

2117076 AL

by Aaron Lupton

Submission date: 29-Feb-2024 11:37AM (UTC+0000)

Submission ID: 225364417

File name: 17892_Aaron_Lupton_2117076_AL_183166_33693749.pdf (3.52M)

Word count: 2726

Character count: 17466

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University Number: 2117076

Module Code: SGEE5005

Assignment Title: Signals and Modulation

Date Submitted: 29nd February 2024

Word Count: 2491

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Executive Summary

The aim of this project is to support the research that is undertaken into signal modulation, in analogue and digital systems. Research was used to investigate the various types of modulation techniques that are available and then are used to compare against each other. The findings from the research can then be used within the project to help obtain better results.

The project was carried out in a classroom-based setting using calibrated equipment and that the project was split into two main areas, the first one being analogue communication systems and the second, digital communication systems. The analogue communication was based on frequency modulation. Once the calculations were found, a signal source, a modulation generator and a power supply with a Pico scope were then used to input and test the calculated and practical values.

The digital was based around Analogue to digital Converters, with the main focus on the 4 bit and 8-bit converters. Within the research the importance of the ADC range was investigated, and how the Nyquist Criterion will affect the sampling rate within the system. The output wave forms for both the 4 bit and 8-bit converters were compared and the recordings were investigated against one another.

1. – Planning and reflection

This assignment's purpose is to research and understand the frequency modulation and analogue digital converter and how they are used to get accurate and consistent results. These types of systems are used in the electrical work place. The research found will then better my knowledge when it comes to carrying out the practical tests. All the work completed will be carried out in G9 in Coleg Sir Gar. How to analyse, evaluate and test the ADC and modulation using Multisim has been understood and completed. Also, when changing certain parameters within the tests will affect the results. When working as a team, all genders and religious beliefs will be respected.

2. Research

2.1 - Experiment 1 – Frequency and Amplitude Modulation

Frequency Modulation (FM) is the process of which the information is extracted from a message source (Carrier wave) in order to maximise the efficiency for transporting data from one place to another. This is done by changing the frequency of the wave. Frequency

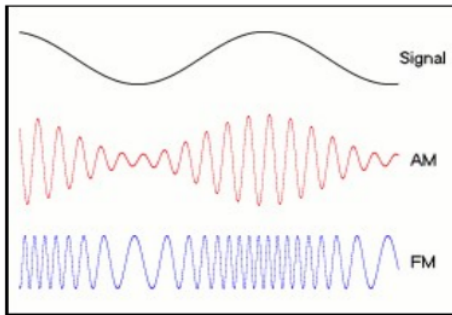


Figure 1 Frequency Modulation (FM)

Modulation is vital due to its skill to reduce noise and improve the quality of the radio reception, the amplitude of the carrier is kept constant but the frequency of the wave will change (Modulation, 2022). Amplitude Modulation and frequency modulation both transmit data using the method of a modified carrier wave, but the main difference between

the both is that the FM; the carrier wave frequency is changed as per the transmit data, whereas in the AM the carrier wave is modified according to the data (ByJu's, 2019). In Amplitude modulation, only the amplitude of the carrier wave is changed, being reliant on the intensity of the signal, but the frequency of the modulated wave will stay constant. (Heavy.AI, 2022) The modulation factor is determined by:

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

Figure 2 Equation for modulation factor

The modulation factor is vital as it will determine the strength and the quality of the transmitted signal. (Radio.Academy, 2022)

Difference Between AM and FM	
Amplitude Modulation (AM)	Frequency Modulation (FM)
The first successful audio transmission was carried out in the mid-1870s	Developed in 1930 by Edwin Armstrong, in the United States
The radio wave is called a carrier wave, and the frequency and phase remain the same	The radio wave is called a carrier wave, but the amplitude and phase remain the same
Has poor sound quality, but can transmit longer distance	Has higher bandwidth with better sound quality
The frequency range of AM radio varies from 535 to 1705 kHz	The frequency range of FM is 88 to 108 MHz in the higher spectrum
More susceptible to noise	Less susceptible to noise

Figure 3 Difference Between FM and AM

Frequency Modulation		Amplitude Modulation	
Advantages	Disadvantages	Advantages	Disadvantages
1. Improved signal to noise ratio to man made interference.	1. FM cannot cover large areas.	1. The cost of amplitude modulation is low.	1. It requires more than twice the amplitude frequency to modulate the signal with a carrier
2. Smaller geographical interference between neighboring stations.	2. Transmitting and receiving equipment of frequency modulation is complex and expensive.	2. Amplitude modulated signals are reflected by the earth from the ionosphere layer.	2. The efficiency of such a system is very low as it consumes a lot of power for modulations and this causes a considerable operational cost.
3. Less radiated power.	3. Generally, wider channels, 200kHz, are required for FM.	3. They are able to travel a long distance and cover a wider area.	
4. Well defined service areas for given transmitter power.	4. The antennas for FM need to be closely placed for better signals.	4. Required carrier frequency is low.	
		5. It requires a simple transmitter and receiver.	

Figure 5 Advantages + Disadvantages of FM

Figure 5 Advantages + Disadvantages of AM

2.2 - [Experiment 2 – Analogue to Digital Conversion](#)

An ADC (analogue to digital conversion) is the electronic process that converts a continuous analogue input signal to digital binary numbers. (Circuits, 2021)



Figure 6 ADC

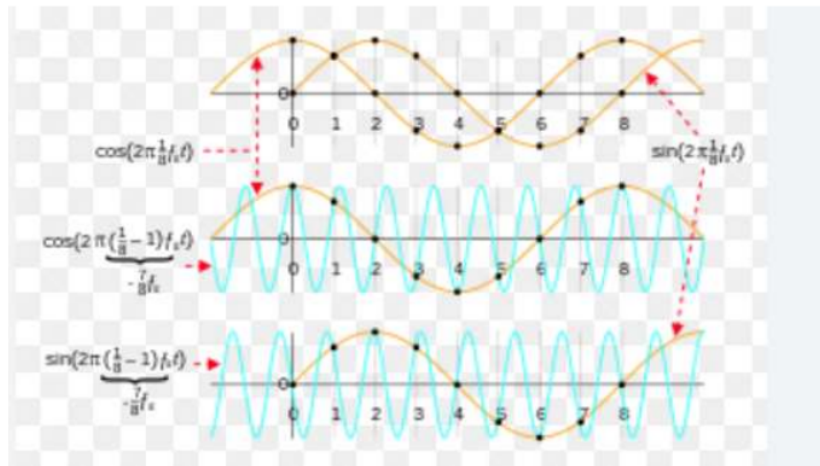
ADCs are vital due to the microcontrollers storing information using digital logic. They are able to compress the information to digital form for efficient storage creating a much more reliable transfer of data and can be easily reproduced. ADCs also provide a link between real world signals and data storage. When choosing an ADC there are a few characterises that need to be met; Bandwidth, numbers of channels required, temperature stability, power consumption, resolution and the Sampling rate. (Atlas, 2023)

[Sampling Rate and Nyquist Criterion](#)

The sampling rate of an ADC refers to the number of samples it takes per second. The signals should be sampled with at least twice the bandwidth of the signal to prevent any loss of data (ADC, 2019). "Nyquist criterion states that a repetitive waveform can be correctly reconstructed provided that the sampling frequency is greater than double the highest frequency that needs to be sampled." (Criterion, Febuary).

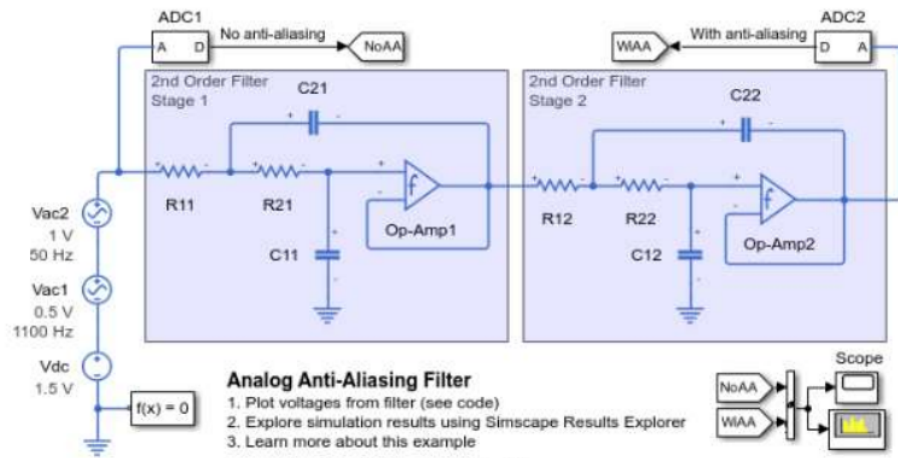
Aliasing

Aliasing occurs when an oscilloscope does not sample the signal fast enough to construct an accurate waveform record. The signal frequency is mis-interpreted, and the waveforms displayed on an oscilloscope become unreadable. Aliasing is basically a form of under sampling. (Tektronix, 2020)



The recall sampling theorem should be; **$f_s > 2f_{max}$**

Aliasing is generally avoided by applying low pass-pass filter or anti-aliasing filters (AAF) to the input signal before sampling and when converting a signal from a higher to a lower sampling. It is needed to filter out the frequencies that are above the Nyquist frequency before you sample the signal. (ScienceDirect, 2021) The frequencies in the signal that are higher than the Nyquist frequency cannot be distinguished from the lower ones, and they appear as false or aliased frequencies in the sampled signal. This can lead to unwanted noise and errors in your signal processing.



3. Method/Results

3.1 - Experiment 1 – Frequency Modulation

The values for the test are shown below in the table.

	Symbol	Values
Frequency Carrier	Fc	455KHz
Carrier Amplitude	Ec	375mA
Frequency of Message	Fm	10KHz
Amplitude of the Message	Em	2V

The calculation for the maximum frequency deviation;

$$\Delta f_c = E_m \times (f_m \times E_m) = 2 \times (10 \times 10^3 \times 2) = 40 \text{ KHz}$$

The maximum and minimum frequency and modulation index calculations are below.

$$f_{\max} = f_c + \Delta f_c = 455 \text{ KHz} + 40 \text{ KHz} = 495 \text{ KHz}$$

$$f_{\min} = f_c - \Delta f_c = 455 \text{ KHz} - 40 \text{ KHz} = 415 \text{ KHz}$$

$$\beta = \frac{\Delta f_c}{f_m} = \frac{40 \text{ KHz}}{10 \text{ KHz}} = 4$$

Using the Bessel table below to calculate the amplitude values.

Bessel Function Table1

Modulation index	Sideband																
	Carrier	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
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									

Figure 7 Bessel Table

Below are the eight coefficients that have been calculated using the Bessel table.

$$j_0 = 375 \times 10^{-3} \times 0.40 = -0.15$$

$$j_1 = 375 \times 10^{-3} \times 0.07 = 0.0263$$

$$j_2 = 375 \times 10^{-3} \times 0.36 = 0.135$$

$$j_3 = 375 \times 10^{-3} \times 0.43 = 0.161$$

$$j_4 = 375 \times 10^{-3} \times 0.28 = 0.105$$

$$j_5 = 375 \times 10^{-3} \times 0.13 = 0.049$$

$$j_6 = 375 \times 10^{-3} \times 0.05 = 0.019$$

$$j_7 = 375 \times 10^{-3} \times 0.02 = 0.008$$

Now, it is possible to calculate the bandwidth using the equation;

$$BW = (\text{Frequency Amplitude values} \times 2) \times F_m = (7 \times 2) \times 10 \text{ KHz} = 140 \text{ KHz}$$

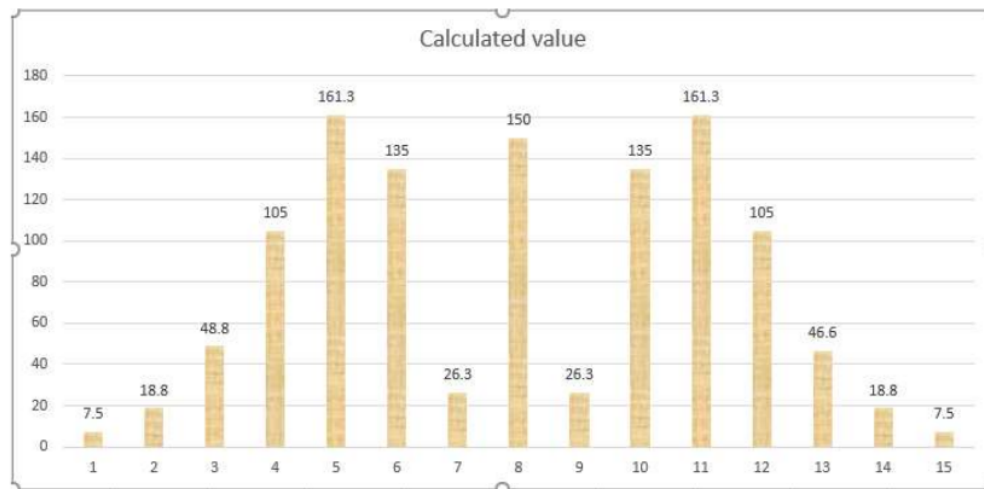


Figure 8 Frequency Spectrum

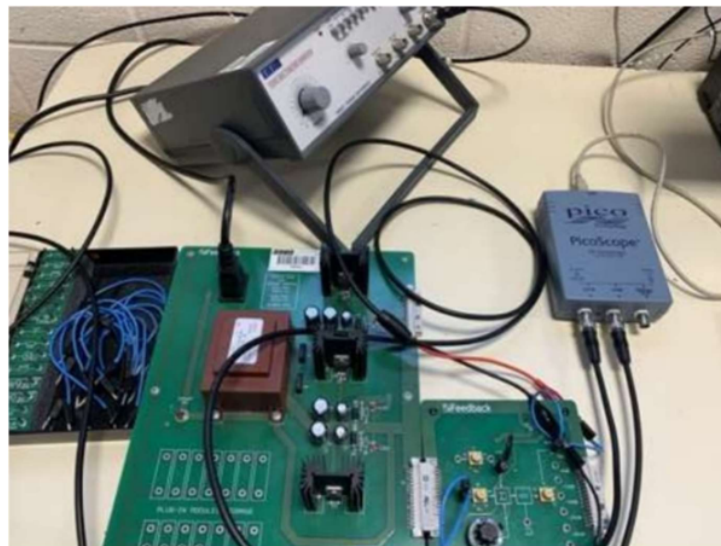


Figure 9 Equipment used for completing the FM Test

2-volt peak to peak, 10Khz message is shown below

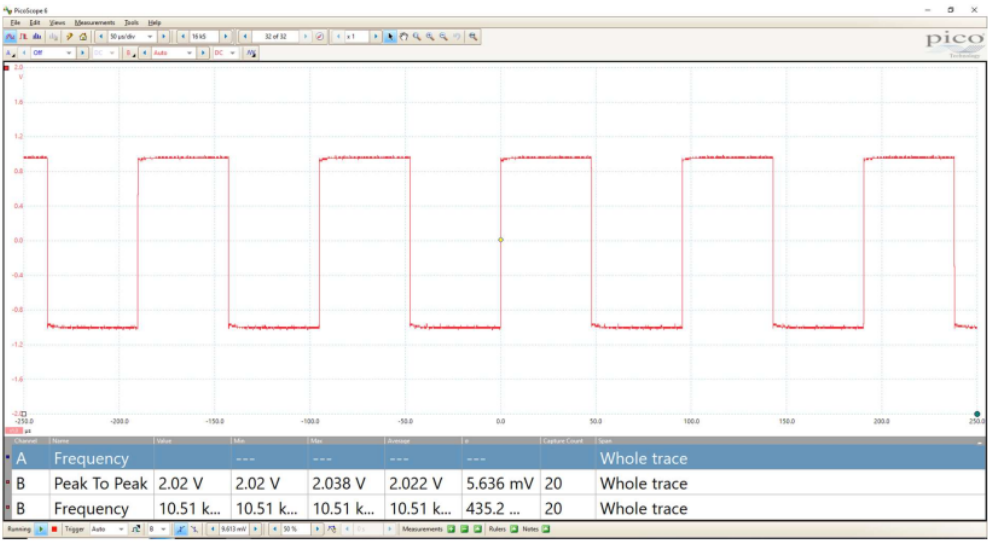


Figure 10 Frequency modulation test

The carrier wave centre frequency of 455Khz, but as mentioned with the deviation included.

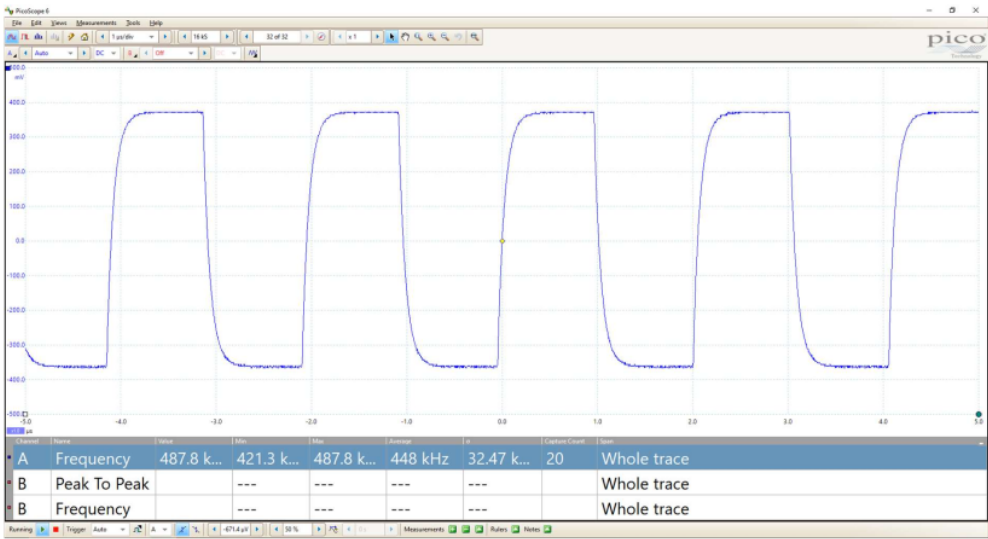


Figure 11 Frequency Modulation Carrier Wave

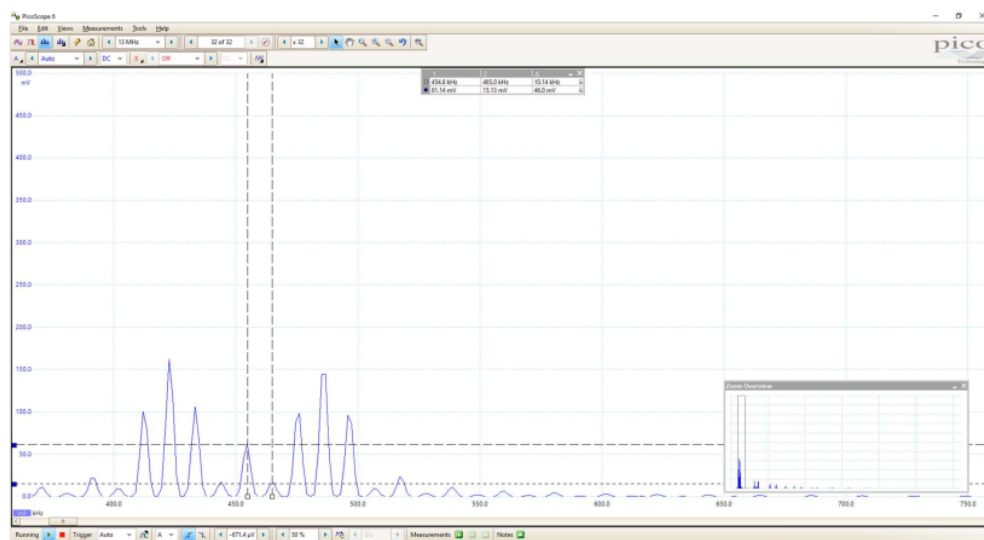


Figure 12 Frequency Spectrum

1	2	Δ	
454.8 kHz	465.0 kHz	10.14 kHz	
61.14 mV	15.13 mV	46.0 mV	

Figure 13 Frequency Spectrum results

3.2 - Experiment 2 – Analogue-Digital Conversion

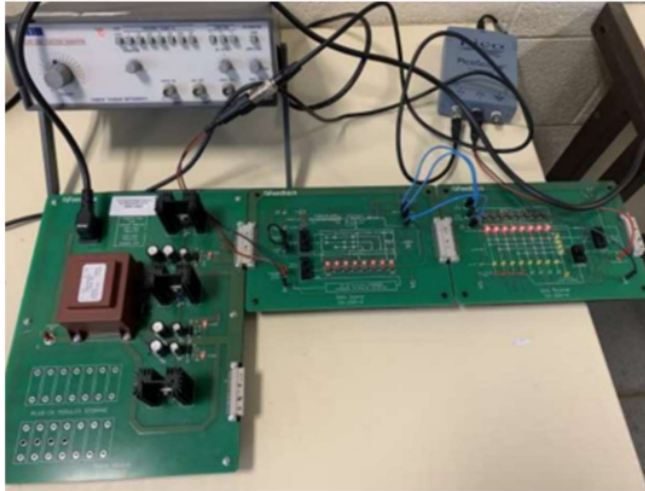


Figure 14 Analogue Digital Converter test setup

This test board includes the ADC set up which can vary from the 4-bit converter to an 8-bit converter and this conversation can be seen through the Pico scope. This test will identify the differences between the 4-bit and 8-bit converter and it is vital that the amplitude of the input signal to the range of the ADC. The test board has a sample rate of 10,000 samples per second with a range of 5Vp-p. By carrying out this test it will also show the relationship between the input frequency and the ADC Sample rate and be able to prove the Nyquist Criterion theory.

The figures below display the differences between the 4-bit converter and the 8-bit converter, with an input frequency of 100Hz and peak to peak voltage at 4V.

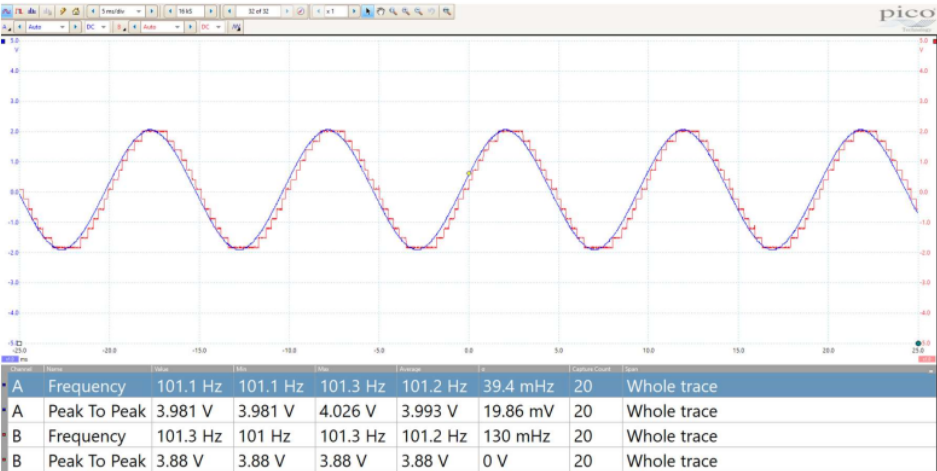


Figure 15 4-Bit ADC

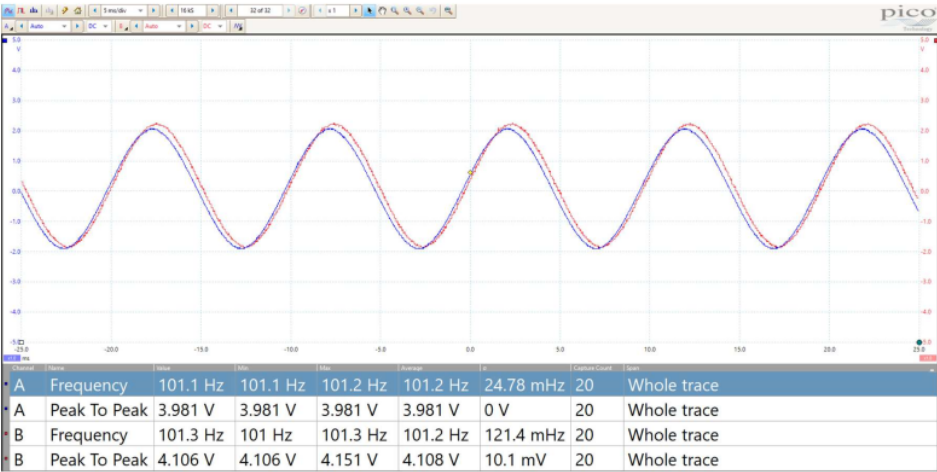


Figure 16 8-bit Converter

Both images above show the 4-bit converter and the 8-bit converters waveform. Both waveforms are a sinewave which is showing the input signal. As you can see from the 4-bit converter the wave form it follows is a bit distorted whereas the 8-bit converter is much more accurate and is following the trend better.

Below are images that show the effect of changing the input amplitude 100Hz from 4V peak to peak to peak to 6V peak to peak. Both tested were completed in increments of 2V peak to peak. As shown below some of the differences can be seen, with some errors in the Pico scope.

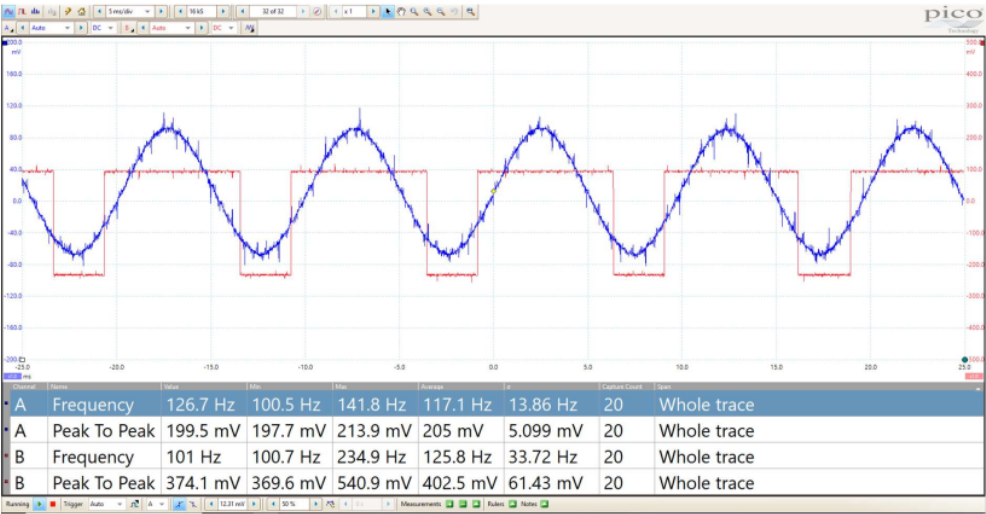


Figure 17 4-bit converter peak to peak amplitude

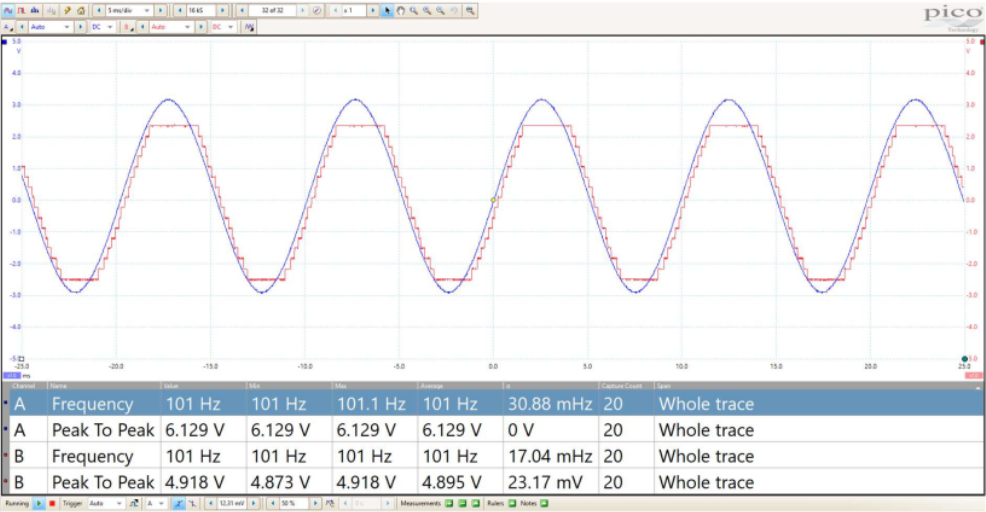


Figure 18 4-bit converter bottoming out

As you can see in figure 18, it shows the 4-bit converter “bottoming out” as the ADC’s range has been reached (0.5V).

The figures below show the effect of changing the input amplitude, 100KHz from 4V peak to peak to 6V peak to peak. The test was completed by increasing the voltage by increments of 2V. Using an 8-bit converter. Again with some errors using the Pico Scope it shows some discrepancies within the system.

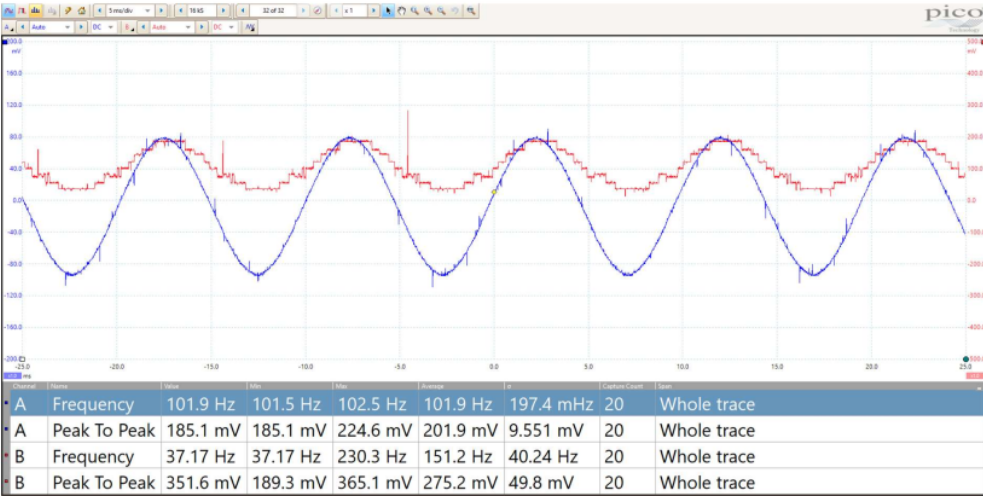


Figure 19 8-bit 4V peak to peak amplitude

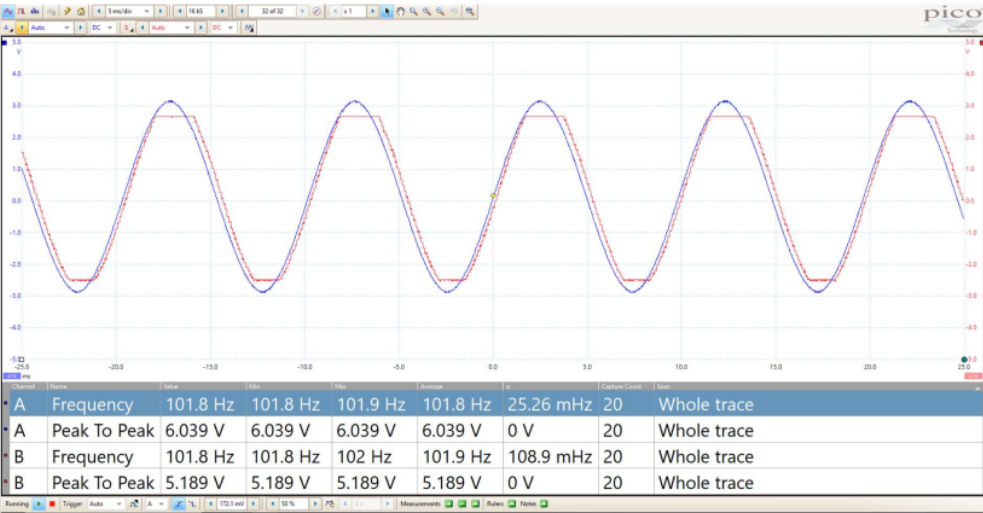


Figure 20 8-bit converter bottoming out

The tables above show that the ADC’s range has been exceeded, similarly to the 4-bit converter results as the input reaches 6V. Even though the ADC’s range has been reached, every sample within the range has been accurate. The results from the over range testing show that the signal amplitude is increased and that the equipment isn’t suited for this test. If a different ADC was chosen to suit the investigation, the results found would be better as it will not bottom out.

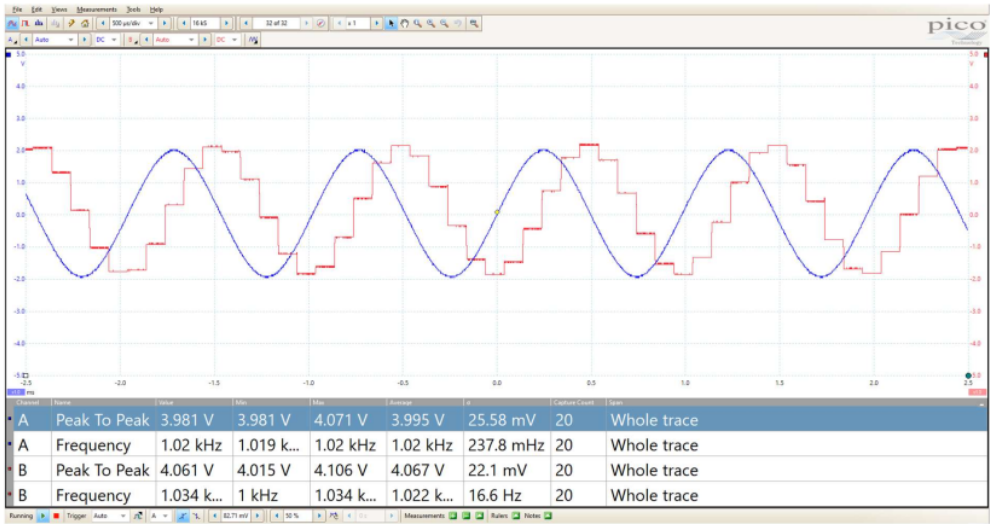


Figure 21 Effects on changing the input frequency in 1KHz at 1KHz

This test shows the relationship between the input signal and the signals frequencies, and how the sampling rate of the ADC is crucial.

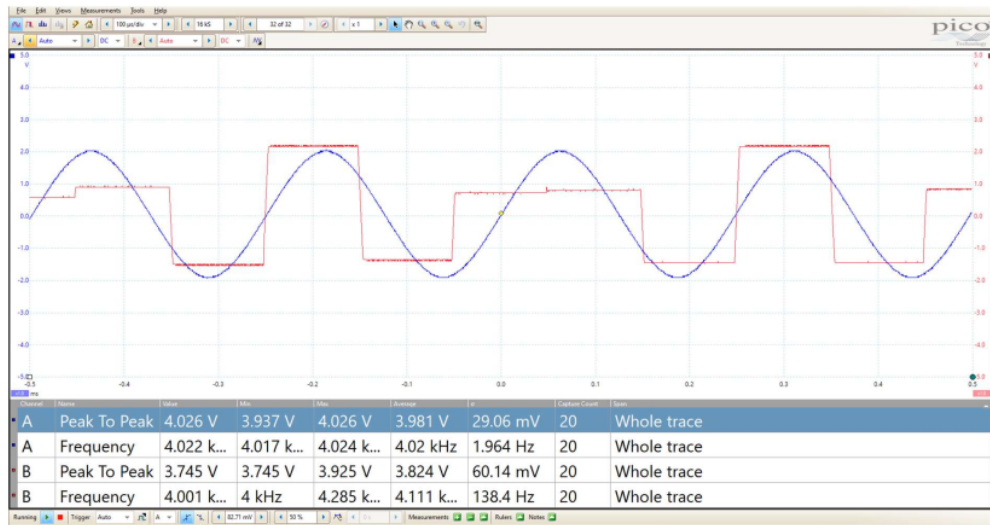


Figure 22 The effects on changing the input frequency in 1KHz at 4KHz

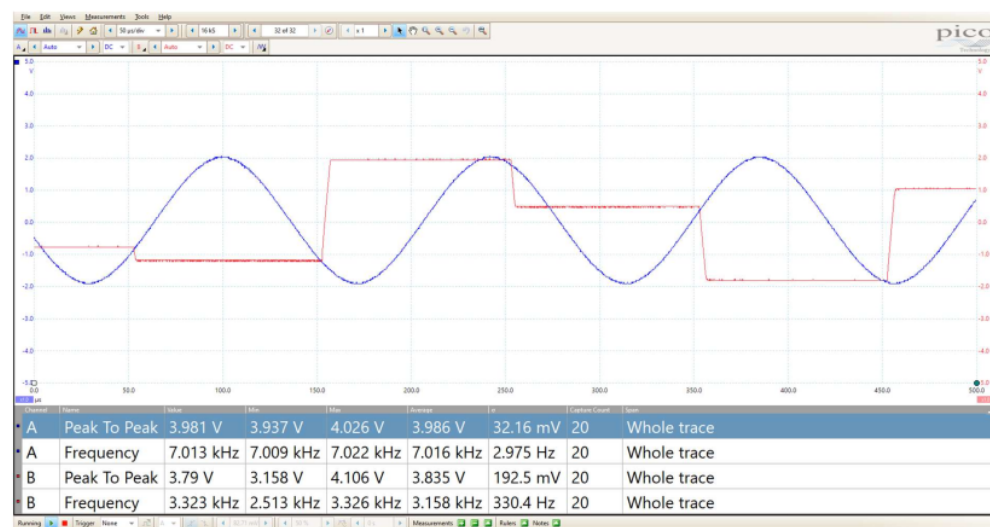


Figure 23 Effect of changing the input frequency in 1kHz at 7KHz

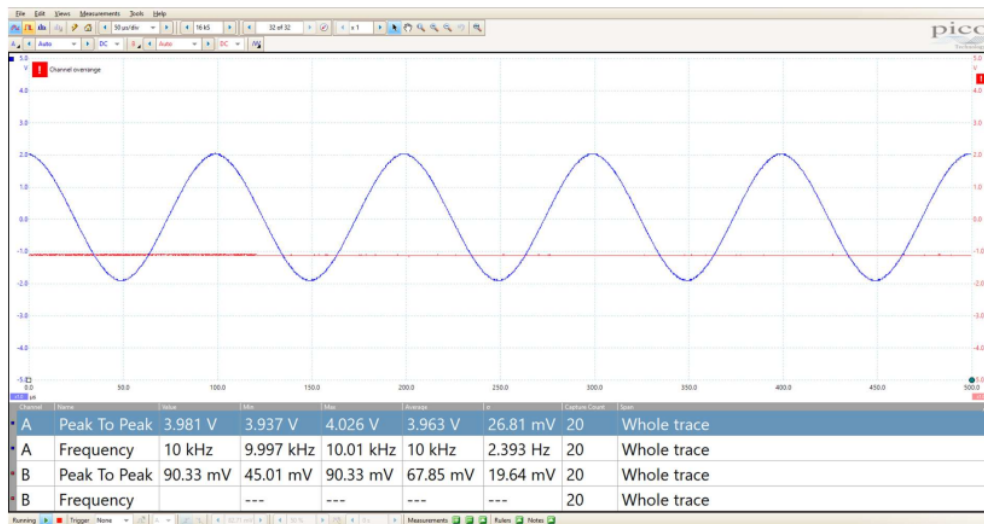


Figure 24 The effects of changing the input frequency in 1KHz at 10Khz

From figure 21 to 24, it shows how the effect on changing the input frequency will have on the sampling rate for the ADC Converter.

4. Analysis

4.1 - Experiment 1 – Frequency Modulation

Analysing the results from the test procedure, the readings from the FM match the frequency spectrum, however there are slight differences with the amplitude in test one. In test one the JO's amplitude level was 61.14mV, and with the calculated values at 150mV. Even though that the amplitude levels do not correspond to each other, they still follow the same trend. The bandwidth of the test is correct and the results from the calculated and simulated match, with the spacings between follows the theory of succeeding the frequency message (10KHz).

4.2 - Experiment 2 – Analogue Digital Conversion

Within the ADC test, it was found that there were some differences between the both results. The relationship between the input signals and the sampling rate is vital to ensure that you don't come across aliasing. The input frequency should be at least double the highest frequency obtained. The testing was taken at 1KHz increments starting from 100Hz to 10KHz. At first, it shows the sampling rate at 100Hz was accurate, but as the test moved towards the 10KHz that is when the discrepancies occurred.

5. Conclusion and recommendations

From carrying out the research it is clear to see that the modulation of frequency is the most effective option as it has less interference within the system. Even though AM is the cheaper option, it is less accurate and can pick up disturbances.

During the FM practical testing, by changing the frequency of the message, the distance between the amplitude values on the frequency spectrum also changes which is proportional in relationship. As well as changing the frequency of the message the deviation frequency will also change. The amplitude then will determine how much the deviation will move. The higher the modulation Index, the increase in modulation values which will result in a higher bandwidth. All of the practical tests carried out were successful, but the only error that was found was within the ADC itself. To ensure that the results can be finely tuned, a change in the ADC could help.

The Analogue to Digital Converter testing was deemed successful as the results from the practical and theoretical results matched even though some of the testing results had some slight differences. Within the testing, it was noted that depending on the resolution of the ADC, it has a knock-on effect in regards to the sine wave. The increase in resolution means a better sine wave produced. The sampling rate also needs to be taken in to consideration with an ADC. The input frequency should be at least double the largest frequency obtained otherwise aliasing could occur.

6. Citation List

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FINAL GRADE

GENERAL COMMENTS

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AARON LUPTON

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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 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.

7

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.

20

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 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.

14

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally good. You used the resources available appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance. You managed to design an efficient circuit that functioned within the specification and achieved this by only asking for assistance when appropriate. Your results were comprehensive and allowed for a good conclusion to be attempted.

SKILLS FOR PROFESSIONAL PRAC.



Your written report was generally well written in a coherent and fluent manner that contained most of the required detail, although it lacked the depth of explanation required in places. You need to be more selective with where you put diagrams and graphs, only put those essential for the explanation in the report, the rest can be referred to in the appendix.