

Assignment 2

by Joseff Jones

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HND Electrical and Electronic Engineering

PSDE5014 – Signals and Digital
Communications
Assignment 2 – Digital Modulation Schemes

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1. Introduction, Aims and Objectives

This second assignment of the unit focuses on digital modulation techniques – the assignment is designed around analogue to digital conversion (ADC) and pulse code modulation (PCM) baseband modulation schemes. A practical experiment was carried out into ADC which involved observing the effects of quantisation noise and aliasing, and gaining an understanding of sampling requirements. In order to gain a strong foundation of knowledge for the practical aspect of the assignment, background research was carried out into digital modulation techniques such as amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK); research into topics such as aliasing and schemes such as pulse code modulation (PCM) and pulse amplitude modulation (PAM) was also carried out.

2. Research into PCM Techniques

Research was carried out into pulse-code-modulation (PCM) techniques along with another technique called pulse-amplitude-modulation (PAM) and a number of modulation schemes such as ASK, FSK, PSK, QPSK and QAM 16. Research was also carried out into aliasing to tie in with the practical experiment.

2.1 – PCM

Modulation is the practice of altering a carrier signal's characteristics in accordance with those of a message signal, the message signal is used to transmit data and the carrier signal is a very high frequency signal which is great for long distance transmission; the modulation technique most commonly used for digital modulation is pulse code modulation (PCM).

A PCM output will comprise of 1s and 0s to become a binary sequence, whereas the input will be analogue i.e. a range of values – the figure below (obtained from www.tutorialspoint.com) shows this.

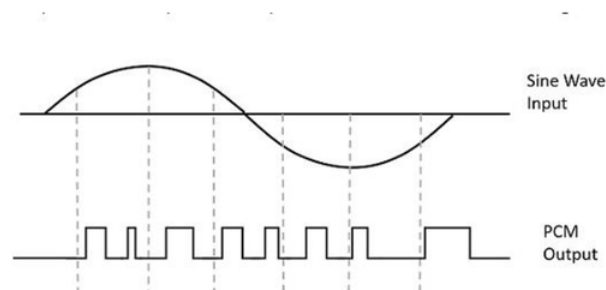


Figure 1 - PCM Output Based on Sine-Wave Input

With pulse code modulation, a sequence of coded pulses represent the signal to be transmitted. The message signal can be deciphered to produce a series of digits to form a binary code; the binary code can be deciphered to identify the amplitude of a signal at any instantaneous value.

Basic elements of PCM

In order to prepare the carrier signal for transmission, a PCM's transmitter consists of sampling, quantizing and encoding elements which are deployed during the analogue to digital conversion. A low pass filter is used just before sampling to reduce aliasing between the carrier signal and message signal.

Once the carrier signal (containing the message signal) is transmitted, the receiver will pick up the signal which will then have an element which regenerates the transmitted signal, an element which decodes the signal and then another element which reconstructs the signal so that it's legible. The block diagram in figure 2 displays the above process (block diagram obtained from www.tutorialspoint.com).

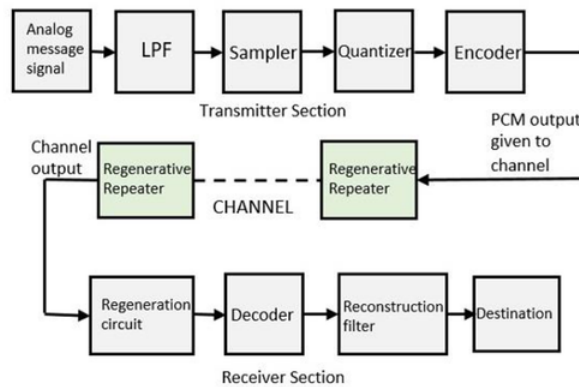


Figure 2 - Block Diagram of Process of PCM

Low-Pass Filter

The low-pass filter is used to prune frequencies found at the input which are greater than the largest frequency of the message signal; this is done to avoid the aliasing of signals.

Sampler

The sampler is the device which collects the sample points of the message signal which are vital to reconstruct the original signal at the receiver end. In accordance with the Nyquist-Shannon sampling theorem, the sampling rate must be at minimum twice the size of the largest frequency found at the input.

Quantizer

The quantizer is used to remove excess or unimportant bits of the sampled data, making the signal smaller in size and thus increasing the chance that the signal will be transmitted properly.

Encoder

The encoder is the main part of the transmitter to convert the signal from analogue to digital – it uses the signal produced by the quantizer and then designates each quantized level an unique binary code – the greater bits the encoder has, the higher in accuracy the signal will be.

Regenerative Repeater

The regenerative repeater is used once to increase the signal strength before transmission, and then again at the receiving end to once again increase signal strength to compensate for any signal loss that might have occurred and also to reconstruct the signal.

Decoder

In order to make use of the encoded signal that was transmitted, a decoder must be used to decipher the code and reproduce the original signal's waveform.

Reconstruction Filter

Typically a low-pass filter, the reconstruction filter is used to reconstruct the transmitted signal back to its original form.

2.2 – PAM

PAM, or pulse amplitude modulation, is a way of modulating a carrier signal using pulses which are manipulated by the carrier signal's amplitude. It works by having a sampler take samples of the input signal at frequent intervals where each sample represents the amplitude of the carrier signal at instantaneous values. The figure below shows this effect in detail (obtained from elprocus.com).

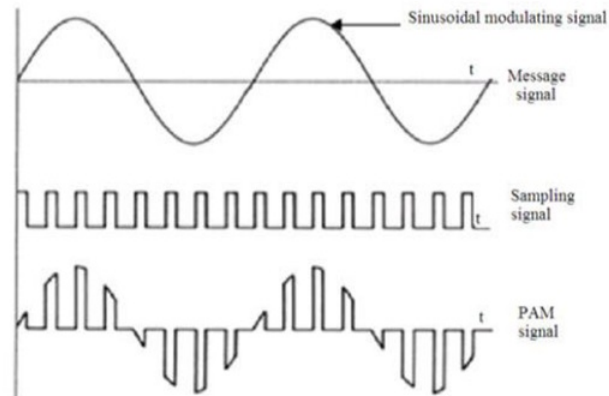


Figure 3 - PAM Effects

PAM is used for a number of applications such as Ethernet communication, micro-controllers and motors.

The advantages of PAM come with its simplicity - modulation and demodulation is a simple process and the construction of transmitter and receiver circuits is relatively simple. "PAM can generate other pulse modulation signals and can carry the message at the same time" (Pulse Amplitude Modulation, 2018).

The disadvantage of PAM is that there needs to be a large bandwidth for transmission, there is some significant noise and the power required for transmission will vary with the pulse amplitude's signal.

There are a total of two types of PAM and a total of two types of sampling techniques for PAM – the two sampling techniques are flat top PAM and also natural PAM.

Flat top PAM is a type where the amplitude of the signal is precisely as sampled, and the top of the amplitude remains flat, see figure below.

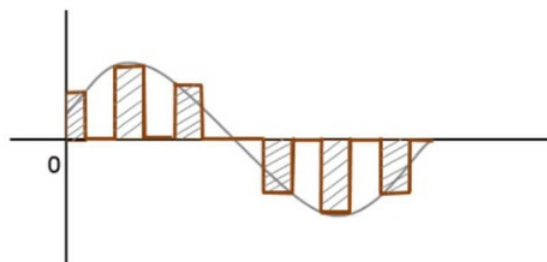


Figure 4 - Flat-Top PAM

Natural PAM is where the pulse is followed by the amplitude of the pulse, making it more accurate. Natural PAM is shown in the figure below.

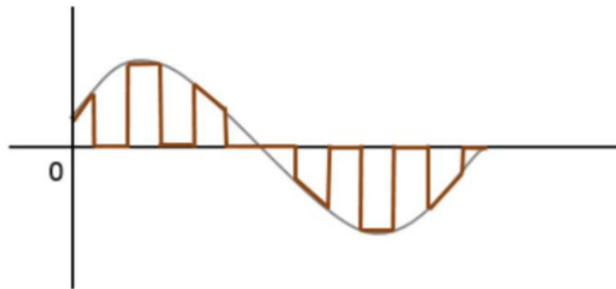


Figure 5 - Natural PAM

The two types of techniques for PAM are single and double polarity PAM.

“Single polarity PAM is a situation where a suitable fixed DC bias is added to the signal to ensure that all the pulses are positive” (Pulse Amplitude Modulation, 2018) whereas double polarity PAM is where the signal’s pulses are both negative values and positive values.

2.3 – Aliasing

Aliasing is a negative phenomenon that occurs when a signal is sampled at more than half the highest frequency found at the input of the signal. The effect of aliasing is to produce inaccurate sampled waveforms and sampled frequencies that are much lower than the actual frequency – for example, a 5kHz sine wave being sampled at 3kHz would produce a 2kHz sine-wave.

Aliasing occurs because sampling at two or fewer times per sine-wave cycle means cycles are missed, and that produces inaccurate readings which means a lower frequency is measured than there actually is. Aliasing can be countered using an anti-aliasing low-pass filter, which limits the frequency range of the input signal so that the maximum frequency does not exceed half of the Nyquist frequency, which is the sampling frequency of the device.

2.4 – Modulation Schemes

Modulation is the act of changing a carrier signal waveform using a modulating signal that contains information to be transmitted. Some common modulation schemes are described below.

PSK

Phase-shift-keying, or PSK, modulates a carrier signal by changing its phase. The modulation is done by altering sine and cosine inputs at a specific time. With PSK, a sine-wave signal has its phase assigned an unique binary digit, and typically every phase will have the same amount of bits. With too many bits PSK can prove ineffective. The receiver of the PSK needs to compare the transmitted signal's phase with a reference signal, this type of system is termed coherent or CPSK. Some common uses for PSK are local area networks and Bluetooth connections.

ASK

Amplitude-shift-keying, or ASK, is a form of modulation that modulates the carrier wave's amplitude. The carrier signal is transmitted when a fixed amplitude and frequency are triggered for a set duration. Similarly to the PSK, the ASK assigns binary values, except the ASK assigns these values to a finite number of amplitudes. ASK is relatively inexpensive but is prone to distortion. The most common form of ASK is called on-off keying (denoted as OOK) and is useful for transmitting binary by using a carrier wave's presence to indicate a 1 and otherwise a 0. ASK is best used for simple applications such as transmitting basic codes such as Morse code.

FSK

Frequency-shift-keying, or FSK, is a modulation scheme that alters the frequency of the carrier signal in accordance with the carrier signal. The FSK modulates the wave so that the when the modulated was has a high frequency it is indicating a 1 and when the is at a low frequency it is indicating a 0. "The binary 1s and 0s are called Mark and Space frequencies" (Frequency Shift Keying, 2018). FSK is used for communications such as amateur radio and emergency broadcasts.

QPSK

Quadrature phase shit keying, or QPSK, is similar to phase-shift keying, except it transmits two binary digits at a time – these digits come in the form of 00, 01, 10 or 11. This is possible because there are four separate phase states i.e. 45° , 135° , 225° and 315° . QPSK is better than most other forms of modulation schemes because is allows for a much higher bandwidth frequency.

QAM-16

Quadrature amplitude modulation, or QAM, utilizes ASK on two carrier waves to transmit two separate message signals or bitstreams. The two carrier waves need to be of the exact same frequency, but also phase-shifted from one another by 90° . The two modulated waves are combined and result is a mix of PSK and ASK. Using the amplitude and phase, it's possible to convey a large amount of data – QAM 16 is a form of QAM that has 16 possible variations to transmit based on the amplitude and phase, the figure below shows where the data is stored along the phase.

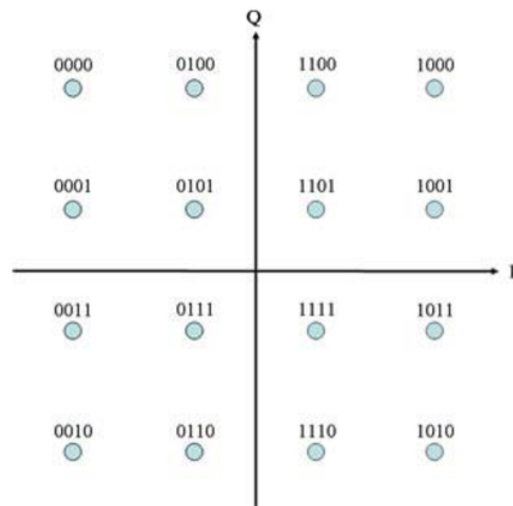


Figure 6 - QAM16

QAM is extremely popular for digital telecommunications as it is effective for transmitting a large amount of data.

3. Experimental Method

The practical aspect of the assignment involved an experiment which exemplified the behaviour of ADCs and their functionalities along with their limitations first-hand. The experiment involved witnessing the effects of changing the number of bits of the ADC, changing the input amplitude for 8-bit and 4-bit ADC's at a constant frequency, and the effects of changing the frequency of the input with a constant amplitude. The sample rate for the ADC was 10kHz and the range was 5Vp-p.

A diagram of the setup for the experiment (taken and altered from the ADC experiment.pdf) can be seen in the figure below.

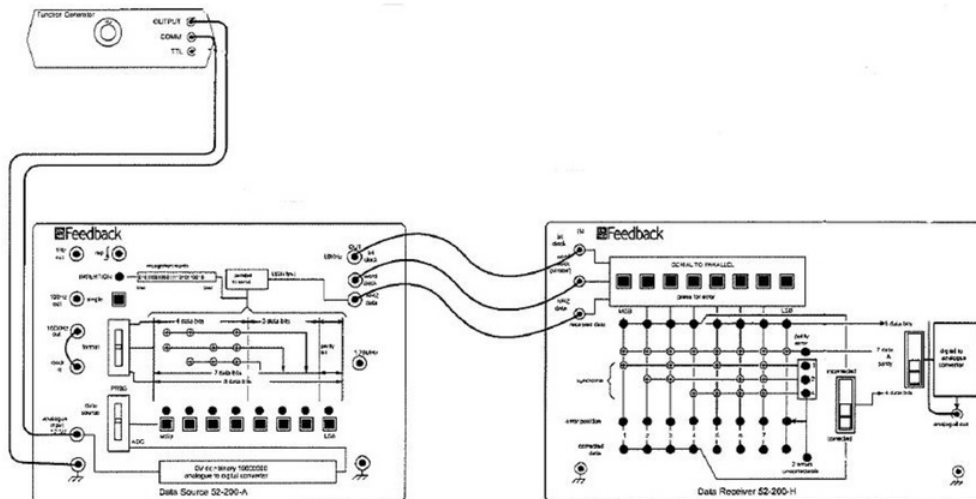


Figure 7 - Practical Experiment Diagram

Effect of Changing the Number of Bits of the ADC

The first thing to be tested was the effect of changing the number of bits of the ADC. This involved first setting the ADC to an 8-bit output with the input frequency set to 100Hz @ 4vp-p; once this was done the ADC was then set to 4-bit and the output was observed.

Effect of Changing the Input Amplitude

The next thing to be tested was the effect of changing the input amplitude for 8-bit and 4-bit ADC's with a constant frequency. This involved setting the input frequency to 100Hz @0V and observing the output. Following this the amplitude was increased in small values and the values at which a new quantisation level is needed were recorded. The resolution of the ADC was then calculated using the following formula:

$$\frac{\text{max value}}{\text{increment value}}$$

This test was then repeated with an 8-bit output, but the levels of quantisation were too small to be recorded.

Effect of Changing the Input Frequency

The final thing to be tested was the effect of changing the input frequency with the amplitude held constant. This involved first setting the ADC to an 8-bit output, and setting the input frequency to 100Hz @4V p-p. On the Picoscope software, red and blue channel frequencies were added in order to compare frequencies. The frequency was increased from 100Hz to 1KHz then 2kHz etc. and outputs were observed at each frequency. The function generator was then set to 4KHz, where the dial was used to increase the frequency in increments of 1kHz to get to 6KHz and then was set to a larger value. Any significant behavioural changes were noted and commented upon.

The experiment was carried out in a group of three, where one member of the group would get measurements using the Picoscope software and take screenshots for evidence and the other two members would set-up the practical to attain the desired outputs while keeping written notes on observations of the practical experiment.

4. Testing and Results

Once the practical rig was set up, the tests for testing the effects changing the number of bits, amplitude and frequency were carried out and a number of results were obtained – this section includes the results of the testing.

The first effect to be observed was the effect of varying the number of bits. To begin, the function generator was set to 100Hz at 4.16V (it was meant to be 4V but the equipment was difficult to calibrate) and the ADC was set to 8-bit. The screenshot for that is shown below.

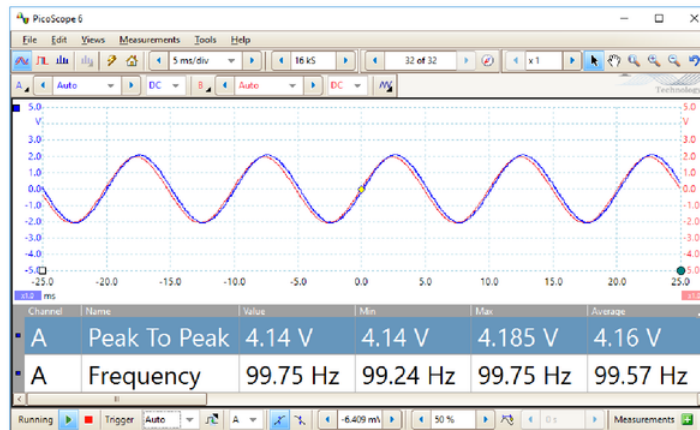


Figure 8 - Practical Experiment 4.16V 8-bit ADC @100Hz

Next, the ADC was set to 4-bit.

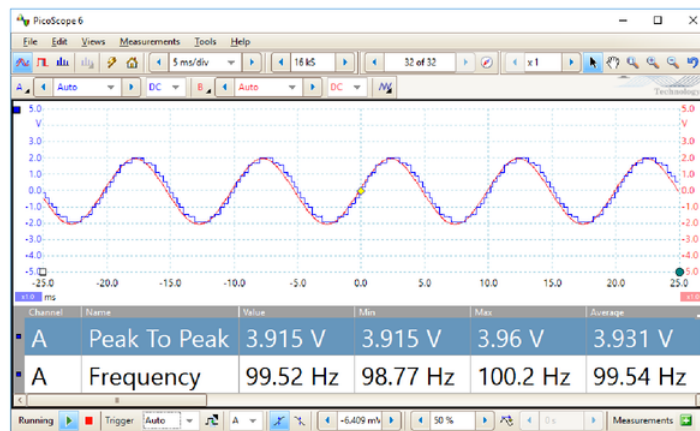


Figure 9 - Practical Experiment 3.915V 4-bit ADC @100Hz

The effect of reducing the number of bits in the ADC was a far less smooth produced waveform, and a stepping effect is observed. This was caused because when there are 8-bits, there $2^8 = 255$ number of steps that are recording values and when there are 4-bits there are only $2^4 = 15$.

The next effect that was observed was the effect of changing the amplitude for 8-bit and 4-bit ADCs with a constant frequency. Firstly, the ADC was set to 4-bit and the input frequency was set to 100Hz @ 333mV (which was as close to 0V as the equipment allowed). The resulting waveform can be seen in the figure below.

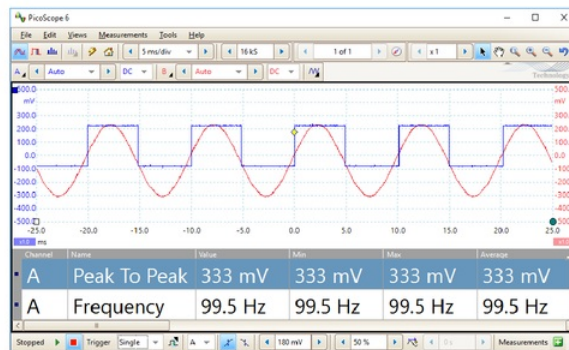


Figure 10 - Practical Experiment 4-bit 333mV @ 100Hz

Next, the amplitude was gradually increased – once the amplitude got to 680mV the number of quantisation levels of the amplitude increased, this can be seen in the figure below.

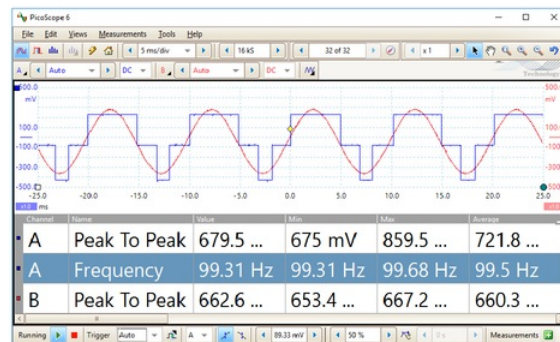


Figure 11 - Practical Experiment 4-bit 720mV @ 100Hz

The amplitude was further increased to 1V and the quantisation level increased again, resulting in five quantisation levels, this is shown in the figure below.

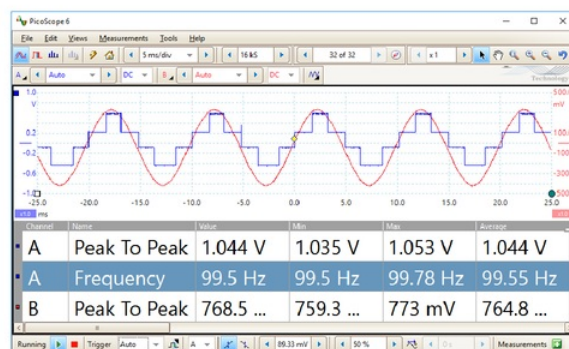


Figure 12 - Practical Experiment 4-bit 1V @ 100Hz

Once more, the amplitude was increased until the quantisation level increased further to show seven total quantisation levels, this can be seen in the figure below.

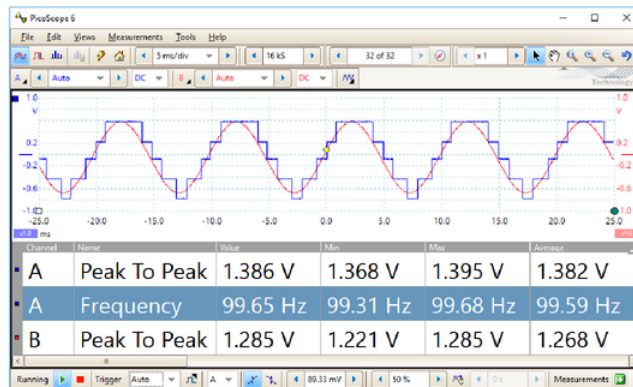


Figure 13 - Practical Experiment 4-bit 1.4V @ 100Hz

This behaviour continued all the way until the maximum amount of quantisation levels were hit and the once the amplitude exceeded that value, the top of the quantised level would just be a flat-line, shown in the figure below.

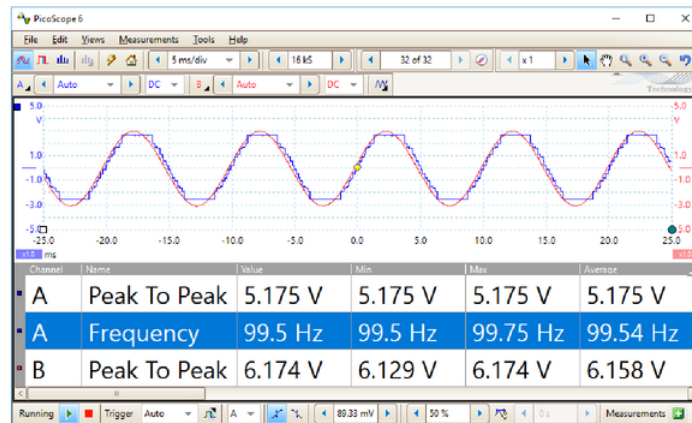


Figure 14 - Practical Experiment 4-bit 5.175V @ 100Hz

The amount of quantisation levels seem to increment every ~340mV and the maximum value at which it incremented seemed to be 5V, using this it's possible to estimate the resolution of the ADC using:

$$\frac{5}{0.34} = 14.7$$

The resolution should be $2^4 = 15$ but since the increment value and maximum value were not accurately measured, 14.7 is close enough to assume that this is correct.

The effect was repeated for 8-bit, but the quantisation levels were so small it wasn't possible to get values accurate enough to determine the resolution.

The next test was to test the effect of changing the frequency of the input with a constant amplitude. The input was first set to 8-bit 100Hz @ 4V p-p, as seen in the figure below.

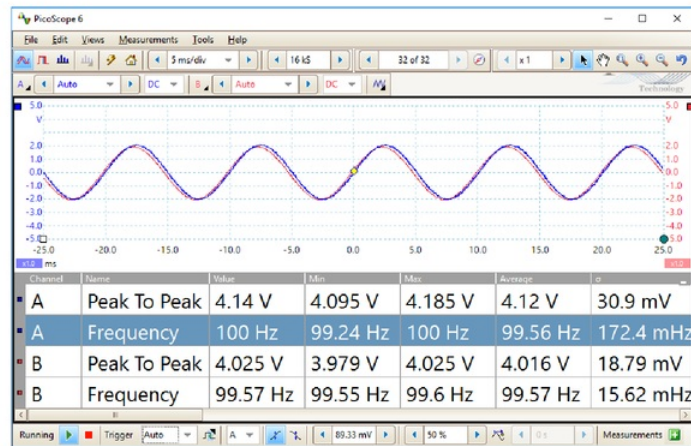


Figure 15 - Practical Experiment 8-bit 4V @ 100Hz

Channel A is in blue and is the input that the ADC is measuring and channel B is in red and is the actual input. Next, the frequency was increased from 100Hz to 1kHz and the effect was observed, shown in the figure below.

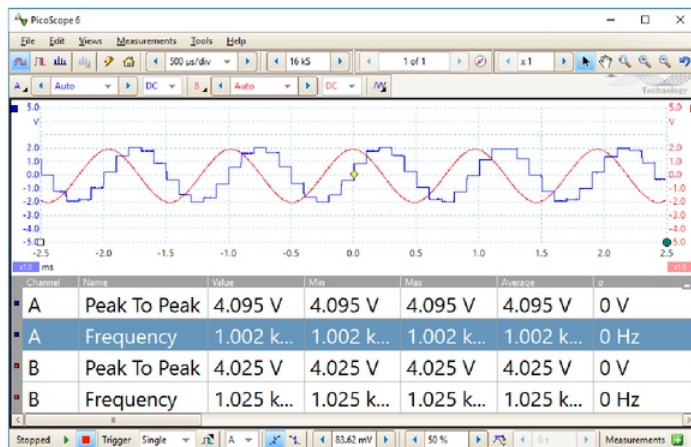


Figure 16 - Practical Experiment 8-bit 4V @ 1kHz

Increasing the frequency caused the sample to create a step-like output on channel A. The amplitude is measured quite accurately and so is the frequency. Next, the frequency was increased to 2kHz, shown in the next figure.

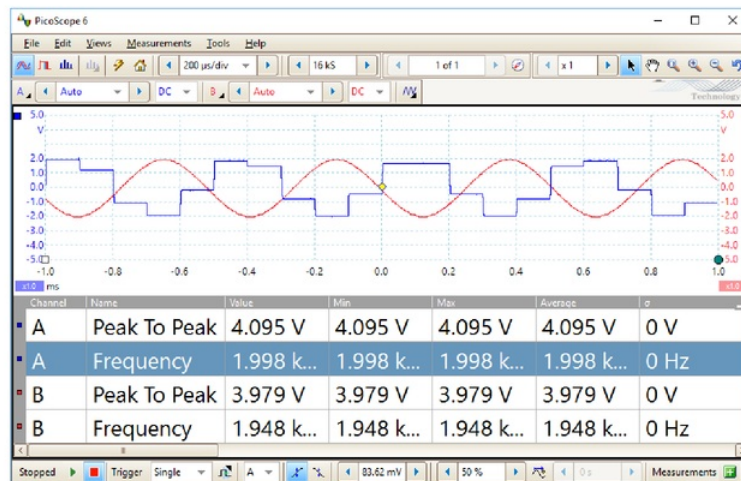


Figure 17 - Practical Experiment 8-bit 4V @ 2kHz

Increasing the frequency further resulted in another stepped-waveform, but with fewer steps this time. Both the amplitude and frequency were measured relatively accurately by channel A. The frequency was increased to 3kHz, shown in the figure below.

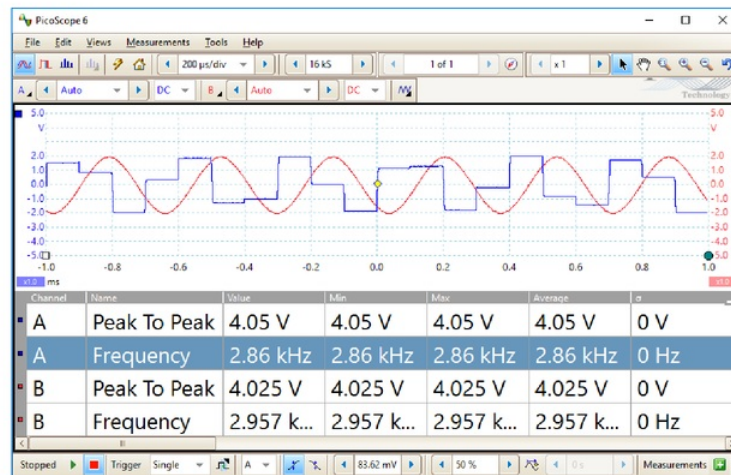


Figure 18 - Practical Experiment 8-bit 4V @ 3kHz

At 3kHz, the ADC measured the frequency to be at 2.86kHz when it was in fact at 3kHz. The produced waveform is completely inaccurate, but the amplitude remains accurate. Next, the frequency was increased to 4kHz.

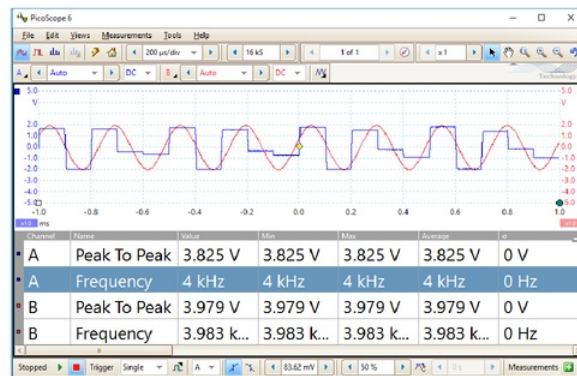


Figure 19 - Practical Experiment 8-bit 4V @ 4kHz

The frequency was set to 4kHz and the ADC measured the correct frequency and amplitude, but the produced waveform was still inaccurate.

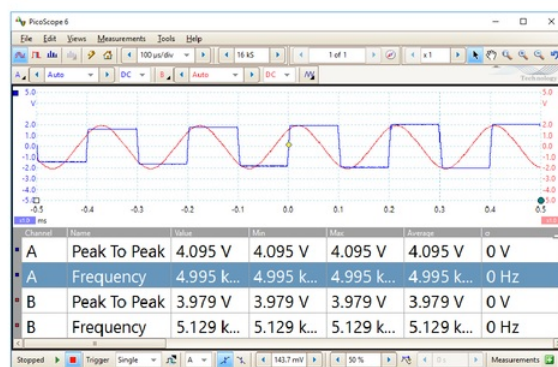


Figure 20 - Practical Experiment 8-bit 4V @ 5kHz

The frequency of the input was set to a little over 5.1kHz but the maximum frequency that was recorded by the ADC was 5kHz; the waveform was essentially just a square-wave at this point.

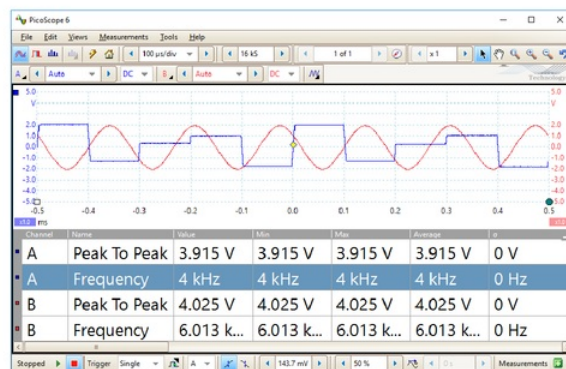


Figure 21 - Practical Experiment 8-bit 4V @ 6kHz

Increasing the frequency of the input to 6kHz resulted in the ADC measuring a frequency of 4kHz; this was wrong and indicated that the maximum value the ADC could measure was 5kHz.

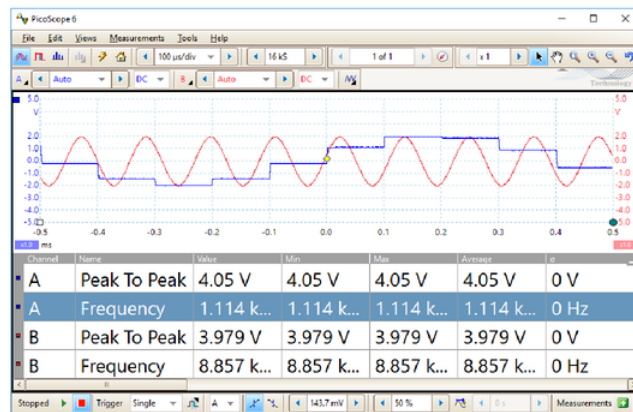


Figure 22 - Practical Experiment 8-bit 4V @ 8.9kHz

When the frequency was pushed much further above 5kHz to 8.9kHz as seen in the above figure, the result was a step-effect caused by aliasing.

The effects of increasing the frequency of the input were: inaccurate waveform representation, aliasing and inaccurate readings of frequency above 5kHz. Because the readings were inaccurate above 5kHz and because the ADC produced a nearly perfect square waveform at 5kHz, this would indicate that the ADC had a sampling rate of 5kHz which is double the maximum value. This proves that Nyquist-Shannon's sampling theorem is correct and that the sampling rate needs to be double the max value in order to accurately measure frequency.

5. Conclusions

With regards to the practical, several effects were observed and recorded. The first effect was the reduction in bits – when the number of bits in the ADC was reduced, the waveform became far less smooth and produced a step-effect. This was caused because when there are 8-bits, there $2^8 = 255$ number of steps that are recording values and when there are 4-bits there are only $2^4 = 15$. The second effect was the effect of changing the amplitude – what would happen is that the quantisation level would increase every 340mV or so, and at 5V the quantisation level wouldn't increase any further and would instead produce a flat-line at 5V. This allowed the estimation of the ADC using:

$$\frac{5}{0.34} = 14.7$$

The resolution should've been $2^4 = 15$ but since the increment value and maximum value were not accurately measured, 14.7 is close enough to assume that this is correct. The final effect to be observed was the effect of altering the frequency - the effects of increasing the frequency of the input were: inaccurate waveform representation, aliasing and inaccurate readings of frequency above 5kHz. Because the readings were inaccurate above 5kHz and because the ADC produced a nearly perfect square waveform at 5kHz, this would indicate that the ADC had a sampling rate of 5kHz which is double the maximum value. This proves that Nyquist-Shannon's sampling theorem is correct and that the sampling rate needs to be double the max value to accurately measure frequency.

The research proved useful when tackling the practical, especially the research into aliasing as aliasing occurred during the practical when altering the frequency.

6. Reference List and Bibliography

References

Frequency Shift Keying. (2018, April 20). Retrieved from tutorialspoint.com:

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

Pulse Amplitude Modulation. (2018, 4 20). Retrieved from elprocus.com:

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Assignment 2

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

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JOSEFF JONES**70****RESEARCH-INFORMED LITERATURE**

There was some evidence of further reading and research from credible and reliable sources. Your interpretation and understanding of the additional research was good and demonstrated an underlying appreciation of the subject. Your references still rely on a small selection of sources and you need to include more in-text references.

6**KNOWLEDGE AND UNDERSTANDING**

The knowledge and understanding of the subject demonstrated by this assignment was generally very good. There were very few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was very good. Your research and explanation was particularly good and extended your knowledge well beyond that contained in the course notes.

21**ANALYSIS**

Your analysis of the task was generally very good, both in class and as shown in this assignment. You have demonstrated very good analytical skills and your approach to the task was logical. You carried out a detailed evaluation of the results and included

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a good conclusion relating the practical results to researched theory.

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally very good. You used the resources available appropriately when conducting the experiment and you used appropriate options for testing and evaluating the circuit performance. Your results were comprehensive and allowed for a good conclusion to be attempted.

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SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was of an appropriate length, you could however be more efficient with your word count. The report was well presented, with good diagrams in appropriate places, good sentence/paragraph structure and clear calculations.

7