5 - Amplitude modulation (AM)

Experiment 5 – Amplitude modulation

Preliminary discussion

In an amplitude modulation (AM) communications system, speech and music are converted into an electrical signal using a device such as a microphone. This electrical signal is called the *message* or *baseband* signal. The message signal is then used to electrically vary the amplitude of a pure sinewave called the *carrier*. The carrier usually has a frequency that is much higher than the message's frequency.

Figure 1 below shows a simple message signal and an unmodulated carrier. It also shows the result of amplitude modulating the carrier with the message. Notice that the modulated carrier's amplitude varies above and below its unmodulated amplitude.
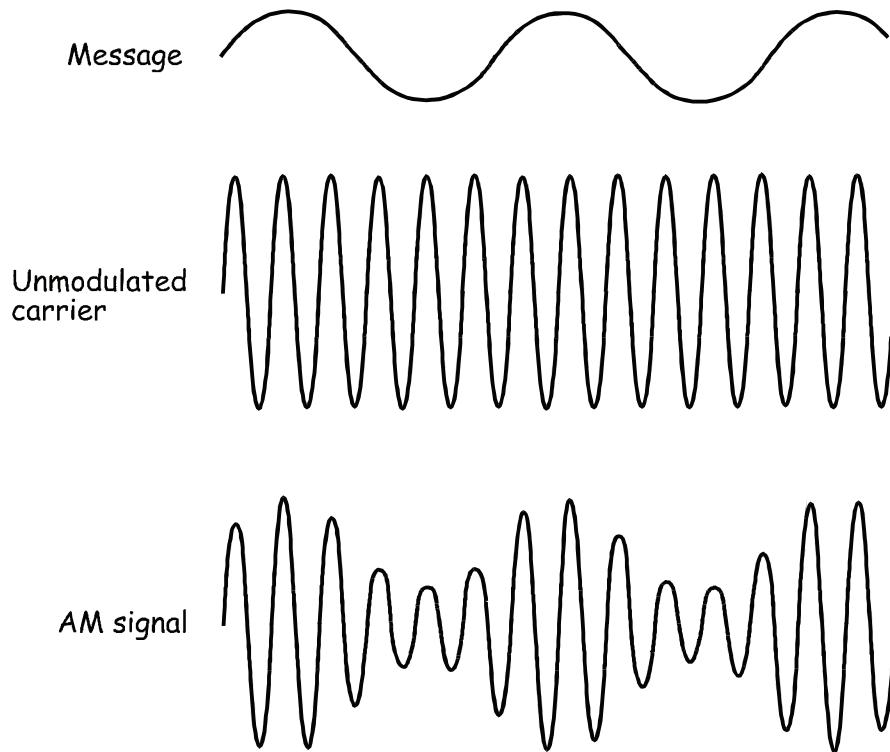

Figure 1

Figure 2 below shows the AM signal at the bottom of Figure 1 but with a dotted line added to track the modulated carrier's positive peaks and negative peaks. These dotted lines are known in the industry as the signal's *envelopes*. If you look at the envelopes closely you'll notice that the upper envelope is the same shape as the message. The lower envelope is also the same shape but upside-down (inverted).
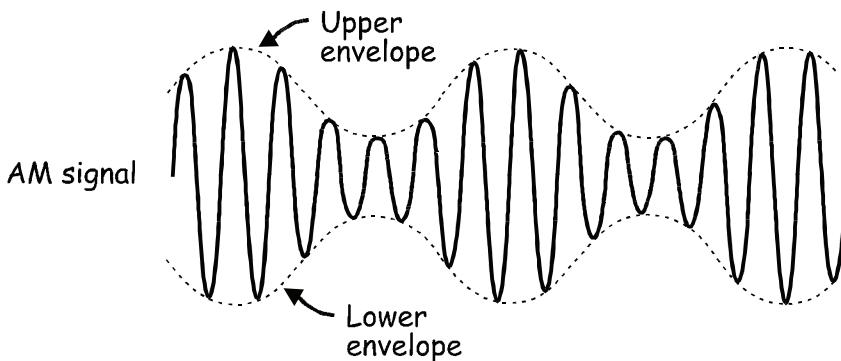

Figure 2

In telecommunications theory, the mathematical model that defines the AM signal is:

$$AM = (DC + message) \times the\ carrier$$

When the message is a simple sinewave (like in Figure 1) the equation's solution (which necessarily involves some trigonometry that is not shown here) tells us that the AM signal consists of three sinewaves:

- One at the carrier frequency

- One with a frequency equal to the sum of the carrier and message frequencies

- One with a frequency equal to the difference between the carrier and message frequencies

In other words, for every sinewave in the message, the AM signal includes a pair of sinewaves – one above and one below the carrier's frequency. Complex message signals such as speech and music are made up of thousands sinewaves and so the AM signal includes thousands of pairs of sinewaves straddling carrier. These two groups of sinewaves are called the *sidebands* and so AM is known as *double-sideband, full carrier* (DSBFC).

Importantly, it's clear from this discussion that the AM signal doesn't consist of any signals at the message frequency. This is despite the fact that the AM signal's envelopes are the same shape as the message.

The experiment

For this experiment you'll use the Emona DATEx to generate a real AM signal by implementing its mathematical model. This means that you'll add a DC component to a pure sinewave to create a message signal then multiply it with another sinewave at a higher frequency (the carrier). You'll examine the AM signal using the scope and compare it to the original message. You'll do the same with speech for the message instead of a simple sinewave.

Following this, you'll vary the message signal's amplitude and observe how it affects the modulated carrier. You'll also observe the effects of modulating the carrier too much. Finally, you'll measure the AM signal's depth of modulation using a scope.

It should take you about 1 hour to complete this experiment.

Equipment

- Personal computer with appropriate software installed

- NI ELVIS II plus USB cable and power pack

- Emona DATEx experimental add-in module

- Two BNC to 2mm banana-plug leads

- Assorted 2mm banana-plug patch leads

 Experiment 5 - Amplitude modulation

Procedure

Part A - Generating an AM signal using a simple message

1.   Ensure that the NI ELVIS II power switch at the back of the unit is off.

2.   Carefully plug the Emona DATEx experimental add-in module into the NI ELVIS II.

3.   Set the *Control Mode* switch on the DATEx module (top right corner) to *PC Control*.

4.   Connect the NI ELVIS II to the PC using the USB cable.

      Note: This may already have been done for you.

5.   Turn on the NI ELVIS II power switch at the rear of the unit then turn on its *Prototyping Board Power* switch at the top right corner near the power indicator.

6.   Turn on the PC and let it boot-up.

7.   Launch the NI ELVISmx software.

✓	Ask the instructor to check your work before continuing.

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8.   Launch the NI ELVIS II Variable Power Supplies VI and click on its *Run* control to activate the hardware.

9.   Adjust the Variable Power Supplies negative output *Voltage* control for an output of about -6V (the exact value is not critical).

10.   You won't need to adjust the Variable Power Supplies VI again so minimise it (but don't close it).

11.   Connect the set-up shown in Figure 3 below.

   **Note:** The NI ELVIS II DMM's inputs are on the left side of the unit.
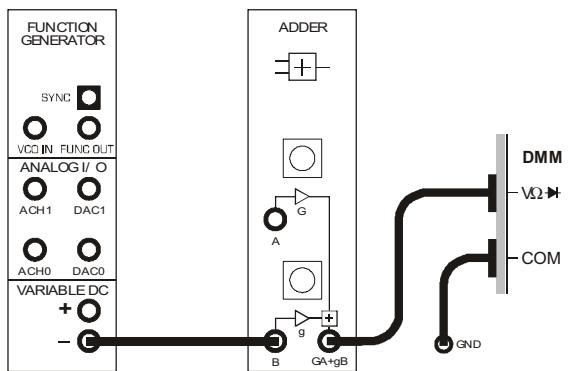
Figure 3

12.   Launch the NI ELVIS II DMM VI and press its *Run* button to activate its hardware.

13.   Set up the DMM for measuring DC voltages.

14.   Launch the DATEx soft front-panel (SFP).

15.   Check you have soft control over the DATEx by activating the PCM Encoder module's **soft** *PDM/TDM* control on the DATEx SFP.

      Note: If you're set-up is working correctly, the PCM Decoder module's LED on the DATEx board should turn on and off.

16.   Locate the Adder module on the DATEx SFP and turn its soft *G* control fully anti-clockwise.

17.   Adjust the Adder module's soft *g* control to obtain a 1V DC output (as measured by the DMM).

18.   Close the DMM VI – you'll not need it again (unless you accidentally change the Adder module's soft *g* control).

19. Connect the set-up shown in Figure 4 below.

   Note 1: The NI ELVIS II scope inputs are on the left side of the unit.

   **Note 2:** Insert the black plugs of the oscilloscope lead into a ground (*GND*) socket.
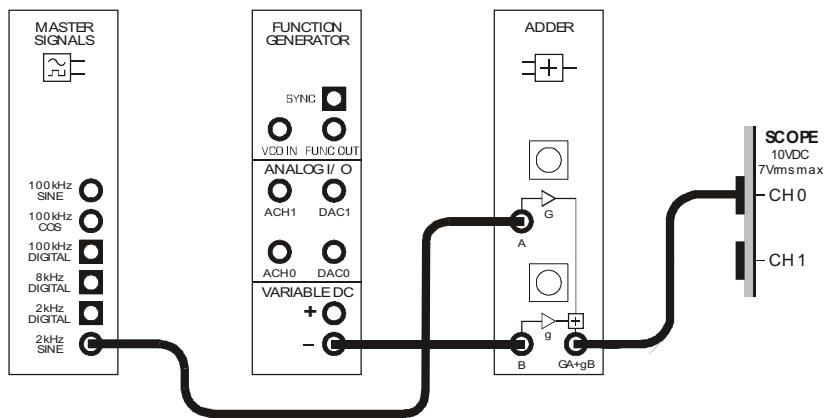
Figure 4

This set-up can be represented by the block diagram in Figure 5 below. It implements the highlighted part of the equation: AM = **(DC + message)** × the carrier.
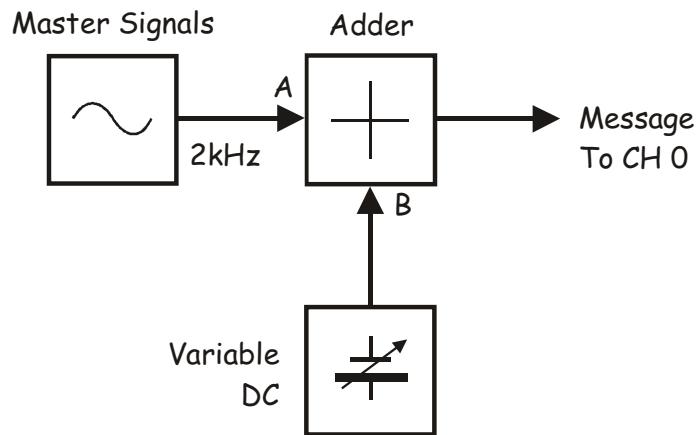

Figure 5

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20. Launch and run the NI ELVIS II Oscilloscope VI.

21. Set up the scope per the procedure in Experiment 1 (page 1-12) with the following changes:

- Channel 0 *Coupling* control to the *DC* position instead of *AC*

- Channel 0 *Scale* control to the *500mV/div* position instead of *1V/div*

- *Trigger Level* control to the *1V* position instead of *0V*

At the moment, the scope's display wont have a trace and there should be a message at the top stating, "***Waiting for Trigger***". This situation is normal and will be corrected when you perform the next step.

22. While watching the Adder module's output on the scope, turn its soft *G* control clockwise to obtain a 1Vp-p sinewave.

Tip: Remember that you can use the keyboard's *TAB* and arrow keys for fine adjustment of the DATEx SFP's controls.

The Adder module's output can now be described mathematically as:

$$AM = (1VDC + 1Vp\text{-}p \text{ 2kHz sine}) \times \text{the carrier}$$

Question 1
In what way is the Adder module's output now different to the signal out of the Master Signals module's *2kHz SINE* output?

Ask the instructor to check
your work before continuing.

23. Modify the set-up as shown in Figure 6 below.

Before you do…
The set-up in Figure 6 builds on Figure 4 so don't pull it apart. Existing wiring is shown as dotted lines to highlight the patch leads that you need to add.
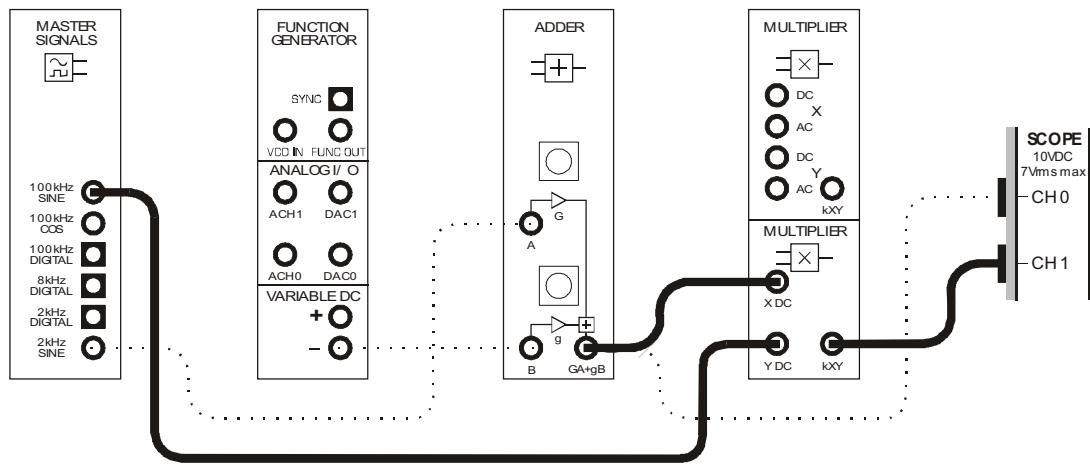

Figure 6

This set-up can be represented by the block diagram in Figure 7 below. The additions that you've made to the original set-up implement the highlighted part of the equation:
AM = (DC + message) **× the carrier**.
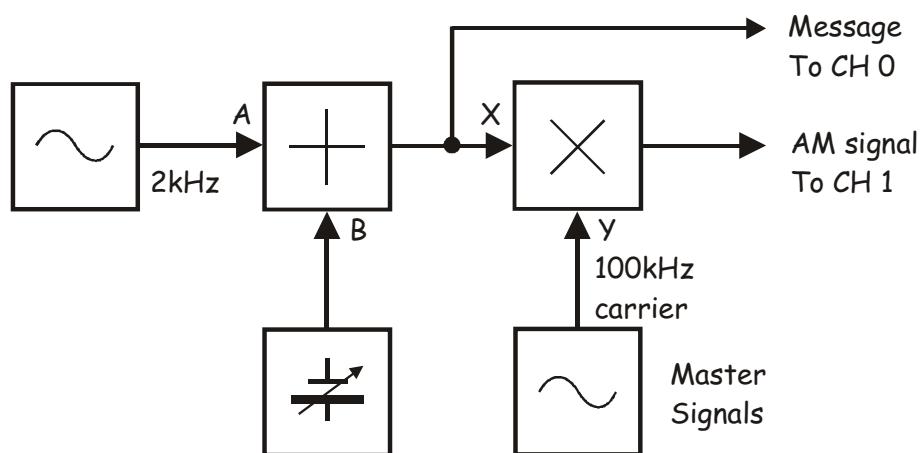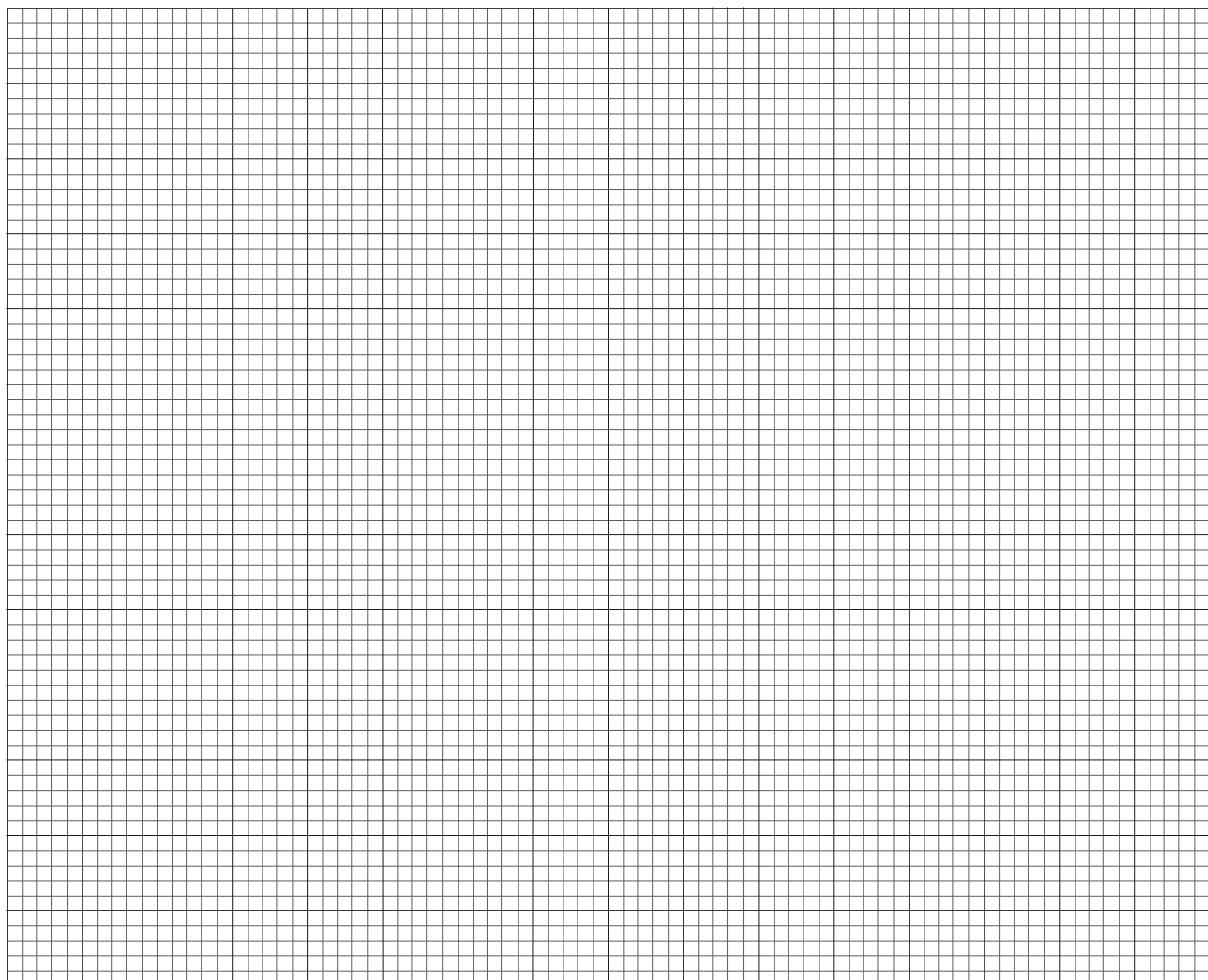
Figure 7

With values, the equation on the previous page becomes:

AM = (1VDC + 1Vp-p 2kHz sine) × 4Vp-p 100kHz sine.

24.   Adjust the scope's *Timebase* control to view only two or so cycles of the message signal.

25.   Activate the scope's Channel 1 input (by checking the Channel 1 *Enabled* box) to view the Multiplier module's output as well as the message signal.

26.   Draw the two waveforms to scale on the graph provided below.

       Tip: Draw the message signal in the upper half of the graph and the AM signal in the lower half.

27. Use the scope's Channel 0 *Position* control to overlay the message with the AM signal's upper envelope then lower envelope to compare them.

    Tip: If you haven't do so already, set the Channel 1 *Scale* control to *500mV/div*.

    Question 2
    What feature of the Multiplier module's output suggests that it's an AM signal? **Tip:** If you're not sure about the answer to the questions, see the preliminary discussion.

    _____

    _____

    Question 3
    The AM signal is a complex waveform consisting of more than one signal. Is one of the signals a 2kHz sinewave? Explain your answer.

    _____

    _____

    Question 4
    For the given inputs to the Multiplier module, how many sinewaves does the AM signal consist of, and what are their frequencies?

    _____

Part B - Generating an AM signal using speech

This experiment has generated an AM signal using a sinewave 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 AM signal looks like when modulated by speech.

28. Disconnect the plug on the Master Signals module's *2kHz SINE* output that connects to the Adder module's *A* input.

29. Connect it to the Speech module's output as shown in Figure 8 below.

    Remember: Dotted lines show leads already in place.
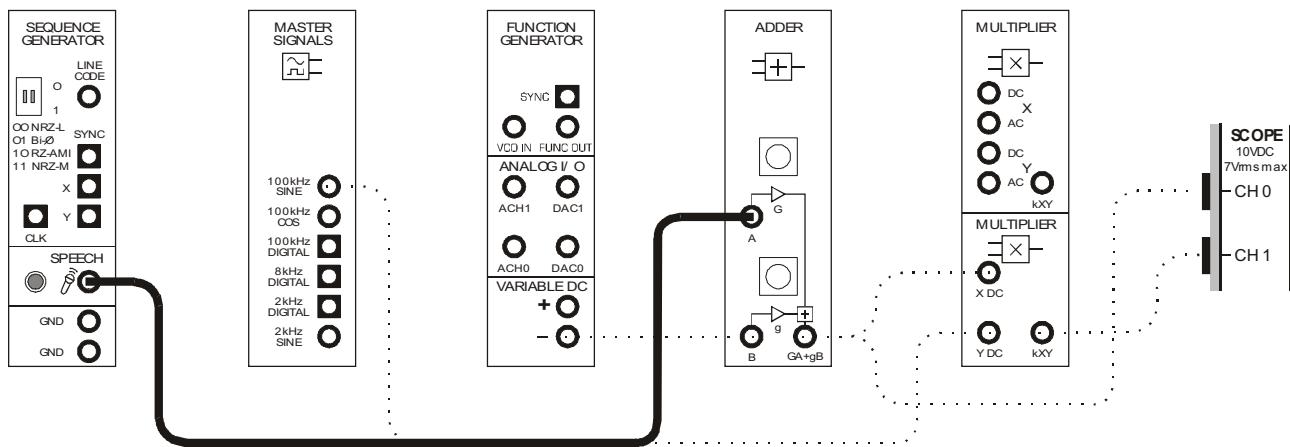

Figure 8

30. Set the scope's *Timebase* control to the *1ms/div* position.

31. Hum and talk into the microphone while watching the scope's display.

Question 5

Why is there still a signal out of the Multiplier module even when you're not humming (or talking, etc)?

Ask the instructor to check
your work before continuing.

Part C – Investigating depth of modulation

It's possible to modulate the carrier by different amounts. This part of the experiment let's you investigate this.

32. Return the scope's *Timebase* control to the *100μs/div* position.

33. Disconnect the plug to the Speech module's output and reconnect it to the Master Signals module's *2kHz SINE* output.

    Note: The scope's display should now look like your drawings on the graph paper on page 5-10.

34. Vary the message signal's amplitude a little by turning Adder module's soft *G* control left and right and notice the effect on the AM signal.

Question 6

What is the relationship between the message's amplitude and the amount of the carrier's modulation?

_____

_____

Ask the instructor to check
your work before continuing.

You probably noticed that the size of the message signal and the modulation of the carrier are proportional. That is, as the message's amplitude goes up, the amount of the carrier's modulation goes up.

The extent that a message modulates a carrier is known in the industry as the *modulation index* (m). Modulation index is an important characteristic of an AM signal for several reasons including calculating the distribution of the signal's power between the carrier and sidebands.

Figure 9 below shows two key dimensions of an amplitude modulated carrier. These two dimensions allow a carrier's modulation index to be calculated.
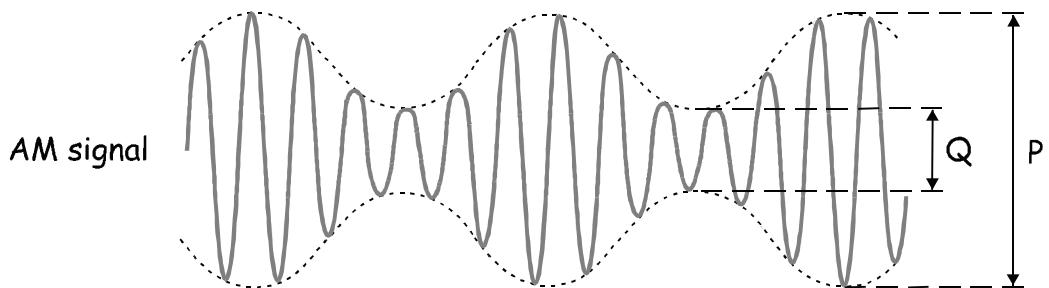
Figure 9

The next part of the experiment lets you practise measuring these dimensions to calculate a carrier's modulation index.

35. Adjust the Adder module's soft *G* control to return the message signal's amplitude to 1Vp-p.

36. Measure and record the AM signal's *P* dimension. Record your measurement in Table 1 below.

37. Measure and record the AM signal's *Q* dimension.

38. Calculate and record the AM signal's depth of modulation using the equation below.

$$m = \frac{P - Q}{P + Q}$$

Table 1

P dimension	Q dimension	m

 Experiment 5 - Amplitude modulation

A problem that is important to avoid in AM transmission is *over-modulation*. When the carrier is over-modulated, it can upset the receiver's operation. The next part of the experiment gives you a chance to observe the effect of over-modulation.

39.   Increase the message signal's amplitude to maximum by turning the Adder module's soft *G* control to about half its travel then fully clockwise and notice the effect on the AM signal.

40.   Set the scope's Channel 0 *Scale* control to *1V/div* and the Channel 1 *Scale* control to *500mV/div*.

41.   Use the scope's Channel 0 *Position* control to overlay the message with the AM signal's envelopes and compare them.

Question 7
What is the problem with the AM signal when it is over-modulated?

_____

_____
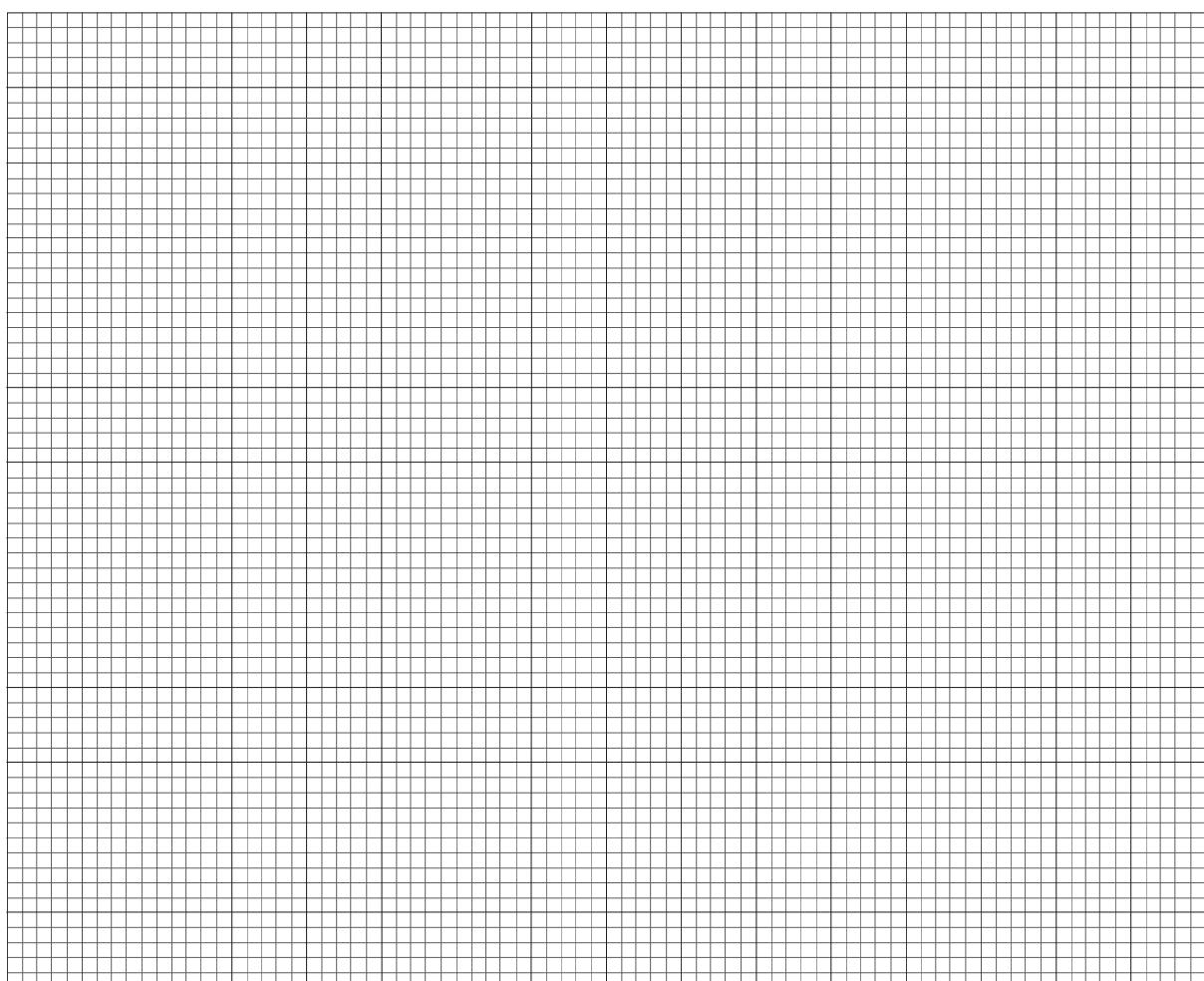
Question 8
What do you think is a carrier's maximum modulation index without over-modulation?

☐   A minus number

☐   0

☐   1

☐   Greater than 1

42. Draw the two waveforms to scale in the space provided below.

Ask the instructor to check
your work before finishing.

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Name: _____

Class: _____

7 - Observations of AM and DSBSC signals in the frequency domain

Experiment 7 – Observations of AM and DSBSC signals in the frequency domain

Preliminary discussion

Experiments 5 and 6 use the Emona DATEx to demonstrate the differences you would see on a scope between the output signals of an AM and DSBSC modulator. To refresh your memory, Figure 1 below shows the AM and DSBSC signals that would be produced by identical inputs (for example, a 1kHz sinewave for the message and a 100kHz sinewave for the carrier).
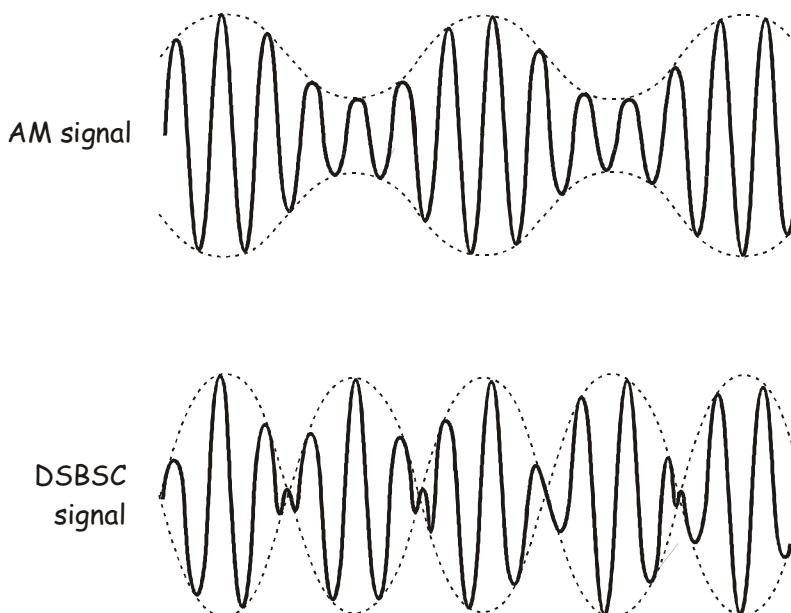
Figure 1

The two signals look different because they contain different sinewaves. That is, they have a different *spectral* composition. The reason for this is explained by the mathematical models of AM and DSBSC. Side-by-side, it's easy to see that the equations are a little different.

$$\text{AM = (DC + message)} \times \text{the carrier} \qquad \text{DSBSC = the message} \times \text{the carrier}$$

And, when the equations are solved for the inputs specified above, we find that the AM and DSBSC signals consist of the following:

AM	DSBSC	Description
100kHz	-	A sinewave at the carrier frequency
101kHz	101kHz	A sinewave with a frequency equal to the sum of the carrier and message frequencies (the upper sideband or USB)
99kHz	99kHz	A sinewave with a frequency equal to the difference between the carrier and message frequencies (the lower sideband or LSB)

As you can see, AM signals include the carrier signal whereas DSBSC signals don't.

When you think about it, a scope's display is actually a graph of time (on the X-axis) versus voltage (on the Y-axis). Importantly, graphs plotted this way are said to be drawn in the *time domain*.

Another way of representing signals like AM and DSBSC signals involves drawing all the sinewaves that they contain on a graph that has frequency for the X-axis instead of time. In other words, they're drawn in the *frequency domain*. When the AM and DSBSC signals in Figure 1 are drawn this way, we get the graphs in Figure 2 below.
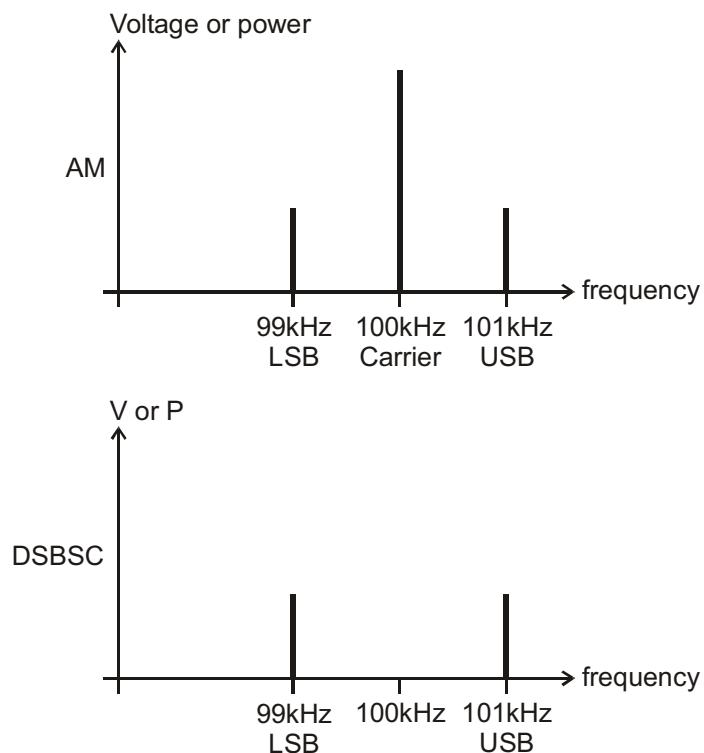

Figure 2

Frequency domain representations of complex signals are very useful for thinking about their spectral composition. They give you a tool for visualising the sinewaves that the signal is made up of. They also help you to see how much of the frequency spectrum the signal occupies. This is the signal's *bandwidth* and is a critical issue in communications and telecommunications.

The bandwidth of AM and DSBSC signals can be calculated in one of two ways. The frequency domain graphs in Figure 2 shows that the signals occupy a portion of the spectrum from the lower sideband up to the upper sideband. That being the case, the bandwidth can be found using the equation:

$$BW = USB - LSB$$

Using this equation we find that the bandwidth of the AM and DSBSC signals in Figure 2 are 2kHz. In situations where the sidebands are made up of more than one sinewave, you must solve the equation using the highest frequency in the USB and the lowest frequency in the LSB.

Now, compare the bandwidth of the signals in Figure 2 (2kHz) with the original signals used to produce them (that is, a 1kHz message and a 100kHz carrier). Notice that their bandwidths are twice the frequency of their message. This gives us the second equation for calculating bandwidth:

$$BW = 2 \times f_m \qquad \text{where } f_m = \text{the message frequency}$$

In situations where the message is made up of more than one sinewave, you must solve the equation using the highest frequency in the message.

The experiment

For this experiment you'll use the Emona DATEx to generate a real AM and DSBSC signal then analyse the spectral elements of the two signals using the NI ELVIS Dynamic Signal Analyzer.

It should take you about 50 minutes to complete this experiment.

Equipment

- Personal computer with appropriate software installed
- NI ELVIS II plus USB cable and power pack
- Emona DATEx experimental add-in module
- Two BNC to 2mm banana-plug leads
- Assorted 2mm banana-plug patch leads

Procedure

Part A – Setting up the AM modulator
To experiment with AM spectrum analysis, you need an AM signal. The first part of the experiment gets you to set one up.

1.   Ensure that the NI ELVIS II power switch at the back of the unit is off.

2.   Carefully plug the Emona DATEx experimental add-in module into the NI ELVIS II.

3.   Set the *Control Mode* switch on the DATEx module (top right corner) to *PC Control*.

4.   Connect the NI ELVIS II to the PC using the USB cable.

      Note: This may already have been done for you.

5.   Turn on the NI ELVIS II power switch at the rear of the unit then turn on its *Prototyping Board Power* switch at the top right corner near the power indicator.

6.   Turn on the PC and let it boot-up.

7.   Launch the NI ELVISmx software.

8.   Launch the NI ELVIS II Variable Power Supplies VI and click on its *Run* control to activate the hardware.

9.   Adjust the Variable Power Supplies negative output *Voltage* control for an output of about -6V (the exact value is not critical).

10.   Launch the NI ELVIS II DMM VI and click on its *Run* control to activate the hardware.

11.   Set up the DMM VI for measuring DC voltages.

12.   Launch the DATEx soft front-panel (SFP).

13.   Check you have soft control over the DATEx by activating the PCM Encoder module's **soft** *PDM/TDM* control on the DATEx SFP.

      Note: If you're set-up is working correctly, the PCM Decoder module's LED on the DATEx board should turn on and off.

14.   Locate the Adder module on the DATEx SFP and turn its soft *G* and *g* controls fully anti-clockwise.

15.   Connect the set-up shown in Figure 3 below.
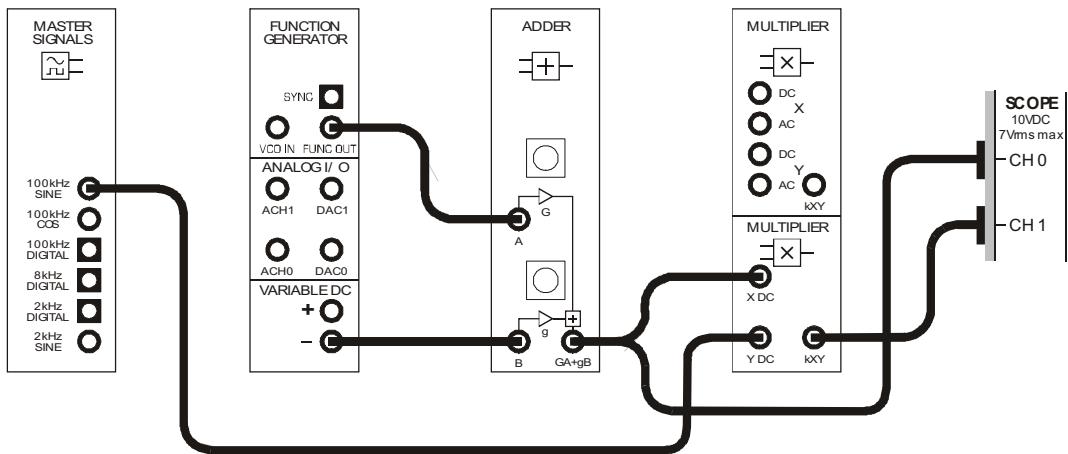
Figure 3

16.   Connect the Adder module's output to the DMM and adjust the module's soft *g* control to obtain a 1V DC output.

   Note 1: You must also connect the DMM's *COM* input to a ground terminal on the Emona DATEx.

   Note 2: Remember also that you can use the keyboards tab and arrow keys for fine adjustment of DATEx soft controls.

17.   Disconnect the DMM and close its VI.

18.   Launch the NI ELVIS II Function Generator VI and click on its *Run* control to activate the hardware.

19.   Adjust the function generator using its soft controls for an output with the following specifications:

   ▪ Waveshape: Sine
   ▪ Frequency: 10kHz exactly
   ▪ Amplitude: 4Vpp
   ▪ DC Offset: 0V

20.   You'll be using the function generator VI again later but minimise its window for now.

21. Launch the NI ELVIS II Oscilloscope VI and click on its *Run* control to activate the hardware.

22. Set up the scope per the procedure in Experiment 1 (page 1-12) with the following changes:

   ▪ Channel 0 *Coupling* control to the *DC* position instead of *AC*
   ▪ Channel 0 *Scale* control to the *500mV/div* position instead of *1V/div*
   ▪ *Timebase* control to the *50μs/div* position instead of *500μs/div*
   ▪ *Trigger Level* control to the *1V* position instead of *0V*

23. Adjust the Adder module's soft *G* control to obtain a 1Vp-p sinewave.

24. Activate the scope's Channel 1 input (by checking the Channel 1 *Enabled* box) to view both the message and the modulated carrier.

   Self check: If the scope's *Scale* control for Channel 1 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. If not, close all windows, check your wiring then repeat the process starting from Step 7.

The set-up can be represented by the block diagram in Figure 4 below. It implements the equation: AM = (1VDC + 1Vp-p 10kHz sine) × 4Vp-p 100kHz sine.
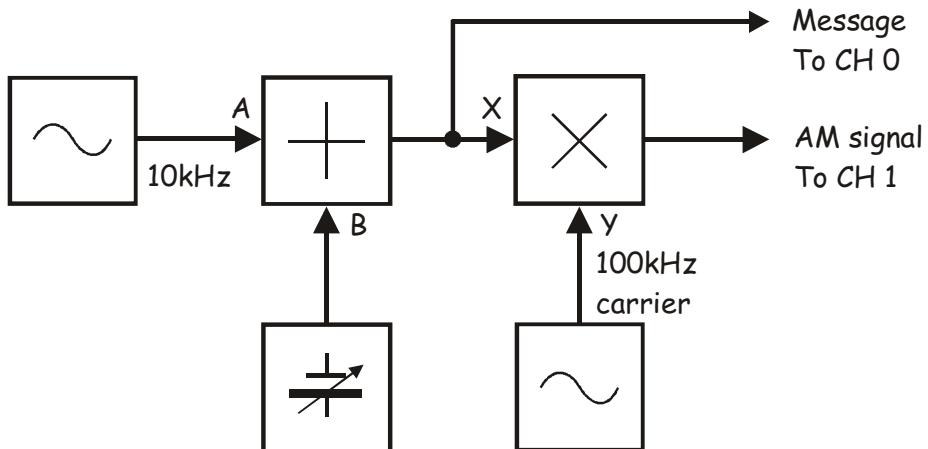

Figure 4

Question 1
For the given inputs to the Multiplier module, what are the frequencies of the three sinewaves on its output?

_____

Question 2
Use this information to calculate the AM signal's bandwidth. **Tip:** If you're not sure how to do this, read the preliminary discussion.

_____

_____

Ask the instructor to check
your work before continuing.

Part B – Setting up the NI ELVIS II Dynamic Signal Analyzer (DSA)

25. Suspend the scope's operation by clicking on its *Stop* control once.

     Note: The scope's display should freeze and its hardware has been deactivated. This is a necessary step as the scope and signal analyzer share hardware resources and so they cannot be operated simultaneously.

26. Minimise the scope's VI.

27. Launch the NI ELVIS II Dynamic Signal Analyzer VI.

     Note: If the Dynamic Signal Analyzer VI has launched successfully, the instrument's window will be visible (see Figure 5).
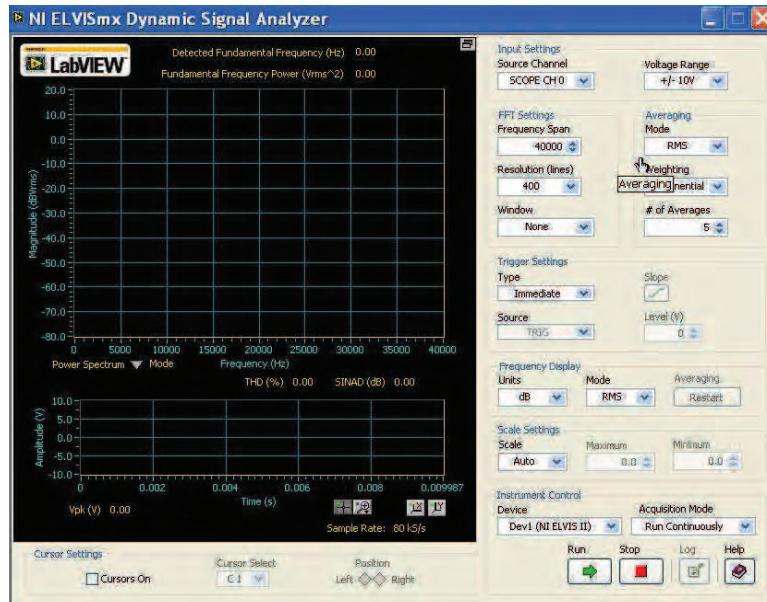

Figure 5

28. Adjust the signal analyzer's controls as follows:

Input Settings

- *Source Channel* to *SCOPE CH 1*
- *Voltage Range* to *±10V*

FFT Settings

- *Frequency Span* to *150,000*
- *Resolution* to *400*
- *Window* to *7 Term B-Harris*

Averaging

- *Mode* to *RMS*
- *Weighting* to *Exponential*
- *# of Averages* to *3*

Trigger Settings

- *Type* to *Edge*

Frequency Display

- *Units* to *dB*
- *Mode* to *RMS*
- *Scale* to *Auto*

Cursor settings

- *Cursors On* box unchecked (for now)

29. Click on the signal analyzer's *Run* control to activate its hardware.

**Note:** If the Signal Analyzer VI has been set up correctly, its display should look like Figure 6 below.

Figure 6

         Experiment 7 - Observations of AM & DSBSC signals in the frequency domain
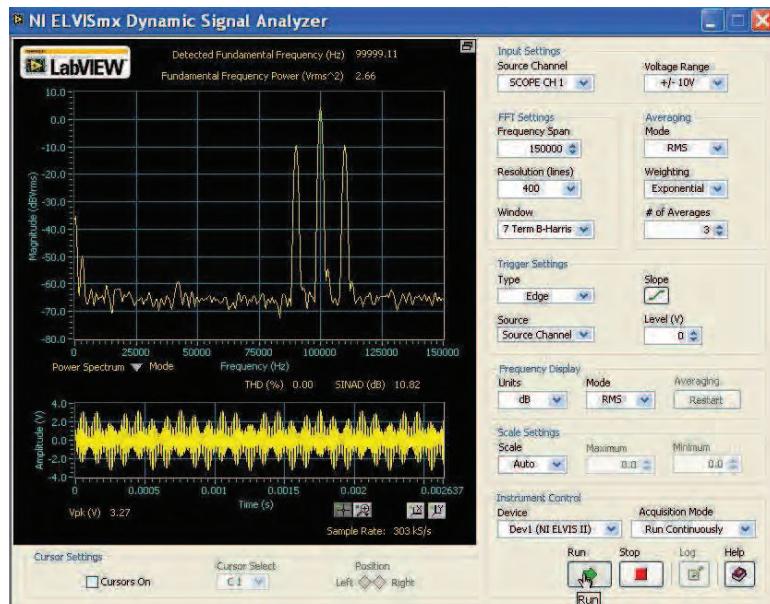
The Signal Analyzer's display needs a little explaining here. There are actually two displays, a large one on top and a much smaller one underneath. The smaller one is a time domain representation of the input (in other words, the display is a scope). Notice that it's showing the AM signal that you set up earlier and saw in Step 24.

The larger of the two displays is the frequency domain representation of the input. Notice that it looks fairly similar to the frequency domain graph for an AM signal in Figure 2 (in the preliminary discussion). The Signal Analyzer's display doesn't have single sharp lines for each of the sinewaves present in the signal because the practical implementation of FFT is not as precise as the theoretical expectation.

Part C – Spectrum analysis of an AM signal
The next part of this experiment let's you analyze the frequency domain representation of the AM signal to see if its frequency components match the values that you mathematically predicted for Questions 1 and 2.

30.   Activate the signal analyzer's cursors by checking (that is, ticking) *Cursors On* box.

       Note: When you do, green horizontal and vertical lines should appear on the signal analyzer's frequency domain display.

The NI ELVIS II Dynamic Signal Analyzer has two cursors *C1* and *C2* that default to the left most side of the display when the signal analyzer's VI is launched. They're repositioned by "grabbing" their vertical lines with the mouse and moving the mouse left or right.

31.   Use the mouse to grab and move the vertical line of cursor *C1*.

       Note: As you do, notice that cursor *C1* moves along the signal analyzer's trace and that the vertical and horizontal lines move so that they always intersect at *C1*.

32.   Repeat Step 31 for cursor *C2*.

       Note: Fine control over the cursors' position is obtained by using the cursor's *Position* control in the *Cursor Settings area (below the display)*.

The NI ELVIS II Dynamic Signal Analyzer includes a tool that measures the **difference** in magnitude and frequency between the two cursors. This information is displayed in green between the upper and lower parts of the display.

33. Move the cursors while watching the measurement readout to observe the effect.

34. Position the cursors so that they're on top of each other and note the measurement.

     Note: When you do, the measurement of difference in magnitude and frequency should both be zero.

Usefully, when one of the cursors is moved to the extreme left of the display, its position on the X-axis is zero. This means that the cursor is sitting on 0Hz. It also means that the measurement readout gives an absolute value of frequency for the other cursor. This makes sense when you think about it because the readout gives the difference in frequency between the two cursors but one of them is zero.

35. Move *C1* to the extreme left of the display.

36. Align *C2* with the highest point in the AM signal's lower sideband.

     Note: This is the sinewave just to the left of the largest sinewave in the display.

37. Measure the sinewave's frequency and record this in Table 1 on the next page.

38. Align *C2* with the highest point in the AM signal's carrier and repeat Step 37.

     Note: This is the largest sinewave in the display.

39. Align *C2* with the highest point in the AM signal's upper sideband and repeat Step 37.

     Note: This is the sinewave just to the right of the carrier.

40. Align *C1* with the highest point in the AM signal's lower sideband and measure the AM signal's bandwidth.

Table 1

LSB frequency	
Carrier frequency	
USB frequency	
Bandwidth	

Question 3
How do the measured values in Table 1 compare with your theoretically predicted values (see Questions 1 and 2)? Explain any differences.

_____

_____

☑ Ask the instructor to check your work before continuing.

As an aside, at this point it looks as though the sidebands are nearly as large as the carrier. However, this is misleading because the vertical axis is logarithmic (that is, it's non-linear). The sidebands are actually much smaller than the carrier. This can be proven as follows:

41. Set the Signal Analyzer's _Units_ control to _Linear_ instead of _dB_.

    Note: This sets the vertical axis to a simple linear voltage measurement instead of decibels.

42. Note the relative sizes of the sinewaves in the signal.

43. Return the Signal Analyzer's _Units_ control to _dB_.

44. Maximise the function generator's VI and increase its output frequency to 20kHz.

45. Use the signal analyzer's cursors to find the AM signal's new bandwidth. Record this in Table 2 below.

    Note: It'll take up to thirty seconds for the display to be fully up to date with the change because it's an average of three sweeps.

46. Increase the function generator's output frequency to 30kHz.

47. Find and record the AM signal's new bandwidth.

Table 2

Bandwidth for fm = 20kHz	
Bandwidth for fm = 30kHz	

Question 4
What's the relationship between the message signal's frequency and the AM signal's bandwidth?

_____

_____

☑ Ask the instructor to check your work before continuing.

48. Return the function generator's output frequency to 10kHz.

49. Wait until the signal analyzer's frequency domain display has fully updated then disconnect the banana plug to the Multiplier module's X input.

50. Wait until the display has fully updated then investigate the frequency of the most significant sinewave on the Multiplier module's output.

Question 5
What is this signal?

_____

Question 6
What's missing and why?

_____

_____

51.   Reconnect the banana plug to the Multiplier module's *X* input.

52.   Disconnect the banana plug to the Multiplier module's *Y* input.

53.   Wait until the display has fully updated then investigate the frequency of the most significant sinewave on the Multiplier module's output.

Question 7
What is this signal?

_____

Question 8
Why are the sidebands missing when there's a message?

_____

_____

☑ Ask the instructor to check your work before continuing.

Part D – Setting up the DSBSC modulator

To experiment with DSBSC spectrum analysis, you need a DSBSC signal. This part of the experiment gets you to set one up.

54.   Suspend the signal analyzer's operation by clicking on its *Stop* control once.

55.   Maximise the function generator's VI and check that its output frequency has been returned to 10kHz.

56.   Set the function generator's output to 1Vpp.

57.   Disassemble the current set-up.

58.   Connect the set-up shown in Figure 7 below.
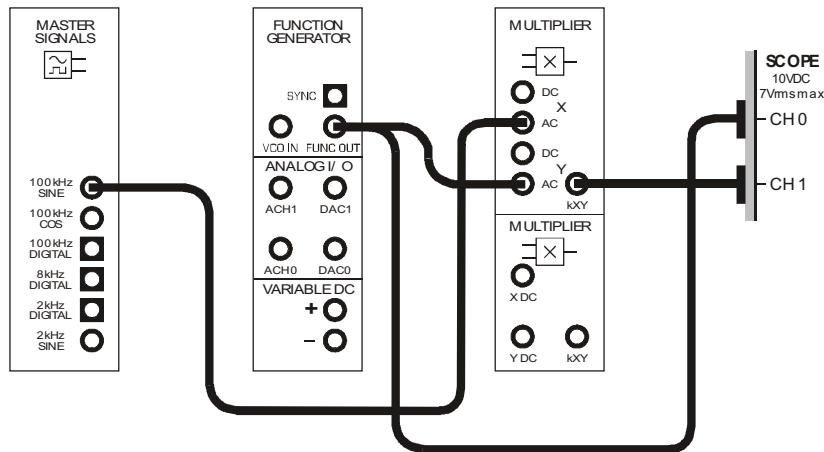
**Figure 7**

This set-up can be represented by the block diagram in Figure 8 on the next page. It implements the equation: DSBSC = 1Vp-p 10kHz sine × 4Vp-p 100kHz sine.

   Experiment 7 - Observations of AM & DSBSC signals in the frequency domain
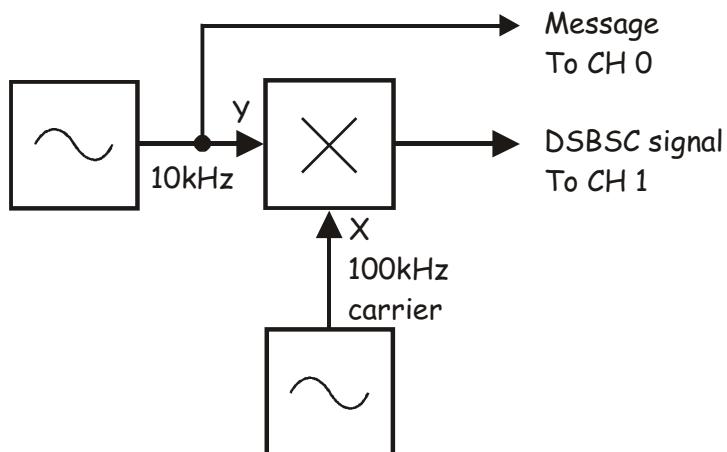
Figure 8

59. Restart the scope and make the following checks and adjustments:

   ▪ Check that the *Timebase* control is set to *50μs/div*
   ▪ Return the *Trigger Level* control to *0V*

Self check: The scope should now display a DSBSC signal with alternating halves of the envelope forming the same shape as the message and is about the same size.

Question 9
For the given inputs to the Multiplier module, what are the frequencies of the two sinewaves on its output?

_____

Question 10
Use this information to calculate the DSBSC signal's bandwidth.

_____

_____

_____

 Ask the instructor to check your work before continuing.

Part E – Spectrum analysis of a DSBSC signal

60. Close the scope's VI.

61. Restart the NI ELVIS II Dynamic Signal Analyzer VI.

     Note: Once the display has had time to update, you should be able to clearly see the DSBSC signal's two sidebands.

You'll also see that the signal has a carrier. However, despite appearances, this signal is very small relative to the sidebands (remember, the scale for the Y-axis is decibels which is a logarithmic unit of measurement). Design limitations in implementing DSBSC mean that there will always be a small carrier component in the DSBSC signal. That's why the second "s" in DSBSC is for "suppressed".

62. Move *C1* to the extreme left of the display.

63. Align *C2* with the DSBSC signal's lower sideband.

64. Measure the sinewave's frequency and record this in Table 3 below.

65. Align *C2* with the DSBSC signal's upper sideband and repeat Step 64.

66. Use the signal analyzer's two cursors to determine and record the DSBSC signal's bandwidth.

Table 3

LSB frequency	
USB frequency	
Bandwidth	

Question 11
How do the measured values in Table 3 compare with your theoretically predicted values (see Questions 9 and 10)?

Question 12
Compare the DSBSC signal's bandwidth with the bandwidth for the AM signal with a 10kHz message (in Table 1). What can you say about the bandwidth requirements of AM and DSBSC signals?

_____

┌───┐
│   ☑   Ask the instructor to check   │
│   your work before continuing.   │
└───┘

67. Find the DSBSC signal's bandwidth for two other message frequencies (say 20kHz and 30kHz).

Question 13
What's the relationship between the message signal's frequency and the DSBSC signal's bandwidth?

_____

_____

┌───┐
│   ☑   Ask the instructor to check   │
│   your work before finishing.   │
└───┘

Name: _____

Class: _____

8 - AM demodulation

Experiment 8 – AM demodulation

Preliminary discussion

If you've completed Experiment 5 then you've seen what happens when a 2kHz 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.
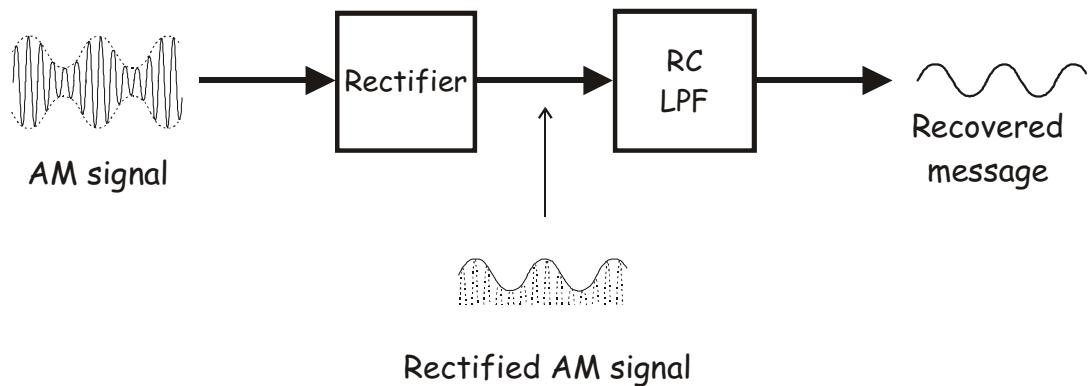

Figure 1

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.

 Experiment 8 – AM demodulation

The experiment

For this experiment you'll use the Emona DATEx to generate an AM signal by implementing its mathematical model. Then you'll set-up an envelope detector using the *Rectifier* and *RC LPF* on the trainer's Utilities module.

Once done, 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 implementing by multiplying it with a local carrier instead of using an envelope detector.

It should take you about 50 minutes to complete Parts A to D of this experiment and another 20 minutes to complete Part E.

Equipment

- Personal computer with appropriate software installed

- NI ELVIS II plus USB cable and power pack

- Emona DATEx experimental add-in module

- Two BNC to 2mm banana-plug leads

- Assorted 2mm banana-plug patch leads

- One set of headphones (stereo)

Procedure

Part A – Setting up the AM modulator
To experiment with AM demodulation you'll need an AM signal. The first part of the experiment gets you to set one up.

1.   Ensure that the NI ELVIS II power switch at the back of the unit is off.

2.   Carefully plug the Emona DATEx experimental add-in module into the NI ELVIS II.

3.   Set the *Control Mode* switch on the DATEx module (top right corner) to *PC Control*.

4.   Connect the NI ELVIS II to the PC using the USB cable.

      Note: This may already have been done for you.

5.   Turn on the NI ELVIS II power switch at the rear of the unit then turn on its *Prototyping Board Power* switch at the top right corner near the power indicator.

6.   Turn on the PC and let it boot-up.

7.   Launch the NI ELVISmx software.

8.   Launch and run the NI ELVIS II Variable Power Supplies VI.

9.   Adjust the Variable Power Supplies negative output *Voltage* control for an output of about -6V (the exact value is not critical).

10.   Launch and run the NI ELVIS II DMM VI.

11.   Set up the DMM VI for measuring DC voltages.

12.   Launch the DATEx soft front-panel (SFP) and check that you have soft control over the DATEx board.

13.   Locate the Adder module on the DATEx SFP and turn its soft *G* and *g* controls fully anti-clockwise.

14.   Connect the set-up shown in Figure 2 below.
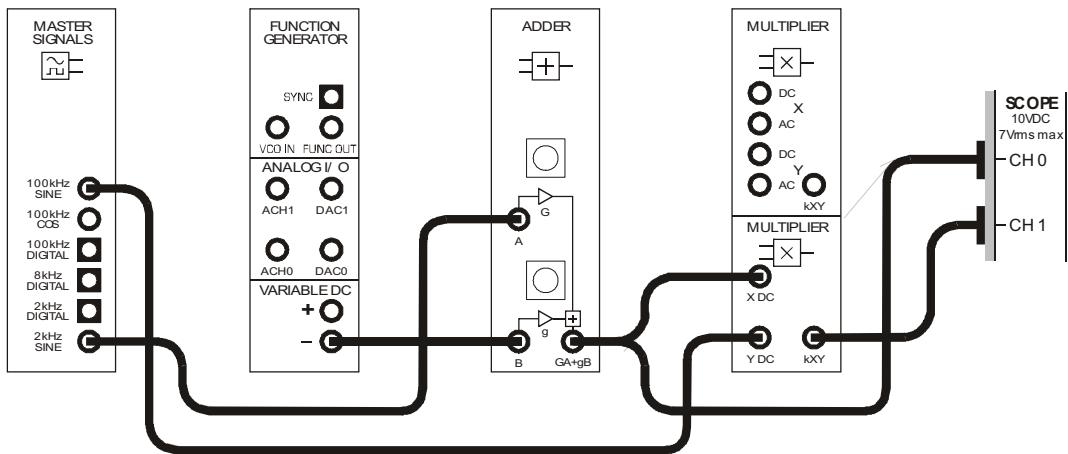
Figure 2

15.   Connect the Adder module's output to the DMM and adjust the module's soft *g* control to obtain a 1V DC output.

Note 1: Remember that you must also connect the DMM's *COM* input to a ground terminal on the Emona DATEx.

Note 2: Remember also that you can use the keyboards tab and arrow keys for fine adjustment of DATEx soft controls.

16.   Disconnect the DMM and close its VI.

17.   Launch and run the NI ELVIS II Oscilloscope VI.

18.   Set up the scope per the procedure in Experiment 1 with the following changes:

   ▪   Channel 0 *Coupling* control to the *DC* position instead of *AC*
   ▪   Channel 0 *Scale* control to the *500mV/div* position instead of *1V/div*
   ▪   *Trigger Level* control to the *1V* position instead of *0V*

19.   Adjust the scope's *Timebase* control to view only two or so cycles of the message signal.

20.   Adjust the Adder module's soft *G* control to obtain a 1Vp-p sinewave.

21. Activate the scope's Channel 1 input to view both the message and the modulated carrier.

Self check: If the scope's *Scale* control for Channel 1 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. If not, close all windows, check your wiring then repeat the process starting from Step 7.

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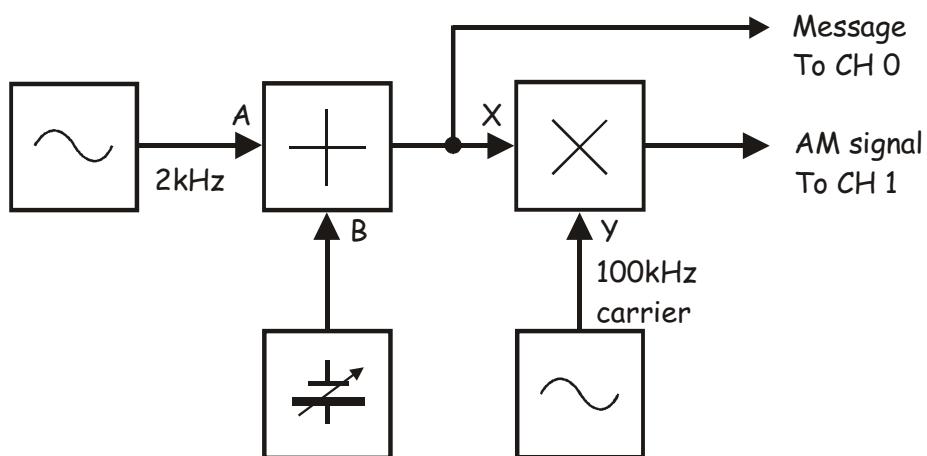
Figure 3

Ask the instructor to check
your work before continuing.

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Part B – Recovering the message using an envelope detector

22.   Modify the set-up as shown in Figure 4 below.

      Remember: Dotted lines show leads already in place.
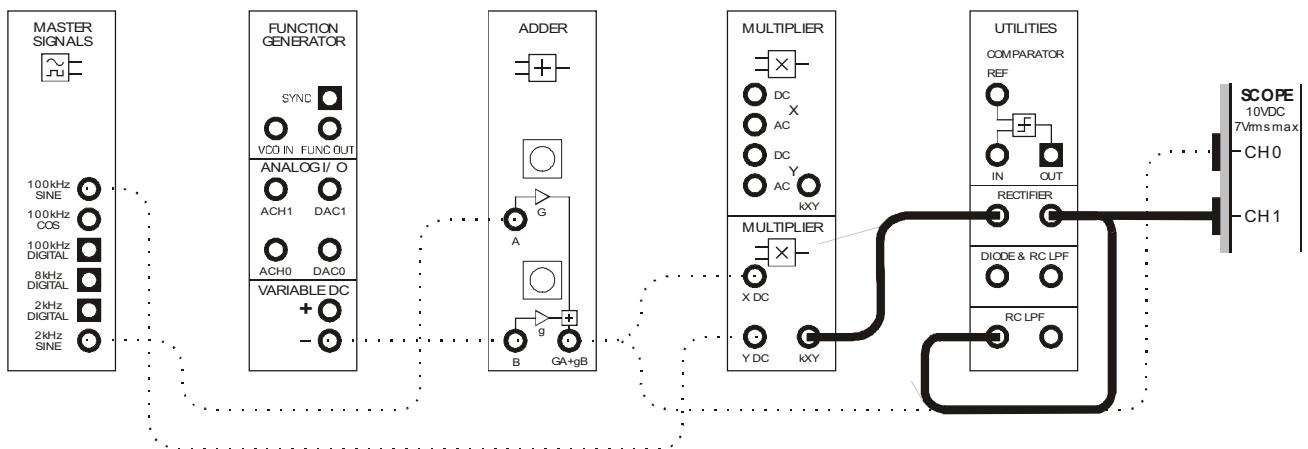
Figure 4

The additions to the set-up can be represented by the block diagram in Figure 5 below. As you can see, it's the envelope detector explained in the preliminary discussion.
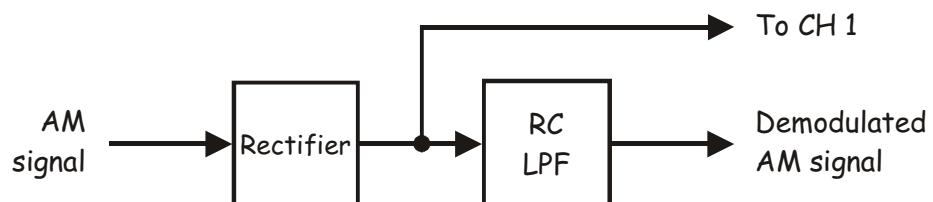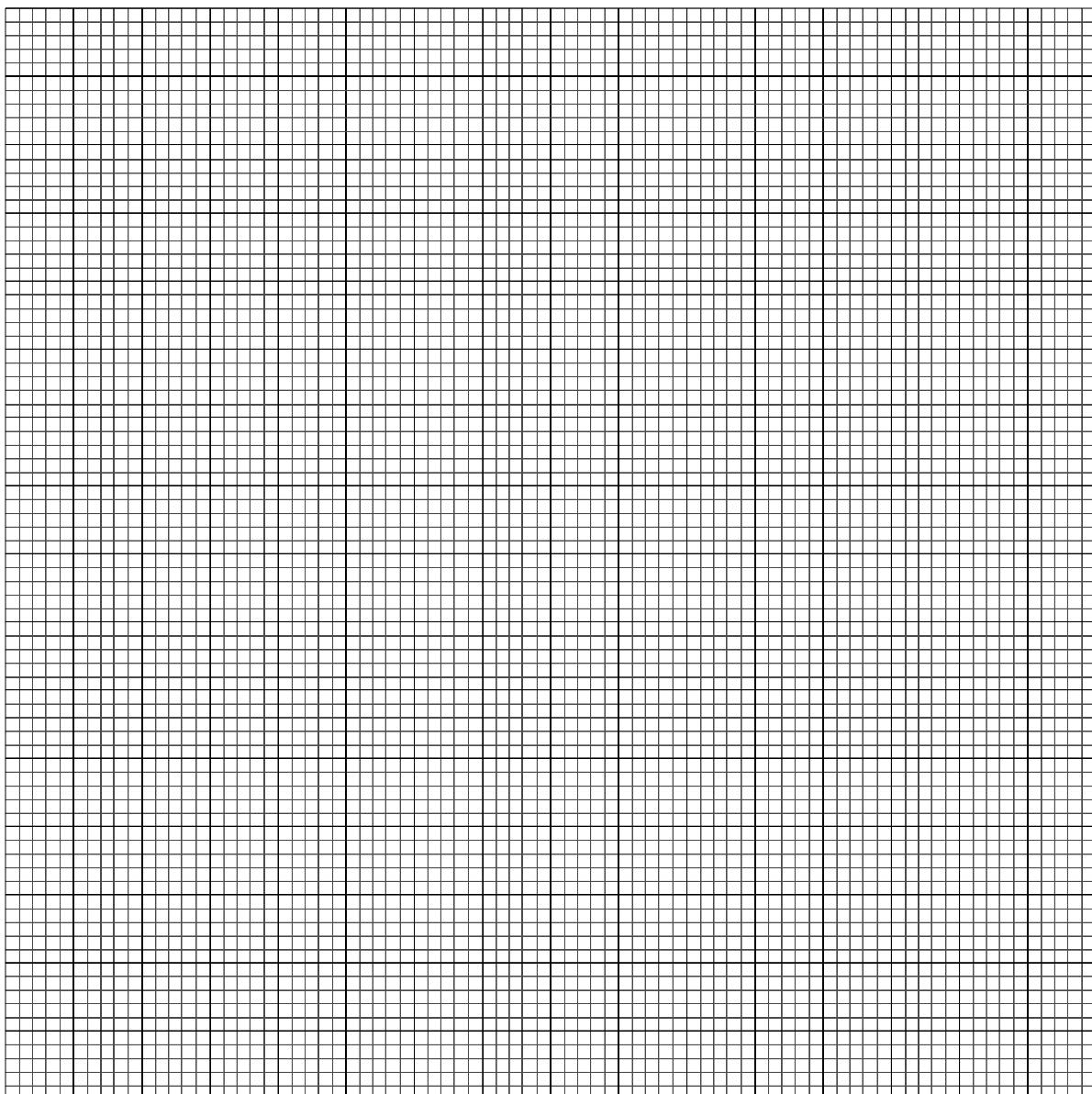

Figure 5

23. Adjust the scope's *Scale* and *Timebase* controls to appropriate settings for the signals.

24. Draw the two waveforms to scale in the space provided below leaving room to draw a third waveform.

    Tip: Draw the message signal in the upper third of the graph and the rectified AM signal in the middle third.

25. Disconnect the scope's *Channel 1* input from the *Rectifier's* output and connect it to the *RC LPF's* output instead.

26. Draw the demodulated AM signal to scale in the space that you left on the graph paper.

Question 1
What is the relationship between the original message signal and the recovered message?

_____

 Ask the instructor to check your work before continuing.

Part C – Investigating the message's amplitude on the recovered message

27. Vary the message signal's amplitude up and down a little (by turning the Adder module's soft G control left and right a little) while watching the demodulated signal.

Question 2
What is the relationship between the amplitude of the two message signals?

_____

_____

28. Slowly increase the message signal's amplitude to maximum while watching the demodulated signal.

Question 3
What do you think causes the heavy distortion of the demodulated signal? **Tip:** If you're not sure, connect the scope's Channel 0 input to the AM modulator's output.

_____

Question 4
Why does over-modulation cause the distortion?

_____

_____

Ask the instructor to check
your work before continuing.

Part D – Transmitting and recovering speech using AM

This experiment has set up an AM communication system to "transmit" a message that is a 2kHz sinewave. The next part of the experiment lets you use the set-up to modulate, transmit, demodulate and listen to speech.

29. If you moved the scope's Channel 0 input to help you answer Question 4, reconnect it to the Adder module's output.

30. Return the message signal's amplitude to 1Vpp (by adjusting the Adder module's soft *G* control).

31. Modify the set-up as shown in Figure 6 below.
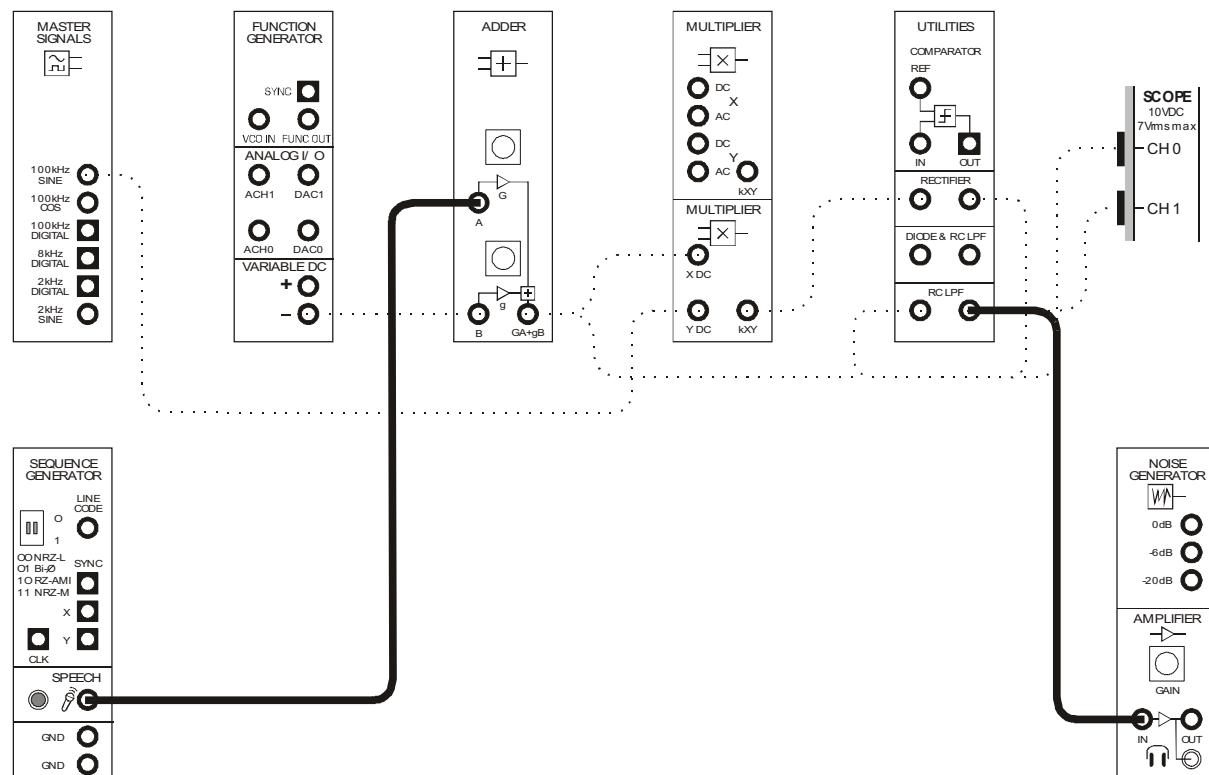
Figure 6

32. Set the scope's *Timebase* control to the *2ms/div* position.

33. Turn the Amplifier module's soft *Gain* control fully anti-clockwise.

34. Without wearing the headphones, plug them into the Amplifier module's headphone socket.

35. Put the headphones on.

36. As you perform the next step, set the Amplifier module's soft *Gain* control to a comfortable sound level.

37. Hum and talk into the microphone while watching the scope's display and listening on the headphones.

> ☑ Ask the instructor to check your work before continuing.

Part E – 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:

- One with a frequency equal to the sum of the two signals' frequencies

- One with a frequency equal to the difference between the two signals' frequencies

The envelope detector works because the rectifier 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:

- Carrier + (carrier + message)

- Carrier + (carrier - message)

- (carrier + message) + (carrier - message)

- Carrier - (carrier + message) which simplifies to just the message

- Carrier - (carrier - message) which also simplifies to just the message

- (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 2kHz message (with a DC component). So, the resulting AM signal consists of three sinewaves: one at 100kHz, another at 102kHz and a third at 98kHz. Table 1 below shows what happens when these sinewaves are cross-multiplied by the rectifier.

Table 1	100kHz×102kHz	100kHz×98kHz	98kHz×102kHz
Sum	202kHz	198kHz	200kHz
Difference	2kHz	2kHz	4kHz

Notice that two of the 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.

[As an aside, the 4kHz sinewave that was generated would pass through the low-pass filter as well and be present on its output along with the 2kHz 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 Emona DATEx module'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.

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38. Return the scope's *Timebase* control to its earlier setting (probably *200μs/div*).

39. Disconnect the envelope detector and modify the set-up to return it to just an AM modulator with a 2kHz sinewave for the message as shown in Figure 7 below.
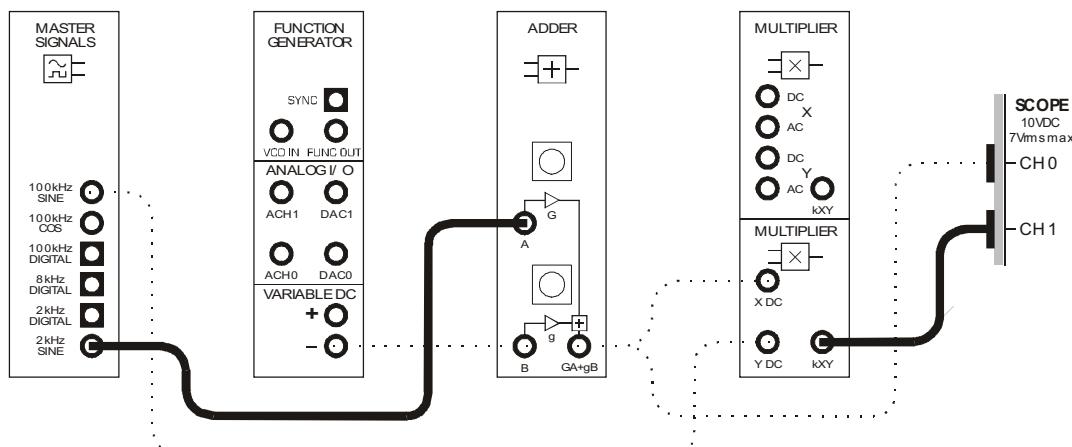

Figure 7

40. Modify the set-up as shown in Figure 8 below.
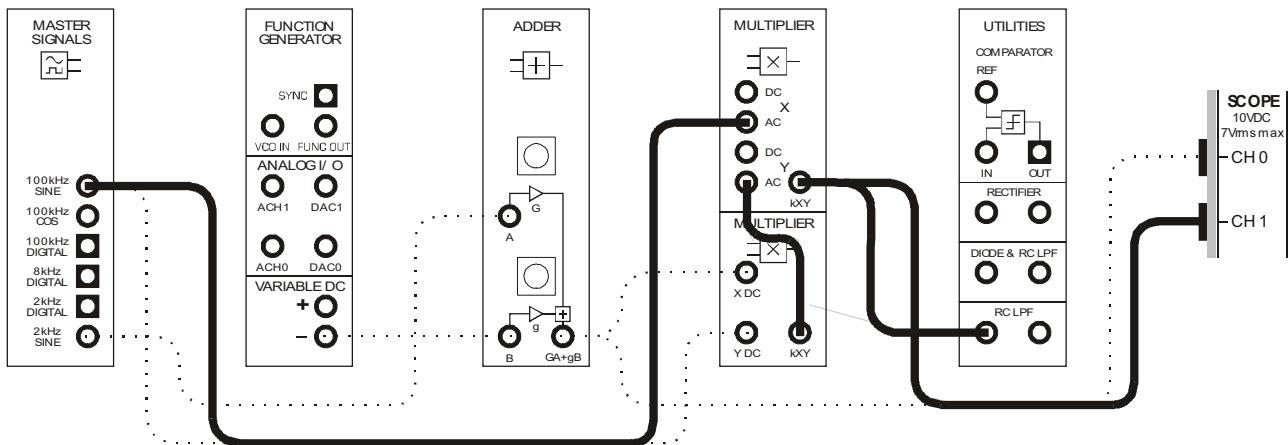
Figure 8

The additions to the set-up in Figure 8 on the previous page can be represented by the block diagram in Figure 9 below. 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.
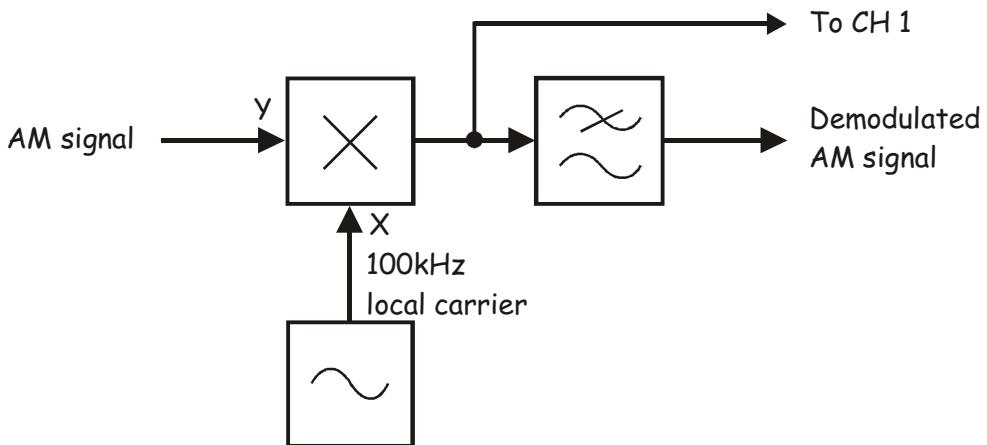

Figure 9

41. Compare the Multiplier module's output with the *Rectifier's* output that you drew earlier (see page 8-8).

Question 5
Given the AM signal (which consists of 100kHz, 102kHz and 98kHz sinewaves) is being multiplied by a 100kHz sinewave:

A) How many sinewaves are present in the Multiplier module's output?

B) What are their frequencies?

_____

_____

_____

_____

42. Disconnect the scope's *Channel 1* input from the Multiplier module's output and connect it to the *RC LPF's* output instead.

43. Compare the *RC LPF's* output with the message and the output *RC LPF's* that you drew earlier (see page 8-8).

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Ask the instructor to check
your work before continuing.

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 (like Figure 3) this is only true for the envelope detector.

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.

44.   Connect the scope's Channel 0 to the AM modulator's output.

45.   Set the scope's *Trigger Level* to *0V*.

       Note: The scope will lose triggering but the display will be adequate for the next steps.

46.   Slowly increase the message signal's amplitude to produce a near 100% modulated AM signal by adjusting the Adder module's soft *G* control.

       Note: Resize the AM and demodulated message signals on the screen as necessary.

47.   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.

Ask the instructor to check
your work before finishing.

                   Experiment 8 – AM demodulation