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1. Research

For both methods of modulation these are the components seen below that are needed to do so.

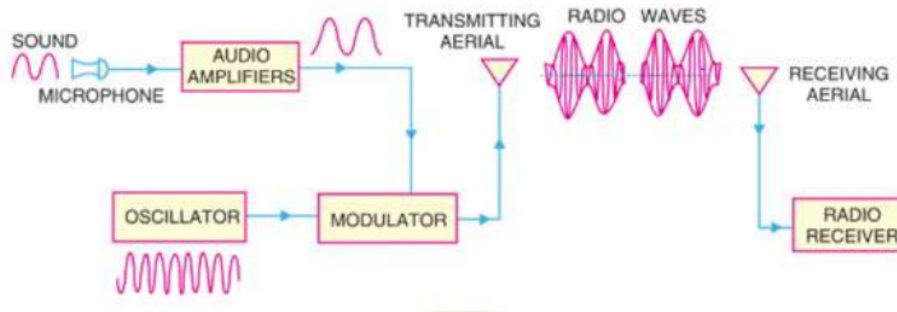


Figure 1 Modulation components

(ROHM, 2020)

Amplitude modulation

Amplitude modulation (AM) to change the amplitude of the carrier, the power level or the voltage of the message is increased or decreased. Throughout this process the frequency of the carrier keep constant. Without any modulation the carrier wave is transmitted by itself, when a sine wave of the message is applied it then increases and decreases in accordance to the message. These principles can be seen in the figure below. (direct, 2021)

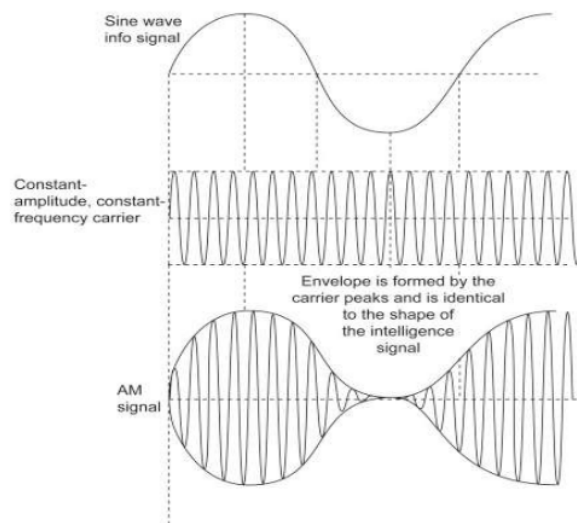


Figure 2 Amplitude modulation

(direct, 2021)

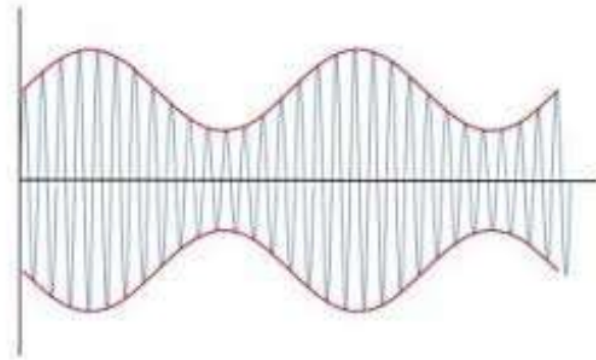


Figure 3 AM with 100% modulation

(academy, 2023)

AM is the cheapest option of two modulation options. From using lower carrier frequencies, AM is able to transmit audio signals over long distances. There are some disadvantages to this method, as there could be noise on the amplitude, this can modulate the signal, which is interference. (academy, 2023)

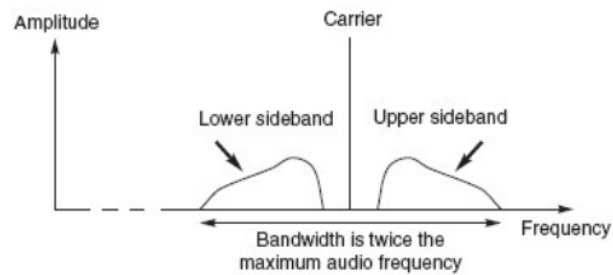


Figure 4 Sideband

(EDN, 2022)

When at 100% modulation. There are two sidebands either side of the carrier. These sidebands can absorb 35% of the power. (EDN, 2022)

Amplitude Modulation	
Disadvantage	Advantage
The use of bandwidth is inefficient	The method is cheap
Detectors can pick up noise interference	The form is straightforward
The power consumption is inefficient	The circuit is simple to build

(academy, 2021)

Frequency modulation

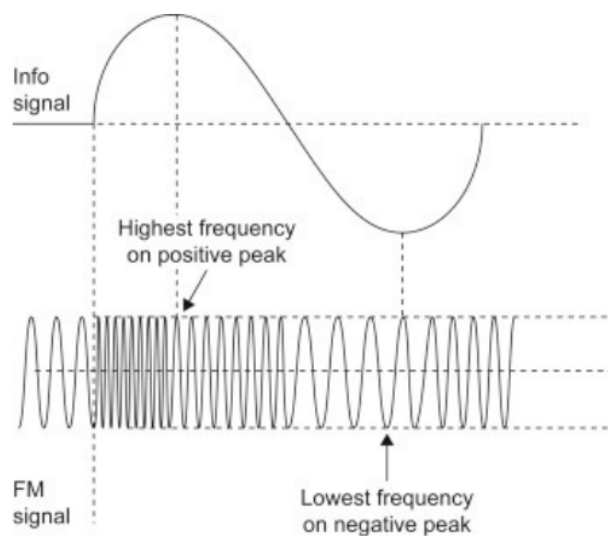


Figure 5 Frequency modulation

(ByJus, 2023)

The method of frequency modulation uses a carrier wave similarly to AM but uses the frequency of the carrier for the information of the incoming signal. As this was modulated by the transmitter, in line with the incoming signal, the carrier wave's frequency increases and decreases. (notes, 2023) Depending on the deviation, this signal depends on this. The maximum deviation signifies the maximum distance the FM wave can be from the initial frequency. Frequency modulation has a higher efficiency, because the modulation index is directed by which signal can be modulated, which can be bigger. However, there is a compromise between performance and efficiency, as from increasing the level of modulation. This in turn increases bandwidth. Where signal levels can vary such as in mobile applications, the frequency modulation method has a resilience to static/ interference. (IOP, 2023)

Frequency modulation	
Disadvantage	Advantage
The demodulator can be more complex than amplitude modulation	The transmitter modulation can be employed at a lower stage
Filters are often needed	Can deal with noise better than AM
Spectral efficiency can be lower differently to other forms	Able to use nonlinear amplifiers

(Petervis, 2023)

Comparison	
AM	FM
Uses a sine wave, but amplitude changes and frequency are persistent	Uses a sine wave, but frequency changes and amplitude are persistent
Operates at 450-1750 MHz	Operates at 75-110 MHz
Can be prone to noise	Can deal with noise better.

(wireless, 2023)

Analogue to digital converters

The variables related to the ADCs quality are sampling frequency, resolution (samples per second), Analogue to digital convertors exist in different simple architecture, however many variations exist for each variation. Different ADCs are needed for different types of test equipment. An example for this is an oscilloscope., it needs high digitising speeds but can sacrifices resolution. Some PCS's plug in digitisers is a bit slower but provides better resolution. (DEWE, 2023)

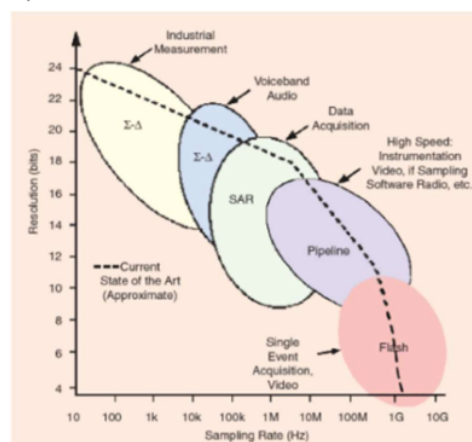


Figure 7 ADC comparison chart

The figure above shows the ADC comparison chart. It shows the relationship between the sampling rate on the X axis and resolution on the Y axis. It is clear to see from the chart that there is an overlap between architecture of ADCs. This indicates their relevance for several applications. Nonetheless, to select the most appropriate ADC the key factor such as required resolution and sampling frequency are important. (Arrow, 2022)

According to (Spectrum, 2023) , "Digitizers convert the samples of an analogue signal into digital values using analogue to digital converters (ADCs). The resolution of the ADC is the number of bits it uses to digitize the input samples. For an n bit ADC, the number of discrete digital levels that can be produced is 2^n . Thus, a 12-bit digitizer can resolve 2^{12} or 4096 levels. The least significant bit represents the smallest interval that can be detected and in the case of a 12 bit digitizer is $1/4096$ or 2.4×10^{-4} ." The higher resolution used the more accurate the ADC is; however, this compromises the processing power. This may conclude in slowing down the ADC and cause interference. When considering which ADC resolution to select, a consideration into how much processing power is available is needed.

Resolution	Ideal Dynamic range	Minimum Voltage Increment
8 Bit	256:1	3.92 mV
10 Bit	1024:1	0.98 mV
12 Bit	4096:1	0.244 mV
14 Bit	16384:1	61 μ V
16 Bit	65536:1	15 μ V

Figure 8 ADC resolution steps

2. Planning and Reflection

The assignment's purpose is to research and identify methods of modulation and analogue to digital converters and understand them. These systems are typically used in modern manufacturing industries. There will be multiple tests taken. The system is in Coleg Sir Gar will be researched and modified; this is in room G8 in the college. When working as a team, all genders and ethnicities will be respected. How to evaluate, design, implement and test ADCs and modulation using Multisim has been understood after conducting the assignment. And the effect of changing certain parameters will affect the characteristic of the adc.

3. Experiment 1 Method - Frequency Modulation

Test 1

The values given for the assignment are below.

Frequency modulation		
	Symbol	Value
Frequency carrier	Fc	455 KHz
Carrier amplitude	Ec	375 mA
Frequency of message	Fm	10 KHz
Amplitude of the message	Em	2V

The calculation for maximum frequency deviation is below.

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

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

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

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

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

The coefficients from the Bessel table below are used 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 9 Bessel table

The eight coefficients have been taken from modulation index 4.

$$j0 = 375 \times 10^{-3} \times -0.40 = -0.15$$

$$j1 = 375 \times 10^{-3} \times 0.07 = 0.0263$$

$$j2 = 375 \times 10^{-3} \times 0.36 = 0.135$$

$$j3 = 375 \times 10^{-3} \times 0.43 = 0.161$$

$$j4 = 375 \times 10^{-3} \times 0.28 = 0.105$$

$$j5 = 375 \times 10^{-3} \times 0.13 = 0.049$$

$$j6 = 375 \times 10^{-3} \times 0.05 = 0.019$$

$$j7 = 375 \times 10^{-3} \times 0.02 = 0.008$$

Below is the calculation for the bandwidth.

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

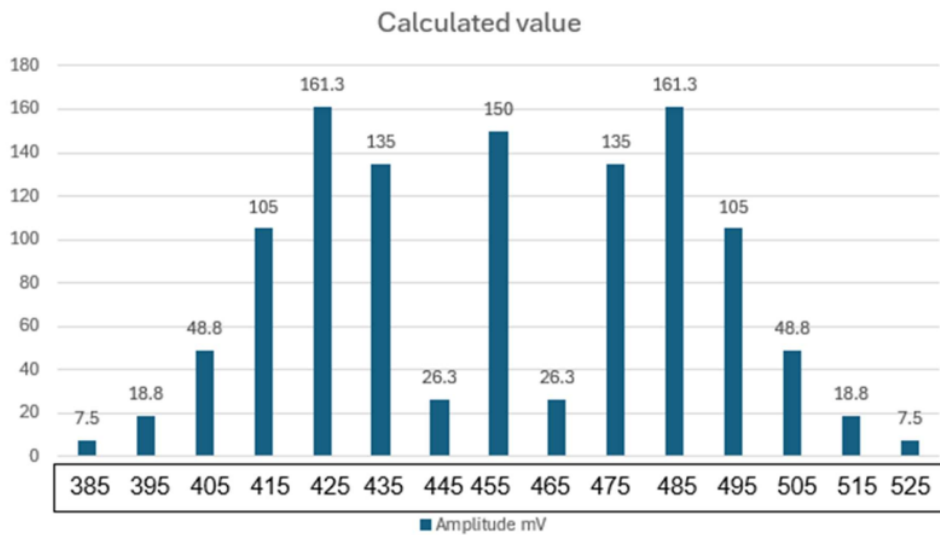


Figure 10 Calculated FM values

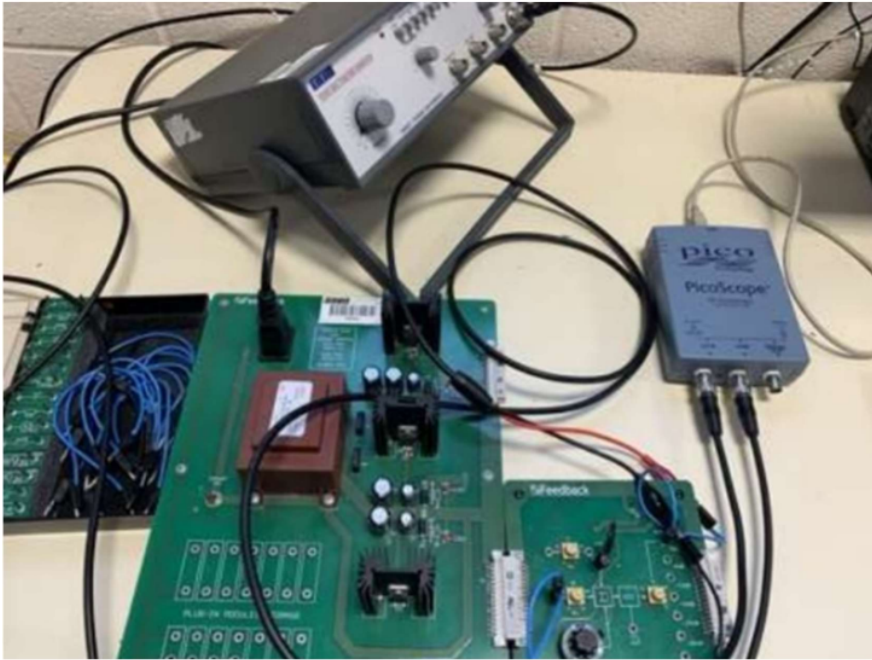


Figure 11 Equipment for FM test

Test 2

The values given for the assignment are below.

Frequency modulation		
	Symbol	Value
Frequency carrier	Fc	455 KHz
Carrier amplitude	Ec	375 mA
Frequency of message	Fm	5 KHz
Amplitude of the message	Em	2V

The calculation for maximum frequency deviation is below.

$$\Delta f_c = E_m \times (f_m \times E_m) = 2 \times (5 \times 10^3 \times 2) = 20 \text{ KHz}$$

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

$$\beta = \frac{\Delta f_c}{f_m} = \frac{40 \text{ KHz}}{5 \text{ KHz}} = 8$$

The coefficients from the Bessel table below are used 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
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						
7.0	0.30	0.00	-0.30	-0.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02					
8.0	0.17	0.23	-0.11	-0.29	-0.10	0.19	0.34	0.32	0.22	0.13	0.06	0.03				

Figure 12
Bessel table

The eight coefficients have been taken from modulation index 8.

$$j_0 = 375 \times 10^{-3} \times 0.17 = -0.06375$$

$$j_1 = 375 \times 10^{-3} \times 0.23 = 0.08625$$

$$j_2 = 375 \times 10^{-3} \times -0.11 = -0.04125$$

$$j_3 = 375 \times 10^{-3} \times -0.29 = -0.10875$$

$$j_4 = 375 \times 10^{-3} \times -0.10 = -0.0375$$

$$j_5 = 375 \times 10^{-3} \times 0.19 = 0.07125$$

$$j_6 = 375 \times 10^{-3} \times 0.34 = 0.1275$$

$$j_7 = 375 \times 10^{-3} \times 0.32 = 0.12$$

$$j_8 = 375 \times 10^{-3} \times 0.22 = 0.0825$$

$$j_9 = 375 \times 10^{-3} \times 0.13 = 0.04875$$

$$j_{10} = 375 \times 10^{-3} \times 0.06 = 0.0225$$

$$j_{11} = 375 \times 10^{-3} \times 0.03 = 0.01125$$

Below is the calculation for the bandwidth.

$$BW = (Frequency\ Amplitude\ values \times 2) \times Fm = (11 \times 2) \times 5\ KHz = 110\ KHz$$

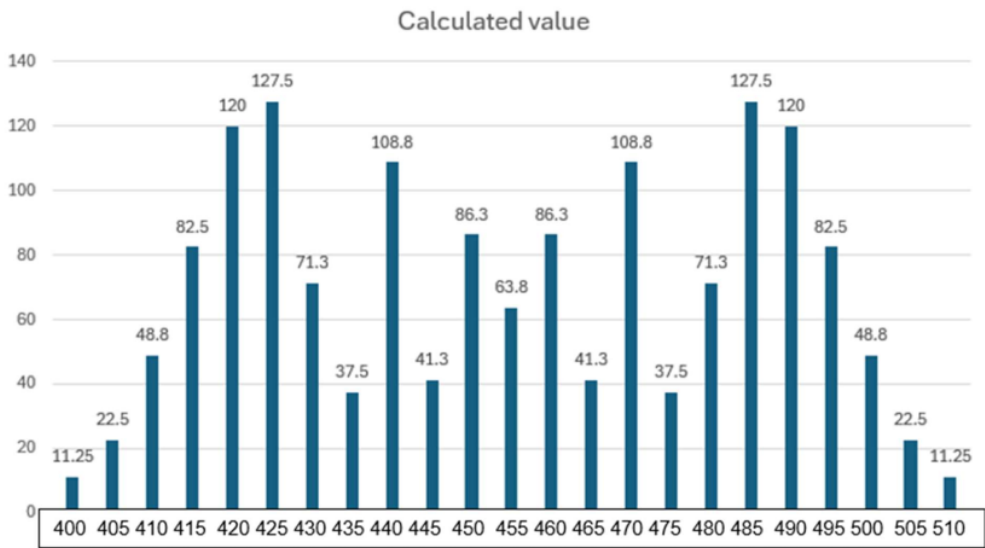


Figure 13 Calculated FM values

4. Experiment 2 Method – Analogue to Digital Conversion

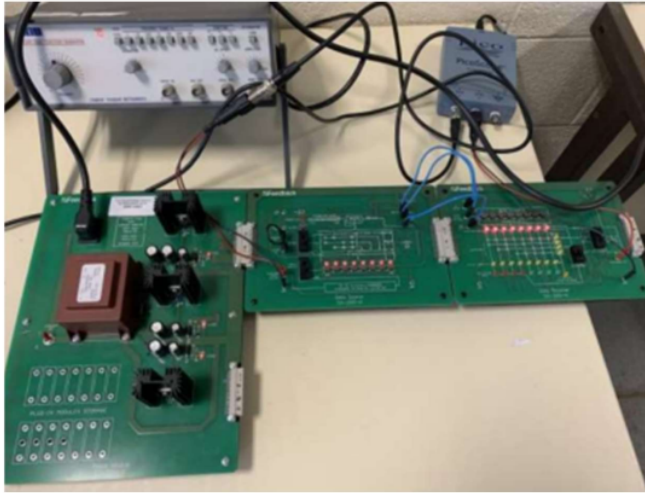


Figure 14 ADC test setup

The test board includes the ADC which can vary from 8-bit and 4-bit. The conversion can be seen through the Picoscope.

The test will outline the differences in the quality of conversion between 4-bit and 8-bit convertors. It is important to match the amplitude of the input signal to the range of an ADC.

The test board had a sample rate of 10,000 samples/second and Range = 5Vp-p

The testing will also show the relationship between the input frequency and the ADC sample rate and the Nyquist Criterion validity.

5. Results

Frequency modulation

Test 1

2-volt peak to peak 10kHz message wave (test 1)

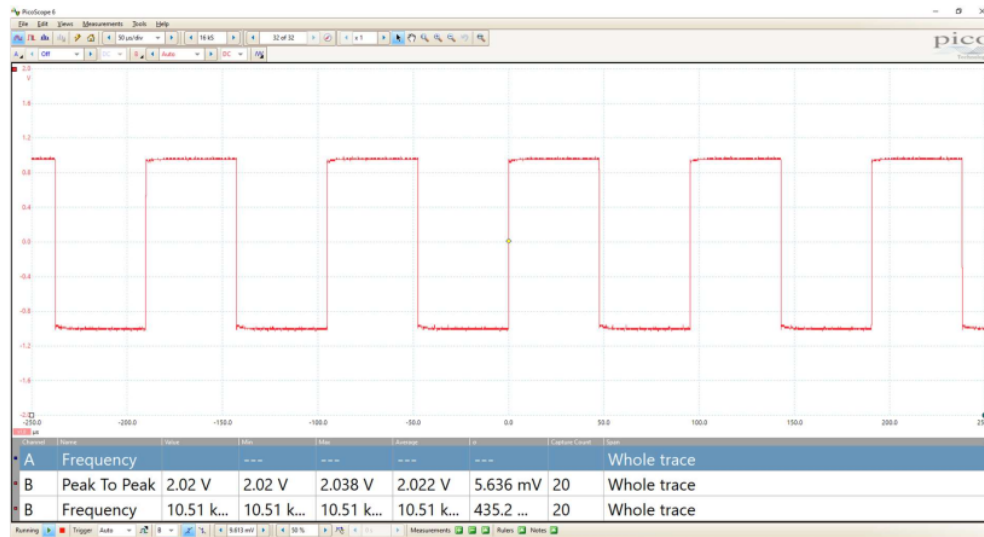


Figure 15 FM test 1

Carrier wave centre frequency of 455kHz, 32kHz deviation (test 1)

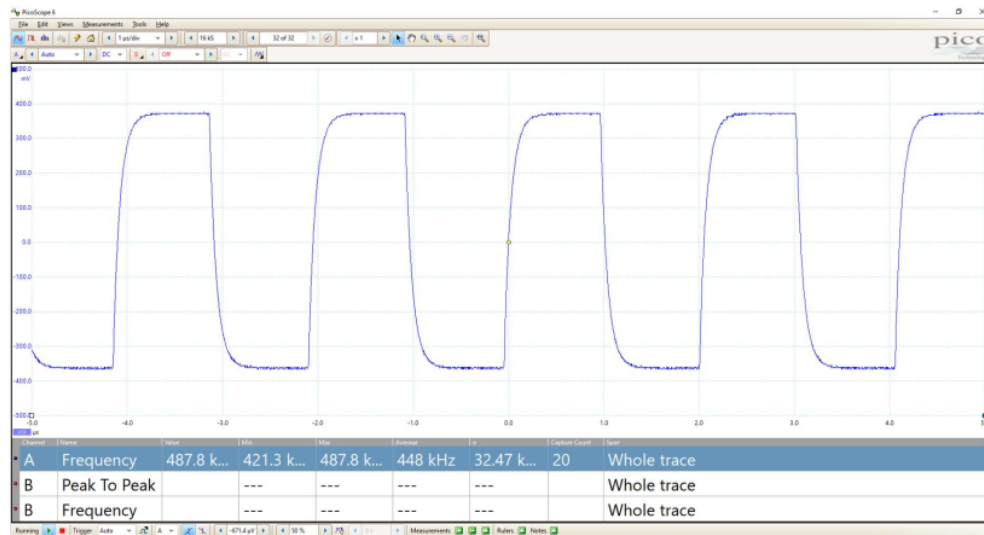


Figure 16 FM test 1

Frequency spectrum (test 1)

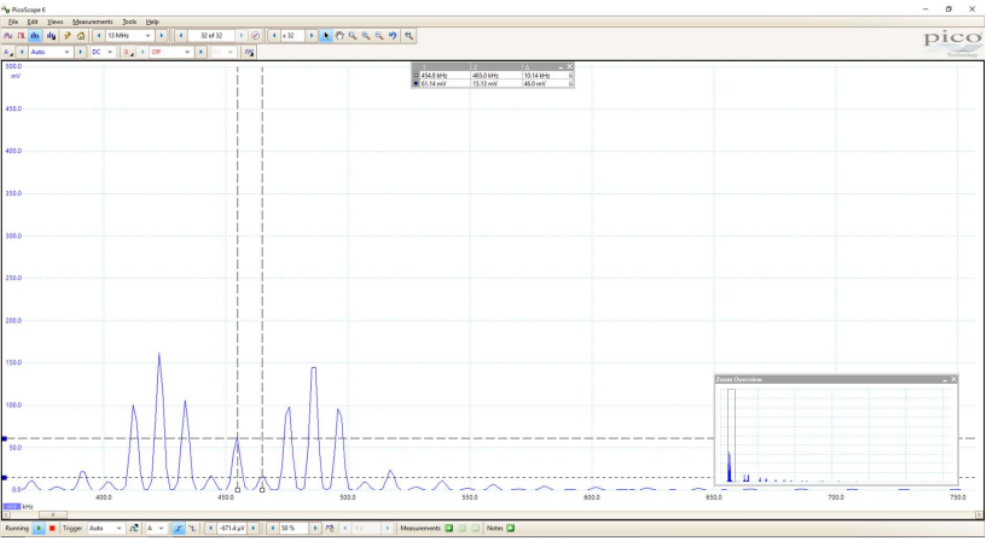


Figure 17 FM test 1

1	2	Δ	-	X
☐ 454.8 kHz	465.0 kHz	10.14 kHz		
☒ 61.14 mV	15.13 mV	46.0 mV		

Figure 18 FM test 1

Test 2
Carrier wave at 5kHz

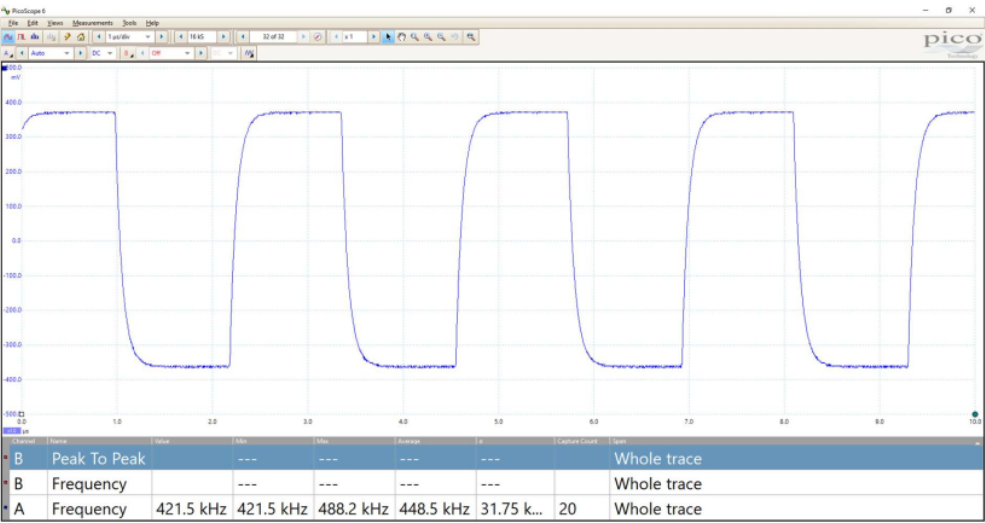


Figure 19 FM test 2

Message Frequency changed from 10 to 5kHz

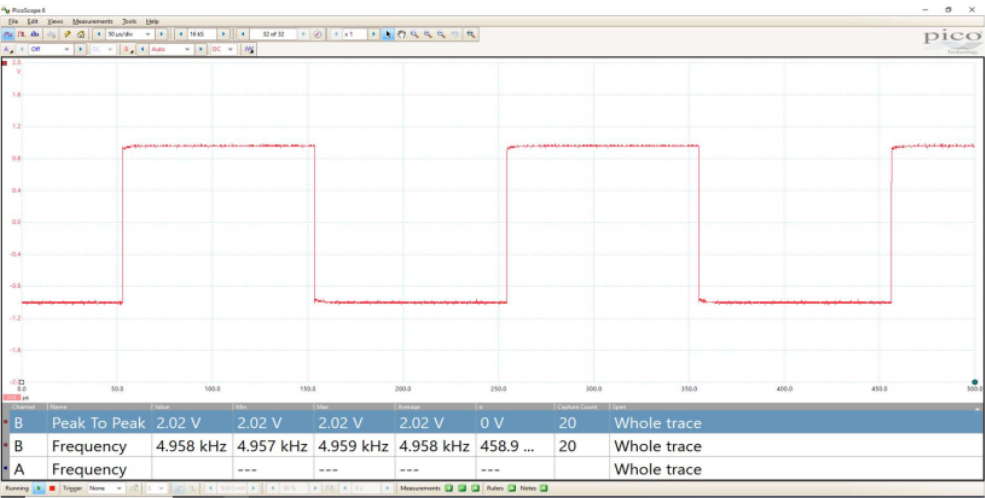


Figure 20 FM test 2

Frequency spectrum.

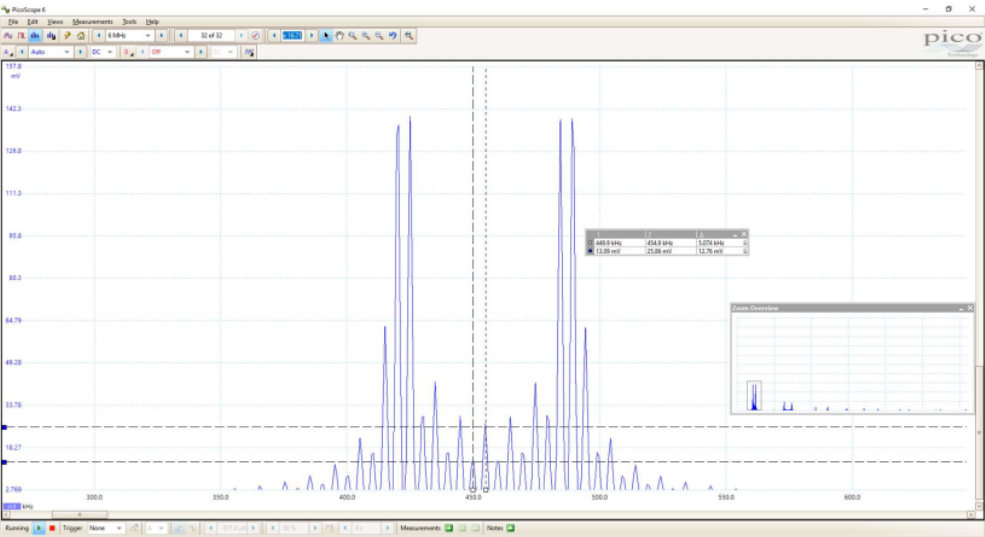


Figure 21 FM test 2

1	2	Δ	
449.9 kHz	454.9 kHz	5.074 kHz	
13.09 mV	25.86 mV	12.76 mV	

Figure 22 FM test 2

ADC

The figures below show the difference between the 4-bit and 8-bit converters. With a input frequency of 100 Hz and peak to peak voltage of 4 V

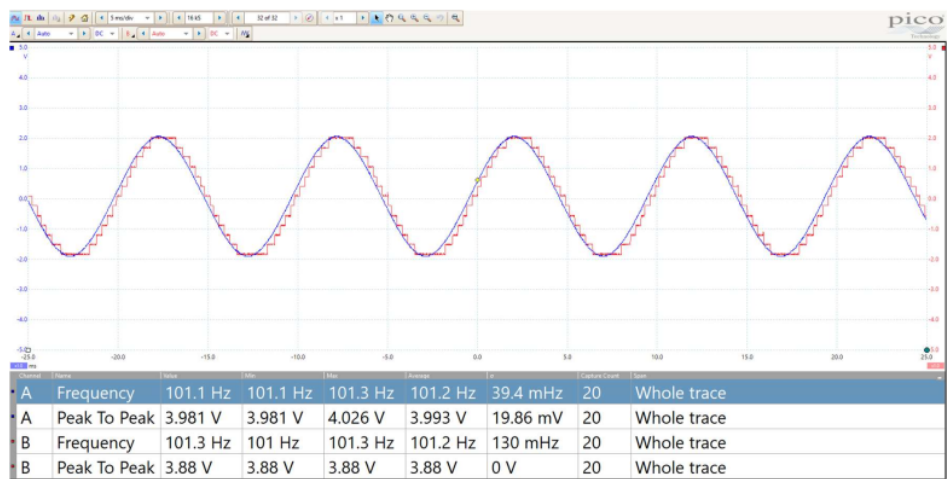


Figure 23 4-bit ADC

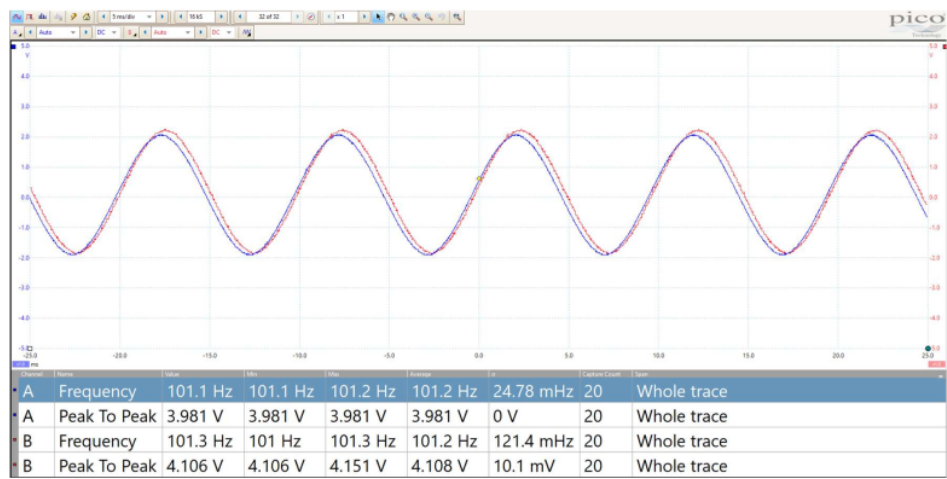


Figure 24 8-bit ADC

The images above show the 4-bit and 8-bit converters and their waveforms. The two follow a sine wave which is the input signal. Despite this the 8-bit ADC performs well as it follows and matches. The two have a square wave characteristic.

The figures below show the effect of changing input amplitude 100Hz from 4V peak to peak to 6v peak to peak. The test was done in increments of 2V peak to peak. Using a 4-bit ADC. However, the figure below shows some errors due to inaccuracies with the Picoscope.

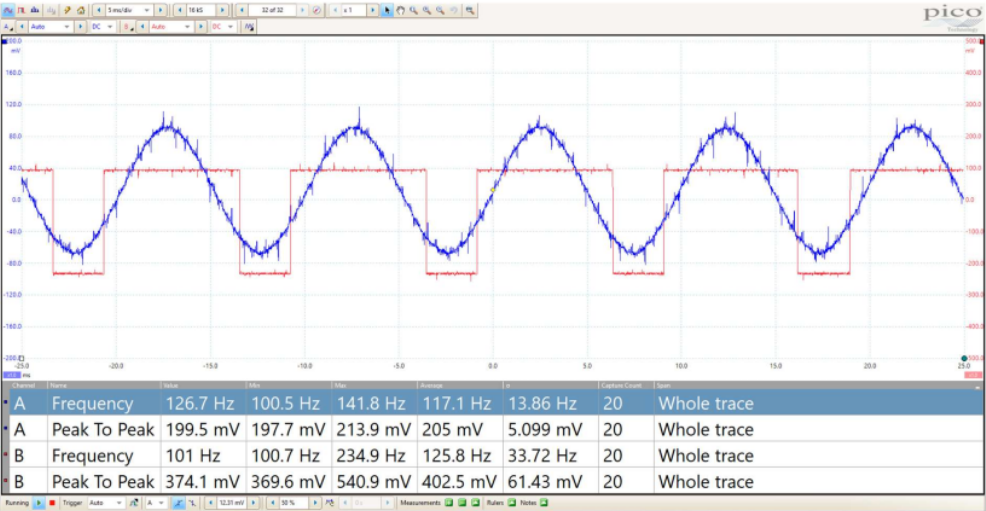


Figure 25 4-bit 4 p-p amplitude

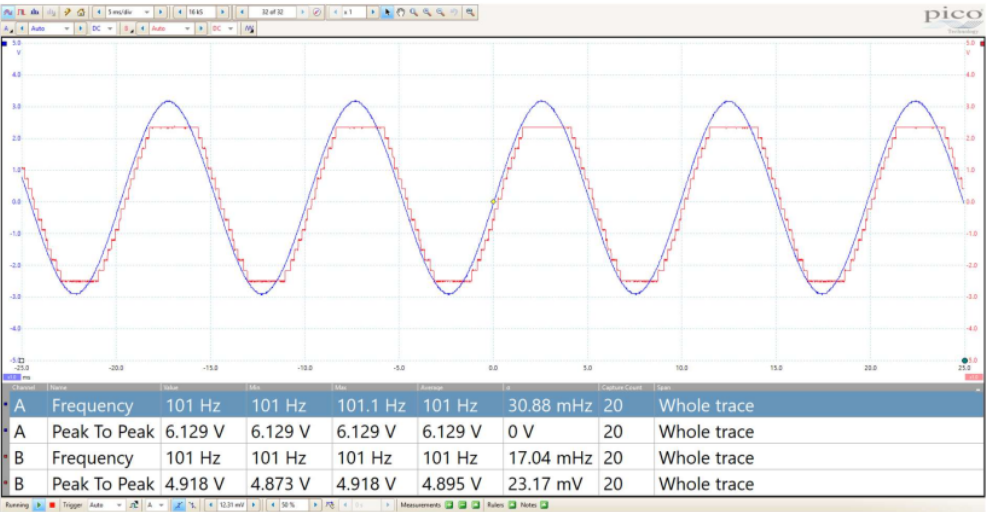


Figure 26 4-bit bottoming out

The figure above shows the effect of the ADC's range being exceeded. Which is 0-5V. As the input reaches over 6V. The signal is clipped and bottoms out.

The figures below show the effect of changing input amplitude 100Hz from 4V peak to peak to 6v peak to peak. The test was done in increments of 2V peak to peak. Using a 8-bit ADC. However, the figure below shows some errors due to inaccuracies with the Picoscope.

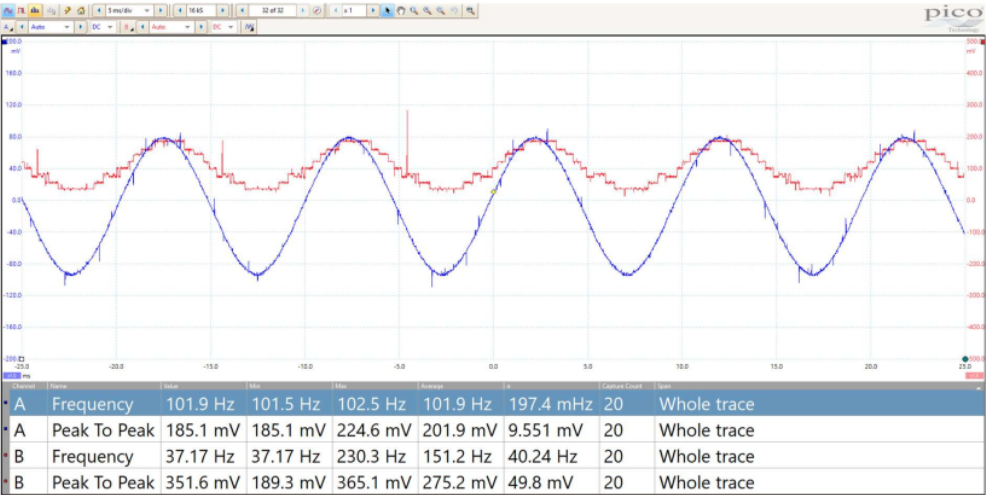


Figure 27 4-bit 4V p-p amplitude

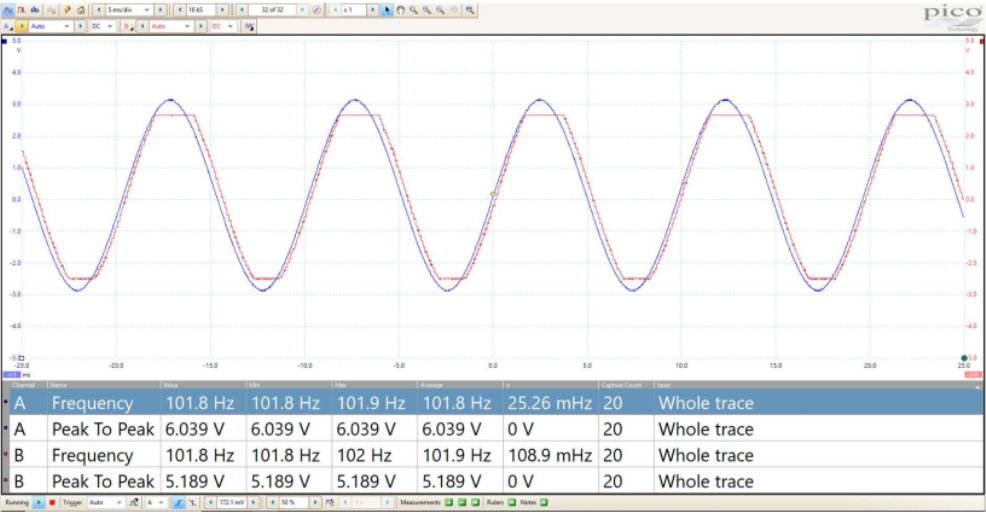


Figure 28 8-bit bottoming out

The figure above shows the effect of the ADC's range being exceeded. Which is 0-5V. As the input reaches over 6V. The signal is clipped and bottoms out. However, every sample withing range has been quantised.

The results from the over range testing shows that when the signal amplitude is increased, it is over the equipment capability. This shows that when choosing an ADC for a specific application, the matching of signal amplitude with the ADCs range is paramount. If not, some of the signal will be lost.

The testing for the investigation into the relationship between the input signal frequency and the sampling rate of the ADC is important and consequently investigate the validity of the Nyquist Criterion can be seen below.

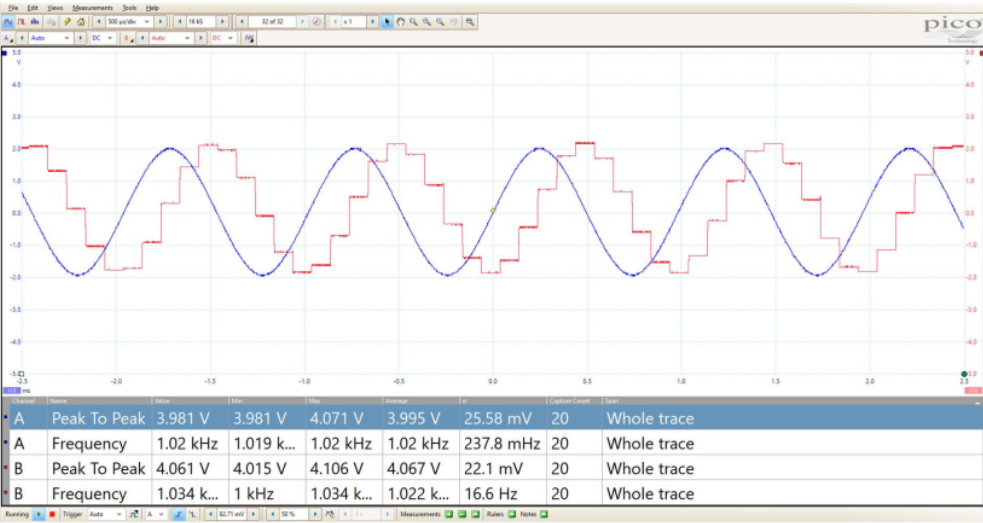


Figure 29 Effect of changing the input frequency in 1kHz at 1KHz

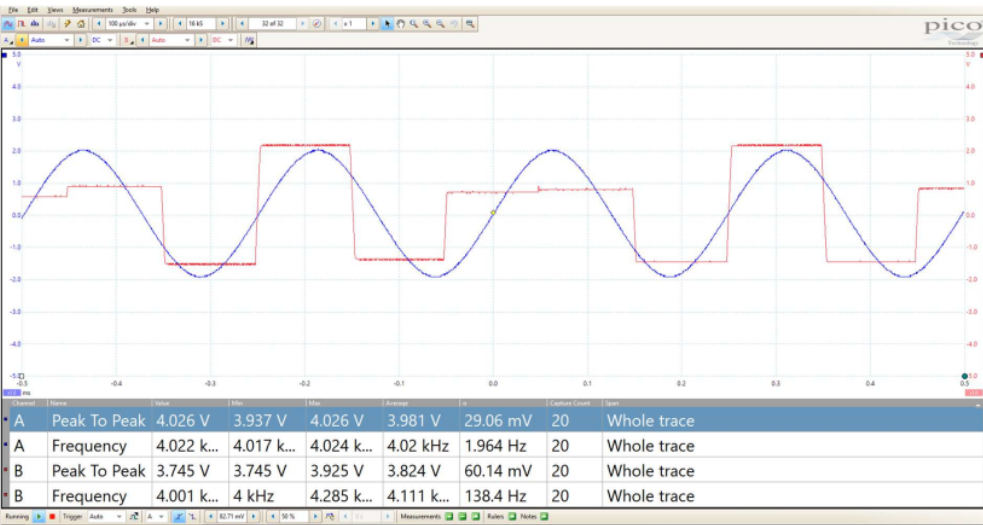


Figure 30 Effect of changing the input frequency in 1kHz at 4KHz



Figure 31 Effect of changing the input frequency in 1kHz at 7KHz

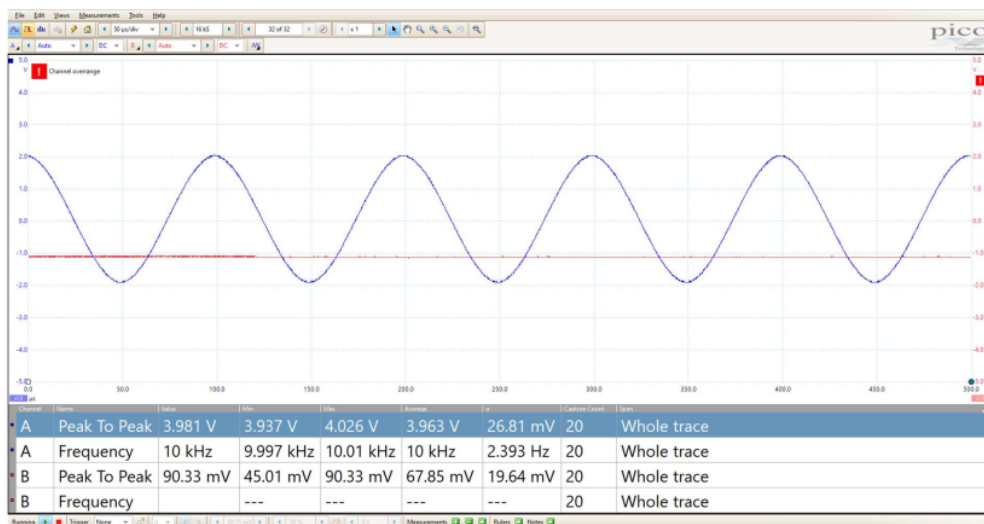


Figure 32 Effect of changing the input frequency in 1kHz at 10KHz

The four figures above show the input frequency and the effect it has on the sampling of the ADC converter.

6. Analysis

Frequency modulation

The readings taken from the frequency modulation frequency spectrum match, however there are discrepancies with the amplitude levels in test one and two. It was measured in test one at J0 the amplitude level was 61.14 mV, differently to the 150-mV calculated. Also, J1 was measured at 15.13 mV where it was calculated as 26.3 mV. It was measured in test one at J0 the amplitude level was 13.09 mV, differently to the 63.8 mV calculated. Also, J1 was measured at 25.86 mV where it was calculated as 86.3 mV. The amplitude readings do not match; however, they do follow the correct trend. Despite this the bandwidth of both tests is correct as they match up with calculated and the spacing between follows the theory of succeeding the frequency of the message, which was 10KHz in test one and 5KHz in test two. This proves the theory. There may be some errors due to the signal source as this itself is an ADC.

ADC

If there were more bits to be used to increase the resolution. The sine wave would be a lot smoother, however there would have to be higher processing power to handle sampling rate the data and a higher bandwidth. Using the same principle, the less sampling the less processing power is needed, making it more efficient, however you may have step outs as seen in the 4-bit example.

The results from the over range testing shows that when the signal amplitude is increased, it is over the equipment capability. This shows that when choosing an ADC for a specific application, the matching of signal amplitude with the ADCs range is paramount. If not, some of the signal will be lost. This is why it's important to match the input signal with the range.

From the testing for the relationship between the input signal frequency and the sampling rate. The testing was taken at 1KHz increments starting from 100Hz up to 10KHz. It shows the sampling at 100 Hz was consistent, however there's discrepancies in the rest of the tests. If the testing was correct, it should've shown that the input frequency should be at least double the highest frequency contained, if not there may be aliasing.

7. Conclusion

From researching FM and AM it was found that the modulation of frequency is the better option as it is much more efficient, and it hinders interference and static and AM doesn't. Though AM is a cheaper option. If FM is chosen, wider channels are needed as it increases the sidebands with a higher modulation index.

It was found through the frequency modulation testing that by changing the frequency of the message, the distance between the amplitude values on the frequency spectrum, this change is proportional. Also, by changing the frequency of the message the deviation frequency changes. And by changing the amplitude of the message changes how far the deviation goes. The higher the modulation index the more amplitude values, which in turn results in a higher bandwidth. The practical tests were successful however there were some errors leading from the signal source being an ADC itself.

The ADC testing was successful as it lined up to theory, despite some of the testing having some discrepancies. It was found that depending on the resolution of the ADC, the higher it is the better sine wave it produces as the range for quantising is higher. The sample rate also plays a part, but this is set. However, the higher sample rate and higher resolution in turn creates a lot of data to produce. It was also found the importance of matching the input signal and the range of the ADC, as some of the signal can be lost if it goes out of range. Also the input frequency should be at least double the biggest frequency contained otherwise there could be aliasing.

A recommended to be considered is the use of a higher bit ADC, such as a 14-bit ADC to provide a smoother digital sine wave. This due to the 16384/1 dynamic range. However, this may cause processing problems.

8. Executive Summary

The purpose of this assignment is to research into ADC methods and signal modulation methods. The initial research saw an insight into amplitude modulation and frequency modulation. The advantages and disadvantages of both were found. It was found that AM is a cheap alternative to FM, also AM is susceptible to noise, but FM isn't.

Through calculations and simulations, frequency modulation theory was proven. However, there were some discrepancies in the amplitude values, but these could have been affected by the signal source, as this is an ADC. Despite this, the bandwidth and frequencies were correct and the spaces between amplitude values relating to the message frequency theory was proven.

The testing was done on a 4-bit and 8-bit ADC. With a sample rate of 10,000 samples per second. It was proven that by increasing the number of bits introduced, the smoother digital signal it produces. It was also found that the input signal must not exceed the range of the ADC. It was found that the input frequency should be at least double the highest frequency contained, if not there may be aliasing.

9. Works Cited

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Sensitivity: general

FINAL GRADE

GENERAL COMMENTS

80/100

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GRADING FORM: CSG-RUBIC

ELIAS THOMAS

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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.

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KNOWLEDGE AND UNDERSTANDING

 The knowledge and understanding of the subject demonstrated by this assignment was generally excellent. There were very 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 highly competent critical understanding of the main concepts and expanded your knowledge well beyond that contained in the course notes.

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ANALYSIS

 Your analysis of the task was excellent, both in class and as shown in this assignment. You have demonstrated highly competent analytical skills and your approach to the task was highly logical. You carried out a detailed evaluation of the results and included an excellent conclusion relating your practical results to accepted theory. You have demonstrated a capacity for independent thought and your interpretation of the quantitative and qualitative data was excellent with sound judgements based on wholly valid arguments.

23

PRACTICAL APPLICATION AND DEP.

 Your application of practical skills for this task was generally excellent. You used both the basic and advanced features of the resources appropriately

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when conducting both experiments and you used appropriate advanced options for testing and evaluating the circuit performance. You managed to evaluate circuit performance and achieved this by rarely asking for assistance thus demonstrating some advanced problem solving skills. Your results were comprehensive and allowed for a detailed conclusion to be written.

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.

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