Oscilloscope and AC Circuits

INTRODUCTION

Now we are going to start using the function generator and the oscilloscope to measure the properties of AC circuits. We will study the transient response to step function inputs for first order RC (resistor-capacitor) and RL (resistor-inductor) circuits.

1. Introduction to Oscilloscopes

Construct the circuit shown in figure 1 using the following components:

R_1 = 10 kΩ
R_2 = 1 kΩ
v_{in} = 5 V DC

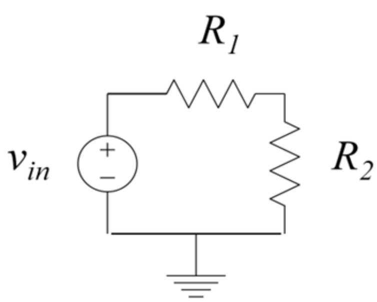
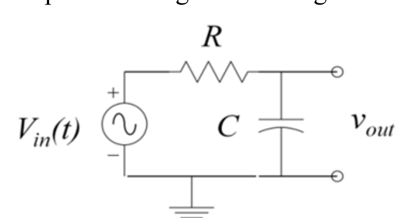


Figure 1. Voltage divider circuit.

The oscilloscope is a useful instrument for studying the behavior of an electronic circuit. We will be using a Tektronics oscilloscope. Set the scope up to get a single trace for channel 1. For a DC measurement, the sweep time is unimportant. Set the vertical scale to 0.5 volt per box. Ground channel 1 and adjust the vertical offset to center the trace on the display. Then set up the scope probes to measure the voltage drop across R_2. First read the value off the display by eye by judging the location of the trace with respect to the display scale; then use the measure button to determine the voltage on channel 1. Record both values.

The scope is really most useful for time varying signals. Replace the DC voltage source with the function generator. Set it to provide a sine wave with a 5 $_{\text{Vpp}}$ signal at 1 kHz. Now use the scope to measure the AC voltage drop across R_2. Set the sweep rate to 250 sec per box and the vertical scale to 0.2 V per box. To set the trigger on the scope, first click on the trigger menu button. Set *type = edge*, *source = ch1*, *slope = rising*. Adjust the trigger until the arrow is somewhere between ground and the peak of the signal. Sketch the waveform. Now read the amplitude off of the display by eye; next use the cursors and the measure button. Record both values.

Next change the waveform of the function generator to a square wave. Use the scope to investigate the rising and falling edges of the signal. Sketch the waveform providing details of the edges.



2. Series RC Circuit (also called Low Pass Filter)

Construct the circuit shown in figure 2 using the following components:
C = 0.1 µF (also 0.001 µF and 10 µF)
R = 2.7 kΩ
vin = 4Vpp 1 kHz square wave

Figure 2. Series RC circuit.

Use the function generator as the voltage source. Set it for a square wave with a frequency of 1 kHz and an amplitude of 2 V. Adjust the scope appropriately for this signal. Sketch the waveforms of v_{in} and v_C in your lab notebook. Note that you can set v_{in} on ch1 and v_C on ch2. From your sketch of the waveform, determine the time constant of the circuit. Compare this value to the theoretical value (= RC).

Now repeat this measurement procedure with two other capacitors with nominal values of 0.001 µF and 10 µF. Note that you will need to adjust the frequency of the function generator and the sweep rate of the scope to get the best image of the rise or fall of the output waveform.

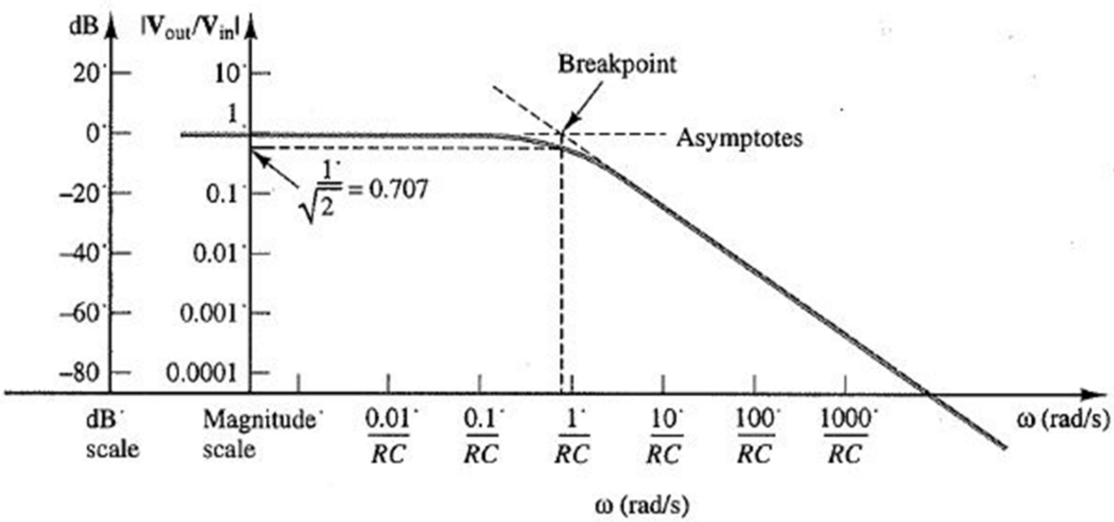
Start with the 0.1 µF capacitor in the circuit again. Continue to use the function generator as the AC source, but now use a 4V peak-to-peak sine wave as the vin source signal. Use both channels of the oscilloscope to monitor v_{in} and $v_{out} = v_C$ simultaneously showing their phase relationship as follows. Connect Ch. 1 to v_{in} and Ch. 2 to v_{out} . Set the oscilloscope to trigger on Ch. 1 only and adjust the trigger level until the trace starts at zero with positive slope. Ch. 1 will now display a sine wave. The phase difference of Ch. 2 will now be evident through the different starting value of its trace and the overall horizontal displacement of the Ch. 2 waveform relative to Ch. 1.
The input and output signals can be expressed as:
$v_{in}(t) = V_{inmax}\sin(t)$,
$v_{out}(t) = V_{outmax}\sin(t + \phi)$,

where V_{inmax} and V_{outmax} are the amplitudes of the input and output waveforms, respectively, ω is the angular frequency, and ϕ is the phase shift.

Note that both the amplitude and phase change with the frequency. The product RC has units of time and is called the time constant for this circuit. For angular frequencies ω<<(1/RC), the capacitor acts like an open circuit because it acts as though it has infinite impedance. Therefore, no ac current flows through the capacitor, or in the circuit at all, and $v_{out} = v_{in}$, and the phase shift is 0°.

For angular frequencies ω>>(1/RC), exactly the opposite case is true. The capacitor acts like a short circuit (i.e., like a wire), and there is no voltage across it. Therefore, the voltage drop v_{out} across the capacitor is zero

Make a table of values showing how the amplitude and the phase differ as you change the frequency over several decades (i.e., over several factors of 10) below and above the breakpoint frequency, ω_b(1/RC). Make a log-log plot of the amplitude versus frequency. This is called a Bode plot and should look like the graph below.



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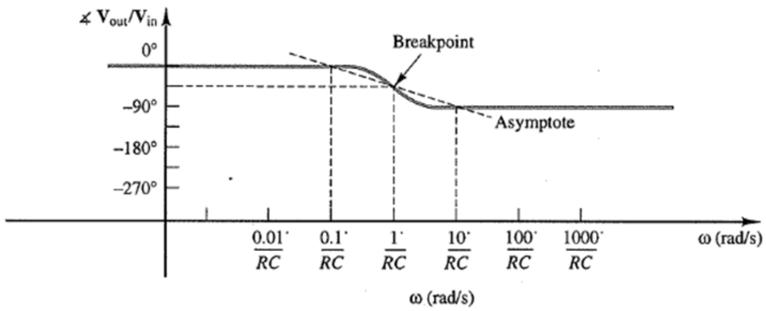
Note that phase shift also changes with frequency. For ω<<(1/RC), the phase shift is 0°, as already stated above. For ω> ~(10/RC), the phase shift of v_{out} is -90°. Thus, if you plot the phase shift as a function of frequency, here is what you should see:



If you have time, you can measure how the amplitude and phase shift as a function of frequency differ for the other sizes of capacitors, 0.001 μF and 10 μF).

3. Parallel RL Circuit

Construct the circuit shown in figure 3 using the following components:

L = 160 H
R = 1 kΩ
v_{in} = 4V_{pp} 30 kHz square wave

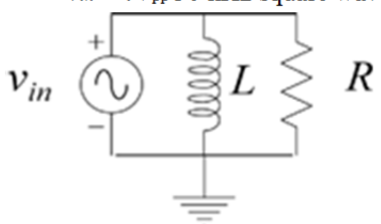


Figure 3. Parallel RL circuit.

Use the function generator as the voltage source. Set it for a square wave pulse with a frequency of 30 kHz and an amplitude of 2 V. Sketch the waveforms of v_L in your lab notebook. From your sketch of the waveform, determine the time constant of the circuit. Compare this value to the theoretical value (= L/R). Note that if the internal resistance of the function generator were 0Ω , then v_L would simply be a square wave; however, the function generator has a 50Ω internal resistance.

4. Diode circuit. Attach to the signal generator a 1kΩ resistor and a diode in series.
Put channel 1 of the oscilloscope across the signal generator, and channel 2 across the diode. Observe the signal. Then reverse the diode and observe the signal again. What is the difference? Do you know why it occurs?

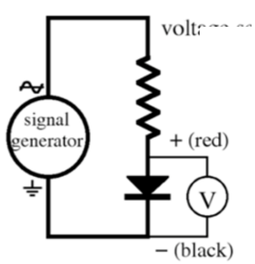


Figure 4. Resistor-Diode circuit.

5. LED circuit. In the circuit above, use a 330Ω resistor and replace the diode above by an LED (light emitting diode. What happens to the signal now? Does the diode light up? What happens if you reverse the LED?

2. RL High Pass Filter

Design an RL high-pass filter with f_0 = 100 kHz using a 140 μH inductor and a resistor. The 'design part of this exercise is to pick a resistance value. Remember that inductors are the least *ideal* of the basic circuit components. That means that inductors often have a significant internal resistance which needs to be considered when you are building your circuit. You should try to measure this resistance an consider how it will affect the circuit which you hav designed. Build the RL high pass filter circuit and take enough data to make Bode plots for gain and phase. For your report, include a description of how you designed the circuit and the two Bode plots (ea of which includes data points and a theoretical plot)

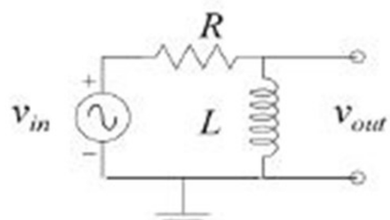


Figure 2: RL high pass filter circuit.

3. RLC Band Pass Filter

Construct the circuit shown in figure 3 using the following components:

- $C = 0.1$ μF
- $L = 140$ μH
- $R = 22$, 39, and 82 Ω
- $v_{in} = 2V_{pp}$

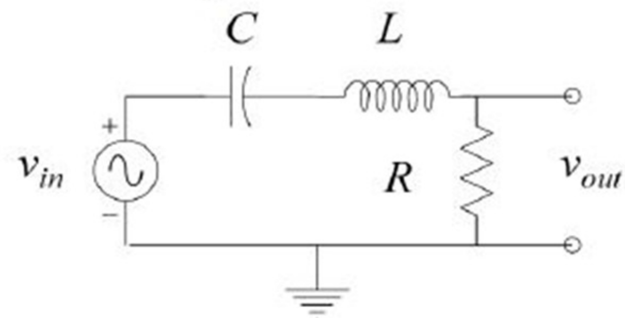


Figure 3: RLC bandpass circuit.

Determine the Q factor ($Q = (1/R)\sqrt{L/C}$) for all three values of the resistor (22, 39, and 82 Ω). To do this, you will need to take measurements on either side of the resonant peak (ω_0). Pick three frequencies on each side of ω_0 and measure the voltage gain $A_v(\omega)$. Your resonant peak will vary in sharpness. You probably want to pick these frequencies 'on the fly', i.e find the tow frequencies (ω_1 and ω_2) where the amplitude falls to root two of its maximum ($A_v(\omega) = 1/\sqrt{2}$). Then make measurements at two other values (one above and one below ω_1 or ω_2. Do this for each of the three resistors. Plot $20\log_{10}(A(\omega))$ vs. $\log_{10}(\omega/\omega_0)$ for each of the resistors. Plot ϕ vs. $\log_{10}(\omega/\omega_0)$ for each of the resistors. What is the bandwidth in each case?