SINGLE-SIDEBAND GENERATOR

Balancing out the undesired sideband in a vacuum-tube circuit eliminates need for highly selective filters in power-line carrier systems for telemetering or voice communication

By M. A. HONNELL

Associate Professor of Electrical Engineering Georgia School of Technology Atlanta, Georgia

A COMPARISON of a-m, f-m, and single-sideband systems for power-line carrier transmission appeared recently in the literature.[1] To the writer's knowledge, most single-sideband systems require the use of highly selective filters and, in some cases, require a double modulation process to separate the sidebands sufficiently for effective filtering.

Basic Theory

There is another approach to the problem of generating single-sideband signals which appears not to have been exploited. This system makes the use of highly selective filters unnecessary, because the undesired sideband is balanced out in a vacuum-tube circuit.

An examination of the equations for amplitude-modulated signals in Table I reveals some interesting possibilities.[2] Let us consider the following pair of equations for an amplitude-modulated signal

$$\sin A\,(1 + m\cos B) =$$
$$\sin A + \frac{m}{2}\sin(A - B) + \frac{m}{2}\sin(A + B) \quad (1)$$
$$\cos A\,(1 + m\sin B) =$$
$$\cos A - \frac{m}{2}\sin(A - B) + \frac{m}{2}\sin(A + B) \quad (2)$$

where

$A = 2\,\pi f_c\, t$
$B = 2\,\pi f_s\, t$
m = modulation factor

If the amplitude-modulated signals are generated in a balanced modulator[3], the carriers are readily eliminated, and the resulting signals at the output of the balanced modulators are of the form

$$G\sin(A + B) + G\sin(A - B) \quad (3)$$
$$G\sin(A + B) - G\sin(A - B) \quad (4)$$

where G is the modulator conversion gain.

It is apparent that if these signals are added, the resultant is the upper sideband, while if they are subtracted the resultant is the lower sideband.

The Practical System

The block diagram of a system constructed to generate a single sideband using this technique is shown in Fig. 1. An examination of Eq. (1) and (2) and Fig. 1 reveals that the carrier as well as the signal frequencies must be shifted 90 degrees in order to obtain the desired phase relations. This is readily achieved in the case of the fixed carrier frequency

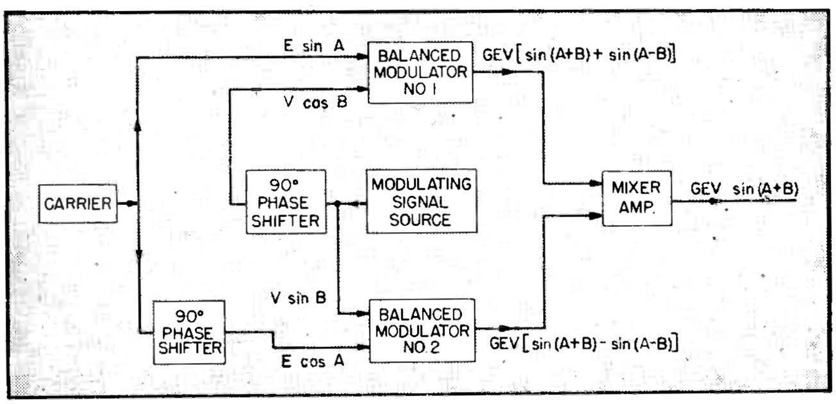

FIG. 1—Block diagram of single-sideband generator using two balanced modulators. The mixer is a linear amplifier

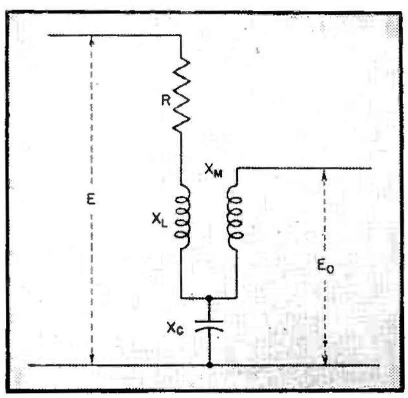

FIG. 2—Schematic circuit diagram of the 90-degree phase shifter

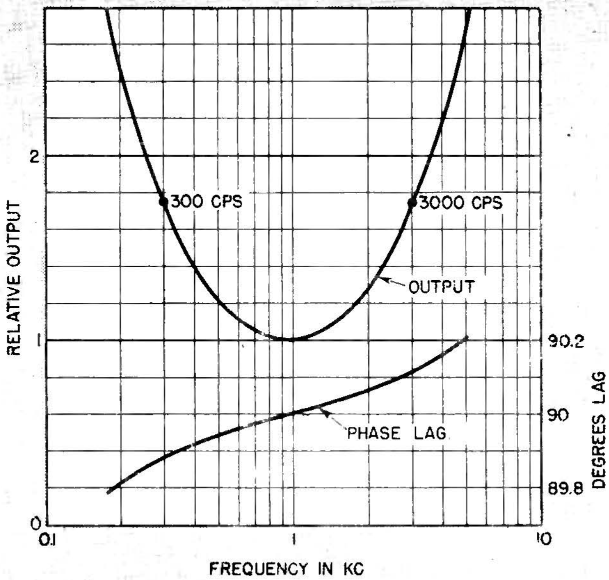

FIG. 3—Calculated amplitude and phase response of phase shifter with $R = 100{,}000$ ohms, $C = 2.34$ microfarads, and $L = M = 0.012$ henry

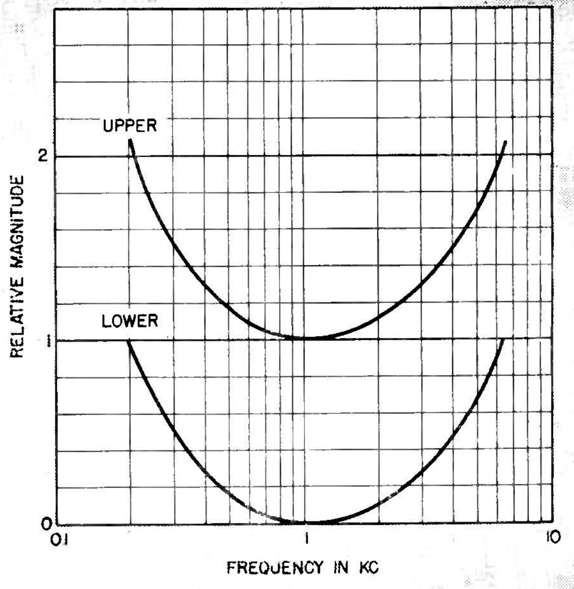

FIG. 4—Measured relative magnitudes of upper and lower sidebands, plotted as a function of the modulating frequency of the system

through the use of a simple phase shifter.[4] If the modulating signals are one or more fixed telemetering frequencies, the required 90-degree phase shifts for these frequencies may be obtained by using a phase shifter of the resistor-capacitor type.

90-Degree Phase Shifter

The problem of shifting a band of telephonic voice frequencies of from 300 to 3,000 cycles is inherently more difficult. It is necessary, in the ideal case, to shift this band of frequencies 90 degrees and at the same time leave the relative magnitudes unchanged. The necessary sine-cosine relationship can be obtained electronically by using an additional pair of modulators and a simple filter.

A passive network which gives a reasonable approach to this problem is shown in Fig. 2, while its amplitude and phase response characteristics are shown in Fig. 3. The amplitude response of this phase shifter is

$$\frac{E_o}{E} = \frac{X_C + X_M}{\sqrt{R^2 + (X_L - X_C)^2}} \qquad (5)$$

When R is much greater than $(X_L - X_C)$, this becomes very closely

$$E_o/E = (X_C + X_M)/R \qquad (6)$$

The phase response of the network is

$$\phi = -90^\circ - \tan^{-1}(X_L - X_C)/R \qquad (7)$$

Referring to Fig. 3, it is seen that the amplitude response varies through a range of 1.75/1 over the frequency band of 300 to 3,000 cps. While this variation is undesirable in an ideal system, it is compensated in part through the use of an output tuned circuit resonated to the mid-frequency of the desired sideband. In addition, this response characteristic partially corrects for the frequency discrimination due to the usual microphones, receivers and speech-band repeat coils.

System Performance

The single-sideband generator outlined in Fig. 1 and using the phase shifter of Fig. 2 was constructed to check the possibilities of the proposed system. A carrier frequency of 8,000 cps was chosen in order that all frequencies through the second harmonic of the carrier would fall within the range of a standard harmonic wave analyzer.

Balanced square-law modulators were used, and since the experimental system contained no filters or tuned circuits, it was necessary to make the carrier amplitude much greater than the signal amplitude so that the residue of the signal would be negligibly small at the output of the modulators.[5] Although the second harmonic of the carrier at the output of each balanced mod-

TABLE I. EQUATIONS OF AMPLITUDE-MODULATED WAVES

$$\sin A\,(1 \pm m \sin B) = \sin A \pm \frac{m}{2}\cos(A - B) \mp \frac{m}{2}\cos(A + B)$$

$$\sin A\,(1 \pm m \cos B) = \sin A \pm \frac{m}{2}\sin(A - B) \pm \frac{m}{2}\sin(A + B)$$

$$\cos A\,(1 \pm m \sin B) = \cos A \mp \frac{m}{2}\sin(A - B) \pm \frac{m}{2}\sin(A + B)$$

$$\cos A\,(1 \pm m \cos B) = \cos A \pm \frac{m}{2}\cos(A - B) \pm \frac{m}{2}\cos(A + B)$$

where $A = 2\pi f_c t$
$B = 2\pi f_s t$
f_c = carrier frequency
f_s = modulating signal frequency

ulator is quite large, it is cancelled when the outputs of the two modulators are combined in the mixer amplifier.

Figure 4 shows the measured magnitudes of upper and lower sidebands, plotted as a function of the modulating frequency and normalized about the 1,000-cps value of the upper sideband. These experimental values check very closely with the expected magnitudes on the basis of the calculated response of the phase shifter as shown in Fig. 3.

Referring to Fig. 4, it is to be noted that for an 8,000-cps carrier the 1,000-cps point on the upper-sideband curve represents a sideband frequency of 9,000 cps, whereas the corresponding point on the lower-sideband curve represents a frequency of 7,000 cps. A parallel-resonant circuit or a simple double-tuned coupled circuit tuned to 9,000 cps and placed in the output of the mixer amplifier of Fig. 1 will flatten the upper-sideband curve and will discriminate against the lower-sideband frequencies.

Figure 5 shows the measured upper- to lower-sideband ratios plotted in decibels as a function of the modulating frequency. It is to be noted that this ratio exceeds 10 db from 300 to 3,000 cps. The data for the plotted curves was obtained on the single-sideband generator shown in Fig. 6, containing no filters or tuned circuits and practically no shielding. The results represent, therefore, the most pessimistic of operating conditions. For carrier transmission or for radio transmission, simple tuned circuits would be employed in the amplifiers following the mixer amplifier, with a resultant improvement in discrimination against the undesired sideband.

If it is desired to pass the lower sideband and to balance out the upper sideband, this is accomplished by reversing the polarity of either the carrier or the signal voltage fed to one of the modulators. This result may also be achieved by reversing the polarity of the output voltage of one of the modulators. Measured characteristics for this case are similar to Fig. 4 and 5.

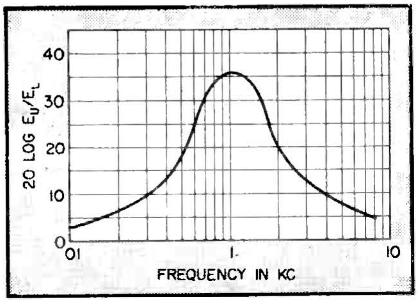

FIG. 5—Measured upper to lower sideband ratios in db

The characteristics of this particular system do not represent the optimum performance that can be obtained from a single-sideband generator of this type. In the opinion of the writer, this generator has the advantage of simplicity over the usual single-sideband systems. The complete success of the system lies in the design of a wide-band 90-degree phase shifter. However, it is to be remembered that a simple 90-degree phase shifter suffices if the modulating signals are fixed telemetering frequencies.

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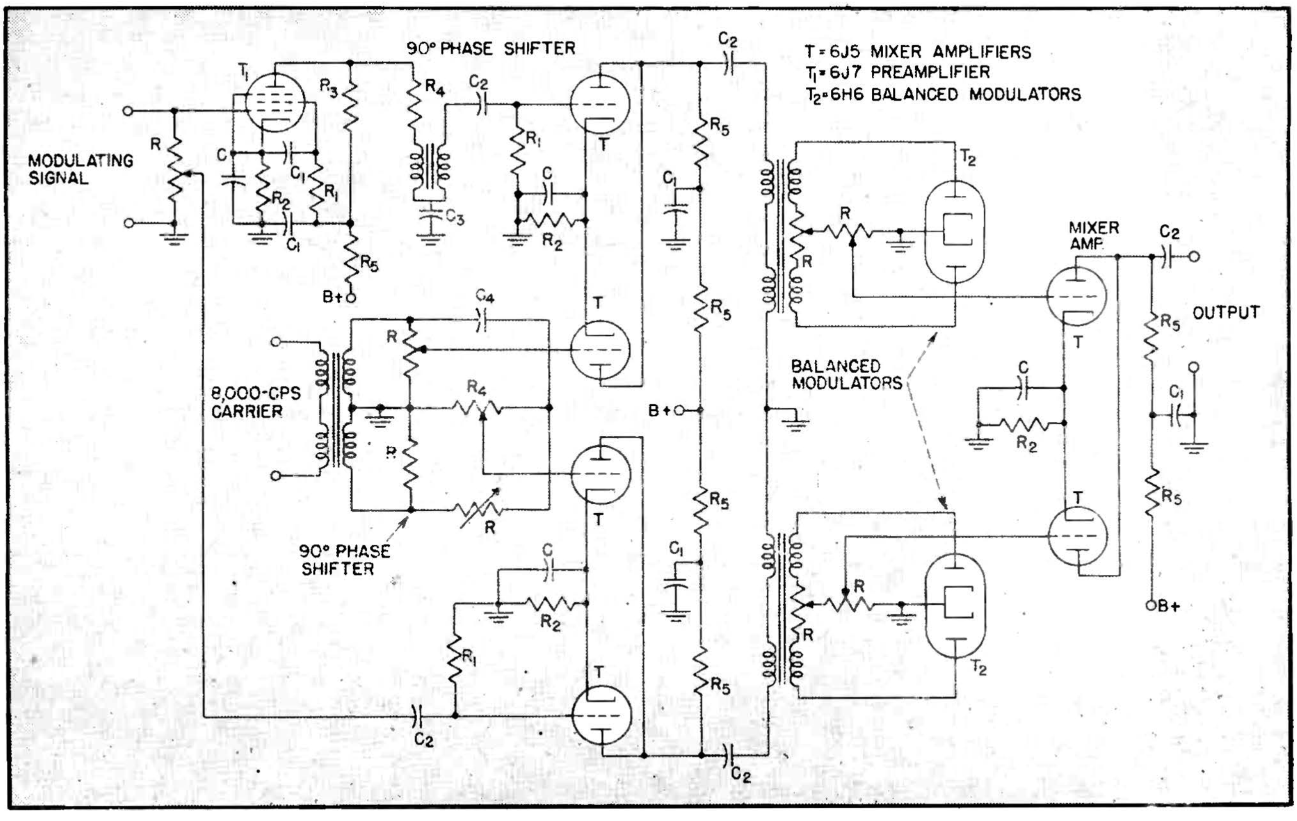

FIG. 6—Circuit of experimental single-sideband generator