A Novel Approach for Single Sideband Modulation using Hilbert Transform

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ABSTRACT

This paper presents a new microcontroller based robot working in 4 modes namely Line Follower, Edge Detector, and Obstacle Detector & Path Finder. In this paper the above objective is achieved by using ATMEGA168 Microcontroller alongside combination of sensors and switches and LED.

Keywords: Line Follower, Edge Detector, Obstacle Detector, Path Finder, Microcontroller, Sensor, Switches, Motor.

I. INTRODUCTION

Single Sideband (SSB) Modulation is an efficient form of Amplitude Modulation (AM) that uses half the bandwidth used by AM. Amplitude-modulated wave consists of a carrier and two identical sidebands spaced above and below the carrier by an amount equal to the modulating frequency. This technique is most popular in applications such as telephony, HAM radio, and HF communications, like voice communications. SSB was then used for long distance telephone lines, as part of a technique known as frequency-division multiplexing (FDM). FDM is started by telephone companies in the 1930s.[8]

A sideband is a frequency band which is higher than or lower than the carrier frequency, containing a certain quantity of power as a result of the modulation process. The sidebands consist of all the Fourier components of the modulated signal except the carrier. Any modulation produces sidebands less or more, both or only one. The spectral components in the AM signal equal distances above and below the carrier frequency contain identical information because they are complex conjugates of each other.[8][2]

To generate an SSB signal by Hilbert transform method, two different versions of the original signal are generated, which are mutually 90° out of phase (orthogonal) for any single frequency within the operating bandwidth. Each one of these signal versions the modulates carrier waves of one frequency that are also 90° out of phase (orthogonal) with each other. Then by either adding or subtracting the resulting out of phased signals, lower (LSB) or upper sideband (USB) signal will be resulted. This approach has a benefit of that it allows an use of analytical expression for SSB signals, which can be used to understand important effects such as synchronous detection of SSB signals at receiving side.[7][1]

Figure 1: Single Side Band Modulation

1.1 Double side Band Modulation

A simple form of AM is the Double Sideband (DSB) Modulation, which typically consists of two frequency-shifted copies of a modulated signal on either side of a carrier frequency. More precisely this is referred to as a DSB Suppressed Carrier, and is defined as[3].

\[ f(n) = m[n] \cos \left( \frac{2\pi f_c n}{f_s} \right) \]  

where \( m[n] \) is usually referred to as the message signal and \( f_c \) is the carrier frequency. As shown in the equation above, DSB modulation consists of multiplying the message signal \( m[n] \) by the carrier \( \cos (2\pi f_c n/f_s) \), therefore, we can use the modulation theorem of Fourier transforms to calculate the transform of \( f[n] \)

\[ f(f) = 1/(2)(M(f-f_c) + [M(f + f_c)]) \]  

Where \( M(f) \) is the Discrete-time Fourier Transform (DTFT) of \( m[n] \). If the message signal is low pass with bandwidth \( W \), then \( F(f) \) is a band pass signal with twice the bandwidth. Let’s look at an example DSB signal and its spectrum.

1.2 Single Side Band Modulation

In DSB-SC it is observed that there is symmetry in the band structure. So, even if one half is transmitted, the other
half can be recovered at the receiver.[1] By doing so, the bandwidth and power of transmission is reduced by half.

Depending on which half of DSB-SC signal is transmitted, there are two types of SSB modulation
1. Lower Side Band (LSB) Modulation
2. Upper Side Band (USB) Modulation

Figure 2: SSB Signal from original signal

1.3 Ideal Hilbert Transform
Hilbert transform is a basic tool in Fourier analysis which is important part of signal processing, and enables realization for conjugate of a given function including Fourier series.[8]

The discrete Hilbert Transform is a process by which a signal’s negative frequencies are phase-advanced by 90 degrees and the positive frequencies are phase-delayed by 90 degrees. Shifting the results of the Hilbert Transform (+j) and adding it to the original signal creates a complex signal as we’ll see below.

If \( m[n] \) is the Hilbert transform of \( m_r[n] \), then:

\[
m_c[n] = m_r[n] + jm_l[n]
\]

Is a complex signal known as the Analytic Signal. The diagram below shows the generation of an analytic signal by means of the ideal Hilbert Transform.

Figure 3: Generation of an Analytic Signal by Means of the Ideal Hilbert Transform

One important characteristic of the analytic signal is that its spectral content lies in the positive Nyquist interval. This is because if we shift the imaginary part of our analytic (complex) signal by 90 degrees (+j) and add it to the real part, the negative frequencies will cancel while the positive frequencies will add. This results in a signal with no negative frequencies. Also, the magnitude of the frequency component in the complex signal is twice the magnitude of the frequency component in the real signal. This is similar to a one-sided spectrum, which contains the total signal power in the positive frequencies.

Spectral Shifter
Using the message signal \( m[n] \) defined above we’ll create an analytic signal by employing the Hilbert Transform, which will then be modulated to the desired center frequency. The scheme is shown in the diagram below.

Figure 4: Creation of an analytic signal by employing the Hilbert Transform

Implementation of SSB Modulation
SSB modulated signal, \( f[n] \) can be written as

\[
f[n] = R\left[ m_c[n]exp\left(\frac{j2\pi f_o n}{f_s}\right)\right]
\]

where \( m_c[n] \) is the analytic signal defined as

\[
m_c[n] = m[n] + jm[n]
\]

Expanding that equation and taking the real part we get

\[
f[n] = m[n]\cos\left(\frac{2\pi f_o n}{f_s}\right) - m[n]\sin\left(\frac{2\pi f_o n}{f_s}\right)
\]

This results in a single sideband, upper sideband (SSBU). Similarly, we can define the SSB lower sideband (SSBL) by

\[
f[n] = R\left[ m_c[n]exp\left(-\frac{j2\pi f_o n}{f_s}\right)\right]
\]

\[
f[n] = m[n]\cos\left(\frac{2\pi f_o n}{f_s}\right) + m[n]\sin\left(\frac{2\pi f_o n}{f_s}\right)
\]

The SSBU equation above suggests a more efficient way of implementing SSB. Rather than performing the complex multiplication of \( m_c[n] \) with \( \exp(j*2^\pi*fo*n/fs) \) and then throwing away the imaginary part.

Figure 5: SSB Modulation
II. SIMULATION RESULT

Figure 6: Message Signal

Figure 7: Mean Square Power Spectrum of the Message Signal

Figure 8: Double-Sided Power Spectrum

Figure 9: Message Signal and Modulated Message Signal

Figure 10: Periodogram Mean-Square Spectrum Estimate

Figure 11: Plot The Spectral Content Of The Analytic Signal Constructed From Our Message Signal M[N]

Figure 12: Plot shown above signal has been modulated to a new center frequency of Fo without creating the frequency pairs

Figure 13: Zero-Phase Response of the Filter
III. CONCLUSION

In this paper we use an approximation to the Hilbert Transform which can produce analytic signals and are useful in many signal applications that require spectral shifting. For this we first modulate the signal for single side band without Hilbert transform and then we compare the result with Hilbert transformed single side band message signal and we have seen how an approximate Hilbert Transformer can be used to implement Single Sideband Modulation.

REFERENCES