

1708174

by Jordan Gough

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1. Executive Summary

The aim of this report was to investigate the different methods of modulation and conversion of signals and identify how these methods are affected through a change in characteristics of the input. Research was carried out into different methods of modulation, such as frequency and pulse code modulation, along with analogue-to-digital conversion. This research provided different expectations and predictions into how the process will be affected.

To verify the possible effects, practical testing was carried out on frequency modulation and analogue-to-digital conversion. The frequency modulation created an amplitude spectrum, which was analysed and compared with the expected values that were gained through a series of calculations. Despite the calculations, there were still some differences between theory and practical, most notably the absence of some peaks.

Multiple tests were completed on the analogue-to-digital conversion to gather a wide variety of results. These results were used to find key information, such as conversion quality and ADC range.

Using the information gathered, an analysis between the practical results and theoretical expectations was completed to highlight the instances in which the experiment complied with the theory and when it did not.

You should also include a summary of the results and main conclusions.

2. Research into Analogue and Digital Communication Systems and Techniques

2.1 Amplitude and Frequency Modulation Techniques

Amplitude modulation varies the carrier frequency's amplitude, or voltage, to compliment the amplitude of the modulating signal. An example of amplitude modulation in practice can be seen below.

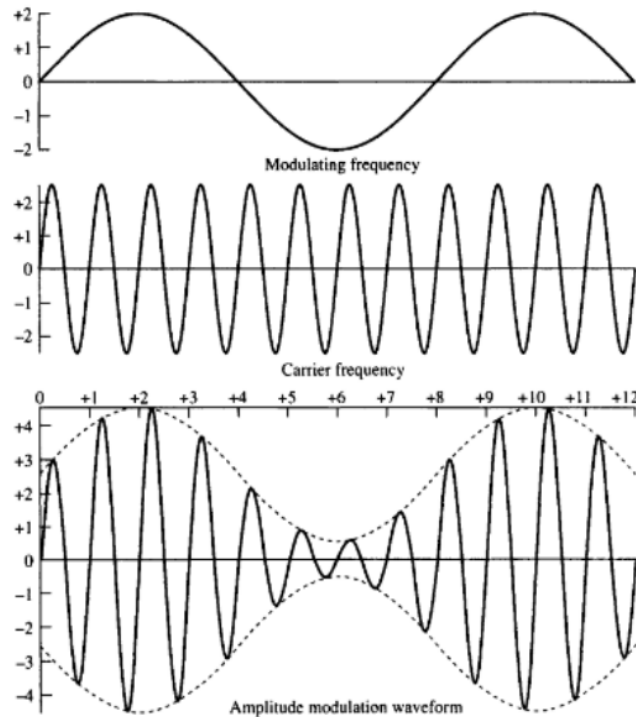


Figure 1 - Amplitude Modulation Example
(Smillie, 1999)

In the example, it can be seen that the amplitude of the carrier frequency changes once it is modulated. However, the carrier is now contained within an 'envelope' formed from the modulating frequency. (Smillie, 1999)

Aside from the differences in amplitude, the frequencies of both waves are noticeably different. In particular, the frequency of the carrier is much larger than that of the modulating signal. Upon the modulation of the carrier, sidebands are produced. When displaying the amplitude modulation as a frequency spectrum, the sidebands are away from the carrier at a frequency matching the

modulating signal. Therefore, the bandwidth of is equal to the modulating frequency doubled, due to the upper and lower sidebands. One issue with the use of amplitude modulation is the power requirement. The power required is large and thus means that any portable equipment involved in transmission will have high costs and short battery life. The power consumption can be reduced by using a different technique of modulation, namely the double-sideband modulation. Here, the carrier is not present post-modulation and therefore is not transmitted. By transmitting the sidebands, the power is reduced and the bandwidth remains unchanged. (Leis, 2019)

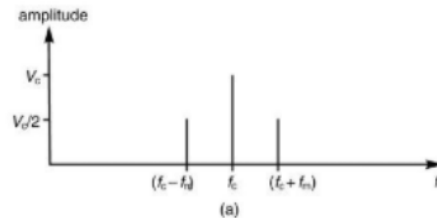


Figure 2 - Amplitude Spectrum
(Crecraft & Gergely, 2002)

One issue with using amplitude modulation for transmission is that the amplitude can be affected by any noise that is present. The noise that can be present in the transmitter or receiver will cause the amplitude to change and issues may arise during demodulation. By using frequency modulation, the amplitude does not change and, therefore, isn't affected by noise. (Leis, 2019)

Again, the carrier signal is changed by this technique. However, it is the frequency that is varied, rather than the amplitude. This can be completed by using a voltage-controlled oscillator. When using an oscillator, a larger frequency output is produced by increasing the voltage. When using amplitude modulation, the amplitude of the carrier follows that of the modulating signal. Whereas, when using frequency modulation, the frequency of the carrier is higher when the amplitude of the modulating frequency is higher. (Crecraft & Gergely, 2002)

Shown below is an example of a frequency modulated waveform.

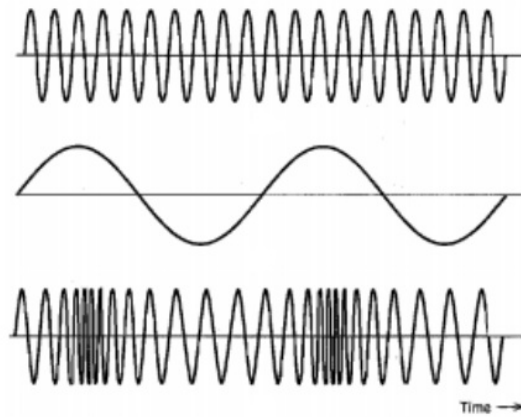


Figure 3 - Frequency Modulation Example
(Hayking, 2001)

Again, frequency modulation produces a spectrum. However, more components are displayed on the spectrum and every component has its own side frequencies. So, there can be many side frequencies on the spectrum – all of which are separated from each other by the same amount.

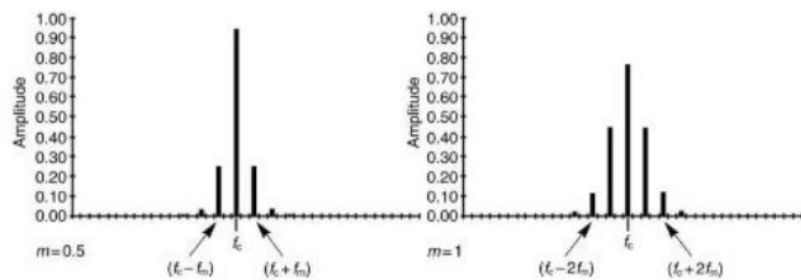


Figure 4 - Frequency Spectrum
(Crecraft & Gergely, 2002)

2.2 Digital Communication Techniques

2.2.1 Analogue-to-Digital Conversion

Analogue-to-digital conversion (ADC) is used to produce a digital code output that represents an analogue signal input. An issue that arises when using analogue-to-digital conversion is a time delay that is introduced when the conversion is being completed. (Hiley, et al., 2016)

One example of an ADC that can be used is a successive approximation converter. Here, the conversion relies on an analogue input being compared to the digital output being produced. The digital output produced is feedback into a digital-to-analogue converter to produce a second analogue input signal, which is how the digital output and the analogue input are compared. The comparison in place induces the time delay on the system. Due to the use of a comparator, a digital signal of 0 or 1 will be produced from the inputs. Therefore, the comparator output will follow one of the following options;

- If the digital signal is greater than the analogue signal, the comparator output will be 1.
- If the digital signal is equal to the analogue signal, the comparator output will be 0.
- If the digital signal is less than the analogue signal, the comparator output will be 0.

(Hiley, et al., 2016)

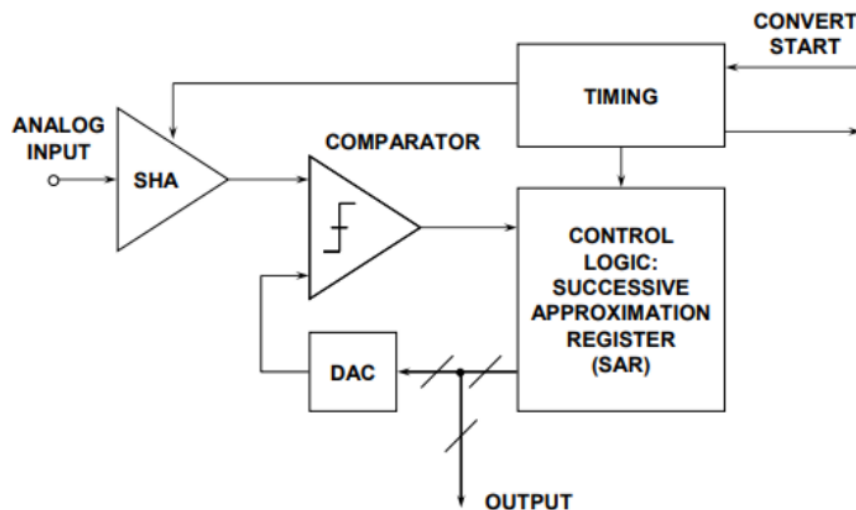


Figure 5 - Successive Approximation ADC Circuit
(Kester, 2008)

Another possible converter that can be used is a flash ADC, which provides much quicker operation, thus reducing the time delay. This is because the converter uses multiple comparators to

simultaneously compare the input to reference voltage steps, produced by resistors. If the input voltage is lower than the reference, the comparator will produce a 0 for an output and if it is higher, the output will be a 1. With these outputs, a combination logic can then produce a digital code relating to the analogue input voltage. (Storey, 2017)

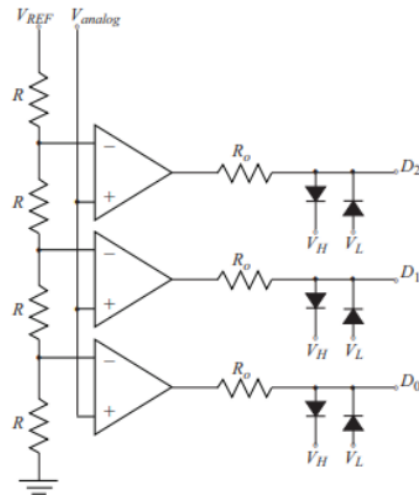


Figure 6 - Flash ADC Circuit
(Schubert & Kim, 2016)

Shown below is a graph that compares the resolution and sample rates of different ADC types.

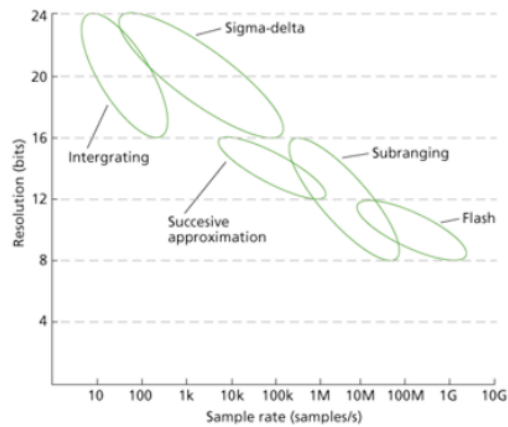


Figure 7 - ADC Resolution Graph
(Rowe, 2002)

2.2.2 Pulse Modulation

Pulse modulation is another method of modulation that can be applied to signals. There are two distinct types of pulse modulation, analogue and digital.

When using analogue, the signal is modulated for transfer over an analogue channel by varying a pulsed waveform's characteristics. One example of this is pulse amplitude modulation. In this case, the waveform is sampled regularly. Using the magnitude at these points, the pulse amplitude is modulated. As with other amplitude modulation techniques, this is also affected by noise and does not account for the pulse time.

When using digital, the signal is modulated for transfer over a digital channel by representing the input signal with an array of pulses. One example of this is pulse code modulation. Here, the waveform is converted into a word that represents the signal. Once in this format, the binary code for the produced word is produced using a series of pulses. (Storey, 2017)

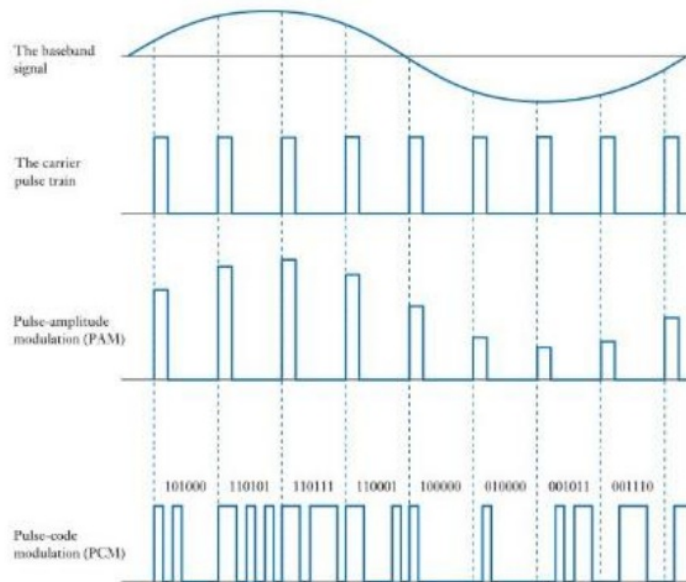


Figure 8 - Pulse Modulation Examples
(Storey, 2017)

2.2.3 Modulation Schemes

Quadrature phase shift keying (QPSK) is a type of digital modulation which again means that it doesn't suffer from noise. In a typical digital transmission, the signal is one of two states – 0 or 1. However, when using QPSK, two bits are modulated simultaneously and the signal can take one of four states – 00, 01, 10 or 11. This is because the carrier signal is modulated by shifting the phase, rather than changing the frequency. Therefore, there are four possible phase shift values that correspond to the states – 45° , 135° , 225° and 315° . Once the states have been assigned, the carrier wave is modulated by applying the phase shift. (Keim, 2016)

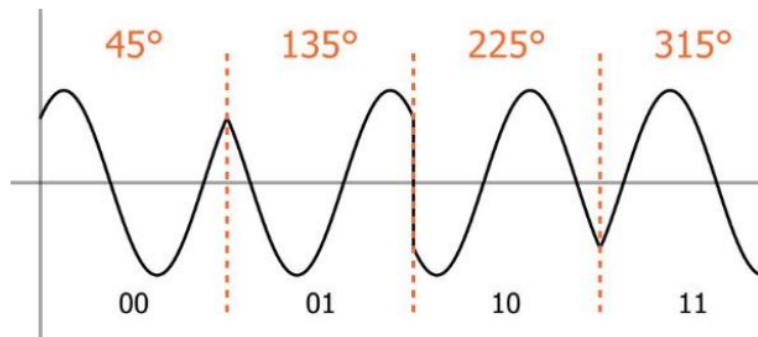


Figure 9 - QPSK Example
(Keim, 2016)

Quadrature amplitude modulation, or QAM, is a modulation method that uses two carriers, referred to as in-phase and quadrature, which are 90° out of phase or sine and cosine waves. Once modulated, they are combined. This modulation method is seen as containing both amplitude and phase modulation. When using an IQ diagram, 16 points, or 4-bits, can be identified. The number of points present relates to the naming of QAM 16. This number of points can be increased from 32 to 1024. However, the increasing points allows noise to become present. An example of an IQ diagram can be seen below. (Leis, 2019)

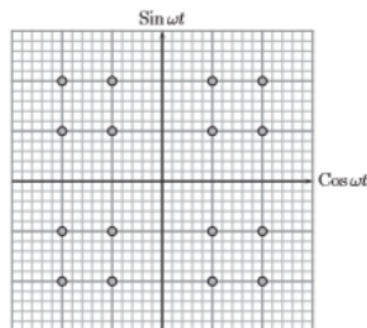


Figure 10 - In-phase/Quadrature Diagram
(Leis, 2019)

Plesiosynchronous digital hierarchy is used to transmit large amounts of data over communication networks, such as fibre optics. This is achieved using multiplexers which transmit when triggered by a clock. Therefore, the different parts of the system are not fully synchronised due to the clock periods. In many cases, PDH has been replaced with synchronous digital hierarchy, which is another high-speed transmission method. Unlike PDH, the bit rate of each multiplexer is the same and they share a clock, which allows them to transmit synchronously using lasers on fibre optics. (Fiber Optical Networking, 2015)

3. Experimental Method

3.1 Frequency Modulation

Using a frequency modulator with an FM carrier of 20kHz per volt, a 455kHz carrier wave, with amplitude of 375mV, was modulated by a 10kHz square wave signal. Using these details, the maximum frequency deviation can be deduced.

$$\text{Maximum Frequency Deviation, } \Delta F_c = f_c \times E_s$$

$$\therefore \Delta F_c = 20k \times 2 = 40kHz$$

The maximum frequency deviation can be used to then calculate the modulation index, which is the ratio between ΔF_c and the modulating signal.

$$\text{Modulation Index, } \beta = \frac{\Delta F_c}{F_s}$$

$$\therefore \beta = \frac{40}{10} = 4$$

When modulating a wave, the amplitude values will be displayed on a spectrum. To ensure that the values that are displayed on the spectrum are correct, calculations can be completed to provide verification. This is achieved by using a Bessel table and the carrier amplitude. The Bessel table can be seen below.

β	J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9
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	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	0.01

Figure 11 - Bessel Table

The calculations, seen below, will use the row where β is 4.0. Here, the calculations will start at 455kHz and continue for seven intervals of 10kHz above and below.

$$J_0 = 0.375 \times 0.4 = 0.15V \text{ (455kHz)}$$

$$J_1 = 0.375 \times 0.07 = 0.02625V \text{ (445kHz, 465kHz)}$$

$$J_2 = 0.375 \times 0.36 = 0.135V \text{ (435kHz, 475kHz)}$$

$$J_3 = 0.375 \times 0.43 = 0.16125V \text{ (425kHz, 485kHz)}$$

$$J_4 = 0.375 \times 0.28 = 0.105V \text{ (415kHz, 495kHz)}$$

$$J_5 = 0.375 \times 0.13 = 0.04875V \text{ (405kHz, 505kHz)}$$

$$J_6 = 0.375 \times 0.05 = 0.01875V \text{ (395kHz, 515kHz)}$$

$$J_7 = 0.375 \times 0.02 = 0.0075V \text{ (385kHz, 425kHz)}$$

$$\text{Bandwidth} = 525k - 385k = 140kHz$$

These amplitude values should produce a spectrum that resembles the following diagram.

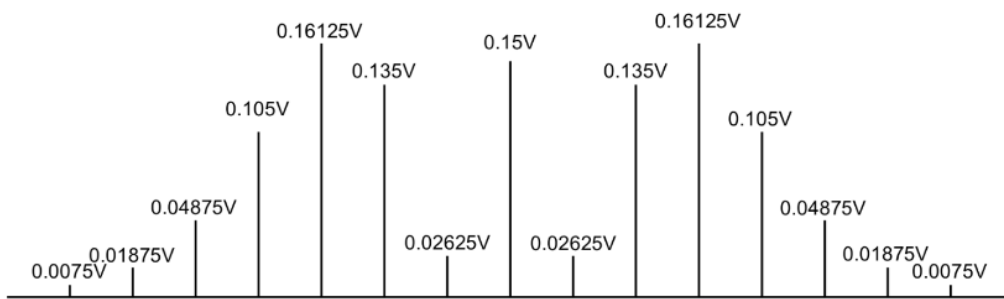


Figure 12 - Amplitude Spectrum Sketch

To obtain the practical spectrum, the 52-200-Q supply board and 52-100-A signal source board can be connected to a modulation generator and a Picoscope. Using the two channels on the Picoscope, one can be configured to measure the frequency output from the signal board and the other to measure the frequency and peak-to-peak voltages from the generator.

3.2 Analogue to Digital Conversion

Using the 52-200-A source board and the 52-200-B format board, the signal from the modulation generator can be converted from analogue to digital. Whilst completing the conversions, the following will be tested.

- How the number of bits affects the analogue-to-digital conversion.
- How the amplitude changes a 4-bit and 8-bit conversion with a constant frequency.
- How the frequency changes a 4-bit and 8-bit conversion with a constant amplitude.

These tests should provide an insight into the how analogue-to-digital converters behave using different input signal condition, but also the differences in quality between 4-bit and 8-bit conversion. It should also display the performance parameters of the ADCs, such as the range and sample rate.

4. Testing, Results and Analysis

4.1 Frequency Modulation

To use the modulation generator for frequency modulation, a square-wave at 1Hz and 6V peak-to-peak should be input into the source board. The frequency control on the source board should also be set to 455kHz. Setting these values was achieved using the Picoscope channels to measure frequency and peak-to-peak voltage. An example of the frequency control setting can be seen below.

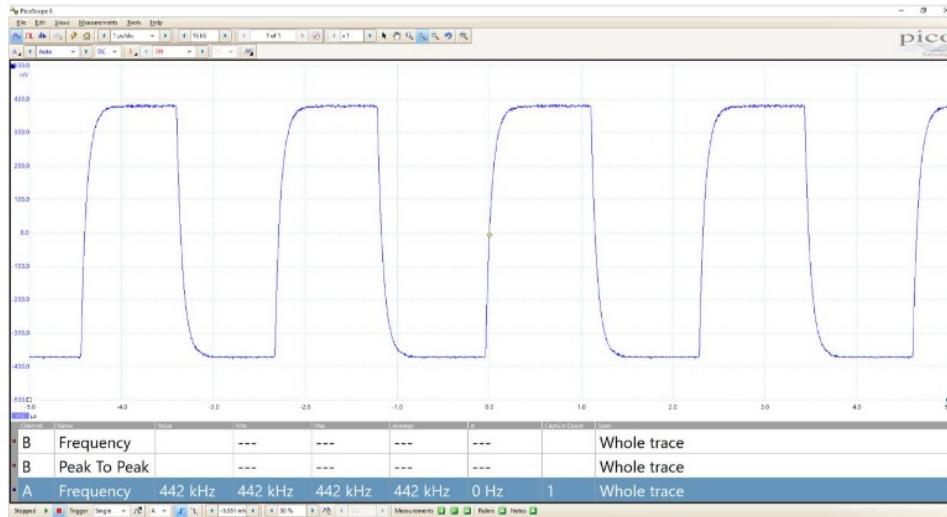


Figure 13 - Frequency Control at 455kHz

To view the side frequencies for the spectrum, the modulation generator can be set at 20kHz and 2V peak-to-peak. Once this is set, the Picoscope can be set to spectrum analyser mode and the amplitudes will be displayed.

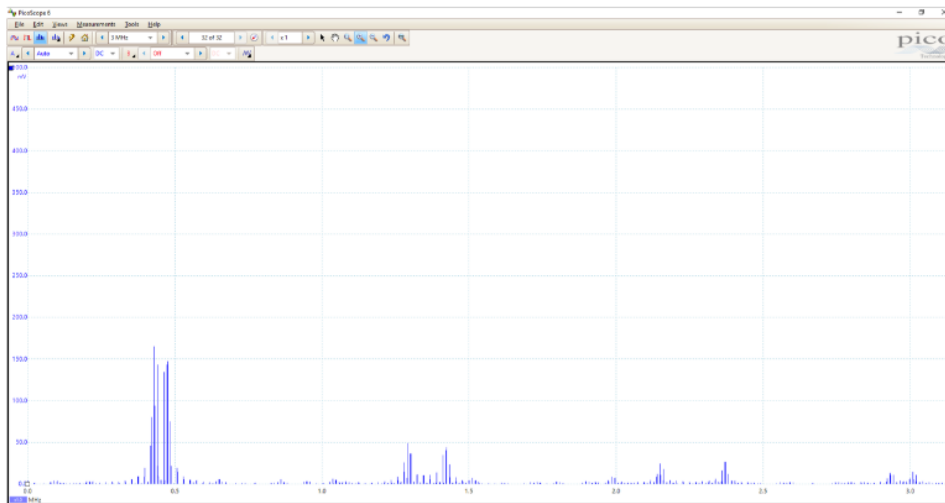


Figure 14 - Picoscope Spectrum Analyser

With the amplitudes displayed, the side frequencies can be identified. This is achieved by focusing on the frequency amplitude's around 455kHz.

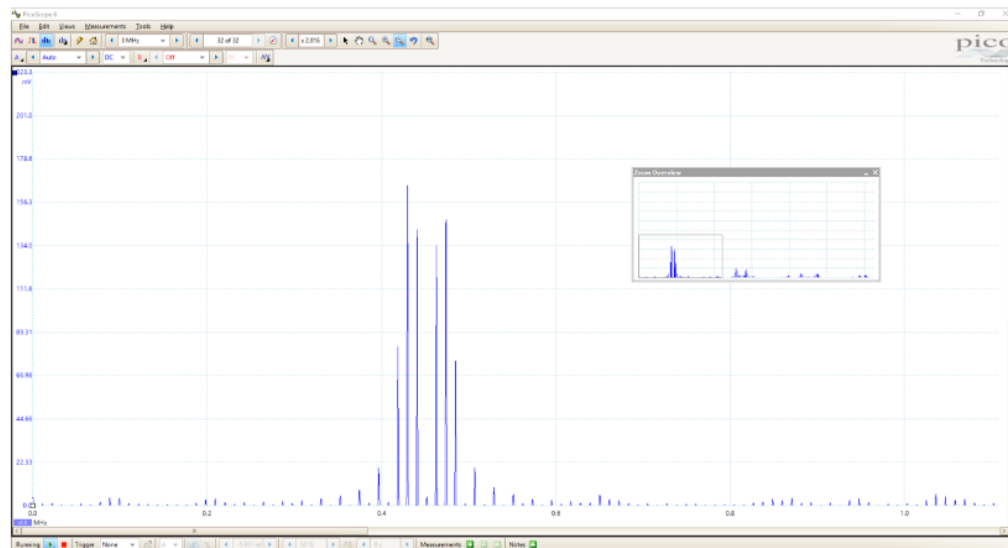


Figure 15 - Side Frequencies

When comparing the Picoscope display to the sketch produced using the calculated values, some differences appear. The most noticeable difference that appears is the lack of the centre frequency at 0.15V and the two either side at 0.02625V. Instead of these appearing, a small point appears in the centre of the two 0.135V points. Due to this, the bandwidth is larger than expected, at 250kHz.

4.2 Analogue to Digital Conversion

When using an analogue-to-digital converter, the number of bits in use can affect the quality. With the generator at 100Hz and 4V peak-to-peak, the following 4-bit conversion is produced.

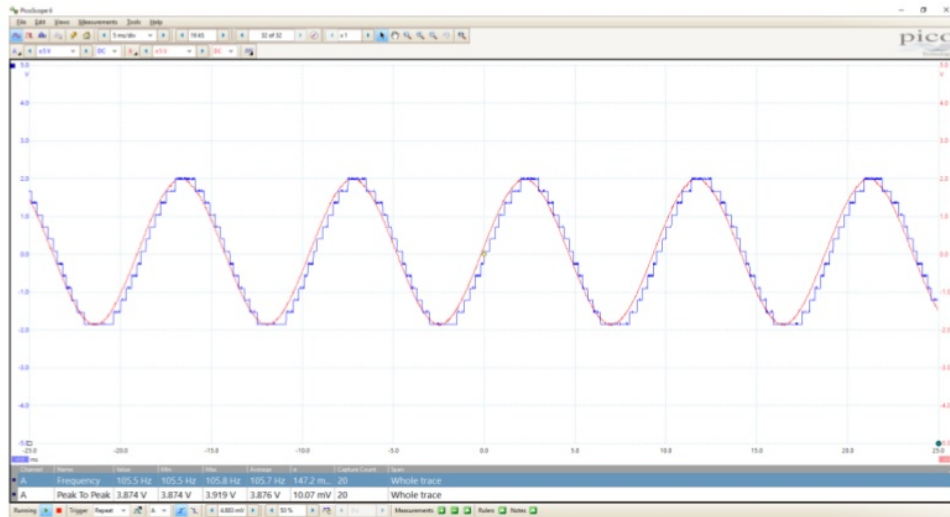


Figure 16 - 4-bit Conversion at 100Hz and 4V p-p

By changing the source and format boards to 8-bit, the following is produced.

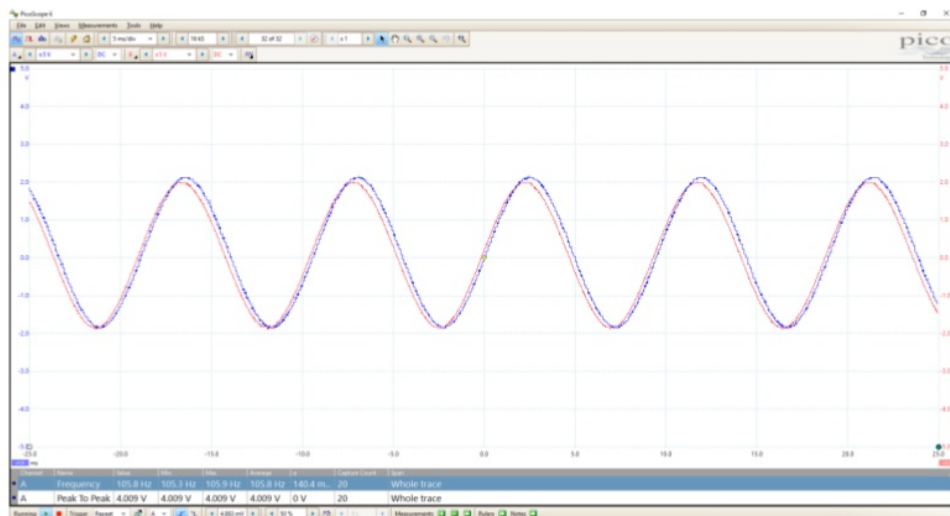


Figure 17 - 8-bit Conversion at 100Hz and 4V p-p

Here, by using the 8-bit conversion, the wave is much smoother and, thus, produces a much better-quality signal. This is because the 8-bit ADC has a larger resolution and can produce an output at 256 values, whereas a 4-bit ADC can only produce 16 values. Therefore, there will be less separation

between each sample on an 8-bit converter. This means that the larger the number bits, the better the conversion quality.

When the frequency of the signal is held constant and the amplitude is changed, the performance parameters of the ADC can be found. These include the quantisation level of the ADC and the resolution. To do this, the input frequency is set to 100Hz and 0V for a 4-bit system. The output produced can be seen below.

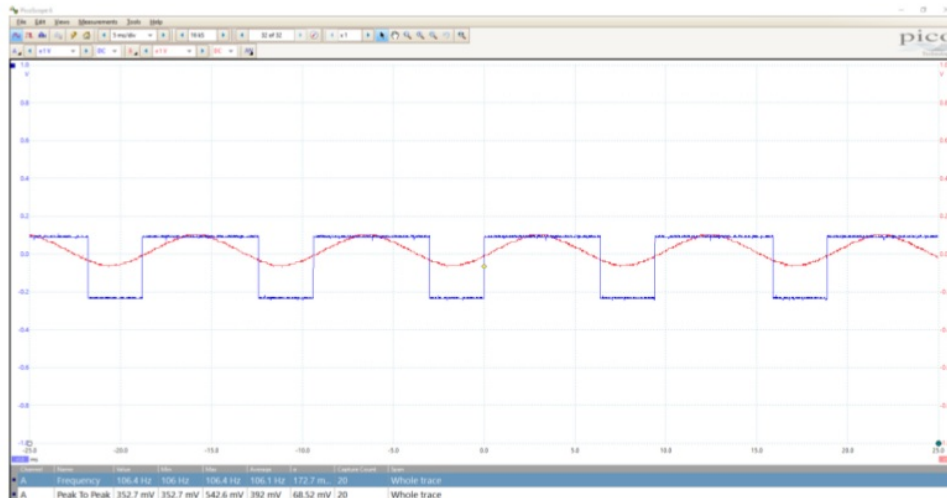


Figure 18 - 4-bit Conversion at 100Hz and 0V p-p

This shows that at a small amplitude, the quality of conversion is poor. By increasing the amplitude, more output values will become apparent.

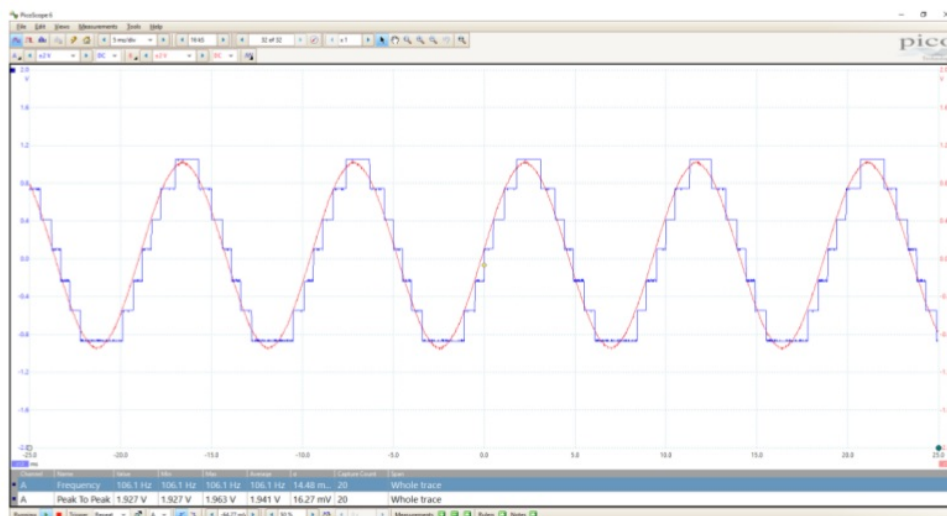


Figure 19 - 4-bit Conversion at 100Hz and 2V p-p

By increasing the amplitude, the additional outputs are displayed. However, upon increasing the amplitude towards 6V peak-to-peak, the output stopped increasing.

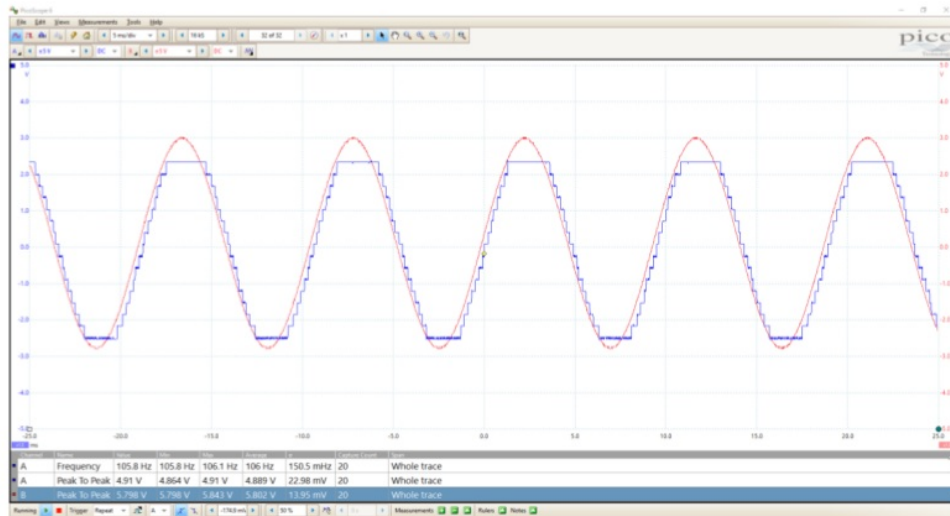


Figure 20 - 4-bit Conversion at 100Hz and 6V p-p

Despite reaching an input amplitude of 6V peak-to-peak, the output amplitude only reached 5V peak-to-peak before it reached its maximum value. Therefore, this shows that the ADC is unsuitable to be used with an input value of higher than 5V. By changing the ADC to 8-bit, the performance is the same, but with a different resolution.

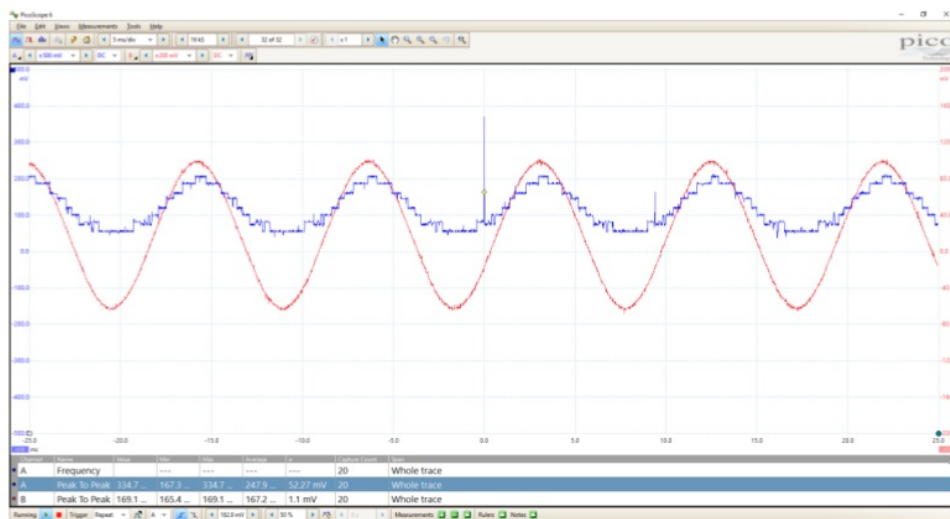


Figure 21 - 8-bit Conversion at 100Hz and 0V p-p

When a small input is applied, there are still fewer output values. However, it does display more output values than it does in 4-bit. Again, increasing the amplitude to 6V peak-to-peak causes the ADC output to stop at 5V peak-to-peak.

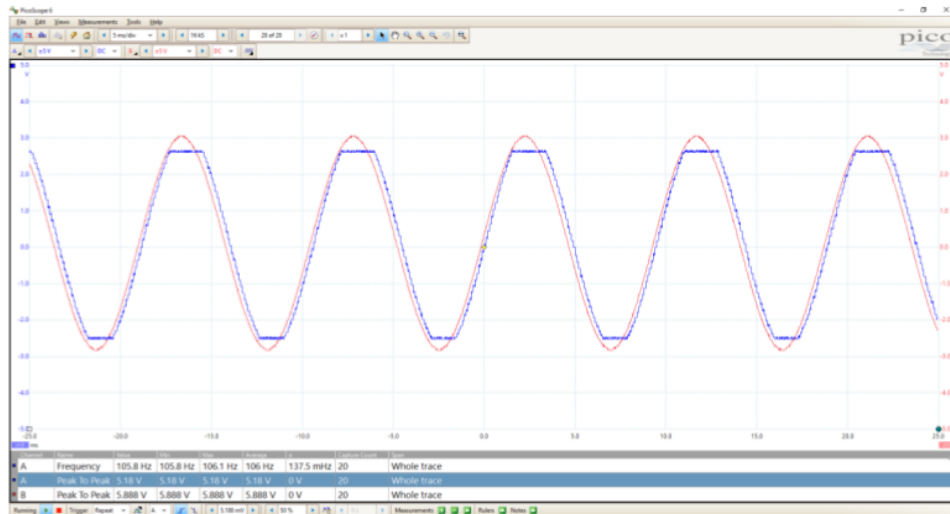


Figure 22 - 8-bit Conversion at 100Hz and 6V p-p

At 8-bit, the output voltage is slightly higher than that of 4-bit, but it still does not reach the 6V peak-to-peak output that it should be. This further confirms that the ADC is unsuitable for values greater than 5V peak-to-peak input and the quantisation levels must be increased to accommodate input values greater than these.

To see how the frequency affects the conversion, the input can be set to 4V peak-to-peak and different frequency input values can be selected. Using an 8-bit ADC, the frequency can be increased in decades. This will provide a variety of different outputs to analyse. Shown below is the output when the input is set to 10Hz.

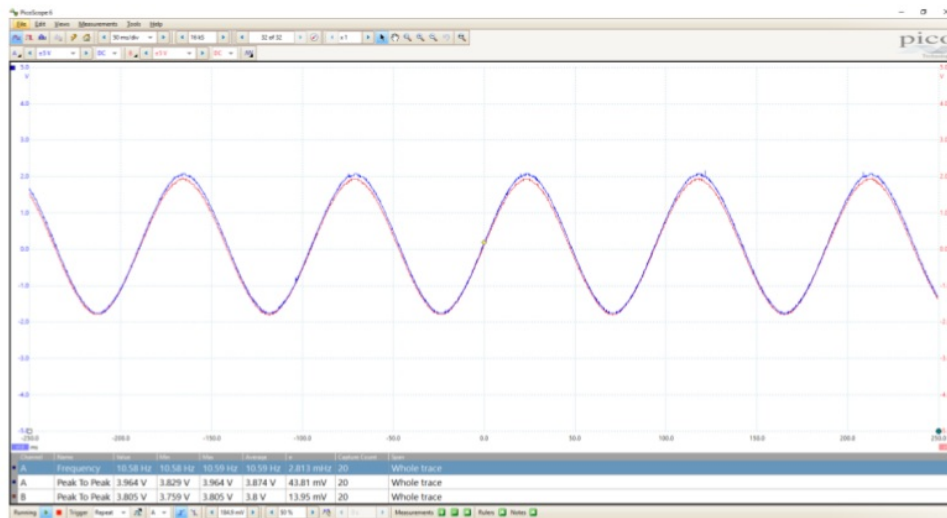


Figure 23 - 8-bit Conversion at 10Hz and 4V p-p

At 10Hz, the conversion quality is very good. The output signal produced is of better quality than the output shown previously at 100Hz. The output changes more drastically as it increases.

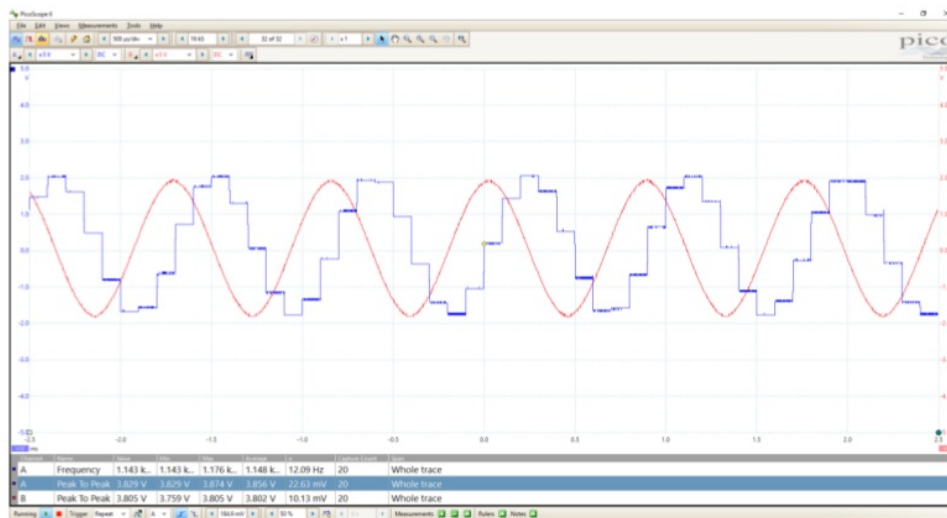


Figure 24 - 8-bit Conversion at 1kHz and 4V p-p

At 1kHz, the output is seen as a lower quality than the input signal that is being received from the generator. The quality is also much worse than the previous conversions. By further increasing the frequency, the quality of the conversion worsens.

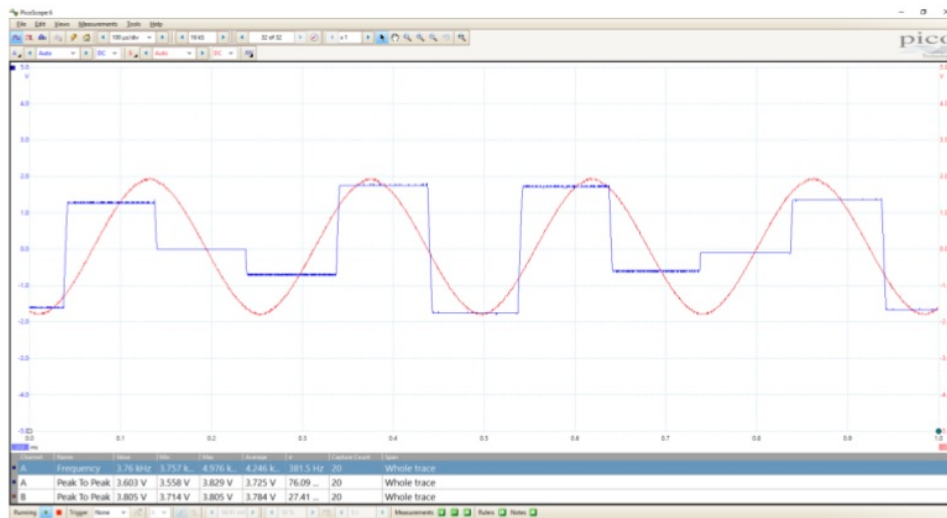


Figure 25 - 8-bit Conversion at 4kHz and 4V p-p

At 4kHz, there are even fewer output values being produced by the ADC. This shows that by increasing the frequency and keeping the amplitude constant, the quality deteriorates.

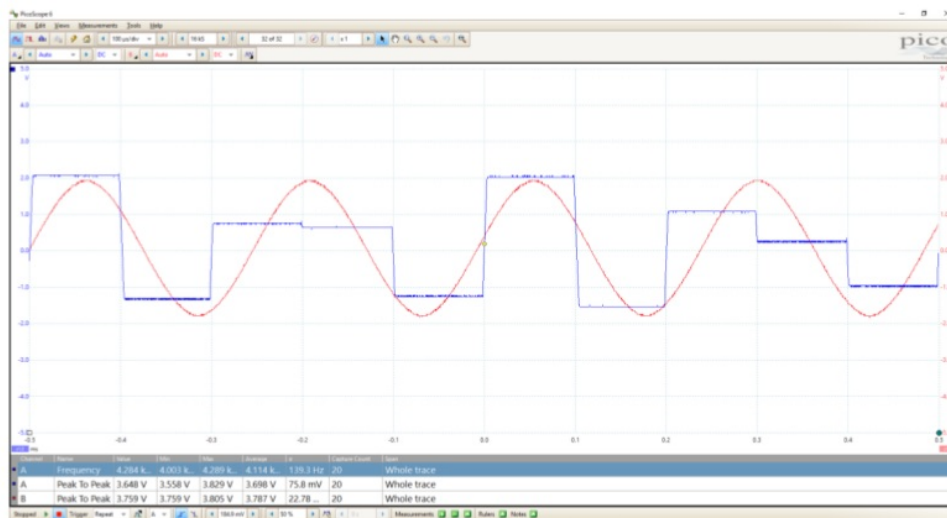


Figure 26 - 8-bit Conversion at 4.2kHz and 4V p-p

At 4.2kHz, the changes in quality are much less noticeable than when the frequency increases by decades. This also applies to changing the frequency by larger amounts, but keeping within the decade. Show below is an input signal of 6kHz, which still produces a signal with few output values.

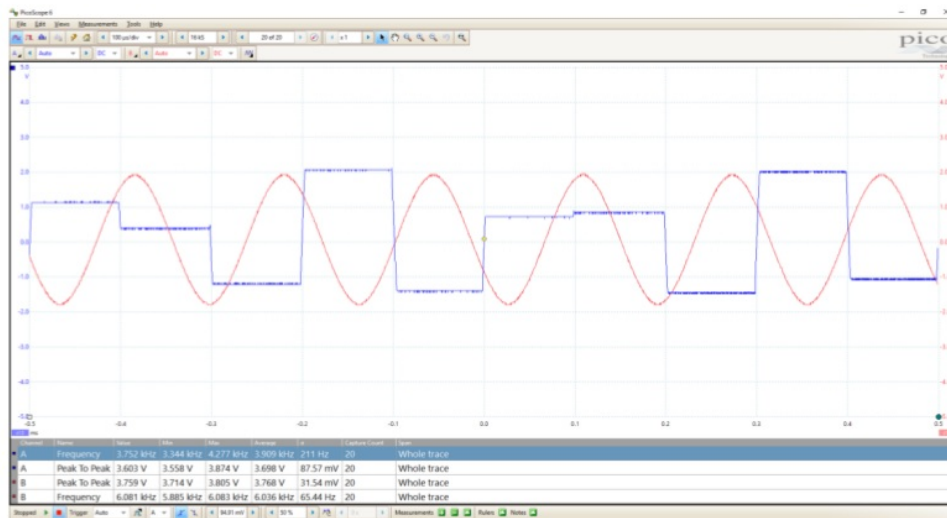


Figure 27 - 8-bit Conversion at 6kHz and 4V p-p

At an input signal of 10kHz, which is another decade increase, the number of full waves being inputted and outputted is disproportional and part of the input signal is lost. Therefore, this shows that when the amplitude remains constant, the quality of conversions degrades as the frequency increases by larger amounts and thus the 8-bit ADC is more suitable for input signals with a smaller frequency.

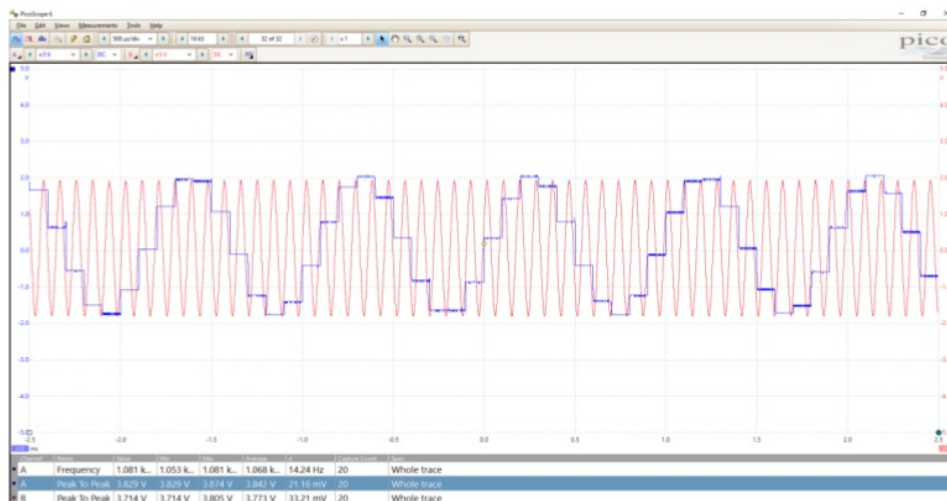


Figure 28 - 8-bit Conversion at 10kHz and 4V p-p

A table of results for both FM and ADCs would have clarified your results, especially when proving the Nyquist Criterion.

5. Conclusions and Recommendations

Using the research carried out into modulation and conversion, practical experiments were completed to ensure the theoretical predictions and expectations can be proven in practice. The two tests carried out include frequency modulation and analogue-to-digital conversion.

When completing the frequency modulation, it was found that the centre frequency was not present on the spectrum. However, the other sideband frequencies were seen and did generally correspond to the calculations completed for the amplitude of each point. Another noticeable difference between the calculations made and the practical experiment is the bandwidth. The bandwidth in the experiment is larger than that expected from the calculations. Despite the larger bandwidth, each point on the spectrum separated by the same frequency value of roughly 20kHz, which is expected given the frequency deviation and modulating frequency.

The analogue-to-digital conversion was carried out on two different bit values – 4-bit and 8-bit. This provided two different results for the same tests, allowing for comparison and analysis in performance. When testing the effect that the number of bits has on a conversion, it was noticed that the 8-bit conversion produces a much smoother response, due to there being more points on the wave. By changing the amplitude of the input signal, the conversion quality was not affected, but the converter would not operate after it reached 5 volts. This was the maximum output amplitude produced, regardless of the input amplitude and number of bits. Using a constant amplitude and a changing frequency displayed the issue with the sampling rate of the ADC. If the frequency was too high, it would not sample at a consistent rate that was often enough so fell behind and did not convert correctly. This therefore showed that the Nyquist Criterion is important and thus the frequency should never exceed half of the sampling rate.

Despite carrying out these tests, amplitude modulation could have been completed practically to compare to the frequency modulation. Further testing could be carried out into other modulation methods, such as pulse code modulation, to prove the additional research that was completed. This will give an extensive range of modulation methods to compare and determine the most effective for signal processing. Additionally, more values of bits could be tested for analogue-to-digital conversion to further prove that the quality improves with the number of bits. Again, different converters could have been tested to identify the most effective method of analogue-to-digital conversion. Another alternative would be to complete digital-to-analogue testing and research and compare the performance between each conversion direction.

6. Works Cited

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7. Appendix

FINAL GRADE

GENERAL COMMENTS

Instructor

66/100

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Text Comment. You should also include a summary of the results and main conclusions.

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Text Comment. A table of results for both FM and ADCs would have clarified your results, especially when proving the Nyquist Criterion.

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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

7/10

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 reasonably detailed and mainly accurate. There were very few gaps in your knowledge of the basic concepts and your understanding of the higher level concepts was demonstrated to a limited degree - you could have explained in more detail how the circuit evolved. Further work – Your explanations need to be more detailed and written with a greater emphasis on critical evaluation rather than description.

20/30

ANALYSIS



Your explanation of the process 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.

18/30

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally good. You used the resources available appropriately when for testing and evaluating the circuit performance. Your results were comprehensive and allowed for a good conclusion to be attempted, although tabulating results would have been beneficial.

14/20

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