Oscilloscope and AC Circuits

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~~

5Vpp
1kHz

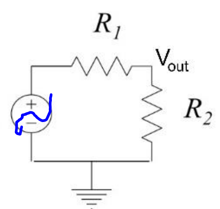


Figure 1. Voltage divider circuit.

$$V_{in} = I(R_1 + R_2)$$
$$V_{out} = IR_2$$
$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

The oscilloscope is a useful instrument for studying the behavior of an electronic circuit. We will be using a Tektronix 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.

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

Construct the circuit shown in figure 2 using the following components:
C = ~~0.01 μF =10nF~~ 100nF = 0.1 μF
R = ~~1.5kΩ~~ 10kΩ
V_{in} = 4Vpp (peak to peak),
7 kHz square wave

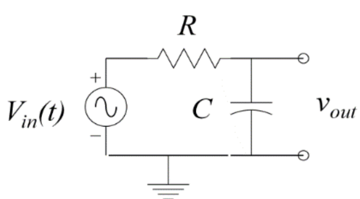


Figure 2. Series RC circuit. $\omega = 2\pi f,\ f = \frac{1}{T}$, where T=period.

$$V_{out} = \frac{Z_C}{R + Z_C} V_{in} = \frac{\frac{1}{i\omega C}}{R + \frac{1}{i\omega C}} V_{in} = \frac{1}{i\omega RC + 1} V_{in}$$

$$|V_{out}| = \frac{1}{\sqrt{1 + \omega^2 R^2 C^2}} |V_{in}|$$

For low frequencies, $\omega = 0$, and $|V_{out}| = |V_{in}|$.
For high frequencies, $\omega \to \infty$, and $|V_{out}| = 0$.
See next page for additional description and Bode plot of log amplitude vs. log frequency.
When $\omega = \frac{1}{RC}$, $|V_{out}| = \frac{1}{\sqrt{2}} |V_{in}| = 0.707 |V_{in}|$

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, which is $RC=1.5x10^3 x\ 10^{-8}\ sec= 1.5x\ 10^{-5}$ sec= 15 μsec..

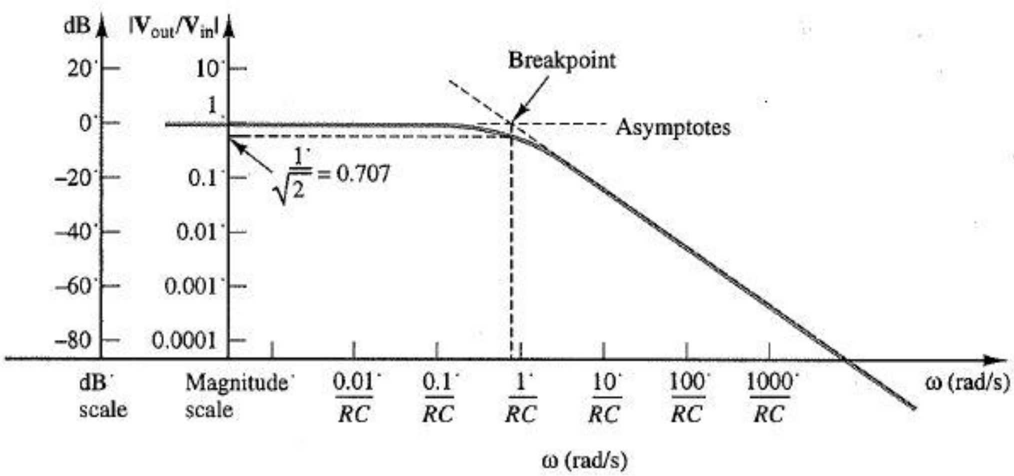
Now change the function generator to produce a 4V peak-to-peak sine wave as the vin source signal. Use both channels of the oscilloscope to monitor v_{in} and $v_{out} = v_C$ simultaneously showing their phase relationship as follows. Connect Ch. 1 to v_{in} and Ch. 2 to v_{out} . Set the oscilloscope 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.

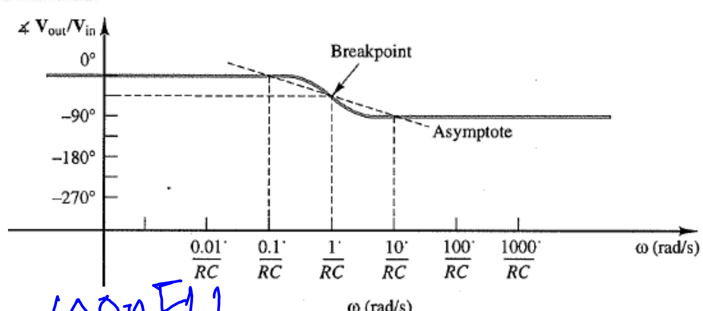
Note that both the amplitude and phase change with the frequency. The product RC has units of time and is called the time constant for this circuit. For angular frequencies ω<<(1/RC), the capacitor acts like an open circuit because it acts as though it has infinite impedance. Therefore, no ac current 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

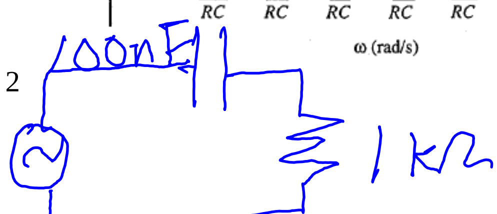
Turn the frequency knob and watch how the amplitude and phase of the output signal changes. A log-log plot of the amplitude versus frequency is called a Bode plot and should look like the graph below.



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:



High Pass Filter



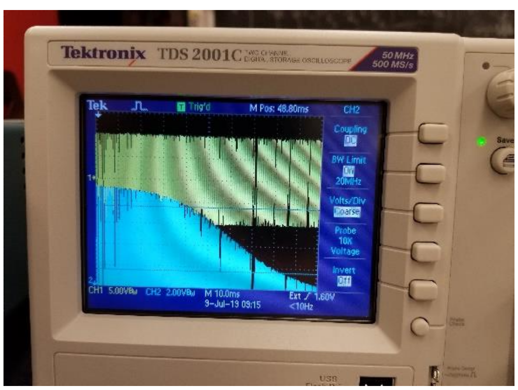
Now we will use a special method to show a real time view of amplitude vs. log frequency (almost a Bode plot!) directly on your oscilloscope. Use the Agilent 33210A Function/Arbitrary Waveform Generator as your ac voltage source. We are going to sweep the frequency (i.e., change it in a controlled way as a function of time).

Turn on a sine wave of 1 kHz and set the amplitude to 4V pp. Turn the function generator output on and plug it into Channel 1 of your oscilloscope using a tee. Also connect it to your RC (low pass) filter as the input voltage signal using a BNC cable that terminates in two alligator clips.

Now push the sweep button. Try linear sweep first. Set Start frequency to 1kHz and Stop frequency to 100kHz. Set sweep time to 100mS. Push Trigger Setup, and set for Internal and rising edge, and then push Done.

The oscilloscope should show varying frequencies. Put the sync signal from the function generator on Channel 2 of your oscilloscope and trigger on it. Adjust the time scale of your scope to 10mS per division; then 100mS fills the whole screen of 10 divisions horizontally. Now move the sync signal to the External trigger input of the oscilloscope, and use the trigger menu to select External Trigger. Move the trigger signal to the far left of the screen (instead of being in the middle, which is the default.)

Now put a scope probe on channel 2 and clip it onto the node between the R and C. Since the ground reference is set by the input signal from the function generator. The scope will measure V_C with respect to ground. Push the button for Log sweep, and the amplitude of V_C should vary with frequency like the Bode plot above. The frequency scale should now correspond to 1kHz at the left end, 10kHz in the middle, and 100kHz on the right. Move the vertical position so that zero is at the bottom of the screen. Now you have a plot that looks like a Bode plot, but with amplitude on a linear scale. You can now see directly why this is called a low pass filter. When the amplitude is 0.707 of the maximum, you can read off the frequency of the breakpoint, which is $f=1/(2\pi RC)=10.6$ kHz.



Now we can compare this with the output voltage measured across the resistor instead of the capacitor. Remember that the frequency generator sets the zero for the circuit, so reverse the red and black leads from its output so that the black lead is connected to the resistor instead of the capacitor. Leave the scope probe on the node between R and C. Your Bode-type plot should now look like the output from a high-pass filter.