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Single-sideband Suppressed-carrier Modulation and Demodulation: Principles, Analysis, Circuits, and Applications

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Abstract: This comprehensive article provides an in-depth exploration of single-sideband (SSB) modulation and demodulation techniques. The article discusses the principles, fundamental methods, and circuits involved in SSB modulation, highlighting its efficiency as an analog amplitude modulation method for long-distance information transmission while effectively utilizing available bandwidth. A comparative analysis of various modulation methods, including conventional amplitude modulation, double-sideband (DSB)modulation, vestigial sideband (VSB) modulation, frequency modulation (FM), phase modulation (PM), and single-sideband (SSB) modulation, is presented. Furthermore, the article delves into the diverse applications of SSB analog amplitude modulation.

Keywords: Analog modulation, Singl-sideband suppressed carrier modulation, Analog communication.

1. Introduction

Modulation, a fundamental concept in communication, plays a crucial role in overcoming the challenges of transmitting information over long distances. In today's fast-paced world, effective communication has become an essential aspect of our daily lives. With a wide range of communication methods available, such as instant messaging, email, video conferencing, and social media platforms, we have the ability to connect and exchange information with others effortlessly [1].

Despite these advancements, transmitting information over long distances can still be problematic, especially when using conventional methods like telegraphs or telephone lines. This is where modulation comes into the picture. Modulation, simply put, is the process of modifying a carrier signal to carry information from the source to the destination. It allows us to encode the message signal onto a carrier signal, enabling efficient and reliable transmission over long distances.

By applying modulation techniques, we can overcome challenges such as signal degradation, interference, and noise that occur during the transmission process. Modulation not only helps to amplify and propagate the signal effectively but also allows for the simultaneous transmission of multiple signals through frequency, phase, or amplitude modulation. This ensures optimal utilization of available bandwidth and enhances the overall efficiency of communication systems[2]. One such modulation technique is single-sideband (SSB) modulation, which has gained recognition for its efficiency and effectiveness in analog amplitude modulation applications.

In this article, we will explore the principles underlying SSB modulation techniques and examine the circuits employed in both modulation and demodulation processes. Additionally, a comparative analysis will be conducted to evaluate the advantages and drawbacks of various analog modulation methods, including conventional amplitude modulation (AM), double-sideband (DSB) modulation, vestigial sideband (VSB) modulation, frequency modulation (FM), and phase modulation (PM).

Furthermore, we will delve into the diverse applications of SSB analog modulation in different fields and industries. From commercial broadcasting to naval communication, SSB has demonstrated its versatility and reliability in transmitting information over long distances with relatively low power consumption [3]. Understanding the applications of SSB modulation will shed light on its practical significance and potential for further advancements in communication technology.

The remainder of this article is structured as follows: Section II introduces the concept of modulation, providing a brief overview of its importance in long-distance communication.

Section III focuses on the principles and theory behind SSB modulation, elucidating its efficiency in analog amplitude modulation. Section IV delves into the circuitry employed for SSB modulation and demodulation, highlighting the engineering aspects of implementing this technique. Section V offers a comparative analysis of SSB modulation and other analog modulation methods, examining their respective strengths and weaknesses. Section VI explores the applications of SSB modulation in various industries and fields. Finally, the article concludes in Section VII with a summary of the key findings and a glimpse into the future potential of SSB analog modulation in the realm of communication.

Through this comprehensive exploration, readers will acquire a deeper understanding of SSB modulation techniques, their practicality, and their significant role in achieving efficient and reliable information transmission over long distances.

2. SSB Modulation Method

Single Sideband (SSB) modulation, also known as Single - sideband Suppressed-carrier (SSB-SC) modulation, is a wireless transmission technology widely used in modern communication systems. In SSB modulation, only one sideband is transmitted along with the carrier signal, which effectively utilizes the bandwidth. There are two well-known methods of SSB modulation - the frequency discrimination SSB modulation method and the phase discrimination SSB modulation method[5].

2.1. Frequency Discrimination

The process of single-sideband (SSB) modulation involves the transmission of either the upper or lower sideband of a double-sideband suppressed carrier (DSB-SC) signal. The generation of a single-sideband signal can be achieved through two distinct types of frequency discrimination methods.

One common method for generating a single-sideband (SSB) signal involves two steps. Firstly, a balanced modulator is employed to produce an intermediate signal containing the suppressed carrier frequency along with both upper and lower sidebands (referred to as the double-sideband or DSB signal). Secondly, a filtering process is applied to the DSB signal to selectively choose either the upper or lower sideband for transmission, effectively generating the desired SSB signal. This process ensures that only one sideband, either the upper or lower, is transmitted while suppressing the carrier and the other sideband.

Figure 1 illustrates the frequency discrimination method used for generating a single-sideband (SSB) signal. In this diagram, the modulated signal is multiplied by the carrier signal, resulting in a double-sideband (DSB) signal. By applying a filter to the DSB signal, one of the sidebands can be removed, effectively obtaining a single-sideband signal at the output. This process ensures that only the desired sideband is transmitted, while the carrier and the other sideband are eliminated.

Mathematically, the message signal is represented as m(t), and the carrier signal is represented as c(t) :

$$m(t) = A_m \cos(2\pi f_m t) \tag{1}$$

$$c(t) = A_c \cos(2\pi f_c t) \tag{2}$$

The expression for the double-sideband (DSB) modulated signal can be given as follows:

$$s_{dsb}(t) = m(t)c(t) \tag{3}$$

Then we have Equation(4).

$$\begin{aligned} s_{dsb}(t) &= A_m A_c \cos(2\pi f_m t) \cos(2\pi f_c t) \\ &= \frac{A_m A_c}{2} \cos[(2\pi f_c + 2\pi f_m) t] \\ &+ \frac{A_m A_c}{2} \cos[(2\pi f_c - 2\pi f_m) t] \end{aligned} \tag{4}$$

After that we can obtain the upper sideband and lower sideband respectively from the above formula of DSB:

$$s_{uSSB}(t) = \frac{A_m A_c}{2} \cos[(2\pi f_c + 2\pi f_m) t] \tag{5}$$

$$s_{lSSB}(t) = \frac{A_m A_c}{2} \cos[(2\pi f_c - 2\pi f_m) t] \tag{6}$$

Then we can obtain :

$$s_{DSB}(t) = s_{uSSB}(t) + s_{lSSB}(t) \tag{7}$$

Expanding (5), we are able to derive Equation 8:

$$\begin{aligned} s_{uSSB}(t) &= \frac{A_m A_c}{2} \cos[(2\pi f_c + 2\pi f_m) t] \\ &= \frac{A_m A_c}{2} [\cos(2\pi f_c t) \cos(2\pi f_m t) \\ &- \sin(2\pi f_c t) \sin(2\pi f_m t) \end{aligned} \tag{8}$$

By expanding Equation 6, we are able to derive Equation 9.

$$\begin{aligned} s_{lssb}(t) &= \frac{A_m A_c}{2} \cos[2\pi (f_c - f_m) t] \\ &= \frac{A_m A_c}{2} [\cos(2\pi f_c t) \cos(2\pi f_m t) \\ &+ \sin(2\pi f_c t) \sin(2\pi f_m t)] \end{aligned} \tag{9}$$

Writing (8) and (9) in compact form,

$$\begin{aligned} &s_{ssb}(t) \\ &= \frac{A_m A_c}{2} [\cos(2\pi f_c t) \cos(2\pi f_m t) \\ &\mp \sin(2\pi f_c t) \sin(2\pi f_m t)] \end{aligned} \tag{10}$$

Equation (10) describes the SSB (single sideband) wave, with the negative sign indicating the upper sideband SSB wave, and the positive sign indicating the lower sideband SSB wave.

In the frequency domain,

$$\begin{aligned} S(f) &= M(f) * C(f) \\ &= \frac{A_m}{2} [\delta(f - f_m) + \delta(f + f_m)] \\ &* \frac{A_c}{2} [\delta(f - f_c) + \delta(f + f_c)] \\ &= \frac{A_m A_c}{4} [\delta(f - f_c - f_m) \\ &+ \delta(f - f_c + f_m) \\ &+ \delta(f + f_c - f_m) \\ &+ \delta(f + f_c + f_m)] \end{aligned} \tag{11}$$

upper sideband : $f = f_c + f_m$ and $f = -f_c - f_m$

lower sideband : $f = f_c - f_m$ and $f = -f_c + f_m$

We use a filter to remove the portion of the sideband that contains duplicate information, and only keep either the upper or lower sideband.

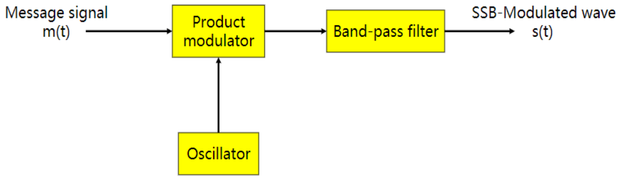

Figure 1. The diagram of the frequency discrimination method

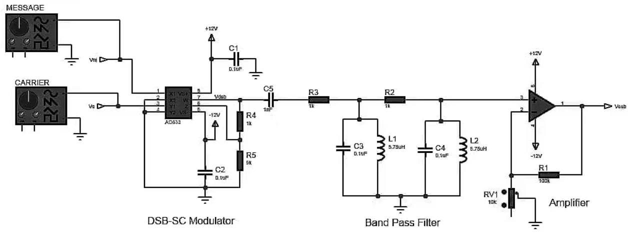

Figure 2. The modulator circuits with frequency discrimination method

2.2. Phase Discrimination

In SSB modulation Phase discrimination method, two DSB signals are generated which are out of phase and summer or subtracter circuit is used to either produce upper or lower sideband SSB signal. The diagram of phase discrimination SSB modulation is shown in the figure:3 Wide-band phase-shifter is designed to produce the Hilbert transform in response to the incoming message signal. To interfere with the in-phase path so as to eliminate power in one of the two sidebands, depending on whether upper SSB or lower SSB is the requirement. According to equation (10), we can also rewrite $s_1(t)$ as follows:

$$\begin{aligned} s_1(t) &= \frac{A_mA_c}{2}\left[\cos\left(2\pi f_c t\right)\cos\left(2\pi f_m t\right)\right. \\ &\left.\mp\sin\left(2\pi f_c t\right)\sin\left(2\pi f_m t\right)\right] \\ &= \frac{A_mA_c}{2}\left[\cos\left(2\pi f_c t\right)\cos\left(2\pi f_m t\right)\right. \\ &\left.\mp\sin\frac{A_mA_c}{2}\left(2\pi f_c t\right)\sin\left(2\pi f_m t\right)\right] \end{aligned} \tag{12}$$

The Hilbert transform of the signal m(t) can be considered as the convolution of m(t) and the impulse response $\frac{1}{\pi t}$. Therefore, it can be interpreted as a wideband phase shift filter, characterized by its transfer function expressed as follows:

$$H(f) = -jsgn(f) \tag{13}$$

By using Hilbert transform of message signal m(t) = Am cos (2πfmt) ,we have

$$\hat{m}(t) = A_m\sin\left(2\pi f_m t\right) \tag{14}$$

$$\begin{aligned} s_{ssb}(t) &= \frac{A_c}{2}\cos\left(2\pi f_c t\right)m(t) \\ &\mp\frac{A_c}{2}\hat{m}(t)\sin\left(2\pi f_c t\right) \end{aligned} \tag{15}$$

Similarly, the carrier signal is a 90-degree phase shifted using the passive phase shifter circuit and we have

$$\hat{c}(t) = A_c\sin\left(2\pi f_c t\right) \tag{16}$$

Then $\hat{c}(t)\hat{m}(t) = A_cA_m \sin(2\pi f_c t)\sin(2\pi f_m t)$ is obtained which can also be represented by Equation:17.

$$\begin{aligned} \hat{c}(t)\hat{m}(t) &= \frac{A_mA_c}{2}\left[\cos\left(2\pi f_c t - 2\pi f_m t\right)\right. \\ &\left.-\cos\left(2\pi f_c t + 2\pi f_m t\right)\right] \end{aligned} \tag{17}$$

According to Equation 4 and Equation 17, we can derive the expressions for lower sideband SSB(Equation18) and upper sideband SSB (Equation19):

$$\begin{aligned} s_l(t) &= \frac{A_mA_c}{2}\cos\left[\left(2\pi f_c + 2\pi f_m\right)t\right] \\ &+\frac{A_mA_c}{2}\cos\left[\left(2\pi f_c - 2\pi f_m\right)t\right] \\ &+\frac{A_mA_c}{2}\left[\cos\left(2\pi f_c t - 2\pi f_m t\right)\right. \\ &\left.-\cos\left(2\pi f_c t + 2\pi f_m t\right)\right] \end{aligned} \tag{18}$$

$$\begin{aligned} s_u(t) &= \frac{A_mA_c}{2}\cos\left[\left(2\pi f_c + 2\pi f_m\right)t\right] \\ &+\frac{A_mA_c}{2}\cos\left[\left(2\pi f_c - 2\pi f_m\right)t\right] \\ &-\frac{A_mA_c}{2}\left[\cos\left(2\pi f_c t - 2\pi f_m t\right)\right. \\ &\left.-\cos\left(2\pi f_c t + 2\pi f_m t\right)\right] \end{aligned} \tag{19}$$

If an adder circuit is employed, the equation for the lower sideband (SSB) modulated signal, $s_l(t)$, can be expressed as Equation 18:

$$\begin{aligned} s_l(t) =&\frac{A_mA_c}{2}\left[\cos\left(2\pi f_c t + 2\pi f_m t\right)\right. \\ &\left.+\cos\left(2\pi f_c t - 2\pi f_m t\right)\right] \\ &+\frac{A_mA_c}{2}\left[\cos\left(2\pi f_c t - 2\pi f_m t\right)\right. \\ &\left.-\cos\left(2\pi f_c t + 2\pi f_m t\right)\right] \\ &= A_mA_c\cos\left(2\pi f_c t - 2\pi f_m t\right) \end{aligned} \tag{20}$$

If a subtractor circuit is utilized, the equation for the upper sideband (SSB) modulated signal, u(t), can be represented as Equation 19:

$$
\begin{aligned}
s_u(t) = &\frac{A_m A_c}{2}\left[\cos\left(2\pi f_c t + 2\pi f_m t\right)\right. \\
&\left.+ \cos\left(2\pi f_c t - 2\pi f_m t\right)\right] \\
&- \frac{A_m A_c}{2}\left[\cos\left(2\pi f_c t - 2\pi f_m t\right)\right. \\
&\left.- \cos\left(2\pi f_c t + 2\pi f_m t\right)\right] \\
&= A_m A_c \cos\left(2\pi f_c t + 2\pi f_m t\right)
\end{aligned}
\tag{21}
$$

In the frequency domain, input the spectrum of m(t) into H(f) and output $\widehat{M}$ (f), that means Equation22

$$
\begin{aligned}
\hat{M}(f) &= M(f)H(f) \\
&= -j\frac{A_m}{2}[\delta(f - f_m) \\
&+ \delta(f + f_m)]sgn(f)
\end{aligned}
\tag{22}
$$

As we can see from $\widehat{M}$(f)that the amplitude of frequency -f_m of $\widehat{M}$(f) is inversed

by Hilbert transform, and the amplitude of frequency fm is the same with that in M(f).

After the carrier wave c(t) = $A_c\cos(2\pi f_c t)$ is input into -90 degree phase shifter, $A_c\sin(2\pi f_c t)$ is obtained and then is multiplied by$\widehat{m}$(t), that means $A_c A_m \sin(2\pi f_m t)\sin(2\pi f_c t)$ in the time domain whose spectrum is

$$
\begin{aligned}
&\frac{A_c}{2j}[\delta(f - f_m) - \delta(f + f_m)] * \frac{A_m}{2j}[\delta(f - f_c) \\
&- \delta(f + f_c)] \\
&= \frac{-A_m A_c}{4}[\delta(f - f_m) - \delta(f + f_m)] * [\delta(f - f_c) \\
&- \delta(f + f_c)] \\
&= \frac{-A_m A_c}{4}[\delta(f - f_c - f_m) - \delta(f - f_c + f_m) \\
&- \delta(f + f_c - f_m) + \delta(f + f_c + f_m)]
\end{aligned}
\tag{23}
$$

Now, let's go back to the Equation(11), if Equation11 abstract Equation23, we have the upper sideband:

$$
\frac{A_m A_c}{2}[\delta(f - f_c - f_m) + \delta(f + f_c + f_m)] \tag{24}
$$

, where the frequency is $f_c + f_m$

If Equation11 plus Equation23, we have the lower sideband:

$$
\frac{A_m A_c}{2}[\delta(f - f_c + f_m) + \delta(f + f_c - f_m)] \tag{25}
$$

, where the frequency is $f_c - f_m$.

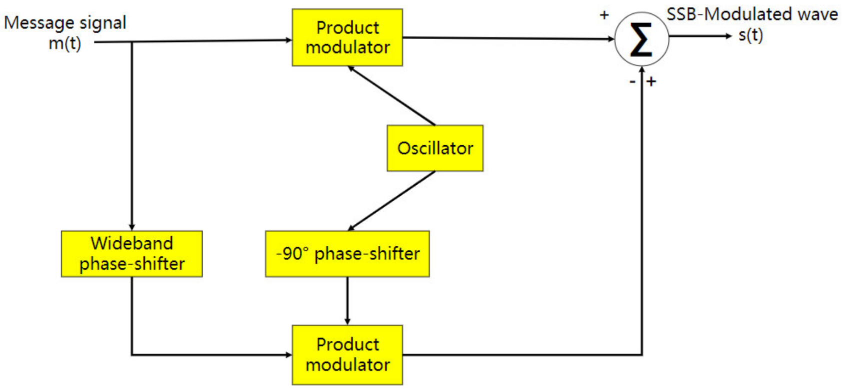

Figure 3. The diagram of the phase discrimination method

3. SSB Demodulatio Method

Single Side Band Suppressed Carrier demodulation is the process of recovering the message signal from an SSB-modulated waveform. For SSB modulated signal, we can apply coherent detection including multiplicative coherent detection and additive coherent detection to demodulate the signal[6]. In this section, how to demodulate an SSB modulated signal to recover the message signal with Multiplicative Coherent Detection is focused on and Additive Correlation Detection is also simply explained.

Coherent detection is a demodulation approach where the frequency of the local oscillator signal generated on an AM receiver is synchronized with the carrier signal frequency. Put simply, for accurate reproduction of the original information, the signal generated at the receiver for demodulation needs to have the same frequency and phase as the carrier signal used during modulation. Any mismatch in frequency or phase can result in demodulation distortion, making it impossible to accurately reproduce the original message signal. To ensure synchronization between the demodulated signal and carrier signal, phase-locked loops and other techniques are commonly employed at the receiver.

The diagram multiplicative coherent detection is illustrated in Figure:4. Multiplying the modulated signal s(t) by the carrier wave c(t) produces wave r(t) indicated from Equation 28 to Equation 30.

$$
s(t) = cos(2\pi f t)m(t) \mp \hat{m}(t)sin(2\pi f t) \tag{26}
$$

$$
c(t) = cos(2\pi f t) \tag{27}
$$

$$
r(t) = s(t)c(t) \tag{28}
$$

$$\begin{aligned} r(t) &= [cos(2\pi ft)m(t) \\ &\mp \hat{m}(t)sin(2\pi ft)]cos(2\pi ft) \\ &= [cos^2(2\pi f_c t)m(t) \mp \hat{m}(t)sin(2\pi f_c t)cos(2\pi f_c t)] \end{aligned} \tag{29}$$

$$\begin{aligned} r(t) = \frac{1}{2}m(t) + \frac{1}{2}m(t)cos(4\pi f_c t) \\ \mp \frac{1}{2}\hat{m}(t)sin(4\pi f_c t) \end{aligned} \tag{30}$$

As we can see from Equation30, f_c is high frequency and it exists in the second term and last term, so we can remove the term which contains f_c by low pass filter. After that we can get the first term $\frac{1}{2}$m(t), then an operational amplifier should be applied to recover the magnitude of message signal m(t).

In the frequency domain,

$$\begin{aligned} S(f) = \frac{A_m A_c}{4}[\delta(f - f_c - f_m) + \delta(f - f_c \\ + f_m) + \delta(f + f_c - f_m) + \delta(f + f_c + f_m)] \end{aligned} \tag{31}$$

Multiplying Equation:31 S(f) by $\frac{A_c}{2}[\delta(f - f_c) + \delta(f + f_c)]$ that is the spectrum of carrier wave $A_c cos(2\pi f_c t)$ and we have Equation:32.

Equation 32 exhibits four frequency components: $-2f_c + f_m$, $2f_c - f_m$, f_m, and $-f_m$. After undergoing low-pass filtering, only f_m and $-f_m$ are reserved, which means the m(t)'s frequency component is recovered successfully.

$$\begin{aligned} R'(f) = \frac{A_c^2 A_m}{8}[\delta(f - f_m) + \delta(f + f_m) \\ + \delta(f - 2f_c + f_m) + \delta(f + 2f_c - f_m)] \end{aligned} \tag{32}$$

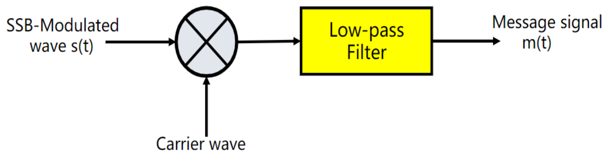

Figure 4. The diagram of multiplicative coherent detection

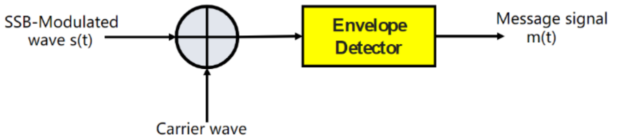

Figure 5. The diagram of additive coherent detection

The diagram for additive coherent detection is illustrated in Figure5. This technique involves adding a local carrier wave to the SSB-modulated signal, resulting in a signal that closely resembles a conventionally AM modulated signal with carrier wave components. Subsequently, enveloping detection can be applied to demodulate this similar conventional AM-modulated signal.

4. Matlab Experiments

This section details the implementation of an experiment that performs SSB modulation and demodulation with MATLAB. Modulation with Frequency Discrimination and Demodulation with Multiplicative Coherent Detection are employed in this experiment. The message signal is m(t) = $A_m sin(2\pi f_m t)$ with f_m = 2Hz and A_m = 1V . The carrier wave is c(t) = $A_c sin(2\pi f_c t)$ with f_c = 20Hz and A_c = 2V .

4.1. SSB Modulation Experiment with Frequency Discrimination

The spectral and waveform characteristics of both the carrier wave and double-sideband (DSB) wave can be observed in Figure 6. The DSB wave is generated by modulating the message signal onto the carrier wave through multiplication.

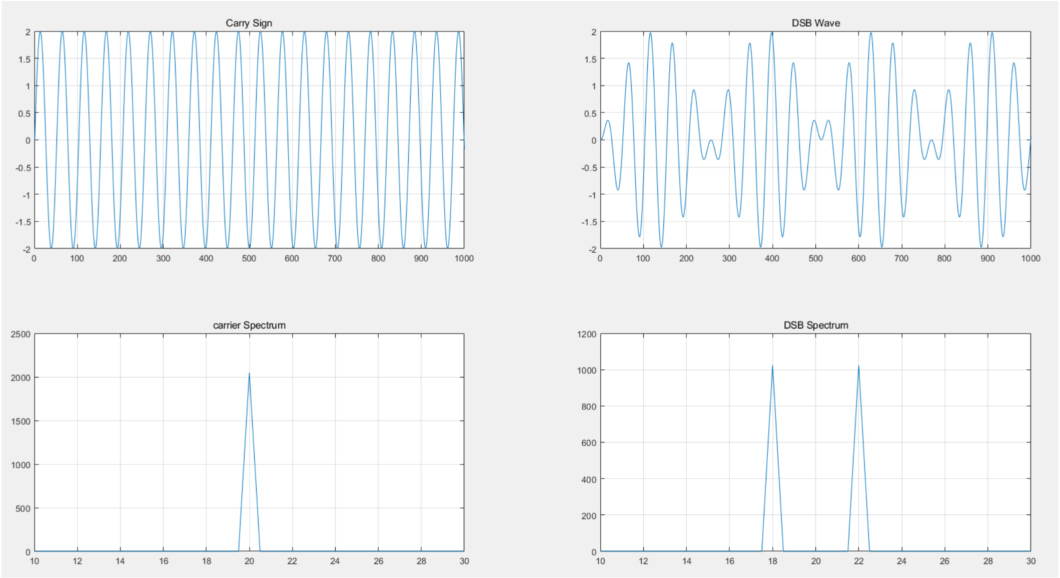

Figure 6. The spectrum and waveform of the carrier wave and DSB wave

The Ellipse low pass filter and high pass filter are both demonstrated in Figure:7. After applying the Ellipse low pass filter and high pass filter, the generated DSB signal is split into two components: the lower sideband (LSSB) and the upper sideband (USSB). The LSSB contains only the signals that were originally below the carrier frequency, while the

USSB contains only the signals that were originally above the carrier. Both of these sidebands have a bandwidth equal to the original message signal, and both their spectrum and waveform are shown in Figure:8. By removing the unwanted sideband, the desired single sideband (SSB) signal is obtained, which means the process of modulation is accomplished.

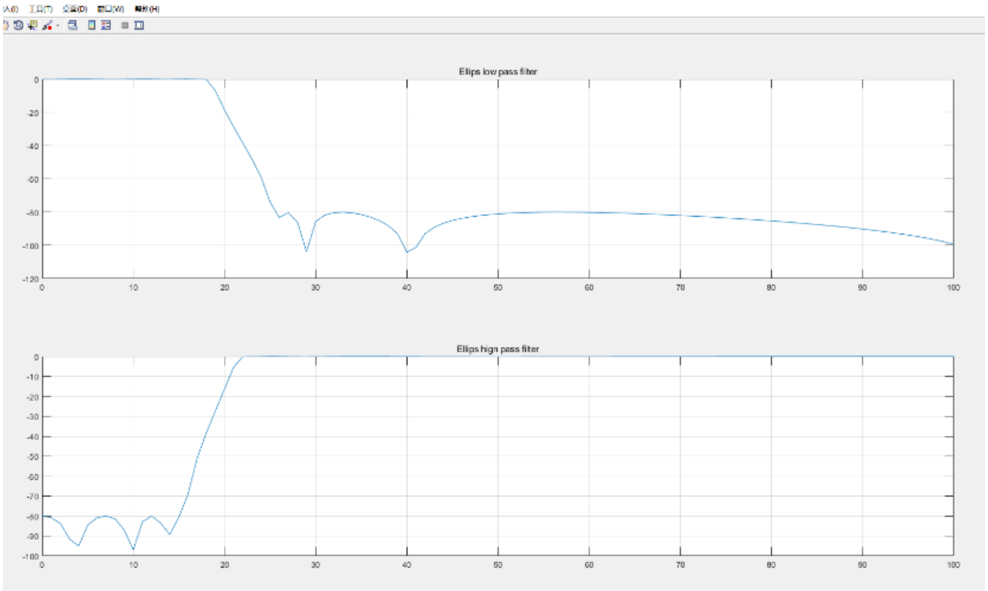

Figure 7. The lower sideband and the upper sideband

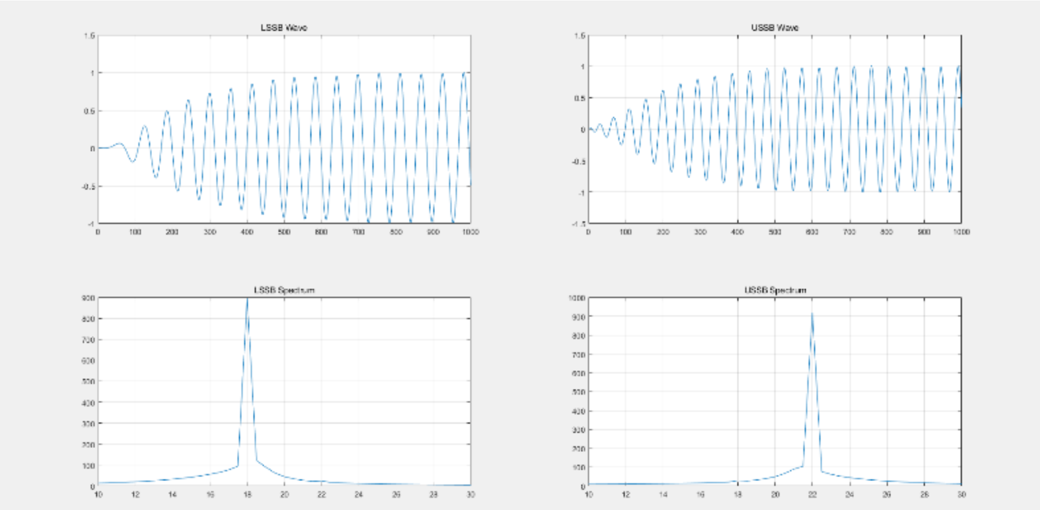

Figure 8. The lower sideband and the upper sideband

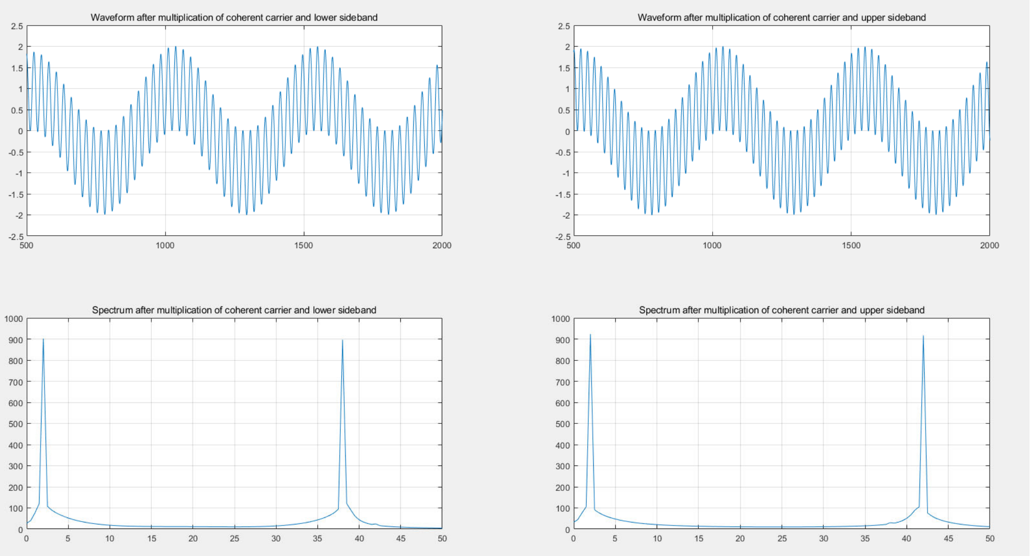

Figure 9. Demodulation by employing product modulator

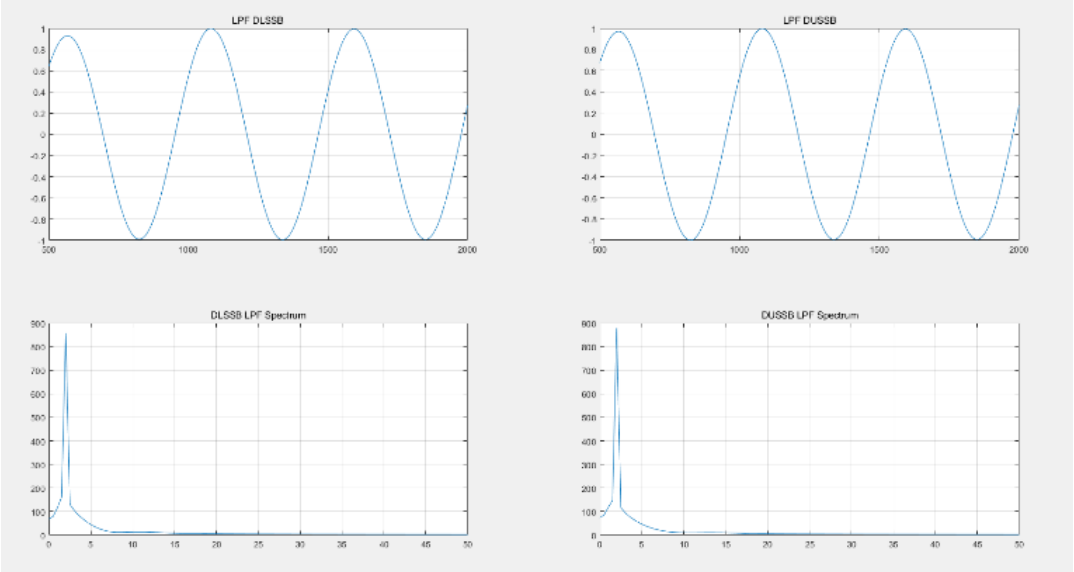

Figure 10. Demodulation by employing LPF

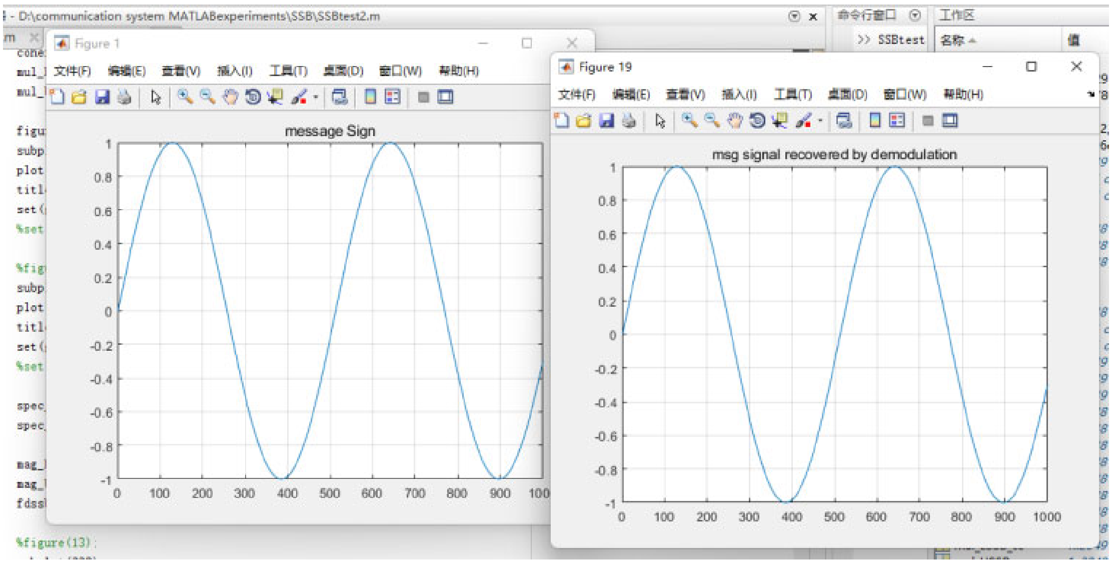

Figure 11. Comparison

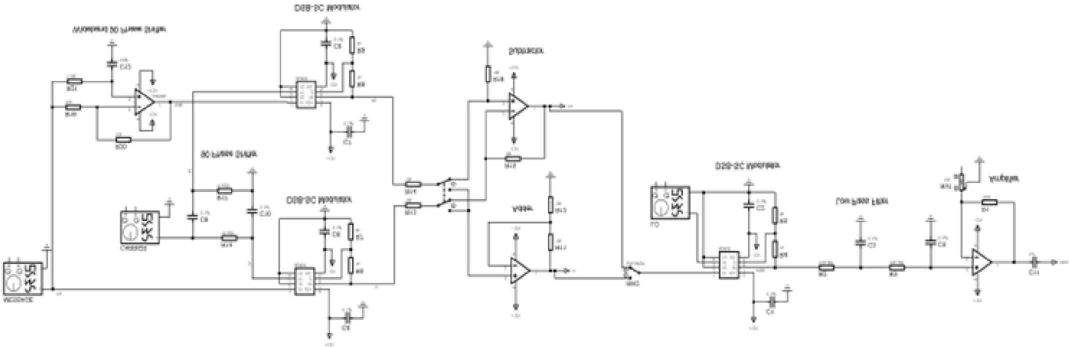

Figure 12. Modulation with phase discrimination and multiplicative coherent detection demodulation circuit

4.2. SSB Demodulation Experiment with Multiplicative Coherent Detection

We have the SSB signal in the last subsection. Moving forward to this subsection, our attention shifts toward the recovery of the message signal by coherent detection in which the message signal is recovered from both the LSSB signal and the USSB signal respectively.

We have the consequences shown in Figure:9 after the multiplication of local oscillated coherent carrier wave and two kinds of SSB signals respectively.

Next, a low pass filter is demanded to remove the high-frequency components and only the frequency components below a certain cutoff frequency of the low pass filter are allowed to pass through, which means only the important low-frequency components shown in Figure:10 are left behind.

To examine the demodulation process, both the original message and the recovered signal are placed side by side for comparison. This can be seen in the detailed Figure:11. By analyzing the two signals together, it was clear that the demodulation process had been successful in extracting the original information from the modulated signal.

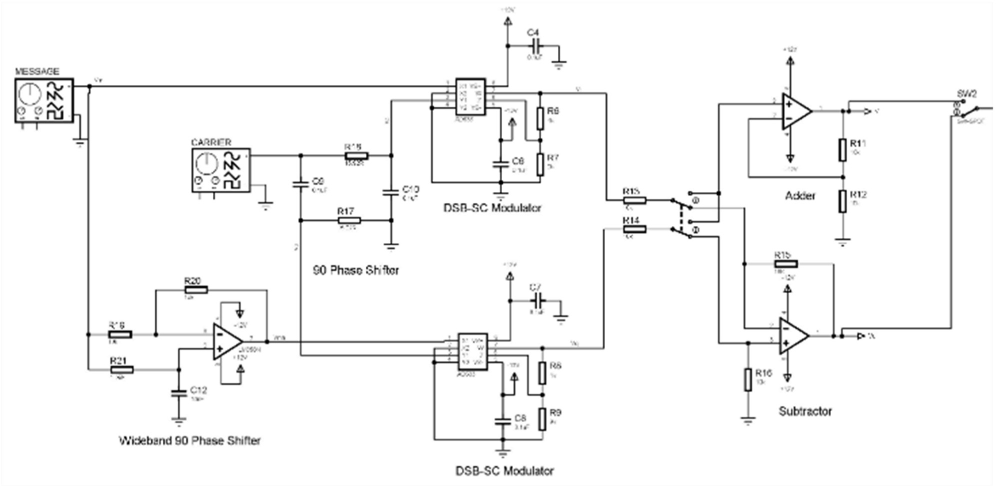

Figure 13. Modulator circuit with phase discrimination method

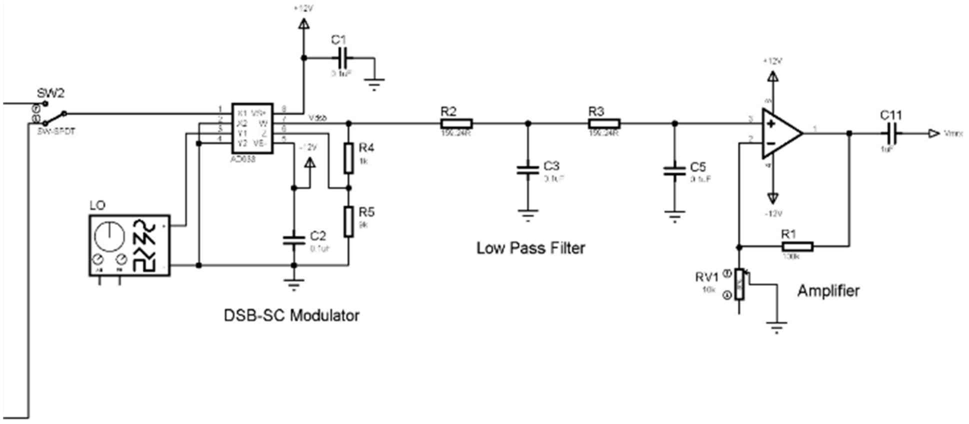

Figure 14. Multiplicative coherent detection demodulator circuit

5. Circuits Construction

In this section, the modulation with phase discrimination method and the demodulation with multiplicative coherent detection is applied and the simulation of its circuits is constructed as shown in Figure:12.

5.1. Modulator Circuits

The SSB modulator circuit(Figure:13) with phase discrimination method consists of two DSB-SC modulators, one wideband 90 degree phase shifter, one -90-degree phase shifter, one Adder, and one Subtractor. article

The message signal m(t) is transformed into its Hilbert transform $\hat{m}(t)$ by passing it through a wideband 90-degree phase shifter. This process is achieved by applying Equation14 and Equation 22, which were explained in detail in the SSB Modulation Method section. Simultaneously, the -90 degree phase shifter transforms carrier signal c(t) to $\hat{c}(t)$ as described by Equation16 which has been also explained in the section of SSB Modulation Method.

Two DSB-SC modulators are employed to generate two types of DSB signals, which have been elaborated by Equation 11 and Equation 17. The DSB-SC modulator, commonly called product modulator, is implemented using the AD633 analog multiplier integrated circuits[3], which multiplies the incoming signal with the carrier signal to generate the DSB signal. The choice of sideband is determined by an Adder and Subtractor, which remove one of the sidebands from the DSB signal. This process is governed by Equation18, Equation19, Equation20, Equation21, Equation25, and Equation24.

When Adder is turned on, the upper sideband is removed, and the lower sideband is selected. Alternatively, when Subtractor is turned on, the lower sideband is eliminated and the upper sideband is chosen. By selectively removing one of the sidebands, the SSB signal can be generated efficiently, achieving high spectral efficiency and reducing bandwidth requirements compared to conventional AM techniques.

5.2. Demodulator Circuits

The SSB demodulator circuit(Figure:14) is composed of the DSB-SC modulator, passive low-pass filter, and operational amplifier. In this portion of circuits, the DSB-SC modulator multiplies the modulated signal with locally generated carrier signal c(t). This process results in a signal with two sidebands that are symmetrical around the carrier frequency. However, only one of these sidebands is needed to recover the original message signal. Then to extract the desired sideband, this modulated signal is passed through the passive low-pass filter to generate the signal with the same frequency as the message signal, and finally, the operational amplifier is employed to adjust the amplitude of that signal to match the original message signal m(t).

6. Evaluation and Applications

This section illustrates the advantages and disadvantages of some types of SSB modulation and SSB demodulation methods. Additionally, the article simply compares several other modulation methods, including conventional amplitude modulation, double sideband (DSB) modulation, vestigial sideband (VSB) modulation, frequency modulation (FM), phase modulation (PM), and single sideband (SSB) modulation, along with their corresponding application areas.

6.1. SSB Modulation

For SSB modulation, the frequency discrimination method is the most intuitive approach, which generates a double-sideband amplitude-modulated signal and then uses a filter to remove one of the sidebands while preserving the other[7]. The disadvantage of this method is that it requires high-quality filters: the filter used to remove the unwanted sideband must have strong attenuation characteristics, and the filter used to preserve the desired sideband must pass it through without distortion[6]. However, implementing such filters in practice is not easy.

The phase discrimination method for generating SSB modulated signals involves first sending the low-frequency modulation signal and carrier into a -90-degree phase shifter, and then inputting the phase-shifted carrier signal and message signal into a multiplier(product modulator), as well as the unshifted message signal and carrier signal into another multiplier(product modulator)[8]. Finally, the outputs from both multipliers are added or subtracted to cancel out one of the sidebands.This method does not require high-quality filters, but it does require the phase shifter to accurately produce a -90-degree phase shift for the low-frequency modulation signal across a wide bandwidth, which might be challenging to achieve in practice[8].

6.2. SSB Demodulation

For SSB demodulation, coherent detection is used, which involves two types: multiplicative coherent detection and additive coherent detection[3]. Both methods require the generation of a local carrier wave that matches the frequency and phase of the modulation carrier wave, and the accuracy of the local carrier wave greatly impacts the demodulation performance of the receiver.

The additive coherent detection method has several advantages. It is less sensitive to high-frequency noise because it can use lowpass filters, making it more immune to noise than the multiplicative detection method[6]. Additionally, it has a higher tolerance for frequency errors and local oscillator drift, which makes it perform better in long-term stable transmission scenarios. Additive coherent detection is also relatively simple to implement compared to other methods and does not require complex calculations such as multiplication, reducing costs[3]. Finally, it is suitable for circumstances where the signal amplitude is weak or the noise level is relatively high, as it has lower requirements for signal amplitude and can still output an accurate demodulated signal[3].

One of the advantages of the multiplicative coherent detection method is that achieves high demodulation accuracy with perfect demodulation of the input signal, resulting in good stability and linearity, which means that even if the input signal is very weak, there will be less distortion generated compared to other methods[6]. Additionally, it is suitable for high SNR scenarios and is often used in communication systems. However, the multiplicative coherent detection method has a lower tolerance for frequency errors and local oscillator drift compared to addictive coherent detection due to the need for precise matching of the local oscillator frequency and input signal[9]. Despite this limitation, the multiplicative coherent detection method is flexible in implementation and can adapt to different signal frequencies by altering the local oscillator frequency, providing greater flexibility in application.

Hence, the multiplicative coherent detection method is suitable for scenarios with high SNR[6], large signal amplitude, and high demodulation accuracy requirements. The addictive coherent detection is more suitable for scenarios with small signal amplitude, long-term stable transmission requirements, and relatively high noise levels[6]

6.3. Other Modulation Methods

Conventional AM is one of the simplest modulation methods. The modulated signal contains information of the carrier signal,where the amplitude of the carrier signal is determined by the magnitude of the modulated signal and the shape of the message signal determines the envelope of the modulated wave. The advantage of AM is its simplicity and low hardware cost, but it has low bandwidth utilization and is susceptible to noise interference, resulting in poor transmission quality. AM is widely used in amplitude-modulated broadcasting, shortwave communication, and other fields.

Double sideband modulation is similar to conventional AM, but it actually involves transmitting two complete sidebands together, which requires more power and bandwidth. DSB is technically mature, but due to its bandwidth usage and sensitivity to noise, it has been replaced by other more efficient modulation methods.

SSB modulation is a method that can effectively utilize spectrum space, requires less power, and has better anti-noise performance than conventional AM and DSB modulation.By transmitting only one sideband, it reduces bandwidth usage and saves frequency resources and power. The percent power saving is 83.33% at 100 % modulation. Moreover, as the bandwidth increases, the amount of noise added to the signal will increase. That means its transmission quality is better and can effectively reduce noise interference which is due to the reduced bandwidth.

However, the SSB transmitter and receiver require excellent frequency stability to ensure high-quality signal transmission. Even a slight change in frequency can negatively impact the transmitted and received signal quality. This is why SSB is not typically used for transmitting high-quality music but is well-suited for mobile communication systems like satellite phones, where signals must travel long distances with limited bandwidth.It is also widely utilized in military communication systems due to its capability to provide secure and reliable transmission over long distances. When combined with frequency hopping and encryption techniques, it becomes an effective tool for preventing interception by unauthorized parties. It can also be used for television transmission in areas where bandwidth is limited. This is particularly useful in remote or rural areas where cable or fiber optic connections may not be available. VSB modulation is based on SSB modulation, which uses certain techniques to leave some bandwidth to improve the processing efficiency and restoration quality at the receiver.

Compared to single sideband modulation, the advantage of vestigial sideband (VSB) modulation is that it can better utilize frequency spectrum resources, resulting in higher transmission quality. Additionally, VSB modulation has a more reliable transmission performance in harsh environments. However, compared to single-sideband modulation, the design and implementation of VSB modulation are more complex and require higher computing and processing capabilities. Moreover, VSB modulation has some issues with signal recovery and requires more complex receivers to process the remaining sideband information.

FM is a modulation method that uses message signals to change the frequency of the carrier signal to transmit the information and has better noise resistance and higher transmission quality because it uses variable frequency transmission with less noise affecting. The disadvantage of FM is that it requires more bandwidth and has higher hardware costs. It is widely used in broadcasting, television, wireless communication, and other fields.PM is another modulation method that uses modulation signals to change the phase of the carrier signal to transmit information. Compared to FM, PM has better noise resistance but requires higher hardware requirements. It is commonly used in digital communication fields.

7. Conclusion

The power efficiency of DSB modulation systems is lower than that of conventional AM as all power is allocated to the sidebands with no carrier power. However, since the information carried by both upper and lower sidebands is identical, transmitting both sidebands is redundant and results in a decrease in system efficiency and bandwidth utilization. To address this issue, SSB modulation is often utilized, which has a narrower bandwidth of only half that of DSB and only requires just one sideband transmission, improving overall bandwidth utilization and decreasing transmission power. Compared to conventional AM utilizing the same total power, SSB modulation significantly enhances the SNR at the receiver, leading to increases in communication distance.

Single sideband (SSB) modulation has proven to be an efficient method that effectively utilizes available bandwidth while requiring less power and having better antinoise performance compared to conventional AM and DSB modulation. However, it does require high-quality filters and excellent frequency stability. SSB is well-suited for mobile communication systems like satellite phones and military communication systems because it allows for long-distance communication with relatively low power and bandwidth-limited requirements, making it a popular choice for communication equipment used in remote locations or situations where power sources and bandwidth are limited.

The illustration below compares several types of modulated waves in terms of spectrum utilization, anti-noise performance, and equipment complexity.

- Spectrum utilization:
SSB > V SB > DSB ≈ AM > FM

- Anti-noise performance:
FM > DSB > SSB > V SB > AM

- Equipment Complexity:
AM < DSB ≈ FM < SSB ≈ VSB

Their main applications:

- Conventional AM: Shortwave radio broadcasting

- DSB:Point-to-point dedicated communication, low-bandwidth signal multiplexing system[8]

- SSB: Shortwave radio broadcasting, voice and audio multiplexed communication

- VSB: Data transmission, commercial television broadcasting[5]

- FM: Data transmission, radio broadcasting, microwave relay[5].

8. Summary

The article extensively discusses the principles and techniques of single-sideband (SSB) modulation and demodulation. It covers the analysis of SSB modulation methods, including frequency discrimination and phase discrimination, and explores the corresponding circuits involved. The article also highlights two coherent detection methods for SSB demodulation.

Furthermore, the review emphasizes the importance of comprehending the distinctions among different modulation methods to determine the most suitable approach for specific applications.

In summary, this article provides a comprehensive analysis of SSB modulation and demodulation, offering valuable insights for researchers and practitioners in the field. It sheds light on the advantages and disadvantages of various techniques, aiding in the effective utilization of SSB modulation for diverse communication applications

References

[1] K. S. Shanmugam, “Digital and analog communication systems,” NASA STI/Recon Technical Report A, vol. 80, p. 23225, 1979.

[2] S. S. Haykin, Introduction to analog and digital communications. Wiley, 2007.

[3] J. B. Hagen, Radio-frequency electronics: circuits and applications. Cambridge University Press, 2009.

[4] J. G. Proakis and M. Salehi, Fundamentals of communication systems. Pearson Education India, 2007.

[5] M. C. Jeruchim, P. Balaban, and K. S. Shanmugan, Simulation of communication systems: modeling, methodology and techniques. Springer Science & Business Media, 2006.

[6] zeng xing wen, liu nai an, chen jian, et al., “High-frequency electronic circuits,” 2004.

[7] wangweidong, High Frequency Electronic Circuit. Electronic Industry Press, 2020.

[8] H. Yu, Communication Electronic Circuit. Tsinghua University Press Co., Ltd., 2005.

[9] L. Frenzel, Principles of electronic communication systems. McGraw-Hill, Inc., 2007.