BIOPOTENTIAL FILTERS

EE 471 – F2016

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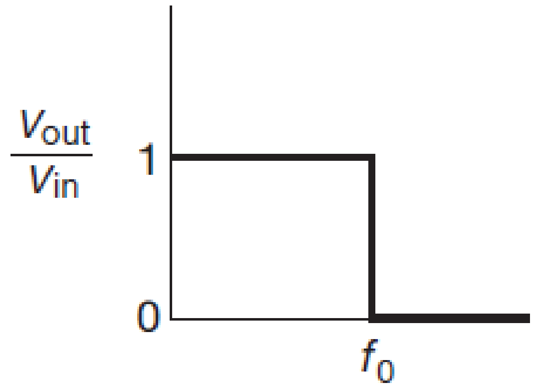
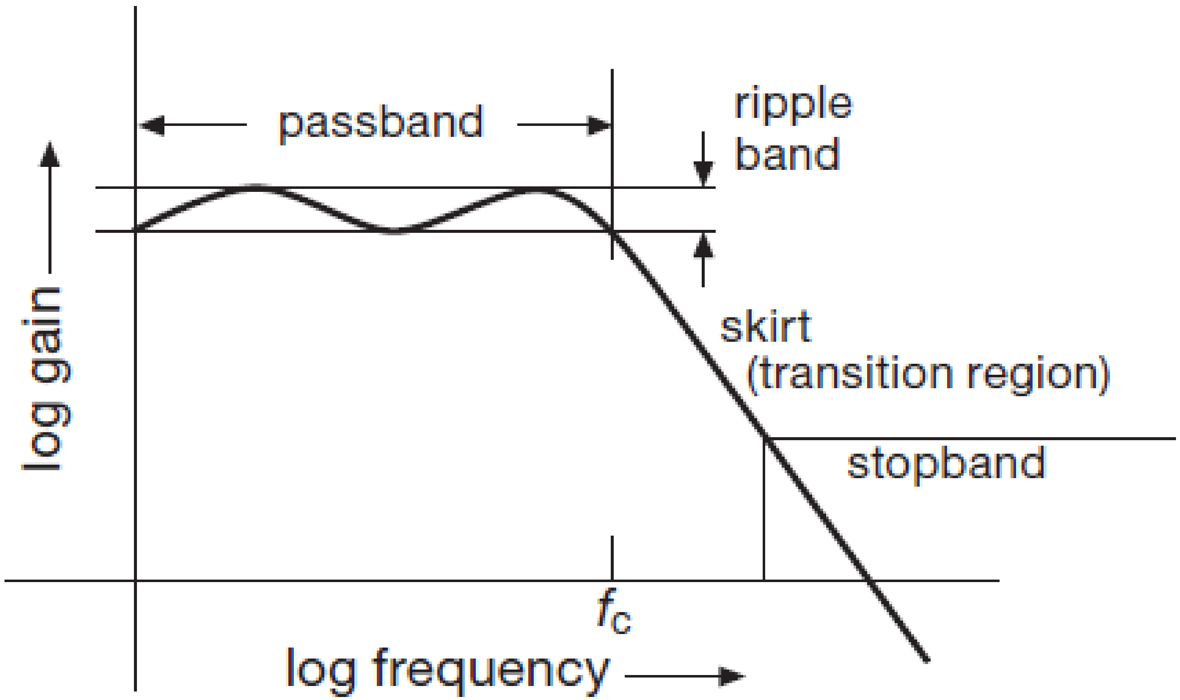
Why Use Filters?

- Detection of a wanted signal may be impossible if unwanted signals and noise are not removed sufficiently by filtering
- Electronic filters allow some signals to pass, but stop others
  - To be more precise, filters allow some signal frequencies applied at their input terminals to pass through to their output terminals with little or no reduction in signal level
- Passive Filters: Rely on passive R, L, and C components only
- Active Filters: Involve Op Amps

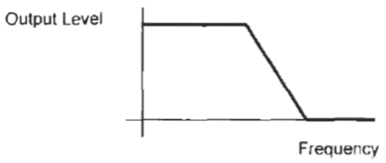


Ideal brick-wall lowpass filter

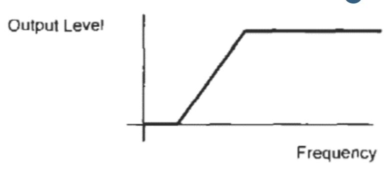
Practical Filter Response



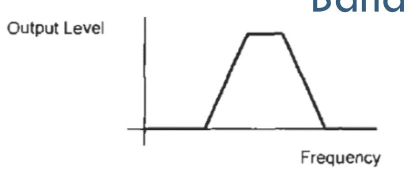
Lowpass



Highpass



Bandpass



Bandstop

Analog Filter Normalization

- A normalized filter is one in which the passband cutoff point is at $\omega = 1$ rad/s
- Passive filters are normalized for a 1 Ω load impedance
- The reason for normalization is to make the calculation of values simple
- Passive analog filters can be designed using tables of normalized component values
  - Same set of normalized component values can be used to design passive lowpass, highpass, bandpass, and bandstop filters with any load impedance

Common Filter Response Functions

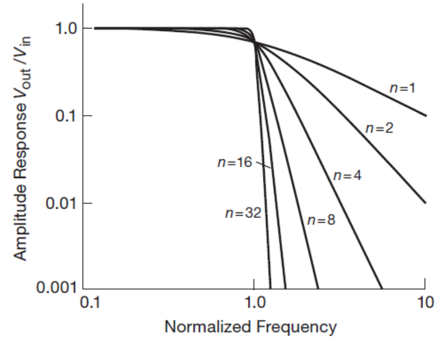
- Butterworth filter

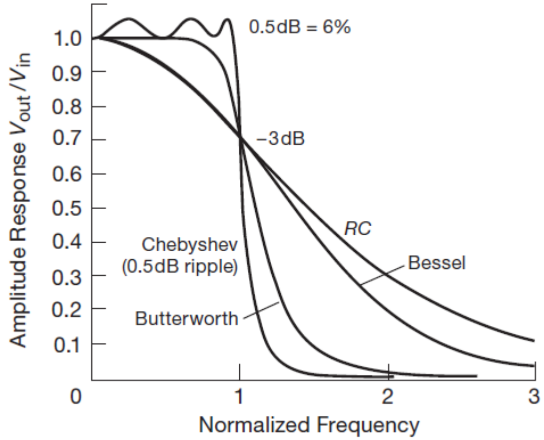
$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{[1+(f/f_c)^{2n}]^{\frac{1}{2}}}$$

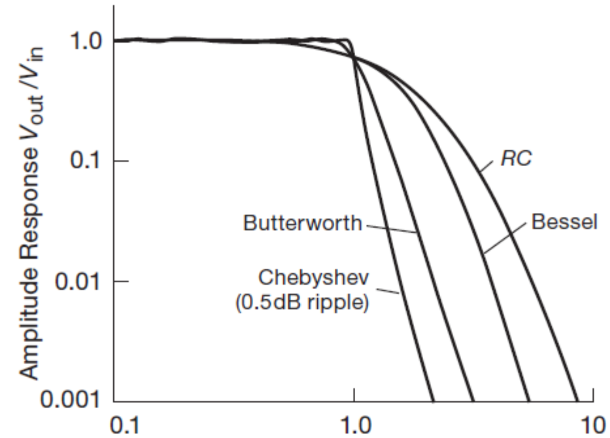
- Chebyshev filter

$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{[1+\varepsilon^2 C_n^2(f/f_c)]^{\frac{1}{2}}}$$

- Bessel filter
- Elliptic function (Cauer) filter

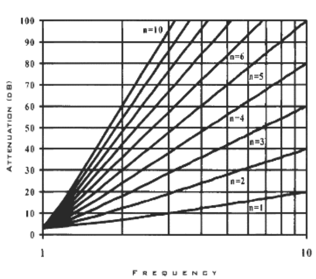






Design with Normalized Analog Filters

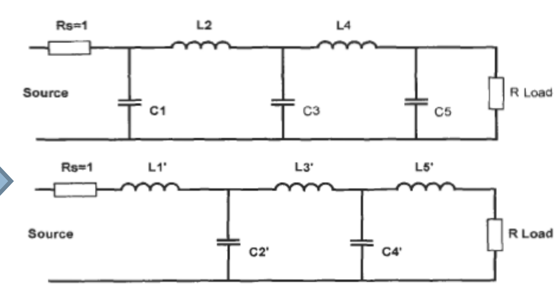
- Select the type of response required
- Determine the filter order using the frequency response graphs
- Use normalized analog filter tables to obtain a set of normalized component values
- Scale the obtained normalized component values for the frequency, impedance, and frequency response (lowpass, highpass, etc.) as required



Order	C1	L2	C3	L4	C5	L6	C7	L8	C9	L10
1	2.0000									
2	1.41421	1.41421								
3	1.00000	2.00000	1.00000							
4	0.76537	1.84776	1.84776	0.76537						
5	0.61803	1.61803	2.00000	1.61803	0.61803					
6	0.51764	1.41421	1.93185	1.93185	1.41421	0.51764				
7	0.44504	1.24698	1.80194	2.00000	1.80194	1.24698	0.44504			
8	0.39018	1.11114	1.66294	1.96157	1.96157	1.66294	1.11114	0.39018		
9	0.34730	1.00000	1.53209	1.87938	2.00000	1.87938	1.53209	1.00000	0.34730	
10	0.31287	0.90798	1.41421	1.78201	1.97538	1.97538	1.78201	1.41421	0.90798	0.31287
	L1′	C2′	L3′	C4′	L5′	C6′	L7′	C8′	L9′	C10′

$$L = \frac{RL^*}{2\pi F_c}$$

$$C = \frac{C^*}{2\pi F_c R}$$



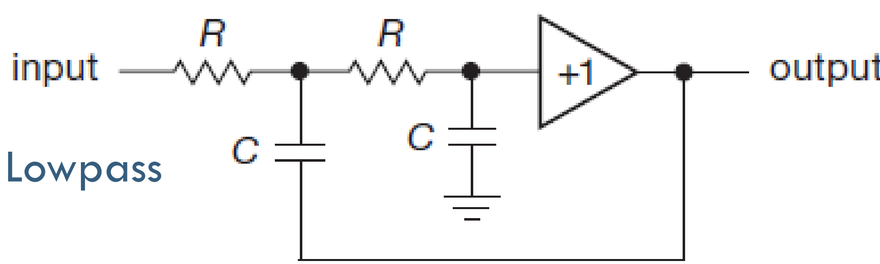
Passive Filter Design Issues

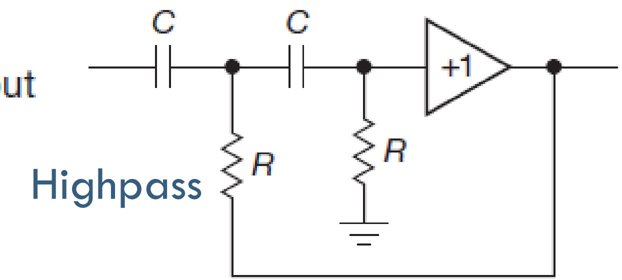
- (+) Synthesis of filters from passive components (*R*, *L*, and C) is highly developed, with rich literature of traditional handbooks and now software tools making such designs easy
- (-) Inductors are bulky, expensive, and always non-ideal (lossy)
- (-) Passive filters using *L* and C are not electrically tunable

- We need a way to make *inductor-less* filters with the same characteristics of ideal *RLC* filters
- Active filters allow us to do that

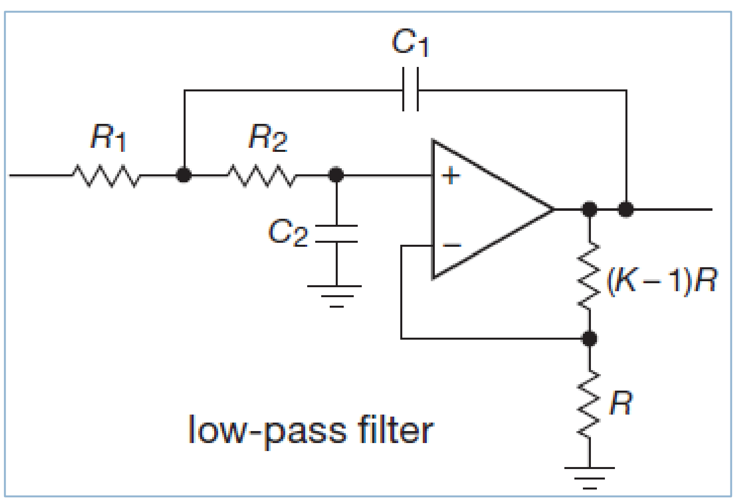
Sallen-Key Filters

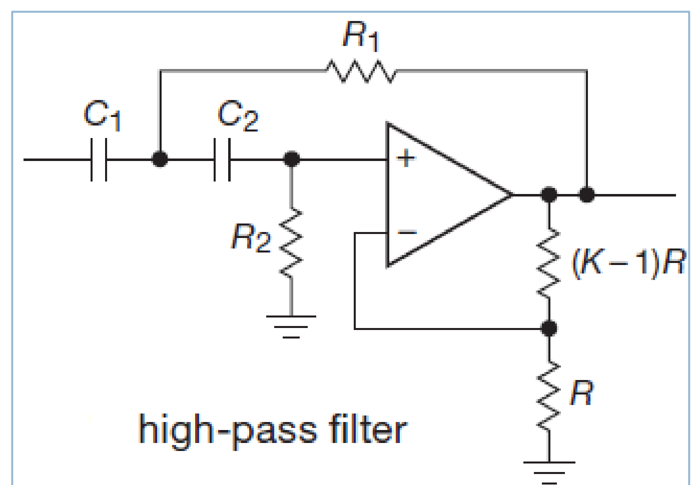
- Simple Sallen-Key Filters: Gain=1 and 2 poles (2nd order)





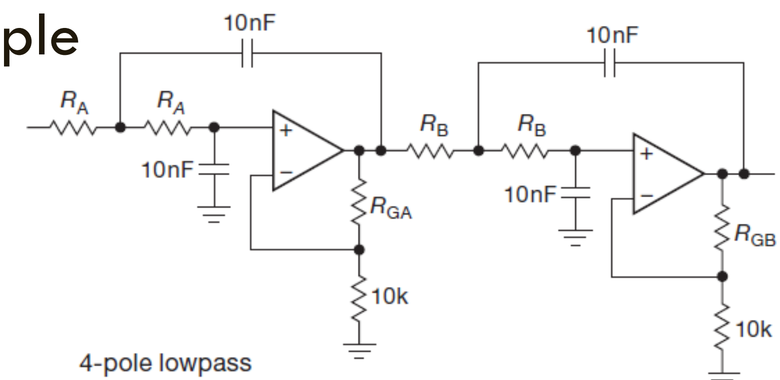
- Voltage Controlled Voltage Source (VCVS) filters: Gain=K > 1





VCVS Filter Design Using Table

- To construct *n*-pole filter, cascade *n*/2 VCVS sections
  - Within each section, $R_1=R_2=R$, and $C_1=C_2=C$
  - Set gain K of each stage according to table entries
- To calculate values for R and C:
  - Butterworth: use $RC= 1/2\pi f_c$
  - Chebyshev/Bessel: use $RC= 1/2\pi c_n f_c$
- Example



4-pole lowpass
f_C = 100 Hz

Filter Type	R_A	R_{GA}	R_B	R_{GB}	Gain
Bessel	110k	845Ω	100k	7.68k	1.91
Butterworth	158k	1.54k	158k	12.4k	2.57
Chebyshev (0.5dB)	267k	5.76k	154k	16.5k	4.21

Table 6.2 VCVS Lowpass Filters

Poles	Butter-worth	Bessel		Chebyshev (0.5dB)		Chebyshev (2dB)	
	K	c_n	*K*	c_n	*K*	c_n	*K*
2	1.586	1.272	1.268	1.231	1.842	0.907	2.114
4	1.152	1.432	1.084	0.597	1.582	0.471	1.924
	2.235	1.606	1.759	1.031	2.660	0.964	2.782
6	1.068	1.607	1.040	0.396	1.537	0.316	1.891
	1.586	1.692	1.364	0.768	2.448	0.730	2.648
	2.483	1.908	2.023	1.011	2.846	0.983	2.904
8	1.038	1.781	1.024	0.297	1.522	0.238	1.879
	1.337	1.835	1.213	0.599	2.379	0.572	2.605
	1.889	1.956	1.593	0.861	2.711	0.842	2.821
	2.610	2.192	2.184	1.006	2.913	0.990	2.946

Design of VCVS Other Filter Responses

- Same lowpass filter design table is used for all filter types
- To design highpass filter, interchange R and C components
  - Butterworth filters: everything else remains unchanged
  - Bessel and Chebyshev filters: K values remain same, but normalizing factors c_n must be inverted (i.e., $1/c_n$)
- To design bandpass filter, cascade overlapping lowpass and highpass filters
- To design band-reject filter, sum outputs of two nonoverlapping lowpass and highpass filters

Reading Assignment

- Read Chapter 6 of *Art of Electronics*