Physics 4L Laboratory 3 (2026) - Time dependent signals

We continue our analysis of time-dependent signals.

3.1. Voltage divider - AC

We study the voltage divider circuit with periodic waves to learn some of the systematic issues that arise with time-dependent signals in the laboratory. Build the circuit in Figure 3.1.

Start with a sine wave at 1 kHz with an output of ± 5 V for $\mathbf{V_{in}}(t)$. Use an oscilloscope, with an oscilloscope probe, to measure the output. You can read the amplitudes on the screen. *Better yet, the cursors are very handy for this measurement.*

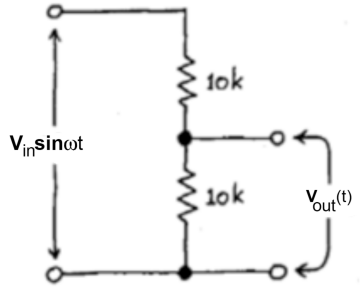


Figure 3.1: Voltage divider with a sinusoidal input. $\mathbf{V_{in}}(t)$ and $\mathbf{V_{out}}(t)$ denote waveforms.

Q1. What is the output at $V_{out}(t)$. Do you expect the amplitude of the output to be frequency dependent?

Test your ideas by measuring $\mathbf{V_{out}}(t)$ as a function of frequency. This is best done using two channels on the oscilloscope, one displaying $\mathbf{V_{out}}(t)$ and the other $\mathbf{V_{in}}(t)$.

Q2. What happens at high frequencies, *i.e.*, at or above 1 MHz; document with a SCREENSHOT?

Switch to a square wave; you may be limited to 1 MHz..

Q3. What happens to the waveform at the output, documented with a SCREENSHOT? Why?

Let's revisit the utility of the oscilloscope probe. This probe has high input resistance and low input capacitance. Measure $\mathbf{V_{out}}(t)$ at high frequencies with a sine wave input as above, but switch from an oscilloscope probe to a clip lead (*remember to adjust the input attenuation on the oscilloscope input*).

Q4. Does use of the probe make a difference? Include a SCREENSHOT Why?

We now pick up the first component with a time-varying I-V relation, the capacitor, and use RC circuits to explore the interpretations of different resistor/capacitor configurations.

3.2 A basic RC circuit

We begin with the time dependence of an RC circuit, configured as a low-pass filter (Figure 3.2):

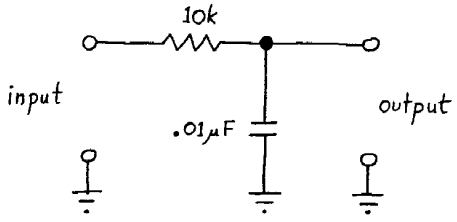


Figure 3.2: RC circuit as a low-pass filter.

Recall that, for a step input, theoretical calculations for ideal components predict that the voltage should rise as $V_{out} = V_{app}[1 - exp(-t/\tau)]$ at the onset of a long pulse and decay at the offset of a long pulse as $V_{out} = V_{app} \cdot exp(-t/\tau)$, where $\tau \equiv RC$ ($\cong 100\ \mu s$ in the above example).

Q5. Record the input wave and the output of the RC circuit as a SCREENSHOT from the oscilloscope. Measure the time constant τ by determining the time for the output to drop to $exp(-1)$= 0.37 of the initial amplitude.

Q6. Does the measured time constant equal the product RC?

Recall that **R**s and **C**s have tolerances, so measure the exact values for your components.

Q7. Measure the time to climb from 0 % to 63 %. Is it the same as the time to fall to 37 %? If not, identify what is amiss in your way of taking these readings!

3-3. Differentiator

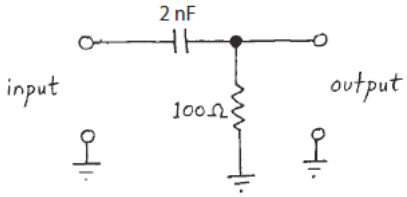


Figure 3.3: RC differentiator.

Construct the *RC differentiator* shown in Figure 3.3. Use the function generator to drive it with a square wave with an initial amplitude of 0.I V and a frequency of 100 kHz.

Q8. Does the output make sense? Show the results as a SCREENSHOT and explain what you see.

Now try a 100 kHz triangle wave.

Q8. Show a SCREENSHOT and explain what you see.

Lastly, try a sine wave.

Q10. Show a SCREENSHOT and explain what you see.

3.4. Integrator

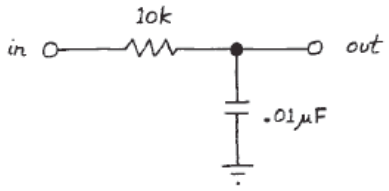


Figure 3.4: RC integrator.

Construct the *integrator* circuit shown in Figure 3.4. Drive it with a 100 kHz ramp, or triangular wave at the maximum output level of the function generator, about 10 V.

Q11. Take a SCREENSHOT. Describe what you observe.

Q12. Take a SCREENSHOT. What is the shape of the waveform? *Hint: it is not a sine wave.*

This circuit, of course, is only an *approximation* to an integrator. To see this, drop the input frequency. Step your way down to 1 kHz.

Q13. Take SCREENSHOTs as you are lowering the drive frequency and report what happens. Why does the circuit fail as an integrator at low frequencies?

3-5. Low-pass filter

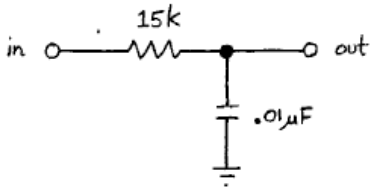


Figure 3.5: RC low-pass filter.

Construct the low-pass filter shown in Figure 3.5. This is nearly the same as the "integrator" in Figure 3.2, but we are going to look at its features in a different way.

The frequency for which the amplitude falls by a factor of $1/\sqrt{2}$, is denoted as the "the -3 dB point" where $f_{-3dB} = 1/(2\pi RC)$. One deciBell or dB is defined by dB ≡ 20 log (V_{out}/V_{in}). A drop in signal by 3 dB is equal to attenuation by a factor of $10^{-3/20} = 0.7079$, which is close to $1/\sqrt{2} = 0.7071$. Hence the colloquial notation.

Drive the circuit with a sine wave, sweeping over a large frequency range, to observe its low-pass property.

Q14. What is the f_-3dB frequency for the circuit in Figure 3.5? Show a SCREENSHOT that includes the input and output sinusoids.

Let's now quantify the filter. Measure the attenuation starting at $f = 0.1f_{-3dB}$ and extend to $f = 10f_{-3dB}$ in about 20 logarithmically-spaced steps (10 per decade)

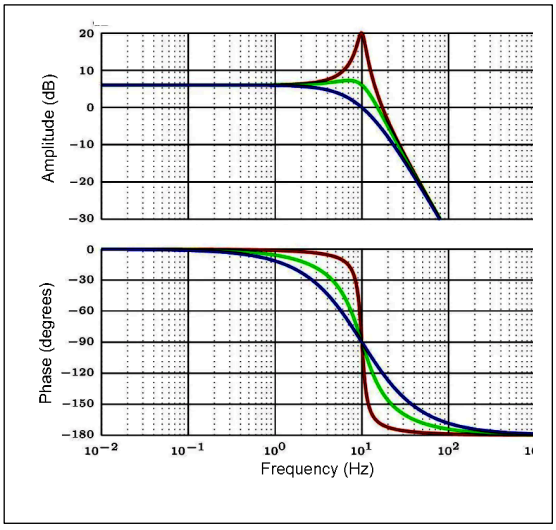
Q15. Plot the magnitude of these data on a log-log scale.

Plotting with a logarithmic axis scale means the plot's linearly spaced tick marks correspond to logarithmic steps in the axis variable. Plotting on a log-log scale means to plot both the x (frequency) and y (e.g., amplitude) axes on a logarithmic scale.

Q16 Why is a log-log plot useful?

Q17. Plot the phase shift on a log-linear plot. What is the limiting value of the phase, both at very low and at very high frequencies?

A log-linear scale means plot the x (frequency) axis on a logarithmic scale and the y (e.g., phase) axis on a linear scale.



The phase shift, denoted Δϕ, can be measured from the temporal shift in zero-crossing, denoted Δt, of the input and output signals relative to the period, denoted T = 1/f, for which $\Delta\phi = 360\ f\ \Delta t$ in degress or $\Delta\phi = 2\ \pi\ f\ \Delta t$ in radians.

A semi-automated way to measure both amplitude and phase-shift is to use a built- in function in the digital oscilloscope: Press "**Measure**", select "**Add measurement**", select "**Amplitude**" and set the two input channels, and select "**Phase**" and set the same two input channels. The combined amplitude and phase plots comprise a Bode plot.

3-6. High-pass filter

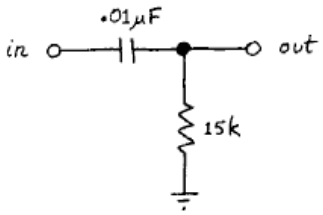


Figure 3.6: RC high-pass filter.

Construct a high-pass filter (Figure 3.6) with the components that you used for the low-pass filter but clearly in different positions.

Q18. Choose a sine input with a peak-to-peak voltage of 5Vand determine this circuit's -3 dB point.

Q19. Construct the bode plot. Check to see if the output amplitude at low frequencies, i.e., well below the -3 dB point, is proportional to frequency.

Q20. What is the limiting phase shift, both at very low frequencies and at very high frequencies? Include one or more SCREENSHOTS.

Q21. Why was the circuit in Figure 3.5 called a low-pass filter. Why was the circuit in Figure 3.6 called a high-pass filter?