EE 220/220L Circuits I (Fall 2019)
Laboratory 8 Use of the Function Generator and Oscilloscope

Background

In prior labs, we have used DC power supplies for our independent current and voltage sources. In this lab, we will begin to study time-varying signals, and learn how to calculate and measure the effective (AKA: RMS) value of periodic signals (a preview of section 11.4 in our text).

A **function generator** is an instrument that can generate various periodic voltage waveforms (e.g., sinusoidal, square-wave, etc.). If these voltages are measured with a digital multimeter (DMM) on the AC voltage setting, it will display a voltage that represents a root-mean-squared (RMS) or effective value of the voltage waveform (see Chap. 11). However, it gives no information on the shape of the waveform. To view the voltage waveform as a function of time, an instrument called an **oscilloscope** is used. The goal of this lab is to introduce these two instruments to the students.

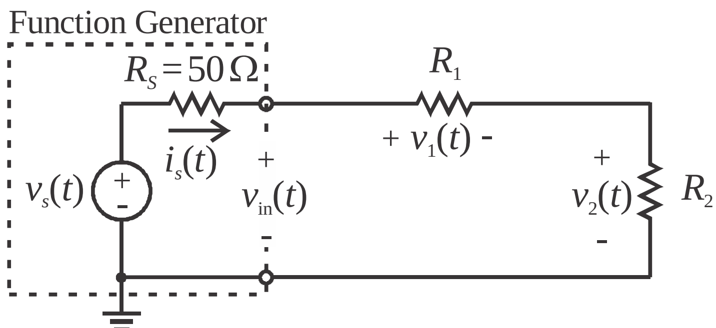

Figure 1 Test Circuit

Preliminary

1) For the test circuit shown in Figure 1, calculate how the source voltage $v_s(t)$ should divide, i.e., calculate $v_{in}(t)$, $v_1(t)$, and $v_2(t)$ in terms of $v_S(t)$, given $R_1 = 3.3\text{ k}\Omega$ and $R_2 = 6.8\text{ k}\Omega$. **Note:** Ohm's Law, Kirchhoff's Current Law (KCL), and Voltage Law (KVL) apply to time-varying signals. Therefore, the voltage division rule still applies.
2) Have the lab instructor or TA sign-off on your preliminary before you begin the experiment.

Experiment

The instructor will demonstrate function generators and oscilloscopes at beginning of each section, be prepared to take notes. A guide/tutorial is available at the course web page. **Bring a USB flash drive** (use default FAT32 file format). **Do NOT rename variables** for experimental work.

1) Set function generator to output source voltage $v_s(t) = V_{dc} + V_m \cos(\omega t)$, where $V_{dc} = 1.8\text{ V}$, $V_m = 2\text{ V}$ ($4\ V_{pp}$) & $\omega = 2\pi f = 1670\pi$ rad/s ($f = 835$ Hz), by connecting directly to the oscilloscope set to **DC coupling**. Use smallest time/horizontal scale that will display two periods of $v_s(t)$. Set vertical scale so $v_s(t)$ is as large as possible while staying on screen (leave ch. 1 reference level centered). Display and record peak-to-peak $V_{s,\text{pp,oscDC}}$, average $V_{s,\text{DC,oscDC}}$, and RMS $V_{s,\text{RMS,oscDC}}$ voltages (see menu for **Measure** button) as well as frequency f (see menu for **Utility** button). Save **bitmap** (*.bmp file) screen shot of $v_s(t)$ to USB flash drive. Repeat with oscilloscope set to **AC coupling**, recording $V_{s,\text{pp,oscAC}}$, $V_{s,\text{DC,oscAC}}$, and $V_{s,\text{RMS,oscAC}}$. Insert labeled print-outs in logbook.

   Why direct connection? The function generator has an internal 50 Ω resistance. If the circuit is connected, the oscilloscope does not measure the ideal source voltage $v_s(t)$, but instead the input voltage $v_{in}(t) = v_s(t) - i_s(t)(50)$. If the function generator is connected directly to the oscilloscope (huge input resistance), there is virtually no current flow, i.e., $i_s(t) \approx 0$, and $v_{in}(t) \simeq v_s(t)$.

2) Using the DMM, measure and record the values of resistors R_1 and R_2 as well as the DC $V_{s,\mathrm{DC,DMM}}$ and AC $V_{s,\mathrm{RMS,DMM}}$ source voltages.

3) Connect circuit shown in Figure 1. Using the DMM on the **AC voltmeter** setting, measure and record $V_{\mathrm{in,RMS,DMM}}$, $V_{1,\mathrm{RMS,DMM}}$, and $V_{2,\mathrm{RMS,DMM}}$. Using the DMM on the **DC voltmeter** setting, measure and record $V_{\mathrm{in,DC,DMM}}$, $V_{1,\mathrm{DC,DMM}}$, and $V_{2,\mathrm{DC,DMM}}$.

4) Next, display $v_{\mathrm{in}}(t)$ [CH 1], $v_1(t)$, & $v_2(t)$ [CH 2] on oscilloscope with both channels set to **DC coupling**. Use same scale and reference levels for all waveforms. Save **bitmap** screen shot of waveforms to a USB flash drive. Insert *labeled* print-out of the waveforms (i.e., identify overall plot and label each waveform) in your logbook. Repeat using **AC coupling**.

   Hints: The oscilloscope always measures voltage with respect to ground. To display voltage $v_1(t)$, calculate $v_{\mathrm{in}}(t)$ - $v_2(t)$ using the **Math Menu** (i.e., CH 1 - CH 2).

5) Using oscilloscope (**DC coupling**), display and record the peak-to-peak, average (i.e., DC), and RMS voltages for $v_{\mathrm{in}}(t)$ & $v_2(t)$, i.e., $V_{\mathrm{in,pp,oscDC}}$, $V_{2,\mathrm{pp,oscDC}}$, $V_{\mathrm{in,DC,oscDC}}$, $V_{2,\mathrm{DC,oscDC}}$, $V_{\mathrm{in,RMS,oscDC}}$, & $V_{2,\mathrm{RMS,oscDC}}$. Then, calculate $V_{1,\mathrm{pp,oscDC}} = V_{\mathrm{in,pp,oscDC}} - V_{2,\mathrm{pp,oscDC}}$, $V_{1,\mathrm{DC,oscDC}} = V_{\mathrm{in,DC,oscDC}} - V_{2,\mathrm{DC,oscDC}}$ and $V_{1,\mathrm{RMS,oscDC}} = V_{\mathrm{in,RMS,oscDC}} - V_{2,\mathrm{RMS,oscDC}}$.

6) Using oscilloscope (**AC coupling**), display and record the peak-to-peak, average (i.e., DC), and RMS voltages for $v_{\mathrm{in}}(t)$ & $v_2(t)$, i.e., $V_{\mathrm{in,pp,oscAC}}$, $V_{2,\mathrm{pp,oscAC}}$, $V_{\mathrm{in,DC,oscAC}}$, $V_{2,\mathrm{DC,oscAC}}$, $V_{\mathrm{in,RMS,oscAC}}$, & $V_{2,\mathrm{RMS,oscAC}}$. Then, calculate $V_{1,\mathrm{pp,oscAC}} = V_{\mathrm{in,pp,oscAC}} - V_{2,\mathrm{pp,oscAC}}$, $V_{1,\mathrm{DC,oscAC}} = V_{\mathrm{in,DC,oscAC}} - V_{2,\mathrm{DC,oscAC}}$ and $V_{1,\mathrm{RMS,oscAC}} = V_{\mathrm{in,RMS,oscAC}} - V_{2,\mathrm{RMS,oscAC}}$. Which of these measurements are the same and which are different from those taken using DC coupling?

7) Have the lab instructor or TA sign-off on your measurements before you disassemble the circuit.

Analysis and Conclusions

- Using the measured values of R_1 and R_2 and the voltage relationships calculated in preliminary, compute the ratios $v_{\mathrm{in}}(t)/v_S(t)$, $v_1(t)/v_S(t)$, and $v_2(t)/v_S(t)$. Then, using these ratios and the actual equation for $v_s(t)$, write out equations for $v_{\mathrm{in}}(t)$, $v_1(t)$ and $v_2(t)$.
- Next, compute expected RMS voltages $V_{s,\mathrm{RMS,comp}}$, $V_{\mathrm{in,RMS,comp}}$, $V_{1,\mathrm{RMS,comp}}$, & $V_{2,\mathrm{RMS,comp}}$ for $v_s(t)$, $v_{\mathrm{in}}(t)$, $v_1(t)$, & $v_2(t)$ (see hints). Also, compute expected RMS voltages $V_{s,\mathrm{RMS,compAC}}$, $V_{\mathrm{in,RMS,compAC}}$, $V_{1,\mathrm{RMS,compAC}}$, & $V_{2,\mathrm{RMS,compAC}}$ for only the AC parts of $v_s(t)$, $v_{\mathrm{in}}(t)$, $v_1(t)$, & $v_2(t)$ (see hints).
- Using DMM measurements, compute the ratios $V_{\mathrm{in,RMS,DMM}}/V_{s,\mathrm{RMS,DMM}}$, $V_{1,\mathrm{RMS,DMM}}/V_{s,\mathrm{RMS,DMM}}$, $V_{2,\mathrm{RMS,DMM}}/V_{s,\mathrm{RMS,DMM}}$, $V_{\mathrm{in,DC,DMM}}/V_{s,\mathrm{DC,DMM}}$, $V_{1,\mathrm{DC,DMM}}/V_{s,\mathrm{DC,DMM}}$ and $V_{2,\mathrm{DC,DMM}}/V_{s,\mathrm{DC,DMM}}$.
- Using oscilloscope measurements (DC coupling), compute the ratios $V_{\mathrm{in,RMS,oscDC}}/V_{s,\mathrm{RMS,oscDC}}$, $V_{1,\mathrm{RMS,oscDC}}/V_{s,\mathrm{RMS,oscDC}}$, $V_{2,\mathrm{RMS,oscDC}}/V_{s,\mathrm{RMS,oscDC}}$, $V_{\mathrm{in,DC,oscDC}}/V_{s,\mathrm{DC,oscDC}}$, $V_{1,\mathrm{DC,oscDC}}/V_{s,\mathrm{DC,oscDC}}$, and $V_{2,\mathrm{DC,oscDC}}/V_{s,\mathrm{DC,oscDC}}$.
- Using oscilloscope measurements (AC coupling), compute the ratios $V_{\mathrm{in,RMS,oscAC}}/V_{s,\mathrm{RMS,oscAC}}$, $V_{1,\mathrm{RMS,oscAC}}/V_{s,\mathrm{RMS,oscAC}}$, and $V_{2,\mathrm{RMS,oscAC}}/V_{s,\mathrm{RMS,oscAC}}$.
- Fill-in the following RMS voltages, DC voltages and voltage ratios tables.
- Discuss/explain differences between computed/predicted and measured values and ratios. How do the DC and RMS readings from the DMM and oscilloscope compare? If significantly different, explain. Does voltage division work for both AC and DC components? Summarize and comment on any other observations.

Hints: In general, RMS voltage: $V_{\text{RMS}} \equiv \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} [v(t)]^2\, dt}$ where $v(t)$ is a DC or periodic time-varying voltage of period T. The RMS voltages for a few voltage waveforms are:

- DC waveform: $v(t) = V_{dc} \;\Rightarrow\; V_{\text{RMS}} = |V_{dc}|$
- Sinusoidal waveform: $v(t) = V_m \cos(\omega t + \theta) \;\Rightarrow\; V_{\text{RMS}} = V_m / \sqrt{2}$
- Sinusoidal waveform w/ DC offset: $v(t) = V_{dc} + V_m \cos(\omega t + \theta) \;\Rightarrow\; V_{\text{RMS}} = \sqrt{V_{dc}^2 + V_m^2 / 2}$

Table 1 RMS Voltages

voltage	computed (V)	computed- AC only (V)	DMM (V)	osc.- DC coupling (V)	osc.- AC coupling (V)
$v_S(t)$					
$v_{\text{in}}(t)$					
$v_1(t)$					
$v_2(t)$					

Table 2 DC Voltages

voltage	computed (V)	DMM (V)	osc.- DC coupling (V)	osc.- AC coupling (V)
$v_S(t)$				
$v_{\text{in}}(t)$				
$v_1(t)$				
$v_2(t)$				

Table 3 Voltage Ratios

ratio	computed	DMM- DC	DMM- AC	osc.- DC (DC coupling)	osc.- RMS (DC coupling)	osc.- RMS (AC coupling)
v_{in} / v_S						
v_1 / v_S						
v_2 / v_S						