

Lab Manual:  
Communications Principles  
  
Using the EMONA Communications board for NI ELVIS III



Lab 8: FM Modulation

List of Updates

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# Lab 8: FM Modulation

In this lab you will generate a frequency modulated signal using a variety of message sources and measure the power and bandwidth of this FM signal by viewing the signal in the time and frequency domains. As well you will calculate the frequency deviation of the modulator circuit.

## Learning Objectives

After completing this lab, you should be able to complete the following activities.

1. Generate a real FM signal using multiple messages
2. Examine a real FM signal with scope and compare it to its original message
3. Calculate the power in the FM signal
4. Describe the bandwidth of an FM signal
5. Calculate the frequency deviation of the FM modulator

## Prerequisites

You should have completed Lab 1 and Lab 2 and be familiar with the equipment, its use and the handling precautions for the equipment.

## Required Tools and Technology

|  |  |
| --- | --- |
| Platform: NI ELVIS III Instruments used in this lab:   * Oscilloscope-Time * Oscilloscope-FFT * Function Generator | * Install Instruments: [http://www.ni.com/documentation/en/ni-elvis-iii/latest/getting-started/installing-the-soft-front-panel/](http://www-preview.ni.com/documentation/en/ni-elvis-iii/1.0/getting-started/installing-the-soft-front-panel/) * Access instruments <https://measurementslive.ni.com> * View User Manual <http://www.ni.com/en-us/support/model.ni-elvis-iii.html> * View tutorials <https://www.youtube.com/playlist?list=PLvcPIuVaUMIWm8ziaSxv0gwtshBA2dh_M> |
| Hardware: Emona Communications Board Components used in this lab:   * Four BNC to 2mm banana-plug leads * Assorted 2mm banana-plug patch leads * Set of headphones or earbuds | * View User Manual <http://www.ni.com/en-us/support/model.emona-communications-board-for-ni-elvis-iii.html> |

## Expected Deliverables

In this lab, you will collect the following deliverables:

* Calculations
* Data from measurements
* Observations

Your instructor may expect you complete a lab report. Refer to your instructor for specific requirements or templates.

## Section 1: FM Modulation

## Theory and Background

A disadvantage of the AM, DSBSC and SSB communication systems is that they are susceptible to picking up electrical noise in the transmission medium (the *channel*). This is because noise changes the amplitude of the transmitted signal and the demodulators of these systems are designed to respond to amplitude variations.

As its name implies, frequency modulation (FM) uses a message’s amplitude to vary the frequency of a carrier instead of its amplitude. This means that the FM demodulator is designed to look for changes in frequency instead. As such, it is less affected by amplitude variations and so FM is less susceptible to noise. This makes FM a better communications system in this regard.

There are several methods of generating FM signals but they all basically involve an oscillator with an electrically adjustable frequency. The oscillator uses an input voltage to affect the frequency of its output. Typically, when the input is 0V, the oscillator outputs a signal at its *rest* frequency (also commonly called the *free-running* or *center* frequency). If the applied voltage varies above or below 0V, the oscillator’s output frequency deviates above and below the rest frequency. Moreover, the amount of deviation is affected by the amplitude of the input voltage. That is, the bigger the input voltage, the greater the deviation.

Figure 1 shows a bipolar squarewave message signal and an unmodulated carrier. It also shows the result of frequency modulating the carrier with the message.

Fig%209-1

Figure 1: Sketch of FM signals

There are a few things to notice about the FM signal. First, its envelopes are flat – recall that FM doesn’t vary the carrier’s amplitude. Second, its period (and hence its frequency) changes when the amplitude of the message changes. Third, as the message alternates above and below 0V, the signal’s frequency goes above and below the carrier’s frequency. (Note: It’s equally possible to design an FM modulator to cause the frequency to change in the opposite direction to the change in the message’s polarity.)

Before discussing FM any further, an important point must be made here. A squarewave message has been used in this discussion to help you visualise how an FM carrier responds to its message. In so doing, Figure 1 suggests that the resulting FM signal consists of only two sinewaves (one at a frequency above the carrier and one below). However, this isn’t the case. For reasons best left to your instructor to explain, the spectral composition of the FM signal in Figure 1 is much more complex than implied.

This highlights one of the important differences between FM and the modulation schemes discussed earlier. The mathematical model of an FM signal predicts that even for a simple sinusoidal message, the result is a signal that potentially contains many sinewaves. In contrast, for the same sinusoidal message, an AM signal would consist of three sinewaves, a DSBSC signal would consist of two and an SSBSC signal would consist of only one. This doesn’t automatically mean that the bandwidth of FM signals is wider than AM, DSBSC and SSBSC signals (for the same message signal). However, in the practical implementation of FM communications, it usually is.

There’s another important difference between FM and the modulation schemes discussed earlier. The power in AM, DSBSC and SSBSC signals varies depending on their modulation index. This occurs because the carrier’s RMS voltage is fixed but the RMS sideband voltages are proportional to the signals’ modulation index. This is not true of FM. The RMS voltage of the carrier and sidebands varies up and down as the modulation index changes such that the square of their voltages always equal the square of the unmodulated carrier’s RMS voltage. That being the case, the power in FM signals is constant.

Finally, when reading about the operation of an FM modulator you may have recognised that there is a module on the Emona Communications board that operates in the same way - the VCO output of the function generator. In fact, a voltage-controlled oscillator is sometimes used for FM modulation (though there are other methods with advantages over the VCO).

## 1.2 Implement: Modulating the VCO with two discrete levels

For this experiment you’ll generate a real FM signal using the VCO module on the board. First you’ll set up the VCO module to output an unmodulated carrier at a known frequency. Then you’ll observe the effect of frequency modulating its output with a squarewave then speech. You’ll then use the NI ELVIS III FFT mode on the Oscilloscope to observe the spectral composition of an FM signal in the frequency domain and examine the distribution of power between its carrier and sidebands for different levels of modulation.

It should take you about 40 minutes to complete this experiment.

**Powering up the ELVIS III + EMONA Communications Board**

|  |  |
| --- | --- |
| 1. | Ensure that the NI ELVIS III Application Board power button at the top left corner of the unit is OFF (not illuminated). |

|  |  |
| --- | --- |
| 2. | Carefully plug the Emona Communications board (ECB) into the NI ELVIS III ensuring that it is fully engaged both front and back. |

|  |  |
| --- | --- |
| 3. | Ensure that you have connected the NI ELVIS III to the PC using the USB cable and that the PC is turned on. |

|  |  |
| --- | --- |
| 4. | Turn on the Application Board *Power* button by pressing it once and confirm that it is illuminated. The LEDs on the ECB should also be illuminated. If they are not, then switch the unit off immediately and check for connection or insertion errors. |

|  |  |
| --- | --- |
| 5. | Open the Instrument Launcher software in your browser and select the required instruments. |

Table 1 Scope Configuration

|  |  |
| --- | --- |
| Channel Voltage range | 2 V/div |
| Horizontal Timebase | 50us/div |
| Trigger | Analog Edge, Chan 1, Rising |
| Probe Attenuation | 1x |

|  |  |
| --- | --- |
| 6. | Connect the set-up shown in Figure 2. |

|  |  |
| --- | --- |
| 7. | Set the VCO module’s *GAIN* to minimum (fully anti-clockwise) and then set the *FREQ* control to give an output sinusoid of about 100kHz. This has a period of 10us, so you can easily fine tune it in the time domain. |

|  |  |
| --- | --- |
| 8. | Slowly increase the *GAIN* to maximum (fully clockwise). |

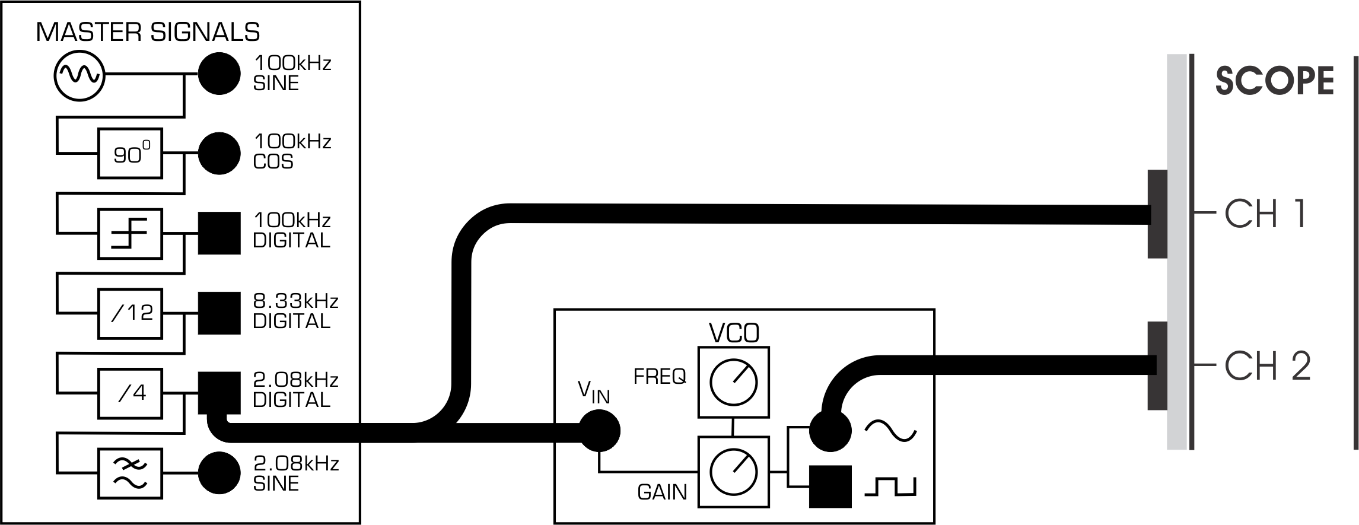


Figure 2: Patching for FM with VCO

This set-up can be represented by the block diagram in Figure 4. The Master Signals module is used to provide a 2.08kHz squarewave message signal and the VCO is the FM modulator with an unmodulated center frequency of 100kHz.

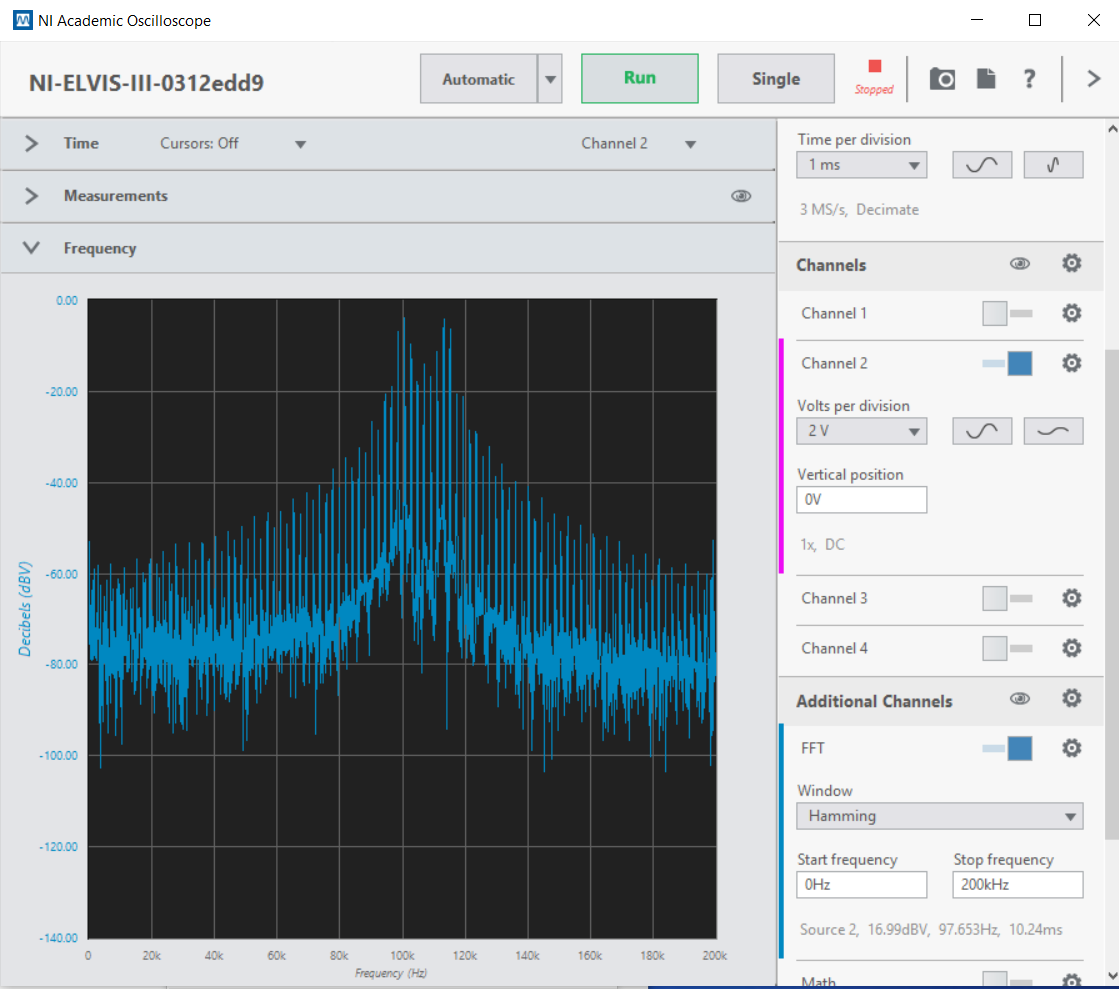


Figure 3: Example of FM signal in frequency domain

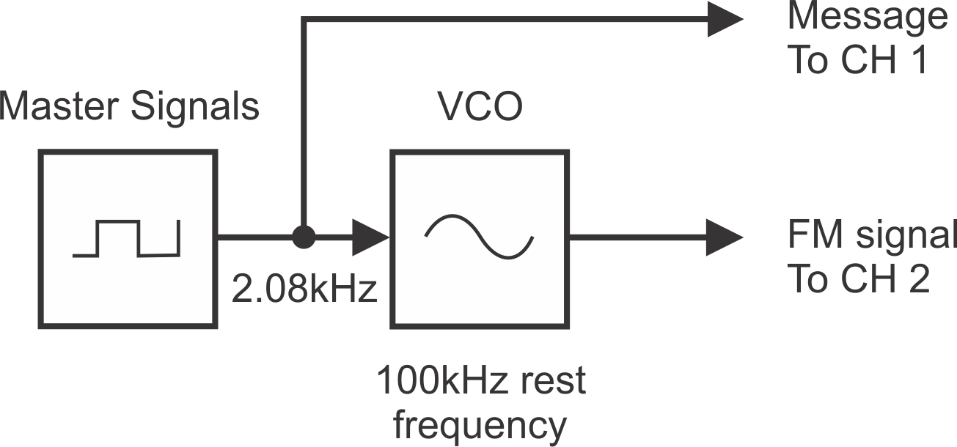


Figure 4: Block diagram for FM with VCO

|  |  |
| --- | --- |
| 9. | View both the input and output to the VCO module, and trigger the scope on the rising edge of the squarewave input. |

|  |  |
| --- | --- |
| 10. | Observe the difference in frequency in the output for a 0V input versus a +5 V input level. This exercise serves to demonstrate how the VCO is modulated by an input signal. You should use SINGLE mode on the scope to stabilise the signal for measurements purposes and trigger off of an edge of the input signal. |

* 1. With GAIN at maximum, measure the frequency for both states of the output signals. What are they ?

|  |
| --- |
|  |
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|  |

|  |  |
| --- | --- |
| 11. | Enable the FFT mode of the Oscilloscope instrument. Change the scopes timebase to 1ms/div. |

|  |  |
| --- | --- |
| 12. | Set the frequency span for the FFT displayed from say 0kHz to 200kHz for a broad overview of the frequency domain. Vary the VCO GAIN control and observe the effect on the output spectrum. |

|  |  |
| --- | --- |
| 13. | Capture a screenshot of the FFT and append to your report. Annotate your report appropriately so as to identify the waveforms captured. Use the cursors to highlight important levels and transition points in the waveform if necessary. |

## 1.3 Implement: Generating an FM signal using speech

So far, this experiment has generated an FM signal using a squarewave for the message. However, the message in commercial communications systems is much more likely to be speech and music. The next part of the experiment lets you see what an FM signal looks like when modulated by speech.

|  |  |
| --- | --- |
| 1. | Return the scope’s *Trigger Level* control to *0V*. |

|  |  |
| --- | --- |
| 2. | Disconnect the plugs to the Master Signals module’s *2.08kHz DIGITAL* output. |

|  |  |
| --- | --- |
| 3. | Connect them to the Speech module’s output as shown in Figure 5. |

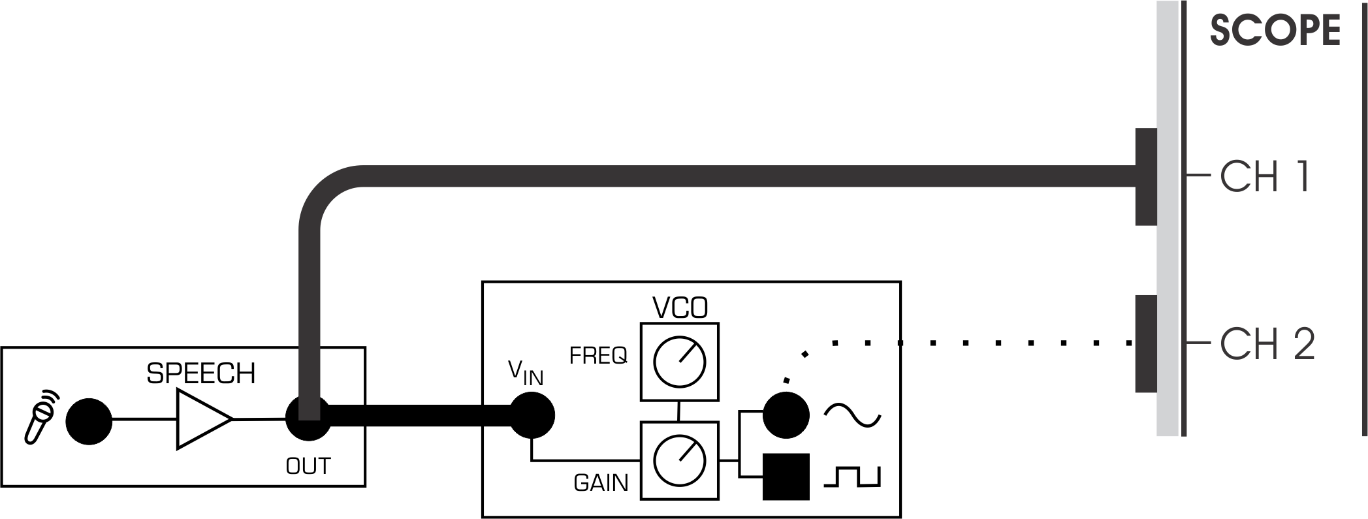


Figure 5: Modulating the VCO with speech

|  |  |
| --- | --- |
| 4. | Set the scope’s *Timebase* control to the 1*00µs/div* position. |

|  |  |
| --- | --- |
| 5. | Hum, clap and talk into the microphone while watching the scope’s display. |

## 1.4 Implement: Power in an FM signal

As mentioned earlier, the power in an FM signal is constant regardless of its level of modulation. This part of the experiment lets you see this for yourself.

|  |  |
| --- | --- |
| 1. | Locate the VCO module. |

|  |  |
| --- | --- |
| 2. | Keep the previous set-up from Figure 5 |

|  |  |
| --- | --- |
| 3. | Or you can change the input to connect to GND. Step 4 makes this unnecessary. |

|  |  |
| --- | --- |
| 4. | Set the VCO module’s *GAIN* to minimum (fully anti-clockwise) and then set the *FREQ* control to give an output sinusoid of about 100kHz. This has a period of 10us, so you can easily fine tune it in the time domain. |

|  |  |
| --- | --- |
| 5. | Open the FFT mode on the scope and view the spectrum. |

|  |  |
| --- | --- |
| 6. | Once done, one significant sinewave should be displayed. |

|  |  |
| --- | --- |
| 7. | Confirm this is the case. |

|  |  |
| --- | --- |
| 8. | Measure the frequency of the sinewave and verify that it’s the VCO’s rest frequency (that is, 100kHz). |

|  |  |
| --- | --- |
| 9. | View the measurement of the signal’s RMS voltage. Record this in Table 1. |

|  |  |
| --- | --- |
| 10. | Square and record this voltage. |

Table 1

|  |  |
| --- | --- |
| **Unmodulated**  **Carrier** | **Unmodulated**  **Carrier** |
|  |  |

Why square the signal’s RMS voltage? To answer this question, remember that we’re investigating the power in an FM signal but signal analyzers (and most other test equipment) can’t measure power. However, one of the power equations () tells us that power and the square of a signal’s RMS voltage (that is, ) are proportional values. That being the case, we can investigate power in an FM signal indirectly by investigating the square of the signal’s RMS voltage because whatever is true of one must also be true of the other (regardless of *R*).

|  |  |
| --- | --- |
| 11. | Modify the set-up as shown in Figure 6. |

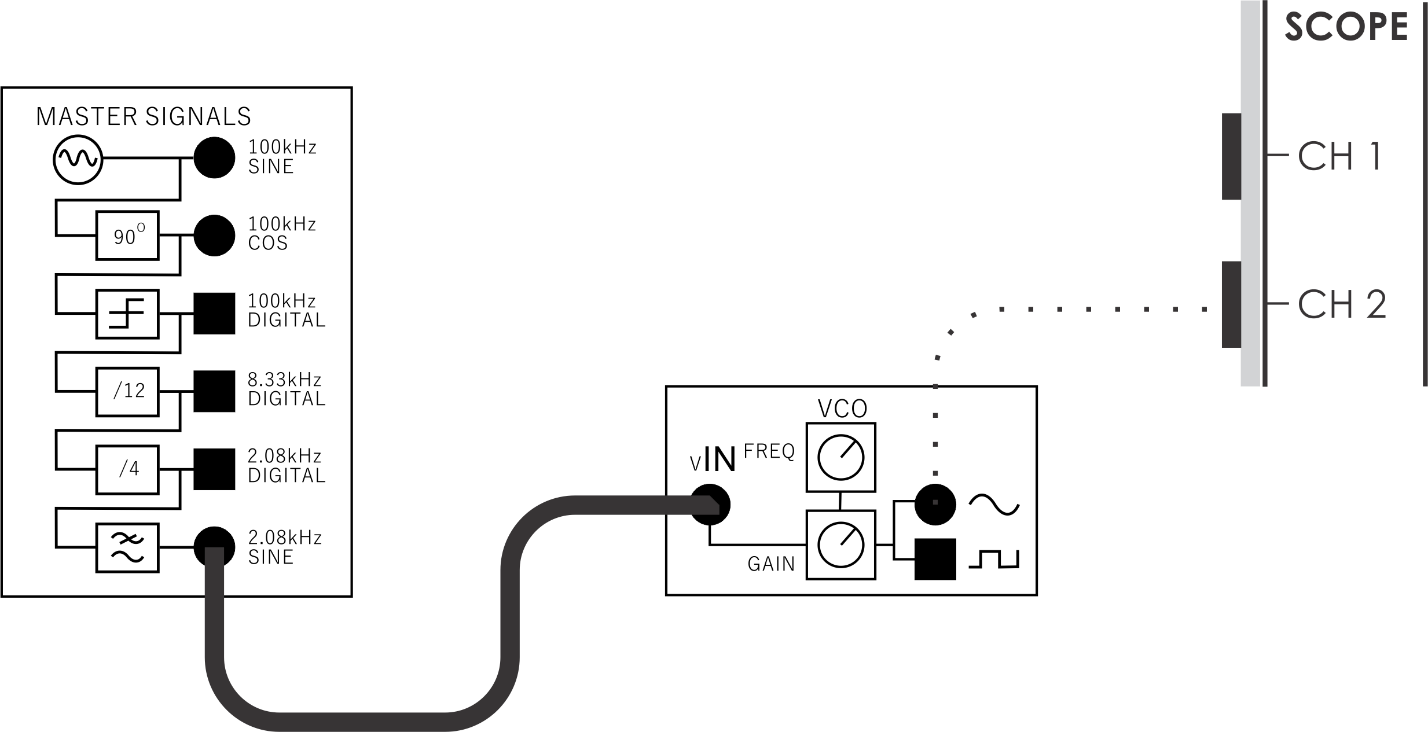


Figure 6: Modulating the VCO with 2.08kHz sinusoid

The carrier will now be frequency modulated by a low level message signal. This means that the signal analyzer’s display will show about four sidebands. As these sidebands are small relative to the carrier, they can be better observed by temporarily setting the Spectrum analyzer’s *Units* option to *dB* instead of *Linear*.

|  |  |
| --- | --- |
| 12. | If you haven’t already done so, return the analyzer’s *Units* option to *Linear*. |

|  |  |
| --- | --- |
| 13. | Use the VCO module’s *Gain* control to adjust the modulation of the FM signal slightly until only five sinewaves are clearly visible in the signal’s spectrum. |

|  |  |
| --- | --- |
| 14. | Use the cursor to measure the RMS voltage of these sinewaves and record them in Table 2. |

|  |  |
| --- | --- |
| 15. | Square and record the voltages. |

|  |  |
| --- | --- |
| 16. | Add and record the squared voltages. |

Table 2

|  |  |  |
| --- | --- | --- |
| **Sinewave** |  |  |
| **1** |  |  |
| **2** |  |  |
| **3** |  |  |
| **4** |  |  |
| **5** |  |  |
|  | **Total** |  |

|  |  |
| --- | --- |
| 17. | Use the VCO module’s *Gain* control to increase the modulation of the FM signal until the carrier **drops to zero for the first time**. |

|  |  |
| --- | --- |
| 18. | Repeat these steps for the six most significant sinewaves in the signal recording your measurements in Table 3. |

Table 3

|  |  |  |
| --- | --- | --- |
| **Sinewave** |  |  |
| **1** |  |  |
| **2** |  |  |
| **3** |  |  |
| **4** |  |  |
| **5** |  |  |
| **6** |  |  |
|  | **Total** |  |

* 1. How do the totals in Tables 2 and 3 compare with each other and the value in Table 1?

|  |
| --- |
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* 1. What do these measurements help to prove? Explain your answer.

|  |
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## 1.5 Implement: Bandwidth of an FM signal

The spectral composition of an FM signal can be complex and consist of many sidebands. Usually, many of them are relatively small in size and so an engineering decision must be made about how many of them to include as part of the signal’s bandwidth. There are several standards in this regard and a common one involves including all sidebands that are equal to or greater than 1% of the unmodulated carrier’s power (or ). This part of the experiment lets you use this criterion to measure FM signal bandwidth.

|  |  |
| --- | --- |
| 1. | Use the VCO module’s *Gain* control to adjust the modulation of the FM signal slightly until only five sinewaves are clearly visible in the signal’s spectrum. |
| 2. | Use the signal analyzer’s *C1* cursor to identify the lowest frequency sinewave in the FM signal with a  equal to or greater than 1% of the value in Table 1.  **Note:** You have to do this by measuring the RMS voltage of the smallest sinewaves and square the value until you find the first one with a  equal to or greater than 1% of the value in Table 1. |

|  |  |
| --- | --- |
| 3. | Use the signal analyzer’s *C2* cursor to identify the highest frequency sinewave in the FM signal with a voltage equal to or greater than 1% of the value in Table 1. |

|  |  |
| --- | --- |
| 4. | The signal analyzer’s *df (Hz)* reading is a measurement of the difference in frequency between its cursors. Following Steps 40 and 41, this reading is the FM signal’s bandwidth. Record this value in Table 4. |

Table 4

|  |
| --- |
| **FM signal’s**  **bandwidth** |
|  |

* 1. Calculate the bandwidth of a 100kHz carrier amplitude modulated by a 2kHz sinewave.

|  |
| --- |
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|  |

* 1. How does the FM signal’s bandwidth compare to an AM signal’s bandwidth for the same inputs?

|  |
| --- |
|  |
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|  |

* 1. How far apart are each of the sidebands ?

|  |
| --- |
|  |
|  |
|  |

|  |  |
| --- | --- |
| 5. | Use the VCO module’s *Gain* control to increase the modulation of the FM signal until the carrier **drops to zero for the first time** |

|  |  |
| --- | --- |
| 6. | Repeat steps 40 to 42 recording your measurement in Table 5. |

Table 5

|  |
| --- |
| **FM signal’s**  **bandwidth** |
|  |

* 1. What is the relationship between the message signal’s amplitude and the FM signal’s bandwidth?

|  |
| --- |
|  |
|  |
|  |