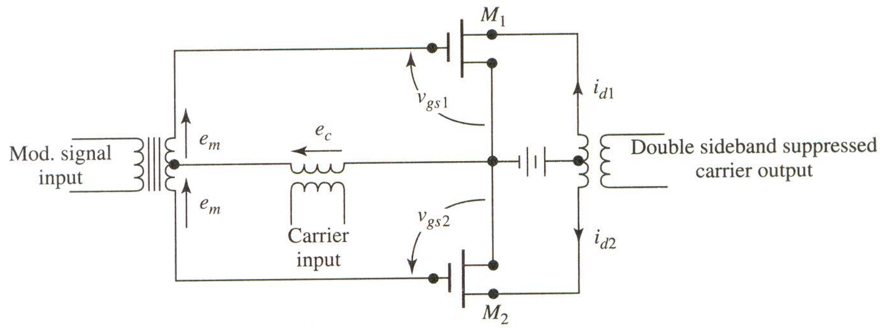

Figure 9.3.1 FET singly balanced modulator circuit.

$$V_{gs1} = e_c + e_m \tag{9.3.1}$$

$$V_{gs2} = e_c - e_m \tag{9.3.2}$$

$$i_{d1} = I_o + aV_{gs1} + bV_{gs1}^2 \tag{9.3.3}$$

$$i_{d2} = I_o + aV_{gs2} + bV_{gs2}^2 \tag{9.3.4}$$

$$i_p = i_{d1} - i_{d2} = a(V_{gs1} - V_{gs2}) + b(V_{gs1} + V_{gs2})(V_{gs1} - V_{gs2}) \tag{9.3.5}$$

Substituting Eqs. (9.3.1) and (9.3.2) into (9.3.5) gives

$$i_p = 2a(e_m) + 4b(e_m)(e_c) \tag{9.3.6}$$

Substituting cosinusoidal signals in Eq. (9.3.6) yields the output

$$i_p = 2aE_{m\,\max} \cos \omega_m t + 2bE_{c\,\max}E_{m\,\max}[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t] \tag{9.3.7}$$

This output contains the original modulating signal and the two sidebands about the carrier frequency position. The carrier is absent. It should be noted that any imbalance in the circuit so that either the a's or b's for the two FETs differ from each other will allow some of the carrier signal to feed through to the output. In practice, the FETs would be a very closely matched pair on a single chip, and the bias currents to the two FETs would be adjusted for minimum carrier feedthrough. Since the output would be fed through a band-pass filter, the low-frequency modulating signal component would be removed at that point.

Integrated-circuit Doubly Balanced Modulators

The disadvantages of the FET circuit described are that the modulating input signal feeds through to the output, the circuit is difficult to balance, and the input and output require specially balanced transformers. Integrated-circuit doubly balanced modulators like the LM1596 described in Section 5.10 operate as multiplier circuits that produce only sideband pairs at the output. Application is simple, requiring only bias and an appropriate band-pass filter to eliminate sideband pairs at harmonics of the carrier. Very little adjustment is required to obtain good balance.

An important advantage of the integrated-circuit balanced modulator is that, when it is operated with a large carrier signal, the output signal amplitude is independent of the carrier amplitude. The result is that the output amplitude depends only on the amplitude of the input signal (which is the modulating signal when it is used as a modulator or the sideband signal when it is used as a demodulator).

Doubly Balanced Diode Ring Modulator

A circuit known as the *double-balanced ring modulator,* which is widely used in carrier telephony, is shown in Fig. 9.3.2(a). The name comes from the fact that the circuit is balanced to reject both the carrier and modulating signals using a ring of diodes. The output contains only sideband pairs about the carrier frequency position and several of its harmonics.

Operation of the circuit is similar to that described for the integrated-circuit balanced modulator in Section 5.10. A large signal carrier acts as a switching signal to alternate the polarity of the modulating signal at the carrier frequency. With a negative carrier voltage V_c applied, diodes *AB* and *CD* conduct and diodes *AD* and *BC* block to give the effective connection shown in Fig. 9.3.2(b). With a positive carrier voltage, diodes *AD* and *BC* conduct and diodes *AB* and *CD* block to give the connection of Fig. 9.3.2(c). The effect is to multiply the modulating signal by a fixed-amplitude square wave at the carrier frequency, producing the required DSBSC signal, with harmonics. Band-pass filters remove the unwanted harmonics from the output. Fig. 9.3.3 shows the time response waveform for a single sinusoid of modulation and its spectrum.

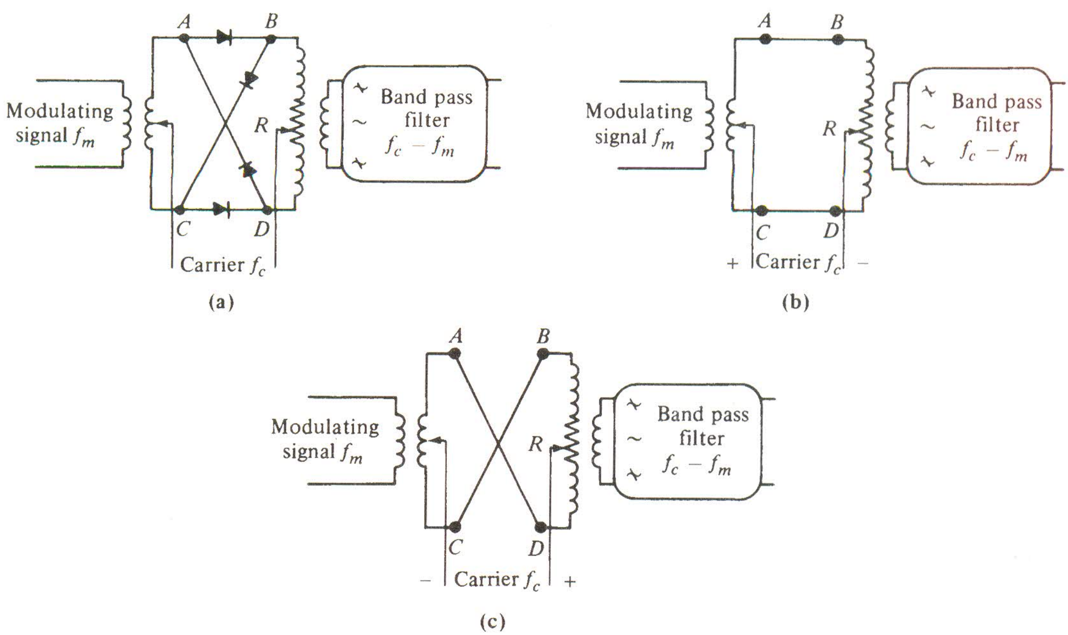

Figure 9.3.2 (a) Double-balanced ring modulator; (b) the conducting paths when diodes *AB* and *CD* are forward biased; (c) the conducting paths when diodes *BC* and *DA* are forward biased.

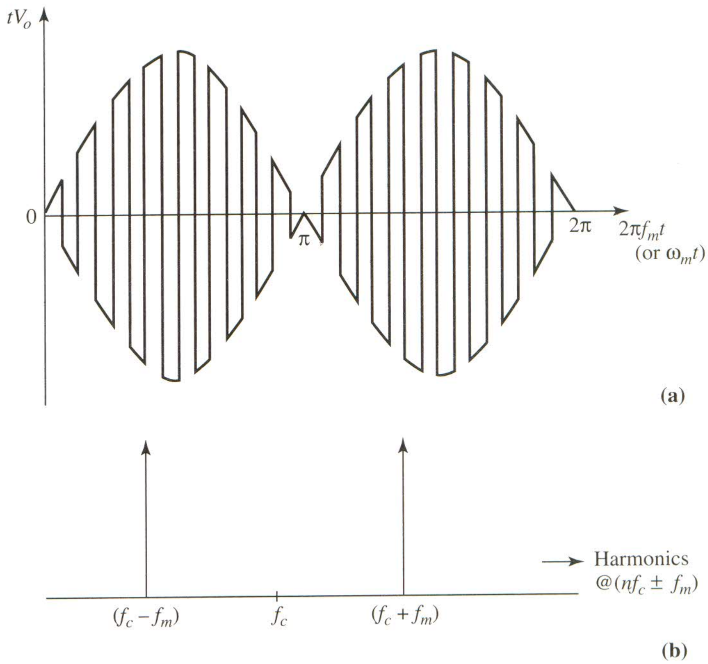

Figure 9.3.3 (a) Time waveform of a DSBSC signal for one cycle of modulation. (b) Spectrum for the signal of (a).

These circuits have been extensively used for low-frequency telephone applications, where they require balanced input and output transformers and some adjustment of circuit balance for good performance. Care must be exercised if the ring modulator is used at radio frequencies, since the high-level carrier signal may result in the radiation of interference. The doubly balanced diode ring circuit is widely used as a mixer in microwave applications where shielded enclosures prevent radiation.

9.4 SSB Generation

Balanced Modulator–Filter Method

Early SSB transmitters used balanced modulator circuits to generate DSBSC signals followed by sideband filters to remove the unwanted sidebands. Such a transmitter is illustrated in Fig. 9.4.1. Initial modulation takes place in the balanced modulator at a low frequency (such as 100 kHz) because of the difficulty of making adequate filters at higher frequencies. The filter is a bandpass filter with a sharp cutoff at each side of the band pass to obtain satisfactory adjacent sideband rejection. In this case, a single-sideband filter is used, and the carrier oscillator crystal is switched to place the desired sideband in the filter window. Alternatively, two sideband filters (one for each sideband) could be used with a fixed carrier frequency.

The filtered signal is up-converted in a mixer (the second balanced modulator) to the final transmitter frequency and then amplified before being

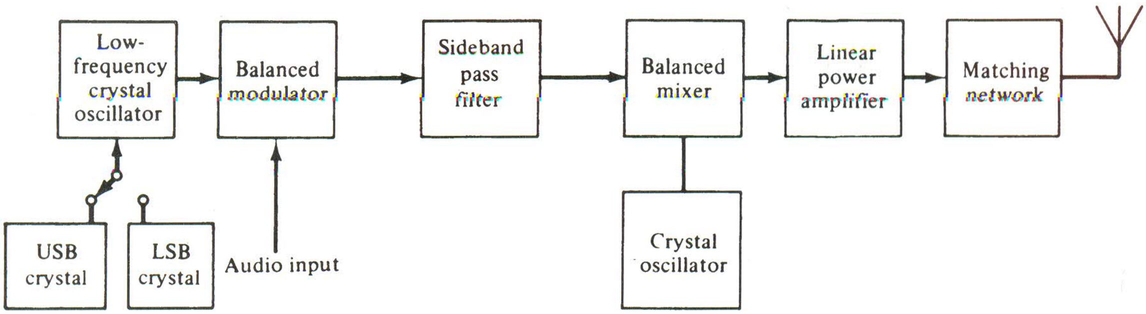

Figure 9.4.1 Single-sideband suppressed carrier transmitter using band-pass filters to eliminate the unwanted sideband.

coupled to the antenna. Linear power amplifiers are used to avoid distorting the sideband signal, which might result in regeneration of the second sideband or distortion of the modulated information signal.

The sideband filters are the critical part of this system. Early sideband filters were expensive and did not have the sharp cutoff characteristic required. The integrated ceramic filters available now offer a very inexpensive and effective solution to this problem.

Phasing Method

Figure 9.4.2 shows a different means of obtaining an SSBSC signal. This circuit does not have any sideband filters, and the primary modulation can be done at the transmitting frequency. It relies on phase shifting and cancellation to eliminate the carrier and the unwanted sideband.

Assume cosinusoidal signals for both carrier and modulation and that the circuit shown produces the lower side frequency, given by

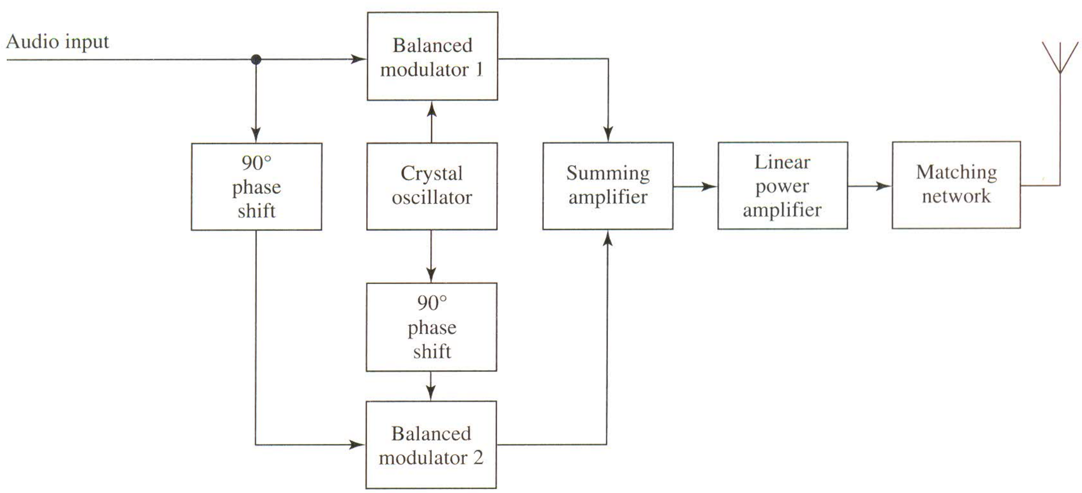

Figure 9.4.2 SSB suppressed carrier transmitter using phase shift to obtain cancellation of sidebands.

$$e_{\text{LSF}} = E_{L\,\max} \cos(\omega_c - \omega_m)t \tag{9.4.1}$$

The standard trigonometric identity for the difference of two angles gives

$$e_{\text{LSF}} = E_{L\,\max}[\cos \omega_c t \cos \omega_m t + \sin \omega_c t \sin \omega_m t] \tag{9.4.2}$$

but

$$\sin \omega_c t = \cos\left(\omega_c t - \frac{\pi}{2}\right) \tag{9.4.3}$$

$$\sin \omega_m t = \cos\left(\omega_m t - \frac{\pi}{2}\right) \tag{9.4.4}$$

Therefore,

$$e_{\text{LSF}} = E_{L\,\max}\left[\cos \omega_c t \cos \omega_m t + \cos\left(\omega_c t - \frac{\pi}{2}\right) \cos\left(\omega_m t - \frac{\pi}{2}\right)\right] \tag{9.4.5}$$

The first term on the right of Eq. (9.4.5) is the result of balanced modulator 1, which multiplies the two unshifted signals. The second term is the result of balanced modulator 2, which multiplies the two signals, each shifted by −90°. The −90° shift for the carrier is easily accomplished by feeding the signal through a controlled current source (transconductance amplifier) into a capacitor. The phase shifting network for the baseband signal must accurately provide a constant 90° phase shift over a wide frequency range. Such circuits are tricky to build.

The carrier signal is canceled out in this circuit by both of the balanced modulators, and the unwanted sidebands cancel at the output of the summing amplifier. It is left as an exercise for the student to expand the outputs of the two balanced modulators into sideband form and show that the cancellation does occur on summing. The two outputs are summed to produce the lower sideband signal.

Examination of the trigonometric identity shows that if the two outputs are subtracted instead of added the upper sideband will result, since

$$\begin{aligned} e_{\text{USF}} &= E_{U\,\max} \cos(\omega_c + \omega_m)t \\ &= E_{U\,\max}[\cos \omega_c t \cos \omega_m t - \sin \omega_c t \sin \omega_m t] \end{aligned} \tag{9.4.6}$$

While the system is more complex than one using filters, the individual circuits are quite straightforward, and by using integrated-circuit balanced modulators, very little adjustment is required. Only a simple band-pass filter to remove any harmonics is required in the output before application to the final transmitter amplifier.

It should be noted that the modulation signal is usually a broad band of frequencies of varying amplitudes, which the modulator system must not distort. If the capacitor–transconductance amplifier combination causes such distortion, complete cancellation of the unwanted sideband will not occur, and the wanted sideband will have distortions introduced into it. The third method described next eliminates this problem.

Third Method

The third method of generating SSBSC modulation is attributed to D. K. Weaver and was developed during the 1950s. It is similar to the phase shifting method presented previously, but it differs in that the modulating signal is first modulated on a low-frequency subcarrier (including phase shifts), which is then modulated onto the high-frequency carrier.

The circuit connections for generating an LSB signal are shown in Fig. 9.4.3. Modulators $BM1$ and $BM2$ both have the unshifted modulating signal as inputs. $BM1$ also takes the low-frequency subcarrier with a 90° shift introduced in it from the oscillator signal. $BM2$ takes the subcarrier signal directly from the oscillator. Assuming unity magnitudes and cosinusoidal single-frequency modulation, the output from $BM1$ becomes

$$e_{BM1} = \cos\left(\omega_o t + \frac{\pi}{2}\right)\cos \omega_m t$$

$$= \frac{1}{2}\left[\cos\left(\omega_o t + \omega_m t + \frac{\pi}{2}\right) + \cos\left(\omega_o t - \omega_m t + \frac{\pi}{2}\right)\right] \tag{9.4.7}$$

and the output of $BM2$ becomes

$$e_{BM2} = \cos \omega_o t \cos \omega_m t = \frac{1}{2}[\cos(\omega_o t + \omega_m t) + \cos(\omega_o t - \omega_m t)] \tag{9.4.8}$$

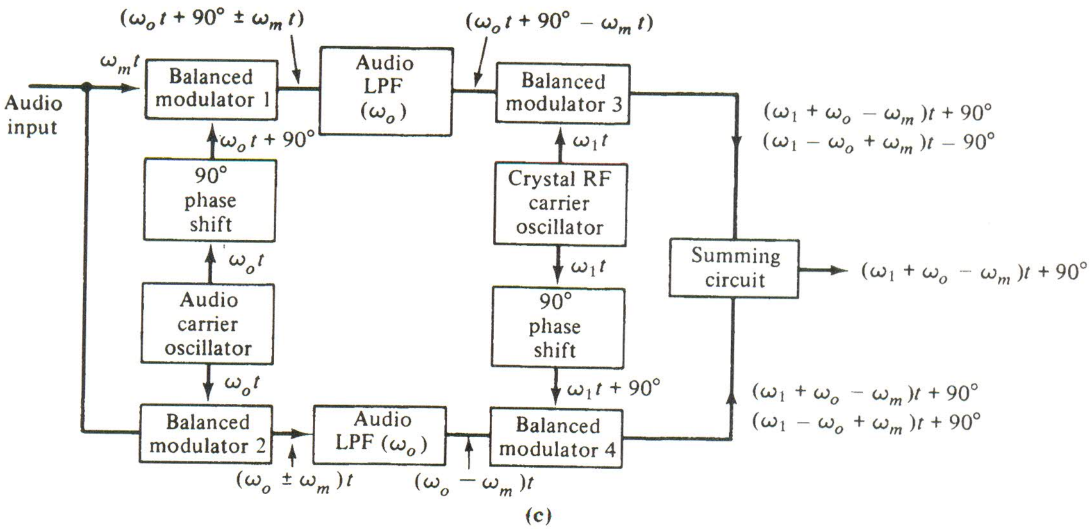

Figure 9.4.3 The "third method" of generating an SSBSC signal.