

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



Lab 9: FM Demodulation

List of Updates

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# Lab 9: FM Demodulation

In this lab you will begin with a frequency modulated signal based on the previous lab and construct a demodulation process which translates the frequency variations into voltage variation in a linear manner. The ability to translate between signal domains is an important principle across many topics. There are several methods to achieve this and in this experiment you will explore the introductory method of zero-crossing detection.

## Learning Objectives

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

1. Describe a zero-crossing detection method
2. Discuss frequency to voltage translation
3. Recover a variety of FM modulated messages
4. Describe the FM spectrum of FM modulated speech

## 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 (supplied by user) | * View User Manual   <http://www.ni.com/en-us/support/model.emona-communications-board-for-ni-elvis-iii.html> |
| Software: NI ELVIS III Function Generator File used in this lab (available in lab folder):   * ECB\_positive1V\_DC.csv | * Access instrument <https://measurementslive.ni.com> |

## 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 demodulation

## 1.1 Theory and Background

There are as many methods of demodulating an FM signal as there are of generating one. Examples include: the *slope detector*, the *Foster-Seeley discriminator,* the *ratio detector*, the *phase-locked loop* (PLL), the *quadrature FM demodulator* and the *zero-crossing detector*. It’s possible to implement several of these methods using the Emona Communications board, but for an introduction to the principles of FM demodulation, the zero-crossing detector is used here.

**The zero-crossing detector**

The zero-crossing detector is a simple yet effective means of recovering the message from FM signals. Its block diagram is shown in Figure 1.

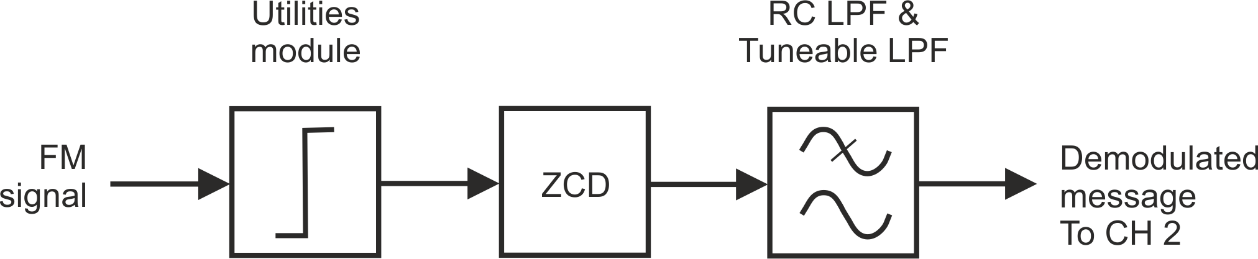


Figure 1: Block diagram for zero-crossing detection

The received FM signal is first passed through a comparator to clip it heavily, effectively converting it to a squarewave. This allows the signal to be used as a trigger signal for the zero-crossing detector circuit (ZCD).

The ZCD generates a pulse of fixed duration every time the squared-up FM signal crosses zero volts (either on the positive or the negative transition but not both). Given the squared-up FM signal is continuously crossing zero, the ZCD effectively converts the squarewave to a continuous rectangular wave with a fixed *mark* time.

When the FM signal’s frequency changes (in response to the message), so does the rectangular wave’s frequency. Importantly though, as the rectangular wave’s mark is fixed, changing its frequency is achieved by changing the duration of the space and hence the signal’s mark/space ratio (or *duty cycle*). This is shown in Figure 2 using an FM signal that only switches between two frequencies (because it has been generated by a squarewave for the message).

Fig 12-2

Figure 2: ZCD operation timing diagram

Recall from the theory of complex waveforms, pulse trains are actually made up of sinewaves and, in the case of Figure 2, a DC voltage. The size of the DC voltage is affected by the pulse train’s duty cycle. The greater its duty cycle, the greater the DC voltage.

That being the case, when the FM signal in Figure 2 switches between the two frequencies, the DC voltage that makes up the rectangular wave out of the ZCD changes between two values. In others words, the DC component of the rectangular wave is a copy of the message signal that produced the FM signal in the first place. Recovering this copy is a relatively simple matter of picking out the changing DC voltage using a low-pass filter.

Importantly, this demodulation technique works equally well when the message is a sinewave or speech.

## 1.2 Implement: Setting up the FM Modulator

For this experiment you’ll use the Emona Communications board to generate an FM signal using a VCO. Then you’ll set-up a zero-crossing detector and verify its operation for variations in the message’s amplitude.

It should take you about 50 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. |

|  |  |
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| 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 | 10us/div |
| Trigger | Analog Edge, Chan 1, Rising |
| Probe Attenuation | 1x |

|  |  |
| --- | --- |
| 6. | Use the ELVIS III Function Generator output Channel 2 to create a DC voltage of about 1V by loading the Custom waveform file “ECB\_positive1V\_DC.csv”. |

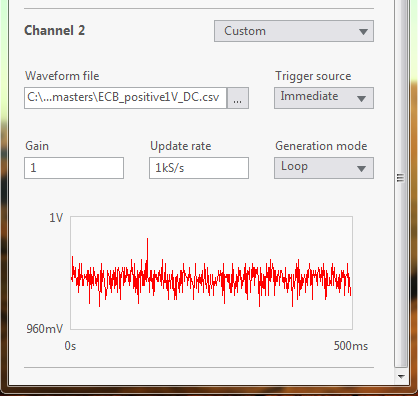


Figure 3: Setting up DC voltage using Function Generator

|  |  |
| --- | --- |
| 7. | Connect the set-up shown in Figure 4. |

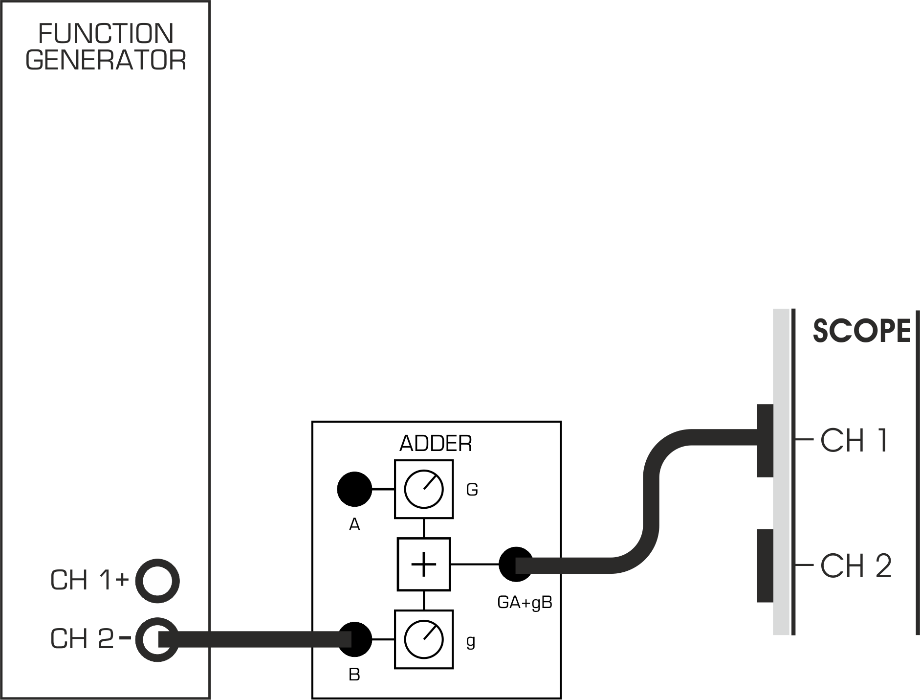


Figure 4: Patching to create variable DC voltage

|  |  |
| --- | --- |
| 8. | Locate the Adder module on the board and turn its *G* control fully anti-clockwise. This branch is not used. |

|  |  |
| --- | --- |
| 9. | Adjust the Adder module’s *g* control to obtain a 2V DC output (as measured using the Scope). |

|  |  |
| --- | --- |
| 10. | Patch the 2V DC voltage out of the ADDER into the VCO input and set the VCO *GAIN* control to minimum (fully anti-clockwise). |

|  |  |
| --- | --- |
| 11. | Activate the scope’s Channel 2 input to view the FM signal on the VCO’s output as well as the DC message signal on Channel 1. Trigger the scope on Channel 2 so the sinewave is stable (set Trigger Source to Channel 2). |
| 12. | Adjust the VCO carrier frequency to 85kHz using the *FREQ* control, while ensuring that the VCO’s *GAIN* is minimum. This sets the FM modulator’s resting frequency to be 85kHz. |

This set-up can be represented by the block diagram in Figure 5. The positive voltage output from the Function Generator and the Adder module are being used to provide a simple DC message and the VCO implements the FM modulator with a carrier frequency of 85kHz.

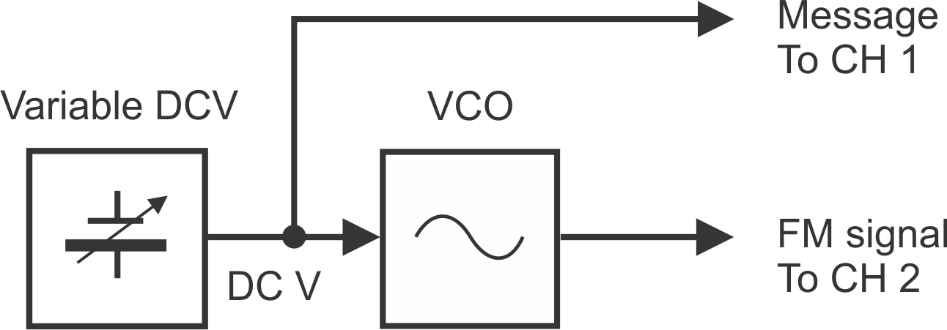


Figure 5: DC input into VCO module

|  |  |
| --- | --- |
| 13. | Vary the VCO input’s *GAIN* control from minimum (zero) and confirm that the VCO’s output frequency changes accordingly i.e.: increases with voltage |
| 14. | Vary the VCO input’s *GAIN* control to give an output frequency of about 100kHz for the input control voltage of +2V. Do NOT vary this *GAIN* control from now on. |

## 1.3 Implement: Setting up the zero-crossing detector

|  |  |
| --- | --- |
| 1. | Locate the Tuneable Low-pass Filter module on the board and turn its *GAIN* control fully clockwise (maximum gain). |

|  |  |
| --- | --- |
| 2. | Turn the Tuneable Low-pass Filter module’s TUNE control fully clockwise (maximum passband). |

|  |  |
| --- | --- |
| 3. | Modify the set-up as shown in Figure 6. |

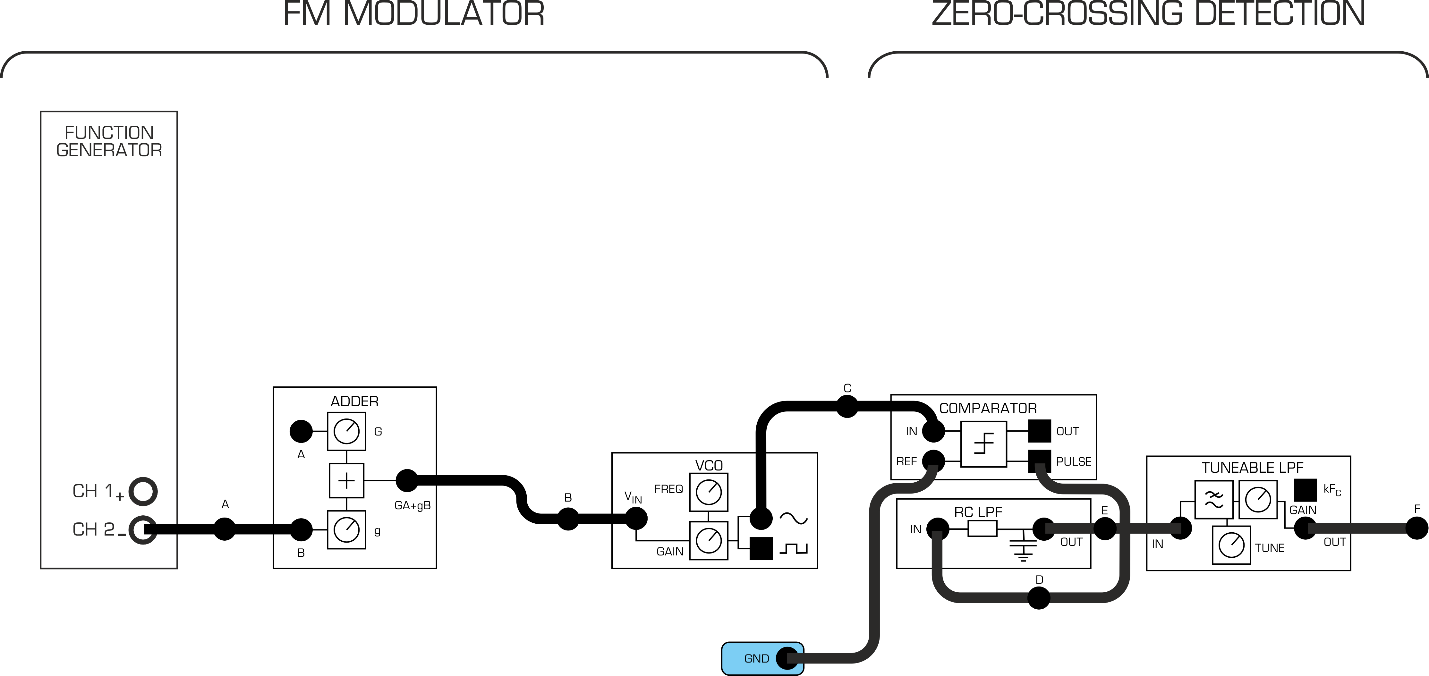


Figure 6: Patching for FM modulator and demodulator

The additions to the set-up can be represented by the block diagram in Figure 7. The Comparator module is used to clip the FM signal at the zero-volt level, effectively turning it into a squarewave which is independent of amplitude. The Comparator module also has a built-in PULSE output which triggers a fixed length pulse (monostable pulse) on the negative edge of the squarewave output. This implements the zero-crossing detector function (ZCD) in Figure 7. To complete the FM demodulator, the RC Low-pass Filter module and Tuneable Low-pass Filter module combination is used to pick-out the changing DC component of the ZCD’s PULSE output.

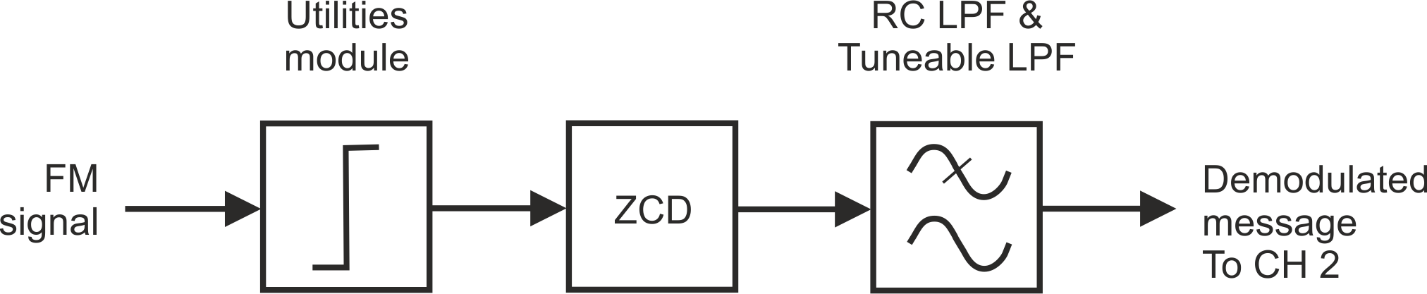


Figure 7: Block diagram for FM demodulation

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  | **Note:** The RC LPF and Tuneable LPF modules are used in combination because the Tuneable LPF is a clocked “switched capacitor” filter which uses internal sampling technology. These types of filters are subject to *aliasing* (a concept that is covered in later experiments) which can cause problems in sampled systems. To avoid such problems, we use the RC LPF as an *anti-aliasing* pre-filter for the Tuneable LPF. If time permits, explore this part of the experiment without the RC LPF. |  |
|  |  |  |

The entire set-up can be represented by the block diagram in Figure 8.

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| 4. | View the output signal from the RC LPF (point E in Figure 6). Its input is a narrow pulse repeating at approximately 98kHz. |

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| --- | --- | --- | --- |
| 1-1 Why does the output from the RC LPF still contain high frequency components from the squarewave input?   |  | | --- | |  | |  | |  | |

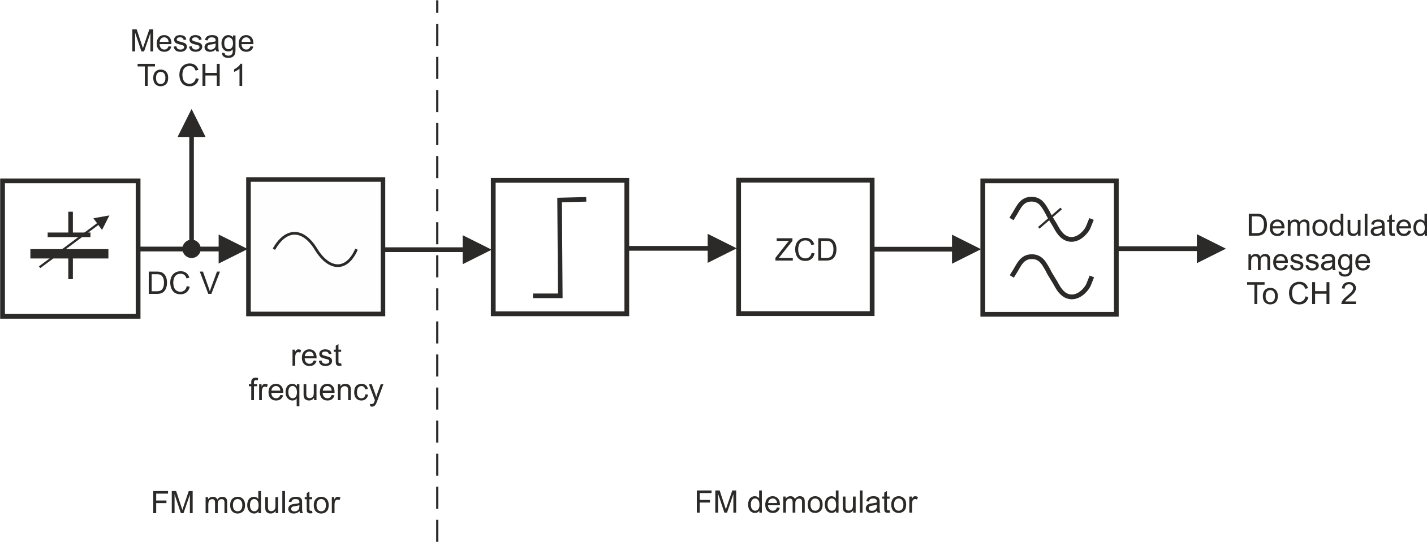


Figure 8: Block diagram for FM modulation and demodulation

You will now use the Tuneable Low-pass Filter to isolate the DC component of the ZCD for the voltage range of the input signal we plan to use.

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| --- | --- |
| 5. | Keep the Vin voltage at +2V DC with the VCO output frequency at about 100kHz. |

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| --- | --- |
| 6. | Set the scope’s Channel 2 *Scale* control to the *1V/div* position and connect it to the output of the RC LPF module.  **Note:** You should now see a 250mVp-p wave with a DC offset of approximately 2V. This is the filtered pulse train out of the ZCD by the RC LPF only. |

|  |  |
| --- | --- |
| 7. | Now move the Channel 2 scope lead to view the output of the TUNEABLE LPF (at point F in Figure 6). Confirm that you now see a steady DC voltage. Any variations have been attenuated by this filter.  **Note 1:** You have now eliminated all non-DC components from this signal. That said, the filter will still allow the message signal to pass because only the higher frequency components from the squarewave have been eliminated.  **Note 2:** You do not need to reduce the cutoff frequency of the TUNEABLE LPF because its maximum passband frequency is still much lower than the components from the squarewave. |

|  |  |
| --- | --- |
| 8. | Vary the ADDERs GAIN control between minimum and maximum which changes the Vin voltage to the VCO between 0V and about +2V.  **Note 1:** As you do, you should notice that the DC voltage out of the Tuneable Low-pass Filter module varies as well. This variation is slight so look closely. The duty cycle of the ZCD output will vary as well.  **Note 2:** If this doesn’t happen, check that the scope’s Channel 1 *Coupling* control is set to the DC position. |

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| 9. | Now to investigate the VCO output for a negative going Vin voltage. |

|  |  |
| --- | --- |
| 10. | Using the ELVIS III Function Generator, output Channel 2 which is currently loaded with “ECB\_positive1V\_DC.csv”. To create a negative voltage out of the Function Generator set the Function Generator Gain setting to -1. This will output a -1V DC voltage into the ADDER module. Set the ADDER module’s GAIN control to change the Vin voltage to the VCO to about -2V. |

|  |  |
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| 11. | Confirm that the VCO output frequency is now lower than its resting frequency of 85kHz and is about 70kHz. As you would expect, a negative going Vin causes the VCO frequency to reduce to below its resting frequency. |

|  |  |
| --- | --- |
| 12. | Return to a positive voltage for Vin, by resetting the Gain setting in the Function generator window to +1. |

## 1.4 Implement: Investigating the operation of the zero-crossing detector

The next part of the experiment lets you verify the operation of the zero-crossing detector.

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| --- | --- |
| 1. | Rearrange the scope’s connections to the set-up as shown in Figure 9. Connect scope Channels 1 and 2 to point C and the Comparator OUT port. |

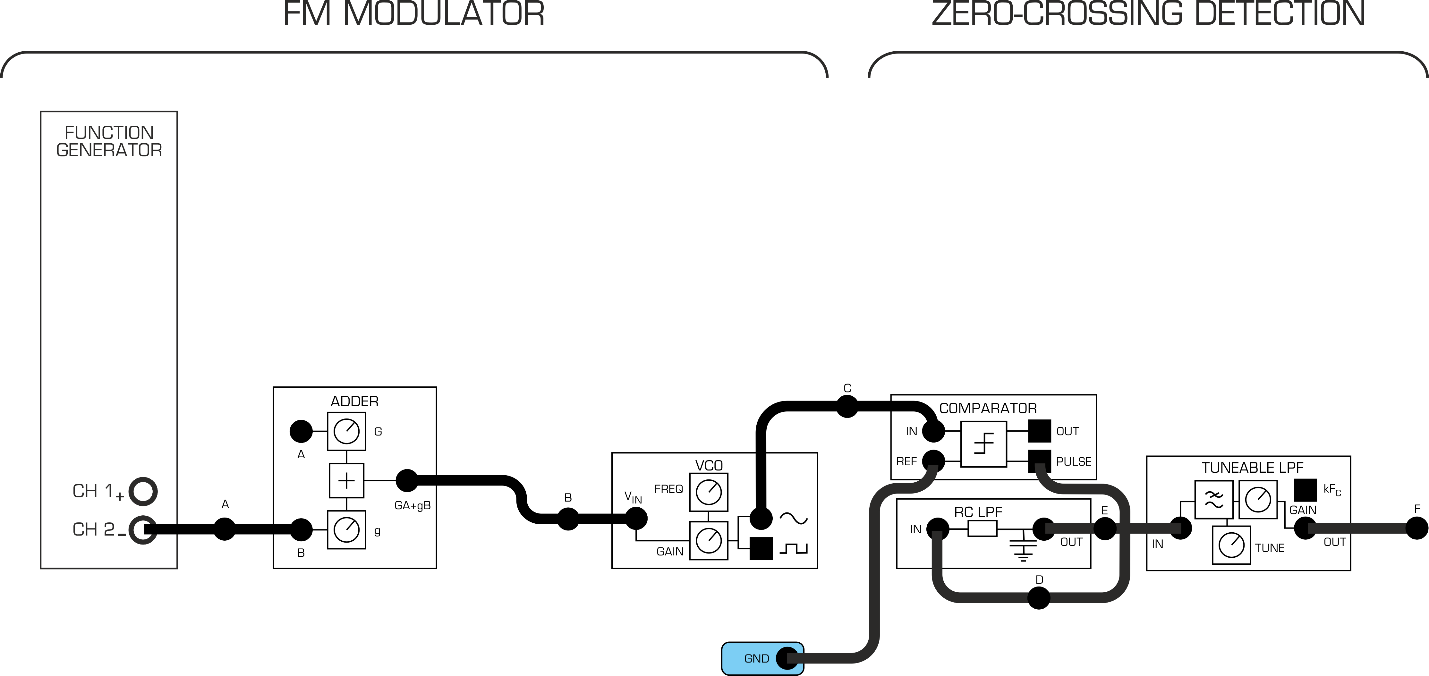


Figure 9: Patching for FM modulator and demodulator

The new scope connections can be shown using the block diagram in Figure 10.

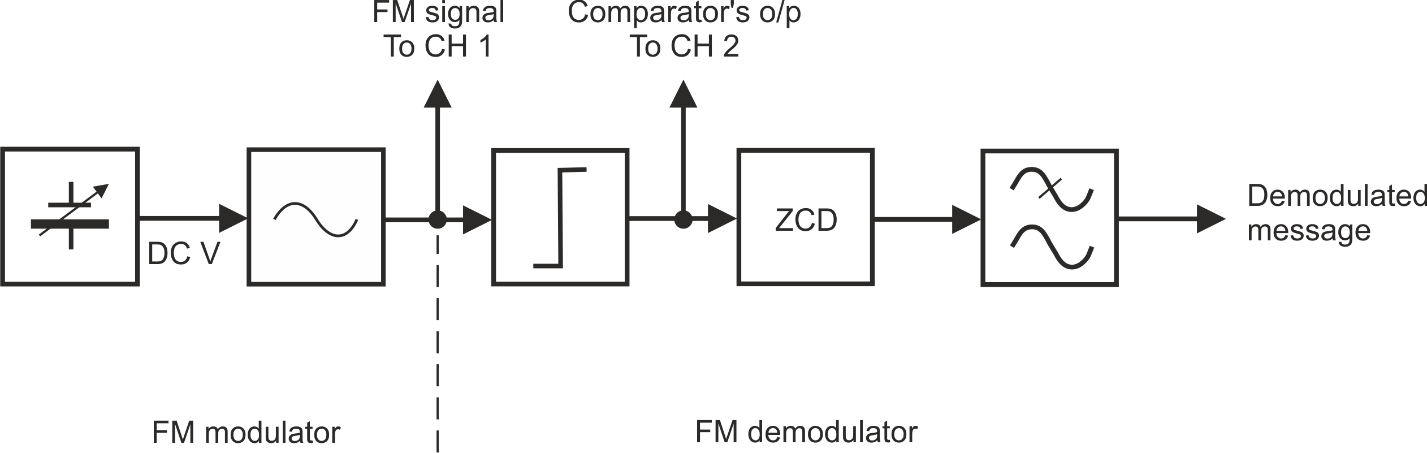


Figure 10: Block diagram for viewing Comparator

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| --- | --- |
| 2. | Vary the ADDER GAIN which changes the Vin voltage.  **Note:** This will cause small but noticeable changes in the FM signal’s frequency. |

|  |  |
| --- | --- |
| 3. | As you vary the FM signal’s frequency, pay close attention to the mark-space ratio (that is, the duty cycle) of the Comparator’s output.  **Tip:** You may find it helpful to adjust the scope’s *Vertical Position* controls to separate the signals on the display. |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 1-2 Does the mark-space ratio of the signal on the Comparator’s output change?   |  | | --- | |  | |  | |  | | |
| 1-3 What does this tell us about the DC component of the comparator’s output?   |  | | --- | |  | |  | |  | | |
| 4. | | Rearrange the scope’s connections to the set-up as shown in Figure 11. Connect the scope Channels 1 and 2 to point D and the Comparator OUT port. |

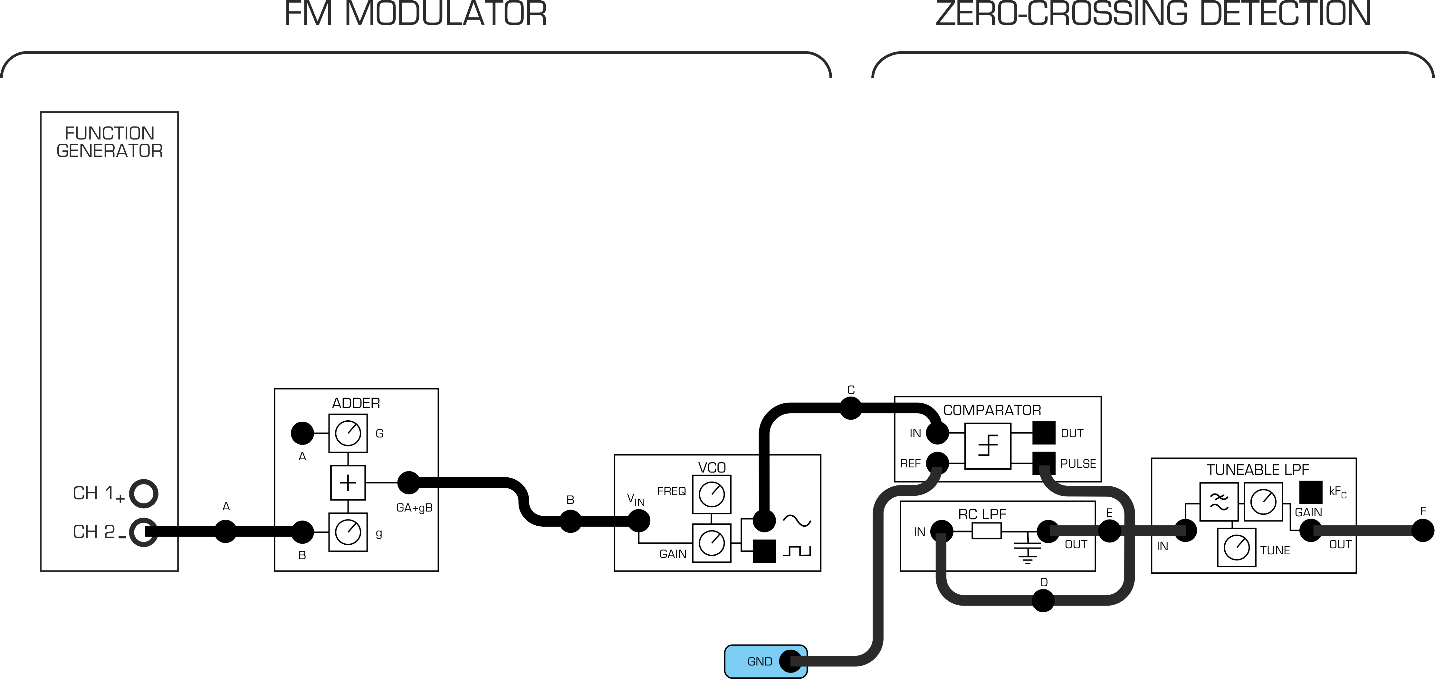


Figure 11: Patching for FM modulator and demodulator

The new scope connections can be shown using the block diagram in Figure 12.

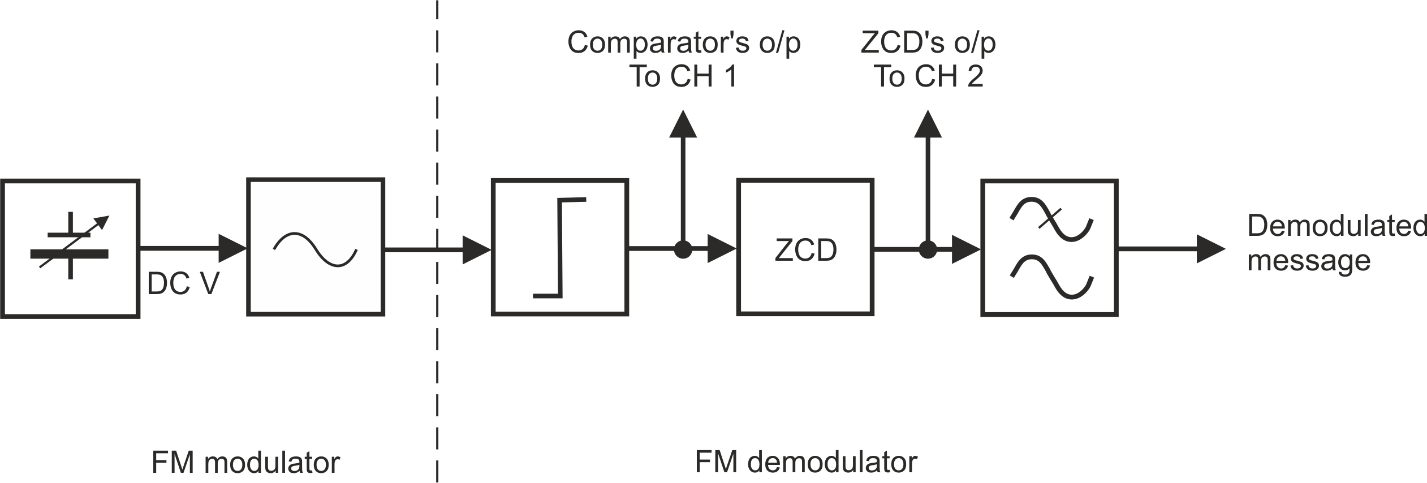


Figure 12: Block diagram for viewing Zero Crossing Detector

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| 5. | Vary the ADDER GAIN which changes the Vin voltage to model and changing message voltage in. |
| 6. | As you perform the step above, note how the frequency of the two signals changes. |

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| 7. | Turn on the scope’s cursors. |
| 8. | Use the scope’s cursors to measure the width of the ZCD output’s mark and space for different DC input voltages.  **Note:** The time difference between the two cursors is displayed directly above the Channel 1 & 2 measurements and is denoted as *dT*.  **Tip:** You may find it helpful to turn the scope’s Channel 1 off as you do this and set its *Timebase* control to *10µs/div* when measuring the mark’s width. |

|  |  |  |  |
| --- | --- | --- | --- |
| 1-4 As the FM signal changes frequency so does the ZCD’s output. What aspect of the ZCD’s output signal changes to achieve this?   |  | | --- | |  | |  | |  | |
| 1-5 What does this tell us about the DC component of the comparator’s output?   |  | | --- | |  | |  | |  | |

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| 9. | If you deactivated the scope’s Channel 1 then reactivate it and return its *Timebase* control to *50µs/div*. |

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| --- | --- |
| 10 | Rearrange the scope’s connections to the set-up as shown in Figure 13. IMPORTANT: Use the scope Channels 1 and 2 to view points D and F of Figure 13. |

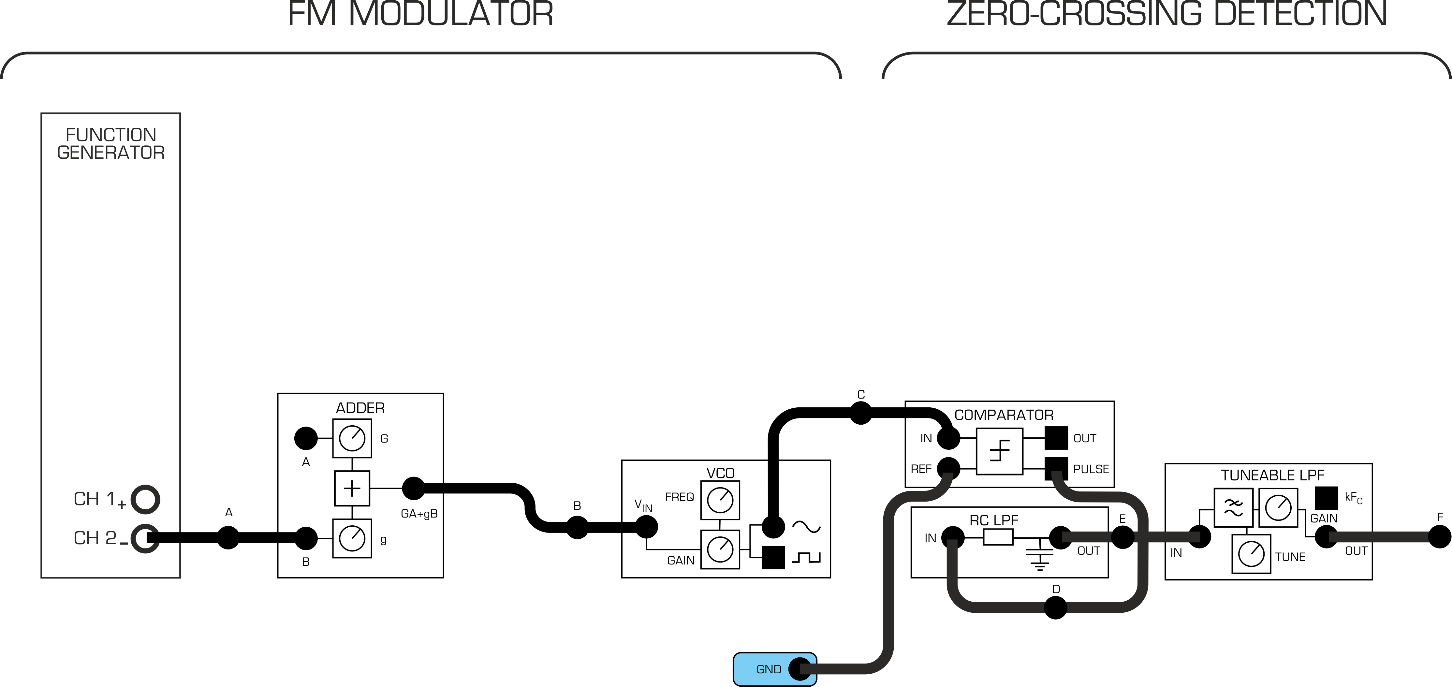


Figure 13: Patching for FM modulator and demodulator

The new scope connections can be shown using the block diagram in Figure 14.

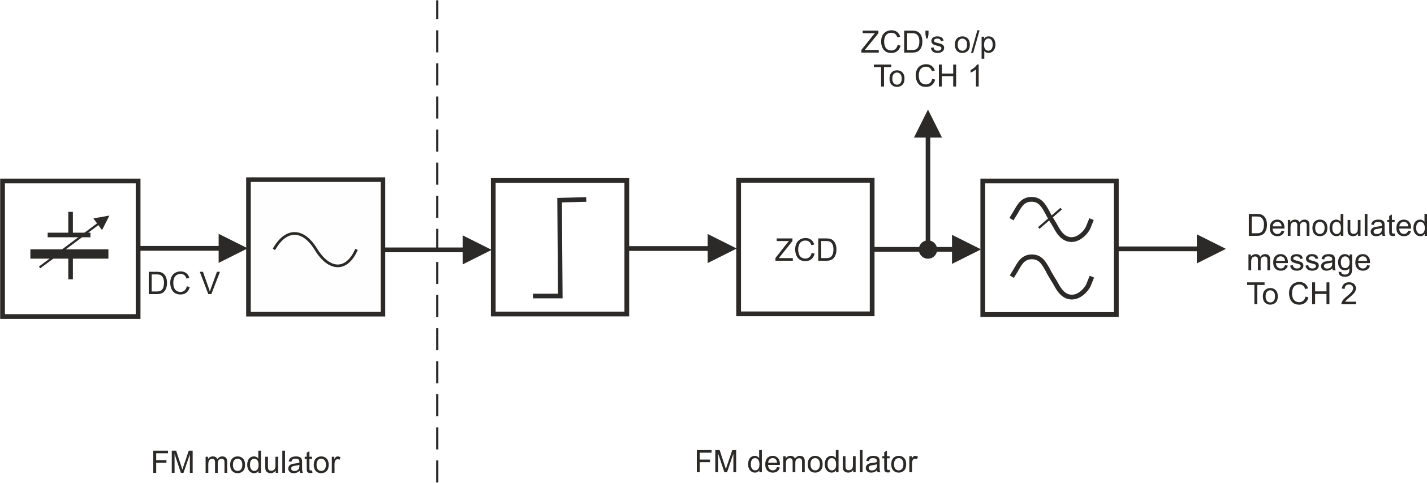


Figure 14: Block diagram for viewing Filtering

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| 11. | If you’ve adjusted the scope’s Channel 2 *Vertical Position* control, re-zero it. |

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| 12 | Vary the ADDERs GAIN control in small steps again to model an FM signal’s changing frequency. |

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| 13 | As you perform the step above, compare the outputs from the ZCD (at the PULSE output terminal) and the Tuneable Low-pass Filter module. |

1-6 Why does the Tuneable Low-pass Filter module’s DC output go up as the mark-space ratio of the ZCD’s output goes up?

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1-7 If the original message is a sinewave instead of a variable DC voltage, what would you expect to see out of the Tuneable Low-pass Filter module and why?

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## Section 2: Transmitting and recovering a sinewave using FM

This experiment has set up an FM communication system to “transmit” a message that is a DC voltage which varies from -2V to +2V. The next part of the experiment lets you use the set-up to modulate, transmit and demodulate a test signal (a sinewave).

|  |  |
| --- | --- |
| 1. | If it’s not already, turn the Tuneable Low-pass Filter module’s *Gain* control fully clockwise. |

|  |  |
| --- | --- |
| 2. | Modify the set-up as shown in Figure 15. |

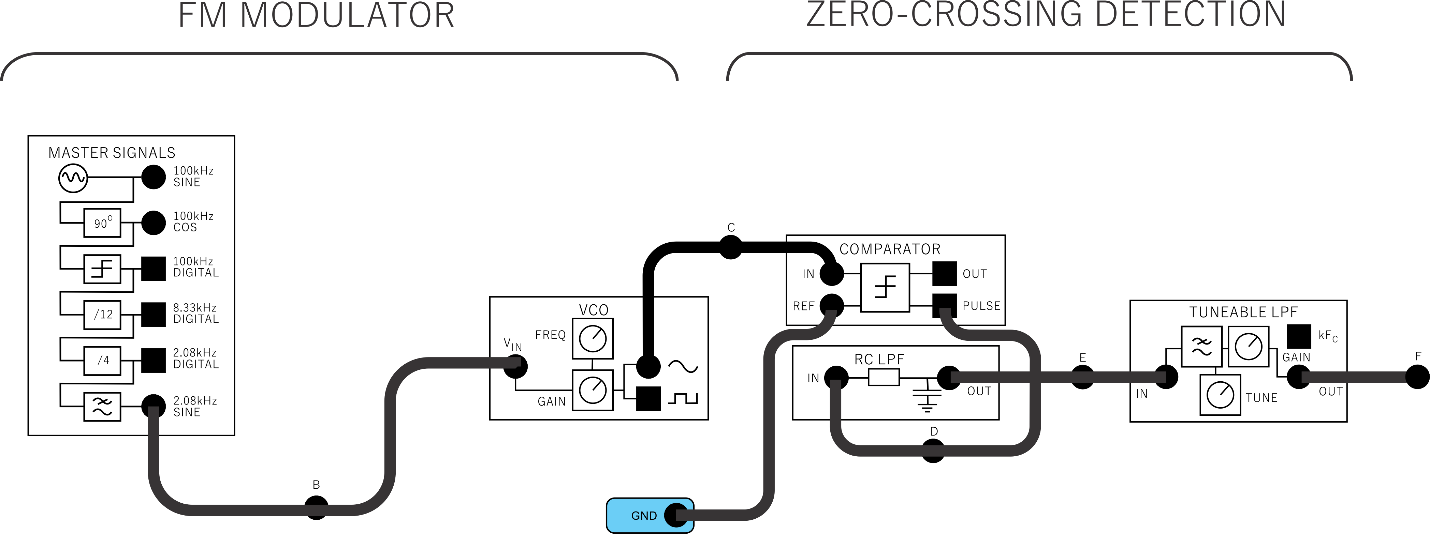


Figure 15: Patching for sinewave input signal

This modification to the FM modulator only, can be shown using the block diagram in Figure 16. Notice that the message is now provided by the Master Signals module’s *2.08kHz SINE* output. View this signal at point B with Channel 1 on the scope.

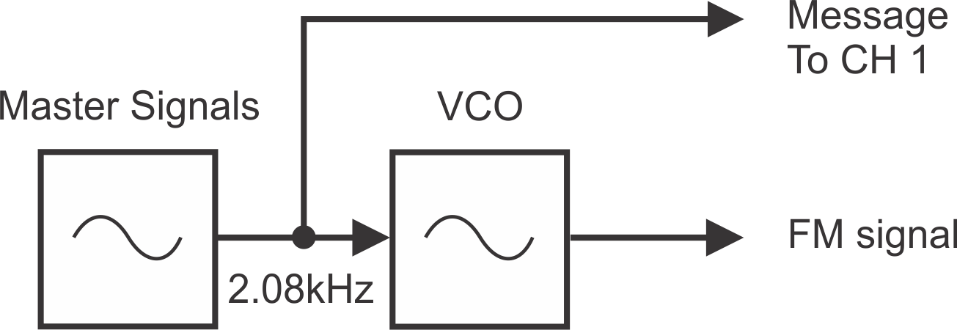


Figure 16: Block diagram for sinewave input to modulator

|  |  |
| --- | --- |
| 3. | Make the following adjustments to the scope’s controls:   1. *Scale* control for Channel 0 to *1V/div* and to *1V/div* for Channel 1 2. *Input Coupling* control for both channels to *AC* 3. *Trigger Type* to *Analog Edge* 4. *Trigger Source* to *Channel 1* 5. *Timebase* control to *200µs/div* |

|  |  |
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| 4. | Without needing to vary the TUNEABLE LPFs cutoff frequency you will already be viewing the demodulated 2.08kHz message sinewave with an amplitude of approximately 500mVp-p (at point F) |

2-1 What does the FM modulator’s output signal tell you about the ZCD signal’s duty cycle?

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## Section 3: Transmitting and recovering speech using FM

The next part of the experiment lets you use the set-up to modulate, transmit and demodulate speech.

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| 5. | Disconnect the plugs to the Master Signals module’s *2.08kHz SINE* output. |

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| 6. | Modify the set-up as shown in Figure 18. You will replace the sinewave input signals with a Speech signal from the microphone module. Continue to view the input message at point B, as well as the output at point F of Figure 18. |

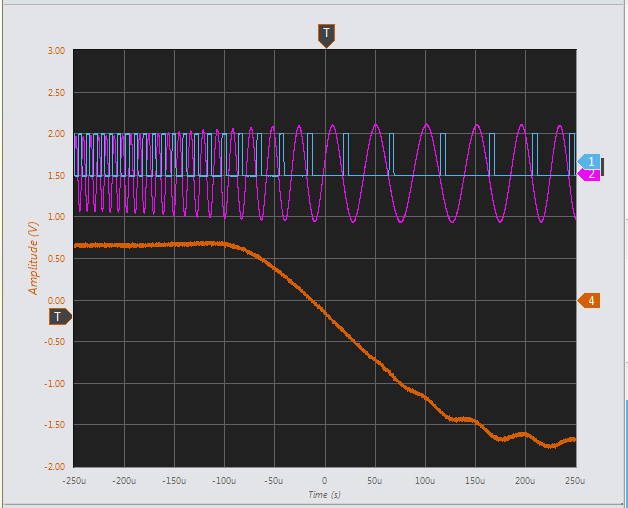


Figure 17: Example signals for FM, ZCD and demodulated output

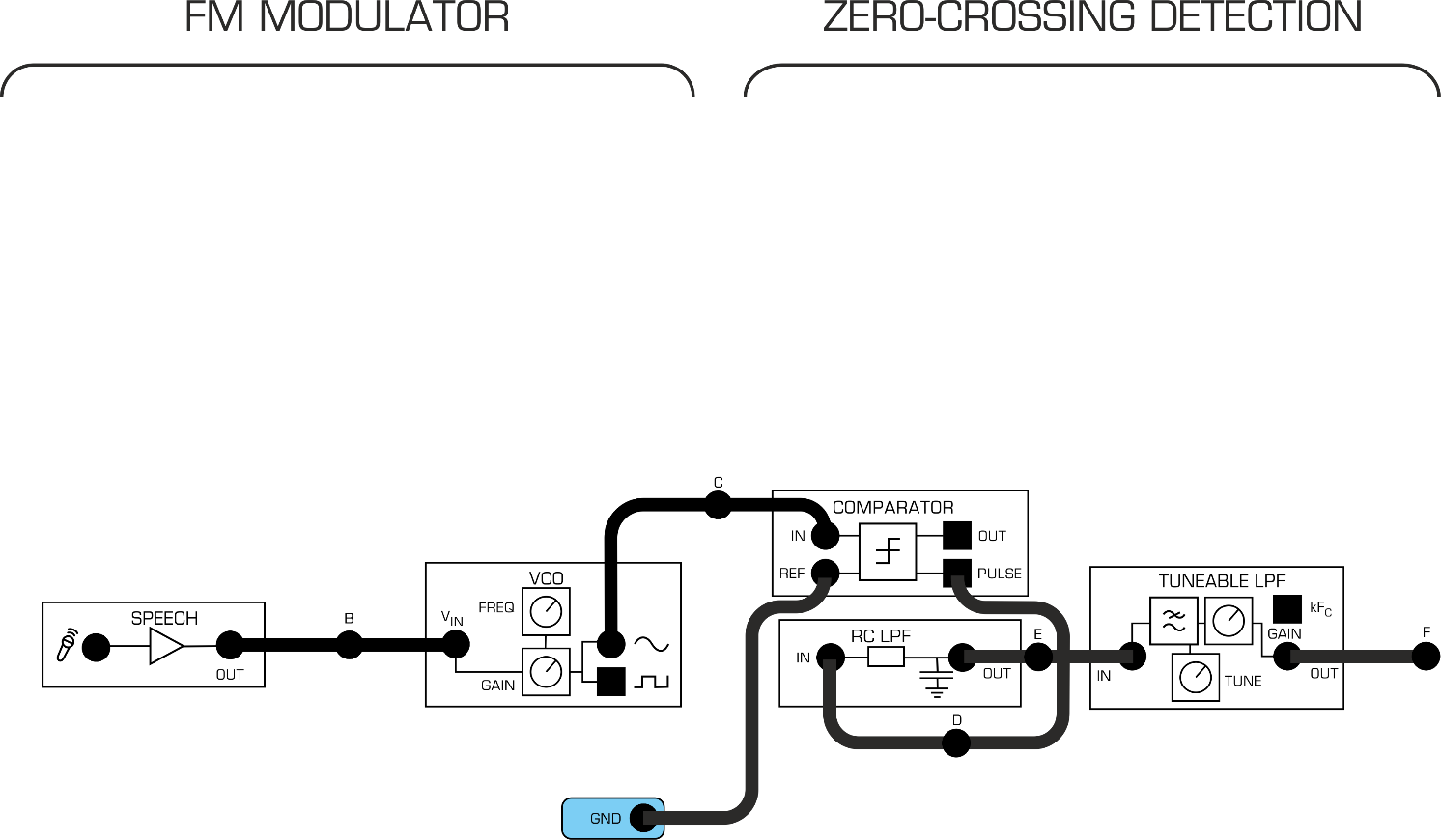


Figure 18: Patching for speech input to modulator

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| 7. | Set the scope’s *Timebase* control to the *2ms/div* position. |

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| 8. | Locate the Amplifier & Headphone Output module on the board and turn its *Gain* control fully anti-clockwise to minimum. |

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| 9. | Without wearing the headphones, plug them into the Amplifier & Headphone Output module’s headphone socket. |

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| 10. | Put the headphones on. |
| 11. | As you perform the next step, set the Amplifier & Headphone Output module’s *Gain* control to a comfortable sound level. |

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| 12. | Hum and talk into the microphone while watching the scope’s display and listening on the headphones. |

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| 13. | Once you have completed viewing the signal with the scope, open the FFT mode on the scope to view the spectrum of the frequency modulated speech (at point C of Figure 18). Try whistling into the microphone. This will help you to see the difference between single tones and speech during modulation. |