E12 Final Project:

Op Amps versus RLC Filters

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Introduction

Our goal in this project was to experiment with various filtering methods for radio communications. Our original goal was to create filters to pass 1.09 GHz ADS-B aircraft tracking signals.

Although theoretically possible, filtering at high frequencies was not easily realizable. We had more success filtering FM radio frequencies, around 90 MHz.

We attempted to compare a passive RLC series filter and an active Sallen-Key Op-Amp filter. We were unable to construct the RLC filter due to physical constraints, but the Op-Amp filter was successfully built.

Data Acquisition

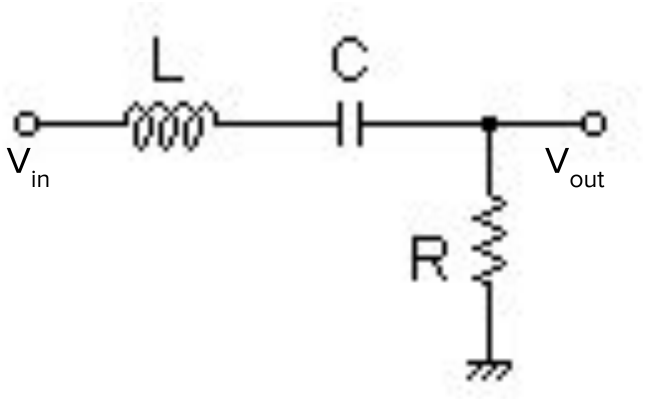
Our data collection was done using an Airspy Mini USB device and Length v-dipole antenna

Filters were placed in-line, between the antenna and USB device

To analyze the data, we used SDRSharp (SDR#) and SpectrumSpy, both from Airspy

RLC Circuit

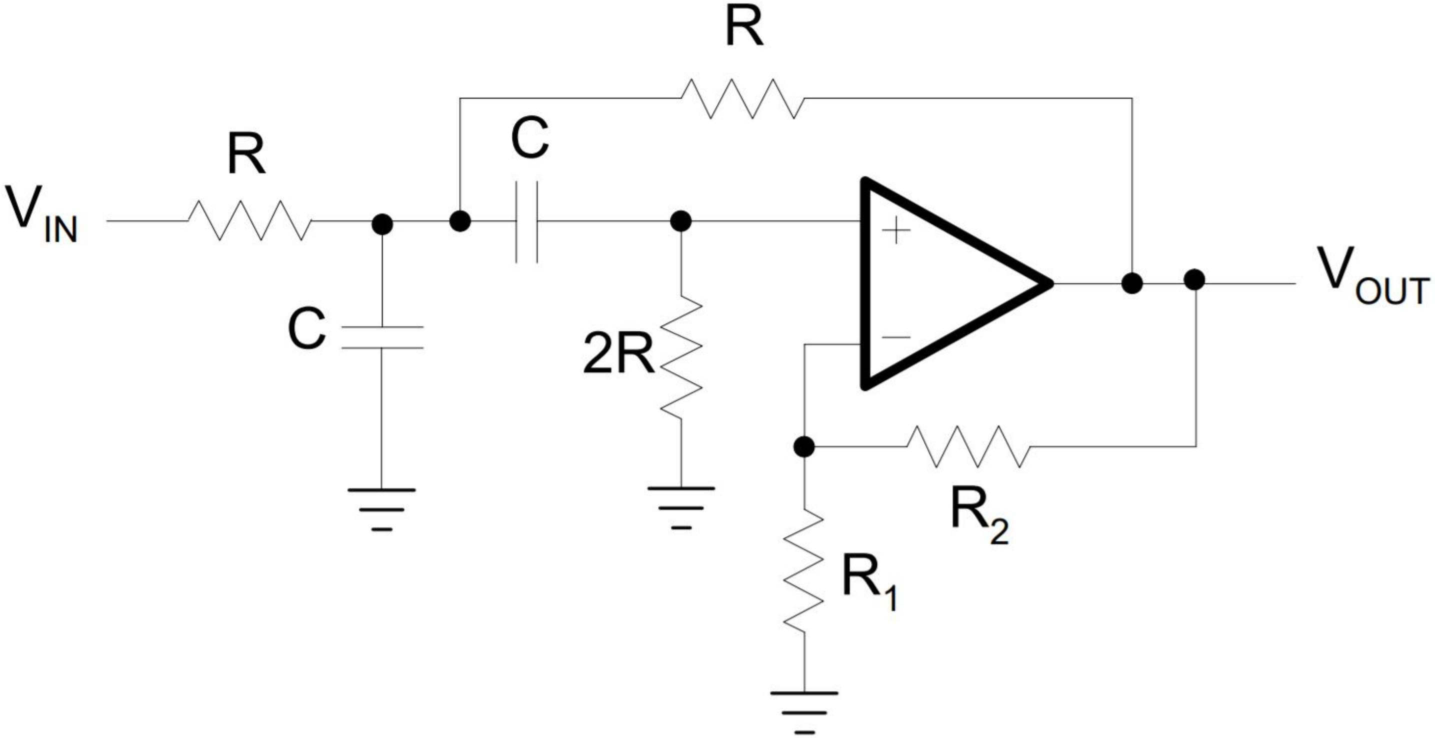
Our passive filter measures the voltage across the resistor of a series RLC circuit.



Op-Amp Circuit

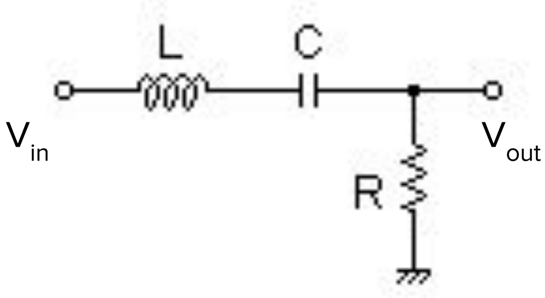
Sallen-Key Topology

- Simple
- Adds Gain



Theory: RLC

Basic RLC Bandpass Design



$$Q = \frac{1}{2\zeta}$$

$$f_m = \frac{1}{2\pi\sqrt{LC}}$$

$$\frac{V_{out}}{V_{in}} = \frac{2\zeta(2\pi f_0)s}{s^2 + 2\zeta(2\pi f_0)s + (2\pi f_0)^2} = \frac{\frac{R}{L}s}{s^2 + \frac{R}{L}s + \frac{1}{LC}}$$

Sourced From Okawa Electric Design

Theory: RLC

Center Frequency: 97.75 MHz, the middle of the FM band

L = 10 µH, the smallest inductor available

$$f_m = \frac{1}{2\pi\sqrt{LC}}$$

C = 0.265 pF

Bandwidth: 20.5 MHz, to capture the entire FM band

$$Q = \frac{f_m}{\beta}$$

Q = 4.768

Theory: RLC

With Q = 4.768

$$Q = \frac{1}{2\zeta}$$

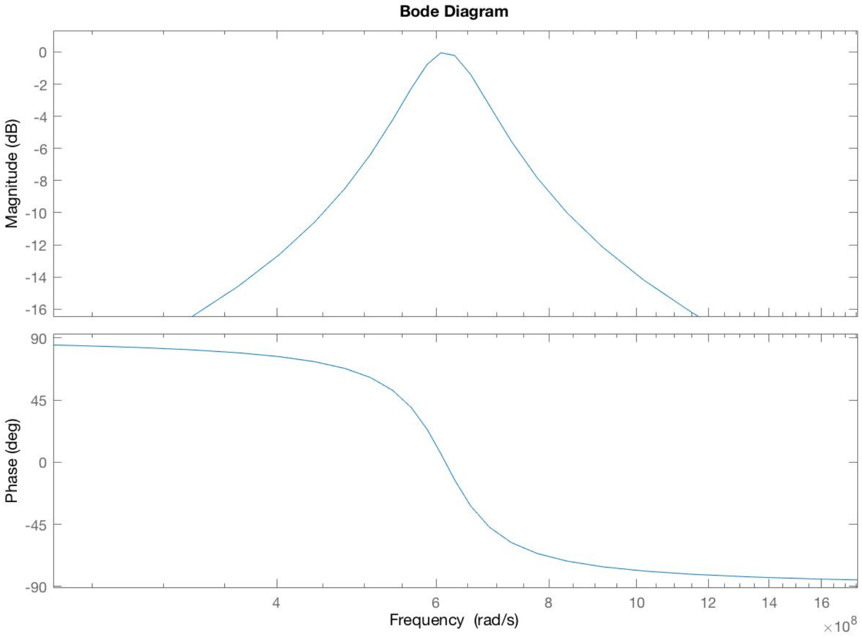
ζ = 0.104866

Calculate value of R

$$2\zeta(2\pi f_0)s = \frac{R}{L}s$$

R = 1.288 kΩ

Theoretical: RLC Circuit

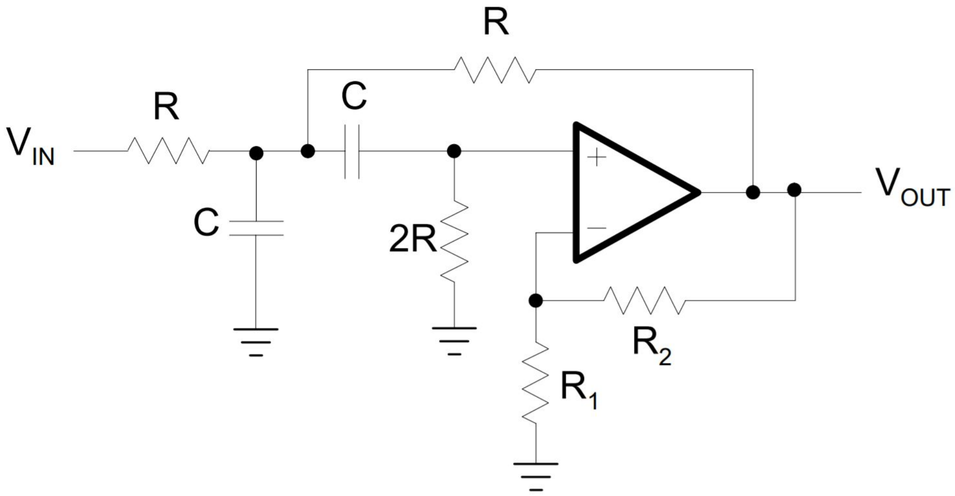


$$H(s) = \frac{1.288e08\ s}{s^2 + 1.288e08\ s + 3.774e17}$$

- Steeper magnitude change than OP Amp filter
- Magnitude of peak at 0, due to lack of amplification
- Peak is centered near the targeted frequency

Theory: OP Amp

Sallen-Key Design:



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

$$Q = \frac{f_m}{\beta} \quad Q = \frac{1}{3 - G}$$

$$G = 1 + \frac{R_2}{R_1}$$

$$A_m = \frac{G}{3 - G}$$

Sourced from *Op-Amps for Everyone (2002)* Texas Instruments

Theory: OP Amp

Center Frequency: 97.75 MHz, the middle of the FM band

C = 5 pF, the smallest capacitor available

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

R = 326 Ω

Bandwidth: 20.5 MHz, to capture the entire FM band

$$Q = \frac{f_m}{\beta}$$

Q = 4.768

Theory: OP Amp

From Q=4.768, gain and amplification at center frequency can be calculated

$$Q = \frac{1}{3-G}$$

G=2.8

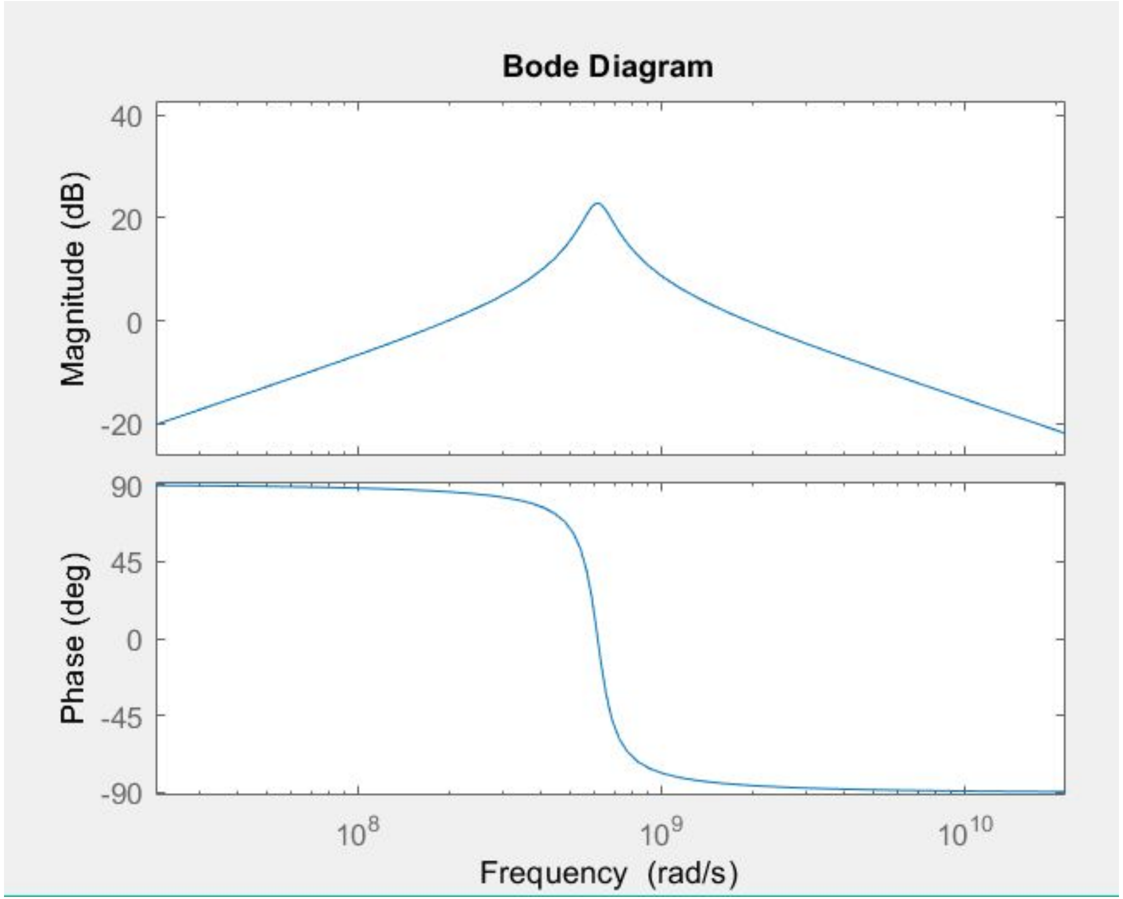
$$A_m = \frac{G}{3-G}$$

Am = 14

$$G = 1 + \frac{R_2}{R_1}$$

R1 = 1 kΩ R2 = 1.8 kΩ

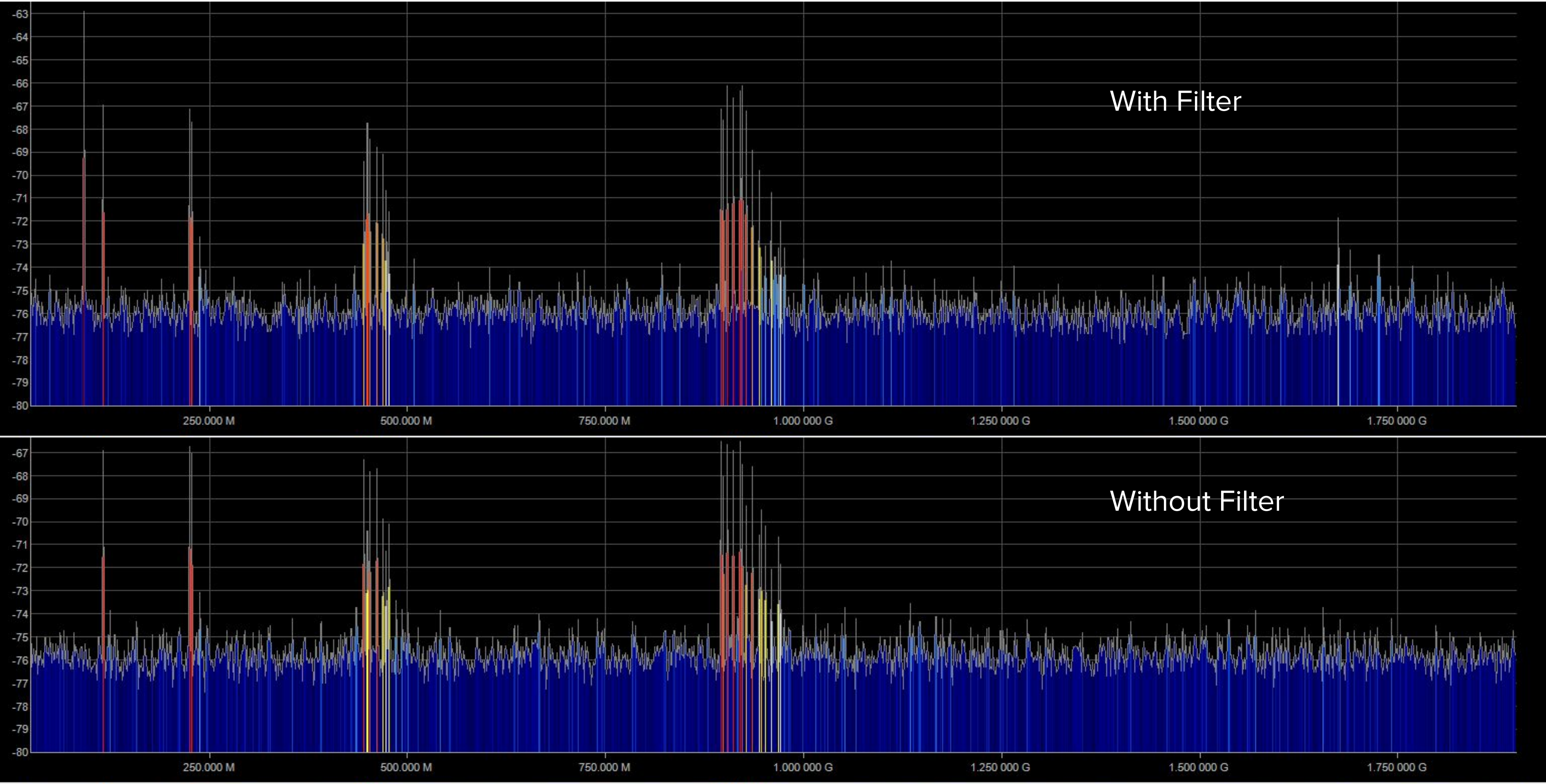
Observations v. Theoretical: Op-Amp



$$H(s) = \frac{1.718e09\ s}{s^2 + 1.227e08\ s + 3.764e17}$$

- Magnitude is greater than 0 at the peak
- Peak width is 20.5 Mhz to accommodate the entire FM band

Observations v. Theoretical: Op-Amp



Summary

RLC Bandpass not physically realizable

- C = 0.265 pF
- Attemped to make, but would have required too many capacitors in series

OP Amp Bandpass was physically realizable

- Did not successfully filter
- Amplified our desired band

Conclusion

The original goal of making a 1.09 GHz filter for receiving ADS-B aircraft tracking signals was not realizable.

Lower frequency filtering was possible for an active filter, but not for a passive filter.

The filter did not successfully block signals outside of the pass band, but it did amplify those within.

To remedy this, proper RF shielding would be necessary.