

1708165 assignment 1

by Adam Bedner

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SGEE5005

Signals and Modulation

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3. Executive summary

This assignment is constructed with three main blocks. A research and two practical tasks. The research centred on amplitude and frequency modulations as well as Analogue to Digital converters. Some lesser important concepts related to digital communication have also been researched.

The first practical task that was carried out was about frequency modulation. It was a practical investigation to prove that the concepts researched were correct and for deeper understanding of the concept of frequency modulation.

The second practical tasks were about ADCs (analogue to digital converters). This in-depth investigation was conducted to test the boundaries of successive approximation ADCs. The investigation was based on the results of the research. The ADC was tested for different input signal frequencies and amplitudes and compared to the reconstructed output for similarity in frequency and amplitude but also keeping an eye for any aliasing (distortion).

*You
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summaris
e the
results
and
conclusio
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4. Research into analogue and digital communication systems and techniques.

4.1 Evaluation of modulation techniques

This section will investigate the different types of modulation as well as the techniques or sub-types of those. The section is concentrated in AM (Amplitude Modulation) and FM (Frequency Modulation). The PM (Phase modulation) will also be briefly stated which will be necessary for next section (4.2 Digital modulation techniques)

4.1.1 Amplitude modulation techniques

Amplitude Modulation uses the changes in the amplitude of a carrier wave to transmit signal (Fig. 1). It is a relatively easy way of modulating signals and transmitting them wirelessly, although AM is likely to be distorted by any man-made or natural factors such as lightning, high power electrical equipment. That is due to alterations of amplitude of the transmitted signal. (Metha & Metha, 2007)

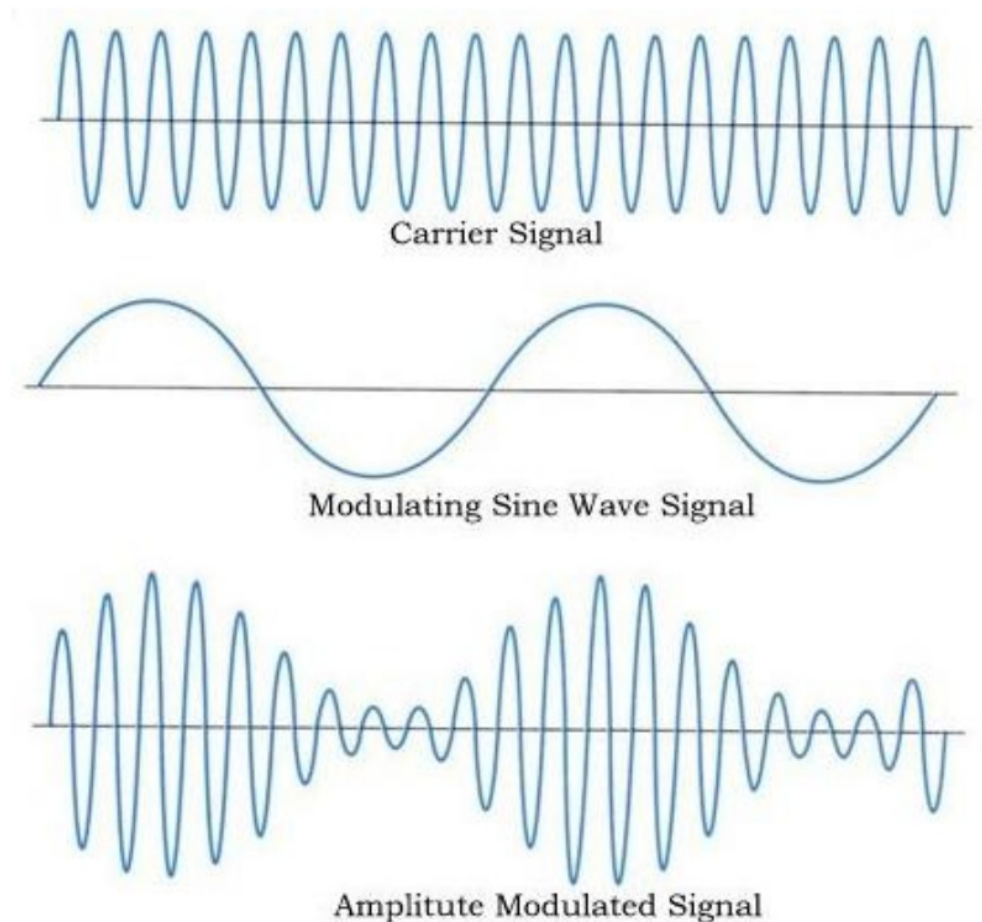


Fig. 1 example showing carrier frequency, signal frequency and modulated frequency

The amplitude of the AM wave can be calculated by the following formula:

$$\text{Amplitude of AM wave} = E_C + mE_C \cos \omega_m t$$

Where:

$$E_C = \text{Amplitude of the carrier}$$

$$\omega_m = \text{frequency of the carrier}$$

From that, the formula for instantaneous voltage of AM wave can be derived knowing that

$$e = \text{Amplitude} * \cos \omega_c t$$

$$e = (E_C + E_m \cos \omega_m t) * \cos \omega_c t$$

$$e = E_C \cos \omega_c t + \frac{mE_C}{2} \cos(\omega_m + \omega_c)t + \frac{mE_C}{2} \cos(\omega_m - \omega_c)t$$

The terms $\frac{E_m}{2} \cos(\omega_m + \omega_c)t$ and $\frac{E_m}{2} \cos(\omega_m - \omega_c)t$ represent the two side bands ($f_c + f_m$ and $f_c - f_m$ respectively) of the AM modulated signal (Fig. 2) and the frequency difference between those two points define the bandwidth required by the specific message signal. From that it can be seen that the bandwidth required is twice the message's frequency.

Typical amplitude modulation spectra

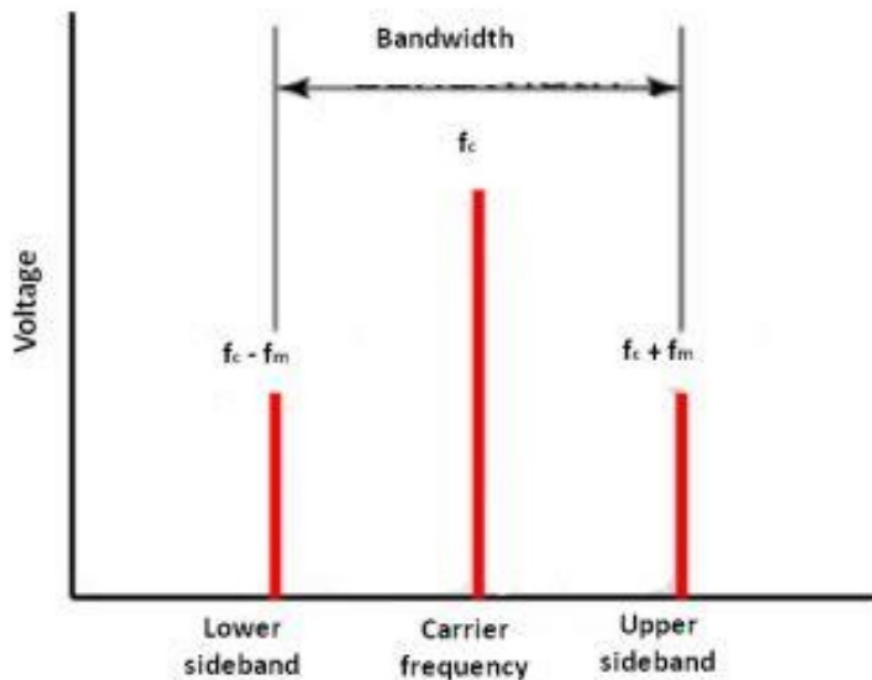


Fig. 2 Spectrum analyse of a typical, sinusoidally modulated, AM signal

The depth of modulation, or modulation factor m , is the relation between the RMS voltage of the message signal (V_m) and the RMS value of unmodulated carrier frequency. It expresses to which degree the carrier frequency is modulated and it is calculated using the following formula: (Green, 2000)

$$m = \frac{\text{R.M.S. value of } V_m(t)}{\text{R.M.S. value of unmodulated carrier frequency}}$$

Having the right modulation factor is essential. That is well explained by V.K. Metha in his book "principles of electronics": "Modulation factor is very important since it determines the strength and quality of the transmitted signal. In an AM wave, the signal is contained in the variations of the carrier amplitude. When the carrier is modulated to a small degree, the amount of carrier amplitude variation is small. Consequently, the audio signal being transmitted will not be very strong. The greater the degree of modulation, the stronger and clearer will be the audio signal. It may be emphasised here that if a carrier is overmodulated, distortion will occur during reception." (2007, p. 416) The distortion due to overmodulating is shown on Fig. 5.

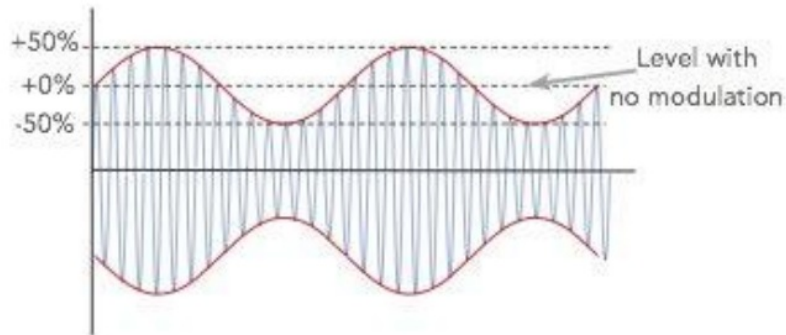


Fig. 3 Carrier modulated to 50% by a sinusoidal message signal

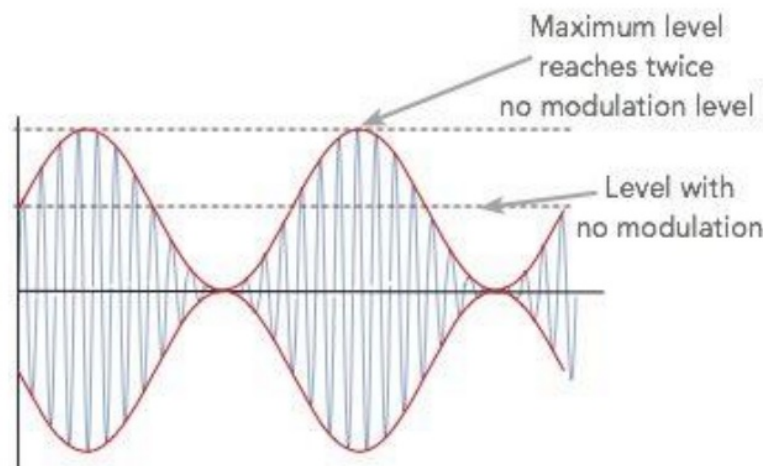


Fig. 4 Carrier modulated to 100% by a sinusoidal message signal

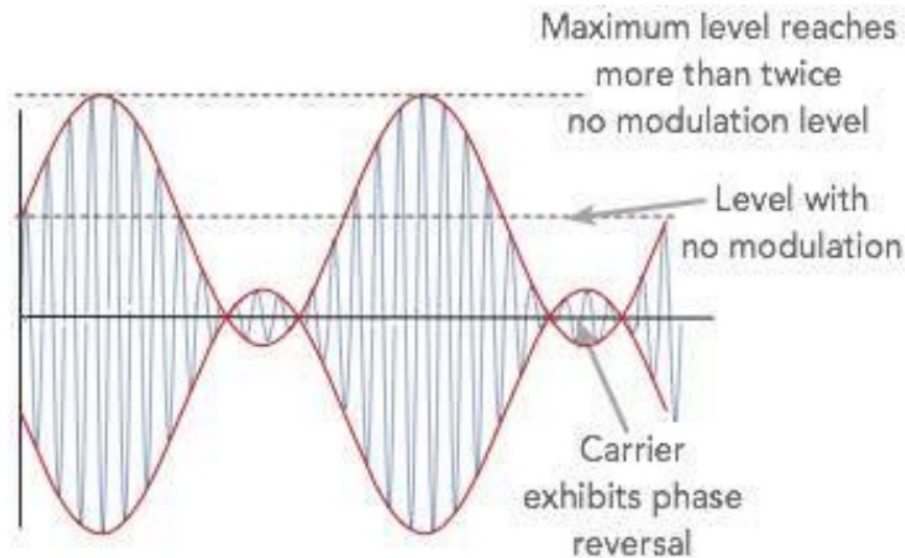


Fig. 5 Carrier modulated to over 100% by a sinusoidal message signal

There is a number of different techniques used to achieve amplitude modulation. Following there is a brief description of the three main ones.

Double-sideband full carrier amplitude modulation

It is the simplest and easiest achievable AM modulation technique. It doesn't require very sophisticated equipment to either transmit or receive the signal. Therefore, it is suitable for mass production such as commercial radios. But because this technique transmits the signal that contains the information and the carrier signal which does not contain any useful information, it is not very efficient to transmit wirelessly. (Metha & Metha, 2007)

Double-sideband suppressed carrier amplitude modulation

This technique suppresses the carrier frequency when transmitted, making it much more economical. But this technique requires more sophisticated equipment to be able to transmit or receive as a balanced modulator is required at the modulation stage.

Single-sideband amplitude modulation

As both, the upper and lower sidebands transmit the same information, one of those can also be omitted. This reduces the bandwidth required from $2f_m$ to f_m . To achieve modulation through this technique is usually much more complex and expensive than the previous one and it is used only in point-to-point transmission or in cases where there is only a few receivers.

*With a limited word count
try to keep your research
relevant to the topic being
investigated.*

4.1.2 Frequency modulation techniques

In frequency modulation the amplitude of the carrier is constant, but the carrier's frequency is changed with accordance of the amplitude of the signal message. When the amplitude of the signal increases, the frequency of the carrier increases and vice-versa. Therefore, the signal frequency defines rate of change of the carrier's frequency. (Metha & Metha, 2007)

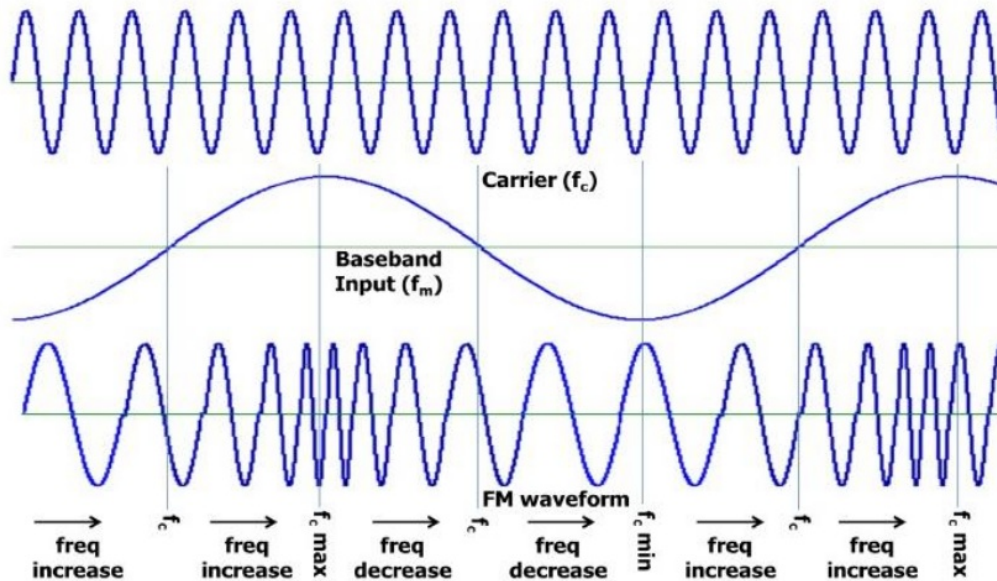


Fig. 6 Example of sine modulated FM signal

Every FM transmitting system has a specific transfer characteristic (k), which defines the deviation of the carrier frequency in kHz or MHz per volt applied to the input. Using that information, the maximum frequency deviation can be calculated if the input peak voltage (E_s) is known:

$$\Delta f_c = k E_s$$

(Metha & Metha, 2007)

Frequency spectrum of an FM wave

The frequency spectrum of an FM wave is difficult and complex to calculate. That is because, if f_c and f_s are carrier and signal frequencies, then the spectrum of the FM wave would have the following frequencies: f_c ; $f_c \pm f_s$; $f_c \pm 2f_s$; $f_c \pm 3f_s$; Etc. (Metha & Metha, 2007)

Although those calculations are made easier thanks to modulation index (β) and the Bessel Table (Appendix A).

The modulation index is calculated as follows:

$$\beta = \frac{\Delta f_c}{f_s}$$

Depending on the value of the modulation index, there will be 1 or more J . Each of them represents a magnitude of a carrier frequency component and its amplitude is defined by the corresponding multiplying number from the Bessel table. Fig. 7 shows an example of Spectrum analysis of an FM wave.

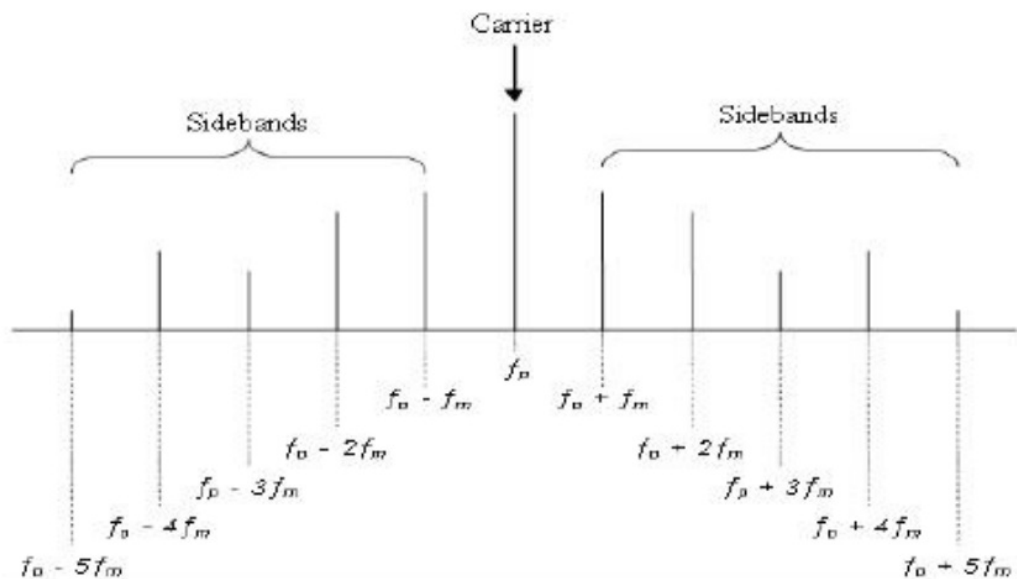


Fig. 7 example of a spectrum analysis of an FM wave

4.1.3 Phase Modulation

Phase modulation is usually used in digital circuit and it consists of changing the phase of the carrier according with the amplitude of the signal.

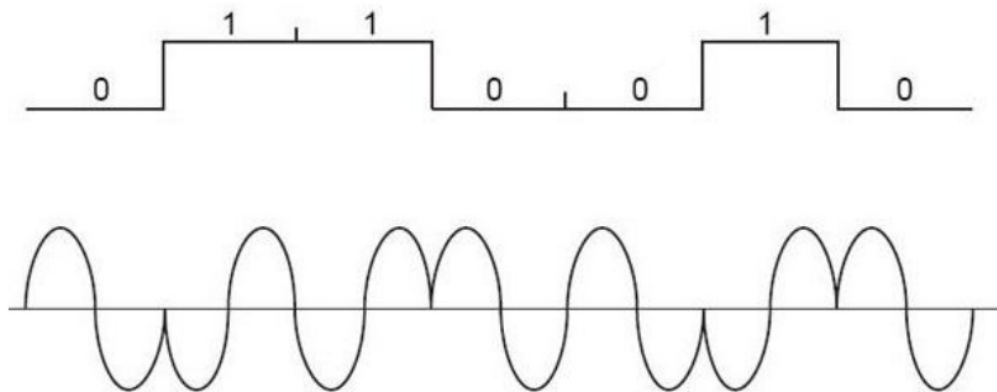


Fig. 8 Example of a phase modulated signal

4.2 Digital communication techniques

4.2.1 ADC (analogue to Digital converter)

An ADC is a system that converts an analogue signal to a digital one. That is achieved by sampling the analogue signal in time and amplitude. That quantizes the linear values of time and amplitude of the analogue signal. The signal must be sampled enough times so the sampled signal can be re-converted back to analogue signal. If the signal is not sampled enough it will come out with a lot of distortion or as a completely different signal. That is called aliasing. The minimum sampling frequency for a given signal's frequency is given by the Nyquist Criterion, according to which, the sampling frequency should be twice the input frequency.

$$f_{\text{sampling}} = f_{\text{input sig}}$$

(Christensson, 2008)

The quality of the ADC's signal is dependant on the resolution. The resolution defines into how many parts the input signal can be divided. The amount of divisions can be calculated by 2^n , where n is the resolution of the ADC. (ex. 8-bit resolution $\Rightarrow 2^8 = 256$ divisions).

The sensitivity of an ADC is an important aspect when designing a circuit as it will affect the quality of the signal. Sensitivity can be calculated by dividing max. input Voltage by number of possible divisions. (Gudino, 2018)

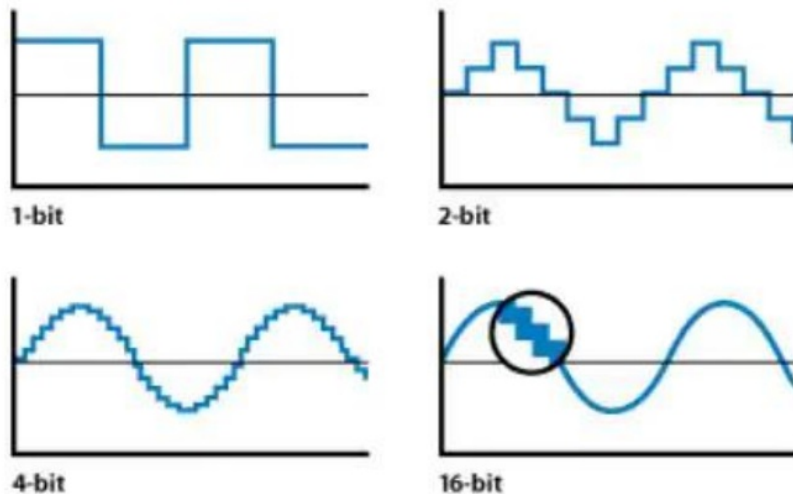


Fig. 9 Comparison of different resolution ADCs

Successive Approximation ADC

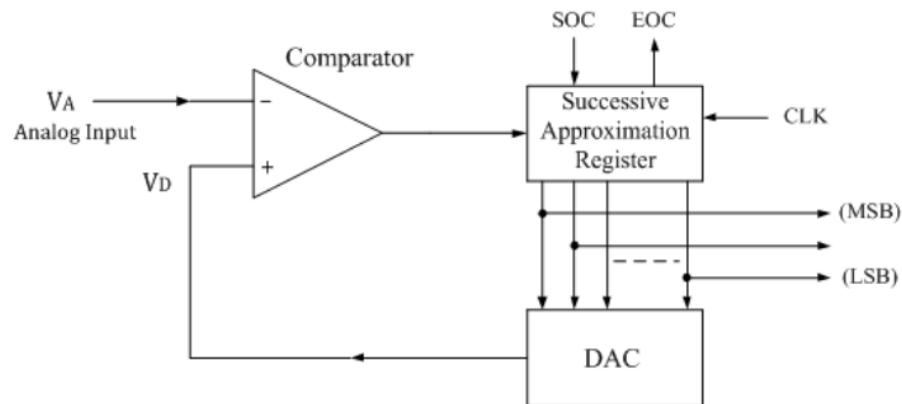


Fig. 10 Block diagram of a successive approximation ADC

It is a slow but stable and reliable ADC. It requires one clock cycle to convert one bit. Therefore, if this ADC is used as an 8-bit ADC, it requires 8 clock cycles to create 8-bit code from the input signal. Although that doesn't have much effect on system running with low frequency analogue signals, it can become quite complex when used with high frequency applications. That is due the fact that this ADC uses a single comparator to code the incoming signal. As shown on the block diagram (Fig. 10), the voltage reference for the comparator is fed from the DAC (Digital to analogue) part that reconverts the last encoded bit into a voltage reference for the next bit. (Gudino, 2018)

Flash ADC

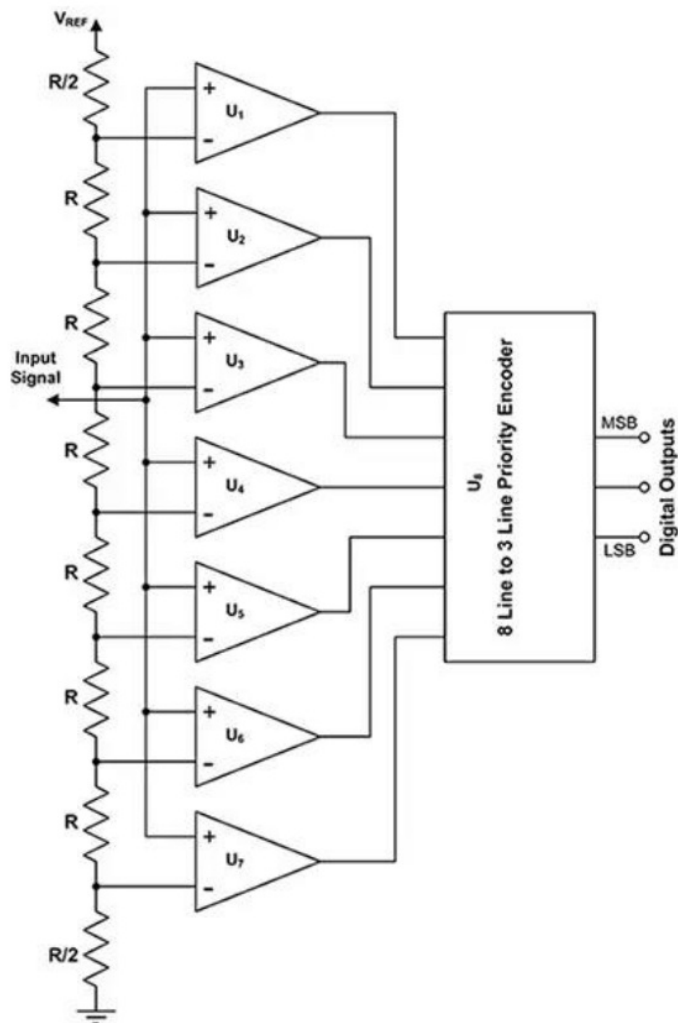


Fig. 11 Block diagram of a 3-bit flash ADC

As the name suggests, this ADC is much faster than the Successive approximation ADC. This ADC can convert the incoming signal to any bit-rate code in a single clock cycle. That is because it uses many comparators, one for each step. The downside of it is that it needs $2^n - 1$ comparators (n =number of bits). So, an 8-bit ADC would need 255 comparators, and a 16-bit – 65,535 comparators. Only recently the technology has developed enough for that to be viable for inexpensive mass production. (Maxim Integrated, 2014)

4.2.3 Modulation schemes

The modulation schemes can be divided in sections according to their spectral efficiency, which is defined by bits/Hz.

A simple binary encoding has a spectral efficiency of 1bit/Hz. Although, that can be improved, 16-QAM is a good example, with 4bit/Hz. QAM schemes uses PSK (phase-shift keying) and ASK (amplitude-shift keying). As Andrew W. Davies noted in his article "Modulation Schemes: Moving digital Data With Analogue Signals": "QAM is a proven technique for the transmission of digital data over a wide range of channels from voiceband modems at 9600 bps to microwave links transmitting hundreds of Mbps." (1997)

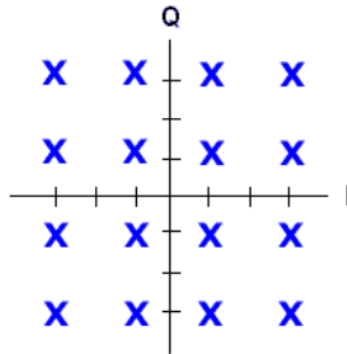


Fig. 12 Constellation for 16-QAM modulation scheme

Another modulation scheme is QPSK. Compared to QAM, it is slower but much more robust against any interferences which makes it ideal for long distance transmissions. The spectral efficiency of QPSK is 1.5bit/Hz.

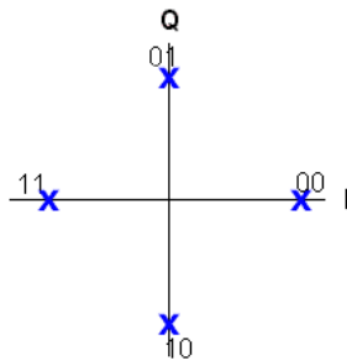


Fig. 13 Constellation for QPSK modulation scheme

A good range of sources for the research on ADCs, less so for modulation.

5. Frequency modulation – Practical experiment

5.1 Theoretical expectations

Before performing the practical experiment, some calculations were made to figure out what kind of results to expect. The values during the experimental experiment will be the following:

- Carrier frequency (f_c)=455kHz with an amplitude (V_{cpk}) of 375mV
- Signal Frequency (f_s)=10kHz with an amplitude (V_{spk}) of 2V
- FM transfer characteristic = 20kHz/V

Using those values, it is possible to calculate the maximum frequency deviation (Δf_c) and then, Modulation index (β).

$$\Delta f_c = (f_c + V_{spk} * FM \text{ transfer characteristic}) - f_c = \\ = (455kHz + 2 * 20kHz) - 455kHz = 40kHz$$

$$\beta = \frac{\Delta f_c}{f_s} = \frac{40kHz}{10kHz} = 4$$

Now using the Bessel table shown below, and knowing that $\beta=4$, it is been determined that there is seven components to the frequency transmitted. Using the coefficients from the table, the values for each component are calculated. Also, the carrier frequency will oscillate between 415kHz and 495kHz.

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

$$\begin{array}{ll} J_0 = 0.40 * 375mV = 150mV & @ f_c \pm 0 * f_s = 455kHz \\ J_1 = 0.07 * 375mV = 26.25mV & @ f_c \pm 1 * f_s = 445kHz, 465kHz \\ J_2 = 0.36 * 375mV = 135mV & @ f_c \pm 2 * f_s = 435kHz, 475kHz \\ J_3 = 0.43 * 375mV = 161.25mV & @ f_c \pm 3 * f_s = 425kHz, 485kHz \\ J_4 = 0.28 * 375mV = 105mV & @ f_c \pm 4 * f_s = 415kHz, 495kHz \\ J_5 = 0.13 * 375mV = 48.75mV & @ f_c \pm 5 * f_s = 405kHz, 505kHz \\ J_6 = 0.05 * 375mV = 18.75mV & @ f_c \pm 6 * f_s = 395kHz, 515kHz \\ J_7 = 0.02 * 375mV = 7.5mV & @ f_c \pm 7 * f_s = 385kHz, 525kHz \end{array}$$

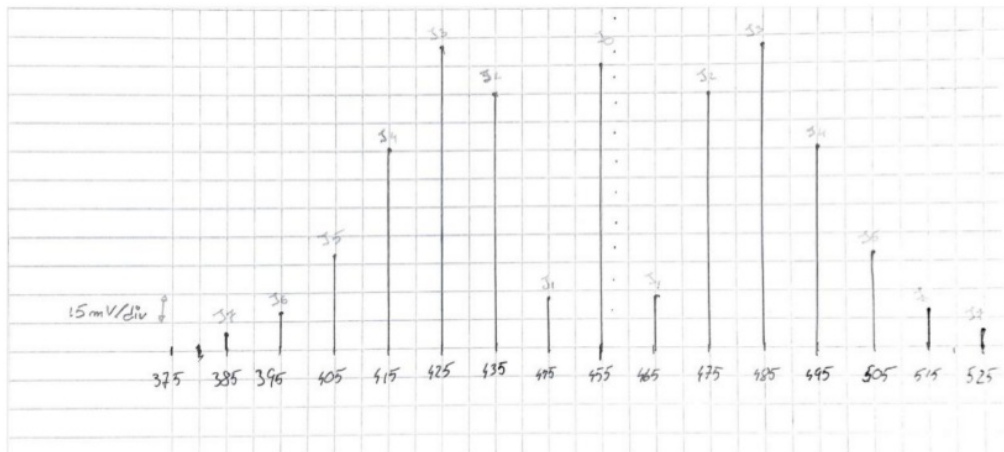


Fig. 14 Sketch of expected result on spectrum analyser

5.2 Practical results

The experiment was conducted using feedback instruments. Below is shown the signal frequency (Fig. 15) and the modulated carrier frequency at its maximum (Fig. 17) and minimum (Fig. 16). The frequencies and amplitudes are not 100% accurate, but they are within an acceptable tolerance. Also, the signal frequency has a slight DC offset. Those inaccuracies could cause the results to be not as accurate.

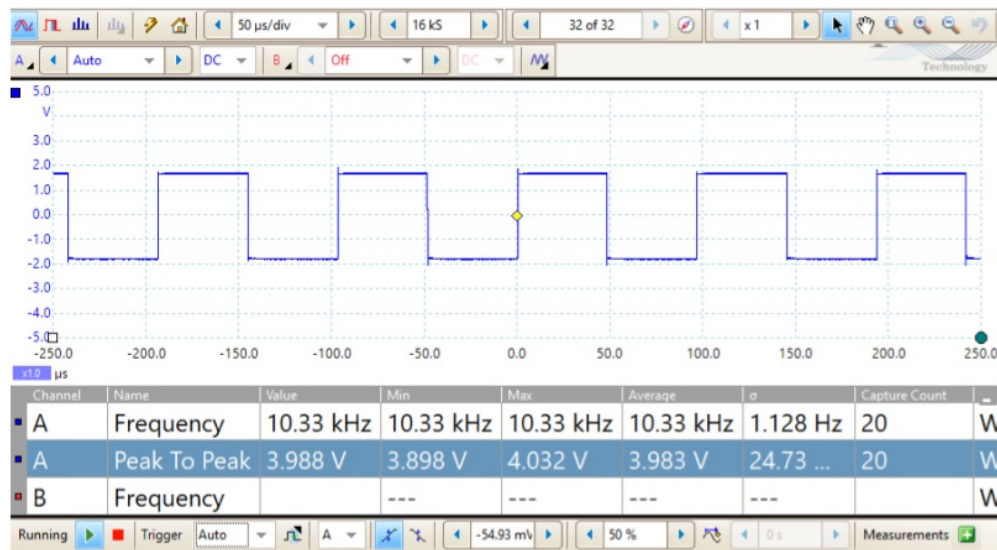


Fig. 15 Signal frequency

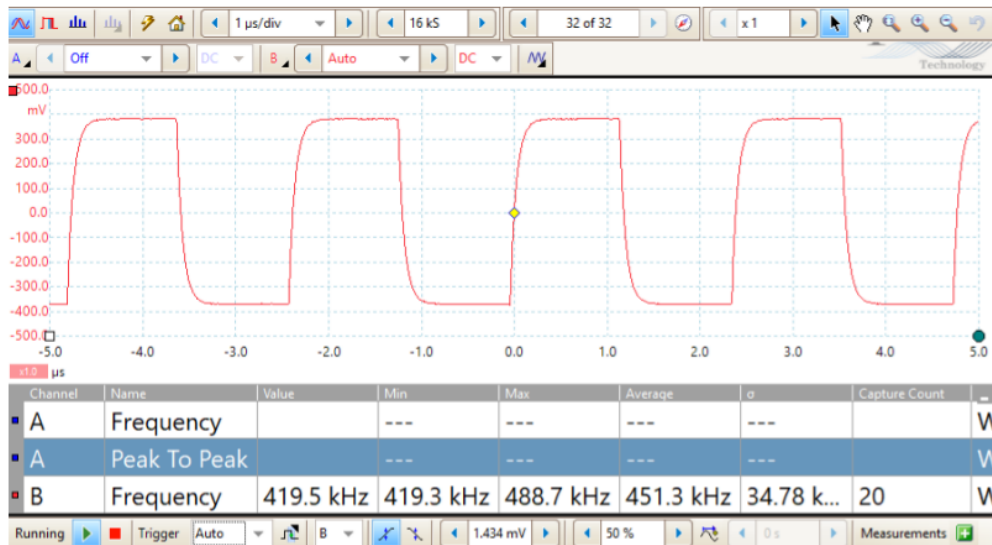


Fig. 16 Carrier frequency at its minimum

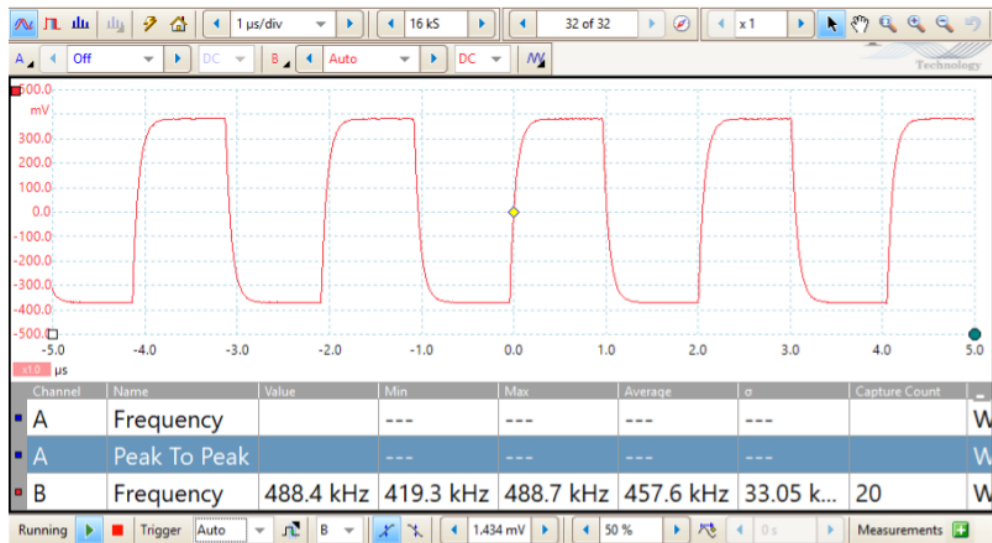


Fig. 17 Carrier frequency at its maximum

After that, the oscilloscope was set spectrum analyser function and the results were recorded (Fig. 18, Fig. 19). When comparing those results with the sketch, some similarities can be seen in the pattern of the side components, but the central frequency is very different. The results were measured and recorded in the table below.

	J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7
mV	49.94	35.11	75.97	157.7	107.4	23	19.98	6.356
$f_{c-upper}$	454	443.6	433.2	423	412.6	402.3	391.9	381.6
$f_{c-lower}$		464.3	474.6	484.9	495.3	505.6	515.9	526.3

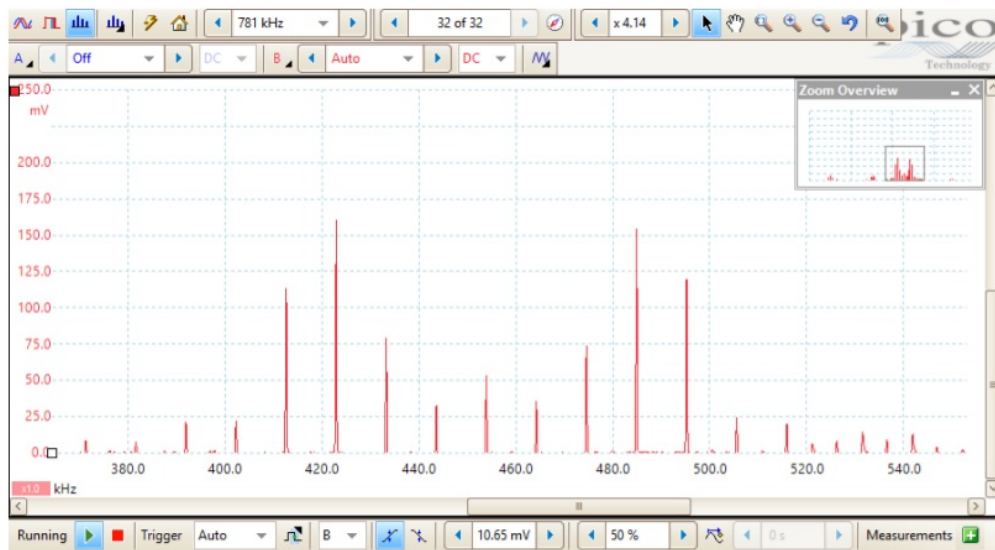


Fig. 18 Spectrum analyser results

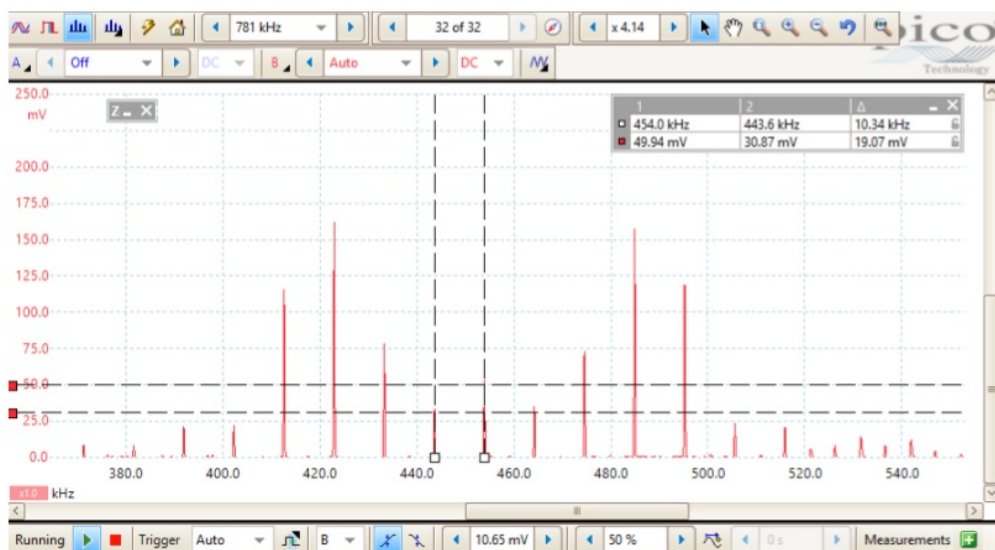


Fig. 19 Spectrum analyser results with cursors

5.3 FM experiment conclusion

The table below shows a comparison between the measured and calculated values. The modulation index values for the practical are calculated using the measured amplitudes. On that table is easier to spot where the biggest differences are than when comparing the spectrum analysis graphically. J_0 , J_2 and J_5 are the ones with the biggest difference. The rest of the components are reasonably close together. Also, the upper frequency position of the components is a bit offset in the practical. That is probably due to the slight DC offset of the signal.

		J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7
Practical	mV	49.94	35.11	75.97	157.7	107.4	23	19.98	6.356
	$f_{c-upper}$	454	443.6	433.2	423	412.6	402.3	391.9	381.6
	$F_{c-lower}$		464.3	474.6	484.9	495.3	505.6	515.9	526.3
	β	0.13	0.09	0.20	0.42	0.29	0.06	0.05	0.02
Calculated	mV	150	26.25	135	161025	105	48.75	18.75	7.5
	$f_{c-upper}$	455	445	435	425	415	405	395	385
	$F_{c-lower}$		465	475	485	495	505	515	525
	β	0.40	0.07	0.36	0.43	0.28	0.13	0.05	0.02

*A very good set of results
considering the limitations of
the equipment.*

6. ADCs – Practical experiment

In this task, the author has experimented with ADCs, comparing the quality between 4 and 8-bit ADCs, the importance of matching the amplitude and the frequency.

6.1 4-bit vs 8-bit ADCs

To compare the two, the same amplitude (2V) and frequency (100Hz) were used. This way, it is ensured that the comparison will be valid and fair. The comparison is shown on Fig. 20. It is very clear that the signal on the right (8-bit) is much closer to the original signal than the one on the left (4-bit). That confirms the research, showing that the higher the bit-rate, the higher the quality of the reconverted signal.

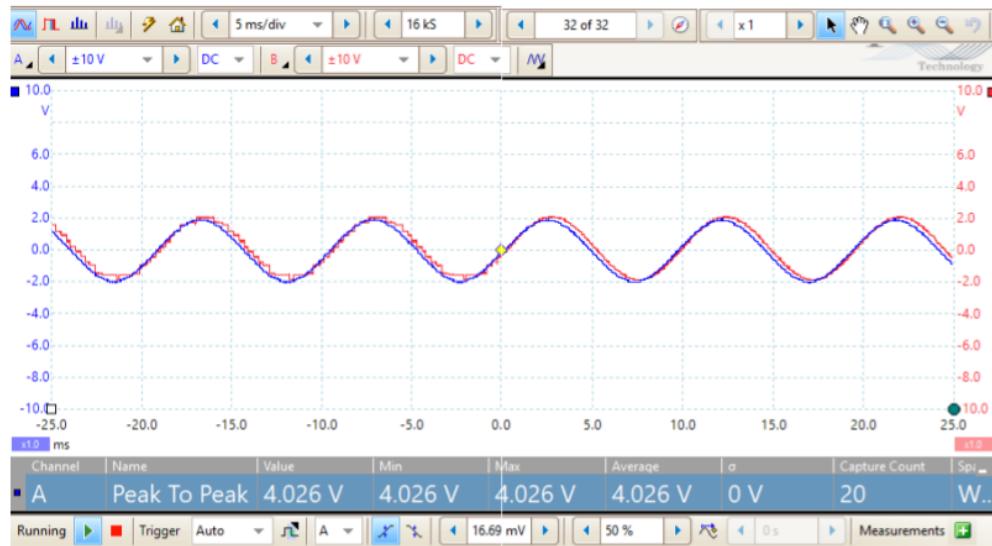


Fig. 20 Comparison between 4-bit (left) and 8-bit (Right) ADCs

You could have zoomed in a bit closer to show the "jaggedies" more clearly.

6.2 Significance of the amplitude on ADC's input

The figure below (Fig. 21) shows the effects of oversteering the input of an ADC. As the signal was outside of the operating range of the ADC; anything above the range was not encoded and therefore, lost. When the signal is reconverted, the “chopped-off” peaks introduce interference and harmonics (aliasing). That can also damage the ADC.

On the other hand, if the signal is too weak, it is possible that it will not trigger enough steps to encode the signal truthfully, inducing aliasing on the output.

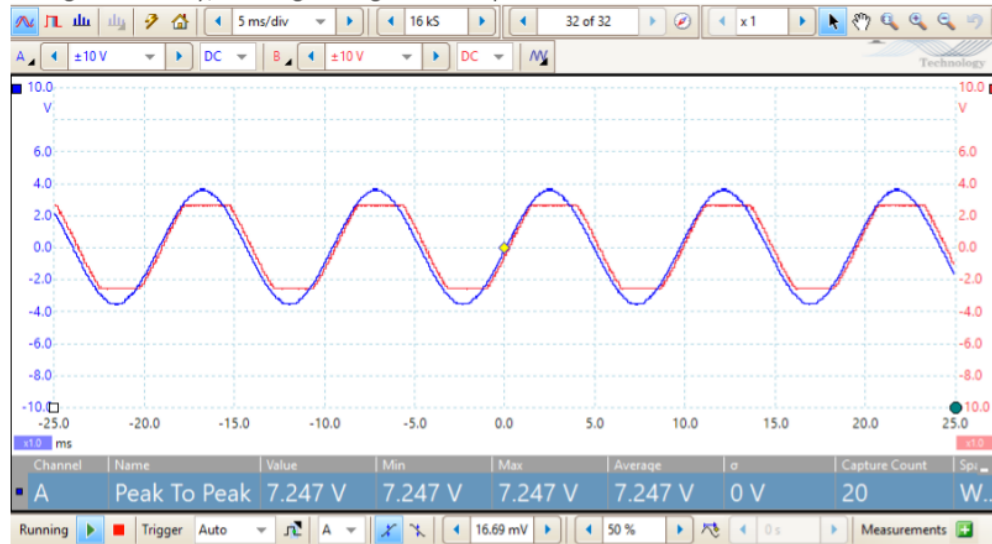


Fig. 21 Example of the effect of applying a signal outside ADCs operating range

6.3 Significance of frequency matching in ADCs

The following figures shows and proves the Nyquist Criterion, According to whom, knowing that the ADC used for the experiment has a clock of 5kHz, it should operate properly up to half that frequency.

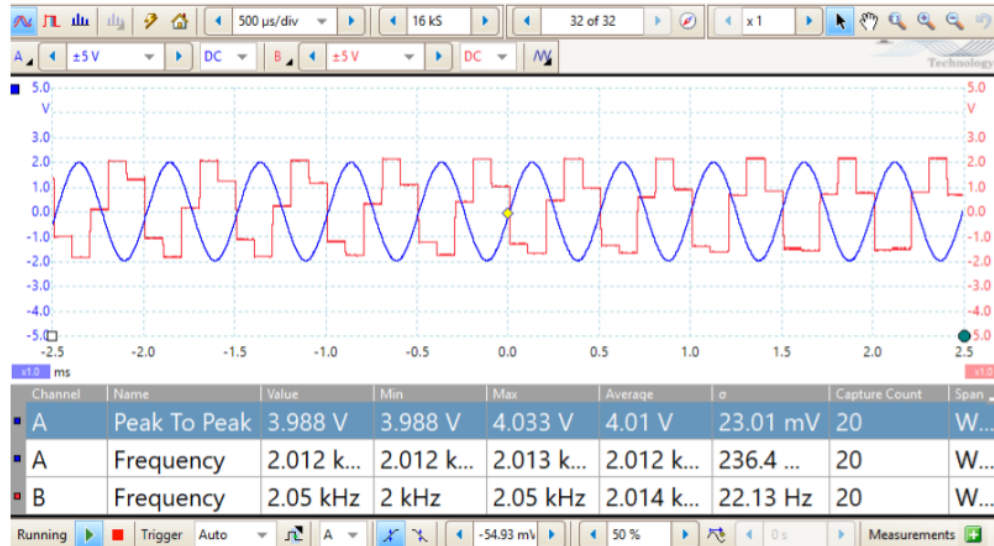


Fig. 22 ADC's Performance at 2kHz

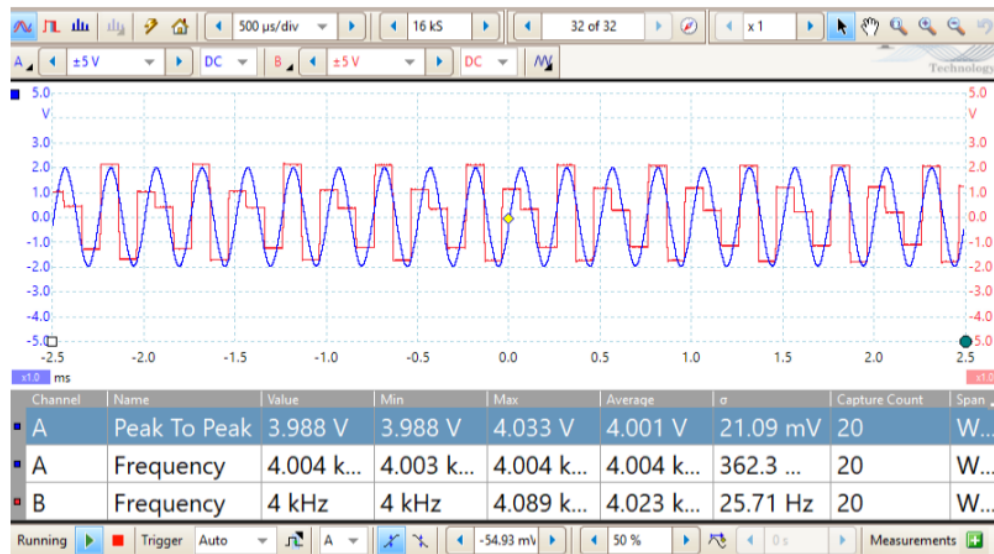


Fig. 23 ADC's Performance at 4kHz

Fig. 22 shows the ADC with an 2kHz input signal, about half the speed of ADC's clock. The ADC is managing about 4-5 samples per cycle. For comparison, on Fig. 23 there is a 4kHz input to the ADC, now there is only two samples per cycle, and although it seems to be working ok, there could be some aliasing happening at the output.

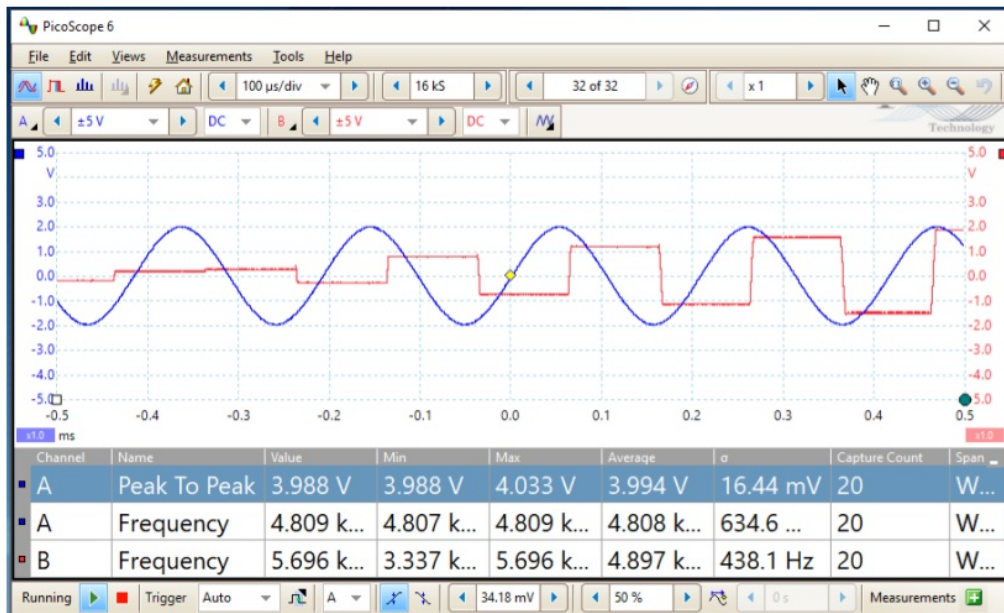


Fig. 24 ADC's Performance at 4.8kHz

On Fig. 24, the ADC is supplied with a 4.8kHz input signal. The output here doesn't look anything like the input, as where on Fig. 23 the output was similar to the input. And although the average output frequency is 4.8kHz, the maximum and minimum are 5.69kHz and 3.33kHz respectively, meaning that there is a lot of aliasing happening at the output. Fig. 25 shows the result of taking the ADC's input up to 9kHz. The output signal has so much aliasing that the oscilloscope is incapable of measuring the output frequency.

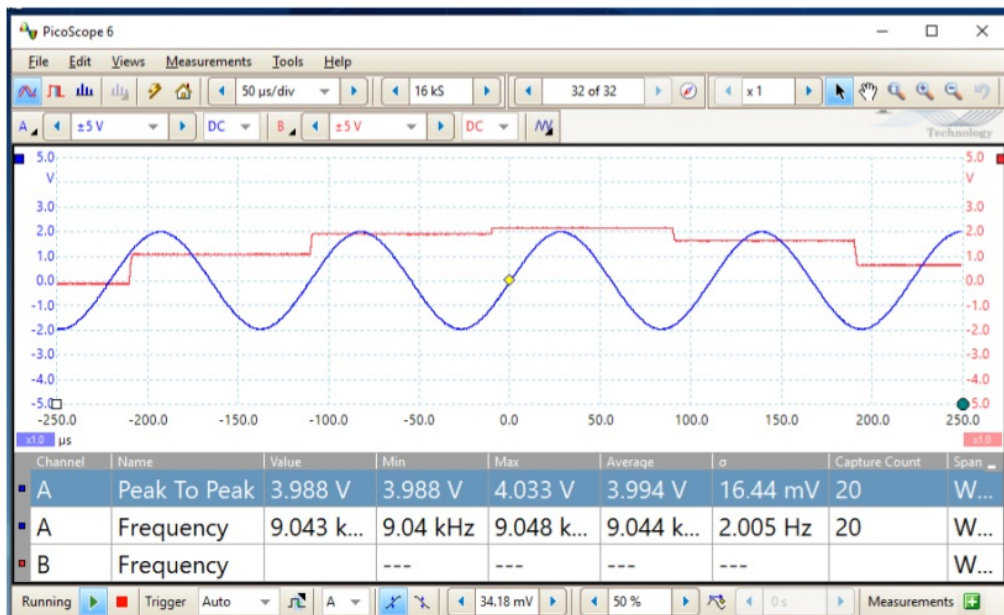


Fig. 25 ADC's Performance at 9kHz

Input frequency	Output frequency		
	Average	Maximum	Minimum
101Hz	101Hz	101Hz	100.8Hz
1.144kHz	1.143kHz	1.176kHz	1.136kHz
2kHz	2.014kHz	2.05kHz	2kHz
4kHz	4.023kHz	4.089kHz	4kHz
4.4kHz	4.442kHz	4.489kHz	4.376kHz
4.8kHz	4.897kHz	5.696kHz	3.337kHz
5.4kHz	4.628kHz	5kHz	4.294kHz
6kHz	3.9kHz	4.282kHz	3.346kHz
7kHz	2.9kHz	3.32kHz	2.85kHz
8kHz	---	---	---
9kHz	---	---	---
10.02kHz	724kHz	1.773GHz	2.495kHz

The above table is a better representation of what is happening with the output as the input gets closer and passes the frequency of the ADC's clock, which is 5kHz here. As it gets closer, the frequency starts to drift a bit more (max/min) and once the clock's speed is passed, the output's frequency does not settle, oscillates, and does not represent the original signal (aliasing).

The analysis should have focused on readings around 5kHz, this would demonstrate the Nyquist Criteria in more detail.

7. Conclusion and recommendations

Overall, the research has shown an understanding of the different types of modulation and ADCs. It has shown the strong and weak points of both, amplitude and frequency modulation. It has presented some characteristics of frequency modulation which were tested and investigated further in the first practical task.

The second practical task was driven by the ADC research and it has proven the boundaries of successive approximation ADC.

*There was a lot of scope
for analysis and
conclusions in this
assignment.*

Appendix A

FM SIDE FREQUENCIES FROM BESSEL FUNCTIONS

		n OR ORDER															
$\times$ (m_f)	(Carrier) J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9	J_{10}	J_{11}	J_{12}	J_{13}	J_{14}	J_{15}	J_{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	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.5	0.51	0.56	0.23	0.06	0.01	—	—	—	—	—	—	—	—	—	—	—	—
2.0	0.22	0.58	0.35	0.13	0.03	—	—	—	—	—	—	—	—	—	—	—	—
2.5	-0.05	0.50	0.45	0.22	0.07	0.02	—	—	—	—	—	—	—	—	—	—	—
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	—	—	—	—	—	—	—	—
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	—	—	—	—	—
9.0	-0.09	0.24	0.14	-0.18	-0.27	-0.06	0.20	0.33	0.30	0.21	0.12	0.06	0.03	0.01	—	—	—
10.0	-0.25	0.04	0.25	0.06	-0.22	-0.23	-0.01	0.22	0.31	0.29	0.20	0.12	0.06	0.03	0.01	—	—
12.0	0.05	-0.22	-0.08	0.20	0.18	-0.07	-0.24	-0.17	0.05	0.23	0.30	0.27	0.20	0.12	0.07	0.03	0.01
15.0	-0.01	0.21	0.04	-0.19	-0.12	0.13	0.21	0.03	-0.17	-0.22	-0.09	0.10	0.24	0.28	0.25	0.18	0.12

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1708165 assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

64/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

Text Comment. You should cover each section, so you need to summarise the results and conclusions.

PAGE 6

PAGE 7

PAGE 8

PAGE 9

Text Comment. With a limited word count try to keep your research relevant to the topic being investigated.

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

Text Comment. A good range of sources for the research on ADCs, less so for modulation.

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

Text Comment. A very good set of results considering the limitations of the equipment.

PAGE 21

Text Comment. You could have zoomed in a bit closer to show the "jaggedies" more clearly.

PAGE 22

PAGE 23

PAGE 24

PAGE 25

Text Comment. The analysis should have focused on readings around 5khz, this would demonstrate the Nyquist Criteria in more detail.

PAGE 26

Text Comment. There was a lot of scope for analysis and conclusions in this assignment.

PAGE 27

PAGE 28

GRADING FORM: CSG-RUBIC

ADAM BEDNER

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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.

6/10

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.

21/30

ANALYSIS

 Your analysis of the task was generally satisfactory, both in class and as shown in this assignment,

15/30

however it did tend more towards descriptive rather than analytical. You have demonstrated some analytical skills and your approach to the task was logical. You wrote a short conclusion that demonstrated some skills in analysing quantitative and qualitative data, however this was generally basic in nature. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory and provide a detailed critical analysis of this.

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally good. You used the resources available appropriately 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.

15/20

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was generally good and contained most of the required detail, it was also written in a coherent and logical way. The available word count was in the main effectively used.

7/10