

Operational Amplifiers

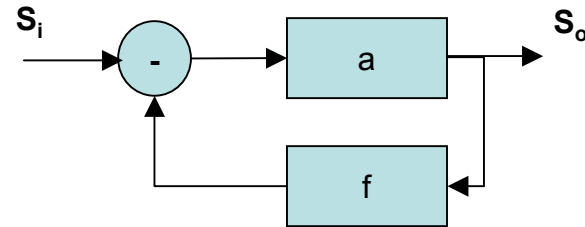
Overview

- **Desired features:**
 - Differential input
 - Infinite voltage gain
 - Infinite input resistance
 - Zero output resistance
- **Applications**
 - Switched capacitor
- **MOS topologies**
 - Two stage MOS
 - Two stage MOS with cascode
 - MOS telescopic-cascode
 - MOS folded-cascode
 - MOS Active-cascode

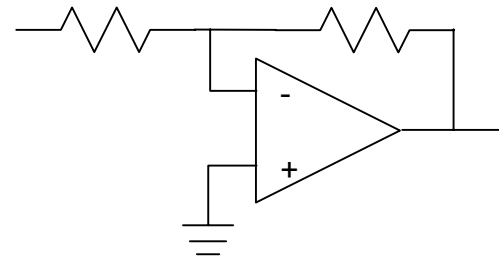
Applications

- **Feedback concept**

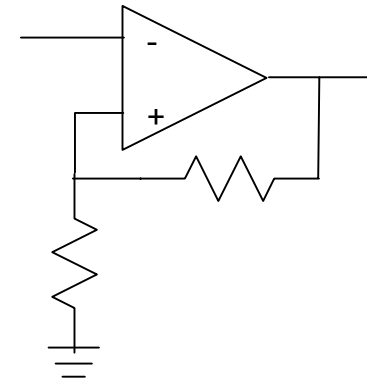
- All op-amp works on the principle of feedback, where feedback network senses output, and develop feedback that will be subtracted from input



- **Inverting amplifier**

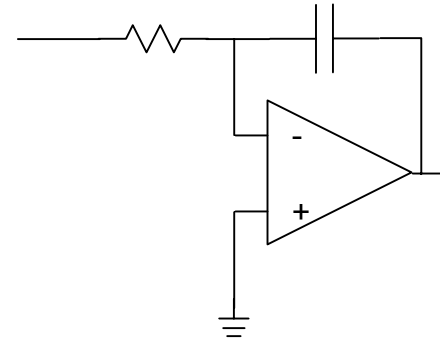


- **Non-inverting amplifier**



Applications (cont.)

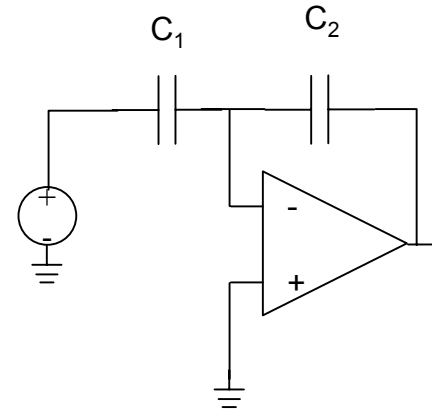
- **Differential amplifier**
- **Integrator/differentiator**
- **Switched capacitor**
 - Monolithic integration on CMOS
 - Using capacitors instead of resistors
 - Dealing with charge
 - Suitable for MOS technology



Switched Capacitor

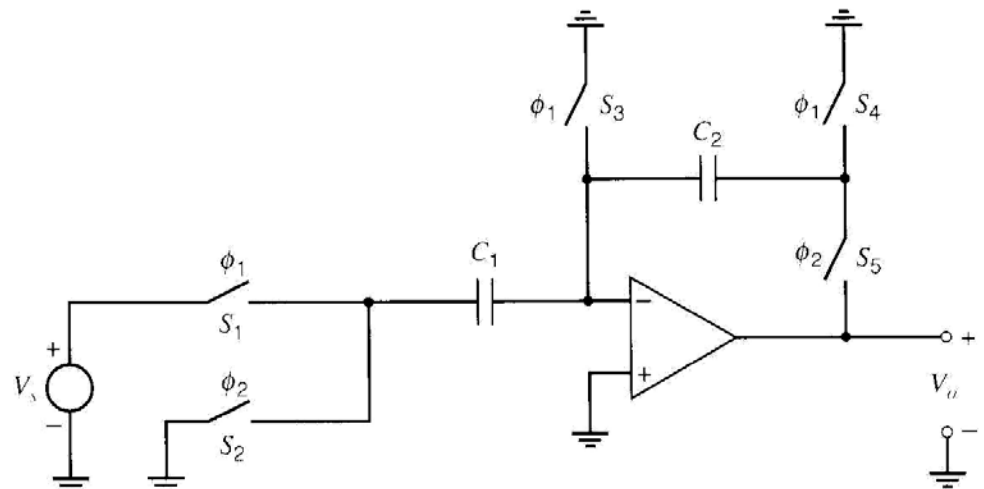
- **An inverting amplifier with capacitive load**

- Gain is proportional to capacitor ratios
- No DC path



- **Adding switches to fix the problem**

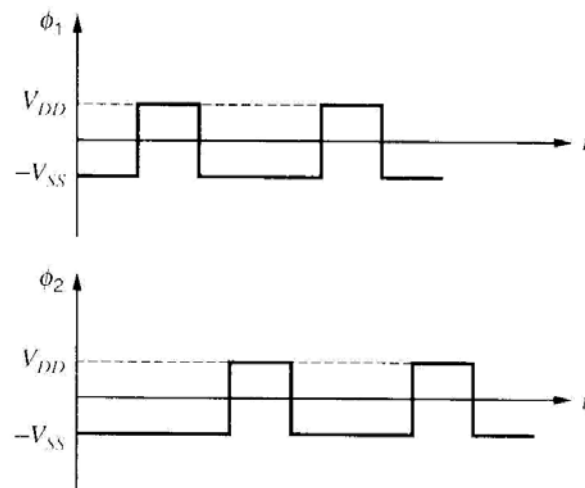
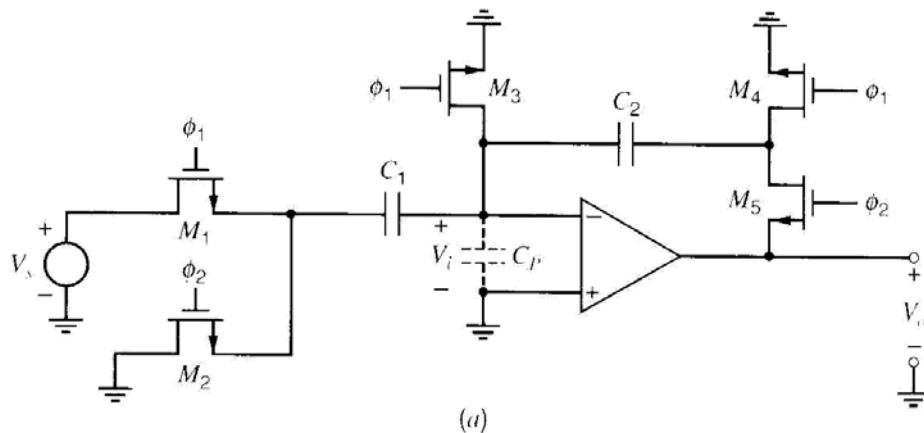
- Non-overlapping clocks



Switched Capacitor (cont.)

- In real life

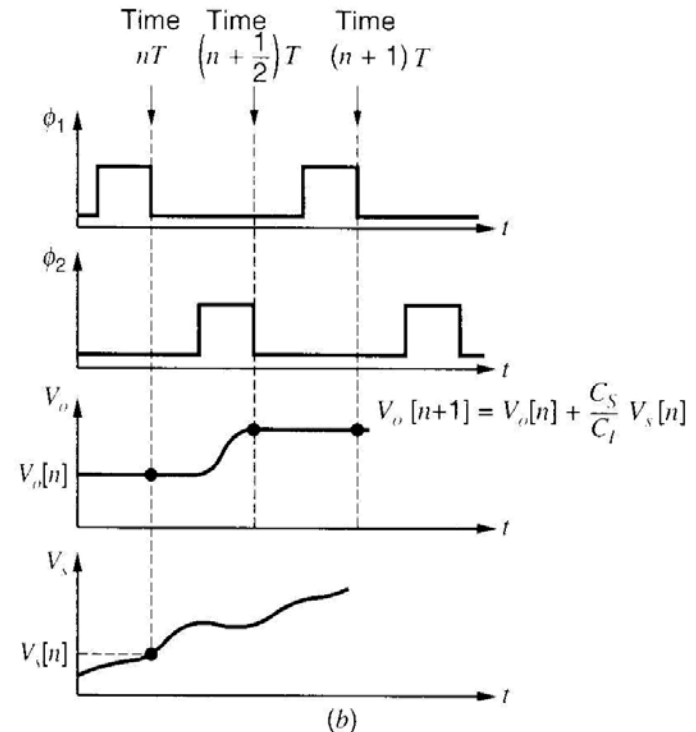
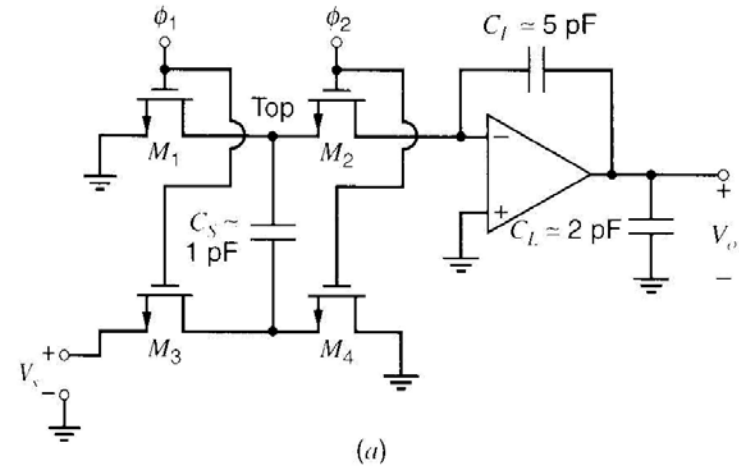
- The gain of op-amp is finite
- Limited effect from parasitic capacitances



Switched Capacitor Integrator

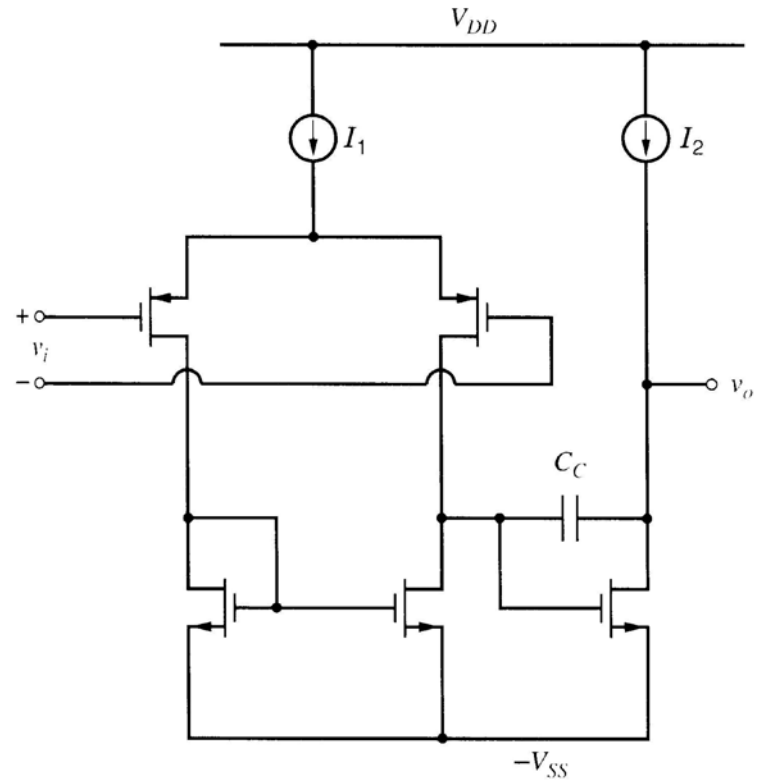
- **Building block for monolithic filters**

- Frequency response insensitive to parasitic
- Time constant controlled by capacitance ratios than absolute values



Two-Stage MOS Op-Amp

- **Two stages are:**
 - Differential input
 - Gain output
- **Performance:**
 - Input resistance
 - Output resistance
 - Voltage gain



Two-Stage MOS Op-Amp (cont.)

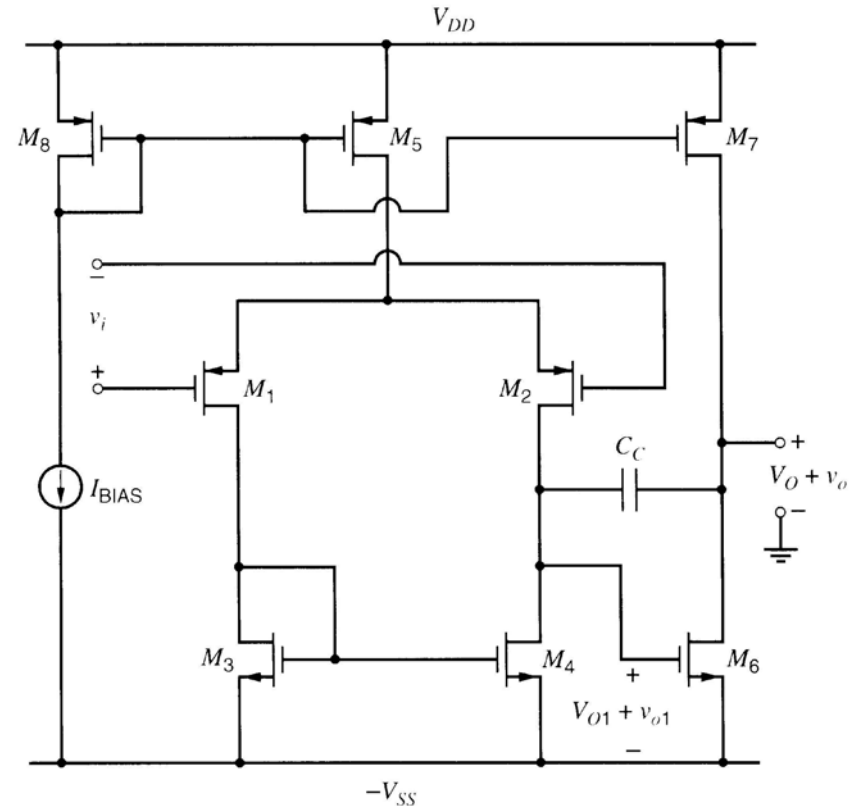
- **Performance:**

- Output swing

- Input offset voltage

- Systematic caused by design as we trade off for other performances

- Random caused by mismatch between pieces where they need to be identical



Two-Stage MOS Op-Amp (cont.)

- **Performance:**

- CMRR

$$CMRR \approx \frac{2}{V_{ov}(dp)} \frac{2}{V_{ov}(mir)} \left(\frac{V_A(dp)V_A(mir)}{|V_A(dp)| + |V_A(mir)|} \right)$$

- Common mode input range

$$V_{t3} - |V_{t1}| + V_{ov3} - V_{ss} < V_{IC} < V_{DD} - |V_{t1}| - |V_{ov1}| - |V_{ov5}|$$

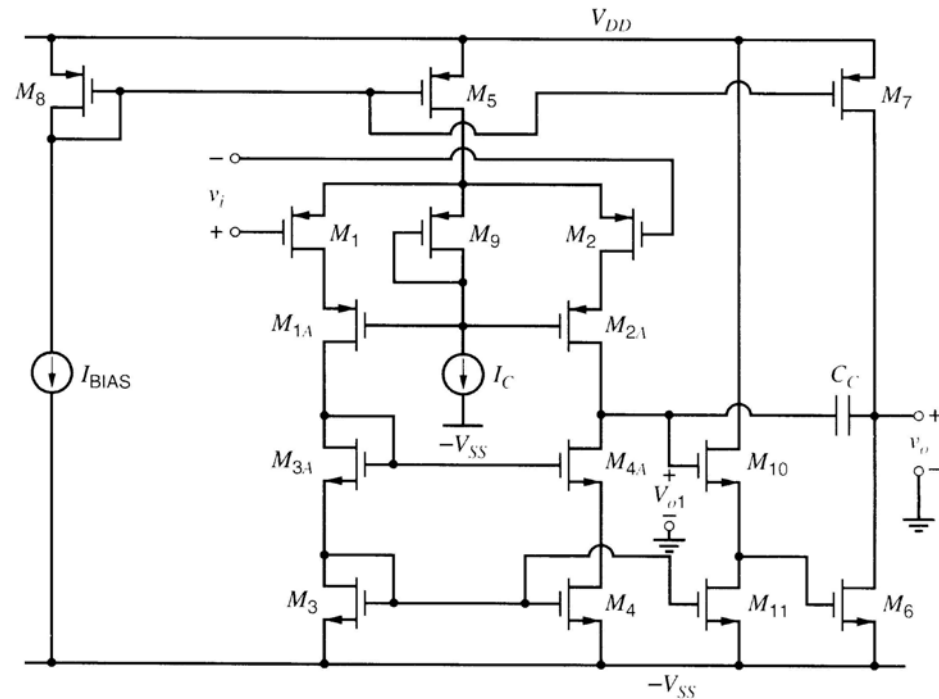
- PSRR (low frequency)

$$PSRR^+ \rightarrow \infty$$

$$PSRR^- \approx - \frac{2}{V_{ov}(dp)} \frac{2}{V_{ov}(mir)} \left(\frac{|V_{A2}|V_{A4}}{|V_{A2}| + V_{A4}} \right) V_{A6}$$

Two-stage MOS Op-Amp with Cascode

- **Goal: increasing the voltage gain without frequency degradation**
 - Using cascode for differential pair to increase unloaded output impedance
 - Degrades the input swing

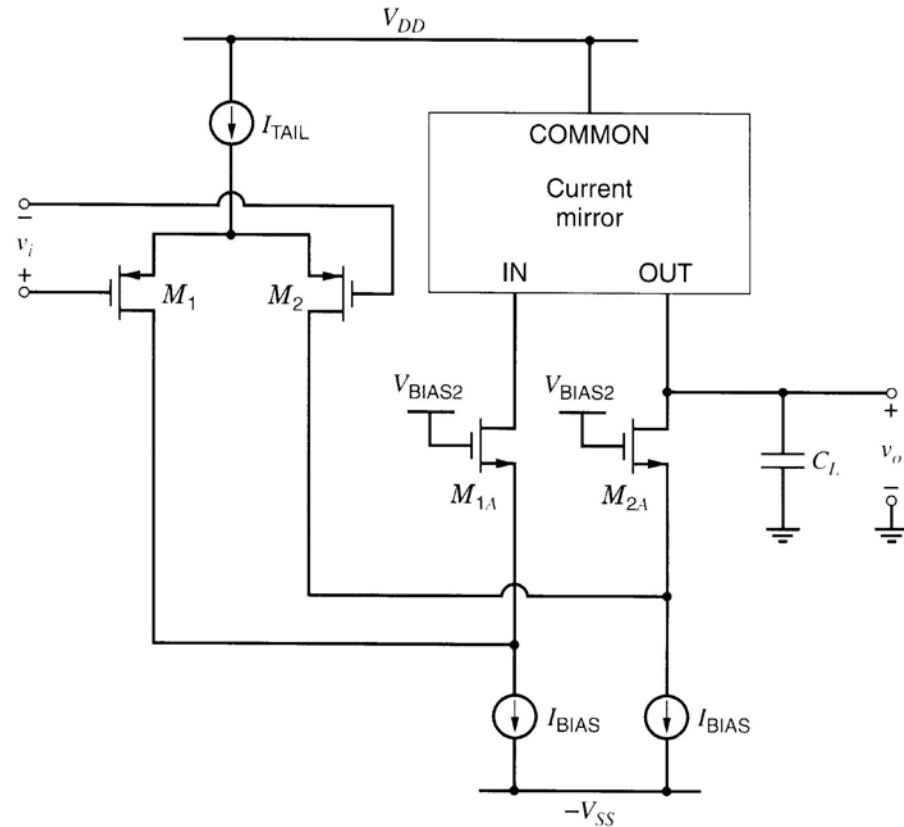


MOS Telescopic Cascode Op-Amp

- **Sometimes just the gain provided by cascode stage is sufficient => drop the second stage in previous topology**
- **Limitations**
 - Poor common mode input range
 - Limited output swing
 - Minimum supply requirements

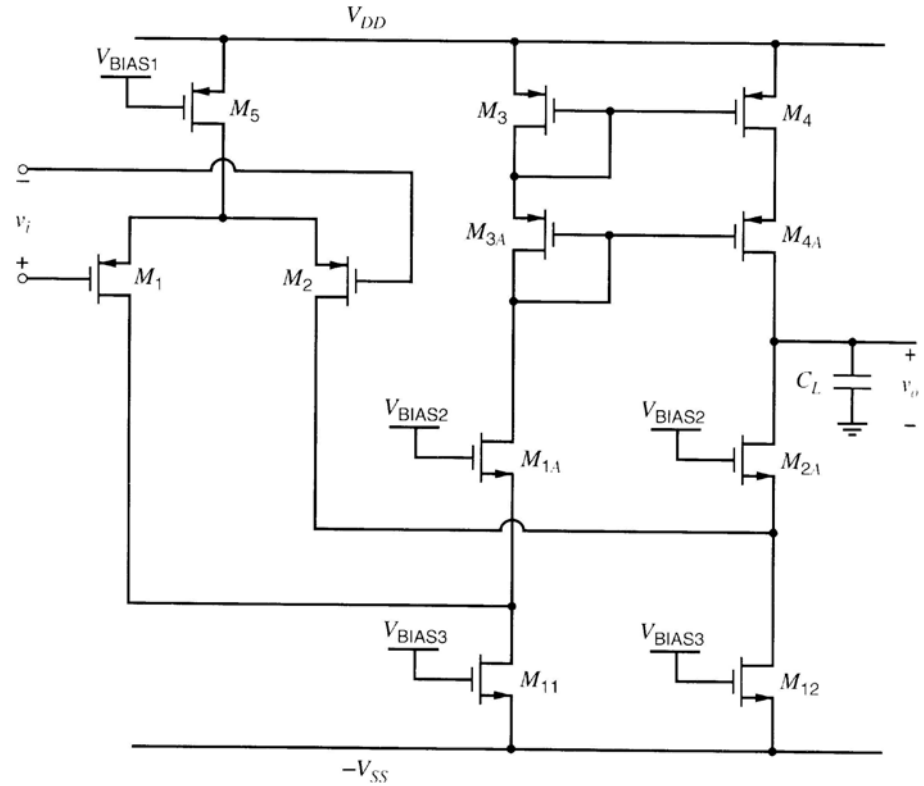
MOS Folded Cascode

- Goal: to address the low output swing and limited common mode input range
- Folded since it reverses the signal flow direction



MOS Folded Cascode

- Schematic of a folded cascode Op-Amp



Summary

- Review some of the methods to design a MOS Op-Amp
- Assignments: 6.2, 6.3, 6.4, 6.8, 6.10, 6.15