Waveform Synthesis and Spectral Analysis

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I. Introduction

In this exercise, we explored the modulation and demodulation of signals. We started by modeling an amplitude modulated (AM) signal in software, and then passing it through a virtual channel, that could optionally add noise to the signal. Then, we demodulated the resulting signal. We repeated this same process with a Double-Sideband Suppressed Carrier (DSB-SC) signal and observed the differences.

II. Modulating DSB-AM

Generating dual side band amplitude modulated (DSB-AM or simply, AM) signals is quite simple. Given a message signal $m(t)$, carrier frequency f_c, and the amplitude of the carrier signal A_c, the resulting AM signal is defined as

$$s(t) = A_c(1 + m(t))\cos(2\pi f_c t). \tag{1}$$

For our first synthesis of an AM signal, we chose a simple single-tone message at 10Hz, and modulated it with a carrier frequency of 100Hz. Our message signal was given an amplitude of $\frac{1}{2}$ and we selected 1 to be the amplitude of the broadcast signal. The resulting message signal was $m(t) = \frac{1}{2}\sin(2\pi 10t)$, and the resulting AM signal was $s(t) = (1 + \frac{1}{2}\sin(2\pi 10t))\cos(2\pi 100t)$. The waveform of the single tone AM signal is seen in figure1. The waveform traces out a shape that resembles our original $m(t)$, while the frequency of the signal itself is the carrier frequency f_c.

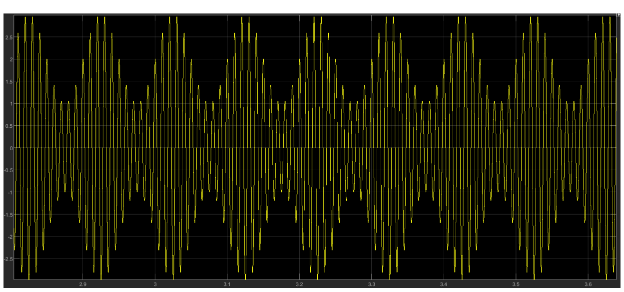

Fig. 1. Single tone AM waveform

It becomes easier to see what is actually happening when the signal is observed in the frequency domain, illustrated in figure 2. The transmitted signal two identical copies of the spectrum of $m(t)$ centered at $\pm f_c$ rather than 0. Additionally, the spectrum includes a frequency contribution at the carrier frequency. This contribution means that power is being used to transmit the carrier frequency in addition to the signal itself. Using power to transmit the carrier signal reduces the overall efficiency of the transmission.

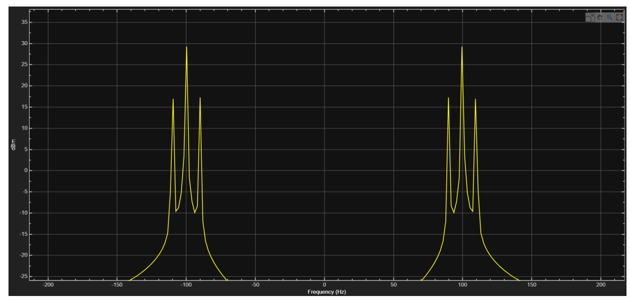

Fig. 2. Single tone AM frequency components

III. Modulating DSB-SC

To increase efficiency, other methods of AM transmission were devised. One of these methods is known as dual side band suppressed carrier (DSB-SC). DSB-SC is a form of amplitude modulation that aims to remove the frequency contribution of the carrier frequency. A DSB-SC signal is synthesized in a very similar manner to the original AM method, but slightly simpler. A DSB-SC signal is defined as

$$s(t) = A_c m(t)\cos(2\pi f_c t). \tag{2}$$

Using the same $m(t)$ and f_c as before, our DSB-SC signal was $s(t) = \frac{1}{2}\sin(2\pi 10t)\cos(2\pi 100t)$, and its corresponding waveform is seen in figure 3. The envelope of this waveform crosses zero as opposed to staying above zero in the case of DSB-AM.

Another difference between DSB-SC and DSB-AM becomes apparent when observing the signal in the frequency domain, pictured in figure 4. Again, the spectrum of the message signal is shifted to be centered at f_c, but now the frequency contribution at f_c is reduced, or suppressed, hence the name ”suppressed carrier”.

IV. Demodulation

Demodulation is the process of recovering the original message from a modulated signal. For our tests we used a product detector to demodulate the signals. A product detector

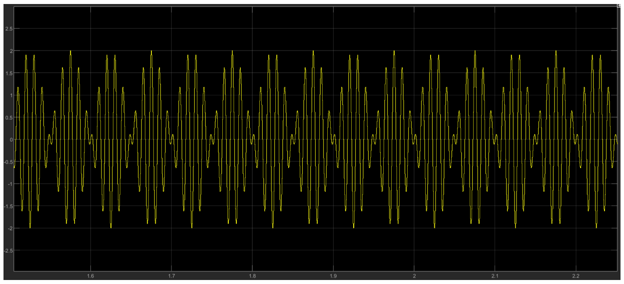

Fig. 3. DSB-SC signal

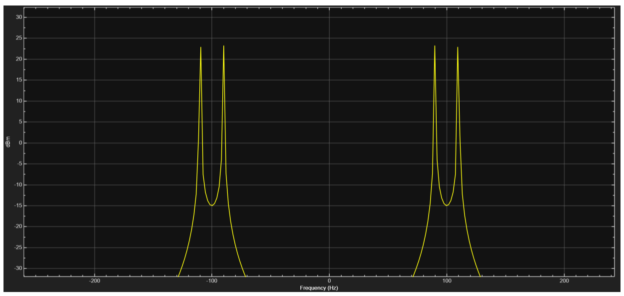

Fig. 4. DSB-SC results

works by first multiplying the received signal by a sinusoidal tone matching the carrier frequency. Doing so exploits the identity

$$\cos^2(x) = \frac{1+\cos(2x)}{2} \tag{3}$$

essentially doubling the carrier frequency. Then a low-pass filter is applied, with the cutoff frequency equal to the highest frequency in the message signal to leave only the message signal. We applied our product detector to both DSB-AM and DSB-SC signals, as seen in figure 5. While a very similar signal is recovered in both cases, it is important to note that the DSB-AM signal has a DC offset, while the DSB-SC signal has no DC offset. Additionally, both signals are attenuated compared to the original message signal. This attenuation is a result of the product filter scaling the signal by a factor of $\frac{1}{2}$. Another small difference was the carrier frequency appeared to be better attenuated in the case of DSB-SC, meaning the message signal was better recovered.

Real signals will pick up some noise between the transmitter and receiver. Therefore, we also added some Gaussian noise to the signal before demodulating it. We opted to add noise such that the SNR was 3dB. The result after demodulation is seen in figure 6. The overall shape of the signal was preserved, but due to the nature of Gaussian noise, some noise will inevitably get through the low-pass filter.

V. Conclusion

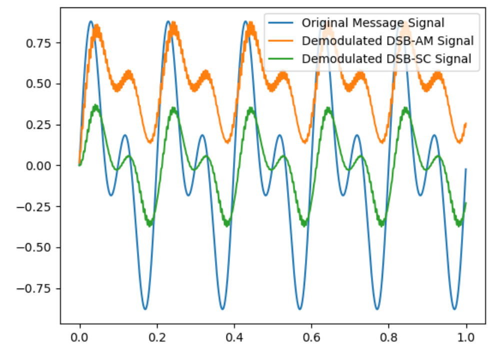

Fig. 5. Demodulated signal

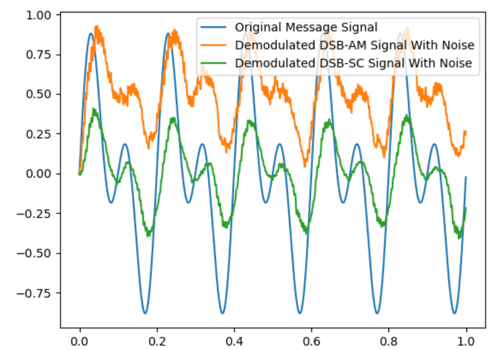

Fig. 6. Demodulated noisy signal

VI. Appendix

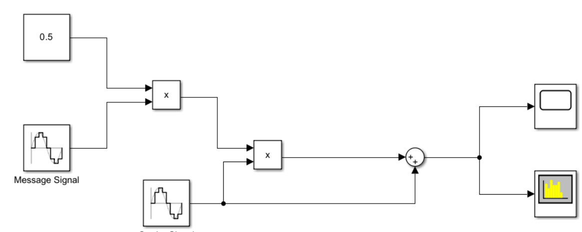

Fig. 7. AM Schematic

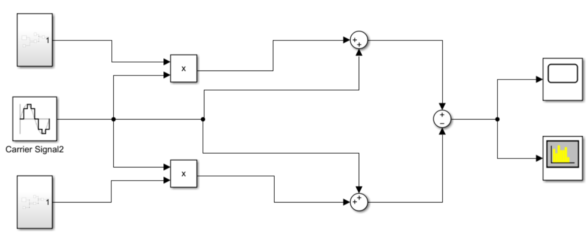

Fig. 8. DSB-SC schematic