

1909751

by Alex Williams

Submission date: 10-Mar-2022 11:55PM (UTC+0000)

Submission ID: 173162832

File name: 11778_Alex_Williams_1909751_179515_380391189.pdf (2.04M)

Word count: 4710

Character count: 28548

65-70

Course: BSc (Hons) Electrical and Electronic Engineering
Module: SGEE5005 Signal and Digital Comms
Assignment: Signals and Modulation
Name: Alex Williams
University number: 1909751
Date submitted: 10/03/22
Word count: 2732

- ① GOOD RESEARCH, BUT EMPHASISE THE WORD COUNT ON THE EXPERIMENT TOPICS.
- ② BOTH EXPERIMENTS WERE CONDUCTED IN FULL AND SHOWED A GOOD UNDERSTANDING OF BOTH CONCEPTS.
- ③ RESULTS & ANALYSIS WERE GOOD. A TABLE OF RESULTS FOR THE ADC SAMPLING THEOREM WOULD HAVE BEEN BETTER.
- ④ CONCLUSIONS WERE GOOD, BUT YOU COULD HAVE BEEN MORE CRITICAL IN THE ANALYSIS OF ADC DATA RATE.
- ⑤ SOME DIAGRAMS WOULD HAVE BEEN BETTER IN THE APPENDIX, OTHERWISE PRESENTATION WAS GOOD.

Table of Contents

1. Executive summary.....	4
2. Research into analogue and digital communication systems and techniques.....	5
2.1 Amplitude Modulation (AM) and Frequency (FM) Modulation	5
2.1.1 Amplitude Modulation (AM).....	6
2.1.2 Frequency Modulation (FM).....	7
2.2 Evaluation of the Development of Digital Communication Techniques.....	8
2.2.1 Analogue to Digital Convertors (ADCs).....	8
2.2.2 Pulse Amplitude Modulation (PAM) Techniques	10
2.2.3 Pulse Code Modulation (PCM) Techniques	11
2.2.4 Synchronous Digital Hierarchy (SDH) as a Digital Communication System	13
3. Experimental Method for Experiment 1- Frequency Modulation	15
4. Testing, Results and Analysis for Experiment 1	16
5. Experimental Method for Experiment 2- Analogue to Digital Conversion.....	21
6. Testing, Results and Analysis for Experiment 2	22
7. Conclusion and recommendations	25
8. Works Cited	26
9. Appendix.....	29
9.1 Appendix 1 Frequency Modulation Experiment Set Up.....	29
9.2 Appendix 2 Bessel Table	30
9.3 Appendix 3 ADC Experiment Set Up	31

Figure 1: Effects of Modulation (Kumar, 2004)	5
Figure 2: Modulation Types (Gupta, 2013)	5
Figure 3: Modulation and Transmission Process	6
Figure 4: Typical Amplitude Modulation Spectra (Herres, 2018)	7
Figure 5: Frequency Modulation (Elprocus, n.d.)	7
Figure 6: Schematic Diagram of ADC (Ashrit, n.d.)	8
Figure 7: Block diagram of ADC stages (Electrical Technology, n.d.)	9
Figure 8: Example of Increasing Resolution (Gudino, 2018)	10
Figure 9: Pulse Amplitude Modulation Signal (EL-PRO-CUS, n.d.)	10
Figure 10: The circuit diagram of PAM (BYJU'S, 2019)	11
Figure 11: Block diagram of PAM (BYJU'S, 2019)	11
Figure 12: Comparison of a Sine Wave Input with the Corresponding Instantaneous PCM output (Tutorials Point, n.d.)	12
Figure 13: Basic Elements of Pulse Code Modulation System (EL-PRO-CUS, n.d.)	12
Figure 14: STM-1 Frame Structure (Manske, 2011)	14
Figure 15: Wave Spectrum Using Calculated Data	17
Figure 16: Channel A 6Vp-p	17
Figure 17: Channel A 4Vp-p	18
Figure 18: Channel A 2Vp-p	18
Figure 19: Side Frequencies	19
Figure 20: Wave Spectrum Comparison Graph	20
Figure 21: 8-bit ADC	22
Figure 22: 4-Bit ADC	22
Figure 23: ADC 5kHz Input	23
Figure 24: ADC 6kHz Input	24
Figure 25: ADC > 7kHz	24
 Table 1: SDH Hierarchy (based on multiples of 4) and Frame composition (Rumsey, 2003)13	
Table 2: Bessel Table Comparison of Results	19

1. Executive summary

Research found that there are different forms of modulation, with AM and FM being most commonly used to transmit data by modulating the carrier signal. If a waveform is modulated too much it can become over modulated and when transmitted there is a risk of some of the waveform being cut off. The sidebands of the frequency can be determined by the modulation index in conjunction with the Bessel table to find out the amplitude at each sideband frequency. The bandwidth can then be calculated from the outside sidebands this was later proven in the first practical experiment when the modulation index and frequency deviation were calculated and the Bessel table was used to find the sideband amplitude with the results recorded and the wave spectrum produced. *FIRST PARAGRAPH IS A BIT DISTORTED*

The second experiment investigated ADCs and the use of 4-bit and 8-bit ADCs and how they affect the transmission. A 4-bit ADC has a much lower resolution and can be harder for the wave to be quantized. However, 8-bit will have a better resolution with 256 different levels to encode the waveforms' data when it is transmitted. 8-bit is slower to transmit as a result of the extra data and can be ~~excessive~~ for smaller waveforms and the excess data can make the system slow.

The validity of Nyquist Criterion was investigated that the sampling frequency has to be twice the input frequency. This was proven with samples being taken at different frequencies. The wave form was accurate and kept the square wave shape up until 5kHz. At 6kHz the output started to become lower with ~~some~~ disfigurement on the square wave then about 7kHz the receiver stopped receiving the frequency and the square wave was completely deformed.

2. Research into analogue and digital communication systems and techniques

2.1 Amplitude Modulation (AM) and Frequency (FM) Modulation

In signal and communications transmission, two types of modulation occur: Amplitude Modulation (AM) and Frequency Modulation (FM). They are both used to transmit data by modifying a carrier signal. The difference being that in FM, the carrier wave frequency is modified as per the transmitted data, compared to AM where the carrier wave is modified according to the data (BYJU'S, 2019). These differences are shown in Figure 1.

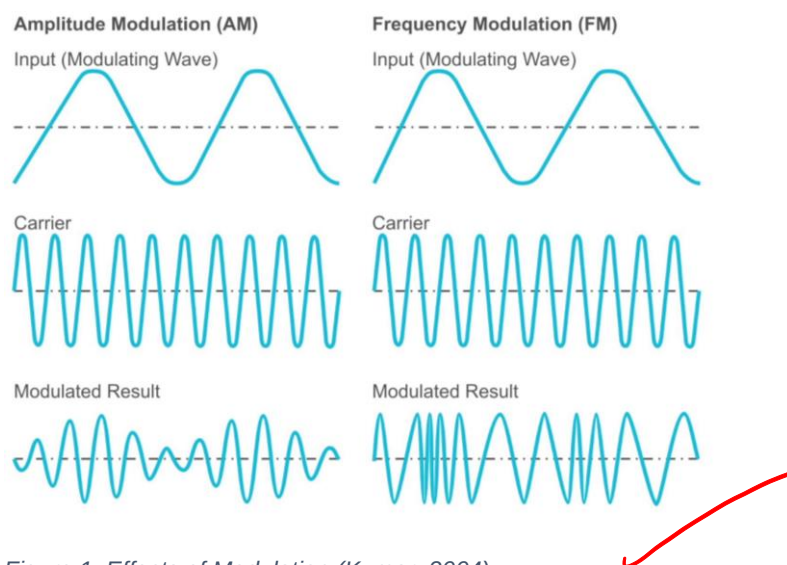


Figure 1: Effects of Modulation (Kumar, 2004)

Modulation refers to the change of a characteristic of the carrier wave (Kumar, 2004, p. 1686). Figure 2 shows different modulation methods.

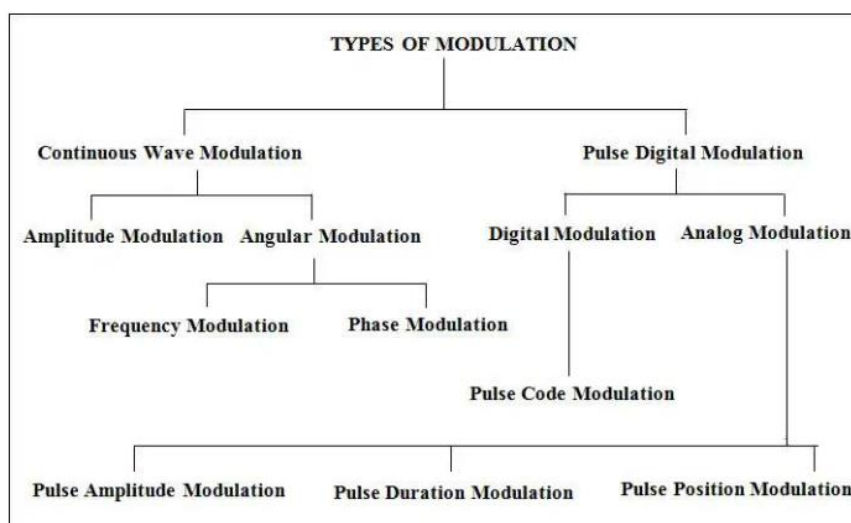


Figure 2: Modulation Types (Gupta, 2013)

Once the signal has been modulated, it can be wirelessly transmitted to be received by a receiver. The process is illustrated in Figure 3.

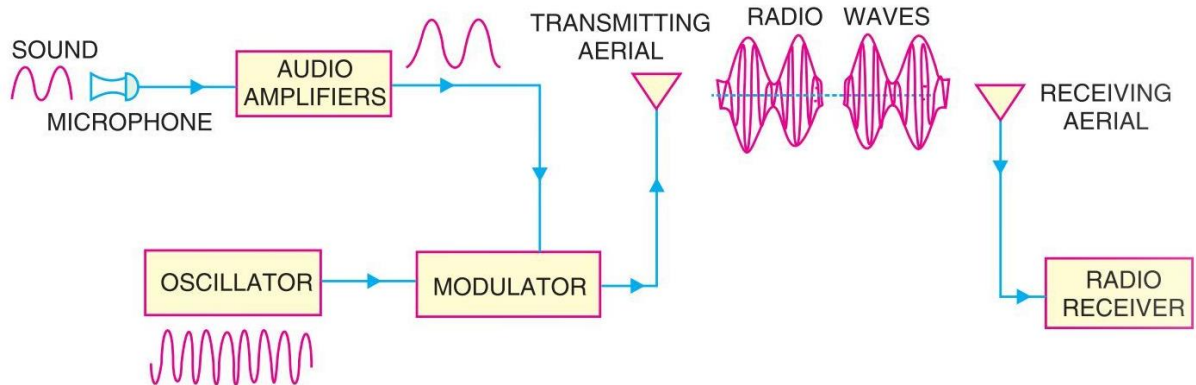


Figure 3: Modulation and Transmission Process

2.1.1 Amplitude Modulation (AM)

The easiest form of modulation is AM where the carrier signal's amplitude is made to replicate the shape of the information-carrying signal such as a pulse signal or voice (Sobot, 2020, p. 341). However, AM waves are subject to interference from a range of sources such as different motor types. (Innovation, Science and Economic Development Canada, 2010).

The extent to which a wave is modulated by is known as the modulation factor and can be calculated using Equation 1.

$$\text{Modulation factor, } m = \frac{\text{Amplitude of change of carrier wave}}{\text{Normal Carrier amplitude (unmodulated)}}$$

Equation 1: Modulation Factor

For perfect modulation, the modulation factor should be 1. However, if the signal is over modulated it, can become distorted and parts of the transmitted message can be lost. This occurs when the modulation factor is greater than 1.

The bandwidth varies depending on the signal frequency. In AM, the bandwidth is twice the signal frequency. The bandwidth has a lower and upper limit and can be written as, $f_c - f_m$ and $f_c + f_m$. Figure 4 shows an example of a typical amplitude modulation spectra. The sidebands represent the upper and lower limits of the bandwidth with the height representing the amplitude. The bandwidth is calculated by the difference in the sidebands (Herres, 2018).

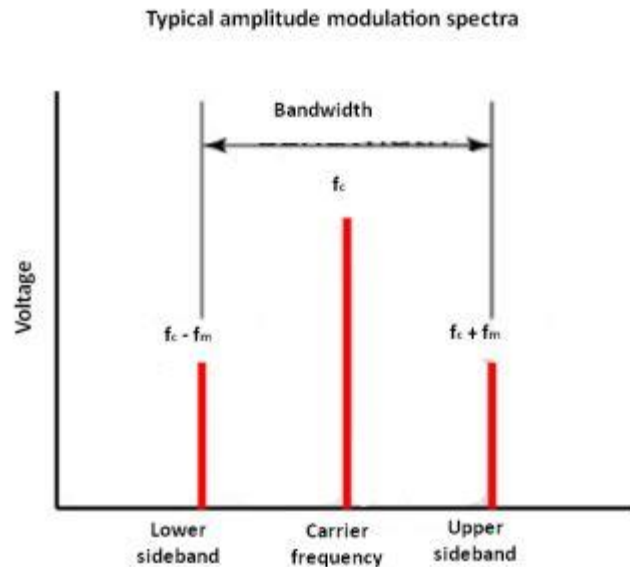


Figure 4: Typical Amplitude Modulation Spectra (Herres, 2018)

2.1.2 Frequency Modulation (FM)

In FM, the modulating signal changes the frequency of the carrier waveform whilst the amplitude stays the same, as shown in Figure 5. One method to achieve FM is to vary the capacitance of a resonant LC circuit in a transmitter (Plonus, 2020).

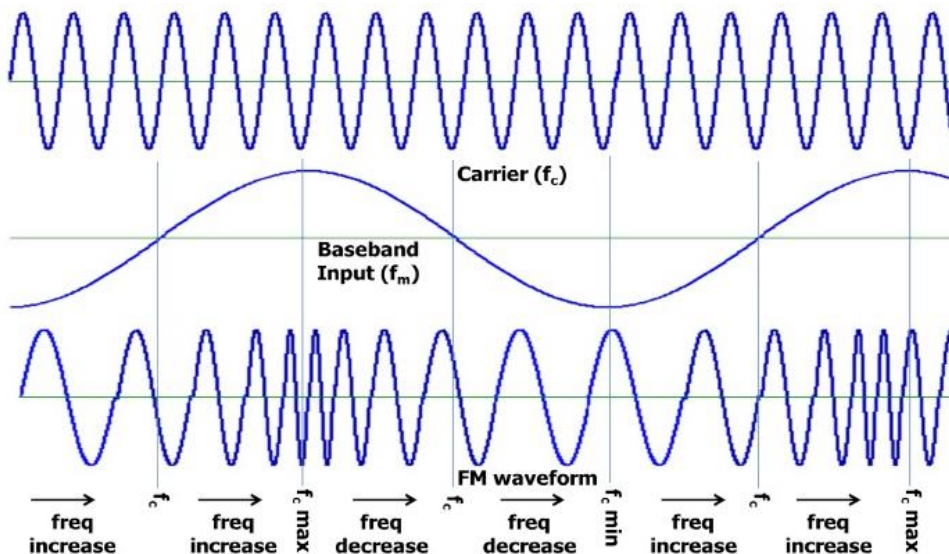


Figure 5: Frequency Modulation (Elprocus, n.d.)

The change in the carrier frequency produced by the amplitude of the modulating signal is frequency deviation. The change is represented by Δf . The relationship between frequency deviation of the carrier and the modulated signal frequency is known as the modulation index (Elprocus, n.d.). This can be calculated using the formula in Equation 2.

$$m_f = \Delta f / f_m$$

Equation 2: Modulation Index

FM has the advantage of having a large operating range, a very high efficiency and is less subject to interference. Nevertheless, AM uses less bandwidth than FM and requires less technical receiver and transmitter circuits (Sastry, 1997).

2.2 Evaluation of the Development of Digital Communication Techniques

2.2.1 Analogue to Digital Convertors (ADCs)

ADCs are electronic devices which convert a continuous analogue input signal such as voltage into discrete digital numbers (binary) so that it can be processed by micro-controllers as illustrated in Figure 6. Toulson and Wilmshurst state ADCs effectively “measure the input voltage and give a binary output number proportional to its size” (2012). Possible input signals include audio, light, temperature and motion.

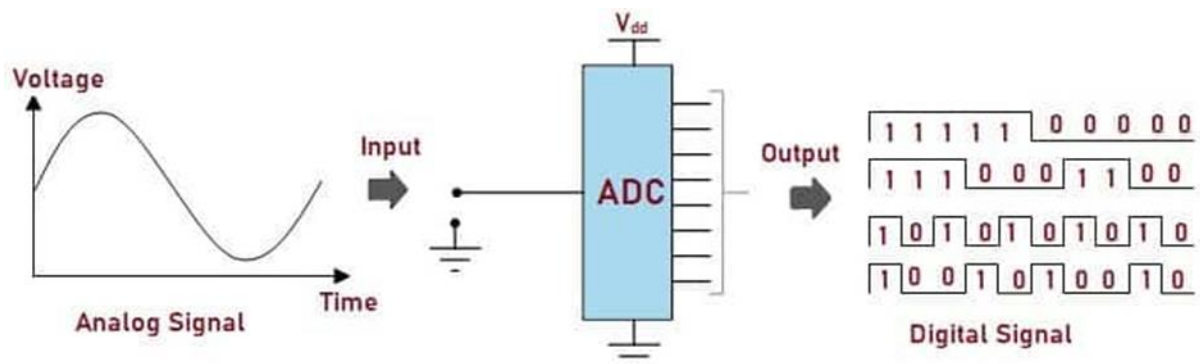


Figure 6: Schematic Diagram of ADC (Ashrit, n.d.)

ADCs sample the analogue signal at a specific sampling frequency where the sample amplitude is maintained and held in the 'hold' block. The hold sample is subsequently quantized into a discrete value which is then converted into a discrete binary number by its encoder as shown in Figure 7.

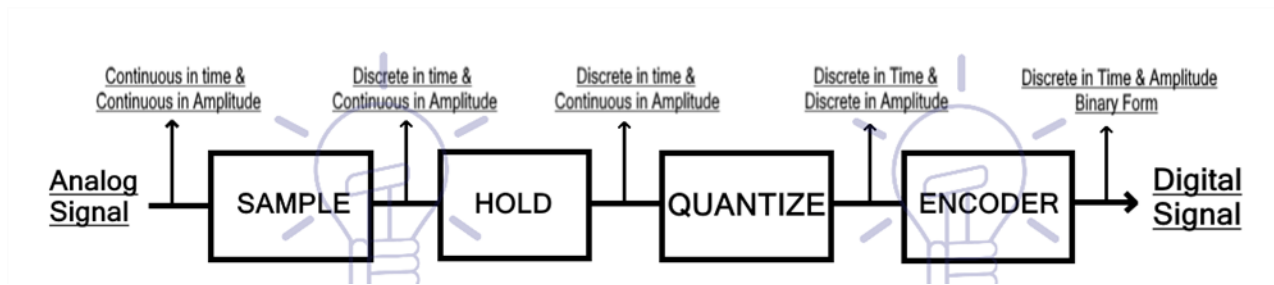


Figure 7: Block diagram of ADC stages (Electrical Technology, n.d.)

The sampling rate and quantization level (bit rate) determine the accuracy of the digital value that captures the original analogue signal (Electrical Technology, n.d.).

Increasing the sampling rate increases accuracy. According to the sampling theorem, provided the input is sampled above the Nyquist rate i.e. twice the highest-frequency component of the analogue signal to be sampled, then all frequencies in the signal can be perfectly reconstructed (Tan & Jiang, 2019). Equation 3 shows the Nyquist Criterion where f_s is the Nyquist frequency and $f_{\max}$ is the maximum frequency that appears in the signal.

$$f_s > 2 * f_{\max}$$

Equation 3: Nyquist Criterion

Aliasing can occur if frequencies above half the Nyquist rate are sampled since they are incorrectly detected as lower frequencies. This can result in distortion and some of the frequencies in the original signal being lost in the reconstructed signal (Zawistowski & Shah, 1992). Aliasing can be prevented by utilising low-pass filters.

During the quantization and encoding stage, error is introduced between input voltage and output binary representation. The degree of error depends on the ADCs resolution. Increasing the resolution increases the accuracy of its output. This is illustrated in Figure 8 using a sine wave. As shown, when the bit length increases, the more it represents its original analogue signal.

GOOD RESEARCH ON FM/ADC. SITUATION
GIVE A GOOD BASIS FOR YOUR CONCLUSIONS.

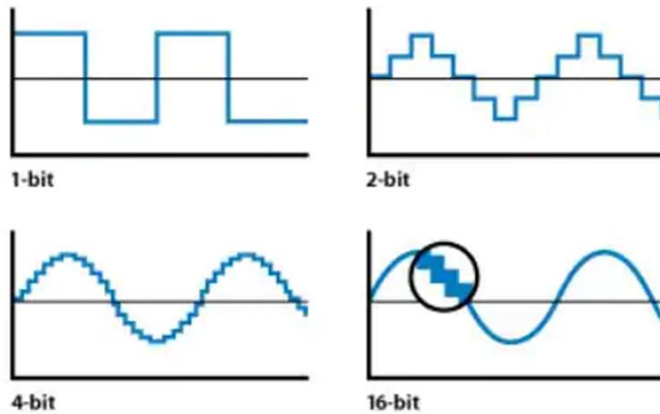


Figure 8: Example of Increasing Resolution (Gudino, 2018)

2.2.2 Pulse Amplitude Modulation (PAM) Techniques

PAM is a type of analogue to digital conversion technique where the signal wave is modulated during data transmission by altering the amplitudes of each pulse in a regular time sequence of electromagnetic pulses (ECSTUFF4U, n.d.). Essentially, the analogue signal is sampled either by natural sampling method or flat top sampling and is converted to a discrete-time continuous-amplitude signal. (Electronics Coach, n.d.).

In PAM, the amplitude of the pulse is proportional to the amplitude of the modulating signal. Figure 9 is an example of a PAM signal.

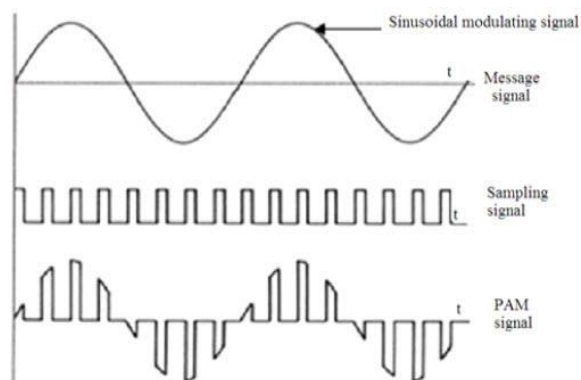


Figure 9: Pulse Amplitude Modulation Signal (EL-PRO-CUS, n.d.)

There can be an infinite number of possible pulse amplitudes, allowing increased data throughput over existing networks, but it's mostly some power of two so the final output can be digital. For instance, in level-4 PAM, there are 2^2 discrete pulse amplitudes; in 8-PAM there are 2^3 discrete pulse amplitudes and so on (BYJU's, 2019). PAM-4 was developed due to the

increased need for more data to be delivered at higher data rates as it allows twice the data rate compared with PAM-2 (Apena, 2018).

There are two main types of PAM:

- (1) Single Polarity- a suitable DC bias is added to the signal so all pulses are positive
- (2) Double polarity-pulses are both negative and positive.

The circuitry and block diagram of PAM are shown in Figure 10 and Figure 11.

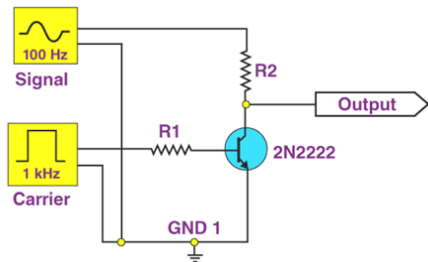


Figure 10: The circuit diagram of PAM (BYJU'S, 2019)

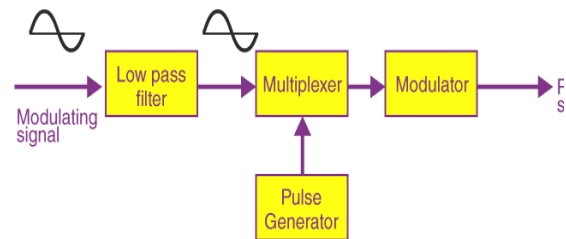


Figure 11: Block diagram of PAM (BYJU'S, 2019)

PAM is the simplest pulse modulation technique without the need for complex circuitry, data can be transmitted quickly and efficiently using conventional copper wires and PAM can also generate other pulse modulation signals whilst simultaneously carrying the message. However, very large bandwidths are required for transmission, the transmitter power varies and has lower power efficiency and higher noise interference compared with other types of analogue modulation. Nevertheless, PAM is utilised in many applications such as ethernet communication, electronic drivers for LED lighting, micro-controllers for generating the control signals, photo-biology and digital television (EL-PRO-CUS, n.d.).

2.2.3 Pulse Code Modulation (PCM) Techniques

According to Garg (2007), PCM is a digital technique for transmitting analogue data by converting analogue signals into digital form using sampling and quantization. Instead of a pulse train, the signal is pulse code modulated to convert its analogue information into a binary sequence of 0s and 1s, with each digit representing the approximate amplitude of the signal sample at that instant. Figure 12 illustrates the PCM output corresponding to instantaneous values of a given sine wave (Tutorials Point, n.d.).

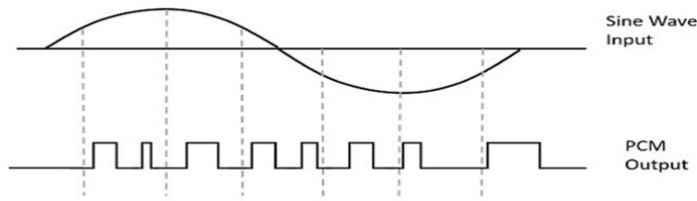


Figure 12: Comparison of a Sine Wave Input with the Corresponding Instantaneous PCM output (Tutorials Point, n.d.)

A PCM system comprises: (a) transmitter section where sampling of the analogue signal, quantizing, and encoding occurs (b) transmission path and (c) receiver section where regeneration of the impaired signal, decoding and reconstruction of the quantized pulse train occurs (Tutorials Point, n.d.). This is shown in Figure 13.

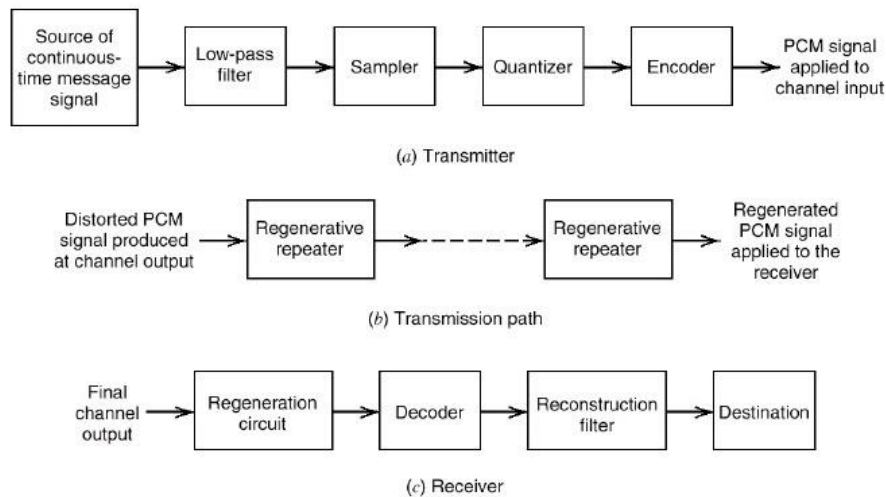


Figure 13: Basic Elements of Pulse Code Modulation System (EL-PRO-CUS, n.d.)

PCM has the advantage of having higher noise immunity and transmission efficiency, it's easily multiplexed and is convenient for long-distance communication. Nevertheless, encoding, decoding and quantizing circuitry is complex and compared with other analogue systems, requires a large bandwidth for transmission. In the PCM process, it's possible to digitise all forms of analogue data e.g. full-motion video, music telemetry, etc . Consequently, it's utilised in multiple applications including space communication, satellite transmission systems, telephony, CDs, computers and temperature regulation, etc (EL-PRO-CUS, n.d.).

2.2.4 Synchronous Digital Hierarchy (SDH) as a Digital Communication System

SDH is a European standard used for high-speed data transmission of telecommunication and digital signals. It was developed to eliminate synchronisation issues associated with its predecessor PDH (Plesiosynchronous Digital Hierarchy) with increased data transfer rates, and is used world-wide. It provides a more flexible network infrastructure, which is simpler, based on optical fibres (Carritech, 2018). Babatunde and Mbarouk advise that “unlike PDH, SDH is based on repeated hierarchy of fixed length frames designed to carry isochronous traffic channels” (2014, p. 679). Standardised technology is utilised where the digital multiplexer’s inputs or data stream are of the same rate and derived from a common clock source, therefore allowing exact timings. As it’s synchronous, it enables single stage multiplexing and de-multiplexing, thus eliminating hardware complexity. (Rumsey, 2003)

SDH uses a basic rate of 155.52 Mbit/s, called STM-1 (Synchronous Transport Module-1). Higher levels increase by a factor of 4 each time to form its transport hierarchy as illustrated in Table 1.

SDH Frame	Frame Composition	Bit Rate (Mbit/s)
STM-1	1xSTM1	155.52
STM-4	4xSTM1	622.080
STM-16	16xSTM1	2488.3
STM-64	64xSTM1	9953.28

Table 1: SDH Hierarchy (based on multiples of 4) and Frame composition (Rumsey, 2003)

According to Rumsey, (2003) the STM-1 frame is transmitted at 125 μ s (microseconds), resulting in 8,000 frames per second on the circuit and comprises payload blocks, overhead blocks and pointers. The STM-1 base frame is structured as follows and is presented in Figure 14.

- Length: 270 columns of bytes with 9 rows = 2430 bytes
- Byte: 1-byte = 8 bit
- Duration (Frame repetition time): 125 μ s i.e. 8000 frame/s
- Rate (Frame capacity): $2430 \times 8 \times 8000 = 155.5200$ Mbit/s
- Payload = $2349\text{bytes} \times 8\text{bits} \times 8000\text{frames/sec} = 150.336$ Mbit/s

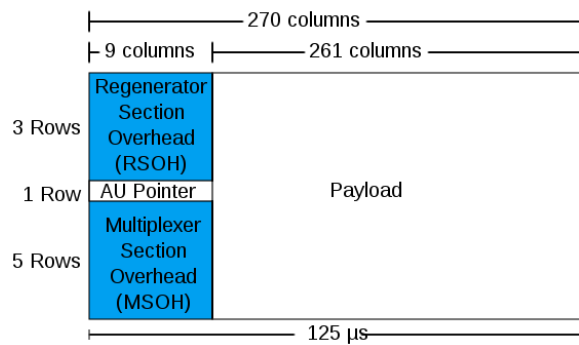


Figure 14: STM-1 Frame Structure (Manske, 2011)

The key benefits of SDH due to its composition and frame structures include: use of simplified multiplexing and demultiplexing, synchronous networking and supports multi-point networking, capacity to transport existing PDH signals and broadband signals, supports multi-vendors and different operators, allows quick recovery from failure, easy growth to higher bit rates and optical fibre bandwidth can be increased without limit. It can also provide network transport services on LAN such as video conferencing and interactive multi-media. However, it does require complicated SDH equipment and as it uses OAM software it is vulnerable to computer viruses (ECSTUFF4U, 2021).

3. Experimental Method for Experiment 1- Frequency Modulation

The experiment was set up to investigate frequency modulation using Feedback Instruments pack “Analogue Communications” and circuitry shown in Appendix 1. A Pico-scope was used to monitor the frequencies with channel A monitoring the input frequency and channel B the output. The modulation generator was then set to give a square wave of 10kHz and a 2v amplifier. The peak-to-peak voltage and frequencies were adjusted on the generator with results monitored. The carrier has a frequency of 455kHz and an amplitude of 375mV. Consequently, the bandwidth on a spectrum analyser could be determined from the side frequencies and the Bessel co-efficients measured.

4. Testing, Results and Analysis for Experiment 1

The maximum frequency deviation was calculated using Equation 4.

$$\text{Max Frequency Deviation, } \Delta f = KE_s = 20k \times 2 = 40kHz$$

Equation 4: Maximum Frequency Deviation

From this, the modulation index (β) can be calculated using Equation 5.

$$\text{Modulation Index and } \beta = \frac{\Delta f}{f_s} = \frac{40kHz}{10kHz} = 4$$

Equation 5: Modulation Index

The Bessel table can then be used to work out the spectrum of the wave using the calculated modulation index (β) to give an indication of expected results. The full Bessel table is presented in Appendix 2 and when looking at (β)=4, there are 7 sidebands. The frequency and amplitude are shown below:

@ $f_c \pm 0 \times f_s = 455kHz$	$E_c \times J_0 = 0.40 \times 375mV = 150mV$
@ $f_c \pm 1 \times f_s = 445kHz \text{ and } 465kHz$	$E_c \times J_1 = 0.07 \times 375mV = 26.25mV$
@ $f_c \pm 2 \times f_s = 435kHz \text{ and } 475kHz$	$E_c \times J_2 = 0.36 \times 375mV = 135mV$
@ $f_c \pm 3 \times f_s = 425kHz \text{ and } 485kHz$	$E_c \times J_3 = 0.43 \times 375mV = 161.25mV$
@ $f_c \pm 4 \times f_s = 415kHz \text{ and } 495kHz$	$E_c \times J_4 = 0.28 \times 375mV = 105mV$
@ $f_c \pm 5 \times f_s = 405kHz \text{ and } 505kHz$	$E_c \times J_5 = 0.13 \times 375mV = 48.75mV$
@ $f_c \pm 6 \times f_s = 395kHz \text{ and } 515kHz$	$E_c \times J_6 = 0.05 \times 375mV = 18.75mV$
@ $f_c \pm 7 \times f_s = 385kHz \text{ and } 525kHz$	$E_c \times J_7 = 0.02 \times 375mV = 7.5mV$

Using the theoretical data, the spectrum of the wave was produced and the bandwidth calculated as shown in Figure 15.

TABLE OF RESULTS COULD GO
IN THE APPENDIX.

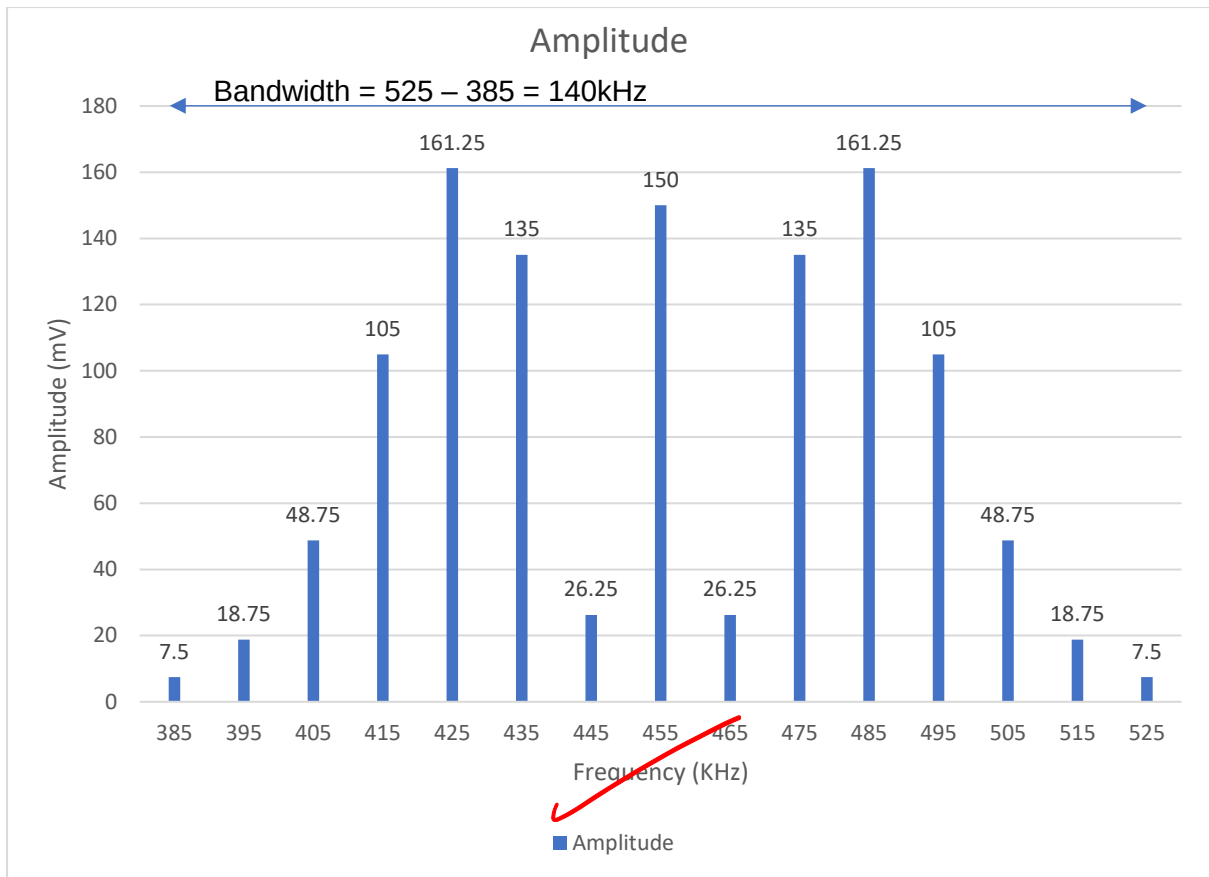


Figure 15: Wave Spectrum Using Calculated Data

The Pico-scope was then used to look at the wave-forms. The peak-to-peak voltage was adjusted to 6Vp-p, 4Vp-p and 2Vp-p. Visually, the wavelengths are getting smaller which will reduce the bandwidth. The wave-forms are shown in Figure 16 to Figure 18.

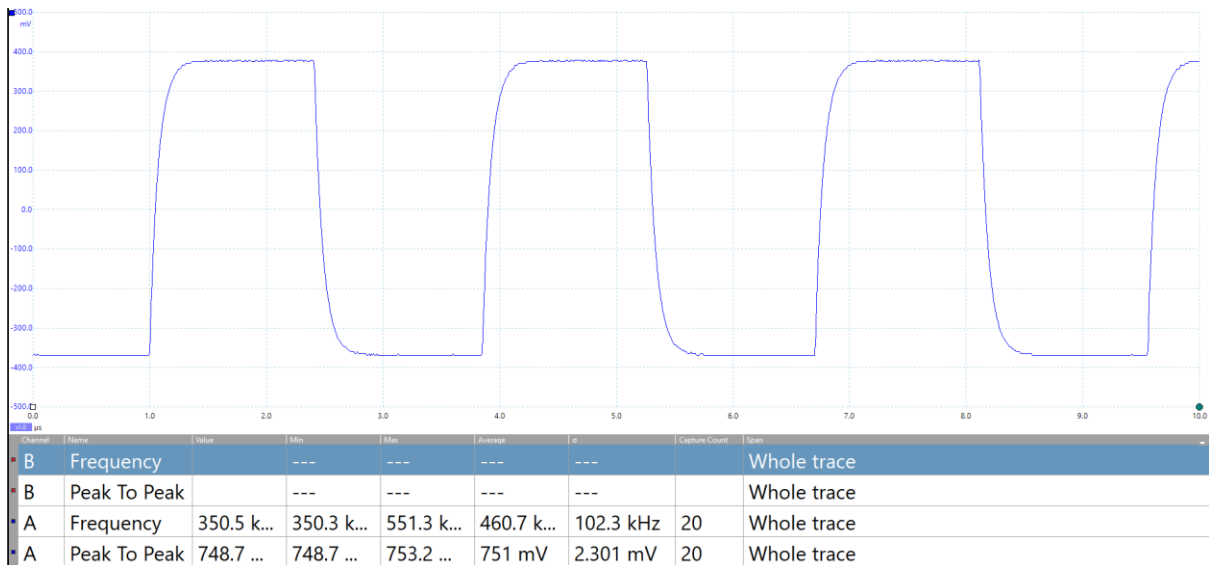


Figure 16: Channel A 6Vp-p

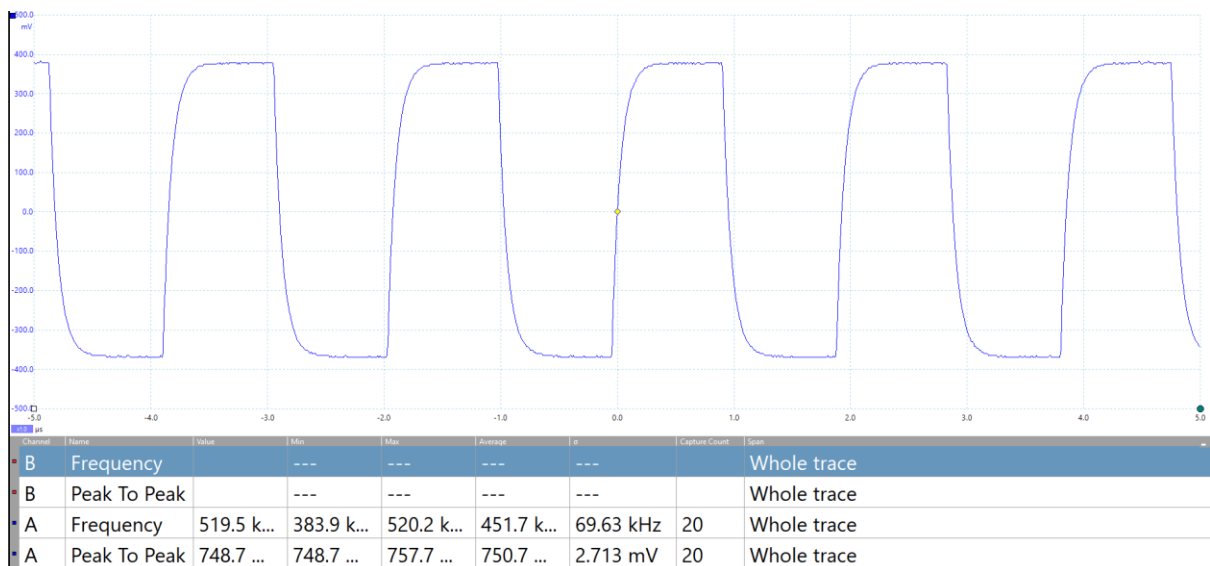


Figure 17: Channel A 4Vp-p

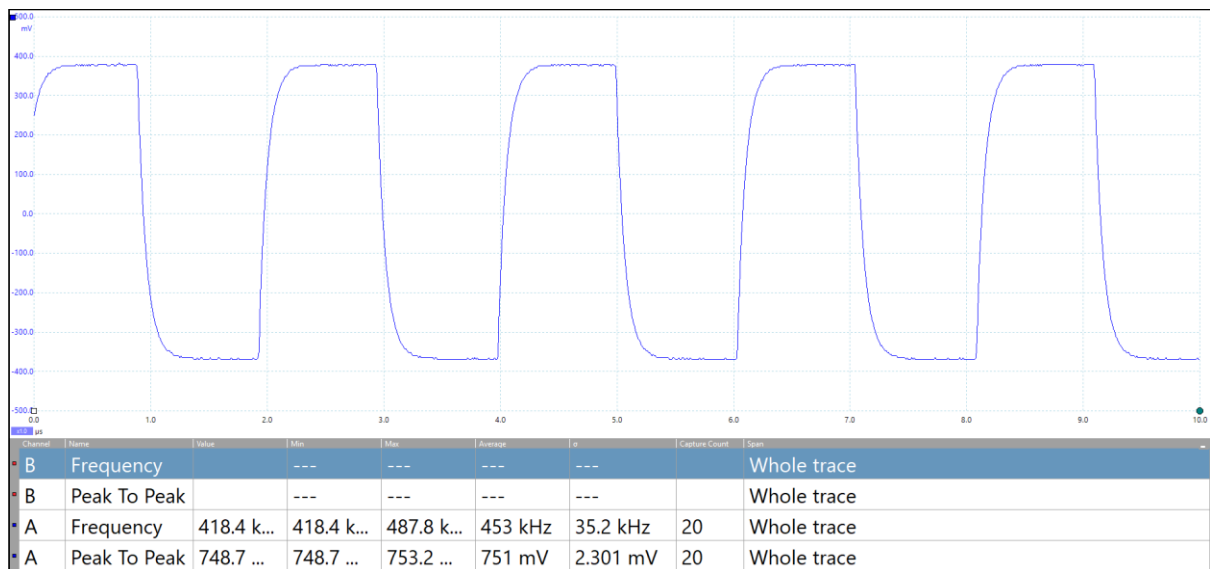


Figure 18: Channel A 2Vp-p

Fig 16-18 $\Rightarrow$ APPENDIX.

The side frequencies were displayed with the modulation generator set to 20kHz and 2Vp-p. The spectrum was then analysed with readings taken to be compared against the theoretical predictions from the Bessel table. Figure 19 shows the side frequencies on the Pico-scope where data was collected.

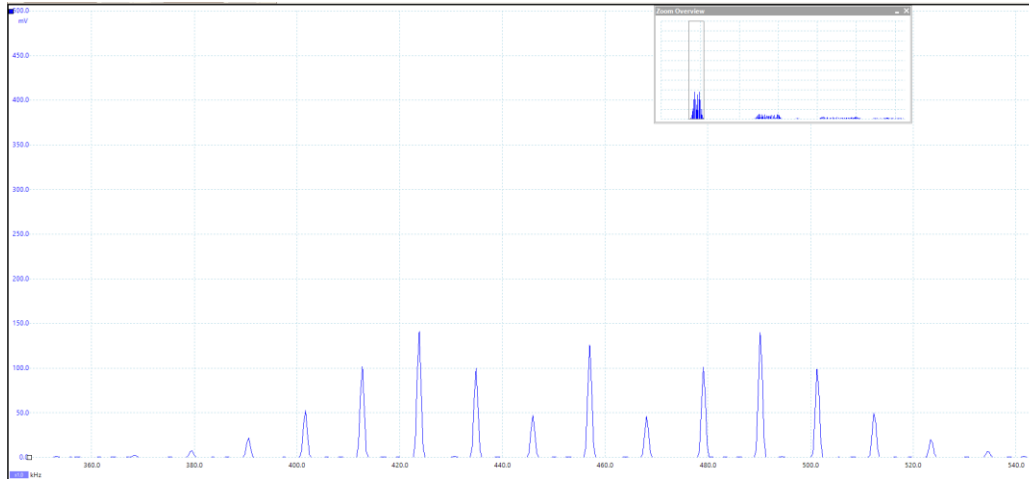


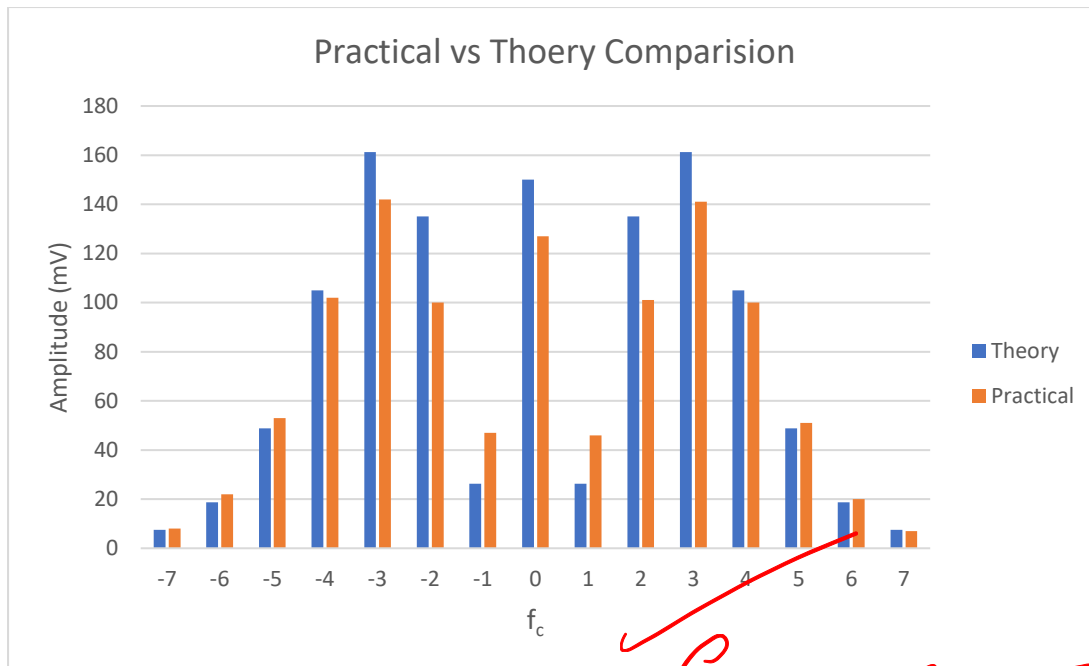
Figure 19: Side Frequencies

The data comparison is presented in Table 2 and the generated graph in Figure 20.

			J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7
F_c -Lower	Practical	Amplitude (mV)	127	47	100	142	102	53	22	8
		Frequency (kHz)	457	446	435	424	413	402	391	380
	Calculated	Amplitude (mV)	150	26.25	135	161.25	105	48.75	18.75	7.5
		Frequency (kHz)	455	445	435	425	415	405	395	385
F_c -Upper	Practical	Amplitude (mV)	127	46	101	141	100	51	20	7
		Frequency (kHz)	457	468	479	490	501	512	523	534
	Calculated	Amplitude (mV)	150	26.25	135	161.25	105	48.75	18.75	7.5
		Frequency (kHz)	455	465	475	485	495	505	515	525

Table 2: Bessel Table Comparison of Results

GOOD TABLE, BUT PUT
IN THE APPENDIX AS GRAPH
IS NOW SHOWN.



Good Result.

Figure 20: Wave Spectrum Comparison Graph

The graph in Figure 20 demonstrates that the side frequencies follow the same trend in both practical and theory showing the wave form takes the same shape. The frequencies of the side bands are different between the two. This could be down to human error on the practical tasks as the side band frequencies are 11kHz apart instead of 10. This error would explain the difference in amplitude between theory and practical. However, the difference is marginal.

5. Experimental Method for Experiment 2- Analogue to Digital Conversion

The experiment was set up to investigate analogue to digital communication (ADC) for the behaviour, requirements and limitations of ADCs. The Feedback Ltd equipment was set up as shown in Appendix 3. The frequency was set and adjusted accordingly and the number of bits was changed between 4 and 8, comparing their results. The results were monitored and recorded. Nyquist Criterion was then investigated by changing the input frequency while monitoring the output.



6. Testing, Results and Analysis for Experiment 2

The input frequency was set to 100Hz at 4Vp-p with the ADC set to 8-bit before being switched to 4-bit. The trace from the Pico-scope is shown in Figure 21 and Figure 22. The blue trace is the input and the red traces the output.

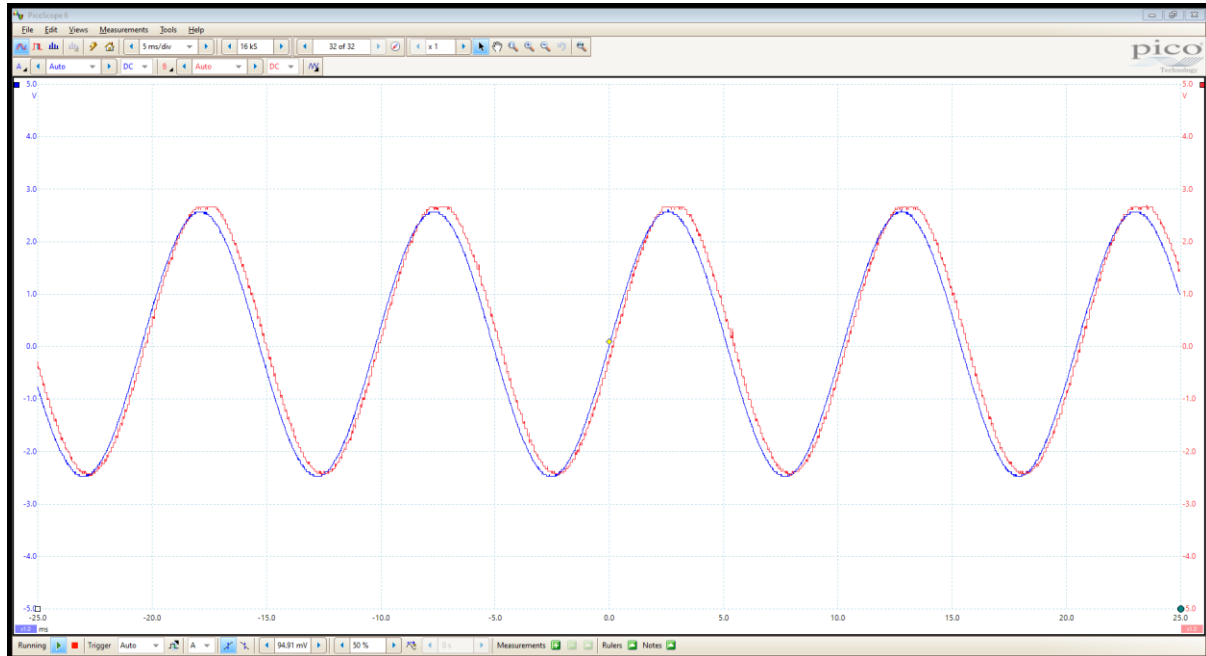


Figure 21: 8-bit ADC

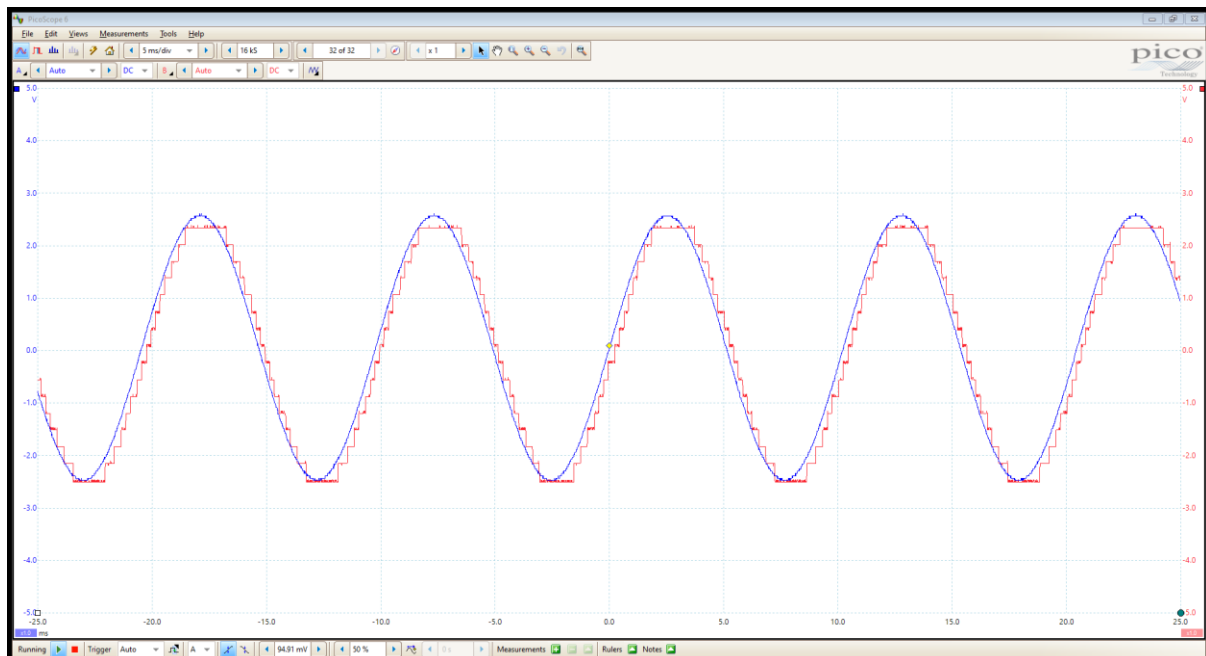


Figure 22: 4-Bit ADC

As shown in the traces, both waveforms take the shape of the input. However, the 8-bit waveform is much smoother and has less jagged edges when compared to the 4-bit, meaning

the 8-bit ADC is a better match to the input source. A 4-bit ADC has 16 levels leading to lower accuracy and a lower resolution. Lower resolution will indicate the output will also be of a lower quality. Compared to the 8-bit ADC which has a better quantisation as it has 256 levels, which allows for a much better resolution, and leads to a better quality output. The downside is that an 8-bit ADC can hold much more data, meaning it will take longer to transmit data.

RANGE

ADCs have various range limitations, if the input signal is outside of the range, the signal risks not being encoded. The range will help with the quantisation. If the range is too small it will have a much smaller sample of data to analyse to generate the binary number from. Likewise if the range matches the input signal there is more data in the waveform that can be analysed and converted into the binary code.

SAMPLING RATE AND INPUT FREQUENCY

The ADC used has a sample rate of 10,000 samples per second and a range of 5Vp-p. The sampling frequency must be at least twice the input frequency as per the sampling theorem. The sampling frequency of 10kHz was used. The input frequency was increased and the output waveforms changed as seen in Figure 23 to Figure 25.

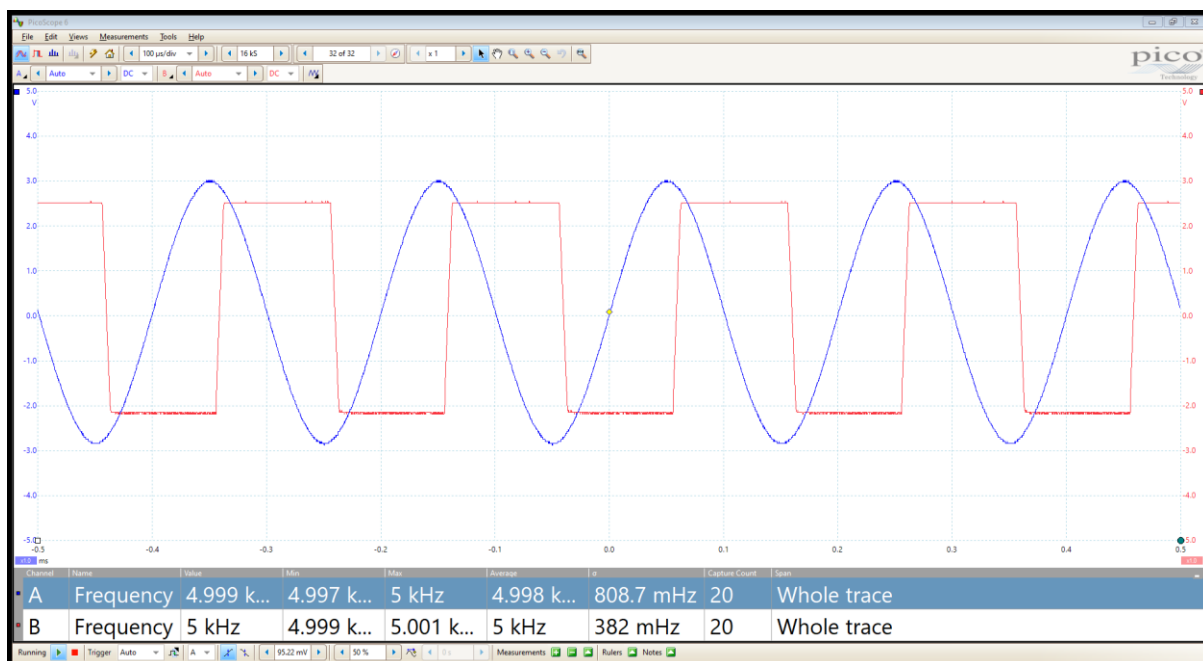


Figure 23: ADC 5kHz Input

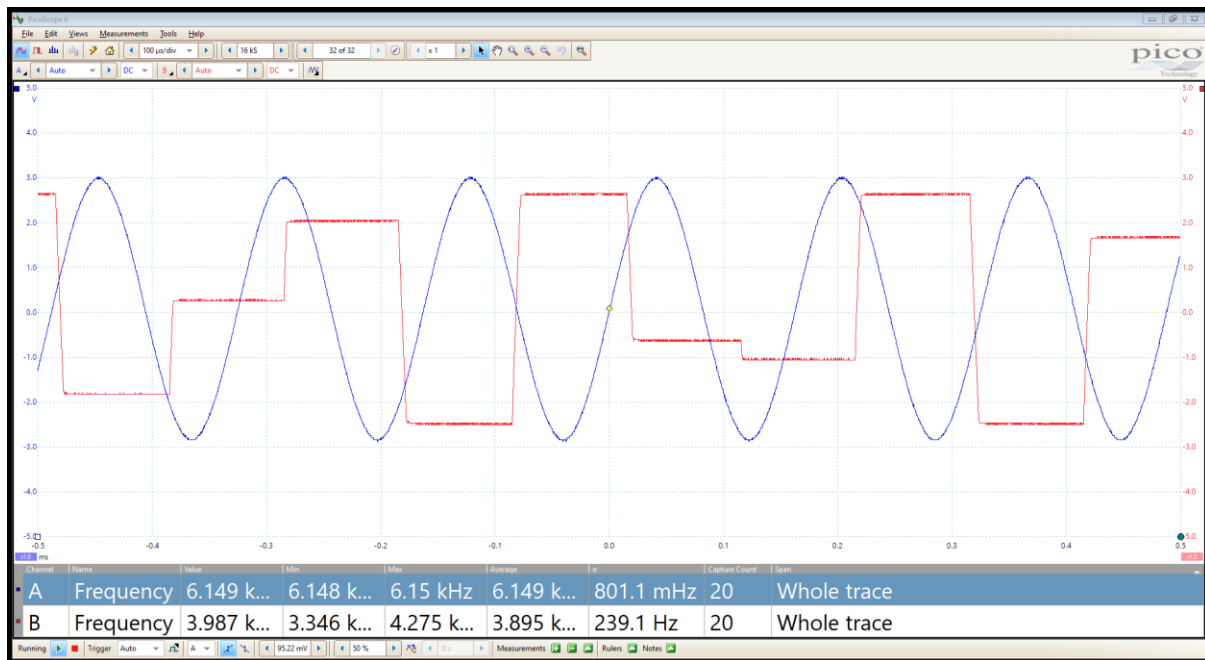


Figure 24: ADC 6kHz Input



Figure 25: ADC > 7kHz

The validity of Nyquist is proven when comparing the output waveforms and readings. At 5kHz the output frequency is still matching the input and the waveform is as expected. As the frequency increases over the threshold of twice the input frequency the output starts to deform and there is a drop on the output frequency. When increased to above 7kHz the waveform is heavily distorted and the output frequency is lost by the receiver. Figure 25 shows the loss of reading of any output frequency on channel B.

A TABLE OF RESULTS WOULD
HAVE BEEN BETTER

f_{in}	f_{out}
1k	1
2k	2
4k	4
5k	5
10k	3

7. Conclusion and recommendations

AM and FM are both types of modulation that can be applied to a wave form with the main difference being the wave carrier is modulated in FM compared with the amplitude being modified in AM.

Upon evaluating digital communications techniques, it was concluded that the accuracy of the ADCs can be improved by increasing the sampling rate and its resolution. It was noted that aliasing can occur when the Nyquist Criterion is violated. In Pulse Amplitude Modulation (PAM) and Pulse Code Modulation (PCM) techniques, it was determined that pulse levels in PCM are quantized, whereas pulses can have any value in PAM, with PAM being an analogue conversion technique. When looking at SDH, research showed that it allowed for high-speed data transmission of telecommunication and digital signals with SDH frame composition and data rates from STM-1 to STM-64 based on multiples of four times 155.52mbit/s to form its hierarchy.

YOU JUST
WTO TO
CONCLUDE
THE
EXPERIMENT

The maximum frequency deviation and modulation index can be calculated to find the sideband frequencies of an FM signal by using the Bessel table and the modulation index of the table. In the practical experiments, the theory supported the practical as each side band was the same frequency apart. The theory and practical results were not an exact match but the error was consistent so each sideband in the practical task was 11kHz apart which validates the theory as the amplitude followed the same trend, the discrepancy can be put-down to the equipment used as the frequency was set with a dial and not a fixed digital display. However the bandwidth between practical and theory are different.

IT WILL BE AS IT DEPENDS ON FM

4 and 8-bit ADCs were investigated and 8-bit was better due to its better resolution and quantisation. Therefore, the signal is more accurately transmitted and is of a better quality. The disadvantage is that it holds more data and therefore transmits slower. As determined from the research, error can be introduced whilst the sound is quantized and encoded. The better the resolution the less error occurs which supports the practical experiment of the 8-bit wave form being a higher quality at the receiver.

The validity of Nyquist Criterion was proven as the output frequency started to differ once the input frequency went over half the sampling frequency. As proven in Figure 25, when greater than 7kHz for the practical experiment the output frequency signal was lost by the receiver.

DO EACH CONCLUSION SEPARATELY RATHER
THAN GOING BACK AND FORTH BETWEEN FM
AND ADCs.

8. Works Cited

Apena, W. O., 2018. Performance evaluation of PAM-4 and PAM-2 Modulation Techniques using MATLAB. *European Journal of Engineering Research and Science*, 3(5), pp. 36-40.

Ashrit, L., n.d. *Analog to Digital Converter (ADC) – How it Works, Types, Applications*.

[Online]

Available at: <https://electricalfundablog.com/analog-to-digital-converter-adc/>

[Accessed 8th March 2022].

Babatunde, O. & Mbarouk, S., 2014. A review of Plesiochronous Digital Hierarchy (PDH) and. *International Journal of Scientific Research Engineering & Technology (IJSRET)*, 3(3), pp. 677-681.

BYJU'S, 2019. *Difference Between AM And FM*. [Online]

Available at: <https://byjus.com/physics/difference-between-am-and-fm/>

[Accessed 13th January 2022].

BYJU's, 2019. *Pulse Amplitude Modulation*. [Online]

Available at: <https://byjus.com/physics/pulse-amplitude-modulation/>

[Accessed 8th March 2022].

Carritech, 2018. *Synchronous Digital Hierarchy (SDH): Explained*. [Online]

Available at: <https://www.carritech.com/news/synchronous-digital-hierarchy-sdh-explained/>

[Accessed 5th March 2022].

ECSTUFF4U, 2021. *SDH advantages and disadvantages*. [Online]

Available at: <https://www.ecstuff4u.com/2020/03/sdh-advantages-disadvantages.html>

[Accessed 6th March 2022].

ECSTUFF4U, n.d. *Advantages and disadvantages of pulse amplitude modulation*. [Online]

Available at: <https://www.ecstuff4u.com/2018/08/advantages-disadvantages-pulse-amplitude-modulation.html>

[Accessed 8th March 2022].

Electrical Technology, n.d. *Analog to Digital Converter (ADC) – Block Diagram, Factors & Applications*. [Online]

Available at: <https://www.electricaltechnology.org/2019/02/analog-to-digital-converter-adc.html>

[Accessed 8th March 2022].

Electronics Coach, n.d. *Pulse Amplitude Modulation (PAM)*. [Online]
Available at: <https://electronicscoach.com/pulse-amplitude-modulation.html>
[Accessed 8th March 2022].

Elprocus, n.d. *Frequency Modulation and Its Applications*. [Online]
Available at: <https://www.elprocus.com/frequency-modulation-and-its-applications/>
[Accessed 7th March 2022].

EL-PRO-CUS, n.d. *Pulse Amplitude Modulation*. [Online]
Available at: <https://www.elprocus.com/pulse-amplitude-modulation/>
[Accessed 8th March 2022].

EL-PRO-CUS, n.d. *Pulse Code Modulation and Demodulation*. [Online]
Available at: <https://www.elprocus.com/pulse-code-modulation-and-demodulation/>
[Accessed 9th March 2022].

Garg, V. K., 2007. *Pulse Code Modulation*. [Online]
Available at: [https://www.sciencedirect.com/topics/engineering/pulse-code-modulation#:~:text=Pulse%20code%20modulation%20\(PCM\)%20is,serial%20bit%20stream%20of%20words](https://www.sciencedirect.com/topics/engineering/pulse-code-modulation#:~:text=Pulse%20code%20modulation%20(PCM)%20is,serial%20bit%20stream%20of%20words)
[Accessed 6th March 2022].

Gudino, M., 2018. *Engineering Resources: Basics of Analog-to-Digital Converters*. [Online]
Available at: <https://www.arrow.com/en/research-and-events/articles/engineering-resource-basics-of-analog-to-digital-converters>
[Accessed 8th March 2022].

Gupta, S., 2013. *Different Types of Modulation*. [Online]
Available at: <https://www.eeweb.com/different-types-of-modulation/>
[Accessed 7th March 2022].

Herres, D., 2018. *Understandng bandwidth concepts*. [Online]
Available at: <https://www.testandmeasurementtips.com/understanding-bandwidth-concepts/>
[Accessed 7th March 2022].

Innovation, Science and Economic Development Canada, 2010. *Cutting Through...Interference on AM and FM Radios*. [Online]
Available at: <https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01379.html>
[Accessed 7th March 2022].

Kumar, N., 2004. *Comprehensive Physics XII*. 1 ed. New Delhi: Laxmi Publications.

Manske, M., 2011. *SDH STM1 Frame*. [Art].

Plonus, M., 2020. *Electronics and Communications for Scientists and Engineers*. 2nd ed. Illinois: Butterworth-Heinemann.

Rumsey, J., 2003. *Technical Tutorial*. [Online]

Available at: <https://drive.google.com/file/d/1DpGK1dpKUPmDfFapp-pcWEwbqQWJshA4/view>

[Accessed 5th March 2022].

Sastry, S., 1997. *Frequency Modulation*. [Online]

Available at: <https://people.eecs.berkeley.edu/~sastry/ee20/modulation/node4.html>

[Accessed 8th March 2022].

Sobot, R., 2020. *Wireless Communication Electronics: Introduction to RF Circuits and Design Techniques*. 2nd ed. Cergy-Pontoise: Springer.

Tan, L. & Jiang, J., 2019. *Shannon Sampling Theorem*. [Online]

Available at: <https://www.sciencedirect.com/topics/computer-science/shannon-sampling-theorem>

[Accessed 6th March 2022].

Toulson, R. & Wilmshurst, T., 2012. *Analog-to-Digital Converter*. [Online]

Available at: <https://www.sciencedirect.com/topics/engineering/analog-to-digital-converter>

[Accessed 6th March 2022].

Tutorials Point, n.d. *Pulse Code Modulation*. [Online]

Available at:

https://www.tutorialspoint.com/digital_communication/digital_communication_pulse_code_modulation.htm

[Accessed 8th March 2022].

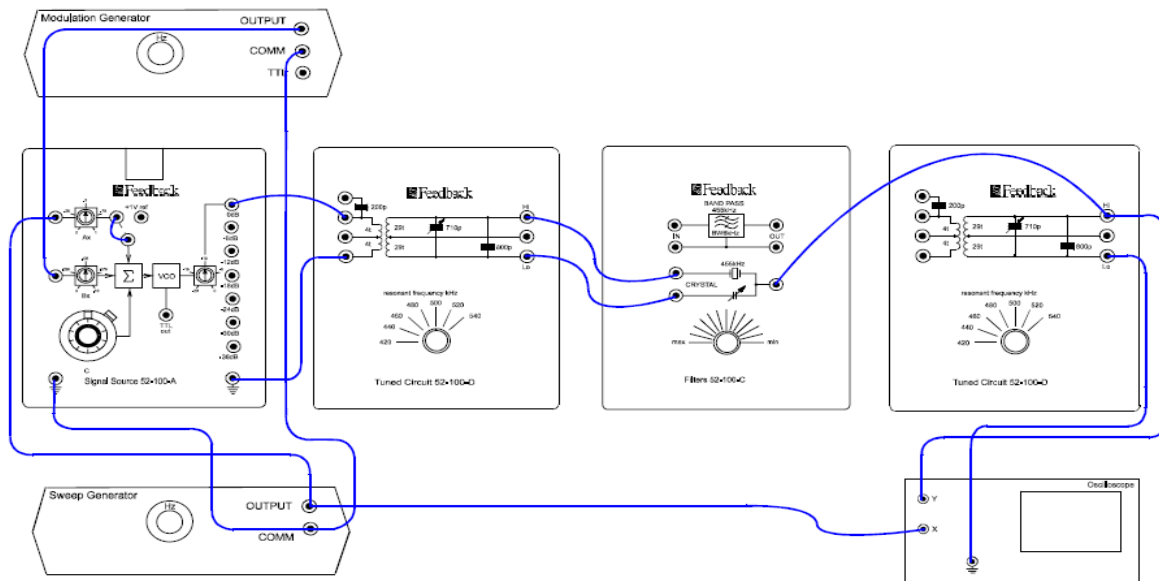
Zawistowski, T. & Shah, P., 1992. *An Introduction to Sampling Theory*. [Online]

Available at: <http://www2.egr.uh.edu/~glover/applets/Sampling/Sampling.html>

[Accessed 8th March 2022].

9. Appendix

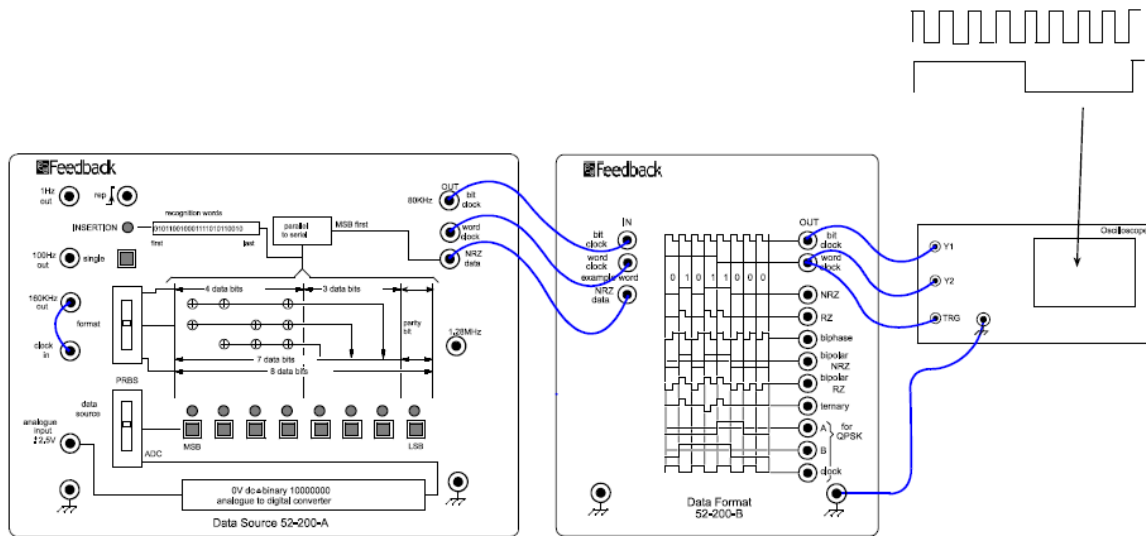
9.1 Appendix 1 Frequency Modulation Experiment Set Up



9.2 Appendix 2 Bessel Table

Modulation index	Sideband									
	Carrier	1	2	3	4	5	6	7	8	9
0.00	1.00									
0.25	0.98	0.12								
0.5	0.94	0.24	0.03							
1.0	0.77	0.44	0.11	0.02						
1.5	0.51	0.56	0.23	0.06	0.01					
2.0	0.22	0.58	0.35	0.13	0.03					
2.41	0	0.52	0.43	0.20	0.06	0.02				
2.5	-0.05	0.50	0.45	0.22	0.07	0.02	0.01			
3.0	-0.26	0.34	0.49	0.31	0.13	0.04	0.01			
4.0	-0.40	-0.07	0.36	0.43	0.28	0.13	0.05	0.02		
5.0	-0.18	-0.33	0.05	0.36	0.39	0.26	0.13	0.05	0.02	
5.53	0	-0.34	-0.13	0.25	0.40	0.32	0.19	0.09	0.03	0.01
6.0	0.15	-0.28	-0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02

9.3 Appendix 3 ADC Experiment Set Up



Specification of ADC: Sample rate = 10,000 samples/second and Range = 5Vp-p

FINAL GRADE

GENERAL COMMENTS

Instructor

66/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

PAGE 31

GRADING FORM: CSG-RUBIC

ALEX WILLIAMS

66

RESEARCH-INFORMED LITERATURE



There was very good evidence of further reading and research from credible and reliable sources. Your interpretation and understanding of the additional research was good and demonstrated a

7

very good underlying appreciation of the subject. Your references were appropriate to the task and applied with few errors or inconsistencies. Your reference list was of an appropriate length for this assignment.

KNOWLEDGE AND UNDERSTANDING

 The knowledge and understanding of the subject demonstrated by this assignment was generally very good. There were few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was demonstrated to a high degree. You have demonstrated a competent critical understanding of the main concepts and expanded your knowledge beyond that contained in the course notes.

21

ANALYSIS

 Your explanation of the experimental procedure was good and the conclusions showed that you can interpret quantitative and qualitative data, although this was often descriptive. You could have evaluated the results and specified whether they concurred with theory suggesting reasons for any discrepancies. You have however demonstrated good analytical skills and your approach to the task was logical. Arguments made in the conclusions were mostly valid and demonstrated a good understanding of the topic. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory.

18

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally very good. You used the resources appropriately when conducting both experiments and you used appropriate options for testing and evaluating the circuit performance. You managed to confirm that both circuits functioned within the specification and achieved this by only asking for assistance when appropriate thus demonstrating some advanced problem solving skills. Your results were comprehensive and allowed for a detailed conclusion to be attempted.

13

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was generally good and contained most of the required detail, it was also written in a coherent and logical way. The available word count was in the main effectively used.

7