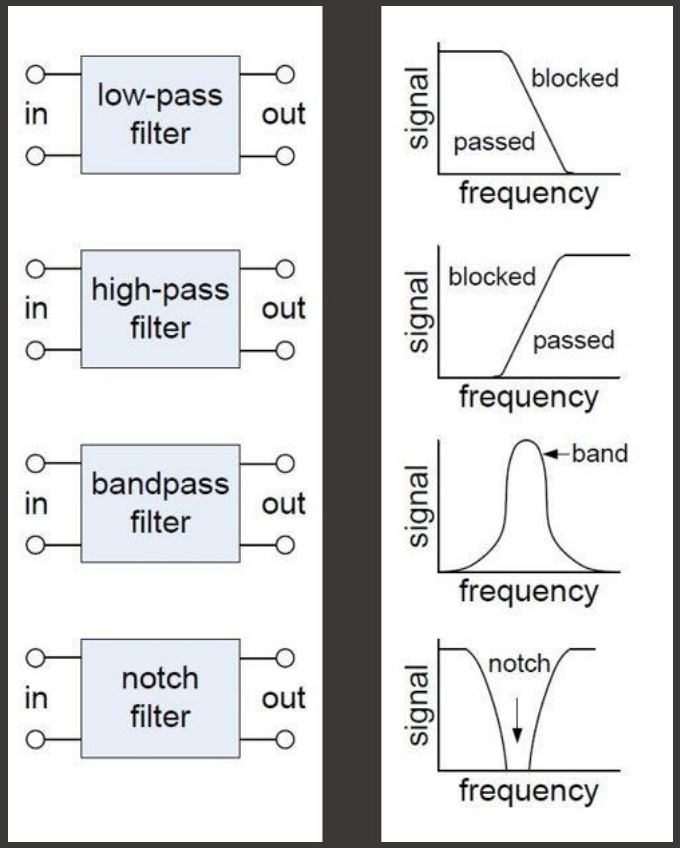
Filtering and Working in the Frequency Domain

Mar-2019



Tonight

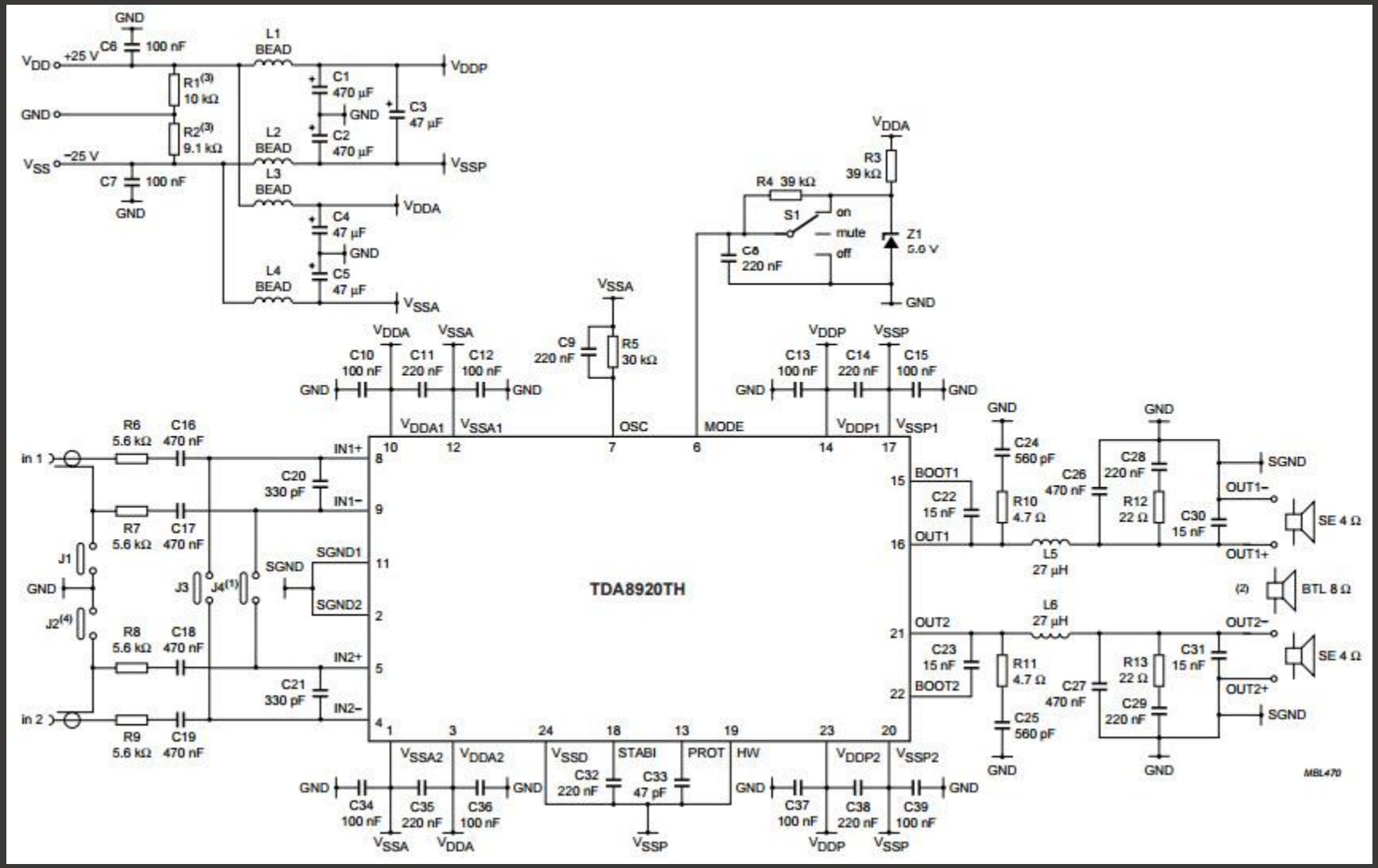
1. Learn how to think in terms of the frequency domain

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

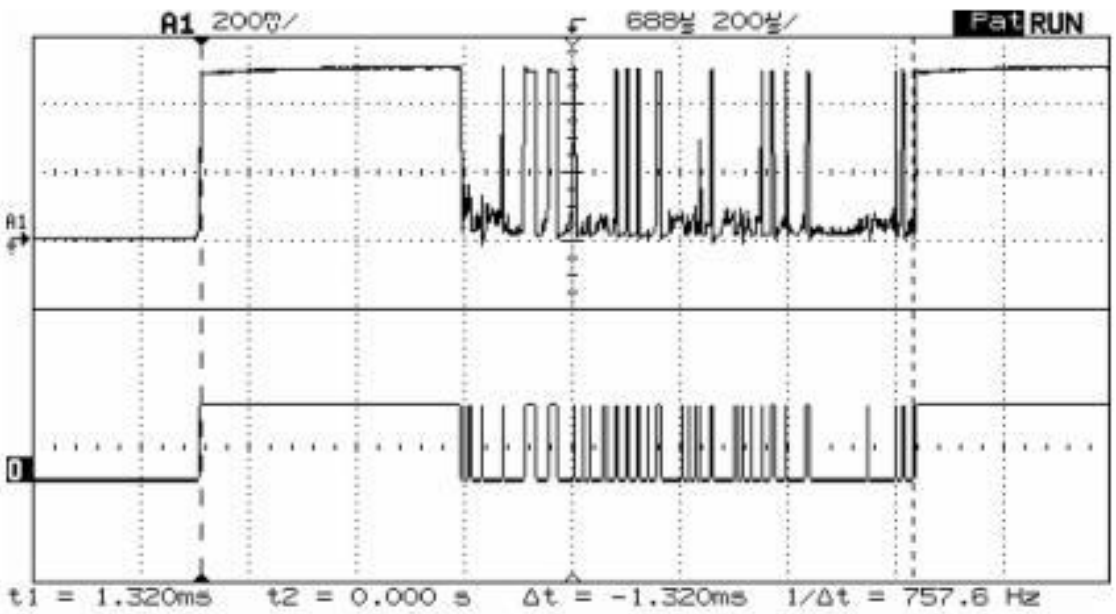
Audio electronics

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

Analog/mixed-signal electronics

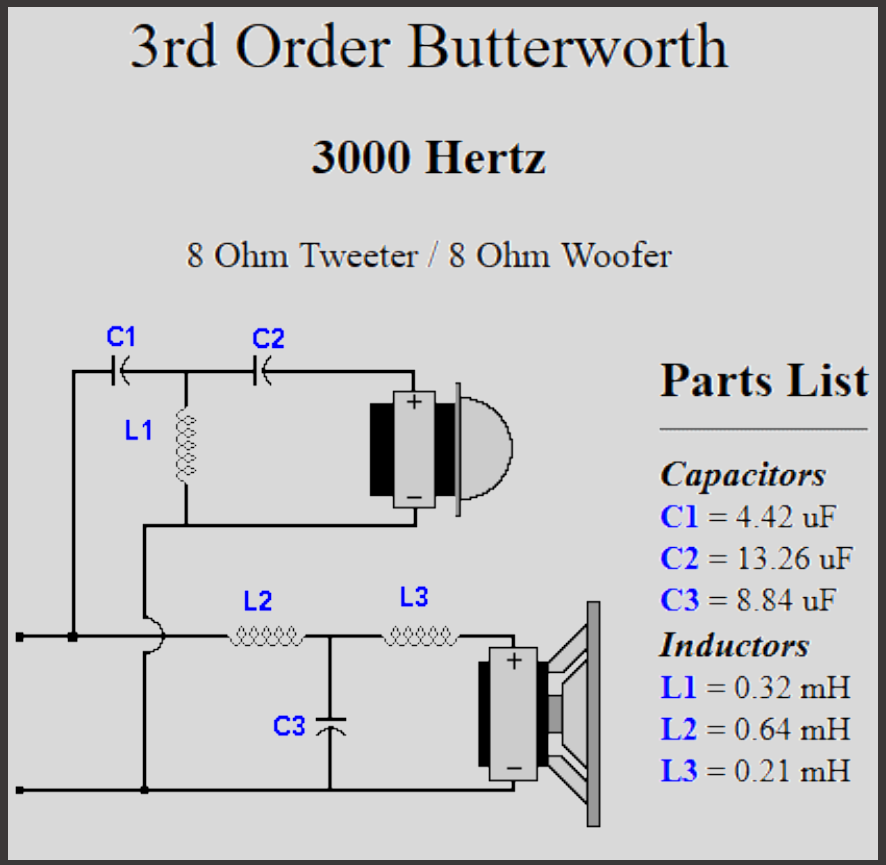
- Sensor noise
- Analog-Digital signal conversion
- Digital-Analog signal conversion

Switch Debouncing



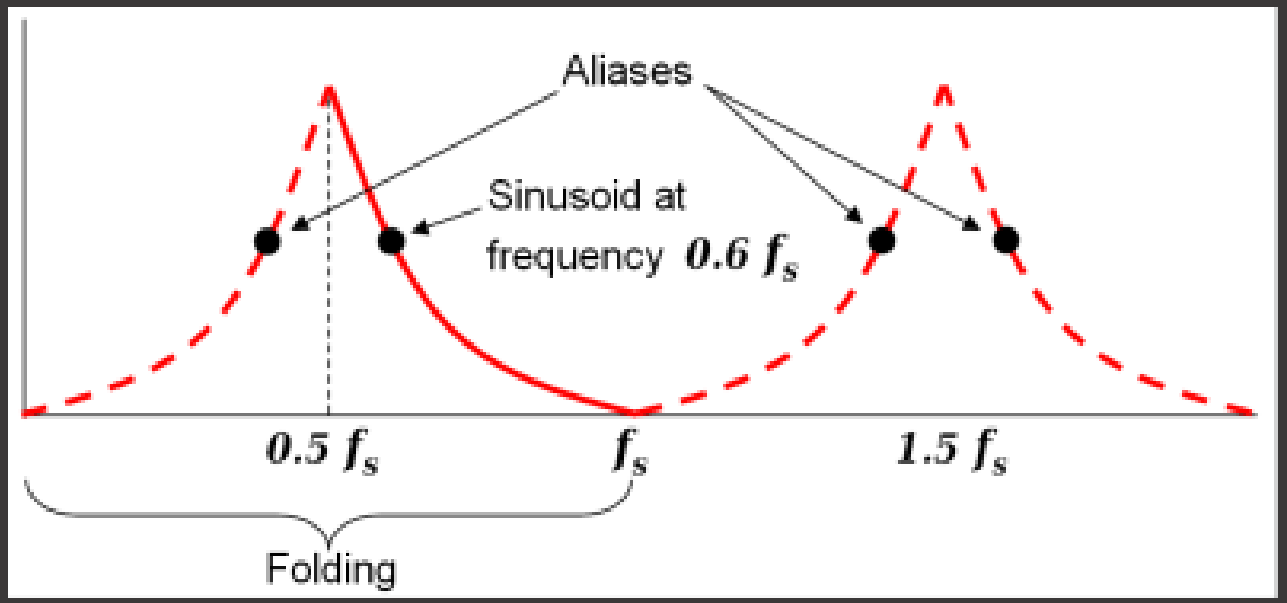
Switch Q – when released, it goes high for 480 µsec before generating 840 µsec of hash, a sure way to blow an interrupt system mad if poorly designed.

Speaker Crossover



https://www.diyaudioandvideo.com/Tutorial/DesignBuildCrossover/

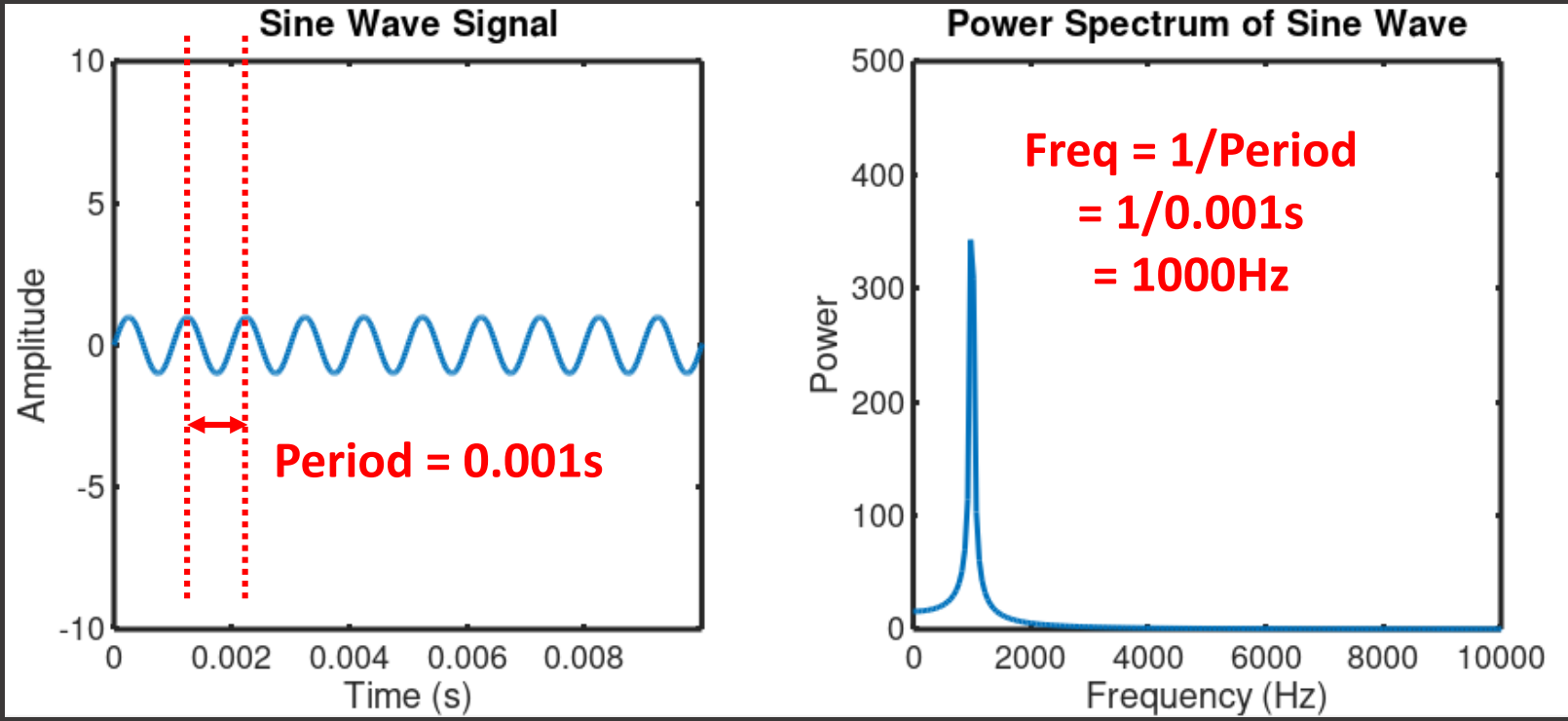
ADC Example - Aliasing



https://en.wikipedia.org/wiki/Nyquist_frequency

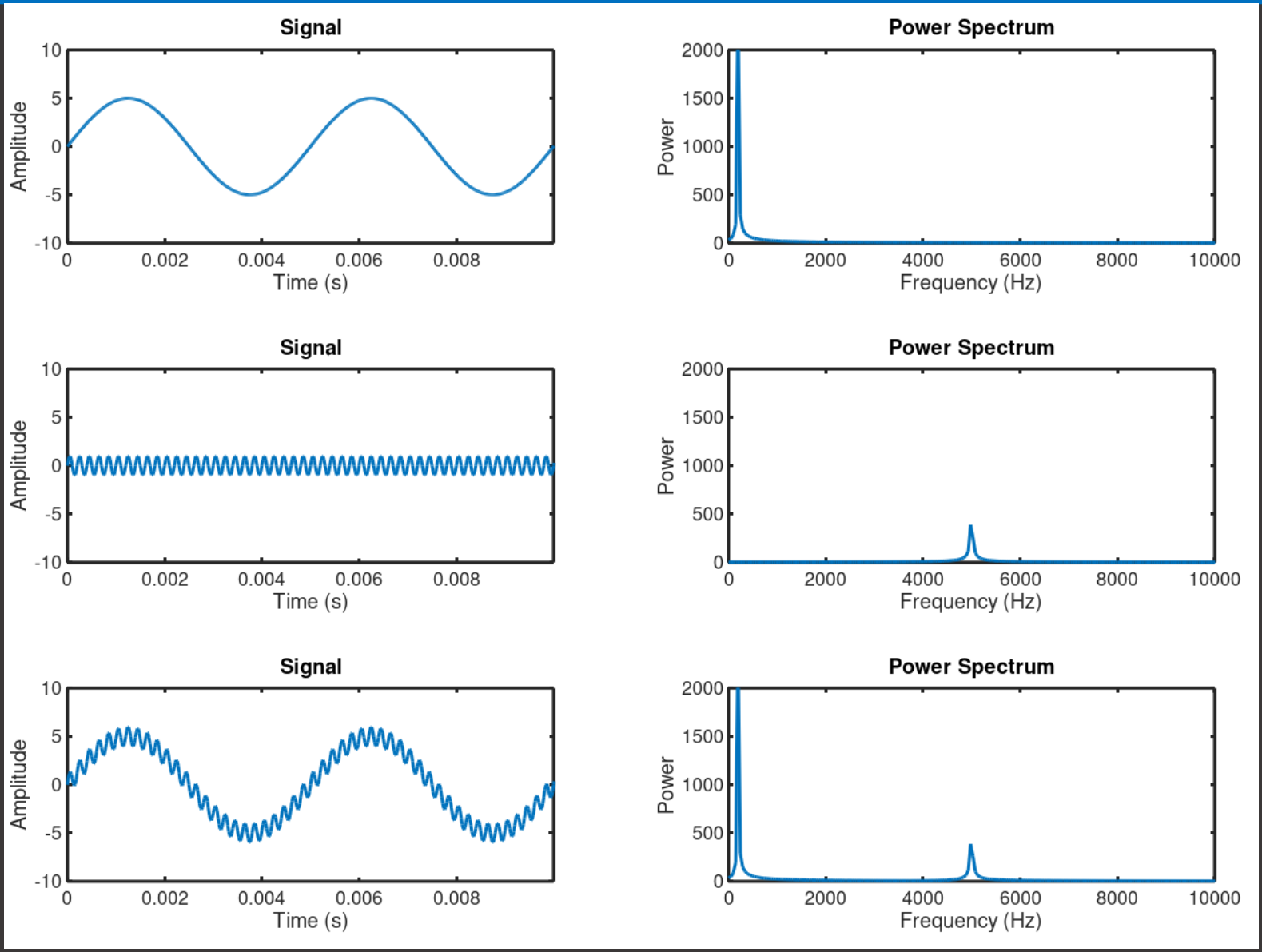
Time vs Frequency Domain

Time vs Frequency Domain

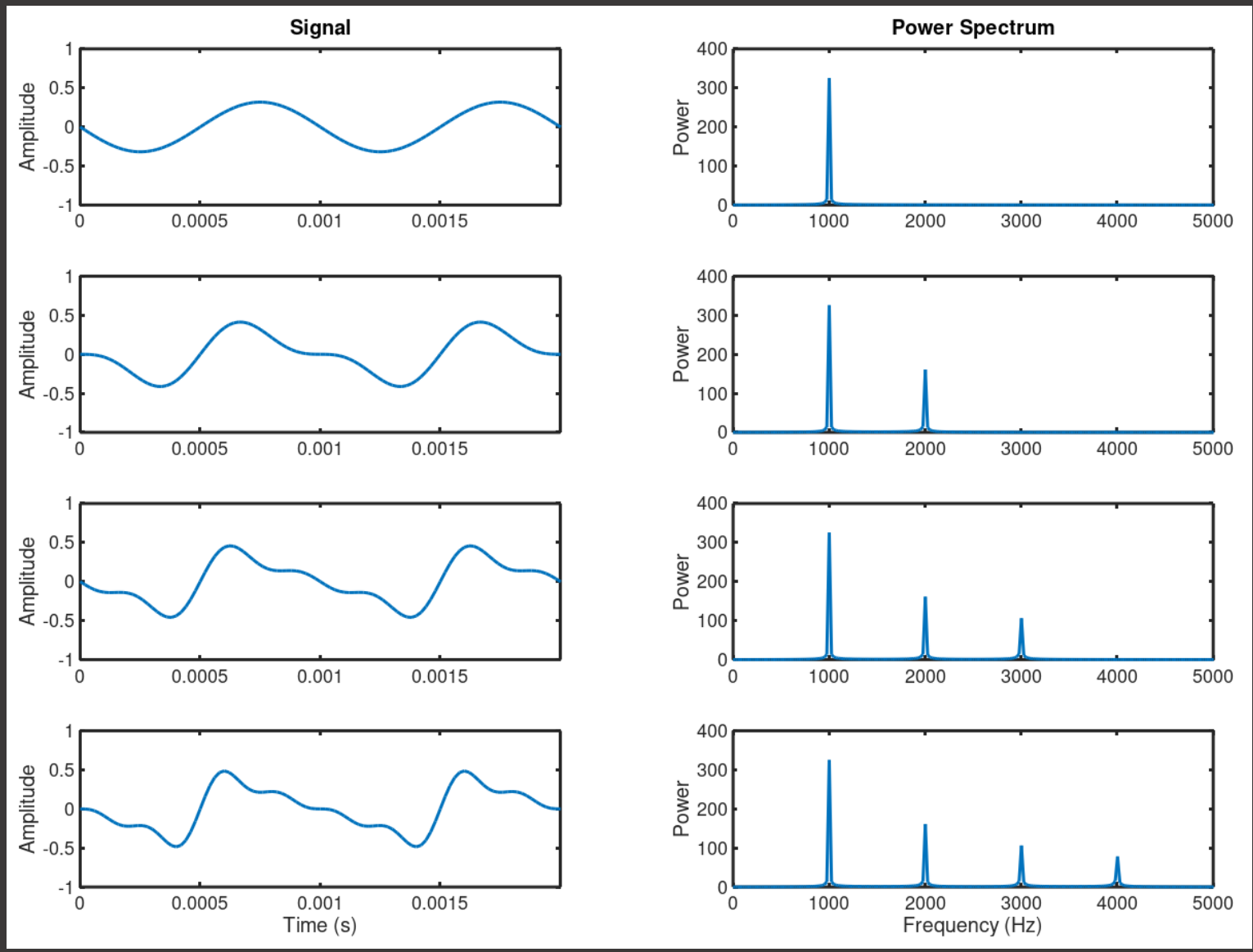


Frequency = 1 / Period

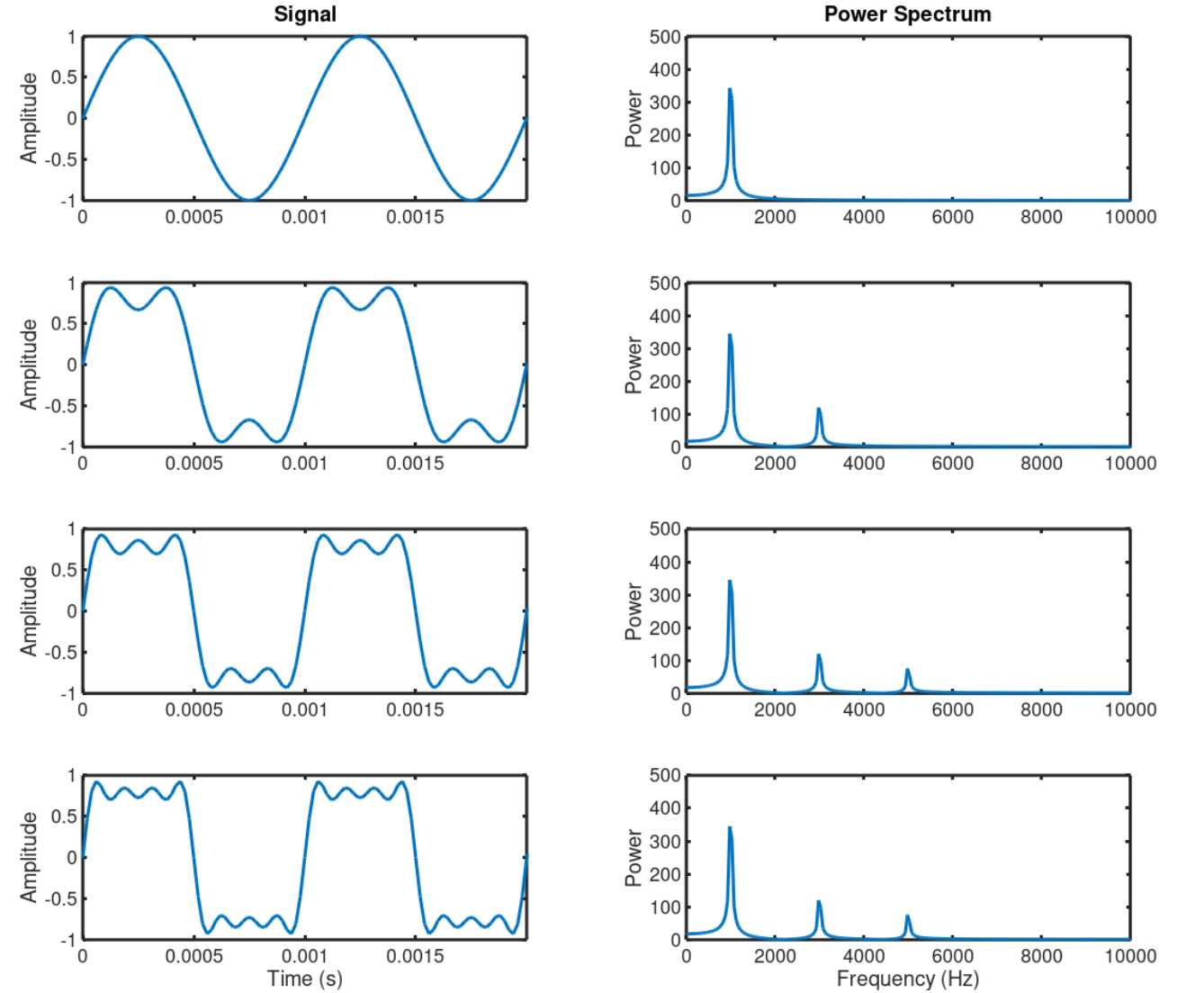
2 Sine Waves Added Together



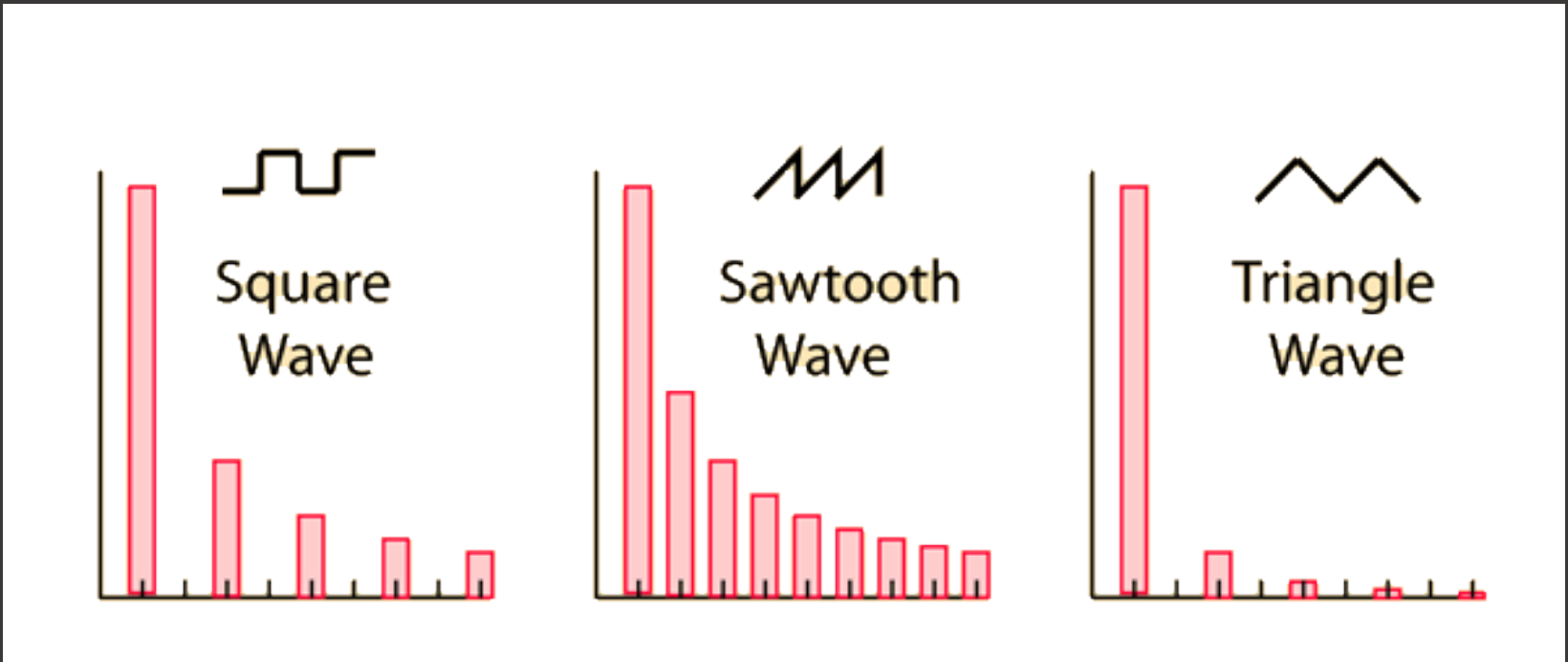
Creating a Waveform from “Harmonics”



Square Wave = Odd Harmonics

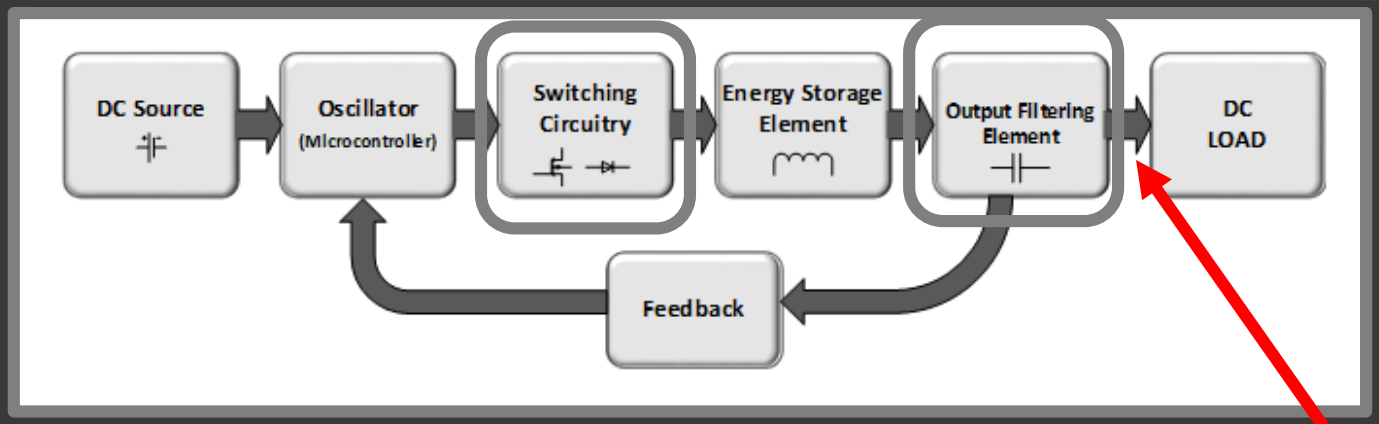


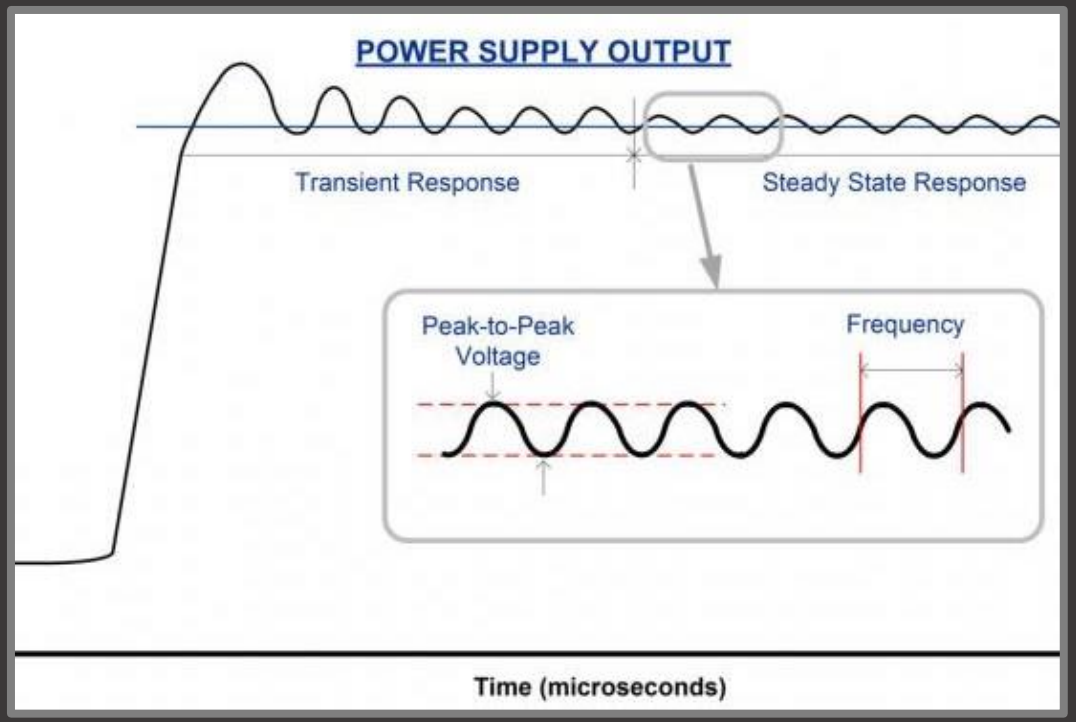
Common Waveforms

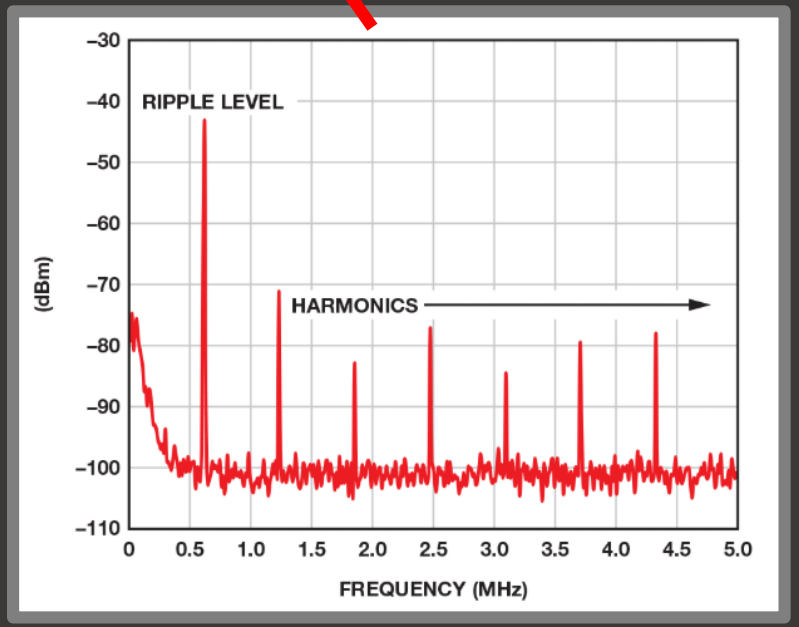


Note: vertically symmetric waveforms tend not to have even harmonics

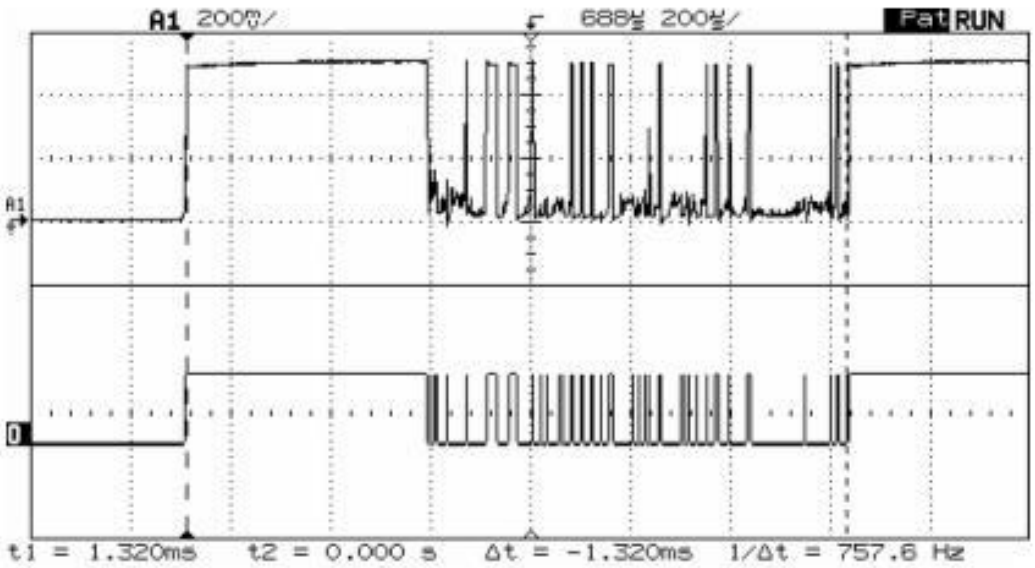
Switching Power Supply Noise







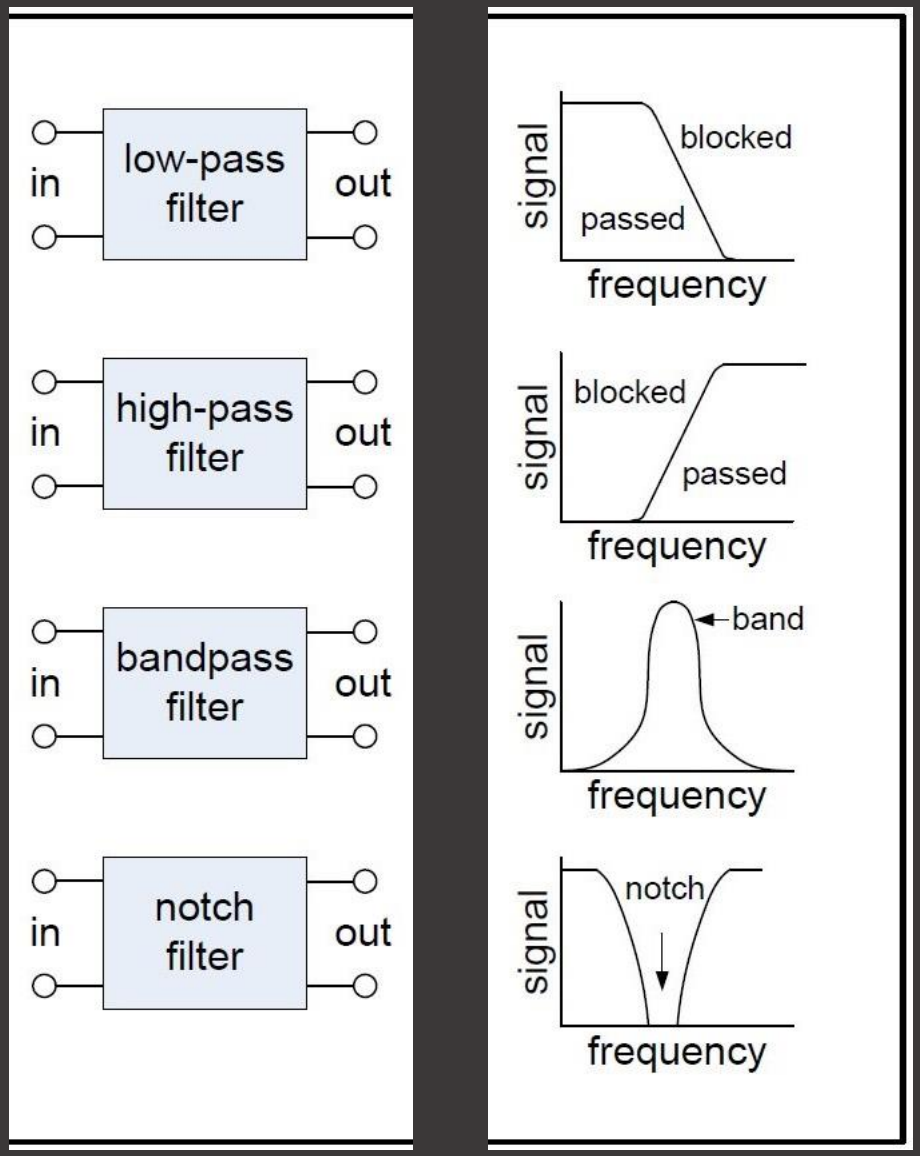
Switch Debouncing



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.

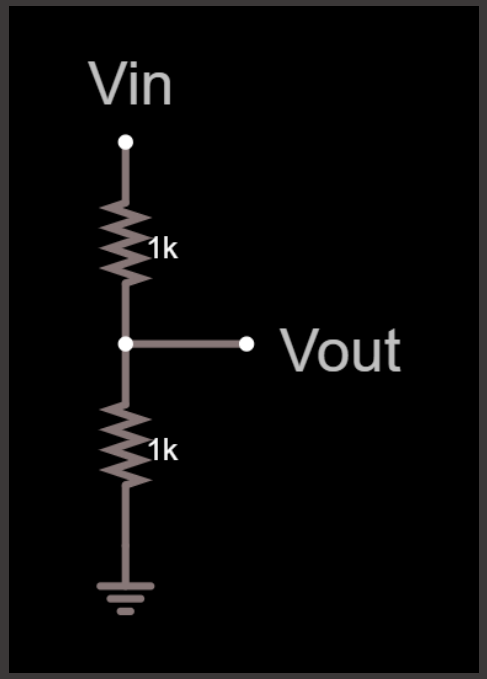
What frequencies might need to be retained vs rejected?

Types of Filters

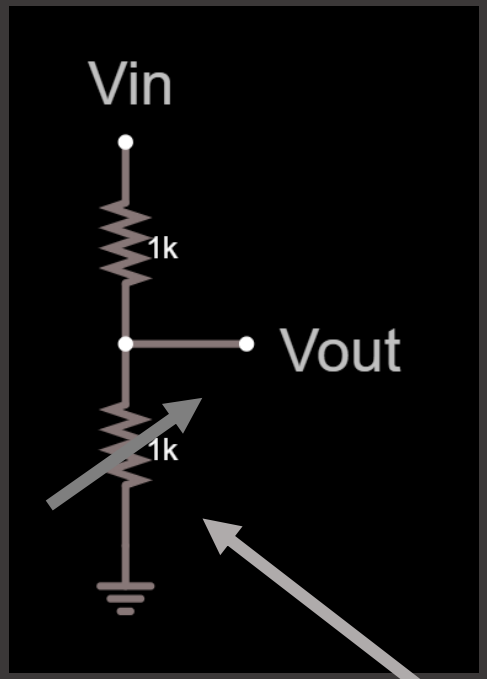


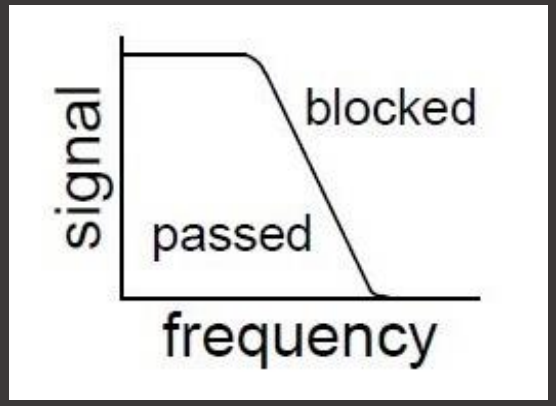
A Conceptual Low Pass Filter

All-pass



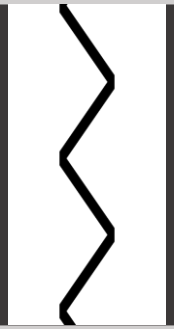
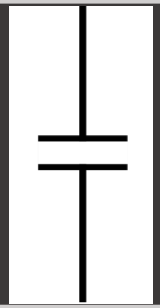
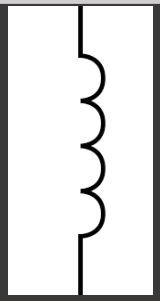
Low-pass





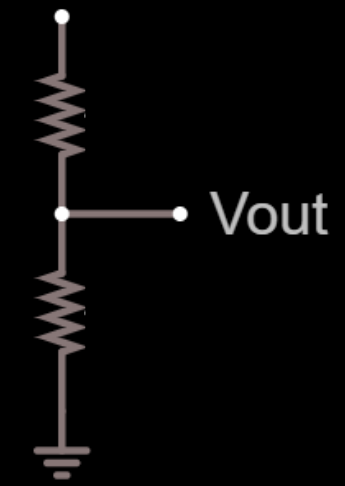
Decreases with frequency

RLC Components vs Frequency

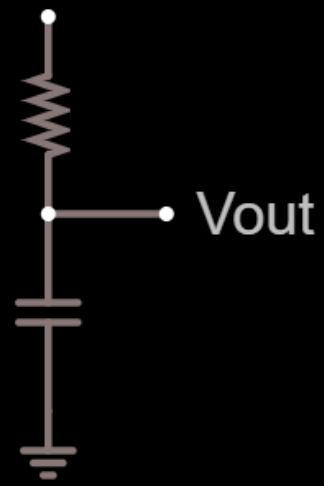
	DC Resistance/ AC Reactance	Change w/ freq?
	R	=
	$X_C \propto \frac{-1}{fC}$	↓
	$X_L \propto fL$	↑

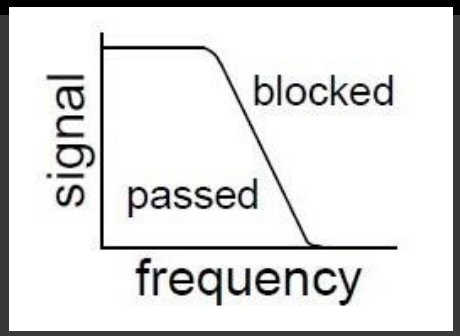
RC Filters

All-Pass

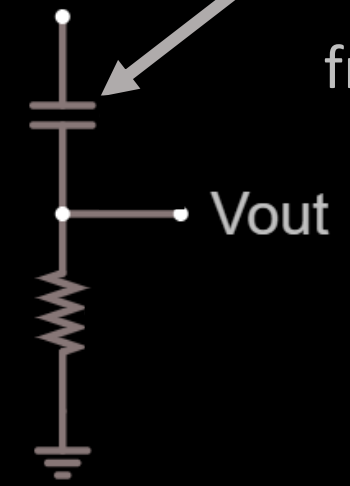


Low-Pass

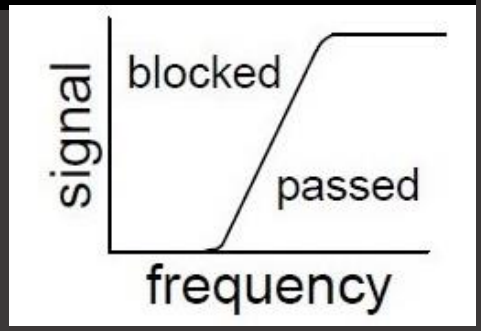




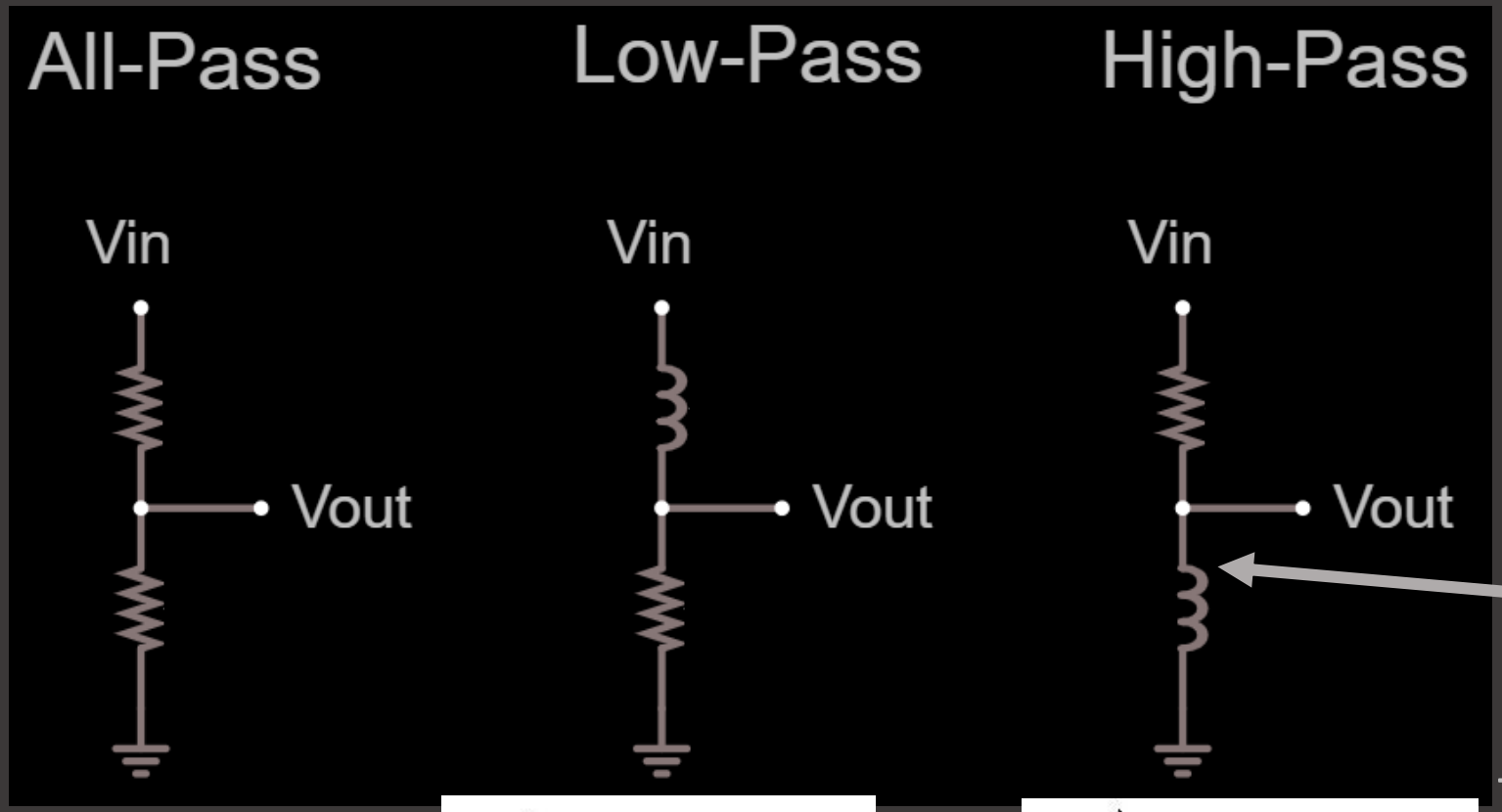
High-Pass

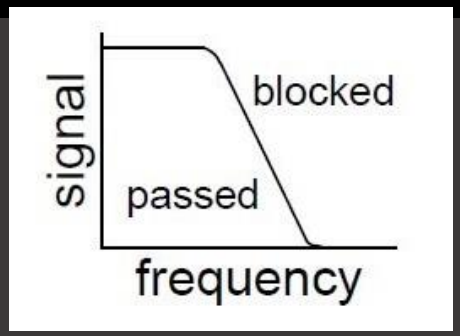


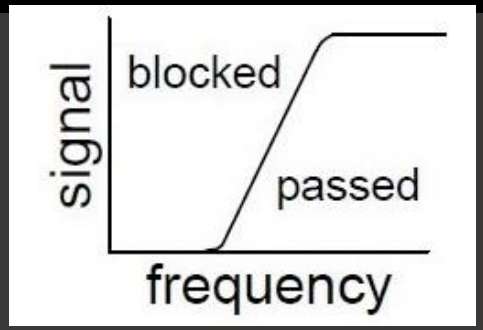
Decreases with frequency



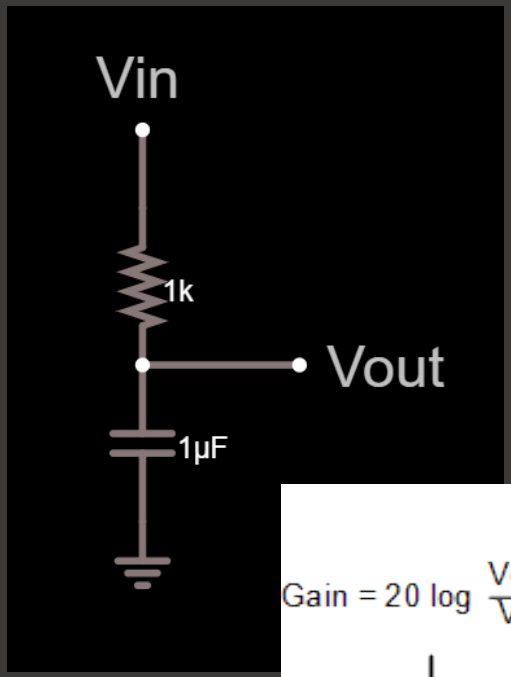
LC Filters


All-Pass
Low-Pass
High-Pass
Vin
Vout
Vin
Vout
Vin
Vout
Increases with frequency


signal
blocked
passed
frequency


signal
blocked
passed
frequency

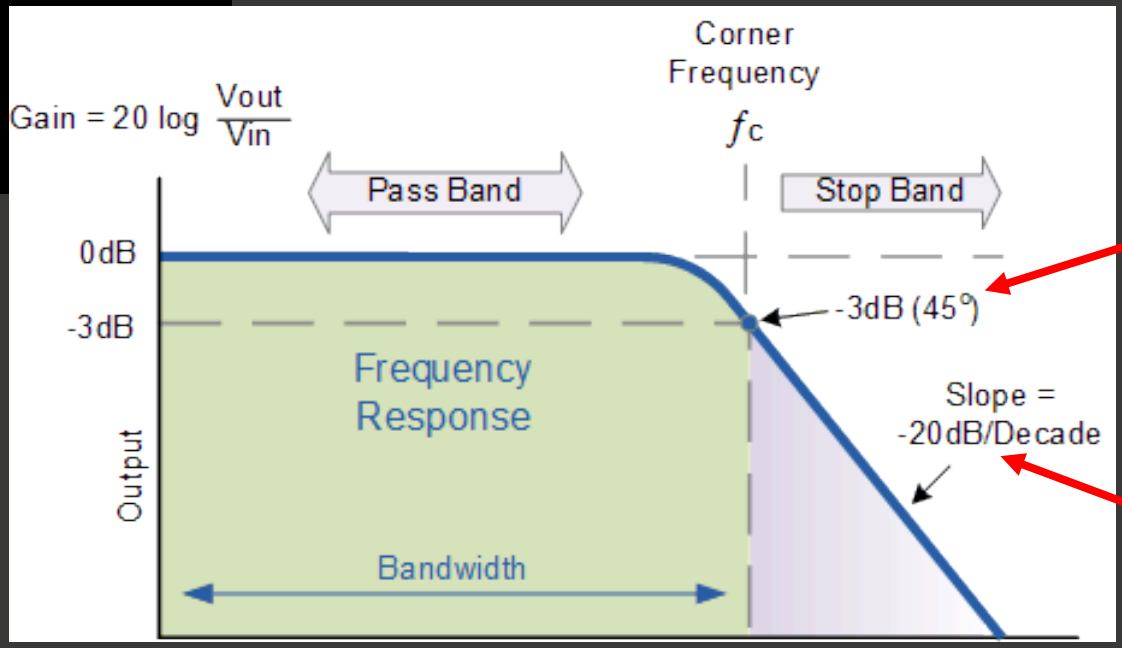
RC Low Pass Filter



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

$$f_c = {}^{1}/_{(1000 \times 1x10^{-6})}$$

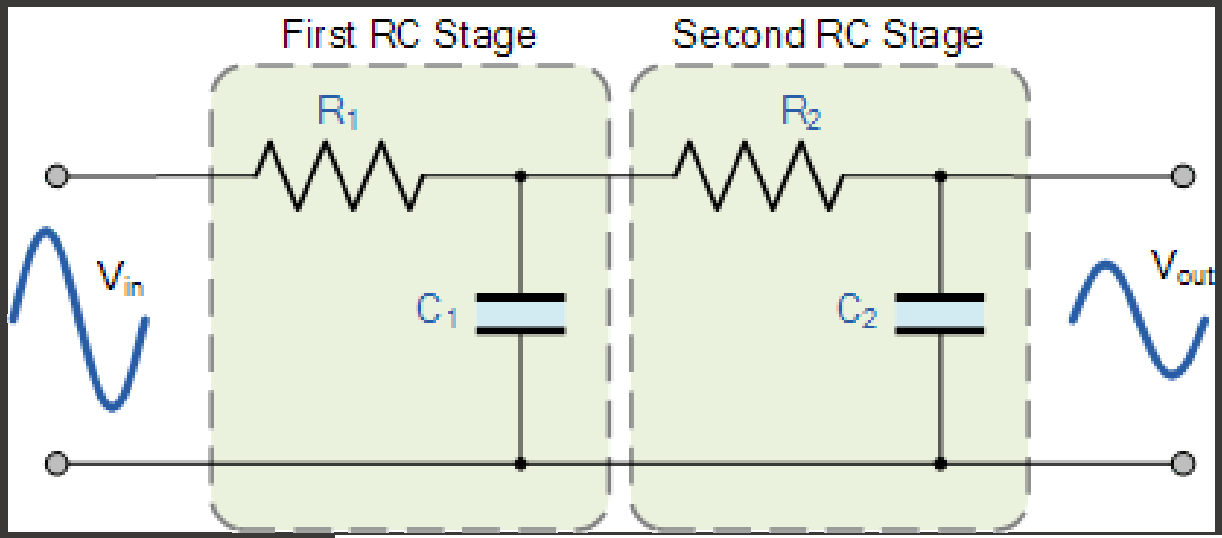
$$f_c = {}^{1}/_{0.001} = 1000 \text{ Hz}$$

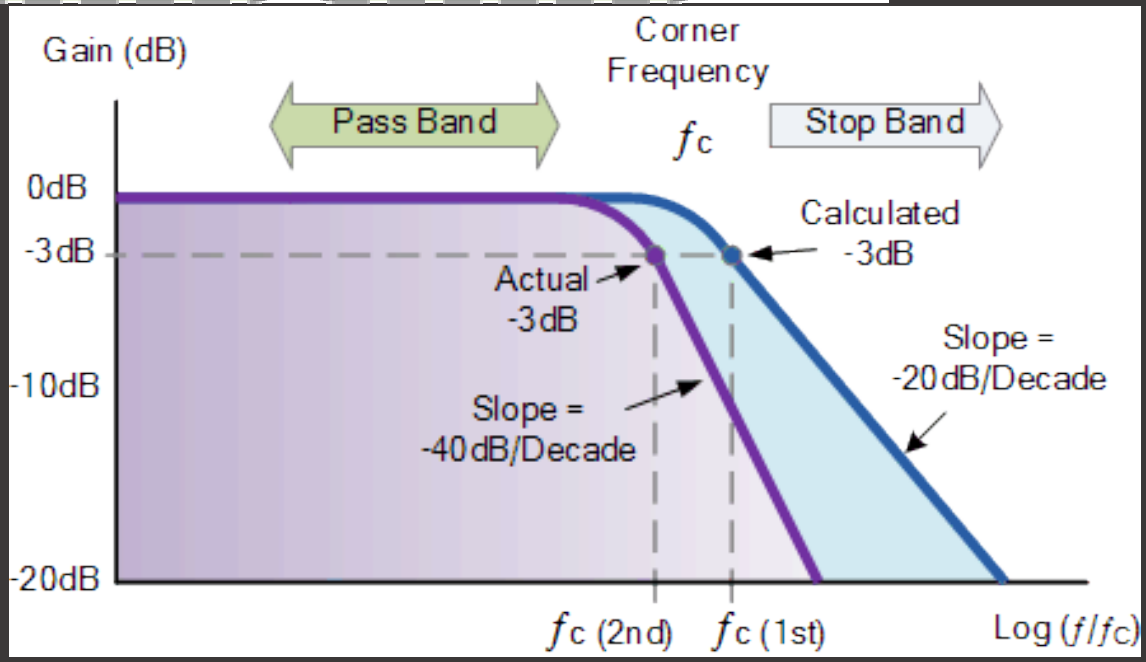


-3dB =0.707

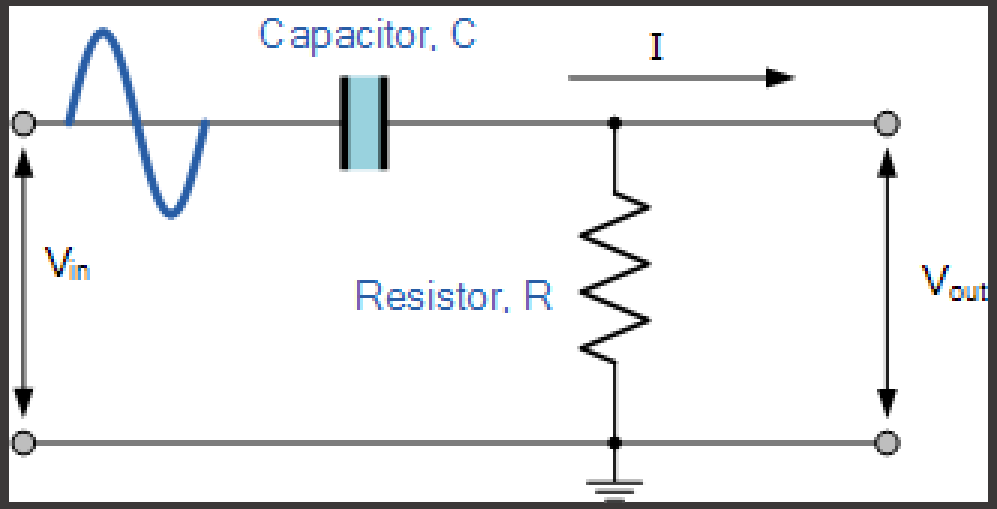
-20dB = 0.1

2nd Order Low Pass Filter

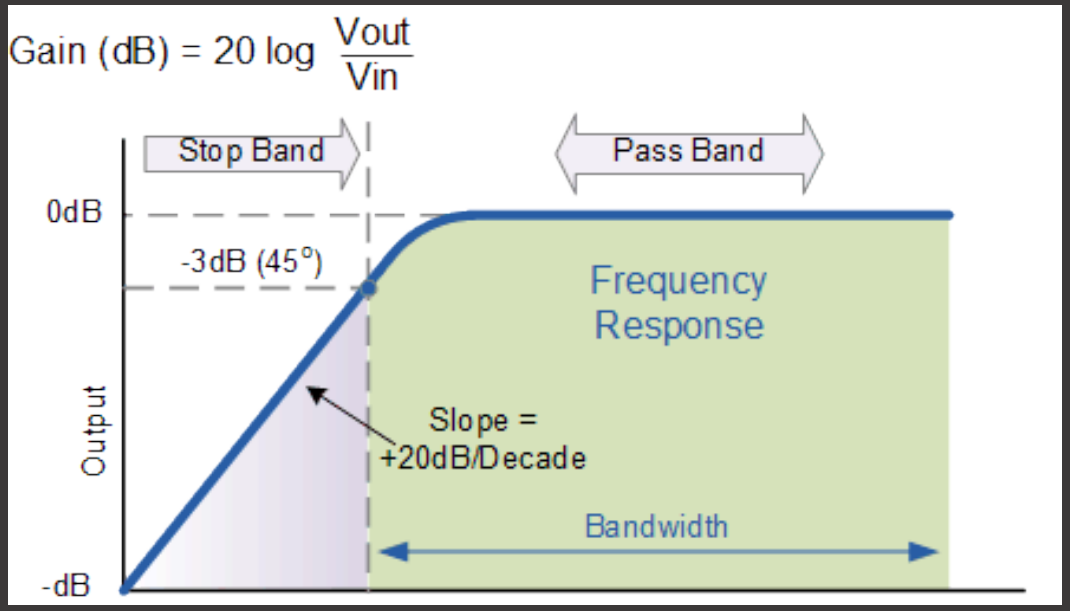




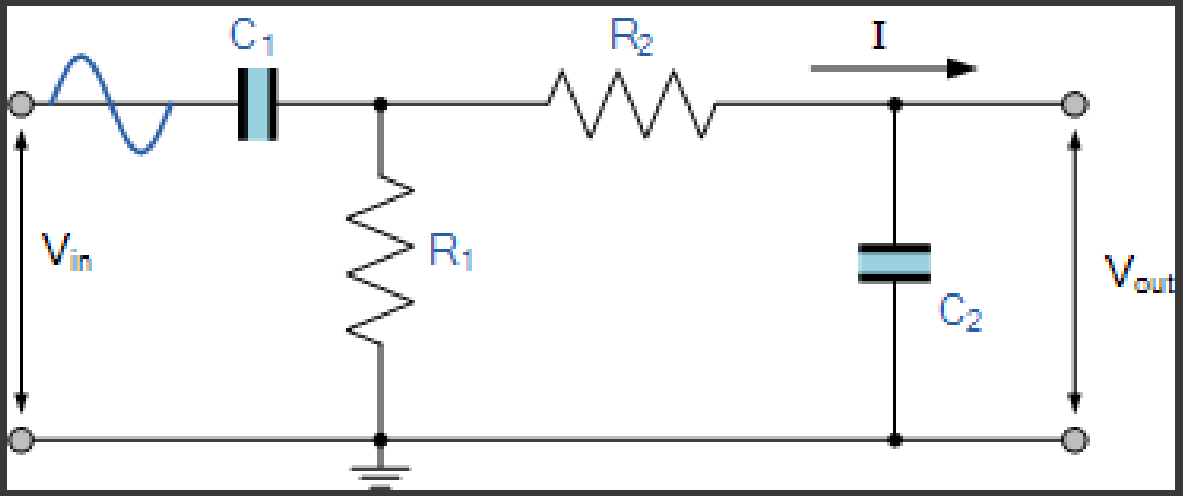
RC High Pass Filter



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

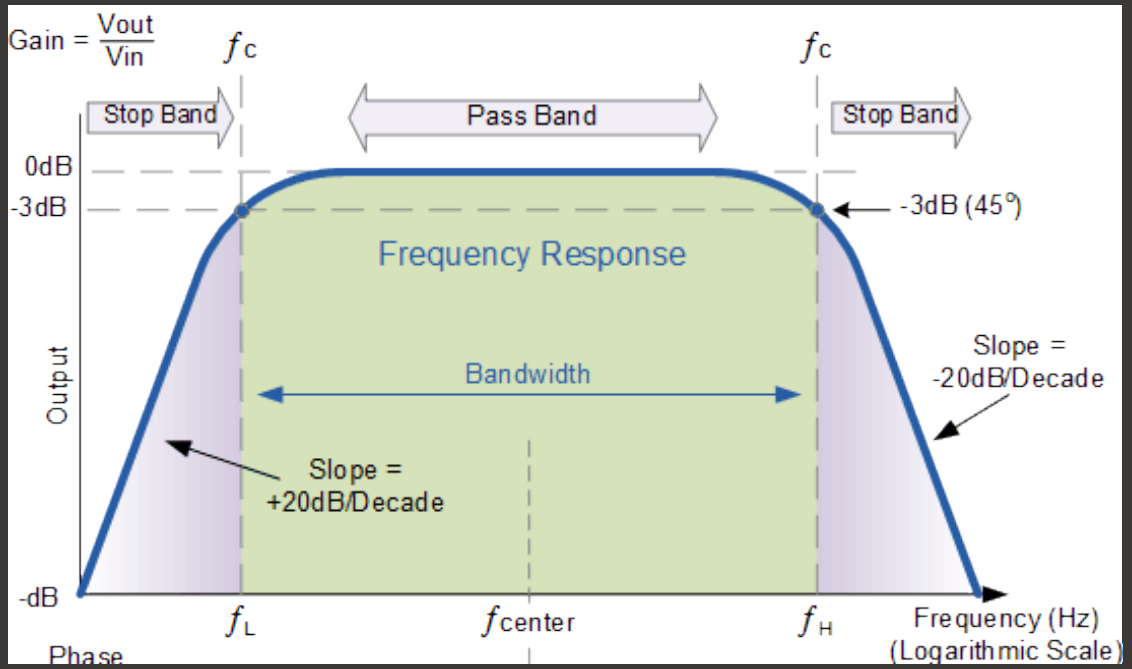


RC Band Pass Filter

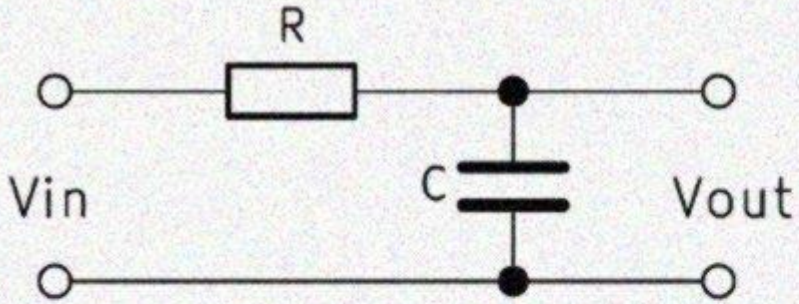


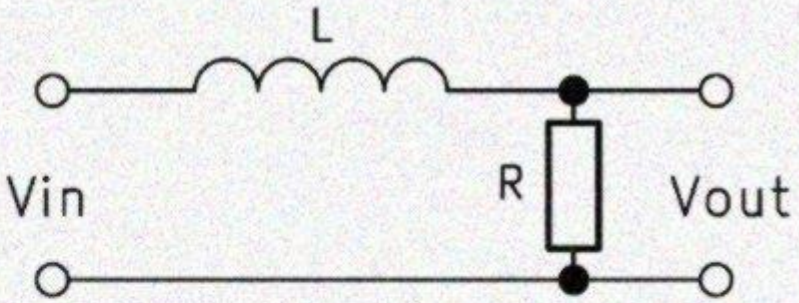
$$f_L = \frac{1}{R_2 C_2}$$

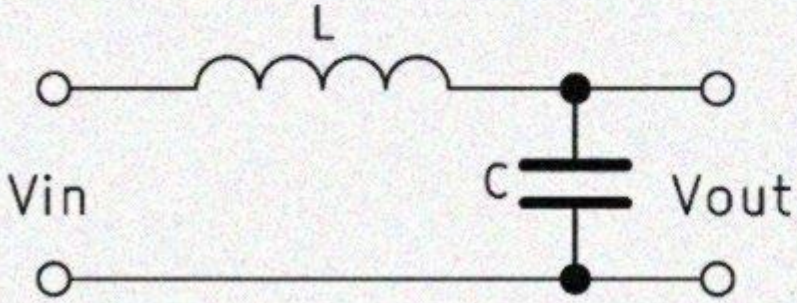
$$f_U = \frac{1}{R_1 C_1}$$

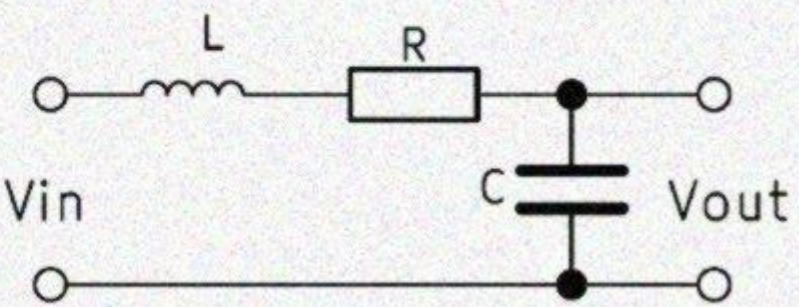


Low Pass Filter Variations

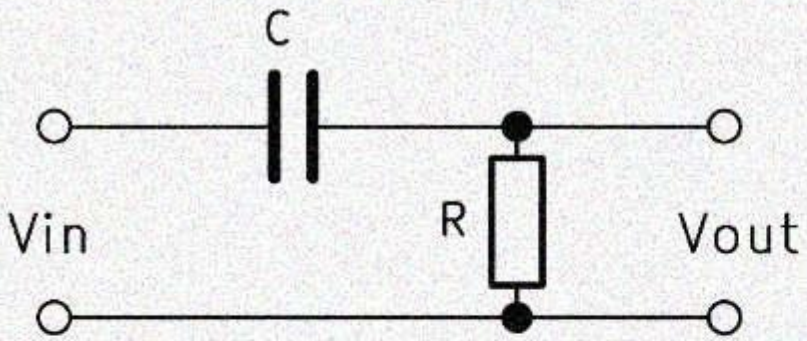


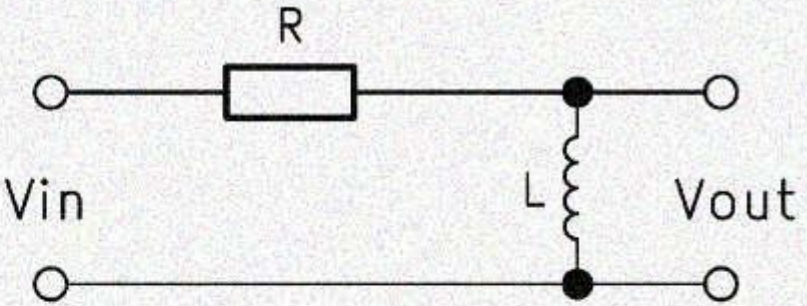


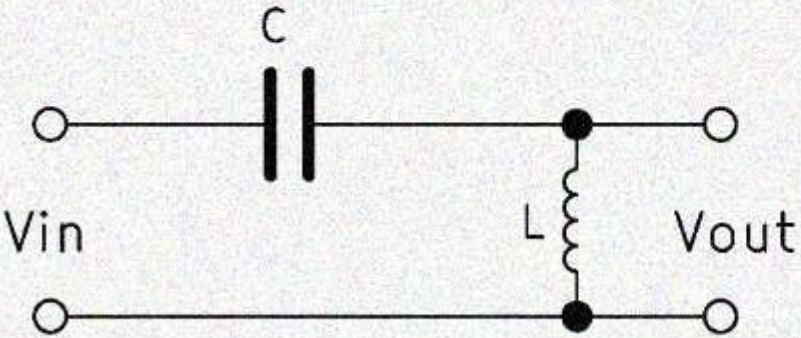


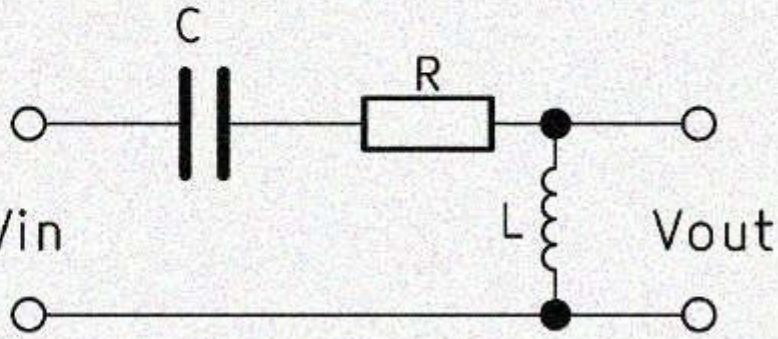


High Pass Filter Variations

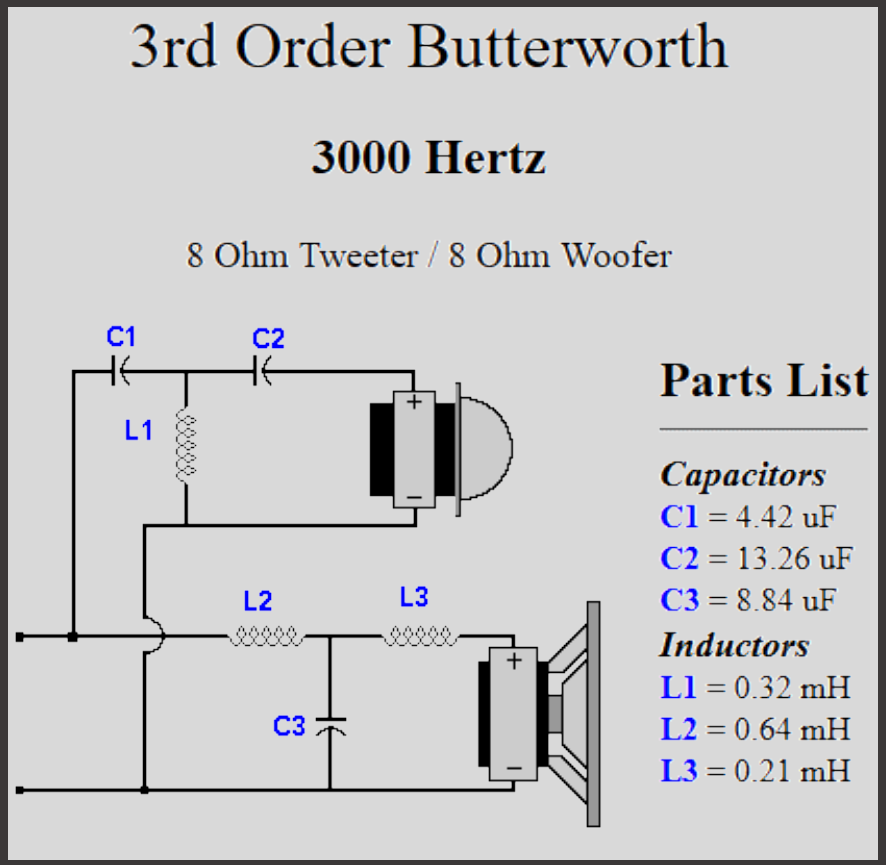




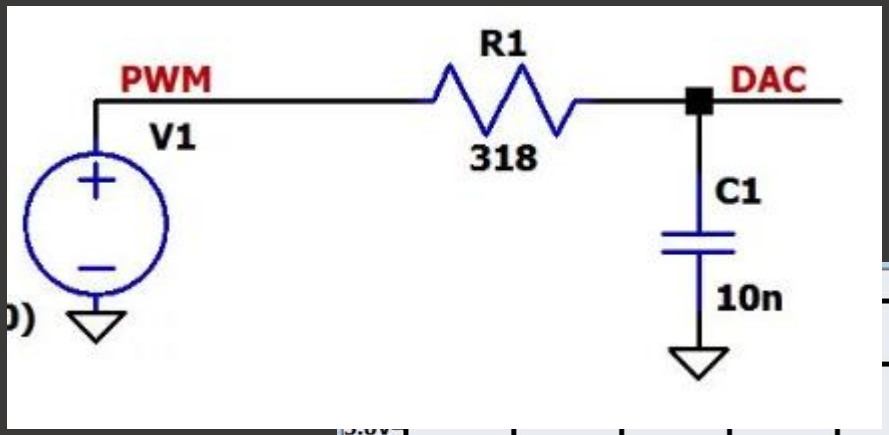


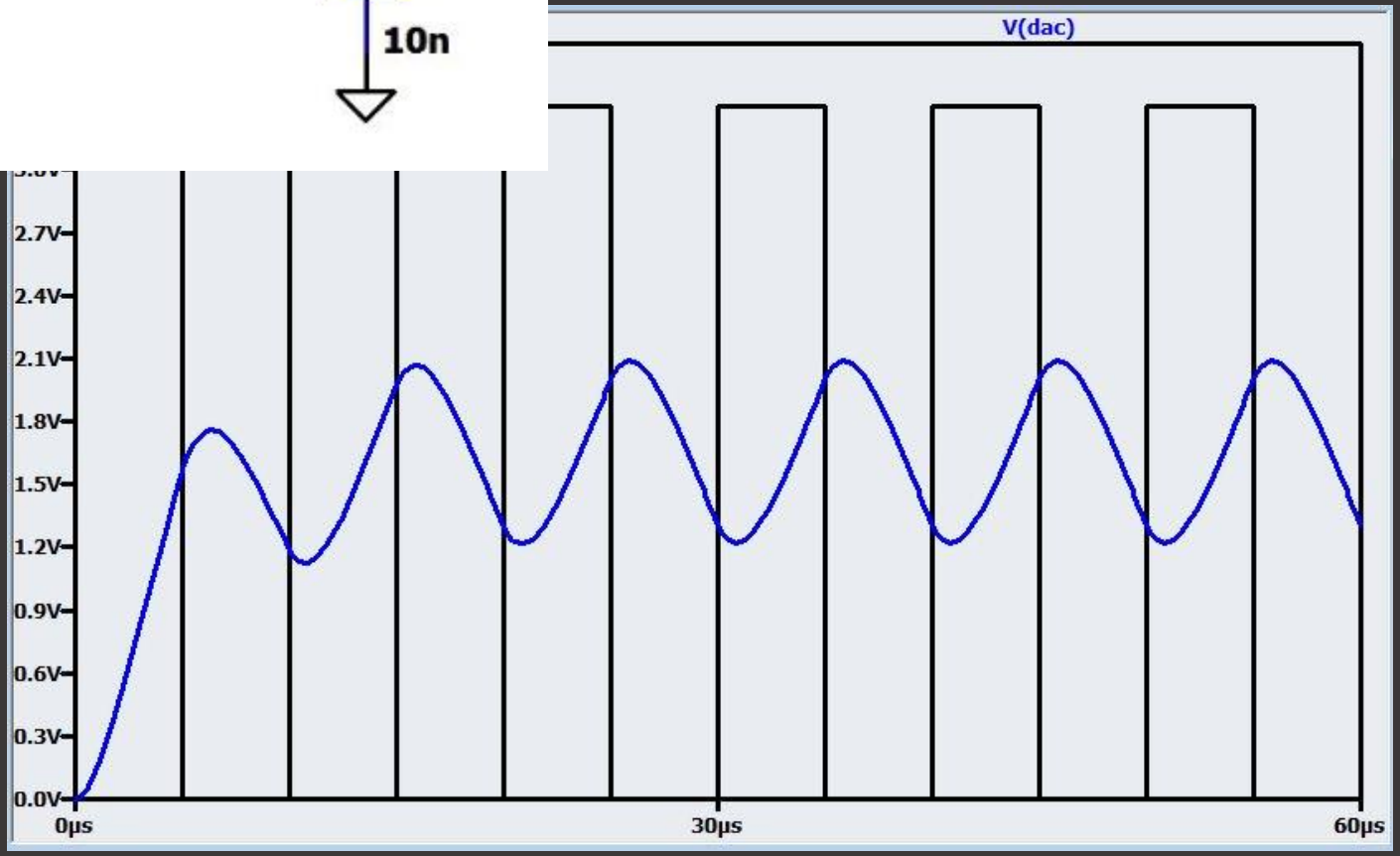


Practical Example - Crossover

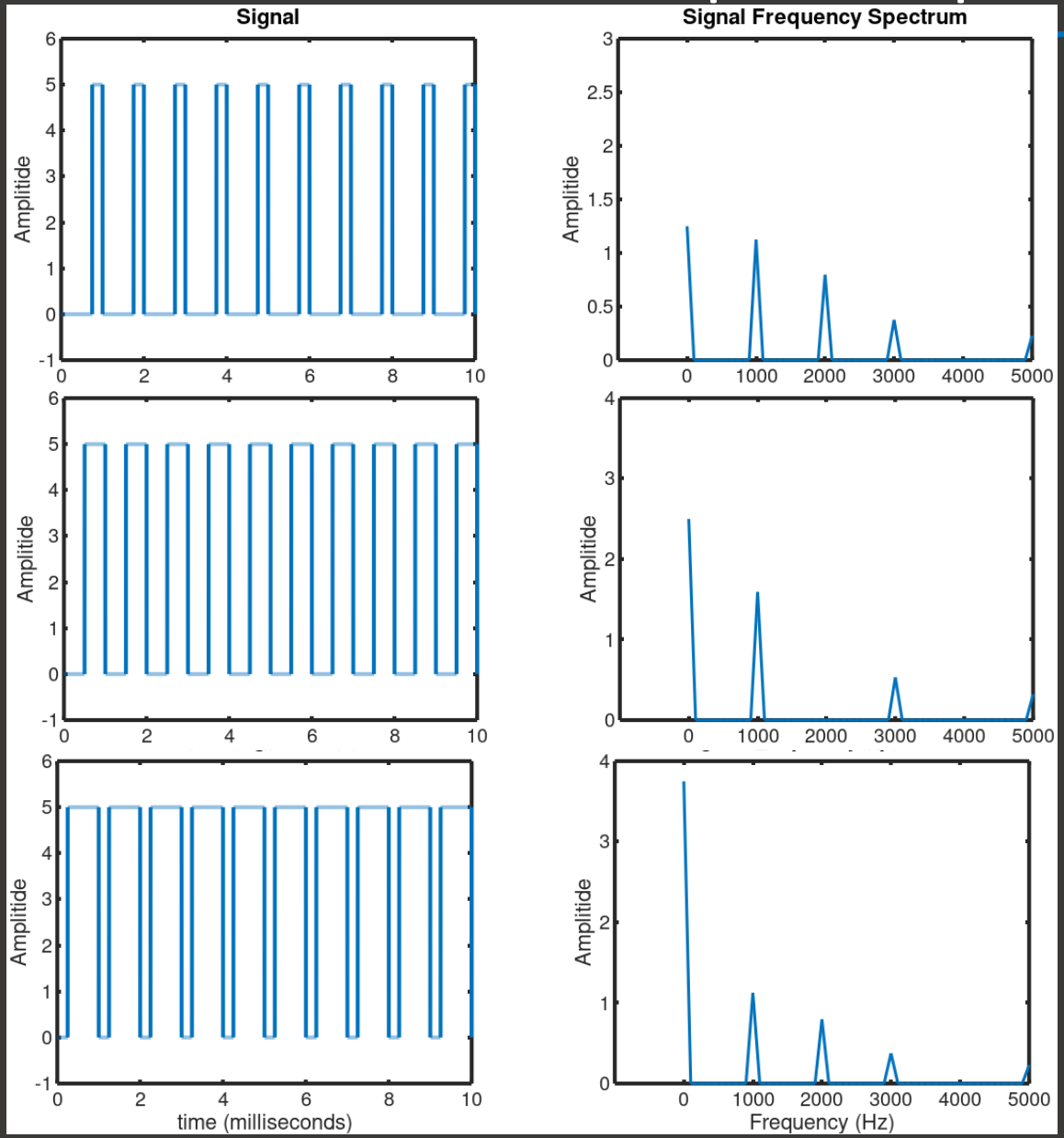


Example: Arduino PWM Filtering





PWM Freq Components



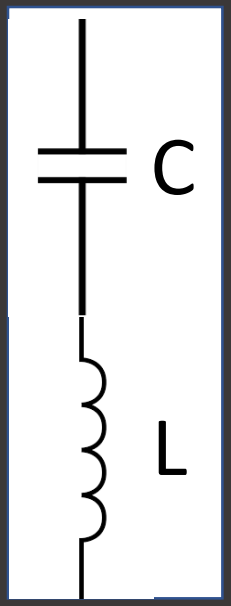
25% Duty Cycle

50% Duty Cycle

75% Duty Cycle

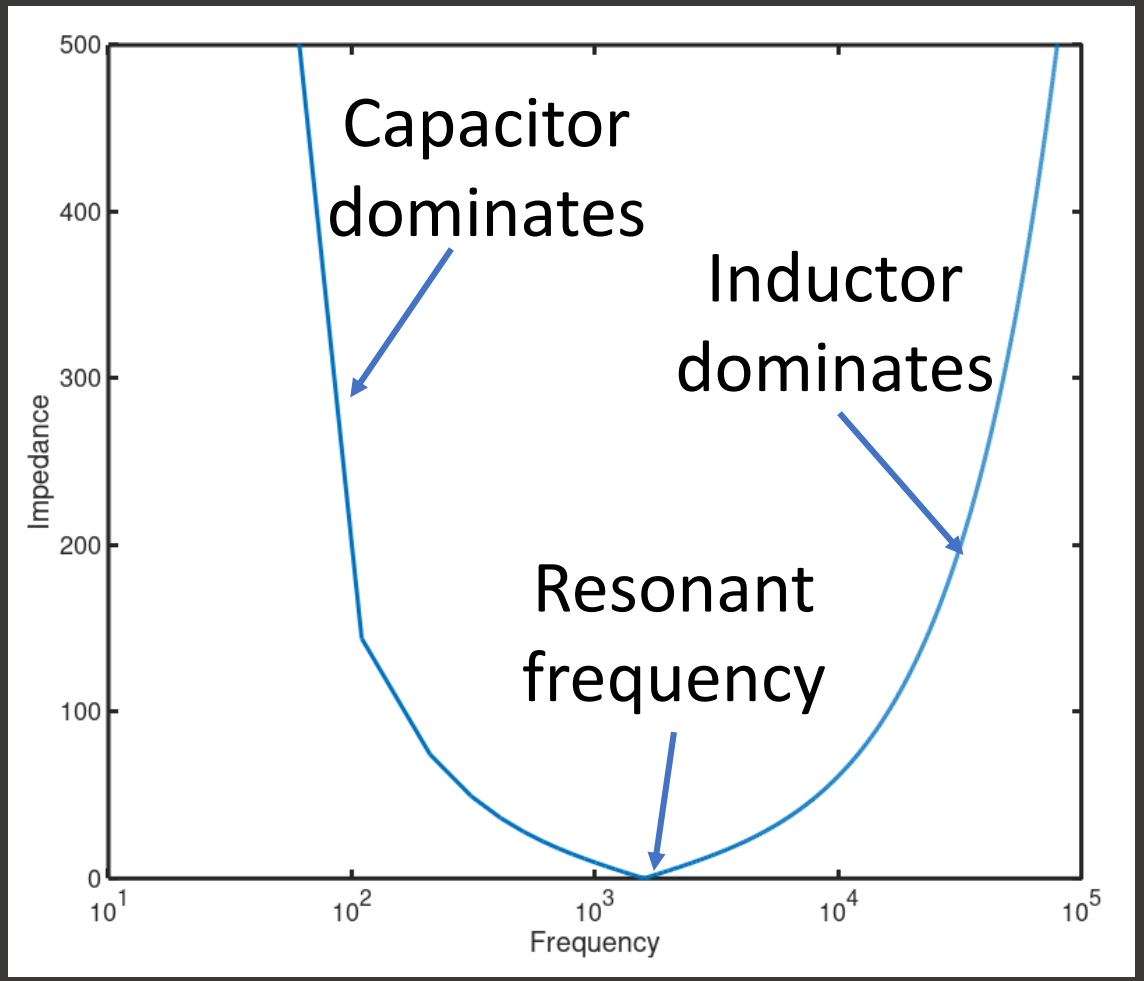
Power Supply Noise and Bypassing

LC Resonant Circuit Detail



$$X_C = \frac{-1}{2\pi f C}$$

$$X_L = 2\pi f L$$

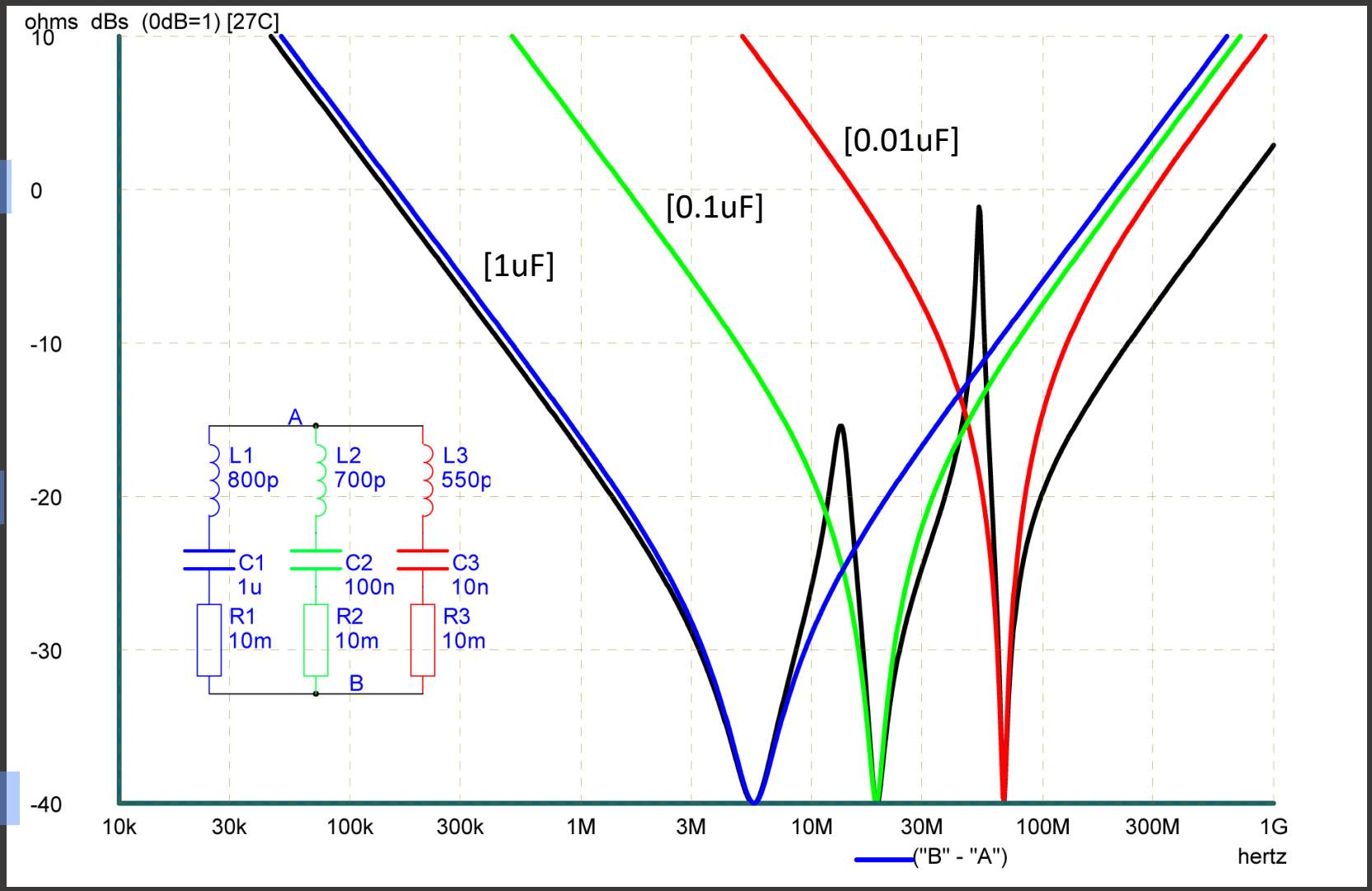


Real World Capacitor Bypassing

[1Ω]

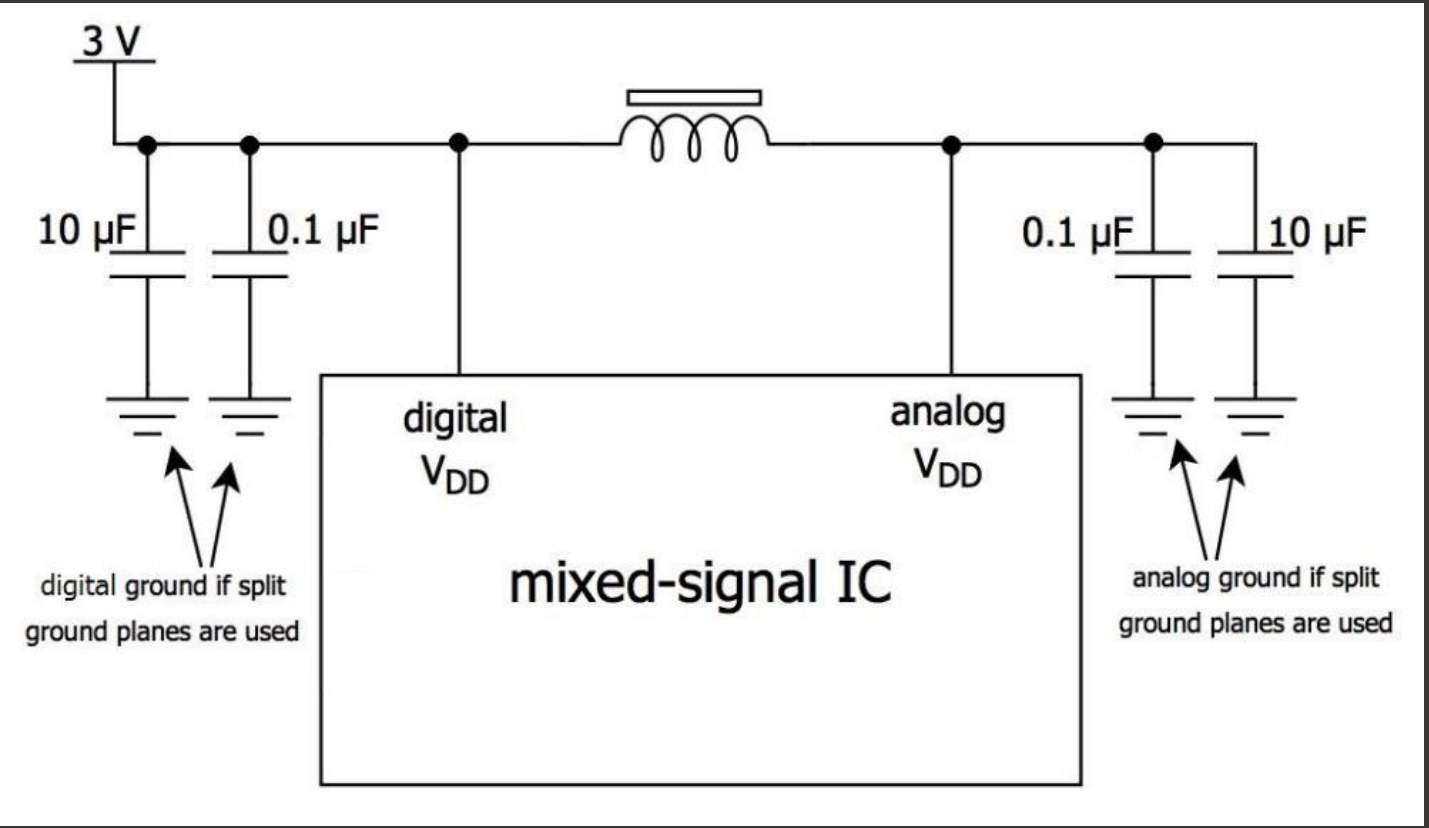
[0.1Ω]

[0.01Ω]



Source: https://www.planetanalog.com/document.asp?doc_id=527551

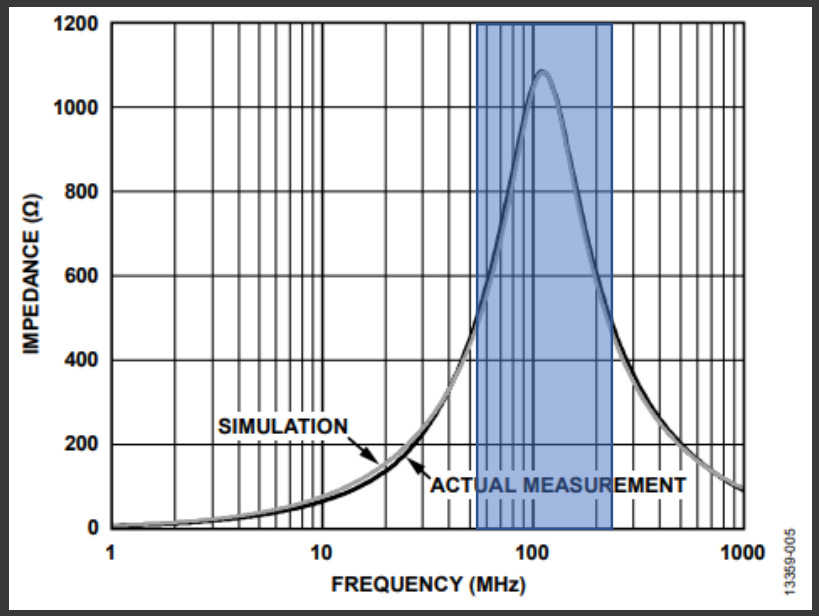
Filter Digital Noise From Analog



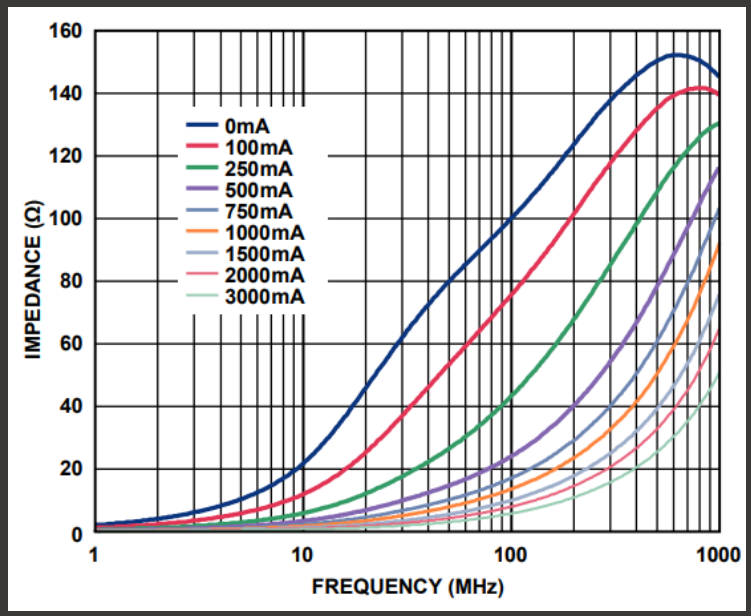
A ferrite bead is sort of a poor (lossy) inductor, converting AC to heat

Source: All About Circuits: Choosing and Using Ferrite Beads

Ferrite Bead Notes



Tyco BMB2A1000LN2

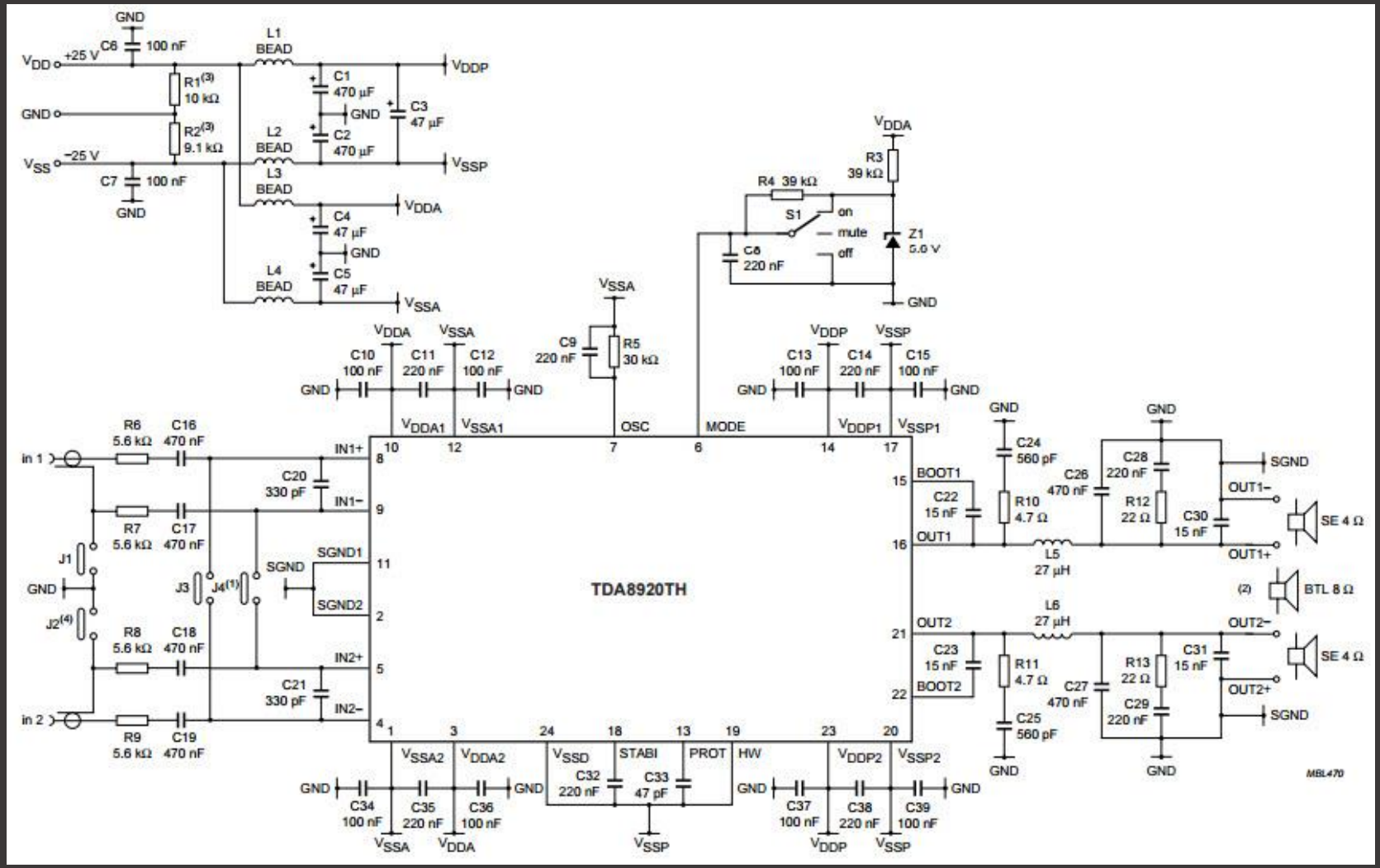


TDK MPZ1608S101A

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=PLRIGIzu0Z7KlBkiI9nNfMmRy4ZTzGr0RN&index=15&t=0s