Spring 2002

EEE598D: Analog Filter & Signal Processing Circuits

Instructor:

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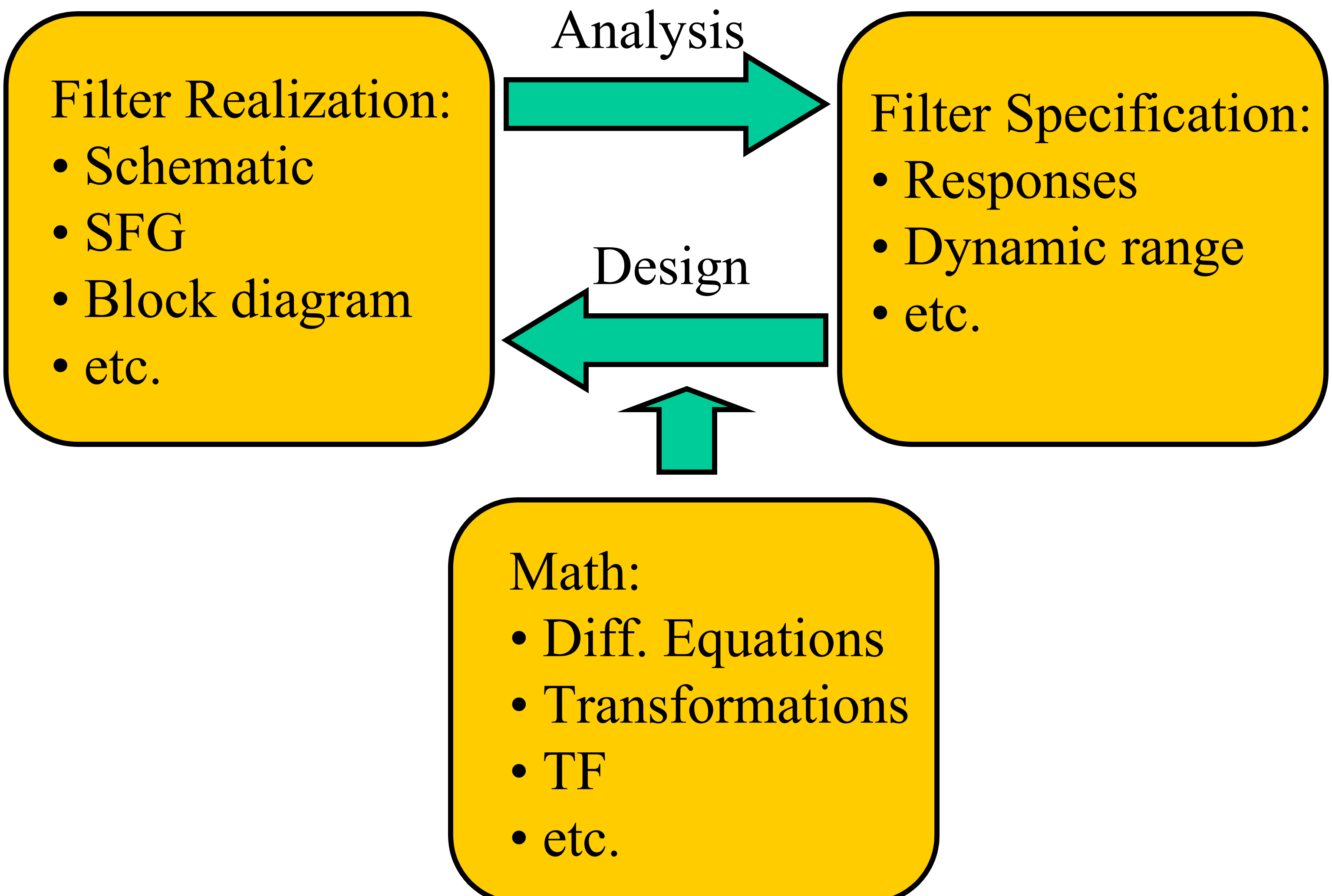
Today: Active RC & MOS-C Circuits

- Basic VLSI Passive & Active Components
- Tuning of Integrated CT Filters
- VCR Structures
- Basic Active RC and MOS-C Circuit Blocks

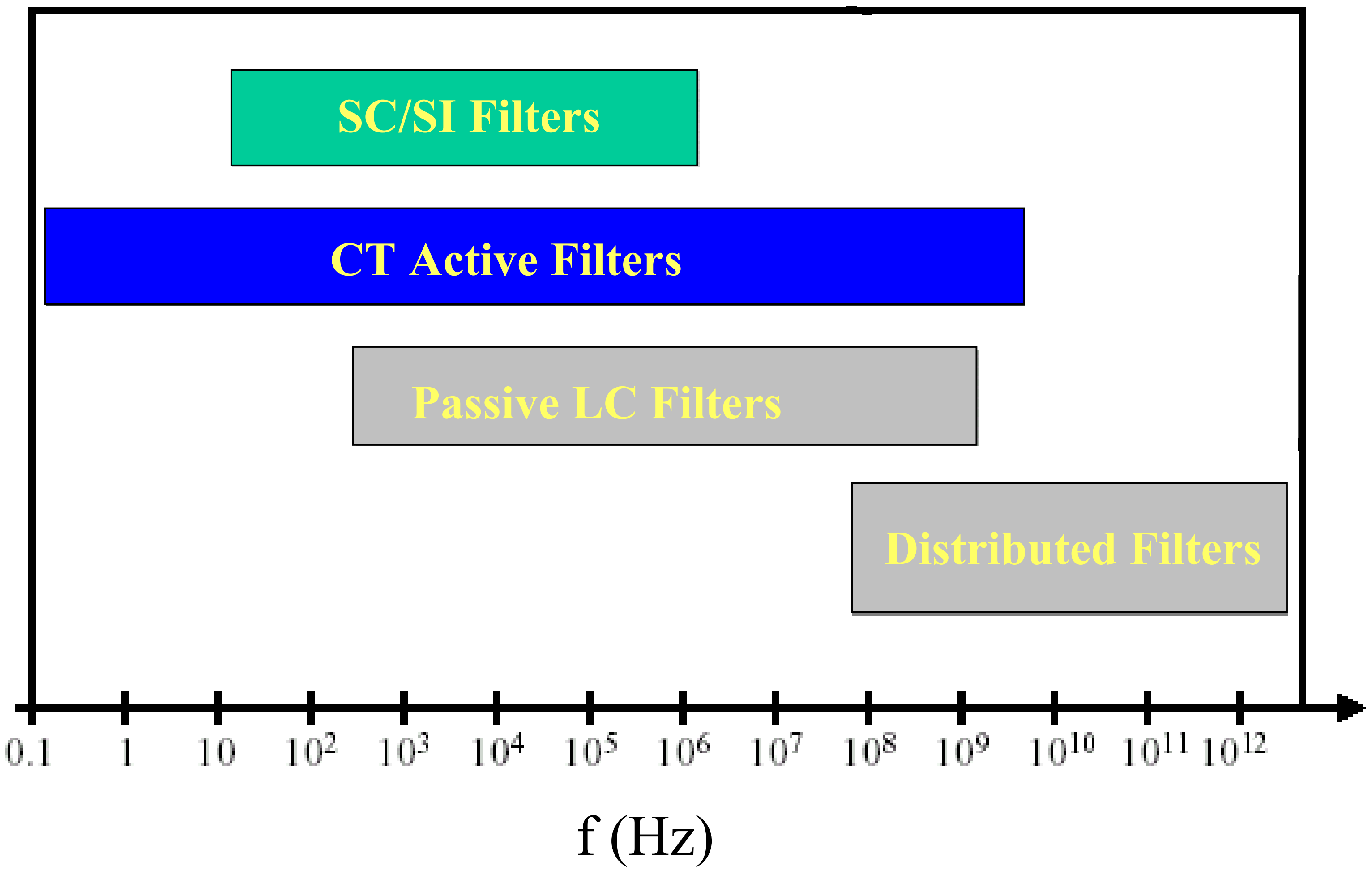
Typical Filter Design Problems



Desired Features for VLSI Filters

- Compatible with VLSI process
- Immunity to parasitic effects, fabrication tolerances, and environment variations
- Large dynamic range
- Good power supply rejection
- Low power and small chip area

Typical Operation Region of VLSI Filters

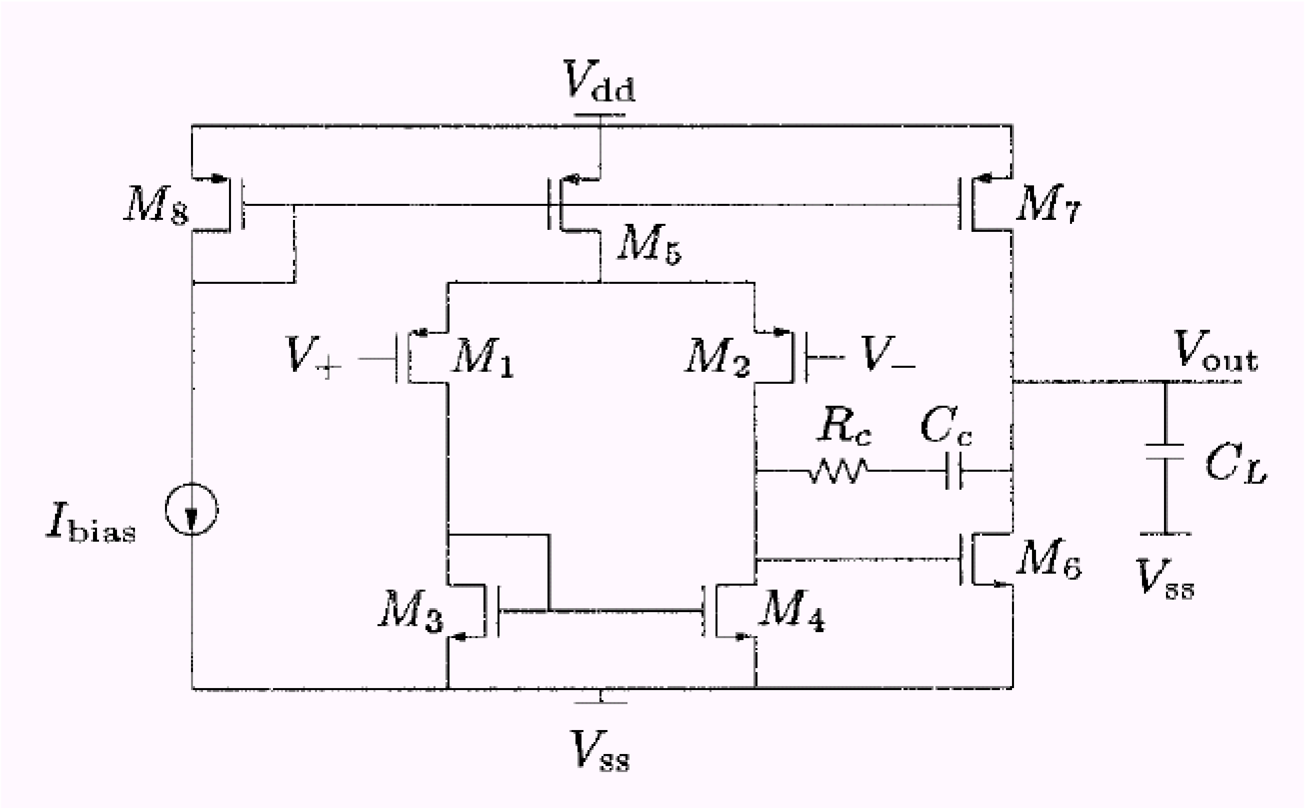


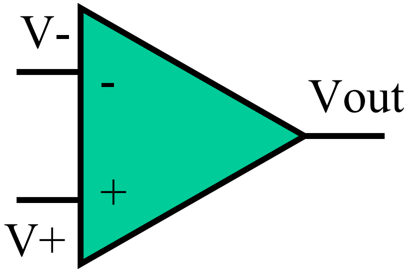
VLSI Active RC and MOS-C Filters

- Direct mapping of discrete active RC filters to VLSI active RC filters with CMOS compatible R, C, and Opamp realization.
- For MOS-C filters, resistors are mapped to MOS VCRs.
- Tuning is usually required due to parameter variation of the VLSI components.

CMOS Opamp Structures

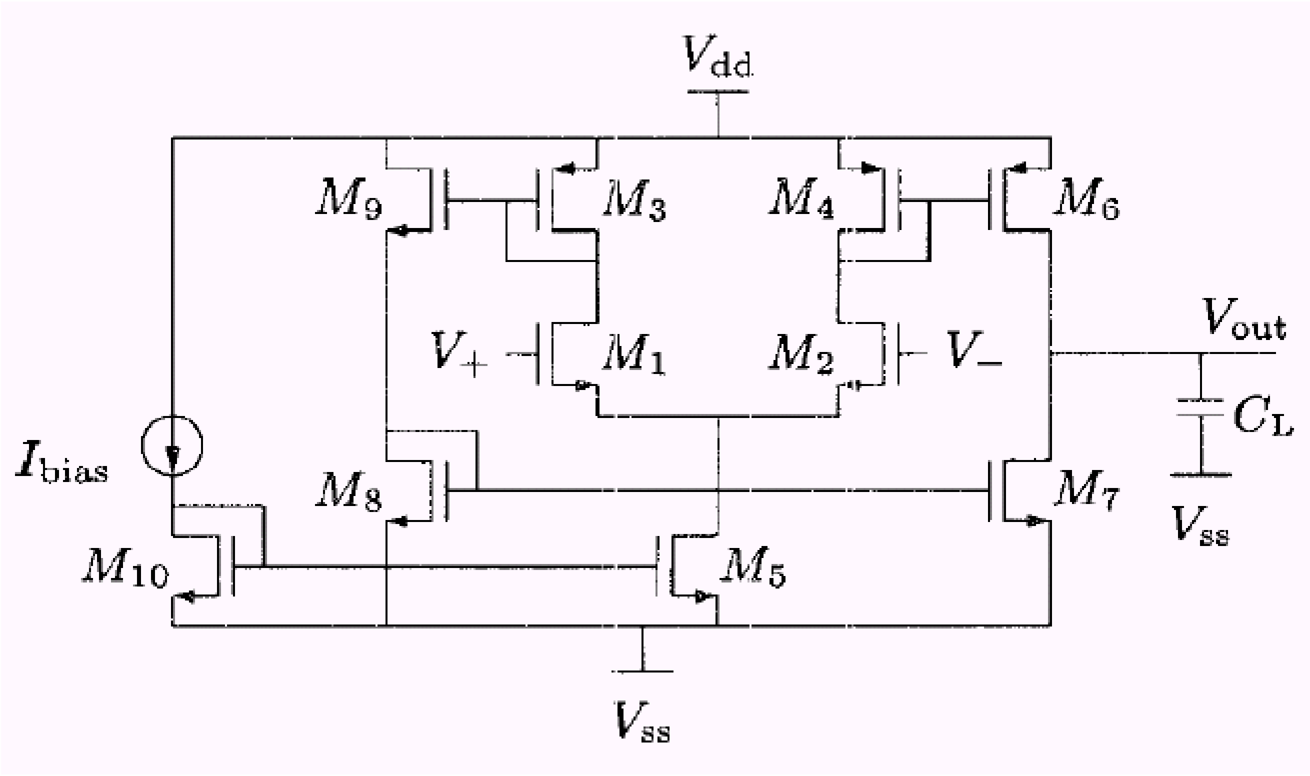
- 2-stage Opamp

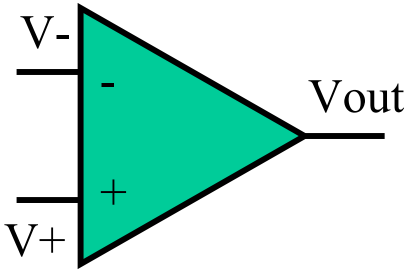




CMOS Opamp Structures

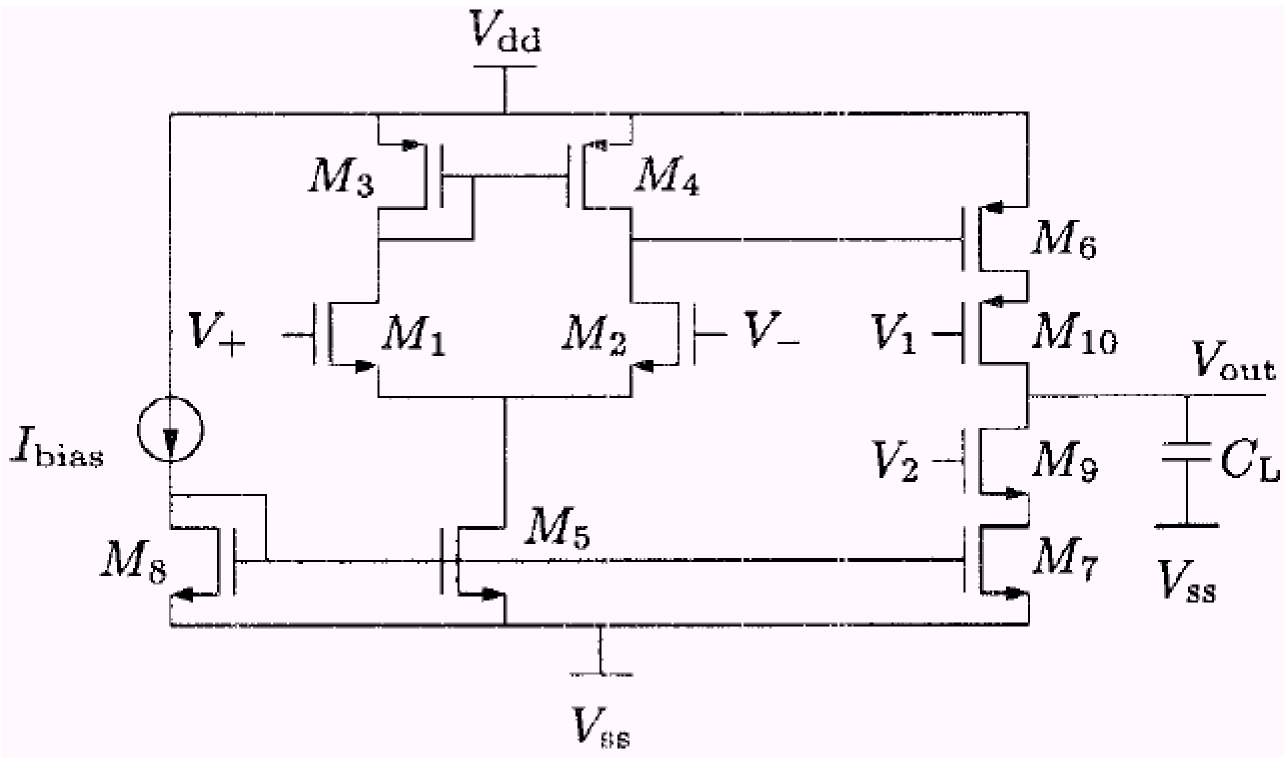
- OTA

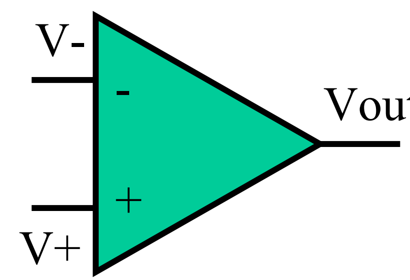




CMOS Opamp Structures

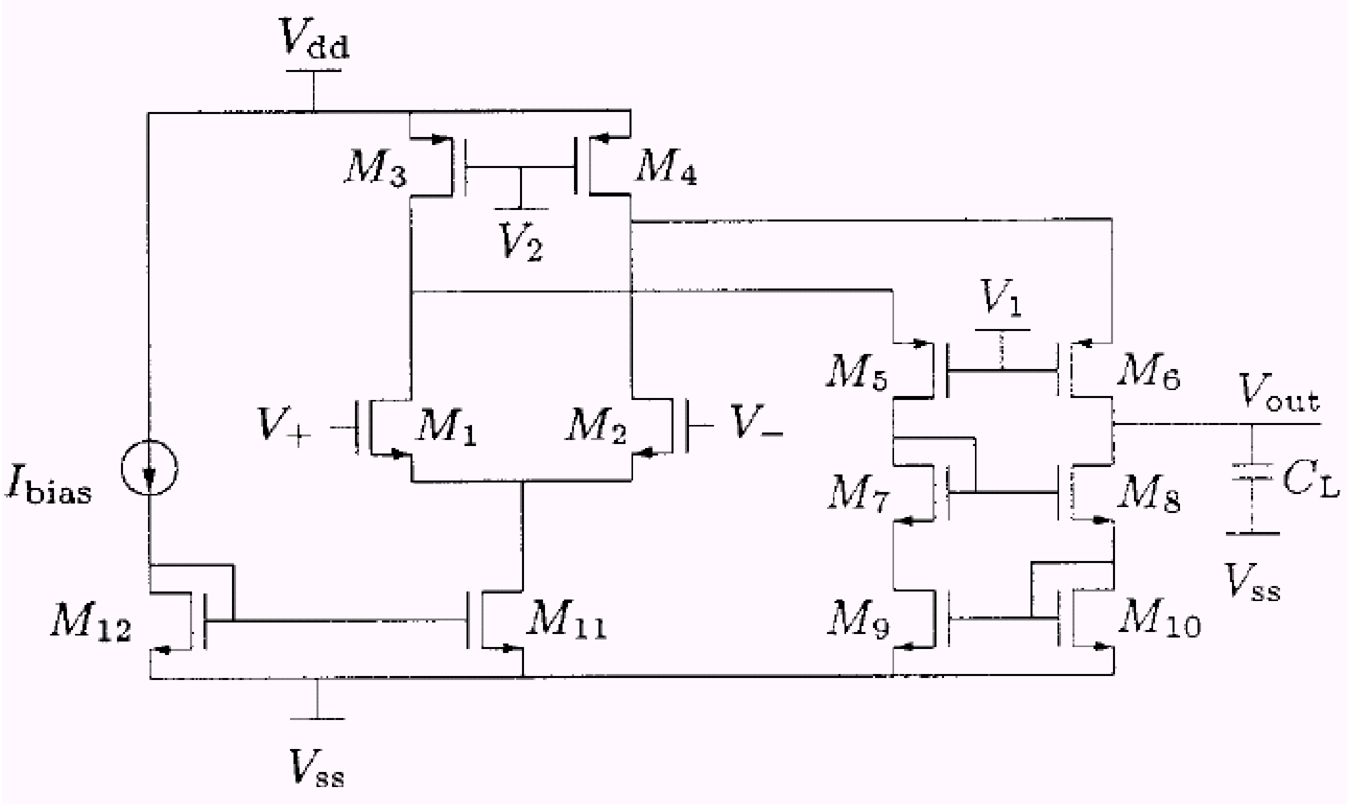
- 2-stage Cascode Opamp

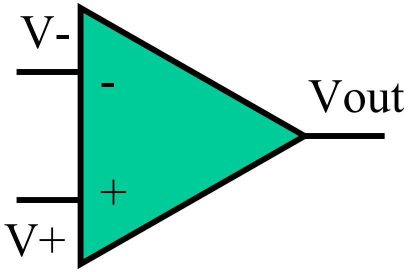




CMOS Opamp Structures

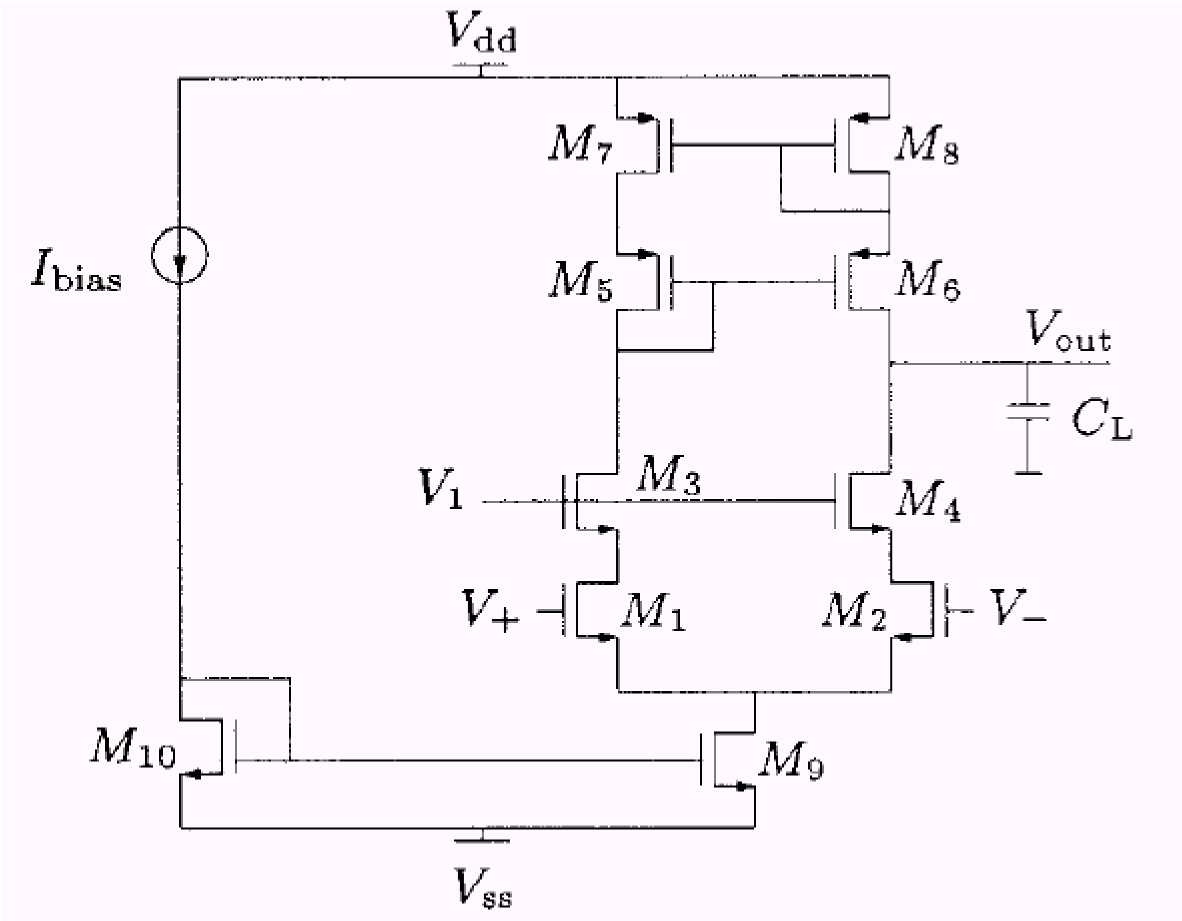
- Folded Cascode Opamp

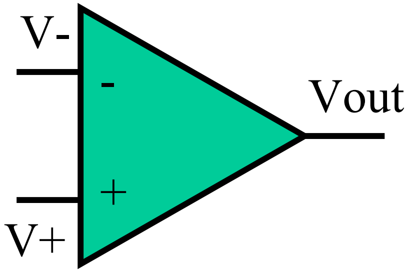




CMOS Opamp Structures

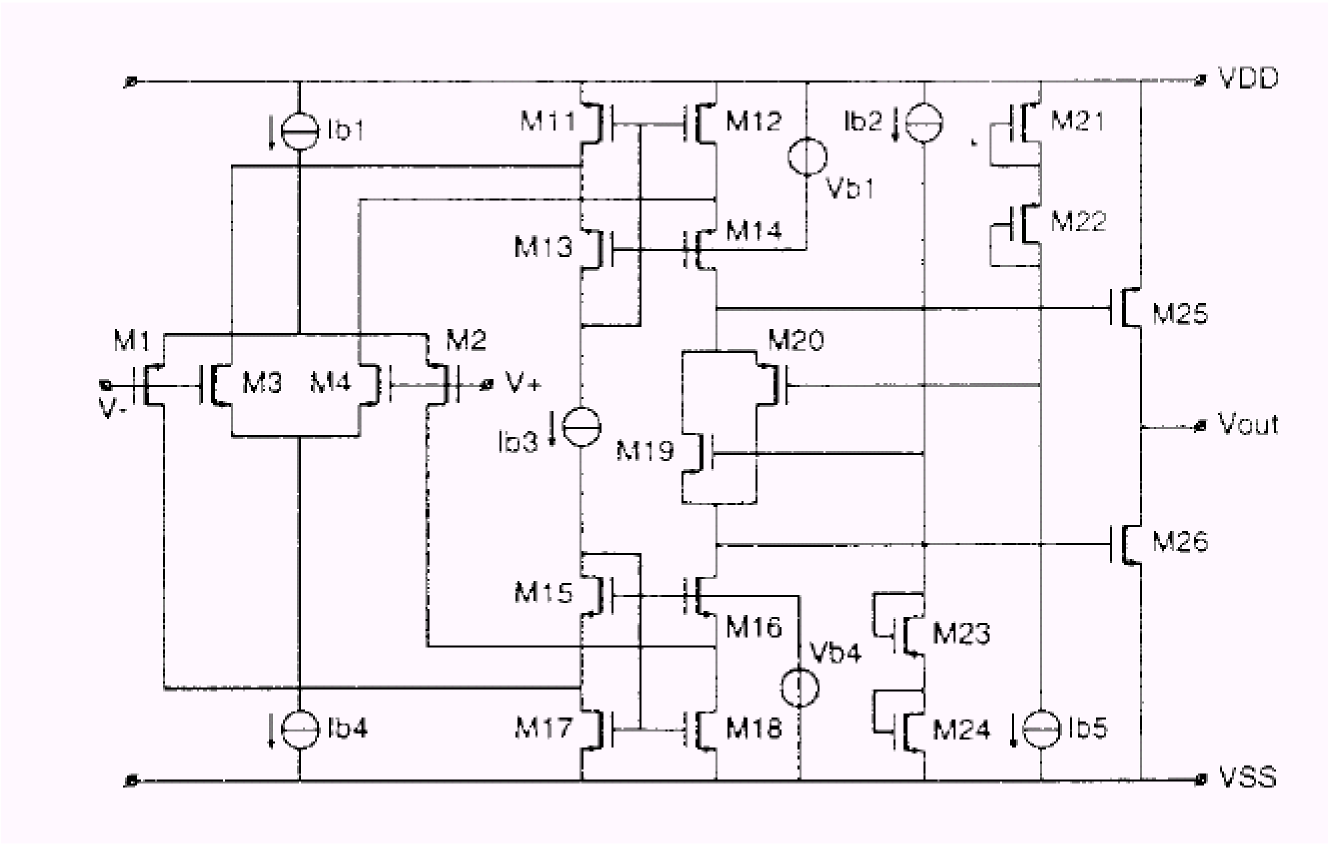
- Telescopic Opamp

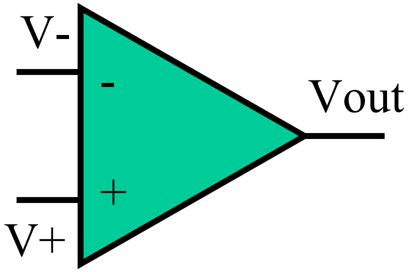




CMOS Opamp Structures

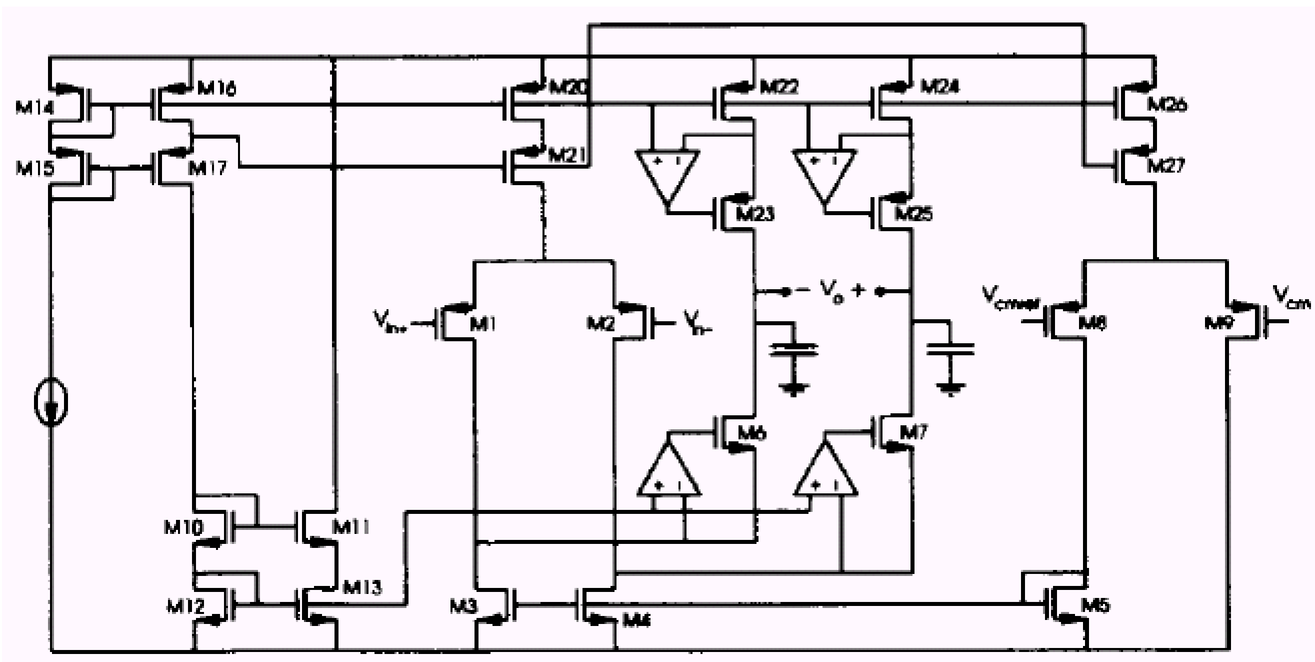
- Rail-to-rail Opamp

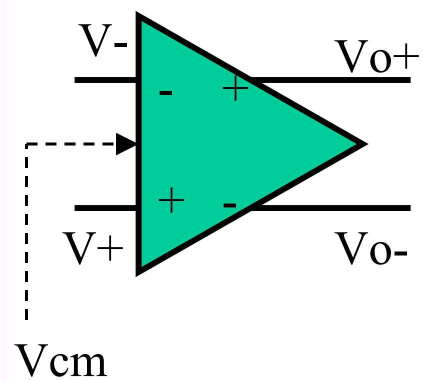




CMOS Opamp Structures

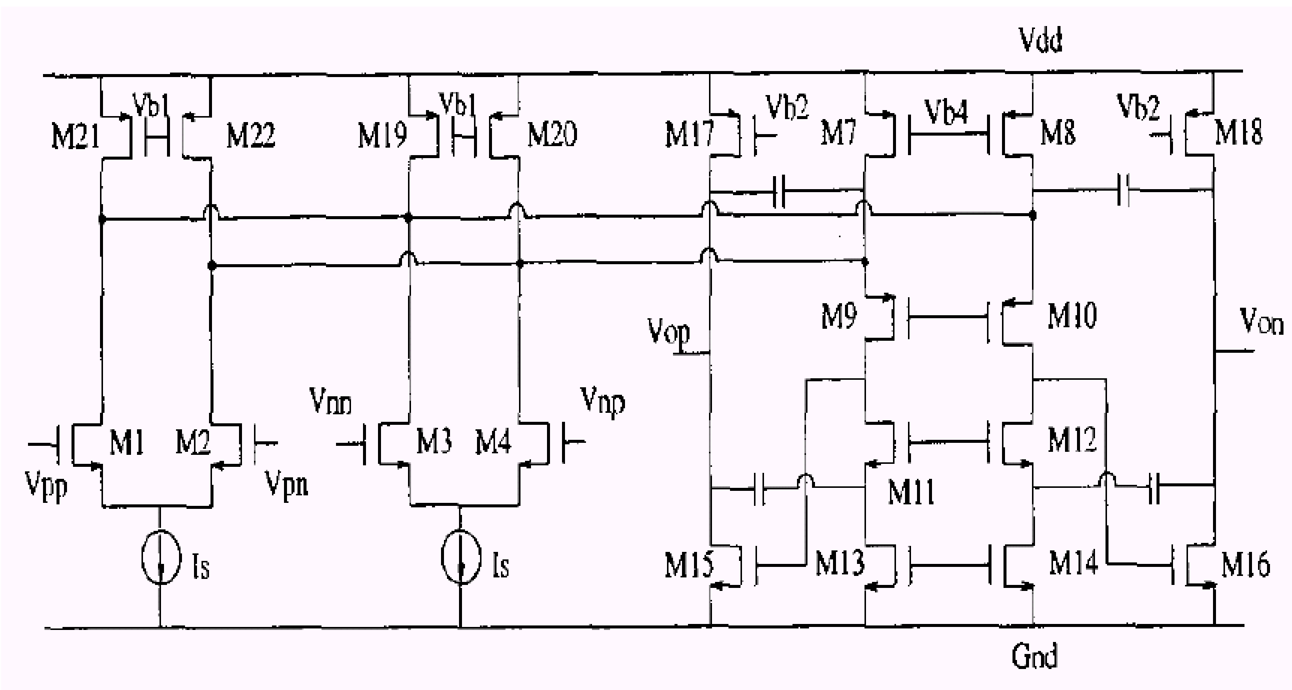
- Fully Differential Opamp

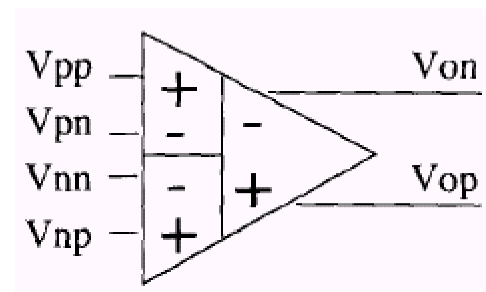




CMOS Opamp Structures

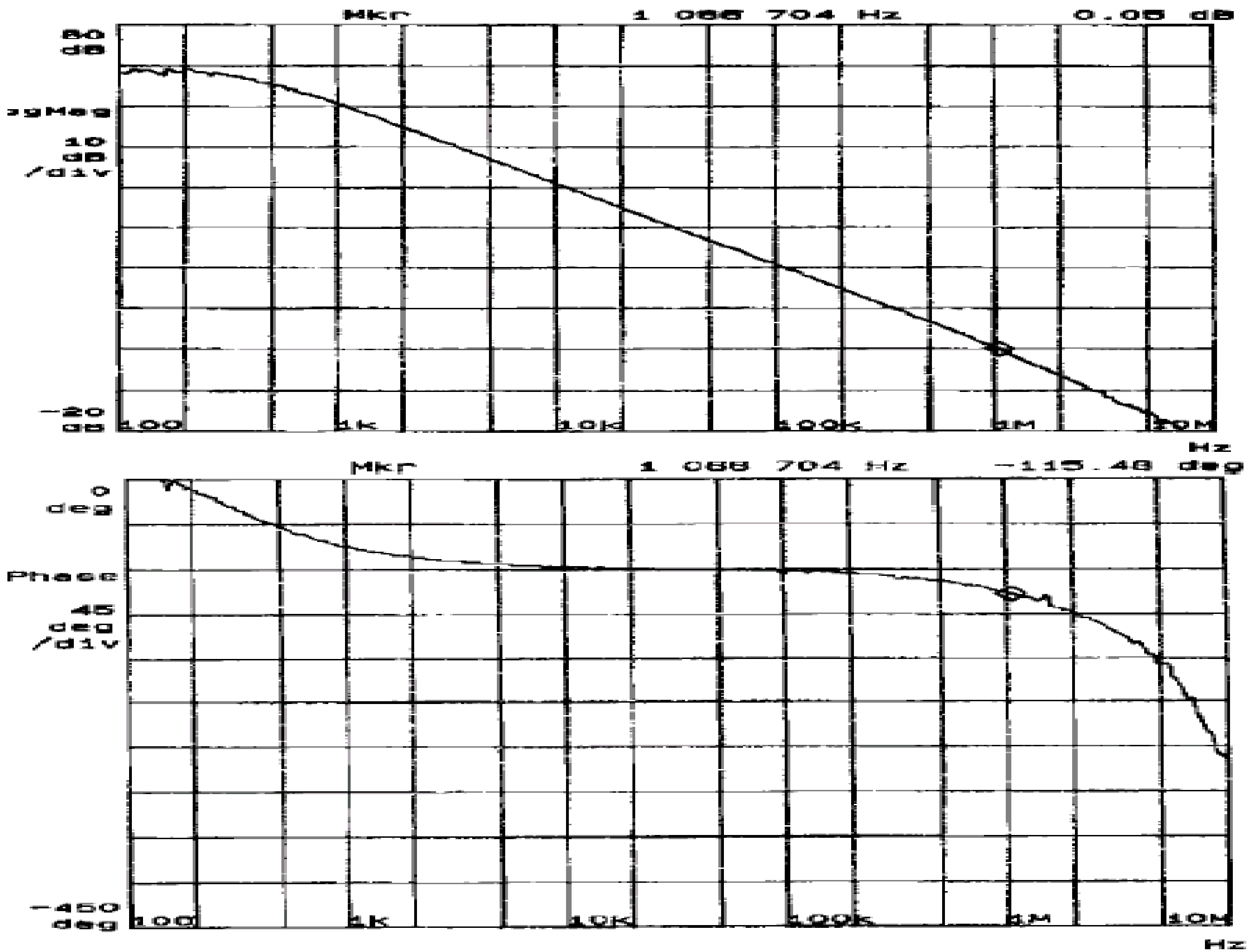
- Differntial Difference Amplifer (DDA)





$$V_o = V_{op} - V_{on} = A_0[(V_{pp} - V_{pn}) - (V_{np} - V_{nn})]$$

Typical Opamp Responses

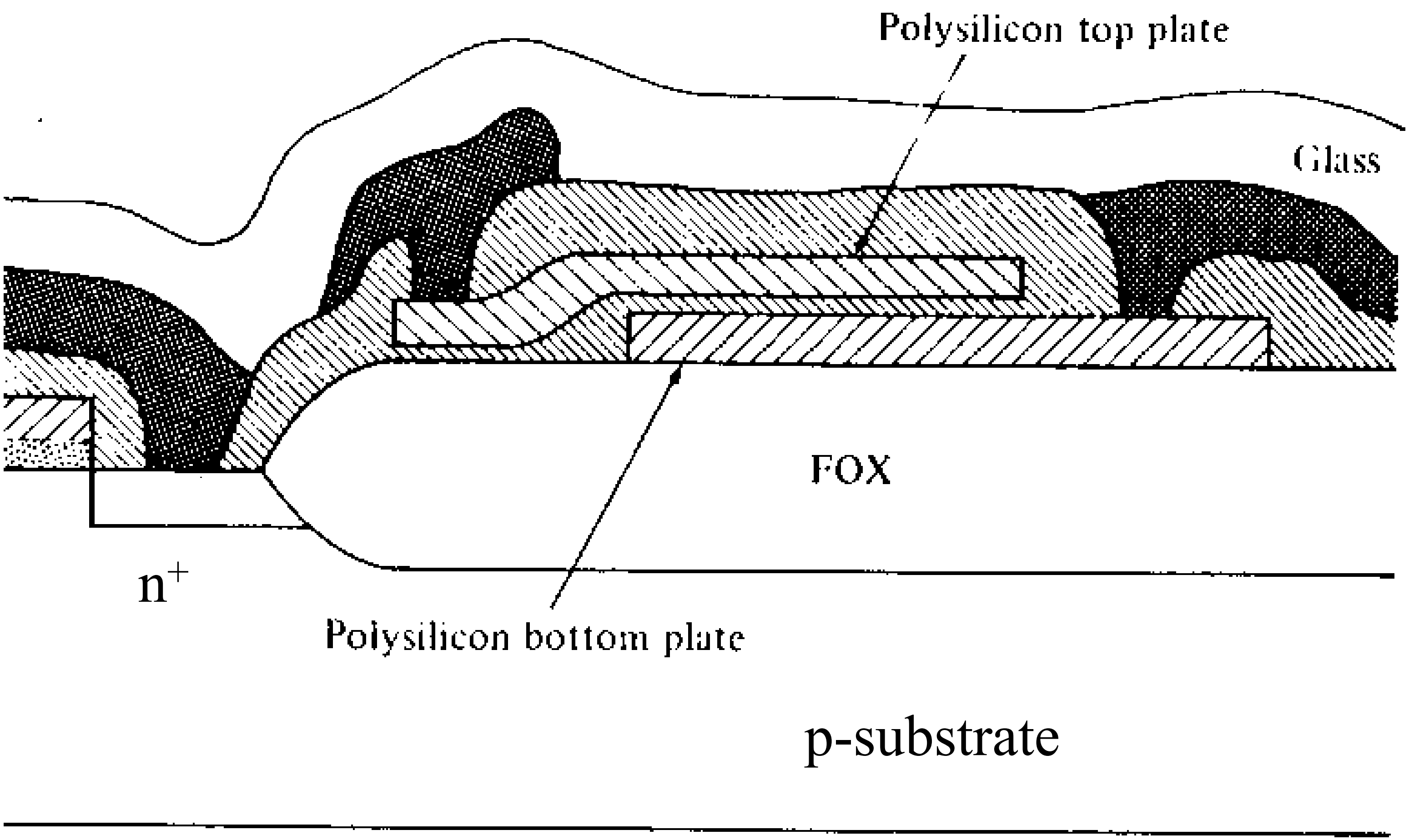


VLSI Capacitor Structures

- Gate capacitors
  - high density, but Nonlinear
- Junction capacitors
  - Highly nonlinear
- Poly(metal)-to-poly (metal) capacitors
  - Good linearity and high Q
- Fractal capacitor
  - High density and good linearity
  - More complicated structure

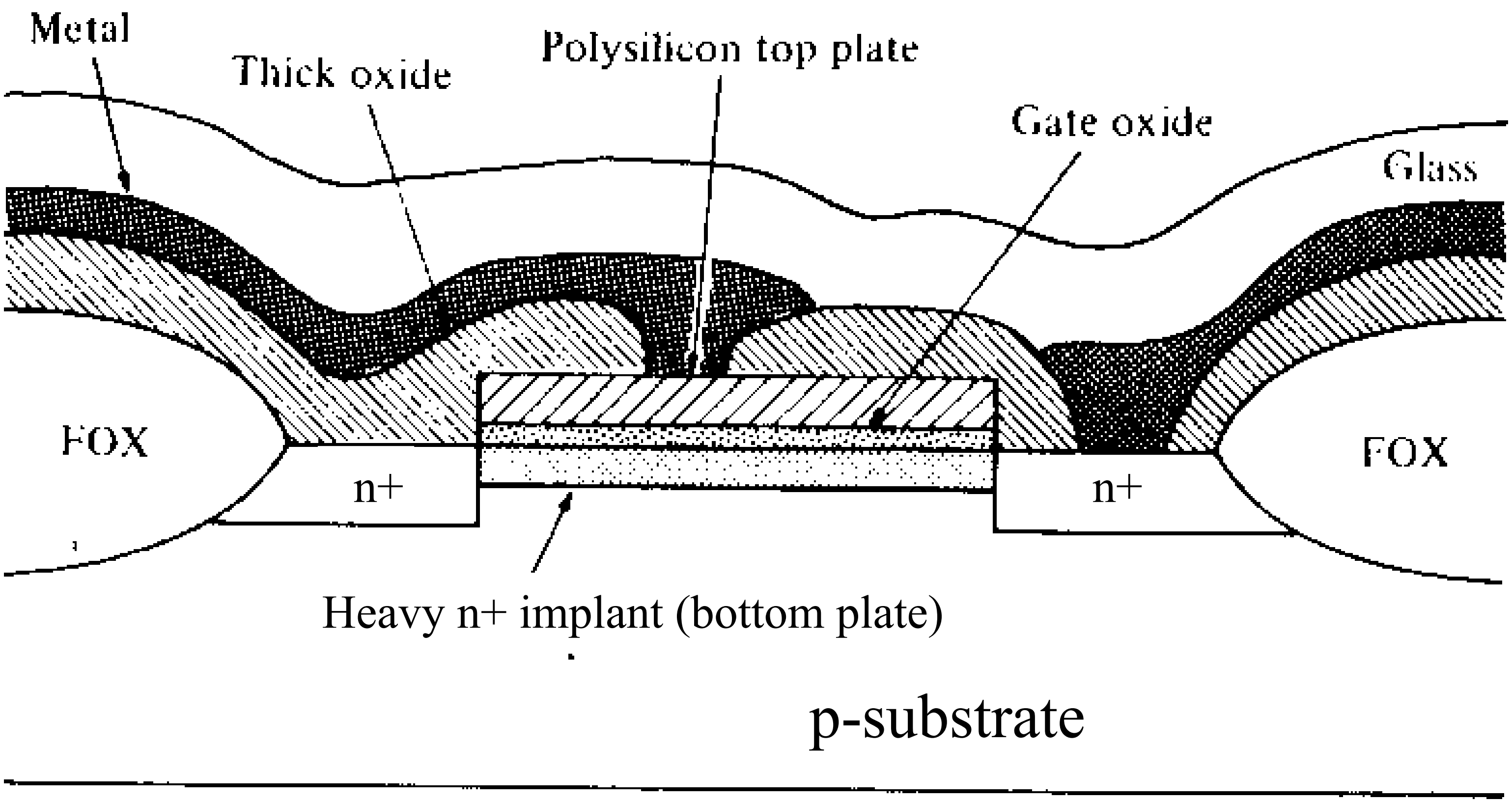
VLSI Capacitor Structures

- Double-Poly Capacitor



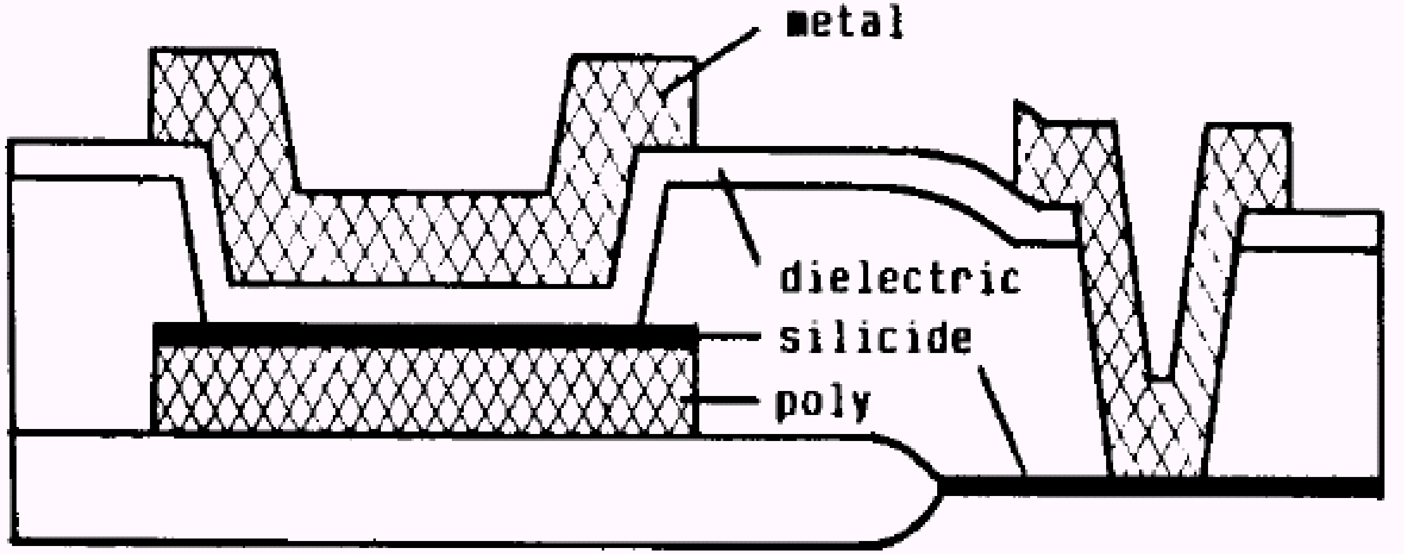
VLSI Capacitor Structures

- MOS Capacitor



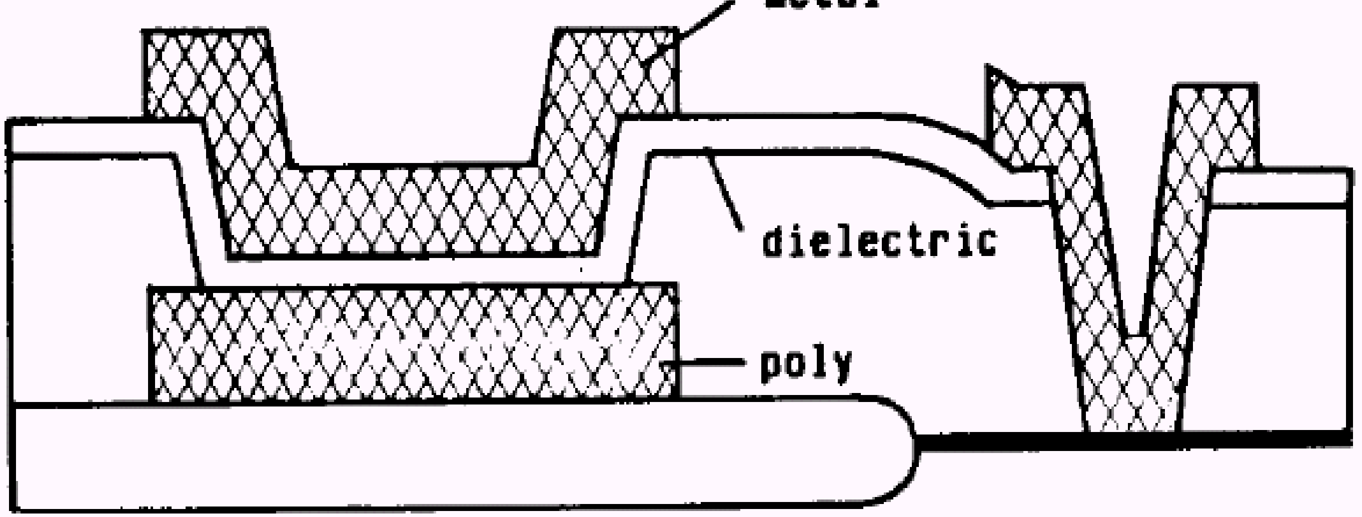
VLSI Capacitor Structures

- Metal-Polycide Capacitor



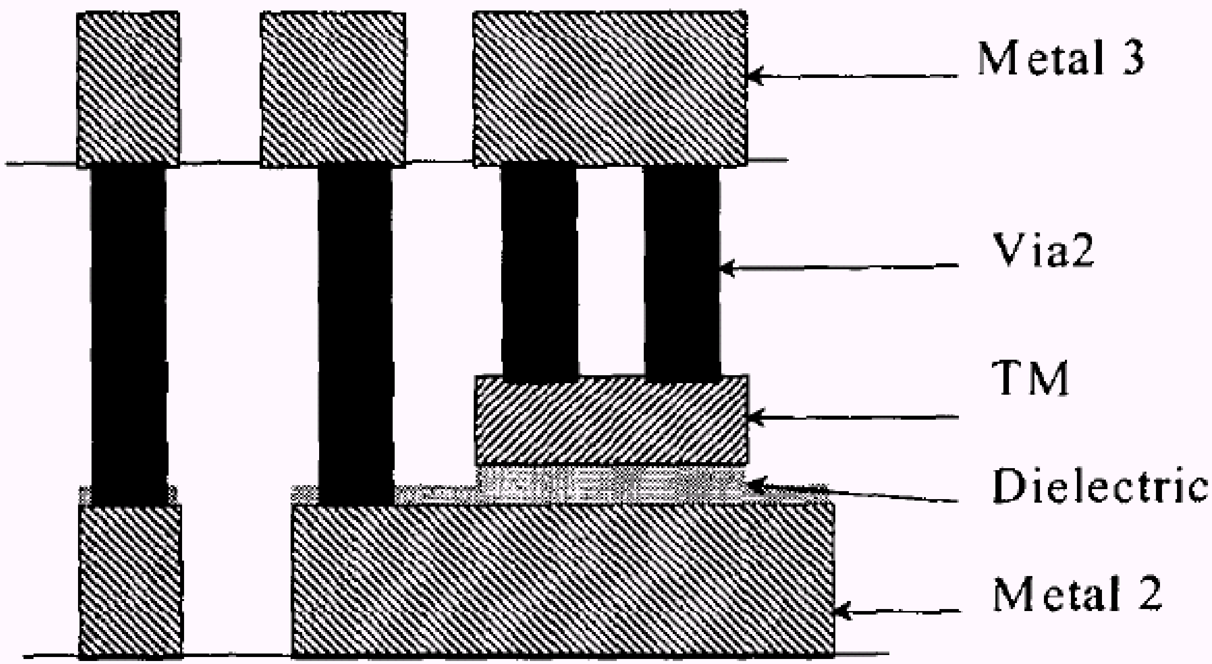
VLSI Capacitor Structures

- Metal-Polycide Capacitor



VLSI Capacitor Structures

- Metal-Insulator-Metal (MIM) Capacitor



MIM Capacitor Structure

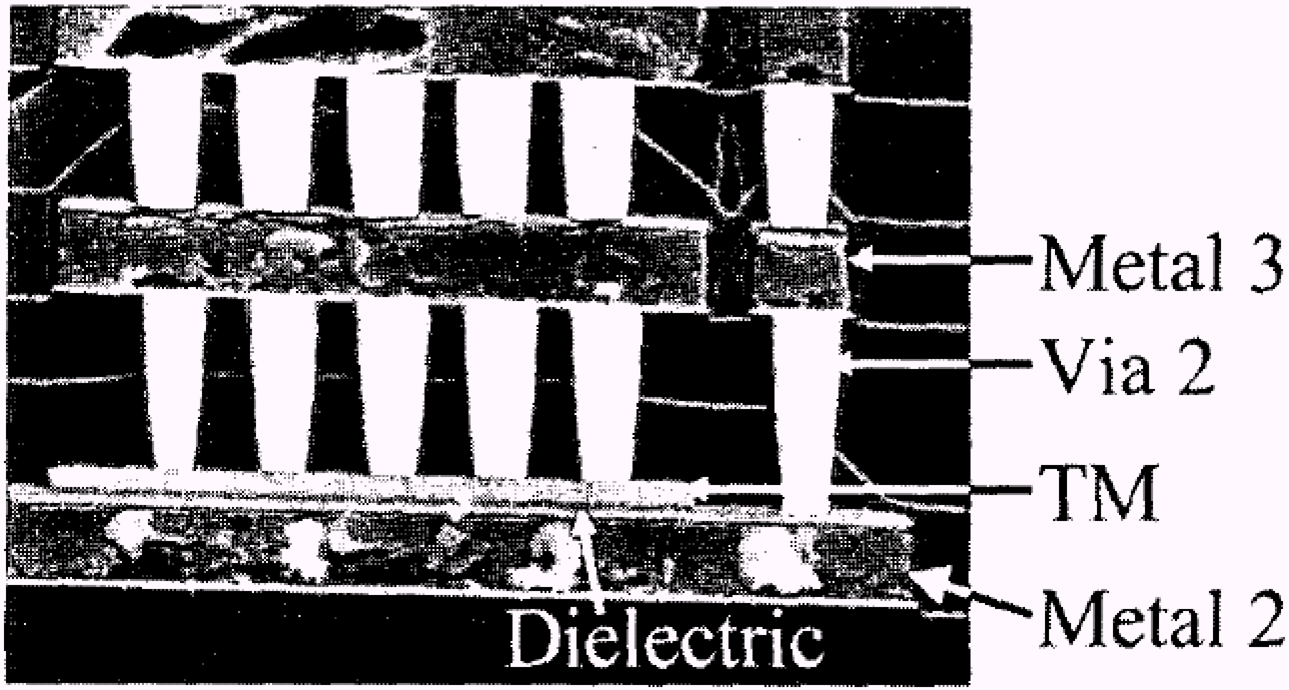
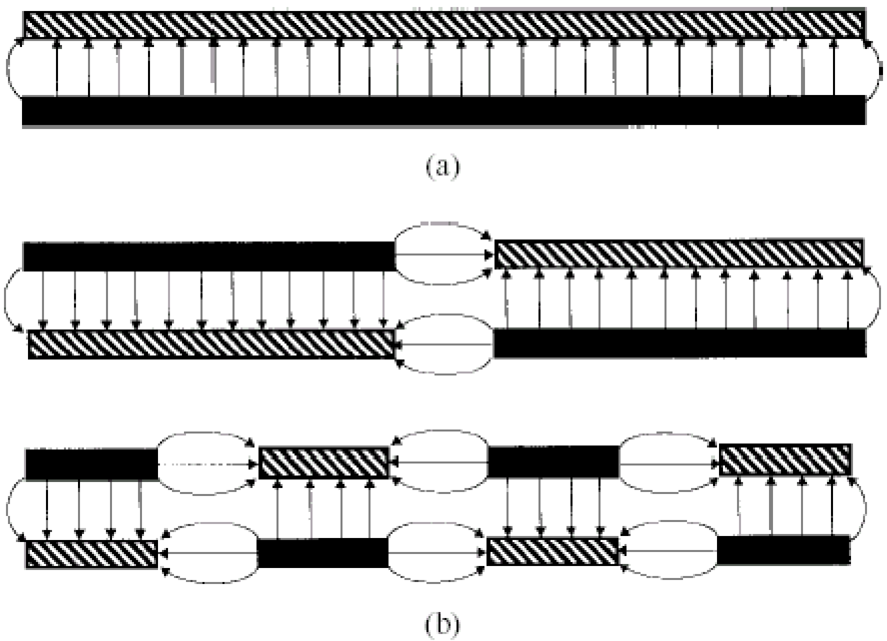


Fig. 2: Cross-section SEM photomicrograph across a typical MIM capacitor. Note that the shallow via 2 provides connectivity between top plate (TM) of capacitor to metal 3 and the deep via 2 provides connectivity of bottom plate (metal 2) to metal 3.

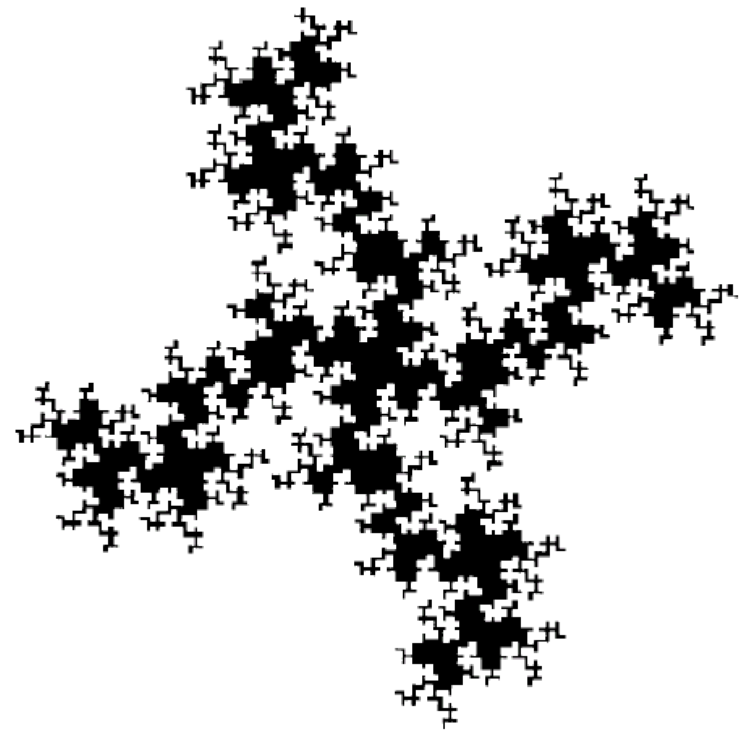
VLSI Capacitor Structures

- Fractal capacitor



(a)

(b)



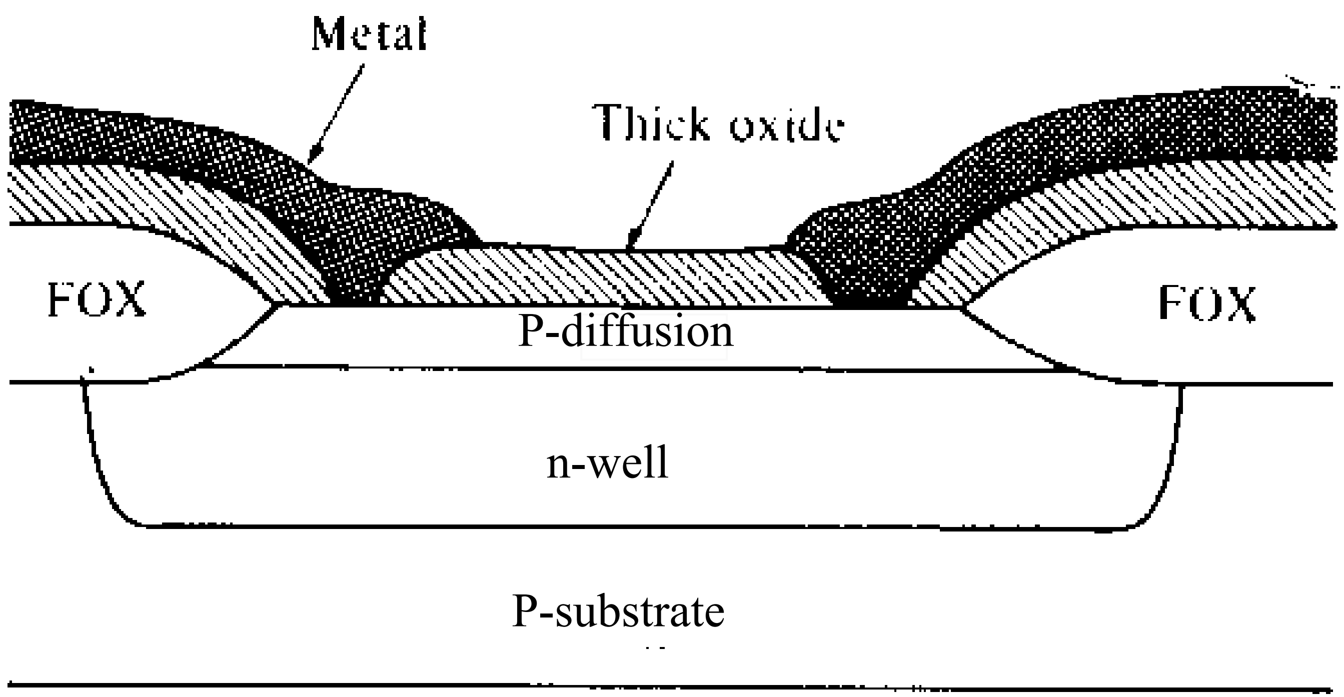
- Enhancement (~ 2.3x) of capacitance/area with lateral coupling

VLSI Resistor Structures

- Diffusion Resistors
- Poly Resistors
- Well Resistors
- Pinch Resistors

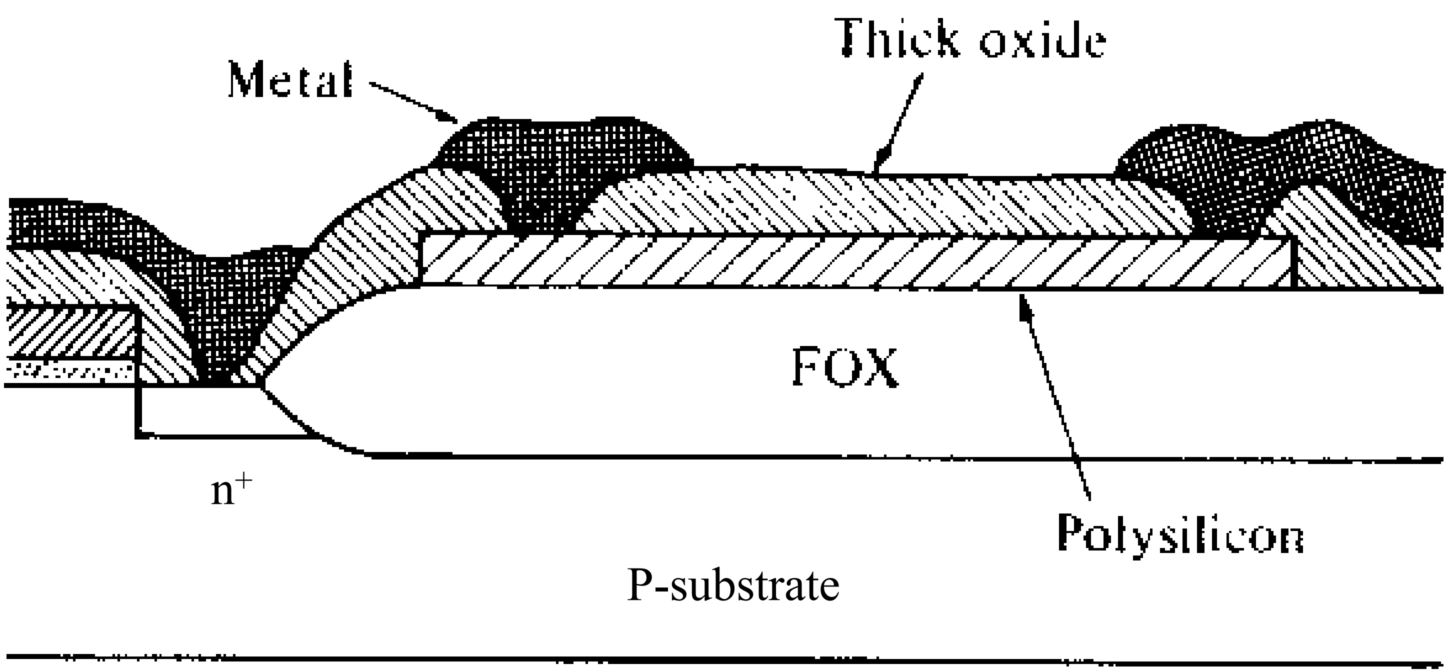
VLSI Resistor Structures

- Diffusion Resistor



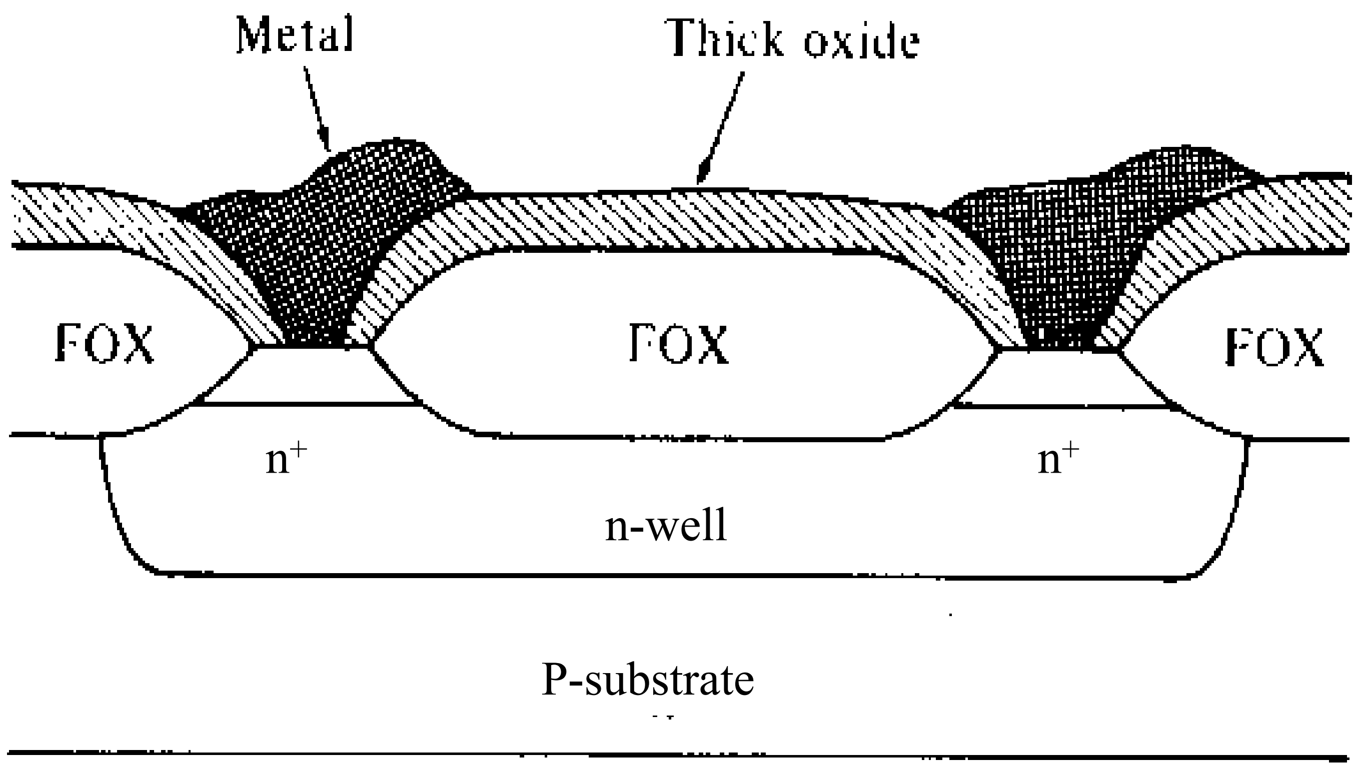
VLSI Resistor Structures

- Poly Resistor



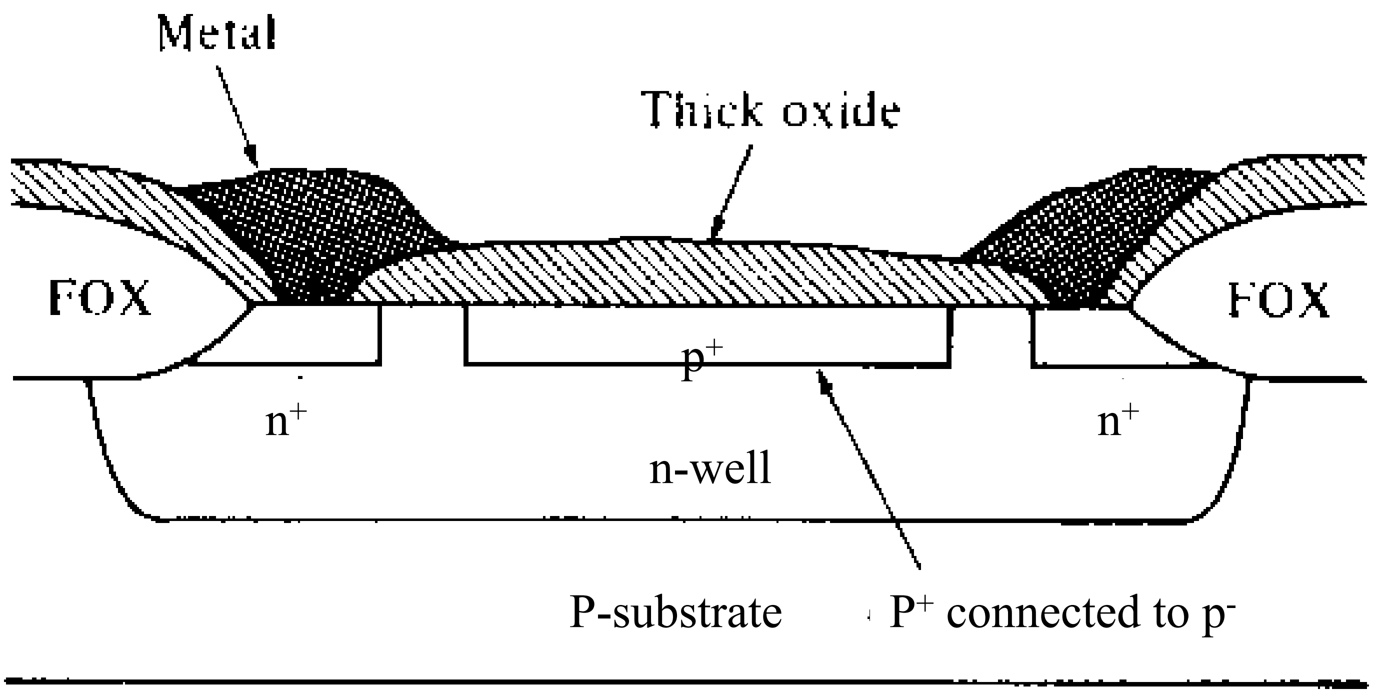
VLSI Resistor Structures

- Well Resistor



VLSI Resistor Structures

•Pinch Resistor



Example of Passive Element Accuracy

Approximate Performance Summary of CMOS Passive Components.

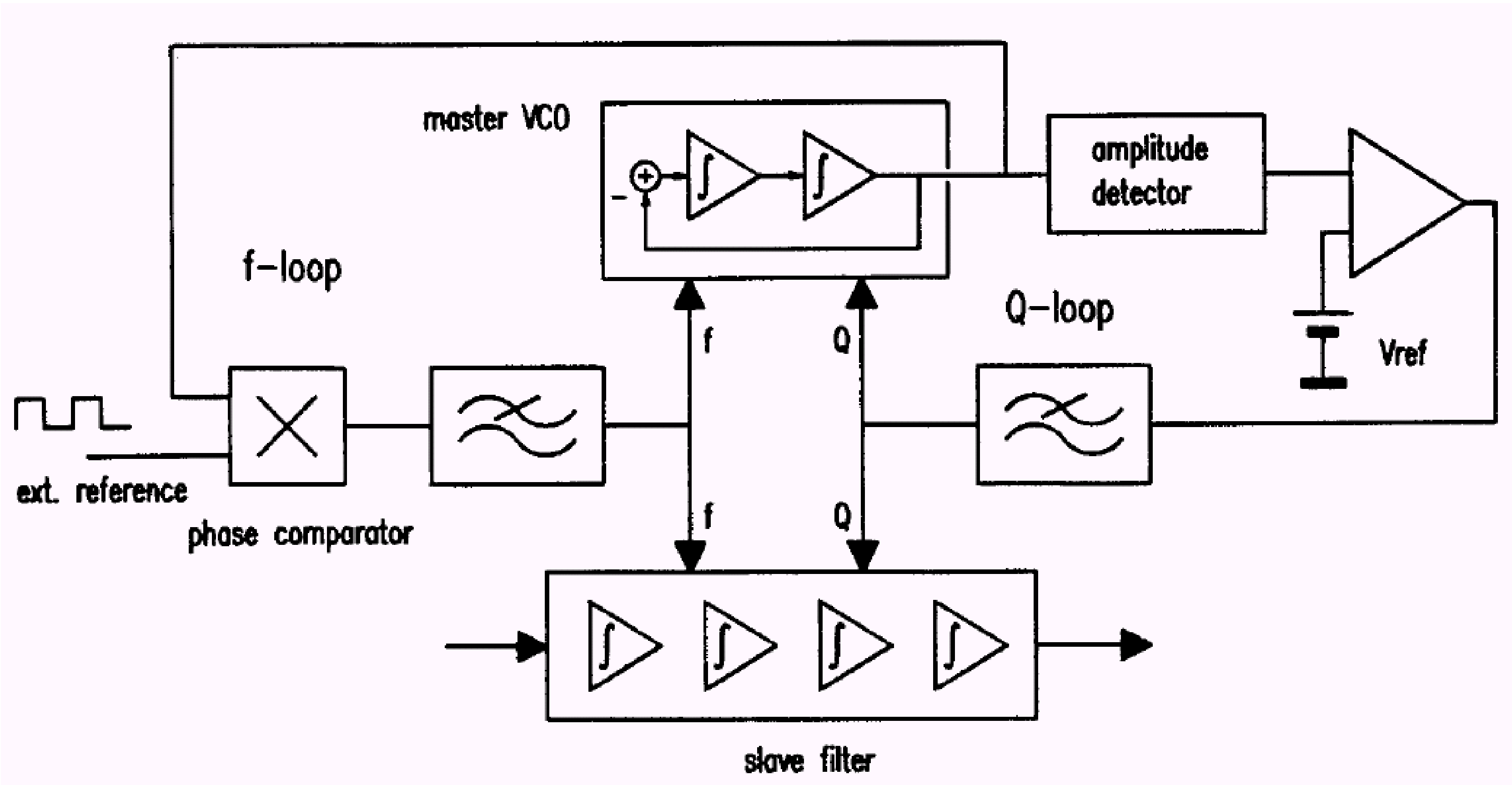
Component Type	Range of Values	Relative Accuracy	Temperature Coefficient	Voltage Coefficient	Absolute Accuracy
Poly/poly capacitor	0.3–0.4 fF/μ^2	0.06%	25 ppm/°C	50 ppm/V	20%
MOS capacitor	0.35–0.5 fF/μ^2	0.06%	25 ppm/°C	20 ppm/V	10%
Diffused resistor	10–100 ohms/sq.	2% (5 μm width)	1500 ppm/°C	200 ppm/V	35%
Poly resistor	30–200 ohms/sq.	2% (5 μm width)	1500 ppm/°C	100 ppm/V	30%
Ion impl. resistor	0.5–2k ohms/sq.	1% (5 μm width)	400 ppm/°C	800 ppm/V	5%
p-well resistor	1–10k ohms/sq.	2%	8000 ppm/°C	10k ppm/V	40%
pinch resistor	5–20k ohms/sq.	10%	10k ppm/°C	20k ppm/V	50%

Tuning of VLSI CT Filters

- Tuning required for CT integrated filters to account for capacitance and resistance/transconductance variations — 30% time-constant variations
- Must account for process, temperature, aging, etc.
- While absolute tolerances high, ratio of two like components can be matched to under 1%
- Tuning can often be the MOST difficult part of a CT integrated filter design
- Note that SC/SI filters do not need tuning as their transfer-function accuracy set by ratio of capacitors (or transistors) and a clock-frequency

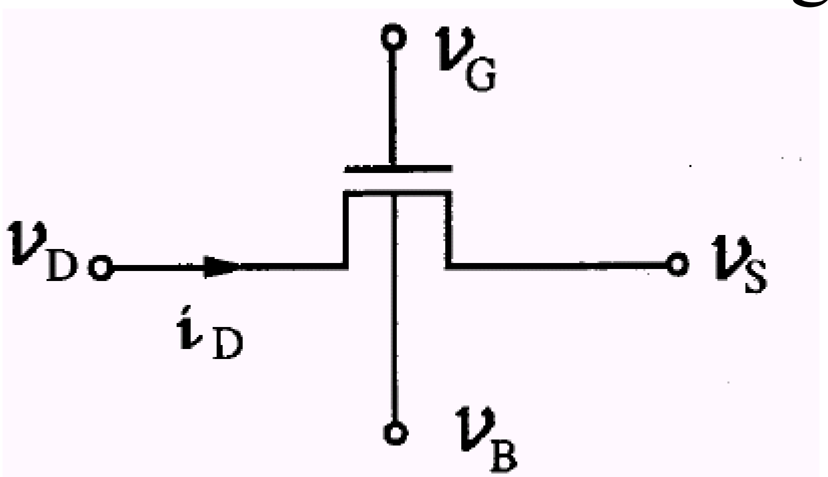
Tuning of VLSI CT Filters

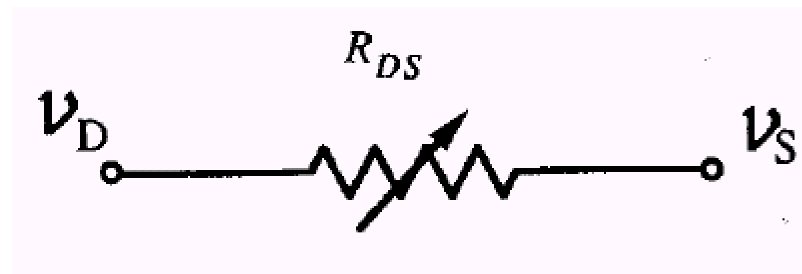
- Example:



VLSI VCR Structures

- Basic MOS voltage controlled resistor (VCR)





$$I = \beta (V_G - V_T - \frac{V_d + V_s}{2})(V_d - V_s)$$

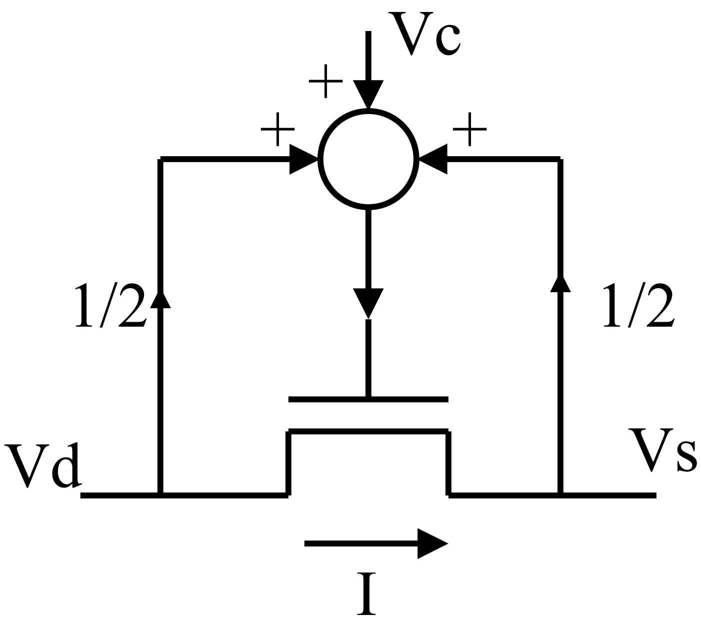
$$R = \frac{1}{\beta (V_G - V_T - \frac{V_d + V_s}{2})}$$

Control voltage

Nonlinear term

VLSI VCR Structures

- Linear MOS VCR - 1st approach



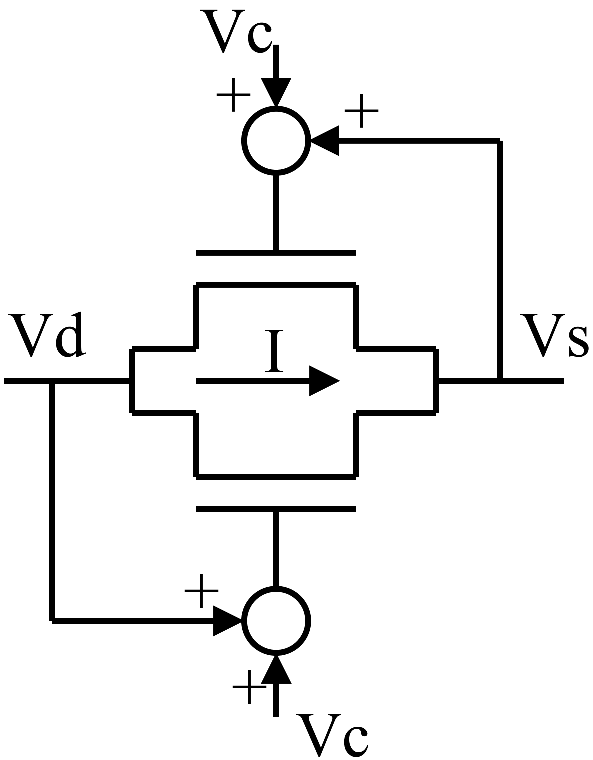
Control voltage

Let $V_G = \frac{V_d + V_s}{2} + V_C$

Then $R = \frac{1}{\beta\left(V_C - V_T\right)}$

VLSI VCR Structures

- Linear MOS VCR - 2nd approach



$$I = \beta(V_c + V_d - V_T - \frac{V_d + V_s}{2})(V_d - V_s)$$

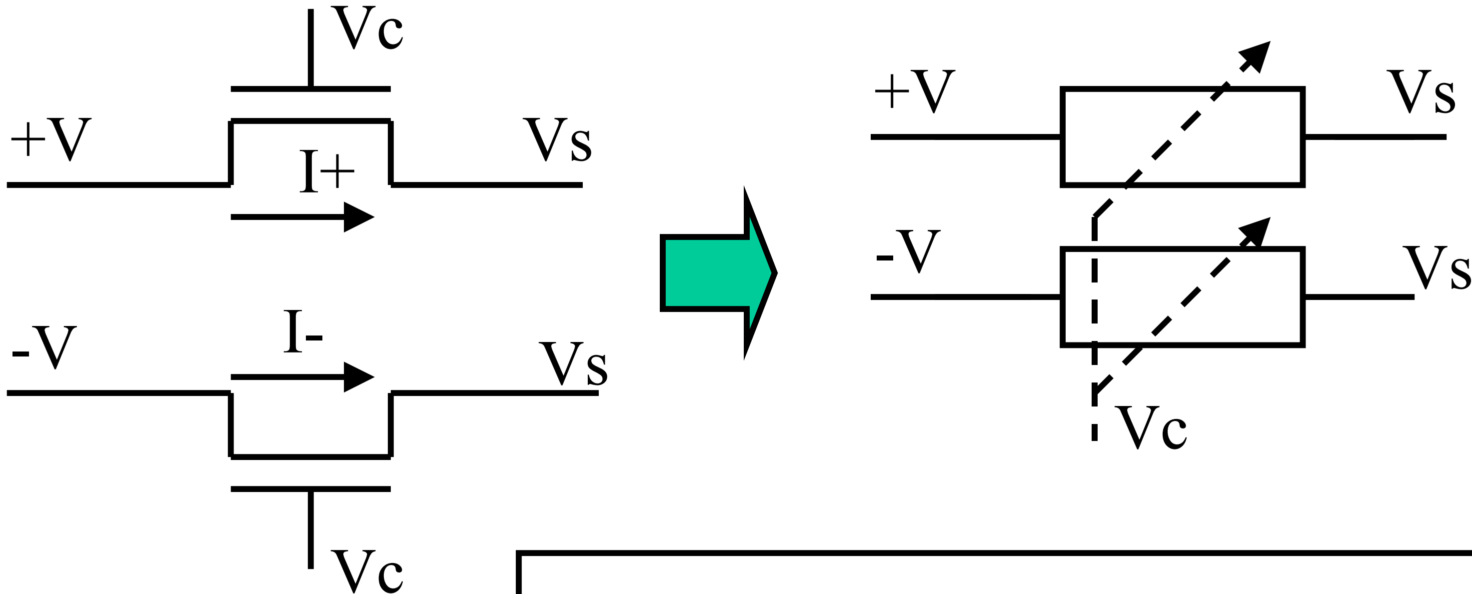
$$+ \beta(V_c + V_s - V_T - \frac{V_d + V_s}{2})(V_d - V_s)$$

$$= 2\beta(V_{cs} - V_T)(V_d - V_s)$$

$$R = \frac{1}{2\beta(V_G - V_T)}$$

VLSI VCR Structures

- Linear MOS VCR - 3rd approach

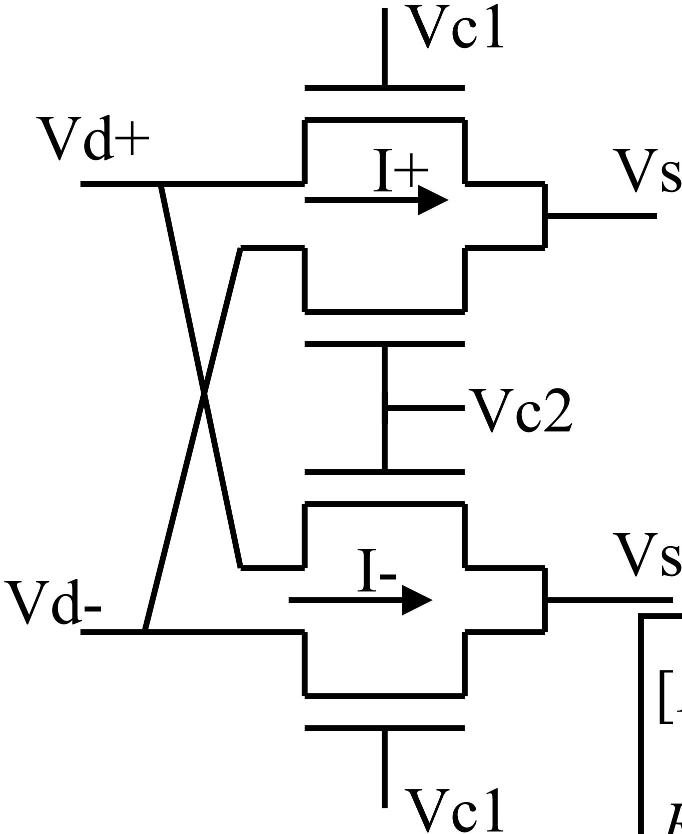


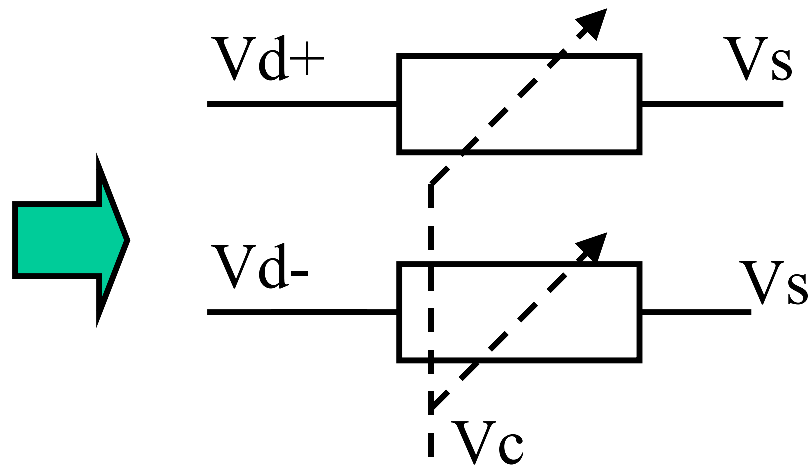
$$[I_+ - I_-] = \beta(V_C - V_T)[(+V - V_s) - (-V - V_s)]$$

$$R = \frac{1}{\beta(V_C - V_T)}$$

VLSI VCR Structures

- Linear MOS VCR - 4th approach



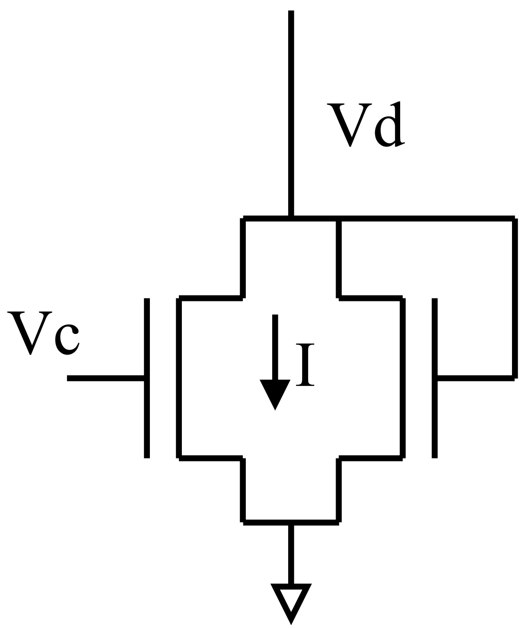


$$[I_+ - I_-] = \beta(V_{C2} - V_{C2})[(V_{d+} - V_s) - (V_{d-} - V_s)]$$

$$R = \frac{1}{\beta(V_{C2} - V_{C2})}$$

VLSI VCR Structures

- Grounded Linear MOS VCR



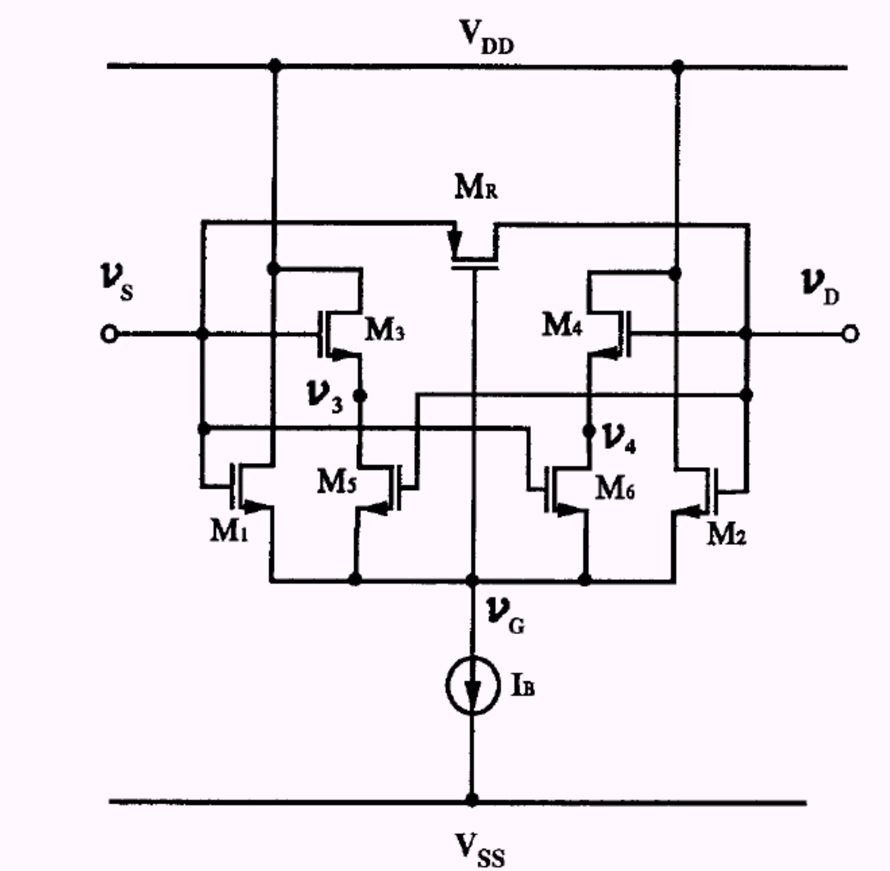
$$I = \frac{\beta}{2}(V_d - V_T)^2 + \beta(V_c - V_T - \frac{V_d}{2})V_d$$

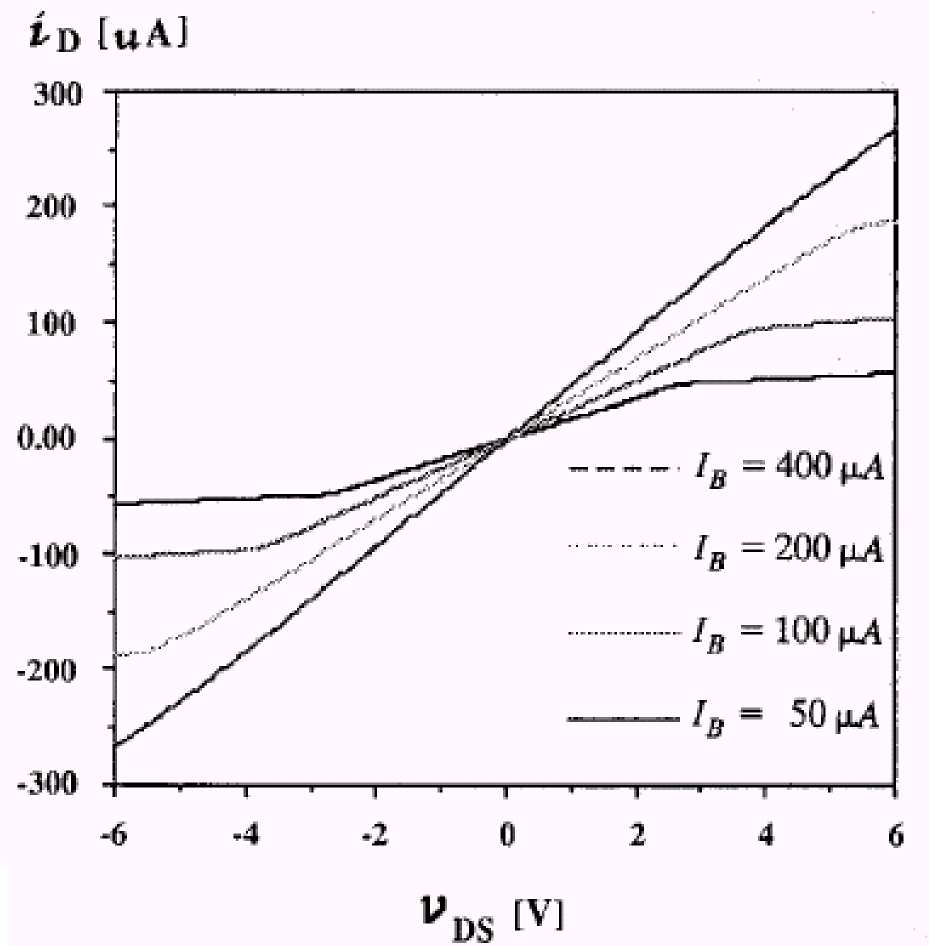
$$= \beta(V_c - 2V_T)V_d + \frac{\beta}{2}(V_T)^2$$

$$R = (\frac{dI}{dV_d})^{-1} = \frac{1}{\beta(V_c - 2V_T)}$$

VLSI Resistor Structures

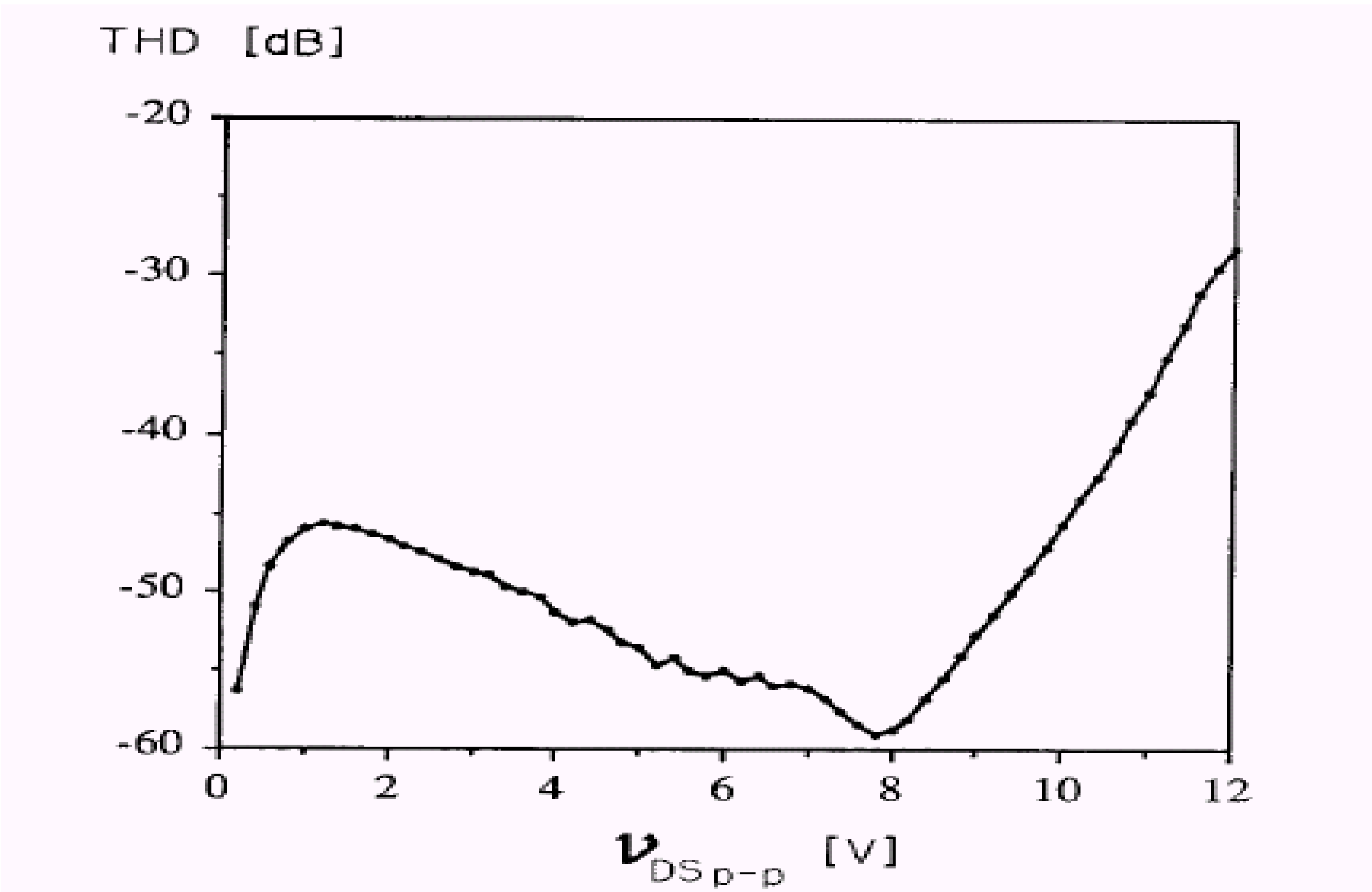
- MOS VCR Implementation





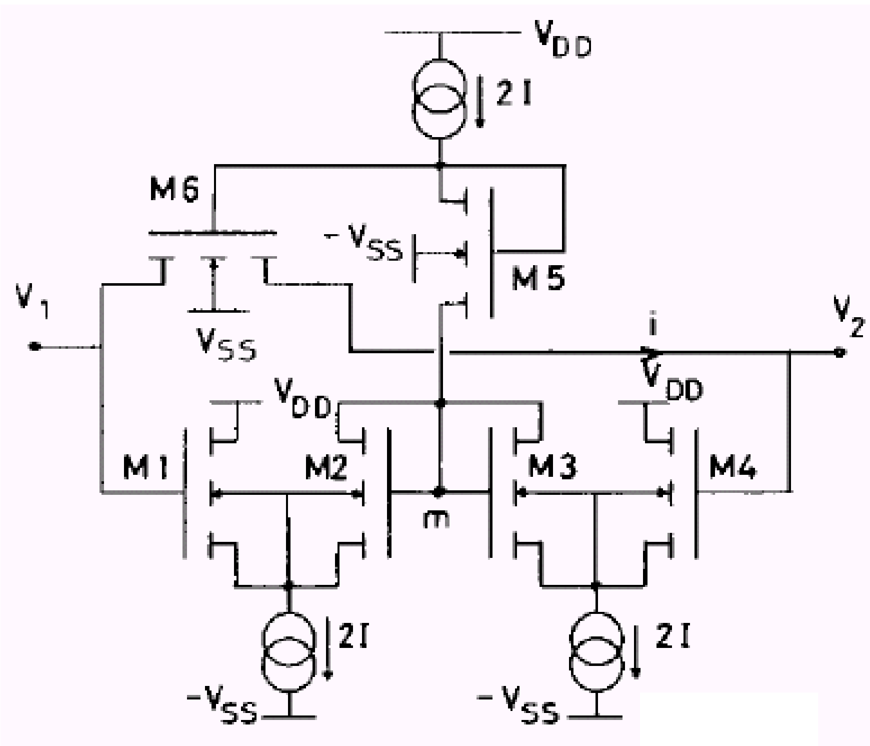
VLSI Resistor Structures

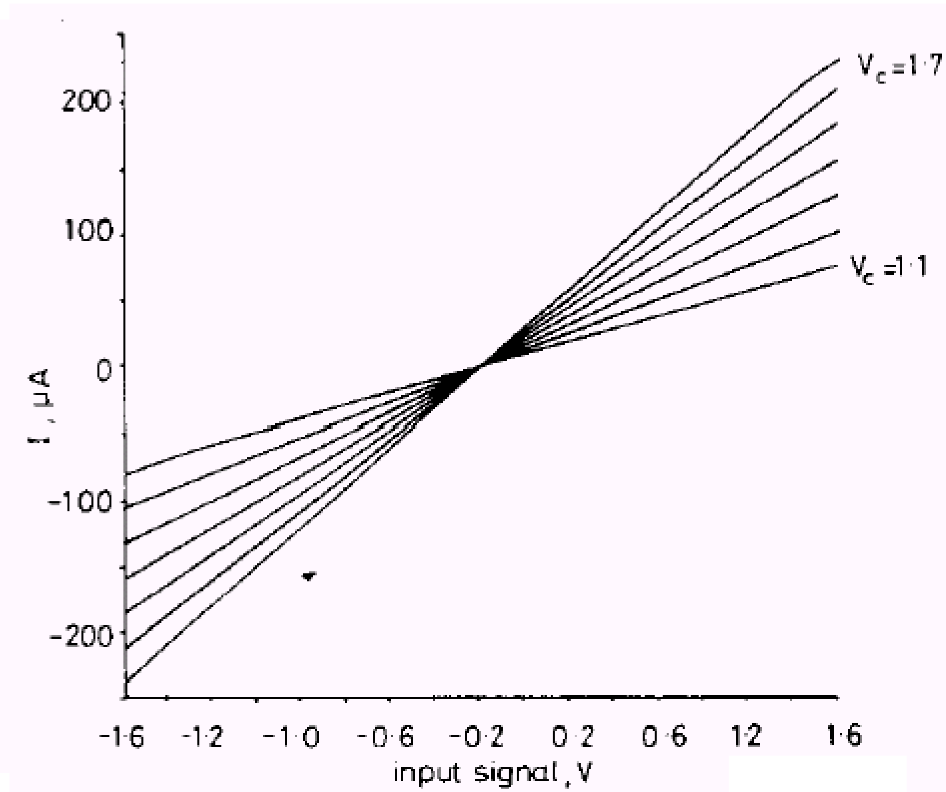
- MOS VCR Implementation



VLSI Resistor Structures

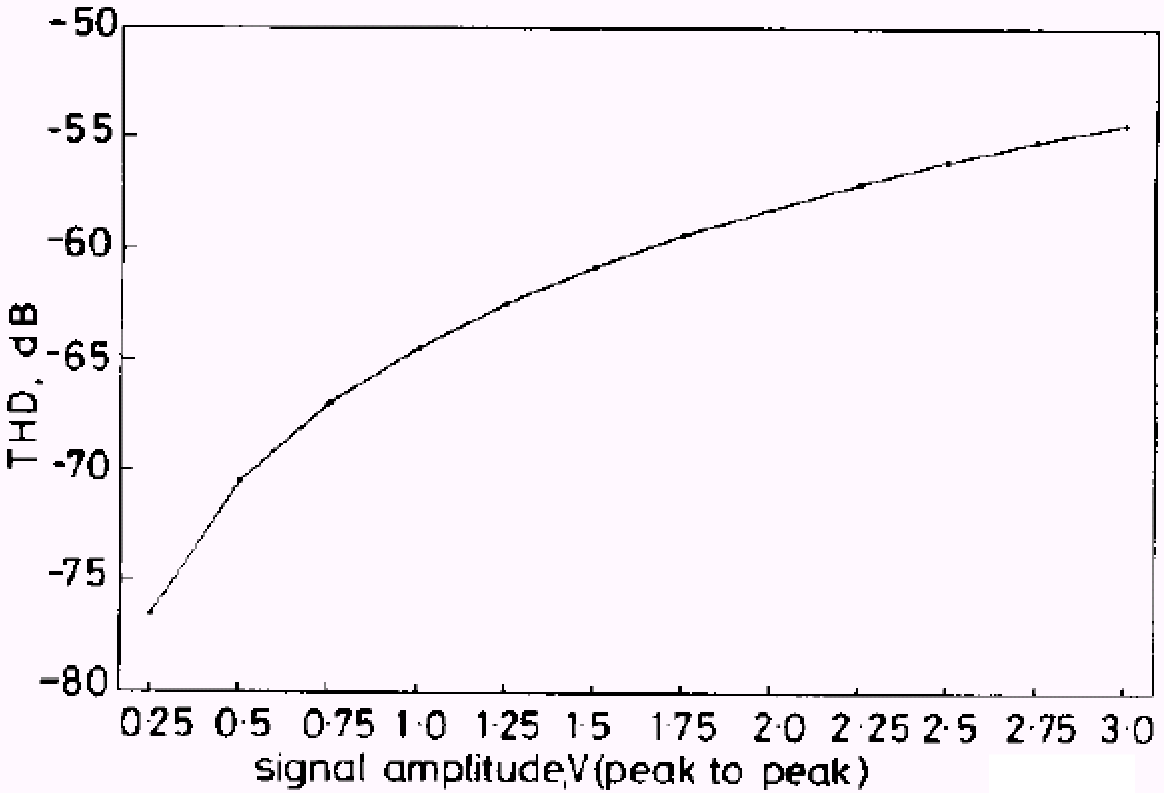
- MOS VCR Implementation





VLSI Resistor Structures

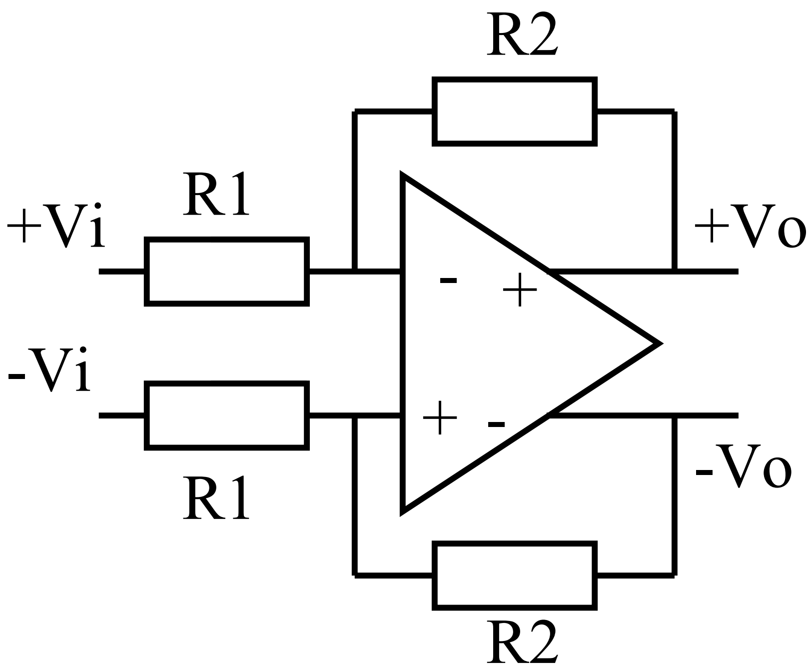
- MOS VCR Implementation



Distortion against signal amplitude (nominal resistance 10 kΩ)

Basic Active RC Circuits

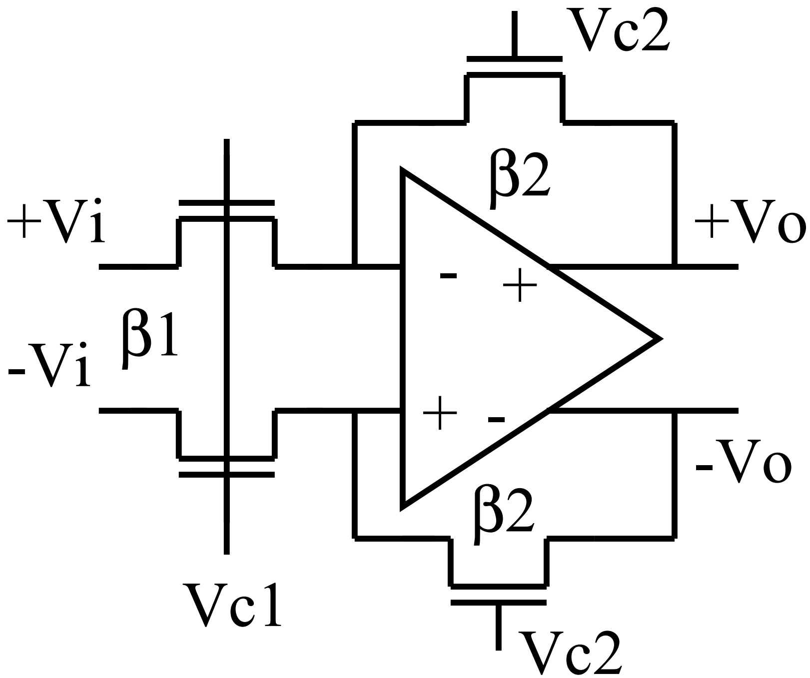
- Fully differential gain stage



$$\frac{V_o}{V_i} = -\frac{R_2}{R_1}$$

Basic MOS-C Circuits

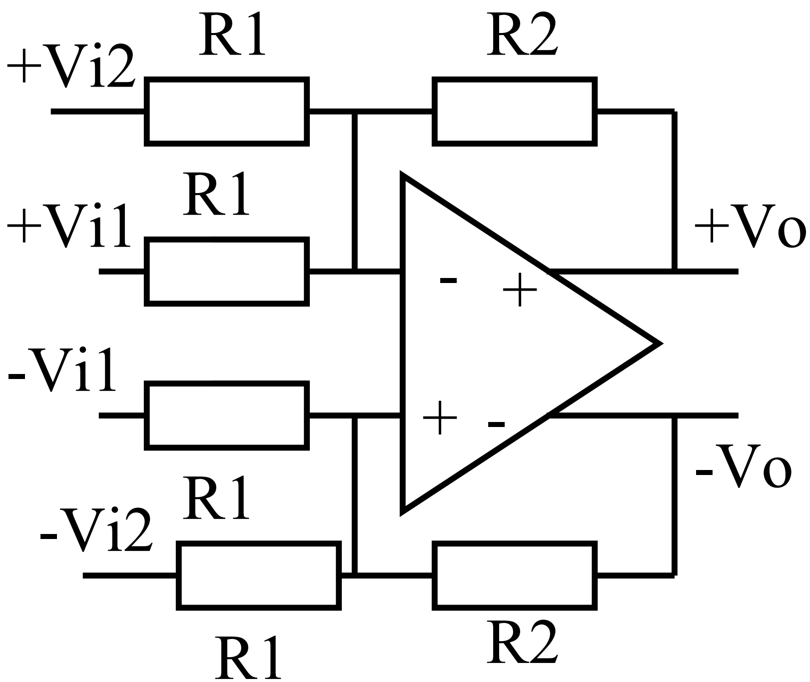
- Fully differential gain stage



$$\frac{V_o}{V_i} = -\frac{\beta_1 (V_{c1} - V_T)}{\beta_2 (V_{c2} - V_T)}$$

Basic Active RC Circuits

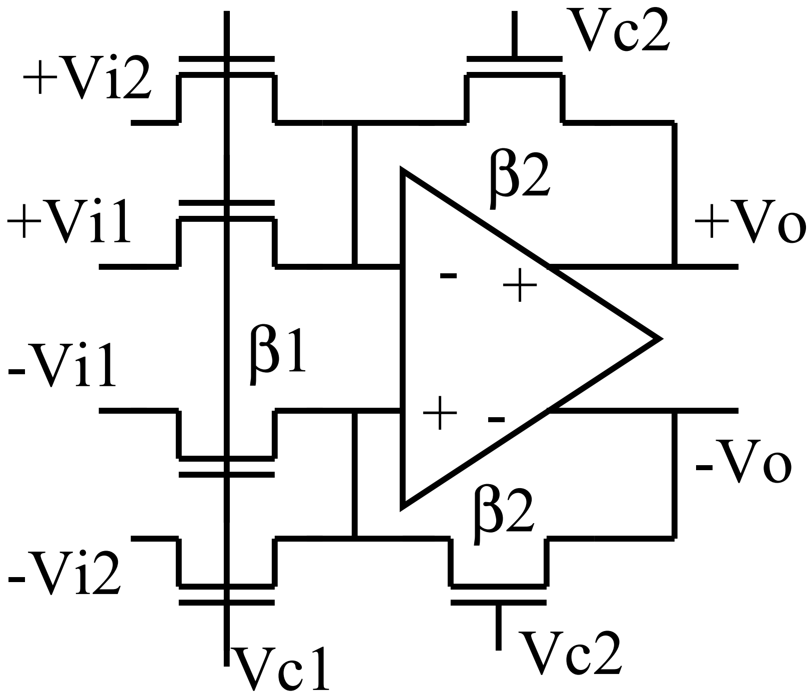
- Fully differential adder stage



$$V_o = -\frac{R_2}{R_1}(V_{i1} + V_{i2})$$

Basic MOS-C Circuits

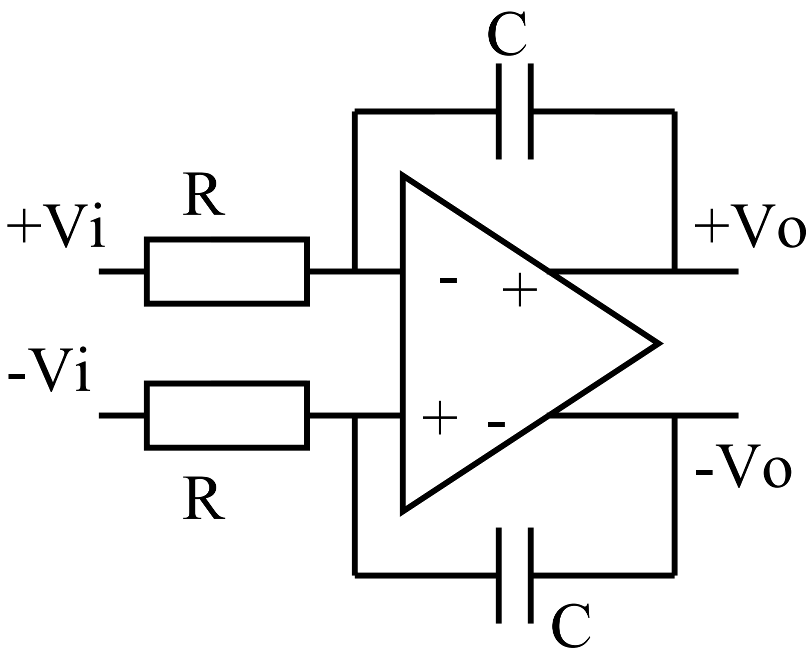
- Fully differential adder



$$V_o = -\frac{\beta_1 (V_{c1} - V_T)}{\beta_2 (V_{c2} - V_T)} (V_{i1} + V_{i2})$$

Basic Active RC Circuits

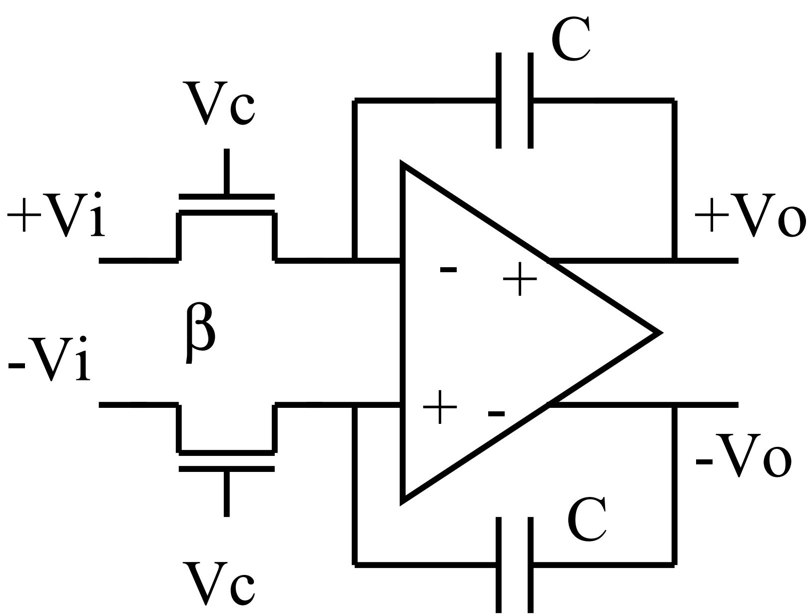
- Fully differential integrator



$$\frac{V_o}{V_i}(s) = -\frac{1}{RCs}$$

Basic MOS-C Circuits

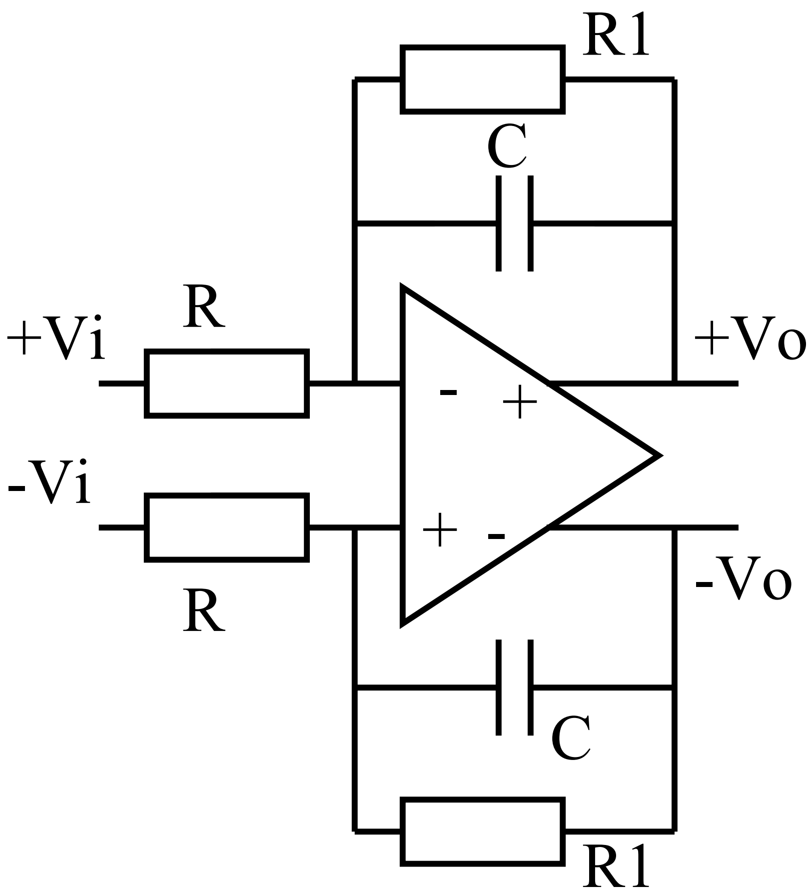
- Fully differential integrator



$$\frac{V_o}{V_i}(s) = -\frac{1}{\dfrac{Cs}{\beta(V_c - V_T)}}$$

Basic Active RC Circuits

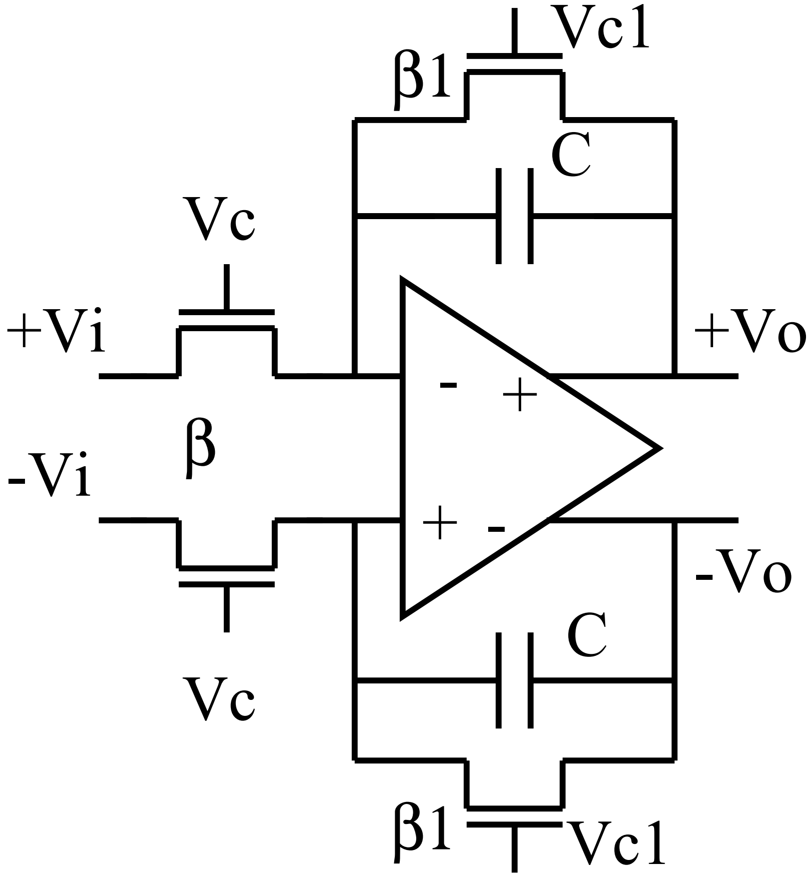
- Fully differential lossy integrator



$$\frac{V_o}{V_i}(s) = -\frac{1}{RCs + \frac{R}{R_1}}$$

Basic MOS-C Circuits

- Fully differential lossy integrator



$$\frac{V_o}{V_i}(s) = -\frac{1}{\dfrac{Cs}{\beta(V_c - V_T)} + \dfrac{\beta_1(V_{c1} - V_T)}{\beta(V_c - V_T)}}$$