Lecture 58:

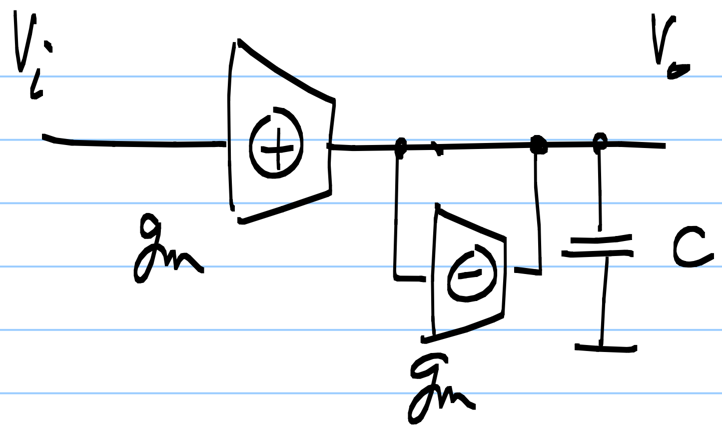
Higher order filters:

Even order: can be factored into 2^{nd} order poly.

Odd order: can be factored into 2^{nd} order poly & 1 1^{st} order poly.

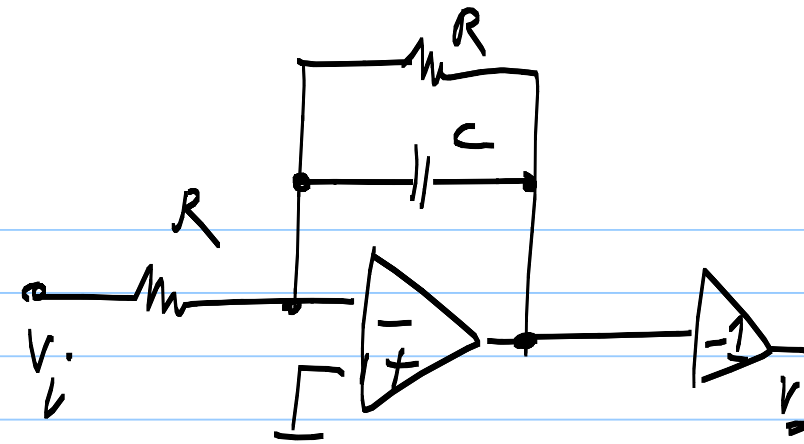
6^{th} order: 3×2^{nd} order

7^{th} order: 3×2^{nd} order $+$ 1^{st} order



$$\frac{V_o}{V_i} = \frac{g_m}{g_m + sC}$$

$$= \frac{1}{1 + sC/g_m}$$

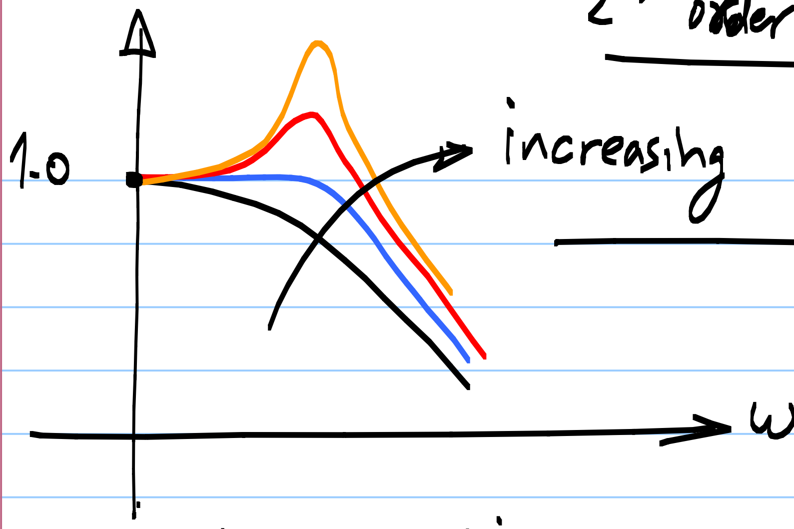


$$\frac{V_o}{V_i} = \frac{1}{1 + sCR}$$

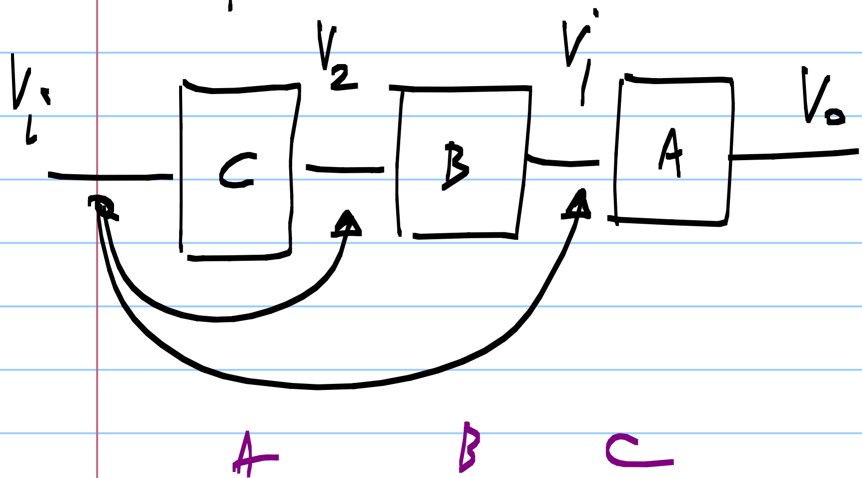
High order filter realization: N^{th} order filter

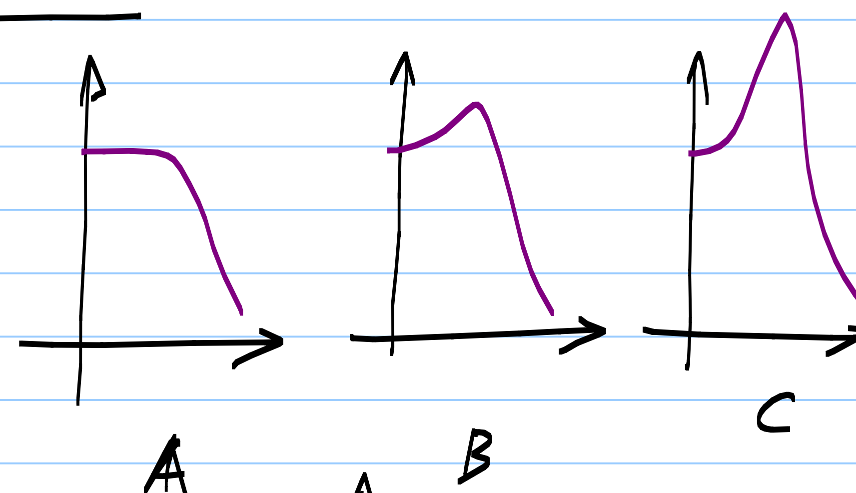
* Cascade of $\frac{N}{2}$ $\left(\frac{N-1}{2}\text{ if } N \text{ is odd}\right)$ 2^{nd} order filters (and one 1^{st} order if N is odd)
  {both g_m-C & active-RC}

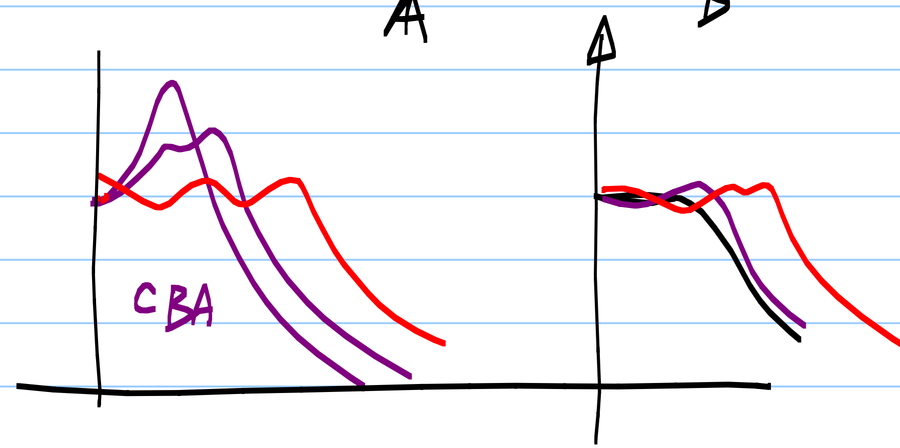
2nd order filter:



increasing quality factor



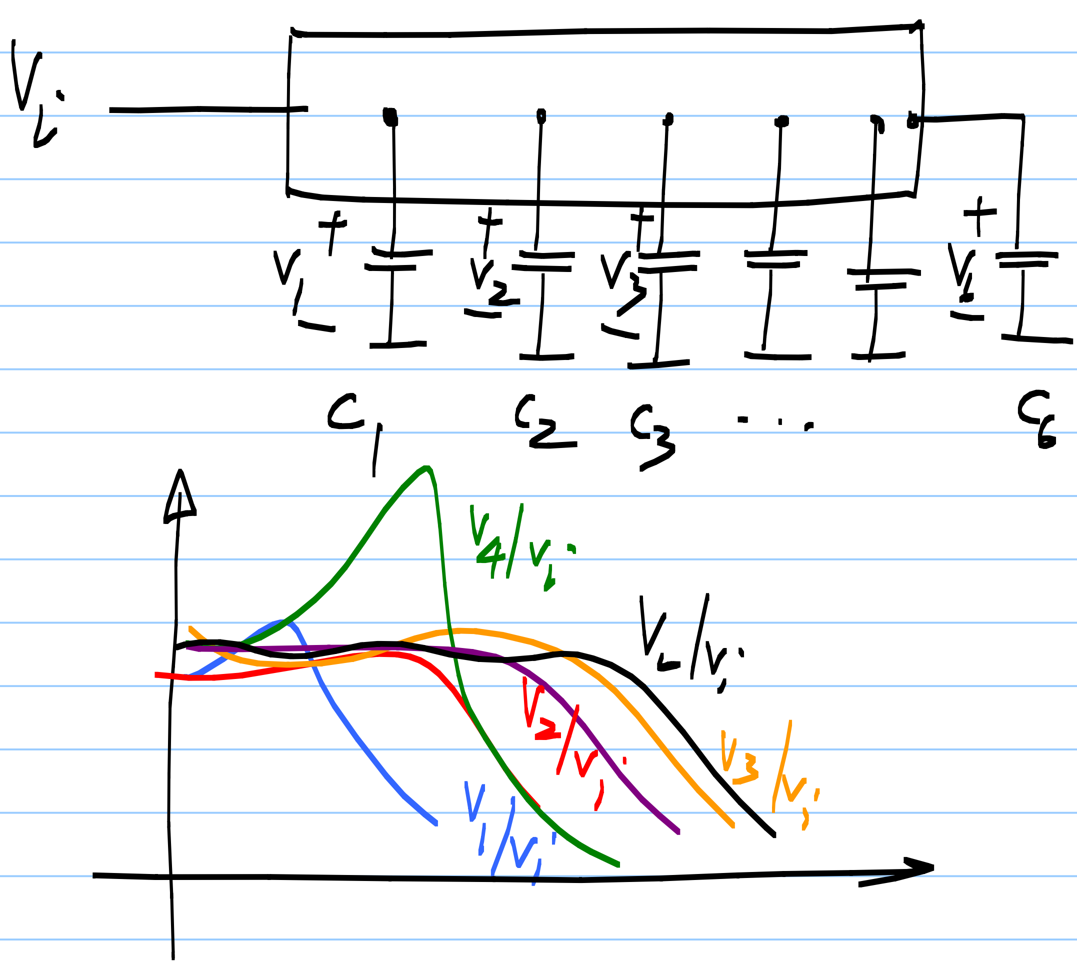




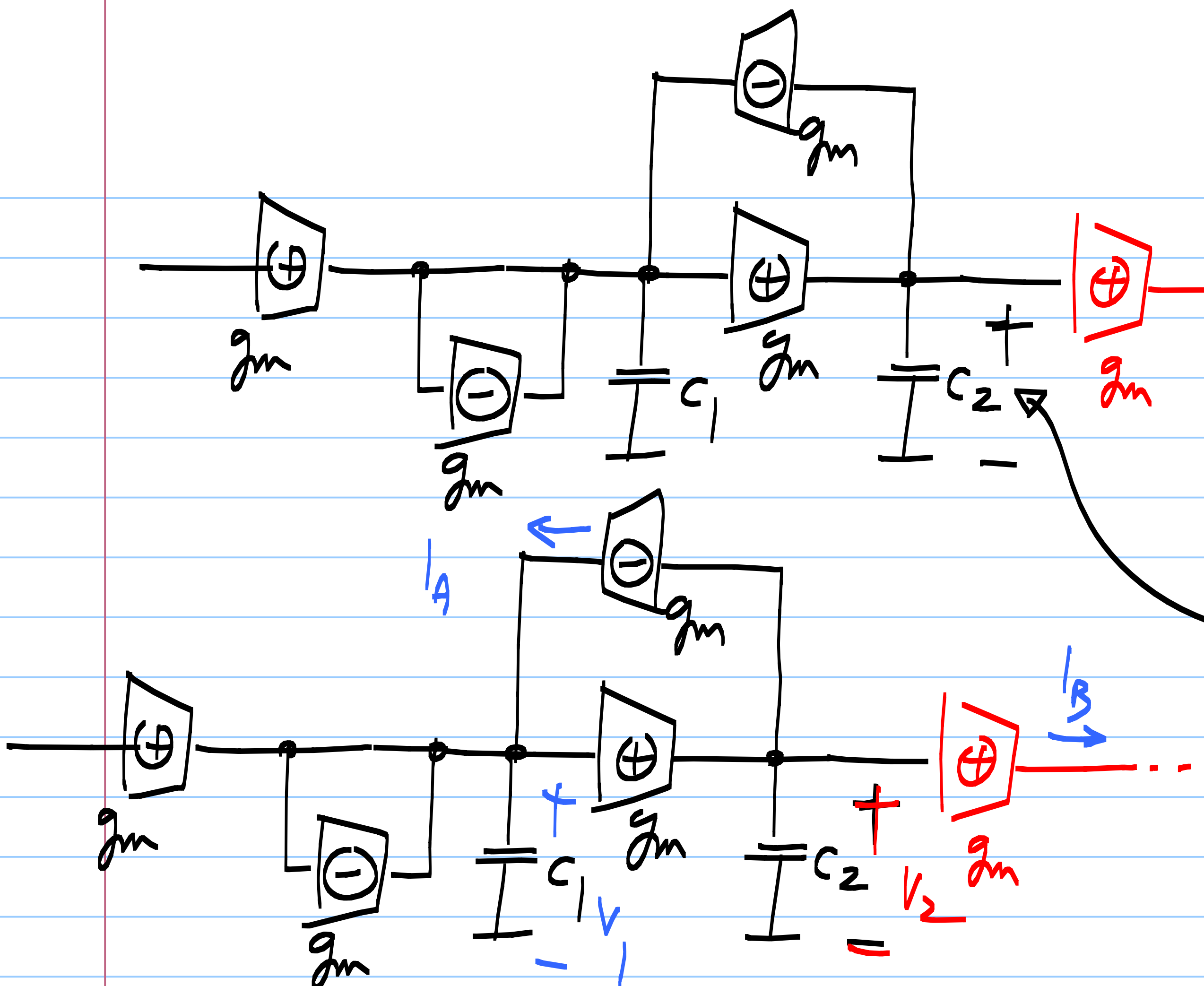
Ordering of 2^{nd} order sections:

* 1^{st} order ; 2^{nd} order sections with the lowest quality factor filter first increasing quality factors

* Equalize the maximum of transfer function magnitudes from the input to all the g_m (OP AMP) outputs in the circuit.



V_i
+
V_1
−
V_2
V_3
V_L
C_1
C_2
C_3
...
C_6
V_4/V_i
V_L/V_i
V_2/V_i
V_3/V_i
V_1/V_i



max. of transfer fn. magnitude has to be reduced by 2x {6dB}

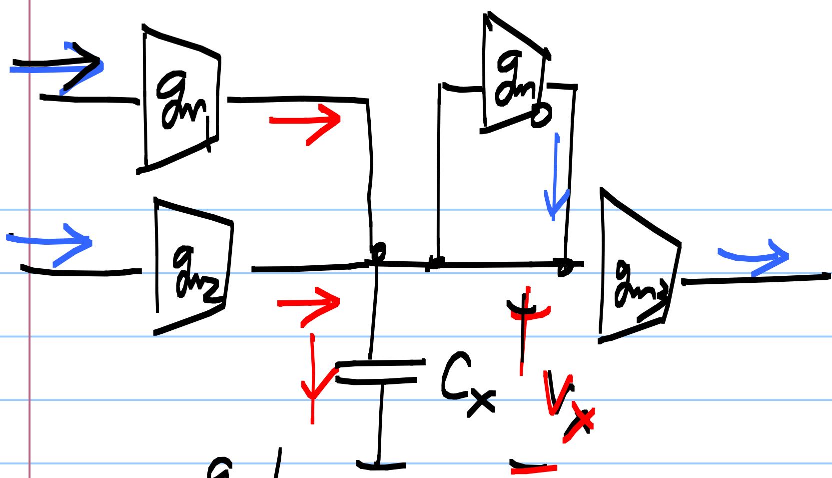
g_m-C filter:

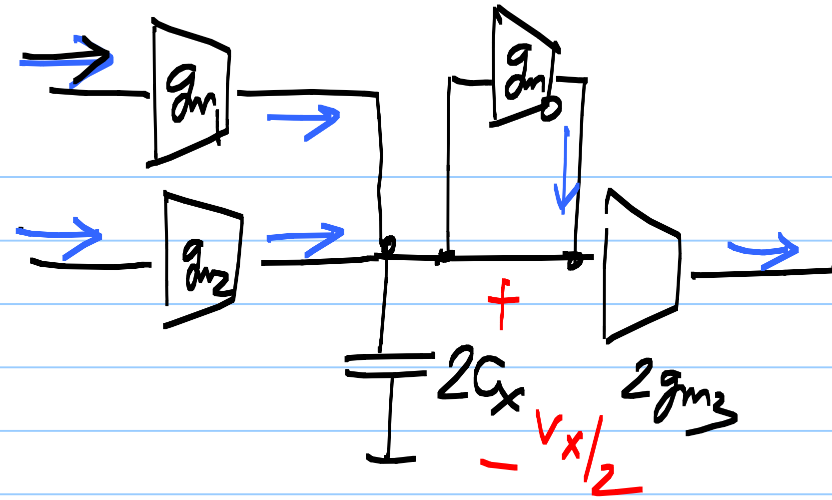
* Voltage across capacitor C_x must be reduced by 2x
* Current flowing through C_x reduced by 2x

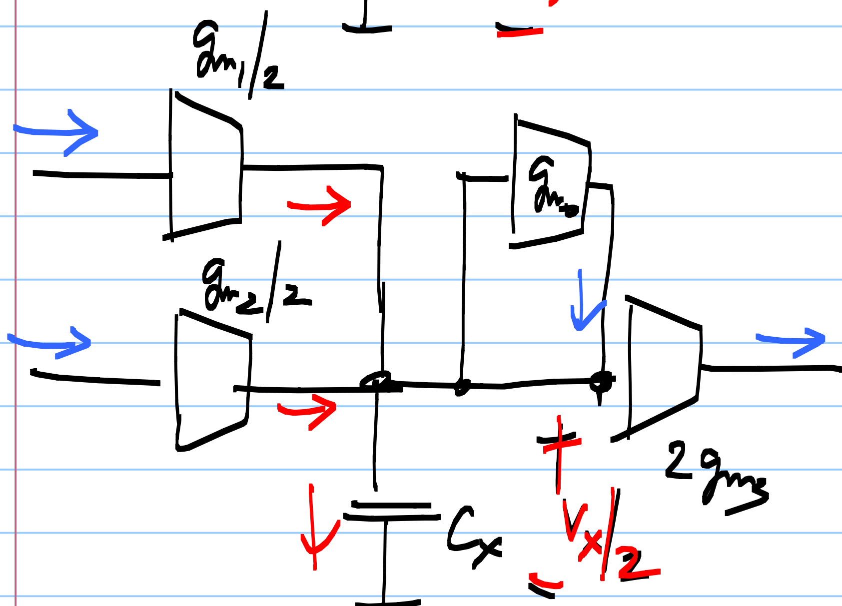
  ⇒ g_ms whose outputs are connected to C_x must redue by 2x

  g_ms whose inputs are connected to C_x must increase by 2x

  g_ms with i/p & o/p connected to C_x: unchanged


gm1
gm2
gm1
gm3
Cx
+
Vx
-

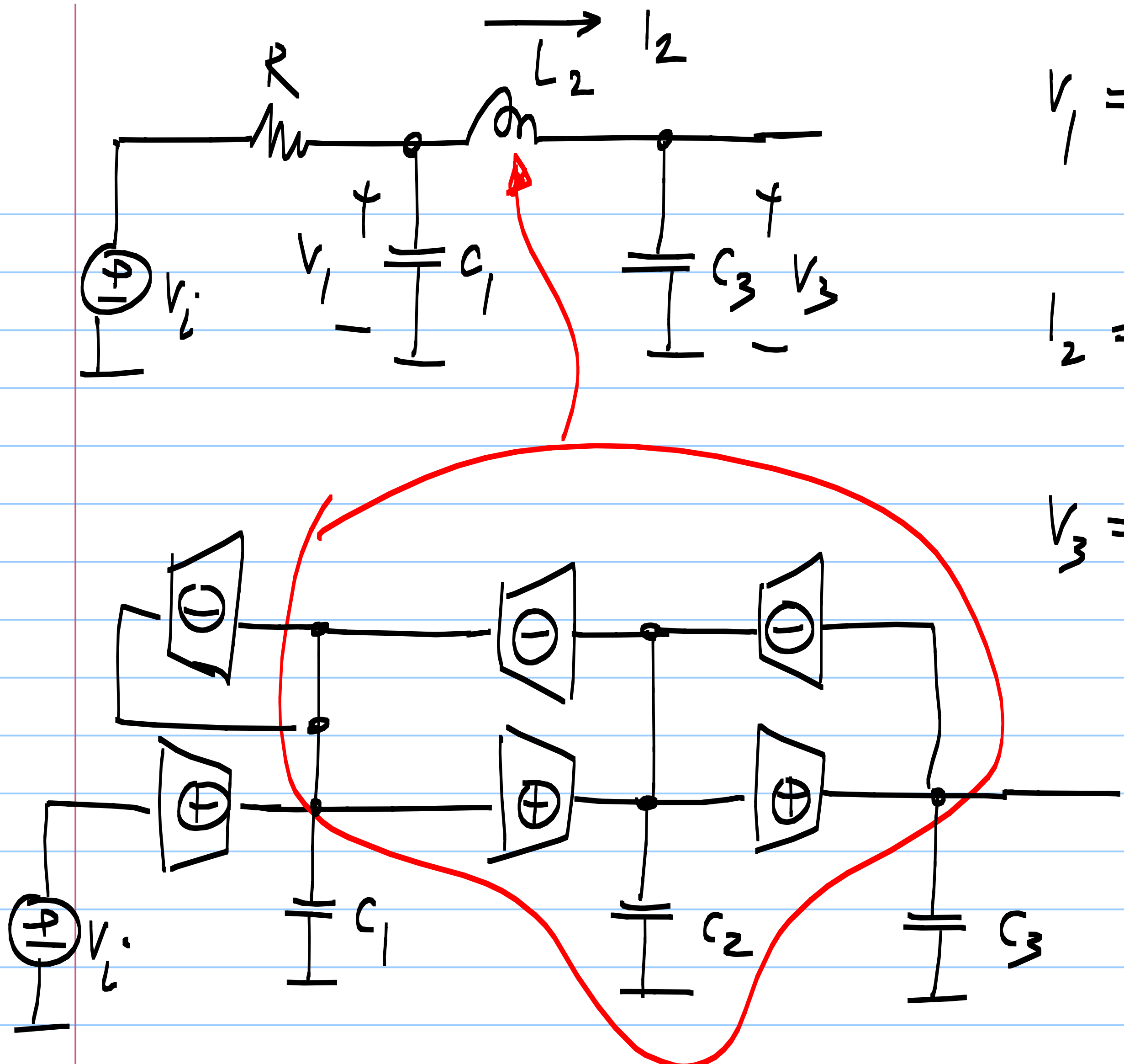

gm1
gm2
gm1
+
2Cx
2gm3
Vx/2
-


gm1/2
gm2/2
gm1
+
2gm3
Cx
Vx/2
-

* Increase C_x by 2x

g_ms whose inputs are connected to C_x must increase by 2x

[Node scaling to maintain equal transfer fn. magnitude peaks]



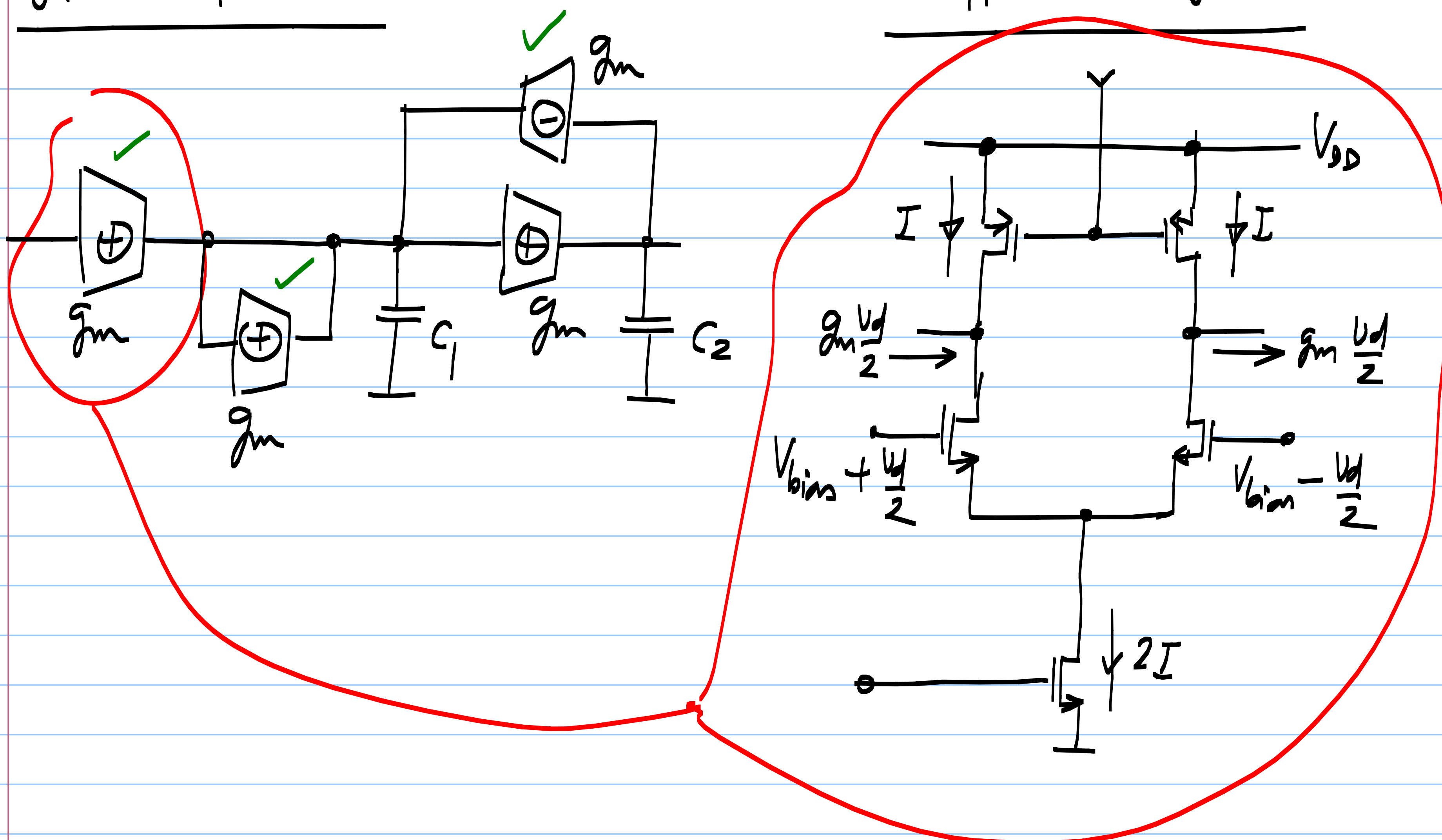
$$V_1 = \frac{\frac{V_i - V_1}{R} - I_2}{sC_1}$$

$$I_2 = \frac{V_1 - V_3}{sL_2}$$

$$V_3 = \frac{I_2}{sC_3}$$

g_m-C filter:

Differential pair:



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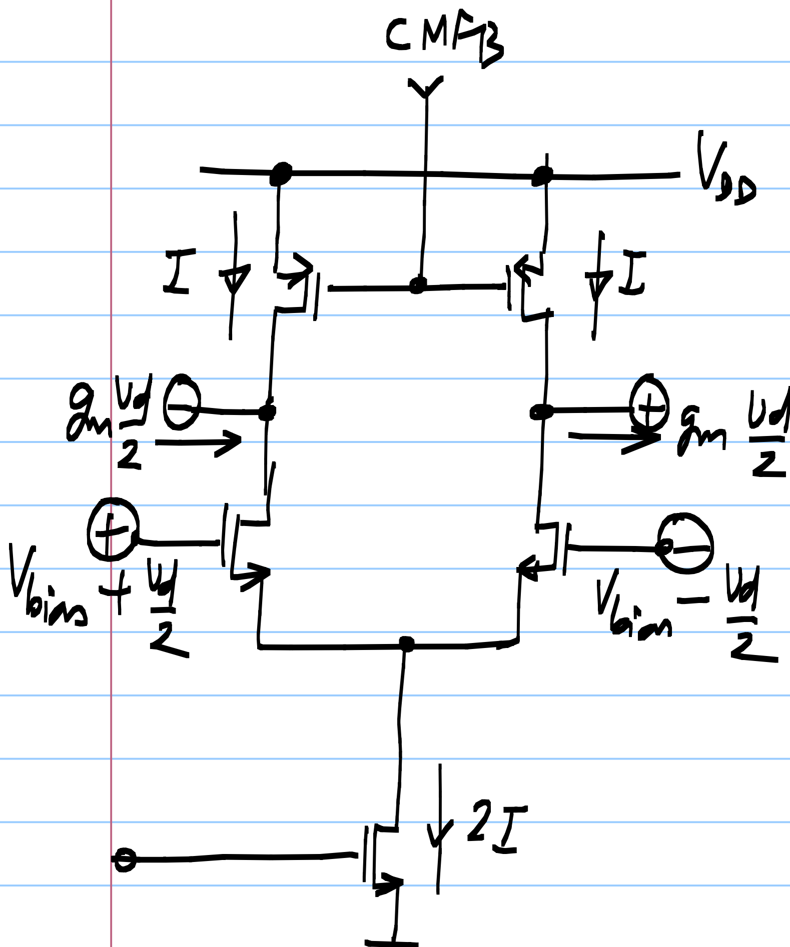
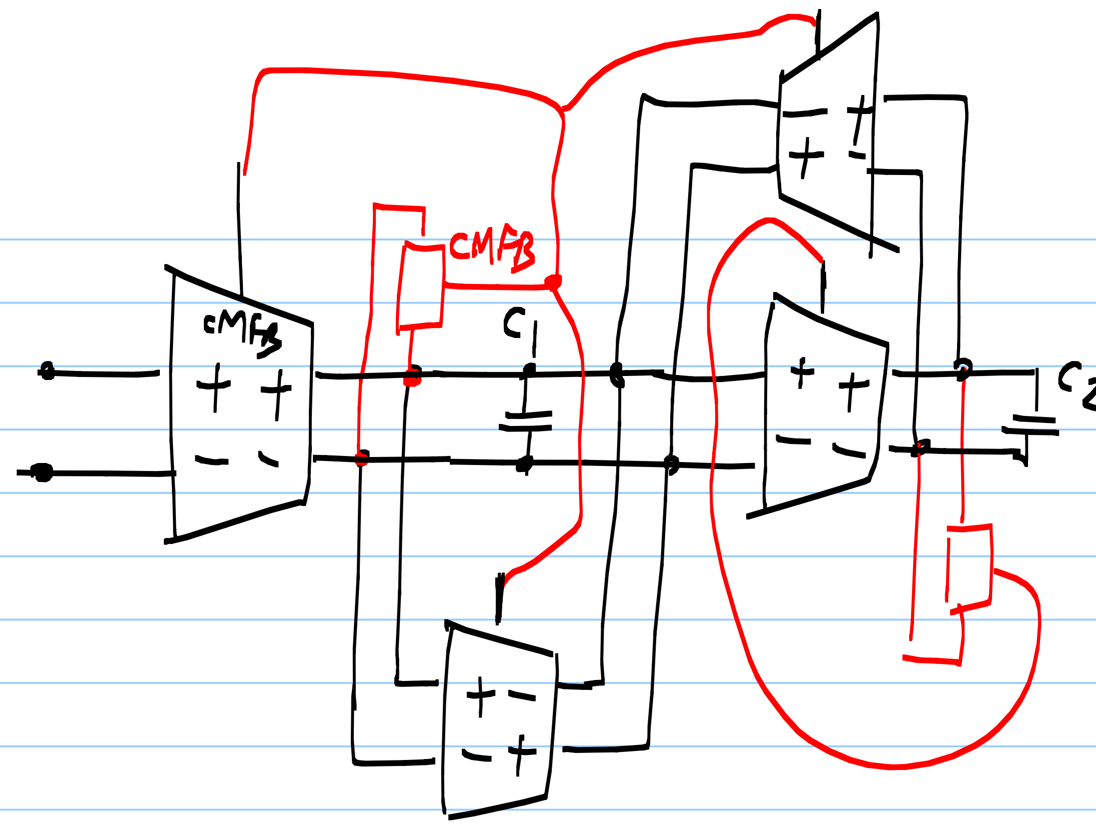
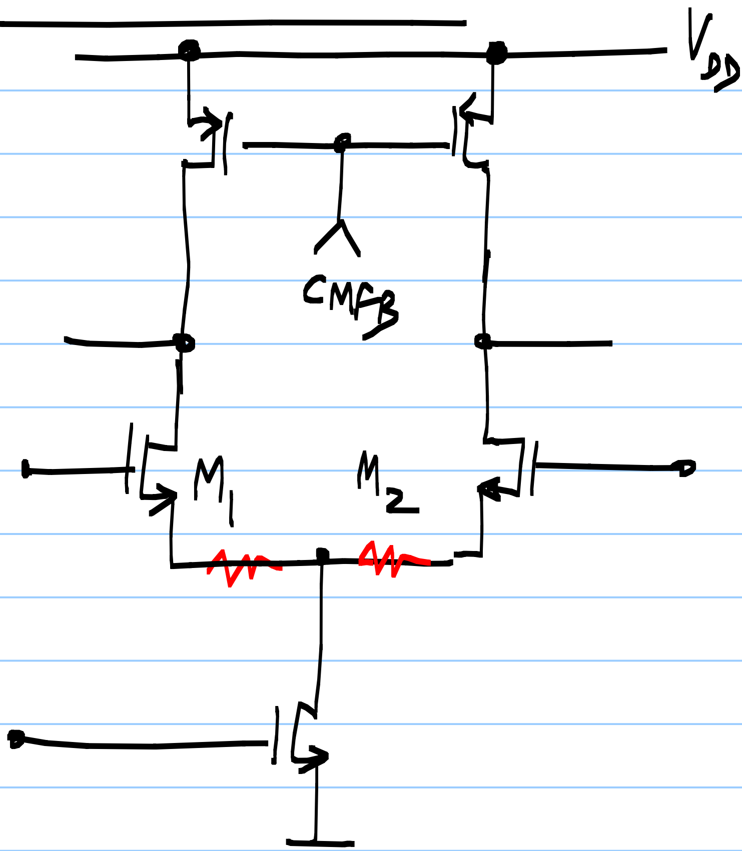

CMFB
VDD
I
I
gm vd/2
gm vd/2
2I
Vbias + vd/2
Vbias − vd/2


CMFB
CMFB
C1
C2

Transconductor:



* Linearity: Use as high $V_{GS} - V_T$ as possible for $M_{1,2}$

* Degeneration resistors improved linearity

$$g_m = \frac{g_{m1}}{1 + g_{m1} R} \simeq \frac{1}{R}$$

Active filter design:

* Determine type, order, transfer function
  [MATLAB, filter tables]
* Cascade of biquads / high order
  (operational simulation)
* Active prototype implementation
* Node scaling (equal max. magnitude response
* Choose g_m / OPAMP & implement the filter

* Simulate the noise / distortion

* Noise $\longleftrightarrow$ Impedance scaling

$$\left.\begin{array}{l} g_m \rightarrow N g_m \\ R \rightarrow R/N \\ C \rightarrow C \\ W/L \rightarrow N \cdot W/L \end{array}\right\} \Rightarrow$$

N times lower $\overline{v_n^2}$;
N times higher power