9

Single-sideband Modulation

9.1 Introduction

Communications in the HF bands have become increasingly crowded in recent years, requiring closer spacing of signals in the spectrum. Single-sideband systems requiring only half the bandwidth of normal AM and considerably less power are used extensively in this portion of the spectrum as a result.

It was noted in Chapter 8 that each sideband of a normal AM signal contains all the information necessary for signal transmission and recovery. It was also pointed out that for 100% sinusoidal modulation each sideband contains one-sixth of the total signal power, while the carrier contains two-thirds of the total power. Furthermore, the carrier itself carries no information contributed by the modulating signal. Figure 9.1.1 shows a comparison of the signal spectra of normal AM (DSBFC) in (a), double-sideband suppressed carrier (DSBSC) in (b), upper-sideband SSB (SSBSC) in (c), and lower-sideband SSB in (d). Note that in (c) and (d) only one sideband is present and that each requires only one-half of the bandwidth of either (a) or (b).

9.2 Single-sideband Principles

In Section 8.9 it is shown that the output from a balanced modulator contains the term

$$e(t) = ke_m(t) \cos \omega_c t \tag{9.2.1}$$

where k is the multiplier constant. With cosinusoidal input $e_m(t) = E_{m\,\max} \cos \omega_c t$, the modulator output becomes a DSBSC signal containing two side frequencies,

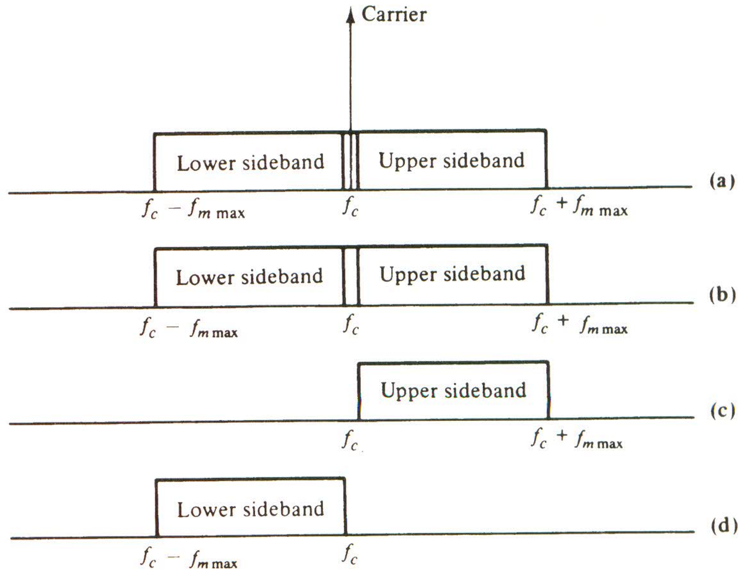

Figure 9.1.1 Amplitude-modulated signal spectra: (a) normal amplitude modulation, or double-sideband full carrier; (b) double-sideband suppressed carrier (DSBSC); (c) single-sideband suppressed carrier (SSBSC) using the upper sideband (USB); (d) single-sideband suppressed carrier (SSBSC) using the lower sideband (LSB).

$$\begin{aligned} e(t) &= kE_{m\,\max} \cos \omega_m t \cos \omega_c t \\ &= E_{\max}[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t] \end{aligned} \tag{9.2.2}$$

where $E_{\max} = k(E_{m\,\max}/2)$.

Now if one of the side frequencies in the DSBSC signal is removed, either by filtering or by cancellation, the other side frequency will remain. For cosinusoidal modulation the *upper side frequency* (USF) signal is described by

$$e_{\mathrm{USF}} = E_{\max} \cos(\omega_c + \omega_m)t \tag{9.2.3}$$

and the *lower side frequency* (LSF) signal is described by

$$e_{\mathrm{LSF}} = E_{\max} \cos(\omega_c - \omega_m)t \tag{9.2.4}$$

Since all the transmitted power goes into the side frequency, then

$$P_T = \frac{E^2_{\max}}{2R} \tag{9.2.5}$$

This should be compared to Eq. (8.6.3) for a standard AM signal.

Where the modulating signal contains a band of frequencies (usually the case in practice), the terms *upper sideband* (USB) and *lower sideband* (LSB) are used.

Demodulation of a single-sideband signal is achieved by multiplying it with a locally generated *synchronous* carrier signal at the receiver. Detectors using this principle are called *product detectors,* and balanced modulator circuits are used for this purpose. It is important that the carrier be as closely synchronized in frequency and phase with the original carrier as possible to avoid distortion of the modulated output.

To demonstrate that the multiplying process does demodulate an SSB signal, consider an LSF signal $E_{\max} \cos(\omega_c - \omega_m)t$ multiplied by a local oscillator signal $E_{c\max} \cos \omega_c t$ using a balanced modulator with a gain k. Equation (5.10.11) shows that the mixer operating with a large oscillator input signal contains a term

$$\begin{aligned} e_{\text{out}} &= kE_{\max} \cos(\omega_c - \omega_m)t \cos \omega_c t \\ &= \frac{kE_{\max}}{2}[\cos \omega_m t + \cos(2\omega_c - \omega_m)t] \end{aligned} \tag{9.2.6}$$

The first term on the right of the equation is the required information signal, while the second term is the lower side frequency at the second harmonic of the local carrier frequency. Low-pass filtering easily removes this, leaving only the demodulated information (or baseband) signal as

$$e_{bb}(t) = \frac{kE_{\max}}{2} \cos \omega_m t \tag{9.2.7}$$

9.3 Balanced Modulators

Balanced modulators are the building blocks from which a wide variety of frequency mixers, modulators, and demodulators are built. Any circuit that multiplies two input signals while canceling the feedthrough of one of these is a singly balanced modulator, and one that cancels both is a doubly balanced modulator. The output contains a double-sideband suppressed carrier signal.

An FET Singly Balanced Modulator Circuit

Figure 9.3.1 shows two matched FETs connected in a differential amplifier, which acts as a singly balanced modulator in which the carrier oscillator signal is canceled from the output, but the modulating signal appears in the output. The input (modulating) signal is applied in the differential input mode, and the carrier signal is applied as a common-mode signal. The signal applied to the gate of M_1 is the sum of the two input voltages $(e_c + e_m)$, while the signal applied to M_2 is the difference $(e_c - e_m)$. These two components are squared by the second-order terms of the transistor transfer functions. The common-mode carrier signal remaining is canceled as the two drain currents are subtracted in the output transformer primary.