ECE20007: Experiment 6

Time-Varying Signals and superposition

Ben Manning, Purdue University
Conner Hack, Editor
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1 Application

While DC voltage has a lot of applications, since many of our modern devices need DC voltages for power, it has its limitations. For example, transmitting DC power over large distances is not very practical. To better transport electricity, we use a voltage signal that changes over time, known as Alternating Current (AC), allowing us to transfer power many miles before it needs to be interacted with again. Time-varying signals have a lot of other applications too; signals that oscillate also allow us to communicate around the world and even in space by carrying information using high-frequency radio and microwaves.

In order to generate these signals that change over time, we use a function generator. While different brands and models of function generators may work differently, or have different user interfaces, they all have the same purpose of generating sinusoidal, saw-tooth, triangle, and square waves. Along with generating these signals, the function generators often allow the user to adjust different properties of the wave, such as the amplitude, frequency, and phase. More technical generators can even create random sequences or take input from an attached computer to generate unique and arbitrary signals.

Just like any other circuit, analyzing AC signals can be complicated since we cannot visually see the energy moving around the circuit especially if the signal is changing thousands (or billions) of times a second. To assist with this, scientists and engineers rely on oscilloscopes to visualize what a signal looks like at different points in a circuit.

2 Experiment Purpose

The main reason for this lab is to get acquainted with the function generator and oscilloscope that you will be using in lab. As mentioned in the Application section, engineers and scientists regularly rely on function generators to create specific patterns that replicate what happens in a product and an oscilloscope to help visualize what happens. It is not an easy task to directly conceptualize what happens in a circuit with electricity oscillating many times a second, so we will be looking at fairly simplistic waves this lab. As the labs continue and as you move forward in classes, the waves will get more complex and have different applications.

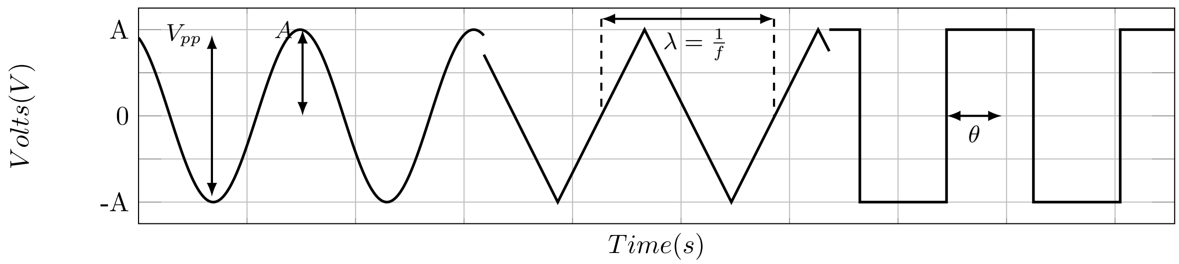
Note: This lab, especially the reading, is going to be pretty math-heavy expecting you to know general calculus. While you will not have to directly do any of the derivations yourself, you should be familiar with how the results are derived. As you move on to more complex systems and non-periodic signals, calculating and deriving RMS values and superimposed systems becomes more complex, and being able to program a script to do the math for you will require your knowledge of the process of the derivations.

3 AC Signals

Alternating current signals are most often defined as signals that change with time. Mathematically speaking, the signal voltage (or current) is a function of time using the below formula:

$$V(t) = A * sin(2\pi f t + \theta) + \beta \tag{1}$$

Where A represents the amplitude of the wave in Volts or Amps depending on the value being analyzed, f is the frequency in Hertz (Hz), θ is the phase change in radians or degrees depending on the unit reference, and β is the offset of the wave with the same units as amplitude. The sine function shows the shape of the wave, with other options often being a triangle or square wave. A cosine wave can be used instead of a sine wave as long as the user knows that a cosine wave is just a sine wave with a phase shift of $\pi/2$, or 90^o. Examples of the common wave forms used, Sine, Triangle, and Square waves, can be found in Figure 2. For all intents and purposes of this lab, waves generated will be considered periodic, where the same pattern repeats continuously. This allows us to use similar equations regardless of the shape of the wave and makes analysis more direct.



a) $A * sin(2\pi ft + \theta)$ b) $A * tri(2\pi ft + \theta)$ c) $A * sq(2\pi ft + \theta)$

Figure 1: Sine (a), Triangle (b), and Square (c) waves

Sine Waves

Sine waves are your "classic" waves that were likely introduced in a high school geometry or trigonometry course and have a smooth transition from peak to peak. Sine waves are used in many applications to simulate phenomena in nature, like how pressure moves through a medium, such as sound, or waves at the beach. Sine waves are also commonly used to represent light traveling through time and space. At time 0, a sine wave will have an amplitude of 0. Adjusting the phase of a sine wave by $\pi/2$ will provide a cosine wave, where now at time 0, the amplitude would be at a peak. In a purely mathematical sense, one of the most popular definitions of sine and cosine functions provide a relationship between the x component and the y component of a point on a circle. This is why the shape of the wave is smooth. In electronics, we often don't care if the wave is sine or cosine because they are basically the same wave with a phase shift one way or the other, and very rarely are we looking at the time=0 condition. More times than not, we are looking at phase relationship between multiple waves, like in power transmission, not the individual wave itself.

Triangle and Saw-tooth Waves

A triangle wave is a wave that steadily ramps up to a maximum peak and then steadily ramps back down to the lower peak in a linear fashion. While triangle waves look similar to sine waves, the key differences are the linear nature of the ramp and the points at the top and the bottom. Mathematically, a triangle wave is an infinite sum of odd harmonic (Integer multiple of the base frequency) sine waves decreasing in amplitude as frequency increases. Now, when we want a triangle wave in a lab or product, we don't *usually* add up an infinite amount of harmonics; instead, a piece-wise function is made to simulate a triangle wave.

A saw-tooth wave is just a modified triangle wave. When assigning parameters for a triangle wave in a function generator, symmetry is a value that can be adjusted based on how much of the wave is increasing linearly. If the symmetry is close to 0% or 100%, one will see a wave that ramps up linearly, and then immediately drops or vise versa, respectively. This gives the visual look of teeth on a saw. A triangle wave usually has 50% symmetry, meaning half of the wave is increasing linearly, and half is decreasing.

Note: Some will say the triangle wave is a modified saw-tooth wave. There is nothing wrong with this statement; it is purely a personal preference one way or the other.

Square Waves

A square wave is, in its simplest form, a binary pulse, not unlike a button press. Just like a button, where it is either pressed or not pressed, a square wave is either high or low. Square waves are most commonly found when using digital logic and clock sequences for computers where a 1 is on and a 0 is off. When working with digital electronics, a square wave is usually the start of a wave, and then it is modified to make a sine or triangle wave using assorted components to either smooth out the wave or adjust the sides so it increases more gradually. Just like triangle waves, square waves have a symmetry value, too, relating to how much they are on versus how much they are off. This is often described as a duty cycle. This is very important when it comes to controlling motor speed in industrial and hobby environments. Mathematically, a square wave is the infinite sum of all harmonics of a sine wave, but this is again often simulated with a piece-wise function.

Fun Fact: Human ears can actually tell the difference between these waves when they are sent through a speaker. It is a fun thought experiment to think about why this might be, and important when thinking about how we synthesize instruments using a computer. A sine wave generates what is often called a "pure tone." This sounds like a tuning fork, an acoustic guitar, or a piano. A square wave has a harsher or "buzzer" feel to it, and is often used to simulate a drum. Humans can even tell the difference between a triangle and saw-tooth wave. A triangle wave (looking similar to a sine wave) will be less intense and sound "breathy" like a flute; where a saw-tooth wave will have more of a metallic or "brassy" sound like a trumpet.

3.1 Root-Mean-Square of Periodic Waveforms

A common parameter when setting up a wave on a function generator is the peak-to-peak value. This is simply the range that the wave is achieving. If a wave has an amplitude of 2V, it would have a maximum peak at 2V, and a minimum peak at -2V assuming no offset, so the total range is 4V. The other way to say this is the peak-to-peak value is twice that of the amplitude (A).

$$V_{pp} = 2A \tag{2}$$

While peak-to-peak values allow us to see the full range of the wave, it doesn't tell us a lot about how the wave will act in a circuit. Conceptualizing how a wave will act on the large scale or over a long period of time can be a bit confusing. It would be really helpful to get an "effective voltage" or what the wave would act like if it were measured with a DC voltmeter. We cannot just take an average of the wave because a no-offset wave has equal parts that are positive and negative, so the average would be pretty close to 0. That would lead to wanting to get both sides of the wave to positive, which is can be done by squaring the value that would be oscillating. Now that the value is always positive, we can take the average, and then take the square root of the average to get back to the original range of the value. As to not use up all of the creativity in the room, in electronics this value is called the **Root-Mean-Square, or RMS**, of the voltage or the current. To further elaborate, we take the square root, of the mean (Average) of the square of the value to get the "effective" or "DC equivalent" of the value. For any wave, the following formula is generalized:

$$V_{RMS} = \sqrt{\frac{1}{T} \cdot \int_0^T V(t)^2 dt} \tag{3}$$

Where T is the time of 1 period of the wave. In its real form, T would approach infinity since it can be used for any period or frequency, but it is ultimately unnecessary for the depth of this lab. As an example, let's find the RMS value for a sine wave. Let's start with no offset, no phase shift, and the frequency is 1Hz.

$$V(t) = A \cdot sin(2\pi t) \tag{4}$$

If a wave is defined with Equation 4, we can plug this into our RMS equation to look like:

$$V_{RMS} = \sqrt{\frac{1}{T} \cdot \int_0^T (A \cdot sin(2\pi t))^2 dt} \tag{5}$$

Since the amplitude is constant, it can be removed from the integral and the radical. Using trigonometric identities, we can simplify the sine function to a cosine function in Equation 6:

$$V_{RMS} = A \cdot \sqrt{\frac{1}{2 \cdot T} \cdot \int_0^T (1 - cos(4\pi t)) dt} \tag{6}$$

Solving the integral gives us Equation 7:

$$V_{RMS} = A \cdot \sqrt{\frac{1}{T} \cdot \frac{T}{2}} = \frac{A}{\sqrt{2}} \tag{7}$$

That seems much easier than having to take an integral every time! This term is called AC RMS, which tells us the DC equivalent value of the AC portion of the signal. Fortunately, AC RMS values for all of the standard periodic waves collapse into reasonable calculations.

Shape	**AC RMS Expression**
Sine	$\frac{A}{\sqrt{2}}$
Triangle	$\frac{A}{\sqrt{3}}$
Square	A
DC	A

It should be noted that frequency does not change the RMS value. Keep in mind that T (period) and f (frequency) are reciprocals of each other, take a moment to convince yourself of this using the above equations. It might also be worth your time to convince yourself that the RMS expression for a square wave is the original amplitude of the wave. Keep in mind what a square wave is and how RMS is calculated. Adding an offset to a periodic wave does change this situation a little. Going back to the calculus momentarily, let's start with the same wave as before, but now it has a DC offset of β

$$V(t) = A \cdot sin(2\pi t) + \beta \tag{8}$$

Putting this wave in our RMS equation gives us:

$$V_{RMS} = \sqrt{\frac{1}{T} \cdot \int_0^T (A \cdot sin(2\pi t) + \beta)^2 dt} \tag{9}$$

The offset makes it so we can no longer move A out of the integral, but it doesn't change too much. Moving through the same steps as before, we end up with:

$$V_{RMS} = \sqrt{\left(\frac{A}{\sqrt{2}}\right)^2 + \beta^2} \tag{10}$$

Which can be rewritten as:

$$V_{RMS}^2 = \left(\frac{A}{\sqrt{2}}\right)^2 + \beta^2 \tag{11}$$

A few things should be noticed here. First, the normal RMS value and the offset are both in the final equation independent from each other. Second, the relationship that all three components are in looks very similar to the Pythagorean Theorem. That is because it is the Pythagorean Theorem! This equation provides us with the DC RMS value which combines the AC RMS value with the DC Offset.

3.2 Measuring RMS

When measuring periodic waves, there are three values that one should keep in mind.

1. **Average:**
   While we can't just take the average of a periodic value, the average of the wave still tells us important information, which is essentially the DC offset of the wave. If the wave amplitude is very small, then we basically have a DC signal.

2. **AC RMS:**
   As derived in the previous section, the AC RMS value allows us to better understand what the AC part of the wave will act like in the long term. In terms of a circuit, it doesn't care that a signal is oscillating, it just reacts to whatever voltage it has at that moment. If we don't care about the DC offset and just focus on the small variations in the signal, AC RMS gives us a better way to analyze that.

3. **DC RMS:**
   DC RMS combines both the average (DC offset) and the AC RMS values into one value so the full relationship can be observed.

When using a multimeter, make sure you know how to measure each of these components. AC RMS will likely be called ACV and ACI for voltage and current respectively. The DC offset will be DCV and DCI. This is also the setting you would use to measure DC values. This makes sense since the multimeter would just be averaging the input voltage over some pre-programmed amount of time. Not many multimeters will have an option to combine the two values to get DC RMS, but that is okay since you now know how to calculate it.

Especially for engineers, it is important to have a multimeter that has TRUE RMS. TRUE RMS means that the meter will essentially do an infinite sum and average of the signal that you are measuring. This means that regardless of the shape or other variations, you will get a proper RMS reading. If the meter does not have TRUE RMS, it is likely only calibrated to measure sine waves since that is what most people use the AC functions to measure (e.g. the voltage and current coming out of a wall outlet in their home). This will cause errors if you try to measure non-sine waves, and can even cause errors over 40%!

3.3 Ohm's Law with Time-Varying Signals

Ohm's Law does not rely on time; it holds true for every moment in every circuit that we analyze in this lab. If a resistance is known for a certain part of a circuit, as voltage (or current for that matter) changes, the current (or voltage) will adjust accordingly. Because of this, RMS values can be used instead of instantaneous values. This makes our lives easier and keeps the intense calculations to a minimum. This also works when calculating power. If one would like to derive it, finding the average power of an AC circuit will actually end with them deriving the RMS equation!

4 Superposition of waves

Just like DC sources, we can combine different AC waves into one collective signal in a process called superposition. This practice is routine and critical for wireless data transmission, such as WiFi, Bluetooth, and radios.

Take a simple AM (amplitude modulation) radio wave, the same type of wave you see in your car or desktop radio when you use AM mode. AM signals consists of two waves, a high frequency, high amplitude **carrier wave**, the frequency you tune to in your radio, and a low frequency, low amplitude, **data wave** which is the voice or music you hear through the speakers. This can be made into a general schematic that consists of two sources in parallel, some loading-prevention resistors, and a load, such as an antenna or additional transmitter circuitry.

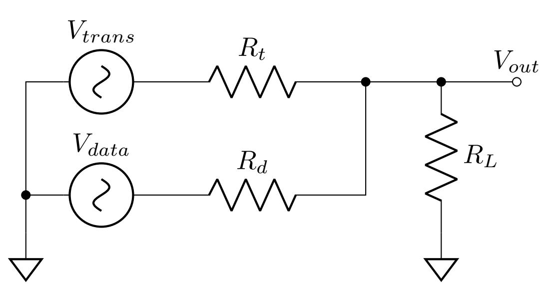


Figure 2: General principle schematic of a radio transmitter

Having multiple sources in a circuit does make the math a bit more tedious, but it is manageable. In AC, we can use RMS values to make our math more direct, and practical, as the RMS values will allow us to get a good idea of the total power available at the load. This also allows us to not have to worry about the oscillations at this time. Once we have an idea of how the circuit is acting, we can simulate it in Spice or your preferred programming language to get a visual representation of the wave. For example, if we have a transmission source at $10V_{rms}$ with a loading resistor (R_t) at 500Ω, a data source at $3V_{rms}$ with a loading resistor (R_d) at 500Ω, and a load with equivalent resistance of 50Ω (a common impedance of a radio antenna), we can determine the voltage and the output power of our system.

Just like when deriving equivalent circuits, we will approach determining total outputs one source at a time. Also like equivalent circuits, we will "turn off" our sources with the same principles, such as making voltage sources short circuits, and current sources open circuits.

Starting with the transmission wave, if we "turn off" the data wave, we will have a voltage divider setup with R_t on top, with R_d and R_L in parallel creating the bottom resistor.

$$V_{Trans->out} = V_{trans} * \frac{R_d//R_L}{R_d//R_L + R_t} = 10V_{rms} * \frac{45.5\Omega}{45.5\Omega + 500\Omega} = 0.85V_{rms} \tag{12}$$

Calculating power can be done the same way as in DC by using our standard power equations.

$$P_{trans} = V_{trans}^2/(R_d//R_L + R_t) = 10V_{rms}^2 * (45.5\Omega + 500\Omega) = 183mW \tag{13}$$

The same process can be used for the data wave by turning off the transmission wave.

$$V_{Data->out} = V_{data} * \frac{R_t//R_L}{R_t//R_L + R_d} = 3V_{rms} * \frac{45.5\Omega}{45.5\Omega + 500\Omega} = 0.25V_{rms} \tag{14}$$

$$P_{data} = V_{data}^2/(R_t//R_L + R_d) = 3V_{rms}^2/(45.5\Omega + 500\Omega) = 16.5mW \tag{15}$$

Since we are working with RMS voltages, we cannot just directly add our two output voltages together like we would DC voltages. Remember that they are still oscillating signals, not just a DC value. For the bulk of our calculations, we can treat the signals as DC, but we need to treat them as AC signals when we recombine them. In order to determine our total RMS voltage at the output, we combine our signals in the same way we combine AC RMS and DC RMS signals: using the Pythagorean Theorem.

$$V_{out}^2 = 0.85V_{rms}^2 + 0.25V_{rms}^2, \quad V_{out} = 0.87V_{rms} \tag{16}$$

$$P_{out} = 0.87V_{rms}^2/50\Omega = 15.7mW \tag{17}$$

Combining our voltages at V_{out} gives us a total output voltage of $0.87V_{rms}$, with a total power output across the load at $15.7mW$. That means that this system would have a power loss of over 90%! This is why choosing proper loading resistors that work with your loads is so important. On the other side, a lot of wireless transmission circuits have very low equivalent resistance, often less than 100Ω, which makes loading a very large issue, and we do tend to have a lot of our power lost, and not go to the actual transmission. This is why so much time and money are put into making better, more efficient transmission systems. Today, most high-end transmission systems only have about a 30% power loss.

Your AM radio waves really are just these two signals superimposed on each other, and you can even make an AM transmitter and receiver with a 555 timer (Project 2). Your other waves, such as WiFi and Bluetooth are much more complex with added data for encryption and other smaller waves to help stabilize bandwidth and power are added too. Even your FM radio waves have multiple waves combined to allow for stereo sound, and sub-carriers that carry digital data such as the text that will show up with the song name and station call-sign. Superposition is used on the receiver side too, but instead of adding waves together, we remove them. The receiver listens for the carrier wave by being tuned to the proper frequency, removes the carrier wave, and sends the data wave over to the speakers.

5 Function Generator

When you want to test a signal inside of a circuit, a function generator is the way to do so. Function generators come in all shapes, sizes, abilities, and price ranges. While different function generators will have different tolerances and abilities, they all serve the same purpose, which is to drive a DC (or time-varying) signal to a circuit. Shape, amplitude, frequency, offset, and even phase can all be adjusted on most commercially available function generators.

Just like a battery, function generators have an internal resistance on the output, which can be seen in the model in figure 3. This resistance is almost always set to 50Ω as an industry standard that dates back to the 1930s.
Think back to Lab 2, where voltage dividers and loading was tested. If Vout has a load with fairly low resistance,

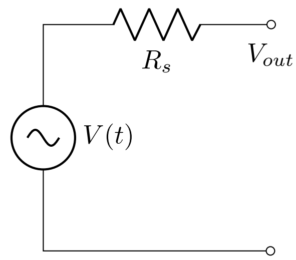


Figure 3: standard model of a function generator. R_s is the internal resistance of the function generator, usually set to 50Ω.

say around 100Ω, this would create a voltage divider with the internal resistance R_s, and the output voltage would be dropped by about a third compared to what is being generated! This drop becomes even larger if the load is less than 50Ω. To combat this situation, most function generators have two function modes: 50Ω, and High Impedance (which is often abbreviated to "Hi-Z").

These modes don't actually change the output impedance of the function generator, but they tell the function generator what it is attached to. In the 50Ω mode, the function generator assumes the load is going to be around 50Ω. Since it has an internal resistance of 50Ω, the voltage divider equation tells us that half of the voltage will get dropped across the internal resistance, and half will get dropped across the main load. So, if we want $2V_{pp}$ across the load, the function generator will actually output $4V_{pp}$, or double the assigned voltage. This mode is used often in very high frequency settings (past 1MHz) as the wave tends to be smoother. When working with telecommunication equipment, which that usually operate at very high frequencies, the loads tend to be fairly low resistance.

In Hi-Z mode, which we will be using almost exclusively in lab, the function generator assumes that the load will be much larger than the internal resistance, reducing the effect of the voltage divider, so there is no need to adjust the voltage. This makes things go smoother for us as we don't accidentally put double the voltage through our circuit. Make sure to set your function generator to HI-Z for this lab unless specifically told otherwise!

6 More Oscilloscope Tools

When working with AC signals, oscilloscopes become increasingly more helpful, as they can allow us to visualize the waves going into a system, throughout, and at the end. In the last lab, you used the basic functions such as setting your positions and using cursors, but there are even more tools that make our lives a little easier.

6.1 Oscilloscope Coupling

When AC signals have DC offsets, it is often used as a shift of power, which is helpful in practical applications, but we often don't really need to see that on the oscilloscope as we are often more concerned about the oscillating part of the signal. In fact, sometimes the offset is so large that it pushes the signal out of the range of the oscilloscope. AC coupling allows us to remove the DC component of a wave by sending the signal through a capacitor, which will then center the signal around 0V on the oscilloscope. As a DC charge is applied to a capacitor, the capacitor starts acting like an open circuit, preventing current flow. As an AC wave is applied, the capacitor can discharge and recharge with the signal, and the output will just be the changing part of the wave, or the AC signal. If you are having trouble conceptualizing this, try setting up a simple AC signal with a DC offset in LTspice, and add a capacitor between the input and the output (similar to Figure 4) but without the chassis ground connections.
Just like in the terminology for RMS calculations, AC coupling allows us to just see the AC portion of the signal, whereas the DC coupling allows us to see both the AC and DC components. The switch that handles the coupling in most oscilloscopes is a relay, so you will often hear a "click" as the transition happens. Not every oscilloscope on the market has the ability to AC couple a signal. If you are in this situation, you can use an external capacitor to achieve the same result, just make sure you remember to remove the capacitor if you are attaching your signal to a load that needs the DC offset! Just like any other circuit, capacitors will take time to charge and discharge depending on the capacitance and the equivalent resistance of your circuit. This will skew your signal, so it might take some tinkering to get the right capacitor to minimize interference.

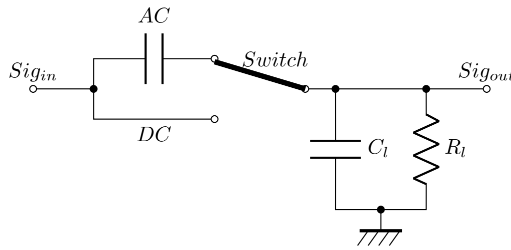


Figure 4: Internals of an oscilloscope showing how coupling is toggled. AC triggering is setup in a similar fashion without the connection to the chassis ground. C_l and R_l help with impedance matching of the attached probe at Sig_{in}.

6.2 Oscilloscope Triggering

If your signal is moving very quickly, or starts and ends in a few milliseconds, such as a USB data signal, it would be very helpful to be able to tell the oscilloscope to start showing data and/or start recording the data once that signal starts or hits a certain threshold. Triggering allows us to tell the oscilloscope to start recording data once a condition is met. These conditions can vary, different oscilloscopes will have different options on how to do this, but the vast majority of oscilloscopes on the market will have a type of triggering called "Edge Triggering," which will start recording data once the signal passes above (rising edge) or below (falling edge) a voltage threshold.

6.2.1 Normal and Auto Mode

Inside of the triggering menu on an oscilloscope, you will have a variety of options to adjust to help you get the best visualization of your signal. Along with the type of triggering you are performing, you can also tell the oscilloscope to help you out in Normal or Auto mode. In Auto mode, the oscilloscope will try to set a stable image every few seconds, even if the trigger condition isn't met. Auto Mode does need to get triggered at least once for it to work properly, otherwise it will look like the signal is racing by.

In Normal Mode, the oscilloscope will only trigger once the threshold is met and in the right direction. If the threshold is not met, the signal will either look frozen or blank depending on the formatting of the oscilloscope. This can be confusing, since the signal can say on the screen, even if you turn off the signal. Make sure to find an icon on the oscilloscope screen that tells you if the signal is triggered or not.

6.2.2 Hold-off

There are times were we want the oscilloscope to wait a certain time after the trigger condition is met before it triggers again. The Hold-off function allows us to tell the oscilloscope to wait at least the set amount of time before trying to trigger the signal again. This is helpful for non-periodic signals in getting an understanding of what is happening in the signal before we move on to a different part. Most hold-off settings are set to a few nanoseconds by default, but can be adjusted to a few seconds, or even a few minutes if you really want to. If you are holding off for more than a few seconds, it is recommended to use the "single" or "Start/Stop" functions to pause the screen. That way, the screen doesn't change abruptly.

6.2.3 Trigger Coupling

Just like coupling your signal, your trigger settings can be coupled as well. This means we can treat a signal with a DC offset as if it was AC coupled, and adjust the trigger setting based on the amplitude of the signal using AC triggering. This is really helpful if you have an unpredictable or varying DC offset. The menu for this setting is a bit tricky though. In DC coupling, or just triggering the signal as it is viewed on the screen will show you a trigger line on the screen, which you will not get in AC triggering. There will likely be a trigger icon on the screen to tell you at what voltage your trigger is set to.

Important: Your trigger coupling is set AFTER the coupling of the signal. Treat these functions in series with each other, where the signal (coupled or not) will then be sent to the trigger function. This will change how you use your trigger mode. If you AC couple your signal, DC triggering will work the same way as AC triggering, since the signal is centered around 0V.

6.3 Persistence

Most modern oscilloscopes will allow you to take a snapshot of a signal on the screen and then overlay the actual signal on top, known as persistence (since the signal persists on the screen). This can be a continuous process or just a quick capture. The menu for persistence will vary on the oscilloscope, but generally it will be under a "display" or "View Waveform" menu.

Prelab

7 Waves and RMS values

1. Create an equation and a computer generated model of a triangle wave with an amplitude of 3V, frequency of 1KHz, and a DC offset of 1V. Provide a screenshot of the wave for the assignment.
   It is recommended this model is made in MATLAB, Python, or Spice.
2. Calculate the DC RMS and AC RMS voltage values of the wave from Step 1.
3. Repeat Steps 1 and 2 for a sine wave with an amplitude of 2V, frequency of 1KHz, and DC offset of 4V.
4. What output mode should the function generator be in for this lab?
5. What oscilloscope viewing mode should be used to view a very slow signal with a frequency of 0.2Hz? Why is this mode better than other modes for this purpose?

8 Superposition of Signals

1. Using the schematic in Figure 2, calculate the RMS output voltage and power loss of a superimposed signal with a $2Vpp$, $+2V$ offset, $50Hz$ transmission sine wave and loading resistance of $10k\Omega$, and a $5Vpp$, $1Hz$ **triangle** data wave with a loading resistance of $5.6K\Omega$. The output load will have a resistance of $56K\Omega$.
   Note: These are not realistic values for a transmission setup, but they will allow for more reliable results for this lab.
2. Using Spice, MATLAB, or Python, simulate the superimposed signal in a transient state (showing the waveform) and verify your calculations. Capture an image of the simulated signal. Setup your system to show 2 periods of the slow wave.

In-lab

You are not permitted to use Auto-Scale this lab. We will know!

9 Measuring RMS values

This task might take you a little while in order to get used to the oscilloscope and function generator. The main purpose of this task is to get you comfortable manipulating controls to make signals as clear and useful as possible.

1. Use the function generator to generate a triangle wave with an amplitude of 3V, DC offset of 1V, and a frequency of 1KHz.
2. Use a Digital Multimeter (DMM) to measure the RMS voltage and the frequency of the wave. Document the values in your lab notebook.
3. Compare your computed RMS voltage with the measured RMS values. Do they agree? Does the DMM measure AC RMS or DC RMS? Calculate a percent error between the calculated values and the measured values.
4. Attach the signal to your oscilloscope and adjust the oscilloscope to show the signal **with the DC offset** using Auto Trigger. Show 3 periods of your signal, and a reasonable voltage/division so you can adequately see the signal.
5. Use persistence to capture the waveform with the DC offset.
6. AC couple your signal, and re-trigger your signal so it is stable and both the current and captured signals are adequately visible. Keep your voltage/division the same so the DC offset is accurate for the captured signal.
7. Use cursors or your measurement tools on the oscilloscope to verify your peak-to-peak and RMS values.
8. Capture a screenshot of your display that shows both the DC and AC coupled signal and measurements using BenchVue or using a USB drive that can be plugged into the oscilloscope. **DO NOT take a picture with a camera!** Images like these can cause glare and inconsistent resolution.
9. Repeat the above steps for the sine wave calculations from the Prelab, with an amplitude of 2V, frequency of 1KHz, and DC offset of 4V.

10 Superposition of waves

1. Create the circuit from Figure 2 with the values used in the Prelab. Don't forget about your common grounds!
2. Use triggering and coupling to get a stable image for the carrier wave, data wave, and the total superimposed wave. Capture a screenshot of your display for all three settings using BenchVue or using a USB drive that can be plugged into the oscilloscope. **DO NOT take a picture with a camera!** Images like these can cause glare and inconsistent resolution.
3. Use your cursors and measurement tools on the oscilloscope to determine the total power output of your system, then calculate your percent error compared to your calculations in the prelab.