

BEng Embedded
Electronic Systems
Radio Frequency
Systems ACDA5019
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1 Introduction

The effect of noise in Amplitude Modulation (AM), Double-sideband suppressed-carrier (DSB-SC) modulation, and Frequency Modulation (FM) systems will be explored in this assignment. All three modulation options transmit modulated signals through a channel, which in the real-world are subject to noise, distorting the modulated message signal.

Each modulation method can be used to transmit analogue or digital information across a channel however, only analogue modulation will be explored in this assignment.

The effects of noise in DSB-SC and FM systems will be explored and the demodulated signal will be contrasted with the original message signal.

2 Background Research / Literature Review

Nathan Stubblefield broadcasted audio using a method similar to modern Amplitude Modulation [1]. Vibrations over a spark gap, which acted as the carrier signal, would modulate this carrier frequency and a receiver is described as “[responding] to” “secondary vibrations” [1]. This is similar to the modern-day equivalent, an envelope detector.

Frequency modulation was invented later, and is preferred due to its greater immunity [2] to noise in a channel, since noise is additive to the instantaneous amplitude of a signal, and FM demodulation examines a signal's instantaneous frequency. During lightning events, FM systems would be more resistant to noise from the surroundings of the receivers, making them preferred over AM.

3 Task 1 – Amplitude Modulation

3.1 Introduction to Amplitude Modulation

Amplitude Modulation (AM) varies the amplitude of the modulated signal according to the amplitude of the original message signal. AM contains an upper and lower side band, at $f_c + f_m$ and $f_c - f_m$ [3] respectively. These can be observed by connecting the output of the modulated AM signal to a spectrum analyser in Simulink®, shown below in Figure 1.

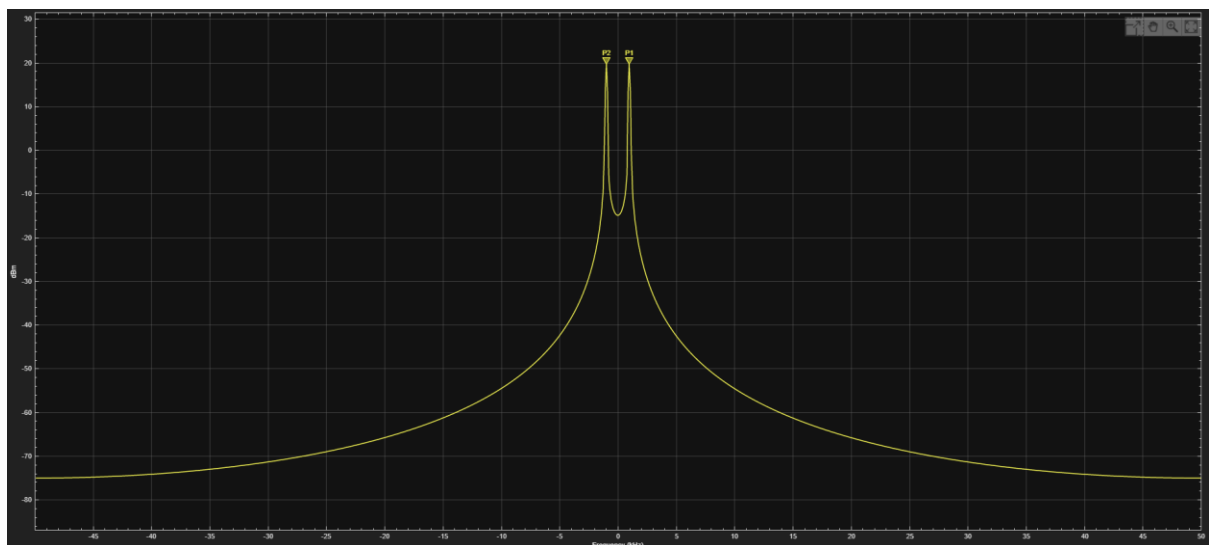


Figure 1: A modulated AM signal before it enters a channel for transmission

3.2 Block Diagram

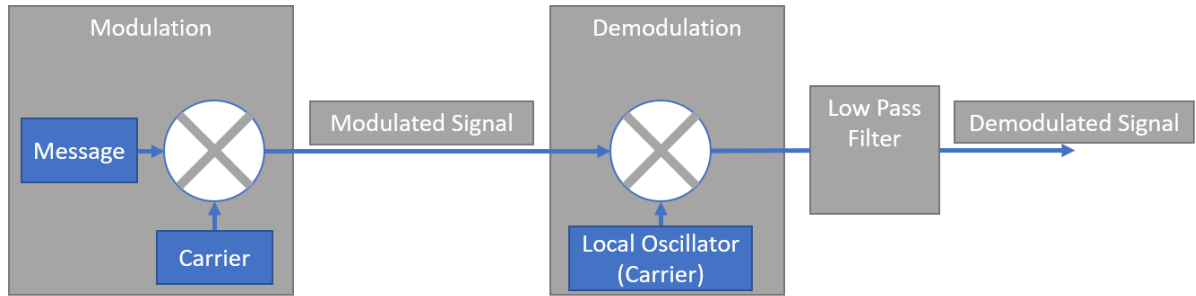


Figure 2: A generic block diagram of an Amplitude Modulation system

3.3 Circuit Design

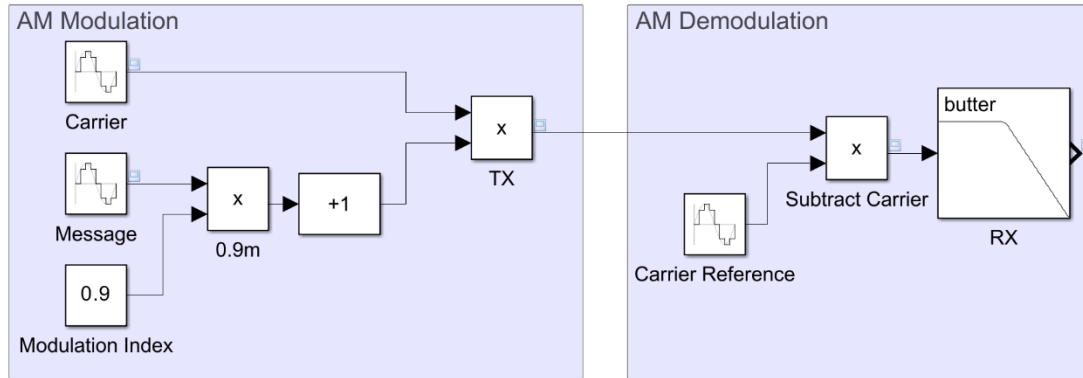


Figure 3: An Amplitude Modulation circuit designed in MATLAB® Simulink®

3.4 Architecture

3.4.1 Transmitter

The circuit shown above in Figure 1 shows an AM Modulation, AM Demodulation and filtering simulation designed in Simulink®. The AM section multiplies the message with a modulation index, A_m , of 0.9. This value falls below the value for critical modulation, $A_m = 1$ [3], which will be discussed further during analysis. The importance of a modulation index equal to or below 1 is the signal is not distorted.

3.4.2 Receiver

To demodulate the signal transmitted from the modulator, the carrier is subtracted by use of a mixer, taking the modulated signal and a reference carrier as inputs. It is important to note that not all AM systems must use a carrier reference to demodulate the modulated signal. An envelope detector takes the original signal and passes it through a diode and low pass filter. This benefits from several advantages as a local carrier reference is not required in the demodulator: Lower complexity as the circuitry to generate the carrier reference is not required; Special considerations do not have to be taken to deal with propagation delay through the channel as the local carrier must be mixed with the modulated signal in phase.

3.5 Simulated Outputs and Results

The message and carrier frequencies in the simulation were set to 100Hz and 1000Hz respectively, instead of the specified 1000Hz and 10000Hz. Various signals became distorted in an unexpected

manner at these frequencies. Changing the sample time did not resolve this issue. Examples can be seen in Annex A, where Figure 20 shows that unexpected peaks are observed on a spectrum analyser.

3.5.1 Over Modulation

Over modulation occurs when the modulation index, A_m , is greater than 1. In this situation, the carrier falls below 0V and a 180° phase reversal occurs <lecture 2 ref>. This is demonstrated below in Figure 4 (“Subtract Carrier”) where the out of phase sections of the wave produce a negative signal when mixed with the local oscillator. This would be especially problematic for circuits utilising an envelope detector because a diode would cause some of this information to be discarded. However, a local oscillator and mixer have been used instead of an envelope detector which allows the original message to still be recovered, as demonstrated at the bottom of Figure 4.

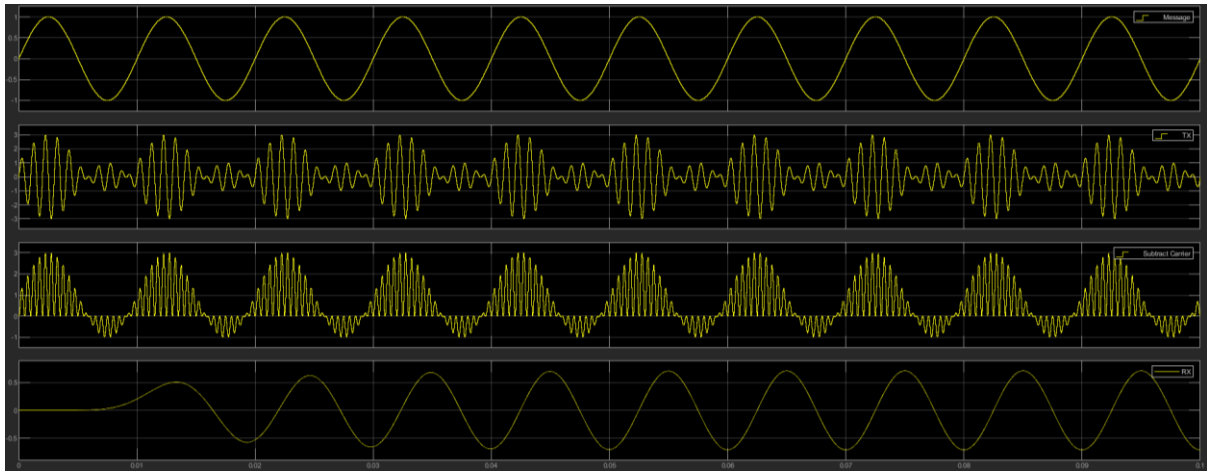


Figure 4: Over modulation in an AM circuit. The modulation index is set to 2.0

3.5.2 Under Modulation

A modulated AM signal is considered to be under modulated when the modulation index, A_m , is lesser than 1 [3]. Unlike over modulation, under modulation does not distort the modulated signal. However, the drawback of under modulating a signal is after demodulation the resulting signal is of a smaller amplitude than a critically modulated signal (discussed in the following section). This can be observed below in the final oscilloscope plot of Figure 5, where the signal has a peak-to-peak voltage of 0.1, compared to a peak-to-peak voltage of 0.8V in Figure 6. A weaker signal means that the transmission is more susceptible to noise than a critically modulated signal.

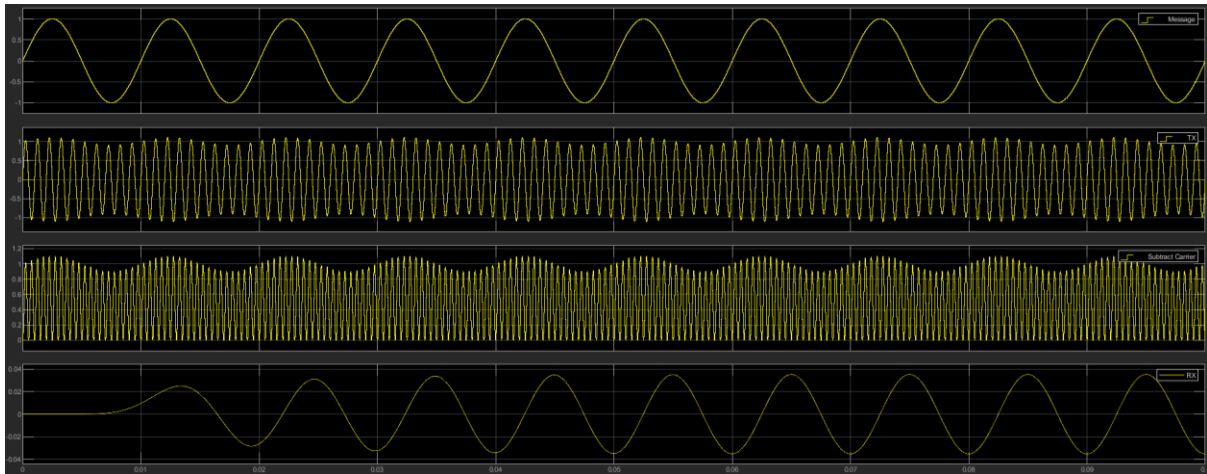


Figure 5: Under modulation in an AM circuit. The modulation index is set to 0.1

3.5.3 Critical Modulation

Critical modulation is a balance between over and under modulation, where the modulation index, A_m , is equal to 1. When a signal is critically modulated, the modulated signal can fall to 0, unlike under and over modulation. In this configuration, the greatest Signal to Noise Ratio (SNR) can be achieved. Figure 6 below demonstrates critical modulation. The carrier signal is modulated to 0V when the message signal is at a voltage of -1.

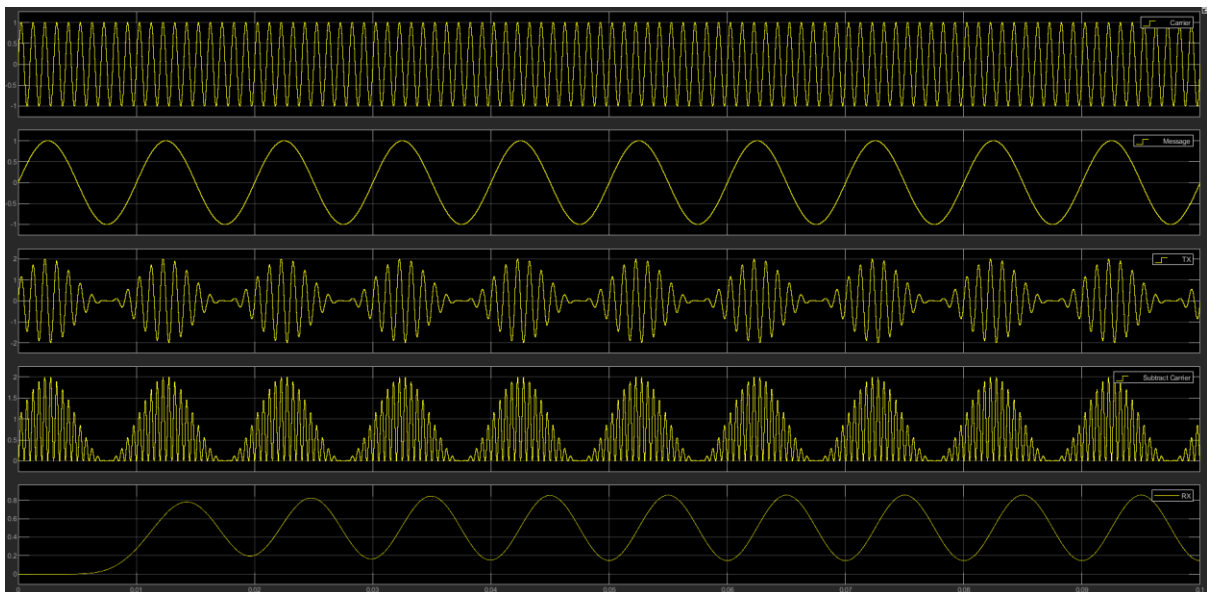


Figure 6: Critical modulation in an AM circuit. The modulation index is 1.0

4 Task 2 – Dual Side Band Suppressed Carrier (DSB-SC)

4.1 Introduction to DSB-SC

DSB-SC is a type of amplitude modulation that offers more efficient transmission when compared to AM as two thirds of energy is typically wasted “in the carrier, which carries no information” [4]. This provides a DSB-SC circuit an opportunity to transmit the same message an AM circuit, but with less susceptibility to noise. Instead, two separate modulators are used for the upper and lower side bands and the carrier is completely suppressed. An example of this can be seen under analysis.

4.2 Block Diagram

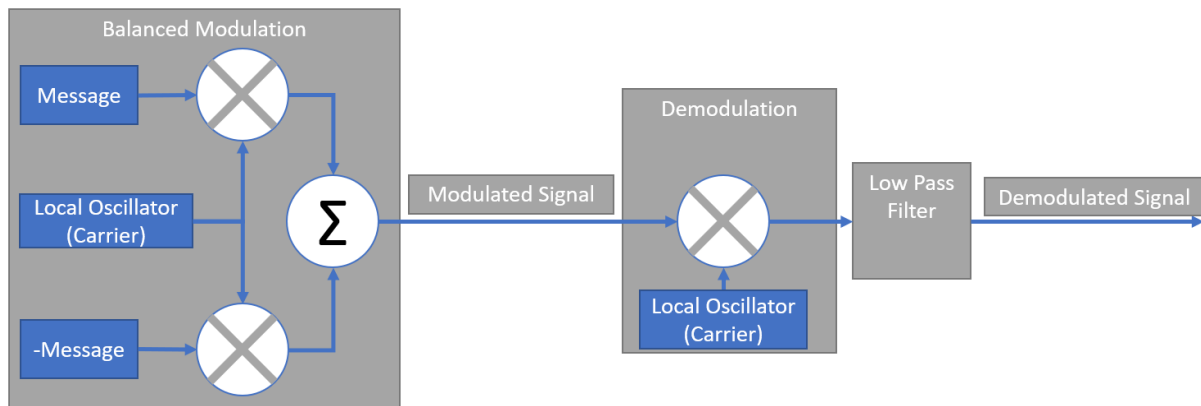


Figure 7: A block diagram of a DSB-SC circuit

4.3 Circuit Design

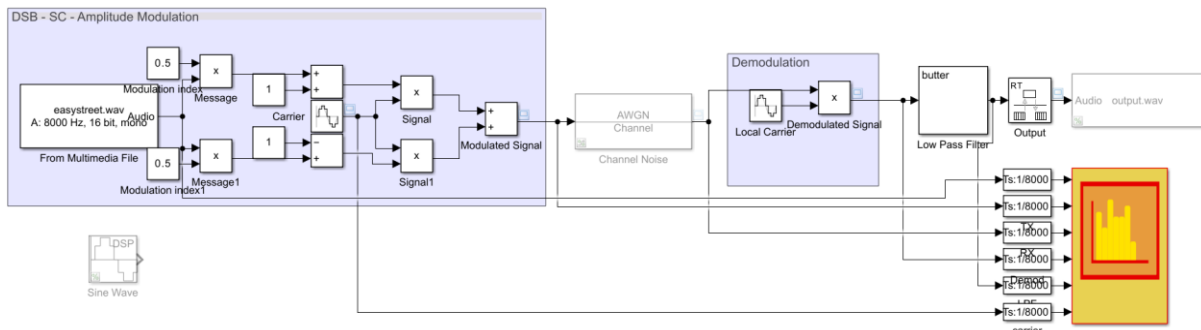


Figure 8: A DSB-SC circuit designed in MATLAB® Simulink®

4.4 Architecture

4.4.1 Transmitter

The circuit shown above in Figure 8 shows a DSB-SC Modulation, Demodulation and filtering simulation designed in Simulink®. The modulation section multiplies the message with a modulation index, A_m , of 0.9. This value falls below the value for critical modulation where $A_m = 1$, which will be discussed further during analysis. The importance of a modulation index equal to or below 1 is the signal is not distorted.

4.4.2 Receiver

The receiver works in the same manner as Task 1, mixing a local carrier with the received signal and passing the demodulated signal through a low pass filter to remove the undesirable higher frequencies. As with AM, an envelope detector may be used here in place of mixing in a local carrier.

4.5 Simulated Outputs and Results

4.5.1 Multimedia message in the time domain

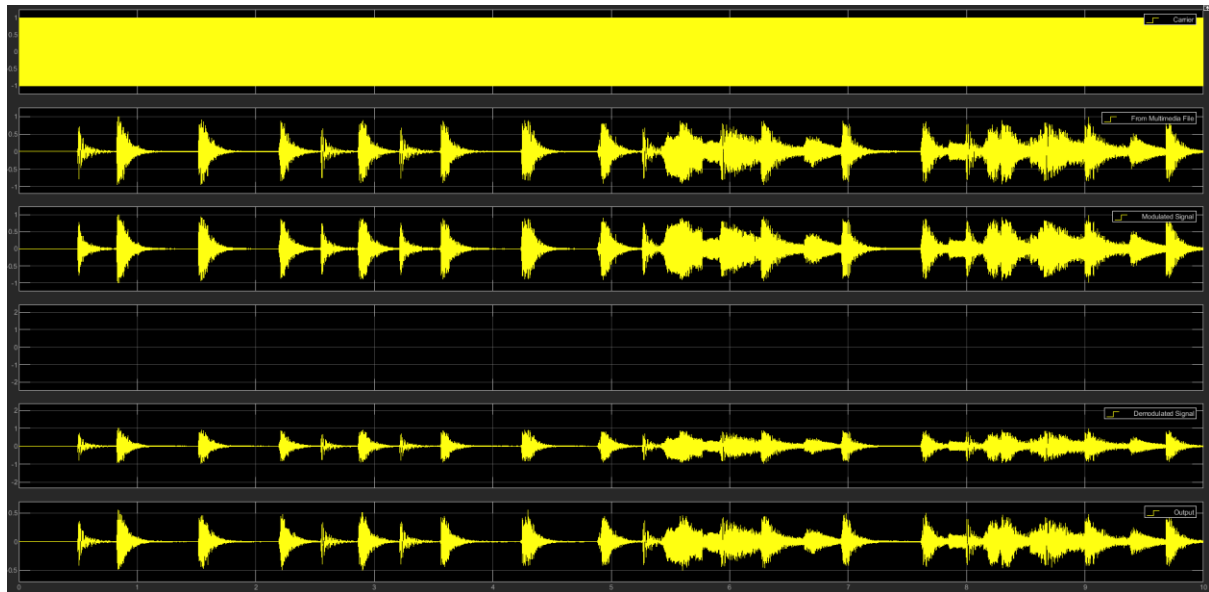


Figure 9: A multimedia message transmitted and received through a DSB-SC simulation

Shown above in Figure 9 are the oscilloscope plots for a 10 second audio file that has been modulated and demodulated in the DSB-SC circuit. The received signal is attenuated by just under 50% and has a slight delay from the low pass filter. Figure 10 below highlights a shorter sample of the 10 second audio file where the delay and attenuation can clearly be observed.

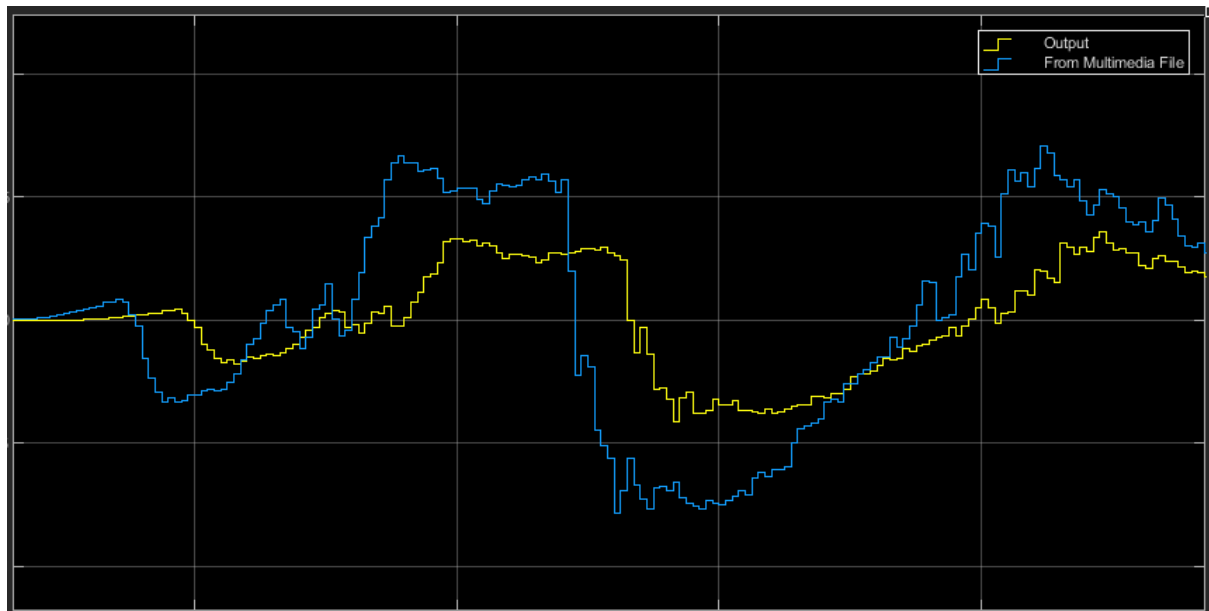


Figure 10: Attenuated and delayed output signal compared to the original message in a DSB-SC simulation

4.5.2 Multimedia message in the frequency domain

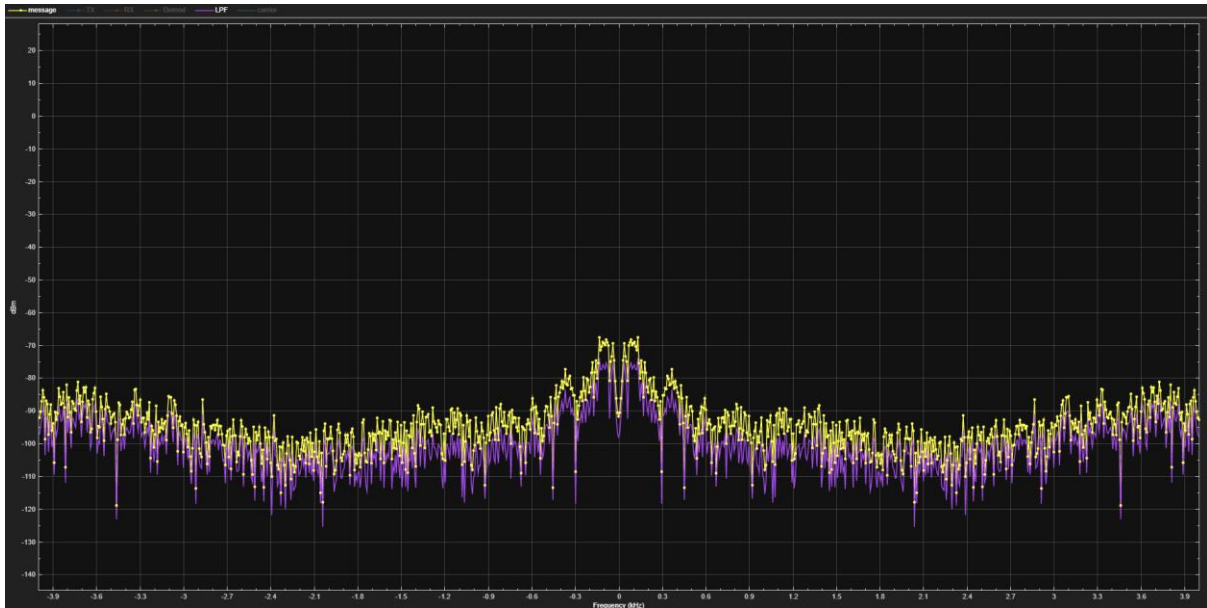


Figure 11: Spectrum Analyser view of the message and filtered signals in a DSB-SC simulation

The message and filtered signals look similar here, but are not identical due to the use of a local oscillator to demodulate the signal. The signal is also attenuated slightly due to passing through a filter.

4.6 Analysis of the effect of noise in a DSB-SC system



Figure 12: Spectrum Analyser view of the message and filtered signals in a DSB-SC simulation with noise present in the channel

Figure 12 above shows a spectrum analysis of the message signal (yellow) and demodulated signal (purple). The filtered signal is attenuated compared to the original signal. This is a consequence of passing the demodulated signal through a low pass filter. Additionally, above 3.9kHz there is a signal which was not present in the original message signal, which is due to noise that has mixed with the signal during its transmission in the channel. This means that white noise will be heard in audible frequency ranges where there previously wasn't any, on top of reducing the signal to noise ratio.

The use of a low pass filter here helps to remove the effects of noise that present themselves as distortion that can be measured in the higher frequencies. Low pass filters help to improve the

received signal however, they do have some drawbacks. Firstly, filter adds a delay which means the spectrum analyser will look at two slightly different sections of the message, but the majority of these sections will overlap, this is fortunately negligible for this case. Secondly, the filter attenuated the signal. This means that the received signal will be quieter before factoring in losses that may be incurred whilst transmitting through a carrier that attenuates the signal with distance.

5 Task 3 – FM Modulation

5.1 Introduction to FM

FM is a type of frequency modulation that has varies the instantaneous frequency of the modulated signal based on the voltage of the message signal. [5] Compared to AM and DSB-SC, it offers feedback during demodulation that can help to improve its signal to noise ratio through the use of a Phase-Locked Loop [6]. Another benefit when compared to types of AM is that FM “is more resistance to additive noise than AM” [7].

5.2 Block Diagram

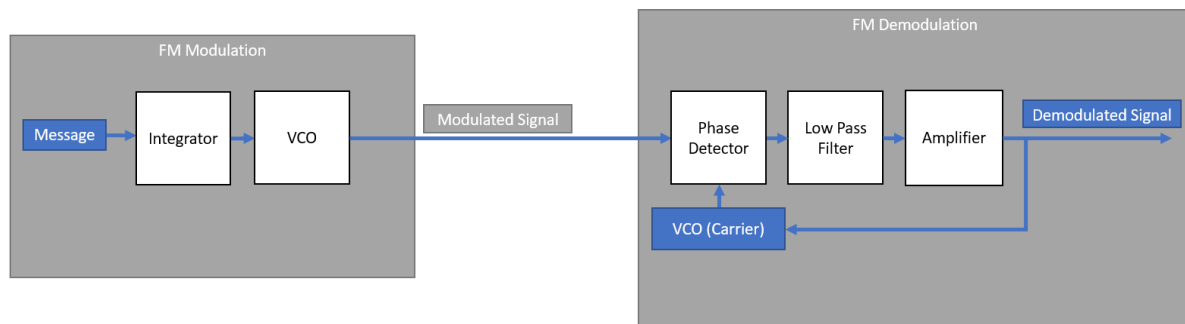


Figure 13: A block diagram of an FM circuit

5.3 Circuit Design

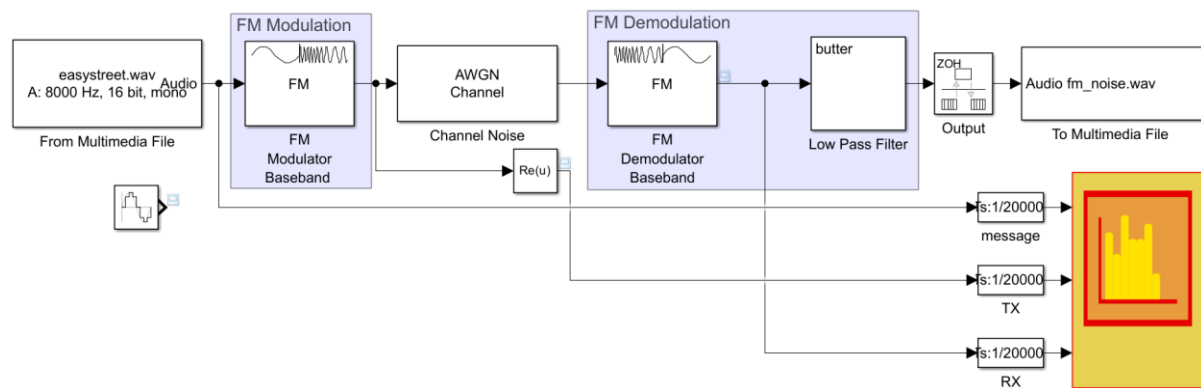


Figure 14: An FM circuit designed in MATLAB® Simulink®

5.4 Architecture

5.4.1 Transmitter

The circuit shown above in Figure 14 show an FM Modulation and Demodulation simulation designed in Simulink®. The FM Modulation section uses an FM Modulator Baseband block to handle the modulation of the message signal. The leftmost block of Figure 13 shows how the FM signal is modulated by the FM Modulator Baseband. The message signal is connected to an integrator which

outputs a voltage based on the input voltage for a short period of time $\delta(t)$. This is then be fed into a Voltage Controlled Oscillator (VCO) which outputs a voltage proportional to the input voltage.

5.4.2 Receiver

The receiver section uses an FM Demodulator Baseband block to demodulate the modulated signal and recover the original signal. The circuit diagram shows the process the FM Demodulator Baseband block undertakes to recover the original signal. The modulated signal is passed into a phase detector before going into a low pass filter and VCO to provide feedback. This type of circuit is a Phase-Locked Loop [6].

5.5 Simulated Outputs and Results

5.5.1 Multimedia message in the time domain

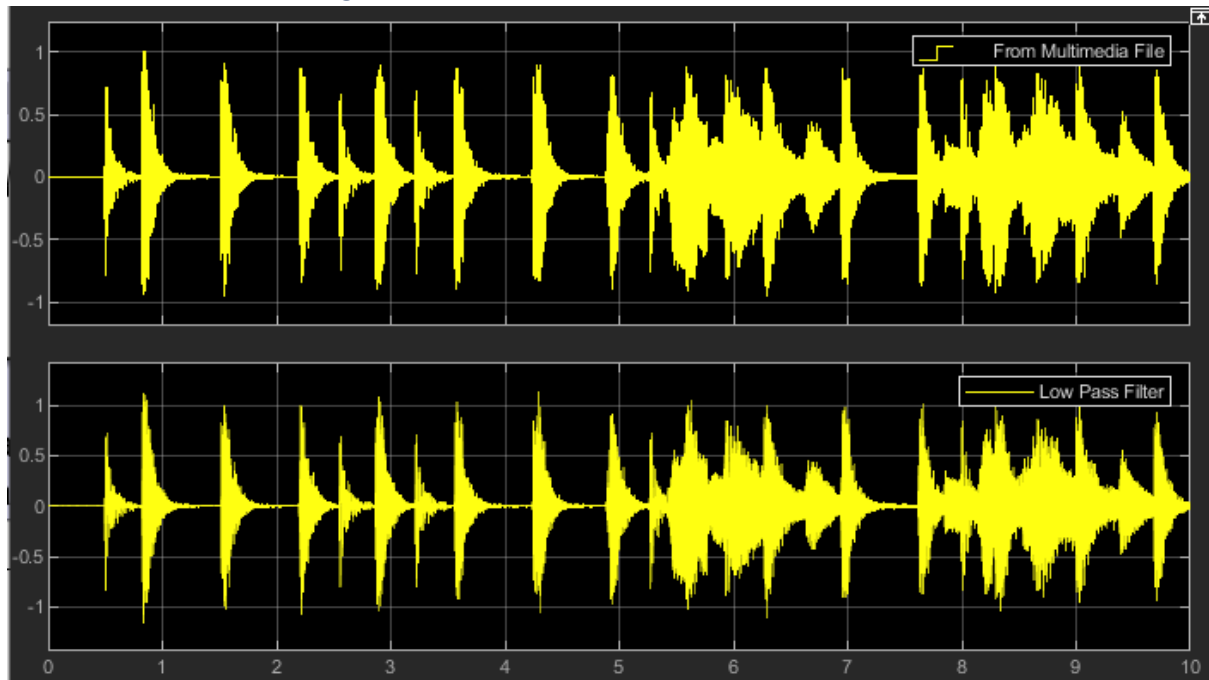


Figure 15: Message and demodulated signals from an FM simulation shown on an oscilloscope

Shown above in Figure 15 are the oscilloscope plots for a 10 second audio file that has been modulated and demodulated in the FM circuit. The received signal is attenuated by just under 50% and has a slight delay from the low pass filter. Figure 16 below highlights a shorter sample of the 10 second audio file where the short delay from the low pass filter can be observed.

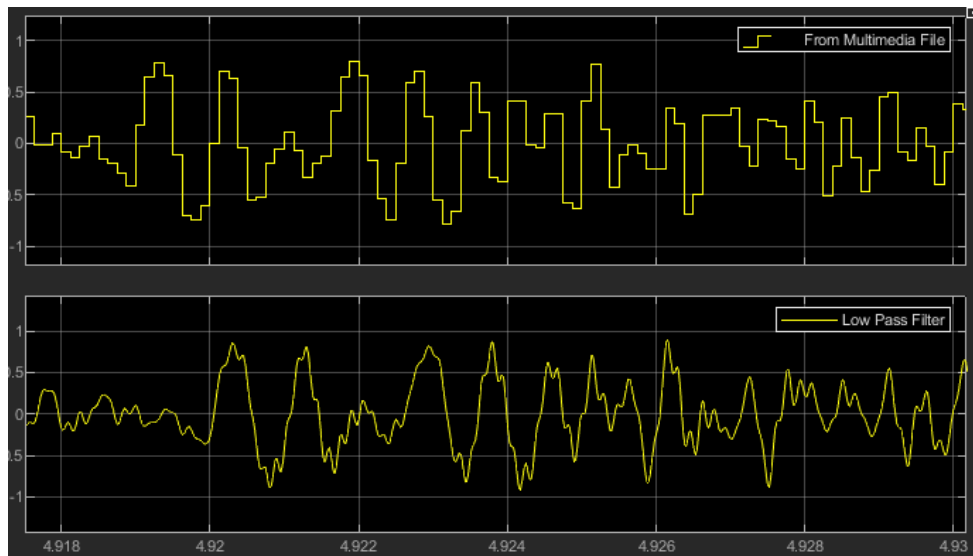


Figure 16: Delayed output signal compared to the original message in an FM simulation

5.5.2 Multimedia message in the frequency domain

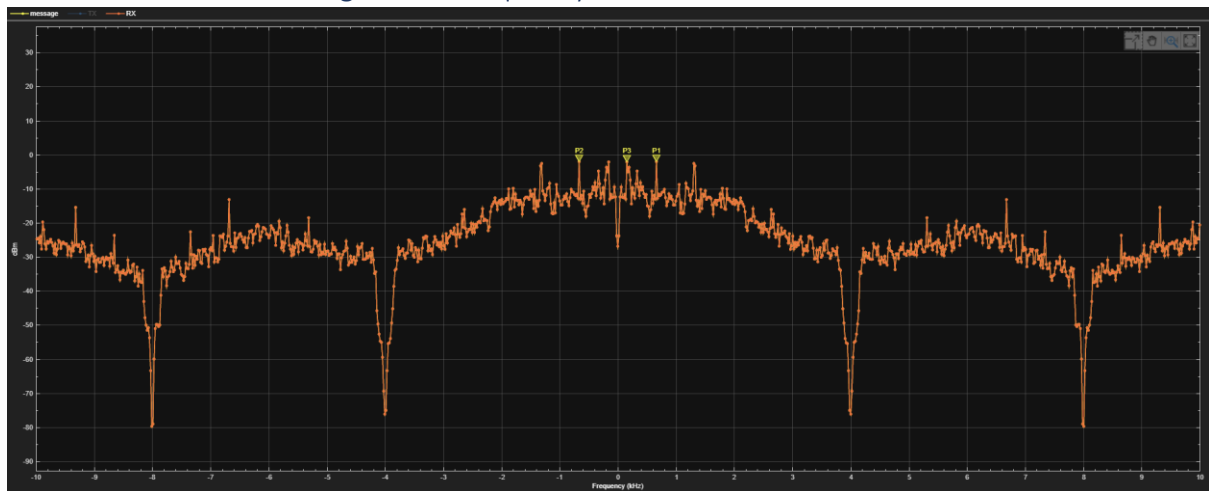


Figure 17: Original and demodulated signals in an FM simulation

Figure 17 above shows the original message signal and demodulated signal as shown on a spectrum analyser. The two signals are identical, showing both FM modulation and demodulation are working perfectly in this circuit.

5.6 Analysis of the effect of noise in an FM system

After noise has been added to the channel, the spectrum analyser shows that noise has been added to the signal at frequencies where there was and absence of signal before. This can be seen in the figure below.

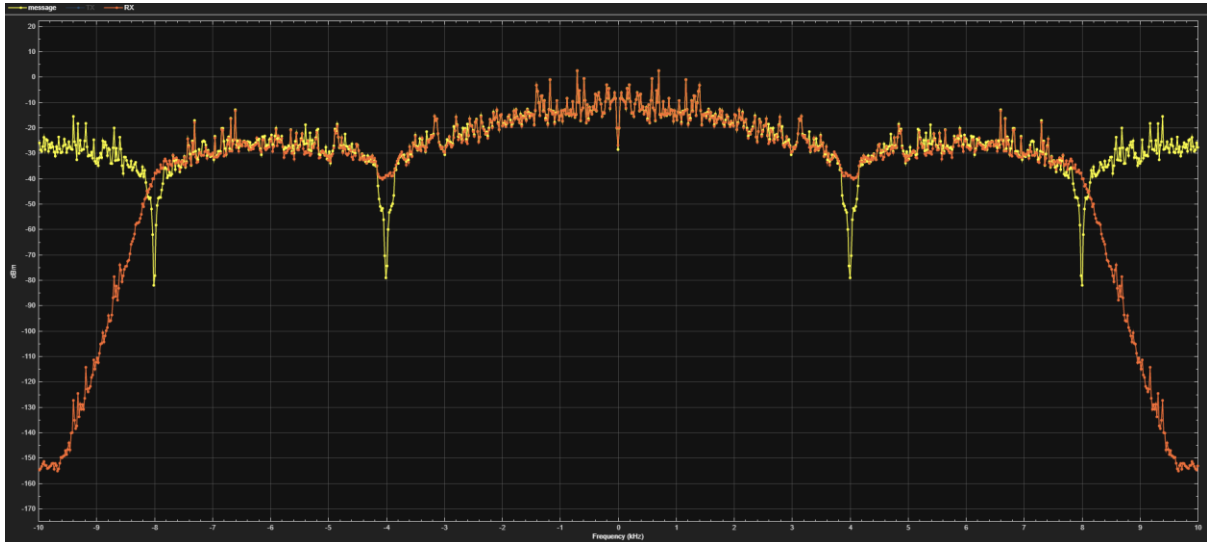


Figure 18: Noise added to a channel in an FM simulation

6 Conclusion

Noise affects AM and FM simulations to different degrees. This assignment explored the differences in performance of DSB-SC and FM simulations when subject to the same levels of white gaussian noise. Listening to the recordings generated at the end of Simulink® simulations, the FM recording which was received in the presence of noise has less audible noise when compared to the DSB-SC recording.

7 Recommendations

For communication systems that require operation in environments that are subject to varying levels of background noise, an FM implementation would be the recommended implementation to explore first, as it boasts a greater resistance to noise over DSB-SC. However, FM systems are more expensive to implement. Where budget and complexity are a concern, an AM implementation such as DSB-SC should be explored instead.

8 References

- [1] H. Seals, John, *Kentucky Inventor Solves Problem of Wireless Telephony*, Atlanta, Ga: The Sunny South, 1902.
- [2] US WAR DEPARTMENT, "BASIC PRINCIPLES OF FREQUENCY MODULATION," 1944. [Online]. Available: <https://archive.org/details/47194-army-pictorial-service-basic-principles-of-frequency-modulation>. [Accessed 20 November 2023].
- [3] J. Prince Devaraj, "Radio Frequency Systems Lecture 2 – Modulation and Demodulation Powerpoint," University of Wales Trinity Saint David, Swansea, 2023.
- [4] J. Prince Devaraj, "Radio Frequency Systems Lecture 3 – Types of AM Powerpoint," University of Wales Trinity Saint David, Swansea, 2023.
- [5] H. Rosete, "FM Detectors," Analog Devices, 14 June 2019. [Online]. Available: https://wiki.analog.com/university/courses/electronics/electronics_lab_fm_detectors. [Accessed 20 November 2023].
- [6] D. Mercer, "Activity: The Phase Locked Loop," Analog Devices, 20 December 2013. [Online]. Available: <https://wiki.analog.com/university/courses/electronics/electronics-lab-31>. [Accessed 20 November 2023].
- [7] S. A. Tretter, "Chapter 8 Frequency Modulation (FM)," 18 October 2017. [Online]. Available: <https://user.eng.umd.edu/~tretter/commlab/c6713slides/ch8.pdf>. [Accessed 20 November 2023].
- [8] H. Rosete, "Activity: Diode Ring Modulator - ADALM2000," Analog Devices, 20 March 2019. [Online]. Available: https://wiki.analog.com/university/courses/electronics/electronics_lab_diode_ring_modulator. [Accessed 20 November 2023].
- [9] A. Miclaus, "Activity: Envelope Detector [Analog Devices Wiki]," Analog Devices, 22 February 2018. [Online]. Available: <https://wiki.analog.com/university/courses/electronics/electronics-lab-envelope-detector>. [Accessed 20 November 2023].

9 Annex A

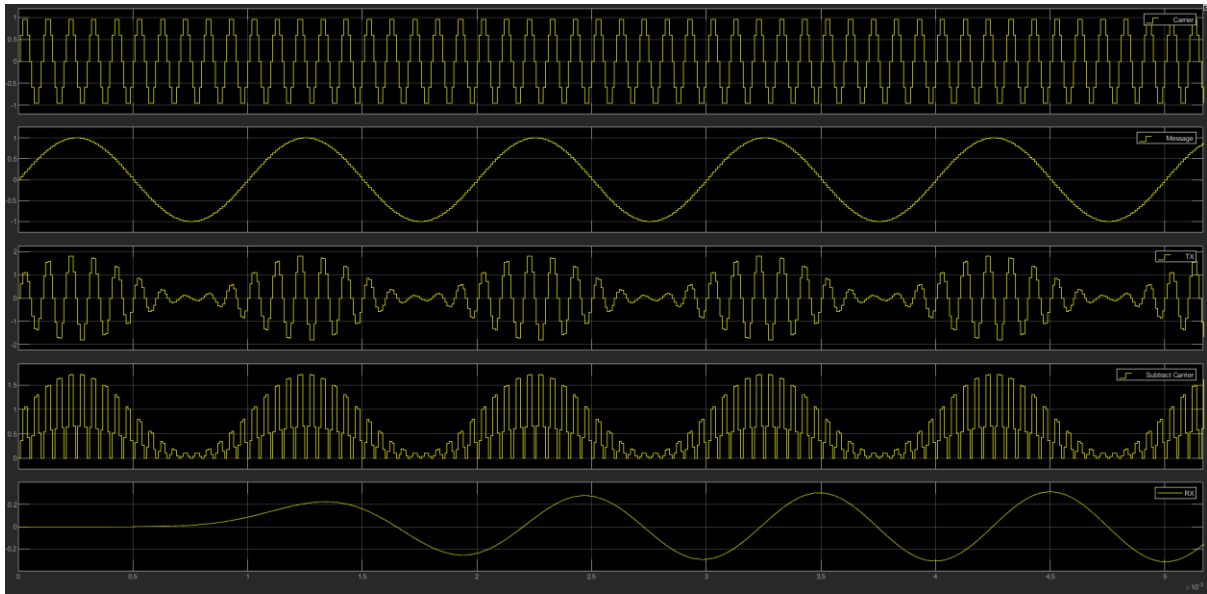


Figure 19: A distorted modulated signal when using higher carrier frequencies

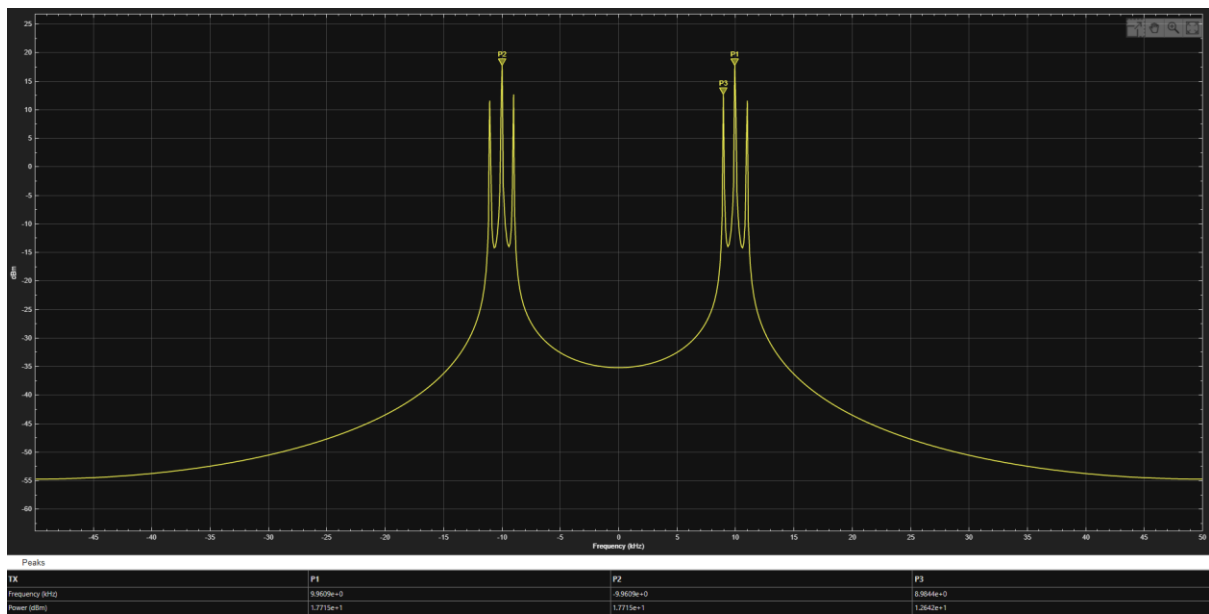


Figure 20: Additional peaks are revealed in the spectrum analyser