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Experiment 88 - Analogue Modulation/Demodulation Techniques

Department of Electrical Engineering & Electronics

September 2019, Ver. 2.4

Important: Marking of all coursework is anonymous. Please complete your details in the box shown above, then fold and glue the corner to keep your personal details anonymous during marking. Do not include your name, student ID number, group number, email or any other personal information anywhere else in this workbook. A penalty will be applied to submissions that do not meet this requirement.

Experiment specifications

Module(s)	ELEC273
Experiment code	88
Semester	1
Level	2
Lab location	Electronics lab-third floor
Work	In groups
Timetabled time	7 hrs
Subject(s) of relevance	Communications, Modulation, Demodulation
Assessment method	This workbook, submitted at the end of the lab
Submission deadline	Same lab day

Marks:

Part I-AM Mod. (20 Marks):	Part IV-DSBSC Demod. (15 Marks):	Bonus: FM Demod.
Part II-DSBSC Mod. (25 Marks):	Part V- FM Mod. (15 Marks):	
Part III-AM Demod. (15 Marks):	Pre-lab test (10 Marks):	**Total mark (100%):**

Instructions:

- **Read this script before attempting the experiment.**
- **The Pre-Lab Questions should be answered before the lab day. They are available on VITAL (Online) and worth 10% of the overall mark of the experiment.**
- **The script questions should be answered while carrying out the experimental procedure.**
- **As you complete each part of the experiment, ensure that your results and calculations are viewed and approved by one of the demonstrators before proceeding.**
- **The completed script should be submitted at the end of the lab to the responsible demonstrator for marking. Failure to do this means you will have no mark for this experiment.**
- **If you have any feedback on your laboratory experience for today, please write it down on the last page of this workbook.**

1 Learning outcomes

At the end of this lab, you will:

- be familiar with the following analogue modulation/demodulation techniques:
  - AM
  - DSBSC
  - FM
- have good practical experience in building and testing analogue modulation/demodulation systems.

2 Apparatus

- Emona Telecoms-Trainer 101 kit.
- Oscilloscope TDS 210.
- Wires of different sizes and BNC cables.

3 Part I: Amplitude modulation (30 Marks)

3.1 Introduction

In an amplitude modulation (AM) communication 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 messages frequency.

Figure 1 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

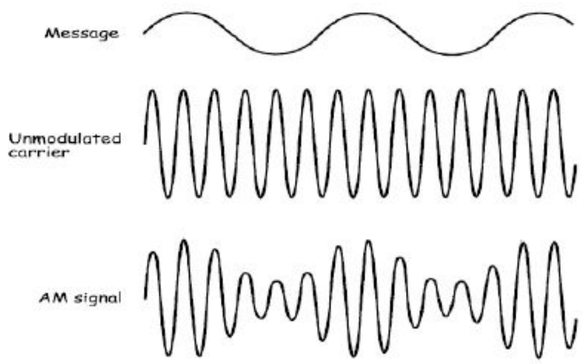

Figure 1: AM modulation concept

amplitude varies above and below its unmodulated amplitude.

Figure 2 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).

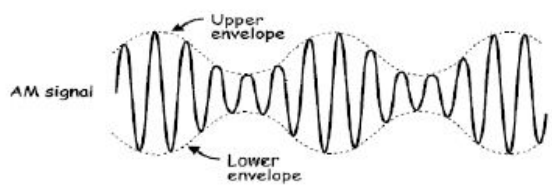

Figure 2: AM signal

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

$$AM = (DC + message) \times \ the\ carrier \tag{1}$$

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.

Experiment A - Generating an AM signal using a simple message

Using the Emona Telecoms-Trainer kit shown in Figure 3, connect the setup represented by the block diagram shown in Figure 4. It implements the highlighted part of the equation: AM = **(DC + message)** × the carrier.

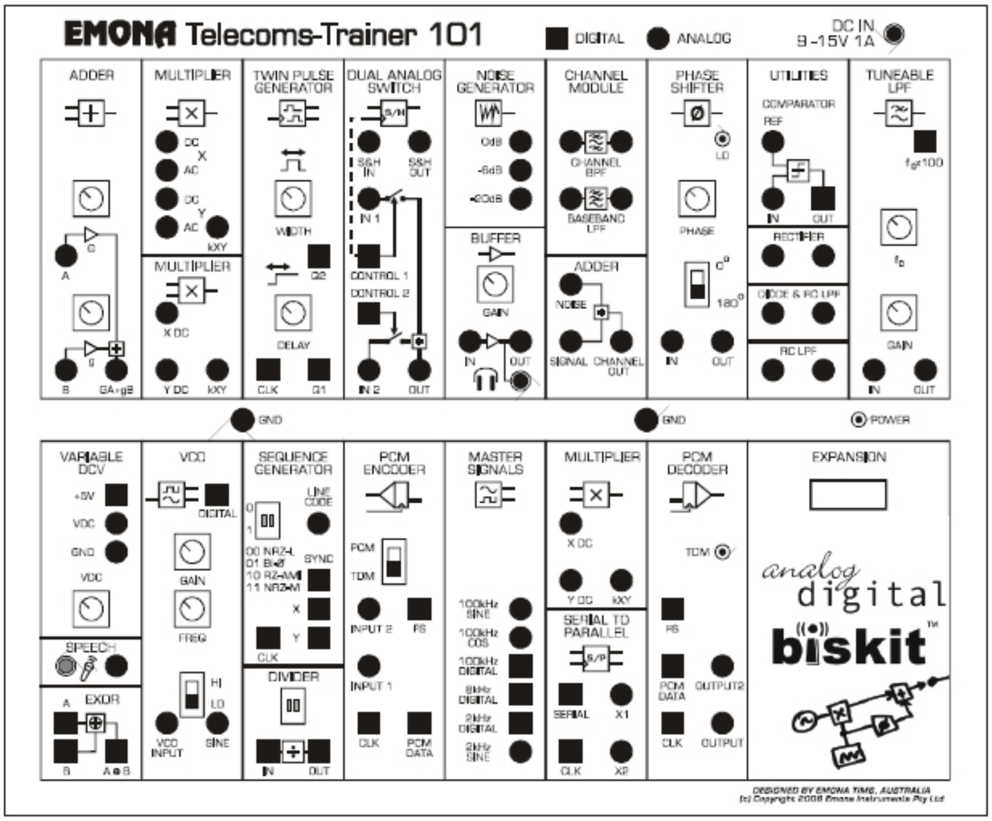

Figure 3: Emona Telecoms-Trainer Kit

- Adjust the settings of the Modules to have the equation above with the following values: AM = **(1.5 VDC + 1.5 Vp-p 2 kHz sine)** × the carrier.

Question 1:

Why is a DC signal added to the message?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

- Modify the setup as shown in Figure 5.
  The additions that you've made to the original setup implement the highlighted part of the equation: AM = (DC + message) × **the carrier**

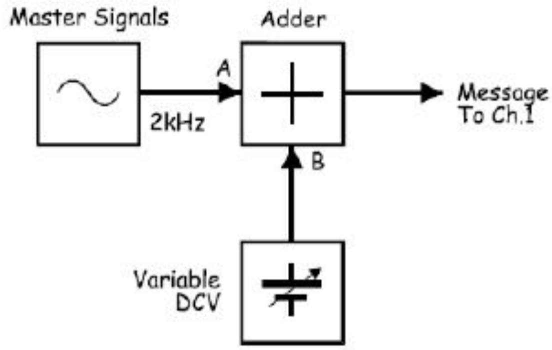

Figure 4: Setup of Experiment A

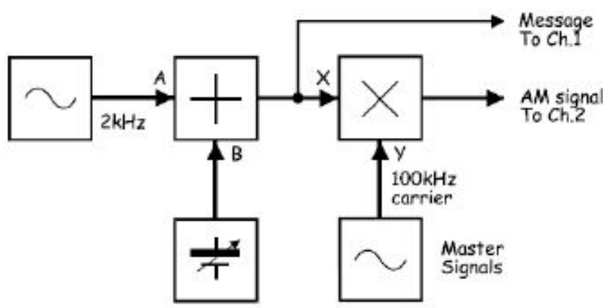

Figure 5: A modified setup of Experiment A

- Set the values as in the equation:
  AM = (1.5 VDC + 1.5 Vp-p 2 kHz sine) × **4 Vp-p 100 kHz sine**.
  N.B. The master signal has a default peak-o-peak value of 4 V.
- Draw the two waveforms to scale in the space provided.
- Use the scope's channel 1 vertical position control to overlay the message with the AM signal's envelopes and compare them.

Question 2:

What is the key characteristic of the envelope of this AM signal?

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

Question 3:

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

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

- 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

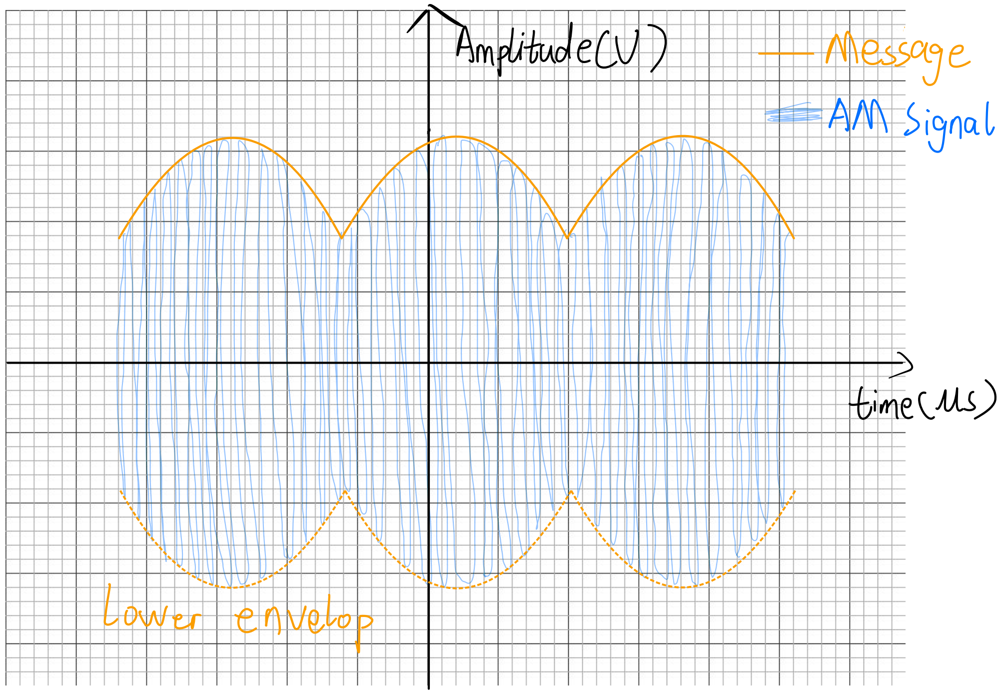

Figure 6: The two waveforms of Experiment A

music. Connect the output of the speech module as the message signal.

Question 4:

Why is there still a signal out of the multiplier module even when you are not talking, whistling, etc?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Experiment B - Investigating the modulation index

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

- Reconnect the adder module A input to the master signals module 2 kHz sine output. Vary the message signal amplitude a little by turning adder module G control left and right and notice the effect on the AM signal.

Question 5:

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

The specific explanation and answer will be placed at the end of this lab script. (Question part)

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

Figure 7 shows two key dimensions of an amplitude modulated carrier. These two dimensions allow a carrier modulation index to be calculated. [N.B. This may be different from what you've learned before in the lectures.]

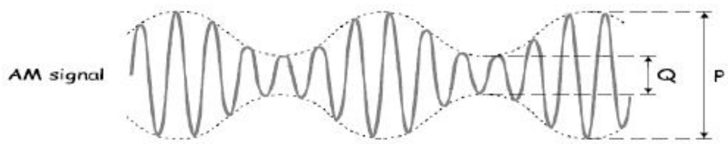

Figure 7: Modulation index parameters

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

$(P = 2.19V - (-2.19V)) = 4.38V$, $Q = 0.52 - (-0.52) = 1.04)$

- Calculate and record the AM signal modulation index using the equation below:

$m = (P - Q)/(P + Q) = (\underset{P}{4.38\,V} - \underset{Q}{1.04V})(\underset{P}{4.38\,V} + \underset{Q}{1.04V}) \approx 0.616$

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

- Increase the message signal amplitude to the maximum and notice the effect on the AM signal. Use Channel 1 vertical position control of the scope to overlay the message with the AM signal envelopes and compare them and draw the two waveforms in the space provided.

Question 6:

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

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

Question 7:

What is a carrier maximum modulation index without over-modulation?

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

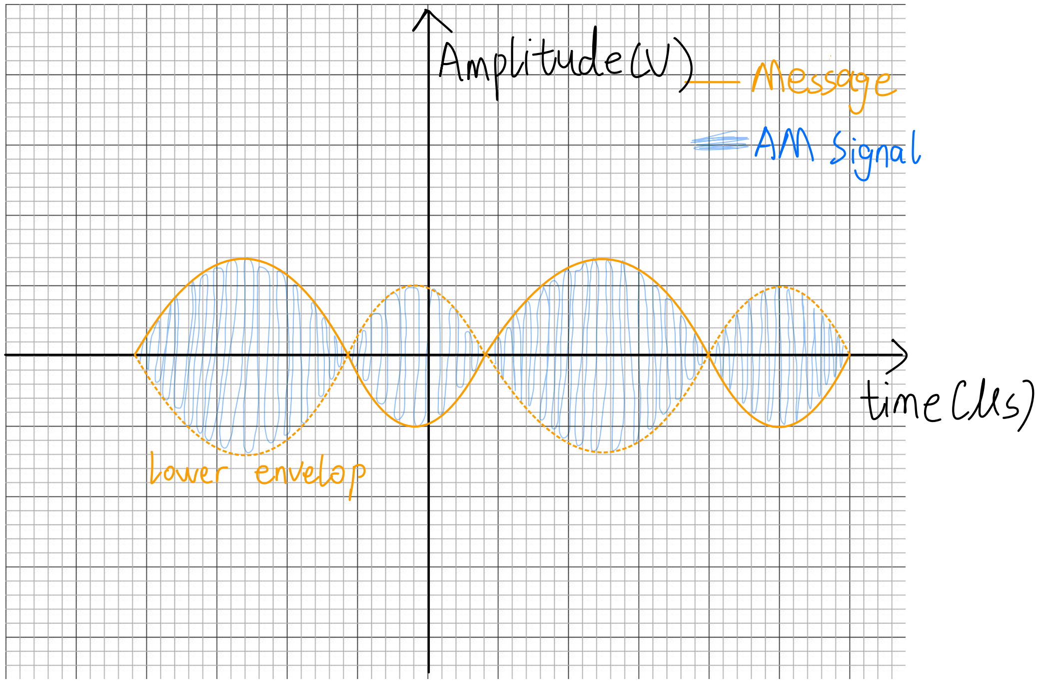

Figure 8: The two waveforms of Experiment B

4 Part II: DSBSC modulation (25 Marks)

4.1 Introduction

DSBSC like AM, DSBSC uses a microphone or some other transducer to convert speech and music to an electrical signal called the message or baseband signal. The message signal is then used to electrically vary the amplitude of a pure sinewave called the carrier. Like AM, the carrier usually has a frequency that is much higher than the message's frequency.

Figure 9 shows a simple message signal and an unmodulated carrier. It also shows the result of modulating the carrier with the message using DSBSC.

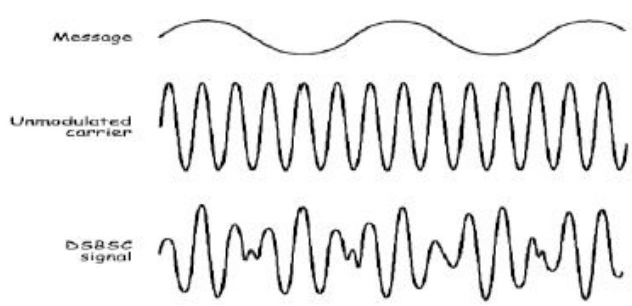

Figure 9: DSBSC modulation signals

So far, there was no much difference between AM and DSBSC. However, consider Figure 10. It is the same as the DSBSC signal at the bottom of Figure 9 but with dotted lines added to track the signal's envelopes (that is, its positive peaks and negative peaks). If you look at the envelopes closely, you will notice that they are not the same shape as the message compared to the case with AM.

Instead, alternating halves of the envelopes form the same shape as the message as shown in

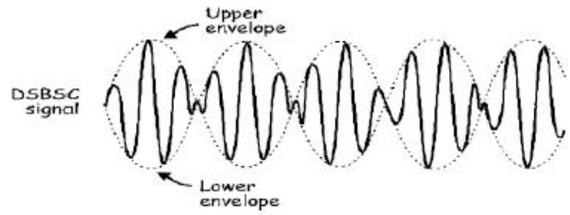

Figure 10: Upper and lower envelopes of a DSBSC signal

Figure 11.

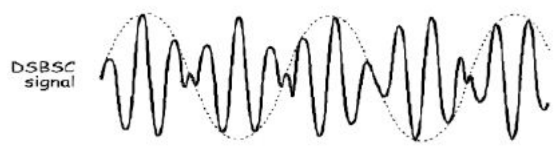

Figure 11: Upper envelope of the DSBSC signal only

Another way to see the difference between DSBSC and AM can be seen by considering the mathematical model that defines the DSBSC signal:

$$DSBSC = the\ message\ \times\ the\ carrier \tag{2}$$

Do you see the difference between the equations for AM and DSBSC? If not, look at the AM equation again.

When the message is a simple sinewave (like in Figure 9), the solution of the equation (which necessarily involves some trigonometry) tells us that the DSBSC signal consists of two sinewaves:

- 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.

Accordingly, the DSBSC signal **does not** contain a sinewave at the carrier frequency. This is an important difference between DSBSC and AM.

Hence, as the solution to the equation shows, DSBSC is the same as AM in that a pair of sinewaves is generated for every sinewave in the message. And, like AM, one is higher than the unmodulated carrier frequency and the other is lower. As message signals, such as speech and music, are made up of thousands of sinewaves (according to Fourier theorem), thousands of pairs of sinewaves are generated in the DSBSC signal and located on either side of the carrier frequency. These two groups are called the **sidebands**.

So, the presence of both sidebands but the absence of the carrier gives us the name of this modulation method - double-sideband, suppressed carrier (DSBSC).

The carrier in AM makes up at least 66% of the signal power but it does not contain any part of the original message and is only needed for tuning. So by not sending the carrier, DSBSC offers a substantial power saving over AM and this is its main advantage.

Experiment A - Generating a DSBSC signal using a simple message

- Connect the setup represented by the block diagram shown in Figure 12, which implements the entire equation: **DSBSC = the message × the carrier**.

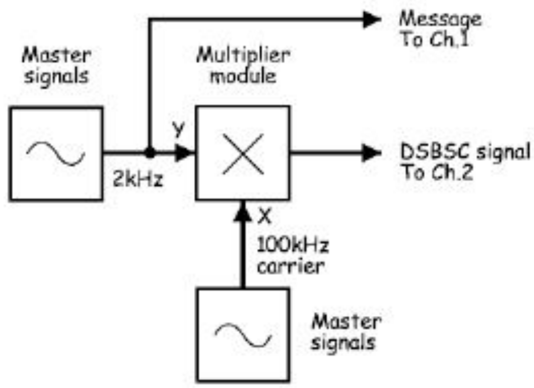

Figure 12: The setup of Experiment A

- Adjust the values, as in the equation: **DSBSC = 4 Vp-p 2 kHz sine × 4 Vp-p 100 kHz sine.**

- Draw the two waveforms to scale in the space provided.

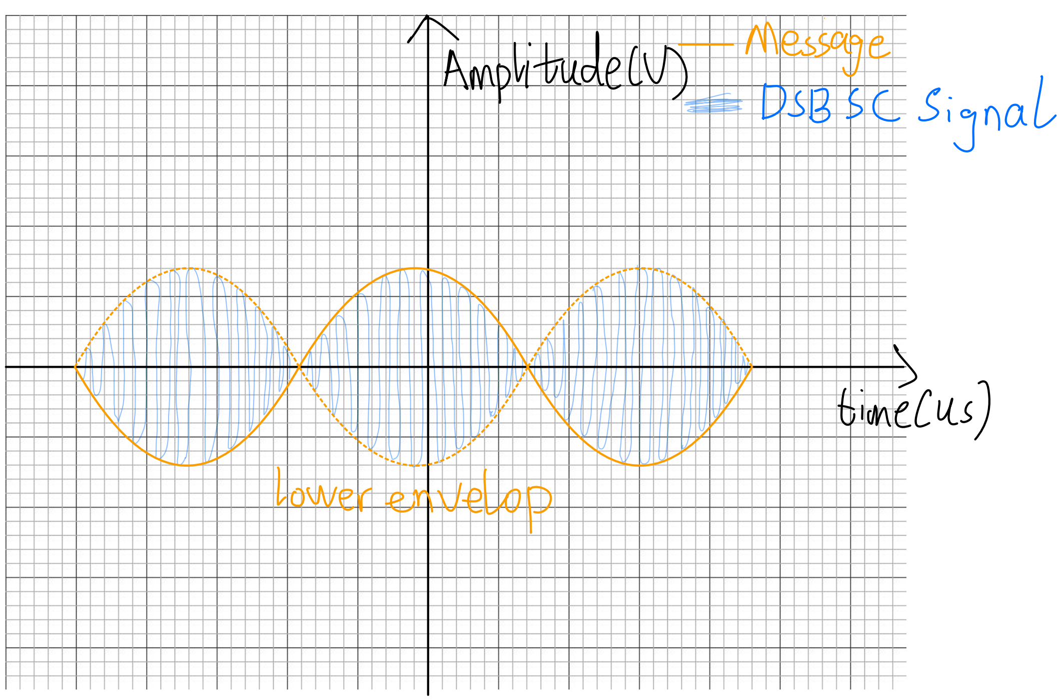

Figure 13: The two waveforms of Experiment A

- Overlay the message with the DSBSC signal envelopes and compare them.

Question 8:

What is the key characteristic of the envelope of this DSBSC signal?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Question 9:

For the given inputs to the multiplier module, how many sinewaves does the DSBSC signal consist of and what are their frequencies?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Question 10:

Why does this make DSBSC signals better for transmission than AM signals?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

- Connect the Speech module output as a message for the modulator.

Question 11:

What is the difference between the speech signal modulation here in DSBSC and the one in AM modulation?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Experiment B - Investigating the modulation index

It is possible to modulate a carrier by different amounts. This part of the experiment lets you investigate this.

- Modify the setup shown in Figure 14.
- Recall from AM experiment that an AM signal has two dimensions that can be measured and used to calculat the modulation index (m). The dimensions are denoted as P and Q.
- Vary the message signal amplitude a little, and observe the effect that this has on the DSBSC signal P and Q dimensions.

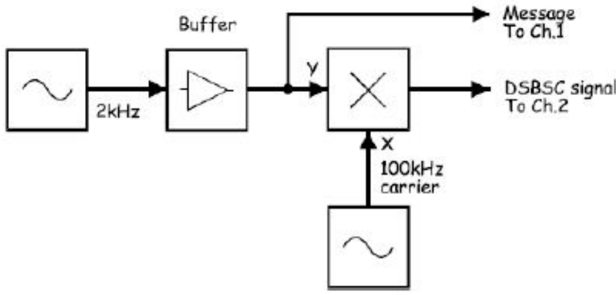

Figure 14: The modified setup of Experiment B

Question 12:

Based on your observations, what is the effect of the message amplitude on the signal dimensions P and Q?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

One of the main reasons for calculating an AM signal modulation index is to be able to calculate the power distribution between the signal carrier and its sidebands. However, DSBSC signals do not have a carrier (remember, it is suppressed). This means that all of the DSBSC signal power is distributed between its sidebands evenly. So there is no need to calculate a DSBSC signal modulation index.

The fact that you can not calculate a DSBSC signal modulation index might imply that you can make either the message or the carrier as large as you like without worrying about overmodulation. This is not true. Making either of these two signals too large can still overload the modulator, resulting in a type of distortion that you have seen before.

- Set the Buffer module gain control to about half of its travel and notice the effect on the DSBSC signal. Draw the new DSBSC signal in the space provided.

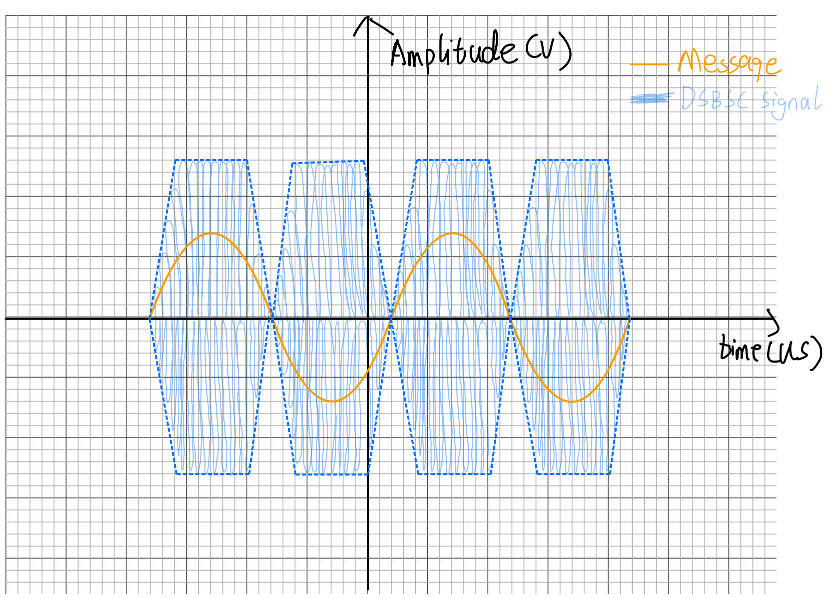

Figure 15: The DSBSC signal of Experiment B

Question 13:

What is the name of this type of distortion? Why?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

5 Part III: AM demodulation (15 Marks)

5.1 Introduction

If you have completed the AM modulation part, then you have seen what happens when you use a 2 kHz sinewave 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 of 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 an AM signals is called an ***envelope detector***. The block diagram of an envelope detector is shown in Figure 16.

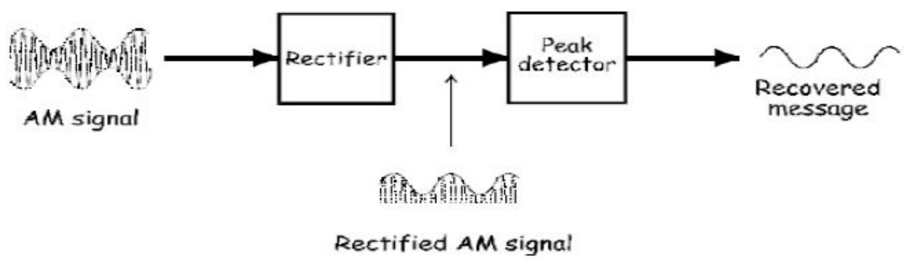

Figure 16: AM demodulation concept

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 a peak detector, which, as its name implies, tracks the peaks of its input. When the input to the peak detector is a rectified AM signal, it tracks the signal envelope. Importantly, as the envelope has the same shape as the message, the peak detector output voltage has also the same shape as the message, and hence the AM signal is demodulated.

A limitation of the envelope detector shown in Figure 16 is that it can not accurately recover the message from over-modulated AM signals. To explain, recall that when an AM carrier is over-modulated, the signal envelope has no longer the same shape as the original message. Instead, the envelope is distorted and so, by definition, this means that the envelope detector will produce a distorted version of the message.

Experiment A - Setting up the AM modulator

- Connect the setup shown in Figure 17, which generates a 100 kHz carrier that is amplitude-modulated by a 2 kHz sinewave message.
- Control the DC level to 1 V, and the message level to 1 Vp-p sinewave.

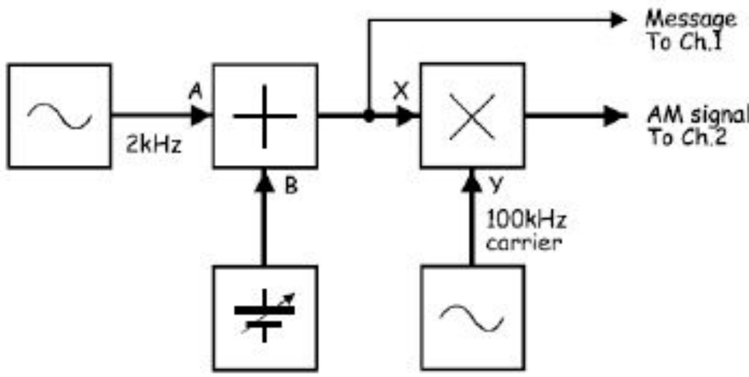

Figure 17: The setup for Experiment A

- Measure the AM signal modulation index.

$Q = 0.42V - (-0.42) = 0.84V)$

$(P = 1.34V - (-1.32) = 2.66V,$

$m = \frac{P-Q}{P+Q} = \frac{2.66-0.84}{2.66+0.84} = \frac{1.82}{3.5} = 0.52$

Experiment B - Recovering the message using an envelope detector

- Connect the setup shown in Figure 18. Use the AM signal that you have generated previously as the input to the setup.

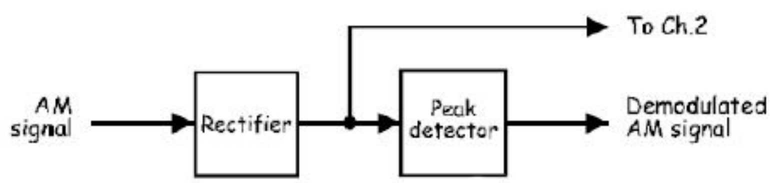

Figure 18: The modified setup for Experiment B

As you can see, Figure 18 is the envelope detector explained in the introduction. Note that an RC low-pass filter is used for the peak detector.

- In the space provided, draw:
  - the AM signal,
  - the rectified signal, and
  - the demodulated AM signal.

Question 14:

Is there any difference between the original message signal and the recovered message? Why?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

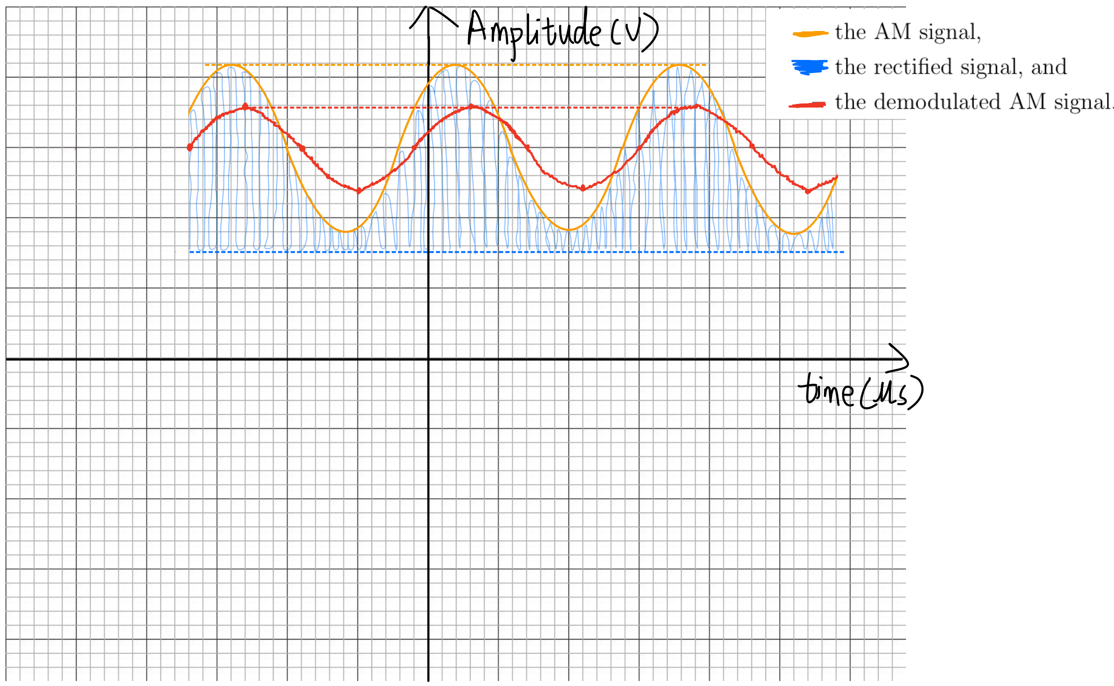

Figure 19: The waveforms of Experiment B

Experiment C - Investigating the message amplitude of the recovered message

- Vary the message signal amplitude up and down a little (by turning the adder module G control left and right) while watching the demodulated signal.

Question 15:

Is there a difference between the amplitude of the two message signals? Why?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

- Slowly increase the message signal amplitude to the maximum while watching the demodulated signal.

Question 16:

What causes the heavy distortion in the demodulated signal?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Experiment D - Transmitting and recovering speech using AM

In this experiment, you will set up an AM communication system to "transmit" a message that is a 2 kHz sinewave. The next part of the experiment lets you use the setup to modulate, transmit, demodulate and listen to speech (this experiment is for observation only).

- Adjust the message signal amplitude back to 1 Vp-p (by turning the adder module G control anti-clockwise), and modify the previous setup to connect the message signal as the speech module output and add a buffer to the output of the RC circuit.

- Plug headphones into the Buffer module headphone socket. Talk, sing or hum while watching the scope display and listening to the voice of the headphones.

Experiment E - The mathematics of AM demodulation

The envelope detector works because the rectifier is a device that **multiplies** all signals on its input with each other. Generally, 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 input, mathematically the rectifier cross-multiplication of all of its sinewaves looks like:

$$Rectifier's\ output = carrier \times (carrier\ +\ message) \times (carrier\ -\ message) \tag{3}$$

If the message signal used to generate the AM signal is a simple sinewave, then the rectifier outputs six sinewaves:

- 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 us do an example with numbers. The AM modulator that you set up at the beginning of this experiment uses a 100 kHz carrier and a 2 kHz message (with a DC component). So, the resulting AM signal consists of three sinewaves: one at 100 kHz, another at 102 kHz and a third at 98 kHz. Table 1 shows what happens when these sinewaves are cross-multiplied by the rectifier.

Table 1: The resultant frequencies after rectification

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

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

Importantly, we do not want the other non-message sinewaves, so to reject them but keep the message, the rectifier output is sent to a low-pass filter (which explains why a low-pass filter can work as a peak detector). Ideally, the filter output will only consist of the message signal. The chances of this can be improved by making the carrier 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 that the 4 kHz sinewave that was generated would pass through the low-pass filter as well and be present on its output along with the 2 kHz 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 Telecoms-Trainer 101's multiplier module. However, instead of multiplying the AM signal sinewaves with each other (the Multiplier module does not do this), it must be multiplied with an additional pure 100 kHz sinewave. The next part of this experiment lets you demodulate an AM signal this way.

- Modify the setup as shown in Figure 20.

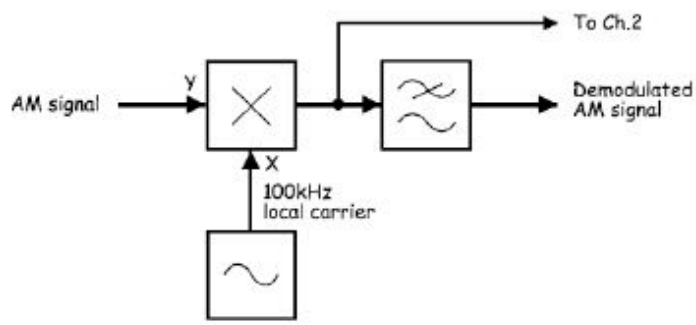

Figure 20: The setup of Experiment E

- Compare the Multiplier module output with the Rectifier output that you drew earlier in the envelope detector.

Question 17:

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

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

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

B) What are their frequencies?

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

- Compare the RC low-pass filter output with the message and the output RC low-pass filter that you drew earlier in the envelope detector.

6 Part IV: DSBSC demodulation (15 Marks)

6.1 Introduction

You have seen how the envelope detector can be used to recover the original message from an AM signal (that is, demodulate it). Unfortunately, the envelope detector can not be used to demodulate a DSBSC signal.

To understand why, recall that the envelope detector outputs a signal that is a copy of its input envelope. This works well for demodulating AM because the signal envelopes are of the same shape as the message that produced it in the first place. However, recall that a DSBSC signal envelopes are not the same shape as the message.

Instead, DSBSC signals are demodulated using a circuit called a ***product detector*** (also known as a synchronous detector or switching detector). The basic block diagram of such a circuit is shown in Figure 21.

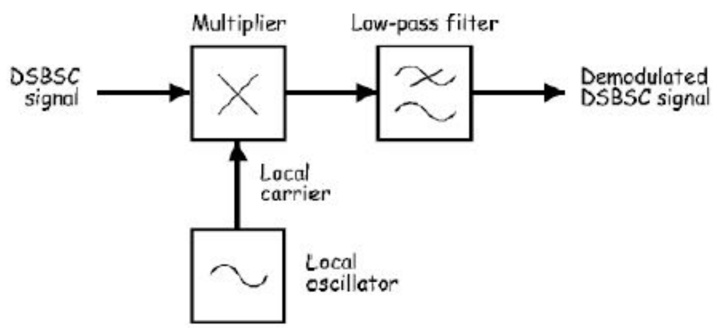

Figure 21: DSBSC demodulation system

As the name implies, the product detector uses multiplication, so mathematics is necessary to explain its operation. The incoming DSBSC signal is multiplied by a pure sinewave that must be of the same frequency as the DSBSC signal suppressed carrier. This sinewave is generated by the receiver and is known as the ***local carrier***.

To see why this process recovers the message, let us describe the product detection mathematically:

$$DSBSC\ demodulator's\ output \ = \ the\ DSBSC\ signal \ \times \ the\ local\ carrier \tag{4}$$

Importantly, recall that DSBSC generation involves the multiplication of the message with the carrier, which produces sum and difference frequencies. In this case, the above equation can be rewritten as:

$$DSBSC\ demodulator's\ output \ = \ [(carrier\ +\ message) + (carrier\ -\ message)] \times carrier \tag{5}$$

Hence, we have four sinewaves:

- carrier + (carrier + message),
- carrier + (carrier - message),
- carrier - (carrier + message), which simplifies to just the message (why?),
- carrier - (carrier - message), which also simplifies to just the message (why?).

Now, notice that two of the product outputs are sinewaves at the message frequency. In other words, the message has been recovered. As the two message signals are in phase, they simply add together to make one larger message (**why?**).

Notice also that two of the products are non-message sinewaves. These sinewaves are unwanted and so a low-pass filter is used to reject them while keeping the message.

Experiment A - Setting up the DSBSC modulator and demodulator

Obviously, to test the DSBSC demodulation, you need a DSBSC signal. The first part of the experiment performs this.

- Connect the setup shown in Figure 22. It uses a 100 kHz carrier that is DSBSC modulated by a 2 kHz sinewave message.

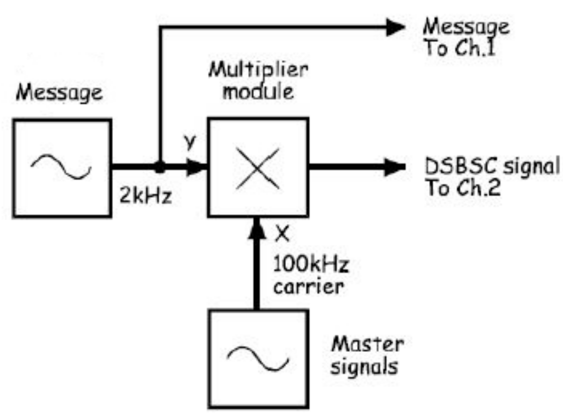

Figure 22: The setup used to generate a DSBSC signal

- Connect the setup shown in Figure 23 to demodulate the above DSBSC signal.

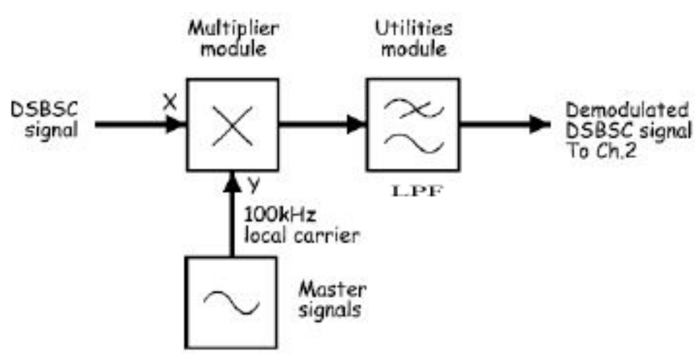

Figure 23: The setup used to demodulate the above DSBSC signal

- In the space provided below, draw:
  - the message signal,
  - the DSBSC signal, and
  - the demodulated DSBSC signal.

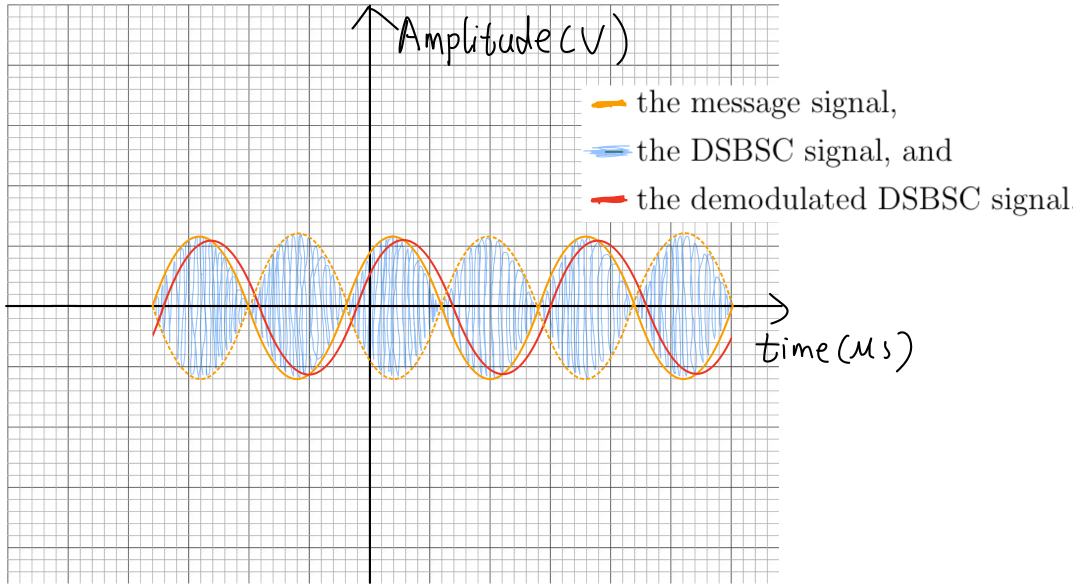

Figure 24: The waveforms of Experiment A

The entire setup is represented by the block diagram shown in Figure 25. It highlights the fact that the modulator carrier is "stolen" to provide the product detector local carrier. This means that the two carriers are **synchronised** which is necessary for DSBSC communication to work.

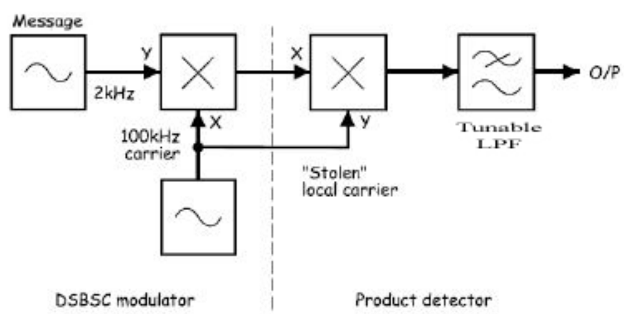

Figure 25: The complete setup for modulation/demodulation of a DSBSC signal

Question 18:

Why must a product detector be used to recover the message instead of an envelope detector?

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

Experiment B - Investigating the message amplitude of the recovered message

- Add a buffer module to the DSBSC modulator setup as in Figure 26. Use the same product detector setup in the previous part to demodulate the DSBSC.

- Vary the message amplitude up and down a little while observing the demodulated message signal.

Question 19:

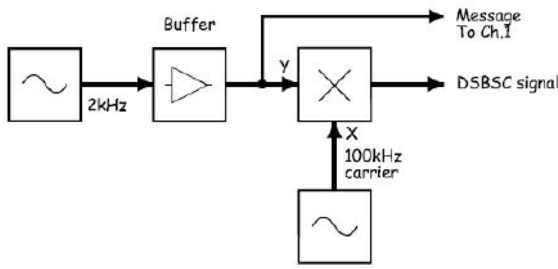

Figure 26: The setup for Experiment B

What is the difference between the amplitude of the two message signals (the original and the recovered)? Why?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

- Slowly increase the message amplitude to maximum until the demodulated signal becomes distorted.

Question 20:

What causes the distortion in the demodulated signal?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Experiment C - Transmitting and recovering speech using DSBSC

- Use the speech module output as a message signal. Plug it into the buffer module headphone socket, and talk, sing or hum while observing the scope display and listening to the voice on the headphones (this experiment is for observation only).

Experiment D - Carrier synchronisation

The synchronisation between the modulator carrier signal and the product detector local carrier is very crucial for a correct operation of a DSBSC communication system. Any phase or frequency difference between the two signals adversely affects the system performance.

Recall that the product detector generates two copies of the message. Recall also that they are in phase with each other and so they simply add to form one larger message. However, if there is a phase error between the carriers, the product detector two messages will have a phase error. One of them will have the sum of the phase errors and the other the difference. In other words, the two messages are out-of-phase with each other.

If the carriers phase error is small (say about 10°), the two messages still add together to form one larger signal but not as large as when the carriers are in phase. As the carriers phase error increases, the recovered message gets smaller. Once the phase error exceeds 45°, the two messages begin to subtract from each other (why?). When the carriers phase error is 90°, the two messages end up 180° out-of-phase and completely cancel each other out.

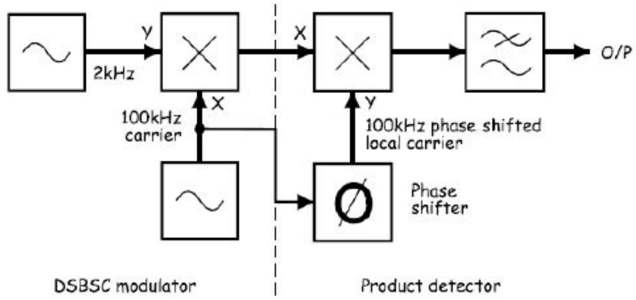

Figure 27: The setup for Experiment D

- Modify the DSBSC setup as shown in Figure 27. The phase shifter module allows a phase error between the DSBSC modulator carrier and the product detector local carrier to be introduced.

- Slowly increase the amplitude of the message signal (you may need a buffer module) until you can comfortably hear the demodulated 2 kHz tone.
- Vary the phase shifter module phase adjust control left and right while watching and listening to the effect on the recovered message.
- Adjust the phase shift control until the recovered message is the largest.

Question 21:

Given the size of the recovered message amplitude, what is the likely phase error between the two carriers?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

- Adjust the phase shift control until the recovered message is the smallest.

Question 22:

Given the size of the recovered message new amplitude, what is the likely phase error between the two carriers?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

7 Part V: Frequency modulation (15 Marks)

7.1 Introduction

A disadvantage of the AM and DSBSC communication systems is that they are susceptible to electrical noise in the transmission medium (the channel). This is because noise changes the amplitude of the transmitted signal and the demodulators of these systems are affected by amplitude variations.

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

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

Figure 28 shows a simple message signal (a bipolar squarewave) and an unmodulated carrier. It also shows the result of frequency modulating the carrier with the message.

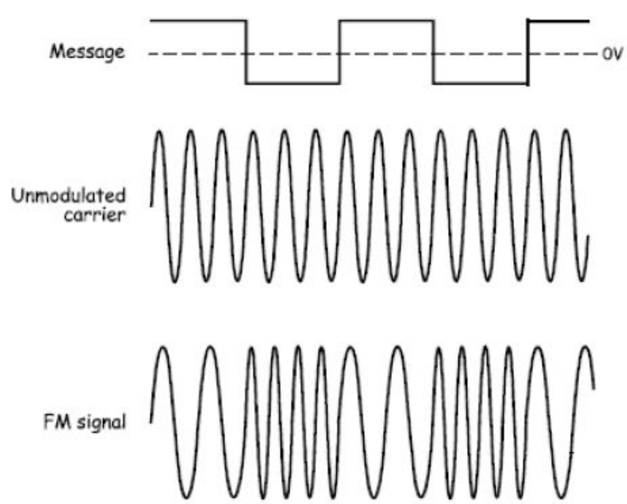

Figure 28: FM modulation concept

There are a few things to notice about the FM signal. Firstly, its envelopes are flat - recall that FM does not vary the carrier amplitude. Secondly, its period (and hence its frequency) changes when the amplitude of the message changes. Thirdly, as the message alternates above and below 0 V, the signal frequency goes above and below the carrier frequency. (Note: It is equally possible to design an FM modulator to cause the frequency to change in the opposite direction to the change in the message polarity.)

Experiment A - Frequency modulating a squarewave

- Connect the setup shown in Figure 29. The master signals module is used to provide a 2 kHz squarewave message signal and the VCO module is the FM modulator with a 10 kHz carrier.
- Set the VCO module rest frequency to 10 kHz.

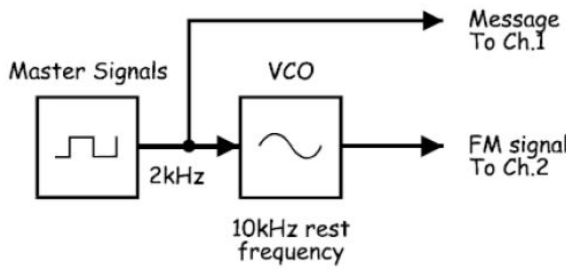

Figure 29: The setup for Experiment A

Question 23:

How many sinewaves are at the output of the VCO module?

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

Question 24:

Why do the sinewaves have different frequencies?

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

Question 25:

Which sinewave corresponds with the squarewave upper peak? (the one with the lower frequency or the higher frequency?)

The specific explanation and answer will be placed at the end of this lab script.
(Question part)

- Measure the period of the lower and higher frequency sinewaves. Record this in Table 2, and calculate the frequencies.

Table 2: FM modulating a square wave

	Period	**Frequency**
Low frequency sinewave	$100\mu s$	10 kHz
High frequency sinewave	$60\mu s$	16.67 kHz

$\leftarrow \frac{1}{100\mu s} = 10kHz$

$\leftarrow \frac{1}{60\mu s} = 16.67kHz$

Question 26:

Do either of these sinewaves have the same frequency as the VCO module rest frequency? Why?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Question 27:

What do the FM signal two sinewaves tell you about the message signal?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Experiment B - Generating an FM signal using speech

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

- Connect the speech module output as a message signal.
- Talk, sing or hum while watching the scope display.
- Slowly make your hum louder and louder without changing its pitch.

Question 28:

What happens to the VCO module output as you talk louder? Why?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

8 Part VI: FM demodulation (Bonus)

8.1 Introduction

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 is possible to implement several of these methods using the Emona Telecoms-Trainer 101, but for an introduction to the principles of FM demodulation, only the **zero-crossing detector** is used in this experiment.

The zero-crossing detector (ZCD) is a simple yet effective means of recovering a message from FM signals. The block diagram of the ZCD is shown in Figure 30.

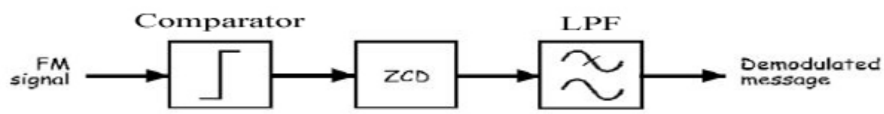

Figure 30: The zero-crossing detector

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

The ZCD generates a pulse with a 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 rectangular wave (pulses) with a fixed mark time.

When the FM signal frequency changes (in response to the message), the rectangular wave frequency does change as well. Importantly though, as the rectangular wave mark is fixed, changing its frequency is achieved by changing the duration of the space and, hence, the signal mark/space ratio (or duty cycle). This is shown in Figure 31 using an FM signal that only switches between two frequencies (because it has been generated by a squarewave as the message).

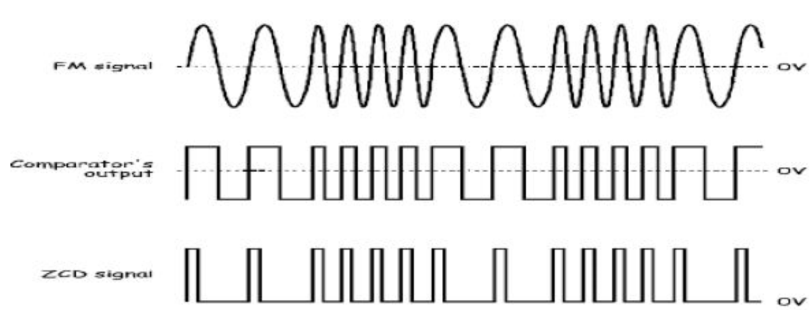

Figure 31: The ZCD signal

Recall from Fourier theorem that pulse trains are actually made up of sinewaves and a DC voltage. The amount of the DC voltage is affected by the pulse train duty cycle. The greater its duty cycle, the greater the DC voltage.

That being the case, when the FM signal in Figure 31 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 squarewave 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.

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

Experiment A - Setting up the FM modulator

- Connect the setup shown in Figure 32. The variable DCV module is being used to provide a simple DC message and the VCO module implements a frequency modulator with a carrier frequency of about 100 kHz.

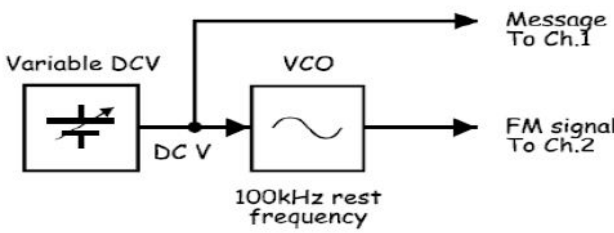

Figure 32: The setup for Experiment A

Experiment B - Setting up the zero-crossing detector

- Locate the twin pulse generator module and turn its width control fully anti-clockwise.
- Set the twin pulse generator module delay control fully anti-clockwise.
- Locate the tuneable low-pass filter module and set its gain control to about the middle of its travel.
- Turn the tuneable low-pass filter module cut-off frequency adjust control fully clockwise.
- Connect the setup as shown in Figure 33.

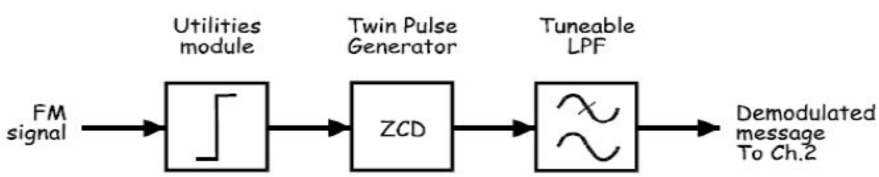

Figure 33: The setup for Experiment B

- The comparator on the utilities module is used to clip the FM signal, effectively turning it into a squarewave. The positive edge-triggered twin pulse generator module is used to implement the zero-crossing detector. To complete the FM demodulator, the baseband LPF on the channel module is used to pick up the changing DC component of the twin pulse generator module output.
- The complete setup can be represented by the block diagram in Figure 34.

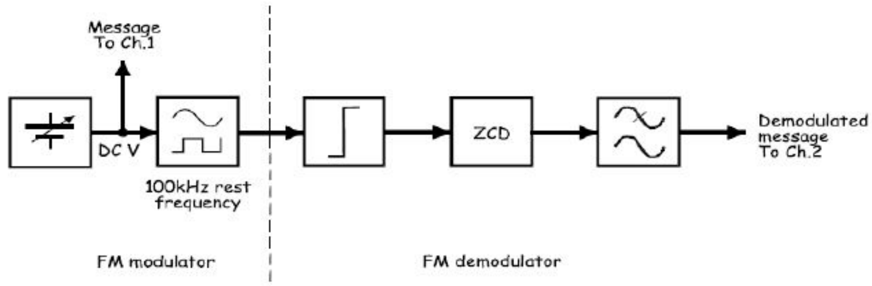

Figure 34: The complete setup for Experiment B

- Vary the variable DCV module DC voltage control left and right.

  Note: If the FM demodulator is working, the DC voltage out of the tuneable low-pass filter module should vary as you do.

Experiment C - Investigating the operation of the zero-crossing detector

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

- Rearrange the scope connections as shown in Figure 35.

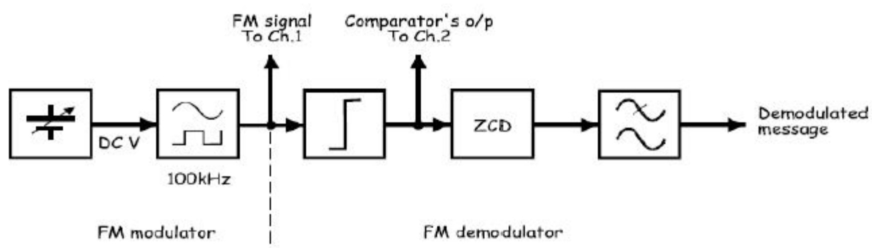

Figure 35: The setup for Experiment C

Question 29:

Why does the FM signal have one frequency only in this case?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

- Vary the variable DCV module DC voltage control left and right to model a FM signal with continuously changing frequency.
- As you perform the step above, examine the wave shape of the comparator output.

Question 30:

What type of a waveform does the comparator output?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Question 31:

What does this tell you about the DC component of the comparator output?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

- Rearrange the scope connections as shown in Figure 36.

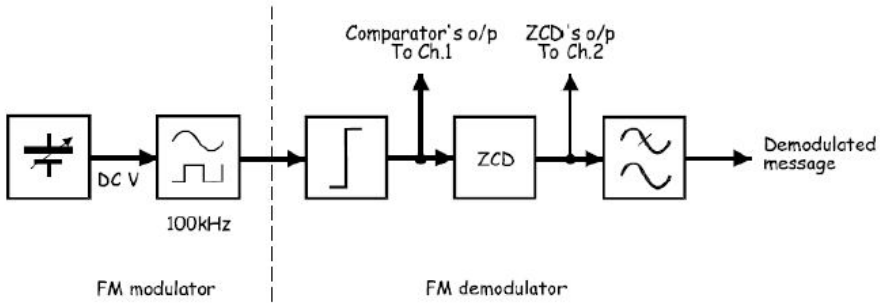

Figure 36: The modified setup for Experiment C

- Vary the variable DCV module DC voltage control left and right to model a FM signal with continuously changing frequency.

  Tip: Do this slowly to avoid confusing the scope triggering circuitry.
- As you perform the step above, compare the outputs from the comparator and the twin pulse generator module (the ZCD).

Question 32:

What type of waveform does the ZCD output?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

Question 33:

As the FM signal changes frequency so does the ZCD output, what aspect of the signal changes to achieve this? (circle the right ones)

- Neither the signal mark nor space
- Only the signal mark
- Only the signal space
- Both the signal mark and space

Question 34:

What does this tell you about the DC component of the ZCD output?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

The next part of the experiment lets you verify your answer to the last question.

- Rearrange the scope connections as shown in Figure 37.

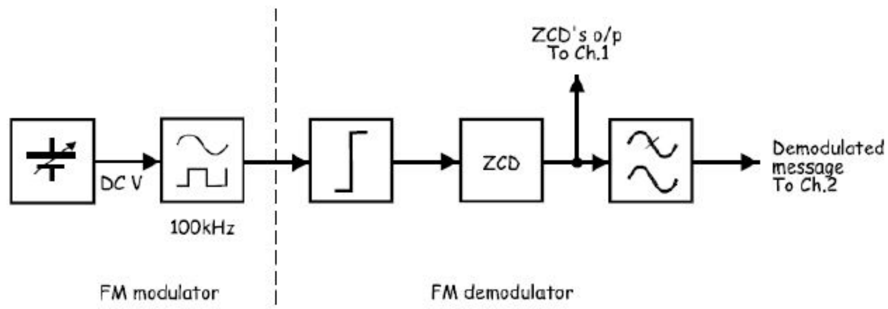

Figure 37: The final setup for Experiment C

- Vary the variable DCV module DC voltage control left and right to model an FM signal with continuously changing frequency.
- As you perform the step above, compare the outputs from the twin pulse generator module (the ZCD) and the baseband LPF.

  Tip: You may find it helpful to set the scope channel 2 vertical attenuation control to 0.5 V/division setting.

Question 35:

If the original message is a sinewave instead of a variable DC voltage, what would you expect the output of the baseband LPF be?

The specific explanation and answer will be placed at the end of this lab script. (Question part)

9 Assessment and Marking Scheme

This experiment is assessed by means of a workbook. Don't forget to submit this workbook to the responsible demonstrator **before leaving the lab** (one workbook must be submitted per student). The marking scheme for this workbook is as follows:

- Part I - AM Mod: **20 Marks**
- Part II - DSBSC Mod: **25 Marks**
- Part III - AM Demod: **15 Marks**
- Part IV - DSBSC Demod: **15 Marks**
- Part V - FM Mod: **15 Marks**
- Part VI - FM Demod: **instructor's decision**
- The pre-lab test: **10 Marks**

10 Plagiarism and Collusion

Plagiarism and collusion or fabrication of data is always treated seriously, and action appropriate to the circumstances is always taken. The procedure followed by the University in all cases where plagiarism, collusion or fabrication is suspected is detailed in the Universitys Policy for Dealing with Plagiarism, Collusion and Fabrication of Data, Code of Practice on Assessment, Category C, available on `http://www.liv.ac.uk/tqsd/pol_strat_cop/cop_assess/appendix_L_cop_assess.pdf`.

Follow the following guidelines to avoid any problems:

(1) Do your work yourself.

(2) Acknowledge all your sources.

(3) Present your results as they are.

(4) Restrict access to your work.

Reference

- "EmonEmona 101 Trainer Lab Manual", http://www.ett101.com, Emona Instruments, 2008.

Version history:

Name	Date	Version
Dr A. Al-Ataby	February 2015	Ver. 2.3
Dr A. Al-Ataby	February 2014	Ver. 2.2
Dr A. Al-Ataby	February 2013	Ver. 2.1
Dr A. Al-Ataby	February 2012	Ver. 2.0
Dr N. Al-Zubi	September 2009	Ver. 1.0

Feedback:

If you have any feedback on your laboratory experience for this experiment (e.g. timing, difficulty, clarity of script, demonstration ...etc) and suggestions to how the experiment may be improved in the future, please write them down in the space below. This feedback is important for future versions of this script and to enhance the laboratory process, and will not be assessed. If you wish to provide this feedback anonymously, you may do so by detaching this page and submitting it to the Student Support Centre (fifth floor office).

Question 1
Why is a DC signal added to the message?

First of all, the experiment must ensure that all signals are **positive**, because the receiver cannot distinguish positive or negative modulated signals, so a DC voltage is added. When the modulated signal passes through the **zero**, the modulated signal will "**reflect**" about the **baseline** and the phase will reverse. Due to this **phase inversion**, the demodulated signal will show extreme distortion and the negative peaks will also reverse [1]. Additionally, the modulation signal will not distort if the whole signal shifts upwards and **exceeds x-axis**.

In addition, adding DC voltage can make the **modulation index** of the modulated signal **less than the unit**, which will help to receive the signal in the receiver.

Moreover, adding DC voltage can also permit the modulated carrier to be demodulated at the receiver by a means other than **synchronous** detection [2]. If deleting the DC voltage, there will be no carrier components, which may lead to **lose the frequency of carrier**. If the frequency of carrier is lost, the signal will not be recovered successfully.

Question 2
What is the key characteristic of the envelope of this AM signal?

The upper envelop is the **same shape** as the message, the lower envelop is also the **same shape but upside-down(Inverted)**.

In addition, the lower and upper envelop will **follow the change** in the amplitude of the AM and message (Sinewave) signals. When the signal of the message rises, the AM signal and upper envelop will also rise.

Question 3
For the given inputs to the multiplier module, how many sinewaves does the AM signal consist of and what are their frequencies?

Three sinewaves (98KHz 100KHZ 102KHz)

This is because the mathematical model that defines the AM signal is:

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

And the message is a simple sinewave, therefore, AM consists of three sinwaves:

1.One frequency is the same frequency with the carrier frequency
2.One is the sum of carrier and message frequencies
3.One is the difference between carrier and message frequencies

The frequency of carrier is 100KHz, and the frequency of message is 2KHz, Therefore, the AM signal consists three sinwaves with different frequenies.

Question 4

Why is there still a signal out of the multiplier module even when you are not talking, whistling, etc?

Since **DC voltage** is added to the experiment, there will be a signal even if there is no speech. When there is no speech, the AM signal will not be 0. According to the formula, the AM signal will be the multiplication of DC and the carrier, therefore, there is still a signal.

In addition, even if the student is not speaking, the **noise** in the environment may be considered, and the inevitable sound in the environment will also have an impact on the experiment.

Moreover, the purpose of multiplier is multiplying the input signal with the carrier signal. When the message signal is zero, the input will also be **multiplied with the carrier signal**. And the sideband will be generated as a result. However, the carrier frequency will be larger than the actual signal frequency, which may lead to the filter can not filtered out the sidebands properly.

Question 5

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

First, the size of message signal and the modulation of the carrier are **proportional**, which means that as the message goes up, the amount of carrier modulation will also goes up.

Additionally, the relationship between the amplitude of the message and the amount of the carrier modulation is:

$$y(t) = (2\pi fct + A.m(t))$$

Where fc is the carrier frequency and m(t) is the amplitude of the message. Therefore, the proportional relationship can also be seen from the above formula.

Question 6

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

When the carrier is over-modulated, there will be **upset** the receiver operation. The maximum magnitude of modulating signal will be greater than the maximum magnitude of carrier signal.

Moreover, the modulated signal gets **phase inverted**, which means the phase will change by 180° at **each crossing point**. In other words, the **lower excursion** of the signal will drive the carrier amplitude **below zero**. Therefore, the signal from the receiver will be distorted.

Moreover, when the signal is over-modulated, the **modulation index** will be over than 1, which may lead to the distortion of the signal. In this condition, the envelop detector can not recover the original signal.

Question 7
What is a carrier maximum modulation index without over-modulation?

According to the formula, the maximum **modulation index** without over-modulation：

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

From the analysis of **experimental values**, the value of P is 2.6-(-2.2)=4.8V, and the value of Q will be 0.1-(-0.1)=0.2V. According to the above formula, index will be:

$$m = \frac{4.8 - 0.2}{4.8 + 0.2} = 0.92$$

From the analysis of **theoretical values**, when the carrier achieve the maximum modulation without the over-modulated, the value of Q will be **equa**l to 0. When the maximum value is achieved, the envelops will be tangent to the y-axis, causing Q to become 0. The diagram can be seen in the following diagram.

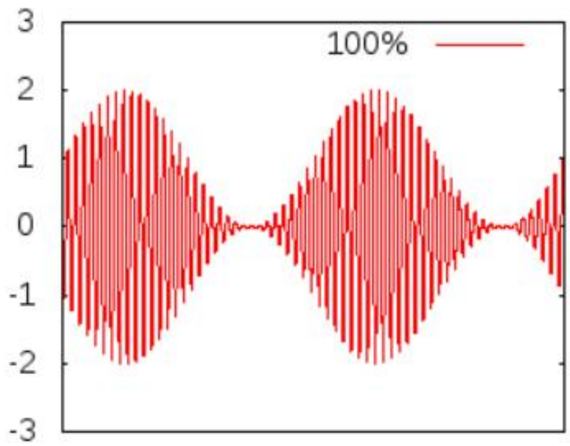

Figure 1: The maximum modulation [3]

Therefore, the according to above formula, the theoretical value of modulation index will be:

$$m = \frac{4.8 - 0}{4.8 + 0} = 1$$

Question 8
What is the key characteristic of the envelope of this DSBSC signal?

First, only **alternating the halves** of the envelops from the same shape as the message. A specific example can be seen in the figure below:

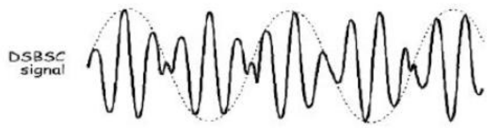

Figure 2: Upper envelope of the DSBSC signal [4]

Additionally, only the **sidebands** are transmitted without the carrier as it gets suppressed [5].

Question 9

For the given inputs to the multiplier module, how many sinewaves does the DSBSC signal consist of and what are their frequencies?

2(102KHz and 98KHz)

This is because the mathematical model that defines the DSBSC is:

$$DSBSC = message * the\ carrier$$

And the message is a **simple** sinewave, therefore, AM consists of two sinwaves:

1.One is the sum of carrier and message frequencies
2.One is the difference between carrier and message frequencies

The frequency of carrier is 100KHz, and the frequency of message is 2KHz, Therefore, the AM signal consists two sinwaves with different frequenies.

Question 10

Why does this make DSBSC signals better for transmission than AM signals?

The carrier is suppressed and two sidebands are transmitted in DSBSC. However, the carrier signal is transmitted along with two sidebands. The **efficiency** of DSBSC will be higher than AM and DSBSC requires less power for transmission.

Moreover, the carrier in AM accounts for at least **66%** of the signal power, but it does not contain any part of the original message and is only used for **tuning**. Therefore, by not transmitting the carrier, DSBSC provides a lot of **energy saving** than AM, which is its main advantage.

Additionally, DSBSC is an amplitude modulation wave without the carrier, which means that

DSBSC carries **less power** for the transmission than that of AM signal.

Question 11
What is the difference between the speech signal modulation here in DSBSC and the one in AM modulation?

Alternating the halves of the envelops will be shown in this experiment. Instead, the upper and lower envelops will be shown in the AM modulation. Although the speech signal is irregular, it is still very obvious that the signal changes from the up to the low.

This is because that AM will always has a **carrier components** with the combination of carrier and message signal component, which means that two parts will be consisted. First part is carrier and second part is the multiplication of message with carrier. However, DSBSC does have two parts.

DSBSC does not have the frequency of the carrier, but AM modulation includes this frequency. In AM modulation, speech is made up of thousands sinewaves and so the AM signal includes **thousands of pairs** of sinewaves straddling carrier [4]. However, thousands of pairs of sinewaves are generated in the DSBSC signal and located on either **side** of the carrier frequency [4].

Question 12
Based on your observations, what is the effect of the message amplitude on the signal dimensions P and Q?

Through observation, when the gain of buffer is increased, the signal will be **enlarged as a whole**, and the **amplitude** of the signal will also **increase**. When the amplitude of the signal gradually increases, **the values of P and Q will also increase**. This means that when the message's amplitude is varied, the dimension of P and Q will be both affected. And the relationship between the message amplitude and the signal dimensions is proportional.

Question 13
What is the name of this type of distortion? Why?

Amplitude distortion(clipping)

Because the output amplitude is not a **linear function** of the input amplitude. In the experiment, two signals were made to too large which may lead to **overload the modulator**. Distortion occurred because only the amplitude was changed in the experiment. The main cause of Amplitude distortion is **non-linear** amplification, which can also been observed from the waveform.

Moreover, when the input signal **exceeds the maximum amplitude** of the buffer(Amplifier), the output signal will be **clipped** in the positive and negative excursion. When the amplification is set too large, the sufficient large input amplitude causes **clipping** and make the peak parts of the signal be **clipped-off**. Therefore, the output signal may be clipped if the input is **overdriven**.

Question 14
Is there any difference between the original message signal and the recovered message? Why?

Yes, there is still some differences between the original message and the recovered message (**Amplitude and the phase** are different).

The rectifier stage chops the AM signal in **half**, and letting only one envelop pass. After that, a peak detector was also added, which is used to **track** the signal envelop. However, in this experiment, the envelope detector can not accurately recover the message from **over-modulated** signals. This is because that the signal will no longer the same shape as the original signal when AM carrier is over-modulated. If the amplitude of the signal is greater than the carrier, the distortion will happen to the recovered signal.

Moreover, the original signal is modulated and received by demodulation and pass through **low pass filter**, which may lead to release the amplitude of the recovered. Therefore, the amplitude of the recovered signal will approximate **half** of the amplitude of the original signal, which is in line with the expect. Since the original signal has gone through many **transmission phases** and recovered through **multiple filters**, the amplitude of the recovered signal will be **attenuated**.

Additionally, there is also some **phase shift** between the original signal and the recovered signal, which is also because of the buffer.

In addition, some errors including the **noise**, in the process of transmitting the signal, may cause the recovered signal to be different from the original signal.

Question 15
Is there a difference between the amplitude of the two message signals? Why?

Yes

Since the peak detector will **track the peaks** of the input. In this experiment, the peak detector will track the signal envelop when the input is the rectified signal. Because the envelop has the **same shape** as the message, the peak detector output will have the same shape of two message.

When **increasing** the amplitude of the signal **a little**, the difference is **not obvious**. But when the increased amplitude exceeds the maximum amplitude of the unmodulated signal, the **clipping** of the signal will happen and the signal will be distorted.

When **decreasing** the amplitude of the signal **a little**, the difference will also be not obvious. Therefore, **little variation** will not affect the signal and there will be very similar signal after demodulation.

When the amplitude of the signal is at the maximum amplitude, if the carrier signal amplitude is less than the message, there will be **phase reversal**. This is because the demodulated envelop of the signal may be distorted due to the **less amplitude** of the carrier signal than the signal which give distorted envelop.

Question 16
What causes the heavy distortion in the demodulated signal?

First, the **clipping** may lead to the heavy distortion. When the input signal exceeds the maximum amplitude, the output signal will be clipped in the positive and negative excursion, which may cause clipping and make the peak parts of the signal be clipped-off.

Secondly, the the **delays in channel and uneven multiplexing** may also cause distortion.

More importantly, if the signal is **over-modulated**, which will cause deviation from the specific bandwidth and starts superimposing with the bandwidth of other carrier signals. Additionally, the unnecessary data exceeding the complete modulation threshold may also lead to distortion including **noise**.

Question 17
Given the AM signal (which consists of 100 kHz, 102 kHz and 98 kHz sinewaves) is being multiplied by a 100 kHz sinewave:

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

6 sinwaves but 2 sinewaves are the same

B）What are their frequencies?

202KHz, 198KHz, 200KHz, 2KHz, 2KHz,4KHz

This is because the mathematical model that defines the rectifier cross-multiplication is:

$$\text{Rectifier output} = carrier * (\text{carrier+message}) * (\text{carrier- message})$$

And the message is a **simple** sinewave, therefore, the rectifier outputs six sinewaves:

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)

Since the sinewaves of 4 and 5 are the same, the frequency of output is the frequency of the message, so the final output will also have two same frequencies (2KHz).

Question 18
Why must a product detector be used to recover the message instead of an envelope detector?

Envelop detector works well for demodulating AM because the signal envelopes are of the **same shape** as the message that produced it in the first place. However, DSBSC signal envelopes are **not the same shape** as the message (there will be **negative voltage** in DSBSC signal). Therefore, the product detector must be used to take place the envelop detector.

A product detector is a type of demodulator used for AM signals. Rather than converting the envelope of the signal into the decoded waveform like an envelope detector, the product detector takes the product of the modulated signal and a local oscillator, which is also a **frequency mixer**.

To make sure that two carries are **synchronised**, product detector must also be used instead of envelop detector. The modulator carrier may be **stolen** to provide the product detector local carrier.

In addition, due to the previous experiment, the AM signal needs to be rectified to ensure that only the signal has **one peak value** at the same time. However, the rectifier is not used in this experiment. Therefore, the envelop detector cannot be used this time, and it needs to be replaced with a product detector.

Question 19
What is the difference between the amplitude of the two message signals (the original and the recovered)? Why?

First, the **amplitude** of two message signals are different. Since a buffer module is added in the experiment, it will amplify or reduce the size of the signal.

The reason is that the original signal has gone through many transmission phases and recovered through multiple filters, the amplitude of the recovered signal will be **attenuated**. In other words, the original signal is modulated and received by demodulation and pass through low pass filter, which may lead to release the amplitude of the recovered. Therefore, the amplitudes of the two signals are not the same.

Moreover, if keeping increasing the amplitude of the signal to reach the **maximum amplitude**, there is also clipping in the recovered signal. In this experiment, adding a buffer module may also cause the signal to be **clipped**.

Additionally, it can be seen that there is a phase difference between the two signals through observation. This is because there is a phase error between the carries and the effect of buffer may also affect the phase of the two signals, causing the two signals to appear phase shift.

Question 20
What causes the distortion in the demodulated signal?

First, the **clipping** may lead to the heavy distortion. When the input signal exceeds the maximum amplitude, the output signal will be **clipped** in the positive and negative excursion, which may cause **clipping** and make the peak parts of the signal be clipped-off.

Secondly, the **delays in channel and uneven multiplexing** may also cause distortion.

More importantly, if the signal is **over-modulated**, which will cause deviation from the specific bandwidth and starts superimposing with the bandwidth of other carrier signals. Additionally, the **unnecessary data exceeding** the complete modulation threshold may also lead to distortion including noise. Over-modulation lead to DSBSC signal **clipped**.

Additionally, because the frequency and the phase are changed when increasing the amplitude, the distortion will appear.

Question 21
Given the size of the recovered message amplitude, what is the likely phase error between the two carriers?

Through experiment, the phase error will approximate 140°. It can be seen that through adjusting the phase shift control until the recovered message is the largest, the phase error between the two carries will be 140°.

Question 22
Given the size of the recovered message new amplitude, what is the likely phase error between the two carriers?

Similarly, the phase error between the two carries will approximate 40°. It can be seen that through adjusting the phase shift control until the recovered message is the smallest, the phase error between the two carries will be 40°

Question 23
How many sinewaves are at the output of the VCO module?

2 sinewaves

First, if the applied voltage varies above or below 0 V, the oscillator output frequency deviates **above and below the rest frequency** [4]. FM uses the a message amplitude to vary the frequency of a carrier instead of amplitude. Since the Master signal has **only two voltage levels**, two different sinewaves are used as output.

Question 24
Why do the sinewaves have different frequencies?

Similar to the above question, FM uses the a message amplitude to vary the frequency of a carrier instead of amplitude. Additionally, the VCO uses and input **voltage level** to change the frequency of its output. Moreover, as the message **alternates above or below 0 V**, the signal frequency goes **above or below** the carrier frequency [4]. Since the Master signal (Square signal) selected in the experiment has only two different voltage levels, the frequency of the sinewave will also be different .

Question 25
Which sinewave corresponds with the squarewave upper peak? (the one with the lower frequency or the higher frequency?)

Lower frequency

This is because the amount of **deviation** is affected by the amplitude of the input voltage. The **larger** the input voltage (upper peak), the greater the deviation [4]. The lower frequency has greater deviation. Therefore, the lower frequency will correspond with the squarewave upper peak.

Additionally, from the lab script, we know that lower frequency corresponds to **upper peak** and the higher frequency corresponds to lower peak. The specific diagram can be seen below.

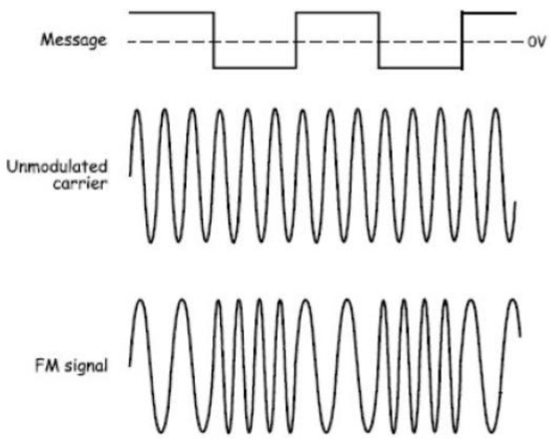

Figure 3 : FM modulation [4]

When the signal is in the upper peak stage, the sinewave corresponding to the FM signal has a larger period and a smaller frequency.

Question 26

Do either of these sinewaves have the same frequency as the VCO module rest frequency? Why?

Both sinewaves **do not have the same frequency** as the VCO module rest frequency.

This is because the **upper and lower peak voltage are not equal to 0V** and the oscillator outputs a signal at its rest frequency only when the input is 0V. Therefore, they will not be a rest frequency.

According to the lab script, if the applied voltage varies above or below 0 V, the oscillator output frequency deviates above and below the rest frequency [4]. The deviation will depend on the amplitude of the input signal.

Question 27

What do the FM signal two sinewaves tell you about the message signal?

Since there are **only two sinewaves** with different frequencies, it can be judged that the message has only two different voltages, so it can be judged that the message is probably **a square wave** with only two different voltage levels.

From the perspective of **amplitude**, since the obtained FM signal has only two deviations, it can be determined that the message signal has only **two amplitudes** with different values. This is because the amplitude of the message will determine the deviation.

From the perspective of **period and frequency**, since the period of each different sinewaves can be calculated, then the period of each stage (Upper peak and lower peak stage) of the message can be known, and then the overall period and frequency of the message and FM signal can also be known. Through calculations, it can be seen that the period of the message will approximate 160us, which is in line with expectations.

Question 28

What happens to the VCO module output as you talk louder? Why?

The amount of deviation will increase when I talk louder. And the frequency can be decreased when I talk louder.

If I increase the volume of the sound (increase the amplitude of the sound), the amount of **deviation** of sinewaves will change. The bigger the input amplitude, the greater the deviation [4]. Additionally, when increasing the amplitude of the voice, the **frequency** of the FM signal can be increased. This is because changing the frequency will affect the deviation of sinewaves. As the amount of deviation changes, sinewaves will also change.

Question 29

Why does the FM signal have one frequency only in this case?

Frequency modulation (FM) uses a **message amplitude** to vary the frequency of a carrier instead of its **amplitude**. Therefore, the input signal has only a fixed DC voltage, and the input amplitude in this experiment will not change. Since there is only **one fixed input**, the FM signal will only have one frequency.

Question 30

What type of a waveform does the comparator output?

Square waveform

The received FM signal is first passed through a comparator to heavily **clip** it, effectively converting it to a squarewave. This allows the signal to be used as a trigger signal for the zero-crossing detector circuit [4]. Therefore, comparator takes AC signal as input, and the comparator will compare the input signal with the **reference DC voltage**, which will produce the square wave.

Question 31

What does this tell you about the DC component of the comparator output?

First, the DC component of the rectangular wave is a **copy** of the squarewave that produced the FM signal in the first place [4]. Recovering this copy is a relatively simple matter of picking out the changing DC voltage using a low-pass filter.

Additionally, there are **three different situations** to consider for this issue:

If the input voltage (AC signal) is less than the DC signal, the output voltage will be negative.

If the input voltage (AC signal) is equal to the DC signal, the output voltage will be zero.

If the input voltage (AC signal) is larger than the DC signal, the output voltage will be positive.

Additionally, if the reference DC voltage changes, the **frequency** will also change. When DC voltage increases, the frequency of the output will also increase. Importantly, as the rectangular wave mark is fixed, changing the frequency can be achieved by changing the duration of the space and the signal mark/space ratio (or duty cycle) [4].

Question 32
What type of waveform does the ZCD output?

Pulse-train waveform

It can be seen from the experiment that the pulse is **repetitive and separated in time by a fixed and often constant interval**. The ZCD generates a pulse with **a fixed duration** every time the squared-up FM signal **crosses zero volts** (either on the positive or the negative transition). Given the squared up FM signal is continuously **crossing zero**, the ZCD effectively converts the squarewave to a rectangular wave (pulses) with a fixed mark time [4].

Additionally, the **duration** of each pulse and its **amplitude** are also made constant. They is the characters of pulse train waveform. Additionally, from the lab script, pulse trains are actually made up of **sinewaves and a DC voltage**. The amount of the DC voltage is affected by the **pulse train duty cycle**. The greater its duty cycle, the greater the DC voltage [4].

Question 33
As the FM signal changes frequency so does the ZCD output, what aspect of the signal changes to achieve this? (circle the right ones)
- **Neither the signal mark nor space**
- **Only the signal mark**
- **Only the signal space**
- **Both the signal mark and space**

The choice “Both the signal mark ad space ” is correct.

The reasons are that the **longer the pulse, the greater the DC components**. And the comparator is on the utilities module, which is used to clip the FM signal and demodulate the signal. Therefore, two aspects are both needed to achieve it.

Another reason is that when the FM signal frequency changes, the rectangular wave frequency will change as well. Importantly, as the rectangular wave **mark is fixed**, changing its **frequency** is achieved by changing the **duration of the space** and the **signal mark/space ratio** (or duty cycle).

Question 34
What does this tell you about the DC component of the ZCD output?

The DC components will affect the **frequency** of the AM signal. And the changed AM signal will change the comparator's output. Finally, the comparator's output will change the ZCD signal. Therefore, the amount of the DC voltage is affected by the **pulse train duty cycle**, which means that the greater its duty cycle, the greater the DC voltage.

Through the experiment, if the **reference DC voltage** changes, the frequency will also change. This is because that when DC voltage increases, the frequency of the output will also increase. Additionally, the **gain** may be increased because the DC voltage changes.

Question 35
If the original message is a sinewave instead of a variable DC voltage, what would you expect the output of the baseband LPF be?

In the experiment, I took pictures of the experiment, and the picture obtained in the experiment is as follows:

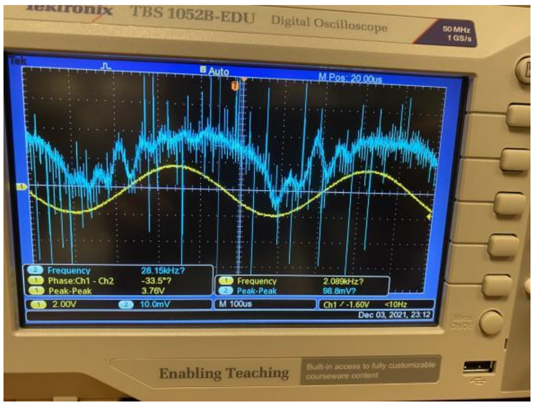

Figure 4 : The expected output of the baseband LPF

It can be seen from the experimental figure that the final output will **roughly follow** the trend of sinewave. When the amplitude of the sinewave decreases, the output will also decrease. However, it can also be seen that the output obtained is **not a perfect sinewave**, the waveform is very uneven and there are many **abnormal points**. There are **amplitude difference and the phase difference**, which is because the signal have passed the ZCD and some filters. Additionally, there may also be some **noise** which may affect the output signal.

In others words, recovering this **copy** is a relatively simple matter of picking out the changing **sinewave** voltage using a low-pass filter.

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