

1708159

by Jonathon Williams

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1. Executive Summary

This report focusses on signals and modulation. Specifically, the types of modulation like amplitude modulation (AM) and frequency modulation (FM). It shows research of how modulation factors can affect a signal and put a signal into distortion.

It investigates through research, calculations and practical experiments into frequency modulation, as to how the frequency modulation and deviation can affect factors like the side bands.

Analogue to Digital Converters (ADC) are also investigated through research and practical experiments. It is shown in this report how aliasing can occur when the Nyquist Criterion is violated. The Nyquist Criterion says that the sampling frequency must be twice the maximum frequency that appears in the signal.

The resolution of an ADC is proven practically, looking at identical input signals that are converted by a 4 and 8-bit ADC. It is proven that the 8-bit ADC is the better of the two, providing an accurate conversion of the signal.

In addition, other digital communication techniques are evaluated through research, and explanations given as to their practical applications used in communication systems. These include Pulse Amplitude Modulation (PAM) and Pulse Code Modulation (PCM) techniques, Quadrature amplitude modulation (QAM) and Quadrature phase key shifting (QPSK) modulation schemes and Plesiosynchronous and synchronous digital hierarchy schemes (PDH and SDH).

The report explains how PAM is a simple and basic form of analogue modulation, whereas PCM converts an analogue signal to digital through the means of sampling and quantization. QAM is a scheme that moderates two sine waves which are out of phase with each other by 90° . However, QPSK is a form of phase key shifting where two bits are modulated at once using four possible carriers. It is slower than QAM-16 but provides high noise immunity and low probability of error making ideal for long distance operations. PDH and SDH are both associated with multiplex technology used in telecommunication systems, but the report outlines the main differences and advantages and disadvantages.

*The last 2 paragraphs
aren't required, and you
need to cover the results
and main conclusions.*

2. Research into analogue and digital communication systems and techniques

Modulation is the process of changing one characteristic (e.g. amplitude, frequency or phase) of a carrier wave in accordance with the intensity of the signal. (Kumar, 2004, p. 1686). There are several available modulation techniques which are classed by the type of modulation used. Figure 1 below shows the different types of modulation.

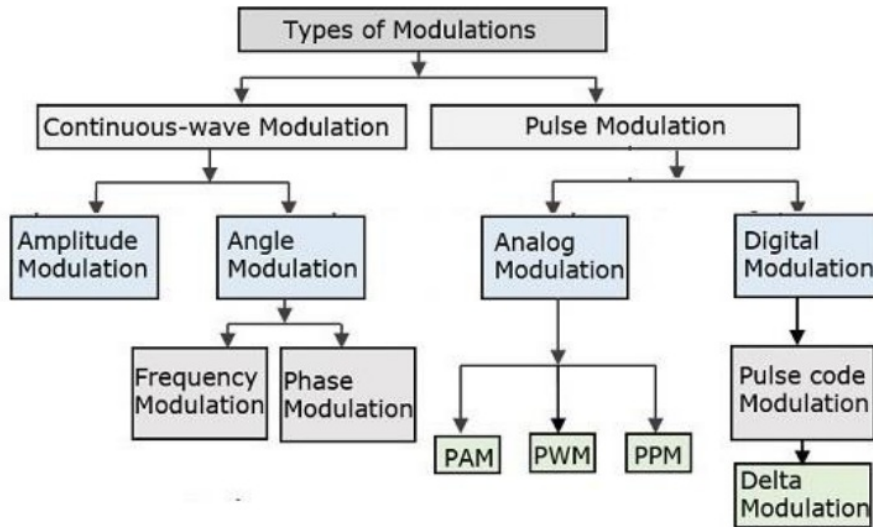


Figure 1: Types of Modulation

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

AM and FM are methods for broadcasting radio signals. AM is where the radio wave (known as the carrier wave) is modulated in amplitude by a signal to be transmitted whereas in FM, the carrier wave is modulated in frequency. Figure 2 below shows how the signal wave is affected by AM and FM. The carrier wave is modulated by the signal wave. The signal is then able to transmit wirelessly and be received by a receiver, which is outlined in Figure 3.

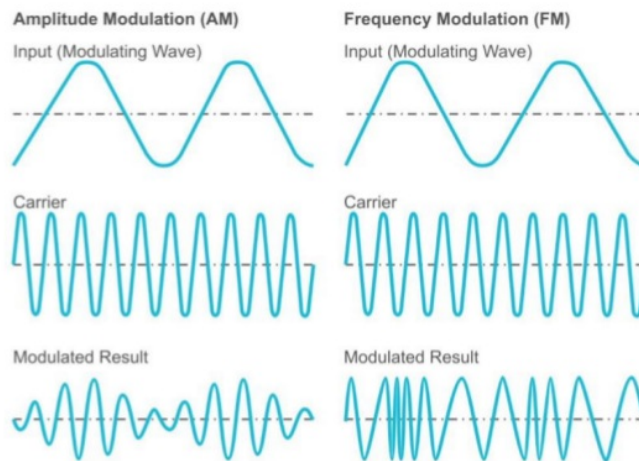


Figure 2: AM & FM Modulation wave example

(Kumar, 2004)

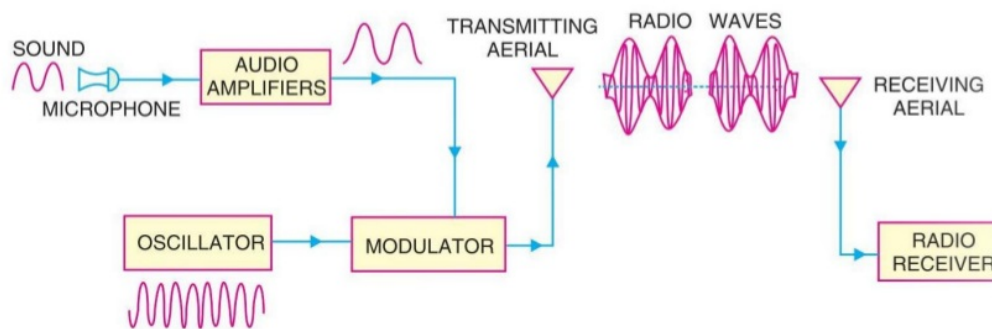


Figure 3: Modulation, transmission and receiving process

Amplitude modulation is the easiest way to modulate a signal. However, AM waves are subject to interference. This interference can come from a range of sources from motors such as those in vacuum cleaners, blow-dryers and sewing machines. (Innovation, Science and Economic Development Canada, 2010)

The extent a wave is modulated by is called the modulation factor which can be calculated using Equation 1 below.

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

Equation 1: Modulation Factor

The greater the modulation is the clearer the signal will be, however, if a signal becomes over modulated it can become distorted. Over modulation occurs when the modulation factor is greater than 1.

In amplitude modulation, the bandwidth is twice the signal frequency. This is shown as the bandwidth is made up from the two side frequencies, $f_c - f_s$ and $f_c + f_s$. When sidebands are drawn, the height of the lines represent the amplitude of the components present. For

example, a 2kHz is transmitted with a carrier frequency of 800kHz. The lower sideband would be 798 kHz and the upper band would be 802 kHz. The bandwidth can then be calculated as the differences between the two sidebands, which is 4kHz which is also twice the signal frequency. Figure 4 helps to illustrate this.

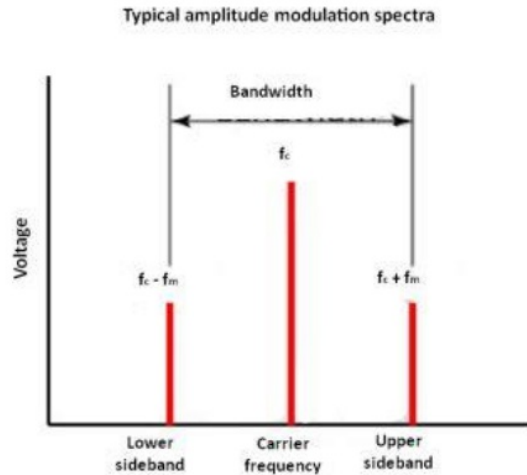


Figure 4: AM Sideband Frequencies

(Herres, 2018)

In frequency modulation, the carrier amplitude stays the same, it is the frequency of the signal that changes. Figure 5 below shows this.

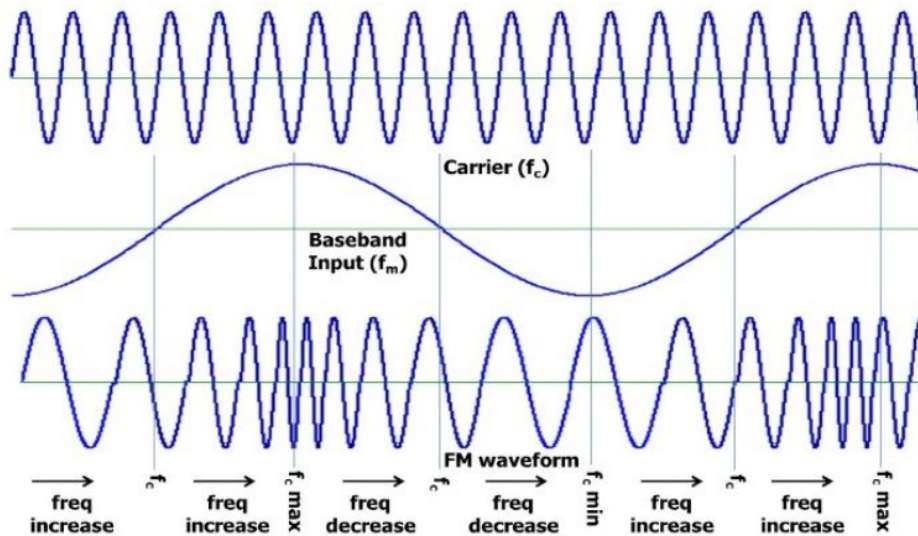


Figure 5: Frequency Modulation

(Elprocus, ND)

The change in the frequency between the maximum and the minimum is known as frequency deviation. This change is denoted by Δf . The ratio of the frequency deviation of the carrier to the frequency of the modulated signal is known as the modulation index. This can be calculated using Equation 2.

$$mf = \Delta f / f_m$$

Equation 2: Modulation Index

The main advantages of FM over AM are that there is a very high efficiency of transmission with a large operating range. FM generally has less interference due to the frequency being the part that is modulated. However, AM uses less bandwidth (20 times less) and it needs less complicated transmitter and receiver circuits. (Sastry, 1997)

2.2 Analogue to digital convertors (ADC)

ADCs, in its simplest form, converts an analogue signal, such as audio, light and motion, then digitizes it into a binary format that can be processed by digital equipment such as micro-controllers. (Christensson, 2008).

ADCs work by sampling an analogue signal and turning it into digital. The higher the sample rate of an ADC, the higher frequencies it can handle. Figure 6 below illustrates the effect of taking too few samples. This effect, known as aliasing shows that the when the samples are reconstructed by the ADC, there are parts of the signal missing.

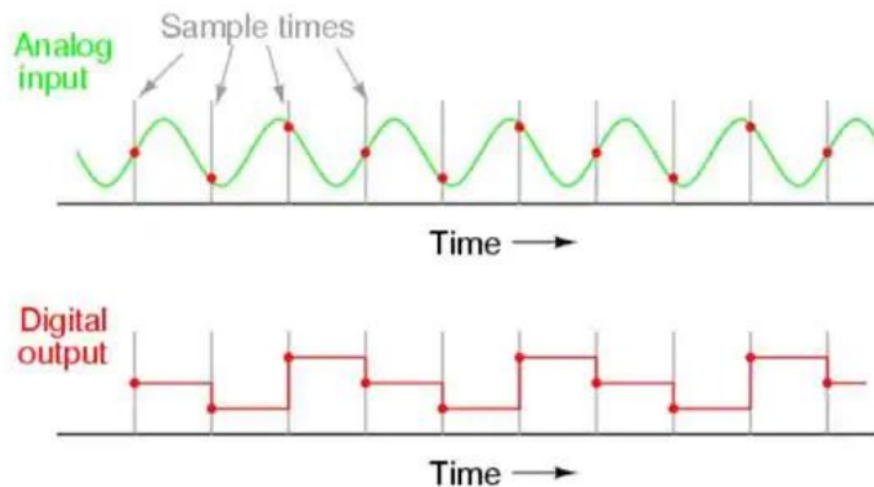


Figure 6: Aliasing effect

(Kuphaldt, 2007)

Aliasing usually exists when Nyquist Criterion is violated. The Nyquist Criterion says that the sampling frequency needs to be at least twice as much as the highest frequency in the signal. To put the theorem in an equation, it would look like Equation 3 below where, N_{Nyquist} is the Nyquist frequency and f_{Max} is the maximum frequency that appears in the signal.

$$f_{Nyquist} = 2f_{Max}$$

Equation 3: Nyquist Equation

The resolution of an ADC can increase the accuracy of its output. This is illustrated in Figure 7. As seen, as the bit length was increased, the more it will look like its analogue input. For the purpose of the illustration, the input signal for Figure 7 was a sine wave.

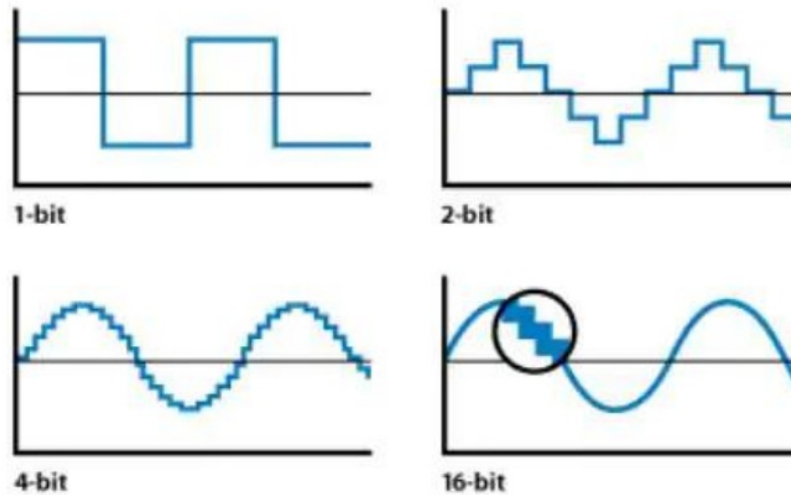


Figure 7: Resolution example

(Gudino, 2018)

2.3 Pulse Amplitude Modulation (PAM)

PAM is the simplest and most basic form of analogue pulse modulation, where the amplitudes of regularly spaced pulses are varied in proportion to the corresponding sample values of a continuous message signal (El-Sherif & Hussein, ND). It is essentially converting an analogue signal into a discrete one which is continuous in amplitude but discrete in time. The possible number of amplitudes can be endless, but is usually some power of 2 e.g. in level-4 PAM there are 2^2 discrete pulse amplitudes, in PAM-8 there are 2^3 discrete pulse amplitudes etc so that the final output signal can be digital (BYJU's, ND).

There are 2 types of PAM: single polarity where a suitable DC bias is added to the signal so that all the pulses are positive and double polarity where the pulses are both negative and positive.

Figure 8 and Figure 9 below show a circuit and block diagram of PAM respectively.

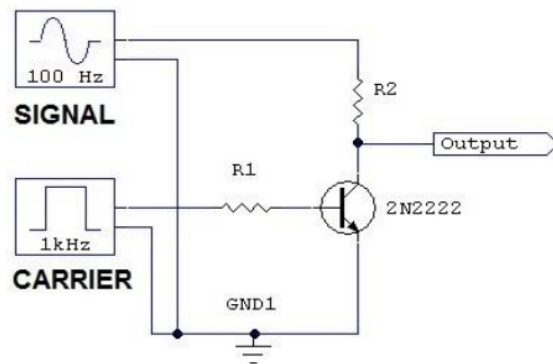


Figure 8: PAM circuit diagram

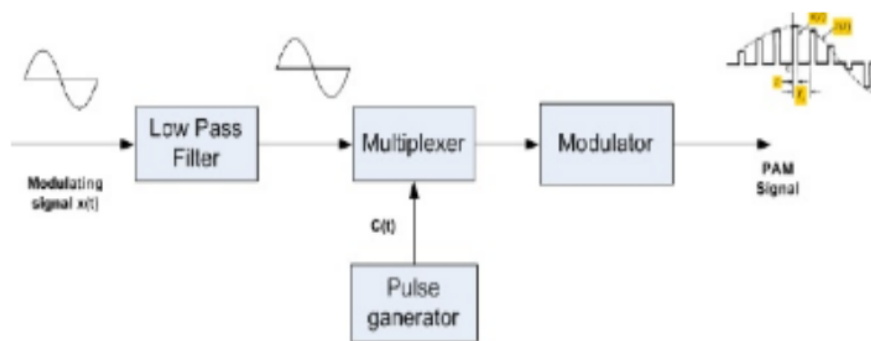


Figure 9: PAM block diagram

(BYJU's, ND)

According to W.O. Apena (2018), PAM-2 is failing to cope with the increase in the need for data and “higher data rate with respect to noisy channel”. Consequently, PAM-4 was developed which allows twice the data rate compared with PAM-2. However, following tests undertaken, it was determined that PAM-4 is more susceptible to noise than PAM-2.

PAM has the advantage that it is the simplest pulse modulation technique and enables the possibility of sending more than one signal on the same channel, each having a certain time slot using Time Division Multiplexing. However, noise interference is higher than other types of analogue modulation, PAM has lower power efficiency due to the variance in pulse amplitude signal, the transmitter power varies and transmission bandwidth is too large (RF Wireless World, 2012). Nevertheless, it has several uses, namely:

- Ethernet communication
- PAM-4 is used in photo- biology
- Used in micro-controllers for generating the control signals
- Used as electronic drivers for LED lighting
- Pam-8 can be used for digital television

2.4 Pulse Code Modulation (PCM)

PCM is a technique used to convert an analogue signal to digital using sampling and quantization (where the excessive bits are reduced and the data is confined) and is the most basic form of digital pulse modulation. The analogue information is converted into a binary sequence of 0s and 1s. Figure 10 below is an example of a PCM output with regards to instantaneous values of a certain sine wave. (Tutorials Point, ND)

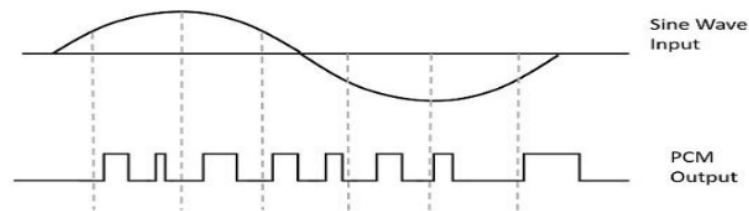


Figure 10: PCM Output compared with a Sine wave input

A PCM system contains three main blocks: a PCM transmitter (comprising sampling, quantizing and encoding), a transmission path/channel and receiver (where regeneration of the impaired signal takes place, decoding and reconstruction). Figure 11 below is a block diagram of PCM showing this:

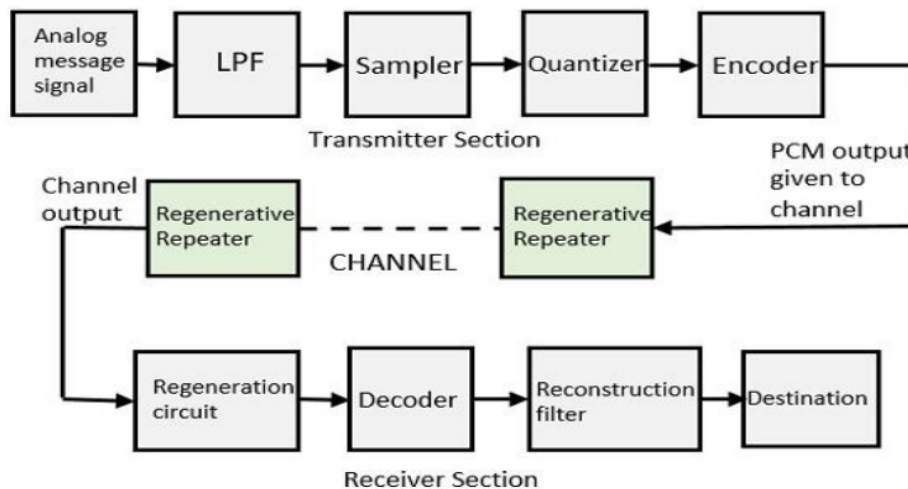


Figure 11: PCM block diagram

(Tutorials Point, ND)

There are several advantages of PCM: it is convenient for long distance communication, has a higher transmitter efficiency and less noise distortion. However, PCM requires a large bandwidth compared with other analogue systems and requires very complex encoding, decoding and quantizing circuitry.

Following the development of PCM, it has many uses such as telephony (which was its first practical application) and is used in satellite transmission systems, space communication, and digital audio applications such as compact discs, and computers.

(Polytechnic Hub, 2017)

2.5 Modulation Schemes

Quadrature amplitude modulation (QAM) and Quadrature phase key shifting (QPSK) are both modulation schemes used in many communications systems e.g. Wi-Fi (IEEE 802.11), mobile phones, satellite communication and 3G wireless technologies. This is due to the high spectral efficiencies (measured as bit/s/Hz i.e. number of bits transported within a second and within a given bandwidth) which can be achieved for data transmission. (Masood, 2013)

2.5.1 Quadrature amplitude modulation (QAM)

QAM is a scheme that “moderates two sinusoidal carriers 90° out-of-phase with each other” (Sheridan Eng & Kocot, 2013). It uses both amplitude -shift keying (ASK) and phase-shift keying (PSK) to represent binary data. High spectral efficiencies can be achieved by setting suitable constellation sizes e.g. QAM-16 which uses 4 bits per time interval or symbol. According to Louis E. Frenzel Jr (2018), this causes the data rate to quadruple in the same bandwidth compared with 2- QAM. Figure 12 and Figure 13 below show the circuit for producing QAM-16 and its resulting constellation diagram. QAM is advantageous due to its efficient use of channel bandwidth and it supports a high data rate, making it preferable to use in wireless and radio communication networks (Elprocus, ND). QAM-16 and QAM-64 are specifically used for digital terrestrial television.

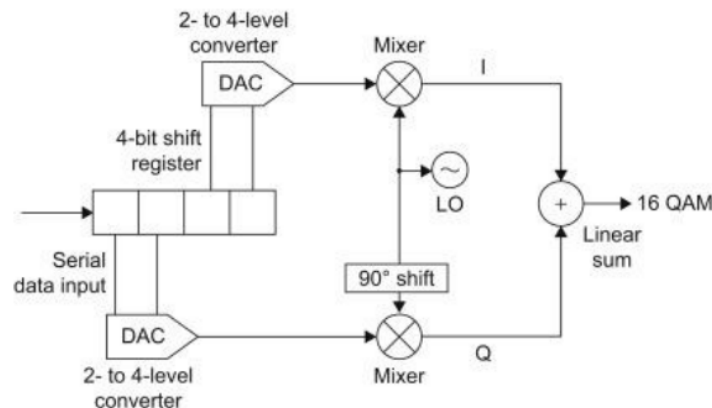


Figure 12: Overview of how 16-QAM is generated

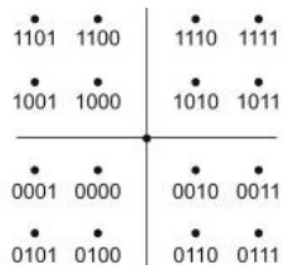


Figure 13: 16-QAM constellation diagram

(Frenzel JR,, 2018)

2.5.2 Quadrature phase key shifting (QPSK)

QPSK is a form of Phase Shift Keying “in which two bits are modulated at once, selecting one of four possible carrier phase shifts (0, 90, 180, or 270 degrees)” (Maxim integrated, ND). This is shown in Figure 14 below which is the QPSK constellation, with every two input bits mapping to one of four symbols.

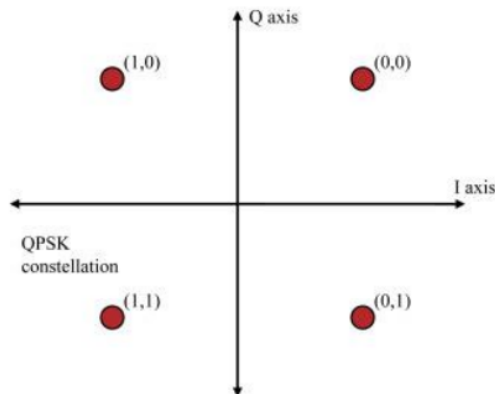


Figure 14: QPSK constellation

(Parker, 2017)

According to Andrew W. Davis (1997), QPSK delivers approximately 1.5 bits/Hz of bandwidth used. Although slower than QAM-16, QPSK provides high noise immunity and low probability error, making it ideal to operate over long distances where there are other several interfering sources. Consequently, QPSK is preferred for sending data from a computer or network in cable modem applications. It is also used in wireless, mobile and satellite communication systems.

2.6 Plesiosynchronous Digital Hierarchy (PDH) and Synchronous Digital Hierarchy (SDH)

Both PDH and SDH are popular technologies widely used in the telecommunication sectors for the easy transfer of massive data over digital transport equipment. (Ad-net, 2008)

In PDH the data rate which is controlled by a clock in the equipment generating the data is not the same throughout the transmission network. Hence, different data streams can run at similar but slightly different rates, making multiplexing and de-multiplexing very complex. Furthermore, as every manufacturer has its own standards, due to PDH having different multiplexing hierarchies, it is difficult to integrate interconnecting networks together. In addition, according to the same article by RF Wireless World (2012), “PDH was not scalable to support high capacity bandwidth” and therefore was not suitable to meet the growing internet requirements for transmitting signals. Figure 15 show the working requirements of PDH.

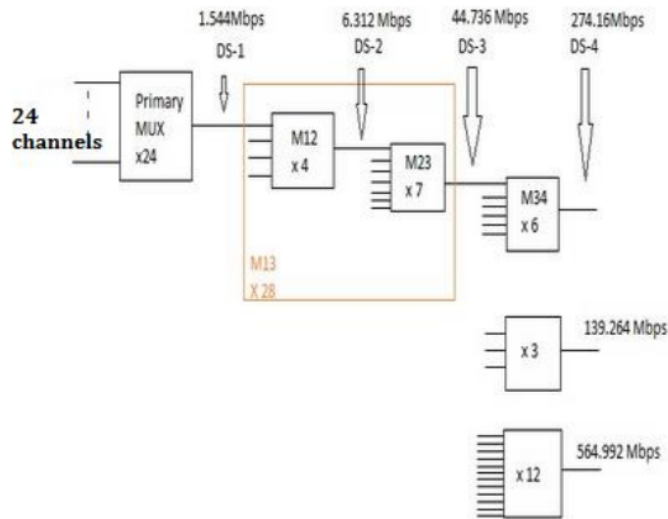


Figure 15: Working requirements of PDH

(Fiber Optical Networking, 2015)

Although PDH is still used mainly in point to point applications as it is cheaper, due to some of the above weaknesses, PDH is now largely replaced by synchronous digital hierarchy (SDH). SDH is a European standard used for high-speed data transmission of telecommunication and digital signals at much higher rates than the PDH system. It uses standardised technology where the digital multiplexer's inputs or data stream are of the same rate and derived from a common clock, therefore allowing exact timings. As acknowledged in an entry by Fiber Optical Networking (2015), SDH is able to transport large quantities of digital signals over the same optical fiber, using lasers or consistent light being emitted from LEDs, without synchronization problem therefore providing a simple and flexible network infrastructure. Figure 16 below show the working principles of SDH:

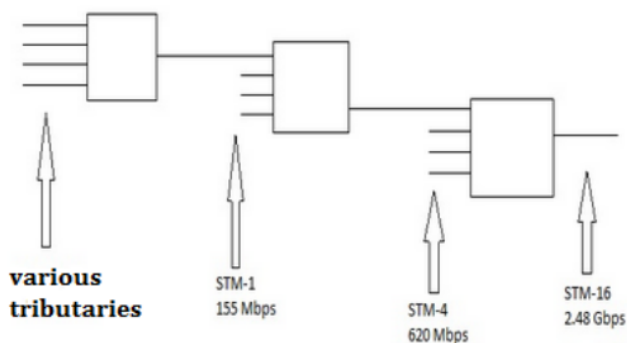


Figure 16: The working principle of SDH

However, according to Fiber Optical Networking, although SDH has many advantages of PDH, the utilisation rate of SDH bandwidth is relatively low, therefore resulting in the reduction of data frames utilised to transmit signals. In addition, due to the type of software it has adopted (OAM) as the monitoring and maintenance instrument, it is lacking in network security. Nevertheless, the benefits far outweigh the disadvantages.

3. Experimental Methods

The Feedback Ltd kits were set up as per Appendix C and Appendix D for the FM and the ADC experiment respectively. During the FM experiment the Pico scope channel 'A' was used to display the input frequency and 'B' was used for the output frequency. The frequency of the modulation generator was adjusted by a factor of 10 each time to observe the effect.

During the ADC experiment, three things were investigated:

- the effect of changing the resolution
- changing the amplitude while keeping frequency constant and
- altering frequency while keeping the amplitude constant.

During the third ADC experiment, the frequencies were chosen around the 5kHz due to the sampling frequency being 5kHz and trying to prove the Nyquist Criterion.

4. Testing, results and analysis

4.1 Frequency Modulation (FM)

A 455kHz carrier has an amplitude of 375mV and is frequency modulated by a 10kHz square-wave signal of amplitude 2V. The modulator has an FM transfer characteristic of 20kHz per volt.

The maximum frequency deviation (Δf_c) is calculated using Equation 4.

$$\Delta f_c = (f_c + V_{spk} \times FM \text{ Transfer characteristic}) - f_c$$

Equation 4: Maximum Frequency Deviation

Carrier frequency (f_c) = 455kHz with an amplitude (V_{ick}) of 375mV

Signal Frequency (f_s) = 10kHz with an amplitude (V_{spk}) of 2V

FM transfer characteristic = 20kHz/V

$$\Delta f_c = (455kHz + 2 \times 20kHz) - 455kHz$$

$$\Delta f_c = 40kHz$$

Once the frequency deviation is known, the modulation index (β) can be calculated using Equation 5.

$$\beta = \frac{\Delta f_c}{f_s} = \frac{40kHz}{10kHz} = 4$$

Equation 5: Modulation Index

Using the above results, you can look up the modulation index in the Bessel table in Appendix A. This will give you an indication of the expected result that would be shown when analysing on a spectrum analyser. The modulation index is 4, when looking at the Bessel table there are 7 sidebands. The expected results are shown below.

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

Appendix B shows what you would expect on a spectrum analyser.

The test equipment was set up as shown in Appendix C. Figure 17 to Figure 19 below shows the Pico scope trace.

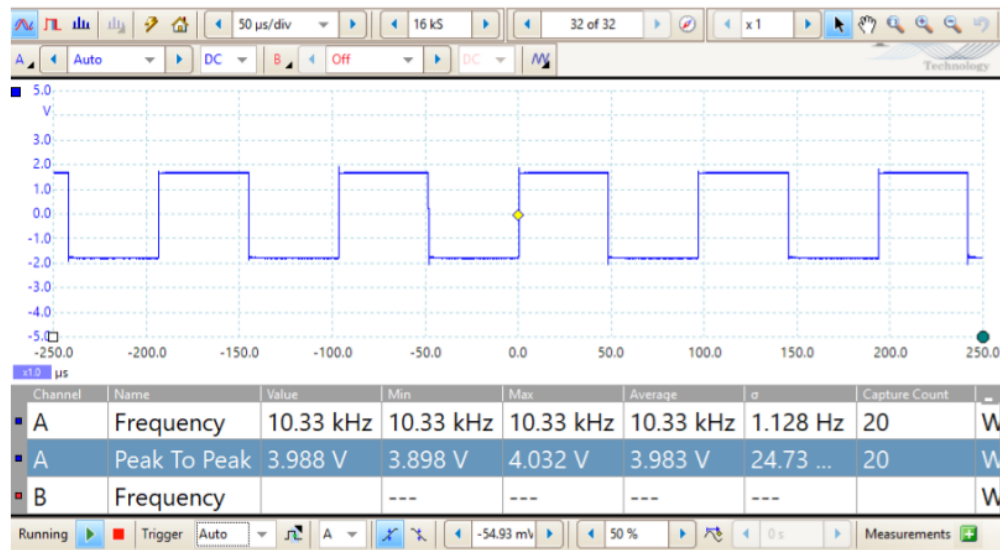


Figure 17: Signal frequency

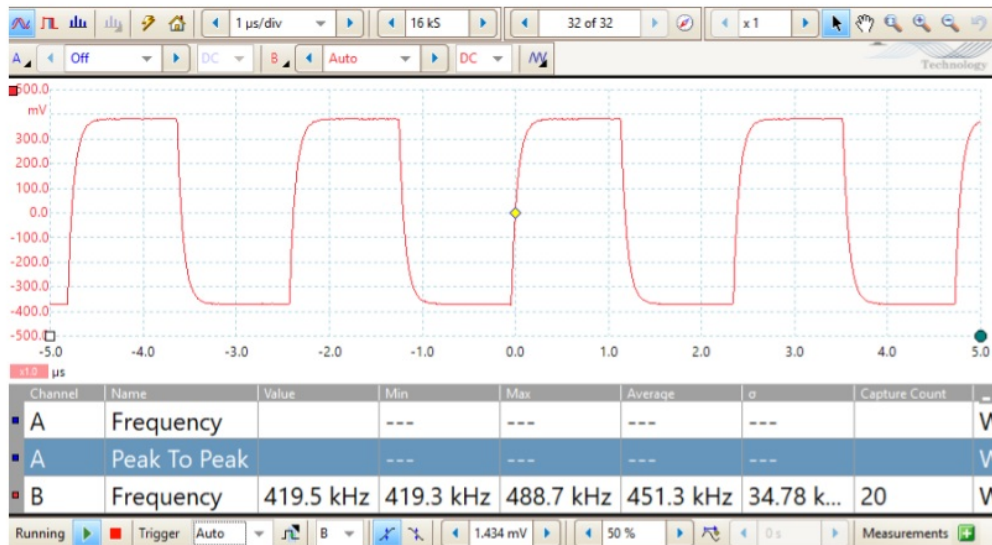


Figure 18: Minimum carrier frequency

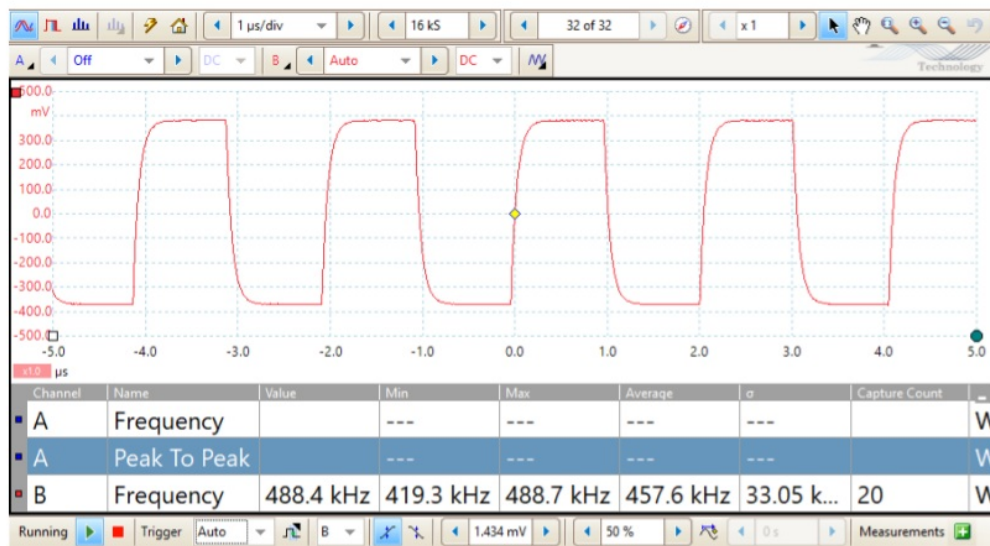


Figure 19: Maximum carrier frequency

The spectrum analyser function on the Pico scope was used to obtain the spectrum analysis displayed in Figure 20.

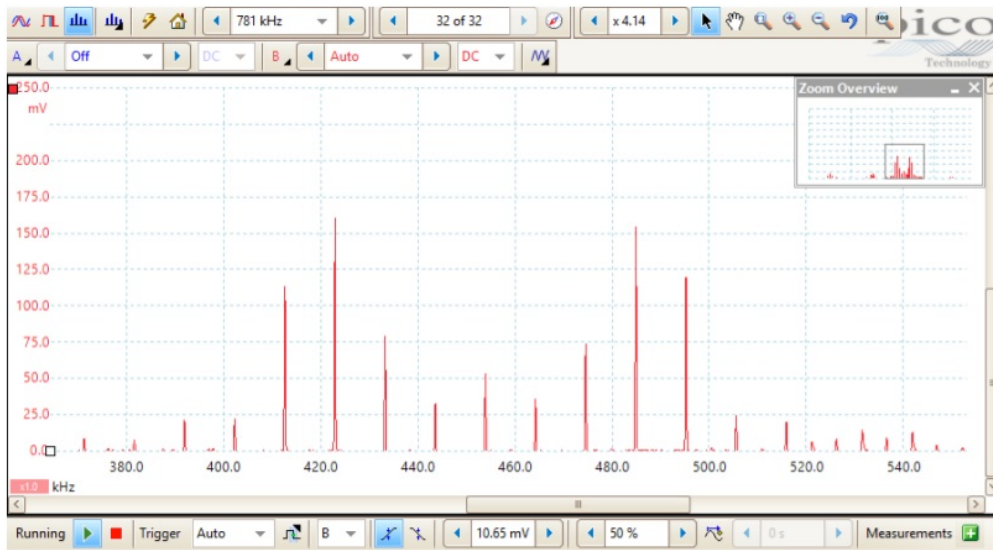


Figure 20: Spectrum Analyser

Using the Pico scope analysis tools, the sideband frequencies were able to be recorded and compared to the values calculated using the bezel table. (Shown in Figure 21 and displayed in Table 1).

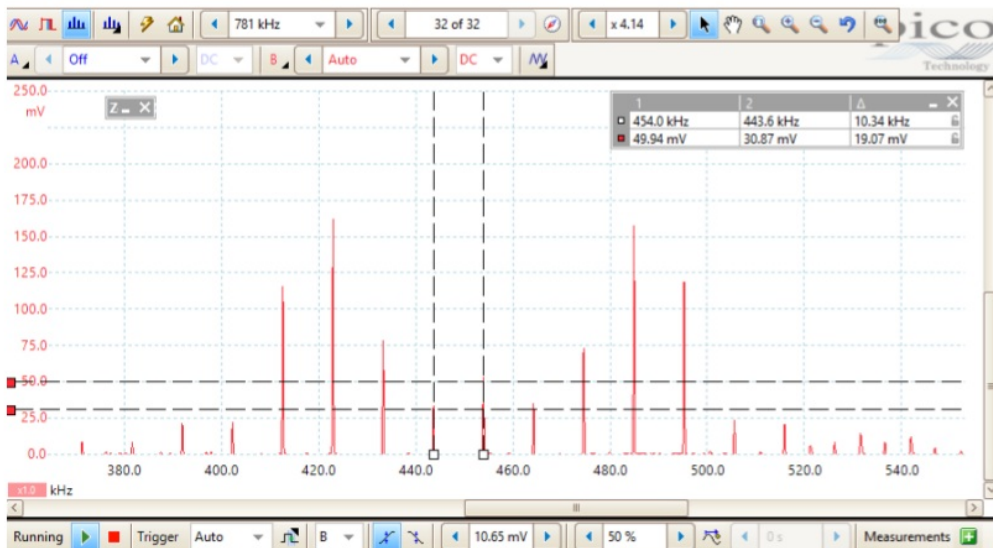


Figure 21: Spectrum analyser with data cursors

Table 1: FM Practical and theoretical values

A very good set of results

		J ₀	J ₁	J ₂	J ₃	J ₄	J ₅	J ₆	J ₇
Practical	mV	49.94	35.11	75.97	157.7	107.4	23	19.98	6.356
	f _c	454	443.6	433.2	423	412.6	402.3	391.9	381.6
	upper F _c		464.3	474.6	484.9	495.3	505.6	515.9	526.3
	lower F _c								
	B	0.13	0.09	0.20	0.42	0.29	0.06	0.05	0.02
Calculated	mV	150	26.25	135	161025	105	48.75	18.75	7.5
	f _c	455	445	435	425	415	405	395	385
	upper F _c		465	475	485	495	505	515	525
	lower F _c								
	B	0.40	0.07	0.36	0.43	0.28	0.13	0.05	0.02

Table 1 compares the results obtained practically using the equipment detailed previously to the expected values worked out theoretically from calculations. From the table, it is clear to see that J₀, J₂, and J₅ are the results with the biggest variance.

4.2 Analogue to Digital Conversion (ADC)

The Feedback Ltd kit was set up as shown in Appendix D.

The resolution of an ADC was investigated to prove what had been detailed earlier on in this report, i.e. that the greater the resolution, the more accurate the conversion of the signal is. To do this, a signal of 2V amplitude and 100Hz frequency was used. Figure 22 & Figure 23 below can be used to compare the two resolutions.

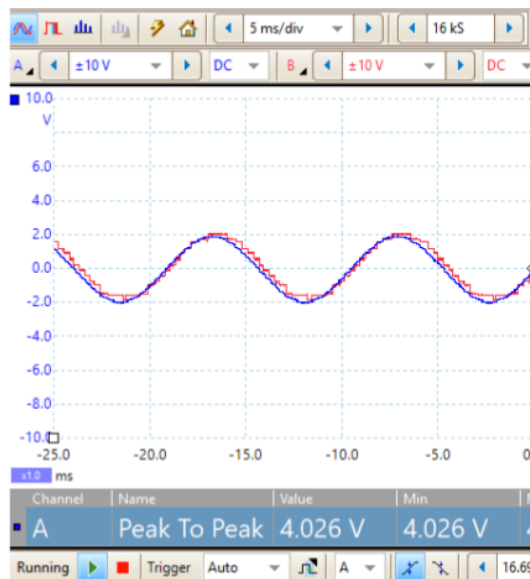


Figure 22: 4-bit resolution ADC

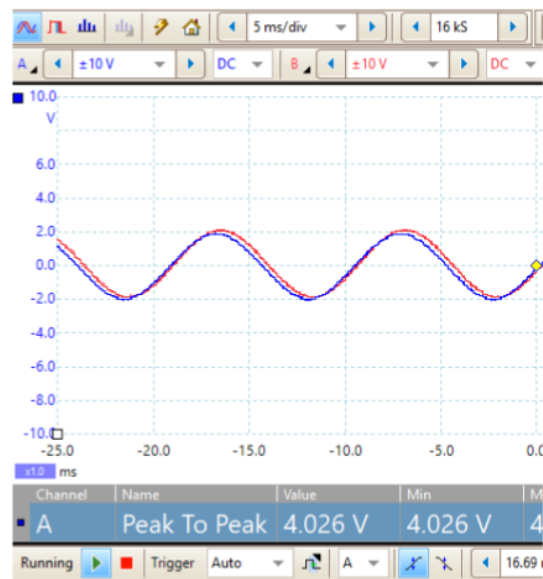


Figure 23: 8-bit resolution ADC

As shown in the above figures, the output (red) of the ADC in the higher resolution is smoother and closer to the original source (blue). This reinforces the research, that the higher the resolution of the ADC, the smoother and better the quality of the resulting output.

All ADCs have an input range, if an input signal is outside of the range of the ADC, the signal is at risk of not being encoded. When the input is then converted into digital, the peaks can be chopped off as shown in Figure 24.

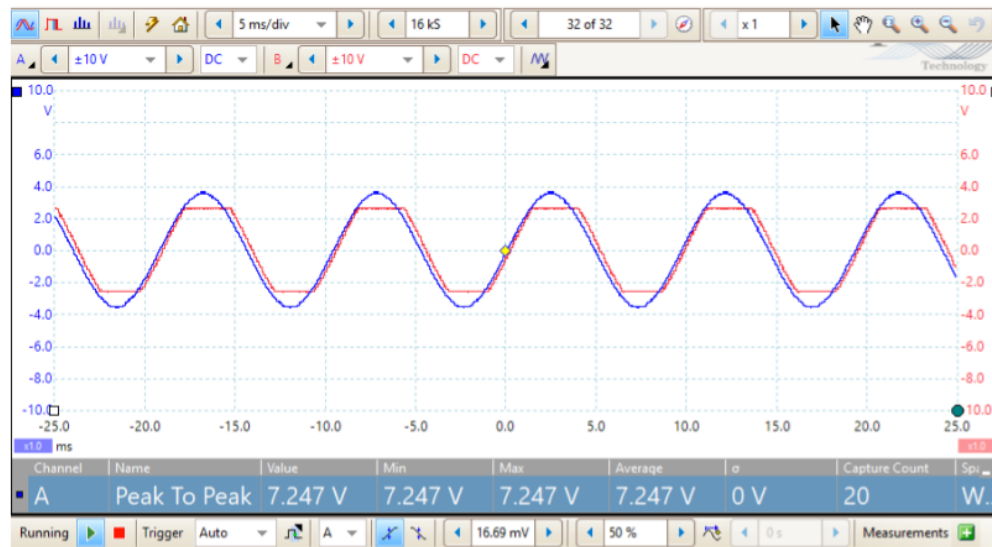


Figure 24: Result of using a signal outside of the ADCs range

To prove the Nyquist Criterion as explained earlier, a 5kHz signal was used. Following the criterion, the ADC should function correctly until half of that frequency.

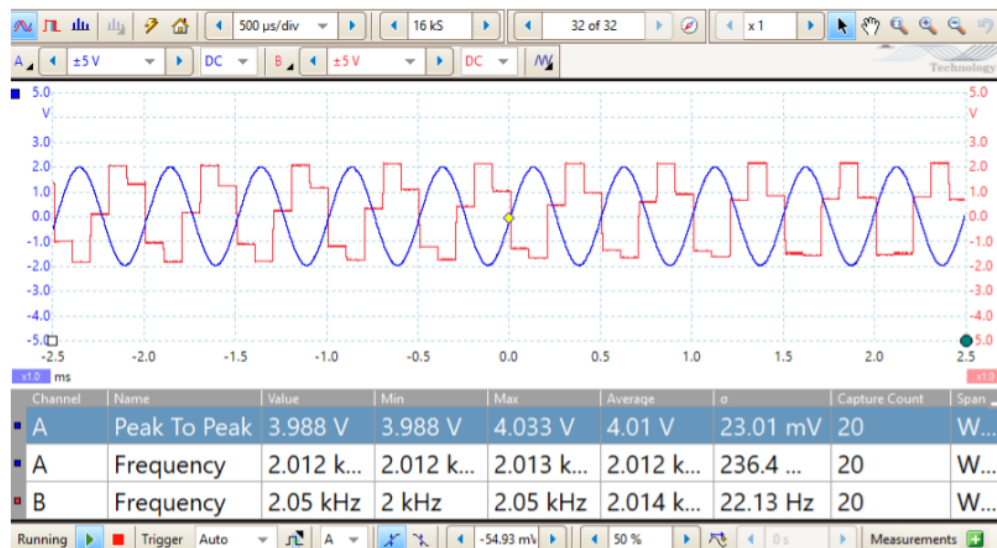


Figure 25: ADC at 2kHz

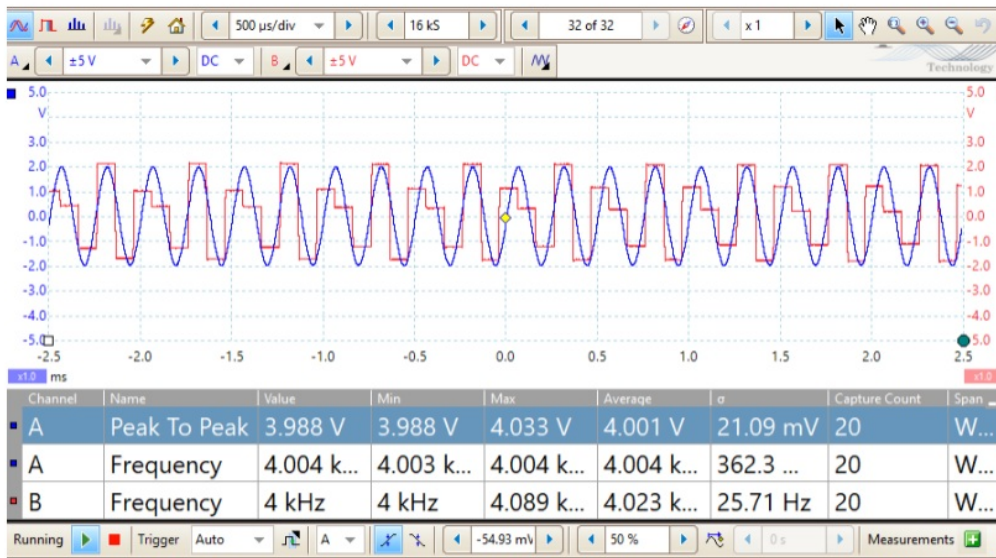


Figure 26: ADC at 4kHz

Figure 25 shows the ADC coping with the input which is more than half the sampling frequency. Figure 26 depicts that there are 2 samples per cycle compared to the 4 in Figure 25. At this frequency, the trace looks good, however, there could be aliasing happening at the output. Figure 27 has the input at 4.8kHz (96% of sampling frequency) the output of the ADC is nothing like the input. The min and max values backup that there is a lot of aliasing occurring.

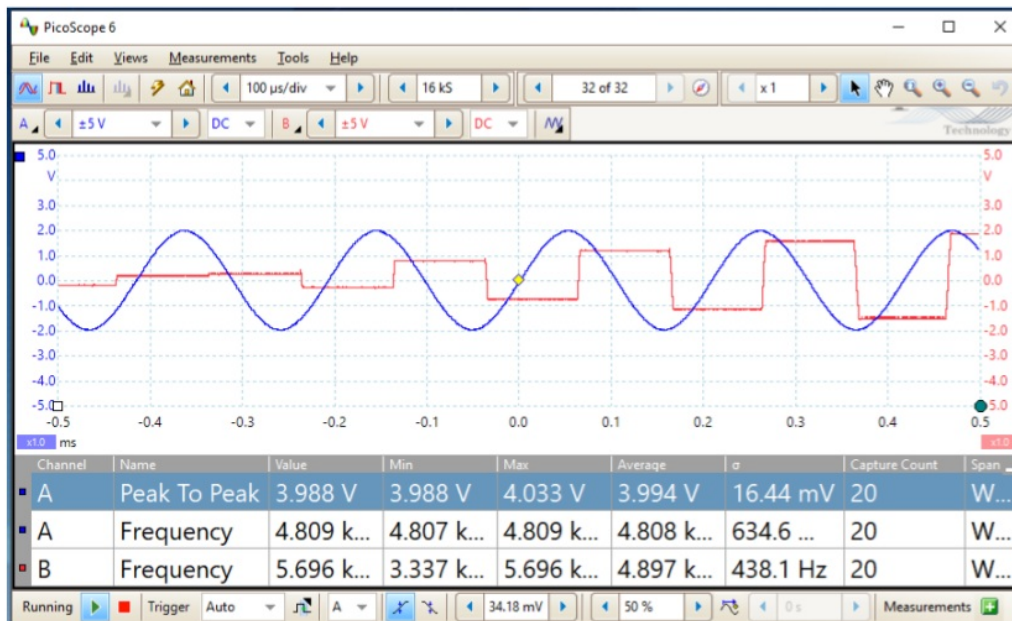


Figure 27: ADC at 4.8kHz

This is proven even more when the frequency is increased to 9kHz. Almost the double the sampling frequency and over 3.5 times what it should be according to the Nyquist Criterion.

*A table of
results
showing input
and output
frequencies,
especially
around 5khz*

5. Conclusions and recommendations

From the research and the experiments, it can be concluded that you can accurately lookup and calculate the side band frequencies of an FM signal using the Bessel table. There can be some discrepancies but this could be down to the accuracy of the equipment that has been used. The ADC experiments validates the research. As proven by the Pico scope traces in Figure 22 and Figure 23 the higher the resolution, the better the conversion was with less error.

The Nyquist Criterion was explored and was hard to prove that it needed to exactly double the sampling frequency. However, this could be down to the accuracy of the kit. When the signals did not meet the criterion by a significant value, the result was obvious.

To further develop knowledge, other methods could have been tested to investigate further amplitude modulation and pulse code modulation.

*A bit short
considering the
amount of
potential
investigation.*

6. Reference list and bibliography

References

- Ad-net, 2008. *What is SDH and what is the difference between SDH and PDH?*. [Online]
Available at: <https://www.ad-net.com.tw/what-is-sdh-and-what-is-the-difference-between-sdh-and-pdh/>
[Accessed 19th April 2020].
- 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.
- BYJU's, ND. *Pulse Amplitude Modulation Circuit*. [Online]
Available at: <https://byjus.com/physics/pulse-amplitude-modulation/>
[Accessed 17th March 2020].
- Christensson, P., 2008. *ADC Definition*. [Online]
Available at: <https://techterms.com/definition/adc>
[Accessed 29th February 2020].
- Davis, A. W., 1997. *Modulation Schemes: Moving Digital Data With Analog Signals*. [Online]
Available at: <https://www.eetimes.com/modulation-schemes-moving-digital-data-with-analog-signals/#>
[Accessed 19th March 2020].
- Donaldson, R. & Chan, D., 1969. Analysis and Subjective Evaluation of Differential Pulse-Code Modulation Voice Communication Systems. *IEEE Transactions on Communication Technology*, 17(1), pp. 10-19.
- Elprocus, ND. *Frequency Modulation and Its Applications*. [Online]
Available at: <https://www.elprocus.com/frequency-modulation-and-its-applications/>
[Accessed 29th February 2020].
- Elprocus, ND. *Quadrature Amplitude Modulation : Working Principle and Its Applications*. [Online]
Available at: <https://www.elprocus.com/quadrature-amplitude-modulation/>
[Accessed 20th March 2020].
- El-Sherif, A. & Hussein, N. M., ND. *Modern Academy for Engineering and Technology Electronics Engineering and Communication Technology Dpt*. [Online]
Available at: <http://eng.modern-academy.edu.eg/e-learning/comm/Comm2%20Lectures.pdf>
[Accessed 17th March 2020].
- Fiber Optical Networking, 2015. *The Comparison Of PDH And SDH*. [Online]
Available at: <http://www.fiber-optical-networking.com/the-comparison-of-pdh-and-sdh.html>
[Accessed 19th March 2020].
- Frenzel JR,, L. E., 2018. Chapter 8 - Cell Phones: It Is Now Possible to Do Anything Wirelessly: Talk, Text, Email, Web Browse, Games, Whatever. In: *Electronics Explained*. Austin, TX: Newnes, pp. 195-216.
- Frenzel Jr, L. E., 2018. *Electronics Explained*. 2nd ed. Austin, Tx: Elsevier Science.

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 29th February 2020].

Herres, D., 2018. *Understanding bandwidth concepts*. [Online]
Available at: <https://www.testandmeasurementtips.com/understanding-bandwidth-concepts/>
[Accessed 29th February 2020].

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 21 February 2020].

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

Kuphaldt, T. R., 2007. *Lessons In Electric Circuits -- Volume IV*. [Online]
Available at: https://www.ibiblio.org/kuphaldt/electricCircuits/Digital/DIGI_13.html
[Accessed 29th February 2020].

Library of Congress, 2010. *Sustainability of Digital Formats: Planning for Library of Congress Collections*. [Online]
Available at: <https://www.loc.gov/preservation/digital/formats/fdd/fdd000016.shtml>
[Accessed 18th March 2020].

Masood, R. F., 2013. *Adaptive Modulation (QPSK, QAM)*. [Online]
Available at: <https://arxiv.org/abs/1302.7145>
[Accessed 18th March 2020].

Maxim integrated, ND. *Glossary Definition for QPSK*. [Online]
Available at:
<https://www.maximintegrated.com/en/glossary/definitions.mvp/term/QPSK/gpk/244>
[Accessed 19th March 2020].

Parker, M., 2017. *Digital Signal Processing 101*. 2nd ed. Oxford: Bewbes.

Polytechnic Hub, 2017. *Advantages, disadvantages and application of PCM (pulse code modulation)*. [Online]
Available at: <https://www.polytechnichub.com/advantages-disadvantages-application-pcm-pulse-code-modulation/>
[Accessed 18th March 2020].

RF Wireless World, 2012. *Advantages and Disadvantages of PAM PWM PPM*. [Online]
Available at: <https://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-PAM-PWM-PPM.html>
[Accessed 17th March 2020].

RF Wireless World, 2012. *PDH vs SDH | Difference between PDH and SDH*. [Online]
Available at: <https://www.rfwireless-world.com/Terminology/PDH-vs-SDH.html>
[Accessed 19th March 2020].

Sacko, D. & Kéita, A. A., 2017. Techniques of Modulation: Pulse Amplitude Modulation, Pulse Width Modulation, Pulse Position Modulation. *International Journal of Engineering and Advanced Technology (IJEAT)*, 7(2), pp. 100-108.

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

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

[Accessed 29th February 2020].

Sheridan Eng, J. & Kocot, C., 2013. Chapter 14 - VCSEL-Based Data Links. In: *Optical Fiber Telecommunications*. Cambridge: Academic Press, pp. 501-554.

Tutorials Point, ND. *Pulse Code Modulation*. [Online]

Available at:

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

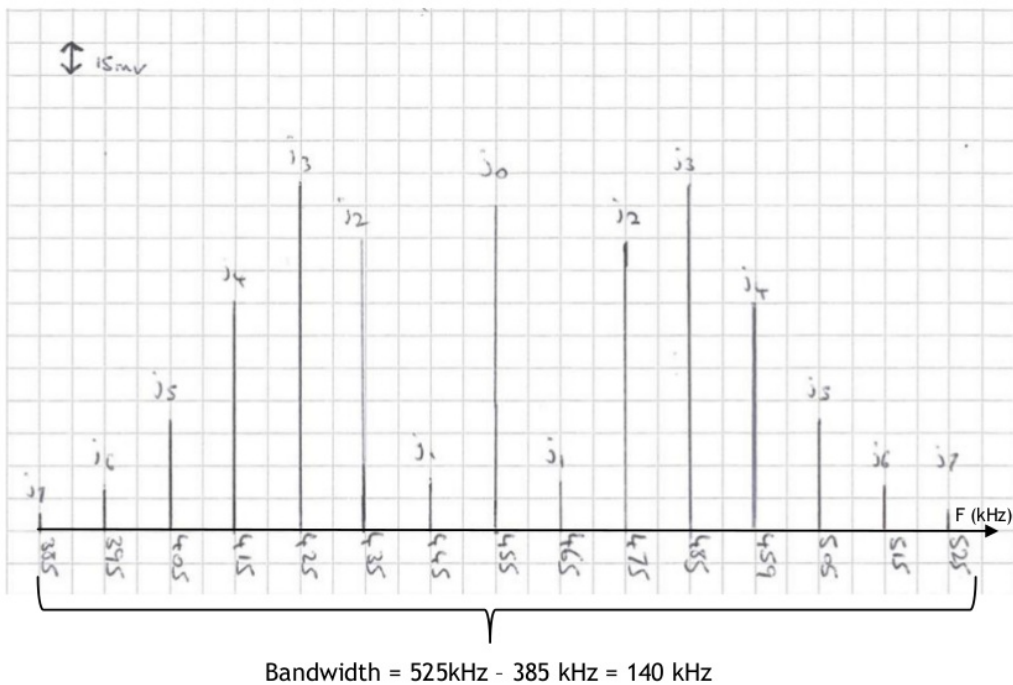
[Accessed 18th March 2020].

7. Annexe for diagrams, data sheets, results

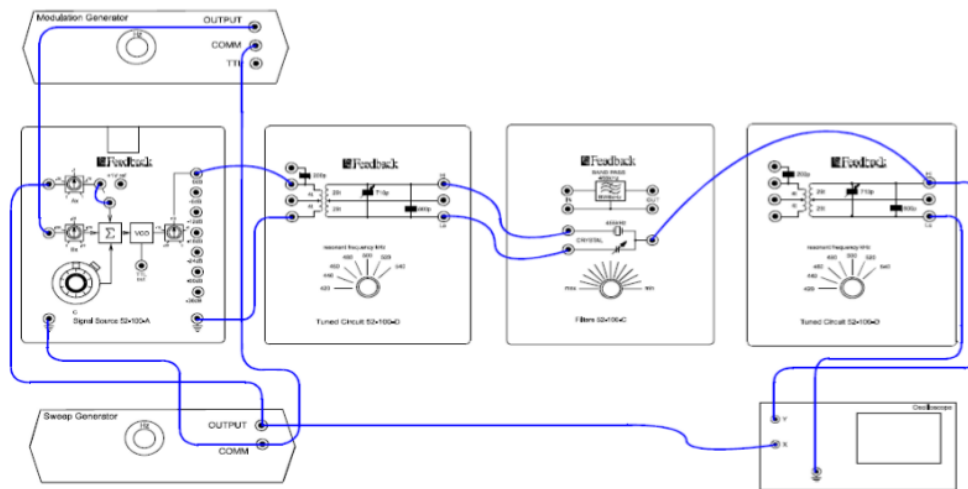
Appendix A Bessel Table

x	Bessel-function order, n															
m_f	J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9	J_{10}	J_{11}	J_{12}	J_{13}	J_{14}	J_{15}
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	—	—	—	—	—	—	—

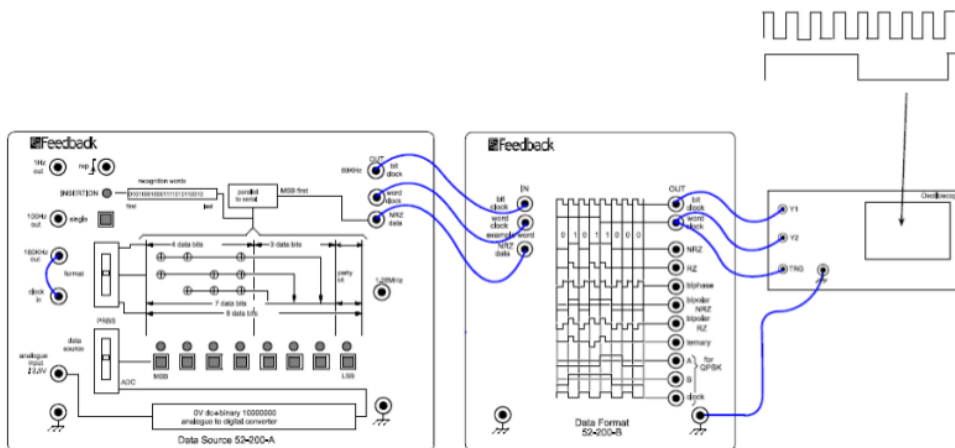
Appendix B



Appendix C



Appendix D



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

Text Comment. The last 2 paragraphs aren't required, and you need to cover the results and main conclusions.

PAGE 5

PAGE 6

PAGE 7

PAGE 8

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PAGE 12

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PAGE 17

PAGE 18

PAGE 19

PAGE 20

Text Comment. A very good set of results

Text Comment. Zoom in to show the jaggedies more clearly

PAGE 21

PAGE 22

PAGE 23

Text Comment. A table of results showing input and output frequencies, especially around 5khz

PAGE 24

Text Comment. A bit short considering the amount of potential investigation.

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

GRADING FORM: CSG-RUBIC

JONATHON
WILLIAMS

0

RESEARCH-INFORMED LITERATURE



There was evidence of extensive further reading and research from credible and reliable sources. Your interpretation and understanding of the additional research was very good and demonstrated a deep underlying appreciation of the subject. Your references were consistently applied and appropriate to the task and your reference list was of an appropriate length for this assignment.

8/10

KNOWLEDGE AND UNDERSTANDING



The knowledge and understanding of the subject demonstrated by this assignment was reasonably extensive. There were very few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was demonstrated to a limited degree. You have demonstrated some critical understanding of the main concepts and expanded your knowledge beyond that contained in the course notes, however your explanations need to be more detailed and written with a greater emphasis on critical evaluation rather than description.

21/30

ANALYSIS



Your analysis of the task was generally satisfactory, both in class and as shown in this assignment, however it did tend more towards descriptive rather than analytical. You have demonstrated some

15/30

analytical skills and your approach to the task was logical. You wrote a short conclusion that demonstrated some skills in analysing quantitative and qualitative data, however this was generally basic in nature. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory and provide a detailed critical analysis of this.

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally very good. You used the resources appropriately and you used appropriate options for testing and evaluating the circuit performance. You managed to design an effective circuit that 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.

15/20

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was written in a professional and confident style, however you still need to be more efficient with your word count. The report was very well presented, with excellent diagrams in appropriate places, good sentence/paragraph structure and clear calculations.

7/10