Scilab Xcos case study project on

The Comparative Study of Analog and Digital Modulations in Communication Systems

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Abstract:

Modulation is a fundamental technique in communication systems that enables the transmission of information over various media by varying the properties of a carrier signal. Analog modulation techniques, such as Amplitude Modulation (AM), Frequency Modulation (FM), and Phase Modulation (PM), modify continuous signals, while digital modulation schemes, including Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK), encode discrete data. This study aims to simulate and analyze both analog and digital modulation techniques using Scilab Xcos, an open-source graphical modeling and simulation tool. The insights and techniques presented herein serve as a valuable resource for researchers, engineers, and practitioners engaged in the design and optimization of communication systems operating in challenging fading environments.

Index terms: Modulation, AM, FM, PM, ASK, FSK, Xcos.

1 Introduction:

Generally**,** the source/baseband signals produced from various sources are not suitable for direct transmission over a nosy environment. These signals are further modified into an suitable form to facilitate transmission. This conversion process is known as **modulation.** In this process, a low frequency baseband signals is used to modify some parameter of a high frequency carrier signal to enable efficient transmission over a communication channel.

Modulation can be classified into:

1. Analog Modulation (used for continuous-time signals)
2. Digital Modulation (used for discrete-time signals)

2. Problem Formulation

To transmit the information over a longer distance, we need to perform modulation, which is necessary for any communication system. This ensures increased power, long range, and reduced antenna size. For a given application scenario, we must determine which modulation strategy, so called analog variants such as AM, FM, PM, that deal with analog information sources or digital counterparts like ASK, FSK, PSK which balances spectral occupancy, power efficiency, noise robustness, and implementation complexity. The formulation, therefore, involves modeling the baseband message, the carrier, and defining quantitative performance to identify the system constraints such as allowable power, regulatory bandwidth limits, and hardware cost. By establishing these criteria up front, we can systematically compare each scheme's theoretical capabilities and practical trade-offs. The ultimate goal is to select or hybridize the modulation techniques that satisfy the specified communication requirements while minimizing resource expenditure.

3. Basic concepts related to the topic

3.1 Analog Modulation Techniques

Analog modulation techniques modify the **amplitude, frequency, or phase** of the carrier signal.

3.1.1 Amplitude Modulation (AM)

- **Definition**: Amplitude Modulation (AM) is one of the oldest and simplest forms of analog modulation, where the amplitude of a high-frequency carrier signal is varied in proportion to the instantaneous amplitude of the modulating (message) signal. It is widely used in AM radio broadcasting.
- **Mathematical Formulation**:
  - **Modulating Signal (Message Signal, Low Frequency):**

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

where:

- A_m = Amplitude of the message signal
- f_m = frequency of the message signal

- ○ **Carrier Signal (High Frequency):**

$$c(t) = Ac\ cos(2\pi fct)$$

- A_c = Amplitude of the message signal
- f_c = frequency of the carrier signal
  - ○ **AM Signal Equation**

    - ○ $S_{AM}(t) = A_{c[}1+\mu cos(2\pi f_m t)]cos(2\pi f_c t)$

Where,

μ=Ac/Am = Modulation Index (must be ≤ 1 to avoid distortion)

- **Scilab-Xcos Implementation**

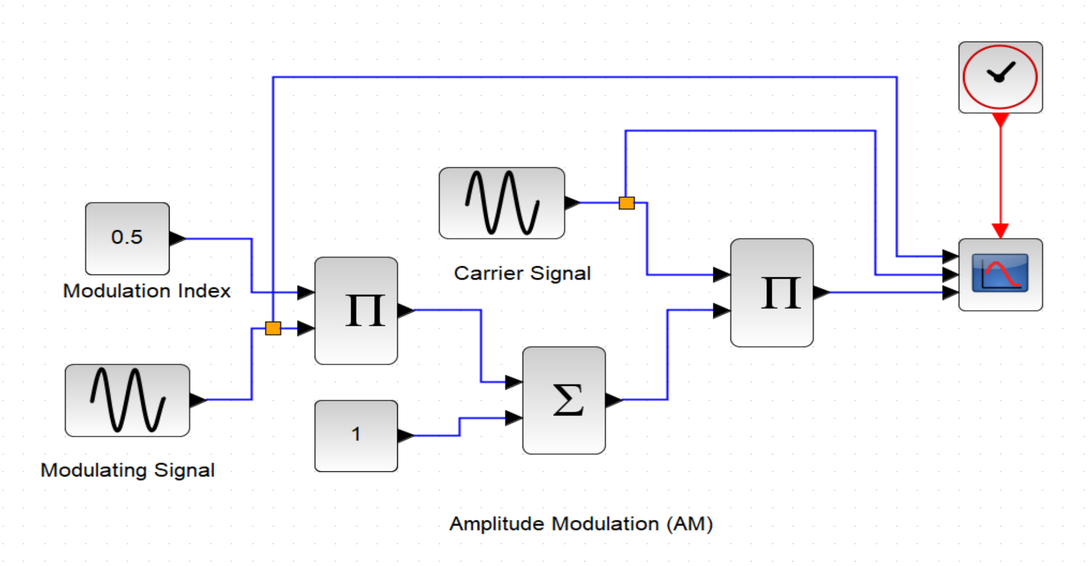


Figure 1: Amplitude Modulator

3.1.2 Frequency Modulation (FM):

Frequency Modulation (FM) is an analog modulation technique where the frequency of the carrier wave is varied in proportion to the instantaneous amplitude of the modulating signal. FM is widely used in FM radio broadcasting (88-108 MHz), television audio, and two-way radio systems due to its superior noise immunity compared to AM.

- **Mathematical Formulation of FM:**

$$S_{FM}(t)=Ac\ cos(2\pi f_c t+2\pi k_f \int m(\tau)\ d\tau)$$

Where, kf = Frequency sensitivity (Hz/volt). The instantaneous frequency $f_i(t)$ of the FM wave is $f_i(t)=fc+k_f\, m(t)$

- **Scilab-Xcos Implementation**

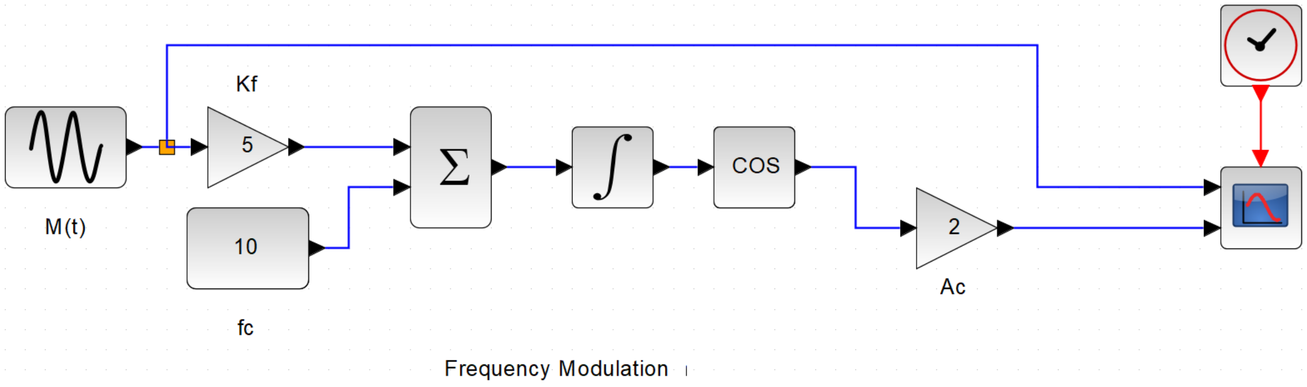


Figure 2: Frequency Modulator

3.1.3 Phase Modulation (PM) :

Phase Modulation (PM) is an analog modulation technique where the phase of the carrier signal is varied in proportion to the instantaneous amplitude of the message signal. While similar to Frequency Modulation (FM), PM has distinct characteristics that make it useful in Wireless, RADAR, and Satellite communications

- **Mathematical Formulation of PM:**

The phase-modulated signal is

$$S_{PM}(t)=Ac\cos(2\pi f_c t + k_p\, m(t))$$

Where, k_p = Phase sensitivity (radians/volt)

- **Scilab-Xcos Implementation**

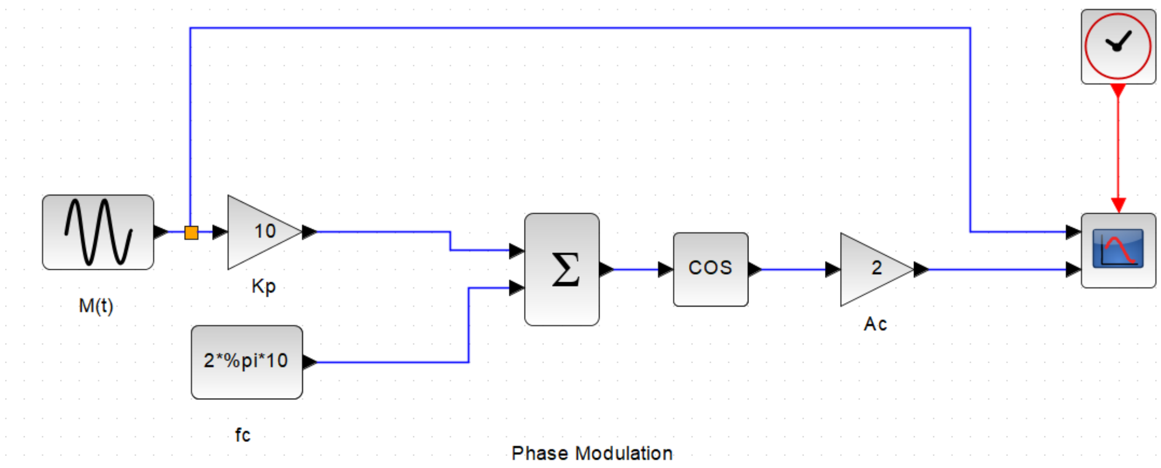


Figure 3: Phase Modulator

3.2 Digital Modulation Techniques:

Digital modulation encodes binary data into analog carrier signals for efficient transmission. Unlike analog modulation (AM/FM/PM), it represents discrete bits (0s and 1s) using variations in amplitude, frequency, or phase.

3.2.1 Amplitude Shift Keying (ASK):

Amplitude Shift Keying (ASK) is a fundamental digital modulation technique where the amplitude of a high-frequency carrier signal is varied to represent binary data (0s and 1s). It is the simplest form of digital modulation and is widely used in optical communications (e.g., fiber optics), RFID tags, and low-cost wireless systems.

$SASK(t)=\{Ac\cos(2\pi fct)$ for bit '1'

0 for bit '0'$\}$

In ASK:

- **Binary '1'**: Carrier signal is transmitted at full amplitude.
- **Binary '0':** Carrier signal is suppressed (zero amplitude).

- **Scilab-Xcos Implementation**

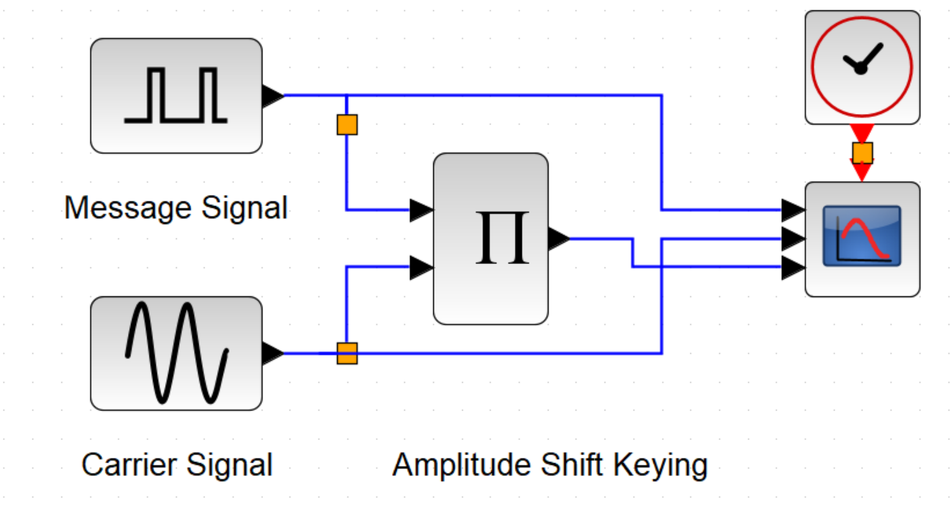


Figure 4: ASK Modulator

3.2.2 Frequency Shift Keying (FSK)

Frequency Shift Keying (FSK) is a digital modulation technique where the frequency of the carrier signal is varied in accordance with the digital input signal while keeping the amplitude and phase constant.

Mathematical Representation of FSK

$$S_{FSK}(t) = \{ Ac \sin(2\pi f_1 t) \text{ for bit '1'} \quad Ac \sin(2\pi f_2 t) \text{ for bit '0'} \}$$

FSK represents binary data by switching between two distinct frequencies:

- **Binary 1** is transmitted as a high-frequency carrier signal (f_1).
- **Binary 0** is transmitted as a low-frequency carrier signal (f_2).

Frequency Deviation (Δf): The difference between the two frequencies.

- **Scilab-Xcos Implementation**

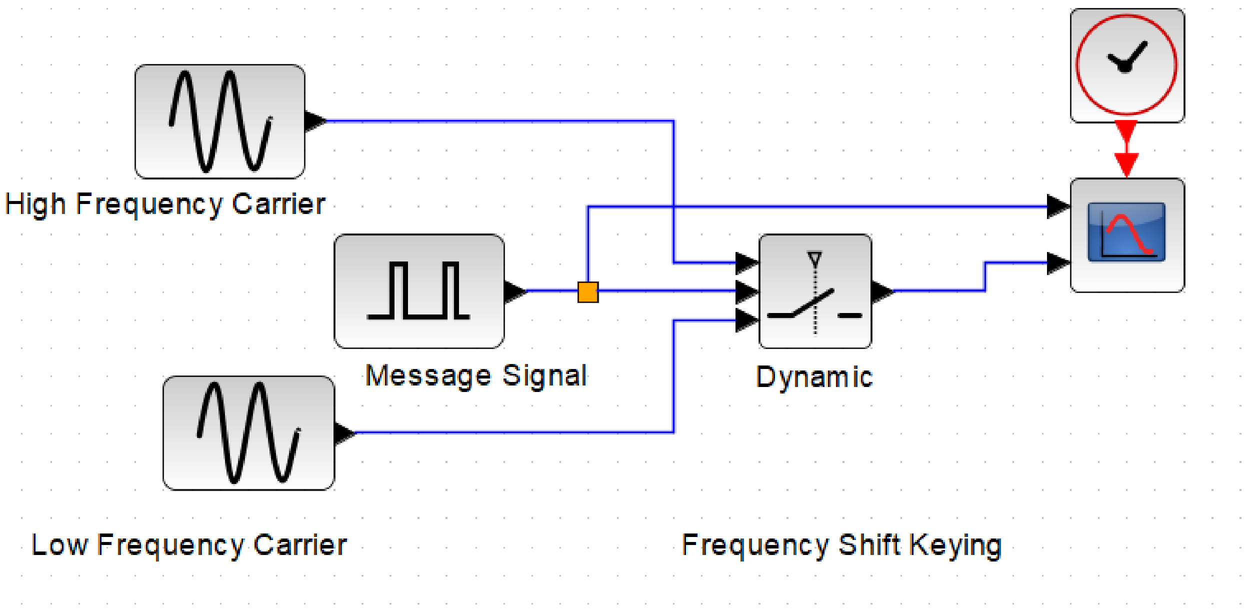


Figure 5: FSK Modulator

3.2.3 Phase Shift Keying (PSK):

Phase Shift Keying (PSK) is a digital modulation technique where the **phase** of the carrier signal is varied to represent digital data while keeping amplitude and frequency constant.

Mathematical Formulation of PSK:

$$S_{PSK}(t) = \{Ac\ \sin(2\pi fct) \text{ for bit '1'} \quad -Ac\ \sin(2\pi fct) \text{ for bit '0'}\}$$

- Uses **two phases (0° and 180°)**. i.e **Binary 1** → One phase (e.g., 0°) and **Binary 0** → Another phase (e.g., 180°)
- **Scilab-Xcos Implementation**

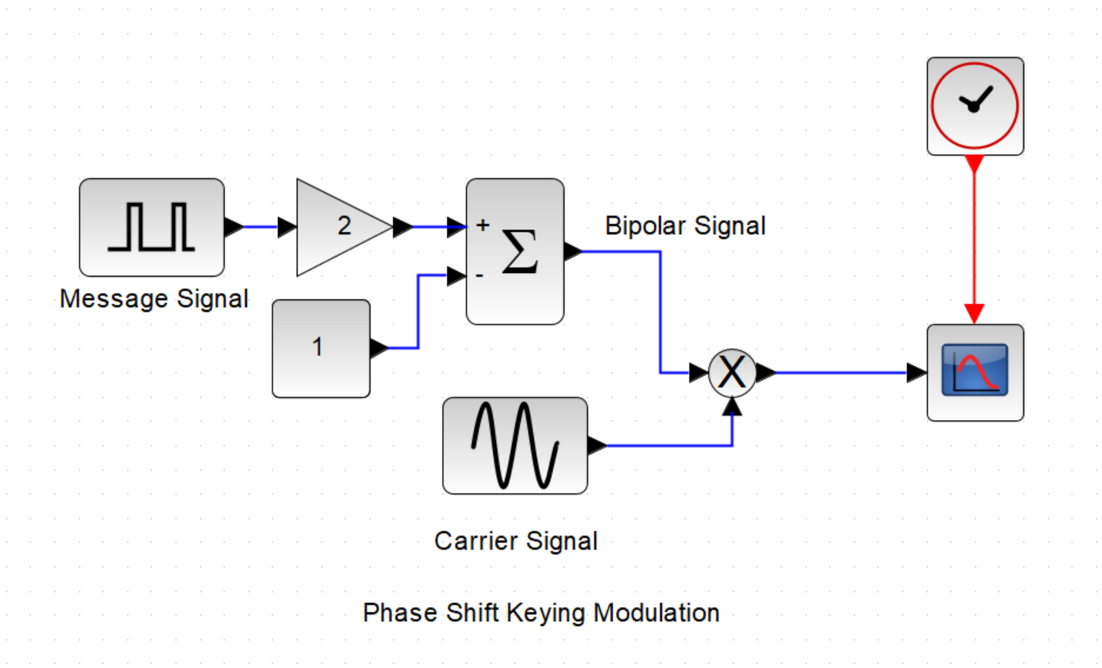
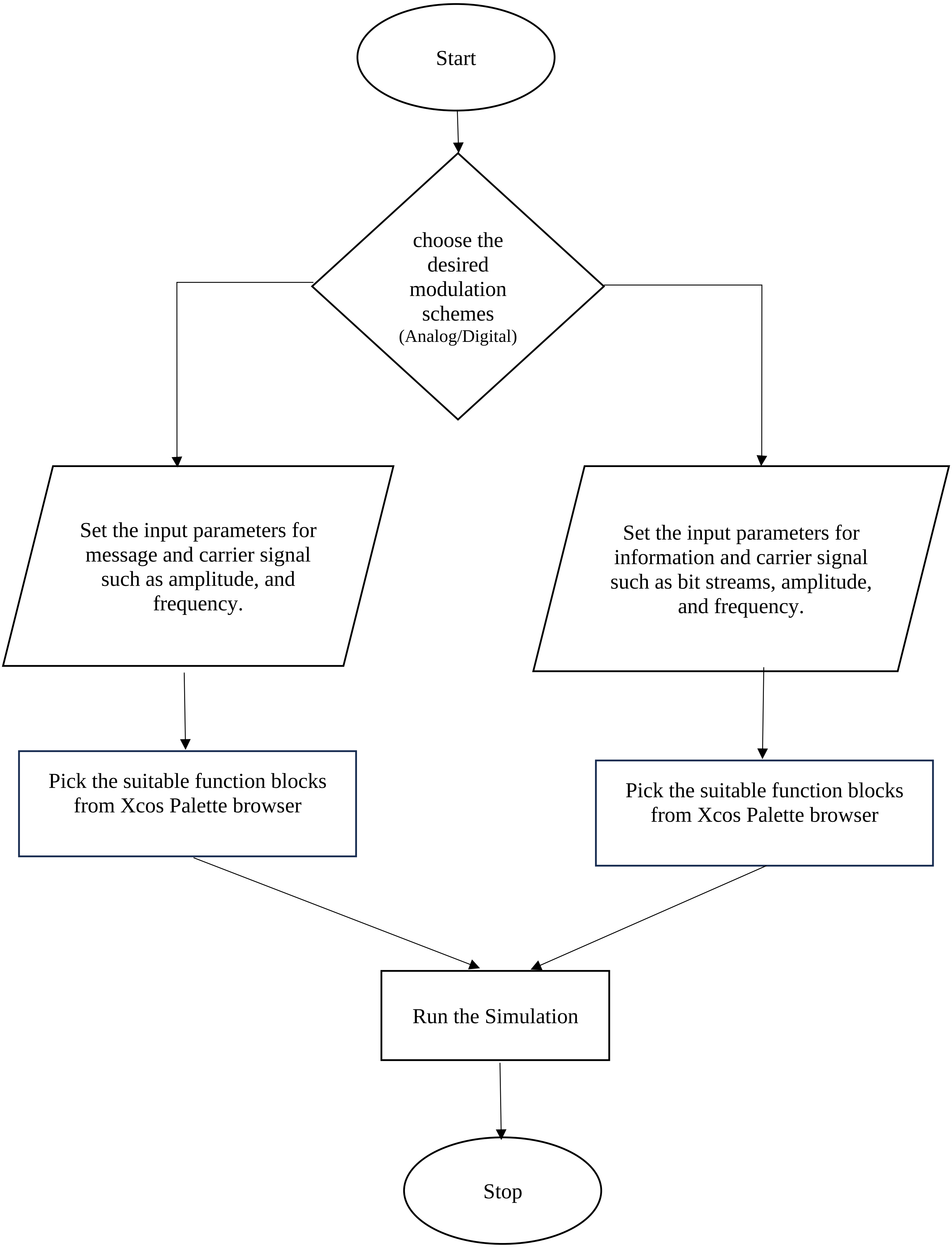


Figure 6: PSK Modulator

4 Flowchart


Start
choose the desired modulation schemes (Analog/Digital)
Set the input parameters for message and carrier signal such as amplitude, and frequency.
Set the input parameters for information and carrier signal such as bit streams, amplitude, and frequency.
Pick the suitable function blocks from Xcos Palette browser
Pick the suitable function blocks from Xcos Palette browser
Run the Simulation
Stop

5 Software/Hardware used

Operating System: Windows 11

Toolbox: None

Hardware: Personal Computer with 12th Gen Intel Core Processor, 16GB RAM

Software: Xcos, Scilab Version: 6.1.1

6 Procedure of Execution

To generate the plots, follow these steps in Scilab-Xcos

• **Step 1:** Launch Scilab on your computer and type xcos in the Scilab console.

• **Step 2:** Load the xcos of your choice named

– “AM.zcos”, (For Amplitude Modulation)
– “FM.zcos”, (For Frequency Modulation)
– “PM.zcos”, (For Phase Modulation)
– “ASK.zcos”, (For Amplitude Shift Keying)
– “FSK.zcos”, (For Frequency Shift Keying)
– “PSK.zcos”. (For Phase Shift Keying)

• **Step 3:** Run the model by selecting the triangular icon of "start" in the toolbar.

• **Step 4:** Observe the result. Each plot will display the simulated behavior. To test different scenarios, modify the system parameters (e.g., amplitude, modulation index, information data, etc) in the respective “zcos” file before running.

7 Results and Discussion

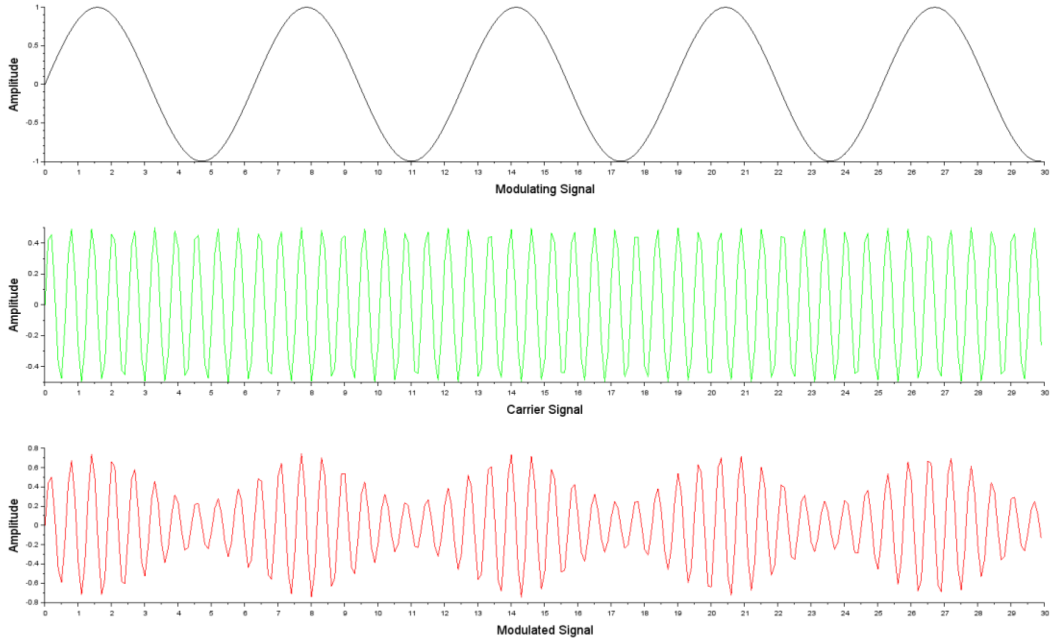


Figure 7: Amplitude Modulated Waveform

Figure 7 illustrates the amplitude modulation (AM) plot, which reveals a direct correlation between the modulating signal, carrier signal, and the resulting modulated signal. As shown in the figure, the frequency of the carrier wave remains constant, but its amplitude changes, creating an envelope that follows the shape of the modulating signal. The depth of modulation depends on the modulation index, μ. For instance, if $\mu = 0.5$, the carrier amplitude varies by 50% above (and below) its unmodulated level, as is shown in the waveform. Further if $\mu = 1$, the modulated amplitude reaches 100%. With 100% modulation, the wave amplitude sometimes reaches zero, and this represents full modulation using standard AM.

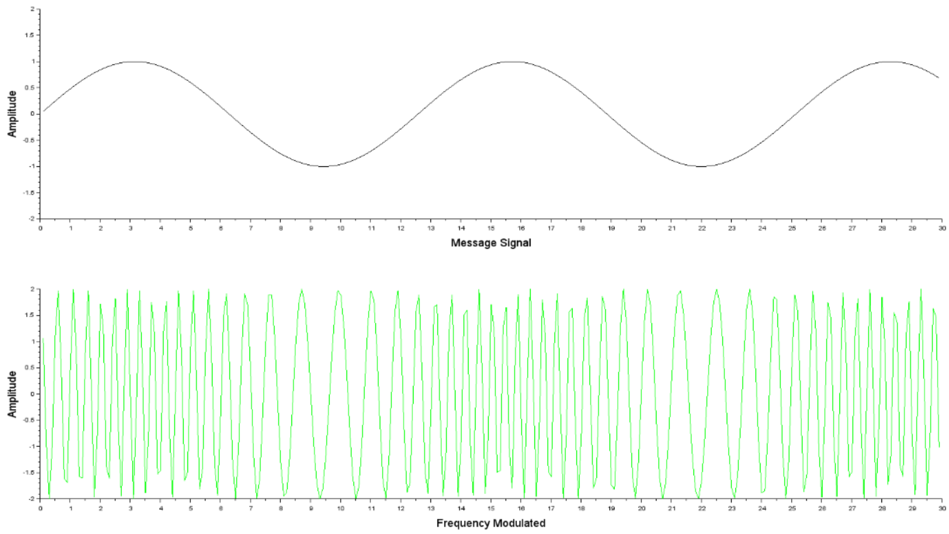


Figure 8: Frequency Modulated Waveform

Figure 8 depicts a frequency-modulated (FM) waveform. FM is characterized by a constant amplitude but a varying frequency that changes proportionately to the modulating signal. The graph illustrates that the FM modulated signal appears to compress and expand, with higher instantaneous frequency where the modulating signal's amplitude is positive and lower instantaneous frequency where it is negative. Unlike AM, the envelope of an FM wave remains flat, but the spacing between peaks (zero crossings) changes dynamically.

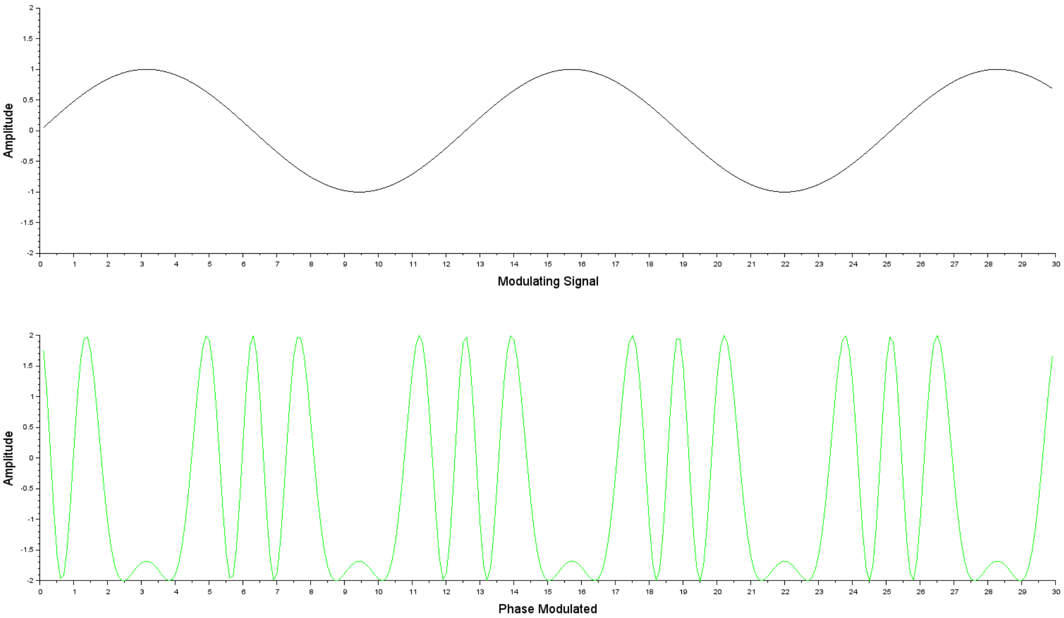


Figure 9: Phase Modulated Waveform

Figure 9 illustrates the phase modulated waveform. PM is a type of angle modulation; hence, unlike FM, where frequency deviations occur, PM directly alters the phase shift of the carrier. Similar to FM, the envelope of a PM signal remains unchanged, making it resilient to amplitude noise.

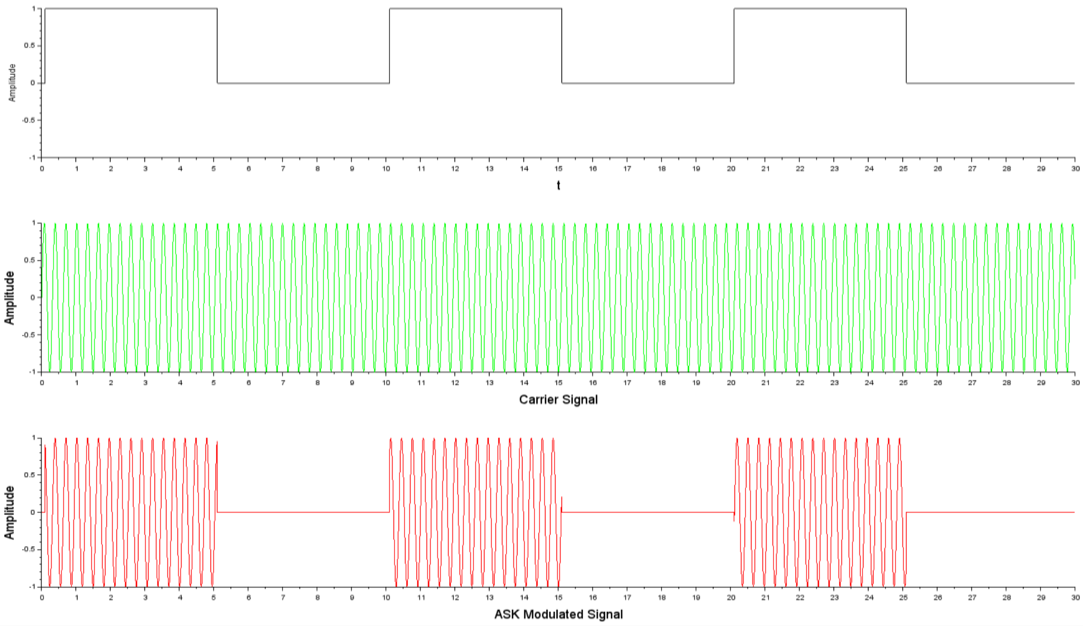


Figure 10: Amplitude Shift Keying Modulated Waveform

Figure 8 illustrates ASK modulated waveform. A binary ASK (BASK), in its simplest form, where a "1" is transmitted as a burst of the carrier wave at a fixed amplitude, while a "0" is represented by the absence of the carrier (or a lower amplitude). The resulting waveform consists of abrupt transitions between "on" and "off" states, creating a discontinuous envelope that mirrors the digital bitstream. Unlike analog AM, ASK is used for digital data transmission, where simplicity and power efficiency are prioritized over robustness in noisy environments.

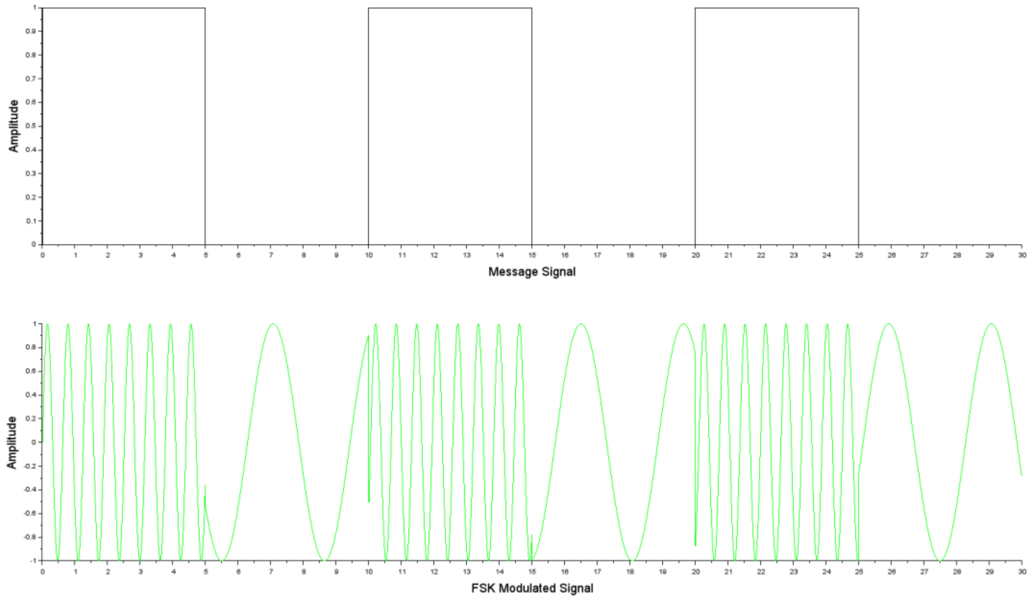


Figure 11: Frequency Shift Keying Modulated Waveform

Figure 11 shows the FSK modulated waveform. In Binary FSK (BFSK), a "1" is transmitted as a high-frequency burst of the carrier, while a "0" is represented by a lower frequency. The resulting waveform shows smooth transitions between frequencies, preserving a constant amplitude but shifting the instantaneous frequency abruptly at each symbol boundary. FSK is more resilient to noise than ASK.

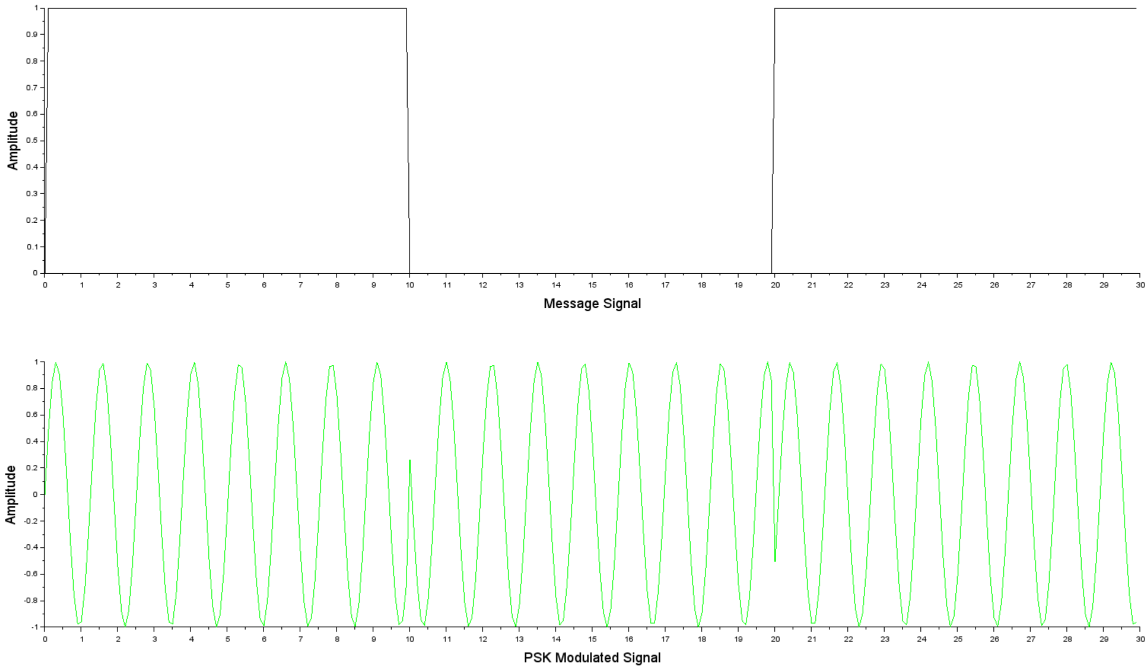


Figure 12: Phase Shift Keying Modulated Waveform

Figure 11 shows the PSK modulated waveform. In Binary PSK (BPSK), a "0" and "1" are distinguished by a 180° phase shift (e.g., 0° for "0" and 180° for "1"), creating abrupt transitions in the waveform where the carrier inverts polarity. The PSK waveform maintains a constant amplitude, but its phase discontinuities appear as sudden "jumps" at symbol boundaries. Unlike ASK or FSK, PSK is highly resistant to noise and interference, as data is encoded in phase differences rather than amplitude or frequency.

8 References

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