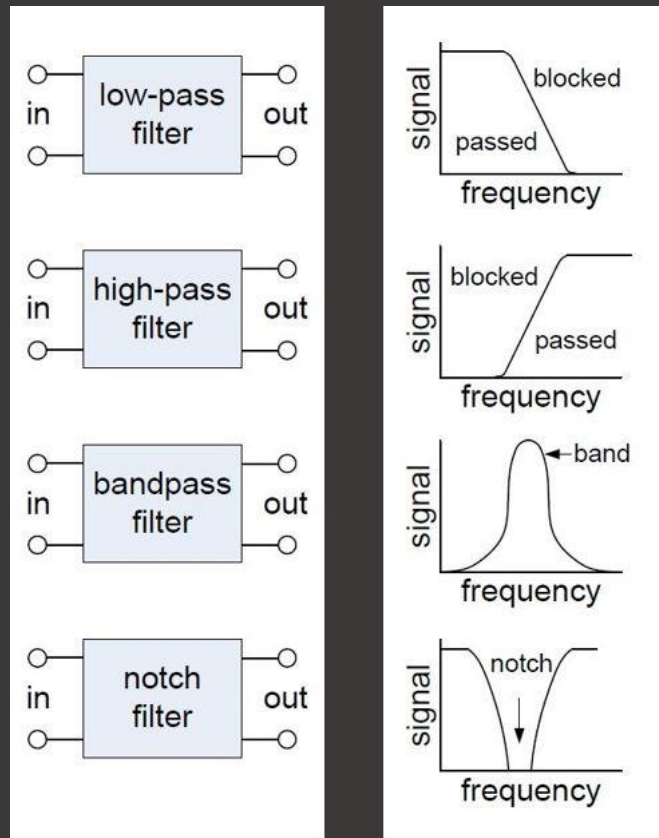


Filtering and Working in the Frequency Domain

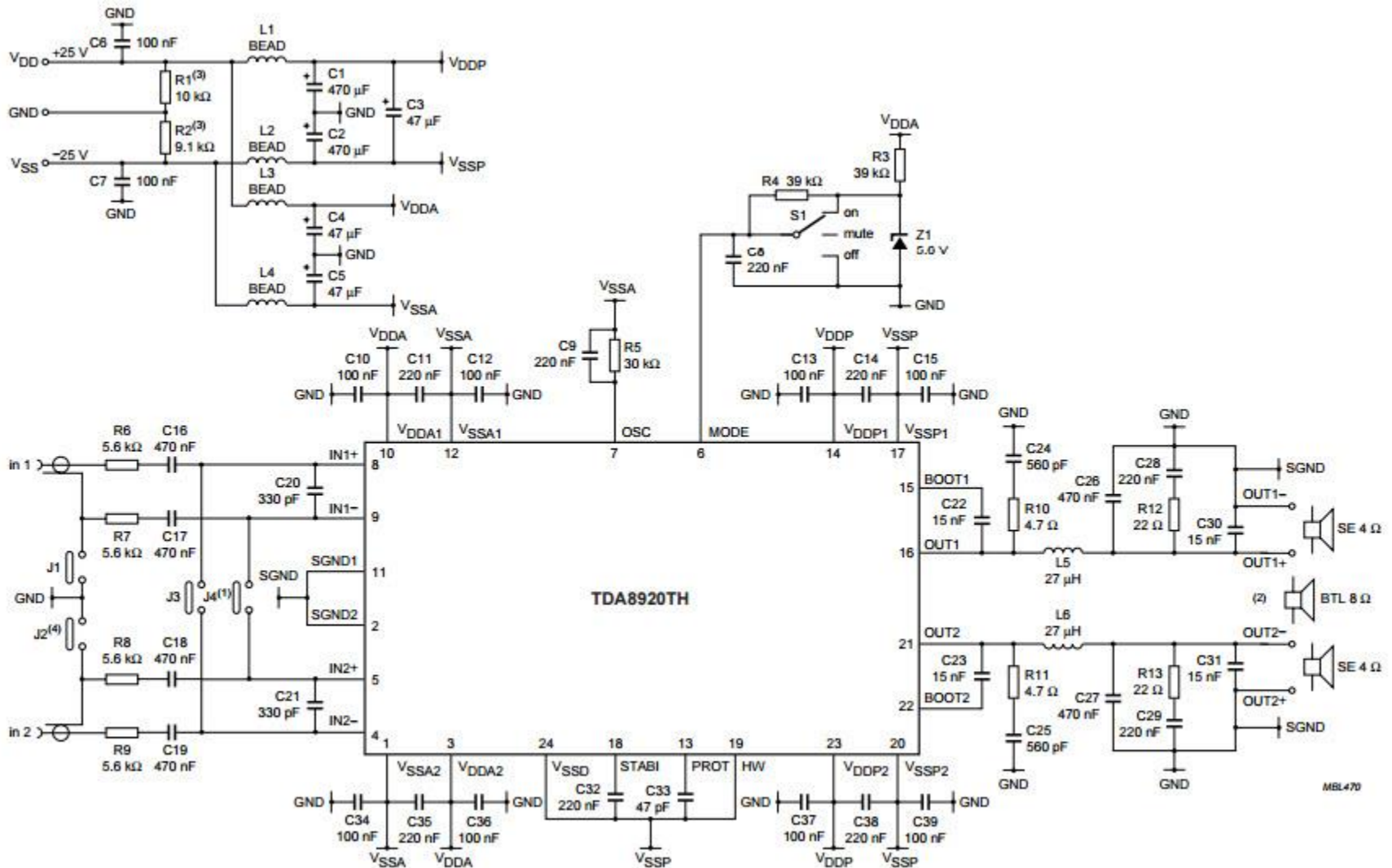
Mar-2019



Tonight

1. Learn how to think in terms of the frequency domain
2. Understand basic filter types
3. Practical examples
4. Power supply bypassing/filtering

Intimidating? Check back after class!



Why use filters?

Part of moving from functional to functioning WELL

(Almost) all power supplies need filtering

Mechanical switches

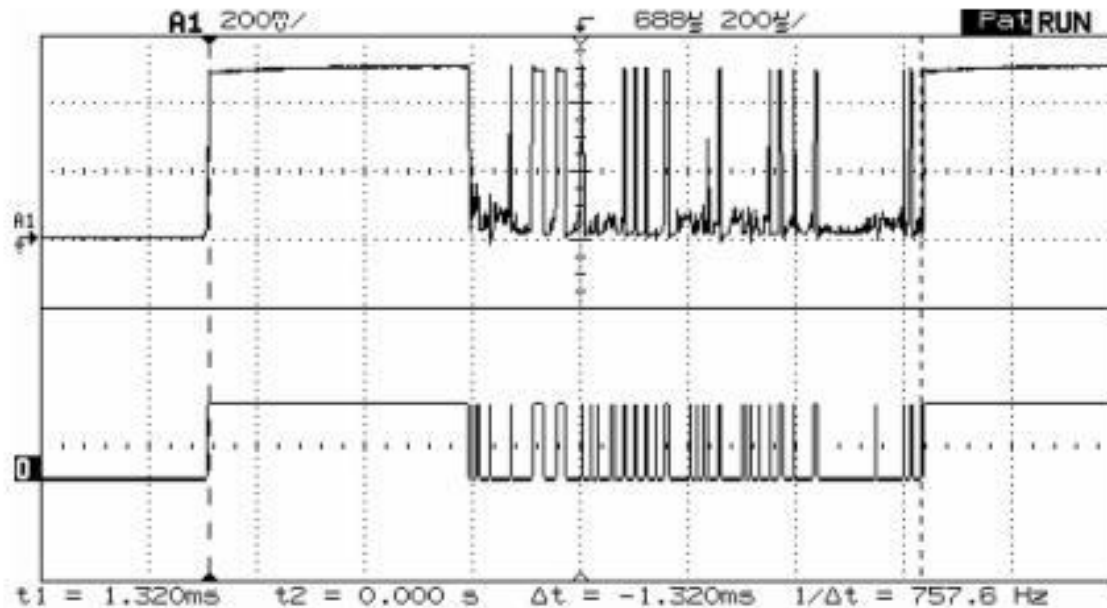
Audio electronics

- Cross-overs
- Equalizers
- Class D audio amplifiers need filtering

Analog/mixed-signal electronics

- Sensor noise
- Analog-Digital signal conversion
- Digital-Analog signal conversion

Switch Debouncing



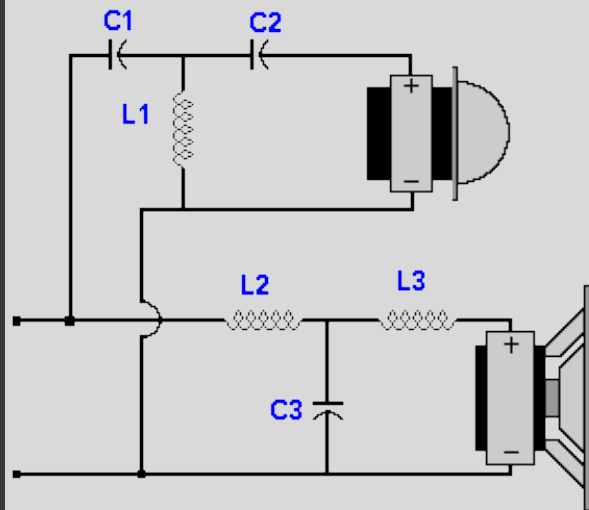
Switch Q – when released, it goes high for 480 μsec before generating 840 μsec of hash, a sure way to blow an interrupt system mad if poorly designed.

Speaker Crossover

3rd Order Butterworth

3000 Hertz

8 Ohm Tweeter / 8 Ohm Woofer



Parts List

Capacitors

C1 = 4.42 μF

C2 = 13.26 μF

C3 = 8.84 μF

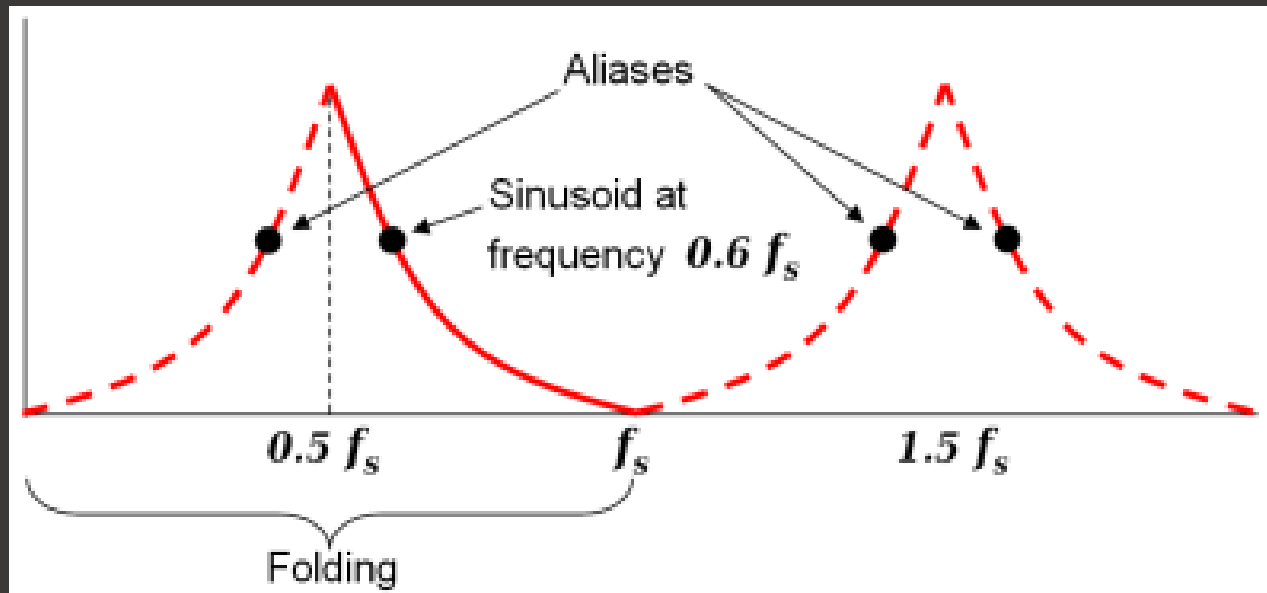
Inductors

L1 = 0.32 mH

L2 = 0.64 mH

L3 = 0.21 mH

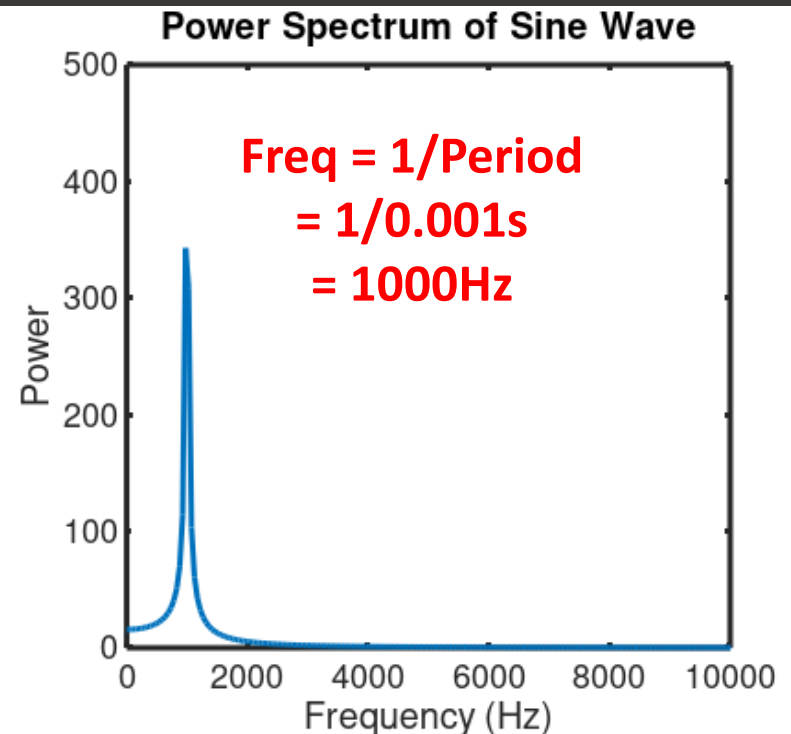
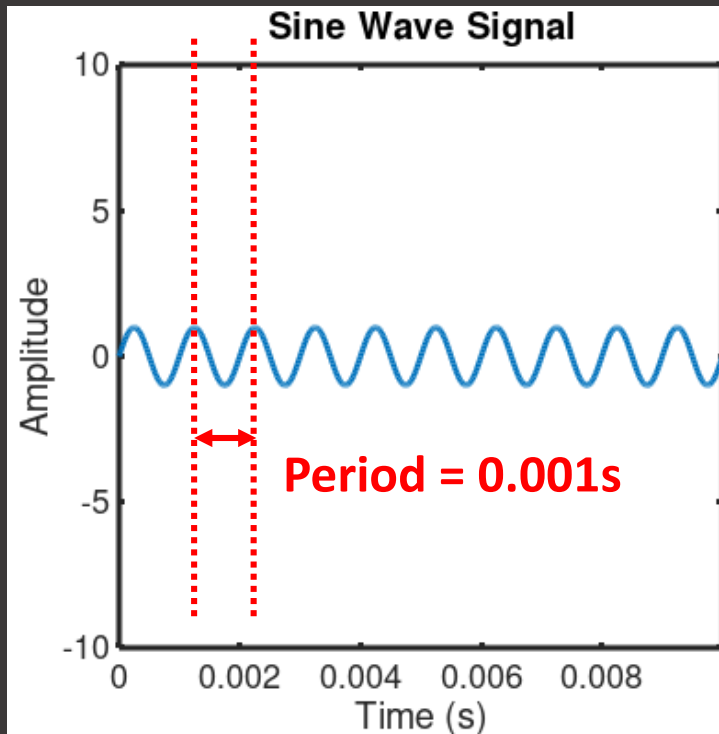
ADC Example - Aliasing



Time vs Frequency Domain

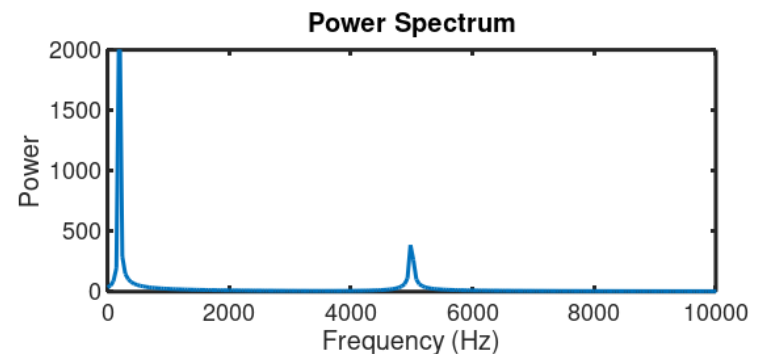
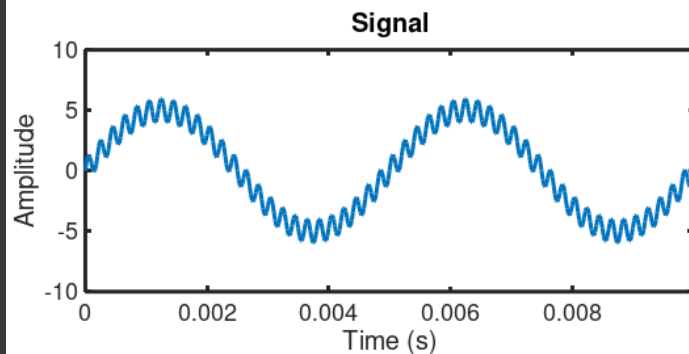
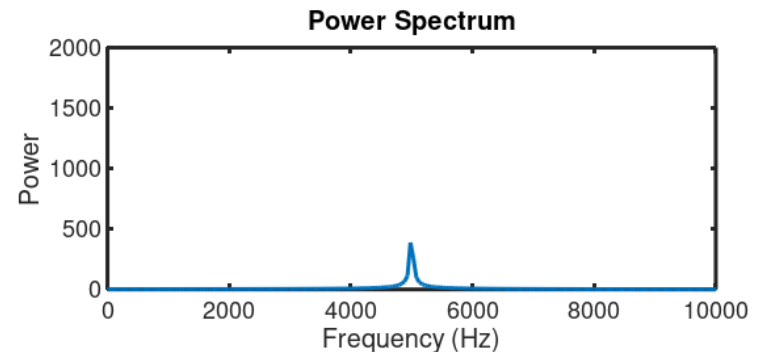
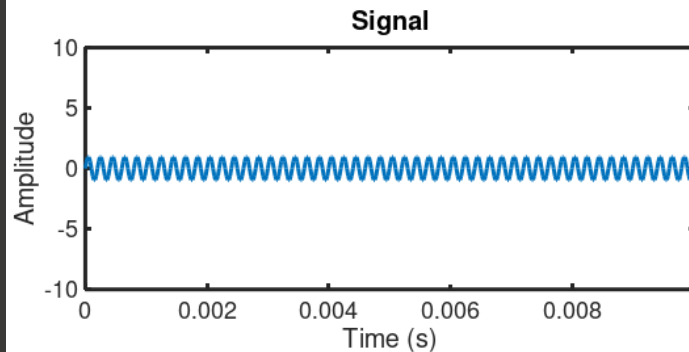
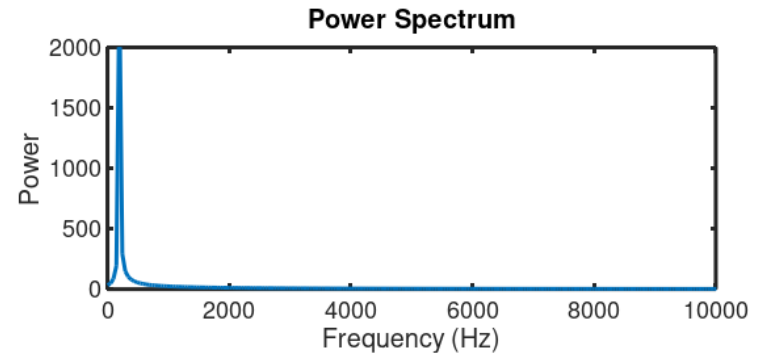
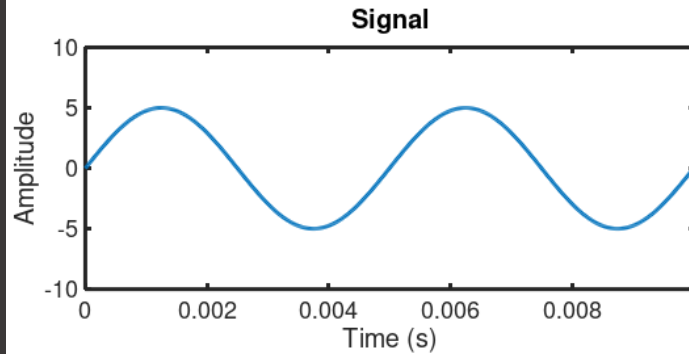


Time vs Frequency Domain

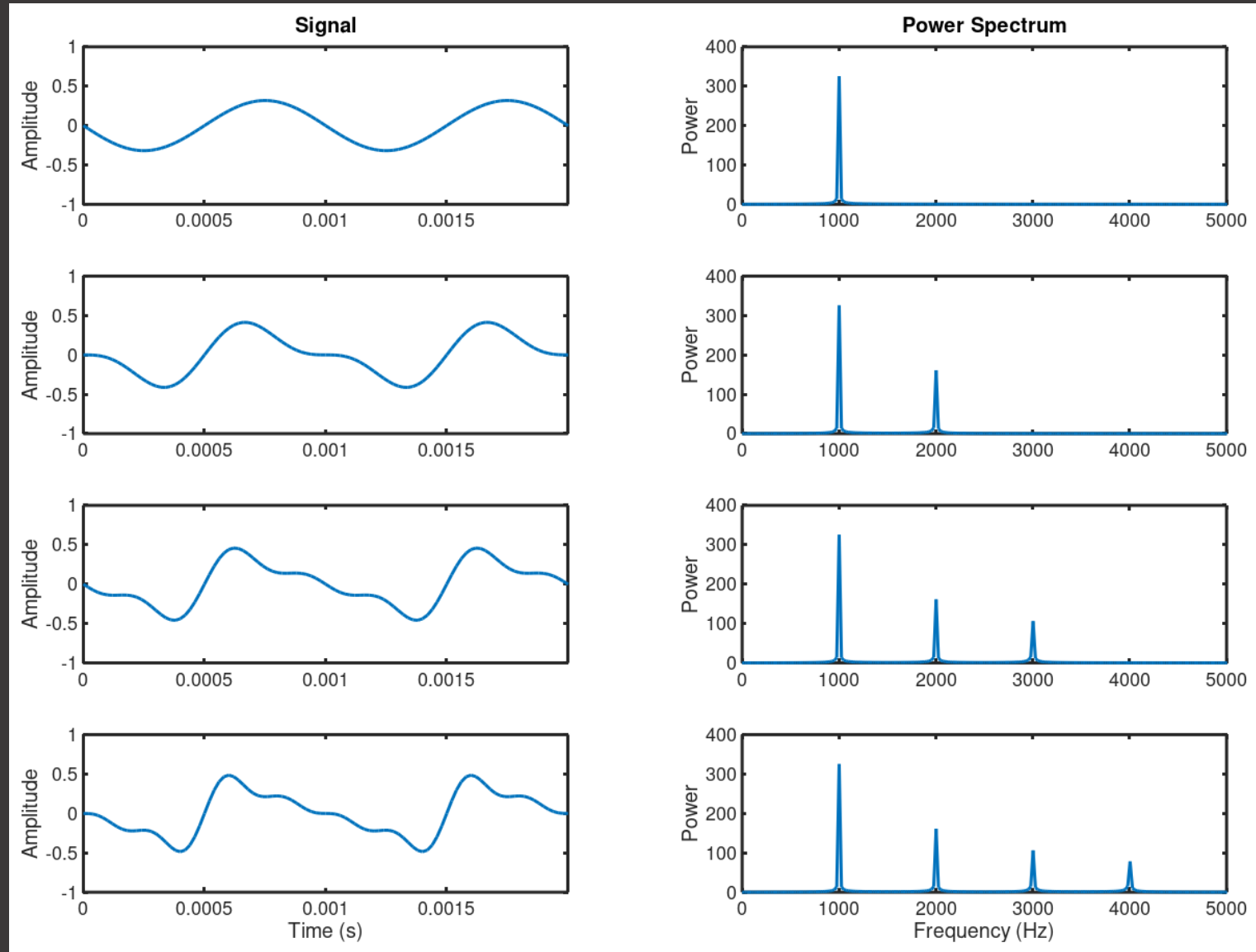


$$\text{Frequency} = 1 / \text{Period}$$

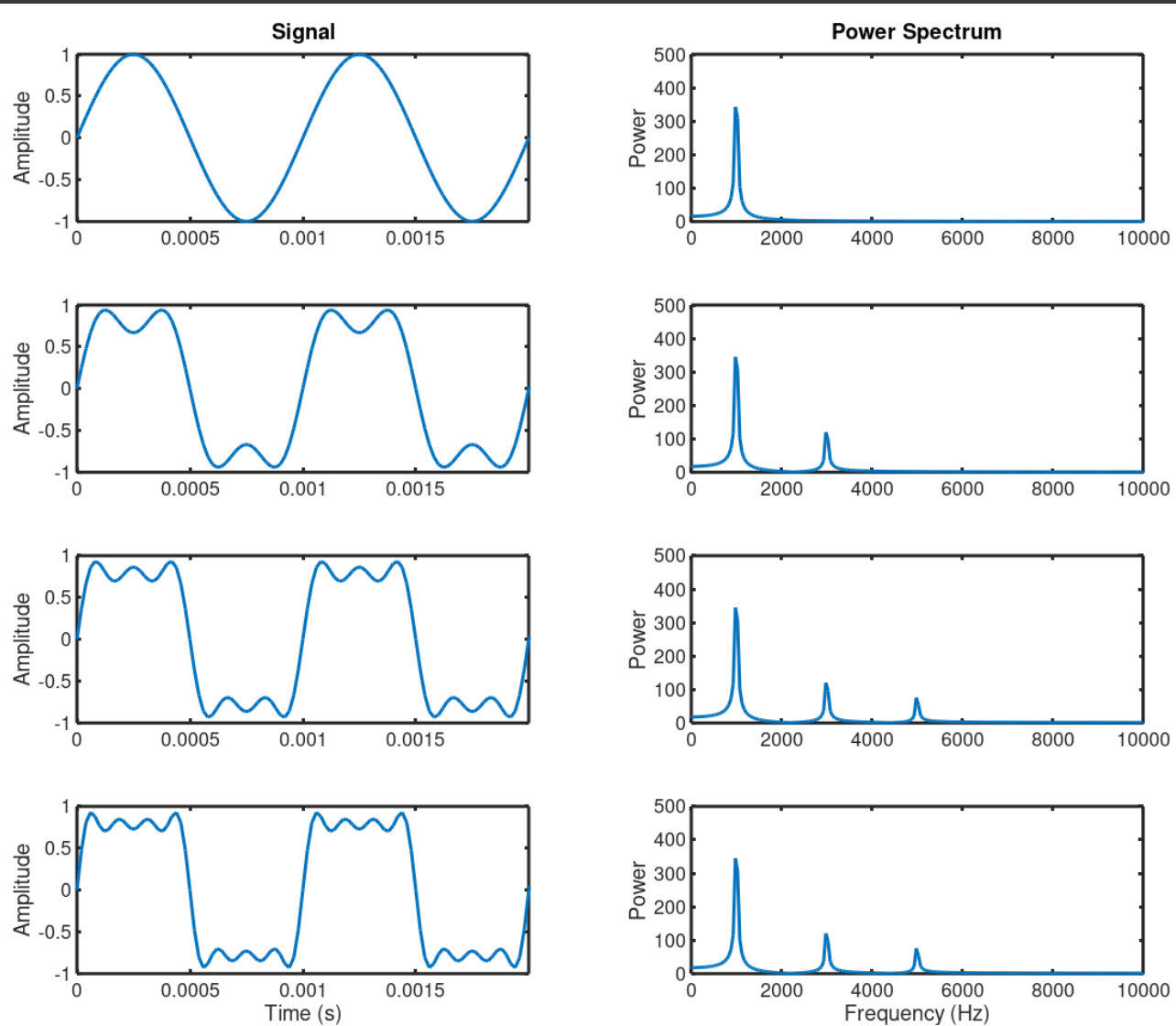
2 Sine Waves Added Together



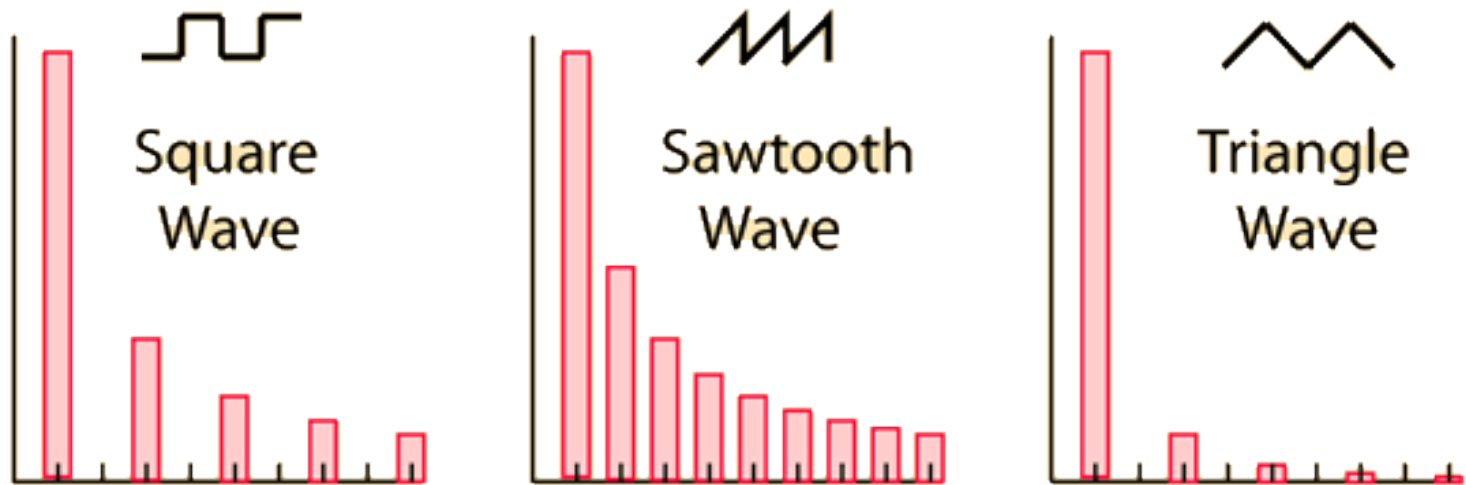
Creating a Waveform from “Harmonics”



Square Wave = Odd Harmonics

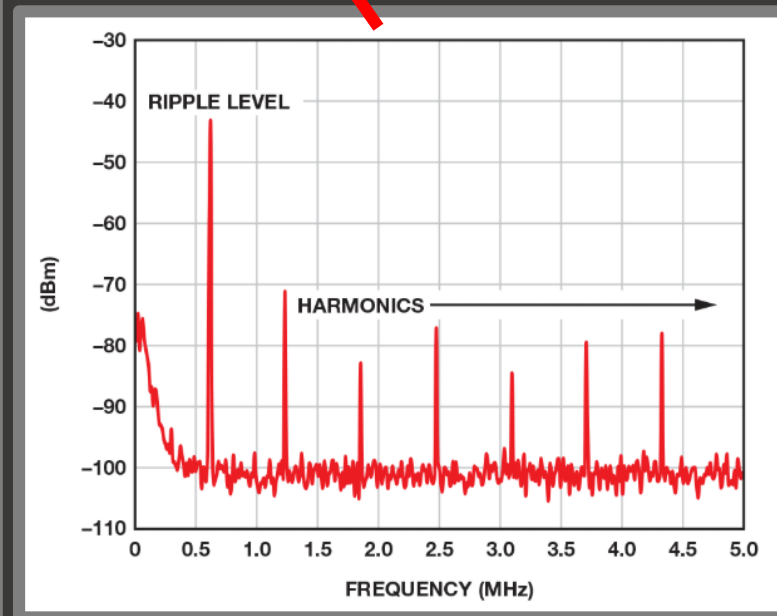
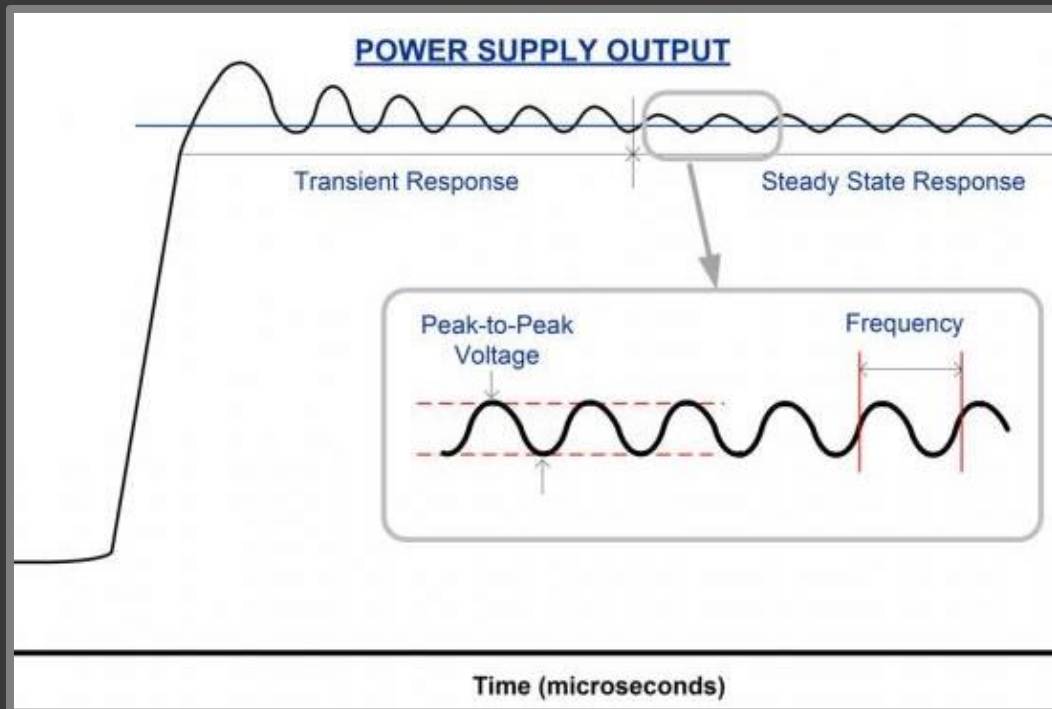
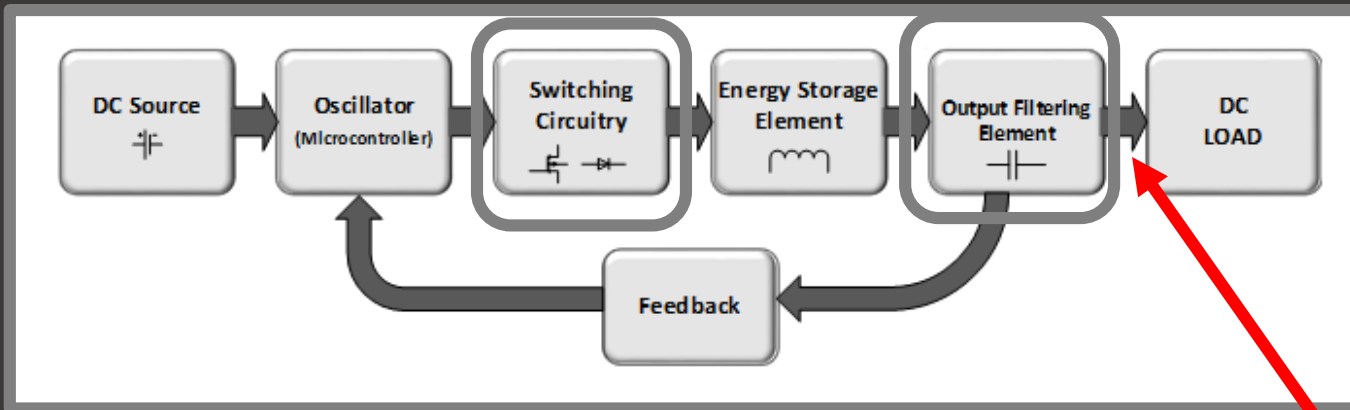


Common Waveforms

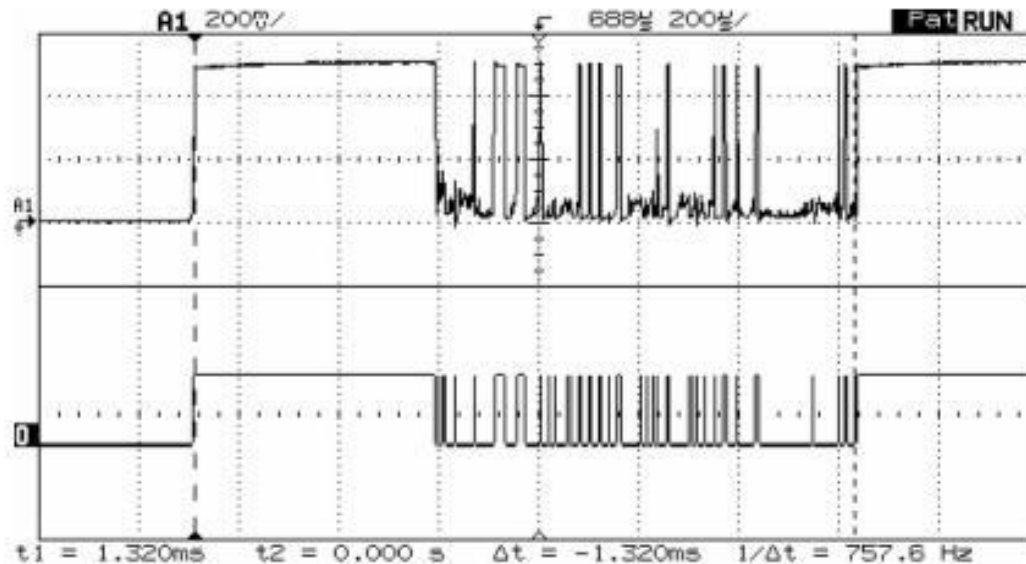


Note: vertically symmetric waveforms tend not to have even harmonics

Switching Power Supply Noise



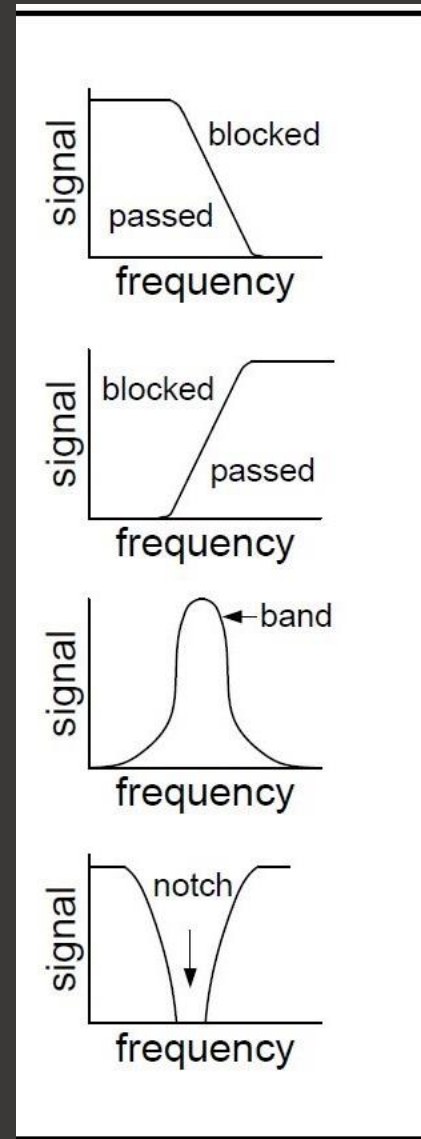
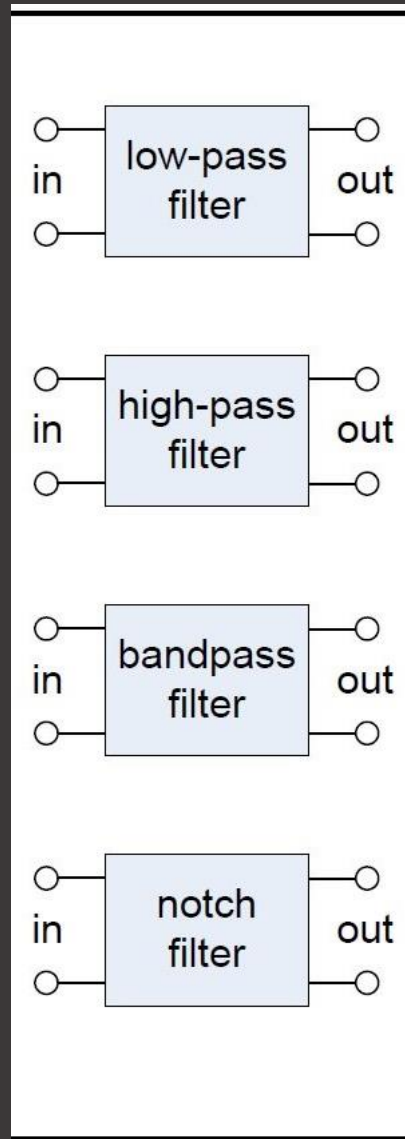
Switch Debouncing



Switch Q – when released, it goes high for 480 μsec before generating 840 μsec of hash, a sure way to blow an interrupt system mad if poorly designed.

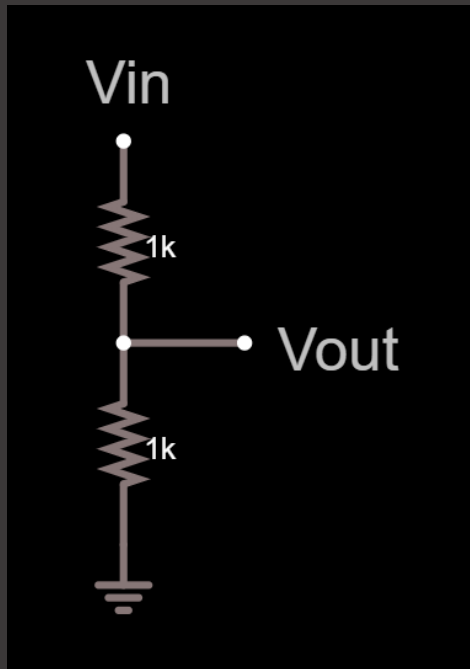
What frequencies might need to be retained vs rejected?

Types of Filters

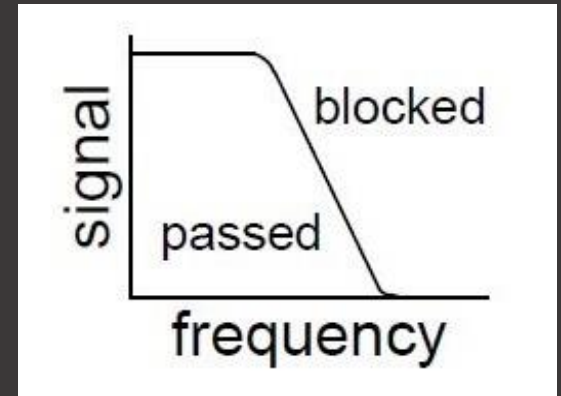
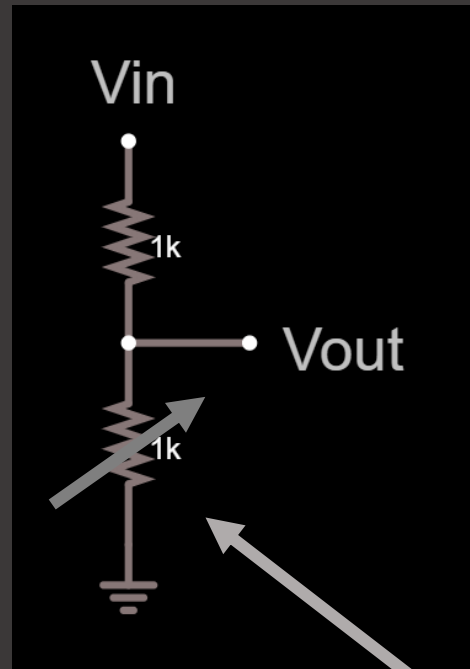


A Conceptual Low Pass Filter

All-pass


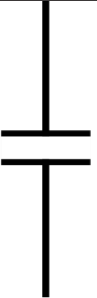





Low-pass



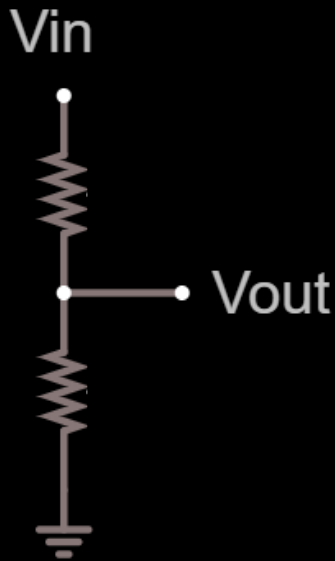
Decreases with
frequency

RLC Components vs Frequency

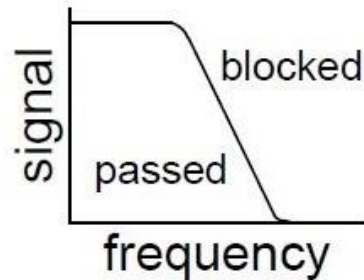
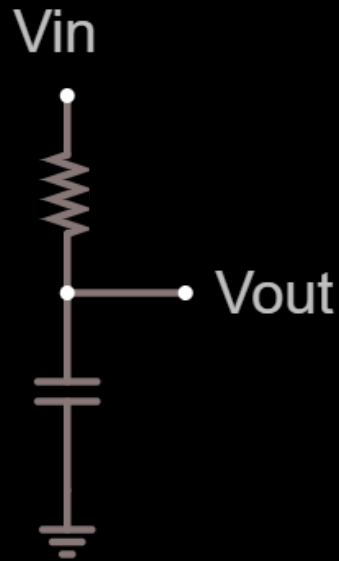
	DC Resistance/ AC Reactance	Change w/ freq?
	R	$=$
	$X_C \propto \frac{-1}{fC}$	
	$X_L \propto fL$	

RC Filters

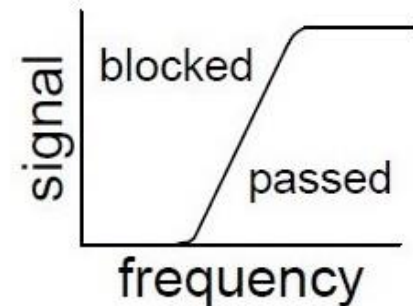
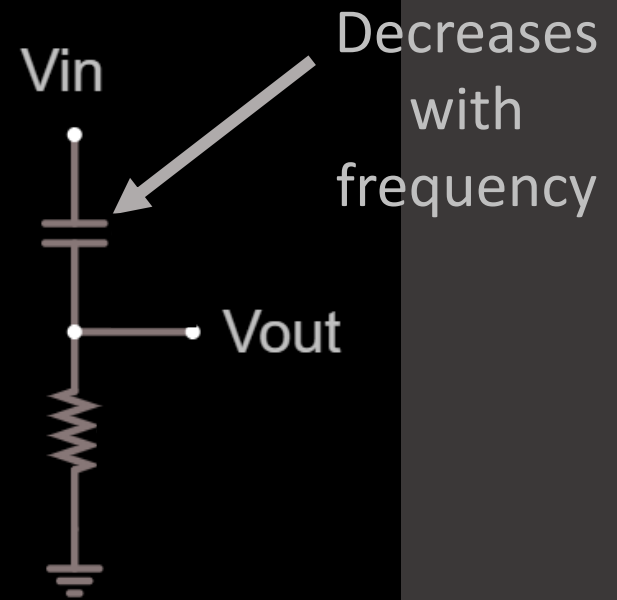
All-Pass



Low-Pass

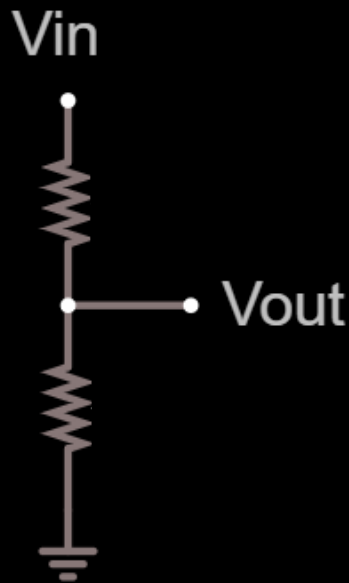


High-Pass

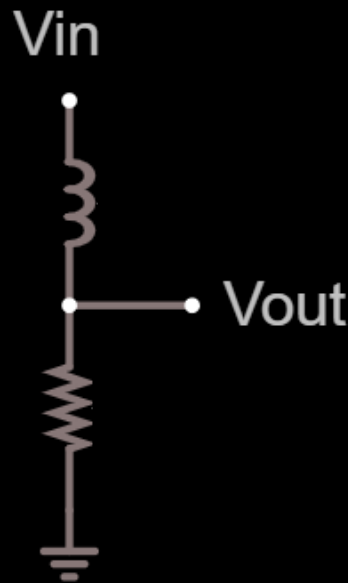


LC Filters

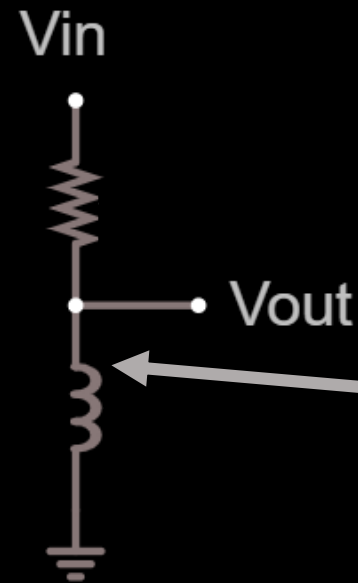
All-Pass



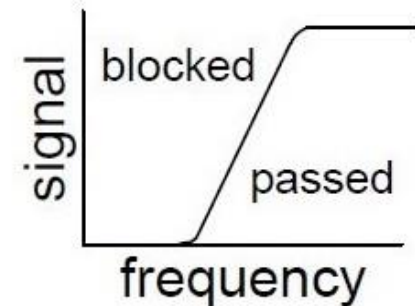
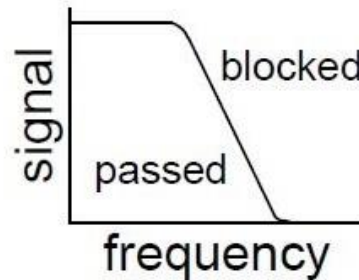
Low-Pass



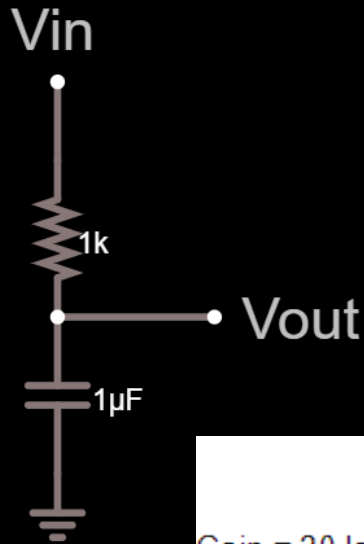
High-Pass



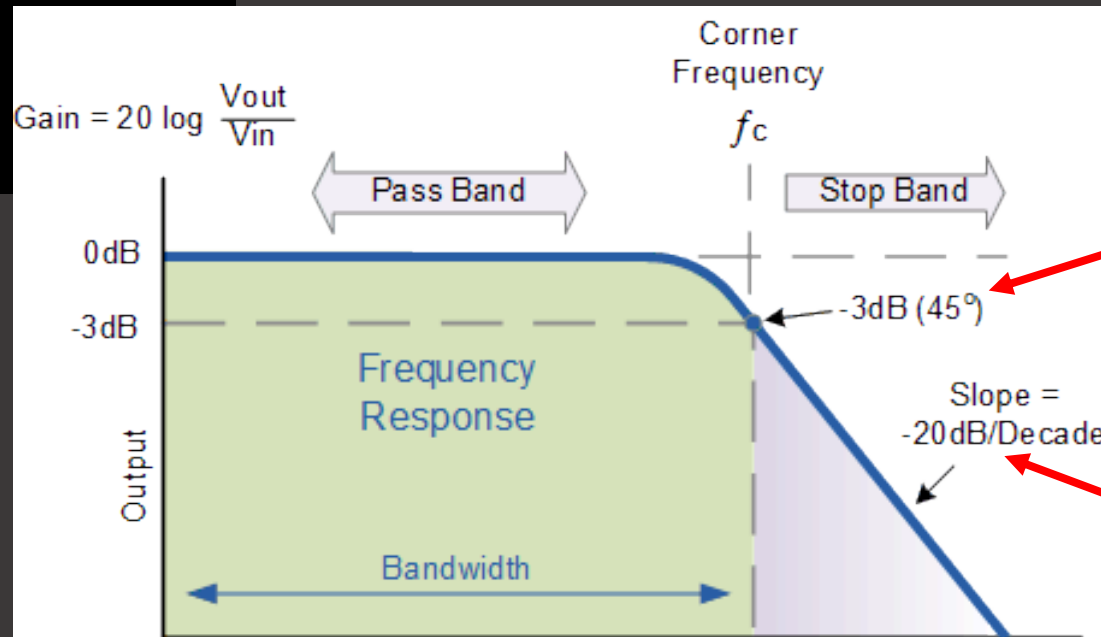
Increases
with
frequency



RC Low Pass Filter



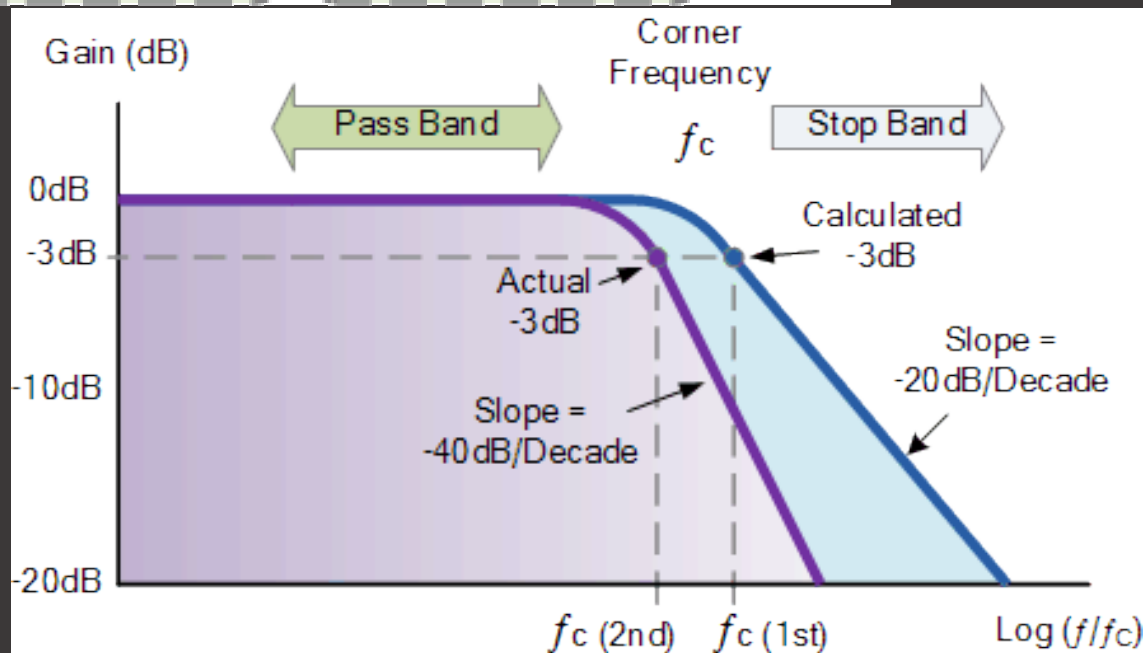
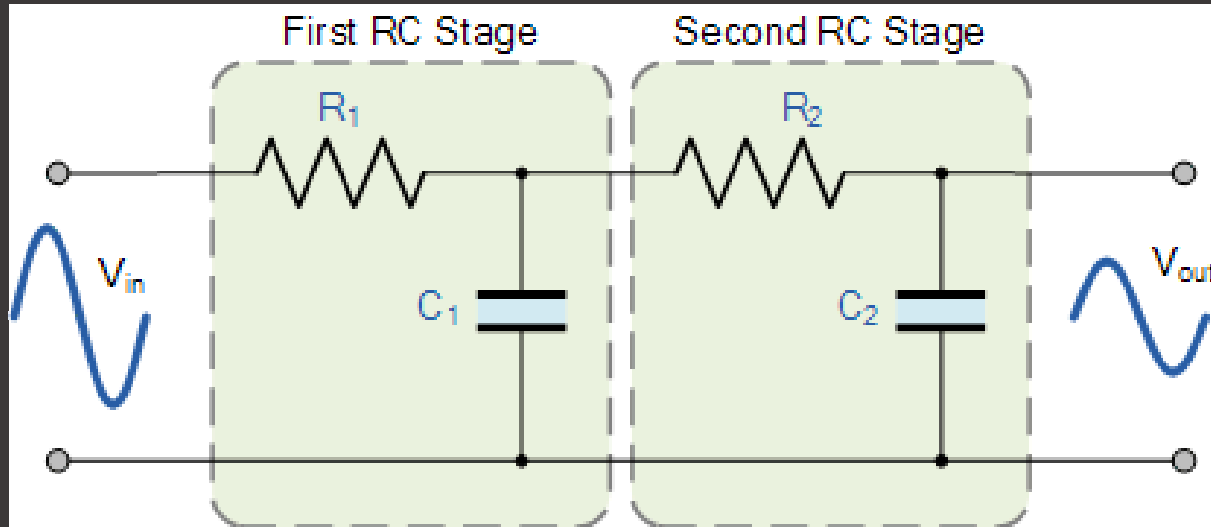
$$f_c = \frac{1}{2\pi RC}$$



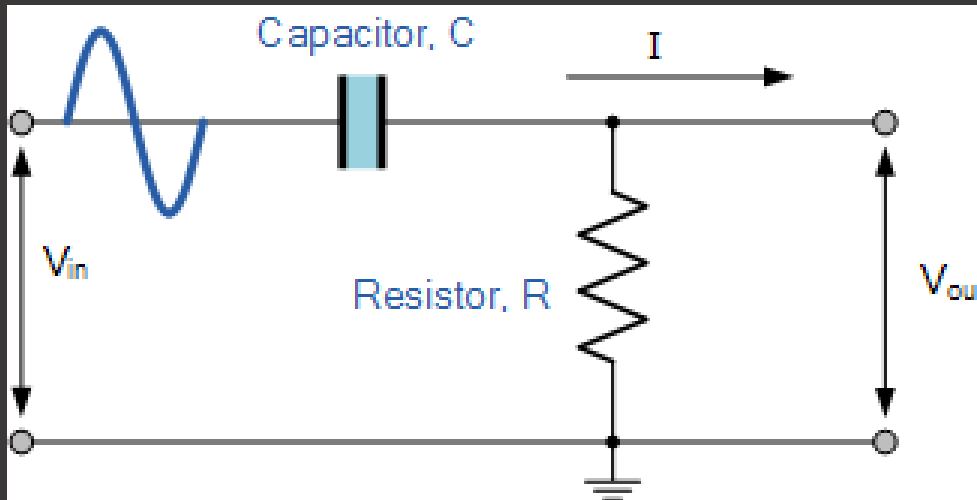
-3dB = 0.707

-20dB = 0.1

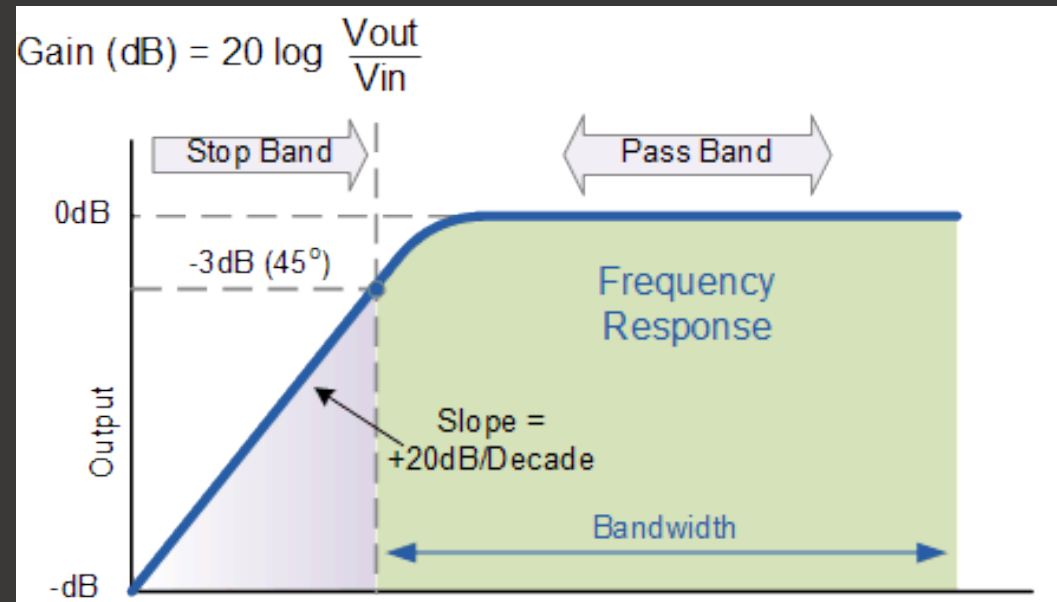
2nd Order Low Pass Filter



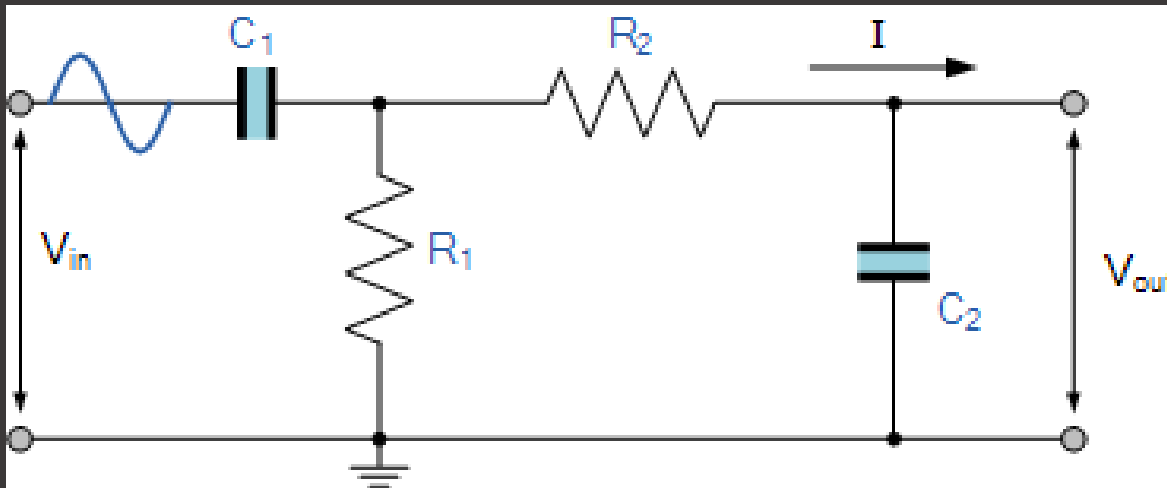
RC High Pass Filter



$$f_c = \frac{1}{RC}$$

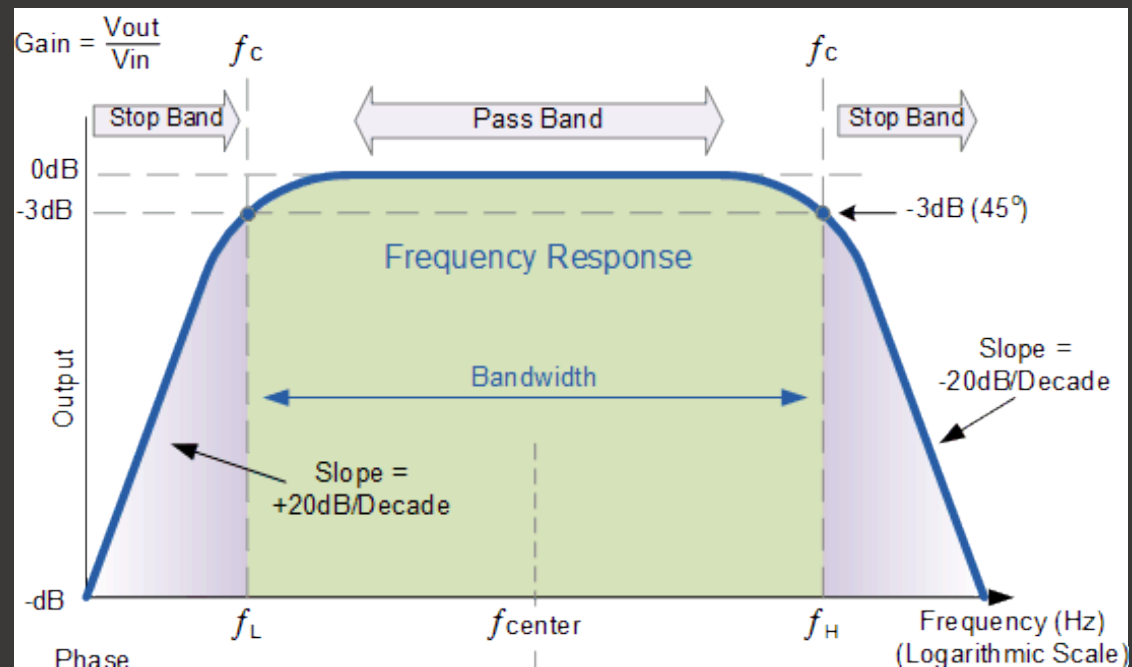


RC Band Pass Filter

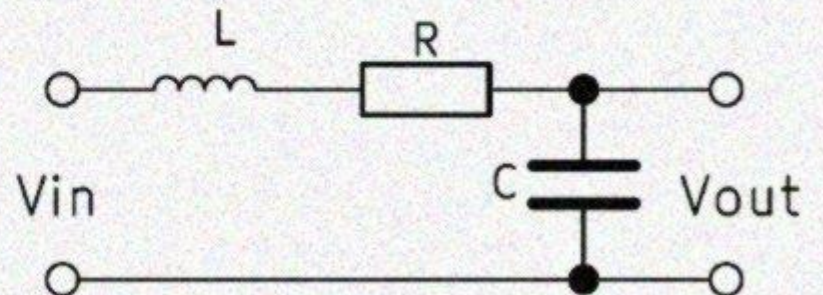
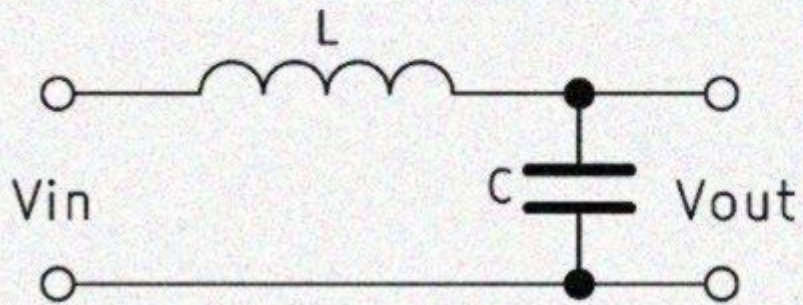
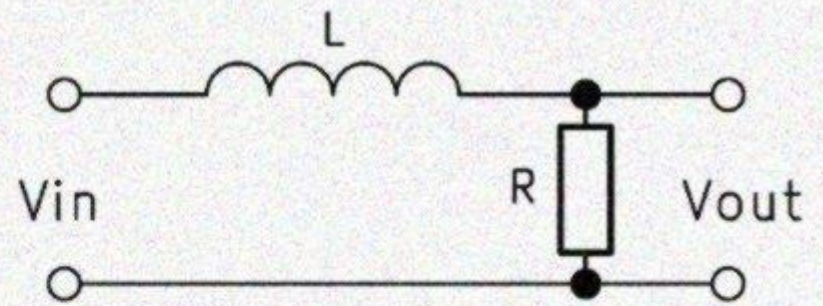
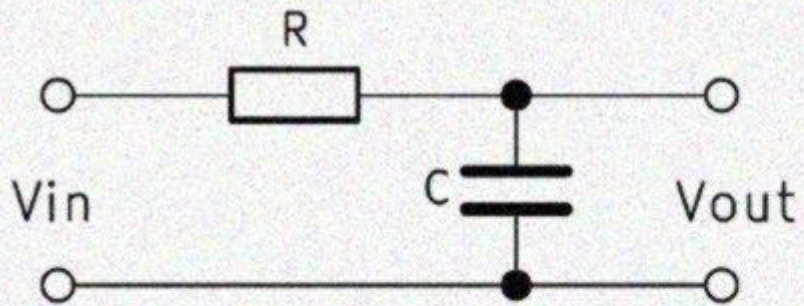


$$f_L = \frac{1}{R_2 C_2}$$

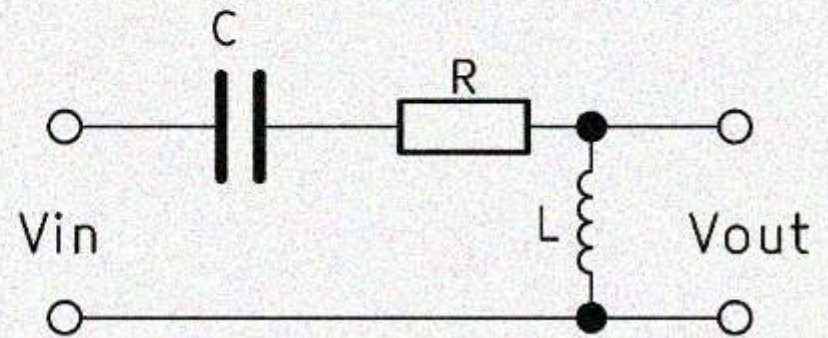
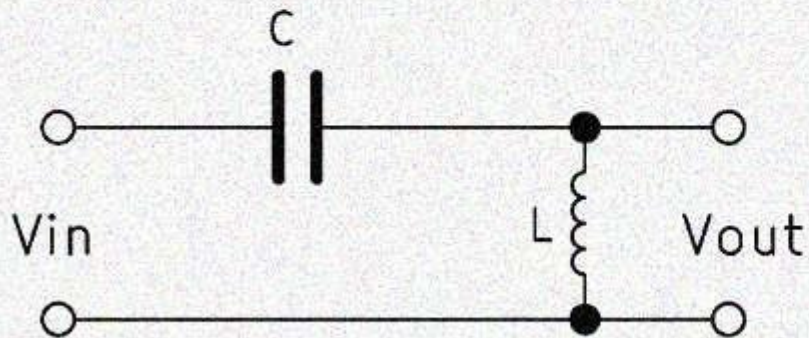
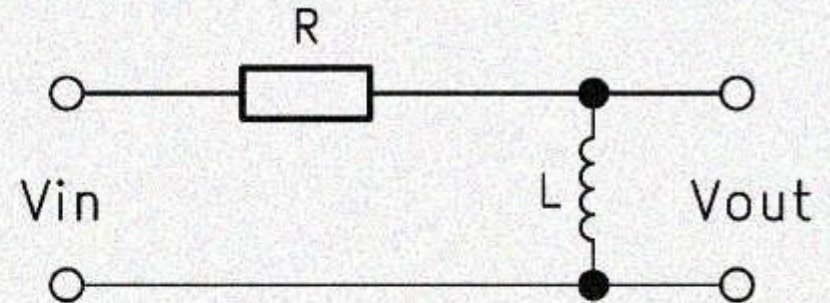
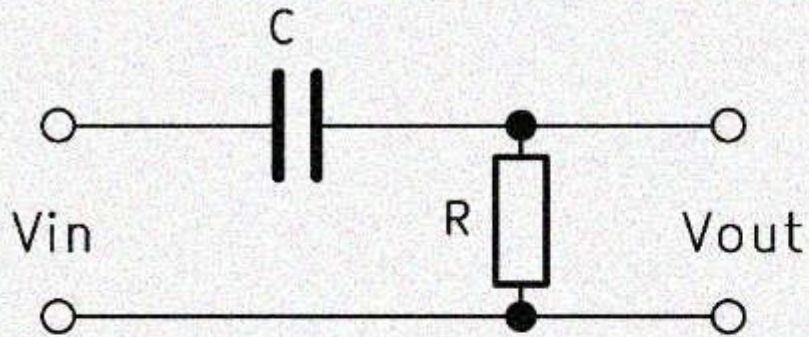
$$f_U = \frac{1}{R_1 C_1}$$



Low Pass Filter Variations



High Pass Filter Variations

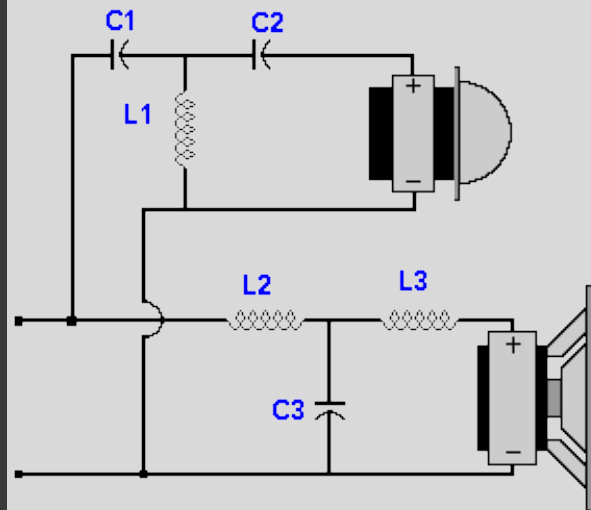


Practical Example - Crossover

3rd Order Butterworth

3000 Hertz

8 Ohm Tweeter / 8 Ohm Woofer



Parts List

Capacitors

C1 = 4.42 μF

C2 = 13.26 μF

C3 = 8.84 μF

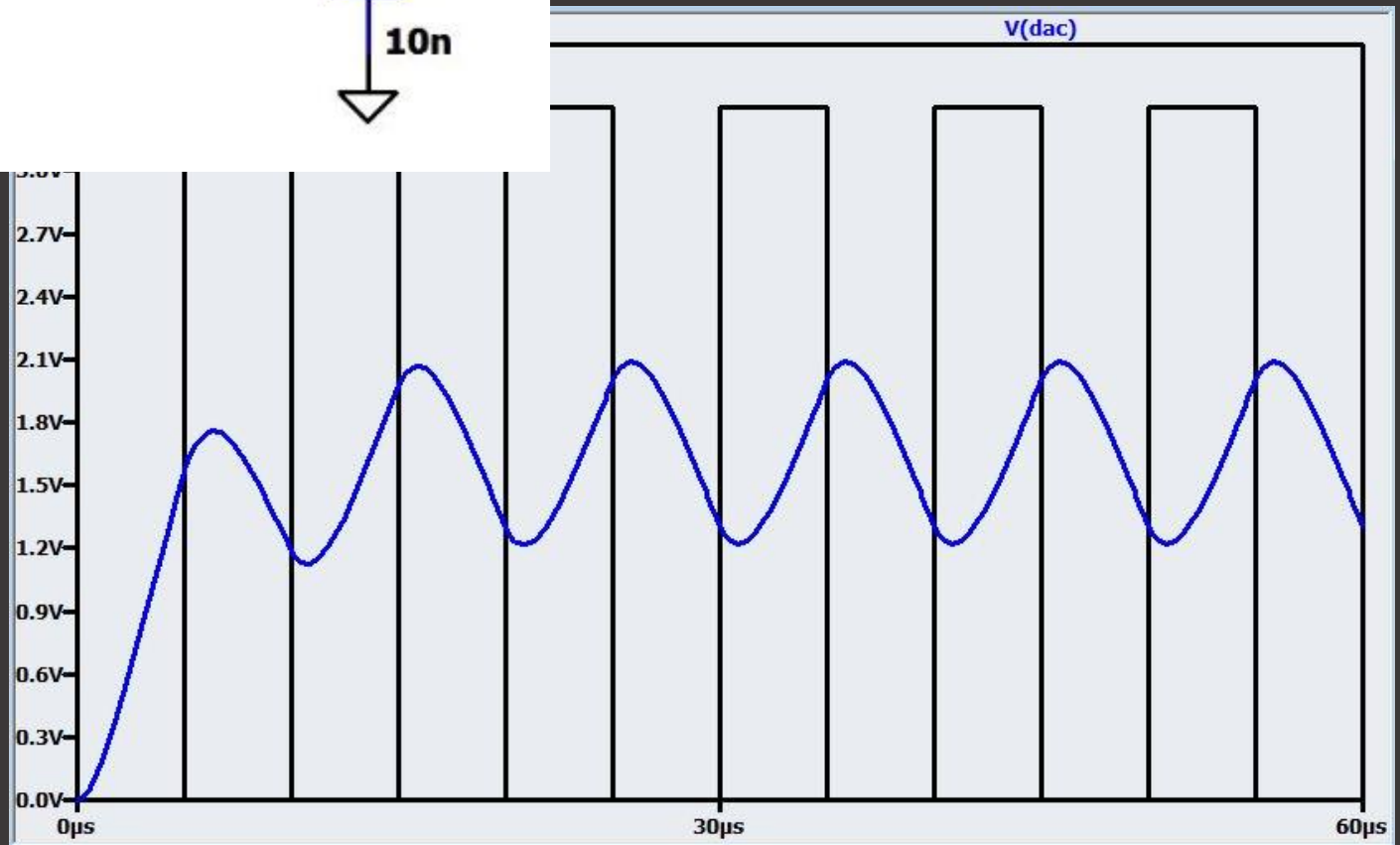
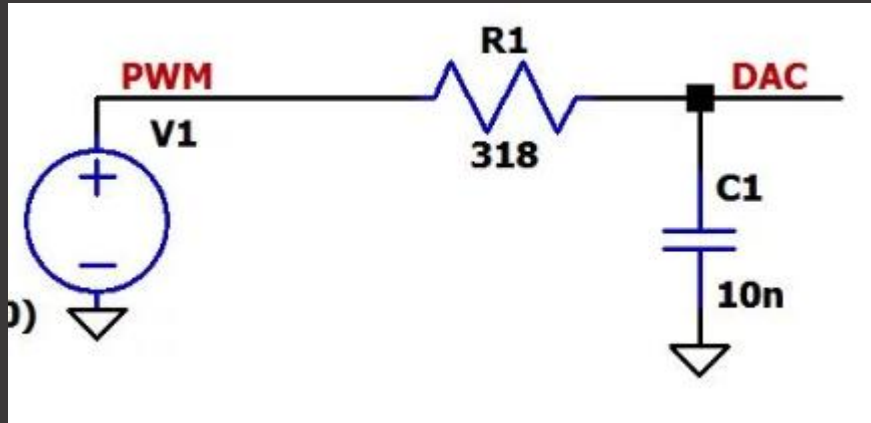
Inductors

L1 = 0.32 mH

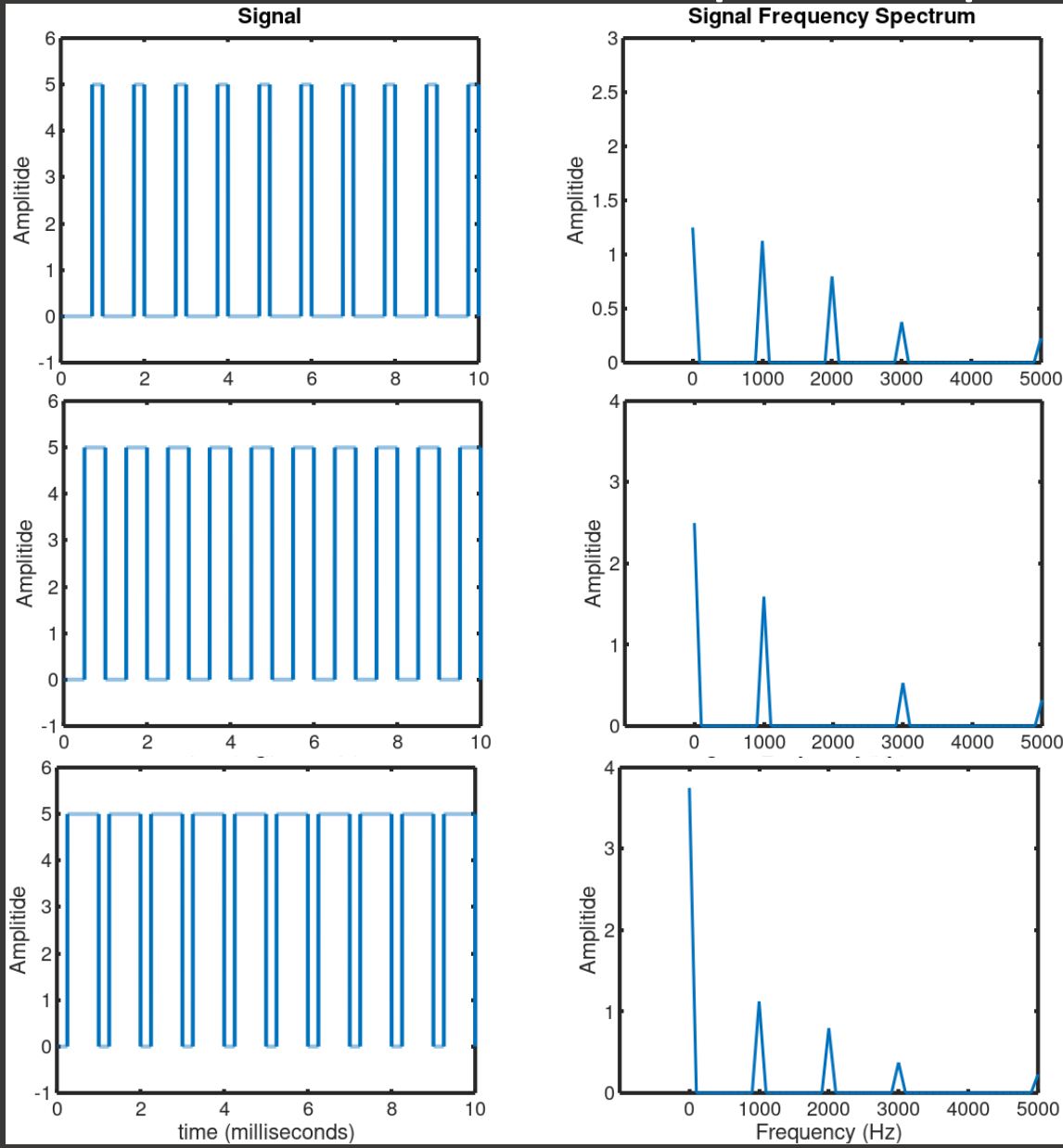
L2 = 0.64 mH

L3 = 0.21 mH

Example: Arduino PWM Filtering



PWM Freq Components



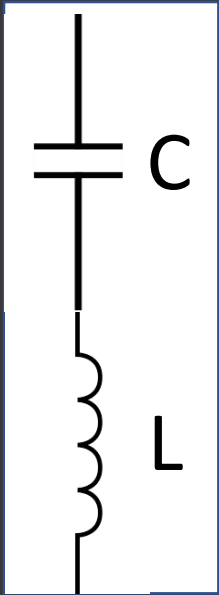
25% Duty Cycle

50% Duty Cycle

75% Duty Cycle

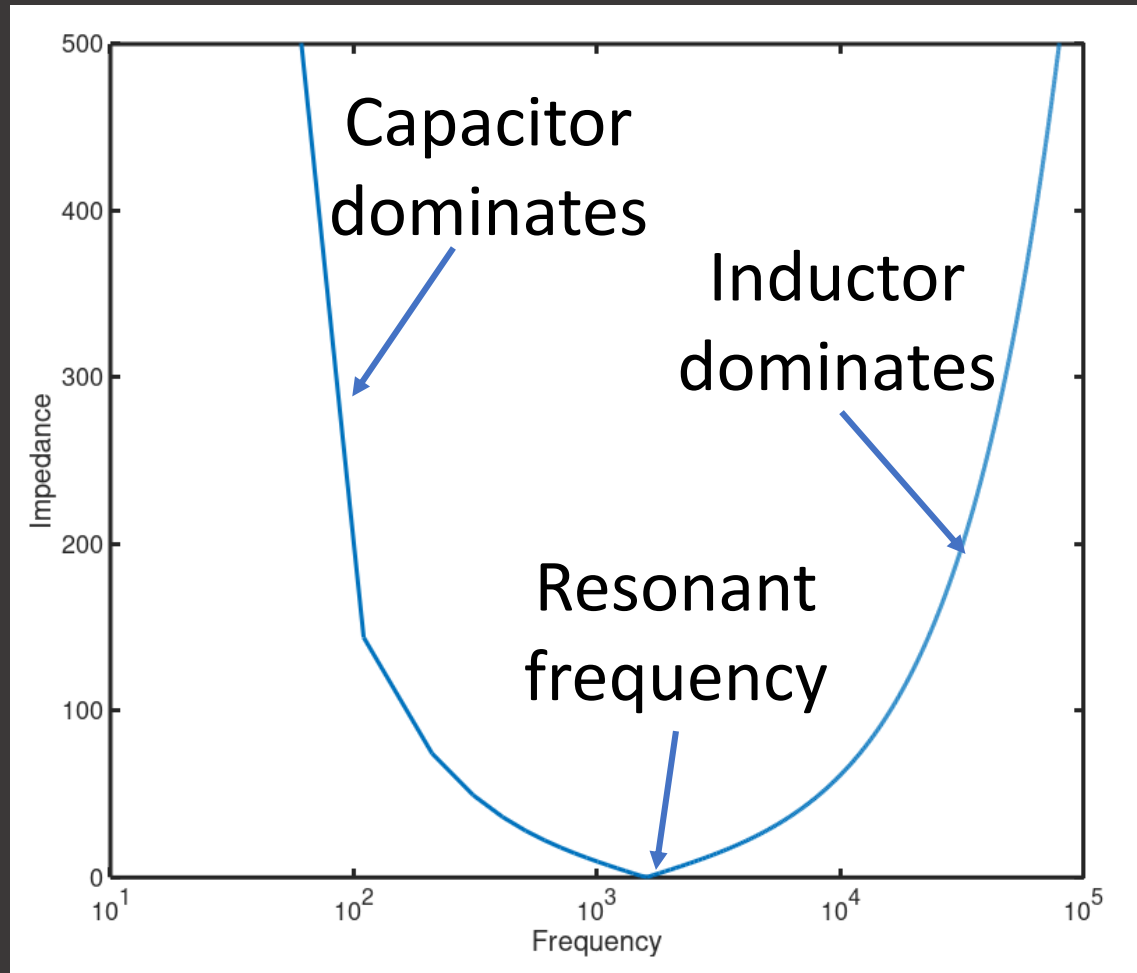
Power Supply Noise and Bypassing

LC Resonant Circuit Detail

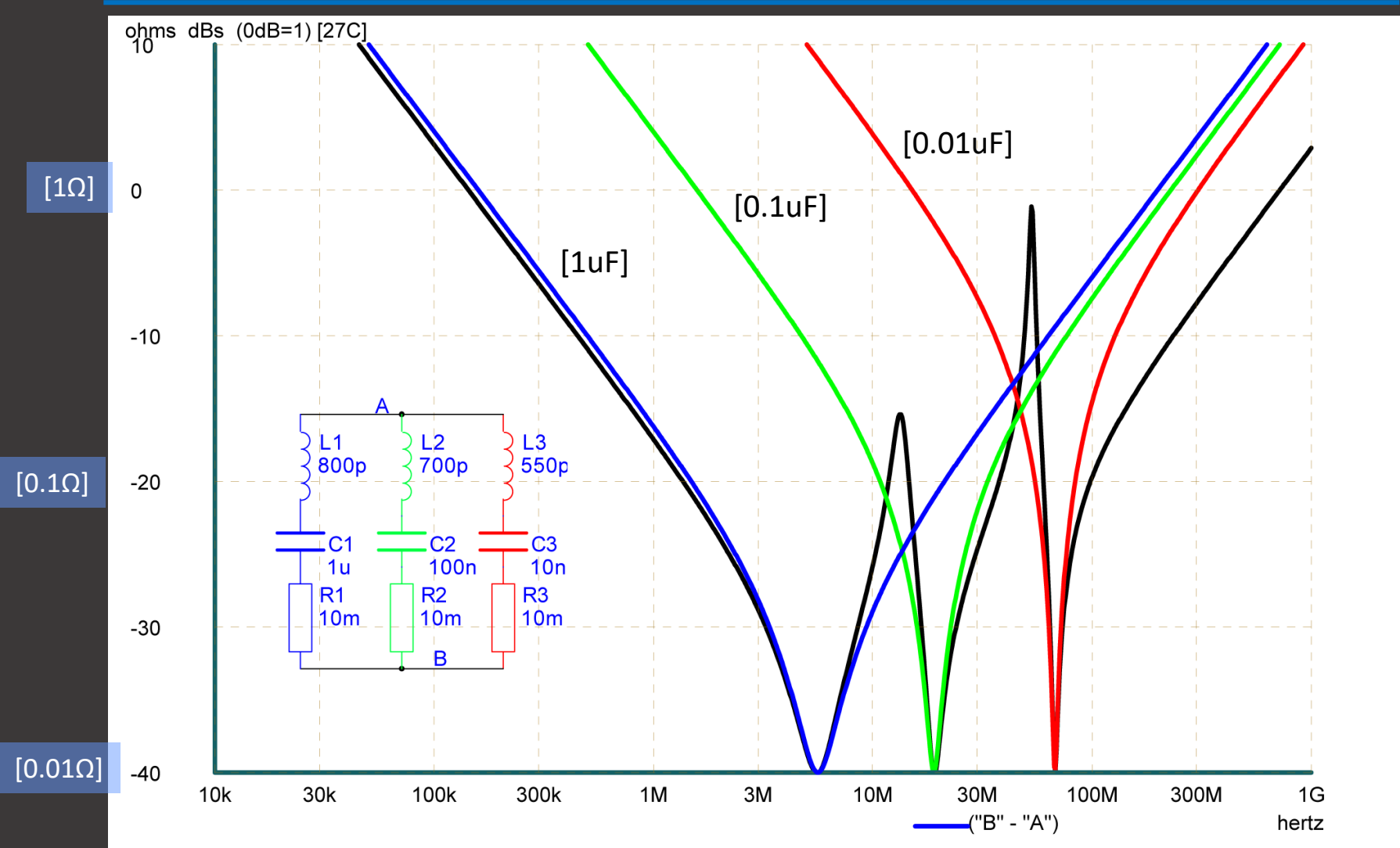


$$X_C = \frac{-1}{2\pi fC}$$

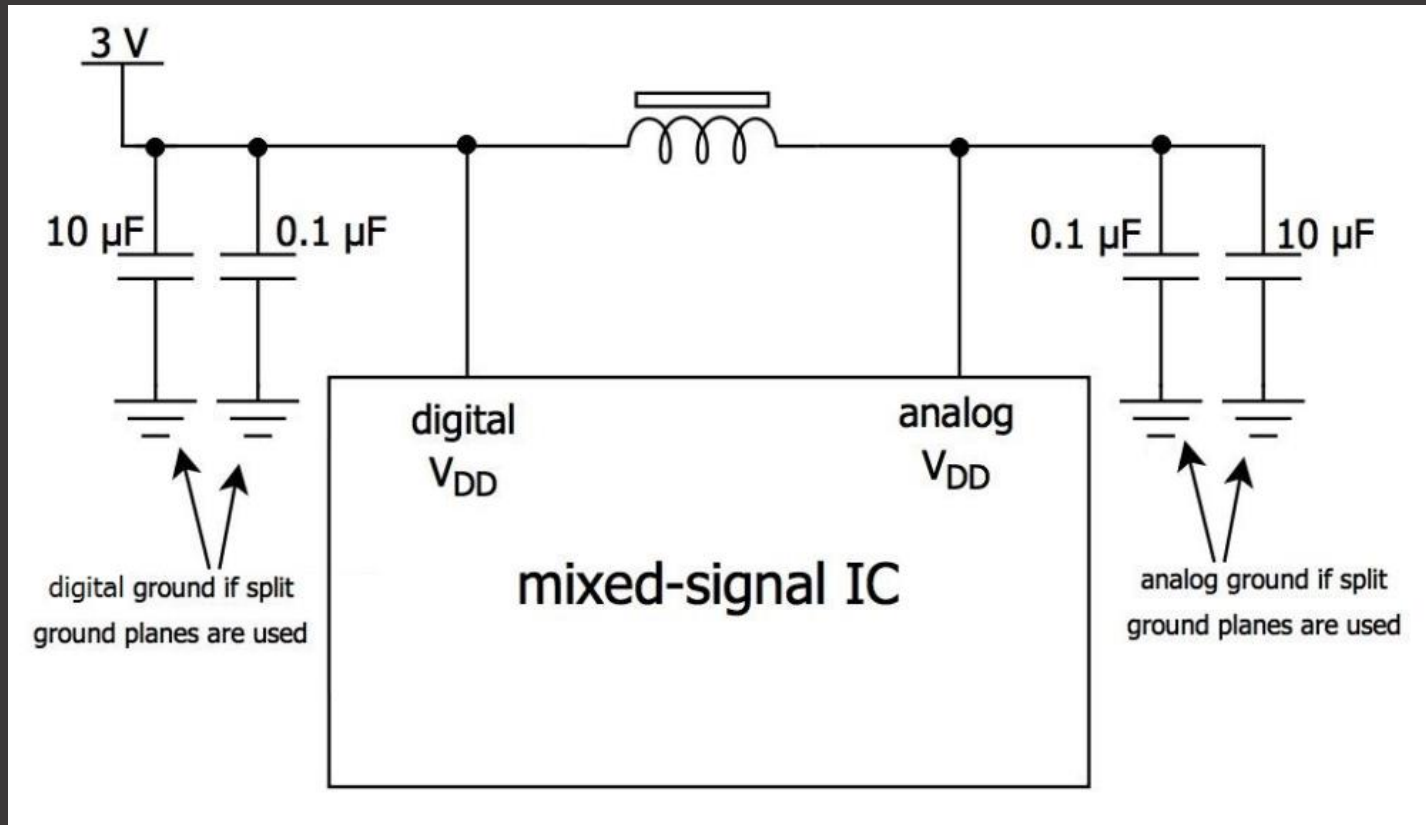
$$X_L = 2\pi fL$$



Real World Capacitor Bypassing

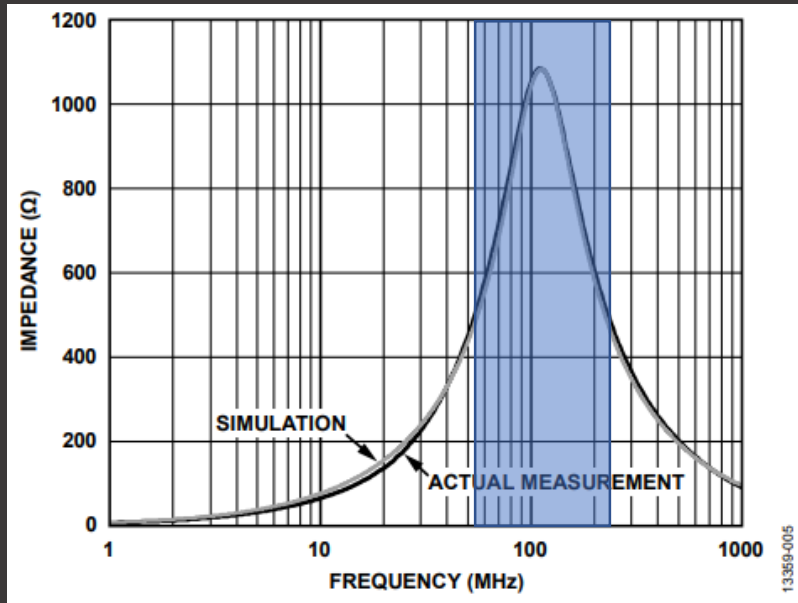


Filter Digital Noise From Analog

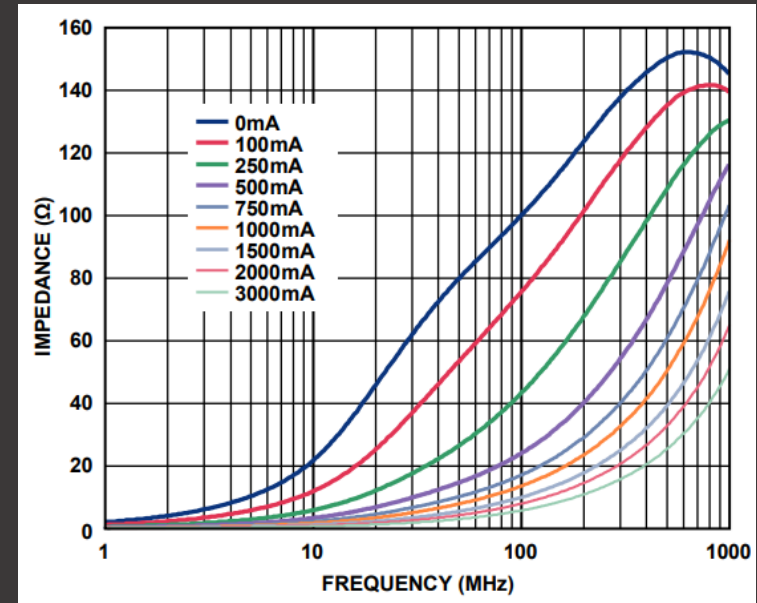


A ferrite bead is sort of a poor (lossy) inductor, converting AC to heat

Ferrite Bead Notes



Tyco BMB2A1000LN2

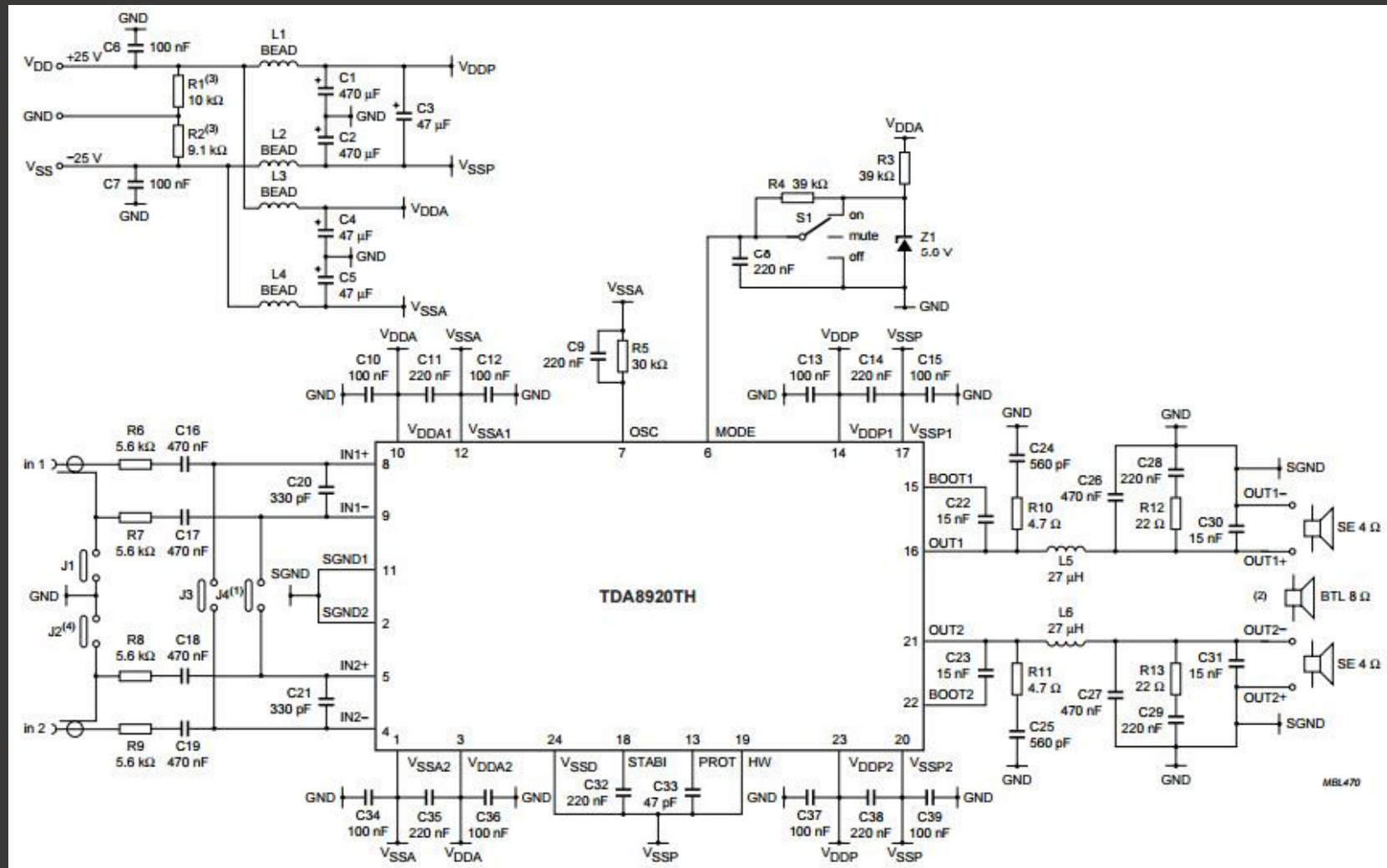


TDK MPZ1608S101A

Choose bead for high impedance @ freq of interest
Choose current rating ~5x higher than bias

From: Analog Devices AN-1368 Ferrite Bead Demystified

Let's take another look!



Week 2: Lab Time!

Option 1: Microcontroller PWM Filter

- Build RC low pass filter
- Adjust, measure with oscilloscope

Option 2: Analog Switch Debounce

- Build RC low pass filter
- Adjust, measure with oscilloscope

Pre-Class Review

<https://www.youtube.com/watch?v=EQtwswJuUPs>

<https://www.youtube.com/watch?v=vN9aR2wKv0U>

[https://www.youtube.com/watch?v=EQtwswJuUPs&list=PLRI
Glzu0Z7KlBkil9nNfMmRy4ZTzGr0RN&index=15&t=0s](https://www.youtube.com/watch?v=EQtwswJuUPs&list=PLRI
Glzu0Z7KlBkil9nNfMmRy4ZTzGr0RN&index=15&t=0s)