

RF Systems Assignment - Harry Woollands

by Harry Woollands

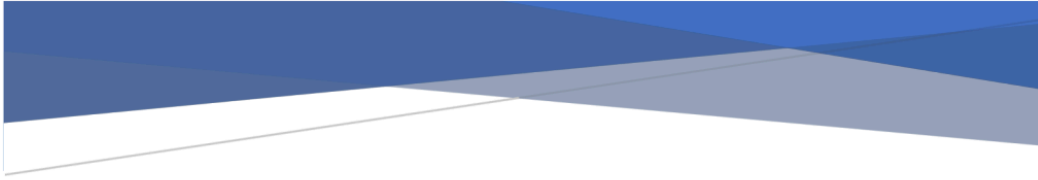
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INVESTIGATING THE EFFECT OF NOISE IN SSB-SC AND DSB-SC

ACDA5019 - Radio Frequency Systems

2184 Words

Abstract

This report investigates the effect of noise on Amplitude Modulation, Single-Sideband Suppressed-Carrier Modulation, and Double-Sideband Suppressed-Carrier Modulation, determining which modulation scheme has the greatest performance, using bandwidth efficiency, power utilization and noise resistance as comparison points. The results of the study reveal that Single-Sideband Suppressed-Carrier Modulation, has the greatest performance of the three modulation types.

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Introduction

Radio Frequency (RF) is defined as the rate of oscillation of the electromagnetic spectrum, from frequencies ranging from 3 kHz to 300 GHz [1]. These frequencies are divided into a number of different frequency bands, each of which are used for different RF system applications.

RF systems are essential in modern communication. They provide the wireless transmission and receiving of electromagnetic signals. Examples of common RF systems are radios, radar and Wi-Fi. An RF system contains a number of components which allow them to communicate. These include, transmitters, receivers, filters, modulators and demodulators [2].

This assignment will investigate the effect of noise in Amplitude Modulation (AM), Single-Sideband Suppressed-Carrier (SSB-SC) Modulation, and Double-Sideband Suppressed-Carrier (DSB-SC) Modulation systems, beginning with examining AM in both the time and frequency domains, by varying the modulation index of the system. Following this, both SSB-SC and DSB-SC will be examined with and without the influence of different levels of Additive White Gaussian Noise (AWGN). Finally, the three types of modulation schemes will be compared, using their bandwidth efficiency, power density and noise resistance as comparison points. This comparison will result in a conclusion where it will be determined which modulation scheme has the greatest performance. To achieve this, models for each of the modulation schemes will be designed using *Simulink*, a block diagram simulation tool within *MATLAB*.

Background Research/Literature Review

Amplitude Modulation (AM) [3]

Amplitude Modulation is a modulation technique where a carrier signals amplitude is varied when a wave is being transmitted. There are two signals used in this technique; the message signal, and the carrier signal. The carrier signals amplitude is varied in accordance with the message signals amplitude, creating the modulated carrier signal. Advantages of AM is that it is cheap form of modulation compared to alternative modulation techniques. This is because it is relatively easy to implement as it mainly requires a simple transmitter and receiver. However, due to this, AM is susceptible to noise interference, and therefore received signal quality can be poor. A common use of AM is radio transmission.

Single-Sideband Suppressed-Carrier Modulation (SSB-SC) [4]

Single-Sideband Suppressed-Carrier Modulation is a modulation technique that is a more advanced type of AM modulation. SSB-SC only transmits one of the two sidebands of the carrier signal, either the lower sideband or the upper sideband. This technique works as both the lower and upper sidebands hold the same data, therefore it is only necessary to transmit one. When transmitting the signal, one sideband and the carrier signal are suppressed, with the remaining sideband transmitted. Advantages of SSB-SC is that it uses less bandwidth than AM, and therefore less of the EM spectrum is being used. Another positive of SSB-SC is its power efficiency, as only one sideband is being transmitted instead of both sidebands and the carrier signal. However, it is more complex and therefore more expensive than AM. A common use of SSB-SC is radar communications.

Double-Sideband Suppressed-Carrier Modulation (DSB-SC) [5]

Double-Sideband Suppressed-Carrier Modulation is another modulation technique that is a more advanced type of AM modulation. Compared with SSB-SC, DSB-SC transmits both upper and lower sidebands instead of a single sideband, whilst the carrier signal remains suppressed. An advantage of DSB-SC is that due to both of the sidebands being transmitted, it has a greater robustness than SSB-SC. However, due to both sidebands being transmitted, DSB-SC requires more bandwidth than SSB-SC. This results in DSB-SC being less power efficient than SSB-SC, but still more efficient than AM due to the carrier frequency not being transmitted. A common use of DSB-SC is in television broadcasting.

Circuit Diagrams

Amplitude Modulation (AM)

Figure 1 below shows the circuit diagram for the AM. The message signal is multiplied by the modulation index, then multiplied together with the carrier signal, creating the modulated signal. The modulated signal is then taken as an absolute value, before going through filters, as well as a gain block to put it in phase with the original message signal. The message, carrier, modulated and demodulated signals are also each put through an FFT block, allowing them to output signals for the spectrum analyser. The authors student number ends in a 6, therefore the modulation index is set to 0.6, as per the brief's instructions.

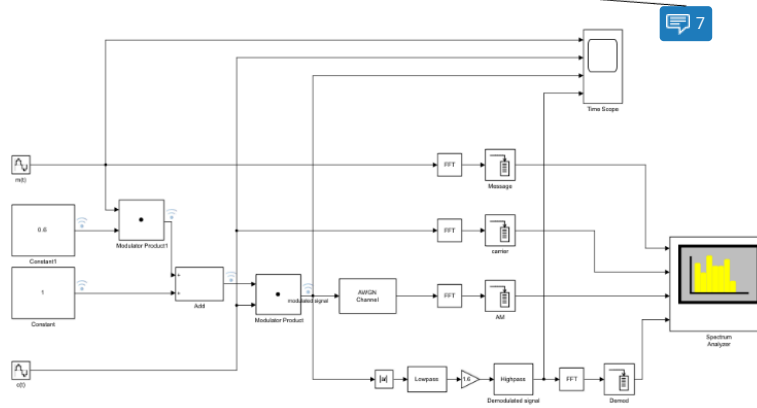


Figure 1. AM circuit diagram.

To calculate the message signal and carrier signal the following equations are used [6]:

$$m(t) = A_m \cos(2\pi f_m t)$$

$$c(t) = A_c \cos(2\pi f_c t)$$

Where:

A_m = Amplitude of the message signal

A_c = Amplitude of the carrier signal

f_m = Frequency of the message signal

f_c = Frequency of the carrier signal

Using these equations, it can be determined that the equation to calculate the AM wave is:

$$s(t) = [A_c + A_m \cos(2\pi f_m t)] \cos(2\pi f_c t)$$

Double-Sideband Suppressed-Carrier Modulation (DSB-SC)

Figure 2 below shows the circuit diagram for the DSB-SC modulator. The modulated signal is created in the same way as in AM, using product and adder blocks. However, due to DSB-SC transmitting both the upper and lower sidebands, two signals are created. This can be seen through the second message and carrier signals. The demodulation of the signal also works similarly to AM; however, another carrier signal is also required. This is because in DSB-SC the sidebands are transmitted, but the carrier frequency is not. Therefore, another carrier frequency is required to demodulate back to the original message signal.

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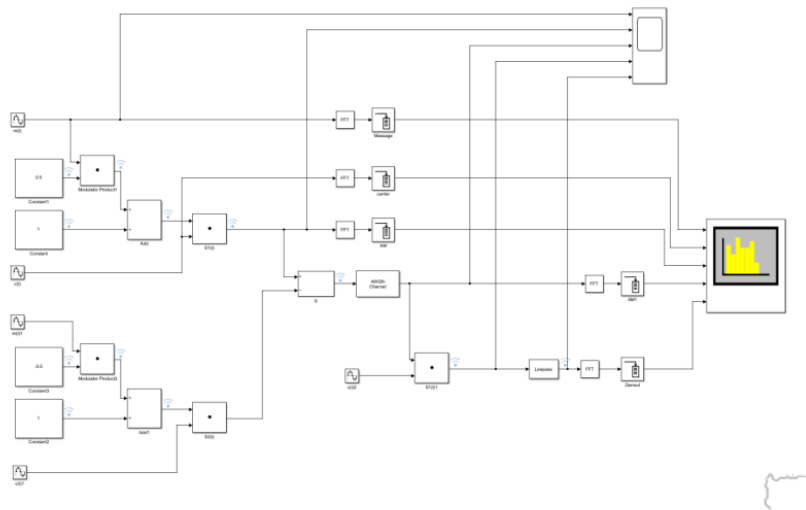


Figure 2. DSB-SC circuit diagram.

The equations of the DSB-SC sidebands are [7]:

$$f_{USB} = f_c + f_m$$

$$f_{LSB} = f_c - f_m$$

Where:

f_m = Frequency of the message signal

f_c = Frequency of the carrier signal

The equations for $m(t)$ and $c(t)$ for DSB-SC are the same as in AM. To determine the equation for the modulated signal:

$$s(t) = m(t)c(t)$$

Substituting in $m(t)$ and $c(t)$ the final modulated signal equation is:

$$s(t) = A_m A_c \cos(2\pi f_m t) \cos(2\pi f_c t)$$

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Single-Sideband Suppressed-Carrier Modulation (SSB-SC)

Figure 3 below shows the block diagram for the SSB-SC modulator. Two message signals and carrier signals are multiplied together, one set in phase, and one set 90 degrees out of phase. These two products are then combined, producing the modulated signal. As in DSB-SC, a carrier signal is required in the demodulating process, as in SSB-SC only one sideband is transmitted, and the carrier signal is not.

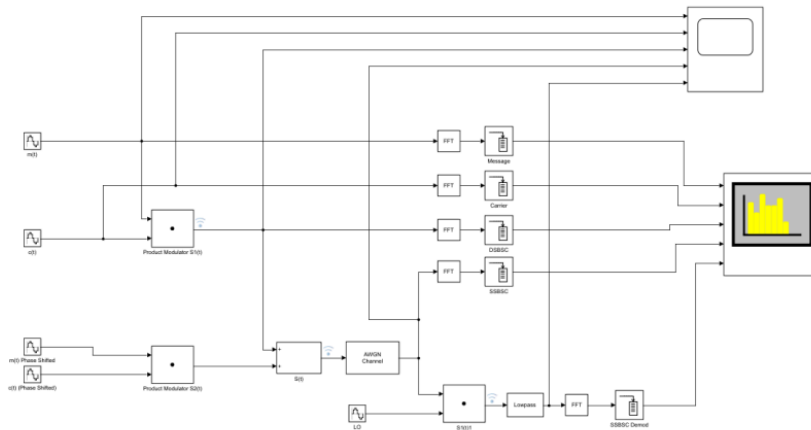


Figure 3. SSB-SC circuit diagram.

Once again, the equations for $m(t)$ and $c(t)$ for SSB-SC are the same as for AM and DSB-SC. To calculate the modulated signal for the upper sideband the following equation is used [8]:

$$s(t) = (A_m A_c / 2) \cos[2\pi(f_c + f_m)t]$$

And for the lower sideband:

$$s(t) = (A_m A_c / 2) \cos[2\pi(f_c - f_m)t]$$

Where:

A_m = Amplitude of the message signal

A_c = Amplitude of the carrier signal

f_m = Frequency of the message signal

f_c = Frequency of the carrier signal

Task 1

Task 1 was to examine Amplitude Modulation in the time domain and the frequency domain. To do this, a spectrum analyser and a time scope were used. The AM circuit designed that was previously

seen in Figure 1 was used to obtain the following results. Figure 4 below shows the spectrum and scope plots for AM with a modulation index of 0.6.

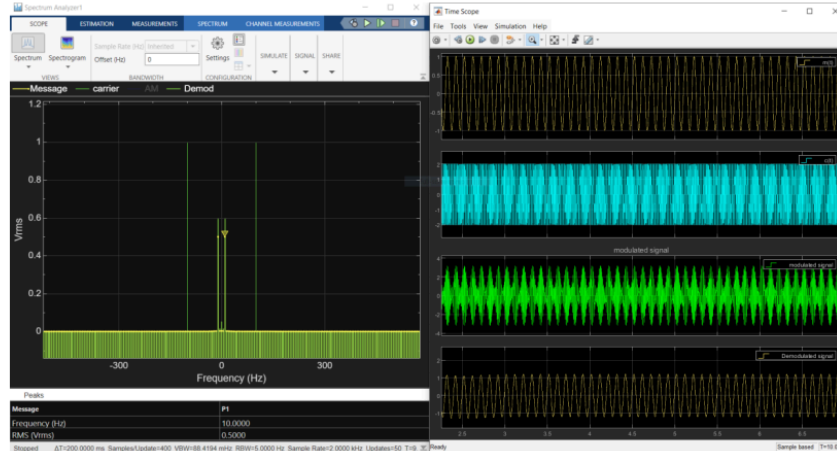


Figure 4. AM Modulation at Modulation Index 0.6.

Next, the modulation index was changed to understand what the impact of over modulating the signal is. It can be observed that the Root Mean Square (RMS) value has increased from 0.6 Vms with 0.6 modulation index up to 1.2 Vms with 1.5 modulation index on the spectrum analyser. Also, on the time scope the amplitude of the demodulating signal has increased from just above 1 with 0.6 modulation index down to 3 with 1.5 modulation index. Figure 4 below shows the spectrum and scope plots for AM with a modulation index of 1.5.

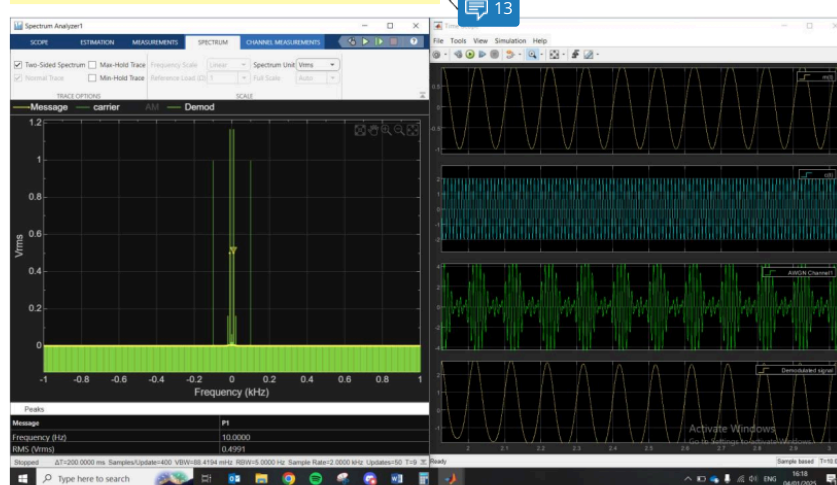


Figure 5. AM Modulation at Modulation Index 1.5.

Finally, the modulation index charged to 1, which is critical modulation. It can be observed that the RMS value has increased from 0.6 Vms with 0.6 modulation index up to 1 Vms with 1 modulation index on the spectrum analyser. Also, on the time scope the amplitude of the demodulating signal has up to 2 with 1 modulation index. Figure 6 below shows the spectrum and scope plots for AM with a modulation index of 1.

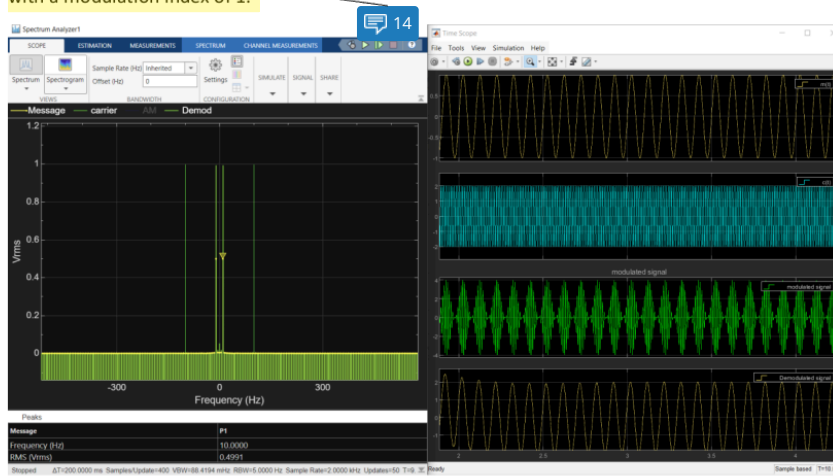


Figure 6. AM Modulation at Modulation Index 1.

Task 2

Task 2 was to design a DSB-SC modulator and demodulate a signal back to the message signal and display it in the frequency and time domain, with a modulation index of 0.5. The DSB-SC circuit designed that was previously seen in Figure 2 was used to obtain the following results. Figure 7 below shows the spectrum and scope plots for DSB-SC.

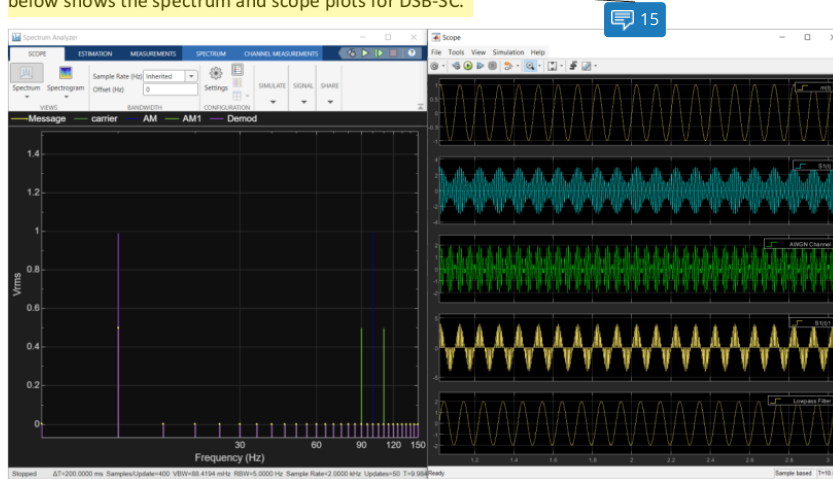


Figure 7. DSB-SC Modulation at 0.5 modulation index with no added noise.

Next, random noise was introduced to the modulator. To do this, an Additive White Gaussian Noise component was added to the block diagram. Firstly, -10dB of noise was added. Figure 8 below shows the spectrum and scope plots with the added noise. The spectrum reveals that the base level of noise has increased, as well as one sideband being larger than the other, whereas they were equal before introducing noise. On the scope, the demodulated signal is significantly different to the original message signal. Finally, the amplitude of the modulated signal is not consistent, and differs from peak to peak. The wavelength of the modulated signal is also not consistent, with peaks appearing at irregular intervals.

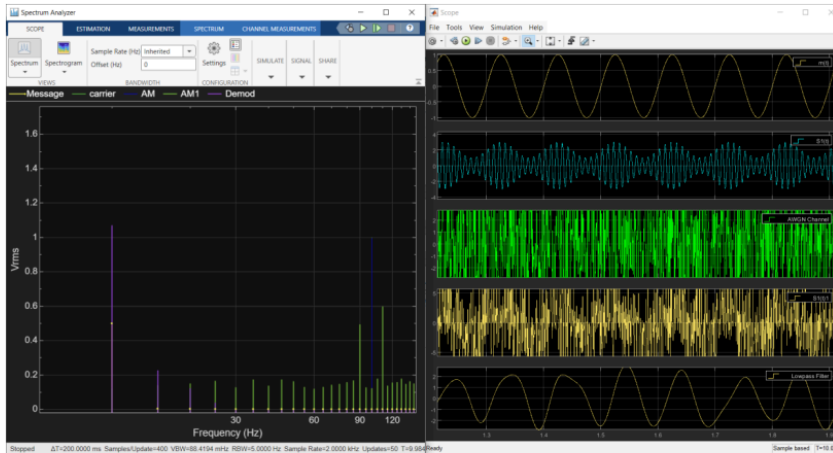


Figure 8. DSB-SC Modulation with -10dB added noise.

Next, the additive noise was increased to -30dB. Figure 9 below shows the spectrum and scope plots with the added noise. On the spectrum, it is no longer possible to identify the two sidebands, as the base level noise has taken over. On the scope, the demodulated signal is unrecognisable. The peaks and troughs are completely irregular, with no consistent amplitude or wavelength.

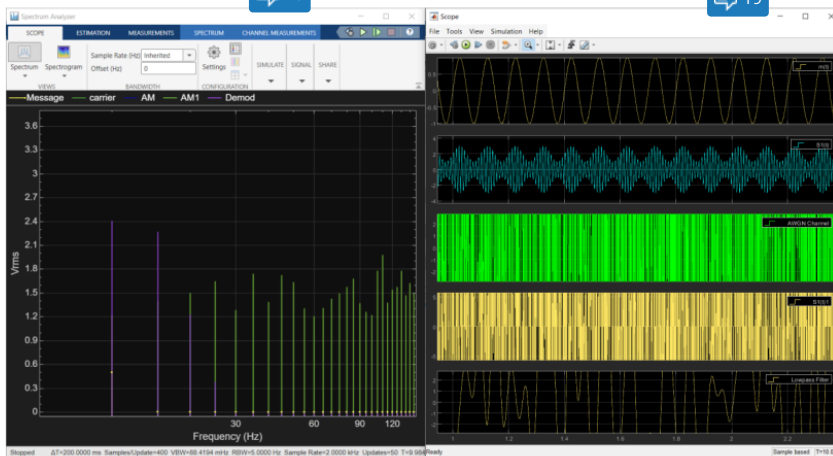


Figure 9. DSB-SC Modulation with -30dB added noise.

Task 3

Task 3's brief was almost identical to Task 2's, however, using an SSB-SC modulator instead of a DSB-SC. Unlike for DSB-SC, the SSB-SC circuit previously seen in Figure 3 had to be slightly redesigned to incorporate the modulation index. Figure 10 below shows the modified SSB-SC circuit.

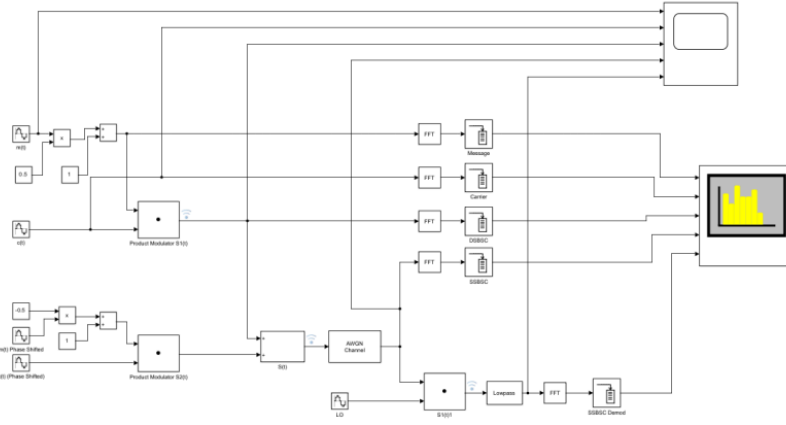


Figure 10. Edited SSB-SC Circuit.

Using the new circuit, Figure 11 below shows the spectrum and scope plots for SSB-SC modulation/demodulation with a modulation index of 0.5.

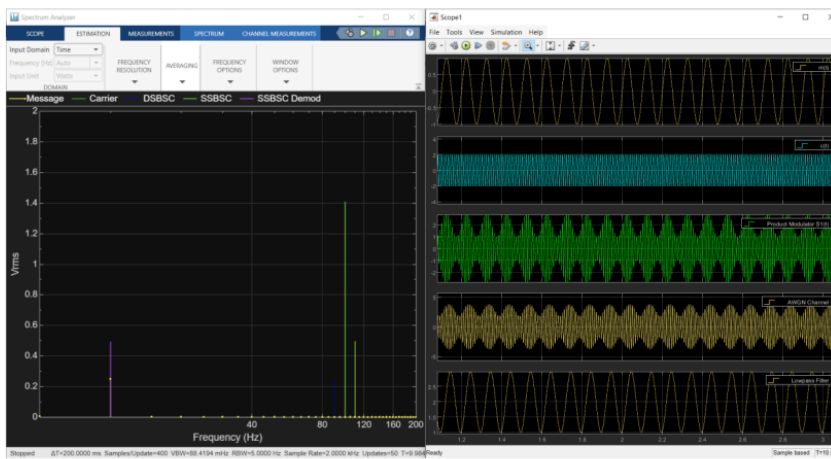


Figure 11. SSB-SC Modulation at 0.5 modulation index with no added noise.

Next, noise was added to the system. Figure 12 below shows the spectrum and scope plots with -10dB of added noise. It can be observed that the baseline noise level on the spectrum has increased,

as well as the demodulated signal differing from the message signal. The amplitude of the wave is more varied; however, the signal still resembles the original message signal.

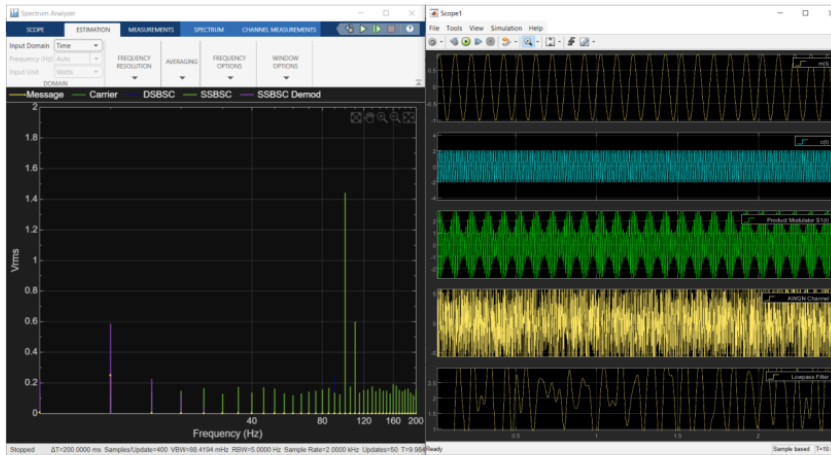


Figure 12. SSB-SC Modulation with -10dB added noise.

Figure 13 below shows the spectrum and scope for SSB-SC with -30dB of noise. It can be seen that on the scope that the baseline noise has increased enough so that it is not easily possible to identify the sideband. On the scope, the modulated signal bears no resemblance to the message signal.

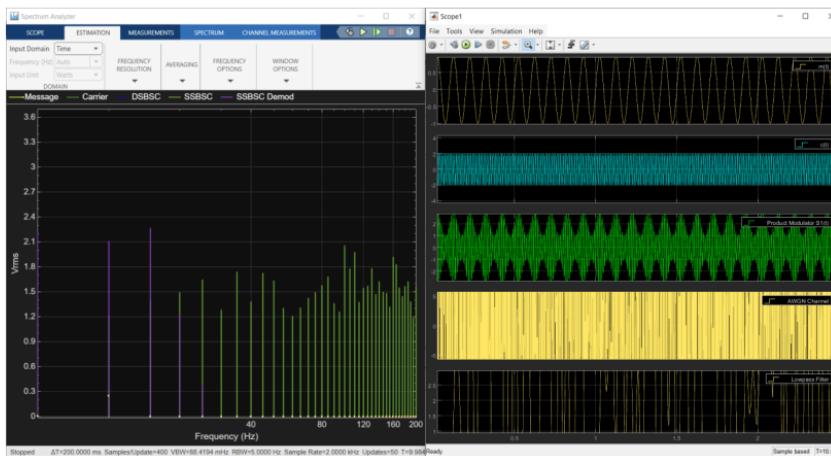


Figure 13. SSB-SC Modulation with -30dB added noise.

Task 4

Task 4 was to measure and compare the performance of AM, DSB-SC and SSB-SC, and reach a conclusion on which modulation technique performs the best. To determine this, three comparison points will be used; bandwidth efficiency, power utilization, and noise resistance. To compare these the spectrum plots used in tasks 1,2 and 3 will be used, as well as Figures 14 and 15 shown below, which are plots of AM with -10dB and -30dB of added noise.

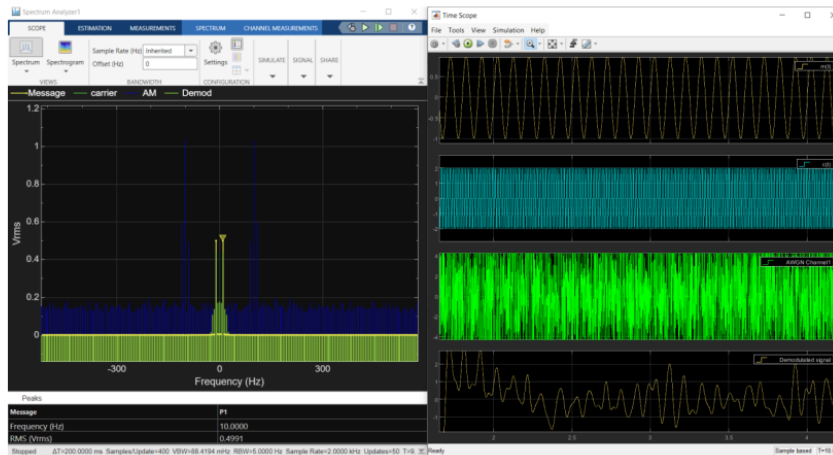


Figure 14. AM Modulation with -10dB added noise.

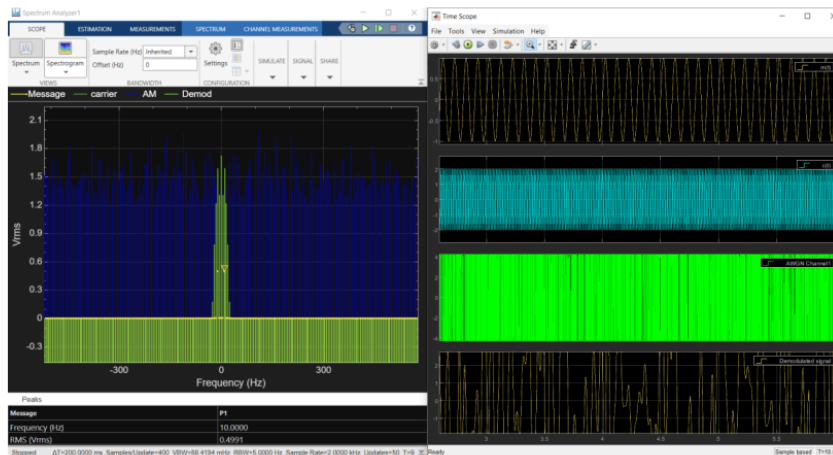


Figure 15. AM Modulation with -30dB added noise.

The first comparison point to look at is bandwidth efficiency. For AM, bandwidth is calculated using the equation $2f_m$, where f_m is the highest frequency of the message signal. Likewise, DSB-SC is also calculated using $2f_m$. However, SSB-SC is calculated using f_m . The spectrums reveal AM has a

bandwidth of 200Hz ($2 \times 100\text{Hz}$), DSB-SC's is 220Hz ($2 \times 110\text{Hz}$) and SSB-SC's 110Hz, and therefore the most bandwidth efficient.

The next comparison point is power utilization. SSB-SC is the most power efficient, followed by DSB-SC, and then AM. This is because AM has to use power to transmit its carrier signal as well as its two sidebands. DSB-SC is more efficient than AM as the carrier is not transmitted, and SSB-SC is twice as efficient as DSB-SC as only one sideband is transmitted.

The final comparison point is noise resistance. Using the  22 and -30dB noise levels, it is not possible to distinguish any meaningful difference between the modulation types using the spectrum analyser only. However, this is not entirely surprising, as the noise tolerance of SSB-SC and DSB-SC are very similar [9], and AM only slightly worse.

Therefore, it can be concluded that SSB-SC has the highest performance. It is the outright best of the modulation types in two of three comparison points. DSB-SC has the second highest performance due to its superior power utilization, and AM has the worst performance. However, this conclusion is based solely on spectrum performance, and AM still has a use in the real world due to its simplicity and low cost.

Conclusion

In conclusion, this report has investigated the effect of noise on AM, SSB-SC and DSB-SC modulation schemes, determining that SSB-SC has the greatest performance of the three modulation types, including the greatest bandwidth efficiency and power utilization. This report has demonstrated an understanding of each of the three modulation types, highlighting their design, performance and practical uses. In addition to this, the importance of choosing the correct modulation technique depending on what data is being transmitted has been showcased, with all three techniques having an important place in modern communications.

If this work was to be taken further, one thing I would do would be to add a Bit Error Rate (BER) calculator to the designs. This would enable more accurate analysis of how noise effects the modulation schemes, as using only the spectrum makes analysis challenging. The next step would be to conduct physical tests using hardware. This would provide a direct comparison between simulation and real-world results, deepening understanding of how the modulation schemes are made, and the effect of real-world noise on the systems.

References

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

73/100

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Comment 1 |  Knowledge & Understanding (20)

The advantages are effectively captured.



Comment 2 |  Engagement with literature(10)

More details on modulation index could be included. The basics are well covered, but any references should be properly cited.



Comment 3 |  Knowledge & Understanding (20)

The explanation of power efficiency is well articulated, and the concepts of SSB-SC are clearly understood. However, the phase discrimination method and its role in suppressing one sideband and the carrier should be explicitly detailed.



Comment 4 |  Engagement with literature(10)

More references are needed to support the discussion.



Comment 5 |  Cognitive skills (20)

Including power efficiency values from referenced journals would be beneficial, as it would allow for a comparative analysis with the observed output values.



Comment 6 |  Knowledge & Understanding (20)

The concepts of DSB-SC are well explained, and the discussion on power efficiency is appreciable.

**Comment 7** | Knowledge & Understanding (20)

The block operation is clearly explained.

**Comment 8** | Cognitive skills (20)

It is commendable that the expressions are included, providing a clear connection between mathematical expressions and real-time applications.

**Comment 9**

The block operation is clearly explained.

**Comment 10** | Cognitive skills (20)

Well captured mathematically.

**Comment 11** | Practical Application (30)

The Blocks are well captured.

**Comment 12** | Practical Application (30)

The screen shots are well captured.

**Comment 13** | Cognitive skills (20)

Good observation is made with different values of modulation index.

**Comment 14** | Cognitive skills (20)

keen observation

**Comment 15** | Practical Application (30)

A clear basic explanation of the working of DSB-SC is provided, but including amplitude and power values would help in comparing with the noise-added blocks for better analysis.

**Comment 16** | Practical Application (30)

Good observation

**Comment 17** | Cognitive skills (20)

Presenting the amplitude and power values in a table format would enhance the clarity and strength of the analysis.

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Comment 18 | Cognitive skills (20)

Additional parameters such as SNR (I/O), figure of merit, performance in terms of power, and bandwidth should be considered for a more detailed analysis.



Comment 19 | Cognitive skills (20)

It is commendable that the research incorporates various SNR values, making the theory more evident.

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Comment 20 | Transferable skills (20)

A good flow of structure and organisation is maintained, allowing the reader to connect with the concepts seamlessly and follow the analysis with clarity.



Comment 21

Well said.

PAGE 16



Comment 22 | Cognitive skills (20)

It would be better if the amplitude values were provided, as they would enhance the clarity and depth of the analysis.

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Comment 23 | Engagement with literature(10)

It is evident that the report includes references, but incorporating more journal papers with relevant values would strengthen the writing. Proper citations should be consistently included throughout the report.

GRADING FORM: RF_UPDATED_2025

ENGAGEMENT WITH LITERATURE(10)

Demonstrated understanding of AM, DSB-SC, and SSB-SC techniques by referencing key theoretical principles. Discussed noise impact, modulation index, and performance metrics using scholarly resources.



The understanding of AM, DSB-SC, and SSB-SC techniques is clear, but the references to theoretical principles needs is limited.

6.5**KNOWLEDGE & UNDERSTANDING (20)**

Explored modulation systems in time and frequency domains, analysing critical, over, and under modulation. Applied modulation index and signal design to understand carrier signal variations and noise effects.



Task 1: (a) (i) Good understanding of AM principles. Time and frequency analysis, and signal definitions are accurate and complete.

Task 1: (a) (ii) Task shows meaningful observations for modulation types but misses depth in certain areas.

Task 1: (b) Explains AM demodulation clearly but lacks depth in comparing original and modulated signals.

Task 2: (a) Task explains basic concepts of DSB SC modulation but lacks depth and clear connection to theory.

Task 2: (b) Noise effects are explained well but it is necessary to calculate the theoretical values of SNR(in/Out), Figure of Merit, Power to compare with the values obtained after simulation.

Task 3: (a) : SSB SC modulation and demodulation are well explained but need more depth in noise

14.1

analysis.

Task 3: (b): mentions noise effects but needs stronger reasoning and more examples.

Task 4: (a) Task covers spectrum and power density but misses detailed reasoning about noise tolerance.

Task 4: (b) Task comparison is basic and misses clarity.

COGNITIVE SKILLS (20)

Analysed and compared demodulated signals with original modulating signals. Evaluated system performance metrics, including spectrum, power density, and noise resistance, to assess modulation techniques.



Task 1 (a): The analysis is clear but could have more detail. Comparisons are relevant but lack depth. Metrics like spectrum, time scope, and modulation indices are used but not fully explored.

Task 1 (b): The demodulation process is very clear and detailed. Comparisons are meaningful and insightful, showing key differences and similarities. The analysis is deep and well-supported with strong reasoning.

Task 2 (a) & (b): The modulation and demodulation processes for DSBSC are clear but need more detail.

Task 3 (a) & (b): The modulation and demodulation processes for SSBSC are clear but could include more detail.

Task 4 (a) & (b): Performance metrics are incomplete. Comparisons and graphs are minimal, and no meaningful conclusion is drawn.

12.6

PRACTICAL APPLICATION (30)

Implemented AM, DSB-SC, and SSB-SC modulation and demodulation using time scopes and spectrum analysers. Introduced random noise to

evaluate distortion effects and conducted real-world performance measurements.



Task 1 (a) (i): Exceptional use of tools and clear demonstration of signals with a deep understanding of behaviour.

Task 1 (a) (ii): Good application of modulation index variations. Demonstrates strong skill and clarity, but theoretical calculations and practical values need to be included to clearly relate the analysis to the expected outcomes.

Task 1 (b): Thorough explanation of AM demodulation. Results are accurate, with proper comparisons and strong theoretical alignment.

Task 2 (a): Demonstrates accurate DSB-SC modulation. Observations are precise, and tools are used effectively.

Task 2 (b): Noise analysis is thorough and aligns with theoretical expectations. Observations are well-documented.

Task 3 (b): Noise analysis is comprehensive, with clear and precise documentation of observations.

Task 4 (a): Limited understanding of the processes, with observations that are vague with theory.

Task 4 (b): Comparisons are done explaining the references but not with the analysis.

23.25

TRANSFERABLE SKILLS (20)

Demonstrated systematic reporting skills through performance analysis and practical communication challenges. Showcased effective communication, clear organisation, and time management in a well-structured, standard-compliant report.



Exceptional transferable skills are demonstrated through effective communication, clear organisation of ideas, and systematic reporting.

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