Experiment 88 – Analogue Modulation/Demodulation Techniques

Abstract

This experiment studies the following AM, DSBSC and FM analogue modulation/demodulation techniques. And understand the basic principles of various modulation and demodulation techniques and the advantages and disadvantages between them. Also, gain a better understanding of the experimental equipment. Have some practical experience in building and testing analogue modulation/demodulation systems.

Declaration

I confirm that I have read and understood the University's definitions of plagiarism and collusion from the Code of Practice on Assessment. I confirm that I have neither committed plagiarism in the completion of this work nor have I colluded with any other party in the preparation and production of this work. The work presented here is my own and in my own words except where I have clearly indicated and acknowledged that I have quoted or used figures from published or unpublished sources (including the web). I understand the consequences of engaging in plagiarism and collusion as described in the Code of Practice on Assessment.

Contents

1 Introduction

1.1 Objectives

The aim of this experiment is to study and practically test some important analogue modulation and demodulation techniques such as AM, DSBSC and FM. In addition, to gain practical experience in building and testing analogue modulation/demodulation systems using the Emona Telecoms Trainer 101 kit.

1.2 Theoretical Background

Modulation is the process of using the baseband signal to control the change in one or more parameters of the carrier signal, on which the information is loaded to form the modulated signal for transmission, while demodulation is the reverse process of modulation, in which the original baseband signal is recovered from the change in parameters of the modulated signal by specific methods. Modulation is achieved by varying the amplitude, phase, or frequency of the high frequency carrier to match the baseband signal. Demodulation, on the other hand, is the process of extracting the baseband signal from the carrier so that it can be processed and understood by the intended receiver. Modulation can be divided into two categories: linear modulation and non-linear modulation. Linear modulation includes Amplitude Modulation (AM), Double Sideband Suppress Carrier (DSB-SC), etc. Non-linear amplitude modulation is more resistant to interference, including Frequency Modulation (FM), frequency shift keying (FSK), phase shift keying (PSK), differential phase shift keying (DPSK), etc. Linear modulation is characterised by the fact that it does not change the original spectral structure of the signal, while non-linear modulation changes the original spectral structure of the signal. The main difference between analogue modulation and digital modulation is that analogue modulation is the continuous modulation of certain parameters of the carrier signal and the continuous valuation of the modulation parameters of the carrier signal at the receiving end, while digital modulation is the use of certain discrete states of the carrier signal to characterise the transmitted information and only the discrete modulation parameters of the carrier signal are detected at the receiving end [1].

2 Materials and Methods/Procedure

2.1 Materials

- Emona Telecoms-Trainer 101 kit
- Oscilloscope TDS 210
- Different wires and BNC cables

2.2 Methods/Procedure

- Connecting the different modules of the Emona Telecoms-Trainer 101 kit to an oscilloscope to observe the signal.

Fig.1. Emona Telecoms-Trainer 101 kit [2]

3 Results and Analysis

3.1 Part I: Amplitude modulation

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

  Ans: It must be ensured that all signals are positive, as the receiver cannot distinguish between positive or negative modulated signals. Also, the added DC component must be greater than the amplitude of the modulated signal so that the signal is all moved above the time axis, otherwise different distortions will occur, which is not conducive to envelope detection to obtain a good original signal. For example, when the DC component is smaller than the signal amplitude or when it is zero, a part of the signal will be missing, making it impossible to recover the initial signal.

- **Question 2: What is the key characteristic of this AM signal?**

  Ans: The upper envelope will have the same shape as the message and the lower envelope will have the same shape, but upside down. In addition, the lower and upper envelopes will follow the changes in amplitude of the AM and message signals. As the signal of the message rises, the AM signal and the upper envelope 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?**

  Ans: Three sinewaves, **98 kHz, 100 kHz, 102 kHz**. Amplitude modulation consists of three sine waves: one is the difference between the carrier frequency and the message frequency. One is the same frequency as the carrier frequency. One is the sum of the carrier and message frequencies. The carrier frequency is 100 kHz and the message frequency is 2 kHz, so the AM signal consists of three sine waves of different frequencies.

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

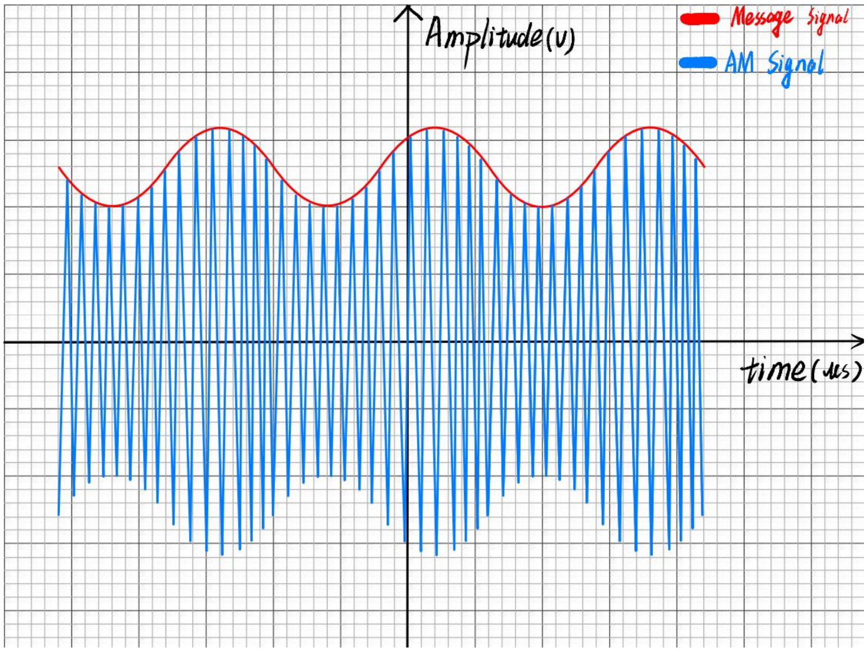

Fig 2: The two waveforms of Experiment A

- **Question 4: Why is there still a signal out of the multiplier module even when you're not talking, whistling, etc?**

  Ans: Due to the inclusion of DC voltage, there will be a signal even when there is no speech. When there is no speech, the AM signal will not be 0. In addition, the inevitable sound in the environment will also have an influence on the experiment. The purpose of the multiplier is to multiply the input signal with the carrier signal. When the message signal is zero, the input will also be multiplied by the carrier signal and the result will be a sideband. However, the carrier frequency will be greater than the actual signal frequency which may result in the filter not being able to filter out the sidebands effectively.

- **Question 5: What is the relationship between the message's amplitude and**

the amount of the carrier's modulation?

Ans: The size of the message signal is proportional to the modulation of the carrier, which increases as the amplitude of the message increases. The equation for the relationship between the amplitude of the message and the amount of carrier modulation is: $\boldsymbol{y(t) = 2\pi fct + Am(t)}$

- Calculate and record the AM signal's modulation index using the equation below.

$$m = (P - Q)/(P + Q) = \frac{4.36 - 1.04}{4.36 + 1.04} \approx 0.615$$

- **Question 6: What is the problem with the AM signal when it is over-modulated?**

  Ans: When a carrier is over-modulated, it will disrupt receiver operation. Also, AM over-modulation causes the carrier to invert its phase when the amplitude of the modulated signal is above a certain level. As a result, the signal from the receiver will be distorted. In addition, when the signal is over-modulated, the modulation index will be greater than one, which can cause distortion of the signal and thus prevent the envelope detector from correctly recovering the original signal.

- **Question 7: What is a carrier's maximum modulation index without over-modulation?**

  Ans: Carrier's maximum modulation index without over-modulation is **1.** When the modulation index is greater than 0 and less than or equal to 1, all can be retrieved using the envelope detector without distortion. However, when the modulation index is greater than 1 it results in a phase reversal of a segment of the signal. This prevents the envelope detector from recovering the initial signal correctly.

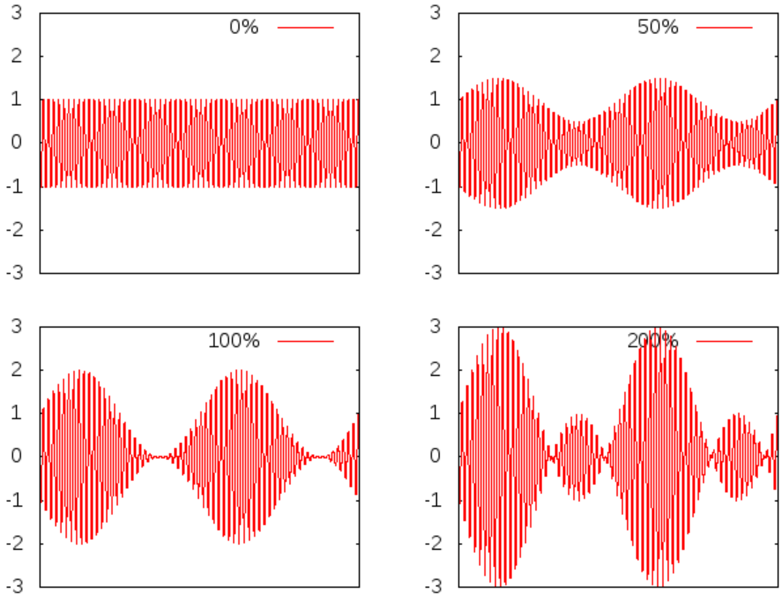

Fig 3: Carriers at different modulation indices [3]

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

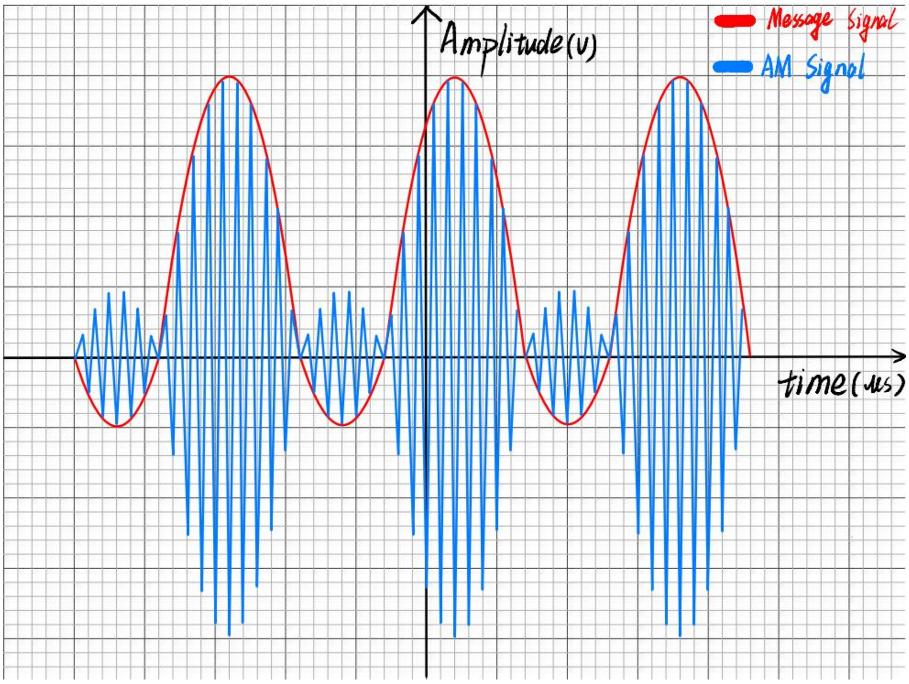

Fig 4: The two waveforms of Experiment B

3.2 Part II: DSBSC modulation

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

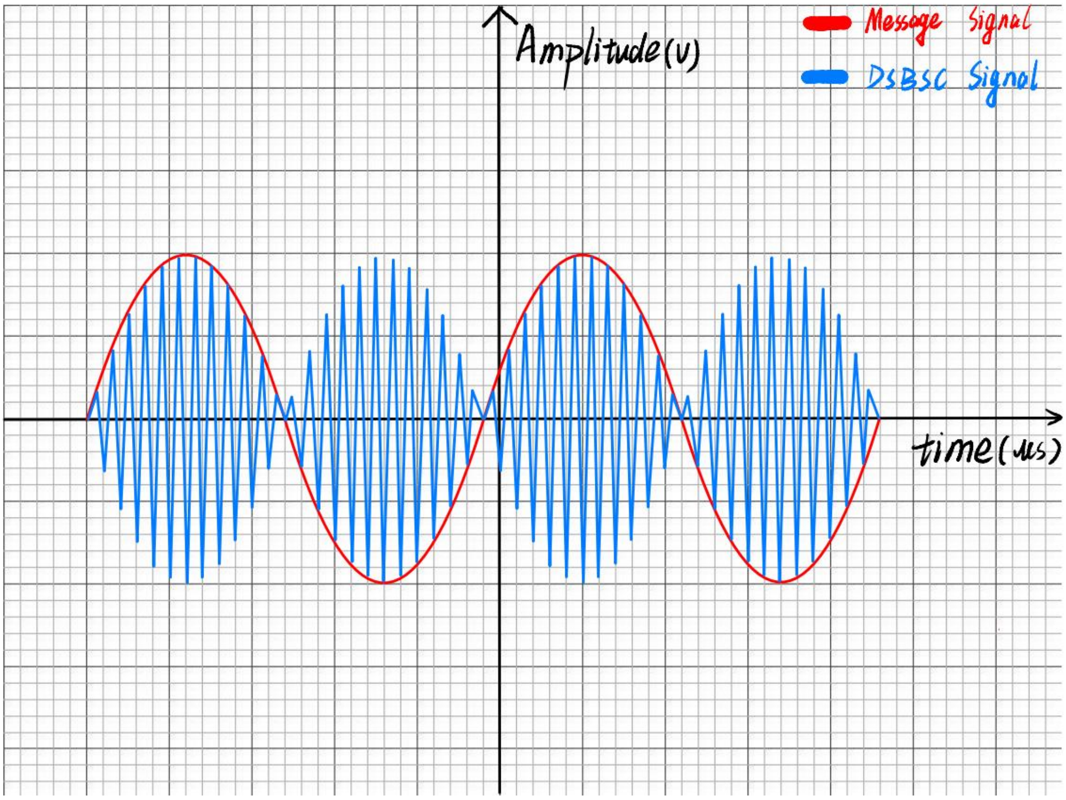

Fig 5: The two waveforms of Experiment A

- **Question 8: What is the key characteristic of this DSBSC signal?**

  Ans: The carrier component of the DSBSC does not carry information, so no carrier component is sent and the power efficiency is greatly improved. Most of the power is distributed in the sidebands, so for the same power, DSBSC can transmit more energy than AM for baseband signals.

- **Question 9: For the given inputs to the multiplier module, how many sinewaves does the DSBSC signal consist of and what are their frequencies?**

  Ans: Two sinewaves, **102 kHz, 98 kHz**. The frequency of the carrier is 100 kHz and the frequency of the message is 2 kHz. the DSBSC contains two sinewaves, one as their difference and one as their sum.

- **Question 10: Why does this make DSBSC signals better for transmission than AM signals?**

  Ans: No carriers are transmitted in DSBSC, only the two sidebands are sent. AM, on the other hand, transmits the carrier signal together with the two sidebands. This means that for the same power, DSBSC can transmit a higher energy baseband signal than AM. Furthermore, 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, not sending a carrier makes DSBSC much more energy efficient than AM, which is its main advantage. In addition, DSBSC is an amplitude modulated waveform without a carrier, which means that DSBSC transmits less power than AM signals.

- **Question 11: What is the difference between the speech signal modulation here in DSBSC and that one in AM modulation.**

  Ans: In the DSBSC alternate halves of the envelope are displayed. Conversely, AM modulation will show the upper and lower envelopes. Although the speech signal is irregular, the change from high to low signal is still very visible. This is because AM has a carrier component and a combination of carrier and message signal components. The first part is the carrier and the second part is the multiplication of the message and the carrier. DSBSC, however, has two components. DSBSC does not have the frequency of the carrier, but AM modulation includes that frequency. In AM modulation, speech consists of thousands of sine waves, so the AM signal includes thousands of pairs of sine waves across the carrier.

- **Question 12: Based on your observations, what is the effect of the message's**

amplitude on the signal dimensions P and Q?

Ans: By observation, when the gain of the buffer is increased, the signal is amplified and the amplitude of the signal increases. As the amplitude of the signal gradually increases, the values of P and Q also increase. As the amplitude of the message changes, the dimensionality of both P and Q is affected. Furthermore, the relationship between message amplitude and signal dimensionality is proportional.

- Set the Buffer module's 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 below.

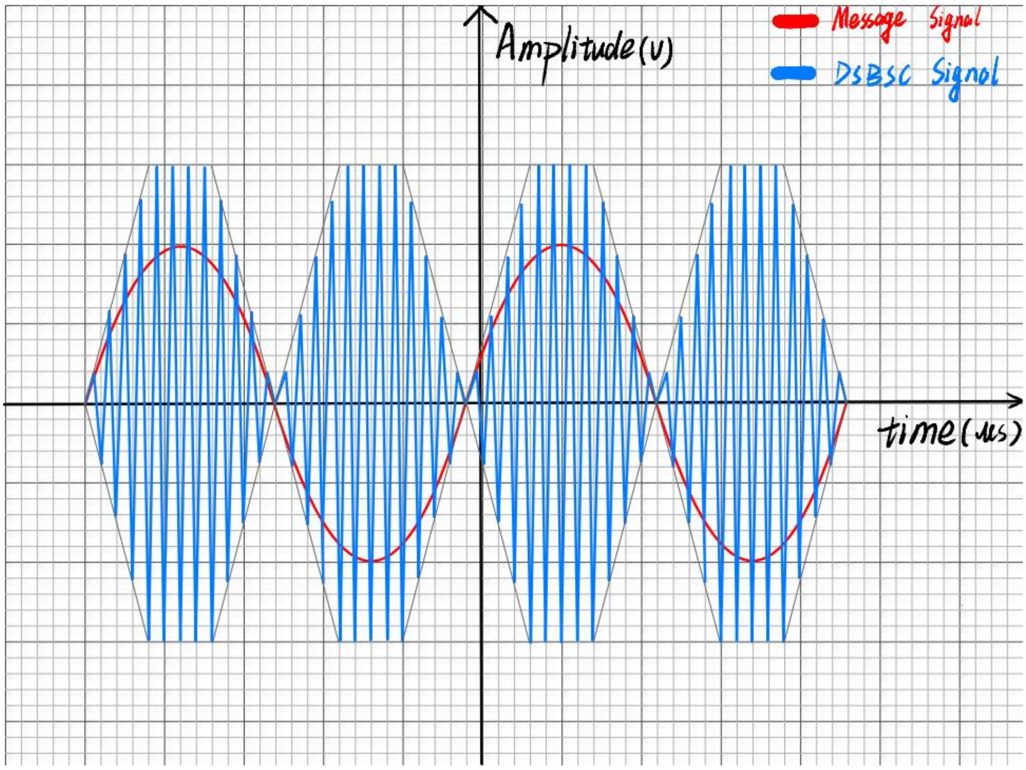

Fig 6: The DSBSC signal of Experiment B

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

  Ans: Peak clipping. This is because the output amplitude is not a linear function of the input amplitude. The main cause of amplitude distortion is non-linear amplification, which can be observed in the waveform. In addition, when the input signal exceeds the maximum amplitude of the amplifier, the output signal is clipped in both positive and negative offset. When the amplification is set too large, too large an input amplitude can cause peak clipping and cause the peak portion of the signal to be clipped. Thus, if the input is overdriven, the output signal can be clipped.

3.3 Part III: AM demodulation

- Measure the AM signal's modulation index.

$$m = \frac{P-Q}{P+Q} = \frac{2.64-0.84}{2.64+0.84} \approx 0.517$$

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

  Ans: The **amplitude** of the original message is twice the amplitude of the recovered message and there is a slight difference in **phase**.

  The recovered signal differs from the original signal in amplitude. The envelope detector cannot recover the message accurately from the overmodulated signal. This is because when the AM carrier is overmodulated, the signal will no longer be the same as the original signal. If the amplitude of the signal is greater than the carrier, the recovered signal will be distorted. In addition, the original signal is modulated and received by demodulation and passed through a low-pass filter, which may result in the release of the recovered amplitude. As a result, the amplitude of the recovered signal will be close to half the amplitude of the original signal, as expected. The amplitude of the recovered signal will be attenuated as the original signal has undergone many transmission phases and is recovered through multiple filters.

There is also some phase shift between the original and recovered signals, again due to the buffers. Inevitably some errors in the transmission of the signal may cause the recovered signal to differ from the original.

- In the space provided, draw:
  1. the AM signal,
  2. the rectifier signal, and
  3. the demodulated AM signal.

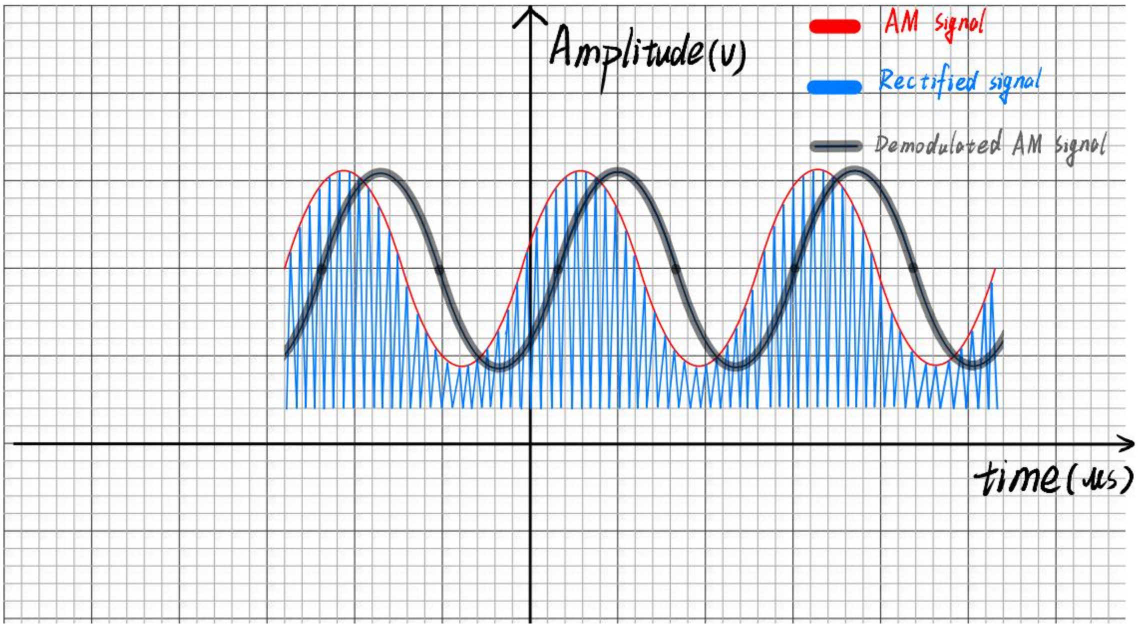

Fig 7: The waveforms of Experiment B

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

  Ans: There is a difference, but it is not significant as the peak detector will track the peak of the input. When the input is a rectified signal, the peak detector will follow the signal envelope. Because the envelope has the same shape as the message, the peak detector output will have the same shape of both messages. When the amplitude of the signal is increased slightly, the difference is not significant. However, when the increased amplitude exceeds the maximum amplitude of the unmodulated signal, clipping of the signal will occur and the signal will be distorted. When the amplitude of the signal is reduced slightly, the difference will also be insignificant. Therefore, a small change will not affect the signal and the demodulation will result in a very similar signal.

- **Question 16: What causes the heavy distortion in the demodulated signal?**

  Ans: The signal is clipped which may cause severe distortion. When the input signal exceeds the maximum amplitude, the output signal will be clipped in both positive and negative amplitudes. More importantly, if the signal is over-modulated, this will result in deviations from a specific bandwidth and begin to overlap with the bandwidth of other carrier signals.

- **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's output?

  Ans: 4 sine waves, as 2 sine waves are identical.

  B) What are their frequencies?

  Ans: 202 kHz, 200 kHz, 198 kHz, 2 kHz.

3.4 Part IV: DSBSC demodulation

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

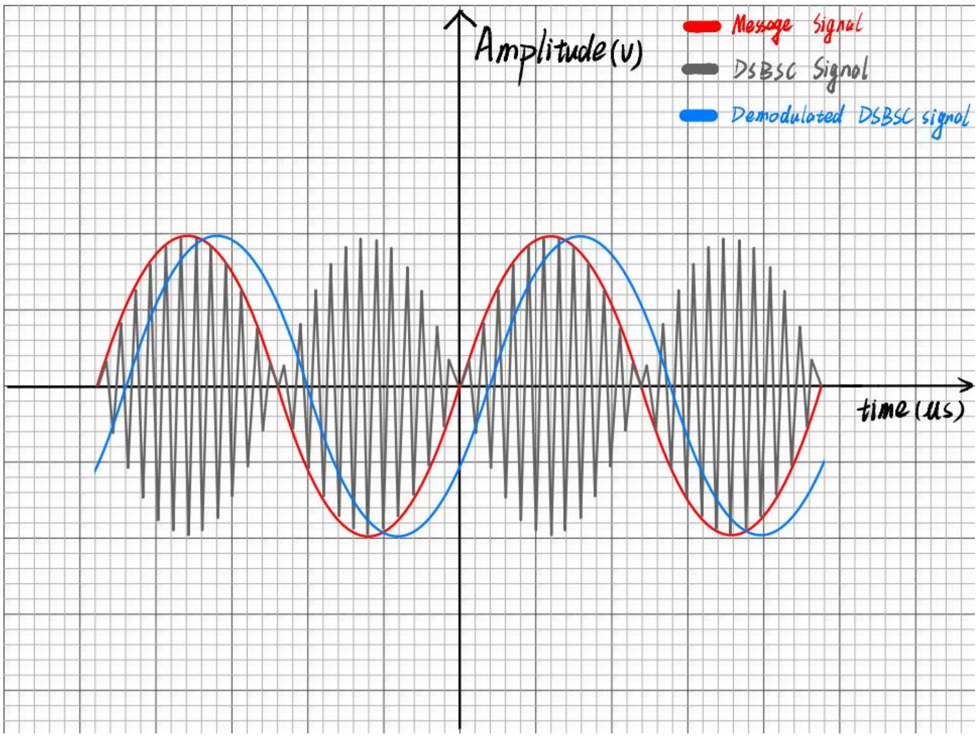

Fig 8: The waveforms of Experiment A

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

  Ans: The envelope detector is suitable for demodulating AM because the shape of the signal envelope is the same as the shape of the message that generated it in the first place. However, there will be negative voltages in the DSBSC. Therefore, a product detector must be used instead of an envelope detector. The product detector is a demodulator for AM signals. Instead of converting the envelope of the signal into a decoded waveform, as is the case with envelope detectors, the product of the modulated signal and the local oscillator is used. To ensure that the two carriers are synchronised, then a product detector must be used instead of an envelope detector. The modulator carrier may be stolen to provide the product detector local carrier.

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

Ans: The amplitude of the initial message signal is slightly smaller than the recovered signal. Due to the addition of the buffer module in the experiment, it will amplify or reduce the size of the signal. The reason for this is that the original signal went through many transmission stages and was recovered through multiple filters and the amplitude of the recovered signal will be attenuated. The original signal is modulated and received through demodulation and passed through a low-pass filter, which may result in releasing the amplitude of the recovered signal. As a result, the amplitudes of the two signals are not the same.

- **Question 20: What causes the distortion in the demodulated signal?**

  Ans: Peak clipping can cause severe distortion. When the input signal exceeds the maximum amplitude, this causes clipping and causes the peak portion of the signal to be clipped. Channel delays and uneven multiplexing can also lead to distortion. More importantly, if the signal is over-modulated, this will lead to deviations from a particular bandwidth and start to overlap with the bandwidth of other carrier signals. In addition, distortion can also result due to changes in frequency and phase as the amplitude is increased.

- **Question 21: Given the size of the recovered message's amplitude, what is the likely phase error between the two carriers?**

  Ans: In the experiment it was observed that the phase error was close to $140°$. It is easy to see that by adjusting the phase shift until the recovered message is maximum, the phase error between the two carriers is close to $140°$.

- **Question 22: Given the size of the recovered message's new amplitude, what**

is the likely phase error between the two carriers?

Ans: The phase error between the two carriers will be close to 40°. It is easy to see that by adjusting the phase shift control until the recovered message is minimal, the phase error between the two carriers will be 40°.

3.5 Part V: Frequency modulation

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

  Ans: Two sinewaves. FM uses the message amplitude to change the frequency of the carrier waveform rather than the amplitude. Since the main signal has only two voltage levels, two different sine waves are used as outputs.

- **Question 24: Why do the sinewaves have different frequencies?**

  Ans: FM uses the message amplitude to change the frequency of the carrier, not the amplitude. And the VCO uses and input voltage level to vary the frequency of its output. In addition, when the message alternates up or down at 0V, the signal frequency is higher or lower than the carrier frequency. The main signal in the experiment has only two different voltage levels and the frequency of the sine wave will be different.

- **Question 25: Which sinewave corresponds with the squarewave's upper peak? (The lower or higher frequency?)**

  Ans: lower frequencies. This is because the amount of deviation is influenced by the amplitude of the input voltage. The higher the input voltage, the greater the deviation. And the lower the frequency, the greater the deviation. Therefore, a lower frequency will correspond to a square wave upper peak.

- 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 us	10 KHZ
High frequency sinewave	60 us	16.67 KHZ

- **Question 26: Do either of these sinewaves have the same frequency as the VCO module's rest frequency? Why?**

  Ans: The frequencies of the two sine waves are different from the rest frequency of the VCO module. This is because the upper and lower peak voltages are not 0V and the oscillator only outputs a signal at its rest frequency when the input is 0V.

- **Question 27: What do the FM signal two sinewaves tell you about the message signal?**

  Ans: As there are only two sine waves with different frequencies, it can be determined that the message probably only has two square waves with voltage levels. In terms of amplitude, since the FM signal obtained has only two deviations. From this it can be determined that the message signal has only two different values of amplitude. In terms of frequency, since the period of each different sine wave can be calculated, it is thus possible to know that the period of the upper and lower peak phases of the message is approximately 160 us, in addition to the total period and frequency of the message and FM signal.

- **Question 28: What happens to the VCO module's output as you talk louder? Why?**

  Ans: When I talk louder, the amount of deviation increases and the frequency decreases.

If I increase the volume of my voice, the amount of deviation of the sine wave changes. The higher the input amplitude, the greater the deviation. Furthermore, when increasing the amplitude of the sound, the frequency of the FM signal can be increased.

3.6 Part VI: FM demodulation (Bonus)

- **Question 29: Why does the FM signal have one frequency only in this case?**

  Ans: FM uses the message amplitude to change the frequency of the carrier, not its amplitude. Therefore, the input signal has only one fixed DC voltage. As there is only one fixed input, the FM signal has only one frequency.

- **Question 30: What type of a waveform does the comparator output?**

  Ans: Square waveform. The received FM signal is sharply clipped by a comparator, which converts it to a square wave. This allows the signal to be used as a trigger signal for the over-zero detector circuit. The comparator therefore takes the AC signal as an input and the comparator compares the input signal with a reference DC voltage to produce a square wave.

- **Question 31: What does this tell us about the DC component of the comparator's output?**

  Ans: The DC component of the rectangular wave is a copy of the square wave that originally generated the FM signal, using a low-pass filter to detect the changing DC voltage. If the input signal is smaller than the DC signal, the output voltage will be negative. If the input signal is equal to the DC signal, the output voltage will be zero. If the input signal is greater than the DC signal, the output voltage will be positive.

- **Question 32: What type of waveform does the ZCD output?**

  Ans: The pulse train waveform. It has been observed experimentally that pulses are repetitive and periodic, and that the ZCD generates pulses of fixed duration each time the FM signal crosses zero volts. Given that the FM signal crosses zero continuously, the ZCD effectively converts the square wave into a rectangular wave with a fixed mark time.

- **Question 33: As the FM signal changes frequency so does the ZCD's output, what aspect of the signal changes to achieve this? (circle the right ones)**

  - **Neither the signal's mark nor space**
  - **Only the signal's mark**
  - **Only the signal's space**
  - **Both the signal's mark and space** ✓

  Ans: Both the signal mark and space.

- **Question 34: What does this tell us about the DC component of the ZCD's output?**

  Ans: The smaller the frequency the larger the DC component, which will affect the frequency of the AM signal. The altered AM signal will change the output of the comparator. The output of the comparator will then change the ZCD signal. The amount of DC voltage is therefore influenced by the duty cycle of the pulse string, so the greater its pulse duty cycle, the greater the DC voltage.

- **Question 35: If the original message is a sinewave instead of a variable DC voltage, what would you expect to see out of the baseband LPF?**

Ans: The output will roughly follow the trend of a sine wave. From the experiments it was found that the output obtained was not a perfect sine wave and the waveform was very uneven. There is a large amplitude difference as well as a small phase difference due to the signal passing through the ZCD and some filters. In addition, there may be some noise that may affect the output signal.

6 Conclusions

This experiment investigates the following AM, DSBSC and FM analogue modulation/demodulation techniques. And to understand the basic principles of various modulation and demodulation techniques and the advantages and disadvantages between them. In addition, to gain a better understanding of the experimental equipment. This experiment has given me some practical experience in building and testing analogue modulation and demodulation systems.

7 References

[1] rainbow70626, "modulation and demodulation techniques," Developer's online home. [Online]. Available: https://www.cnblogs.com/rainbow70626/p/4937667.html. [Accessed: 27-Nov-2022].

[2] García-Fernández, A., 2022. Ver. 2.5. *Experiment 88 – Analogue Modulation/Demodulation Techniques*. [online] Canvas.liverpool.ac.uk. Available at: https://liverpool.instructure.com/courses/59021/pages/experiment-88?module_item_id=1543468

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