



Introduction to Arbitrary/Function Generators

Lab Experiment



A collection of lab exercises to introduce you to the basic features and functions of an arbitrary/function generator in order to generate common stimulus signals for electronic measurements.



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Laboratory Experiment Introduction***Objectives***

1. Understand the block diagram and basic controls of an Arbitrary/Function Generator.
2. Learn how to generate several basic electronic signals.
3. Learn how to verify the signal's parameters with oscilloscope measurements.

Equipment List

1. One Tektronix AFG3000 Series Arbitrary/Function Generator (excluding the AFG3011 model).
2. One 50 Ω BNC cable.
3. One Tektronix MSO2000 or DPO2000 Series digital oscilloscope.

Overview of an Arbitrary/Function Generator

Introduction

An Arbitrary/Function Generator (AFG) is an electronic test instrument that generates a wide variety of electrical signals. You can use AFGs to simply generate a series of basic test signals, replicate real-world signals, or create signals that are not otherwise available. These signals can then be used to learn more about how a circuit works, to characterize an electronic component, and to verify electronic theories.

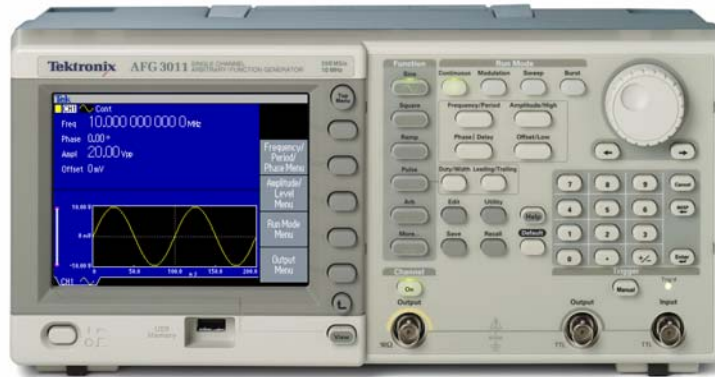
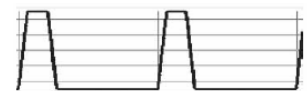
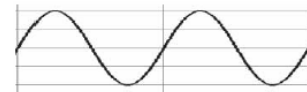


Figure 1: Tektronix Arbitrary/Function Generator

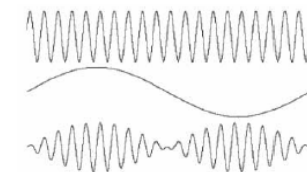
AFGs are most commonly used to generate basic test signals such as a:

- **Sine Wave:** A curved wave shape defined by the mathematical sine function.
- **Square Wave:** A wave shape consisting of repeating square pulses.
- **Pulse Wave:** A waveform with a fast rising edge, a period of time at a constant amplitude, and a fast falling edge.

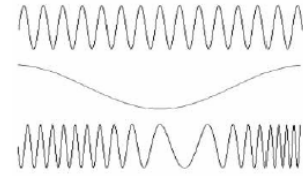


AFGs can also generate a variety of modulated signals such as:

- **Amplitude Modulation (AM):** A type of analog modulation in which amplitude variations embed lower-frequency information into a carrier signal of higher frequency.



- **Frequency Modulation (FM):** A type of analog modulation in which frequency variations embed lower-frequency information into a carrier signal of higher frequency.



Finally, AFGs can generate complex, user-defined signals such as:

- **Arbitrary waveform:** Waveform designed in software or captured by an oscilloscope, such as this heartbeat waveform.
- **Standard test signal with impairments:** A waveform with noise or other impairment added, such as noise on a sine wave.



A digital signal generator can be represented by the following simplified block diagram:

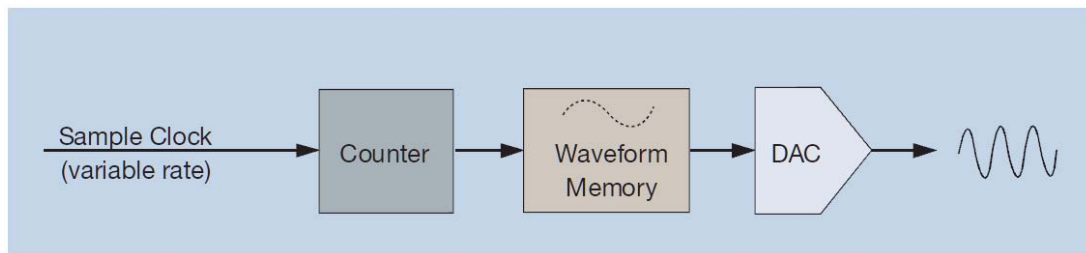


Figure 2: Digital Signal Generator Simplified Block Diagram

This signal generator works by sequentially reading waveform data values from memory and converting them from digital to analog form with a Digital-to-Analog Converter (DAC). The shape and amplitude of the waveform is specified by the data, while the frequency of the signal is specified by the sample clock.

Similar to digital oscilloscopes, there are many different ways to specify the performance of AFGs, but the most important four are bandwidth, sample rate, memory depth, and vertical resolution.

- **Bandwidth:** The frequency range of the signal source; defined as the frequency at which the sine wave signal is attenuated by 3 dB, or has been reduced by about 30%.
- **Sample Rate:** The maximum clock or sample rate at which the signal source can operate. As with oscilloscopes, this limits the timing resolution of the signal.
- **Memory Depth:** The number of data points used to record a waveform, which determines the maximum amount of waveform data.
- **Vertical (Amplitude) Resolution:** The smallest voltage increment that can be programmed in a signal source. Resolution is the data word width, in bits, of the instrument's DAC.

Instrument Controls

A typical signal generator has many controls. You need to select the type of signal to generate, the amplitude and offset, frequency or period, and other signal parameters. Although this may initially seem complex, let's go through the instrument step-by-step and highlight the most important controls.

There are three sets of controls needed to set up a basic signal: function, run mode, and the specific parameters for the selected signal. And the display shows all of the relevant information for the selected type of waveform. Each of these sections will be discussed in detail in the following lab experiments.

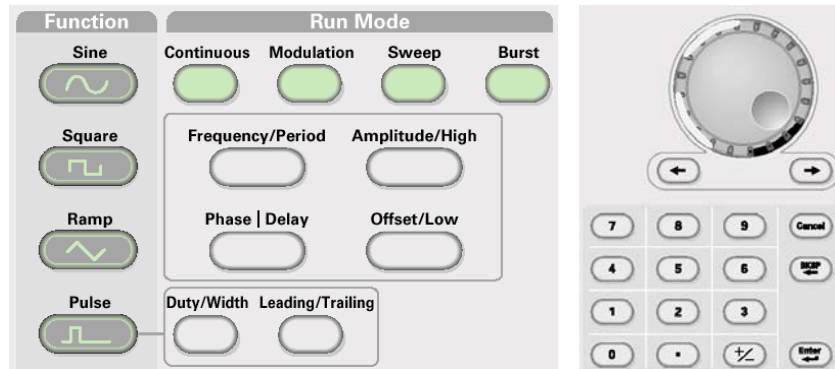


Figure 3: AFG3000 Series Front Panel Buttons

Before proceeding, here are a few hints that will make the labs easier:

1. Decide which type of signal you want to generate and select it with the Function button on the front panel. Some less common signals are selected from the on-screen menu once you select the category of signal.
2. When you select a signal type, the relevant signal parameters are shown on the display and a menu of controls appears at the right side of the screen. The menu items are prioritized from top-to-bottom. If you go through them in that order, the setup should be straight forward.
3. The display shows a representation of the chosen signal type, complete with detailed amplitude and time scales, giving you instant verification of your selection.

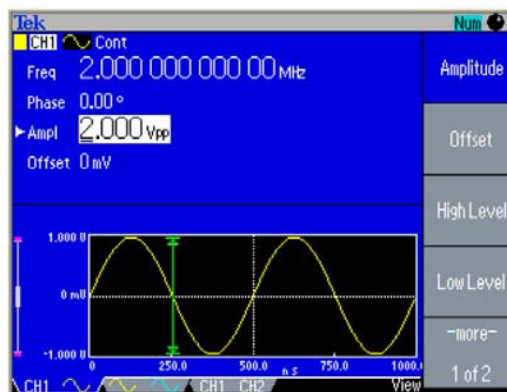


Figure 4: AFG3000 display showing signal type and parameters.

4. When you press a side bezel button to change a numerical parameter, the display will indicate which digit can be changed with the thumbwheel. You can use the arrow keys by the thumbwheel to select which digit is selected. You can also simply type in the numerical value with the front panel key pad. As you type in the numbers, a menu of relevant units are presented and you can select them with a press of a side bezel button.
5. You can easily switch between input formats with dedicated front panel buttons. For example, you may want to specify a sine wave by frequency but specify a pulse train by period. The front panel shortcut keys switch easily between parameter input modes.
6. Select the Run mode. For these labs, this will usually be Continuous.
7. Press the Output On button to turn on the output. To protect your circuit, the output is off by default and only activated when you are ready for a signal.

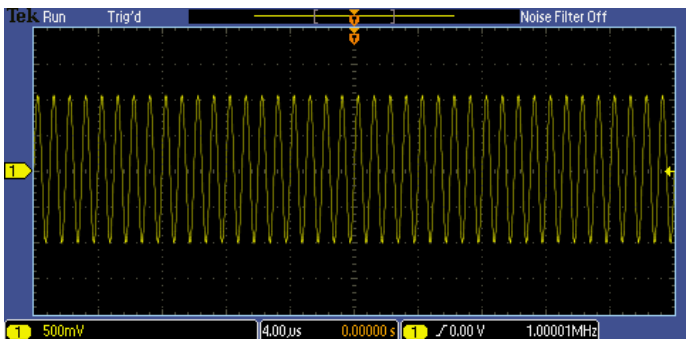


Key Points to Remember

1. An Arbitrary/Function Generator (AFG) generates a wide variety of electrical signals. You can use AFGs to generate a series of basic test signals, replicate real-world signals, or create signals that are not otherwise available.
2. The four most important parameters used to specify the performance of an AFG are bandwidth, sample rate, memory depth, and vertical resolution.
3. To set up an AFG, you need to select the type of signal to generate, the amplitude and offset, frequency or period, and other signal parameters. This requires using three sets of controls: function, run mode, and the specific parameters for the selected signal.

Exercise

1. Describe one real-world situation in which you might need an AFG to test your circuit.

Initial Setup	
<i>Setting up the Laboratory Experiment</i>	
1.	The following steps will configure the AFG3000 arbitrary/function generator and the MSO/DPO2000 oscilloscope for the following labs.
2.	By default, the AFG3000 will generate a 1 MHz sine wave.
a.	Power up the AFG3000 by pressing the power switch on the lower left corner of the instrument.
b.	Press the front panel Default button and the OK side bezel button to set the generator to a known state.
c.	Connect the BNC cable to the AFG3000 channel 1 output.
3.	Typically, it is important to match the source and load impedances to assure proper signal amplitudes, maximize power transfer, and to minimize reflections, especially at high frequencies. To simplify this lab, the MSO/DPO2000 Series oscilloscope's 1 M Ω high input impedance will be connected to the 50 Ω output impedance of the AFG3000. You will then set up the AFG3000 Series to work correctly with a high-impedance load.
a.	On the AFG3000, press the Output Menu side bezel button, press the Load Impedance side bezel button, press the High Z side bezel button, and press the Top Menu front panel button.
4.	The next series of steps will set up the oscilloscope.
a.	Power up the MSO/DPO2000 oscilloscope.
b.	Press the front panel Default Setup button to set the oscilloscope to a known state.
c.	Attach the end of the BNC cable to the channel 1 input.
d.	Press the yellow 1 button to show the channel 1 menu.
e.	Press the Probe Setup bottom bezel button to display the Probe Setup side menu.
f.	Press the Set to 1X side bezel button.
g.	Set the vertical Scale to 500 mV/div .
h.	Press the Menu Off button twice to remove the menus.
i.	Press the AFG3000 front panel channel 1 Output On button.
5.	After setting up the generator and oscilloscope correctly, the oscilloscope display should look about like this
	

Key Points to Remember

1. The AFG3000 Series signal generator has 50 Ω output impedance.
2. It is important to match the source and load impedances to assure proper signal amplitudes, maximize power transfer, and to minimize reflections, especially at high frequencies.
3. Because the MSO/DPO2000 Series oscilloscopes have a high input impedance, you need to set the AFG3000 Series to work correctly with a high-impedance load.

Exercise

1. Which of the following statements is not true concerning the default state of the AFG3000?
 - a. Generates a 1 MHz square wave.
 - b. It has a 50 Ω output impedance.
 - c. It generates a 2 V_{pk-pk} signal across a 1 M Ω load.
2. Why is it important for the source and load impedances to be matched?
 - a. Assure proper signal amplitudes.
 - b. Maximize power transfer.
 - c. Minimize reflections, especially at high frequencies.
 - d. All the above.

Generating Sine Wave Signals

Using the AFG3000 to Generate a Sine Wave

1. The following steps will explore using an AFG to generate a sine wave while using an oscilloscope to monitor the signal.
 - a. Turn the inner **Zoom** Wave Inspector control on the MSO/DPO2000 clockwise to examine an individual cycle of the sine wave.
 - b. When you are done, press the magnifying glass button to turn off zoom.
 - c. Press the MSO/DPO2000 front panel **Measure** button to display the automatic measurements menu.
 - d. Press the **Add Measurement** bottom bezel button. The oscilloscope's automatic measurements will be used to verify that the signal is generated as expected.
 - e. Using the multipurpose **a** control, select the **Frequency** measurement from the list and press the **OK Add Measurement** side bezel button.
 - f. Using the multipurpose **a** control, select the **Peak-to-peak** measurement from the list and press the **OK Add Measurement** side bezel button.
 - g. Press the **Menu Off** button once to remove the side menu.
2. The signal parameters can be easily controlled with the AFG3000 Series' front panel controls, either with the thumbwheel or the numeric keypad.
 - a. Press the **Sine** function button on the front panel to program the AFG3000 to generate a sine wave. (The sine function should already be selected from the previous exercise; however, this is the step you would typically take when selecting a new signal type.)
 - b. Press the AFG3000 front panel **Frequency/Period** button. Notice that the Freq readout is highlighted on the display and that one of the digits in the readout is underlined. This digit can be adjusted with the thumbwheel.
 - c. Turn the thumbwheel clockwise one position. Notice that the readout indicates **2.000... MHz**.

d. Press the right arrow button to move the cursor one position to the right. Using the thumbwheel, adjust the frequency to 2.500... MHz . Notice that the oscilloscope's frequency measurement shows 2.5 MHz as expected.
e. On the AFG3000 keypad, press the 5 button and press the MHz side bezel button to directly enter a 5.000... MHz frequency. Notice that the oscilloscope's frequency measurement shows 5 MHz as expected.
3. The most common way to view signals on an oscilloscope is in the "time domain", that is, where the X axis represents time. Another way to represent a signal is in the "frequency domain" with a Fast Fourier Transform (FFT) display, where the horizontal axis represents frequency.
a. Press the MSO/DPO2000 front panel M button to display the Math menu.
b. Press the FFT bottom bezel button.
c. Press the Menu Off button once to remove the side menu.
4. You'll notice that there is one dominant frequency component. The horizontal axis starts at 0 Hz at the left side of the display and the horizontal scale is 5 MHz/div, so the "fundamental" frequency is 5 MHz. The vertical axis still represents the amplitude of the signal, but it is a logarithmic scale with units of decibels referenced to a Volt (dBV), where $dBV = 20 * \log_{10}(\text{Volts})$.
a. Using the MSO/DPO2000 multipurpose b control, set the Math Vertical Scale to 10.0 dB .
b. Using the MSO/DPO2000 multipurpose a control, set the Math Vertical Position to 4 div .
c. Press the MSO/DPO2000 Menu Off button once to remove the bottom menu.
5. You may have noticed that there are other peaks on the FFT waveform. If you measure their relative heights to the fundamental, you will find that they are approximately 50 dB smaller. If you convert this logarithmic measurement into percentages, you'll find that these components are <1% of the fundamental. Because these other components are so small, you know you have a fairly pure sine wave.
Key Points to Remember
1. To program the AFG3000 to generate a sine wave, you must define a frequency (or period) and amplitude. The AFG3000 will pre-set these values which you can then change for your application. 2. The most common way to view signals on an oscilloscope is in the "time domain", that is, where the X axis represents time. Another way to represent a signal is in the "frequency domain" with a Fast Fourier Transform (FFT) display, where the horizontal axis represents frequency. 3. In the FFT display mode, a pure sine wave will have only one peak at the fundamental frequency of the waveform. Impurities in the sine wave may create low amplitude harmonics and spikes.
Exercise
1. Using what you have learned, program the AFG3000 to generate a 10 MHz, 1 V _{pk-pk} sine wave. Write down your steps.

Generating Square Wave Signals

Using the AFG3000 to Generate a Square Wave

1. In addition to sine waves, the AFG3000 Series family is able to generate other standard waveform types: square waves, pulses, ramps and more. In the following series of steps, we will explore generating square wave signals.
 - a. Press the AFG3000 front panel **Square** button to generate a square wave signal at the same fundamental frequency as the sine wave in the previous experiment.
 - b. Press the AFG3000 front panel **Frequency/Period** button. Set the frequency to 5 MHz.
 - c. Press the AFG3000 front panel **Amplitude** button. Set the amplitude to $2 V_{pk-pk}$.
 - d. Look at the oscilloscope display. Notice there are frequency components which occur at integer multiples of the fundamental frequency. These are called harmonics.
2. As we know from Fourier Analysis theory, an ideal square wave has a spectrum consisting of the fundamental and odd harmonics. Because this is an imperfect square wave, there are some even harmonics, but they're much smaller than the odd harmonics. Remember, the FFT vertical scale is logarithmic!

Key Points to Remember

1. To program the AFG3000 to generate a square wave, you must define a frequency (or period) and amplitude. The AFG3000 will pre-set these values which you can then change for your application.
2. An ideal square wave has a spectrum consisting of the fundamental and odd harmonics.

Exercise

1. What is the amplitude of the third and fifth harmonic of the 5 MHz, $2 V_{pk-pk}$ square wave? Hint: You may want to turn off the channel 1 (yellow) waveform by pressing the yellow **1** front panel button and either use the oscilloscope's graticule or cursors to measure the harmonics.

When done, press the **Cursors** front panel button twice to remove cursors. Press the yellow channel **1** front panel button to bring the yellow waveform back on the display then press the **M** front panel button to overlay the FFT display on top. Press the **Menu Off** button to remove menus.

Generating Digital Signals	
<i>Using the AFG3000 to Generate a Digital Pulse Stream</i>	
1.	The previous waveforms you generated were centered around ground. However, most digital signals are not. Instead, they typically extend from a lower value of about 0 V to a high value of a few volts. In this section, we will explore creating digital pulse streams commonly used in digital test applications.
a.	Press the AFG3000 front panel Pulse button. By default, the AFG3000's pulse waveform looks the same as a square wave. However, the pulse waveform allows you to adjust more signal parameters.
2.	By adjusting the parameters of the pulse waveform, you can easily produce digital signals. For example, you can generate a 1.8 V digital clock pulse signal with a 25% duty cycle (the signal is high for 25% of each period).
a.	Press the AFG3000 front panel Amplitude/High button twice to select the High parameter.
b.	On the AFG3000 keyboard, type in 1.8 and press the Enter button to directly specify a 1.8V high signal level.
c.	Press the AFG3000 front panel Offset/Low button to select the Low parameter.
d.	On the AFG3000 keypad, type in 0 and press the Enter button to directly specify a low level of 0 mV.
e.	Press the AFG3000 front panel Duty/Width button to select the Duty cycle parameter.
f.	Using the thumbwheel set the Duty cycle to 25.000...% .
g.	Notice that, as you change the duty cycle of the waveform, the harmonics vary considerably. Specifically notice the amplitudes of the higher-order harmonics.
3.	The rise- and fall-times of a digital signal are determined by the signal's high frequency components. Faster rise- and fall-times require higher amplitude harmonics. In the following steps, we will use the AFG3000 controls to vary the signal's rise- and fall-time and notice the effect this has on the signal's frequency content as shown on the MSO/DPO2000's FFT display.
a.	Using the MSO/DPO2000 front panel Trigger Level control, set the edge trigger level to 1V .
b.	Press the AFG3000 front panel Leading/Trailing button to select the Leading edge (rise-time) parameter.
c.	On the AFG3000 keypad, type in 25 and press the Enter button to directly specify a rise time of 25 nsec.
d.	Press the AFG3000 front panel Leading/Trailing button to select the Trailing edge (fall-time) parameter.
e.	On the keypad, type in 25 and press the Enter button to directly specify a fall-time of 25 nsec.
f.	Notice that when the rise- and fall-times are slowed down, the amplitudes of the higher-order harmonics decrease.
Key Points to Remember	
1.	Most digital signals extend from a low value of about 0 V to a high value of a few Volts.
2.	By using the AFG3000 pulse function, you can produce a digital signal by specifying the high amplitude, low amplitude, period and duty cycle of the signal.
3.	As the duty cycle of the waveform changes, the harmonics vary considerably.
4.	When the rise- and fall-times are slowed down, the amplitudes of the higher-order harmonics decrease and conversely, when the rise- and fall-times increase, the amplitudes of the higher-order harmonics increase.

Exercise

1. Using what you've learned, measure the amplitudes of the third and fifth harmonics of a 5 MHz pulse stream with 25 ns rise- and fall-times, 35% duty cycle, and $V_{\text{Low}} = 0 \text{ V}$ and $V_{\text{High}} = 1.4 \text{ V}$.
 - a. Now, change the duty cycle to 50%. Measure the amplitudes of the third and fifth harmonics.
 - b. Change the rise- and fall-time to 18 ns. Measure the amplitudes of the third and fifth harmonics.
 - c. Change $V_{\text{High}} = 2.0 \text{ V}$. Measure the amplitudes of the third and fifth harmonics.

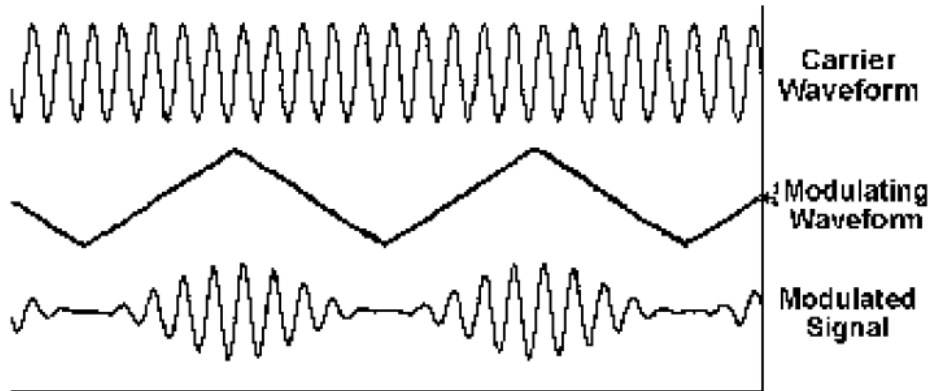
When done, press the **Cursors** front panel button twice to remove cursors. Press the yellow channel **1** front panel button to bring the yellow waveform back on the display then press the **M** front panel button to overlay the FFT display on top. Press the **Menu Off** button to remove menus.

Generating Modulated Signals with AFGs

Introduction

Amplitude Modulation

Amplitude Modulation (AM) is a technique often used to transmit radio signals. AM changes the amplitude of the carrier waveform as the amplitude of the modulating signal varies.



Glossary Of Terms for AM Modulation

- **Carrier Waveform:** The original waveform whose amplitude parameter is modified.
- **Modulating Waveform:** The signal that determines the changes to the original waveform (carrier). In this lab, we will use an internally generated sine wave signal.
- **Modulation Depth:** The extent of the amplitude variation expressed as a percentage. At 0% modulation, the output amplitude is half of the set amplitude. At 100% modulation, the output amplitude equals the selected value. Modulation depth can be set from 0% to 120% modulation.

An AM signal is represented by the equation

$$v(t) = A_c [1 + am(t)] \cos(2\pi f_c t)$$

Where:

A_c = the signal amplitude

a = modulation index

$m(t)$ = normalized modulating signal (maximum value is 1)

f_c = carrier frequency

Using the AFG3000 to Generate an AM Modulated Signal

1. In this section, you will use an AFG to generate an amplitude modulated (AM) waveform and examine its frequency components with an oscilloscope.
 - a. Press the AFG3000, front panel **Sine** button.
 - b. Press the AFG3000 front panel **Frequency/Period** button.
 - c. On the AFG3000 keypad, type in **500** and press the **kHz** side bezel button to directly enter a 500.000... kHz "carrier" frequency.
 - d. Using the MSO/DPO2000 front panel Horizontal **Scale** control, set the horizontal scale to **200 usec/div**.
 - e. Notice the MSO/DPO2000 FFT frequency axis has changed to 125 kHz/div.
2. When we look at a 500 kHz sine wave on the oscilloscope, we see the expected single component

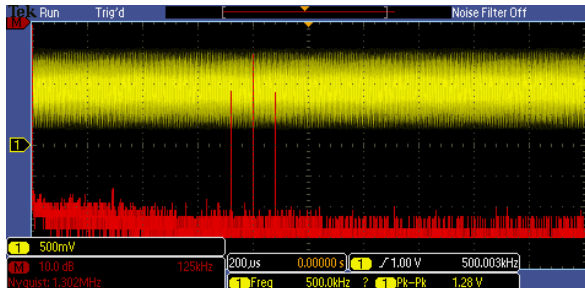
at the fundamental 500 kHz frequency.
a. Press the AFG3000 front panel Modulation button to display the modulation menu.
3. With the default 10 kHz AM modulation, we see the expected +/- 10 kHz AM side-bands around the fundamental.
a. Press the AM Frequency side bezel button to select the AM Frequency parameter.
b. On the AFG3000 keypad, type 50 and press the kHz side bezel button to directly enter a 50.00 kHz “carrier” frequency.
c. When we turn on 50 kHz AM modulation, we see the expected +/- 50 kHz AM side-bands around the fundamental.
Key Points to Remember
1. The FFT of a sine wave has a single component at the fundamental frequency. 2. With AM modulation, the FFT of the signal has sidebands around the fundamental. The sidebands are spaced the same distance from the fundamental as the modulation frequency.
Exercise
1. Using what you’ve learned, program the AFG3000 to generate an AM modulated signal with a 1 MHz carrier waveform and 25 kHz AM modulation. On the oscilloscope, measure the frequency and amplitude of the sidebands.

Final Exercise

1. To describe a sine wave, you must specify _____ .
 - a. Period, duty cycle, V_{Low} and V_{High}
 - b. Harmonics
 - c. Frequency and amplitude
 - d. Amplitude and duty cycle

2. To program an arbitrary/function generator to generate a square wave, you must specify _____ .
 - a. Period, duty cycle, V_{Low} and V_{High}
 - b. Frequency and amplitude
 - c. Amplitude and duty cycle
 - d. Rise-time and Fall-time

3. What type of modulation is shown here?
 - a. Amplitude
 - b. Phase
 - c. Frequency
 - d. None



4. When the rise-time of a digital pulse stream increases, the amplitude of higher-order harmonics will _____ .
 - a. Decrease
 - b. Increase
 - c. Stay the same
 - d. Impact can't be predicted

5. As you increase the frequency of a sine wave, the position of the fundamental component in the FFT display will _____ .
 - a. Move to the right
 - b. Move to the left
 - c. Move higher on the display
 - d. Impact can't be predicted

6. This final exercise will require the use of the skills and knowledge gained to this point.
 - a. Set up the AFG3000 to generate a 75 kHz ramp signal with $V_{Low} = 0\text{ V}$ and $V_{High} = 1\text{ V}$.
 - b. Press the MSO/DPO2000's front panel **Default Setup** button to set the oscilloscope to a known state. Remember to set the probe attenuation to 1X!
 - c. Set up an FFT display of the ramp signal, showing several of the harmonics.
 - d. Measure the frequency and amplitude of the third and fifth harmonics.

 - e. Set the symmetry of the ramp signal to 100%.
 - f. Measure the frequency and amplitude of the third and fifth harmonics.

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