Lecture 14: Filters

0. Review

1. Passive Filters

2. Active Filters

- PreLab 5b (Multisim) due at lab session
- HW 6 due this Fri (Nov 08)
- Exam #2 next Tue (Nov 12)

→ HW 4, 5, 6

→ Q2 4, 5, 6 sample on website

→ Sample exam on course website

Textbook Reading:

19-1 Ideal Responses

19-2 Approximate Responses

19-3 Passive Filters

19-4 First order stages

19-5 VCVS unity-gain 2^{nd} order LPF

19-6 Higher order filters

0. Review

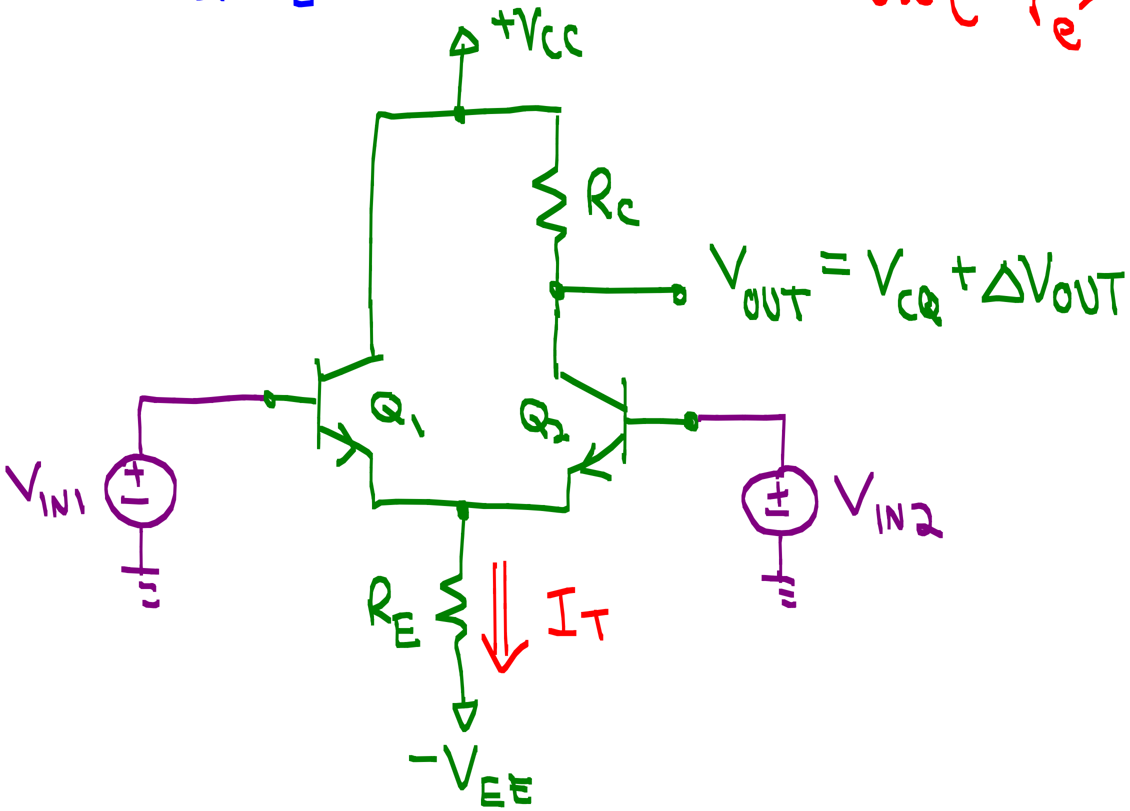
$$V_{OUT} = V_{CQ} + \underbrace{\boxed{A_d}\,\Delta V_{IN} + \boxed{A_{CM}}\,V_{CM}}_{\Delta V_{OUT}}$$

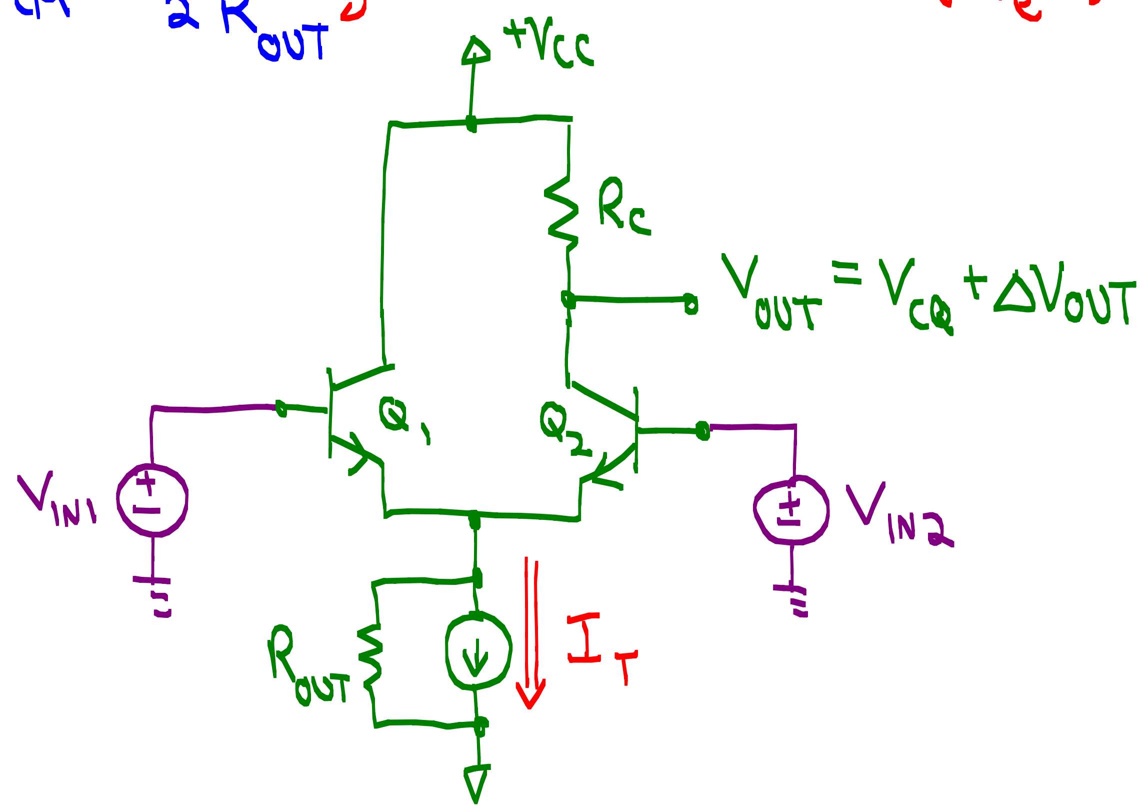
$$\Delta V_{IN} = V_{IN1} - V_{IN2}$$

$$V_{CM} = \tfrac{1}{2}\left(V_{IN1} + V_{IN2}\right)$$

$$\left.\begin{aligned} A_d &= \frac{\alpha R_C}{2 r_e'} \\ A_{CM} &= -\frac{\alpha R_C}{2 R_E} \end{aligned}\right\} \quad CMRR = 20\log_{10}\left|\frac{A_d}{A_{CM}}\right| = 20\log_{10}\left(\frac{R_C}{r_e'}\right)$$

$$\left.\begin{aligned} A_d &= \frac{\alpha R_C}{2 r_e'} \\ A_{CM} &= -\frac{\alpha R_C}{2 R_{OUT}} \end{aligned}\right\} \quad CMRR = 20\log_{10}\left|\frac{A_d}{A_{CM}}\right| = 20\log_{10}\left(\frac{R_{OUT}}{r_e'}\right)$$



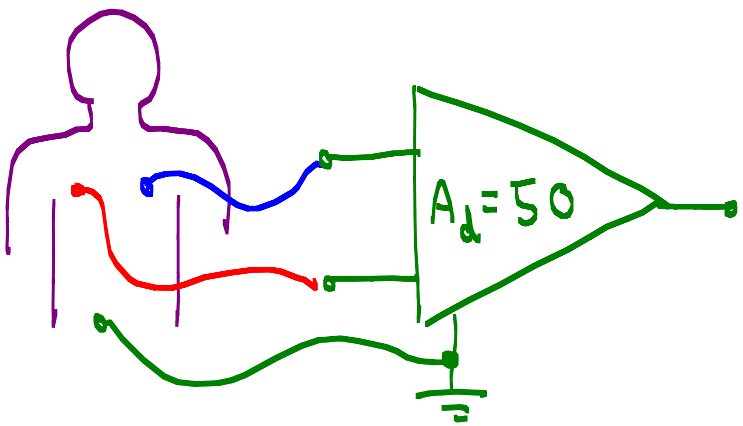


1. Passive Filters

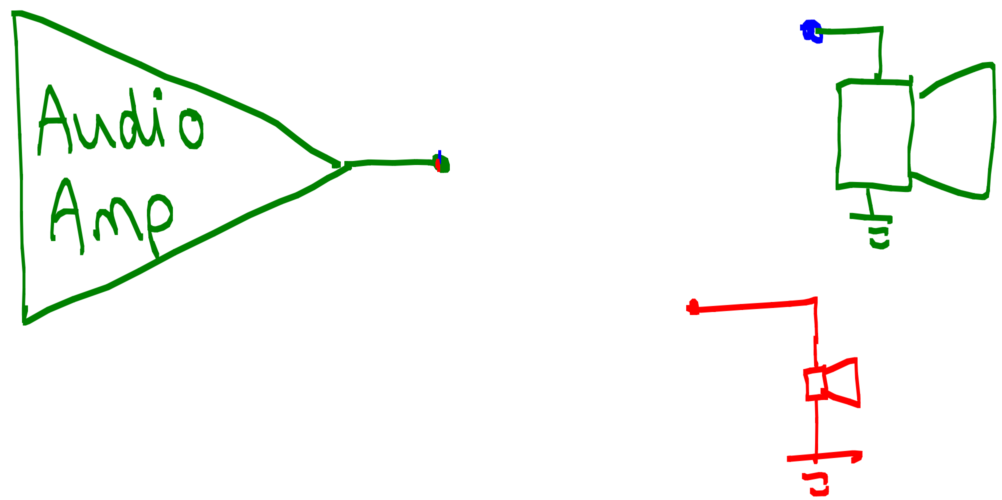
A. Intro

- In many applications, the desired signal competes with <u>noise</u>.

Ex: ECG

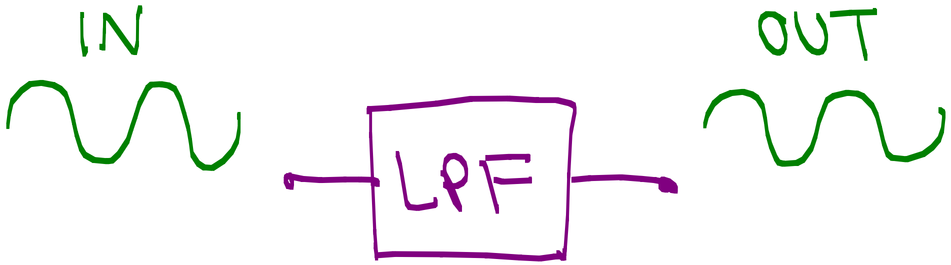


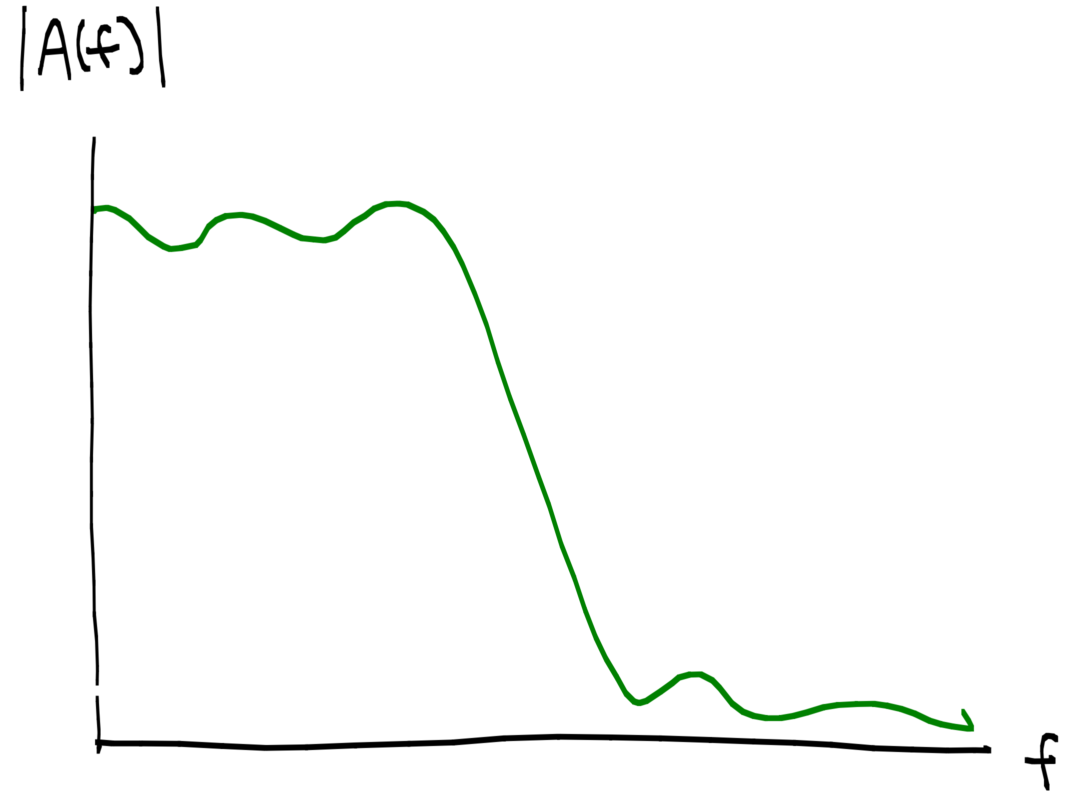
- Other applications use filters to separate signals.



- We will only discuss low-pass filters, but most concepts apply to high-pass and band-pass filters.

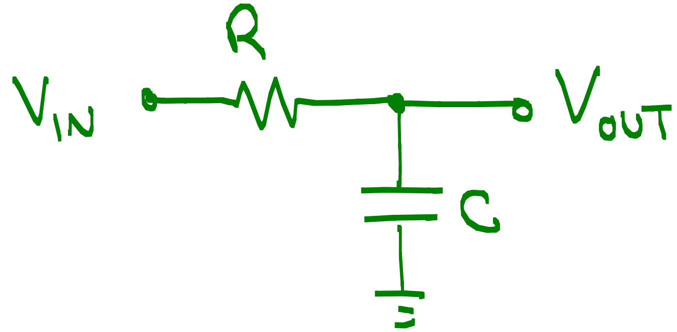
B. Filter Parameters





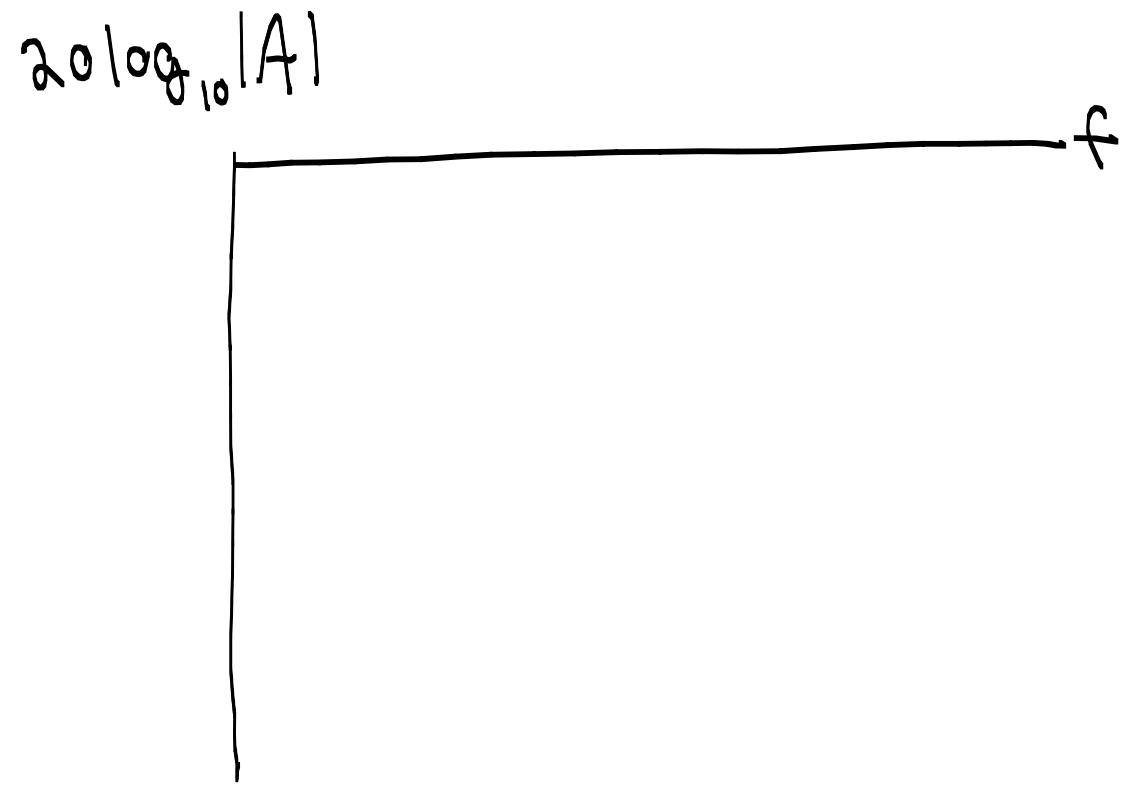
- The gain of a low-pass filter has three "frequency zones":

C. Passive RC Filter
(1st order filter)



$V_{OUT} =$

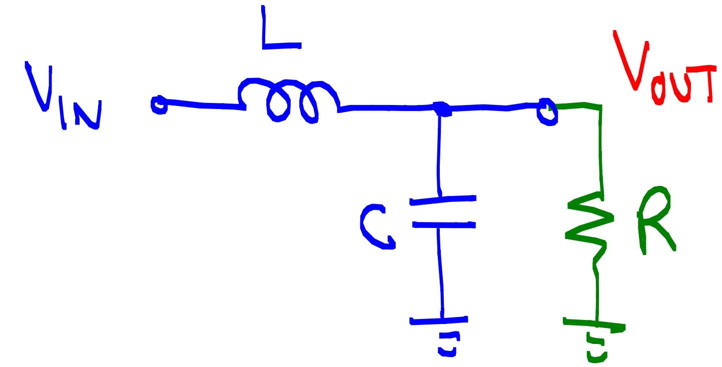
Filter Gain



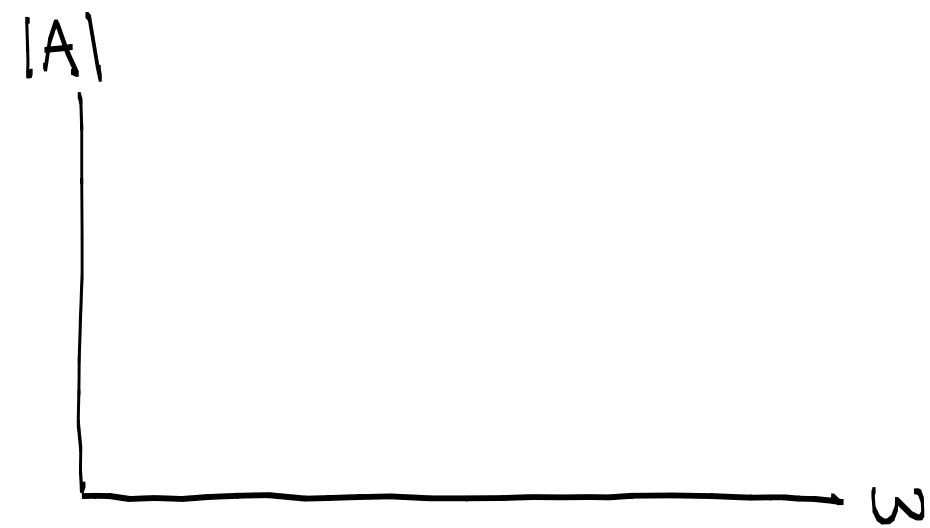
$|A(f)|$

D. Passive LC filter

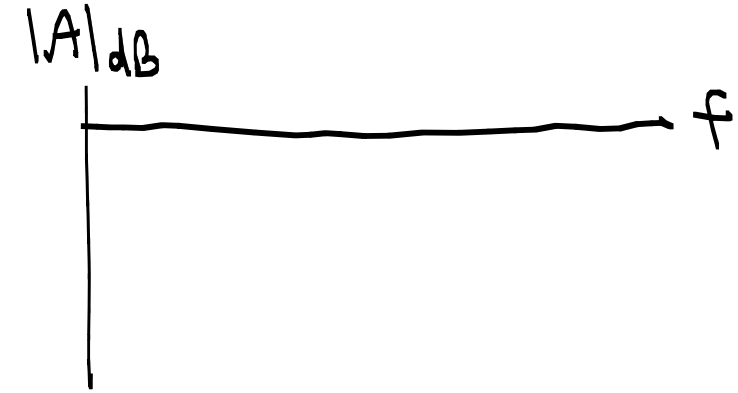
An LC circuit can produce faster freq roll off.



$$\Rightarrow \frac{V_{OUT}}{V_{IN}} =$$



- Simple RC filter (1st order filter) is OK if a gradual rolloff is acceptable.



Q: Higher order = Multiple passive filters?

A: NO!

Disadvantage:

Q: Can we make ________ filters with same properties as RLC circuits?

2. Active Filters

→ Active filters can produce very steep roll-off without inductors!

- **Butterworth Filter**

$|A(f)| =$

$\boxed{1^{st}\text{ order Butterworth}}$ (n = 1)

$\boxed{2^{nd} \text{ order Butterworth}}$

$$|A| = \frac{1}{\sqrt{\quad}}$$

- A simple implementation is to use a "Sallen-and-Key" design.

① $Q =$

② $f_c =$

$\boxed{\text{Example}}$ $R = 30K$, $C_1 = 820\,pF$

$C_2 = 1.64\,nF$

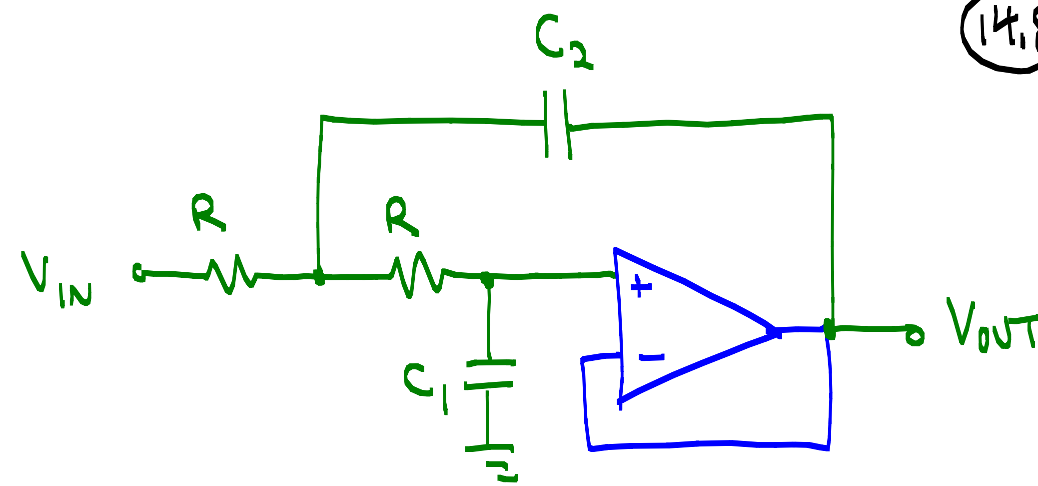
- Is Q correct?

- f_c?

Design Example

2^{nd} order Butterworth LPF

with $-30\,dB$ gain at $10\,kHz$



1

2

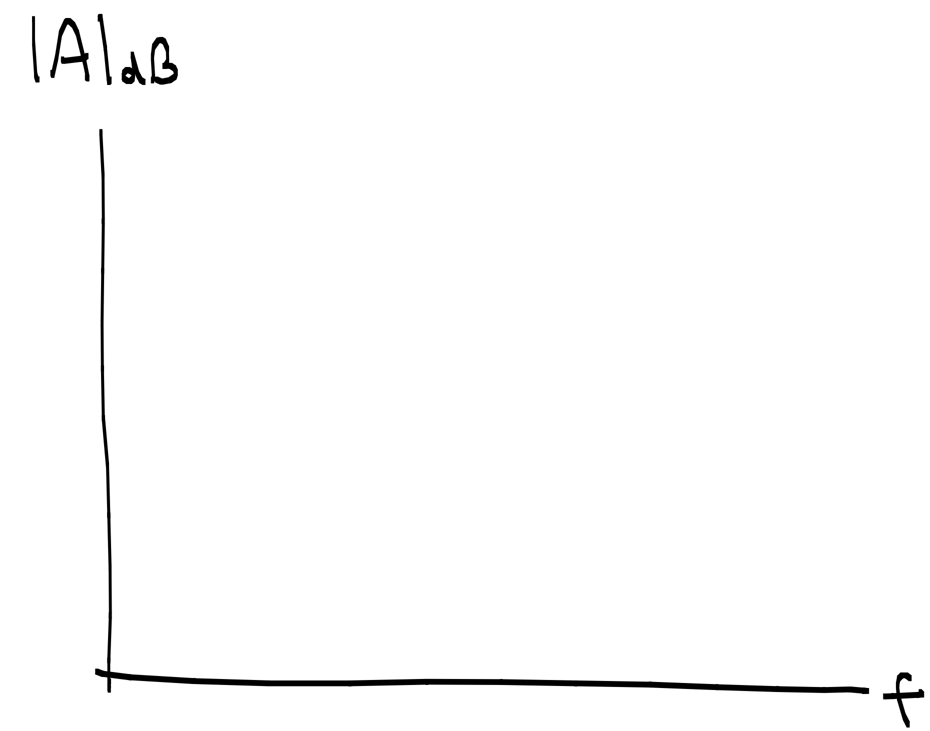
3

• Higher Order Butterworth

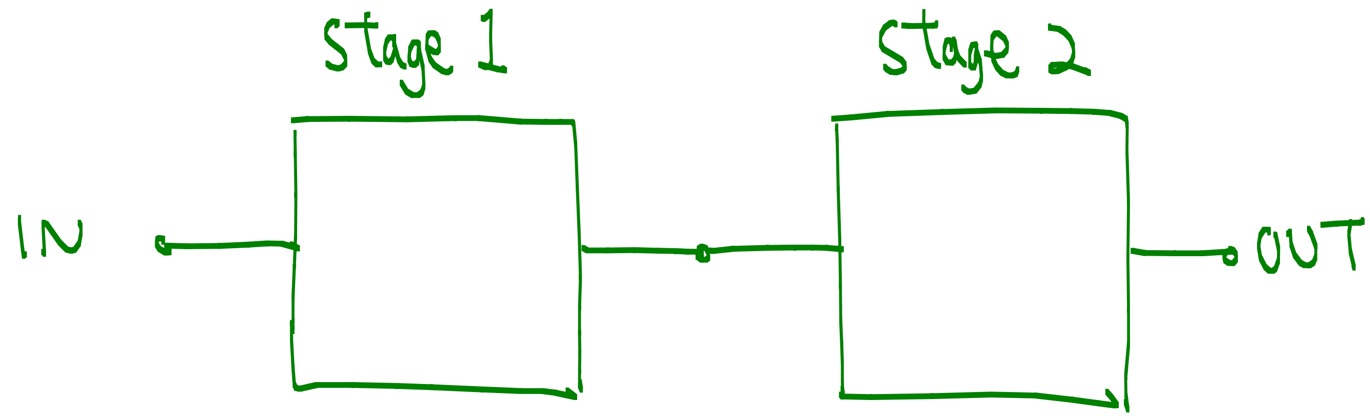
How to make a 4^{th} order Butterworth?

$$|A| = \frac{1}{\sqrt{\quad}}$$

we cannot simply cascade two identical 2^{nd} order Butterworth filters.



- Fortunately, we can cascade two $n=2$ Sallen-Key filters



- This technique can be used for higher orders:

(Table 19-3 in textbook)

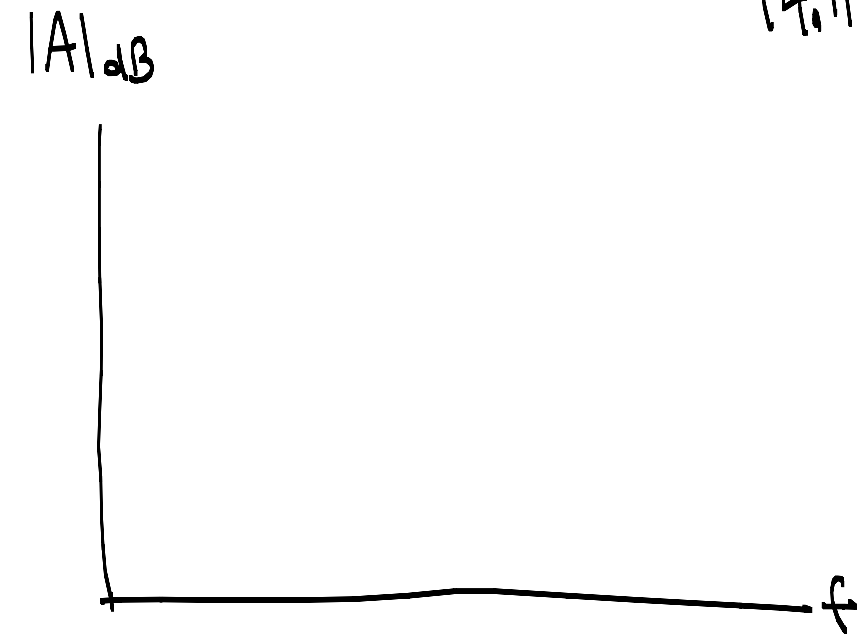
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
$n=2$					
$n=4$					
$n=6$					
$n=8$					
$n=10$					

• Chebyshev Filter

→ Produce a steeper transition than Butterworth

BUT,

→ Same op amp circuit, but the filter parameters are slightly more complicated...



$Q =$

$f_p =$

$f_c =$

A_p :

Ex: $n = 2$ Chebyshev

→ $A_p = 0.69\,dB$

$Q = 0.9$

$f_c = 0.874 f_p$