

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



Lab 5: Amplitude Demodulation

List of Updates

|  |  |
| --- | --- |
| **Date** | **Details** |
| 4/1/2018 | Completed final document |
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# Lab 5: Amplitude demodulation

In this Lab you will recover a variety of messages from an amplitude modulated carrier signal using two methods and develop an understanding of the demodulation process in the time and frequency domains.

If you’ve completed Experiment 4 then you’ve seen what happens when a 2.08kHz sinewave is used to amplitude modulate a carrier to produce an AM signal. Importantly, you would have seen a key characteristic of an AM signal – its envelopes are the same shape as the message (though the lower envelope is inverted).

Recovering the original message from a modulated carrier is called *demodulation* and this is the main purpose of communications and telecommunications receivers. The circuit that is widely used to demodulate AM signals is called an *envelope detector*. The block diagram of an envelope detector is shown in Figure 1 below.

Fig 8-1

Figure 1: Block diagram of AM demodulation

As you can see, the rectifier stage chops the AM signal in half letting only one of its envelopes through (the upper envelope in this case but the lower envelope is just as good). This signal is fed to an RC LPF which tracks the peaks of its input. When the input to the RC LPF is a rectified AM signal, it tracks the signal’s envelope. Importantly, as the envelope is the same shape as the message, the RC LPF’s output voltage is also the same shape as the message and so the AM signal is demodulated.

A limitation of envelope detector shown in Figure 1 is that it cannot accurately recover the message from over-modulated AM signals. To explain, recall that when an AM carrier is over modulated the signal’s envelope is no-longer the same shape as the original message. Instead, the envelope is distorted and so, by definition, this means that the envelope detector must produce a distorted version of the message.

## Learning Objectives

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

1. Generate a real AM signal
2. Examine a real AM signal with scope and compare it to its original message
3. Use multiple message sources in your AM examination
4. Demodulate an AM signal using two different methods
5. Describe the effects and meaning of over- and under-modulation of the carrier
6. Compare original and demodulated signals
7. Explain the term” product modulation” as well as the math.

## Prerequisites

You should have completed Lab 1 & 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> |
| 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: Amplitude modulation (AM)

## 1.1: Theory and background

For this experiment you’ll use the EMONA Communications board (ECB) to generate an AM signal by implementing its mathematical model. Then you’ll set up an envelope detector using the *Diode* and *RC LPF* on the ECB’s Utilities module.

After completing these steps, you’ll connect the AM signal to the envelope detector’s input and compare the demodulated output to the original message and the AM signal’s envelope. You’ll also observe the effect that an over-modulated AM signal has on the envelope detector’s output.

Finally, if time permits, you’ll demodulate the AM signal by multiplying it with a local carrier instead of using an envelope detector.

It should take you about 60 minutes to complete this experiment.

## 1.2 Implement: Setting up the AM modulator

You will now build a model of the system being studied and explore its performance.

**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 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 board 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, Channel 1, Rising |
| Probe Attenuation | 1x |

To experiment with AM demodulation, you’ll need to generate an AM signal. The first part of the experiment gets you to set one up.

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| --- | --- |
| 6. | Use the ELVIS III Function Generator *Channel 2* output to create a DC voltage of about 1V by loading the Custom waveform file “ECB\_positive1V\_DC.csv”. Set the Update Rate to 100kS/s and click the *Run* button to start the Generator. |
| 7. | Connect the Function Generator *Channel 2* to input B of the ECB Adder module on the ECB. |
| 8. | Connect *Channel 1* of the scope to the output of the Adder module on the ECB. |
| 9. | Turn the Adder module’s *G* control fully anti-clockwise. |
| 10. | Adjust the Adder module’s *g* control to obtain about 1V DC output as measured by the scope. |
| 11. | Connect the set-up shown in Figure 2. |

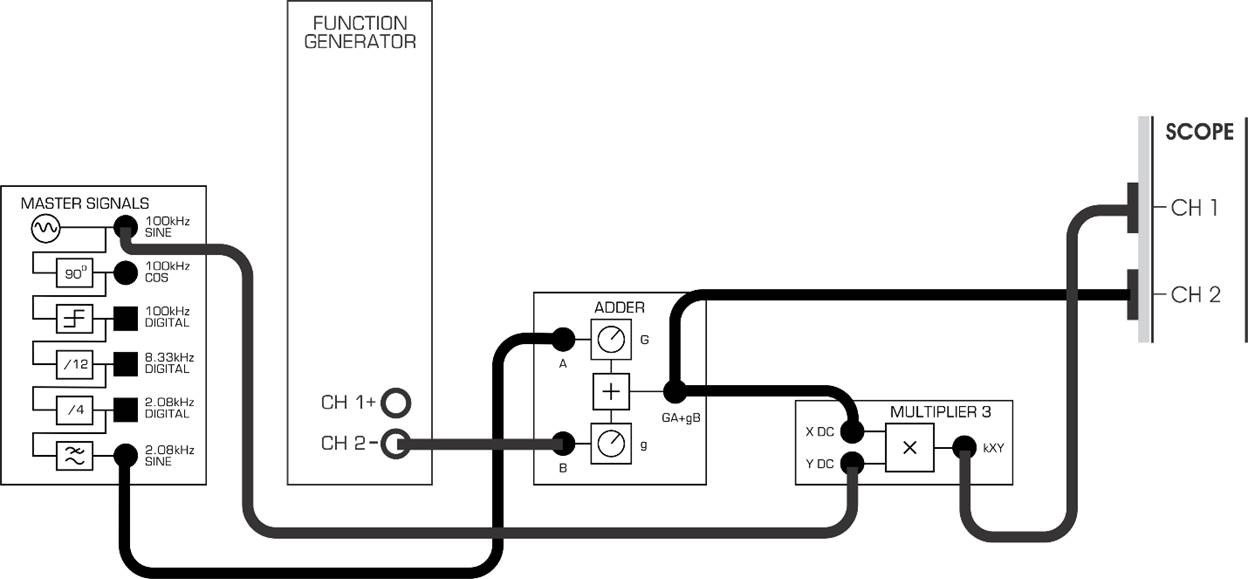


Figure 2: Setting up an AM signal

|  |  |
| --- | --- |
| 10. | Set up the scope as per following:   1. Display Channel 1 2. Channel 1 *Coupling* to *DC* 3. Channel 1 *Scale* (Volts per Division) control to the *500mV/div* position instead of *1V/div* 4. *Trigger Level* control to the *1V* position instead of *0V* |
| 11. | Adjust the Adder module’s *G* control to obtain a 1Vp-p sinewave. |
| 12. | Adjust the scope’s *Timebase* control to view about two cycles of the message signal. |
| 13. | Activate the scope’s *Channel 2* input to view the modulated carrier.  **Self check:** If the scope’s *Scale* control for *Channel 2* is set to the *1V/div* position, the scope should now display an AM signal with envelopes that are the same shape and size as the message. |

The set-up in Figure 2 can be represented by the block diagram in Figure 3. It generates a 100kHz carrier that is amplitude modulated by a 2.08kHz sinewave message.

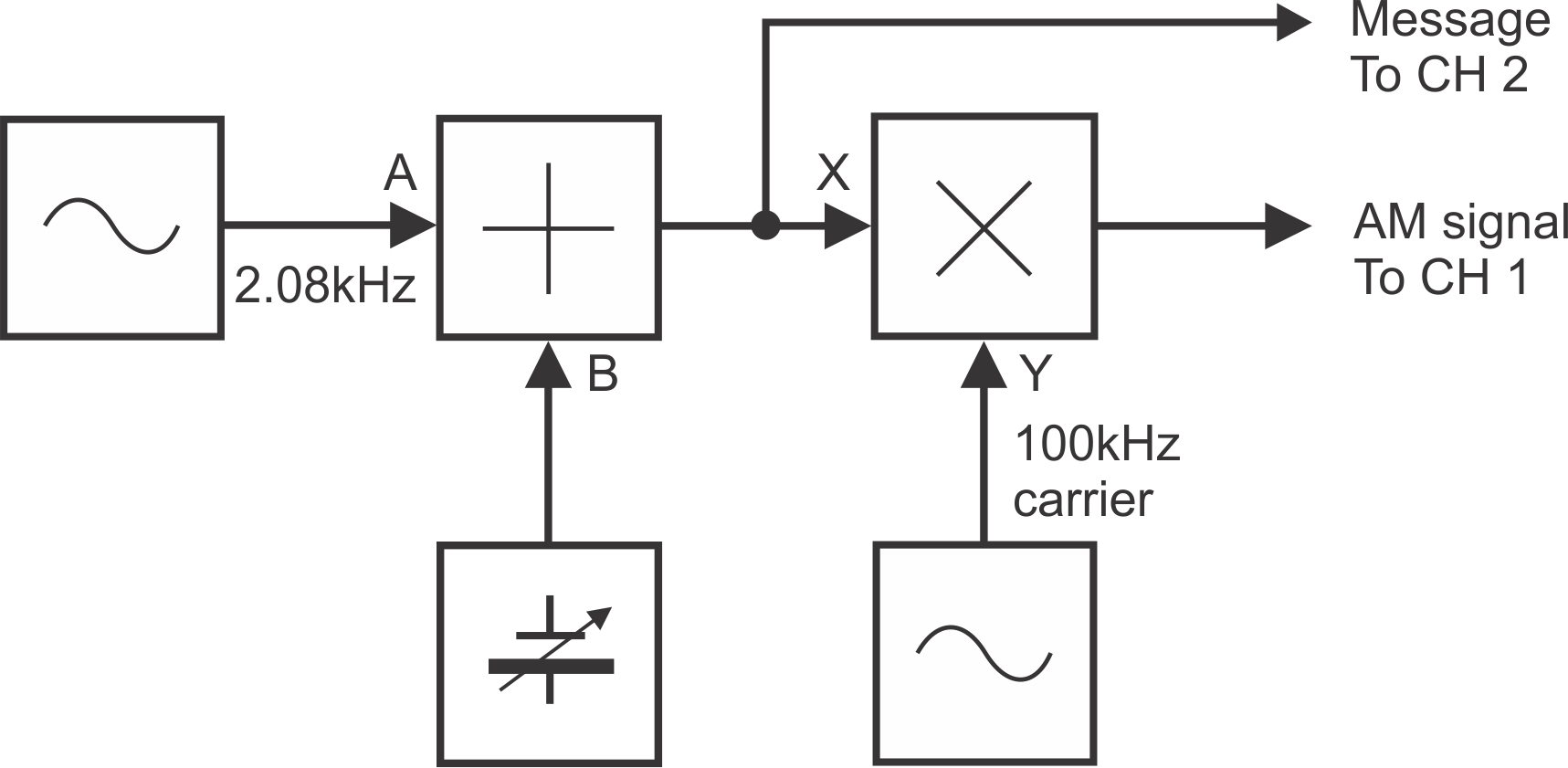


Figure 3: Block diagram for AM

1. Enable the FFT mode of the Oscilloscope instrument. Adjust the settings as per the example shown in Figure 4. Be aware that the FFT resolution is linked to the Scope’s horizontal timebase. Explore this relationship by playing around with the Time per division settings. You will find that you can either have an optimum time display or an optimum frequency display but not both at the same time.

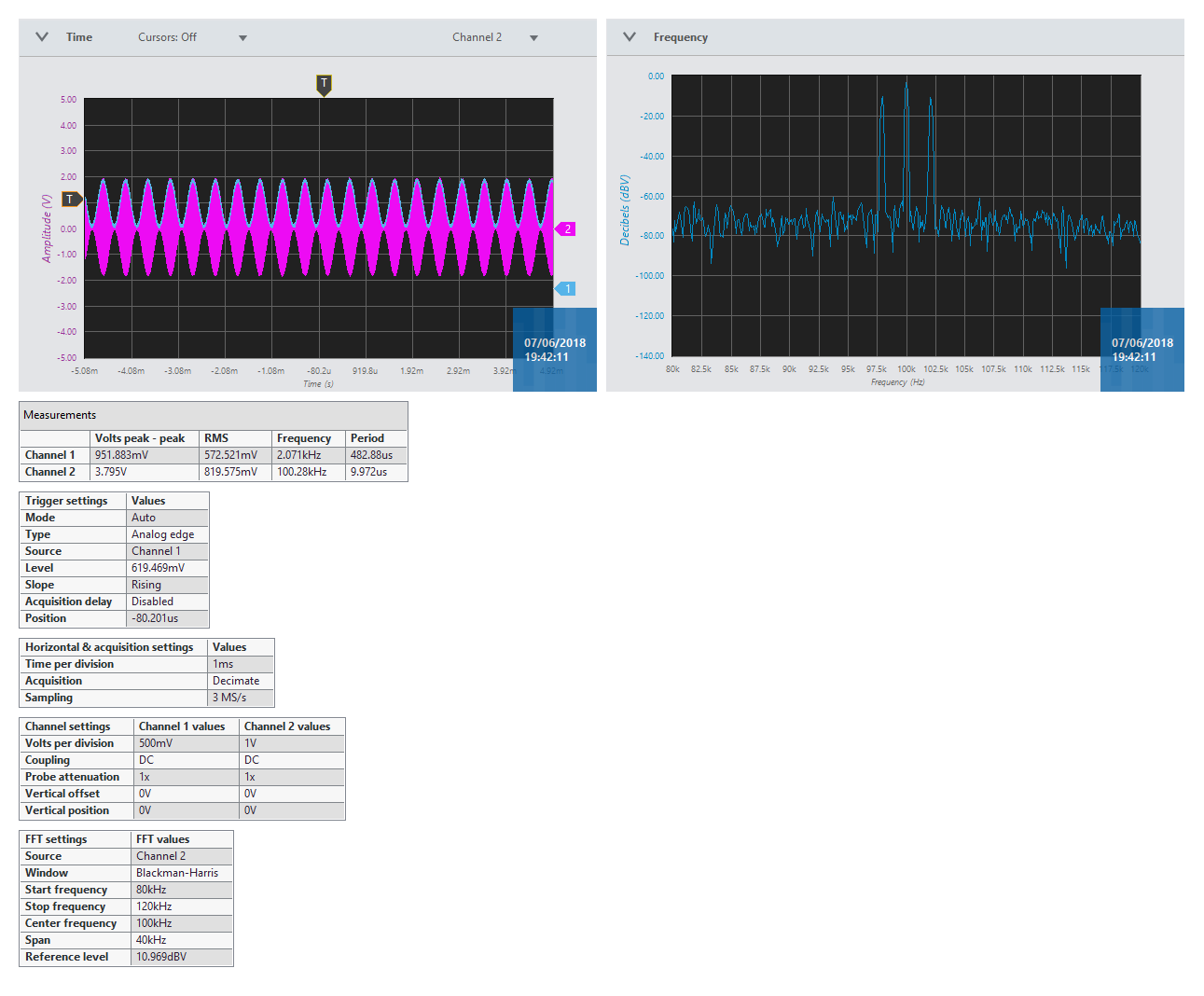


Figure : Example Scope and FFT capture for AM

The scope and FFT capture report in Figure 4 is obtained by pressing the “camera” icon in the top right of the Oscilloscope instrument panel. It conveniently records all the settings as well.

## 1.3 Implement: Recovering the message using an envelope detector

1. Modify the set-up as shown in Figure 5.   
     
   **Note:** Dotted lines show leads already in place.

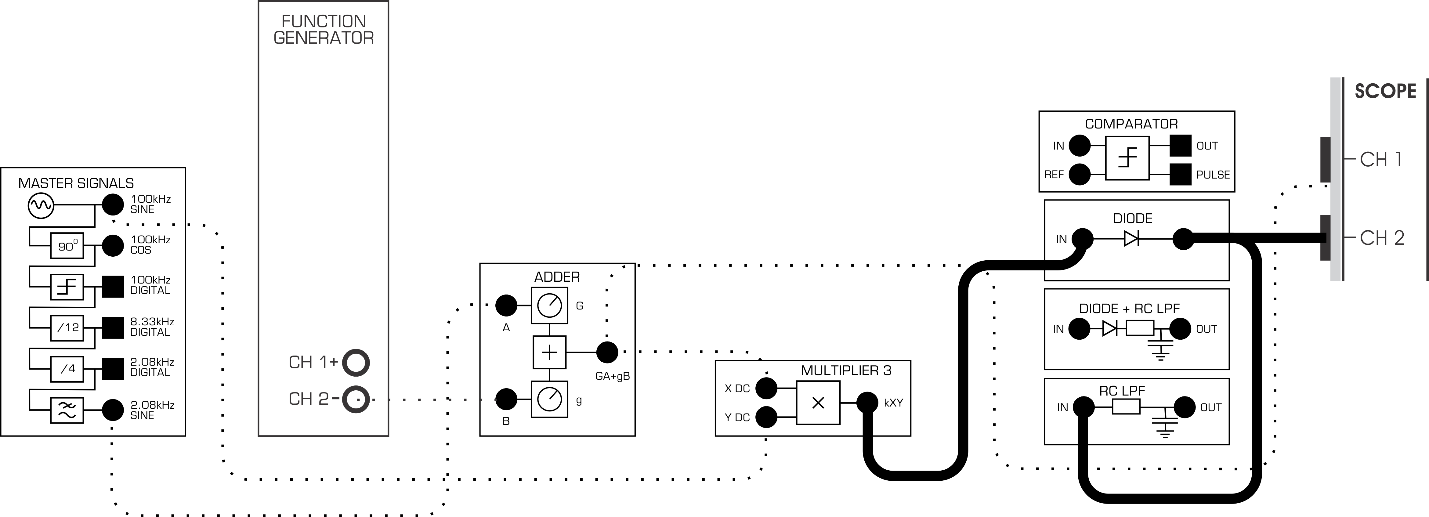


Figure 5: Using the envelope detector

The additions to the set-up can be represented by the block diagram in Figure 6. As you can see, it’s the envelope detector explained in the preliminary discussion.

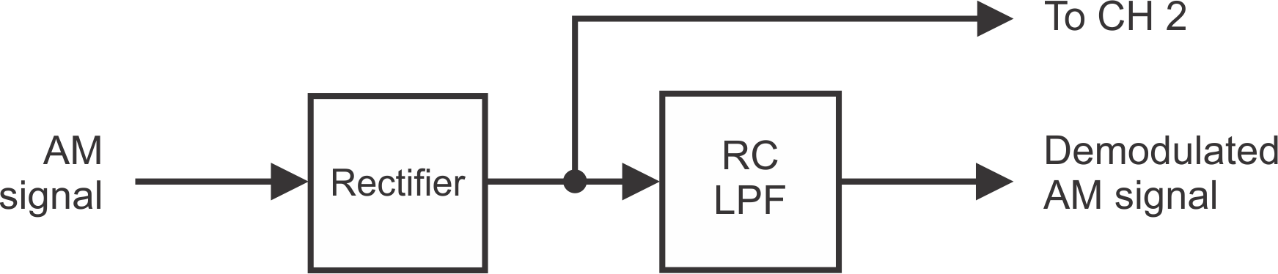


Figure 6: Block diagram for envelope detection

1. Adjust the scope’s *Scale* and *Timebase* controls to appropriate settings for the signals.
2. Disconnect the scope’s *Channel 2* input from the Diode’s output and connect it to the *RC LPF’s* output instead.
3. Capture a screenshot of the scope showing the recovered signal before and after the LPF 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. What is the relationship between the original message signal and the recovered message?

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## 1.4 Implement: Investigating the message’s amplitude on the recovered message

1. Vary the message signal’s amplitude up and down a little by turning the Adder module’s *G* control left and right. As you do so, watch the demodulated signal.
   1. What is the relationship between the amplitude of the two message signals?

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1. Slowly increase the message signal’s amplitude to maximum while watching the demodulated signal.
   1. What do you think causes the heavy distortion of the demodulated signal?   
        
      **Tip:** If you’re not sure, connect the scope’s *Channel 1* input to the AM modulator’s output.

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* 1. Why does over-modulation cause the distortion?

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## 1.5 Implement: Transmitting and recovering speech using AM

This experiment has set up an AM communication system to “transmit” a message that is a 2.08kHz sinewave. The next part of the experiment lets you use the set-up to modulate, transmit, demodulate and listen to speech.

1. If you moved the scope’s *Channel 1* input to help you answer Question 1-4, reconnect it to the Adder module’s output.
2. Return the message signal’s amplitude to 1Vpp by adjusting the Adder module’s *G* control.
3. Modify the set-up as shown in Figure 7. The change is simply moving the input from the 2.08kHz sine to the Speech output.

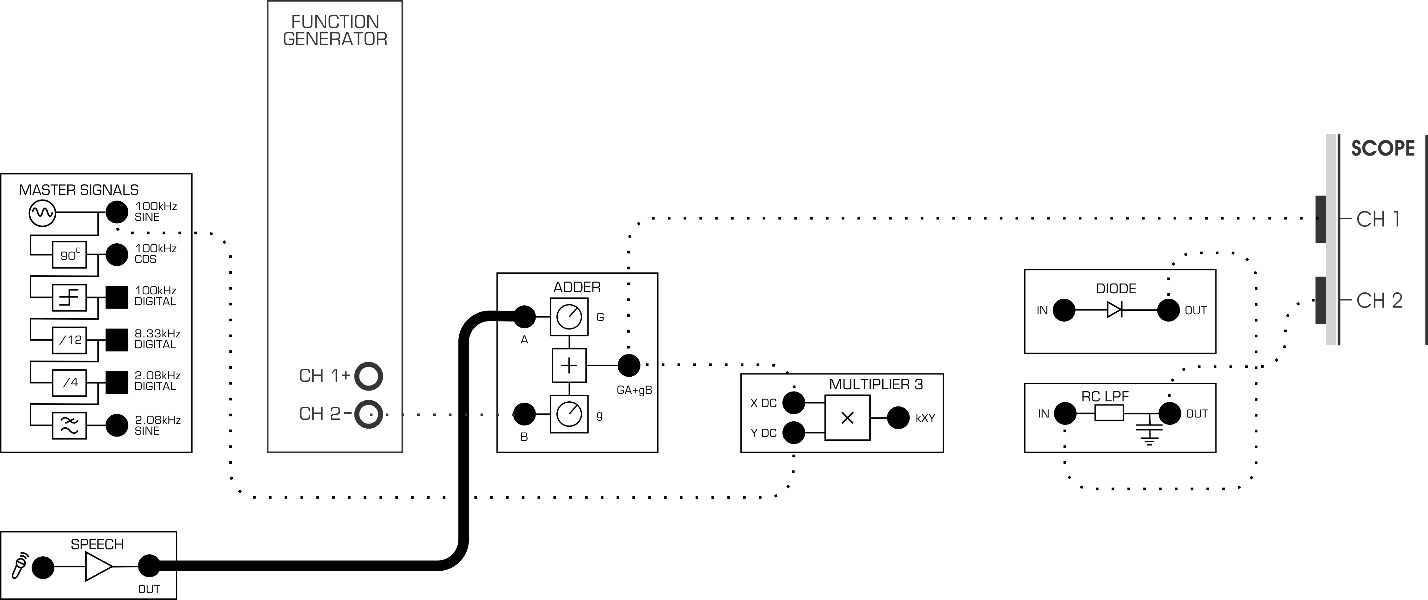


Figure 7: Using speech as a message

1. Set the scope’s *Timebase* control to the *2ms/div* position.
2. Connect the output of the RC LPF to the Amplifier modules input. Turn the Amplifier module’s *Gain* control fully anti-clockwise to minimum.
3. Without wearing the headphones, plug them into the Amplifier module’s headphone socket.
4. Put the headphones on.
5. As you perform the next step, set the Amplifier module’s *Gain* control to a comfortable sound level.
6. Hum and talk into the microphone while watching the scope’s display and listening on the headphones. Clapping near the microphone gives very clear distinct signals.

## Section 2: The mathematics of AM demodulation

AM demodulation can be understood mathematically because it is uses multiplication to reproduce the original message. To explain, recall that when two pure sinewaves are multiplied together (a mathematical process that necessarily involves some trigonometry that is not shown here) the result gives two completely new sinewaves:

1. One with a frequency equal to the sum of the two signals’ frequencies
2. One with a frequency equal to the difference between the two signals’ frequencies

The envelope detector works because the rectifier (diode) is a device that multiplies all signals on its one input with each other. Ordinarily, this is a nuisance but not for applications like AM demodulation. Recall that an AM signal consists of a carrier, the carrier plus the message and the carrier minus the message. So, when an AM signal is connected to a rectifier’s input, mathematically the rectifier’s cross multiplication of all of its sinewaves looks like:

Rectifier’s Output = Carrier × (Carrier + Message) × (Carrier – Message)

If the message signal used to generate the AM signal is a simple sinewave then, when the equation above is solved, the rectifier outputs six sinewaves at the following frequencies:

1. Carrier + (Carrier + Message)
2. Carrier + (Carrier - Message)
3. (Carrier + Message) + (Carrier - Message)
4. Carrier - (Carrier + Message) which simplifies to just the Message
5. Carrier - (Carrier - Message) which also simplifies to just the Message
6. (Carrier + Message) - (Carrier - Message)

To make this a little more meaningful, let’s do an example with numbers. The AM modulator that you set up at the beginning of this experiment uses a 100kHz carrier and a 2.08kHz message (with a DC component). So the resulting AM signal consists of three sinewaves: one at 100kHz, another at 102.08kHz and a third at 97.92kHz. Table 1 below shows what happens when these sinewaves are cross-multiplied by the rectifier.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **100kHz×102.08kHz** | **100kHz×97.92kHz** | **97.92kHz×102.08kHz** |
| **Sum** | 202.08kHz | 197.92kHz | 200kHz |
| **Difference** | 2.08kHz | 2.08kHz | 4.16kHz |

Table 1

Notice that two of the resulting sinewaves are at the message frequency. In other words, the message has been recovered! And, as the two messages are in phase, they simply add together to make a single bigger message.

Importantly, we don’t want the other non-message sinewaves so, to reject them but keep the message, the rectifier’s output is sent to a low-pass filter. Ideally, the filter’s output will only consist of the message signal. The chances of this can be improved by making the carrier’s frequency much higher than the highest frequency in the message. This, in turn, makes the frequency of the “summed” signals much higher and easier for the low-pass filter to reject.

**Note**: the 4.16kHz sinewave that was generated would pass through the low-pass filter as well and be present on its output along with the 2.08kHz signal. This is inconvenient as it is a signal that was not present in the original message. Luckily, as the signal was generated by multiplying the sidebands, its amplitude is much lower than the recovered message and can be ignored.

An almost identical mathematical process can be modelled using the ECB’s Multiplier module. However, instead of multiplying the AM signal’s sinewaves with each other (the Multiplier module doesn’t do this), they’re multiplied with a locally generated 100kHz sinewave. The next part of this experiment lets you demodulate an AM signal this way.

## 2.1 Implement: Product demodulation of AM

1. Return the scope’s *Timebase* control to its earlier setting (probably *200µs/div*).
2. Disconnect the envelope detector and modify the set-up to return it to just an AM modulator with a 2.08kHz sinewave for the message as shown in Figure 8.

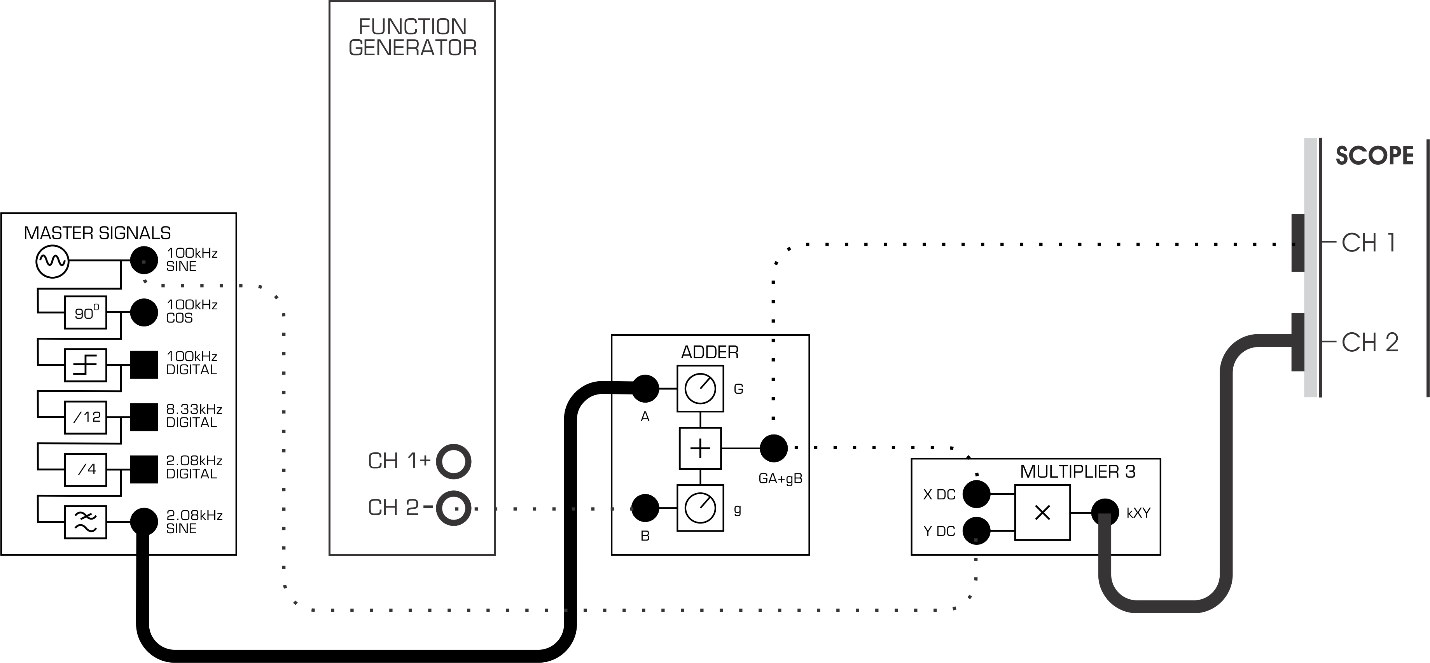


Figure 8: AM with a 2.08kHz message

1. Modify the set-up as shown in Figure 9.

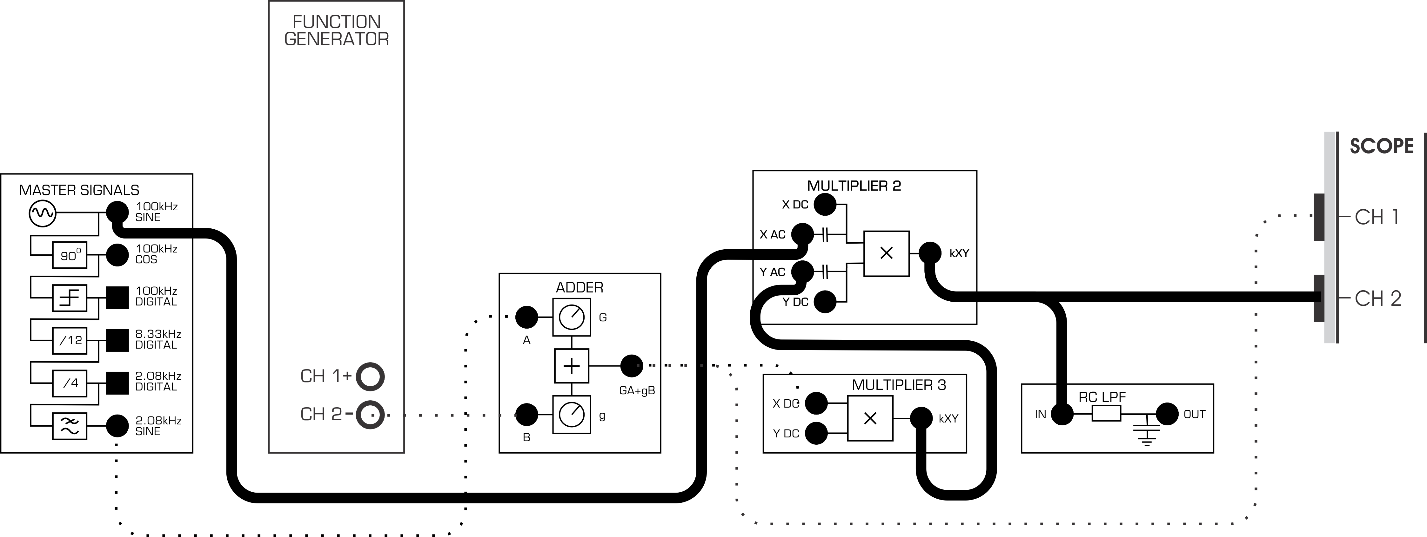


Figure 9: Patching for product demodulation

The additions to the set-up in Figure 9 can be represented by the block diagram in Figure 10. The Multiplier module models the mathematical basis of AM demodulation and the *RC Low-pass filter* on the Utilities module picks out the message while rejecting the other sinewaves generated.

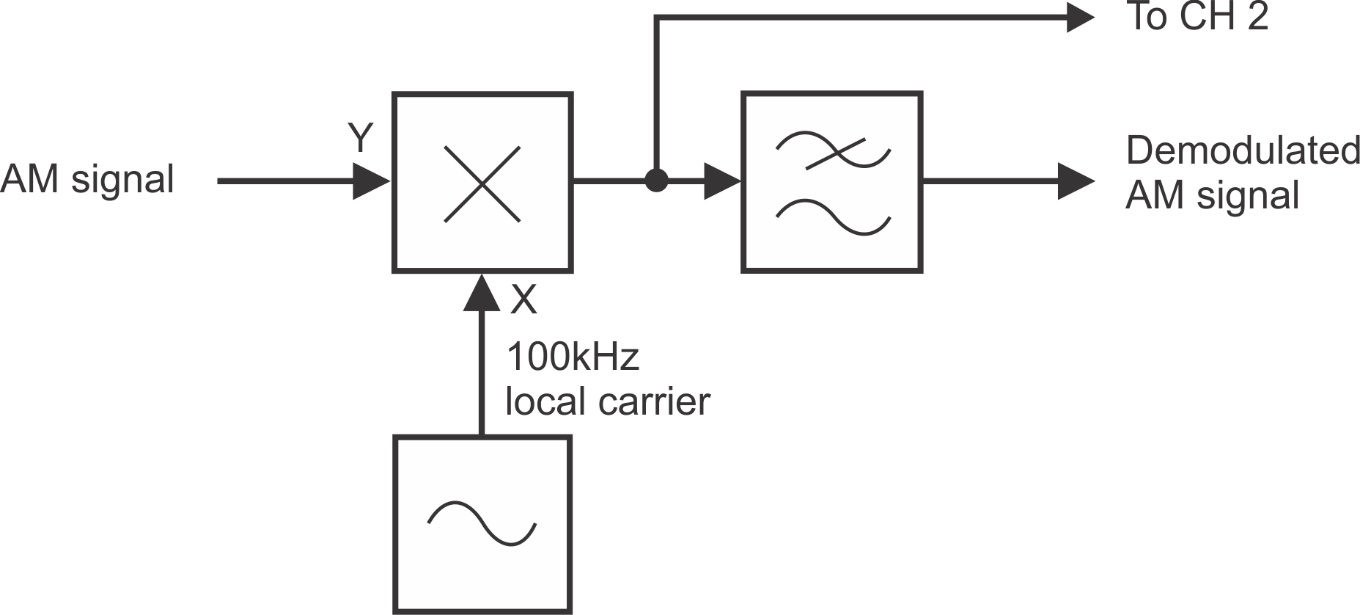


Figure 10: Block diagram for product demodulation

1. Compare the Multiplier module’s output with the Rectifier’s output that you captured earlier.
   1. Given the AM signal (which consists of 100kHz, 102.08kHz and 97.92kHz sinewaves) is being multiplied by a 100kHz sinewave:
2. How many sinewaves are present in the Multiplier module’s output?
3. What are their frequencies?

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1. Disconnect the scope’s *Channel 2* input from the Multiplier module’s output and connect it to the *RC LPF’s* output instead.
2. Compare the *RC LPF’s* output with the message and the output *RC LPF’s* that you captured earlier.

A common misconception about AM is that, once the signal is over-modulated, it’s impossible to recover the message. However, when the AM signal is generated using an ideal or near-ideal modulator (such as Figure 3) this is only true for the envelope detector.

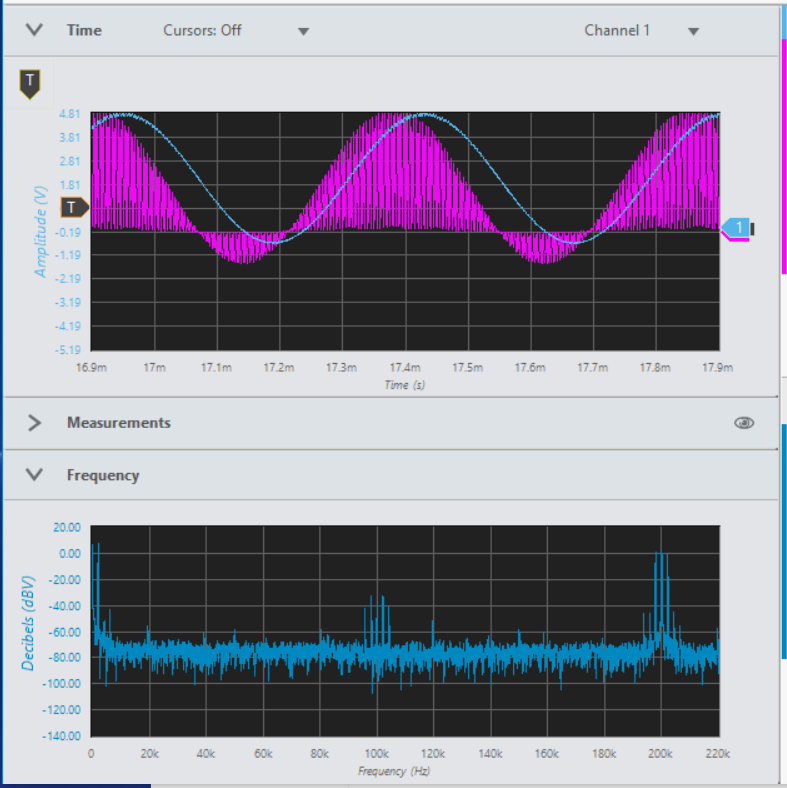


Figure 11: Overmodulated AM example recovered without distortion

The AM demodulation method being implemented in this part of the experiment (called *product detection* – though it is more accurate to call it *product demodulation*) doesn’t suffer from this problem as it’s not designed to recover the message by tracking one of the AM signal’s envelopes. The final part of this experiment demonstrates this.

|  |  |
| --- | --- |
| 7. | Connect the scope’s Channel 1 to the AM modulator’s output. |

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| 8. | Set the scope’s *Trigger Level* to 0V.  **Note:** The scope will lose triggering but the display will be adequate for the next steps. |

|  |  |
| --- | --- |
| 9. | Slowly increase the message signal’s amplitude to produce a near 100% modulated AM signal by adjusting the Adder module’s *G* control.  **Note:** Resize the AM and demodulated message signals on the screen as necessary. |

|  |  |
| --- | --- |
| 10. | Slowly increase the message signal’s amplitude to produce an AM signal that is modulated by more than 100% while paying close attention to the demodulated message signal. |

As an aside, the commercial implementation of AM modulation commonly involves a Class C amplifier for efficiency (that is, to minimise power losses). When a Class C amplifier is operated at depths of modulation above 100% the circuit’s operation no-longer corresponds with the model of an AM modulator in Figure 3. Importantly, in addition to producing an envelope that is not the same as the original message, the over-modulated Class C circuit produces extra frequency components in the spectrum. This means that neither the envelope detector nor the product demodulator can reproduce the message without distortion.