1. Test and Measurement

<u>Chapter 1 Goals</u>

- Become familiar with lab test equipment
- Generate and measure sine waves
- Become familiar with amplitude modulation
- Generate and measure an AM signal

Your lab station should have 1 each of the following:

AFG1062 Arbitrary Function Generator
Tektronix MDO 3032 oscilloscope
Tenma DC power supply
Omega HHM90 digital multimeter (DMM)
USB Device (you need to bring your own)

The following tasks are designed to familiarize you with the equipment. Some helpful pointers are included, and your teaching assistant will be able to help you as well. Before you begin, spend a few minutes examining the buttons on the instruments. Remember that the goal is to get familiar with the equipment, so feel free to deviate from the procedure and do a little experimenting.

1.0 Oscilloscope Basics

Like a Battle Axe is to Gimli, or an oil rag is to a mechanical engineer, the oscilloscope is an indispensable tool of the electrical engineer! An oscilloscope (or "**o-scope**" for short) can measure both digital and analog waveforms (so rather like a double-bladed battle axe, then).

- The oscilloscope typically has a Voltage axis and a Time axis as can be seen in Fig. 1.1(a). The axis units are represented as either volts/division (read as "volts per division") or seconds/division. The screen is crisscrossed by horizontal and vertical lines which are the divisions. An oscilloscope with the voltage scale set to 1 V/div will display one volt per horizontal line and a scope with the time scale set to 100 µs/div will display 100 µs per vertical line.

- Voltage scale can be adjusted using the *scale* knob above the BNC input (see Fig. 1.1(b)). Each channel may have different voltage scales.

- Time scale can be adjusted by turning the *scale* knob located in the "horizontal" area (see Fig. 1.1(c)).

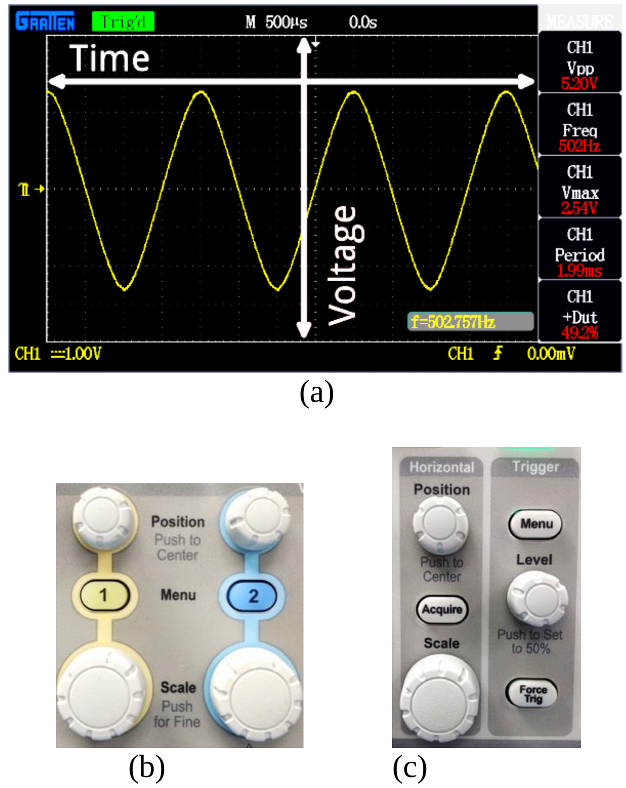

Figure 1.1: (a) the O'scope's view screen (b) voltage adjustment knobs, (c) time adjustment knobs

NOTES

- When attempting to see a signal on the oscilloscope, **select appropriate scales for the Time and Voltage axis** as the *autoscale* button will often not focus on the desired settings, especially with low frequency AM signals. It may also do weird things to your settings (so please don't rely on this or TA will lose their mind). For example, if you wanted to display a 1 kHz signal with a 100 mV amplitude, a good time scale would be set around 500 μs/div (which is approximately half the anticipated period) and a good voltage scale would be set around 50 mV/div (which is approximately half the anticipated amplitude). See Figure 1.2 for a "good" sine wave display

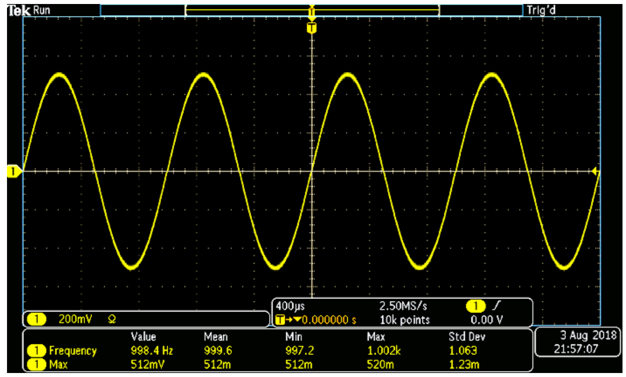

Figure 1.2: a properly scaled sine wave display

<u>1.0a Triggering</u>

Since you are now familiar with the basic concepts of setting up the scales of your oscilloscope, there is another import concept to learn about: **triggering**.

- The trigger is devoted to **stabilizing** and **focusing** the oscilloscope. The trigger tells the scope what parts of the signal to "trigger" on and start measuring. If your waveform is periodic, the trigger can be manipulated to keep the display static and unflinching. A poorly triggered wave will produce seizure-inducing sweeping waves.

- The trigger should be set in order to produce a clear waveform. You may have to change the level of the trigger by adjusting the *trigger level* knob.

- You may also need to change the trigger coupling and edge conditions to make it display the signal more clearly. This can be accomplished by changing the settings located in the *trigger menu*.

- **Helpful Hint:** when using the oscilloscope, many of the buttons you use will bring up a menu that can dominate the screen. To close the active menu, you can press the *Menu Off* button located near the bottom right corner of the screen.

NOTES

1.1 Simple Sine Waves

1. The following bullets will show you how to use the AFG 1062 function generator to produce a 1V amplitude 10 kHz sine wave and view it on the MDO 3032 oscilloscope. See Figure 1.3

- Turn on power to the 1062 function generator and the MDO 3032 oscilloscope.

- On the 1062 function generator, select the *sine waveform button* under the display. On the right of the display, press the *Ampl/High* button. Here, you can either set the "High" or maximum voltage of your sine signal or select the peak-to-peak value by interchangeably pressing that corresponding button. In our case, the maximum voltage is 1V or the peak-to-peak voltage is 2V. You can either enter in the corresponding voltage by using the *number pad* or the *main knob* on the generator. Using the *number pad* will allow you to choose different units. Set *Ampl* to 2 Vpp and set the *Offset* to 0V.

- You need to insure the modulation is off at this point. Check to see if the function generator button labeled *Mod* is glowing. If it is, the modulation is on and you will need to turn it off. To turn off the modulation click the *mod* button and then select the *continuous* option.

- On the 1062 function generator, press the *Offset/Low button*. Here you can either set the "Low" or minimum voltage of your sine signal or select the DC offset of the signal by interchangeably pressing that corresponding button. In our case, the minimum voltage is -1 V and there is no DC offset. Selecting these values is the same as in the previous step.

- On the 1062 function generator, press the *Freq/Period button*. Here you can either set the frequency or the period of the sine wave by interchangeably pressing that corresponding button. In our case, the frequency of the signal is 10 kHz. Before displaying the sine wave on the oscilloscope, make sure the *On/Off button* above the channel 1 port on the generator is selected to turn on the output. **Only enable the output after you verify the signal shown on the function generator display is correct.**

- Use a BNC-to-BNC cable with one end plugged into the output cable port on the 1062 Channel 1 port and run the other end of the cable to Channel 1 of the oscilloscope.

- On the 3032, set a reasonable voltage (~1V/div) and time scale (~40μs/div) for your input signal. **Avoid blindly using the *autoscale* button!!**

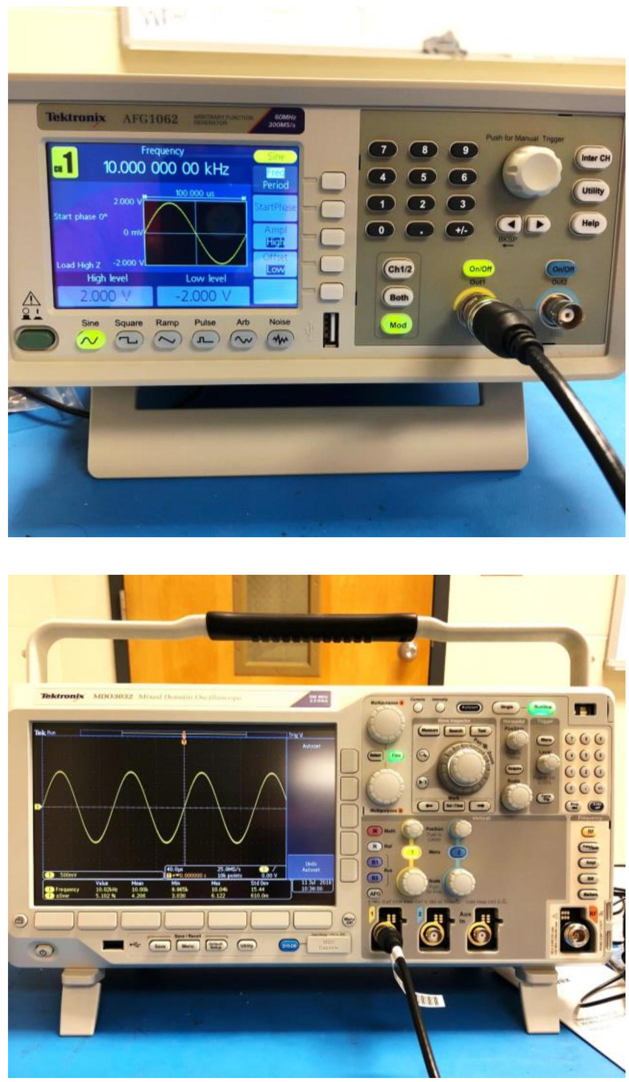

Figure 1.3: A 10 kHz sine wave generated by the AFG1062 is displayed on the MDO3032.

- Adjust the scope's *Trigger Level knob* (discussed on page 2) until you see a sine wave.

- Averaging the data will sharpen the signal. Press the *Acquire button* under the Horizontal area of the oscilloscope. Select *Mode* on the screen using the square buttons underneath. Select *Average* to the right on the screen menu. Set "Averages" to 16. Using the *Multipurpose a* knob, toggle the available averages selections (4,8,16…512) to 16.

- In order to save the signal as a .png screen capture on a USB device, directly to the right of the power button on the oscilloscope is a USB port. Plug in a USB device and press the *Save* button under the "Save/Recall" display. **Don't forget to save figures for your eportfolio!**

- Now press the *cursors* button at the top of the scope. This brings up a pair of cursor lines that are adjusted with the *multipurpose a* and *multipurpose b* knobs. Notice that there is a smaller horizontal tick mark on each of the cursor lines. These can be used to measure the peak-to-peak voltage of the signal. Adjust these cursor lines so that they are positioned at each peak of the signal. The "Delta" should read about 2V. **If it does not read 2V**, first check the output settings of your FGEN. If the FGEN is set incorrectly, you may have used the *autoscale* button and it may have changed other hidden settings without you realizing them. Press the yellow *Channel 1* button and look at the impedance settings and attenuation settings. If using a BNC cable, the impedance should be set to 50Ω. If using an oscilloscope probe you may need to change the values. Please ask your TA for help or clarification if needed.

- There are several different ways to use cursors on this oscilloscope. First, press and hold the *cursors* button. Notice a menu of options at the bottom of the oscilloscope display. Currently, the *Cursors* option is set as *Waveform*. Using the large buttons right below the oscilloscope display, select *Screen* instead. This will allow you to interchange between horizontal and vertical cursors.

- Interchange between horizontal and vertical cursors by using the large button under the *Bars* option. You can also interchange between horizontal and vertical cursors by interchangeably selecting the *Select* button in-between multipurpose a and multipurpose b knobs.

- The signal frequency may or may not be displayed at the bottom of the screen. In order to display this or other measurements, press *Measure* underneath the *Cursors* button. Select *Add Measurement* displayed on the screen. Select *Measurement Type* at the right of the screen. Using *Multipurpose knob b*, select "Frequency". Then select *OK* in order to display the frequency value on the main screen.

- If at any point you experience difficulty with the signal, please feel free to ask the TA for help.

- It is helpful to think about what the desired oscilloscope timescale should be to verify that the *Autoset* button, if used (not advised), sets the time scale appropriately. The signal frequencies are given in Hertz where Hz = s^{-1}

- Since the period of a signal is the inverse of the frequency, it is a good practice to adjust the timescale of the oscilloscope (adjusted with the *scale knob*) to somewhere near the period. For instance, a 1 kHz signal has a period of 1ms so the time scale should be set to something at or below 1ms (250μs or 500μs).

- Given a 10 kHz signal, what would be a good setting for the timescale?

  Time Scale: __________________

2. View the Sine wave on the Omega DMM.

- Disconnect the frequency generator from the scope. Set the DMM to read 20V AC and probe the output of the function generator:

  DMM Voltage: _________

  Is the voltage what you expect? Do you think the DMM is measuring amplitude or RMS?

1.2 Amplitude Modulation

Signals received by an AM radio are amplitude-modulated, meaning that the intelligence signal (usually an audio signal of voice or music) is carried along via a carrier wave. The intelligence is said to modulate the amplitude of the carrier. This is observed in Figure 1.4, where a 10 kHz carrier is modulated by a 1 kHz sine wave intelligence signal. While a typical amplitude modulation scheme would feature a carrier frequency much larger than the intelligence, here a relatively small carrier frequency is chosen for better visualization of the AM signal. The amount of modulation is given by the modulation index, *m*, which is the ratio of the intelligence amplitude to the carrier amplitude. In the figure, a 0.5 modulation index is shown. This is sometimes referred to as "50% modulation." Care is taken in the modulation scheme not to overmodulate.

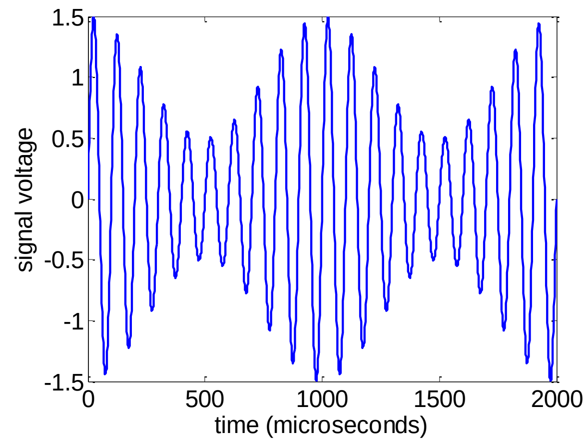

Figure 1.4: AM signal with f_i = 1 kHz and f_c = 10 kHz, with 0.5 modulation index

Question: Since you want to see the intelligence signal of the modulated waveform, what would be a good setting for the timescale of a signal with a 1 kHz intelligence frequency and a 1 MHz carrier frequency?

Time Scale: ___________________

It is instructive to observe the *spectrum* of an AM signal. The AM signal of Figure 1.4 has the spectrum shown in Figure 1.5 featuring 3 frequency components: the carrier frequency f_c, the lower side frequency f_c-f_i, and the upper side frequency f_c+f_i. Notice that the intelligence frequency, f_i, does not itself appear in the spectrum. Now, if this AM signal is fed through a detector, the intelligence is extracted and only the f_i is observed in the output spectrum (Figure 1.6).

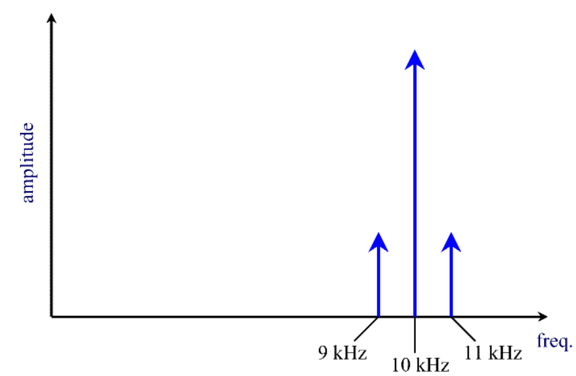

Figure 1.5: the spectrum of the AM signal of Fig. 1.4.

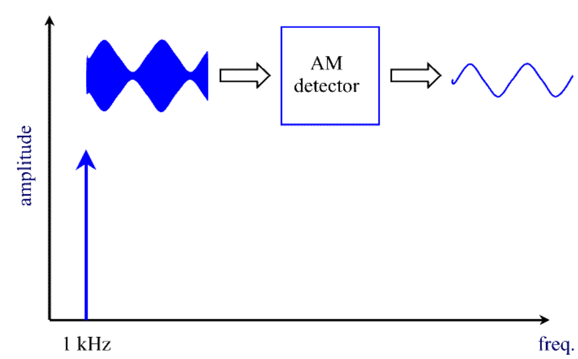

Figure 1.6: intelligence extracted by an AM detector has the spectrum shown.

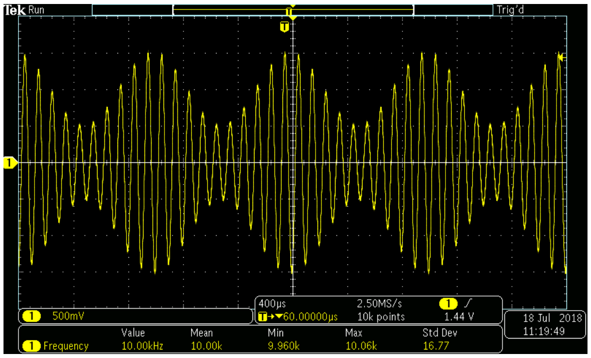

Figure 1.7: An amplitude modulated wave with 50% modulation

1.2a A Simple AM Signal

1. Here we will use the AFG1062 Arbitrary Function Generator to create an amplitude modulated signal, which you will view on the scope (see Fig. 1.7)

- Change the generator frequency to something big, like 10 kHz.

- Employ internal modulation (a 1 kHz signal). Internal modulation means you are generating an intelligence frequency from the same device, in our case the AFG1062 function generator, as the carrier frequency.

- Press the *Mod* button. Select *Mod* on the screen display using the buttons on the function generator. Press the *Type* button on the generator display in order to select the type of modulation, in our case AM. Select the *AM Frequency* on the display and enter in 1 kHz for the signal using either the *number pad* or the *knob*. Select *Depth* on the display and enter in 50 for 50% modulation using the *number pad* or the *knob*. Make sure your source of modulation is internal.

- Set the voltage and amplitude scales appropriately. Here you want to see the wave like shown in Fig. 1.7 so you want to adjust the time scale (using the *Horizontal Scale knob*) to a time scale using the intelligence frequency. **Note that *autoset* will zoom in on the carrier frequency.** You want to set the voltage scale (using the *Scale knob* by the input port) to a setting reasonable when compared to the overall amplitude of the system input.

- Adjust the scope's *Trigger Level knob* (discussed on page 2) until you get an amplitude modulated signal similar to the one in Figure 1.7. You may have to increase or decrease this trigger level. **Don't forget to save figures for your eportfolio!**

- **Helpful Hint**: To turn off the modulation click the *mod* button and then select the *continuous* option.

1.2b AM Signal Frequency Spectrum

1. Here we will use the AFG1062 Arbitrary Function Generator to create an amplitude modulated signal, which you will view on the oscilloscope using the Spectrum Analyzer – **But first, disconnect the cable from the oscilloscope and turn off the output of the function generator by pressing the *on/off* button (light should now be off)**

- You may think to yourself, "Why the heck do I need to see this with a spectrum analyzer? Why do I even care about the frequency domain when I have time (domain)?" to which your wise TA will say, "You will soon see the value young Padawan."

- For fun, set the carrier frequency to 1230 kHz. With *Amplitude* to 100 mVpp and *Offset* to 0 V. Why? 1. because as writer of the manual I just want to, 2. because changing the frequency is good practice for you, 3. because that aligns with my screenshots, 4. and most importantly you will be using this frequency often throughout the lab and I want you to be able to set the spec-an up correctly.

- Leave the intelligence at 1 kHz and set the *modulation depth* to 50%

- **Very important, verify that the voltage amplitude of your signal is below 1 volt! Which it is if you just set it to 100 mVpp.** If not, you may exceed the maximum input power level and damage the spectrum analyzer and will owe Auburn University a new oscilloscope! This will be a bad day for all here.

Figure 1.8: buttons to use with spectrum analyzer

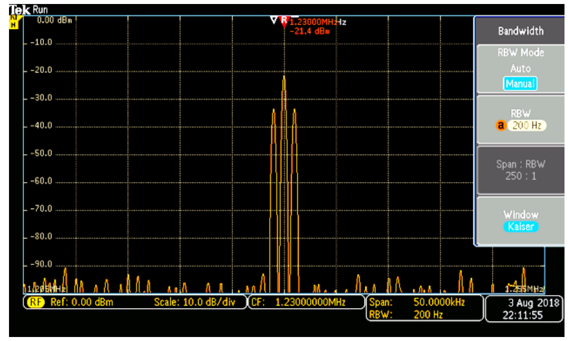

Figure 1.9: waveform spectrum

- Once you have verified you have a power level **much below 20 dBm**, connect your FGEN to the RF input of the O-scope with a BNC to BNC cable. Then press the orangish *RF* button and it should light up to show it is on (Fig. 1.8). Turn off any other active plots (the Math mode or channel inputs).

- Now it is time to configure the display. Press the *Freq/Span* button (see Fig. 1.8) and select the center frequency as the frequency of interest: 1.23 MHz, and set the span to 50 kHz.

- Select the *Ampl* button and set the reference label to 0 dBm.

- Select the *BW* button and set the RBW (resolution bandwidth) to 200 Hz. **NOTE:** To measure the signal power, a spec-an basically sweeps a filter across the frequency of interest and measures the power level at each location. Therefore, the smaller the RBW, the more precise each measurement is as less noise and other stuff gets in. But, the smaller the RBW is the more time it takes to measure a set frequency span, so you need to find the best trade-off between span and RBW if using later.

- You should now see the spectrum of the AM waveform as seen in Figure 1.9. **Don't forget to save figures for your eportfolio!**

- Now using the *Markers* button (cursors don't work in the RF mode) fill out Table 1.1 below. You may need to play with the marker settings (threshold, Manual Markers, etc) to get accurate readings.

- Repeat the above step, but adjust for 100% modulation (keep maximum amplitude at 100 mV, minimum should be about zero). Now repeat steps 4 through 7 and fill in Table 1.2.

- **Note the power level is dBm not dB.** R is the system impedance of 50 Ω

$$dB = 10log\left(\frac{P(W)}{1}\right)$$

$$dBm = 10log\left(\frac{P(W)}{1000}\right) = 10log(P(W)) + 30$$

$$P(W) = 10^{\frac{dBm-30}{10}}$$

$$P(W) = \frac{V_{rms}^2}{R}$$

$$V_{amplitude} = \sqrt{2} * V_{rms}$$

Table 1.1: Spectrum information (~50% modulation)

	Frequency	dBm level	Voltage amplitude
Lower sideband			
Carrier			
Upper sideband			

Table 1.2: Spectrum information (~100% modulation)

	Frequency	dB level	Voltage amplitude
Lower sideband			
Carrier			
Upper sideband			

- Can you think of any other usages for the spectrum analyzer?

1.3 AM Signal Frequency Spectrum (FFT method)

Here we will look at the AM signal with the use of the oscilloscope's built-in fast Fourier transform (FFT) feature. The FFT is a software implementation of a Fourier transform, which as you should remember from signals class "decomposes a function of time (a signal) into the frequencies that make it up, in a way similar to how a musical chord can be expressed as the frequencies (or pitches) of its constituent notes." This is very handy when analyzing signals as you will learn in later labs and classes.

1. Connect the AFG1062 function generator output the oscilloscope input channel 1. Now adjust the function generator to a 50 kHz sine wave with a 100mV peak-to-peak value. Set your time and voltage scales appropriately.

2. Make sure your source of modulation is "Internal," is set to 1kHz, and select a depth of 50%. Adjust the time base (the horizontal "scale" knob) to achieve "400 μs." Now adjust the trigger to see the AM wave.

3. Press the Math or red *M button* on your oscilloscope and select operation "FFT" at the bottom of the display (may need to turn off spectrum analyzer display). You may want to press the *yellow channel 1* button in between the channel knobs to remove the time base signal from the display. Adjust the same *horizontal scale knob* (it may be at f = 125 kHz) to 12.5 kHz. Turn on the cursors using the *Cursors* button. Use them to find the peak at your carrier frequency. To clean up the signal, press the *Acquire* button under the Horizontal menu, at the bottom of the screen select the *Mode* and change it to *High Res*.

Helpful Hint: Use the Wave Inspector for more precise measurements and zooming.

4. You should now see your sidebands. It should look oddly similar to the results from the spectrum analyzer! Record the frequency and dB level in Table 1.1 for the carrier and sidebands. It may help to change the cursors to get a better amplitude or frequency measurement (Long press *Cursors* and swap between *Waveform* and *Screen* as needed). **Don't forget to save figures for your eportfolio!**

5. Convert the recorded dB **(Note the power level is dBm not dB)** levels to voltage amplitudes using the following information: According to the scope manual, the dB value is referenced to 0 dB at 1 V_{RMS}. This means our dB value is related to the RMS value by:

$$dB = 20\log\left(\frac{V_{rms}}{1}\right),$$

or

$$V_{rms} = 10^{dB/20},$$

and finally,

$$V_{amplitude} = \sqrt{2}\ V_{rms}.$$

Record the voltage amplitudes in Table 1.1.

6. Repeat step 3, but adjust for ~100% modulation (keep maximum amplitude at 100 mV, minimum should be about zero). Now repeat steps 4 through 7 and fill in Table 1.3.

Table 1.3: Spectrum information (~50% modulation)

	Frequency	dB level	Voltage amplitude
Lower sideband			
Carrier			
Upper sideband			

Table 1.4: Spectrum information (~100% modulation)

	Frequency	dB level	Voltage amplitude
Lower sideband			
Carrier			
Upper sideband			

- Are the values the same as using the Spectrum Analyzer? If not what is different and why?

- Finally you have completed lab 1!! Clean up your station and put away cables properly following the signage on the cable rack and any TA instruction.