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by Jordan Rees

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Assignment Title: Signals and Modulation

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- ① RESEARCH WAS OK, BUT RANGE OF SOURCES WAS LIMITED.
- ② KNOWLEDGE WAS SKETCHY AT TIMES IN BOTH THE RESEARCH AND THE EXPERIMENT.
- ③ BOTH PRACTICALS WERE CARRIED OUT SUCCESSFULLY.
- ④ CONCLUSIONS + ANALYSIS WERE TOO DESCRIPTIVE. YOU COULD HAVE ANALYSED WHY IT IS IMPORTANT TO MATCH AN IOL TO THE DATA.
- ⑤ SOME DIAGRAMS SHOULD HAVE BEEN IN THE TEXT RATHER THAN THE APPENDIX OF SPECTRUM ANALYSIS GRAPH.

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1. Executive Summary

In this assignment research was done on Amplitude and frequency modulation, ADCs, PAM and PCM and digital communication system SDH. Experiment 1 was then carried out which included calculations that would be compared to the practical tests done. The practical tests were set up using test equipment where the FM waveforms were shown. Analysis of the results was then done. Experiment 2 was to analyse ADCs. Such as the difference in quality of conversion between 4 and 8 bit convertors. The importance to match the amplitude of the input signal to the range of an ADC and the relationship between the input signal frequency and the sampling rate of the ADC. Analysis was done on these tests and compared to the established theory. A conclusion was then done to explore what was learnt during the assignment.

2. Research into analogue and digital communication systems and techniques (1000)

2.1 Amplitude and frequency modulation techniques

Modulation is when the frequency, amplitude or phase of a carrier wave changes in compliance with the signal's intensity. Below are 2 types of modulation techniques.

2.1.1 Amplitude modulation (AM)

3 useful points for Amplitude modulation is when the amplitude of a high frequency carrier wave is adjusted in compliance with the intensity of the signal. The amplitude of the carrier wave varies at the signal frequency (f_s). Only the amplitude of the carrier wave is changed in amplitude modulation and the frequency stays the same. This is called carrier frequency (f_c).

Figure 1 shows the audio electrical signal. Figure 2 shows the constant amplitude carrier wave. Figure 3 shows the amplitude modulated wave. These can be found in the appendix

The amplitude of the half cycles positive and negative is changed in compliance with the signal. For example, ~~when~~ when the signal increases positively the amplitude of the carrier wave also increases. When the half cycle is negative the carrier waves amplitude decreases.

An important factor in amplitude modulation is the modulation factor. This is to determine the peak variation ratio used, this is dependant on the maximum design variation of the certain type of modulation. The maximum design variation is when the instantaneous amplitude of the modulated signal gets to 0. Below is the equation for the modulation factor.

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

Equation 1: Modulation factor

There are some limitations to using AM such as:

Noisy reception.

This is because the amplitude variations are within the signal. The radio signal cannot distinguish between the desired signal and the amplitude variations.

(its.bldrdoc, 2021) (byjus, 2022) (demodulation, 2021)

AM PRODUCES A MODULATION ENVELOPE WHICH IS A COMPLEX WAVEFORM WITH f_c , $f_c + f_m$, $f_c - f_m$

2.1.2 Frequency modulation

In frequency modulation Only the frequency of the carrier wave is adjusted in accordance with the signal in frequency modulation. The variation of the carrier waves frequency is dependent on the signal's instantaneous amplitude. This is shown in figure 4 in the appendix. As you can see at A, C, E and G the signal voltage is at 0 therefore the carrier frequency is unchanged. At B and F, the signal is at its peak, therefore it is at max carrier frequency. When the signal is at its lowest at D the carrier frequency is at its minimum. Frequency modulation is mostly used over a smaller distance. The frequency modulation index is mostly over 1. A high bandwidth range is used of 200KHz. It works off a high frequency range that varies between 88-108 megahertz. It uses an infinite amount of side bands. The signal and sound received from FM is of high quality. Examples of where FM is used is in FM radio broadcasting, magnetic tape-recording systems, radar and videoing transmission systems. (demodulation, 2021) (heavy.ai, 2022)

FM IS NOT RESTRICTED TO THESE FREQUENCIES.

2.2 Development of digital communication techniques

2.2.1 Analogue to digital convertors (ADCs)

ADC are used to convert an analogue signal into a digital signal so that it can be read by certain systems for example a microcontroller cannot read analogue values only digital. This is because microcontroller can only see "levels" of voltage. There are 2 factors that determine the voltage levels these are the ADC's resolution and the voltage of the system. Digital signals are shown by a series of separate values where the signal is broken down into sequences which is dependent on sampling rate or the time series. Figure 5 in the appendix shows an analogue and digital signal. There are a steps that takes place when converting analogue to digital signals in an ADC. Firstly, the signal is sampled it is then quantified so that the signals resolution can be determined. Then the binary values are set and sent to the system so that the digital signal can be read.

The important aspects of an ADC are its resolution and sampling rate or (sampling frequency). The sampling rate of the ADC is tied to its speed. The sampling rate is measured by "samples per second" which is in SPS, S/s or Hz for frequency. This is how many data points or samples it takes per second. If the sampling rate is higher, it means it can handle higher frequencies. If the sample rate of an ADC is low and the frequency is high it can cause aliasing which is when the ADC cannot reconstruct the original analogue signal. This means that the incorrect data will be read by the system. An example of this is shown in figure 6 of the appendix. As you can see the sampling rate is not able to keep up with the analogue input which causes incorrect data to be read. A way to figure out if aliasing will occur is to use Nyquist theorem. This states that the sampling rate should be twice as much

as the highest signal frequency. Below in equation 2 shows the equation used. Low pass filters can also be used in the system to reduce unexpected frequencies from outside noise.

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

Where,

$f_{Nyquist}$ = Nyquist frequency

f_{Max} = The max frequency that appears in the signal

Equation 2: Nyquist theorem equation

The resolution of the ADC is the length of the bits of the ADC. The more bits the more precise the system will be. In figure 7 of the appendix is the digital output of different resolutions. As you can see a 1 bit has only 2 levels. As the number of bits is increased it makes the signal more accurate to the original analogue signal. The resolution is dependant on the voltage and bit length. (Arrow, 2018) (elprocus, 2013) (Tutorials, 2021)

2.2.2 Pulse amplitude modulation (PAM)

Pulse amplitude is when the pulse's amplitude is controlled by the modulation signals instantaneous amplitude. This signal is sampled at intervals which is then made proportional to the instantaneous amplitude of the signal. Doing this allows the transmission of data by encoding the amplitude over a sequence of signal pulses. In figure 8 of the appendix shows the PAM signal.

There are 2 types of PAM these are:

Flat Top PAM

At the pulse occurrence the amplitude is directly proportional to the amplitude of the modulating signal. The signals amplitude cannot be changed with reference to the analogue signal that is being sampled.

Natural PAM

At the pulse occurrence the amplitude is directly proportional to the amplitude of the modulating signal. For the rest of the half cycle, it then follows the amplitude of the pulse. Based on the modulating signal the signals amplitude can be changed. Below is the natural PAM equation.

$$u_p(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos \frac{2\pi n t}{T_s}$$

A LITTLE HIGH NOW

$$= a_0 + a_1 \cos \frac{2\pi n t}{T_s} + a_2 \cos \frac{4\pi n t}{T_s} + \dots$$

Equation 3: PAM equation

(elprocus, 2013)

Synchronous Digital Hierarchy (SDH)

As stated by Andrew Zola "Synchronous Digital Hierarchy (SDH) is a group of fiber optic transmission rates that transport digital signals with different capacities". (Zola, 2021) SDH combines high rate and low bit rate data streams. Due to the network being synchronous users can extract individual bit streams easily. This system was put in place instead of Plesiochronous Digital Hierarchy (PDH) this is because SDH provides faster and cheaper network interconnections. There are many uses for SDH these are: transporting Asynchronous Transfer Mode cells, transmission systems for broadband, PDH signals, Ethernet aggregations, and other communication signals. The main reason SDH was developed is to reduce synchronization problems for telephone and bulk data exchanges. The rate of data transfer is also increased. ✓

3. Experimental method for experiment 1

In experiment 1 frequency modulation. A 455kHz carrier has an amplitude of 375mV which is frequency modulated by a 10kHz square wave signal with a 2V amplitude. In this experiment the FM transfer characteristic will be 20kHz per volt.

3.1 Maximum frequency deviation and modulation index

To calculate the maximum frequency deviation (Δf) an equation is used. This is shown in the equation below.

$\Delta f = \text{modulator transfer characteristic} \times \text{message amplitude}$

$$\Delta f = 20\text{KHz} \times 2 = 40\text{KHz}$$

Equation 4: Maximum frequency deviation

To calculate the modulation index an equation is used. This is shown in the equation below.

$$mf = \frac{\Delta f}{f_s} = \frac{40\text{KHz}}{10\text{KHz}} = 4$$

Equation 5: Modulation index

3.2 Amplitude values and diagram

After working out mf the coefficients can then be worked out for the amplitude values at different frequencies. These are shown below.

$$J_0=0.4, J_1=0.07, J_2=0.36, J_3=0.43, J_4=0.28, J_5=0.13, J_6=0.05, J_7=0.02.$$

To calculate the amplitude the equation below was used.

$$EC \times J_0-J_7.$$

Equation 6: Amplitude equation

This equation was then applied to do the different frequencies shown below.

$$\text{At } 455\text{KHz } EC \times J_0 = 375\text{mv} \times 0.4 = 150\text{mv}$$

$$\text{At } 445 \text{ and } 465\text{KHz } EC \times J_1 = 375\text{mv} \times 0.07 = 26.25\text{mv}$$

$$\text{At } 435 \text{ and } 475\text{KHz } EC \times J_2 = 375\text{mv} \times 0.36 = 135\text{mv}$$

$$\text{At } 425 \text{ and } 485\text{KHz } EC \times J_3 = 375\text{mv} \times 0.43 = 161.25\text{mv}$$

$$\text{At } 415 \text{ and } 495\text{KHz } EC \times J_4 = 375\text{mv} \times 0.28 = 105\text{mv}$$

$$\text{At } 405 \text{ and } 505\text{KHz } EC \times J_5 = 375\text{mv} \times 0.13 = 48.75\text{mv}$$

$$\text{At } 395 \text{ and } 515\text{KHz } EC \times J_6 = 375\text{mv} \times 0.05 = 18.75\text{mv}$$

WHERE DID
THESE VALUES
COME FROM?

THIS SHOULD GO IN
THE APPENDIX AND THE
GRAPH PUT HERE. THIS
WOULD IMPROVE READABILITY.

At 385 and 525KHz $EC \times J7 = 375\text{mv} \times 0.02 = 7.5\text{mv}$ ✓

With these values a diagram can be made showing the bandwidth against the amplitude. This is shown in figure 9 in the appendix.

3.3 Practical experiment

A practical experiment was carried out to see if the calculated values match. In figure 10 of the appendix shows the set up for the test equipment. The amplitude on the modulation generator was then reduced in 2V steps and the frequency deviation was recorded. This is shown in figure 11-13 in the appendix.

NOT REQUIRED FOR THE ASSIGNMENT.

The side frequencies and bandwidth were then recorded on a spectrum analyser this is shown in figure 14 of the appendix.

EQUIPMENT WAS SET UP AS PER THE ASSIGNMENT SPECIFICATION AND A SPECTRUM ANALYSER WAS USED TO DISPLAY THE COMPONENTS, THIS IS SHOWN IN FIGURE 14.

4. Testing, results and analysis for experiment 1(300)

When looking at the results from the experiment and the calculations it shows that all results match. These results also backed by the research done on FM this proves that the experiment and calculations are correct. On figure 11 in the appendix. The voltage is 2Vp-p.

NOT NEEDED.

The frequency is at 350.5KHz. If you compare this to figure 12 the 4Vp-p this has 418.4KHz and figure 13 6Vp-p which has a frequency of 519.5KHz. It shows that the higher the p-p

voltage the higher the frequency which is backed by research which states "the frequency of the carrier wave is adjusted in accordance with the signal in frequency modulation. The variation of the carrier waves frequency is dependent on the signal's instantaneous amplitude." In figure 14 the graph shows the amplitude against the bandwidth, this matches the calculations which proves that the experiment was done correctly.

YOU NEED TO COMPARE THE RESULTS WITH THEORY, & A TABLE OR OVERLAY THE GRAPHS.

5. Experimental method for experiment 2 (200)

In this experiment the difference in the quality of conversion between 4- and 8-bit converters was analysed along with the importance of matching the amplitude of the input signal to the range of the ADC and the relationship between the input signal frequency and sampling rate of the ADC. In figure 15 of the appendix shows the set up for the test equipment. The sample rate of the ADC is 10,000 samples/second and a range of 5Vp-p ✓

WASTED
WORDS
AS THEY
ARE
REPEATED
LATER.

The first procedure was to see the effect of changing the number of bits on the ADC. The ADC was firstly set to 8bits and the frequency at 100Hz at 4Vp-p. This is then repeated but at 4 bits. In figure 16-17 of the appendix shows the 4 bit and 8 bit output.

The second procedure was to change the input amplitude for the 4 and 8 bit ADC with a constant frequency. The input frequency was set to 100Hz at 0V. The amplitude was then increased up to 6Vp-p in increments the output was then observed. This is shown in figure 18-25 in the appendix.

The third procedure was to see the effect of changing the input frequency with the amplitude held constant. This was done by increasing the frequency in decades from 100Hz to 1MHz at 4Vp-p. This is shown in figure 26-30 in the appendix.

The fourth procedure was to set the function generator to 4Khz and increase the frequency in 200Hz steps to 6KHz then 1KHz steps to 10KHz and see any change in the waveforms. This is shown in figure 31-44 in the appendix.

6. Testing, results and analysis experiment 2 (300)

HEADING

The first procedure was to see the effect of changing the number of bits of the ADC. With the 4 bit ADC shown in figure 16 of the appendix. The accuracy of the wave is low this is because in a 4bit ADC there are only 16 levels. Therefore, the amount of data extracted from the analogue signal is less. In an 8 bit ADC there is a better resolution, this is because with an 8 bit there is 256 levels therefore more data can be extracted from the analogue signal therefore the output will be more accurate and more closely represent the analogue signal.

This is shown in figure 17 of the appendix. If you compare the 4 bit and 8 bit the 8 bit gives a more accurate output compared to the 4 bit. This is also backed by the research.

→ A LOWER FREQUENCY WOULD HAVE GIVEN BETTER RESULTS.
HEADING

The second procedure was to see the effect of changing the input amplitude for the 4 bit and 8 bit ADC with a constant frequency. In figure 18 of the appendix shows a 4 bit with a 0vp-p input amplitude. As the ADC is a 5Vp-p the whole range of the ADC is not being used therefore it is inefficient and won't give an accurate representation of the waveform. As the voltage is being increased to 2vp-p and 4vp-p shown in figure 19-20 of the appendix more of the range of the ADC is being used which will give a more accurate output waveform. It is also more efficient due to the whole range of the ADC is being used. In figure 21 of the appendix the input amplitude is increased to 6Vp-p which is higher than the range of the ADC. When this happens the whole input signal cannot be sampled which is proven by the graph. The same test was then repeated for an 8 bit ADC. As shown in figure 22 of the appendix at the 0vp-p. Due to the number of bits being increased more data can be extracted from the input signal which will give a more accurate output than the 4 bit ADC at

0Vp-p. But due to the input amplitude being 0V the accuracy is still low. As the p-p is increased in figure 23-24 in the appendix. A more accurate output wave is being produced. This is because the number of bits has increased and more range of the ADC is being used. Once again in figure 25 in the appendix the input amplitude is at 6Vp-p which is more than the range of the ADC therefore not all of the data from the input signal can be extracted which will give you a less accurate output signal. This shows that when trying to get an accurate output signal it is important that the input amplitude matches the range of the ADC.

HEADING.

The third procedure was to see the effect of changing the input frequency while keeping the amplitude constant. in figure 26 in the appendix the frequency was set to 100Hz which matched the input frequency, therefore an accurate output signal was produced. In figure 27-30 the frequency was increased in decades up to 1MHz. As you can see the frequency is too high therefore the output signal will be inaccurate.

The function generator was then set to 4KHz and the frequency was increased. In figure 31-36 the frequency was increased from 4KHz to 5KHz as the frequency is being increased there will be more samples of the input waveform being taken. This will give a more accurate output signal. From figure 37-44 the waveform becomes aliased which means the ADC cannot re-construct the analogue signal accurately. This is because of Nyquist theorem where the frequency should be half the sample rate of the ADC. With the ADC used in this experiment the sampling rate is 10,000 samples per second therefore the frequency cannot be more than 5KHz. This is proven in figures 37-44 because as the frequency is being increased the output signal is becoming more aliased.

f_{in}	f_{out}
1 kHz	1 kHz
4 kHz	4 kHz
5 kHz	4.8 kHz
7 kHz	3 kHz

A TABLE WOULD BE BETTER HERE. RATHER THAN A SERIES OF SCREENSHOTS.

7. Conclusions and recommendations (500)

When doing this assignment many things have been learnt such as analogue and frequency modulation, ADC, PAM and PCM techniques and digital communication system SDH. Research was done on these topics which was then used in the experiments to prove the theory that was researched and that the experiments were done correctly. While doing the experiments an understanding of how to set up test equipment to monitor a frequency modulated signal and an ADCs. An understanding of how to use calculations to create theoretical values and see how they compare to practical investigation. While doing the practical investigation on frequency modulation the calculated and practical values matched which shows that the tests done were accurate. This is also backed by the research which is established theory. A practical experiment was then done on ADCs where the effect of changing the number of bits on the ADC. It was shown that an 8 bit ADC was a lot more accurate of that of a 4 bit ADC. This was backed by the graph shown from the practical and the research. The second procedure was changing the input amplitude for a 4 and 8 bit ADC. In this procedure it showed that the closer the input amplitude matched the range of the ADC the better output signal it will have. The third procedure was to see the effect of changing the input frequency with a constant amplitude. This showed that the most accurate output signal was half the sample rate of the ADC which was 5KHz. This is proven by the Nyquist theorem. This experiment has shown that there are 3 factors that need to be considered while choosing an ADC. These are the number of bits of the ADC. The Higher number of bits the more levels which will give a more accurate output signal. The second is the ADC range, the range of the ADC should match that of the input amplitude to get the most accurate output signal. The third is the sampling rate of the ADC, the sampling rate should be double the input frequency, this is to prevent aliasing and to get the most accurate output signal.

*MORE A NARRATIVE OF WHAT YOU DID
RAKER THAN A CRITICAL ANALYSIS.
ONE OF THE MAIN CONSIDERATIONS IS DATA RATE,
POOR ADC SENDS MORE DATA THAN
NECESSARY AND BOGS SYSTEMS DOWN.*

8. Citation list

Works Cited

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9. Appendices

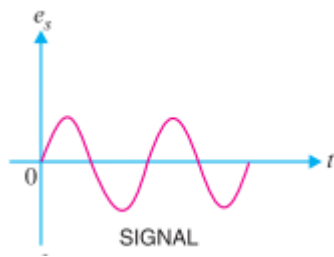


Figure 1: Audio electrical signal

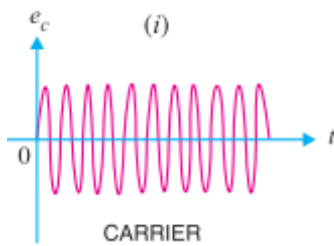


Figure 2: carrier wave of constant amplitude

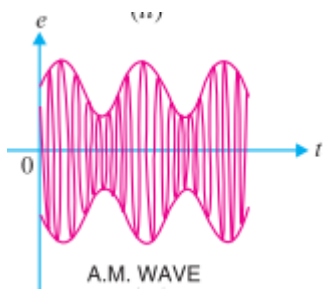


Figure 3: amplitude modulated (AM) wave.

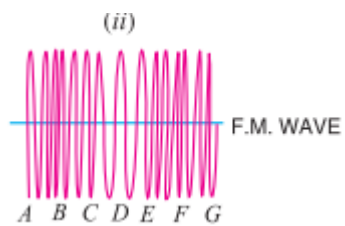


Figure 4: FM wave

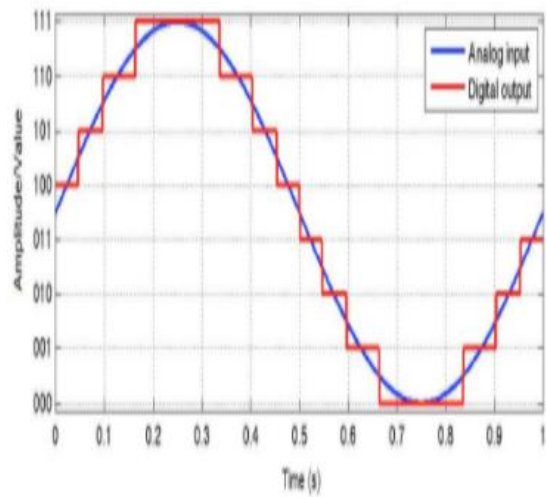


Figure 5: Analogue and digital signal

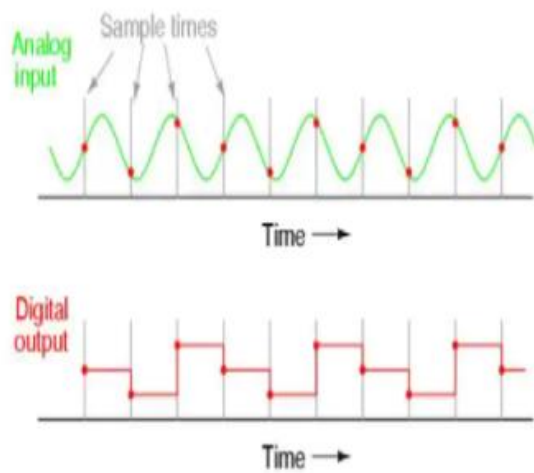


Figure 6: Analogue/digital sampling rate

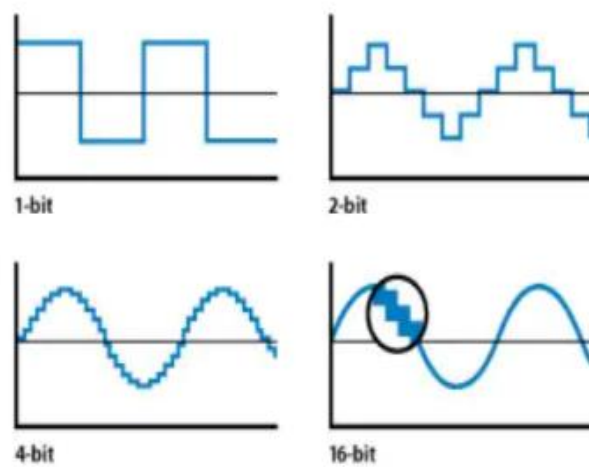


Figure 7: Digital output wave resolution

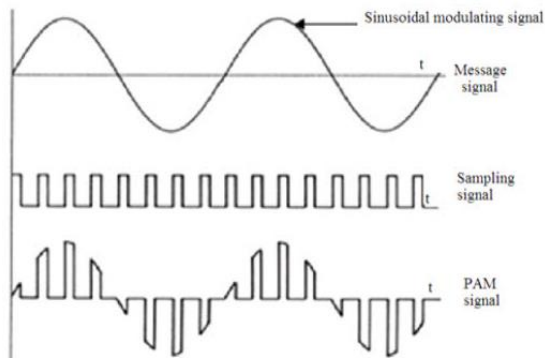


Figure 8: Pulse Amplitude Modulation Signal

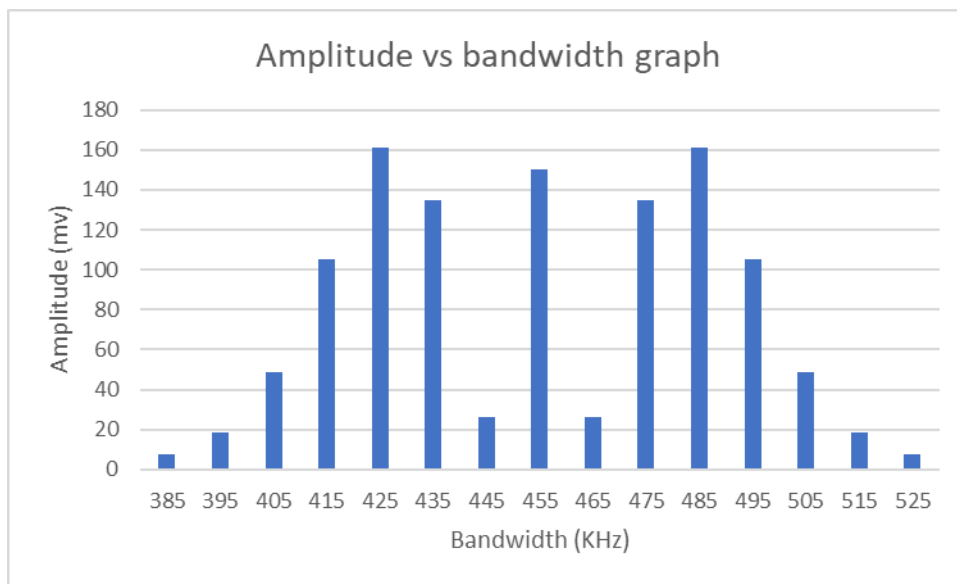


Figure 9: Amplitude vs bandwidth graph

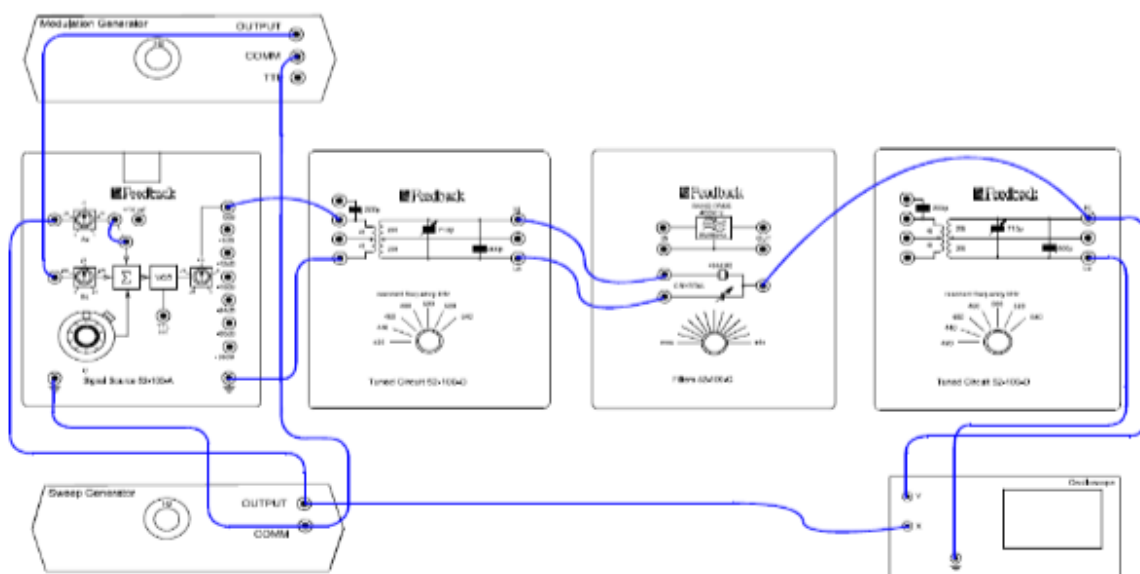


Figure 10: Experiment 1 test equipment set up

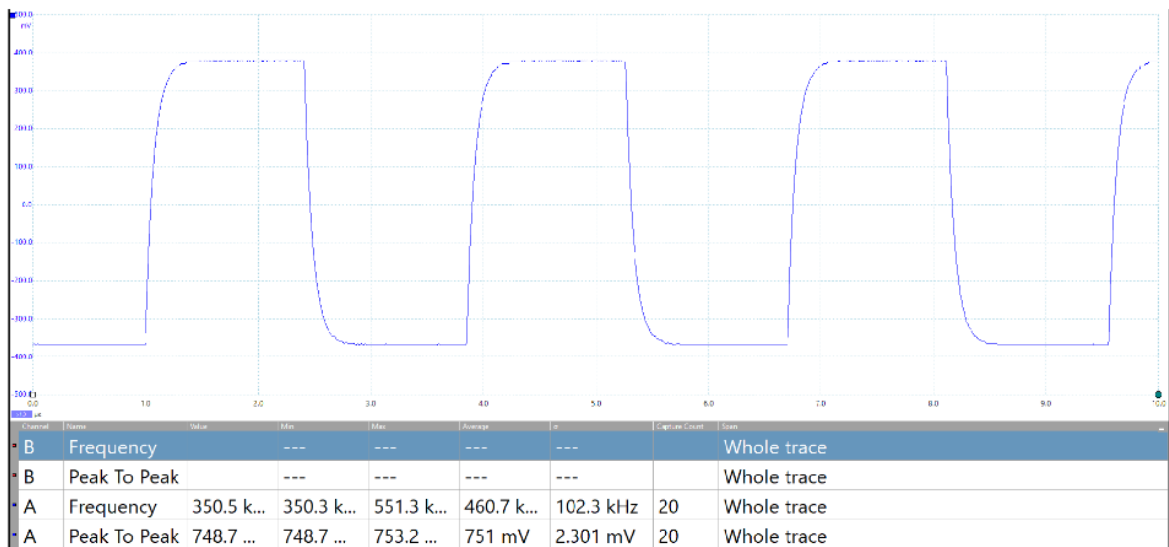


Figure 11: Carrier frequency deviation 2Vp-p

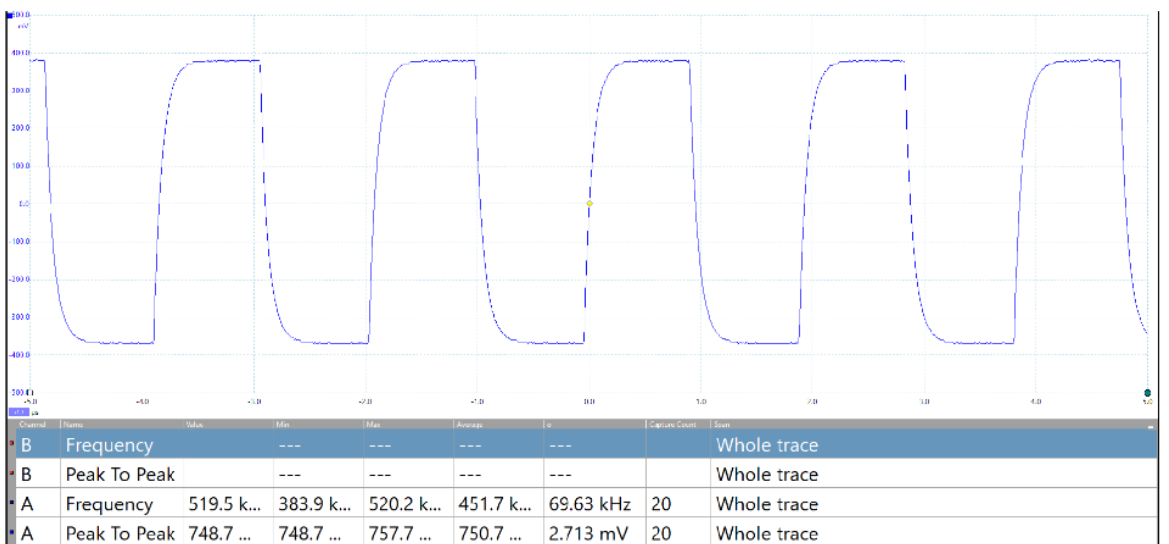


Figure 12: Carrier frequency deviation 6Vp-p

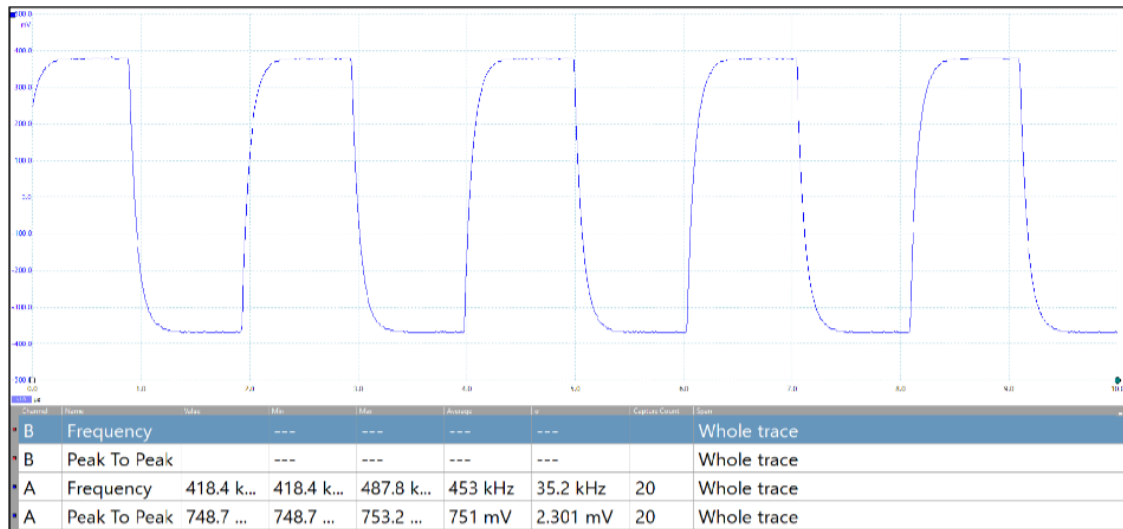


Figure 13: Carrier frequency deviation 4Vp-p

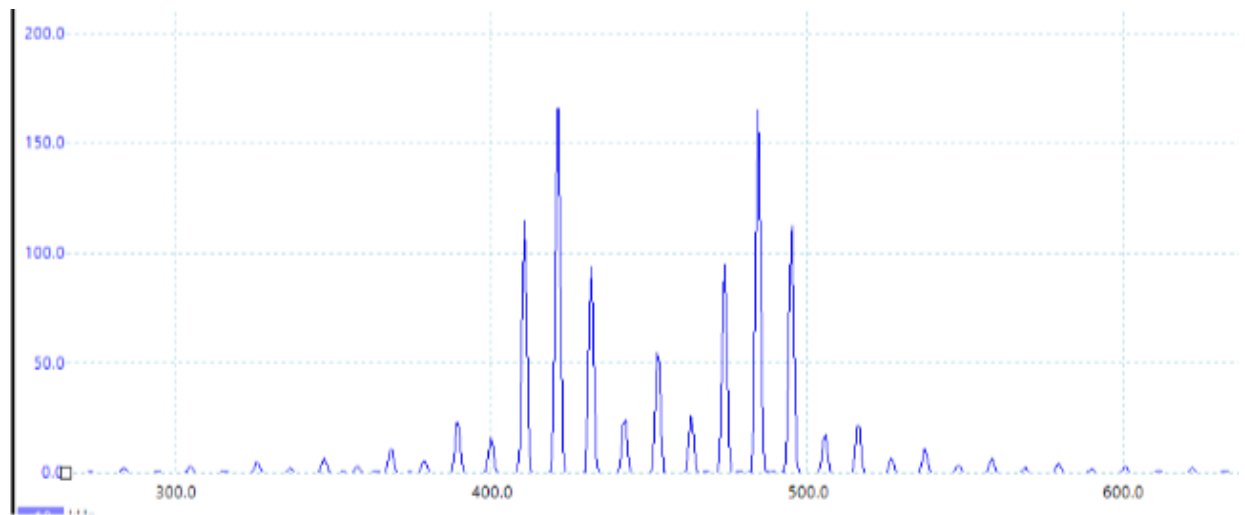


Figure 14: Spectrum analyser

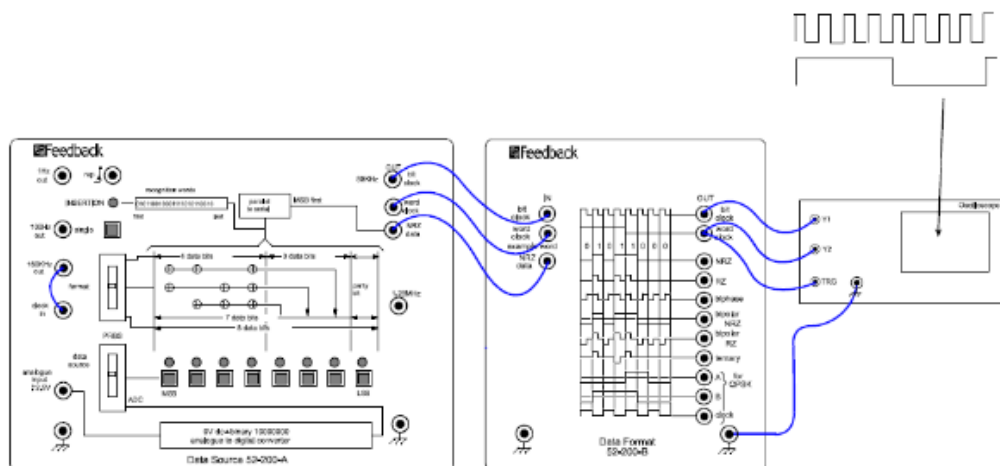


Figure 15: Experiment 2 test equipment set up

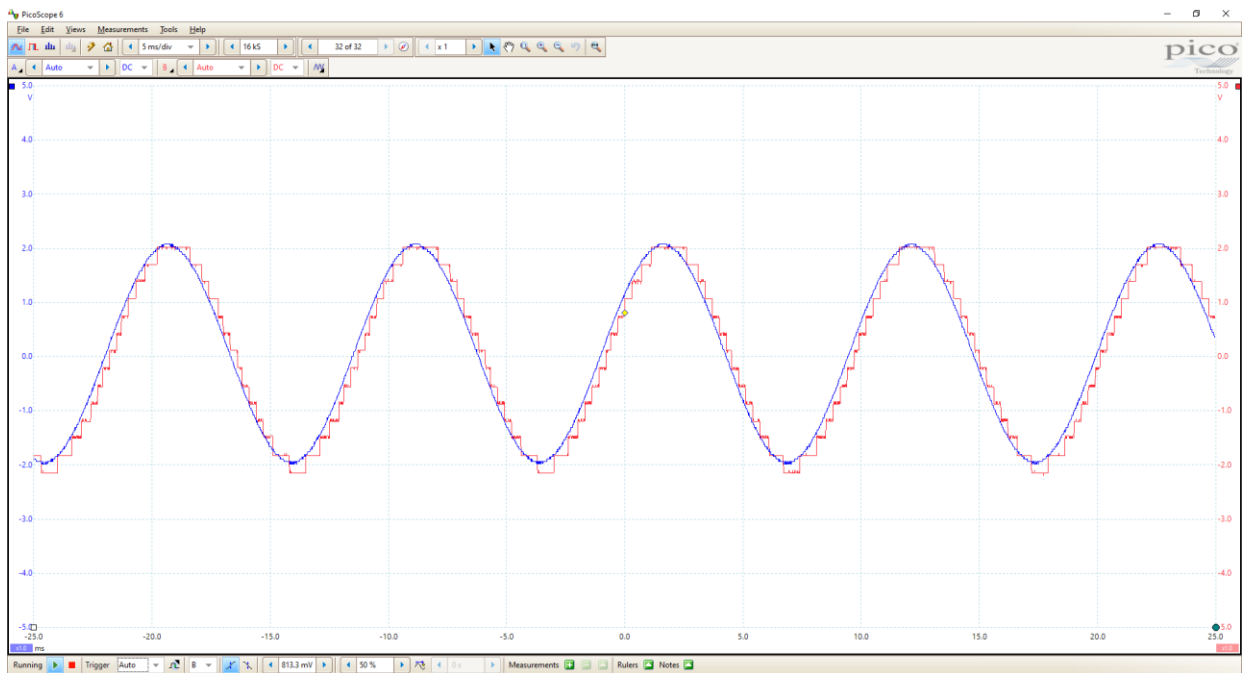


Figure 16: Experiment 2, 4 bit output

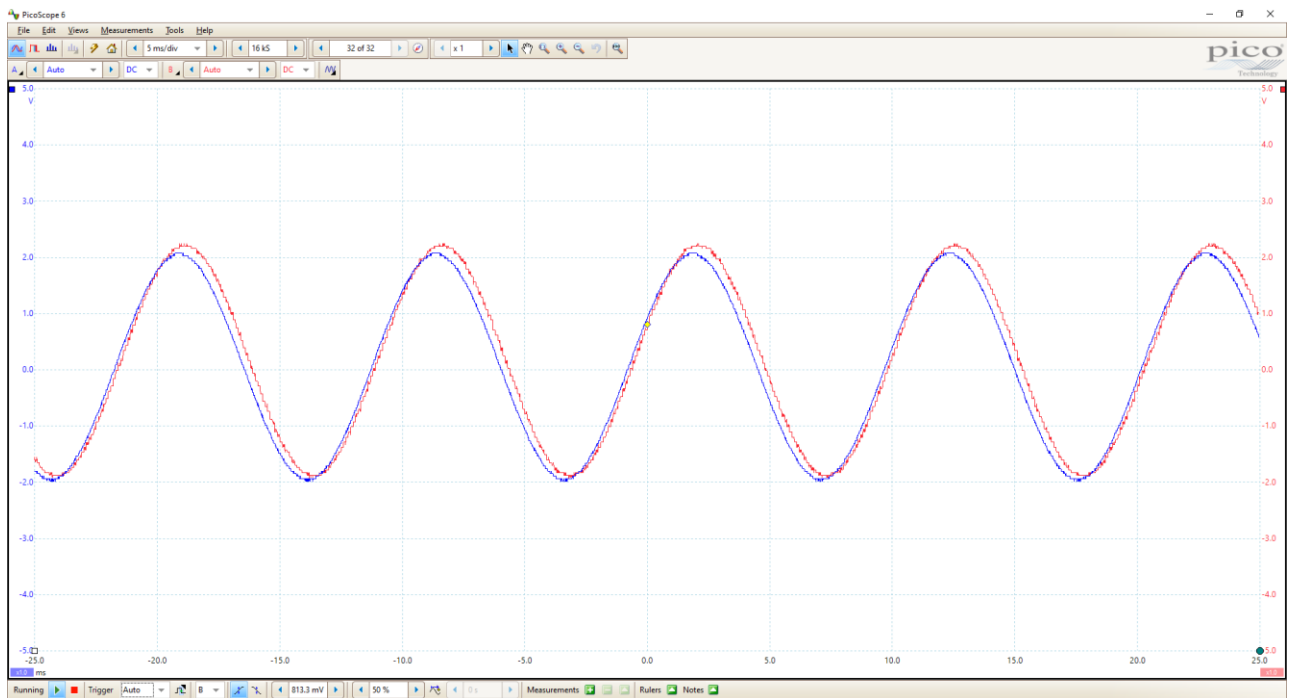


Figure 17: Experiment 2, 8 bit output

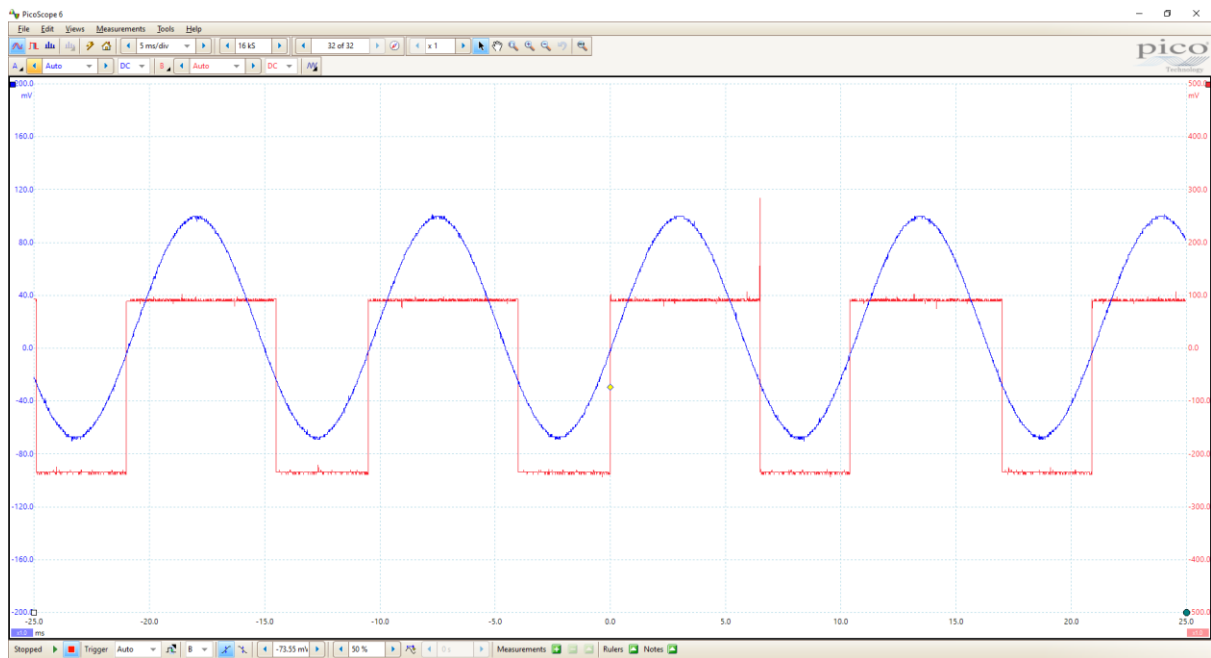


Figure 18: 4bit at 0v

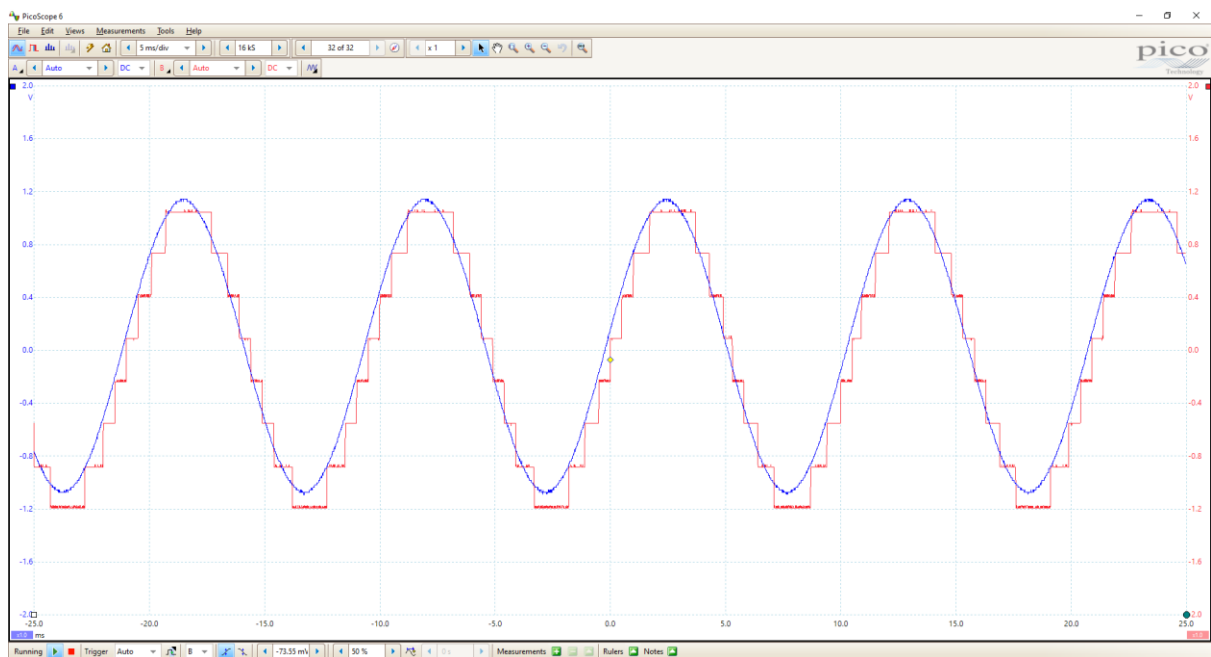


Figure 19: 4bit at 2v

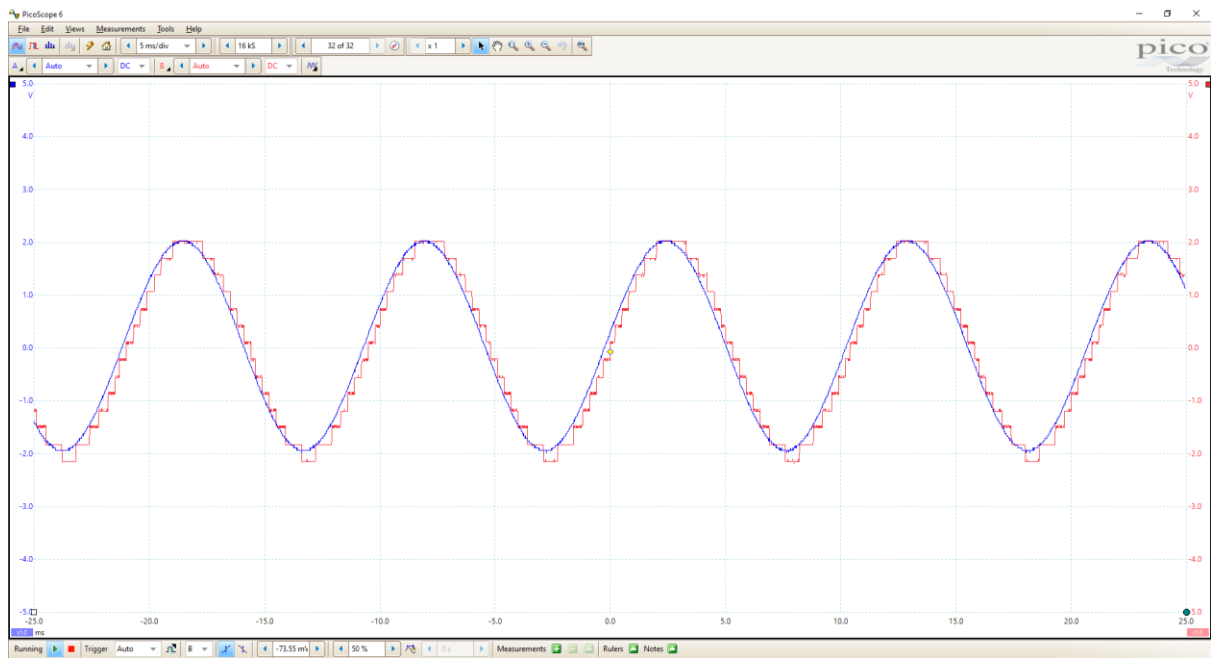


Figure 20: 4bit at 4v

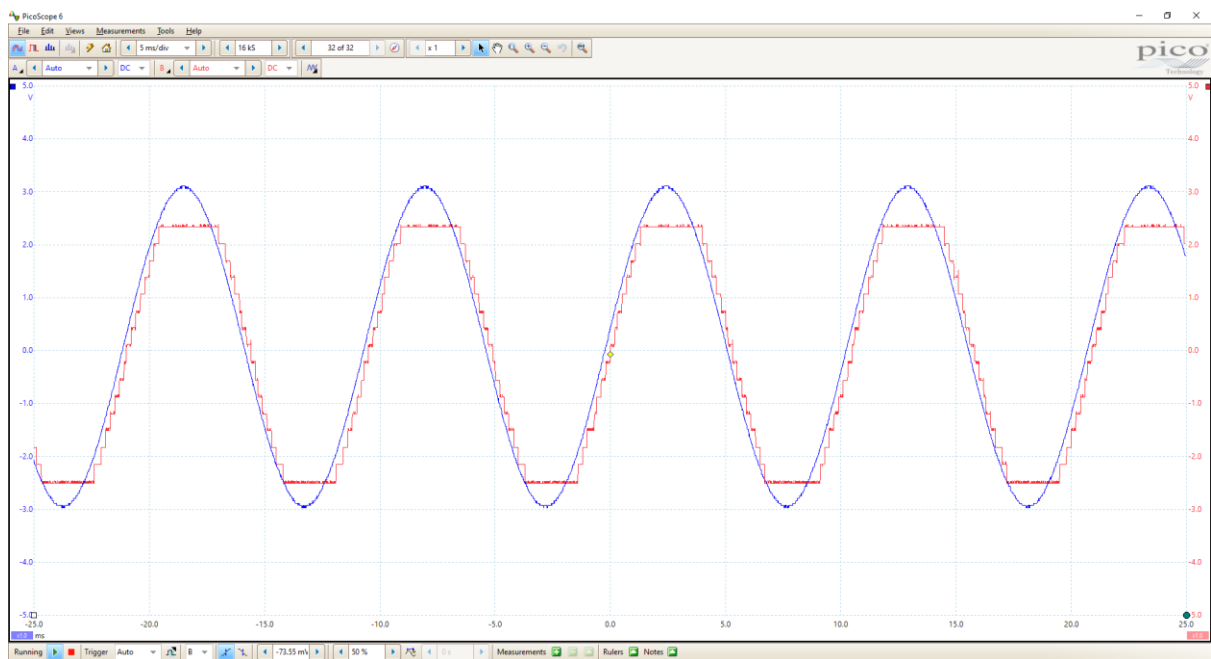


Figure 21: 4bit at 6v

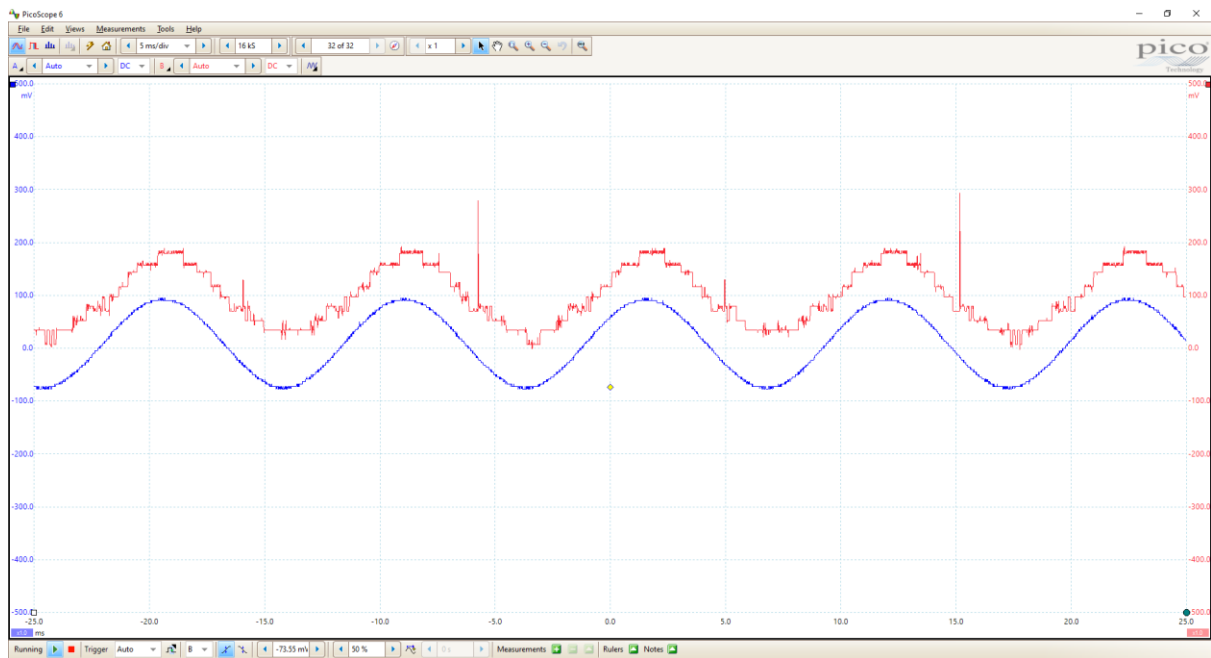


Figure 22: 8bit at 0v

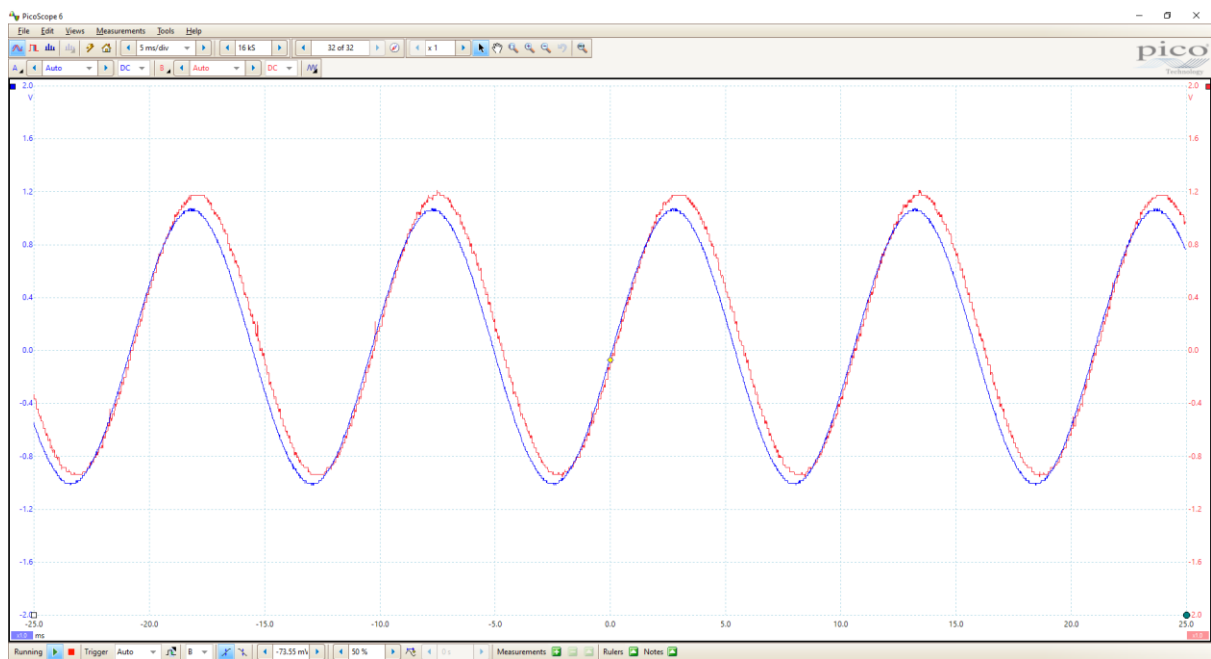


Figure 23: 8bit at 2v

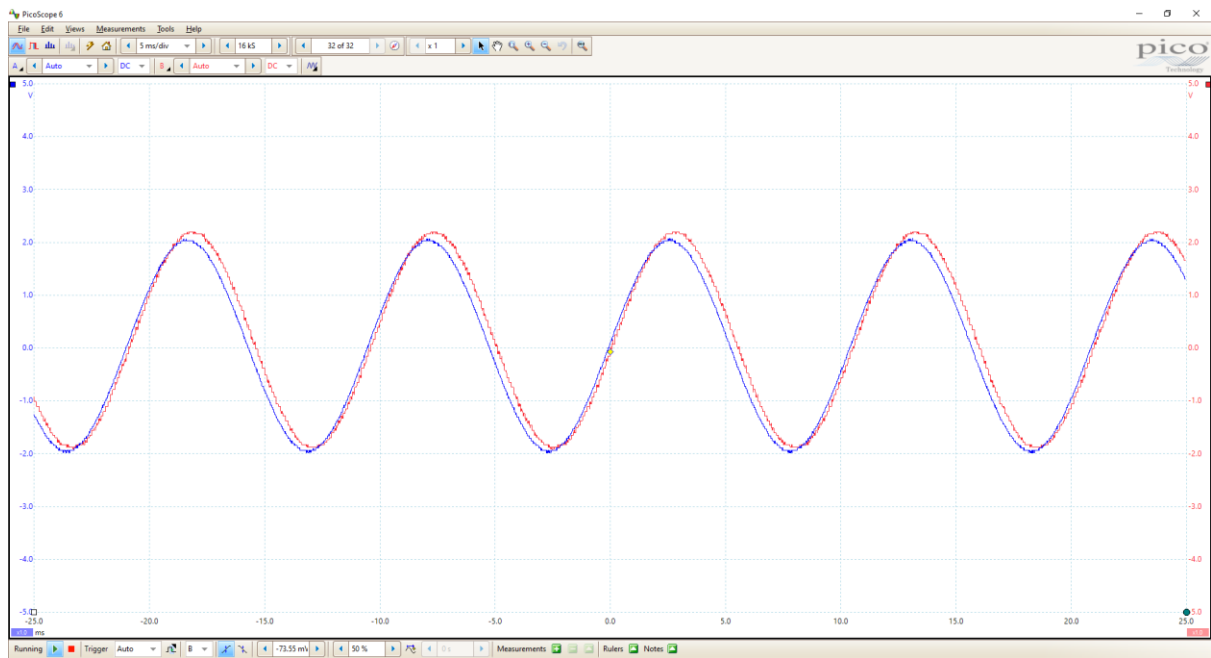


Figure 24: 8bit at 4v

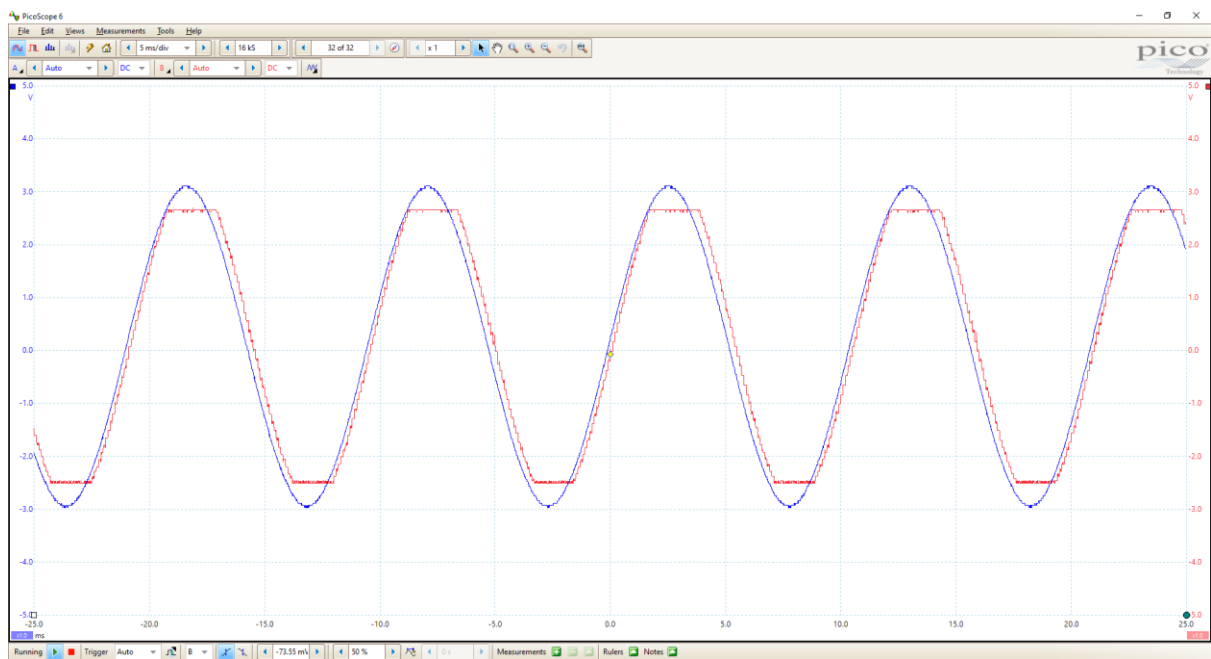


Figure 25: 8bit at 6v

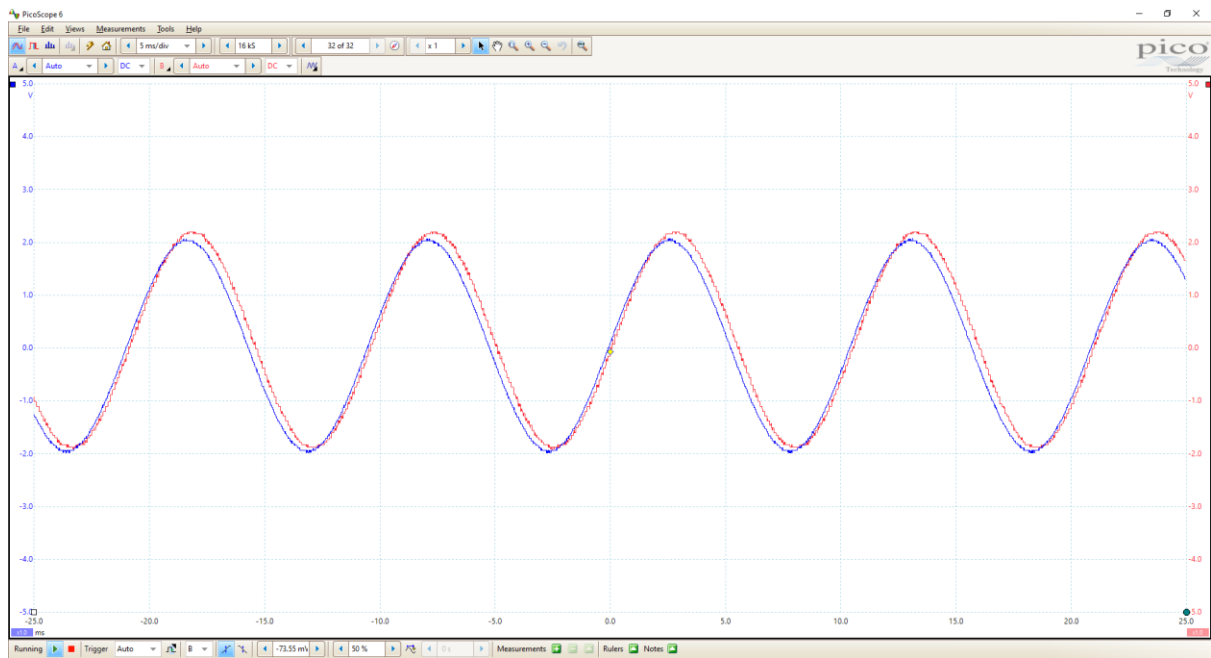


Figure 26: 8bit 4v4p-p at 100Hz

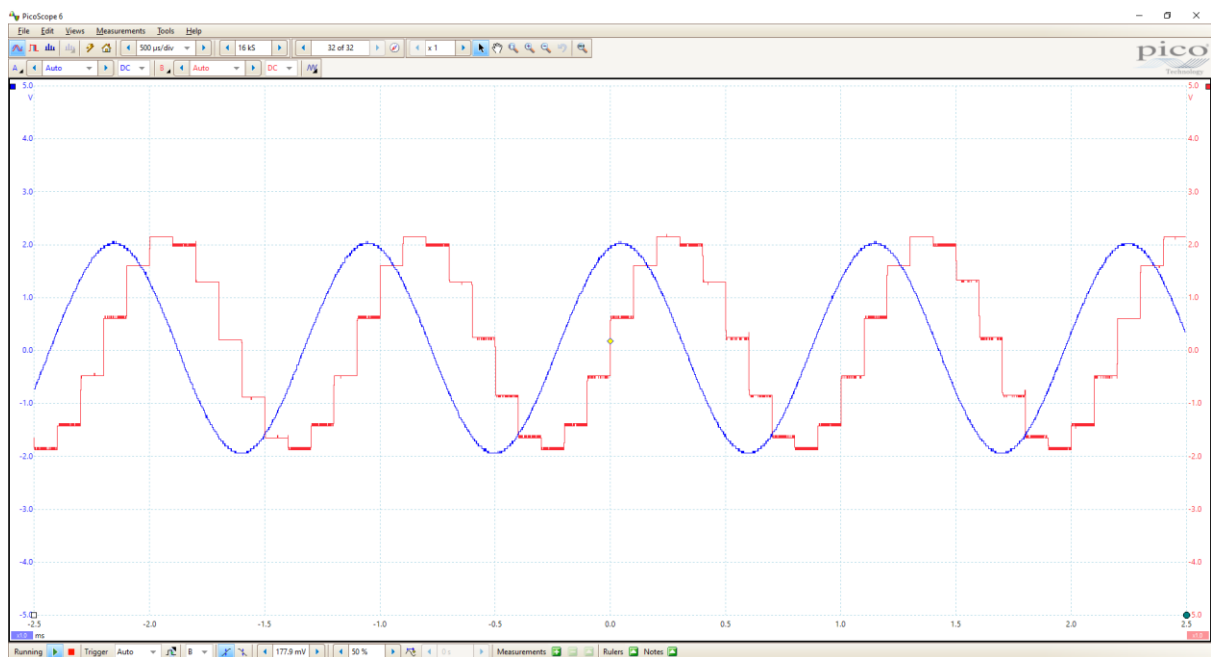


Figure 27: 8bit 4v4p-p at 1KHz

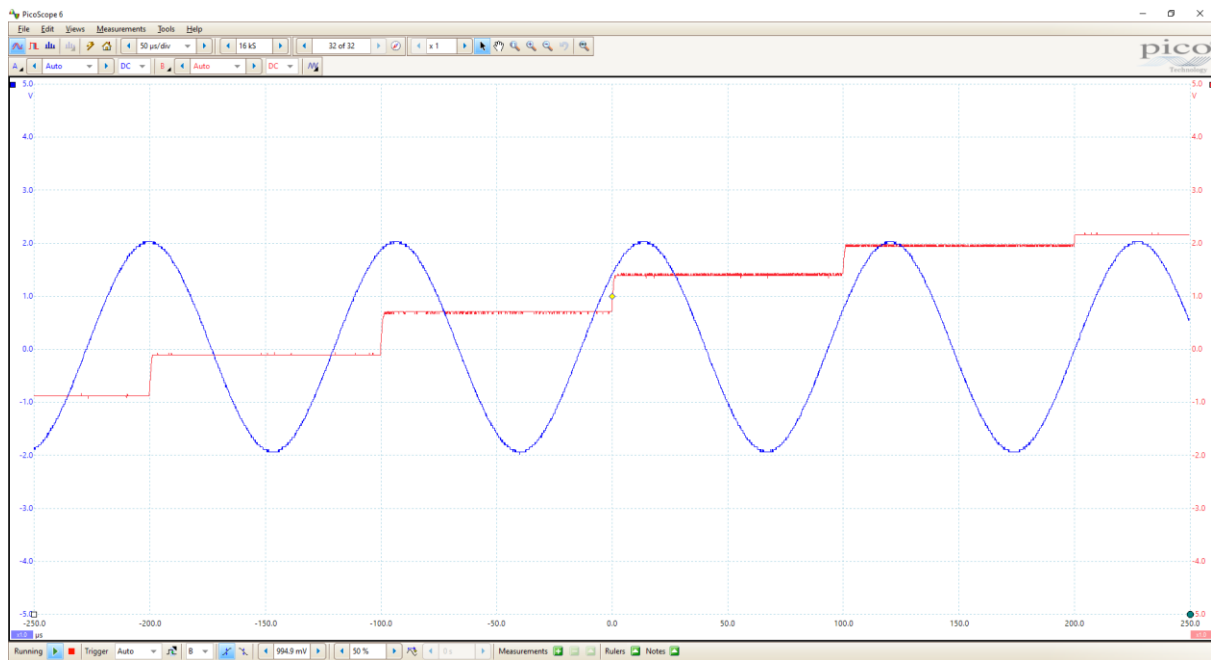


Figure 28: 8bit 4v4p-p at 10KHz

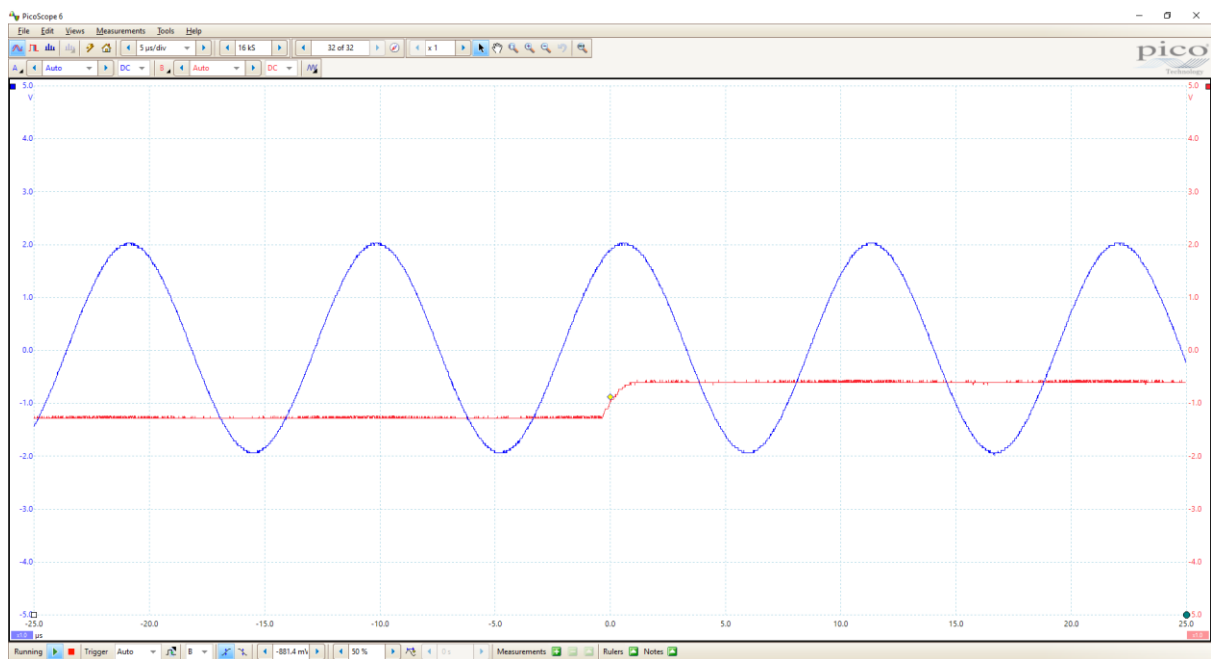


Figure 29: 8bit 4v4p-p at 100KHz Too High.

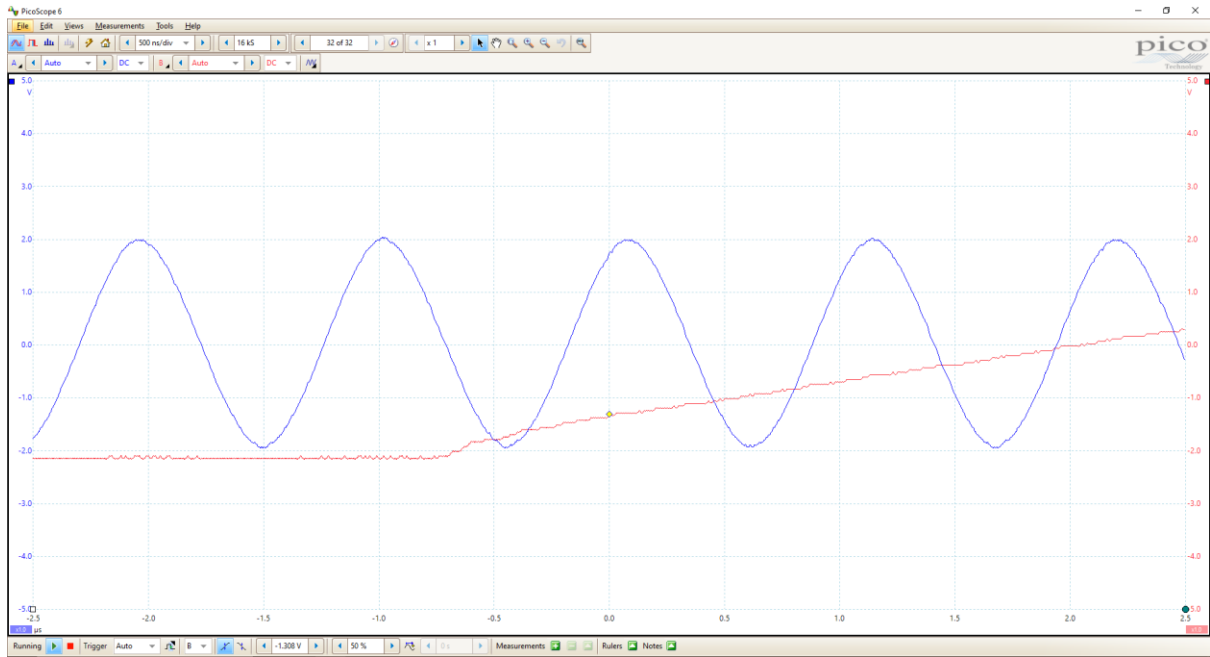


Figure 30: 8bit 4v4p-p at 1MHz *FAR TO HSU.*

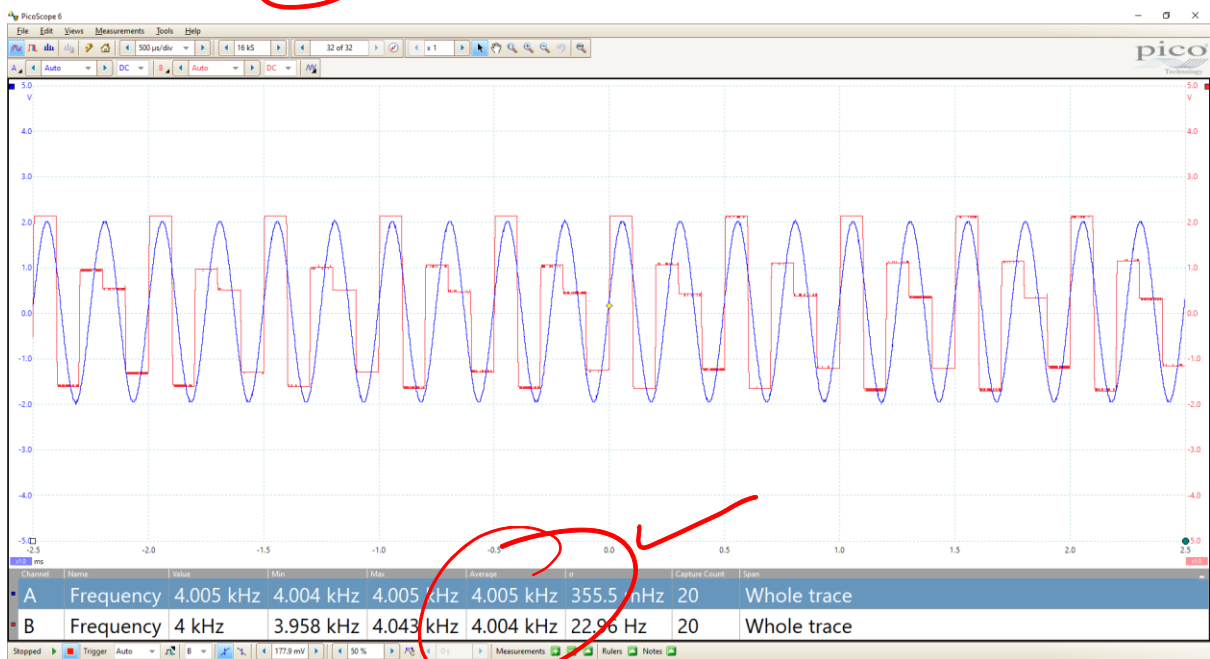


Figure 31: 8bit ADC 4KHz 4vp-p

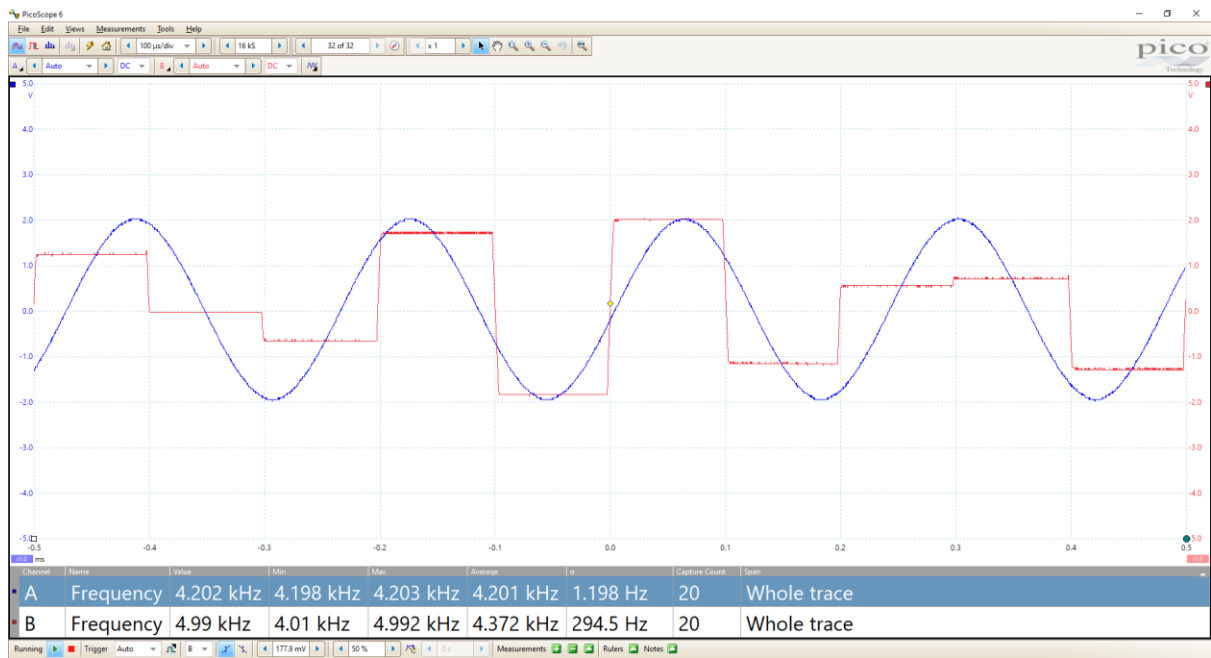


Figure 32: 8bit ADC 4.2KHz 4vp-p

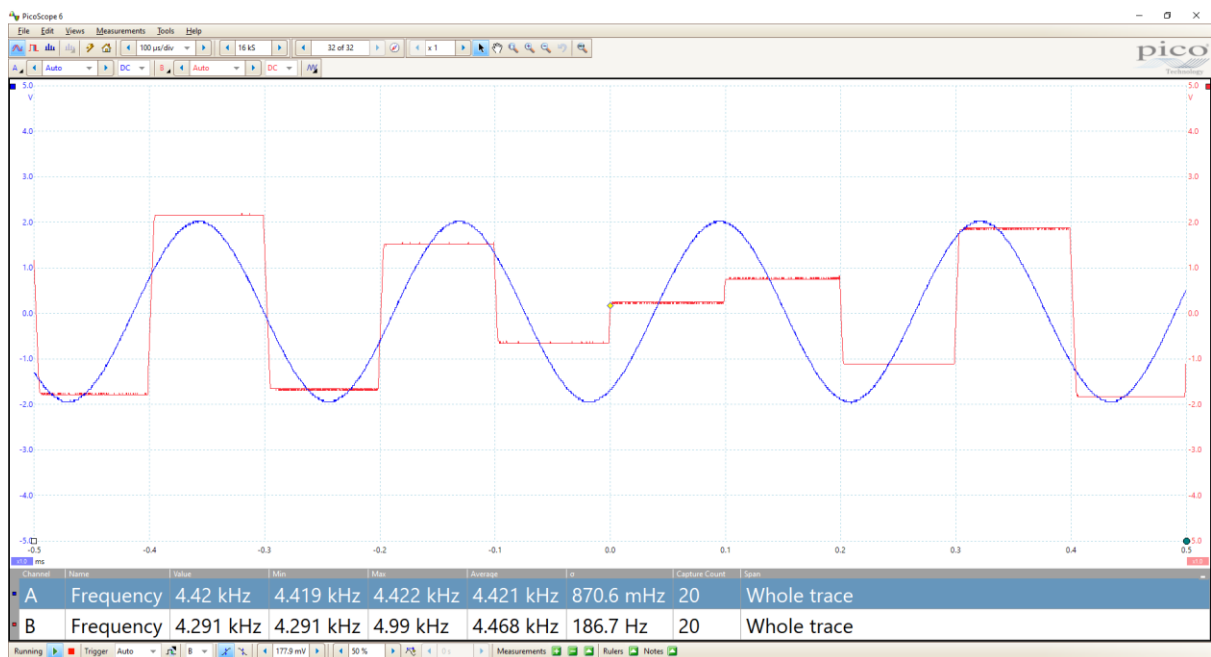


Figure 33: 8bit ADC 4.4KHz 4vp-p

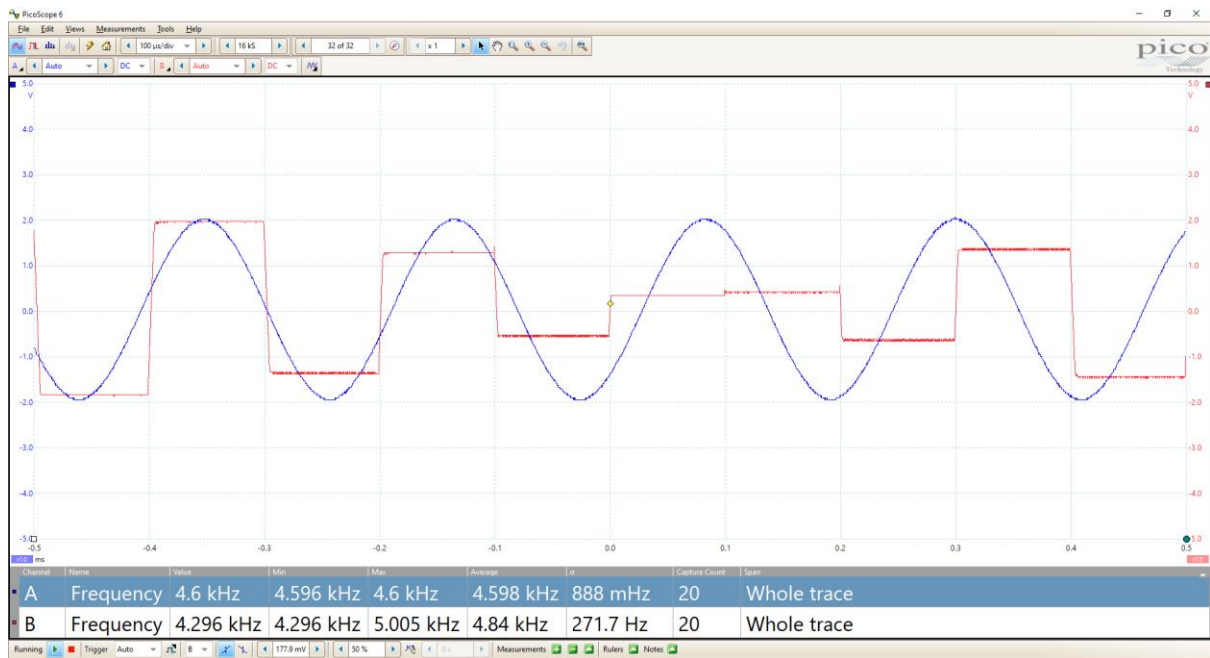


Figure 34: 8bit ADC 4.6KHz 4vp-p

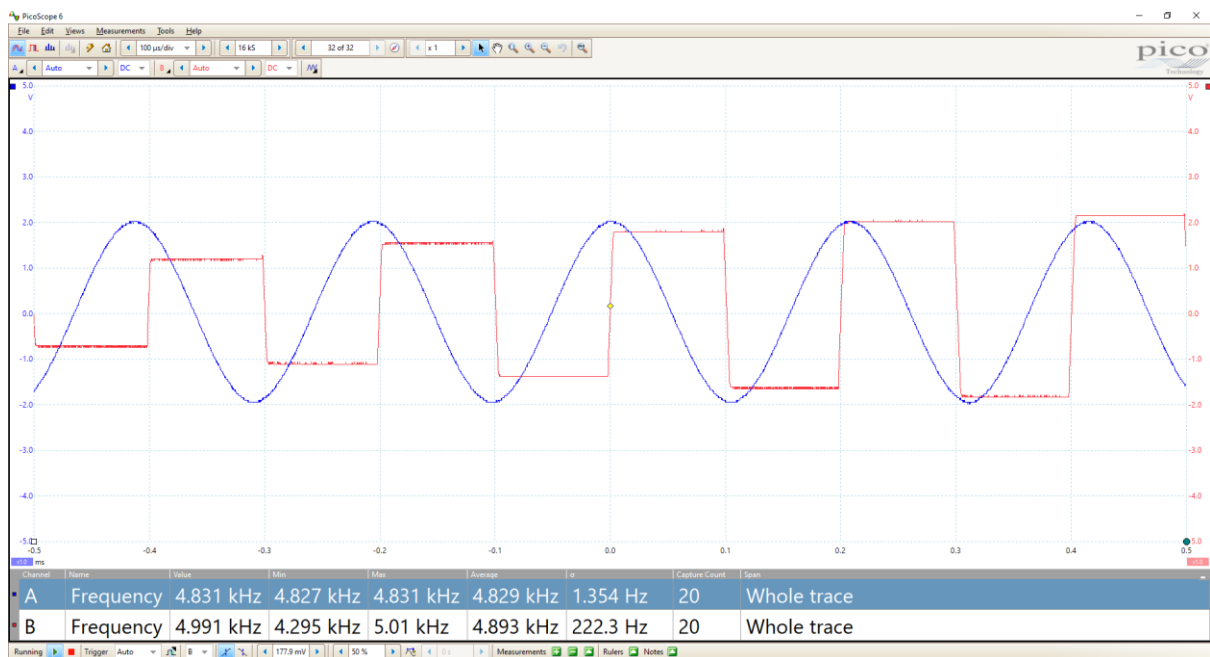


Figure 35: 8bit ADC 4.8KHz 4vp-p

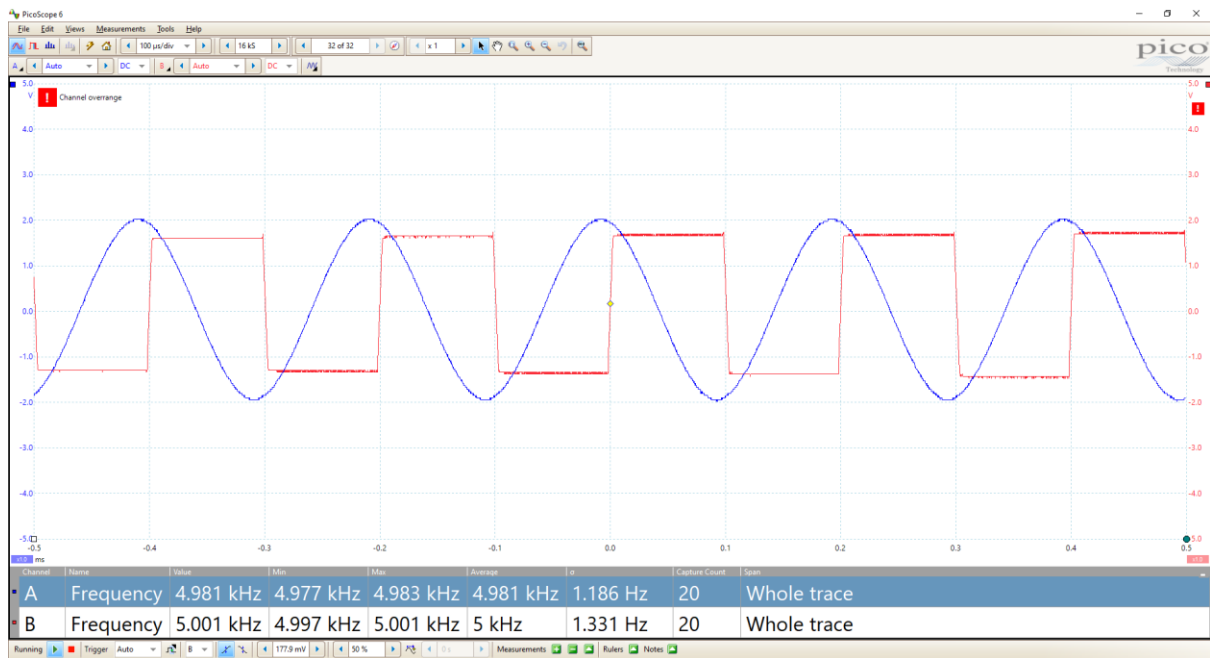


Figure 36: 8bit ADC 5KHz 4vp-p

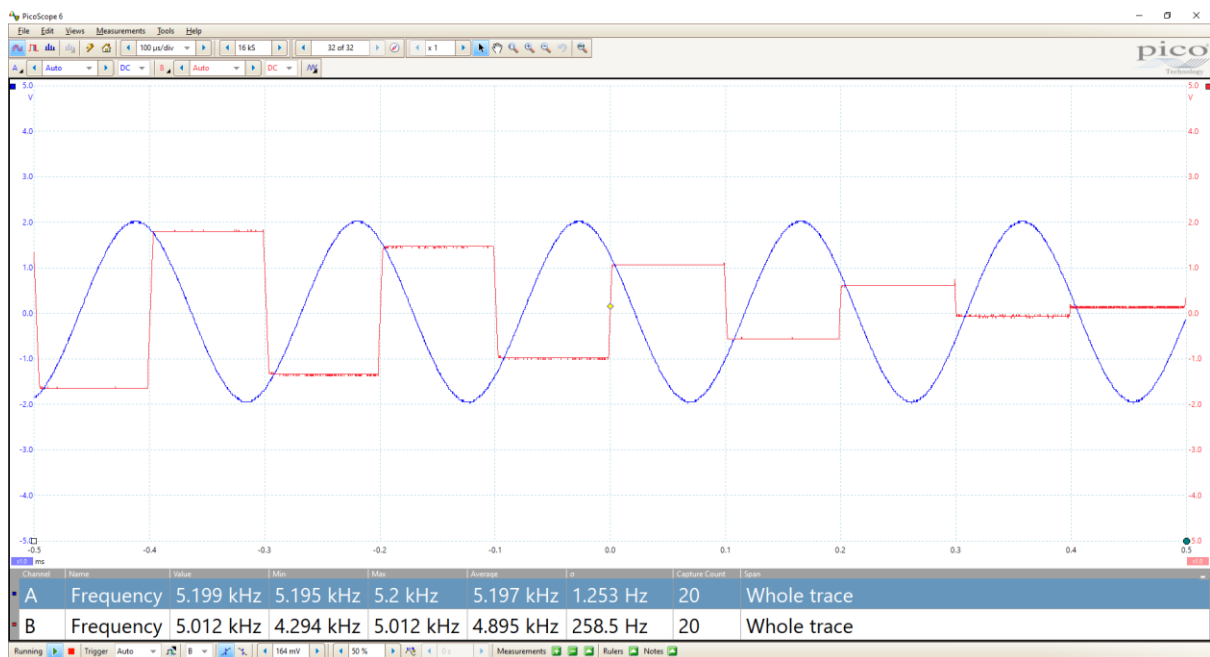


Figure 37: 8bit ADC 5.2KHz 4vp-p

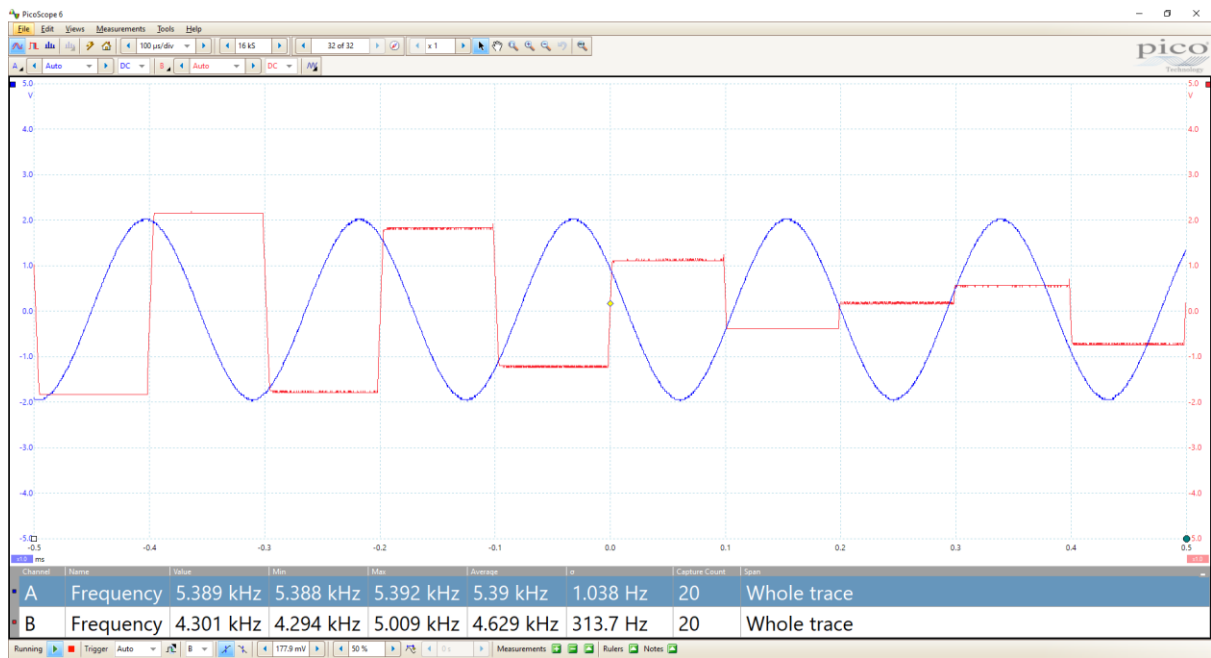


Figure 38: 8bit ADC 5.4KHz 4vp-p

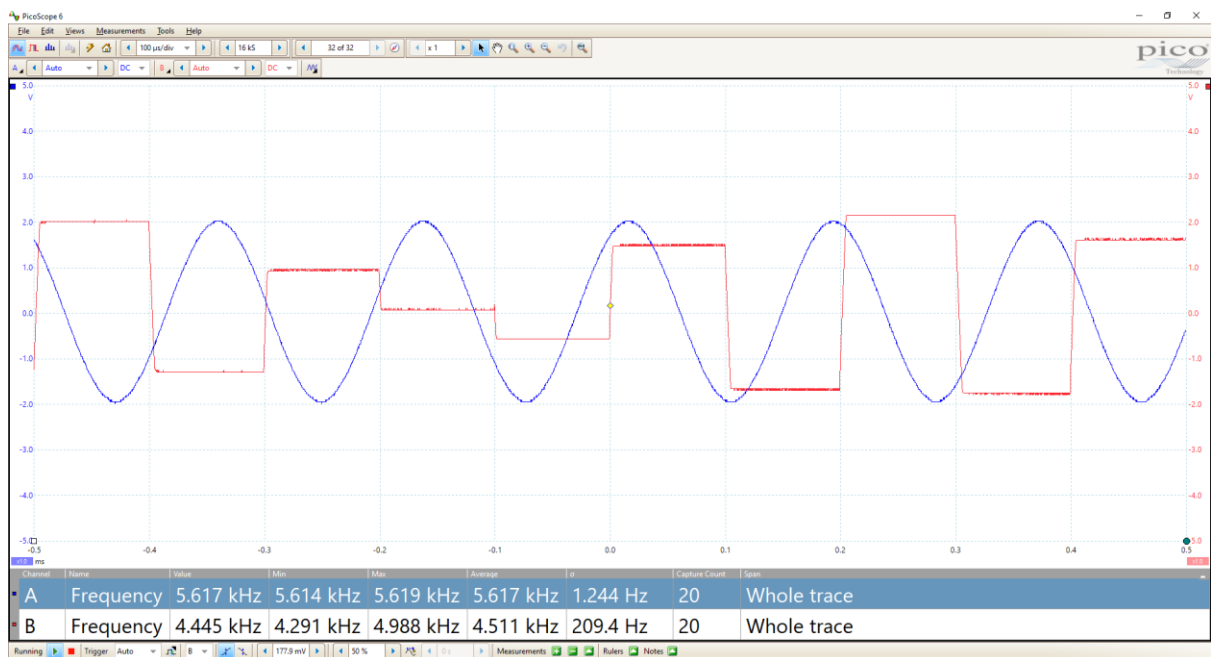


Figure 39: 8bit ADC 5.6KHz 4vp-p

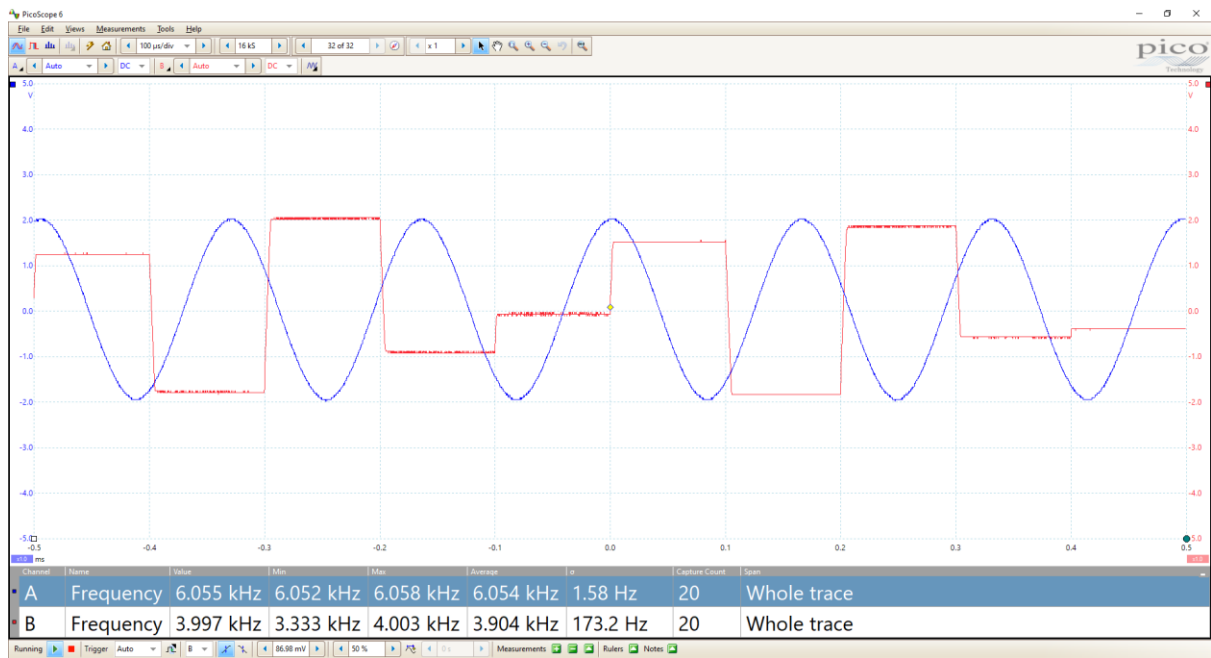


Figure 40: 8bit ADC 6KHz 4vp-p

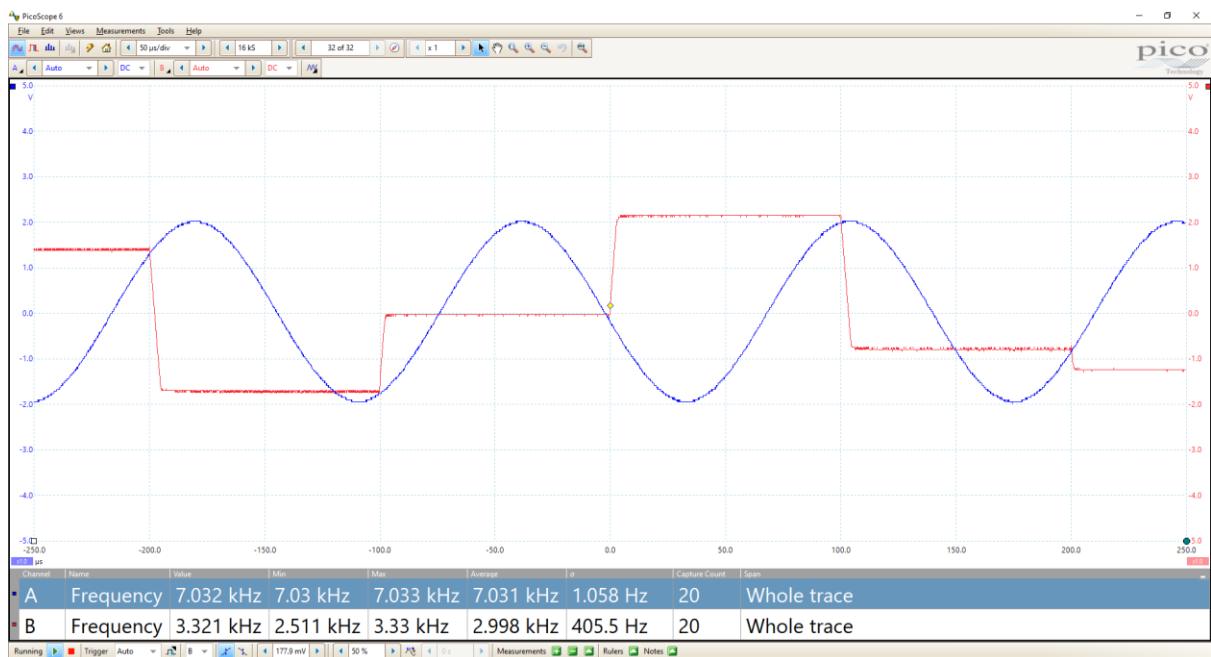


Figure 41: 8bit ADC 7KHz 4vp-p

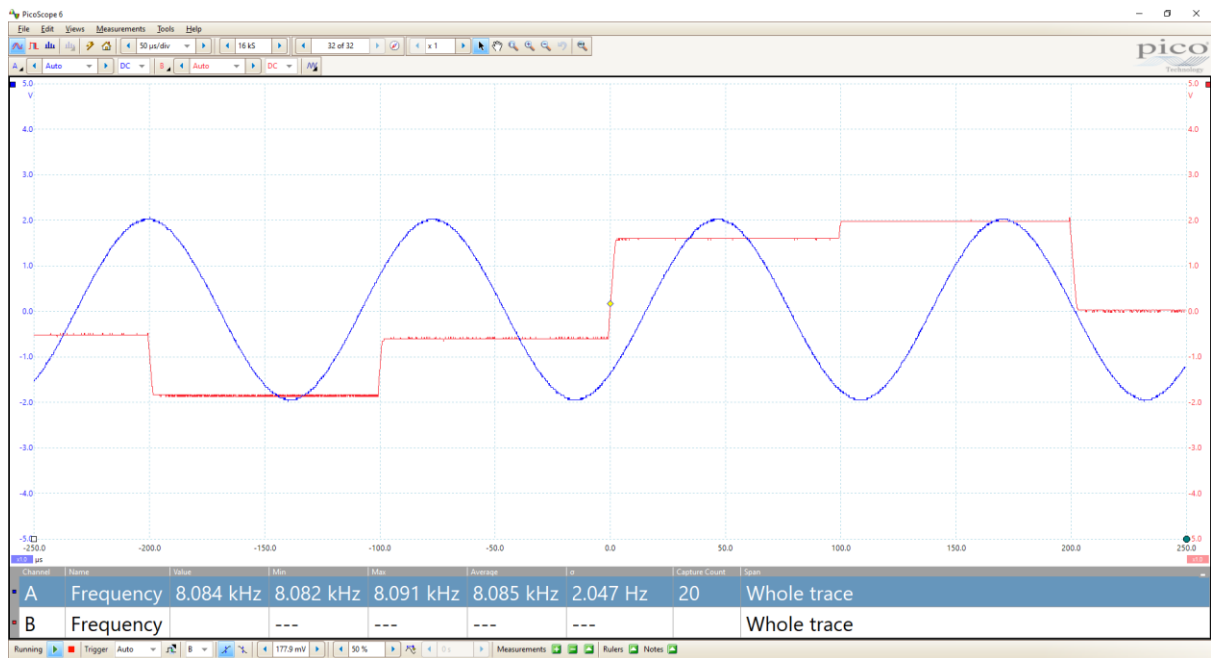


Figure 42: 8bit ADC 8KHz 4vp-p

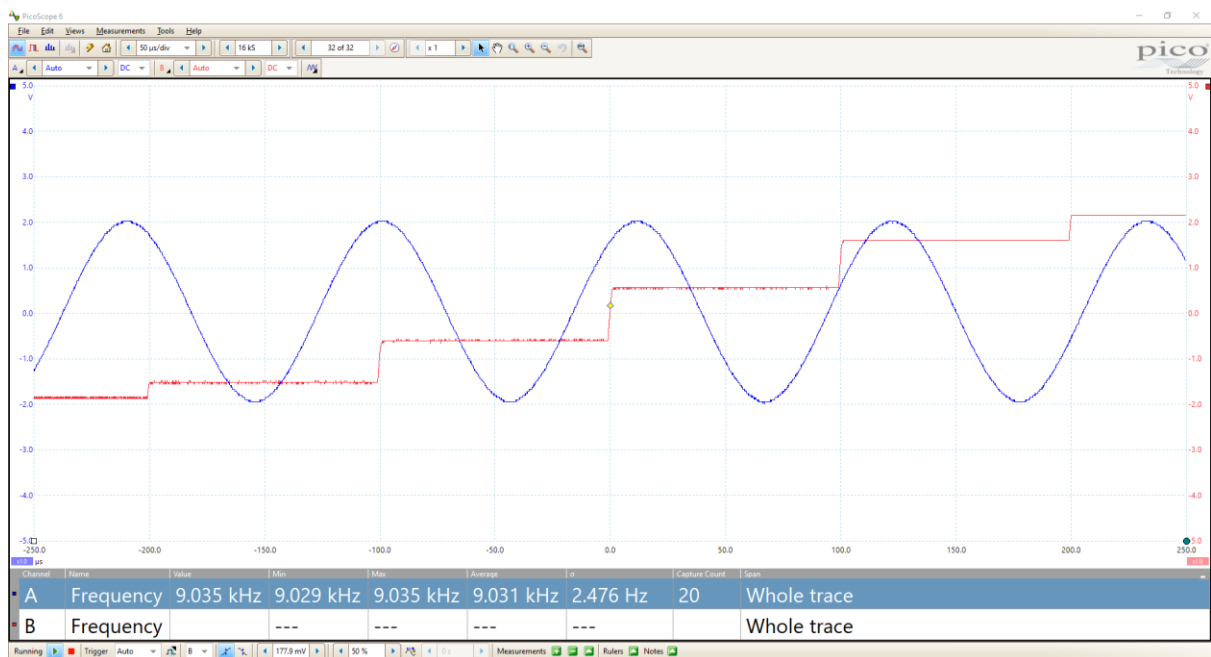


Figure 43: 8bit ADC 9KHz 4vp-p

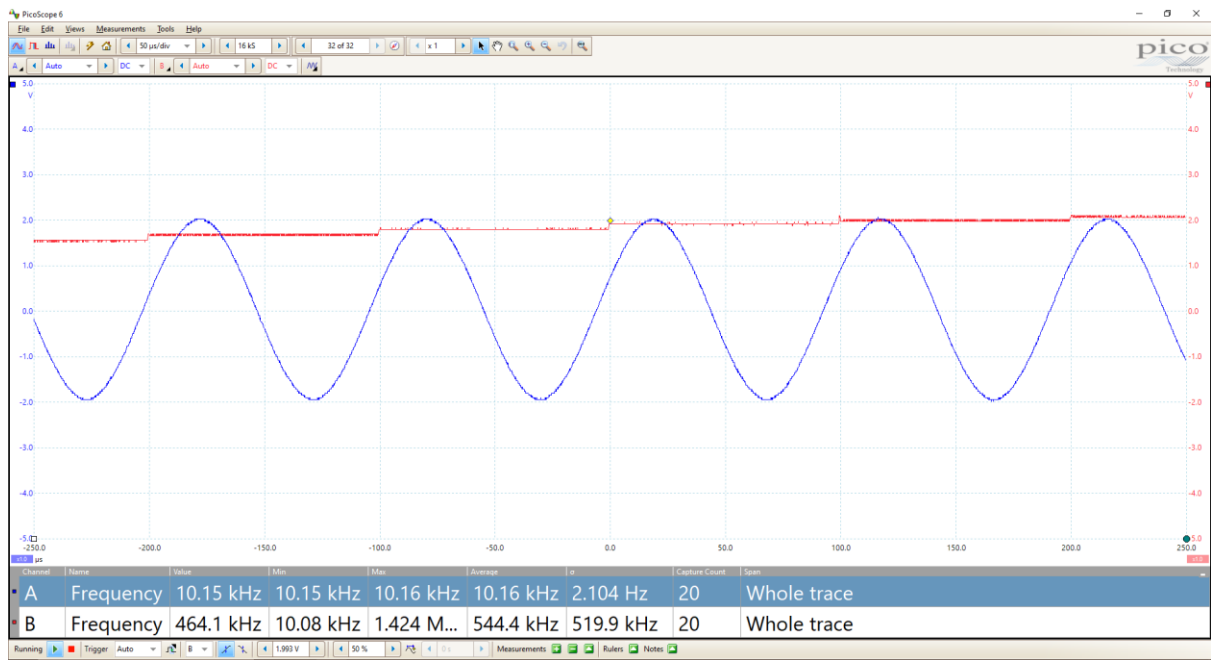


Figure 44: 8bit ADC 10KHz 4vp-p

FINAL GRADE

GENERAL COMMENTS

Instructor

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GRADING FORM: CSG-RUBIC

JORDAN REES

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RESEARCH-INFORMED LITERATURE



There was evidence of further reading and research with the inclusion of a reference list and appropriate in text referencing. Your interpretation and understanding of the additional research was good. Your references were appropriate to the task and your reference list was of an appropriate length for this assignment. Some of the sources were over-used and you should consider widening your range of sources for future assignments.

5

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.

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ANALYSIS



Your explanation of the experimental procedure 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

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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.

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally good. You used the resources available appropriately when conducting both experiments and you used appropriate options for testing and evaluating the circuit performance. You managed to evaluate that the circuits 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.

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SKILLS FOR PROFESSIONAL PRAC.



Your written report was reasonably well presented in terms of content and layout and was mostly structured in a coherent way, however you need to be much 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.

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