Name/NetID:	Teammate:

Module: Measurements of Time-Varying signals

To get more experience with your bench equipment while playing with the signal generator, digital multimeter (DMM), and the oscilloscope let's experiment a little more about the measurements often made to characterize time-varying signals. The bench equipment is optimized to perform measurements on periodic signals. The oscilloscope provides a visual representation of periodic signals providing quantitative information about amplitude, period… But the DMM is also capable of measuring parameters associated with time-varying signals. This module is meant to show the relationship between what you see on the oscilloscope and what you measure with the DMM.

Bur first let's understand what is meant by a "time-varying signal" so that you can understand what you are trying to measure as well as tease out the meaning associated with the nomenclature.

In a sense all voltages generated in Nature or by humans are time-varying. Even sources that are considered constant like a smoke-detector running continuously once a battery is inserted, or the power supply that is part of your bench equipment will continuously provide a constant voltage to be used during the experiment. But the batteries run-down and you always turn off the power on your bench I am sure.

Engineers divide signals into two basic categories with the designations DC or direct current, and AC or alternating current. These are historical designations dating back at least to the time of the great debate between Thomas Edison advocating wiring homes with a constant voltage and current, and Westinghouse and Tesla advocating wiring homes with a sinusoidally varying (or alternating) voltage and current.

A more useful way to think about the distinction is to recognize that some systems like circuits using a battery or power supply that the circuit has reached a steady-state – these are considered DC circuits. All the really fast time-variations have settled down to a steady-state. How even the simplest of circuits involving only a power supply and resistors come to a steady-state is very complicated. The power supply once connect to the circuitry launches a wave that sets up charge distributions so the circuitry ends up in a state where simple relations, like Ohm's Law, are valid. Luckily for most applications this takes on the order of pico-seconds for the transient, or initial time variations to become undetectable.

All other signals for which the time variations are detectable over time scales that we can measure are considered time-varying. There are two broad classes of time-varying signals. Signals with obvious periodicity are the ones for which the designation AC or alternating current was coined. Periodic signals appear in many applications like delivering power generation and

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distribution, broadcasting, and many others. However, signals that are not periodic appear in almost every application we use to interface with computer technology. Microphones, speakers, even your eye are all examples of devices that generate time-varying voltages. You can probably think of many different examples in this day of 3D gaming platforms, cell phones, and computer interfaces of all kinds.

So let's see what information we can get about these signals from our measurement equipment.

Procedures

Periodic signals

Most power companies distribute a sinusoidal signal that we know is time-varying because Westinghouse won the debate. But if you have ever done any house wiring yourself, or watched someone else check the voltages available at any outlet they usually use a hand-held multimeter. If you are an engineer in the field debugging a piece of equipment and you need to make measurements of AC signals you probably won't have an oscilloscope but you will have a multimeter, that may or may not be digital, so let's see how multimeters responds to time-varying signals generated by the signal generator while monitoring the actual signal with the oscilloscope.

- ✓ Set up the signal generator to output a sine wave with a peak-to-peak amplitude of 6V.
- ✓ Set the initial frequency of the signal to 1 Hz.
- ✓ Set the DMM in DC voltage measuring mode.
- ✓ Connect the signal generator to the DMM in the configuration to measure voltages and also to the oscilloscope. A t-connector will help you connect the signal generator to both measurement devices.
- ✓ Set the time increment of the oscilloscope to the 1s using the knob in the horizontal section of the scope.

Question 1: OSILLOSCOPE Adjust the time interval so that the time interval per division is 1 sec – wait a bit for the oscilloscope to fill the screen. Plot the waveform and show that the period and amplitude are as expected for a 1 Hz sine wave. Explain why you can see the waveform being drawn on the screen. This is evident from the gap in the waveform where the oscilloscope is "drawing."

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Question 2: Because the frequency of the signal is so low the values are tracking the time changing value of the voltage. Describe what you see.

- ✓ Look at the DMM and find the Min/Max button. Push this button. It actually stores the maximum and minimum voltage readings. The beeps indicate when the DMM is storing a new maximum or minimum value.
- ✓ Let's retrieve the max and min values and compare them to the ones you measured by eye in response to Question 2. Push the blue shift button and then the button with > on it and Recall in blue written above it. For the purposes of this tutorial the blue designation will be indicated in parentheses. The display should say Min-Max. Now push the button with the down-arrow(4). You can toggle back and forth between the Min and Max values using the right-arrow(Recall) and left-arrow(On/Off) buttons and the average and the

Question 3: Write down the Min and Max values as measured by the DMM.

- ✓ Hitting the DC V(AC V) button will return you to the measurement mode. To turn off the Min/Max mode simply push the Min/Max(dBm) button again.

Question 4: Use the Freq(Period) button to have the DMM estimate the frequency and period of the sine wave. Write these values. Since the period is so low it takes a moment to make an accurate estimate. Compare the value of the period as given by the signal generator, measurement taken from the oscilloscope, and the DMM. They all should be very close to the same value.

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- ✓ Check the frequency and period to see that they provide an accurate measurement at 1kHz.
- ✓ Return the DMM to DC V mode.

Question 5: Slowly increase the frequency of the square wave at the signal generator to 1KHz. Describe how the value displayed on the DMM and signal on the oscilloscope change.

Question 6: The value on the DMM stops changing when the frequency is high enough because the circuitry used to measure the voltage cannot respond fast enough. What is this value for the sine wave?

Question 7: Set the frequency to 1Khz and plot the sine wave that you see on the oscilloscope (make sure that at least 2 periods are showing on the scope). Now draw/plot a line corresponding to the voltage that you read on the DMM on the graph.

While responding to question 6 you should have read a value of ~0V on the DMM. This is because the multimeter is responding to the time-average value of the signal. If you look at a single period of the sine-wave that is symmetric around 0V like the signal you generated in question 7 you will see that the arithmetic mean is 0 even though the voltage as seen on the oscilloscope

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varies from a value of 2.5 to -2.5V. The signal spends the same amount of time at positive voltage as a negative voltage so the average is zero.

For *sinusoidally* time-varying signals the time-average value is not a useful number. If you connect a sinusoidally time-varying signal like that coming from the outlets in your home, to an incandescent light bulb it turns on. So another measure of the voltage and current is often used. It is this value that is shown when the DMM is in AC V mode (or AC I if measuring current).

- ✓ Change the digital multimeter's mode to AC V by pushing the button labeled AC V.
- ✓ Keep the parameters of the sine at a frequency of 1Khz, peak-to-peak amplitude of 5V and a 0V offset.

Question 8: What is the value read on the DMM. It should be non-zero even though the sine-wave is still symmetric about 0V.

Question 9: Add this value to your plot.

Instead of taking the arithmetic mean of the signal the DMM computes what is called the Root-Mean-Square average. This interpretation was devised to provide a value related to the amount of power associated with the device under test. Now when you hear that the output voltage from your house outlets is 120V you will know that 120V is actually the Root-Mean-Square average of the sinusoidal signal that is available at the outlet.

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The RMS values of the voltage and current are akin to the standard deviation in statistics. The mean of a set of numbers like the mid-term grades in one of your classes gives you some information about how the grades are distributed but the mean of the set [0,0,0,0,0,100,100,100,100,100] is the same as the set [50,50,50,50,50,50,50,50,50,50]. To get more information you turn to the standard deviation. As engineers we turn to the RMS value.

Root-Mean-Square:

If you have a time-varying signal $f(t)$ or a set of numbers taken at even intervals of time $f(n\Delta T)$ where is the sampling interval then the RMS of the function f representing either the ***voltage or current*** (v(t) or i(t)) can be found by:

Step 1. **S**quare the signal.

$$f(t)^2$$

Step 2. Take the time average or **M**ean of the signal.

a. Periodic signals: Find the mean of the signal over a period

$$\frac{1}{T}\int_0^T f(t)^2 dt$$

b. Aperiodic signals: Equivalent to the standard deviation of a zero-mean signal.

Step 3. Take the square **R**oot of the result.

$$\sqrt{\frac{1}{T}\int_0^T f(t)^2 dt}$$

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Question 10: Measure the RMS voltage for a square wave, and a triangle wave – keep the frequency, amplitude, offset the same for all signals. Confirm through calculations that the RMS of each signal that appears on the oscilloscope is the same that as measured by the DMM in AC V mode. Did you get the same values as measured by the multimeter?

Before you leave your experimentation with using the DMM to measure values relating to periodic time-varying signals it is important to know how the DMM measures the RMS value in AC V mode.

- ✓ Without changing any of the other setting on the signal generator choose a square wave. Monitor the RMS voltage with the DMM in AC V mode.

Question 11: Make sure the duty cycle of the square wave is 50% by pushing the blue button and the Offset(%Duty) button. What is the resulting RMS voltage measured by the DMM. Explain the value you get.

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Question 12: Now change the duty cycle recording the AC V for the indicated duty cycles.

% Duty Cycle	V_{RMS} (V)
20	
30	
40	
50	
60	
70	
80	

To understand why the value changes you have to look at how the DMM obtains the AC V measurement. If the DMM computed the V_{RMS} according to the algorithm described above the V_{RMS} for the square wave without an offset should not change with duty-cycle.

Question 13: Explain the assertion that " the V_{RMS} for the square wave without an offset should not change with duty-cycle."

The graph below summarizes the information that is gathered by the DMM and the oscilloscope.

- V_{avg} is the time average of the signal: $\frac{1}{T}\int_0^T f(t)dt$

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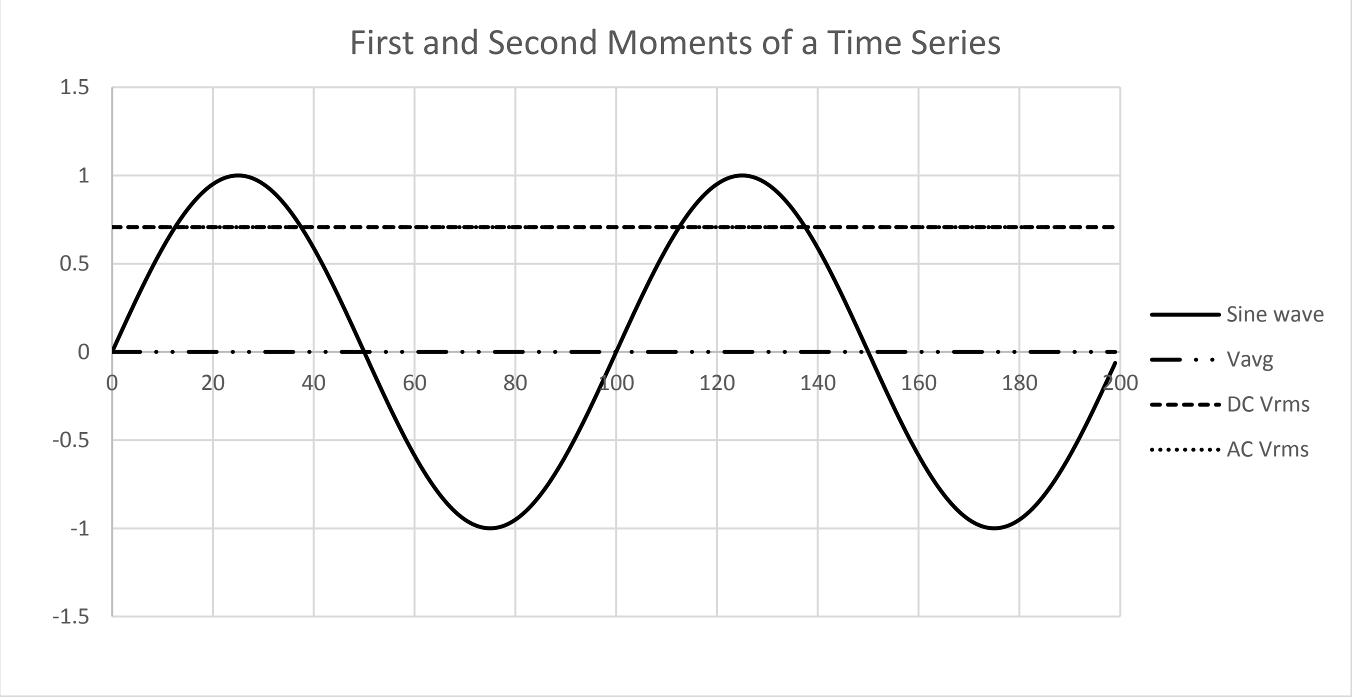
- DC V_{rms} is the Root Mean Square (or True) voltage computed using f(t) with no modification: $\sqrt{\frac{1}{T}\int_0^T f(t)^2 dt}$ NOTE: this is NOT the way the DMM computes its AC V signal.
- AC V_{rms} is computed by removing the V_{avg} value and then computing the RMS: $\sqrt{\frac{1}{T}\int_0^T (f(t) - V_{avg})^2 dt}$

As long as the signal is a zero-mean sine wave the DC and AC V_{rms} are obviously the same. Since the multimeter removes any offset by AC-coupling the input signal – just like the oscilloscope – the input will always be zero-mean so the measurement "should" give an accurate measure of the RMS voltage with the offset removed by the multimeter for any waveform.

Unfortunately, the multimeter circuitry is optimized to measure sinusoidally time-varying signals. If given a square wave, the circuitry inside the multimeter does not respond correctly so a confusing number appears. This happens with all signals that have very abrupt changes. The error introduced can be accounted for, but that is beyond the scope of this module.



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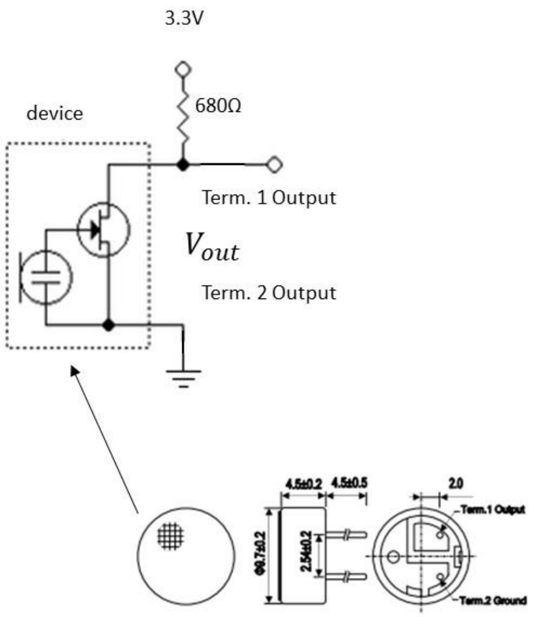
Aperiodic signals

For most time-varying signals that are aperiodic (have no consistent periodicity) it is difficult to see the signal or take any meaningful measurements of parameters. Engineers usually rely on other methods, but the oscilloscopes on your bench are actually capable of visualizing one time or occasional events.

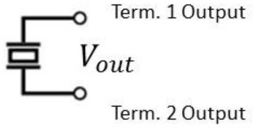
- ✓ The microphone circuit, piezo-electric vibration sensor, or the potentiometer circuit. Simply hook up the oscilloscope to output of one of them. NOTE: to see a decent signal from the microphone the scope MUST be AC-coupled!!!! Measure the voltage between the points labeled **Term. 1 Output** and **Term. 2 Output**.
- ✓ Most of these circuits/devices need a stimulus – for example, the microphone circuit needs noise very close to it to generate a signal. Watch the oscilloscope screen to catch the fleeting signal.
- ✓ Push the button to the right of the big, green Run/Stop button that reads Single. When pushed it is orange. When a signal is detected the oscilloscope takes a snapshot of the voltage.

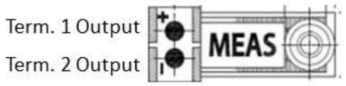
Microphone circuit



This diagram is taken from the datasheet showing the pinouts.

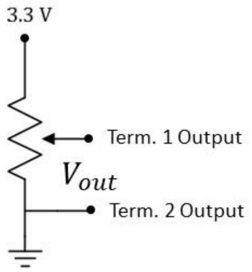
Piezo-Eelectric Vibration Sensor Circuit





This diagram is taken from the datasheet showing the voltage polarity.

Potentiometer Circuit



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Question 15: Stimulate one of the circuits. The oscilloscope should capture a snapshot of the voltage just following the initial excitation of the circuit. Describe and sketch the signal. Repeat for the other circuits.

What to expect:

- Microphone circuit – a voltage that is on the order of +/- 50 – 100 mV. If the range of the oscilloscope is correct the output is very dramatic. It should be very responsive to sounds in the room. Since the electret microphones are a little fragile some may be bad. If you do not see an output that clearly responds to your voice or music your microphone is probably dead. May it Rest In Peace.
- Piezo-electric vibration sensor. When the flap is moved a very large voltage signal is obtained. The voltage is often +/- 7V or more.
- Potentiometer – turning the knob changes the voltage between the values that you set. You determine the speed of the change.