

RF Systems Martin White

by Martin White

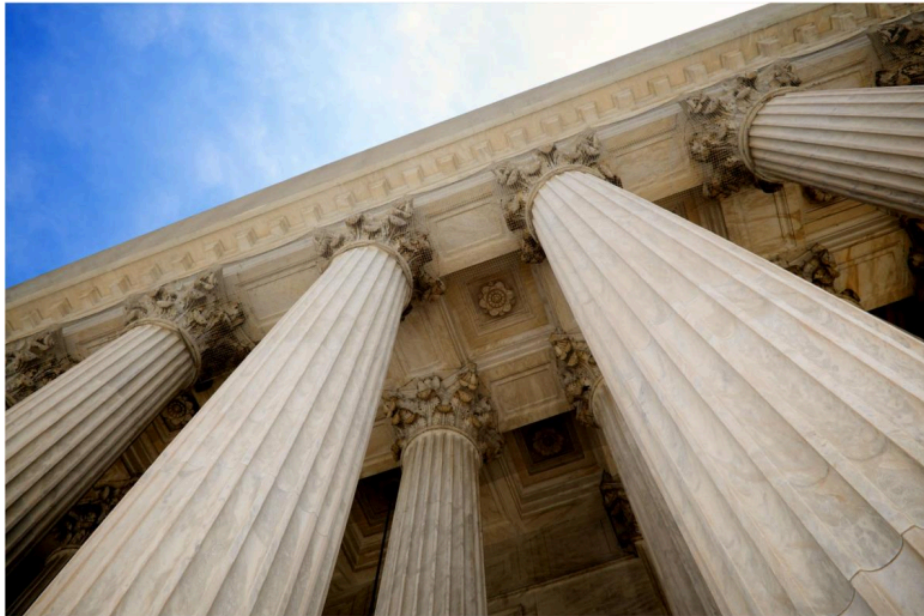
Submission date: 06-Jan-2025 12:38PM (UTC+0000)

Submission ID: 247321673

File name: 42524_Martin_White_RF_Systems_Martin_White_629023_1713099799.docx (335.16K)

Word count: 1785

Character count: 11629



RF Systems

SSB-SC AND DSB-SC

Martin White | Embedded Electronics | 22/12/2024

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Introduction

Radio Frequency (RF) communication systems underpin modern wireless communication, enabling data transmission over long distances in applications such as broadcasting, mobile networks, and the Internet of Things (IoT). Modulation techniques are central to RF communication, allowing data to be encoded onto carrier waves for efficient and reliable transmission. Among these, Amplitude Modulation (AM), Double Sideband Suppressed Carrier (DSB-SC), and Single Sideband Suppressed Carrier (SSB-SC) are widely employed.

This report explores the effects of noise on AM, DSB-SC, and SSB-SC systems. By simulating these systems in MATLAB/Simulink, the study evaluates key performance metrics such as signal-to-noise ratio (SNR), power efficiency, and bandwidth utilization. The goal is to identify the modulation technique most robust to noise while maintaining efficient performance. In addition to practical simulations, theoretical analyses of these systems' architectures and their performance in noisy environments are included.

Background Research

RF Communication Basics

RF systems transmit information by propagating electromagnetic waves. Modulation techniques ensure efficient data encoding on carrier waves, optimizing power and bandwidth use. Communication efficiency and system robustness strongly depend on the modulation strategy used.

AMPLITUDE MODULATION (AM): In AM, the amplitude of the carrier wave varies in proportion to the modulation signal. Although AM is simple and widely used, it has inefficiencies because the carrier and sidebands transmit information. Due to its wide power distribution, noise significantly impacts AM, making it more susceptible to distortion in noisy environments.

DOUBLE SIDEBAND SUPPRESSED CARRIER (DSB-SC): This technique reduces energy consumption. The information is encoded in both sidebands, which requires precise synchronization at the receiver. DSB-SC is more energy efficient than AM but remains sensitive to noise. Its implementation reduces the total transmitted power by avoiding redundant transmission of the carrier.



SINGLE SIDEBAND SUPPRESSED CARRIER (SSB-SC): By transmitting a single sideband, SSB-SC improves spectral efficiency and reduces bandwidth requirements. It is ideal for highly efficient communications but requires complex receiver designs for precise signal recovery. SSB-SC is particularly beneficial in bandwidth-limited environments such as marine and aviation communications.

NOISE IN RF SYSTEMS: Sources of noise in communications include internal (e.g., thermal noise) and external (e.g., atmospheric disturbances) factors. These distortions affect the signal quality and the accuracy of the transmitted data. Understanding the effects of noise is crucial for optimizing communication systems. As RF studies show, radio frequency signals are often subject to increased sensitivity to noise due to atmospheric and device-induced distortions.



Noise is not just an external factor; it also occurs inside electronic components. For example, thermal noise in resistors and shot noise in semiconductors can cause unpredictable fluctuations that affect signal clarity. The propagation environment, including multipath reflections and attenuation due to physical obstacles, further exacerbates noise-related problems. Therefore, noise analysis must include a combination of theoretical modelling and practical simulation to accurately assess its impact on communication systems.

Literature Review

Studies have shown that noise significantly affects the performance of RF systems, particularly AM, which is less resilient due to its wide power distribution. The inefficiency arises from the even distribution of power across carriers and sidebands, making AM signals highly susceptible to additive white Gaussian noise (AWGN).

DSB-SC offers better noise tolerance but requires precise timing for demodulation. The literature  highlights that coherent detection methods can mitigate the effects of noise but increase the complexity of receiver design. SSB-SC systems offer superior performance in noisy conditions due to their efficient use of bandwidth and focus on a single sideband. However, their complex implementation limits their wide use in cost-sensitive applications.

 Simulation tools such as MATLAB/Simulink are essential for analysing these systems. Several studies have modelled the effects of noise on RF communications to demonstrate the robustness of SSB-SC and identify conditions under which DSB-SC can outperform conventional AM. The research also suggests exploring hybrid modulation techniques to further improve noise immunity and system efficiency.

A comparative analysis of these modulation techniques shows an obvious trade-off between complexity and performance. While additive manufacturing is simple, it performs poorly in noisy environments. DSB-SC strikes a balance between complexity and efficiency but suffers from carrier synchronization issues. While SSB-SC is very efficient, it requires advanced filtering and detection mechanisms to achieve optimal performance. This highlights the need for further innovation to address these limitations. 

Circuit Design and Block Diagrams



AM SYSTEM DESIGN:

The AM system consists of a carrier wave generator, a modulator, and a demodulator. The modulator superimposes the low-frequency message signal onto the high-frequency carrier, and the demodulator extracts the original signal. Typical AM transmitters use high-level or low-level modulation, depending on whether modulation occurs at the final amplifier stage or earlier in the process.



DSB-SC SYSTEM DESIGN:

A balanced modulator generates the DSB-SC signal by combining the carrier and message signal. At the receiver, coherent detection using a synchronized carrier allows demodulation. Noise is added to observe its effects on signal recovery. The absence of a carrier in DSB-SC systems minimizes power waste but necessitates exact frequency and phase alignment at the receiver.

SSB-SC SYSTEM DESIGN:

The SSB-SC system employs the phase discriminator method. This involves generating a DSB-SC signal, followed by filtering to isolate a single sideband. At the receiver, coherent detection is used to extract the original signal. The reduced bandwidth requirement allows efficient power utilization while maintaining high-quality signal transmission.



Block diagrams for each system illustrate the flow from the transmitter to the receiver, highlighting critical components such as modulators, noise sources, and filters. In AM and DSB-SC systems, filtering after modulation minimizes spurious emissions, ensuring signal clarity in noisy channels.

In Simulink implementations, pre-configured blocks like oscillators, modulators, and spectrum analyzers help model signal behaviour under varying noise conditions. Advanced simulation tools allow the introduction of realistic noise sources, including AWGN and impulse noise, enabling comprehensive performance evaluation.

Transmitter and Receiver Architectures

AM TRANSMITTER AND RECEIVER:

The transmitter includes an oscillator, amplitude modulator, and antenna. The receiver consists of an envelope detector and a low-pass filter for signal recovery. The simplicity of AM receivers allows low-cost implementation but makes them prone to noise and signal fading. AM systems often use automatic gain control (AGC) circuits to stabilize signal strength.

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DSB-SC TRANSMITTER AND RECEIVER:

The transmitter employs a balanced modulator and antenna for signal radiation. The receiver utilizes a coherent detector and low-pass filter to recover the original signal, emphasizing the importance of carrier synchronization. This architecture reduces redundancy in transmitted signals, optimizing power usage. Techniques like Costas loops are used for carrier recovery in DSB-SC systems.

SSB-SC TRANSMITTER AND RECEIVER:

The transmitter features a product modulator and bandpass filter to isolate the desired sideband. The receiver employs a coherent detector and phase-locked loop for accurate signal recovery. This design ensures that minimum bandwidth is used, making SSB-SC the preferred choice for bandwidth-limited applications. Advanced SSB-SC receivers may incorporate digital signal processing (DSP) techniques to enhance noise suppression and signal clarity.

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In all three architectures, the choice of components plays a critical role in determining overall system performance. Factors such as oscillator stability, filter precision, and the linearity of amplifiers can significantly affect the quality of signal transmission and reception. Moreover, environmental factors like temperature and humidity can impact circuit performance, necessitating robust design and testing.

Simulated Outputs and Results

Simulations were conducted in MATLAB/Simulink to analyse the systems in both time and frequency domains, with and without noise.

AM Results:

Time Domain: Modulated signal shows variations in amplitude corresponding to the message signal.

Frequency Domain: Carrier and sidebands are visible, occupying a wide bandwidth.

Noise Impact: Noise introduces amplitude distortions, reducing signal clarity. Higher noise levels make the modulated signal indistinguishable, degrading signal quality. Signal recovery is particularly challenging without proper filtering.

DSB-SC Results:

Time Domain: Modulated signal shows amplitude variations without the carrier.

Frequency Domain: Two sidebands are visible without a carrier component, reducing power wastage.

Noise Impact: Noise distorts the signal, but coherent detection recovers the message with moderate accuracy. Random noise introduces phase mismatches, slightly impacting recovered signal quality. Increased noise power levels result in noticeable signal degradation.

SSB-SC Results:

Time Domain: Single sideband modulation is evident, with reduced signal components.

Frequency Domain: Only one sideband is present, minimizing bandwidth usage.

Noise Impact: SSB-SC demonstrates superior noise tolerance, maintaining higher signal clarity compared to AM and DSB-SC. Even under significant noise conditions, SSB-SC signals retain intelligibility due to reduced spectral interference.

Graphs generated during simulation highlight differences in recovered signal integrity under varying noise conditions, emphasizing SSB-SC's robustness. These visual representations further illustrate the importance of bandwidth and power efficiency in mitigating noise impacts.

Analysis of Results

The analysis focused on three performance metrics: bandwidth efficiency, power utilization, and noise tolerance.

Bandwidth Efficiency: SSB-SC is the most efficient, requiring half the bandwidth of AM and DSB-SC. By eliminating redundant spectral components, SSB-SC maximizes spectral efficiency. DSB-SC's dual-sideband structure, while effective, doubles the bandwidth requirement compared to SSB-SC.

Power Utilization: DSB-SC eliminates carrier power wastage, offering better power efficiency than AM. SSB-SC further optimizes power usage by transmitting only one sideband, ensuring minimal energy loss. AM's carrier and sideband transmission result in higher energy consumption.

Noise Tolerance: SSB-SC has the highest immunity to noise due to its narrow bandwidth and reduced signal components. AM is the most susceptible to noise, while DSB-SC provides moderate noise resistance. These results are consistent with theoretical predictions regarding spectral and energy efficiency.

The results also suggest that under extremely noisy conditions, SSB-SC can maintain intelligible communication, whereas AM and DSB-SC performance deteriorates more rapidly. This aligns with the practical observation that SSB-SC is preferred in professional communication systems requiring high reliability, such as aviation and military communications.

Conclusion

The study demonstrates that noise significantly impacts RF communication systems, with varying effects depending on the modulation technique. SSB-SC out-performs AM and DSB-SC in bandwidth efficiency, power utilization, and noise tolerance, making it the ideal choice for high-performance applications. However, its complex implementation poses challenges for widespread adoption. DSB-SC offers a balanced trade-off between efficiency and complexity, while AM remains suitable for basic applications requiring low-cost and straightforward implementation.

These findings underscore the importance of selecting appropriate modulation techniques based on specific application requirements, particularly in noisy environments where signal integrity is critical.

References

- [1] Analog Communication - DSBSC Modulation - Tutorials point," *Tutorialspoint.com*, 2019.
https://www.tutorialspoint.com/analog_communication/analog_communication_dsbsc_modulation.htm

FINAL GRADE

GENERAL COMMENTS

22/100

PAGE 1

PAGE 2

PAGE 3



Comment 1 |  Knowledge & Understanding (20)

The tasks results and analysis are missing.

PAGE 4



Comment 2 |  Knowledge & Understanding (20)

The basic understanding of modulation techniques, including AM, DSB-SC, and SSB-SC were well demonstrated.



Comment 3 |  Engagement with literature(10)

Great! Sources of noise and their effects on RF communication are highlighted.



Comment 4 |  Knowledge & Understanding (20)

The impact of noise on these techniques and their theoretical foundations were discussed.

PAGE 5



Comment 5

It could be better is the concepts of balanced modulator and phase discriminator theories are included.



Comment 6 |  Engagement with literature(10)

Well Done. The literature review includes basic discussions on AM, DSB-SC, and SSB-SC techniques.

-



Comment 7 | Engagement with literature(10)

Citations are minimal, and theoretical principles are not well-developed.

PAGE 6



Comment 8 | Practical Application (30)

No Simulink screen dumps or block diagrams provided.



Comment 9 | Knowledge & Understanding (20)

Analyses such as Modulation index is nowhere found in the report.



Comment 10 | Knowledge & Understanding (20)

Key observations such as SNR, frequency, and power calculations are missing

PAGE 7



Comment 11 | Knowledge & Understanding (20)

It is appreciable that general outlines of transmitter and receiver architectures are included.



Comment 12 | Cognitive skills (20)

It could be better if the blocks diagrams are included when explaining the architecture.

PAGE 8



Comment 13 | Transferable skills (20)

The report has a clear structure with sections for introduction, background, results, and conclusion which is appreciable but lacks visual aids, such as graphs and tables, screen dumps to support report.

PAGE 9



Comment 14 | Cognitive skills (20)

Comparison of bandwidth efficiency and utilisation is appreciable.



Comment 15 | Cognitive skills (20)

Although the report includes accurate theoretical discussions, it fails to provide the necessary analysis to meet all the tasks, which are largely absent throughout. Connecting to the expected

results would only be possible by presenting practical evidence, such as simulating the systems in Simulink, analysing time and frequency scopes, and calculating values like power, SNR, and Figure of Merit along with theoretical calculations. Applying different SNR values to DSB-SC and SSB-SC and comparing their efficiencies is crucial. However, the required simulations, scope outputs, and calculations are entirely missing.

GRADING FORM: RF_UPDATED_2025

MARTIN WHITE

21.85

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 minimal, and references to theoretical principles are very limited. The discussion on noise impact and performance metrics is lacks proper detail.

4.5

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) Minimal understanding of AM principles. The explanation is too vague, with no examples.

3.75

Task 1: (a) (ii) Fails to describe critical, over, and under modulation. Observations are absent.

Task 1: (b) Fails to explain demodulation.

Comparisons are missing entirely.

Task 2: (a) DSB SC modulation and demodulation are vaguely described. Noise effects are missing.

Task 2: (b) Noise effects in DSB SC demodulation are limited.

Task 3: (a) SSB SC modulation and demodulation are poorly described, with no examples or noise analysis.

Task 3: (b) Noise effects in SSB SC demodulation are less explained.

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 missing . Comparisons and metrics like spectrum, time scope, or modulation indices are absent.

Task 1 (b): The demodulation process is missing. Comparisons are irrelevant or missing. The analysis is absent with no effort shown.

Task 2 (a) & (b): The modulation and demodulation processes are missing. Observations and innovation are absent.

Task 3 (a) & (b): The modulation and demodulation processes for SSBSC are missing. Observations and innovative ideas are absent.

Task 4 (a) & (b): Performance metrics,

1.3

comparisons, and graphs are missing. No conclusions are drawn based on theoretical and observed value calculations.

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.

0.3



Task 1 (a) (i): No demonstrated skills in tool usage or signal demonstration.

Task 1 (a) (ii): Fails to demonstrate modulation variations or explain carrier impact.

Task 1 (b): No explanation or results for AM demodulation. No block diagrams, screen dumps, or practical skills demonstrated.

Task 2 (a): No implementation of DSB-SC modulation. Observations, block diagrams, and screenshots are completely absent.

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

Task 3 (a): No explanation or observations for SSB-SC modulation. No block diagrams, screenshots, or meaningful observations provided.

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

Task 4 (a): No evidence of practical setup or meaningful observations. Fails to demonstrate understanding of processes.

Task 4 (b): Fails to compare modulation techniques. Conclusions are unsupported and observations are missing.

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.



Transferable skills are adequate, with basic communication skills, acceptable organisation, and systematic reporting.

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