# Lab 06: Passive Filter Circuits

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# 1 Abstract

This lab introduces frequency domain behavior of passive filters composed of resistors, capacitors, and inductors. Through experimentation with low-pass and high-pass filters, as well as an underdamped RLC configuration, the frequency response and phase shift characteristics are observed. Emphasis is placed on understanding cutoff frequency, amplitude response, and the resonance phenomenon.

# 2 Introduction

While earlier labs focused on transient response, this experiment shifts the focus to the steady-state sinusoidal behavior of filters. The goal is to understand how the amplitude and phase of a circuit's output vary as a function of frequency. By examining first-order filters and a second-order resonant circuit, intuition is built for applications in audio electronics, communication systems, and signal processing.

Filters are circuits that selectively allow or reject certain frequencies. Low-pass filters allow low frequencies to pass while attenuating higher ones. High-pass filters do the opposite. The transition point between passing and attenuation is the cutoff frequency, defined where the output amplitude is $\frac{1}{\sqrt{2}}$ of the input.

# 3 Theory

## 3.1 Low-Pass RC Filter

A first-order RC low-pass filter has the following configuration:

The transfer function is:

$$H(f) = \frac{1}{1 + j2\pi f RC}$$

The cutoff frequency is given by:

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

## 3.2 High-Pass RC Filter

A high-pass RC filter simply swaps the resistor and capacitor:

The transfer function becomes:

$$H(f) = \frac{j2\pi f RC}{1 + j2\pi f RC}$$

With the same cutoff frequency:

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

## 3.3 Second-Order RLC Circuit (Bandpass Filter)

An underdamped RLC circuit exhibits resonance. The circuit is:

Its transfer function peaks at:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad \text{(resonant frequency)}$$

And has a quality factor $Q$:

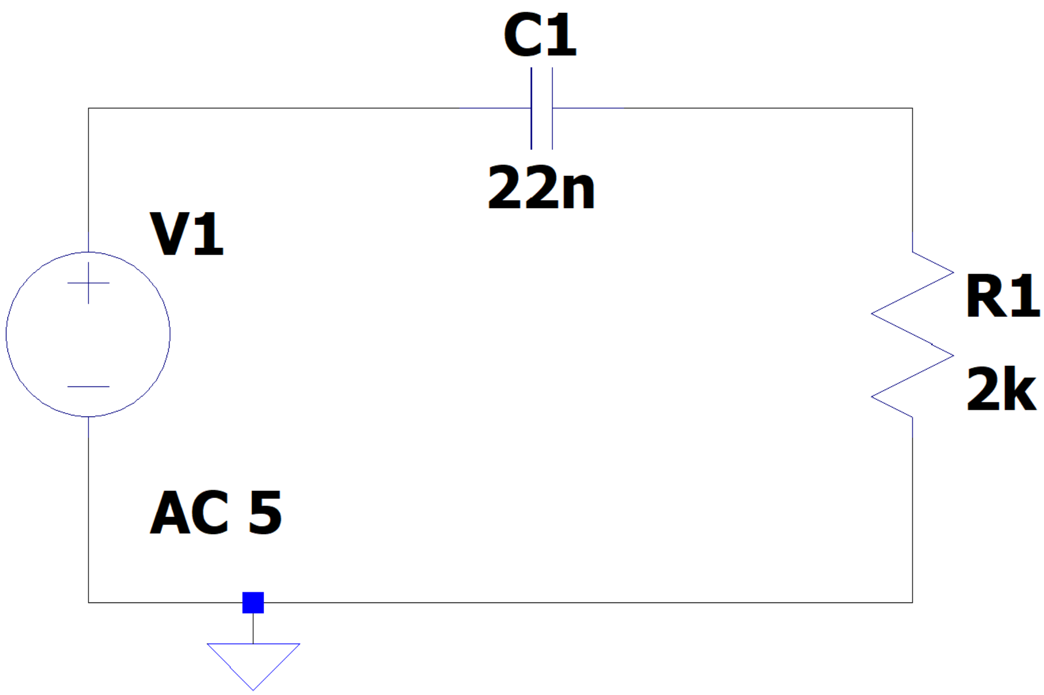
$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

# 4 Experimental Procedures

## 4.1 Circuit One: RC High-Pass Filter

A $22nF$ capacitor was substituted in place of the $15nF$ capacitor. A high pass filter is formed when the output of an RC circuit is taken off the resistor.

Cutoff Frequency - $3556.31Hz$
Cutoff Frequency Phase - $45.49°$

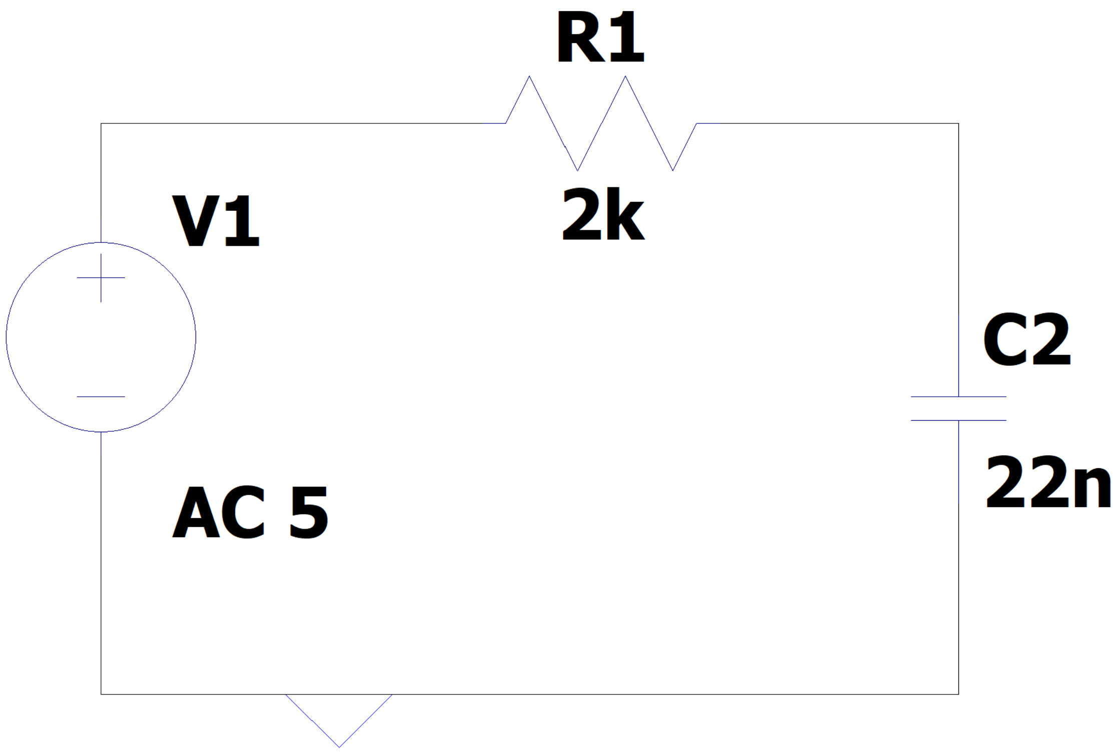



- Input signal: $5\,V_{pp}$ sine wave
- Frequency sweep: 1 Hz to 100 MHz
- Measure amplitude and phase of output across resistor.

## 4.2 Circuit Two: RC Low-Pass Filter

A typical low-pass filter is formed when the output of an RC circuit is taken off the capacitor.

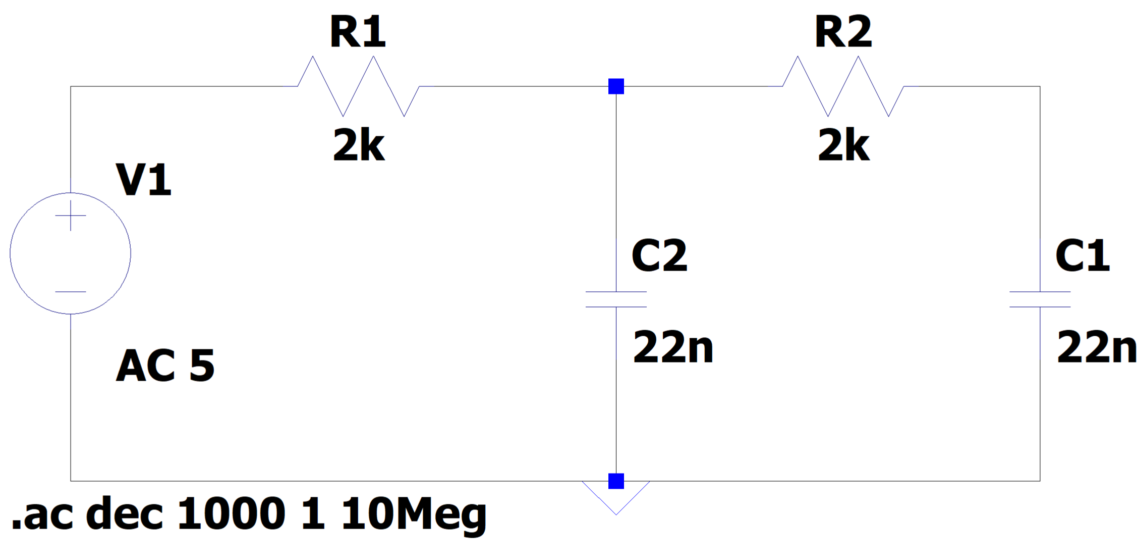
Cutoff Frequency - $3681.29Hz$ Cutoff Frequency Phase - $-45.50°$




- Same input signal and frequency sweep
- Measure output across capacitor

### 4.3 Circuit Three: Parallel Capacitor Low Pass Filter

Cutoff Frequency: $1377.21Hz$
Cutoff Frequency Phase: $-53.18°$

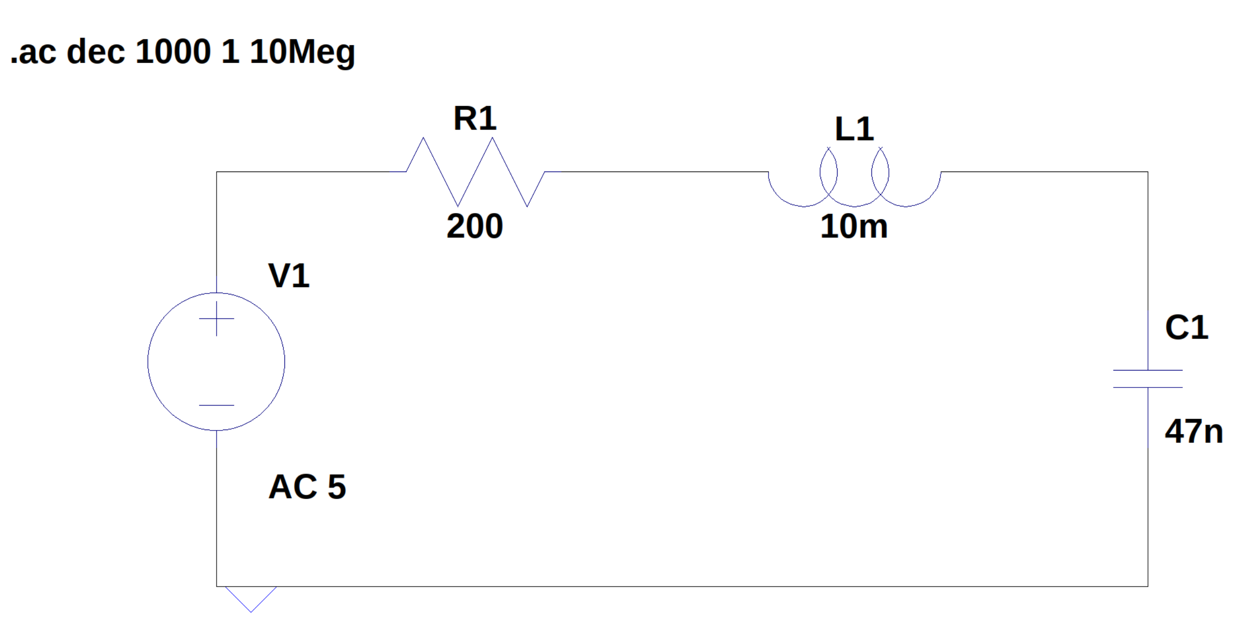



- Determine resonant frequency and bandwidth
- Plot Bode plot of magnitude response

## 4.4 Circuit Four Series RLC Bandpass Filter

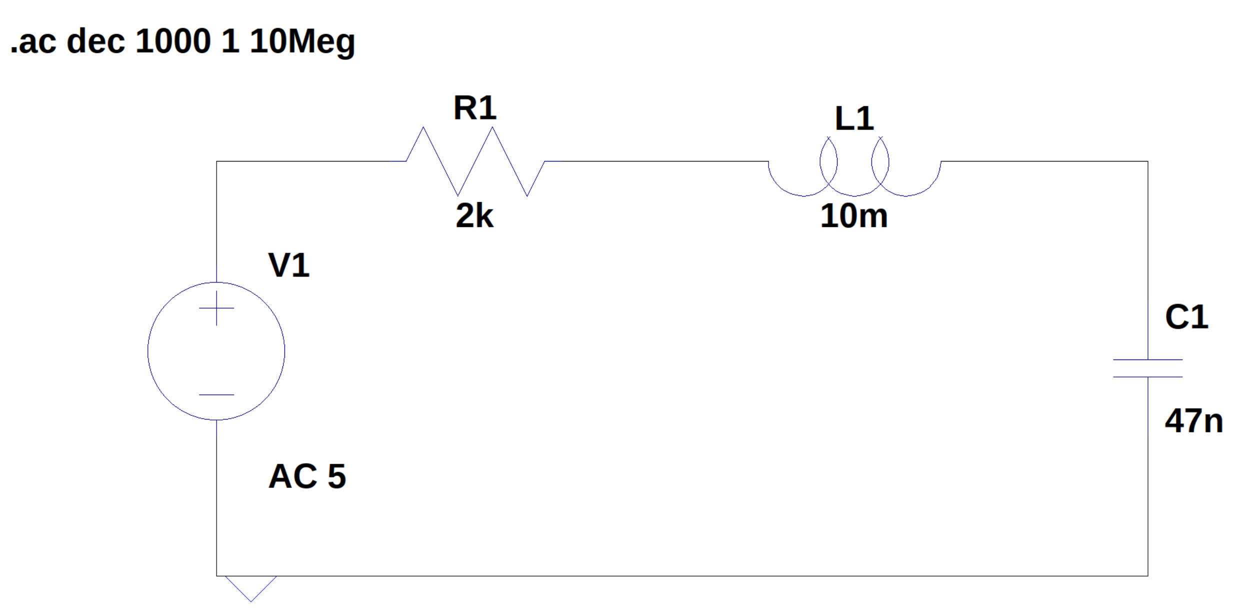
### 4.4.1 Resistor at $200\Omega$

Cutoff Frequencies:
$5105.05Hz$, $-30.278°$
$5597.57$, $-28.30°$



- Determine resonant frequency and bandwidth
- Plot Bode plot of magnitude response

#### 4.4.2 Resistor at 2000Ω



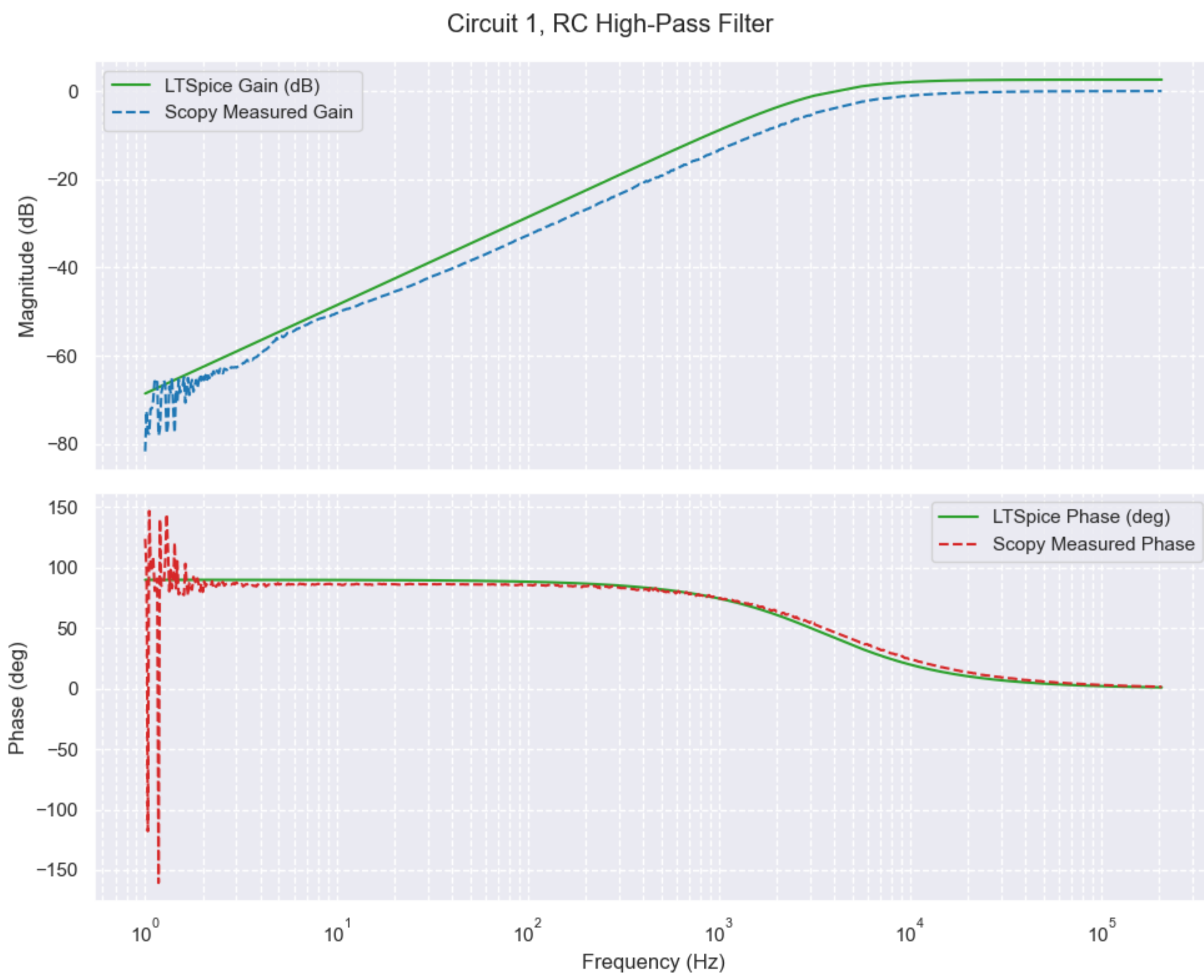

- Determine resonant frequency and bandwidth
- Plot Bode plot of magnitude response

# 5 Results and Discussion

## 5.1 Low-Pass Filter Analysis

Table 1: Scopy Measurements – Circuit 1: RC High-Pass Filter

| Frequency (Hz) | Gain (dB) | Phase (°) |
|---:|---:|---:|
| 1.00 | -81.680 | 123.927 |
| 5.99 | -54.359 | 86.142 |
| 35.94 | -41.073 | 86.300 |
| 215.44 | -26.350 | 85.221 |
| 1291.55 | -11.371 | 70.992 |
| **3569.05** | **-4.393** | **50.071** |
| 7742.64 | -1.522 | 30.026 |
| 46415.90 | -0.076 | 6.315 |
| 278256.00 | 0.014 | 1.098 |
| 10000000.00 | 0.040 | -0.450 |

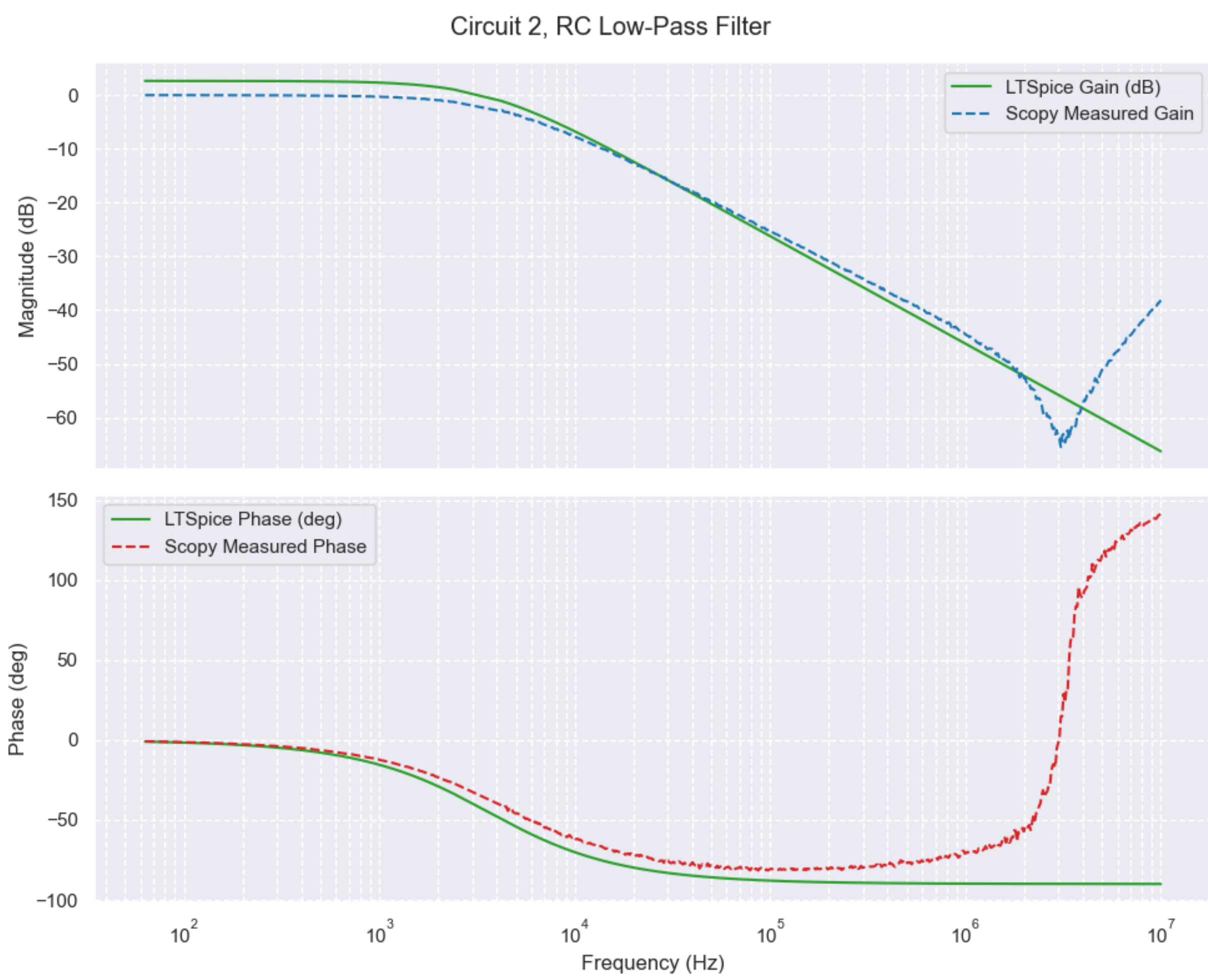



- Compare theoretical cutoff with measured
- Plot amplitude response and extract $-3\,\mathrm{dB}$ point

## 5.2 High-Pass Filter Analysis

Table 2: Scopy Measurements – Circuit 2: RC Low-Pass Filter

| Frequency (Hz) | Gain (dB) | Phase (°) |
|---:|---:|---:|
| 1.00 | -0.045 | -0.779 |
| 5.99 | -0.031 | -0.058 |
| 35.94 | -0.036 | -0.487 |
| 215.44 | -0.063 | -2.738 |
| 1291.55 | -0.507 | -15.575 |
| **3686.10** | **-2.466** | **-37.314** |
| 7742.64 | -6.089 | -56.304 |
| 46415.90 | -19.171 | -78.441 |
| 278256.00 | -33.672 | -78.289 |
| 10000000.00 | -38.133 | 141.555 |



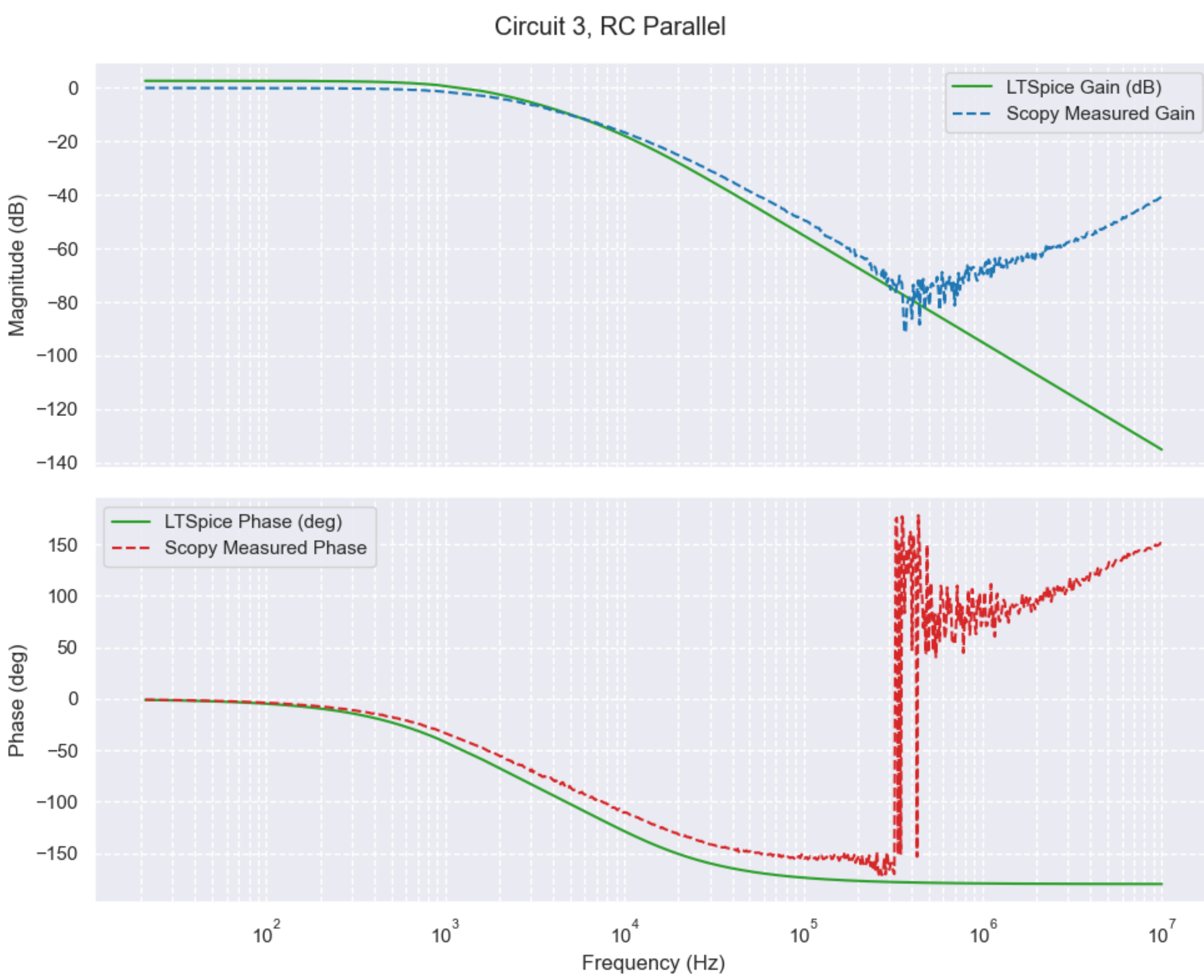

- Same analysis as low-pass

- Note phase shift at low frequencies

## 5.3 RC Parallel Filter

Table 3: Scopy Measurements – Circuit 3: RC Parallel Low-Pass Filter

| Frequency (Hz) | Gain (dB) | Phase (°) |
|---|---|---|
| 1.00 | -0.072 | -0.738 |
| 5.99 | -0.048 | -0.242 |
| 35.94 | -0.061 | -1.382 |
| 215.44 | -0.156 | -7.839 |
| **1377.65** | **-2.385** | **-42.622** |
| 7742.64 | -14.098 | -101.253 |
| 46415.90 | -37.471 | -147.796 |
| 278256.00 | -66.917 | -168.630 |
| 1668100.00 | -64.770 | 101.918 |
| 10000000.00 | -40.640 | 150.371 |

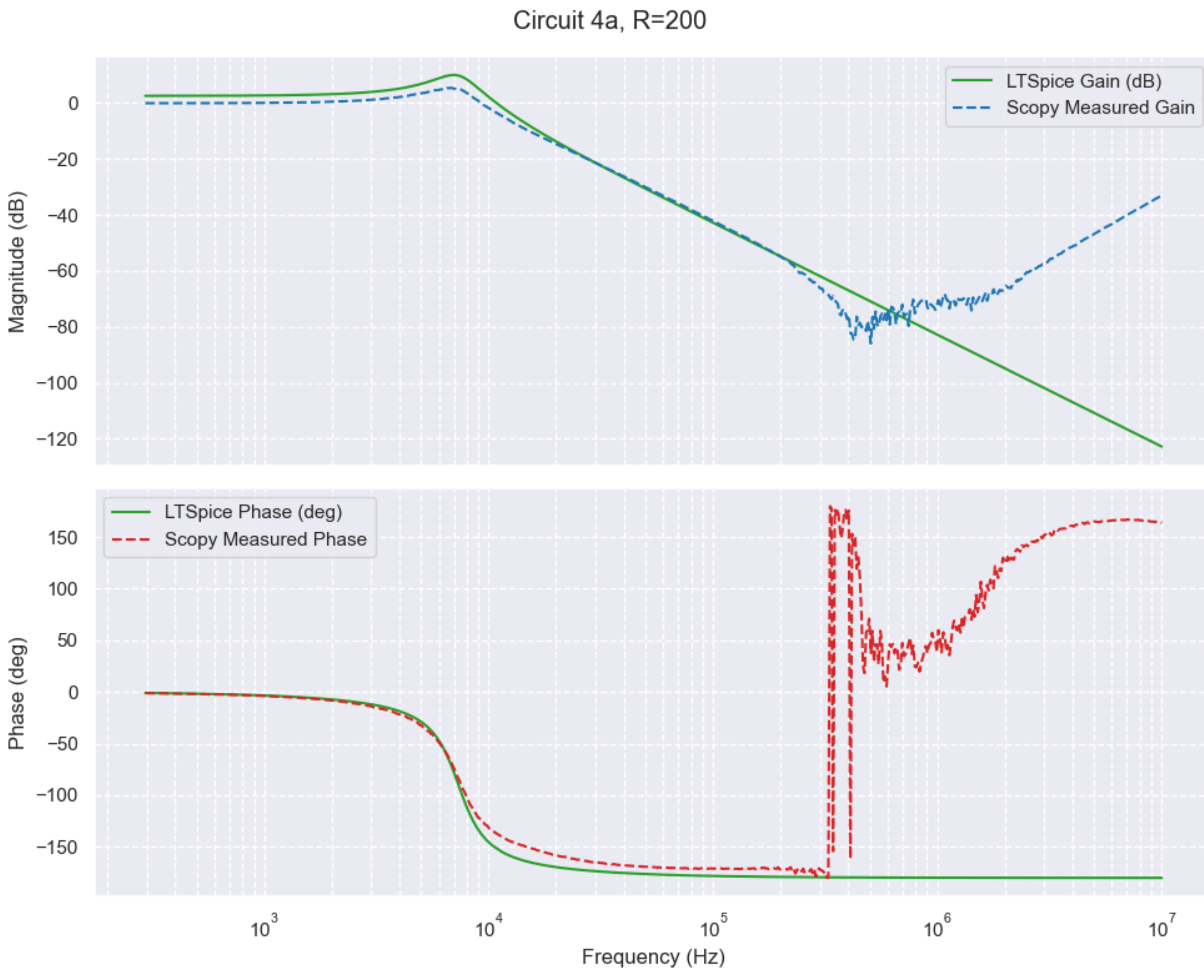


- Compare calculated resonant frequency with observed
- Discuss the role of $Q$ and peak amplitude

## 5.4 RLC Bandpass Filter

Table 4: Scopy Measurements – Circuit 4a: Series RLC Bandpass Filter ($R = 200\,\Omega$)

| **Frequency (Hz)** | **Gain (dB)** | **Phase (°)** |
|---:|---:|---:|
| 1.00 | 18.009 | 1.113 |
| 5.99 | -0.016 | -0.019 |
| 35.94 | -0.016 | -0.138 |
| 215.44 | -0.017 | -0.797 |
| 1291.55 | 0.174 | -5.155 |
| **5089.87** | **3.675** | **-33.948** |
| **5607.23** | **4.286** | **-40.791** |
| 7742.64 | 4.358 | -95.247 |
| 46415.90 | -28.705 | -168.845 |
| 278256.00 | -64.036 | -175.566 |


Circuit 4a, R=200
LTSpice Gain (dB)
Scopy Measured Gain
Magnitude (dB)
0
−20
−40
−60
−80
−100
−120
LTSpice Phase (deg)
Scopy Measured Phase
Phase (deg)
150
100
50
0
−50
−100
−150
$10^3$
$10^4$
$10^5$
$10^6$
$10^7$
Frequency (Hz)

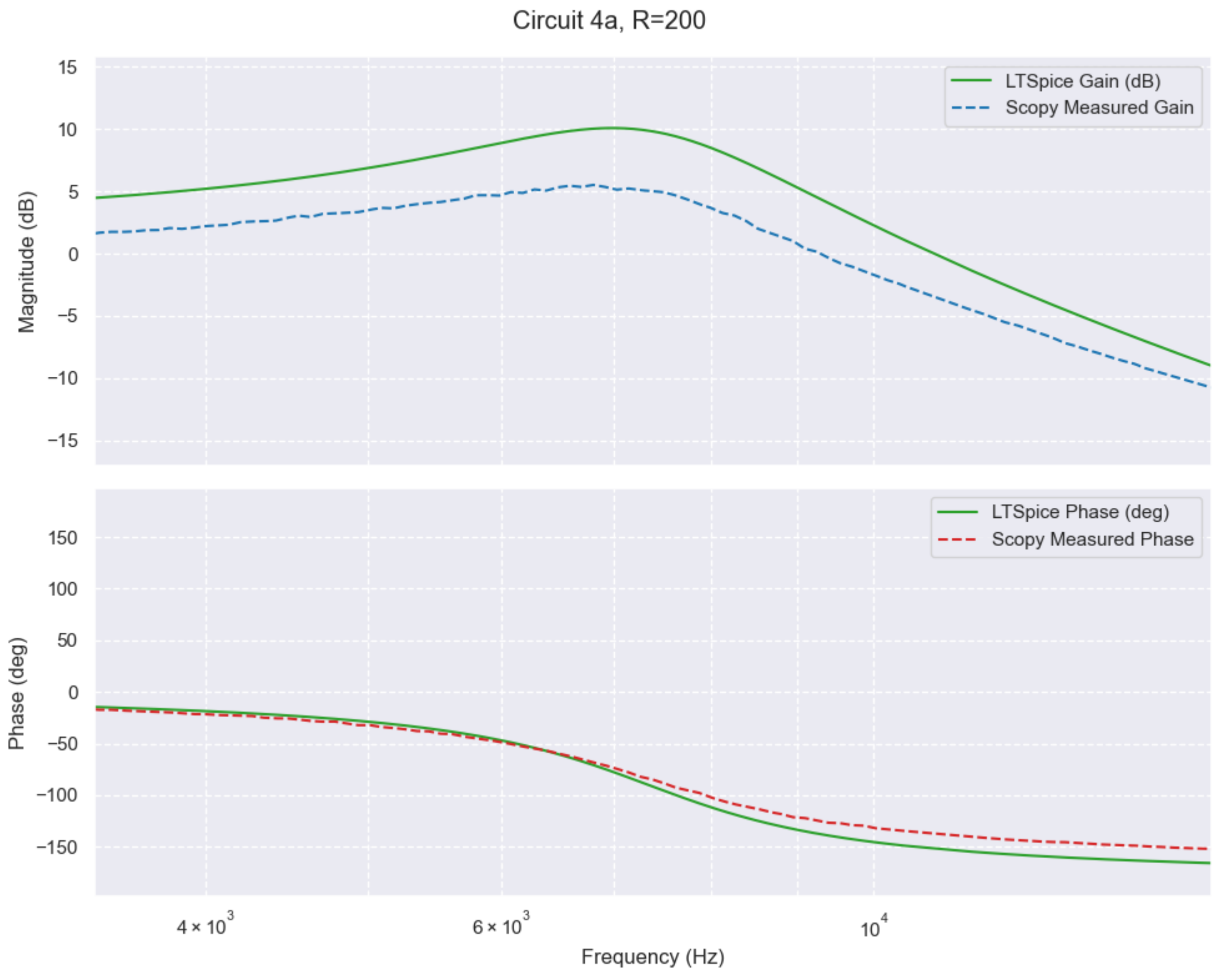
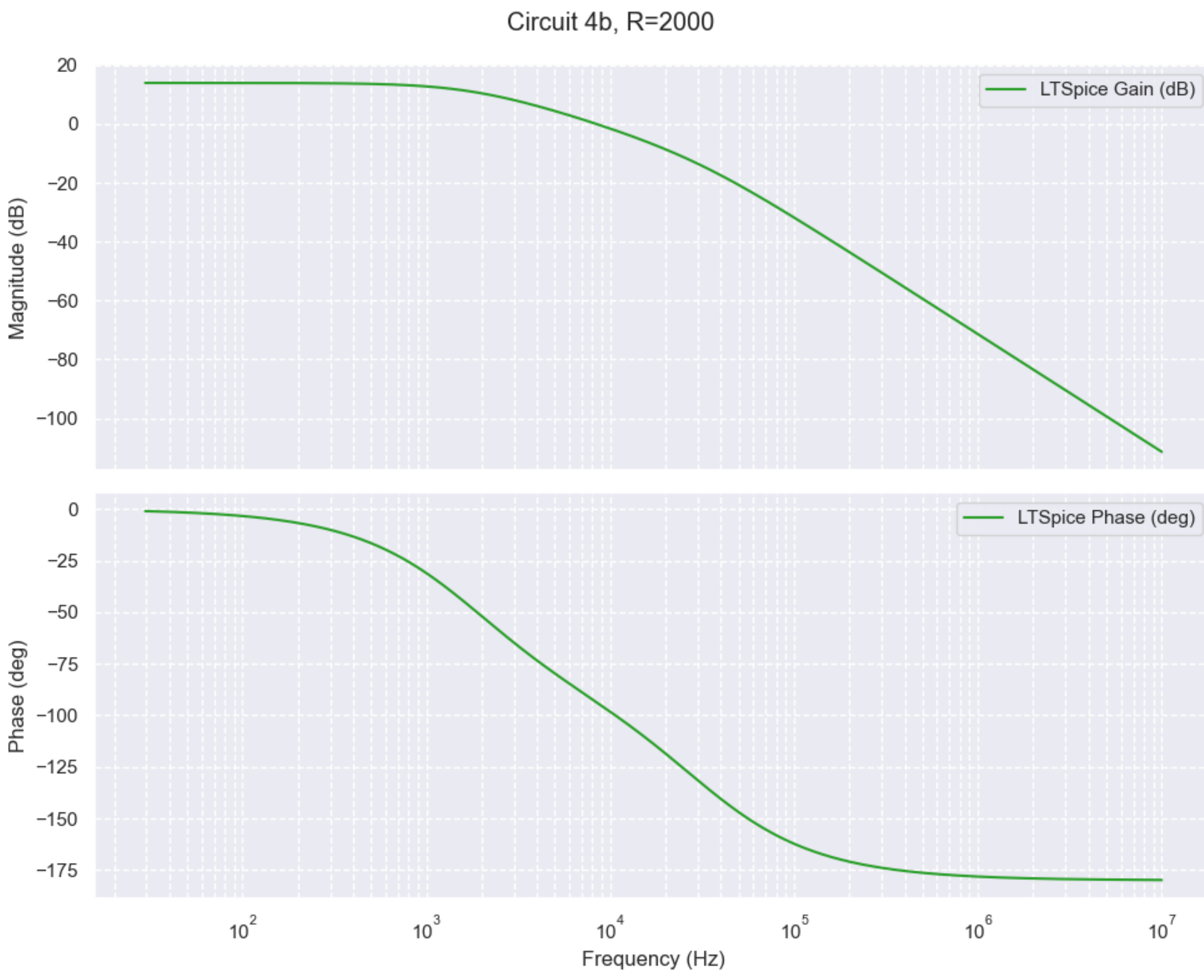



Figure 1: Area of Interest

### 5.5 RLC Low Pass Filter




## 6 Conclusion

This lab demonstrated the role of passive filters in shaping the frequency content of signals. First-order filters showed characteristic −20 dB/decade roll-off near cutoff, while the second-order RLC circuit showed clear resonant behavior. Agreement between theory, simulation, and measurement confirms the behavior of these filters and prepares students for future work in frequency-selective networks and analog signal processing.