

RFSystems assignment

by Ethan Anderson

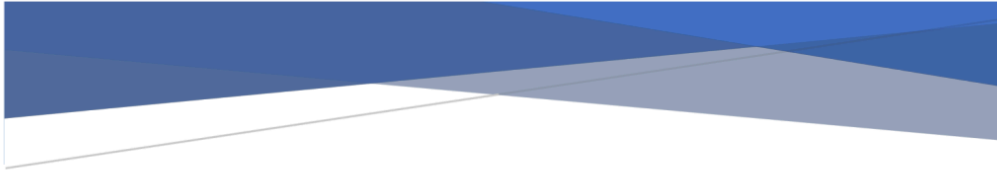
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RF SYSTEMS

Laboratory Report

BENG2-PT Embedded Electronic Systems
RF Systems ACDA5019

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Introduction

In modern communication systems, ensuring the integrity of transmitted signals is paramount. Amplitude Modulation (AM) and its refinements, Single-Sideband – Suppressed Carrier (SSB-SC), and Double-Sideband – Suppressed Carrier (DSB-SC), are common methods of modulating a message signal, containing information, onto a carrier signal which oscillates at a frequency more desirable for Over The Air (OTA) radio transmission.

During OTA transmission, these modulated waves are susceptible to the degradation of their Signal to Noise Ratio (SNR) due to the presence of background noise and interference. This is undesirable for communication systems as a reduced SNR will ultimately require compromises (like increased transmit power, shorter path length) to achieve the desired signal quality.

This report investigates and compares the effect of additive noise on AM, SSB-SC, and DSB-SC modulation schemes through a series of simulations conducted in Matlab's Simulink modelling tool. The performance of each modulation scheme will be assessed and compared in both the time and frequency domain.

The core function and applications of each modulation scheme will also be investigated and explained through a literature review and background research section, commenting on each system's past commercial implementation and current uses.

Background Research

Modulation schemes are used to encode a message signal onto a carrier wave. This is used because a carrier signal will have more desirable characteristics for OTA transmission. Among various techniques, AM, SSB-SC, and DSB-SC are widely used for analogue modulation in RF communication systems. SSB-SC and DSB-SC are refinements of basic Amplitude Modulation and differ in terms of spectral efficiency, power efficiency and their complexity and cost to implement.

Amplitude Modulation

Amplitude modulation is one of the earliest and most basic examples of analogue modulation techniques, where the amplitude of the carrier wave is varied in proportion to the message signal. A typical spectral usage of an AM signal includes a carrier frequency and two sidebands, resulting in a bandwidth requirement of $2f_m$, where f_m is the maximum frequency of the modulating signal. Despite its simplicity and widespread use in applications like commercial radio broadcasting, Amplitude Modulation is relatively inefficient as most of its power is concentrated in the carrier frequency, which alone does not carry any useful information [1].

AM systems are particularly susceptible to noise, as variations in amplitude can easily be distorted by interference introduced from background noise. This susceptibility, along with its spectral inefficiency in comparison to contemporary analogue modulation schemes [1], makes AM relatively outdated and less suitable for applications requiring high signal fidelity or robustness in the presence of a high-noise environment [2]. However, its simplicity to implement and compatibility with legacy radio receivers ensure its relevance in certain domains and applications.

Double-Sideband – Suppressed Carrier

DSB-SC, and the similar SSB-SC, are refinements of the fundamental Amplitude Modulation scheme by removing the carrier component, instead concentrating all available transmit power in the sidebands (where the information from the message signal is transmitted). This significantly increases power efficiency, as the transmitted signal now consists solely of the two sidebands and the carrier frequency is eliminated. For DSB-SC, the bandwidth requirement remains the same as AM ($2f_m$)

[1], but the power is more efficiently concentrated. Demodulating DSB-SC requires coherent demodulation, which involves multiplying the received signal with a coherent (same frequency and in-phase) copy of the original carrier signal used by the modulator [3]. This increases the complexity of the RF electronics within the demodulator, which can increase cost.

In comparison to AM, as mentioned DSB-SC is more power efficient, however it is still not ideal as it transmits redundant information, due to its sidebands being identical to each other, on either side of the carrier frequency. This redundancy results in a spectral efficiency which is less than ideal, a downside which is addressed by SSB-SC modulation. Applications of DSB-SC include early analogue television audio transmissions [4].



Single-Sideband – Suppressed Carrier

SSB-SC takes the spectral and power efficiency of DSB-SC further by transmitting only one sideband, reducing the required frequency bandwidth to f_m . This significant improvement in spectral efficiency makes SSB-SC suitable for applications where spectral bandwidth is at a premium, notably the majority of commercial communication systems where the available frequency spectrum is heavily regulated and densely populated [5]. Additionally, eliminating the redundant sideband reduces the transmitter's power requirements, making SSB-SC a more power-efficient solution by comparison. This enables either a reduction in transmit power for the same SNR, or identical transmit power and an increased SNR (resulting in greater signal fidelity and an improved range).

However, like DSB-SC, the advantages of SSB-SC come at the cost of increased transmitter and receiver complexity, increasing the cost of manufacturing and implementation of these systems. The modulation and demodulation of SSB-SC signals require filtering techniques to isolate a single sideband [2].

Comparison

- Spectral efficiency: SSB-SC, due to its elimination of one sideband, is the most spectrally efficient modulation scheme, with its bandwidth being equal to the maximum frequency of the modulating signal. AM and DSB-SC are equally as spectrally efficient, requiring twice the maximum frequency.
- Power efficiency: Likewise, SSB-SC is the most power efficient as it only requires a single sideband to transmit all of the message data. DSB-SC is marginally more power efficient than AM, due to its elimination of the central carrier frequency.

- Complexity: The trade off to improved spectral and power efficiency is an increased complexity within the modulators and demodulators. DSB-SC and SSB-SC both require coherent demodulation (using a synchronised copy of the carrier signal), and SSB-SC also requires precise filtering to eliminate one sideband.
- Robustness in noise: The premise of this investigation is to explore the performance of the three modulation schemes in the presence of Additive White Gaussian Noise (AWGN), used to model real-world noise conditions. Tranter and Zeimer [4] explain that DSB-SC and SSB-SC, being carrier-less, are less prone to noise. This report will investigate whether the same conclusion can be reached using simulation techniques.

Practical Considerations

The choice of modulation scheme depends on the specific application and its constraints, particularly in frequency and power capacity. AM remains popular in radio broadcasting due to its simplicity and compatibility with existing infrastructure and receivers; however its usage is dwindling [6]. DSB-SC, while historically significant, is less commonly used today and has for the most part been replaced by SSB-SC due to its similarity and superior spectral efficiency. Spectral efficiency is ideal in the modern, regulated and bandwidth-constrained frequency spectrum despite its increased complexity.

Simulation Models

AM

This section will examine a simulation of Amplitude Modulation, investigating the effects of varying the modulation index to achieve Critical, Over and Under Modulation and how the scheme performs under the presence of AWGN. Initially, the modulation index was set to 0.7.

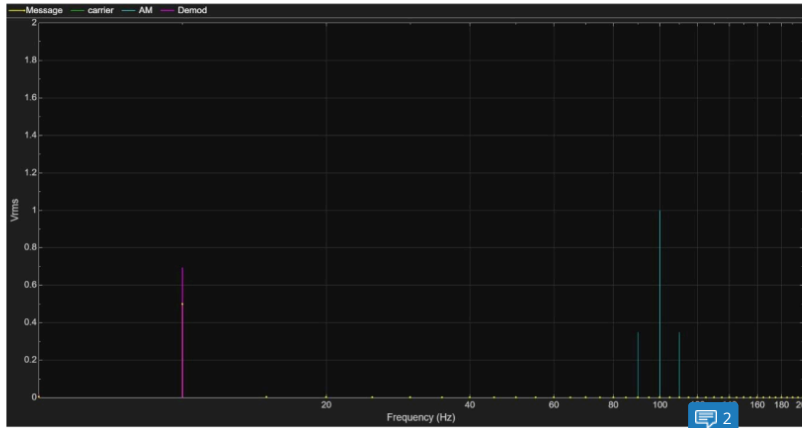


Figure 1: AM frequency spectrum with modulation index 0.7

Figure 1 shows the AM resultant frequency spectrum, after modulation, with a modulation index of 0.7. Here, the spectral distribution of the Amplitude Modulated wave is apparent. The message signal, shown in purple, is at a much lower frequency (10Hz) compared to the carrier signal, shown in turquoise. The sidebands are also clearly visible and highlights how much wasted power AM uses to transmit the carrier frequency.

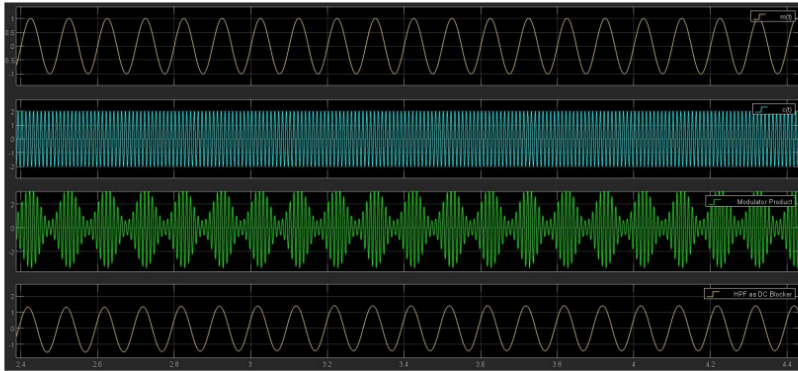


Figure 2: AM time scope

Figure 2 shows the same AM signal in the time domain. The time scope makes the difference in frequency between the message and carrier signal clear, as well as highlighting the slight under modulation that happens when the modulation index is 0.7. This is shown on the modular product signal, in other words the transmitted signal. Ideally, this signal would be critically modulated with the minimum signal amplitude reaching 0. Critical modulation maximises the efficiency of modulation and encodes the entire message signal onto the carrier without losses.

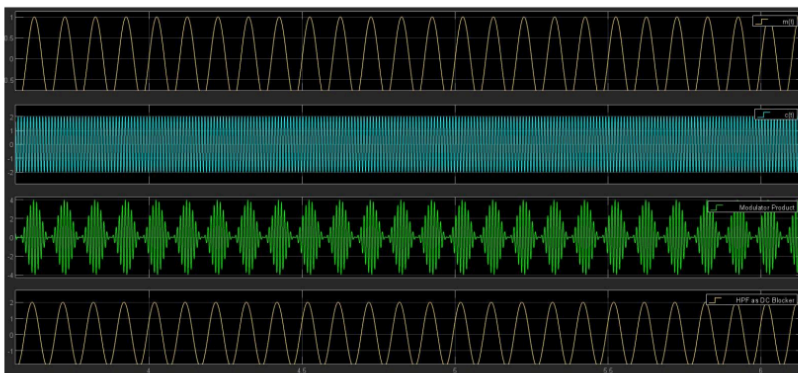


Figure 3: AM Critical Modulation

Figure 3 shows an Amplitude Modulated signal where critical modulation is achieved, by using a modulation index of 1. This means the ratio of message to carrier signal amplitude is 1:1, and the entirety of the message signal is encoded onto the carrier signal without losses. This is shown on the modulated signal with the signal reaching 0 amplitude.

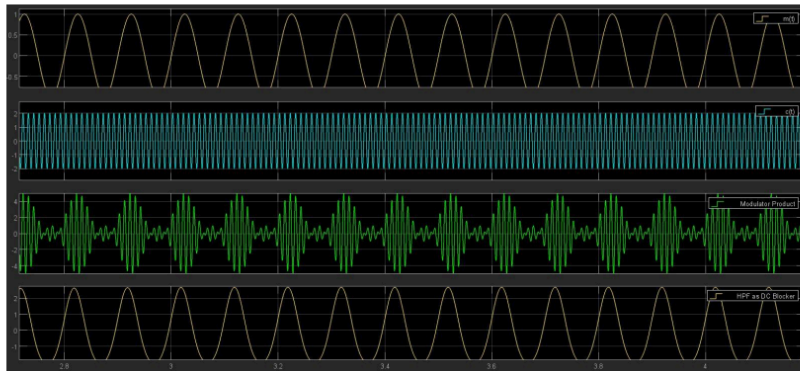


Figure 4: AM with over modulation

Figure 4 shows the effects of using a modulation index which is too high (1.5). The AM signal is overmodulated, causing irregularities to occur when the signal's amplitude is near 0. This ultimately results in a loss of data from the message signal and disparities between the original and demodulated message signal. In this example, a phase shift has occurred between the two signals.

DSB-SC



Figure 5: DSB-SC Frequency spectrum

Figure 5 shows the spectral usage of DSB-SC. Here it is apparent that the carrier wave signal has been suppressed and only the sidebands are transmitted over the air, meaning DSB-SC is a more power efficient modulation scheme.

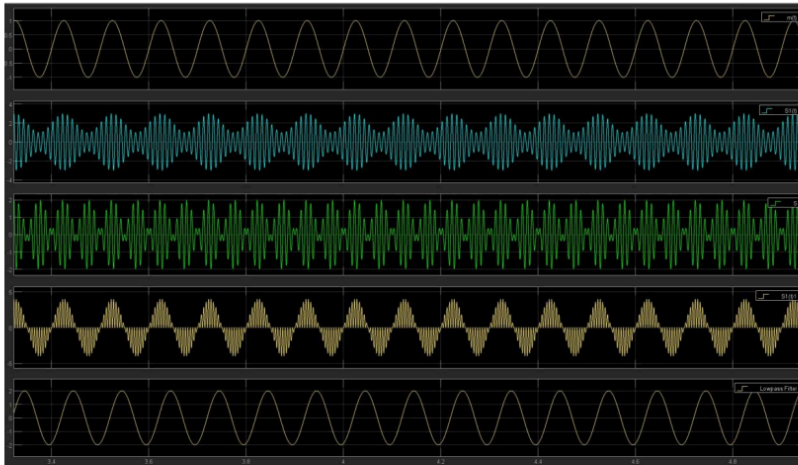


Figure 6: DSB-SC Time scope

Figure 6 shows the DSB-SC modulation scheme in the time domain, with samples at different steps of the process. The final modulated signal, $S(1)$, most clearly shows the core working principle of DSB-SC: suppressing the carrier wave. Here, only the positive and negative (relative to the carrier wave) sidebands are transmitted as data carriers, meaning DSB-SC is more power efficient. The modulated and demodulated message signals are completely coherent without the presence of added noise.

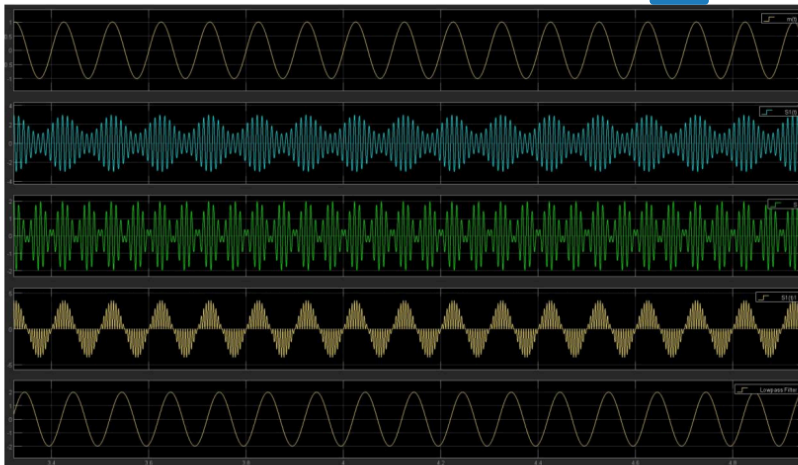


Figure 7: DSB-SC with AWGN

Now, an AWGN block has been introduced to the simulation to model interference caused by OTA transmission. At an SNR of -20dB, it is clear that there is some disruption to the received message signal and the modulated signal has been affected by the noise.

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SSB-SC

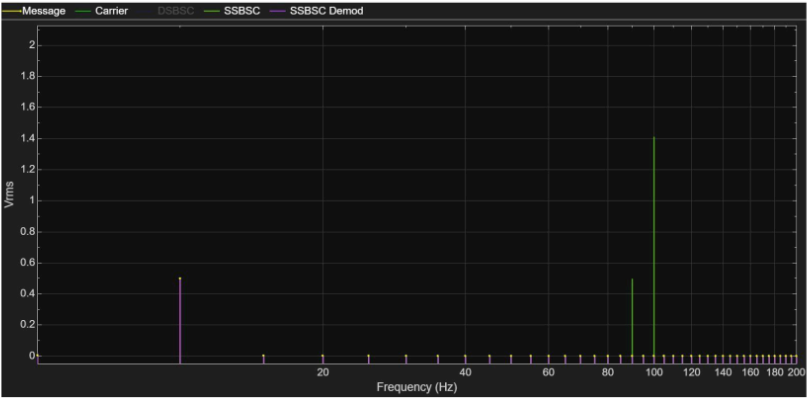


Figure 8: SSB-SC Spectral usage

Figure 8 shows the frequency spectrum of an SSB-SC signal, along side a sample of the carrier signal for sake of comparison. The figure shows how SSB-SC suppresses the positive sideband of the carrier signal and the carrier signal itself, improving spectral and power efficiency when compared to AM or DSB-SC.

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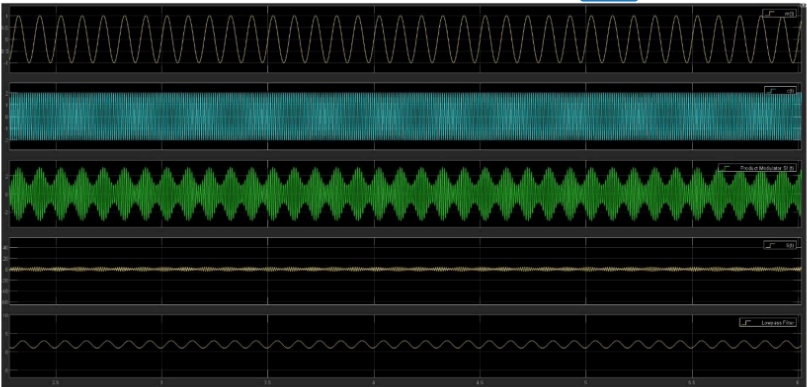


Figure 9: SSB-SC time domain

Figure 9 shows the SSB-SC signal in the time domain. The suppression of one sideband is apparent, however even in a noise-less environment there is an effect on the demodulated message signal. Namely, there is a noticeable amplitude decrease between the received and transmitted message signals. However, this is easily rectified with the use of a low noise amplifier in the receiver architecture.

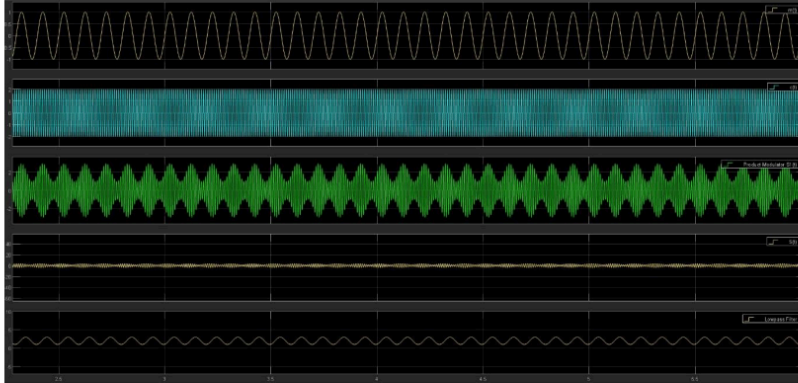


Figure 10: SSB-SC with AWGN

Now, an AWGN noise block has been used to introduce pseudo-random noise into the system. At an SNR of -20dB, it is clear that again the introduction of noise has affected the received message signal (on top of its reduction in amplitude), however not as significantly as basic Amplitude Modulation.

Comparison and Conclusion

This report has investigated the impact of Additive White Gaussian Noise on Amplitude Modulation (AM), Double-Sideband Suppressed-Carrier (DSB-SC), and Single-Sideband Suppressed-Carrier (SSB-SC) modulation systems, conducted in MATLAB Simulink.

The simulations demonstrated that AM, while straightforward to implement and widely used in commercial radio broadcasting, is more susceptible to noise interference when compared to DSB-SC and SSB-SC. This makes it less suitable for high-noise environments.

While DSB-SC and SSB-SC performed similarly in the presence of additive noise, it is important to recall that SSB-SC is also a more spectrally and power-efficient modulation scheme, due to its suppression of one sideband compared to DSB-SC, and suppression of the centre carrier frequency when compared to basic AM. Owing to this spectral and power efficiency, as well as suitable robustness to noise, SSB-SC is the best performing modulation scheme across the assessed categories.



References

- [1] J. G. Proakis and S. Masoud, Communication Systems Engineering, 2nd Ed., Prentice Hall International Editions, Pearson Education.
- [2] W. Tomasi, Electronic communications systems : fundamentals through advanced, Upepr Saddle River, N.J.: Pearson/Prentice Hall, 2004.
- [3] University of Maryland, "Chapter 6: Double-Sideband Suppressed-Carrier Amplitude Modulation," [Online]. Available: <https://user.eng.umd.edu/~tretter/commlab/c6713slides/ch6.pdf>. [Accessed January 2025].
- [4] R. E. Ziemer and W. H. Tranter, Principles of Communications - Systems, Modulation and Noise, 7th Ed., Wiley, 2014.
- [5] Office of Communications (Ofcom) (His Majesty's Government), "The United Kingdom Frequency Allocation Table," 22 June 2017. [Online]. Available: <https://www.ofcom.org.uk/spectrum/frequencies/uk-fat/>. [Accessed January 2025].
- [6] British Broadcasting Corporation (BBC), "Radio station turns off medium wave after 30 years," 15 January 2024. [Online]. Available: <https://www.bbc.co.uk/news/articles/c4ny5r7j518o>. [Accessed January 2025].

RFSystems assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

45/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5



Comment 1 | Engagement with literature(10)

Citations and references need to be more comprehensive and well-integrated for greater impact.

PAGE 6

PAGE 7



Comment 2 | Practical Application (30)

Including block diagrams for all tasks would provide a clearer understanding of how the connections were made and the process flow.



Comment 3 | Knowledge & Understanding (20)

This clearly demonstrates that AM demodulation has been performed. However, to address Task 1(b), further explanations on the AM demodulation process are required.



Comment 4 | Knowledge & Understanding (20)

Good Observation. It could be better if more explanation is given specifically stating the reason for the low frequency.

PAGE 8



Comment 5 | Knowledge & Understanding (20)

Keen Observation!



Comment 6 | Transferable skills (20)

sentence could be more powerful if it is written 'accurate encoding without distortion

,



Comment 7 | Knowledge & Understanding (20)

The phrase "with the signal reaching 0 amplitude" is technically correct, but it might be better to clarify that the envelope of the carrier reaches zero amplitude at the minimum point, which is characteristic of critical modulation.

PAGE 9



Comment 8 | Knowledge & Understanding (20)

The application of modulation index values is effective, and the screenshots clearly highlight the differences across the three criteria. A comparative analysis would help identify the best output and key considerations for optimal AM modulation.



Comment 9 | Cognitive skills (20)

The spectrum comparison and analysis should be conducted by evaluating parameters such as power, SNR, noise power, figure of merit, and their values in comparison with the obtained practical results.

PAGE 10



Comment 10 | Knowledge & Understanding (20)

Keen observation!

PAGE 11



Comment 11 | Cognitive skills (20)

To further analyse, calculate the SNR after the inclusion of noise



Comment 12 | Cognitive skills (20)

Good. To score higher marks, provide more details on how and what factors contributed to spectral and power improvement. Include evidence by presenting exact numerical values through the appropriate calculations.

PAGE 12

PAGE 13



Comment 13 | Cognitive skills (20)

Comparisons are generally made by addressing the basic concepts of all modulation techniques. However, what is missing here are the theoretical formulas and expected results, which should be applied practically to make the conclusions more precise.



The communication is somewhat effective, and the reporting follows a structure but lacks depth in certain areas. The organisation of ideas is present but could benefit from better coherence and flow. Clarity in the presentation needs improvement to make the overall delivery more impactful and professional.

GRADING FORM: RF_UPDATED_2025

ETHAN ANDERSON

44.86

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.



A basic understanding of modulation techniques is demonstrated. However, the references to theoretical principles are minimal, and the analysis of noise impact and modulation index is quite shallow.

5.7

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) Shows basic understanding of AM principles. Explanation is fine but misses some key details.

Task 1: (a) (ii) Describes critical, over, and under modulation with minimal detail. Observations lack clarity.

Task 1: (b) Weak explanation of demodulation. Comparisons are vague.

8.19

Task 2: (a) DSB SC modulation and demodulation are briefly described. Noise effects are not discussed in detail.

Task 2: (b) Noise effects in DSB SC demodulation are not properly explained.

Task 3: (a) SSB SC modulation and demodulation are described with minimal detail, and noise effects are missing.

Task 3: (b) Noise effects in SSB SC demodulation are poorly explained and lack detail.

Task 4: (a) Fails to discuss spectrum, power density, or noise tolerance.

Task 4: (b) Fails to compare modulation techniques. Bandwidth and power utilisation are not addressed.

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 unclear or incomplete. Comparisons are weak, and the use of spectrum, time scope, or modulation indices is minimal.

Task 1 (b): The demodulation process is limited. Comparisons are minimal. The analysis is shallow with satisfactory points.

Task 2 (a) & (b): The modulation and demodulation processes are seen but with limited explanation. Observations are vague, with no innovation.

Task 3 (a) & (b): The modulation and demodulation processes for SSBSC are seen but with limited explanation. Observations are vague, with no innovation.

Task 4 (a) & (b): Performance metrics, comparisons, and graphs are missing. No conclusions or analysis of spectrum or noise tolerance are provided.

7.17

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.

13.8



Task 1 (a) (i): Basic understanding of tools is demonstrated but lacks clarity in signal demonstration.

Task 1 (a) (ii): Demonstrates modulation variations but lacks detailed insights into carrier impact.

Task 1 (b): Limited explanation of AM demodulation. Block diagrams designed are missing. Screen dumps are clear. Demonstrating limited practical skills.

Task 2 (a): implementation of DSB-SC modulation is seen. Observations lack depth, and block diagrams are missing.

Task 2 (b): Noise analysis is entirely missing and lacks meaningful explanation.

Task 3 (a): Minimal explanation of SSB-SC modulation. Block diagrams are missing which is seen in the submission. Observations lack depth. Minimal explanation of SSB-SC modulation.

Task 3 (b): No meaningful noise analysis is provided.

Task 4 (a): Insufficient practical setup with unclear observations. Measurements are irrelevant or missing.

Task 4 (b): Insufficient comparison of modulation techniques, with no meaningful analysis or conclusions.

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.



Limited transferable skills are demonstrated, with weak communication skills and unorganised

10

reporting.