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Numerical Analysis of Applied Modulation Techniques from Fundamental Concepts Using MATLAB

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Abstract:

The paper mainly focuses on the Numerical Analysis of Applied Modulation Techniques from Fundamental Concepts Using MATLAB. The research problem in this study is to implement the computerized graphical user interface for communication engineers for advanced modulation techniques for future wireless communication system. The solution for this research problem is to develop the effective software programming with MATLAB. The specific objective of this study is to contribute the Numerical Analysis for researchers of communication system implementation and students from the communication engineering studies. Before studying the advanced modulation techniques, the impulse response signal is a vital role to enhance the development of communication signals in real system design. In this study, the amplitude modulation and frequency modulation techniques are emphasized for software implementation. The specific implementation flowcharts for the design of graphical user interface for advanced modulation techniques. The physical parameters which are used in this study confirm the real applications for future wireless communication system design methodologies. The simulation results from the graphical user interface in this study approve the advanced modulation techniques for experimental studies in communication engineering related fields. The graphical user interface design in this paper has been accomplished with the help of MATLAB environments.

Keywords:

Numerical Analysis, Modulation Techniques, Communication System Design, MATLAB, Simulation Approaches

1. Introduction

Modulation is the important technique to enhance the information signal by using high frequency signals called carrier signal to achieve the modulation signal for communication purposes [1]. There are three fundamental modulation techniques like amplitude modulation, frequency modulation and phase modulation in communication system design. The mathematical expressions on those three modulation methods are clearly stated in fundamental of communication science. Telecommunications comprehends a massive assortment of subdisciplines, and any behavior must incursion a balance between the breadth of treatment and depth in specific areas [2]. An impression with adequate technical detail to facilitate coverage from the physical layer (how the electrical or wireless or optical signal is encoded) over and done with to the exemplification of real-world information (images, sounds) and then to the movement of that data from one point to another and as a final point [3] how to encode information and ensure its secure transmission were introduced in this paper.

The prominence is on operations that can be accomplished on signals, which are important to create telecommunication subsystems such as modulators. It starts from very elementary signal types such as Amplitude Modulation (AM) and proceeds to develop the theory for other types of modulation, toward newer techniques such as Orthogonal Frequency Division Multiplexing (OFDM), and the concept of spread spectrum. It is very important to develop the advanced modulation techniques from the ultimate idea with software approaches [4,5].

The rest of the paper is organized as follows. Section II presents the background theory of the fundamental concepts of modulation techniques with mathematical expressions. Section III mentions the implementation processes based on the flowchart system. Section IV presents the simulation results from the computer aided software design for amplitude modulation and frequency modulation. Section V concludes the simulation analyses in this paper.

1.1. Background Theory

The fundamental concepts to implement the foundation of signal creation are vital role to understand the advanced modulation techniques. The modeling of the signals in mathematical expression is very important to enhance the feature of signals in communication system design.

The mathematical expression for sinc function is expressed in the following equation [6].

$$\text{sinc } \theta = \frac{\sin \theta}{\theta} \tag{1}$$

1.2. Amplitude Modulation Concepts

The carrier as a sinusoidal and the expression is as follows:

$$x_c(t) = A_c \cos\omega_c t \tag{2}$$

Amplitude Modulation was the principal category of modulation reconnoitered traditionally and still discoveries extensive expenditure. It is also used in aggregation with other more progressive types of modulation. At its unpretentious, on–off keying of an antiquated telegraph signal may be well thought-out to be AM, since that is either modulation on ($A_c = A_m$) or modulation off ($A_c = 0$).

The modulation m (t) to be transmitted may hypothetically be any signal, but for the commitments of analysis, it is usual to just use a pure tone sinusoidal signal [7,8].

Mathematically, the resultant modulated waveform is then

$$x_{AM}(t) = m(t)\ _{\cos\omega ct} + Ac \cos\omega_c t \tag{3}$$

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The carrier is suggestively higher in frequency than the modulation – in fact so high, that it would not ordinarily be visible on this scale. Nevertheless, for the purposes of illustration, it is customary to "slow down" the carrier so that a few cycles might be seen. After the maneuver of multiplication of the carrier by the modulation, and then further addition of some of the carrier waveform, the modulated waveform looks as shown. In effect, it basically changes the amplitude of the carrier in response to the amplitude of the modulation. This waveform may be analyzed by principal defining the modulation index as

$$\mu = A_m / A_c \tag{4}$$

Using a fixed-frequency modulation signal,

$$m(t) = A_m \cos\omega_m t \tag{5}$$

the AM signal may then be rearranged to

$$\begin{aligned} x_{AM}(t) &= A_c \cos\omega_c t + A_m \cos\omega_m t \cos\omega_c t \\ &= A_c(1 + \mu \cos\omega_m t) \cos\omega_c t \end{aligned} \tag{6}$$

Note that it doesn't difficulty whether we use sine or cosine for the carrier, since just a phase shift is compulsory. Likewise, overall the modulation signal m (t) will be certain more complex form such as speech, music, or digital data, but all these other signals may be disintegrated into the sum of sine and cosine waves. Figure.1 shows an AM waveform with the covering put on top. Obviously, the covering reflects the modulating signal. What we wish to recuperate (demodulate) is the upper (or lower) covering. The amplitudes marked at V_{max} and V_{min} provide useful information about the waveform and can be associated back to the modulation index.

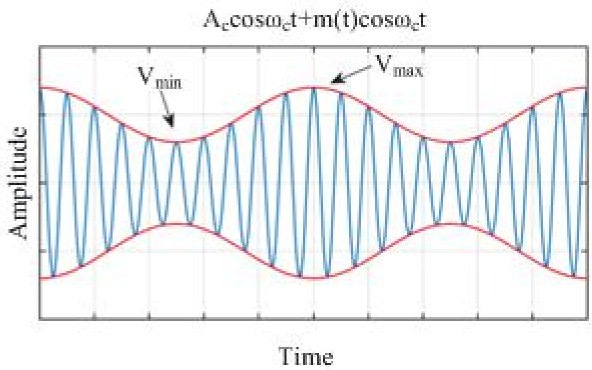

Figure 1. *Standard Amplitude Modulation Waveform.*

When $\cos\omega_m t$ is a maximum, it will equal to +1. At this point, denote the value of $x_{AM}(t)$ as V_{max}. Then we have

$$V_{max} = A_c(1 + \mu) \cos\omega_c t \tag{7}$$

When $\cos\omega_m t$ is a minimum, it will equal to −1. By symmetry, at this point the value of $x_{AM}(t)$ will be denoted as V_{min}. Then we have

$$V_{min} = A_c(1 - \mu) \cos\omega_c t \tag{8}$$

Dividing these two equations at the peak of the carrier (when $\cos\omega_c t = 1$) and solving for μ, we find that

$$\mu = (V_{max} - V_{min})/(V_{max} + V_{min}) \tag{9}$$

Thus, it is possible to determine the modulation index from the waveform measurements. Furthermore, examination of the figure shows that the carrier amplitude is really just the average of the maximum and minimum:

$$A_c = (V_{max} + V_{min})/2 \tag{10}$$

and the modulation amplitude is the average of the difference

$$A_m = (V_{max} - V_{min})/2 \tag{11}$$

The process of AM changes the amplitude of the carrier. The carrier itself is a single, pure tone. Substituting a single-tone modulation m(t) = A_m cosω_mt into the AM generation equation, we have

$$x_{AM}(t) = A_m \cos\omega_m t \cos\omega_c t + A_c \cos\omega_c t \tag{12}$$

The first term is the product of two sinusoids. It is not immediately obvious what frequency components this would produce. However, using the trigonometrical expansion for cos α cos β followed by the substitutions $\alpha \rightarrow \omega_c$t and $\beta \rightarrow \omega_m$t, we end up with

$$\cos\omega_c t \cos\omega_m t = 1/2[\cos(\omega_m t + \omega_c t) + \cos(\omega_m t - \omega_c t)] \tag{13}$$

This sum/difference of cosines is the form we require, and so the AM waveform is

$$x_{AM}(t) = A_c \cos\omega_c t + Am/2 \cos(\omega_c \pm \omega_m)t \tag{14}$$

Manifestly, the spectrum for a fixed amplitude modulating signal m(t) at frequency ω_m results in a frequency component at ω_c with amplitude A_c, as well as at $\omega_c \pm \omega_m$ with amplitude $A_m/2$. The previous is the result of adding the carrier, and the concluding is, circuitously, the result of the multiplication of carrier and modulation. Since $\mu = A_m/A_c$, the amplitude Am⁄2may be reworked as $\mu A_c/2$ – that is, it is proportional to the modulation index μ.

1.3. Frequency Modulation Concepts

In Frequency Modulation (FM), the amplitude of the modulated signal waveform does not alteration. FM demodulation does not rest on the amplitude of the established, modulated signal – and in that lays the essential advantage of FM.

For another possibility to AM, which is sensitive to noise and not very power proficient, it may be helpful to return to the original proposition for modulation. That is, we wish to transmit a signal m (t) by means of a modification in the carrier wave x_c(t):

$$x_c(t) = A_c \cos(\omega_c t + \phi_c) \tag{15}$$

Up to now, in AM only the amplitude A_c of the carrier was transformed and this was made to show a discrepancy with the modulating signal m (t). But from the equation, it is clear that we have other parameters to influence: the frequency ω_c and phase ϕ_c. Since frequency and phase are associated, it is not surprising that the modulation schemes resulting from a change in frequency or phase are also interrelated.

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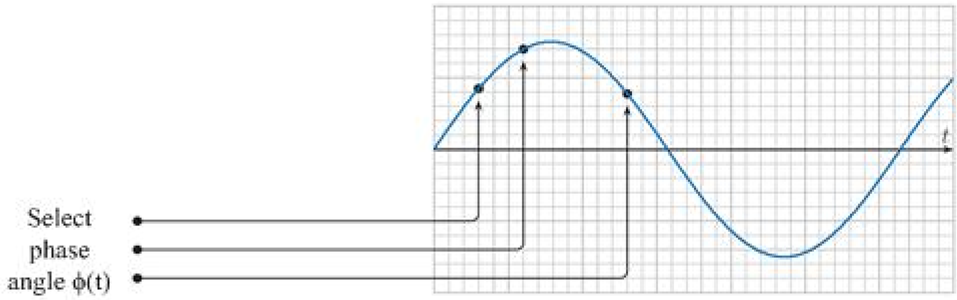

Figure 2. *Engendering a Time Waveform Regarded as Stepping over and done with a Phase Angle.*

Contemplate Figure.2, which shows how we might hypothesize the generation of a time waveform as stepping through the phase angle. As we incrementally step through phase angles, a "lookup" of a sine wave proofs the conforming amplitude. When we reach the end of this sine wave lookup table, we modestly degenerate to the start again, since the waveform is monotonous. The frequency of the wave is administered by how fast we step through the phase angles. Thus, the rate of change of the phase is essentially the frequency. In converse, given a frequency (in radians per second) of a waveform, and a time δt, we can work out how many radians were stepped through in that time period. Thus, amassing or assimilating (summing up) frequency over time tells us the phase. It might be worth noting that theoretically all of the argument of the cosine function – the ($\omega_c t + \phi_c$) part of the appearance – is a phase angle. The exact notation has been deliberated for some time; however conventional usage in telecommunications is to call ϕ the phase angle and to symbolize it as positive or negative according to the problem being conversed. It is also necessary sometimes to refer to the on the spot frequency, since if we keep changing the phase ϕ_c, then the actual frequency is changed either side of ω_c.

Likening the frequency modulated waveform to the carrier, it should be clear that the frequency of the modulated signal is highest when the modulating signal amplitude is prevalent, and the frequency is lowest when the modulating amplitude is nethermost. The frequency matches that of the carrier when the modulating voltage is zero. This is as it should be: the modulation is just elbowing the carrier oscillator up or down.

2. Implementation

The implementation steps for creation of MATLAB functions based on impulse response, amplitude modulation and frequency modulation are expressed in this section.

2.1. Creation of Sinc Function

Figure 3 shows the flowchart of implementation for sinc function in MATLAB environments. At first, the number of samples and maximum time limit were initialized. The "negative" time has to be calculated. The time of zero crossing shall be initialized. The sinc function equation shall be calculated based on the mathematical expressions. The response of sinc function could be displayed in the simulation window.

2.2. Creation of Amplitude Modulation Signal and its Frequency Spectra

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Figure 4 illustrates the flowchart of implementation for amplitude modulation signal. The number of samples and maximum time limit were initialized. The parameters of carrier signal were initialized. The parameters of information signal were initialized.

The amplitude modulation equation was calculated. The response of amplitude modulation signal was displayed.

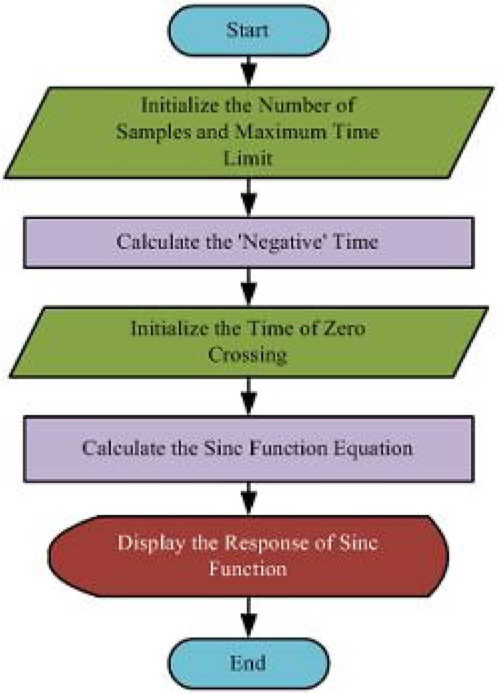

Figure 3. *Flowchart of Implementation for Sinc Function in MATLAB Environments.*

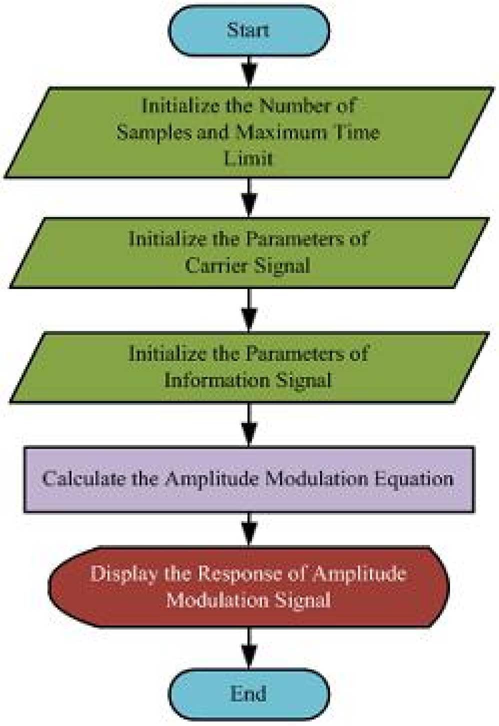

Figure 4. *Flowchart of Implementation for Amplitude Modulation Signal.*

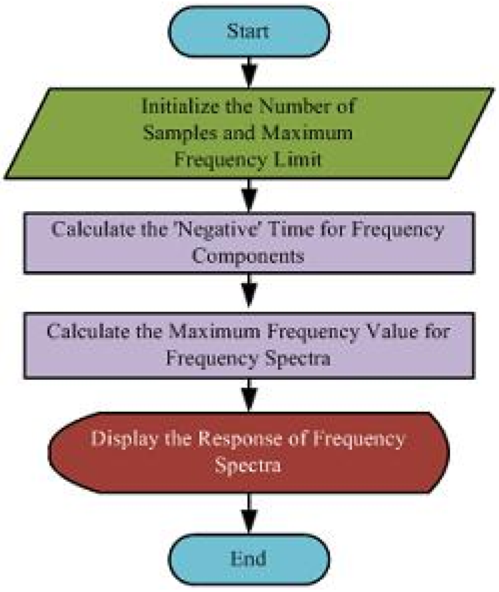

Figure 5. *Flowchart of Implementation for Frequency Spectra.*

Figure 5 demonstrates the flowchart of implementation for frequency spectra. The number of samples and maximum frequency limit were initialized. The "negative" time for frequency components was calculated. The maximum frequency value for frequency spectra was calculated. The response of frequency spectra was displayed.

2.3. Creation of Frequency Modulation Signal

Figure 6 mentions the flowchart of implementation for frequency modulation signal. The number of samples and waveform parameters were initialized. The carrier signal was initialized. The information signal was initialized. The parameters for frequency modulation were initialized. The integral of modulated signal was calculated. The combination with carrier to produce FM was calculated. The first stage of FM demodulation was calculated. The response of frequency modulation signal was displayed.

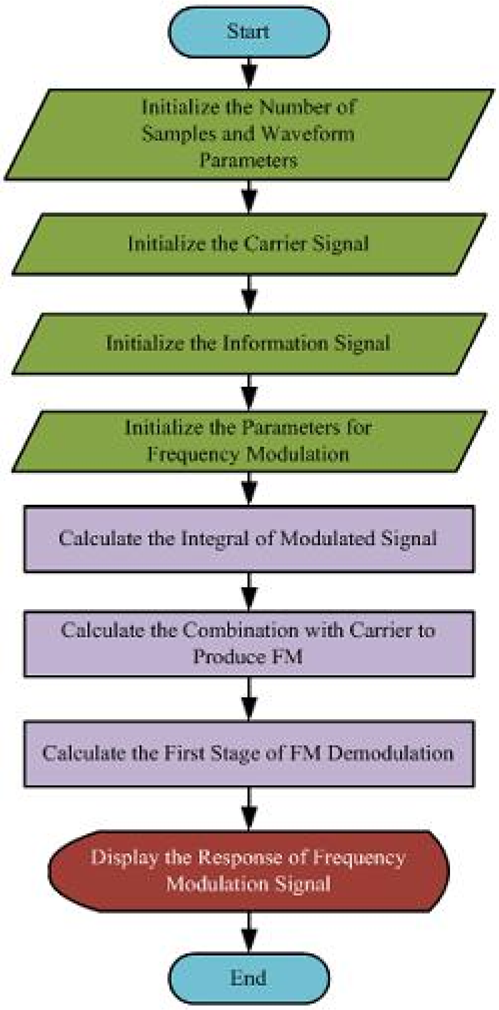

Figure 6. *Flowchart of Implementation for Frequency Modulation Signal.*

3. Results

The simulation design with graphical user interface for implementing the advanced modulation techniques has been completed according to the implementation flowcharts and respective physical parameters. In this analysis, there have been three main steps for simulation methods. The first one is development of impulse response signals for fundamental idea. The second one is to complete the amplitude modulation

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techniques. The last one is to accomplish the frequency modulation techniques. The details implementations are demonstrated in the following sections.

3.1. Results on Impulse Response

The result of sinc function is very fundamental for signal processing approaches. Figure 7 demonstrates the sinc function. The development of the sinc function is started from the impulse response of the signal which was the fundamental idea of constructing the complicated signals from the simple signals in signal processing conepts.

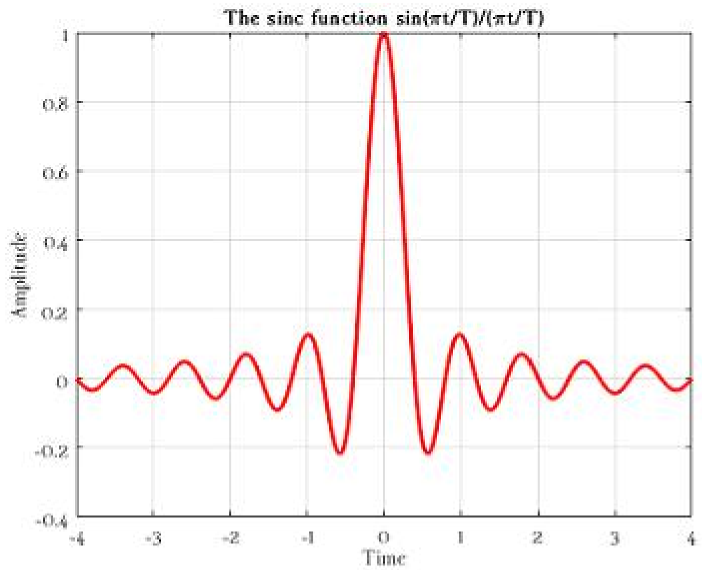

***Figure** 7. The Sinc Function.*

3.2. Results on Amplitude Modulation

Figure 8 (a) shows the amplitude modulation waveform (A_c = 2.0, f_c = 4.0, A_m = 1.0, f_m = 0.4, μ = 0.50), and (b) shows the frequency spectra. Figure.9 (a) illustrates the amplitude modulation waveform (A_c = 2.0, f_c = 4.0, A_m = 0.5, f_m = 0.2, μ = 0.25), and (b) illustrates the frequency spectra. Figure.10 (a) demonstrates the amplitude modulation waveform (A_c = 2.0, f_c = 2.0, A_m = 1.5, f_m = 0.2, μ = 0.75), and (b) demonstrates the frequency spectra. Figure.11 (a) mentions the amplitude modulation waveform (A_c = 2.0, f_c = 4.0, A_m = 2.0, f_m = 0.4, μ = 1.0), and (b) mentions the frequency spectra. Figure.12 (a) expresses the amplitude modulation waveform (A_c = 3.0, f_c = 5.0, A_m = 3.0, f_m = 0.5, μ = 1.0), and (b) expresses the frequency spectra.

The sidebands are separated from the carrier by an amount equal to the modulating frequency. Figures (a) of 8 to 12 show time waveforms with their corresponding frequency spectra. As a result of the mathematical analysis, we now know that the frequency components will consist of the carrier of amplitude A_c, with sidebands either side of the carrier, at frequencies $\omega_c \pm \omega_m$ of amplitude $A_m/2 = \mu A_c/2$. The frequencies come directly from our analysis, where we had cosine terms of the form cos ($\omega_c \pm \omega_m$) t. The frequency spectrum shows the amplitude, so that even if they were negative, the magnitude would be positive.

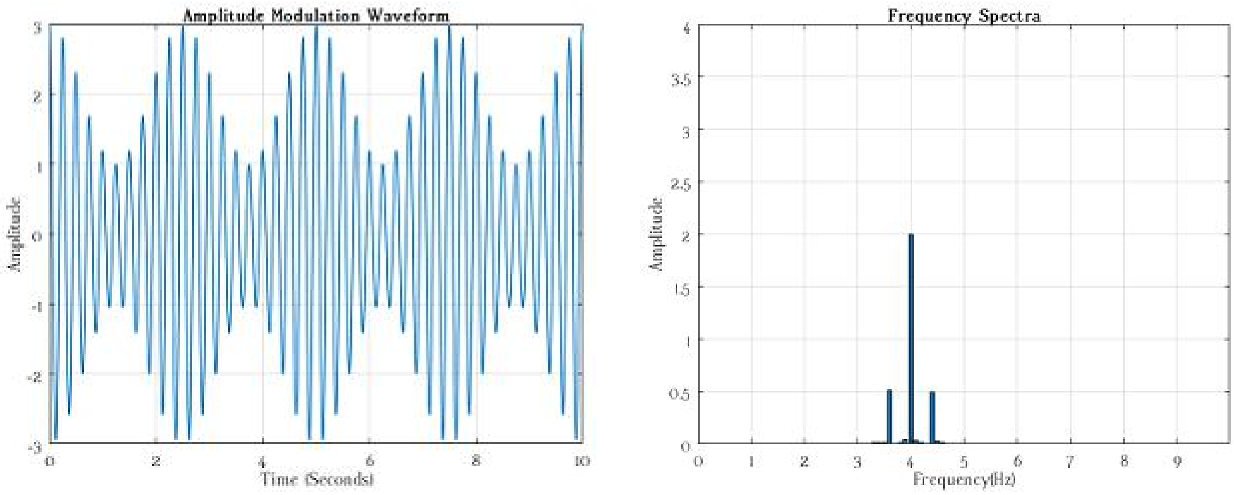

Figure 8. *(a) Amplitude Modulation Waveform (Ac = 2.0, fc = 4.0, Am = 1.0, fm = 0.4, μ = 0.50), (b) Frequency Spectra.*

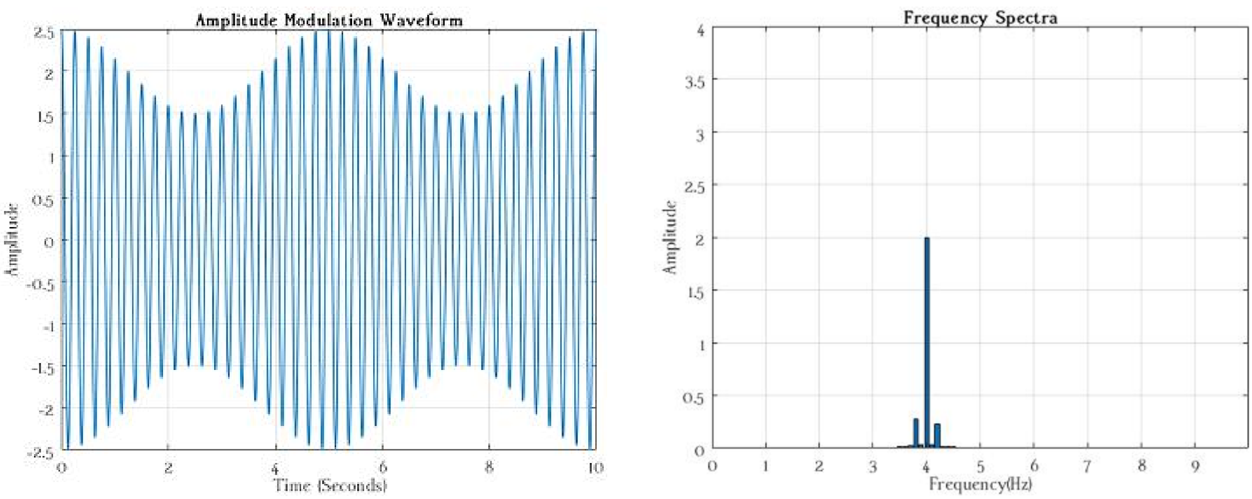

Figure 9. *(a) Amplitude Modulation Waveform (Ac = 2.0, fc = 4.0, Am = 0.5, fm = 0.2, μ = 0.25), (b) Frequency Spectra.*

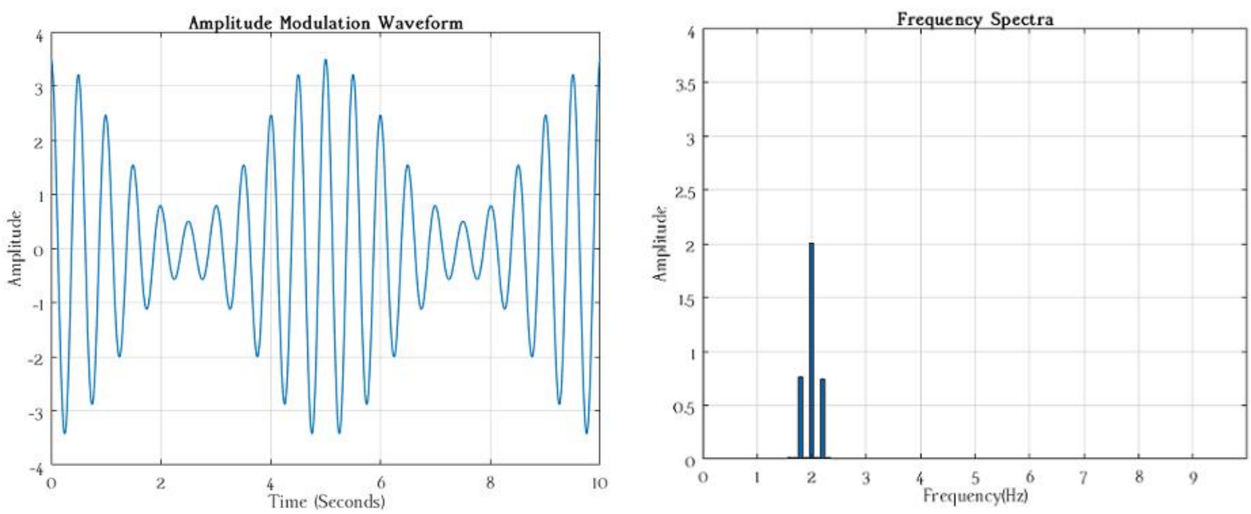

Figure 10. *(a) Amplitude Modulation Waveform (Ac = 2.0, fc = 2.0, Am = 1.5, fm = 0.2, μ = 0.75), (b) Frequency Spectra.*

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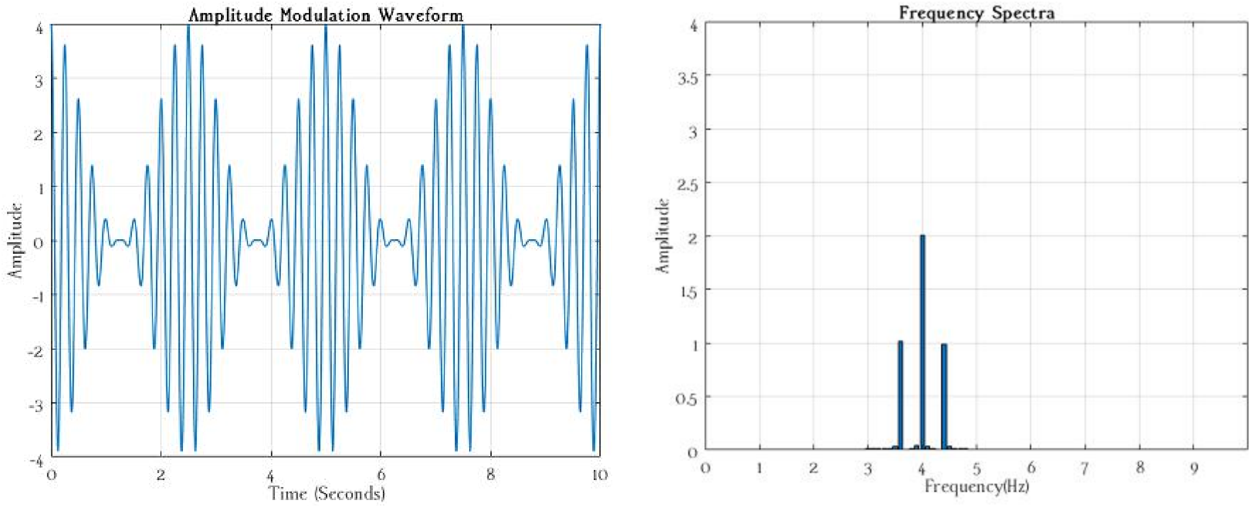

Figure 11. *(a) Amplitude Modulation Waveform (Ac = 2.0, fc = 4.0, Am = 2.0, fm = 0.4, μ = 1.0), (b) Frequency Spectra.*

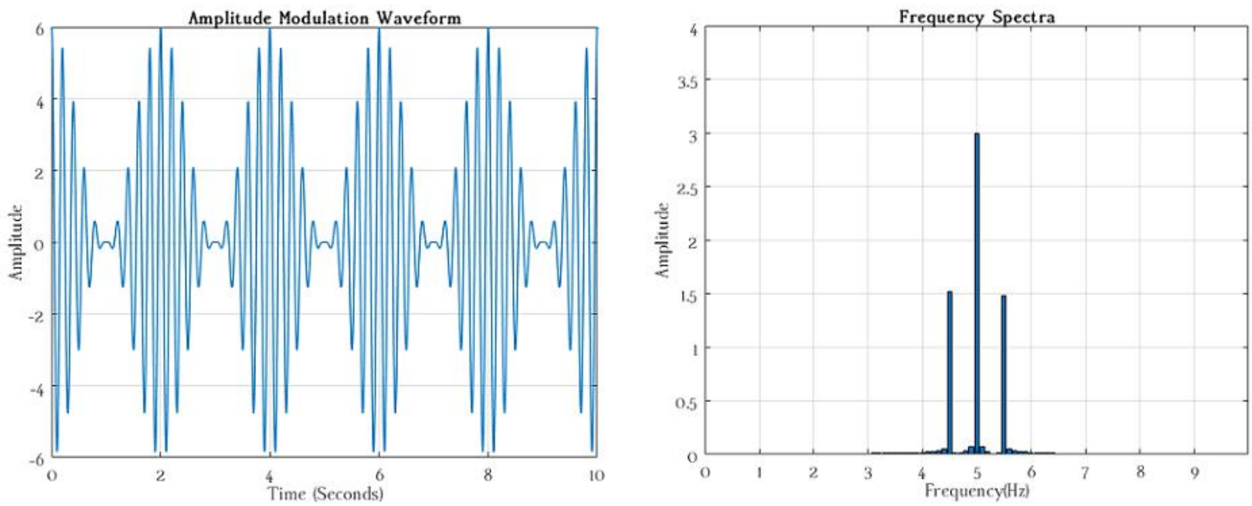

Figure 12. *(a) Amplitude Modulation Waveform (Ac = 3.0, fc = 5.0, Am = 3.0, fm = 0.5, μ = 1.0), (b) Frequency Spectra.*

The two sidebands mean that AM uses a bandwidth effectively twice the modulating frequency. This in turn implies that the bandwidth required is larger than it ought to be and has implications when we have multiple RF channels with different AM signals. Figures (b) of 8 to 12 illustrate this in the frequency domain. Each of the radio channels must be strictly limited in their bandwidths as illustrated, and this in turn places a restriction on the highest frequency that may be modulated onto each channel. We can find and plot the frequency components as follows. The FFT operation shown below converts the time waveform into its corresponding frequency spectrum.

3.3. Results on Frequency Modulation

Figure 13 shows the frequency modulation signal (f_c = 3, f_m = 0.2, A_m = 1, A =2, k_f = 10). Figure.14 illustrates the frequency modulation signal (f_c = 6, f_m = 0.4, A_m = 2, A =4, k_f = 20). Figure.15 demonstrates the frequency modulation signal (f_c = 2, f_m =

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0.1, A_m = 0.5, A =2, k_f = 15). Figure.16 highlights the frequency modulation signal (f_c = 3, f_m = 0.1, A_m = 2.0, A =3, k_f = 10).

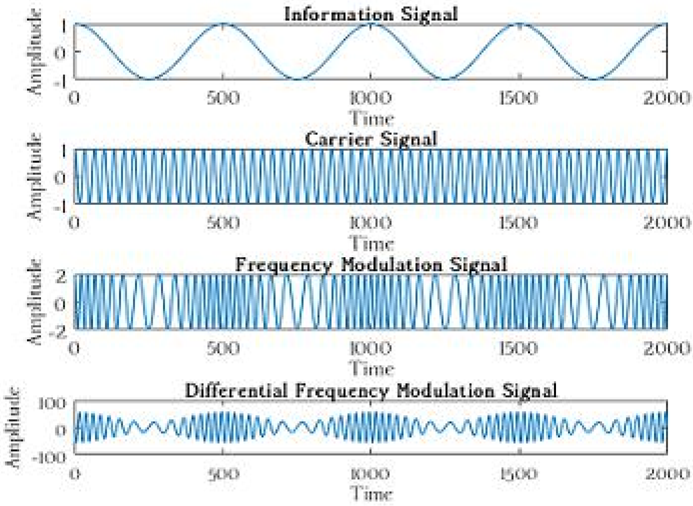

Figure 13. *Frequency Modulation Signal (fc = 3, fm = 0.2, Am = 1, A =2, kf = 10).*

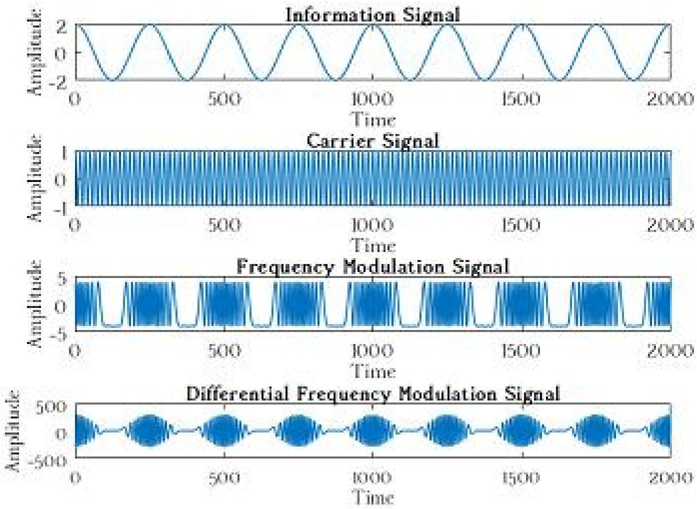

Figure 14. *Frequency Modulation Signal (fc = 6, fm = 0.4, Am = 2, A =4, kf = 20).*

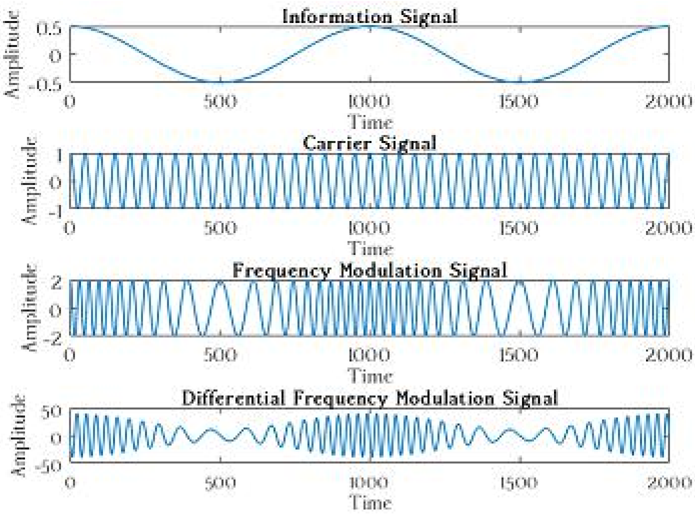

Figure 15. *Frequency Modulation Signal (fc = 2, fm = 0.1, Am = 0.5, A =2, kf = 15).*

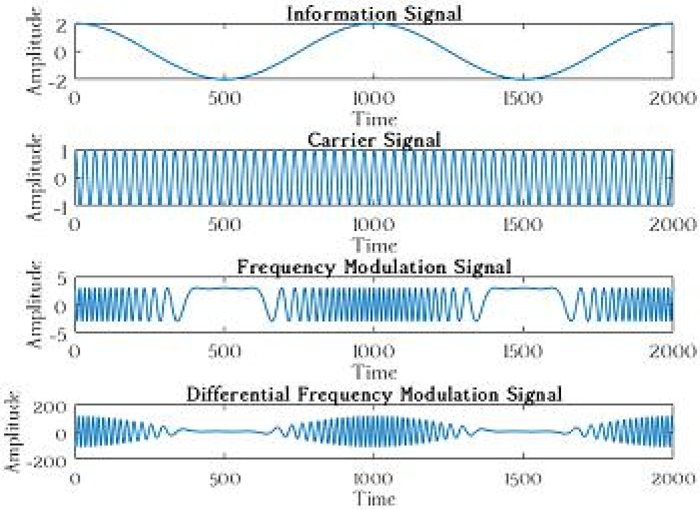

Figure 16. *Frequency Modulation Signal (fc = 3, fm = 0.1, Am = 2.0, A =3, kf = 10).*

4. Conclusion

The amplitude modulation and frequency modulation results in this paper were accomplished to observe the clear condition of communication signal development in reality. The implementation plan or process flowcharts are very important to improve the software-based approaches for modulation techniques. The developed software designs are useful for analyzing the matching condition of the high performance applications. The 100% amplitude modulation index is implemented in this study because the idea condition is necessary for experimental studies. Similarly, the frequency modulation signal could also be improved based on the physical parameters from the systems' requirement. According to the simulation results of sinc function response, amplitude modulation and frequency modulations, the software designers could easily implement the computer aided software by using the mathematical modeling of the targeted system in experimental studies for future development. The specific objective of this study was confirmed to give the idea for implementation of the computer aided software design for researchers of communication system implementation and students from the communication engineering studies.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Author Contributions

This study is mainly focused on the applied modulation techniques for undergraduate students in Electronics and Communication students based on the fundamental concepts with the help of MATLAB language. There have been several literature background ideas for implementing the mathematical modeling of the modulation techniques for experimental studies. This work emphasizes on the numerical analysis to develop the applied modulation techniques such as amplitude modulation and frequency modulation for communication system related subjects. This work could be provided the fundamental concepts with the help of numerical analysis especially computer supported applied design for implementation of mathematical expressions for undergraduate students.

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