Objectives
1.) Compare peak and RMS voltages of AC power.
2.) Learn about the characteristics of AC voltmeters.

Note: Select a bench site where the Krohn-Hite function generator includes a DC offset feature (look at the right-most button).

Experiment
In this experiment you will take all your measurements with the Weston, the APPA, and the oscilloscope and compare the different values that they give you. You may as well connect the meters and the scope together now. This might be easier if you unplug their own leads and use leads from the wire kit.

For a few measurements you will also take a reading with a Fluke 8050A Digital multimeter. Unlike most meters, this meter reads true RMS values. Unfortunately we only have two of these, so your TA will check them out and let you use them as you need them.

Most meters do not read the true RMS value of an AC waveform, although they still show an RMS value. They estimate the RMS ($V_{RMS}$) value based on the rectified average ($V_{RA}$) or peak ($V_p$) value of a waveform. These estimates are calibrated to work out exactly for a sinusoidal waveform but are not quite right for other waveforms. The reason they estimate the RMS is that the rectified average and peak values are much easier to measure than true RMS.

Create a large table in your notebook for all the voltmeter readings. Start with a column labeled source, then make an extra-wide column for the scope so that you can show your peak-to-peak ($V_{pp}$) measurements as well as the RMS values calculated from $V_{pp}$. Include columns for the Weston, the APPA, and the Fluke 8050A, although you will only use this last meter a few times.

AC Power RMS
First, let’s confirm that all these meters are actually calibrated to read the RMS of a sinusoidal waveform. You will find a panel in your bench with a large black switch, some graphics that look a little like my figure, some red terminals, and some fuses. This is the bench-mounted 14 v power transformer. You will use it in several labs to come. Today you’ll simply measure the secondary voltage as shown. Write “Power Transformer” in the first column of your table and then
record the readings of your meters in their respective columns. They probably show about 14 V. (Assuming the switch is on and the fuse is OK—replace fuse if necessary.) Let’s see if these readings correspond to the RMS value of the AC voltage.

Hook the scope to the same terminals and find the peak-to-peak voltage from the scope. The amplitude, or peak value of the sinusoidal waveform is half of the peak-to-peak. Calculate the RMS value from $V_p$. Is it about 14 V? (Note: it might be a little low because this transformer distorts the sinusoid somewhat, but it should be close.) Did the meters show the RMS value?

**Meter Responses**

**Sinusoid:** Turn off the power transformer and connect the scope to the output of the Knone-Hite function generator. Push the sine wave button and set the frequency to about 60 Hz. Adjust the AMPLITUDE knob so the output is 8 $V_{pp}$ on the scope ($V_p = 4$ V). This should be 2.83 V RMS. Take measurements or make calculations to fill in the next row of your table. Do the meters show RMS for sinusoids?

The meters could be measuring true RMS or they could be measuring the peak voltage ($V_p$) and multiplying by 0.707 or they could be measuring rectified average ($V_{RA}$) and multiplying by 1.111. All of these methods will produce the same reading for a sine wave, as shown below.

\[
V_{RMS} = \frac{V_p}{\sqrt{2}} = 0.707 V_p \\
V_{RA} = \frac{2}{\pi} V_p = 0.6366 V_p \\
V_{RMS} = 1.111 V_{RA}
\]

**Triangle:** Let’s try the same measurements with a triangular waveform. Observe the scope and adjust the function generator to produce an 8 $V_{pp}$ triangle wave (see figure snippet below). Do the meters show the RMS of a triangle wave correctly? ($V_{RMS}$ is shown below.) Are they a little high, or a little low?

\[
V_{RMS} = \frac{V_p}{\sqrt{3}} \\
V_{RA} = \frac{V_p}{2}
\]

Most meters do not measure the true RMS of an AC voltage. Some actually measure the peak voltage $V_p$ and multiply it by 0.707 to display a $V_{RMS}$. This works fine for a sine wave, but not for any other waveform. In this case, if a meter measured the $V_p$ of your triangular waveform and multiplied it by 0.707, what would it display? Does this correspond to what you see on the meters?

The majority of inexpensive meters actually measure the rectified average ($V_{RA}$) of the waveform. The rectified average is the average of the absolute value of the voltage (take
all the negative parts and make them positive). They measure this $V_{RA}$ and multiply it by 1.111 to display a $V_{RMS}$. Again, this works fine for a sine wave, but not for any other waveform. In this case, if a meter measured the $V_{RA}$ of your triangular waveform and multiplied it by 1.111, what would it display? Does this correspond to what you see on the meters?

Get the Fluke 8050A meter from your TA and confirm that it reads the true RMS of this triangular wave.

**Square:** Observe the scope and adjust the function generator to produce an 8 V$_{pp}$ square wave. Use the Fluke 8050A meter from your TA and confirm that it reads the true RMS of this square wave. Give this meter back now, as you won’t need it again for a few minutes.

$$V_{RMS} = V_p = V_{RA}$$

Do the other meters read correctly now? Are they a little high, or a little low? If a meter measured the $V_p$ of your square waveform and multiplied it by 0.7071, what would it display? Does this correspond to what you see on the meters? If a meter measured the $V_{RA}$ of your square waveform and multiplied it by 1.111, what would it display? Does this correspond to what you see on the meters?

What do these meters actually measure, $V_{RMS}$, $V_p$, or $V_{RA}$?

**DC Offset Effects**

Now let’s see what the meters do if we add some DC into the mix. (If your Krone-Hite doesn’t have a DC offset button and knob, use the WaveTek—you may need help from your TA.) Observe the scope and adjust the function generator to produce an 8 V$_{pp}$ sine wave with a 4 V$_{DC}$ offset. (The scope input switch must be set to DC.) Now you have a sine wave that swings between 0 V and 8 V. Make sure that the waveform is not clipped on the top (turn the DC offset up too high to see what I mean). If it is clipped, turn down the DC offset as much as you need to cure the problem.

$$V_{RMS} = \sqrt{V_{RMS(AC)}^2 + V_{DC}^2}$$

Do any of the meters read correctly now? Do any of them even respond to the added DC? Get the 8050A and try it. Oddly enough, not even that meter reads this correctly. Actually, most meters filter out the DC before measuring the AC. Do all these meters do that?
Frequency response
The final meter characteristic we will look at in this lab has nothing to do with RMS. I want you to find the frequency response of each meter. So far we have only measured waveforms at about 60 Hz. All AC meters should measure sine waves correctly at t 60 Hz because that's the power frequency. Most will also work well up to 400 Hz because 400 Hz is common in aircraft. Meters vary greatly in how well they work above 400 Hz, some work well but most do not.

Remove the DC offset from your sine wave and turn up the frequency until the 8050A starts to read a little off (say 5% high or 5% low). Write down the frequency as the upper limit of that meter. Now give that meter back, you're done with it.

Turn the frequency back down and repeat this for each of the other meters. Also look for weird effects (especially the APPA 95) and note them. I think you may be surprised to see which meter does the best here.

Conclude
As always, check off and write a conclusion. In particular, draw some conclusions about how the meters work and their frequency response characteristics.