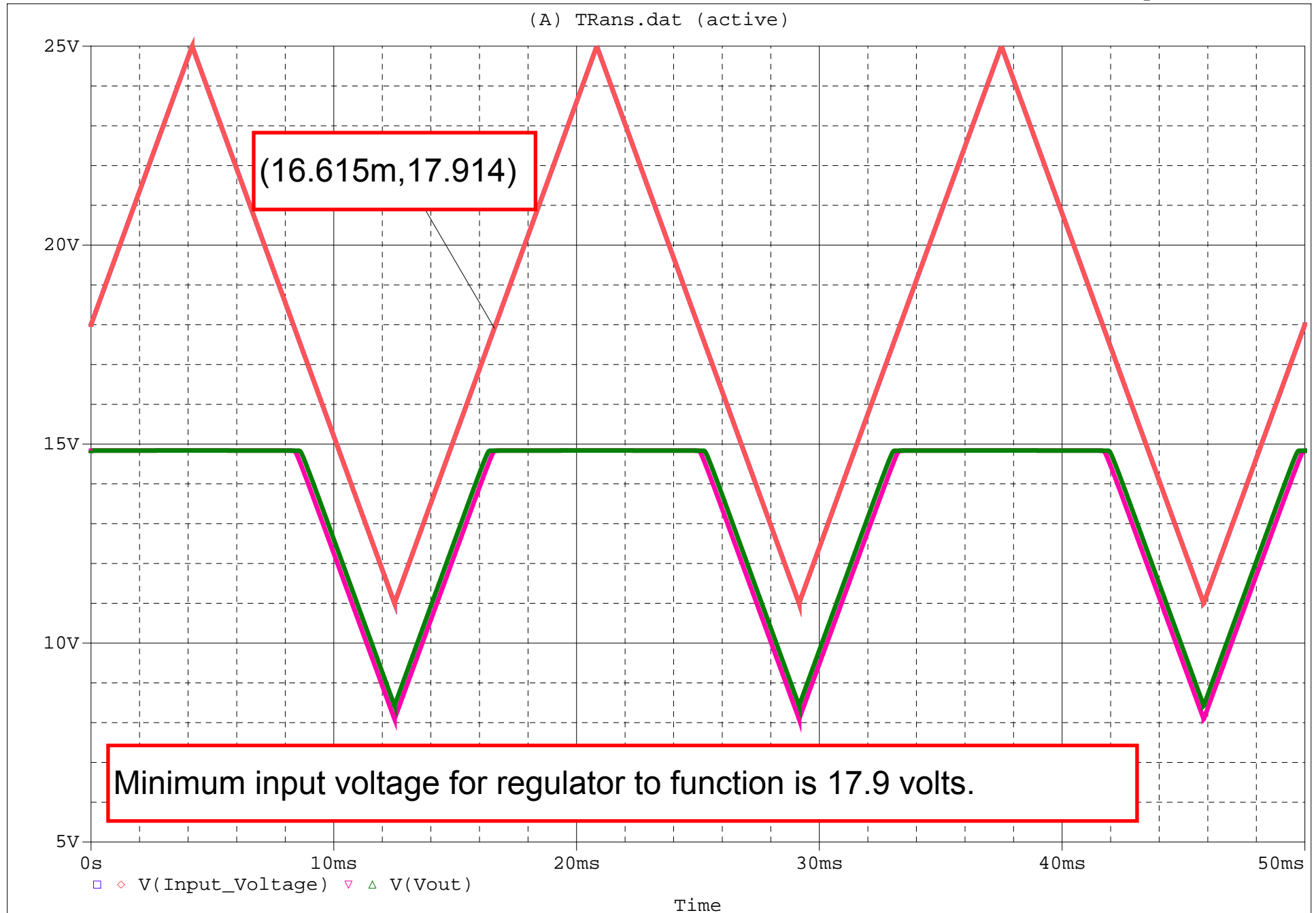
** Profile: "SCHEMATIC1-TRans" [C:\Website\Rose_Classes\ECE556\Notes\Orcad\OPAMP-Linear REGulator\1\op-...
Date/Time run: 12/07/03 Temperature: 27.0

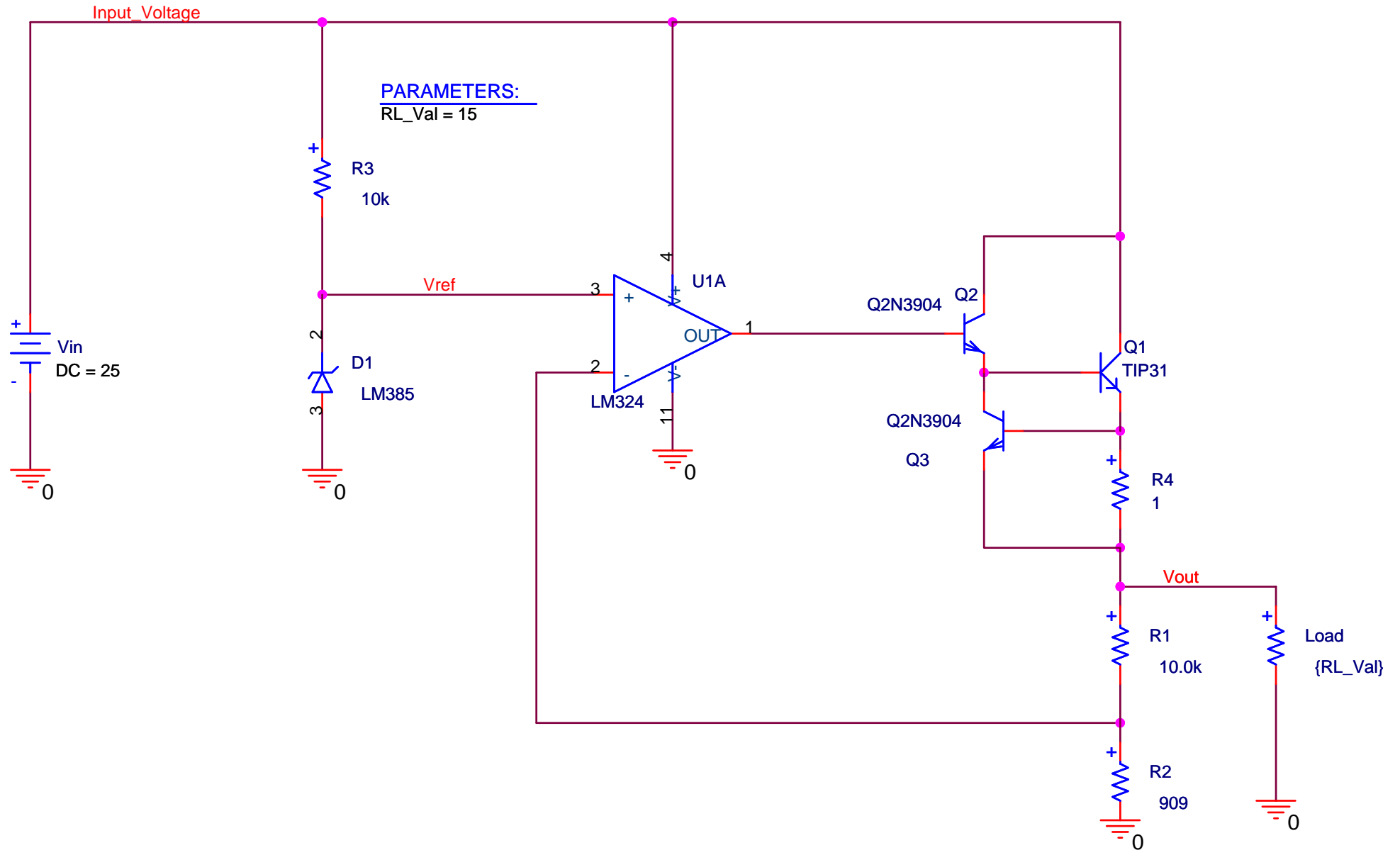




Part Vtri

What happens when the input voltage becomes too small?





Analysis type:

DC Sweep

Options:

 Primary Sweep Secondary Sweep Monte Carlo/Worst Case Parametric Sweep Temperature (Sweep) Save Bias Point Load Bias Point

Sweep variable

 Voltage source

Name:

 Current source

Model type:

 Global parameter

Model name:

 Model parameter Temperature

Parameter name:

RL_Val

Sweep type

 Linear

Start value:

1.5

 Logarithmic

Decade

End value:

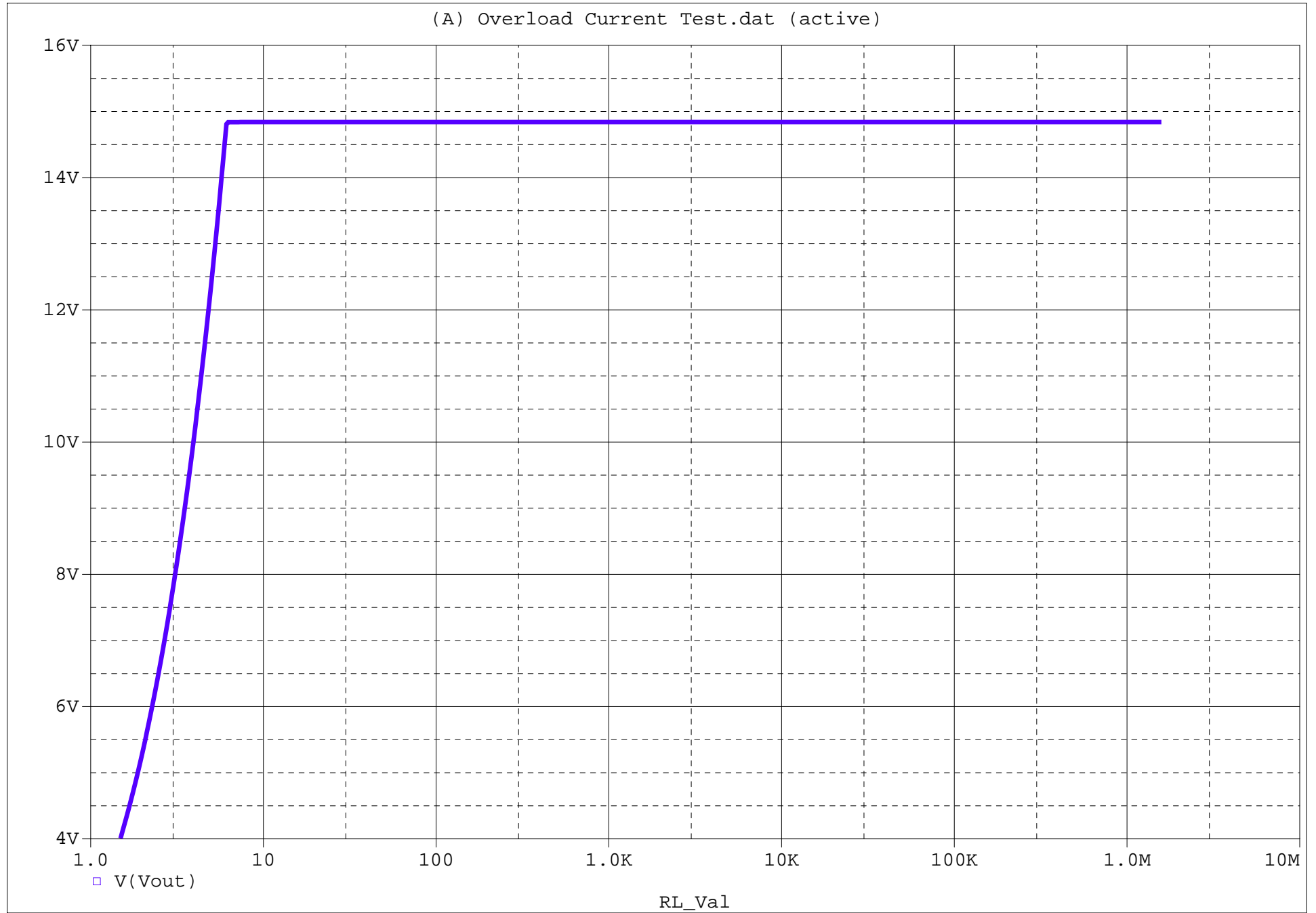
1.5MEG

Points/Decade:

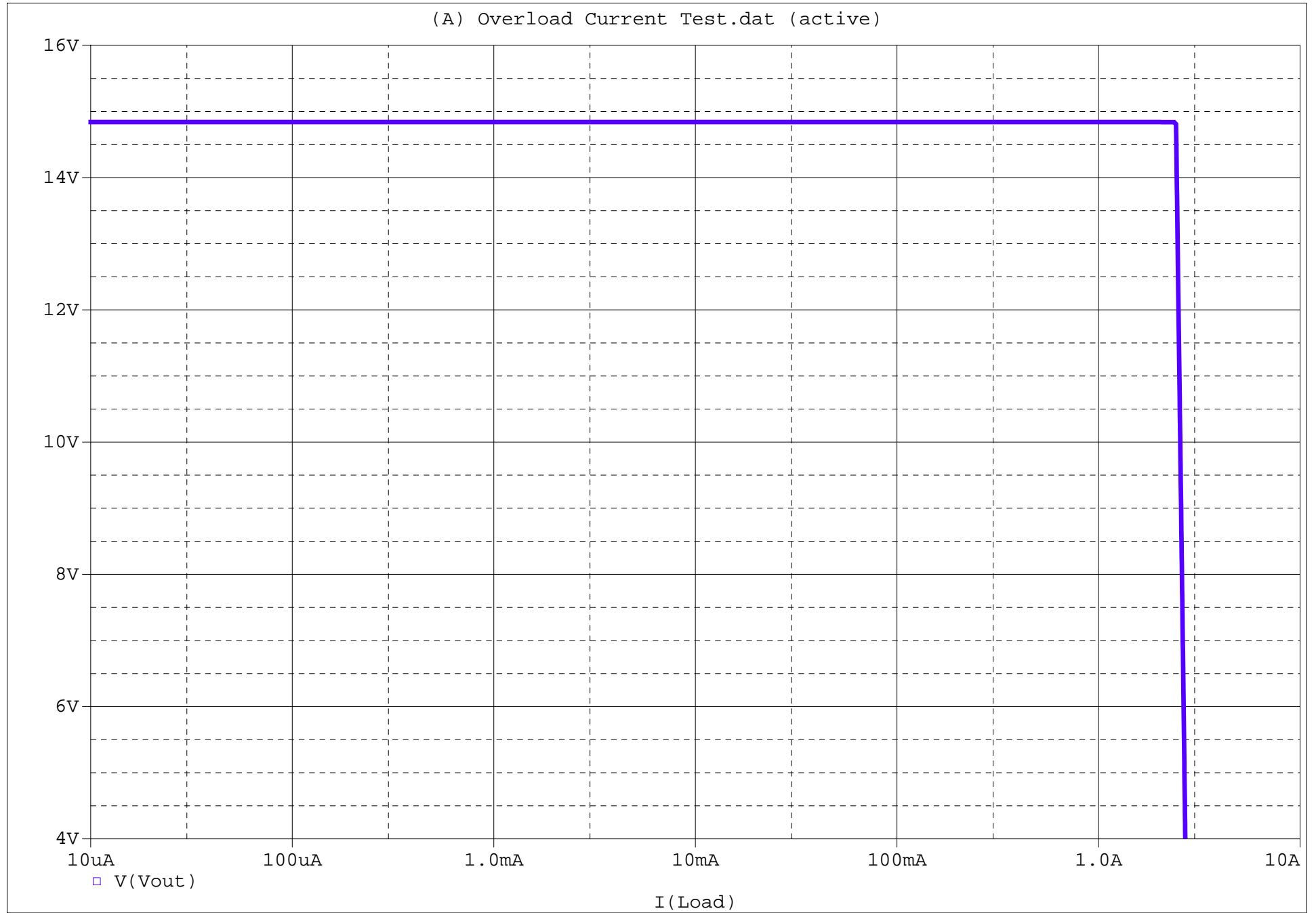
100

 Value list

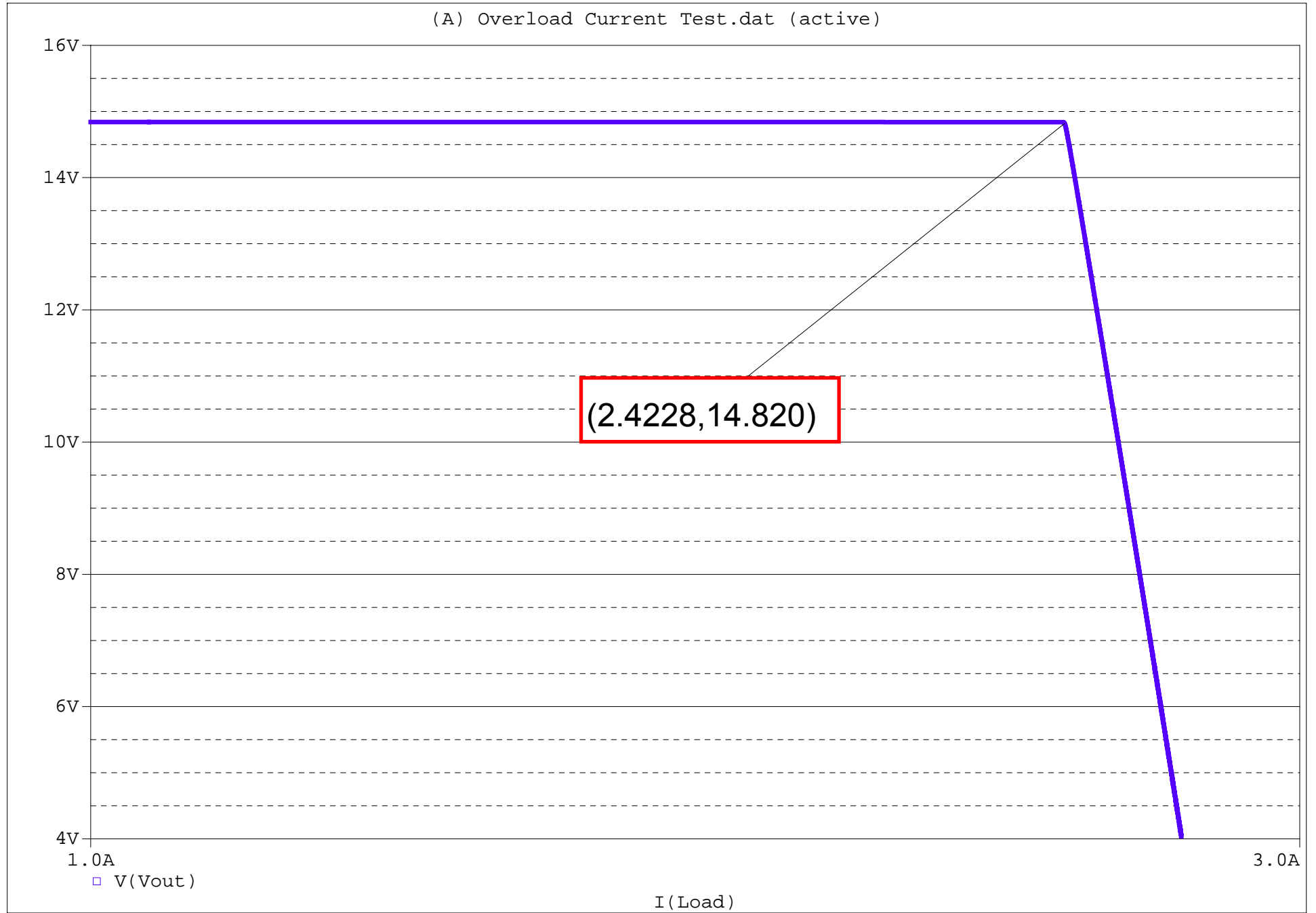
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Date/Time run: 12/07/03 Temperature: 27.0



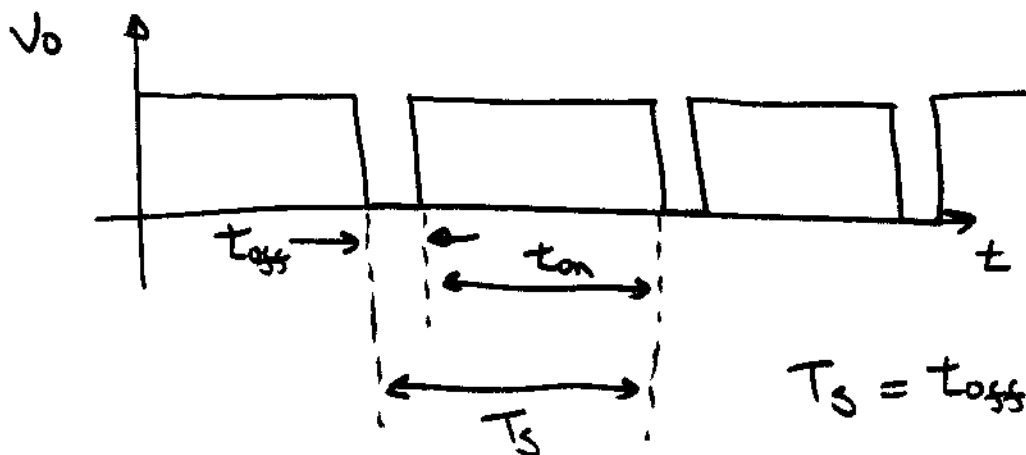
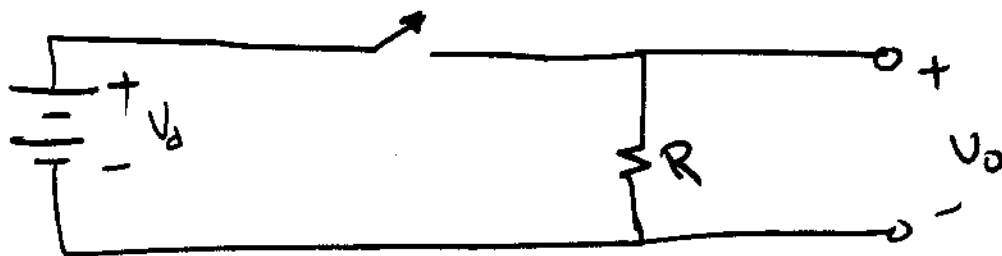
** Profile: "SCHEMATIC1-Overload Current Test" [C:\Website\Rose_Classes\ECE556\Notes\Orcad\OPAMP-Linear...
Date/Time run: 12/07/03 Temperature: 27.0



** Profile: "SCHEMATIC1-Overload Current Test" [C:\Website\Rose_Classes\ECE556\Notes\Orcad\OPAMP-Linear...
Date/Time run: 12/07/03 Temperature: 27.0



DC - DC Step Down Converter (BUCK)



$$T_s = t_{\text{off}} + t_{\text{on}} = \text{const}$$

$$\langle V_o \rangle = \frac{1}{T_s} \int_{T_s} V_o(t) dt = \frac{1}{T_s} \int_0^{t_{\text{off}}} 0 \cdot dt + \frac{1}{T_s} \int_{t_{\text{off}}}^{t_{\text{on}} + t_{\text{off}}} V_d dt$$

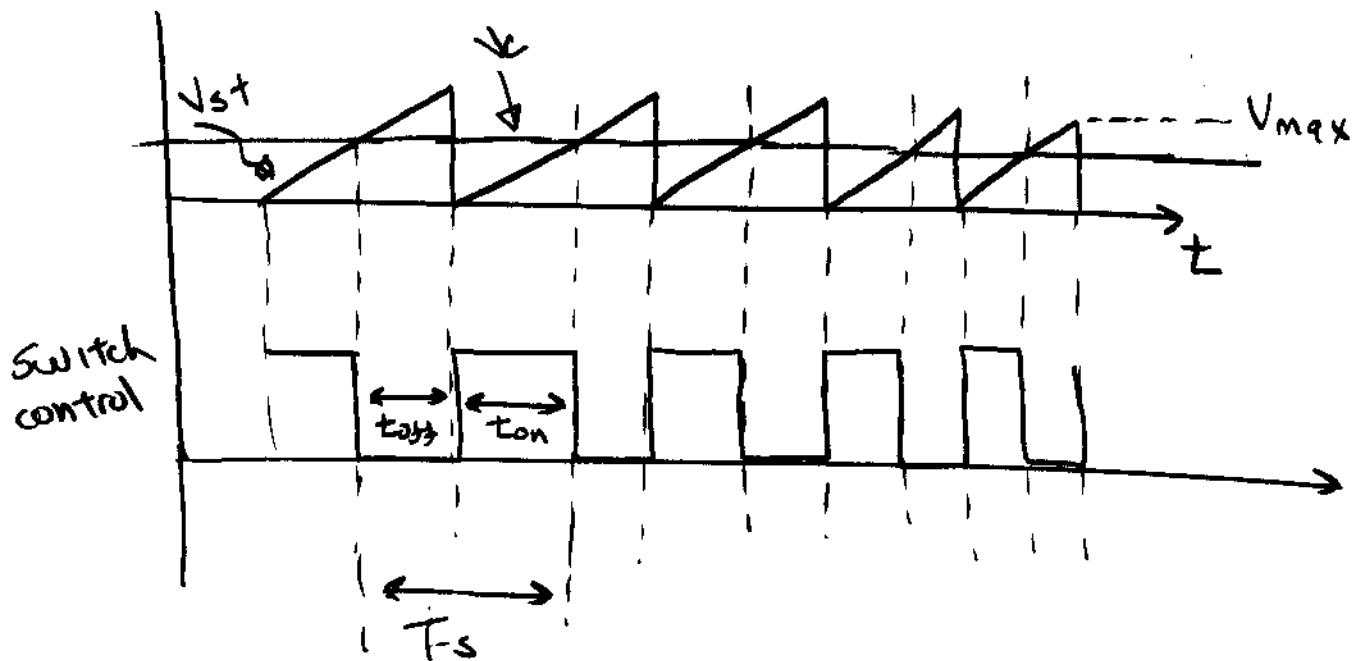
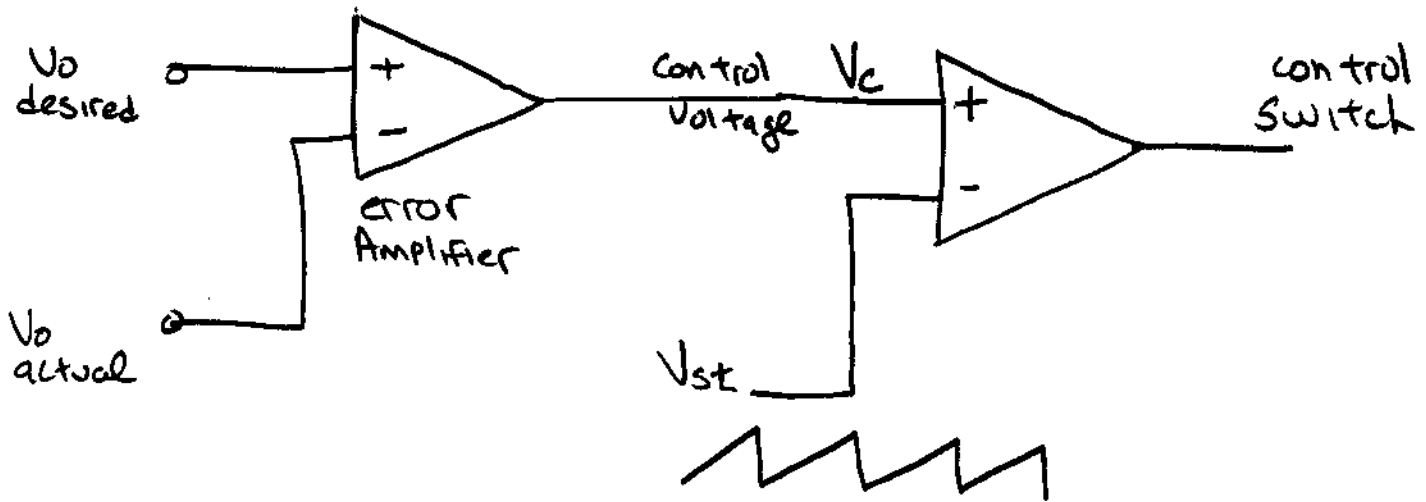
$$\langle V_o \rangle = \frac{t_{\text{on}}}{T_s} V_d$$

Let $D = \frac{t_{\text{on}}}{T_s} = \text{duty Cycle}$

$$\Rightarrow \langle V_o \rangle = D V_d$$

$\Rightarrow V_o$ only depends on
Duty Cycle, NOT
Frequency

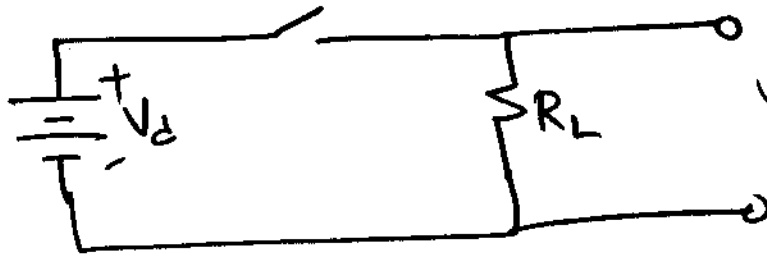
Control of DC-DC Supply



- Switching Frequency $F_s = \frac{1}{T_s}$

- as error increases, t_{on} increases

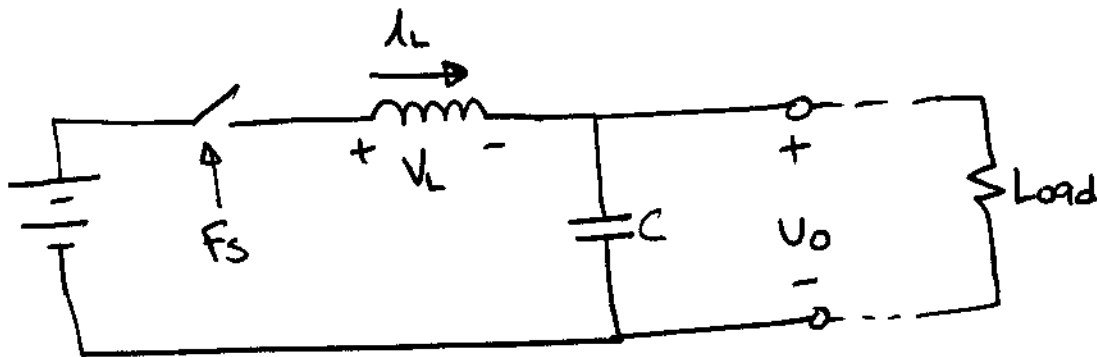
$$D = \frac{t_{on}}{T_s} = \frac{V_c}{V_{max}}$$



$$V_o = \frac{t_{on}}{T_s} V_d = D V_d$$

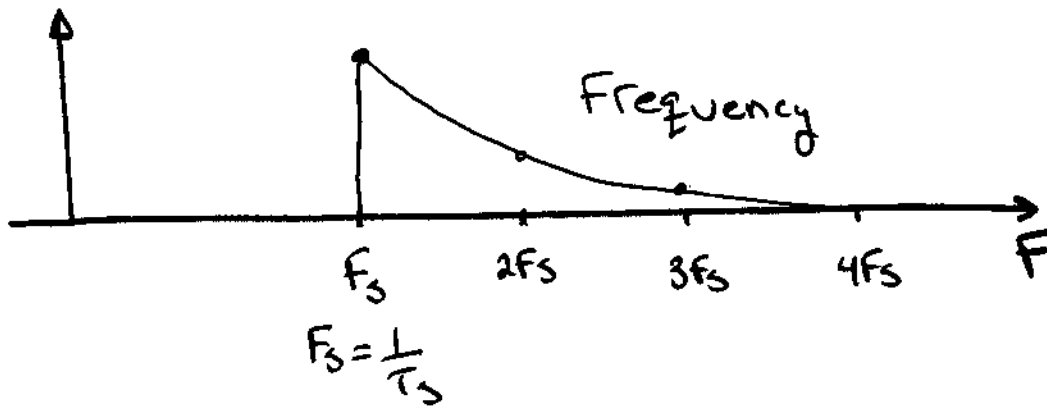
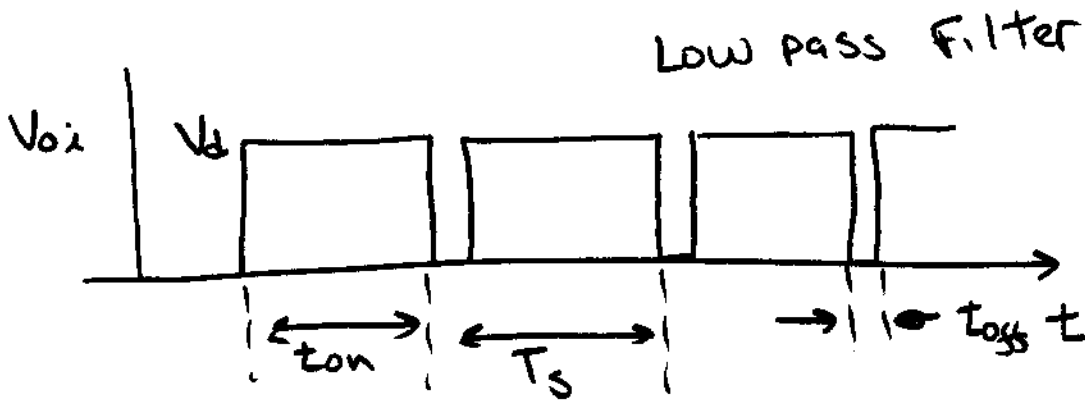
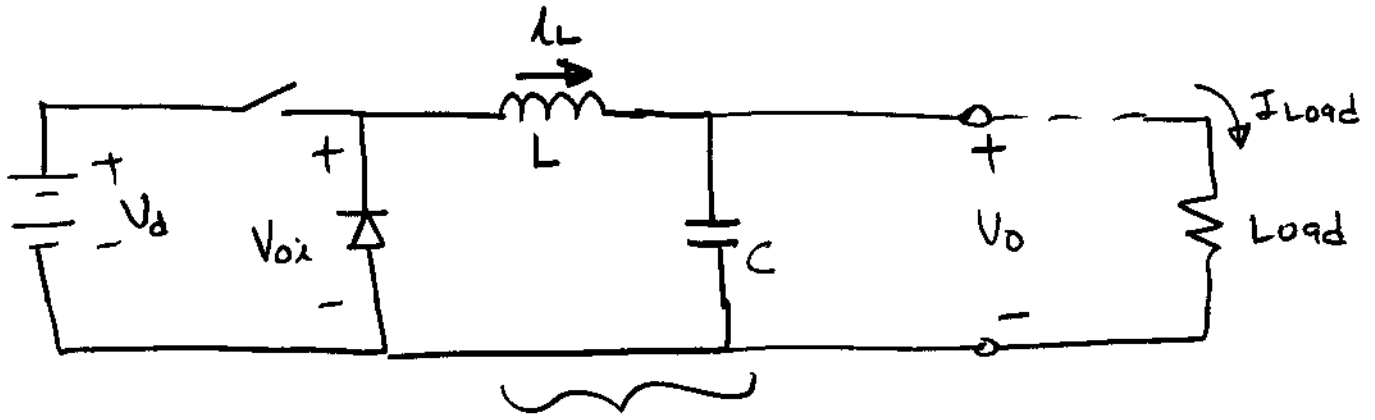
V_o has lots of ripples:

⇒ add a low pass filter



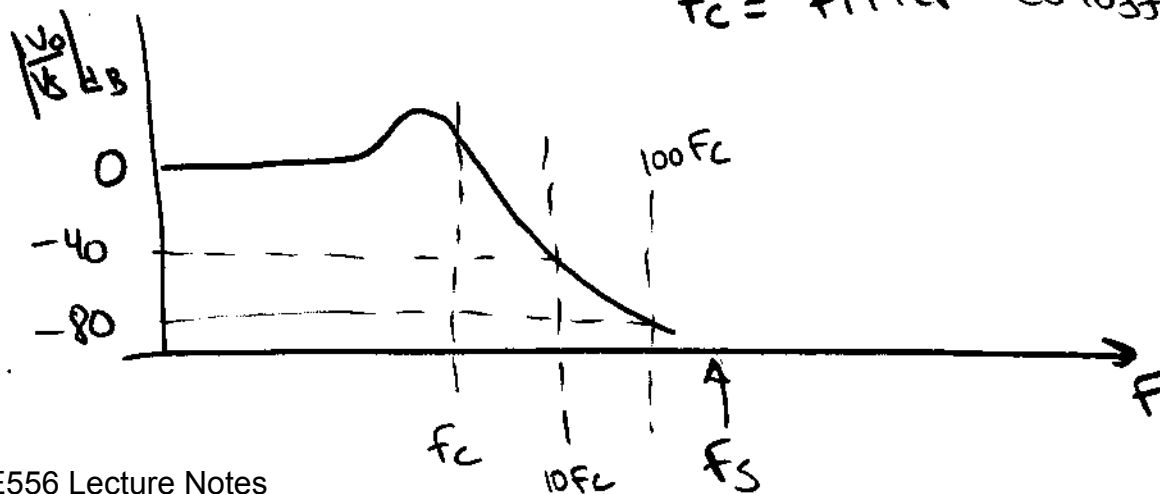
$F_s =$ Switching frequency

- What is the problem with this circuit?
- When switch opens, inductor current can not go to zero instantaneously.



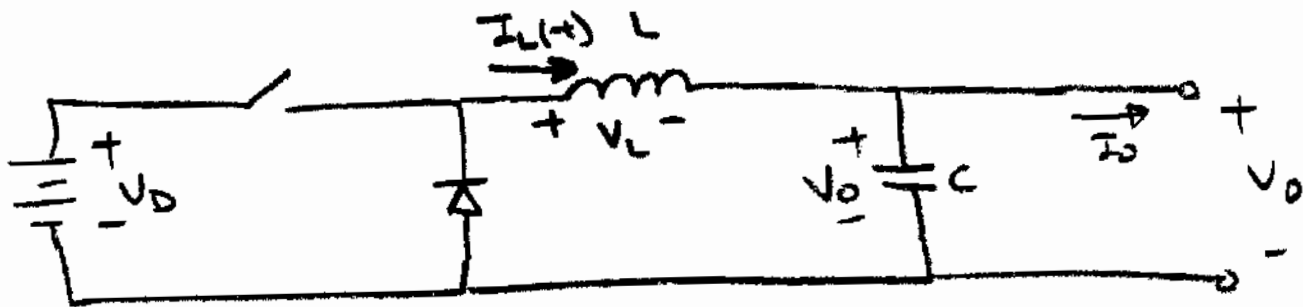
Low Pass Filter

f_c = Filter Cutoff Frequency



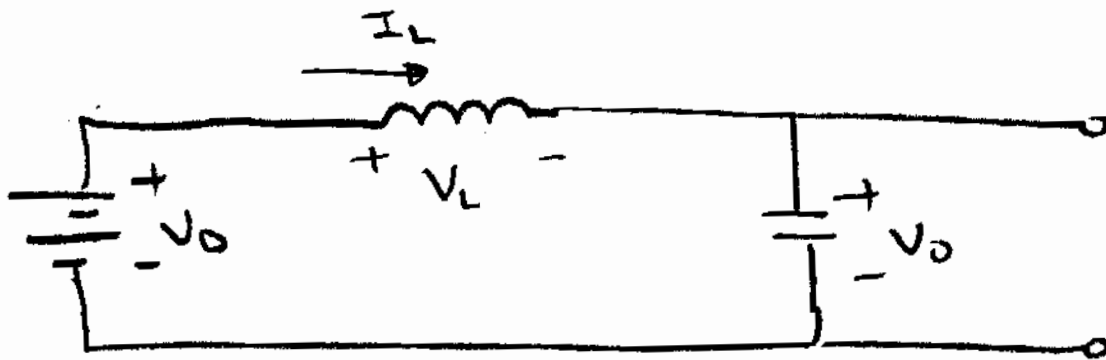
Buck converter - Continuous mode

①



- For a buck converter, $V_D > V_o$

- When the switch is on (closed), the diode is off and we have



$$V_L = V_D - V_o$$

Since $V_D > V_o$, $V_L > 0$

$$\text{From } V_L = L \frac{dI_L(t)}{dt}$$

we get

②

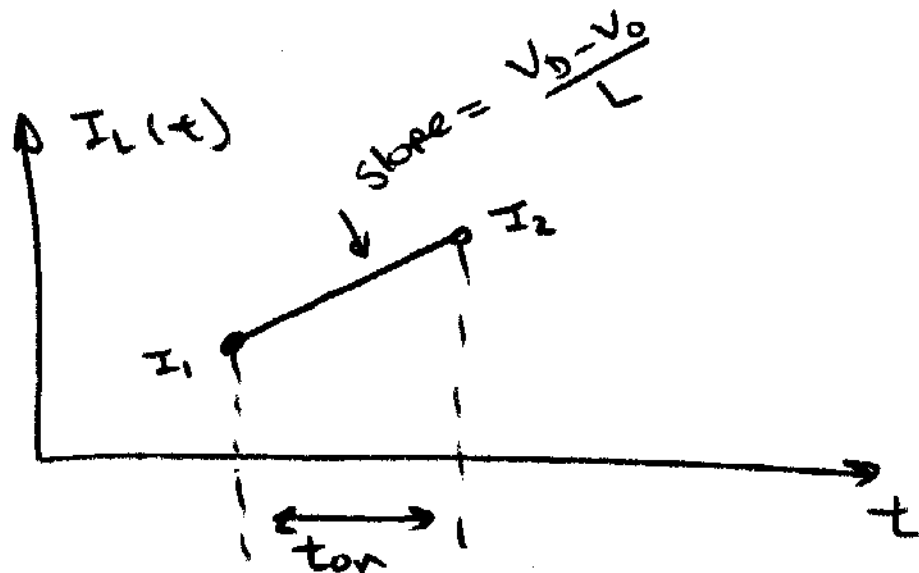
$$i_L(t) = \frac{1}{L} \int V_L(t) dt + I.C.$$

when the switch is closed, we have
(during t_{on})

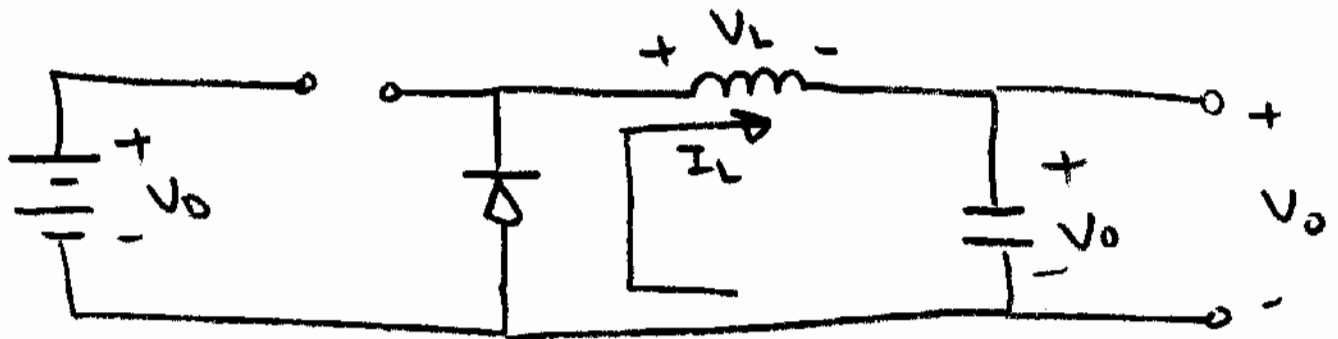
$$i_L(t) = \frac{1}{L} \int (V_D - V_0) dt + I.C. = \frac{V_D - V_0}{L} t + I.C.$$

\Rightarrow The inductor current increases

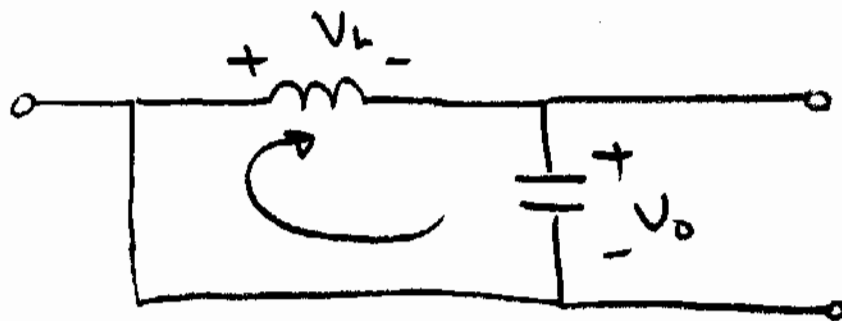
with slope $\frac{V_D - V_0}{L}$



When the switch opens, current through ⁽³⁾ the inductor cannot go to zero instantaneously so current must flow through the diode



Assume that the diode is ideal \Rightarrow
Replace the diode by a short:



During t_{off} , the switch is open and

$$V_L = -V_0$$

$$\text{So } V_L < 0$$

From $V_L = L \frac{dI_L}{dt}$

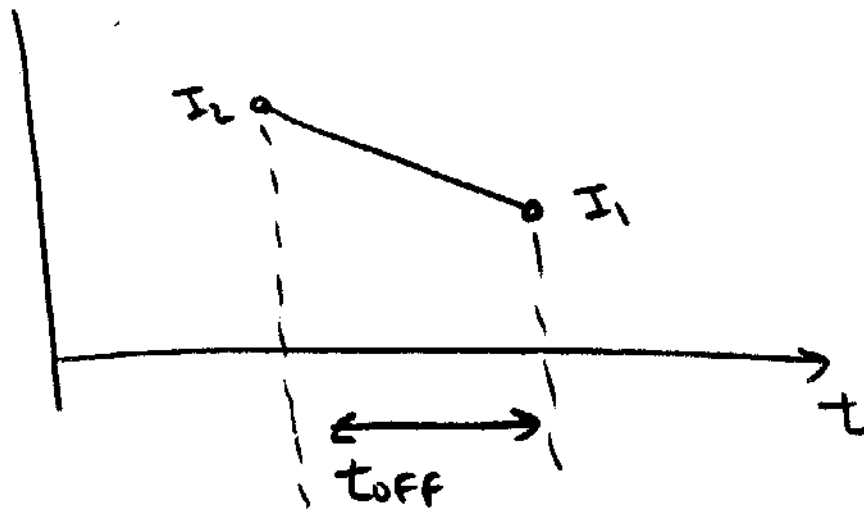
(4)

$$I_L(t) = \frac{1}{L} \int V_L(t) dt + I.C.$$

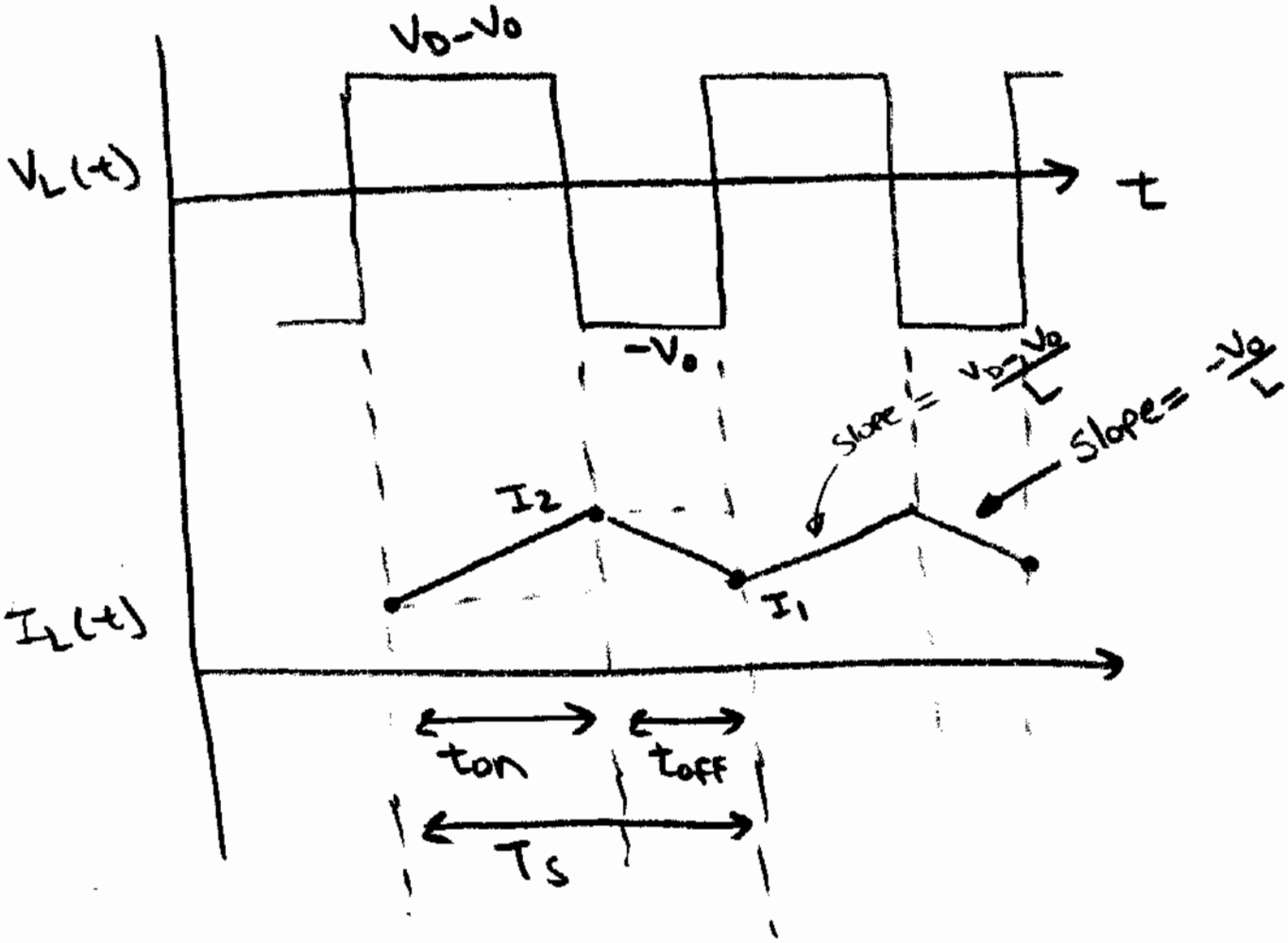
$$= \frac{1}{L} \int -V_o dt + I.C.$$

$$= \frac{-V_o t}{L} + I.C.$$

When the switch is off, the inductor current decreases with slope $-\frac{V_o}{L}$



The complete Picture is



t_{on} - Switch on or closed

t_{off} - Switch off or open

Continuous mode - Inductor current never goes to zero.

Step 1 : in steady state, the average voltage across the inductor is zero. why?

$$\int_0^T v_L(t) dt = 0$$

$$= \int_0^{ton} (V_D - V_o) dt + \int_{ton}^T -V_o dt$$

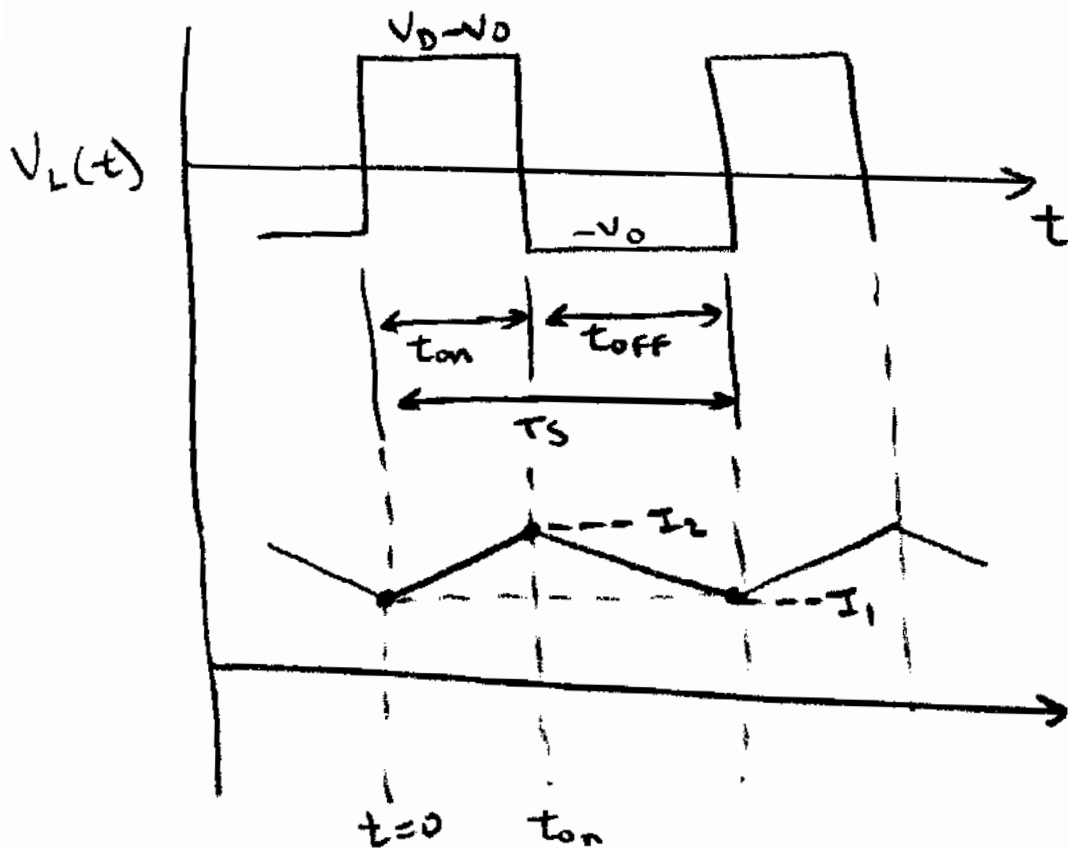
$$= (V_D - V_o) ton - V_o(\tau - ton) = 0$$

$$\Rightarrow V_D ton - V_o \tau = 0$$

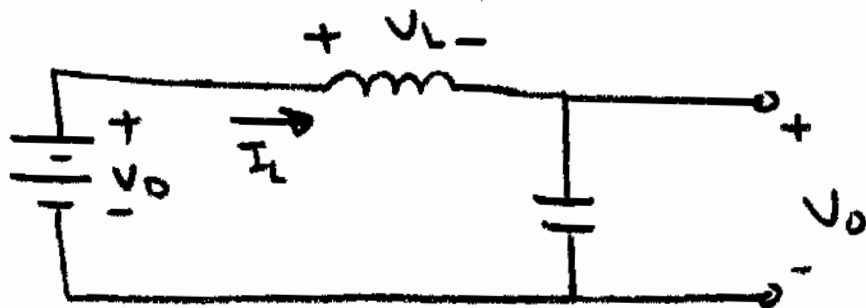
$$\Rightarrow \boxed{V_o = \frac{V_D ton}{\tau} = D V_D} \quad \text{where } D = \frac{ton}{\tau}$$

Step 2 : Inductor current

(7)



during t_{on} we have



$$V_L = V_D - V_0$$

$$V_L(t) = L \frac{dI_L(t)}{dt} \Rightarrow I_L(t) = \frac{1}{L} \int V_L(t) dt + I_{L0}$$

8

During t_{on} we have

$$i_L(t) = \frac{1}{L} \int_0^t (V_D - V_0) dt + I_1$$

at $t = t_{on}$, the inductor current has reached I_2

$$I_2 = \frac{1}{L} \int_0^{t_{on}} (V_D - V_0) dt + I_1$$

$$\Rightarrow I_1 - I_2 = \left(\frac{V_D - V_0}{L} \right) t_{on}$$

If we do the same analysis during t_{off} ,
we get the same equation as above.

Step 3: Avg output current

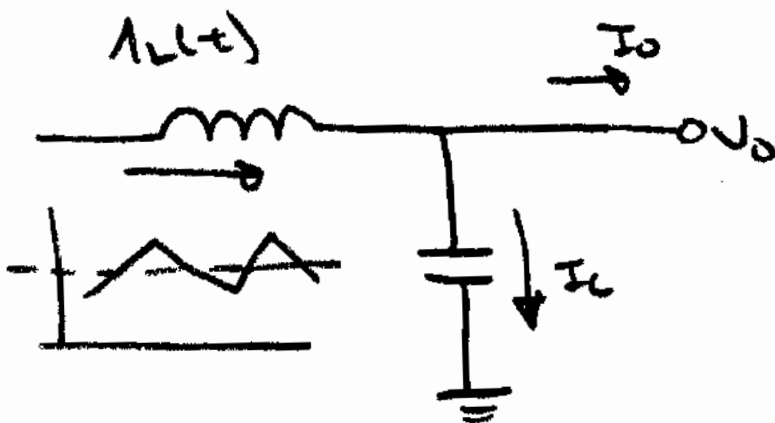
- In the Boost and Buck Boost converters we do in the future, we will set

$$P_o = P_{in} \quad \text{or} \quad V_o I_o = V_D I_D \quad \text{and we}$$

will get an equation for $I_1 + I_2$.

- For our Buck regulator we could also set $P_o = P_{in}$ and solve as well.

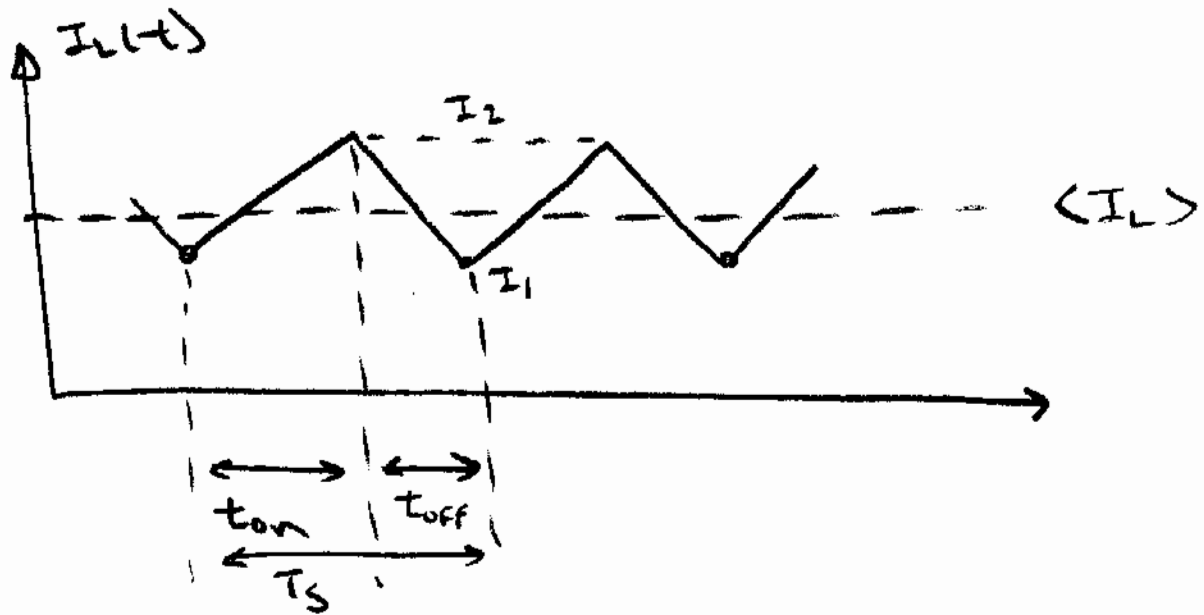
- Instead, we will look at the average inductor current



- NO DC current flows through the cap because the cap is an open circuit to DC
- only the AC ripple flows through the cap. We will use this later to figure out the ripple at the supply output.
- If all the ripple current flows through the cap, the DC current must flow through the output

$$\Rightarrow I_0 = \text{DC Inductor current} \\ = \text{Average inductor current}$$

$$\Rightarrow I_0 = \langle I_L \rangle = \text{Time Average} \\ \text{Inductor current}$$



during t_{on} $I_L(t) = I_1 + m t$ where $m = \frac{I_2 - I_1}{t_{on}}$

during t_{off} $I_L(t) = I_2 + m t$ where $m = \frac{I_1 - I_2}{t_{off}}$

$$\langle I_L \rangle = \frac{1}{T_s} \int_0^{T_s} I_L(t) dt = \frac{1}{T_s} \left[\int_0^{t_{on}} I_{L1}(t) dt + \int_0^{t_{off}} I_{L2}(t) dt \right]$$

$$= \frac{I_1 + I_2}{2}$$

$$= I_0$$

$$I_0 = \frac{I_1 + I_2}{2}$$

In continuous mode

$$\textcircled{1} \quad V_o = \frac{t_{on}}{T} V_d = D V_d$$

$$\textcircled{2} \quad \left\{ \begin{array}{l} I_2 - I_1 = \frac{V_d - V_o}{L} t_{on} \end{array} \right.$$

$$\textcircled{3} \quad \left\{ \begin{array}{l} \frac{I_1 + I_2}{2} = I_o \quad - \text{Avg output current} \end{array} \right.$$

The current is continuous if $I_1 > 0$
 - Find condition when circuit operates in
 continuous mode

Find I_1 :

$$I_1 - I_2 = \frac{V_o - V_d}{L} t_{on} \quad \textcircled{a}$$

$$I_1 + I_2 = 2 I_o \quad \textcircled{b}$$

Add

$$2 I_1 = \left(\frac{V_o - V_d}{L} t_{on} \right) + 2 I_o$$

Solve for $I_1 = 0$

$$2I_1 = \left(\frac{V_0 - V_D}{L}\right)t_{on} + 2I_0 = 0$$

$$t_{on}\left(\frac{V_0 - V_D}{L}\right) + 2I_0 = 0 \Rightarrow \boxed{I_0 = \left(\frac{V_D - V_0}{2L}\right)t_{on}}$$

So $I_1 > 0$ if $I_0 > \left(\frac{V_D - V_0}{2L}\right)t_{on}$

so for continuous mode

$$\begin{aligned} V_0 &= \frac{t_{on}}{T} V_D = D V_D \\ I_2 - I_1 &= \frac{V_D - V_0}{L} t_{on} \\ \frac{I_1 + I_2}{2} &= I_0 \\ I_0 &> \left(\frac{V_D - V_0}{2L}\right)t_{on} \end{aligned}$$

as I_0 changes, $D = \text{const}$

Choosing the Capacitor

Method 1

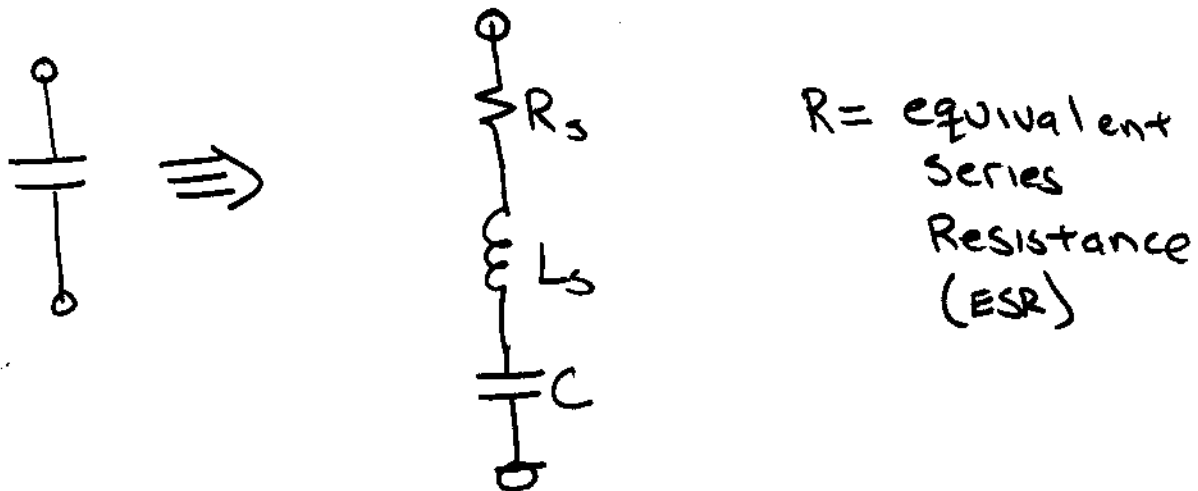
- Design L + C as Low Pass Filter

Choose $F_c < \frac{F_s}{100}$

Then $F_c = \frac{1}{2\pi \sqrt{LC}}$

Method 2

Use a Real model of a Capacitor



Below 300K - 500 KHz, Ignore L_s



- Two Ripple Components due to C + R_s
- The Two Ripple components are out of phase, but for worst case analysis, we shall Assume they add in phase.

- For Typical Electrolytic $R_s C = \text{const}$

- Typical Values For $R_s C$ are in the Range 50 to $80 \times 10^{-6} \mu\text{s}$

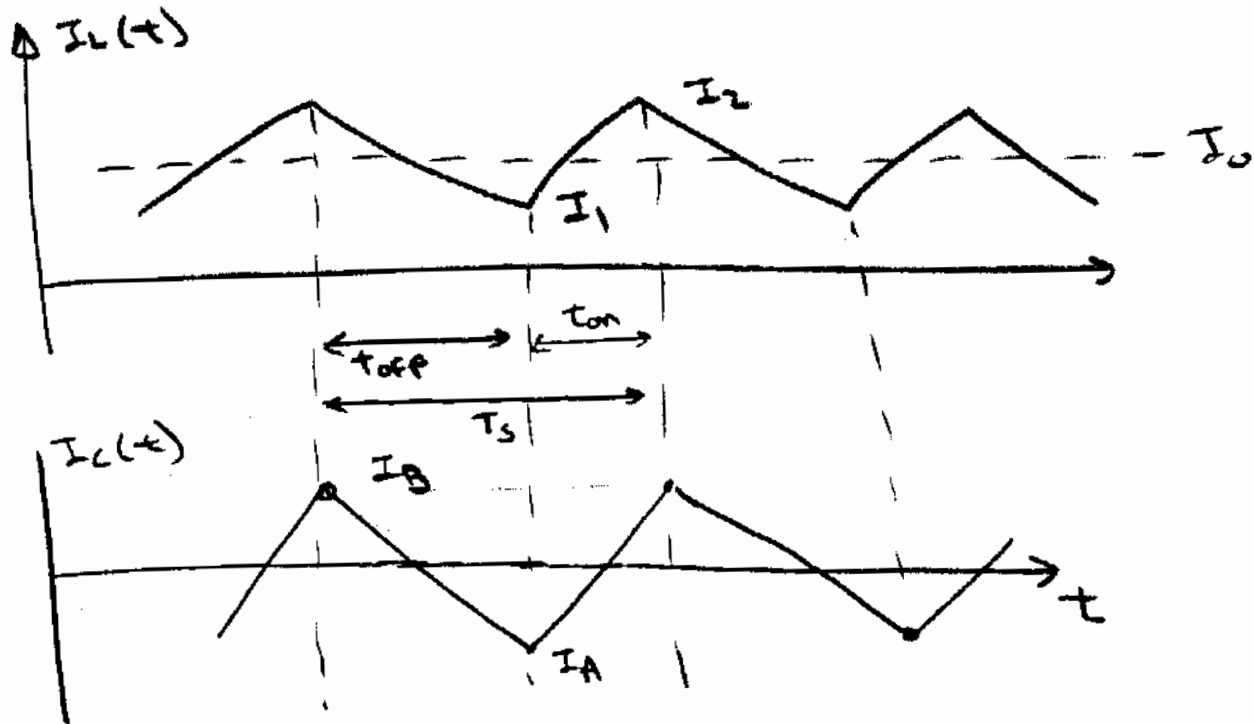
Ripple Voltage due to R_s is

$$V_{RR} = (I_2 - I_1) R_s$$

Capacitor ripple current

①

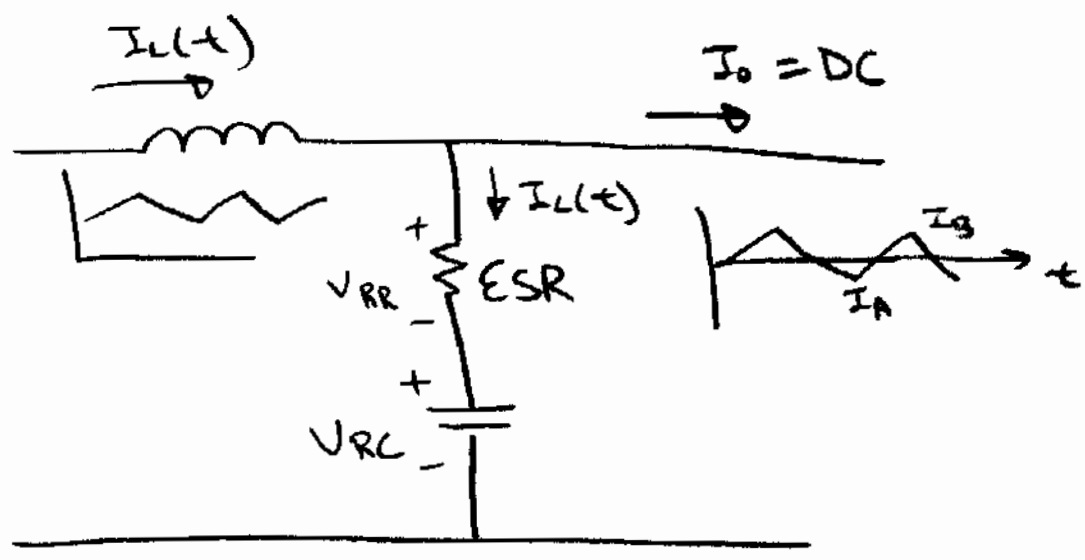
$$I_C = I_L - I_0 \quad \text{where} \quad I_0 = \frac{I_1 + I_2}{2}$$



$$I_B = I_2 - I_0 = I_2 - \frac{I_1 + I_2}{2} = \frac{I_2 - I_1}{2}$$

$$I_A = I_1 - I_0 = I_1 - \frac{I_1 + I_2}{2} = \frac{I_1 - I_2}{2}$$

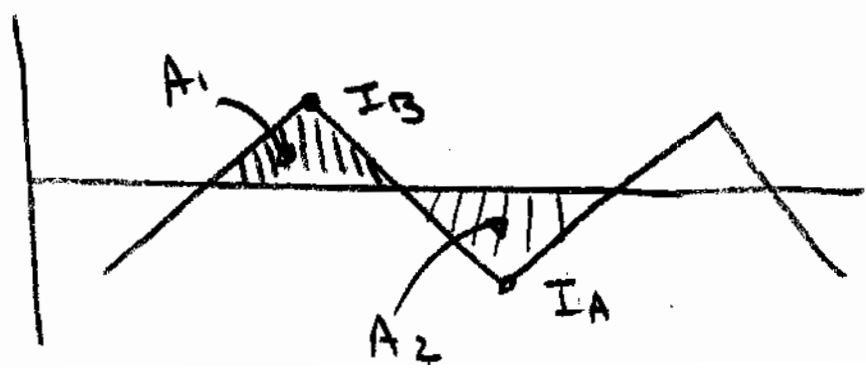
$$= -\left(\frac{I_2 - I_1}{2}\right) = -I_B$$



The ripple current $I_C(t)$ flows through the ESR and generates a ripple voltage

$$V_{RR} = (I_B - I_A) ESR = (I_2 - I_1) ESR$$

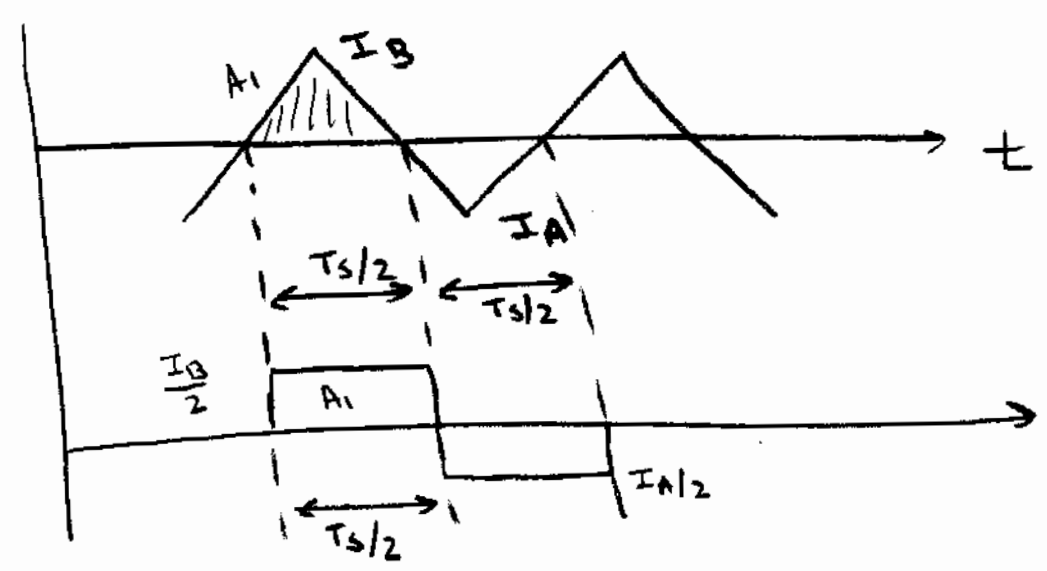
- I_C also flows through the cap and charges and discharges the cap



- During A_1 , we put charge into the cap and the voltage increases.
- During A_2 , we remove charge from the cap and its voltage decreases.
- Use $Q = CV$ to find ripple voltage

$$Q = A_1 = A_2$$

- Note $A_1 = A_2$ because the average capacitor voltage remains constant



(4)

$$A_1 = \left(\frac{I_B}{2}\right)\left(\frac{T_s}{2}\right) = \frac{I_B T_s}{4} \quad \text{and} \quad I_B = \frac{I_2 - I_1}{2}$$

$$\Rightarrow A_1 = \frac{(I_2 - I_1) T_s}{8} = \Delta$$

$$\text{From } \Delta = CV \Rightarrow V = \frac{\Delta}{C}$$

$$\Rightarrow V_{RC} = \left(\frac{I_2 - I_1}{8}\right)\left(\frac{T_s}{C}\right)$$

This is the peak-to-peak ripple because A_1 increases V_0 and A_2 returns V_0 to where it originally was.

(5)

Capacitor RMS Ripple Current

$$I_{C_{RMS}} = \sqrt{\frac{1}{T_s} \int_0^{T_s} I_C^2(t) dt} = \sqrt{\frac{1}{T_s} \int_0^{T_s} (I_L(t) - I_O)^2 dt}$$

Buck Regulator Summary
continuous mode

$$V_O = \frac{t_{on}}{T} V_D = D V_D$$

$$D = \frac{t_{on}}{T_s}$$

$$I_2 - I_1 = \frac{V_D - V_O}{L} t_{on}$$

$$\frac{I_1 + I_2}{2} = I_O$$

$$I_O > \left(\frac{V_D - V_O}{2L} \right) t_{on}$$

$$V_{RR} = (I_2 - I_1) ESR$$

$$V_{RC} = \frac{(I_2 - I_1) T_s}{8C}$$

ECE 456

Buck Regulator Design - Continuous Mode Operation

Define useful units for Electrical Engineering

$$\mu\text{s} \equiv 10^{-6} \cdot \text{sec}$$

Specify Input Voltage

$$V_D := 15 \cdot \text{volt}$$

Specify Output Voltage

$$V_o := 5 \cdot \text{volt}$$

Specify Switching Frequency

$$F_S := 20 \cdot \text{kHz}$$

$$T_S := \frac{1}{F_S}$$

$$T_S = 50 \mu\text{s}$$

Find on time assuming continuous mode operation.

$$t_{\text{on}} := \frac{V_o}{V_D} \cdot T_S$$

$$t_{\text{on}} = 16.7 \mu\text{s}$$

Specify the Max output Current

$$I_o := 5 \cdot \text{amp}$$

Design the buck regulator so that it operates in the continuous mode for currents down to 10% of the max current.

$$I_{o_min} := 0.1 \cdot I_o$$

$$I_{o_min} = 0.5 \text{ amp}$$

Find L so that the buck regulator operates in continuous mode for the min output current

$$L := \frac{V_D - V_o}{2 \cdot I_{o_min}} \cdot t_{on} \quad L = 167 \mu\text{H}$$

Choose the next larger size std. inductor $L := 335 \mu\text{H}$

With chosen inductor, find min current for continuous operation

$$I_{o_min} := \frac{V_D - V_o}{2 \cdot L} \cdot t_{on} \quad I_{o_min} = 249 \text{ mA}$$

For the Max output current, find I1 and I2

$$I_1 := I_o \quad I_2 := I_o$$

Given

$$\frac{I_2 + I_1}{2} = I_o$$

$$I_2 - I_1 = \frac{V_D - V_o}{L} \cdot t_{on}$$

$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} := \text{find}(I_1, I_2)$$

$$I_2 = 5.249 \text{ amp}$$

$$I_1 = 4.751 \text{ amp}$$

$$I_2 - I_1 = 498 \text{ mA}$$

For the Min output current, find I1 and I2

$$I_{1_} := I_{o_min} \quad I_{2_} := I_{o_min}$$

Given

$$\frac{I_{2_} + I_{1_}}{2} = I_{o_min}$$

$$I_{2_} - I_{1_} = \frac{V_D - V_o}{L} \cdot t_{on}$$

$$\begin{pmatrix} I_{1_} \\ I_{2_} \end{pmatrix} := \text{find}(I_{1_}, I_{2_})$$

$$I_{2_} = 498 \text{ mA} \quad I_{1_} = 0 \text{ mA} \quad I_{2_} - I_{1_} = 498 \text{ mA}$$

Choose the filter capacitor.

Assume that the major component of the ripple comes from the capacitor ESR

Specify the ripple due to the ESR $V_{RR} := 10 \cdot \text{mV}$

$$\text{ESR} := \frac{V_{RR}}{(I_{2_} - I_{1_})} \quad \text{ESR} = 0.02 \Omega$$

For all electrolytic caps, assume that $ESR \cdot C = 80 \mu s$

$$C := \frac{80 \cdot \mu s}{ESR} \quad C = 3980 \mu F$$

Choose the next size std capacitor $C := 4700 \cdot \mu F$

Calculate the new ESR with the chosen capacitor

$$ESR := \frac{80 \cdot \mu s}{C} \quad ESR = 0.017 \Omega$$

Find the ripple due to the capacitor charging and discharging:

$$V_{RC} := \frac{(I_2 - I_1) \cdot T_S}{8 \cdot C} \quad V_{RC} = 0.662 \text{ mV}$$

Find the ripple due to the ESR

$$V_{RR} := (I_2 - I_1) \cdot ESR \quad V_{RR} = 8.468 \text{ mV}$$

Calculate the RMS ripple current for the capacitor.

The capacitor current is the inductor current minus the output current.

Define an equation for the inductor current during t_{on} .

$$I_{L1}(t) := I_1 + \frac{(I_2 - I_1)}{t_{on}} \cdot t$$

Define an equation for the inductor current during t_{off} .

$$t_{\text{off}} := T_S - t_{\text{on}} \quad t_{\text{off}} = 33 \mu\text{s}$$

$$I_{L2}(t) := I_2 + \frac{(I_1 - I_2)}{t_{\text{off}}} \cdot t$$

Calculate the Capacitor RMS ripple current

$$I_{\text{RMS}} := \sqrt{\frac{1}{T_S} \cdot \left[\int_{0 \cdot \text{sec}}^{t_{\text{on}}} (I_{L1}(t) - I_o)^2 dt + \int_0^{t_{\text{off}}} (I_{L2}(t) - I_o)^2 dt \right]}$$

$$I_{\text{RMS}} = 143.619 \text{ mA}$$

Summary

Inductor

$$L = 0.335 \text{ mH}$$

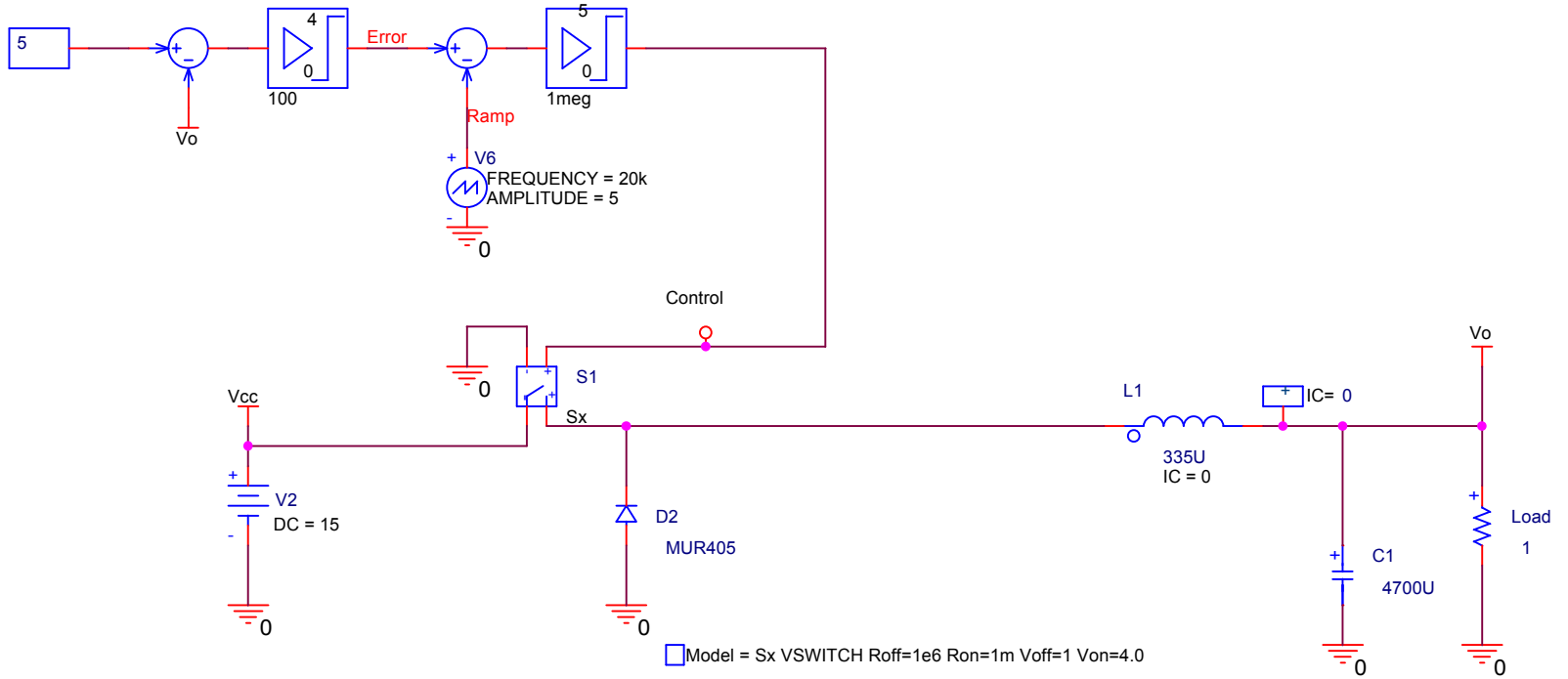
$$\text{Peak Current Rating} \quad I_2 = 5.249 \text{ amp}$$

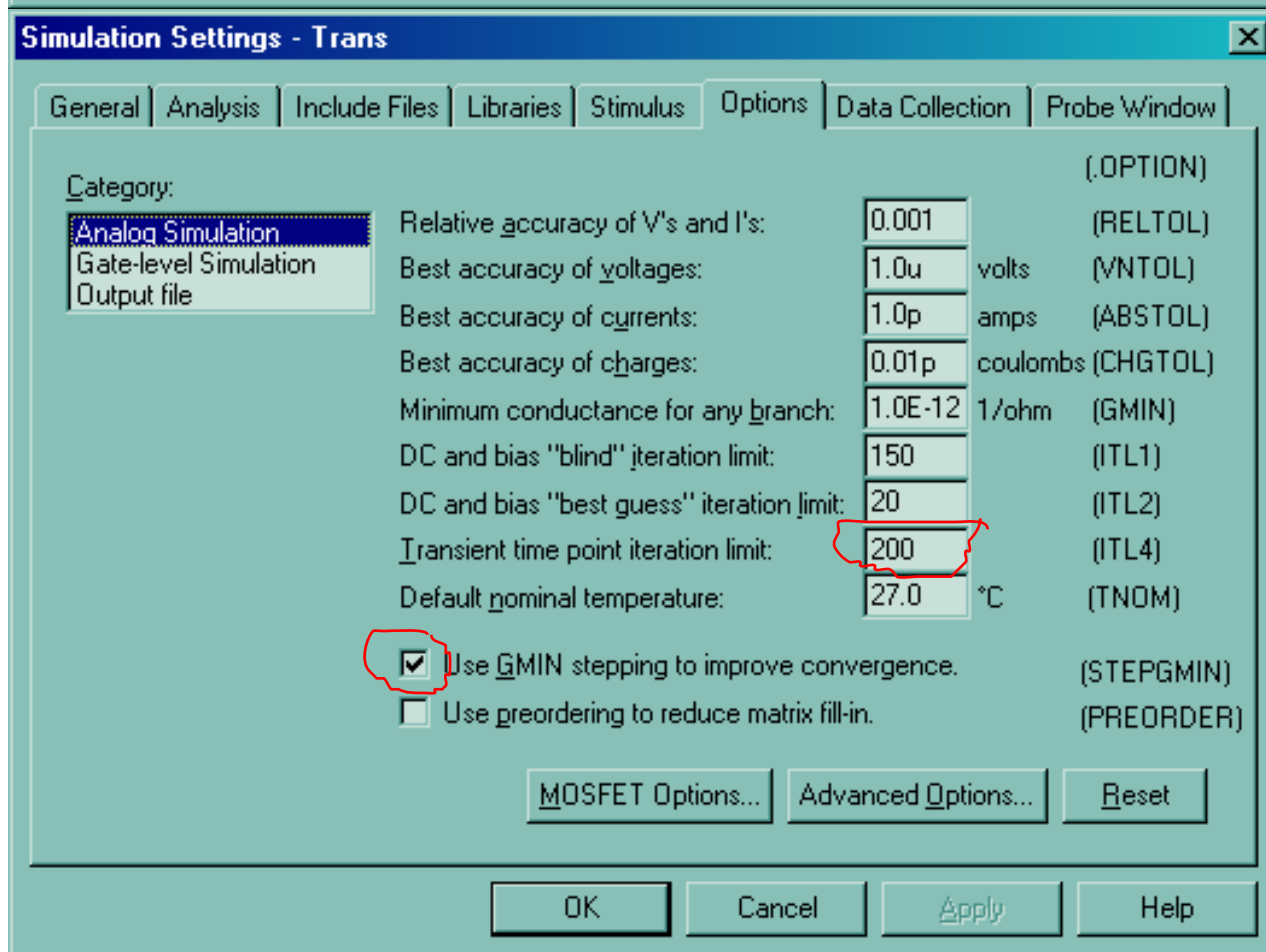
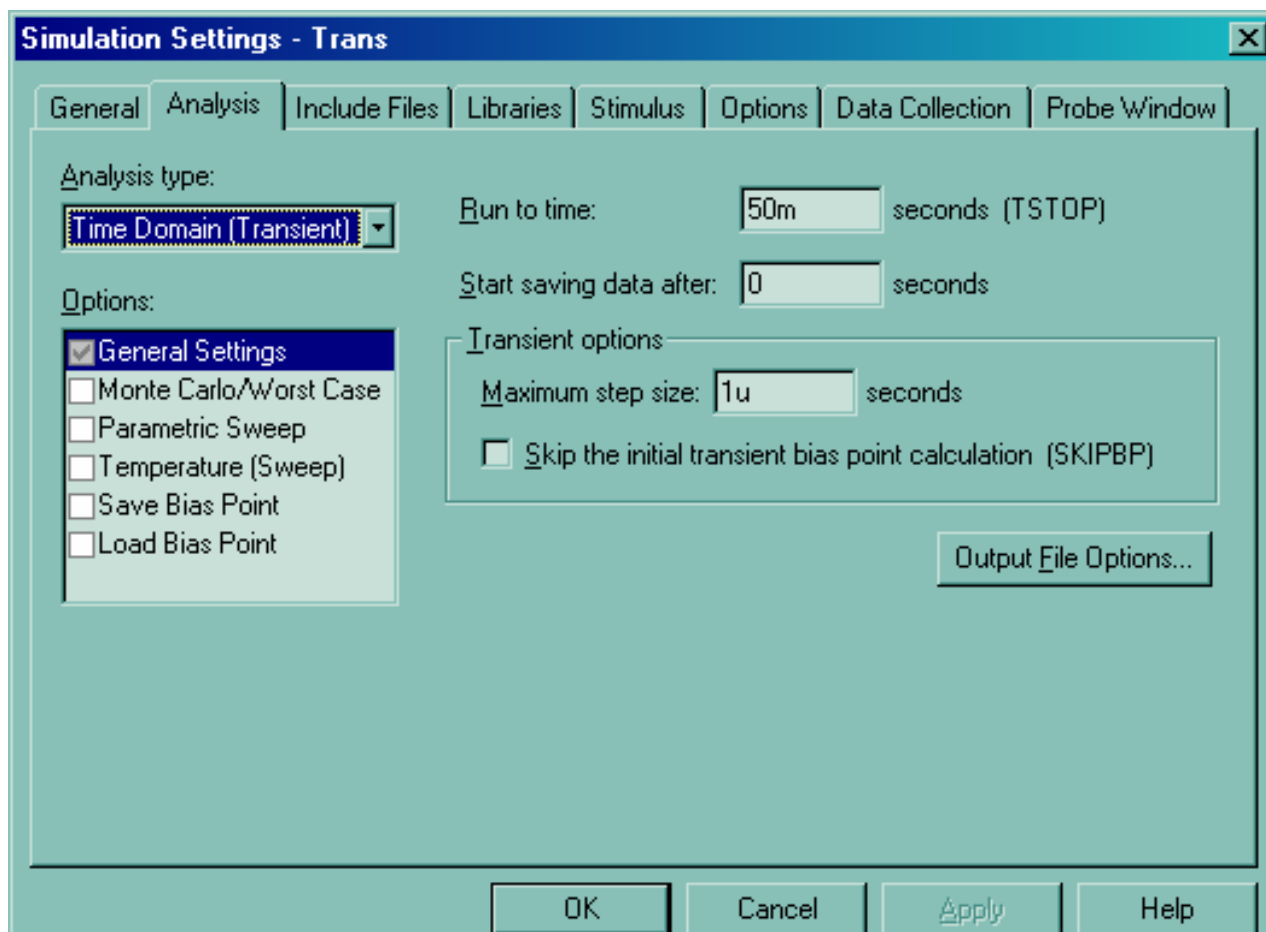
$$\text{Avg Current Rating} \quad I_o = 5 \text{ amp}$$

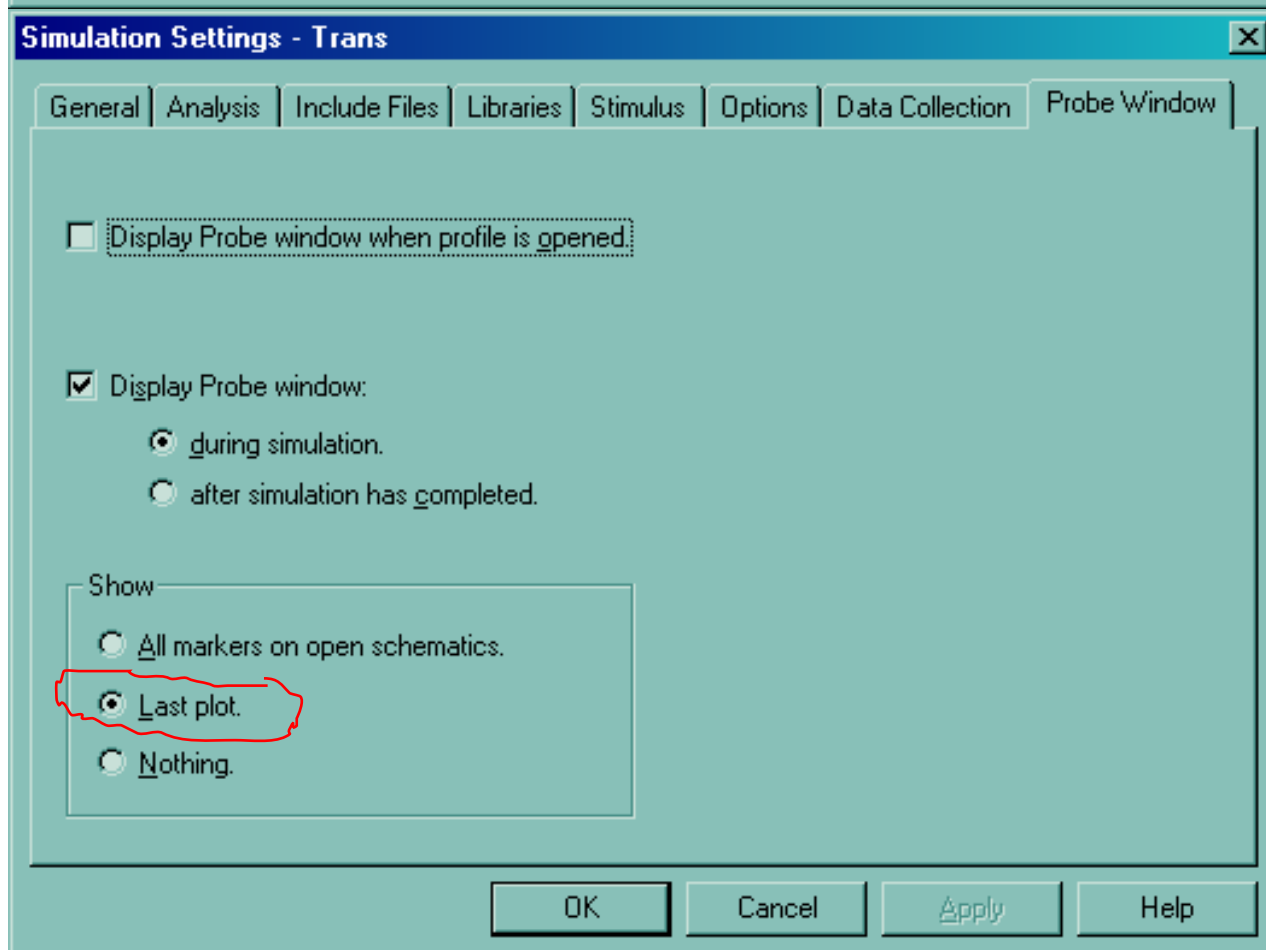
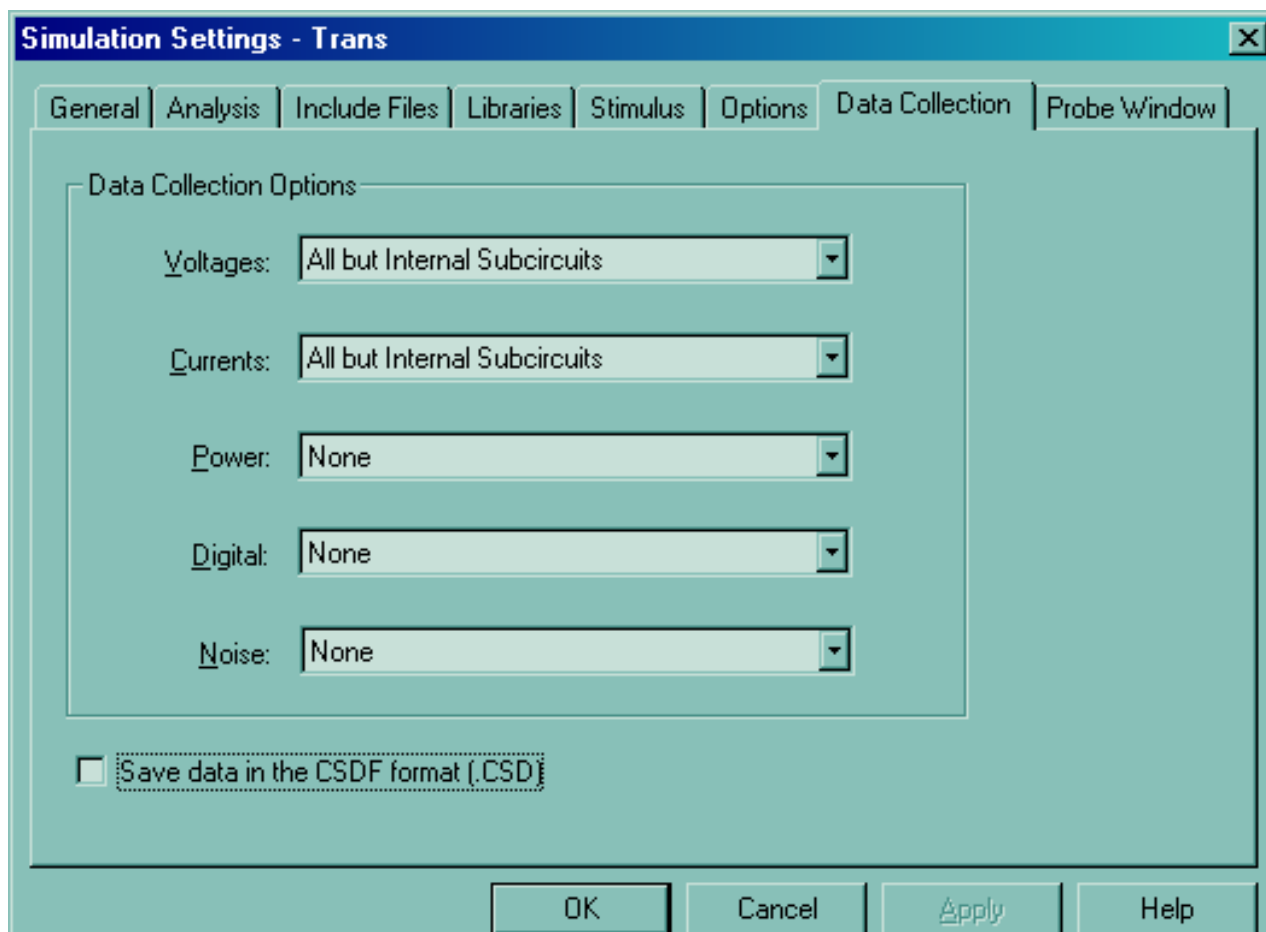
Capacitor

$$C = 4700 \mu\text{F}$$

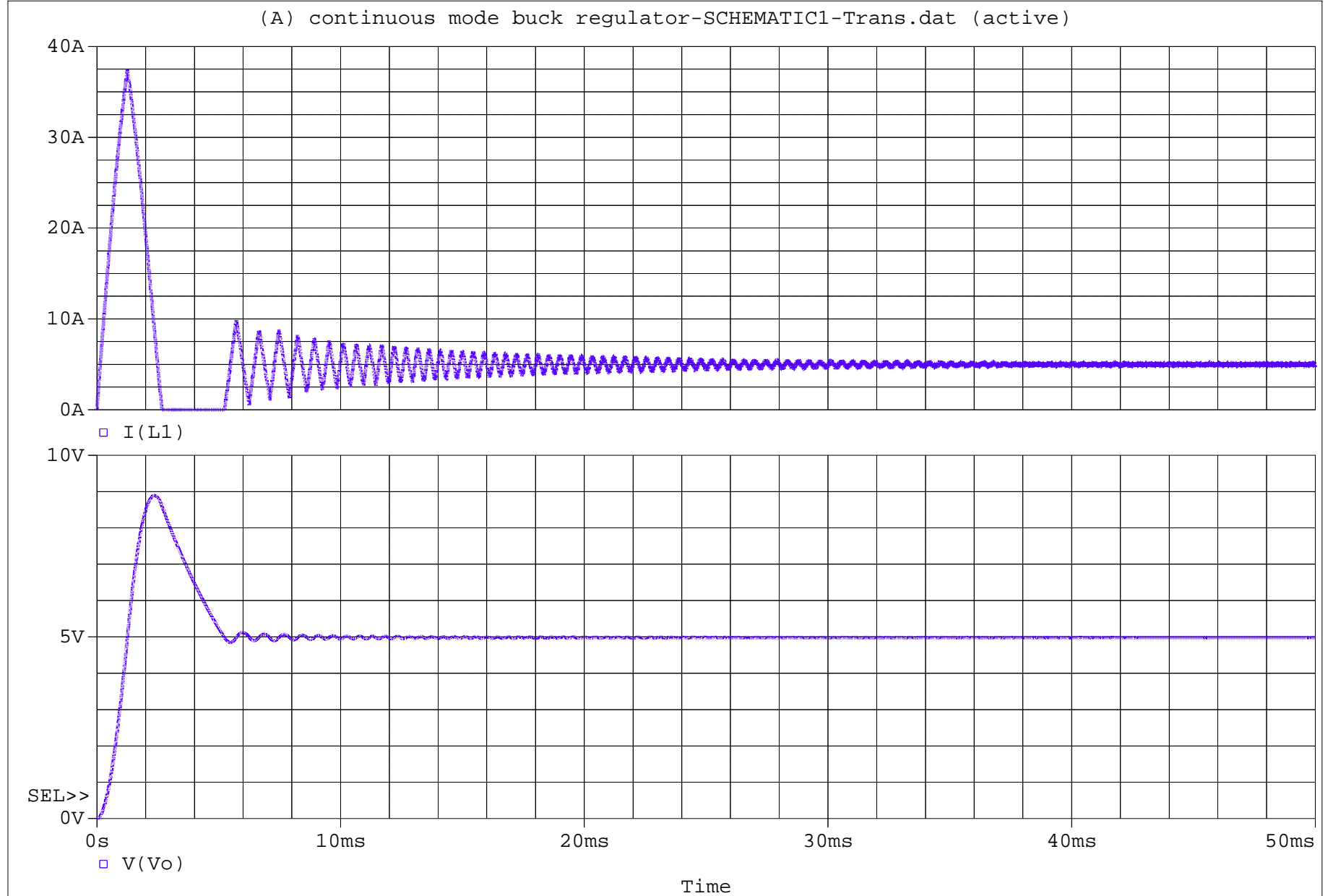
$$\text{RMS Ripple Current Rating} \quad I_{\text{RMS}} = 0.144 \text{ amp}$$







** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\Notes\Orcad\Buck Regulator\continu...
Date/Time run: 01/03/03 12:35:11 Temperature: 27.0

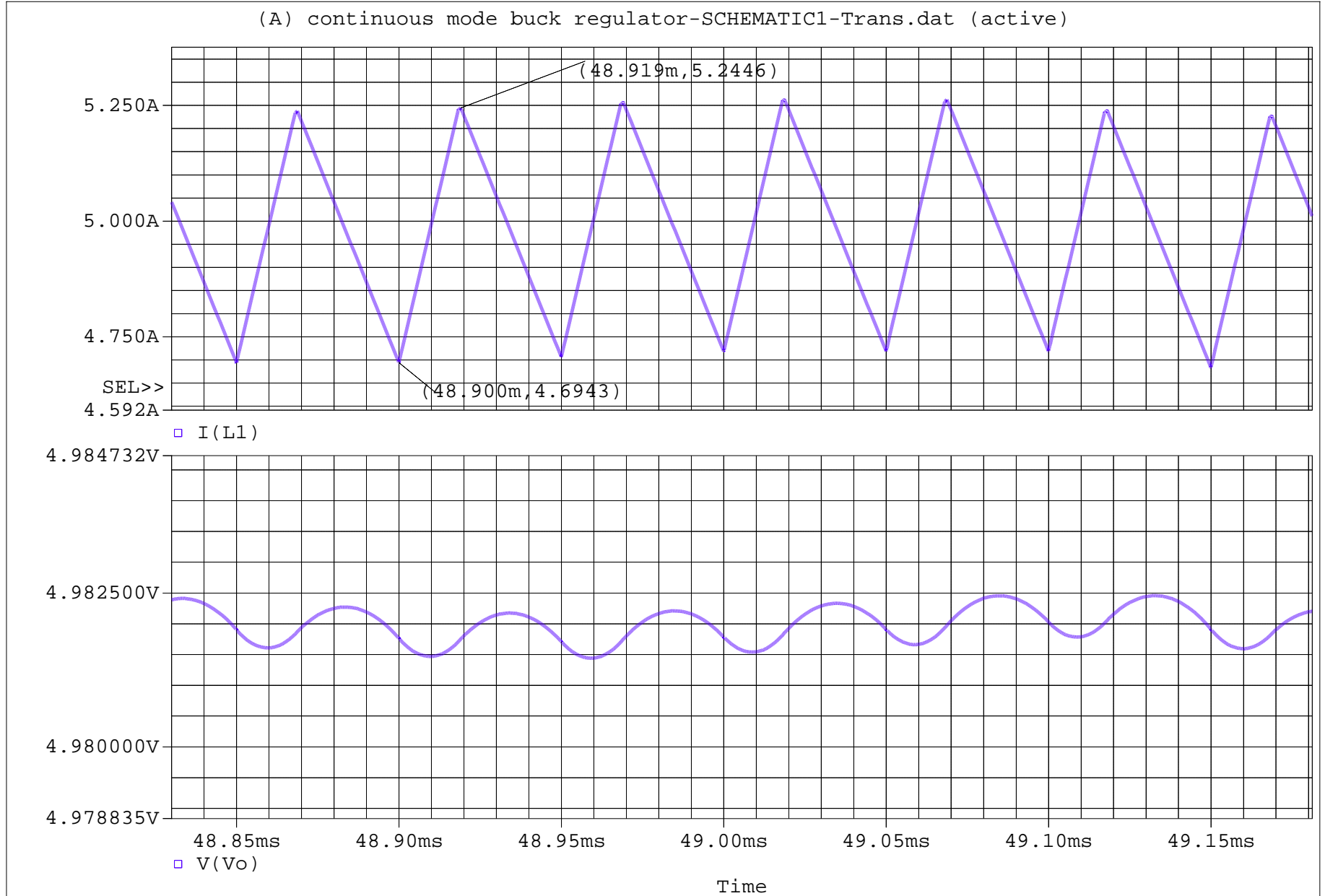


Date: January 03, 2003

Page 1

Time: 12:49:57

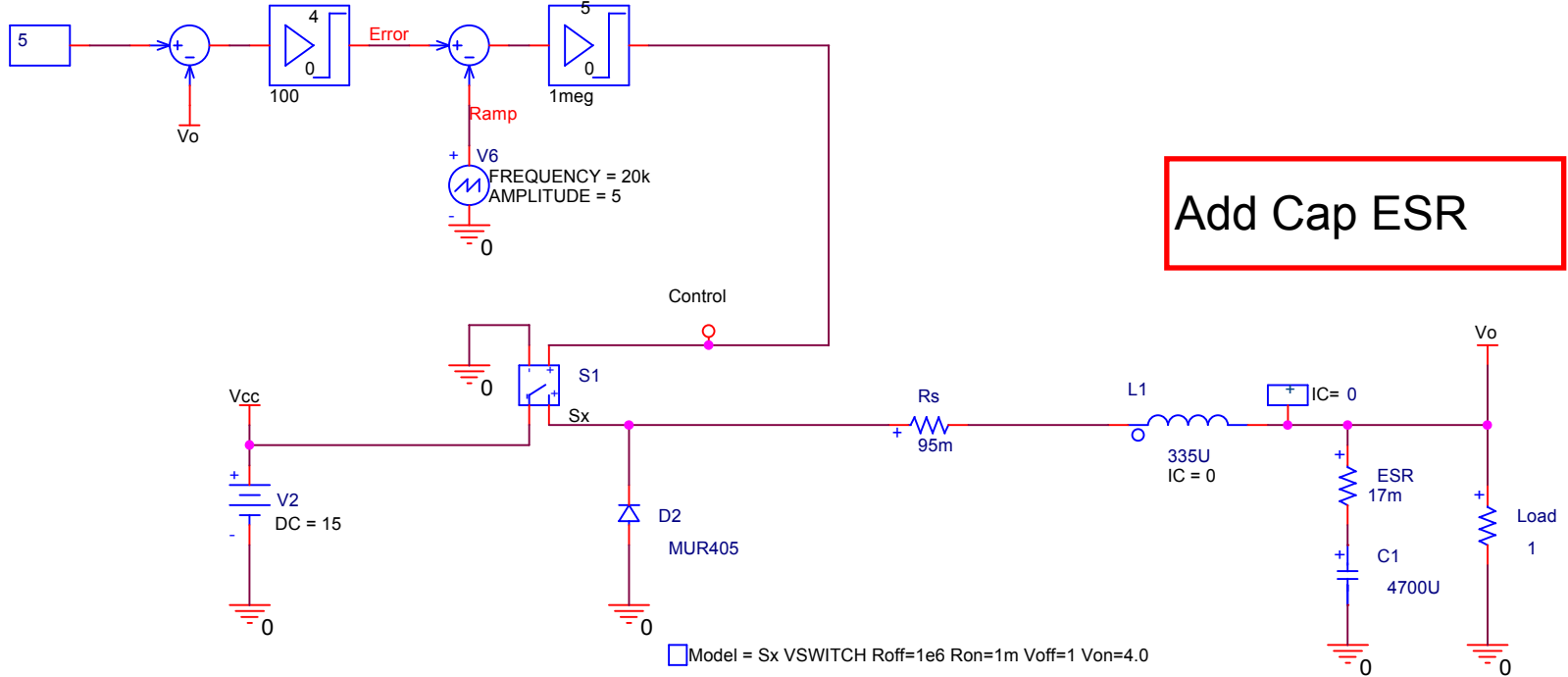
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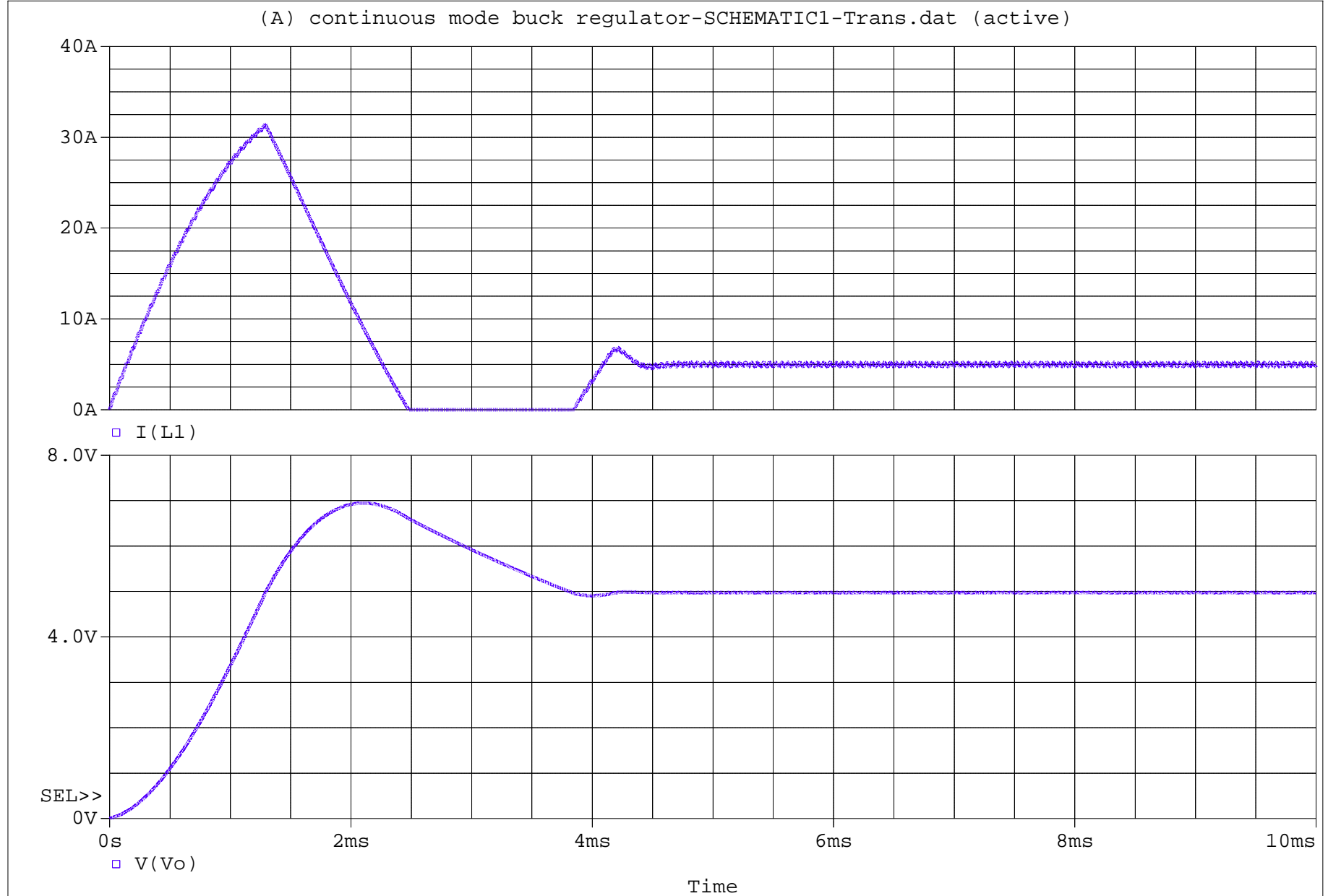
Date: January 03, 2003

Page 1

Time: 13:10:23



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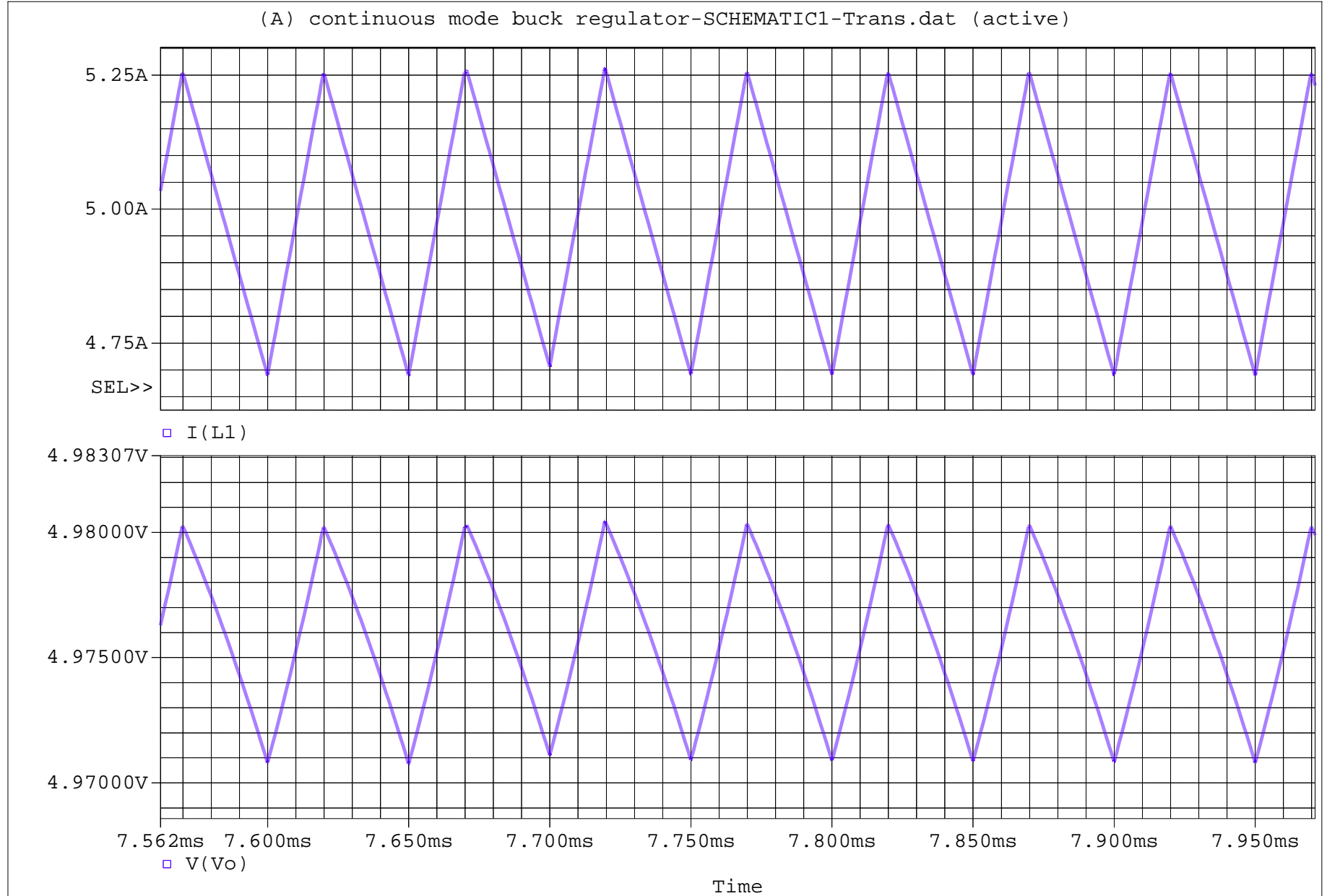


Date: January 03, 2003

Page 1

Time: 13:30:59

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Date: January 03, 2003

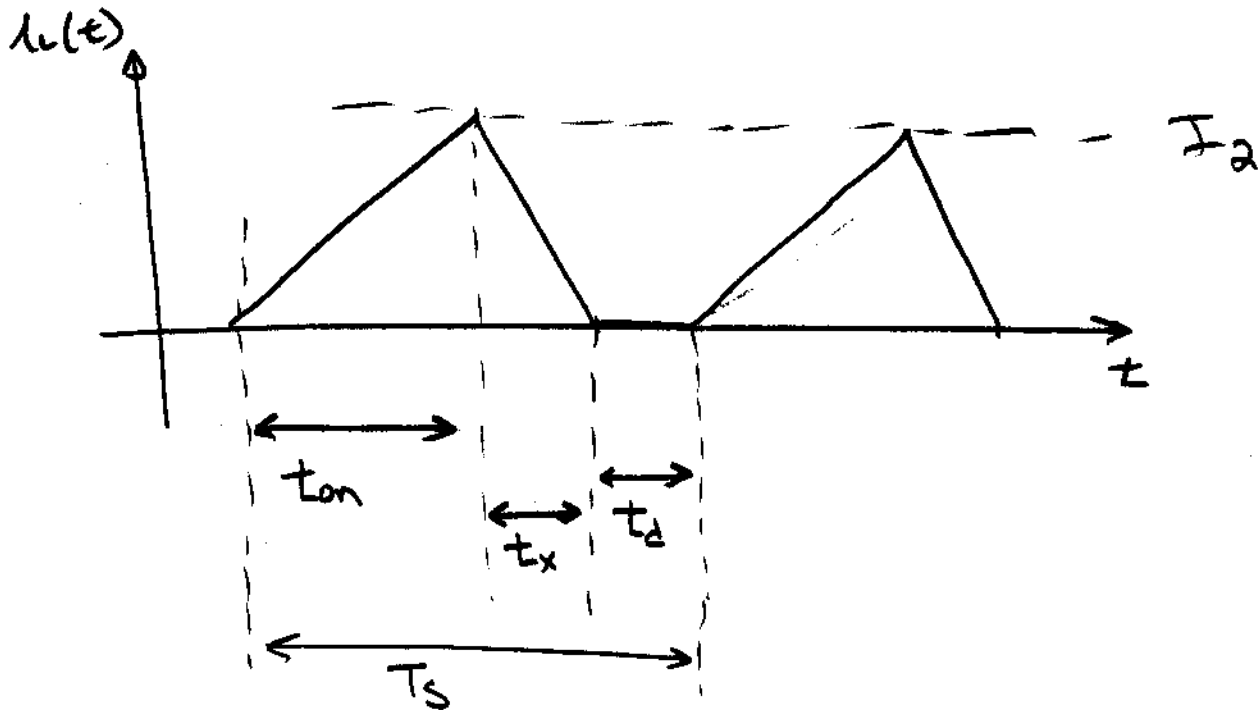
Page 1

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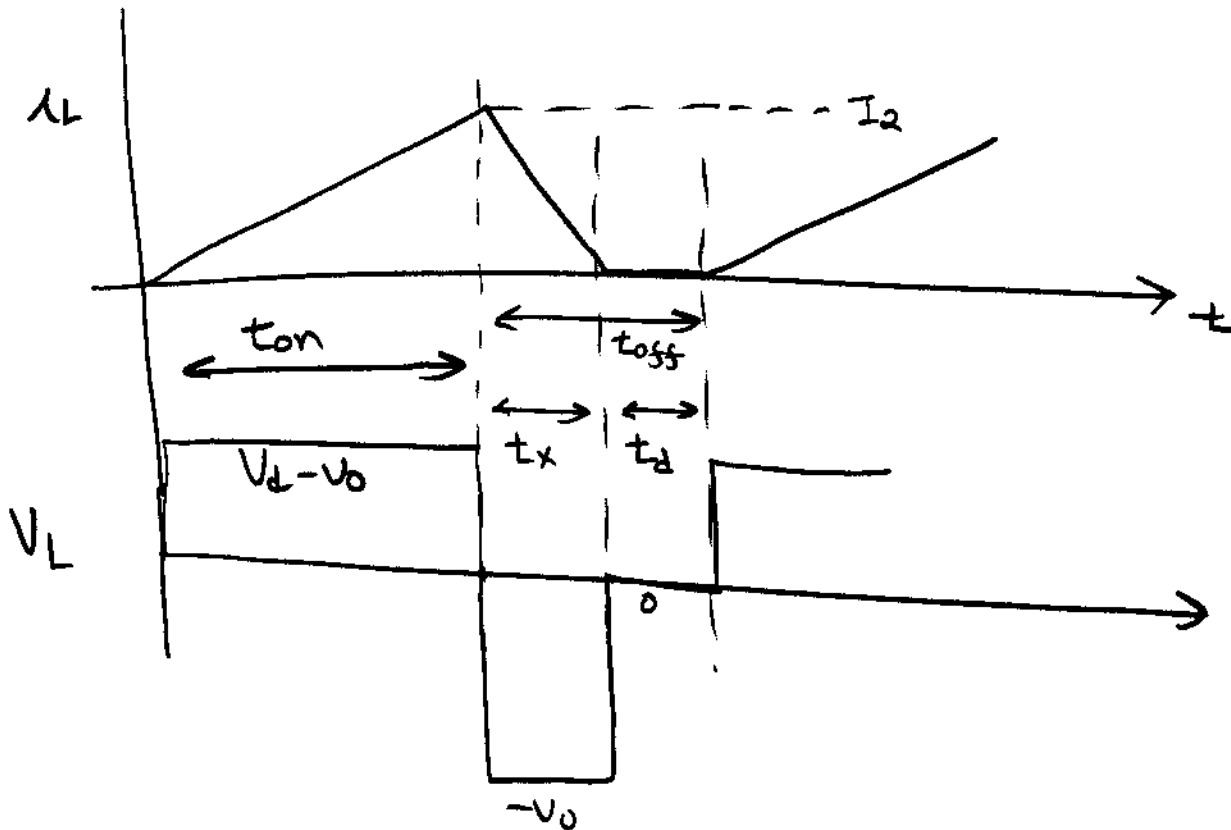
Buck Regulator - Discontinuous mode

as $I_o \downarrow, I_1 \rightarrow 0$

Inductor current is zero sometimes



In discontinuous mode, All energy stored in the inductor is dumped to output



for Average inductor current to be const,

$$\int_{T_s} V_L(t) dt = 0 \text{ for one period}$$

so

$$(V_d - V_o) t_{on} + (-V_o) t_x + 0 t_d = 0$$

$$V_o = V_d \left[\frac{t_{on}}{t_{on} + t_x} \right] \quad (1)$$

For an inductor

$$V_L = L \frac{di_L(t)}{dt} \Rightarrow i_L(t) = \frac{1}{L} \int V_L dt$$

For t_{on}

$$I_2 = \frac{1}{L} (V_d - V_o) t_{on} \quad (2)$$

For t_x

$$I_2 = \frac{1}{L} (V_o) t_x \quad (3)$$

Find average current

during t_{on} and t_x

$$\langle \hat{i}_L \rangle = I_2/2 \quad - \text{avg inductor current}$$

during T_s

$$\langle i_L \rangle = \langle \hat{i}_L \rangle \left(\frac{t_{on} + t_x}{T_s} \right)$$

so

$$\langle i_L \rangle = \frac{I_2}{2} \left(\frac{t_{on} + t_x}{T_s} \right) = I_o \quad (4)$$

Solve equation (4) for $t_{on} + t_x$

$$t_{on} + t_x = \frac{2 I_0 T_s}{I_2}$$

Sub into (1)

$$V_o = V_d \left[\frac{t_{on}}{\frac{2 I_0 T_s}{I_2}} \right]$$

OR

$$V_o = V_d \left[\frac{t_{on} I_2}{2 I_0 T_s} \right] \quad (5)$$

Now eliminate I_2 with eq. (2)

$$V_o = V_d \left[\frac{t_{on} (V_d - V_o) t_{on}}{2 I_0 T_s L} \right]$$

So

$$V_o \left[1 + \frac{V_o t_{on}^2}{2 I_o T_s L} \right] = \frac{t_{on}^2 V_o^2}{2 I_o T_s L}$$

$$V_o = \frac{t_{on}^2 V_o^2}{2 I_o T_s L + V_o t_{on}^2}$$

$$I_o \leq \left(\frac{V_o - V_o}{2L} \right) t_{on}$$

OR

$$\frac{V_o}{V_o} = \frac{D^2 V_o}{\frac{2 I_o L}{T_s} + D^2 V_o}$$

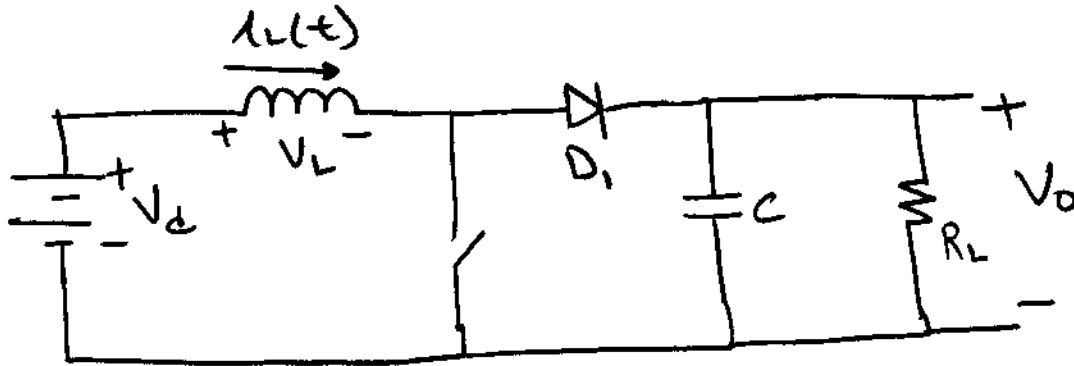
in Dis continuous mode - To keep V_o const with changing I_o , can change D .

$$D = \frac{t_{on}}{T_s}$$

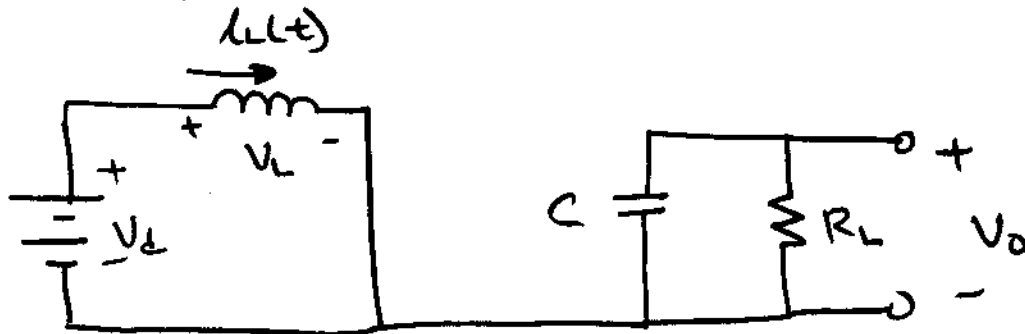
Boost Converter

(Step-Up) converter

$$V_o > V_d$$

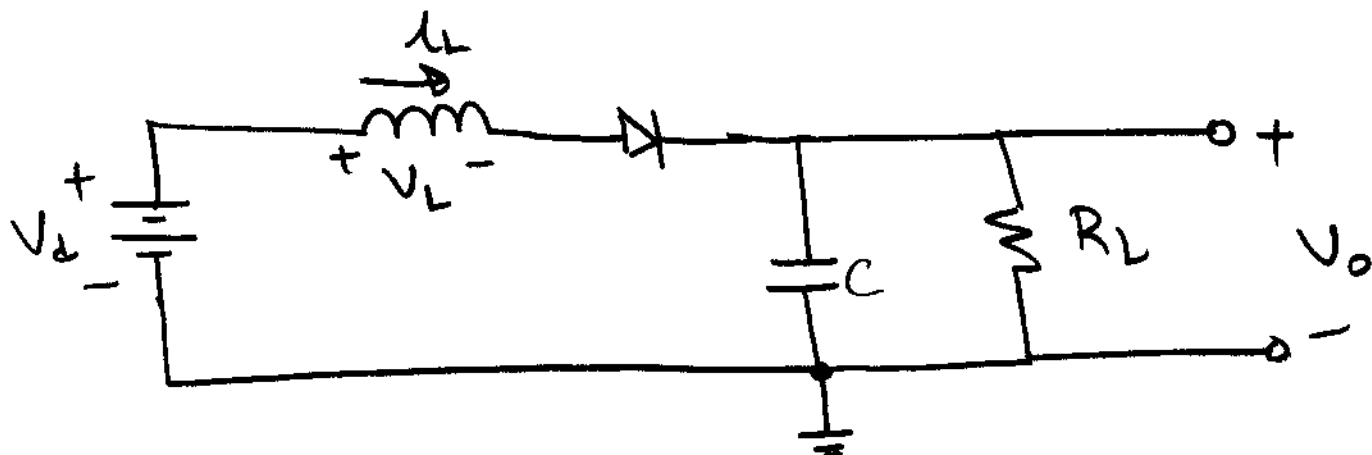


During t_{on} : switch closed, $D = \text{off}$



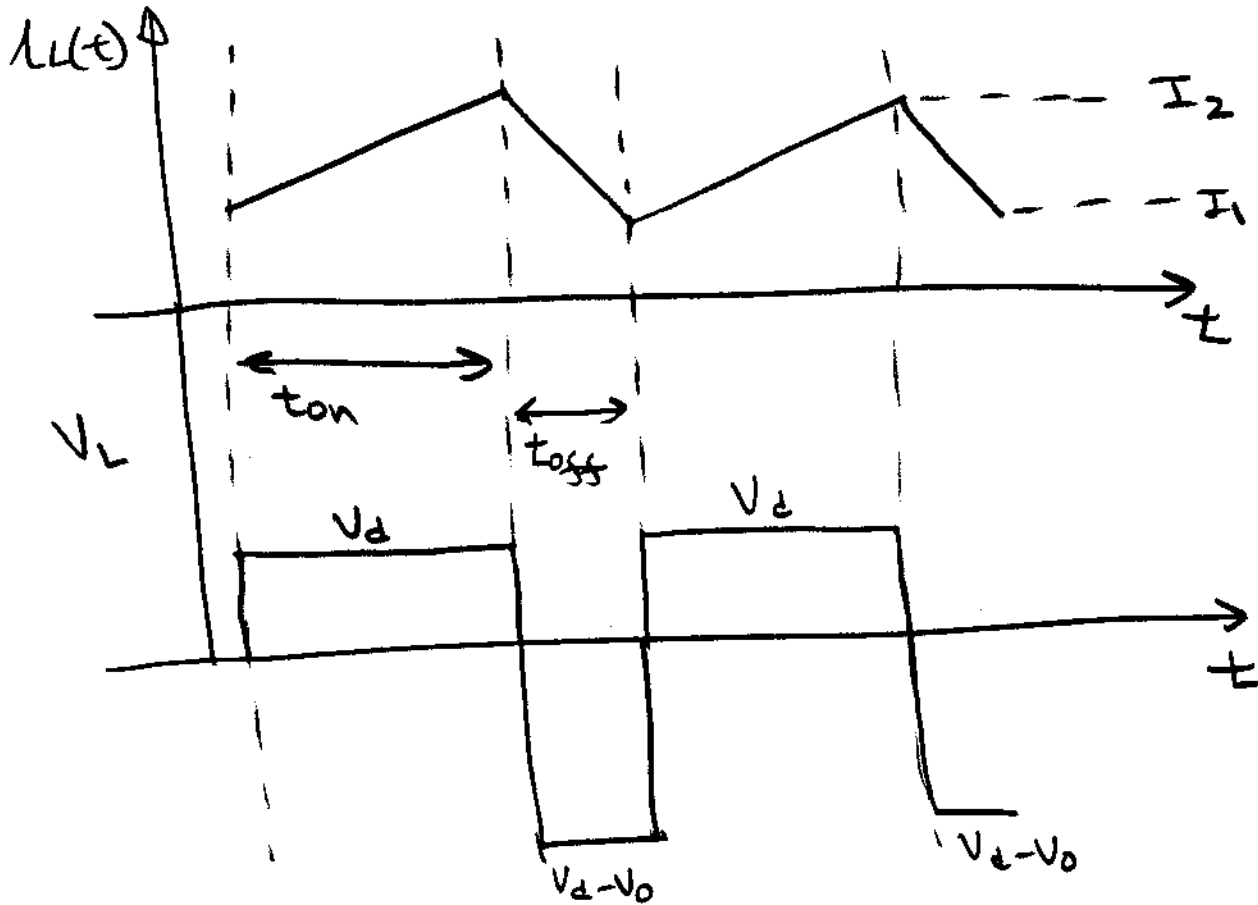
- Inductor charges from V_d
- Capacitor supplies power to Load
- $V_L = V_d$
- Inductor current increases

During t_{off} : Switch open, $D_1 = on$



- Assume diode is ideal
- $V_L = V_d - V_o$ & Since $V_o > V_d$,
the inductor current will decrease
- Inductor sources power to
C and R_L

Continuous mode



$$T_s = t_{on} + t_{off}$$

Since in steady state, the integral of $V_L = 0$ over one cycle

$$\int_{T_s} V_L(t) dt = 0$$

$$\Rightarrow (V_d t_{on}) + (V_d - V_o)(T_s - t_{on}) = 0$$

$$V_d T_s = V_o (T_s - t_{on})$$

$$V_o = V_d \left[\frac{T_s}{T_s + t_{on}} \right] = V_d \left[\frac{1}{1-D} \right] \quad (1)$$

$$\text{where } D = \frac{t_{on}}{T_s}$$

Assuming a lossless circuit

$$\text{Power}_{in} = \text{Power}_{out}$$

$$V_d I_o = V_o I_o \Rightarrow \frac{I_o}{I_o} = \frac{V_d}{V_o}$$

$$\text{OR } \frac{I_o}{I_o} = (1-D)$$

Where I_o = average input current

what does I_o look like?

$$I_o = i(t)$$

$$\text{SO } I_o = \frac{I_1 + I_2}{2} \quad (2) \quad - \text{Avg input current}$$

$$\text{SO } I_o = \frac{I_o}{1-D} \quad - \text{from before}$$

30

$$\frac{I_1 + I_2}{2} = \frac{I_0}{1-D} \quad (3)$$

Now using $V_L = L \frac{di}{dt}$

$$i_L(t) = \frac{1}{L} \int V_L dt + i.c.$$

$$I_2 = \frac{1}{L} \int_0^{t_{on}} V_d dt + I_1$$

$$I_2 = \frac{V_d t_{on}}{L} + I_1$$

$$(I_2 - I_1) = \frac{V_d t_{on}}{L} \quad (4)$$

$$I_2 - I_1 = \frac{V_d t_{on}}{L}$$

$$\frac{I_1 + I_2}{2} = \frac{I_0}{1-D}$$

$$I_0 = \frac{I_1 + I_2}{2}$$

$$V_o = V_d \left[\frac{1}{1-D} \right]$$

Next: Find the boundary where the inductor current becomes discontinuous

$$\Rightarrow I_1 = 0$$

Solve for I_1

$$I_1 + I_2 = \frac{2I_0}{1-D} \quad (3)$$

$$I_2 - I_1 = \frac{V_d t_{on}}{L}$$

$$2I_1 = \frac{2I_0}{1-D} - \frac{V_d t_{on}}{L}$$

Solve for $I_1 = 0$

$$\frac{2I_0}{1-D} - \frac{V_d t_{on}}{L} = 0$$

$$I_0 = \left(\frac{V_d t_{on}}{2L} \right) (1-D)$$

From equation 1, $1-D = \frac{V_d}{V_0}$

So we need

$$I_0 \geq \left(\frac{V_d t_{on}}{2L} \right) \left(\frac{V_d}{V_0} \right)$$

Summary

Boost Regulator in continuous mode

$$V_o = V_d \left[\frac{1}{1-D} \right]$$

$$D = \frac{t_{on}}{T_s}$$

$$I_o = I_D [1-D]$$

$$t_{on} + t_{off} = T_s$$

$$\left(\frac{I_1 + I_2}{2} \right) = I_D = \frac{I_o}{1-D}$$

$$I_2 - I_1 = \frac{V_d t_{on}}{L}$$

$$I_o \geq \left(\frac{V_d t_{on}}{2L} \right) \left(\frac{V_d}{V_o} \right) \quad ; \quad \text{For continuous mode}$$

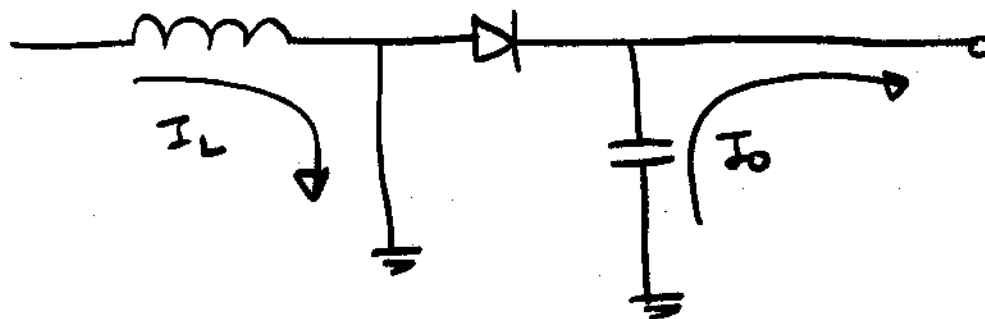
In continuous mode operation, the Boost Regulator has a right half plane zero.

This makes the boost Regulator difficult to stabilize in continuous mode.

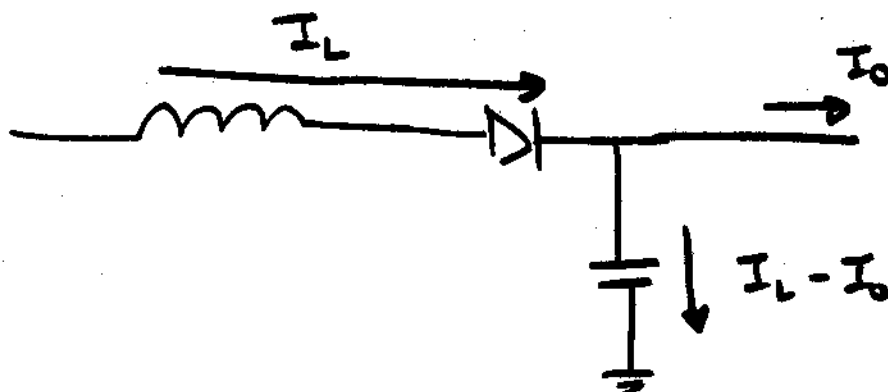
Capacitor Rms Ripple Current

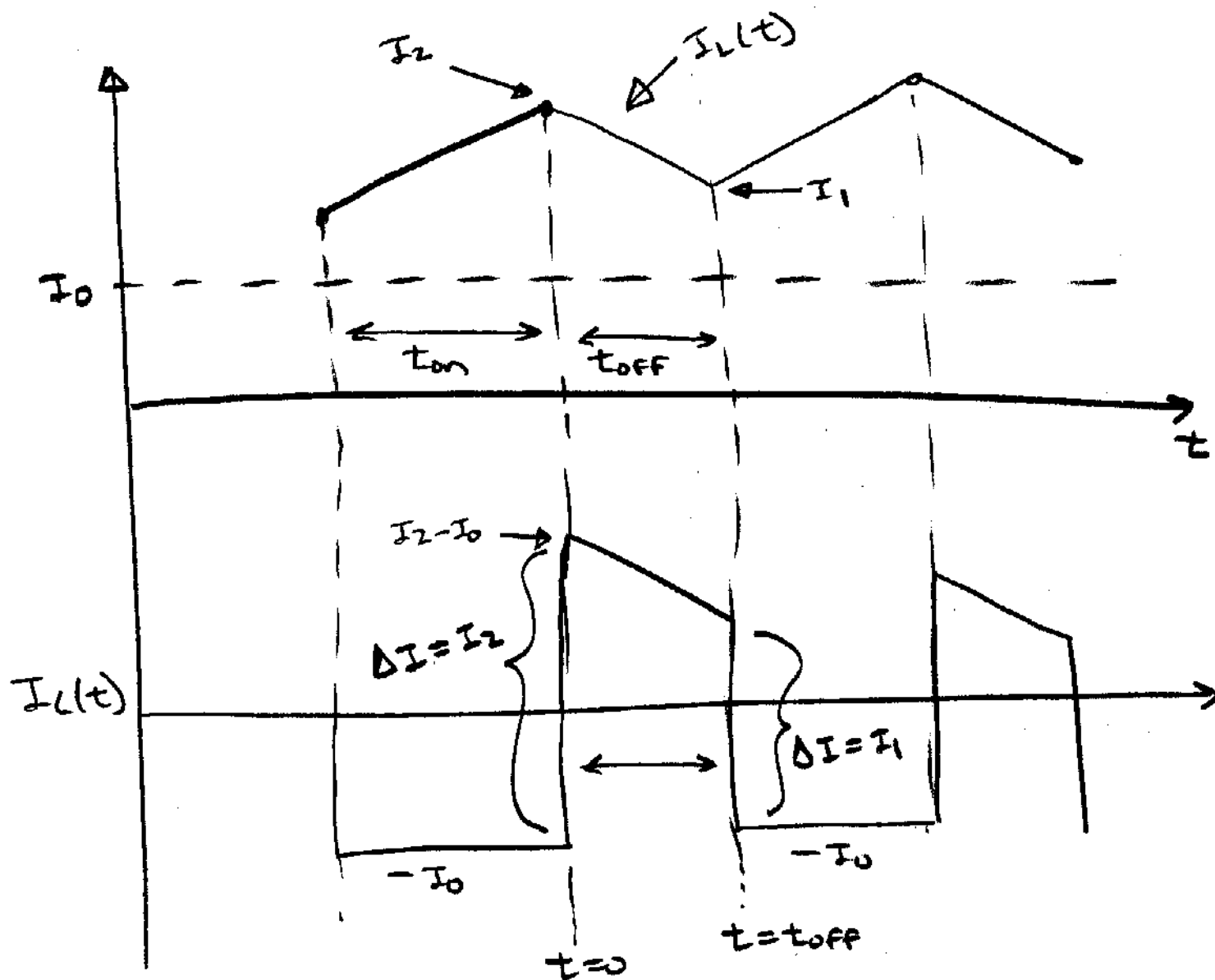
For the continuous Boost Converter

- During T_{on} , The switch is on and the capacitor must supply current I_o to the load



- During T_{off} , The switch is off. The inductor provides I_o to the output and also charges the capacitor





- for $0 \leq t \leq t_{off}$, $I_L(t) = I_2 - m t$

where $m = \frac{I_2 - I_1}{t_{off}}$ and

$$I_c(t) = I_L(t) - I_0$$

- for other times, $I_c(t) = -I_0$

$$I_{CRMS} = \sqrt{\frac{1}{T_s} \left[\int_0^{T_{ON}} (-I_0)^2 dt + \int_0^{T_{OFF}} (I_L(t) - I_0)^2 dt \right]}$$

Ripple voltage due to ESR = $\Delta I R_{ESR}$

OR $V_{RR} = I_2 R_{ESR}$

Ripple voltage due to charge being removed from the cap.

$$\Delta V = \frac{\Delta q}{C}$$

During t_{on} , the amount of charge removed from C is $\Delta q = I_0 t_{on}$

So $\Delta V = \frac{I_0 t_{on}}{C} = \text{Ripple due to Cap charge \& Discharge}$

Electrolytic capacitors

General introduction

ELECTRICAL BEHAVIOUR

CHARACTERISTICS OF ELECTROLYTIC CAPACITORS VARY WITH TEMPERATURE, TIME AND APPLIED VOLTAGE.

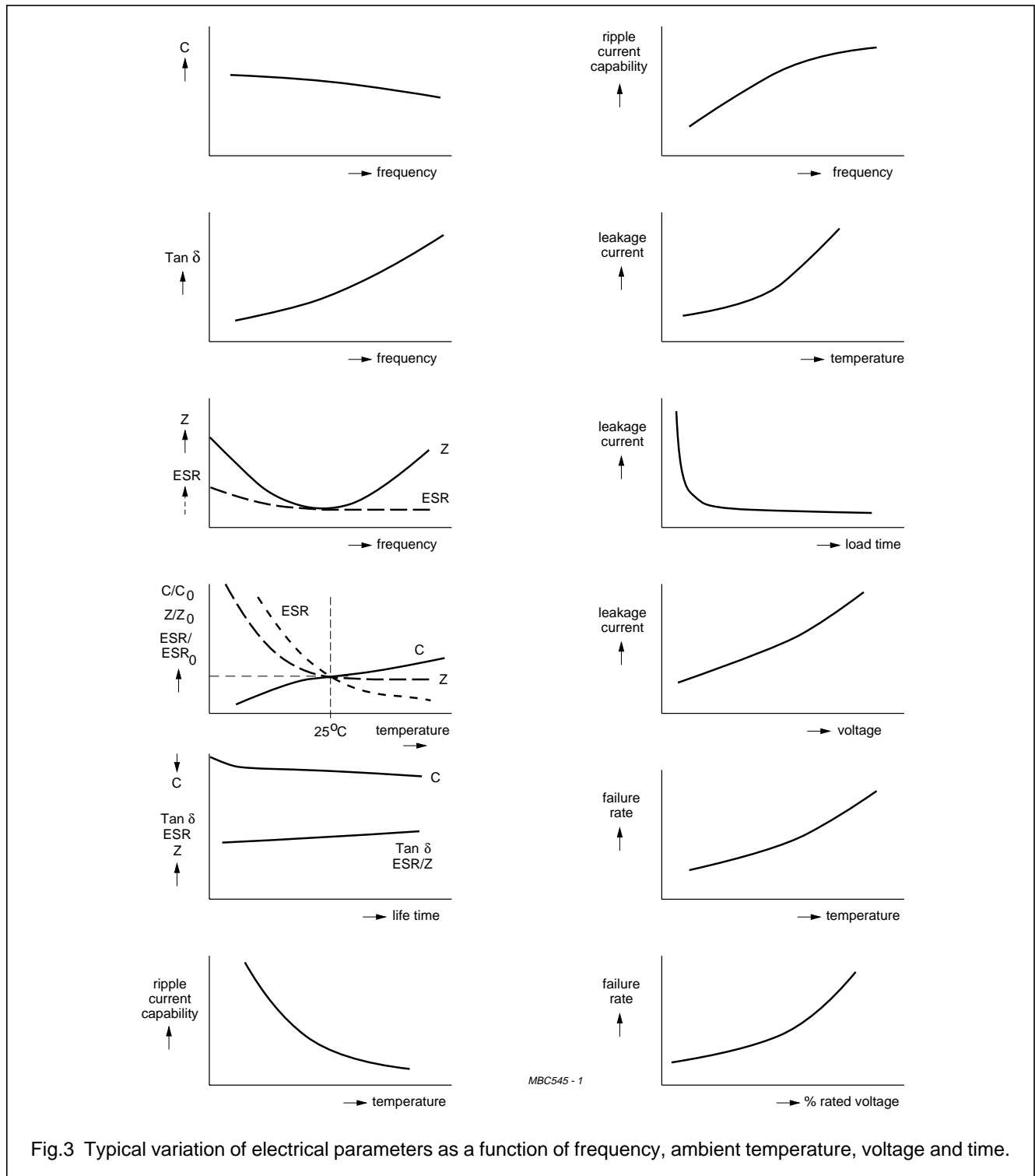
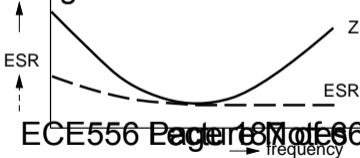


Fig.3 Typical variation of electrical parameters as a function of frequency, ambient temperature, voltage and time.

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TS-UP Series two terminal snap-in

- Compact size for general purpose and industrial applications
- **NEW:** 500 WV ratings, 40mm diameter sizes, extended capacitance ratings
- Wide range of case sizes including 20mm lengths for low profile applications
- Can vent construction



Rated Working Voltage:	16 ~ 250 VDC	350 ~ 500 VDC
Operating Temperature:	-40 ~ +85°C	-25 ~ +85°C
Nominal Capacitance:	120 ~ 68000µF (±20% tolerance)	33 ~ 680µF (±20% tolerance)
Dissipation Factor: (120 Hz, +20°C)	Working Voltage [V]:	16 25 35 50 63 80 100 160 ~ 500
	Max. D.F. (%):	50 40 35 30 25 20 20 15
For capacitance values > 33000µF, add the value of: $\frac{(\text{rated cap. } [\mu\text{F}] - 33000)}{1000}$		
Endurance:	3000 hours* at +85°C with maximum specified ripple current (see page 4) *2000 hours for 20mm diameter or 20mm length sizes	

Part Number System

E	C	P	A	B	C	D	E	F	A	B	L	G	X
Common Code/ Terminal Type		Voltage Code	Series	Capacitance Code		Case Diameter		Suffix, Top Vinyl Plate 25 ~ 50mm lengths					
ECOS		6.3mm Length Terminal (Standard)		A		20mm		A With Plate					
ECEC		4.0mm Length "Short" Terminal (See page 7)		B		22mm		B Without plate					
				C		25mm		20mm length					
				D		30mm		L With Plate					
				E		35mm		G Without plate					
				F		40mm		Extended Capacitance Ratings					
								X With plate					

Ripple Current
Multipliers:
Page 7

TS-UP Standard Ratings

Cap. (µF)	Size (mm) D x L	Max 85°C R.C. (A _{rms})		Max. 20°C ESR (Ω)		Panasonic Part Number	Cap. (µF)	Size (mm) D x L	Max 85°C R.C. (A _{rms})		Max. 20°C ESR (Ω)		Panasonic Part Number
		120Hz	10k-100kHz	120Hz	20kHz				120Hz	10k-100kHz	120Hz	20kHz	
16 VDC Working, 20 VDC Surge							25 VDC Working, 32 VDC Surge						
6800	20 x 25	3.15	3.62	0.098	0.083	ECOS1CP682AA	4700	20 x 25	3.05	3.51	0.113	0.090	ECOS1EP472AA
8200	20 x 30	3.47	3.99	0.081	0.069	ECOS1CP822AA	5600	20 x 30	3.36	3.86	0.095	0.076	ECOS1EP562AA
10000	20 x 35	3.78	4.35	0.066	0.056	ECOS1CP103AA	6800	20 x 35	3.47	3.99	0.078	0.062	ECOS1EP682AA
12000	20 x 35	4.52	5.20	0.062	0.053	ECOS1CP123AA	8200	20 x 40	3.57	4.11	0.065	0.052	ECOS1EP822AA
15000	20 x 40	5.26	6.05	0.053	0.045	ECOS1CP153AA	3300	22 x 20	1.60	1.84	0.176	0.141	ECOS1EP332BL
4700	22 x 20	1.60	1.84	0.159	0.135	ECOS1CP472BL	3300	22 x 25	1.68	1.93	0.161	0.129	ECOS1EP332BA
4700	22 x 25	1.77	2.04	0.159	0.135	ECOS1CP472BA	4700	22 x 25	2.39	2.75	0.113	0.090	ECOS1EP472BA
6800	22 x 25	2.57	2.96	0.110	0.093	ECOS1CP682BA	5600	22 x 25	2.86	3.29	0.095	0.076	ECOS1EP562BA
8200	22 x 25	3.10	3.57	0.091	0.077	ECOS1CP822BA	6800	22 x 30	3.47	3.99	0.078	0.062	ECOS1EP682BA
10000	22 x 30	3.78	4.35	0.075	0.063	ECOS1CP103BA	8200	22 x 30	3.57	4.11	0.065	0.052	ECOS1EP822BA
12000	22 x 30	4.52	5.20	0.062	0.053	ECOS1CP123BA	10000	22 x 35	3.78	4.35	0.058	0.046	ECOS1EP103BA
15000	22 x 35	5.26	6.05	0.053	0.045	ECOS1CP153BA	12000	22 x 40	4.10	4.72	0.048	0.039	ECOS1EP123BA
18000	22 x 40	5.57	6.41	0.046	0.039	ECOS1CP183BA	15000	22 x 50	4.63	5.32	0.039	0.031	ECOS1EP153BA
22000	22 x 45	6.10	7.02	0.038	0.032	ECOS1CP223BA	4700	25 x 20	1.80	2.07	0.123	0.099	ECOS1EP472CL
6800	25 x 20	1.80	2.07	0.110	0.093	ECOS1CP682CL	6800	25 x 25	3.47	3.99	0.078	0.062	ECOS1EP682CA
10000	25 x 25	3.78	4.35	0.075	0.063	ECOS1CP103CA	8200	25 x 25	3.57	4.11	0.065	0.052	ECOS1EP822CA
12000	25 x 25	4.52	5.20	0.062	0.053	ECOS1CP123CA	10000	25 x 30	3.78	4.35	0.058	0.046	ECOS1EP103CA
15000	25 x 30	5.26	6.05	0.053	0.045	ECOS1CP153CA	12000	25 x 35	4.10	4.72	0.048	0.039	ECOS1EP123CA
18000	25 x 30	5.57	6.41	0.046	0.039	ECOS1CP183CA	15000	25 x 40	4.63	5.32	0.039	0.031	ECOS1EP153CA
22000	25 x 35	6.10	7.02	0.038	0.032	ECOS1CP223CA	18000	25 x 45	5.47	6.29	0.035	0.028	ECOS1EP183CA
27000	25 x 45	6.31	7.26	0.031	0.026	ECOS1CP273CA	22000	25 x 50	6.10	7.02	0.029	0.023	ECOS1EP223CA
33000	25 x 50	6.84	7.87	0.025	0.021	ECOS1CP333CA	6800	30 x 20	2.30	2.65	0.078	0.062	ECOS1EP682DL
10000	30 x 20	2.40	2.76	0.083	0.070	ECOS1CP103DL	10000	30 x 25	3.78	4.35	0.058	0.046	ECOS1EP103DA
22000	30 x 30	6.10	7.02	0.038	0.032	ECOS1CP223DA	12000	30 x 30	4.10	4.72	0.048	0.039	ECOS1EP123DA
27000	30 x 35	6.31	7.26	0.031	0.026	ECOS1CP273DA	15000	30 x 30	4.63	5.32	0.039	0.031	ECOS1EP153DA
33000	30 x 40	6.84	7.87	0.025	0.021	ECOS1CP333DA	18000	30 x 35	5.47	6.29	0.035	0.028	ECOS1EP183DA
39000	30 x 45	6.94	7.98	0.021	0.018	ECOS1CP393DA	22000	30 x 40	6.10	7.02	0.029	0.023	ECOS1EP223DA
47000	30 x 50	7.47	8.59	0.019	0.017	ECOS1CP473DA	27000	30 x 45	6.21	7.14	0.023	0.019	ECOS1EP273DA
15000	35 x 20	3.20	3.68	0.055	0.047	ECOS1CP153EL	33000	30 x 50	6.84	7.87	0.020	0.017	ECOS1EP333DA
33000	35 x 30	6.84	7.87	0.025	0.021	ECOS1CP333EA	10000	35 x 20	2.70	3.11	0.061	0.049	ECOS1EP103EL
39000	35 x 35	6.94	7.98	0.021	0.018	ECOS1CP393EA	27000	35 x 35	6.21	7.14	0.025	0.020	ECOS1EP273EA
47000	35 x 40	7.47	8.59	0.021	0.019	ECOS1CP473EA	33000	35 x 40	6.84	7.87	0.020	0.017	ECOS1EP333EA
56000	35 x 45	8.73	10.04	0.019	0.018	ECOS1CP563EA	39000	35 x 45	7.36	8.46	0.019	0.017	ECOS1EP393EA
68000	35 x 50	9.05	10.41	0.018	0.017	ECOS1CP683EA	47000	35 x 50	8.00	9.20	0.017	0.015	ECOS1EP473EA
68000	40 x 40	9.05	10.41	0.018	0.017	ECOS1CP683FA	47000	40 x 40	8.00	9.20	0.017	0.015	ECOS1EP473FA
82000	40 x 50	10.29	11.83	0.016	0.015	ECOS1CP823FA	56000	40 x 50	8.96	10.30	0.016	0.015	ECOS1EP563FA

Cap. (μ F)	Size (mm) D x L	Max 85°C R.C. (A_{rms})		Max. 20°C ESR (Ω)		Panasonic Part Number
		120Hz	10k~100kHz	120Hz	20kHz	

25 VDC Working, 32 VDC Surge

4700	20 x 25	3.05	3.51	0.113	0.090	ECOS1EP472AA
5600	20 x 30	3.36	3.86	0.095	0.076	ECOS1EP562AA
6800	20 x 35	3.47	3.99	0.078	0.062	ECOS1EP682AA
8200	20 x 40	3.57	4.11	0.065	0.052	ECOS1EP822AA

Electrolytic capacitors

General introduction

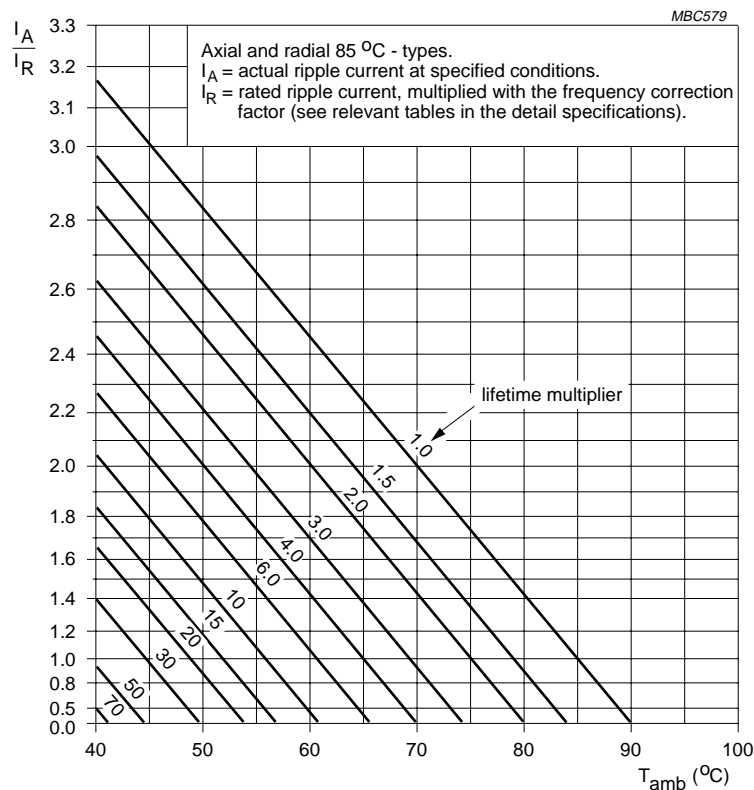
CALCULATION OF USEFUL LIFE BY MEANS OF
'LIFE-TIME NOMOGRAMS'

Based on the Arrhenius law and on experience for some decades, a nomogram is specified in the detail specification for each range, where the influence of ambient temperature and ripple current on the expected useful life is shown. Ripple currents at other frequencies than specified must be corrected using the frequency conversion tables in the relevant detail specification.

The ratio of ripple current (I_A/I_R) is plotted on the vertical axis and the ambient temperature (T_{amb}) on the horizontal.

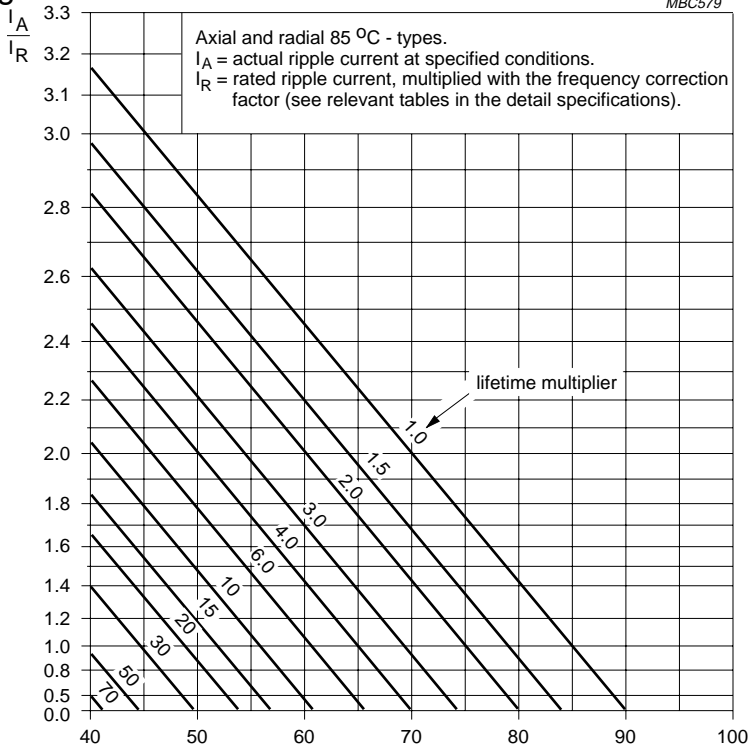
At the intersection of these two operational conditions the appropriate multiplier (correction factor) for useful life can be read. The useful life under certain conditions shall be calculated by multiplying (or dividing respectively) the specified useful life, with the resultant correction factor.

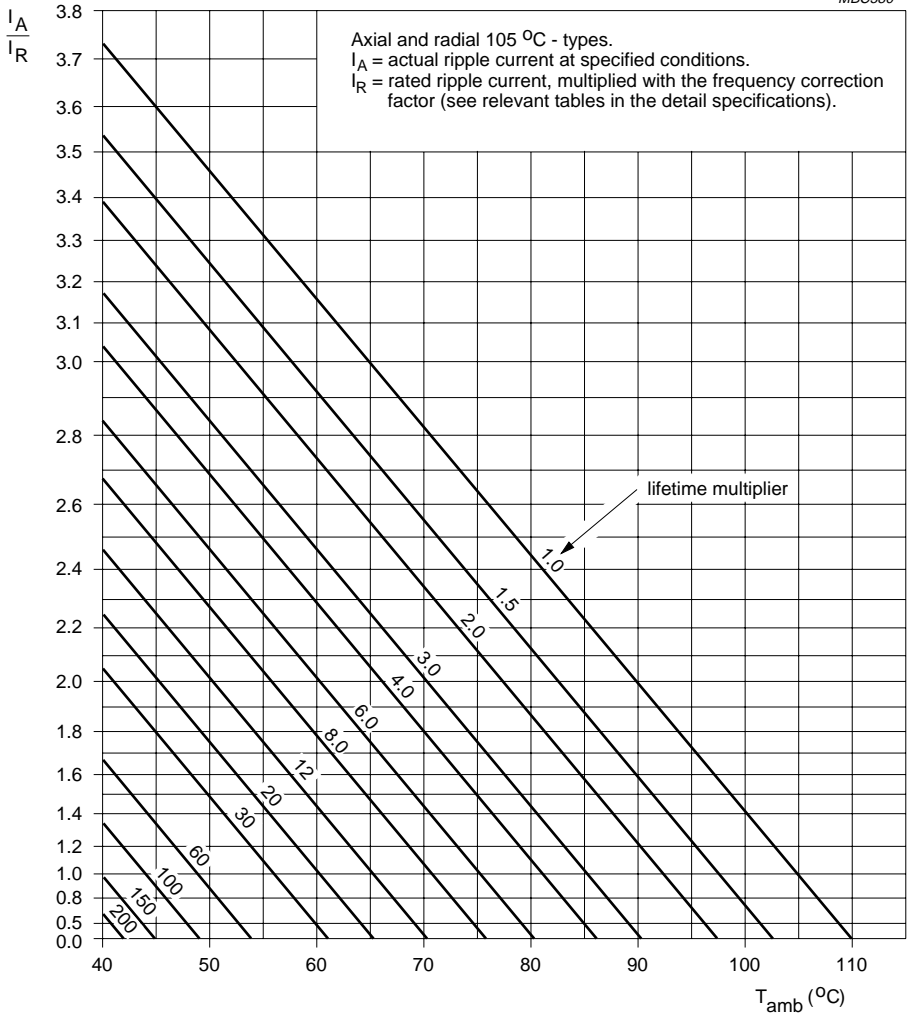
The useful life determined by this procedure is normally valid for applications without forced cooling. Under certain conditions and with additional cooling, the useful life may be considerably extended.



Axial and radial 85 °C types.

Fig.14 Typical example of a life-time nomogram: useful life as a function of ambient temperature and ripple current load.





ECE 556

Boost Regulator Design - Continuous Mode Operation

$$\mu\text{s} \equiv 10^{-6} \cdot \text{sec}$$

Specify Input Voltage $V_D := 5 \cdot \text{volt}$

Specify Output Voltage $V_o := 10 \cdot \text{volt}$

Specify Switching Frequency $F_S := 20 \cdot \text{kHz}$

$$T_S := \frac{1}{F_S} \quad T_S = 50 \mu\text{s}$$

Specify the Assumed Efficiency $\text{Eff} := 100\%$

You should assume 80 to 85% efficiency in your designs.

The output Power is $P_{\text{out}} := \frac{20 \cdot \text{watt}}{\text{Eff}}$

The output current is $I_o := \frac{P_{\text{out}}}{V_o} \quad I_o = 2 \text{ amp}$

Find t_{on} and t_{off}

$$T_{off} := 1 \cdot \mu s \quad T_{on} := 1 \cdot \mu s$$

Given

$$\frac{T_{on}}{T_S} = \frac{V_o - V_D}{V_o} \quad T_{on} + T_{off} = T_S$$

$$\begin{pmatrix} T_{on} \\ T_{off} \end{pmatrix} := \text{Find}(T_{on}, T_{off}) \quad T_{on} = 25 \mu s \quad T_{off} = 25 \mu s$$

$$D := \frac{T_{on}}{T_S} \quad D = 0.5 \%$$

Find the range of Inductors that will operate in continuous mode

Specify the minimum current we want the supply to operate in the continuous mode

$$I_{min} := \frac{I_o}{10} \quad I_{min} = 0.2 \text{ amp}$$

$$L := \frac{V_D \cdot T_{on}}{2 \cdot I_{min}} \cdot \frac{V_D}{V_o}$$

For Continuous Mode, We need L greater than $L = 156.25 \mu H$

Choose the Inductor $L := 335 \cdot \mu H$ Pulse Engineering PE-51518

Find the Min and max inductor currents

$$I_1 := 1 \cdot \text{amp} \quad I_2 := 1 \cdot \text{amp}$$

Given

$$\frac{I_1 + I_2}{2} = \frac{I_o}{1 - D} \quad I_2 - I_1 = V_D \cdot \frac{T_{\text{on}}}{L}$$

$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} := \text{Find}(I_1, I_2) \quad I_1 = 3.813 \text{ amp} \quad I_2 = 4.187 \text{ amp}$$

Now choose the capacitor based on the ripple voltage due to charge being removed from the cap while the switch is on and the capacitor is sourcing current to the load.

$$\text{Specify the amount of ripple allowed} \quad V_{\text{CR}} := 50 \cdot \text{mV}$$

$$C := \frac{I_o \cdot T_{\text{on}}}{V_{\text{CR}}} \quad C = 1 \times 10^3 \mu\text{F}$$

$$\text{Choose the next size standard cap} \quad C := 1500 \cdot \mu\text{F}$$

Recalculate the ripple due to the cap being discharged

$$V_{\text{CR}} := I_o \cdot \frac{T_{\text{on}}}{C} \quad V_{\text{CR}} = 33.333 \text{ mV}$$

Choose the filter capacitor using ESR Calculations.

Assume that the major component of the ripple comes from the capacitor ESR

Specify the ripple due to the ESR $V_{CR} := 100 \cdot \text{mV}$

$$\text{ESR} := \frac{V_{CR}}{I_2} \quad \text{ESR} = 0.024 \Omega$$

For all electrolytic caps, assume that $\text{ESR} \cdot C = 80 \mu\text{s}$

$$C := \frac{80 \cdot \mu\text{s}}{\text{ESR}} \quad C = 3.349 \times 10^3 \mu\text{F}$$

Choose the next size std capacitor $C := 4700 \cdot \mu\text{F}$

$$\text{ESR} := 80 \cdot \frac{\mu\text{s}}{C} \quad \text{ESR} = 0.017 \Omega$$

Calculate the RMS current using the actual waveform to estimate the capacitor lifetime.

$$m := \frac{I_2 - I_1}{T_{\text{off}}} \quad I_L(t) := I_2 - m \cdot t$$

$$I_{\text{rms}} := \sqrt{\frac{1}{T_S} \left[\int_{0 \cdot \text{sec}}^{T_{\text{on}}} (-I_o)^2 dt + \int_{0 \cdot \text{sec}}^{T_{\text{off}}} (I_L(t) - I_o)^2 dt \right]}$$

$$I_{\text{rms}} = 2.001 \text{ amp}$$

Summary

$$L = 335 \mu\text{H}$$

$$I_2 = 4.187 \text{ amp}$$

$$I_1 = 3.813 \text{ amp}$$

$$\frac{I_1 + I_2}{2} = 4 \text{ amp}$$

$$T_{\text{on}} = 25 \mu\text{s}$$

$$T_{\text{off}} = 25 \mu\text{s}$$

$$D = 50\%$$

$$V_D = 5 \text{ volt}$$

$$V_o = 10 \text{ volt}$$

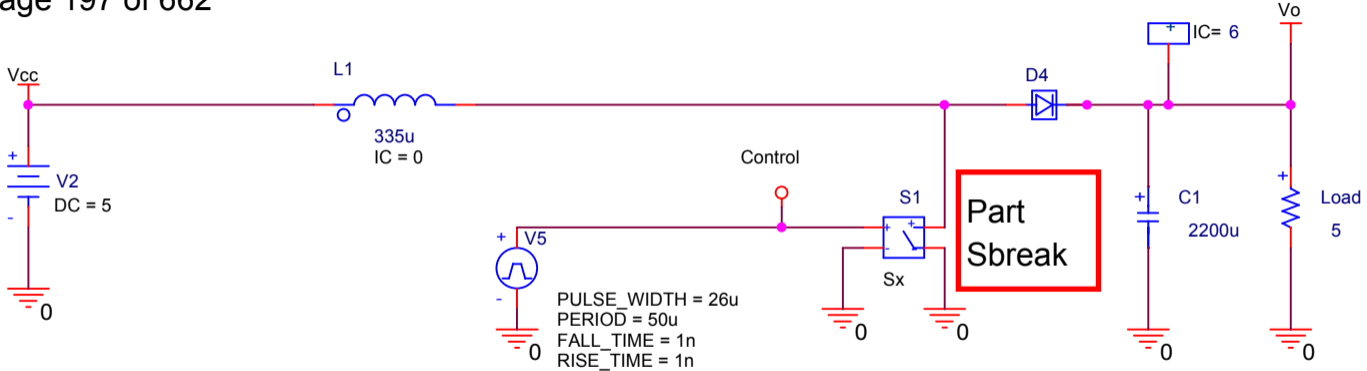
$$I_o = 2 \text{ amp}$$

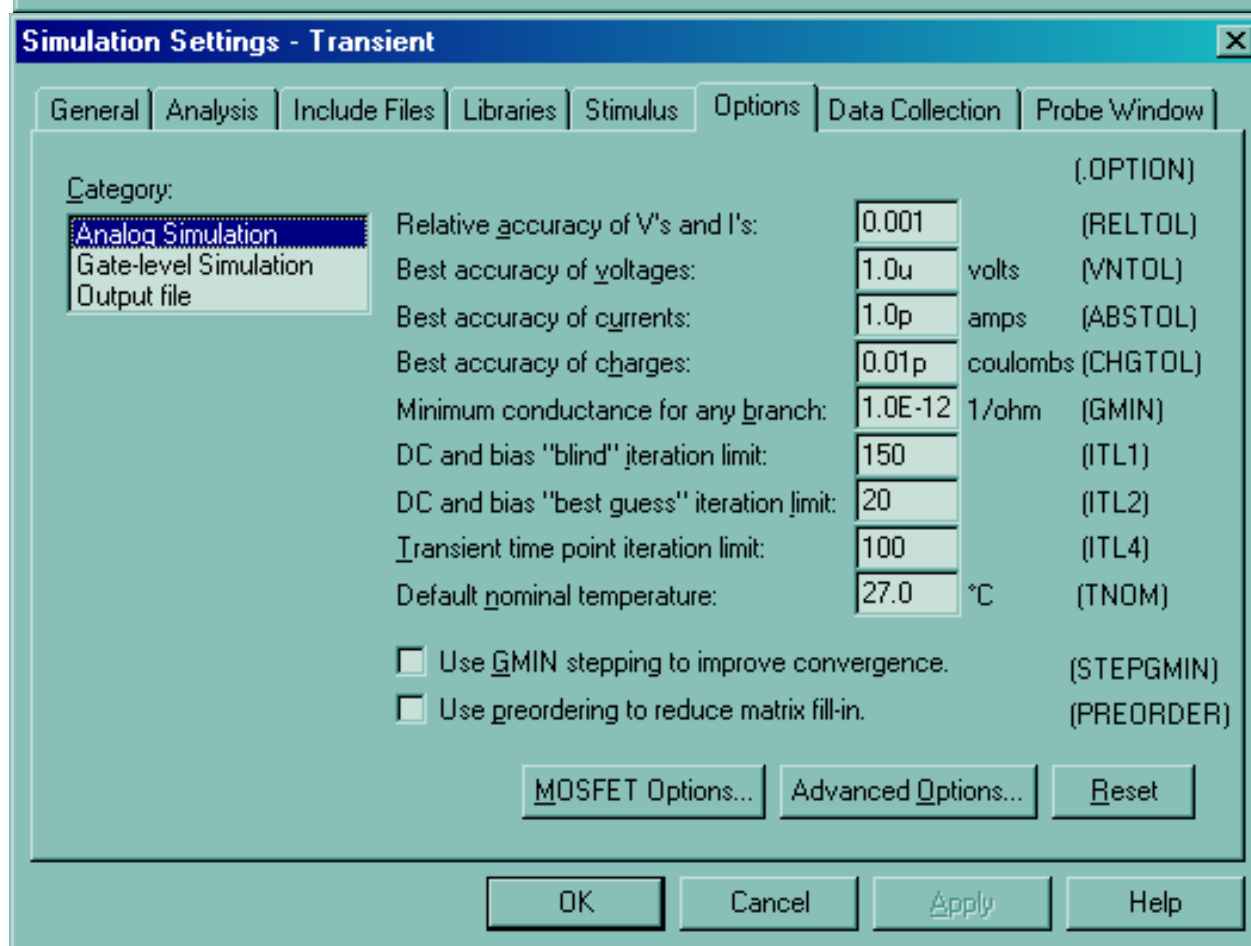
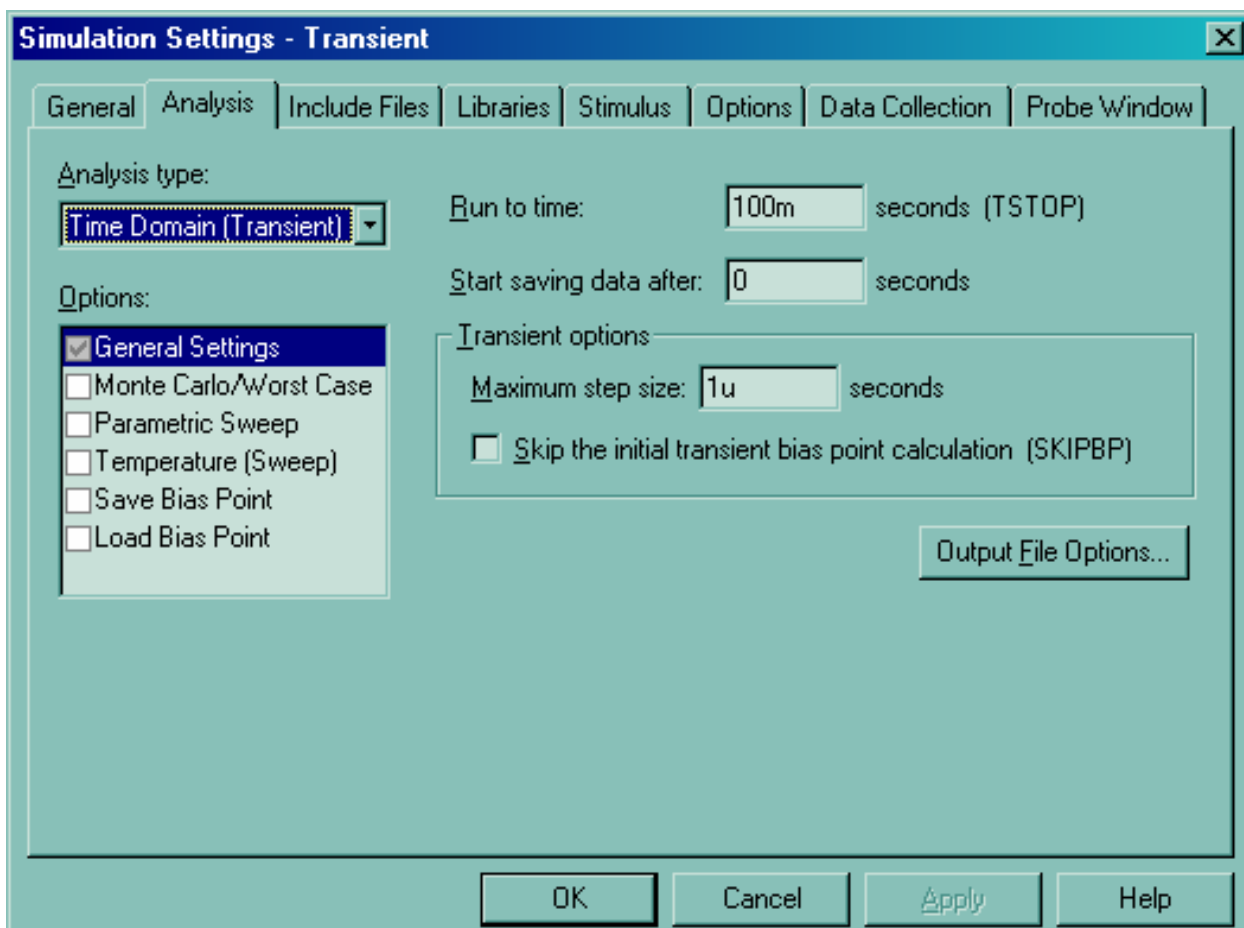
$$C = 4700 \mu\text{F}$$

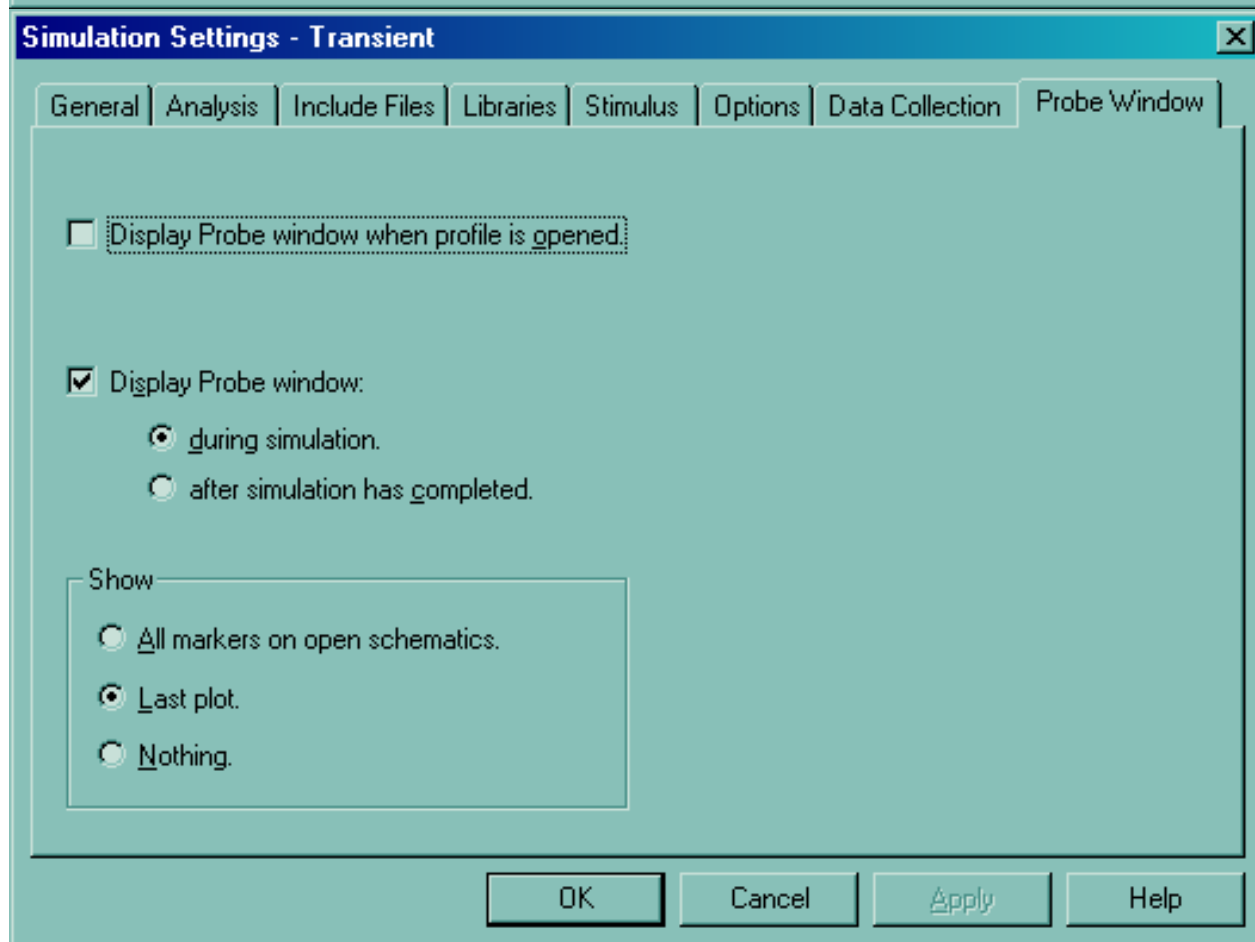
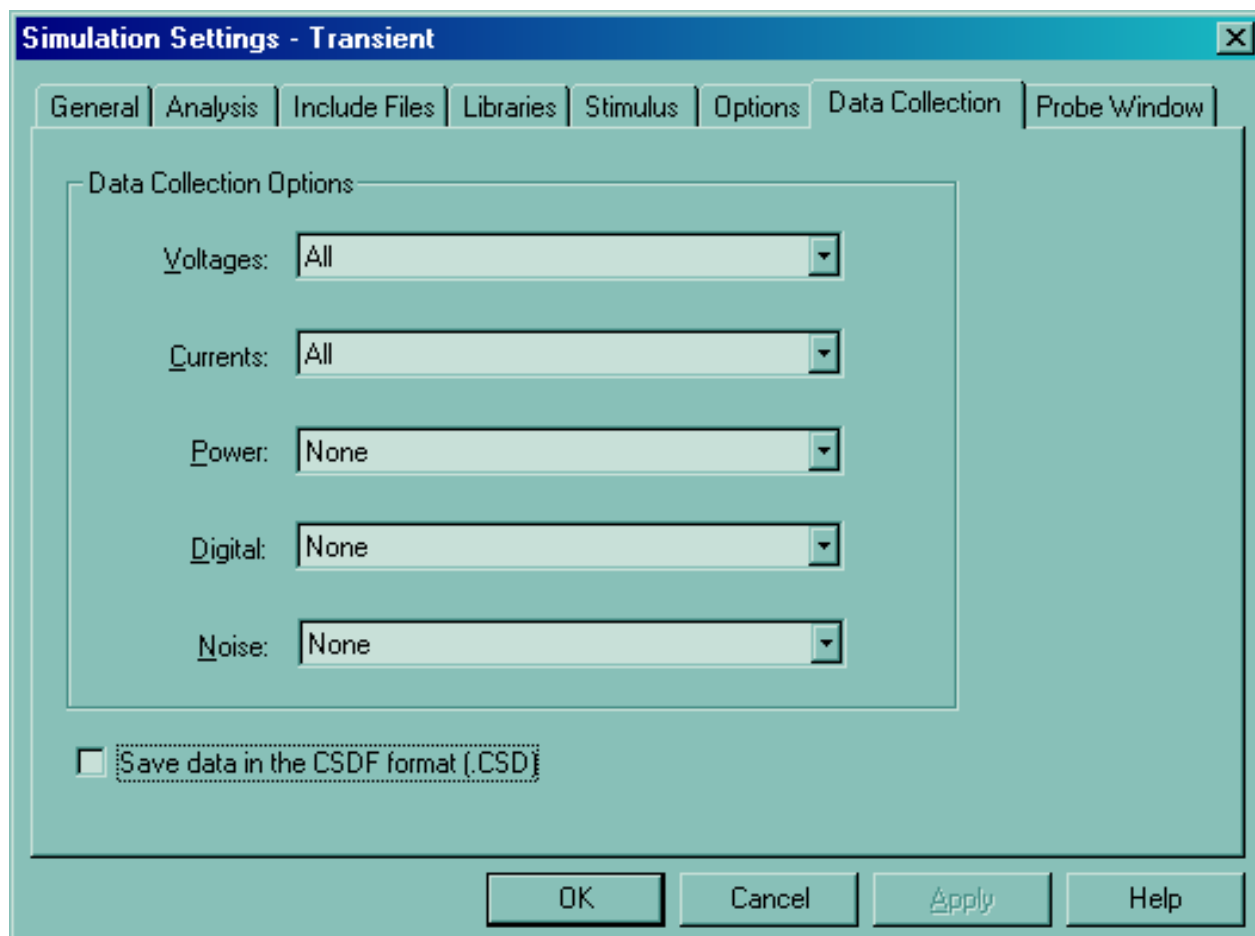
$$V_{\text{CR}} = 100 \text{ mV}$$

$$I_{\text{rms}} = 2.001 \text{ amp}$$

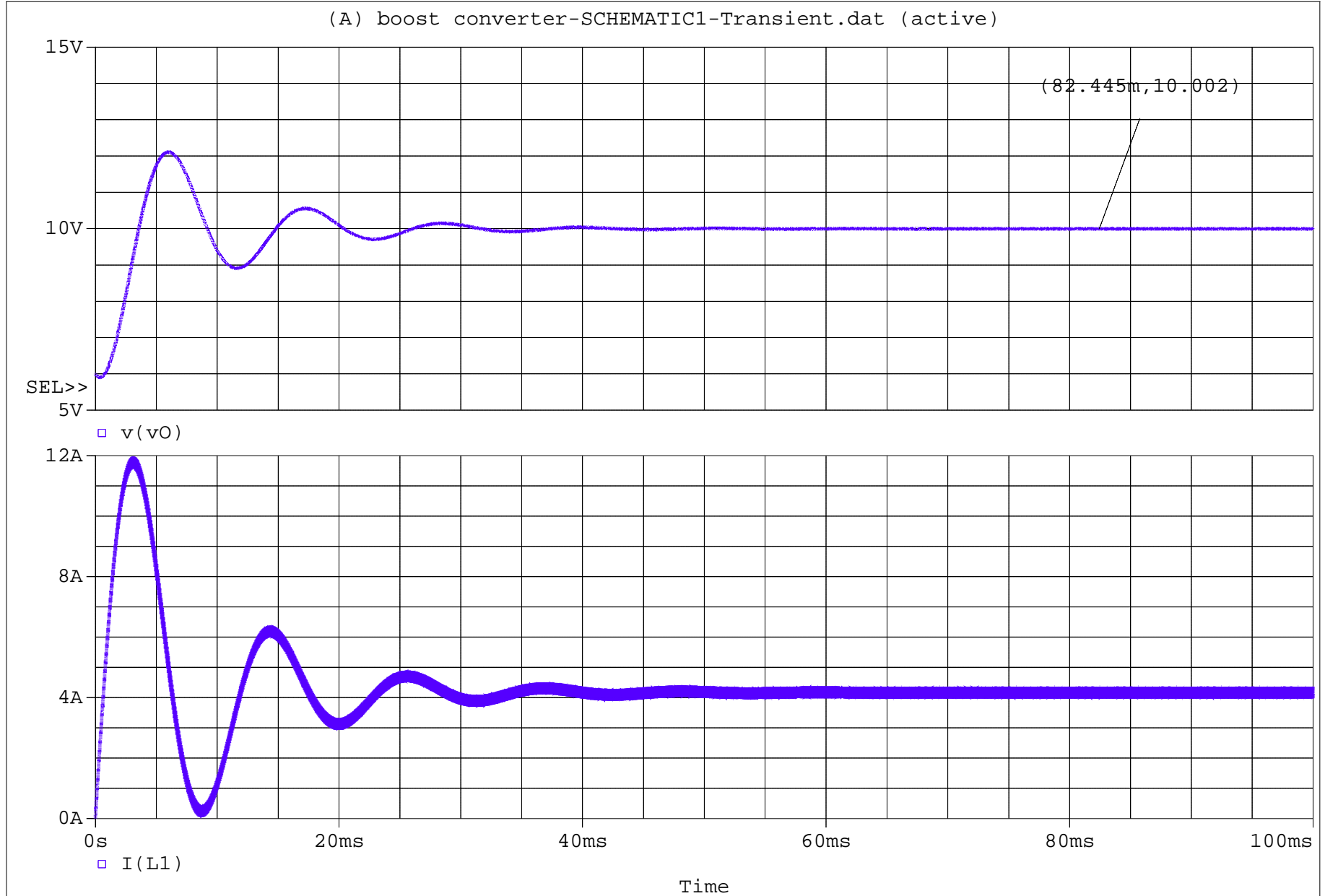
$$V_o = 10 \text{ volt}$$







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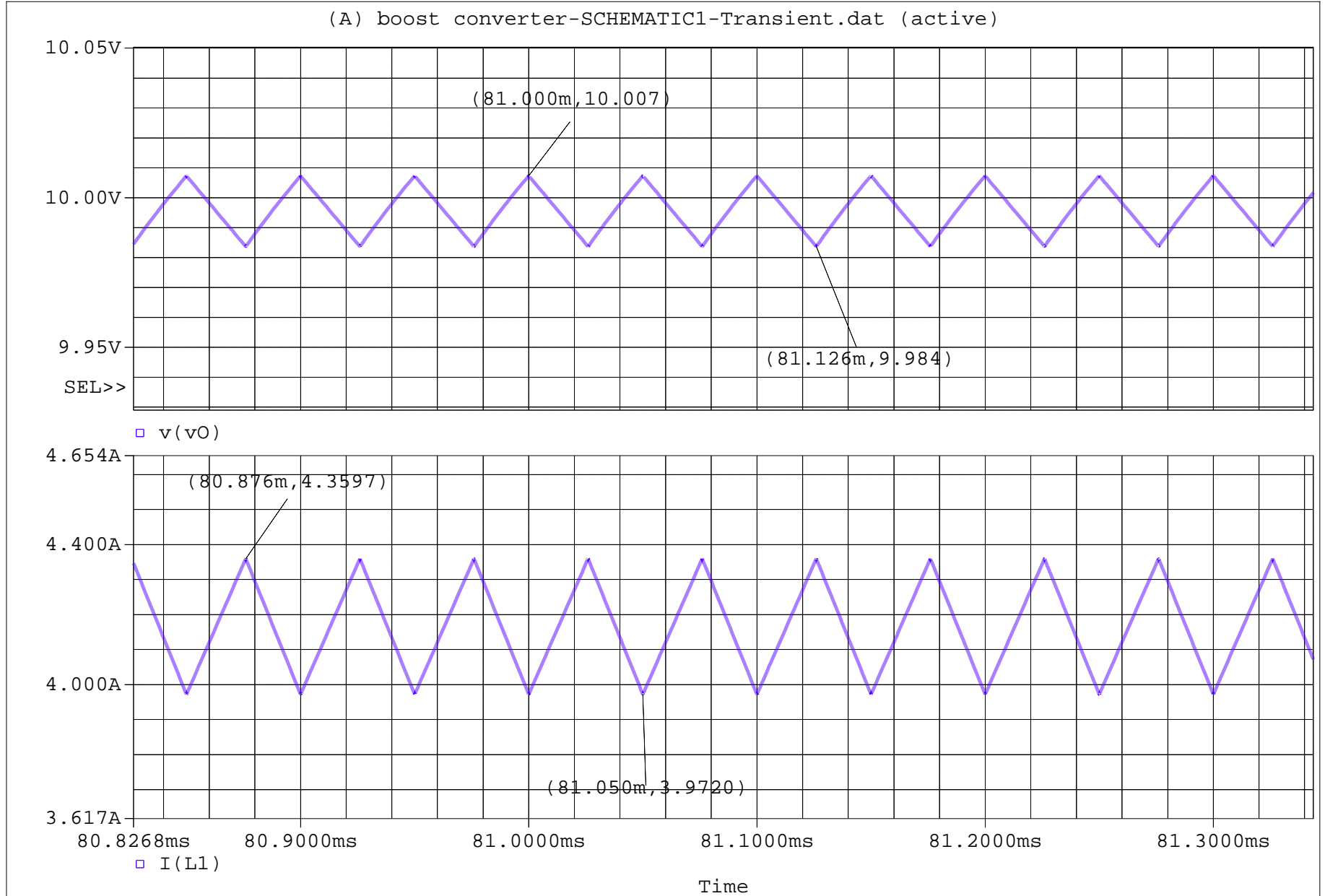


Date: December 04, 2002

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Time: 13:09:38

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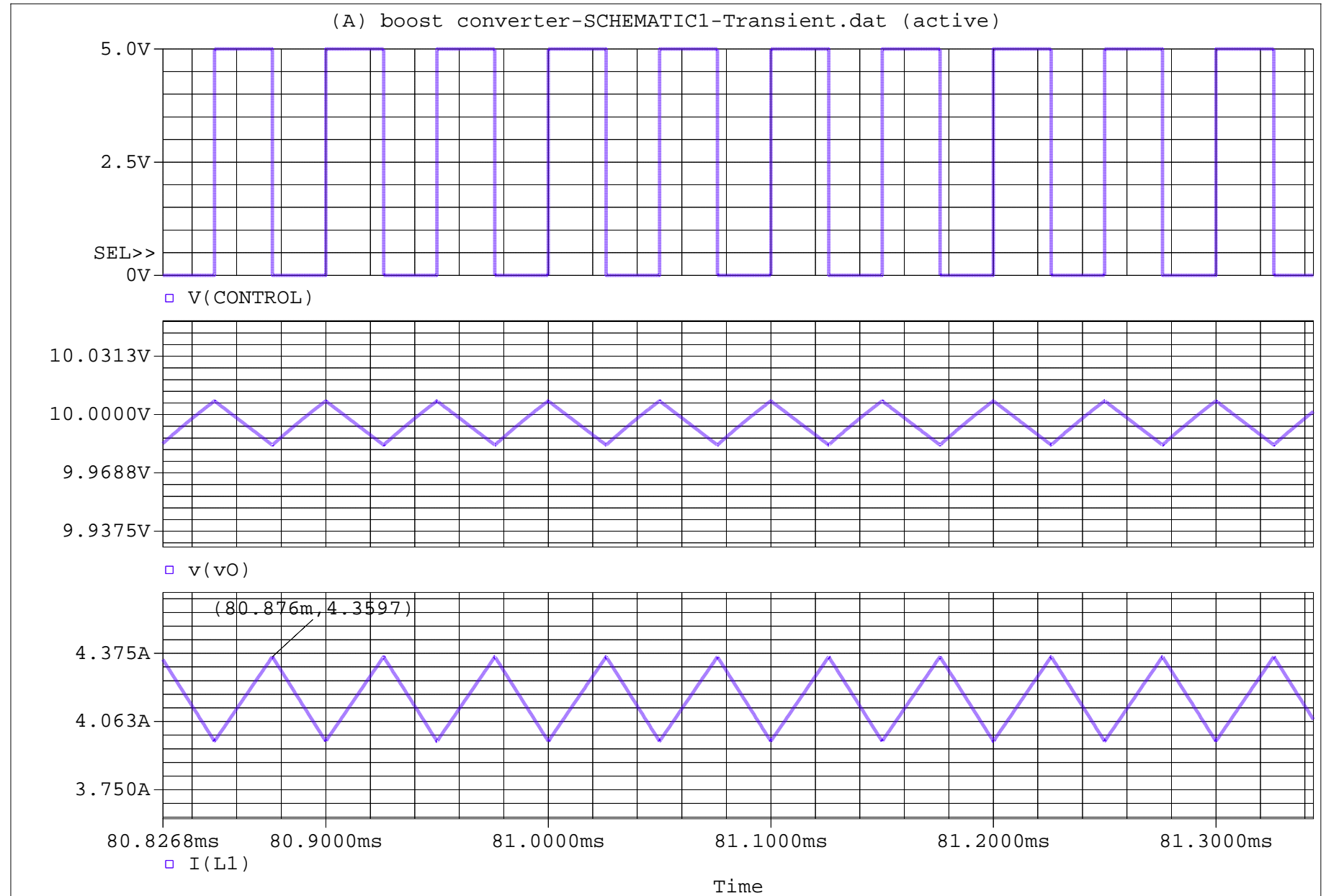


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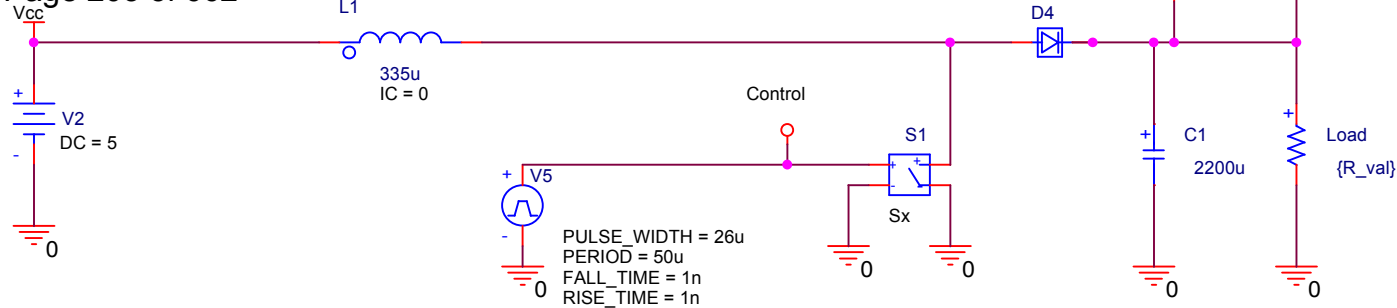
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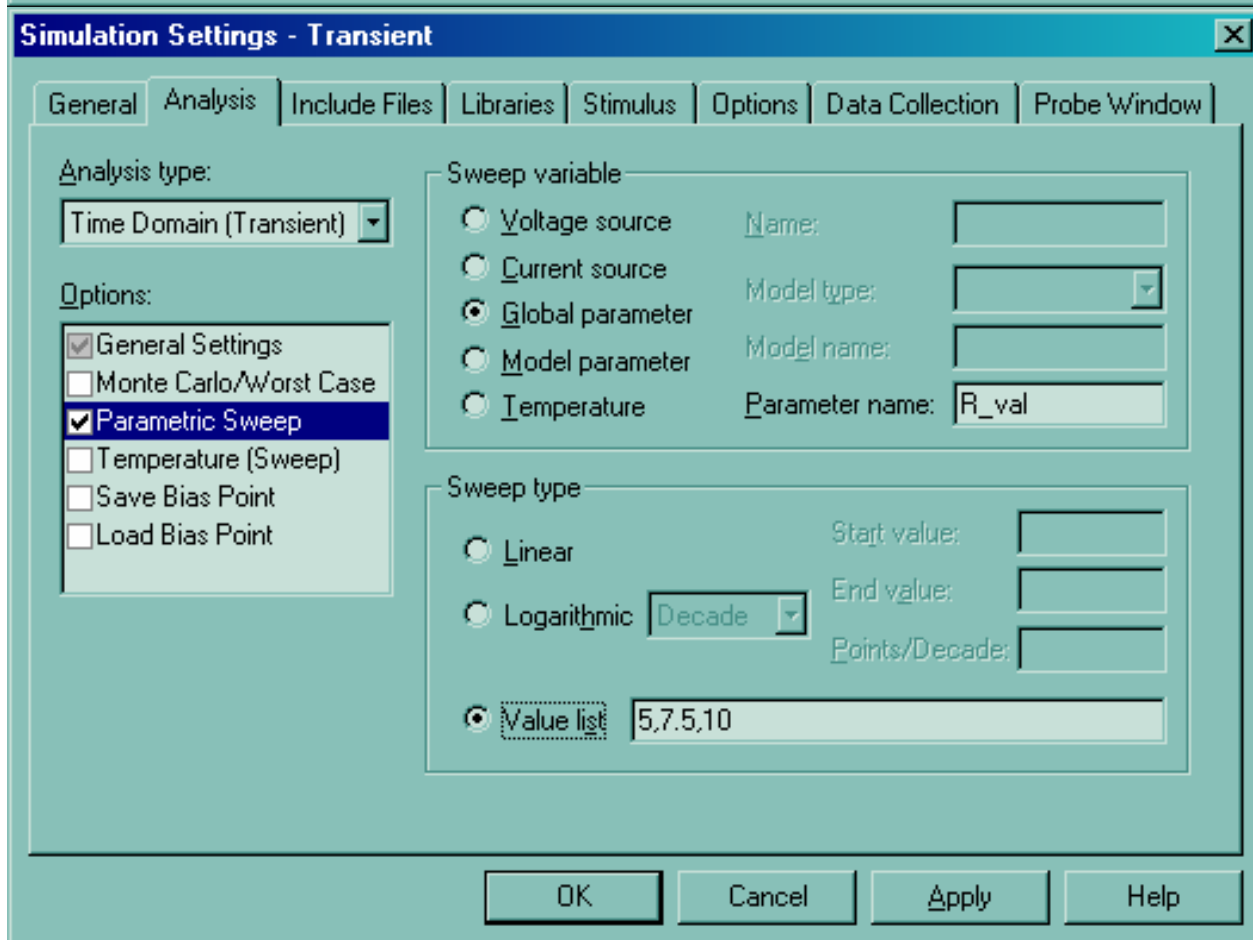
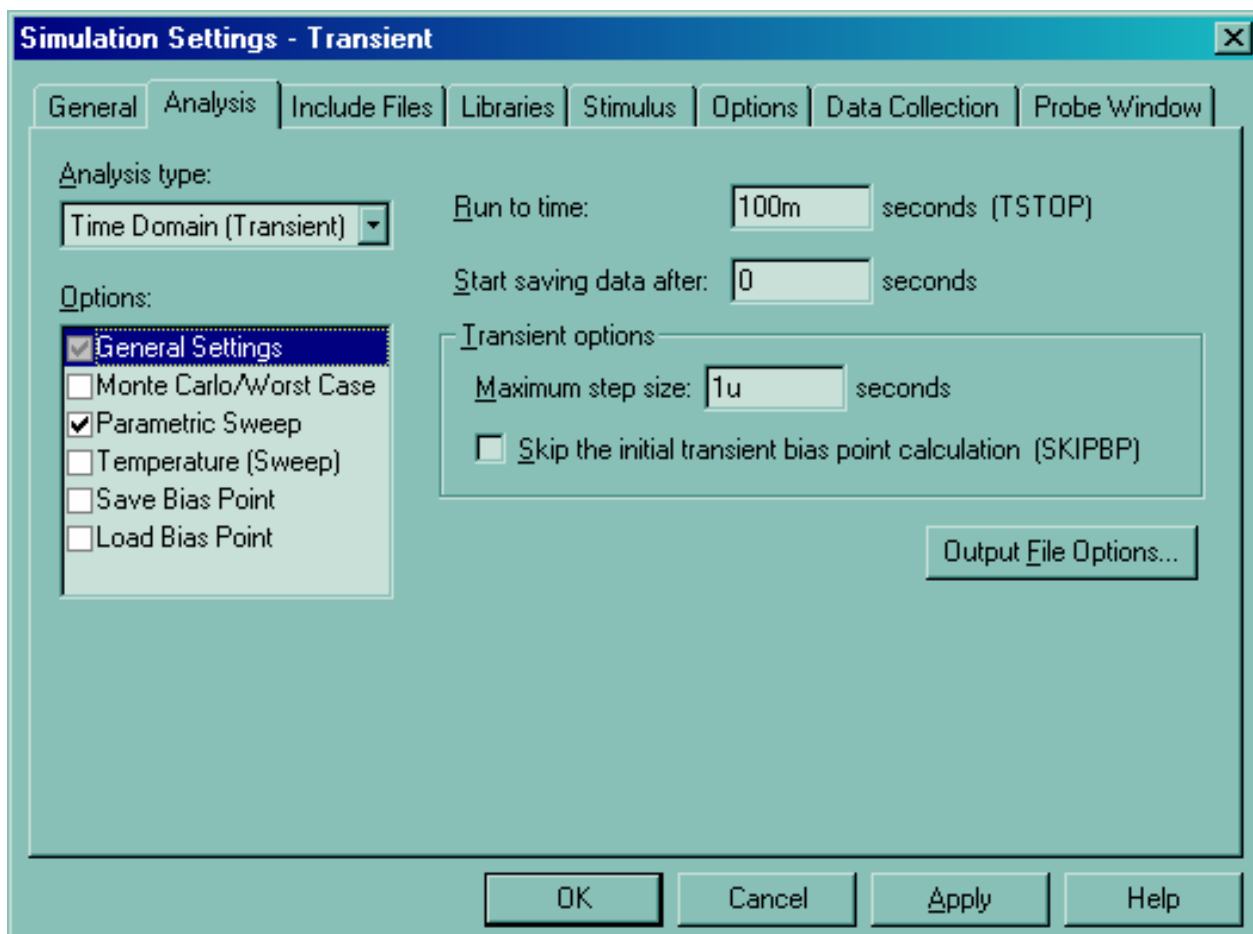
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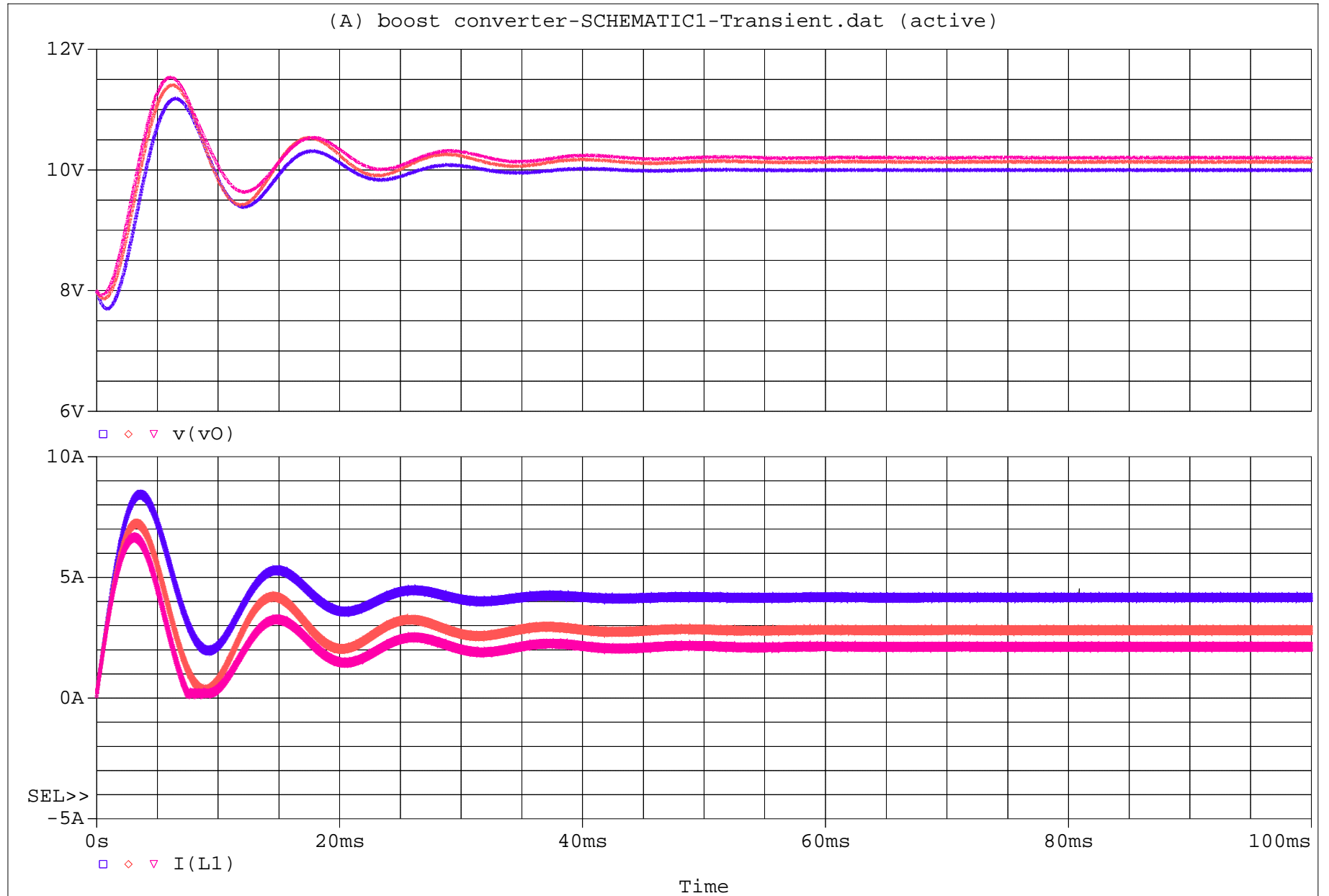
Time: 13:14:35



PARAMETERS:
 $R_{val} = 5$



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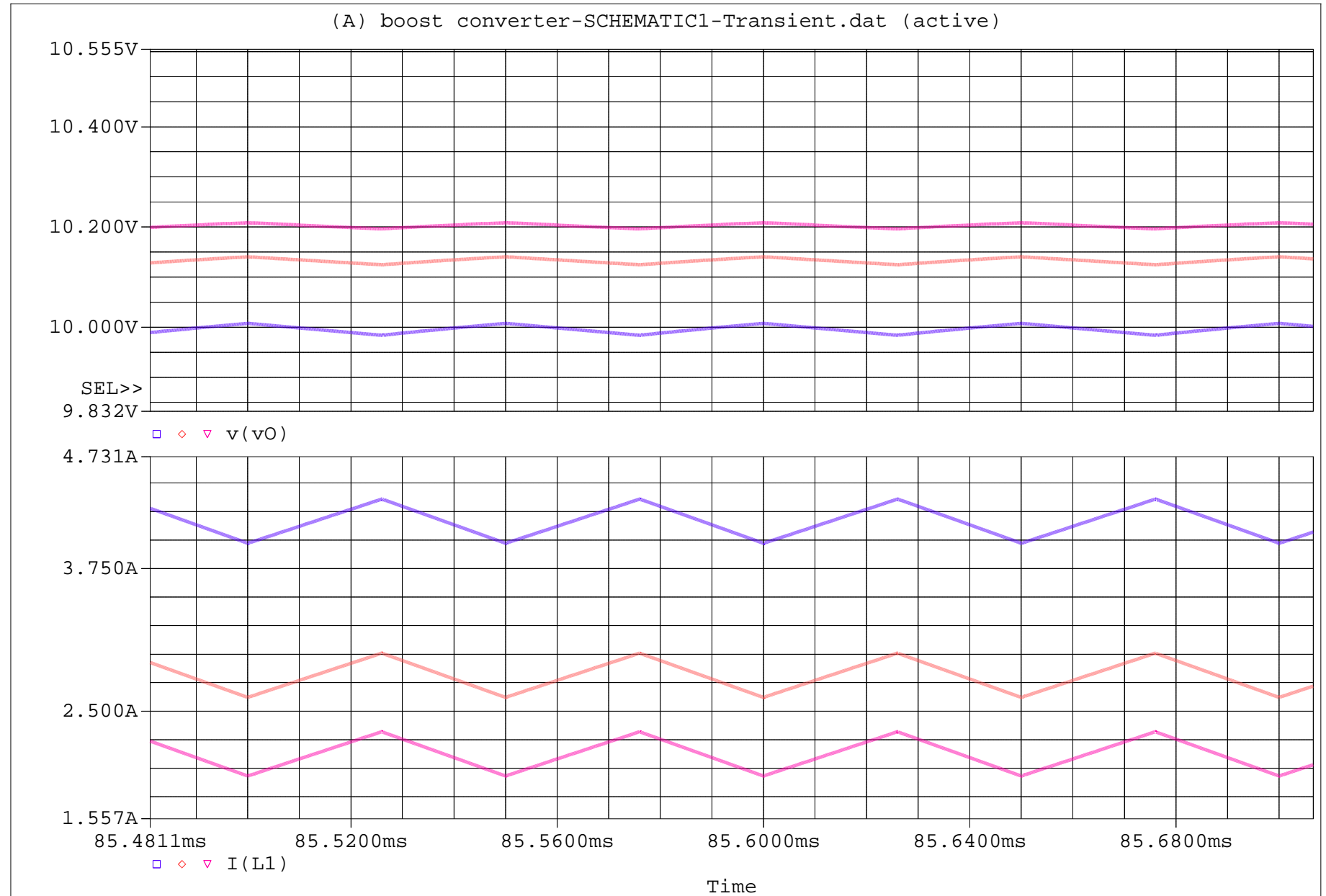


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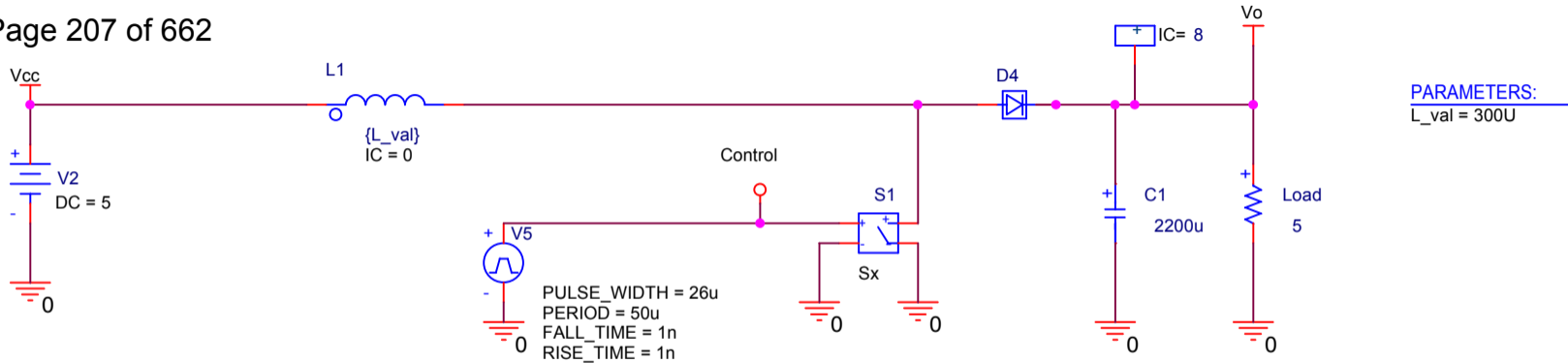
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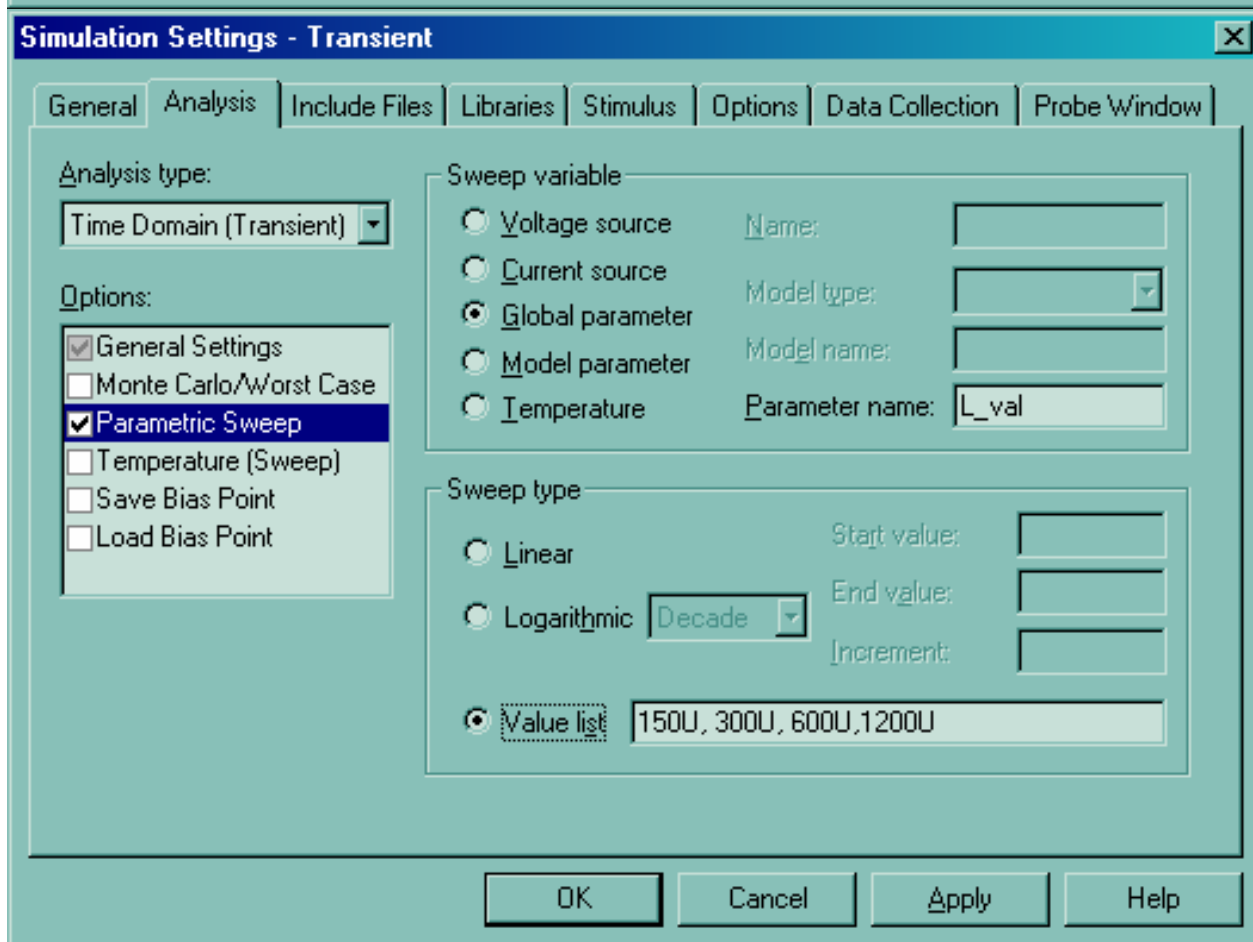
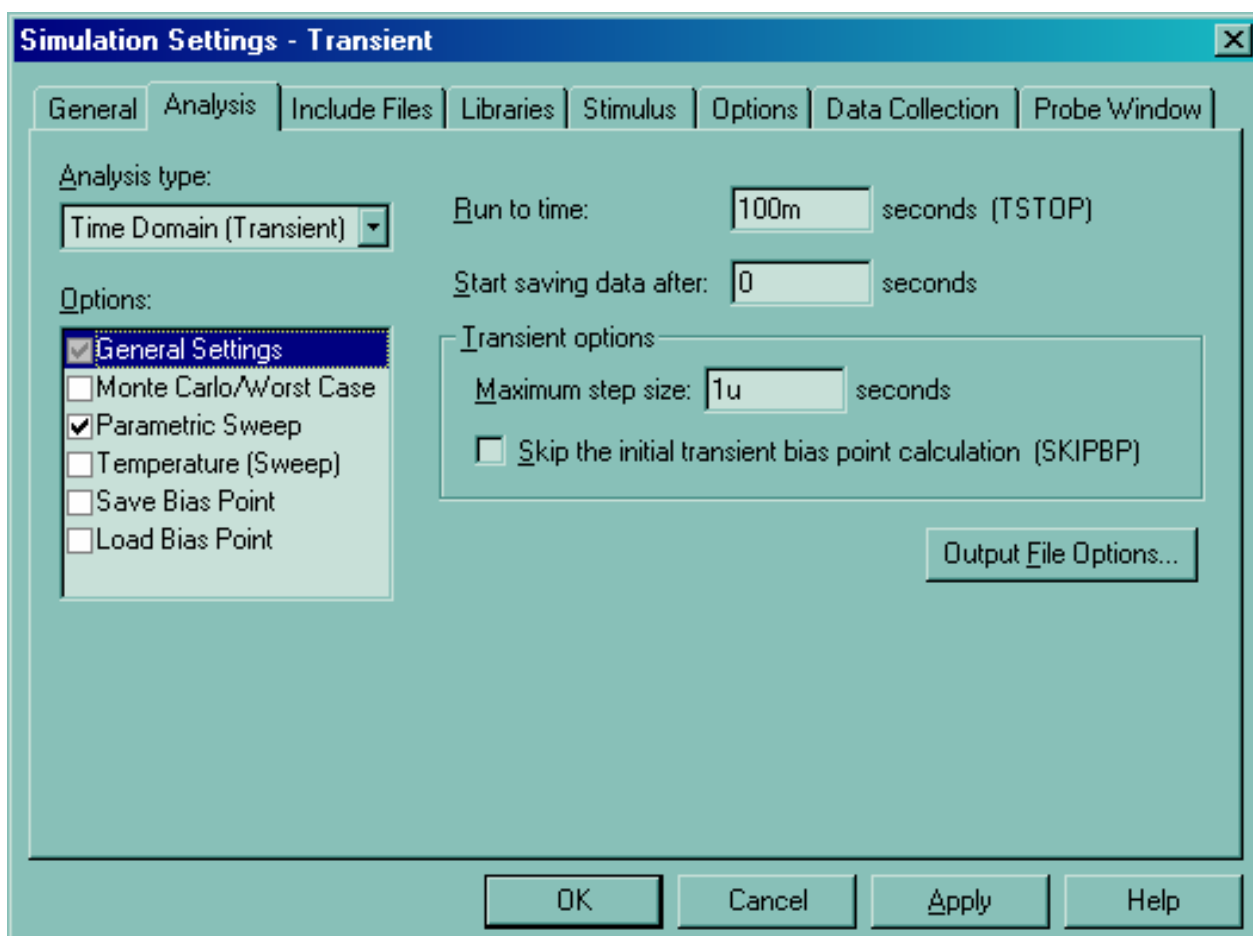
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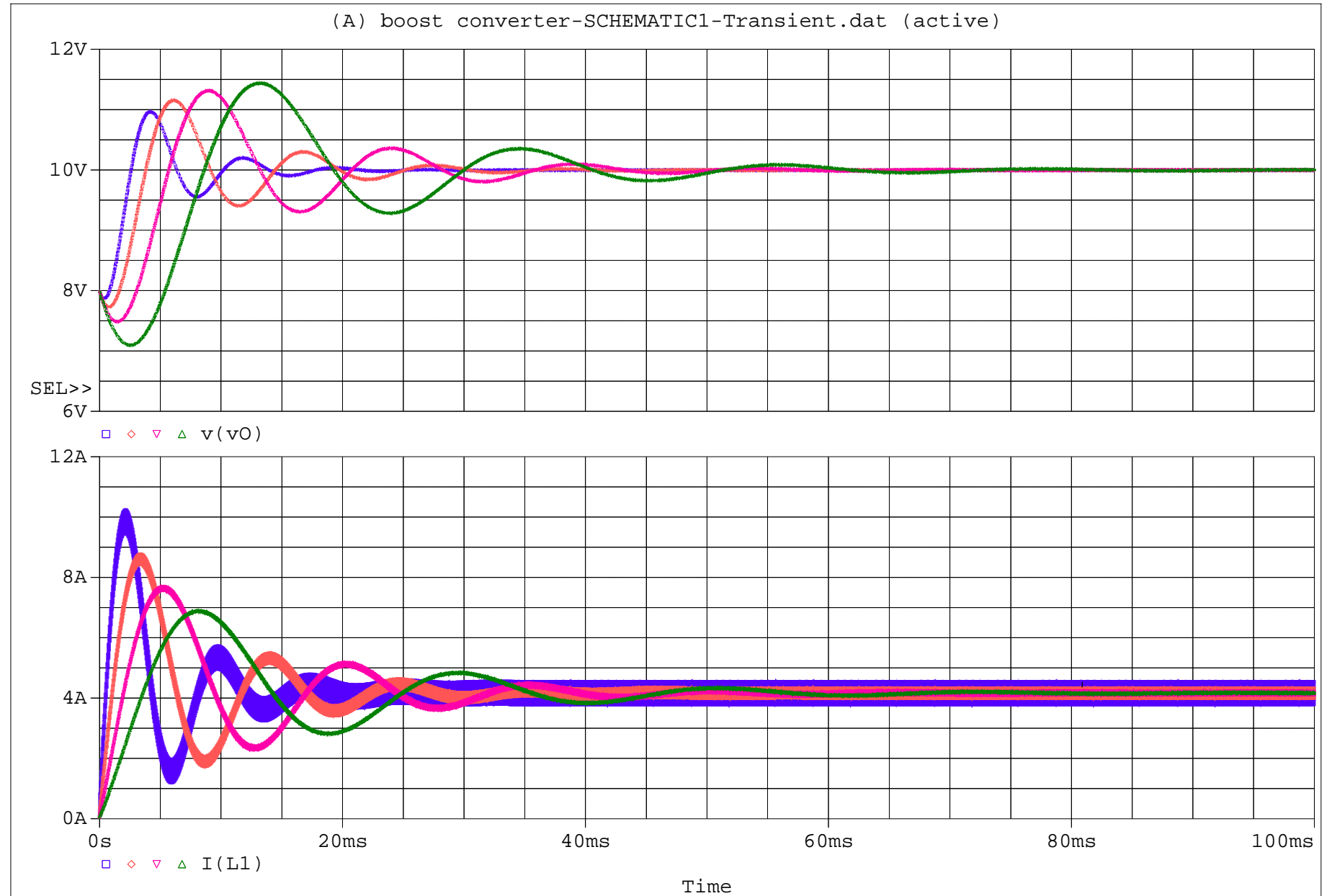


PARAMETERS:
 $L_val = 300U$

Model = Sx VSWITCH Roff=1e6 Ron=1m Voff=1 Von=4.0



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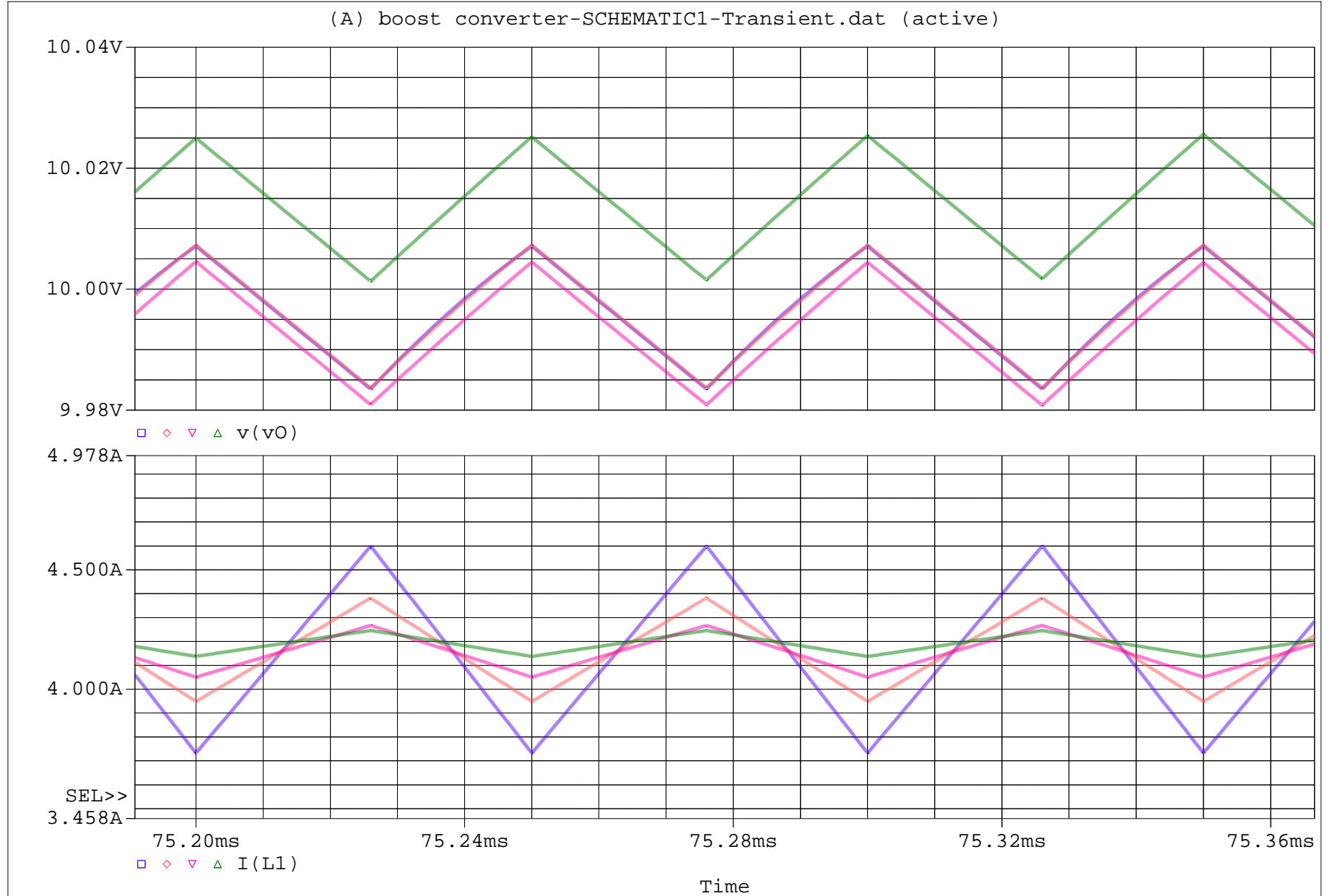


Date: December 04, 2002

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Time: 14:12:14

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 Date/Time run: 12/04/02 14:07:46 Temperature: 27.0



Date: December 04, 2002

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Time: 14:13:06

ECE 556

Boost Regulator Design - Continuous Mode Operation

$$\mu\text{s} \equiv 10^{-6} \cdot \text{sec}$$

Specify Input Voltage $V_D := 5 \cdot \text{volt}$

Specify Output Voltage $V_o := 10 \cdot \text{volt}$

Specify Switching Frequency $F_S := 200 \cdot \text{kHz}$

$$T_S := \frac{1}{F_S} \quad T_S = 5 \mu\text{s}$$

Specify the Assumed Efficiency $\text{Eff} := 100\%$

You should assume 80 to 85% efficiency in your designs.

The output Power is $P_{\text{out}} := \frac{20 \cdot \text{watt}}{\text{Eff}}$

The output current is $I_o := \frac{P_{\text{out}}}{V_o} \quad I_o = 2 \text{ amp}$

Find t_{on} and t_{off}

$$T_{off} := 1 \cdot \mu s \quad T_{on} := 1 \cdot \mu s$$

Given

$$\frac{T_{on}}{T_S} = \frac{V_o - V_D}{V_o}$$

$$T_{on} + T_{off} = T_S$$

Ton 10 times smaller than before

$$\begin{pmatrix} T_{on} \\ T_{off} \end{pmatrix} := \text{Find}(T_{on}, T_{off})$$

$$T_{on} = 2.5 \mu s \quad T_{off} = 2.5 \mu s$$

$$D := \frac{T_{on}}{T_S}$$

$$D = 0.5 \%$$

Find the range of Inductors that will operate in continuous mode

Specify the minimum current we want the supply to operate in the continuous mode

$$I_{min} := \frac{I_o}{10}$$

$$I_{min} = 0.2 \text{ amp}$$

$$L := \frac{V_D \cdot T_{on}}{2 \cdot I_{min}} \cdot \frac{V_D}{V_o}$$

For Continuous Mode, We need L greater than $L = 15.625 \mu H$

Choose the Inductor $L := 33.5 \cdot \mu H$

Inductor 10 times smaller than before

Find the Min and max inductor currents

$$I_1 := 1 \cdot \text{amp} \quad I_2 := 1 \cdot \text{amp}$$

Given

$$\frac{I_1 + I_2}{2} = \frac{I_o}{1 - D} \quad I_2 - I_1 = V_D \cdot \frac{T_{\text{on}}}{L}$$

$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} := \text{Find}(I_1, I_2) \quad I_1 = 3.813 \text{ amp} \quad I_2 = 4.187 \text{ amp}$$

Now choose the capacitor based on the ripple voltage due to charge being removed from the cap while the switch is on and the capacitor is sourcing current to the load.

Specify the amount of ripple allowed $V_{\text{CR}} := 50 \cdot \text{mV}$

$$C := \frac{I_o \cdot T_{\text{on}}}{V_{\text{CR}}} \quad C = 100 \mu\text{F}$$

Cap 10 times smaller than before

Choose the next size standard cap $C := 150 \cdot \mu\text{F}$

Recalculate the ripple due to the cap being discharged

$$V_{\text{CR}} := I_o \cdot \frac{T_{\text{on}}}{C} \quad V_{\text{CR}} = 33.333 \text{ mV}$$

Choose the filter capacitor using ESR Calculations.

Assume that the major component of the ripple comes from the capacitor ESR

Specify the ripple due to the ESR $V_{CR} := 100 \cdot \text{mV}$

$$\text{ESR} := \frac{V_{CR}}{I_2} \quad \text{ESR} = 0.024 \Omega$$

For all electrolytic caps, assume that $\text{ESR} \cdot C = 80 \mu\text{s}$

$$C := \frac{80 \cdot \mu\text{s}}{\text{ESR}} \quad C = 3.349 \times 10^3 \mu\text{F}$$

Choose the next size std capacitor $C := 4700 \cdot \mu\text{F}$

$$\text{ESR} := 80 \cdot \frac{\mu\text{s}}{C} \quad \text{ESR} = 0.017 \Omega$$

Cap same as before.

Calculate the RMS current using the actual waveform to estimate the capacitor lifetime.

$$m := \frac{I_2 - I_1}{T_{\text{off}}} \quad I_L(t) := I_2 - m \cdot t$$

$$I_{\text{rms}} := \sqrt{\frac{1}{T_S} \left[\int_{0 \cdot \text{sec}}^{T_{\text{on}}} (-I_o)^2 dt + \int_{0 \cdot \text{sec}}^{T_{\text{off}}} (I_L(t) - I_o)^2 dt \right]}$$

$$I_{\text{rms}} = 2.001 \text{ amp}$$

Summary

$$L = 33.5 \mu\text{H}$$

$$I_2 = 4.187 \text{ amp}$$

$$I_1 = 3.813 \text{ amp}$$

$$\frac{I_1 + I_2}{2} = 4 \text{ amp}$$

$$T_{\text{on}} = 2.5 \mu\text{s}$$

$$T_{\text{off}} = 2.5 \mu\text{s}$$

$$D = 50\%$$

$$V_D = 5 \text{ volt}$$

$$V_O = 10 \text{ volt}$$

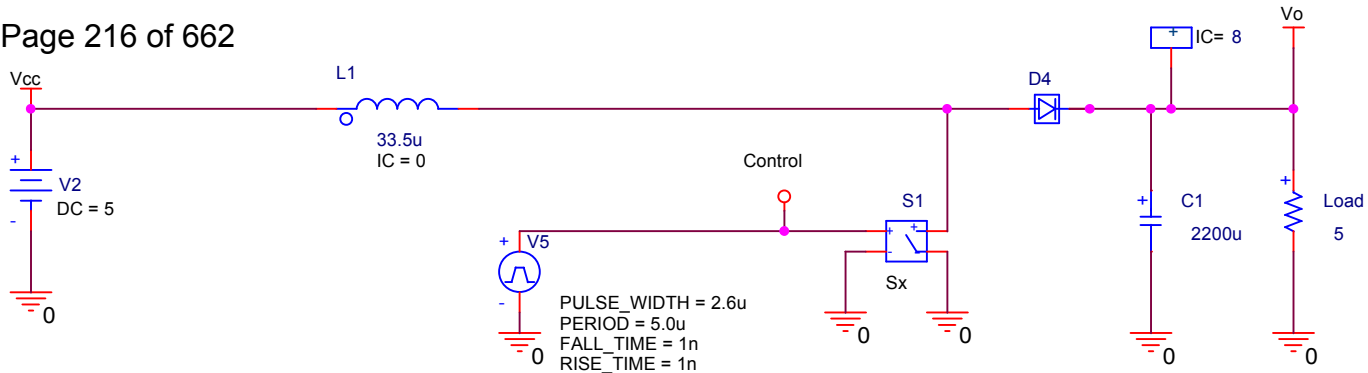
$$I_O = 2 \text{ amp}$$

$$C = 4700 \mu\text{F}$$

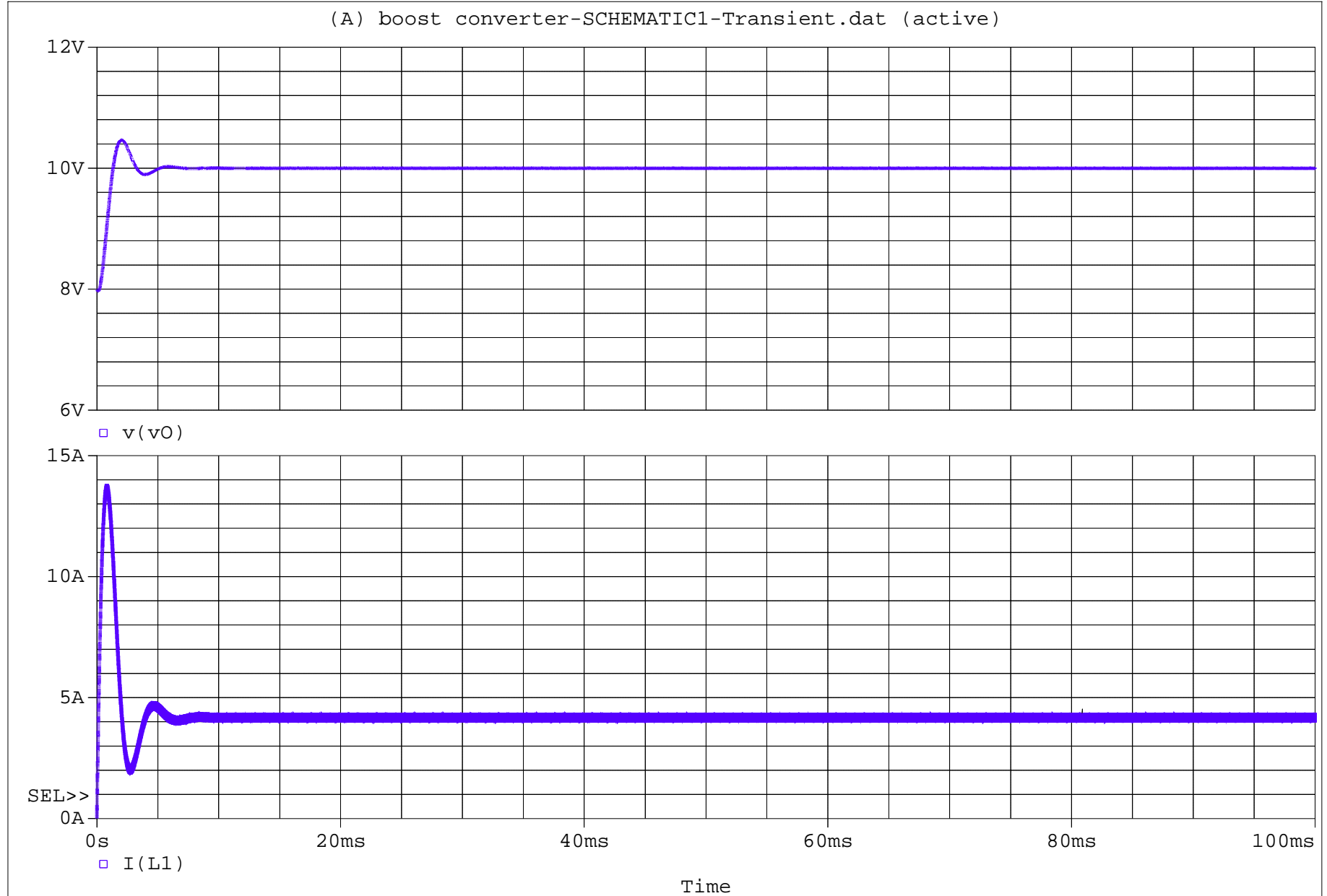
$$V_{\text{CR}} = 100 \text{ mV}$$

$$I_{\text{rms}} = 2.001 \text{ amp}$$

$$V_O = 10 \text{ volt}$$



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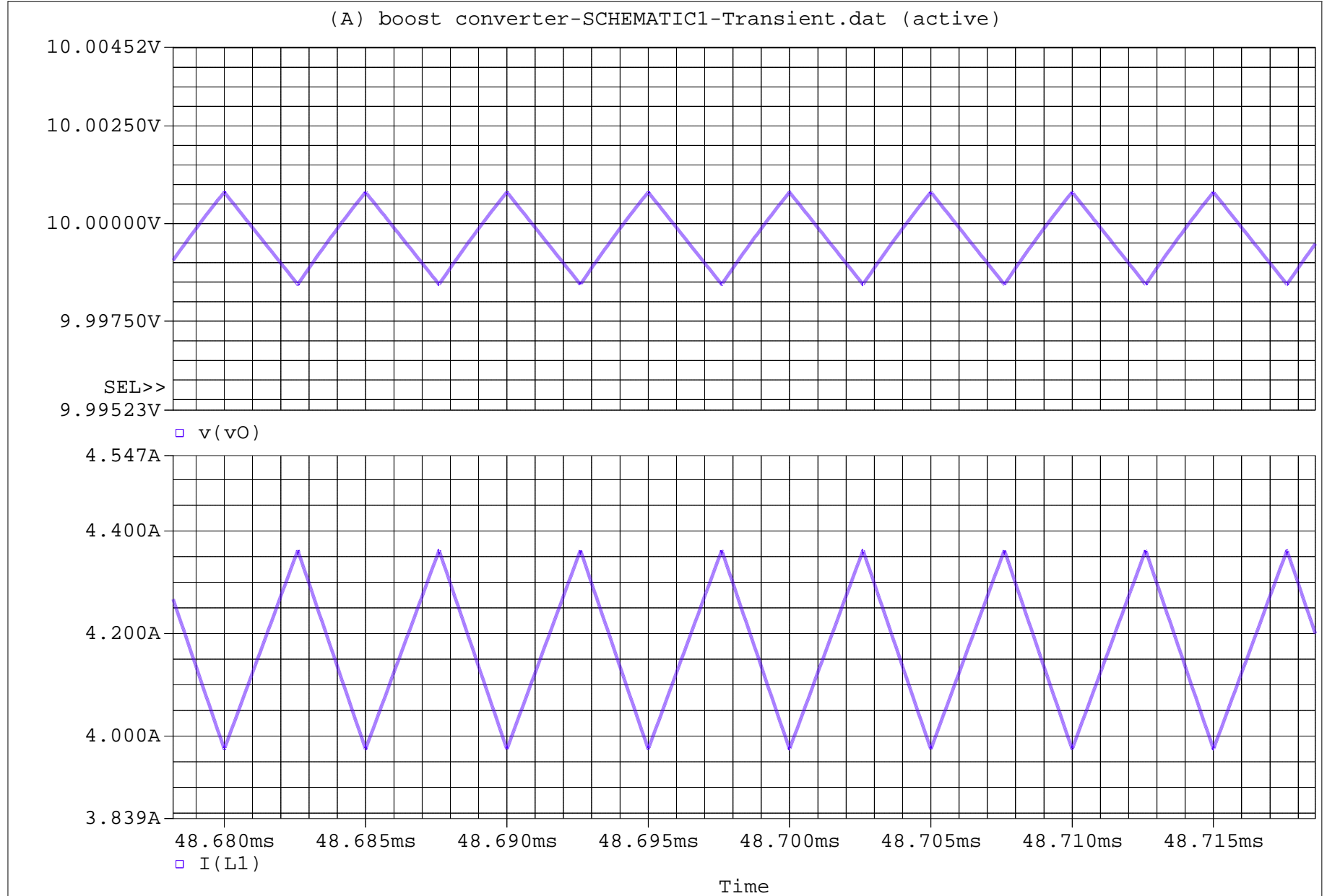


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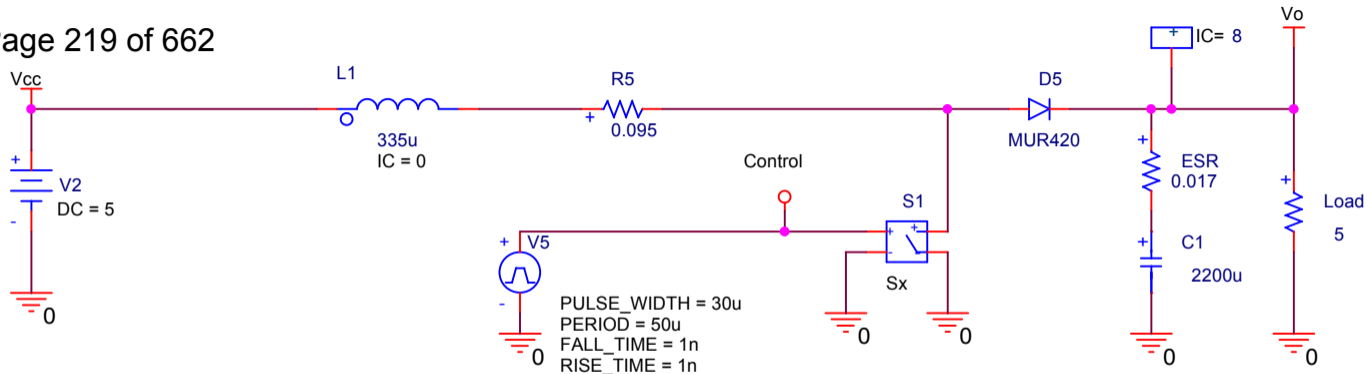
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Date: December 04, 2002

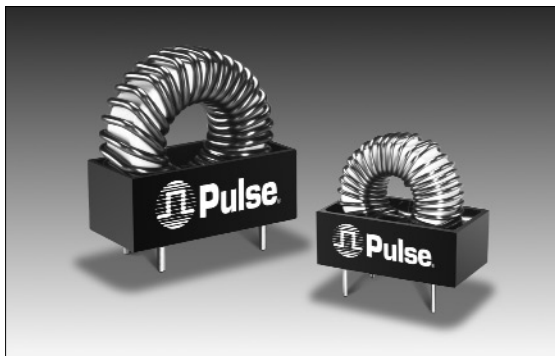
Page 1

Time: 14:30:31



Model = Sx VSWITCH Roff=1e6 Ron=10m Voff=1 Von=4.0

TOROIDAL INDUCTORS HIGH CURRENT



- Cost-effective designs
- Semi-encapsulated construction
- Maximum operation temperature of 130°C (Ambient + Rise)
- A 2:1 inductance swing from zero to maximum current

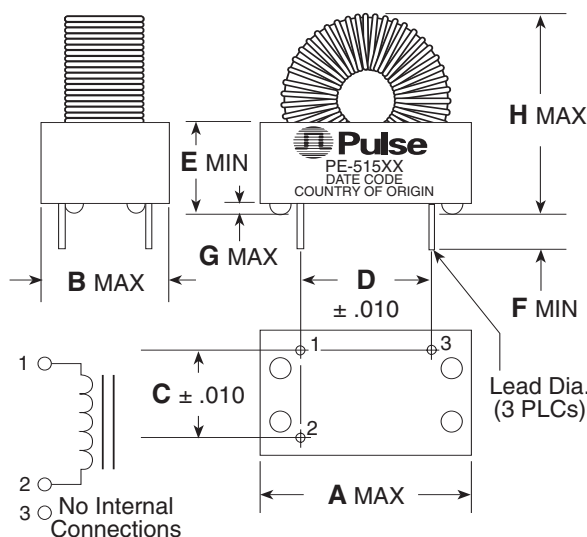
Electrical Specifications @ 25°C

Part Number	REFERENCE OPERATING VALUES					DESIGN CONTROL VALUES				
	Inductance Typical (μH) ²	I _{DC} (AMPS)	ET _{OP} ¹ (V-μSec)		Energy Storage (μJ MIN) ³	Inductance No DC (μH) (±20%)	50 kHz Test mV No DC _s	DCR (Ω MAX)	Size Code	Lead Diameter (in ±.003)
			20 kHz	40 kHz						
PE-51506	17.0	17.0	190	130	2460	40.0	140	0.0065	3	0.081
PE-51507	32.0	16.0	290	200	4100	70.7	270	0.0092	4	0.081
PE-51508	60.0	16.0	390	270	7700	120.0	470	0.012	5	0.081
PE-51509	14.0	10.0	135	95	700	28.5	73	0.009	1	0.057
PE-51510	23.0	11.0	170	120	1400	43.5	130	0.012	2	0.057
PE-51511	43.0	10.0	280	195	2150	85.5	210	0.018	3	0.057
PE-51512	90.0	10.0	430	300	4500	158.0	420	0.028	4	0.057
PE-51513	144.0	10.0	570	400	7200	262.0	700	0.032	5	0.057
PE-51514	32.0	6.6	200	140	700	60.5	110	0.025	1	0.040
PE-51515	52.0	7.0	230	160	1275	92.0	190	0.032	2	0.040
PE-51516	98.0	6.0	400	280	1765	188.0	310	0.048	3	0.040
PE-51517	175.0	6.0	620	425	3150	315.0	560	0.068	4	0.040
PE-51518	335.0	6.0	840	580	6030	571.0	1000	0.095	5	0.040
PE-51520	400	3.6	600	420	2700	688.0	640	0.130	3	0.036

NOTES:

- To prevent excessive temperature rise, limit ET_{OP} to the rated ET_{OP} specified. This is not a saturation limit. Temperature rise of inductors is 40°C MAX at MAX current and rated ET_{OP}.
- A 2:1 nominal inductance swing from no I_{DC} to operating I_{DC} gives improved protection against current discontinuities at light loading. Inductance increases with greater ET_{OP}. Reference values occur at I_{DC} and low flux density.
- $\frac{LI^2}{2}$ rating is the ability of the inductor to store energy.
- Design control test voltage is critical. Inductance increases with voltage.

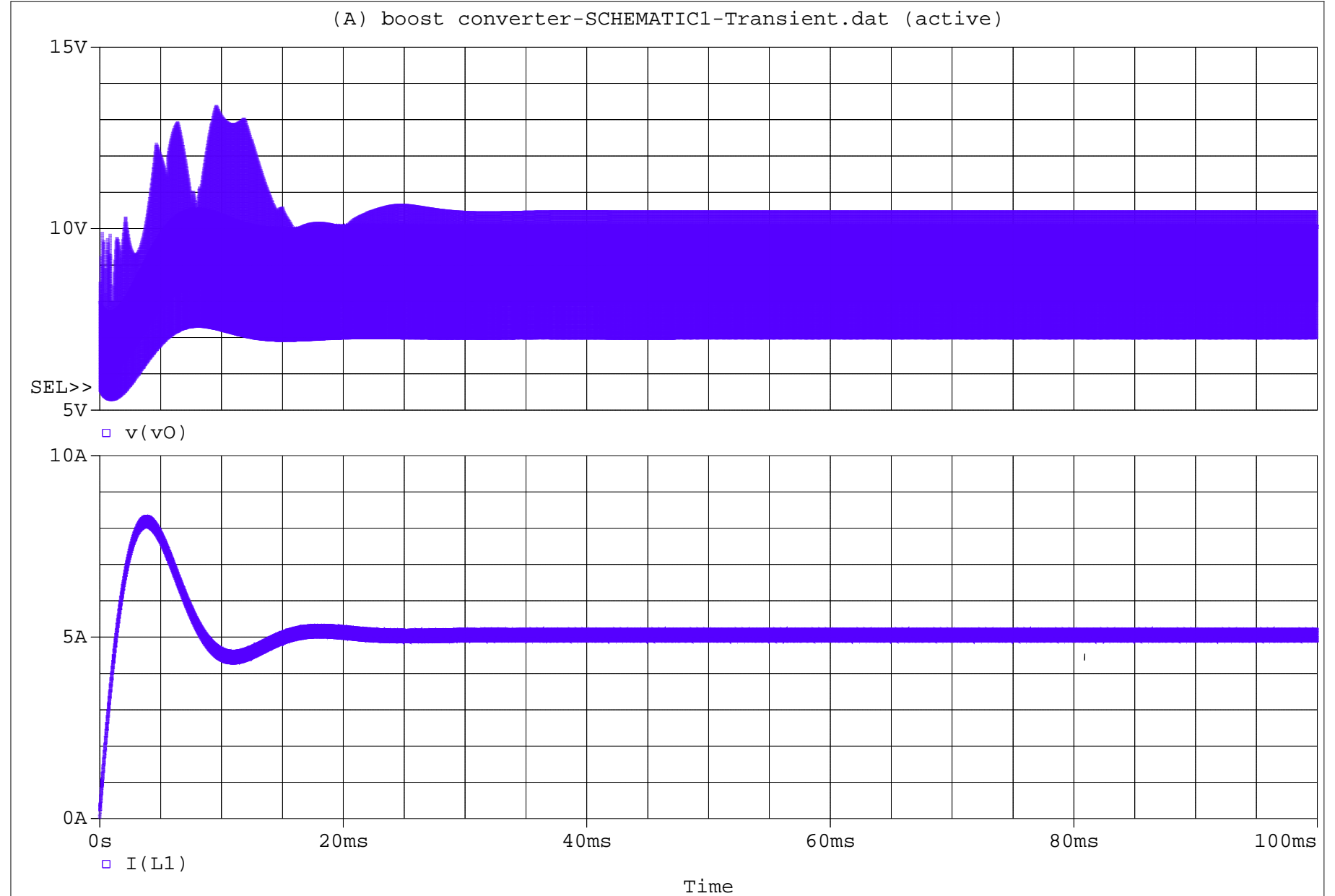
Mechanicals



Size Code	1	2	3	4	5
A	1.20/30,48	1.44/36,57	1.60/40,64	1.95/49,53	2.30/58,42
B	0.60/15,24	0.80/20,32	0.80/20,32	0.91/23,11	1.11/28,19
C	0.40/10,16	0.60/15,24	0.60/15,24	0.70/17,78	0.90/22,85
D	0.80/20,32	0.90/22,86	0.90/22,86	1.20/30,48	1.50/38,10
E	0.45/11,43	0.70/17,78	0.70/17,78	0.90/22,86	1.00/25,40
F	0.20/5,08	0.20/5,08	0.20/5,08	0.20/5,08	0.20/5,08
G	.015/0,381	0.03/0,76	0.03/0,76	0.03/0,76	0.03/0,76
H	1.20/30,48	1.44/36,57	1.72/43,68	2.00/50,80	2.30/58,42

Dimensions: $\frac{\text{Inches}}{\text{mm}}$
 Unless otherwise specified, all tolerances are $\pm \frac{.010}{.025}$

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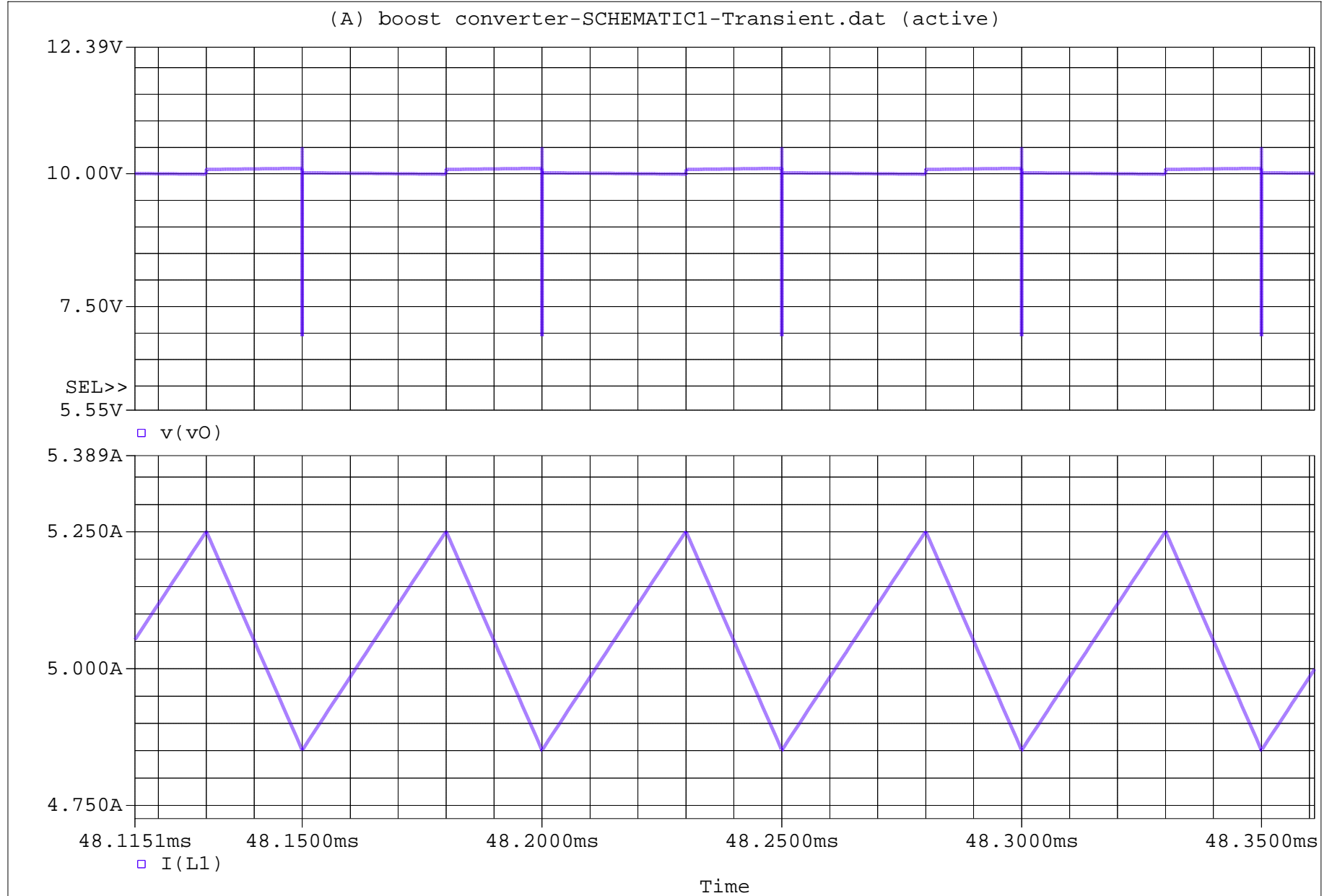


Date: December 04, 2002

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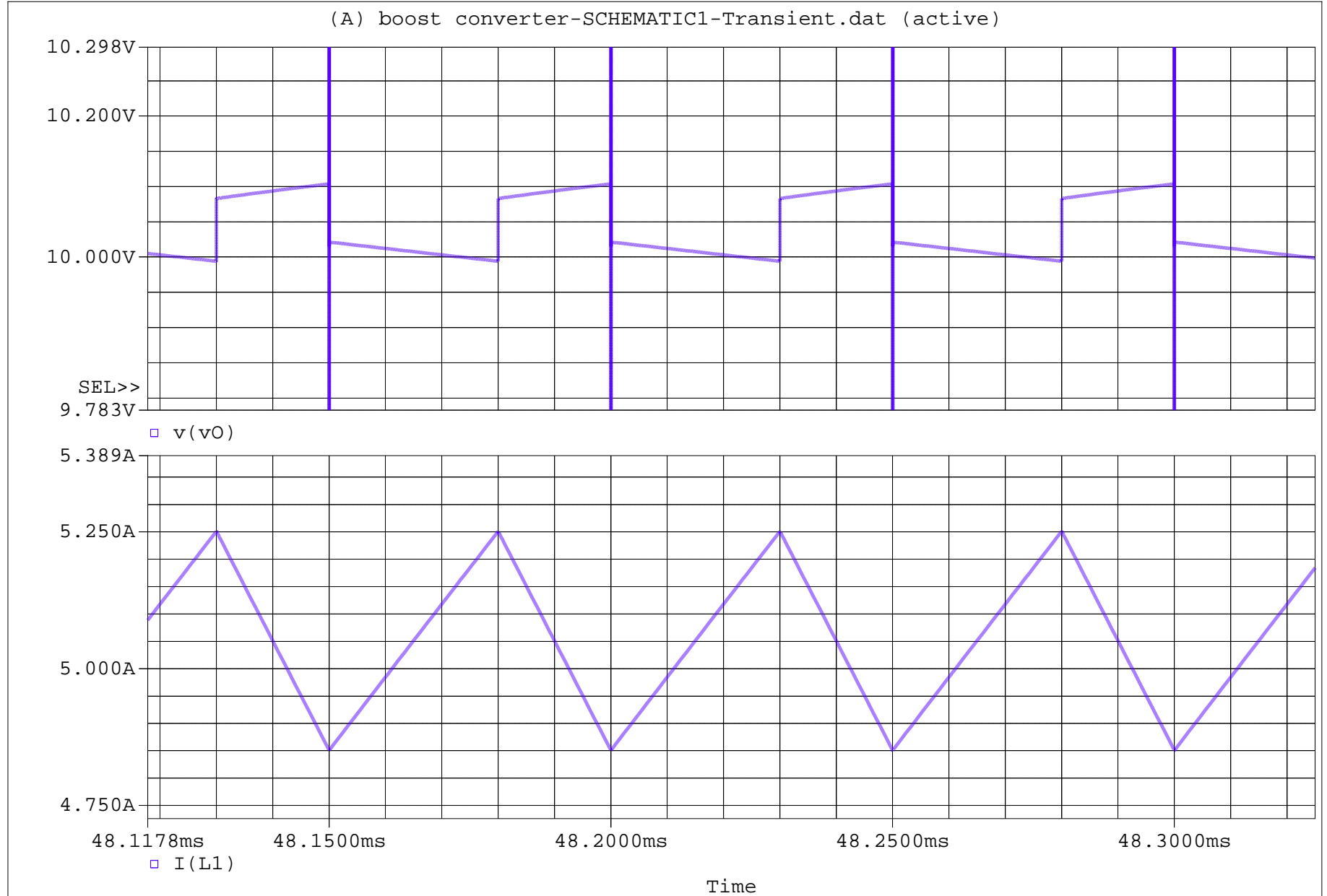


Date: December 04, 2002

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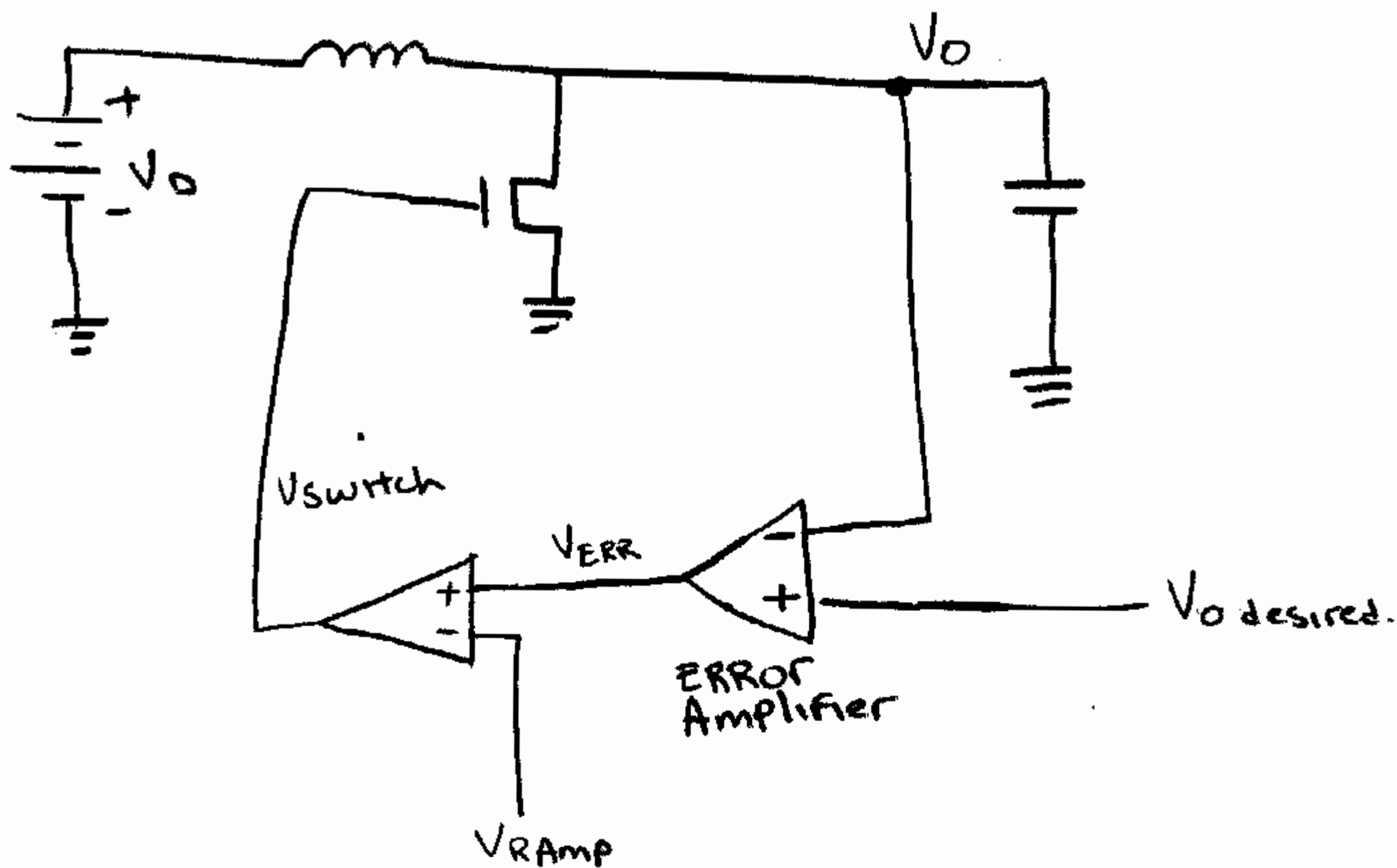


Date: December 04, 2002

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Time: 14:43:35

Pulse width modulation

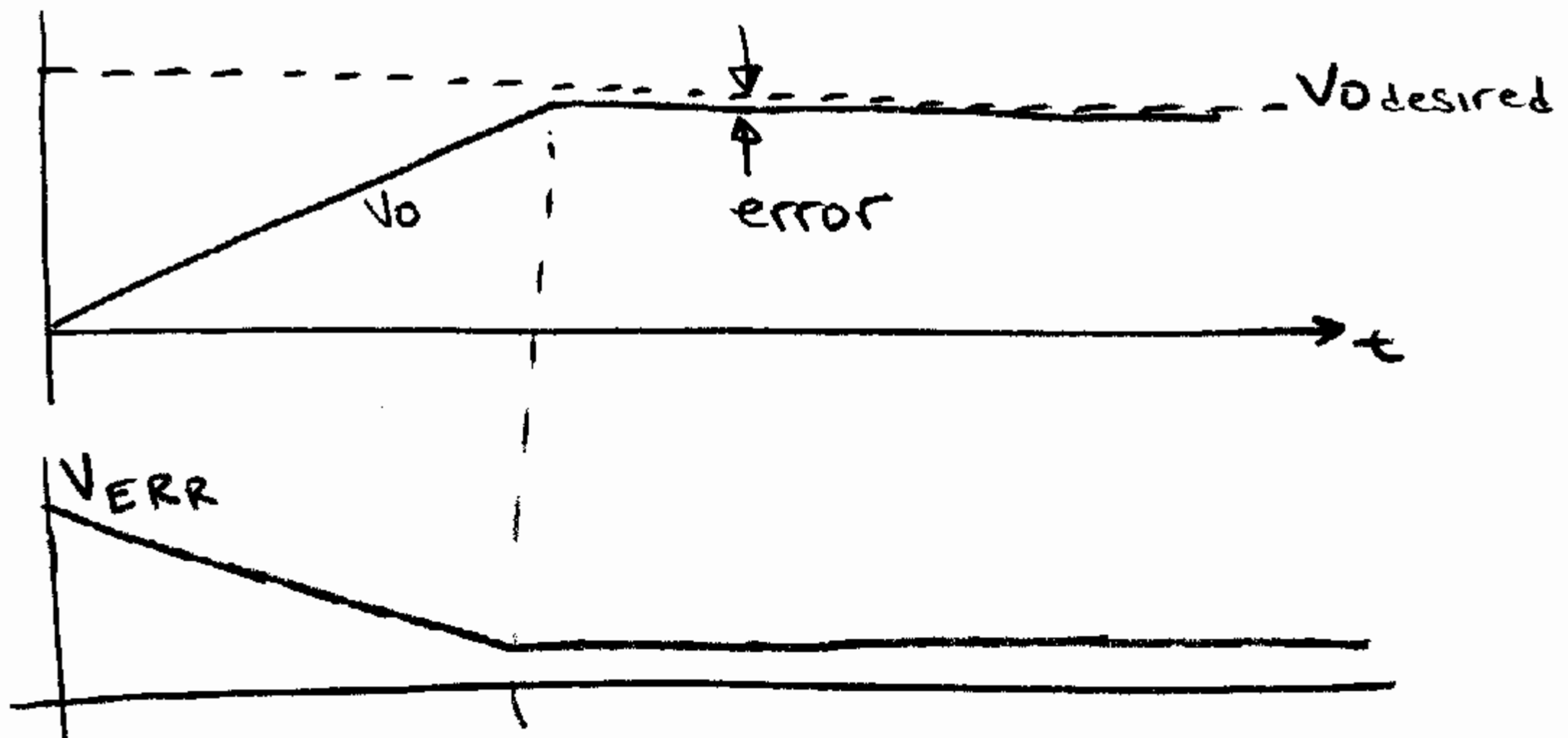


$$V_o = V_0 \left(\frac{1}{1-D} \right) = V_0 \left[\frac{T_s}{T_s - t_{on}} \right]$$

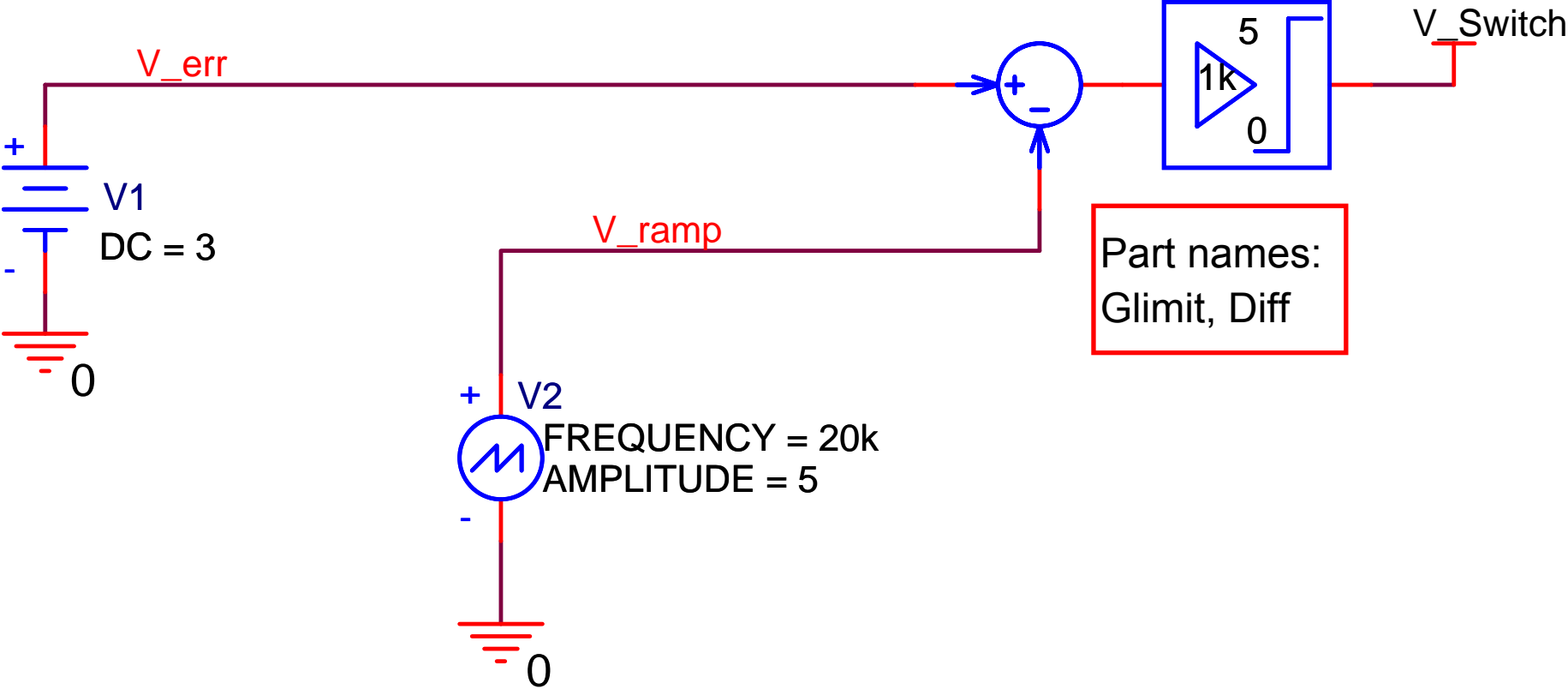
as we increase t_{on} , V_o increases.

- The error Amplifier produces a signal (V_{ERR}) that indicates how far away V_o is from $V_o \text{ desired}$.
- If V_o is far away from $V_o \text{ desired}$, the error signal is large and positive

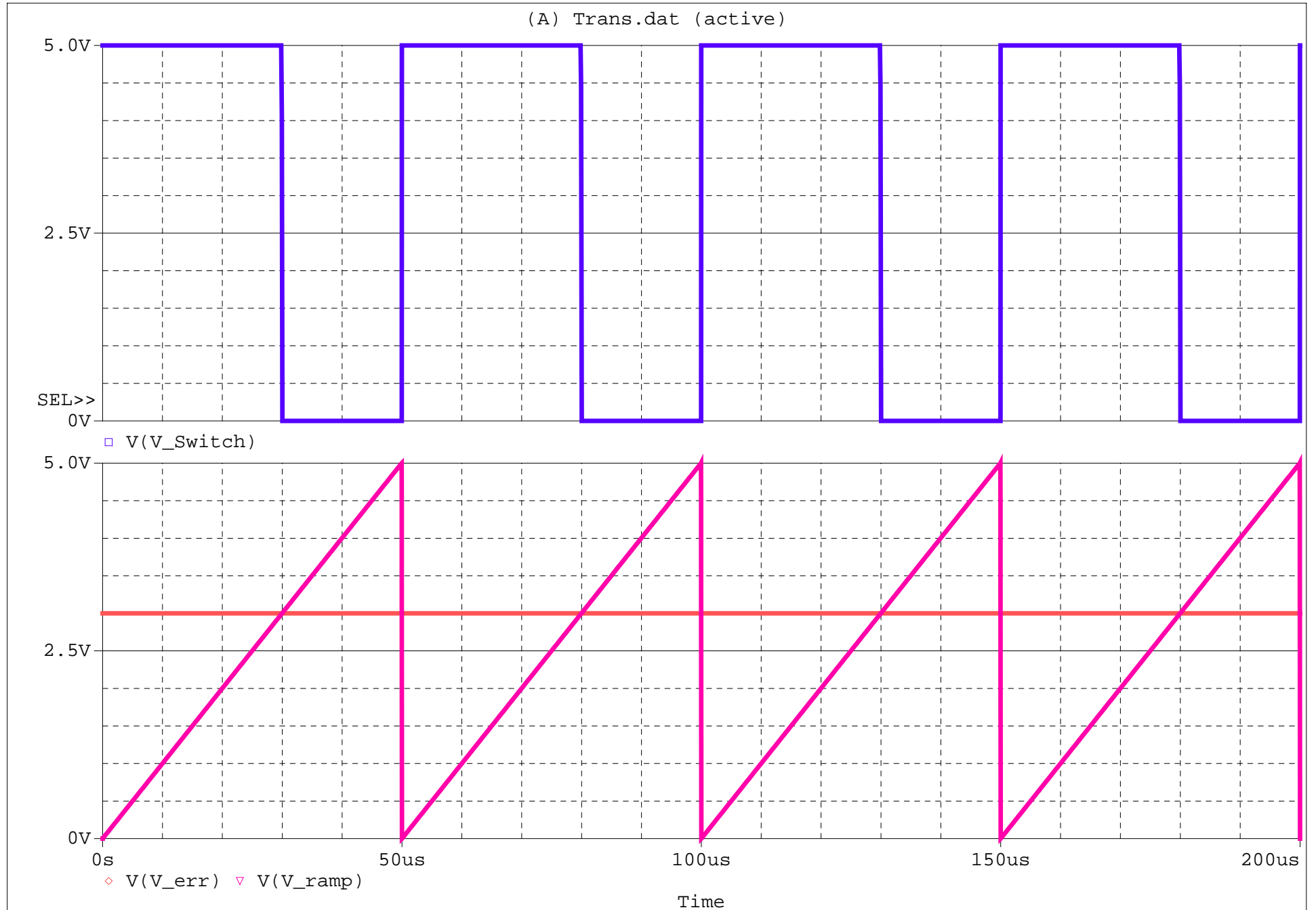
- As V_o becomes more positive and closer to, the error voltage (V_{ERR}) decreases



- The error voltage controls the comparator
- The amount of error (the difference between V_o and $V_{o\text{desired}}$) is controlled by the gain of the error amplifier
- Higher gain yields lower error

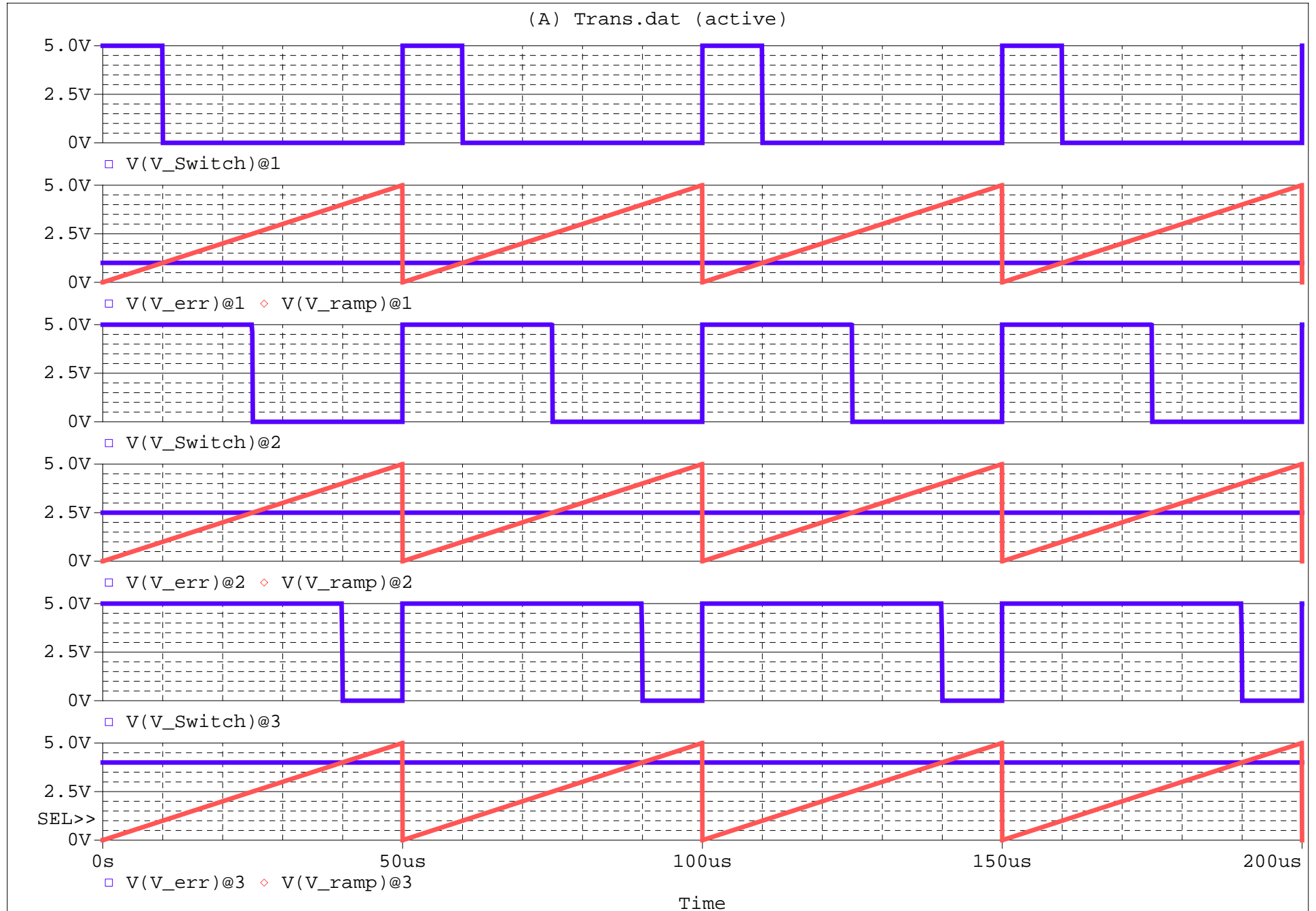


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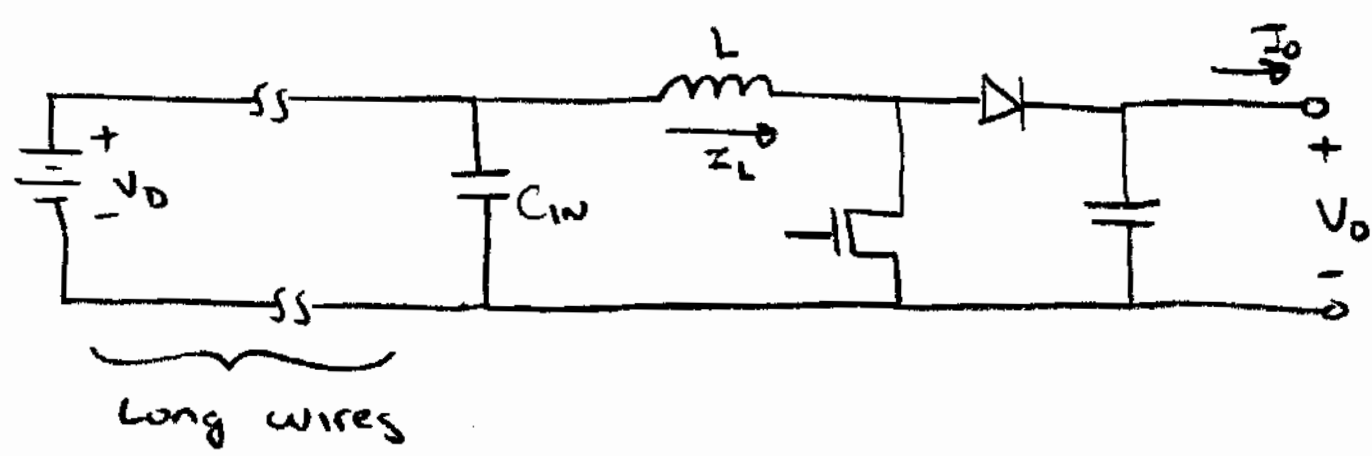


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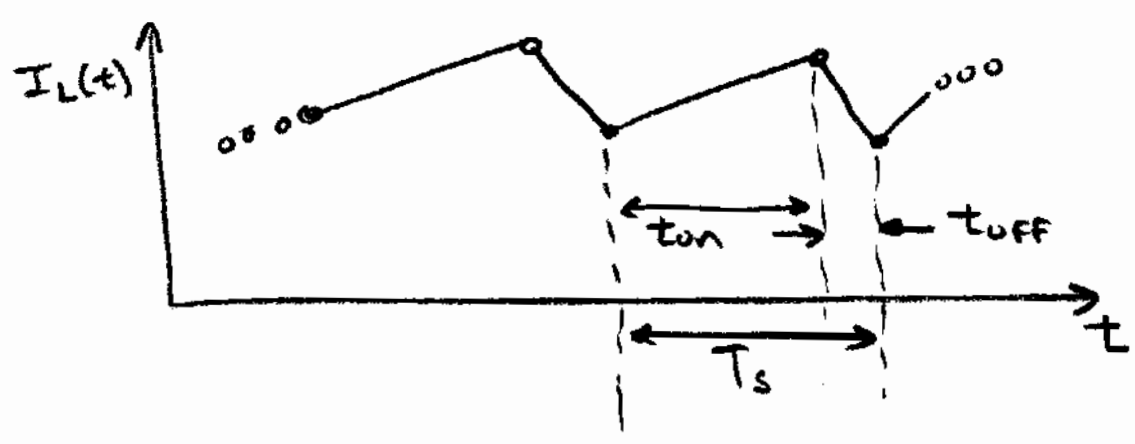
(A) Trans.dat (active)



How do we determine the size of the input capacitor for a boost regulator?

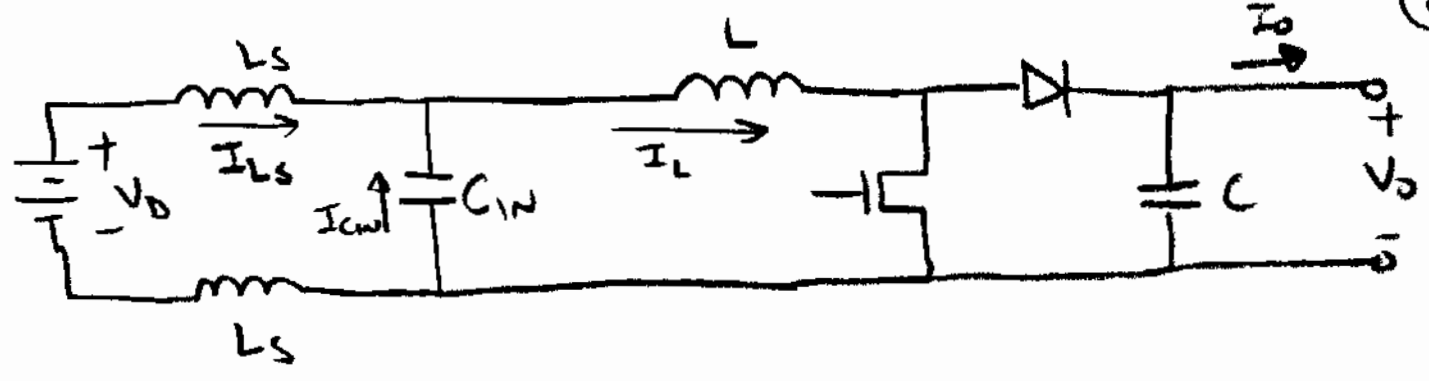


- The current through the inductor is known

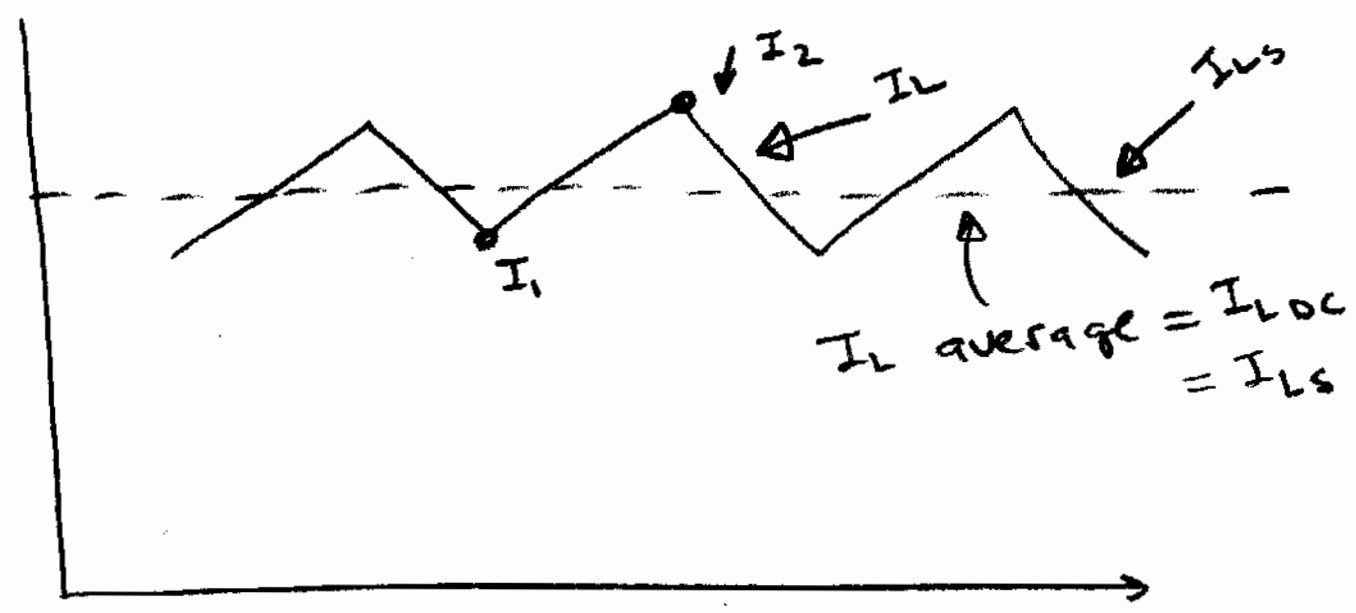


- Assume that the long wires connecting the input power supply V_D to our Boost converter can be modeled by an inductance

2



- The inductor current I_L has a DC component and an AC component
- In the worst case Assume that all of the DC current flows through L_s and all of the AC current flows through C_{in}
- KCLs $I_L = I_{Cin} + I_{Ls}$



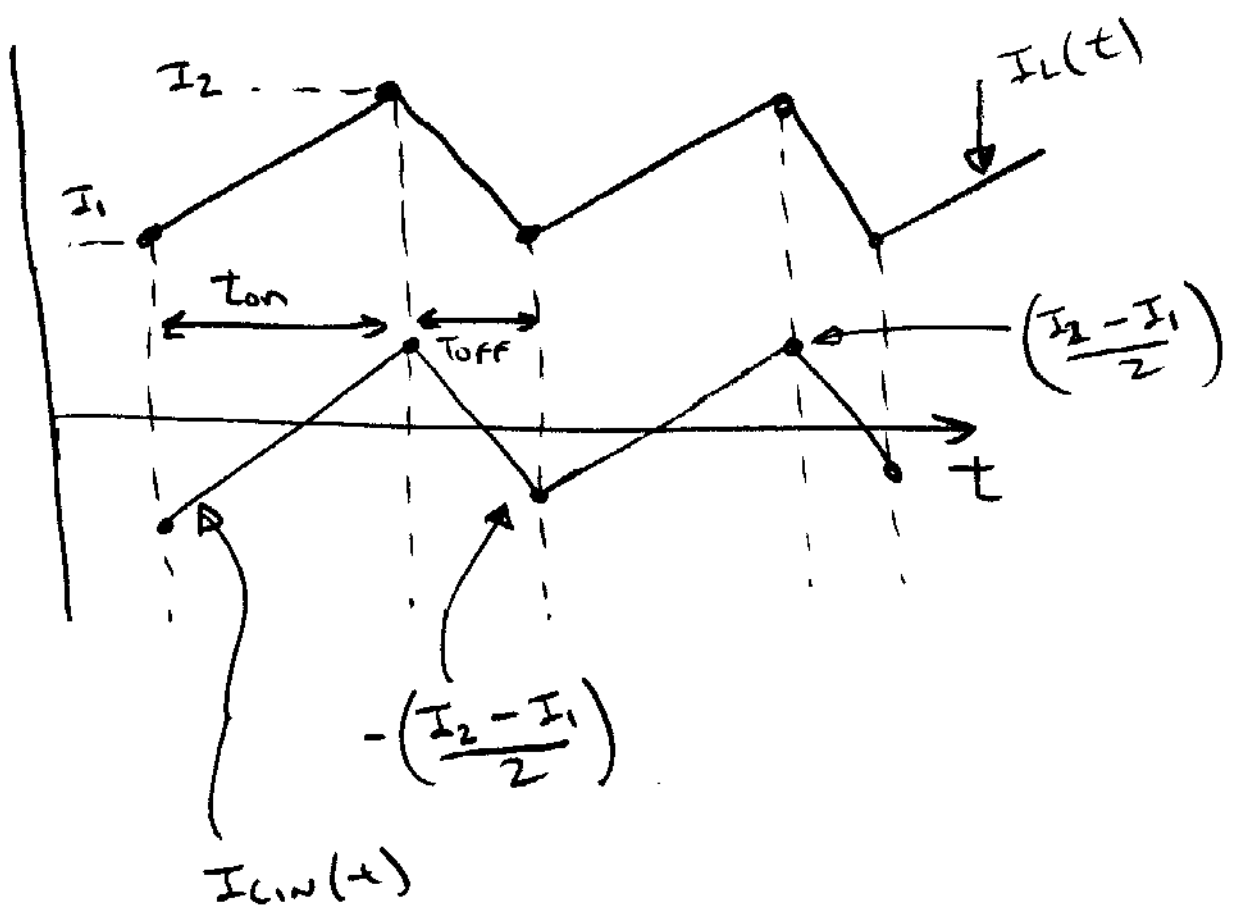
- The average current through L is also

The DC current $\langle I_L \rangle = \frac{I_1 + I_2}{2} = I_{Ls}$

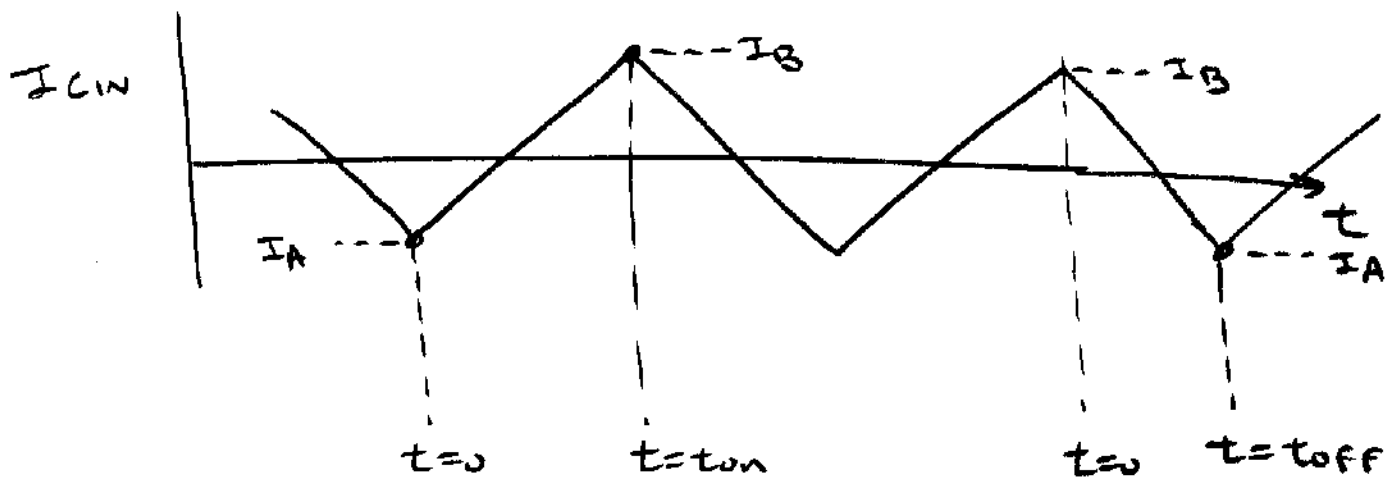
- From KCL's $I_{Cw} = I_L - I_{Ls} = I_L - \left(\frac{I_1 + I_2}{2}\right)$

$$I_{Cw}|_{max} = I_2 - \left(\frac{I_1 + I_2}{2}\right) = \left(\frac{I_2 - I_1}{2}\right)$$

$$I_{Cw}|_{min} = I_1 - \left(\frac{I_1 + I_2}{2}\right) = -\left(\frac{I_2 - I_1}{2}\right)$$



we can write an equation for the current through C_{in}



$$I_B = \frac{I_2 - I_1}{2}$$

$$I_A = -\frac{(I_2 - I_1)}{2}$$

From 0 to t_{on}

$$I_{Cin_1}(t) = I_A + m_1 t$$

$$\text{where } m_1 = \frac{I_B - I_A}{t_{on}}$$

From 0 to t_{off}

$$I_{Cin_2}(t) = I_B + m_2 t$$

$$\text{where } m_2 = \frac{I_A - I_B}{t_{off}}$$

we can calculate the Rms Cap current (5)

as

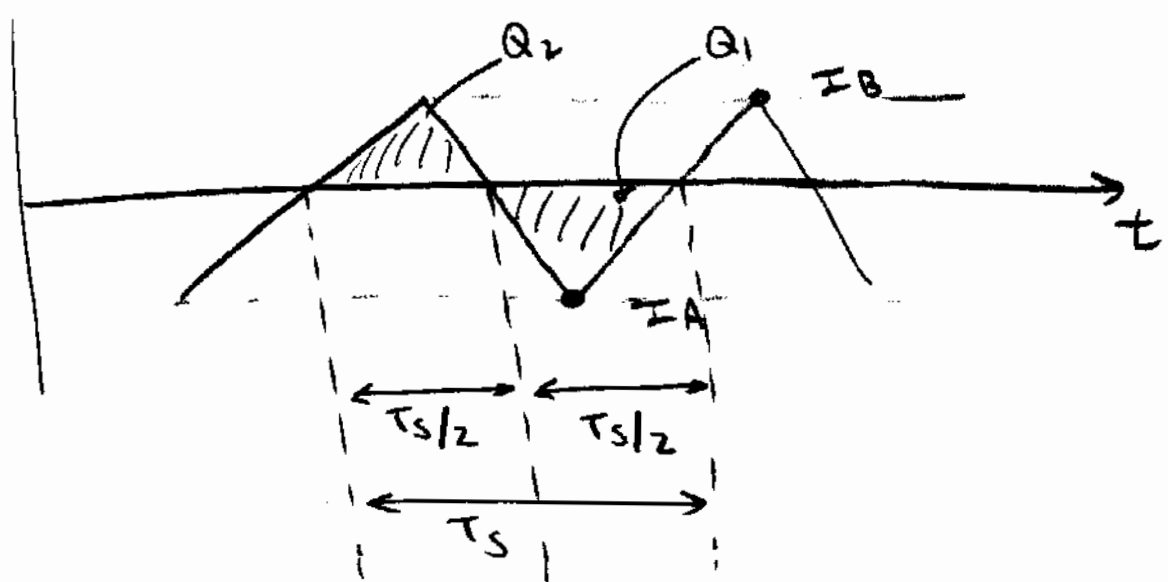
$$I_{C_{in}}|_{RMS} = \sqrt{\frac{1}{T} \int_0^T [I_{C_{in}}(t)]^2 dt}$$
$$= \sqrt{\frac{1}{T} \left[\int_0^{t_{on}} (I_{C_{in1}}(t))^2 dt + \int_0^{t_{off}} (I_{C_{in2}}(t))^2 dt \right]}$$

Ripple due to ESR

- The peak-to-peak capacitor current is $I_B - I_A$
- all of this current flows through the ESR and generates a peak-to-peak voltage

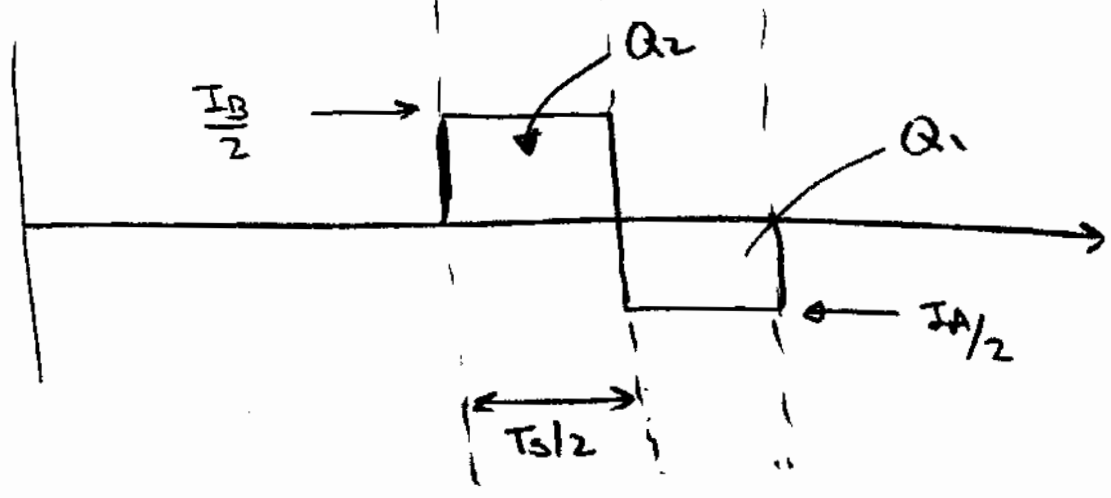
$$V_{RIPPLE}|_{ESR} = ESR(I_B - I_A) = ESR[I_2 - I_1]$$

Ripple due to Capacitor charge/discharge



If the capacitor Average Voltage Remains const,

Then $Q_2 = Q_1$



$$Q_2 = \left(\frac{I_B}{2}\right)\left(\frac{T_s}{2}\right) = \frac{I_B T_s}{4}$$

From $Q = CV \Rightarrow V = \frac{Q}{C}$

$\Rightarrow V_{Ripple} \begin{cases} \text{charge} \\ \text{Discharge} \end{cases} = \frac{Q_2}{C} = \frac{I_B T_s}{4C}$

This is the peak-to-peak ripple. During Q_2 , we add charge to the cap and the voltage increases. During Q_1 , we remove charge from the cap and the voltage returns to where it started.

Calculation of Continuous Boost Regulator Input Capacitor

Specify Currents From the Continuous Boost Regulator Design

$$I_1 := 4 \cdot \text{amp} \quad I_2 := 6 \cdot \text{amp}$$

Calculate the capacitor peak current. Assume that all of the inductor ripple current flows through capacitor.

$$I_A := I_1 - \frac{(I_1 + I_2)}{2} \quad I_B := I_2 - \frac{(I_1 + I_2)}{2}$$

$$I_A = -1 \text{ A}$$

$$I_B = 1 \text{ A}$$

$$\mu\text{s} := 10^{-6} \cdot \text{sec}$$

Specify the frequency and on time

$$F_S := 20 \cdot \text{kHz} \quad T_S := \frac{1}{F_S}$$

$$D := 80\% \quad t_{\text{on}} := D \cdot T_S \quad t_{\text{off}} := T_S - t_{\text{on}}$$

$$t_{\text{on}} = 40 \mu\text{s} \quad t_{\text{off}} = 10 \mu\text{s}$$

Define a time dunction for the capacitor during the on time. Assume that at $t=0$, the current is I_A . At $t=t_{on}$, the current is I_B .

$$m_1 := \frac{I_B - I_A}{t_{on}}$$

$$I_{Con}(t) := I_A + m_1 \cdot t$$

Define a time dunction for the capacitor during the off time. Assume that at $t=0$, the current is I_B . At $t=t_{off}$, the current is I_A .

$$m_2 := \frac{I_A - I_B}{t_{off}}$$

$$I_{Coff}(t) := I_B + m_2 \cdot t$$

Calculate the Capacitor RMS Ripple current

$$I_{Crms} := \sqrt{\frac{1}{T_S} \cdot \left[\int_{0 \cdot \text{sec}}^{t_{on}} (I_{Con}(t))^2 dt + \int_0^{t_{off}} (I_{Coff}(t))^2 dt \right]}$$

$$I_{Crms} = 0.577 \text{ A}$$

Calculate the capacitor peak-to-peak ripple voltage due to ESR.

Specify the ripple due to the ESR $V_{CR} := 200 \cdot \text{mV}$

$$\text{ESR} := \frac{V_{CR}}{I_B - I_A} \quad \text{ESR} = 0.1 \Omega$$

For all electrolytic caps, assume that $\text{ESR} \cdot C = 80 \mu\text{s}$

$$C := \frac{80 \cdot \mu\text{s}}{\text{ESR}} \quad C = 800 \mu\text{F}$$

Assume a capacitor tolerance of -20%, +80%

$$C_{\text{act}} := \frac{C}{0.8} \quad C_{\text{act}} = 1 \times 10^3 \mu\text{F}$$

Choose the next size std capacitor $C := 1000 \cdot \mu\text{F}$

Calculate the ripple with the chosen capacitor value using the nominal capacitor value.

$$\text{ESR} := \frac{80 \cdot \mu\text{s}}{C} \quad \text{ESR} = 0.08 \Omega$$

$$V_{\text{CRact}} := \text{ESR} \cdot (I_B - I_A) \quad V_{\text{CRact}} = 160 \text{mV}$$

Now choose the capacitor based on the ripple voltage due to charge being removed from the cap while the switch is on and the capacitor is sourcing current to the load.

Specify the amount of ripple allowed $V_{CR} := 200 \cdot \text{mV}$

Calculate the amount of charge added to the cap when the ripple current is positive.

$$\Delta q := \frac{T_S \cdot I_B}{4}$$

Calculate the capacitor needed from $q = CV$.

$$C := \frac{\Delta q}{V_{CR}} \quad C = 62.5 \mu\text{F}$$

Assume a capacitor tolerance of -20%, +80%

$$C_{\text{act}} := \frac{C}{0.8} \quad C_{\text{act}} = 78.125 \mu\text{F}$$

Choose the next size std capacitor $C := 1000 \cdot \mu\text{F}$

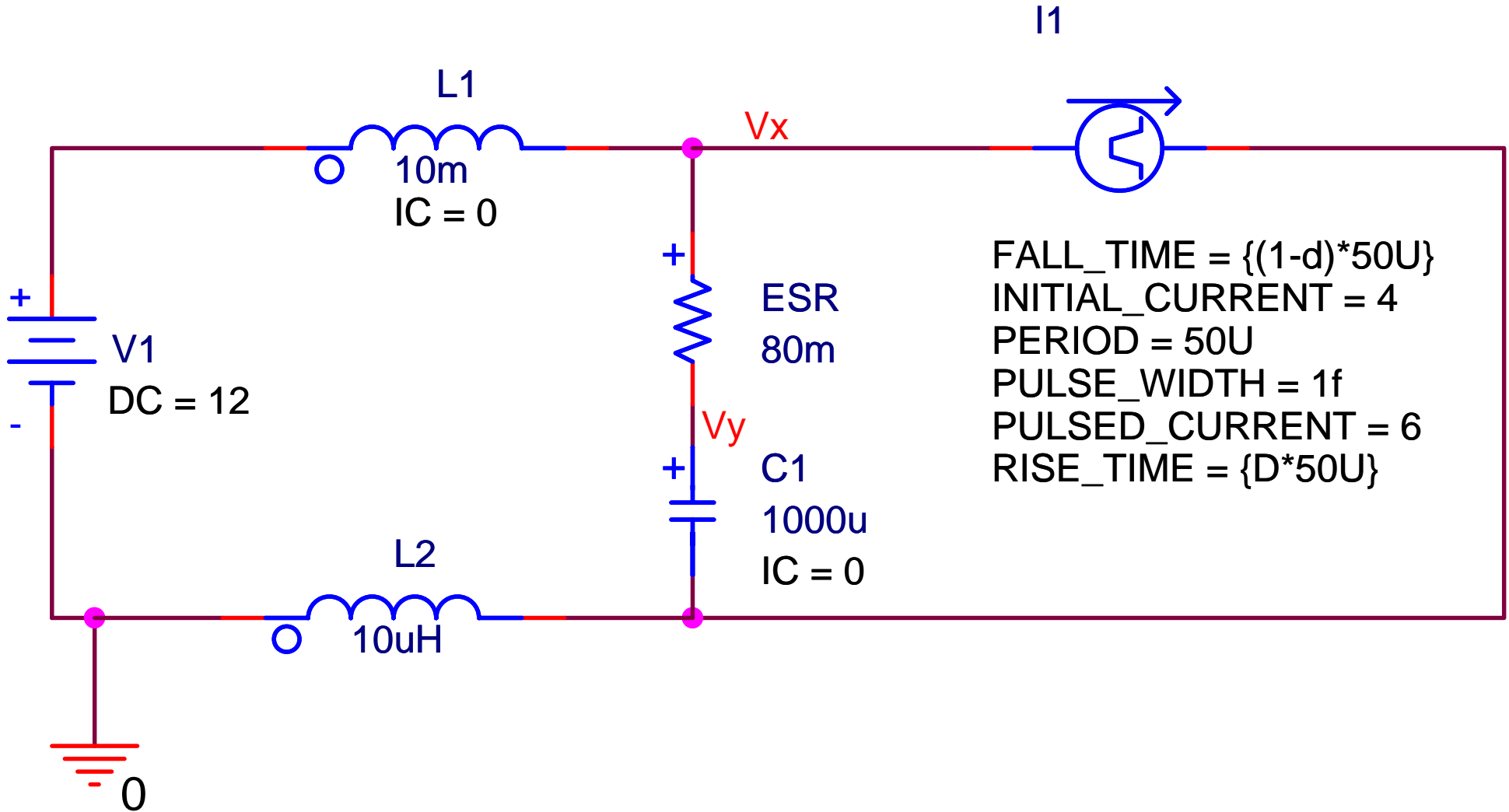
Calculate the ripple with the chosen capacitor.

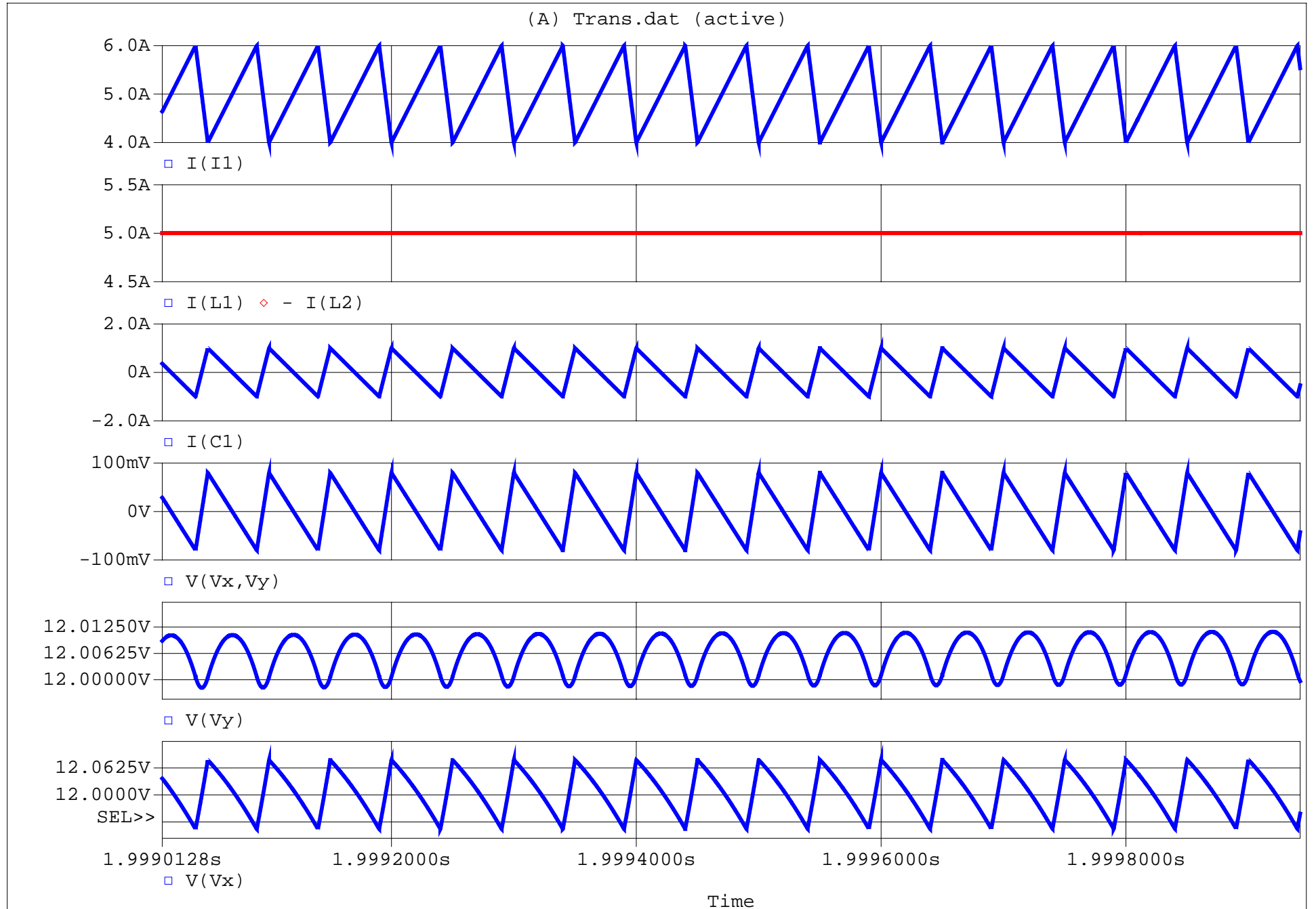
$$V_{CR\text{act}} := \frac{\Delta q}{C} \quad V_{CR\text{act}} = 12.5 \text{mV}$$

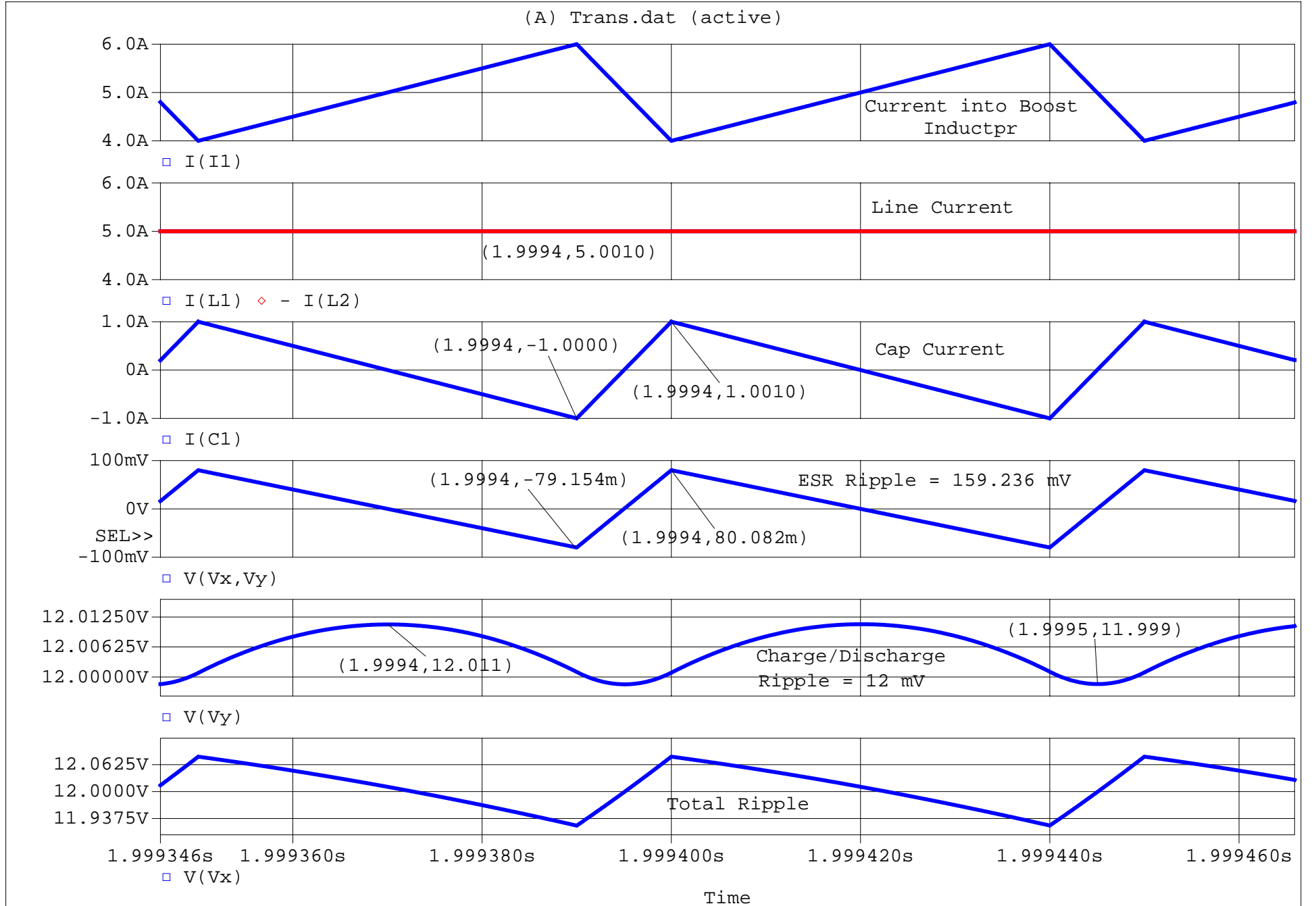
Note that this is the peak-to-peak ripple due to the cap charging and discharging.

PARAMETERS:

$D = 0.8$

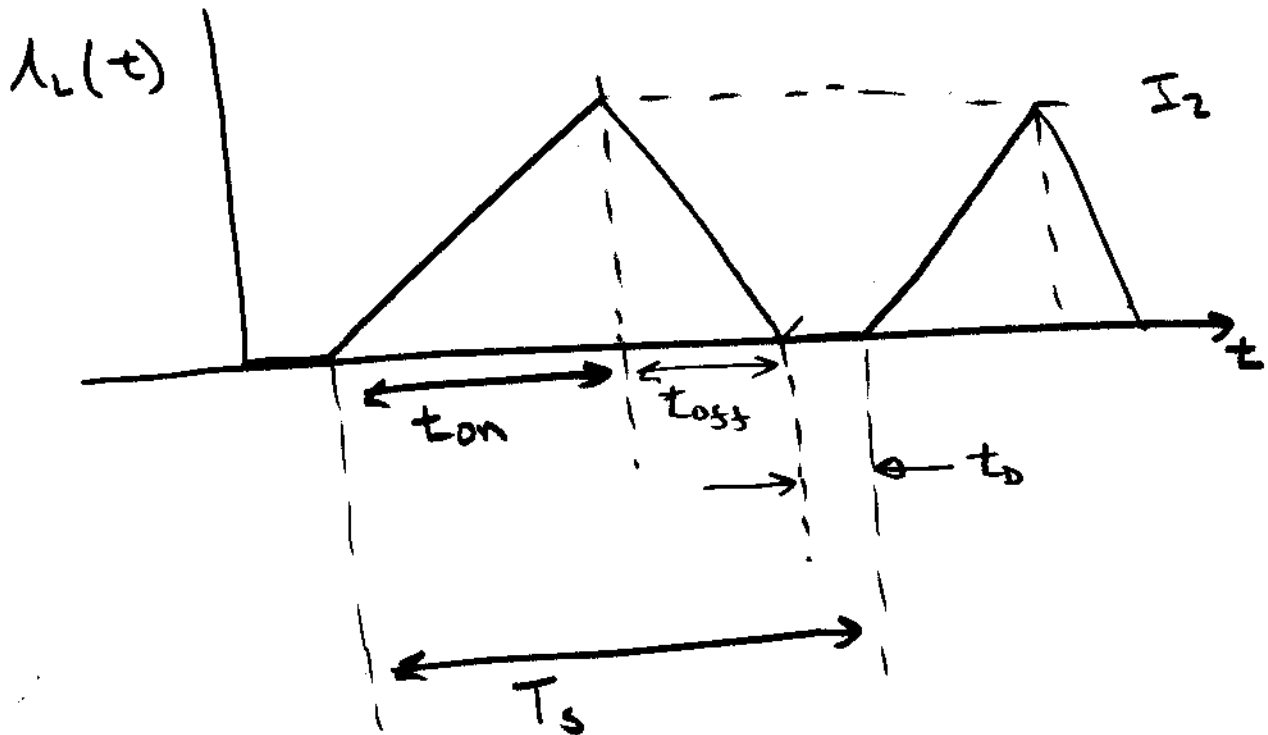
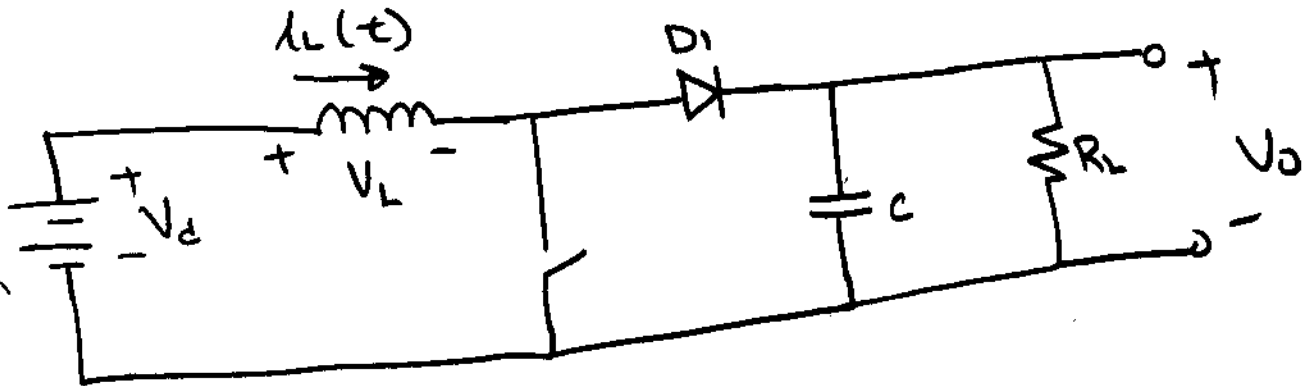




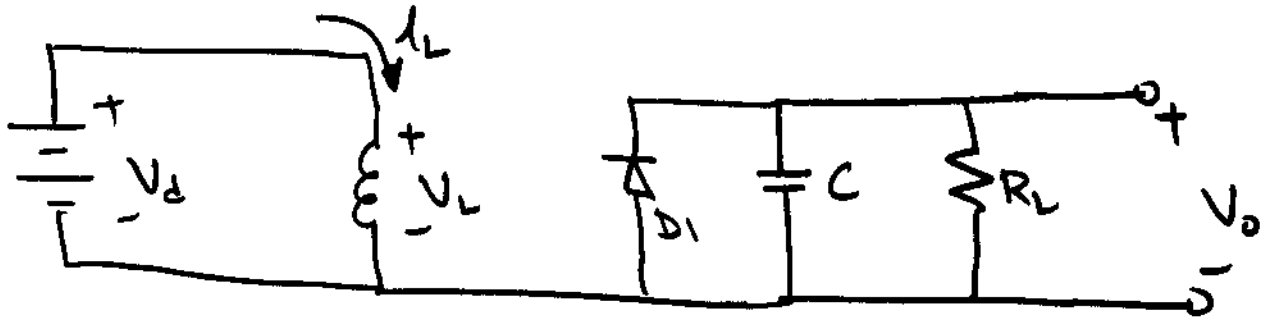


Boost Regulator

Discontinuous mode


 $t_0 = \text{dead Time}$

During t_{on} we have



C supplies power to R_L

$D1 = \text{off}$

$V_L = V_d$

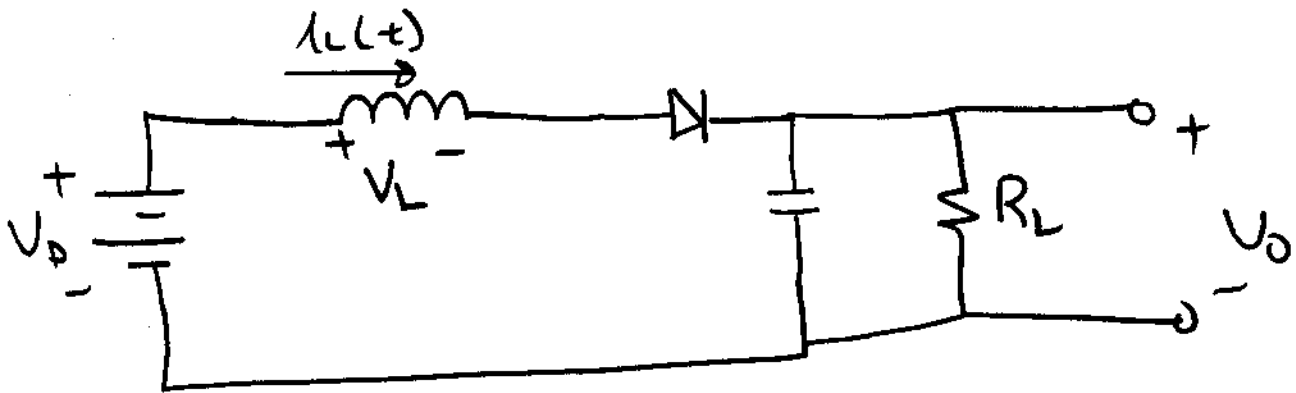
For the inductor: $V_L = L \frac{di_L(t)}{dt}$

$$i_L(t) = \frac{1}{L} \int_0^{t_{on}} V_L(t) dt$$

OR

$$I_2 = \frac{V_d t_{on}}{L} \quad (1)$$

During t_{off} we have



- Diode is ideal

- $D_1 = \text{ON}$

- $V_L = V_d - V_o$; $V_L < 0 \Rightarrow i_L(t) \downarrow$

For the inductor: $V_L = L \frac{di_L(t)}{dt}$

$$i_L(t) = \frac{1}{L} \int V_L(t) dt + I_a$$

OR

$$0 = \frac{1}{L} \int_{t_{\text{on}}}^{t_{\text{on}} + t_{\text{off}}} (V_d - V_o) dt + I_a$$

$$\text{OR } I_a = \frac{V_o - V_d}{L} t_{\text{off}} \quad (2)$$

To ensure discontinuous mode
 Choose $t_d = 0.2 T_s$

$$\Rightarrow \boxed{t_{on} + t_{off} \leq 0.8 T_s} \quad (3)$$

Power balance: Avg power delivered
 by source

$$P_D = V_d \langle i_L \rangle$$

During $t_{on} + t_{off}$ $\langle \hat{i}_L \rangle = \frac{I_2}{2}$
 so over T_s

$$\langle i_L \rangle = \langle \hat{i}_L \rangle \frac{(t_{on} + t_{off})}{T_s}$$

$$= \frac{I_2}{2} \left[\frac{t_{on} + t_{off}}{T_s} \right]$$

OR

$$P_D = \frac{V_d I_2}{2} \left[\frac{t_{on} + t_{off}}{T_s} \right]$$

and from equation ①, $I_2 = \frac{V_d t_{on}}{L}$

$$P_D = \frac{V_d^2 t_{on}}{2LT_s} [t_{on} + t_{off}]$$

Output power $P_o = V_o I_o$

so $P_o = P_D$

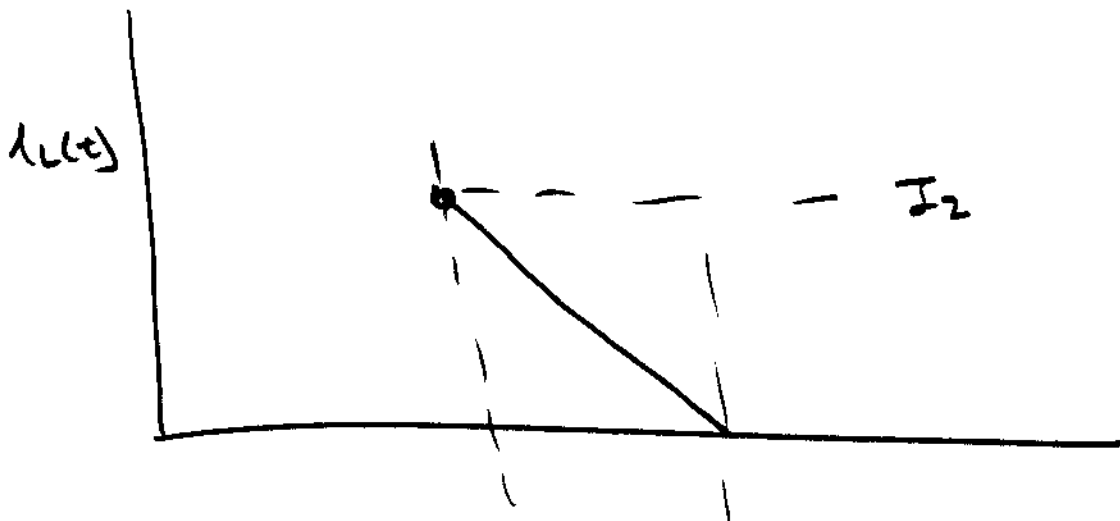
$$V_o = \frac{V_d^2 t_{on}}{2LT_s I_o} [t_{on} + t_{off}] \quad \text{④}$$

Energy balance

- Energy dissipated in Load for Entire cycle

$$E_o = V_o I_o T_s$$

DURING Loss



- all energy stored in L is delivered to Load
- Source V_d delivers energy to Load

$$E_L = \frac{1}{2} L I_2^2$$

$$I_2 = \frac{V_d t_{on}}{L}$$

$$\Rightarrow E_L = \frac{1}{2L} V_d^2 t_{on}^2$$

Now Find Energy delivered by the source

$$E_s = V_d \langle I_d \rangle t_{loss}$$

$$\langle I_d \rangle = \frac{I_2}{2} = \frac{V_d t_{on}}{2L}$$

so

$$E_s = V_d \langle I_d \rangle t_{off} = \frac{V_d^2 t_{on}}{2L} t_{off}$$

so for energy balance

$$E_L + E_s = E_o$$

$$\frac{1}{2L} V_d^2 t_{on}^2 + \frac{1}{2L} V_d^2 t_{on} t_{off} = V_o I_o T_s$$

OR

$$\frac{1}{2L} V_d^2 t_{on} [t_{on} + t_{off}] = V_o I_o T_s$$

Same as power balance.

Boost Regulator Summary

Discontinuous mode

$$\left. \begin{aligned} I_a &= \frac{V_d t_{on}}{L} \\ I_a &= \left(\frac{V_o - V_d}{L} \right) t_{off} \end{aligned} \right\} \frac{t_{on}}{t_{off}} = \frac{V_o - V_d}{V_d}$$

$$t_{on} + t_{off} \leq 0.8 T_s$$

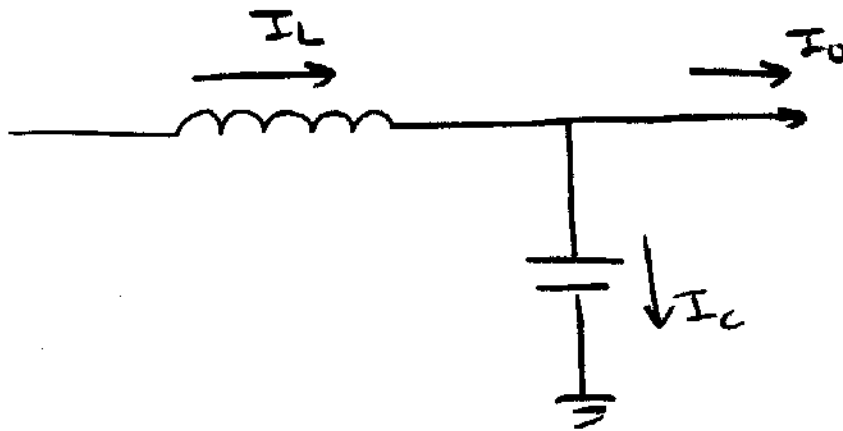
$$V_o = \frac{V_d^2 t_{on}}{2L T_s I_o} \left[t_{on} + t_{off} \right]$$

$$I_o \leq \left(\frac{V_d t_{on}}{2L} \right) \left(\frac{V_d}{V_o} \right) \quad \text{for discontinuous mode}$$

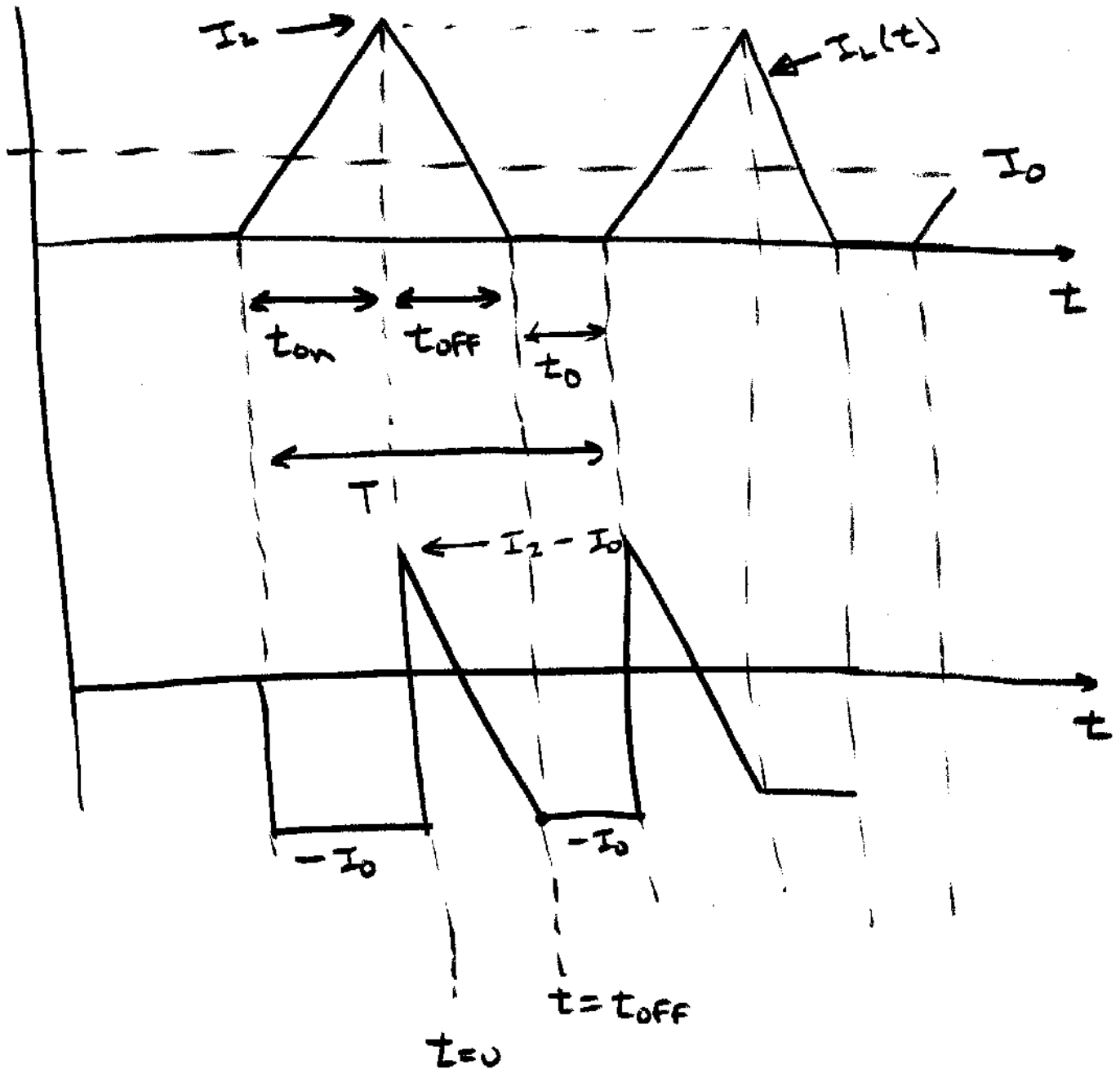
Boost Converter Discontinuous mode

Capacitor RMS Ripple Current

- During t_{on} and t_{dead} , the capacitor must supply current to the output ($I_c = -I_o$)
- During t_{off} , current flows through the inductor and supplies the output current and charges the capacitor



$$I_c = I_L - I_o$$



- During $0 \leq t \leq t_{OFF}$ $I_L(t) = I_2 \left[1 - \frac{t}{t_{OFF}} \right]$

and $I_c = I_L(t) - I_0$

- During other times

$$I_c = -I_0$$

$$I_{C_{Rms}} = \sqrt{\frac{1}{T_s} \left[\int_0^{t_{on} + t_o} (-I_o)^2 dt + \int_0^{t_{off}} (I_L(t) - I_o)^2 dt \right]}$$

EE 456

Boost Regulator Design - Discontinuous Mode Operation

Specify Output Voltage $V_o := 10 \cdot \text{volt}$ $\mu\text{S} \equiv 10^{-6} \cdot \text{sec}$

Specify Input Voltage $V_D := 5 \cdot \text{volt}$

Specify Switching Frequency $F_S := 20 \cdot \text{kHz}$

$$T_S := \frac{1}{F_S} \quad T_S = 5 \times 10^{-5} \text{ sec}$$

Specify the Max Output Power and Efficiency $P_{\text{out}} := 20 \cdot \text{watt}$ $\text{Eff} := 100 \cdot \%$

Calculated the power for the design

$$P_{\text{design}} := \frac{P_{\text{out}}}{\text{Eff}} \quad P_{\text{design}} = 20 \text{ watt}$$

Calculate the output current

$$I_{\text{out}} := \frac{P_{\text{design}}}{V_o} \quad I_{\text{out}} = 2 \text{ amp}$$

Find T_{on} and T_{off}

$$T_{\text{off}} := 1 \cdot \text{sec} \quad T_{\text{on}} := 1 \cdot \text{sec}$$

Given

$$\frac{T_{\text{on}}}{T_{\text{off}}} = \frac{V_o - V_D}{V_D}$$

$$T_{\text{on}} + T_{\text{off}} = 0.8 \cdot T_S$$

$$\begin{pmatrix} T_{\text{on}} \\ T_{\text{off}} \end{pmatrix} := \text{Find}(T_{\text{on}}, T_{\text{off}})$$

$$T_{\text{on}} = 19 \mu\text{S}$$

$$T_{\text{off}} = 19 \mu\text{S}$$

$$T_{\text{dead}} := T_S - T_{\text{on}} - T_{\text{off}}$$

$$T_{\text{dead}} = 12 \mu\text{S}$$

Find the range of Inductors that will operate in discontinuous mode

$$L := \frac{V_D \cdot T_{\text{on}}}{2 \cdot I_{\text{out}}} \cdot \frac{V_D}{V_o}$$

For Discontinuous Mode, We need L less than

$$L = 11.875 \mu\text{H}$$

Find the inductor Value

$$L := \frac{V_D^2 \cdot T_{\text{on}}}{2 \cdot V_o \cdot T_S \cdot I_{\text{out}}} \cdot (T_{\text{on}} + T_{\text{off}})$$

$$L = 9.025 \mu\text{H}$$

Choose a standard size inductor

$$L := 10 \mu\text{H}$$

Coilcraft PCV-1-103-10

Find the peak current

$$I_2 := V_D \cdot \frac{T_{\text{on}}}{L} \quad I_2 = 9.5 \text{ amp}$$

Choose the filter capacitor.

Assume that the major component of the ripple comes from the capacitor ESR

Specify the ripple due to the ESR

$$V_{\text{RR}} := 100 \cdot \text{mV}$$

$$\text{ESR} := \frac{V_{\text{RR}}}{(I_2)} \quad \text{ESR} = 0.01053 \Omega$$

For all electrolytic caps, assume that $\text{ESR} \cdot C = 80 \mu\text{s}$

$$C := \frac{80 \cdot 10^{-6} \cdot \text{sec}}{\text{ESR}} \quad C = 7600 \mu\text{F}$$

Choose the next size std capacitor

$$C := 8200 \cdot \mu\text{F}$$

$$\text{ESR} := \frac{80 \cdot 10^{-6} \cdot \text{sec}}{C}$$

Calculate the new ESR with the chosen capacitor

$$\text{ESR} = 9.756 \times 10^{-3} \Omega$$

Calculate the Capacitor RMS Ripple Current

$$I_L(t) := I_2 \cdot \left(1 - \frac{t}{T_{\text{off}}} \right)$$

$$I_{\text{rms}} := \sqrt{\frac{1}{T_S} \cdot \left[\int_{0 \cdot \text{sec}}^{T_{\text{on}} + T_{\text{dead}}} I_{\text{out}}^2 dt + \int_{0 \cdot \text{sec}}^{T_{\text{off}}} (I_L(t) - I_{\text{out}})^2 dt \right]}$$

$$I_{\text{rms}} = 2.866 \text{ amp}$$

Summary

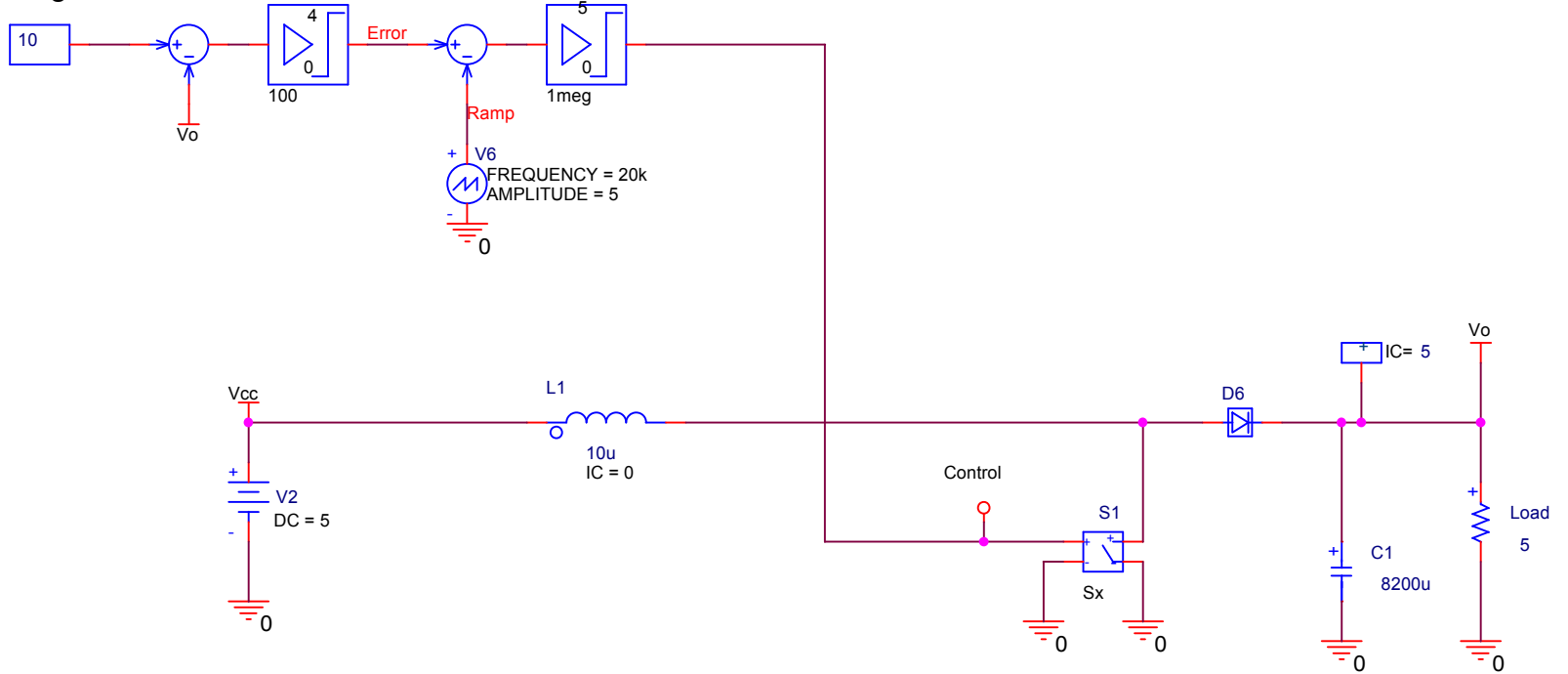
$$L = 10 \mu\text{H} \quad I_2 = 9.5 \text{ amp}$$

$$T_{\text{on}} = 19 \mu\text{S} \quad T_{\text{off}} = 19 \mu\text{S}$$

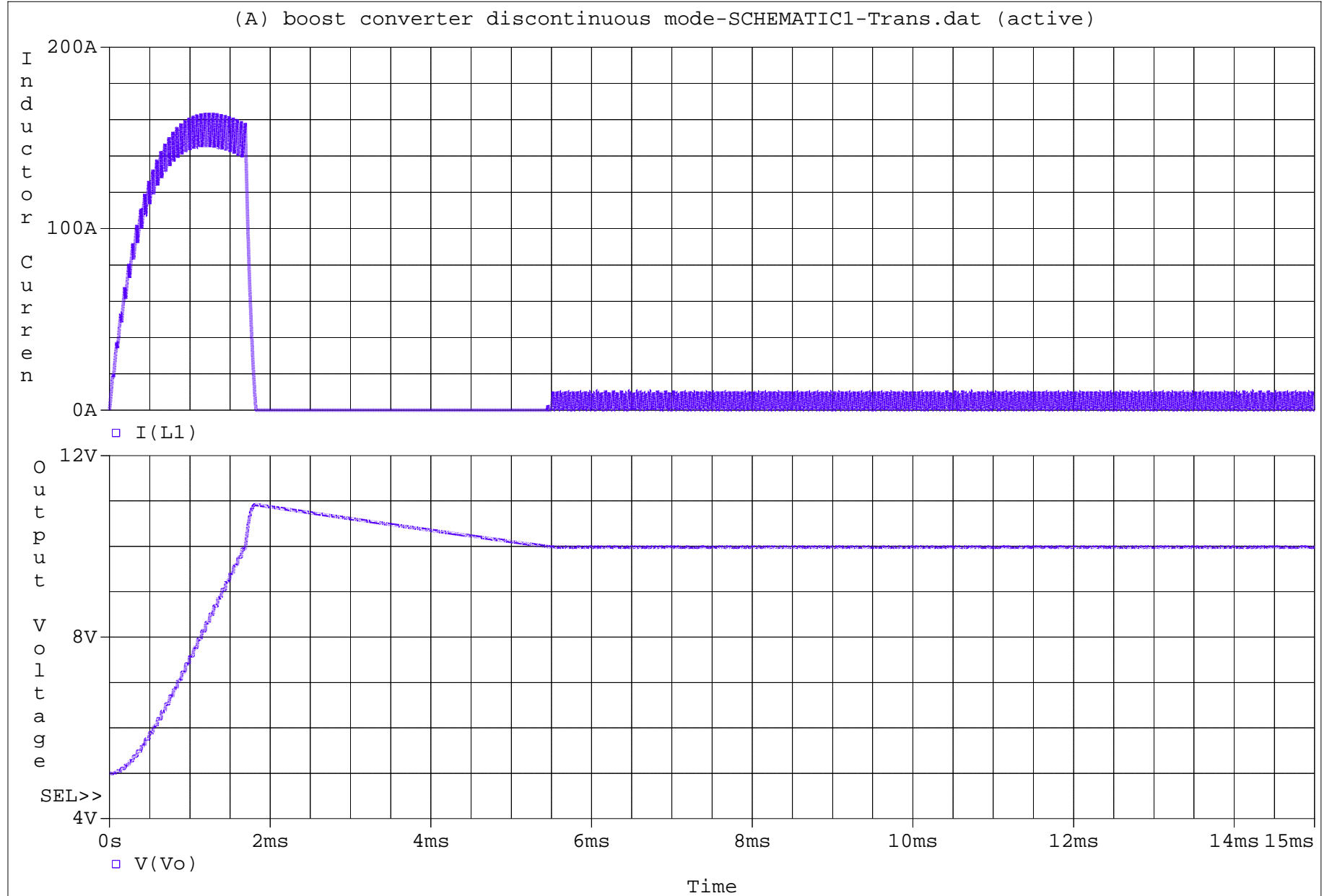
$$V_D = 5 \text{ volt} \quad V_O = 10 \text{ volt} \quad I_{\text{out}} = 2 \text{ amp}$$

$$C = 8.2 \times 10^3 \mu\text{F} \quad V_{\text{RR}} = 100 \text{ mV} \quad I_{\text{rms}} = 2.866 \text{ amp}$$

$$\text{Cap Voltage } \forall V_O = 10 \text{ volt}$$



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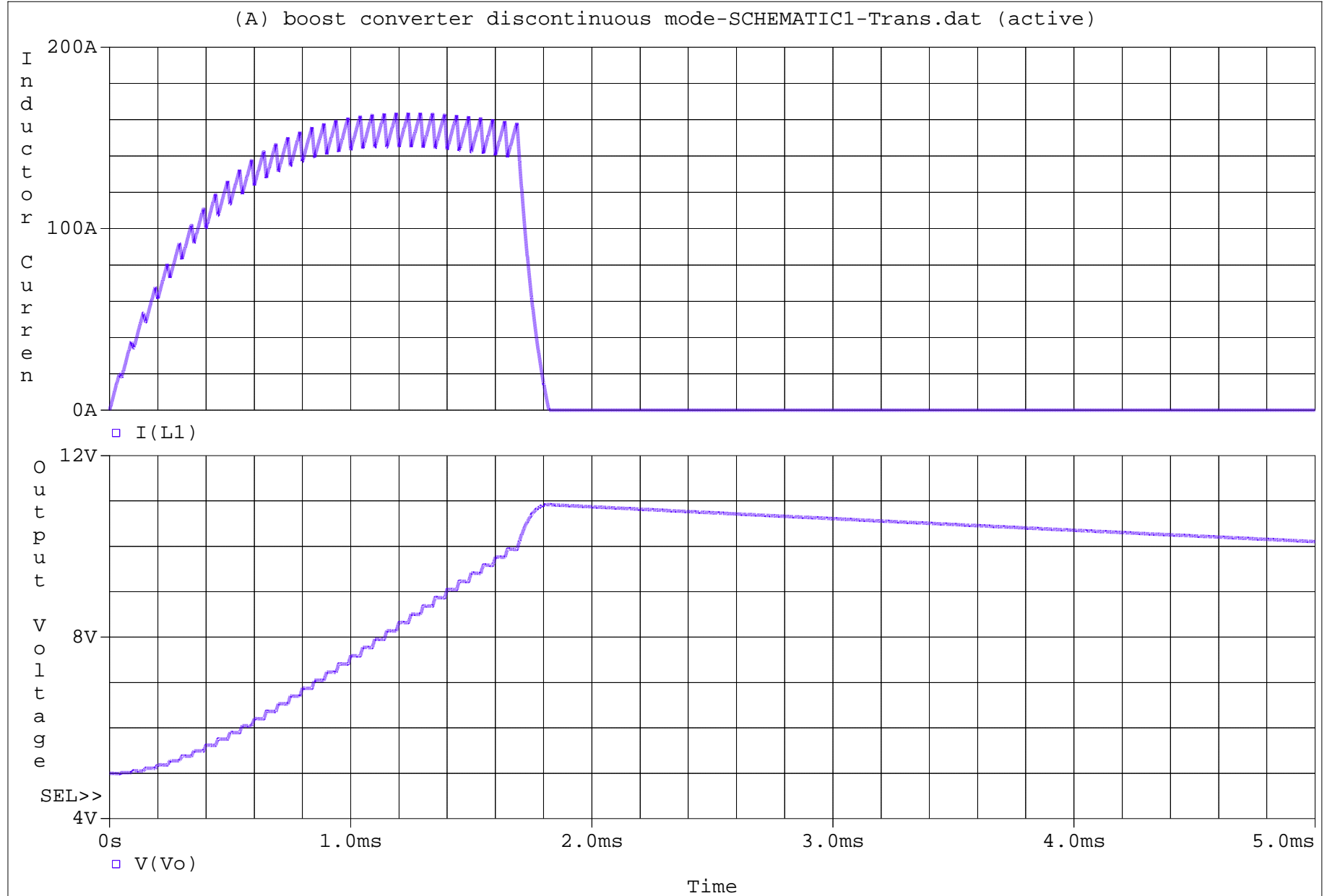


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Page 1

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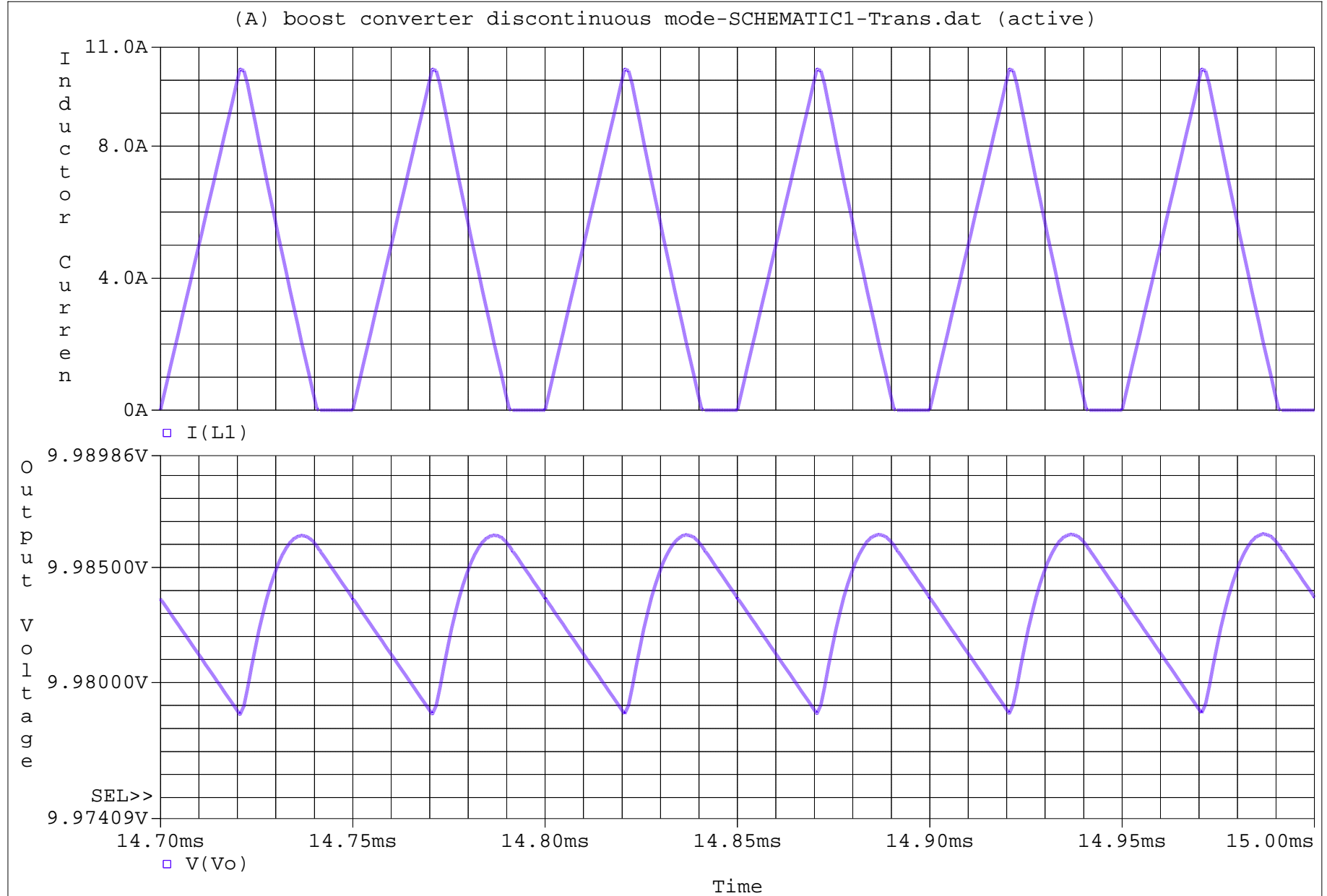


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Page 1

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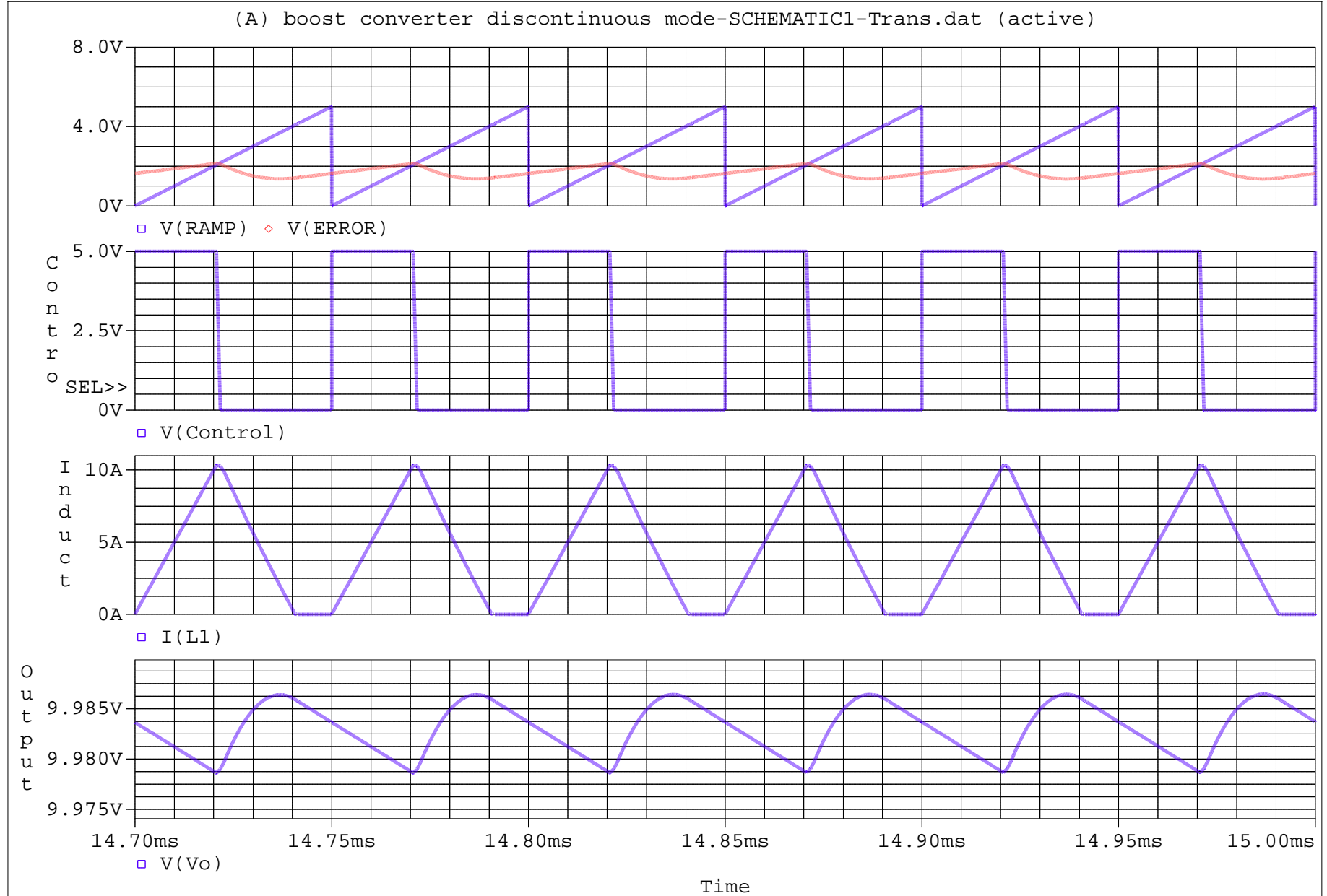


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Page 1

Time: 12:35:22

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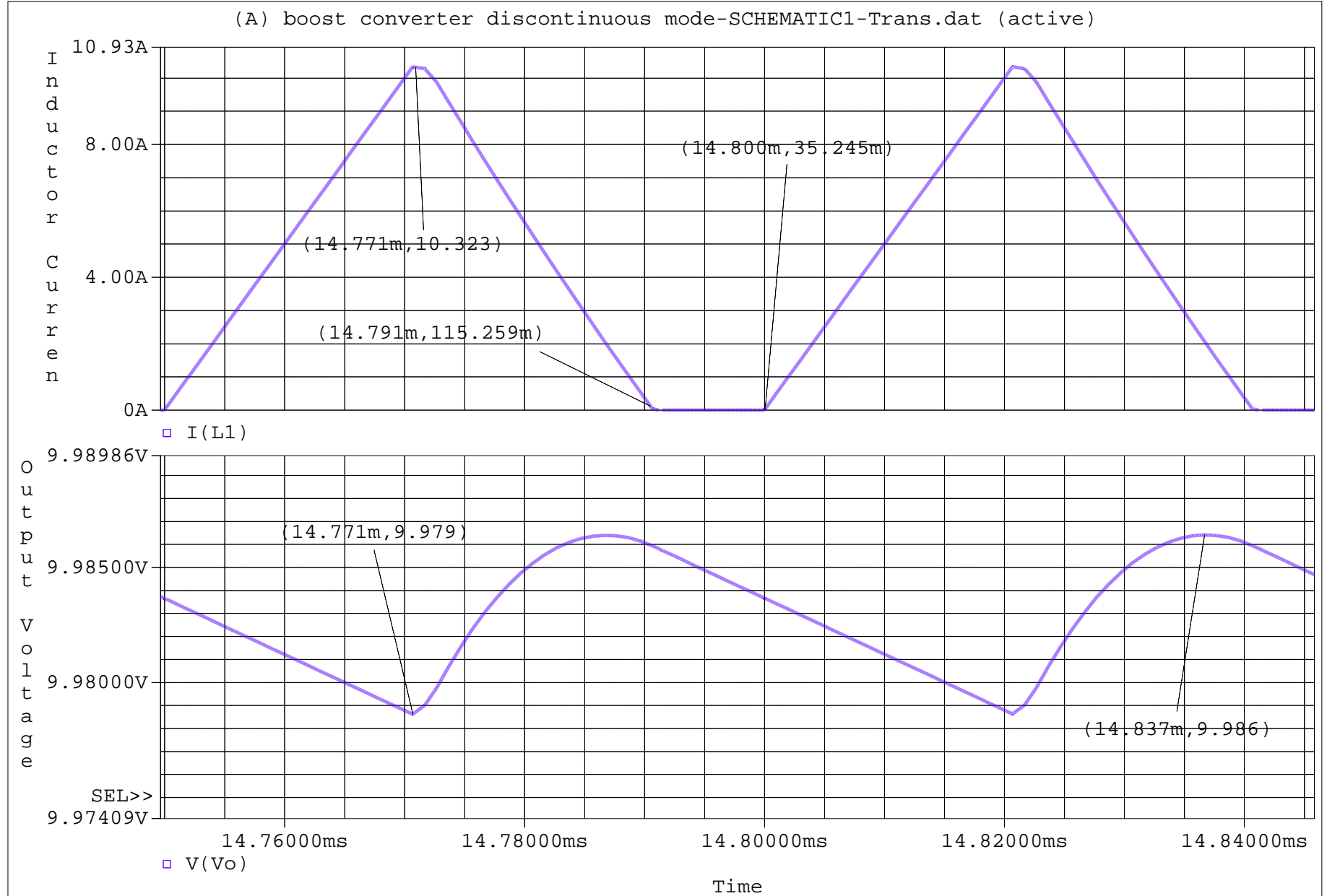


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Page 1

Time: 12:37:15

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Date: December 11, 2002

Page 1

Time: 12:39:11

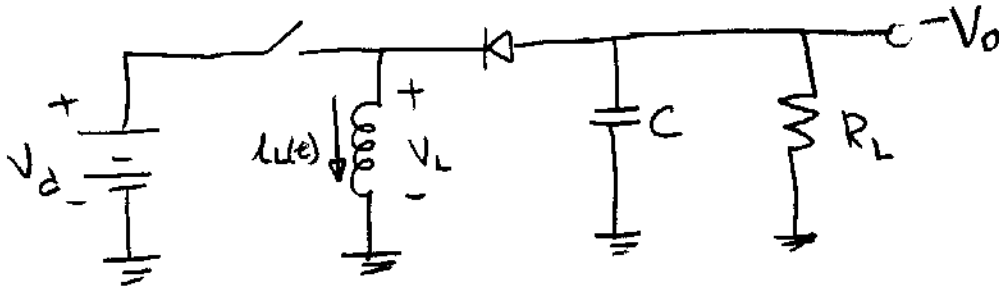
5V to 10V Boost converters

- COMPARISON OF CONTINUOUS mode and discontinuous mode Designs

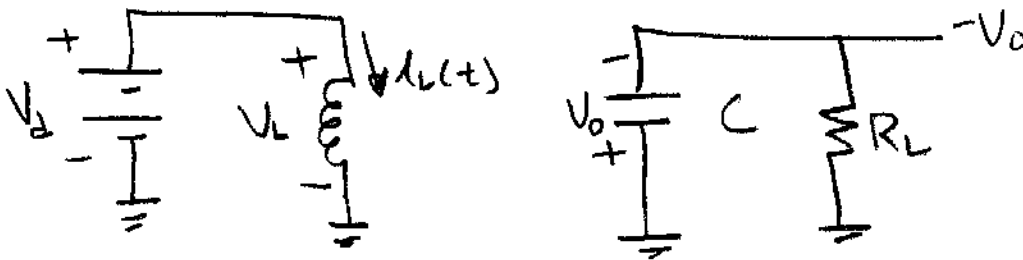
- $V_{in} = 5V$, $V_o = 10V$, $I_o = 2A$, Ripple = 100mV

	I_1	I_2	L	C	Capacitor Rms Ripple Current
Continuous mode	3.93A	4.187A	335 μ H	4700 μ	2A
Discontinuous mode	0A	9.5A	10 μ H	8200 μ	2.866A

Polarity Inverting Regulator OR BUCK-BOOST Regulator



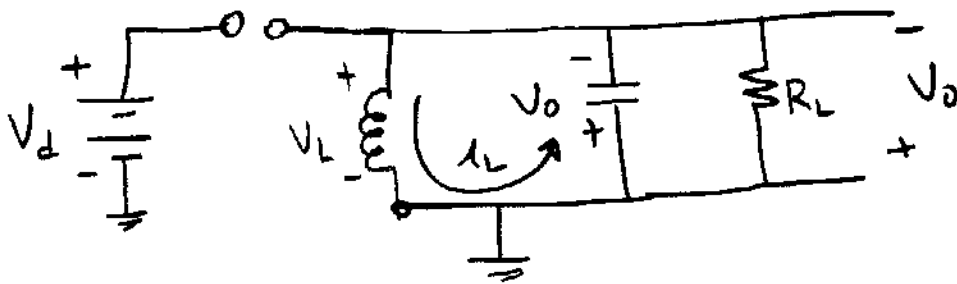
DURING t_{on} :- Switch Closed
D = off



- Capacitor supplies power to load

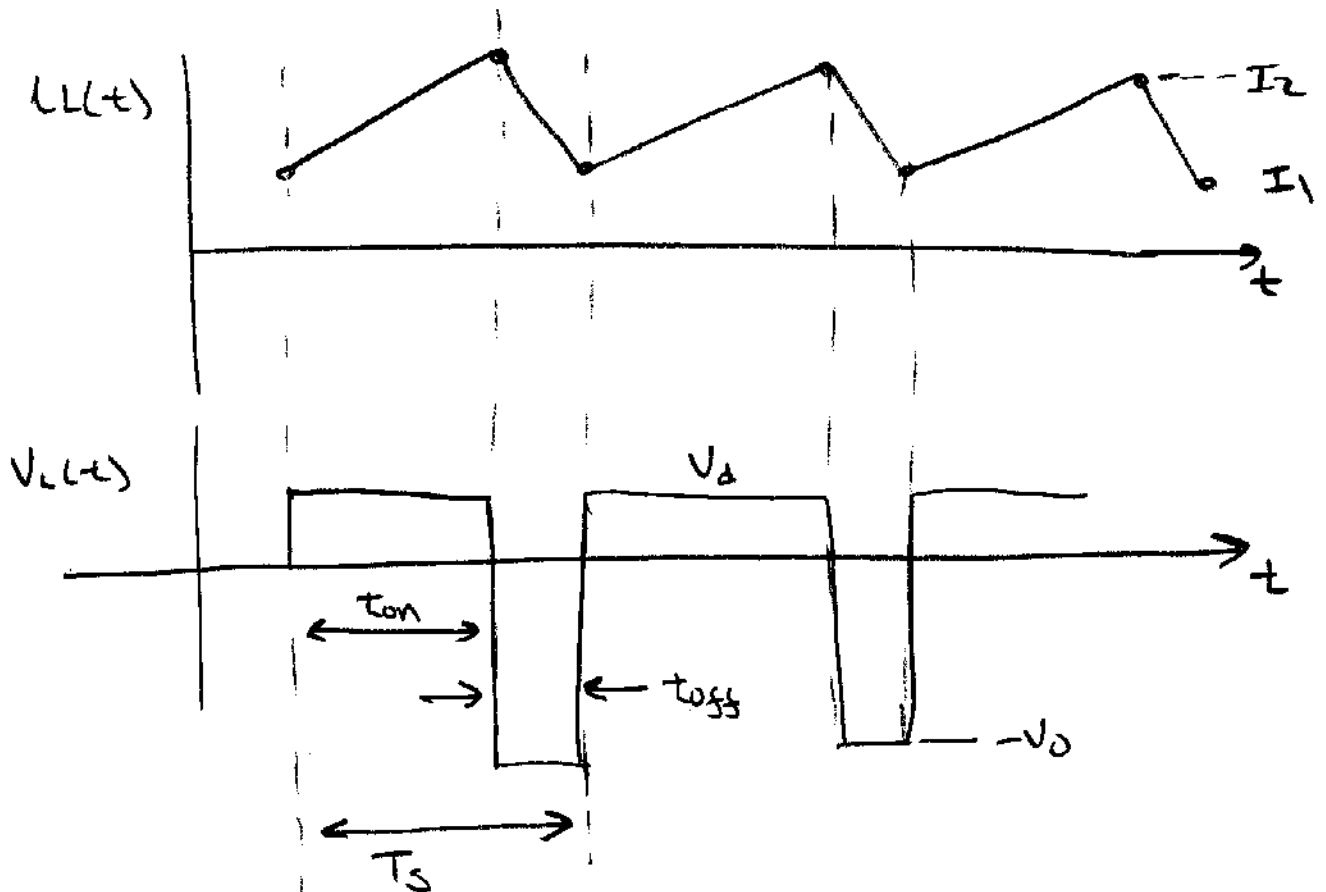
$$V_L = V_d$$

During t_{off} : Switch = off
 $D = on$



- $V_L = -V_o$
- Capacitor supplies power to Load
- Inductor dumps energy to capacitor

CONTINUOUS mode operation



- In Continuous mode $I_L > 0$

and $t_{on} + t_{off} = T_s$

- Since in steady state, the average current over one cycle is constant,

$$\int_{T_s} V_L(t) dt = 0$$

OR $V_d t_{on} + (-V_o t_{off}) = 0$

OR $V_d t_{on} - V_o (T_s - t_{on}) = 0$

OR $\boxed{\frac{V_o}{V_d} = \frac{t_{on}}{T_s - t_{on}} = \frac{D}{1-D}}$; $D = \frac{t_{on}}{T_s}$ (1)

Assuming a lossless circuit, $P_d = P_o$, OR

$$V_d I_d = V_o I_o$$

Where I_d = average input current and

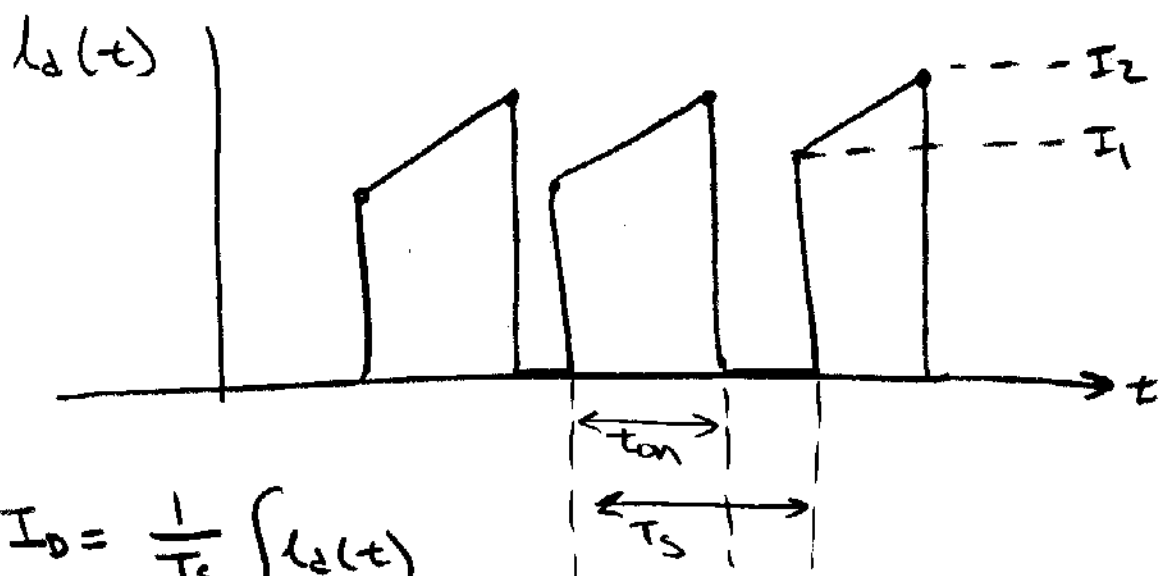
I_o = average output current

Since $P_d = P_o$

$$\frac{I_o}{I_d} = \frac{V_d}{V_o} = \frac{1-D}{D} \quad (2)$$

- Now find the average input current

- V_d only supplies current during t_{on}



$$I_o = \frac{1}{T_s} \int i_d(t)$$

$$I_o = \left(\frac{I_1 + I_2}{2} \right) \frac{t_{on}}{T_s} = \left(\frac{I_1 + I_2}{2} \right) D$$

Sub into eq (2)

$$I_o = \frac{1-D}{D} I_d$$

$$I_o = \frac{1-D}{D} \left(\frac{I_1 + I_2}{2} \right) D$$

$$\boxed{I_1 + I_2 = \frac{2 I_o}{1-D}} \quad (3)$$

Next use $v_L(t) = L \frac{di_L}{dt}$

$$i_L(t) = \frac{1}{L} \int v_L dt + i.c.$$

$$I_2 = \frac{1}{L} \int_0^{t_{on}} v_d dt + I_1$$

$$\boxed{I_2 - I_1 = \frac{V_d t_{on}}{L}} \quad (4)$$

- Next, Find the boundary between
CONTINUOUS + DISCONTINUOUS mode.

\Rightarrow solve for I_1

$$I_1 + I_2 = \frac{2I_0}{1-D}$$

$$(-) \quad I_2 - I_1 = \frac{V_d t_{on}}{L}$$

$$2I_1 = \left(\frac{2I_0}{1-D} \right) - \frac{V_d t_{on}}{L}$$

For the boundary btw continuous and
discontinuous mode, solve for $I_1 = 0$

$$0 = \frac{2I_0}{1-D} - \frac{V_d t_{on}}{L}$$

$$I_0 = \left(\frac{V_d t_{on}}{2L} \right) (1-D)$$

OR

$$\boxed{I_0 \geq \frac{V_d t_{on}}{2L} (1-D)}$$

Summary

Buck-Boost in
continuous mode

$$V_o = V_d \left[\frac{D}{1-D} \right]$$

$$I_o = I_d \left[\frac{1-D}{D} \right]$$

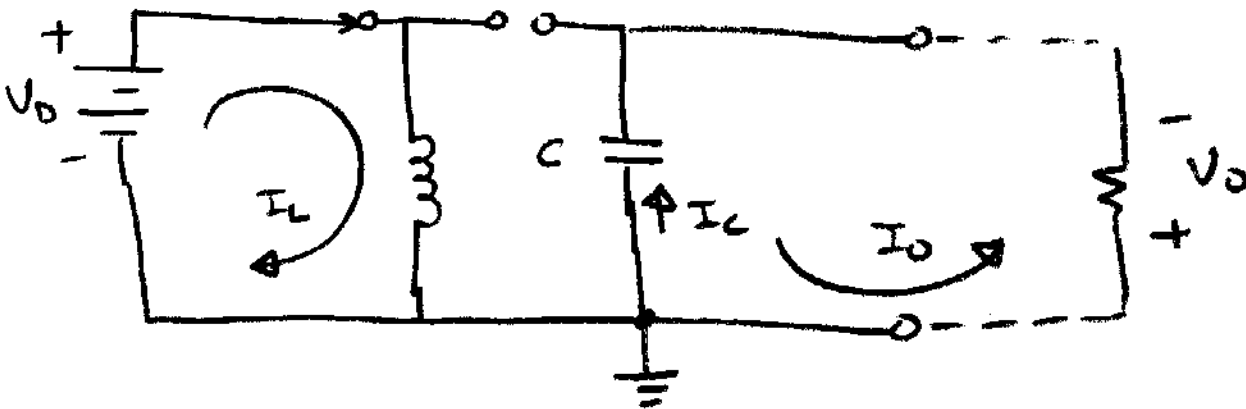
$$I_1 + I_2 = \frac{2 I_o}{1-D}$$

$$I_2 - I_1 = \frac{V_d t_{on}}{L}$$

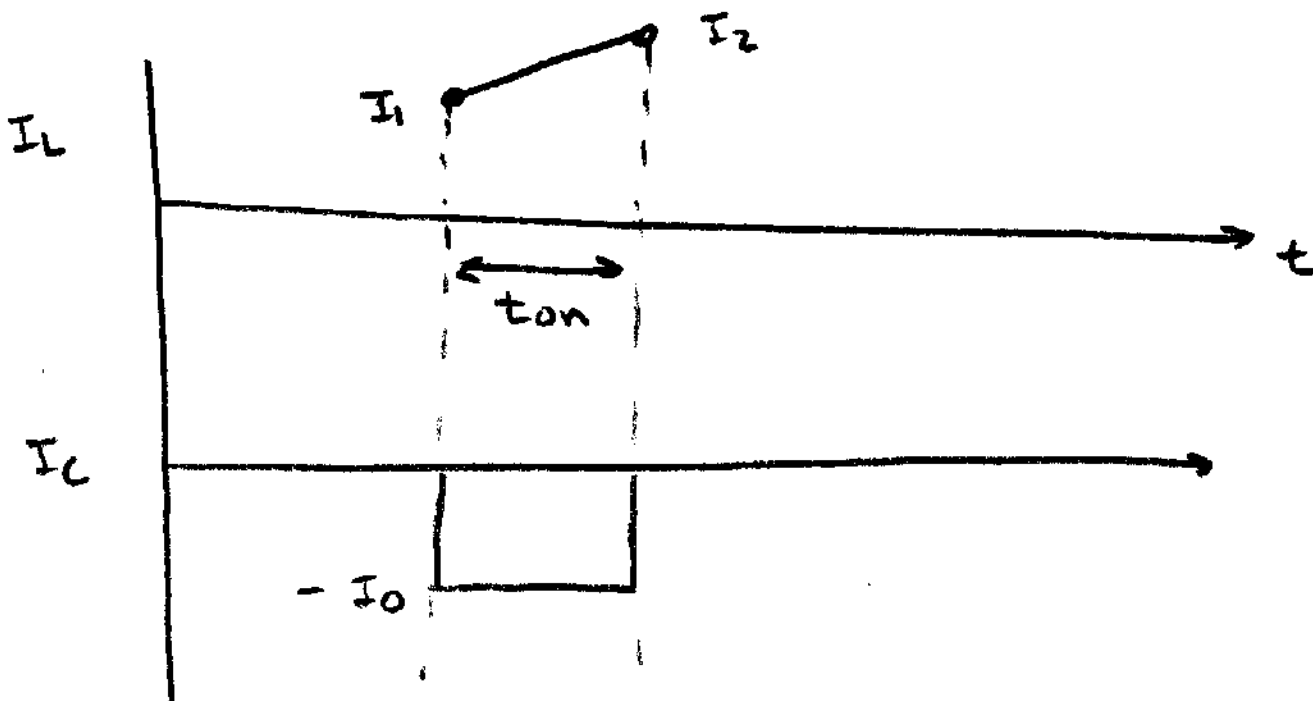
$$I_o \geq \frac{V_d t_{on}}{2L} (1-D)$$

- Calculation of Capacitor Ripple Current

- During t_{on} , the diode is off and the capacitor must supply the entire output current

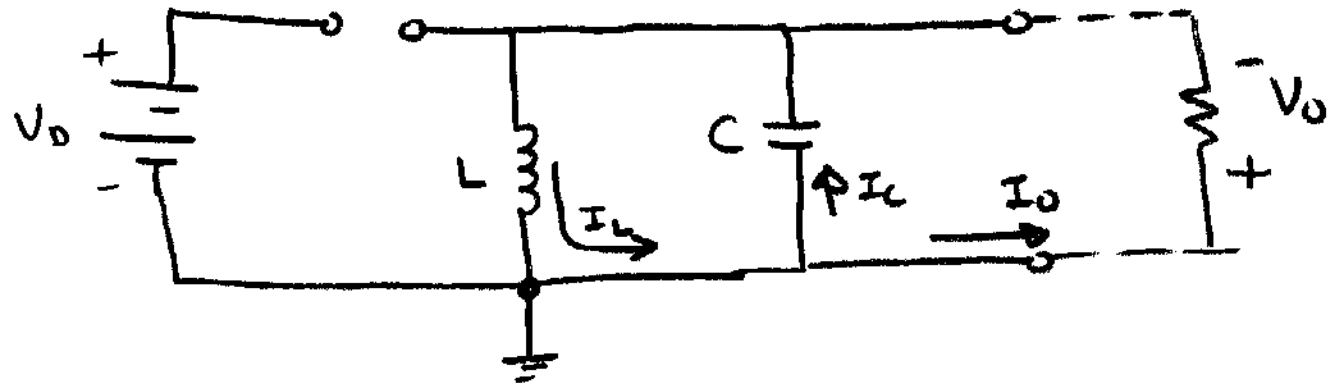


During t_{on} The inductor charges from I_1 to I_2

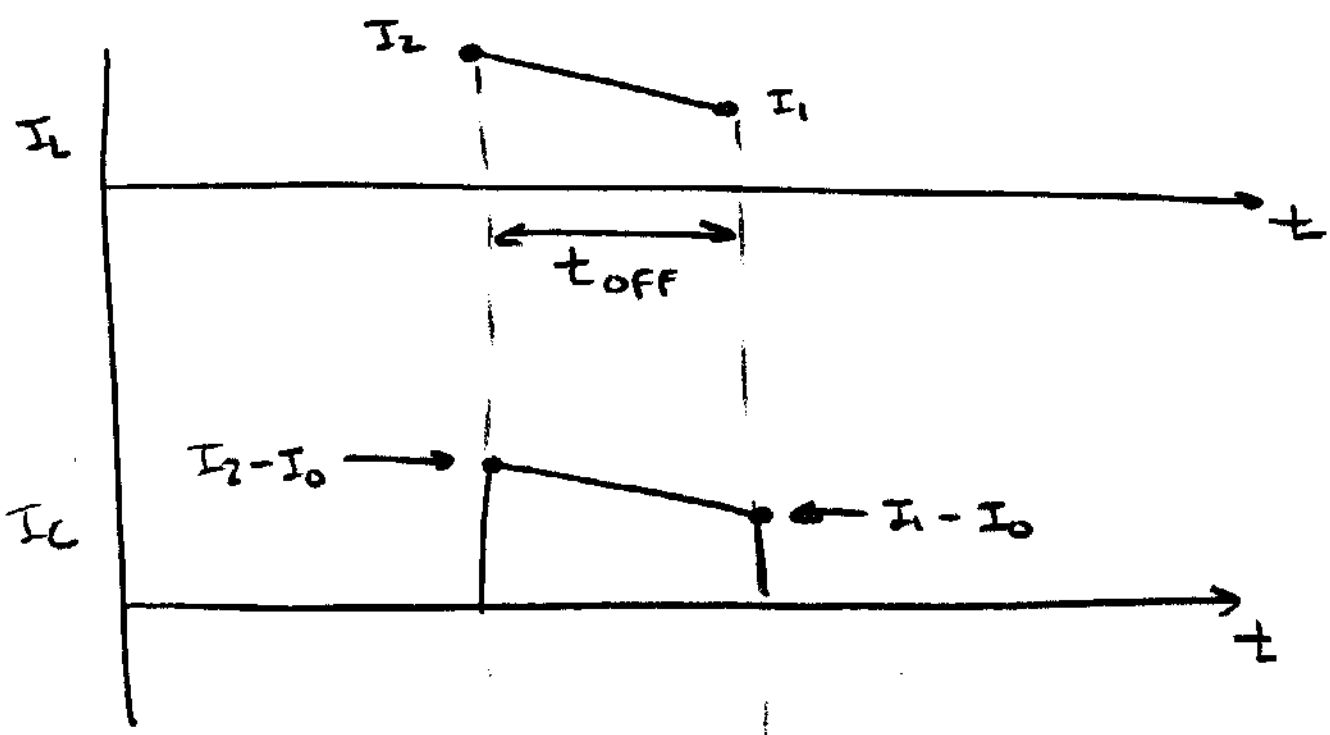


- During t_{off} , the inductor charges the capacitor and supplies current to the output

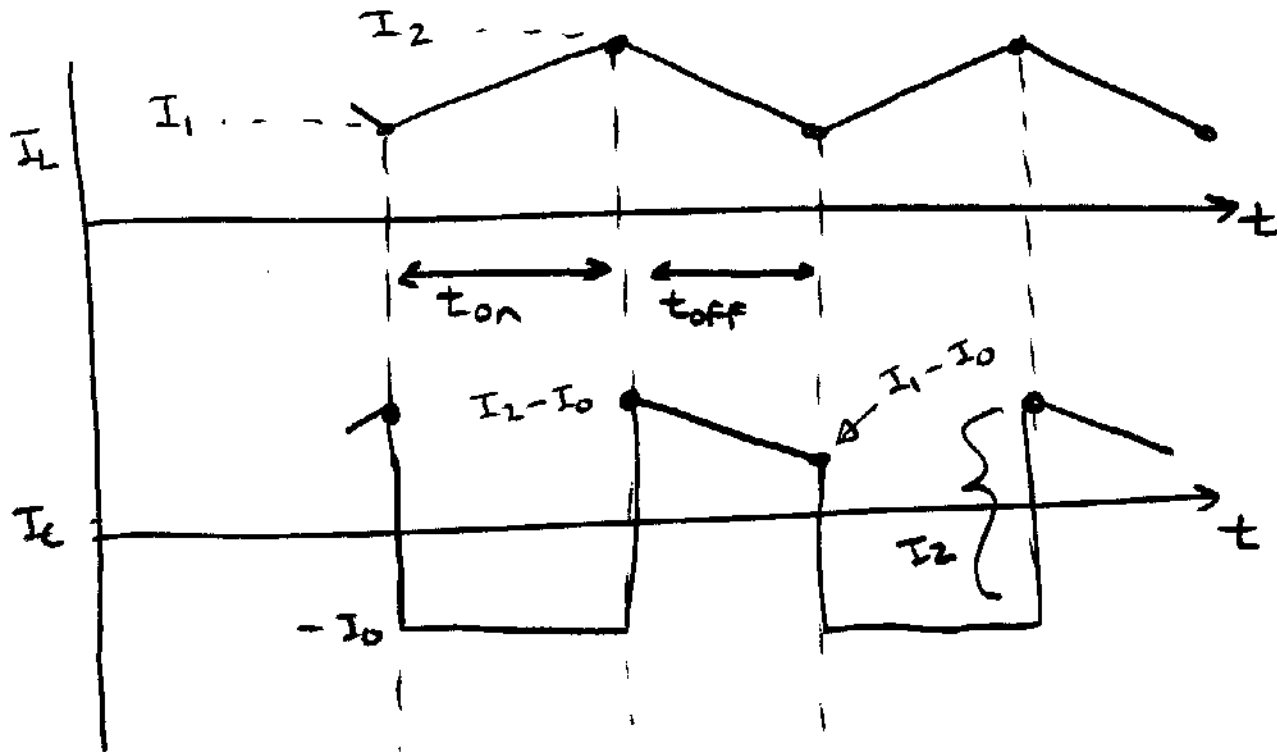
$$\Rightarrow I_C = I_L - I_O$$



- During t_{off} , the inductor discharges from I_2 to I_1



- The complete picture is



$$I_{Rms} = \sqrt{\frac{1}{T_s} \left[\int_0^{t_{on}} (-I_0)^2 dt + \int_0^{t_{off}} (I_2 - I_0) dt \right]}$$

during t_{off} , we can express $I_L(t)$ as

$$I_L(t) = I_2 + m t$$

$$\text{where } m = \frac{I_1 - I_2}{t_{off}}$$

Also: Ripple due to ESR is

$$V_{CR} = I_2 \cdot ESR$$

EE 456

Buck-Boost Regulator Design Continuous Mode Operation

$$\mu\text{s} := 10^{-6} \cdot \text{sec} \quad \text{m}\Omega := \frac{\Omega}{1000}$$

Specify Input Voltage

Specify Output Voltage

$$V_D := 12 \cdot \text{volt}$$

$$V_o := -12 \cdot \text{volt}$$

Specify Switching Frequency

$$F_S := 40 \cdot \text{kHz}$$

$$T_S := \frac{1}{F_S} \quad T_S = 25 \mu\text{s}$$

Specify the Assumed Efficiency

$$\text{Eff} := 85\%$$

Specify the Max output Current

The output Power is

$$P_{\text{out}} := \frac{50 \cdot \text{watt}}{\text{Eff}}$$

The output current is

$$I_o := \left| \frac{P_{\text{out}}}{V_o} \right| \quad I_o = 4.902 \text{ amp}$$

Find T_{on}

$$t_{on} := 1 \cdot \mu s$$

Given

$$-V_o = V_D \cdot \left(\frac{t_{on}}{T_S - t_{on}} \right)$$

$$t_{on} := \text{Find}(t_{on})$$

$$t_{on} = 12.5 \mu s$$

$$t_{off} := T_S - t_{on}$$

$$t_{off} = 12.5 \mu s$$

$$D := \frac{t_{on}}{T_S}$$

$$D = 50 \%$$

Find the range of Inductors that will operate in continuous mode

Specify the minimum current we want the supply to operate in the continuous mode

$$I_{min} := \frac{I_o}{10}$$

$$L := \frac{V_D \cdot t_{on}}{2 \cdot I_{min}} \cdot (1 - D)$$

For Continuous Mode, We need L greater than

$$L = 76.5 \mu H$$

Choose the Inductor $L := 90 \cdot \mu\text{H}$

Pulse
Engineering
PE-51512

Find the Min and max inductor currents

$$I_1 := 1 \cdot \text{amp} \quad I_2 := 1 \cdot \text{amp}$$

Given

$$\frac{I_1 + I_2}{2} = \frac{I_o}{1 - D}$$

$$I_2 - I_1 = V_D \cdot \frac{t_{\text{on}}}{L}$$

$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} := \text{Find}(I_1, I_2) \quad I_1 = 8.971 \text{ amp} \quad I_2 = 10.637 \text{ amp}$$

Inductor Average Current is $\frac{I_1 + I_2}{2} = 9.804 \text{ amp}$

Choose the filter capacitor using the capacitor ESR. Assume that the major component of the ripple comes from the capacitor ESR.

Specify the ripple due to the ESR $V_{CR} := 100 \cdot \text{mV}$

$$\text{ESR} := \frac{V_{CR}}{I_2} \quad \text{ESR} = 9.401 \text{ m}\Omega$$

For all electrolytic caps, assume that $\text{ESR} \cdot C = 80 \text{ms}$

$$C := \frac{80 \cdot \mu\text{s}}{\text{ESR}} \quad C = 8510 \mu\text{F}$$

Choose the next size std capacitor $C := 10000 \cdot \mu\text{F}$

Calculate the Capacitor RMS Ripple Current

Define a function for the inductor current $I_L(t) := I_2 + \frac{(I_1 - I_2)}{t_{\text{off}}} \cdot t$

$$I_{\text{rms}} := \sqrt{\frac{1}{T_S} \cdot \left[\int_{0 \cdot \text{sec}}^{t_{\text{on}}} (-I_0)^2 dt + \int_{0 \cdot \text{sec}}^{t_{\text{off}}} (I_L(t) - I_0)^2 dt \right]}$$

$$I_{\text{rms}} = 4.914 \text{ amp}$$

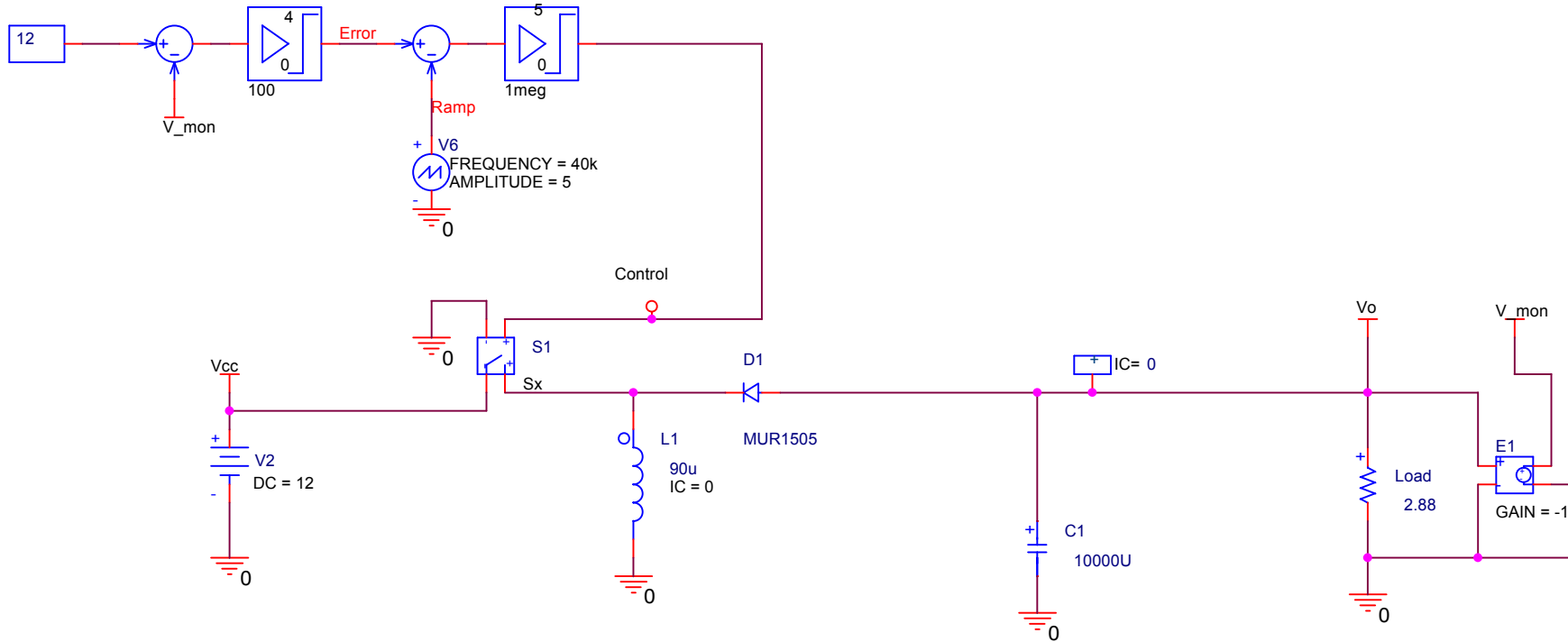
Summary

$$L = 90 \mu\text{H} \quad I_2 = 10.637 \text{ amp} \quad \frac{I_2 + I_2}{2} = 10.637 \text{ amp}$$

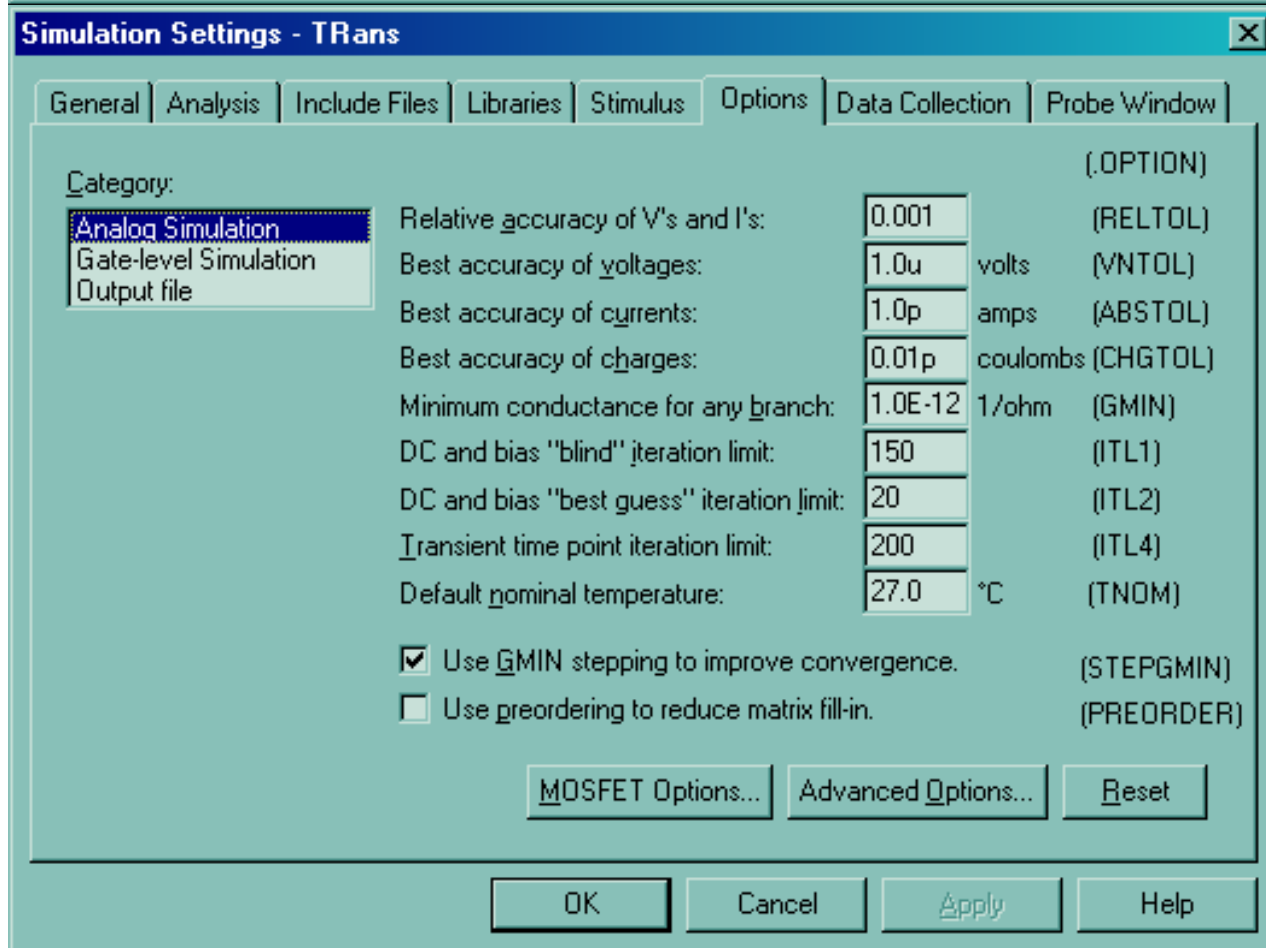
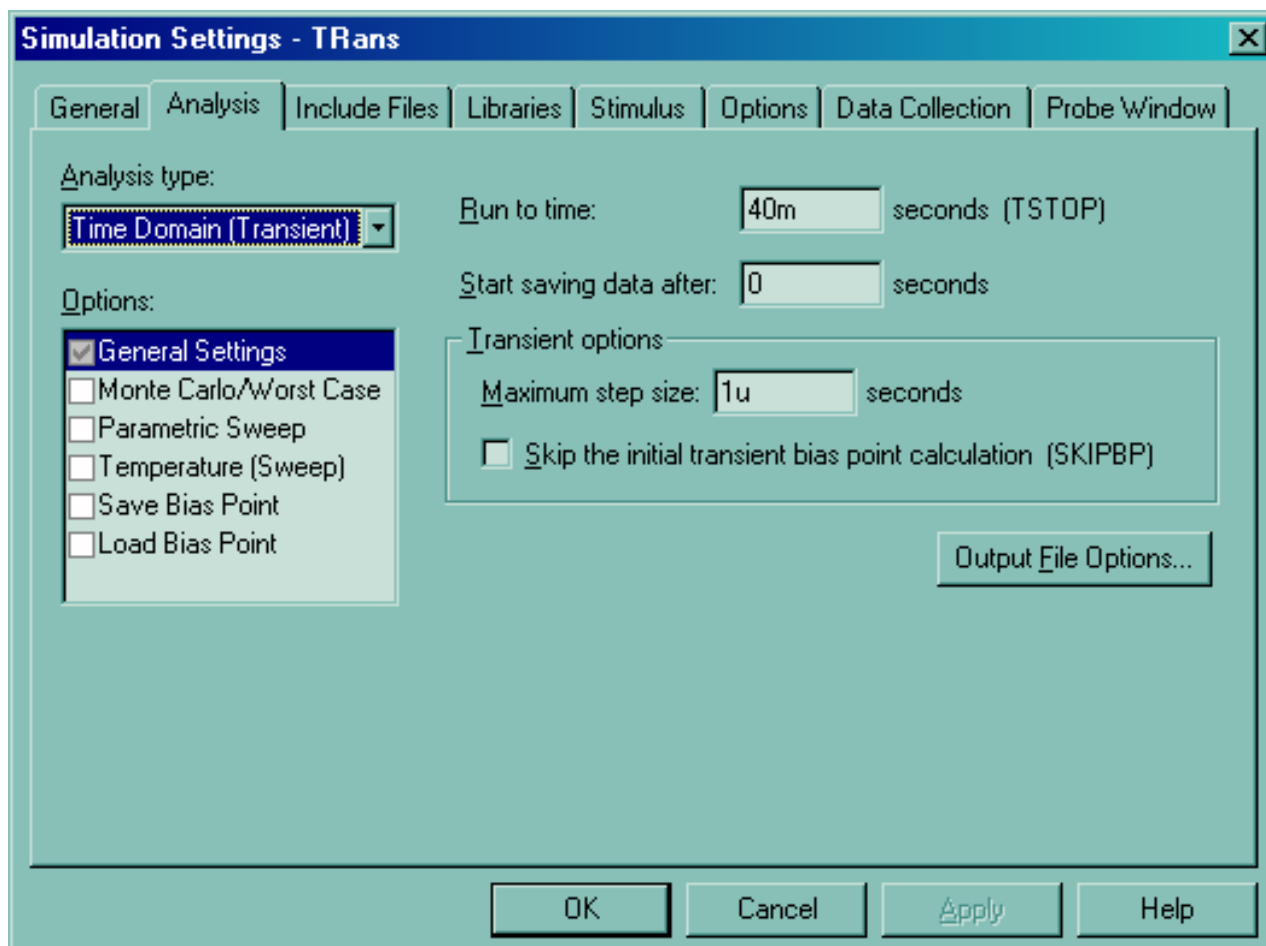
$$t_{\text{on}} = 12.5 \mu\text{s} \quad t_{\text{off}} = 12.5 \mu\text{s}$$

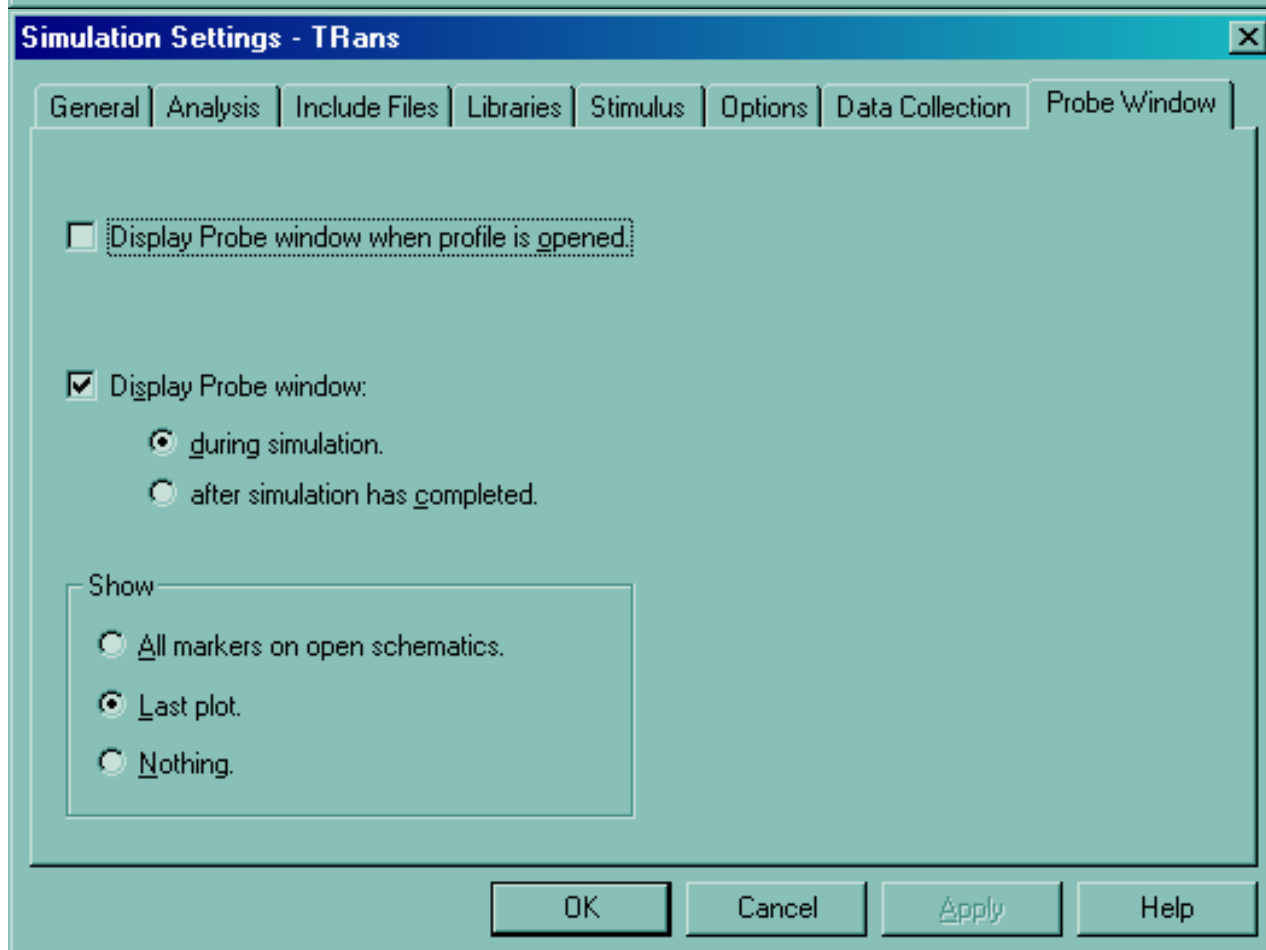
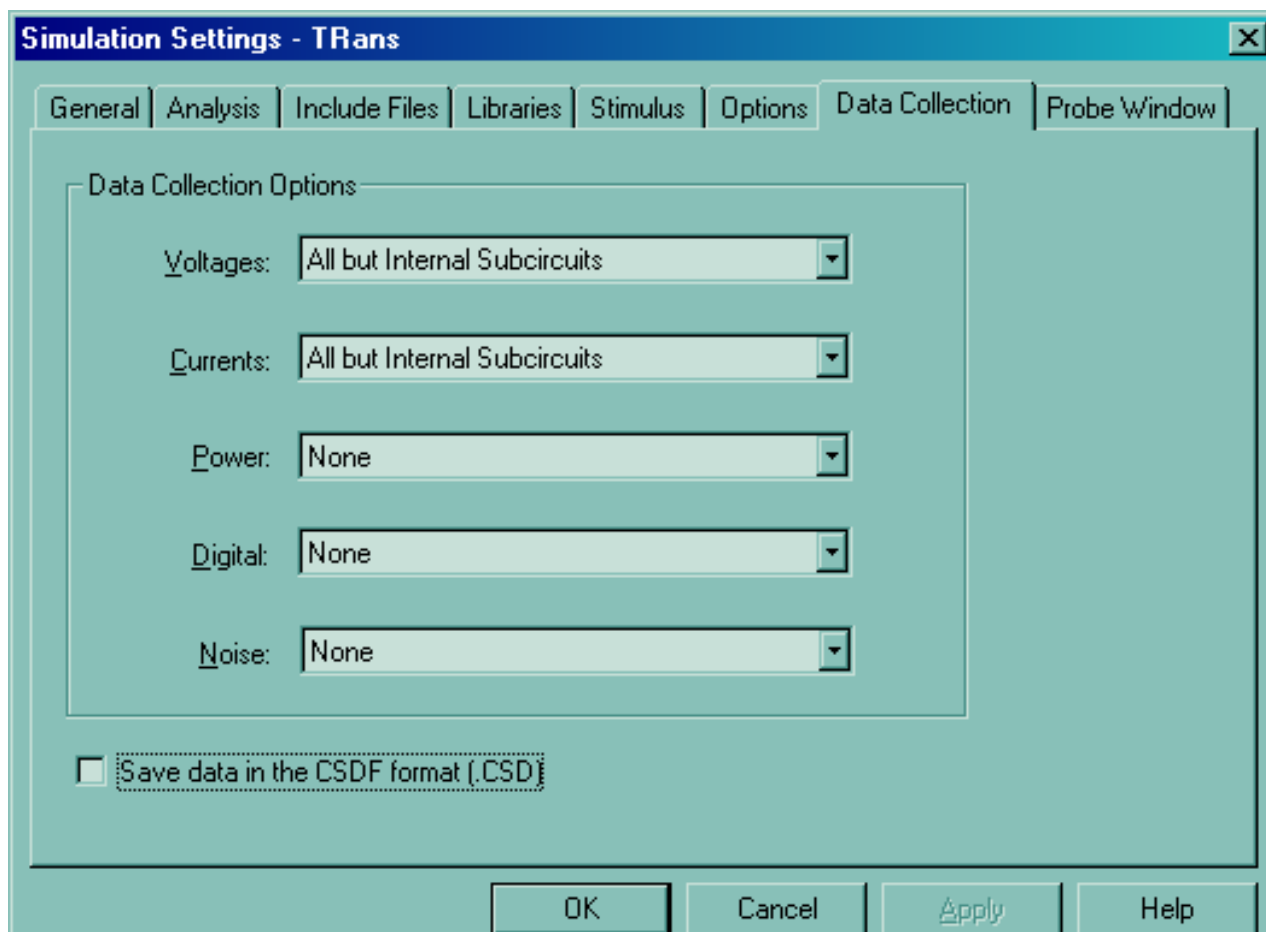
$$V_D = 12 \text{ volt} \quad V_o = -12 \text{ volt} \quad I_o = 4.902 \text{ amp}$$

$$C = 10000 \mu\text{F} \quad V_{\text{CR}} = 100 \text{ mV} \quad I_{\text{rms}} = 4.914 \text{ amp}$$

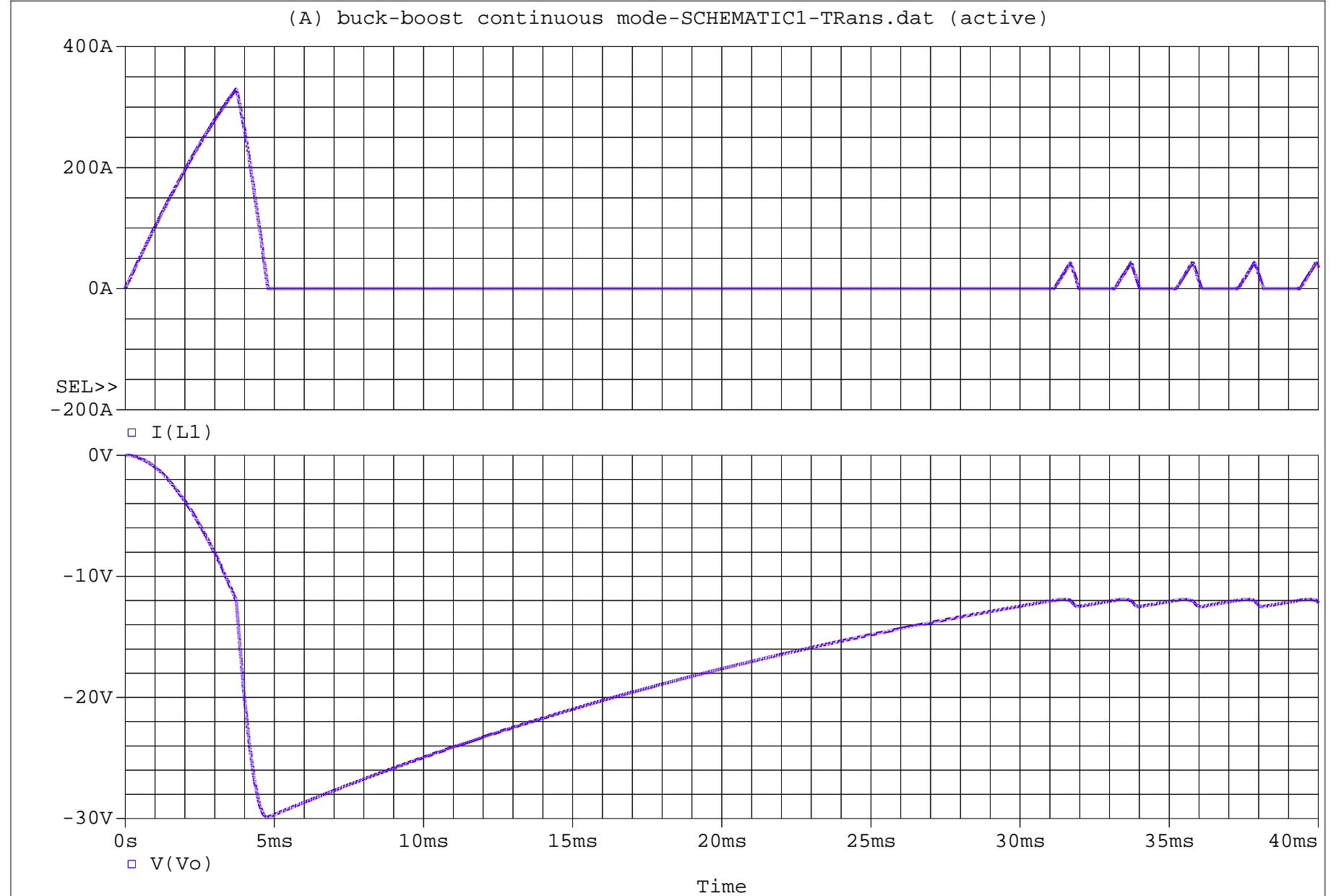


Model = Sx VSWITCH Roff=1e6 Ron=1m Voff=1 Von=4.0





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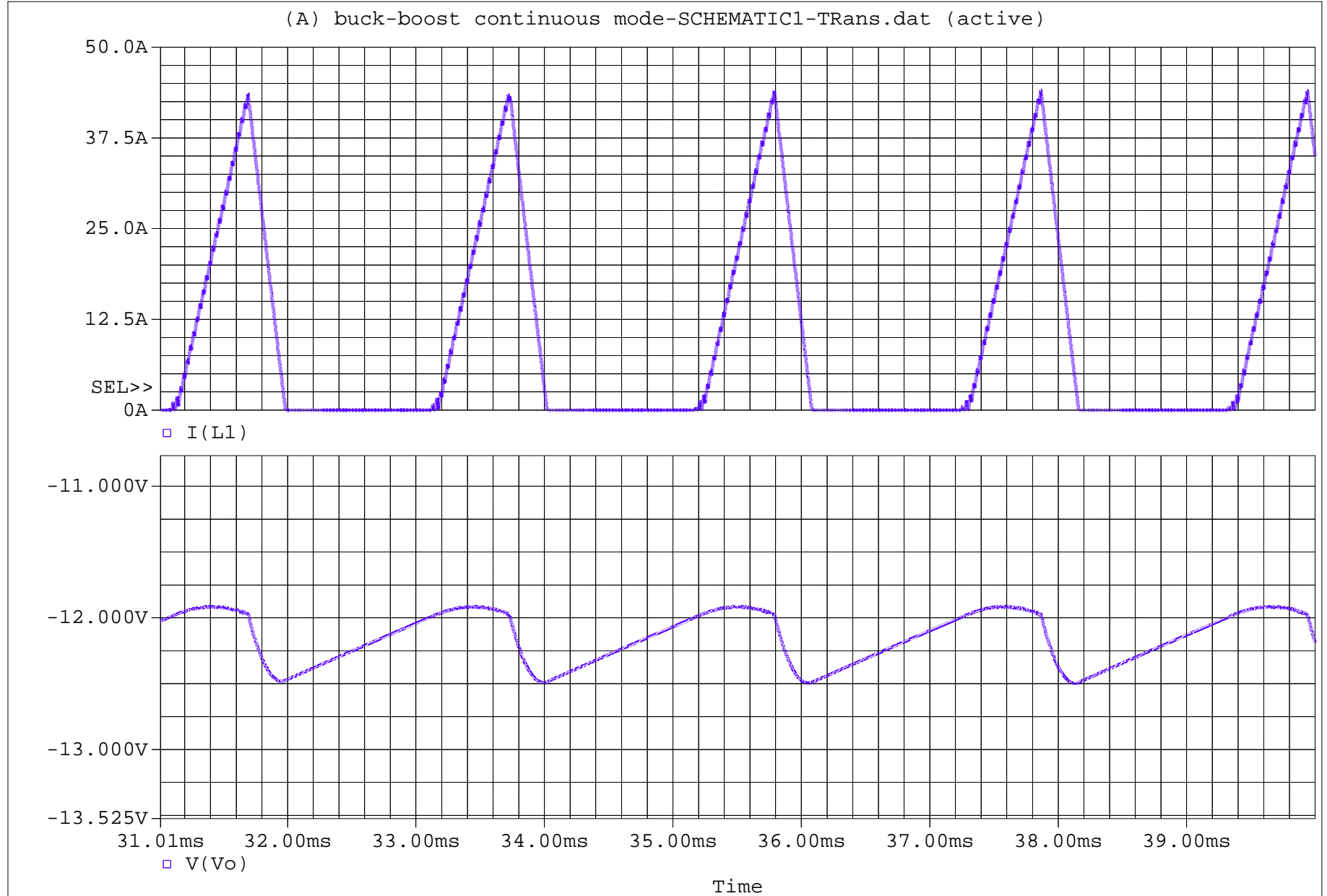


Date: January 09, 2003

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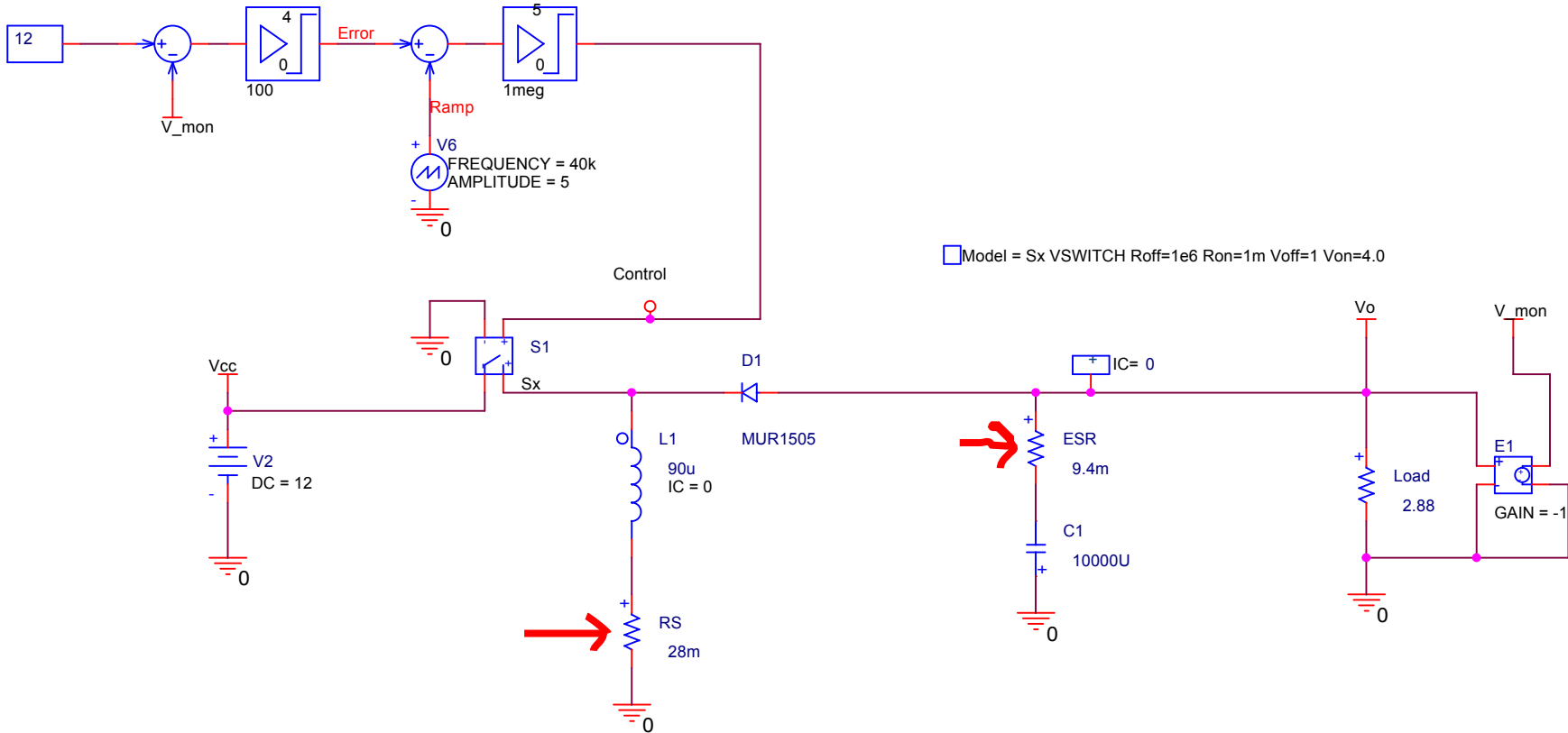
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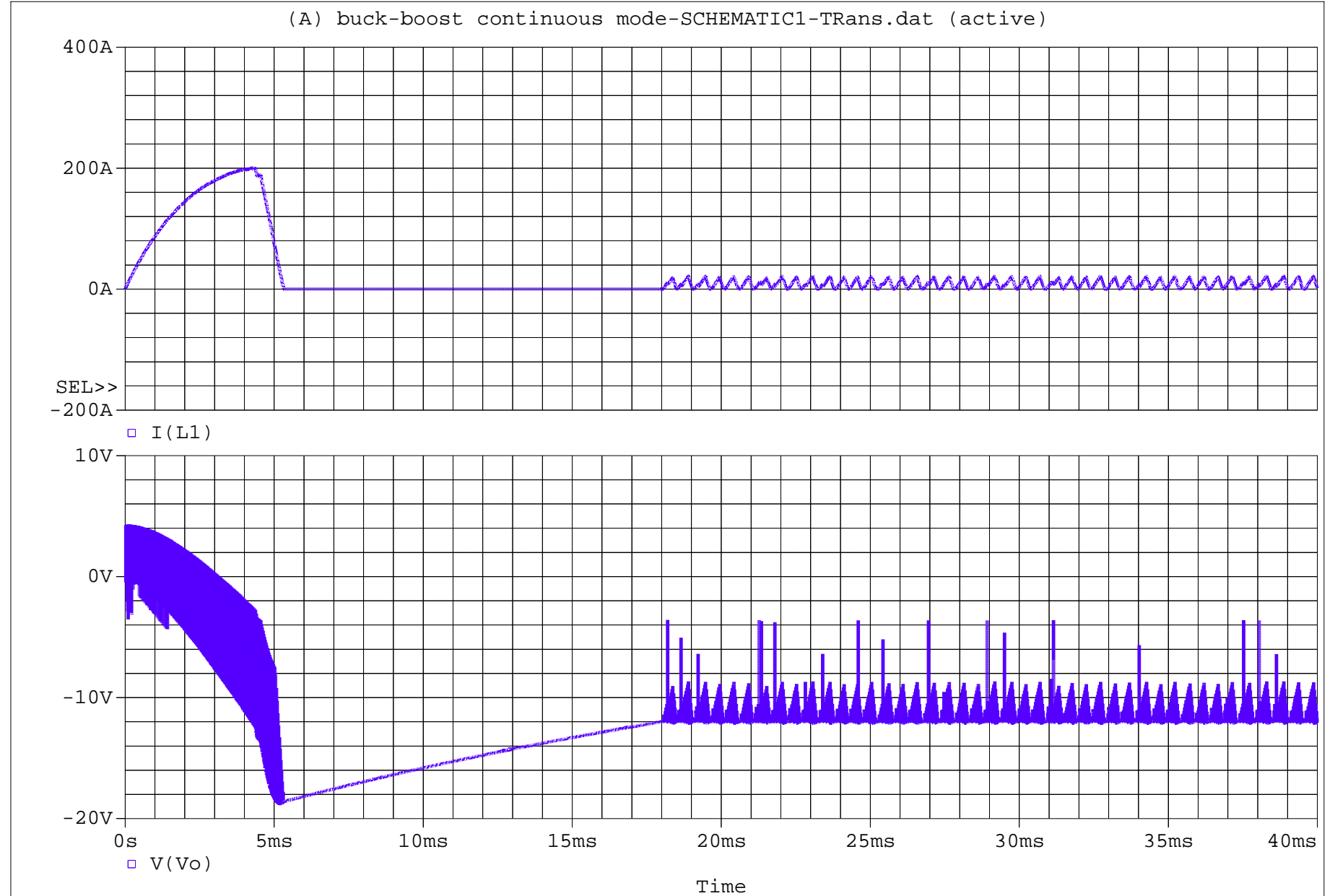
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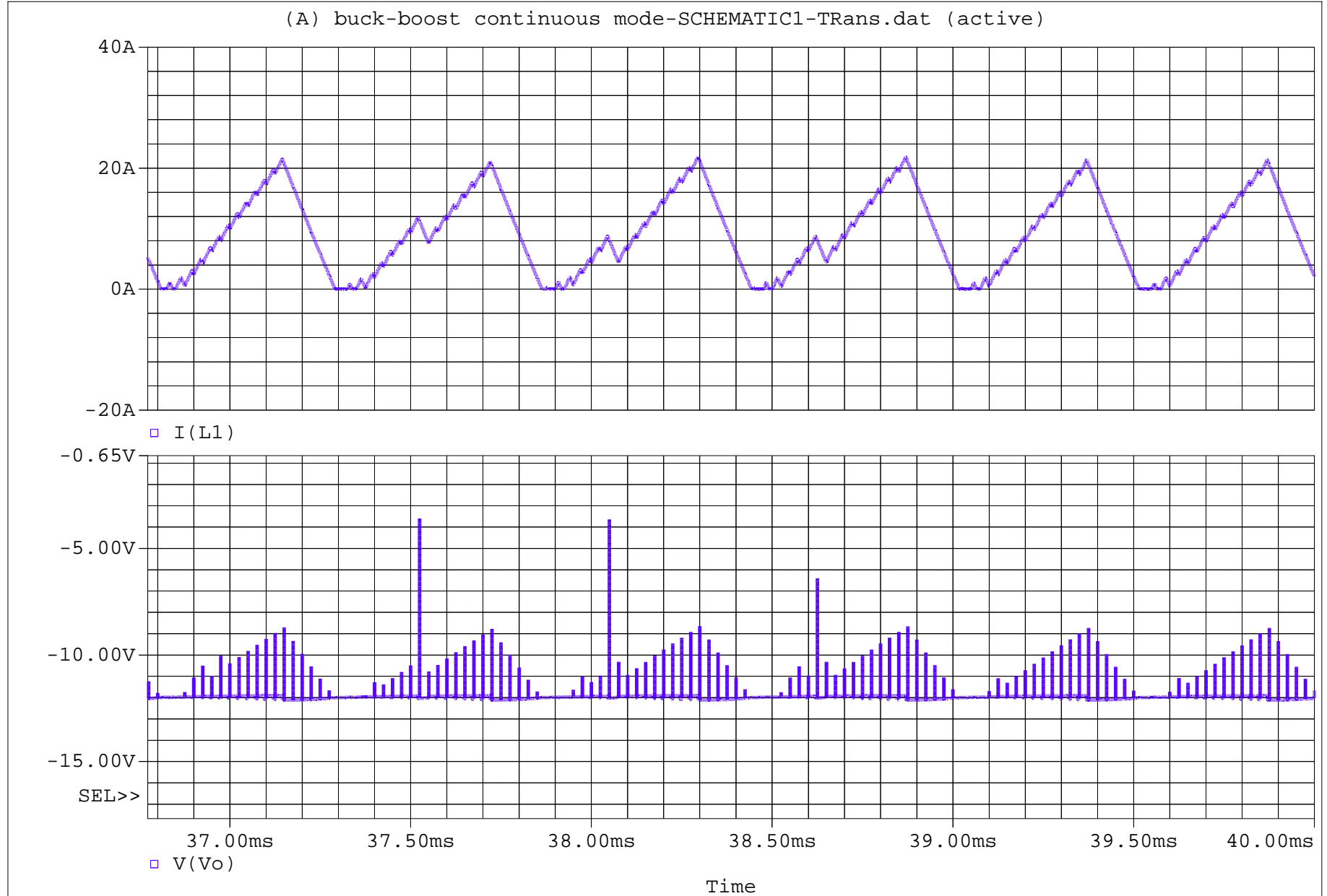


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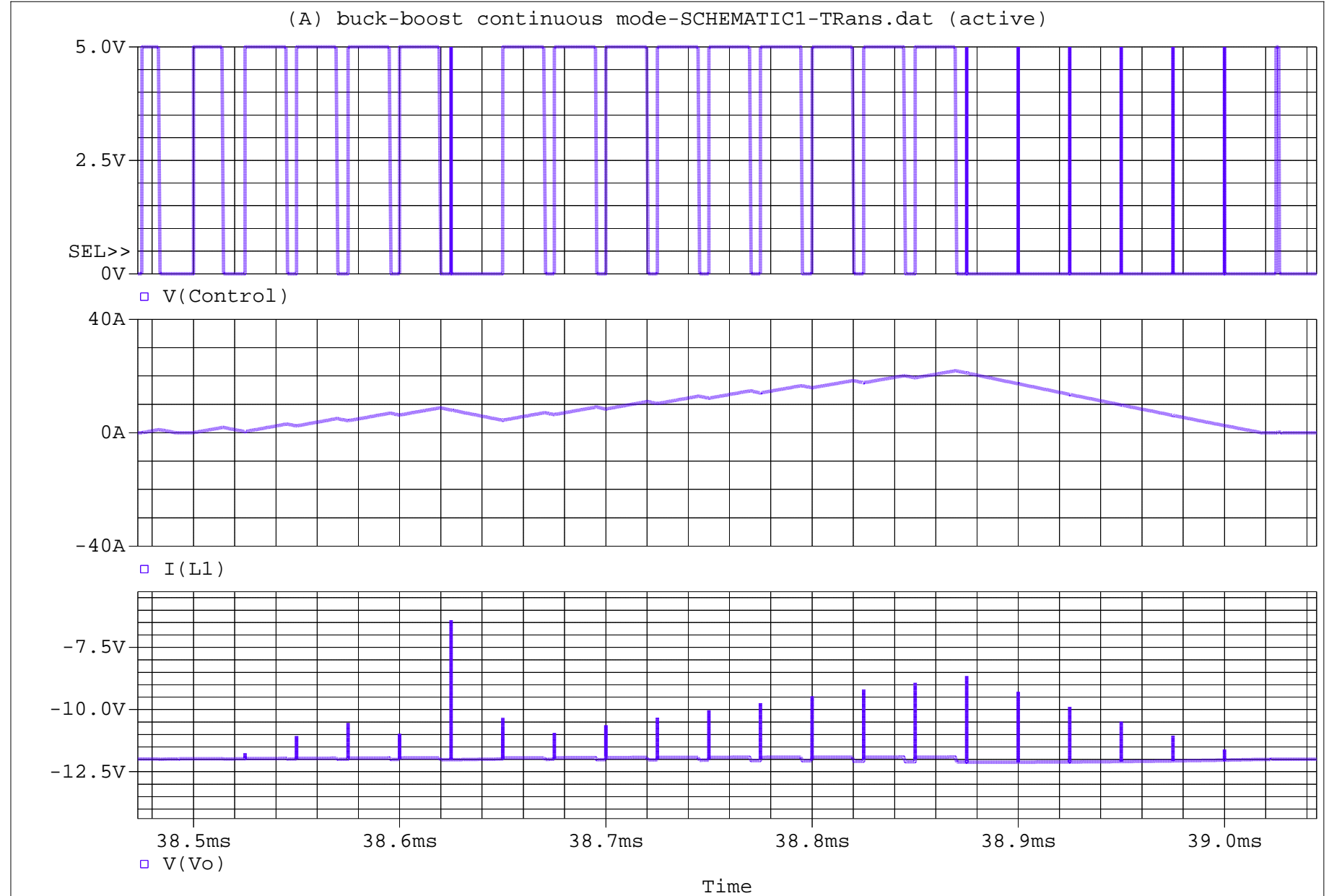


Date: January 09, 2003

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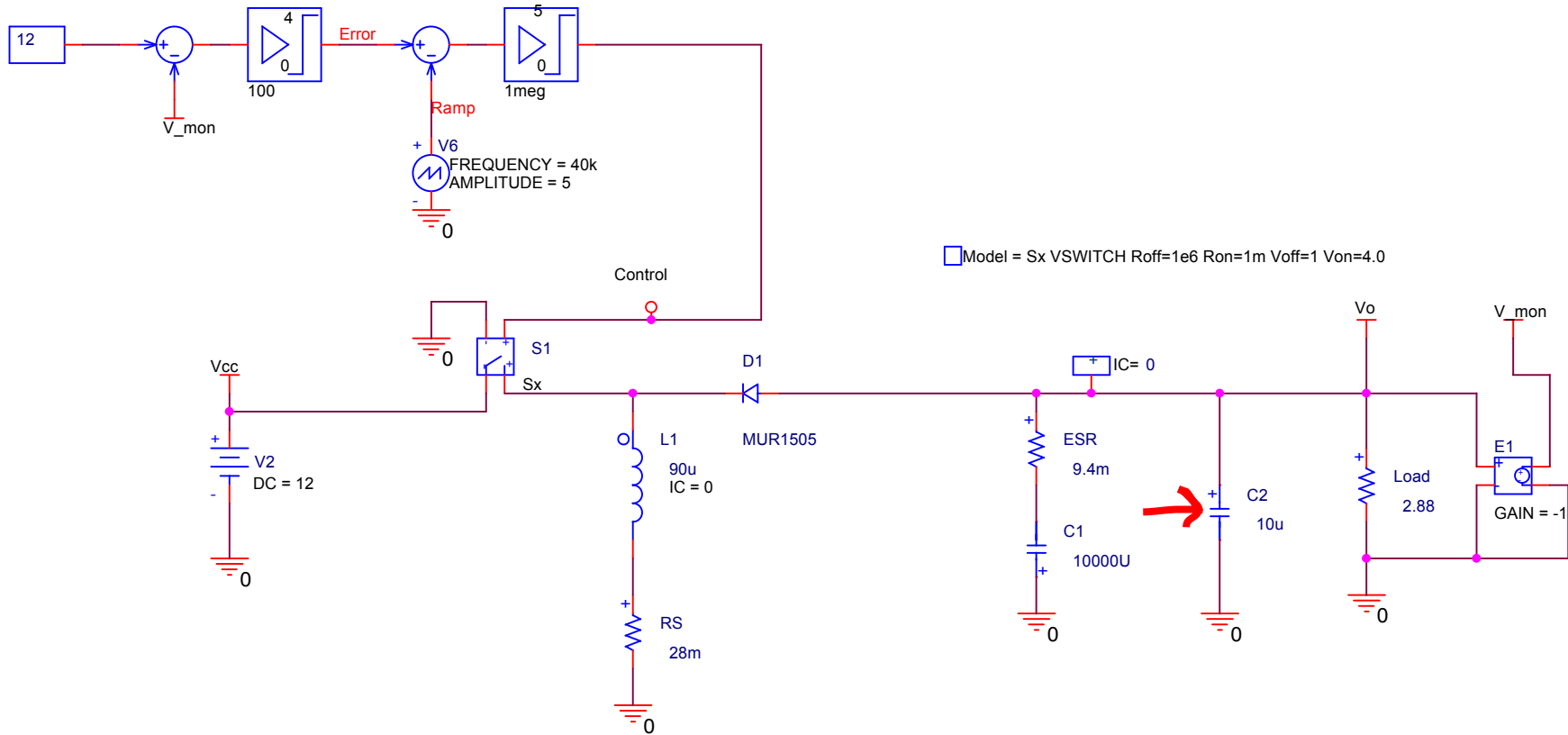
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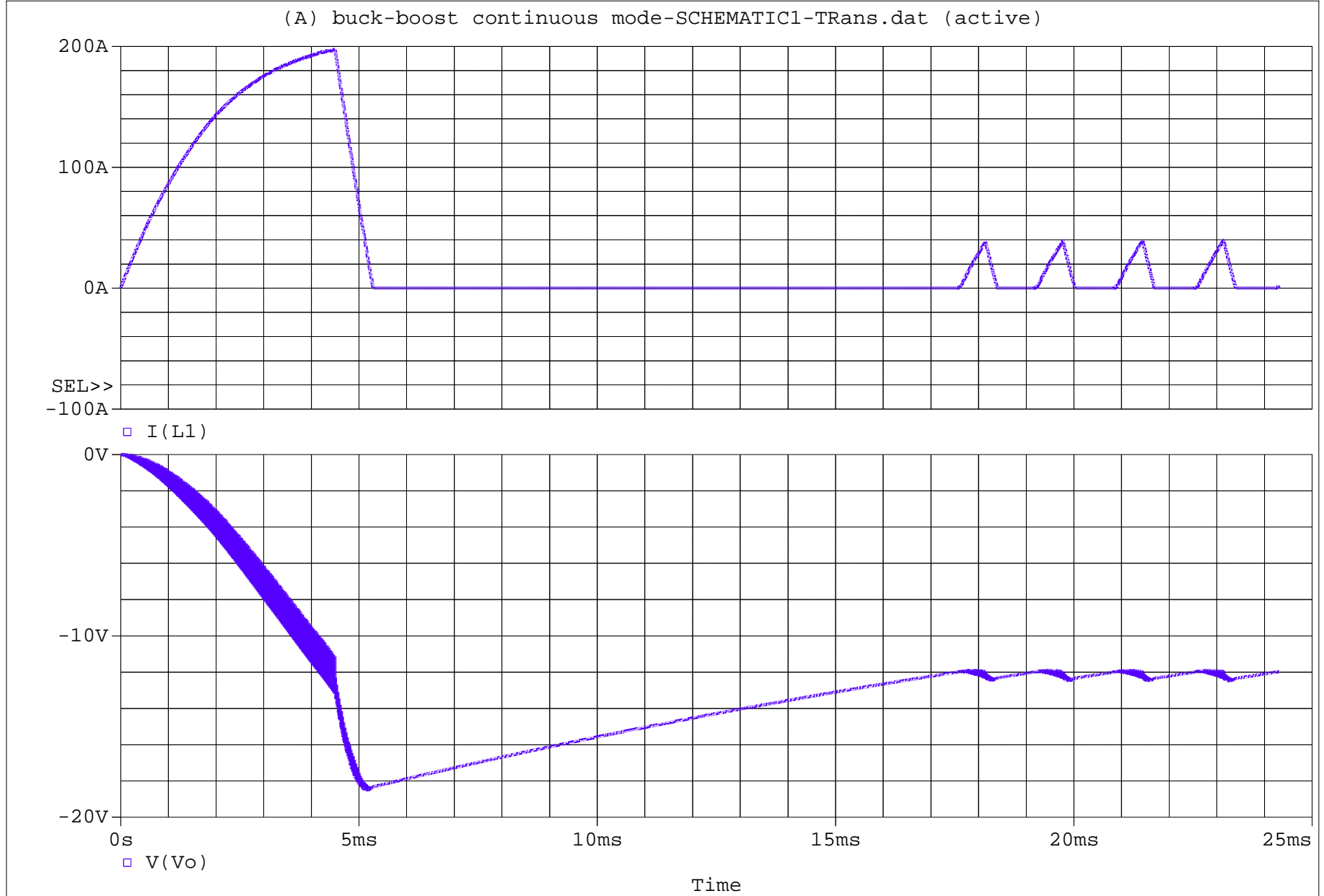
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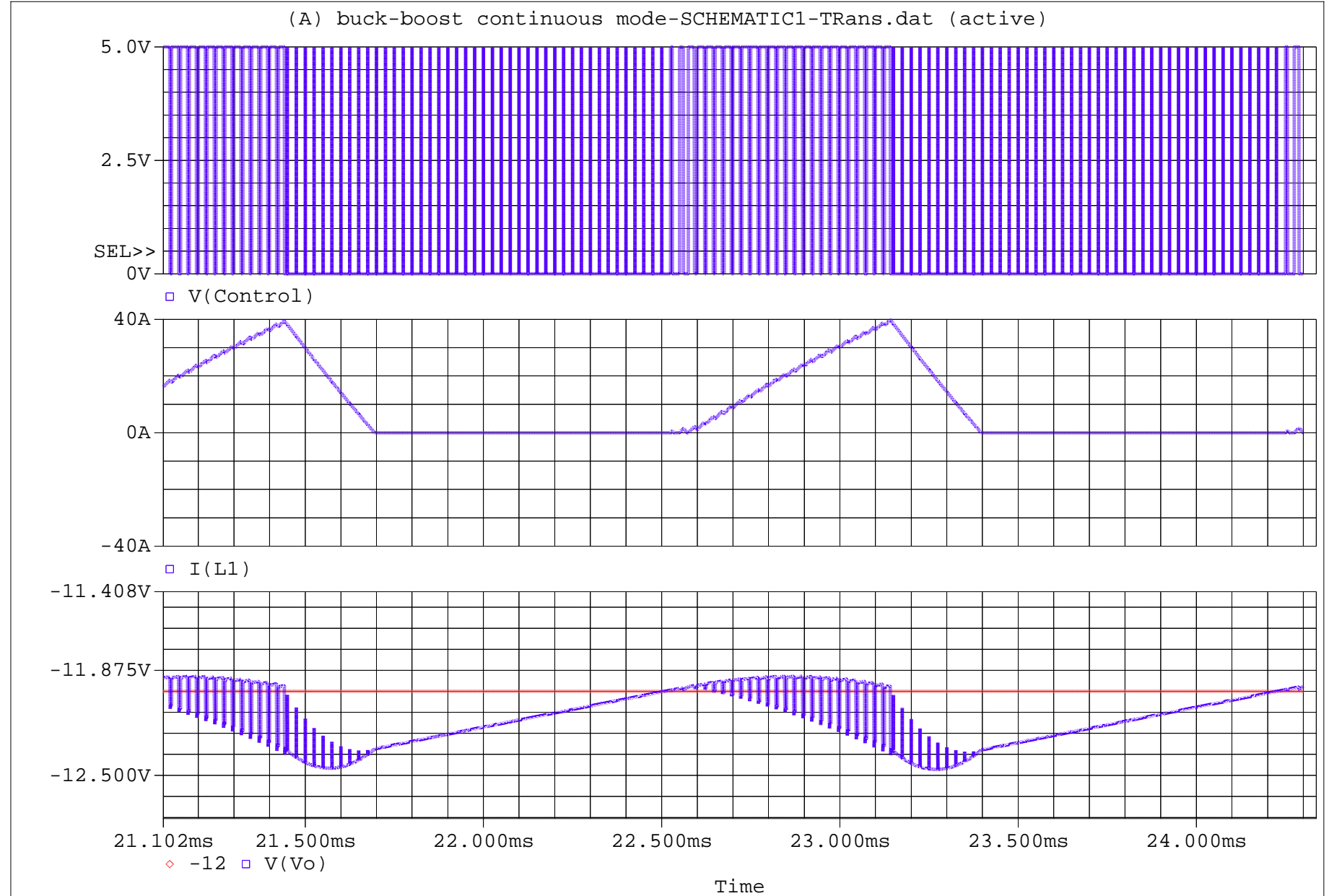


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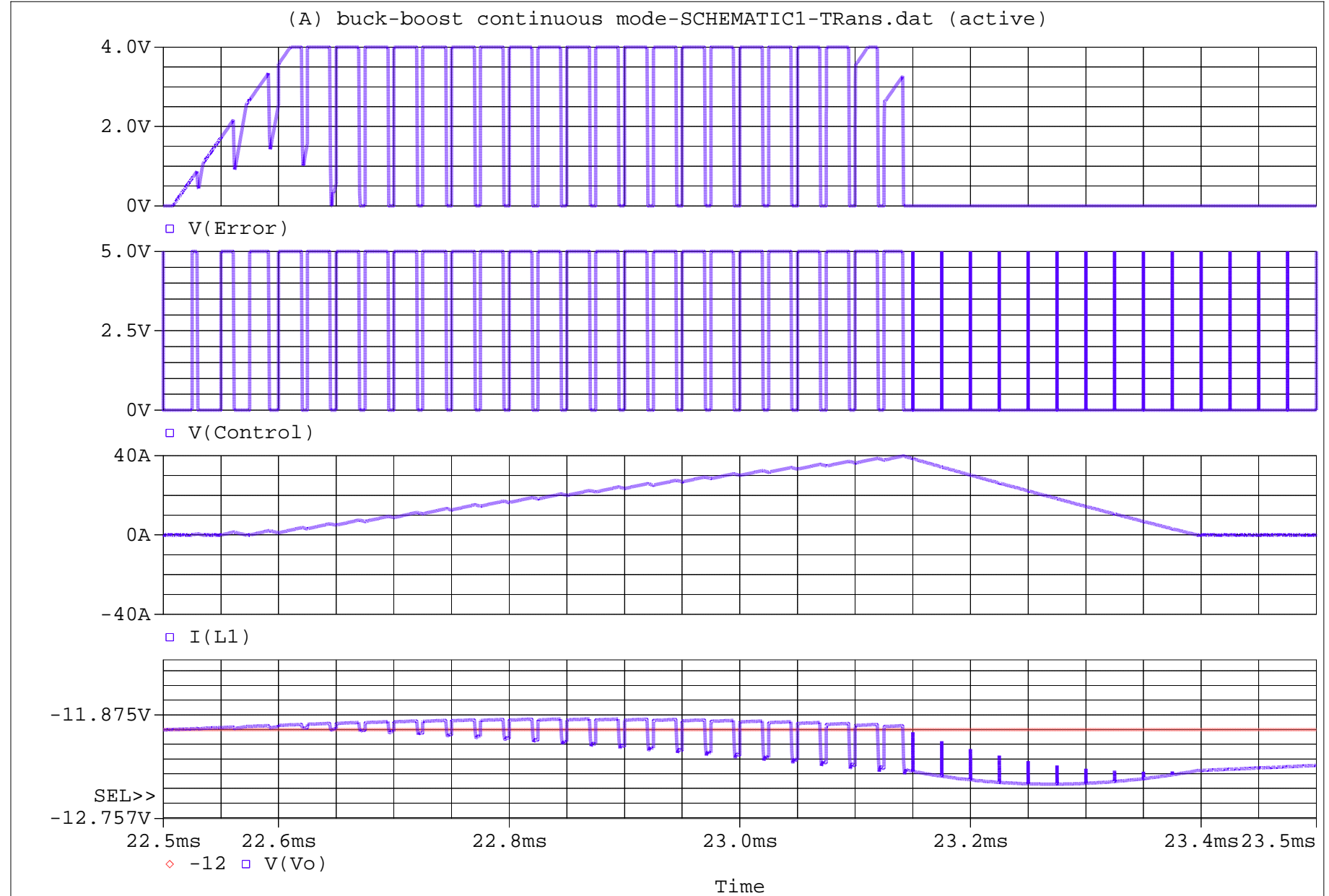


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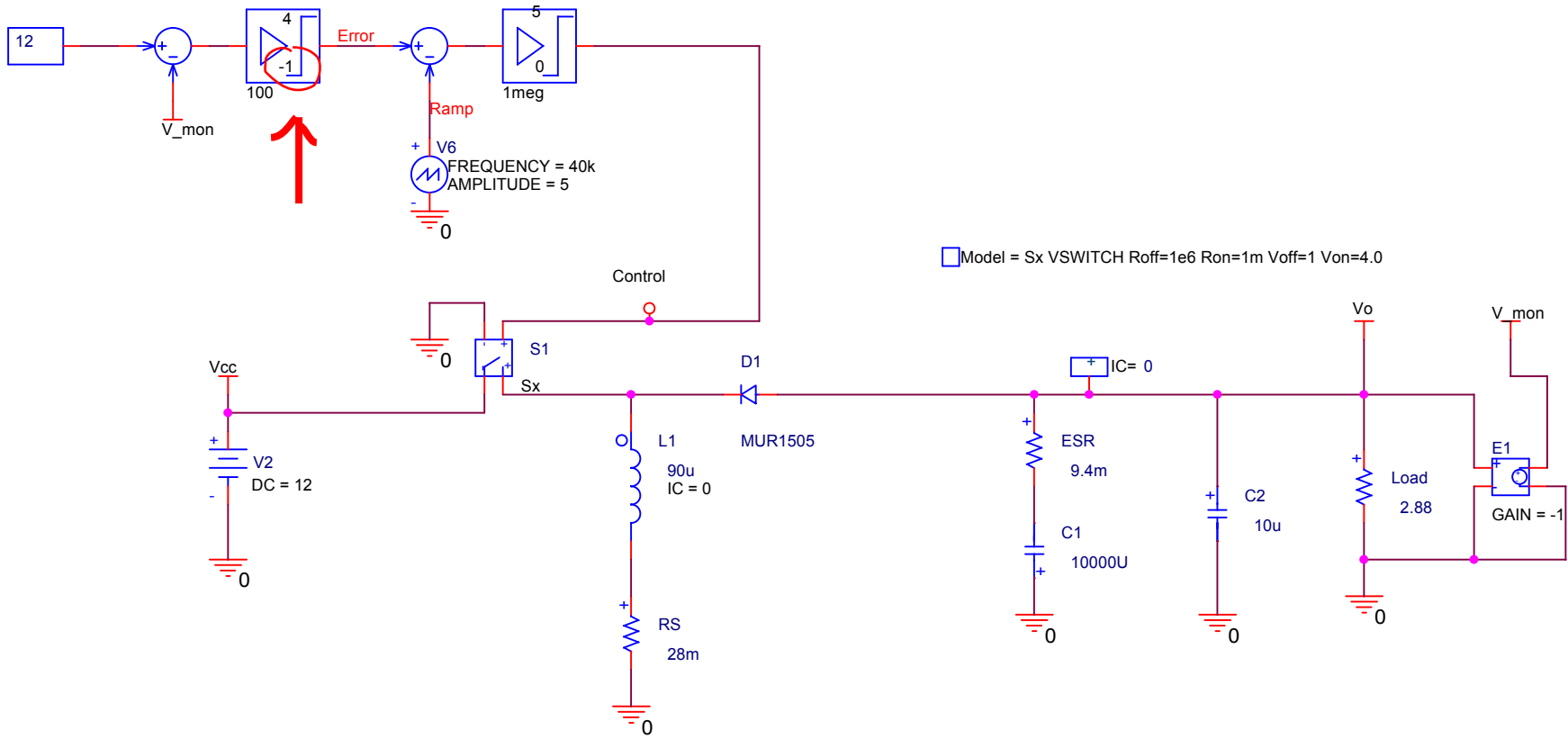
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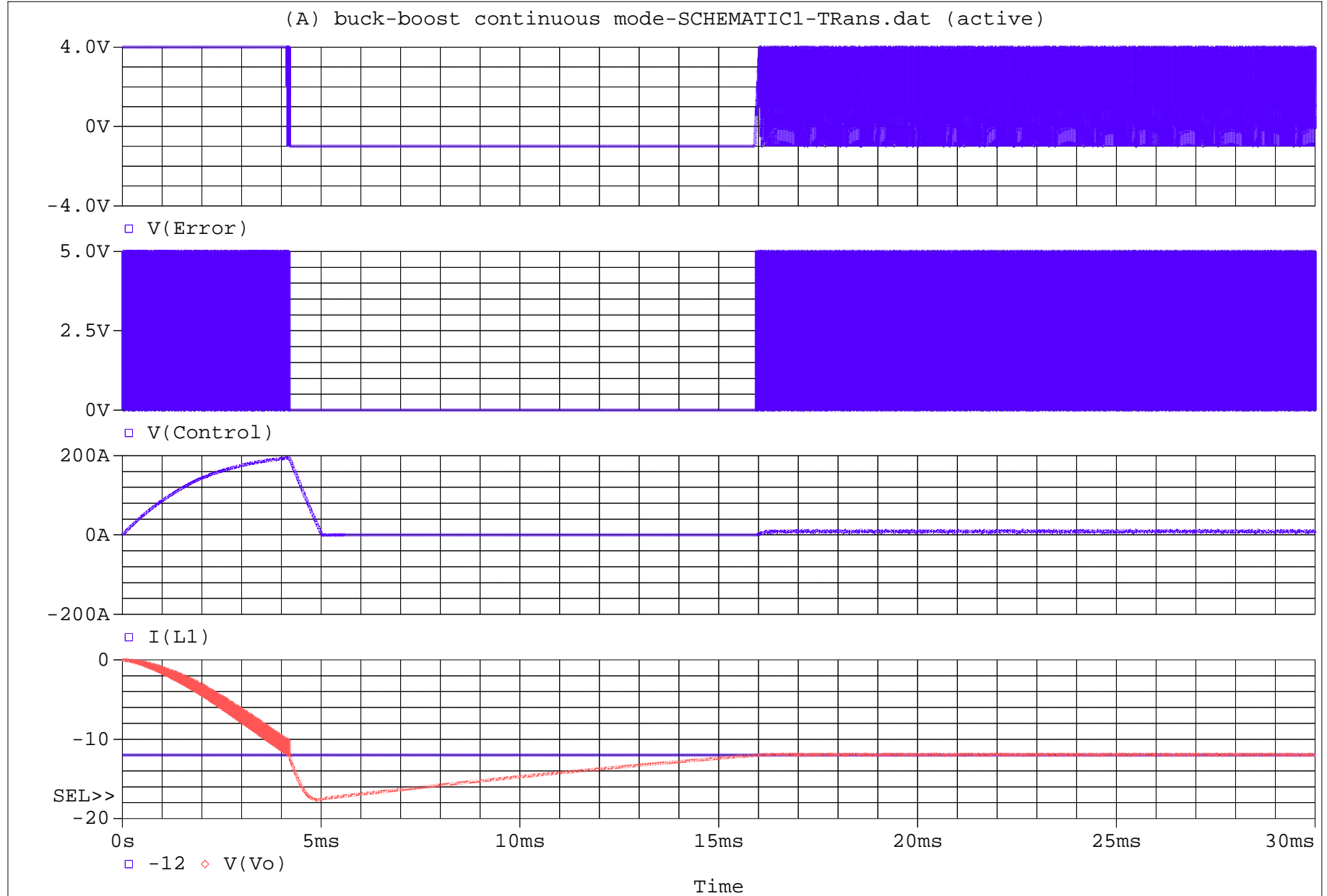
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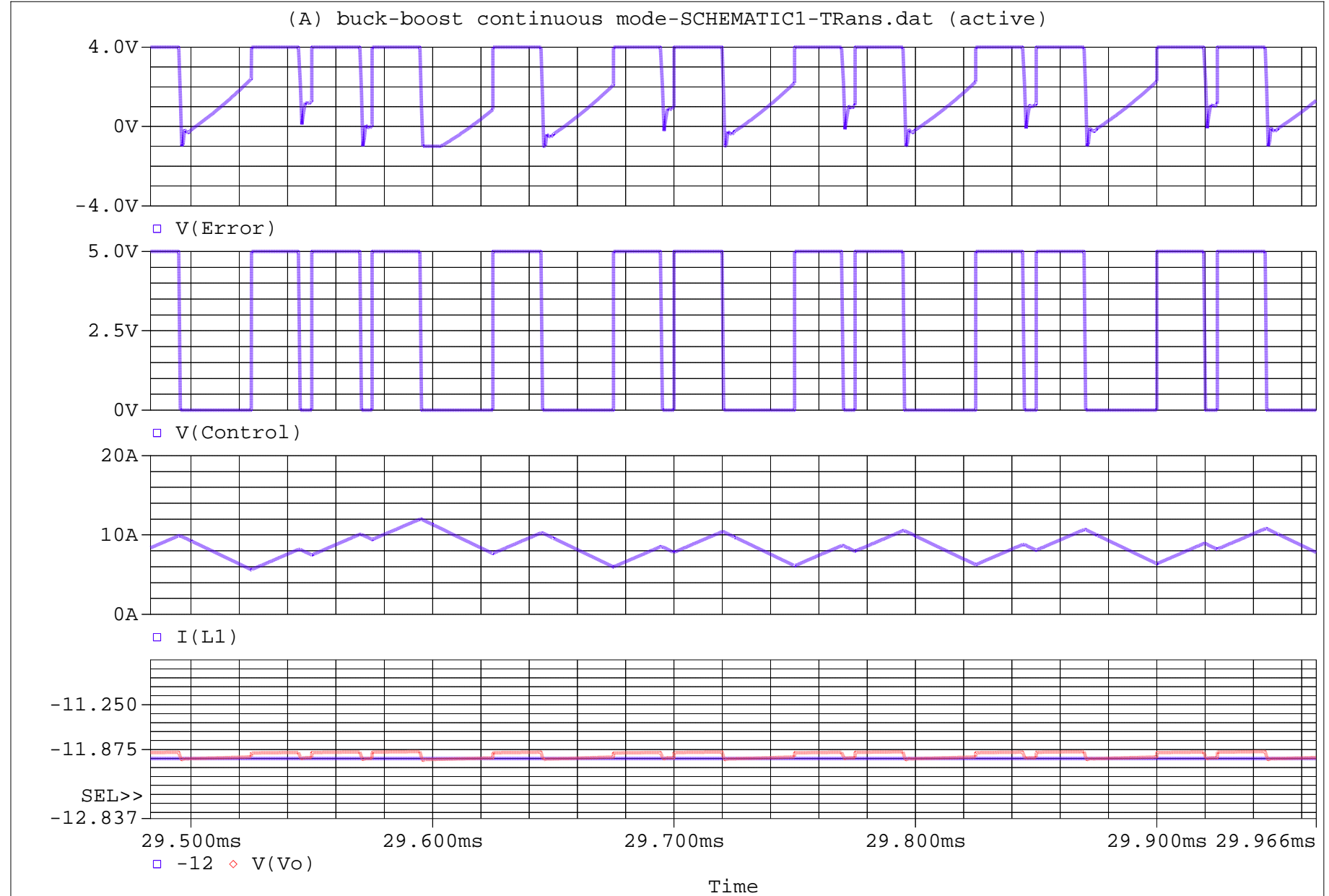


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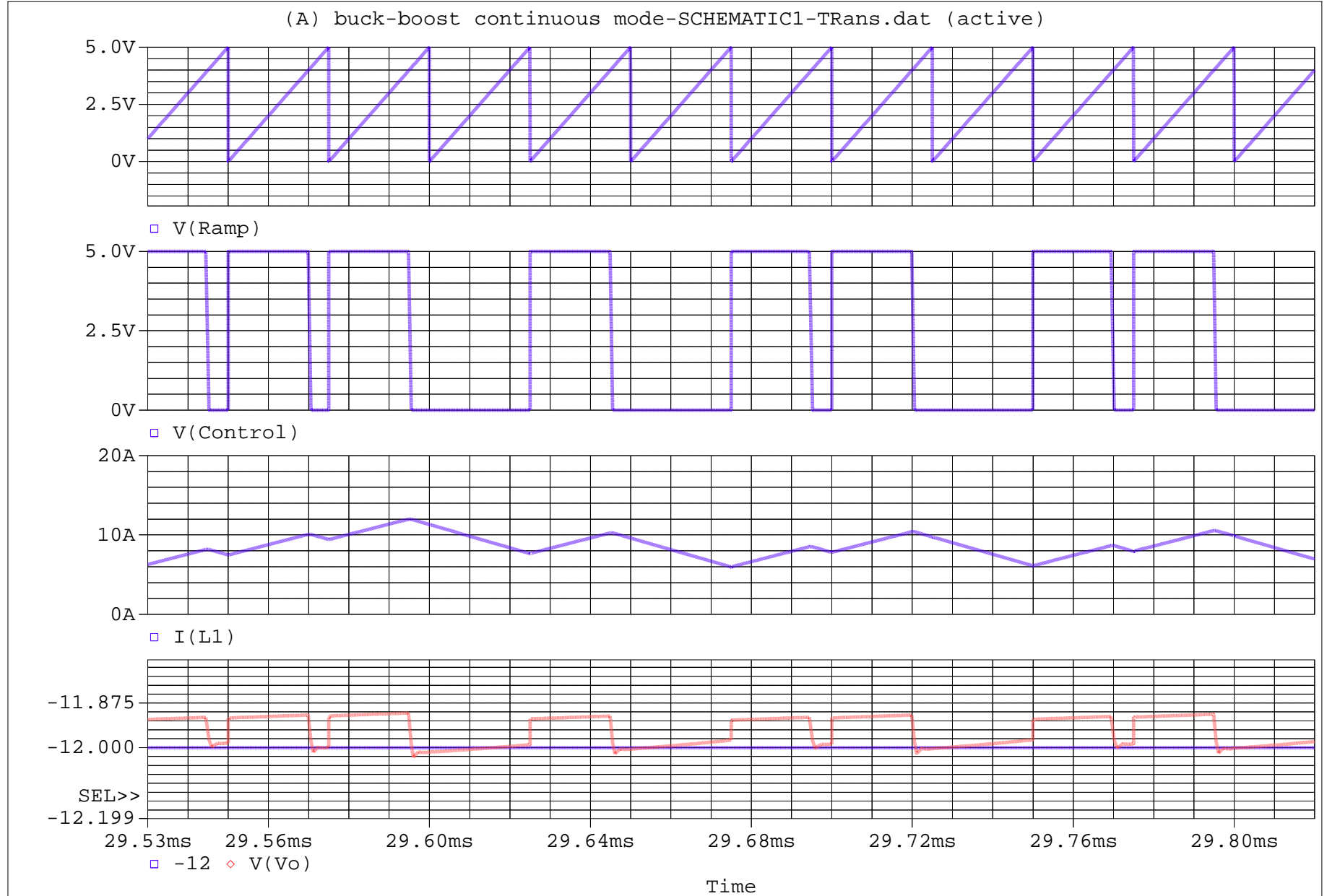


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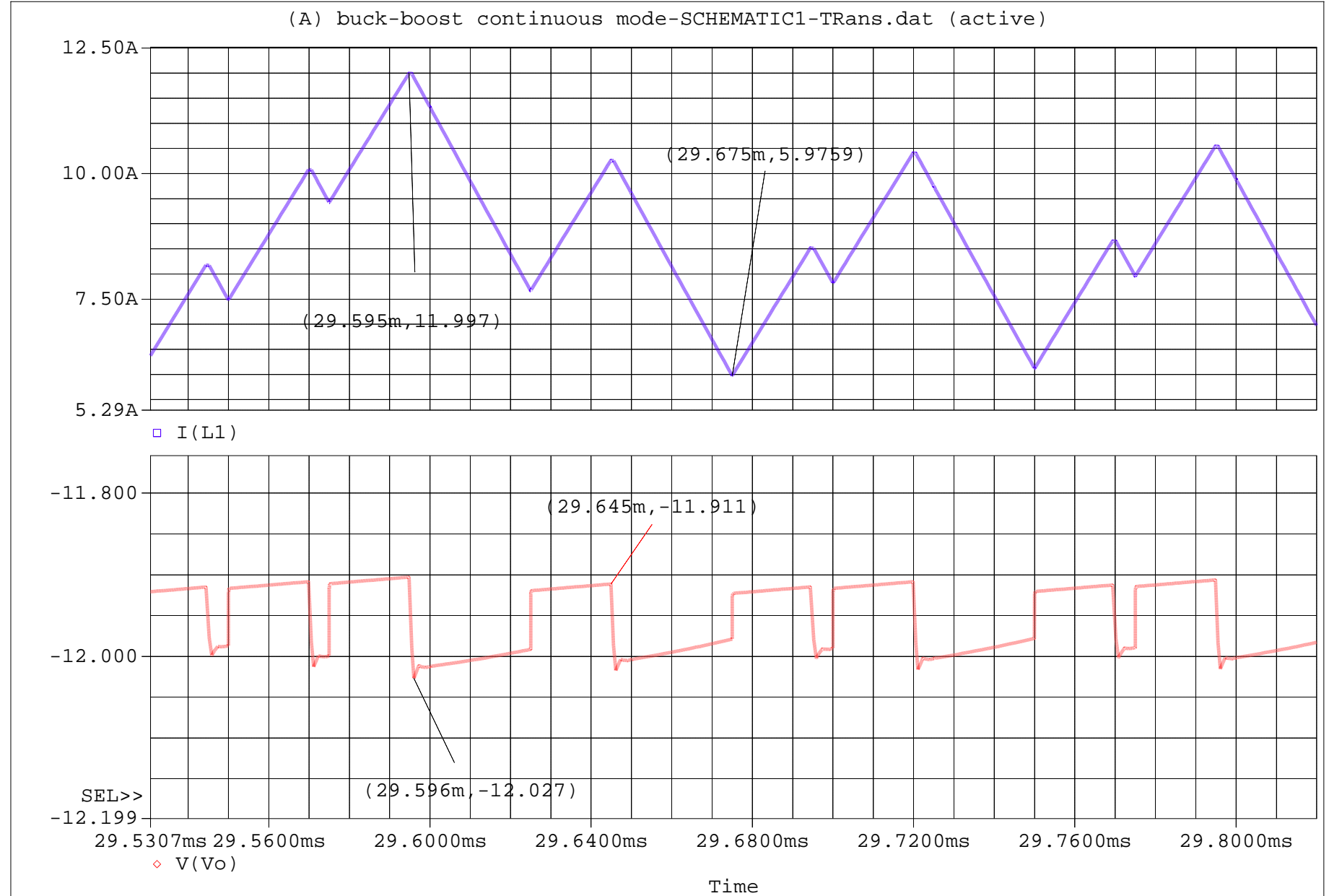


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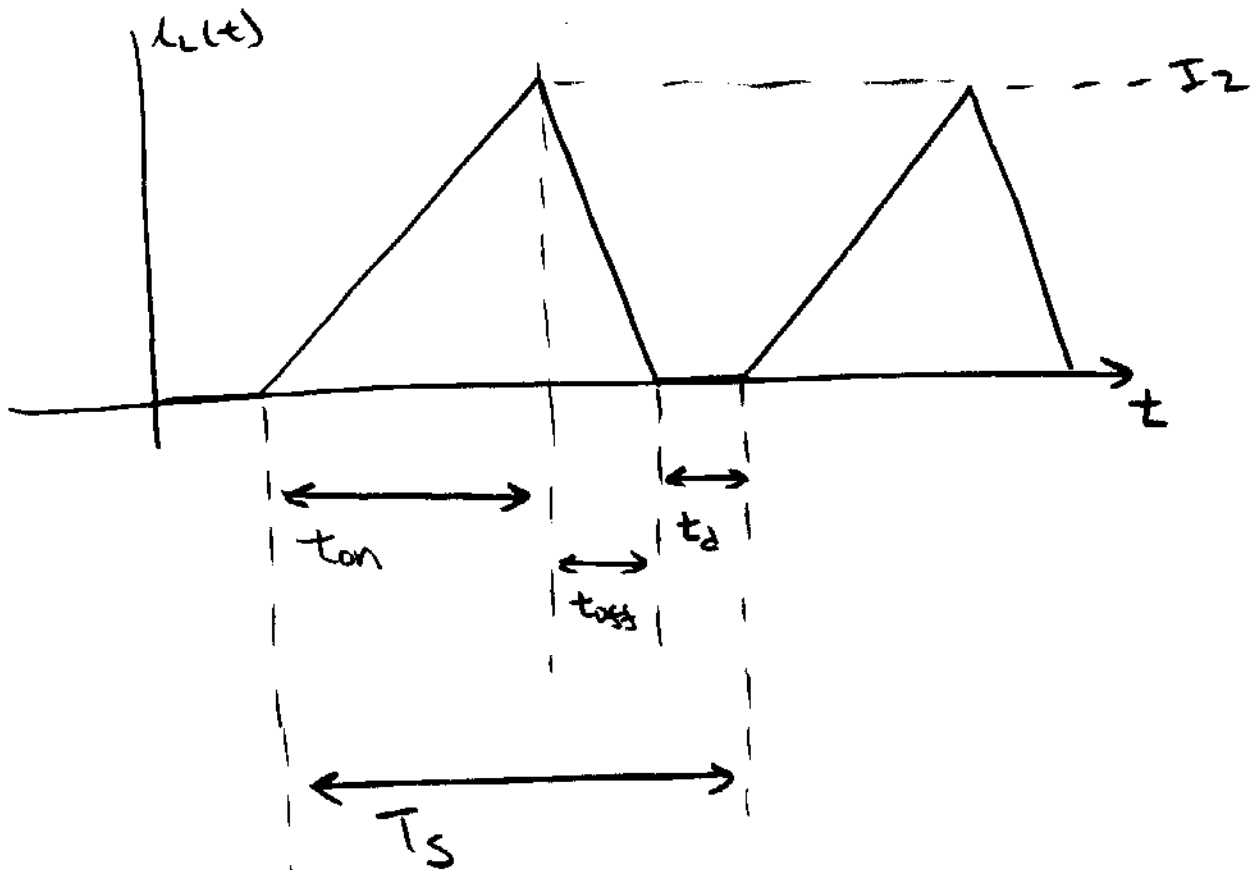
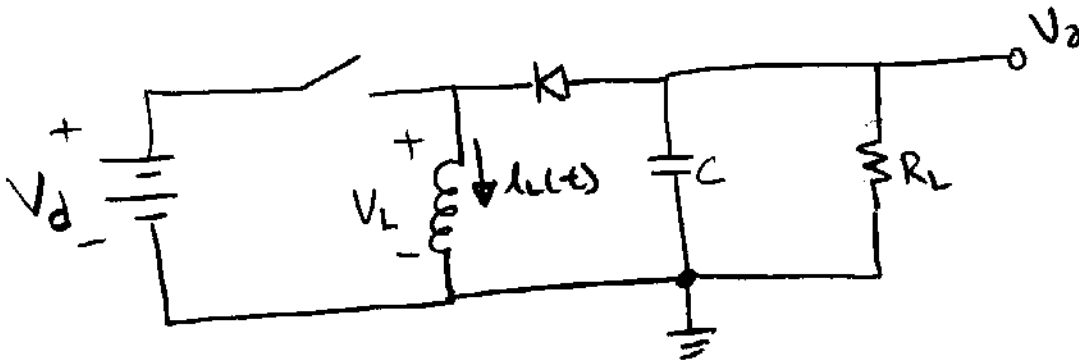
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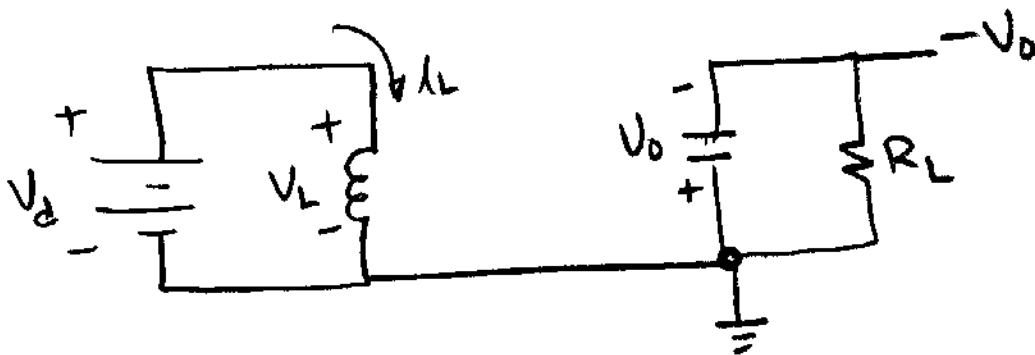
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BUCK-BOOST Regulator

Discontinuous mode



During t_{on} we have



For the inductor, $V_L = L \frac{dI_L}{dt}$

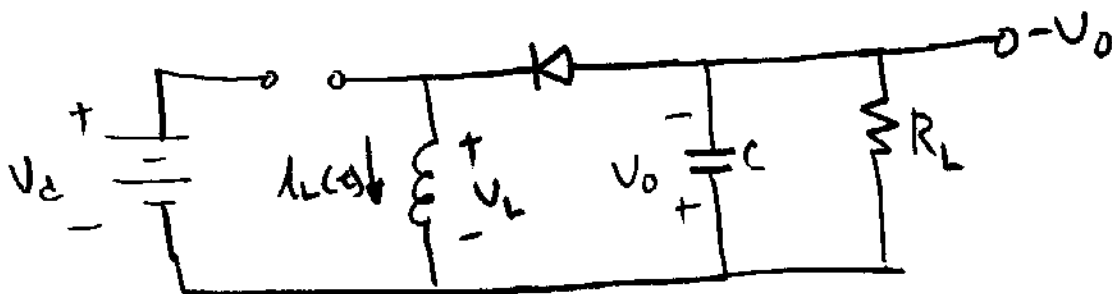
$$I_L(t) = \frac{1}{L} \int V_L(t) dt + I_{L.C.}$$

OR

$$I_2 = \frac{1}{L} \int_0^{t_{on}} V_d dt$$

$$I_2 = \frac{V_d t_{on}}{L} \quad \text{①}$$

During t_{off} We have



- Diode is Ideal

- $D = ON$

- $V_L = -V_o$

For the inductor $V_L = L \frac{di_L}{dt}$

$$i_L(t) = \frac{1}{L} \int V_L(t) dt + I_2$$

OR

$$0 = \frac{1}{L} \int_{t_{on}}^{t_{on} + t_{off}} (-V_o) dt + I_2$$

$$I_2 = \frac{V_o t_{off}}{L} \quad \textcircled{2}$$

- To ensure discontinuous mode operation

Choose $t_d = 0.2 T_s$

$$\Rightarrow t_{on} + t_{off} \leq 0.8 T_s \quad (3)$$

Energy balance

- Energy dissipated by load during a cycle

$$E_o = V_o I_o T_s$$

- During t_{off} , all energy stored in L is delivered to load

$$E_L = \frac{1}{2} L I_2^2$$

but from (1), $I_2 = \frac{V_d t_{on}}{L}$

So

$$E_L = \frac{1}{2} L \left(\frac{V_d^2 t_{on}^2}{L^2} \right)$$

$$E_L = \frac{V_d^2 t_{on}^2}{2L}$$

Energy balance

$$E_L = E_o$$

$$\frac{V_d^2 t_{on}^2}{2L} = V_o I_o T_s$$

$$\boxed{V_o = \frac{V_d^2 t_{on}^2}{2L I_o T_s}} \quad (4)$$

BUCK-BOOST Summary

Discontinuous mode

$$\left. \begin{aligned} I_2 &= \frac{V_d t_{on}}{L} \\ I_2 &= \frac{V_o t_{off}}{L} \end{aligned} \right\} \Rightarrow \frac{t_{on}}{t_{off}} = \frac{V_o}{V_d}$$

$$t_{on} + t_{off} \leq 0.8 T_s$$

$$V_o = \frac{V_d^2 t_{on}^2}{2L I_o T_s}$$

$$I_o \leq \frac{V_d t_{on}}{2L} (1-D) \quad \text{For discontinuous mode}$$

EE 456

Buck-Boost Regulator Design Discontinuous Mode Operation

$$\text{m}\Omega \equiv \Omega \cdot 0.001 \quad \mu\text{s} := \text{sec} \cdot 10^{-6} \quad \mu\text{J} := \text{joule} \cdot 10^{-6}$$

Specify Input Voltage $V_D := 12 \cdot \text{volt}$

Specify Output Voltage $V_o := -12 \cdot \text{volt}$

Specify Switching Frequency $F_S := 40 \cdot \text{kHz}$

$$T_S := \frac{1}{F_S} \quad T_S = 25 \mu\text{s}$$

Specify the Assumed Efficiency $\text{Eff} := 85\%$

The output Power is $P_{\text{out}} := \frac{50 \cdot \text{watt}}{\text{Eff}}$

The output current is $I_o := \left| \frac{P_{\text{out}}}{V_o} \right| \quad I_o = 4.902 \text{ amp}$

Find Ton and Toff

$$t_{\text{off}} := 1 \cdot \mu\text{s} \quad t_{\text{on}} := 1 \cdot \mu\text{s}$$

Given

$$\frac{t_{\text{on}}}{t_{\text{off}}} = \frac{|V_o|}{V_D}$$

$$t_{\text{on}} + t_{\text{off}} = 0.8 \cdot T_S$$

$$\begin{pmatrix} t_{\text{on}} \\ t_{\text{off}} \end{pmatrix} := \text{Find}(t_{\text{on}}, t_{\text{off}}) \quad t_{\text{on}} = 10 \mu\text{s} \quad t_{\text{off}} = 10 \mu\text{s}$$

Find the range of Inductors that will operate in discontinuous mode

$$D := \frac{t_{\text{on}}}{T_S} \quad L := \frac{V_D \cdot t_{\text{on}}}{2 \cdot I_o} \cdot (1 - D)$$

For discontinuous Mode, We need L less than $L = 7.344 \mu\text{H}$

Solve for the exact size inductor needed. Use the energy balance equation.

$$L := \frac{V_D^2 \cdot t_{\text{on}}^2}{2 \cdot |V_o| \cdot I_o \cdot T_S} \quad L = 4.896 \mu\text{H}$$

Find the peak current

$$I_2 := V_D \cdot \frac{t_{on}}{L} \quad I_2 = 24.51 \text{ amp}$$

Now that we know the approximate values needed for the inductor, choose a standard size inductor and then resolve the problem.

Some Pulse Engineering Specs PE-51590 $L := 14 \cdot \mu\text{H}$

$$\text{Volt_Sec} := 95 \cdot \text{volt} \cdot \mu\text{s}$$

$$\text{Energy_Storage} := 700 \cdot \mu\text{J}$$

$$I_{DC} := 10 \cdot \text{amp}$$

$$I_{\max} := \frac{\text{Volt_Sec}}{L} \quad I_{\max} = 6.786 \text{ amp}$$

$$I_{\max} := \sqrt{\frac{2 \cdot \text{Energy_Storage}}{L}} \quad I_{\max} = 10 \text{ amp}$$

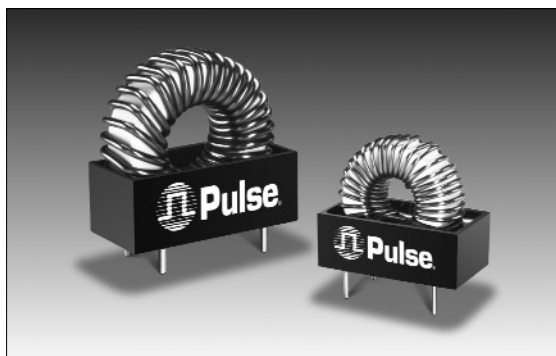
What is the saturation current of this inductor? I don't know. Use 2 in parallel to get $7 \mu\text{H}$. This will give us a different I_2 , t_{on} , t_{off} .

$$L := 7 \cdot \mu\text{H}$$

Calculate the needed I_2 to store the amount of energy needed per cycle.

$$I_2 := \sqrt{\frac{-2 \cdot V_o \cdot I_o \cdot T_S}{L}} \quad I_2 = 20.498 \text{ amp}$$

TOROIDAL INDUCTORS HIGH CURRENT



- Cost-effective designs
- Semi-encapsulated construction
- Maximum operation temperature of 130°C (Ambient + Rise)
- A 2:1 inductance swing from zero to maximum current

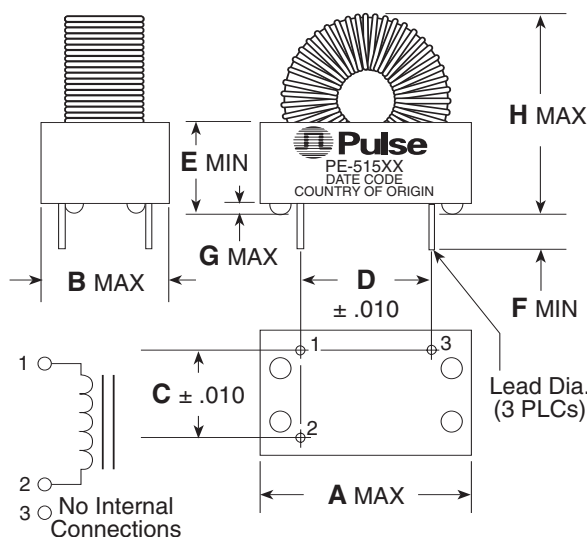
Electrical Specifications @ 25°C

Part Number	REFERENCE OPERATING VALUES					DESIGN CONTROL VALUES				
	Inductance Typical (μH) ²	I _{DC} (AMPS)	ET _{OP} ¹ (V-μSec)		Energy Storage (μJ MIN) ³	Inductance No DC (μH) (±20%)	50 kHz Test mV No DC _s	DCR (Ω MAX)	Size Code	Lead Diameter (in ±.003)
			20 kHz	40 kHz						
PE-51506	17.0	17.0	190	130	2460	40.0	140	0.0065	3	0.081
PE-51507	32.0	16.0	290	200	4100	70.7	270	0.0092	4	0.081
PE-51508	60.0	16.0	390	270	7700	120.0	470	0.012	5	0.081
PE-51509	14.0	10.0	135	95	700	28.5	73	0.009	1	0.057
PE-51510	23.0	11.0	170	120	1400	43.3	130	0.012	2	0.057
PE-51511	43.0	10.0	280	195	2150	85.5	210	0.018	3	0.057
PE-51512	90.0	10.0	430	300	4500	158.0	420	0.028	4	0.057
PE-51513	144.0	10.0	570	400	7200	262.0	700	0.032	5	0.057
PE-51514	32.0	6.6	200	140	700	60.5	110	0.025	1	0.040
PE-51515	52.0	7.0	230	160	1275	92.0	190	0.032	2	0.040
PE-51516	98.0	6.0	400	280	1765	188.0	310	0.048	3	0.040
PE-51517	175.0	6.0	620	425	3150	315.0	560	0.068	4	0.040
PE-51518	335.0	6.0	840	580	6030	571.0	1000	0.095	5	0.040
PE-51520	400	3.6	600	420	2700	688.0	640	0.130	3	0.036

NOTES:

- To prevent excessive temperature rise, limit ET_{OP} to the rated ET_{OP} specified. This is not a saturation limit. Temperature rise of inductors is 40°C MAX at MAX current and rated ET_{OP}.
- A 2:1 nominal inductance swing from no I_{DC} to operating I_{DC} gives improved protection against current discontinuities at light loading. Inductance increases with greater ET_{OP}. Reference values occur at I_{DC} and low flux density.
- $\frac{LI^2}{2}$ rating is the ability of the inductor to store energy.
- Design control test voltage is critical. Inductance increases with voltage.

Mechanicals



Size Code	1	2	3	4	5
A	1.20/30,48	1.44/36,57	1.60/40,64	1.95/49,53	2.30/58,42
B	0.60/15,24	0.80/20,32	0.80/20,32	0.91/23,11	1.11/28,19
C	0.40/10,16	0.60/15,24	0.60/15,24	0.70/17,78	0.90/22,85
D	0.80/20,32	0.90/22,86	0.90/22,86	1.20/30,48	1.50/38,10
E	0.45/11,43	0.70/17,78	0.70/17,78	0.90/22,86	1.00/25,40
F	0.20/5,08	0.20/5,08	0.20/5,08	0.20/5,08	0.20/5,08
G	.015/0,381	0.03/0,76	0.03/0,76	0.03/0,76	0.03/0,76
H	1.20/30,48	1.44/36,57	1.72/43,68	2.00/50,80	2.30/58,42

Dimensions: $\frac{\text{Inches}}{\text{mm}}$
 Unless otherwise specified, all tolerances are $\pm \frac{.010}{.25}$

Now calculate the value of t_{on} and t_{off} to get that peak current.

$$t_{\text{on}} := \frac{I_2 \cdot L}{V_D} \qquad t_{\text{on}} = 11.957 \mu\text{s}$$

$$t_{\text{off}} := \frac{I_2 \cdot L}{-V_o} \qquad t_{\text{off}} = 11.957 \mu\text{s}$$

If $t_{\text{on}} + t_{\text{off}} > T_S$ then the inductor is too big and the regulator will operate in the continuous mode.

$$\frac{t_{\text{on}} + t_{\text{off}}}{T_S} = 0.957$$

Calculate the dead time

$$t_d := T_S - t_{\text{on}} - t_{\text{off}} \qquad t_d = 1.086 \mu\text{s}$$

This dead time is too small. Try another inductor.

EE 456

Buck-Boost Regulator Design Discontinuous Mode Operation

$$\text{m}\Omega \equiv \Omega \cdot 0.001 \quad \mu\text{s} := \text{sec} \cdot 10^{-6} \quad \mu\text{J} := \text{joule} \cdot 10^{-6}$$

Specify Input Voltage $V_D := 12 \cdot \text{volt}$

Specify Output Voltage $V_o := -12 \cdot \text{volt}$

Specify Switching Frequency $F_S := 40 \cdot \text{kHz}$

$$T_S := \frac{1}{F_S} \quad T_S = 25 \mu\text{s}$$

Specify the Assumed Efficiency $\text{Eff} := 85\%$

The output Power is $P_{\text{out}} := \frac{50 \cdot \text{watt}}{\text{Eff}}$

The output current is $I_o := \left| \frac{P_{\text{out}}}{V_o} \right| \quad I_o = 4.902 \text{ amp}$

Find Ton and Toff

$$t_{\text{off}} := 1 \cdot \mu\text{s} \quad t_{\text{on}} := 1 \cdot \mu\text{s}$$

Given

$$\frac{t_{\text{on}}}{t_{\text{off}}} = \frac{|V_o|}{V_D}$$

$$t_{\text{on}} + t_{\text{off}} = 0.8 \cdot T_S$$

$$\begin{pmatrix} t_{\text{on}} \\ t_{\text{off}} \end{pmatrix} := \text{Find}(t_{\text{on}}, t_{\text{off}}) \quad t_{\text{on}} = 10 \mu\text{s} \quad t_{\text{off}} = 10 \mu\text{s}$$

Find the range of Inductors that will operate in discontinuous mode

$$D := \frac{t_{\text{on}}}{T_S} \quad L := \frac{V_D \cdot t_{\text{on}}}{2 \cdot I_o} \cdot (1 - D)$$

For discontinuous Mode, We need L less than $L = 7.344 \mu\text{H}$

Solve for the exact size inductor needed. Use the energy balance equation.

$$L := \frac{V_D^2 \cdot t_{\text{on}}^2}{2 \cdot |V_o| \cdot I_o \cdot T_S} \quad L = 4.896 \mu\text{H}$$

Find the peak current

$$I_2 := V_D \cdot \frac{t_{on}}{L} \quad I_2 = 24.51 \text{ amp}$$

Now that we know the approximate values needed for the inductor, choose a standard size inductor and then resolve the problem.

Some Pulse Engineering Specs PE-51590 $L := 22 \cdot \mu\text{H}$

$$\text{Volt_Sec} := 44 \cdot \text{volt} \cdot \mu\text{s} \quad \text{Energy_Storage} := 275 \cdot \mu\text{J}$$

$$I_{DC} := 5 \cdot \text{amp}$$

$$I_{\max} := \frac{\text{Volt_Sec}}{L} \quad I_{\max} = 2 \text{ amp}$$

$$I_{\max} := \sqrt{\frac{2 \cdot \text{Energy_Storage}}{L}} \quad I_{\max} = 5 \text{ amp}$$

What is the saturation current of this inductor? I don't know. Use 4 in parallel to get $5.5 \mu\text{H}$. This will give us a different I_2 , t_{on} , t_{off} .

Coil Craft Inductor PCV-0-103-20 $L := 10 \cdot \mu\text{H}$

$$I_{SAT} := 20 \cdot \text{amp}$$






Use two of the coilcraft Parts in parallel.

$$L := 5 \cdot \mu\text{H}$$

LOW COST INDUCTORS

Electrical Information



-  Available in vertical, low profile and *Klipmount™*
-  SMPS averaging filter
-  Characterized for general purpose use and ripple filters
-  Single-layer designs
-  Can be used as differential mode inductors in EMI filters³

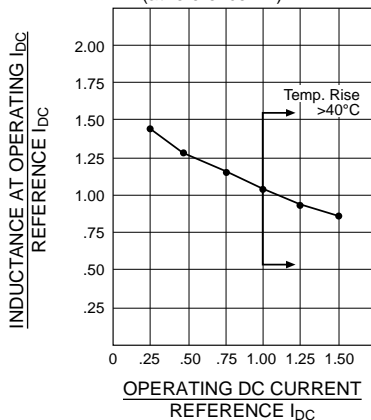
Electrical Specifications @ 25°C — Operating Temperature -30°C to 130°C

REFERENCE OPERATING VALUES						DESIGN CONTROL VALUES					
Vertical Part Number	Low Profile Part Number	Inductance Typical (μH) ¹	I _{DC} (AMPS)	ET _{TOP} (V-μSec)	Energy Storage (μJ) ⁴	Inductance No DC (μHy) ±20%	20 KHz Test mV No DC ²	DCR (Ω MAX) ⁶	Coil Size Code	Klip Mount Package*	Lead Diameter (In) ±.003
PE-51591	PE-92421	20	2.0	52	40	32.8	33	.060	H	—	.020
PE-92100	—	25	2.6	30	85	20.7	22	.043	A	KM1	.020
PE-92101	PE-92401	50	2.6	50	169	45.7	45	.071	B	KM2	.020
PE-92102	PE-92402	100	2.6	90	338	94.1	90	.100	C	KM3	.020
PE-92103	—	35	2.6	55	118	28.4	36	.037	B	KM2	.025
PE-92104	PE-92404	70	3.0	85	315	61.0	73	.052	C	KM3	.025
PE-92105	PE-92405	145	3.0	140	653	141.8	140	.087	D	KM4	.025
PE-92106	—	285	3.0	300	1283	264.1	340	.140	E	KM5	.025
PE-92107	—	450	3.0	425	2025	436.3	500	.200	F	—	.025
PE-92108	PE-92408	100	3.6	130	648	90.7	110	.045	D	KM4	.032
PE-92109	—	165	4.0	240	1320	152.0	260	.070	E	KM5	.032
PE-92110	—	270	4.0	350	2160	263.9	400	.100	F	—	.032
PE-92111	—	40	4.0	70	320	37.9	57	.027	C	KM3	.032
PE-51590	PE-92420	22	5.0	44	275	20.3	37	.020	G	—	.032
PE-92112	PE-92412	100	5.0	200	1250	90.7	180	.034	E	KM5	.042
PE-92113	—	170	5.0	300	2125	159.7	310	.050	F	—	.042
PE-92114	PE-92414	55	5.0	100	688	54.9	88	.023	D	KM4	.042
PE-92115	—	95	7.0	225	2328	96.0	200	.025	F	—	.051
PE-92116	PE-92416	55	7.0	150	1348	49.1	100	.017	E	KM5	.051
PE-92117	—	55	10.0	175	2750	55.9	120	.013	F	—	.064

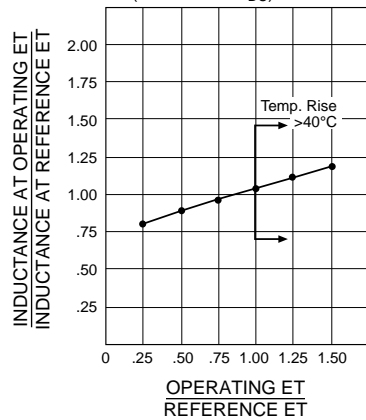
*Parts available with *KlipMount* option can be ordered by adding a "K" suffix to the part number (i.e. PE-92100K).

Relationships Between Reference and Operating Conditions

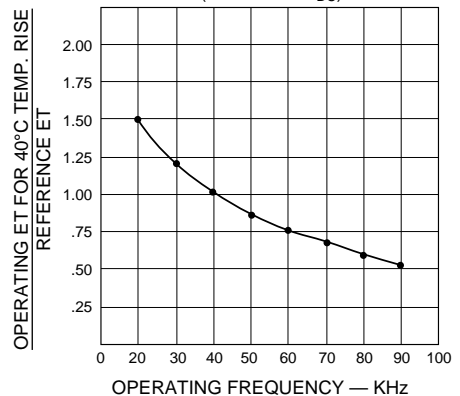
Inductance vs. DC Current (at reference ET)



Inductance vs. Operating ET (at reference I_{DC})



Max. Operating ET vs. Frequency (at reference I_{DC})



PCV-0 Series – Continued

Part Number	Inductance ¹ (μ H)	Isat ² (Amps)	Irms ³ (Amps)	DCR Max (Ω)	A Max	B Max	C $\pm .015/0,38$	D $\pm .004/0,10$
PCV-0-103-20	10 $\pm 10\%$	20	20	.006	.75/19,1	1.8/45,7	.60/15,2	.075/1,91
PCV-0-153-03	15	3	3	.025	.50/12,7	1.0/25,4	.42/10,7	.035/0,89
PCV-0-153-10	15	10	10	.020	.52/13,2	1.0/25,4	.42/10,7	.054/1,37
PCV-0-223-03	22	3	3	.035	.50/12,7	1.0/25,4	.42/10,7	.035/0,89
PCV-0-223-05	22	5	5	.023	.50/12,7	1.0/25,4	.42/10,7	.042/1,07
PCV-0-223-10	22	10	10	.015	.66/16,8	1.3/33,0	.42/10,7	.060/1,52
PCV-0-273-05	27	5	5	.024	.50/12,7	1.0/25,4	.49/12,5	.042/1,07
PCV-0-333-12	33	12	12	.017	.70/17,8	1.3/33,0	.55/14,0	.060/1,52
PCV-0-473-03	47	3	3	.050	.55/14,0	1.0/25,4	.42/10,7	.035/0,89
PCV-0-473-05	47	5	5	.035	.65/16,5	1.1/28,0	.70/17,8	.042/1,07
PCV-0-473-10	47	10	10	.022	.85/21,6	1.3/33,0	.70/17,8	.060/1,52
PCV-0-823-03	82	3	3	.110	.50/12,7	.65/16,5	.375/9,5	.028/0,71
PCV-0-104-01	100	1	1	.190	.40/10,2	.90/22,9	.30/7,6	.020/0,51
PCV-0-104-03	100	3	3	.072	.55/14,0	1.2/30,5	.70/17,8	.035/0,89
PCV-0-104-05	100	5	5	.055	.65/16,5	1.3/33,0	.70/17,8	.042/1,07
PCV-0-154-03	150	3	3	.140	.60/15,2	1.2/30,5	.43/10,9	.028/0,71
PCV-0-154-05	150	5	5	.065	.65/16,5	1.3/33,0	.70/17,8	.042/1,07
PCV-0-184-05	180	5	5	.110	.60/15,2	1.2/30,5	.43/10,9	.035/0,89
PCV-0-224-03	220	3	3	.210	.55/14,0	1.2/30,5	.42/10,7	.025/0,64
PCV-0-274-04	270	4	4	.250	.95/24,0	.72/18,3	.71/18,0	.030/0,76
PCV-0-274-10	270	10	10	.160	1.1/28,0	1.0/25,4	.72/18,3	.038/0,97
PCV-0-394-03	390	3	3	.250	1.1/28,0	1.0/25,4	.72/18,3	.035/0,89
PCV-0-394-05	390	5	5	.190	1.1/28,0	1.0/25,4	.72/18,3	.038/0,97

PCV-1 Series

Part Number	Inductance ¹ (μ H)	Isat ² (Amps)	Irms ³ (Amps)	DCR Max (Ω)	A Max	B Max	C $\pm .015/0,38$	D $\pm .004/0,10$
PCV-1-152-15	1.5 $\pm 15\%$	15	15	.003	.65/16,5	.90/22,9	.42/10,7	.068/1,73
PCV-1-182-10	1.8	10	10	.006	.65/16,5	1.1/27,9	.42/10,7	.054/1,37
PCV-1-182-15	1.8	15	15	.003	.65/16,5	1.1/27,9	.42/10,7	.068/1,73
PCV-1-472-03	4.7	3	3	.021	.62/15,7	.85/21,6	.42/10,7	.035/0,89
PCV-1-472-05	4.7	5	5	.012	.62/15,7	.85/21,6	.42/10,7	.042/1,07
PCV-1-472-10	4.7	10	10	.012	.62/15,7	1.1/27,9	.42/10,7	.054/1,37
PCV-1-103-03	10 $\pm 10\%$	3	3	.026	.63/16,0	.85/21,6	.42/10,7	.035/0,89
PCV-1-103-05	10	5	5	.020	.62/15,7	.85/21,6	.42/10,7	.042/1,07
PCV-1-103-10	10	10	10	.013	.63/16,0	1.1/27,9	.42/10,7	.054/1,37
PCV-1-153-10	15	10	10	.020	.70/17,8	1.4/35,6	.42/10,7	.060/1,52
PCV-1-223-03	22	3	3	.035	.62/15,7	1.1/27,9	.42/10,7	.035/0,89
PCV-1-223-05	22	5	5	.023	.62/15,7	1.1/27,9	.42/10,7	.042/1,07
PCV-1-223-10	22	10	10	.018	.70/17,8	1.4/35,6	.42/10,7	.060/1,52
PCV-1-473-03	47	3	3	.050	.65/16,5	1.1/27,9	.42/10,7	.035/0,89
PCV-1-473-05	47	5	5	.033	.90/22,9	1.2/30,5	.70/17,8	.042/1,07
PCV-1-473-10	47	10	10	.022	.90/22,9	1.4/35,6	.70/17,8	.060/1,52
PCV-1-104-03	100	3	3	.072	.90/22,9	1.3/33,1	.70/17,8	.035/0,89
PCV-1-104-05	100	5	5	.055	.90/22,9	1.4/35,6	.70/17,8	.042/1,07
PCV-1-184-03	180	3	3	.150	.63/16,0	1.2/30,5	.42/10,7	.028/0,71
PCV-1-304-05	300	5	5	.160	1.1/27,9	1.0/25,4	.70/17,8	.038/0,97
PCV-1-394-05	390	5	5	.190	1.1/27,9	1.0/25,4	.70/17,8	.038/0,97

¹ Tested at 15.75 kHz, .1 Vrms, with DC bias applied up to the rated current.

² Inductance drop = 10% typ. at Isat.

³ $\Delta T = 40^\circ\text{C}$ rise typ. at Irms (85°C ambient).

Parts in bold type are included in Coilcraft Designer's Kit No. P205.



Specifications subject to change without notice. Document 135-2 Revised 7/31/00

1102 Silver Lake Road Cary, Illinois 60013 Phone 847/639-6400 Fax 847/639-1469

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Calculate the needed I_2 to store the amount of energy needed per cycle.

$$I_2 := \sqrt{\frac{-2 \cdot V_o \cdot I_o \cdot T_S}{L}} \quad I_2 = 24.254 \text{ amp}$$

Now calculate the value of t_{on} and t_{off} to get that peak current.

$$t_{\text{on}} := \frac{I_2 \cdot L}{V_D} \quad t_{\text{on}} = 10.106 \mu\text{s}$$

$$t_{\text{off}} := \frac{I_2 \cdot L}{-V_o} \quad t_{\text{off}} = 10.106 \mu\text{s}$$

If $t_{\text{on}} + t_{\text{off}} > T_S$ then the inductor is too big and the regulator will operate in the continuous mode.

$$\frac{t_{\text{on}} + t_{\text{off}}}{T_S} = 0.808$$

Calculate the dead time

$$t_d := T_S - t_{\text{on}} - t_{\text{off}} \quad t_d = 4.789 \mu\text{s}$$

This dead time is OK.

Choose the filter capacitor using the capacitor ESR.

Specify the ripple due to the ESR $V_{CR} := 100 \cdot \text{mV}$

$$\text{ESR} := \frac{V_{CR}}{I_2} \quad \text{ESR} = 4.123 \text{ m}\Omega$$

For all electrolytic caps, assume that $\text{ESR} \cdot C = 80 \text{ms}$

$$C := \frac{80 \cdot \mu\text{s}}{\text{ESR}} \quad C = 19403 \mu\text{F}$$

Choose the next size std capacitor $C := 22000 \cdot \mu\text{F}$

Calculate the Capacitor RMS Ripple Current

Define a function for the inductor current $I_L(t) := I_2 - \frac{I_2}{t_{\text{off}}} \cdot t$

$$I_{\text{rms}} := \sqrt{\frac{1}{T_S} \cdot \left[\int_{0 \cdot \text{sec}}^{t_{\text{on}} + t_d} (-I_0)^2 dt + \int_{0 \cdot \text{sec}}^{t_{\text{off}}} (I_L(t) - I_0)^2 dt \right]}$$

$$I_{\text{rms}} = 7.432 \text{ amp}$$

Summary

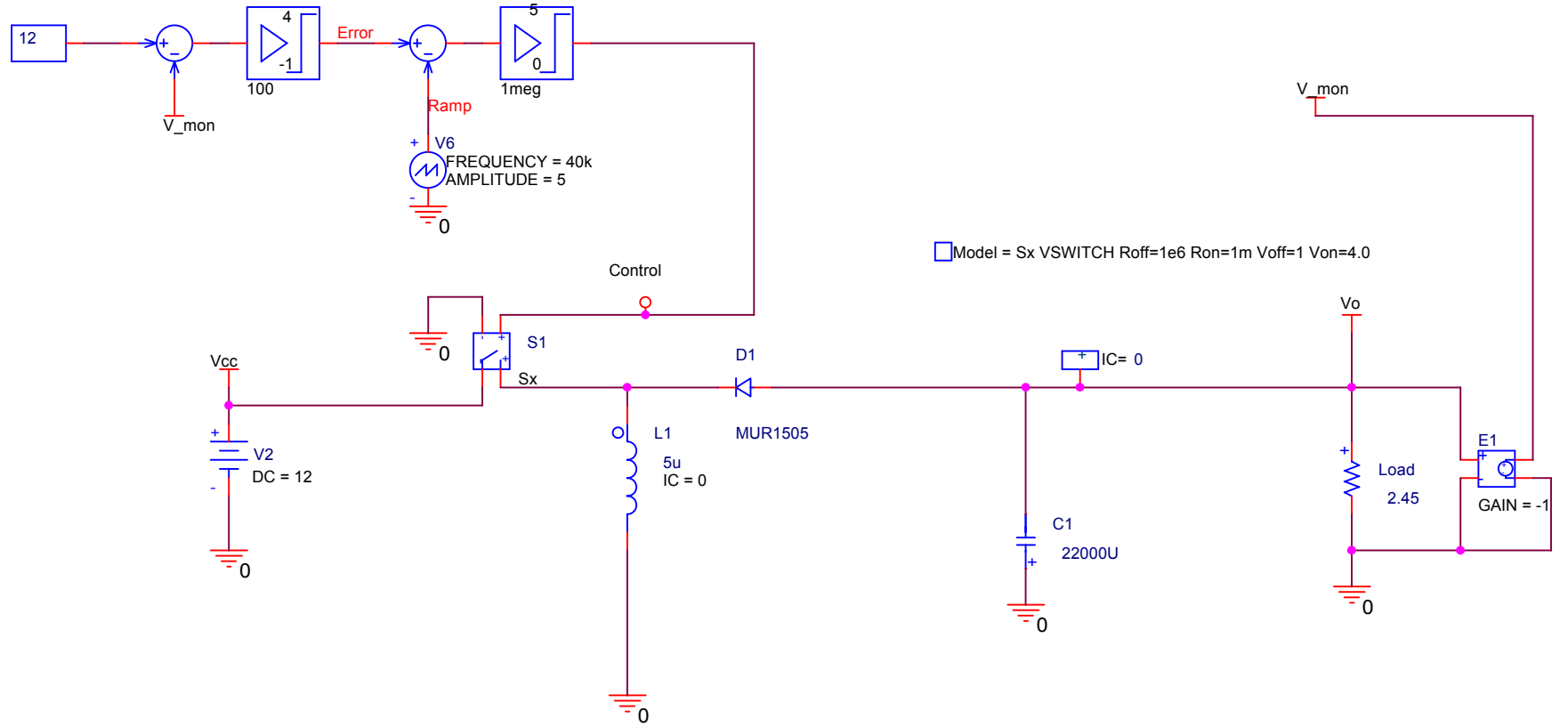
$$L = 5 \mu\text{H} \quad I_2 = 24.254 \text{ amp}$$

$$t_{\text{on}} = 10.106 \mu\text{s} \quad t_{\text{off}} = 10.106 \mu\text{s}$$

$$V_D = 12 \text{ volt} \quad V_o = -12 \text{ volt} \quad I_o = 4.902 \text{ amp}$$

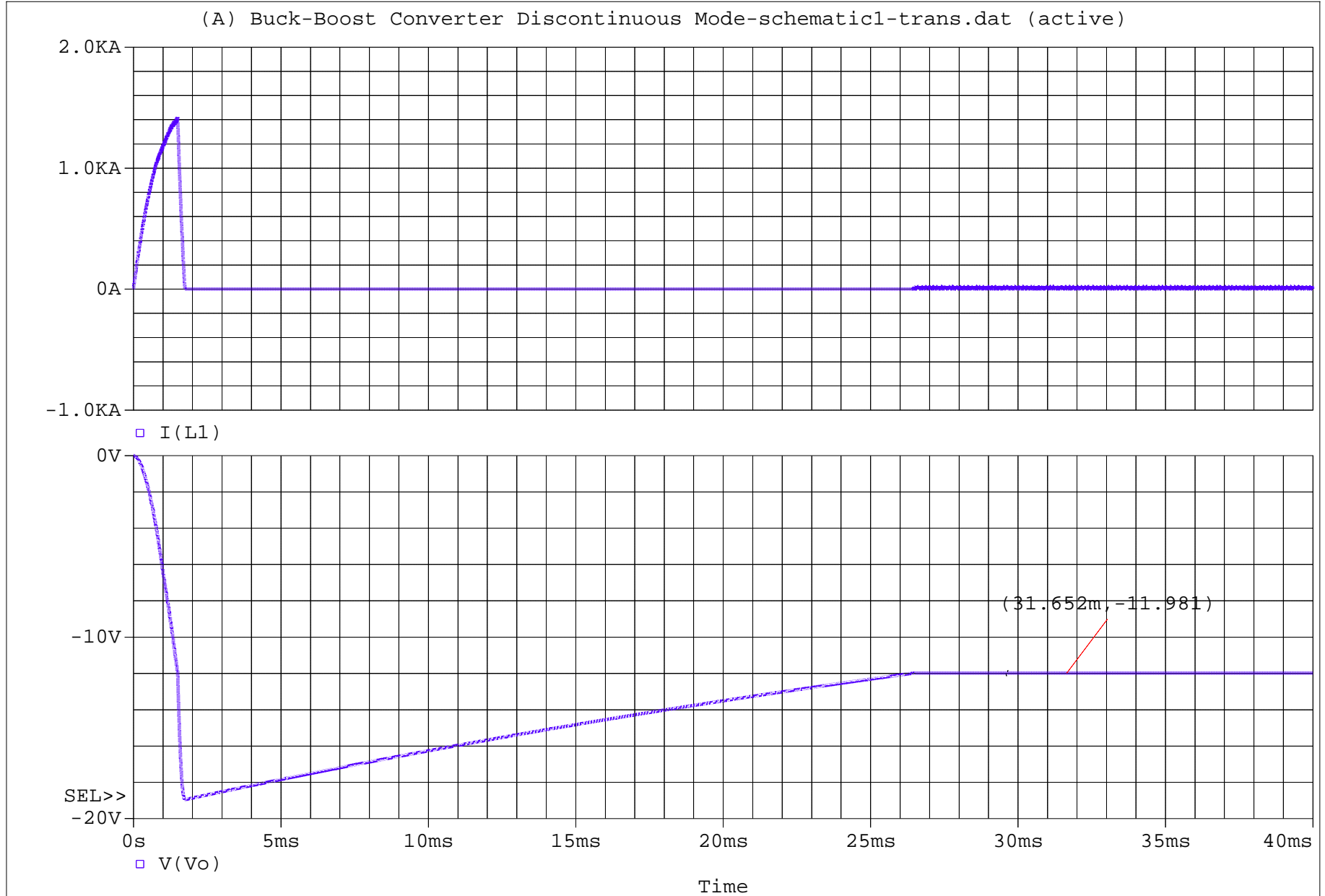
$$C = 22000 \mu\text{F} \quad V_{\text{CR}} = 100 \text{ mV}$$

$$I_{\text{rms}} = 7.432 \text{ amp}$$



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		Name: Marc E. Herniter Class: ECE456	
Size A	Document Name		Rev 1
Date: Monday, January 13, 2003		Sheet 1 of 1	

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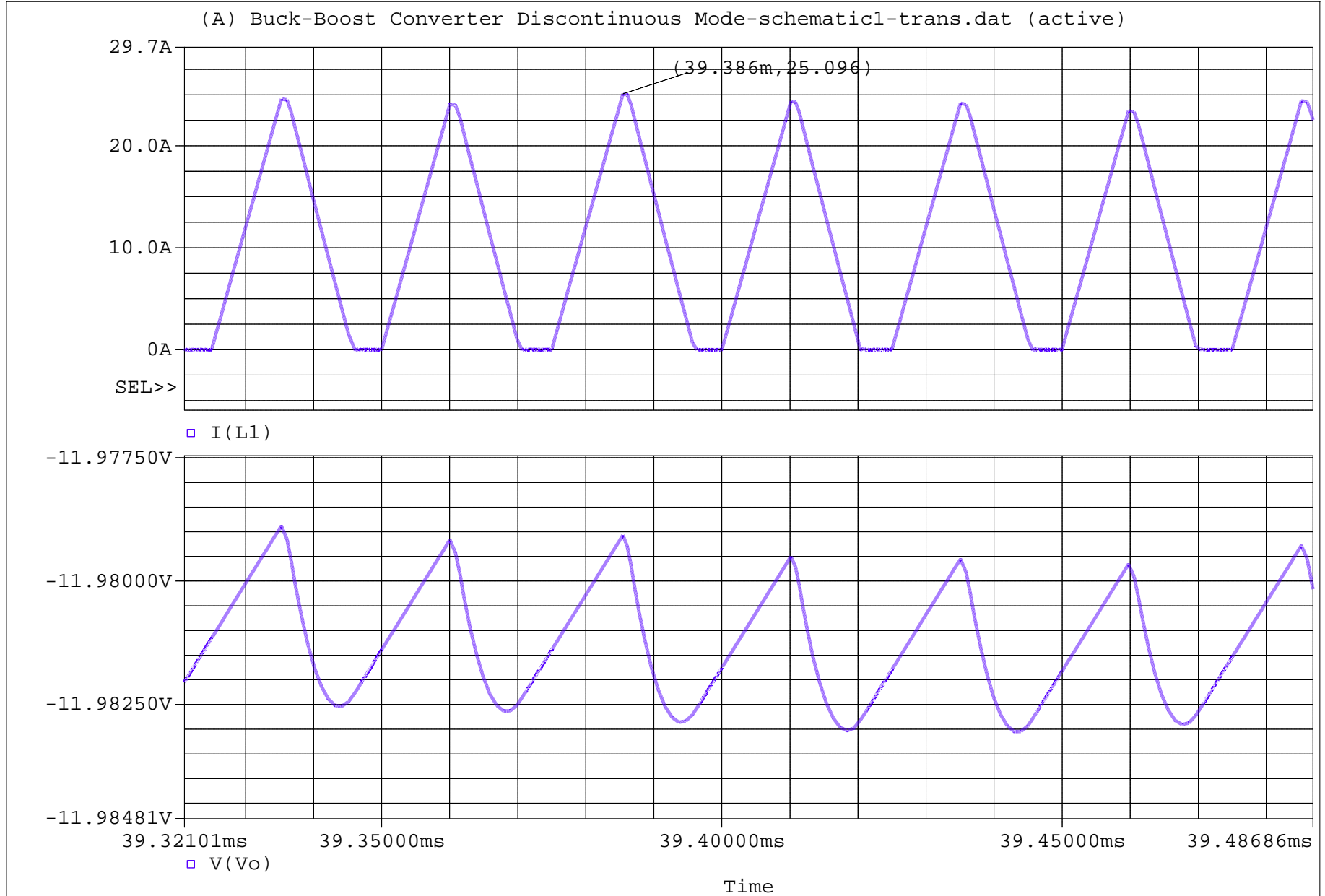


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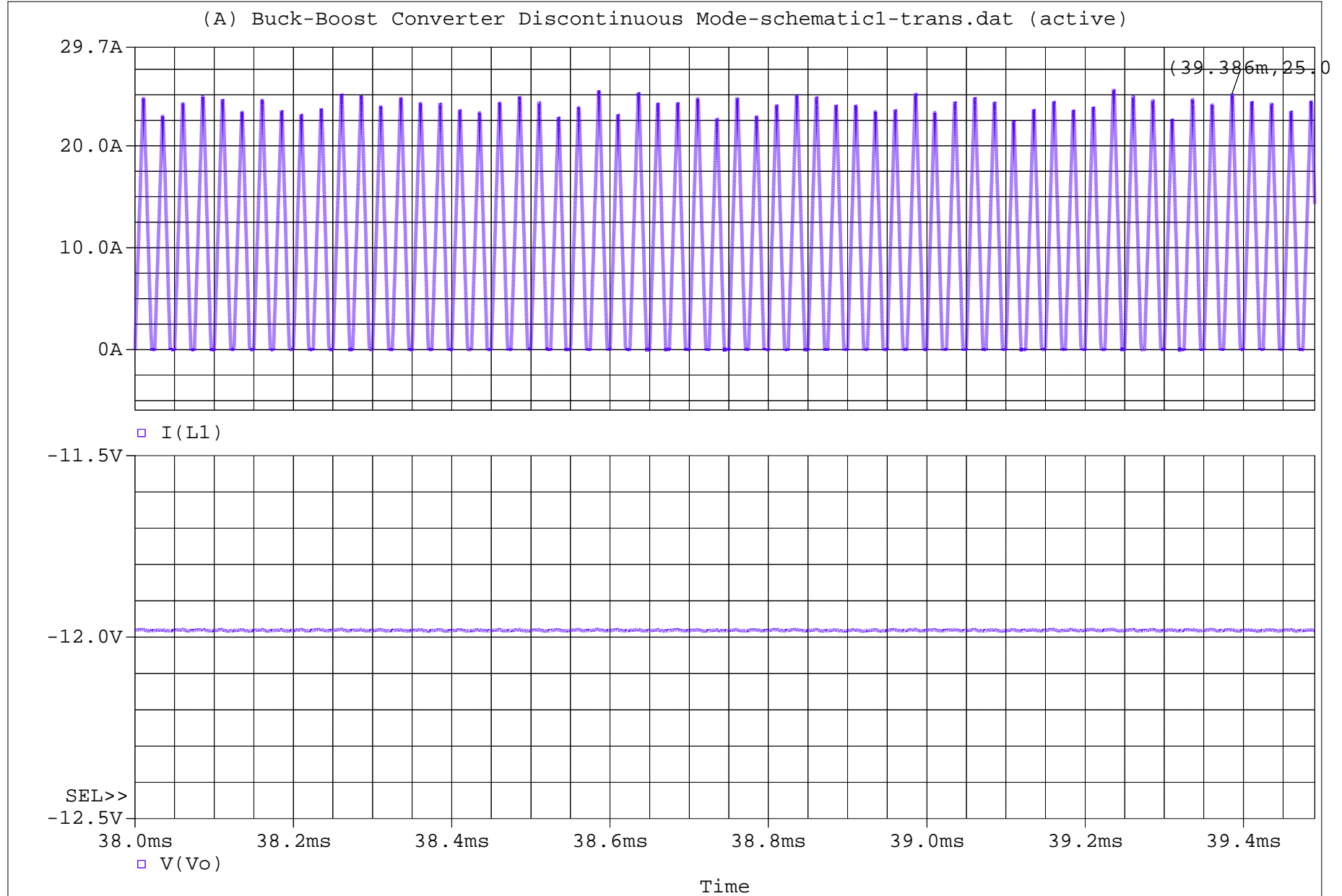


Date: January 13, 2003

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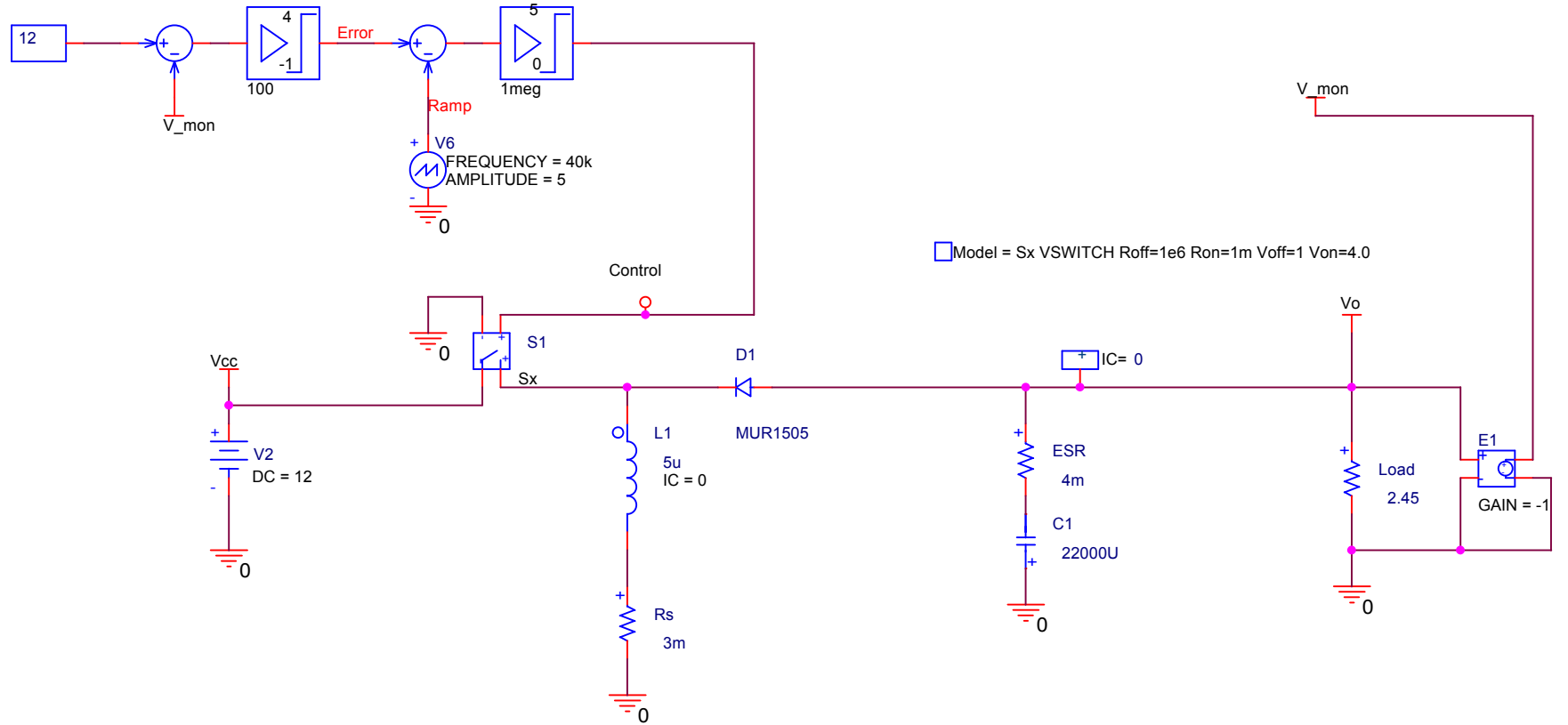
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Date: January 13, 2003

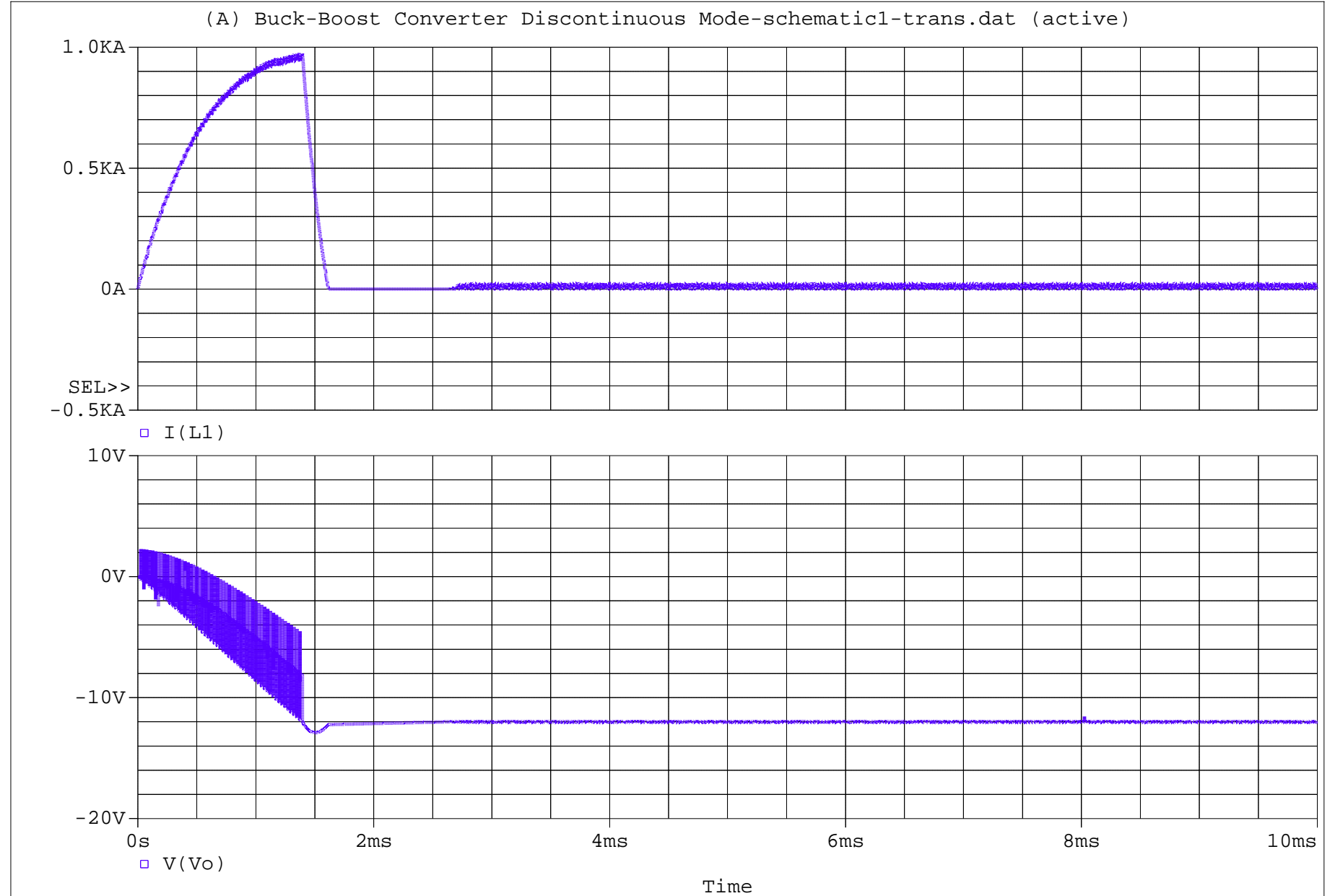
Page 1

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** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\Notes\Orcad\Buck-Boost Converter\b...
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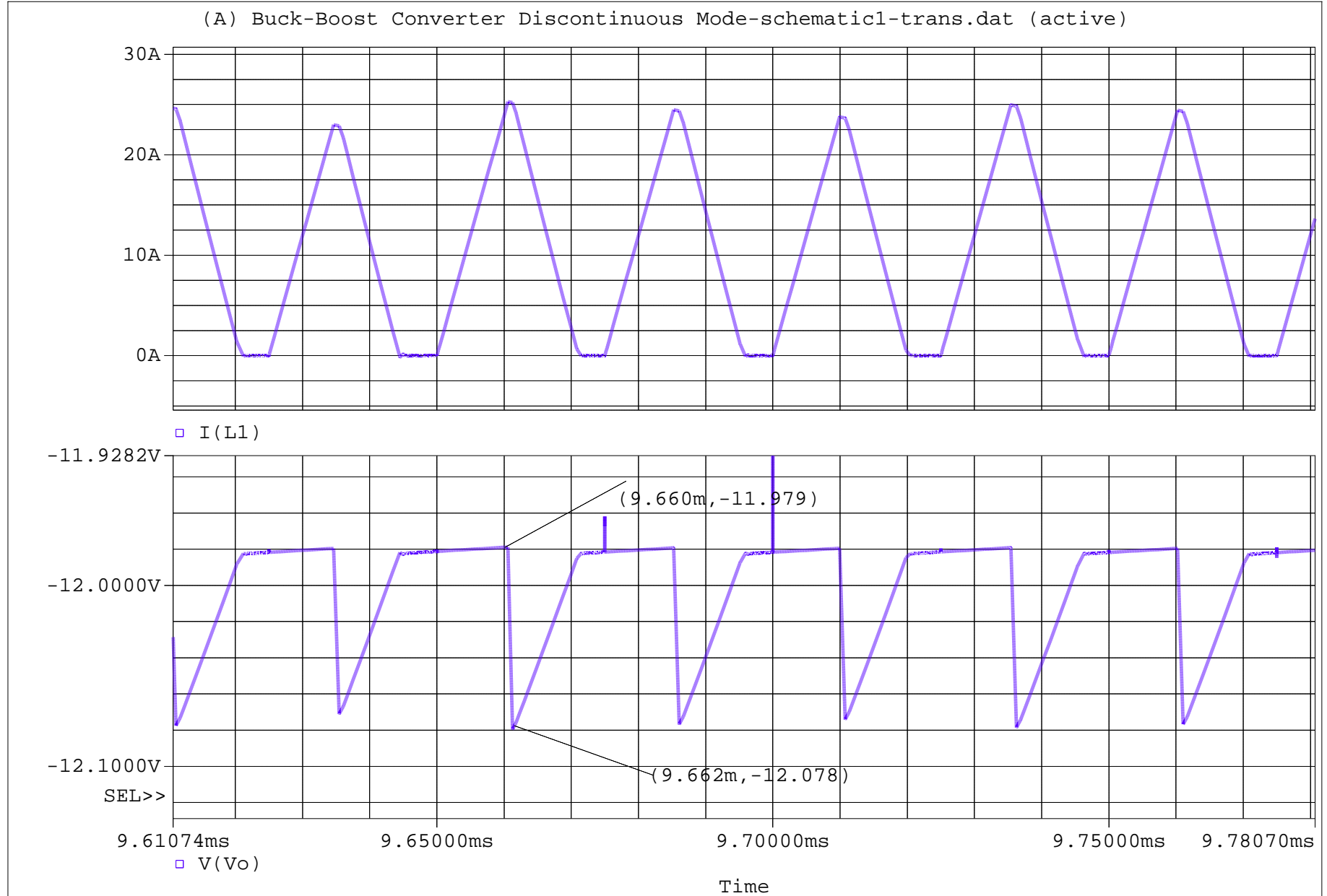


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Page 1

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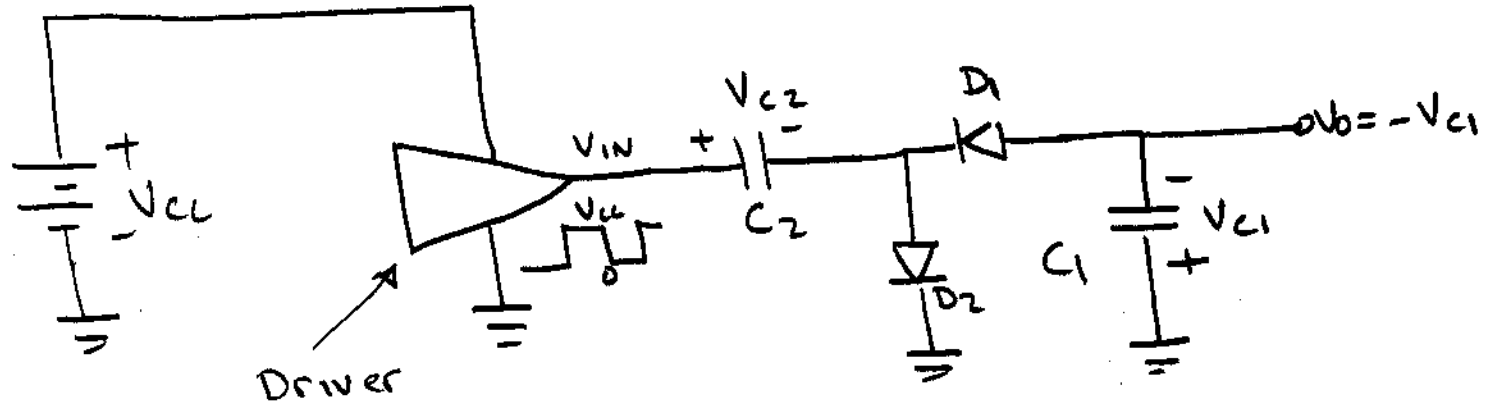
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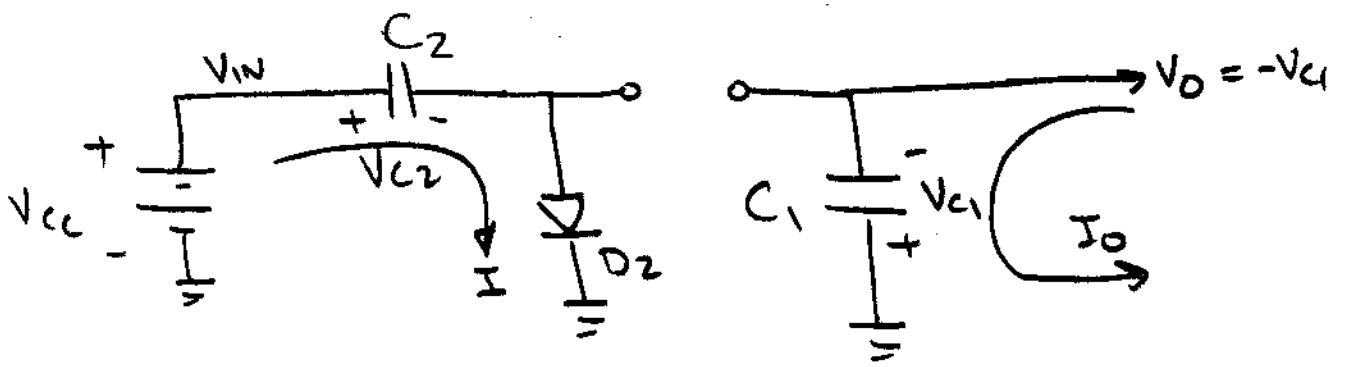
Inverting Charge Pump

①

- A method for creating a negative supply from a positive supply (Low power without inductors)

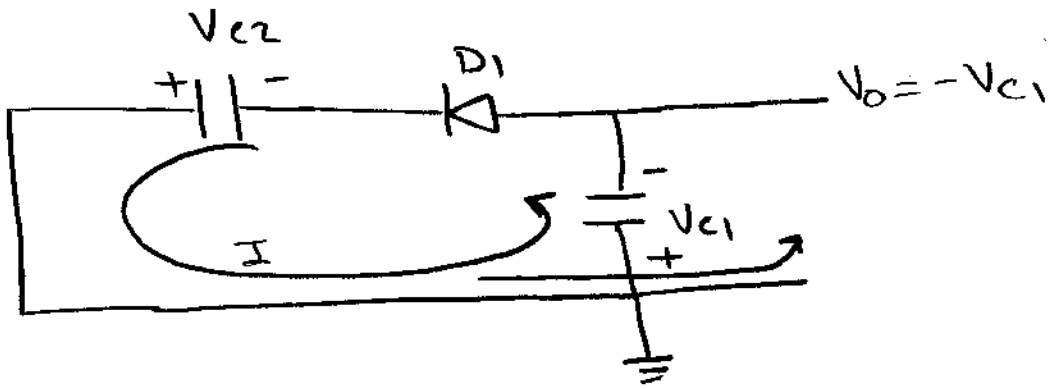


when $V_{in} = V_{cc}$, $D_1 = \text{OFF}$, $D_2 = \text{ON}$



- The output of the driver charges up C_2
- C_1 supplies power to the load

When the output of the driver is Low,
 $D_2 = \text{off}$, $D_1 = \text{on}$, and C_2 Transfers charge
 to C_1 and the Load

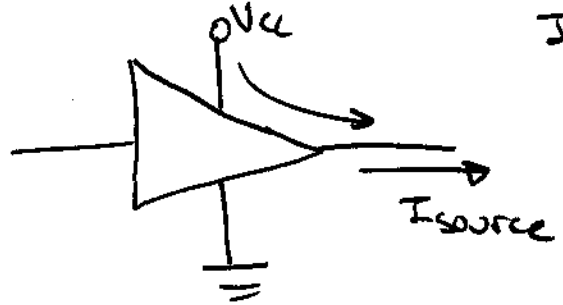


- For current to flow, $V_{c1} < V_{c2}$

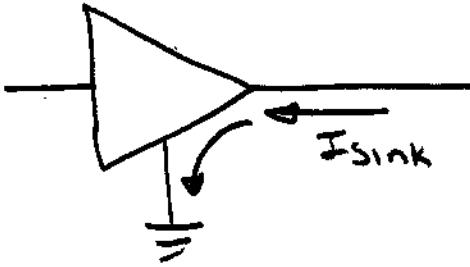
Driver

- Typically the driver is current limited

- When the output is high, the driver can source a max current of

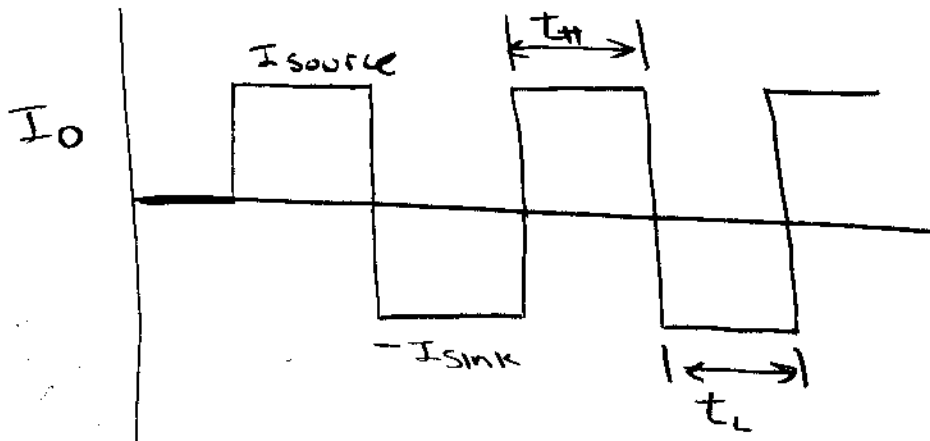
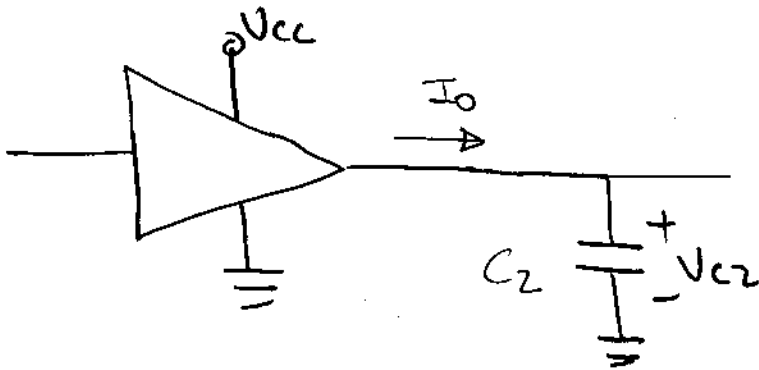


- when the output of the driver is low,
It can sink a maximum current of I_{sink}

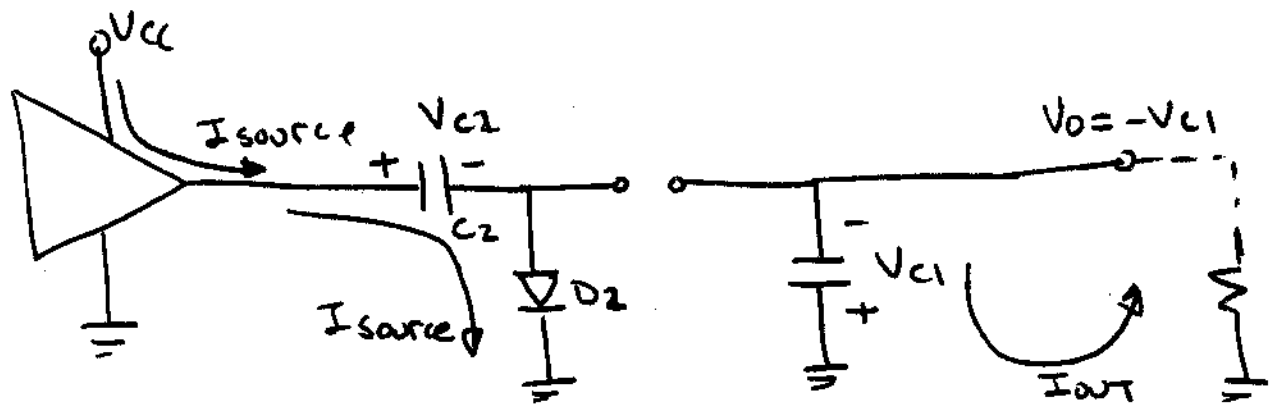


- we will be charging and discharging a capacitive load

- w

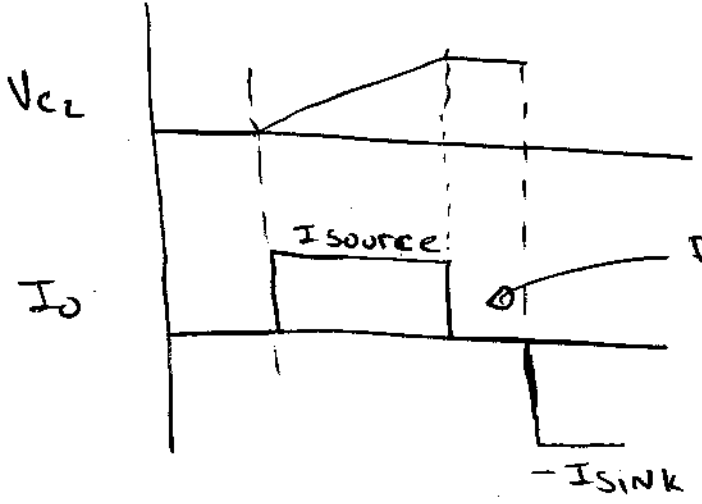


DURING t_H , C_2 is charging



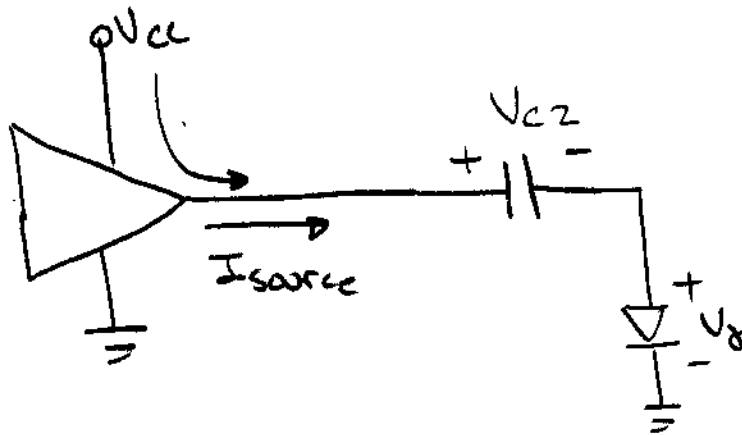
- The highest voltage C_2 can charge to is V_{cc}
- To get maximum charge transfer, want current flowing for all of t_H .
- If C_2 is too small, V_{c2} will reach V_{cc} and stop charging

C_2 too small



during this time, no power is being extracted from V_{cc} .

- For maximum charge transfer (Power transfer) from V_{CC} to C_2 , want I_{source} flowing for entire $t_H \Rightarrow D_2$ is always on

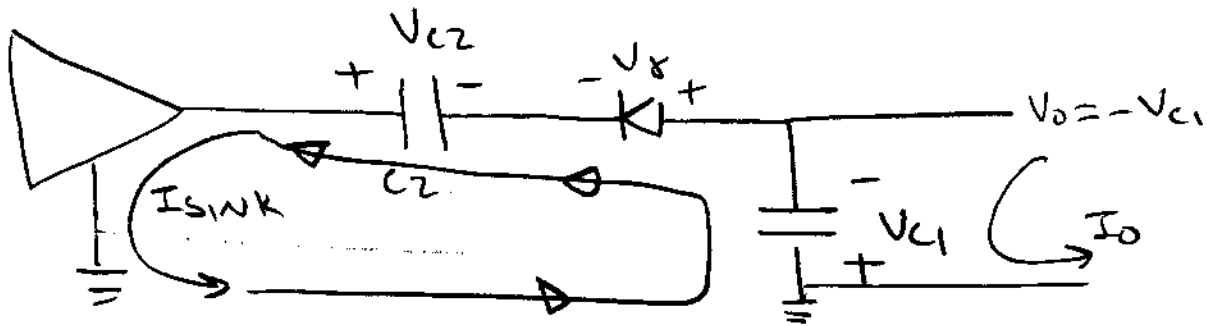


- The highest voltage V_{c2} can charge to is $V_{c2} = V_{CC} - V_t$

- When $V_{c2} = V_{CC} - V_t$, the charge stored in C_2 is $q_{I} = C_2 V_{c2} = C_2 [V_{CC} - V_t]$

- During t_H , the charge transferred from V_{CC} to C_2 is $I_{source} t_H$

- During t_L , charge is transferred from C_2 to C_1 and the output



- For current to flow, $V_{c1} < V_{c2} - V_d$

- Since $V_{c2} \Big|_{\max} \leq V_{cc} - V_d$ it must be true

that $V_{c1} \leq V_{cc} - 2V_d$

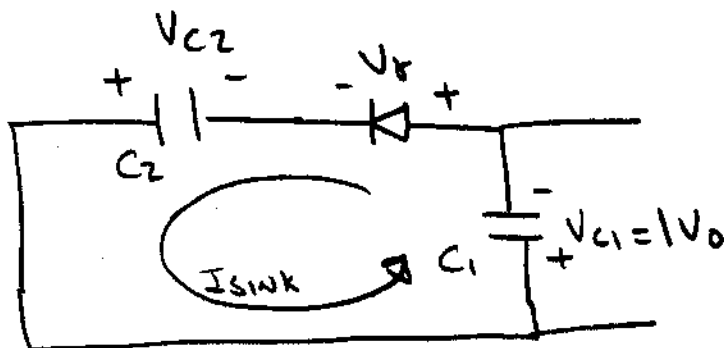
- To get all of the charge that was transferred from V_{cc} to C_2 , to be transferred from C_2 to C_1 and the output, it must be true that

$$I_{\text{source}} t_H = I_{\text{sink}} t_L \quad (1)$$

- Calculate the charge transfer from C_2 to C_1 and V_0
- at the end of t_H , the max voltage on C_2 was $V_{CC} - V_T$, and the charge stored was

$$Q_{\pm} = C_2 [V_{CC} - V_T]$$

- Assume $C_1 = \text{big}$ so that $V_{C1} = |V_0|$ does not change much when we dump charge into it.
- C_2 is small and V_{C2} discharges to V_{C1}



- Since $C_2 \ll C_1$ and I_{sink} always flows for the entire time t_L , at the end of t_L

$$V_{C2} = V_{C1} + V_T = |V_0| + V_T$$

- at the end of t_L , the charge stored on C_2 is

$$Q_F = C_2 V_{c2} = C_2 [|V_{o1}| + V_t]$$

- The charge transferred from C_2 to C_1 and the output is

$$\begin{aligned} Q_T &= Q_I - Q_F \\ &= C_2 [V_{cc} - V_t] - C_2 [|V_{o1}| + V_t] \\ &= C_2 [V_{cc} - 2V_t - |V_{o1}|] \end{aligned}$$

Note that $|V_{o1}| < V_{cc} - 2V_t$ or no charge will flow from C_2 to C_1

- The charge transferred from C_2 to $C_1 + V_0$ is equal to the charge pumped through the driver

$$I_{\text{source}} t_H = I_{\text{sink}} t_L = C_2 [V_{CC} - 2V_T - |V_0|]$$

Solve for C_2

$$C_2 = \frac{I_{\text{source}} t_H}{V_{CC} - 2V_T - |V_0|}$$

Do we round C_2 up or down?

- If we choose C_2 too small, then during t_H , V_{C_2} will hit its maximum of $V_{CC} - V_T$ and stop charging. This limits charge flow into C_2 and power drawn from V_{CC}

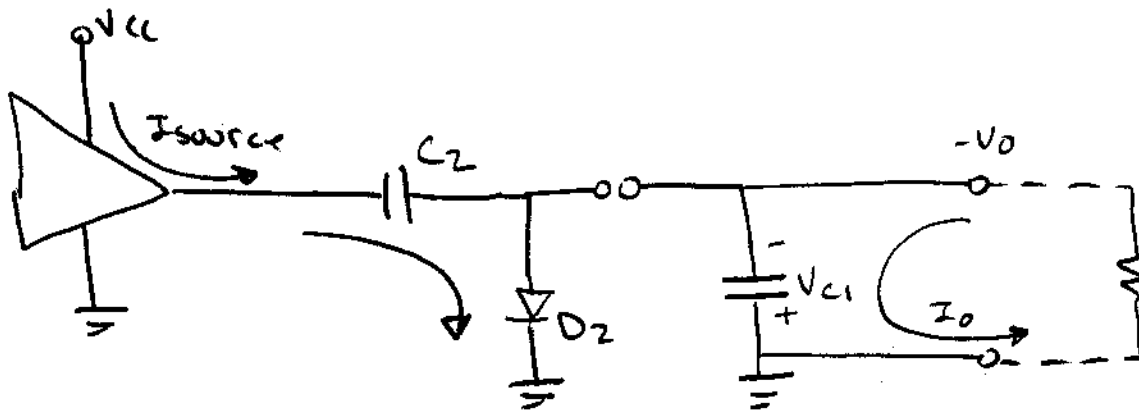
$$C_2 \geq \frac{I_{\text{source}} t_H}{V_{CC} - 2V_T - |V_o|} \quad (2)$$

- The ripple on C_2 is

$$\Delta V_{C2} = \frac{I_{\text{source}} t_H}{C_2}$$

choosing C_1

During t_H , C_1 supplies power to the Load

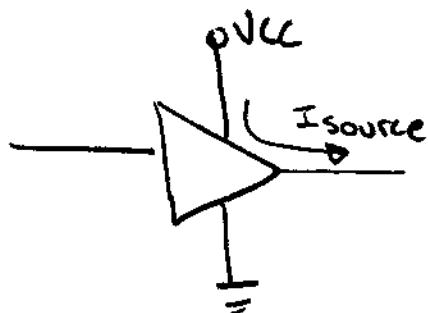


$$\Delta V_{C1} = \frac{I_o t_H}{C_1}$$

choose $C_1 \geq \frac{I_{\text{out}} t_H}{\Delta V_{C1}} \quad (3)$

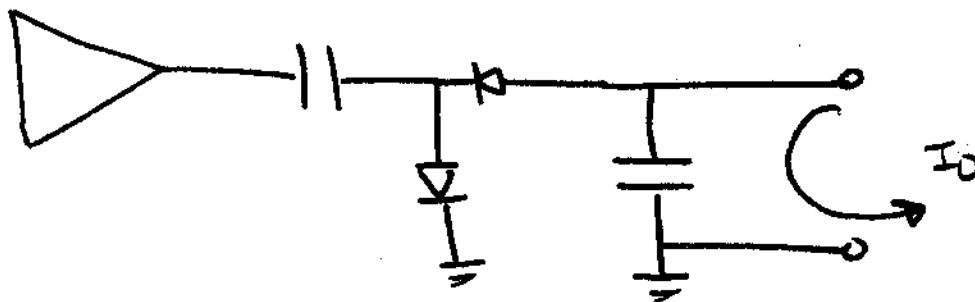
where ΔV_{C1} is the output ripple

- Look at the charge balance
- The charge transferred into our network from V_{CC} is



$$Q_{IN} = I_{source} t_H$$

- Charge is flowing out of the network for an entire period, $T_s = t_H + t_L$



$$Q_{OUT} = T_s I_O$$

- Through conservation of charge

$$I_{in} = I_{out}$$

OR

$$I_{source} t_H = I_o t_s$$

$$\Rightarrow I_o = I_{source} \frac{t_H}{t_s} \quad (4)$$

4/5/21

Inverting Charge Pump Summary

- Integrated Circuit Limitations

I_{source} , I_{sink}

- output voltage $|V_o| \leq |V_{cc}| - 3V$

- switching frequency $t_H + t_L = T_s$

- max output current $I_o|_{max} = I_{source} \left[\frac{t_H}{T_s} \right] [0.9]$

- charge transfer $\frac{I_{sink}}{I_{source}} = \frac{t_H}{t_L}$

- capacitors

$$C_1 \geq \frac{I_{o,max} t_H}{\Delta V_o}$$

$$C_2 \geq \left[\frac{I_{source} t_H}{V_{cc} - |V_o| - 2V_r} \right]$$

Inverting Charge Pump

$$\mu\text{s} \equiv 10^{-6} \cdot \text{sec}$$

Specify the driver specifications

$$I_{\text{Sink}} := 400 \cdot \text{mA} \quad I_{\text{Source}} := 400 \cdot \text{mA}$$

Specify V_{CC} and the output voltage

$$V_{\text{CC}} := 12 \cdot \text{volt} \quad V_{\text{O}} := V_{\text{CC}} - 3 \cdot \text{volt}$$

Specify the ripple output voltage

$$V_{\text{ripple}} := 100 \cdot \text{mV}$$

Specify the switching frequency

$$F_{\text{S}} := 20 \cdot \text{kHz}$$

$$T_{\text{S}} := \frac{1}{F_{\text{S}}} \quad T_{\text{S}} = 50 \mu\text{s}$$

Calculate the high and low times

$$t_H := 1 \cdot \mu\text{s} \quad t_L := 1 \cdot \mu\text{s}$$

Given

$$\frac{t_H}{t_L} = \frac{I_{\text{Sink}}}{I_{\text{Source}}} \quad t_H + t_L = T_S$$

$$\begin{pmatrix} t_L \\ t_H \end{pmatrix} := \text{find}(t_L, t_H) \quad t_L = 25 \mu\text{s} \quad t_H = 25 \mu\text{s}$$

Calculate the Maximum possible output current

$$I_{O_max} := I_{\text{Source}} \cdot \frac{t_H}{T_S} \cdot 90\%$$

Calculate C1

$$C_1 := \frac{I_{O_max} \cdot t_H}{V_{\text{ripple}}} \quad C_1 = 45 \mu\text{F}$$

Choose the next largest standard value for C1

$$C_1 := 50 \mu\text{F}$$

Specify the standard Diode drop

$$V_{\gamma} := 1 \cdot \text{volt}$$

Calculate C2

$$C_2 := \frac{I_{\text{Source}} \cdot t_H}{V_{CC} - V_o - 2 \cdot V_{\gamma}}$$

$$C_2 = 10 \mu\text{F}$$

Choose the next largest standard value.

$$C_2 := 10 \cdot \mu\text{F}$$

Calculate the ripple across C1

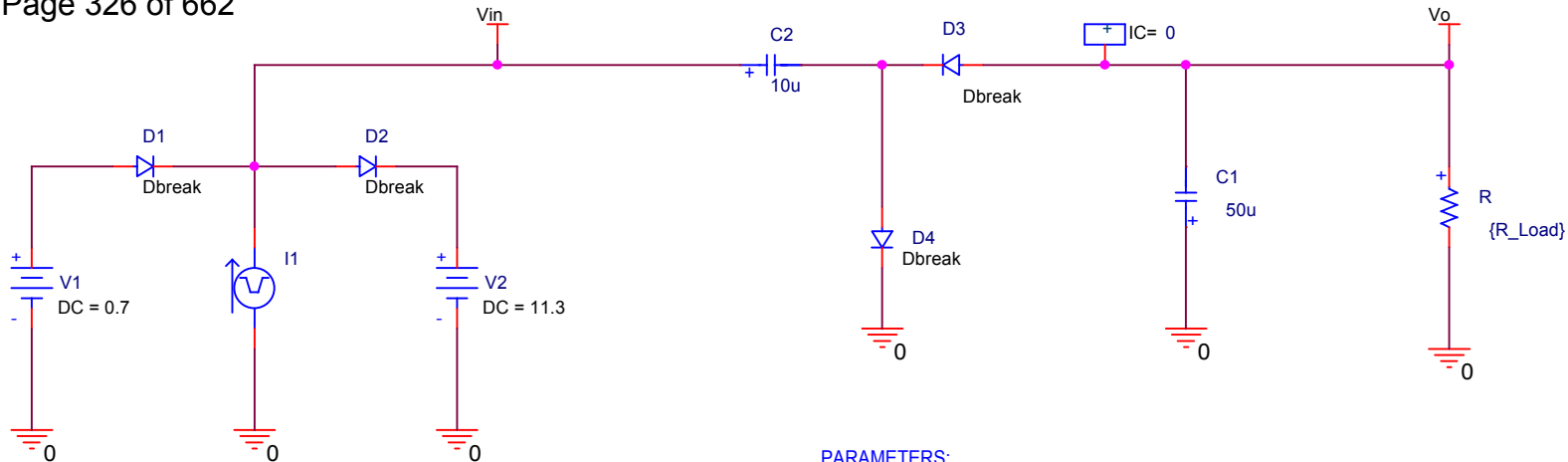
$$\Delta V_{C1} := \frac{I_{o_max} \cdot t_H}{C_1}$$

$$\Delta V_{C1} = 90 \text{ mV}$$

Calculate the ripple across C2

$$\Delta V_{C2} := \frac{I_{\text{Source}} \cdot t_H}{C_2}$$

$$\Delta V_{C2} = 1 \text{ V}$$

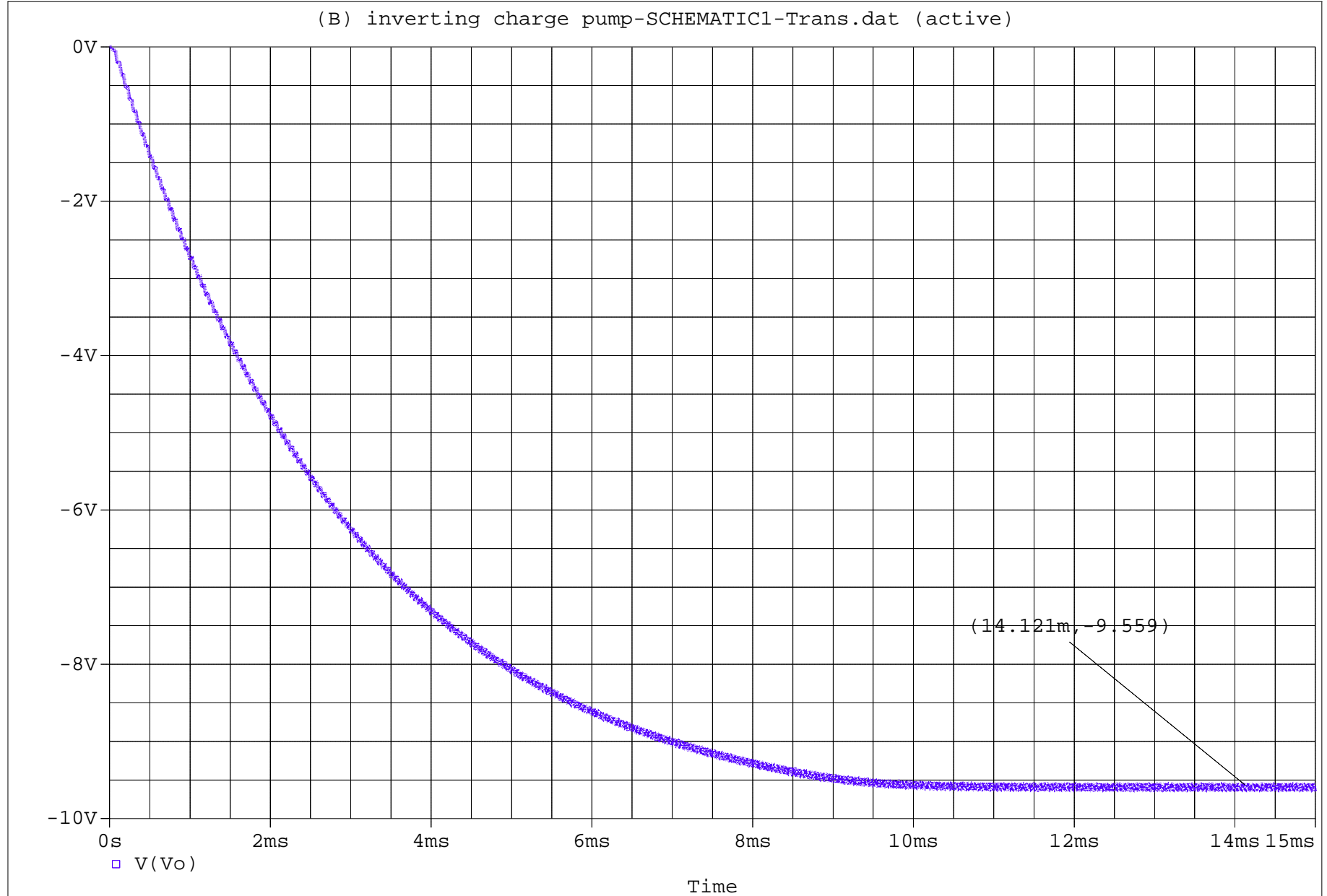


PARAMETERS:
R_Load = 50

0 to 12 V pulse
supply with
400 mA source/Sink

A	
+ SCHEMATIC1 : PAGE1 : I1	
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DELAY_TIME	0
Designator	
FALL_TIME	1n
Graphic	IPULSE.Normal
ID	
Implementation	
Implementation Path	
Implementation Type	<none>
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PCB Footprint	
PERIOD	50u
Power Pins Visible	<input type="checkbox"/>
Primitive	DEFAULT
PSpiceOnly	TRUE
PSpiceTemplate	I*@REFDES %+ %- \n+PULSE @INITIAL_CURRENT @PULSED_CURRENT ?DELAY_TIME
PULSE_WIDTH	25u
PULSED_CURRENT	400m
Reference	I1
RISE_TIME	1n
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Source Library	C:\PROGRAM FILES\ORCADLITE\CAPTURE\LIBRARY\PSpICE\CLASS.OLB
Source Package	IPULSE
Source Part	IPULSE.Normal
Value	IPULSE

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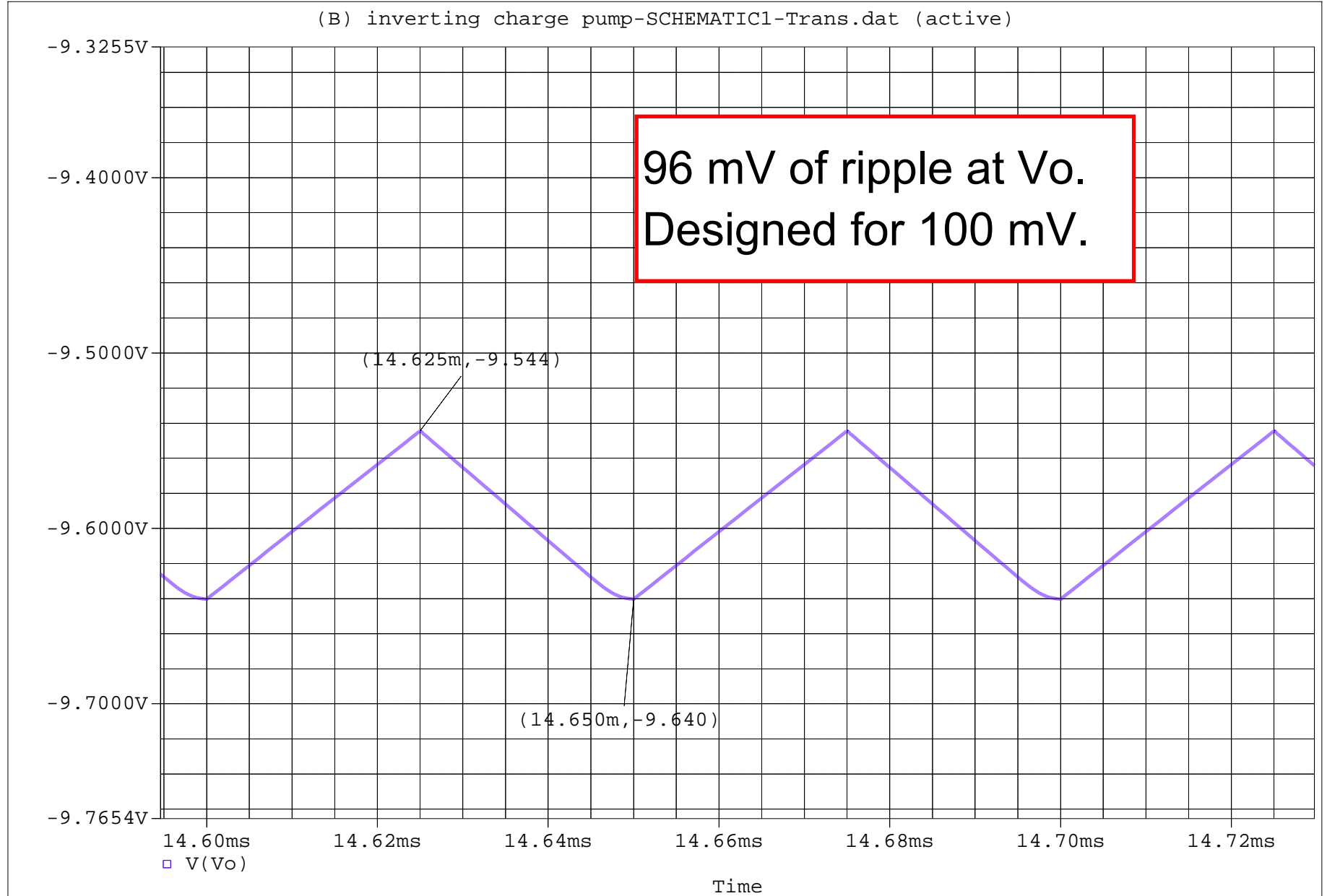


Date: January 14, 2003

Page 1

Time: 12:34:09

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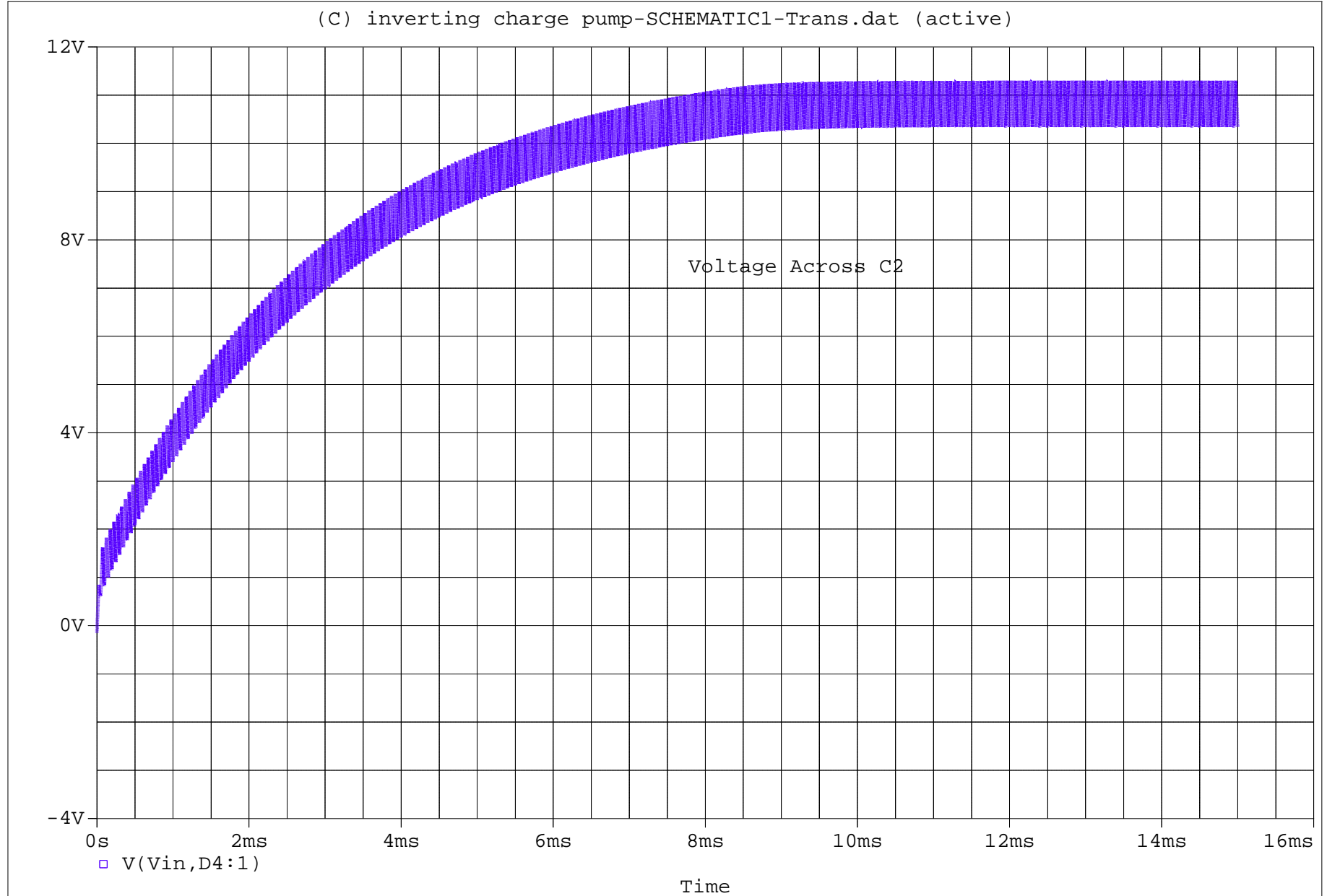


Date: January 14, 2003

Page 1

Time: 12:35:02

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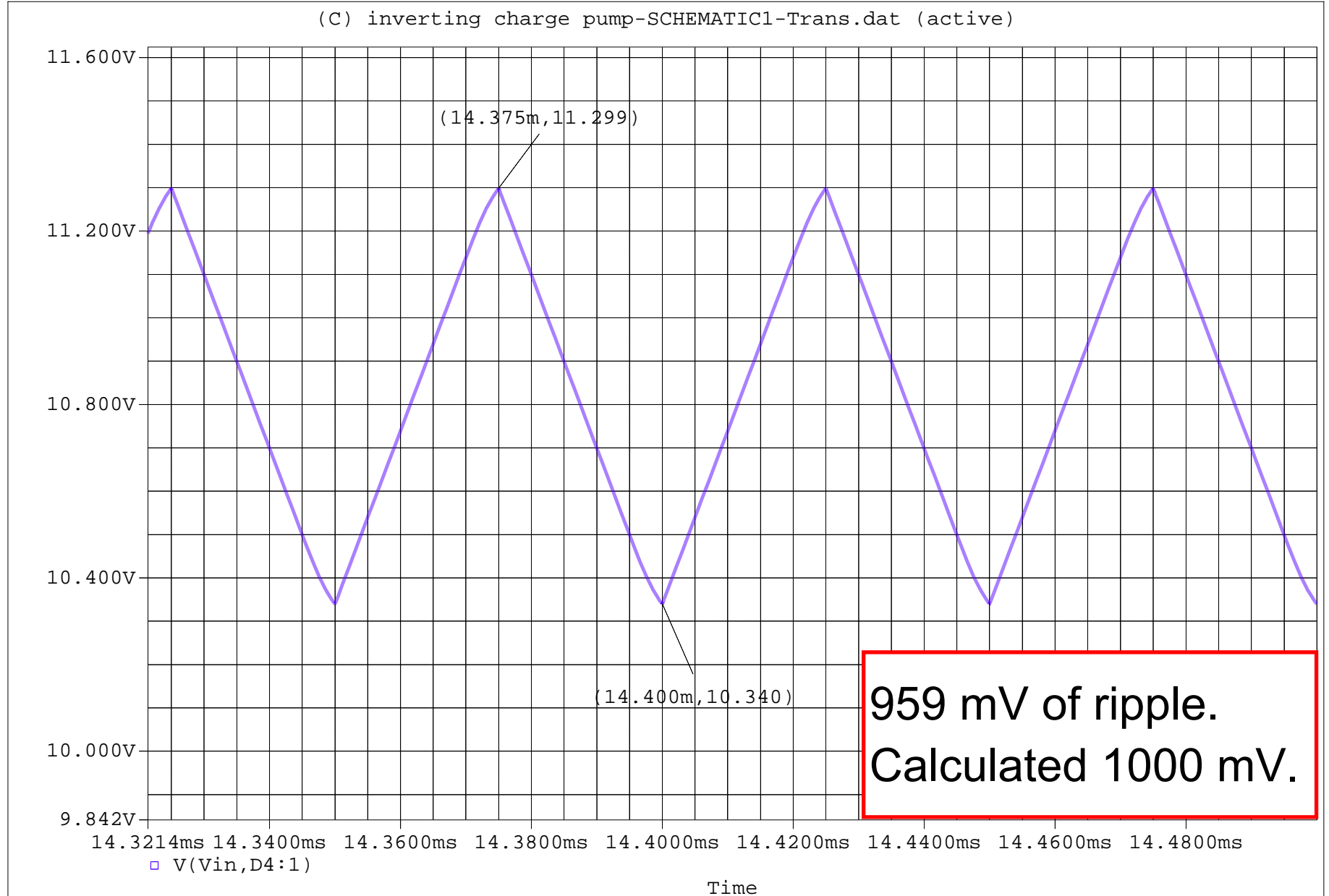


Date: January 14, 2003

Page 1

Time: 12:35:56

** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Inverting Charge Pump\...
Date/Time run: 01/14/03 12:32:59 Temperature: 27.0

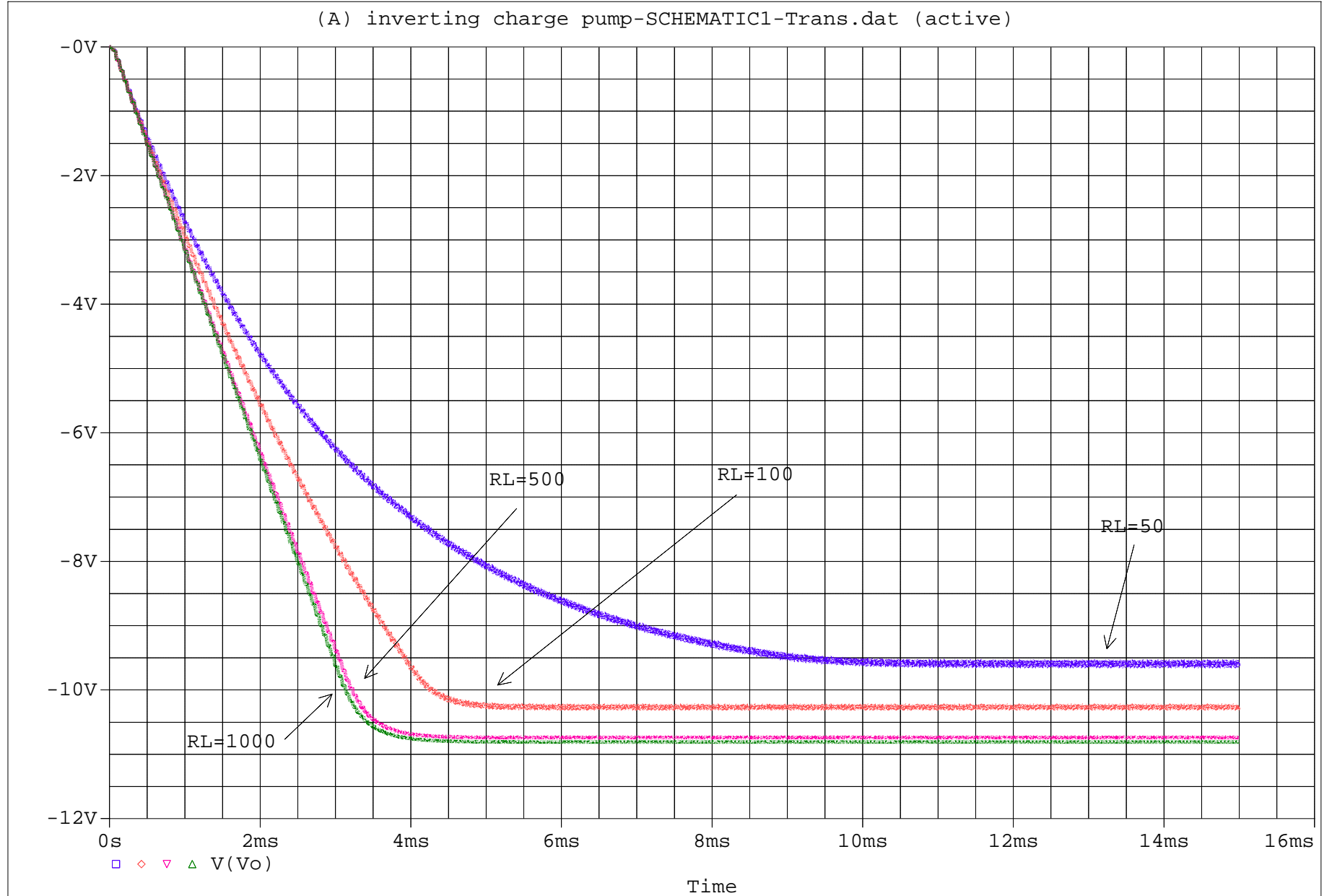


Date: January 14, 2003

Page 1

Time: 12:36:50

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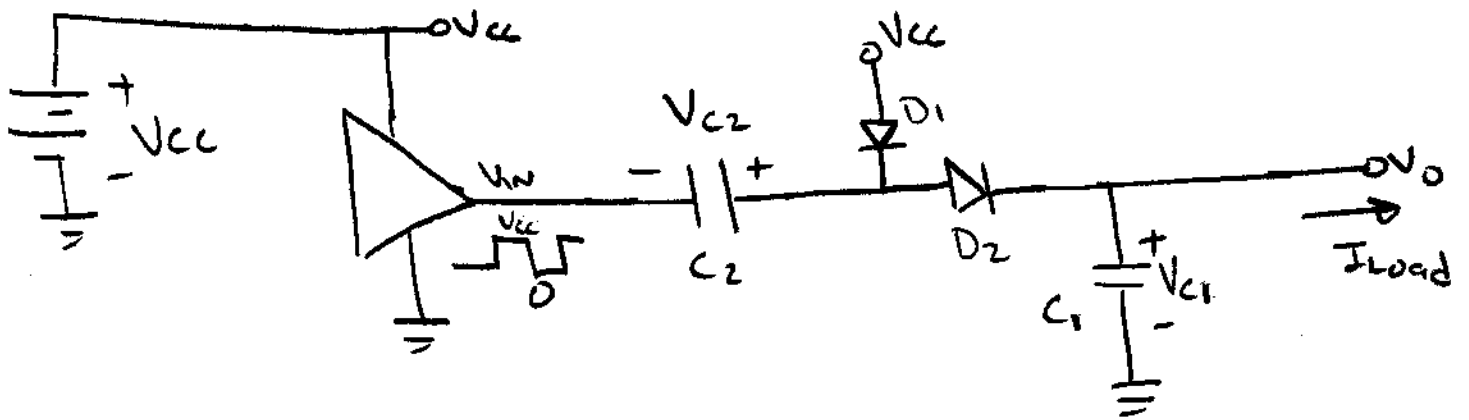


Date: January 14, 2003

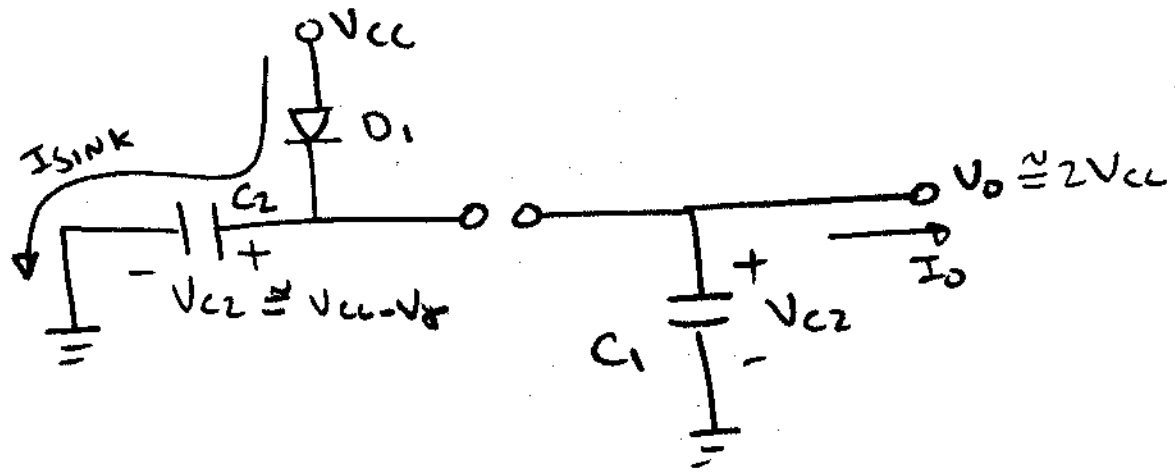
Page 1

Time: 12:39:56

Voltage Doubling Charge Pump



When $V_{in} = \text{Low}$, $D_1 = \text{ON}$, $D_2 = \text{OFF}$.

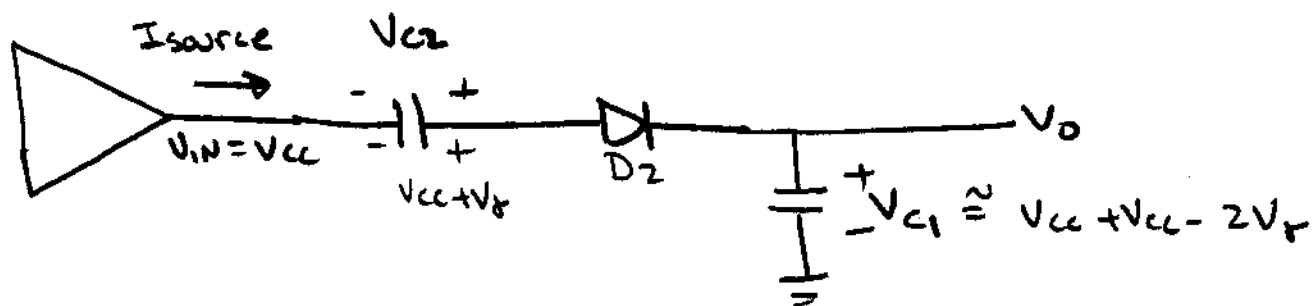


- C_2 charges through D_1 and the driver output
- C_1 supplies power to the Load

- When the output of the driver is high,

$D_1 = \text{OFF}$ and $D_2 = \text{ON}$, C_2 transfers charge

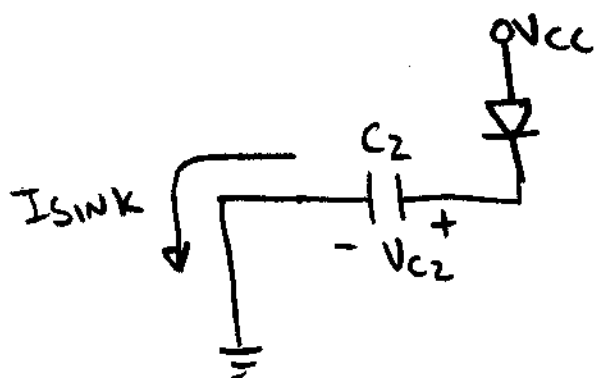
to C_1



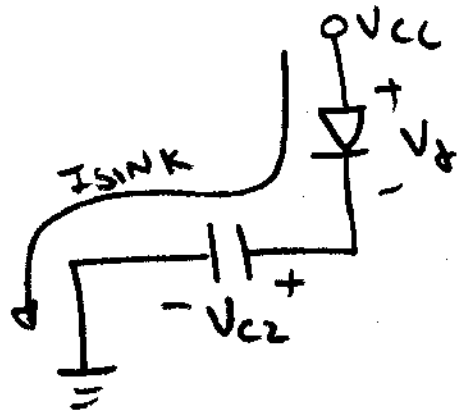
for current to flow, $V_{C2} + V_{CC} > V_{C1}$

EQUATIONS

During t_L , C_2 charges through D_1



- To get the most charge into C_2 , want + current flowing for entire time t_L . Since current always flows, the diode always has a diode voltage drop of V_f . \Rightarrow The highest C_2 can charge is $V_{CC} - V_f$



$$V_{C2} \leq V_{CC} - V_f$$

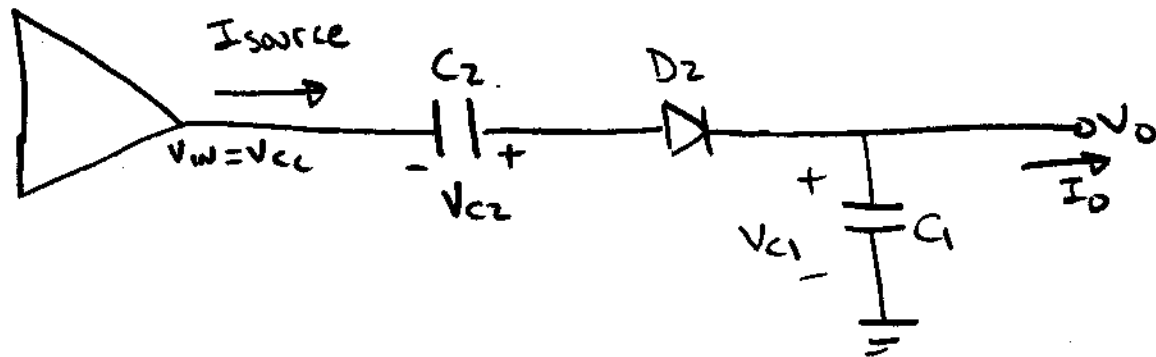
- When $V_{C2} = V_{CC} - V_f$, the charge stored

in C_2 is
$$Q_{I} = C_2 V_{C2} = C_2 [V_{CC} - V_f]$$

- during t_L , the charged transferred to

C_2 is
$$I_{SINK} t_L$$

- During t_H , charge is transferred from C_2 to C_1 and the output



- For current to flow, $v_{c1} < v_{cc} + v_{c2} - V_f$

- Since $v_{c2} \leq V_{cc} - V_f$ it must be true

$$\text{that } v_{c1} \leq 2V_{cc} - 2V_f$$

- To move all of the charge that was placed on C_2 during t_L to C_1 and the output, it must be true that

$$I_{sink} t_L = I_{source} t_H \quad (1)$$

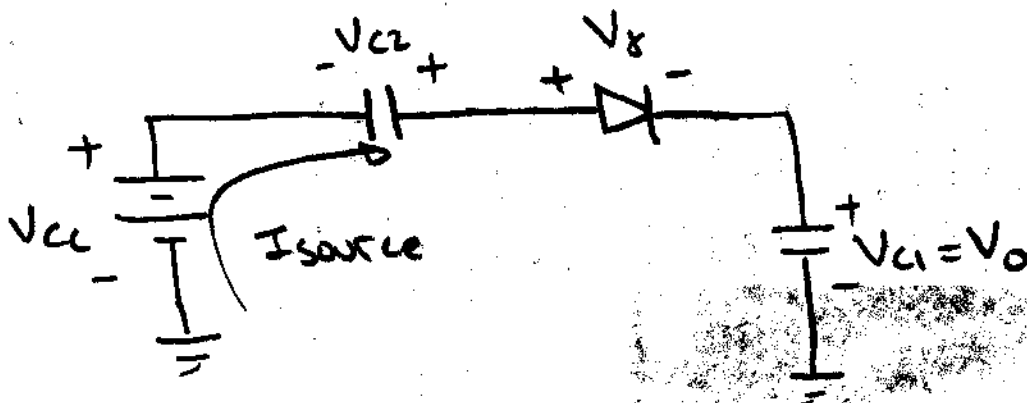
- Calculate the charge transfer from C_2 to C_1 and V_0

- at the end of t_L , the max voltage on C_2 was $V_{CC} - V_r$, and the charge stored

$$Q_I = C_2 [V_{CC} - V_r]$$

- assume $C_1 = \text{big}$ so that $V_{C1} = V_0$ does not change much when we dump charge into it.

- C_2 is small and discharges to obey KVL



$$\text{KVL: } V_{C2} = V_0 + V_r - V_{CC}$$

- Since $C_2 \ll C_1$ and I sink always flows for the entire time T_H , at the end of T_H

$$V_{c2} = V_0 + V_T - V_{cc}$$

- at the end of T_H , the charge stored on C_2 is

$$q_F = C_2 V_{c2} = C_2 [V_0 + V_T - V_{cc}]$$

- The charge transferred from C_2 to C_1 and the output is $q_T = q_I - q_F$

OR

$$\begin{aligned} q_T &= C_2 [V_{cc} - V_T] - C_2 [V_0 + V_T - V_{cc}] \\ &= C_2 [2V_{cc} - 2V_T - V_0] \end{aligned}$$

It must be true that $V_0 < 2V_{cc} - 2V_T$ or No charge will be transferred

- The charge transferred from C_2 to C_1 & the output must be equal to the charge pumped through the driver

$$I_{\text{source}} t_H = I_{\text{sink}} t_L = C_2 [2V_{CC} - 2V_T - V_o]$$

- solve for C_2

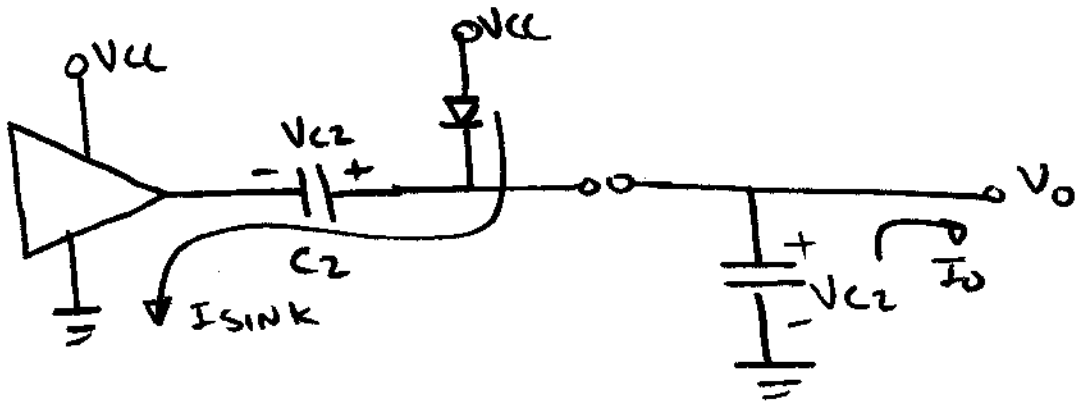
$$C_2 = \frac{I_{\text{sink}} t_L}{2V_{CC} - 2V_T - V_o}$$

- Round up C_2 to prevent V_{C2} from reaching V_{CC} too quickly and stop charging (same thing as we found for the inverting charge pump)

$$C_2 \geq \frac{I_{\text{sink}} t_L}{2V_{CC} - 2V_T - V_o} \quad (2)$$

Choosing C_1

During t_L , C_1 supplies power to the Load



$$\Delta V_{c1} = \frac{I_o t_L}{C_1}$$

$$\Rightarrow \text{choose } C_1 \geq \frac{I_o t_L}{\Delta V_{c1}} \quad (3)$$

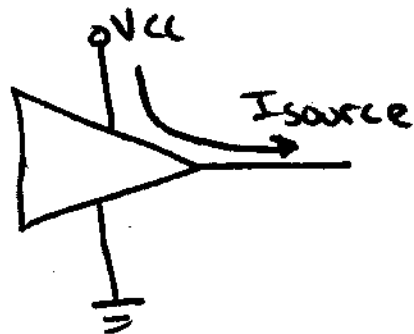
Where ΔV_{c1} is the ripple on the output.

- Next, look at the Energy balance.

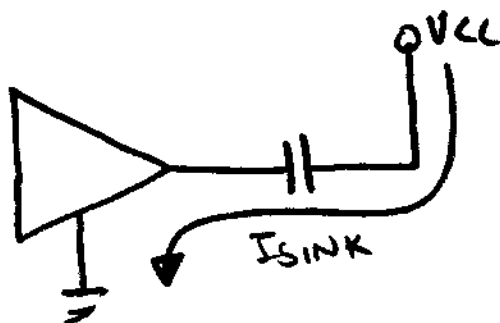
- Energy supplied to the Load for one cycle is

$$E_D = V_o I_o T_s$$

- During t_H , the energy drawn from V_{CC} is $E_H = V_{CC} I_{SOURCE} t_H$



- During t_L , the energy drawn from the source is $E_L = V_{CC} I_{SINK} t_L$



- Energy from V_{CC} equals energy to load

$$V_{CC} I_{SINK} t_L + V_{CC} I_{SINK} t_H = V_O I_O T_S$$

- USING $T_H + T_L = T_S$

and $I_{\text{sink}} T_L = I_{\text{source}} T_H$

we get

$$2 V_{CC} I_{\text{source}} T_H = V_O I_O T_S$$

So

$$I_O = \frac{2 V_{CC}}{V_O} \frac{T_H}{T_S} I_{\text{source}}$$

- Since $V_O \approx 2V_{CC}$

$$I_O \approx \frac{T_H}{T_S} I_{\text{source}} \quad (4)$$

Same as inverting
charge pump

Voltage Doubling Charge Pump SUMMARY

- Integrated Circuit Limitations

I_{source}, I_{sink}

- Output Voltage $V_o \leq 2V_{cc} - 3V$ - APPROX

- Switching Frequency $t_H + t_L = T_s$

- max output current $I_{omax} = I_{source} \left[\frac{t_H}{t_L} \right] [0.9]$

- Charge transfer $\frac{I_{sink}}{I_{source}} = \frac{t_H}{t_L}$

- Capacitors

$$C_1 \geq \frac{I_{omax} t_L}{\Delta V_o}$$

$$C_2 \geq \frac{I_{sink} t_L}{2V_{cc} - 2V_{\gamma} - V_o}$$

Voltage Doubling Charge Pump

$$\mu\text{s} \equiv 10^{-6} \cdot \text{sec}$$

Specify the driver specifications

$$I_{\text{Sink}} := 200 \cdot \text{mA} \quad I_{\text{Source}} := 200 \cdot \text{mA}$$

Specify V_{CC} and the output voltage

$$V_{\text{CC}} := 15 \cdot \text{volt} \quad V_{\text{O}} := 24 \cdot \text{volt}$$

Specify the ripple output voltage

$$V_{\text{ripple}} := 240 \cdot \text{mV}$$

Specify the switching frequency $F_{\text{S}} := 20 \cdot \text{kHz}$

$$T_{\text{S}} := \frac{1}{F_{\text{S}}} \quad T_{\text{S}} = 50 \mu\text{s}$$

Calculate the high and low times

$$t_H := 1 \cdot \mu\text{s} \quad t_L := 1 \cdot \mu\text{s}$$

Given

$$\frac{t_H}{t_L} = \frac{I_{\text{Sink}}}{I_{\text{Source}}} \quad t_H + t_L = T_S$$

$$\begin{pmatrix} t_L \\ t_H \end{pmatrix} := \text{find}(t_L, t_H) \quad t_L = 25 \mu\text{s} \quad t_H = 25 \mu\text{s}$$

Calculate the Maximum possible output current

$$I_{O_max} := I_{\text{Source}} \cdot \frac{t_H}{T_S} \cdot 90\%$$

Calculate C1

$$C_1 := \frac{I_{O_max} \cdot t_L}{V_{\text{ripple}}} \quad C_1 = 9.375 \mu\text{F}$$

Choose the next largest standard value for C1

$$C_1 := 10 \cdot \mu\text{F}$$

Specify the standard Diode drop

$$V_{\gamma} := 1 \cdot \text{volt}$$

Calculate C2

$$C_2 := \frac{I_{\text{Sink}} \cdot t_L}{2V_{CC} - V_o - 2 \cdot V_{\gamma}}$$

$$C_2 = 1.25 \mu\text{F}$$

Choose the next largest standard value.

$$C_2 := 2 \cdot \mu\text{F}$$

Calculate the ripple across C1

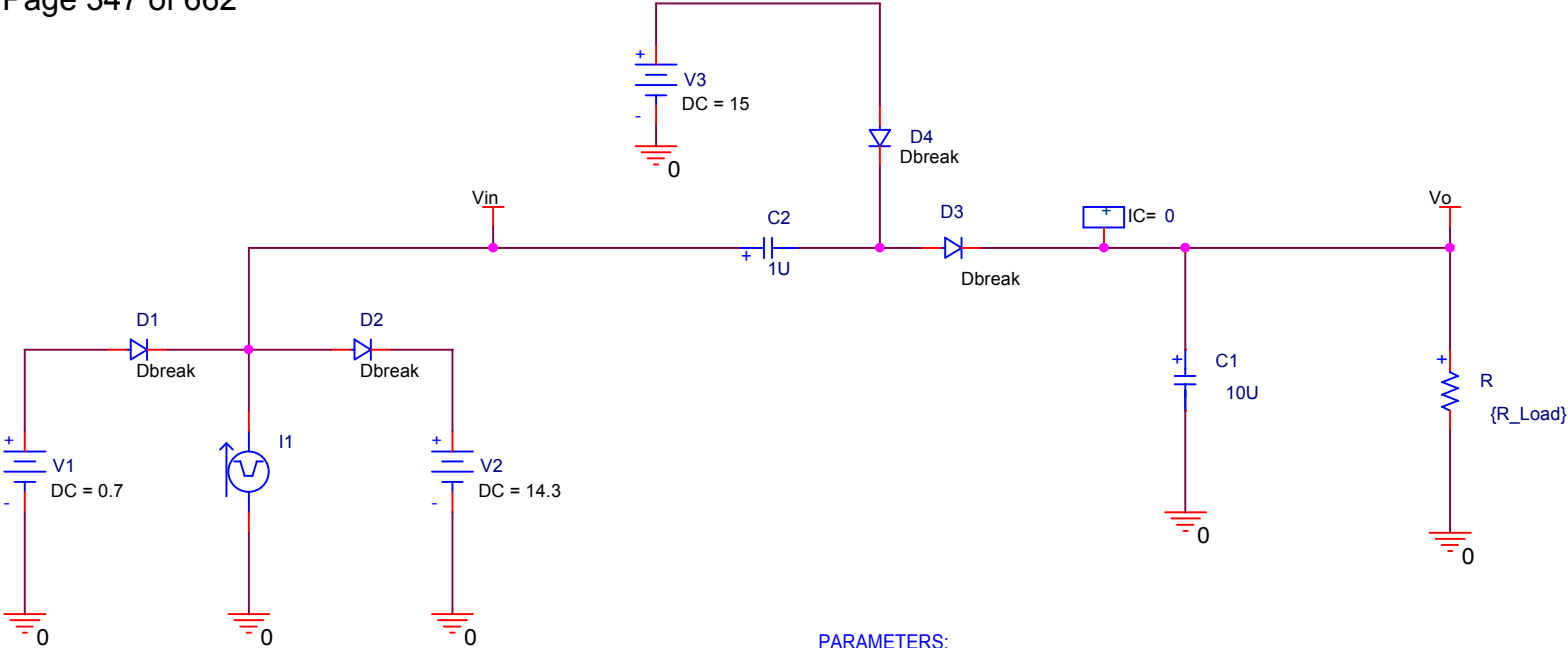
$$\Delta V_{C1} := \frac{I_{o_max} \cdot t_H}{C_1}$$

$$\Delta V_{C1} = 225 \text{ mV}$$

Calculate the ripple across C2

$$\Delta V_{C2} := \frac{I_{\text{Source}} \cdot t_H}{C_2}$$

$$\Delta V_{C2} = 2.5 \text{ V}$$

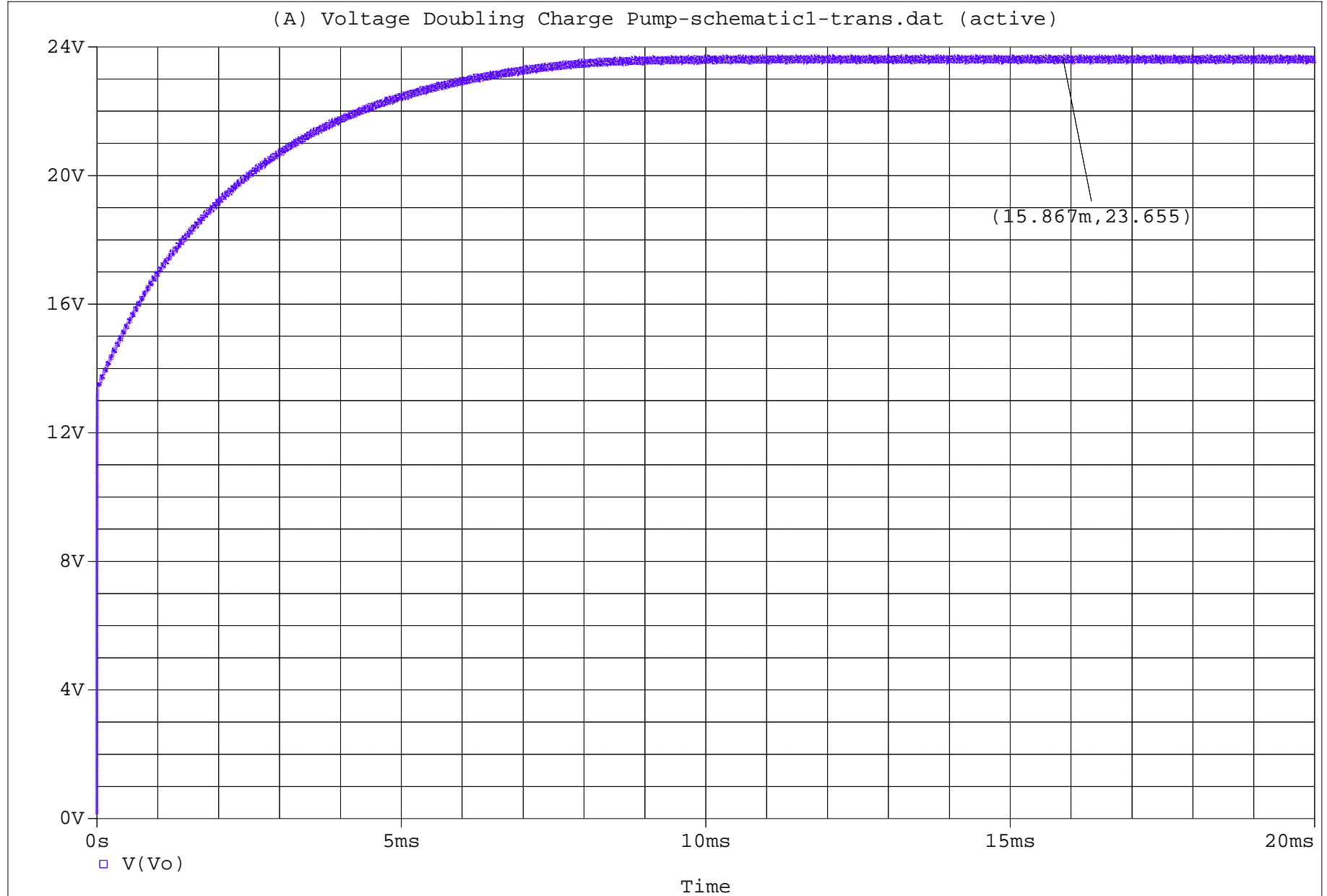


PARAMETERS:
 R_Load = 240

0 to 15 V pulse
 supply with
 200 mA source/Sink
 ECE558 Lecture Notes

A	
	+ SCHEMATIC1 : PAGE1 : I1
BiasValue Power	
Color	Default
DELAY_TIME	0
Designator	
FALL_TIME	1n
Graphic	IPULSE.Normal
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PULSED_CURRENT	200m
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RISE_TIME	1n
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Source Part	IPULSE.Normal
Value	IPULSE

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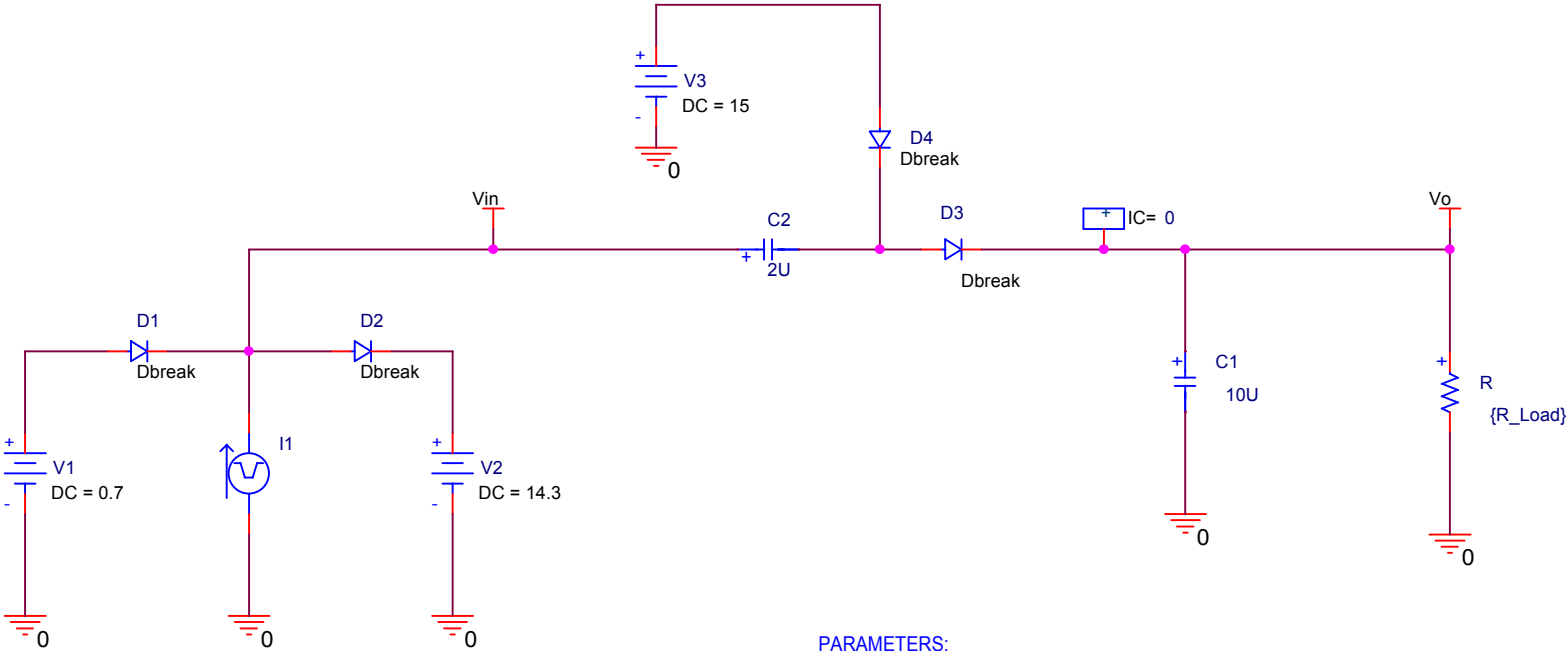


Date: January 16, 2003

Page 1

Time: 12:50:58

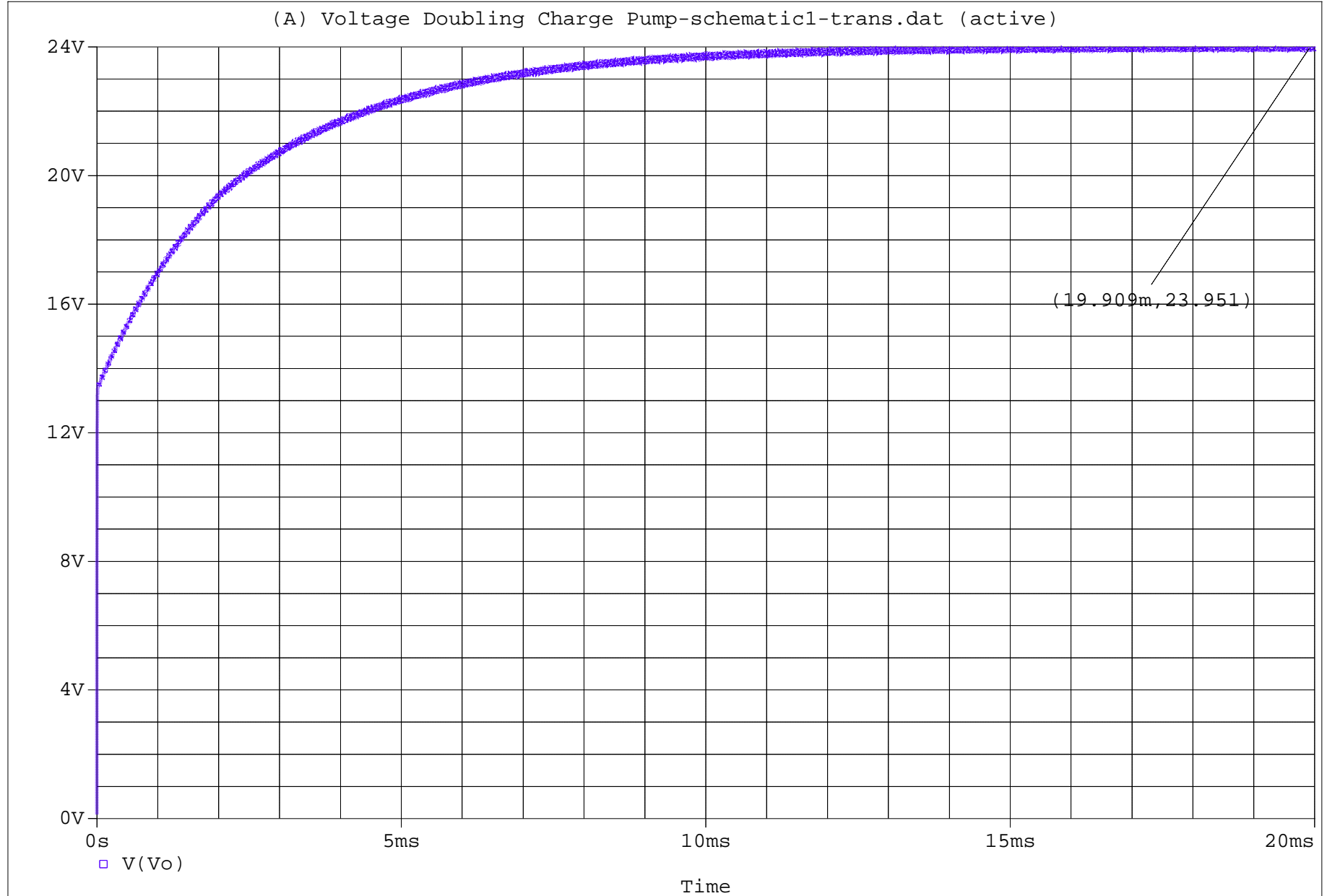
Changed C2 to 2UF to see if we are limited by the charge transfer to C2 from VCC.



PARAMETERS:
 $R_{Load} = 240$

0 to 15 V pulse supply with 200 mA source/Sink

** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Voltage Doubling Charg...
Date/Time run: 01/16/03 12:52:54 Temperature: 27.0

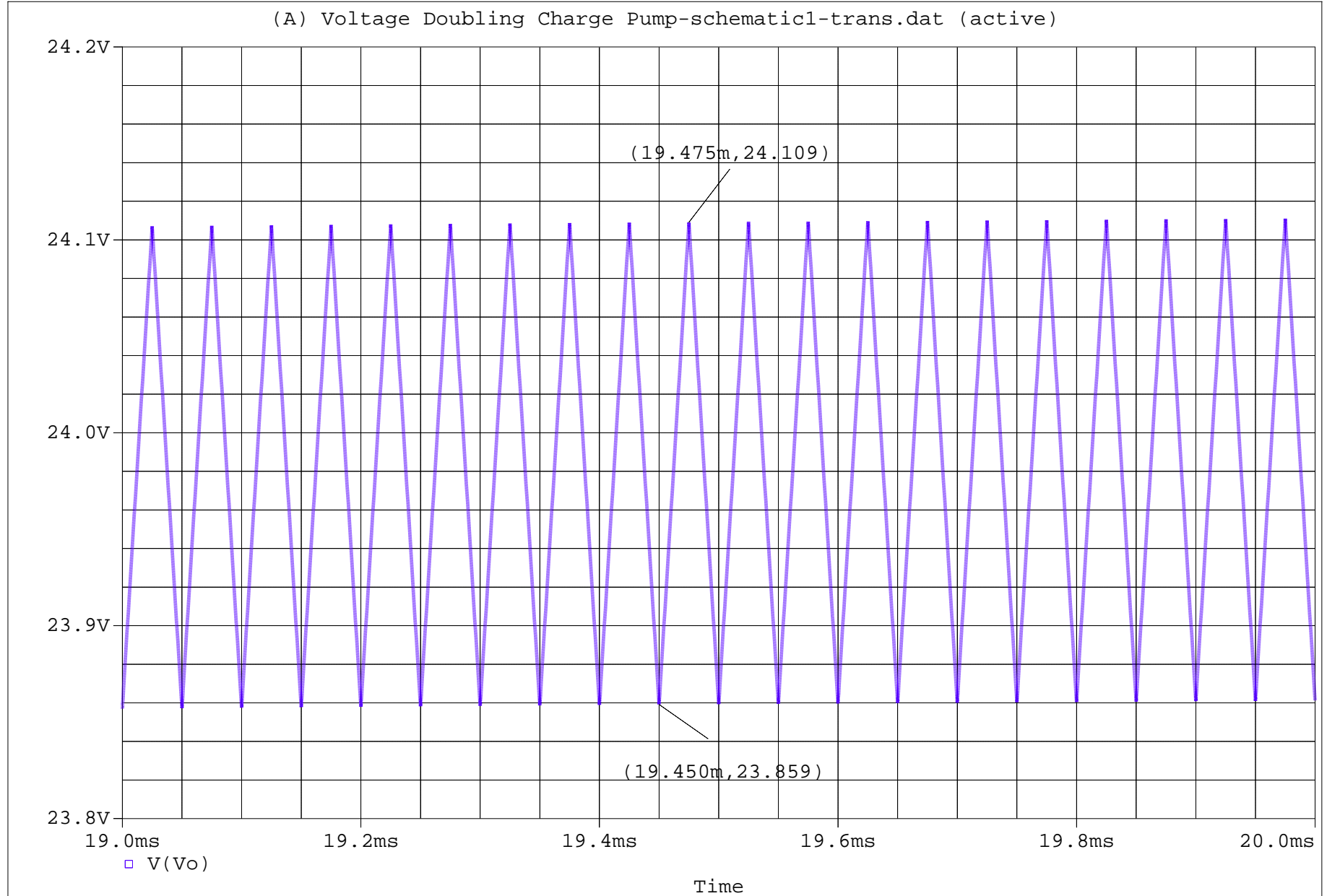


Date: January 16, 2003

Page 1

Time: 12:53:58

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Date/Time run: 01/16/03 12:52:54 Temperature: 27.0

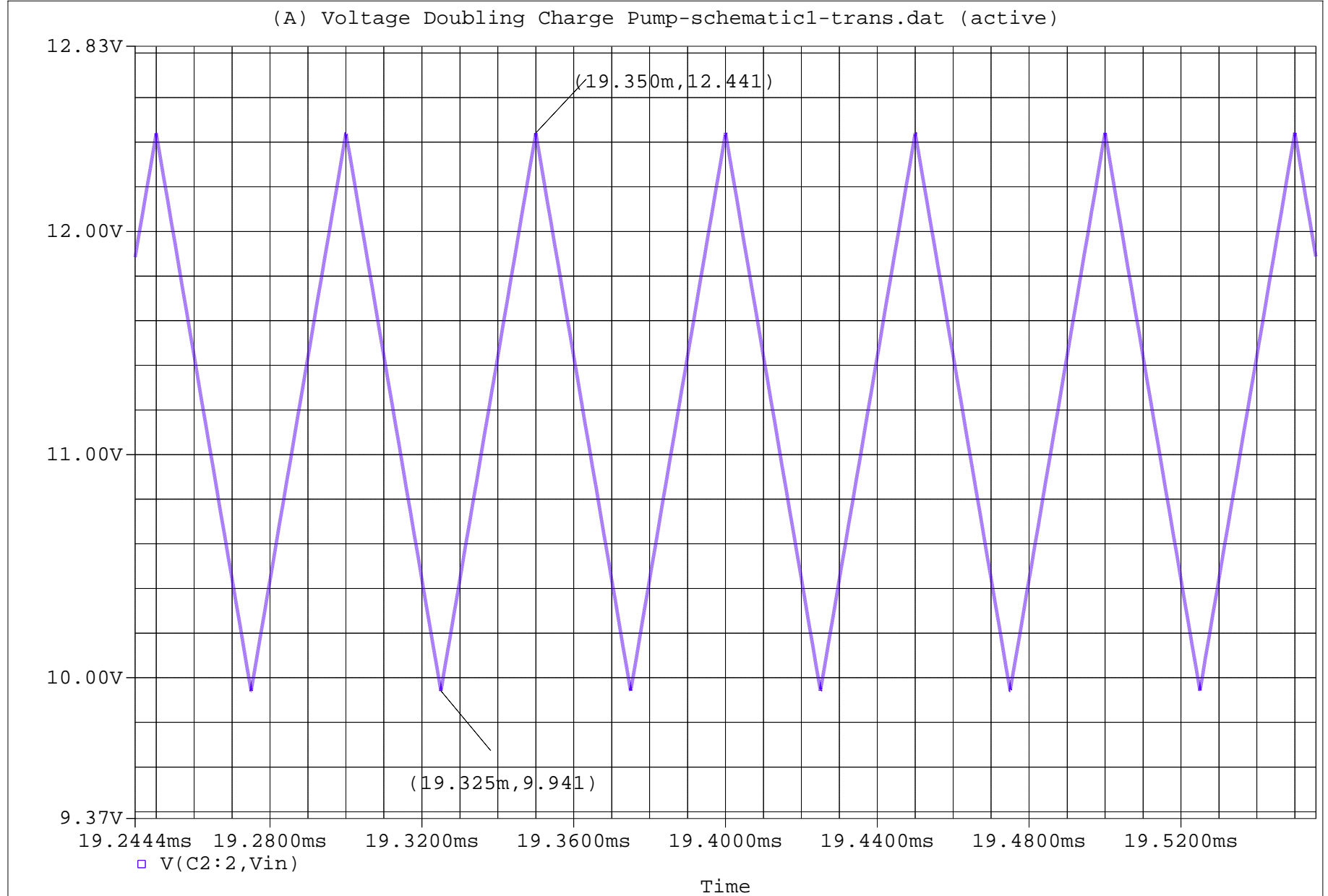


Date: January 16, 2003

Page 1

Time: 12:55:54

** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Voltage Doubling Charg...
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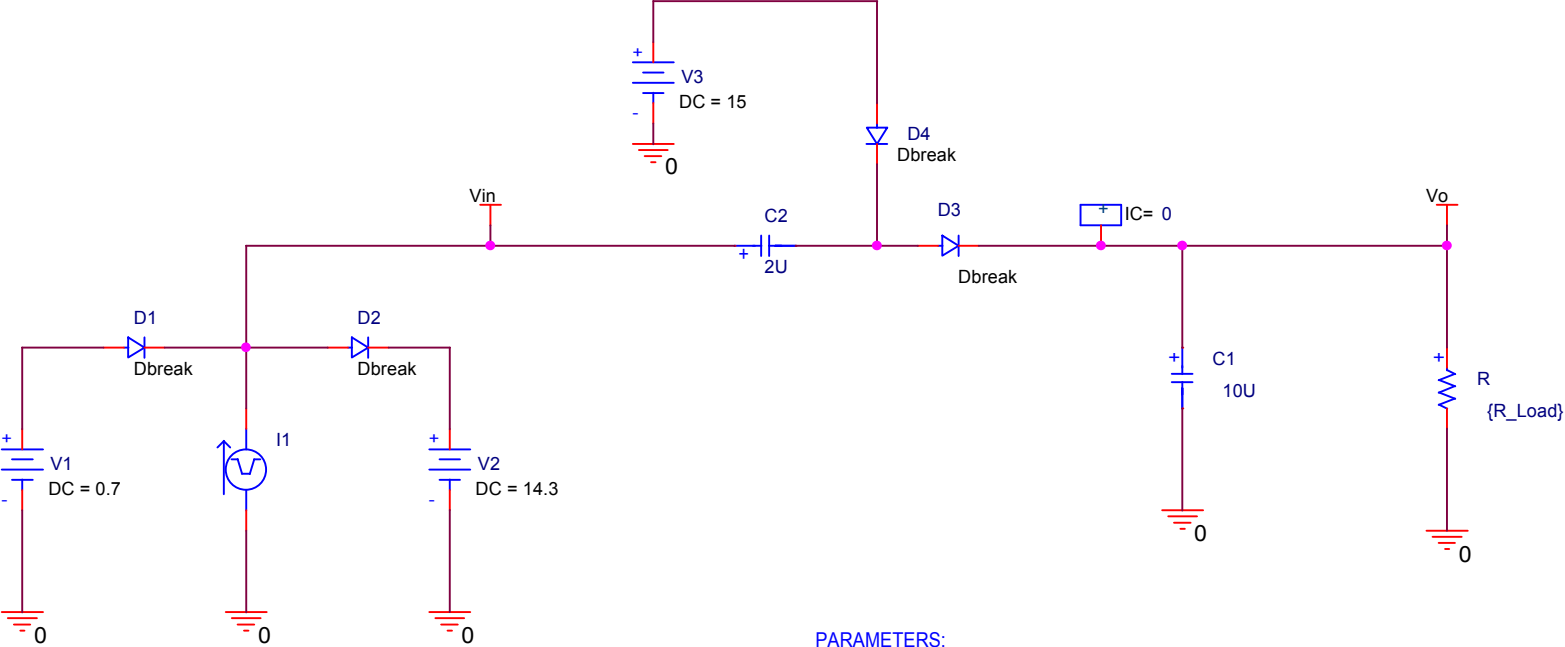


Date: January 18, 2003

Page 1

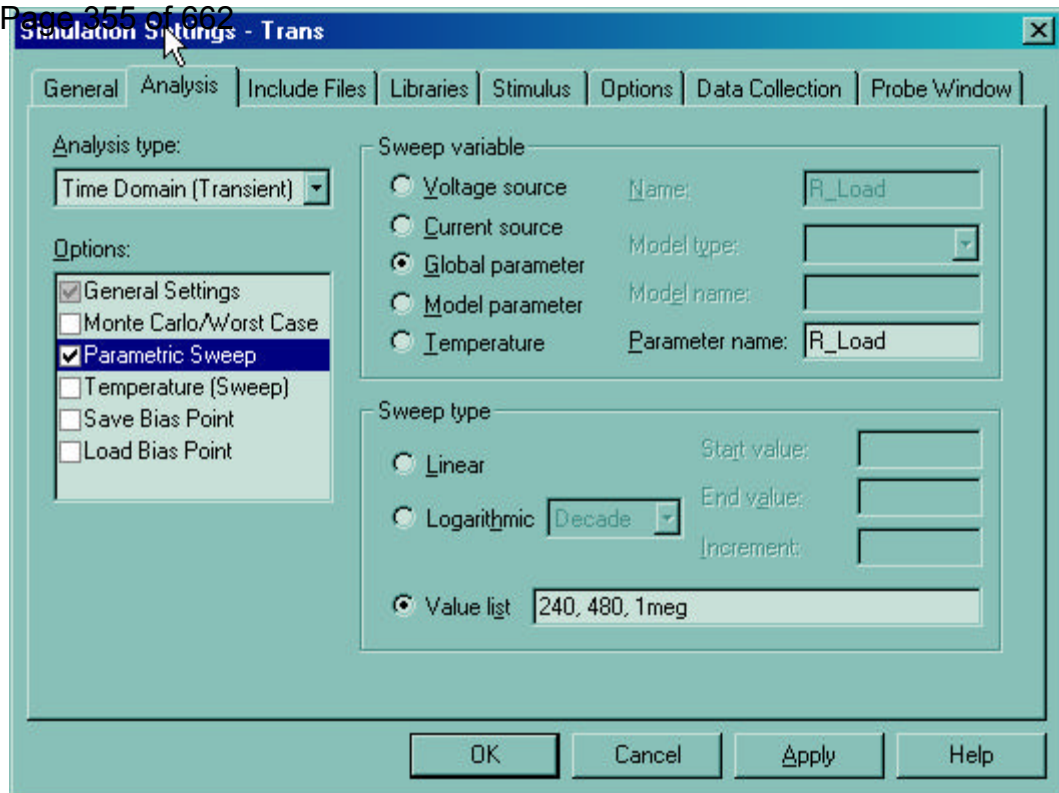
Time: 15:07:35

Changed C2 to 2UF to see if we are limited by the charge transfer to C2 from VCC.

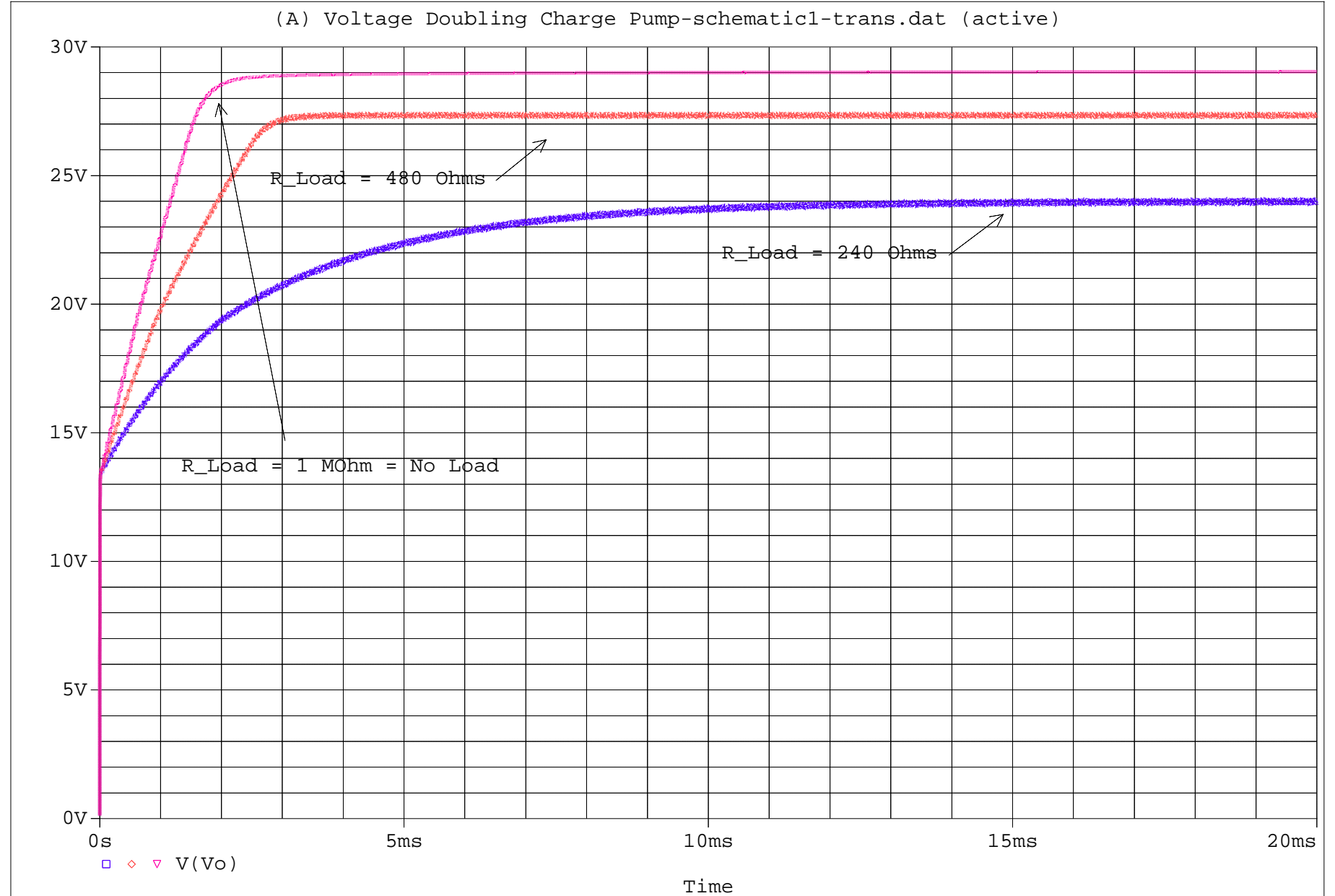


PARAMETERS:
R_Load = 240

0 to 15 V pulse
supply with
200 mA source/Sink



** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Voltage Doubling Charg...
Date/Time run: 01/16/03 12:57:36 Temperature: 27.0

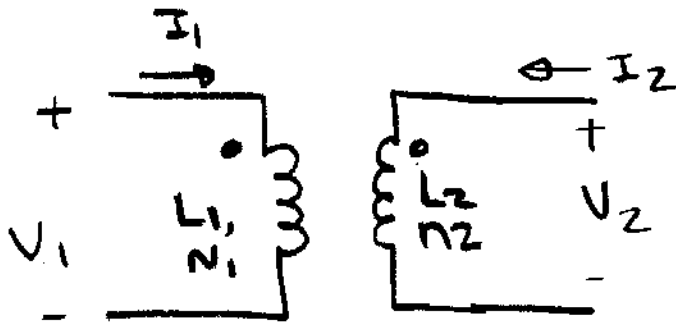


Date: January 16, 2003

Page 1

Time: 12:59:35

Transformer Review



$$k = \frac{M}{\sqrt{L_1 L_2}}$$

$$V_1 = L_1 \frac{dI_1}{dt} + m \frac{dI_2}{dt}$$

$$V_2 = m \frac{dI_1}{dt} + L_2 \frac{dI_2}{dt}$$

Ideal Transformer

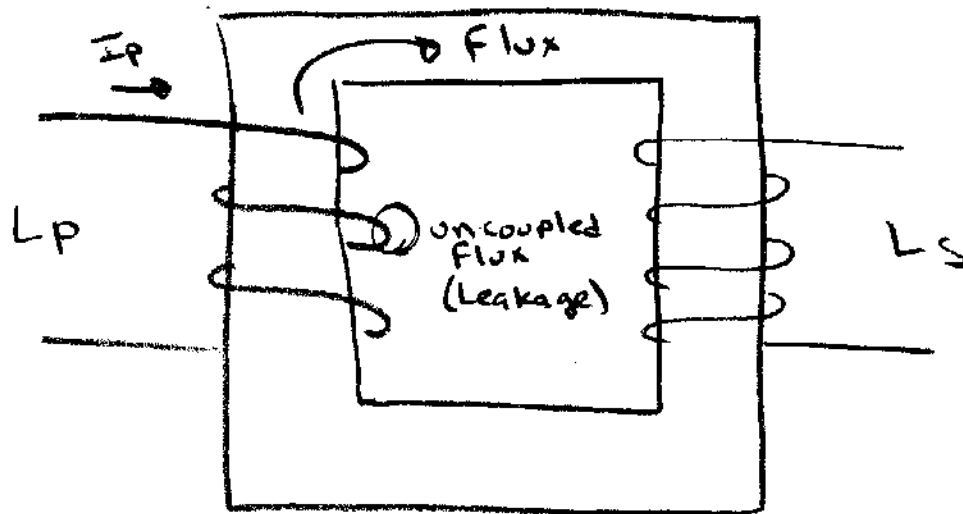
$$V_1 = \frac{N_1}{N_2} V_2, \quad I_1 = \frac{N_2}{N_1} I_2$$

$$\frac{N_1}{N_2} = \sqrt{\frac{L_1}{L_2}}$$

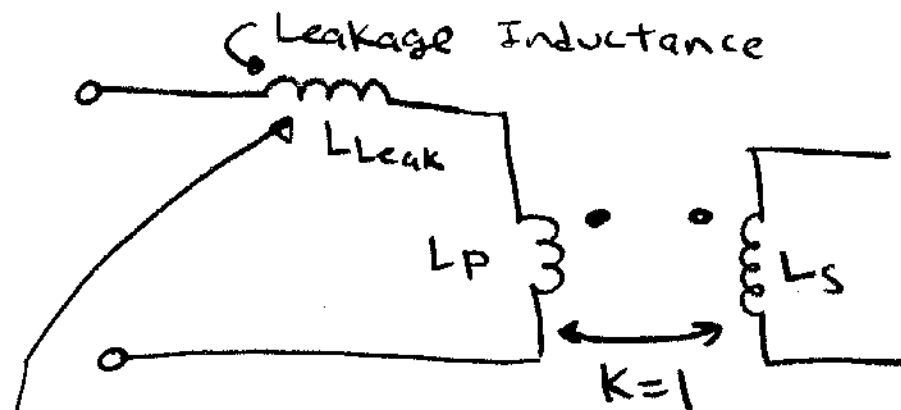
k = Coefficient of coupling, For Ideal

Transformer, $k=1$

Leakage Inductance



- Not all of the flux from the primary winding is coupled to the secondary.
- This Leakage Flux can be modelled as a series inductance with the primary



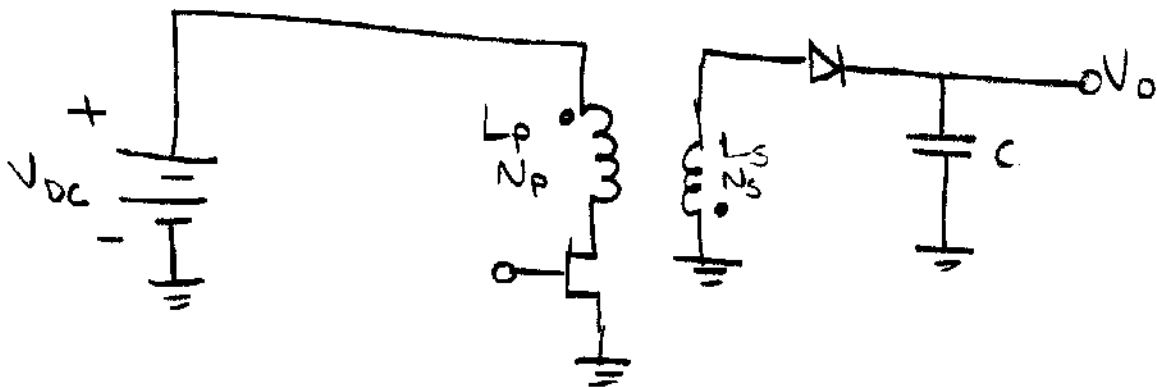
No energy stored here is coupled to the secondary

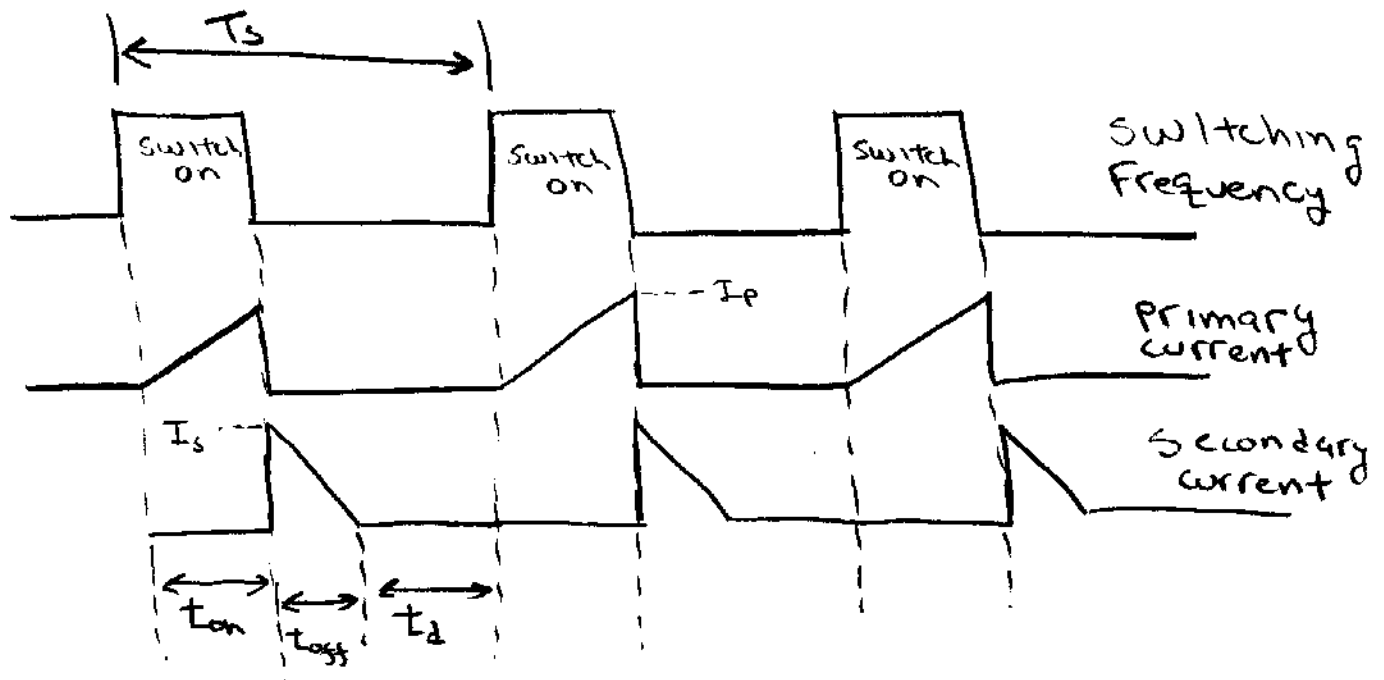
- Typically $L_{Leak} = 10\%$ of L_p

Fly Back Topology

- Typically used for power Below 150W
- Does not require the inductor used in the forward type regulator
- Easily interleaved/Paralleled.
- Can be used for high voltage (<5kV)
- Requires a snubber

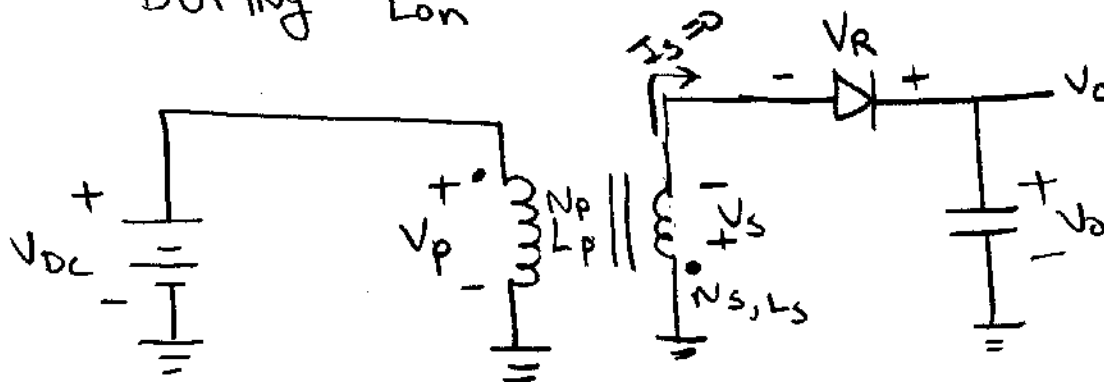
Fly back Topology





Assume switches and diodes are ideal.

During t_{on}



$$V_p = V_{DC}$$

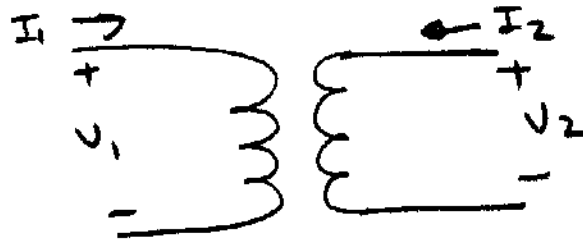
$$V_s = \frac{N_s}{N_p} V_p = \frac{N_s}{N_p} V_{DC}$$

$$\Rightarrow V_R = V_o + \frac{N_s}{N_p} V_{DC} \quad \text{- Reverse voltage across the diode}$$

$$\Rightarrow \text{Diode is off}$$

- Since the diode is OFF, $I_s = 0$

\Rightarrow No secondary current implies that the primary acts as an inductor. Remember our XFMR equation



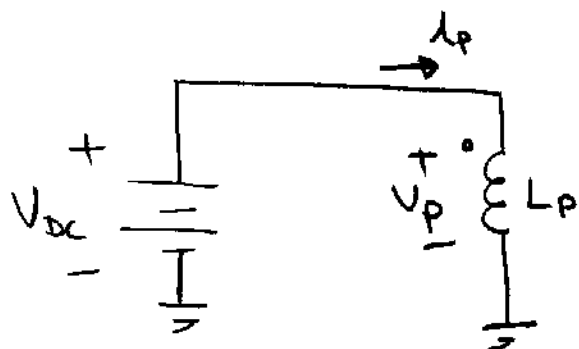
$$\frac{d\lambda_1}{dt} = \frac{V_1}{L_1} + \underbrace{\frac{N_2}{N_1} \frac{d\lambda_2}{dt}}_0$$

Since $\frac{d\lambda_2}{dt} = 0$

$$\frac{d\lambda_1}{dt} = \frac{V_1}{L_1} \quad \leftarrow \text{Just the equation for an inductor.}$$

\Rightarrow we treat the primary and secondary halves as inductors that exchange energy.

Look at the primary



$$V_p = L_p \frac{dI_p(t)}{dt} \Rightarrow I_p(t) = \frac{1}{L_p} \int_0^{t_{on}} V_p(t) dt$$

in this case $V_p(t) = V_{dc}$ so

$$I_p(t) = \frac{V_{dc}}{L_p} \int_0^{t_{on}} dt = \frac{V_{dc} t_{on}}{L_p}$$

so the primary current is a
Ramp of peak value $\frac{V_{dc} t_{on}}{L_p}$



Peak stored energy

$$E = \frac{1}{2} L_p I_p^2 = \frac{(V_{dc} t_{on})^2}{2L_p}$$

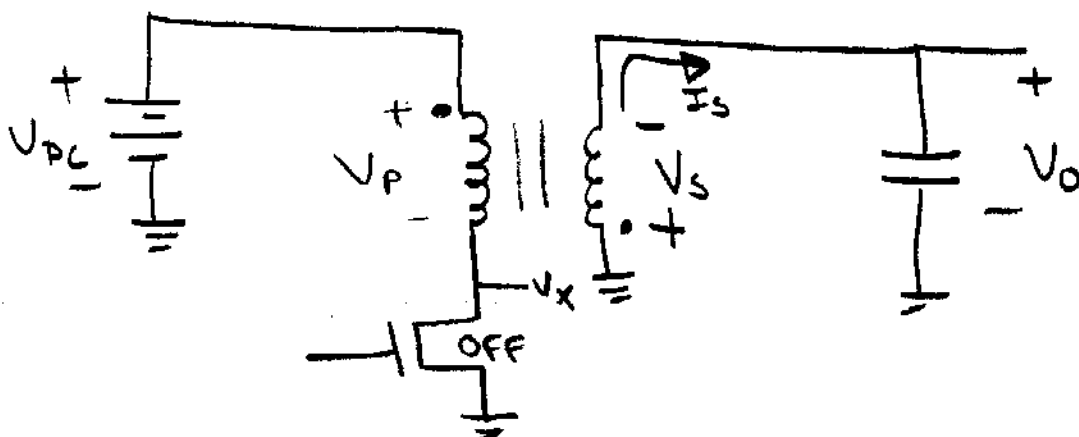
Input power is $P_{in} = E(F_s) = E/T_s$

so
$$P_{in} = \frac{(V_{dc} t_{on})^2}{2 L_p T_s}$$

- When the switch turns off, all energy stored is transferred to the secondary

- Current can't flow in primary because the switch is OFF,

- Current can flow in the secondary



$$V_X = V_{DC} - V_P$$

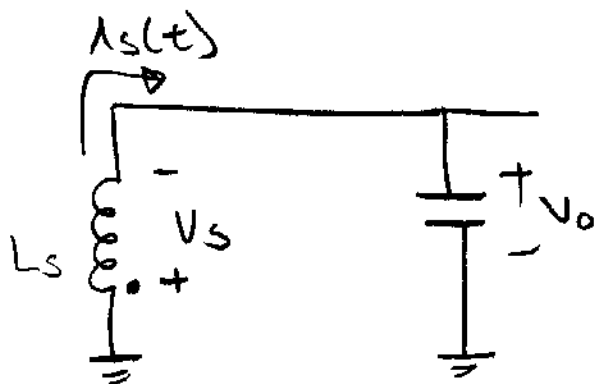
$$V_S = -V_O \quad - \text{Reverse voltage ramps down the Secondary current}$$

$$V_P = \frac{N_P}{N_S} (-V_O)$$

\Rightarrow Switch OFF voltage is

$$V_X = V_{DC} - V_P = V_{DC} + \frac{N_P}{N_S} V_O$$

\Rightarrow Since there is no primary current, treat the secondary as an inductor



$$V_s(t) = L_s \frac{dI_s(t)}{dt}$$

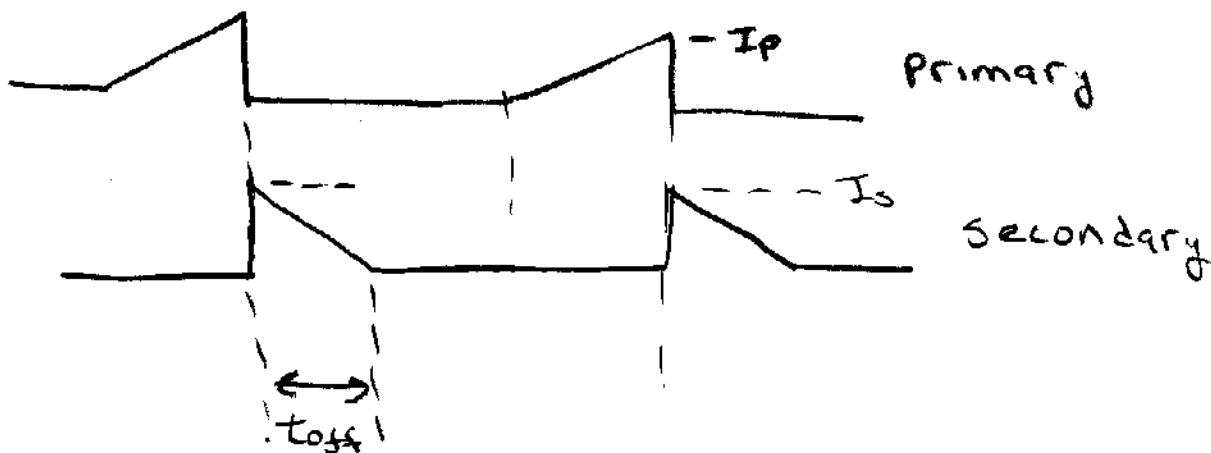
$$I_s(t) = \frac{1}{L_s} \int_0^{t_{off}} V_s(t) dt + I_{s.c.}$$

in our case, $V_s(t) = -V_o = \text{const}$

so

$$I_s(t) = -\frac{V_o}{L_s} \int_0^{t_{\text{off}}} dt + I.C.$$

Negative
going Ramp



Questions:

- 1) what is t_{off}
- 2) what is inductor peak initial current

When current switches from the Primary to the Secondary, the energy stored in the core is constant

$$\underbrace{\frac{1}{2} L_p I_p^2}_{(V_{oc} t_{on})^2} = \frac{1}{2} L_s I_s^2$$

$$\frac{(V_{oc} t_{on})^2}{2 L_p} = \frac{1}{2} L_s I_s^2$$

Solve for I_s

$$I_s = \sqrt{\frac{L_p}{L_s}} \quad I_p = \frac{V_{oc} t_{on}}{\sqrt{L_s L_p}}$$

Now Find t_{oss}

$$I_s(t) = -\frac{V_o}{L_s} \int_0^{t_{oss}} dt + \frac{V_{oc} t_{on}}{\sqrt{L_s L_p}}$$

at $t = t_{oss}$, $I_s(t) = 0$

so

$$\frac{+V_o t_{oss}}{L_s} = \frac{V_{oc} t_{on}}{\sqrt{L_s L_p}}$$

$$\Rightarrow t_{oss} = \frac{V_{oc}}{V_o} \sqrt{\frac{L_s}{L_p}} t_{on}$$

Also, for safety margin, we want

$$t_{\text{loss}} + t_{\text{on}} = 0.8 T_s$$

Flyback Summary

Diode Voltage Rating: $V_R = V_o + \frac{N_s}{N_p} V_{\text{oc}}$

Primary peak current: $I_p = \frac{V_{\text{oc}} t_{\text{on}}}{L_p}$

Peak input power: $P_{\text{in}} = \frac{(V_{\text{oc}} t_{\text{on}})^2}{2L_p T_s}$

Voltage stress on switch: $V_x = V_{\text{oc}} + V_{\text{snub}}$

Primary to secondary current: $I_s = \sqrt{\frac{L_p}{L_s}} I_p = \frac{V_{\text{oc}} t_{\text{on}}}{\sqrt{L_s L_p}}$

$$t_{\text{loss}} = \frac{V_{\text{oc}}}{V_o} \sqrt{\frac{L_s}{L_p}} t_{\text{on}}$$

- Design Considerations/Options/Limitations

- Design for max power?

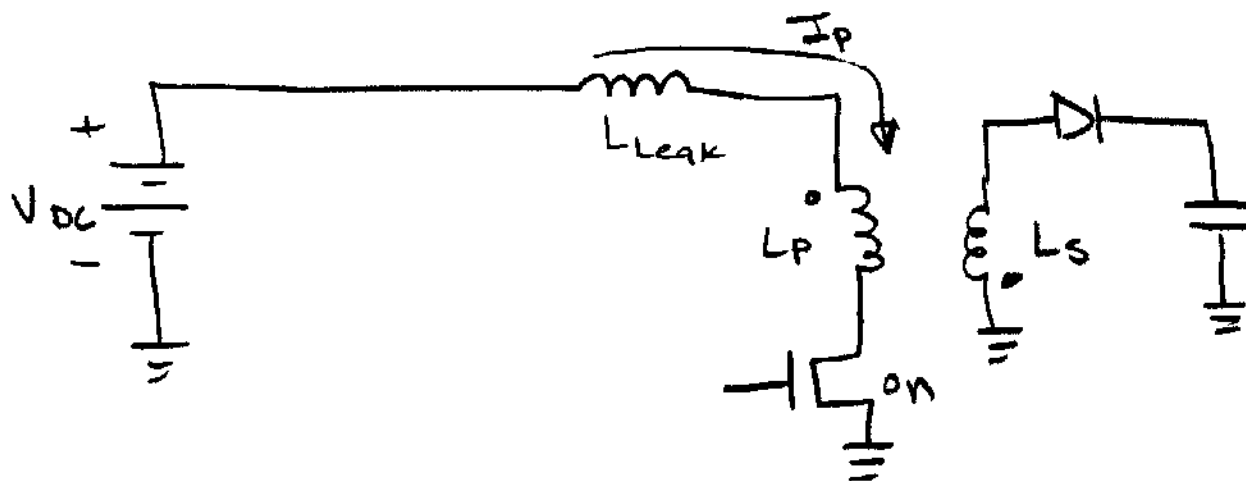
- Design for max I_p ? Is I_p your
Limitation?

- Is Switch voltage stress your
Limitation?

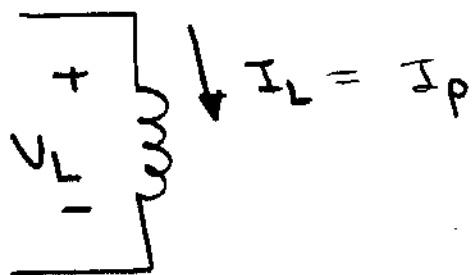
- Is Switch current your Limitation?

- Power Capabilities compared to other
topologies. Primary voltage constant in
all cases.

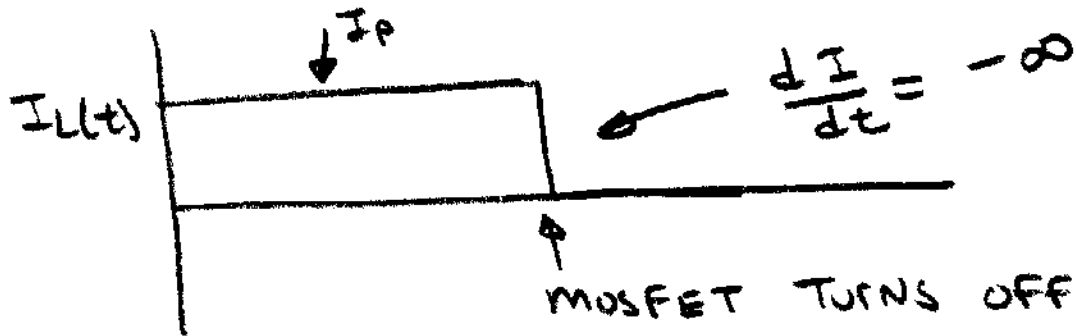
Flyback topology - The effect of Leakage Inductance



- when the switch is on, we charge up L_P and L_{Leak} .
- when the switch turns off, the current in L_P can go to zero, because it is coupled to L_S . However, L_{Leak} is an inductor and the current cannot change instantaneously.

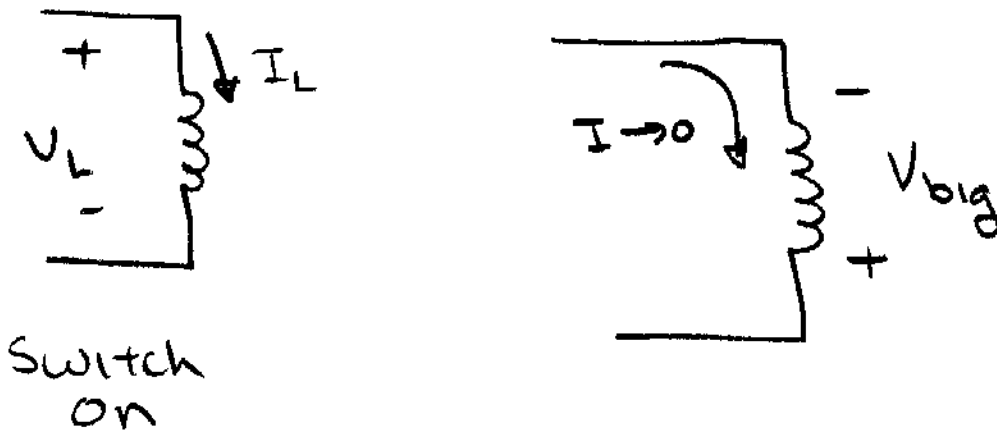


- when the switch turns off we are doing the following to $I_L(t)$

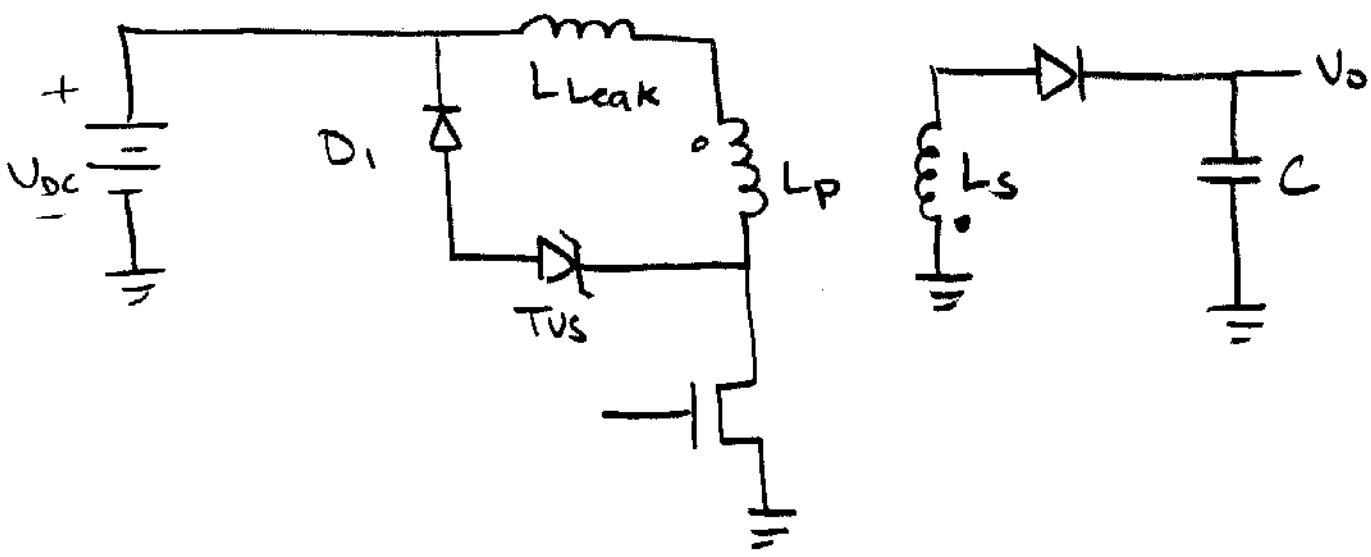


Since $\frac{dI}{dt} = -\infty$, $V_L = L_{Leak} \frac{dI}{dt} = -\infty$

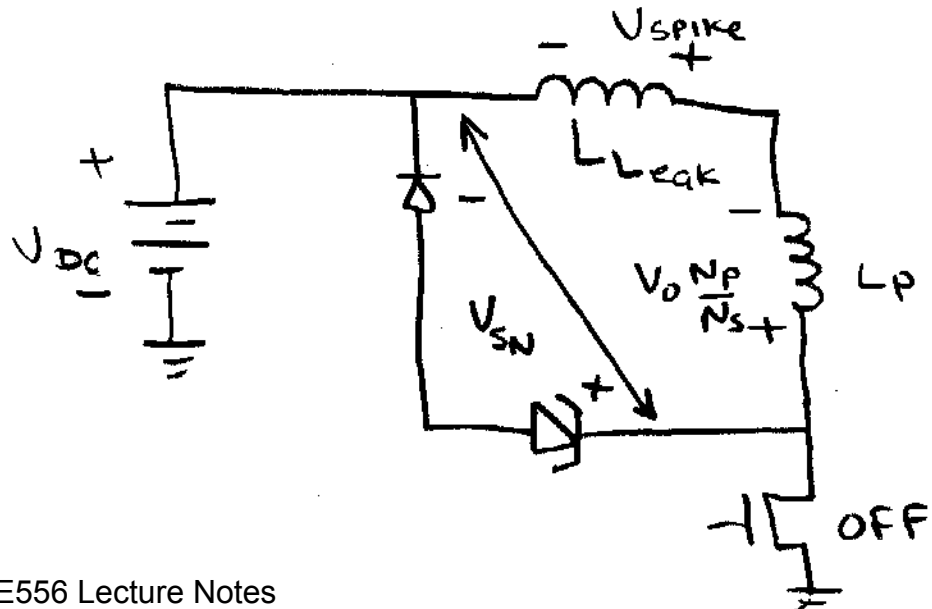
\Rightarrow The voltage flips and becomes very large



\Rightarrow Turning off a Transformer with Leakage requires a CKT to Limit the Voltage Spikes



- When the switch turns off, the voltage across the primary is limited to the breakdown voltage of the TVS (A TVS is a fast Zener designed for surge suppression)



$$V_{SN} = V_{SPI} + V_0 \frac{N_p}{N_s}$$

- Choose

$$V_o \frac{N_p}{N_s} < V_{sn} \quad \text{where } V_{sn} \text{ is}$$

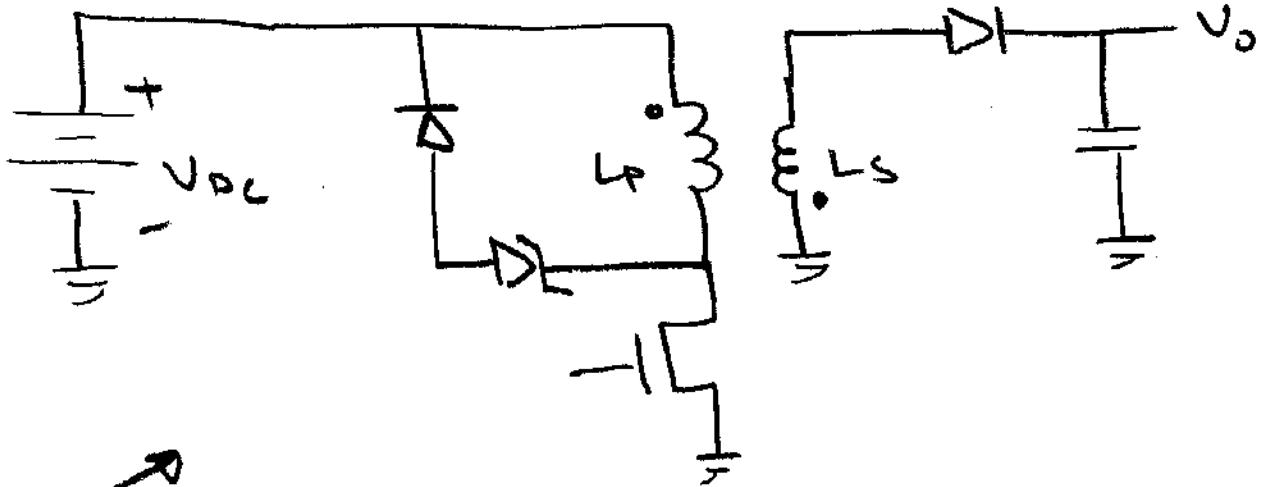
the breakdown
voltage of the TVS

- Choose

$$V_{\text{switch}} > V_{oc} + V_{sn}$$

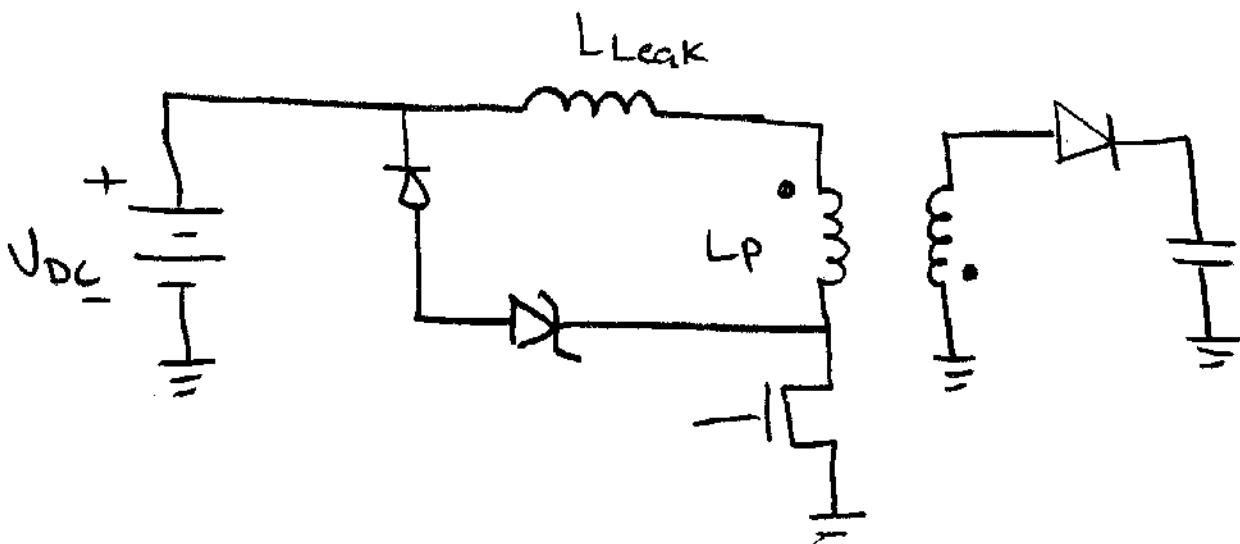
where V_{switch} is the voltage
rating of the switch

- Remember, you don't add L_{Leak} to your ckt when you build it.



what you build

How you model it



ECE 456

Flyback Switching Power Supply Design Discontinuous Mode Operation

$$\mu\text{s} \equiv 10^{-6} \cdot \text{sec}$$

Specify Input Voltage $V_{\text{DC}} := 12 \cdot \text{volt}$

Specify Output Voltage $V_o := 500 \cdot \text{volt}$

Specify the output power $P_{\text{out}} := 50 \cdot \text{watt}$

Output Current $I_o := \frac{P_{\text{out}}}{V_o}$ $I_o = 0.1 \text{ amp}$

Specify the regulator efficiency $\text{Eff} := 80 \cdot \%$

Calculate the required input power

$$P_{\text{in}} := \frac{P_{\text{out}}}{\text{Eff}} \quad P_{\text{in}} = 62.5 \text{ watt}$$

Specify the peak switch current $I_P := 20 \cdot \text{amp}$

Specify Switching Frequency $F_S := 20 \cdot \text{kHz}$

$$T_S := \frac{1}{F_S} \quad T_S = 50 \mu\text{s}$$

Specify the dead time

$$t_{\text{dead}} := 0.2 \cdot T_S$$

$$t_{\text{dead}} = 10 \mu\text{s}$$

Given the peak current, and required input power, find the primary inductance.

$$L_P := 100 \cdot \mu\text{H}$$

Given

$$P_{\text{in}} = 0.5 \cdot L_P \cdot I_P^2 \cdot F_S$$

$$L_P := \text{Find}(L_P) \quad L_P = 15.625 \mu\text{H}$$

Given the peak current, and max and min input voltages, find t_{on} .

$$t_{\text{on}} := \frac{I_P \cdot L_P}{V_{\text{DC}}} \quad t_{\text{on}} = 26.042 \mu\text{s}$$

Note that t_{on} must be less than the switching period, T_S

$$T_S = 50 \mu\text{s}$$

If t_{on} is too big, we need to specify a new value for the peak primary current I_P .

Calculate $T_{\text{off max}}$

$$t_{\text{off}} := T_S - t_{\text{on}} - t_{\text{dead}}$$

$$t_{\text{off}} = 13.958 \mu\text{s}$$

Choose the secondary inductance to use the full off time to discharge the core.

$$L_S := L_P \cdot \left(\frac{t_{\text{off}} \cdot V_o}{t_{\text{on}} \cdot V_{\text{DC}}} \right)^2 \quad L_S = 7.793 \text{ mH}$$

Calculate the peak current at the output

$$N := \sqrt{\frac{L_S}{L_P}} \quad N = 22.333$$

$$I_S := \sqrt{\frac{L_P}{L_S}} \cdot I_P \quad I_S = 0.896 \text{ amp}$$

Check the output Power

$$0.5 \cdot L_S \cdot I_S^2 \cdot F_S = 62.5 \text{ watt}$$

Calculate the minimum voltage we will need for our snubber TVS.

$$V_{\text{snub}} := \sqrt{\frac{L_P}{L_S}} \cdot V_o \quad V_{\text{snub}} = 22.388 \text{ volt}$$

Choose a standard TSV breakdown voltage $V_{\text{TVS}} := 45 \cdot \text{volt}$

Designed specifically for the protection of sensitive electronics used in automotive, heavy industrial environments, and against voltage transients induced by lightning in other applications. Ideal for the protection of I/O interfaces, Vcc bus, and other integrated circuits.

FEATURES

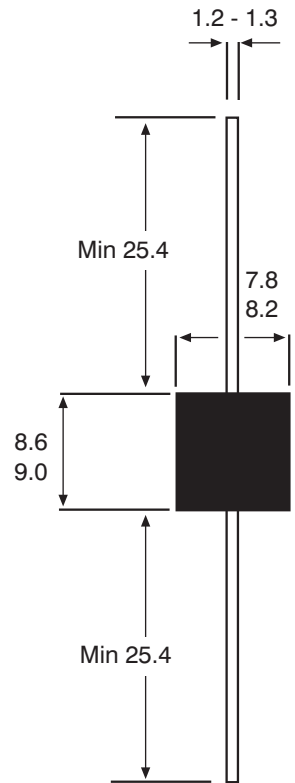
- Stand-off voltage range 5.0 to 180 Volts
- Uni-directional and Bi-directional
- Glass passivated junction
- Low clamping factor
- 100% surge tested
- UL recognised

MAXIMUM RATING

- Peak Pulse Power (Ppk): 5000 Watts (10 x 1000µs)@25°C (see diagram on page 6 for wave form)
- 8 watt steady state
- Response time: 1×10^{-12} seconds (theoretical)
- Forward surge rating: 400 Amps, 8.3ms half sine wave, (uni-directional devices only)
- Operating & storage temperature: -55°C to +150°C

MECHANICAL CHARACTERISTICS

- Case: JEDEC R6; Moulded plastic over glass passivated junction
- Terminals: Axial leads, solderable per MIL-STD-202 Method 208
- Solderable leads = 230°C for 10 seconds (1.59mm from case)
- Marking: cathode band, (positive terminal, uni-directional devices only), device code, logo
- Weight: 2.0 grammes (approx)



All dimensions in mm

Figure 1 - Capacitance vs. Stand-off Voltage

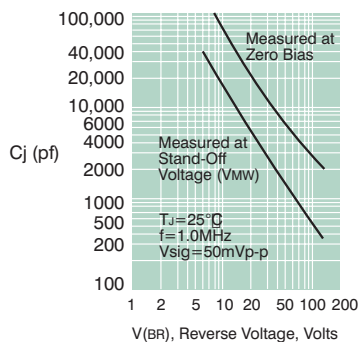
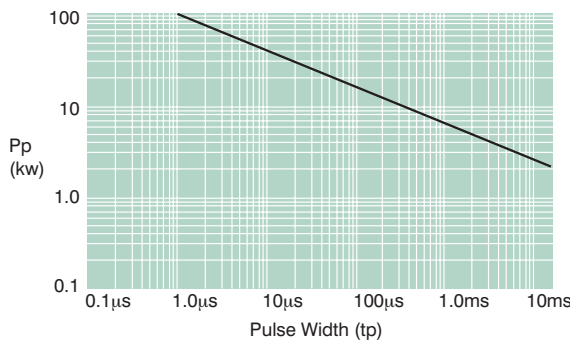
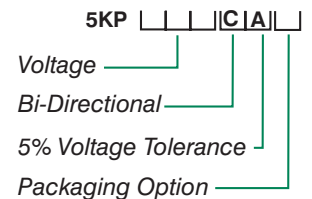


Figure 2 - Peak Pulse Power vs. Pulse Time



ORDERING INFORMATION



B = Bulk (500 pcs)
T = Tape and reeled (1000 pcs)

5KP5.0 - 5KP180C series

ELECTRICAL SPECIFICATION @ Tamb 25°C

Part Number (Uni)	Part Number (Bi)	Reverse Stand off Voltage V_R (Volts)	Breakdown Voltage V_{BR} (Volts) @ I_T			Maximum Reverse Leakage I_R @ V_R (μ A)	Maximum Clamping Voltage V_C @ I_{PP} (Volts)	Maximum Peak Pulse Current I_{PP} (A)	Max Voltage Temperature Variation of V_{BR} (mV/°C)
			MIN	MAX	(mA)				
5KP5.0	5KP5.0C*	5.0	6.40	7.30	50.0	5000.0	9.6	520.0	4.0
5KP5.0A	N/A	5.0	6.40	7.00	50.0	5000.0	9.2	543.0	4.0
5KP6.0	5KP6.0C	6.0	6.67	8.15	50.0	5000.0	11.4	439.0	4.0
5KP6.0A	5KP6.0CA	6.0	6.67	7.37	50.0	5000.0	10.3	485.0	4.0
5KP6.5	5KP6.5C	6.5	7.22	8.82	50.0	2000.0	12.3	407.0	4.0
5KP6.5A	5KP6.5CA	6.5	7.22	7.98	50.0	2000.0	11.2	447.0	4.0
5KP7.0	5KP7.0C	7.0	7.78	9.51	50.0	1000.0	13.3	378.0	5.0
5KP7.0A	5KP7.0CA	7.0	7.78	8.60	50.0	1000.0	12.0	417.0	5.0
5KP7.5	5KP7.5C	7.5	8.33	10.20	5.0	250.0	14.3	350.0	6.0
5KP7.5A	5KP7.5CA	7.5	8.33	9.21	5.0	250.0	12.9	388.0	6.0
5KP8.0	5KP8.0C	8.0	8.89	10.90	5.0	150.0	15.0	333.0	6.0
5KP8.0A	5KP8.0CA	8.0	8.89	9.83	5.0	150.0	13.6	367.0	6.0
5KP8.5	5KP8.5C	8.5	9.44	11.50	5.0	50.0	15.9	314.0	7.0
5KP8.5A	5KP8.5CA	8.5	9.44	10.40	5.0	50.0	14.4	347.0	7.0
5KP9.0	5KP9.0C	9.0	10.00	12.20	5.0	20.0	16.9	295.0	8.0
5KP9.0A	5KP9.0CA	9.0	10.00	11.10	5.0	20.0	15.4	325.0	8.0
5KP10*	5KP10C	10.0	11.10	13.60	5.0	15.0	18.8	266.0	9.0
5KP10A*	5KP10CA	10.0	11.10	12.30	5.0	15.0	17.0	294.0	9.0
5KP11	5KP11C	11.0	12.20	14.90	5.0	10.0	20.1	249.0	10.0
5KP11A	5KP11CA	11.0	12.20	13.50	5.0	10.0	18.2	274.0	10.0
5KP12*	5KP12C	12.0	13.30	16.30	5.0	10.0	22.0	227.0	11.0
5KP12A*	5KP12CA	12.0	13.30	14.70	5.0	10.0	19.9	251.0	11.0
5KP13	5KP13C	13.0	14.40	17.60	5.0	10.0	23.8	210.0	12.0
5KP13A	5KP13CA	13.0	14.40	15.90	5.0	10.0	21.5	232.0	12.0
5KP14	5KP14C	14.0	15.60	19.10	5.0	10.0	25.8	194.0	13.0
5KP14A	5KP14CA	14.0	15.60	17.20	5.0	10.0	23.2	215.0	13.0
5KP15	5KP15C	15.0	16.70	20.40	5.0	10.0	26.9	188.0	15.0
5KP15A	5KP15CA	15.0	16.70	18.50	5.0	10.0	24.4	206.0	15.0
5KP16	5KP16C	16.0	17.80	21.80	5.0	10.0	28.8	176.0	18.0
5KP16A	5KP16CA	16.0	17.80	19.70	5.0	10.0	26.0	192.0	16.0
5KP17	5KP17C	17.0	18.90	23.10	5.0	10.0	30.5	164.0	19.0
5KP17A	5KP17CA	17.0	18.90	20.90	5.0	10.0	27.6	181.0	18.0
5KP18	5KP18C	18.0	20.00	24.40	5.0	10.0	32.2	155.0	20.0
5KP18A	5KP18CA	18.0	20.00	22.10	5.0	10.0	29.2	172.0	19.0
5KP20	5KP20C	20.0	22.20	27.10	5.0	10.0	35.8	139.0	24.0
5KP20A	5KP20CA	20.0	22.20	24.50	5.0	10.0	32.4	154.0	22.0
5KP22	5KP22C*	22.0	24.40	29.80	5.0	10.0	39.4	127.0	27.0
5KP22A	5KP22CA*	22.0	24.40	26.90	5.0	10.0	35.5	141.0	24.0
5KP24*	5KP24C	24.0	26.70	32.60	5.0	10.0	43.0	116.0	30.0
5KP24A*	5KP24CA	24.0	26.70	29.50	5.0	10.0	38.9	128.0	27.0
5KP26*	5KP26C	26.0	28.90	35.30	5.0	10.0	46.6	107.0	33.0
5KP26A*	5KP26CA	26.0	28.90	31.90	5.0	10.0	42.1	119.0	29.0
5KP28	5KP28C	28.0	31.10	39.00	5.0	10.0	50.1	99.0	34.0

Suffix 'C' denotes Bi-directional device. Suffix 'A' denotes 5% tolerance device, no suffix denotes a 10% tolerance device.

1. For Bi-directional devices having V_R of 10 volts and below, the I_R limit is doubled.
2. $V_F = 3.5$ Volts max. for devices of $V_R < 100V$, and $V_F = 5.0$ Volts max for devices of $V_R > 100V$. $I_F = 100A$, 300 μ S square wave.

* Preferred voltages.

ELECTRICAL SPECIFICATION @ Tamb 25°C

Part Number (Uni)	Part Number (Bi)	Reverse Stand off Voltage V_R (Volts)	Breakdown Voltage V_{BR} (Volts) @ I_T			Maximum Reverse Leakage I_R @ V_R (μ A)	Maximum Clamping Voltage V_C @ I_{PP} (Volts)	Maximum Peak Pulse Current I_{PP} (A)	Max Voltage Temperature Variation of V_{BR} (mV/°C)
			MIN	MAX	(mA)				
5KP28A	5KP28CA	28.0	31.10	34.40	5.0	10.0	45.5	110.0	30.0
5KP30	5KP30C	30.0	33.30	40.70	5.0	10.0	53.5	93.0	38.0
5KP30A	5KP30CA	30.0	33.30	36.80	5.0	10.0	48.4	103.0	35.0
5KP33	5KP33C*	33.0	36.70	44.90	5.0	10.0	59.0	85.0	41.0
5KP33A	5KP33CA*	33.0	36.70	40.60	5.0	10.0	53.3	94.0	38.0
5KP36	5KP36C	36.0	40.00	48.90	5.0	10.0	64.3	78.0	45.0
5KP36A	5KP36CA	36.0	40.00	44.20	5.0	10.0	58.1	86.0	40.0
5KP40	5KP40C	40.0	44.40	54.30	5.0	10.0	71.4	70.0	50.0
5KP40A	5KP40CA	40.0	44.40	49.10	5.0	10.0	64.5	78.0	45.0
5KP43	5KP43C	43.0	47.80	58.40	5.0	10.0	76.7	65.0	54.0
5KP43A	5KP43CA	43.0	47.80	52.80	5.0	10.0	69.4	72.0	49.0
5KP45	5KP45C	45.0	50.00	61.10	5.0	10.0	80.3	62.0	57.0
5KP45A	5KP45CA	45.0	50.00	55.30	5.0	10.0	72.7	69.0	51.0
5KP48	5KP48C	48.0	53.30	65.20	5.0	10.0	85.5	58.0	62.0
5KP48A	5KP48CA	48.0	53.30	58.90	5.0	10.0	77.4	65.0	55.0
5KP51	5KP51C	51.0	56.70	69.30	5.0	10.0	91.1	55.0	65.0
5KP51A	5KP51CA	51.0	56.70	62.70	5.0	10.0	82.4	61.0	60.0
5KP54*	5KP54C	54.0	60.00	73.30	5.0	10.0	96.3	52.0	70.0
5KP54A*	5KP54CA	54.0	60.00	66.30	5.0	10.0	87.1	57.0	64.0
5KP58	5KP58C	58.0	64.40	78.70	5.0	10.0	103.0	49.0	77.0
5KP58A	5KP58CA	58.0	64.40	71.20	5.0	10.0	93.6	53.0	69.0
5KP60*	5KP60C	60.0	66.70	81.50	5.0	10.0	107.0	47.0	79.0
5KP60A*	5KP60CA	60.0	66.70	73.70	5.0	10.0	96.8	52.0	70.0
5KP64	5KP64C	64.0	71.00	86.90	5.0	10.0	114.0	44.0	85.0
5KP64A	5KP64CA	64.0	71.00	78.60	5.0	10.0	103.0	49.0	75.0
5KP70	5KP70C	70.0	77.00	95.10	5.0	10.0	125.0	40.0	93.0
5KP70A	5KP70CA	70.0	77.00	86.00	5.0	10.0	113.0	44.0	84.0
5KP75	5KP75C	75.0	83.30	102.00	5.0	10.0	134.0	37.0	100.0
5KP75A	5KP75CA	75.0	83.30	92.10	5.0	10.0	121.0	41.0	90.0
5KP78	5KP78C	78.0	86.70	106.00	5.0	10.0	139.0	36.0	104.0
5KP78A	5KP78CA	78.0	86.70	95.80	5.0	10.0	126.0	40.0	94.0
5KP85	5KP85C	85.0	94.40	115.00	5.0	10.0	151.0	33.0	113.0
5KP85A	5KP85CA	85.0	94.40	104.00	5.0	10.0	137.0	36.0	102.0
5KP90	5KP90C*	90.0	100.00	122.00	5.0	10.0	160.0	31.0	120.0
5KP90A	5KP90CA*	90.0	100.00	111.00	5.0	10.0	146.0	34.0	109.0
5KP100	5KP100C	100.0	111.00	136.00	5.0	10.0	179.0	28.0	134.0
5KP110	5KP110C*	110.0	122.00	149.00	5.0	10.0	196.0	26.0	147.0
5KP120	5KP120C	120.0	133.00	1603.0	5.0	10.0	215.0	23.0	158.0
5KP150*	5KP150C	150.0	166.00	204.00	5.0	10.0	268.0	18.5	200.0
5KP180	5KP180C	180.0	200.00	244.00	5.0	10.0	320.0	15.0	240.0

Suffix 'C' denotes Bi-directional device. Suffix 'A' denotes 5% tolerance device, no suffix denotes a 10% tolerance device.

1. For Bi-directional devices having V_R of 10 volts and below, the I_R limit is doubled.
 2. $V_F = 3.5$ Volts max. for devices of $V_R < 100V$, and $V_F = 5.0$ Volts max for devices of $V_R > 100V$. $I_F = 100A$, 300 μ S square wave.
- * Preferred voltages.

Calculate the switch maximum voltage stress

$$V_X := V_{DC} + V_{TVS} \quad V_X = 57 \text{ volt}$$

Calculate the Diode reverse voltage

$$V_R := V_o + \sqrt{\frac{L_S}{L_P}} \cdot V_{DC} \quad V_R = 768 \text{ volt}$$

Choose the filter capacitor.

Assume that the major component of the ripple comes from the capacitor ESR

Specify the ripple due to the ESR $V_{RR} := 1000 \cdot \text{mV}$

$$\text{ESR} := \frac{V_{RR}}{I_S} \quad \text{ESR} = 1.117 \Omega$$

For all electrolytic caps, assume that $\text{ESR} \cdot C = 80 \mu\text{s}$

$$C := \frac{80 \cdot \mu\text{s}}{\text{ESR}} \quad C = 72 \mu\text{F}$$

Choose the next size std capacitor $C := 100 \cdot \mu\text{F}$

Calculate the new ESR with the chosen capacitor

$$\text{ESR} := \frac{80 \cdot \mu\text{s}}{C} \quad \text{ESR} = 0.8 \Omega$$

Find the ripple due to the ESR with the chosen capacitor

$$V_{RR} := (I_S) \cdot ESR \quad V_{RR} = 716.418 \text{ mV}$$

Calculate the Capacitor RMS Ripple Current

Define a function for the Secondary inductor current

$$I_{LS}(t) := I_S - \frac{I_S}{t_{off}} \cdot t$$

$$I_{rms} := \sqrt{\frac{1}{T_S} \left[\int_{0 \cdot \text{sec}}^{t_{on}} (-I_o)^2 dt + \int_{0 \cdot \text{sec}}^{t_{off}} (I_{LS}(t) - I_o)^2 dt \right]}$$

$$I_{rms} = 0.24 \text{ amp}$$

Summary

Input Specs $P_{in} = 62.5$ watt $V_{DC} = 12$ volt

Output Specs $P_{out} = 50$ watt $V_o = 500$ volt $V_{RR} = 716.4$ mV

Switch Specs $I_P = 20$ amp $V_X = 57$ volt

Transformer Specs

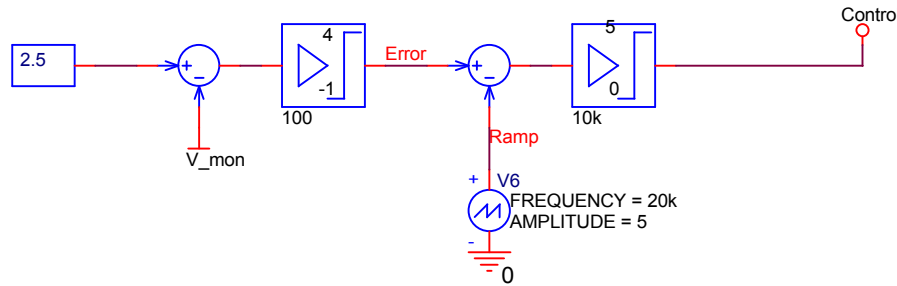
Primary $L_P = 15.625$ μ H $I_P = 20$ amp

Secondary $L_S = 7793$ μ H $I_S = 0.896$ amp

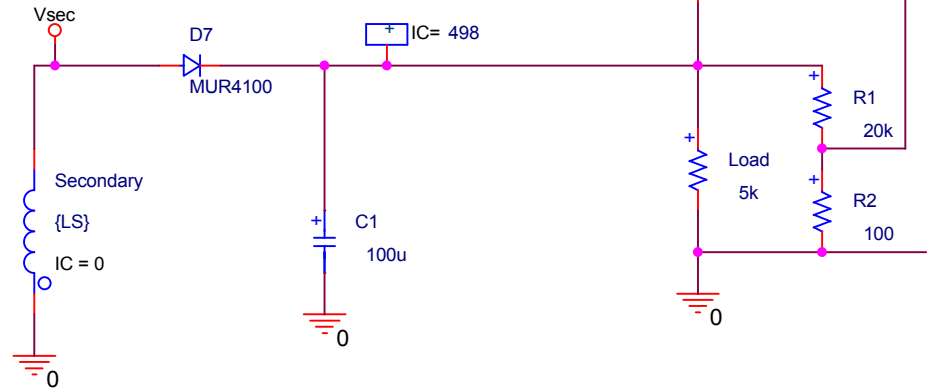
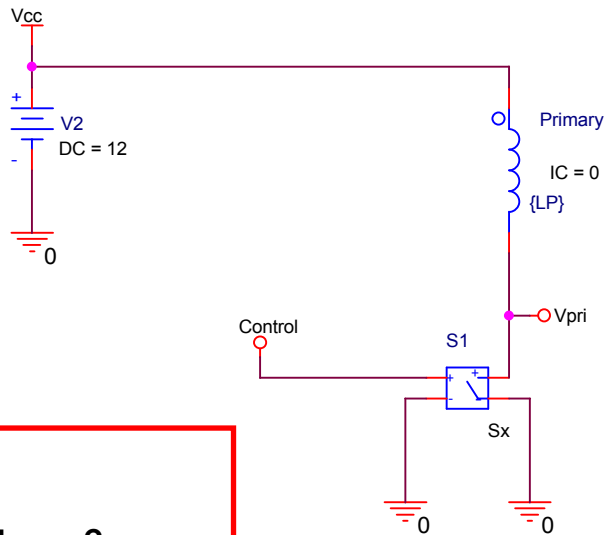
Diode Specs $I_S = 0.896$ amp $V_R = 768$ volt

TVS $V_{TVS} = 45$ volt

PARAMETERS:
 LS = 7793U
 L_Leak = {0.1*LP}
 LP = 15.6U



Model = Sx VSWITCH Roff=1e6 Ron=10m Voff=1 Von=4.0



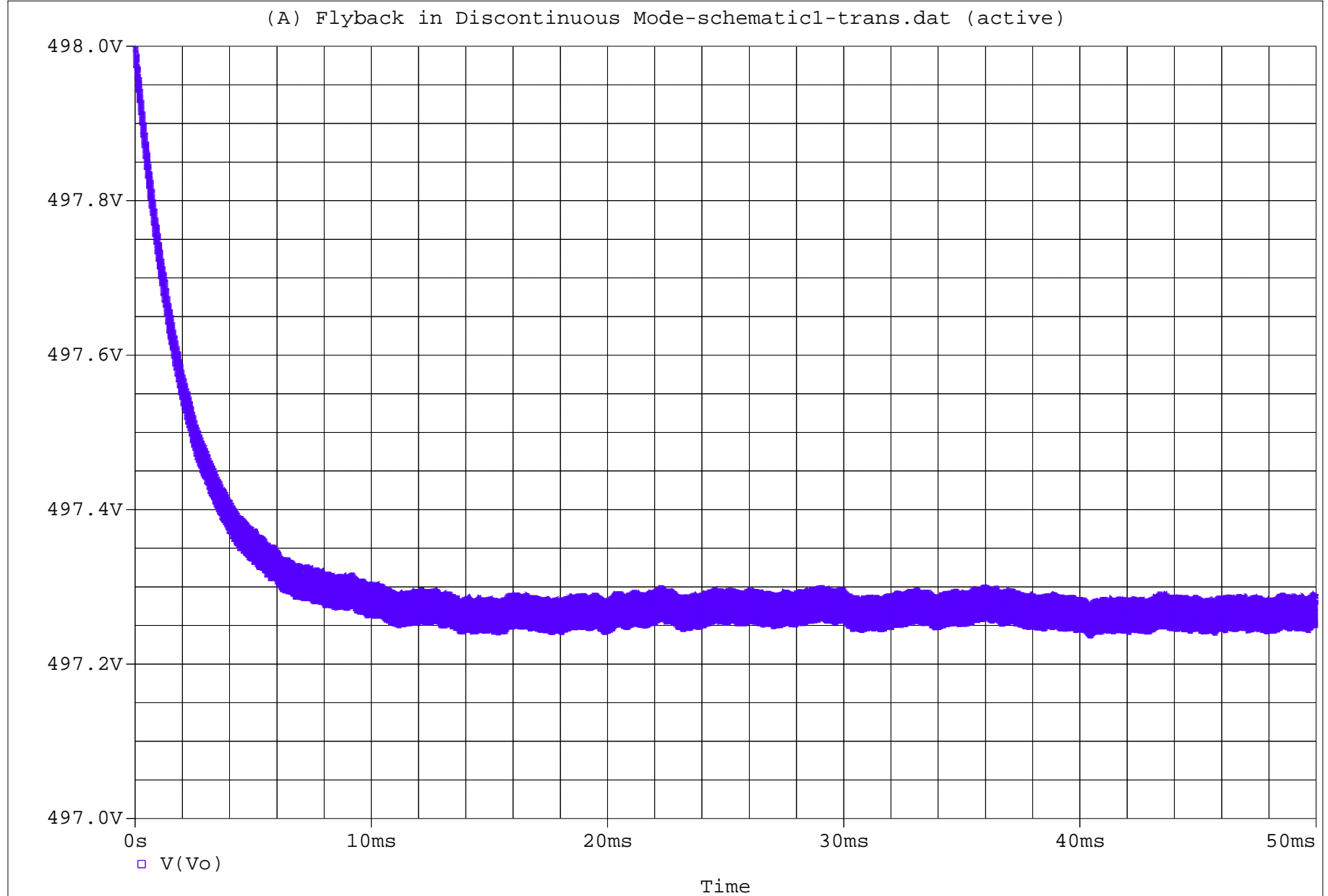
K1 COUPLING = .999
 L Primary L Secondary

No
 Snubber &
 Leakage
 Inductance

ECE Department
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Name: Marc E. Hermiter		Class: ECE456
Size A	Document Name	Rev 1
12V to -25 Volt Buck-Boost Discontinuous Mode		
Date: Thursday, January 23, 2003	Sheet 1	of 1

** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\Notes\Orcad\Flyback Converter\flyb...
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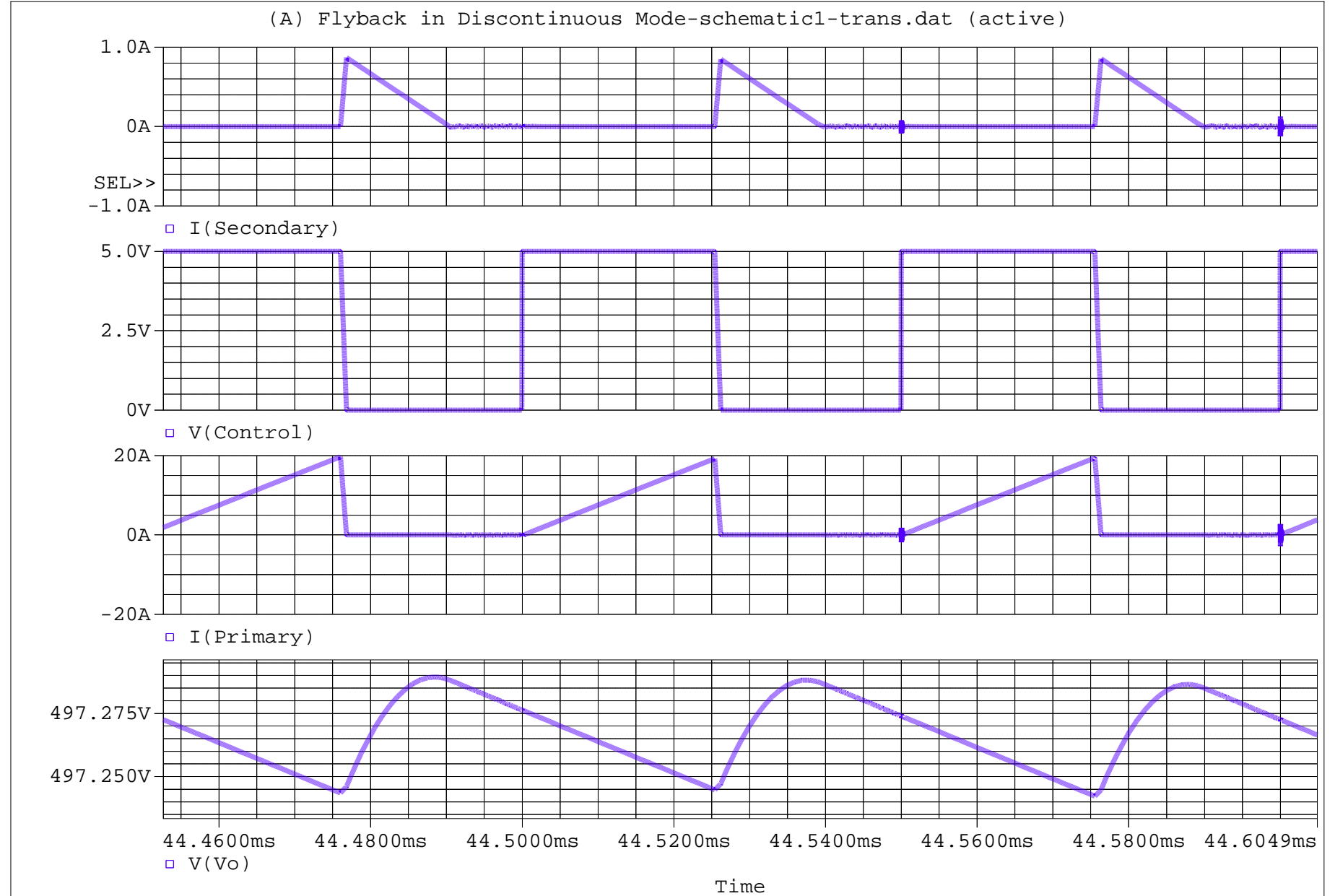


Date: January 23, 2003

Page 1

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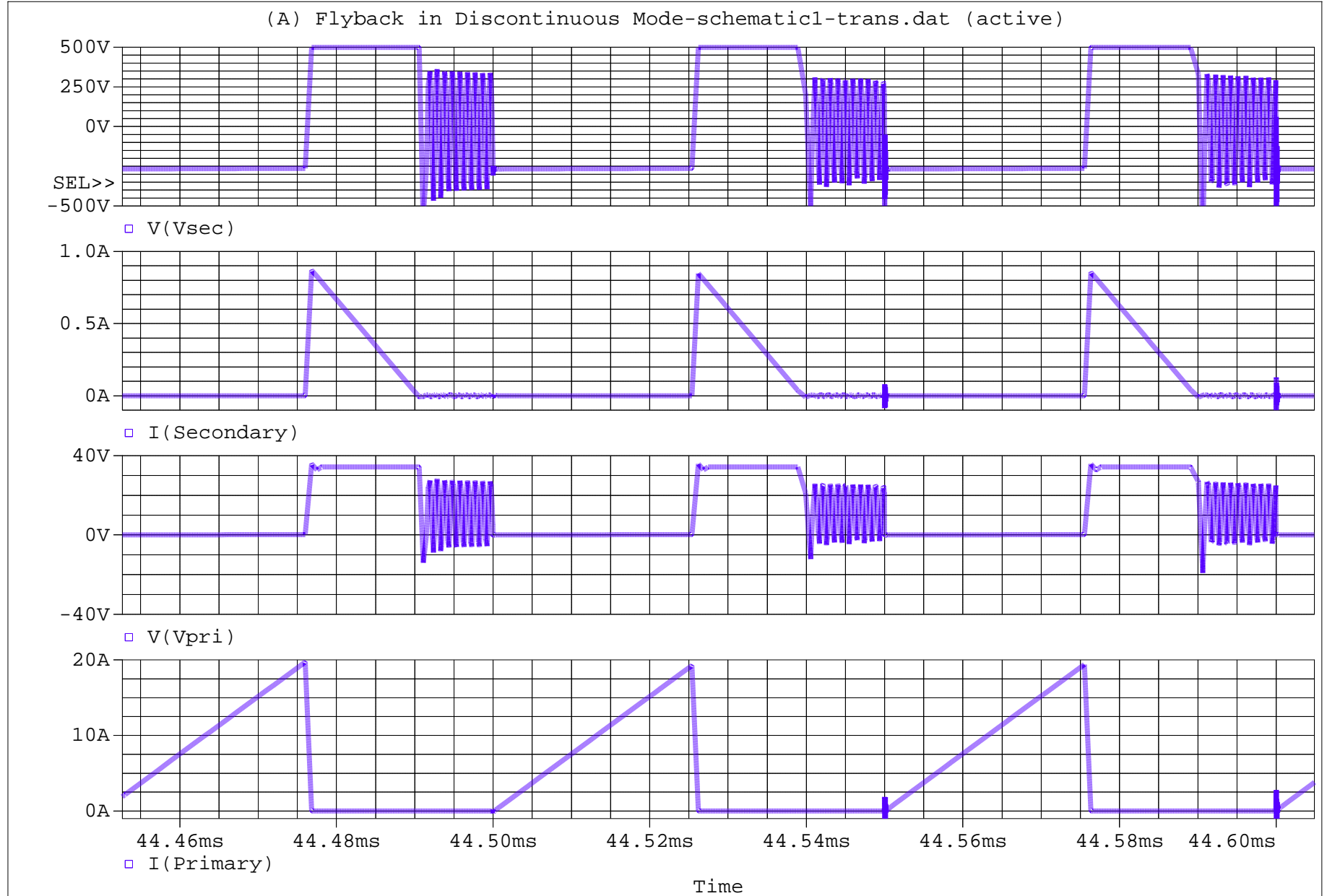


Date: January 23, 2003

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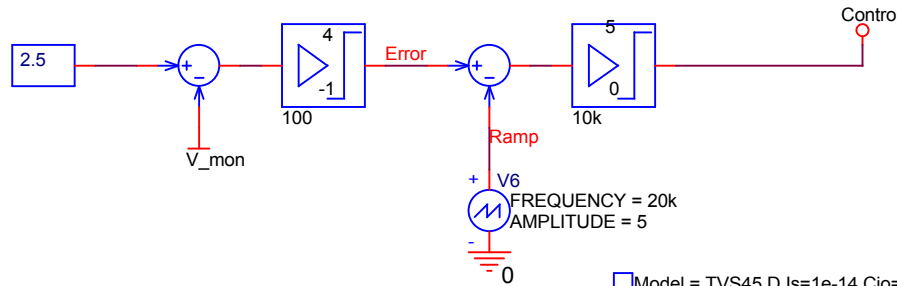


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Page 1

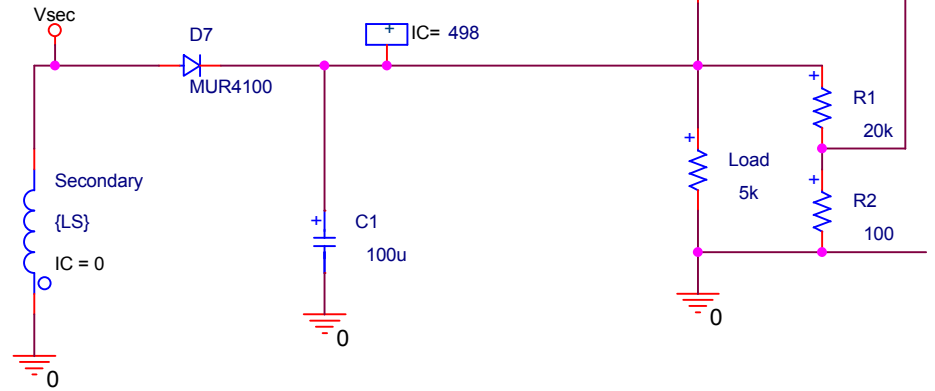
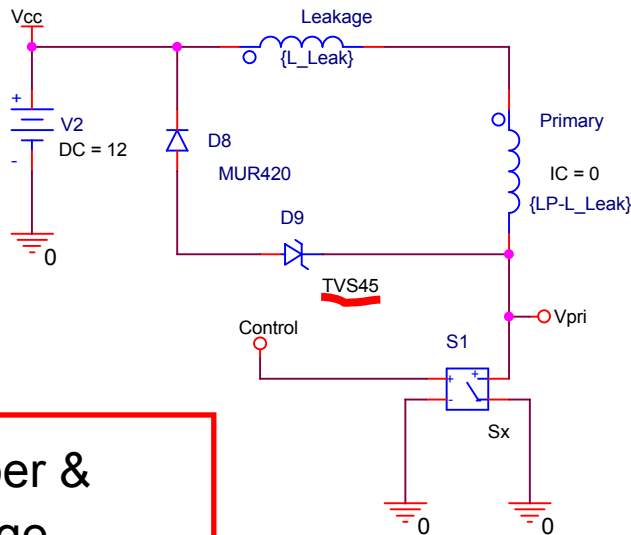
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PARAMETERS:
 LS = 7793U
 L_Leak = {0.1*LP}
 LP = 15.6U



Model = TVS45 D Is=1e-14 Cjo=.1pF Rs=10m BV=45 IBV=3

Model = Sx VSWITCH Roff=1e6 Ron=10m Voff=1 Von=4.0



K1 COUPLING = .999
 L Primary L Secondary

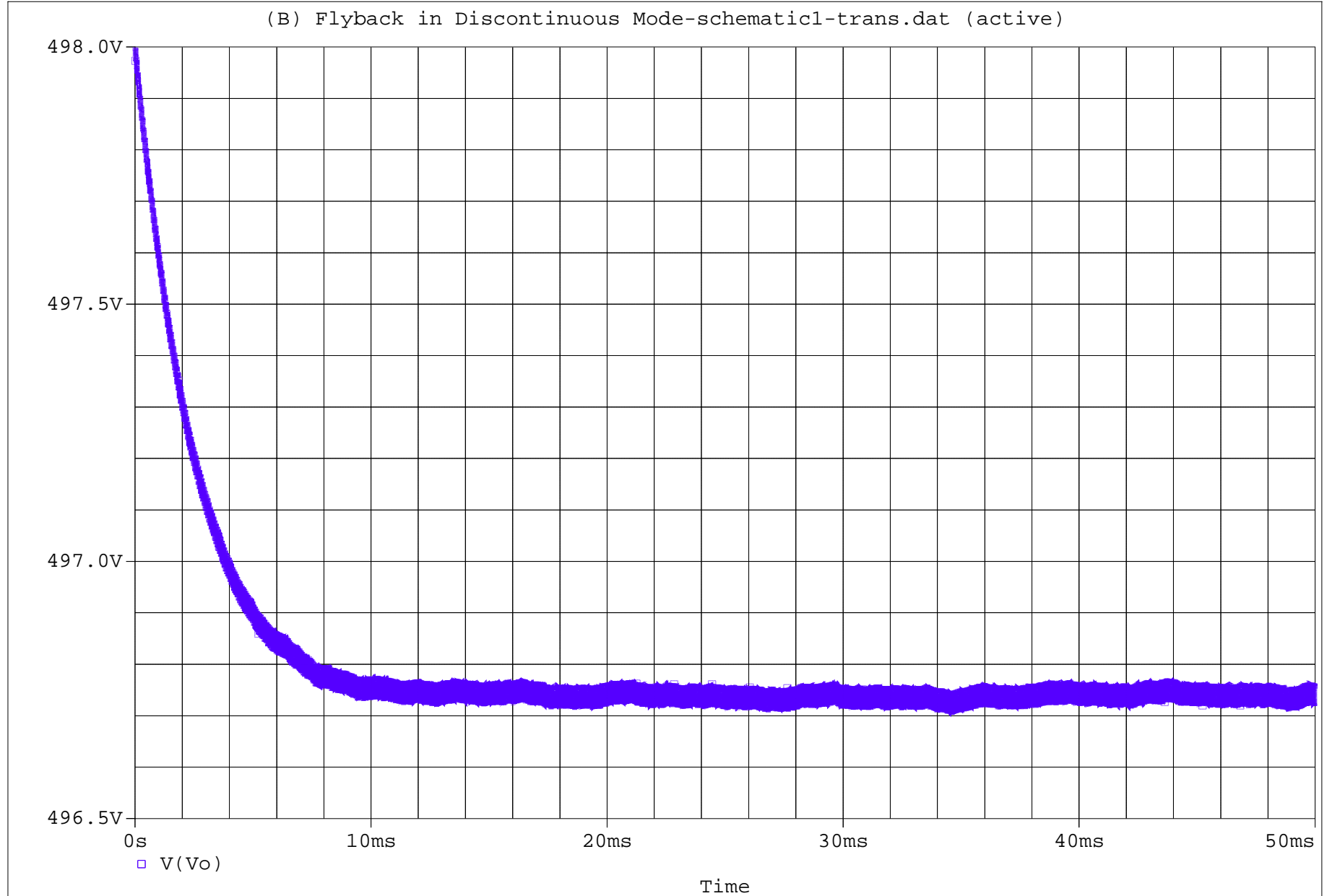
Snubber &
 Leakage
 Inductance
 Added

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Name: Marc E. Hermiter		Class: ECE456
Size A	Document Name	Rev 1
12 V to 500 V Flyback Converter		
Date: Thursday, January 23, 2003	Sheet	1 of 1

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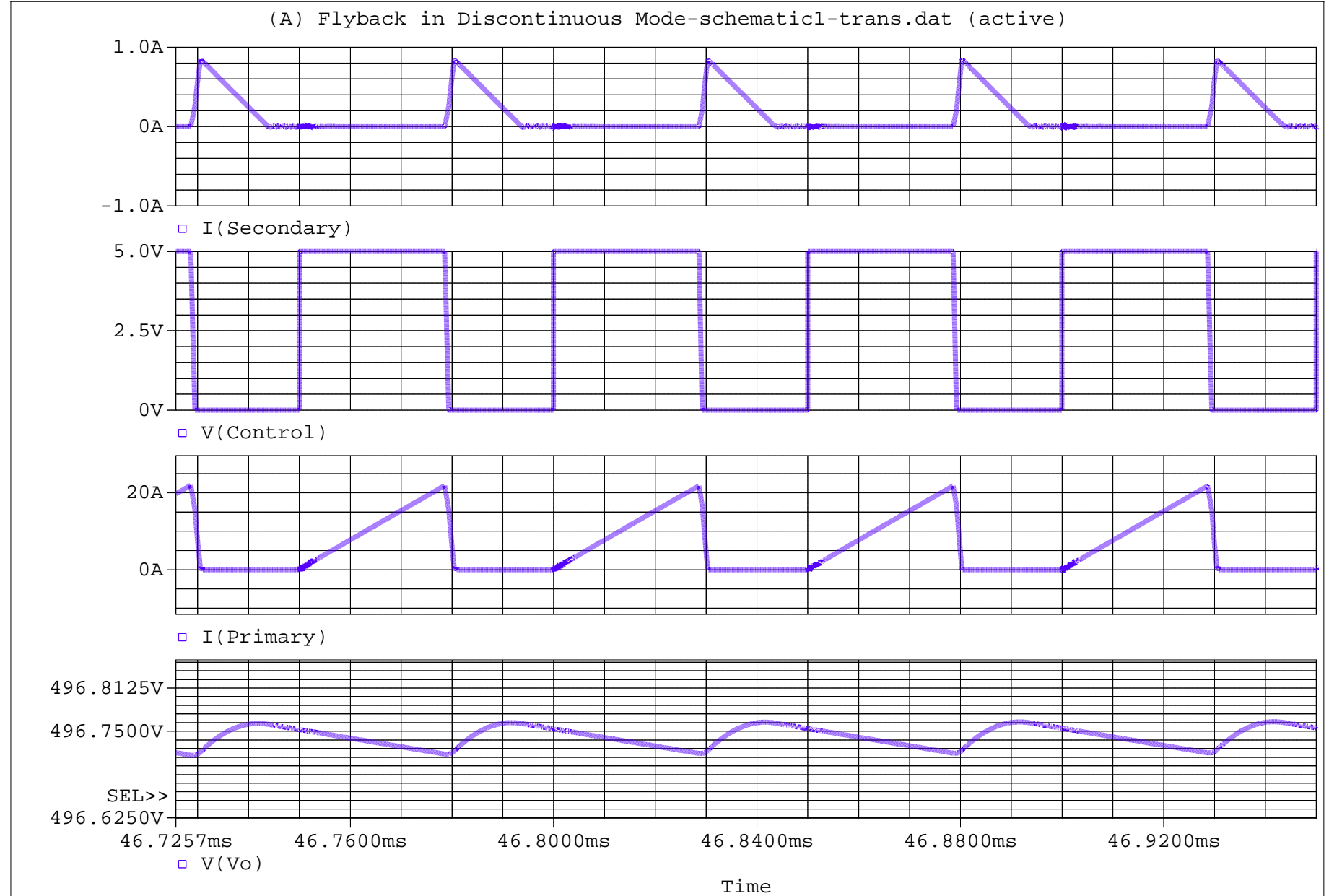


Date: January 23, 2003

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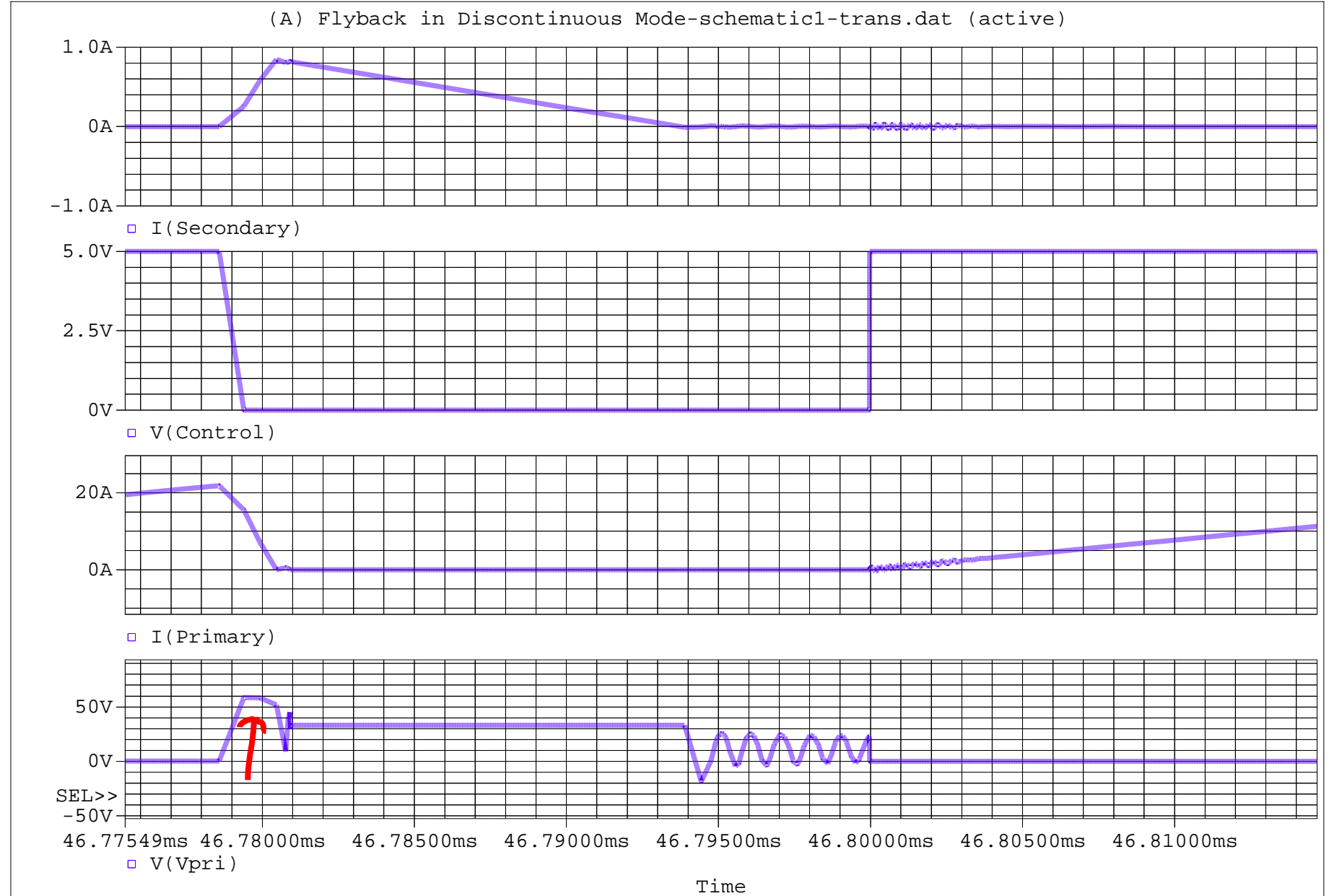


Date: January 23, 2003

Page 1

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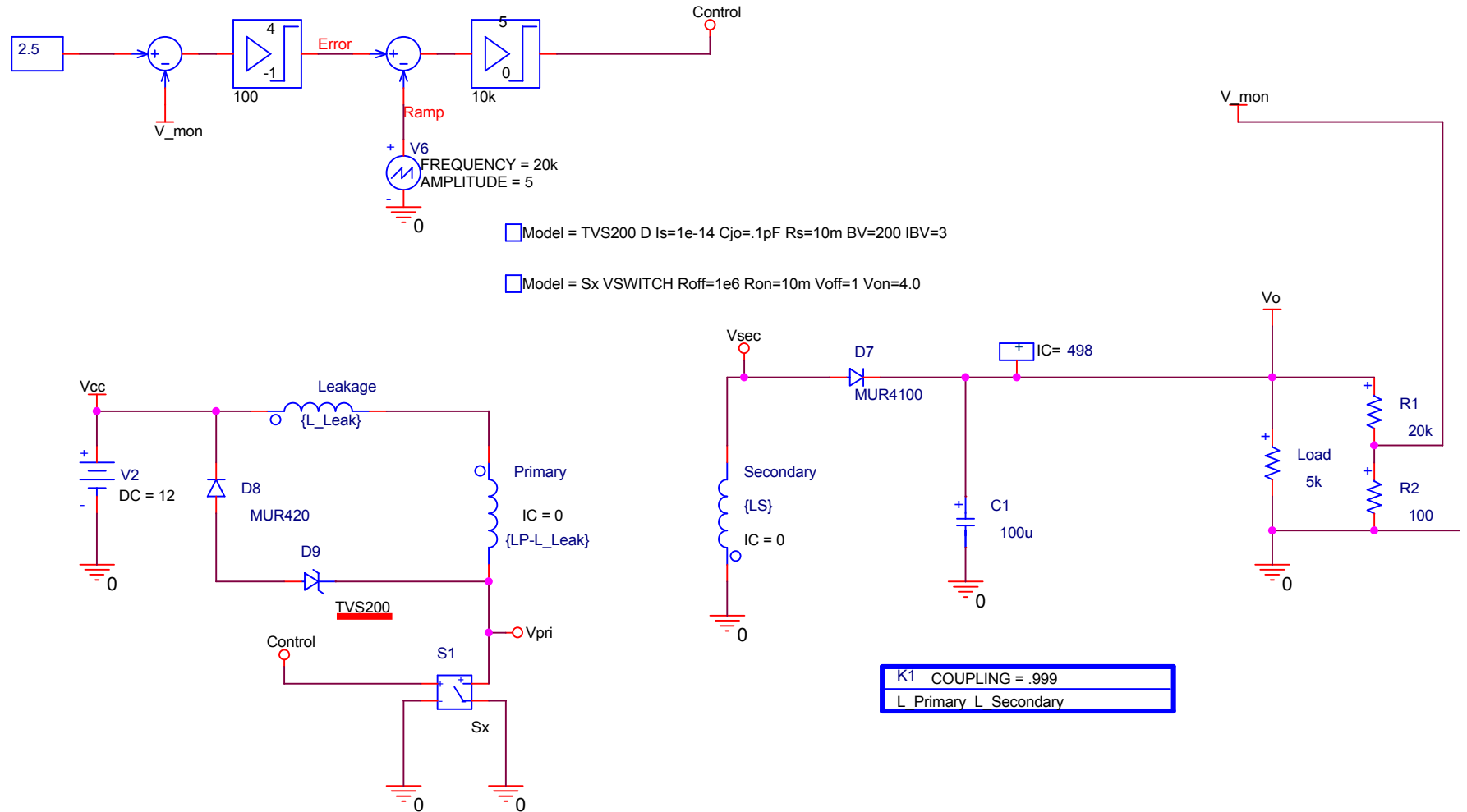


Date: January 23, 2003

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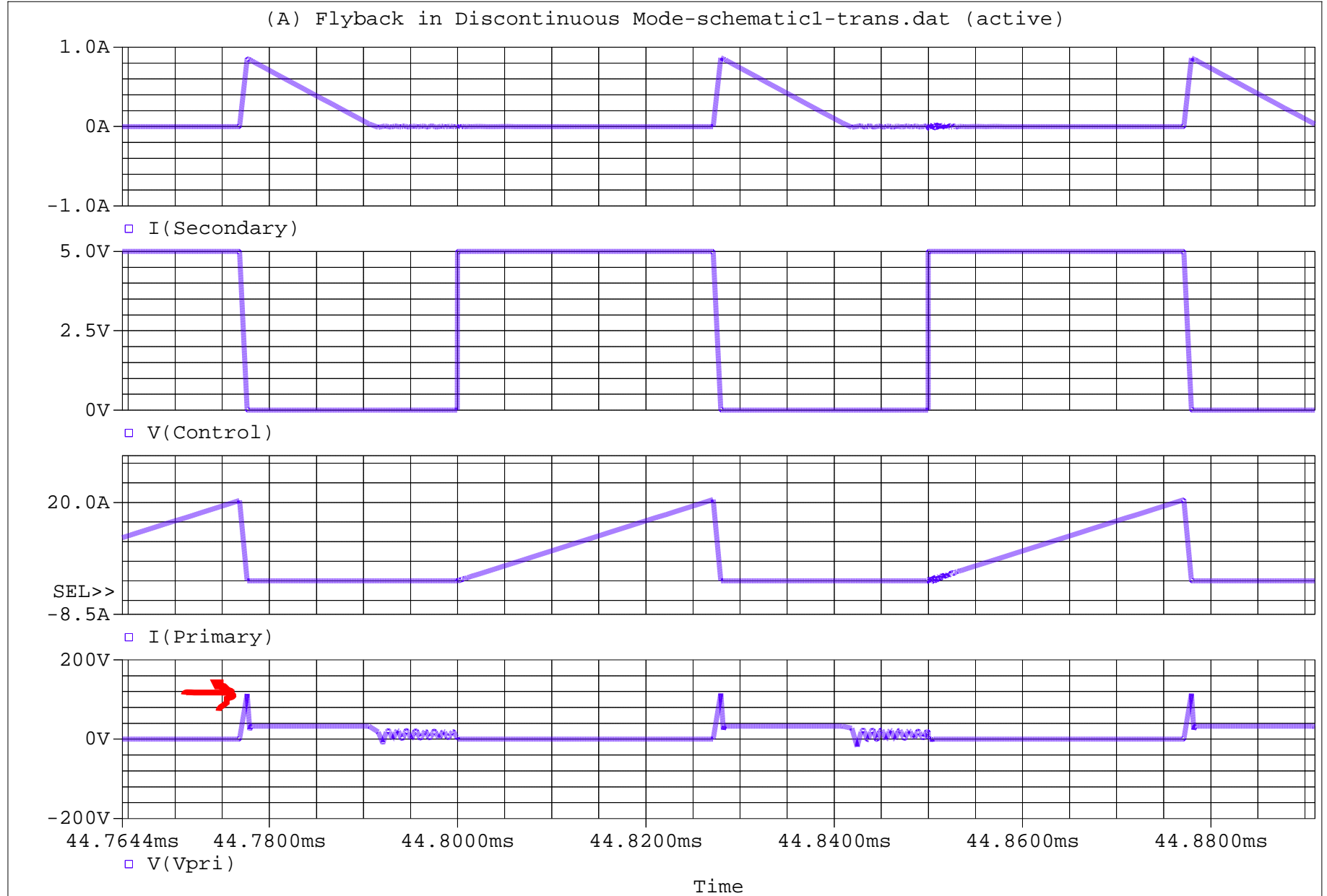
Time: 13:07:49

PARAMETERS:
 LS = 7793U
 L_Leak = {0.1*LP}
 LP = 15.6U



		ECE Department 5500 Wabash Avenue Terre Haute, IN 47803 Ph: (812) 877-8512 FAX: (253) 369-9536	
		Name: Marc E. Hermiter Class: ECE456	
Size A	Document Name		Rev 1
Date: Thursday, January 23, 2003		Sheet 1 of 1	

** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\Notes\Orcad\Flyback Converter\flyb...
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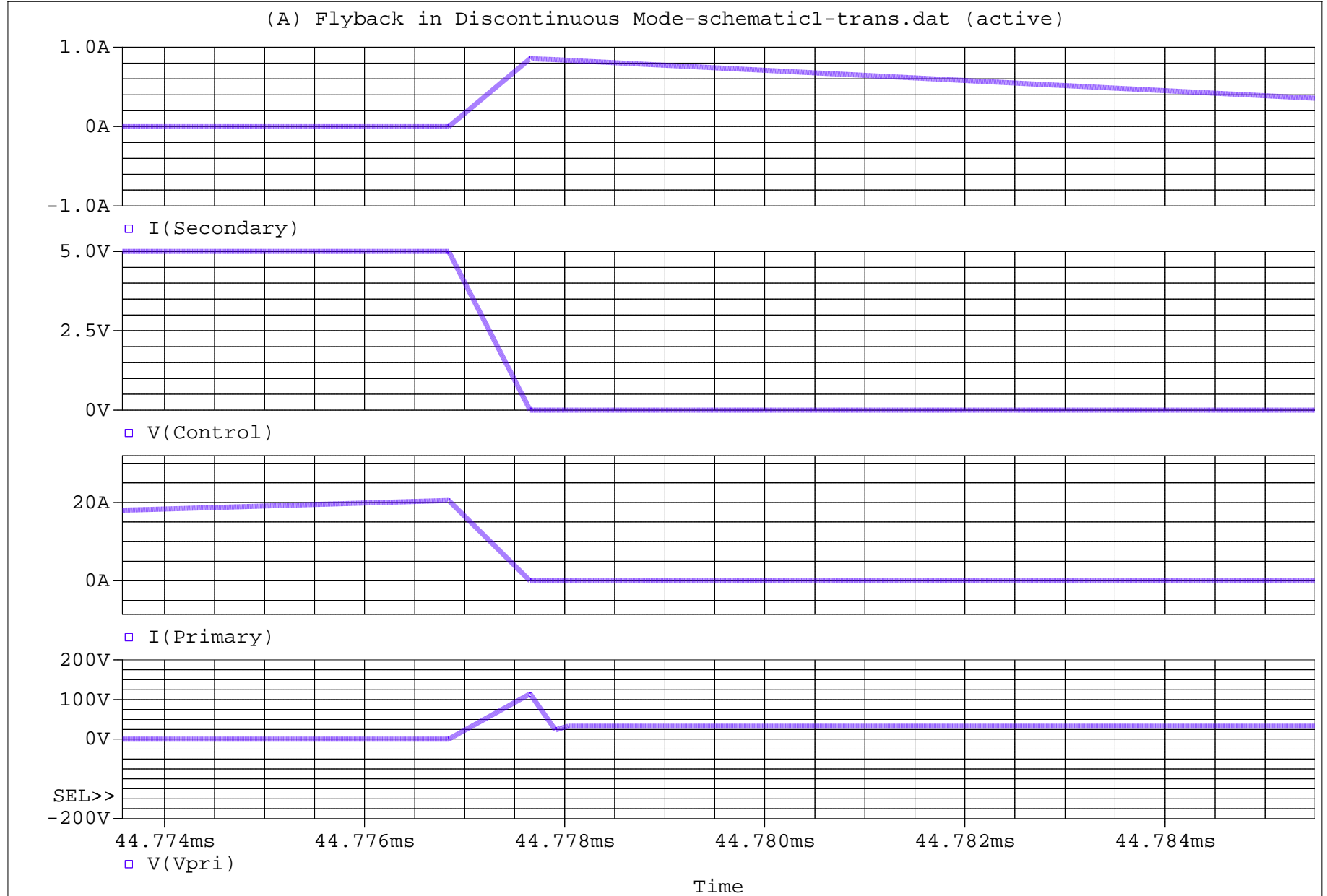


Date: January 23, 2003

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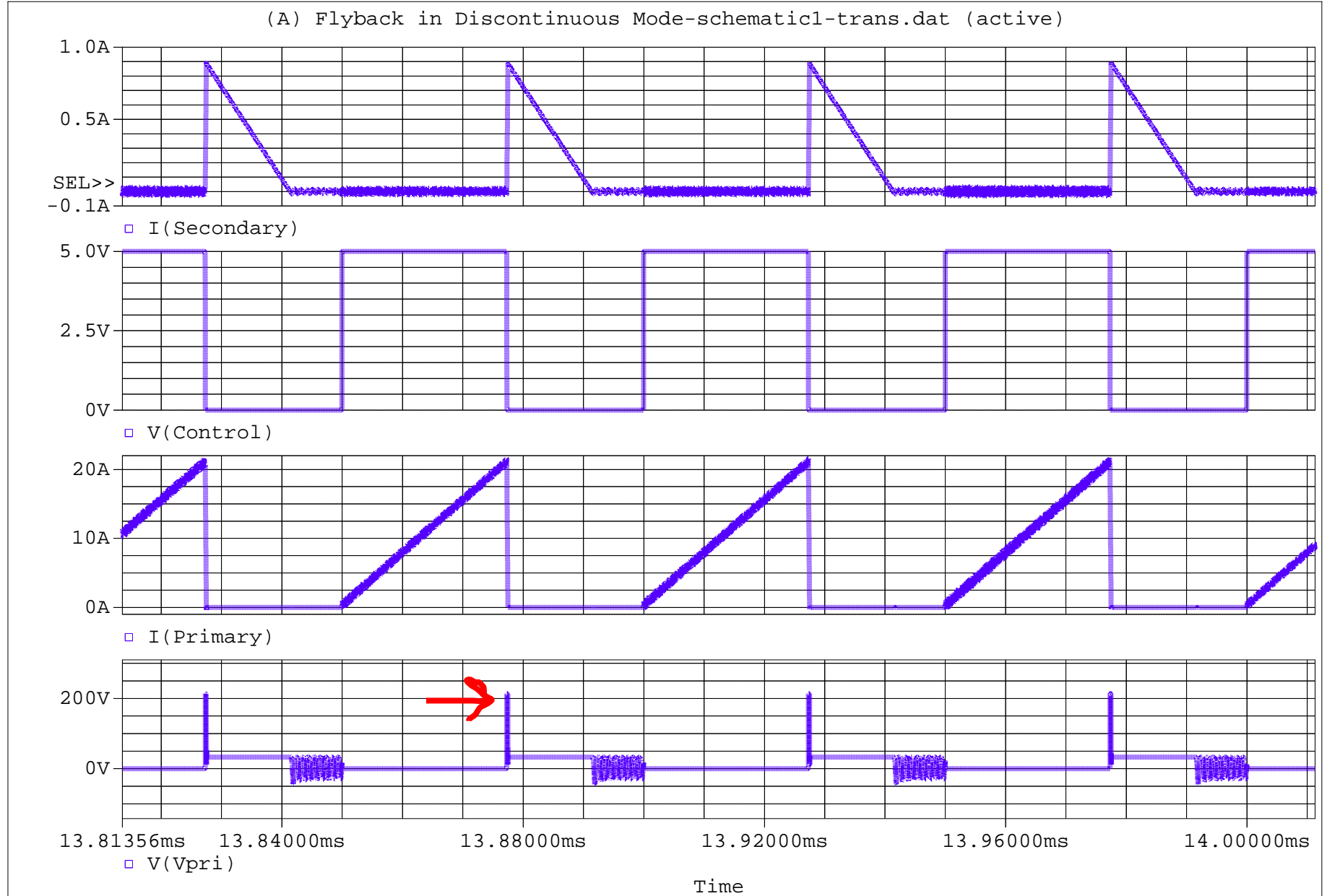


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Page 1

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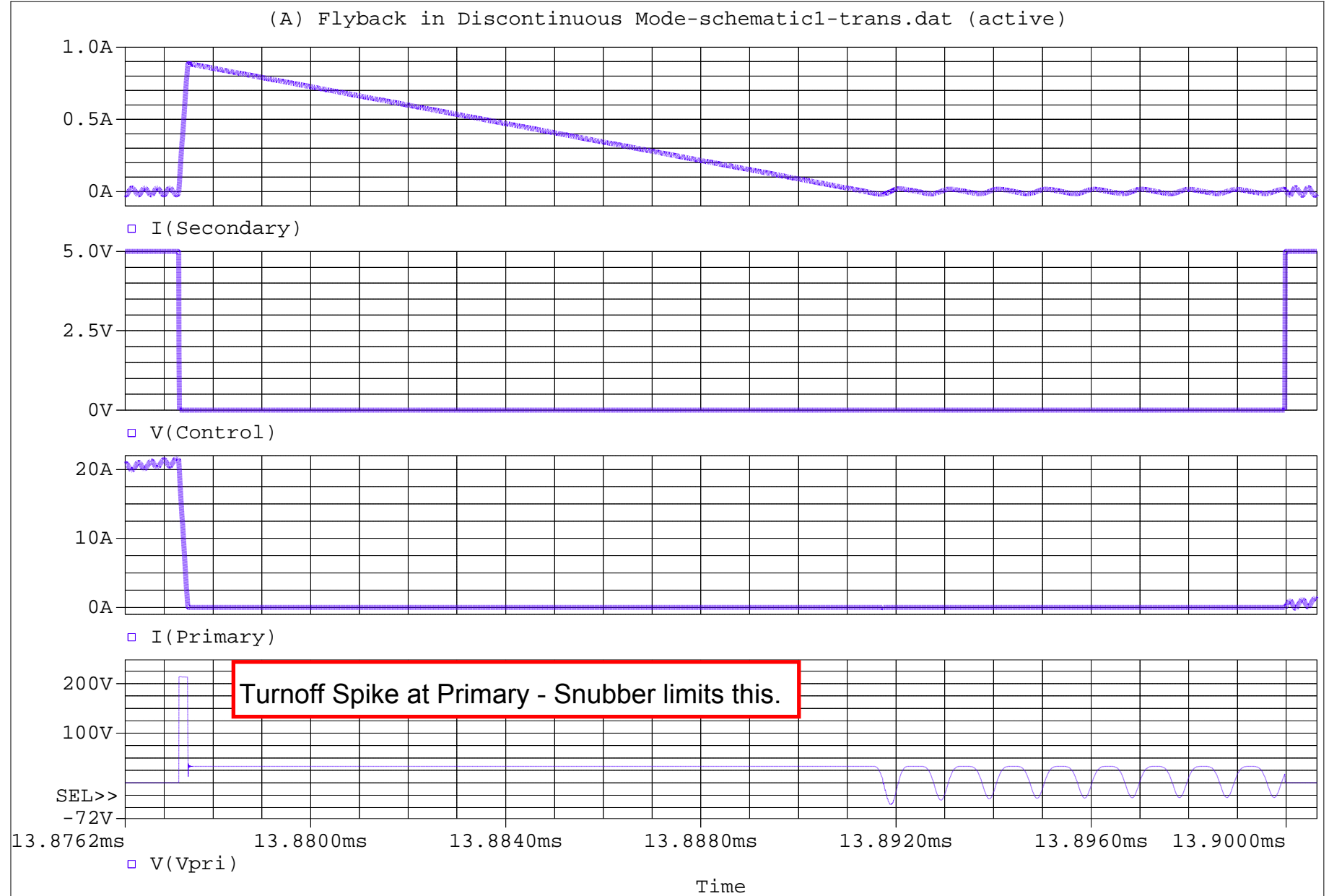


Date: January 23, 2003

Page 1

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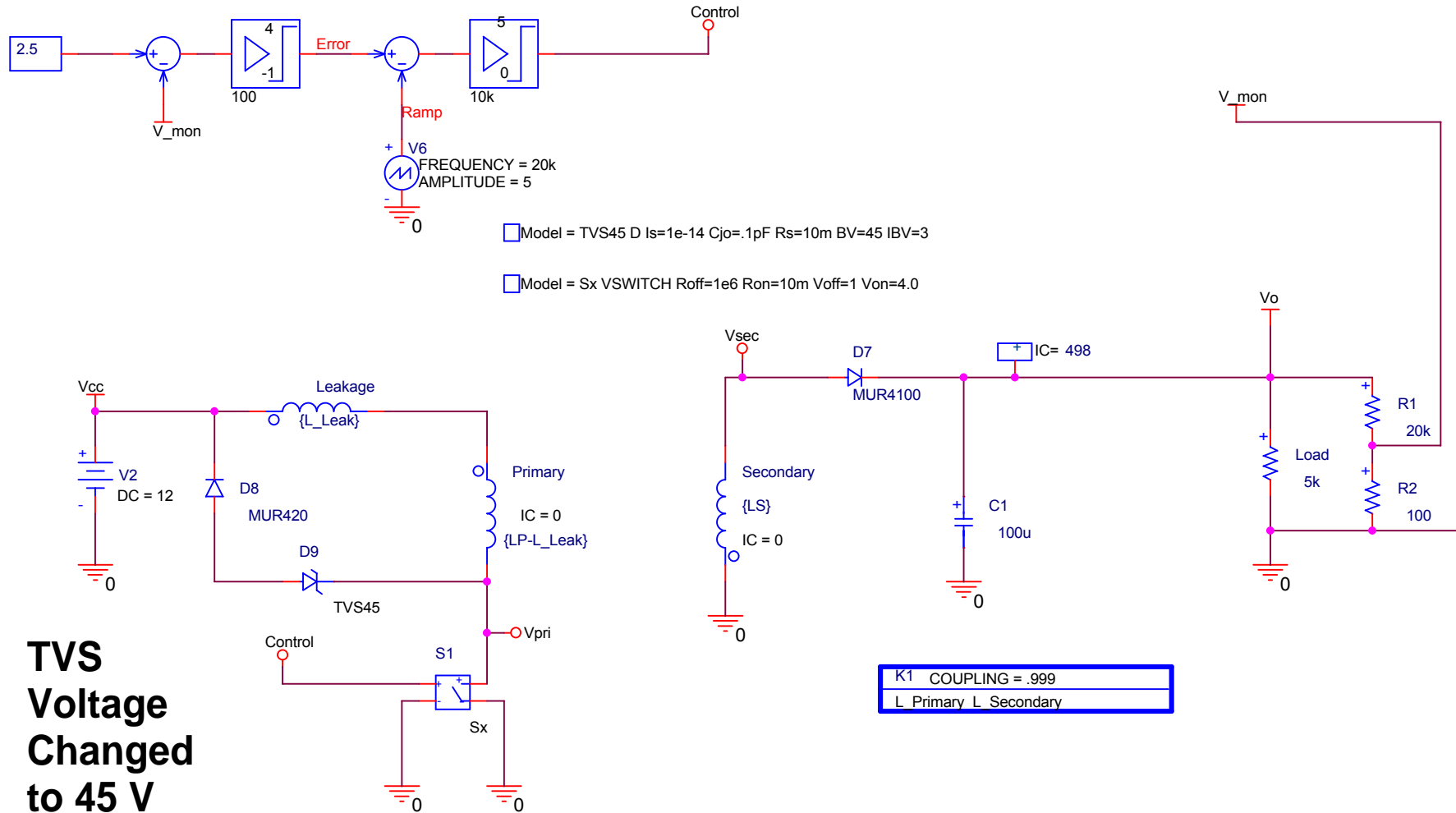


Date: January 23, 2003

Page 1

Time: 16:03:59

PARAMETERS:
 LS = 7793U
 L_Leak = {0.1*LP}
 LP = 15.6U



**TVS
 Voltage
 Changed
 to 45 V**

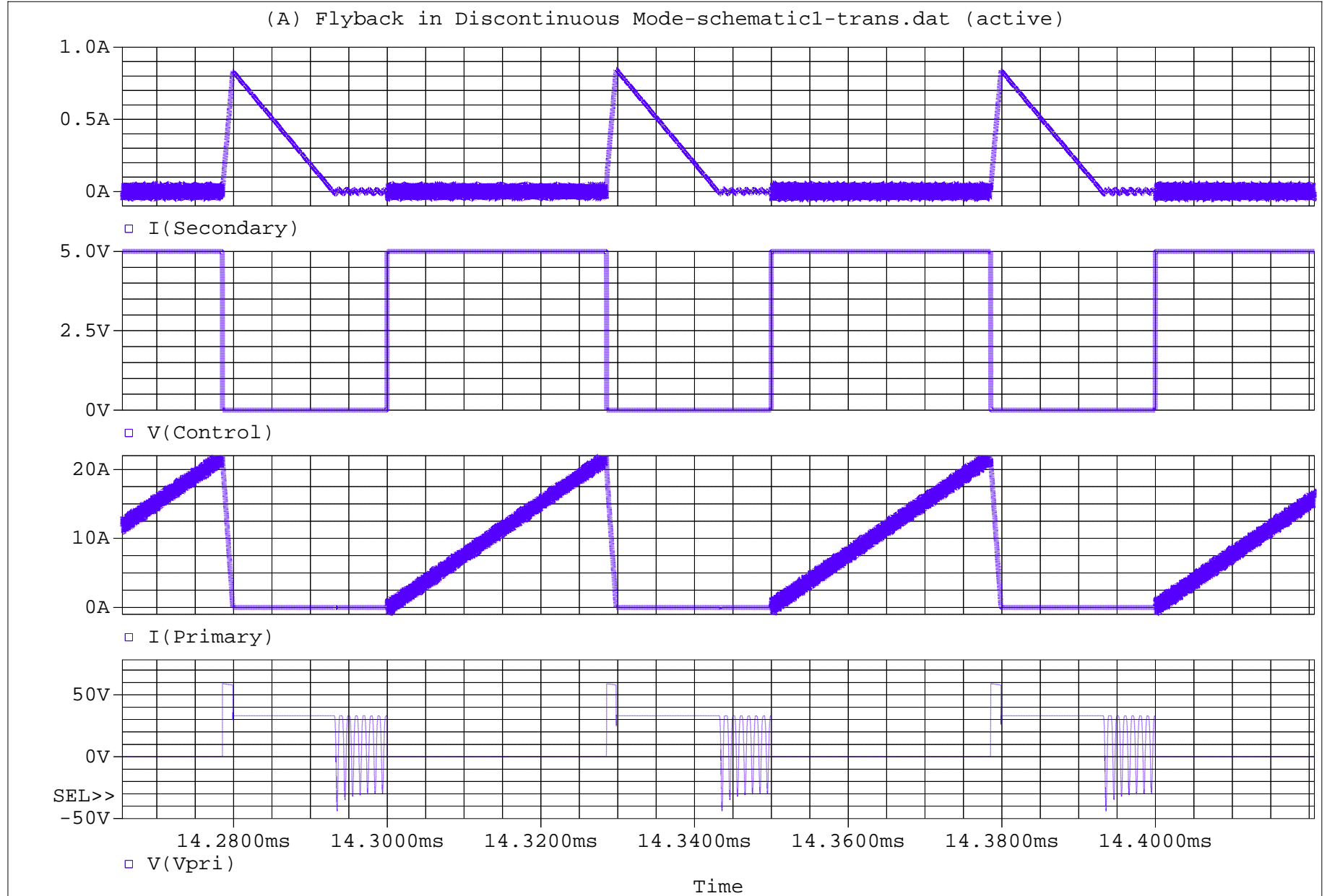
K1 COUPLING = .999
 L Primary L Secondary

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Name: Marc E. Hermiter		Class: ECE456
Size A	Document Name	Rev 1
12 V to 500 V Flyback Converter		
Date: Thursday, January 23, 2003	Sheet 1	of 1

** Profile: "SCHEMATIC1-Trans" [C:\WEBSITE\ROSE_CLASSES\ECE456\Notes\Orcad\Flyback Converter\flyb...
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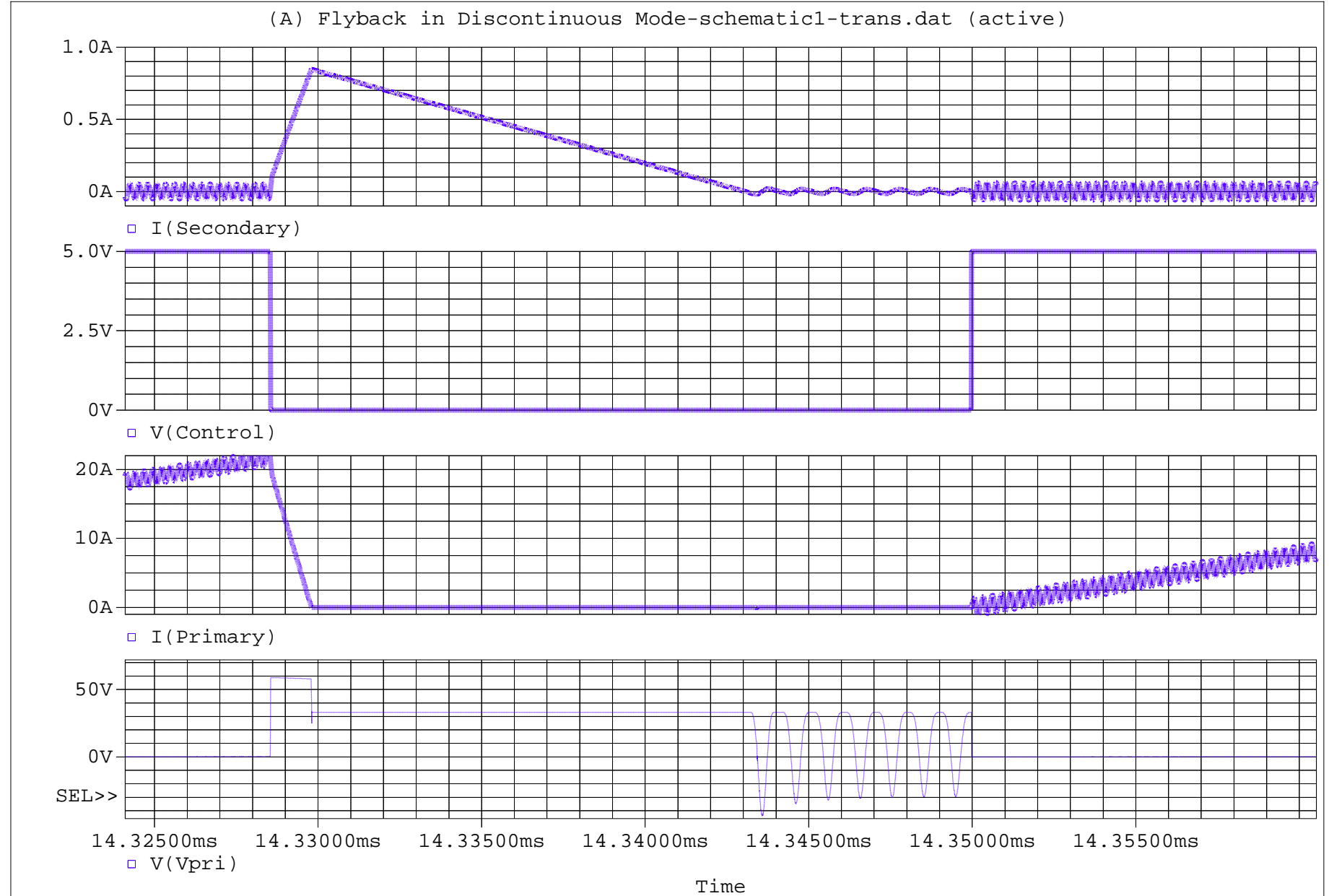


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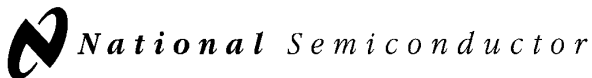
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Date: January 23, 2003

Page 1

Time: 16:15:18



March 1995

LM2574/LM2574HV Series SIMPLE SWITCHER™ 0.5A Step-Down Voltage Regulator

General Description

The LM2574 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 0.5A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2574 series offers a high-efficiency replacement for popular three-terminal linear regulators. Because of its high efficiency, the copper traces on the printed circuit board are normally the only heat sinking needed.

A standard series of inductors optimized for use with the LM2574 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed $\pm 4\%$ tolerance on output voltage within specified input voltages and output load conditions, and $\pm 10\%$ on the oscillator frequency. External shutdown is included, featuring 50 μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

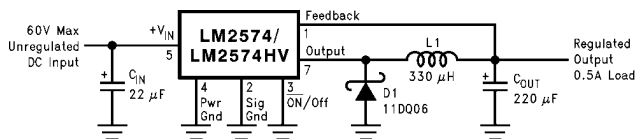
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) $\pm 4\%$ max over line and load conditions
- Guaranteed 0.5A output current
- Wide input voltage range, 40V, up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

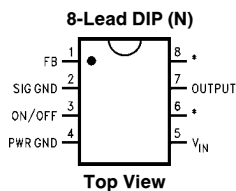
Typical Application (Fixed Output Voltage Versions)



TL/H/11394-1

Note: Pin numbers are for 8-pin DIP package.

Connection Diagrams

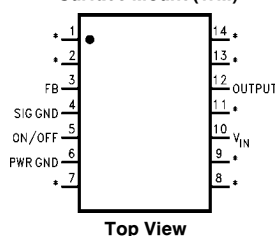


TL/H/11394-2

*No internal connection, but should be soldered to PC board for best heat transfer.

Order Number LM2574-3.3HVN, LM2574HVN-5.0, LM2574HVN-12, LM2574HVN-15, LM2574HVN-ADJ, LM2574N-3.3, LM2574N-5.0, LM2574N-12, LM2574N-15 or LM2574N-ADJ
See NS Package Number N08A

14-Lead Wide Surface Mount (WM)



TL/H/11394-3

Order Number LM2574HVM-3.3, LM2574HVM-5.0, LM2574HVM-12, LM2574HVM-15, LM2574HVM-ADJ, LM2574M-3.3, LM2574M-5.0, LM2574M-12, LM2574M-15 or LM2574M-ADJ
See NS Package Number M14B

Patent Pending
SIMPLE SWITCHER™ is a trademark of National Semiconductor Corporation.

LM2574/LM2574HV Series SIMPLE SWITCHER 0.5A Step-Down Voltage Regulator

TOP221-227

TOPSwitch-II Family

Three-terminal Off-line PWM Switch



Product Highlights

- Lowest cost, lowest component count switcher solution
- Cost competitive with linears above 5W
- Very low AC/DC losses – up to 90% efficiency
- Built-in Auto-restart and Current limiting
- Latching Thermal shutdown for system level protection
- Implements Flyback, Forward, Boost or Buck topology
- Works with primary or opto feedback
- Stable in discontinuous or continuous conduction mode
- Source connected tab for low EMI
- Circuit simplicity and Design Tools reduce time to market

Description

The second generation *TOPSwitch-II* family is more cost effective and provides several enhancements over the first generation *TOPSwitch* family. The *TOPSwitch-II* family extends the power range from 100W to 150W for 100/115/230 VAC input and from 50W to 90W for 85-265 VAC universal input. This brings *TOPSwitch* technology advantages to many new applications, i.e. TV, Monitor, Audio amplifiers, etc. Many significant circuit enhancements that reduce the sensitivity to board layout and line transients now make the design even

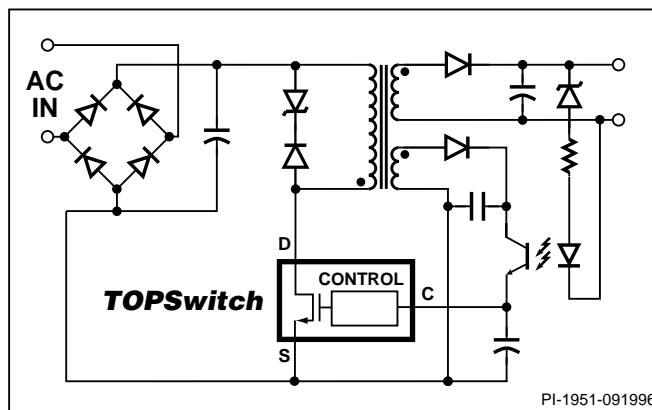
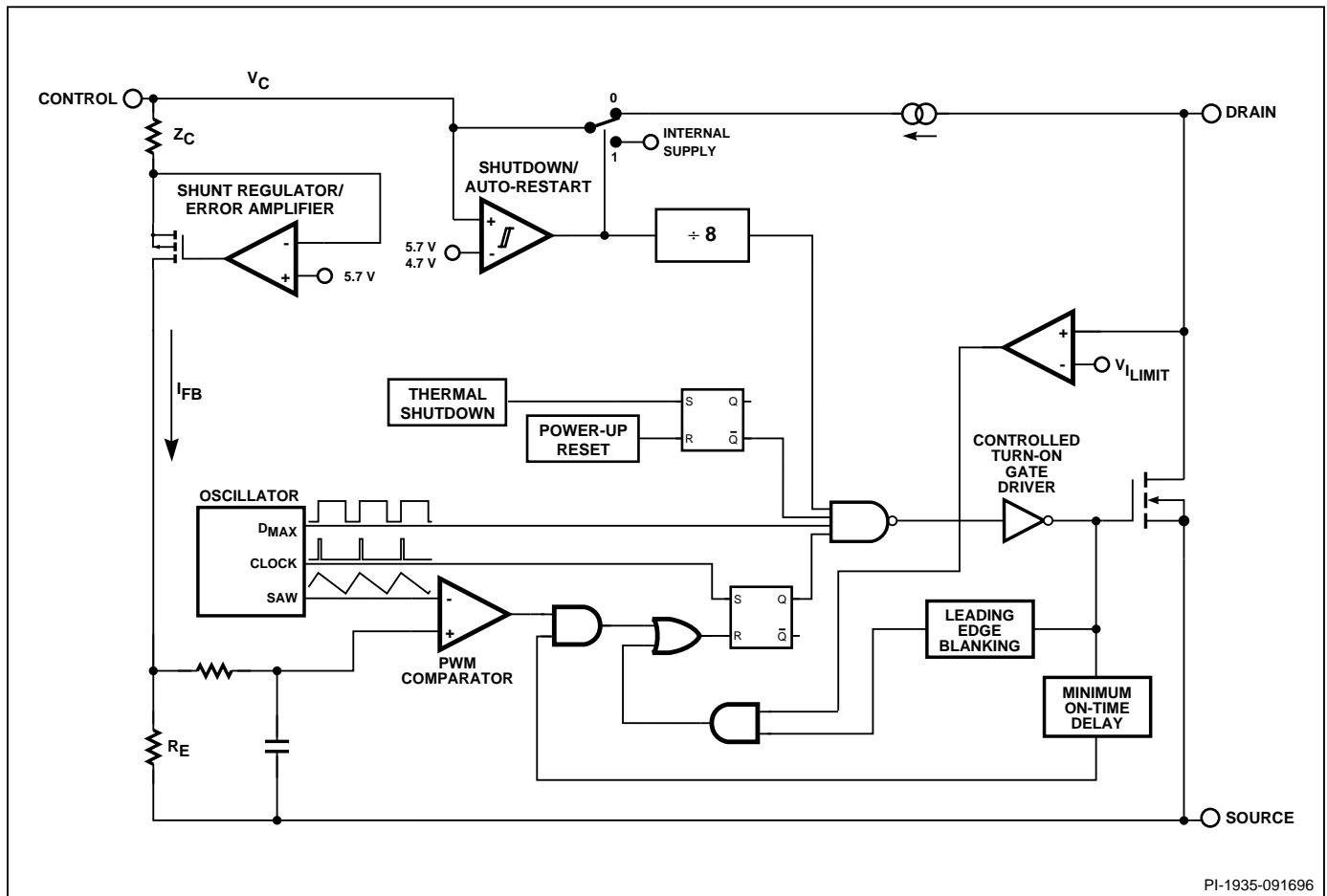


Figure 1. Typical Flyback Application.

easier. The standard 8L PDIP package option reduces cost in lower power, high efficiency applications. The internal lead frame of this package uses six of its pins to transfer heat from the chip directly to the board, eliminating the cost of a heat sink. *TOPSwitch* incorporates all functions necessary for a switched mode control system into a three terminal monolithic IC: power MOSFET, PWM controller, high voltage start up circuit, loop compensation and fault protection circuitry.

OUTPUT POWER TABLE					
TO-220 (Y) Package ¹			8L PDIP (P) or 8L SMD (G) Package ²		
PART ORDER NUMBER	Single Voltage Input ³ 100/115/230 VAC $\pm 15\%$	Wide Range Input 85 to 265 VAC	PART ORDER NUMBER	Single Voltage Input ³ 100/115/230 VAC $\pm 15\%$	Wide Range Input 85 to 265 VAC
	$P_{MAX}^{4,6}$	$P_{MAX}^{4,6}$		$P_{MAX}^{5,6}$	$P_{MAX}^{5,6}$
TOP221Y	12 W	7 W	TOP221P or TOP221G	9 W	6 W
TOP222Y	25 W	15 W	TOP222P or TOP222G	15 W	10 W
TOP223Y	50 W	30 W	TOP223P or TOP223G	25 W	15 W
TOP224Y	75 W	45 W	TOP224P or TOP224G	30 W	20 W
TOP225Y	100 W	60 W			
TOP226Y	125 W	75 W			
TOP227Y	150 W	90 W			

Notes: 1. Package outline: Y03A 2. Package Outline: P08A or G08A 3. 100/115 VAC with doubler input 4. Assumes appropriate heat sinking to keep the maximum *TOPSwitch* junction temperature below 100° C. 5. Soldered to 1 sq. in. (6.45 cm²), 2 oz. copper clad (610 gm/m²) 6. P_{MAX} is the maximum practical continuous power output level for conditions shown. The continuous power capability in a given application depends on thermal environment, transformer design, efficiency required, minimum specified input voltage, input storage capacitance, etc. 7. Refer to key application considerations section when using *TOPSwitch-II* in an existing *TOPSwitch* design.



PI-1935-091696

Figure 2. Functional Block Diagram.

Pin Functional Description

DRAIN Pin:

Output MOSFET drain connection. Provides internal bias current during start-up operation via an internal switched high-voltage current source. Internal current sense point.

CONTROL Pin:

Error amplifier and feedback current input pin for duty cycle control. Internal shunt regulator connection to provide internal bias current during normal operation. It is also used as the connection point for the supply bypass and auto-restart/compensation capacitor.

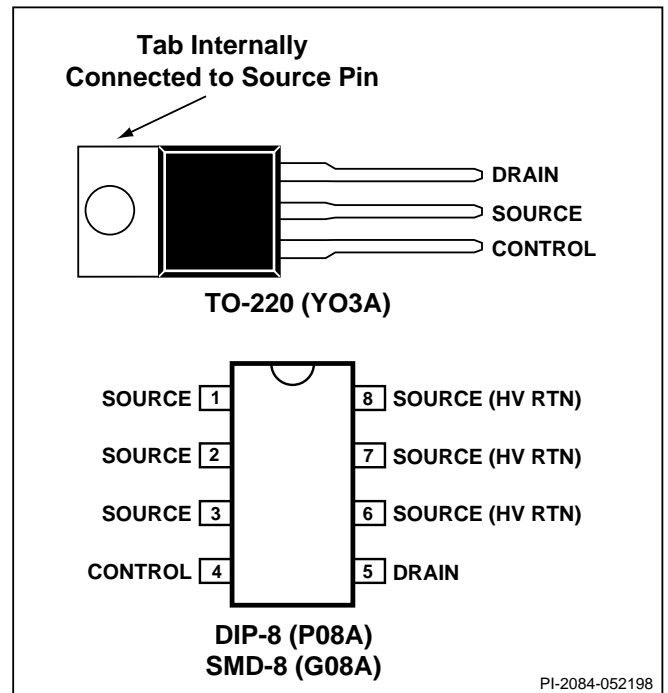
SOURCE Pin:

Y package – Output MOSFET source connection for high voltage power return. Primary side circuit common and reference point.

P and G package – Primary side control circuit common and reference point.

SOURCE (HV RTN) Pin: (P and G package only)

Output MOSFET source connection for high voltage power return.



PI-2084-052198

Figure 3. Pin Configuration.

High-Voltage Current-Mode PWM Controller

Ordering Information

+V _N		Feedback Accuracy	Max Duty Cycle	Package Options			
Min	Max			14 Pin Plastic DIP	20 Pin Plastic PLCC	14 Pin Narrow Body SOIC	Die
10V	120V	< ± 1%	49%	HV9110P	HV9110PJ	HV9110NG	HV9110X
9.0V	80V	± 2%	49%	HV9112P	HV9112PJ	HV9112NG	HV9112X
10V	120V	< ± 1%	99%	HV9113P	HV9113PJ	HV9113NG	HV9113X

Standard temperature range for all parts is industrial (-40° to +85°C).

Features

- 10 to 120V input range
- Current-mode control
- High efficiency
- Up to 1.0MHz internal oscillator
- Internal start-up circuit
- Low internal noise

Applications

- DC/DC converters
- Distributed power systems
- ISDN equipment
- PBX systems
- Modems

Absolute Maximum Ratings

+V _{IN} , Input Voltage	HV9110/9113	120V
	HV9112	80V
V _{DD} , Logic Voltage		15.5V
Logic Linear Input, FB and Sense Input Voltage		-0.3V to V _{DD} +0.3V
Storage Temperature		-65°C to 150°C
Power Dissipation, SOIC		750mW
Power Dissipation, Plastic DIP		1000mW
Power Dissipation PLCC		1400mW

General Description

The Supertex HV9110 through HV9113 are a series of BiCMOS/DMOS single-output, pulse width modulator ICs intended for use in high-speed high-efficiency switchmode power supplies. They provide all the functions necessary to implement a single-switch current-mode PWM, in any topology, with a minimum of external parts.

Because they utilize Supertex's proprietary BiCMOS/DMOS technology, they require less than one tenth of the operating power of conventional bipolar PWM ICs, and can operate at more than twice their switching frequency. Dynamic range for regulation is also increased, to approximately 8 times that of similar bipolar parts. They start directly from any DC input voltages between 10 and 120VDC, requiring no external power resistor. The output stage is push-pull CMOS and thus requires no clamping diodes for protection, even when significant lead length exists between the output and the external MOSFET. The clock frequency is set with a single external resistor.

Accessory functions are included to permit fast remote shutdown (latching or nonlatching) and undervoltage shutdown.

For similar ICs intended to operate directly from up to 450VDC input, please consult the data sheet for the HV9120/9123.

For detailed circuit and application information, please refer to application notes AN-H13 and AN-H21 to AN-H24.

11/12/01

Supertex Inc. does not recommend the use of its products in life support applications and will not knowingly sell its products for use in such applications unless it receives an adequate "products liability indemnification insurance agreement." Supertex does not assume responsibility for use of devices described and limits its liability to the replacement of devices determined to be defective due to workmanship. No responsibility is assumed for possible omissions or inaccuracies. Circuitry and specifications are subject to change without notice. For the latest product specifications, refer to the Supertex website: <http://www.supertex.com>. For complete liability information on all Supertex products, refer to the most current databook or to the Legal/Disclaimer page on the Supertex website.

Regulating Pulse Width Modulators

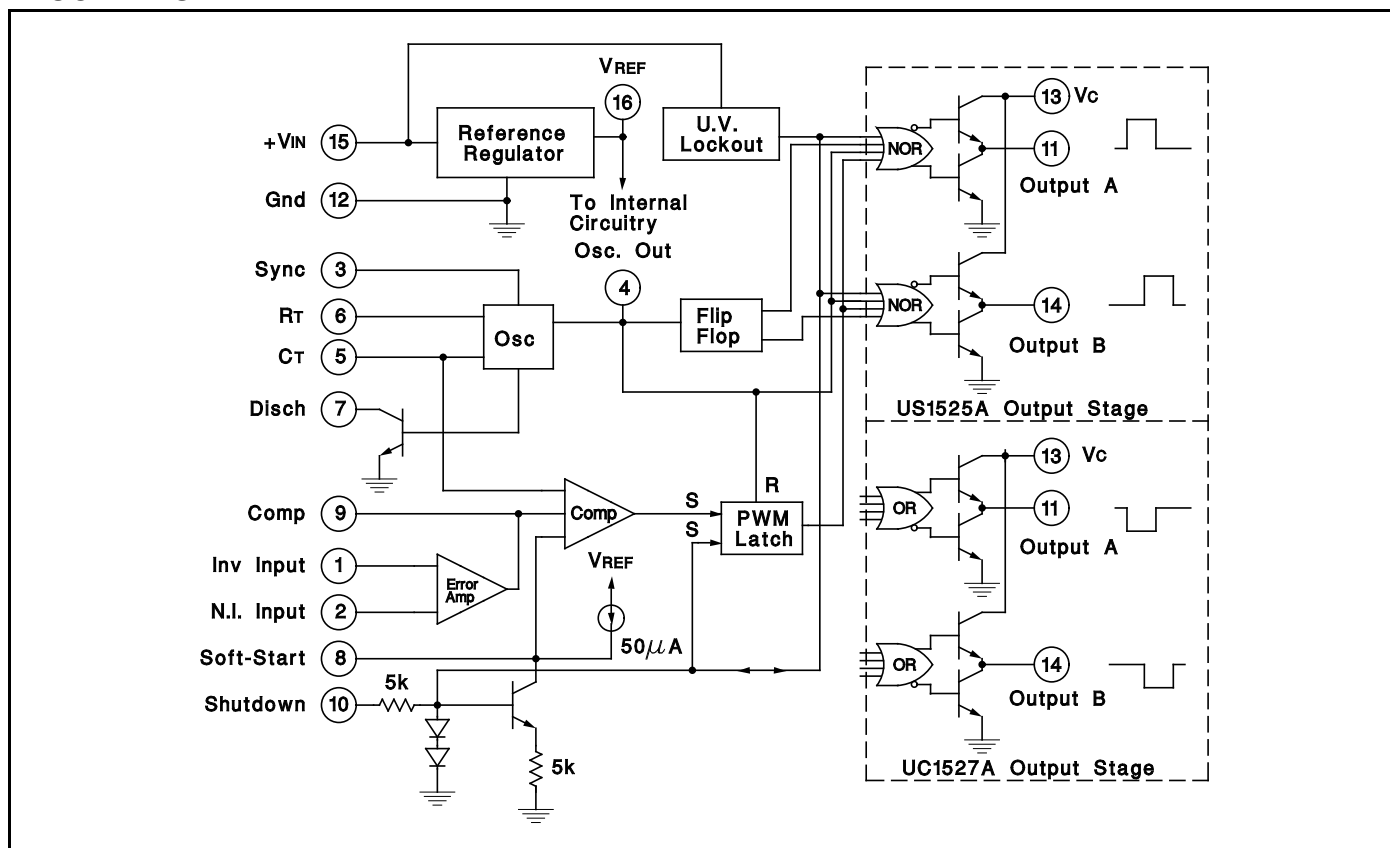
FEATURES

- 8 to 35V Operation
- 5.1V Reference Trimmed to $\pm 1\%$
- 100Hz to 500kHz Oscillator Range
- Separate Oscillator Sync Terminal
- Adjustable Deadtime Control
- Internal Soft-Start
- Pulse-by-Pulse Shutdown
- Input Undervoltage Lockout with Hysteresis
- Latching PWM to Prevent Multiple Pulses
- Dual Source/Sink Output Drivers

DESCRIPTION

The UC1525A/1527A series of pulse width modulator integrated circuits are designed to offer improved performance and lowered external parts count when used in designing all types of switching power supplies. The on-chip +5.1V reference is trimmed to $\pm 1\%$ and the input common-mode range of the error amplifier includes the reference voltage, eliminating external resistors. A sync input to the oscillator allows multiple units to be slaved or a single unit to be synchronized to an external system clock. A single resistor between the C_T and the discharge terminals provides a wide range of dead-time adjustment. These devices also feature built-in soft-start circuitry with only an external timing capacitor required. A shutdown terminal controls both the soft-start circuitry and the output stages, providing instantaneous turn off through the PWM latch with pulsed shutdown, as well as soft-start recycle with longer shutdown commands. These functions are also controlled by an undervoltage lockout which keeps the outputs off and the soft-start capacitor discharged for sub-normal input voltages. This lockout circuitry includes approximately 500mV of hysteresis for jitter-free operation. Another feature of these PWM circuits is a latch following the comparator. Once a PWM pulse has been terminated for any reason, the outputs will remain off for the duration of the period. The latch is reset with each clock pulse. The output stages are totem-pole designs capable of sourcing or sinking in excess of 200mA. The UC1525A output stage features NOR logic, giving a LOW output for an OFF state. The UC1527A utilizes OR logic which results in a HIGH output level when OFF.

BLOCK DIAGRAM





LT/SG1525A, LT/SG3525A
LT/SG1527A, LT/SG3527A

Regulating Pulse Width Modulators

NOT RECOMMENDED FOR NEW DESIGNS

Contact Linear Technology for Potential Replacement

FEATURES

- Undervoltage Lockout with Hysteresis
- *Guaranteed* 1% 5.1V Reference
- *Guaranteed* 10mV/1000 Hr Long Term Stability
- Latching PWM
- 8V to 35V Operation
- 100Hz to 400kHz Oscillator
- 400mA Source and Sink Current

APPLICATIONS

- Switching Power Supplies
- Motor Speed Control
- Power Converters

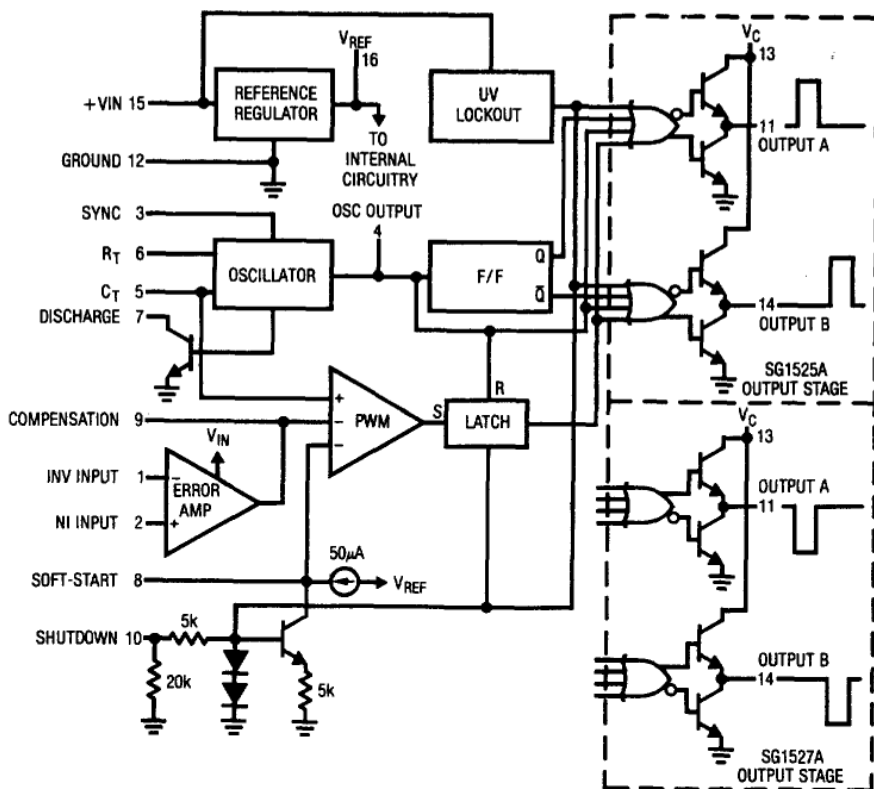
DESCRIPTION

The LT1525A and LT1527A are improved general purpose switching regulator control circuits. Included on the chip are a trimmed 1% voltage subsurface zener reference, oscillator, comparator and high current class B totem pole output drivers. Included in the design of the LT1525A are easy synchronization to an external clock, soft-start and adjustable deadtime control. A shutdown pin allows instantaneous shutdown.

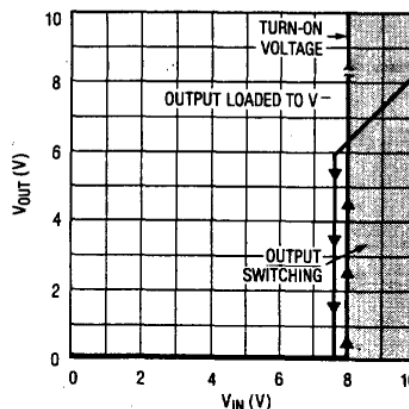
The LT1525A and LT1527A differ only in their output logic phasing. The LT1525A has a low output during the "off" state, while the LT1527A has a high output during the "off" state. Both devices have undervoltage lockout with about 0.5V hysteresis, giving reliable operation even with slowly varying supplies.

The combination of improved features and advanced processing for high reliability make Linear Technology's switching regulators a supreme choice.

BLOCK DIAGRAM



LT1525A Start-Up

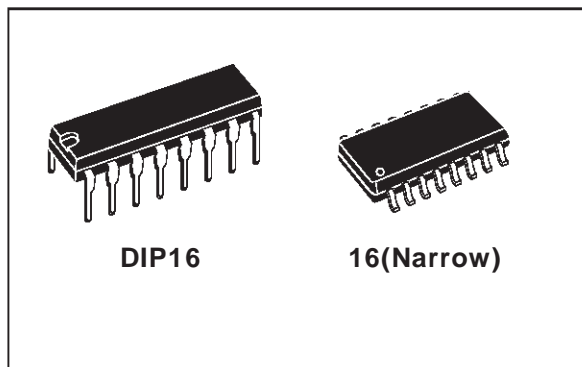




SG2525A
SG3525A

REGULATING PULSE WIDTH MODULATORS

- 8 TO 35 V OPERATION
- 5.1 V REFERENCE TRIMMED TO $\pm 1\%$
- 100 Hz TO 500 KHz OSCILLATOR RANGE
- SEPARATE OSCILLATOR SYNC TERMINAL
- ADJUSTABLE DEADTIME CONTROL
- INTERNAL SOFT-START
- PULSE-BY-PULSE SHUTDOWN
- INPUT UNDERVOLTAGE LOCKOUT WITH HYSTERESIS
- LATCHING PWM TO PREVENT MULTIPLE PULSES
- DUAL SOURCE/SINK OUTPUT DRIVERS

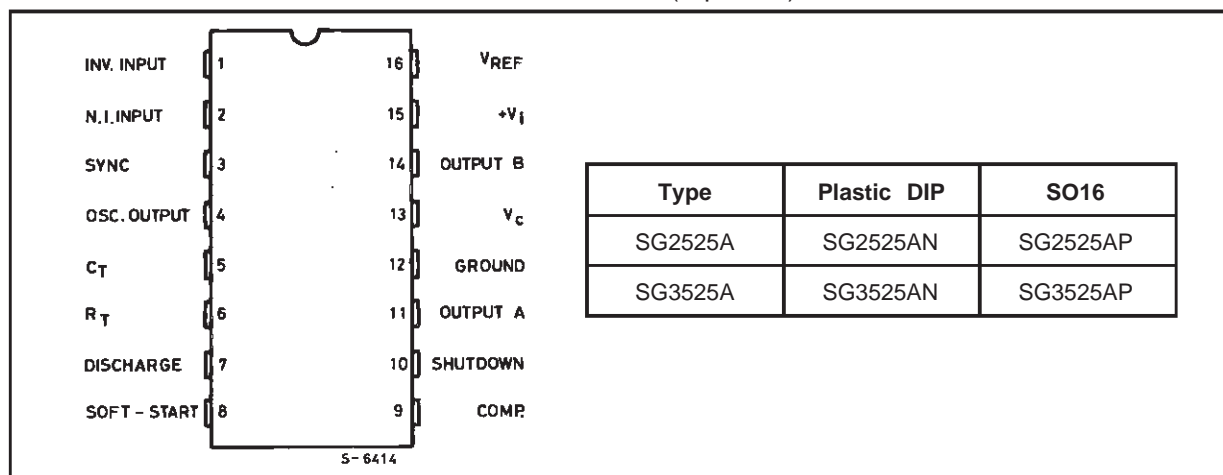


DESCRIPTION

The SG3525A series of pulse width modulator integrated circuits are designed to offer improved performance and lowered external parts count when used in designing all types of switching power supplies. The on-chip +5.1 V reference is trimmed to $\pm 1\%$ and the input common-mode range of the error amplifier includes the reference voltage eliminating external resistors. A sync input to the oscillator allows multiple units to be slaved or a single unit to be synchronized to an external system clock. A single resistor between the C_T and the discharge terminals provide a wide range of dead time adjustment. These devices also feature built-in soft-start circuitry with only an external timing capacitor required. A shutdown terminal controls both the soft-start circuitry and the output stages, providing instantaneous

turn off through the PWM latch with pulsed shutdown, as well as soft-start recycle with longer shutdown commands. These functions are also controlled by an undervoltage lockout which keeps the outputs off and the soft-start capacitor discharged for sub-normal input voltages. This lockout circuitry includes approximately 500 mV of hysteresis for jitter-free operation. Another feature of these PWM circuits is a latch following the comparator. Once a PWM pulse has been terminated for any reason, the outputs will remain off for the duration of the period. The latch is reset with each clock pulse. The output stages are totem-pole designs capable of sourcing or sinking in excess of 200 mA. The SG3525A output stage features NOR logic, giving a LOW output for an OFF state.

PIN CONNECTIONS AND ORDERING NUMBERS (top view)



SG3525A

Pulse Width Modulator Control Circuit

The SG3525A pulse width modulator control circuit offers improved performance and lower external parts count when implemented for controlling all types of switching power supplies. The on-chip +5.1 V reference is trimmed to $\pm 1\%$ and the error amplifier has an input common-mode voltage range that includes the reference voltage, thus eliminating the need for external divider resistors. A sync input to the oscillator enables multiple units to be slaved or a single unit to be synchronized to an external system clock. A wide range of deadtime can be programmed by a single resistor connected between the C_T and Discharge pins. This device also features built-in soft-start circuitry, requiring only an external timing capacitor. A shutdown pin controls both the soft-start circuitry and the output stages, providing instantaneous turn off through the PWM latch with pulsed shutdown, as well as soft-start recycle with longer shutdown commands. The under voltage lockout inhibits the outputs and the changing of the soft-start capacitor when V_{CC} is below nominal. The output stages are totem-pole design capable of sinking and sourcing in excess of 200 mA. The output stage of the SG3525A features NOR logic resulting in a low output for an off-state.

- 8.0 V to 35 V Operation
- 5.1 V \pm 1.0% Trimmed Reference
- 100 Hz to 400 kHz Oscillator Range
- Separate Oscillator Sync Pin
- Adjustable Deadtime Control
- Input Undervoltage Lockout
- Latching PWM to Prevent Multiple Pulses
- Pulse-by-Pulse Shutdown
- Dual Source/Sink Outputs: ± 400 mA Peak

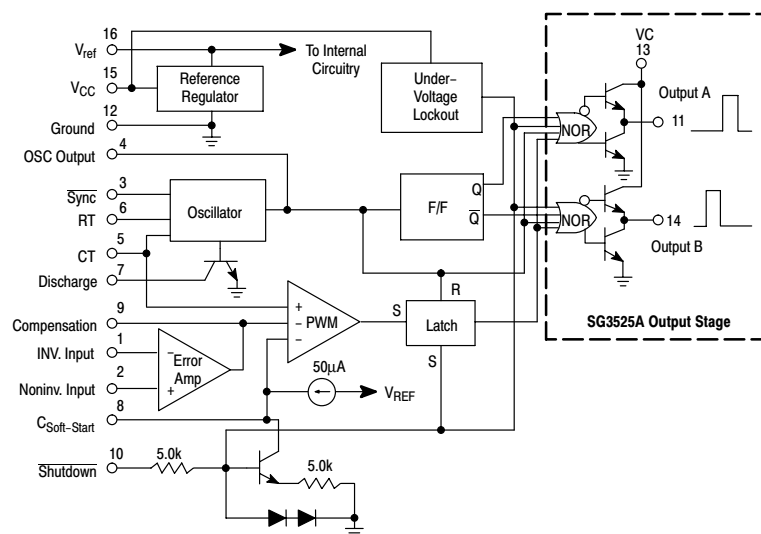


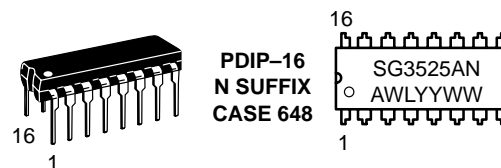
Figure 1. Representative Block Diagram



ON Semiconductor™

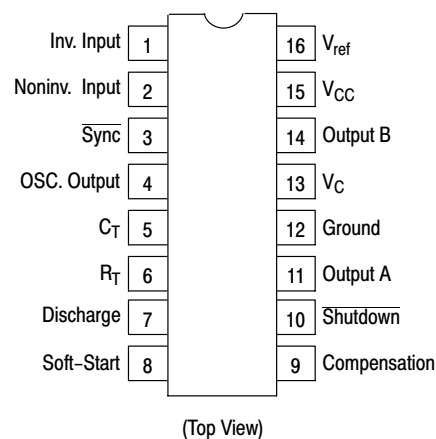
<http://onsemi.com>

MARKING DIAGRAM



A = Assembly Location
 WL = Wafer Lot
 YY = Year
 WW = Work Week

PIN CONNECTIONS



ORDERING INFORMATION

Device	Package	Shipping
SG3525AN	PDIP-16	25 Units/Rail

HEXFET Power MOSFETs
FullPak
N-Channel

International
IR Rectifier

(R2)

FullPak Fully-isolated HEXFETs

International Rectifier is proud to introduce its FullPak line of fully-isolated power MOSFETs. Available in popular-sized package outlines, these devices are designed to provide ease of use, lower costs of assembly, and high reliability.

FullPak HEXFETs are fully-isolated versions of the popular TO-220 and TO-247 ("TO-3P") packages. The well-known benefits of HEXFET power MOSFETs include voltage control, fast switching, temperature stability, ease of paralleling, low on-state resistance, high transconductance, superior dv/dt and avalanche ruggedness, and a broad range of voltages and ratings. In addition, these devices provide the designer with a cost-saving applications in situations where electrical isolation is required.

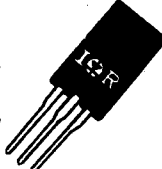
FullPak HEXFETs are excellent for use in a wide array of commercial applications in consumer, automotive, telecommunications, computer and industrial circuits (switching power supplies, amplifiers, and high-energy pulse circuits).

If you have an application where your circuit enclosure and/or heatsinks must be grounded (or your internal circuitry must be isolated from the heatsink/enclosure), then *the FullPak is for you*. Until now, semiconductors were insulated from grounded heatsinks with insulating washers and nylon screws. Improper installation of insulating hardware caused failures which resulted in poor reliability which in turn led to higher manufacturing and servicing costs.

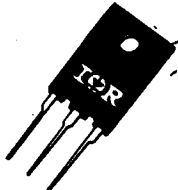
FullPak HEXFETs allow you to mount directly to grounded metal work, eliminating the need for insulating hardware and without a significant change in thermal characteristics. The convenient TO-220 and TO-3P size packages provide the advantage for existing designs and equipment to be retrofitted without modification! The TO-220 FullPak provides 2000 Vdc isolation (1500Vac, 60Hz) while contributing only about 12pF (typ.) from drain to heatsink. The TO-3P FullPak provides 4000Vdc isolation (2000Vac, 60Hz)

See the tables below for the FullPak to fit your needs!

Isolated TO-220

Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (2)	Notes	Case Style
IRFI224 IRFI234 IRFI244	60	0.10 0.050 0.028	14 20 30	9.7 14 21	4.1 3.9 3.1	37 38 48	H9A	(1)	ISO-TO-220 SIMILAR to TO-220AB 
IRFI530 IRFI540	100	0.16 0.077	9.7 17	6.9 12	3.9 3.1	39 48	H9B		
IRFI630 IRFI640	200	0.40 0.18	5.9 9.8	3.7 6.2	3.9 3.1	32 40			
IRFI634 IRFI644	250	0.45 0.28	5.6 7.9	3.5 5.0	3.9 3.1	32 40			
IRFI730 IRFI740	400	1.0 0.55	3.5 5.4	2.2 3.4	3.9 3.1	32 40			
IRFI820 IRFI830 IRFI840	500	3.0 1.5 0.85	2.1 3.1 4.6	1.3 2.0 2.9	4.1 3.9 3.1	30 32 40			

Isolated TO-247

IRFIP044 IRFIP054	60	0.028 0.014	43 64	30 45	1.5 1.3	100 120	H10	(1)	ISO-TO-3P SIMILAR to TO-247AC 
IRFIP140 IRFIP150	100	0.077 0.055	23 31	16 22	1.5 1.3	100 120			
IRFIP240 IRFIP250	200	0.18 0.085	14 22	8.9 14	1.5 1.3	83 96			
IRFIP244 IRFIP254	250	0.28 0.14	11 17	6.9 11	1.5 1.3	83 96			
IRFIP340 IRFIP350	400	0.55 0.30	8 11	5.1 7.0	1.5 1.3	83 96			
IRFIP440 IRFIP448 IRFIP450	500	0.85 0.60 0.40	6.4 7.4 10	4.0 4.7 6.5	1.5 1.4 1.3	83 89 96			

(1) For lead formed options see page 154.

(2) For case outline drawing see page 152.

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Logic-Level HEXFETs

International Rectifier has expanded its line of Logic-Level HEXFETs to include the popular HEXDIP (4-pin plastic Dual-In-line) and surface-mountable D-Pak packages, as well as the original, ever-popular TO-220AB outline.


a full 10V from gate to source to turn on, logic-level HEXFETs require only 5V to achieve full enhancement. This allows direct interface between power loads and logic-IC level output signals — hence the name "logic-level." This simplification of the gate drive requirement means significant cost savings, design simplification and higher reliability through the elimination of costly excess circuitry.

Logic-level HEXFETs feature the same basic characteristics as their well-established standard-gate counterparts — but instead of requiring

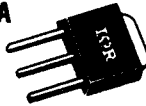
Surface Mount D-Pak (5 Volt Gate to Source)

Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (3)	Notes	Case Style
IRLR014 IRLR024	60	0.20 0.10	8.5 16	6.0 11	5.0 3.0	30 50	H1	(2)	TO-252AA D-Pak 
IRLR110 IRLR120	100	0.54 0.27	4.6 8.4	3.3 5.9	5.0 3.0	30 50			

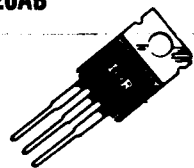
HEXDIP (5 Volt Gate to Source)

Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (3)	Notes	Case Style
IRLD014 IRLD024	60	0.20 0.10	1.7 2.5	1.2 1.8	— —	1 1	H4		HD-1 SIMILAR MO-001AN 
IRLD110 IRLD120	100	0.54 0.27	1.0 1.3	0.70 0.94	— —	1 1			

TO-251 I-Pak (5 Volt Gate to Source)

Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (3)	Notes	Case Style
IRLU014 IRLU024	60	0.20 0.10	8.5 16	6.0 11	5.0 3.0	30 50	H2		TO-251AA I-Pak 
IRLU110 IRLU120	100	0.54 0.27	4.6 8.4	3.3 5.9	5.0 3.0	30 50			

TO-220 (5 Volt Gate to Source)


Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (3)	Notes	Case Style
IRLZ14 IRLZ24 IRLZ34 IRLZ44	60	0.20 0.10 0.050 0.028	10 17 30 50	7.2 12 21 36	3.5 2.5 1.7 1.0	43 60 88 150	H5	(1)	TO-220AB 
IRL510 IRL520 IRL530 IRL540	100	0.54 0.27 0.16 0.077	5.6 9.2 15 28	4.0 6.5 11 20	3.5 2.5 1.7 1.0	43 60 88 150			

(1) For lead formed options see page 154.
(2) For tape and reel options see page 152.


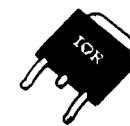
(3) For case outline drawing see page 152.

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HEXSense Current Sensing N-Channel

(4) Part Number	V _{GS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _{DM} Pulse Drain Current (Amps)	P _D Max Power Dissipation (Watts)	Nominal Sense Ratio	Case Outline Number (3)	Case Style
IRCZ24 IRCZ34 IRCZ44	60	0.10 0.060 0.028	17 30 50	12 21 37	2.6 1.7 1.0	780 1410 2590	H6	5 PIN TO-220 SIMILAR to TO-204AA 
IRC530 IRC540	100	0.16 0.077	14 29	10 21	1.7 1.0	1465 2680		
IRC630 IRC640	200	0.40 0.18	9.0 18	5.7 11	1.7 1.0	1490 1495		
IRC834 IRC844	250	0.46 0.28	8.1 14	5.1 8.8	1.7 1.0	2740 2770		
IRC730 IRC740	400	1.0 0.55	5.5 10	3.5 6.3	1.7 1.0	1530 2800		
IRC830 IRC840	500	1.5 0.85	4.5 8.0	3.0 5.1	1.7 1.0	1520 2805		
IRCP054	60	0.014	70	70	0.50	2310		

Surface Mount Devices N-Channel

(4) Part Number	V _{GS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (3)	Notes	Case Style
IRFS120	100	2.4	0.90	0.64	35	4	H3	(2)	TO-243AA SOT-89 
IRFR014 IRFR024	60	0.20 0.10	8.4 16	6.0 11	5.0 3.0	30 50	H1	(2)	TO-252AA D-Pak 
IRFR110 IRFR120	100	0.54 0.27	4.7 8.4	3.3 6.0	5.0 3.0	30 50			
IRFR210 IRFR220	200	1.5 0.8	2.6 4.8	1.7 3.0	5.0 3.0	25 42			
IRFR214 IRFR224	250	2.0 1.1	2.2 3.8	1.4 2.4	5.0 3.0	25 42			
IRFR310 IRFR320	400	3.6 1.8	1.7 3.1	1.1 2.0	5.0 3.0	25 42			
IRFR420	500	3.0	2.4	1.5	3.0	42			
IRFRC20	600	4.4	2.0	1.3	3.0	42			

Surface Mount Devices P-Channel

(4) Part Number	V _{GS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (3)	Notes	Case Style
IRFR9014 IRFR9024	-60	0.50 0.28	-5.6 -9.6	-3.9 -6.8	5.0 3.0	30 50	H1	(2)	TO-252AA D-Pak 
IRFR9110 IRFR9120	-100	1.2 0.60	-3.4 -6.3	-2.4 -4.5	5.0 3.0	30 50			
IRFR9210 IRFR9220	-200	3.0 1.5	-1.9 -3.6	-1.2 -2.3	5.0 3.0	25 42			


(2) For tape and reel options see page 152.

(3) For case outline drawing see page 152..


(4) Additional HEXFET part numbers are available: See numerical index page 191.

195

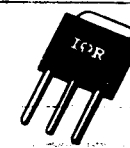
HEXDIP N-Channel

(2) Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (1)	Notes	Case Style
IRFD014 IRFD024	60	0.20 0.10	1.7 2.5	1.2 1.80	— —	1.3 1.3	H4		HD-1 SIMILAR to MO-001AN 
IRFD120 IRFD110 IRFD120	100	2.4 0.54 0.27	0.50 1.0 1.3	0.36 0.71 0.94	— — —	1.3 1.3 1.3			
IRFD210 IRDD220	200	1.5 0.80	0.60 0.80	0.38 0.50	— —	1.0 1.0			


HEXDIP P-Channel

(2) Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (1)	Notes	Case Style
IRFD9014 IRFD9024	-60	0.50 0.28	-1.1 -1.6	-0.80 -1.10	— —	1.3 1.3	H4		HD-1 SIMILAR to MO-001AN 
IRFD9110 IRFD9120	-100	1.2 0.60	-0.70 -1.0	-0.49 -0.70	— —	1.3 1.3			
IRFD9210 IRFD9220	-200	3.0 1.5	-0.40 -0.56	-0.25 -0.36	— —	1.0 1.0			

TO-251 N-Channel

(2) Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (1)	Notes	Case Style
IRFU014 IRFU024	60	0.20 0.10	8.4 16	6.0 11	5.0 3.0	30 50	H2		TO-251AA I-Pak 
IRFU110 IRFU120	100	0.54 0.27	4.7 8.4	3.3 6.0	5.0 3.0	30 50			
IRFU210 IRFU220	200	1.5 0.80	2.6 4.8	1.7 3.0	5.0 3.0	25 42			
IRFU214 IRFU224	250	2.0 1.1	2.2 3.8	1.4 2.4	5.0 3.0	25 42			
IRFU310 IRFU320	400	3.6 1.8	1.7 3.1	1.1 2.0	5.0 3.0	25 42			
IRFU420	500	3.0	2.4	1.5	3.0	42			
IRFUC20	600	4.4	2.0	1.3	3.0	42			

TO-251 P-Channel

(2) Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (1)	Notes	Case Style
IRFU9014 IRFU9024	-60	0.50 0.28	-5.6 -9.6	-3.9 -6.8	5.0 3.0	30 50	H2		TO-251AA I-Pak 
IRFU9110 IRFU9120	-100	1.2 0.60	-3.4 -6.3	-2.4 -4.5	5.0 3.0	30 50			
IRFU9210 IRFU9220	-200	3.0 1.5	-2.0 -3.6	-1.2 -2.3	5.0 3.0	25 42			

(1) For case outline drawing see page 152.

(2) Additional HEXFET part numbers are available: See numerical index page 191.


HEXFET Power MOSFETs

Plastic Insertable Package




196

TO-220 N-Channel

(3) Part Number	V _{GS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (2)	Notes	Case Style
IRFZ14 IRFZ24 IRFZ34 IRFZ44 IRFZ48	60	0.20 0.10 0.050 0.028 0.018	10 17 30 50 50	7.2 12 21 46 50	3.5 2.5 1.7 0.60 0.60	43 60 88 250 250	H5	(1)	TO-220AB
IRF510 IRF520 IRF530 IRF540	100	0.54 0.27 0.16 0.077	5.6 9.2 14 28	4.0 6.5 10 20	3.5 2.5 1.7 1.0	43 60 88 150			
IRF610 IRF620 IRF630 IRF640	200	1.5 0.80 0.40 0.18	3.3 5.2 9.0 18	2.1 3.3 5.7 11	3.5 2.5 1.7 1.0	36 50 74 125			
IRF614 IRF624 IRF634 IRF644	250	2.0 1.1 0.45 0.28	2.7 4.4 8.1 14	1.7 2.8 5.1 8.8	3.5 2.5 1.7 1.0	36 50 74 125			
IRF710 IRF720 IRF730 IRF740	400	3.6 1.8 1.0 0.55	2.0 3.3 5.5 10	1.2 2.1 3.5 6.3	3.5 2.5 1.7 1.0	36 50 74 125			
IRF820 IRF830 IRF840	500	3.0 1.5 0.85	2.5 4.5 8.0	1.6 2.9 5.1	2.5 1.7 1.0	50 74 125			
IRFBC20 IRFBC30 IRFBC40	600	4.4 2.2 1.2	2.2 3.6 6.2	1.4 2.3 3.9	2.5 1.7 1.0	50 74 125			
IRFBE20 IRFBE30	800	6.5 3.0	2.0 5.2	1.2 3.3	2.0 0.60	63 210			
IRFBF20 IRFBF30	900	8.0 3.7	1.8 4.7	1.1 3.0	2.0 0.60	63 210			
IRFBG20 IRFBG30	1000	11.5 5.0	1.3 4.0	0.800 2.5	2.5 0.60	50 210			

TO-220 P-Channel

IRF9214 IRF9224 IRF9234	-60	0.50 0.28 0.14	-6.7 -11 -18	-4.7 -7.7 -13	3.5 2.5 1.7	43 60 88	H5	(1)	TO-220AB
IRF9510 IRF9520 IRF9530 IRF9540	-100	1.21 0.60 0.30 0.20	-4.0 -6.8 -12 -19	-2.8 -4.8 -8.2 -13	3.5 2.5 1.7 1.0	43 60 88 150			
IRF9610 IRF9620 IRF9630 IRF9640	-200	3.0 1.51 0.80 0.50	-1.7 -3.5 -6.5 -11	-1.0 -2.0 -4.0 -6.8	3.5 3.1 1.7 1.0	20 40 75 125			

(1) For lead formed options see page 154.
 (2) For case outline drawing see page 152.

(3) Additional HEXFET part numbers are available: See numerical index page 191.

International Rectifier

ARROW

IRFP064

\$13.72

10 weeks

IRFP054

\$6.75


1600 in stock

HEXFET Power MOSFETs
Plastic Insertable Package

IRFP044
\$4.40

197

TO-247 N-Channel

(3) Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (2)	Notes	Case Style
IRFP044 IRFP054 IRFP064	60	0.028 0.014 0.009	57 70 70	40 70 70	0.83 0.50 0.30	180 300 500	H7	(1)	TO-247AC TO-3P
IRFP140 IRFP150	100	0.077 0.055	31 47	22 33	0.83 0.50	180 300			
IRFP240 IRFP250 IRFP260	200	0.18 0.085 0.070	20 34 38	12 21 24	0.83 0.50 0.50	150 250 250			
IRFP244 IRFP254 IRFP264	250	0.28 0.14 0.095	15 26 32	9.7 17 20	0.83 0.50 0.50	150 250 250			
IRFP340 IRFP350 IRFP360	400	0.55 0.30 0.20	11 18 28	6.9 11 18	0.83 0.50 0.30	150 250 410		\$8.95	
IRFP440 IRFP448 IRFP450 IRFP460	500	0.85 0.60 0.40 0.27	8.8 11 16 25	5.6 6.6 9.9 16	0.83 0.70 0.50 0.30	150 180 250 410			9.5.5
IRFPC30 IRFPC40 IRFPC50	600	2.2 1.2 0.60	4.3 6.8 13	2.7 4.3 8.0	1.2 0.83 0.50	100 150 250			
IRFPE30 IRFPE40 IRFPE50	800	3.0 2.0 1.2	5.2 6.9 11	3.3 4.4 6.7	0.60 0.50 0.35	210 250 360			
IRFPF30 IRFPF40 IRFPF50	900	3.7 2.5 1.6	4.7 4.7 9.1	3.0 3.0 5.8	0.60 0.83 0.35	210 150 360			
IRFPG30 IRFPG40 IRFPG50	1000	5.0 3.5 2.0	4.0 4.3 8.2	2.5 2.7 5.2	0.60 0.83 0.35	210 150 360			

TO-247 P-Channel

Part Number	V _{DS} Drain Source Voltage (Volts)	R _{DS(on)} On-State Resistance (Ohms)	I _D Continuous Drain Current 25°C Case (Amps)	I _D Continuous Drain Current 100°C Case (Amps)	R _{thJC} Max Thermal Resistance (°C/W)	P _D Max Power Dissipation (Watts)	Case Outline Number (2)	Notes	Case Style
IRFP9140 IRFP9240	-100 -200	0.20 0.50	-21 -12	-15 -7.5	0.83 0.83	180 150	H7	(1)	TO-247AC TO-3P

- (1) For lead formed options see page 154.
- (2) For case outline drawing see page 152.

(3) Additional HEXFET part numbers are available: See numerical index page 191.

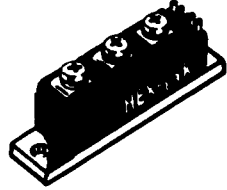
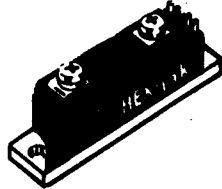
HEXFET POWER MOSFETS

HEX-Pak Modules



198

TO-240 N-Channel

(4) Part Number	V_{DS} Drain Source Voltage (Volts)	$R_{DS(on)}$ On-State Resistance (Ohms)	I_D Continuous Drain Current 25°C Case (Amps)	I_{DM} Pulse Drain Current (Amps)	P_D Max Power Dissipation (Watts)	Case Outline Number (1)	Notes	Case Style			
IRFK2D054	60	0.010	120	480	500	H12	(2)	TO-240AA Half Bridge			
IRFK2D150	100	0.028	72	288							
IRFK2D250	200	0.043	54	216							
IRFK2D350	400	0.15	25	100							
IRFK2D450	500	0.20	22	88							
IRFK2DC50	600	0.35	18	72							
IRFK2DC50	800	0.60	12	48							
IRFK2F054	60	0.010	120	480					(3)		
IRFK2F150	100	0.028	72	288							
IRFK2F250	200	0.043	54	216							
IRFK2F350	400	0.150	25	100							
IRFK2F450	500	0.20	22	88							
IRFK2FC50	600	0.35	16	72							
IRFK2FE50	800	0.60	12	48							
IRFK3D150	100	0.020	125	435	625	(2)					
IRFK3D250	200	0.030	70	280							
IRFK3D350	400	0.10	37	148							
IRFK3D450	500	0.135	33	132							
IRFK3DC50	600	0.23	24	96							
IRFK3F150	100	0.020	125	435				(3)			
IRFK3F250	200	0.030	70	280							
IRFK3F350	400	0.10	37	148							
IRFK3F450	500	0.135	33	132							
IRFK3FC50	600	0.23	24	96							
IRFK4H054	60	0.005	150	960	500	H11	(2)	TO-240AA Parallel Chip			
IRFK4H150	100	0.014	137	548							
IRFK4H250	200	0.021	108	432							
IRFK4H350	400	0.075	50	200							
IRFK4H450	500	0.10	44	176							
IRFK4HC50	600	0.175	35	140							
IRFK4HE50	800	0.30	26	104							
IRFK4J054	60	0.005	150	960					(3)		
IRFK4J150	100	0.014	137	548							
IRFK4J250	200	0.021	108	432							
IRFK4J350	400	0.075	50	200							
IRFK4J450	500	0.10	44	176							
IRFK4JC50	600	0.175	35	140							
IRFK4JE50	800	0.30	26	104							
IRFK6H150	100	0.010	150	720					625	(2)	
IRFK6H250	200	0.015	140	560							
IRFK6H350	400	0.050	75	300							
IRFK6H450	500	0.067	66	264							
IRFK6HC50	600	0.10	48	192							
IRFK6J150	100	0.010	150	720	(3)						
IRFK6J250	200	0.015	140	560							
IRFK6J350	400	0.050	75	300							
IRFK6J450	500	0.067	66	264							
IRFK6JC50	600	0.10	48	192							

(1) For case outline drawing see page 152.

(2) Standard parts.

(3) Extra damped parts

(4) Additional HEXFET part numbers are available: See numerical index page 191.

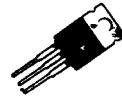
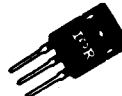
Insulated Gate Bipolar Transistor

**International
IOR Rectifier**

199

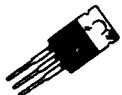
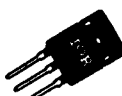
Standard-Speed IGBTs Applications: High Voltage Motor Controls, UPS

< 1 KHz

Part Number	BV _{CES} Collector to Emitter Breakdown Voltage (V)	V _{GE(th)} Gate to Emitter Threshold Voltage		V _{CE(on)} Collector to Emitter Saturation Voltage Max (V)	I _C Continuous Collector Current		E _{ts typ} Total Switching Loss @ T _J = 150°C V _{CC} = 480V		P _D Max. Power Dissip. (W)	Case Outline Number (1)	Notes	Case Style
		Min (V)	Max (V)		@ T _C = 25°C (A)	@ T _C = 100°C (A)	(mJ)	(A)				
IRGBC20S IRGBC30S IRGBC40S	600	3.0	5.5	2.0	19	10	4.1	10	60	IG1		TO-220AB 
				1.9	34	18	7.1	18	100			
IRGPC40S IRGPC50S				1.8	60	31	13	31	160	IG2		TO-247AC (TO-3P) 
				1.6	70	41	16	41	200			

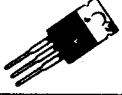
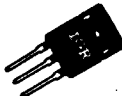
Fast-Speed IGBTs Applications: High Voltage UPS's, Motor Control, Industrial

3-8 KHz

IRGBC20F IRGBC30F IRGBC40F	600	3.0	5.5	2.8	16	9	1.8	9	60	IG1		TO-220AB 
				2.1	31	17	2.5	17	100			
				2.0	49	27	4.4	27	160			
IRGBF20F	900	3.5	5.5	2.5	12	7	1.5	6	—			
IRGPC40F IRGPC50F	600	3.0	5.5	2.0	49	47	4.4	27	160	IG2		TO-247AC (TO-3P) 
				1.7	70	39	6.0	39	200			
IRGPF30F IRGPF40F IRGPF50F	900	3.5	5.5	2.5	24	13	3	12	—			
				2.5	42	23	5	20	—			
				2.5	56	31	10	40	—			
IRGPH40F IRGPH50F	1200	3.5	5.5	2.2	40	22	5	10	—			
				2.2	50	27	10	20	—			

UltraFast™ IGBTs Applications: High Voltage SMPS's, Motor Controls, Robotics

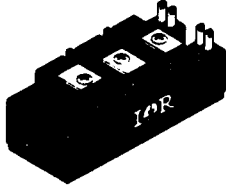
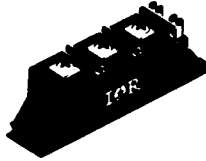
> 10 KHz

IRGBC20U IRGBC30U IRGBC40U	600	3.0	5.5	3.0	13	6.5	0.35	6.5	60	IG1		TO-220AB 
				3.0	23	12	0.59	12	100			
				3.0	40	20	1.5	20	160			
IRGPC40U IRGPC50U				3.0	40	20	1.5	20	160	IG2		TO-247AC (TO-3P) 
				3.0	55	27	1.7	27	200			

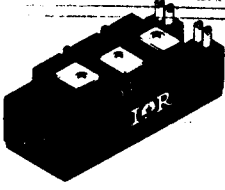
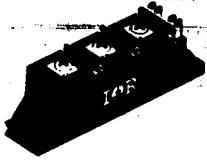
(1) For case outline drawing see page 149.

200

Fast-Speed IGBT Modules

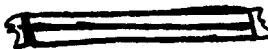
Part Number	BV _{CE(S)} Collector to Emitter Breakdown Voltage (V)	I _C Collector Current	V _{CE(ON)} @ I _C Max	I _{LM} Clamped Inductive Load Current (A)	P _D Max. Power Dissip. Per Switch @ 25°C (W)	Max. ETS/A	Circuit Type	Case Outline Number (1)	Case Style			
		T _C = 25°C (A)										
IRGTI065F06 IRGTI120F06 IRGTI165F06 IRGTI200F06	600	65	2.3	130	179	3.0	Half Bridge	IG3	INT-A-Pak 			
IRGKI065F06 IRGKI120F06 IRGKI165F06 IRGKI200F06		120	2.2	240	298		Low Side Switch Chopper					
IRGNI065F06 IRGNI120F06 IRGNI165F06 IRGNI200F06		165	2.1	330	379		High Side Switch Chopper					
IRGTA050F06 IRGTA090F06		600	50	2.0	100		125	3.0		Half Bridge	IG4	ADD-A-Pak 
IRGKA050F06 IRGKA090F06 IRGKA120F06			90	2.1	180		219			Low Side Switch Chopper		
IRGNA050F06 IRGNA090F06 IRGNA120F06			50	2.0	100		125			High Side Switch Chopper		
			90	2.1	180		219					
			120	2.0	240		278					
			120	2.0	240		278					

UltraFast™ IGBT Modules

IRGTI050U06 IRGTI090U06 IRGTI115U06 IRGTI140U06	600	505	3.1	100	179	0.12	Half Bridge	IG3	INT-A-Pak 			
IRGKI050U06 IRGKI090U06 IRGKI115U06 IRGKI140U06		90	3.0	180	298		Low Side Switch Chopper					
IRGNI050U06 IRGNI090U06 IRGNI115U06 IRGNI140U06		115	2.8	230	379		High Side Switch Chopper					
IRGTA035U06 IRGTA065U06		600	35	3.0	70		125	0.12		Half Bridge	IG4	ADD-A-Pak 
IRGKA035U06 IRGKA065U06 IRGKA090U06			65	2.9	130		202			Low Side Switch Chopper		
IRGNA035U06 IRGNA065U06 IRGNA090U06			35	3.0	70		125			High Side Switch Chopper		
			65	2.9	130		202					
			90	2.7	180		278					
			90	2.7	180		278					

(1) For case outline drawing see page 150.

AL

$$\frac{W}{\text{inch}^{\circ}\text{C}} = 3.5 - 5.6$$


Schottky Rectifiers

201

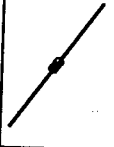





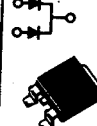
SWITCHMODE™ Schottky power rectifiers with the high speed and low forward voltage drop characteristic of Schottky's metal/silicon junctions are produced with ruggedness and temperature performance comparable to silicon-junction rectifiers. Ideal for use in low-voltage, high-frequency power supplies, and as very fast clamping diodes, these devices feature switching times less than 10 ns, and are offered in current ranges from 1 to 600 amperes, and reverse voltages to 200 volts.

In some current ranges, devices are available with junction temperature specifications of 125°C, 150°C, 175°C. Devices

with higher T_J ratings can have significantly lower leakage currents, but higher forward-voltage specifications. These parameter tradeoffs should be considered when selecting devices for applications that can be satisfied by more than one device type number.

All devices are connected cathode-to-case or cathode-to-heatsink, where applicable. Reverse polarity may be available on some devices upon special request. Contact your Motorola representative for more information.

Table 4 — Schottky Rectifiers

V _{RRM} (Volts)	I _O , AVERAGE RECTIFIED FORWARD CURRENT (Amperes)(1)							
	1		3			5		6
	59-04 Plastic Cathode = Polarity Band 	403A-03 SMB Cathode = Notch 	267-03 Plastic Cathode = Polarity Band 	403-03 SMC Cathode = Notch 	369A-11 DPAK Style 3 	60-01 Metal Style 1 	369A-11 DPAK Style 3 	
20	1N5817		1N5820	MBR320		MBRD320	1N5823	MBRD620CT
25						MBRD320		
30	1N5818		1N5821	MBR330		MBRD330	1N5824	MBRD630CT
35						MBRD330		
40	1N5819	MBRS140T3	1N5822	MBR340	MBRS340T3	MBRD340		
45						MBRD340	1N5825	MBRD640CT
50	MBR150			MBR350		MBRD350		
60	MBR160			MBR360		MBRD360		MBRD650CT
70	MBR170			MBR370				MBRD660CT
80	MBR180			MBR380				
90	MBR190			MBR390				
100	MBR1100	MBRS1100T3		MBR3100				
I _{FSM} (Amperes)	25	40	80	80	80	75	500	75
Max V _F @ I _{FM} = I _O	0.6(2) T _L = 25°C	0.6(2) T _C = 25°C	0.525(2) T _L = 25°C	0.74(2) T _L = 25°C	0.525(2) T _L = 25°C	0.45 T _C = 125°C	0.38(2) T _C = 25°C	0.85 T _C = 125°C
T _J (Max) °C	125	125	125	150	125	150	125	150

(1) I_O is total device output current.

(2) Values are for 40 volt units, lower voltage parts exhibit lower V_F.

Devices listed in bold, italic are Motorola preferred devices.



2

Schottky Rectifiers

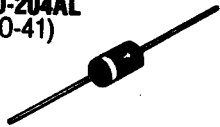
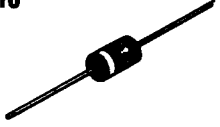
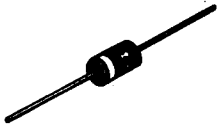
Surface Mount

International
TOR Rectifier

202

Part Number	VRRM (V)	IF(AV) @ Tc		VFM @ IFM (1) (V)	EAS (mJ)	IAR (A)	IRM @ Rated VRWM (1) (mA)	Max. Tj (°C)	Case Outline Number (4)	Notes	Case Style
		(A)	(°C)								
10MQ040	40	1.1	92	0.51	—	—	50	125	J1	(5)	D-64 
10MQ060	60	0.77	110	0.57			7.5				
10MQ090	90	0.77	110	0.65			5.0				
15MQ040	40	1.7		0.55	—	—	50			(1A)	
30WQ03F	30	3.3	105	0.56	—	—	12	125	J5	(5)	TO-252AA (D-PAK) 
30WQ04F	40	3.3	105	0.56			12				
30WQ05F	50	3.3	104	0.60			20				
30WQ06F	60	3.3	104	0.60			20				
30WQ09F	90	3.3	103	0.74			2				
30WQ10F	100	3.3	103	0.74			2				
50WQ03F	30	5.5	92	0.60	—	—	20	125	K1	(5)	
50WQ04F	40	5.5	92	0.60			20				
50WQ05F	50	5.5	89	0.66			30				
50WQ06F	60	5.5	89	0.66			30				
50WQ09F	90	5.5	90	0.77			3				
50WQ10F	100	5.5	90	0.77			3				
6CWQ03F	30	6.6	97	0.63	—	—	20	125	K1	(5)	
6CWQ04F	40	6.6	97	0.63			20				
6CWQ05F	50	6.6	92	0.67			30				
6CWQ06F	60	6.6	92	0.67			30				
6CWQ09F	90	6.6	94	0.79			3				
6CWQ10F	100	6.6	94	0.79			3				

Discrete

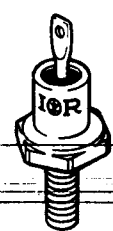
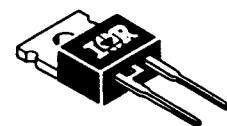
Part Number	VRRM (V)	IF(AV) @ Tc		VFM @ IFM (1) (V)	EAS (2) (mJ)	IAR (3) (A)	IRM @ Rated VRWM (1) (mA)	Max. Tj (°C)	Case Outline Number (4)	Notes	Case Style
		(A)	(°C)								
11DQ03	30	1.1	58	0.50	—	—	6	125	J2	(5)	DO-204AL (DO-41) 
11DQ04	40	1.1	58	0.50			6				
11DQ05	50	1.1	40	0.53			11				
11DQ06	60	1.1	40	0.53			11				
11DQ09	90	1.1	48	0.68			1				
11DQ10	100	1.1	48	0.68			1				
31DQ03	30	3.3	35	0.51	—	—	25	125	J3	(5)	C-16 
31DQ04	40	3.3	35	0.51			25				
31DQ05	50	3.3	19	0.53			30				
31DQ06	60	3.3	19	0.53			30				
31DQ09	90	3.3	25	0.69			4				
31DQ10	100	3.3	25	0.69			4				
50SQ080	80	5	119	0.52	15	1	7	175	J4		DO-204AR 
50SQ100	100	5	119	0.52			7				
80SQ035	35	8	119	0.44	10	1.6	15	175			
80SQ040	40										
80SQ045	45										
90SQ035	35	9	69	0.42	12	1.8	70	150			
90SQ040	40										
90SQ045	45										
95SQ015	15	9	55	0.25	4.5	1	348	100		(1B)(3A)	

- (1) Tj = 125°C unless otherwise specified (see Notes column).
- (2) Tj = 25°C, IAS = IAR.
- (3) Current decaying linearly to zero in 1 μsec.
Frequency limited by Tj max. VA = 1.5 x VR typical unless otherwise specified (see Notes column).
- (4) For case outline drawing see page 160.
- (5) For tape and reel specifications see pages 164-166.

- (1A) For VFM: Tj = 25°C; for IRM: Tj = 125°C.
- (1B) For VFM: Tj = 75°C; for IRM: Tj = 100°C.
- (1D) For VFM: Tj = 70°C; for IRM: Tj = 125°C.
- (1E) For VFM: Tj = 25°C; for IRM: Tj = 125°C.
- (1F) For VFM: Tj = 25°C; for IRM: Tj = 125°C.
- (1G) VFM rated at 50A.
- (1H) VFM rated at 80A.
- (1J) VFM rated at 160A.
- (3A) Current decaying linearly to zero in 1 μsec.
Frequency limited by Tj max. VA = 3 x VR typical.
- (3B) Current decaying linearly to zero in 2 μsec.
Frequency limited by Tj max. VA = 1.5 x VR typical.

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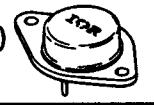
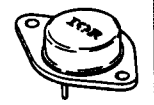
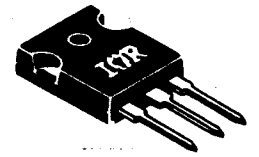
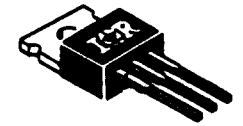
Part Number	VRRM (V)	IF(AV) @ Tc		VFM @ IFM (1) (V)	EAS (2) (mJ)	IAR (3) (A)	IRM @ Rated VRWM (1) (mA)	Max. Tj (°C)	Case Outline Number (4)	Notes	Case Style		
		(A)	(°C)										
6TQ035 6TQ040 6TQ045	35 40 45	6	163	0.51	8	1.2	7	175	J6		TO-220AC		
MBR735 MBR745	35 45	7.5	120	0.57	—	1.0	15	150		(3B)			
8TQ080 8TQ100	80 100	8	157	0.58	7.5	0.5	7	175					
MBR1035 MBR1045	35 45	10	120	0.57	—	1.0	15	150		(3B)			
10TQ035 10TQ040 10TQ045	35 40 45	10	151	0.49	13	2	15	175					
12TQ035 12TQ040 12TQ045	35 40 45	15	120	0.50	16	2.4	70	150					
MBR1635 MBR1645	35 45	16	125	0.57	—	1.0	40	150		(3B)			
18TQ035 18TQ040 18TQ045	35 40 45	18	149	0.53	24	3.6	25	175					
19TQ015	15	19	80	0.32	6.75	1.5	522	100		(1B)(3A)			
20TQ035 20TQ040 20TQ045	35 40 45	20	116	0.51	27	4	105	150					
1N6391	45	25	115	0.78	40	6	40	175		J9		(1E)(1G)	DO-203AA (DO-4)
1N6095 1N6096	30 40	25	105	0.86	40	6	250	125				(1D)(1H)	
SD41	35	30	96	0.58	—	—	125	150	(1F)				
20FQ035 20FQ040 20FQ045	35 40 45	30	111	0.47	40	6	150	150					
21FQ035 21FQ040 21FQ045	35 40 45	30	107	0.51	40	6	150	150					
30FQ035 30FQ040 30FQ045	35 40 45	30	144	0.54	40	6	35	175					
1N6097 1N6098	30 40	50	70	0.86	81	12	250	125	J10		(1D)(1J)	DO-203AB (DO-5)	
SD51	35	60	90	0.66	—	—	200	150			(1F)		
1N6392	45	60	115	0.68	101	15	60	175			(1E)		
50HQ035 50HQ040 50HQ045	35 40 45	60	101	0.53	81	12	200	150					
51HQ035 51HQ040 51HQ045	35 40 45	60	96	0.58	81	12	200	150					
55HQ030	30	60	110	0.41	54	12	280	150					
60HQ080 60HQ100	80 100	60	118	0.70	15	1	20	175					
75HQ035 75HQ040 75HQ045	35 40 45	75	117	0.63	101	15	45	175					
MBR7535 MBR7545	35 45	75	90	0.60	—	—	150	150					
85HQ035 85HQ040 85HQ045	35 40 45	85	112	0.62	114	17	45	175					
95HQ015	15	95	44	0.39	9	2	1000	100					



Notes: See page 40.

Part Number	VRRM (V)	IF(AV) @ Tc		VFM @ IFM (1) (V)	EAS (2) (mJ)	IAR (3) (A)	IRM @ Rated VRWM (1) (mA)	Max. Tj (°C)	Case Outline Number (4)	Notes	Case Style
		(A)	(°C)								
10CTQ150	150	10	145	0.86	6.75	0.30	7	175	K2	(3B)	TO-220AB (6)
12CTQ035	35	12	157	0.63	8	1.2	7	175			
12CTQ040	40										
12CTQ045	45										
15CTQ035	35	15	123	0.65	10	1.5	32	150			
15CTQ040	40										
15CTQ045	45										
MBR1535CT	35	15	105	0.72	—	1.0	15	150			
MBR1545CT	45	15	105	0.72	—	1.0	15	150			
16CTQ080	80	16	145	0.69	7.5	0.5	7	175			
16CTQ100	100										
20CTQ035	35	20	145	0.68	13	2	15	175			
20CTQ040	40										
20CTQ045	45										
MBR2035CT	35	20	135	0.72	—	1.0	15	150			
MBR2045CT	45										
MBR2080CT	80	10	133	0.70	—	0.5	150	150			
MBR2090CT	90										
MBR20100CT	100										
MBR2535CT	35	30	130	0.73	—	1.0	40	150			
MBR2545CT	45										
25CTQ035	35	30	102	0.64	20	3	70	150			
25CTQ040	40										
25CTQ045	45										
30CTQ035	35	30	127	0.70	20	3	15	175			
30CTQ040	40										
30CTQ045	45										
30CTQ050	50	30	97	0.71	13	1.5	45	150			
30CTQ060	60										
32CTQ030	30	30	109	0.53	13	3	97	150			
30CPQ035	35	30	124	0.64	20	3	70	150			
30CPQ040	40										
30CPQ045	45										
30CPQ050	50	30	112	0.70	13	1.5	45	150			
30CPQ060	60										
30CPQ080	80	30	140	0.81	7.5	0.5	7	175			
30CPQ100	100										
30CPQ150	150	30	131	0.93	11.25	0.5	15	175			
MBR3035PT	35	30	105	0.72	—	2.0	100	150			
MBR3045PT	45										
40CPQ035	35	40	120	0.56	27	4	150	150			
40CPQ040	40										
40CPQ045	45										
40CPQ050	50	40	120	0.64	18	2	96	150			
40CPQ060	60										
40CPQ080	80	40	145	0.75	11.25	0.75	15	175			
40CPQ100	100										
MBR3035CT	35	30	105	0.72	—	2.0	60	150			
MBR3045CT	45										
40CDQ035	35	40	135	0.71	27	4	25	175			
40CDQ040	40										
40CDQ045	45										
SD241	35	60	120	0.92	—	—	20	175			
60CDQ035	35	60	112	0.80	40	6	25	175			
60CDQ040	40										
60CDQ045	45										

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Notes: See page 42.

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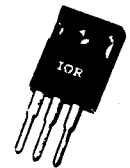
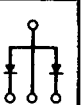
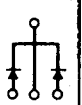
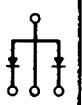
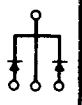
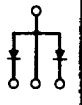
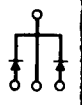
Rectifiers

Ultra-Fast Recovery

1 to 25 Amps






International
IOR Rectifier

Part Number	V _{RWM} (V)	I _{F(AV)} @ T _C		V _{FM} @ I _{F(AV)} (V)	I _{FSM} ⁽¹⁾ @ 60 Hz (A)	R _{thJC} DC (°C/W)	Max. t _{rr} (ns)	Case Outline Number	Notes	Case Style						
		(A)	(°C)													
10DF1 10DF2 10DF4 10DF6 10DF8	100 200 400 600 800	1 1 1 1 1	25 25 25 25 25	1.05 1.05 1.20 1.20 1.20	34 34 34 34 34	115 115 115 115 115	100 100 100 100 100	J2	(2)	DO-204AL DO-41						
11DF1 11DF2 11DF3 11DF4	100 200 300 400	1 1 1 1	63 63 63 63	0.98 0.98 1.25 1.25	31.4 31.4 31.4 31.4	115 115 115 115	35 35 30 30									
30DF1 30DF2 30DF4 30DF6	100 200 400 600	3 3 3 3	40 40 40 40	1.05 1.05 1.25 1.25	90 90 90 90	80 80 80 80	200 200 200 200				J3		C-16			
31DF1 31DF2 31DF3 31DF4	100 200 300 400	3 3 3 3	57 57 57 57	0.98 0.98 1.25 1.25	62.8 62.8 62.8 62.8	80 80 80 80	35 35 30 30									
10MF2	200	1	122	0.98	28	160	50							J1	(3)	D-64
30WF10F 30WF20F 30WF30F 30WF40F	100 200 300 400	3.3 3.3 3.3 3.3	104 104 104 104	1.35 1.35 1.35 1.35	31.4 31.4 31.4 31.4	8 8 8 8	30 30 30 30							J5	(3)	TO-252 D-PAK
50WF10F 50WF20F 50WF30F 50WF40F	100 200 300 400	5.5 5.5 5.5 5.5	104 104 104 104	1.1 1.1 1.1 1.1	47 47 47 47	6 6 6 6	40 40 40 40									
6CWF10F 6CWF20F	100 200	6.6 6.6	117 117	0.98 0.98	47 47	80 80	30 30									
10CTF10 10CTF20 10CTF30 10CTF40	100 200 300 400	10 10 10 10	117 117 112 112	0.98 0.98 1.25 1.25	84 84 84 84	3 3 3 3	35 35 45 45	J7	(5)	TO-220AB						
10JTF10 10JTF20 10JTF30 10JTF40	100 200 300 400	10 10 10 10	117 117 112 112	0.98 0.98 1.25 1.25	84 84 84 84	3 3 3 3	35 35 45 45				(5)					
16CPF10 16CPF20 16CPF30 16CPF40	100 200 300 400	16 16 16 16	113 113 109 109	0.98 0.98 1.25 1.25	126 126 126 126	2 2 2 2	35 35 45 45	J8		TO-247AA						
16JPF10 16JPF20 16JPF30 16JPF40	100 200 300 400	16 16 16 16	113 113 109 109	0.98 0.98 1.25 1.25	126 126 126 126	2 2 2 2	35 35 45 45				(4)					
25CPF10 25CPF20 25CPF30 25CPF40	100 200 300 400	25 25 25 25	93 93 85 85	0.98 0.98 1.25 1.25	157 157 183 183	2 2 2 2	50 50 60 60									
25JPF10 25JPF20 25JPF30 25JPF40	100 200 300 400	25 25 25 25	93 93 85 85	0.98 0.98 1.25 1.25	157 157 183 183	2 2 2 2	50 50 60 60				(4)					

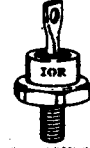


Notes: See page 49.

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Part Number	V _{RRM} (V)	I _{F(AV)} @ T _C		V _{FM} @ I _{F(AV)} (V)	I _R @ V _{RRM} (μA)	R _{thJC} Deg C/W	(14) Typ I _{RRM} (A)	(15) Typ t _{rr} (ns)	(12) Case Outline Number	Notes	Case Style
		(A)	(°C)								
HFA06SD60	600	6	100	—	—	—	—	—	J5		T0252AA D-Pak 
HFA08TB60	600	8	90	—	—	—	—	—	J6		T0220AC 
HFA15TB60	600	15	100	1.7	10	1.7	4	19			
HFA25TB60	600	25	100	—	—	—	—	—			
HFA20TB120	1200	20	100	—	—	—	—	—			
HFA16TA60C	600	16	100	—	—	—	—	—	K2	(5) (16)	T0220AB 
HFA30TA60C	600	30	100	1.7	10	0.85	4	19			
HFA08PB60	600	8	100	—	—	—	—	—	J12		T0247AC MOD 
HFA15PB60	600	15	100	1.7	10	1.7	4	19			
HFA25PB60	600	25	100	—	—	—	—	—			
HFA20PB120	1200	20	100	—	—	—	—	—			
HFA16PA60C	600	16	100	—	—	—	—	—	K3	(16)	T0247AC 
HFA30PA60C	600	30	100	1.7	10	0.83	4	19			
HFA50PA60C	600	50	100	—	—	—	—	—			

Super-Fast Recovery
30 to 60 Amps

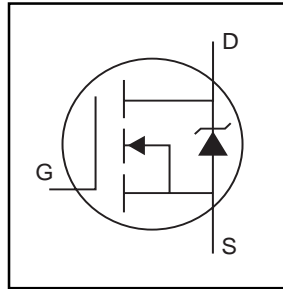
Part Number	V _{RRM} (V)	I _{F(AV)} @ T _C		I _{FSM} (6)		V _{FM} (V)	R _{thJC} DC (°C/W)	I _{rr} (10) (nS)	Case Outline Number (12)	Notes	Case Style
		(A)	(°C)	50 Hz (A)	60 Hz (A)						
30HFU-100	100	30	91	400	420	1.45	0.60	60	R7A	(7) (8) (11) (13)	DO-203AB (DO-5) 
30HFU-200	200	30	91	400	420	1.45	0.60	60			
30HFU-400	400	30	91	400	420	1.45	0.60	60			
30HFU-600	600	30	91	400	420	1.45	0.60	60			
60HFU-100	100	60	82	700	730	1.50	0.36	60		(8) (9) (11) (13)	
60HFU-200	200	60	82	700	730	1.50	0.36	60			
60HFU-400	400	60	82	700	730	1.50	0.36	60			
60HFU-600	600	60	82	700	730	1.50	0.36	60			

- (1) Following any rated load condition and with rated V_{RRM} reapplied.
- (2) Available on tape and reel. See pages 164-166.
- (3) For ordering information on tape and reel see pages 164-166.
- (4) Reverse polarity — common anode devices.
- (5) For lead formed options see pages 167, 168.
- (6) 100% V_{RRM} reapplied.
- (7) V_{FM} conditions: I_{FM} = 30 Apk, T_J = 25°C.
- (8) I_{F(AV)} conditions: 180°C conduction, half sine.
- (9) V_{FM} conditions: I_{FM} = 60 Apk, T_J = 25°C.
- (10) T_J = 25°C, I_F = 1A, -di/dt = 100 A/us, V_R = 30V.
- (11) Available with metric stud on request, to specify add "M" to end of part number (e.g., 60HFU-200M).
- (12) For case outline drawing see page 160 and/or 169.
- (13) Cathode-to-stud. For anode-to-stud, add "R" to basic part number (e.g., 60HFUR-400).
- (14) I_{RRM} @ I_F = I_{F(AV)}, diF/dt = 200A/μs.
- (15) t_{rr} @ I_F = 1A, diF/dt = 200A/μs.
- (16) Specifications are given per leg.

FB180SA10

HEXFET® Power MOSFET

- Fully Isolated Package
- Easy to Use and Parallel
- Very Low On-Resistance
- Dynamic dv/dt Rating
- Fully Avalanche Rated
- Simple Drive Requirements
- Low Drain to Case Capacitance
- Low Internal Inductance



$$V_{DSS} = 100V$$

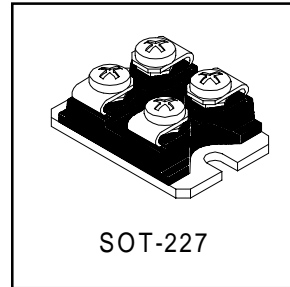
$$R_{DS(on)} = 0.0065\Omega$$

$$I_D = 180A$$

Description

Fifth Generation, high current density HEXFETS are paralleled into a compact, high power module providing the best combination of switching, ruggedized design, very low ON resistance and cost effectiveness.

The isolated SOT-227 package is preferred for all commercial - industrial applications at power dissipation levels to approximately 500 watts. The low thermal resistance and easy connection to the SOT-227 package contribute to its universal acceptance throughout the industry.



Absolute Maximum Ratings

	Parameter	Max.	Units
$I_D @ T_C = 25^\circ C$	Continuous Drain Current, $V_{GS} @ 10V$	180	A
$I_D @ T_C = 100^\circ C$	Continuous Drain Current, $V_{GS} @ 10V$	120	
I_{DM}	Pulsed Drain Current ①	720	
$P_D @ T_C = 25^\circ C$	Power Dissipation	480	W
	Linear Derating Factor	2.7	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②	700	mJ
I_{AR}	Avalanche Current③	180	A
E_{AR}	Repetitive Avalanche Energy④	48	mJ
dv/dt	Peak Diode Recovery dv/dt ⑤	5.7	V/ns
T_J	Operating Junction and	-55 to + 150	°C
T_{STG}	Storage Temperature Range		
V_{ISO}	Insulation Withstand Voltage (AC-RMS)	2.5	kV
	Mounting torque, M4 screw	1.3	N•m

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	0.26	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.05	—	

FB180SA10

Electrical Characteristics @ $T_J = 25^\circ\text{C}$ (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	100	—	—	V	$V_{GS} = 0V, I_D = 250\mu A$
$dV_{(BR)DSS}/dT_J$	Breakdown Voltage Temp. Coefficient	—	0.093	—	V/°C	Reference to $25^\circ\text{C}, I_D = 1\text{mA}$
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	0.0065	Ω	$V_{GS} = 10V, I_D = 108A$ ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	$V_{DS} = V_{GS}, I_D = 250\mu A$
g_{fs}	Forward Transconductance	93	—	—	S	$V_{DS} = 25V, I_D = 108A$
I_{DSS}	Drain-to-Source Leakage Current	—	—	50	μA	$V_{DS} = 100V, V_{GS} = 0V$
		—	—	500		$V_{DS} = 80V, V_{GS} = 0V, T_J = 125^\circ\text{C}$
I_{GSS}	Gate-to-Source Forward Leakage	—	—	200	nA	$V_{GS} = 20V$
	Gate-to-Source Reverse Leakage	—	—	-200		$V_{GS} = -20V$
Q_g	Total Gate Charge	—	250	380	nC	$I_D = 180A$
Q_{gs}	Gate-to-Source Charge	—	40	60		$V_{DS} = 80V$
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	110	165		$V_{GS} = 10.0V$, See Fig. 6 and 13 ④
$t_{d(on)}$	Turn-On Delay Time	—	45	—	ns	$V_{DD} = 50V$
t_r	Rise Time	—	351	—		$I_D = 180A$
$t_{d(off)}$	Turn-Off Delay Time	—	181	—		$R_G = 2.0\Omega$ (Internal)
t_f	Fall Time	—	335	—		$R_D = 0.27\Omega$, See Fig. 10 ④
L_s	Internal Source Inductance	—	5.0	—	nH	Between lead, and center of die contact
C_{iss}	Input Capacitance	—	10700	—	pF	$V_{GS} = 0V$
C_{oss}	Output Capacitance	—	2800	—		$V_{DS} = 25V$
C_{rss}	Reverse Transfer Capacitance	—	1300	—		$f = 1.0\text{MHz}$, See Fig. 5

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	180	A	MOSFET symbol showing the integral reverse p-n junction diode.
I_{SM}	Pulsed Source Current (Body Diode) ①	—	—	720		
V_{SD}	Diode Forward Voltage	—	—	1.3	V	$T_J = 25^\circ\text{C}, I_S = 180A, V_{GS} = 0V$ ④
t_{rr}	Reverse Recovery Time	—	300	450	ns	$T_J = 25^\circ\text{C}, I_F = 180A$
Q_{rr}	Reverse Recovery Charge	—	2.6	3.9	μC	$di/dt = 100A/\mu s$ ④
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11)

② Starting $T_J = 25^\circ\text{C}$, $L = 43\mu H$
 $R_G = 25\Omega$, $I_{AS} = 180A$. (See Figure 12)

③ $I_{SD} \leq 180A$, $di/dt \leq 83A/\mu s$, $V_{DD} \leq V_{(BR)DSS}$,
 $T_J \leq 150^\circ\text{C}$

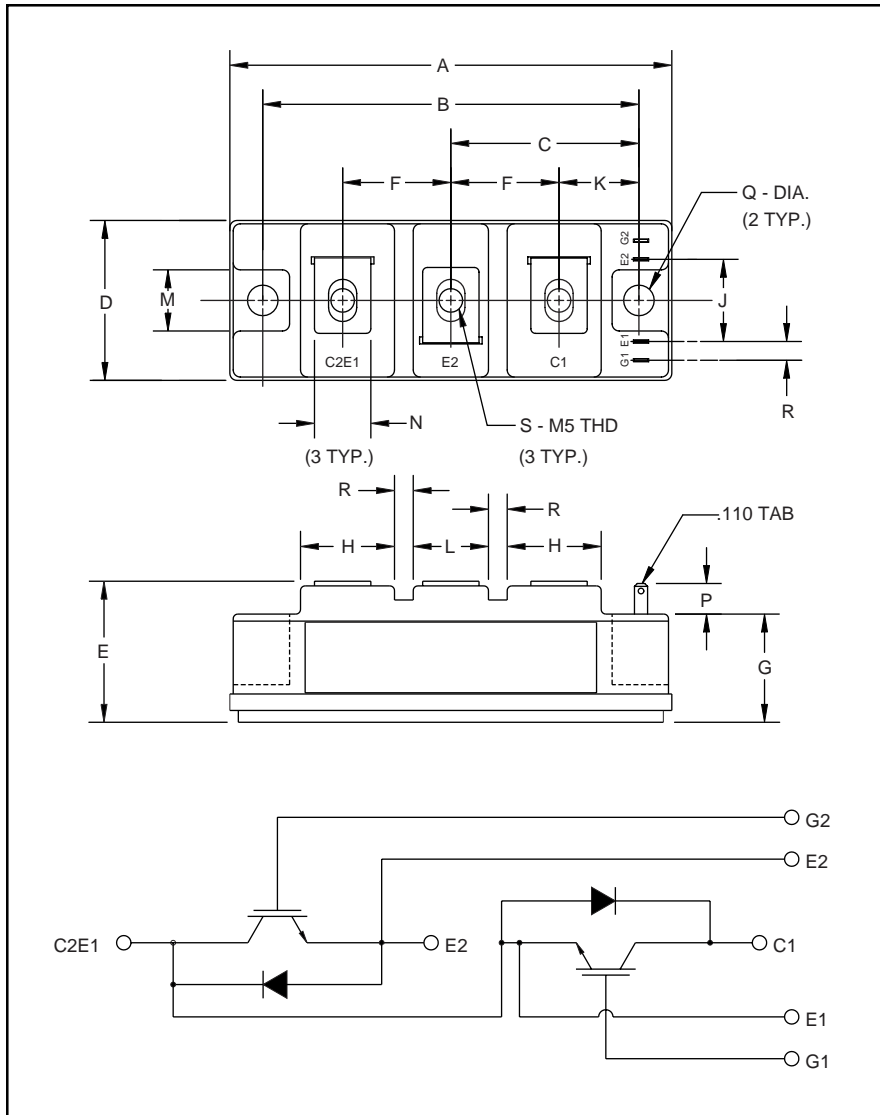
④ Pulse width $\leq 300\mu s$; duty cycle $\leq 2\%$.



Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (724) 925-7272

CM100DY-12H

Dual IGBTMOD™ H-Series Module 100 Amperes/600 Volts



Outline Drawing and Circuit Diagram

Dimensions	Inches	Millimeters
A	3.70	94.0
B	3.150±0.01	80.0±0.25
C	1.57	40.0
D	1.34	34.0
E	1.22 Max.	31.0 Max.
F	0.90	23.0
G	0.85	21.5
H	0.79	20.0
J	0.71	18.0

Dimensions	Inches	Millimeters
K	0.67	17.0
L	0.63	16.0
M	0.51	13.0
N	0.47	12.0
P	0.28	7.0
Q	0.256 Dia.	Dia. 6.5
R	0.16	4.0
S	M5 Metric	M5



Description:

Powerex IGBTMOD™ Modules are designed for use in switching applications. Each module consists of two IGBT Transistors in a half-bridge configuration with each transistor having a reverse-connected super-fast recovery free-wheel diode. All components and interconnects are isolated from the heat sinking baseplate, offering simplified system assembly and thermal management.

Features:

- Low Drive Power
- Low $V_{CE(sat)}$
- Discrete Super-Fast Recovery (70ns) Free-Wheel Diode
- High Frequency Operation (20-25kHz)
- Isolated Baseplate for Easy Heat Sinking

Applications:

- AC Motor Control
- Motion/Servo Control
- UPS
- Welding Power Supplies
- Laser Power Supplies

Ordering Information:

Example: Select the complete part module number you desire from the table below -i.e. CM100DY-12H is a 600V (V_{CES}), 100 Ampere Dual IGBTMOD™ Power Module.

Type	Current Rating Amperes	V_{CES} Volts (x 50)
CM	100	12



Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (724) 925-7272

CM100DY-12H

Dual IGBTMOD™ H-Series Module

100 Amperes/600 Volts

Absolute Maximum Ratings, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Ratings	Symbol	CM100DY-12H	Units
Junction Temperature	T_j	-40 to 150	$^\circ\text{C}$
Storage Temperature	T_{stg}	-40 to 125	$^\circ\text{C}$
Collector-Emitter Voltage (G-E SHORT)	V_{CES}	600	Volts
Gate-Emitter Voltage	V_{GES}	± 20	Volts
Collector Current	I_{C}	100	Amperes
Peak Collector Current	I_{CM}	200*	Amperes
Diode Forward Current	I_{F}	100	Amperes
Diode Forward Surge Current	I_{FM}	200*	Amperes
Power Dissipation	P_{d}	400	Watts
Max. Mounting Torque M5 Terminal Screws	–	17	in-lb
Max. Mounting Torque M6 Mounting Screws	–	26	in-lb
Module Weight (Typical)	–	190	Grams
V Isolation	V_{RMS}	2500	Volts

* Pulse width and repetition rate should be such that device junction temperature does not exceed the device rating.

Static Electrical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Collector-Cutoff Current	I_{CES}	$V_{\text{CE}} = V_{\text{CES}}, V_{\text{GE}} = 0\text{V}$	–	–	1.0	mA
Gate Leakage Current	I_{GES}	$V_{\text{GE}} = V_{\text{GES}}, V_{\text{CE}} = 0\text{V}$	–	–	0.5	μA
Gate-Emitter Threshold Voltage	$V_{\text{GE(th)}}$	$I_{\text{C}} = 10\text{mA}, V_{\text{CE}} = 10\text{V}$	4.5	6.0	7.5	Volts
Collector-Emitter Saturation Voltage	$V_{\text{CE(sat)}}$	$I_{\text{C}} = 100\text{A}, V_{\text{GE}} = 15\text{V}$	–	2.1	2.8**	Volts
		$I_{\text{C}} = 100\text{A}, V_{\text{GE}} = 15\text{V}, T_j = 150\text{ }^\circ\text{C}$	–	2.15	–	Volts
Total Gate Charge	Q_{G}	$V_{\text{CC}} = 300\text{V}, I_{\text{C}} = 100\text{A}, V_{\text{GS}} = 15\text{V}$	–	300	–	nC
Diode Forward Voltage	V_{FM}	$I_{\text{E}} = 100\text{A}, V_{\text{GS}} = 0\text{V}$	–	–	2.8	Volts

** Pulse width and repetition rate should be such that device junction temperature rise is negligible.

Dynamic Electrical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Input Capacitance	C_{ies}		–	–	10	nF
Output Capacitance	C_{Oes}	$V_{\text{GE}} = 0, V_{\text{CE}} = 10\text{V}, f = 1\text{MHz}$	–	–	3.5	nF
Reverse Transfer Capacitance	C_{res}		–	–	2	nF
Resistive	Turn-on Delay Time	$V_{\text{CC}} = 300\text{V}, I_{\text{C}} = 100\text{A},$ $V_{\text{GE1}} = V_{\text{GE2}} = 15\text{V}, R_{\text{G}} = 6.3\Omega$	–	–	120	ns
Load	Rise Time					
Switch	Turn-off Delay Time		–	–	200	ns
Times	Fall Time		–	–	300	ns
Diode Reverse Recovery Time	t_{rr}	$I_{\text{E}} = 100\text{A}, di_{\text{E}}/dt = -200\text{A}/\mu\text{s}$	–	–	110	ns
Diode Reverse Recovery Charge	Q_{rr}	$I_{\text{E}} = 100\text{A}, di_{\text{E}}/dt = -200\text{A}/\mu\text{s}$	–	0.27	–	μC

Thermal and Mechanical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

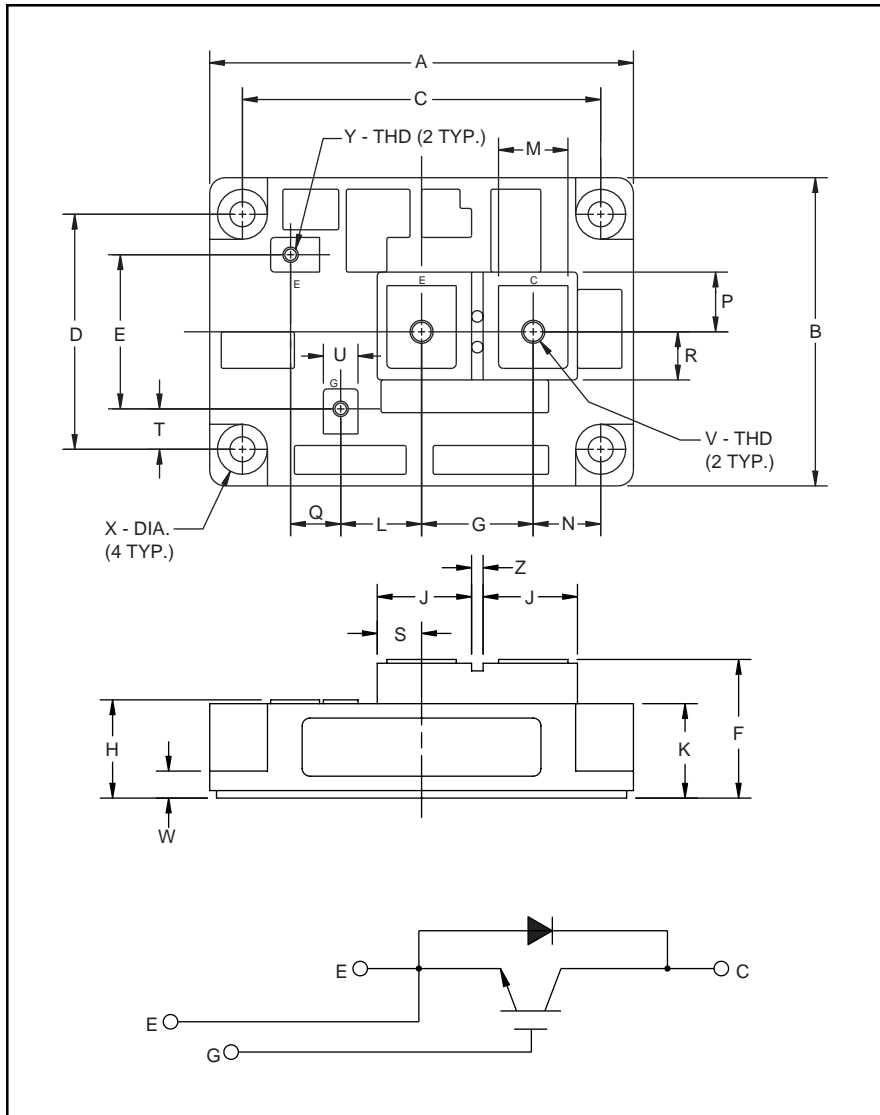
Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Thermal Resistance, Junction to Case	$R_{\text{th(j-c)}}$	Per IGBT	–	–	0.31	$^\circ\text{C}/\text{W}$
Thermal Resistance, Junction to Case	$R_{\text{th(j-c)}}$	Per FWDi	–	–	0.70	$^\circ\text{C}/\text{W}$
Contact Thermal Resistance	$R_{\text{th(c-f)}}$	Per Module, Thermal Grease Applied	–	–	0.075	$^\circ\text{C}/\text{W}$



Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (724) 925-7272

CM600HA-12H

**Single IGBTMOD™
H-Series Module
600 Amperes/600 Volts**



Outline Drawing and Circuit Diagram

Dimensions	Inches	Millimeters
A	4.33	110.0
B	3.15	80.0
C	3.66±0.008	93.0±0.25
D	2.44±0.008	62.0±0.25
E	1.57	40.0
F	1.42 Max.	36.0 Max.
G	1.14	29.0
H	1.00 Max.	25.5 Max.
J	0.96	25.0
K	0.94	24.5
L	0.83	21.0
M	0.71	18.0

Dimensions	Inches	Millimeters
N	0.69	17.5
P	0.61	15.5
Q	0.51	13.0
R	0.49	12.5
S	0.45	11.5
T	0.43	11.0
U	0.35	9.0
V	M8 Metric	M8
W	0.28	7.0
X	0.256 Dia.	Dia. 6.50
Y	M4 Metric	M4
Z	0.12	3.04



Description:

Powerex IGBTMOD™ Modules are designed for use in switching applications. Each module consists of one IGBT Transistor in a single configuration with a reverse-connected super-fast recovery free-wheel diode. All components and interconnects are isolated from the heat sinking baseplate, offering simplified system assembly and thermal management.

Features:

- Low Drive Power
- Low $V_{CE(sat)}$
- Discrete Super-Fast Recovery (70ns) Free-Wheel Diode
- High Frequency Operation (20-25kHz)
- Isolated Baseplate for Easy Heat Sinking

Applications:

- AC Motor Control
- Motion/Servo Control
- UPS
- Welding Power Supplies
- Laser Power Supplies

Ordering Information:

Example: Select the complete part module number you desire from the table below -i.e. CM600HA-12H is a 600V (V_{CES}), 600 Ampere Single IGBTMOD™ Power Module.

Type	Current Rating Amperes	V_{CES} Volts (x 50)
CM	600	12



Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (724) 925-7272

CM600HA-12H
Single IGBTMOD™ H-Series Module
 600 Amperes/600 Volts

Absolute Maximum Ratings, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Ratings	Symbol	CM600HA-12H	Units
Junction Temperature	T_j	-40 to 150	$^\circ\text{C}$
Storage Temperature	T_{stg}	-40 to 125	$^\circ\text{C}$
Collector-Emitter Voltage (G-E SHORT)	V_{CES}	600	Volts
Gate-Emitter Voltage	V_{GES}	± 20	Volts
Collector Current	I_C	600	Amperes
Peak Collector Current	I_{CM}	1200*	Amperes
Diode Forward Current	I_F	600	Amperes
Diode Forward Surge Current	I_{FM}	1200*	Amperes
Power Dissipation	P_d	2100	Watts
Max. Mounting Torque M8 Terminal Screws	-	95	in-lb
Max. Mounting Torque M6 Mounting Screws	-	26	in-lb
Module Weight (Typical)	-	560	Grams
V Isolation	V_{RMS}	2500	Volts

* Pulse width and repetition rate should be such that device junction temperature does not exceed the device rating.

Static Electrical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Collector-Cutoff Current	I_{CES}	$V_{\text{CE}} = V_{\text{CES}}, V_{\text{GE}} = 0\text{V}$	-	-	1.0	mA
Gate Leakage Current	I_{GES}	$V_{\text{GE}} = V_{\text{GES}}, V_{\text{CE}} = 0\text{V}$	-	-	0.5	μA
Gate-Emitter Threshold Voltage	$V_{\text{GE(th)}}$	$I_C = 60\text{mA}, V_{\text{CE}} = 10\text{V}$	4.5	6.0	7.5	Volts
Collector-Emitter Saturation Voltage	$V_{\text{CE(sat)}}$	$I_C = 600\text{A}, V_{\text{GE}} = 15\text{V}$	-	2.1	2.8**	Volts
		$I_C = 600\text{A}, V_{\text{GE}} = 15\text{V}, T_j = 150\text{ }^\circ\text{C}$	-	2.15	-	Volts
Total Gate Charge	Q_G	$V_{\text{CC}} = 600\text{V}, I_C = 600\text{A}, V_{\text{GS}} = 15\text{V}$	-	1800	-	nC
Diode Forward Voltage	V_{FM}	$I_E = 600\text{A}, V_{\text{GS}} = 0\text{V}$	-	-	2.8	Volts

** Pulse width and repetition rate should be such that device junction temperature rise is negligible.

Dynamic Electrical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Input Capacitance	C_{ies}		-	-	60	nF
Output Capacitance	C_{oes}	$V_{\text{GE}} = 0\text{V}, V_{\text{CE}} = 10\text{V}, f = 1\text{MHz}$	-	-	21	nF
Reverse Transfer Capacitance	C_{res}		-	-	12	nF
Resistive	Turn-on Delay Time	$t_{\text{d(on)}}$	-	-	350	ns
	Rise Time	t_r	-	-	700	ns
Switching	Turn-off Delay Time	$t_{\text{d(off)}}$	-	-	350	ns
	Fall Time	t_f	-	-	300	ns
Diode Reverse Recovery Time	t_{rr}	$I_E = 600\text{A}, di_E/dt = -1200\text{A}/\mu\text{s}$	-	-	110	ns
Diode Reverse Recovery Charge	Q_{rr}	$I_E = 600\text{A}, di_E/dt = -1200\text{A}/\mu\text{s}$	-	1.62	-	μC

Thermal and Mechanical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Thermal Resistance, Junction to Case	$R_{\text{th(j-c)}}$	Per IGBT	-	-	0.06	$^\circ\text{C}/\text{W}$
Thermal Resistance, Junction to Case	$R_{\text{th(j-c)}}$	Per FWDi	-	-	0.12	$^\circ\text{C}/\text{W}$
Contact Thermal Resistance	$R_{\text{th(c-f)}}$	Per Module, Thermal Grease Applied	-	-	0.035	$^\circ\text{C}/\text{W}$

MITSUBISHI HVIGBT MODULES CM1200HC-50H

HVIGBT (High Voltage Insulated Gate Bipolar Transistor) Modules

HIGH POWER SWITCHING USE
INSULATED TYPE

CM1200HC-50H



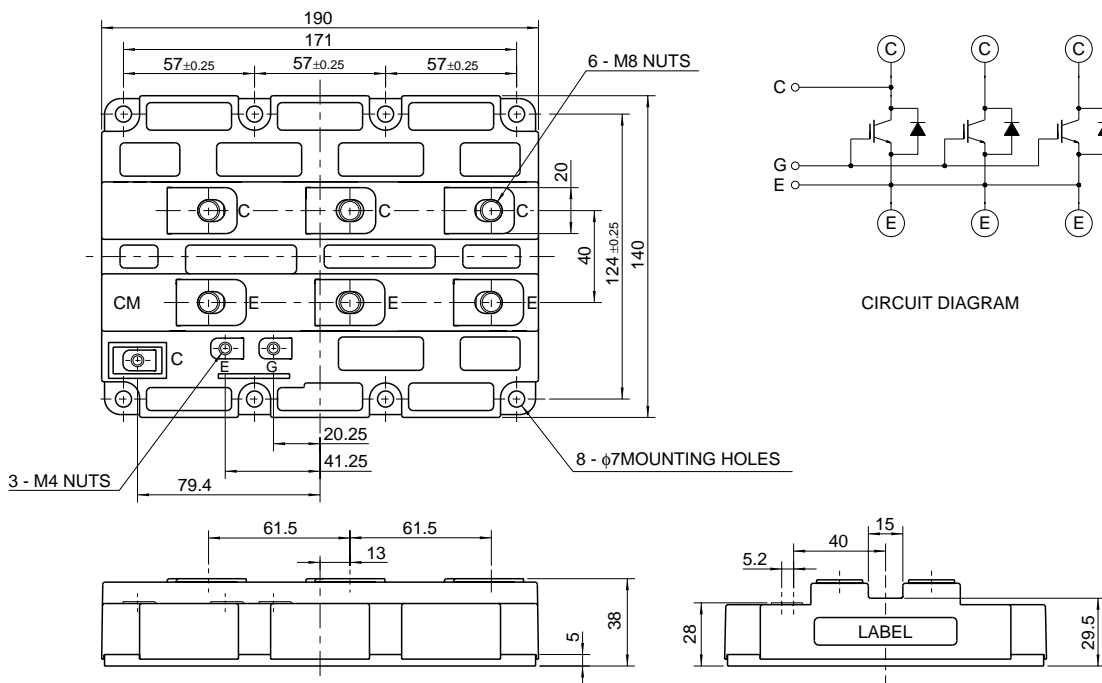
- IC 1200A
- VCES 2500V
- Insulated Type
- 1-element in a pack

APPLICATION

Inverters, Converters, DC choppers, Induction heating, DC to DC converters.

OUTLINE DRAWING & CIRCUIT DIAGRAM

Dimensions in mm



HVIGBT MODULES (High Voltage Insulated Gate Bipolar Transistor Modules)

Oct. 2002



CM1200HC-50H

HIGH POWER SWITCHING USE
INSULATED TYPE

HVIGBT (High Voltage Insulated Gate Bipolar Transistor) Modules

MAXIMUM RATINGS (T_j = 25°C)

Symbol	Item	Conditions	Ratings	Unit
V _{CES}	Collector-emitter voltage	V _{GE} = 0V	2500	V
V _{GES}	Gate-emitter voltage	V _{CE} = 0V	±20	V
I _C	Collector current	T _C = 25°C	1200	A
I _{CM}		Pulse (Note 1)	2400	A
I _E (Note 2)	Emitter current	T _C = 25°C	1200	A
I _{EM} (Note 2)		Pulse (Note 1)	2400	A
P _C (Note 3)	Maximum collector dissipation	T _C = 25°C, IGBT part	15600	W
T _j	Junction temperature	—	-40 ~ +150	°C
T _{stg}	Storage temperature	—	-40 ~ +125	°C
V _{iso}	Isolation voltage	Charged part to base plate, rms, sinusoidal, AC 60Hz 1min.	6000	V
—	Mounting torque	Main terminals screw M8	6.67 ~ 13.00	N·m
		Mounting screw M6	2.84 ~ 6.00	N·m
		Auxiliary terminals screw M4	0.88 ~ 2.00	N·m
—	Mass	Typical value	2.2	kg

ELECTRICAL CHARACTERISTICS (T_j = 25°C)

Symbol	Item	Conditions	Limits			Unit
			Min	Typ	Max	
I _{CES}	Collector cutoff current	V _{CE} = V _{CES} , V _{GE} = 0V	—	—	15	mA
V _{GE(th)}	Gate-emitter threshold voltage	I _C = 120mA, V _{CE} = 10V	4.5	6.0	7.5	V
I _{GES}	Gate-leakage current	V _{GE} = V _{GES} , V _{CE} = 0V	—	—	0.5	μA
V _{CE(sat)}	Collector-emitter saturation voltage	T _j = 25°C	—	2.80	3.64	V
		T _j = 125°C	—	3.15	—	
C _{ies}	Input capacitance	V _{CE} = 10V	—	180	—	nF
C _{oes}	Output capacitance	V _{GE} = 0V	—	13.5	—	nF
C _{res}	Reverse transfer capacitance	—	—	6.0	—	nF
Q _G	Total gate charge	V _{CC} = 1250V, I _C = 1200A, V _{GE} = 15V	—	8.1	—	μC
t _{d(on)}	Turn-on delay time	V _{CC} = 1250V, I _C = 1200A	—	—	1.60	μs
t _r	Turn-on rise time	V _{GE1} = V _{GE2} = 15V	—	—	2.00	μs
t _{d(off)}	Turn-off delay time	R _G = 1.6Ω	—	—	2.50	μs
t _f	Turn-off fall time	Resistive load switching operation	—	—	1.00	μs
V _{EC} (Note 2)	Emitter-collector voltage	I _E = 1200A, V _{GE} = 0V	—	2.50	3.25	V
t _{rr} (Note 2)	Reverse recovery time	I _E = 1200A,	—	—	1.20	μs
Q _{rr} (Note 2)	Reverse recovery charge	die / dt = -2400A / μs (Note 1)	—	350	—	μC
R _{th(j-c)Q}	Thermal resistance	Junction to case, IGBT part	—	—	0.010	K/W
R _{th(j-c)R}		Junction to case, FWDi part	—	—	0.020	K/W
R _{th(c-f)}	Contact thermal resistance	Case to fin, conductive grease applied	—	0.008	—	K/W

Note 1. Pulse width and repetition rate should be such that the device junction temp. (T_j) does not exceed T_{jmax} rating.2. I_E, V_{EC}, t_{rr}, Q_{rr} & die/dt represent characteristics of the anti-parallel, emitter to collector free-wheel diode.3. Junction temperature (T_j) should not increase beyond 150°C.

4. Pulse width and repetition rate should be such as to cause negligible temperature rise.

HVIGBT MODULES (High Voltage Insulated Gate Bipolar Transistor Modules)

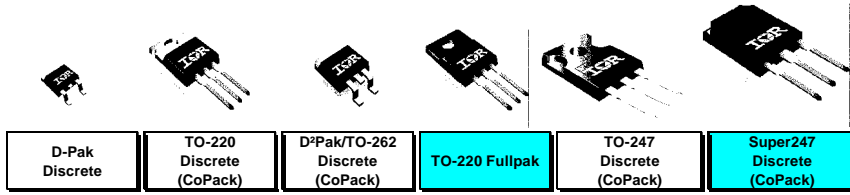
Oct 2002



EXISTING Products	NEW Products released to production in last 6-9 months	UPCOMING Products to be released within next 3-4 months	POTENTIAL Products no current plans... see bus.mgmt.
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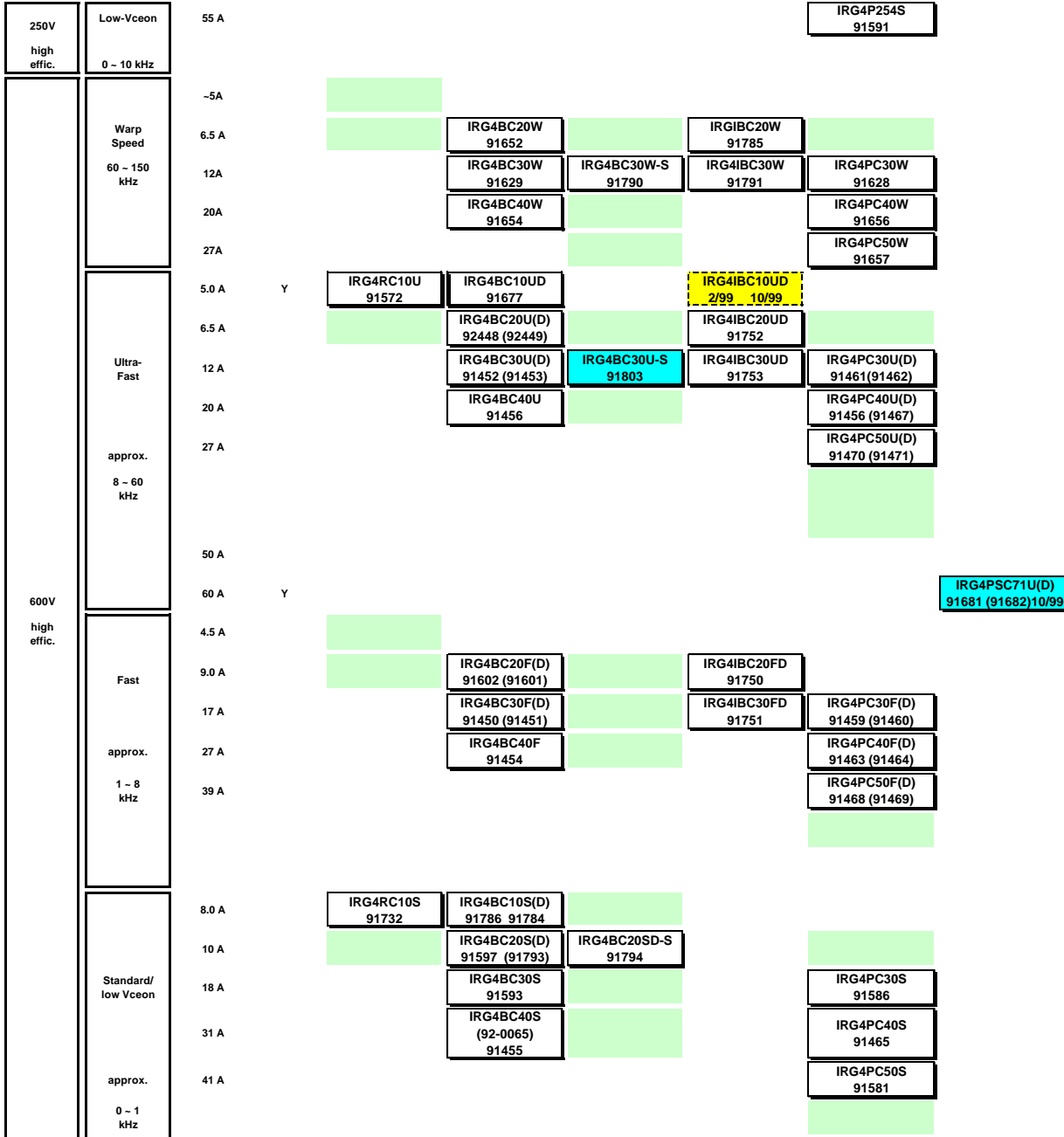
The IR IGBT Navigator

Effective 6 October, 1999



Voltage Speed Ic @100C Change

Highest-Efficiency:



International Rectifier

Voltage	Speed	Ic @100C	Change	D-Pak Discrete	TO-220 Discrete (CoPack)	D ² Pak/TO-262 Discrete (CoPack)	TO-220 Fullpak	TO-247 Discrete (CoPack)	Super247 Discrete (CoPack)
900V high effic.	Warp Speed 20 - 100 kHz	28 A						IRG4PF50W(D) 91710 (91788)	
1200V high effic.	Ultra-Fast approx. 5 - 40 kHz	16 A						IRG4PH40U(D) 91612 (91621)	
		20 A	Y					IRGP20B120UD-E Now 11/99	
		24 A						IRG4PH50U(D) 91574 (91573)	
	42 A								
	Standard (low sat) 0 - 1 kHz	33A						IRG4PH50S 91712	

Short-Circuit-Rated:

600V for Motor Drives	Ultra-Fast for 8 - 25 kHz motors	5.0 A			IRG4BC10K(D) 91733 (91734)				
		9.0 A		IRG4BC20K(D) 91600 (91599)	IRG4BC20K(D)-S 91620 (91598)	IRG4IBC20KD 91689			
		16 A		IRG4BC30K(D) 91596 (91595)	IRG4BC30K(D)-S 91619 (91594)	IRG4IBC30KD 91690	IRG4PC30K(D) 91588 (91587)		
		25 A		IRG4BC40K 91592			IRG4PC40K(D) 91585 (91584)		
		30 A				IRG4PC50K(D) 91583 (91582)			
		60 A	Y					IRG4PSC71K(D) 91683 (91684)10/99	
1200V for Motor Drives	Ultra-Fast for 4-20 kHz motors	5 A	Y		IRG4BH20K-S/L 5/99 10/99			IRG4PH20K(D) 91776 (91777)	
		10 A					IRG4PH30K(D) 91580 (91579)		
		15 A					IRG4PH40K(D) 91578 (91577)		
		24 A					IRG4PH50K(D) 91576 (91575)		
		30 A	Y				IRGP30B120KD-E Now 11/99		
		42 A	Y					IRG4PSH71K(D) 91687 (91688) 7/99 10/99	

Ignition IGBT:

400V	Low-Vceon	14 A	Y		IRGS14C40L Now 12/99				
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KEY:

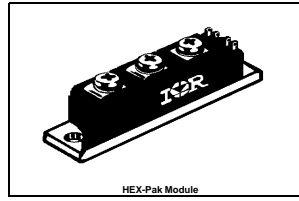
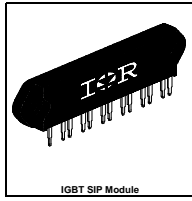
Part Number
FOD document #
Date for SAMPLES
Date for PROD'N

* = not recommended for new designs

The IGBT SIP & HEXPak Navigator

Effective 8 September,

EXISTING Products	NEW Products	UPCOMING Products	POTENTIAL Products
	released to production in last 6-9 months	to be released within next 3-4 months	no current plans... see bus.mgmt.



Voltage	Speed	Ic @ 100 degC	3 Phase Bridge	
600V high effc.	Ultra-Fast	4 A	CPV362M4U 50044	
	approx.	7 A	CPV363M4U 50039	
		10 A	CPV364M4U 50041	
	Fast	5 A	CPV362M4F 50046	
		approx.	9 A	CPV363M4F 50038
		15 A	CPV364M4F 50040	
600V for Motor Drives	Ultra-Fast	3 A	CPV362M4K 50045	
	for	6 A	CPV363M4K 50043	
	8 - 25 kHz	13 A	CPV364M4K 50042	

Voltage	Rds(on)	Ic @ 25 degC	Parallel Chip	Half Bridge
60 V	0.01	120 A		IRFK2D054 IRFK2F054 82790
	0.005	150 A	IRFK4H054 IRFK4J054 27103	
	0.003	350 A	IRFK6H054 IRFK6J054 27128	
100 V	0.028	72 A		IRFK2D150 IRFK2F150 82791
	0.02	125 A		IRFK3D150 IRFK3F150 82797
	0.014	145 A	IRFK4H150 IRFK4J150 27104	
200 V	0.01	150 A	IRFK6H150 IRFK6J150 27110	
	0.043	54 A		IRFK2D250 IRFK2F250 82792
	0.03	70 A		IRFK3D250 IRFK3F250 82798
400 V	0.021	108 A	IRFK4H250 IRFK4J250 27105	
	0.015	140 A	IRFK6H250 IRFK6J250 27111	
	0.15	25 A		IRFK2D350 IRFK2F350 82793
500 V	0.1	37 A		IRFK3D350 IRFK3F350 82799
	0.075	50 A	IRFK4H350 IRFK4J350 27106	
	0.05	75 A	IRFK6H350 IRFK6J350 27112	
600V	0.2	22 A		IRFK2D450 IRFK2F450 82794
	0.135	33 A		IRFK3D450 IRFK3F450 27100
	0.1	44 A	IRFK4H450 IRFK4J450 27107	
800 V	0.067	66 A	IRFK6H450 IRFK6J450 27113	
	0.35	18 A		IRFK2DC50 IRFK2FC50 82795
	0.23	24 A		IRFK3DC50 IRFK3FC50 27101
800 V	0.175	35 A	IRFK4HC50 IRFK4JC50 27108	
	0.1	48 A	IRFK6HC50 IRFK6JC50 27114	
	0.6	12 A		IRFK2DE50 IRFK2FE50 82796
	0.3	26 A	IRFK4HE50 IRFK4JE50 27109	

The Switch Module Navigator

Effective 29 August, 1997

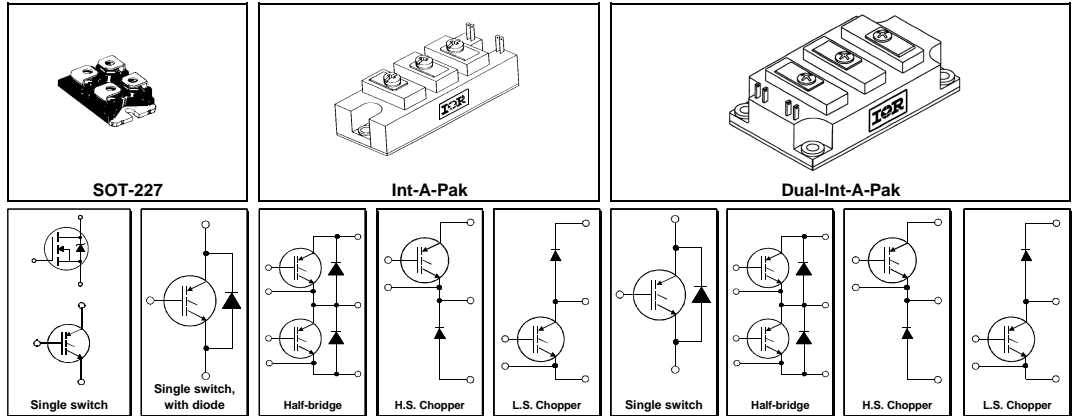
COLOR CODING:

EXISTING Products

NEW Products
released to production in last 6-9 months

UPCOMING Products
to be released within next 3-4 months

POTENTIAL Products
no current plans... see bus.mgmt.

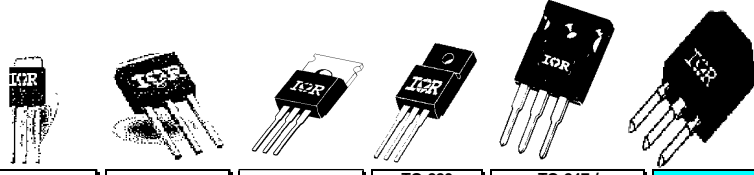


Voltage	Ic	Speed	Change	Single switch	Single switch, with diode	Half-bridge	H.S. Chopper	L.S. Chopper	Single switch	Half-bridge	H.S. Chopper	L.S. Chopper
250V	600 A	S							GA600GD25S 11/97			
	hi-eff. 400 A	S							GA400TD25S 50051			
600V	1000 A	U							GA1000DD60U			
	600 A	U							GA600DD60U			
	500 A	U							GA500TD60U 50048			GA500KS60U
	400 A	U							GA400TD60U 50051			GA400KS60U
	hi-eff.'y 300 A	U							GA300TD60U 50057			GA300KS60U
	for power conversion 250 A	U										
1200V	200 A	U				GA250TS60U 50047						
	150 A	U				GA200TS60U 50058						
	150 A	U				GA150TS60U 50056					GA150NS60U	
	100 A	U				GA100TS60U 50055						
	75 A	U				GA75TS60U 50050					GA75NS60U	
	500 A	U								GA500DD120U	GA500ND120U	GA500KD120U
	500 A	S							GA500DD120S	GA500ND120S	GA500KD120S	
	400 A	U							GA400DD120U	GA400ND120U	GA400KD120U	
	400 A	S							GA400DD120S	GA400ND120S	GA400KD120S	
	300 A	U							GA300DD120U	GA300ND120U	GA300KD120U	
	300 A	S							GA300DD120S	GA300ND120S	GA300KD120S	
	250 A	U								GA250TD120U 11/97	GA250ND120U	GA250KD120U
250 A	S								GA250TD120S	GA250ND120S	GA250KD120S	
200 A	U							GA200DD120U	GA200TD120U 11/97	GA200ND120U	GA200KD120U	
200 A	S							GA200DD120S	GA200TD120S	GA200ND120S	GA200KD120S	
hi-eff.'y 150 A	U											
for power conversion 150 A	S											
125 A	U					GA125TS120U 11/97						
125 A	S					GA125TS120S						
100 A	U					GA100TS120U 10/97						
100A	S					GA100TS120S						
75 A	U					GA75TS120U 12/97						
75 A	S					GA75TS120S						
50 A	U					GA50TS120U 12/97						
50 A	S					GA50TS120S						
100V	180A	HEXFET				FA180SA10 7/97 10/97						
	500V	53A	HEXFET	Y		FA57SA50LC 7/97 10/97						
		38A	HEXFET	Y		FA38SA50LC 91615 6/97 10/97						
600V	200 A	"S" IGBT				GA200SA60S 7/97 10/97						
	200 A	"U" IGBT				GA200SA60U 7/97 10/97						
	75 A	"U" IGBT	Y			GA75DA60U						

The HEXFET™ Through Hole Navigator

COLOR CODING: **EXISTING Products** **NEW Products** released to production in last 6-9 months **UPCOMING Products** to be released within next 3-4 months **POTENTIAL Products** no current plans... see bus.mgmt.

Effective 8 September, 1998



BVdss	Rds(on)	gate, spd	Change	I-Pak	TO-262	TO-220	TO-220 FullPak	TO-247 / TO-3P	Super247
20 V	0.020	LL	Y		IRL3302L 91692	IRL3302 91696			
	0.016	LL	Y		IRL3202L 91675	IRL3202 91695			
	0.013	LL	Y		IRL3102L 91691	IRL3102 91694			
	0.008	LL	Y		IRL3402L 91693	IRL3402 91697			
	0.006	LL	Y		IRL3502L 91676	IRL3502 91698			
30 V	0.040	L	Y	IRLU2703 91335	IRL2703L 91360	IRL2703 91359			
	0.031		Y	IRFU3303 91642					
	0.026 - 0.031	L	Y	IRLU3303 91316	IRL3303L 91323	IRL3303 91322			
	0.020		Y	IRFU3103 5/98, 12/98					
	0.014	L	Y	IRLU3103 91333	IRL3103L 91338	IRL3103 91337			
	0.007	L	Y		IRL2203NL 91367	IRL2203N 91366	IRL2203N 91378		
40 V	0.0090				IRF1104L	IRF1104 91724			
	0.0080	L			IRL1104L	IRL1104			
	0.0065	L			IRL1004L 91644	IRL1004 91702			
55 V	0.200	L	Y	IRLU014N 7/98, 9/98					
	0.070		Y	IRFU024N 91336	IRFZ24NL 91355	IRFZ24N 91354	IRFIZ24N 91501		
	.060-.065	L	Y	IRLU024N 91363	IRLZ24NL 91358	IRLZ24N 91357	IRLIZ24N 91344		
	0.040		Y	IRFU4105 91302	IRFZ34NL 91311	IRFZ34N 91276	IRFIZ34N 91489		
	0.035	L	Y	IRLU2705 91317	IRLZ34NL 91308	IRLZ34N 91307	IRLIZ34N 91329		
	0.024		Y	IRFU1205 91318	IRFZ44NL 91315	IRFZ44N 91303	IRFIZ44N 91403		
	0.022	L	Y	IRLU2905 91334	IRLZ44NL 91347	IRLZ44N 91346	IRLIZ44N 91498		
	0.020		Y		IRFZ46NL 91305	IRFZ46N 91277	IRFIZ46N 91306	IRFP044N 91410	
	0.016		Y		IRFZ48NL 91408	IRFZ48N 91406	IRFIZ48N 91407	IRFP048N 91409	
	0.012		Y		IRF1010NL 91372	IRF1010N 91278	IRF1010N 91373	IRFP054N 91382	
	0.010	L	Y		IRL3705NL 91502	IRL3705N 91370	IRLI3705N 91369		
	0.008		Y		IRF3205L 91304	IRF3205 91279	IRFI3205 91374	IRFP064N 91383	
	0.008	L	Y		IRL2505L 91326	IRL2505 91325	IRLI2505 91327		

BVdss	Rds(on)	gate, spd	Change	I-Pak	TO-262	TO-220	TO-220 FullPak	TO-247 / TO-3P	Super247
-55 V	0.175		Y	IRFU9024N 91506	IRF9Z24NL 91742	IRF9Z24N 91484	IRFI9Z24N 91501 10/97 TBD		
	0.110		Y	IRFU5505 91610	IRF9Z34NL 91525	IRF9Z34N 91485	IRFI9Z34N 91489 10/97 TBD		
	0.060		Y	IRFU5305 91402	IRF5305L 91386	IRF5305 91385			
	0.020		Y		IRF4905L 91478	IRF4905 91280	IRFI4905 91526 10/97 TBD		
60 V	0.200		Y	IRFU014* 90701	IRFZ14L* 90890	IRFZ14* 90507	IRFIZ14G* 90859		
	0.200	L	Y	IRLU014* 90624	IRLZ14L* 90903	IRLZ14* 90556	IRLIZ14G* 90846		
			Y	IRFU024* 90702	IRFZ24L* 90891	IRFZ24* 90594	IRFIZ24G* 90751		
			Y	IRLU024* 90625	IRLZ24L* 90904	IRLZ24* 90557	IRLIZ24G* 90847		
	0.071		Y				IRFIZ24E 91673		
	0.040					IRFZ34E 91672	IRFIZ34E 91674		
	0.026	Y			IRFZ44EL 91714	IRFZ44E 91671			
	0.014	Y			IRF1010EL 91720	IRF1010E 91670			
-60V	0.500		Y	IRFU9014* 90654	IRF9Z14L* 90911	IRF9Z14* 90736	IRFI9Z14G* 90840		
	0.280		Y	IRFU9024* 90655	IRF9Z24L* 90912	IRF9Z24* 90647	IRFI9Z24G* 90841		
	0.140		Y		IRF9Z34L* 90912	IRF9Z34* 90648	IRFI9Z34G* 90842		
75 V	0.013		Y		IRF2807L 91518	IRF2807 91517			
100 V	0.540		Y	IRFU110 90524	IRF/L510L 90895/907	IRF510 90325	IRFI510G 90829		
	.200-.210		Y	IRFU120N 91365	IRF520NL 91340	IRF520N 91339	IRFI520N 91362		
	0.180	L	Y	IRLU120N 91541	IRL520NL 91494	IRL520N 91494	IRLIZ520N 91496		
	0.110		Y	IRFU3910 91364	IRF530NL 91352	IRF530N 91351	IRFI530N 91353		
	0.100	L	Y	IRLU3410 91607	IRL530NL 91349	IRL530N 91348	IRLIZ530N 91350		
	0.052		Y		IRF540NL 91342	IRF540N 91341	IRFI540N 91361	IRFP140N 91343	
	0.044	L	Y		IRL540NL 91495	IRL540N 91495	IRLIZ540N 91497		
	0.036		Y		IRF1310NL 91514	IRF1310N 91504	IRFI1310N 91611	IRFP150N 91503	
	0.028		Y		IRF3710L 91310	IRF3710 91309	IRFI3710 91387 7/97 TBD	IRFP3710 91490	
	0.026	L	Y		IRL2910L 91376	IRL2910 91375	IRLIZ2910 91384 7/97 TBD		
-100 V	0.480		Y	IRFU9120N 91507	IRF9520NL 91522	IRF9520N 91521	IRFI9520N 91501 10/97 TBD		
	0.200		Y		IRF9530NL	IRF9530N 91482	IRFI9530N 91482 7/97 TBD		
	0.117		Y		IRF9540NL 91483	IRF9540N 91437	IRFI9540N 91487 10/97 TBD	IRFP9140N 91492	
	0.060		Y		IRF5210L 91405	IRF5210 91434	IRFI5210 91404 10/97 TBD		
150 V	0.082		Y		IRF3315L 91617	IRF3315 91623			
	0.042		Y		IRF3415L 91509	IRF3415 91477			
-150 V	0.290		Y	IRFU6215 91749 6/98, 12/98	IRF6215L 91643	IRF6215 91479			

BVdss	Rds(on)	gate, spd	Change	I-Pak	TO-262	TO-220	TO-220 FullPak	TO-247 / TO-3P	Super247
200V	1.500		Y	IRFU210 90526	IRF610L 90899	IRF610 90326			
	0.800		Y	IRFU220 90525	IRF620L/L620L 90900/91218	IRF620/L620 90317/91217	IRF/LI620G 90832/91235		
	0.400		Y		IRF630L/L630L 90901/91254	IRF630/L630 90309/91255	IRF/LI630G 90652/91236		
	0.180		Y		IRF640L 90902	IRF/L640 90374/91089	IRF/LI640G 90649/91237	IRFP240 90444	
	0.085							IRFP250 90443	
0.055							IRFP260 90755		
-200V	0.500		Y		IRF9640L 90921	IRF9640 90422	IRFI9640G 90839	IRFP9240 90481	
	0.800		Y		IRF9630L 90920	IRF9630 90352	IRFI9630G 90838		
	1.500		Y	IRFU9220 90522	IRF9620L 90919	IRF9620 90351	IRFI9620G 90874		
	3.000		Y	IRFU9210 90521	IRF9610L 90918	IRF9610 90350	IRFI9610G		
250V	0.075							IRFP264 90756	
	0.140							IRFP254 90540	
	0.280		Y		IRF644L 91006	IRF644 90527	IRFI644G 90739	IRFP244 90588	
	0.450		Y		IRF634L 91005	IRF634 90476	IRFI634G 90738		
	1.100		Y	IRFU224 90600	IRF624L 91004	IRF624 90472	IRFI624G 90833		
-250V	2.000		Y	IRFU214 90703	IRF614L 91003	IRF614 90475	IRFI614G 90831		
	3.000		Y	IRFU9214 91658					
300 LC	1.000						IRFI9634G 91488		
	0.750		Y		IRF737LCL	IRF737LC 91314			
400V	0.200							IRFP360 90586	
	0.300							IRFP350 90445	
	0.550		Y		IRF740L 91010	IRF740 90375	IRFI740G 90651	IRFP340 90456	
	1.000		Y		IRF730L 91009	IRF730 90308	IRFI730G 90650		
	1.800		Y	IRFU320 90598	IRF720L 91008	IRF720 90315	IRFI720G 90834		
400 LC	3.600		Y	IRFU310 90597	IRF710L 91007	IRF710 90327			
	0.200							IRFP360LC 91230	
	0.300							IRFP350LC 91229	
-400 V	0.550					IRF740LC 91068			
	0.550						IRFI740GLC 91209		
450V	6.400		Y	IRFU9310 91663					
	0.350							IRFP354 90995	
	0.630					IRF744 91000	IRFI744G 91002	IRFP344 90998	
500V	1.200					IRF734 90999	IRFI734G 91001		
	0.270							IRFP460 90512	
	0.400							IRFP450 90458	
	0.600							IRFP448 90595	
	0.850		Y		IRF840L 91013	IRF840 90376	IRFI840G 90642	IRFP440 90457	
500V	1.500		Y		IRF830L 91012	IRF830 90311	IRFI830G 90646		
	3.000		Y	IRFU420 90599	IRF820L 91011	IRF820 90324	IRFI820G 90641		

International Rectifier

BVdss	Rds(on)	gate, spd	Change	I-Pak	TO-262	TO-220	TO-220 FullPak	TO-247 / TO-3P	Super247
500 LC	0.150		Y						IRFPS37N50A 4/98 11/98
	0.270							IRFP460LC 91232	
	0.400							IRFP450LC 91231	
	0.850		Y		IRF840LCL	IRF840LC 91069	IRFI840GLC 91208		
600V	0.400							IRFPC60 90870	
	0.600							IRFPC50 90656	
	0.820							IRFPC48 90996	
	1.200		Y		IRFBC40L 91016	IRFBC40 90506	IRFIBC40G 90852	IRFPC40 90511	
	2.200		Y		IRFBC30L 91015	IRFBC30 90482	IRFIBC30G 90851	IRFPC30 90596	
	4.400		Y	IRFUC20 90637	IRFBC20L 91014	IRFBC20 90623	IRFIBC20G 90850		
600 LC	0.400							IRFPC60LC 91234	
	0.600							IRFPC50LC 91233	
	1.200		Y		IRFBC40LCL	IRFBC40LC 91070	IRFIBC40GLC 91211		
800V	1.200							IRFPE50 90573	
	2.000							IRFPE40 90578	
	3.000					IRFBE30 90613	IRFIBE30G 90854	IRFPE30 90612	
	6.500					IRFBE20 90610	IRFIBE20G 90853		
900V	1.600							IRFPF50 90542	
	2.500							IRFPF40 90580	
	3.700					IRFBF30 90616	IRFIBF30G 90856	IRFPF30 90618	
	8.000		Y	IRFBF20L 91665	IRFBF20 90607	IRFIBF20G 90855			
1000V	2.000							IRFPG50 90543	
	3.500							IRFPG40 90576	
	5.000					IRFBG30 90620		IRFPG30 90621	
	11.000					IRFBG20 90604			

KEY:

Part Number	
FOD document #	
Date for SAMPLES	Date for PROD'N

* = not recommended for new designs

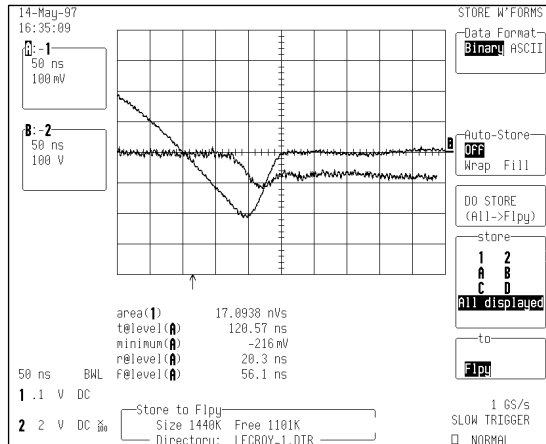
New Fast Recovery Diodes in package D-Pak, D² Pak, TO-220 & TO-247

QUIET^{IR} Series 600V, 60ns

IF (AVG)	8A	10A	10A	20A	20A	20A	30A	40A	60A	60A	80A
Package Style											
Voltage Grade	D-Pak	D ² -Pak	TO-220AC	D ² -Pak	TO-220AC	TO-220 Full Pak	TO-247 3pins	TO-247	TO-247	TO-247 3pins	TO-247 3pins
200	<u>8EWF02S</u> 1,1V 60ns	<u>10ETF02S</u> 1,1V 60ns	10ETF02 1,1V 60ns	<u>20ETF02S</u> 1,3V 60ns	20ETF02 1,3V 60ns	20ETF02FP 1,3V 60ns	30CPF02 1,4V 60ns	40EPF02 1,25V 60ns	60EPF02 1,3V 70ns	60CPF02 1,3V 70ns	80EPF02 1,2V 70ns
400	<u>8EWF04S</u> 1,1V 60ns	<u>10ETF04S</u> 1,1V 60ns	10ETF04 1,1V 60ns	<u>20ETF04S</u> 1,3V 60ns	20ETF04 1,3V 60ns	20ETF04FP 1,3V 60ns	30CPF04 1,4V 60ns	40EPF04 1,25V 60ns	60EPF04 1,3V 70ns	60CPF04 1,3V 70ns	80EPF04 1,2V 70ns
600	<u>8EWF06S</u> 1,1V 60ns	<u>10ETF06S</u> 1,1V 60ns	10ETF06 1,1V 60ns	<u>20ETF06S</u> 1,3V 60ns	20ETF06 1,3V 60ns	20ETF06FP 1,3V 60ns	30CPF06 1,4V 60ns	40EPF06 1,25V 60ns	60EPF06 1,3V 70ns	60CPF06 1,3V 70ns	80EPF06 1,2V 70ns

Vf @ IF (AVG), T_J=25°C, trr @ IF = 1A, -di/dt = 100A/μs, Vr = -30V

Typical Reverse Recovery Waveform



QUIET^{IR} is a new family of power semiconductors developed to increase active noise immunity but maintain the "Fast" recovery characteristics and meet the new Electro-Magnetic Interference (EMI) regulations. During the electrical energy conversion process, some of the electrical energy is not applied to the load but rather transformed in some other disturbing form like heat or noise. These undesirable effects are similar in the way mechanical equipment creates acoustic noise and heat. Reduction of this noise improves energy efficiency and reduces electro-magnetic interference. Typical application characteristics of QUIET^{IR} are:

- Soft recovery
- Low forward voltage drops

Then Applications may include:

- Welding output diodes
- Low EMI Rectifiers for Input Bridge
- Low EMI Rotating Rectifiers for field winding in alternators

QUIET^{IR} *italic*
SMALL^{IR} underline

TO-220 AND TO-247 PACKAGES

VOLTAGE PROCESS	6A TO 12A	15A TO 20A	10 TO 20A	25A TO 30A	30A	40A/60A
	TO-220AC		CENTER TAP TO-220AB		CENTER TAP TO-247AC	
15V OR'ING	—	19TQ015 [20266]	—	—	—	—
30V STANDARD	—	—	—	32CTQ030 [20267]	—	—
45V STANDARD	12TQ045 [20239]	20TQ045 [20056]	15CTQ045 [20240]	25CTQ045 [20242]	30CPQ045 [20297] MBR3045PT [20324]	40CPQ045 [20307]
45V HIGH TEMP	6TQ045 [20283] 10TQ045 [20057] MBR745 [20325] MBR1045 [20317]	18TQ045 [20178] MBR1645 [20319]	12TQ045 [20239] 20CTQ045 [20056] MBR1545CT [20318] MBR2045CT [20320]	30CTQ045 [20332] MBR2545CT	—	—
60V	—	—	—	30CTQ060 [20300]	30CPQ060 [20298]	40CPQ060 [20308]
100V	8TQ100 [20238]	—	16CTQ100 [20192] MBR20100CT [20321]	—	30CPQ100 [20333]	40CPQ100 [20309]
150V	—	—	10CTQ150 [20291]	—	30CPQ150 [20299]	—

Legend: Part Number [FAX-On-Demad Number]

The Schottky Navigator

COLOR CODING

Existing Products

New Products

Upcoming Products

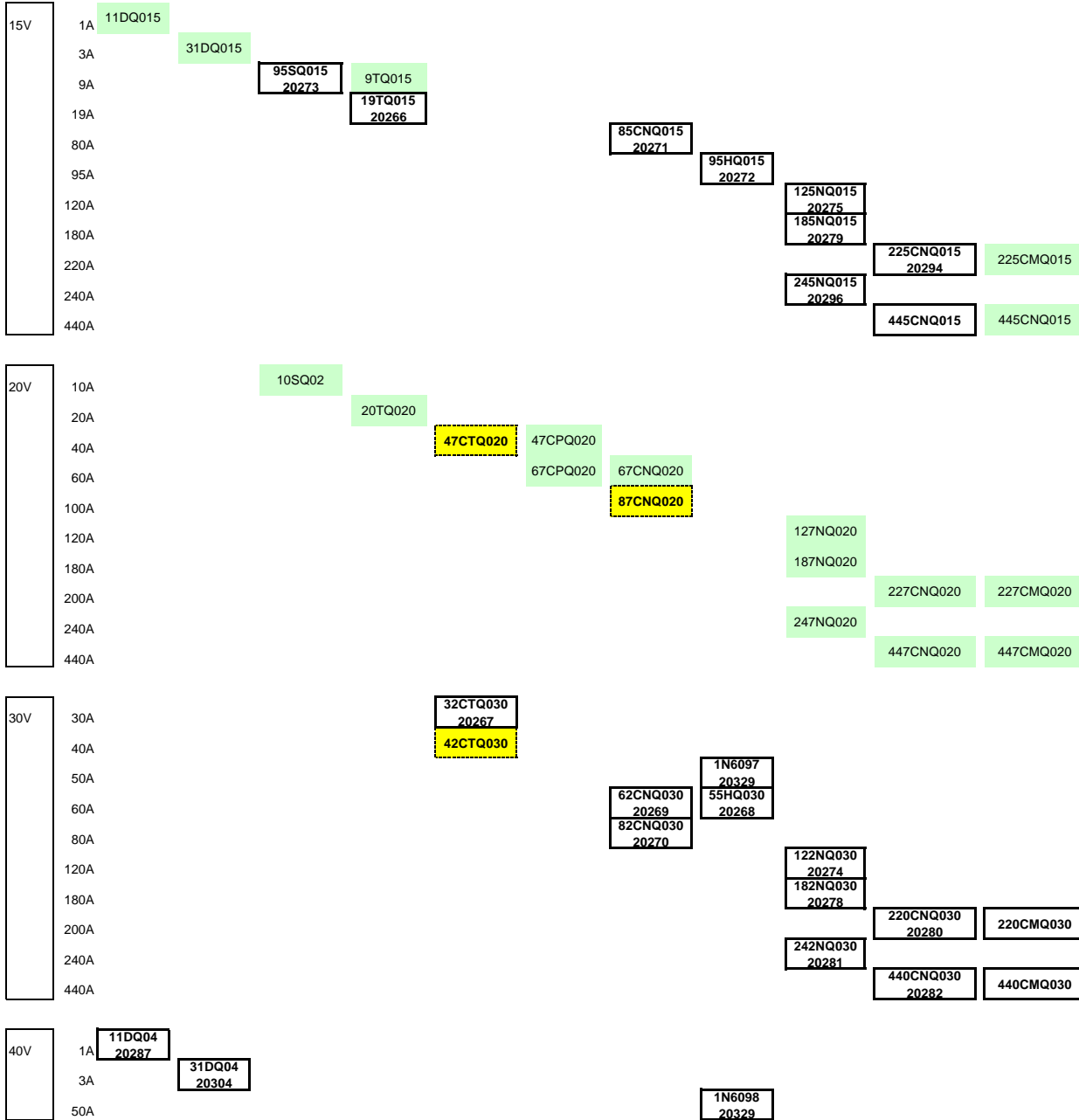
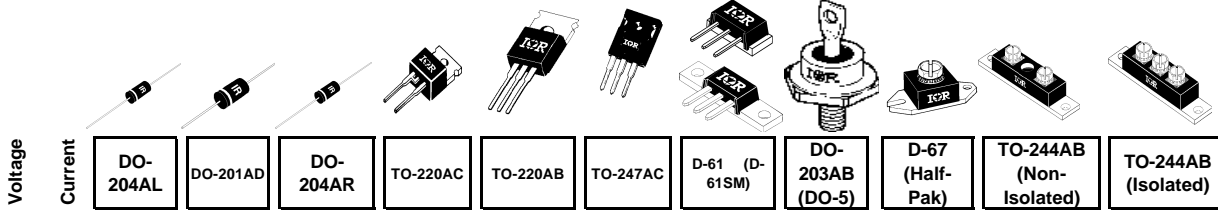
Possible Products

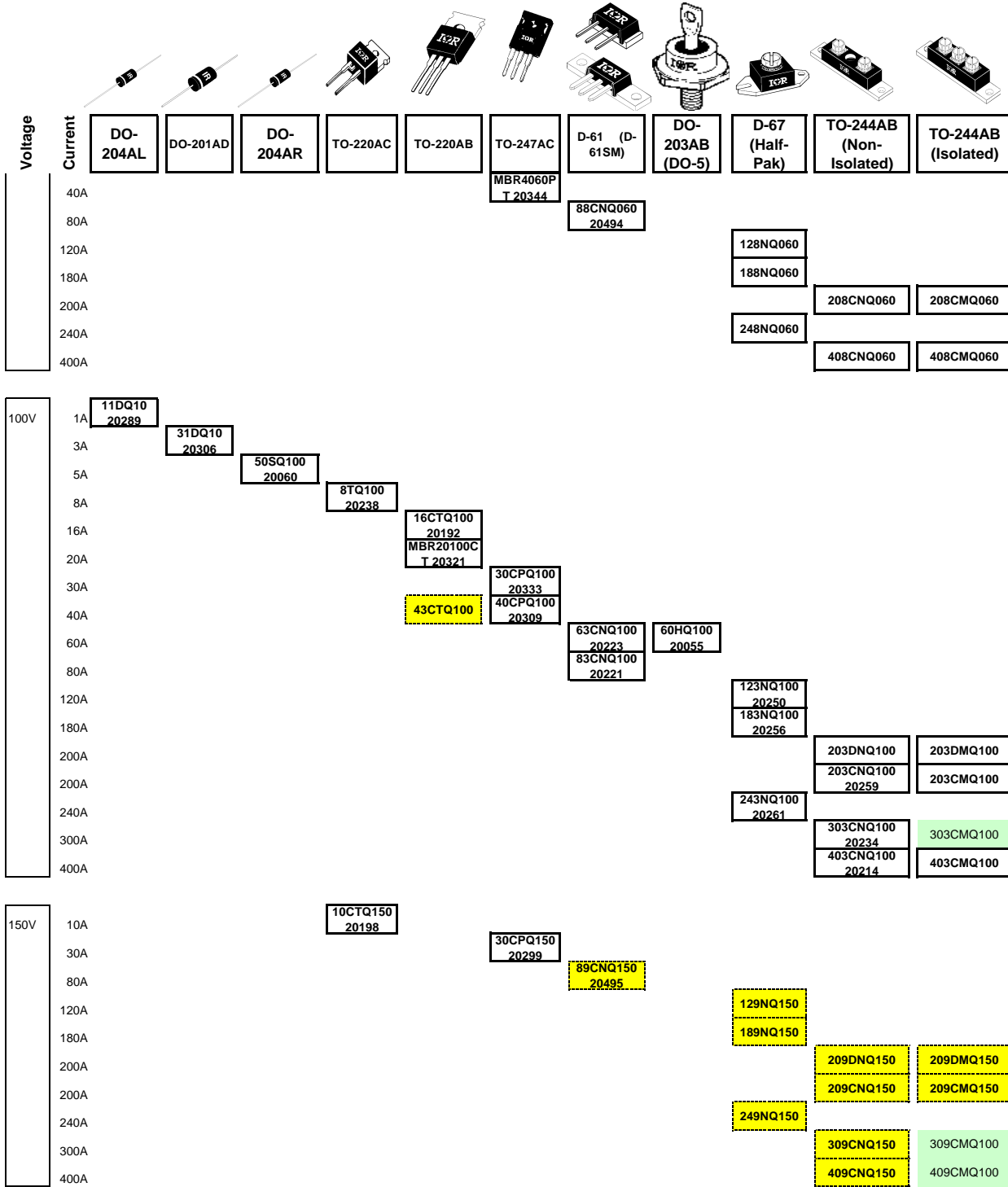
released to production in last year

released within next 6 months

no current plans...see bus.mgmt.

Effective January 1, 1998





Note: Downgrades Not included - Contact Factory For Details



50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

MAX860/MAX861

General Description

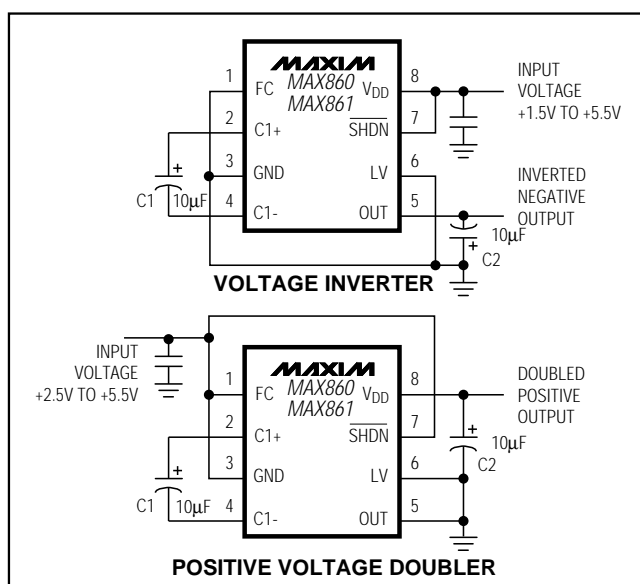
The MAX860/MAX861 charge-pump voltage converters invert input voltages ranging from 1.5V to 5.5V, or double input voltages ranging from 2.5V to 5.5V. Because of their high switching frequencies, these devices use only two small, low-cost capacitors. Their 50mA output makes switching regulators unnecessary, eliminating inductors and their associated cost, size, and EMI. Greater than 90% efficiency over most of the load-current range, combined with a typical operating current of only 200 μ A (MAX860), provides ideal performance for both battery-powered and board-level voltage-conversion applications.

A frequency-control (FC) pin provides three switching-frequencies to optimize capacitor size and quiescent current and to prevent interference with sensitive circuitry. Each device has a unique set of three available frequencies. A shutdown (SHDN) pin reduces current consumption to less than 1 μ A. The MAX860/MAX861 are suitable for use in applications where the ICL7660 and MAX660's switching frequencies are too low. The MAX860/MAX861 are available in 8-pin μ MAX and SO packages.

Applications

Portable Computers
 Medical Instruments
 Interface Power Supplies
 Hand-Held Instruments
 Operational-Amplifier Power Supplies

Typical Operating Circuit



Features

- ◆ 8-Pin, 1.11mm High μ MAX Package
- ◆ Invert or Double the Input Supply Voltage
- ◆ Three Selectable Switching Frequencies
- ◆ High Frequency Reduces Capacitor Size
- ◆ 87% Efficiency at 50mA
- ◆ 200 μ A Quiescent Current (MAX860)
- ◆ 1 μ A Shutdown Supply Current
- ◆ 600mV Voltage Drop at 50mA Load
- ◆ 12 Ω Output Resistance

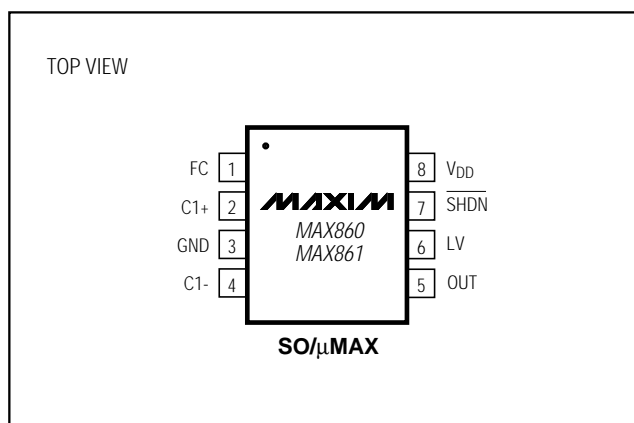
Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX860CSA	0°C to +70°C	8 SO
MAX860CUA	0°C to +70°C	8 μ MAX
MAX860C/D	0°C to +70°C	Dice*
MAX860ESA	-40°C to +85°C	8 SO
MAX860MJA	-55°C to +125°C	8 CERDIP†
MAX861CSA	0°C to +70°C	8 SO
MAX861CUA	0°C to +70°C	8 μ MAX
MAX861C/D	0°C to +70°C	Dice*
MAX861ESA	-40°C to +85°C	8 SO
MAX861MJA	-55°C to +125°C	8 CERDIP†

* Dice are tested at $T_A = +25^\circ\text{C}$, DC parameters only.

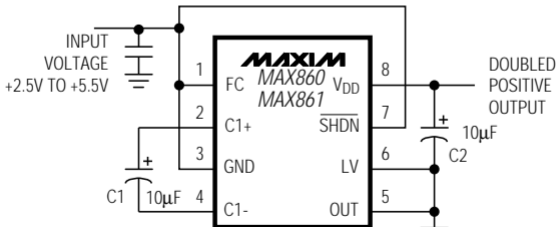
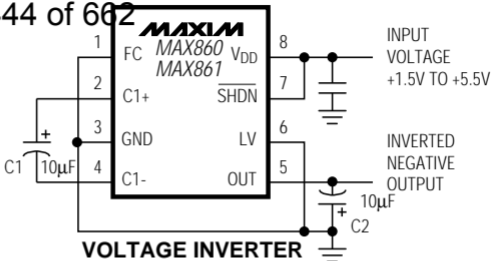
† Contact factory for availability.

Pin Configuration



Maxim Integrated Products 1

Call toll free 1-800-998-8800 for free samples or literature.





1-Cell to 3-Cell, High-Power, Low-Noise, Step-Up DC-DC Converters

General Description

The MAX848/MAX849 boost converters set a new standard of high efficiency and high integration for noise-sensitive power-supply applications, such as portable phones and small systems with RF data links. The heart of these devices is a synchronous boost-topology regulator that generates a fixed 3.3V output (or 2.7V to 5.5V adjustable output) from one to three NiCd/NiMH cells or one Li-Ion cell.

Synchronous rectification provides a 5% efficiency improvement over similar nonsynchronous boost regulators. In standby mode, pulse-skipping PFM operation keeps the output voltage alive with only 150 μ W quiescent power consumption. Fixed-frequency PWM operation ensures that the switching noise spectrum is limited to the 300kHz fundamental and its harmonics, allowing easy post-filtering noise reduction. For even tighter noise spectrum control, synchronize to a 200kHz to 400kHz external clock.

Battery monitoring is provided by a two-channel, voltage-to-frequency analog-to-digital converter (ADC). One channel is intended for a single-cell battery input (0.625V to 1.875V range), while the other channel is for monitoring higher voltages (0V to 2.5V range).

Two control inputs are provided for push-on, push-off control via a momentary pushbutton switch. Upon power-up, an internal comparator monitors the output voltage to generate a power-good output (POK).

The devices differ only in the current limit of the N-channel MOSFET power switch: 0.8A for the MAX848, and 1.4A for the MAX849.

Typical Output Selector Guide

V _{IN} (V)	V _{OUT} (V)	MAX849 I _{OUT} (mA)	MAX848 I _{OUT} (mA)
0.9	3.3	100	70
	5	70	40
1.2	3.3	300	110
	5	200	70
2.4	3.3	750	200
	5	500	130
2.7	3.3	800	250
	5	600	150
3.6	5	1000	300

Pin Configuration at end of data sheet.

Dual Mode is a trademark of Maxim Integrated Products.



Features

- ◆ Up to 95% Efficiency (see *Typical Output Selector Guide* below)
- ◆ 3.3V Dual Mode™ or 2.7V to 5.5V Adj. Output
- ◆ 0.7V to 5.5V Input Range
- ◆ 0.15mW Standby Mode
- ◆ 300kHz PWM Mode or Synchronizable
- ◆ Two-Channel ADC with Serial Output
- ◆ Power-Good Function

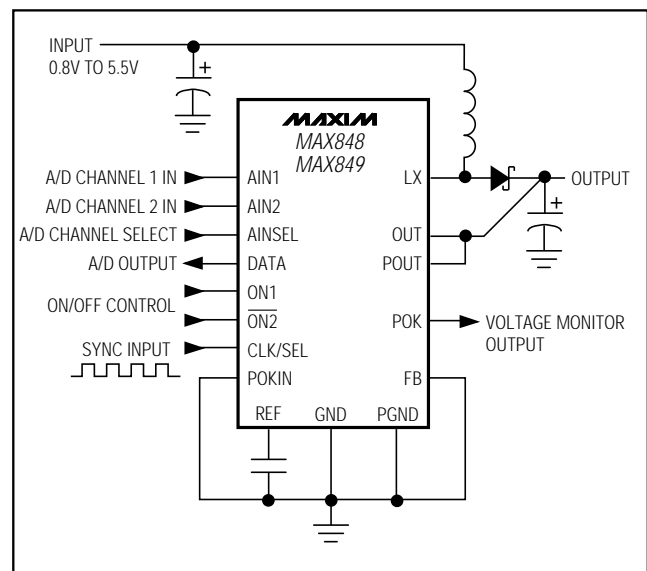
Applications

Digital Cordless Phones PCS Phones
 Cellular Phones Hand-Held Instruments
 Palmtop Computers Personal Communicators
 Local 3.3V to 5V Supplies

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX848ESE	-40°C to +85°C	16 Narrow SO
MAX849ESE	-40°C to +85°C	16 Narrow SO

Typical Operating Circuit

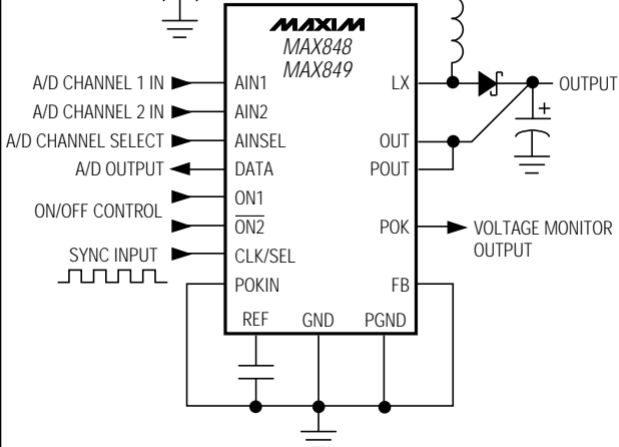


Maxim Integrated Products 1

For free samples & the latest literature: <http://www.maxim-ic.com>, or phone 1-800-998-8800

MAX848/MAX849

0.8V TO 5.5V





High-Efficiency, Step-Up DC-DC Converters for 1V Inputs

MAX1642/MAX1643

General Description

The MAX1642/MAX1643 are high-efficiency, low-voltage, step-up DC-DC converters intended for devices powered by a single alkaline cell. They feature low quiescent supply currents and are supplied in the ultra-small μ MAX package, which is only 1.1mm high. The guaranteed start-up voltage is 0.88V.

Each device consists of an internal 1Ω , N-channel MOSFET power switch; a built-in synchronous rectifier that acts as the catch diode; an oscillator; a reference; and pulse-frequency-modulation (PFM) control circuitry. Both devices feature an independent undervoltage comparator (PFI/PFO). The MAX1642 also includes a 2μ A logic-controlled shutdown mode. The MAX1643 offers a dedicated low-battery detector (BATTLO) in lieu of shutdown.

The output voltage for each device is preset to 3.3V \pm 4%, or can be adjusted from +2V to +5.2V using only two resistors.

Features

- ◆ Built-In Synchronous Rectifier
- ◆ 0.88V Guaranteed Start-Up
- ◆ Ultra-Small μ MAX Package: 1.1mm High
- ◆ 83% Efficiency
- ◆ 4 μ A Quiescent Supply Current into BATT Pin
- ◆ 2 μ A Logic-Controlled Shutdown (MAX1642)
- ◆ Two Undervoltage Detectors (MAX1643)
- ◆ 2V to 5.2V Output Range
- ◆ 20mA Output Current at 1.2V Input
- ◆ Reverse Battery Protection

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX1642C/D	0°C to +70°C	Dice*
MAX1642EUA	-40°C to +85°C	8 μ MAX
MAX1643C/D	0°C to +70°C	Dice*
MAX1643EUA	-40°C to +85°C	8 μ MAX

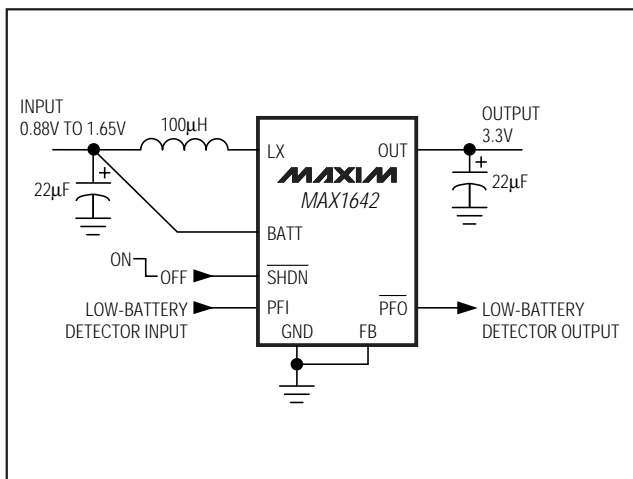
*Dice are tested at $T_A = +25^\circ\text{C}$.

Note: To order these devices shipped in tape and reel, add a -T to the part number.

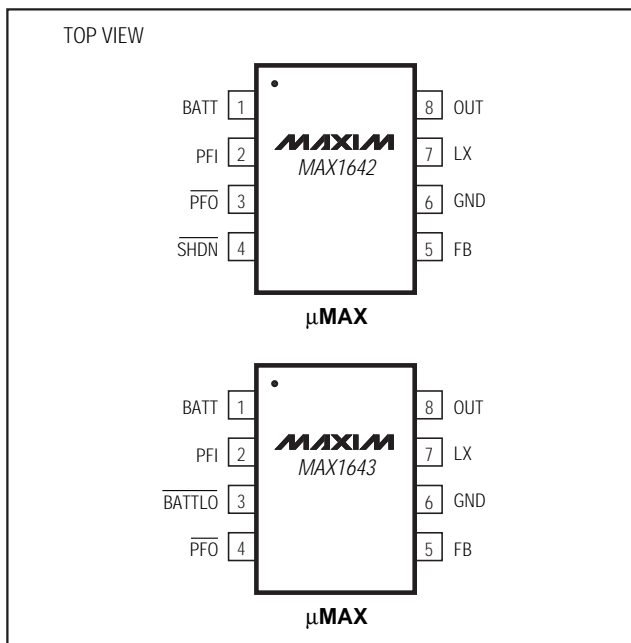
Applications

- Pagers
- Remote Controls
- Pointing Devices
- Personal Medical Monitors
- Single-Cell Battery-Powered Devices

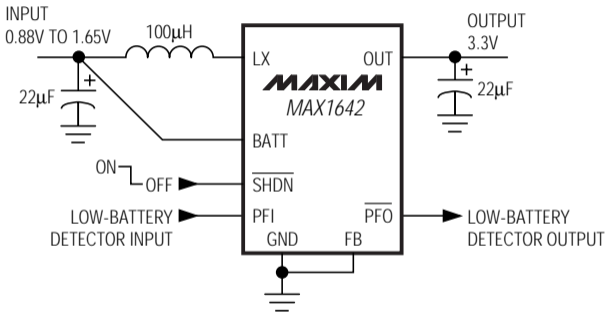
Typical Operating Circuit



Pin Configurations



For free samples & the latest literature: <http://www.maxim-ic.com>, or phone 1-800-998-8800.
For small orders, phone 408-737-7600 ext. 3468.



Micropower, Regulated 5V Charge Pump in a 5-Pin SOT-23 Package

FEATURES

- **Ultralow Power:** $I_{CC} = 6\mu\text{A Typ}$
- **Short-Circuit/Thermal Protected**
- $5\text{V} \pm 4\%$ Regulated Output
- V_{IN} Range: 2.7V to 5V
- **Output Current:** 10mA ($V_{IN} \geq 2.7\text{V}$)
20mA ($V_{IN} \geq 3\text{V}$)
- No Inductors
- **Ultrasmall Application Circuit (0.045in²)**
- 800kHz Switching Frequency
- Available in 5-Pin SOT-23

APPLICATIONS

- Cellular Telephones
- Battery-Operated Equipment
- Local Power Supplies
- Handheld Instruments
- PCMCIA Supplies

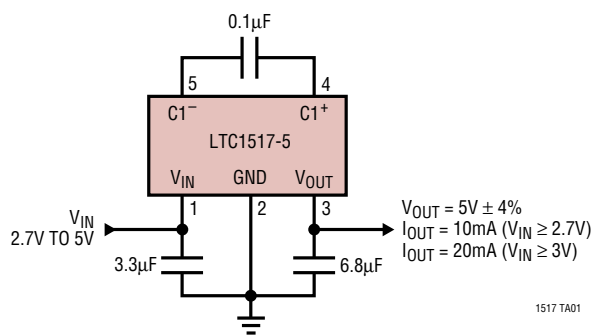
DESCRIPTION

The LTC[®]1517-5 is a micropower charge pump DC/DC converter that produces a regulated 5V output. The input voltage range is 2.7V to 5V. Extremely low operating current (typically 6 μA with no load) and low external parts count (one 0.1 μF flying capacitor and two small bypass capacitors at V_{IN} and V_{OUT}) make the part ideally suited for small, light load battery-powered applications. The total printed circuit board area of the application circuit shown below is only 0.045in².

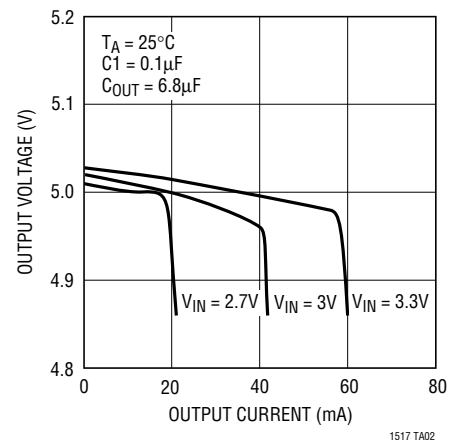
The part operates as a Burst Mode[™] switched-capacitor voltage doubler to produce a regulated output. The part has thermal shutdown capability and can survive a continuous short circuit from V_{OUT} to GND. The device is available in a 5-pin SOT-23 package.

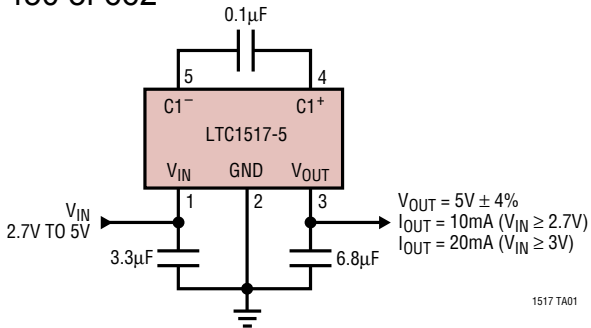
LTC, LTC and LT are registered trademarks of Linear Technology Corporation. Burst Mode is a trademark of Linear Technology Corporation.

TYPICAL APPLICATION



Typical Output Voltage vs Output Current





Description

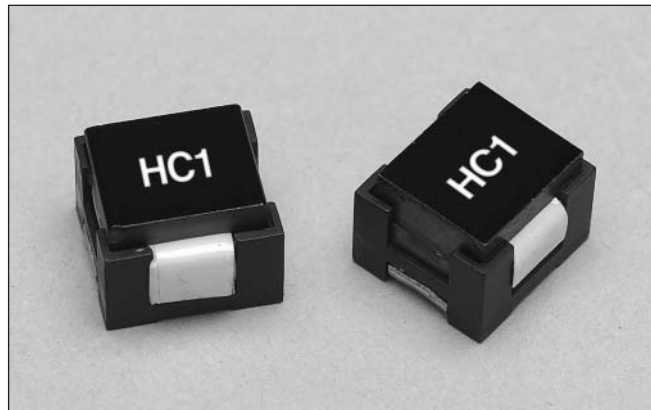
- Designed for high current, low voltage applications
- Low DCR, high efficiency
- Foil construction for higher frequency circuit designs
- Suited for IR and vapor reflow solder
- Frequency range 1kHz to 1MHz

Applications

- Next generation microprocessors
- High current DC-DC converters
- Computers

Environmental Data

- Storage temperature range: -40C to +125C
- Operating ambient temperature range: -40C to +85C (range is application specific).
- Infrared reflow temperature: +260C for 10 seconds maximum


Packaging

- Supplied in tape and reel packaging, 250 per reel

Part Number	Rated Inductance μH	OCL (1) $\pm 15\%$ μH	I _{rms} (2) Amperes (Approx.)	I _{sat} (3) Amperes (Approx.)	DCR (Ω) Max. @ 20°C	Volt- μSec (4) ($\text{V}\mu\text{S}$) (ref.)
HC1-R22	0.22	0.218	51.42	40.5	0.00034	1.83
HC1-R30	0.30	0.291	51.42	31.8	0.00034	1.83
HC1-R57	0.57	0.572	37.83	33.4	0.00063	3.66
HC1-R87	0.87	0.866	28.01	31.0	0.00138	5.49
HC1-1R0	1.0	1.12	28.01	25.4	0.00138	5.49
HC1-1R7	1.7	1.66	22.30	22.2	0.0018	7.33
HC1-2R3	2.3	2.29	22.30	16.7	0.0018	7.33
HC1-3R6	3.6	3.59	16.76	13.4	0.0032	9.16
HC1-5R1	5.1	5.15	12.79	11.2	0.0054	10.99
HC1-7R8	7.8	7.85	12.79	6.7	0.0054	10.99
HC1-100	10	10.5	12.79	5.3	0.0054	10.99

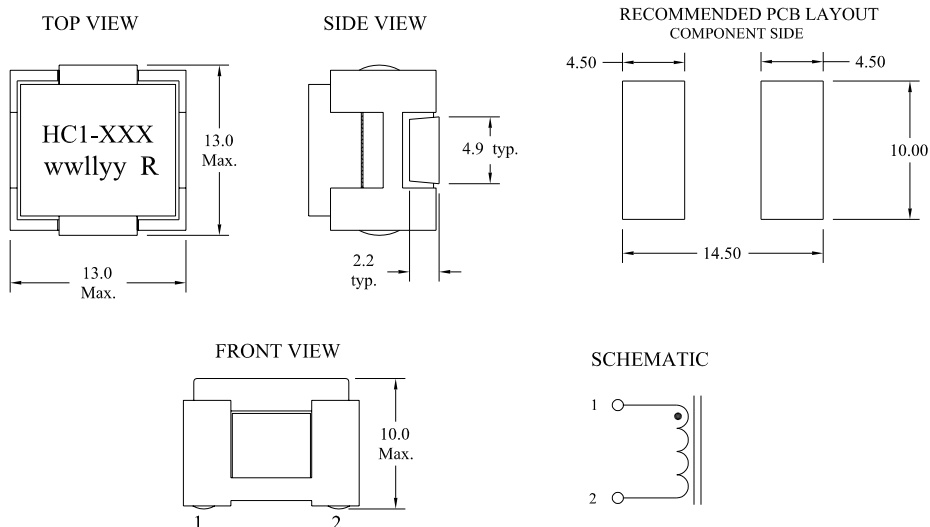
1) OCL (Open Circuit Inductance) Test parameters: 300KHz, .25Vrms, 0.0A_{dc} & I_{sat}.

2) I_{rms} Amperes for approximately ΔT of 40°C. DC current for an approximate ΔT of 40°C without core loss. Derating is necessary for AC currents. It is recommended that the temperature of the part not exceed 125°C under worst case operating conditions verified in the end application.

3) I_{sat} Amperes Peak for approximately 30% rolloff @ 20°C

4) Applied Volt-Time product (V- μS) across the inductor. This value represents the applied V- μS at 200kHz necessary to generate a core loss equal to 10% of the total losses for 40°C temperature rise. See Core Loss Graph.

Units supplied in tape & reel packaging; 250 parts on 13" diameter reel.

Mechanical Diagrams


Dimensions in Millimeters

Description

- Compact footprint for high density, high current/low voltage applications
- Foil technology that adds higher reliability factor over the traditional magnet wire used for higher frequency circuit designs
- Frequency range DC to 1MHz

Applications

- Next generation microprocessors
- Energy storage applications
- DC-DC converters
- Computers

Environmental Data

- Storage temperature range: -40C to +125C
- Operating ambient temperature range: -40C to +85C (range is application specific).
- Infrared reflow temperature: +260C for 10 seconds maximum



Packaging

- Supplied in bulk packaging

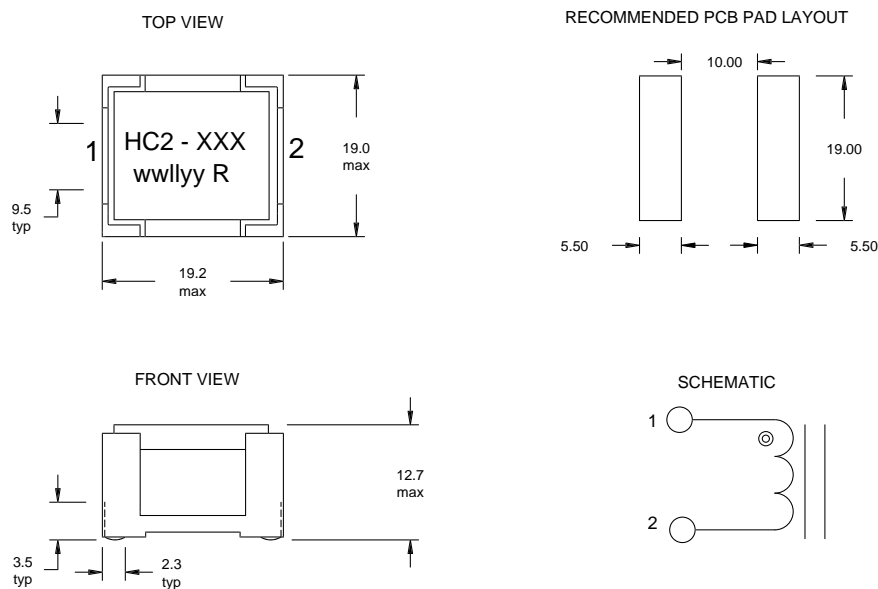
Part Number	Rated Inductance μH	OCL (1) $\mu\text{H} \pm 20\%$	I _{rms} (2) Amperes (Typ.)	I _{sat} (3) Amperes (Typ.)	DCR (4) Ohms (Max.)	Volts (5) μSec
HC2-R47	.47	.52	52.9	63.75	.0006	6.87
HC2-R68	.68	.63	52.9	50.00	.0006	6.87
HC2-1R0	1.0	1.15	33.0	42.50	.0013	10.31
HC2-2R2	2.2	2.00	24.3	31.90	.0023	13.75
HC2-4R7	4.7	4.55	17.0	21.25	.0046	20.62
HC2-6R0	6.0	6.00	17.0	16.50	.0046	20.62

1) Open Circuit Inductance Test Parameters: 300kHz, 0.250 V_{rms}, 0.0 Adc
 2) DC current for an approximate temperature change of 40°C without core loss. Derating is necessary for AC currents. PCB layout, trace thickness and width, air-flow and proximity of other heat generating components will affect the temperature rise. It is recommended that the temperature of the part not exceed 125°C under worst case operating conditions verified in the end application.

3) Peak current for approximately 30% roll-off
 4) Values @ 20°C
 5) Applied Volt-Time product (V- μs) across the inductor. This value represents the applied V- μs at 300kHz necessary to generate a core loss equal to 10% of the total losses for 40°C temperature rise.

Parts packaged in bulk. 45 pieces per tray.

Mechanical Diagrams



Dimensions in Millimeters

Description

- Surface mount inductors designed for higher speed switch mode applications requiring lower inductance, low voltage and high current
- Inductance range from 0.22 uH to 4.81 uH
- Current range from 35.8 to 9.8 Amps
- Frequency range 1kHz to 500kHz

Applications

- Next generation microprocessors
- High current DC-DC converters
- VRM, multi-phase buck regulator
- PC, Workstations, Routers
- Telecom soft switches, Base Stations

Environmental Data

- Storage temperature range: -40°C to +125°C
- Operating ambient temperature range: -40°C to +85°C
- Infrared reflow temperature: +260°C for 10 seconds maximum



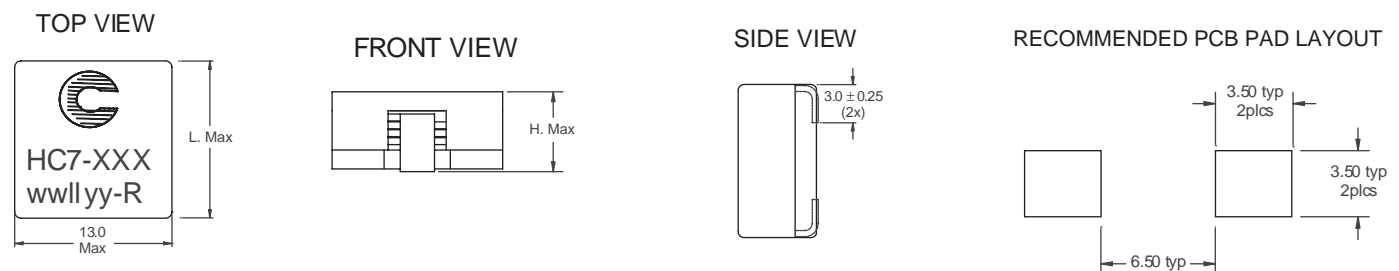
Part Number	Rated Inductance μH	OCL (1) nominal $\pm 20\%$ μH	I _{rms} (2) Amperes (Typ.)	I _{sat} (3) Amperes 15% rolloff	I _{sat} (4) Amperes 30% rolloff	DCR (m Ω) max. @ 20°C	Volts (5) μSec (V μS)
HC7-R20	.20	0.220	35.80	45.8	86.5	0.67	2.27
HC7-R47	.47	0.534	23.40	27.5	51.9	1.60	3.83
HC7-1R0	1.0	1.05	20.30	19.6	37.1	2.10	5.36
HC7-1R5	1.5	1.73	14.20	15.3	28.8	4.30	6.90
HC7-2R2	2.2	2.58	13.00	12.5	23.6	5.20	8.40
HC7-3R9	3.9	3.61	10.40	10.6	20.0	7.90	10.0
HC7-4R7	4.7	4.81	9.80	9.2	17.3	9.00	12.6

- 1) Test Parameters: 100KHz, 1.0Vrms
- 2) I_{rms} Amperes for approximately ΔT of 40°C above 85°C ambient
- 3) I_{sat} Amperes Peak for approximately 15% rolloff (@20°C)
- 4) I_{sat} Amperes Peak for approximately 30% rolloff (@20°C)
- 5) Applied Volt-Time product (V- μS) across the inductor. This value represents the applied V- μS at operating frequency necessary to generate additional core loss which contributes to the 40°C temperature rise. De-rating of the I_{rms} is required to prevent excessive temperature rise. The 100% V-uS rating is equivalent to a ripple current I_{p-p} of 20% of I_{sat} (30% rolloff option).

Units supplied in tape and reel packaging. 13" reels 610 parts per reel. Carrier tape width = 24 mm. Meets EIA standard

Part number definition:
 First 3 characters = Product code and size.
 Last 3 characters = Inductance in μH . R = decimal point.
 If no R is present third character = # of zeros.
 wwllly = (Date Code)
 R = (Revision level)

Mechanical Diagrams



Maximum Dimension

Part Number	Height mm	Length mm
HC7-R20	6.0	14.25
HC7-R47	5.5	13.8
HC7-1R0	5.5	13.8
HC7-1R5	5.5	13.8
HC7-2R2	5.5	13.8
HC7-3R9	5.5	13.8
HC7-4R7	5.5	13.8

Dimensions in Millimeters. All dimensions I+/- 0.2 mm unless otherwise specified. All soldering surfaces are coplanar within 0.15 mm.



**Premier
Magnetics Inc.**



**OFF-LINE
SWITCH MODE
TRANSFORMERS**

"INNOVATORS IN MAGNETICS TECHNOLOGY"

GENERAL ELECTRICAL SPECIFICATIONS AT 25°C - OPERATING TEMPERATURE RANGE 0°C TO +70°C

Units are designed for a Universal AC Input of 85 to 265Vac, 47/440 Hz, Unless otherwise designated.

- 1 = Unit designed for Voltage Doubler input -or- PFC corrected front end.
- 2 = Unit designed for AC Input of 85 to 135Vac, 47/440Hz.
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- * = Designed to power Echelon's PLT-20 Power Line Transceiver



CLICK ON THE RESPECTIVE PART NUMBER TO DISPLAY A DETAIL DATA SHEET

PART NUMBER	Recommended Power Intgr. Controller	APPLICATION DATA			PRIMARY OCL μ HY Typ.	HI-POT Vrms Min.	Recommended		Package Schematic
		Output Voltages Vout Vdc	Output Currents Io_cont Amps	Cont Watt			Output Filter Inductor (L2)	Input Filter CMC (L1)	
POL-05006 ³	TOP210	5.0	0.60	3.0	8100	3000	VTP-01001	PMCU-0220	E16-Horz
TSD-816	TOP210	5.0	0.60	3.0	8100	3000	VTP-01001	PMCU-0220	E16-Horz
TSD-1185	TOP221	5.0	0.70	3.5	2450	3000	VTP-00301	PMCU-0220	E16-Vert
POL-05010 ³	TOP200	5.0	1.00	5.0	4200	3000	VTP-01001	PMCU-0220	E16-Horz
POL-05012	TOP200	5.0	1.20	6.0	1500	3000	VTP-01001	PMCU-0330	E16-Horz
POL-05020	TOP223	5.0	2.00	10.0	500	3000	VTP-01002	PMCU-0330	E16-Vert
POL-05030	TOP202	5.0	3.00	15.0	700	3000	VTP-01002	PMCU-0330	E22/19/6
TSD-778	TOP201	5.0 x 2	1.20/0.80	6.4	700	3500	VTP-01001	PMCU-0330	E22,10pin
TSD-937	TOP204	5/+8/-8	3.0/+1.0	30.0	475	3000	VTP-01002	PMCE-0330	E28/11
TSD-1201	TOP225	5/+9/-9	6/+1.3/-0.13	43.0	810	3000	VTP-01005	PMCU-0330	EI33/29
TSD-1160	TOP225	5/+12/-12	6/+1.0/-0.10	43.0	810	3000	VTP-01005	PMCU-0330	EI33/29
TSD-1390	TOP226	5/12	5.0/3.0	61.0	810	3000	VTP-01005	PMCE-0330	EI33/29
TSD-877	TOP204	5x2 & 15	2.5/0.10	16.0	242	3000	VTP-01002	PMCU-0330	E28/11
TSD-1017	TOP209	5/15	0.02/0.10	1.7	10000	3000	N/A	PMCU-0220	E16-Vert
TSD-1135	TOP209	5/15	0.05/0.12	2.1	10000	3000	N/A	PMCU-0220	E22/19/6
TSD-1305 ⁴	TOP209	5/15	0.05/0.12	2.1	10000	3000	N/A	PMCU-0220	E22/19/6
TSD-1110	TOP224	5/+15/-15	2.2/+0.3	20.0	575	3000	VTP-01002	PMCU-0330	EEL19
TSD-893	TOP201	5/30/+12/-12	1.0/.05/.25/.25	14.0	2000	3000	VTP-01001	PMCU-0330	E30
TSD-876	TOP210	5/12	0.10/0.20	3.0	6000	3000	Bead	PMCU-0220	E19-Horz
TSD-815 ¹	TOP201	5/15	1.0/1.0	20.0	1390	3000	VTP-01001	PMCU-0330	E22/19/6
TSD-858	TOP210	5/24	0.30/0.08	3.4	3420	3000	VTP-01001	PMCU-0220	E19-Horz
TSD-779	TOP202	5/27	1.0/0.50	17.0	620	3000	VTP-01001	PMCU-0100	E22/19/6
TSD-988	TOP214	5/28	1.0/0.50	21.0	440	3000	VTP-01001	PMCU-0100	EEL22
TSD-983	TOP202	5/33	1.0/0.50	21.5	400	3000	VTP-01001	PMCU-0100	E22/19/6
TSD-979	TOP210	5.5/10	0.80/0.05	5.0	4500	3000	VTP-01001	PMCU-0220	E16-Horz
TSD-1046 ³	TOP221	6/25	0.30/0.09	3.9	5760	3000	VTP-00301	PMCU-0220	E22/19/6
TSD-1370	TOP222	6/24	0.55/0.10	5.0	2200	3000	VTP-01001	PMCU-0220	E2425
TSD-1144 ¹	TOP223	6/ -38/ -60	1.2/0.30/.050	20.0	1000	3000	VTP-01001	PMCE-0330	E2425
TSD-940	TOP210	6.5	0.80	5.2	6000	1500	VTP-01001	PMCU-0220	E16-Horz
TSD-860	TOP224	6.9/2x15	0.30/0.60	20.0	1100	3000	VTP-01001	PMCU-0330	E28/11
TSD-1347	TOP224	6.9/24/-15	0.3/0.6/0.2	20.0	900	3000	VTP-01001	PMCU-0330	E28/11

Specifications subject to change without notice.

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**Premier
Magnetics Inc.**



**OFF-LINE
SWITCH MODE
TRANSFORMERS**

"INNOVATORS IN MAGNETICS TECHNOLOGY"

GENERAL ELECTRICAL SPECIFICATIONS AT 25°C - OPERATING TEMPERATURE RANGE 0°C TO +70°C

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PART NUMBER	Recommended Power Intgr. Controller	APPLICATION DATA			PRIMARY OCL μ HY Typ.	HI-POT Vrms Min.	Recommended		Package Schematic
		Output Voltages Vout Vdc	Output Currents Io_cont Amps	Cont Watt			Output Filter Inductor (L2)	Input Filter CMC (L1)	
POL-07050	TOP226	7.0	5.00	35.0	600	3000	VTP-01005	PMCE-0330	E28/11
POL-07003	TOP209P	7.5	0.26	2.0	10000	3000	VTP-01002	PMCU-0330	E16-Vert
TSD-1093⁴	TOP209P	7.5	0.26	2.0	6000	1500	VTP-01002	PMCU-0330	E16-Vert
POL-07020	TOP202	7.5	2.00	15.0	620	3000	VTP-01002	PMCU-0330	E22/19/6
TSD-1024	TOP223P	7.5/15	1.0/0.25	11.3	700	3000	VTP-01002	PMCU-0330	E22/19/6
TSD-1195	TOP224	8/16/16	2.0/0.25/0.25	30.0	800	3000	VTP-01001	PMCE-0330	E30
TSD-794¹	TOP202	8.5	4.00	34.0	1100	3000	VTP-01005	PMCU-2220	E28/11
TSD-880	TOP204	9/24	3.0/0.60	50.0	1000	1500	VTP-01002	PMCE-0330	E30
POL-97505	TOP221	9.75	0.50	4.9	4000	3000	VTP-01001	PMCU-0330	E16-Vert
*POL-97506	TOP221	9.75	0.60	5.8	4000	1500	Bead	PMCU-0220	E19-Horz
TSD-825³	TOP221P	12.0	0.30	3.6	4000	3000	VTP-01001	PMCU-0220	E16-Horz
TSD-935³	TOP200	12.0	0.50	5.0	1280	3000	VTP-01001	PMCU-0220	E19-Horz
TSD-990³	TOP222P	12.0	0.67	8.0	1500	3000	VTP-01001	PMCU-0220	E19-Horz
POL-12012	TOP202	12.0	1.20	15.0	620	3000	VTP-01001	PMCU-0330	E22/19/6
POL-12017	TOP224P	12.0	1.70	20.4	650	3000	VTP-01002	PMCU-0220	E25-Vert
POL-15020	TOP226	12.0	2.50	30.0	628	3000	VTP-01002	PMCU-0330	E28/11
POL-15033	TOP226	12.0	3.00	36.0	600	3000	VTP-01002	PMCE-0330	E30
TSD-762²	TOP103	12.0	3.40	41.0	286	1500	VTP-01002	PMCE-0330	E28/11
TSD-777²	TOP104	12.0	5.00	60.0	298	1500	VTP-01005	PMCE-0330	E30
POL-12208	TOP223	12x2	0.50/0.30	9.6	750	3000	VTP-01001	PMCU-0330	E22/19/6
POL-12216	TOP224	12x2	0.80/0.80	21.5	650	3000	VTP-01001	PMCU-0330	E125-Vert
POL-15033²	TOP104	13.8	4.00	56.0	600	3000	VTP-01002	PMCE-0330	E30
TSD-946³	TOP210	14.0	0.20	3.0	4000	3000	VTP-01001	PMCU-0330	E16-Horz
TSD-1010	TOP210	14.0	0.43	4.5	5000	1500	VTP-01001	PMCU-0330	EFD20
TSD-1003³	TOP210	15.0	0.20	3.0	4000	3000	VTP-01001	PMCU-0330	E16-Horz
TSD-1330³	TOP210	15.0	0.20	3.0	4000	3000	VTP-01001	PMCU-0330	E16-Vert
TSD-737³	TOP223	15.0	1.00	15.0	1060	3000	VTP-01001	PMCU-0330	E22/19/6
POL-15020	TOP226	15.0	2.00	30.0	628	3000	VTP-01002	PMCU-0330	E28/11
POL-15033	TOP226	15.0	3.33	50.0	600	3000	VTP-01002	PMCE-0330	E30
TSD-812	TOP204	15.0	3.33	50.0	810	3000	VTP-01002	PMCE-0330	EER28L

Specifications subject to change without notice.

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		Output Voltages Vout Vdc	Output Currents Io_cont Amps	Cont Watt			Output Filter Inductor (L2)	Input Filter CMC (L1)	
POL-15073 ¹	TOP204	15.0	7.33	110.0	1075	3000	VTP-02007	PMCE-3330	EER28L
POL-15204 ³	TOP200	15x2	0.20/0.20	6.0	1520	3000	VTP-01001	PMCU-0220	E19-Horz
TSD-860	TOP202	+15/6.9	+0.60/0.30	20.0	1100	3000	VTP-01001	PMCU-0330	E28/11
TSD-873 ¹	TOP210	17.0	0.10	1.7	1500	1000	Bead	N/A	EP10-SMD
TSD-1035	TOP221	17.0	0.20	3.5	2000	1500	Bead	N/A	EP10-SMD
TSD-1197	TOP227	17/21/17	2.0/0.25/0.25	90.0	700	3000	VTP-01002	PMCE-0330	E3133/29
TSD-968 ³	TOP202	18x2	0.40/0.40	14.4	630	3000	VTP-01001	PMCU-0330	E22/19/6
POL-22007	TOP202	22.0	0.70	15.4	628	3000	VTP-01001	PMCU-0330	E22/19/6
TSD-924 ⁴	TOP202	22.0	0.70	15.4	628	3000	VTP-01001	PMCU-0330	E22/19/6
POL-24013	TOP204	22.0	1.50	33.0	628	3000	VTP-01002	PMCU-0330	E28/11
POL-24020	TOP226	22.0	2.00	44.0	600	3000	VTP-01002	PMCE-0330	E30
TSD-790	TOP200	24.0	0.15	3.6	2340	3000	VTP-01001	PMCU-0220	E22/19/6
POL-24013	TOP226	24.0	1.30	31.2	628	3000	VTP-01002	PMCU-0330	E28/11
TSD-1043 ⁴	TOP204	24.0	1.30	31.2	628	3000	VTP-01002	PMCU-0330	E28/11
TSD-975	TOP214	24.0	1.30	31.2	657	3000	VTP-01001	PMCU-0330	EPC25
POL-24020	TOP226	24.0	2.00	48	600	3000	VTP-01002	PMCE-0330	E30
POL-24208	TOP226	24.0x2	0.80x2	38.4	650	3000	VTP-01001	PMCU-0330	E25-Vert
POL-24219	TOP227	24.0x2	1.875x2	90.0	750	3000	VTP-01001	PMCE-0330	E25-Vert
POL-28022	TOP204	28.0	2.20	61.6	548	3000	VTP-01002	PMCE-0330	E30
POL-30030 ¹	TOP227Y	28.0	4.00	112.0	500	3000	VTP-01005	PMCE-0160	EI33/29
TSD-1056 ¹	TOP227Y	29/9.5	3.50/0.25	104.0	1000	3000	VTP-01003	PMCE-0330	EI40
POL-30030	TOP227Y	30.0	3.00	90.0	500	3000	VTP-01002	PMCE-0160	EI33/29
POL-40020	TOP227Y	40.0	2.00	80.0	500	3000	VTP-01002	PMCE-0160	EI33/29
POL-45012	TOP204	45.0	1.20	54.0	950	3000	VTP-01002	PMCE-0330	E28/11
TSD-974 ⁵	TOP104	-118	-0.13	15.3	2000	500	VTP-01002	N/A	EFD25

Specifications subject to change without notice.

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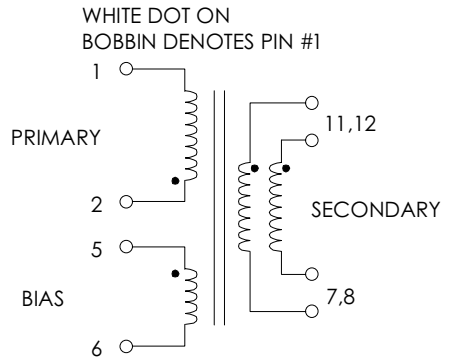
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TABLE 1: ELECTRICAL SPECIFICATIONS AT 25 °C

SWITCHING TRANSFORMER DESIGNED FOR USE WITH POWER INTEGRATIONS PWR-TOP104YAI. REFER TO APPLICATION CIRCUIT OF FIGURE 3.

PARAMETER	SPEC LIMITS			UNITS
	MIN.	TYP.	MAX.	
PRIMARY INDUCTANCE (2-1) VOLTAGE = 0.250Vrms FREQUENCY = 100 KHZ	268	298	328	μHY
TURN RATIO'S: SEC (11,12-7,8) : PRIMARY (2-1) BIAS (5-6) : PRIMARY (2-1)	-----	1:3.88	-----	± 3%
PRI LEAKAGE IND. (SEC SHORTED) VOLTAGE = 0.250Vrms FREQUENCY = 100 KHZ	-----	9.00	12.00	μHY
HIPOT: PRIMARY TO SECONDARY BIAS TO SECONDARY	1500 1500	----- -----	----- -----	Vrms Vrms
APP CIRCUIT PARAMETERS: (1) AC LINE VOLTAGE 47/400 Hz OUTPUT VOLTAGE OUTPUT CURRENT CONTINUOUS OUTPUT CURRENT PEAK LINE REGULATION (85 TO 135Vac) LOAD REGULATION 0-100% RIPPLE	85 ----- 0.0 ----- ----- ----- -----	----- 12.0 ----- ----- 0.20 0.20 50.0	135 ----- 5.0 5.2 ----- ----- -----	Vac Vdc Amps Amps ±% ±% ±mV

FIGURE 1: SCHEMATIC DIAGRAM

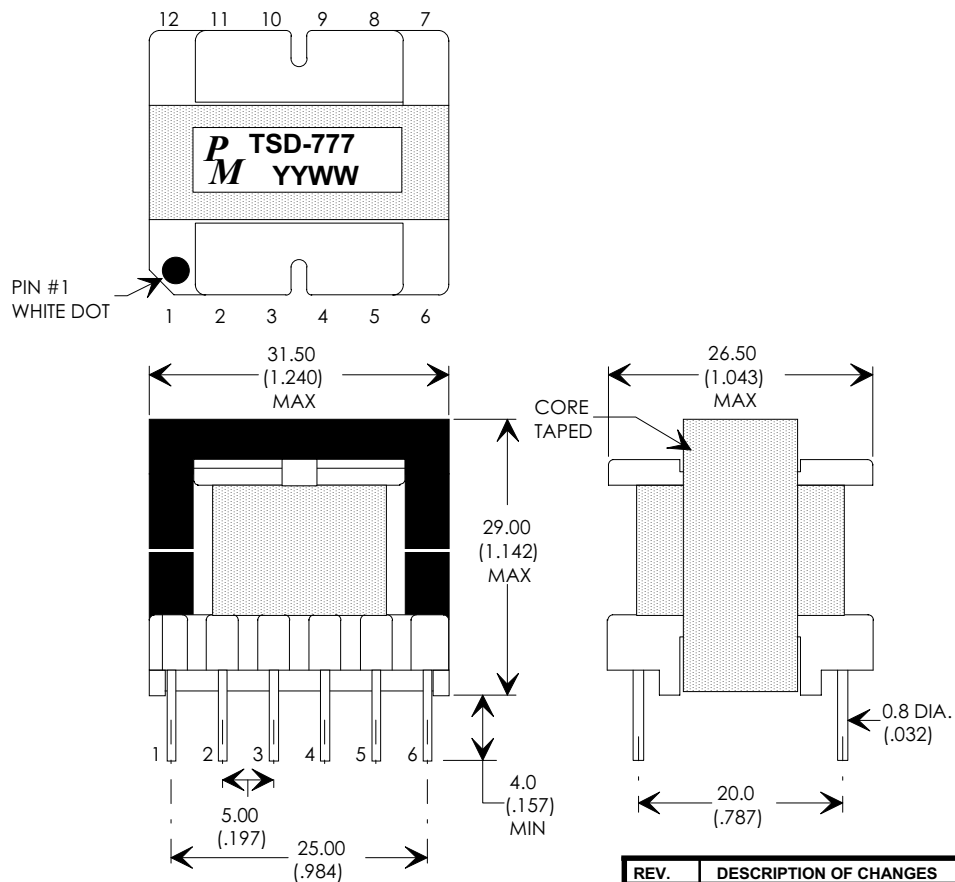


SECONDARY PINS #12 & 11, #8 & 7 MUST BE RESPECTIVELY CONNECTED TOGETHER FOR PROPER OPERATION. I.E. CONNECTED AS ONE PARALLEL WINDING.

NOTE1:
INSULATION SYSTEM:
 A) ALL MATERIALS TO MEET "UL", "CSA" & "IEC" REQUIRMENTS
 B) 130 °C INSULATION SYSTEM.
 C) MARGIN WOUND TO MEET 2.5mm CREEPAGE.
 D) VARNISH FINISHED ASSEMBLY.

(1) REFER TO APPLICATION CIRCUIT OF FIGURE 3.

FIGURE 2: PHYSICAL DIMENSIONS mm (INCHES)



EE30 (FEE30A) -OR- EI30(FEI30), 12-PIN VERTICAL BOBBIN

REV.	DESCRIPTION OF CHANGES
09/05/95	ORIGINAL RELEASE
09/19/95	UPDATED LEAKAGE IND. SPECS.

TRANSFORMER CONTROL DRAWING	
PREMIER P/N: TSD-777	REVISION: 09/19/95
DRAWN BY: TOM O'NEIL	REF: XA-PROTO-60W
SCALE: NONE	SHEET: 1 OF 4



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MM
 DIMENSIONAL TOLERANCES ARE:
 DECIMALS ANGLES
 .X ± .25 ±0° 30'
 .XX ± .15
 DO NOT SCALE DRAWING

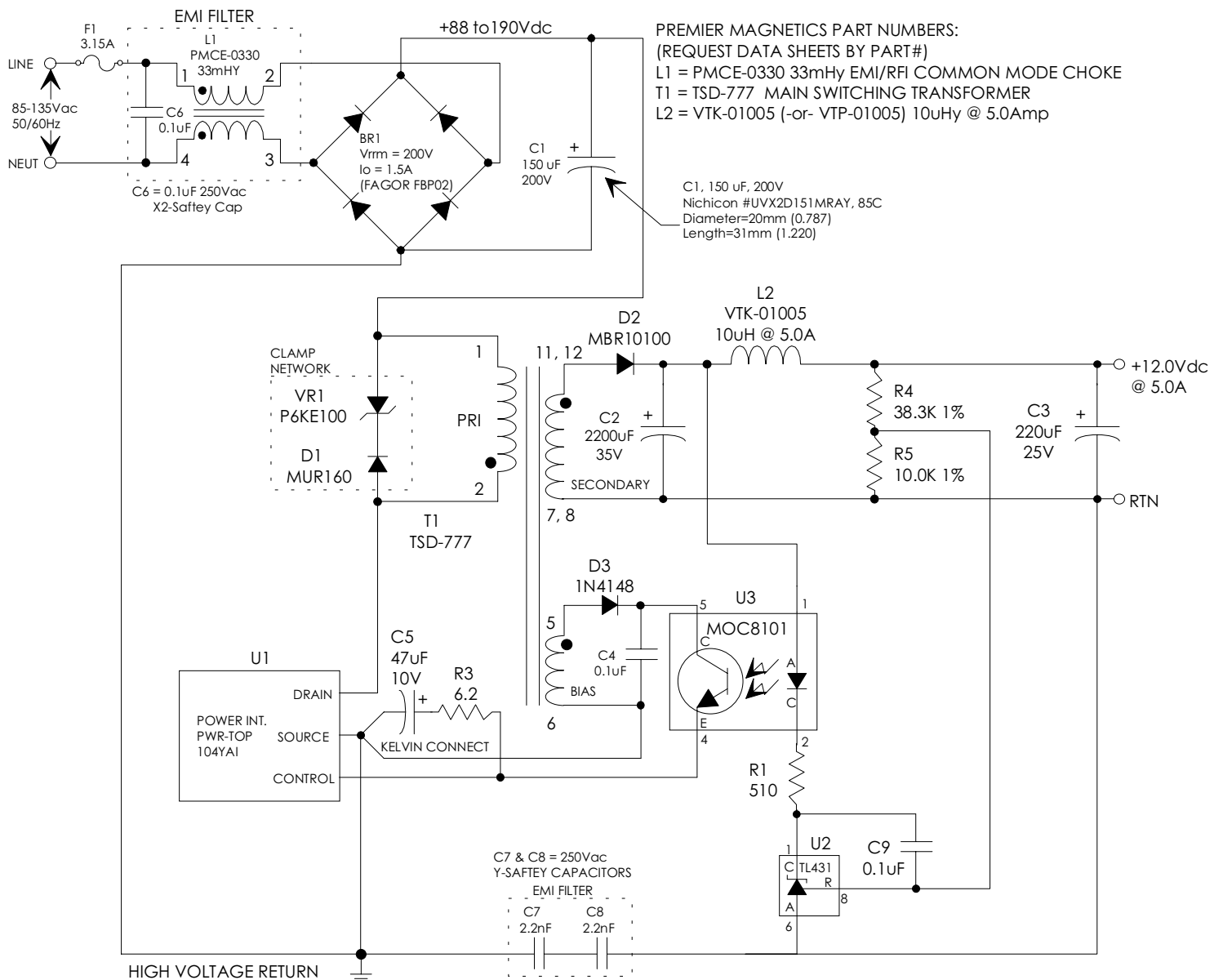
APPLICATION NOTES

Premier Magnetics' TSD-777 Switch Mode Transformer was designed for use with Power Integrations, Inc. PWR-TOP104YA1 three terminal off-line PWM switching regulator in the Flyback Buck-Boost circuit configuration. This conversion topology can provide isolated multiple outputs with efficiencies up to 90%. Premier's TSD-777 transformer has been optimized to provide maximum power throughput.

The PWR-TOPXXX series from Power Integrations, Inc. are self contained 100KHz three terminal voltage controlled PWM switching regulators. This series contains all necessary functions for an off-line switched mode control DC power source. These switching regulators provide a very simple solution to off-line designs. The inductors and transformer used with the PWR-TOPXXX are critical to the performance of the circuit. They define the overall efficiency, output power and overall physical size.

Below is a 110 volt input high precision 60 watt application circuit utilizing Power Integrations PWR-TOP104 switching regulator in the flyback buck-boost configuration. The component values listed are intended for reference purposes only. The soft start capacitor C_{ss} is optional depending on the specific application. Simpler topology is possible depending on the line/load regulation required.

FIGURE 3: TYPICAL APPLICATION CIRCUIT






UNLESS OTHERWISE SPECIFIED
 DIMENSIONS ARE IN MM
 DIMENSIONAL TOLERANCES ARE:
 DECIMALS ANGLES
 .X ± .25 ±0° 30'
 .XX ± .15
 DO NOT SCALE DRAWING

TRANSFORMER CONTROL DRAWING

PREMIER P/N: TSD-777	REVISION: 09/19/95
DRAWN BY: TOM O'NEIL	REF: XA-PROTO-60W
SCALE: NONE	SHEET: 2 OF 4

INDUCTORS DESIGNED FOR NATIONAL'S 150 KHz SIMPLE SWITCHER™



-  Tested and recommended by National Semiconductor
-  Base material meets flammability requirements of UL 94V-0
-  Available in surface mount and through hole versions

Electrical Specifications @ 25°C— Operating Temperature -30° to +130° C

Pulse THT Part Number	Pulse SMT Part Number	National Part Number	In Circuit Operating Parameters ¹			Nominal DCR (Ω)	Package	
			Nominal Inductance (μH)	Rated Current (Amps DC)	Max ² ETop (V-μSec)		Through Hole	Surface Mount
PE-53801	PE-53801S	LM259X-L1	259	0.13	23.1	3.4	LP-25	LCI-20
PE-53802	PE-53802S	LM259X-L2	178	0.16	16.5	2.8	LP-25	LCI-20
PE-53803	PE-53803S	LM259X-L3	118	0.2	13.2	1.8	LP-25	LCI-20
PE-53804	PE-53804S	LM259X-L4	79	0.25	9.9	1.5	LP-25	LCI-20
PE-53805	PE-53805S	LM259X-L5	55	0.3	6.6	1.0	LP-25	LCI-20
PE-53806	PE-53806S	LM259X-L6	39	0.34	6.6	.80	LP-25	LCI-20
PE-53807	PE-53807S	LM259X-L7	26	0.45	6.6	.62	LP-25	LCI-20
PE-53808	PE-53808S	LM259X-L8	374	0.2	75.9	2.7	LP-30	LCI-30
PE-53809	PE-53809S	LM259X-L9	256	0.25	33	2.2	LP-30	LCI-30
PE-53810	PE-53810S	LM259X-L10	176	0.3	26.4	1.4	LP-30	LCI-30
PE-53811	PE-53811S	LM259X-L11	118	0.38	19.8	1.2	LP-30	LCI-30
PE-53812	PE-53812S	LM259X-L12	78	0.46	16.5	0.8	LP-30	LCI-30
PE-53813	PE-53813S	LM259X-L13	55	0.56	13.2	0.5	LP-30	LCI-30
PE-53814	PE-53814S	LM259X-L14	39	0.68	9.9	0.3	LP-30	LCI-30
PE-53815	PE-53815S	LM259X-L15	26	0.84	6.6	0.2	LP-30	LCI-30
PE-53816	PE-53816S	LM259X-L16	17	1.02	6.6	0.1	LP-30	LCI-30
PE-53817	PE-53817S	LM259X-L17	375	0.36	75.9	1.3	LP-37	LCI-37
PE-53818	PE-53818S	LM259X-L18	252	0.44	49.5	0.9	LP-37	LCI-37
PE-53819	PE-53819S	LM259X-L19	173	0.54	36.3	0.6	LP-37	LCI-37
PE-53820	PE-53820S	LM259X-L20	115	0.67	29.7	0.4	LP-37	LCI-37
PE-53821	PE-53821S	LM259X-L21	78	0.82	23.1	0.3	LP-37	LCI-37
PE-53822	PE-53822S	LM259X-L22	54	1.0	16.5	0.2	LP-37	LCI-37
PE-53823	PE-53823S	LM259X-L23	38	1.2	13.2	0.1	LP-37	LCI-37
PE-53824	PE-53824S	LM259X-L24	26	1.48	9.9	0.1	LP-37	LCI-37
PE-53825	PE-53825S	LM259X-L25	18	1.81	9.9	0.06	LP-37	LCI-37
PE-53826	PE-53826S	LM259X-L26	377	0.68	75.9	1.0	LP-44	LCI-44
PE-53827	PE-53827S	LM259X-L27	248	0.83	72.6	0.6	LP-44	LCI-44
PE-53828	PE-53828S	LM259X-L28	168	1.02	56.1	0.4	LP-44	LCI-44
PE-53829	PE-53829S	LM259X-L29	112	1.26	42.9	0.3	LP-44	LCI-44
PE-53830	PE-53830S	LM259X-L30	77	1.54	33	0.2	LP-44	LCI-44
PE-53831	PE-53831S	LM259X-L31	53	1.87	26.4	0.13	LP-44	LCI-44
PE-53932	PE-53932S	LM259X-L32	37	2.24	19.8	0.10	LP-44	LCI-44
PE-53933	PE-53933S	LM259X-L33	24	2.74	16.5	0.07	LP-44	LCI-44
PE-53934	PE-53934S	LM259X-L34	17	3.0	13.2	0.05	KM-10	LCI-44
PE-53935	PE-53935S	LM259X-L35	250	1.5	72.6	0.23	KM-30	HCI-68
PE-54036	PE-54036S	LM259X-L36	168	1.81	75.9	0.18	KM-30	HCI-68
PE-54037	PE-54037S	LM259X-L37	114	2.22	62.7	0.10	KM-30	HCI-68
PE-54038	PE-54038S	LM259X-L38	77	2.7	52.8	0.09	KM-30	HCI-68
PE-54039	PE-54039S	LM259X-L39	53	3.0	42.9	0.08	KM-30	HCI-68
PE-54040	PE-54040S	LM259X-L40	38	3.0	29.7	0.05	KM-30	HCI-68
PE-54041	PE-54041S	LM259X-L41	25	3.0	19.8	0.04	KM-20	LCI-50
PE-54042	—	LM259X-L42	167	2.5	75.9	0.14	KM-40	—
PE-54043	—	LM259X-L43	110	3.0	75.9	0.09	KM-40	—
PE-54044	PE-54044S	LM259X-L44	77	3.0	59.4	0.08	KM-30	HCI-68
PE-53900	—	LM258X-L	19	4.5	32 ³	0.02	KM-30	—

Notes : 1. Inductance values may vary ±20%.
2. ETop rated at 150 KHz except where designated.

3. ETop rated at 100 KHz.
4. SIMPLE SWITCHER™ is a trademark of National Semiconductor Corporation.

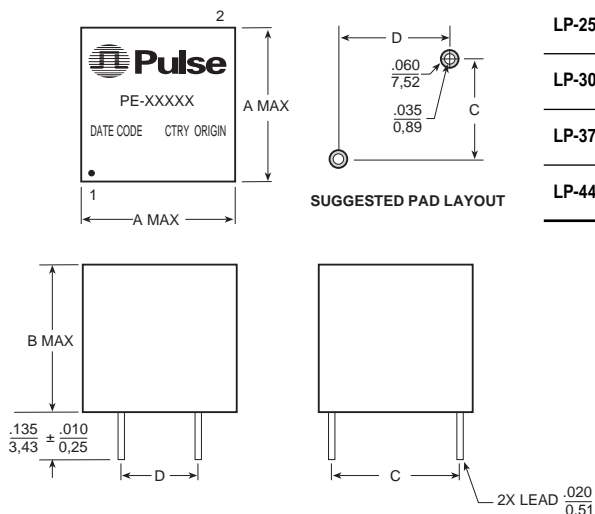
12220 WORLD TRADE DRIVE, SAN DIEGO, CALIFORNIA 92128 • TEL 619-674-8100 • FAX 619-674-8262 • <http://www.pulseeng.com>

INDUCTORS DESIGNED FOR NATIONAL'S 150 KHz SIMPLE SWITCHER™



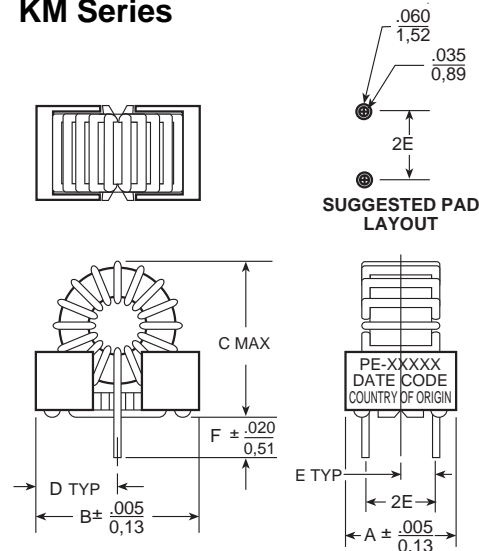
Mechanicals

LP Series



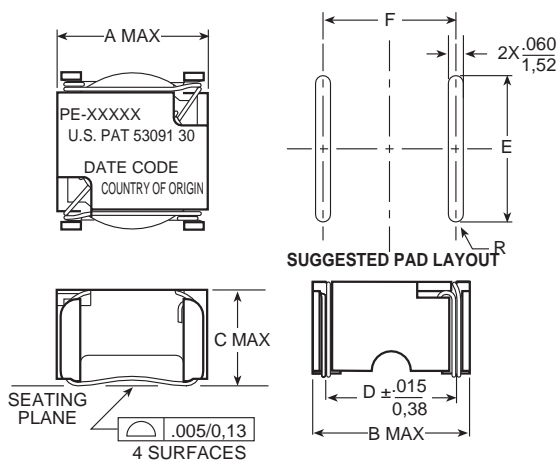
PKG	A	B	C	D
LP-25	$\frac{.360}{9,14}$	$\frac{.310}{7,87}$	$\frac{.250}{6,35}$	$\frac{.250}{6,35}$
LP-30	$\frac{.400}{10,16}$	$\frac{.300}{7,62}$	$\frac{.300}{7,62}$	$\frac{.300}{7,62}$
LP-37	$\frac{.495}{12,57}$	$\frac{.375}{9,52}$	$\frac{.375}{9,52}$	$\frac{.375}{9,52}$
LP-44	$\frac{.635}{16,13}$	$\frac{.365}{9,27}$	$\frac{.500}{12,7}$	$\frac{.300}{7,62}$

KM Series



PKG	A	B	C	D	E	F
KM-10	$\frac{.340}{8,64}$	$\frac{.580}{14,73}$	$\frac{.650}{16,51}$	$\frac{.290}{7,37}$	$\frac{.110}{2,79}$	$\frac{.130}{3,30}$
KM-20	$\frac{.450}{11,43}$	$\frac{.650}{16,51}$	$\frac{.700}{17,73}$	$\frac{.325}{8,26}$	$\frac{.150}{3,81}$	$\frac{.130}{3,30}$
KM-30	$\frac{.450}{11,43}$	$\frac{.830}{21,08}$	$\frac{.950}{24,13}$	$\frac{.415}{10,54}$	$\frac{.150}{3,81}$	$\frac{.130}{3,30}$
KM-40	$\frac{.600}{15,24}$	$\frac{.950}{24,13}$	$\frac{1.00}{25,4}$	$\frac{.475}{12,07}$	$\frac{.225}{5,72}$	$\frac{.130}{3,30}$

LCI Series

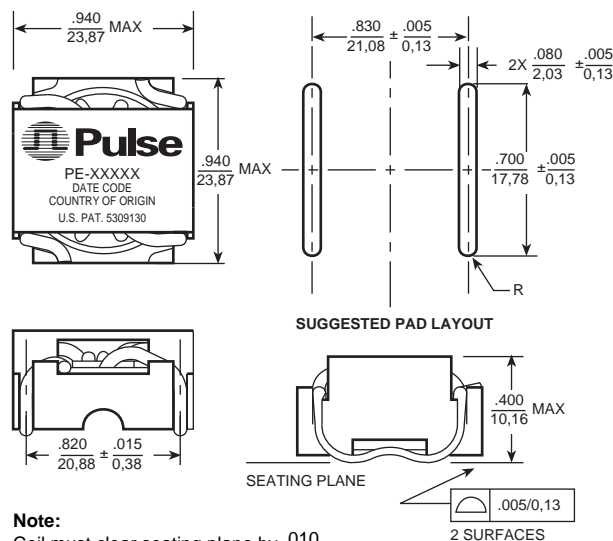


Notes:

1. Dimension "D" is measured across terminal blocks only.
2. Coil must clear seating plane by $\frac{.010}{0,25}$ MIN.

PKG	A	B	C	D	E	F
LCI-20	$\frac{.340}{8,64}$	$\frac{.340}{8,64}$	$\frac{.270}{6,86}$	$\frac{.260}{6,60}$	$\frac{.300}{7,62}$	$\frac{.270}{6,86}$
LCI-30	$\frac{.435}{11,05}$	$\frac{.440}{11,18}$	$\frac{.360}{9,14}$	$\frac{.350}{8,89}$	$\frac{.400}{10,16}$	$\frac{.360}{9,14}$
LCI-37	$\frac{.565}{14,35}$	$\frac{.570}{14,48}$	$\frac{.360}{9,14}$	$\frac{.450}{11,43}$	$\frac{.520}{13,21}$	$\frac{.460}{11,68}$
LCI-44	$\frac{.600}{15,24}$	$\frac{.620}{15,75}$	$\frac{.390}{9,91}$	$\frac{.500}{12,7}$	$\frac{.550}{13,97}$	$\frac{.510}{12,95}$
LCI-50	$\frac{.670}{17,02}$	$\frac{.700}{17,78}$	$\frac{.390}{9,91}$	$\frac{.580}{14,73}$	$\frac{.620}{15,75}$	$\frac{.590}{14,99}$

HCI-68



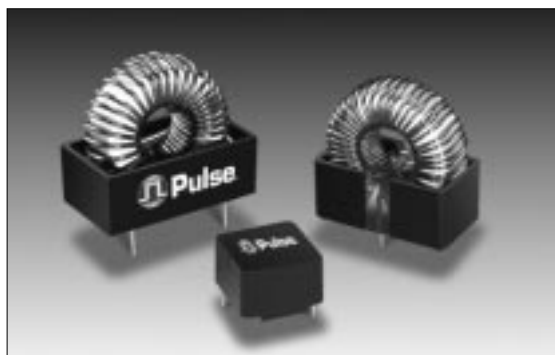
Note:




Coil must clear seating plane by $\frac{.010}{0,25}$ MIN

Dimensions: Inches
mm

Unless otherwise specified, all tolerances are $\pm \frac{.010}{0,25}$

INDUCTORS DESIGNED FOR NATIONAL'S 50 KHz SIMPLE SWITCHER™



-  Designed for use with National's device numbers LM2574/LM2575/LM2576
-  Base material meets flammability requirements of UL 94V-0
-  Performance verified by National Semiconductor

Electrical Specifications @ 25°C— Operating Temperature -30° to +130° C

Part Identification		Reference Operating Values ¹			Design Control Values			
Part Number	Inductor Code	Inductance Typical (μH)	I _{DC} (Amps)	E _{TOP} (V-μSec)	Inductance No DC ² (μH ± 20%)	DCR (Ω MAX)	Package Style	Lead Diameter
PE-53112	L47	47	3.0	90	38	0.05	KM-2.0	.025
PE-92114K	L68	68	3.0	90	55	0.02	KM-4.0	.040
PE-92108K	L100	100	3.0	90	91	0.04	KM-4.0	.032
PE-53113	L150	150	2.0	90	130	0.10	KM-4.0	.025
PE-52626	L220	220	1.4	90	230	0.38	Low Profile	.025 SQ.
PE-53145	L220	220	1.4	90	176	0.14	KM-3.0	.020
PE-52627	L330	330	0.9	90	302	0.74	Low Profile	.025 SQ.
PE-53146	L330	330	0.9	90	267	0.18	KM-3.0	.020
PE-53114	L470	470	0.64	90	426	0.16	KM-4.0	.025
PE-52629	L680	680	.85	90	657	1.25	Low Profile	.025 SQ.
PE-53115	H150	150	3.0	200	136	0.10	KM-4.0	.025
PE-53116	H220	220	3.0	200	167	0.07	KM-5.0	.032
PE-53117	H330	330	3.0	200	292	0.15	KM-5.0	.025
PE-53118	H470	470	2.0	200	369	0.17	KM-5.0	.025
PE-53119	H680	680	1.3	200	562	0.20	KM-5.0	.025
PE-53120	H1000	1000	0.95	200	762	0.24	KM-5.0	.025
PE-53121	H1500	1500	0.62	200	1150	1.00	Case	.032
PE-53122	H220	2200	0.42	200	1730	1.80	Case	.032

NOTES:

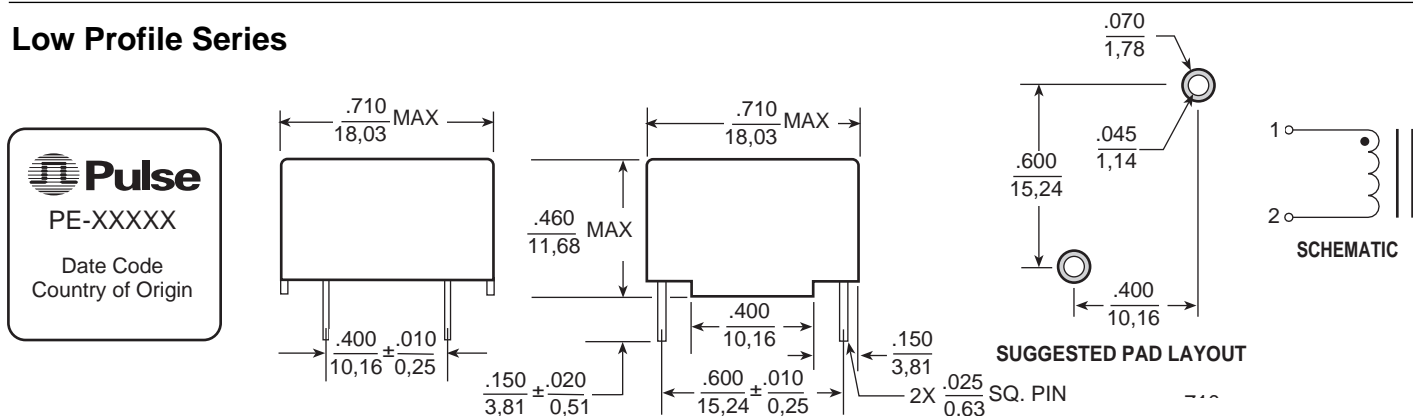
1. Typical inductance occurs at the I_{DC} and E_{TOP} values shown.
2. The control value of inductance is measured at B_{OP} equal to or less than 10 gauss (10 mV @ 20 KHz) without DC current.
3. Inductance decreases with higher values of DC current and increases with lower values of DC current.
4. Inductance increases with increase in B_{OP} or E_{TOP}.
5. SIMPLE SWITCHER™ is a trademark of National Semiconductor Corporation.

INDUCTORS DESIGNED FOR NATIONAL'S 50 KHz SIMPLE SWITCHER™

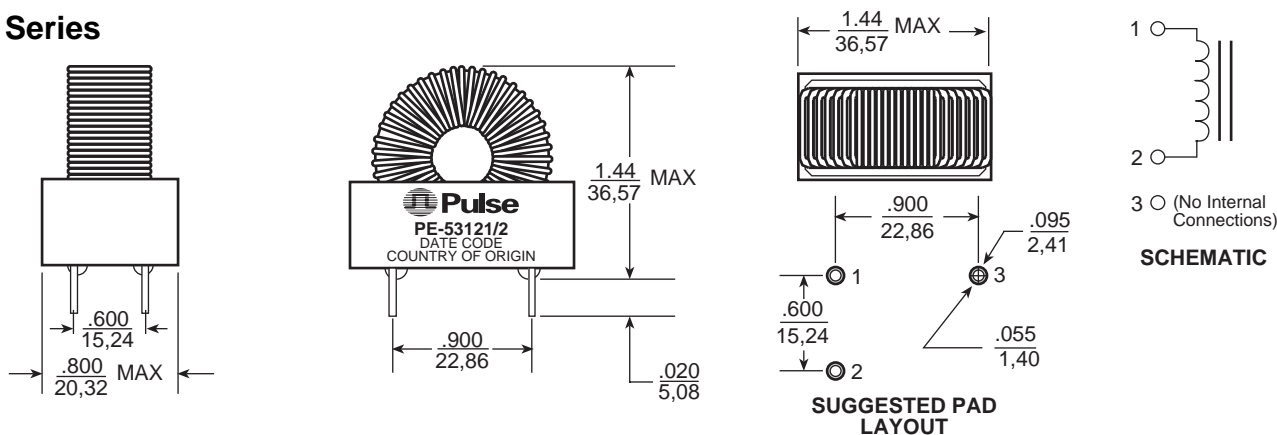


Mechanicals

Low Profile Series



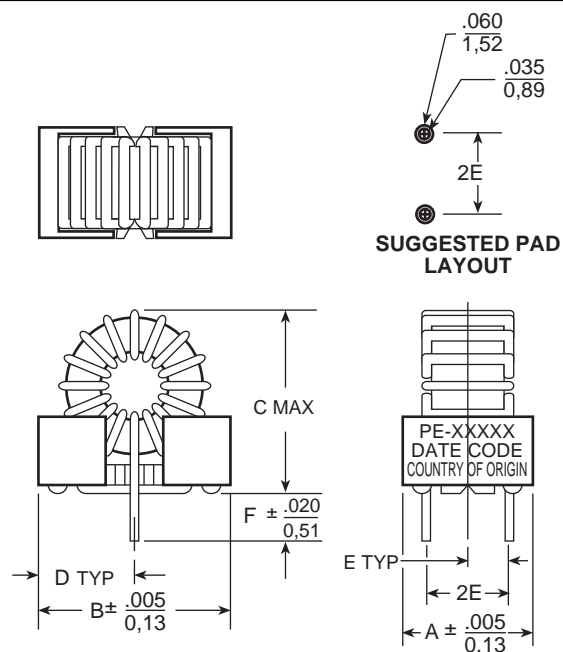
Case Series



KlipMount Series

PKG	A	B	C	D	E	F
KM-2.0	.450 11,43	.650 16,51	.700 17,73	.325 8,26	.150 3,81	.130 3,30
KM-3.0	.450 11,43	.830 21,08	.950 24,13	.415 10,54	.150 3,81	.130 3,30
KM-4.0	.600 15,24	.950 24,13	1.00 25,4	.475 12,07	.225 5,72	.130 3,30
KM-5.0	.700 17,73	1.30 33,02	1.40 35,56	.625 15,88	.250 6,35	.130 3,30

Dimensions: Inches
mm
Unless otherwise specified, all tolerances are $\pm \frac{.010}{0,25}$







MINIATURE SURFACE MOUNT POWER INDUCTORS



NEW!



-  Reliable self-leads
-  Very small size and cost-effective
-  High energy storage and low DC resistance
-  Ideal for DC/DC conversion in notebook computers, PDAs, step-up or step-down converters

Electrical Specifications @ 25°C — Operating Temperature -30°C to +130°C






Pulse Part Number	Reference Values			Control Values		Calculation Data	CoilCraft Part Number
	I _{bc} (amp)	L @ I _{bc} ±15% (μH)	ET (V-μsec)	L w/o DC ±15% (μH)	DCR ±15% (mΩ)	ET ₁₀ (V-μsec)	
ROS 1							
P0430T	2.00	0.6	0.8	0.7	14	476.2	DT1608C-102
P0431T	1.90	0.9	0.8	1.1	18	370.4	DT1608C-152
P0432T	1.50	1.0	1.2	1.1	18	370.4	DT1608C-222
P0433T	1.20	1.7	1.8	1.9	28	277.8	DT1608C-332
P0434T	1.20	2.2	1.8	2.6	34	238.1	DT1608C-472
P0435T	1.00	3.2	2.3	3.9	40	196.1	DT1608C-682
P0436T	0.70	5.1	3.1	6.0	73	158.7	DT1608C-103
P0437T	0.60	6.3	3.3	7.1	100	144.9	DT1608C-153
P0438T	0.50	10.4	4.4	12.2	140	111.1	DT1608C-223
P0439T	0.45	12.7	5.0	14.7	155	101.0	DT1608C-333
P0440T	0.34	20.7	6.5	23.8	250	79.4	DT1608C-473
P0441T	0.29	30	8.4	33.8	280	66.7	DT1608C-683
P0442T	0.24	42.2	9.8	49	440	55.6	DT1608C-194
P0443T	0.20	62	12	72	650	45.7	DT1608C-154
P0444T	0.17	93	14	110	1050	37.0	DT1608C-224
P0445T	0.16	104	15	122	1065	35.1	DT1608C-334
P0446T	0.14	150	18	179	1600	29.0	DT1608C-474
ROS 2							
P0450T	5	0.6	3.0	0.64	7.6	181.8	DT3316P-102
P0451T	5	0.79	3.1	0.86	8.7	151.5	DT3316P-152
P0452T	5	1.29	0.5	1.5	11.4	113.6	DT3316P-222
P0453T	5	1.8	1.0	2.3	13	90.9	DT3316P-332
P0454T	3	2.1	7.5	2.3	13	90.9	DT3316P-472
P0455T	2.5	4.4	10.5	5.13	23	60.6	DT3316P-682
P0456T	2	5.6	13	6.3	26	56.8	DT3316P-103
P0457T	1.8	6.6	14	7.5	33	50.5	DT3316P-153
P0458T	1.5	10.7	15	13.2	70	39.5	DT3316P-223
P0459T	1.3	13.5	21	15.5	60	35.0	DT3316P-333
P0460T	1	27	31	34	90	24.6	DT3316P-473
P0461T	0.9	46	39	57.2	123	18.9	DT3316P-683
P0462T	0.8	48	35	62.5	240	18.2	DT3316P-194
P0463T	0.6	82	55	100	245	14.0	DT3316P-154
P0464T	0.5	90	54	103	305	14.2	DT3316P-224
P0465T	0.4	162	78	180	481	10.0	DT3316P-334
P0466T	0.35	215	87	254	682	8.7	DT3316P-474
P0467T	0.3	320	105	380	1030	7.0	DT3316P-684
P0468T	0.25	420	130	500	1200	6.1	DT3316P-105

LOW PROFILE SELF-LEADED SURFACE MOUNT INDUCTORS



NEW!



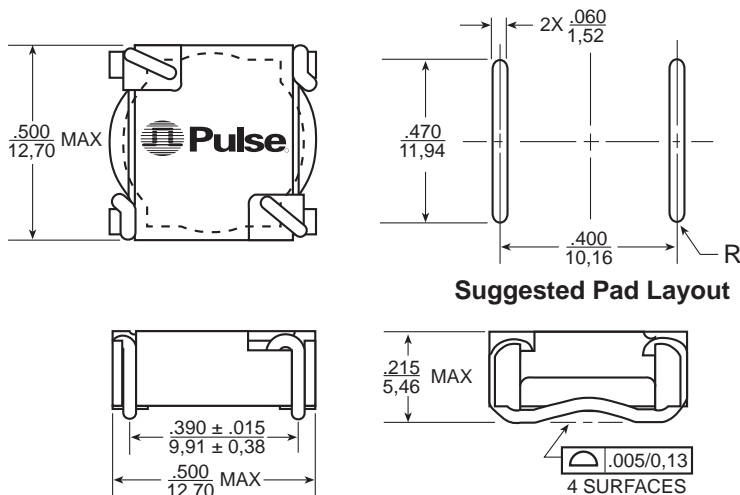
-  Materials meet UL94V-0 rating
-  Suited for IR and vapor reflow solder
-  Fits in half inch high boards for use in lap-top and notebook computers
-  Frequency range of up to 1 MHz
-  Patented, low profile, self-leaded design

Electrical Specifications @ 25°C — Operating Temperature -30°C to +130°C

Part Number	Reference Values				Control Values		Calculation Data	
	I _{dc} (amp)	L @ DC L _{dc} (μH)	ET (V-μsec)	Storage Capacity (μJ)	L w/o DC L _o ±20% (μH)	DCR MAX (mΩ)	100 Gauss ET ₁₀₀ (V-μsec)	1 Amp DC H ₁ (Orsted)
P0153	0.53	439	1.3	61.6	472	1520	17.83	80.37
P0152	0.65	305	1.6	64.4	331	972	14.94	67.34
P0151	0.81	200	1.9	65.6	220	673	12.17	54.85
P0150	0.99	137	2.4	67.0	152	425	10.12	45.61
P0149	1.23	90	3.0	67.8	100	285	8.19	36.93
P0148	1.35	75	3.2	67.9	83	220	7.47	33.67
P0147	1.65	50	4.0	68.6	56	135	6.15	27.69
P0146	2.43	23	5.8	66.9	25	74	4.10	18.46
P0145	3.13	13.3	7.5	64.9	14.6	46	3.13	14.12
P0144	3.80	9.4	9.1	67.7	10.4	32	2.65	11.95

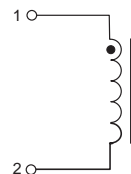
- Notes:**
- The reference inductance is a typical value at the AC and DC excitation listed.
 - Temperature rise is 50°C in typical buck or boost circuits at 250 KHz and with the reference ET applied to the inductor.
 - Total loss in the inductor is 380 mWatts for 50°C temperature rise above ambient.
 - To estimate temperature rise in a given application, determine copper and core losses, divide by 380 and multiply by 50.
 - For the copper loss (mW), calculate $I_{DC}^2 \times R_N$ with R_N in mΩ.
 - The maximum DCR listed is approximately 17% over the nominal DCR (R_N).
 - For core loss (mW), using frequency (f, Hertz) and operating flux density (B, Gauss), calculate $6.11 \times 10^{-18} \times B^{2.7} \times f^{2.04}$.
 - For flux density (B, Gauss), calculate ET (V-μsec) for the application, divide by ET₁₀₀ from the table, and multiply by 100.
 - Limit the DC bias (H) to 46 Orsted. Calculate H (Orsted) by multiplying H₁ from the table by I_{dc} of the application.

Mechanical



Suggested Pad Layout

Schematic



Weight 1.5 grams
 Tape & Reel500/reel
 Tube40/tube

Dimensions: $\frac{\text{Inches}}{\text{mm}}$

Unless otherwise specified all tolerances are $\pm \frac{.010}{.025}$

LOW PROFILE SELF-LEADED SMT DUAL INDUCTORS



NEW!



- ⊕ Materials meet UL94V-0 rating
- ⊕ Suited for IR and vapor reflow solder
- ⊕ Frequency range of up to 1 MHz
- ⊕ Can be used as a simple inductor, 1:1 coupled inductor, or 1:1 transformer

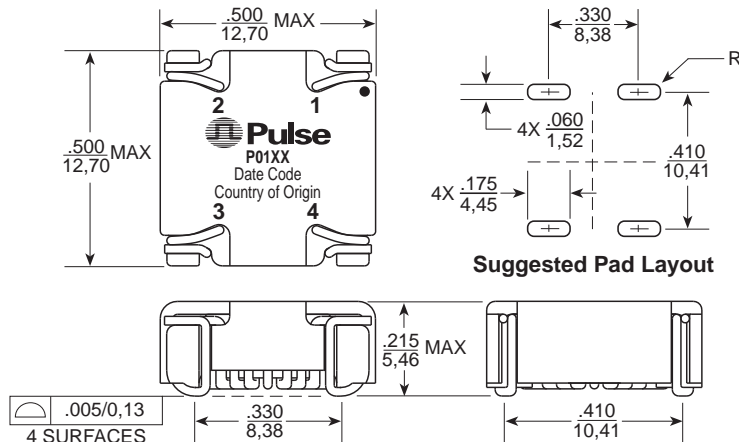
Electrical Specifications @ 25°C — Operating Temperature -30°C to +130°C

ID		Reference Values			Control Values		Calculation Data	
Part Number	Hookup	I _{DC} (amp)	L @ DC L _{DC} (μH)	ET (V-μsec)	L w/o DC L ₀ ±20% (μH)	DCR (MAX) (mΩ)	100 Gauss ET ₁₀₀ (V-μsec)	1 Amp DC H ₁ (Orsted)
P0183	Series	0.61	336.7	92.43	364.0	1295	15.66	70.59
P0182	Series	0.74	245.3	81.70	270.2	897	13.50	60.82
P0181	Series	0.90	170.3	68.99	190.3	603	11.33	51.05
P0180	Series	1.08	117.3	57.00	131.0	424	9.40	42.36
P0183	Parallel	1.22	84.2	46.22	91.0	324	7.83	35.30
P0179	Series	1.32	79.0	46.90	88.2	265	7.71	34.75
P0182	Parallel	1.48	61.3	40.85	67.5	224	6.75	30.41
P0178	Series	1.56	56.2	39.46	62.8	181	6.51	29.32
P0181	Parallel	1.80	42.6	34.49	47.6	151	5.66	25.52
P0177	Series	1.92	37.3	32.25	41.7	119	5.30	23.89
P0180	Parallel	2.16	29.3	28.50	32.8	106	4.70	21.18
P0176	Series	2.60	20.0	23.43	22.1	76.0	3.86	17.38
P0179	Parallel	2.64	19.7	23.45	22.1	66.3	3.86	17.38
P0178	Parallel	3.12	14.1	19.73	15.7	45.3	3.25	14.66
P0175	Series	3.60	9.6	15.62	10.4	43.6	2.65	11.95
P0177	Parallel	3.84	9.3	16.12	10.4	29.8	2.65	11.95
P0174	Series	4.15	7.8	14.61	8.6	30.3	2.41	10.86
P0176	Parallel	5.20	5.0	11.72	5.5	19.0	1.93	8.69
P0175	Parallel	7.20	2.4	7.81	2.6	10.9	1.33	5.97
P0174	Parallel	8.30	2.0	7.31	2.2	7.6	1.20	5.43

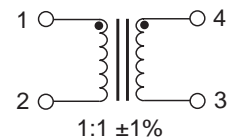
NOTES:

- The reference inductance at rated DC current is a typical value.
- Temperature rise is 50°C in typical buck or boost circuits at 250 KHz and with the reference ET applied to the inductor.
- Total loss in the inductor is 380 mWatts for a 50°C temperature rise above ambient.
- To estimate temperature rise in a given application, determine copper and core losses, divide by 380 and multiply by 50.
- For the copper loss, calculate I_{DC}² X R_N.
- For core loss, using frequency (f) and operating flux density (B), calculate $6.11 \times 10^{-18} \times B^{2.7} \times f^{2.04}$.
- For flux density (B), calculate ET (V-μsec) for the application, divide by ET₁₀₀ from the table, and multiply by 100.
- Limit the DC bias (H) to 46 orstedts. Calculate H by multiplying H₁ from the table by I_{DC} of the application.
- The maximum DCR listed is approximately 17% over the nominal DCR.
- Add suffix "T" to part number for tape and reel package (i.e. P0183T).

Mechanical



Schematic



Weight 1.5 grams
Tape & Reel 500/reel
Tube 40/tube

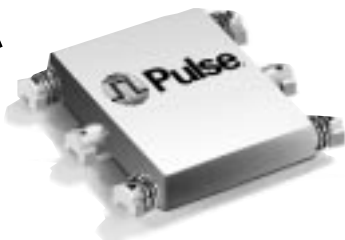
Dimensions: $\frac{\text{Inches}}{\text{mm}}$
Unless otherwise specified,
all tolerances are $\pm \frac{.010}{0.25}$

LOW PROFILE SELF-LEADED POWER INDUCTORS

Designed for PCMCIA Applications



NEW!



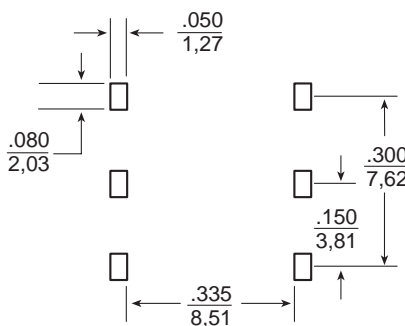
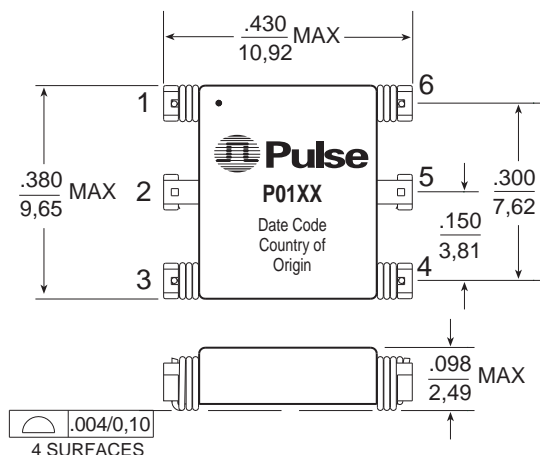
- Small PCMCIA size (.38" X .43" X .098")
- Frequency range: 100 KHz to 1 MHz
- Up to 3 amps rated DC current
- Surface mount, pick and placeable

Electrical Specifications @ 25°C — Operating Temperature -30°C to +130°C

ID		Reference Values			Control Values		Calculation Data	
Part Number	Hookup	I _{DC} (amp)	L @ DC L _{DC} (μH)	ET (V-μsec)	L w/o DC L ₀ ±20% (μH)	DCR (MAX) (mΩ)	100 Gauss ET ₁₀₀ (V-μsec)	1 Amp DC H ₁ (Orsted)
P0108	Series	0.27	122.6	16.55	137.8	1545	2.77	102.50
P0107	Series	0.33	88.5	14.60	100.5	1068	2.37	87.55
P0106	Series	0.40	60.1	12.03	69.1	720	1.96	72.60
P0116	Series	0.44	43.6	9.59	46.9	692	1.62	59.79
P0108	Parallel	0.54	30.7	8.28	34.4	382	1.38	51.25
P0105	Series	0.62	20.1	6.22	21.6	325	1.10	40.57
P0107	Parallel	0.66	22.1	7.30	25.1	267	1.18	43.77
P0104	Series	0.73	15.7	5.74	17.3	236	0.98	36.30
P0106	Parallel	0.80	15.0	6.01	17.3	180	0.98	36.30
P0103	Series	0.86	12.1	5.21	13.5	170	0.87	32.03
P0116	Parallel	0.88	10.9	4.80	11.7	173	0.81	29.89
P0102	Series	1.03	9.0	4.63	10.1	121	0.75	27.76
P0101	Series	1.23	6.4	3.92	7.2	86	0.63	23.49
P0105	Parallel	1.24	5.0	3.11	5.4	81	0.55	20.29
P0100	Series	1.41	5.2	3.67	6.0	66	0.58	21.35
P0104	Parallel	1.46	3.9	2.87	4.3	59	0.49	18.15
P0103	Parallel	1.72	3.0	2.60	3.4	42	0.43	16.01
P0102	Parallel	2.06	2.2	2.32	2.5	30	0.38	13.88
P0101	Parallel	2.46	1.6	1.96	1.8	22	0.32	11.74
P0100	Parallel	2.82	1.3	1.83	1.5	16	0.29	10.68

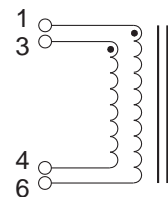
- NOTES:**
1. The reference inductance at rated DC current is a typical value.
 2. Temperature rise is 50°C in typical buck or boost circuits at 500 KHz and with the reference ET applied to the inductor.
 3. Total loss in the inductor is 95 mWatts for 50°C temperature rise above ambient.
 4. To estimate temperature rise in a given application, determine copper and core losses, divide by 95 and multiply by 50.
 5. For the copper loss, calculate I_{DC}² X R_N.
 6. For R_N, multiply DCR_{MAX} by 0.85.
 7. For core loss, using frequency (f) and operating flux density (B), calculate $747 \times 10^{-21} \times B^{2.7} \times f^{2.04}$.
 8. For flux density (B), calculate ET (V-μsec) for the application, divide by ET₁₀₀ from the table, and multiply by 100.
 9. Limit the DC bias (H) to 31 orsted. Calculate H by multiplying H₁ from the table by I_{DC} of the application.
 10. Add suffix "T" to part number for tape and reel package (i.e. P0100T).

Mechanical



SUGGESTED PAD LAYOUT

Schematic



Weight.....0.25 grams
Tape & Reel1250/reel
Tube.....55/tube

Dimensions: Inches
mm
 Unless otherwise specified,
 all tolerances are ± .010
0,25

HIGH AND LOW CURRENT COUPLED INDUCTORS

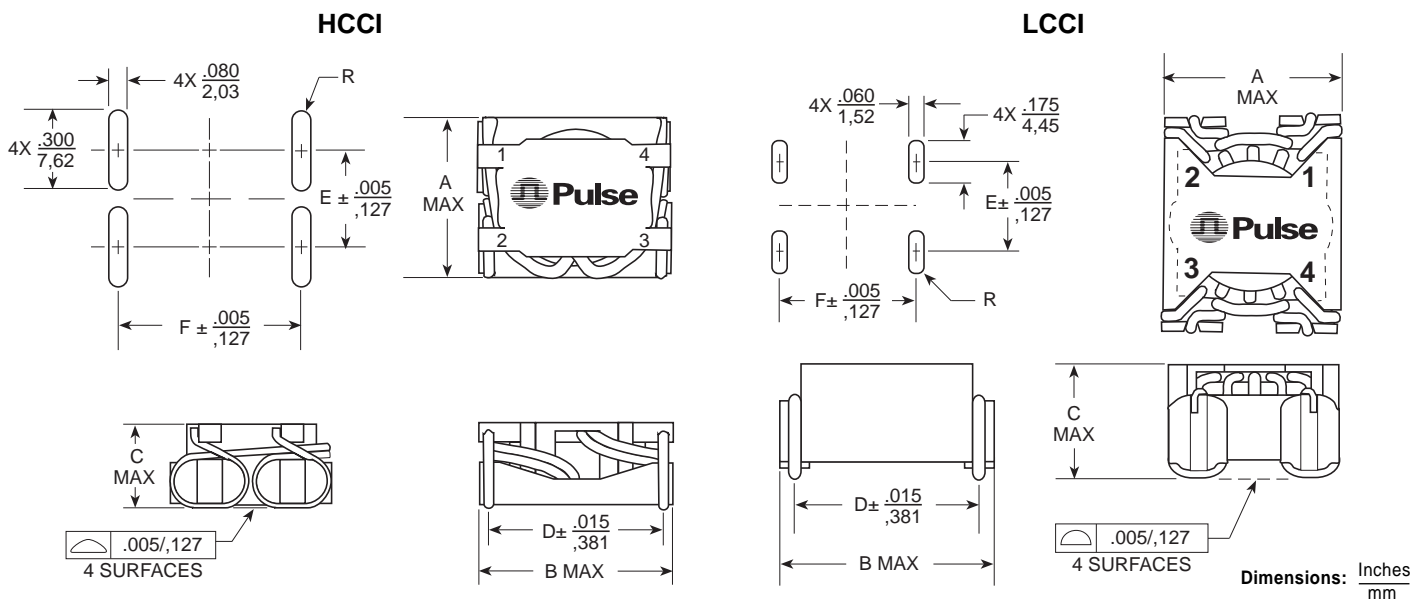


- Self-leaded, surface mount
- Suited for IR and vapor phase reflow soldering
- Frequency range up to 1 MHz

Electrical Specifications @ 25°C — Operating Temperature -30°C to 130°C

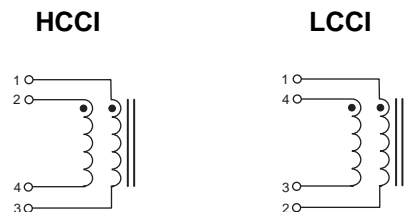
Part Number	I _{dc} (Amps)	L _{w/DC} (μH)	ET (V-μ sec)	Size Code	L _{w/oDC} (μH ± 20%)	Max DCR (mΩ)
PE-53361	23.8	.53	1.00	HCCI-44	.88	1.7
PE-53362	21.0	1.10	1.75	HCCI-50	2.10	3.0
PE-53363	22.4	2.10	3.25	HCCI-68	4.00	3.4
PE-53717	1.1	43.6	7.83	LCCI-37	77.0	309
PE-53718	2.7	21.9	6.90	LCCI-44	39.5	90.5
PE-53719	6.4	4.025	3.135	LCCI-50	6.575	23

Mechanicals



Size Codes						
	HCCI-44	HCCI-50	HCCI-68	LCCI-37	LCCI-44	LCCI-50
A	.715/18,16	.800/20,32	1.000/25,40	.560/14,22	.590/14,99	.670/17,02
B	.865/21,97	.910/23,11	1.110/28,19	.645/16,38	.715/18,16	.770/19,56
C	.390/9,91	.390/9,91	.390/9,91	.350/8,89	.390/9,91	.390/9,91
D	.760/10,30	.800/20,32	1.000/25,40	.520/13,21	.600/15,24	.650/16,51
E	.360/9,14	.440/11,18	.620/15,75	.340/8,64	.370/9,40	.445/11,30
F	.770/19,56	.810/20,57	1.010/25,65	.530/13,46	.610/15,49	.660/16,76

Schematics



SURFACE MOUNT INDUCTORS SELF-LEADED



Electrical Information



- ⊕ Materials meet UL94V-0 rating
- ⊕ Suited for IR and vapor reflow solder
- ⊕ Fits in half inch high boards for use in lap-top and notebook computers
- ⊕ Frequency range of up to 1 MHz
- ⊕ Patented, low profile, self-leaded design

Electrical Specifications @ 25°C — Operating Temperature -30°C to +130°C




REFERENCE VALUES ¹				CONTROL VALUES			CALCULATION DATA		
Pulse Part Number	I _{DC} ² (Amps)	L with DC L _{DC} (μH)	ET	Size Code	L w/o DC L ₀ (μH ± 20%)	DCR R _{DC} (mΩ MAX)	100 Gauss ET ₁₀₀ (V-μSec)	1 Amp DC H _i (Orsted)	DCR R _N (mΩ NOM)
PE-53600	1.40	6.20	1.33	LCI-20	7.0	70.0	0.94	21.9	60.3
PE-53601	1.00	17.6	2.40	LCI-20	22.7	125	1.68	39.3	109
PE-53602	1.40	29.7	4.60	LCI-30	35.3	166	4.12	23.2	141
PE-53604	1.30	58.1	7.83	LCI-37	73.0	290	7.09	28.8	233
PE-53606	0.94	114	10.0	LCI-30	167	380	8.97	50.5	330
PE-53608	0.90	192	15.7	LCI-37	292	560	14.2	57.7	472
PE-53611	0.72	383	23.5	LCI-37	672	862	21.3	86.5	750
PE-53613	0.74	645	36.5	LCI-44	1134	1250	37.2	84.4	1040
PE-53614	0.71	1070	54.4	LCI-50	1950	1700	56.9	95.7	1480
PE-53630	3.4	1.01	0.532	LCI-20	1.10	11.0	0.37	8.74	12.5
PE-53631	2.8	9.4	2.70	LCI-30	12.3	43.4	2.42	13.7	37.8
PE-53632	2.7	16.2	4.29	LCI-37	21.9	63.0	3.88	15.8	54.7
PE-53633	2.7	29.1	6.90	LCI-44	40.5	85.0	7.02	15.9	75.8
PE-53634	2.6	50.0	10.5	LCI-50	72.9	133	11.0	18.5	115
PE-53650	4.8	3.8	1.76	LCI-30	5.20	17.3	1.58	8.87	14.8
PE-53651	5.4	5.1	2.51	LCI-37	7.5	17.7	2.27	9.25	14.3
PE-53652	5.5	9.0	4.06	LCI-44	14.0	22.3	4.13	9.38	19.3
PE-53653	5.1	16.1	6.27	LCI-50	25.9	32.0	6.55	11.0	30.3
PE-53661	8.0	2.5	1.77	LCI-37	3.80	8.3	1.61	6.53	7.20
PE-53662	7.8	4.9	3.04	LCI-44	7.9	12.4	3.10	7.03	10.5
PE-53663	7.2	9.3	4.92	LCI-50	16.0	18.7	5.15	8.67	16.3
PE-53680	11.5	1.32	1.33	HCI-37	2.10	4.0	1.20	4.90	3.39
PE-53681	11.4	2.5	2.23	HCI-44	4.20	5.4	2.27	5.16	4.64
PE-53682	10.4	4.7	3.58	HCI-50	8.4	8.3	3.75	6.30	7.18
PE-53683	10.9	9.4	6.84	HCI-68	17.6	12.3	7.93	6.24	10.7
PE-53690	14.3	0.81	1.035	HCI-37*	1.25	2.5	0.94	381	2.16
PE-53691	13.9	1.68	1.83	HCI-44*	2.80	3.6	1.86	4.22	3.16
PE-53692	12.4	3.5	3.13	HCI-50*	6.5	6.6	3.28	5.52	5.75
PE-53700	15.4	5.2	5.21	HCI-68*	10.5	6.2	6.04	4.75	5.30

NOTES:

- Reference values are for an inductor with a 55°C temperature rise. The core loss is 10% of the copper loss at the ET listed and 500 KHz.
- Core does not saturate abruptly. The ET and DC current are limited by the desired inductance and temperature rise.
- The temperature rise is directly proportional to the total watts loss (I²R plus core loss). The core loss (mW/cc) equals $9.07 \times 10^{-10} f^{1.26} B^{2.11}$. B is the operating flux density (Gauss) due to ripple voltage and f is the operating frequency (Hertz) of the ripple current.
- Standard packaging is in tubes. Optional 13" Tape & Reel packaging can be ordered by adding a "T" suffix to the part number, (i.e. PE-53600T).

INDUCTORS DESIGNED FOR NATIONAL'S 150 KHz SIMPLE SWITCHER™



-  Tested and recommended by National Semiconductor
-  Base material meets flammability requirements of UL 94V-0
-  Available in surface mount and through hole versions

Electrical Specifications @ 25°C— Operating Temperature -30° to +130° C

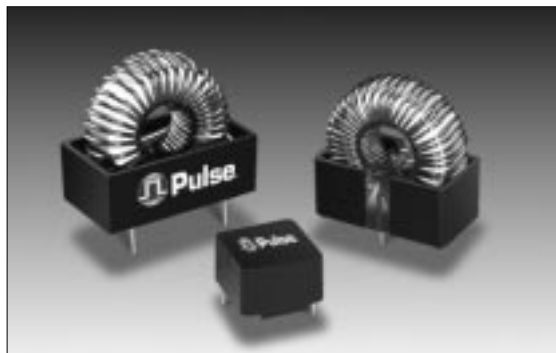
Pulse THT Part Number	Pulse SMT Part Number	National Part Number	In Circuit Operating Parameters ¹			Nominal DCR (Ω)	Package	
			Nominal Inductance (μH)	Rated Current (Amps DC)	Max ² ETop (V-μSec)		Through Hole	Surface Mount
PE-53801	PE-53801S	LM259X-L1	259	0.13	23.1	3.4	LP-25	LCI-20
PE-53802	PE-53802S	LM259X-L2	178	0.16	16.5	2.8	LP-25	LCI-20
PE-53803	PE-53803S	LM259X-L3	118	0.2	13.2	1.8	LP-25	LCI-20
PE-53804	PE-53804S	LM259X-L4	79	0.25	9.9	1.5	LP-25	LCI-20
PE-53805	PE-53805S	LM259X-L5	55	0.3	6.6	1.0	LP-25	LCI-20
PE-53806	PE-53806S	LM259X-L6	39	0.34	6.6	.80	LP-25	LCI-20
PE-53807	PE-53807S	LM259X-L7	26	0.45	6.6	.62	LP-25	LCI-20
PE-53808	PE-53808S	LM259X-L8	374	0.2	75.9	2.7	LP-30	LCI-30
PE-53809	PE-53809S	LM259X-L9	256	0.25	33	2.2	LP-30	LCI-30
PE-53810	PE-53810S	LM259X-L10	176	0.3	26.4	1.4	LP-30	LCI-30
PE-53811	PE-53811S	LM259X-L11	118	0.38	19.8	1.2	LP-30	LCI-30
PE-53812	PE-53812S	LM259X-L12	78	0.46	16.5	0.8	LP-30	LCI-30
PE-53813	PE-53813S	LM259X-L13	55	0.56	13.2	0.5	LP-30	LCI-30
PE-53814	PE-53814S	LM259X-L14	39	0.68	9.9	0.3	LP-30	LCI-30
PE-53815	PE-53815S	LM259X-L15	26	0.84	6.6	0.2	LP-30	LCI-30
PE-53816	PE-53816S	LM259X-L16	17	1.02	6.6	0.1	LP-30	LCI-30
PE-53817	PE-53817S	LM259X-L17	375	0.36	75.9	1.3	LP-37	LCI-37
PE-53818	PE-53818S	LM259X-L18	252	0.44	49.5	0.9	LP-37	LCI-37
PE-53819	PE-53819S	LM259X-L19	173	0.54	36.3	0.6	LP-37	LCI-37
PE-53820	PE-53820S	LM259X-L20	115	0.67	29.7	0.4	LP-37	LCI-37
PE-53821	PE-53821S	LM259X-L21	78	0.82	23.1	0.3	LP-37	LCI-37
PE-53822	PE-53822S	LM259X-L22	54	1.0	16.5	0.2	LP-37	LCI-37
PE-53823	PE-53823S	LM259X-L23	38	1.2	13.2	0.1	LP-37	LCI-37
PE-53824	PE-53824S	LM259X-L24	26	1.48	9.9	0.1	LP-37	LCI-37
PE-53825	PE-53825S	LM259X-L25	18	1.81	9.9	0.06	LP-37	LCI-37
PE-53826	PE-53826S	LM259X-L26	377	0.68	75.9	1.0	LP-44	LCI-44
PE-53827	PE-53827S	LM259X-L27	248	0.83	72.6	0.6	LP-44	LCI-44
PE-53828	PE-53828S	LM259X-L28	168	1.02	56.1	0.4	LP-44	LCI-44
PE-53829	PE-53829S	LM259X-L29	112	1.26	42.9	0.3	LP-44	LCI-44
PE-53830	PE-53830S	LM259X-L30	77	1.54	33	0.2	LP-44	LCI-44
PE-53831	PE-53831S	LM259X-L31	53	1.87	26.4	0.13	LP-44	LCI-44
PE-53932	PE-53932S	LM259X-L32	37	2.24	19.8	0.10	LP-44	LCI-44
PE-53933	PE-53933S	LM259X-L33	24	2.74	16.5	0.07	LP-44	LCI-44
PE-53934	PE-53934S	LM259X-L34	17	3.0	13.2	0.05	KM-10	LCI-44
PE-53935	PE-53935S	LM259X-L35	250	1.5	72.6	0.23	KM-30	HCI-68
PE-54036	PE-54036S	LM259X-L36	168	1.81	75.9	0.18	KM-30	HCI-68
PE-54037	PE-54037S	LM259X-L37	114	2.22	62.7	0.10	KM-30	HCI-68
PE-54038	PE-54038S	LM259X-L38	77	2.7	52.8	0.09	KM-30	HCI-68
PE-54039	PE-54039S	LM259X-L39	53	3.0	42.9	0.08	KM-30	HCI-68
PE-54040	PE-54040S	LM259X-L40	38	3.0	29.7	0.05	KM-30	HCI-68
PE-54041	PE-54041S	LM259X-L41	25	3.0	19.8	0.04	KM-20	LCI-50
PE-54042	—	LM259X-L42	167	2.5	75.9	0.14	KM-40	—
PE-54043	—	LM259X-L43	110	3.0	75.9	0.09	KM-40	—
PE-54044	PE-54044S	LM259X-L44	77	3.0	59.4	0.08	KM-30	HCI-68
PE-53900	—	LM258X-L	19	4.5	32 ³	0.02	KM-30	—




Notes : 1. Inductance values may vary ±20%.
2. ETop rated at 150 KHz except where designated.

3. ETop rated at 100 KHz.
4. SIMPLE SWITCHER™ is a trademark of National Semiconductor Corporation.

12220 WORLD TRADE DRIVE, SAN DIEGO, CALIFORNIA 92128 • TEL 619-674-8100 • FAX 619-674-8262 • <http://www.pulseeng.com>

INDUCTORS DESIGNED FOR NATIONAL'S 50 KHz SIMPLE SWITCHER™



-  Designed for use with National's device numbers LM2574/LM2575/LM2576
-  Base material meets flammability requirements of UL 94V-0
-  Performance verified by National Semiconductor

Electrical Specifications @ 25°C— Operating Temperature -30° to +130° C

Part Identification		Reference Operating Values ¹			Design Control Values			
Part Number	Inductor Code	Inductance Typical (μH)	I _{DC} (Amps)	E _{TOP} (V-μSec)	Inductance No DC ² (μH ± 20%)	DCR (Ω MAX)	Package Style	Lead Diameter
PE-53112	L47	47	3.0	90	38	0.05	KM-2.0	.025
PE-92114K	L68	68	3.0	90	55	0.02	KM-4.0	.040
PE-92108K	L100	100	3.0	90	91	0.04	KM-4.0	.032
PE-53113	L150	150	2.0	90	130	0.10	KM-4.0	.025
PE-52626	L220	220	1.4	90	230	0.38	Low Profile	.025 SQ.
PE-53145	L220	220	1.4	90	176	0.14	KM-3.0	.020
PE-52627	L330	330	0.9	90	302	0.74	Low Profile	.025 SQ.
PE-53146	L330	330	0.9	90	267	0.18	KM-3.0	.020
PE-53114	L470	470	0.64	90	426	0.16	KM-4.0	.025
PE-52629	L680	680	.85	90	657	1.25	Low Profile	.025 SQ.
PE-53115	H150	150	3.0	200	136	0.10	KM-4.0	.025
PE-53116	H220	220	3.0	200	167	0.07	KM-5.0	.032
PE-53117	H330	330	3.0	200	292	0.15	KM-5.0	.025
PE-53118	H470	470	2.0	200	369	0.17	KM-5.0	.025
PE-53119	H680	680	1.3	200	562	0.20	KM-5.0	.025
PE-53120	H1000	1000	0.95	200	762	0.24	KM-5.0	.025
PE-53121	H1500	1500	0.62	200	1150	1.00	Case	.032
PE-53122	H220	2200	0.42	200	1730	1.80	Case	.032

NOTES:

1. Typical inductance occurs at the I_{DC} and E_{TOP} values shown.
2. The control value of inductance is measured at B_{OP} equal to or less than 10 gauss (10 mV @ 20 KHz) without DC current.
3. Inductance decreases with higher values of DC current and increases with lower values of DC current.
4. Inductance increases with increase in B_{OP} or E_{TOP}.
5. SIMPLE SWITCHER™ is a trademark of National Semiconductor Corporation.

INDUCTOR FOR HARRIS SEMICONDUCTOR



Portable Power Converter HIP 5020 Eval 1

NEW!



- Surface mount, self-leaded inductor
- Solution based on efficiency, using Allied Microlite core
- Designed for Notebooks, portables and PCAs
- Wide variety of other inductor sizes and values available

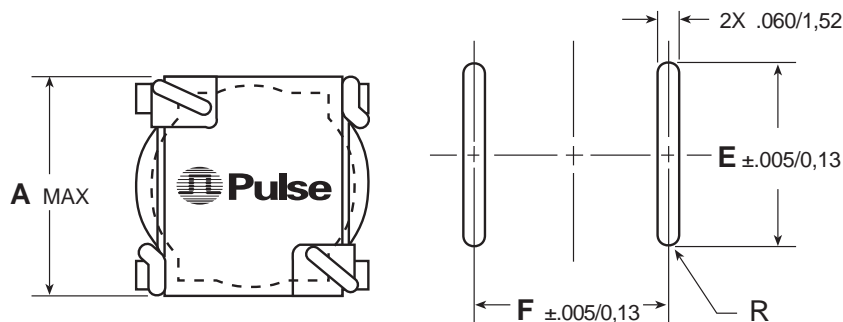
Electrical Specifications @ 25°C — Operating Temperature -30°C to +130°C

Pulse Part Number	Reference Values				Control Values		Calculation Data	
	I _{DC} (amp)	L @ DC L _{DC} (μH)	ET (V-μsec)	Storage Capacity (μJoules)	L w/o DC L _{0±20%} (μH)	DCR MAX (mΩ)	100 Gauss ET ₁₀₀ (V-μsec)	1 Amp DC H ₁ (Orsted)
P0119	4.96	7.4	14.34	90.43	12.7	18.2	1.20	7.42

NOTES:

1. The reference inductance is a typical value at the AC and DC excitation listed.
2. Temperature rise is 55° C in typical buck or boost circuits at 200 KHz and with the reference ET applied to the inductor.
3. Total loss in the inductor is 423 mWatts for 55°C temperature rise above ambient.
4. To estimate temperature rise in a given application, determine the total losses (copper losses + core losses), divide by 423 and multiply by 55.
5. To determine copper losses, calculate:
CopperLoss (mW) = I_{DC}² x R_N (with R_N in mΩ).
6. The maximum DCR listed is approximately 17% over the nominal DCR (R_N).
7. For core loss in mWatts, using frequency (f, Hz) and operating flux density (B, Gauss), calculate: 0.342 x 10⁻¹² x B^{2.13} x f^{1.52}.
8. For flux density (B, Gauss), calculate ET (V-μsec) for the application, divide by ET₁₀₀ factor from the table and multiply by 100.
9. For estimating L with DC current, calculate H by multiplying H₁ from the table by I_{DC} of the application. Using H determine the DC perm Factor (F_{UDC}). Multiply L w/o DC by F_{UDC} for L @ DC.

Mechanical

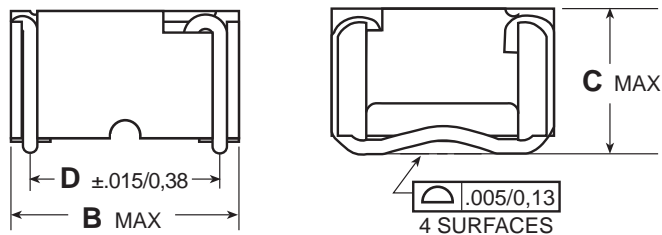


Schematic



Weight 2.4 grams
Tube 30/tube

Suggested PCB Layout

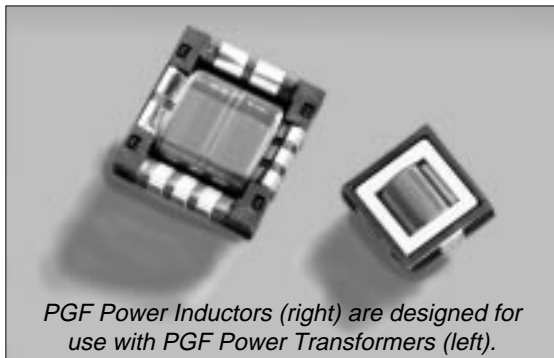


A	B	C	D	E	F
.565	.570	.360	.450	.520	.460
14,35	14,48	9,14	11,43	13,21	11,68

Dimensions: $\frac{\text{Inches}}{\text{mm}}$
Unless otherwise specified, all tolerances are $\pm \frac{.010}{0,25}$

PGF POWER INDUCTORS

High Current, Low Profile, High Frequency

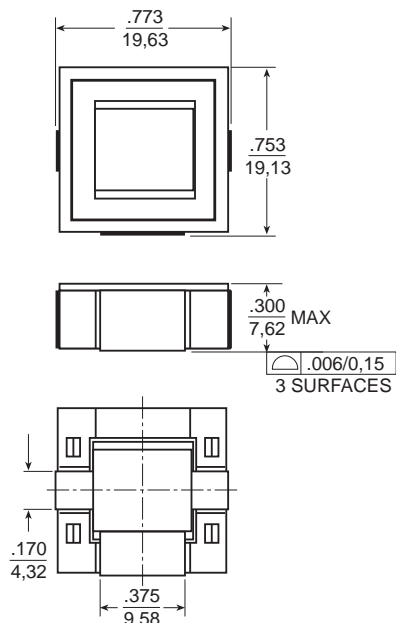


- 15 AMP current capability
- Surface mount
- Heat sinkable

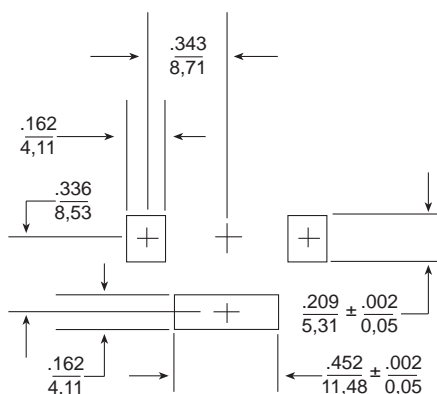
Electrical Specifications* @ 25°C — Operating Temperature -20°C to +85°C

Part Number	Inductance ± 30% at 0 ADC (μH)	Inductance ±30% at IDC (μH)	IDC (MAX ADC at ET MAX)	ET MAX* (V-μSec)	F0 (KHz)	DCR MAX. (milli Ohms)
PE-53974	3.2	1.75	15	6	200-750	4.3
PE-53975	6.7	3.5	10	9	150-750	8.4

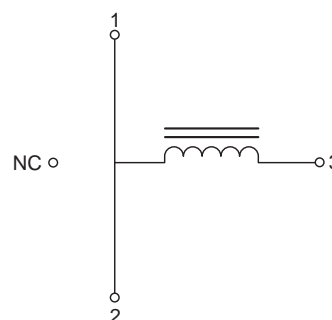
Mechanical



Footprint



Schematic



Dimensions: $\frac{\text{Inches}}{\text{mm}}$
 Unless otherwise specified, all tolerances are $\pm \frac{.010}{0.25}$

Application




These inductors are designed for high current at high ripple frequency. Overall height is 300 mils $\pm 10\%$. The PE-53974

and PE-53975 power inductors are designed to be used with the PE-68471 and PE-68472 surface mount power transformers.

***NOTE:** Specifications are tabulated for 250 KHz operation at 45°C temperature rise with convection cooling only. Heatsinked applications provide higher current and Volt-Microsecond capability.

LOW PROFILE SELF-LEADED CURRENT SENSE INDUCTORS



-  Self-leaded, surface mount
-  Suited for IR and vapor phase reflow soldering
-  Designed for switching power supply applications

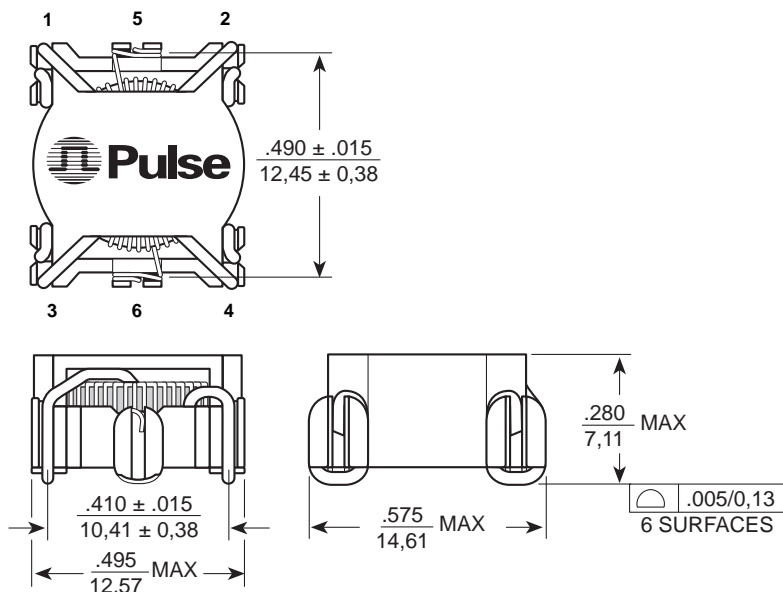
Electrical Specifications @ 25°C — Operating Temperature -30°C to 130°C

Part Number	I (Amps)	R _T (Ω)	Drop (%)	L _s (mH MIN)	R _s (Ω MAX)	Turns (Ns)	Hipot (V _{RMS})
PE-68210	15.3	25	1.3	3.8	.38	50	500
PE-68280	16.3	50	0.7	14.8	.93	100	500
PE-68383	16.4	100	0.3	59.2*	3.9	200	500

NOTES:

1. Inductance is measured at 100 KHz, 20 mVrms. *10KHz, 60 mVrms.
2. Hipot is 500 Vrms, measured at 60 Hz, 2 seconds.
3. I, R_T, and Droop are reference values only.
4. Reference values are for the one turn winding connected in parallel for unipolar operation at 200 KHz.

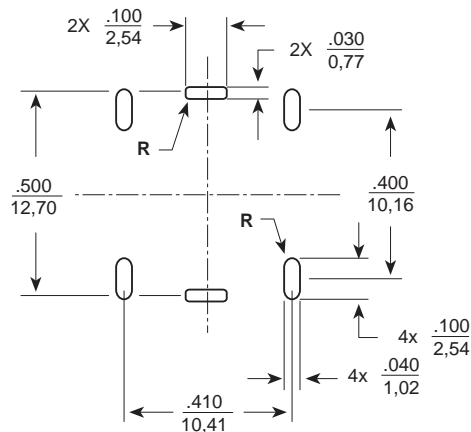
Mechanical



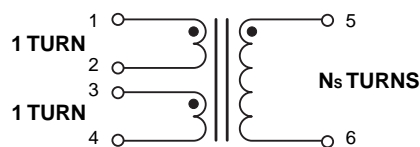
Unless otherwise specified, all tolerances are ± 0.005 / 0.127

Dimensions: Inches / mm

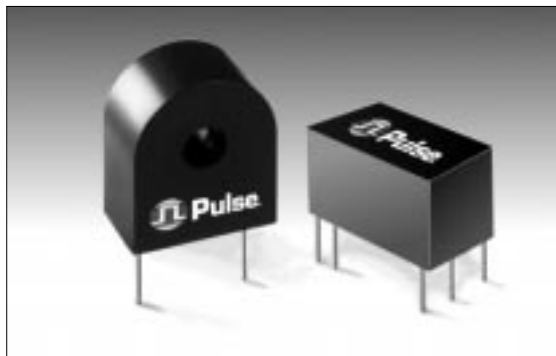
Footprint



Schematic



THOUGH HOLE CURRENT SENSE TRANSFORMERS AND INDUCTORS



- VDE Approved
- Designed for switching power supply applications
- Transformer meets IEC950 insulation requirements
- Frequency range from 20 KHz to 200 KHz

Electrical Specifications @ 25°C — Operating Temperature -30°C to 130°C

Part Number Transformer with 2-1 T Primaries	Schem. Figure	Part Number Transformer with 1T Primary	Schem. Figure	Part Number Inductor without Primary	Schem. Figure	Turns N _s	Secondary Inductance MH (MIN)	Secondary Inductance Test Voltage (15.75 KHz)	R _S (Ω MAX)	R _T (Ω NOM)	Primary Unipolar Amp μ Sec. Rating (MAX)	Primary Bipolar Amp μ Sec. Rating (MAX)
—	1C	PE-63586	1A	PE-51686	2A	50	5.0	0.5	0.7	50	150	300
PE-64487	1C	PE-63587	1A	PE-51687	2A	100	20.0	1.0	1.40	100	300	600
PE-64488	1C	PE-63588	1A	PE-51688	2A	200	80.0	2.0	4.50	200	600	1200
PE-64517	1D	PE-63617	1B	PE-51717	2B	50CT	5.0	0.5	0.7	50	150	300
PE-64518	1D	PE-63618	1B	PE-51718	2B	100CT	20.0	1.0	1.40	100	300	600
PE-64519	1D	PE-63619	1B	PE-51719	2B	200CT	80.0	2.0	4.50	200	600	1200
—	—	PE-63691	1B	—	—	300CT	180.0	3.0	11.0	300	900	1800

NOTES:

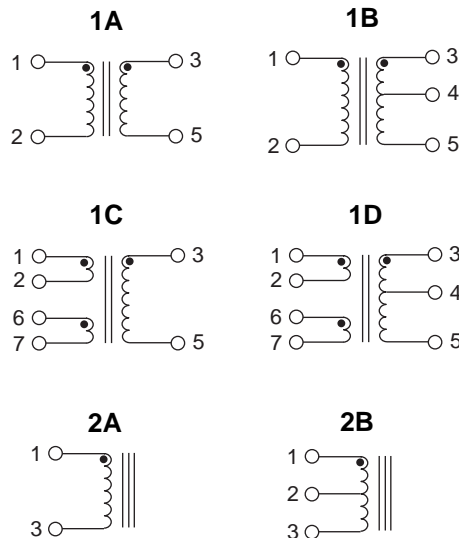
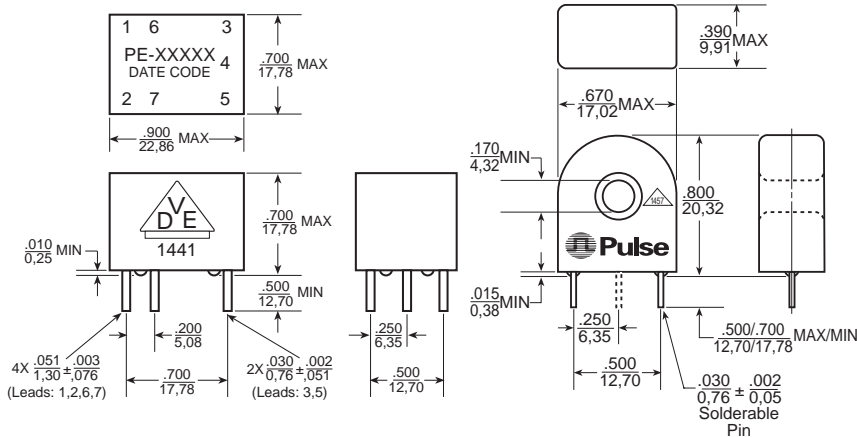
- Maximum ratings specified with rated secondary terminating resistance and 1 turn primary.
- Amp-microsecond (AμSec.) rating of primary equals volt microsecond (VμSec.) rating of secondary when secondary is terminated in rated resistance. (Amp—microseconds is equal to the product of a square pulse of current in amps, times the current pulse width in microseconds.
- Maximum operating temperature 105°C (ambient plus rise).
- When terminated with rated terminating resistance, the inductor scale factor is V_{out} = 1 volt per amp. for center tapped units terminating resistance for each half of winding is listed value divided by two.
- 1 turn primary peak sense current is 20 amps for all parts listed above.

Mechanicals

Schematics

Transformer

Inductor

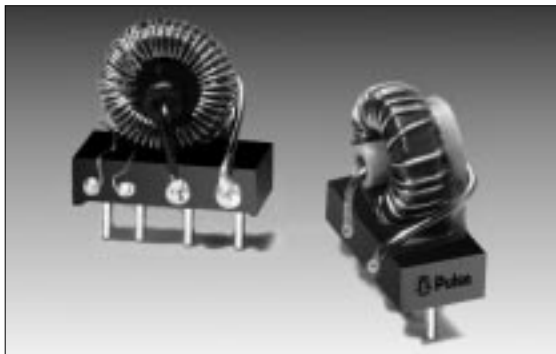


Unless otherwise specified, all tolerances are ± .005 / 0,13

Dimensions: $\frac{\text{Inches}}{\text{mm}}$

500 KHZ CURRENT SENSE TRANSFORMERS & INDUCTORS

Through Hole Package



- Frequency range from 200 to 500 KHz
- 1250 VRMS isolation
- 20 Amp peak sense current

Electrical Specifications @ 25°C — Operating Temperature -30°C to 130°C

Part Number Inductor	Part Number Transformer	RT ¹ (Ω)	Secondary Turns ² N _s	Secondary Inductance ³ (μH MIN)	DCR Secondary (Ω MAX)	DCR Primary (Ω)	V _s (mV)
PE-52876	PE-64976	1.50	10	150	.055	.006	30
PE-52877	PE-64977	3.00	20	600	.097	.006	60
PE-52878	PE-64978	7.50	50	4000	.240	.006	160

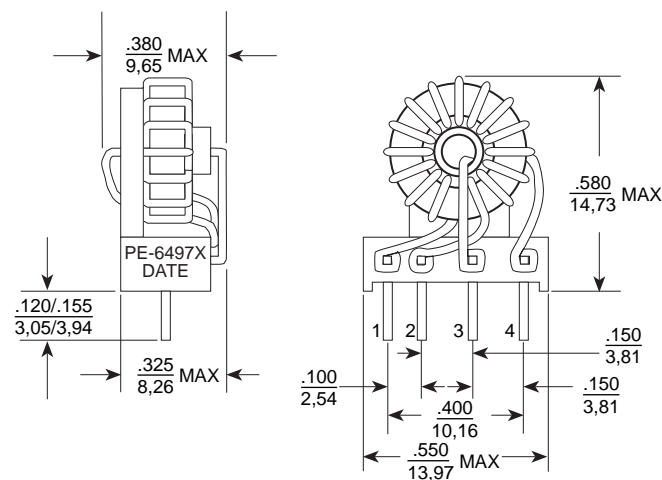
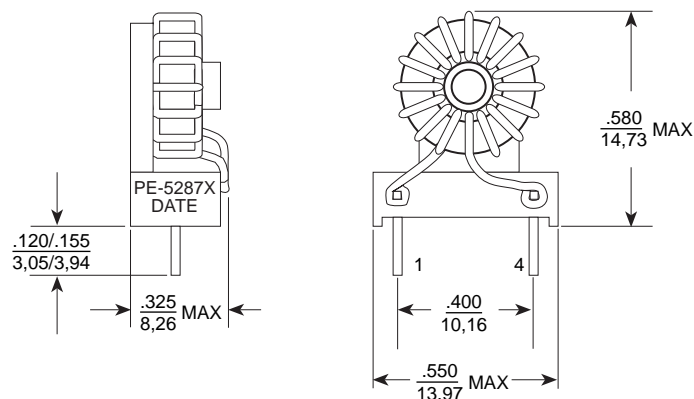
NOTES: 1. Terminating resistance for .15 Volt/Amp
2. ± 1 turn

3. @ 100 KHz, @ V_s

Mechanicals

Inductor

Transformer

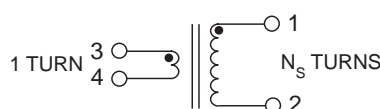
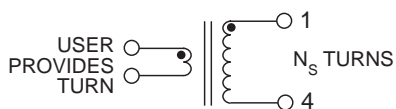


Dimensions: $\frac{\text{Inches}}{\text{mm}}$
Unless otherwise specified, all tolerances are ± $\frac{.010}{0.25}$

Schematics

Inductor

Transformer

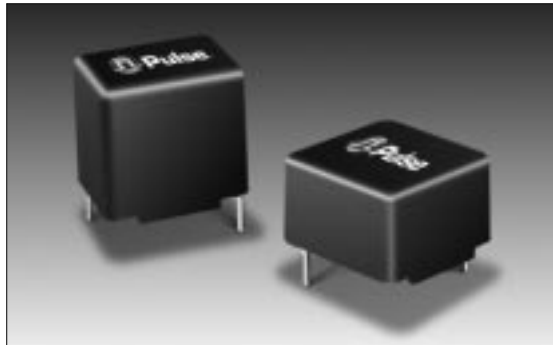


PE-52876, PE-52877, PE-52878

PE-64976, PE-64977, PE-64978

STANDARD LOW POWER INDUCTORS

Switch Mode Power Converters and Ripple Filters



- Designed for general purpose use
- High inductance stability with varying volt-seconds and load currents
- Compact, standard packages
- Low profile or vertical packages

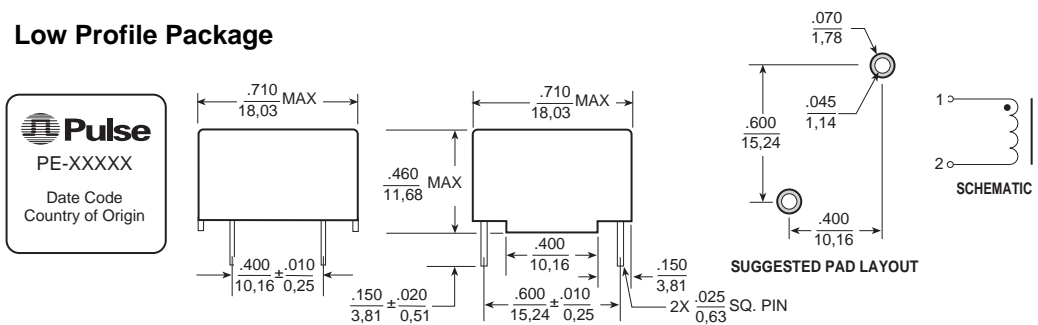
Electrical Specifications @ 25°C — Operating Temperature -30°C to 130°C

REFERENCE OPERATING VALUES						DESIGN CONTROL VALUES		
Low Profile Part Number	Vertical Part Number	Inductance Typical (μH)	I _{DC} (AMPS) ¹	Maximum E _{TOP} ² (V-μSec)	Energy Storage (μJ) ¹	Inductance No DC (μH ± 20%)	20 KHz Test mV No DC	DCR (Ω MAX)
PE-52625	PE-52645	150	1.7	80	215	145	110	.42
PE-52626	PE-52646	220	1.5	90	240	226	140	.42
PE-52627	PE-52647	330	1.0	100	165	316	170	.78
PE-52628	PE-52648	470	.90	120	190	480	210	1.26
PE-52629	PE-52649	680	.85	175	245	690	250	1.50
PE-52630	PE-52650	820	.75	175	230	780	270	2.40
PE-52631	PE-52651	1000	.50	175	125	975	300	2.60

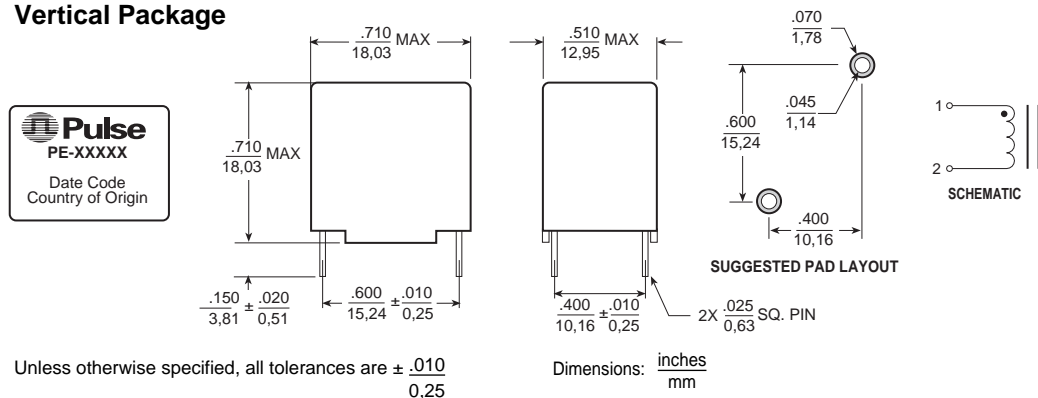
NOTES: 1. I_{DC} rated for 40°C Temperature rise @ low E_{TOP}. 2. Derate current 20% at this E_{TOP}.

Mechanicals

Low Profile Package

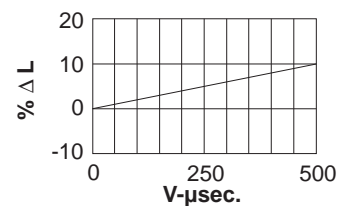


Vertical Package

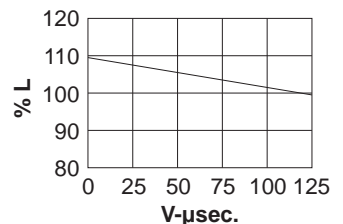


Unless otherwise specified, all tolerances are ± .010 / 0.25 inches / mm

Inductance Characteristics



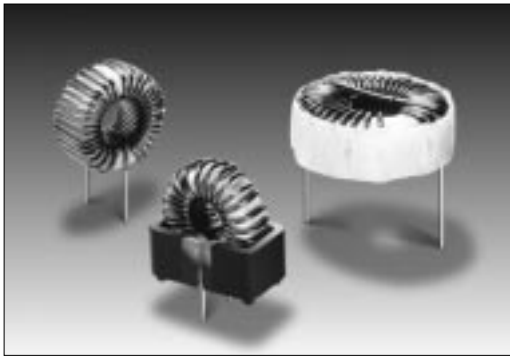
Inductance Variance vs. E.T.








Inductance Variance vs. Load Current

LOW COST INDUCTORS

Electrical Information



-  Available in vertical, low profile and *KlipMount™*
-  SMPS averaging filter
-  Characterized for general purpose use and ripple filters
-  Single-layer designs
-  Can be used as differential mode inductors in EMI filters³

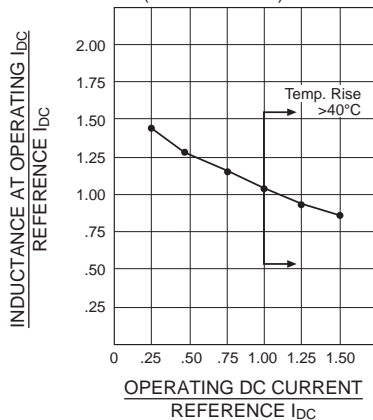
Electrical Specifications @ 25°C — Operating Temperature -30°C to 130°C

REFERENCE OPERATING VALUES						DESIGN CONTROL VALUES					
Vertical Part Number	Low Profile Part Number	Inductance Typical (μH) ¹	I _{DC} (AMPS)	ET _{TOP} (V-μSec)	Energy Storage (μJ) ⁴	Inductance No DC (μHy) ±20%	20 KHz Test mV No DC ²	DCR (Ω MAX) ⁵	Coil Size Code	Klip Mount Package*	Lead Diameter (In) ±.003
PE-51591	—	20	2.0	52	40	32.8	33	.060	H	—	.020
PE-92100	—	25	2.6	30	85	20.7	22	.043	A	KM1	.020
PE-92101	PE-92401	50	2.6	50	169	45.7	45	.071	B	KM2	.020
PE-92102	PE-92402	100	2.6	90	338	94.1	90	.100	C	KM3	.020
PE-92103	—	35	2.6	55	118	28.4	36	.037	B	KM2	.025
PE-92104	PE-92404	70	3.0	85	315	61.0	73	.052	C	KM3	.025
PE-92105	PE-92405	145	3.0	140	653	141.8	140	.087	D	KM4	.025
PE-92106	—	285	3.0	300	1283	264.1	340	.140	E	KM5	.025
PE-92107	—	450	3.0	425	2025	436.3	500	.200	F	—	.025
PE-92108	PE-92408	100	3.6	130	648	90.7	110	.045	D	KM4	.032
PE-92109	—	165	4.0	240	1320	152.0	260	.070	E	KM5	.032
PE-92110	—	270	4.0	350	2160	263.9	400	.100	F	—	.032
PE-92111	—	40	4.0	70	320	37.9	57	.027	C	KM3	.032
PE-51590	—	22	5.0	44	275	20.3	37	.020	G	—	.032
PE-92112	PE-92412	100	5.0	200	1250	90.7	180	.034	E	KM5	.042
PE-92113	—	170	5.0	300	2125	159.7	310	.050	F	—	.042
PE-92114	PE-92414	55	5.0	100	688	54.9	88	.023	D	KM4	.042
PE-92115	—	95	7.0	225	2328	96.0	200	.025	F	—	.051
PE-92116	PE-92416	55	7.0	150	1348	49.1	100	.017	E	KM5	.051
PE-92117	—	55	10.0	175	2750	55.9	120	.013	F	—	.064

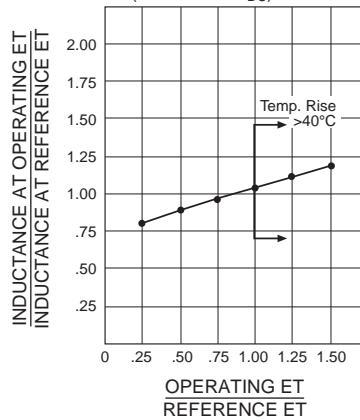
*Parts available with *KlipMount* option can be ordered by adding a "K" suffix to the part number (i.e. PE-92100K).

Relationships Between Reference and Operating Conditions

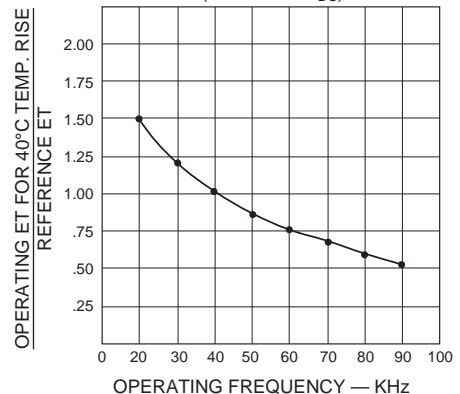
Inductance vs. DC Current (at reference ET)



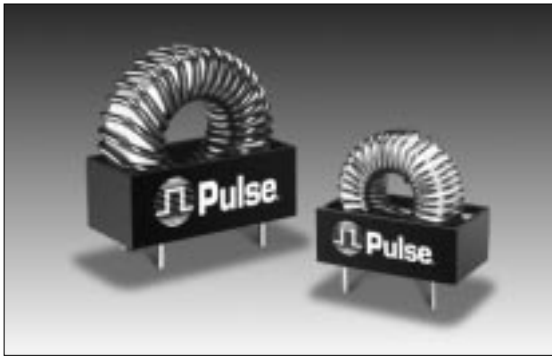
Inductance vs. Operating ET (at reference I_{DC})



Max. Operating ET vs. Frequency (at reference I_{DC})



TOROIDAL INDUCTORS HIGH CURRENT



- Cost-effective designs
- Semi-encapsulated construction
- Maximum operation temperature of 130°C (Ambient + Rise)
- A 2:1 inductance swing from zero to maximum current

Electrical Specifications @ 25°C

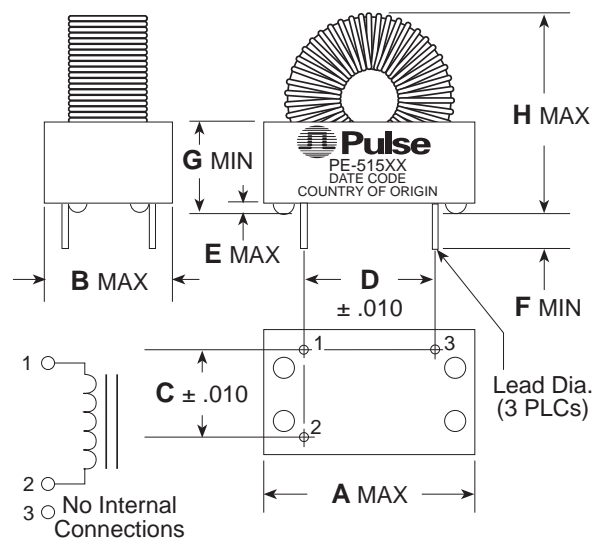
Part Number	REFERENCE OPERATING VALUES					DESIGN CONTROL VALUES				
	Inductance Typical (μH) ²	I _{DC} (AMPS)	ET _{OP} ¹ (V-μSec)		Energy Storage (μJ MIN) ³	Inductance No DC (μH) (±20%)	50 KHz Test mV No DC ⁵	DCR (Ω MAX)	Size Code	Lead Diameter (in ±.003)
			20 KHz	40 KHz						
PE-51506	17.0	17.0	190	130	2460	40.0	140	0.0065	3	0.081
PE-51507	32.0	16.0	290	200	4100	70.7	270	0.0092	4	0.081
PE-51508	60.0	16.0	390	270	7700	120.0	470	0.012	5	0.081
PE-51509	14.0	10.0	135	95	700	28.5	73	0.009	1	0.057
PE-51510	23.0	11.0	170	120	1400	43.5	130	0.012	2	0.057
PE-51511	43.0	10.0	280	195	2150	85.5	210	0.018	3	0.057
PE-51512	90.0	10.0	430	300	4500	158.0	420	0.028	4	0.057
PE-51513	144.0	10.0	570	400	7200	262.0	700	0.032	5	0.057
PE-51514	32.0	6.6	200	140	700	60.5	110	0.025	1	0.040
PE-51515	52.0	7.0	230	160	1275	92.0	190	0.032	2	0.040
PE-51516	98.0	6.0	400	280	1765	188.0	310	0.048	3	0.040
PE-51517	175.0	6.0	620	425	3150	315.0	560	0.068	4	0.040
PE-51518	335.0	6.0	840	580	6030	571.0	1000	0.095	5	0.040
PE-51520	400	3.6	600	420	2700	688.0	640	0.130	3	0.036

Notes:

- To prevent excessive temperature rise, limit ET_{OP} to the rated ET_{OP} specified. This is not a saturation limit. Temperature rise of inductors is 40°C MAX at MAX current and rated ET_{OP}.
- A 2:1 nominal inductance swing from no I_{DC} to operating I_{DC} gives improved protection against current discontinuities at light loading. Inductance increases with greater ET_{OP}. Reference values occur at I_{DC} and low flux density.
- $\frac{LI^2}{2}$ rating is the ability of the inductor to store energy.
- Design control test voltage is critical. Inductance increases with voltage.

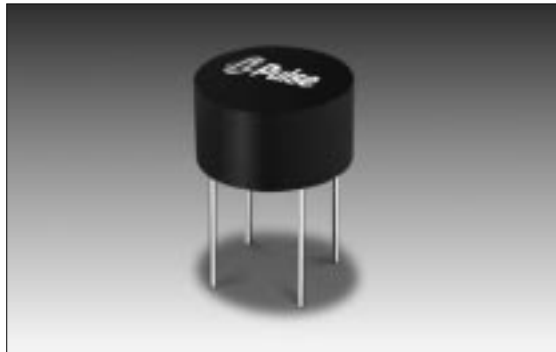
Size Code	1	2	3	4	5	6
A	1.20/30,48	1.44/36,57	1.60/40,64	1.95/49,53	2.30/58,42	1.30/33,02
B	0.60/15,24	0.80/20,32	0.80/20,32	0.91/23,11	1.11/28,21	0.90/22,86
C	0.40/10,16	0.60/15,24	0.60/15,24	0.70/17,78	0.90/22,85	0.66/16,76
D	0.80/20,32	0.90/22,86	0.90/22,86	1.20/30,48	1.50/38,10	0.75/19,05
E	0.45/11,43	0.70/17,78	0.70/17,78	0.90/22,86	1.00/25,40	0.41/10,41
F	0.20/5,08	0.20/5,08	0.20/5,08	0.20/5,08	0.20/5,08	0.10/2,54
G	.015/0,381	0.03/0,76	0.03/0,76	0.03/0,76	0.03/0,76	.015/0,381
H	1.20/30,48	1.44/36,57	1.72/43,68	2.00/50,80	2.30/58,42	1.40/35,56





Mechanicals



Dimensions: $\frac{\text{Inches}}{\text{mm}}$
 Unless otherwise specified, all tolerances are $\pm \frac{.010}{0,25}$

TOROIDAL INDUCTORS HIGH INDUCTANCE



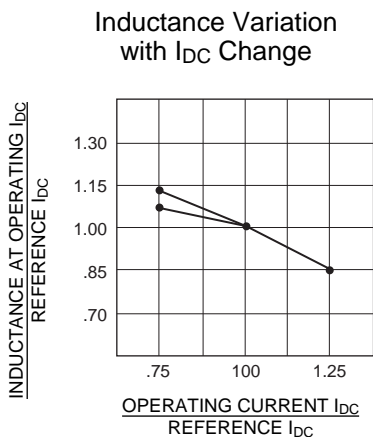
-  High frequency, low loss operation (up to 100 KHz)
-  Encapsulated construction
-  Ambient temperature range of -55°C to +70°C
-  Good inductance stability with temperature

Electrical Specifications @ 25°C

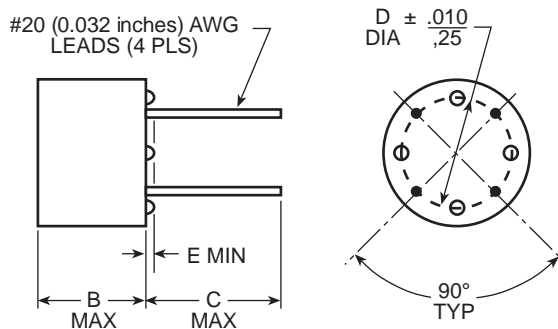
Part Number	REFERENCE OPERATING VALUES				DESIGN CONTROL VALUES		
	Inductance Typical (mH)	I _{DC} (AMPS)	Maximum E _{T OP} (V-μSec)	Energy Storage (μJ MIN) ¹	Inductance No DC (mHy) (±20%) ²	DCR (Ω MAX)	Size Code
PE-50500	0.5	.60	110	90	.72	0.35	7
PE-50501	1.0	.35	160	60	1.51	0.75	7
PE-50502	2.0	.25	225	60	2.88	1.30	7
PE-50503	0.5	1.75	325	765	.72	0.35	8
PE-50506	0.5	2.75	650	1890	.75	0.25	9
PE-50508	2.0	1.50	1200	2250	2.70	0.75	9

NOTES: 1. $\frac{LI^2}{2}$ rating is the ability of the inductor to store energy. 2. Inductance measured at 0.4 Volts and 20KHz.

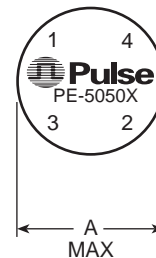
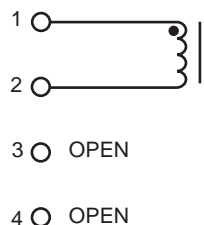
Mechanical



Dimensions: Inches
mm
Unless otherwise specified, all tolerances are ± .010
0,25

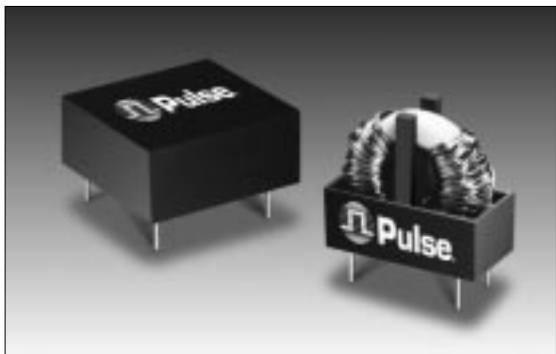







Schematic



Size Code	A	B	C	D	E
7	.754	.400	.500	.625	0.03
	18,92	10,16	12,70	15,87	0,76
8	1.140	.665	.500	1.00	0.03
	28,95	16,89	12,70	25,40	0,76
9	1.416	.850	.500	1.250	0.03
	35,96	21,59	12,70	13,75	0,76

COMMON MODE EMI SUPPRESSION INDUCTORS



-  Low profile or vertical mounting available
-  Windings balanced within one percent
-  For use in switching power supply input filter circuits
-  Dielectric strength 1250 Vrms
-  Designed with 3.0 mm minimum creep distance between windings

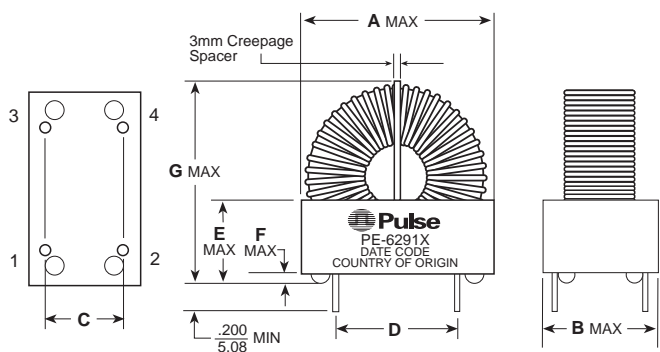
Electrical Specifications @ 25°C— Operating Temperature -30° to +130° C

Low Profile Part Number	Vertical Mount Part Number	Rated RMS Current ¹ (Amps)	Load VA ² at RMS Line		Inductance at 1KHz (mH MIN)	Test Level Volts RMS 1.0KHz	Leakage Inductance 130KHz (µH MIN)	DCR Max. each WDG (Ω)	Package Number	Lead Diameter Inches ± .003	
			117V	220V						Low Profile	Vertical Mount
PE-62891	PE-62911	1.8	210	420	10.0	0.50	130	0.240	1	0.032	0.032
PE-62892	PE-62912	3.5	400	800	3.0	0.20	35	0.060	1	0.032	0.032
PE-62893	PE-62913	6.0	700	1400	1.0	0.08	12	0.020	1	0.036	0.036
PE-62894	PE-62914	2.6	300	600	16.0	1.00	180	0.160	2	0.032	0.040
PE-62895	PE-62915	3.2	375	750	8.0	0.50	90	0.120	2	0.032	0.040
PE-62896	PE-62916	5.2	600	1200	4.0	0.20	45	0.040	2	0.036	0.036
PE-62897	PE-62917	7.5	875	1750	2.0	0.08	25	0.020	2	0.047	0.047

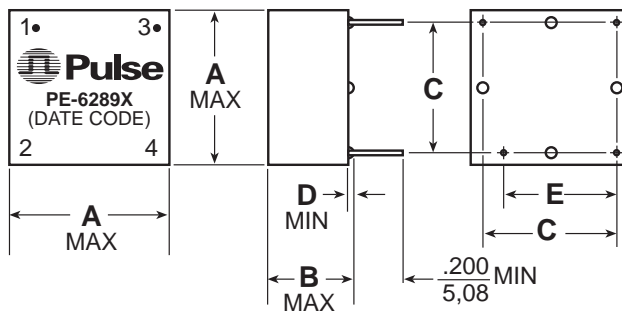
NOTES: 1. Rated RMS current for 40°C rise at any input voltage. 2. **Caution** — do not exceed rated RMS current ratings.

Mechanicals

Vertical Package



Low Profile Package



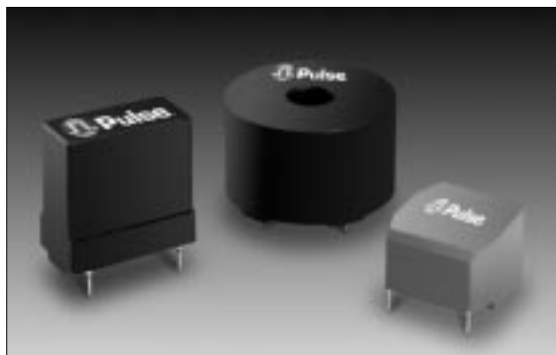
Package Number	A	B	C	D	E	F	G
1	$\frac{1.15}{29,21}$	$\frac{.550}{13,97}$	$\frac{.400}{10,15}$	$\frac{.800}{20,32}$	$\frac{.45}{11,43}$	$\frac{.015}{0,38}$	$\frac{1.15}{29,21}$
2	$\frac{1.44}{36,57}$	$\frac{.800}{20,32}$	$\frac{.600}{15,24}$	$\frac{.900}{22,86}$	$\frac{.70}{17,78}$	$\frac{.030}{0,76}$	$\frac{1.50}{38,10}$




Package Number	A	B	C	D	E
1	$\frac{1.25}{31,75}$	$\frac{.600}{15,24}$	$\frac{1.00}{25,40}$	$\frac{.015}{0,38}$	$\frac{.900}{22,86}$
2	$\frac{1.50}{38,10}$	$\frac{.800}{20,32}$	$\frac{1.28}{32,51}$	$\frac{.010}{0,25}$	$\frac{1.083}{27,50}$

Unless otherwise specified, all tolerances are ± $\frac{.010}{0,25}$

Dimensions: $\frac{\text{Inches}}{\text{mm}}$

500 KHz COMMON MODE EMI INDUCTORS

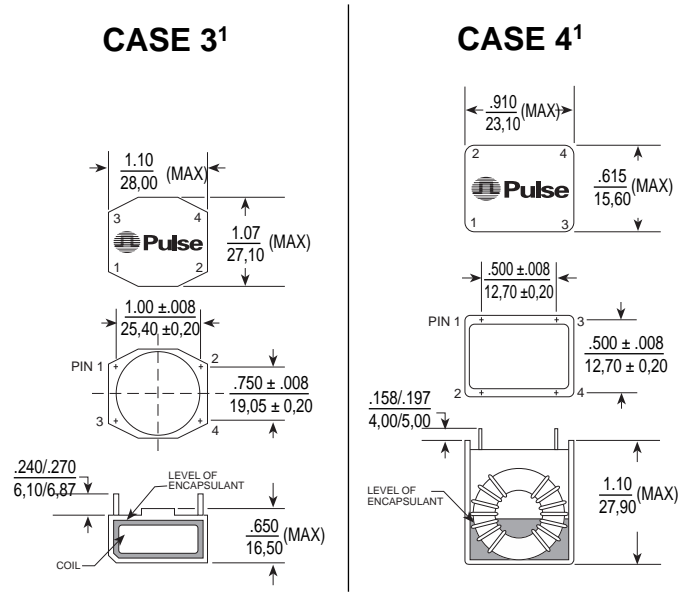
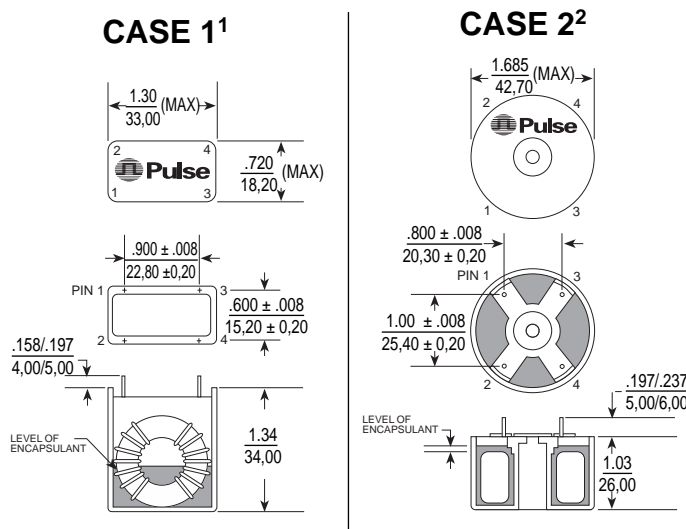


-  Common mode EMI Inductors
-  Designed for higher frequency power conversion
-  For use in SMPS input filtering circuits

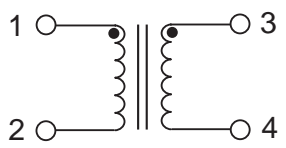
Mechanicals

Elect. Specs. @ 25°C— Operating Temp. -30° to +130° C

Part Number	Rated RMS Current (A.Normal)	Inductance mH (± 30%)	DCR Ohms (MAX)	Case Style	Leakage Inductance (MIN/MAX µH)	Self Resonant (KHz MIN)
PE-96161	0.5	33	1.40	3	160/320	125
PE-96165	1.0	18	0.50	1	120/320	250
PE-96166	1.0	5.6	0.30	3	30/60	850
PE-96168	2.0	15	0.29	1	100/220	250
PE-96173	3.15	5.6	0.10	1	40/80	450
PE-96175	3.15	3.3	0.07	3	15/35	1000
PE-96177	3.15	2.2	0.06	3	10/20	1400
PE-96178	3.15	1.2	0.04	3	6/15	2100
PE-96179	3.15	1.2	0.04	4	5/14	1600
PE-96181	5.0	3.9	0.06	1	25/60	650
PE-96186	6.3	2.7	0.04	1	20/45	650
PE-96187	8.0	3.3	0.033	2	20/45	600
PE-96188	10.0	1.8	0.02	2	10/25	850
PE-96189	12.5	1.5	0.015	2	10/20	900
PE-96190	15.0	1.0	0.01	2	7/15	1000



Schematic



Dimensions: $\frac{\text{Inches}}{\text{mm}}$
 Unless otherwise specified, all tolerances are $\pm \frac{.010}{0.25}$

- NOTES:**
1. Leads have $\frac{.031}{.039}$ / $\frac{.700}{.900}$ diameter.
 2. Self-leaded: **96187** has .036 nom. diameter leads. **96188** and **96189** have .045 nom. diameter leads. **96190** has .051 nom. diameter leads.

Power Inductors – DC1012 Series



These power inductors are especially effective as DC-DC converter boost or buck inductors and as output ripple filter chokes in all types of downsized switching power supplies.

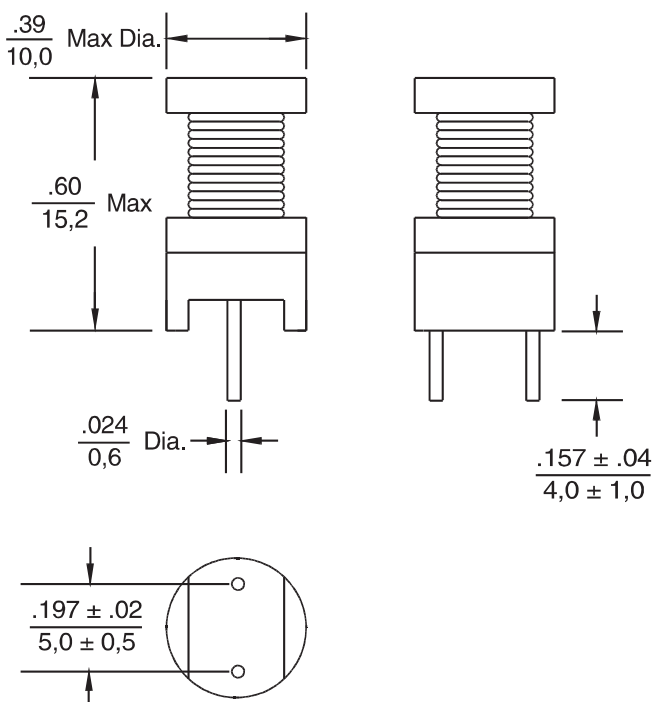
They are ideal for applications requiring small size, cost effective power inductors. The vertical style helps reduce power supply size by saving crucial printed circuit board area. The large inductance available per size makes these parts ideal for all sorts of energy storage, smoothing, and EMI reduction applications.

The Coilcraft DC1012 Series includes a wide range of EIA standard inductance values. Custom versions are also available.

Coilcraft **Designer's Kit P210** contains three samples of all the standard parts shown. To order, contact Coilcraft.

Specifications

Part Number	Inductance ¹ 10% μ H	DCR Max (Ω)	Current Rating ² (Amps)
DC1012-103	10	.026	3.5
DC1012-123	12	.030	3.2
DC1012-153	15	.035	3.0
DC1012-183	18	.038	2.8
DC1012-223	22	.046	2.5
<hr/>			
DC1012-273	27	.070	2.2
DC1012-333	33	.080	2.0
DC1012-393	39	.088	1.8
DC1012-473	47	.100	1.6
DC1012-563	56	.15	1.4
<hr/>			
DC1012-683	68	.17	1.2
DC1012-823	82	.20	1.2
DC1012-104	100	.22	1.2
DC1012-124	120	.29	1.0
DC1012-154	150	.34	.9
<hr/>			
DC1012-184	180	.38	.8
DC1012-224	220	.44	.7
DC1012-274	270	.62	.7
DC1012-334	330	.70	.6



1. Tested at 100 kHz, .1 Vrms.

2. Current rating is based on I^2R loss = 3/8 Watt Max. Inductance drop is 10% typ. at the rated current.

Coilcraft

Document 147 Revised 6/25/97

Power Chokes – Vertical Mount



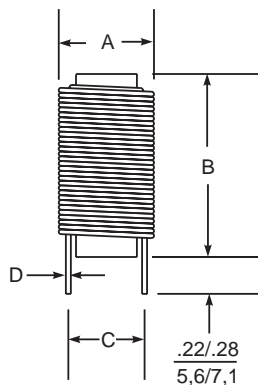
The Coilcraft PCV-0 and PCV-1 Series are low cost power inductors whose simple design provides rugged reliability and performance.

The open core construction of both series provides the highest saturation current available in a low cost power choke. The PCV-1 Series also incorporates a plastic mounting header for maximum lead protection and consistency.

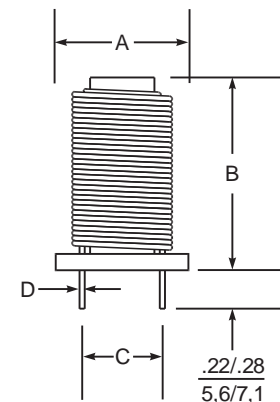
Coilcraft **Designer's Kit P205** contains samples of the values shown in bold as well as values from our PCV-2 Series. To order, contact Coilcraft.

- Low cost
- Wide range of standard values
- All 130°C class insulation

PCV-0 Series



PCV-1 Series



PCV-0 Series

Part Number	Inductance ¹ (μ H)	Isat ² (Amps)	Irms ³ (Amps)	DCR Max (Ω)	A Max	B Max	C $\pm .015/0,38$	D $\pm .004/0,10$
PCV-0-102-25	1.0 $\pm 15\%$	25	25	.002	.60/15,2	.68/17,3	.42/10,7	.068/1,73
PCV-0-102-10	1.0	10	10	.002	.50/12,7	.75/19,1	.42/10,7	.054/1,37
PCV-0-332-10	3.3	10	10	.005	.50/12,7	1.0/25,4	.42/10,7	.054/1,37
PCV-0-472-03	4.7	3	3	.021	.51/13,0	.75/19,1	.42/10,7	.035/0,89
PCV-0-472-05	4.7	5	5	.012	.50/12,7	.75/19,1	.42/10,7	.042/1,07
PCV-0-472-10	4.7	10	10	.012	.50/12,7	1.0/25,4	.42/10,7	.054/1,37
PCV-0-472-20	4.7	20	20	.004	.53/13,5	1.2/30,5	.42/10,7	.068/1,73
PCV-0-103-03	10 $\pm 10\%$	3	3	.023	.50/12,7	.75/19,1	.42/10,7	.035/0,89
PCV-0-103-05	10	5	5	.017	.50/12,7	.75/19,1	.42/10,7	.042/1,07
PCV-0-103-10	10	10	10	.015	.52/13,2	1.0/25,4	.42/10,7	.054/1,37

¹ Tested at 15.75 kHz, .1 Vrms, with DC bias applied up to the rated current.

² Inductance drop = 10% typ. at Isat.

³ $\Delta T = 40^\circ\text{C}$ rise typ. at Irms (85°C ambient).

Parts in bold type are included in Coilcraft Designer's Kit No. P205.

Coilcraft

Specifications subject to change without notice. Document 135-1 Revised 7/31/00

1102 Silver Lake Road Cary, Illinois 60013 Phone 847/639-6400 Fax 847/639-1469

E-mail info@coilcraft.com Web http://www.coilcraft.com Page 484 of 662

PCV-0 Series – Continued

Part Number	Inductance ¹ (μ H)	Isat ² (Amps)	Irms ³ (Amps)	DCR Max (Ω)	A Max	B Max	C $\pm .015/0,38$	D $\pm .004/0,10$
PCV-0-103-20	10 \pm 10%	20	20	.006	.75/19,1	1.8/45,7	.60/15,2	.075/1,91
PCV-0-153-03	15	3	3	.025	.50/12,7	1.0/25,4	.42/10,7	.035/0,89
PCV-0-153-10	15	10	10	.020	.52/13,2	1.0/25,4	.42/10,7	.054/1,37
PCV-0-223-03	22	3	3	.035	.50/12,7	1.0/25,4	.42/10,7	.035/0,89
PCV-0-223-05	22	5	5	.023	.50/12,7	1.0/25,4	.42/10,7	.042/1,07
PCV-0-223-10	22	10	10	.015	.66/16,8	1.3/33,0	.42/10,7	.060/1,52
PCV-0-273-05	27	5	5	.024	.50/12,7	1.0/25,4	.49/12,5	.042/1,07
PCV-0-333-12	33	12	12	.017	.70/17,8	1.3/33,0	.55/14,0	.060/1,52
PCV-0-473-03	47	3	3	.050	.55/14,0	1.0/25,4	.42/10,7	.035/0,89
PCV-0-473-05	47	5	5	.035	.65/16,5	1.1/28,0	.70/17,8	.042/1,07
PCV-0-473-10	47	10	10	.022	.85/21,6	1.3/33,0	.70/17,8	.060/1,52
PCV-0-823-03	82	3	3	.110	.50/12,7	.65/16,5	.375/9,5	.028/0,71
PCV-0-104-01	100	1	1	.190	.40/10,2	.90/22,9	.30/7,6	.020/0,51
PCV-0-104-03	100	3	3	.072	.55/14,0	1.2/30,5	.70/17,8	.035/0,89
PCV-0-104-05	100	5	5	.055	.65/16,5	1.3/33,0	.70/17,8	.042/1,07
PCV-0-154-03	150	3	3	.140	.60/15,2	1.2/30,5	.43/10,9	.028/0,71
PCV-0-154-05	150	5	5	.065	.65/16,5	1.3/33,0	.70/17,8	.042/1,07
PCV-0-184-05	180	5	5	.110	.60/15,2	1.2/30,5	.43/10,9	.035/0,89
PCV-0-224-03	220	3	3	.210	.55/14,0	1.2/30,5	.42/10,7	.025/0,64
PCV-0-274-04	270	4	4	.250	.95/24,0	.72/18,3	.71/18,0	.030/0,76
PCV-0-274-10	270	10	10	.160	1.1/28,0	1.0/25,4	.72/18,3	.038/0,97
PCV-0-394-03	390	3	3	.250	1.1/28,0	1.0/25,4	.72/18,3	.035/0,89
PCV-0-394-05	390	5	5	.190	1.1/28,0	1.0/25,4	.72/18,3	.038/0,97

PCV-1 Series

Part Number	Inductance ¹ (μ H)	Isat ² (Amps)	Irms ³ (Amps)	DCR Max (Ω)	A Max	B Max	C $\pm .015/0,38$	D $\pm .004/0,10$
PCV-1-152-15	1.5 \pm 15%	15	15	.003	.65/16,5	.90/22,9	.42/10,7	.068/1,73
PCV-1-182-10	1.8	10	10	.006	.65/16,5	1.1/27,9	.42/10,7	.054/1,37
PCV-1-182-15	1.8	15	15	.003	.65/16,5	1.1/27,9	.42/10,7	.068/1,73
PCV-1-472-03	4.7	3	3	.021	.62/15,7	.85/21,6	.42/10,7	.035/0,89
PCV-1-472-05	4.7	5	5	.012	.62/15,7	.85/21,6	.42/10,7	.042/1,07
PCV-1-472-10	4.7	10	10	.012	.62/15,7	1.1/27,9	.42/10,7	.054/1,37
PCV-1-103-03	10 \pm 10%	3	3	.026	.63/16,0	.85/21,6	.42/10,7	.035/0,89
PCV-1-103-05	10	5	5	.020	.62/15,7	.85/21,6	.42/10,7	.042/1,07
PCV-1-103-10	10	10	10	.013	.63/16,0	1.1/27,9	.42/10,7	.054/1,37
PCV-1-153-10	15	10	10	.020	.70/17,8	1.4/35,6	.42/10,7	.060/1,52
PCV-1-223-03	22	3	3	.035	.62/15,7	1.1/27,9	.42/10,7	.035/0,89
PCV-1-223-05	22	5	5	.023	.62/15,7	1.1/27,9	.42/10,7	.042/1,07
PCV-1-223-10	22	10	10	.018	.70/17,8	1.4/35,6	.42/10,7	.060/1,52
PCV-1-473-03	47	3	3	.050	.65/16,5	1.1/27,9	.42/10,7	.035/0,89
PCV-1-473-05	47	5	5	.033	.90/22,9	1.2/30,5	.70/17,8	.042/1,07
PCV-1-473-10	47	10	10	.022	.90/22,9	1.4/35,6	.70/17,8	.060/1,52
PCV-1-104-03	100	3	3	.072	.90/22,9	1.3/33,1	.70/17,8	.035/0,89
PCV-1-104-05	100	5	5	.055	.90/22,9	1.4/35,6	.70/17,8	.042/1,07
PCV-1-184-03	180	3	3	.150	.63/16,0	1.2/30,5	.42/10,7	.028/0,71
PCV-1-304-05	300	5	5	.160	1.1/27,9	1.0/25,4	.70/17,8	.038/0,97
PCV-1-394-05	390	5	5	.190	1.1/27,9	1.0/25,4	.70/17,8	.038/0,97

¹ Tested at 15.75 kHz, .1 Vrms, with DC bias applied up to the rated current.

² Inductance drop = 10% typ. at Isat.

³ $\Delta T = 40^\circ\text{C}$ rise typ. at Irms (85 $^\circ\text{C}$ ambient).

Parts in bold type are included in Coilcraft Designer's Kit No. P205.



Specifications subject to change without notice. Document 135-2 Revised 7/31/00

1102 Silver Lake Road Cary, Illinois 60013 Phone 847/639-6400 Fax 847/639-1469

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Axial Lead Power Chokes – PCH-27, 45



Coilcraft's horizontal mount power chokes provide a wide range of inductance in a low profile design.

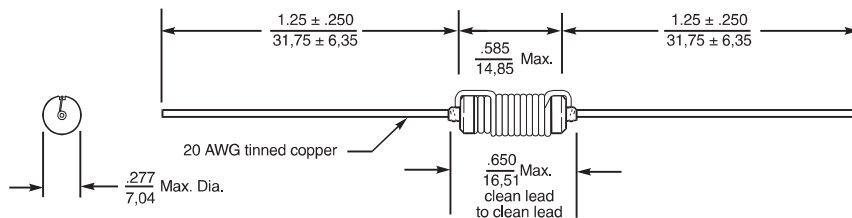
Two sizes are available; the compact PCH-27 Series, and the larger PCH-45 Series with higher current ratings.

They're ideal for use as output chokes in low power, downsized switching power supplies, DC/DC converters and inverters, EMI/RFI noise suppression, and smoothing choke applications.

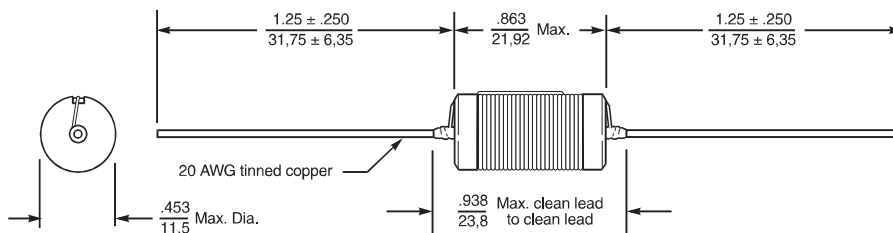
Coilcraft **Designer's Kit No. P209** contains samples of 30 standard parts (2 pieces each) from both series. To order, please contact Coilcraft.

- Wide inductance range in a low profile part
- High saturation current—up to 14.3 Amps DC
- Standard EIA or custom values
- Optional tape and reel packaging
- Designer's Kit of sample parts available
- Most values shipped from stock

PCH-27 SERIES



PCH-45 SERIES



Coilcraft

Specifications subject to change without notice. Document 138-1 Revised 7/8/97

PCH-27 SERIES POWER CHOKES

Part Number	Inductance $\pm 10\%$ Nom	SRF Typ (MHz)	DCR Max (Ohms)	Sat. Current (DC Amps)	Rated Current (AC Amps)
PCH-27-392	3.9 μH	38	.017	7.01	1.7
PCH-27-472	4.7	26	.024	6.16	1.3
PCH-27-562	5.6	25	.025	5.79	1.3
PCH-27-682	6.8	25	.028	5.20	1.3
PCH-27-822	8.2	22	.030	4.70	1.3
PCH-27-103	10	17	.033	4.30	1.3
PCH-27-123	12	16	.037	3.80	1.3
PCH-27-153	15	12	.041	3.41	1.3
PCH-27-183	18	11	.045	3.09	1.3
PCH-27-223	22	10	.064	2.82	1.0
PCH-27-273	27	7	.071	2.53	1.0
PCH-27-333	33	7	.078	2.29	1.0
PCH-27-393	39	7	.085	2.09	1.0
PCH-27-473	47	6	.094	1.88	1.0
PCH-27-563	56	6	.12	1.74	.84
PCH-27-683	68	7	.16	1.57	.67
PCH-27-823	82	4	.22	1.41	.52
PCH-27-104	100	3	.25	1.28	.52
PCH-27-124	120	3	.35	1.17	.42
PCH-27-154	150	3	.39	1.04	.42
PCH-27-184	180	3	.43	.943	.42
PCH-27-224	220	3	.47	.848	.42
PCH-27-274	270	2	.65	.764	.33
PCH-27-334	330	2	.72	.690	.33
PCH-27-394	390	2	.78	.632	.33
PCH-27-474	470	2	1.04	.573	.26
PCH-27-564	560	1	1.14	.520	.26
PCH-27-684	680	1	1.49	.472	.21
PCH-27-824	820	1	2.14	.427	.16
PCH-27-105	1.0 mH	1	2.36	.385	.16
PCH-27-125	1.2	1	2.59	.350	.16
PCH-27-155	1.5	.85	3.57	.312	.13
PCH-27-225	2.2	.65	4.33	.255	.13
PCH-27-275	2.7	.65	5.91	.229	.10
PCH-27-335	3.3	.60	8.63	.207	.083
PCH-27-395	3.9	.60	9.38	.189	.083
PCH-27-475	4.7	.50	10.3	.172	.083
PCH-27-565	5.6	.60	11.2	.157	.083
PCH-27-685	6.8	.40	15.0	.142	.067
PCH-27-825	8.2	.35	21.7	.128	.052
PCH-27-106	10	.30	24.0	.116	.052
PCH-27-126	12	.25	33.2	.105	.040
PCH-27-156	15	.30	47.2	.094	.031
PCH-27-186	18	.30	51.7	.085	.031

Parts in bold type are included in Coilcraft Designer's Kit P209.



Specifications subject to change without notice. Document 138-2 Revised 11/14/97

PCH-45 SERIES POWER CHOKES

Part Number	Inductance $\pm 10\%$ Nom	SRF Typ (MHz)	DCR Max (Ohms)	Sat. Current (DC Amps)	Rated Current (AC Amps)
PCH-45-392	3.90 μ H	34	.008	14.3	4.3
PCH-45-472	4.70	31	.009	13.0	4.3
PCH-45-562	5.60	29	.009	11.9	4.3
PCH-45-682	6.80	26	.010	11.0	4.3
PCH-45-822	8.20	23	.011	9.50	4.3
PCH-45-103	10.0	20	.012	8.93	4.3
PCH-45-123	12.0	17	.013	7.94	4.3
PCH-45-153	15.0	14	.015	7.15	4.3
PCH-45-183	18.0	11	.016	6.50	4.3
PCH-45-223	22.0	10	.017	5.95	4.3
PCH-45-273	27.0	9	.019	5.50	4.3
PCH-45-333	33.0	9	.021	4.93	4.3
PCH-45-393	39.0	8	.025	4.46	4.3
PCH-45-473	47.0	7	.035	4.08	3.4
PCH-45-563	56.0	6	.037	3.76	3.4
PCH-45-683	68.0	5	.044	3.40	2.7
PCH-45-823	82.0	4	.060	3.10	2.1
PCH-45-104	100	3	.086	2.80	1.7
PCH-45-124	120	3	.095	2.55	1.7
PCH-45-154	150	3	.14	2.30	1.3
PCH-45-184	180	2	.15	2.10	1.3
PCH-45-224	220	2	.17	1.90	1.3
PCH-45-274	270	2	.19	1.72	1.3
PCH-45-334	330	2	.21	1.55	1.3
PCH-45-394	390	2	.26	1.43	1.0
PCH-45-474	470	1	.32	1.30	1.0
PCH-45-564	560	1	.38	1.19	.84
PCH-45-684	680	1	.51	1.08	.67
PCH-45-824	820	1	.59	.986	.67
PCH-45-105	1.0 mH	1	.69	.893	.67
PCH-45-125	1.2	1	.78	.817	.67
PCH-45-155	1.5	.75	.92	.729	.67
PCH-45-225	2.2	.70	1.67	.600	.42
PCH-45-275	2.7	.65	2.28	.543	.33
PCH-45-335	3.3	.60	2.59	.491	.33
PCH-45-395	3.9	.55	2.87	.452	.33
PCH-45-475	4.7	.50	3.22	.412	.33
PCH-45-565	5.6	.40	4.25	.377	.26
PCH-45-685	6.8	.35	5.88	.342	.21
PCH-45-825	8.2	.30	6.46	.311	.21
PCH-45-106	10	.30	9.10	.282	.16
PCH-45-126	12	.30	9.99	.257	.16
PCH-45-156	15	.30	11.2	.230	.16
PCH-45-186	18	.20	15.2	.210	.13
PCH-45-226	22	.20	16.8	.190	.13
PCH-45-276	27	.15	18.6	.171	.13
PCH-45-336	33	.15	26.7	.155	.10
PCH-45-396	39	.15	29.0	.143	.10
PCH-45-476	47	.10	31.8	.131	.10
PCH-45-566	56	.10	42.6	.119	.083
PCH-45-686	68	.10	46.9	.108	.083
PCH-45-826	82	.10	64.9	.098	.067
PCH-45-107	100	.10	71.7	.099	.067

Parts in bold type are included in Coilcraft Designer's Kit P209.



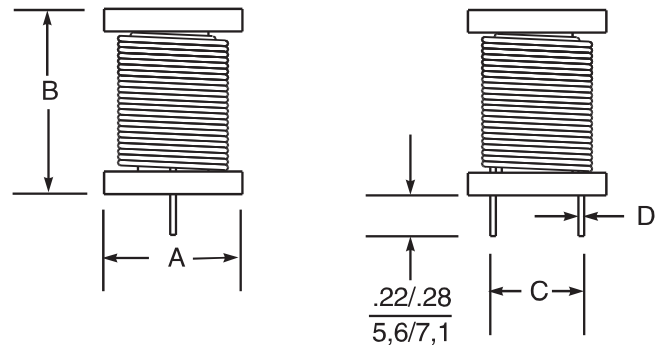
Specifications subject to change without notice. Document 138-3 Revised 11/14/97

Power Chokes – Vertical Mount



The PCV-2 Series uses a ferrite bobbin core to provide the highest possible inductance at the lowest cost. It features 130°C class insulation and comes in a wide range of standard values.

Coilcraft **Designer's Kit P205** contains samples of the parts shown in bold as well as values from our PCV-0 Series. To order, contact Coilcraft.



Part Number	Inductance ¹ ±10% (μH)	Current Rating ² (Amps)	DCR Max (Ω)	A Max	B Max	C ±.015/0,38	D ±.004/0,10
PCV-2-103-05	10	5	.015	.61/15,49	.83/21,08	.42/10,67	.042/1,07
PCV-2-103-10	10	10	.010	.61/15,49	.83/21,08	.50/12,70	.054/1,37
PCV-2-223-05	22	5	.020	.61/15,49	.83/21,08	.42/10,67	.042/1,07
PCV-2-223-10	22	10	.015	.86/21,84	.83/21,08	.58/14,73	.054/1,37
PCV-2-473-05	47	5	.035	.70/17,78	.83/21,08	.48/12,19	.038/0,97
PCV-2-473-10	47	10	.020	1.00/25,40	.83/21,08	.70/17,78	.054/1,37
PCV-2-104-03	100	3	.080	.84/21,34	.83/21,08	.58/14,73	.031/0,79
PCV-2-104-05	100	5	.045	.84/21,34	.83/21,08	.70/17,78	.042/1,07
PCV-2-104-10	100	10	.032	1.05/26,67	1.10/27,94	.88/22,35	.054/1,37
PCV-2-184-05	180	5	.092	.80/20,32	.90/22,86	.58/14,73	.035/0,89
PCV-2-184-10	180	10	.048	1.44/36,58	1.10/27,94	1.05/26,67	.054/1,37
PCV-2-224-05	220	5	.075	1.05/26,67	1.10/27,94	.75/19,05	.042/1,07
PCV-2-274-03	270	3	.13	1.00/25,40	.83/21,08	.75/19,05	.035/0,89
PCV-2-274-05	270	5	.080	1.05/26,67	1.05/26,67	.80/20,32	.042/1,07
PCV-2-274-10	270	10	.060	1.50/38,10	1.10/27,94	1.08/27,43	.054/1,37
PCV-2-394-05	390	5	.13	1.10/29,34	.83/21,08	.85/21,59	.038/0,97
PCV-2-564-02	560	2	.27	.80/20,32	.90/22,86	.57/14,48	.028/0,71
PCV-2-564-06	560	6	.17	1.21/30,73	1.10/27,94	.90/22,86	.038/0,97
PCV-2-564-08	560	8	.090	1.50/38,10	1.43/36,32	1.08/27,43	.054/1,37
PCV-2-684-01	680	1	.70	.70/17,78	.83/21,08	.50/12,70	.018/0,46
PCV-2-105-02	1000	2	.37	1.00/25,40	.83/21,08	.72/18,29	.028/0,71

¹ Tested at 15.75 kHz, .1 Vrms, with DC bias applied up to the rated current.

² Parts are designed for 40°C Max temperature rise at the rated current.

Parts in bold type are included in Coilcraft Designer's Kit No. P205.

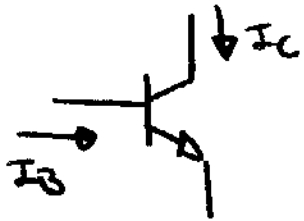
Coilcraft

Document 136 Revised 6/25/97

Switching Devices

①

Bipolar Junction Transistors



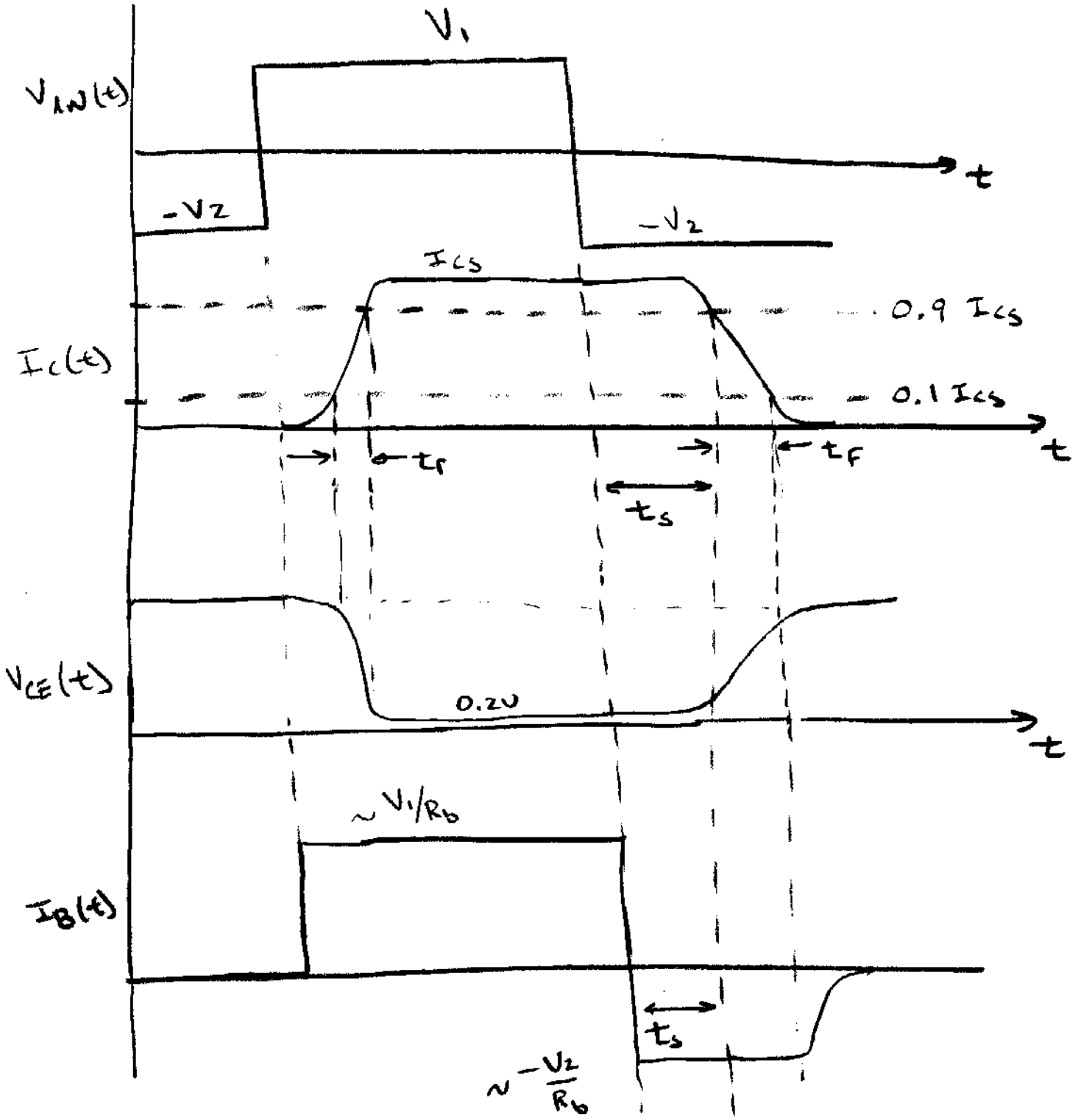
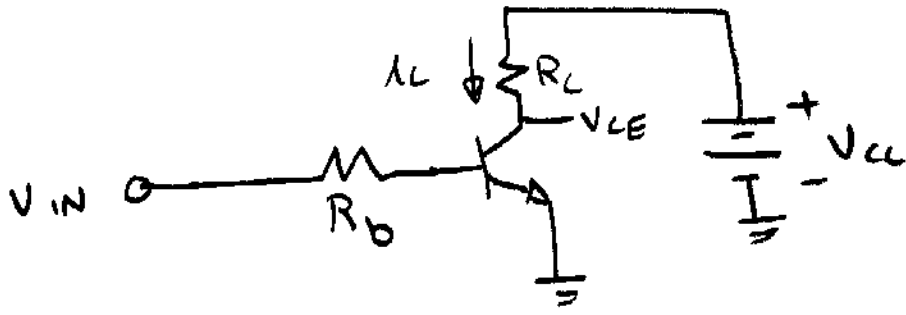
- must saturate to turn on

$$\Rightarrow V_{CE} = 0.3V$$

$$I_B > \frac{I_C}{\beta}$$

- must supply continuous current to Base

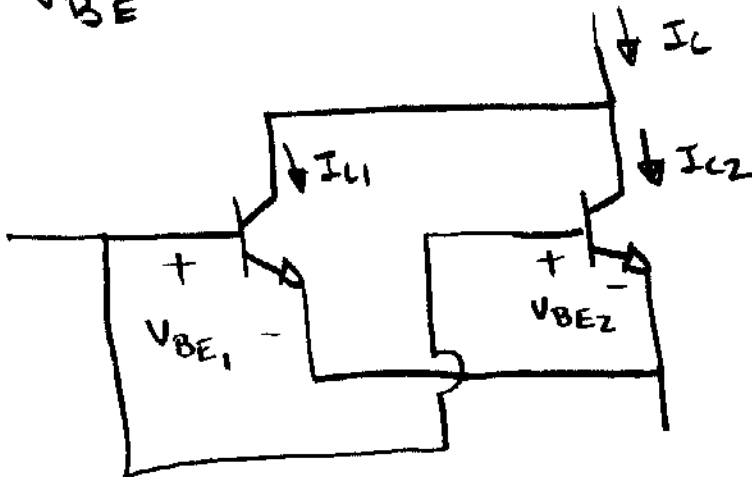
- High voltage capability when off
- Negative temperature coefficient (hard to parallel)
- Storage Time : in order to remove a transistor from saturation, you must remove excess charge from the base region of the device. while you are removing this charge, the collector current remains relatively constant



- Storage time INCREASES with temperature

\Rightarrow as BJT heats up, it takes longer to turn off

- Look at the (-) temperature coefficient for V_{BE}



- Suppose due to slight mismatch that

$$I_{C2} > I_{C1}$$

- Q_2 heats up more than Q_1 .

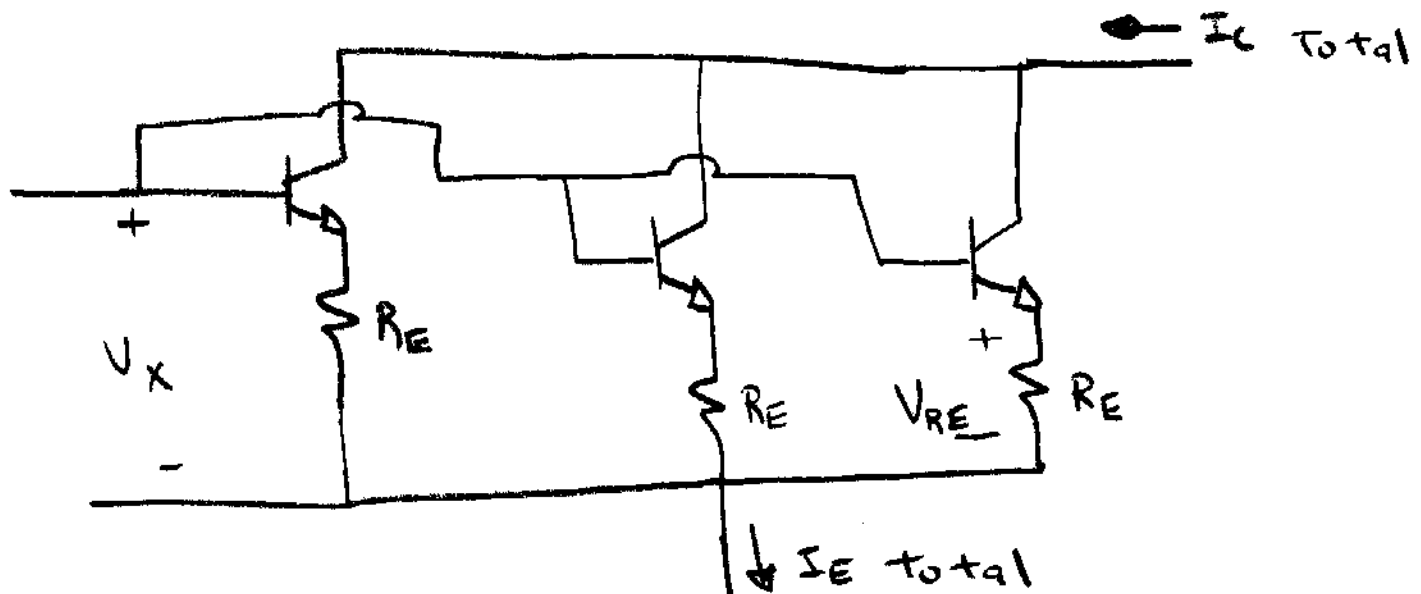
- For BJT's, for constant I_B , V_{BE} decreases by $2\text{mV}/^\circ\text{C}$ increase in Temp. OR

- for constant V_{BE} , I_C doubles for every 10°C increase in temperature.

- Since $I_{C2} > I_{C1}$, Q_2 heats up more than Q_1
- I_{C2} goes up. For constant total I_C , I_{C1} goes down
- Q_2 heats up more. Q_1 cools down
- I_{C2} goes up more. I_{C1} goes down more
- eventually Q_2 hogs all of the current.

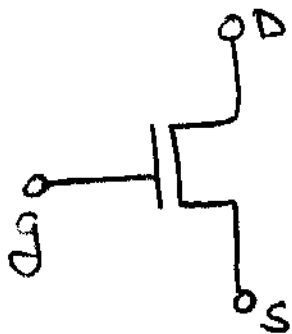
⇒ BJT's are hard to parallel

- One possible fix, add an emitter resistor

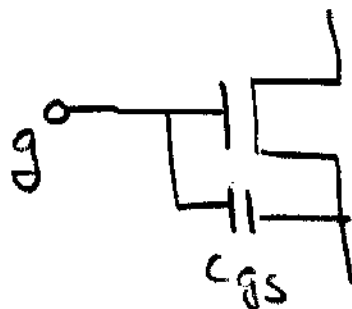


- As I_c through one BJT goes up, V_{RE} also goes up
- Since V_x is constant, as V_{RE} goes up, V_{BE} for that BJT goes down.
- Reducing V_{BE} tends to reduce I_c
- Thermal runaway is reduced or prevented.

MOSFETS



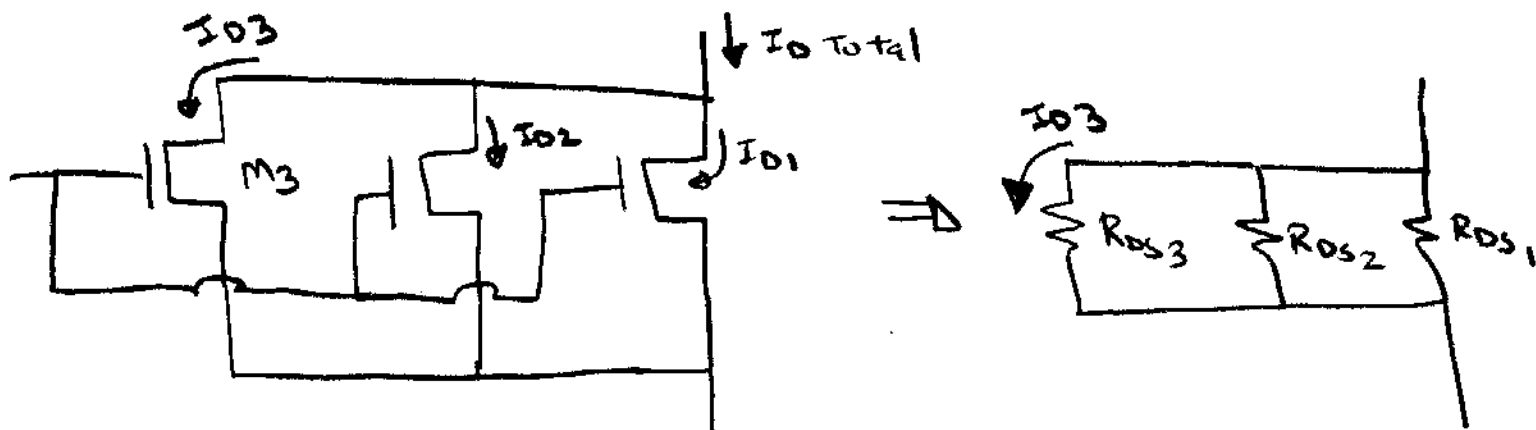
- Looks like a resistor when on (R_{on})
- gate input looks like a capacitor



- mostly NMOS
- PMOS used occasionally

MOSFETS CONTINUED

- To turn on or off the MOSFET, we must charge and discharge C_{gs} quickly
- When on, No DC gate current is required ($I_g = 0$ in steady state)
- Power dissipation due to switching losses and static losses ($I^2 R_{DS(on)}$)
- has a positive temperature coefficient ($R_{DS(on)}$ goes up with temperature) \Rightarrow easy to parallel



- Suppose M_3 draws more current than the other two.
- M_3 dissipates more power, its Temp goes up
- as $T_3 \uparrow$ $R_{\text{oson}_3} \uparrow$
- as $R_{\text{os}} \uparrow$, current is pushed into the other devices lowering I_{O_3}
- No Thermal runaway
- mosFets share the current.
- MOSFets are low voltage devices
 - IxYs Devices
 - 55V, 200A, 4m Ω
 - 60V, 340A, 3m Ω
 - 800V, 44A, 74m Ω
 - 1000V, 12.5A, 90m Ω

Trench Power MOSFET IXUC200N055

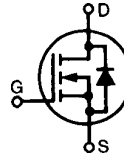
ISOPLUS220™

Electrically Isolated Back Surface

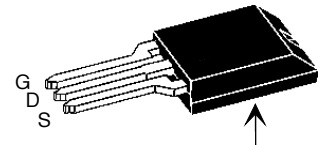
$$V_{DSS} = 55 \text{ V}$$

$$I_{D25} = 200 \text{ A}$$

$$R_{DS(on)} = 5.1 \text{ m}\Omega$$



ISOPLUS 220™



Isolated back surface*

G = Gate, D = Drain,
S = Source

* Patent pending

Symbol	Test Conditions	Maximum Ratings	
V_{DSS}	$T_J = 25^\circ\text{C}$ to 150°C	55	V
V_{GS}	Continuous	± 20	V
I_{D25}	$T_C = 25^\circ\text{C}$; Note 1	200	A
I_{D90}	$T_C = 90^\circ\text{C}$; Note 1	160	A
I_{S25}	$T_C = 25^\circ\text{C}$; Note 1, 2	200	A
I_{S90}	$T_C = 90^\circ\text{C}$; Note 1, 2	140	A
$I_{D(RMS)}$	Package lead current limit	45	A
E_{AS}	$T_C = 25^\circ\text{C}$	500	mJ
P_D	$T_C = 25^\circ\text{C}$	300	W
T_J		-55 ... +175	$^\circ\text{C}$
T_{JM}		175	$^\circ\text{C}$
T_{stg}		-55 ... +150	$^\circ\text{C}$
T_L	1.6 mm (0.062 in.) from case for 10 s	300	$^\circ\text{C}$
V_{ISOL}	RMS leads-to-tab, 50/60 Hz, $t = 1$ minute	2500	V~
F_C	Mounting force	11 ... 65 / 2.4 ... 11	N/lb
Weight		2	g

Features

- Silicon chip on Direct-Copper-Bond substrate
 - High power dissipation
 - Isolated mounting surface
 - 2500V electrical isolation
- Trench MOSFET
 - very low $R_{DS(on)}$
 - fast switching
 - usable intrinsic reverse diode
- Low drain to tab capacitance (<15pF)
- Unclamped Inductive Switching (UIS) rated

Applications

- Automotive 42V and 12V systems
 - electronic switches to replace relays and fuses
 - choppers to replace series dropping resistors used for motors, heaters, etc.
 - inverters for AC drives, e.g. starter generator
 - DC-DC converters, e.g. 12V to 42V, etc.
- Power supplies
 - DC - DC converters
 - Solar inverters
- Battery powered systems
 - choppers or inverters for motor control in hand tools
 - battery chargers

Advantages

- Easy assembly: no screws or isolation foils required
- Space savings
- High power density

Symbol	Test Conditions	Characteristic Values ($T_J = 25^\circ\text{C}$, unless otherwise specified)		
		min.	typ.	max.
$R_{DS(on)}$	$V_{GS} = 10 \text{ V}$, $I_D = 100 \text{ A}$, Note 3 $V_{GS} = 10 \text{ V}$, $I_D = I_{D90}$, Note 3		4.0	5.1 m Ω m Ω
$V_{GS(th)}$	$V_{DS} = V_{GS}$, $I_D = 2 \text{ mA}$	2		4 V
I_{DSS}	$V_{DS} = V_{DSS}$ $V_{GS} = 0 \text{ V}$		$T_J = 25^\circ\text{C}$ $T_J = 125^\circ\text{C}$	20 μA mA
I_{GSS}	$V_{GS} = \pm 20 \text{ V}_{DC}$, $V_{DS} = 0$			$\pm 200 \text{ nA}$

HiPerFET™

Power MOSFETs

Single Die MOSFET

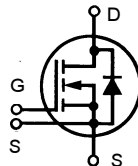
IXFN 340N06

$$V_{DSS} = 60 \text{ V}$$

$$I_{D25} = 340 \text{ A}$$

$$R_{DS(on)} = 3 \text{ m}\Omega$$

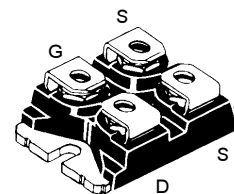
N-Channel Enhancement Mode
Avalanche Rated, High dv/dt, Low t_{rr}



$$t_{rr} \leq 250 \text{ ns}$$

Symbol	Test Conditions	Maximum Ratings	
V_{DSS}	$T_J = 25^\circ\text{C}$ to 150°C	60	V
V_{DGR}	$T_J = 25^\circ\text{C}$ to 150°C ; $R_{GS} = 1 \text{ M}\Omega$	60	V
V_{GS}	Continuous	± 20	V
V_{GSM}	Transient	± 30	V
I_{D25}	$T_C = 25^\circ\text{C}$, Chip capability	340	A
$I_{L(RMS)}$	Terminal current limit	100	A
I_{DM}	$T_C = 25^\circ\text{C}$, pulse width limited by T_{JM}	1360	A
I_{AR}	$T_C = 25^\circ\text{C}$	200	A
E_{AR}	$T_C = 25^\circ\text{C}$	64	mJ
E_{AS}	$T_C = 25^\circ\text{C}$	4	J
dv/dt	$I_S \leq I_{DM}$, $di/dt \leq 100 \text{ A}/\mu\text{s}$, $V_{DD} \leq V_{DSS}$, $T_J \leq 150^\circ\text{C}$, $R_G = 2 \Omega$	5	V/ns
P_D	$T_C = 25^\circ\text{C}$	700	W
T_J		-55 ... +150	$^\circ\text{C}$
T_{JM}		150	$^\circ\text{C}$
T_{stg}		-55 ... +150	$^\circ\text{C}$
V_{ISOL}	50/60 Hz, RMS $t = 1 \text{ min}$ $I_{ISOL} \leq 1 \text{ mA}$ $t = 1 \text{ s}$	2500 3000	V~ V~
M_d	Mounting torque Terminal connection torque	1.5/13 1.5/13	Nm/lb.in. Nm/lb.in.
Weight		30	g

miniBLOC, SOT-227 B (IXFN)
E153432



G = Gate D = Drain
S = Source

Either Source terminal at miniBLOC can be used
as Main or Kelvin Source

Features

- International standard packages
- miniBLOC, with Aluminium nitride isolation
- Low $R_{DS(on)}$ HDMOS™ process
- Rugged polysilicon gate cell structure
- Unclamped Inductive Switching (UIS) rated
- Low package inductance
- Fast intrinsic Rectifier

Applications

- DC-DC converters
- Battery chargers
- Switched-mode and resonant-mode power supplies
- DC choppers
- Temperature and lighting controls

Advantages

- Easy to mount
- Space savings
- High power density

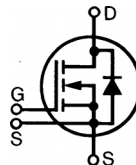
Symbol	Test Conditions	Characteristic Values ($T_J = 25^\circ\text{C}$, unless otherwise specified)		
		min.	typ.	max.
V_{DSS}	$V_{GS} = 0 \text{ V}$, $I_D = 3 \text{ mA}$	60		V
$V_{GH(th)}$	$V_{DS} = V_{GS}$, $I_D = 8 \text{ mA}$	2.0		4.0 V
I_{GSS}	$V_{GS} = \pm 20 \text{ V}_{DC}$, $V_{DS} = 0$			$\pm 200 \text{ nA}$
I_{DSS}	$V_{DS} = V_{DSS}$, $T_J = 25^\circ\text{C}$ $V_{GS} = 0 \text{ V}$, $T_J = 125^\circ\text{C}$			100 μA 2 mA
$R_{DS(on)}$	$V_{GS} = 10 \text{ V}$, $I_D = 100 \text{ A}$ Pulse test, $t \leq 300 \mu\text{s}$, duty cycle $d \leq 2 \%$			3 m Ω

CoolMOS Power MOSFET

IXKN 45N80C

V_{DSS}	I_{D25}	$R_{DS(on)}$
800 V	44 A	74 m Ω

N-Channel Enhancement Mode
Low $R_{DS(on)}$, High V_{DSS} MOSFET



COOLMOS
Power Semiconductors

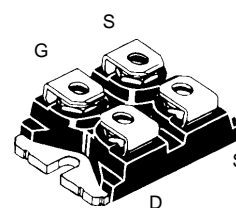
MOSFET

Symbol	Conditions	Maximum Ratings	
V_{DSS}	$T_{VJ} = 25^{\circ}\text{C}$ to 150°C	800	V
V_{GS}		± 20	V
I_{D25}	$T_C = 25^{\circ}\text{C}$	44	A
I_{D90}	$T_C = 90^{\circ}\text{C}$	30	A
dv/dt	$V_{DS} < V_{DSS}$; $I_F \leq 17$ A; $ di_F/dt \leq 100$ A/ μs $T_{VJ} = 150^{\circ}\text{C}$	6	V/ns
E_{AS}	$I_D = 4$ A; $L = 80$ mH; $T_C = 25^{\circ}\text{C}$	670	mJ
E_{AR}	$I_D = 17$ A; $L = 3$ μH ; $T_C = 25^{\circ}\text{C}$	0.5	mJ

miniBLOC, SOT-227 B



E72873



G = Gate
S = Source
D = Drain

Either source terminal at miniBLOC can be used as main or kelvin source

Symbol	Conditions	Characteristic Values ($T_{VJ} = 25^{\circ}\text{C}$, unless otherwise specified)		
		min.	typ.	max.
$R_{DS(on)}$	$V_{GS} = 10$ V; $I_D = I_{D90}$		63	74 m Ω
$V_{GS(th)}$	$V_{DS} = 20$ V; $I_D = 4$ mA;	2		4 V
I_{DSS}	$V_{DS} = V_{DSS}$; $V_{GS} = 0$ V; $T_{VJ} = 25^{\circ}\text{C}$ $T_{VJ} = 125^{\circ}\text{C}$		20	50 μA μA
I_{GSS}	$V_{GS} = \pm 20$ V; $V_{DS} = 0$ V			400 nA
Q_g Q_{gs} Q_{gd}	} $V_{GS} = 10$ V; $V_{DS} = 640$ V; $I_D = 70$ A		332	nC
			36	nC
			168	nC
$t_{d(on)}$ t_r $t_{d(off)}$ t_f	} $V_{GS} = 10$ V; $V_{DS} = 640$ V; $I_D = 70$ A; $R_G = 1.8$ Ω		25	ns
			15	ns
			75	ns
			10	ns
V_F	(reverse conduction) $I_F = 37.5$ A; $V_{GS} = 0$ V		1.0	1.2 V
R_{thJC}				0.33 K/W

Features

- miniBLOC package
 - Electrically isolated copper base
 - Low coupling capacitance to the heatsink for reduced EMI
 - International standard package SOT-227
 - Easy screw assembly
- fast CoolMOS power MOSFET - 3rd generation
 - High blocking capability
 - Low on resistance
 - Avalanche rated for unclamped inductive switching (UIS)
 - Low thermal resistance due to reduced chip thickness
- Enhanced total power density

Applications

- Switched mode power supplies (SMPS)
- Uninterruptible power supplies (UPS)
- Power factor correction (PFC)
- Welding
- Inductive heating

CoolMOS is a trademark of
Infineon Technologies AG.

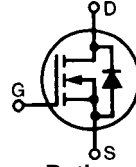
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HiPerFET™ Power MOSFETs

N-Channel Enhancement Mode
High dv/dt, Low t_{rr} , HDMOS™ Family

IXFH/IXFM10N100
IXFH/IXFM12N100
IXFH13N100

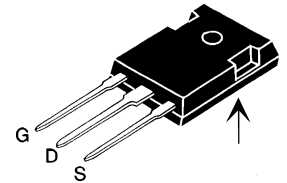


V_{DSS}	I_{D25}	$R_{DS(on)}$
1000 V	10 A	1.20 Ω
1000 V	12 A	1.05 Ω
1000 V	12.5 A	0.90 Ω

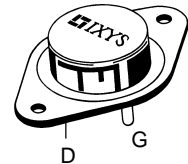
$t_{rr} \leq 250$ ns

Symbol	Test Conditions	Maximum Ratings	
V_{DSS}	$T_J = 25^\circ\text{C}$ to 150°C	1000	V
V_{DGR}	$T_J = 25^\circ\text{C}$ to 150°C ; $R_{GS} = 1$ M Ω	1000	V
V_{GS}	Continuous	± 20	V
V_{GSM}	Transient	± 30	V
I_{D25}	$T_C = 25^\circ\text{C}$	10N100	10 A
		12N100	12 A
		13N100	12.5 A
I_{DM}	$T_C = 25^\circ\text{C}$, pulse width limited by T_{JM}	10N100	40 A
		12N100	48 A
		13N100	50 A
I_{AR}	$T_C = 25^\circ\text{C}$	10N100	10 A
		12N100	12 A
		13N100	12.5 A
E_{AR}	$T_C = 25^\circ\text{C}$	30	mJ
dv/dt	$I_S \leq I_{DM}$, $di/dt \leq 100$ A/ μs , $V_{DD} \leq V_{DSS}$, $T_J \leq 150^\circ\text{C}$, $R_G = 2$ Ω	5	V/ns
P_D	$T_C = 25^\circ\text{C}$	300	W
T_J		-55 ... +150	$^\circ\text{C}$
T_{JM}		150	$^\circ\text{C}$
T_{stg}		-55 ... +150	$^\circ\text{C}$
T_L	1.6 mm (0.062 in.) from case for 10 s	300	$^\circ\text{C}$
M_d	Mounting torque	1.13/10	Nm/lb.in.
Weight		TO-204 = 18 g, TO-247 = 6 g	

TO-247 AD (IXFH)



TO-204 AA (IXFM)



G = Gate,
S = Source,
D = Drain,
TAB = Drain

Features

- International standard packages
- Low $R_{DS(on)}$ HDMOS™ process
- Rugged polysilicon gate cell structure
- Unclamped Inductive Switching (UIS) rated
- Low package inductance
 - easy to drive and to protect
- Fast intrinsic Rectifier

Applications

- DC-DC converters
- Synchronous rectification
- Battery chargers
- Switched-mode and resonant-mode power supplies
- DC choppers
- AC motor control
- Temperature and lighting controls
- Low voltage relays

Advantages

- Easy to mount with 1 screw (TO-247) (isolated mounting screw hole)
- Space savings
- High power density

Symbol	Test Conditions	Characteristic Values ($T_J = 25^\circ\text{C}$, unless otherwise specified)		
		min.	typ.	max.
V_{DSS}	$V_{GS} = 0$ V, $I_D = 3$ mA	1000		V
$V_{GS(th)}$	$V_{DS} = V_{GS}$, $I_D = 4$ mA	2.0		4.5 V
I_{GSS}	$V_{GS} = \pm 20$ V _{DC} , $V_{DS} = 0$			± 100 nA
I_{DSS}	$V_{DS} = 0.8 \cdot V_{DSS}$ $V_{GS} = 0$ V	$T_J = 25^\circ\text{C}$		250 μA
		$T_J = 125^\circ\text{C}$		1 mA
$R_{DS(on)}$	$V_{GS} = 10$ V, $I_D = 0.5 \cdot I_{D25}$	10N100		1.20 Ω
		12N100		1.05 Ω
		13N100		0.90 Ω
Pulse test, $t \leq 300$ μs , duty cycle $d \leq 2$ %				

IXYS reserves the right to change limits, test conditions, and dimensions.

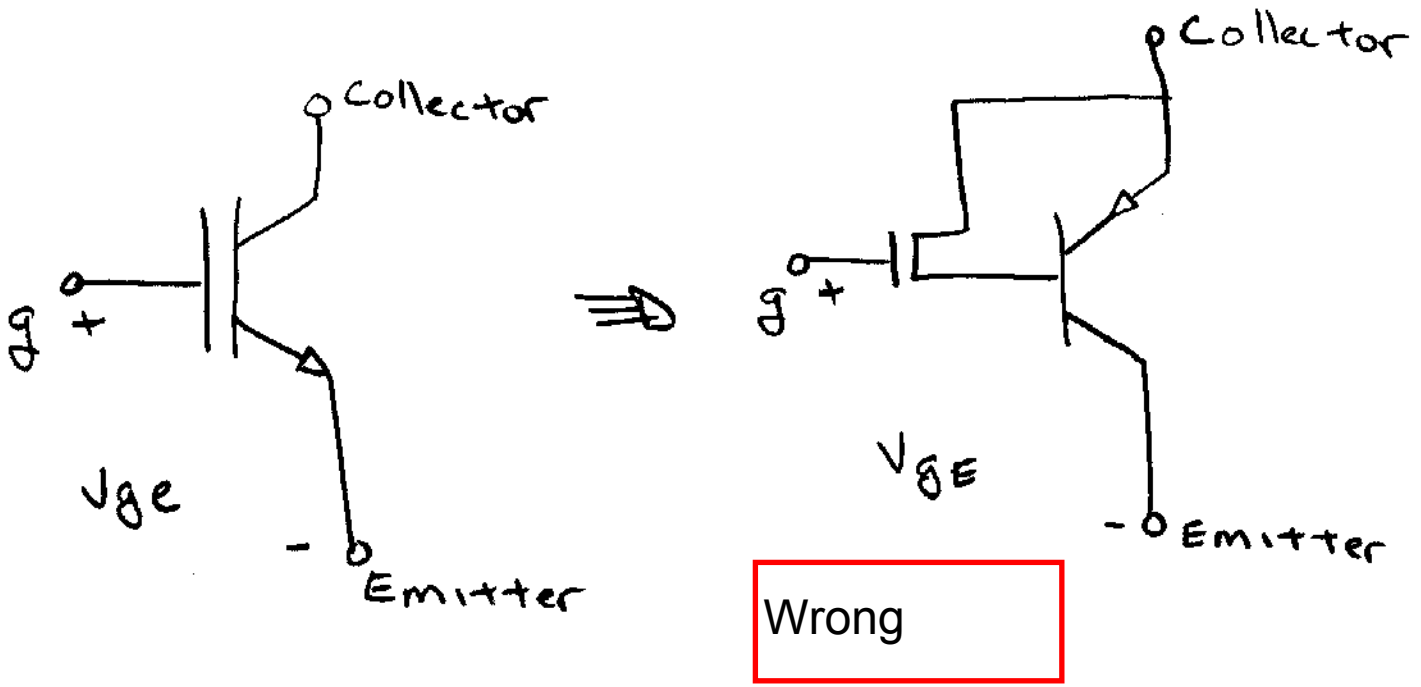
91531F(4/99)

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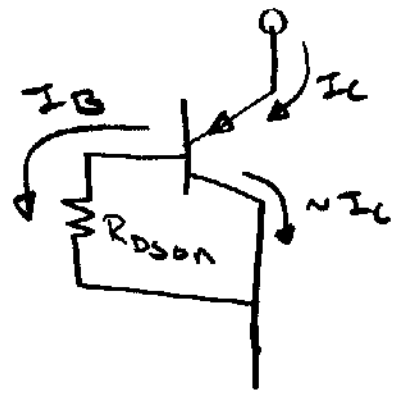
1 - 4

IGBT - Insulated Gate Bipolar Transistor

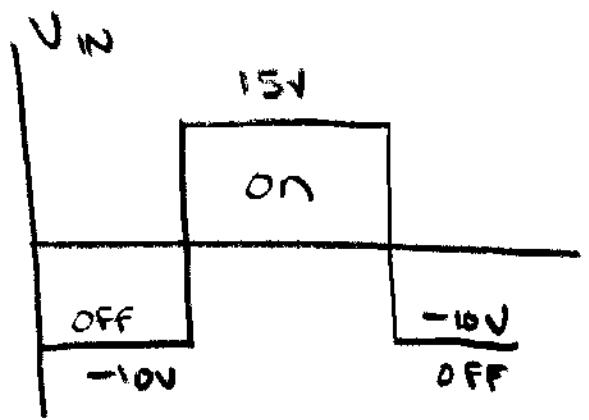
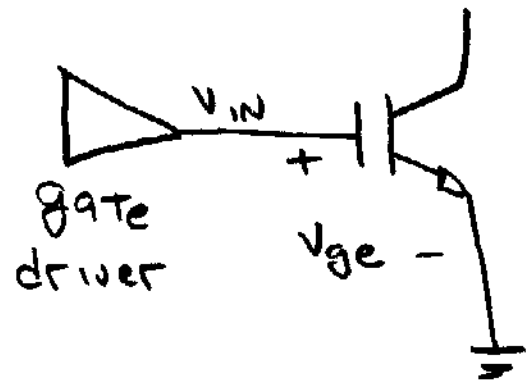
- Combines the high voltage, high current capabilities of a BJT with the low gate drive current of a MOSFET



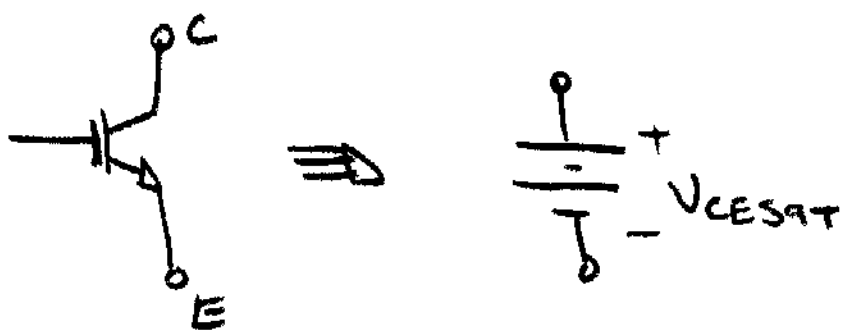
- To turn on, turn on the FET: $V_{ge} > \text{Threshold}$



- Turning off the device may require a negative gate drive



- When the switch is on, it looks like a saturated BJT




$V_{CESAT} = 1.5 \text{ to } 3V \text{ Typical}$

CT30SM-12

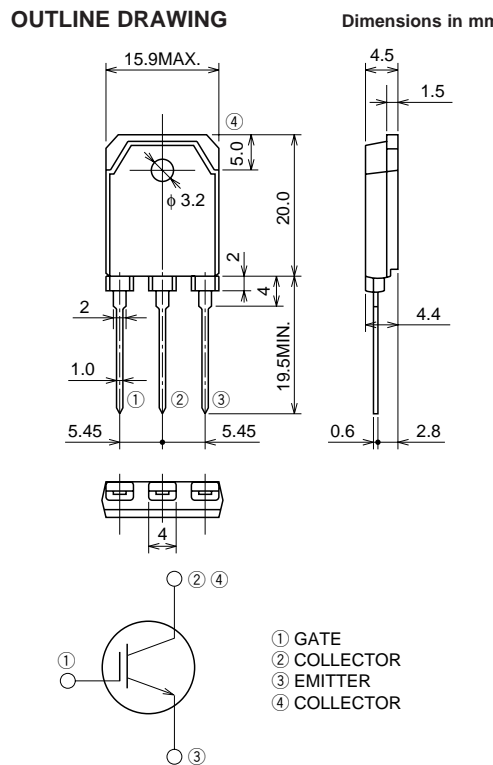
GENERAL INVERTER • UPS USE

CT30SM-12



- VCES 600V
- IC 30A
- High Speed Switching
- Low VCE Saturation Voltage

OUTLINE DRAWING Dimensions in mm



① GATE
② COLLECTOR
③ EMITTER
④ COLLECTOR

TO-3P

APPLICATION

AC & DC motor controls, General purpose inverters, UPS, Power supply switching, Servo controls, etc.

MAXIMUM RATINGS (Tc = 25°C)

Symbol	Parameter	Conditions	Ratings	Unit
V _{CE} S	Collector-emitter voltage	V _{GE} = 0V	600	V
V _{GE} S	Gate-emitter voltage	V _{CE} = 0V	±20	V
V _{GEM}	Peak gate-emitter voltage	V _{CE} = 0V	±30	V
I _C	Collector current		30	A
I _{CM}	Collector current (Pulsed)		60	A
P _C	Maximum power dissipation		250	W
T _j	Junction temperature		-40 ~ +150	°C
T _{stg}	Storage temperature		-40 ~ +150	°C
—	Weight	Typical value	4.8	g

Feb.1999




PRELIMINARY
 Notice: This is not a final specification.
 Some parametric limits are subject to change.

MITSUBISHI INSULATED GATE BIPOLAR TRANSISTOR

CT15SM-24

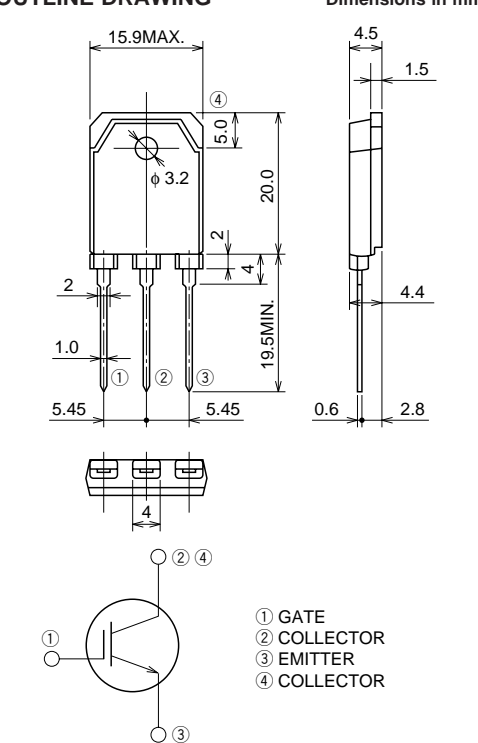
GENERAL INVERTER • UPS USE

CT15SM-24



- VCES 1200V
- IC 15A
- High Speed Switching
- Low VCE Saturation Voltage

OUTLINE DRAWING Dimensions in mm



① GATE
 ② COLLECTOR
 ③ EMITTER
 ④ COLLECTOR

TO-3P

APPLICATION

AC & DC motor controls, General purpose inverters, UPS, Power supply switching, Servo controls, etc.

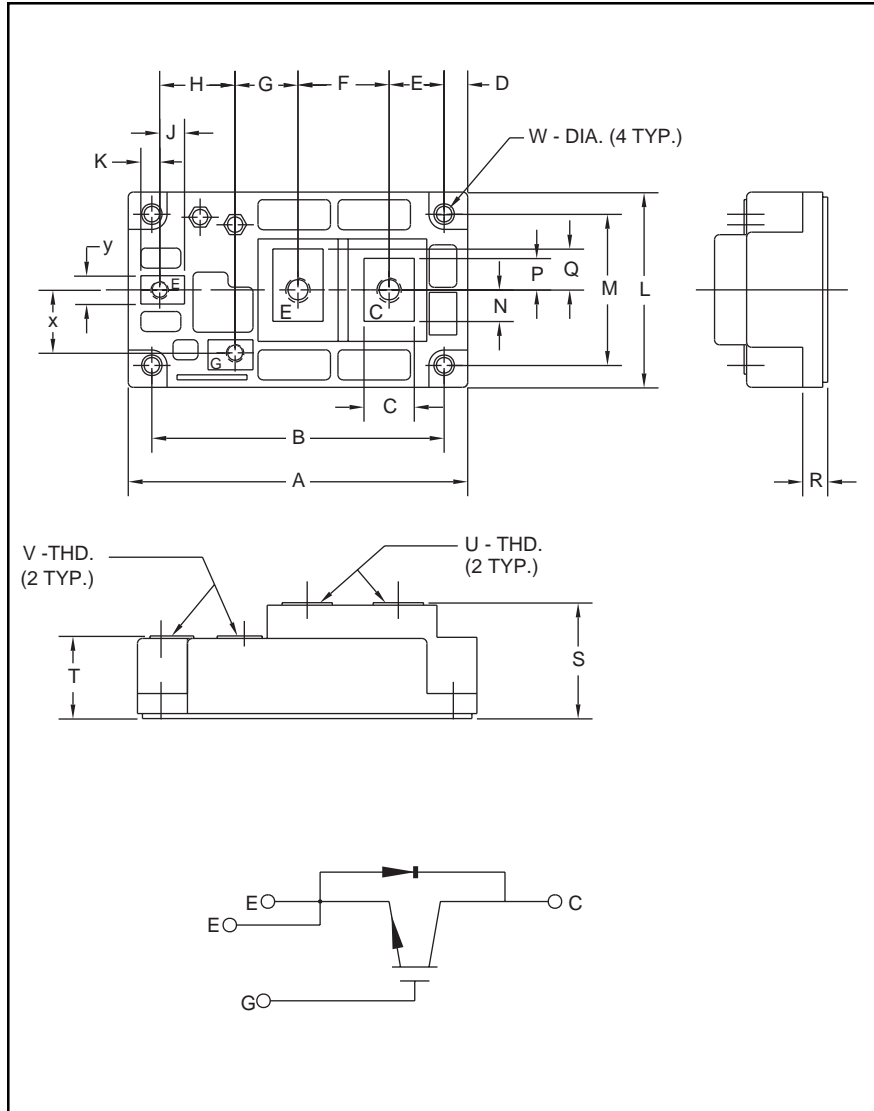
MAXIMUM RATINGS (Tc = 25°C)

Symbol	Parameter	Conditions	Ratings	Unit
V _{CE} S	Collector-emitter voltage	V _{GE} = 0V	1200	V
V _{GES}	Gate-emitter voltage	V _{CE} = 0V	±20	V
V _{GEM}	Peak gate-emitter voltage	V _{CE} = 0V	±30	V
I _C	Collector current		15	A
I _{CM}	Collector current (Pulsed)		30	A
P _C	Maximum power dissipation		250	W
T _j	Junction temperature		-40 ~ +150	°C
T _{stg}	Storage temperature		-40 ~ +150	°C
—	Weight	Typical value	4.8	g

Feb.1999



Trench Gate Design Single IGBTMOD™ 600 Amperes/250 Volts



Outline Drawing and Circuit Diagram

Dimensions	Inches	Millimeters
A	4.25	108.0
B	3.66	93.0
C	0.63	16.0
D	0.30	7.5
E	0.69	17.5
F	1.14	29.0
G	0.79	20.0
H	0.94	24.0
J	0.31	7.9
K	0.24	6.0
L	2.44	62.0
M	1.89	48.0

Dimensions	Inches	Millimeters
N	0.39	10.0
P	0.39	10.0
Q	0.51	13.0
R	0.33	8.5
S	1.42	36.0
T	1.02	25.8
U	M6 Metric	M6
V	M4 Metric	M4
W	0.22	5.5
X	0.79	20.0
Y	0.35	9.0

**Description:**

Powerex IGBTMOD™ Modules are designed for use in switching applications. Each module consists of one IGBT Transistor in a single configuration, with a reverse connected super-fast recovery free-wheel diode. All components and interconnects are isolated from the heat sinking baseplate, offering simplified system assembly and thermal management.

Features:

- Low Drive Power
- Low $V_{CE(sat)}$
- Discrete Super-Fast Recovery Free-Wheel Diodes
- High Frequency Operation (20-25 kHz)
- Isolated Baseplate for Easy Heat Sinking

Applications:

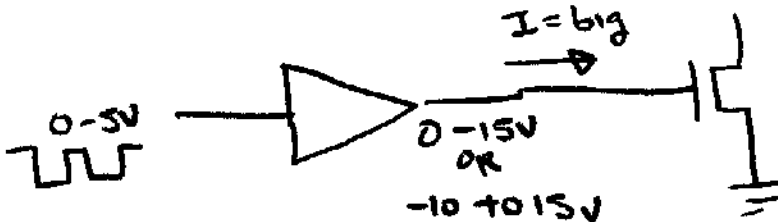
- DC Chopper
- Inverter
- UPS
- Forklift

Ordering Information:

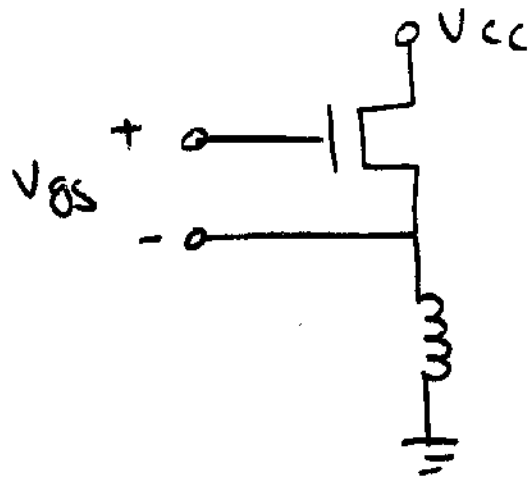
Example: Select the complete nine digit module part number you desire from the table below - i.e. CM600HA-5F is a 250V (V_{CES}), 600 Ampere Single IGBTMOD™ Power Module.

Type	Current Rating Amperes	V_{CES} Volts (x 50)
CM	600	5

- Provide high current, high voltage Drive to turn on or off a switch quickly

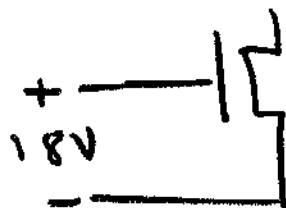


- Used to drive a high side switch



- Provide short-circuit protection
- Provide Electrical Isolation

- can be used to drive a high side or low side (grounded) switch
- output can source 1A pulsed current
- output can sink 2A pulsed current
- floating output can be 500V higher than grounded side input
- WARNING - V_s or V_b cannot go negative or bad things happen (like killing the IR2125)
- short circuit protection.
- gate drive supply from 12 to 18V - allows you to turn on a switch with a large voltage



IR2125

CURRENT LIMITING SINGLE CHANNEL DRIVER

Features

- Floating channel designed for bootstrap operation
Fully operational to +500V
Tolerant to negative transient voltage
dV/dt immune
- Gate drive supply range from 12 to 18V
- Undervoltage lockout
- Current detection and limiting loop to limit driven power transistor current
- Error lead indicates fault conditions and programs shutdown time
- Output in phase with input

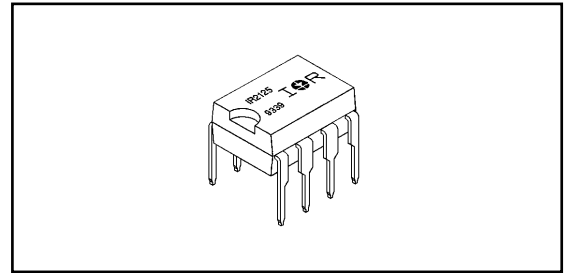
Description

The IR2125 is a high voltage, high speed power MOSFET and IGBT driver with over-current limiting protection circuitry. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL outputs. The output driver features a high pulse current buffer stage designed for minimum driver cross-conduction. The protection circuitry detects over-current in the driven power transistor and limits the gate drive voltage. Cycle by cycle shutdown is programmed by an external capacitor which directly controls the time interval between detection of the over-current limiting conditions and latched shut-

Product Summary

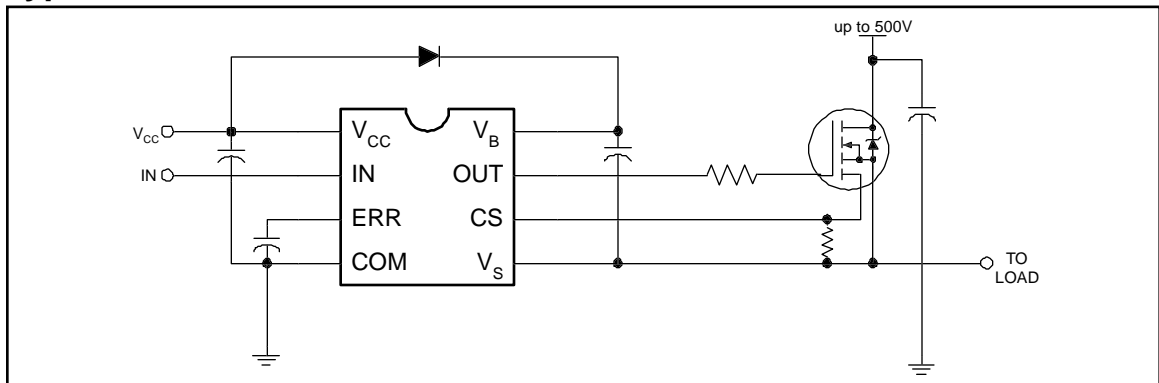
V_{OFFSET}	500V max.
$I_{\text{O+/-}}$	1A / 2A
V_{OUT}	12 - 18V
V_{Csth}	230 mV
$t_{\text{on/off (typ.)}}$	150 & 150 ns

Package

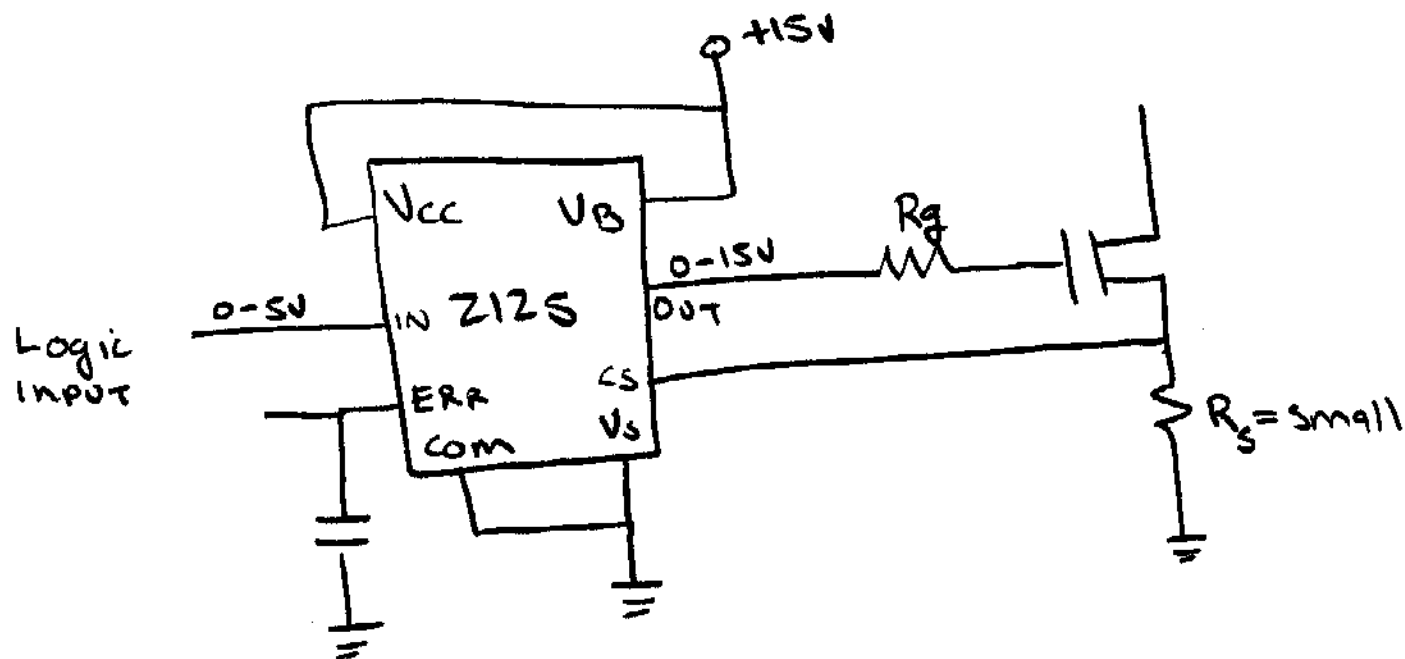


down. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high or low side configuration which operates up to 500 volts.

Typical Connection



- Use as a low side driver



Choose R_g to Limit current to 1A

$$R_g = \frac{V_{omax} - V_{gsmin}}{1A} = \frac{15V - 0V}{1A} = 15\Omega$$

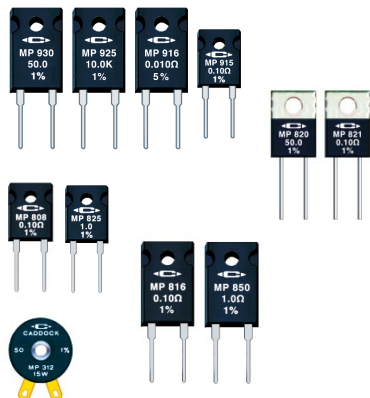
- R_s is a current sensing Resistor

- must be low inductance

- 4-wire shunt is a good choice

- Do not use Thin Film Resistor

Power Resistors, Heat Sink Mountable with Non-Inductive Designs



MP915, MP916, MP925 and MP930 Power Film Resistors

Model MP915, 15 Watts, TO-126 All Molded Package, Resistance Down to 0.02 ohm
 Model MP916, 16 Watts, TO-220 All Molded Package, Resistance Down to 0.01 ohm
 Model MP925, 25 Watts, TO-220 All Molded Package, Resistance From 5K to 100K
 Model MP930, 30 Watts, TO-220 All Molded Package, Resistance Down to 0.02 ohm

MP820 and MP821 Power Film Resistors in the TO-220 Power Package

20 Watt Power Resistor, Power Package with Metal Mounting Tab
 Resistance 0.02 ohm to 10K

MP808 and MP825 Power Film Resistors, TO-126 Style Power Package

Model MP808, 8 Watts, All Molded Package, Resistance 0.02 ohm to 10K
 Model MP825, 25 Watts, Integral Copper Heat Sink, Resistance 0.02 ohm to 10K

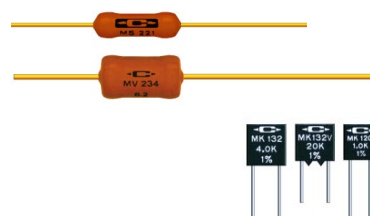
MP816 and MP850 Power Film Resistors, TO-220 Style Power Package

Model MP816, 16 Watts, All Molded Package, Resistance 0.1 ohm to 10 K
 Model MP850, 50 Watts, Integral Copper Heat Sink, Resistance 0.2 ohm to 10K

MP312 and MP330 Power Film Resistors

15 Watt and 30 Watt Ratings with Center Screw Chassis Mounting

Power Resistors, Axial Leads and Radial Leads with Non-Inductive Designs



Type MS Power Film Resistors

Power Rating to 15 Watts, Voltage Rating to 6000 Volts,
 Max. Temperature +275°C, Non-Inductive Design, 17 Models

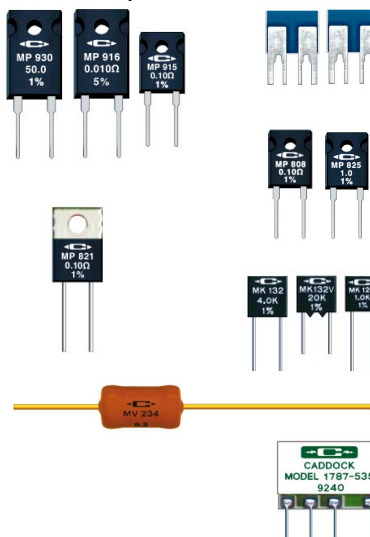
Type MV Low Resistance Power Film Resistors

Resistance from 0.1 ohm to 50 ohms, Power Rating to 10 Watts
 Max. Temperature +275°C, Non-Inductive Design

MK132 and MK120 Precision Power Film Resistors with Non-Inductive Design

3/4 Watt at 400 Volts Max. and 1/2 Watt at 200 Volts Max. at +125°C,
 Resistance 1 ohm to as high as 5 Megohms

Current Sense, Low Resistance with Non-Inductive Designs



Type SR Precision Current Sense Resistors

Compact Design with Kelvin Terminals, Absolute tolerance of 1%,
 Power rating 1.5 Watts, Resistance Values 0.008 ohms to 1.00 ohm

MP915, MP916 and MP930 Power Film Resistors

Model MP915, 15 Watts, TO-126 All Molded Package, Resistance Down to 0.02 ohm
 Model MP916, 16 Watts, TO-220 All Molded Package, Resistance Down to 0.01 ohm
 Model MP930, 30 Watts, TO-220 All Molded Package, Resistance Down to 0.02 ohm

MP808 and MP825 Power Film Resistors, TO-126 Style Power Package

Model MP808, 8 Watts, All Molded Package, Resistance as low as 0.02 ohm
 Model MP825, 25 Watts, Integral Copper Heat Sink, Resistance as low as 0.02 ohm

MP821 Power Film Resistors in the TO-220 Power Package

20 Watt Power Resistor, Power Package with Metal Mounting Tab
 Resistance as low as 0.02 ohm

MK132 and MK120 Precision Power Film Resistors

3/4 and 1/2 Watt Ratings at +125°C, Resistance as low as 1 ohm

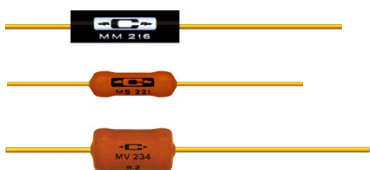
Type MV Low Resistance Power Film Resistors

Resistance as low as 0.1 ohm, Power Rating to 10 Watts,
 Max. Temperature +275°C

Type 1787 Precision Current Sense Resistor Networks

3 and 4-step Current Sense Resistor Networks for Current Sensing in
 Multi-Range Instrumentation, Absolute Tolerance of 0.25% to 0.05%

High Temperature Resistors, 275°C



Type MM Precision Film Resistors

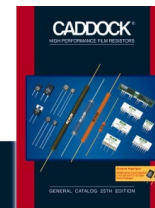
High Temperature Resistors for Geophysical, Aerospace
 and Industrial Requirements, Max. Temperature +275°C

Type MS Power Film Resistors

Power Rating to 15 Watts, Max. Temperature +275°C,
 Non-Inductive Design, 17 Models

Type MV Low Resistance Power Film Resistors

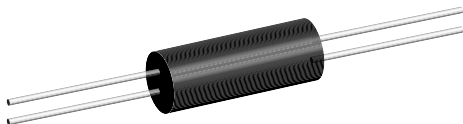
Resistance from 0.1 ohm to 50 ohms, Power Rating to 10 Watts,
 Max. Temperature +275°C, Non-Inductive Design



SPU Molded Style

Vishay Dale

Wirewound Resistors, Molded Style, Current Shunts, Very Low Value, Four Terminal

**FEATURES**

- Molded four-terminal resistors for specialized applications
- Extremely low resistance values for current sensing applications
- Precision resistance tolerance
- Low temperature coefficients
- Complete welded construction

STANDARD ELECTRICAL SPECIFICATIONS

MODEL	POWER RATING * $P_{25^{\circ}\text{C}}$ W	RESISTANCE RANGE Ω $\pm 1\%$	WEIGHT (Typical) g
SPU-50	1	0.001 - 0.060	2.5
SPU-51	2	0.001 - 0.060	3.7
SPU-52	4	0.001 - 0.200	4.8
SPU-53	5	0.010 - 0.500	10.8

• Resistance tolerance available is 0.1%, 0.25%, 0.5%, 1.0%, 3.0% and 5.0% depending on resistor physical design and resistance value.

*Wattage rating is limited to 25 amperes maximum.

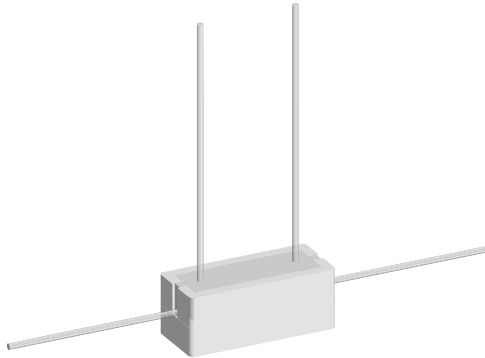
TECHNICAL SPECIFICATIONS

PARAMETER	UNIT	SPU MOLDED STYLE RESISTOR CHARACTERISTICS
Temperature Coefficient	ppm/ $^{\circ}\text{C}$	- 100 (- 10 $^{\circ}\text{C}$ to + 80 $^{\circ}\text{C}$)
Dielectric Withstanding Voltage	V_{AC}	500 minimum
Short Time Overload	-	5 x power for 5 seconds, limited to 25 amperes maximum
Maximum Working Voltage	V	$(P \times R)^{1/2}$
Insulation Resistance	Ω	10,000 Megohm minimum dry

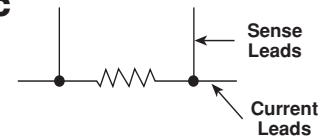
ORDERING INFORMATION

SPU-52 MODEL	200 Ω RESISTANCE Ω	5% TOLERANCE $\pm \%$
-----------------	--	-----------------------------

Wirewound Resistors, Commercial Power, Four Terminal, Low Value

**FEATURES**

- Low Inductance
- Extremely low resistance values
- Current sensing
- Low temperature coefficients
- High power to size ratio
- Ceramic cases are available with circuit board stand-offs (designated with a -3 model ending)
- Superior surge capability
- Complete welded construction
- Special inorganic potting compound and ceramic case provide high thermal conductivity in a fireproof package

SCHEMATIC**STANDARD ELECTRICAL SPECIFICATIONS**

MODEL	POWER RATING P _{40°C} W	RESISTANCE RANGE Ω ± 5% Standard, ± 3% Available	WEIGHT (Typical) g
CPSL-3-5	3	0.01 - 0.10	4.0
CPSL-3-3	3	0.01 - 0.10	4.2
CPSL-5-5	5	0.01 - 0.10	5.2
CPSL-5-3	5	0.01 - 0.10	5.4
CPSL-7-5	7	0.01 - 0.10	7.6
CPSL-10-5	10	0.01 - 0.10	10.2
CPSL-15-5	15	0.01 - 0.10	18.9

TECHNICAL SPECIFICATIONS

PARAMETER	UNIT	CPSL RESISTOR CHARACTERISTICS
Temperature Coefficient	ppm/°C	± 100 maximum
Short Time Overload	-	5 x rated power for 5 seconds
Maximum Working Voltage	V	(P x R) ^{1/2}
Operating Temperature Range	°C	- 65/+ 275
Terminal Strength	lb	10 minimum
Dielectric Withstanding Voltage	V _{AC}	1000

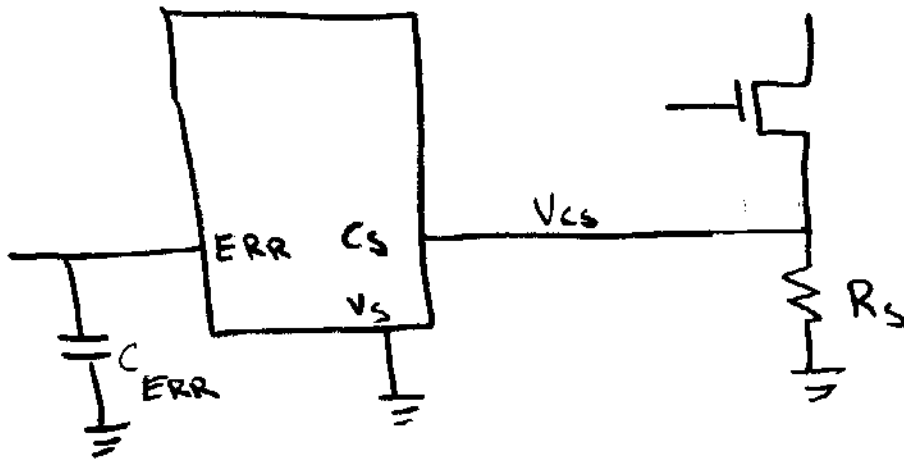
ORDERING INFORMATION

CPSL-10-5
MODEL

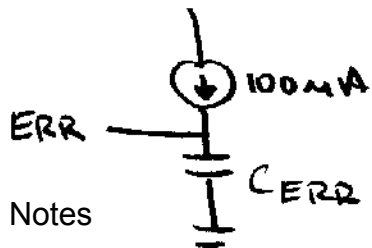
100Ω
RESISTANCE
Ω

10%
TOLERANCE
± %

- Over current Protection



- When V_{cs} goes above the threshold ($V_{cs_{th+}}$) of 230mV, C_{ERR} is charged by a 100 μ A current source.
- If the voltage on the ERR Pin goes above 1.8V, an over current condition is detected: V_{out} is set to zero and ERR is pulled high to use as a Flag.



- Short CKT current duration directly controlled by C_{ERR}

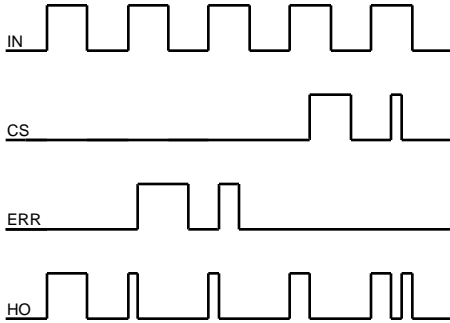


Figure 1. Input/Output Timing Diagram

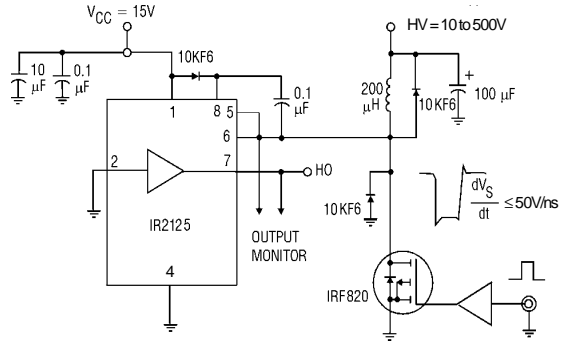


Figure 2. Floating Supply Voltage Transient Test Circuit

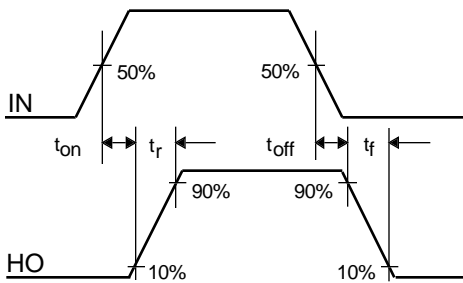


Figure 3. Switching Time Waveform Definitions

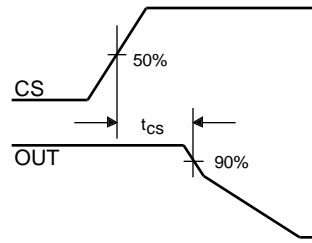


Figure 4. ERR Shutdown Waveform Definitions

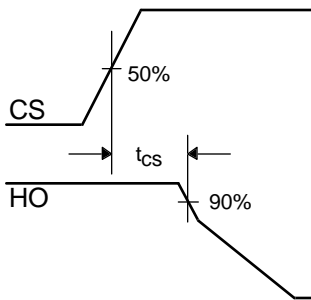


Figure 5. CS Shutdown Waveform Definitions

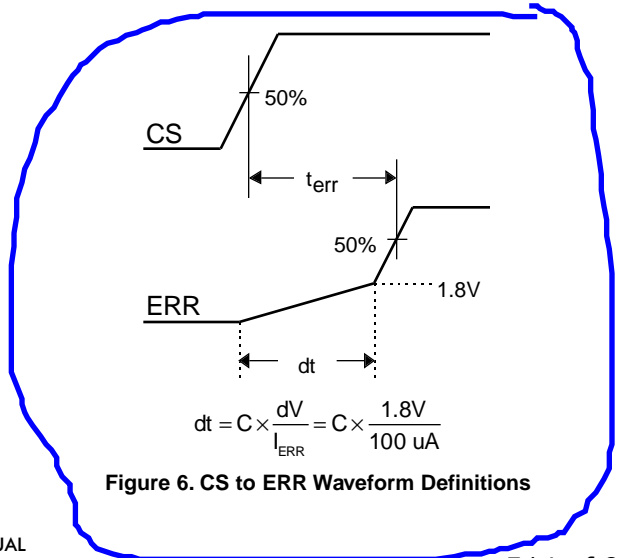
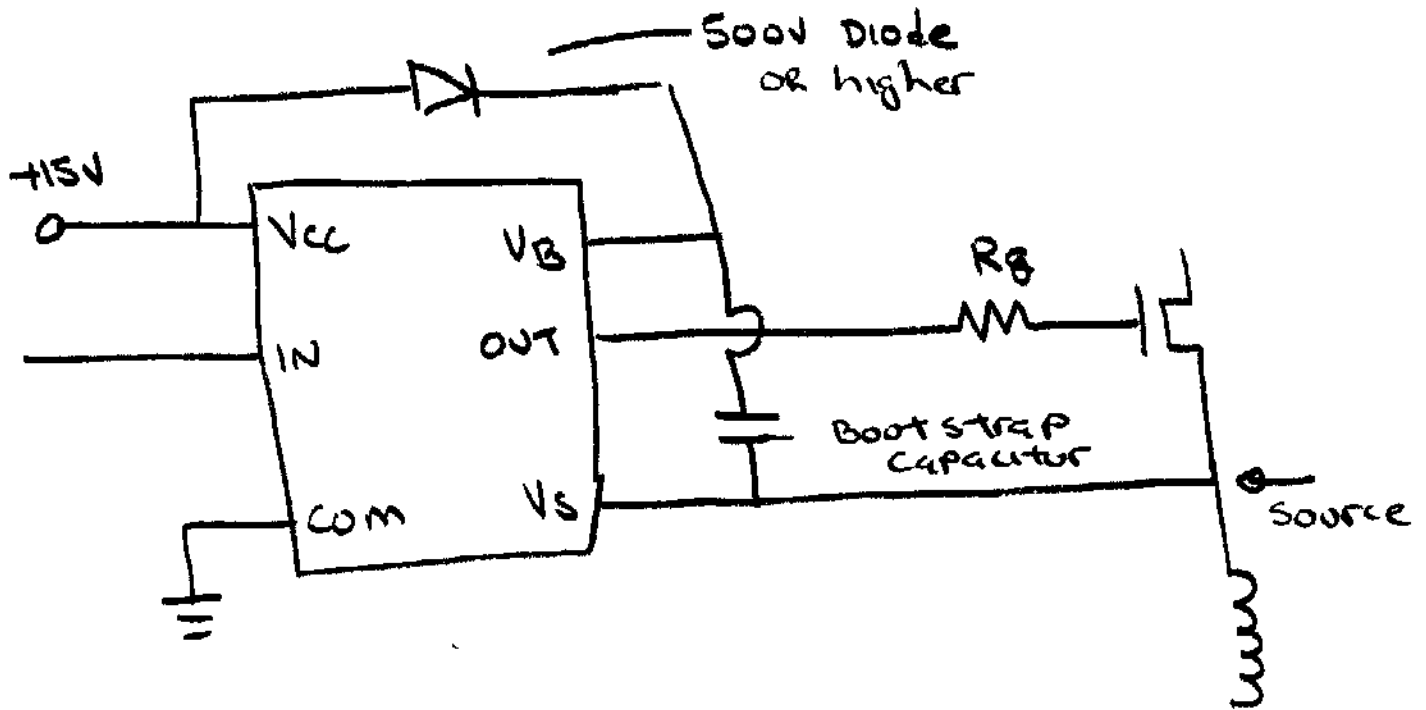
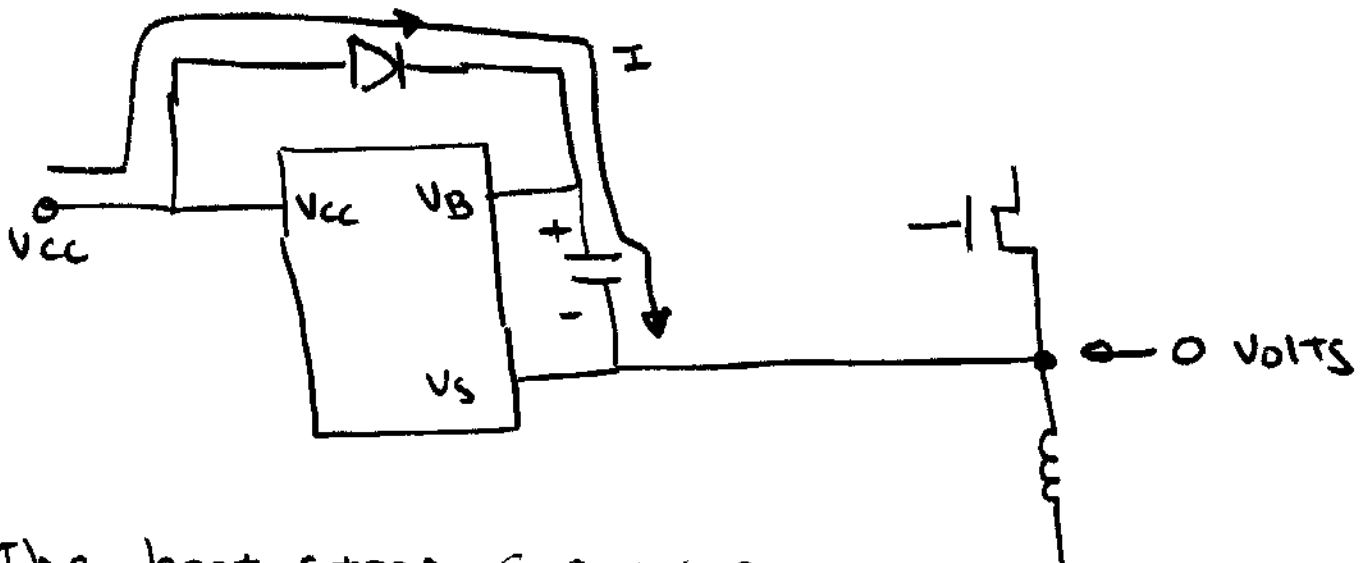


Figure 6. CS to ERR Waveform Definitions

- Floating Gate Drive Application

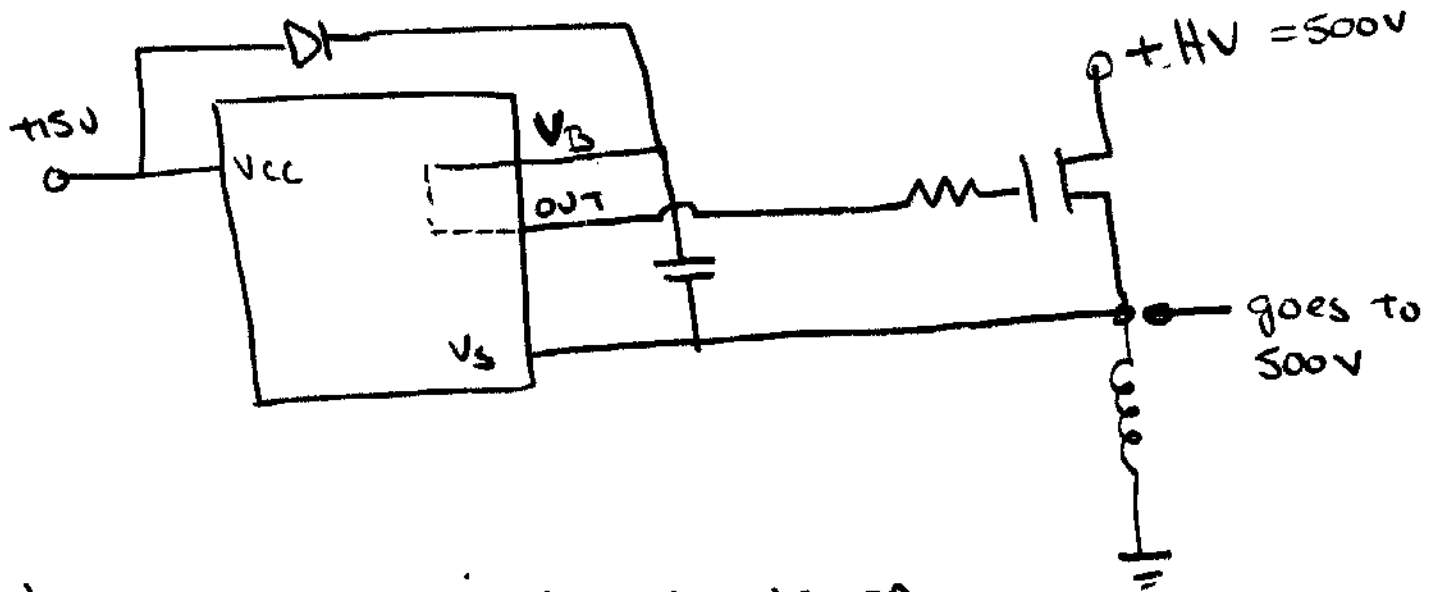


at some point, the source becomes grounded or at ground potential



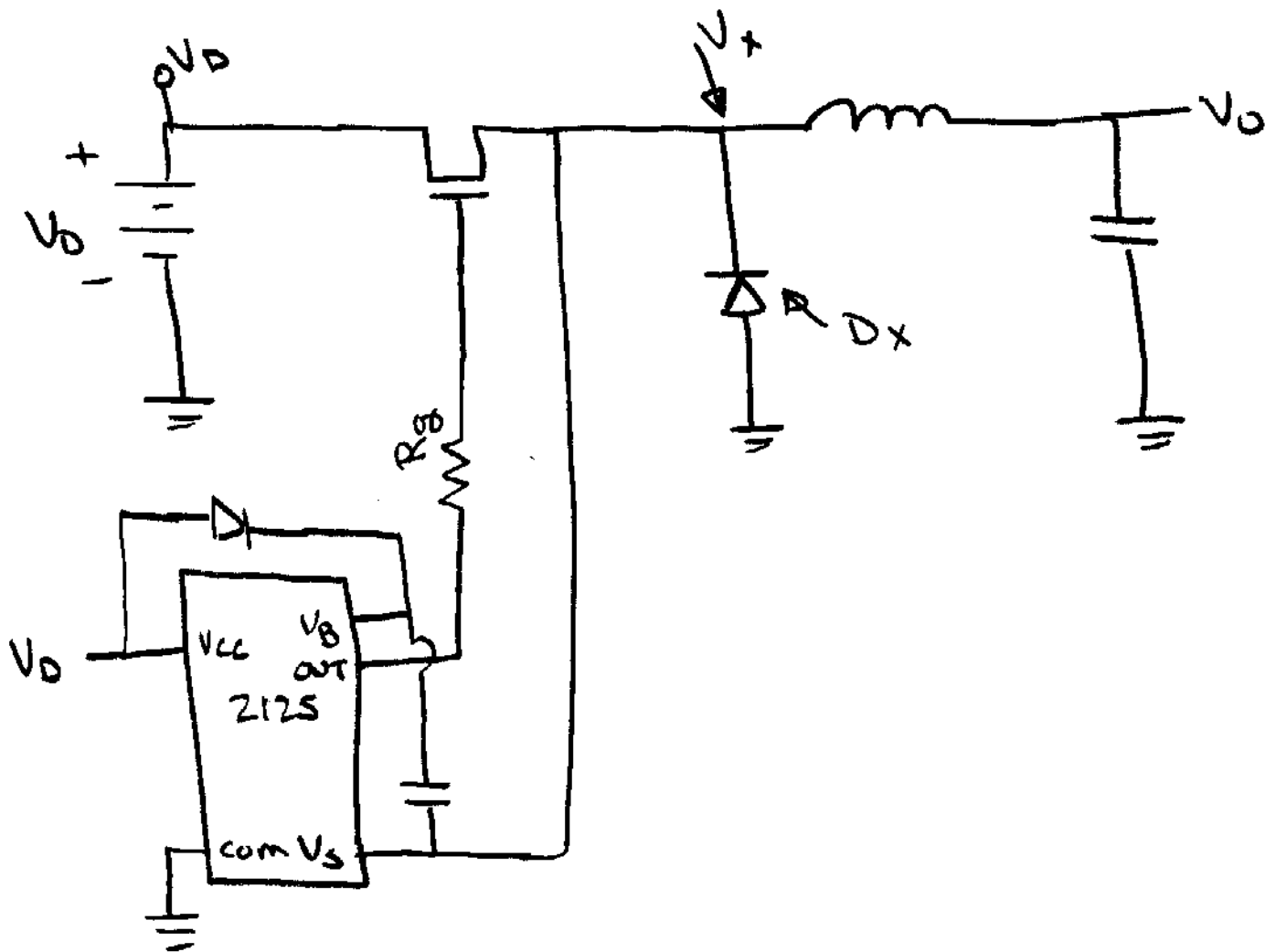
- The bootstrap capacitor charges up to V_{cc} when the source terminal goes to zero volts.

- To turn on the MOSFET, The IR 2125 connects the Boot Strap Capacitor to the output terminal



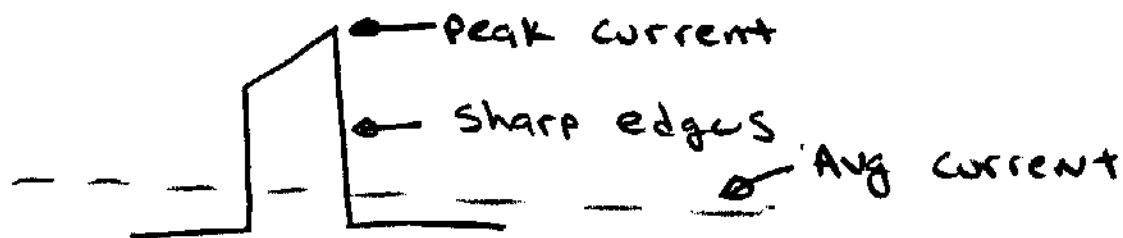
- when the switch turns on, V_S goes to $+HV$ (max of 500V)
- V_B goes to $V_S + 15V$
- The diode is off
- The Boot strap capacitor provides current to charge the MOSFET C_{gs} .
- V_S must return to ground potential to refresh the boot strap capacitor.

- Application in a Buck Converter



- V_x is at zero volts at startup
- V_x goes to -0.7 volts every time D_x turns on.

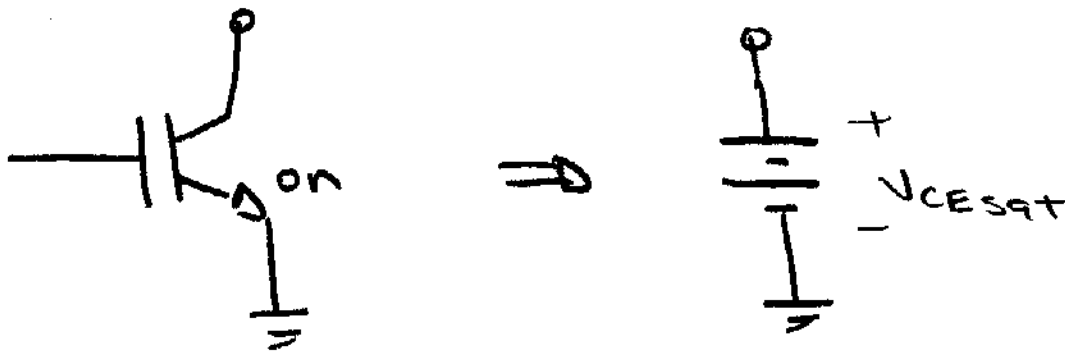
- A problem with using a current sensing resistor is that you need a low inductance, high power resistor that can handle high pulsed currents



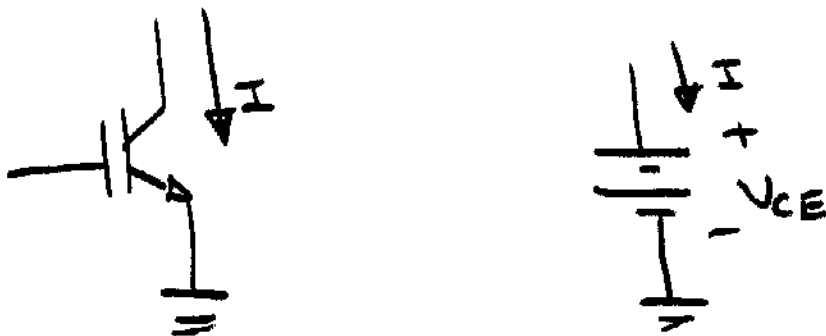
- Sharp edges, high peak current, causes localized heating in thin-film resistors, which causes their failure
- Current sensing resistors waste power and heat up other temperature sensitive components
- Avoid high power current sensing resistors

De-sat over current sensing Circuit for IGBT's

- when an IGBT is on, it looks like a voltage source

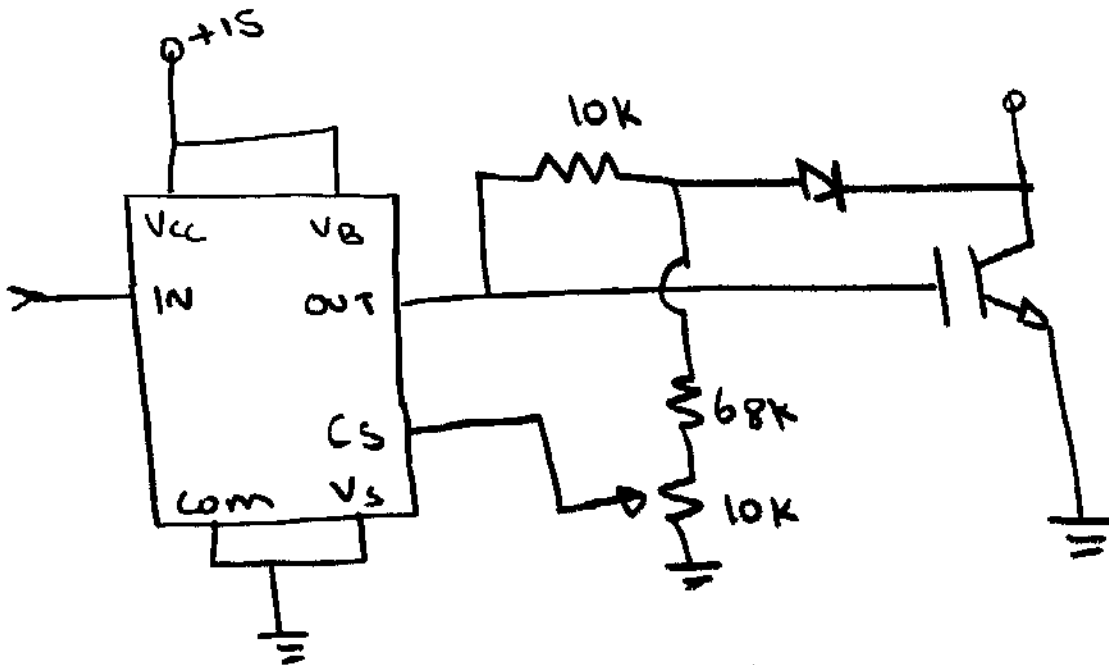


- as the current through the switch goes up, V_{CE} goes up

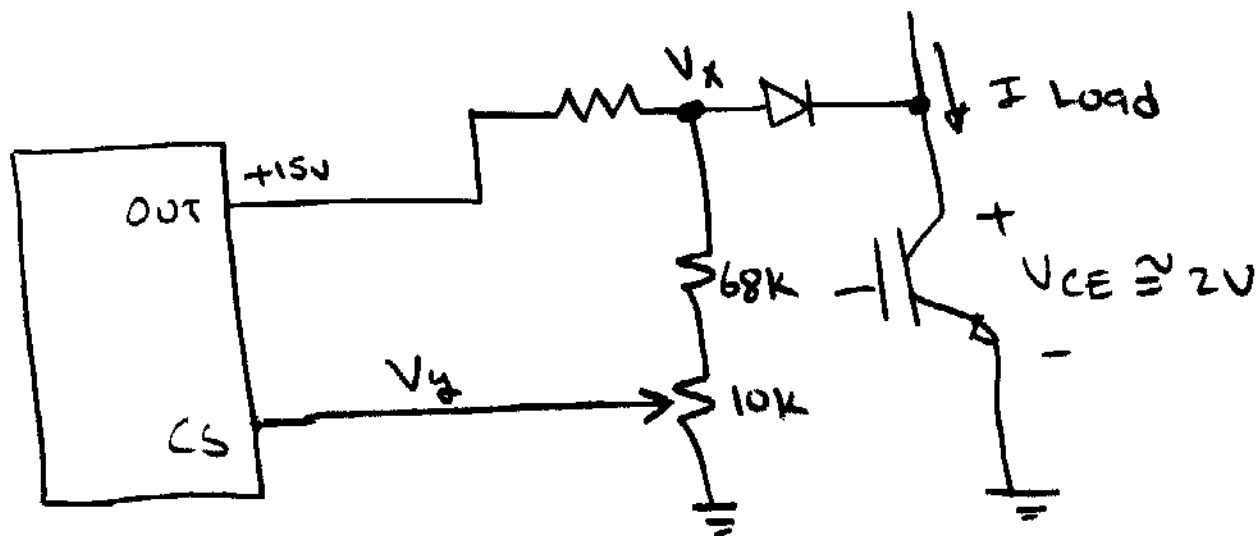


- Sensing I to large is equivalent to sensing when V_{CE} is too large

- It is called a de-sat detector because if V_{CE} becomes too large, the IGBT must be coming out of SAT.
- Want the IGBT sat when on, so V_{CE} too large is an indication that the current is too large.



When V_{out} is high we have



- C_s threshold is 230 mV
- $V_x = V_{CE} + 0.7V \approx 2.7V$ in normal operation
- adjust pot so that if V_{CE} becomes larger than 2V, V_g goes above 230 mV and trips the current limit
- Use the pot to adjust the current limit.

2.0 Amp Output Current IGBT Gate Drive Optocoupler

Technical Data

HCPL-3120

Features

- **2.0 A Minimum Peak Output Current**
- **15 kV/μs Minimum Common Mode Rejection (CMR) at $V_{CM} = 1500$ V**
- **0.5 V Maximum Low Level Output Voltage (V_{OL}) Eliminates Need for Negative Gate Drive**
- **$I_{CC} = 5$ mA Maximum Supply Current**
- **Under Voltage Lock-Out Protection (UVLO) with Hysteresis**
- **Wide Operating V_{CC} Range:**
15 to 30 Volts
- **500 ns Maximum Switching Speeds**
- **Industrial Temperature Range:** -40°C to 100°C
- **Safety Approval**
UL Recognized - 2500 V rms for 1 minute per UL1577
CSA Approval
VDE 0884 Approved with $V_{IORM} = 630$ V peak (Option 060 only)

Applications

- **Isolated IGBT/MOSFET Gate Drive**
- **AC and Brushless DC Motor Drives**

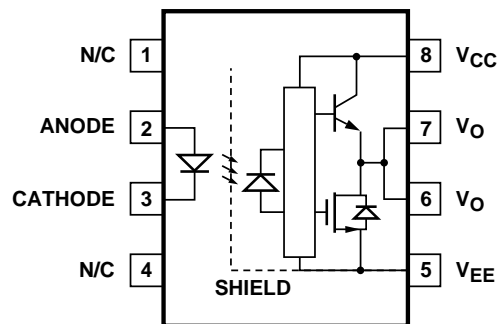
- **Industrial Inverters**
- **Switch Mode Power Supplies (SMPS)**

Description

The HCPL-3120 consists of a GaAsP LED optically coupled to an integrated circuit with a power output stage. This optocoupler is ideally suited for driving power IGBTs and MOSFETs used in

motor control inverter applications. The high operating voltage range of the output stage provides the drive voltages required by gate controlled devices. The voltage and current supplied by this optocoupler makes it ideally suited for directly driving IGBTs with ratings up to 1200 V/100 A. For IGBTs with higher ratings, the HCPL-3120 can be used to drive a discrete power stage which drives the IGBT gate.

Functional Diagram



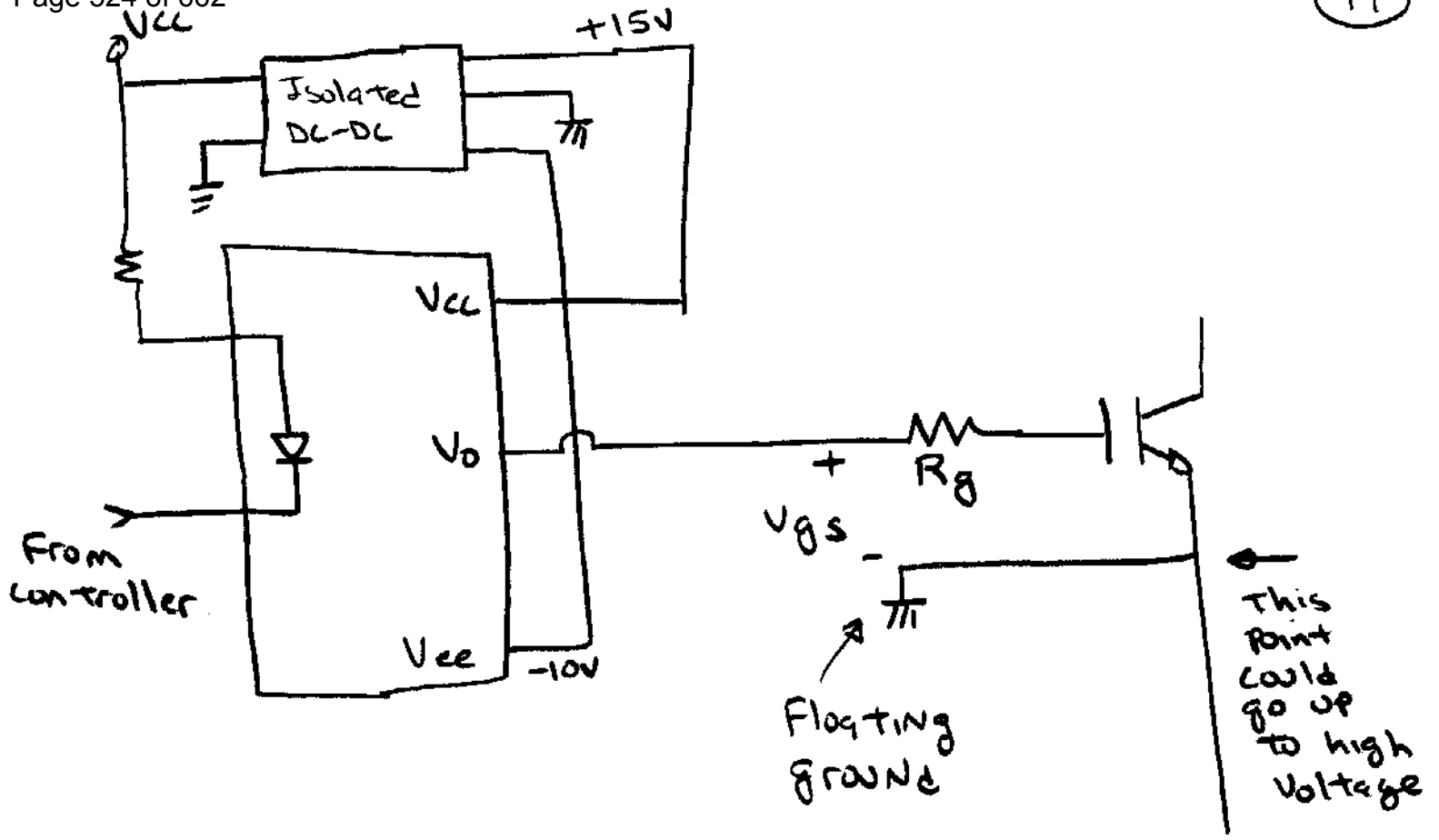
TRUTH TABLE

LED	$V_{CC} - V_{EE}$ "POSITIVE GOING" (i.e., TURN-ON)	$V_{CC} - V_{EE}$ "NEGATIVE GOING" (i.e., TURN-OFF)	V_O
OFF	0 - 30 V	0 - 30 V	LOW
ON	0 - 11 V	0 - 9.5 V	LOW
ON	11 - 13.5 V	9.5 - 12 V	TRANSITION
ON	13.5 - 30 V	12 - 30 V	HIGH

A 0.1 μF bypass capacitor must be connected between pins 5 and 8.

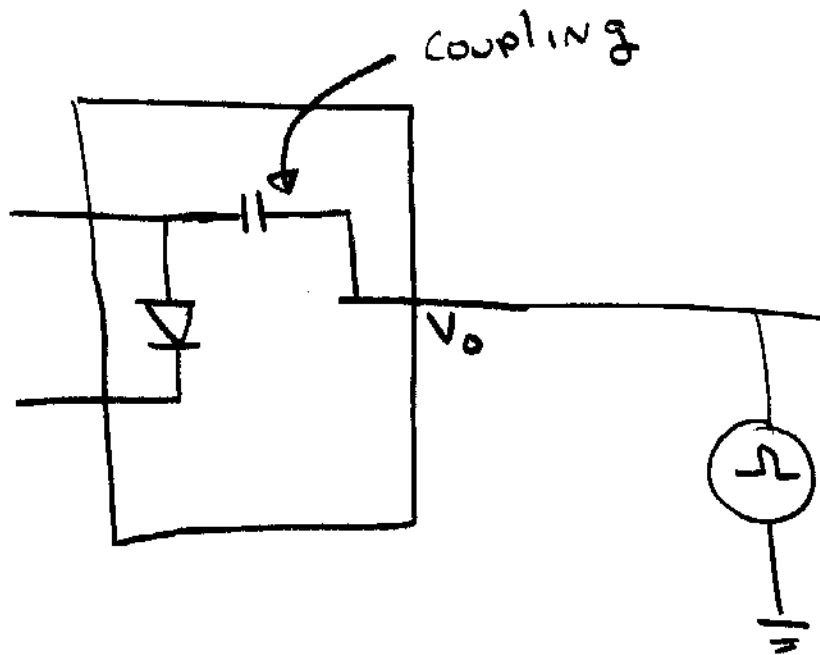
CAUTION: It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by ESD.

- Optical gate drivers provide electrical isolation between the control circuit and high power gate drive.
- Reduces noise transmission between a high power switching device and a control circuit that could be a computer.
- During failure of power switching device, protects the isolated electronics.
- When a high power switch fails, it usually kills most components that are electrically connected to it.
- Requires an isolated supply.

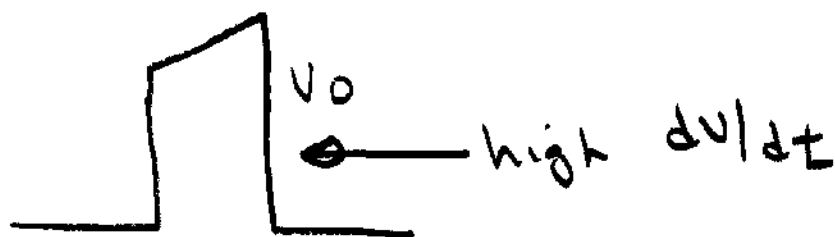


V_{gs} Swings From $-10V$ to $+15V$

- A important spec in optical gate drivers is called Common mode rejection, which is a measure of the coupling between the output and input (between the Isolated Sides).

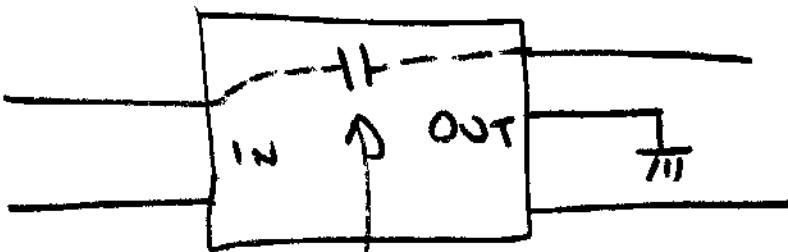


- If V_o is changing rapidly, there will be ^{unwanted} current fed back through the coupling



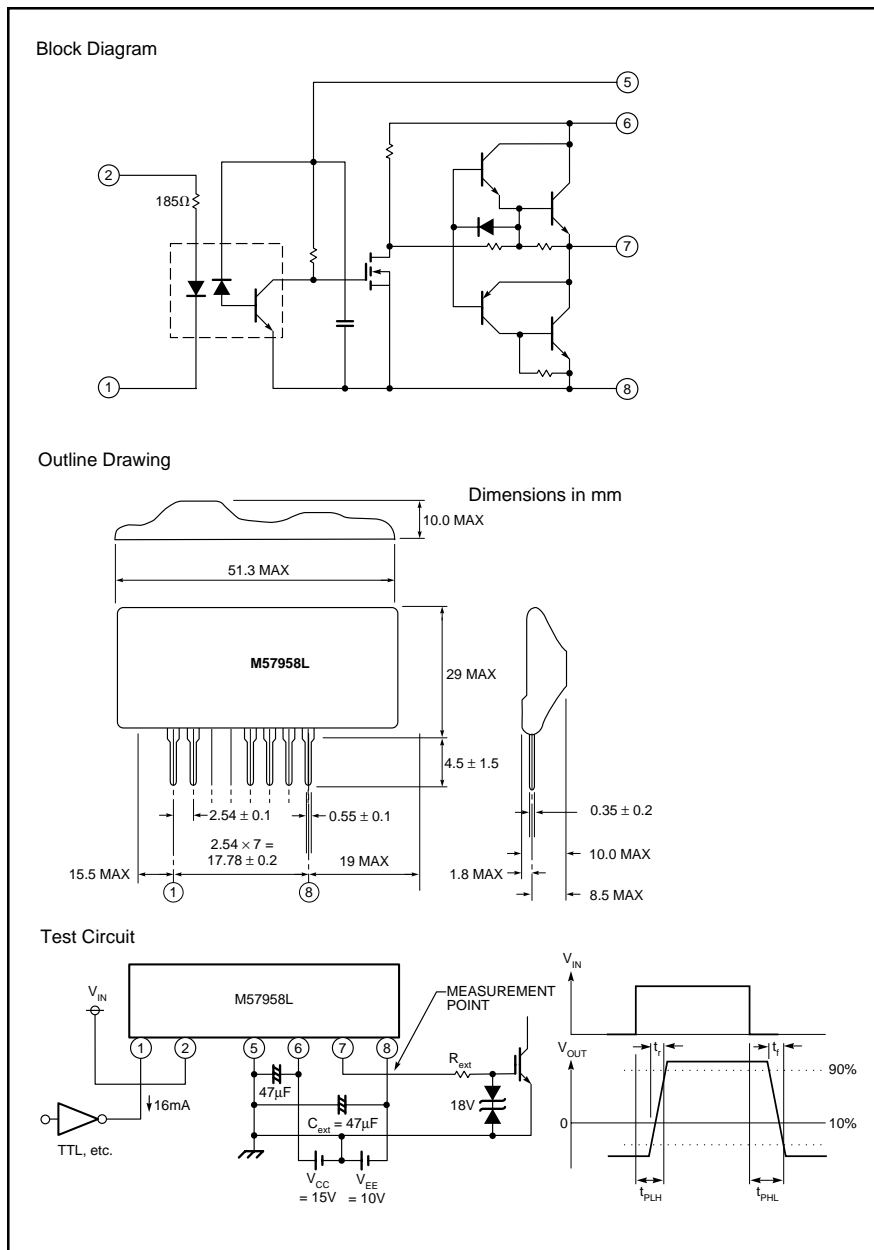
- The edges of a pulse have high dv/dt
- The units of CMR are $kV/\mu s$ and is a measure of how well the driver prevents feedback from a high dv/dt signal

- your Isolated DC-DC converter must also have Low Capacitive Coupling between the input and output to prevent $\frac{dV}{dt}$ Feed back through the DC-DC Supply



must be small

- Cheap converters have high coupling.



Hybrid Integrated Circuit For Driving IGBT Modules

Description:

M57958L is a hybrid integrated circuit designed for driving n-channel IGBT modules in any gate amplifier application. This device operates as an isolation amplifier for these modules and provides the required electrical isolation between the input and output with an optocoupler.

Features:

- Built in high CMRR optocoupler (V_{CMR} : Typical 30kV/μs, Min. 15kV/μs)
- Electrical Isolation between input and output with optocouplers ($V_{ISO} = 2500, V_{RMS}$ for 1 min.)
- TTL compatible input interface
- Two supply drive topology
- Short differential of propagation time (t_{PLH}, t_{PHL} to Max. 1.5μs, Typical 1.0μs)

Application:

To drive IGBT modules for inverter, AC Servo systems, UPS, CVCF inverter, and welding applications.

Recommended Modules:

$V_{CES} = 600V$ Series
(up to 400A Class)

$V_{CES} = 1200V$ Series
(up to 200A Class)

$V_{CES} = 1400V$ Series
(up to 200A Class)

Precaution:

The value of " R_{ext} " should be selected according to the guidelines in Section 4.6.2 of Application Notes.

Also, the value of " R_{ext} " should be selected so that maximum limits, I_{OHP} and I_{OLP} are not exceeded.



Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (724) 925-7272

M57958L

Hybrid IC for IGBT Gate Driver

Absolute Maximum Ratings, $T_a \sim 20^\circ\text{C}$ to 70°C

Item	Symbol	T_a ($^\circ\text{C}$)	Test Conditions	Limit	Units
Supply Voltage	V_{CC}	25	DC	18	Volts
	V_{EE}	25	DC	-12	Volts
Input Voltage	V_I	25	Between Terminal 1 and 2	-1 ~ 7	Volts
Output Voltage	V_O	25	Output Voltage "H"	V_{CC}	Volts
Output Current	I_{OHP}	25	Pulse Width 2 μs , $f = 30\text{kHz}$	-5	Amperes
	I_{OLP}	25	Pulse Width 2 μs , $f = 30\text{kHz}$	5	Amperes
Output Current	I_{OHL}	25	$f = 30\text{kHz}$, $\text{DF} = 50\%$	0.8	Amperes
Isolation Voltage	V_{iso}	25	Sinewave Voltage 60kHz, 1 min.	2500	Vrms
Junction Temperature	T_j	—		100	$^\circ\text{C}$
Operating Temperature	T_{opg}	—		-20 ~ 70	$^\circ\text{C}$
Storage Temperature	t_{stg}	—		*-25 ~ 100	$^\circ\text{C}$

*But differs from H/C condition.

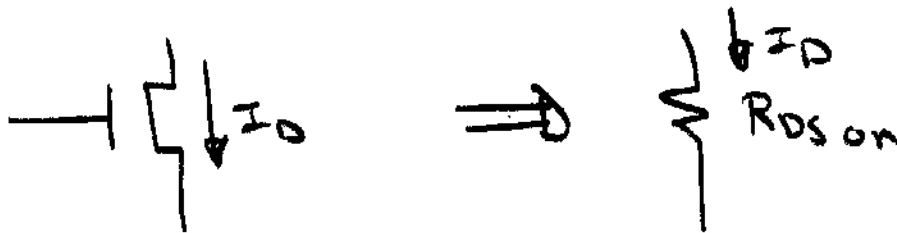
Electrical Characteristics, $T_a = 25^\circ\text{C}$, $V_{CC} = 25\text{V}$

Characteristics	Symbol	V_{CC}/V_{EE} ($^\circ\text{C}$)	T_a ($^\circ\text{C}$)	Test Conditions	Min.	Typ.	Max.	Units
Supply Voltage	V_{CC}	—	25	Recommended Range	14	15	—	Volts
	V_{EE}	—	25	Recommended Range	-9	-10	—	Volts
Pull-up Voltage on Input Side	V_{IN}	—	25	Recommended Range	4.75	5.00	5.25	Volts
"H" Input Current	I_{IH}	15/-10	25	$V_{IN} = 5\text{V}$, $R = 185\Omega$	—	16	—	mA
"H" Output Voltage	V_{OH}	15/-10	25		13	14	—	Volts
"L" Output Voltage	V_{OL}	15/-10	25		-8	-9	—	Volts
Internal Power Dissipation	P_D	15/-10	25	$f = 30\text{kHz}$, $\text{DF} = 50\%$,	—	1.2	—	Watts
				Module 200A, 600V IGBT				
"L-H" Propagation Time	t_{PLH}	15/-10	—	$V_I = 0$ to 4V , $T_j \pm 100^\circ\text{C}$	—	1.0	1.5	μs
"L-H" Rise Time	t_r	15/-10	—	$V_I = 0$ to 4V , $T_j \pm 100^\circ\text{C}$	—	0.6	1.0	μs
"H-L" Propagation Time	t_{PHL}	15/-10	—	$V_I = 5$ to 0V , $T_j \pm 100^\circ\text{C}$	—	1.0	1.5	μs
Fall Time	t_f	15/-10	—	$V_I = 5$ to 0V , $T_j \pm 100^\circ\text{C}$	—	0.4	1.0	μs

Power losses in switches

- Switching devices have two types of losses, static losses and switching losses.

- When a switch is on and is conducting current it dissipates power



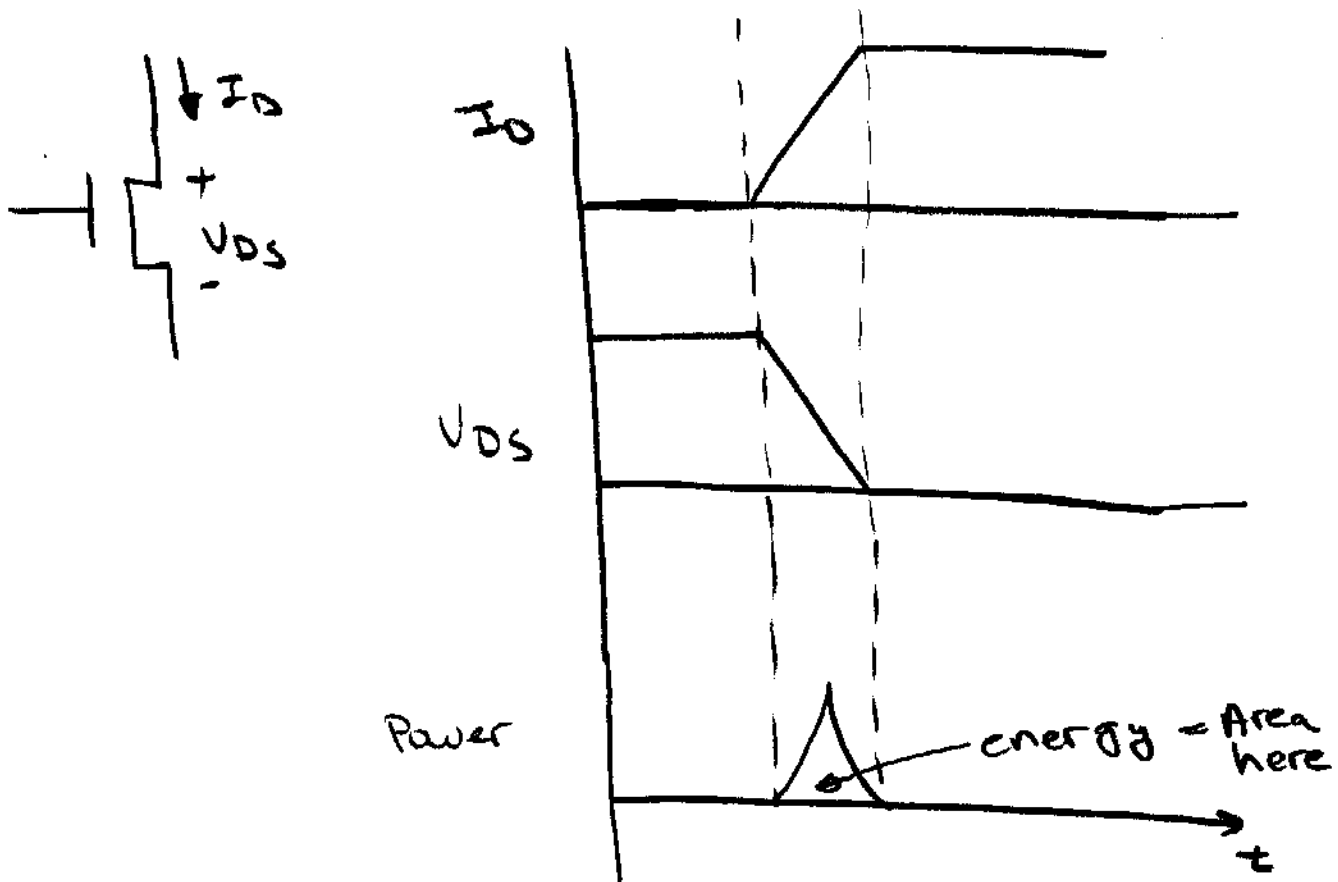
$$P_{\text{static}} = I_D^2 R_{\text{DS(on)}}$$



$$P_{\text{static}} = I_C V_{\text{CE(sat)}}$$

- you cannot avoid static losses

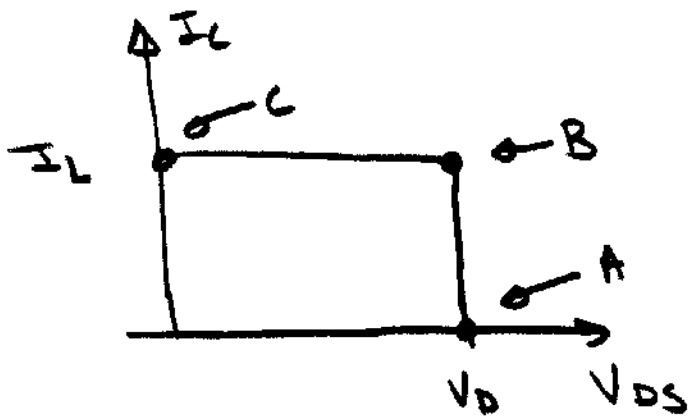
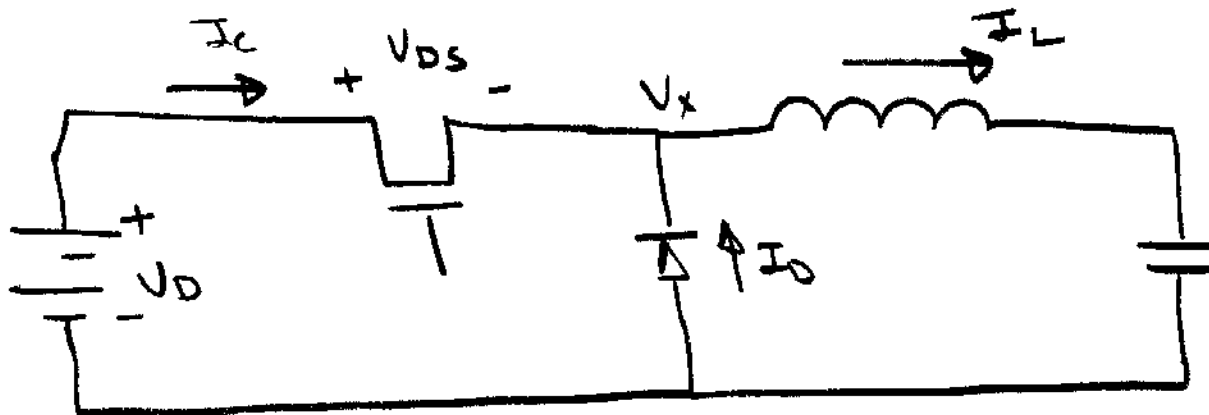
- Switching losses - when you turn on or off a switch, there is a period of time when both the current and voltage are non-zero



- This overlap happens every time a switch turns on or off depending on the topology.
- Switching losses are proportional to switching frequency

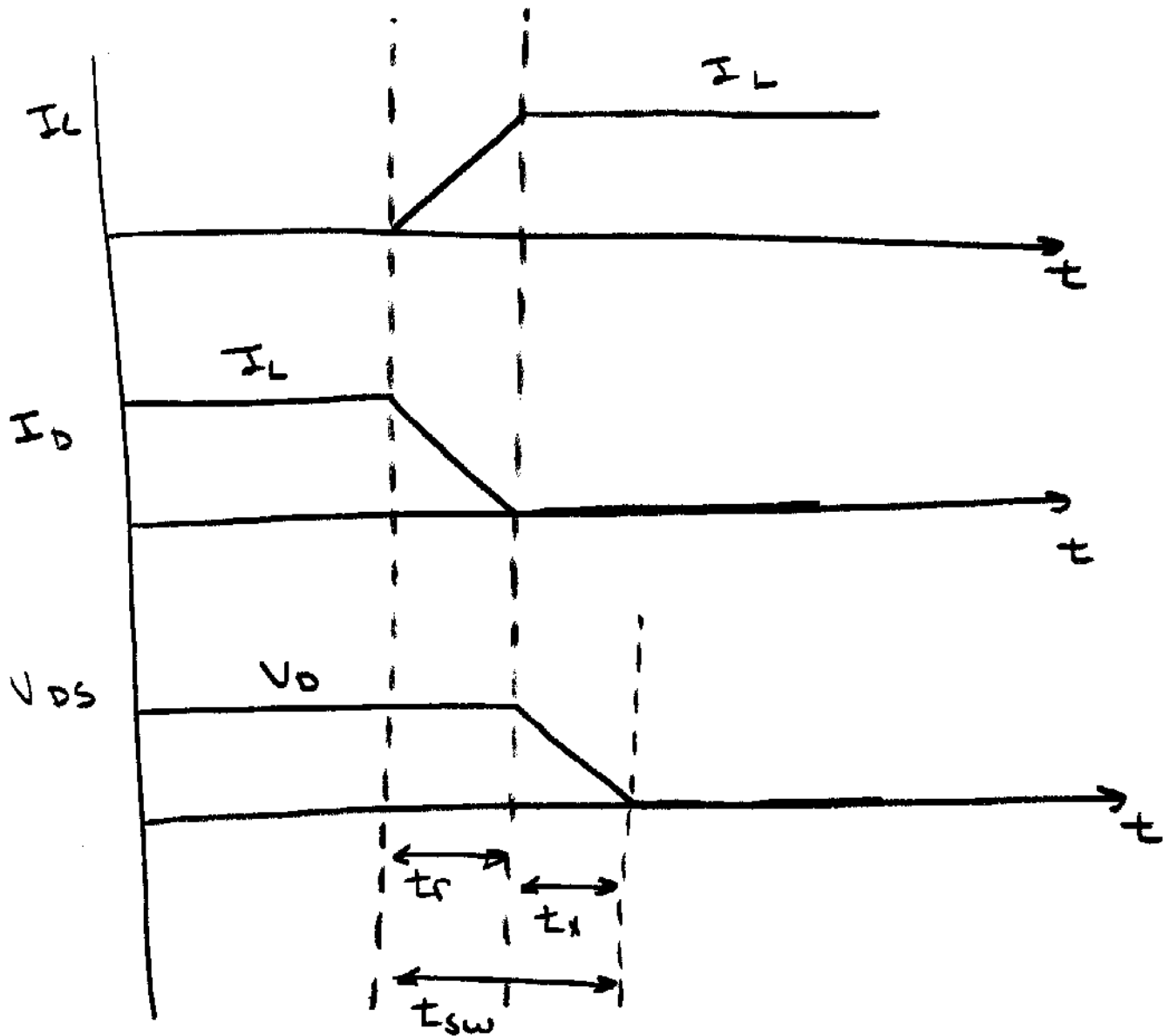
$$\text{Switching Loss} = F_s (\text{energy})$$

Example- Buck Regulator



- Look at the switching losses when the mosfet is off and then turns on.
- while the mosfet is off (point A):
 - I_L Flows through the diode ($I_D = I_L, I_c = 0$)
 - $V_x \approx 0$
 - $V_{DS} \approx V_D$

- as the MOSFET turns on (A to B)
 - I_C increases and I_D decreases
 - $I_L = I_C + I_D$
 - as long as $I_D \neq 0$, the diode is on and $V_x = 0$ and $V_{DS} = V_D$
 - I_C is non zero while $V_{DS} = V_D$
 - I_C goes from 0 to I_L with $V_{DS} = V_D$
 - I_D goes from I_L to zero
- once $I_C = I_L$ we are at point (B)
 - Diode is OFF
 - V_x is free to rise
 - V_{DS} goes from V_{DS} to 0 (B to C)



- Calculate the Average power

- During t_r , $V_{DS} = V_0$, $\langle I_c \rangle = \frac{I_L}{2}$

$$\langle P_{tr} \rangle = V_{DS} \langle I_c \rangle = V_0 \frac{I_L}{2} = \text{average power during } t_r$$

- The energy dissipated during t_r is

$$E_{t_r} = \langle P_{t_r} \rangle t_r = \frac{V_D I_L}{2} t_r$$

- This loss happens once per cycle

- The average power is

$$P_i = F_s E_{t_r} = \frac{V_D I_L}{2} t_r \cdot F_s$$

$$= \frac{V_D I_L}{2} \frac{t_r}{T_s}$$

\Rightarrow Switching loss is proportional to switching frequency.

- during t_x , we have a similar loss

$I_c = I_L$ and V_{DS} goes from V_D to zero

$$\langle V_{DS} \rangle = \frac{V_D}{2}$$

$$\langle P_{t_x} \rangle = \langle V_{DS} \rangle I_L = \frac{V_D I_L}{2}$$

- Energy dissipated during t_x is

$$E_{t_x} = \langle P_{t_x} \rangle t_x = \frac{V_D I_L}{2} t_x$$

- This loss happens once per cycle.

- The average power is

$$P_2 = F_s E_{t_x} = \frac{V_D I_L}{2} t_x \cdot F_s$$

$$= \frac{V_D I_L}{2} \frac{T_x}{T_s}$$

- The total power dissipated during turn-on is

$$\langle P \rangle_{\text{sw-on}} = P_1 + P_2 = \frac{V_D I_L}{2} \left(\frac{t_r + t_x}{T_s} \right)$$

- During turn-off we will trace out path C-B-A and have a similar loss, but the switching times will be different.

- To reduce switching losses:

1) reduce the switching frequency

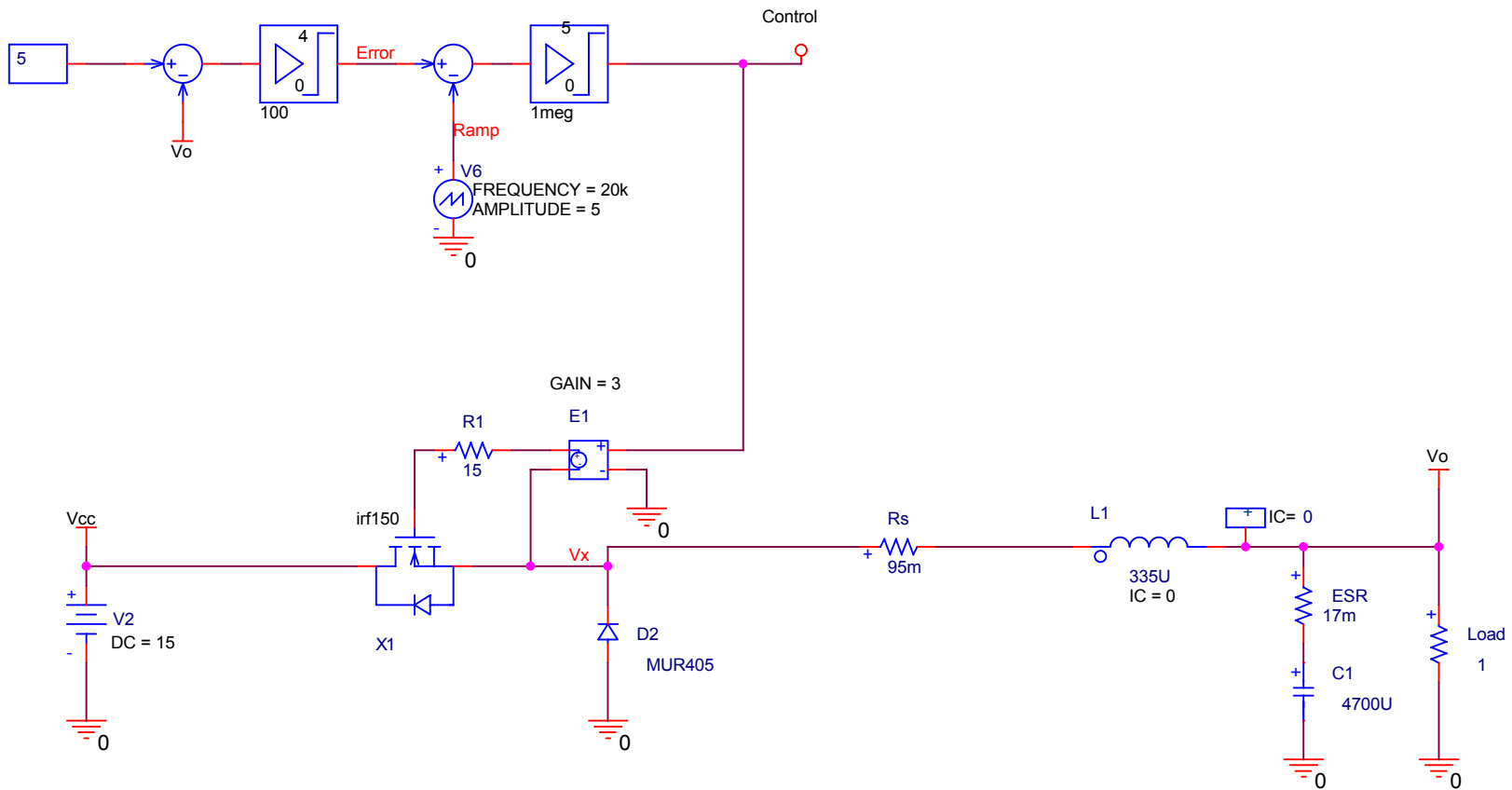
2) use a good gate drive to turn on and off switches quickly.

high current gate drivers reduce t_r and t_x .

- To eliminate (greatly reduce) switching losses, use a resonant topology (also called soft switching)

- ZCS - Zero current switching -
Switch changes while current is zero

- ZVS - Zero voltage switching -
Switch changes while voltage is zero.

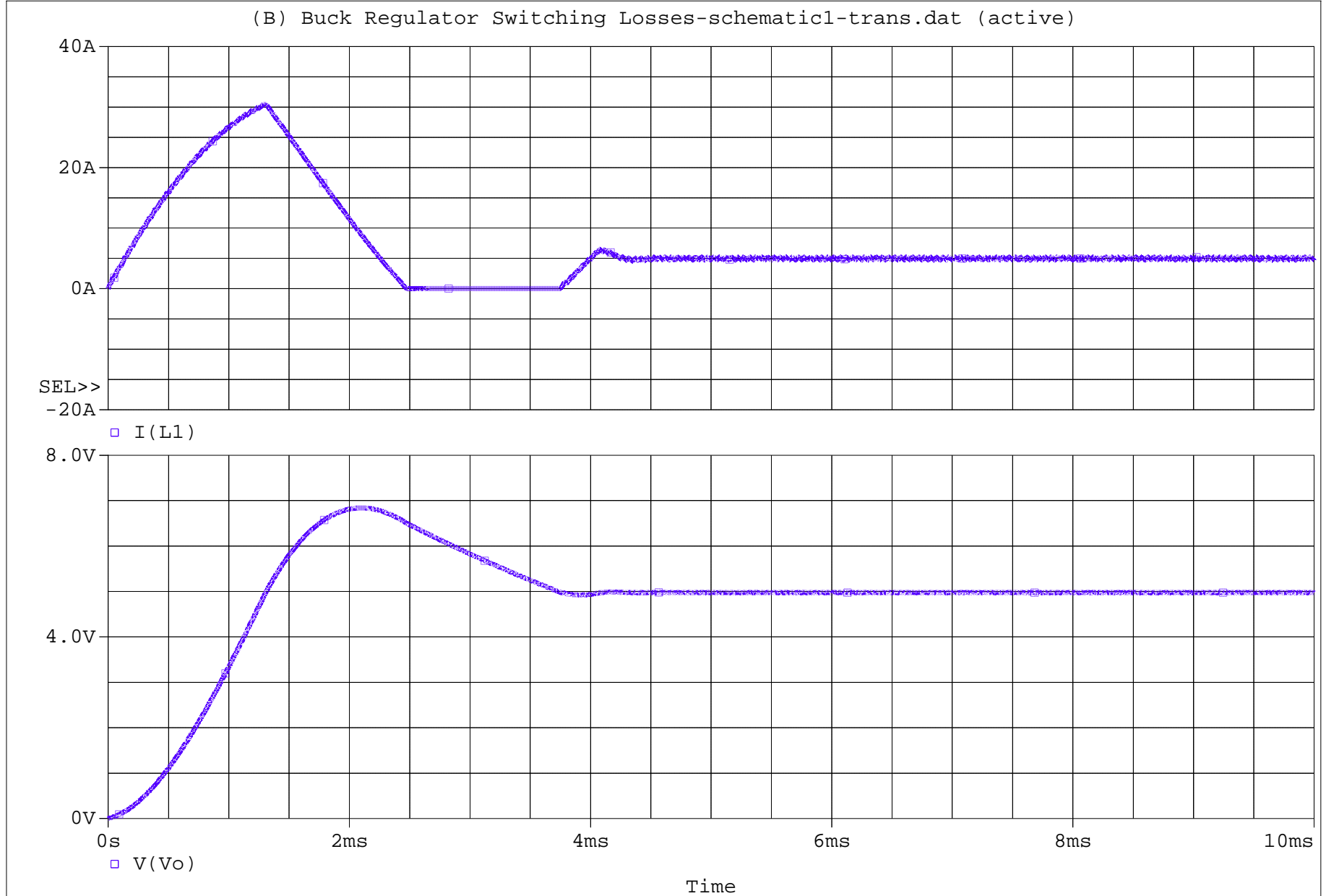


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*Commercial Use or Resale Restricted *
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*****
* Model generated on Dec 17, 96
* MODEL FORMAT: SPICE3
* Symmetry POWER MOS Model (Version 1.0)
* External Node Designations
* Node 1 -> Drain
* Node 2 -> Gate
* Node 3 -> Source
M1 9 7 8 8 MM L=100u W=100u
* Default values used in MM:
* The voltage-dependent capacitances are
* not included. Other default values are:
*   RS=0 RD=0 LD=0 CBD=0 CBS=0 CGBO=0
.MODEL MM NMOS LEVEL=1 IS=1e-32
+VTO=4.07861 LAMBDA=0.000761669 KP=19.0218
+CGSO=3.57784e-05 CGDO=4.96221e-07
RS 8 3 0.0216597
D1 3 1 MD
.MODEL MD D IS=2.01865e-09 RS=0.11592 N=1.5 BV=100
+IBV=0.001 EG=1 XTI=1 TT=1e-07
+CJO=3.28974e-09 VJ=4.39387 M=0.659734 FC=0.1
RDS 3 1 3.2e+06
RD 9 1 0.00224103
RG 2 7 12.1
D2 4 5 MD1
* Default values used in MD1:
*   RS=0 EG=1.11 XTI=3.0 TT=0
*   BV=infinite IBV=1mA
.MODEL MD1 D IS=1e-32 N=50
+CJO=3.78329e-09 VJ=0.607074 M=0.893797 FC=1e-08
D3 0 5 MD2
* Default values used in MD2:
*   EG=1.11 XTI=3.0 TT=0 CJO=0
*   BV=infinite IBV=1mA
.MODEL MD2 D IS=1e-10 N=0.402271 RS=3.00001e-06
RL 5 10 1
FI2 7 9 VFI2 -1
VFI2 4 0 0
EV16 10 0 9 7 1
CAP 11 10 3.78329e-09
FI1 7 9 VFII1 -1
VFII1 11 6 0
RCAP 6 10 1
D4 0 6 MD3
* Default values used in MD3:
*   EG=1.11 XTI=3.0 TT=0 CJO=0
*   RS=0 BV=infinite IBV=1mA
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.ENDS irf150

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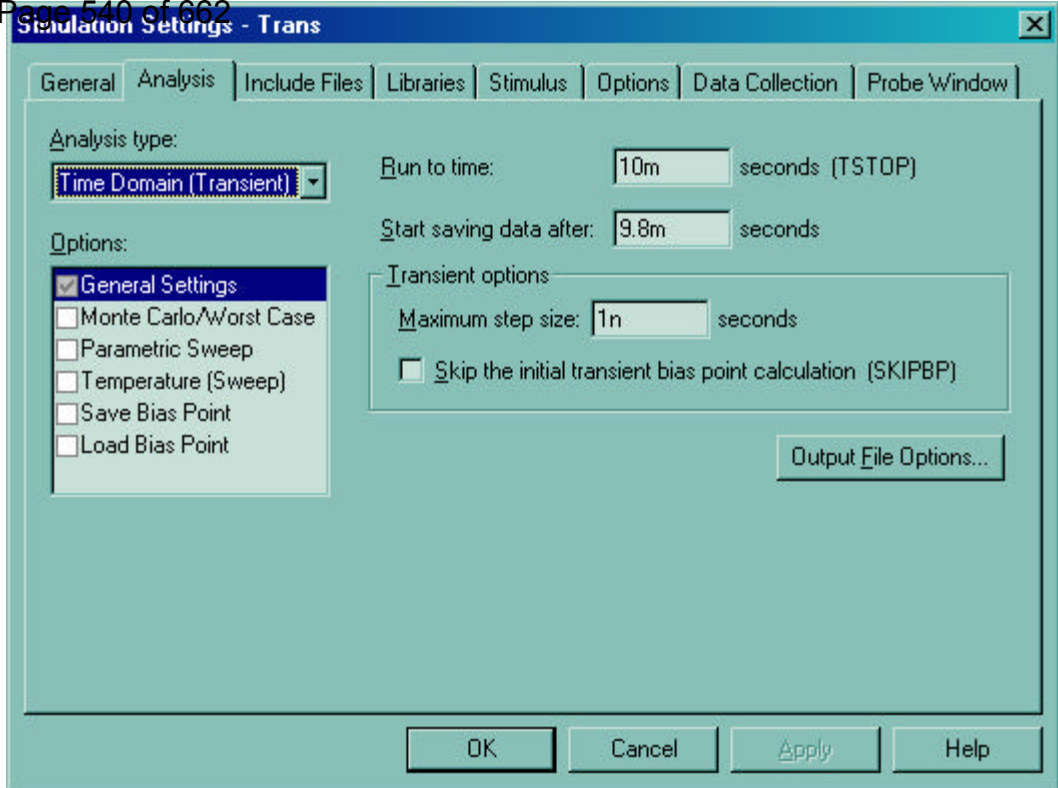
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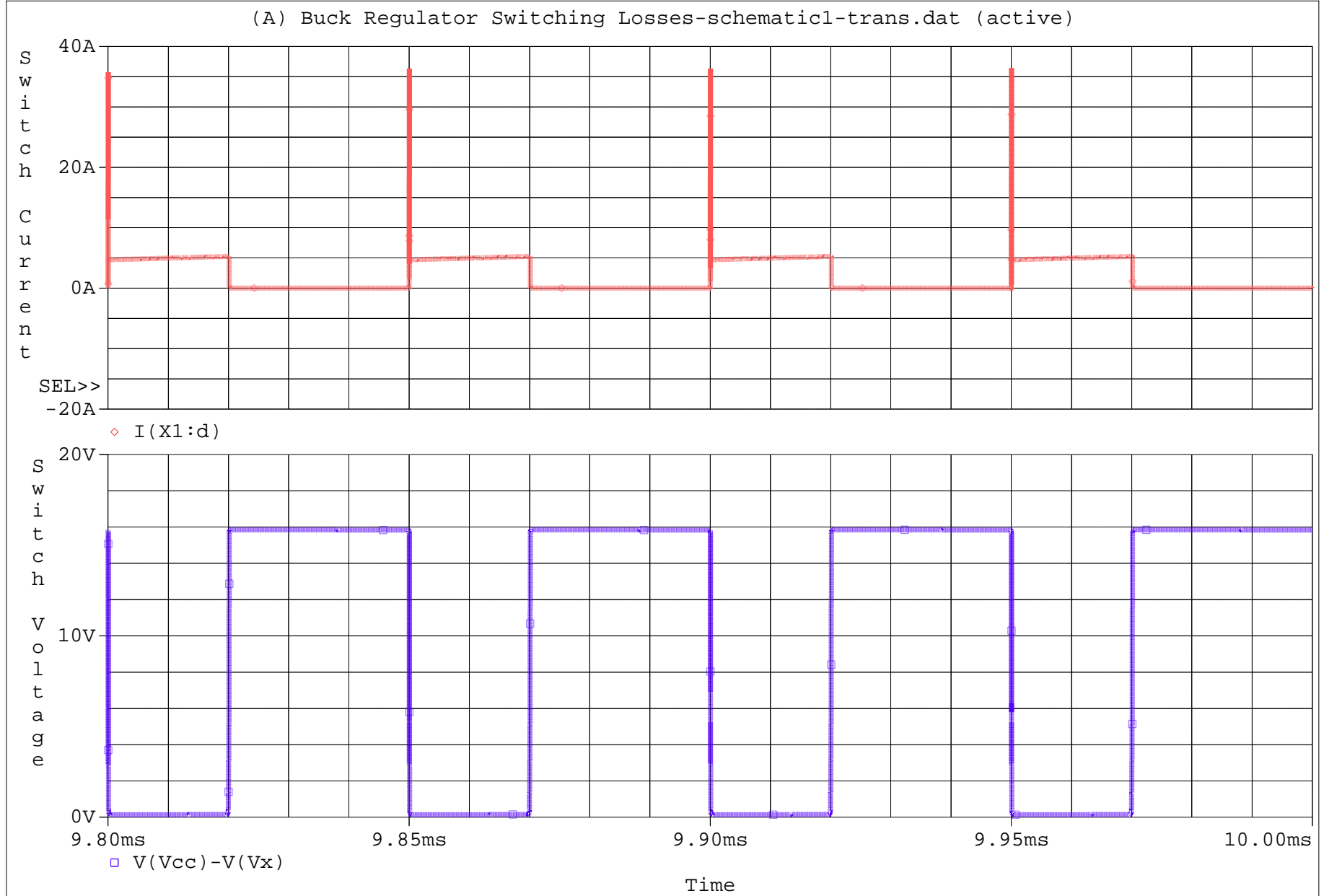
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Page 1

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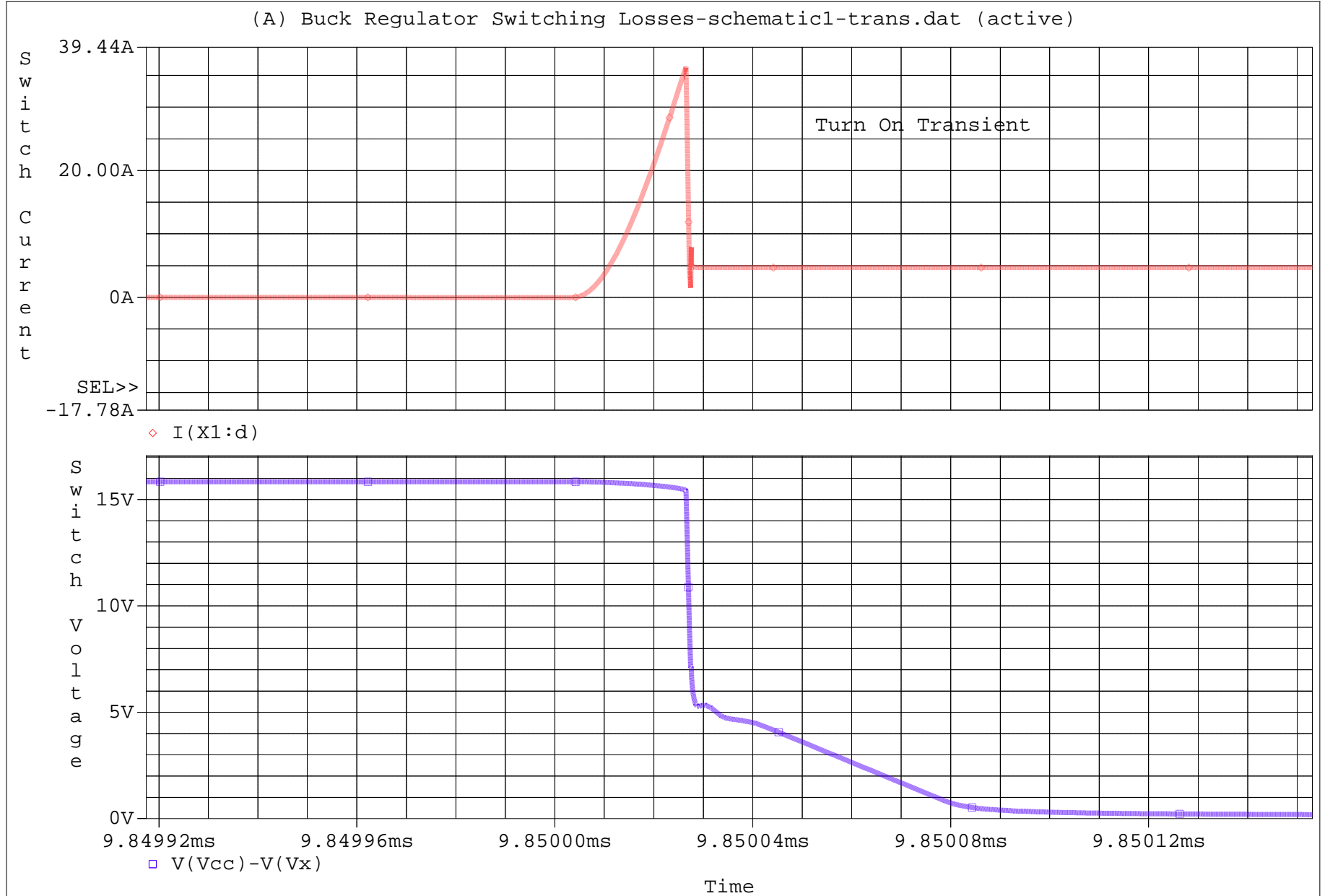


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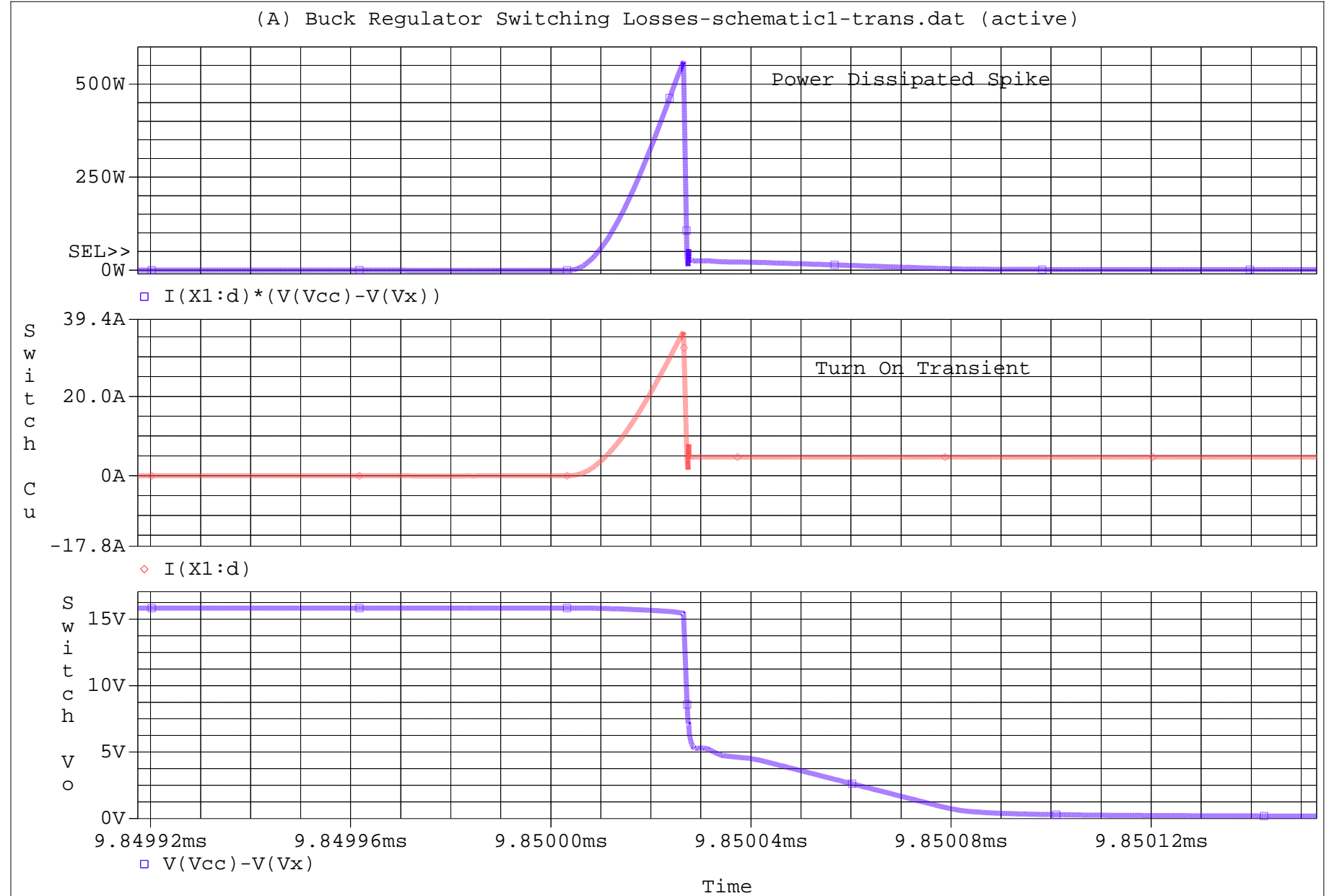


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Page 1

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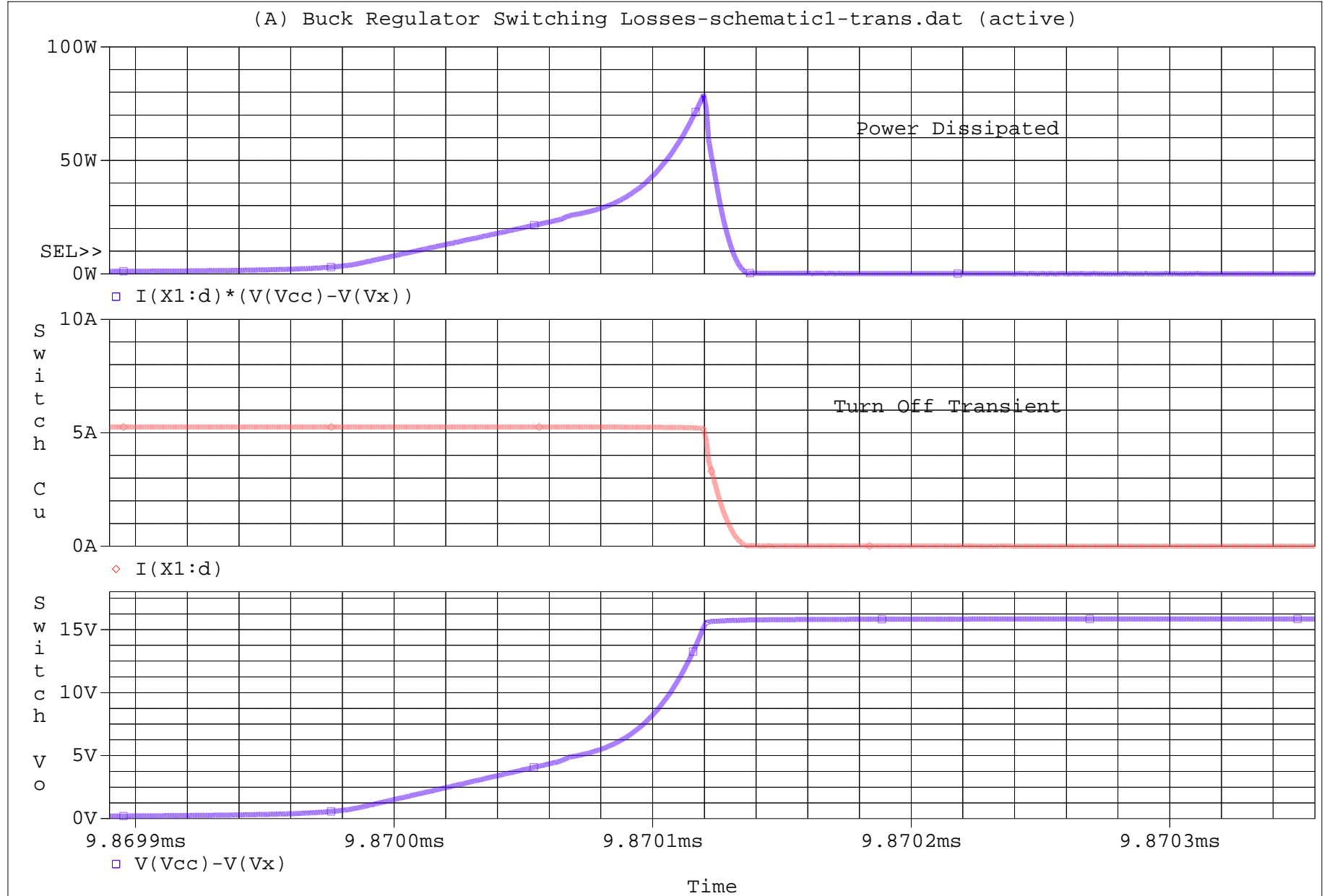


Date: February 04, 2003

Page 1

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Date: February 04, 2003

Page 1

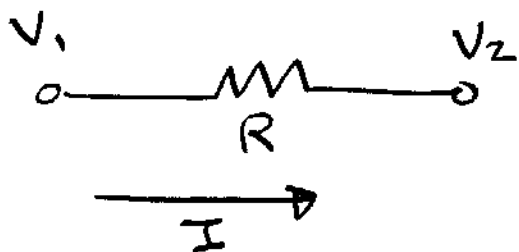
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Heat Sinking

①

- How do we keep a device from burning up?
- If we put a device in a box and provide no way to remove the heat, the enclosure will heat up until something fails
- We must provide a cooling path for all devices
- Here we will look at choosing a heat sink for our semiconductor switches
- Heat flow is analogous to current flow
- Units of heat flow are watts

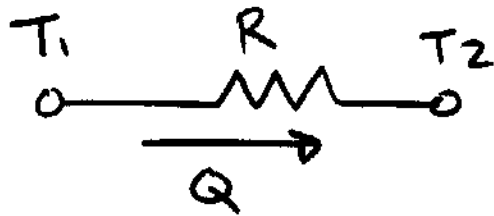
Electrical current



$$I = \frac{V_1 - V_2}{R}$$

$$R = \text{Volts/Amp}$$

Heat Flow

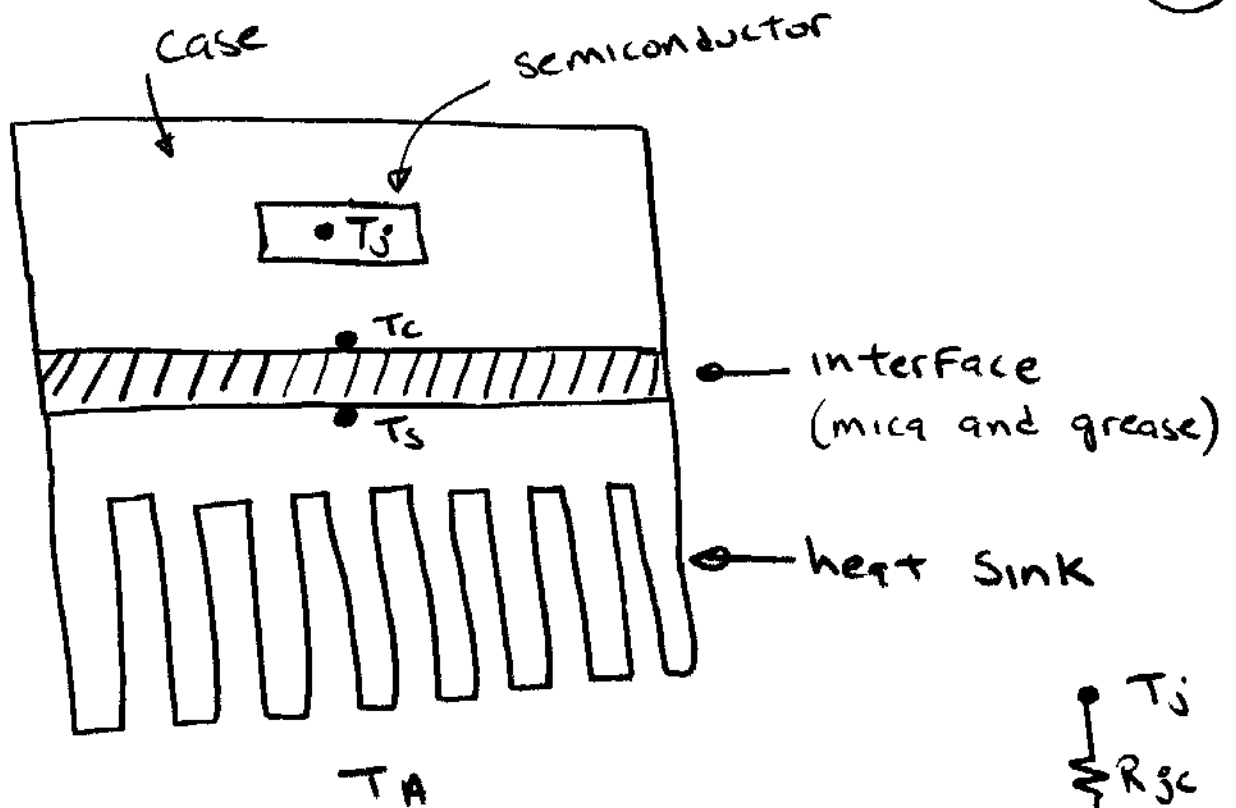


$$Q = \frac{T_1 - T_2}{R}$$

Q = heat flow in watts

R = thermal resistance in $^{\circ}\text{C}/\text{W}$

- In electronic devices the junction generates heat.
- Junction Temperature in $^{\circ}\text{C}$ or $^{\circ}\text{K}$
- MUST keep T_j below a specified maximum



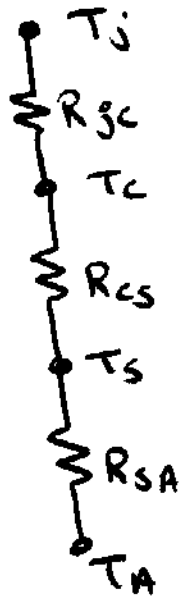
T_j = Junction Temperature

T_c = Case Temperature (mounting side)

T_s = Heat sink Temperature at interface

T_A = Ambient Temperature

R_{jc} = Junction to case Thermal resistance ($^{\circ}C/W$)
- Specified in data sheet



R_{cs} - Case to Sink thermal Resistance

- Specified in Datasheet ($^{\circ}C/W$)
- depends on interface compound
- Use grease or other interface compound

R_{sa} - heat sink resistance to ambient

- Specified by manufacturer
- Depends on air flow
 - Natural convection (No fan)
 - Forced convection (Fan)
 - Air flow (CFM) is important
- Depends on Altitude

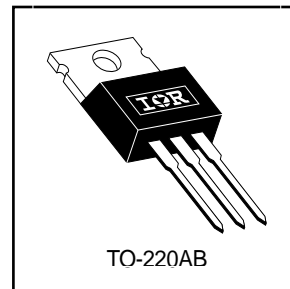
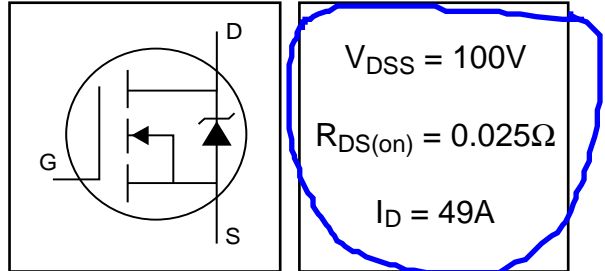
HEXFET® Power MOSFET

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-220 package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost of the TO-220 contribute to its wide acceptance throughout the industry.



Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ $T_C = 25^\circ\text{C}$	Continuous Drain Current, V_{GS} @ 10V	49	A
I_D @ $T_C = 100^\circ\text{C}$	Continuous Drain Current, V_{GS} @ 10V	35	
I_{DM}	Pulsed Drain Current ①	180	
P_D @ $T_C = 25^\circ\text{C}$	Power Dissipation	150	W
	Linear Derating Factor	1.0	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②	530	mJ
I_{AR}	Avalanche Current①	28	A
E_{AR}	Repetitive Avalanche Energy①	15	mJ
dv/dt	Peak Diode Recovery dv/dt ③	5.0	V/ns
T_J	Operating Junction and	-55 to + 175	°C
T_{STG}	Storage Temperature Range		
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 screw	10 lbf•in (1.1N•m)	

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	1.0	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.50	—	
$R_{\theta JA}$	Junction-to-Ambient	—	62	

Thermal Resistance

Page 550 of 662	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	1.0	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.50	—	
$R_{\theta JA}$	Junction-to-Ambient	—	—	

ECE556 Lecture Notes

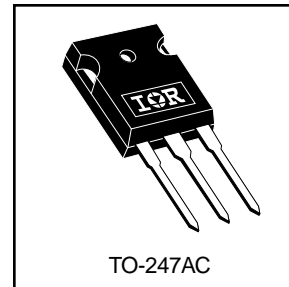
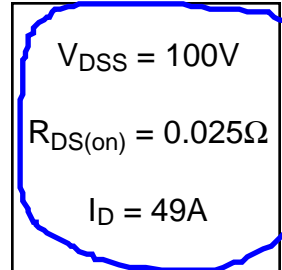
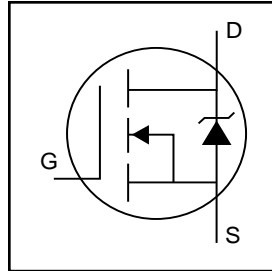
Page 550 of 662

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-247 package is preferred for commercial-industrial applications where higher power levels preclude the use of TO-220 devices. The TO-247 is similar but superior to the earlier TO-218 package because of its isolated mounting hole.



Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ $T_C = 25^\circ\text{C}$	Continuous Drain Current, V_{GS} @ 10V ⑤	49	A
I_D @ $T_C = 100^\circ\text{C}$	Continuous Drain Current, V_{GS} @ 10V ⑤	35	
I_{DM}	Pulsed Drain Current ①⑤	180	
P_D @ $T_C = 25^\circ\text{C}$	Power Dissipation	180	W
	Linear Derating Factor	1.2	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy ②⑤	530	mJ
I_{AR}	Avalanche Current ① ⑤	28	A
E_{AR}	Repetitive Avalanche Energy ①	18	mJ
dv/dt	Peak Diode Recovery dv/dt ③⑤	5.0	V/ns
T_J	Operating Junction and	-55 to + 175	°C
T_{STG}	Storage Temperature Range		
	Soldering Temperature, for 10 seconds		
	Mounting torque, 6-32 or M3 screw	10 lbf•in (1.1N•m)	

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	0.24	0.83	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface			
$R_{\theta JA}$	Junction-to-Ambient		40	

Thermal Resistance

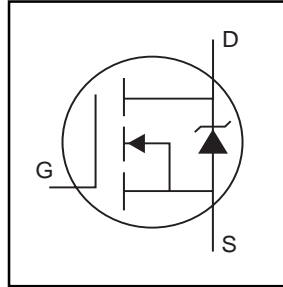
Page 552 of 662	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	0.83	°C/W Page 552 of 662
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	—	
$R_{\theta JA}$	Junction-to-Ambient	—	—	

ECE556 Lecture Notes

FB180SA10

HEXFET[®] Power MOSFET

- Fully Isolated Package
- Easy to Use and Parallel
- Very Low On-Resistance
- Dynamic dv/dt Rating
- Fully Avalanche Rated
- Simple Drive Requirements
- Low Drain to Case Capacitance
- Low Internal Inductance



$$V_{DSS} = 100V$$

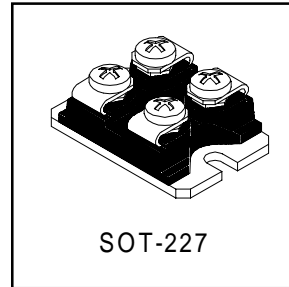
$$R_{DS(on)} = 0.0065\Omega$$

$$I_D = 180A$$

Description

Fifth Generation, high current density HEXFETS are paralleled into a compact, high power module providing the best combination of switching, ruggedized design, very low ON resistance and cost effectiveness.

The isolated SOT-227 package is preferred for all commercial - industrial applications at power dissipation levels to approximately 500 watts. The low thermal resistance and easy connection to the SOT-227 package contribute to its universal acceptance throughout the industry.



Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ $T_C = 25^\circ C$	Continuous Drain Current, V_{GS} @ 10V	180	A
I_D @ $T_C = 100^\circ C$	Continuous Drain Current, V_{GS} @ 10V	120	
I_{DM}	Pulsed Drain Current ①	720	
P_D @ $T_C = 25^\circ C$	Power Dissipation	480	W
	Linear Derating Factor	2.7	W/ $^\circ C$
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy ^②	700	mJ
I_{AR}	Avalanche Current ^③	180	A
E_{AR}	Repetitive Avalanche Energy ^④	48	mJ
dv/dt	Peak Diode Recovery dv/dt ^⑤	5.7	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 150	$^\circ C$
V_{ISO}	Insulation Withstand Voltage (AC-RMS)	2.5	kV
	Mounting torque, M4 screw	1.3	N•m

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	0.05	0.26	$^\circ C/W$
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.05	0.26	

Thermal Resistance

Page 554 of 662	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	0.26	$^{\circ}\text{C/W}$
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.05		

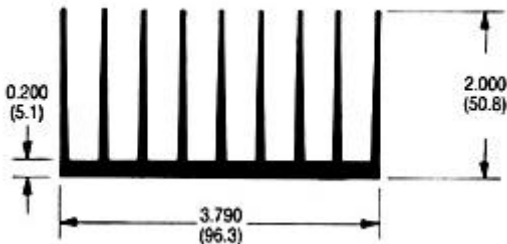
ECE556 Lecture Notes

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Aluminum Extrusion Profiles

To request quote ([click here](#))

5079 **NORMALLY STOCKED** - Click to check current inventory



Click on extrusion to enlarge

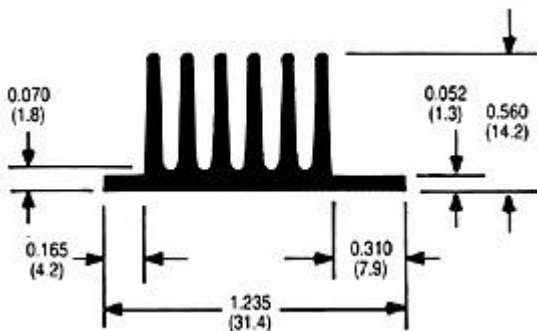
Per. 39.77 in.

WT 2.66 lb/ft

Θ_{sa} 1.50 °C/W/3

Extrusion Online

6270



Click on extrusion to enlarge

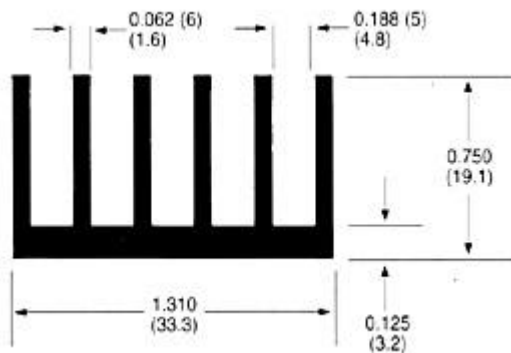
Per. 8.50 in.

WT 0.25 lb/ft

Θ_{sa} 12.00 °C/W/3

Extrusion Online

2158



Click on extrusion to enlarge

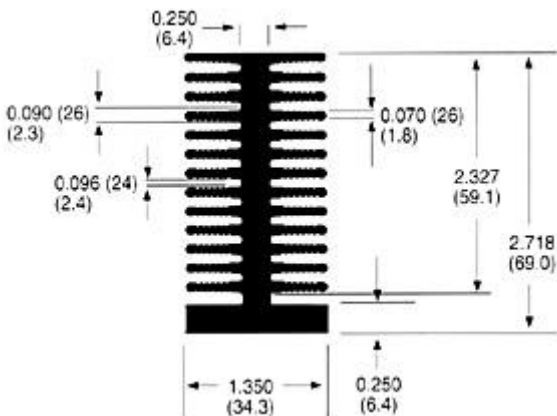
Per. 10.37 in.

WT 0.48 lb/ft

Θ_{sa} 6.80 °C/W/3

Extrusion Online

4228



Click on extrusion to enlarge

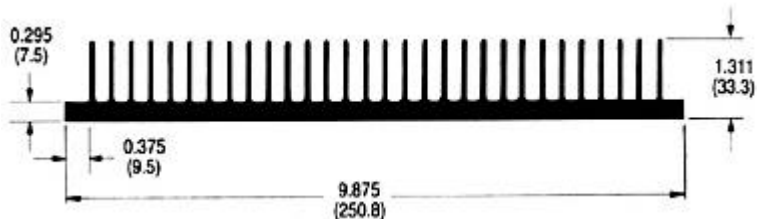
Per. 38.93 in.

WT 2.29 lb/ft

Θ_{sa} 1.90 °C/W/3

Extrusion Online

1703 **NORMALLY STOCKED** [Click to check current inventory](#)



Click on extrusion to enlarge

Per. 78.03 in.
WT 6.15 lb/ft
 Θ_{sa} 0.91 °C/W/3

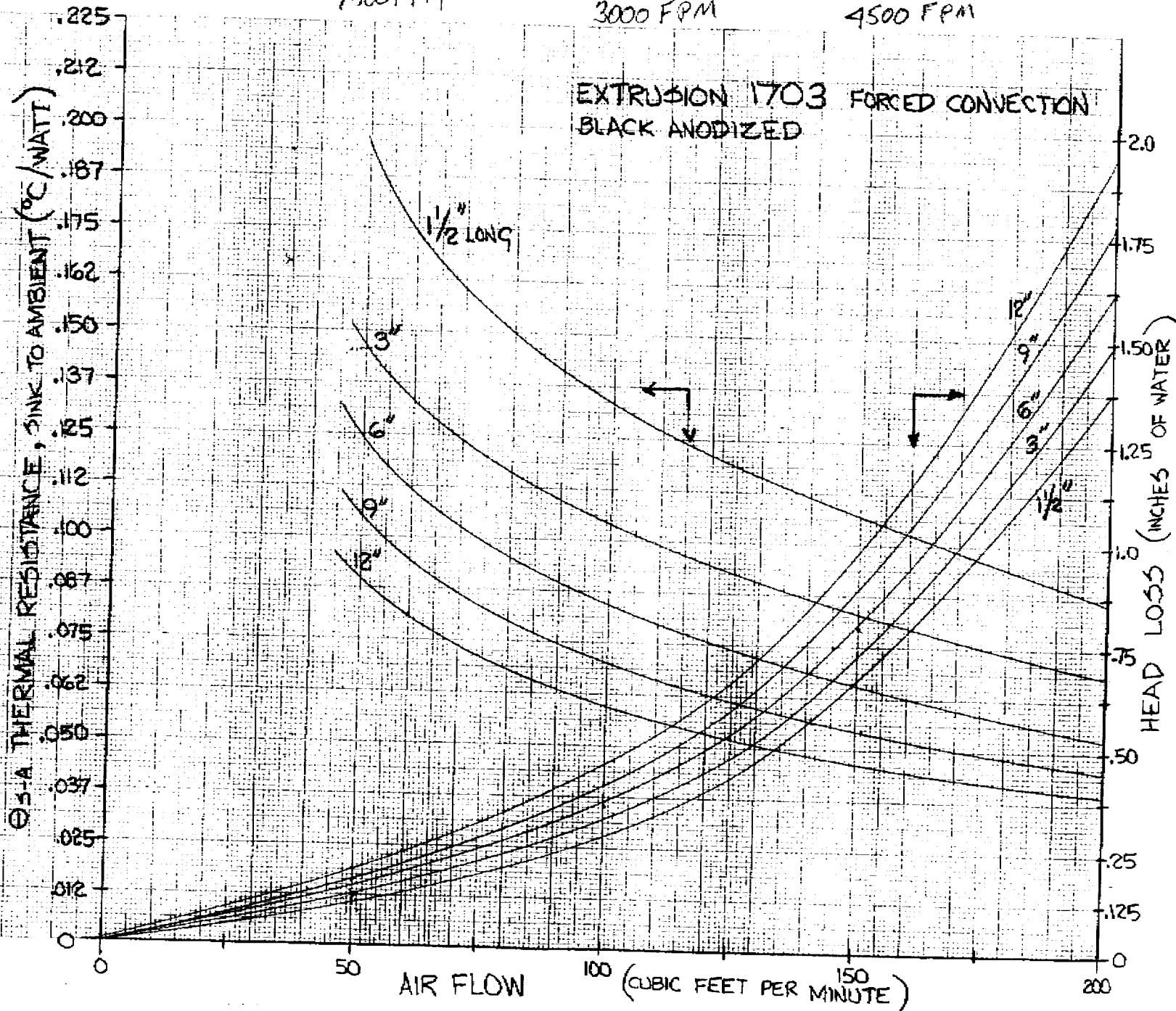
48 1213

EXTRUSION 1703 BLACK ANODIZED

17 MPH
1500 FPM

35 MPH
3000 FPM

50 MPH
4500 FPM



Post-it® Fax Note 7671 # of pages 7

Date 1/12-2

To MARK HENNING

From DAVE HOGWORTHY

Co./Dept. MIN HIGH

Co. WAKEFIELD

Phone # UN-KNOWN

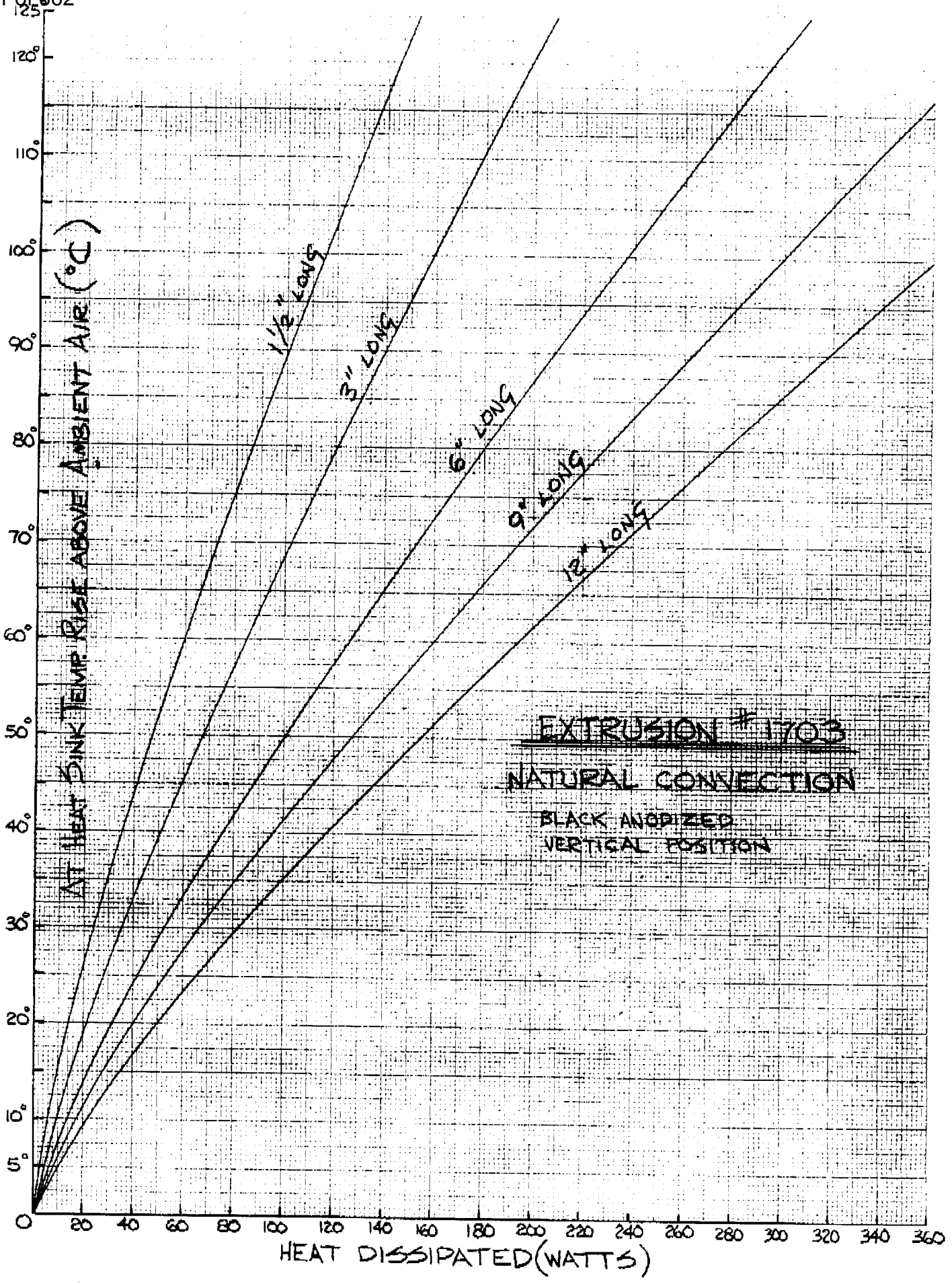
Phone #

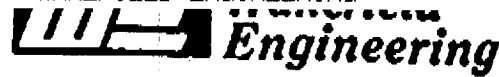
Fax # 520-523-5951

Fax # 781-224-8504

40 1213

40 1213



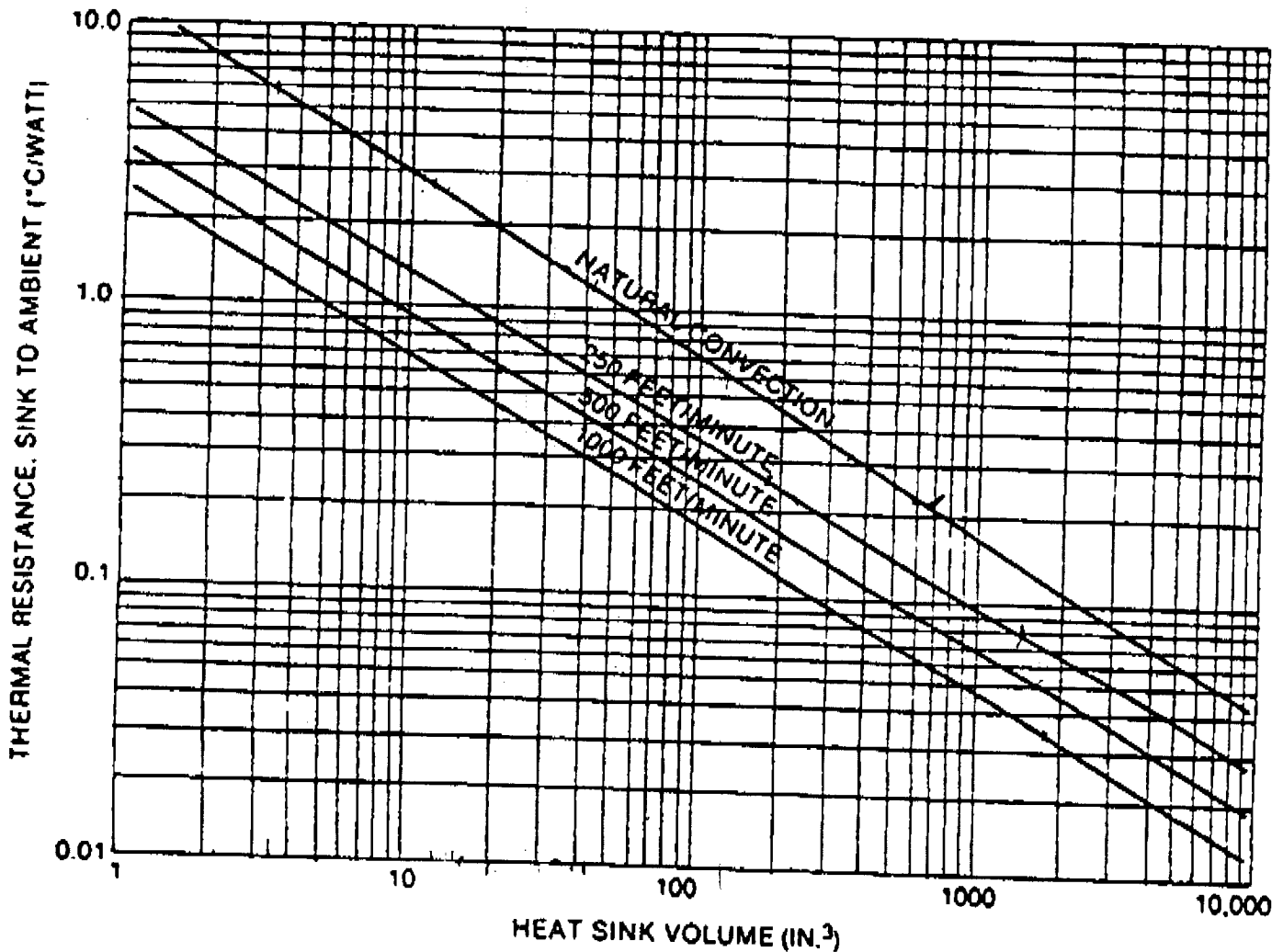


WAKEFIELD ENGINEERING
60 AUDUBON ROAD
WAKEFIELD, MA 01880

TELEPHONE (617)246-5900
FAX (617)246-0874

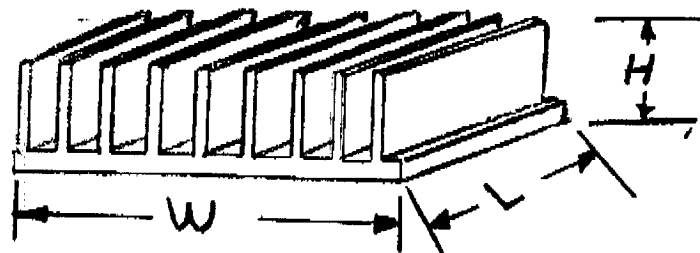
The figure below illustrates the volume required for several heat sinks for a range of thermal resistances, for both natural and forced convection applications. Typically to reduce the thermal resistance by 50%, the heat sink volume must be approximately quadrupled.

THERMAL RESISTANCE VS. HEAT SINK VOLUME-NATURAL AND FORCED CONVECTION

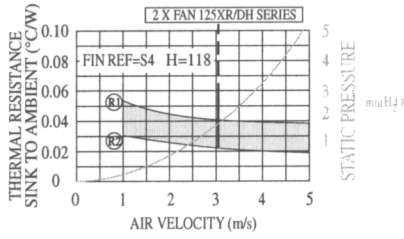


The four curves show the relationship of volume to thermal resistance for natural convection cooling, based on 50°C sink temperature rise above ambient, and forced convection cooling at velocities of 250, 500, and 1,000 feet per minute.

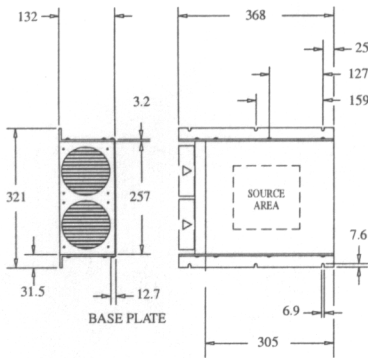
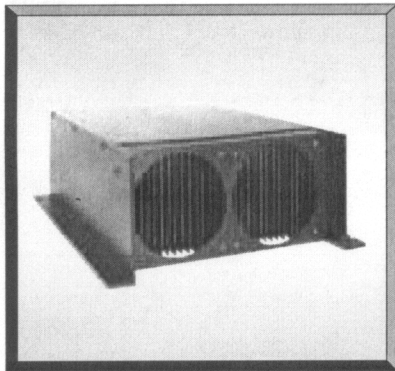
KEEP IT SIMPLE!
VOLUME = L X W X H



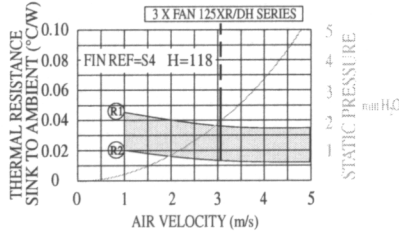
DFC SERIES



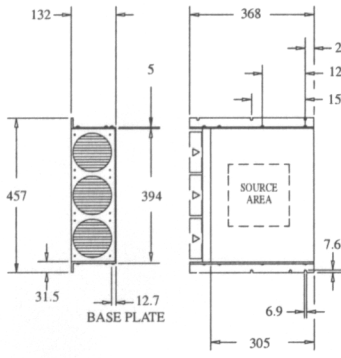
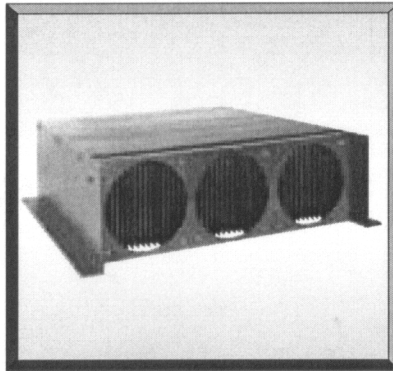
$$R = \frac{\text{SOURCE AREA}}{\text{BASE AREA}} \quad R1=0.01 \quad R2=0.6$$



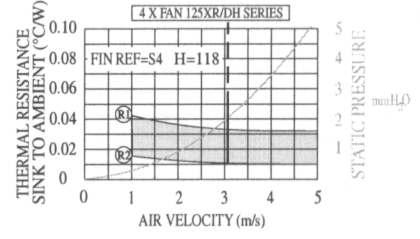
TECHNICAL DATA	
MODEL NO.	DFC305T237S4B
FIN STYLE	SERRATED (S4)
WT. WITHOUT FAN	12.6 kg
BASE AREA	78,385 mm ²
TOTAL CSA	13,699 mm ²
TOTAL PERIMETER	9,246 mm



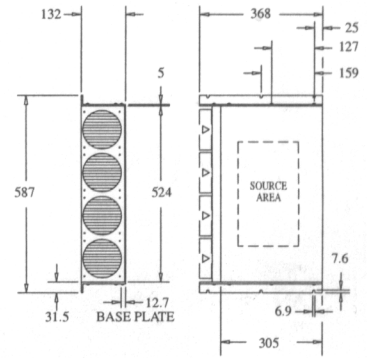
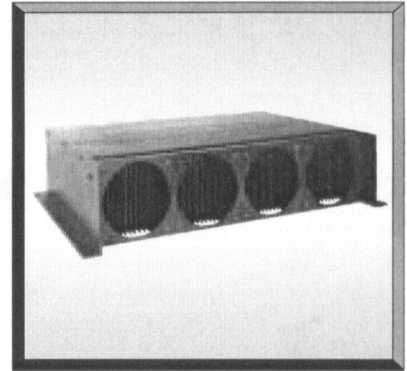
$$R = \frac{\text{SOURCE AREA}}{\text{BASE AREA}} \quad R1=0.01 \quad R2=0.6$$



TECHNICAL DATA	
MODEL NO.	DFC305T257S4B
FIN STYLE	SERRATED (S4)
WT. WITHOUT FAN	18.9 kg
BASE AREA	120,170 mm ²
TOTAL CSA	21,079 mm ²
TOTAL PERIMETER	14,240 mm



$$R = \frac{\text{SOURCE AREA}}{\text{BASE AREA}} \quad R1=0.01 \quad R2=0.6$$



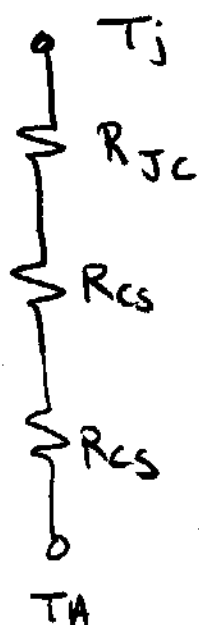
TECHNICAL DATA	
MODEL NO.	DFC305T276S4B
FIN STYLE	SERRATED (S4)
WT. WITHOUT FAN	24.7 kg
BASE AREA	160,125 mm ²
TOTAL CSA	28,101 mm ²
TOTAL PERIMETER	18,986 mm

ORDERING INFORMATION FOR DFC FABFIN® HEATSINKS

- THE STANDARD FINISH IS BLACK ANODIZE. TO SELECT AN ALTERNATE FINISH, REFER TO THE FOLD OUT BACK COVER STEP 6 AND REPLACE THE "B" IN THE MODEL NO. WITH THE ALTERNATIVE SELECTION.
- MOUNTING SURFACE FLATNESS IS 0.03mm MAX. /25mm AND SURFACE ROUGHNESS IS $\sqrt{0.8}$ MAX.
- TO CHANGE THE LENGTH OF THE HEATSINK, CHANGE THE LENGTH DESIGNATOR (305) TO THE mm LENGTH REQUIRED. NON STANDARD LENGTHS WILL ATTRACT A SEPARATE SET-UP CHARGE.
- THE MOUNTING LEGS ARE ATTACHED TO THE HEATSINK BASE PLATE BY 3 X M5X16 PAN HEAD SCREWS PER SIDE AS SHOWN.
- THE DIAMETER OF THE FAN PORT IS 114mm AND 4 X 6-32 SELF-CLINCHING NUTS ARE PROVIDED ON 105mm CENTERS FOR FAN MOUNTING. FANS ARE NOT INCLUDED WITH THE BASIC ASSEMBLY AND MAY BE ORDERED SEPARATELY.
- SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT PRIOR NOTICE.

Heat Sink Design Example

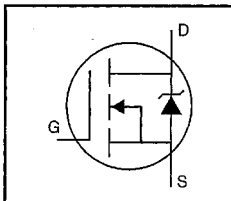
- Choose a heat sink for our 50W Inverting Buck-Boost converter
- Assume efficiency = 80%
 - Heat loss = 20% of 50W = 10 watts.
 - Assume all of this heat flows through our MOSFET switch (not true, but worst case)
- Our circuit has a single IRF540 MOSFET



- Need to solve for R_{cs}

HEXFET® Power MOSFET

- Dynamic dv/dt Rating
- Repetitive Avalanche Rated
- 175°C Operating Temperature
- Fast Switching
- Ease of Paralleling
- Simple Drive Requirements



$$V_{DSS} = 100V$$

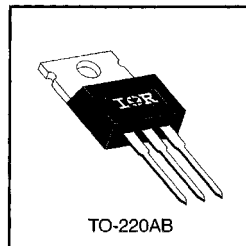
$$R_{DS(on)} = 0.077\Omega$$

$$I_D = 28A$$

Description

Third Generation HEXFETs from International Rectifier provide the designer with the best combination of fast switching, ruggedized device design, low on-resistance and cost-effectiveness.

The TO-220 package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost of the TO-220 contribute to its wide acceptance throughout the industry.



TO-220AB

DATA SHEETS

Absolute Maximum Ratings

	Parameter	Max.	Units	
$I_D @ T_C = 25^\circ C$	Continuous Drain Current, $V_{GS} @ 10 V$	28	A	
$I_D @ T_C = 100^\circ C$	Continuous Drain Current, $V_{GS} @ 10 V$	20		
I_{DM}	Pulsed Drain Current ①	110		
$P_D @ T_C = 25^\circ C$	Power Dissipation	150	W	
	Linear Derating Factor	1.0	W/°C	
V_{GS}	Gate-to-Source Voltage	±20	V	
E_{AS}	Single Pulse Avalanche Energy ②	230	mJ	
I_{AR}	Avalanche Current ①	28	A	
E_{AR}	Repetitive Avalanche Energy ①	15	mJ	
dv/dt	Peak Diode Recovery dv/dt ③	5.5	V/ns	
T_J	Operating Junction and Storage Temperature Range	-55 to +175	°C	
T_{STG}		Soldering Temperature, for 10 seconds		300 (1.6mm from case)
		Mounting Torque, 6-32 or M3 screw		10 lbf•in (1.1 N•m)

Thermal Resistance

	Parameter	Min.	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	—	1.0	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	—	0.50	—	
$R_{\theta JA}$	Junction-to-Ambient	—	—	62	

- From The IRF 540, we have the following specs

$$R_{cs} = 0.5 \text{ } ^\circ\text{C}/\text{W}$$

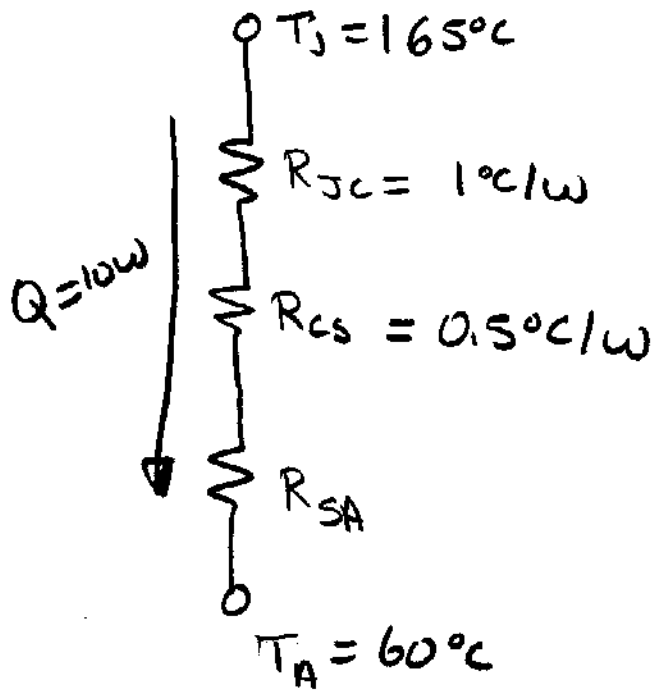
$$R_{jc} = 1.0 \text{ } ^\circ\text{C}/\text{W}$$

$$T_{j\text{max}} = 175 \text{ } ^\circ\text{C}$$

- For our design, Assume

- Ambient temperature = $60 \text{ } ^\circ\text{C}$ (Phoenix)

- $T_{j\text{max}} = 165 \text{ } ^\circ\text{C}$ - allow for design error



$$Q = \frac{T_j - T_A}{R_{jc} + R_{cs} + R_{sa}}$$

Solve for R_{SA}

$$\begin{aligned}
 R_{SA} &= \frac{T_J - T_A}{Q} - R_{JC} - R_{CS} \\
 &= \frac{165^\circ\text{C} - 60^\circ\text{C}}{10\text{W}} - 1^\circ\text{C/W} - 0.5^\circ\text{C/W} \\
 &= 9^\circ\text{C/W}
 \end{aligned}$$

⇒ We need a heat sink with
an R_{SA} of 9°C/W or less

- In the Lab we have the Wakefield
5079 extrusion which has a
thermal resistance of

$$\theta_{SA} = 1.50^\circ\text{C/W/3"}$$

- This means that a 3 inch piece will have a $R_{SA} = 1.5 \text{ } ^\circ\text{C}/\text{W}$
- a 6 inch piece will have $R_{SA} = 0.75 \text{ } ^\circ\text{C}/\text{W}$
- a 9" piece will have $R_{SA} = 0.5 \text{ } ^\circ\text{C}/\text{W}$
- These Thermal resistances are approximate, and the Actual Resistance depends on the placement of devices on the heat sink.
- These thermal resistances are for Natural convection
- we need an $R_{SA} \leq 9 \text{ } ^\circ\text{C}$ so we only need 1" of the 5079 extrusion.
This piece will have $R_{SA} \approx 4.5 \text{ } ^\circ\text{C}/\text{W}$

Design Example

- choose a heat sink for our 50 W

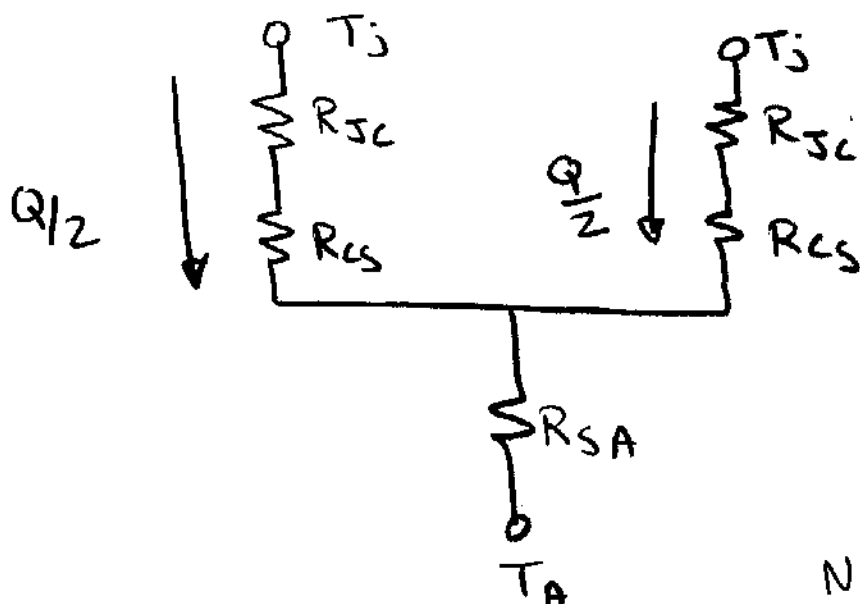
Boost converter

- Assume efficiency = 80%

- Heat loss = 20% of 50W = 10 Watts = Q

- Assume that all of this heat flows through our two MOSFET switches (Not true, but worst case).

- our CKT has two IRF540 MOSFET'S

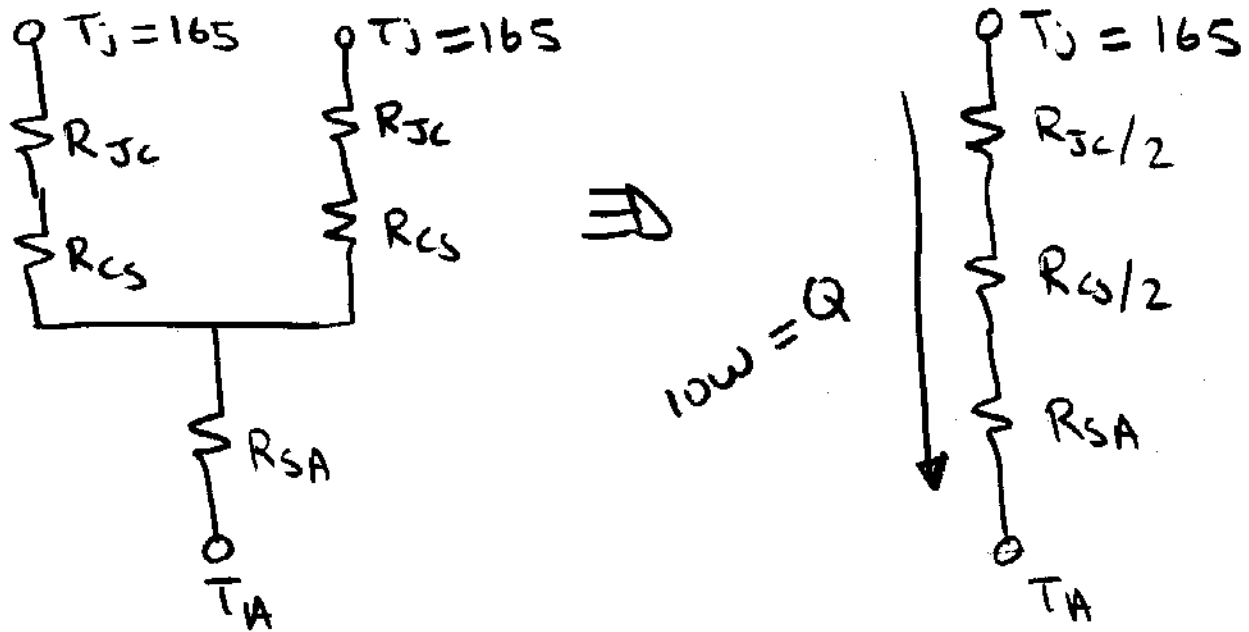


Need to
Find R_{SA}

- For the IRF 540, we have

$$R_{CS} = 0.5 \text{ } ^\circ\text{C}/\text{W} , R_{JC} = 1.0 \text{ } ^\circ\text{C}/\text{W} , T_{j\text{max}} = 175^\circ\text{C}$$

- Design For $T_{j\text{max}} = 165^\circ\text{C}$, $T_A = 60^\circ\text{C}$



$$Q = \frac{T_j - T_A}{\frac{R_{JC}}{2} + \frac{R_{CS}}{2} + R_{SA}}$$

Solve for R_{SA}

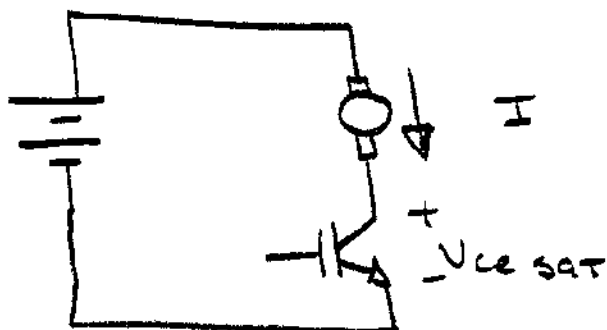
$$\begin{aligned} R_{SA} &= \frac{T_j - T_A}{Q} - \frac{R_{JC}}{2} - \frac{R_{CS}}{2} \\ &= \frac{165^\circ\text{C} - 60^\circ\text{C}}{10\text{W}} - \frac{1^\circ\text{C}/\text{W}}{2} - \frac{0.5^\circ\text{C}/\text{W}}{2} \\ &= 9.75^\circ\text{C}/\text{W} \end{aligned}$$

- For this example, paralleling devices gives us only a slightly smaller heat sink

- In general, paralleling devices allows us to use a smaller heat sink.

Design Example

DC MOTOR CONTROL



- max continuous motor current = 600A
- Max $V_{ce\ on}$ (switch voltage when on) = 2.8V
- max continuous power = $(600A) \times (2.8V) = 1680W$

$Q = \text{heat generated at the junction} = 1680W$

$R_{js} = 0.06\ ^\circ C/W$ - from data book

$T_A = \text{Ambient Air temp} = 30^\circ C = 86^\circ C$

- will not work in phoenix in the summer time.

$R_{cs} = 0.06\ ^\circ C/W$ - Heat sink compound.
Resistance spec on Jar.

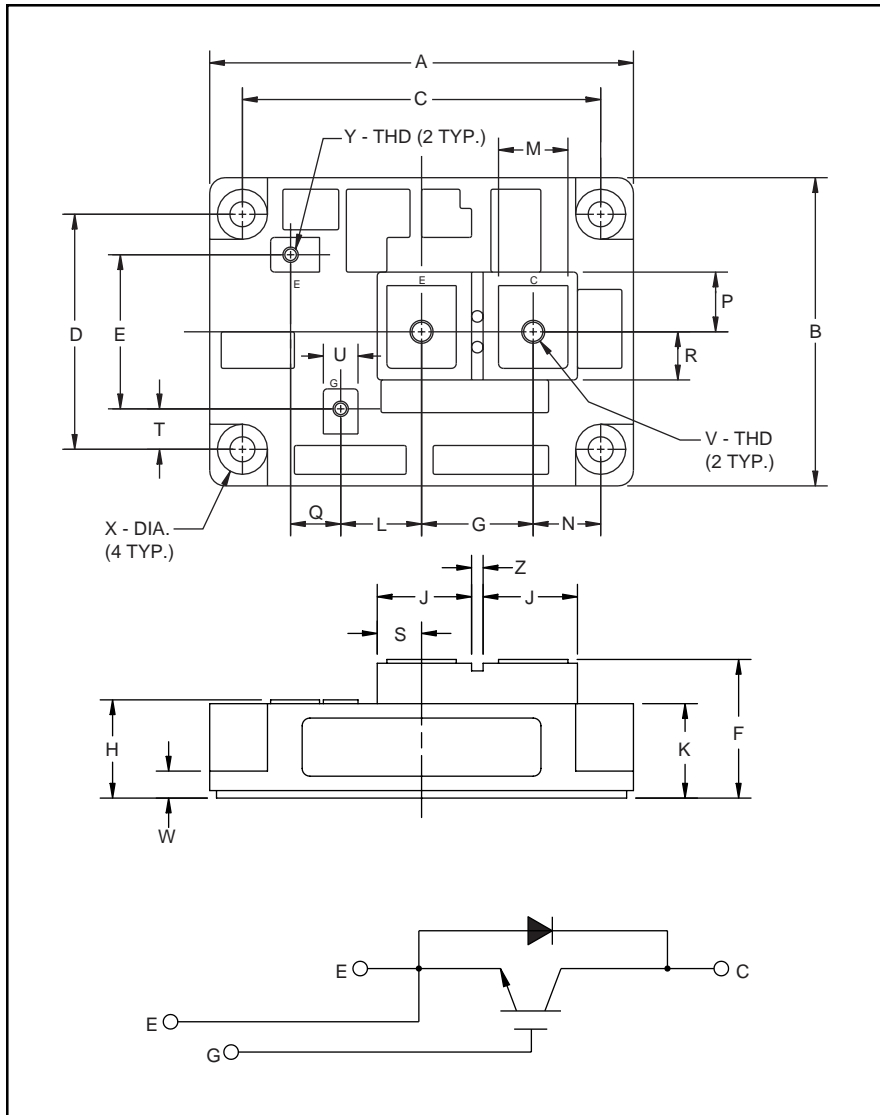
$T_{j\max} = 150^\circ C$ - Data sheet.



Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (724) 925-7272

CM600HA-12H

**Single IGBTMOD™
H-Series Module
600 Amperes/600 Volts**



Outline Drawing and Circuit Diagram

Dimensions	Inches	Millimeters
A	4.33	110.0
B	3.15	80.0
C	3.66±0.008	93.0±0.25
D	2.44±0.008	62.0±0.25
E	1.57	40.0
F	1.42 Max.	36.0 Max.
G	1.14	29.0
H	1.00 Max.	25.5 Max.
J	0.96	25.0
K	0.94	24.5
L	0.83	21.0
M	0.71	18.0

Dimensions	Inches	Millimeters
N	0.69	17.5
P	0.61	15.5
Q	0.51	13.0
R	0.49	12.5
S	0.45	11.5
T	0.43	11.0
U	0.35	9.0
V	M8 Metric	M8
W	0.28	7.0
X	0.256 Dia.	Dia. 6.50
Y	M4 Metric	M4
Z	0.12	3.04



Description:

Powerex IGBTMOD™ Modules are designed for use in switching applications. Each module consists of one IGBT Transistor in a single configuration with a reverse-connected super-fast recovery free-wheel diode. All components and interconnects are isolated from the heat sinking baseplate, offering simplified system assembly and thermal management.

Features:

- Low Drive Power
- Low $V_{CE(sat)}$
- Discrete Super-Fast Recovery (70ns) Free-Wheel Diode
- High Frequency Operation (20-25kHz)
- Isolated Baseplate for Easy Heat Sinking

Applications:

- AC Motor Control
- Motion/Servo Control
- UPS
- Welding Power Supplies
- Laser Power Supplies

Ordering Information:

Example: Select the complete part module number you desire from the table below -i.e. CM600HA-12H is a 600V (V_{CES}), 600 Ampere Single IGBTMOD™ Power Module.

Type	Current Rating Amperes	V_{CES} Volts (x 50)
CM	600	12



Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (724) 925-7272

CM600HA-12H
Single IGBTMOD™ H-Series Module
 600 Amperes/600 Volts

Absolute Maximum Ratings, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Ratings	Symbol	CM600HA-12H	Units
Junction Temperature	T_j	-40 to 150	$^\circ\text{C}$
Storage Temperature	T_{stg}	-40 to 125	$^\circ\text{C}$
Collector-Emitter Voltage (G-E SHORT)	V_{CES}	600	Volts
Gate-Emitter Voltage	V_{GES}	± 20	Volts
Collector Current	I_C	600	Amperes
Peak Collector Current	I_{CM}	1200*	Amperes
Diode Forward Current	I_F	600	Amperes
Diode Forward Surge Current	I_{FM}	1200*	Amperes
Power Dissipation	P_d	2100	Watts
Max. Mounting Torque M8 Terminal Screws	-	95	in-lb
Max. Mounting Torque M6 Mounting Screws	-	26	in-lb
Module Weight (Typical)	-	560	Grams
V Isolation	V_{RMS}	2500	Volts

* Pulse width and repetition rate should be such that device junction temperature does not exceed the device rating.

Static Electrical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Collector-Cutoff Current	I_{CES}	$V_{\text{CE}} = V_{\text{CES}}, V_{\text{GE}} = 0\text{V}$	-	-	1.0	mA
Gate Leakage Current	I_{GES}	$V_{\text{GE}} = V_{\text{GES}}, V_{\text{CE}} = 0\text{V}$	-	-	0.5	μA
Gate-Emitter Threshold Voltage	$V_{\text{GE(th)}}$	$I_C = 60\text{mA}, V_{\text{CE}} = 10\text{V}$	4.5	6.0	7.5	Volts
Collector-Emitter Saturation Voltage	$V_{\text{CE(sat)}}$	$I_C = 600\text{A}, V_{\text{GE}} = 15\text{V}$	-	2.1	2.8**	Volts
		$I_C = 600\text{A}, V_{\text{GE}} = 15\text{V}, T_j = 150\text{ }^\circ\text{C}$	-	2.15	-	Volts
Total Gate Charge	Q_G	$V_{\text{CC}} = 600\text{V}, I_C = 600\text{A}, V_{\text{GS}} = 15\text{V}$	-	1800	-	nC
Diode Forward Voltage	V_{FM}	$I_E = 600\text{A}, V_{\text{GS}} = 0\text{V}$	-	-	2.8	Volts

** Pulse width and repetition rate should be such that device junction temperature rise is negligible.

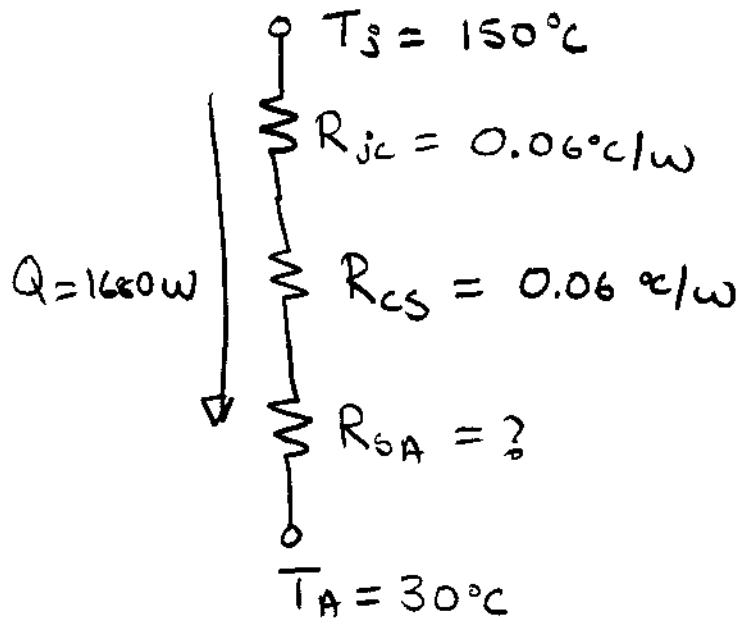
Dynamic Electrical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Input Capacitance	C_{ies}		-	-	60	nF
Output Capacitance	C_{oes}	$V_{\text{GE}} = 0\text{V}, V_{\text{CE}} = 10\text{V}, f = 1\text{MHz}$	-	-	21	nF
Reverse Transfer Capacitance	C_{res}		-	-	12	nF
Resistive	Turn-on Delay Time	$t_{\text{d(on)}}$	-	-	350	ns
Load	Rise Time	t_r	-	-	700	ns
Switching	Turn-off Delay Time	$t_{\text{d(off)}}$	-	-	350	ns
	Fall Time	t_f	-	-	300	ns
Diode Reverse Recovery Time	t_{rr}	$I_E = 600\text{A}, di_E/dt = -1200\text{A}/\mu\text{s}$	-	-	110	ns
Diode Reverse Recovery Charge	Q_{rr}	$I_E = 600\text{A}, di_E/dt = -1200\text{A}/\mu\text{s}$	-	1.62	-	μC

Thermal and Mechanical Characteristics, $T_j = 25\text{ }^\circ\text{C}$ unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Thermal Resistance, Junction to Case	$R_{\text{th(j-c)}}$	Per IGBT	-	-	0.06	$^\circ\text{C}/\text{W}$
Thermal Resistance, Junction to Case	$R_{\text{th(j-c)}}$	Per FWDi	-	-	0.12	$^\circ\text{C}/\text{W}$
Contact Thermal Resistance	$R_{\text{th(c-f)}}$	Per Module, Thermal Grease Applied	-	-	0.035	$^\circ\text{C}/\text{W}$

- Find R_{SA} needed to keep the device from burning up.



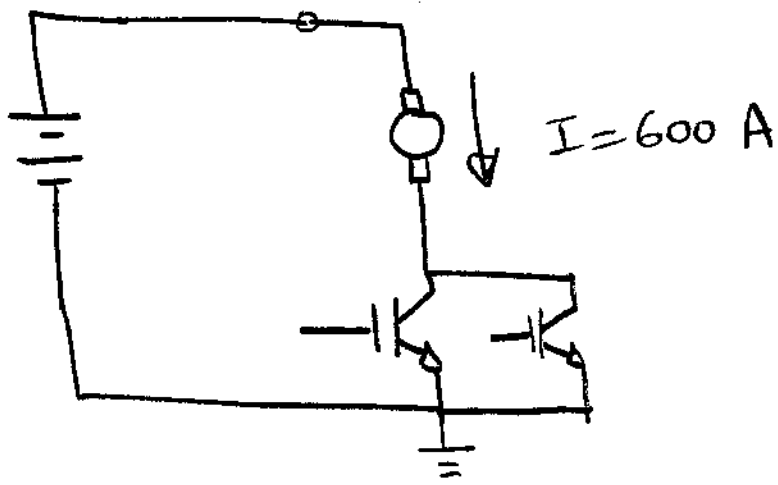
$$Q = \frac{T_j - T_A}{R_{jc} + R_{cs} + R_{SA}}$$

$$\Rightarrow R_{SA} = \frac{T_j - T_A}{Q} - R_{jc} - R_{cs}$$

$$= \frac{(150 - 30)^\circ\text{C}}{1680\text{ W}} - 0.06^\circ\text{C/W} - 0.06^\circ\text{C/W}$$

$$= -0.072^\circ\text{C/W} - \text{Impossible to do}$$

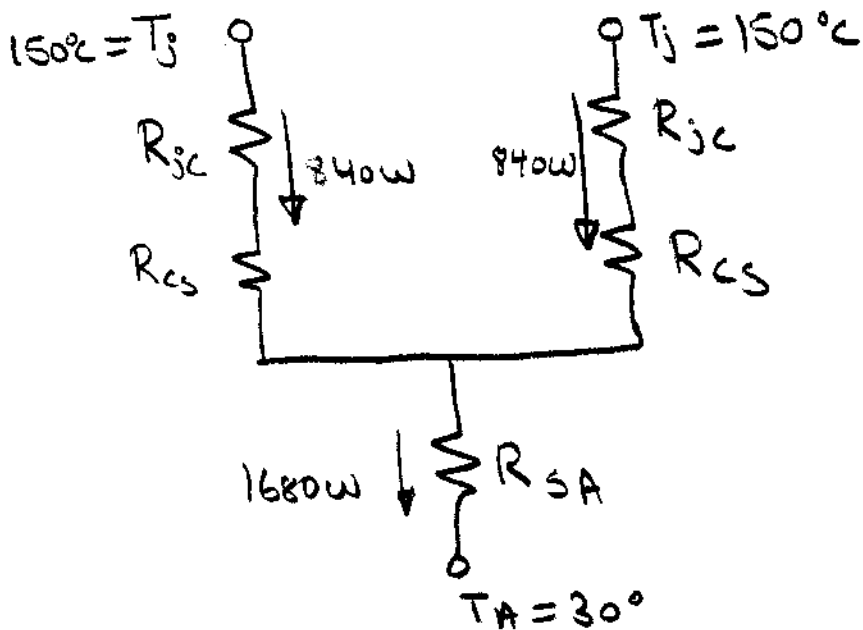
- Use Two IGBTs in Parallel



- Total power dissipated $= I V_{cesat} = (600)(2.8\text{V})$
 $= 1680 \text{ W}$

- Power dissipated per IGBT $= \left(\frac{I}{2}\right) V_{cesat}$
 $= 840 \text{ W}$

- Now Find R_{SA}

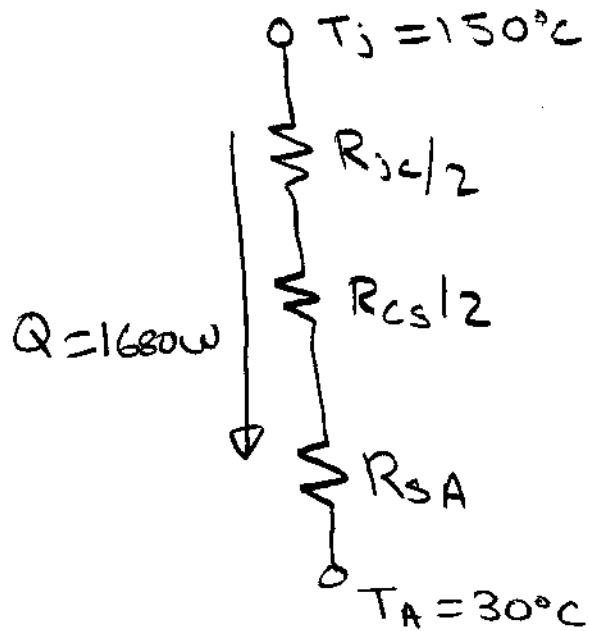


- Assume both junctions are at the same temperature $T_{j1} = T_{j2} = 150^\circ\text{C}$

$$R_{jc1} = R_{jc2} = 0.06^\circ\text{C/W}$$

$$R_{cs1} = R_{cs2} = 0.06^\circ\text{C/W}$$

- Find R_{sa}
- Two devices are thermally in parallel



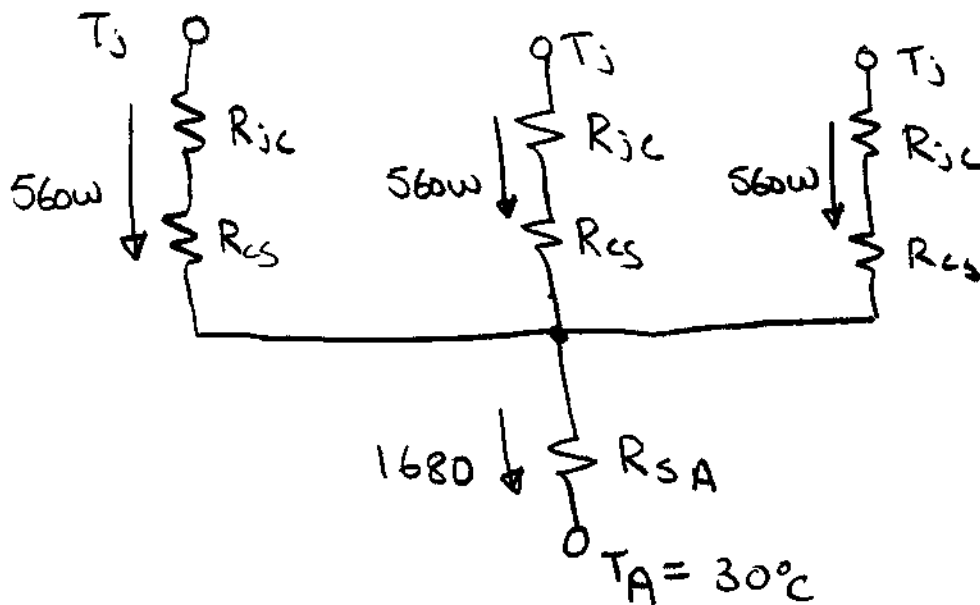
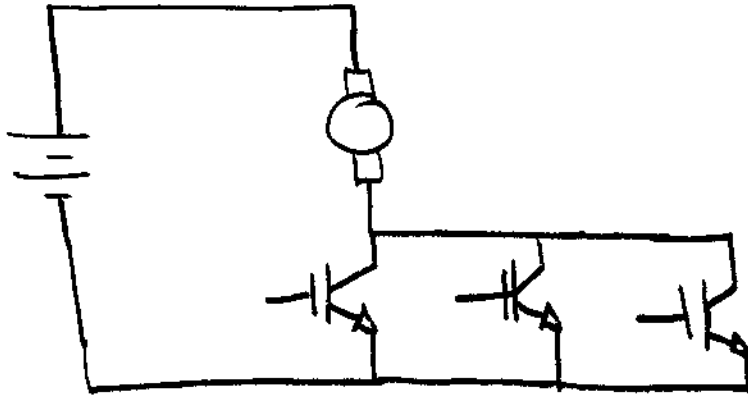
$$Q = \frac{T_j - T_A}{\frac{R_{jc}}{2} + \frac{R_{cs}}{2} + R_{sa}}$$

$$R_{sa} = \frac{T_j - T_A}{Q} - \frac{R_{jc}}{2} - \frac{R_{cs}}{2}$$

$$= \frac{(150 - 30)^\circ\text{C}}{1680\text{W}} - 0.03^\circ\text{C/W} - 0.03^\circ\text{C/W}$$

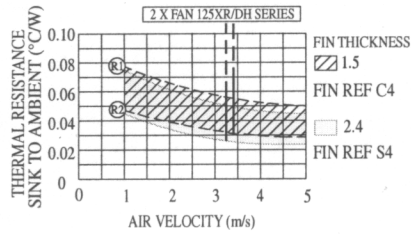
$$= 0.012^\circ\text{C/W} \quad - \text{very small}$$

Try 3 IGBTs

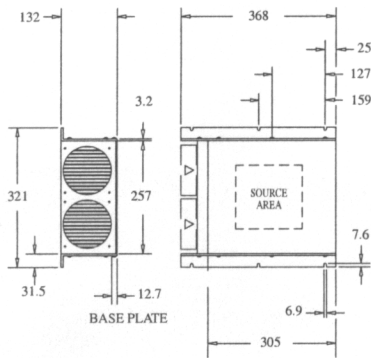
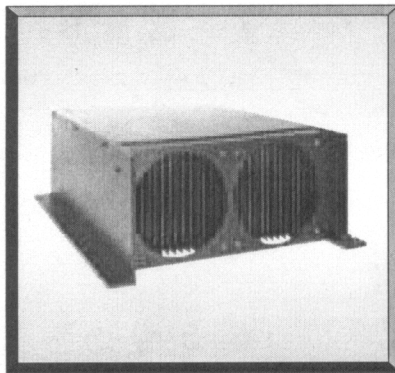


$$\begin{aligned}
 R_{sA} &= \frac{T_j - T_A}{Q} - \frac{R_{jc}}{3} - \frac{R_{cs}}{3} \\
 &= \frac{150^\circ C - 30^\circ C}{1680W} - \frac{0.06^\circ C/W}{3} - \frac{0.06^\circ C/W}{3} \\
 &= 0.03^\circ C/W
 \end{aligned}$$

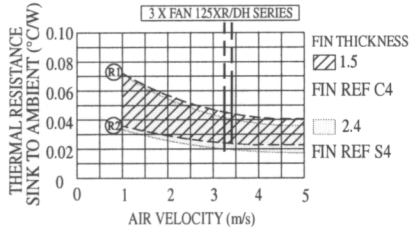
FFC SERIES WITH SIDE FASTENED LEGS AND FAN BRACKET



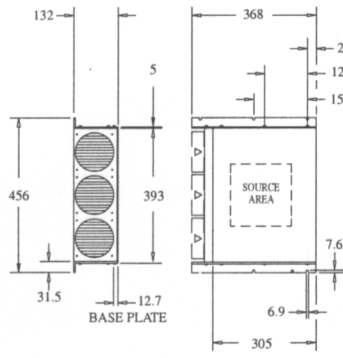
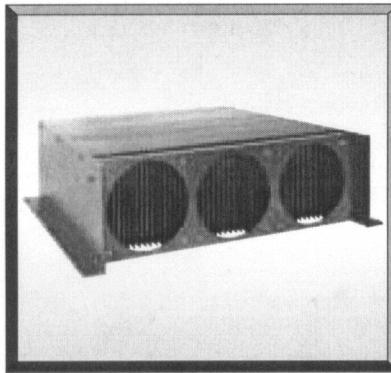
$$R = \frac{\text{SOURCE AREA}}{\text{BASE AREA}} \quad R1=0.01 \quad R2=0.6$$



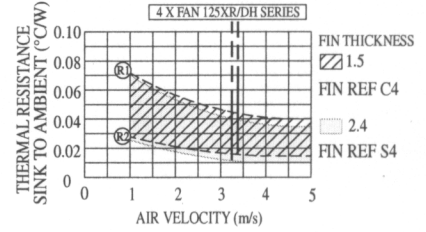
TECHNICAL DATA			
MODEL NO.	FFC305T230S4B	FFC305T230C4B	
FIN STYLE	SERRATED (S4)	CORRUGATED (C4)	
WT. WITHOUT FAN	10.4 kg	8.8 kg	
BASE AREA	78,387 mm ²	78,387 mm	
TOTAL CSA	10,889 mm ²	8,981 mm	
TOTAL PERIMETER	7,800 mm	7,929 mm	



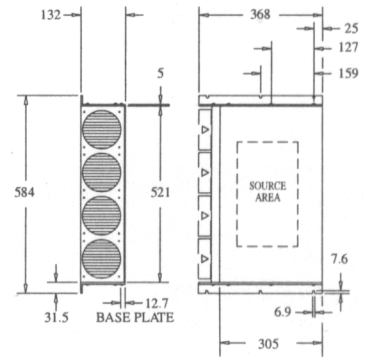
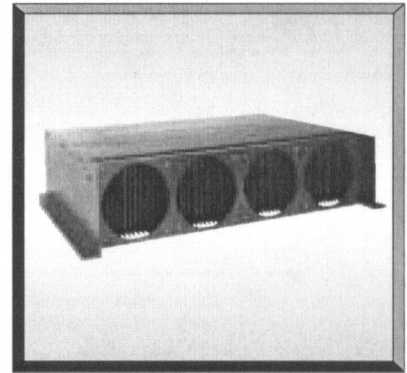
$$R = \frac{\text{SOURCE AREA}}{\text{BASE AREA}} \quad R1=0.01 \quad R2=0.6$$



TECHNICAL DATA			
MODEL NO.	FFC305T246S4B	FFC305T246C4B	
FIN STYLE	SERRATED (S4)	CORRUGATED (C4)	
WT. WITHOUT FAN	15.5 kg	13.2 kg	
BASE AREA	119,865 mm ²	119,865 mm	
TOTAL CSA	16,574 mm ²	13,766 mm	
TOTAL PERIMETER	11,991 mm	12,578 mm	



$$R = \frac{\text{SOURCE AREA}}{\text{BASE AREA}} \quad R1=0.01 \quad R2=0.6$$



TECHNICAL DATA			
MODEL NO.	FFC305T261S4B	FFC305T261C4B	
FIN STYLE	SERRATED (S4)	CORRUGATED (C4)	
WT. WITHOUT FAN	20.7 kg	17.6 kg	
BASE AREA	158,710 mm ²	158,710 mm	
TOTAL CSA	22,098 mm ²	18,356 mm	
TOTAL PERIMETER	15,989 mm	16,251 mm	

ORDERING INFORMATION FOR FFC FABFIN® HEATSINKS

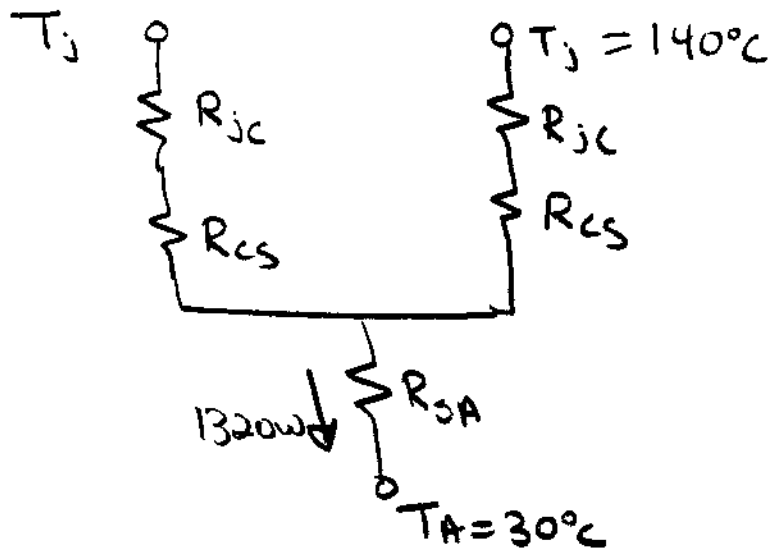
- THE STANDARD FINISH IS BLACK ANODIZE. TO SELECT AN ALTERNATE FINISH, REFER TO THE FOLD OUT BACK COVER STEP 6 AND REPLACE THE "B" IN THE MODEL NO. WITH THE ALTERNATIVE SELECTION.
- MOUNTING SURFACE FLATNESS IS 0.03mm MAX. /25mm AND SURFACE ROUGHNESS IS 1.6 MAX.
- TO CHANGE THE LENGTH OF THE HEATSINK, CHANGE THE LENGTH DESIGNATOR (305) TO THE mm LENGTH REQUIRED. NON STANDARD LENGTHS WILL ATTRACT A SEPARATE SET-UP CHARGE.
- THE MOUNTING LEGS ARE ATTACHED TO THE HEATSINK BASE PLATE BY 3 X M5X16 PAN HEAD SCREWS PER SIDE AS SHOWN.
- THE DIAMETER OF THE FAN PORT IS 114mm AND 4 X 6-32 SELF-CLINCHING NUTS ARE PROVIDED ON 105mm CENTERS FOR FAN MOUNTING. FANS ARE NOT INCLUDED WITH THE BASIC ASSEMBLY AND MAY BE ORDERED SEPARATELY.
- SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT PRIOR NOTICE.

- Problem with this example?
 - Too much power
 - Need a water cooled Heat sink
- This is the worst case max Power. $P_{max} = I V_{cesat}|_{max} = (600A)(2.8V)$

$$V_{CEon} \text{ Typical} \approx 2.2V$$

$$\text{Power} \approx I V_{CEsat} = (600A)(2.2V) = 1320$$

- Re design with $V_{CE} = 2.2V$,
2 IGBTs
- $T_{jmax} = 140^{\circ}C$ - Safety margin
- $T_A = 30^{\circ}C$



$$\begin{aligned}
 R_{SA} &= \frac{T_j - T_A}{Q} - \frac{R_{jc}}{2} - \frac{R_{cs}}{2} \\
 &= \frac{140^\circ\text{C} - 30^\circ\text{C}}{1320\text{W}} - \frac{0.06^\circ\text{C}/\text{W}}{2} - \frac{0.06^\circ\text{C}}{\text{W}} \\
 &= 0.023^\circ\text{C}/\text{W}
 \end{aligned}$$

how to select a heat sink

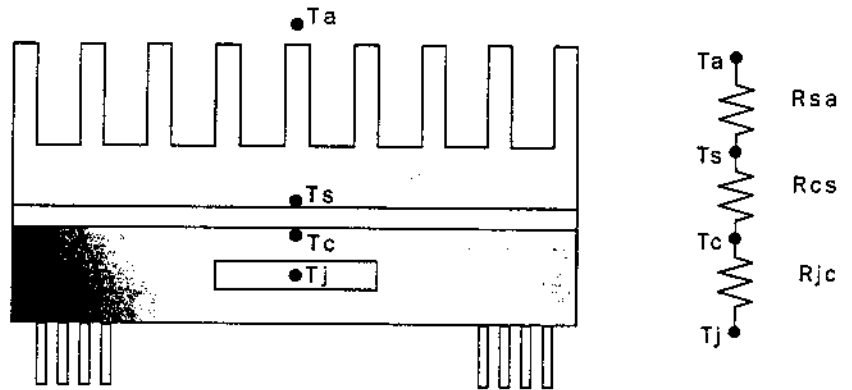


Figure 1: Thermal resistance circuit

Seri Lee
Aavid Thermal Technologies

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Prior to joining Aavid, Dr Lee worked as Research Assistant Professor in the Department of Mechanical Engineering at the University of Waterloo in Canada from where he obtained his Doctorate. Dr Lee is an active participant in many professional societies including IEEE, ASME, AIAA and IEP.



With the increase in heat dissipation from microelectronic devices and the reduction in overall form factors, thermal management becomes a more and more important element of electronic product design.

Both the performance reliability and life expectancy of electronic equipment are inversely related to the component temperature of the equipment. The relationship between the reliability and the operating temperature of a typical silicon semi-conductor device shows that a reduction in the temperature corresponds to an exponential increase in the reliability and life expectancy of the device. Therefore, long life and reliable performance of a component may be achieved by effectively controlling the device operating temperature within the limits set by the device design engineers.

Heat sinks are devices that enhance heat dissipation from a hot surface, usually the case of a heat generating component, to a cooler ambient, usually air. For the following discussions, air is assumed to be the cooling fluid. In most situations, heat transfer across the interface between the solid surface and the coolant air is the least efficient within the system, and the solid-air interface represents the greatest barrier for heat dissipation. A heat sink lowers this barrier mainly by increasing the surface area that is in direct contact with the coolant. This allows more heat to be dissipated and/or lowers the device operating temperature. The primary purpose of a heat sink is to maintain

the device temperature below the maximum allowable temperature specified by the device manufacturer.

Thermal Circuit

Before discussing the heat sink selection process, it is necessary to define common terms and establish the concept of a thermal circuit. The objective is to provide basic fundamentals of heat transfer for those readers who are not familiar with the subject. Notations and definitions of the terms are as follows:

- Q: total power or rate of heat dissipation in W, represents the rate of heat dissipated by the electronic component during operation.
- For the purpose of selecting a heat sink, the maximum operating power dissipation is used.
- T_j: maximum junction temperature of the device in °C. Allowable T_j values range from 115°C in typical microelectronic applications to as high as 180°C for some electronic control devices. In special and military applications, 65°C to 80°C are not uncommon.
- T_c: case temperature of the device in °C. Since the case temperature of a device depends on the location of measurement, it usually represents the maximum local temperature of the case.
- T_s: sink temperature in °C. Again, this represents the maximum temperature of a heat sink at the location closest to the device.
- T_a: ambient air temperature in °C.

Using temperatures and the rate of heat dissipation, a quantitative measure of heat transfer efficiency across two locations of a thermal component can be expressed in terms of thermal resistance R, defined as

$$R = \frac{\Delta T}{Q}$$

where ΔT is the temperature difference between the two locations. The unit of thermal resistance is in °C/W, indicating the temperature rise per unit rate of heat dissipation. This thermal resistance is analogous to the electrical resistance R_e, given by Ohm's law:

$$R_e = \frac{\Delta V}{I}$$

with ΔV being the voltage difference and I the current.

Consider a simple case where a heat sink is mounted on a device package as shown in Fig. 1. Using the concept of thermal resistance, a simplified thermal circuit of this system can be drawn, as also shown in the figure. In this simplified model, heat flows serially from the junction to the case then across the interface into the heat sink, and is

finally dissipated from the heat sink to the air stream.

The thermal resistance between the junction and the case of a device is defined as

$$R_{jc} = \frac{\Delta T_{jc}}{Q} = \frac{T_j - T_c}{Q}$$

This resistance is specified by the device manufacturer. Although the R_{jc} value of a given device depends on how and where the cooling mechanism is employed over the package, it is usually given as a constant value. It is also accepted that R_{jc} is beyond the user's ability to alter or control.

Similarly, case-to-sink and sink-to-ambient resistances are defined as

$$R_{cs} = \frac{\Delta T_{cs}}{Q} = \frac{T_c - T_s}{Q}$$

$$R_{sa} = \frac{\Delta T_{sa}}{Q} = \frac{T_s - T_a}{Q}$$

respectively. Here, R_{cs} represents the thermal resistance across the interface between the case and the heat sink and is often called the interface resistance. This value can be improved substantially depending on the quality of mating surface finish and/or the choice of interface material. R_{sa} is the heat sink thermal resistance.

Obviously, the total junction-to-ambient resistance is the sum of all three resistances:

$$R_{ja} = R_{jc} + R_{cs} + R_{sa} = \frac{T_j - T_a}{Q}$$

Required Heat-Sink Thermal Resistance

To begin the heat sink selection, the first step is to determine the heat sink thermal resistance required to satisfy the thermal criteria of the component. By rearranging the previous equation, the heat sink resistance can be easily obtained as

$$R_{sa} = \frac{T_j - T_a}{Q} - R_{jc} - R_{cs}$$

In this expression, T_j, Q and R_{jc} are provided by the device manufacturer, and T_a and R_{cs} are the user defined parameters.

The ambient air temperature T_a for cooling electronic equipment depends on the operating environment in which the component is expected to be used. Typically, it ranges from 35 to 45°C, if the external air is used, and from 50 to 60°C, if the component is enclosed or is

Material	Conductivity W/in °C	Thickness Inches	Resistance in ² °C/W
Ther-O-Link Thermal Compound	0.010	0.002	0.19
High Performance Thermal Compound	0.030	0.002	0.07
Kon-Dux	0.030	0.005	0.17
A-Dux	0.008	0.004	0.48
1070 Ther-A-Grip	0.014	0.006	0.43
1050 Ther-A-Grip	0.009	0.005	0.57
1080 Ther-A-Grip	0.010	0.002	0.21
1081 Ther-A-Grip	0.019	0.005	0.26
A-PII 220 @ 20psi	0.074	0.020	0.27
1897 In-Si-8	0.010	0.008	0.81
1898 In-Si-8	0.008	0.006	0.78

Table 1: Thermal properties of interface materials¹

Flow condition m/s (ftm)	Volumetric Resistance cm ³ °C/W (in ³ °C/W)
natural convection	500 - 800 (30 - 50)
1.0 (200)	150 - 250 (10 - 15)
2.5 (500)	80 - 150 (5 - 10)
5.0 (1000)	50 - 80 (3 - 5)

Table 2: Range of volumetric thermal resistance

placed in a wake of another heat generating equipment.

The interface resistance R_{cs} depends on the surface finish, flatness, applied mounting pressure, contact area and, of course, the type of interface material and its thickness. Precise value of this resistance, even for a given type of material and thickness, is difficult to obtain, since it may vary widely with the mounting pressure and other case dependent parameters. However, more reliable data can be obtained directly from material manufacturers or from heat sink manufacturers. Typical values for common interface materials are tabulated in Table 1.

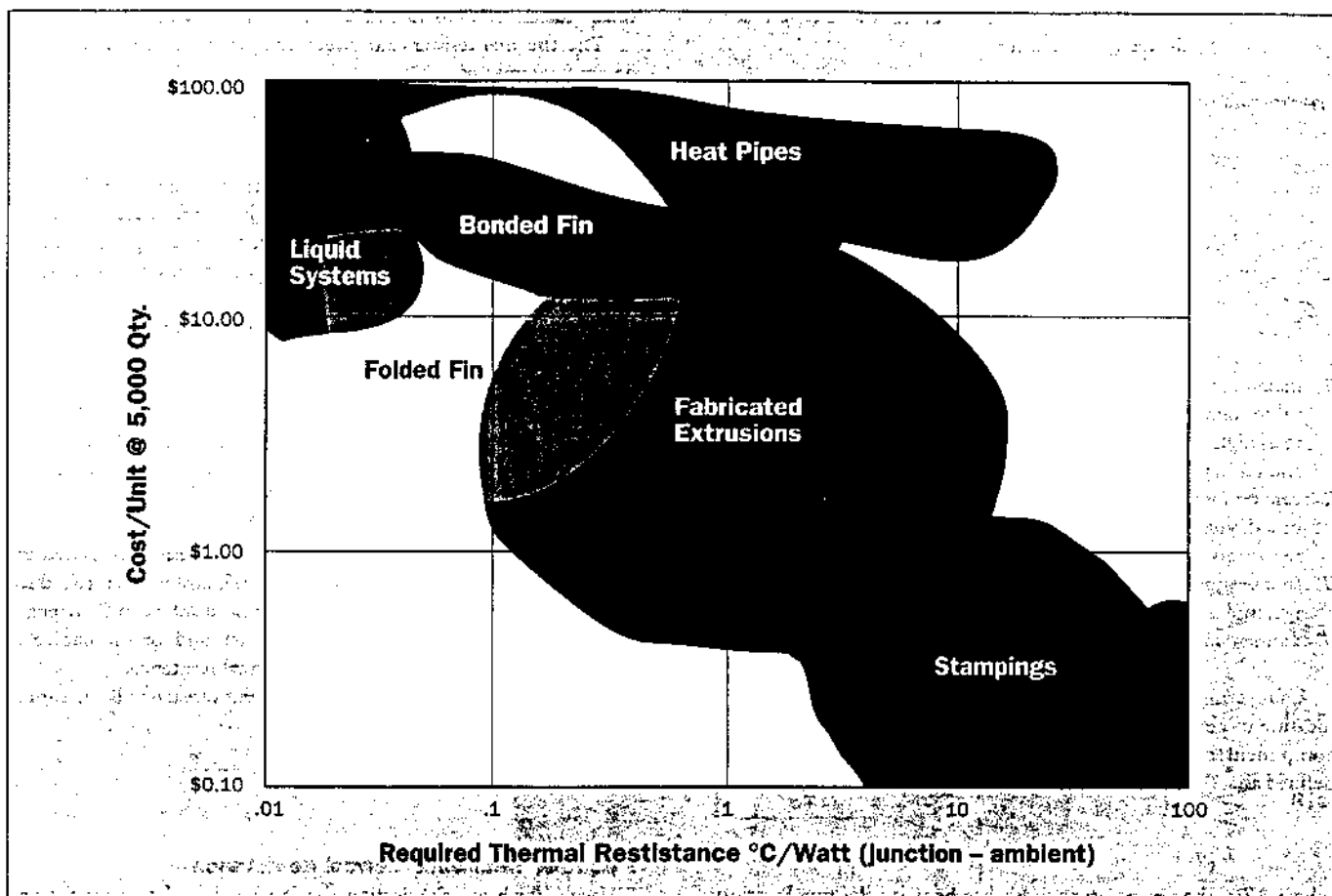


Figure 2: Cost versus required thermal resistance

With all the parameters on the right side of the R_{th} expression identified, it becomes the required maximum thermal resistance of a heat sink for the application. In other words, the thermal resistance value of a chosen heat sink for the application has to be equal to or less than the R_{th} value for the junction temperature to be maintained at or below the specified T_j .

Heat-Sink Selection

In selecting an appropriate heat sink that meets the required thermal criteria, one needs to examine various parameters that affect not only the heat sink performance itself, but also the overall performance of the system. The choice of a particular type of heat sink depends largely on the thermal budget allowed for the heat sink and external conditions surrounding the heat sink. It is to be emphasized that there can never be a single value of thermal resistance assigned to a given heat sink, since the thermal resistance varies with external cooling conditions.

When selecting a heat sink, it is necessary to classify the air flow as natural, low flow mixed, or high flow forced convection. Natural convection occurs when there is no externally induced flow and heat transfer relies solely on the free buoyant flow of air surrounding the heat sink. Forced convection occurs when the flow of air is induced by mechanical means, usually a

fan or blower. There is no clear distinction on the flow velocity that separates the mixed and forced flow regimes. It is generally accepted in applications that the effect of buoyant force on the overall heat transfer diminishes to a negligible level (under 5%) when the induced air flow velocity exceeds 1 to 2 m/s (200 to 400 lfm).

The next step is to determine the required volume of a heat sink. Table 2 shows approximate ranges of volumetric thermal resistance of a typical heat sink under different flow conditions.

The volume of a heat sink for a given flow condition can be obtained by dividing the volumetric thermal resistance by the

required thermal resistance. Table 2 is to be used only as a guide for estimation purposes in the beginning of the selection process. The actual resistance values may vary outside the above range depending on many additional parameters, such as actual dimensions of the heat sink, type of the heat sink, flow configuration, orientation, surface finish, altitude, etc. The smaller values shown above correspond to a heat sink volume of approximately 100 to 200 cm³ (5 to 10 in³) and the larger ones to roughly 1000 cm³ (60 in³).

Flow condition m/s (lfm)	Fin length, mm (in)			
	75 3.0	150 6.0	225 9.0	300 12.0
Natural convection	6.5 0.25	7.5 0.30	10 0.38	13 0.50
1.0 (200)	4.0 0.15	5.0 0.20	6.0 0.24	7.0 0.27
2.5 (500)	2.5 0.10	3.3 0.13	4.0 0.16	5.0 0.20
5.0 (1000)	2.0 0.08	2.5 0.10	3.0 0.12	3.5 0.14

Table 3: Fin spacing (in mm/inches) versus flow and fin length

The above tabulated ranges assume that the design has been optimized for the given flow condition. Although there are many parameters to be considered in optimizing a heat sink, one of the most critical parameters is the fin density. In a planar fin heat sink,

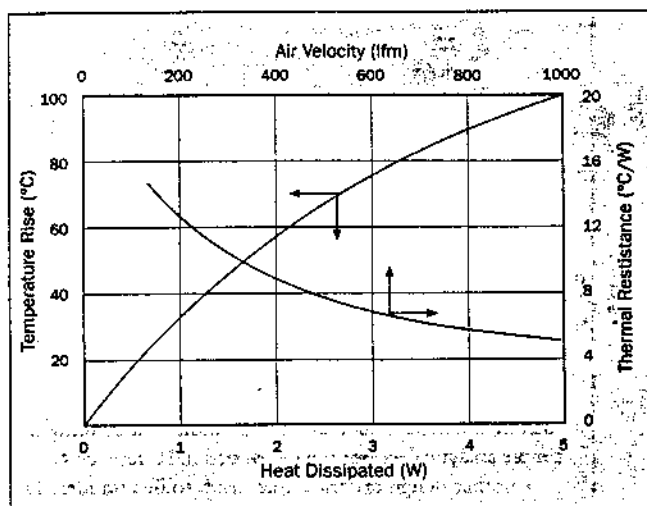


Figure 3: Typical performance graphs

optimum fin spacing is strongly related to two parameters: flow velocity and fin length in the direction of the flow. Table 3 may be used as a guide for determining the optimum fin spacing of a planar fin heat sink in typical applications.

The average performance of a typical heat sink is linearly proportional to the width of the heat sink in the direction perpendicular to the flow, and approximately proportional to the square root of the fin length in the direction parallel to the flow. For example, an increase in the width of a heat sink by a factor of two would increase the heat dissipation capability by a factor of two, whereas an increase in the length of the heat sink by a factor of two would only increase the heat dissipation capability by a factor of 1.4. Therefore, if the choice is available, it is beneficial to increase the width of a heat sink rather than the length of the heat sink. Also, the effect of radiation heat transfer is very important in natural convection, as it can be responsible of up to 25% of the total heat dissipation. Unless the component is facing a hotter surface nearby, it is imperative to have the heat sink surfaces painted or anodized to enhance radiation.

Heat Sink Types

Heat sinks can be classified in terms of manufacturing methods and their final form shapes. The most common types of air-cooled heat sinks include:

1. Stampings: Copper or aluminum sheet metals are stamped into desired shapes. They are used in traditional air cooling of electronic components and offer a low cost solution to low density thermal problems. They are suitable for high volume production, because advanced tooling with high speed stamping would lower costs. Additional labor-saving options, such as taps, clips, and interface materials, can be factory applied to help to reduce the board assembly costs.

Heat sink type	η range, %
Stampings & flat plates	10 - 18
Finned extrusions	15 - 22
Impingement flow	25 - 32
Fan heat sinks	35 - 45
Fully ducted extrusions	45 - 58
Ducted pin fin	78 - 90
Bonded & folded fins	78 - 90

Table 4: Range of heat transfer efficiencies

2. Extrusions: These allow the formation of elaborate two-dimensional shapes capable of dissipating large heat loads. They may be cut, machined, and options added. A cross-cutting will produce omnidirectional, rectangular pin fin heat sinks, and incorporating serrated fins improves the performance by approximately 10 to 20%, but with a slower extrusion rate. Extrusion limits, such as the fin height-to-gap aspect ratio, minimum fin thickness-to-height and maximum base to fin thicknesses, usually dictate the flexibility in design options. Typical fin height-to-gap aspect ratio of up to 6 and a minimum fin thickness of 1.3mm, are attainable with a standard extrusion. A 10 to 1 aspect ratio and a fin thickness of 0.8" can be achieved with special die design features. However, as the aspect ratio increases, the extrusion tolerance is compromised.

3. Bonded/Fabricated Fins: Most air cooled heat sinks are convection limited, and the overall thermal performance of an air cooled heat sink can often be improved significantly if more surface area can be exposed to the air stream. These high performance heat sinks utilize thermally conductive aluminum-filled epoxy to bond planar fins onto a grooved extrusion base plate. This process allows for a much greater fin height-to-gap aspect ratio of 20 to 40, greatly increasing the cooling capacity without increasing volume requirements.

4. Castings: Sand, lost core and die casting processes are available with or without vacuum assistance, in aluminum or copper/bronze. This technology is used in high density pin fin heat sinks which provide maximum performance when using impingement cooling.

5. Folded Fins: Corrugated sheet metal in either aluminum or copper increases surface area and, hence, the volumetric performance. The heat sink is then attached to either a base plate or directly to the heating surface via epoxying or brazing. It is not suitable for high profile heat sinks on account of the availability and fin efficiency. Hence, it allows high performance heat sinks to be fabricated for applications where it is impractical or impossible to use extrusions or bonded fins.

Figure 2 shows the typical range of cost functions for different types of heat sinks in terms of the required thermal resistance.

The performance of different heat sink types varies dramatically with the air flow through the heat sink. To quantify the effectiveness of different types of heat sinks, the volumetric heat transfer efficiency can be defined as

$$\eta = \frac{Q}{m c \Delta T_a}$$

where, m is the mass flow rate through the heat sink, c is the heat capacity of the fluid, and ΔT_a is the average temperature difference between the heat sink and the ambient air. The heat transfer efficiencies have been measured for a wide range of heat sink configurations, and their ranges are listed in Table 4.

The improved thermal performance is generally associated with additional costs in either material or manufacturing, or both.

Thermal Performance Graph

Performance graphs typical of those published by heat sink vendors are shown in Fig. 3. The graphs are a composite of two separate curves which have been combined into a single figure. It is assumed that the device to be cooled is properly mounted, and the heat sink is in its normally used mounting orientation with respect to the direction of air flow. The first plot traveling from the lower left to the upper right is the natural convection curve of the heat sink temperature rise, ΔT_a , versus Q . The natural convection curves also assume that the heat sink is painted or anodized black. The curve from the upper left to lower right is the forced convection curve of thermal resistance versus air velocity. In forced convection, ΔT_a is linearly proportional to Q , hence R_a is independent of Q and becomes a function only of the

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flow velocity. However, the natural convection phenomenon is non-linear, making it necessary to present ΔT_{sa} as a function of Q .

One can use the performance graphs to identify the heat sink and, for forced convection applications, to determine the minimum flow velocity that satisfy the thermal requirements. If the required thermal resistance in a forced convection application is $8^\circ\text{C}/\text{W}$, for example, the above sample thermal resistance versus flow velocity curve indicates that the velocity needs to be at or greater than 2.4 m/s (470 lfm). For natural convection applications, the required thermal resistance R_{sa} can be multiplied by Q to yield the maximum allowable ΔT_{sa} . The temperature rise of a chosen heat sink must be equal to or less than the maximum allowable ΔT_{sa} at the same Q .

The readers are reminded that the natural convection curves assume an optimal orientation of the heat sink with respect to the gravity. Also, the flow velocity in the forced convection graph represents the approach flow velocity without accounting for the effect of flow bypass. There have been a limited number of investigations^{2,3} on the subject of flow bypass. These studies show that flow bypass may reduce the performance of a heat sink by as much as 50% for the same upstream flow velocity. For further consultation on this subject, readers are referred to the cited references.

When a device is substantially smaller than the base plate of a heat sink, there is an additional thermal resistance, called the spreading resistance, that needs to be considered in the selection process. Performance graphs generally assume that the heat is evenly distributed over the entire base area of the heat sink and, therefore, do not account for the additional temperature rise caused by a smaller heat source. This spreading resistance could typically be 5 to 30% of the

Altitude m/ft	Factor
0: sea level	1.00
1000-3000	0.95
1500-5000	0.90
2000-7000	0.86
3000-10000	0.80
3500-12000	0.75

Table 5: Altitude derating factors

total heat sink resistance, and can be estimated by using the simple analytical expression developed in Reference 4.

Another design criterion that needs to be considered in the selection of a heat sink, is the altitude effect. While the air temperature of an indoor environment is normally controlled and is not affected by the altitude change, the indoor air pressure does change with the altitude. Since many electronic systems are installed at an elevated altitude, it is necessary to derate the heat sink performance mainly due to the lower air density caused by the lower air pressure at higher altitude. Table 5 shows the performance derating factors for typical heat sinks at high altitudes. For example, in order to determine the actual thermal performance of a heat sink at altitudes other than the sea level, the thermal resistance values read off from the performance graphs should be divided by the derating factor before the values are compared with the required thermal resistance.

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References

1. Aavid Engineering, Inc, EDS #117, *Interface Materials*, January 1992.
2. R.A. Wirtz, W. Chen, and R. Zhou, *Effect of Flow Bypass on the Performance of Longitudinal Fin Heat Sinks*, ASME Journal of Electronic Packaging, Vol. ~116, pp. ~206-211, 1994.
3. S. Lee, *Optimum Design and Selection of Heat Sinks*, Proceedings of 11th IEEE Semi-Therm Symposium, pp.48 - 54, 1995.
4. S. Song, S. Lee, and V. Au, *Closed Form Equation for Thermal Constriction/Spreading Resistances with Variable Resistance Boundary Condition*, Proceedings of the 1994 IEPS Technical Conference, pp.111 - 121, 1994.

THERMAL MANAGEMENT

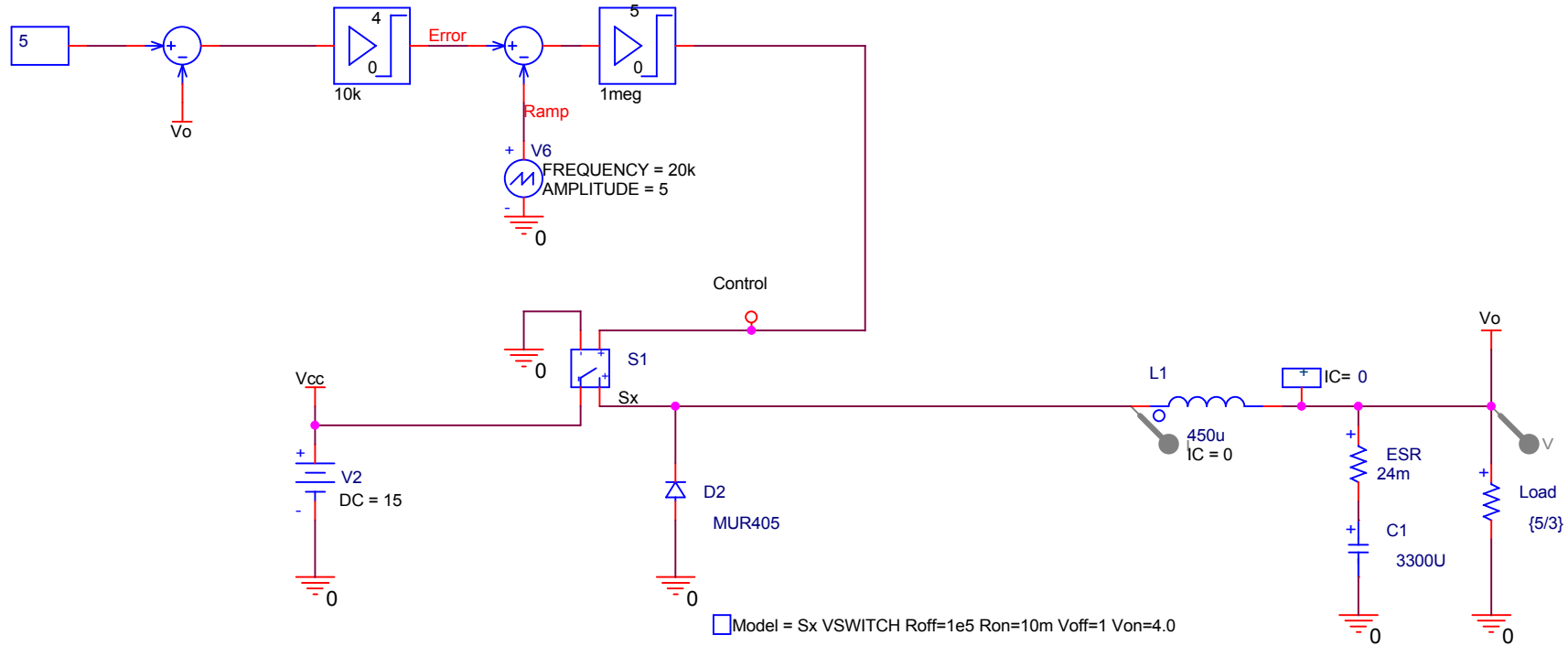
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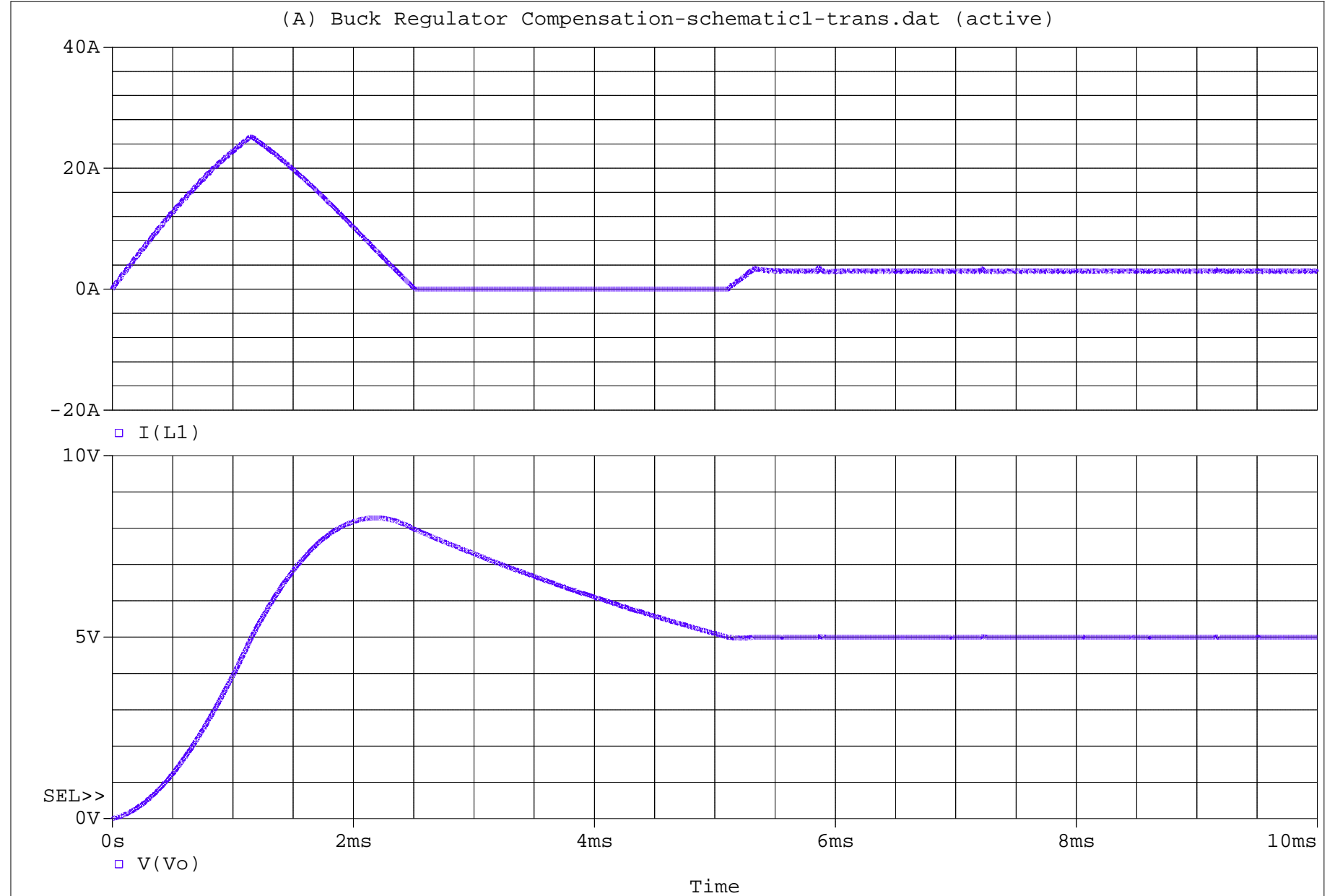
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Reader Enquiry Number 28



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		Continuous Mode Buck Regulator	
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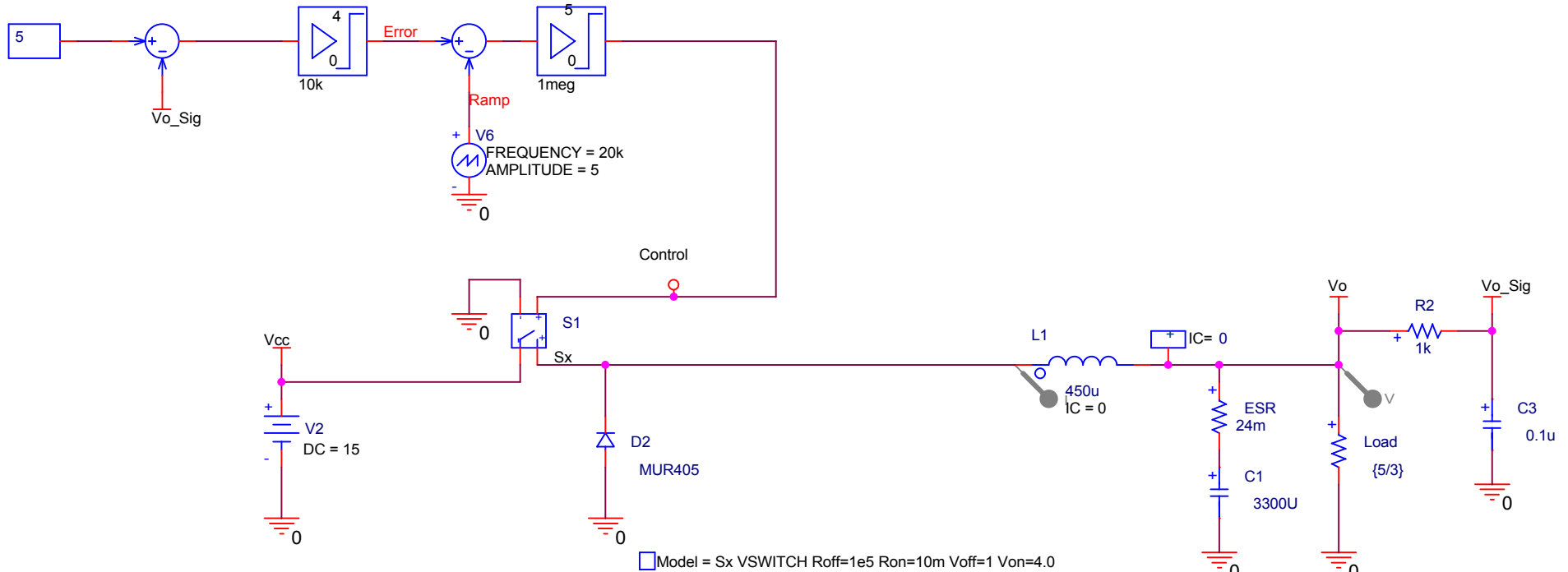
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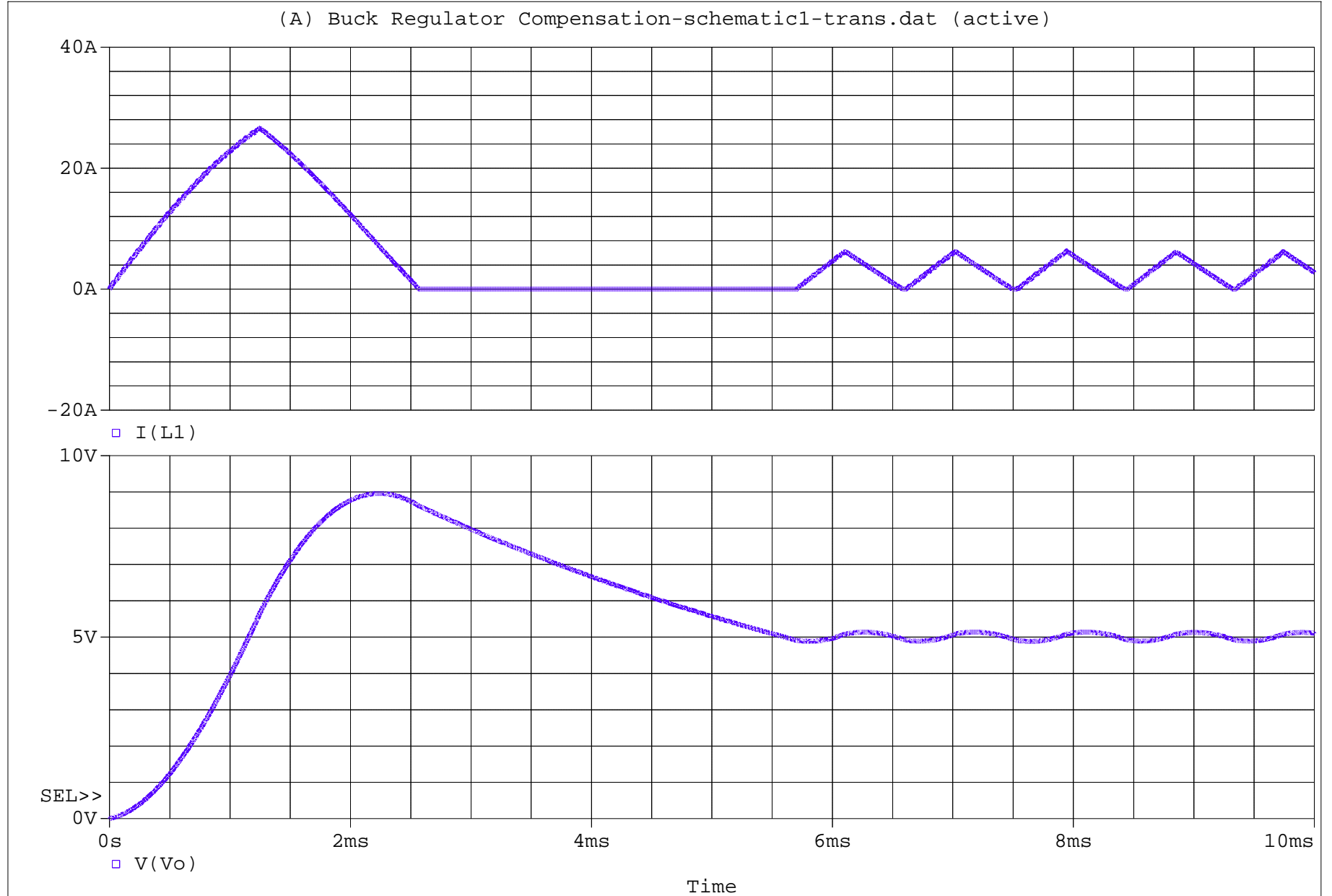
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Low pass filter added. The System is now unstable.

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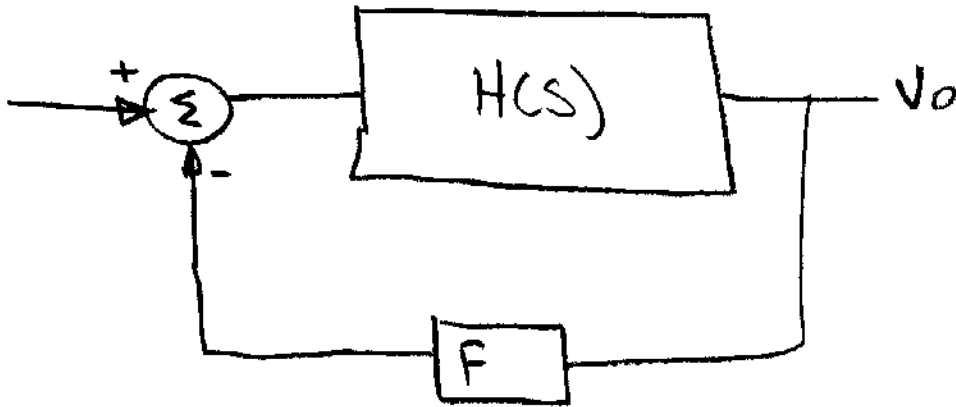


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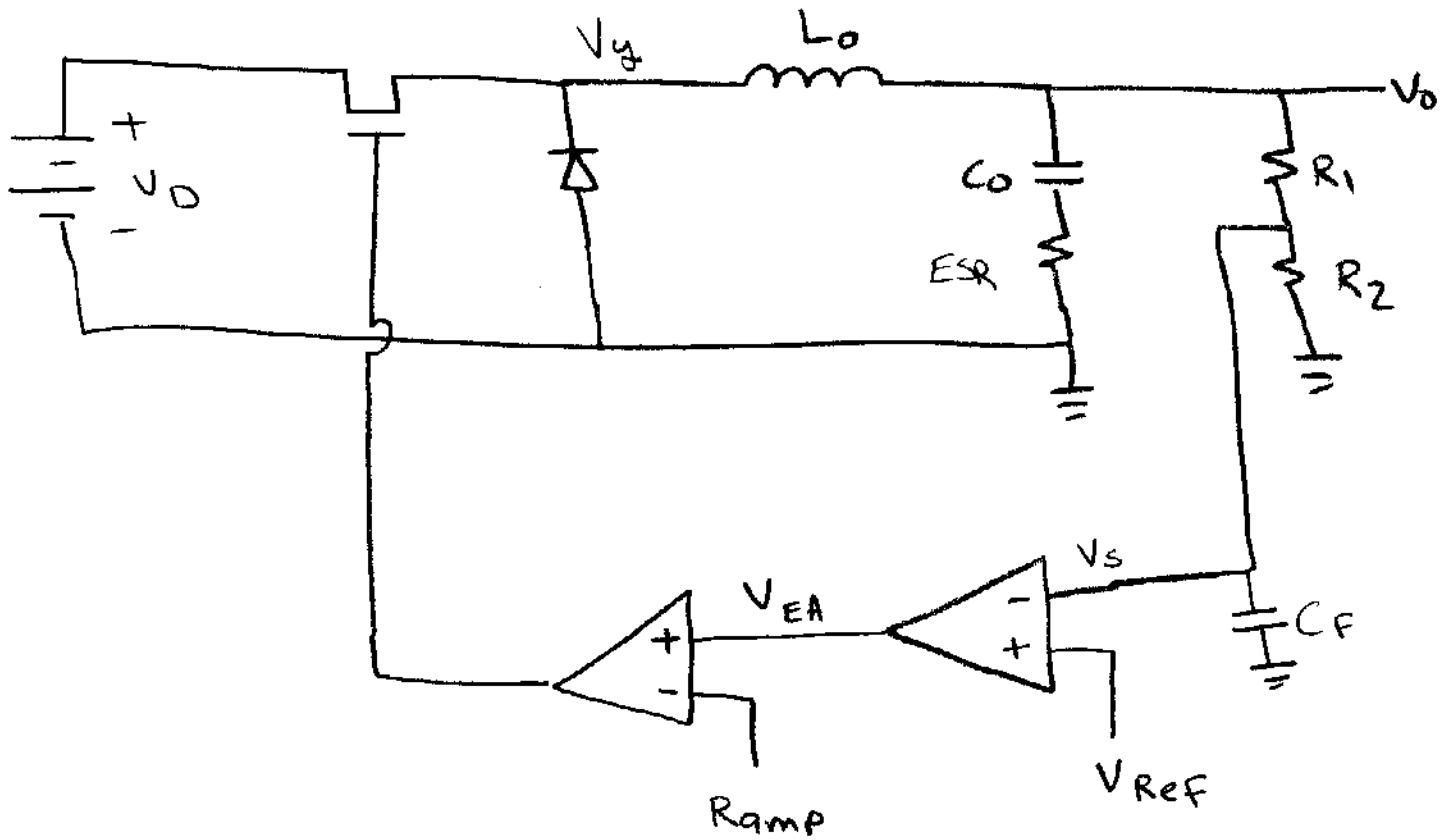
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Switching Power Supply Feedback Loop Stabilization

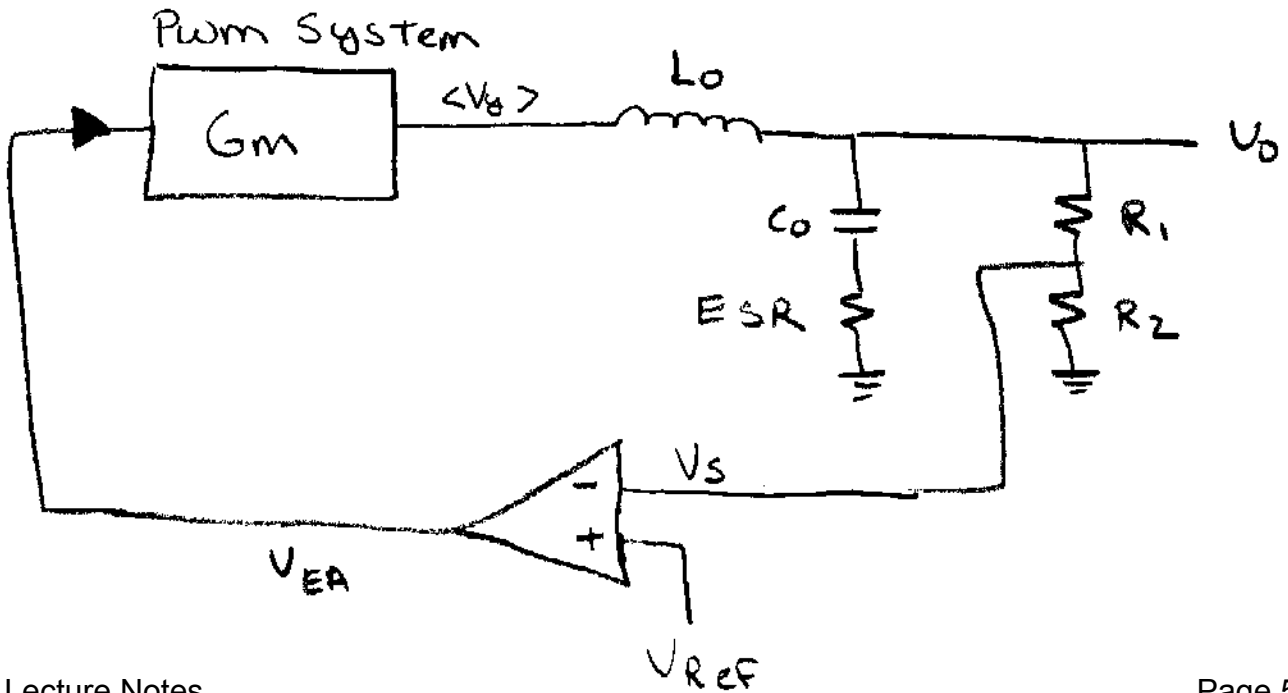


- $\angle FH(s)$ must be less than 180° when $|FH(s)| = 1$
 - Phase margin = $180^\circ - \angle FH(s)$
 - Design for a phase margin $\geq 35^\circ - 45^\circ$
- when $\angle FH(s) = 180^\circ$, $\frac{1}{|FH(s)|} \geq 12\text{dB}$
 \Rightarrow gain margin of 12dB
- when $|FH(s)|$ passes through 0dB, we should only have a slope of -20dB/Dec

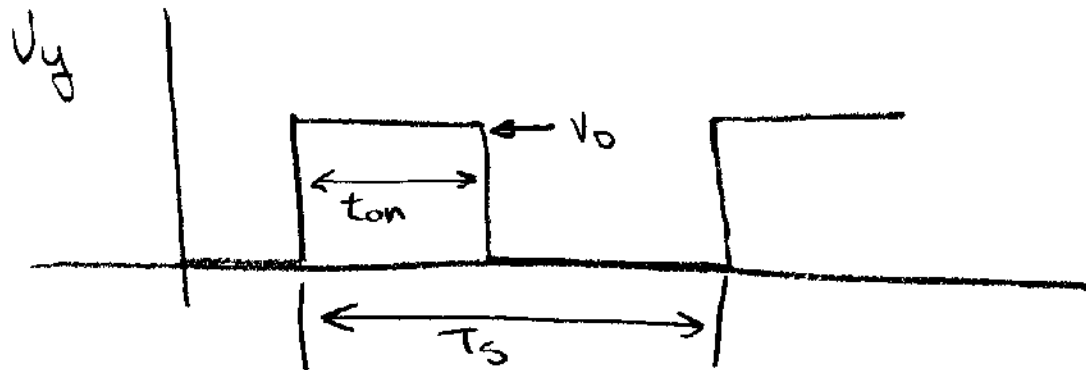
- Look at our PWM Buck converter
- Continuous mode



model



For the Forward Converter

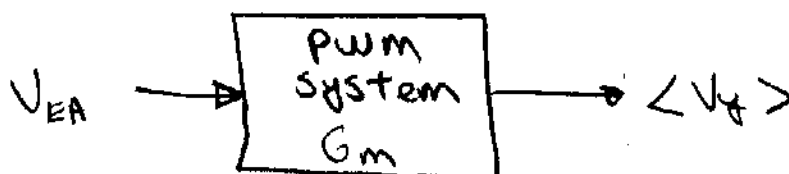


Question: How can we use Linear Feedback theory with a non-linear waveform?

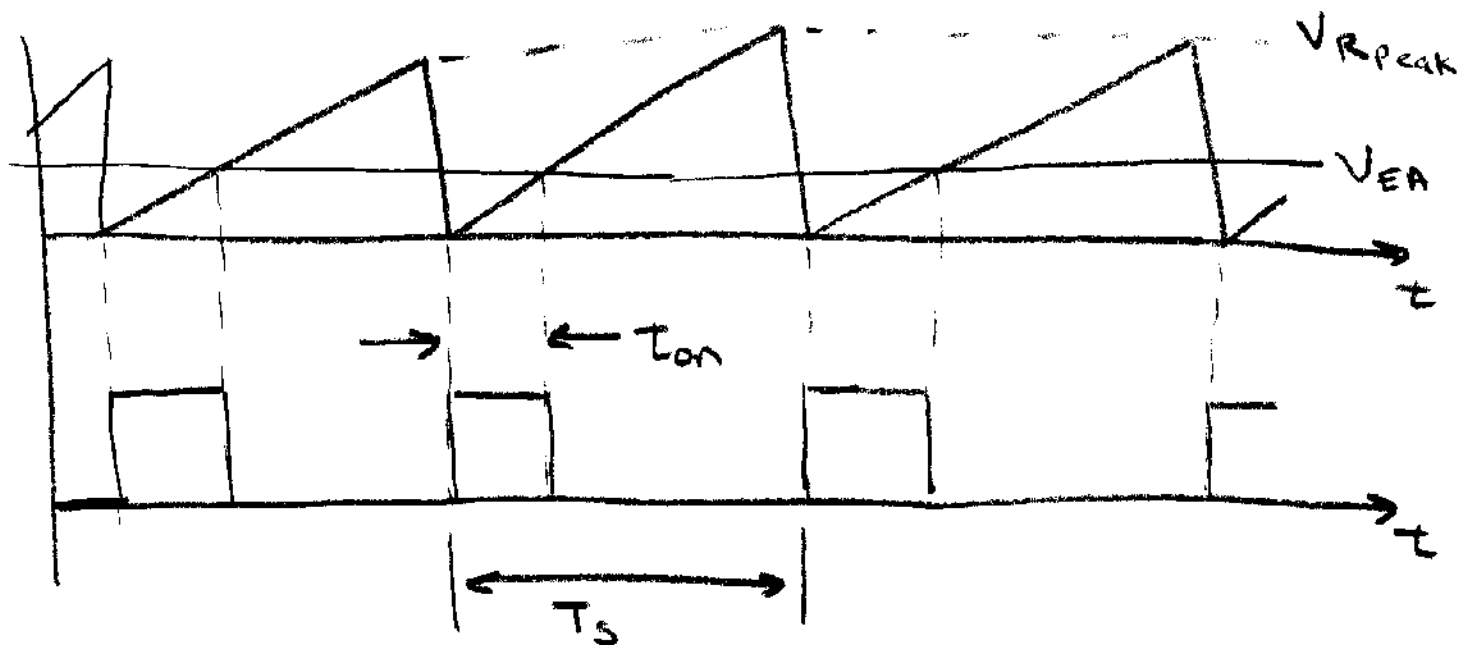
⇒ Linearize the waveform

$$\langle V_g \rangle = V_0 \frac{t_{on}}{T_s} = \text{average voltage at } V_g$$

How do we get The Transfer Function $\frac{\langle V_g \rangle}{V_{EA}}$?



- Look at t_{on} and the Ramp

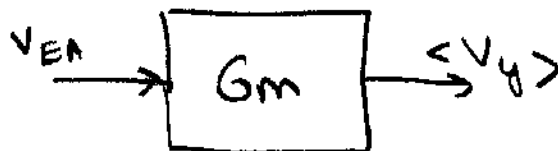


$$\frac{t_{on}}{T_s} = \frac{V_{EA}}{V_{Rpeak}}$$

$$\text{Thus } \langle V_y \rangle = V_D \frac{t_{on}}{T_s} = \frac{V_D V_{EA}}{V_{Rpeak}}$$

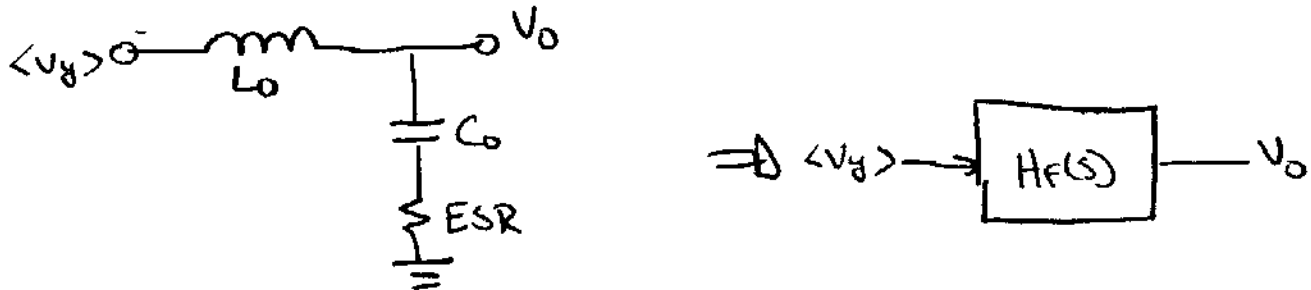
OR

$$G_m \triangleq \frac{V_{yavg}}{V_{EA}} = \frac{V_D}{V_{Rpeak}}$$



$G_m = \frac{V_D}{V_{Rpeak}}$ for a Buck Regulator with a Ramp from 0 to V_{Rpeak}

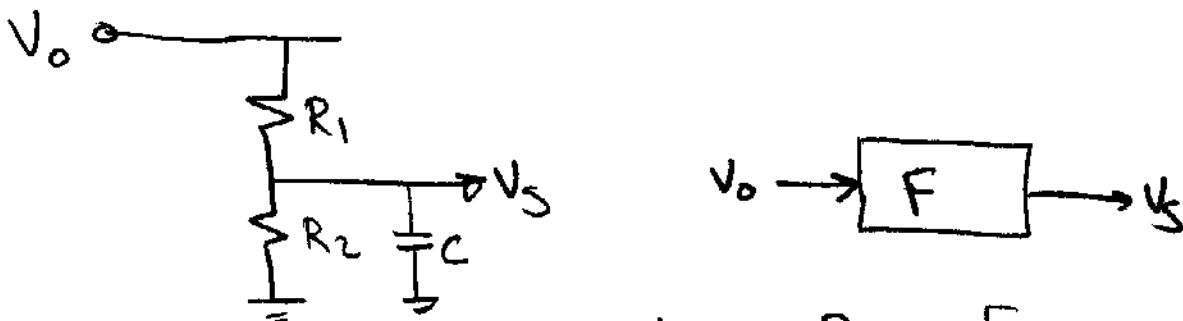
Find Transfer Function for the Filter



$$H_f(s) = \frac{Z_{C_o} + R_{ESR}}{Z_{C_o} + R_{ESR} + Z_{L_o}} = \frac{\frac{1}{sC_o} + R_{ESR}}{\frac{1}{sC_o} + R_{ESR} + sL_o}$$

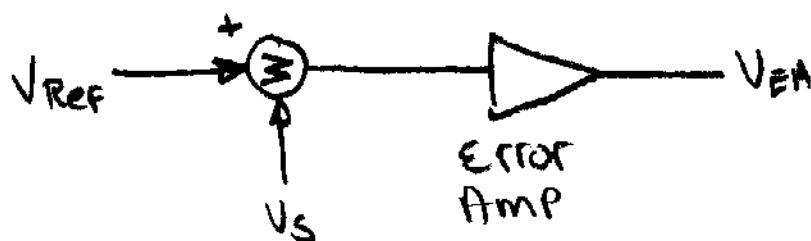
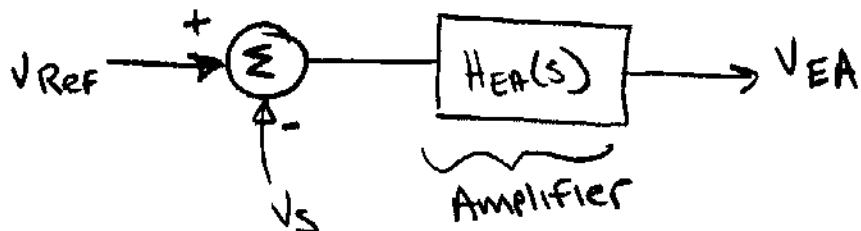
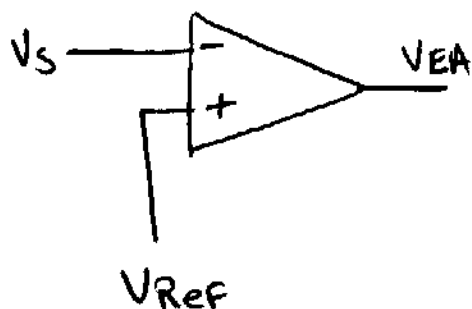
$$H_f(s) = \frac{sC_o R_{ESR} + 1}{1 + sC_o R_{ESR} + s^2 L_o}$$

- Find the Transfer Function for the Attenuator



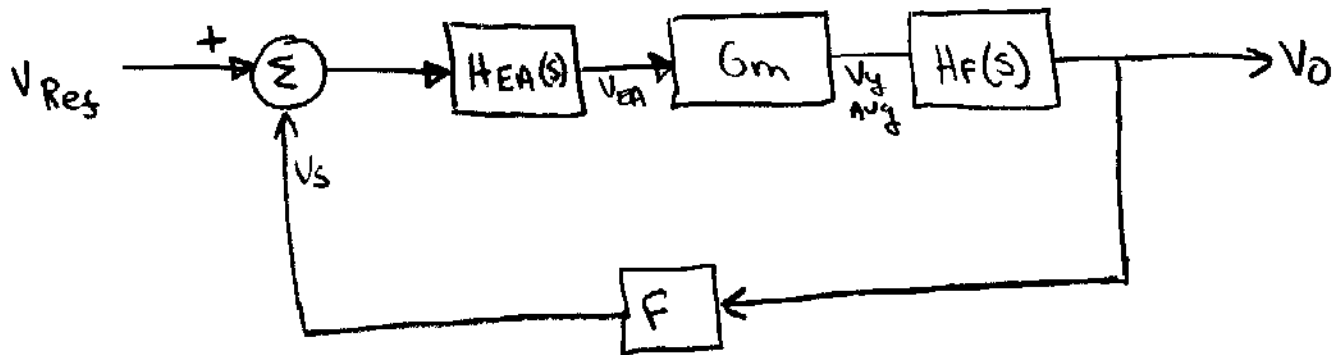
$$F = \frac{V_s}{V_o} = \frac{R_2}{R_1 + R_2} \left[\frac{1}{1 + j\omega C F R_1 \parallel R_2} \right]$$

- Look at the Error Amplifier



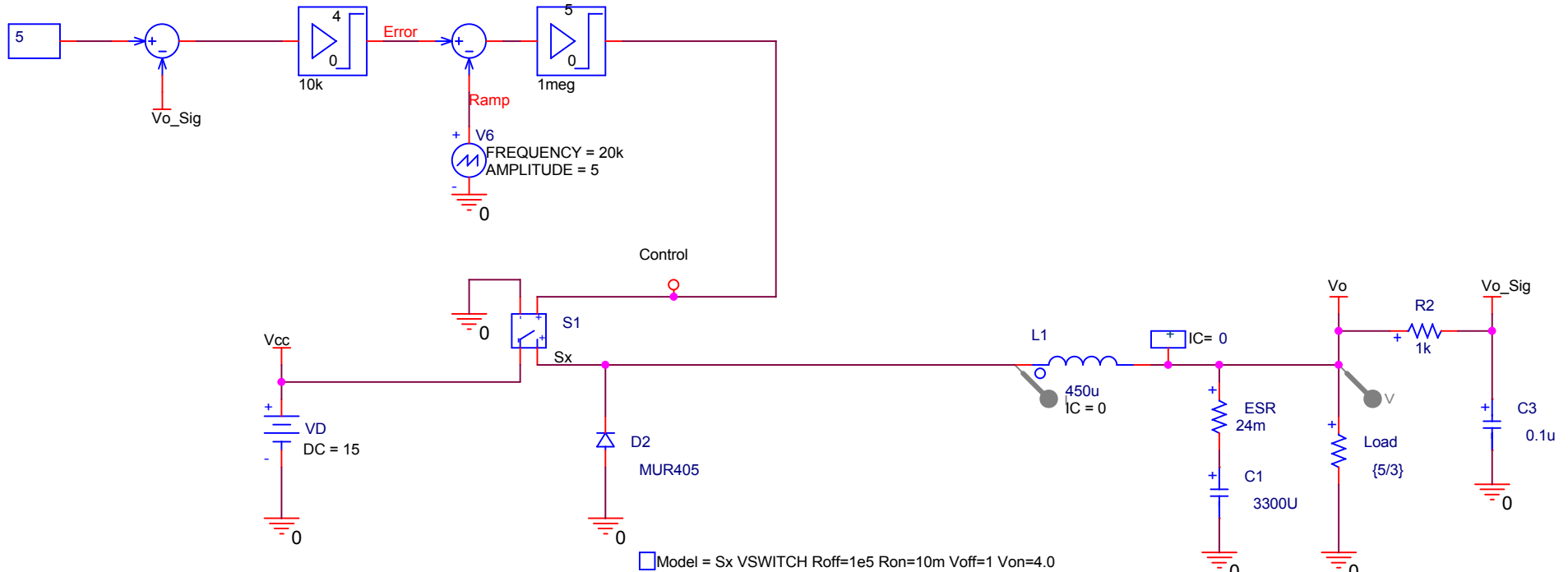
- $H_{EA}(s)$ is usually given and can be modified to compensate for stability.

\Rightarrow our system can be rewritten as




- We can not change F if we want a specific output voltage (we can change the filter cap C_f)
- Can compensate the error amplifier
- Can change $H_f(s)$ - Filter poles

Filter transfer function



Low pass filter added. The System is now unstable.

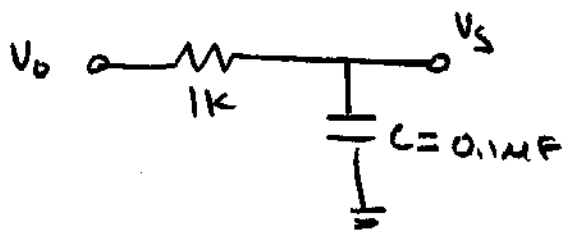
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Look at our Blocks

$$G_m = \frac{V_D}{V_{Rpeak}} = \frac{15V}{5V} = 3$$

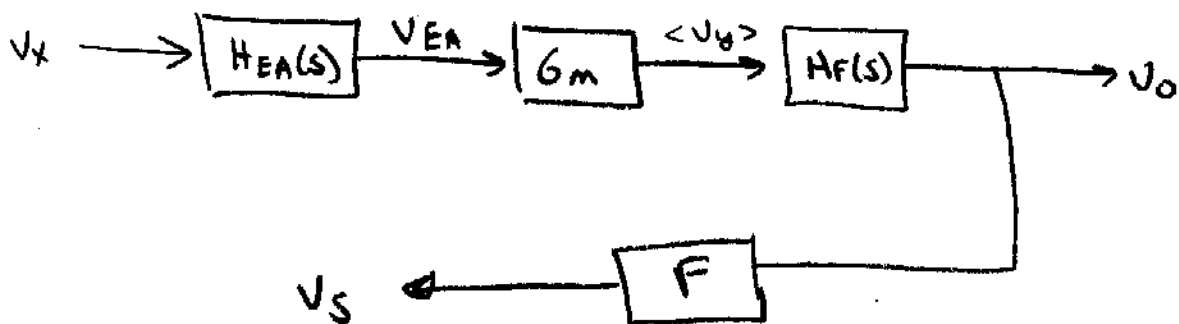
$$H_{EA} = 10K = \text{Error Amp Gain}$$

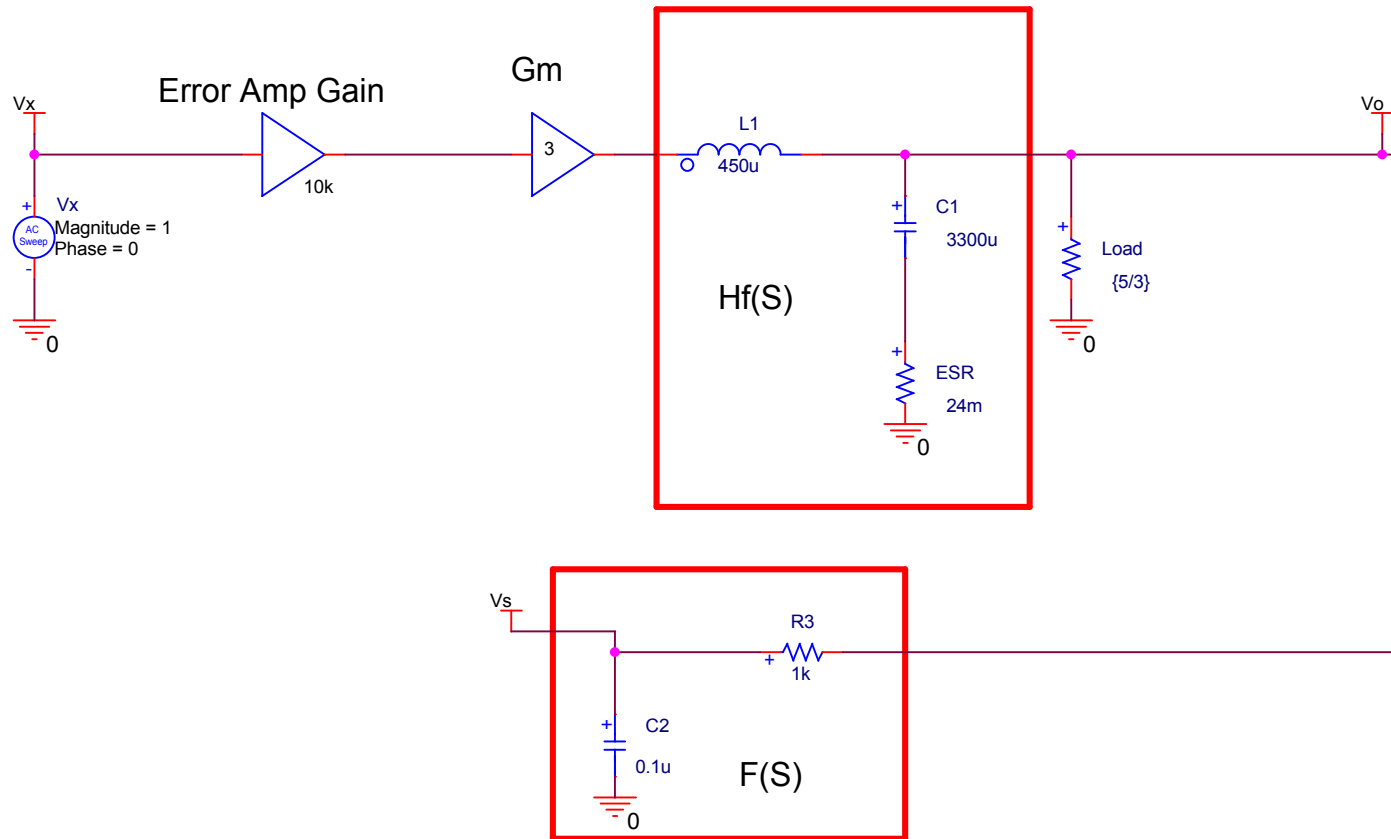
for our Low Pass Filter



$$\frac{V_o}{V_s} = \frac{1}{1 + j\omega RC}$$

- Use an AC Sweep to Look at the Loop Gain

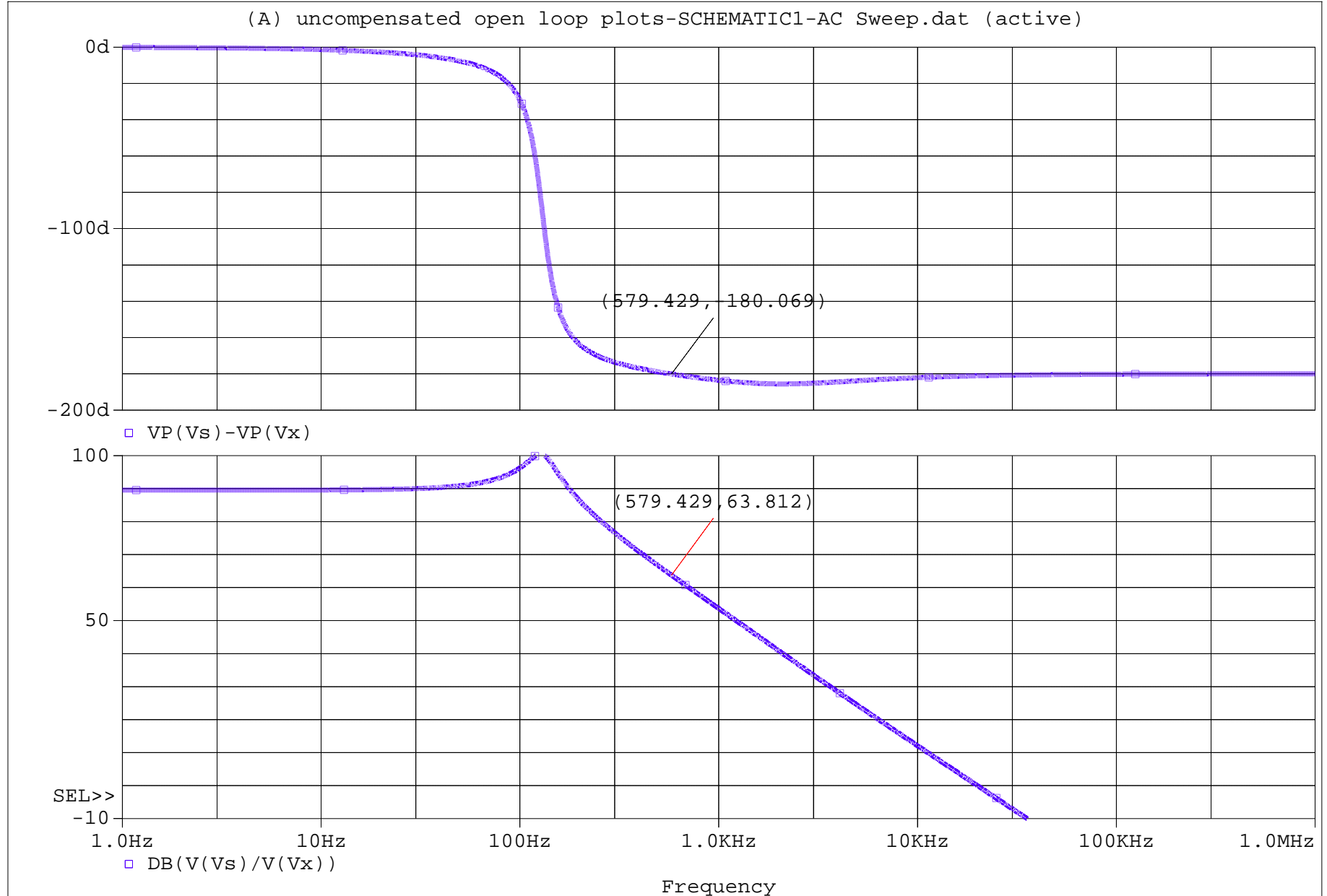




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Date: February 12, 2003

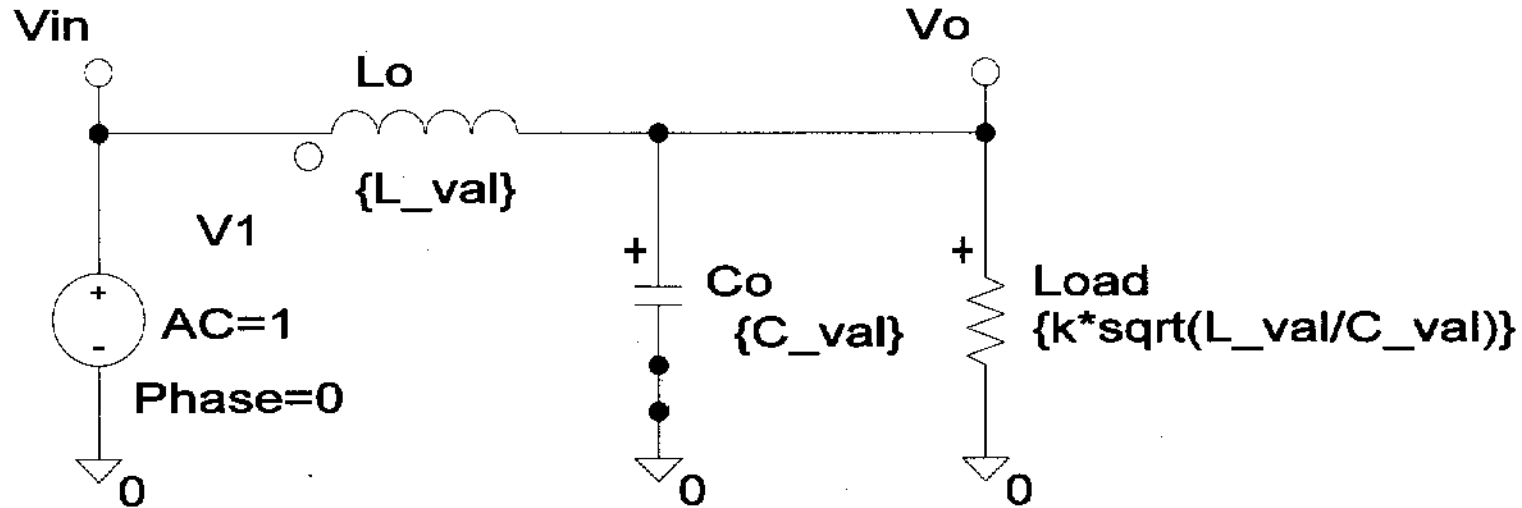
Page 1

Time: 10:01:59

(12)

PARAMETERS:

L_val	1
C_val	1
k	1



- Simulation without ESR
- Filter characteristic without ESR
- Look at the properties of this LC Filter

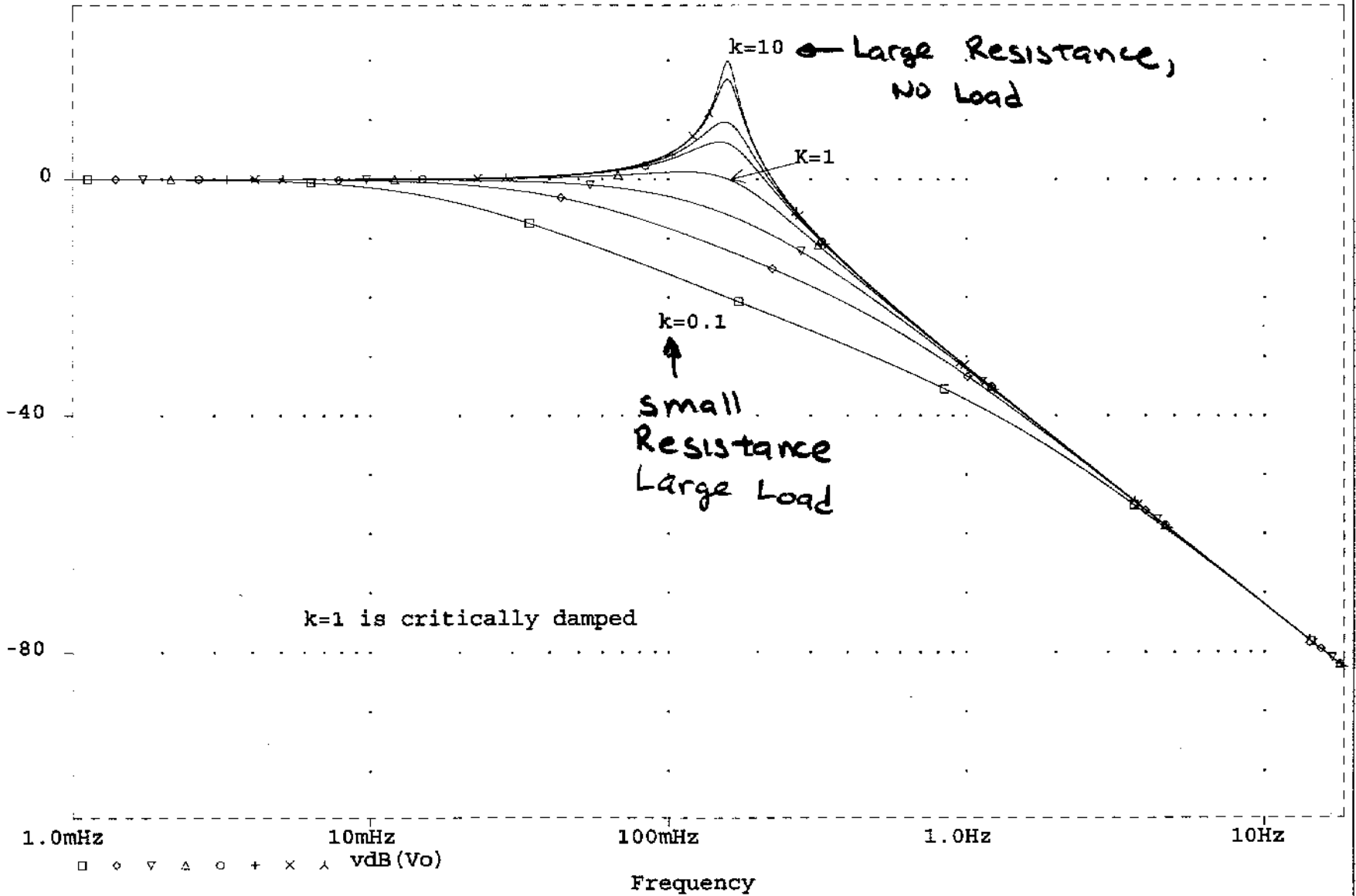
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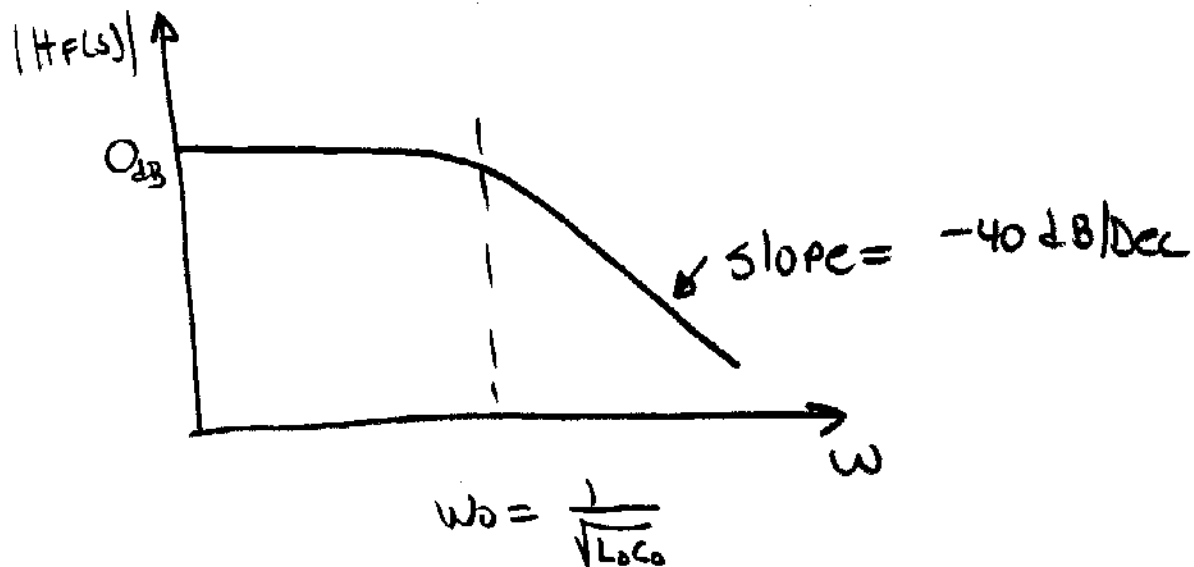
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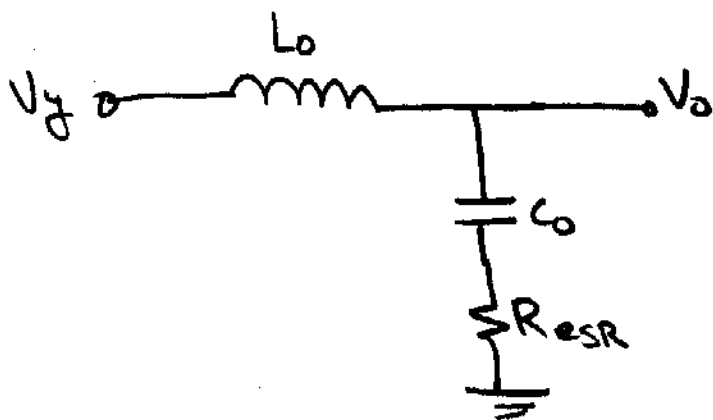
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- We will look at the critically damped case. If the system is stable for $K=1$, it will be stable for other loads

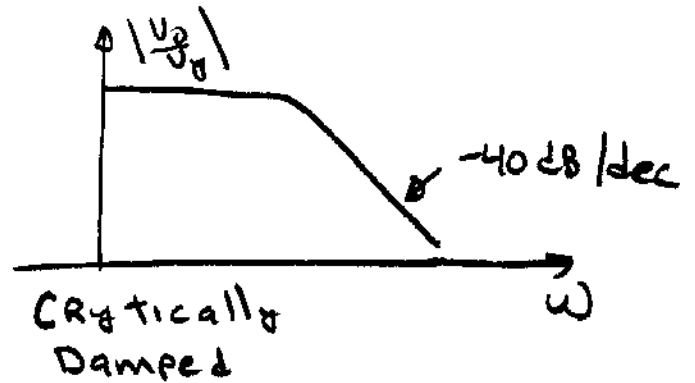
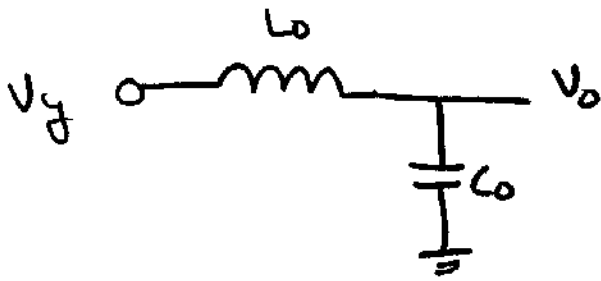


- what effect does R_{esR} have?



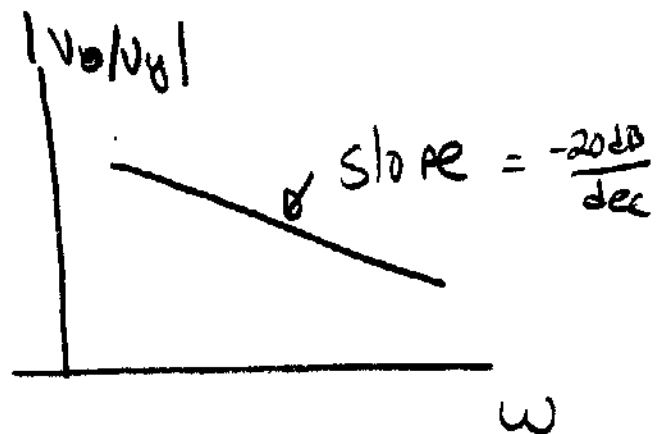
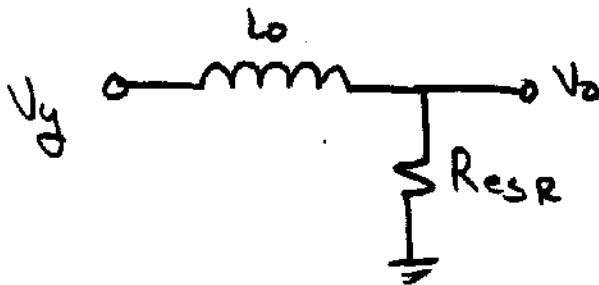
at Low. Frequency $Z_{C_0} \gg R_{esR}$.

The circuit looks like



at high frequency, $Z_{\omega} \ll R_{esR}$

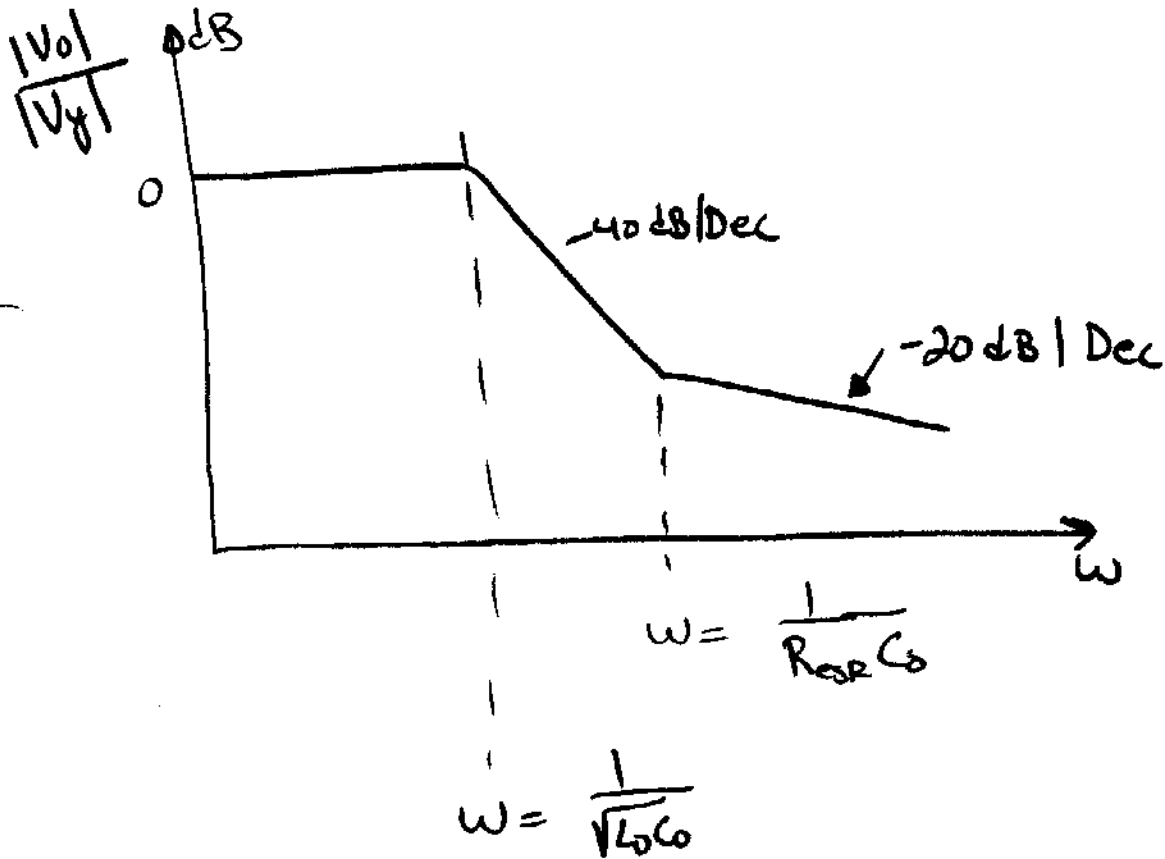
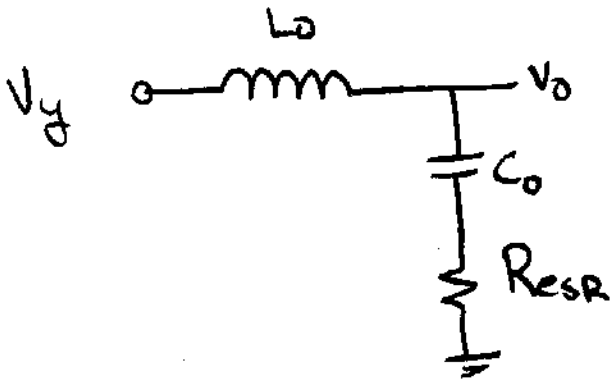
The circuit looks like



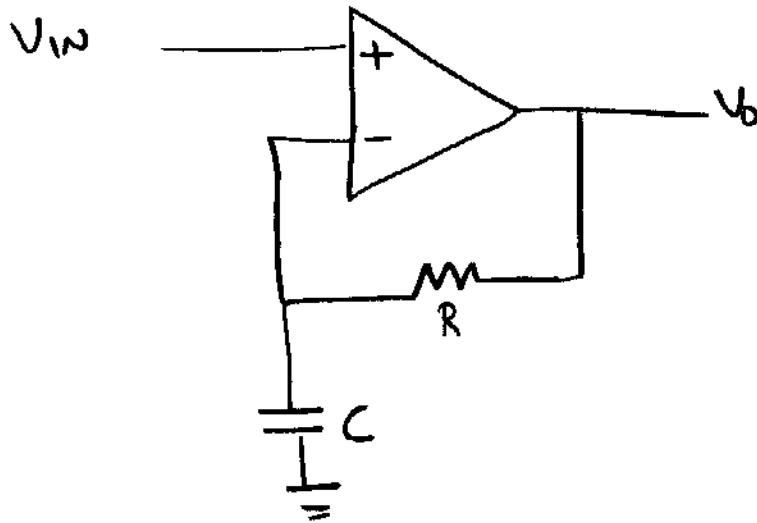
- The circuit changes slope at the pole of C_0 + R_{esR}

$$\omega = \frac{1}{C_0 R_{esR}}$$

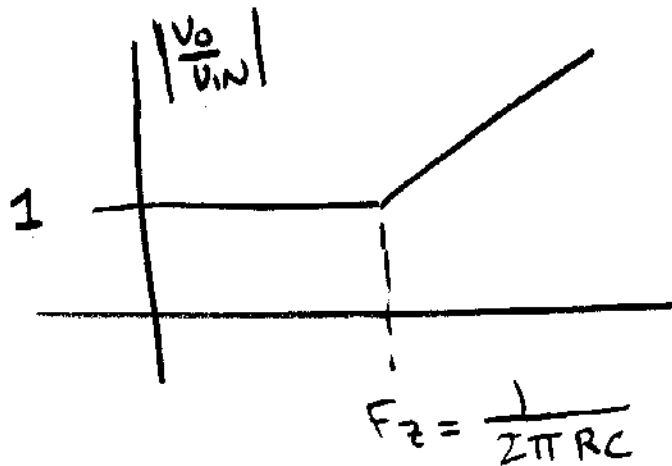
- Overall function looks like



- for our first compensation method, I will add a zero to cancel one of the poles of the L_oG Filter



$$\frac{V_O}{V_{IN}} = 1 + sCR$$



- Choose F_z to cancel one of the poles of the LC Filter

$$\frac{1}{2\pi RC} = \frac{1}{2\pi \sqrt{L_0 C_0}}$$

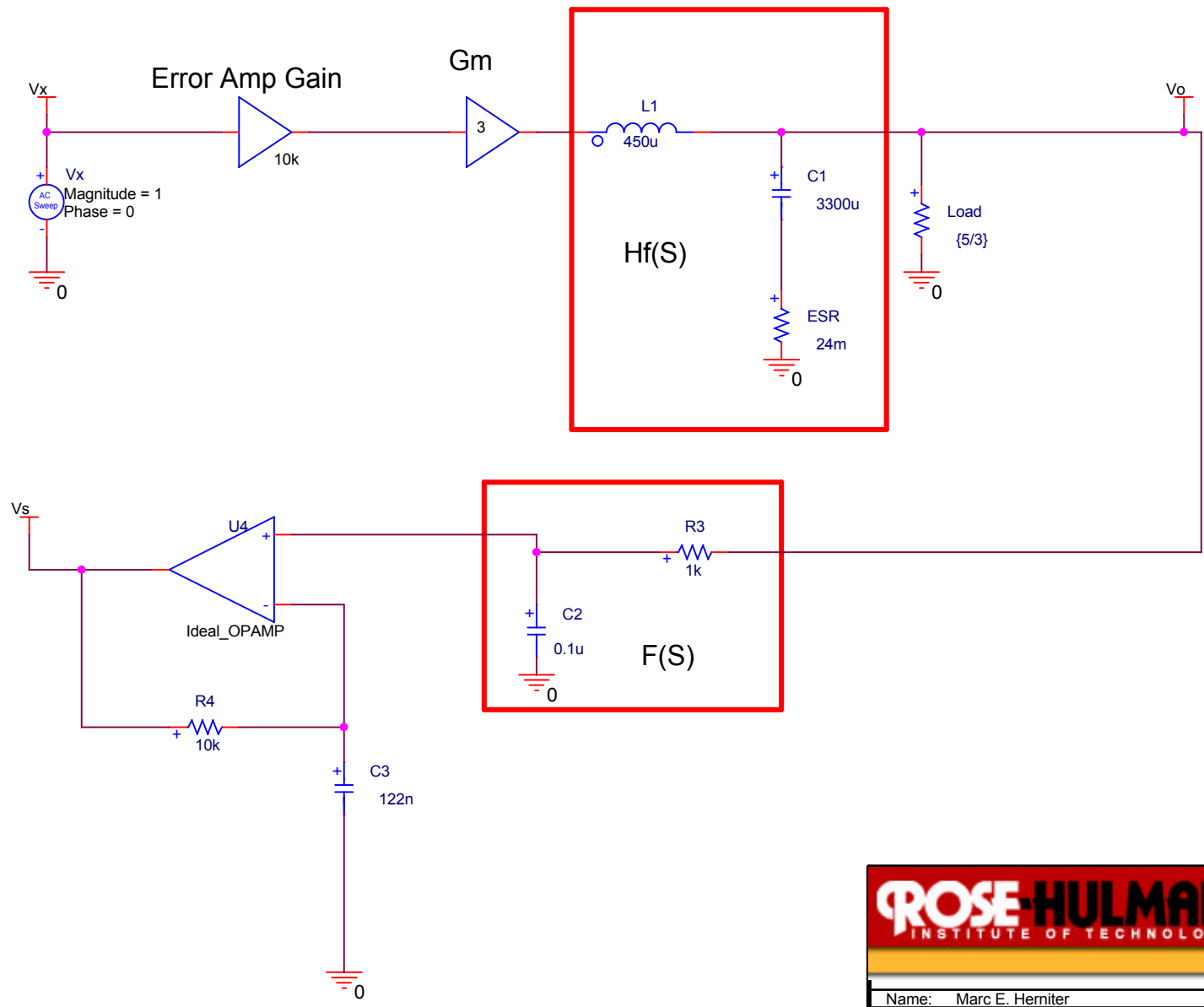
- for our example, $L_0 = 450 \mu\text{H}$, $C_0 = 3300 \mu\text{F}$

- choose $R = 10\text{K}$

$$\Rightarrow C = 122 \text{ nF}$$

WARNING

- The proposed circuit has infinite gain at high frequencies. This is not true if the circuit is realized with a real OPAMP.

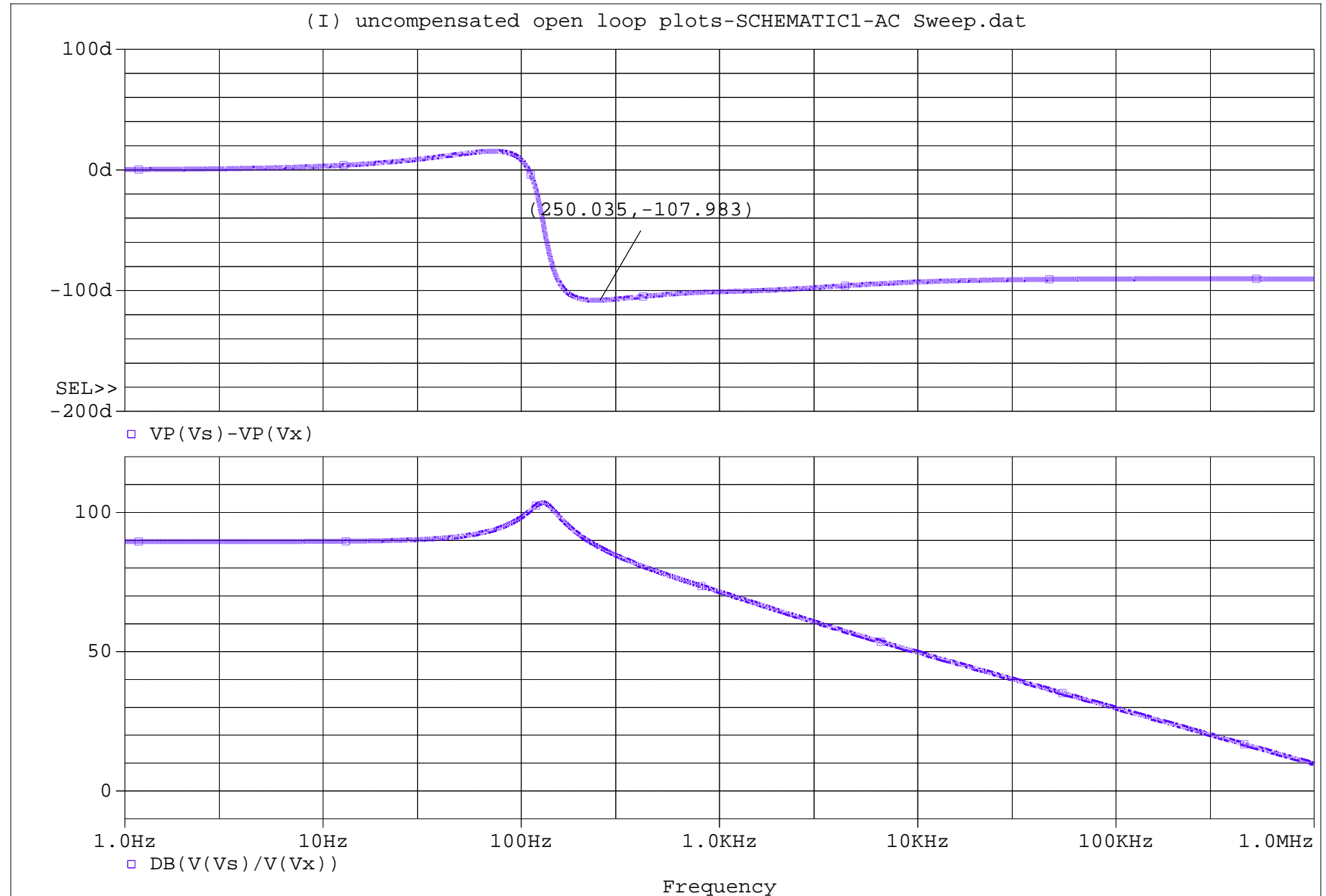


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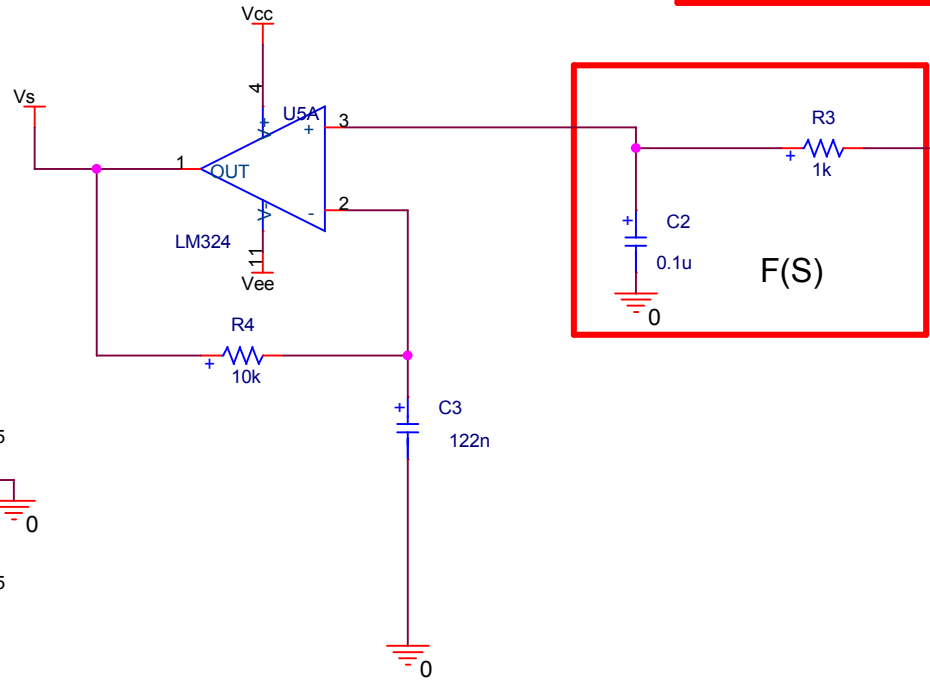
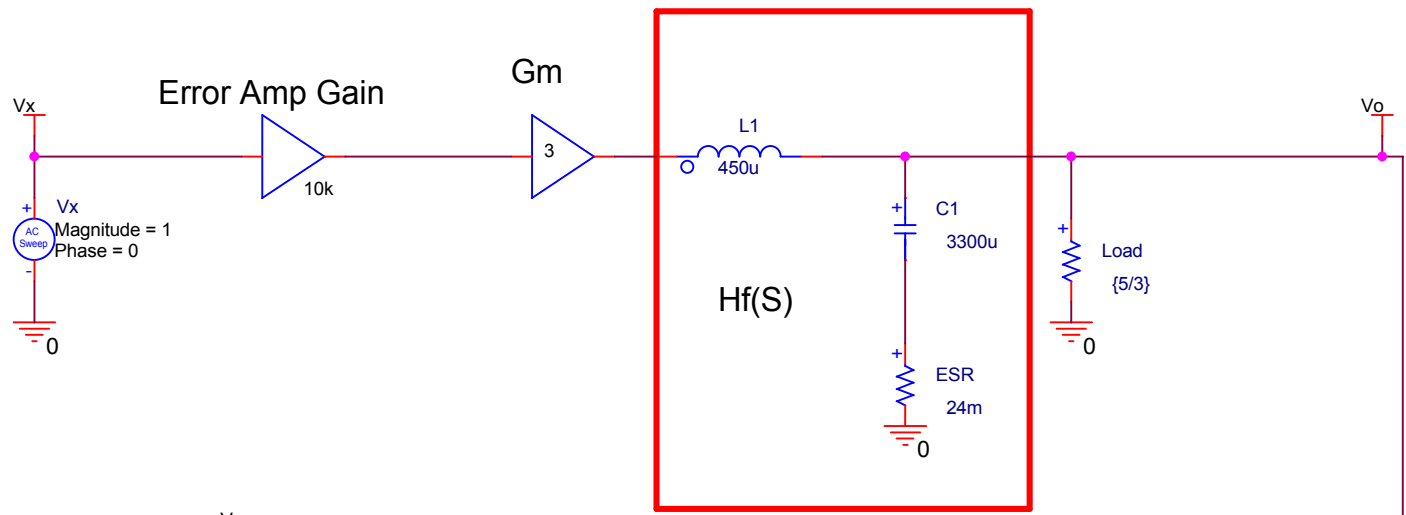
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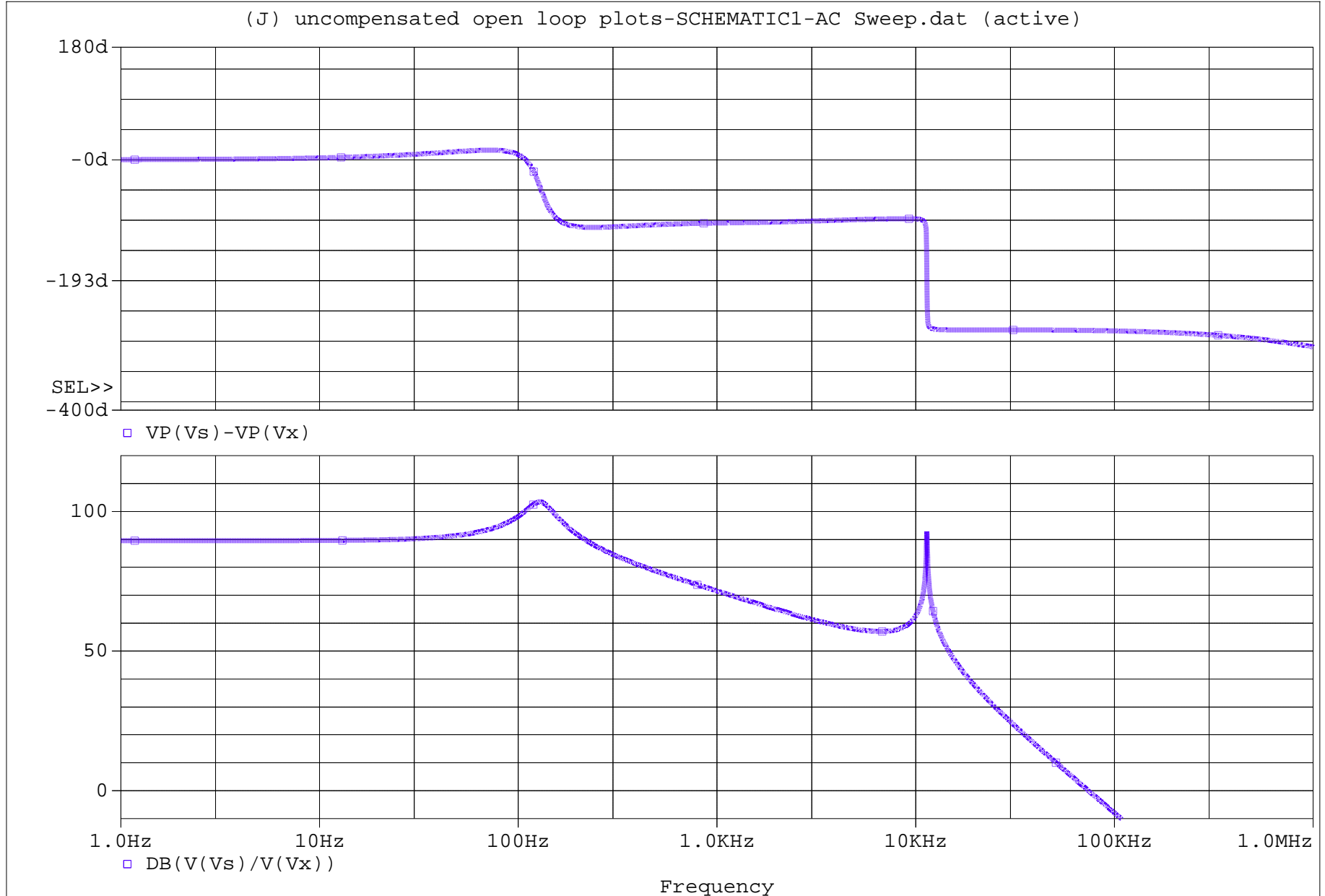




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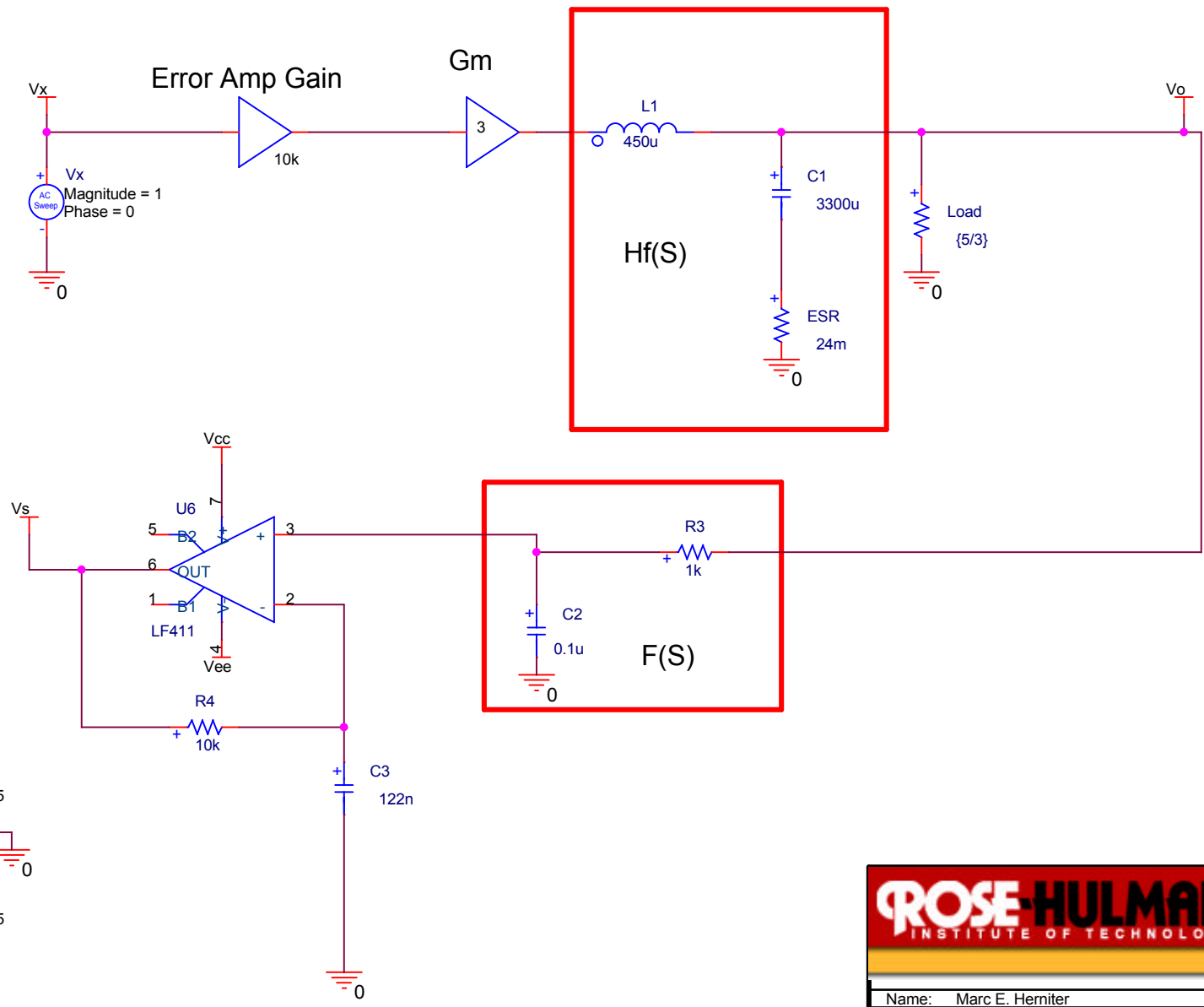
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Date: February 12, 2003

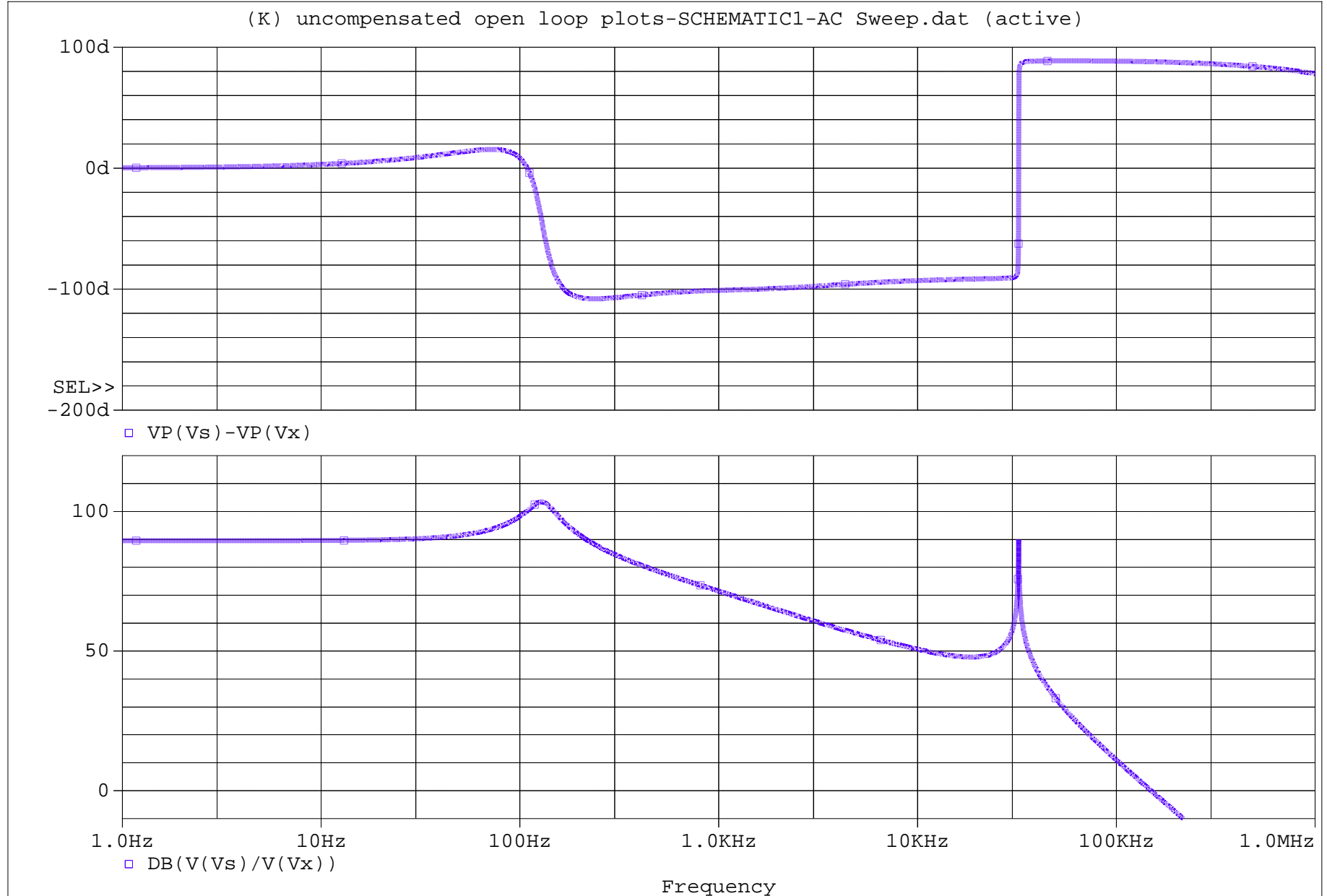
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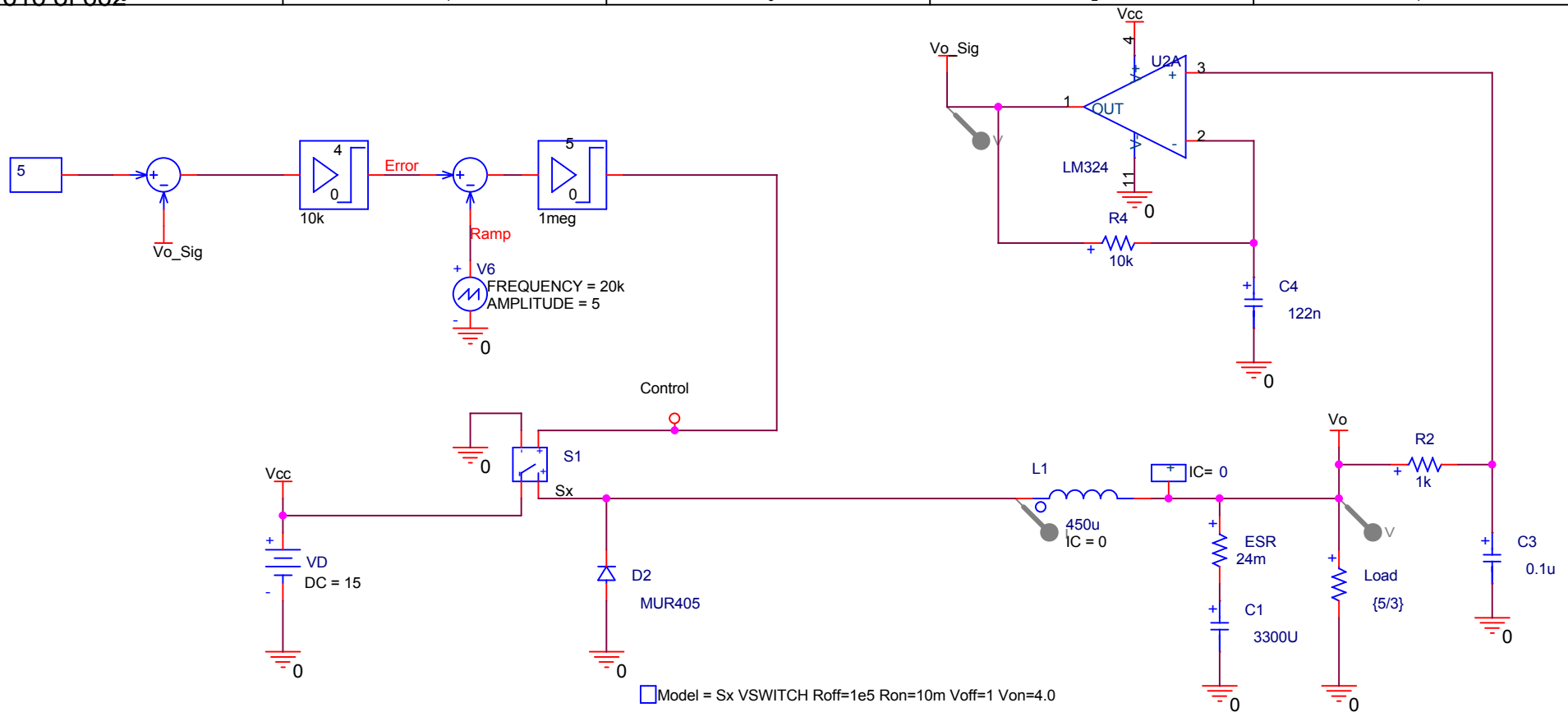
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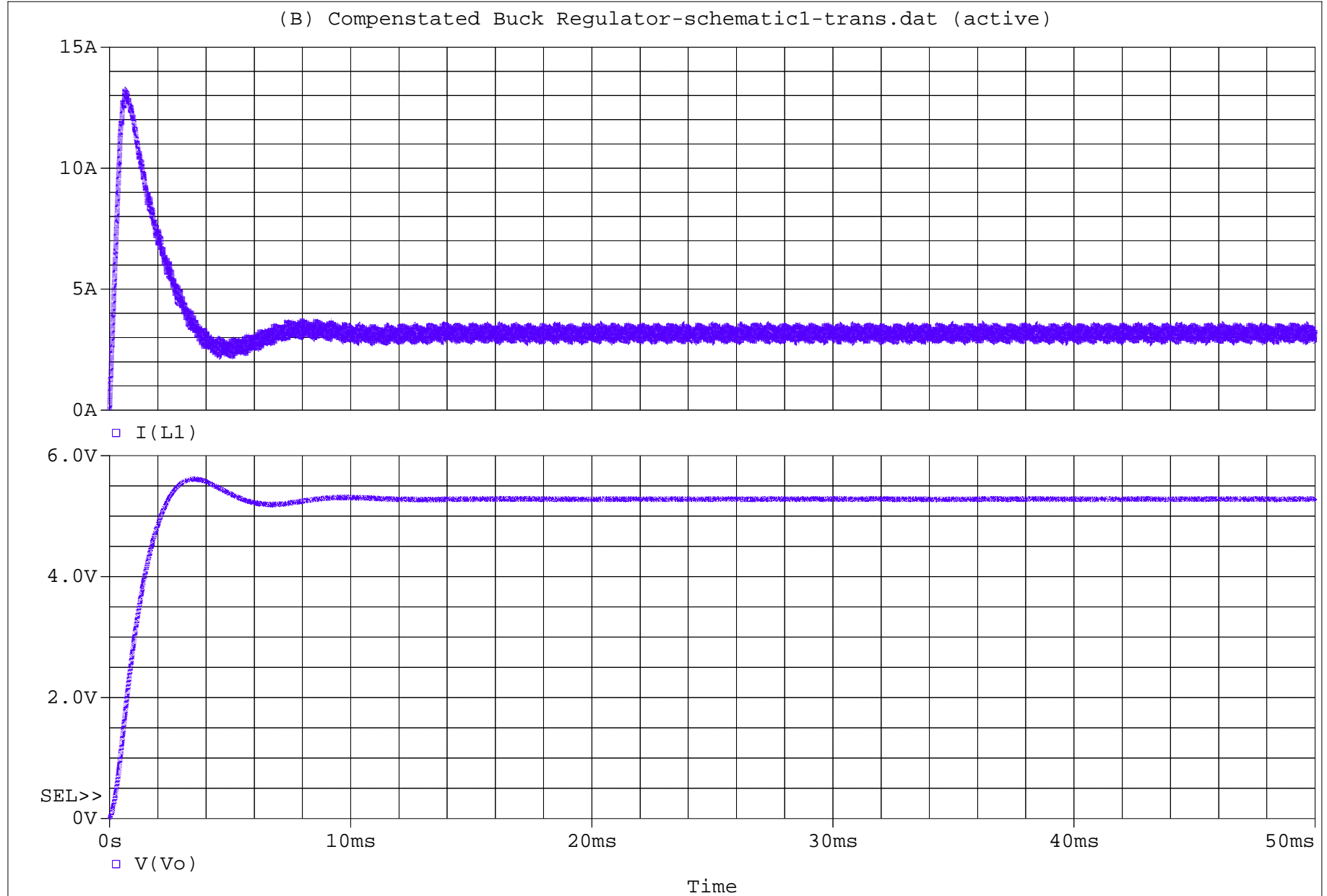
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Compensated system now stable.

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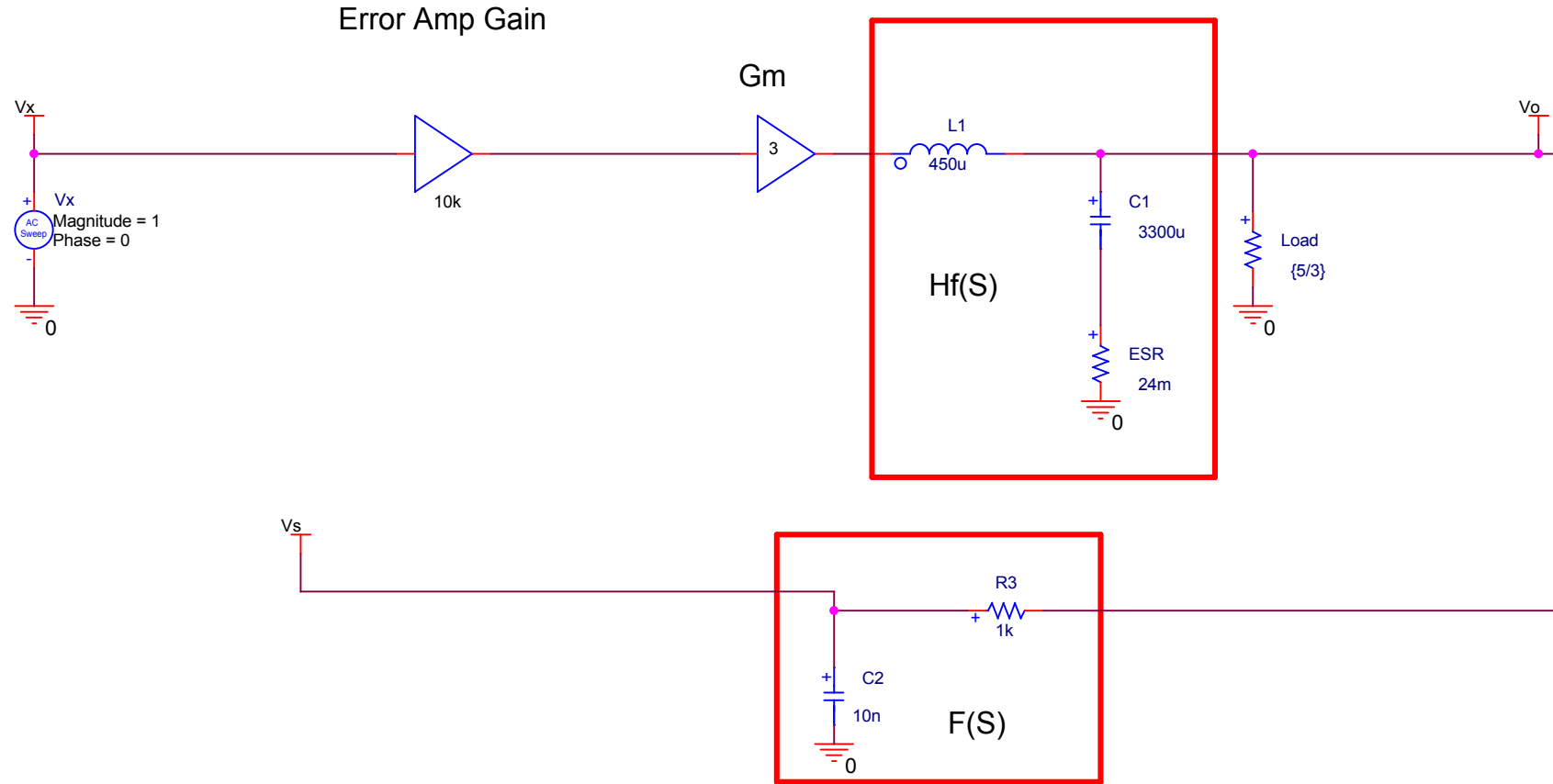
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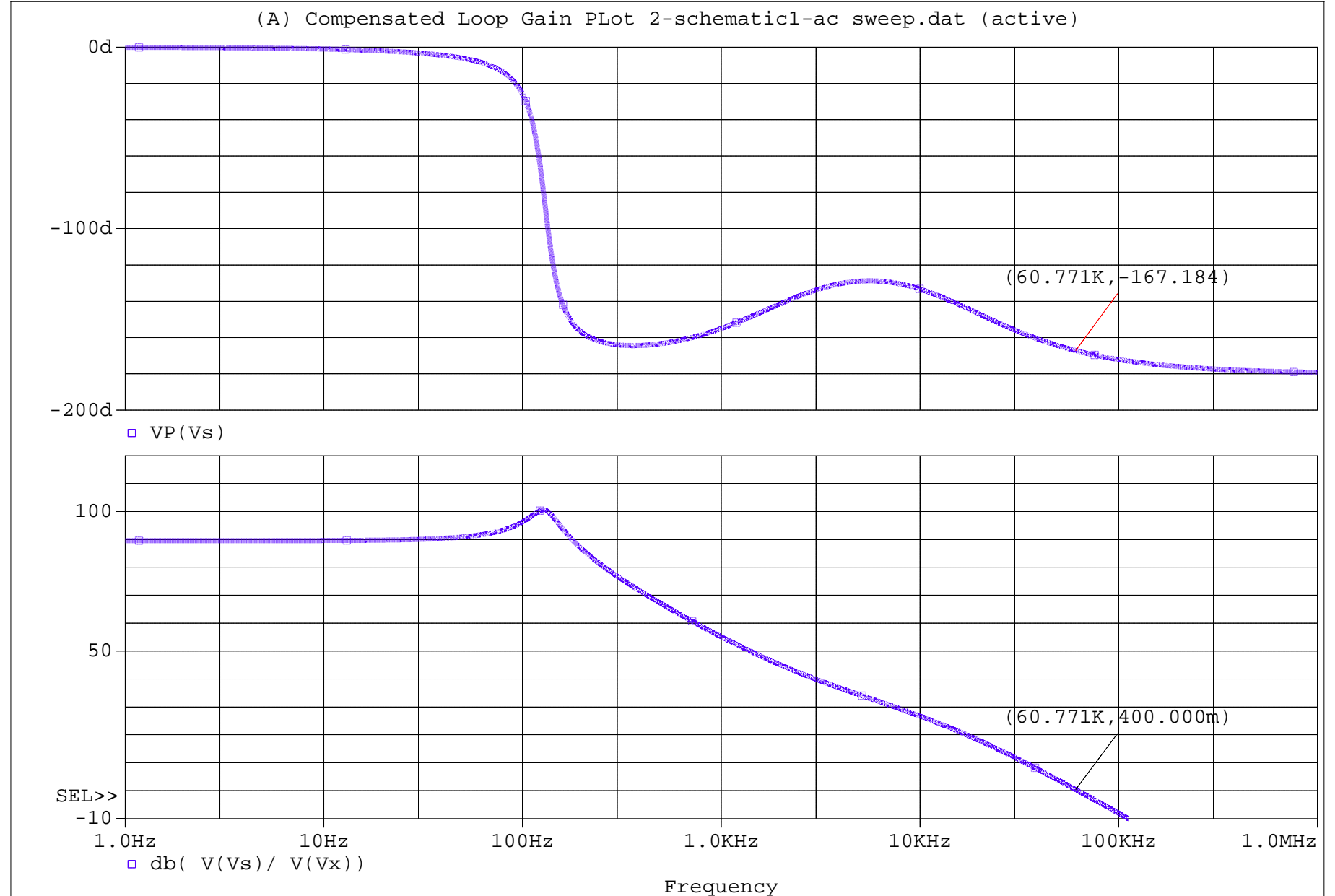
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A	Uncompensated Loop Gain		1
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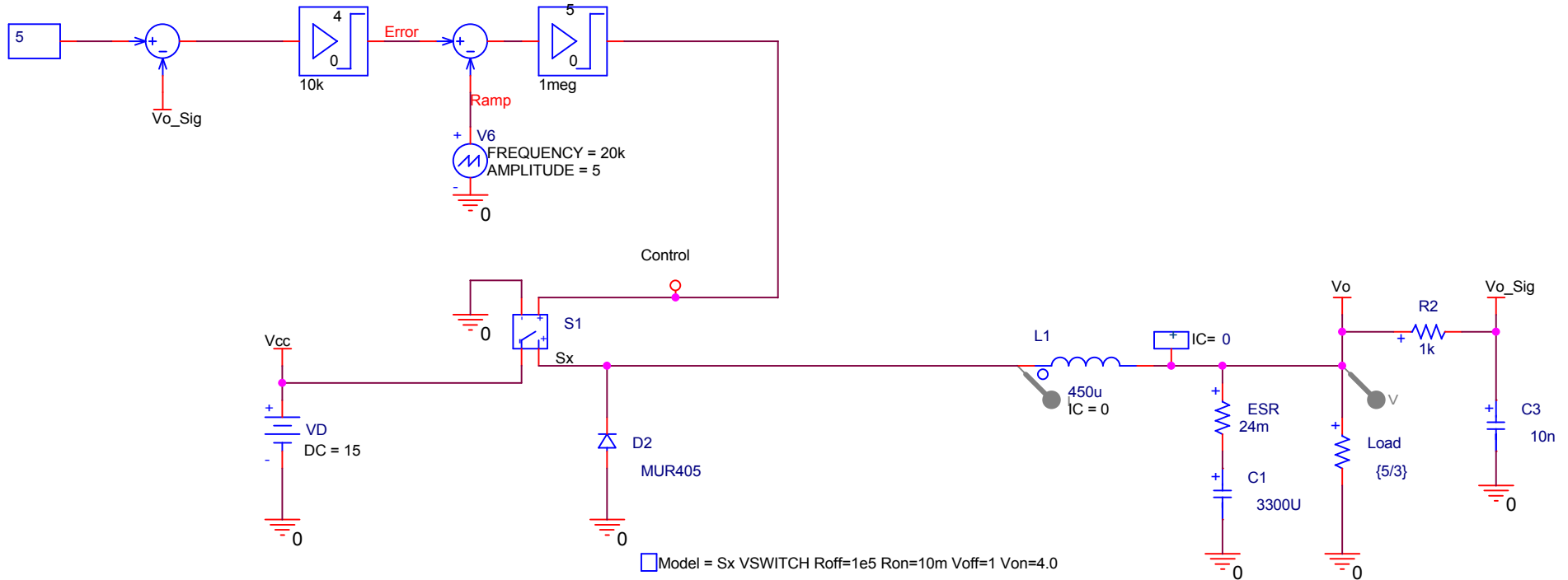
** Profile: "SCHEMATIC1-AC Sweep" [C:\Website\Rose_Classes\ECE456\Notes\Orcad\Compensation\compen...
 Date/Time run: 02/12/03 18:45:58 Temperature: 27.0




Date: February 12, 2003

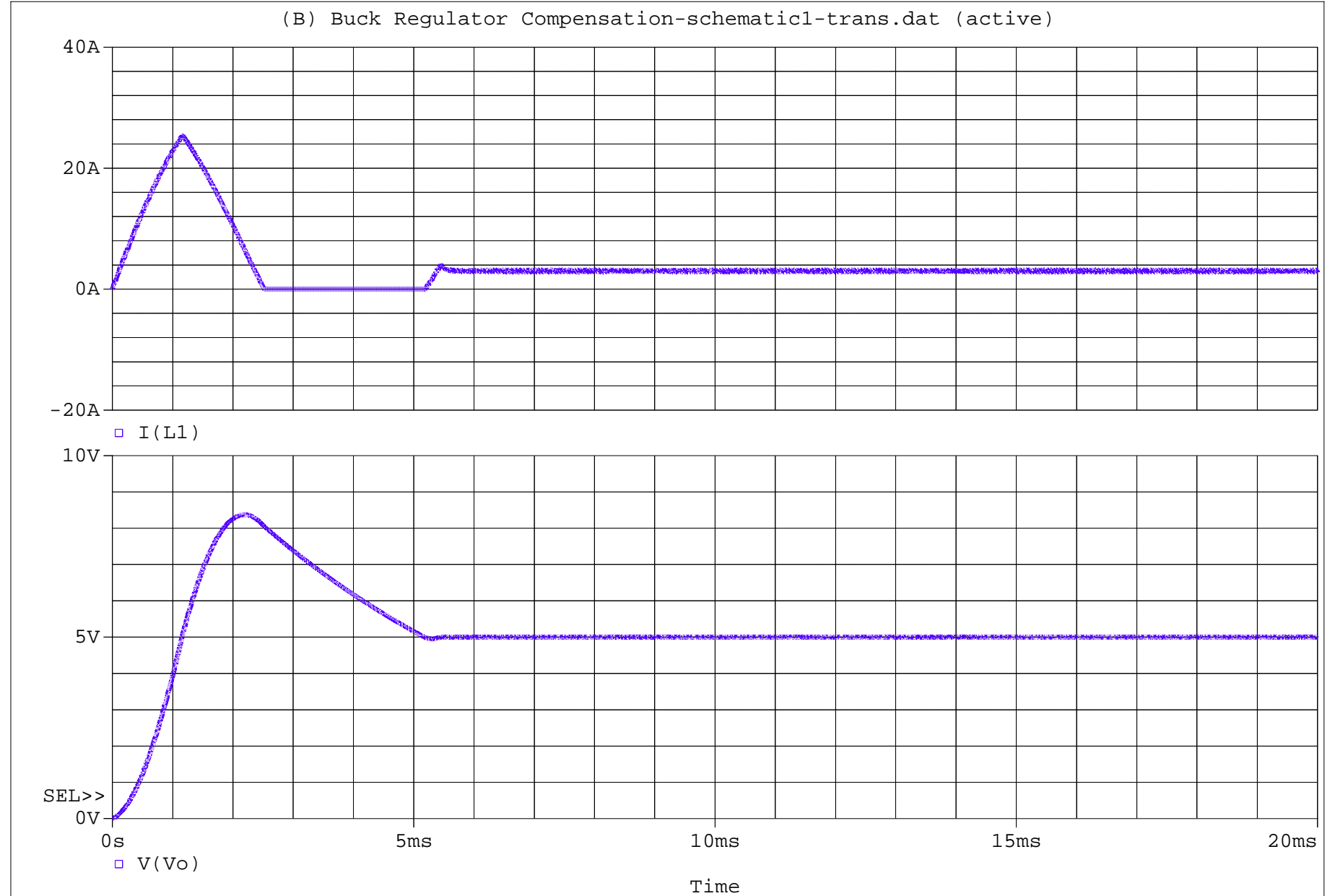
Page 1

Time: 18:48:59



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		Name: Marc E. Hermiter Class: ECE456	
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		Continuous Mode Buck Regulator	
Date:	Wednesday, February 12, 2003	Sheet	1 of 1

** Profile: "SCHEMATIC1-Trans" [C:\Website\Rose_Classes\ECE456\Notes\Orcad\Compensation\buck regu...
Date/Time run: 02/12/03 19:02:40 Temperature: 27.0

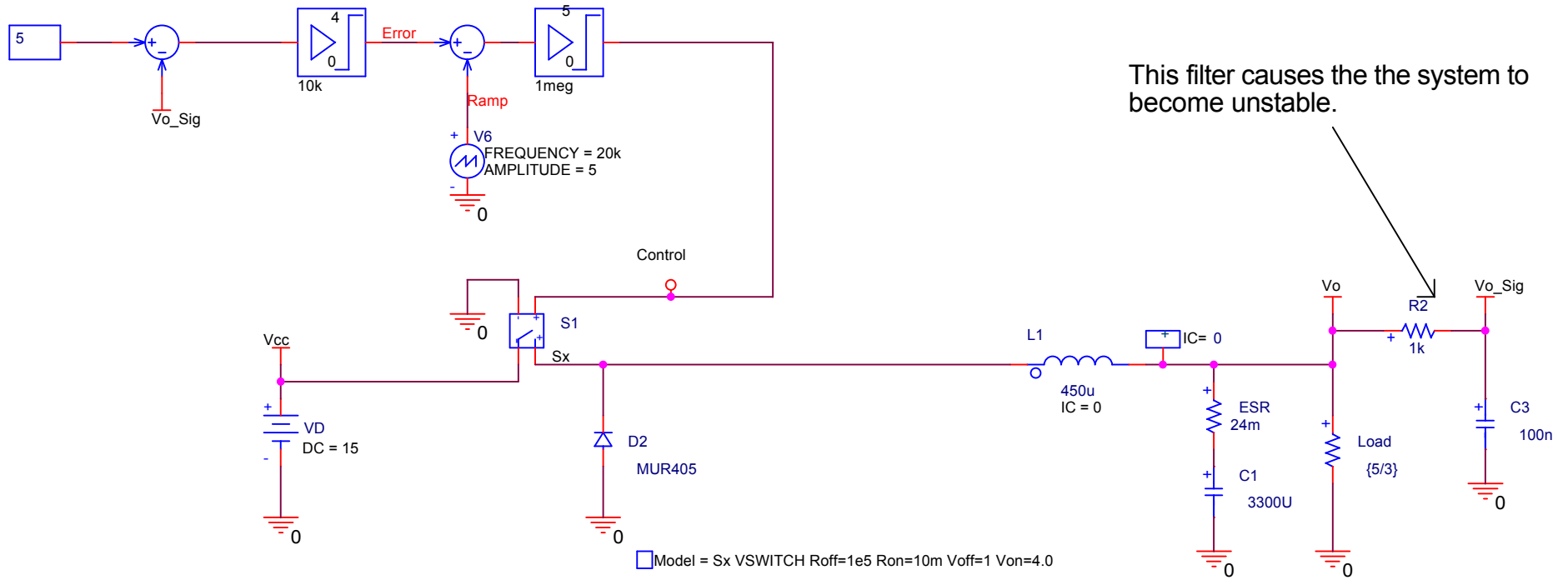


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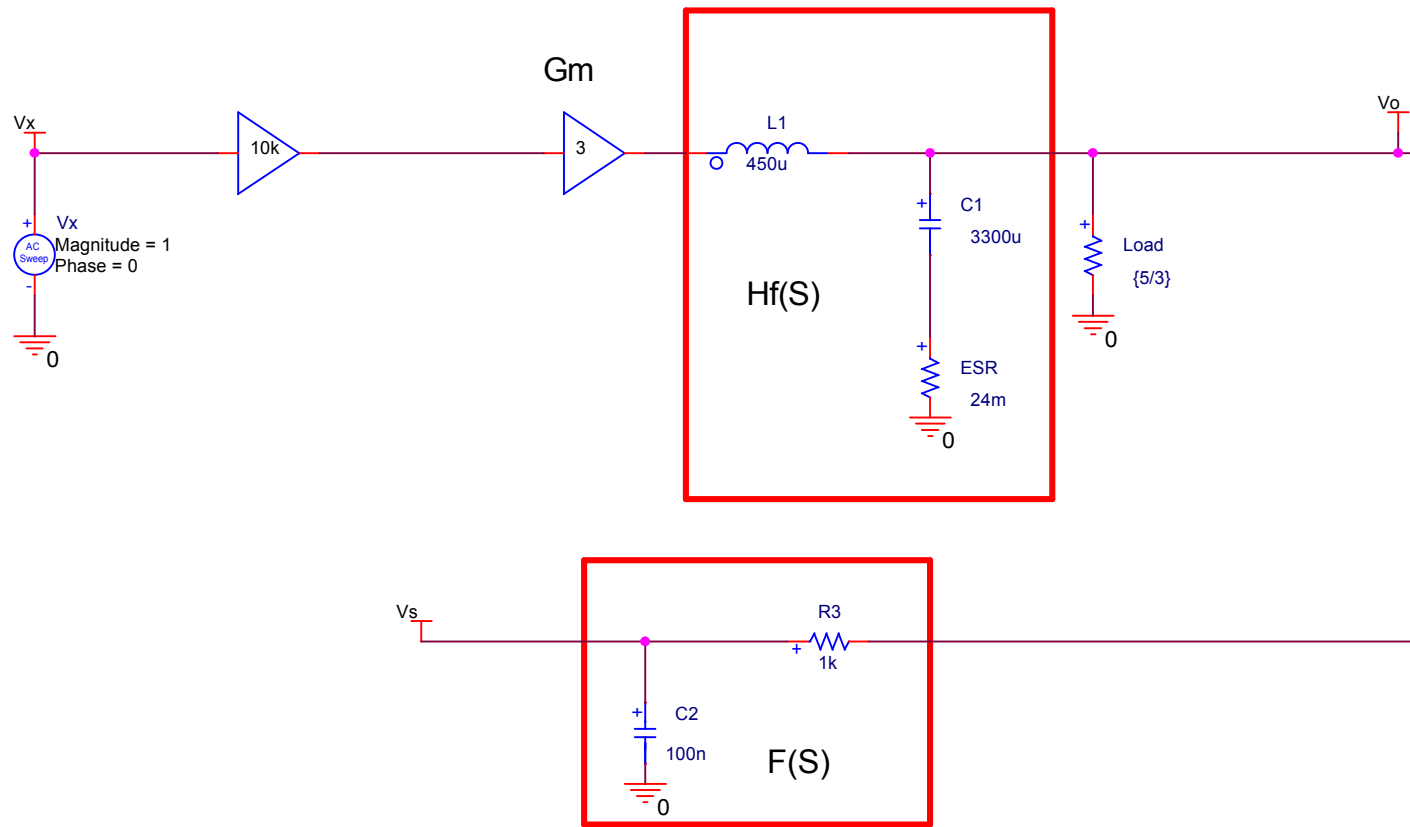
Time: 19:03:28


- Without the Low pass filter in the the feed back loop, the Buck regulator is stable from a gain - phase point of view.
- The zero added by the ESR makes the Total phase less than 180 degrees which keeps the system stable
- The problem is that we need to add a filter because we do not want the feed back loop to respond to the 20 KHz noise nor the 20 KHz ripple across the ESR
- Adding the filter added 90° of phase that makes the system difficult to stabilize.



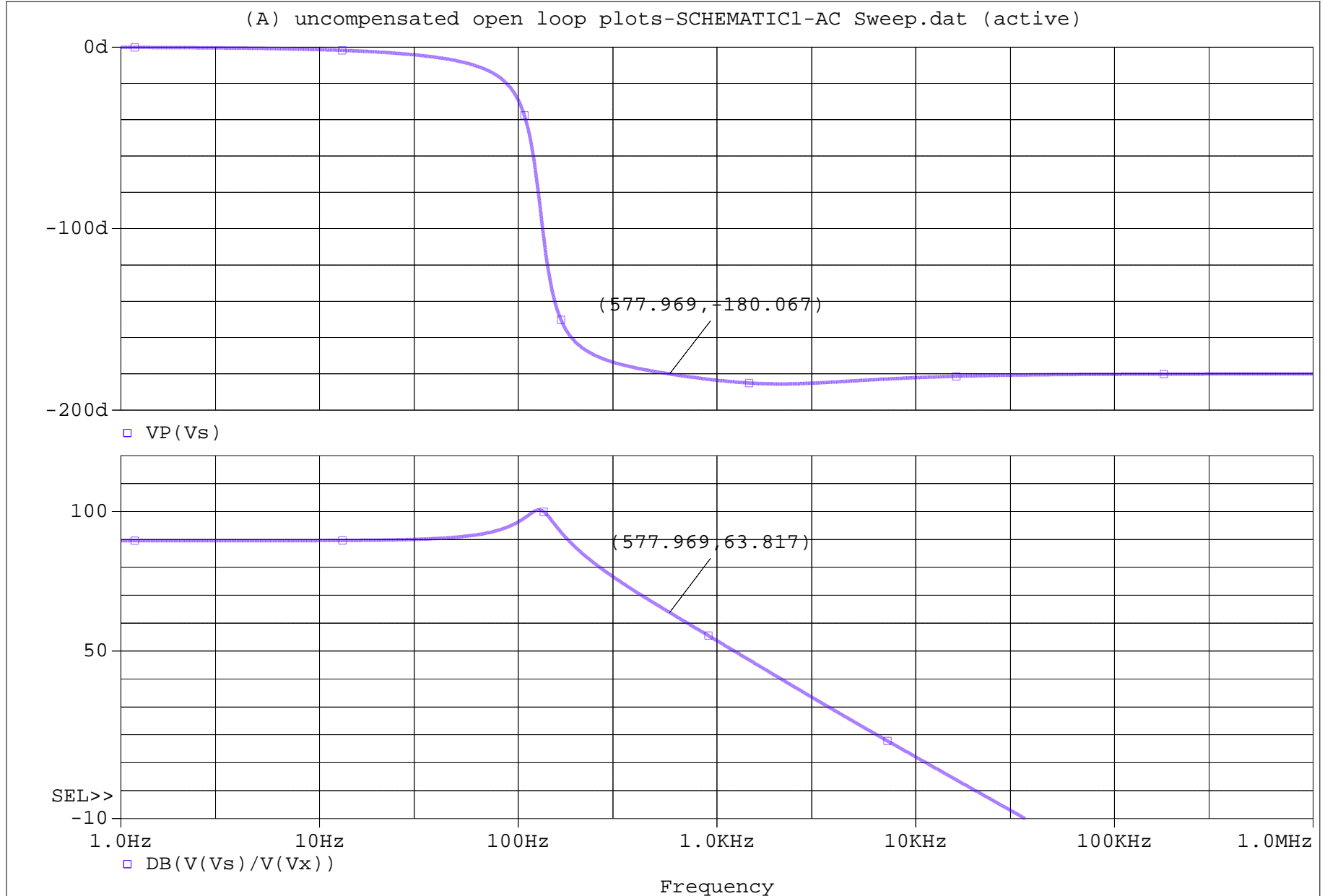
This filter causes the the system to become unstable.

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		Name: Marc E. Herniter Class: ECE 456	
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Uncompensated Loop Gain			
Date: Tuesday, February 18, 2003	Sheet	1	of 1

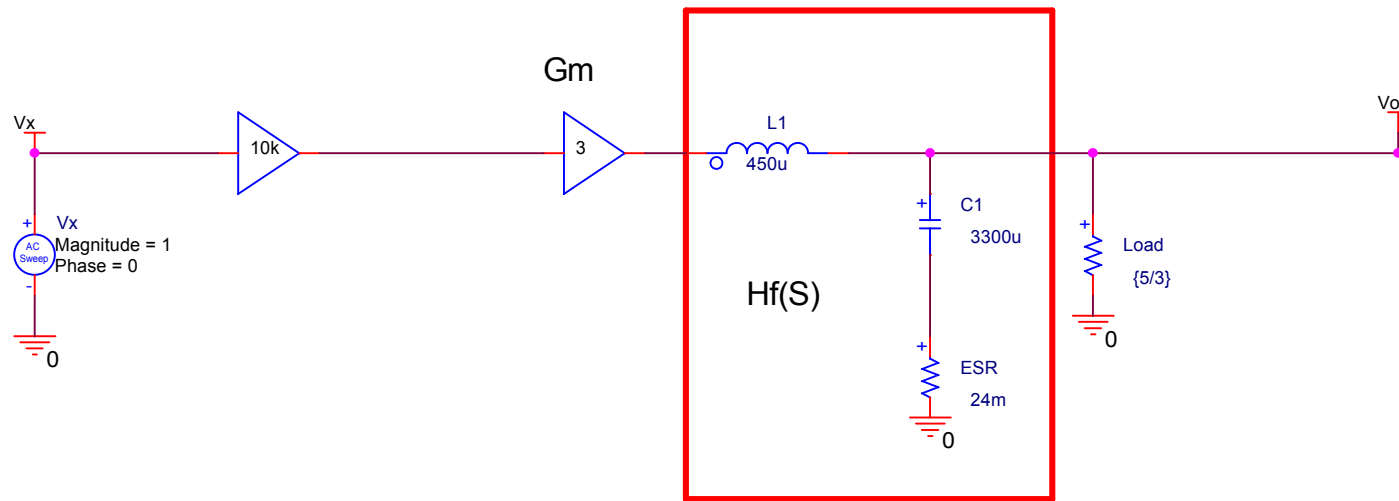
** Profile: "SCHEMATIC1-AC Sweep" [C:\Website\Rose_Classes\ECE456\Notes\Orcad\Compensation\uncomp...
 Date/Time run: 02/18/03 09:14:35 Temperature: 27.0




Date: February 18, 2003

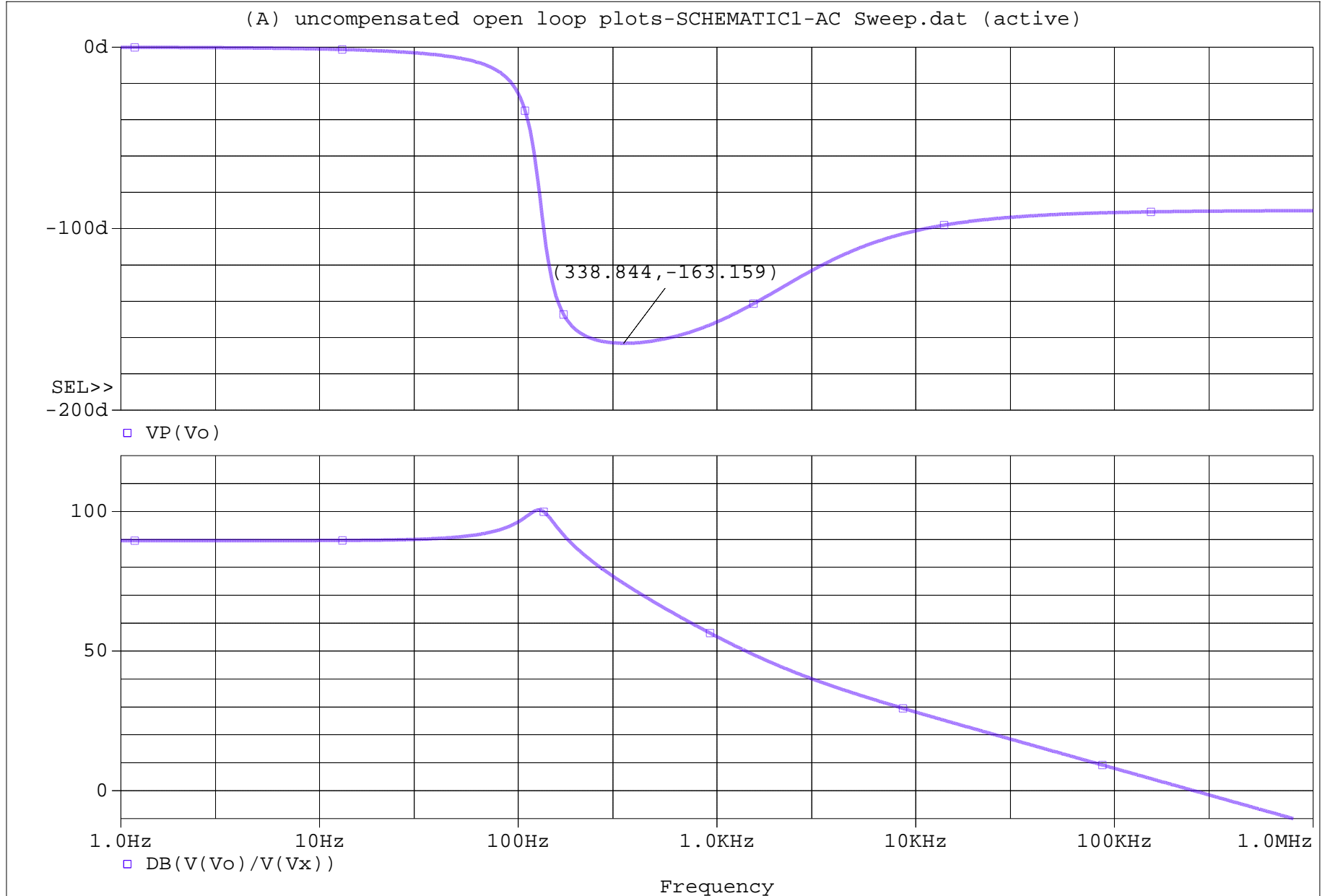
Page 1

Time: 09:18:44



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		Name: Marc E. Herniter Class: ECE 456	
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** Profile: "SCHEMATIC1-AC Sweep" [C:\Website\Rose_Classes\ECE456\Notes\Orcad\Compensation\uncomp...
 Date/Time run: 02/18/03 09:19:15 Temperature: 27.0



Date: February 18, 2003

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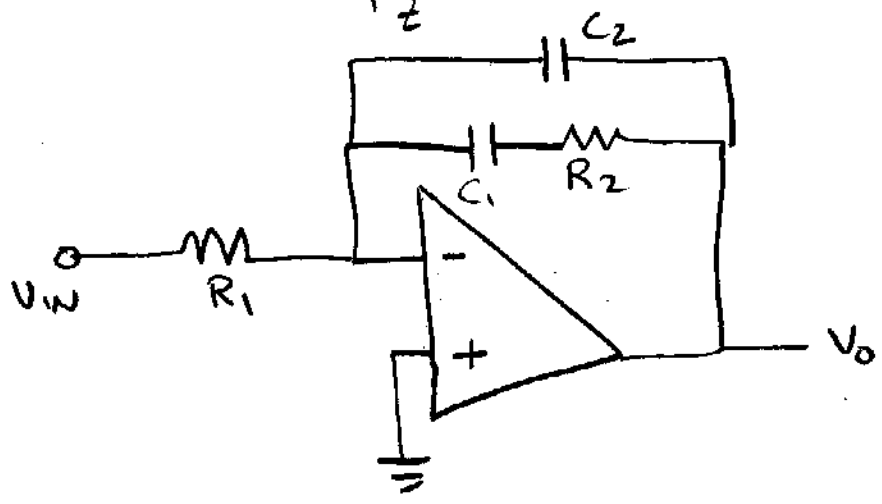
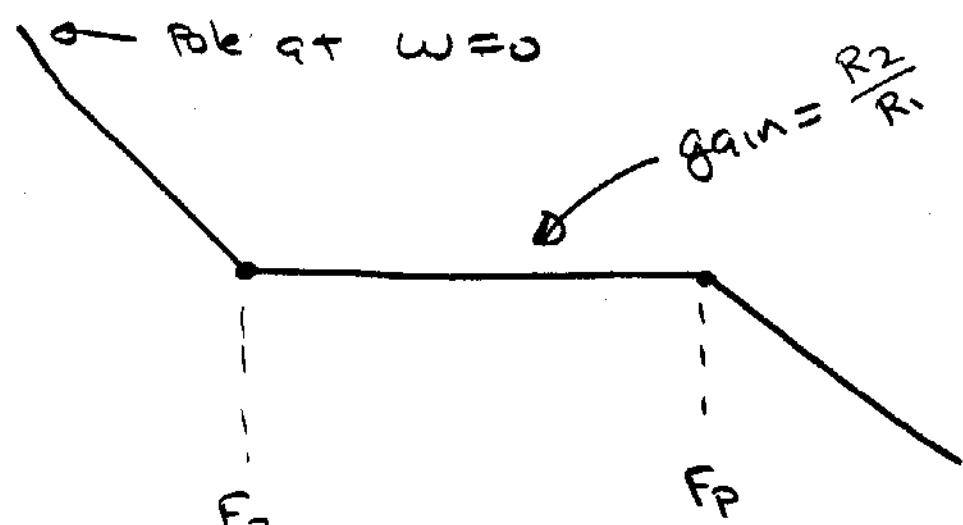
Time: 09:21:37

New method

- modify The Error Amp so that it has

- max gain at DC
- a pole at $\omega = 0$ to roll off the gain high frequency

- Error Amp Transfer function

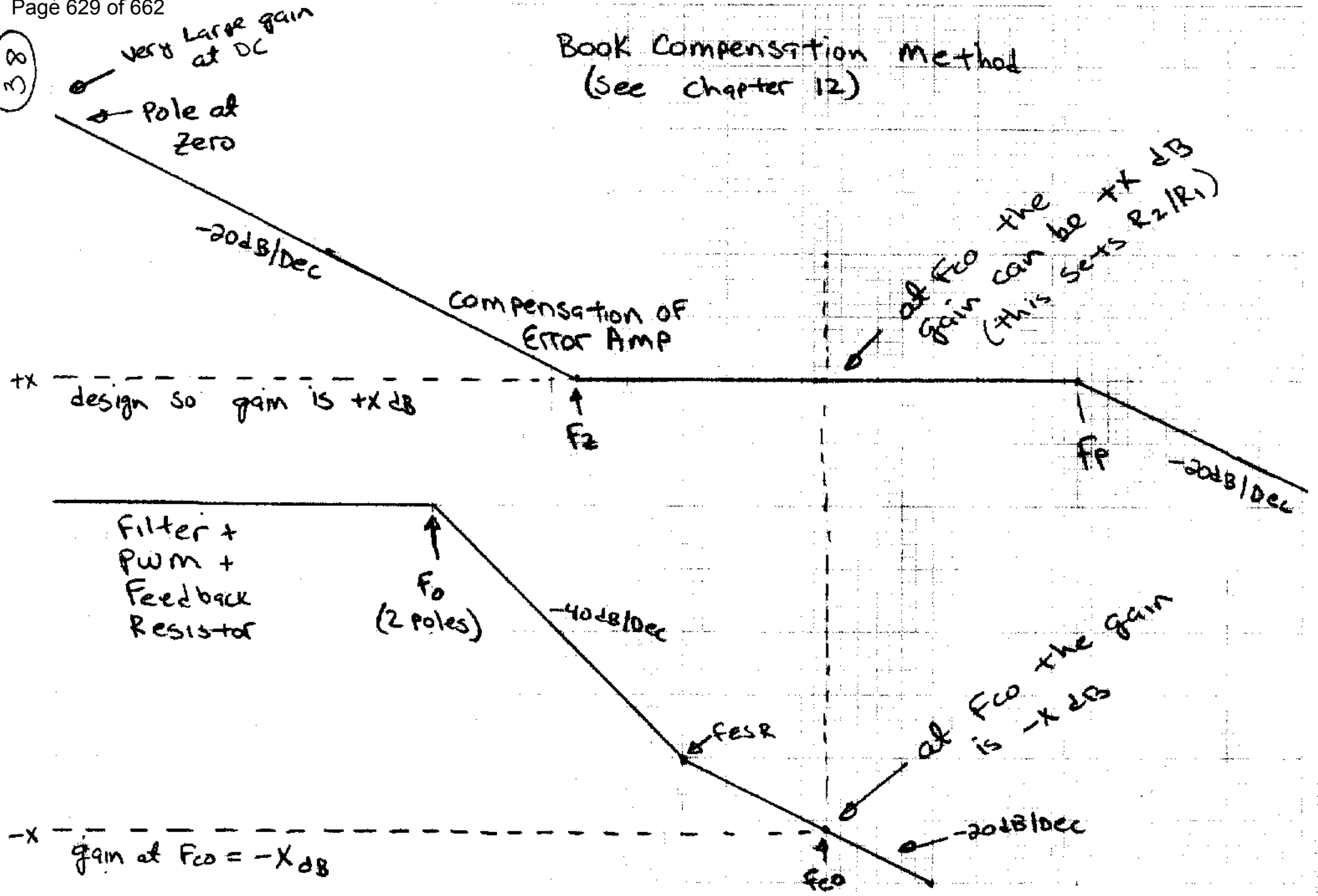


$$gain = \frac{R_2}{R_1}$$

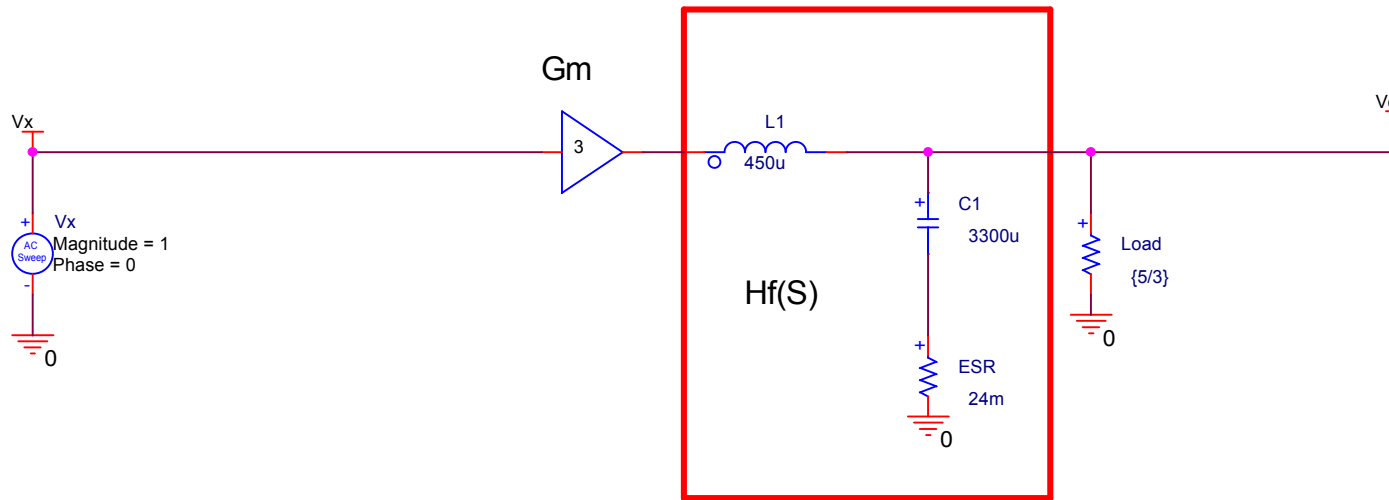
$$F_z = \frac{1}{2\pi R_2 C_1}$$


$$F_p = \frac{1}{2\pi C_2 R_2}$$

Book Compensation Method (see chapter 12)

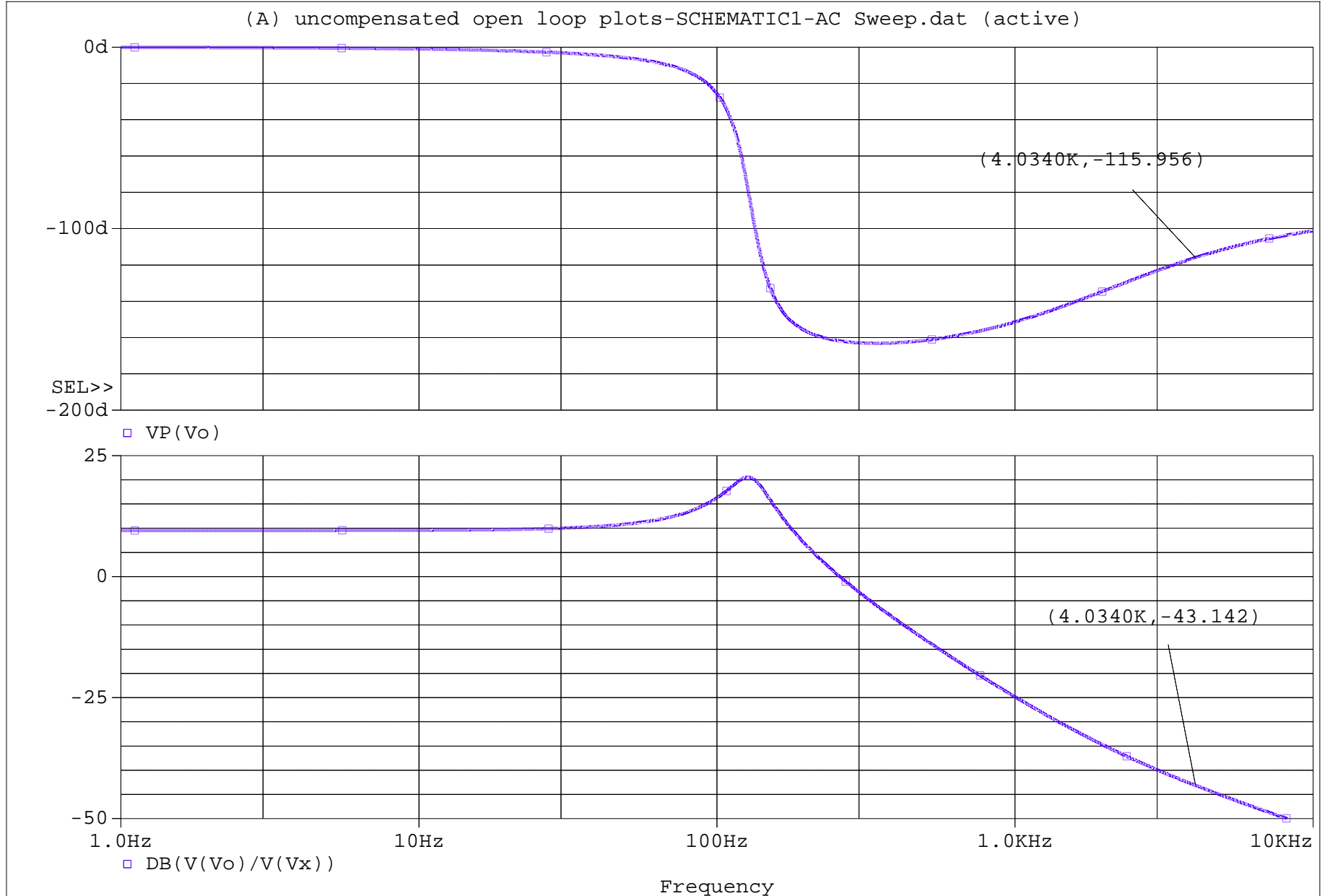


- Choose $F_{co} = F_s / 5$ where F_s is the switching frequency
- F_{co} is the loop cutoff frequency
- At F_{co} , we want the gain around the loop to be less than zero dB.
- Step 1 \Rightarrow Look at the gain plot of the filter, PWM, and feedback. This will determine the gain and R_1 & R_2
- at F_{co} find the gain in dB of the filter, PWM, and feedback resistor
- For our example, $F_s = 20 \text{ kHz}$, so we will use $F_{co} = \frac{F_s}{5} = 4 \text{ kHz}$



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** Profile: "SCHEMATIC1-AC Sweep" [C:\Website\Rose_Classes\ECE456\Notes\Orcad\Compensation\uncomp...
 Date/Time run: 02/18/03 10:05:42 Temperature: 27.0



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Time: 10:07:37

- at 4KHz, the gain is -43 dB, so we

want the gain of our CK+ to be +43 dB

$$\Rightarrow 43 \text{ dB} = 141$$

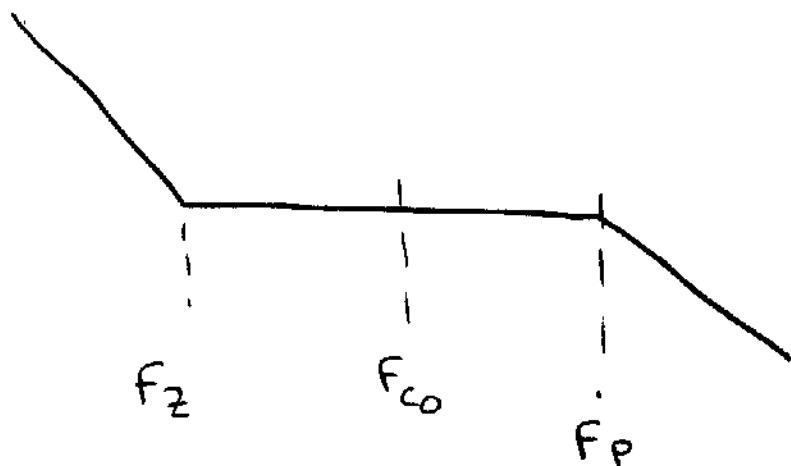
$$\Rightarrow \frac{R_2}{R_1} = 141 \quad \Rightarrow \text{choose } R_1 = 1 \text{ K}$$

$$R_2 = 141 \text{ K}$$

- From the plot we also see that at 4KHz, the phase is -116° .

- For a phase margin of 45° , we would like a total phase of -135° , so our error amplifier circuit can add 19° of phase lag

- we will place the pole in the following arrangement



$$\frac{F_{co}}{F_z} = \frac{F_p}{F_{co}} = K$$

- we are interested in what is the phase added by this filter at frequency F_{co} .
 - or more precisely, we need to add 18° of phase, where should we place F_z and F_p

$$\Theta(F) = 90 - \tan^{-1}\left(\frac{F}{F_z}\right) + \tan^{-1}\left(\frac{F}{F_p}\right)$$

↑
Pole at
Zero

- we are interested in the phase at

$$f = f_{co}$$

$$\Theta(f_{co}) = 90^\circ - \tan^{-1}\left(\frac{f_{co}}{f_z}\right) + \tan^{-1}\left(\frac{f_{co}}{f_p}\right)$$

$$\text{But } \frac{f_{co}}{f_z} = \frac{f_p}{f_{co}} = k \quad \text{so}$$

$$\Theta(f_{co}) = 90^\circ - \tan^{-1}(k) + \tan^{-1}(1/k)$$

For our example we want $\Theta(4k) = 19^\circ$

Find k .

Buck Regulator Crossover Example

Switching Frequency $F_S := 20 \cdot \text{kHz}$

Cutoff Frequency $F_{CO} := \frac{F_S}{5}$ $F_{CO} = 4 \text{ kHz}$

Measured from PSpice $\text{Cross_Over_Gain} := -43$

$\text{Amp_Gain} := 10 \frac{-\text{Cross_Over_Gain}}{20}$ $\text{Amp_Gain} = 141.254$

Choose R1 $R_1 := 1 \cdot \text{k}\Omega$

$R_2 := \text{Amp_Gain} \cdot R_1$ $R_2 = 141.254 \text{ k}\Omega$

Measured_Phase := 116 From PSpice

Phase_Margin := 45

Phase_Needed := $180 - \text{Phase_Margin} - \text{Measured_Phase}$

$$\text{Phase_Needed} = 19$$

$$\text{Solve for K} \quad K := 1$$

Given

$$\text{Phase_Needed} \cdot \frac{\pi}{180} = \frac{\pi}{2} - \text{atan}(K) + \text{atan}\left(\frac{1}{K}\right)$$

$$K := \text{find}(K)$$

$$K = 5.976$$

Find the pole and zero

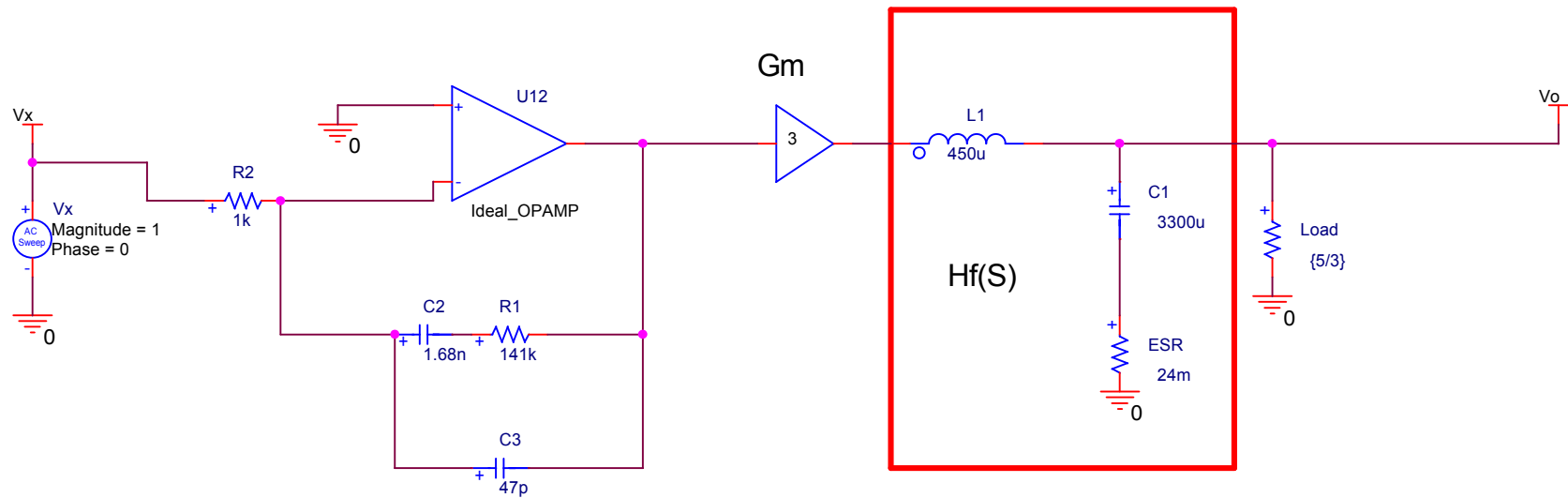
$$F_Z := \frac{F_{CO}}{K} \quad F_Z = 669.37 \text{ Hz}$$

$$F_P := F_{CO} \cdot K \quad F_P = 23.903 \text{ kHz}$$


Solve for C1 and C2

$$C_1 := \frac{1}{2 \cdot \pi \cdot R_2 \cdot F_Z} \quad C_1 = 1.683 \text{ nF}$$

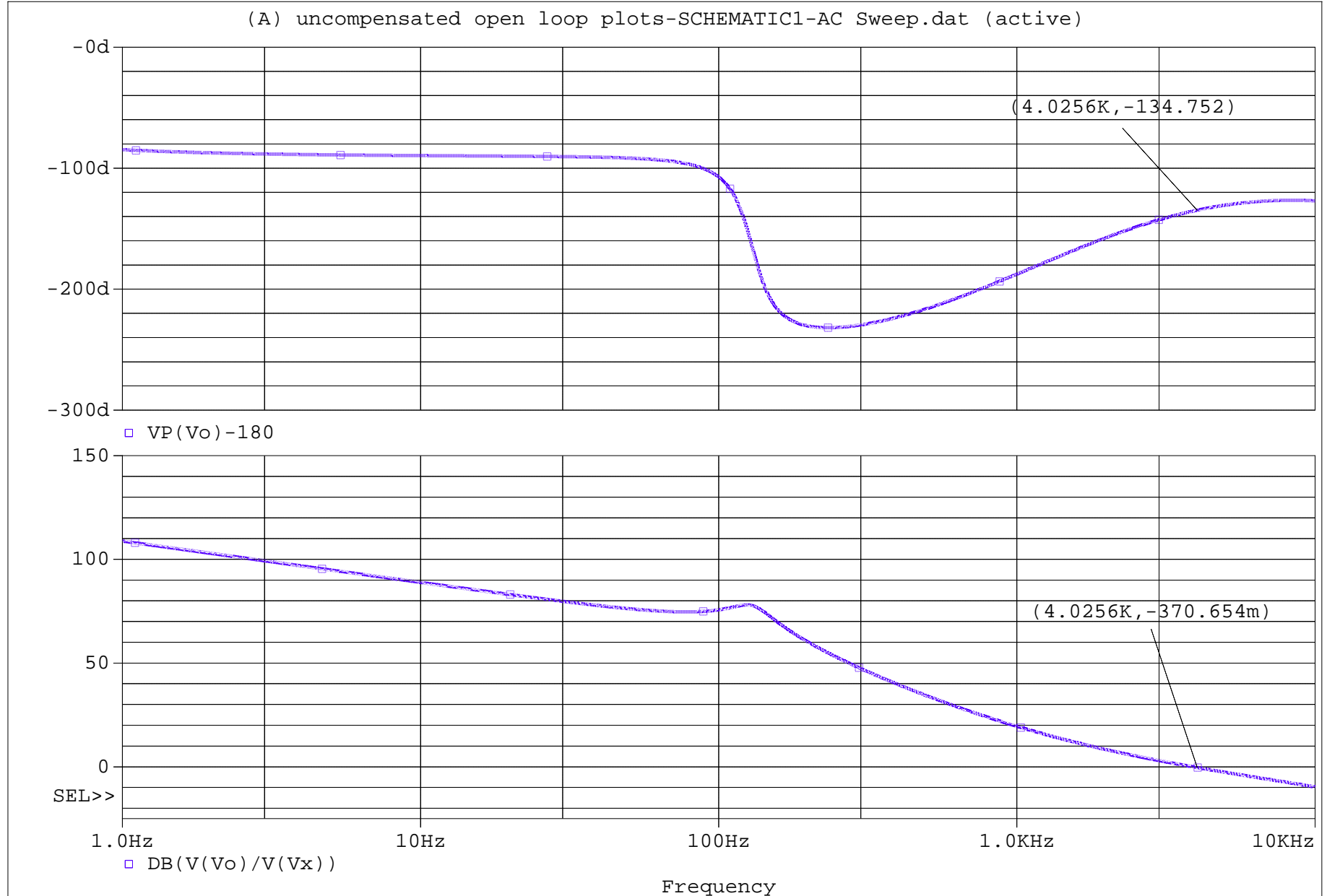
$$C_2 := \frac{1}{2 \cdot \pi \cdot R_2 \cdot F_P} \quad C_2 = 47.137 \text{ pF}$$



Note that we get 180 degrees from the inverting configuration of the OP AMP.

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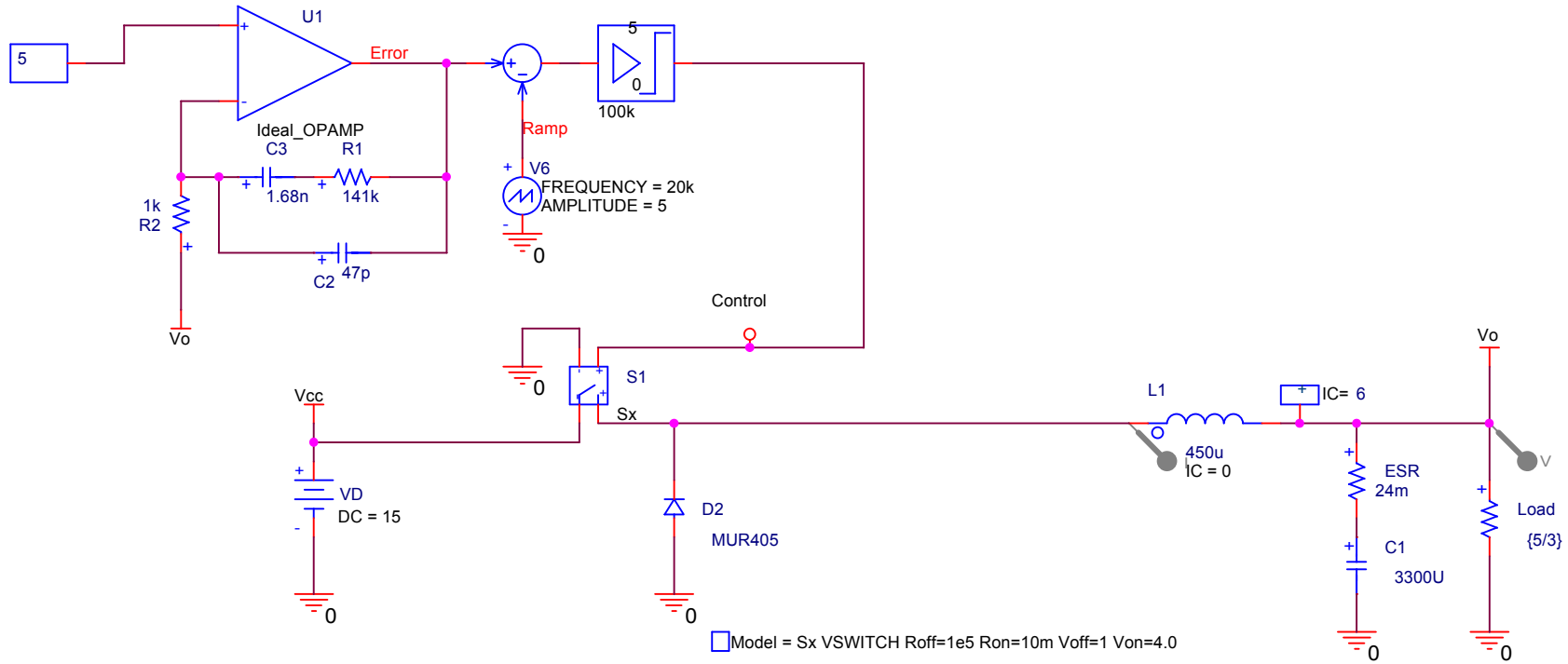
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Date: February 18, 2003

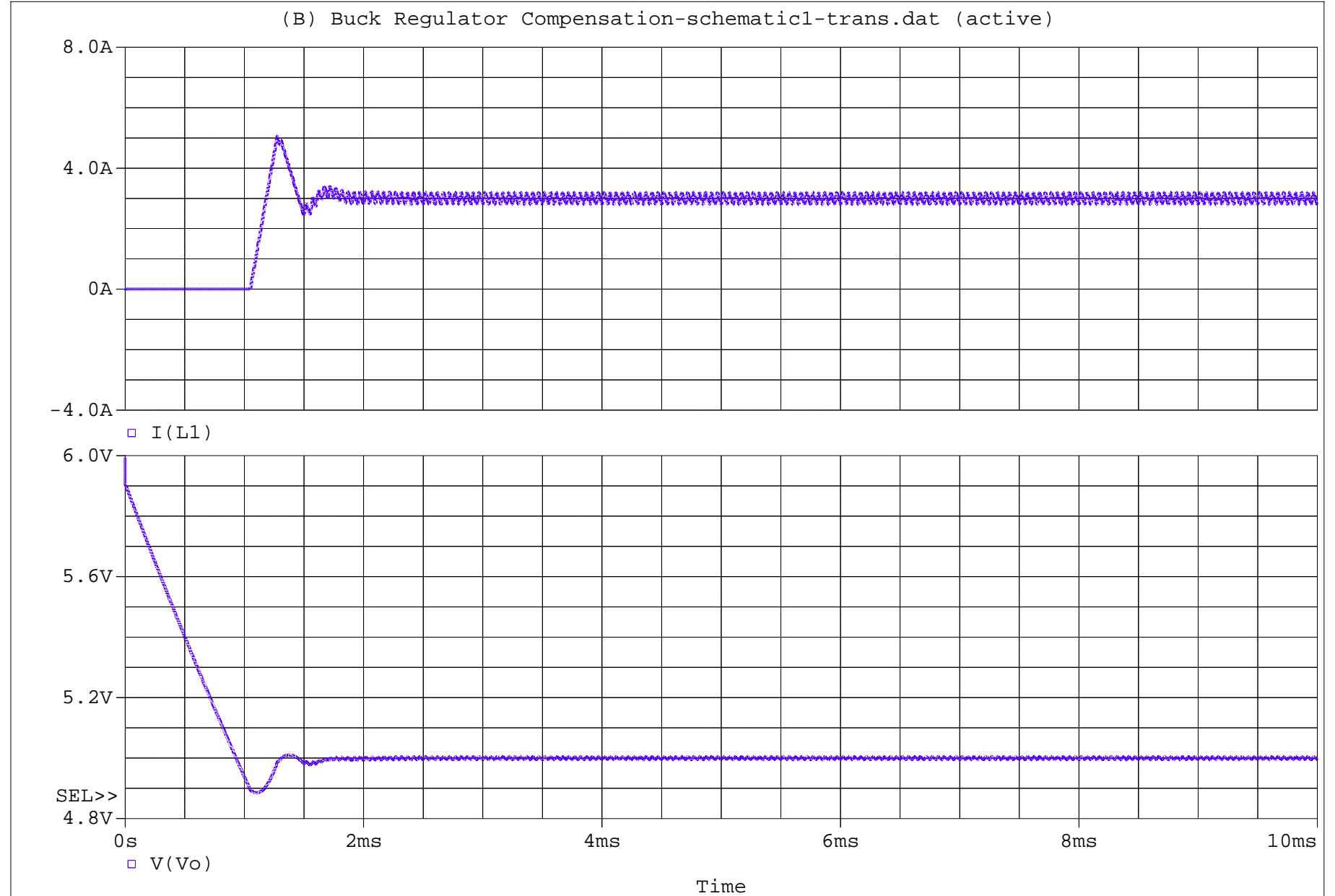
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Time: 11:00:41



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		Name: Marc E. Herniter Class: ECE456	
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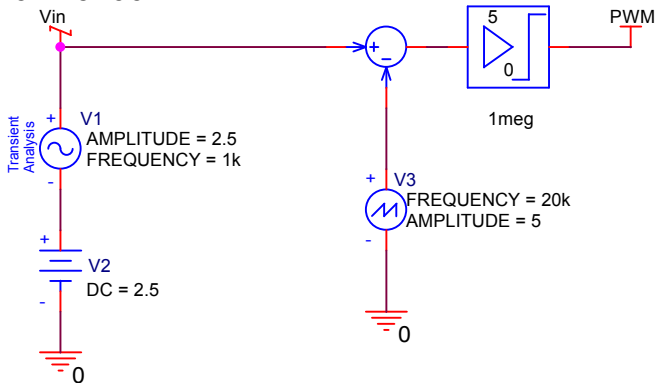
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Date: February 18, 2003

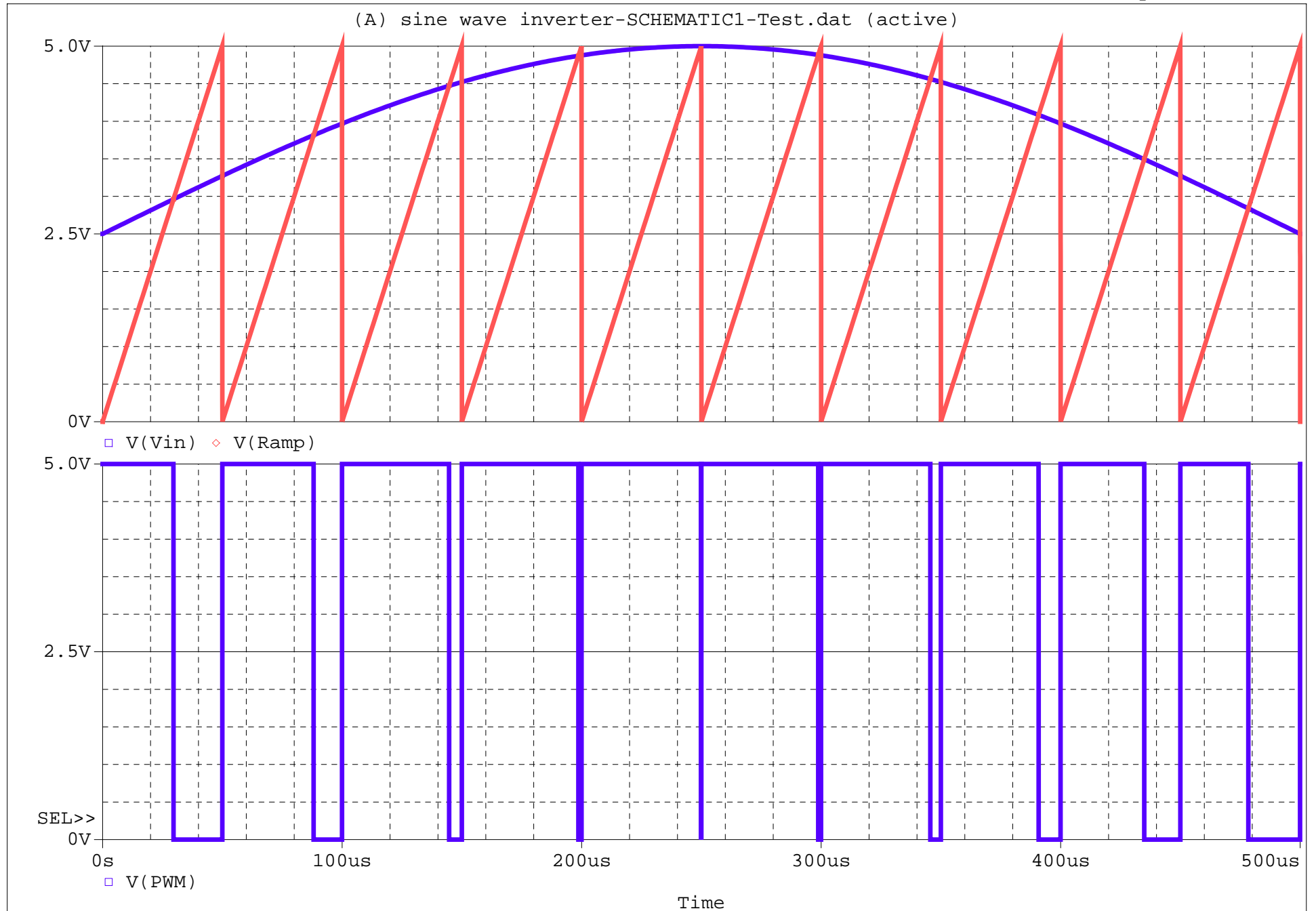
Page 1

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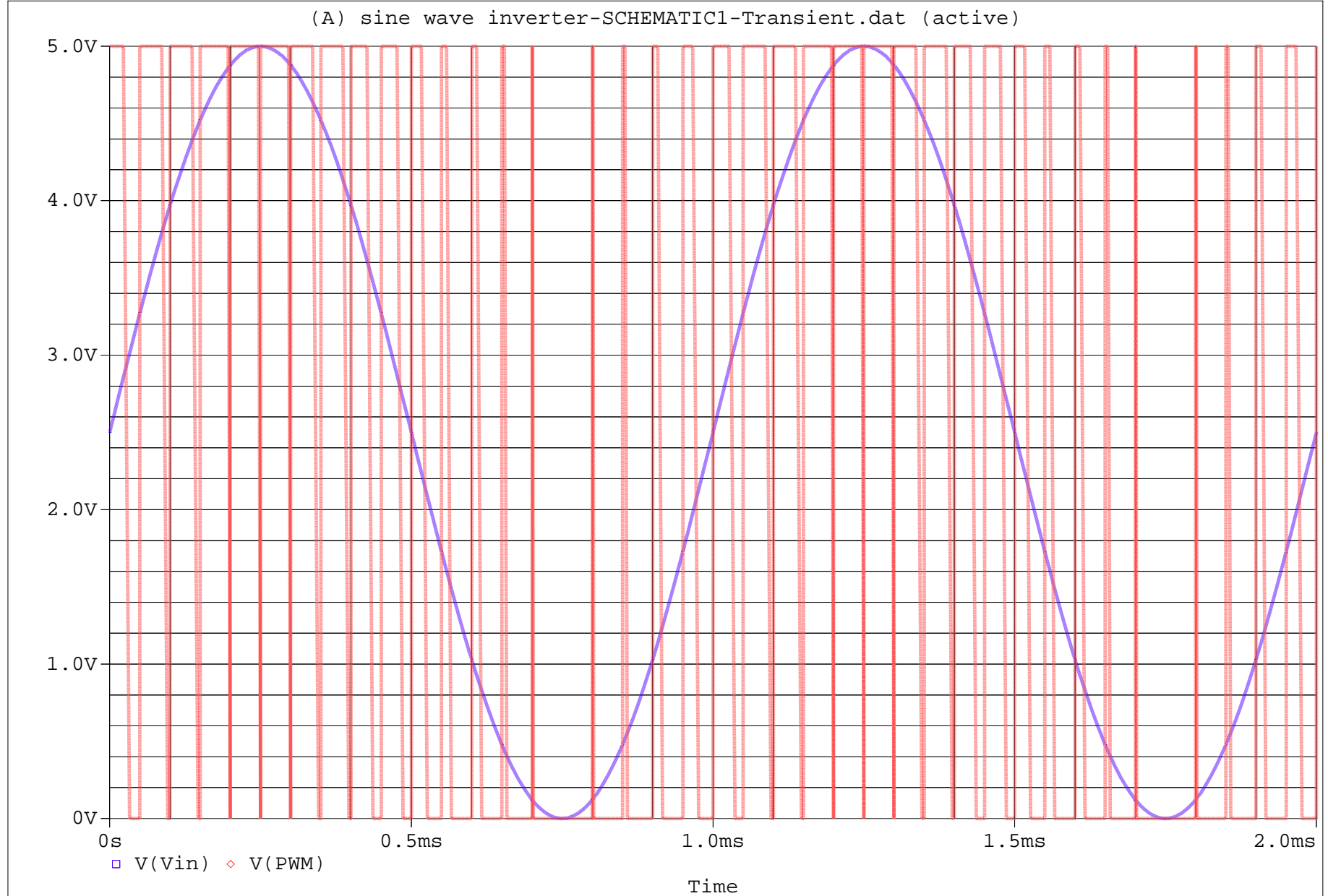


Switching Amplifiers

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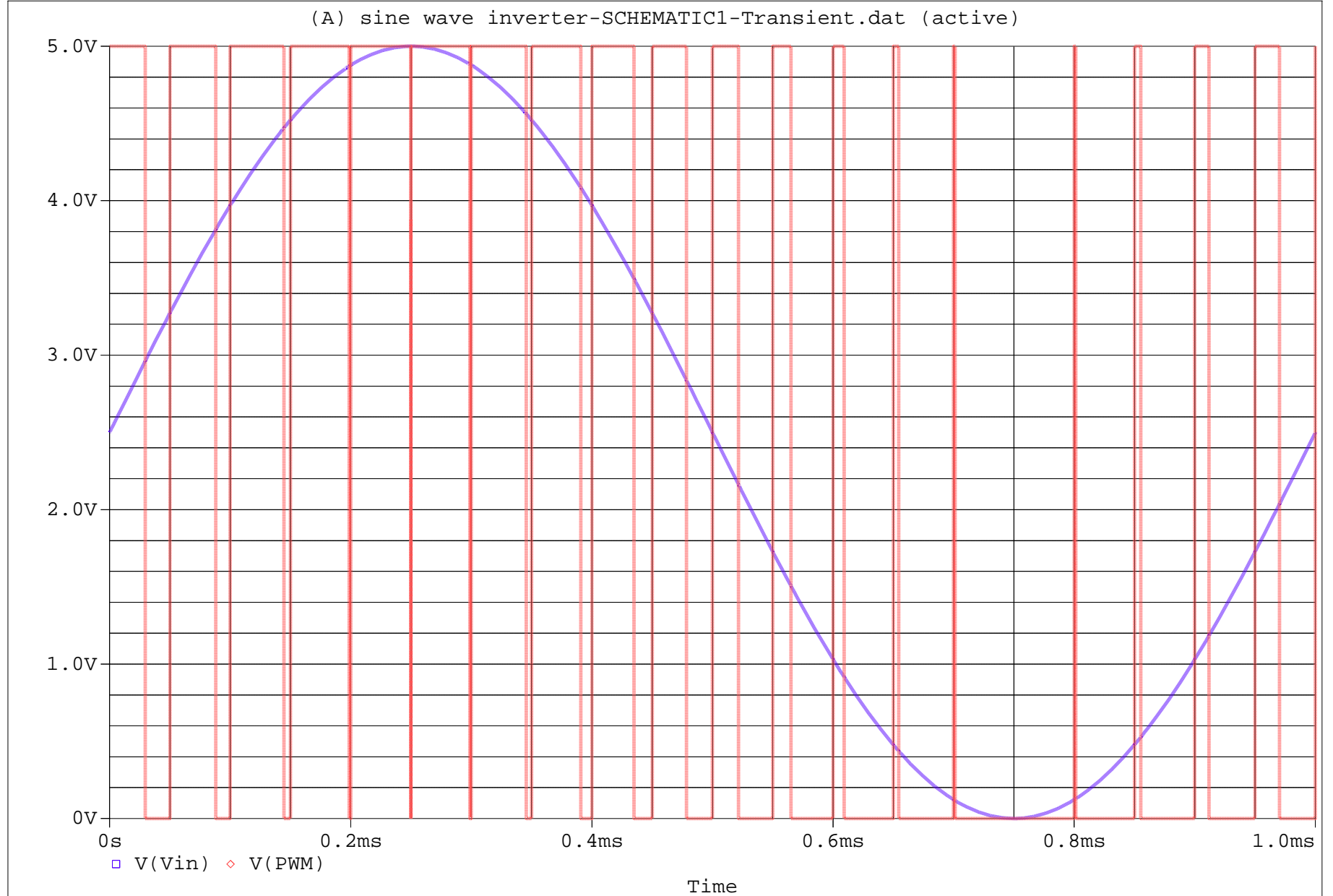


Date: February 19, 2003

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Time: 19:57:39

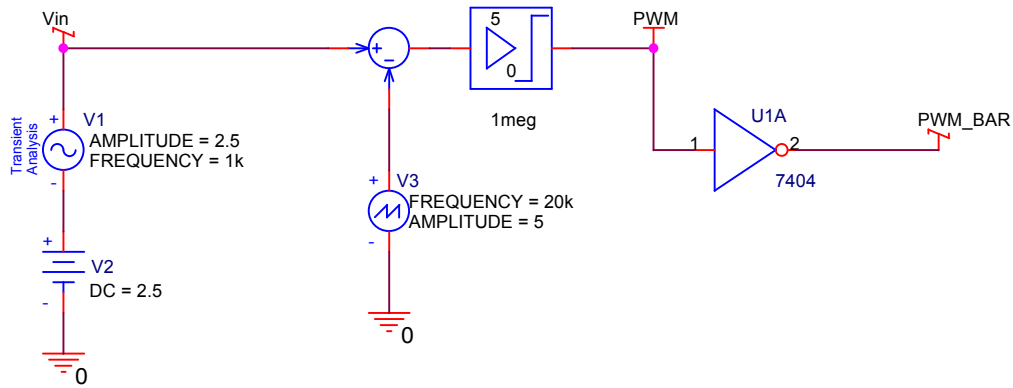
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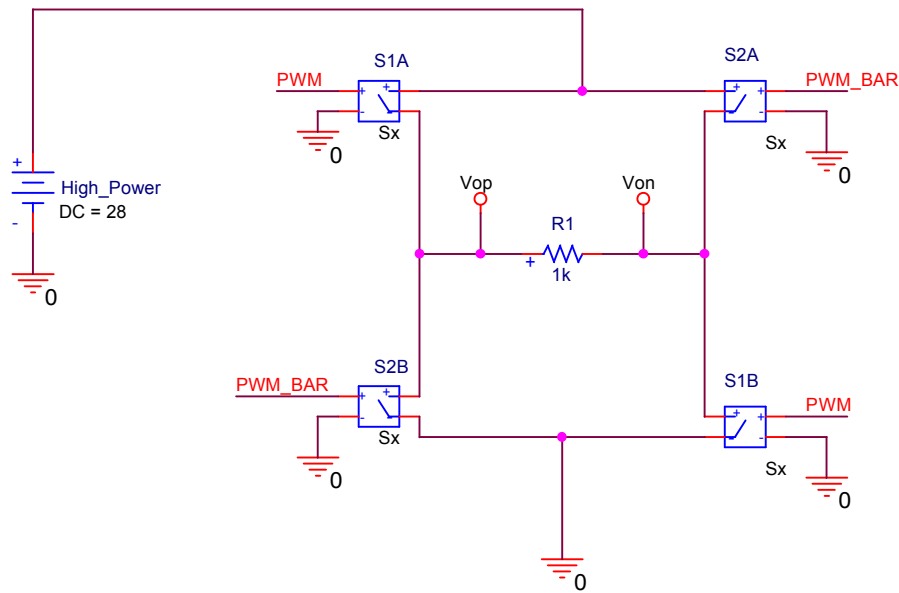
Date: February 19, 2003


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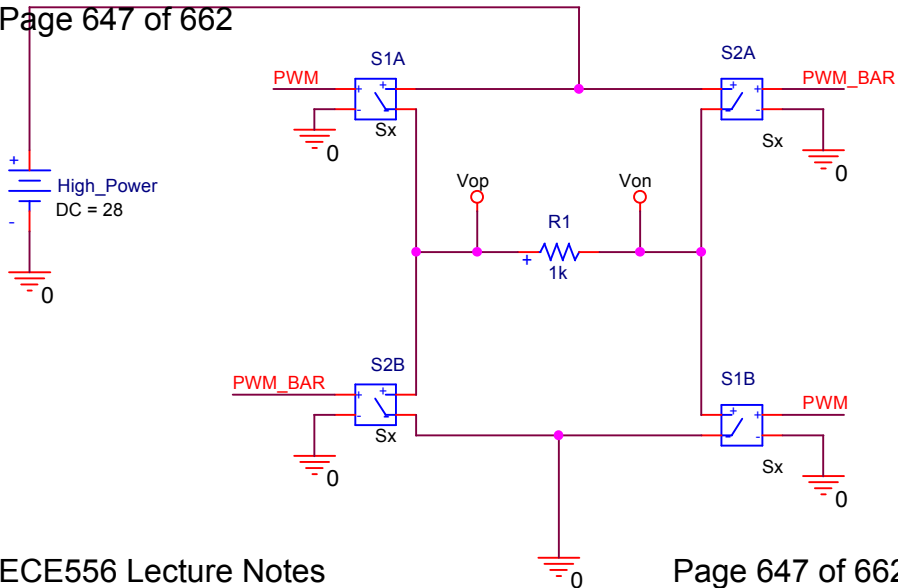
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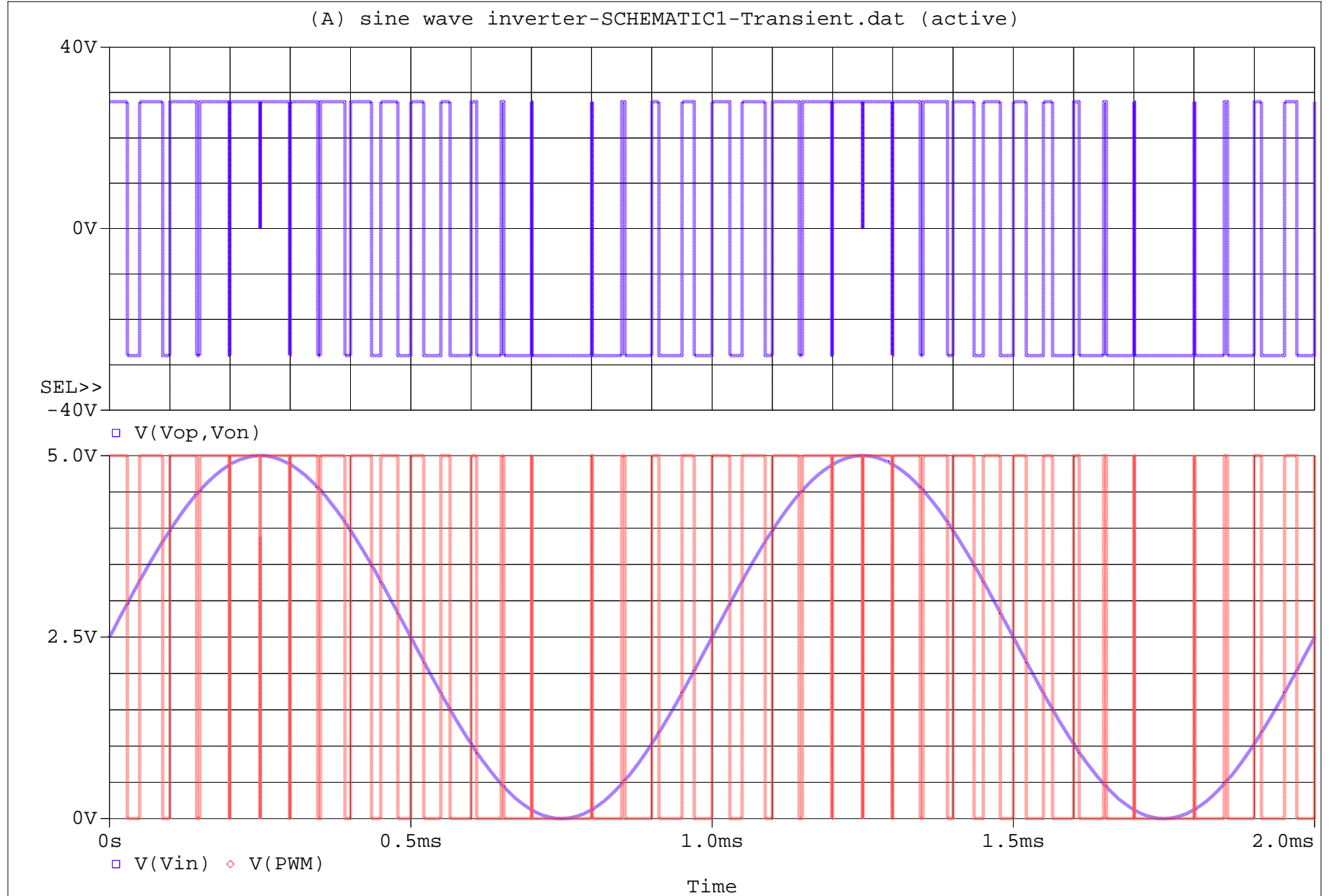
Model = Sx VSWITCH Roff=1e6 Ron=1.0m Voff=1.0 Von=4.0



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** Profile: "SCHEMATIC1-Transient" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Inverter\sine wave...
Date/Time run: 02/19/03 20:08:40 Temperature: 27.0

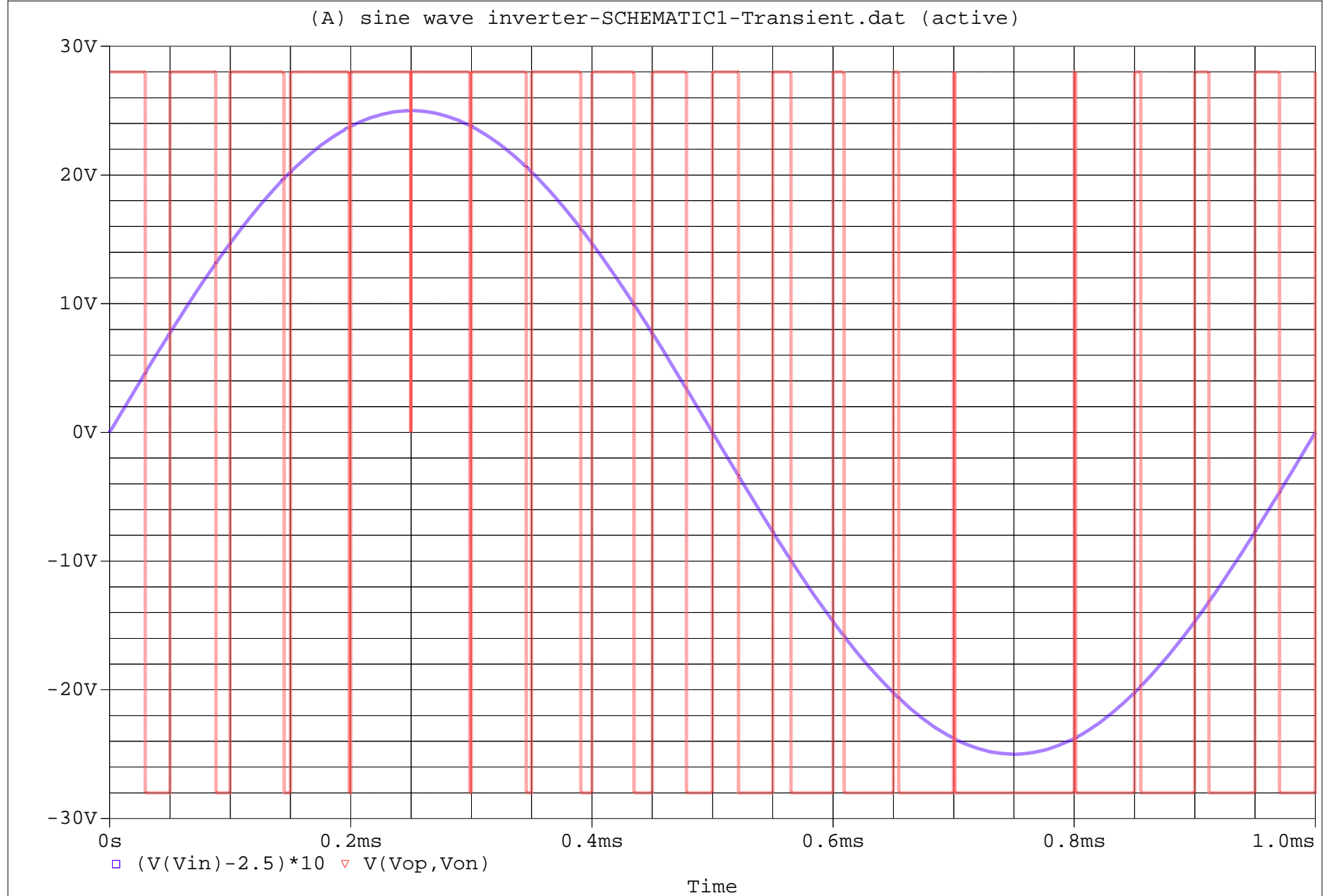


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Time: 20:10:24

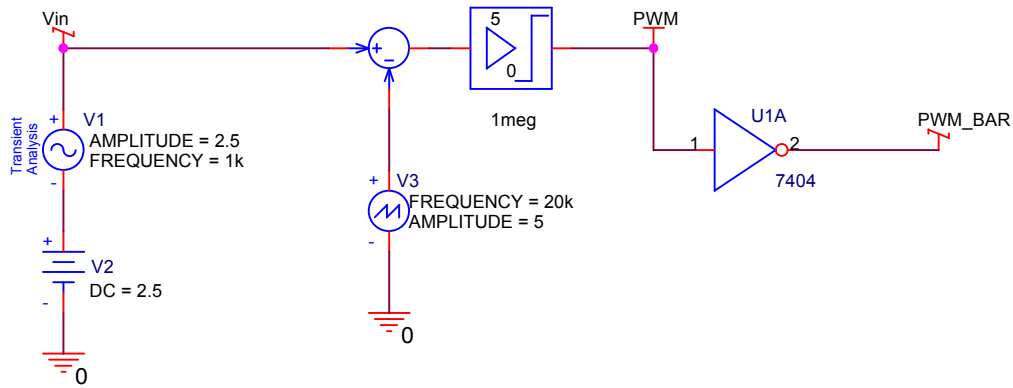
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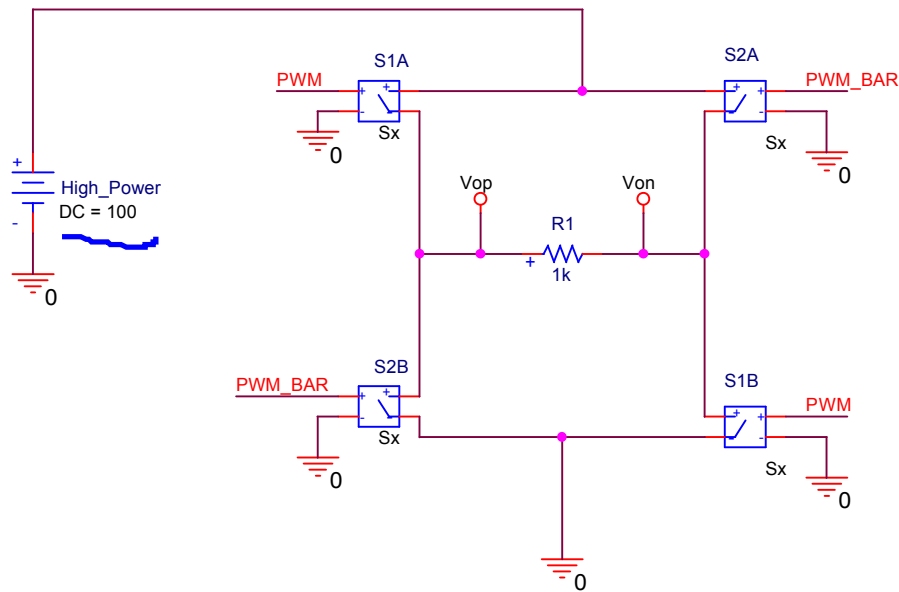
Date: February 19, 2003

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Time: 20:12:49



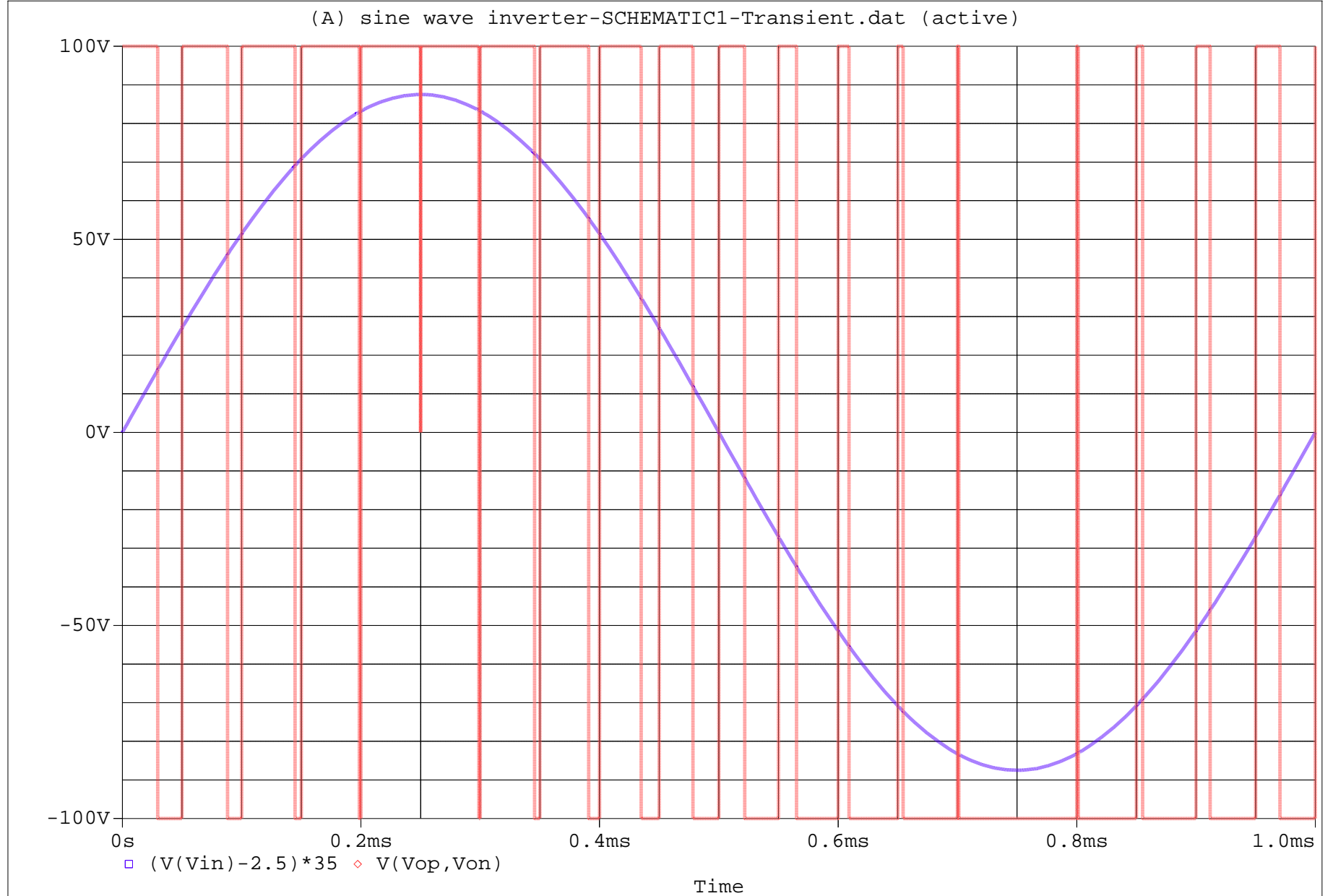
Model = Sx VSWITCH Roff=1e6 Ron=1.0m Voff=1.0 Von=4.0



Rail Voltage Changed to 100 Volts.

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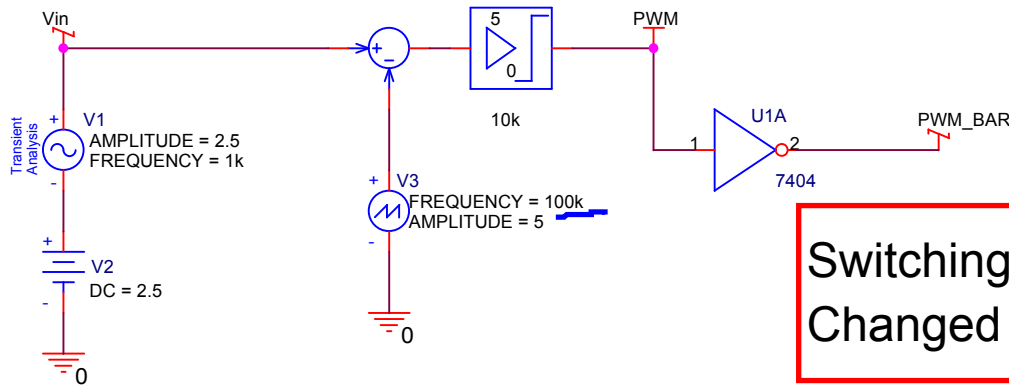
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Date: February 19, 2003

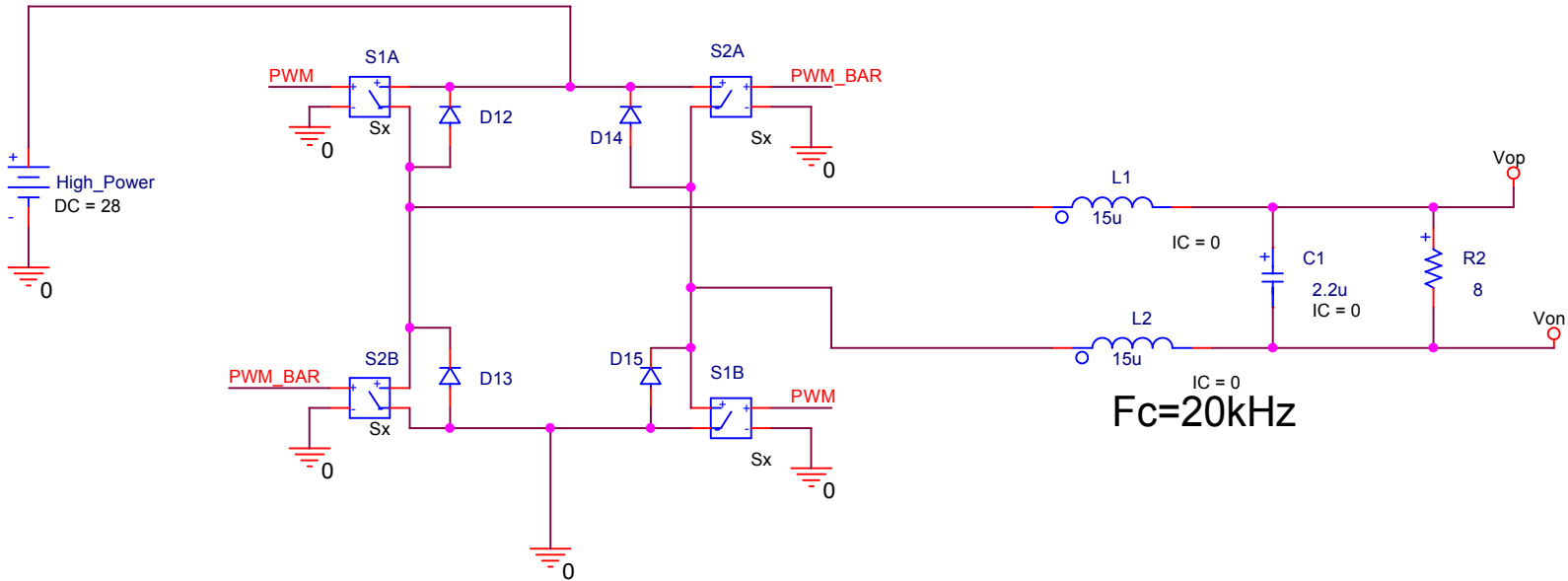
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Time: 20:14:31



Switching Frequency
Changed to 100 KHZ

Model = Sx VSWITCH Roff=1e6 Ron=10.0m Voff=1.0 Von=4.0



Fc=20kHz

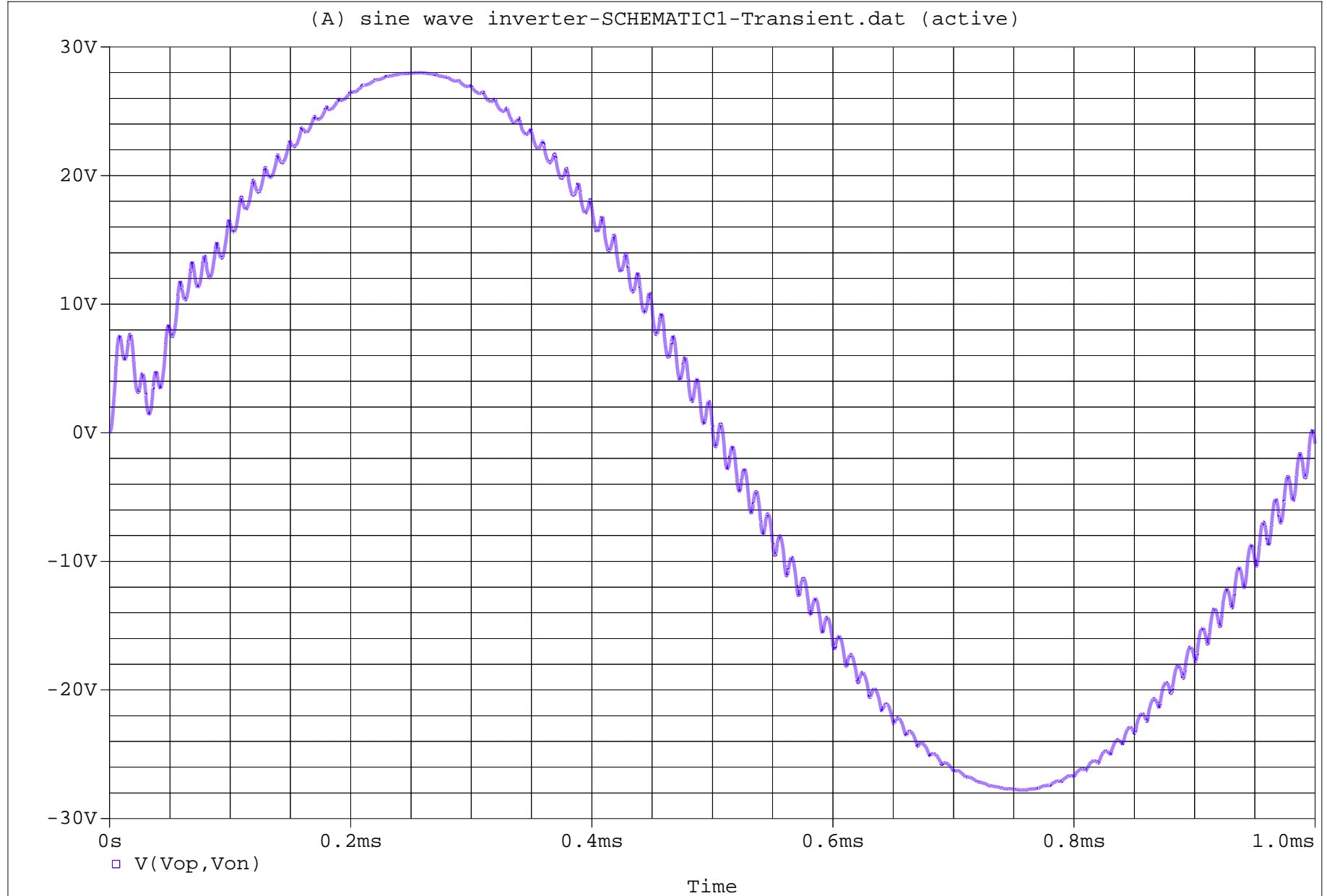
Anti-Parallel Diodes
Added.

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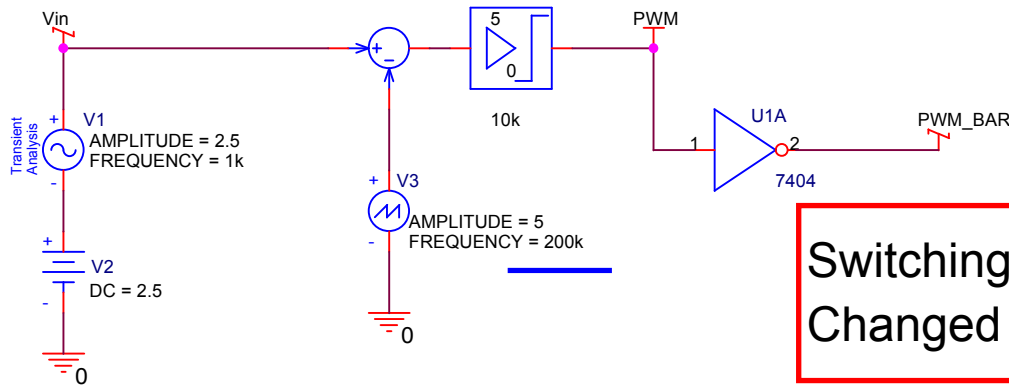
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Date: February 19, 2003

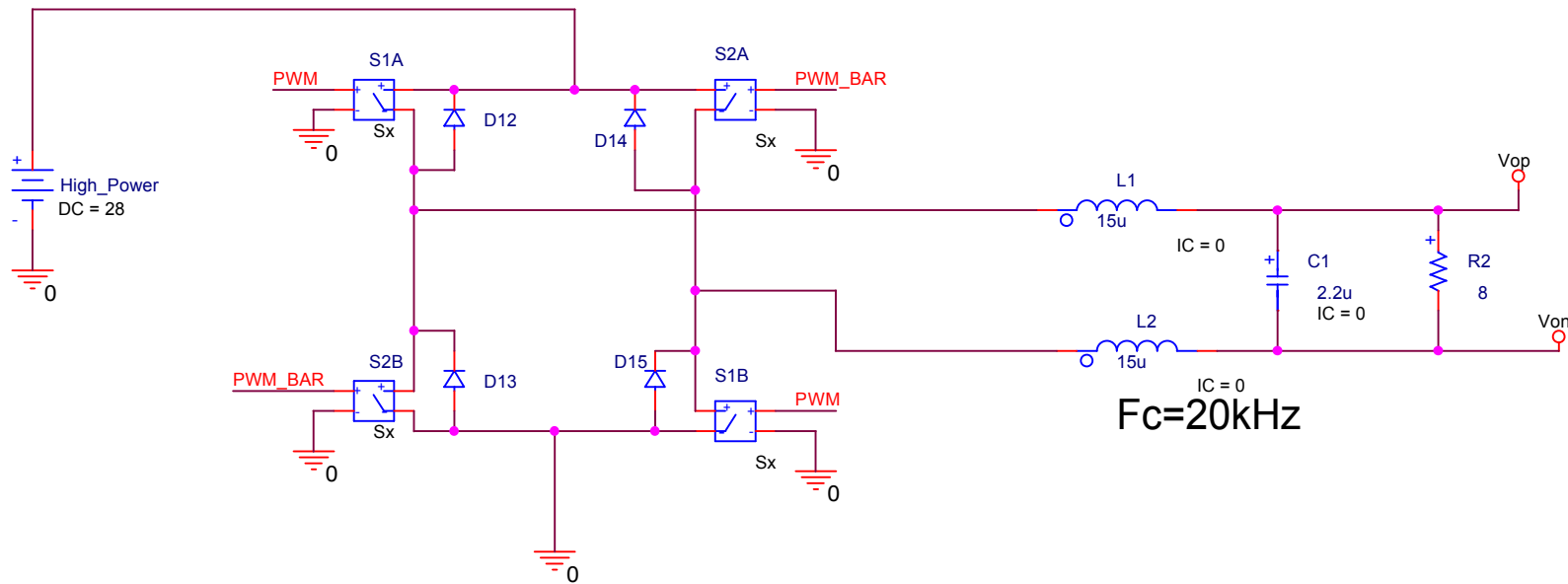
Page 1

Time: 20:45:58



Switching Frequency
Changed to 200 KHZ

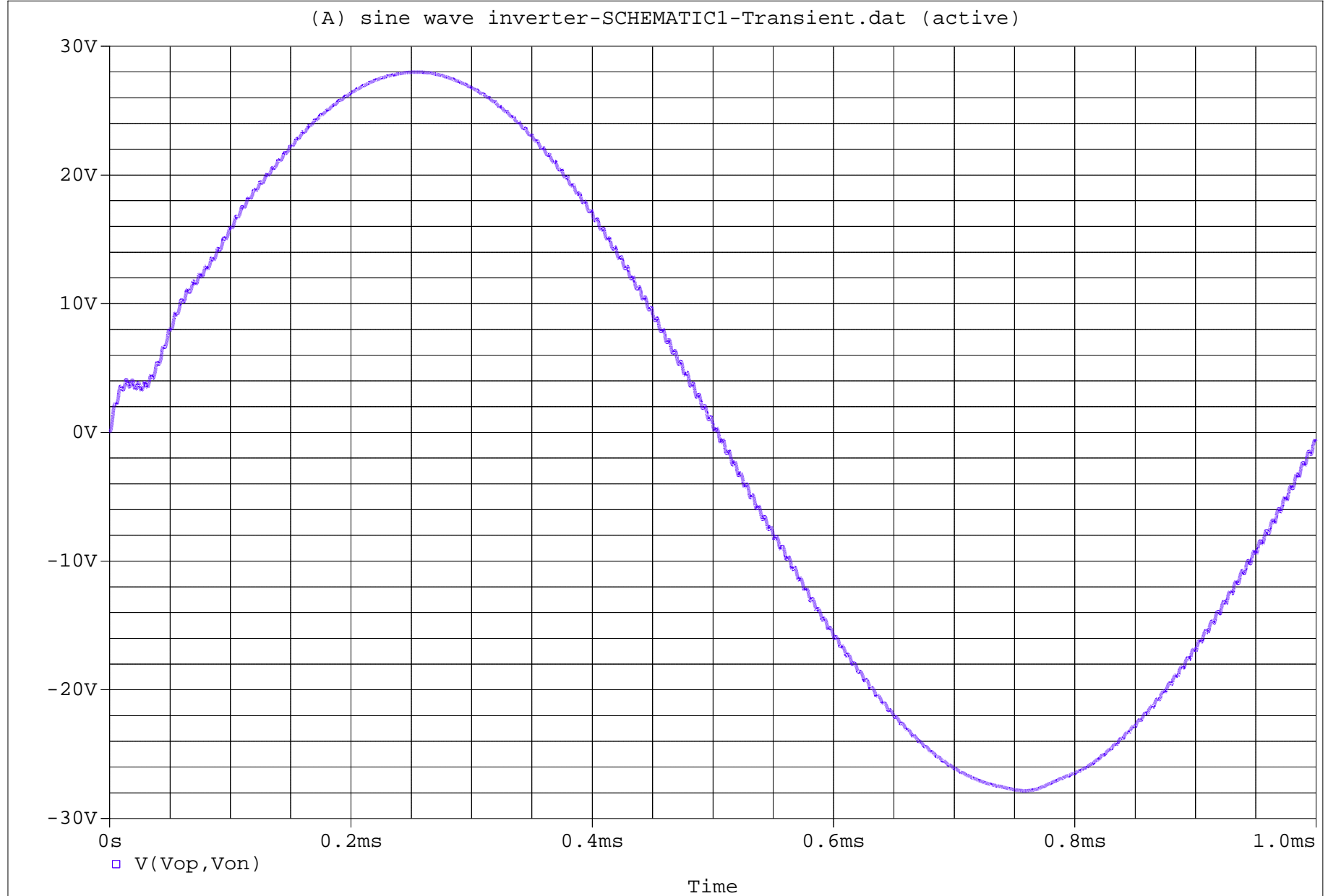
Model = Sx VSWITCH Roff=1e6 Ron=10.0m Voff=1.0 Von=4.0



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** Profile: "SCHEMATIC1-Transient" [C:\WEBSITE\ROSE_CLASSES\ECE456\nOTES\ORCAD\Inverter\sine wave...
Date/Time run: 02/19/03 20:46:46 Temperature: 27.0

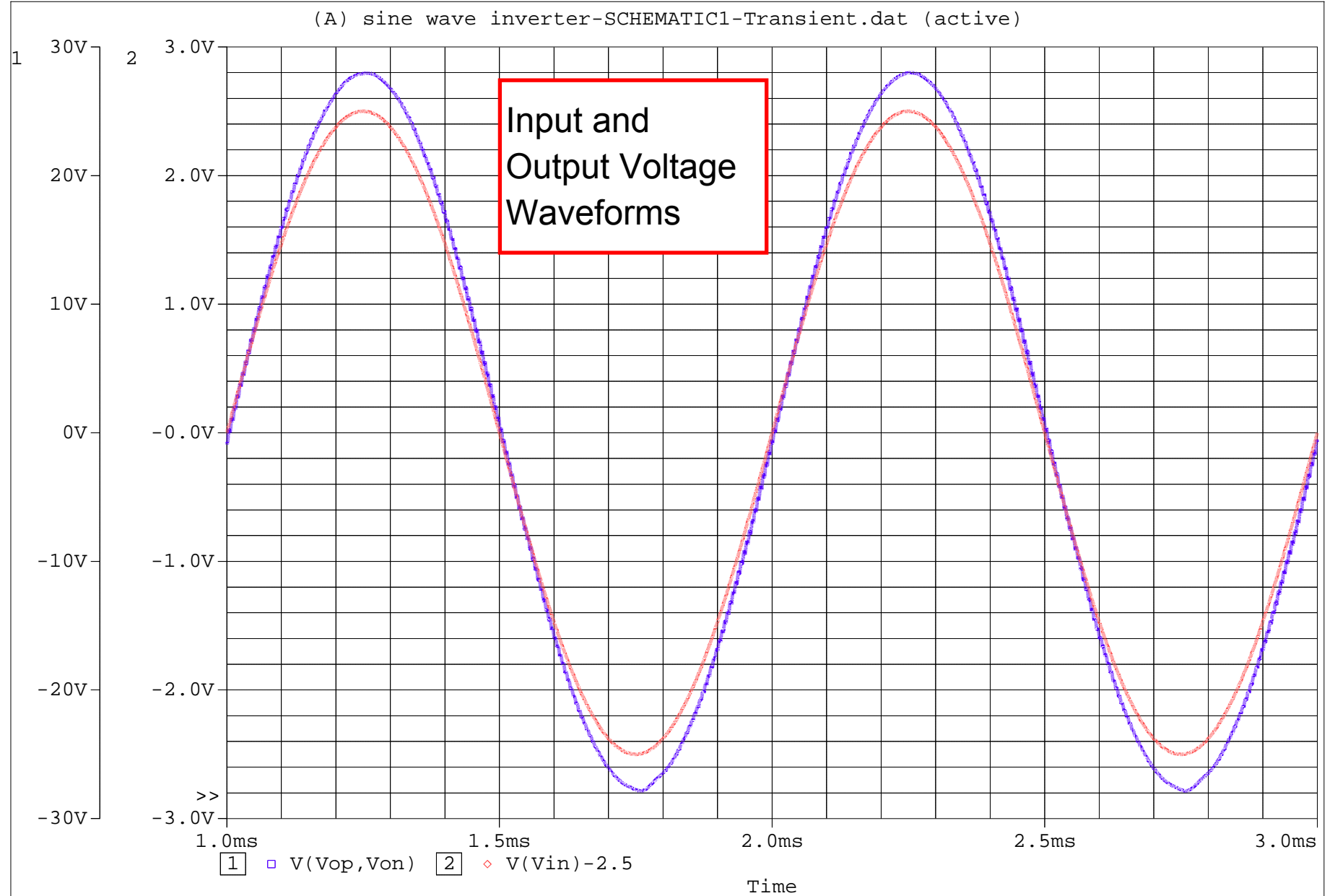


Date: February 19, 2003

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Time: 20:47:18

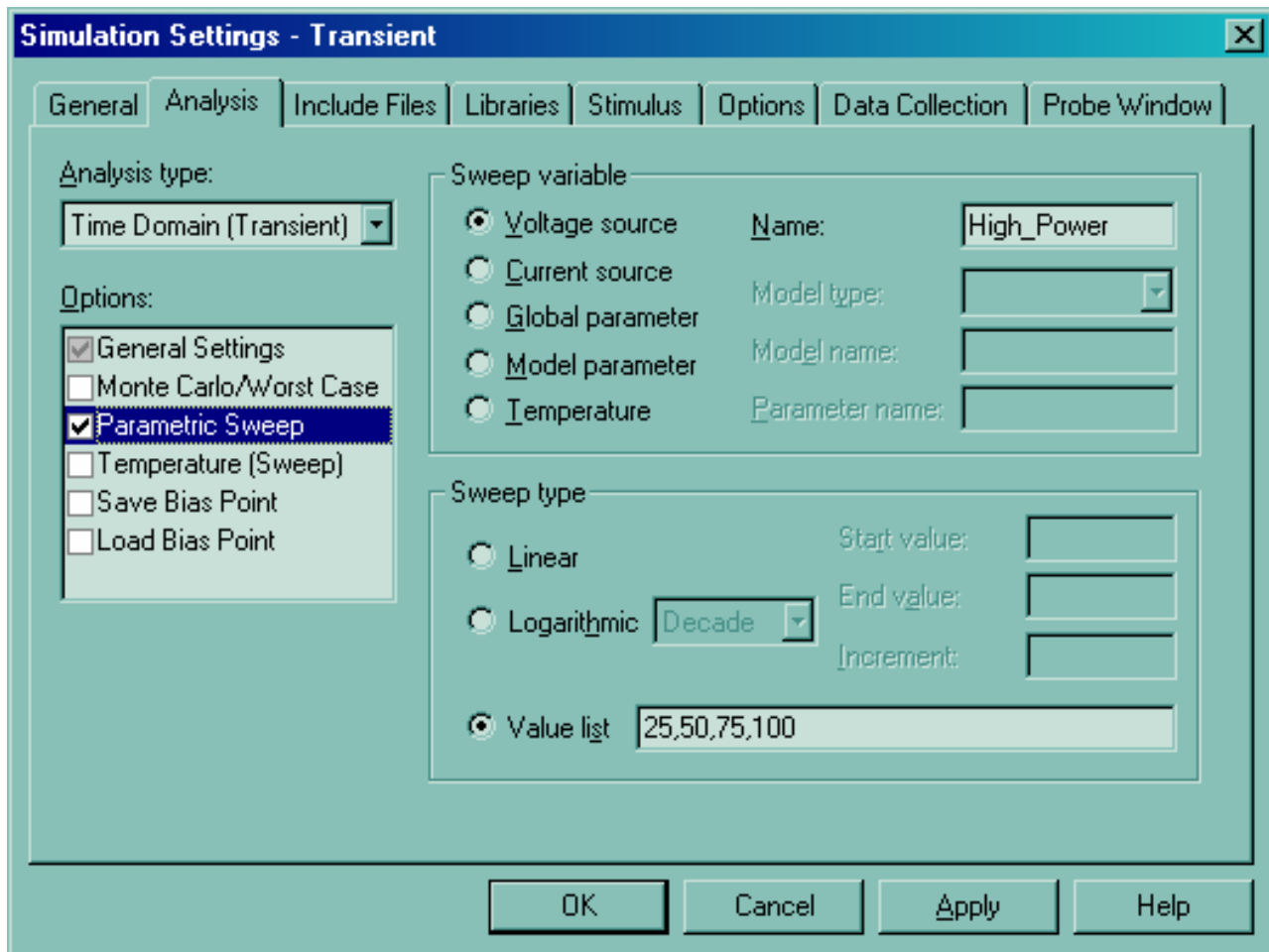
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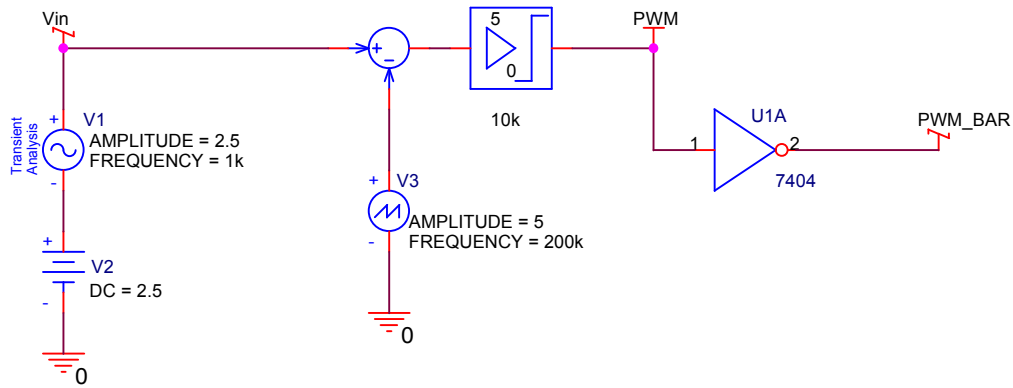


Date: February 19, 2003

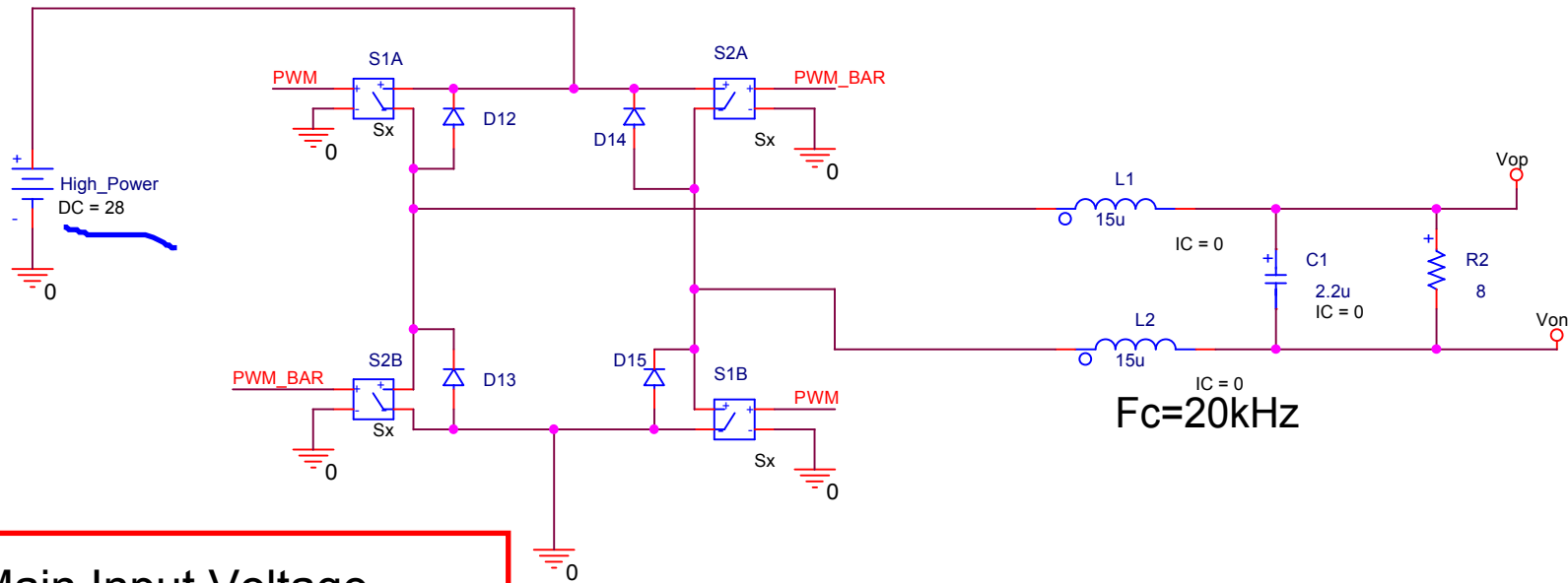
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Time: 20:50:15





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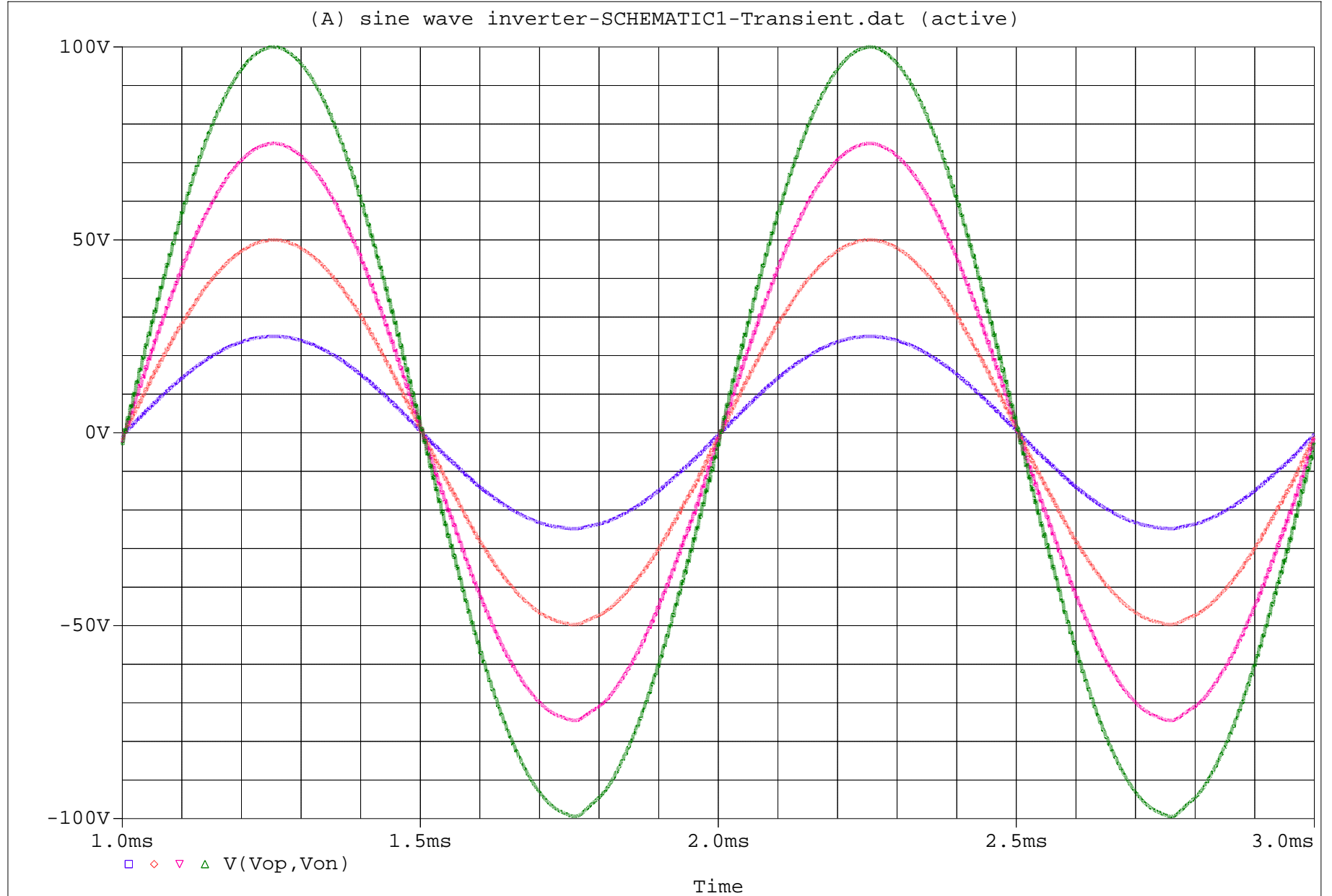
Main Input Voltage stepped from 25, 50, 75, to 100 Volts.

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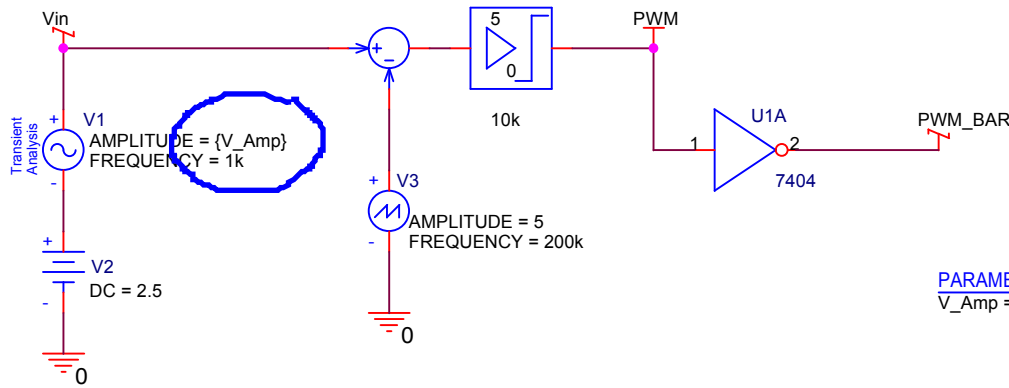
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Date/Time run: 02/19/03 21:00:57 Temperature: 27.0



Date: February 19, 2003

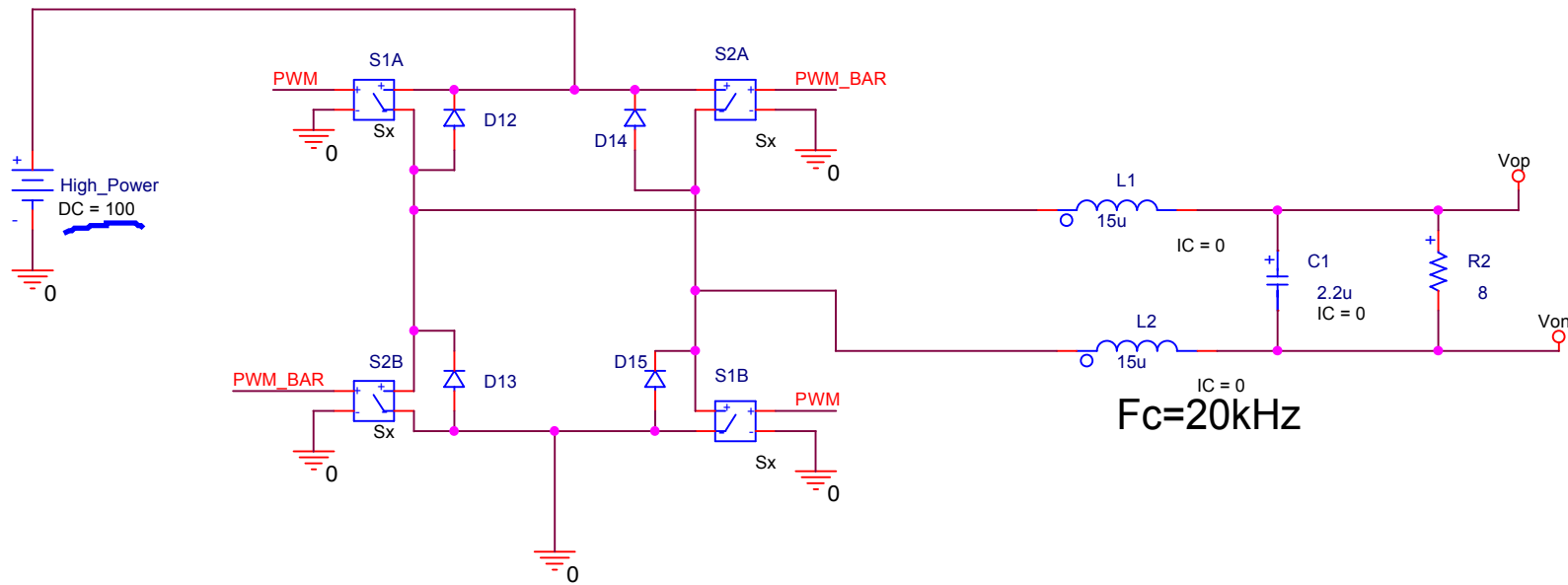
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Time: 21:10:24



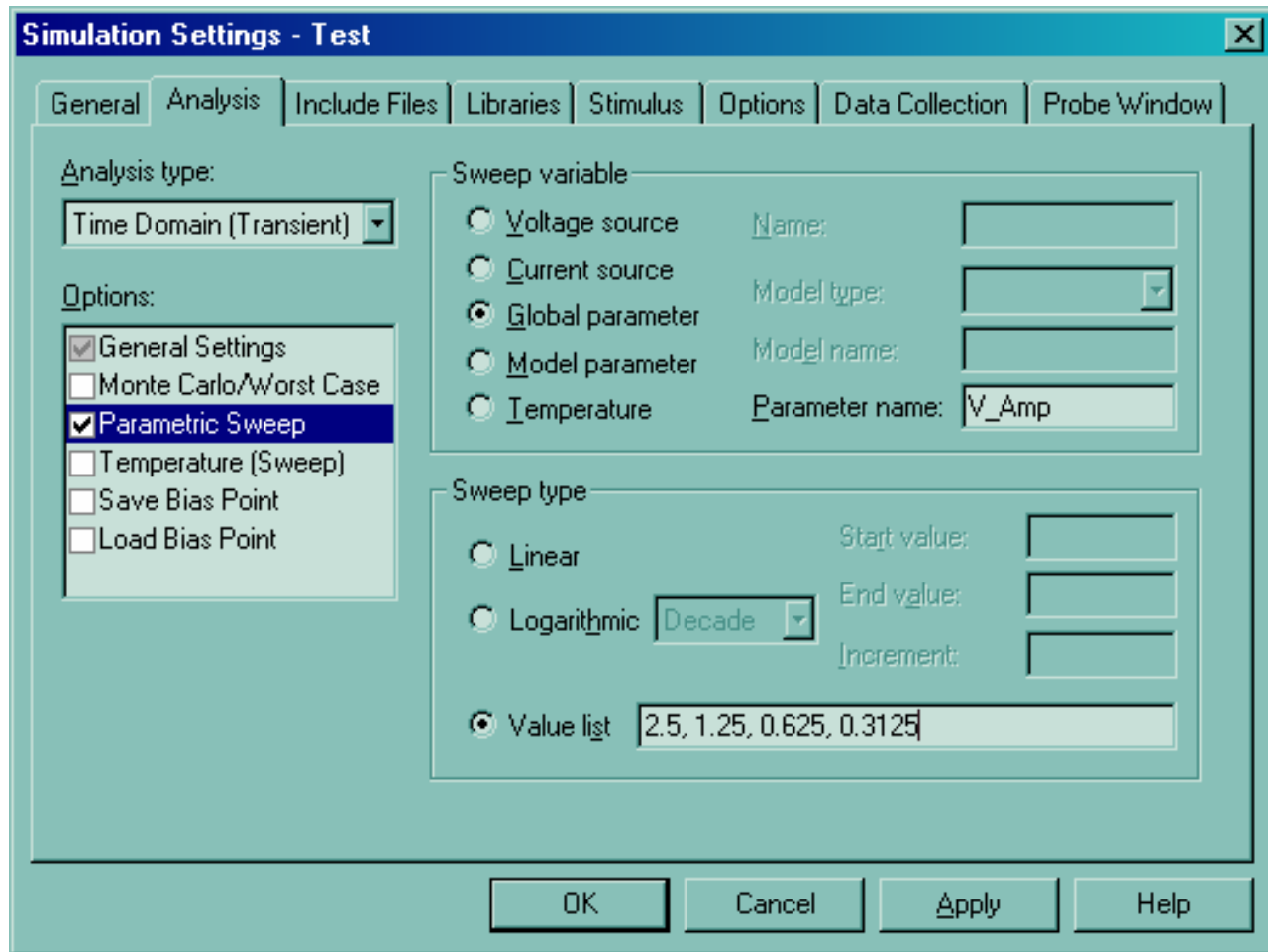
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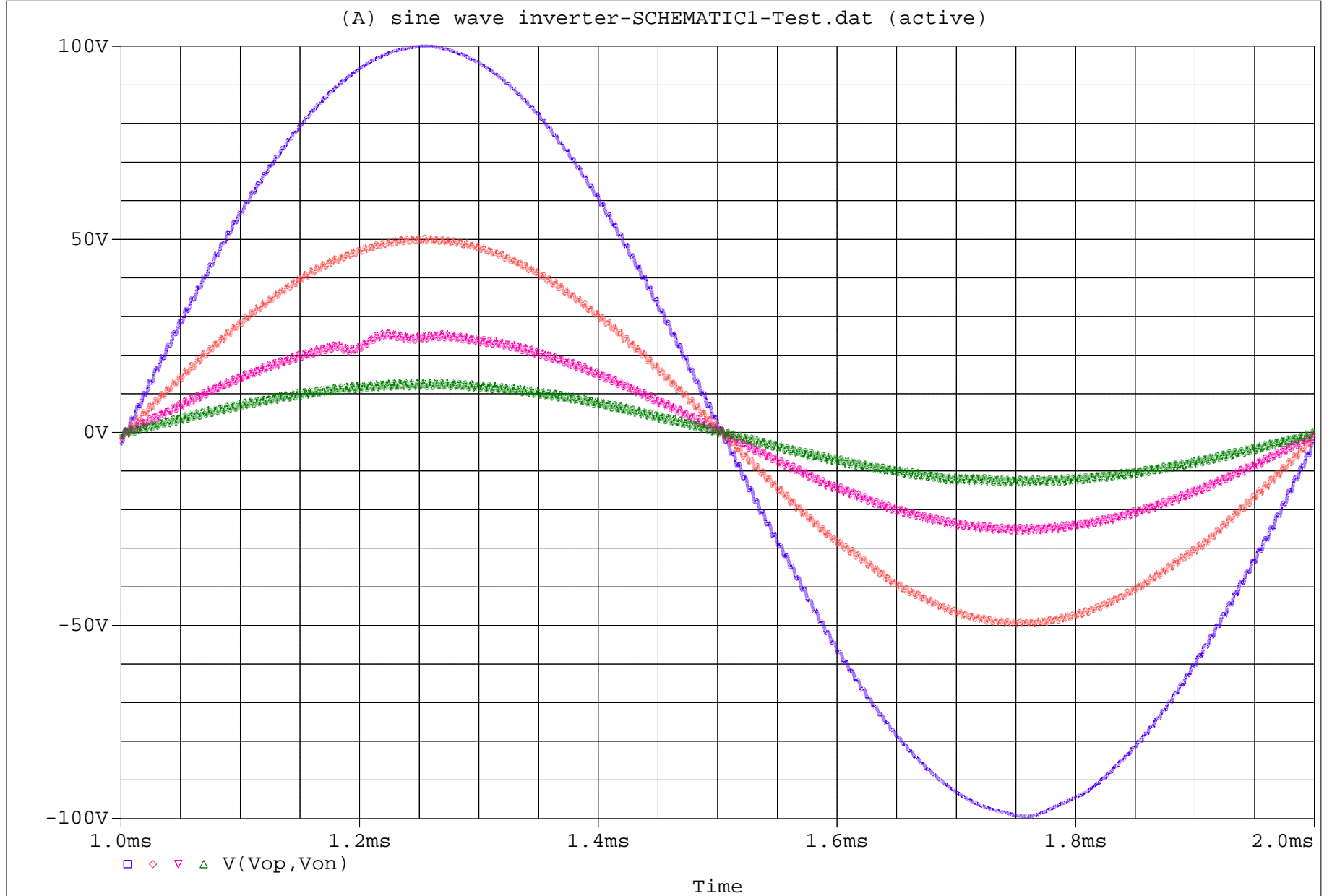


We can also change the properties of the input source to control the

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