Lab 2: AC Introduction & Voltage Dividers

Physics 327

Spring 2025

Goals

Learn about AC (alternating current) circuits, including AC voltage dividers and differentiators, and learn to use the oscilloscope and function generator.

Pre-Laboratory Exercises

To prepare for this laboratory:

1. Read about oscilloscopes in Chapter 17 of the textbook, and familiarize yourself (just briefly) with the manual for the Tektronix TDS2022B oscilloscope and Agilent 33210A function generator, available on Canvas.
2. Construct the voltage divider described in Part B in a SPICE simulation program, such as `LTspice`. Perform step (1) & (2) of part B.1 and record your results.

A Laboratory Equipment

In this laboratory, you will use two new pieces of equipment that deal with time-varying signals: a **function generator** that can produce a variety of time-dependent signals, and an **oscilloscope** that captures and displays such signals. In the appropriate (AC) mode, the **multimeter** can also measure the RMS voltage or current of a signal. To begin, practice with the laboratory equipment:

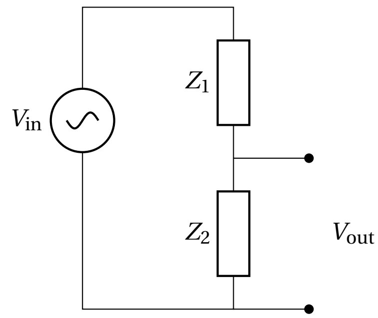
1. Set the function generator (FG) to produce a sine wave with a frequency of about 1 kHz and amplitude of about 1 V.
2. On the oscilloscope, in the menu for Channel 2, select DC coupling. In the trigger menu, choose Channel 2 as the trigger source, and enable Edge Type Triggers. Set the scope time base to about 1 ms.
3. Hook the FG output to the oscilloscope Channel 2 using a coaxial (BNC) cable.[1]
4. Adjust the trigger level on the scope to find the signal. Change the various controls on the FG (frequency, amplitude, and signal shape) to see how the signal changes.

In your lab report, include a description or photos of the frequency and amplitude settings on the FG and the corresponding measurements on the oscilloscope.

[1] This cable, type RG-58, itself has a characteristic impedance of 50 Ω, which depends on the materials and geometry, not length. Like a mechanical wave on a rope, if a signal traveling down this cable "sees" a high impedance (rope end fixed) or low impedance (rope end free), there will be a reflection. Adding an impedance-matched 50 Ω *termination* resistor at the end of the line avoids the reflection, at the cost of half the signal amplitude since it acts as a resistive voltage divider. This is essential for high-speed signaling, but can typically be neglected for our labs.

B AC Voltage Divider

An AC voltage divider is shown below:



This circuit is described by the equation:

$$V_{out} = V_{in}\frac{Z_2}{Z_1 + Z_2}. \tag{1}$$

with component *impedances* indicated by Z. Let Z_1 be a capacitor and Z_2 be a resistor, such that $Z_1 = -\frac{j}{\omega C}$ and $Z_2 = R$, where the imaginary number $j = \sqrt{-1}$. The impedance Z_1 depends on frequency f, since angular frequency $\omega = 2\pi f$, in units of radians per second, or Hz. Thus, the amplitude and relative phase of the output voltage V_{out} will also depend on frequency.

Part 1 Voltage Divider

Set up this circuit with $R = 20$ kΩ and $C = 1000$ pF, and V_{in} provided by the FG output. Connect V_{out} (the circuit's output) to oscilloscope Channel 1 and V_{in} (the signal from the FG) to Channel 2. Make sure the attenuation is set to 1× for both input channels.

Now, using a sinusoidal input voltage from the FG with an amplitude of 1 V, measure the dependence of the **magnitude** and **phase shift** of V_{out} relative to V_{in} and compare to calculations.[2] Note that logarithms here are $\log_{10}$. Include in the lab report all schematics, measurements, and plots, as well as pictures/screenshots of the oscilloscope waveforms.

1. Measure data points at 100 Hz, 300 Hz, 1 kHz, 3 kHz, ..., 1 MHz to get roughly equal spacing in $\log f$.
2. Graph $20\log(V_{out}/V_{in})$ vs. $\log(f)$ (i.e. the Bode plot), and the phase difference (in linear scale) vs. $\log(f)$.
3. Calculate how the theoretically expected ratio V_{out}/V_{in} and phase difference should look as functions of frequency.
4. Compare the theory to data by making graphs of V_{out}/V_{in} and phase difference that show the data and the theory together.

Question 1: How do your measurements compare to the simulation you performed as a pre-laboratory exercise? How do the simulation and measurements compare to theory? Comment on any differences.

Part 2 Time Constants

Next, apply a step function input to the circuit, and investigate the time dependence of the response to determine the exponential *time constant*, $\tau = RC$. Use the function generator to produce a *square wave* signal with 1 kHz frequency.

1. Estimate the time constant of the exponential decay in V_{out} by measuring $v(t)$, the voltage as a function of time, on the scope.

[2] Tip: To measure waveform amplitudes on the oscilloscope automatically, use the MEASURE menu. To measure time offsets between waveforms, try the CURSOR function.

2. Put your V_{out} measurements into an Origin plot and add the expected decay curve derived from the values of R and C.

Question 2: What is the expected time constant τ for this circuit? How does your measured value compare to the calculated value? Comment on any differences.

Part 3 Differentiator

Finally, this circuit can act as a *differentiator*, in which the output is proportional to the derivative (or slope) of the input. Use the function generator to generate a *triangular* waveform. Again, set up the oscilloscope to show both output and input voltages as a function of time. Observe the waveforms using these three frequencies: 100 Hz, 1 kHz and 100 kHz.

Question 3: What is your expectation for the shape of the differentiated output waveforms? Describe the frequency dependence, and compare to theory.