

Aug. 19, 1930.

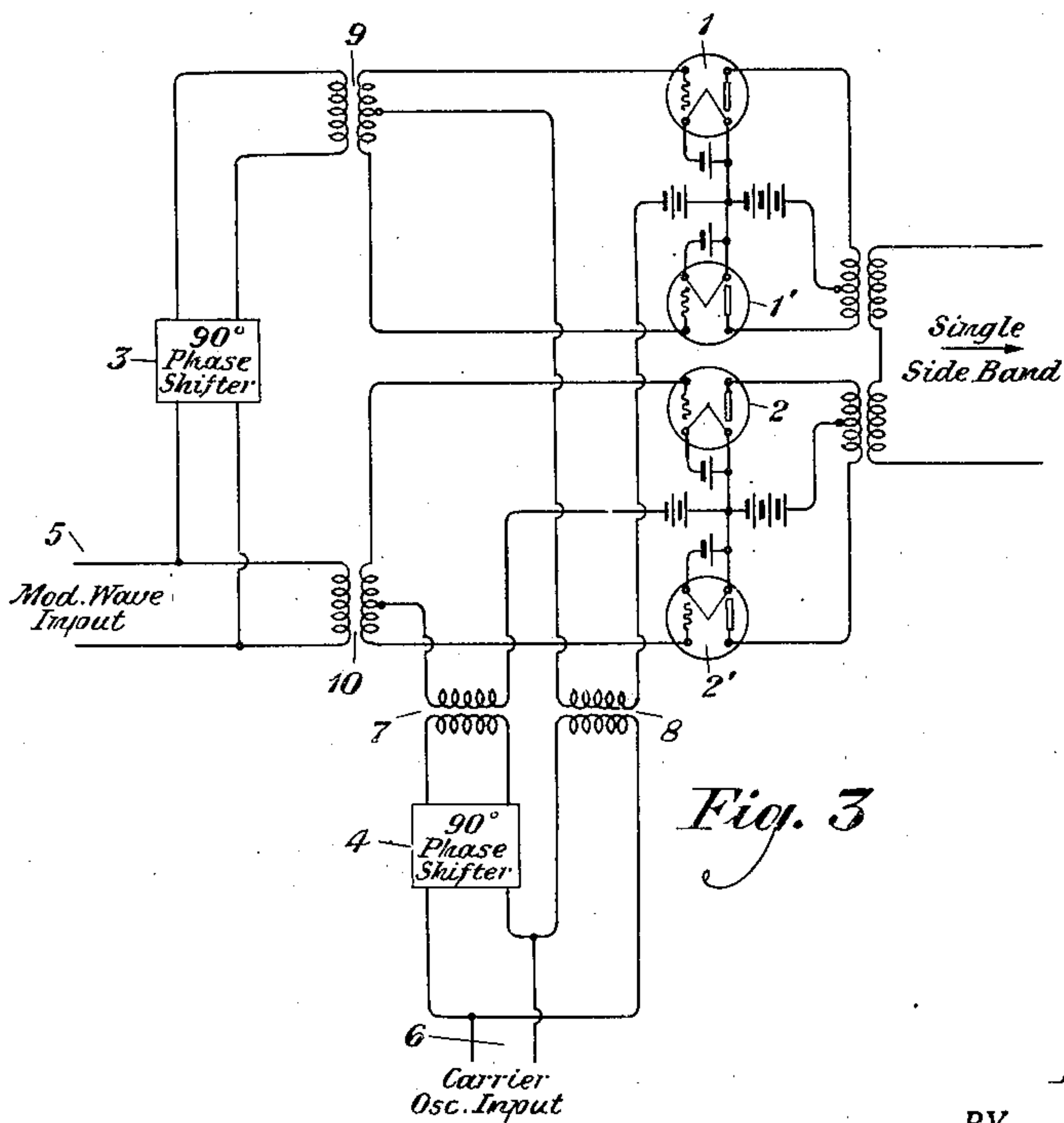
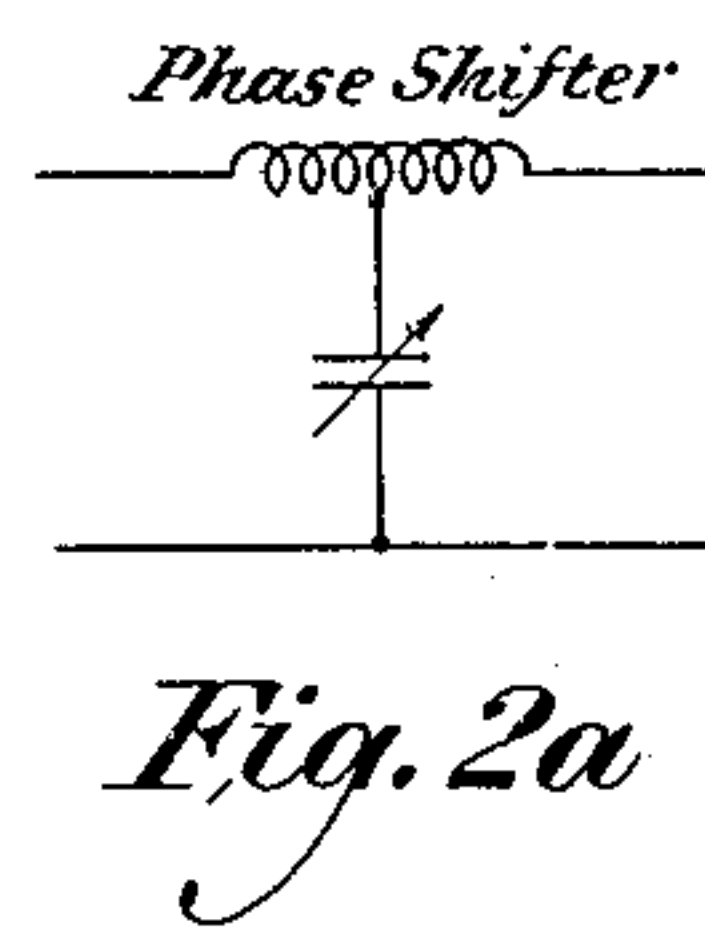
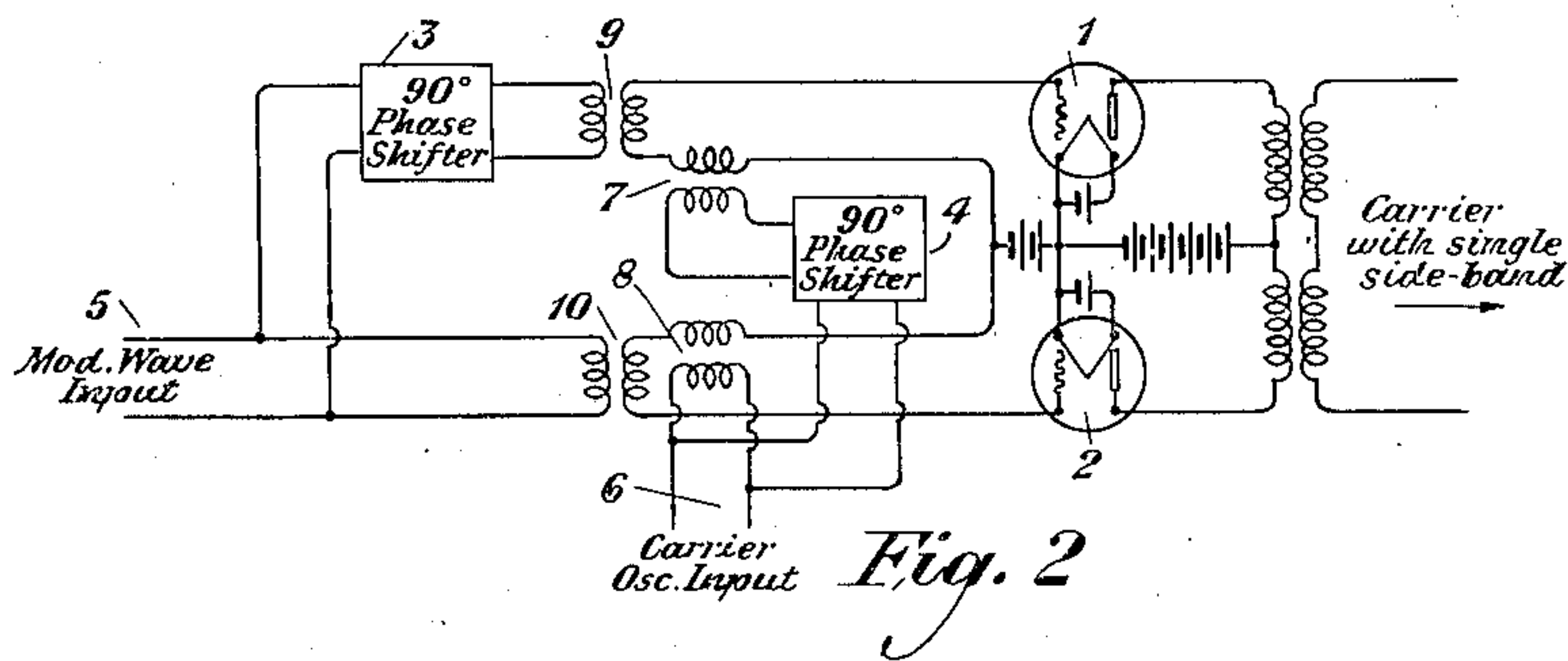
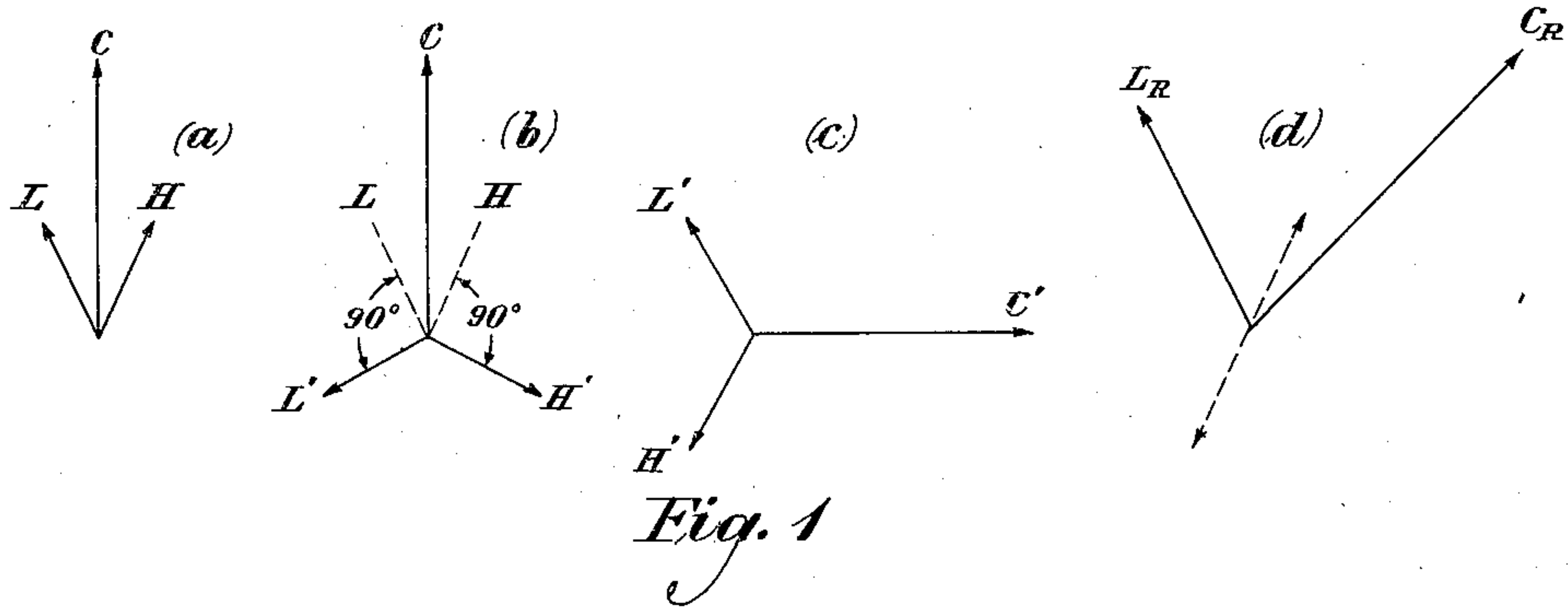
R. K. POTTER

1,773,116

SINGLE SIDE BAND SYSTEM

Filed Jan. 24, 1928

2 Sheets-Sheet 1



INVENTOR.
R. K. Potter
BY *John*
ATTORNEY

Aug. 19, 1930.

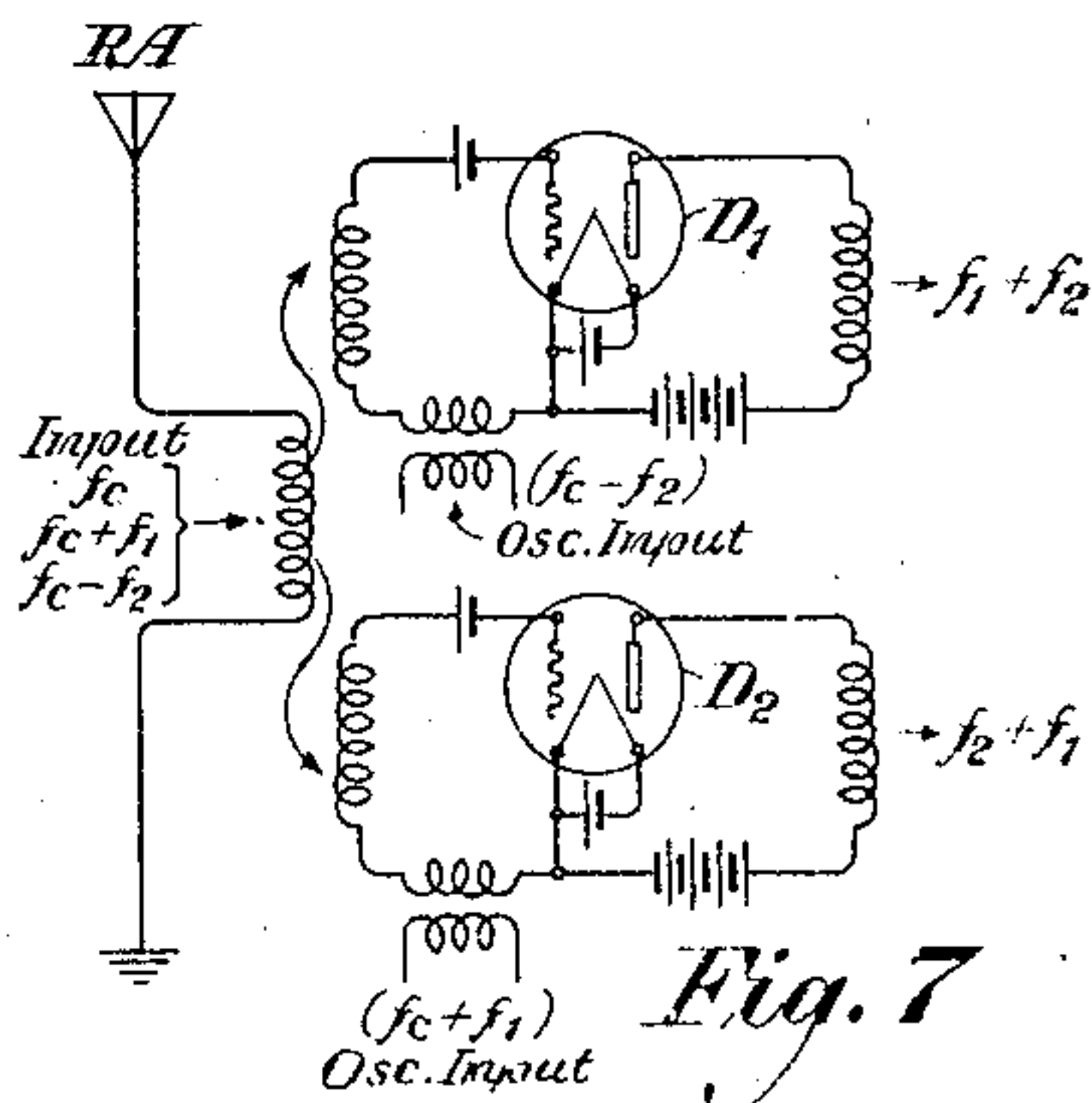
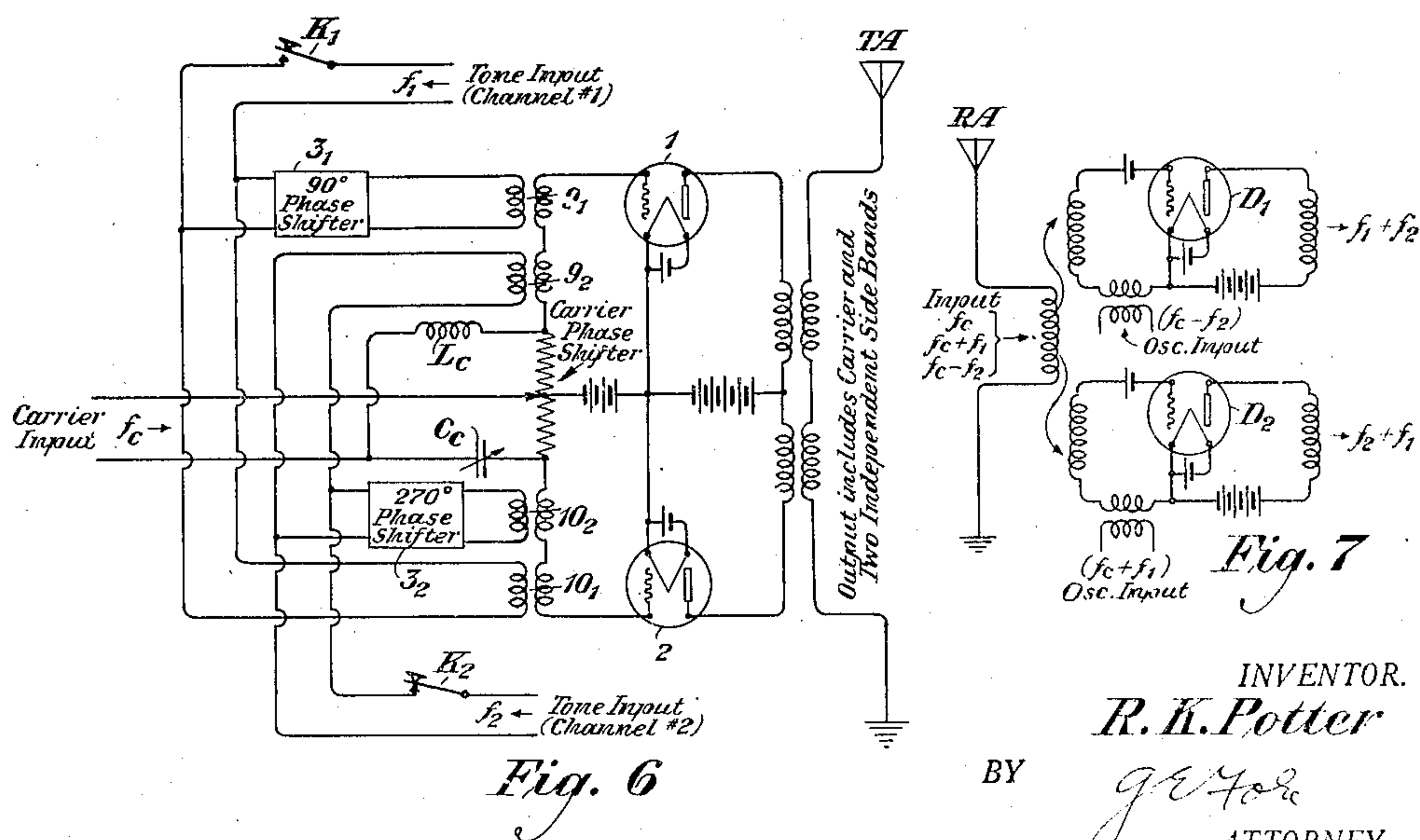
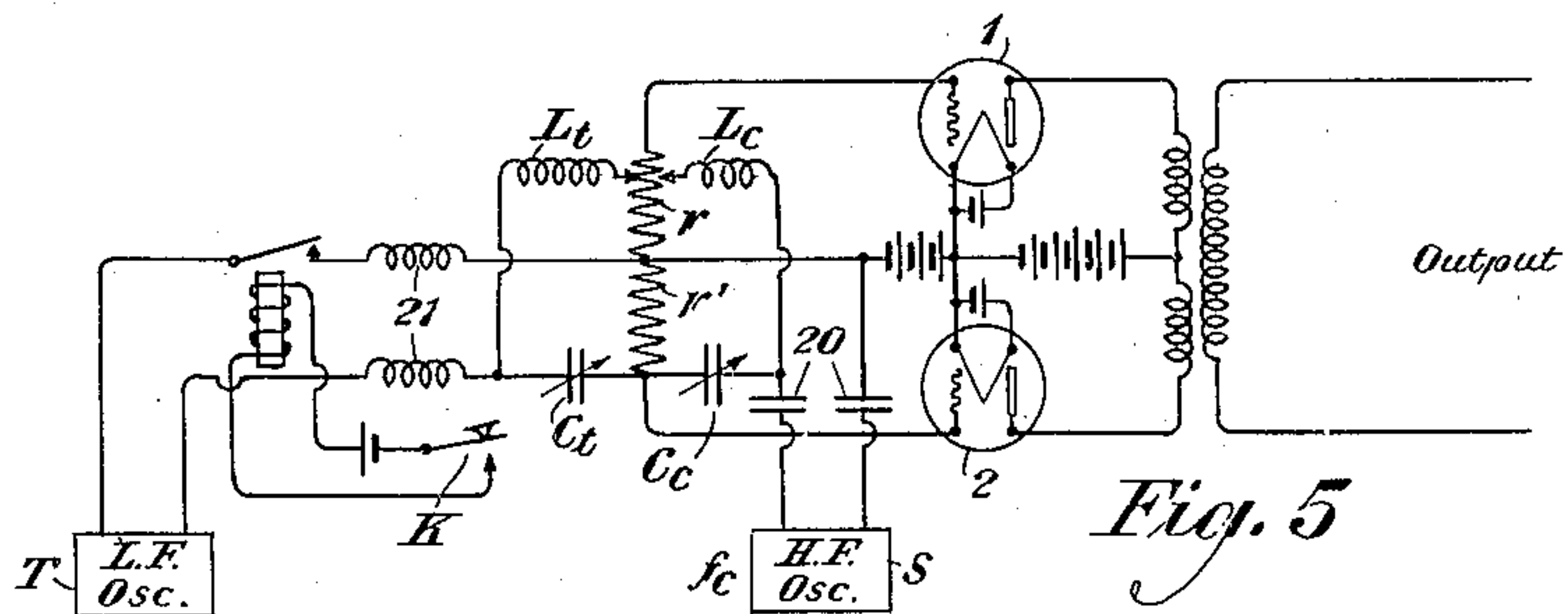
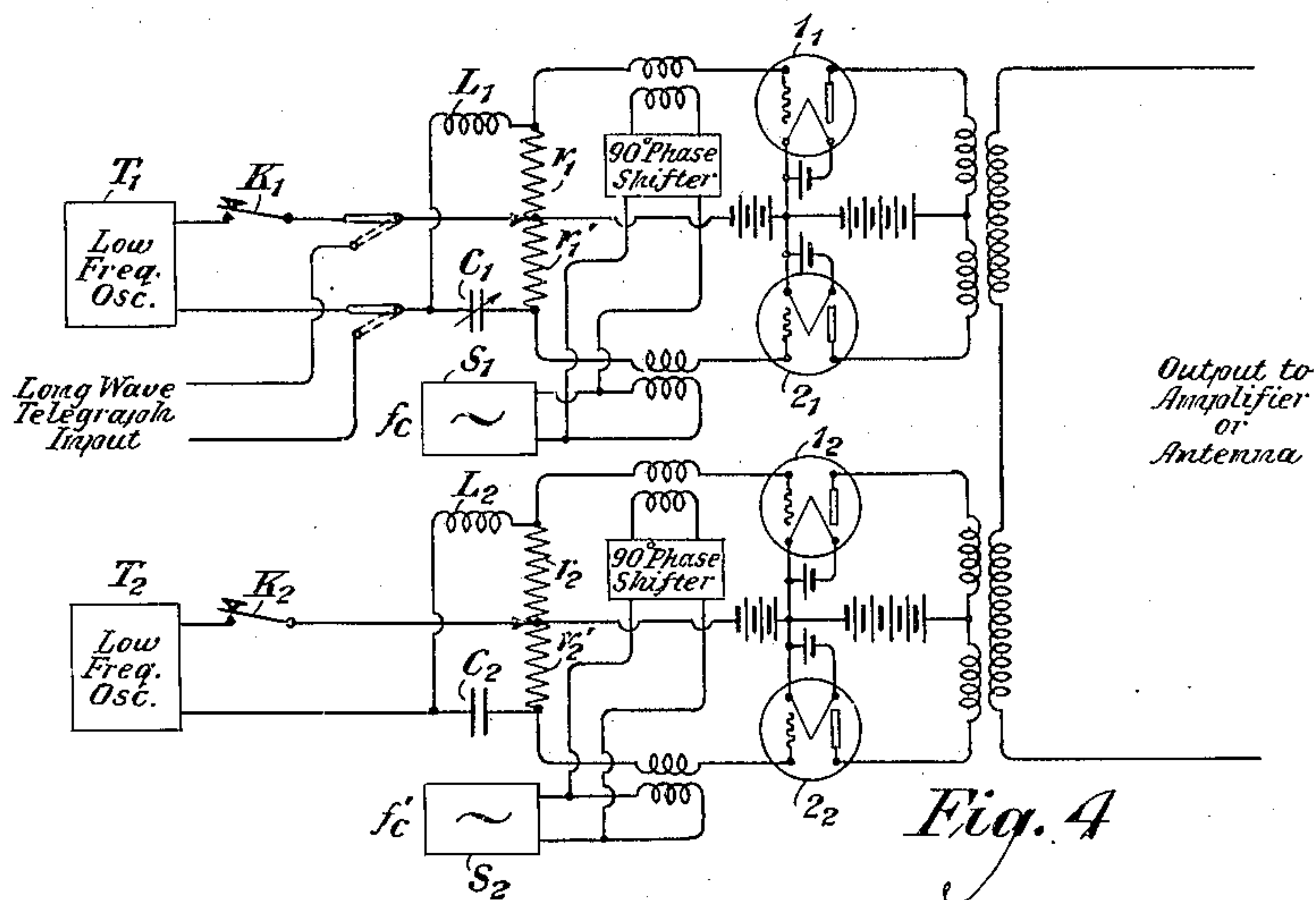
R. K. POTTER

1,773,116

SINGLE SIDE BAND SYSTEM

Filed Jan. 24, 1928

2 Sheets-Sheet 2



INVENTOR.
R. K. Potter
BY
J. E. Forrester
ATTORNEY

UNITED STATES PATENT OFFICE

RALPH K. POTTER, OF NEW YORK, N. Y., ASSIGNOR TO AMERICAN TELEPHONE AND
TELEGRAPH COMPANY, A CORPORATION OF NEW YORK

SINGLE-SIDE-BAND SYSTEM

Application filed January 24, 1928. Serial No. 249,099.

This invention relates to a signaling system, and more particularly to a signaling system in which one of the side-bands or frequencies resulting from modulation is suppressed.

In certain types of signaling systems involving the modulation of waves of different frequencies, it is desirable to suppress the sum or difference products of the combination. Where the separation between the frequencies is sufficient, a filter may be economically employed to suppress the undesired component or components, but where small frequency differences are involved between the upper and lower side components of the modulated wave, a filter so designed as to accomplish the desired result would be very cumbersome, and in some instances altogether impractical.

In accordance with the present invention it is, therefore, proposed to overcome these limitations in filter construction by employing a method of suppressing the side-band or side frequency which involves the use of a "balancing out" effect for the elimination of the undesired components.

The invention will now be more fully understood from the following detailed description when read in connection with the accompanying drawing in which Figure 1 shows vector diagrams illustrating the principles underlying the invention; Fig. 2 illustrates a simple form of balanced modulator for balancing out one of the side-bands; Fig. 2^a illustrates a simple form of phase shifter to be used in connection with the invention; Fig. 3 illustrates a modulator arrangement for balancing out both the carrier and one of the side-bands; Fig. 4 illustrates an embodiment of the invention as applied to multiplex telegraphy; Fig. 5 illustrates a modification of the arrangement disclosed in Fig. 4; Fig. 6 illustrates an embodiment of the invention in which two signals are transmitted, one on the upper side-band with the lower side-band suppressed and the other on the lower side-band with the upper side-band suppressed, both employing the same carrier frequency; while Fig. 7 illustrates a receiving arrangement adapted to be employed in connection

with the transmitting arrangement of Fig. 6.

The general principle underlying the invention involves impressing the same carrier frequency and modulating frequency upon each of two modulators in such a manner that the two carrier frequency components will be substantially 90° out of phase with each other in the two modulators, and also the two signaling components will be substantially 90° out of phase with each other. The manner in which this results in suppressing one of the side frequencies will be understood from the vector diagrams of Fig. 1.

For example, the vector diagram at (a) in Fig. 1 represents an assumed instantaneous relation between a modulated carrier wave and the products resulting from the modulation of such a wave by a wave of constant frequency. In the case of radio transmission, for example, vector C represents the carrier and vectors L and H represent the lower and upper side-band components, respectively, produced by single-tone modulation of this character. With respect to the vector C, the vector L may be considered as rotating clockwise at an angular velocity equal to the angular velocity of the modulating wave. Similarly, the vector H may be considered as rotating counter-clockwise with respect to C at the same rate. In order to complete the conception, it is necessary to visualize a rotation of the whole picture (as given above), counter-clockwise at an angular velocity equal to that of the carrier wave.

If, at the same instant as represented by the vector diagram (a) in Fig. 1, the carrier had been modulated by the same single-tone displaced in phase by 90°, the result would have been as shown at (b) in Fig. 1. Displacement of the carrier in phase by 90° also for this second case would have produced the relations shown at (c) in Fig. 1. If, now, we combine the instantaneous vector pictures of (a) and (c), either the sum or difference products of the two modulations will cancel each other, depending upon the sense of their combination. The resultant vectors produced by one such combination is shown at

(d) in Fig. 1, where the upper side frequency components H balance each other, while the lower side frequency components add to each other to produce the vector L_r and the two carrier components produce a resultant carrier vector C_r .

A circuit which will accomplish this sort of suppression is illustrated in Fig. 2. Here two modulating vacuum tubes 1 and 2 are provided and a carrier frequency from a circuit 6 is supplied to the input circuits of both modulators through transformers 7 and 8. A phase shifter 4 is included between the transformer 7 and the circuit 6 in order that the carrier component supplied to the tube 1 will be 90° out of phase with the carrier component supplied to the tube 2. Likewise, a modulating signal wave from a circuit 5 is applied to the modulating tubes through transformers 9 and 10, a phase shifter 3 being inserted between the transformer 9 and the circuit 5 so that the signal component supplied to the tube 1 will be 90° out of phase with that supplied to the tube 2. The phase shifters 3 and 4 may be of any known type, an example, for purposes of illustration, being shown in Fig. 2^a. It is not essential to the suppression of one side component that the phase shifts be exactly 90° for both waves impressed upon the grid of tube No. 1. It is, however, necessary that the sum of the phase shifts produced in the two waves be approximately 180° . Obviously, the two opposing components must be of the same magnitude to produce complete neutralization.

A mathematical analysis of the theory involved in the operation of this circuit will now be given. Let the instantaneous value of modulated potential in tube 1 of Fig. 2 equal

$$e_1 = (E_o + E_m \cos pt) \sin wt \\ = E_o \sin wt + E_m \cos pt \sin wt \quad (1)$$

where e_1 is the instantaneous voltage in the output of the tube; E_o is a constant proportional to the magnitude of the carrier input; E_m is a constant proportional to the magnitude of the product of the carrier input and the signaling input wave; p is 2π times the signal frequency; w is 2π times the carrier frequency; and t is the time. This expression reduces to,

$$e_1 = E_o \sin wt + \frac{E_m}{2} \sin (w+p)t + \frac{E_m}{2} \sin (w-p)t \quad (2)$$

Here, the first expression on the right-hand side of Equation (2) represents the carrier wave component in the output circuit of the tube; the second expression represents the sum or upper side frequency resulting from modulation; and the third expression represents the difference or lower side frequency resulting from modulation.

By substituting $w-\theta$ and $p-\theta$ for w and p , respectively, in Equation (2), we have

$$e_2 = E_o \sin (w-\theta)t + \frac{E_m}{2} \sin (w-\theta+p-\theta)t \\ + \frac{E_m}{2} \sin (w-\theta-p+\theta)t \\ = E_o \sin (w-\theta)t + \frac{E_m}{2} \sin (w+p-2\theta)t \\ + \frac{E_m}{2} \sin (w-p)t \quad (3)$$

which represents the output of tube 2 in Fig. 2.

Combining Equations (2) and (3) to obtain the output of tubes 1 and 2 working into the same circuit, we have

$$e_1 \pm e_2 = E_o (\sin wt \pm \sin (w-\theta)t) + \\ \frac{E_m}{2} (\sin (w+p)t \pm \sin (w+p-2\theta)t) + \\ \frac{E_m}{2} (\sin (w-p)t \pm \sin (w-p)t) \quad (4)$$

From an analysis of Equation (4), it is evident that if the voltages e_1 and e_2 be added to each other, the two components of frequency $w+p$, being 180° out of phase with each other, will just neutralize each other, while the components of frequency $w-p$, being in phase with each other, will have an additive effect. On the other hand, if the voltages e_1 and e_2 be combined in opposing relation so that the one subtracts from the other, then the components of frequency $w-p$ in Equation (4) will neutralize each other, while the two components of frequency $w+p$ will add to each other. This last is evident from the fact that two waves of the same frequency 180° apart will, when subtracted, assist each other. Consequently, either one of the side frequencies may be eliminated when $\theta=90^\circ$, the side frequency remaining depending upon the sense of the external connection.

In Fig. 2, the output consists of the carrier component and either the sum or difference product of modulation. Fig. 3 illustrates a circuit which utilizes the balanced modulator principle in accomplishing the suppression not only of one side frequency but also of the carrier. Here the upper modulator consists of two tubes 1 and 1', arranged in a push-pull circuit, while the lower modulator likewise consists of two tubes 2 and 2', arranged in a push-pull circuit. The carrier frequency is applied through transformers 8 and 7, respectively, to the common branches of the input circuits of the upper and lower modulators so that the balanced relation of the tubes of each modulator will result in the suppression of the carrier component from the output circuit. The carrier component applied to the lower tube through the transformer 7 is 90° out of phase with that applied to the upper modulator by reason of

the inclusion of the phase shifter 4 in the circuit. The signal frequency is applied serially to the grids of the tubes 1 and 1' through the transformer 9, and serially to the grids of the tubes 2 and 2' through the transformer 10. A phase shifter 3 included between the signal source and the transformer 9 results in the application of the carrier component to the upper push-pull circuit 90° out of phase with the component applied to the lower push-pull circuit. The phase shift introduced into the carrier and signal components results in the suppression of one side frequency just as described in connection with Fig. 2, while the push-pull relation of the two halves of each modulator results in the suppression of the carrier so that only one sideband will be transmitted to the outgoing circuit.

Fig. 4 shows the application of the principle of the circuit of Fig. 2 to a two-channel telegraph system, although it will be obvious that the circuit may be extended to any desired number of channels. A tone frequency for one channel is provided by means of a low frequency oscillator T_1 , the tone being interrupted by means of a key K_1 in accordance with the Morse or other telegraph code. Similarly, a tone for the second channel is supplied by a low frequency oscillator T_2 , which may be of the same frequency as the oscillator for the first channel. This tone is likewise interrupted in accordance with the desired code by means of a key K_2 . A carrier frequency f_c is generated by a source S_1 for the modulating tubes 1₁ and 2₁ of the first channel, a 90° phase shifter being included in one of the connections so that the carrier components applied to the two modulators will be 90° out of phase. A similar carrier source S_2 generates a second carrier frequency f'_c to be applied to the two modulators 1₂ and 2₂ for the second channel.

In order that the modulating wave or signal wave from the source T_1 may be applied to the grids of the two modulators 1₁ and 2₁ 90° out of phase, one conductor wire from the source T_1 is connected to a neutral point with respect to the grids of the two tubes, while the other wire is connected to the grid of the tube 1' through an inductance L_1 connected to a terminal of the resistance r_1 , a similar connection being established with the grid of the lower tube 2₁ through a capacity C_1 connected to the terminal of a second resistance r'_1 . By a proper adjustment of the inductance L_1 and the capacity C_1 the components of the signal frequency will be applied to the grids of the two modulating tubes for the first channel 90° out of phase with each other. By means of a similar arrangement involving inductance L_2 , capacity C_2 and resistances r_2 and r'_2 , components of the signaling frequency for the second channel will be applied to the grids of the modulating

tubes 1₂ and 2₂, respectively, 90° out of phase with each other. The result is that one side frequency corresponding to the tone of the first channel and also a side frequency corresponding to the tone of the second channel will be suppressed.

Where the carrier frequency is to be modulated by a low frequency tone signal or long wave telegraph input transmitted over a line from some distance point, the line terminals will be connected to the grids of the two modulating tubes of the channel, as shown by the dotted line position of the double-throw switch in Fig. 4.

Fig. 5 shows the apparatus for a single channel similar to that of Fig. 4 except that the phase changer for producing a 90° phase shift between the two components of the carrier frequency applied to the two modulator tubes is in this case similar to that employed for shifting the phase of the two signal or tone components. Here one terminal of the carrier source S is connected to the neutral point of the two grids of the tubes 1 and 2, and the other terminal is connected to the grid of the tube 1 through an inductance L_c connected to one terminal of a resistance r , the connection to the grid of the lower tube 2 being established through a condenser C_c connected to a terminal of the resistance r' . Condensers 20 may be included in the carrier connection to isolate the grid battery from the carrier source S and also to prevent the tone frequency from the source T from entering the circuit of the source S . Likewise, inductances 21 may be included in circuit with the tone source T to prevent the carrier frequency from entering the signal circuit.

Fig. 6 illustrates a circuit by means of which the two side-bands corresponding to the same carrier frequency may be utilized as two independent channels for telegraph communication. Here the carrier frequency f_c is applied to the grids of the two modulating tubes 1 and 2 through an inductance L_c and capacity C_c , respectively, thus producing a phase difference of 90° of the two carrier components, just as described in connection with Fig. 5. The tone input for channel No. 1 is controlled by means of a key K_1 and is applied to the grids of tubes 1 and 2 through transformers 9₁ and 10₁, respectively, a 90° phase shifter 3₁ being included in circuit with the transformer 9₁ to produce the desired phase shift between the two tone components at the modulating tubes. Likewise, the tone frequency for the second channel (which may, if desired, have the same frequency as the first channel) is controlled by a key K_2 and is applied through transformers 9₂ and 10₂ to the grids of the two modulating tubes, respectively. A phase shifter 3₂ is included in circuit with the transformer 10₂ so that the tone frequency for the second channel applied to the grid of

the lower tube may be shifted in phase 270° with respect to the tone frequency from the second channel applied to the upper tube.

This circuit will suppress the lower side frequency resulting from modulation by one channel tone, and will suppress the upper side frequency resulting from modulation by the second channel tone. There will remain, however, an upper side frequency and a lower side frequency, the former corresponding to the tone of the first channel and the latter corresponding to the tone of the second channel. One of these side frequencies will be interrupted in accordance with the telegraph signal which interrupts the tone of one channel, and the other side frequency will be interrupted in accordance with the telegraph signal which interrupts the tone frequency of the other channel. If the tone frequencies for the two channels are the same the two side frequencies will be equally separated from the carrier component. The output current will, therefore, include the carrier and two independent side frequencies, each interrupted or modulated in accordance with two independent telegraph signals.

The receiving apparatus for receiving the two channels transmitted by the circuit of Fig. 6 is illustrated in Fig. 7, and comprises two simple detectors D_1 and D_2 each coupled with a receiving antenna RA. If f_c be assumed to be the carrier frequency supplied to the modulators at the sending station, and f_1 and f_2 be assumed to be the two tone frequencies of the two channels, the receiving antenna will receive and apply to the modulating tubes D_1 and D_2 the frequencies f_c , $f_c + f_1$, and $f_c - f_2$. The detector D_1 will then have applied to its input circuit a heterodyne or beating frequency $f_c - f_2$. This will produce a zero beat with the side frequency $f_c - f_2$ carrying the signal for the second channel so that this signal cannot be observed by a telephone receiver. On the other hand, the heterodyne frequency will beat with the side frequency $f_c + f_1$ corresponding to the second channel to produce a beat frequency $f_1 + f_2$, which will be audible and will be interrupted in accordance with the telegraph code which interrupted the tone of channel No. 1 at the transmitter. At the same time there will be heard in the receiver a continuous tone of frequency f_2 due to the heterodyne frequency beating with the carrier component f_c . This frequency will not be present in the receiver where the carrier is suppressed at the transmitter. The received frequency $f_1 + f_2$, corresponding to the desired signal, will have a frequency just twice that of the original tone frequency of the channel, where both channels employ the same tone.

The second demodulator D_2 will be supplied with a heterodyne or beating frequency

$f_c + f_1$, thereby producing a zero beat with the side frequency corresponding to the first channel, but producing an interrupted beat frequency of $f_2 + f_1$, by means of which the telegraph signals in accordance with which the tone frequency of the second channel is interrupted may be heard in the receiver. A continuous tone of frequency f_1 will also be heard in the receiver but this will not be present where the carrier is suppressed at the transmitter. The interrupted tone heard in the receiver associated with the detector d_2 will have a frequency twice that of the tone of the second channel where both channels employ the same tone frequency. In fact, the same tone frequency will be heard in the receivers of both channels, but the tone interruptions will be different.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a signaling system, the method which consists in producing two carrier wave components of the same frequency, shifting one of said components in phase with respect to the other, modulating each of said carrier wave components in accordance with each of two signals to produce for each carrier component a pair of upper side-bands corresponding to the two signals and a pair of lower side-bands corresponding to the signals, and combining the modulation components so that the upper side-bands associated with the two carrier components and corresponding to one signal will oppose each other and so that the lower side-bands associated with the two carrier components and corresponding to the other signal will oppose each other.

2. In a signaling system, the method which consists in producing two carrier wave components of the same frequency, shifting one of said components in phase substantially ninety degrees with respect to the other, producing two components of the one signal wave shifted in phase substantially ninety degrees with respect to each other, producing two components of a second signal shifted in phase substantially two hundred and seventy degrees with respect to each other, modulating one of said carrier components in accordance with one component of each signal, modulating the other carrier component in accordance with the other component of each signal, and combining the resultant modulation products so as to suppress the upper side-bands corresponding to one signal and to suppress the lower side-bands corresponding to the other signal.

3. In a signaling system, a pair of modulators, means to supply to each modulator

5 a carrier current component of the same frequency but shifted in phase with respect to each other, means to produce two components of a first signal shifted in phase with respect to each other in one sense, means to apply one
10 of said signal components to each modulator, thereby producing upper and lower side-bands corresponding to said signal for each carrier component, means to produce two components of a second signal shifted in phase with respect to each other in the opposite sense, means to apply one of the components of said second signal to each modulator, thereby producing upper and lower
15 side-bands corresponding to said second signal for each carrier component, and means to combin the modulation products of both modulators so as to balance out the upper side-bands corresponding to one signal and to balance out the lower side-bands corresponding to the other signal.

4. In a signaling system, a pair of modulators, means to supply to each modulator a carrier current component of the same frequency but shifted in phase approximately
25 ninety degrees with respect to each other, means to produce two components of a first signal shifted in phase approximately ninety degrees with respect to each other, means to apply one of said signal components to each modulator, thereby producing upper and lower side-bands corresponding to said signal for each carrier component, means to produce two components of a second signal shifted in phase with respect to each other approximately two hundred and seventy degrees, means to apply one of the components of said second signal to each modulator, thereby producing upper and lower side-bands corresponding to said second signal
35 for each carrier component, and means to combine the modulation products of both modulators so as to balance out the upper side-bands corresponding to one signal and to balance out the lower side-bands corresponding to the other signal.

45 In testimony whereof, I have signed my name to this specification this 7th day of January, 1928.

50 **RALPH K. POTTER.**

55

60

65