CMOS Voltage Comparator

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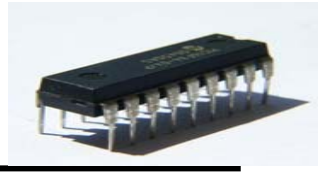
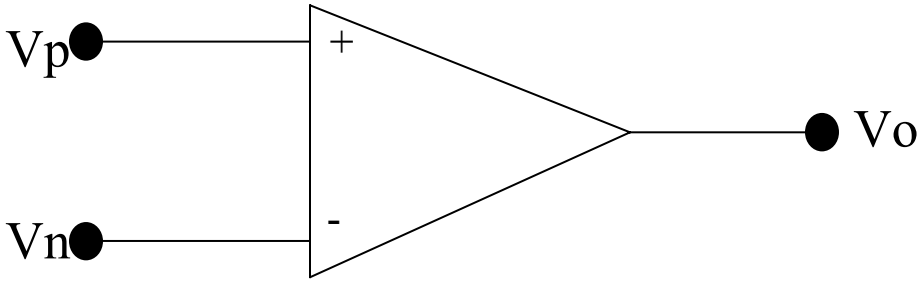
Voltage Comparator Requirement

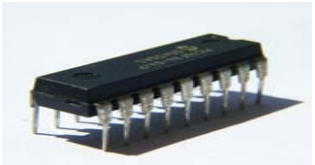


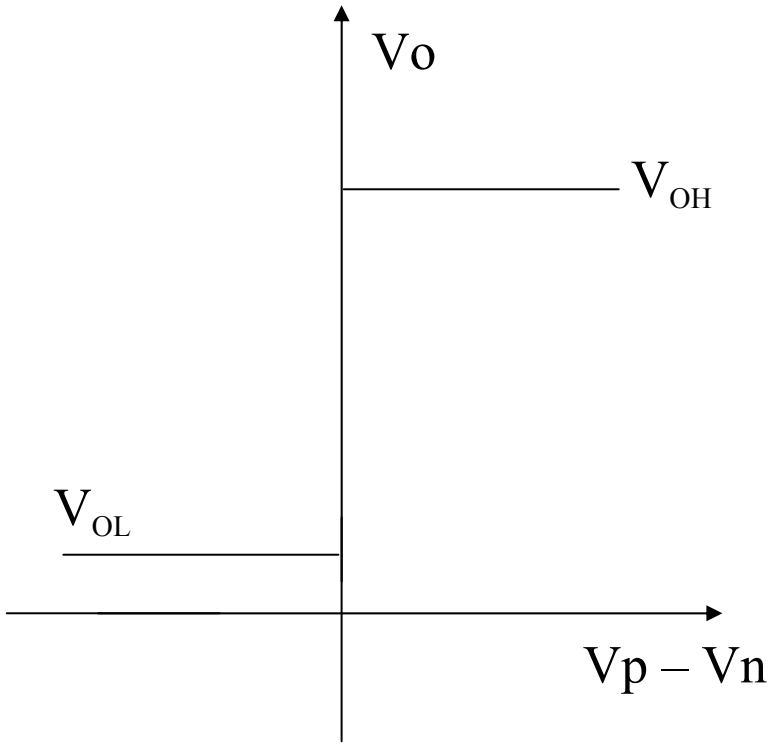
- Compares one analog signal (voltage) to another analog voltage or a reference voltage and gives a binary output depending on the comparison.
- Widely used in Analog to Digital Converter (ADC). Comparator is considered as 1-bit ADC.
- Also used in detection purpose of low swing and high speed digital bus.



Symbol of a comparator

Comparator Static Characteristics





Static Characteristics :

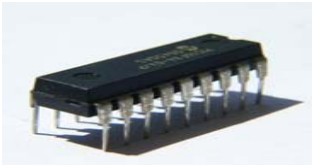
- **Gain**
- **Output High and Low states (V_{OH} and V_{OL})**
- **Input Resolution**
- **Offset**
- **Noise**

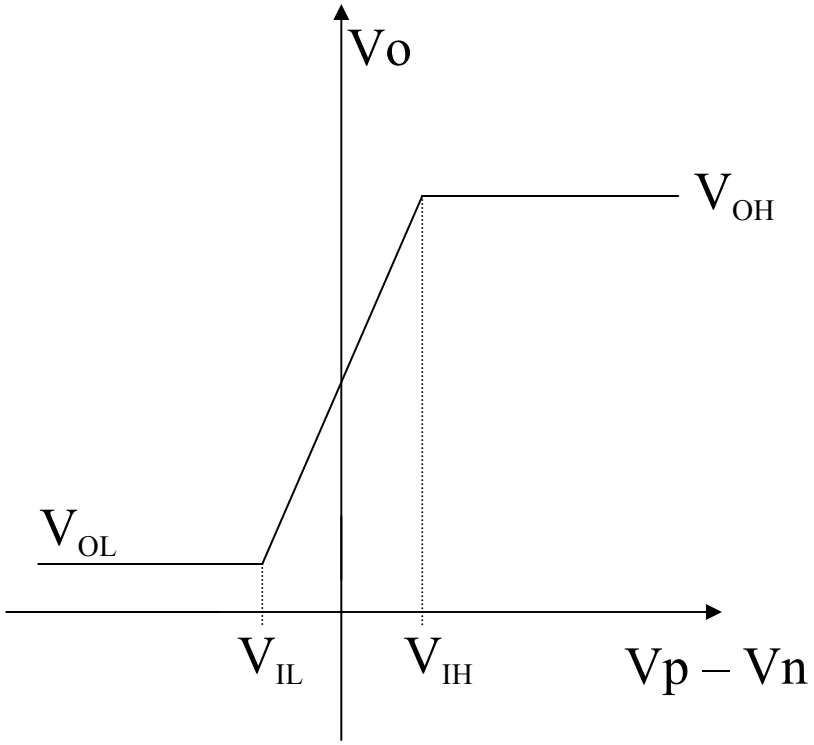
Ideal Voltage Transfer (Gain ~ infinity)

$$A_V = \text{Lim}(\Delta V \rightarrow 0) \{(V_{OH} - V_{OL})/ \Delta V \}$$

Where ΔV is the input voltage change

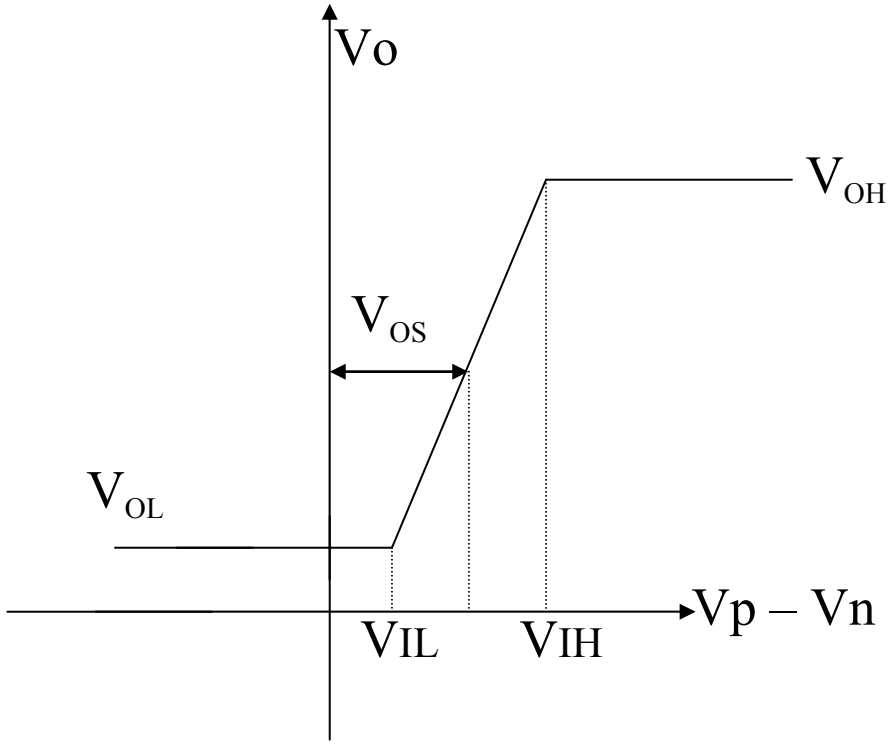
Comparator Static Characteristics





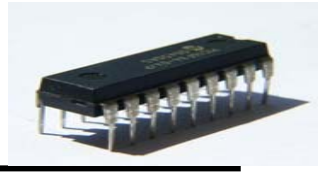
Voltage transfer curve with finite gain.

$$A_V = \{(V_{OH} - V_{OL})/ (V_{IH} - V_{IL})\}$$



Voltage transfer curve with input-offset voltage.

Static Characteristics



• Offset: There are two types of offset, 1. Systematic offset. 2. Random offset.

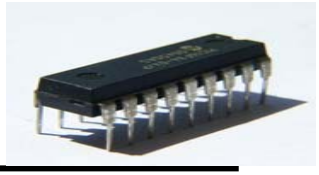
Effect of offset can be reduced but can not be totally avoided

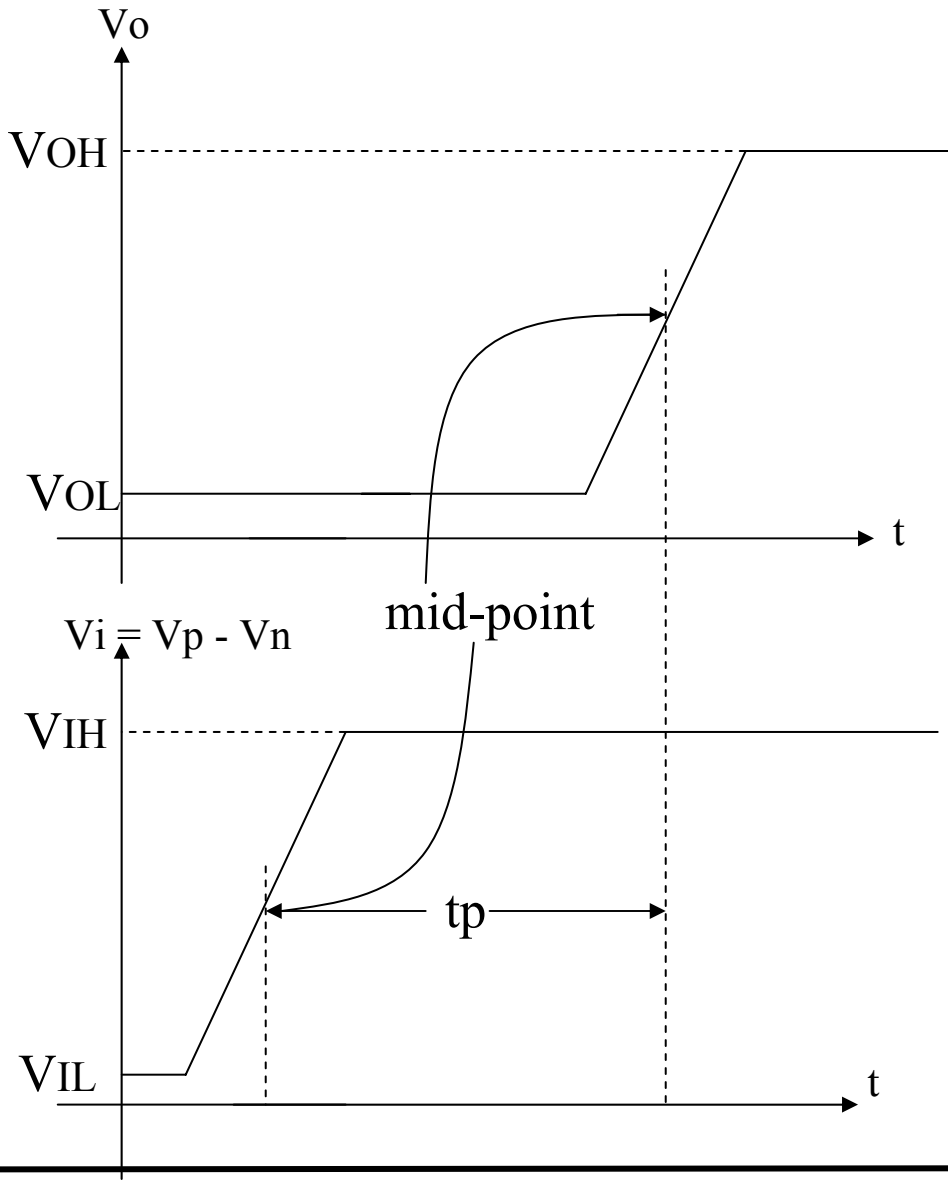
• Resolution : It is the input voltage change necessary to make the output swing to valid binary states.

• Noise: Noise leads to an uncertainty in the transition in the voltage transfer curve. This uncertainty in the transition region can lead to jitter or phase noise.

• Input Common Mode Range (ICMR): This is the input voltage range where the comparator function normally (i.e. meets all other required specification).

Dynamic Characteristics – Propagation Delay



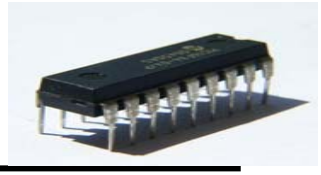


Dynamic Characteristics :

- **Propagation Delay**
- **Slew Rate**

Total Propagation delay time = (Rising propagation delay time + Falling propagation delay time) / 2

Propagation Delay and Slew Rate



- **For a Single Pole System:**

$$A_v(s) = A_v(0) / (s\tau + 1) \Rightarrow V_{out}(t) = A_v(0)\,[1 - \exp(-t/\tau)]\,V_{in}(min)$$

$$V_{out} = (V_{OH} - V_{OL}) / 2 \quad \text{at} \quad t = t_p$$

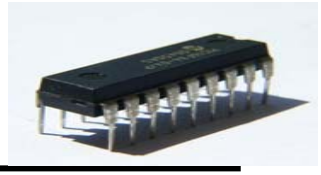
Therefore if $V_{in}(min)$ is applied, $t_p = \tau \ln(2) = 0.693\tau$

Overdrive applied to the input ↑ ⇒ Propagation Delay Time ↓

- For very high input voltage the comparator enters into the large-signal mode of operation. For this case slew-rate defined by the maximum current available will define the propagation delay.

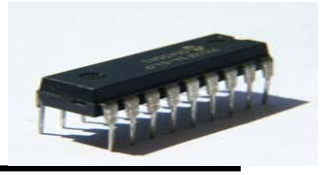
$$i = C\,(dv/dt) \qquad t_p = (V_{OH} - V_{OL}) / 2 * SR$$

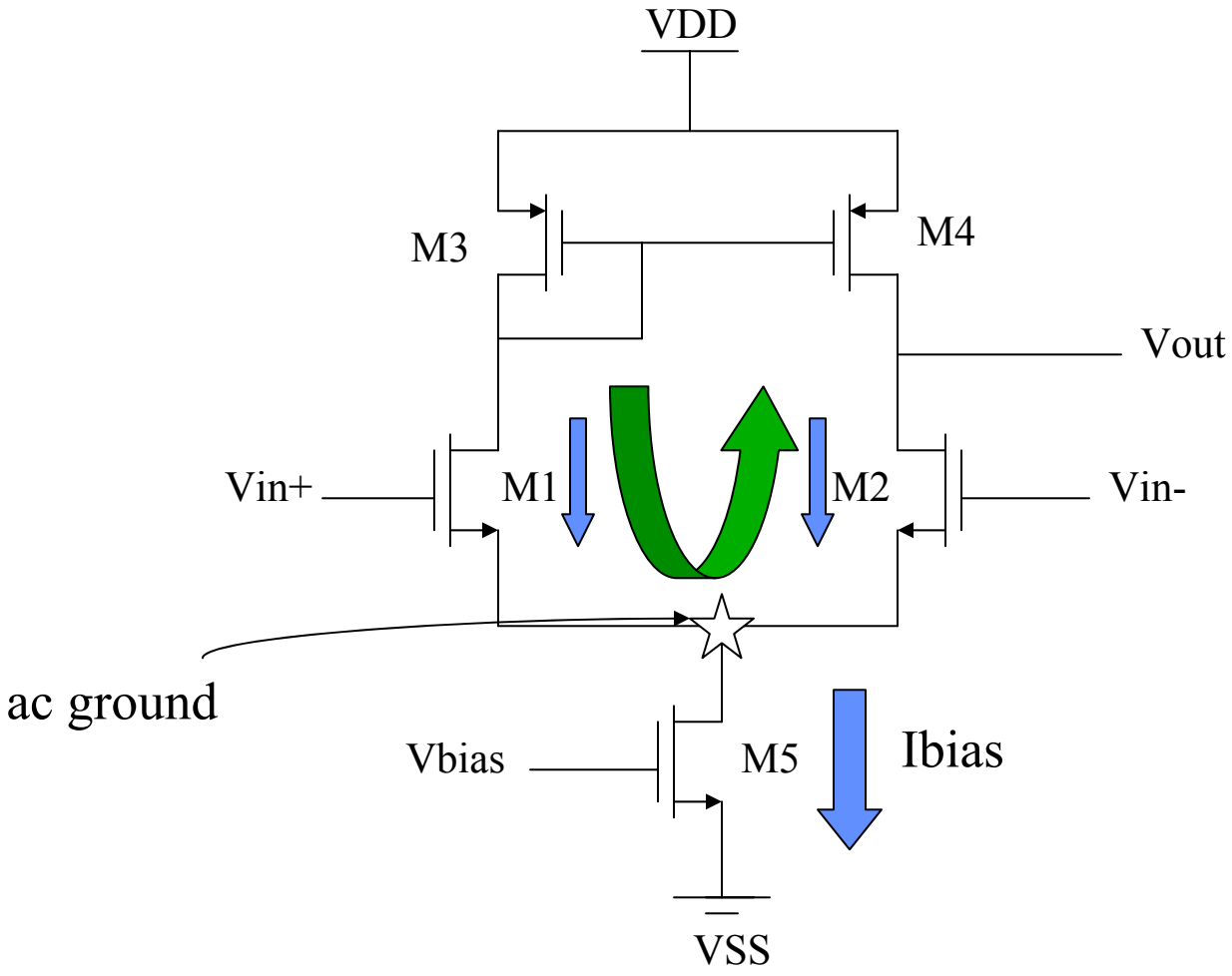
Different Comparator Types



- **Open loop comparator.**
  - These comparator basically are operational amplifier without compensation. Comparators are required to have lesser gain and higher bandwidth than opamps.
- **Regenerative Comparator.**
  - These comparator uses positive feedback like a latch to compare to signals.
- **High Speed Comparator.**
  - These comparators are a combination of above two which leads to a faster response.

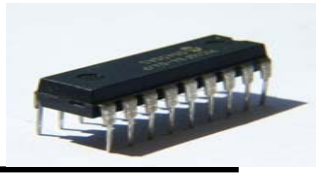
Open Loop Comparator; Differential Amplifier

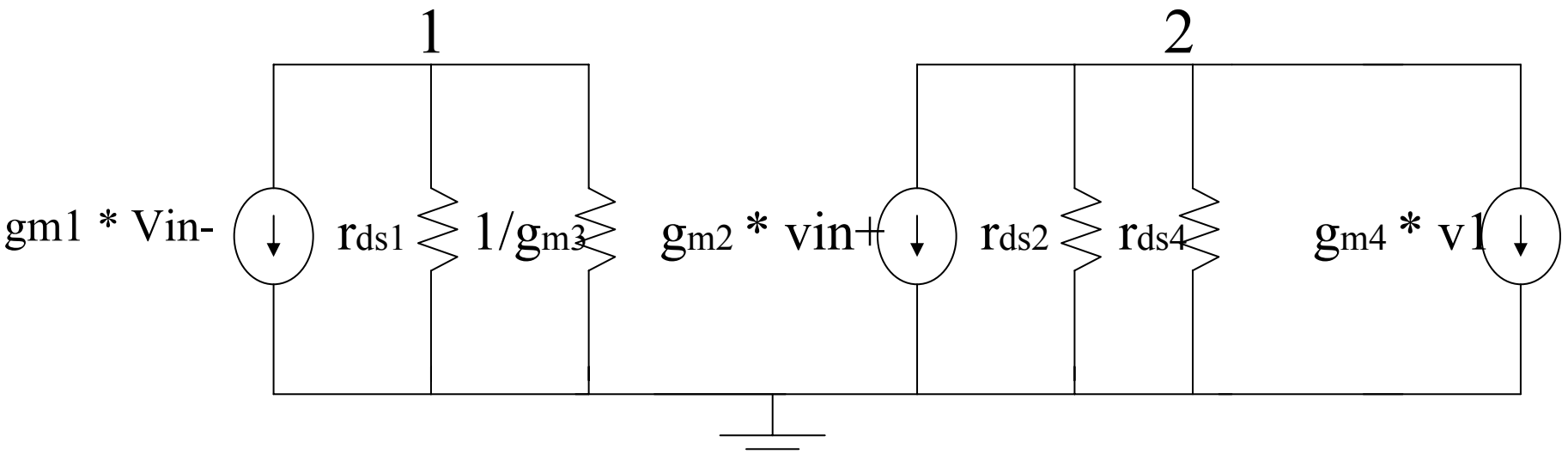




Differential Amplifier

Small Signal Model of Diff. Amp.

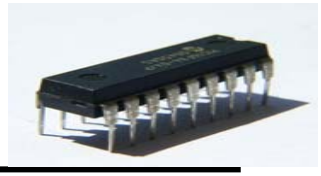


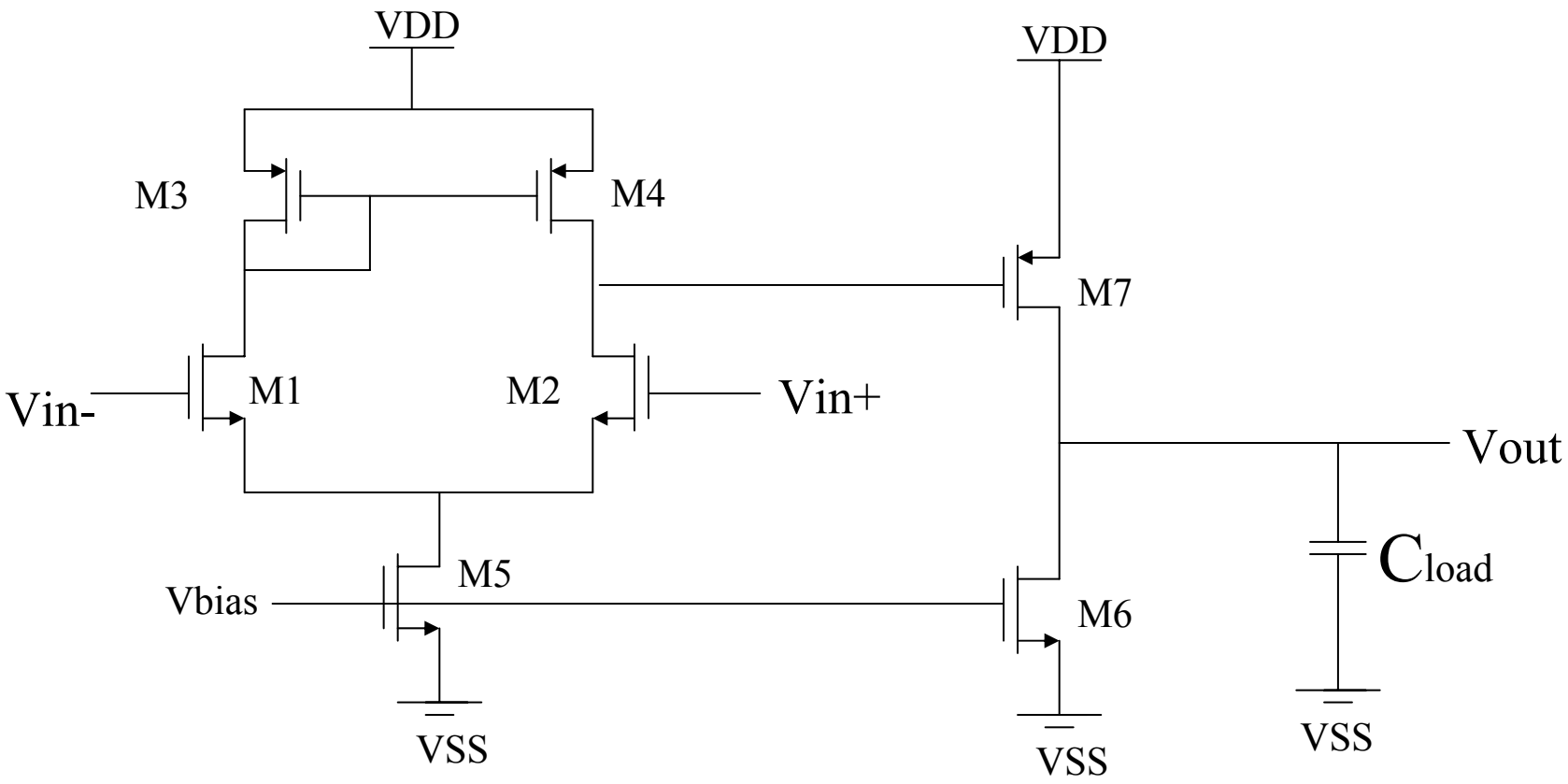


Note: $g_{m1} = g_{m2}$; $g_{m3} = g_{m4}$

Gain : $A_v = g_{m1} (r_{ds2} \,||\, r_{ds4})$

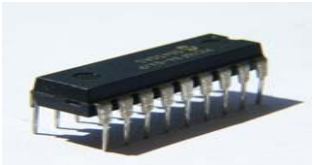
Two Stage Comparator

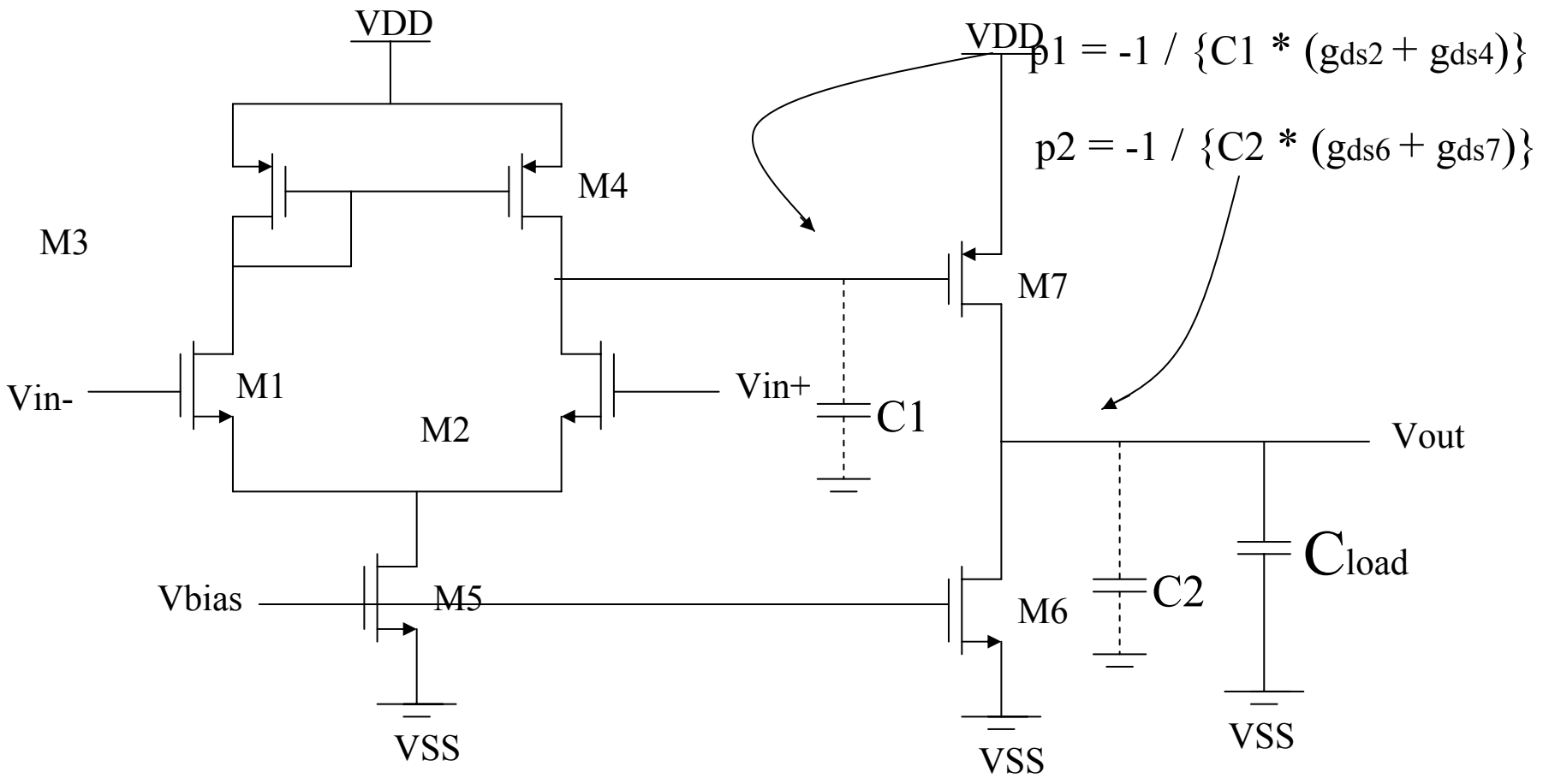




$$\text{Gain, } A_v = g_{m1}\left(r_{ds2} \,||\, r_{ds4} \right) * g_{m7}\left(r_{ds6} \,||\, r_{ds7} \right)$$

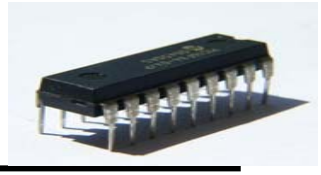
Frequency Response of The Comparator

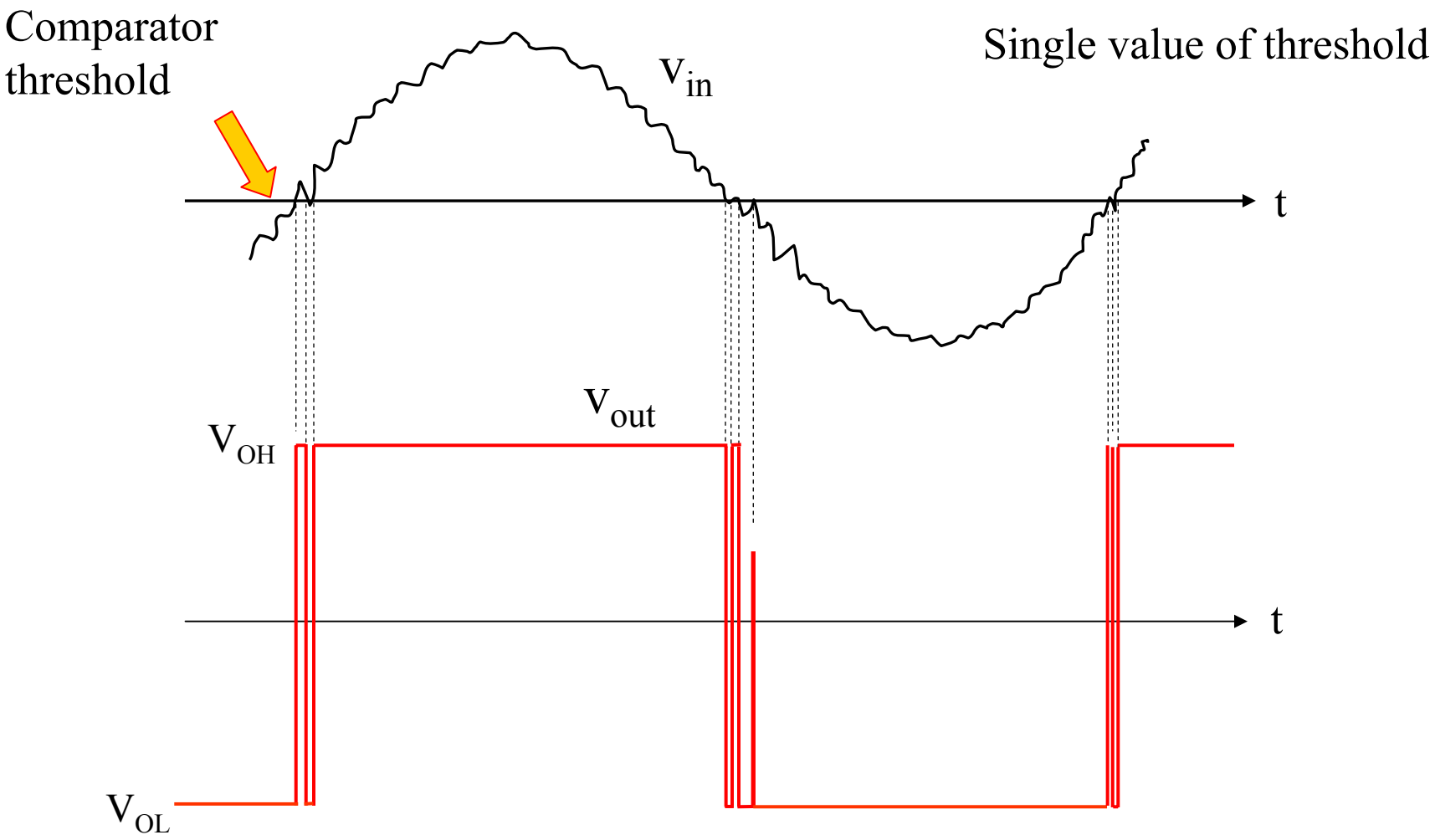




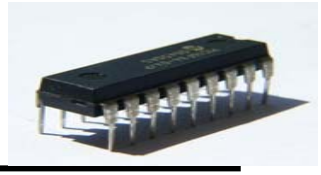
$$V_{out} = A_v(0) * V_{in} [\ 1 + \{p2 * \exp(-t*p1)\} / (p1 - p2) - \{p1 * \exp(-t*p2)\} / (p1 - p2)\ ]$$

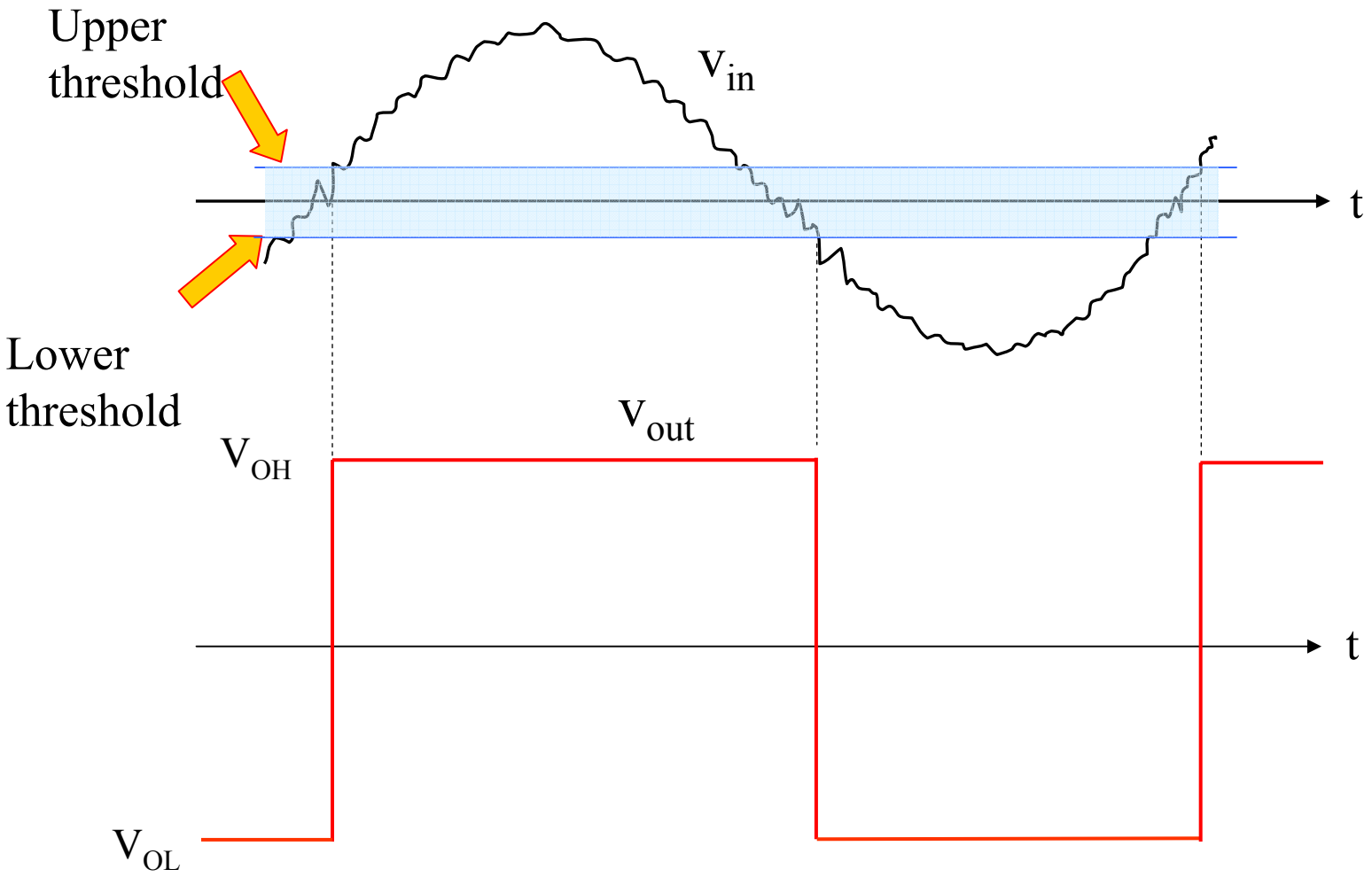
Response of a Comparator in a Noisy Environment





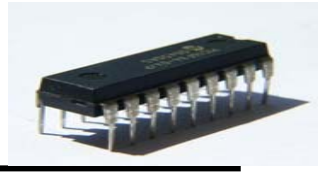
Comparator with Hysteresis in a Noisy Environment





Different trip points for rising and falling V_{in}

Characteristics of a Comparator with Hysteresis



- Comparator threshold changes with the state of the output
  - * One trip point ($\mathbf{V_{TRP}}$+) for V_{OL}
  - * Another trip point ($\mathbf{V_{TRP}}$ -) for V_{OH}

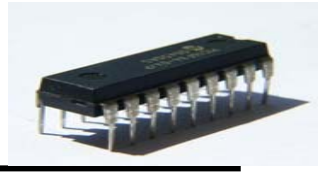
- Existence of a *hysteresis band*
  - * output voltage doesn't change as long as input is within this band.
  - * output changes only when the input *comes out* of the band.

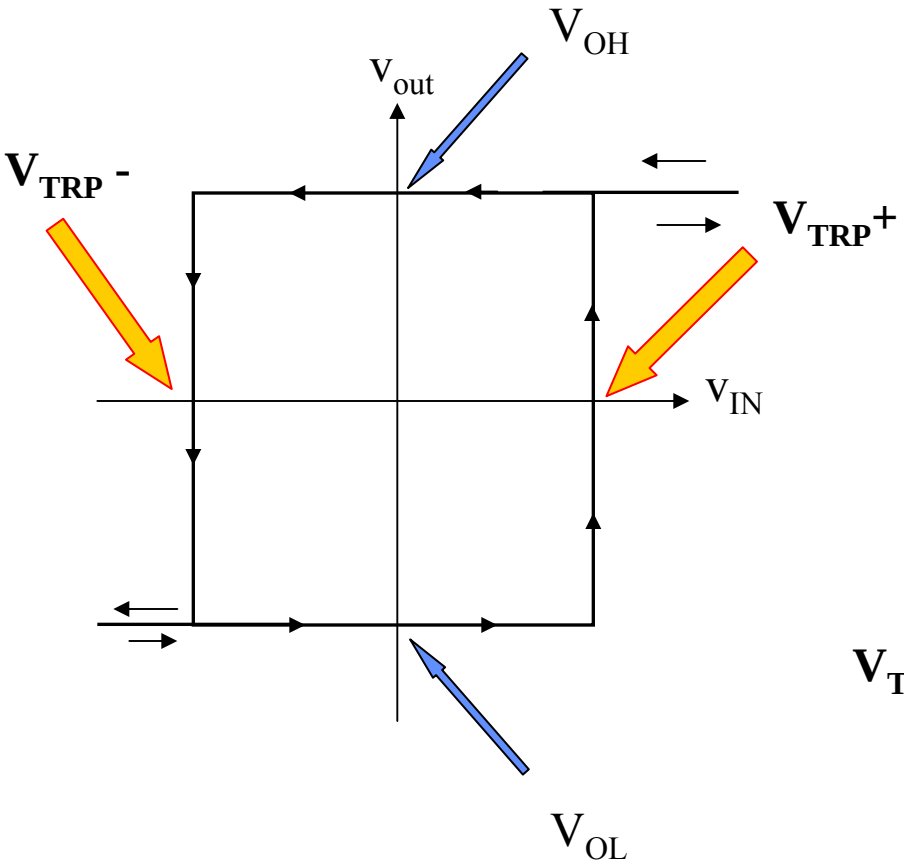
- In a hysteresis comparator the output depends both on the present and the past values of V_{in} ---------- dependency on history.

How to get the hysteresis:

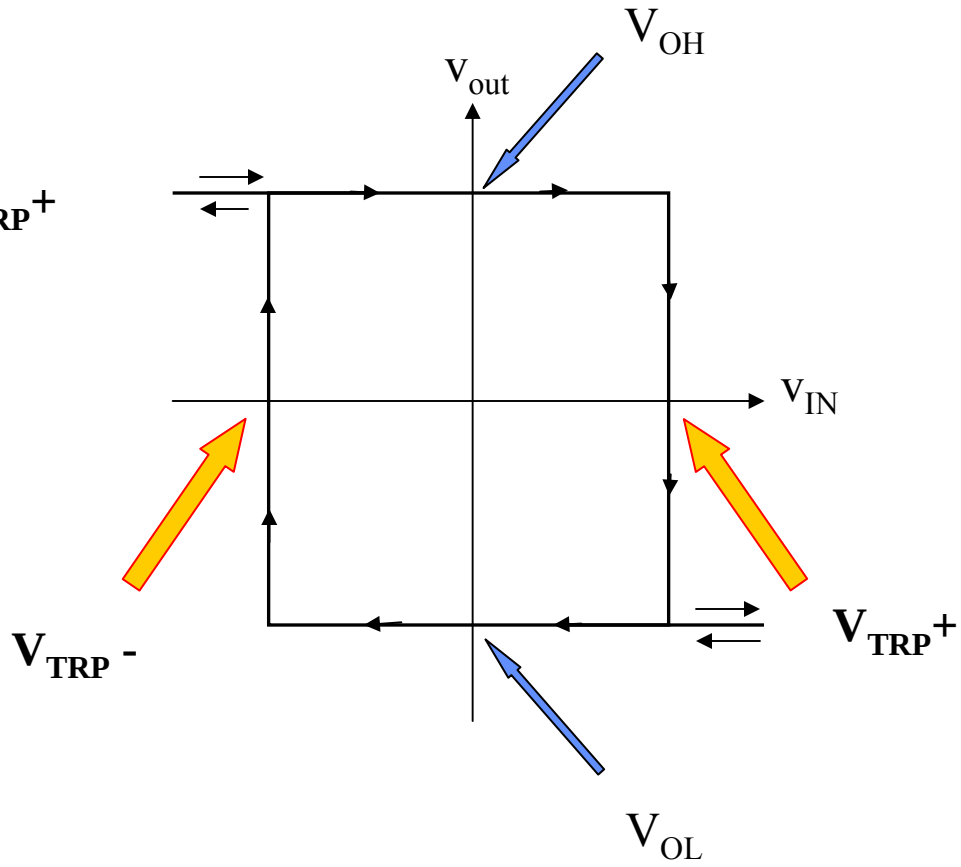
1. External feedback.
2. Internal feedback.

Transfer curve of a Comparator with Hysteresis



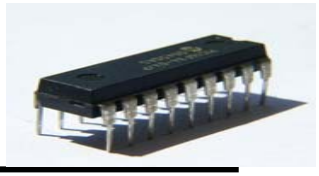


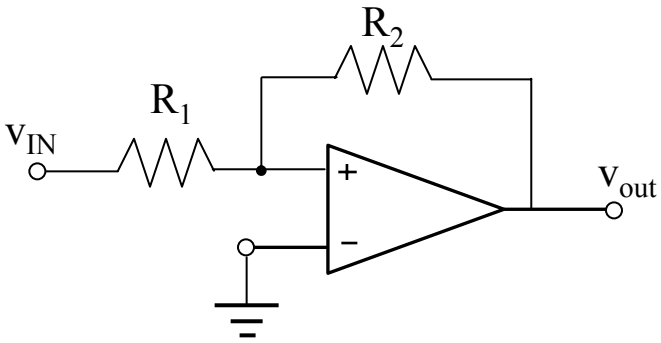
Counterclockwise Bistable

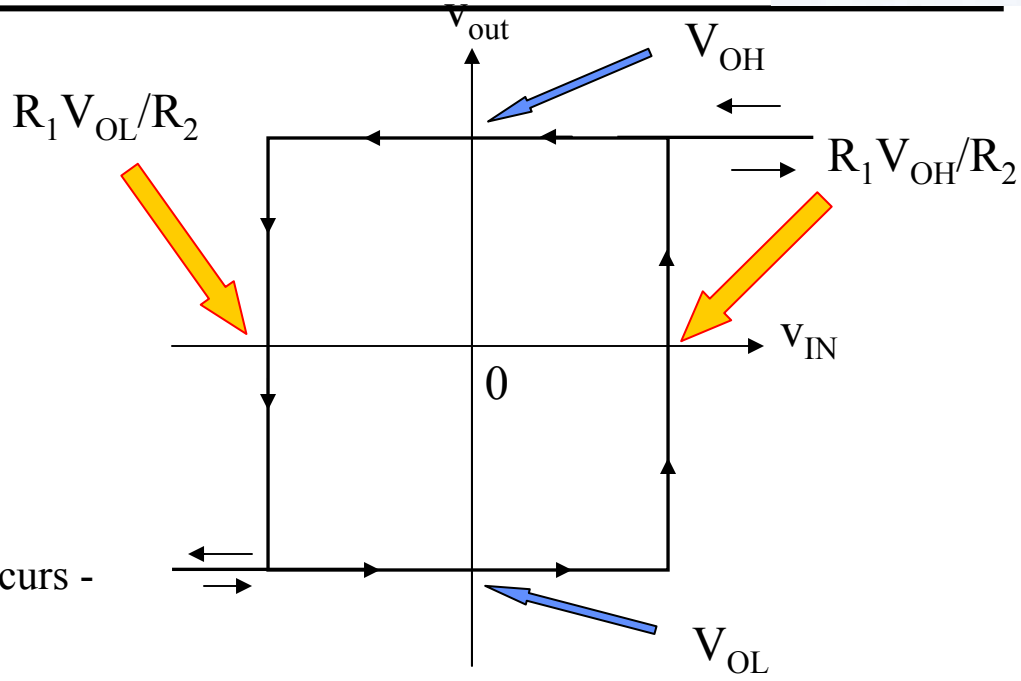


Clockwise Bistable

Noninverting Comparator using External Positive Feedback







Upper Trip Point:

We have $v_{OUT} = V_{OL}$, the upper trip point occurs -

$$0 = \left(\frac{R_1}{R_1 + R_2}\right) V_{OL} + \left(\frac{R_2}{R_1 + R_2}\right) V_{TRP}+$$

$$\rightarrow V_{TRP}+ = -R_1 V_{OL}/R_2$$

Lower Trip Point:

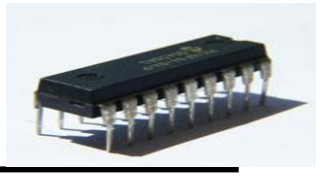
Here we have $v_{OUT} = V_{OH}$, the lower trip point occurs when,

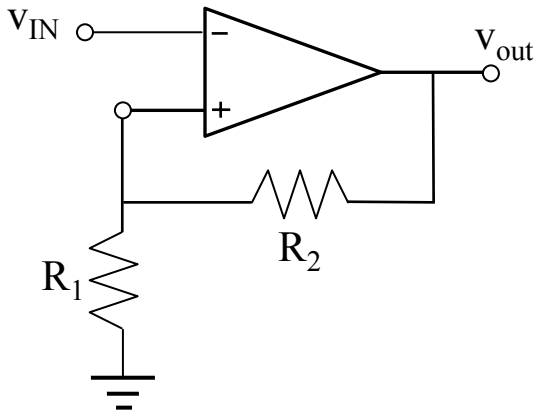
$$0 = \left(\frac{R_1}{R_1 + R_2}\right) V_{OH} + \left(\frac{R_2}{R_1 + R_2}\right) V_{TRP}-$$

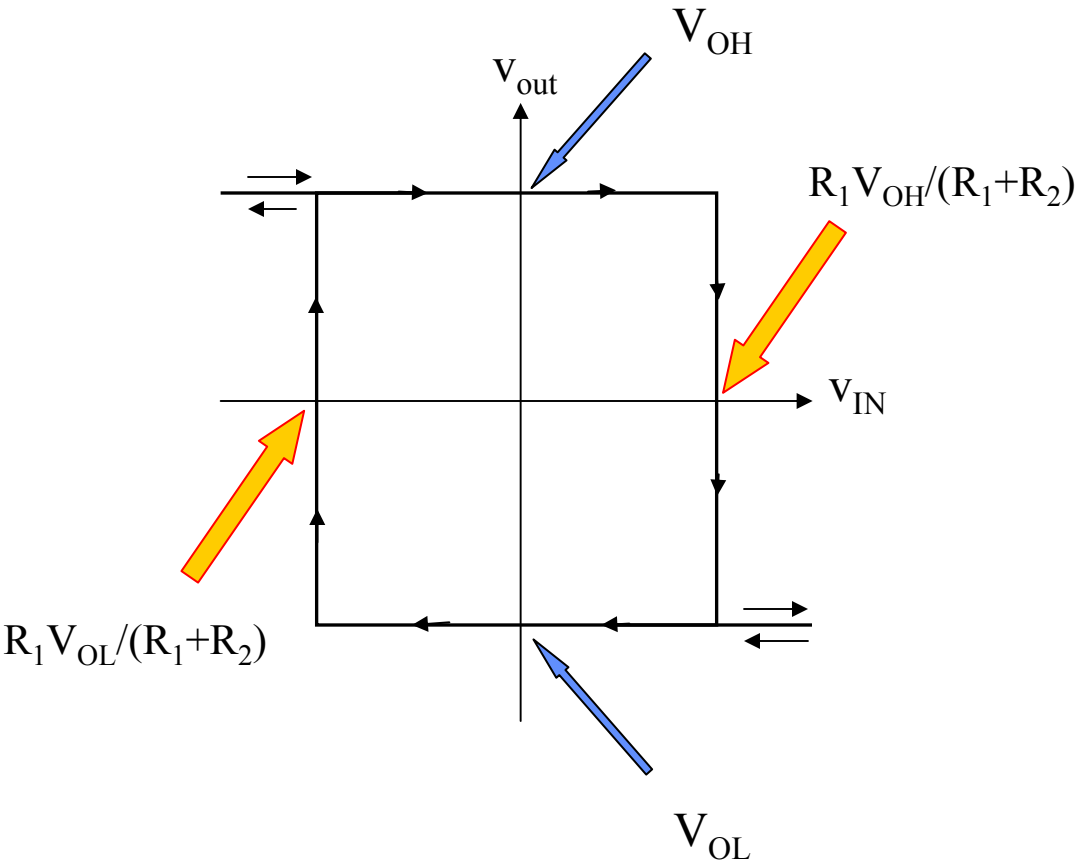
$$\rightarrow V_{TRP}- = -R_1 V_{OH}/R_2$$

Width of the band: $\Delta v_{in} = V_{TRP}+ - V_{TRP}- = (R_1/R_2)(V_{OH} - V_{OL})$

Inverting Comparator using External Positive Feedback







Upper Trip Point:

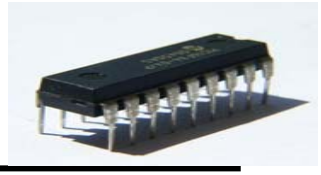
$$V_{TRP}+ = \left(\frac{R_1}{R_1 + R_2}\right) V_{OH}$$

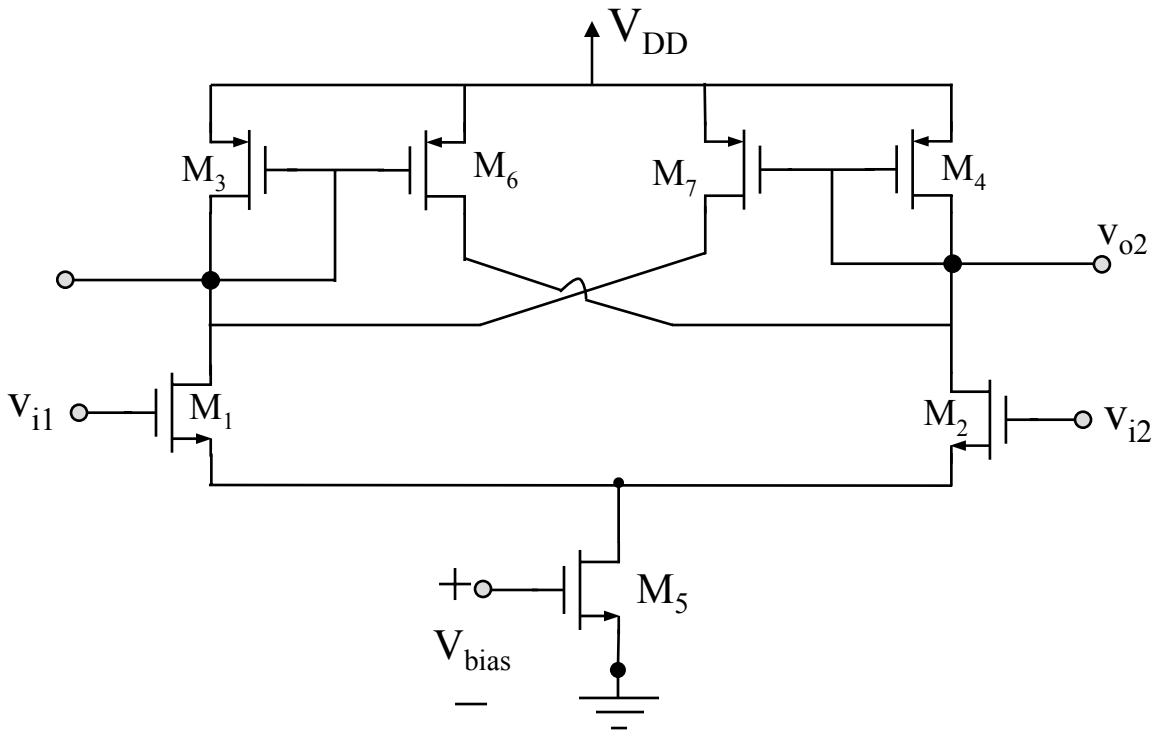
Lower Trip Point:

$$V_{TRP}- = \left(\frac{R_1}{R_1 + R_2}\right) V_{OL}$$

Width of the band: $\Delta v_{in} = V_{TRP}+ - V_{TRP}- = [R_1/(R+R_2)](V_{OH} - V_{OL})$

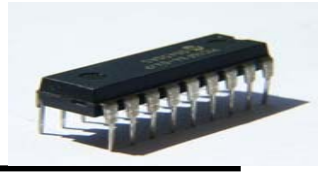
Hysteresis using Internal Positive Feedback

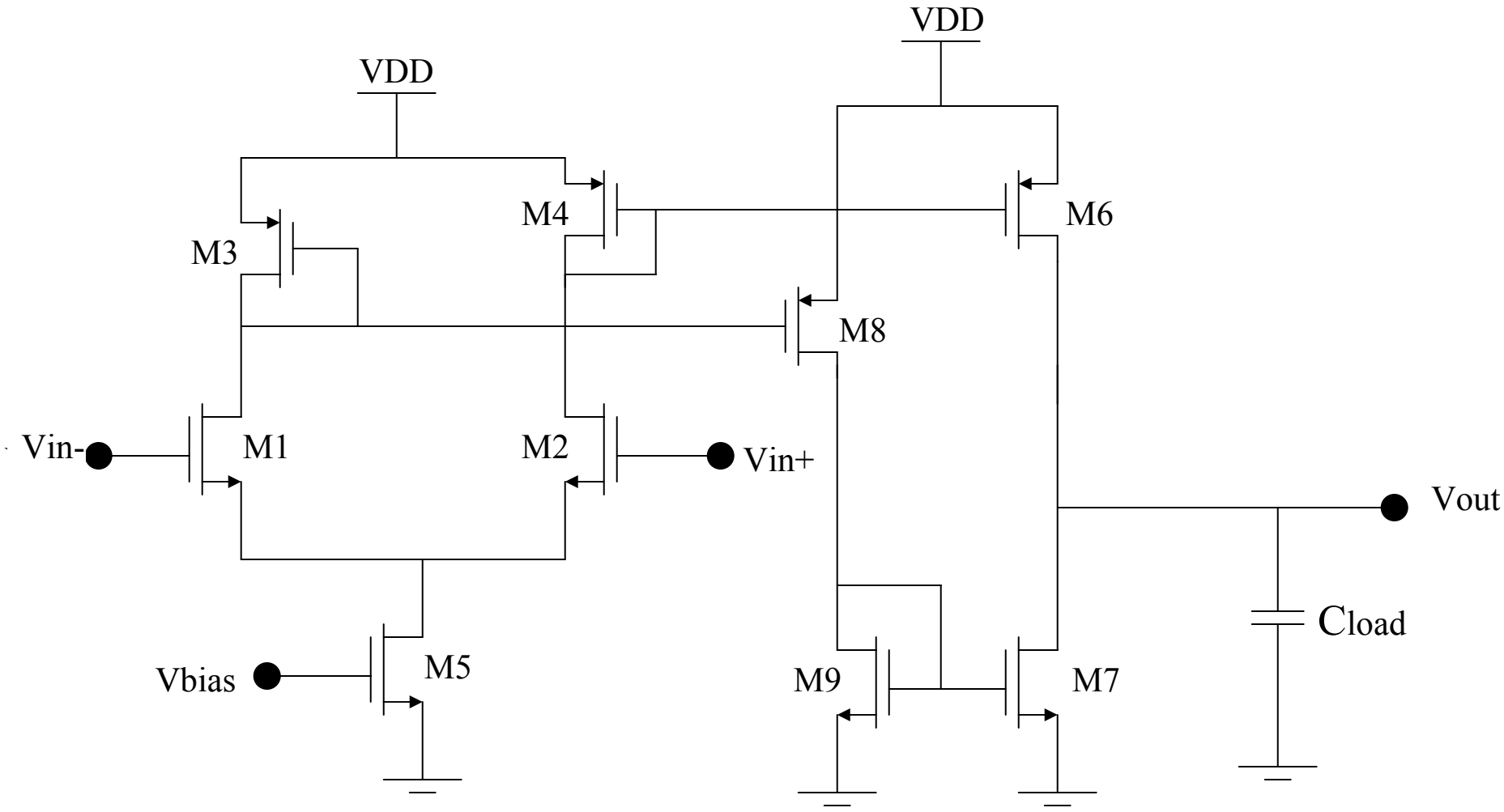




A Simple Comparator with an internal positive feedback

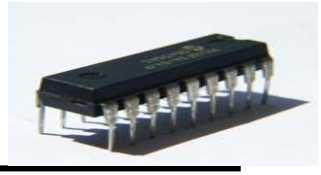
Push-Pull Output Comparators

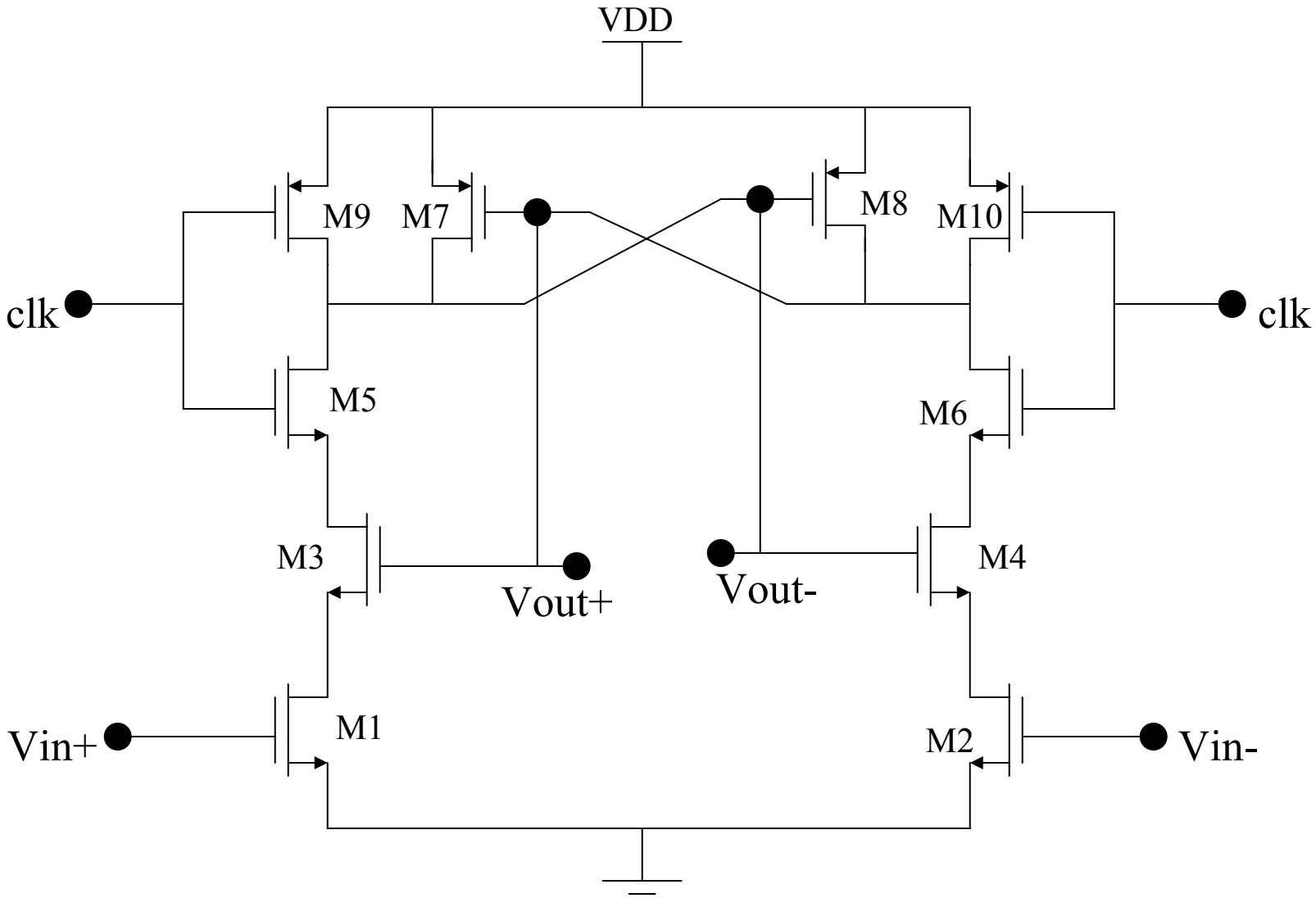




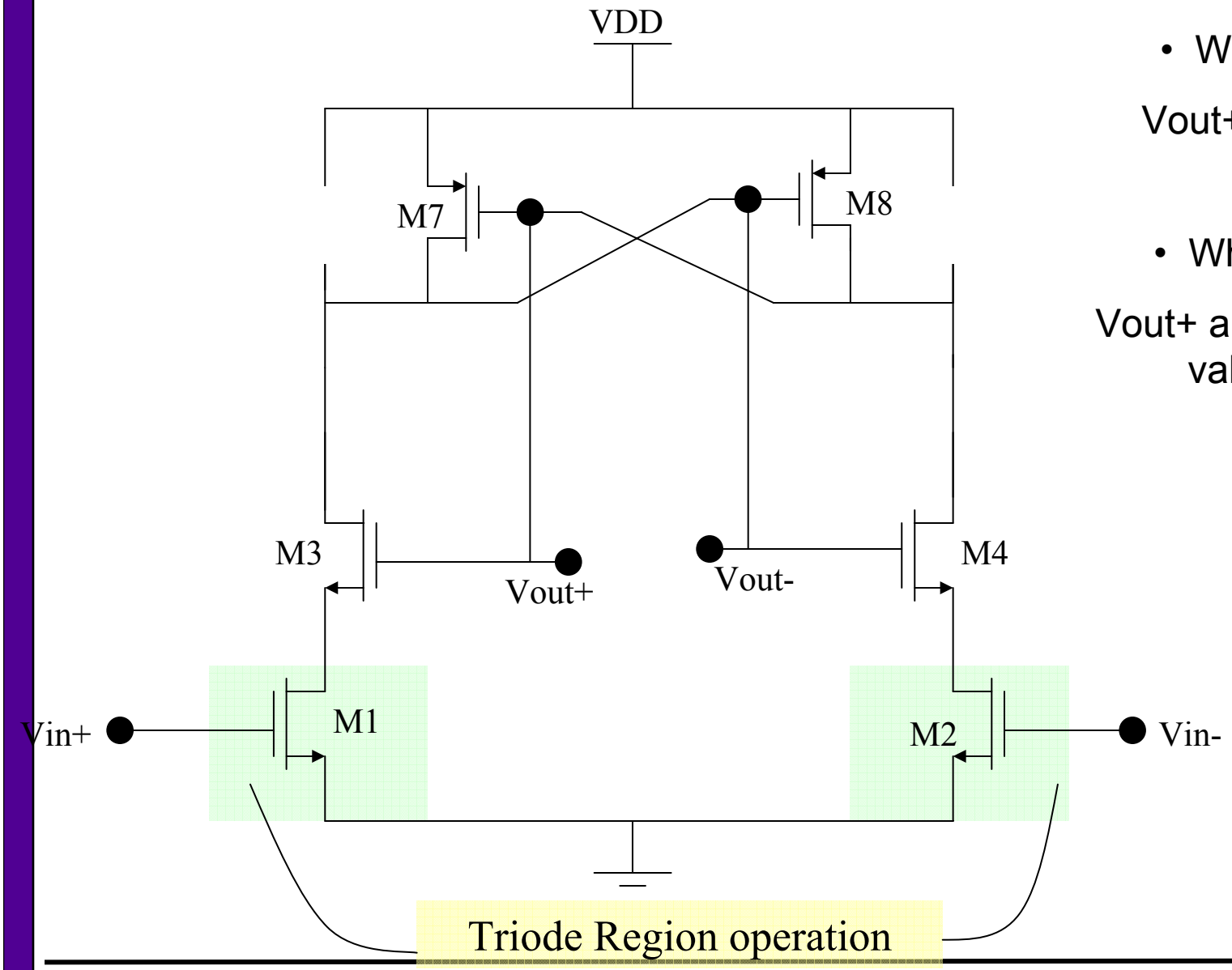
- **Low gain**
- **Able to sink/source large amount of current in the output capacitance.**

Latched Comparator





Latched Comparator - Operation



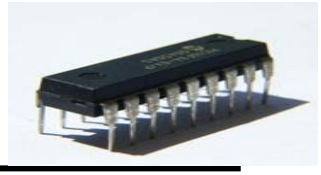
- When CLK=0

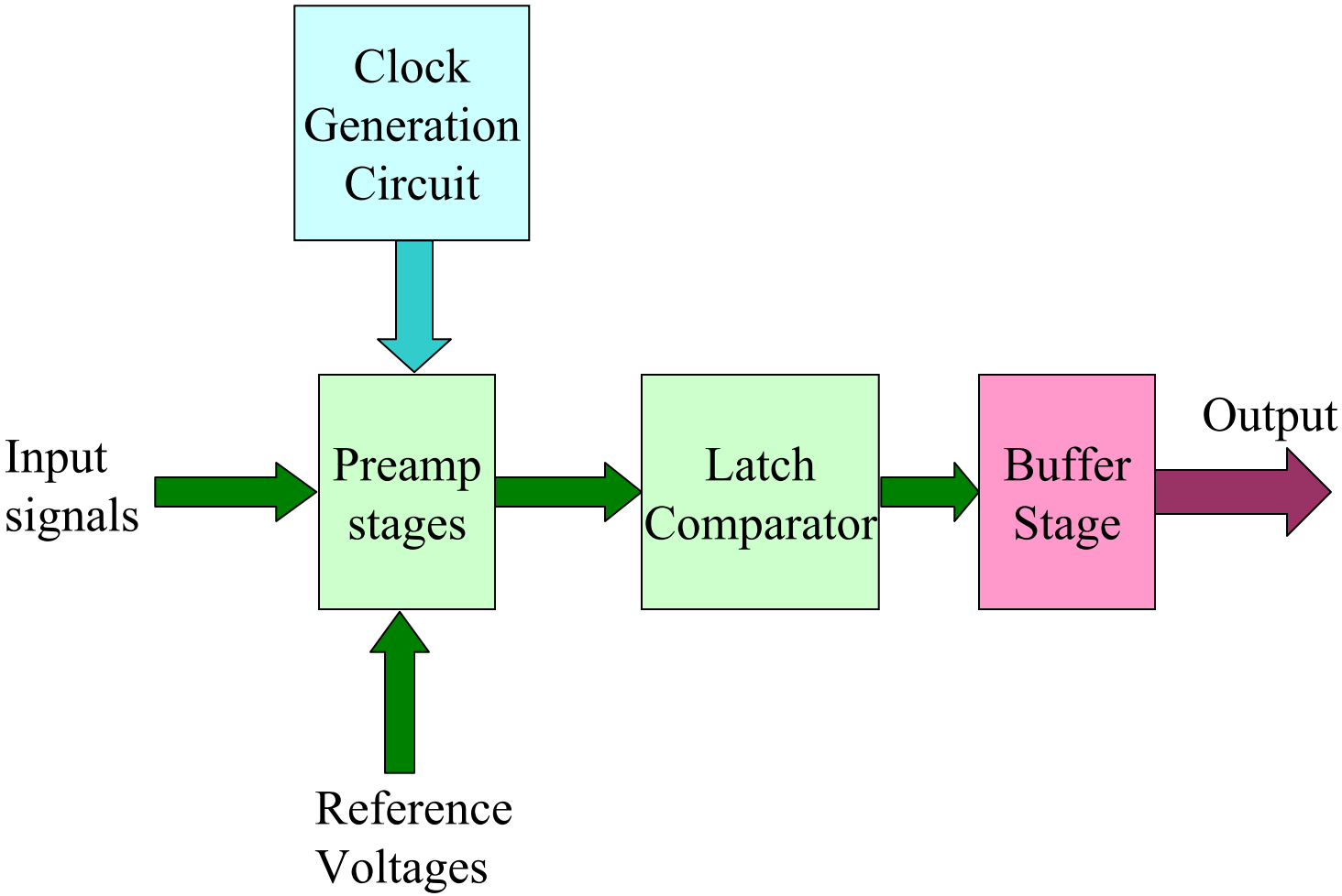
Vout+=Vout-=V_{DD}

- When CLK=1

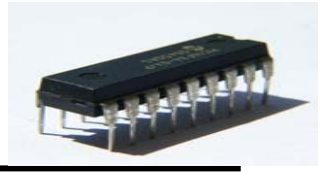
Vout+ and Vout- gives valid output

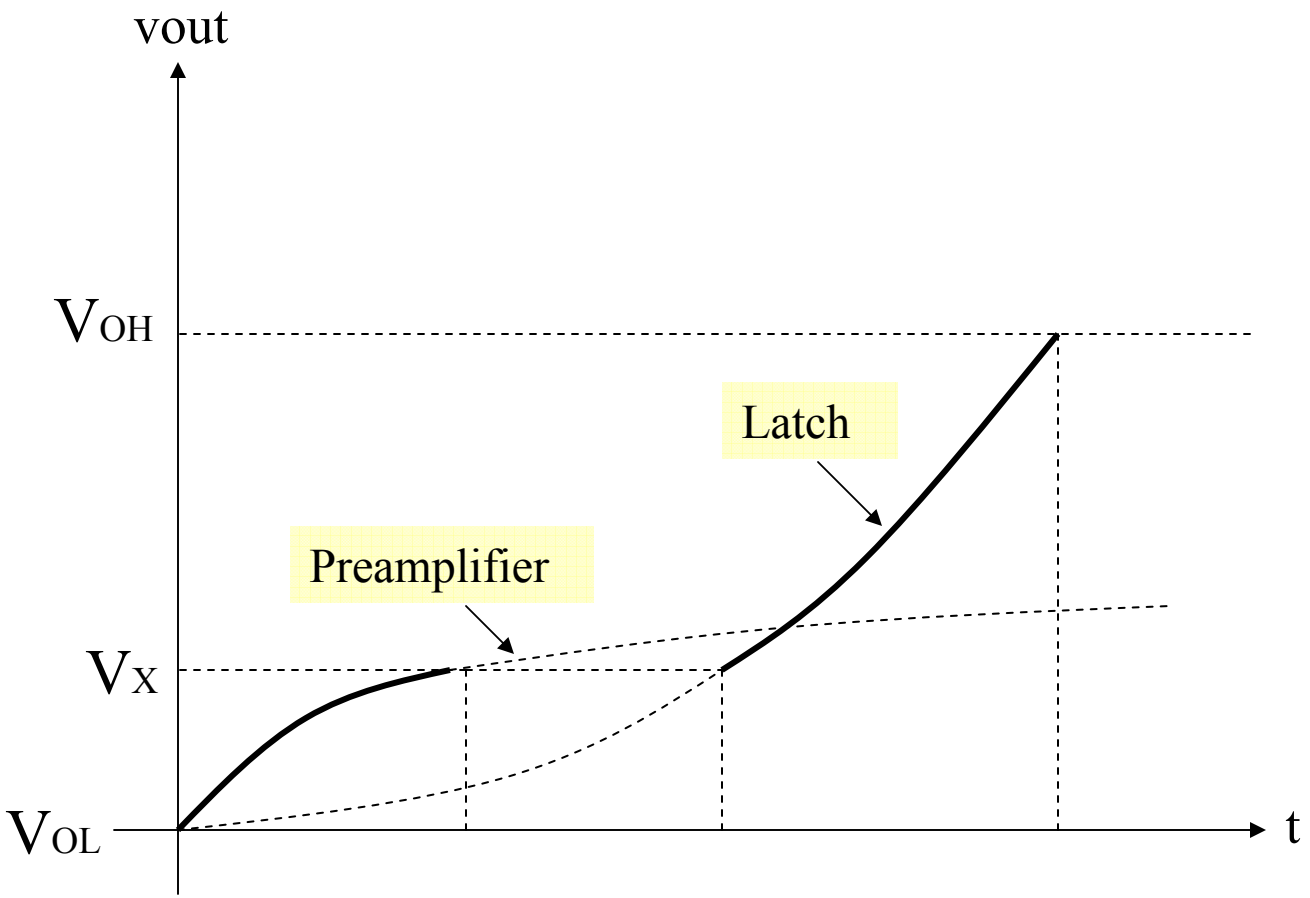
ARCHITECTURE





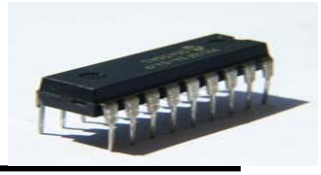
Minimization of Propagation Delay





Use a cascade of linear amplifiers to quickly build up the signal level and apply this amplified signal level to a latch for quick transition to the full binary output swing.

High Speed Comparator Stages

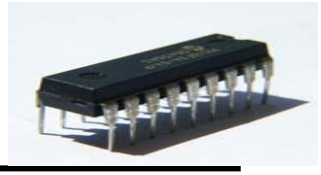


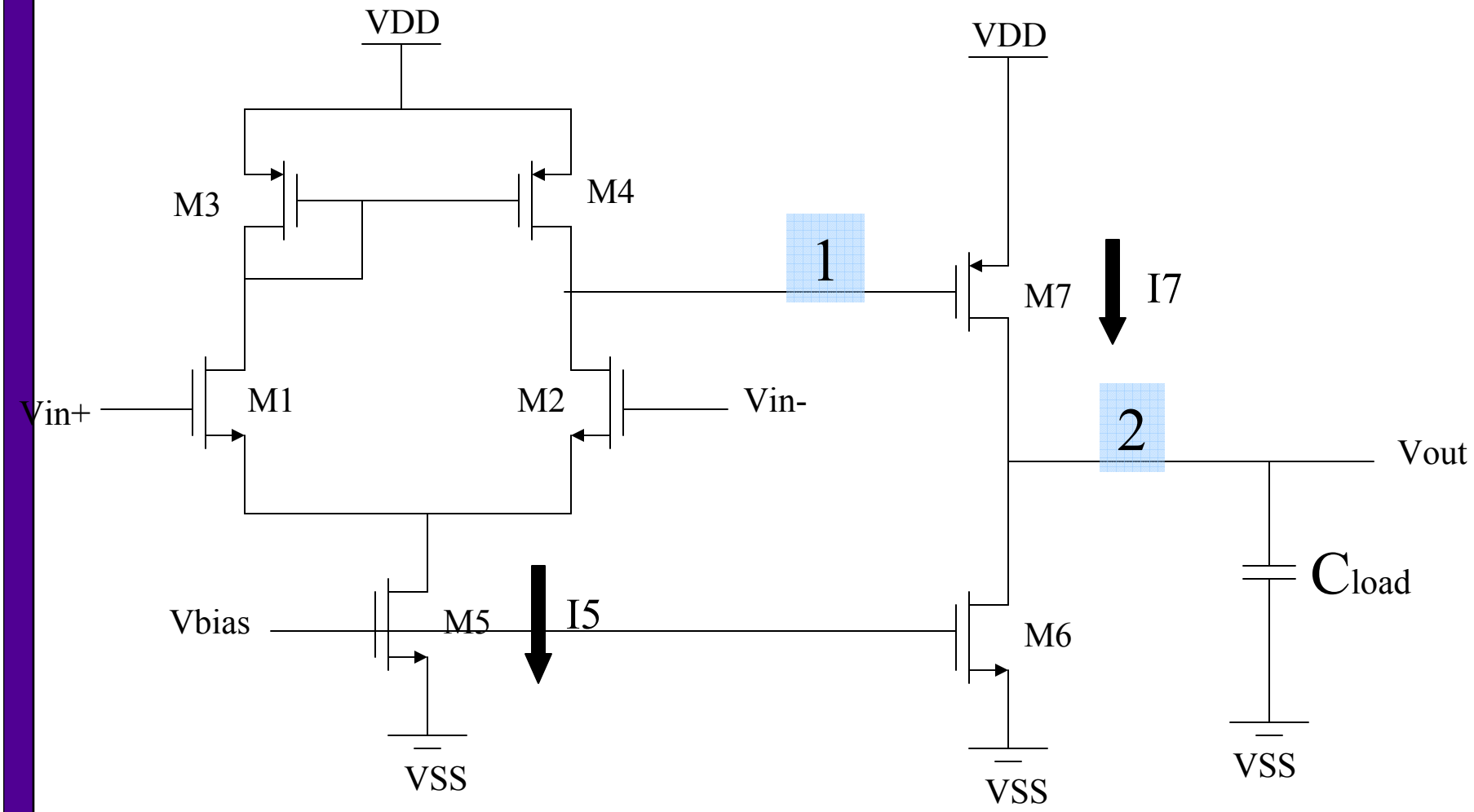
- **The preamplifier advantages:**
  - reduces the comparator input-offset voltage.
  - Reduces kick-back noise.

- **The latch comparator:**
  - Gives high gain.
  - Positive feedback always saturates the output.

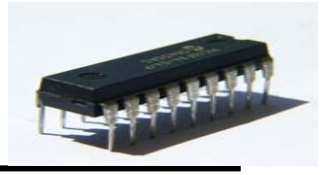
- **The latch comparator:**
  - Drives high load capacitance.
  - Gives output in proper shape.

Design of a two-stage Comparator for slewing response

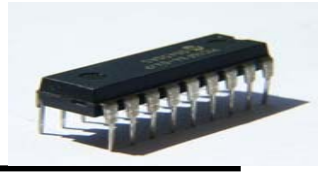




Two Stage Comparator Specifications



- Design a two stage comparator which meets the following specification.(180nm CMOS9, VDD=1.8V)
  - DC gain>100
  - ICMR =0.6V to 1.2V
  - Propagation delay<500ps
  - Min input voltage<20mV.
  - Output capacitance=100fF.
  - Maximum power consumption=1mW.



Have a Nice Day

Thank You

See you in the lab