Experiment 25

High Pass-Low Filters

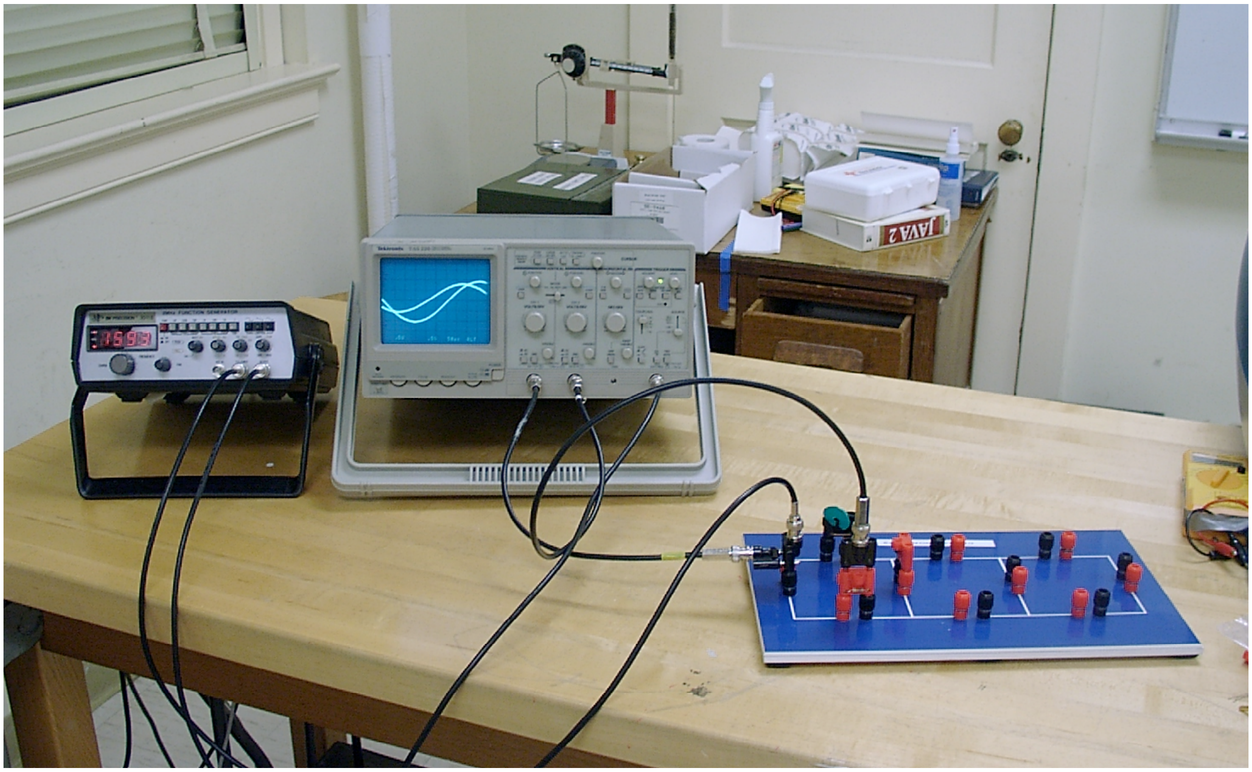


Fig. 25-1

Equipment:

1 Techtronix oscilloscope

4 BNC cables

1 BK oscillator

1 5 mH inductor

1 one K ohm resistor

1 one 470 ohm resistor

1 10nF capacitor

1 jumper

3 BNC to banana jacks

Advance Reading

Serway, Ch 33, Sections 33.5 & 33.9

Objective

The objective of this experiment is to examine the 'frequency behavior' of two types of AC circuits (RC and LR) in a commonly used circuit called a crossover (or high pass low pass) circuit.

Theory

The equations for a series RLC circuit driven by a sinusoidal voltage are developed in Serway section 33.5. The applied voltage

$$\Delta V = V_{\max} \sin(\omega t)$$

has amplitude V_{max}, and angular frequency w. (The circular frequency f, measured in Hz, is related to the angular frequency through $f = \omega / 2\pi$.

The current in the circuit is sinusoidal with the same frequency as the drive.

$$I = I_{\max} \sin(\omega t - \phi)$$

where I_{max} is the current amplitude, and *phi* is the phase angle between the current and the applied voltage. The current amplitude may be found through

$$I_{\max} = \frac{V_{\max}}{Z}$$

where the impedance Z is

$$Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}\ .$$

The resistance is R, and the X's are the inductive and capacitive reactances, respectively.

$$X_L = \omega L = 2\pi f L \text{ and}$$

$$X_C = 1/\omega C = 1/2\pi f C\ .$$

The phase of the current is

$$\phi = \arctan \frac{X_L - X_C}{R}$$

and gives the angle by which the voltage leads the current (or lags if negative).

An application-Speaker crossover network-

Modern loudspeaker systems use several speakers in each cabinet to improve the sound quality and power handling ability. The different speakers are designed to reproduce different ranges of audio frequencies, ranging from tweeters which are good for high frequencies, squawkers for middling frequencies, and woofers for low frequency.

It is important to send only the right frequency range to each speaker, since the speaker can only reproduce a range of frequencies, and electrical energy at other frequencies is wasted and serves only to heat up its voice coil. Thus an electrical system is desired to pass high frequency waves to the tweeter while blocking lower frequencies.

This system is usually placed inside the speaker cabinet. It is called a crossover network and serves to provide the correct band of frequencies to each speaker. See Figure 1 below.

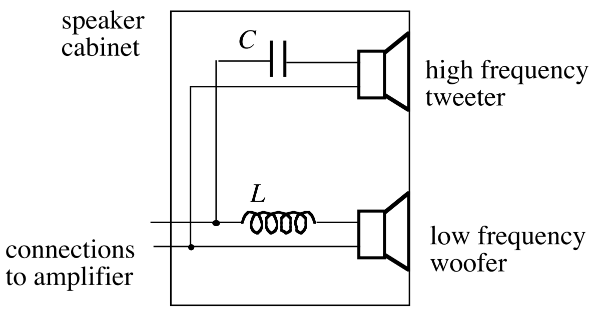


Figure 1

We will consider the simplest kind of crossover network, in the simplest configuration of one woofer and one tweeter. This kind of filter is called a first order filter or a 6 dB filter, since the unwanted power is diminished by a factor of 2 (which is -6 dB) for each octave (ratio of 2) in frequency.

Loudspeakers are generally complicated electromechanical devices, which use the force on a current in a magnetic field to move a diaphragm to produce sound. Over most of the audio range they will look electrically like a resistor (typically about 8 ohms). However, the electrical energy which disappears into the speaker (I^2*R) is not dissipated into heat as in an ordinary resistor, but is translated into sound energy radiated into the air.

The crossover network uses the properties of series RL and RC circuits to deliver the proper electrical signals to each speaker. We will model the speakers as a simple resistors, and explore how the power from the audio amplifier is divided between the speakers at different frequencies. See figure 2.

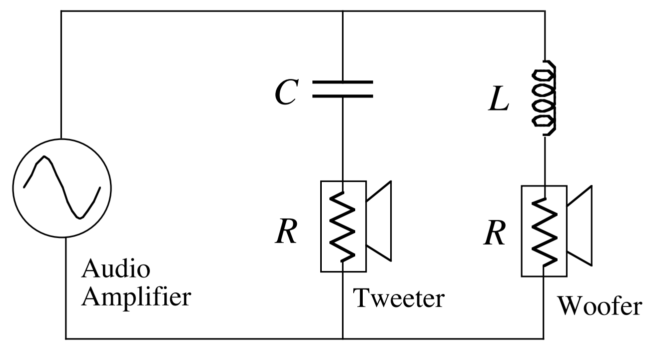


Figure 2

Procedure

Laboratory procedure

1. Build the circuit in the figure 3 below. Connect the oscilloscope to the circuit, with channel 1 across the function generator, and channel 2 across the resistor. The oscilloscope will show the signal trace (voltage versus time). Connect the SYNC out of the generator to the EXT TRIG input of the scope, and set the trigger mode to EXT (external).

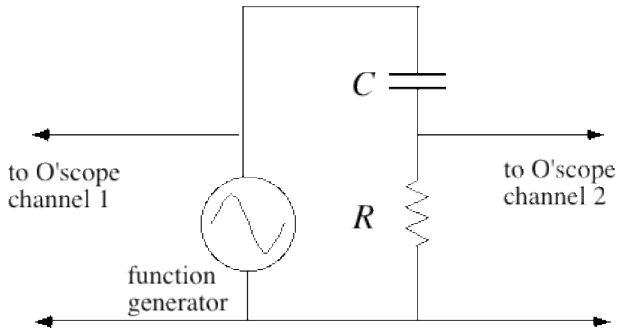


Figure 3-RC high pass circuit

2. Adust with the oscilloscope controls until you have both traces visible on the screen, with about two complete waves of each, and both traces as large as possible without extending off the screen. Adjust the signal generator for a peak-to-peak voltage of about 2 V. (This means the voltage amplitude V_{max} is about 1.0 V).

3. Vary the frequency of the source, and observe the general behavior of the signals. Does the generator voltage vary? Does the resistor voltage vary? Does the phase difference between them vary?

4. Find the approximate half-power (or cutoff) frequency.   This is the frequency (called f_c)for which the output voltage is 70.7 % of the input voltage.

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

where τ=RC or L/R.

Open the high pass spread sheet. Use the following path (i.e., open the following): **Student/Experiments/Highpass Low Pass/Highpass_spread_student.cwk.** Next, save the file using your name before you do anything else. Substitute your calculated (from step 4) cut off frequency into spreadsheet in place of 16kHz.

5. At each of your frequencies record the following values: frequency, input (i.e., signal generator) peak to peak voltage (V_{in}), output (i.e., resistor) peak-peak voltage (V_{out}), and the time delay (ΔT) between zero crossings.

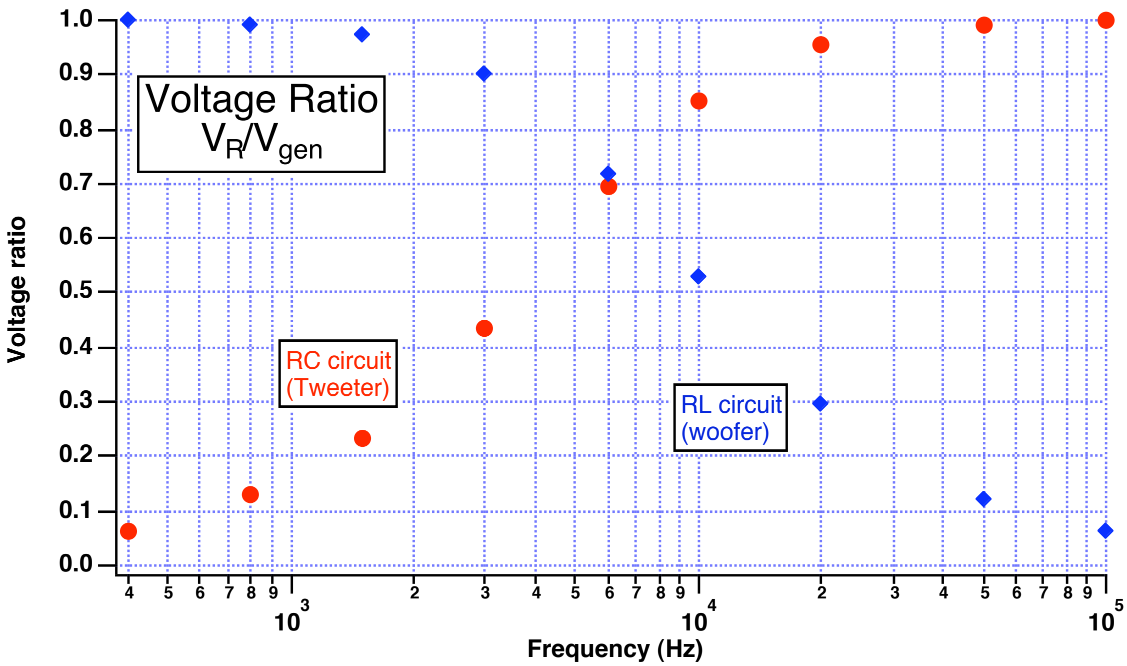
6. Repeat steps 1-5 for RL circuit. *Remember to recalculate fc in step and open low pass spreadsheet in step 4.*

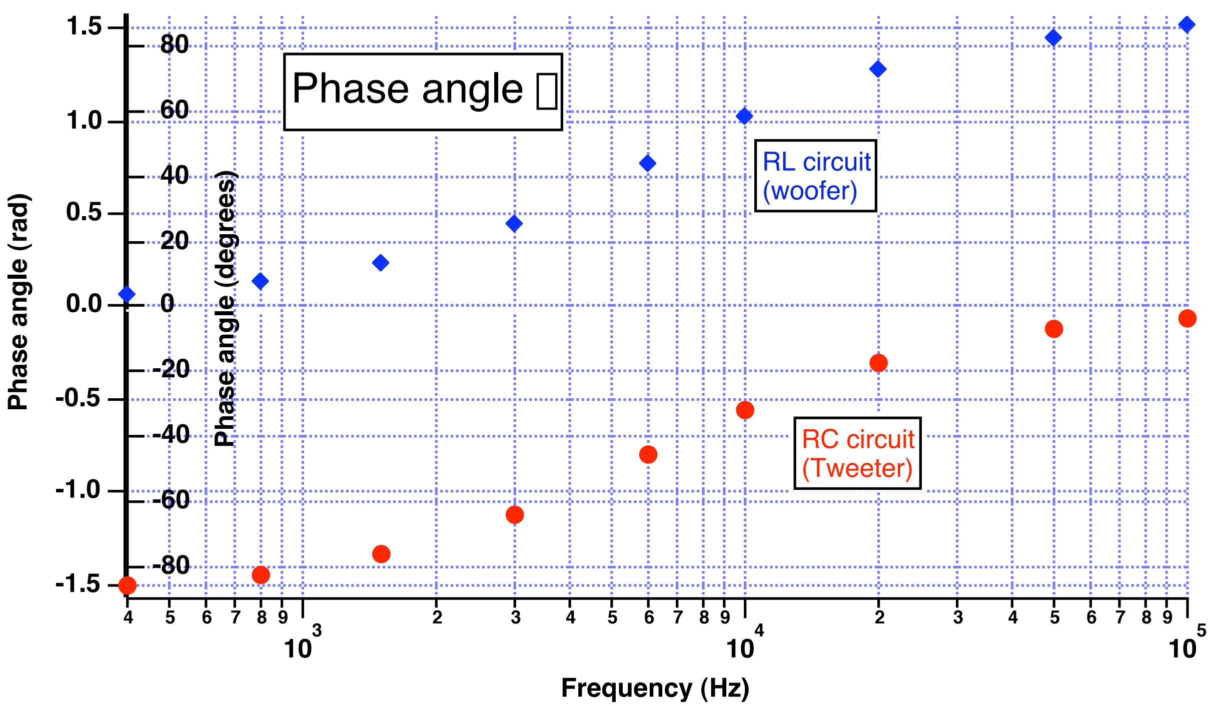
7. Your plots will look better if you use a logarithmic axis for the horizontal (frequency) axis.

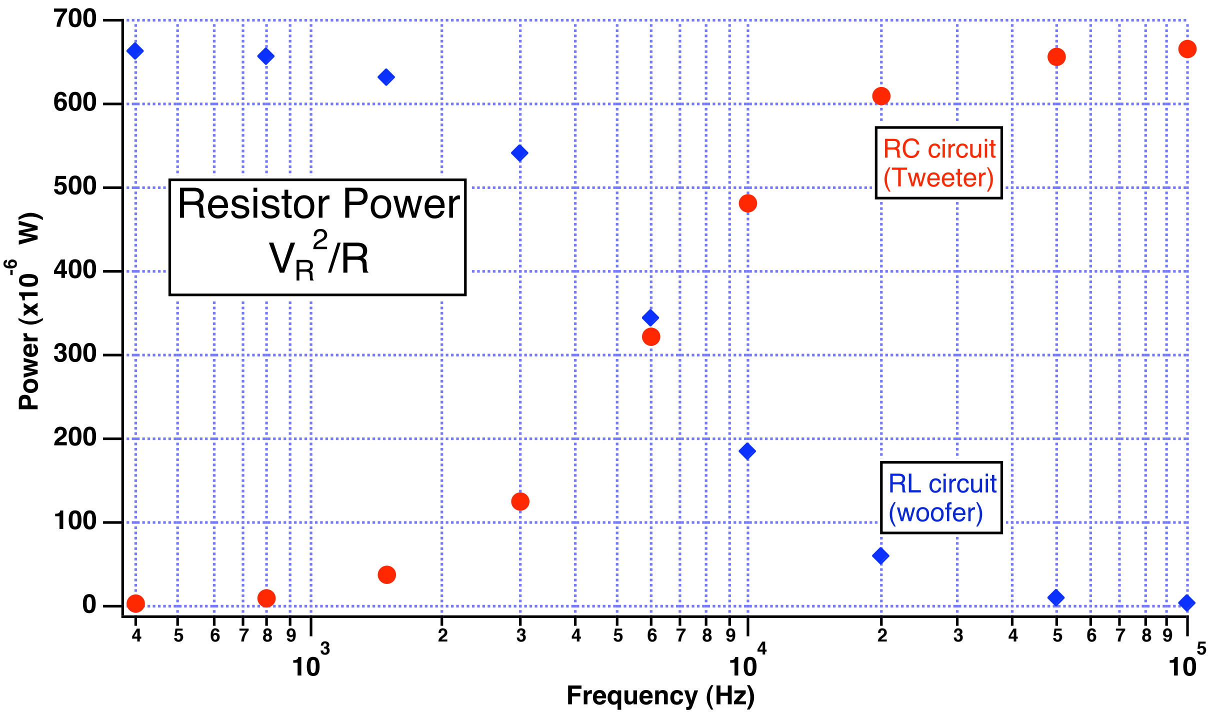
8. Make three graphs, with two plots on each for the RL and RC circuits. One plot is the voltage ratio V_{out}/V_{in}. The second plot is the phase difference. The third plot is resistor power, computed as

$$Power\ resistor = \frac{V_{rms}^2}{R}.$$

See plots below


Voltage Ratio
V_R/V_{gen}
Voltage ratio
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
RC circuit
(Tweeter)
RL circuit
(woofer)
4 5 6 7 8 9
10^3
2 3 4 5 6 7 8 9
10^4
2 3 4 5 6 7 8 9
10^5
Frequency (Hz)


Phase angle
Phase angle (rad)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Phase angle (degrees)
80
60
40
20
0
-20
-40
-60
-80
RL circuit
(woofer)
RC circuit
(Tweeter)
4 5 6 7 8 9
10^3
2 3 4 5 6 7 8 9
10^4
2 3 4 5 6 7 8 9
10^5
Frequency (Hz)



Questions

1. Given

decibel = db= $10\log\left(\frac{P_{out}}{P_{in}}\right)$ and power= $\frac{V^2}{R}$.

Show that

Gain (db) = $20\log\left(\frac{V_{out}}{V_{in}}\right)$.

2. Using the relationships above, show that a **voltage gain** $\left(\frac{V_{out}}{V_{in}}\right)$ of one half, expressed in db results in a reduction of –6 db and a **power gain** power $\left(\frac{P_{out}}{P_{in}}\right)$ of one half, expressed in db results in a reduction of –3db .

3. Given equation 33.4 from text,

$$Gain = \frac{V_o}{V_{in}} = \frac{R}{\sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}}.$$

Show that when the capacitive reactance is equal to R, gain is equal to $\frac{\sqrt{2}}{2}$