Original Research Article

Research and Development of an Experimental Device for Military Communication Using Multi-level Amplitude Shift Keying

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ABSTRACT

Ensuring "timely, accurate, confidential, and secure" communication is a core requirement for military communication systems. Traditional communication systems often use amplitude modulation (AM) due to its simple design and ease of implementation. However, the major drawback of AM is its high sensitivity to noise, making it suitable only for long-wave transmissions, such as AM radio, and challenging to integrate modern technologies like 4G and 5G into military communication systems.

This paper presents the research and development of an experimental military communication device using multi-level shift keying (MASK) modulation. The study explores the mathematical foundation, design, and construction of the MASK modulation and demodulation system. The experimental device was tested under varying noise levels and transmission conditions to evaluate its performance. Results indicate that the MASK-based system significantly improves noise resistance compared to AM systems, ensuring reliable communication even in high-interference environments. These findings demonstrate the potential of MASK for integration into next-generation military communication systems, addressing the stringent demands of modern combat and adverse conditions..

Keywords: AM radio, multi-level Amplitude Shift Keying, Modulation, Demodulation

1. INTRODUCTION

Amplitude Modulation (AM) has long been a staple of traditional communication systems due to its simplicity and low computational requirements. AM is effective in broadcasting over long distances, especially in low-frequency bands, which makes it suitable for applications like AM radio. However, its use in military communication is constrained by several factors:

Susceptibility to Noise and Interference: AM signals are highly sensitive to various types of noise, especially in the presence of environmental factors or enemy jamming in military operations. As the information is encoded in the amplitude of the carrier wave, any fluctuation in the signal amplitude due to noise or interference can significantly degrade the quality of communication.

Limited Compatibility with Modern Technologies: As military communication systems increasingly integrate modern technologies, including 4G and 5G, traditional AM modulation becomes less viable. These technologies rely on more complex modulation schemes that provide better noise immunity, higher data rates, and greater security, which AM cannot match. The lack of adaptability to these newer systems hinders the evolution of military communication infrastructure.

Inadequate Security and Efficiency: AM is not designed with encryption or advanced security mechanisms in mind, which is a significant limitation in military communication where confidentiality and security are paramount. Additionally, the efficiency of AM modulation in terms of bandwidth usage is suboptimal, particularly in scenarios where high data throughput is required.

Amplitude Shift Keying (ASK), and its variations such as Binary Amplitude Shift Keying (BASK) and Multi-level Amplitude Shift Keying (MASK), offer several key benefits that address the limitations of AM in military communication systems:

Noise Immunity: ASK, especially in its multi-level forms, has superior resistance to noise compared to AM. By encoding information in amplitude variations, it offers a more robust method for handling interference and signal degradation. This is particularly important in military environments where communication channels are often disrupted by jamming or natural obstacles.

Compatibility with Modern Technologies: The flexibility of ASK modulation makes it easily adaptable to modern communication systems.MASK, for example, can accommodate multiple amplitude levels, optimizing the use of available bandwidth and enabling higher data transfer rates. As military systems upgrade to integrate 4G and 5G technologies, ASK's inherent adaptability makes it an attractive option for these evolving networks.

Security and Efficiency: ASK, especially in its multi-level form (MASK), can improve the efficiency of data transmission while maintaining security. By using different amplitude levels to represent multiple bits per symbol, MASK can increase the information density without requiring additional bandwidth. Furthermore, when combined with encryption techniques, ASK-based systems can offer secure communication channels resistant to interception, which is crucial in military operations.

While traditional AM modulation has its place in communication systems, its limitations in terms of noise immunity, security, and compatibility with modern technologies make it less suitable for military applications. ASK modulation, particularly in its multi-level forms like MASK, addresses these challenges by providing more efficient use of bandwidth, better resistance to interference, and the adaptability needed to integrate with advanced technologies like 4G and 5G.

The development and application of ASK modulation in military communication systems represent a significant advancement, providing both improved security and performance in challenging environments. As military operations become increasingly dependent on modern digital communication systems, the role of ASK in ensuring timely, secure, and reliable communication will become more crucial, ensuring that military personnel can effectively communicate under even the most demanding conditions.

ASK modulation is not only used in civilian applications (such as RFID, keyless entry systems, and short-range wireless communication) but also in various military applications like Morse code telegraphs, secure telemetry, and remote sensing systems. Its ability to operate effectively in harsh conditions, such as on the battlefield, where environmental factors and signal interference are common, demonstrates its potential for future military communication technologies.

This paper focuses on researching and developing an experimental device for military communication using MASK modulation. Specifically, we study the mathematical foundation and design the system architecture for MASK modulation and demodulation. Additionally, we develop an experimental device to validate these modulation models in real-world environments.

The experimental device serves as a tool for verifying the performance of MASK modulation models. Furthermore, it provides a foundation for the development of communication systems that meet the stringent requirements of military operational environments.

Fig.1. Remote Keyless Entry System

Fig.2. RFID System for Animal Identification

Fig.3. Military Morse Telegraph Machine

2. MULTI-LEVELAMPLITUDE SHIFT KEYING MODULATION

2.1. Mathematical Foundation

- MASK modulation is a modulation method that uses combinations of input digital signal bits to modify the amplitude of the carrier wave at multiple levels (4, 8, etc.). The input signal is divided into bit groups (2, 3, ... bits) to represent information using different amplitude levels. MASK modulation is performed at the MASK transmitter, making it suitable for systems that require the transmission of large amounts of data over a single communication channel.

-The MASK modulation method has the following signal forms:
The input bit sequence s(t). Assume:

$$s(t)=\{0\quad 0\quad 1\quad 1\quad 0\quad 1\quad 0\quad 0\quad 0\quad 1\quad 0\} \tag{1}$$

The NRZ waveform signal with M levels is a sequence of input bits s(t) mapped to corresponding amplitude levels A_k for each bit combination:

$$b(t)=\begin{cases} A_k \\ 0 \end{cases} \tag{2}$$

The carrier signal is:

$$x(t)=\cos(2\pi f_c t) \tag{3}$$

The MASK modulated signal is:

$$y(t)=\sum_{k=1}^{M} A_k.\cos(2\pi f_c t) \tag{4}$$

- After applying the Fourier transform, we obtain:

The spectrum of the signal b(t) is:

$$B(f)=FT\{b(t)\}=\int_{-\infty}^{+\infty} b(t).e^{-j2\pi ft}dt \tag{5}$$

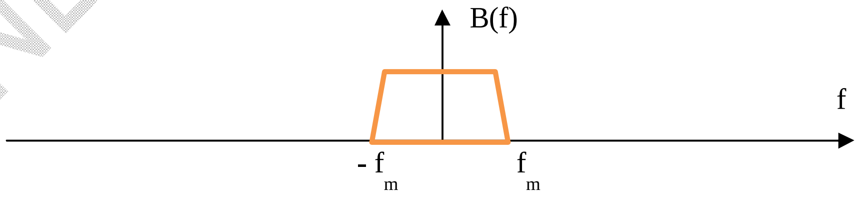
The spectrum of the signal y(t) is:

$$Y(f)=FT\{y(t)\}=\int_{-\infty}^{+\infty} y(t).e^{-j2\pi ft}dt=\int_{-\infty}^{+\infty} b(t).\cos(2\pi f_c t).e^{-j2\pi ft}dt \tag{6}$$

$$Y(f)=\frac{1}{2}\int_{-\infty}^{+\infty} b(t)(e^{j2\pi f_c t}+e^{-j2\pi f_c t})e^{-j2\pi ft}dt \tag{7}$$

$$Y(f)=\frac{1}{2}\int_{-\infty}^{+\infty} b(t).e^{-j2\pi(f+f_c)t}dt+\frac{1}{2}\int_{-\infty}^{+\infty} b(t).e^{-j2\pi(f-f_c)t}dt \tag{8}$$

$$Y(f)=\frac{1}{2}.B(f+f_c)+\frac{1}{2}.B(f-f_c) \tag{9}$$



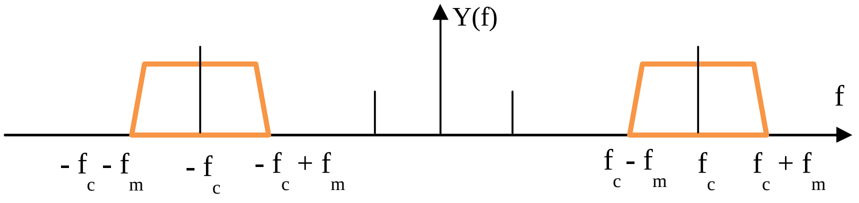


Fig.4. Spectrum of the MASK Signal

Comments:

The signal b(t) has a low frequency but a wide spectrum.

The spectrum of the MASK signal consists of two components: one around $+f_c$ and the other around $-f_c$. The spectral structure of the MASK signal is concentrated around the carrier frequency $\pm f_c$, with the spectral amplitude at these frequencies proportional to the amplitude levels A_k. The MASK modulation process shifts the spectrum of the signal $b(t)$ around the carrier frequency $\pm f_c$.

2.2. Modulation Principle

The structure diagram of the BASK modulator is shown in Figure 5.

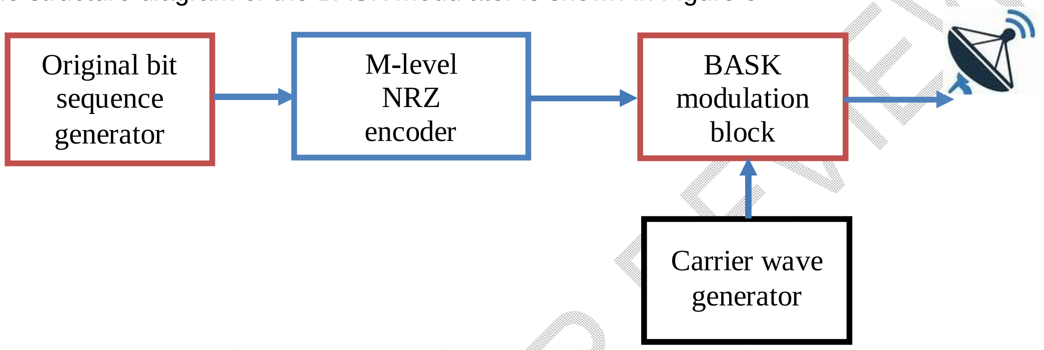


Fig.5. Structure Diagram of the MASK Modulator

Bit Sequence Generator: Generates the input bit sequence that represents the information to be transmitted.

NRZ M-Level Encoder: Converts groups of m bits into different voltage levels. For example, in a 4-ASK scheme (M = 4), each 2-bit group (00, 01, 10, 11) is mapped to corresponding voltage levels of 0, 1, 2, and 3V.

Carrier Signal Generator: Produces a high-frequency oscillation, with the carrier frequency tunable by the user within the range of 100 MHz to 1 GHz. No significant frequency shift is observed from the desired carrier frequency, as the carrier wave generator maintains stability within an acceptable tolerance.

MASK Modulation Block: A switch controlled by the NRZ signal that alters the carrier's amplitude in M levels corresponding to M bit levels. The MASK signal has M amplitude levels, and its frequency is equal to the carrier frequency, allowing the signal to travel long distances. The MASK modulation block multiplies the NRZ pulse with the carrier wave to create the MASK-modulated signal, which is then transmitted through the communication channel.

3. MULTI-LEVELAMPLITUDE SHIFT KEYING DEMODULATION

3.1. Mathematical Foundation

- MASK demodulation is the process of recovering the original digital signal from the MASK-modulated signal. The demodulation process involves determining the amplitude levels of the signal and mapping them back to the corresponding binary bit sequence in order to regenerate the original information. MASK demodulation is performed at the MASK receiver.

- The MASK demodulation method involves the following signal forms:

The received signal at the MASK receiver with noise N(t) is:

$$r(t) = C(t).\cos(2\pi f_c t) + N(t) \quad (10)$$

The base carrier signal: $\cos(2\pi f_c t)$

The result of multiplying the base carrier signal by the received signal:

$$r(t).\cos(2\pi f_c t)=C(t).(\frac{1}{2}+\frac{1}{2}\cos(4\pi f_c t))+N(t).\cos(2\pi f_c t) \quad (11)$$

Comments:

The spectrum of the signal consists of three components:

The low-frequency component corresponding to the envelope C(t), which represents the original information.

The high-frequency component with frequencies at f_c and $2.f_c$.

To recover the original signal, a low-pass filter is needed to remove the high-frequency components and retain the low-frequency ones. The accuracy of recovering the original signal depends on the carrier synchronization technique, noise processing, and NRZ decoding.

3.2. Demodulation Principle

The structure diagram of the BASK demodulator is shown in Figure 6.

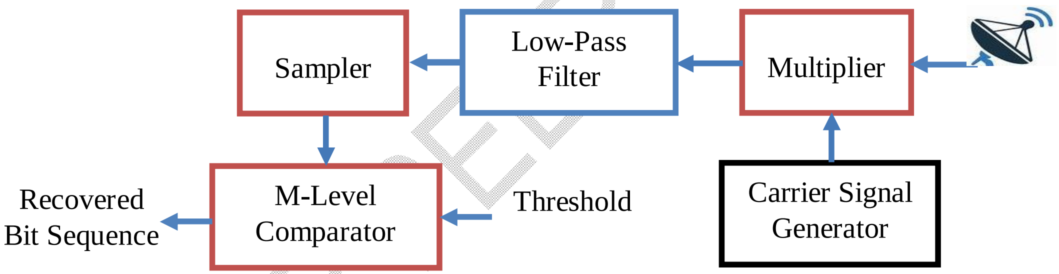


Fig.6. Block Diagram of the MASK Demodulator

Carrier Signal Generator: Generates a harmonic carrier wave with a fixed frequency.

Multiplier: Multiplies the noisy MASK modulated signal with the carrier wave, producing a new signal containing multiple spectral components: a slowly varying amplitude envelope component, high-frequency components at f_c, and $2f_c$.

Low-Pass Filter: Removes high-frequency components, retaining only the amplitude envelope component of the MASK modulated signal.The cutoff frequency of the Low-Pass Filter (LPF) is adjusted in proportion to the selected carrier frequency, ensuring optimal signal filtering.

Sampler: Samples the signal after filtering, converting the continuous signal into a discrete signal.

M-Level Comparator: Compares the sample amplitude with 2^M specific threshold levels. If the sample amplitude is greater than any of the threshold levels, the signal is determined to be the corresponding bit combination mapped to that threshold level. The output from this comparator generates the recovered bit sequence, which corresponds to the original transmitted bit sequence.

4. EXPERIMENTAL EQUIPMENT

4.1. Equipment Introduction

- Figure 7 illustrates the front panel structure and the input/output connectors of the MASK modulation experimental device.The experimental device for MASK modulation, as depicted in the figure, consists of four key modules:

Bit Sequence Generator: This module generates a sequence of binary bits (S), serving as the input digital data for the modulation process.

M-Level NRZ Encoder: Converts the binary bit sequence (S) into an NRZ format signal (B), suitable for modulation.

Carrier Wave Generator: Produces a harmonic carrier wave (X) with a fixed frequency, used for modulating the input signal.

MASK Modulator: Combines the carrier wave (X) and the NRZ signal (B) to produce the MASK modulated signal (Y), which contains amplitude variations corresponding to the input digital data.

This device provides a hands-on platform for studying and analyzing the fundamental principles of MASK modulation.

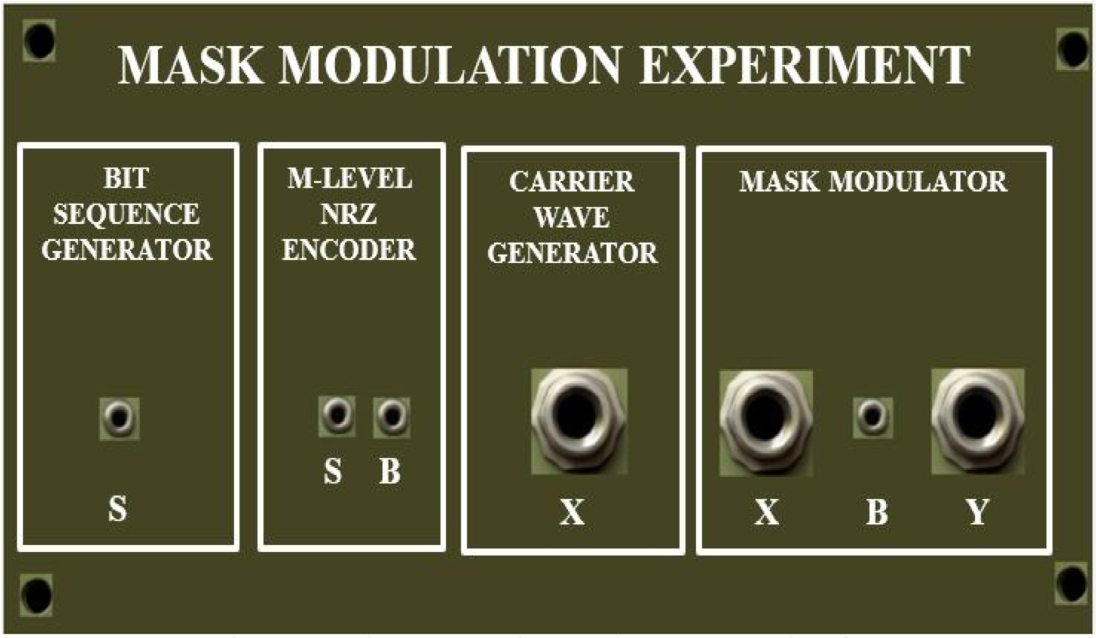


Fig.7. Experimental Equipment for MASK Modulation

- Figure 8 illustrates the front panel structure and the input/output connectors of the MASK demodulation experimental device.The MASK demodulation experimental device, as illustrated in Figure 8, consists of five main modules:

Carrier Wave Generator: Generates the carrier wave (X) required for the demodulation process.
Signal Multiplier: Multiplies the received MASK modulated signal (Y) with the carrier wave (X) to produce a signal containing various frequency components ($X \cdot Y$).

Low-Pass Filter: Eliminates high-frequency components from the mixed signal, preserving the low-frequency component of the amplitude envelope (B).

Sampler: Converts the filtered continuous signal into discrete samples (Bs) for further processing.

M-Level Comparator: Compares the amplitude of the received signal (Bs) with a predefined threshold to determine the corresponding bit sequence (S) for the transmitted data. The threshold can be adjusted via the "Threshold" potentiometers.

Additionally, the device includes various input and output ports (X, Y, $X \cdot Y$, B, Bs, S) to facilitate signal observation and analysis at different stages of the demodulation process.

This experimental device provides a practical platform for understanding and experimenting with the fundamental principles of MASK demodulation.

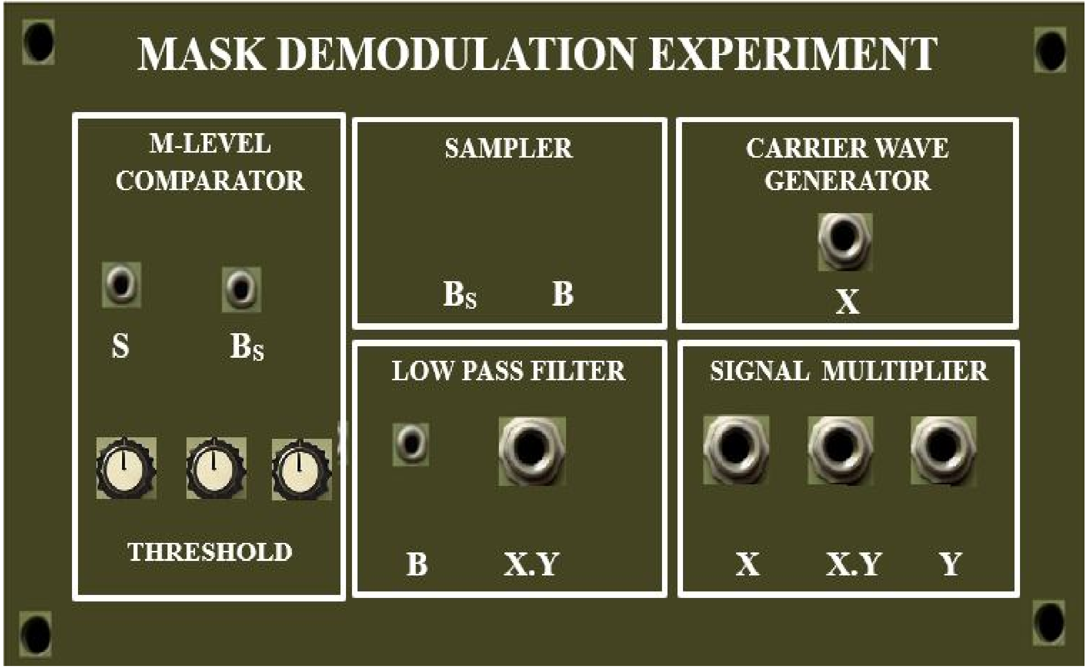


Fig.8. Experimental Equipment for MASK Demodulation

4.2. Experimental Results

- The experimental results of MASK modulation are shown in Figure 9:

Assume a binary input sequence: $s(t) = \{1\ 1\ 0\ 1\ 0\ 0\ 1\ 0\ 1\ 1\}$

The multi-level NRZ encoded signal will have M voltage levels: 0, 1, 2, and 3V.

The carrier wave is a harmonic oscillation with a high frequency.

The MASK-modulated output signal has M=4 amplitude levels, with a frequency equal to the carrier frequency, enabling the signal to be transmitted over long distances.

The constellation diagram consists of M points along the **I**-axis at positions 0, 1, 2, and 3. The **I**-axis represents the real part corresponding to the in-phase component of the carrier wave. The Q-axis represents the imaginary part corresponding to the quadrature component of the carrier wave.

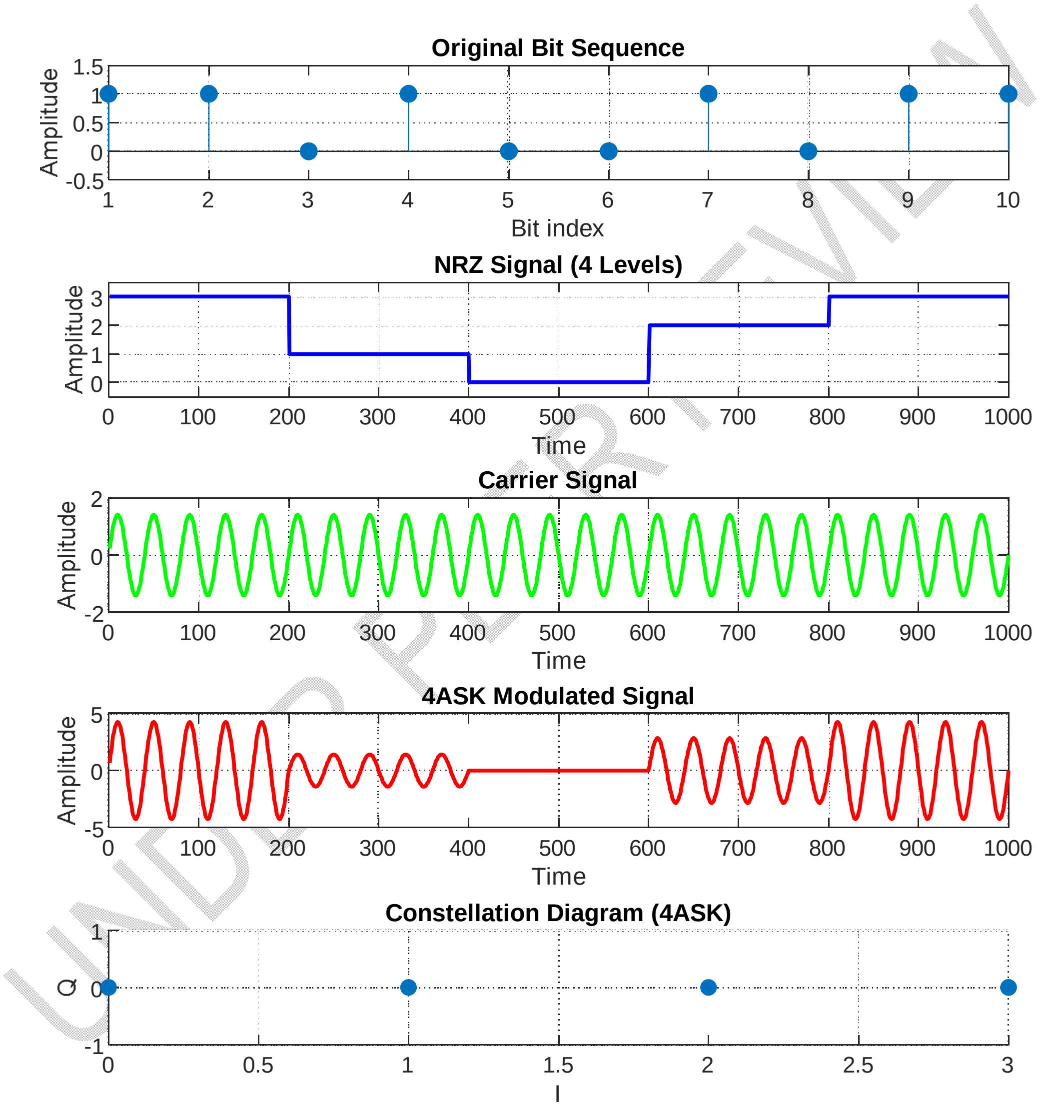


Fig. 9. Graphs of Signals in BASK Modulation

The results of the MASK demodulation are shown in Figure 10. The modulated MASK signal, which contains noise at the receiver input, is multiplied by the carrier wave, generating a new signal with multiple frequency components: the slowly varying envelope component, high-frequency components fc, and 2fc. After passing through a filter, the high-frequency components are removed, and the envelope component is retained for sampling.

The sampled amplitudes are compared against threshold levels of 0V, 1V, 2V, and 3V to determine the corresponding recovered bit combinations: 00, 01, 10, and 11. The comparison results produce a bit stream that corresponds to the original bit stream.

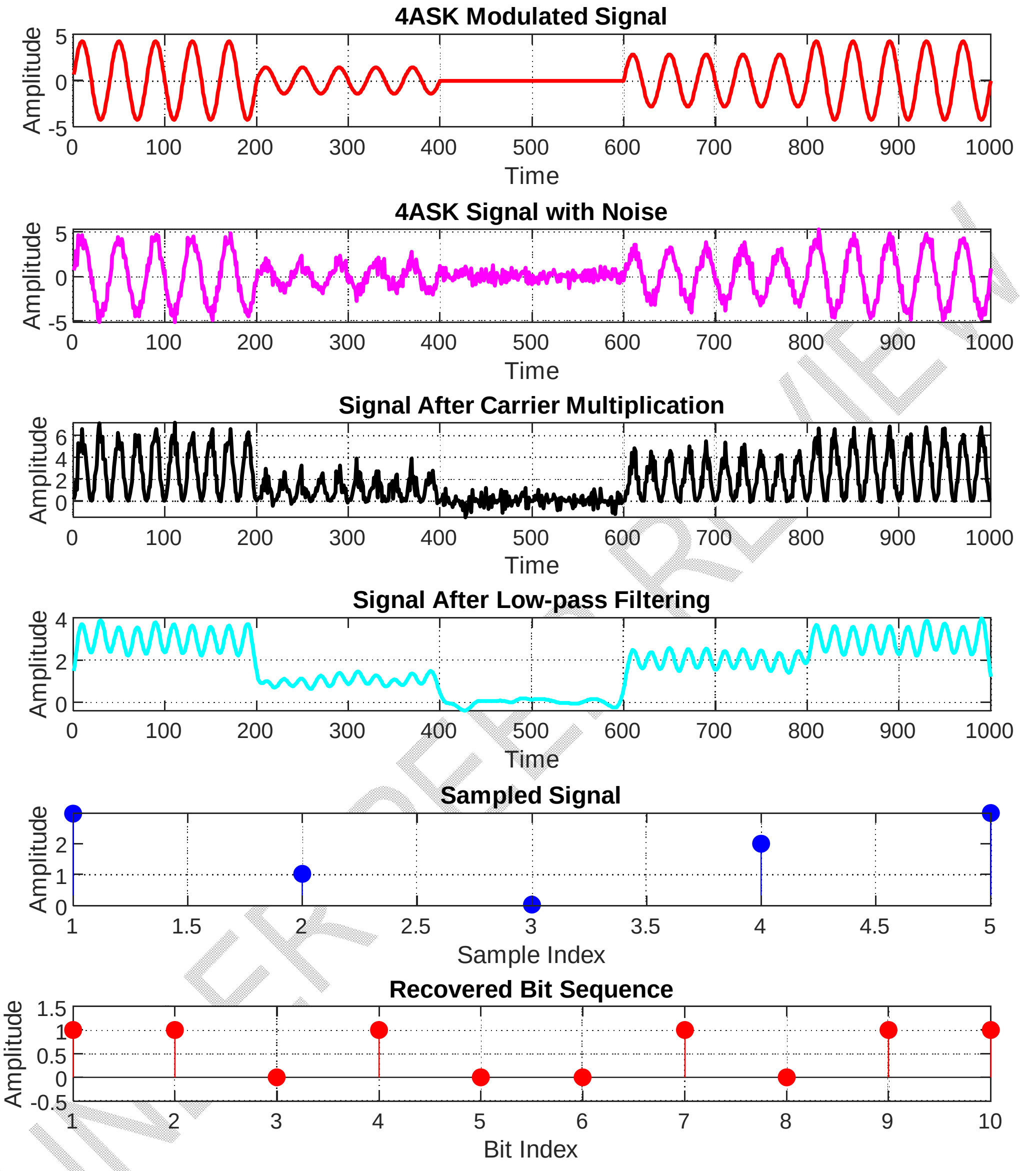


Fig. 10. Graphs of Signals in BASK Demodulation

5. CONCLUSION

This paper has investigated and developed an experimental device for military communication using the Multi-level Amplitude Shift Keying modulation method. The study evaluates the characteristics and applications of this method in information security and safety. The research results confirm that MASK modulation offers advantages in enhancing noise resistance and compatibility with modern communication technologies such as 4G and 5G while maintaining high performance in the harsh environments of military communication systems. The developed MASK modulation and demodulation system not only provides a reliable experimental tool for testing this modulation scheme but also lays a solid foundation for the development of modern military communication devices and systems that fully meet the stringent requirements for security, safety, and effective information transmission in combat environments.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) hereby declare that no generative AI technologies, such as Large Language Models (e.g., ChatGPT, COPILOT) or text-to-image generators, were used in the writing or editing of this manuscript.

COMPETING INTERESTS: The authors have declared that no competing interests exist.

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