

July 8, 1941.

E. PETERSON

2,248,250

SINGLE SIDE-BAND MODULATION

Filed Sept. 21, 1939

2 Sheets-Sheet 1

FIG. 1

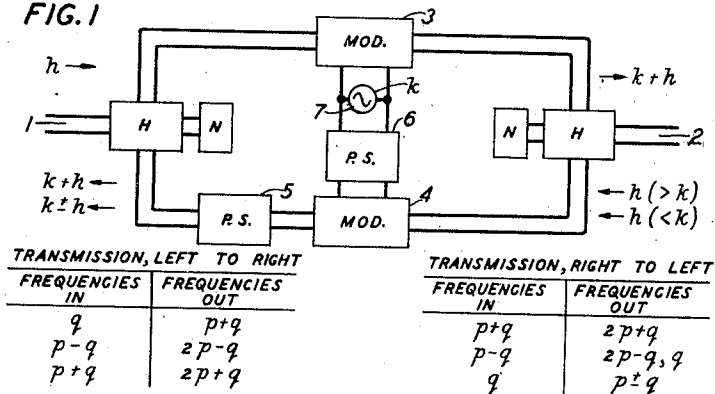


FIG. 2

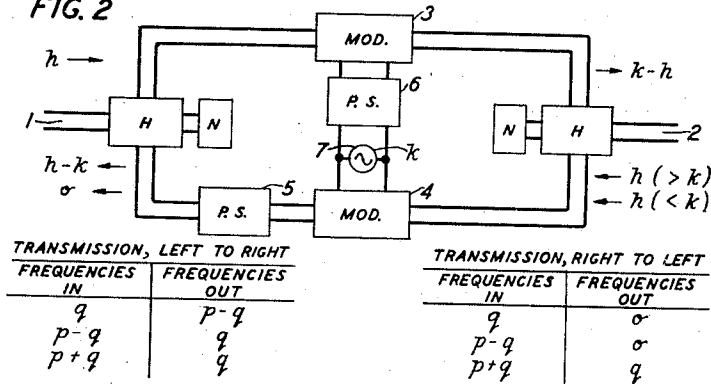
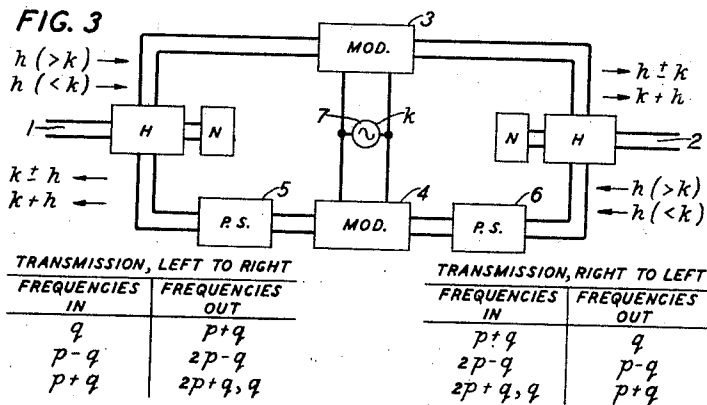


FIG. 3



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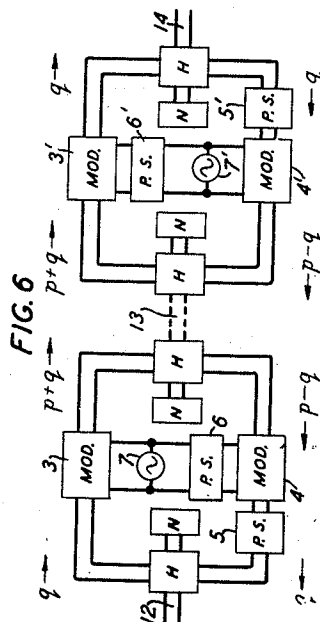
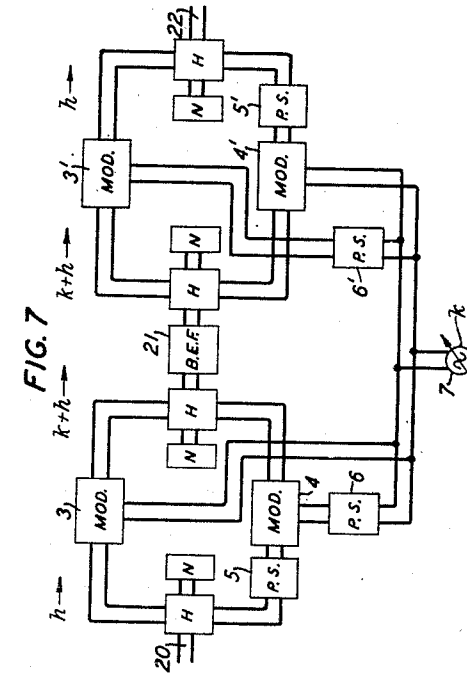
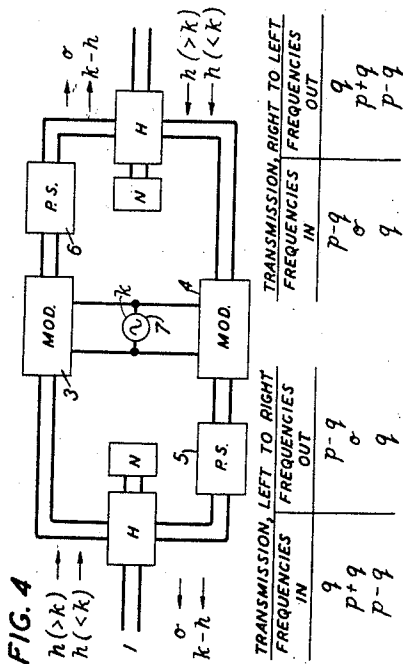
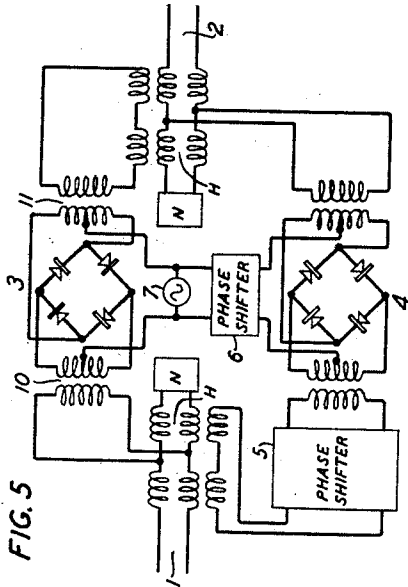
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SINGLE SIDE-BAND MODULATION

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2 Sheets-Sheet 2



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SINGLE SIDE-BAND MODULATION

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5 Claims. (Cl. 178—44)

The present invention relates to wave modulation and more particularly to single side-band modulation and its applications.

A general object of the invention is to provide improved wave translating and wave transmission systems making use of single side-band modulation.

One type of circuit for accomplishing single side-band modulation is disclosed in R. V. L. Hartley Patent 1,666,206, April 17, 1928. This type of circuit uses two modulators and two phase shifters, one for shifting the phase of the applied signal and the other for shifting the phase of the carrier or other high frequency wave.

I have discovered that quite different results can be obtained in single side-band modulating systems using two phase shifting circuits and two modulators, depending upon the arrangement of these elements in the circuit. From the standpoint of frequency translation and whether the circuit behaves similarly or differently in the two directions of transmission, these differences in result are of practical importance.

A feature of the invention, therefore, is such an arrangement of phase shifting and modulating circuits in a single side-band modulating system as will produce any of several different frequency translating effects.

One aspect of the invention is the employment of two different types of single side-band modulating circuits as opposite terminals of a carrier channel.

The nature and objects of the invention will be made more apparent in the detailed description to follow, including the drawings in which:

Figs. 1 to 4 are simplified block-schematic diagrams of circuit configurations in accordance with the invention;

Fig. 5 is a schematic circuit diagram showing a preferred type of circuit of the configuration of Fig. 1;

Fig. 6 is a block-schematic diagram of a two-way carrier channel according to the invention; and

Fig. 7 is a similar diagram of a current amplifying or measuring circuit.

It is shown in the Hartley patent that second order modulation between a carrier frequency p and signal frequency q produces a pair of side-

bands from one of the two modulators, of the form

$$\cos (p+q)t \text{ and } \cos (p-q)t$$

and a pair of side-bands from the second modulator, of the form

$$\cos [(p+q)t+B+C] \text{ and } \cos [(p-q)t+B-C]$$

under the condition that the carrier wave has been shifted by a phase angle B and the signal has been shifted by a phase angle C before their application to the second modulator.

If $B=C=90$ degrees at every frequency in the band, as pointed out by Hartley, addition of the two pairs of side-bands results in cancellation of the upper side-bands and direct addition of the lower side-bands. Subtraction of the two pairs results in cancellation of the lower side-bands and direct addition of the upper side-bands. Either an upper or a lower side-band can be obtained, therefore, depending merely upon turning over a pair of leads or reversing direction of a transformer winding.

If one is more interested in the cancellation of one pair of the side-bands than in the addition in maximum amplitude of the retained side-bands, it is only necessary to make $B=C$ regardless of whether they are 90 degrees or something less, such as 60 degrees or 45 degrees. The addition of the two retained side-bands is in some vectorial relation other than in zero phase and the resultant is less than the arithmetical sum of their separate amplitudes. Moreover, only the lower side-bands can be eliminated if the phase shift is other than 90 degrees provided the circuit configuration is such that the waves of shifted phase are both applied to the same modulator, as assumed in the above formulae. Thus the choice between the side-bands to be retained cannot in such case be determined by merely turning over a pair of leads. This will be made more clear from a consideration of the circuit figures.

Fig. 1 is of the general configuration shown by Hartley with the assumption that all of the phase shift for the signal q is produced in one phase shifting circuit 5. (If desired, two phase shifters could be used as shown in Hartley's drawing to produce the required phase difference.) Terminal connecting lines 1 and 2 lead to hybrid coils H , H and balancing network N , N

as usual, with conjugate branches leading to modulators 3 and 4, respectively. A carrier or fixed frequency source of waves of frequency k is shown at 7, connected directly to modulator 3 and by way of phase shifter 6 to modulator 4. The phase shifter for the signal or other wave in the branch containing modulator 4 is shown at 5. It may be of the type disclosed by Hartley or one of the types disclosed by Zobel in an article published in the Bell System Technical Journal for July 1928 beginning at page 438.

The general frequency translating characteristics of the circuit of Fig. 1 are indicated by the use of symbols h and k , these being frequency components unrestricted as to magnitude except where their relative magnitudes are given. The arrows indicate at which terminal 1 or 2 the components are applied and from which terminal they emerge. The symbols in the same horizontal row are functionally related. Thus, if frequency h is applied at terminals 1, there will appear at terminals 2 the upper side-band only, $k+h$.

While the general translating properties of the circuit can be seen from inspection of the symbols h and k as indicated on the figure, it is also convenient to use a second set of symbols p and q , where p may represent a carrier frequency and q a signal frequency, p always being large compared to q , as is usual in practice. The types of frequency translation secured are given in the tabulations appearing just below the figure. It is noted, for example, that in transmitting from left to right an upper side-band $p+q$ is obtained. If $p+q$ is applied to terminals 2 for transmission from right to left, however, it is noted that no component q results. However, if a lower side-band $p-q$ is impressed on terminals 2, this circuit acts as a demodulator and gives as one output product the frequency q .

The foregoing statements regarding the types of frequency translation obtainable with the circuit of Fig. 1 are on the assumption that the phase shift in the carrier wave is the same as the phase shift at every frequency in the signal band ($B=C$) and that this phase shift is other than 90 degrees for all frequency components, in the phase shifting circuits 5 and 6. For example, there is no indication of a lower side-band $p-q$ for transmission from left to right in the figure as would be possible with phase shifts of 90 degrees at 5 and 6 with an appropriate direction of connection of the terminals of the modulator outputs to the outgoing circuit. This will be clear from the discussion given above.

It is also stated above that in order to secure a lower side-band where a phase shift other than 90 degrees is used, it is necessary to adopt a different circuit configuration such as shown in Fig. 2. This circuit differs from Fig. 1 in that the phase shifter 6 has been moved to a point between the oscillator 7 and the modulator 3. As indicated by the frequency symbols associated with this figure, a speech or other signal wave applied to terminals 1 results in the appearance of a lower side-band at terminals 2.

Fig. 3 presents an interesting case in that it is strictly bilateral; the same frequency translations occur in passing through the circuit in either direction. This differs from the previous circuit configurations in that the two phase shifters 5 and 6 appear in the same branch, one on each side of the modulator in that branch. On the assumption of equal phase shift other than 90 degrees in both carrier and signal, only an upper

side-band is produced in response to application of signal q to either of the terminals. If it is desired to produce a lower side-band, this circuit may be changed to the configuration shown in Fig. 4 which is also a strictly bilateral circuit. In the circuit of Fig. 4 one shifter 5 appears in the circuit on one side of one modulator 4 while the other phase shifter 6 appears on the opposite side of the other modulator 3.

A further characteristic of the circuit of Fig. 3 is that if the signal applied to one of the terminals has a higher frequency than that of the oscillator 7, upper and lower side-bands result, whereas if the frequency order is the reverse of this only a single side-band results. Under similar conditions, Fig. 4 yields no output product or only a lower side-band respectively.

One use for circuits of the type shown in any one of Figs. 1 to 4 is in connection with current analyzers of the heterodyne type or similar situations involving frequency translations including those in which the frequency of the locally produced wave 1 is varied. It is noted in any of these circuits that there are in the output no double frequencies of the input component.

Fig. 5 shows in greater detail the types of modulator circuit which are preferably used in any one of the previously described circuits, although it is to be understood that other types of modulators including space discharge tube modulators may be used. Referring to Fig. 5, where the component parts are identified by the same reference characters as are used in the previous figures, it is seen that the modulators 3 and 4 each comprise a bridge of solid-element rectifiers, preferably of the copper-oxide type. These are connected between the hybrid coils 1 and 2 by means of transformers, such as 10 and 11, the mid-points of which lead to terminals of the oscillator 7 either through phase shifter 6 or not, as the case may be, depending upon the circuit configuration desired. Modulators of this type are more fully disclosed and are claimed in United States patent to F. A. Cowan No. 2,025,158 granted December 24, 1935.

Referring to Fig. 6, there is shown a relatively long carrier transmission line 13 terminating at each end in frequency translating apparatus for two-way repeating between the line 13 and terminal low frequency lines 12 and 14, respectively.

The terminal station at the left will be recognized as the Fig. 1 type of circuit while that on the right is the circuit of the type of Fig. 2 reversed from right to left with respect to its showing in Fig. 2. The parts are identified by reference characters 3, 4, 5, 6 and 7 at the left-hand terminal and the same reference characters primed at the right-hand terminal. The carrier sources 7 and 7' are assumed to generate the same frequency, namely the frequency p , although, of course, they could be arranged to produce different carrier frequencies, if desired.

Reference to the tables of symbols given on Figs. 1 and 2 will show that the system of Fig. 6 transmits an upper side-band $p+q$ from left to right over the line 13 and a lower side-band $p-q$ over the line 13 in a direction from right to left. Each terminal is of a type to demodulate the side-band received from the opposite terminal. Thus single side-band transmission is secured in each direction without the employment of filters or other selective circuits for separating side-bands.

It will be obvious from the description above of Figs. 3 and 4 that two-way carrier systems simi-

lar, in general, to that shown in Fig. 6 can be built up by using, for example, two of the bilateral circuits of Fig. 3 at opposite terminals of a carrier line or by using two terminal stations of the Fig. 4 type.

Such systems would differ from the system of Fig. 6 in that they would transmit the same side-band in both directions.

In case it might be desired to provide a carrier channel that is unilaterally transmitting, the circuit of Fig. 1 may be used at the transmitting terminal to send out an upper side-band and the circuit of Fig. 2 may be used at the receiving terminal to receive the upper side-band and translate it into signal q . This channel will not transmit in the opposite direction, however, for the upper side-band that would result at the right-hand or normally receiving terminal would not produce output speech at the opposite terminal.

The various combinations and circuit configurations illustrate cases in which modulation, demodulation and discrimination between side-bands is secured without the aid of filters or other frequencies selective circuits. One field in which these results are of particular advantage is in high frequency transmission in which separation between adjacent side-bands by means of filters or selective circuits may be difficult or impossible.

In modulation testing it is frequently advantageous to suppress a narrow band of frequencies in the signal in order to make measurements of non-linear distortion in the suppressed region. It has been customary to use a set of fixed band elimination filters to cover the signal frequency band. Fig. 7 discloses how a band elimination filter 21 of fixed band and fixed frequency limits can be used to suppress a frequency band of this width from any desired portion of a band. The circuit configuration resembles that of Fig. 6 but the band elimination filter is inserted in place of the long line 13 and the carrier source 7 is made variable. The band to be measured or tested is applied to the terminals 20 and the frequency of the source 7 is adjusted so that the portion of the band to be eliminated is made to coincide with the limits of the band elimination filter 21. The band in question will be attenuated by some value y decibels. Since the balance in the single side-band modulating system is not perfect, the lower side-band will not be completely suppressed but will be attenuated by some value x decibels. In passing through the demodulation circuit the upper side-band will be stepped down intact to the output circuit 22 and the lower side-band will be further attenuated by x decibels, (it will be assumed) giving a total attenuation of $2x$ decibels for the lower side-band. This will be superposed on the demodulated upper side-band. By suitable circuit design the narrow band may be suppressed to the desired degree.

The invention is not to be construed as limited to the circuit configurations or magnitudes that have been given nor to the circuit details, since all of these are to be considered as typical or illustrative, the scope of the invention being defined in the claims.

What is claimed is:

1. A bilaterally conducting single side-band

modulation circuit comprising a pair of bilaterally conducting modulators, a two-way low frequency circuit coupled to one side of each modulator, a two-way high frequency circuit coupled to the opposite side of each modulator, a carrier wave supply circuit coupled to each modulator, said modulators each producing a pair of side-bands representing modulation products between said carrier wave and a wave supplied from either of said two-way circuits, and phase shifters included in certain of said circuits for causing one side-band of each pair to cancel each other and the opposite side-band of each pair to be superposed to give the resultant output side-band.

2. A bilaterally conducting modulation circuit according to claim 1 in which at least one of said phase shifters is connected between one of said two-way circuits and one of said modulators, and in which said phase shifters are so disposed in the circuit that a wave q in the low frequency circuit produces a single second order side-band in the high frequency circuit and a second order side-band in said high frequency circuit produces a wave q in said low frequency circuit.

3. A bilaterally conducting modulation circuit according to claim 1 in which one of said two phase shifters is in the carrier supply circuit supplying carrier wave p and the other is in circuit with one of said modulators and one of said two-way circuits, such that an input wave q in the low frequency circuit produces a side-band wave $p+q$ in the high frequency circuit and an input side-band wave $p-q$ in the high frequency circuit produces a wave q in the low frequency circuit.

4. A bilaterally conducting modulation circuit according to claim 1 in which one of said two phase shifters is in the carrier supply circuit supplying carrier wave p and the other is in circuit with one of said modulators and one of said two-way circuits, such that an input wave q in the low frequency circuit produces a side-band wave $p-q$ in the high frequency circuit and an input side-band wave $p+q$ in the high frequency circuit produces a wave q in the low frequency circuit.

5. In combination two bilaterally conducting single side-band modulating circuits each having a pair of high frequency terminals and a pair of low frequency terminals, each comprising a pair of bilaterally conducting modulators, a carrier supply circuit therefor and a pair of phase shifters, a two-way channel connecting the high frequency terminals of said circuits, said phase shifters being disposed differently in said two modulating circuits but with one phase shifter in circuit between the carrier supply circuit and one of the modulators and the other in circuit between one of the modulators and one of said pairs of terminals, such that a modulating wave applied to the low frequency terminals of the modulating circuit produces an upper side-band in the case of one of said modulating circuits and a lower side-band in the case of the other of said modulating circuits, and that the side-band produced in each of said modulating circuits when received at the high frequency terminals of the opposite modulating circuit reproduces a wave at the low frequency terminals thereof corresponding to the original modulating wave applied to the opposite modulating circuit.

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