June 27, 1939. C. W. HANSELL 2,163,680

SINGLE SIDE BAND MODULATION

Original Filed April 3, 1936 2 Sheets-Sheet 1

Fig. 1

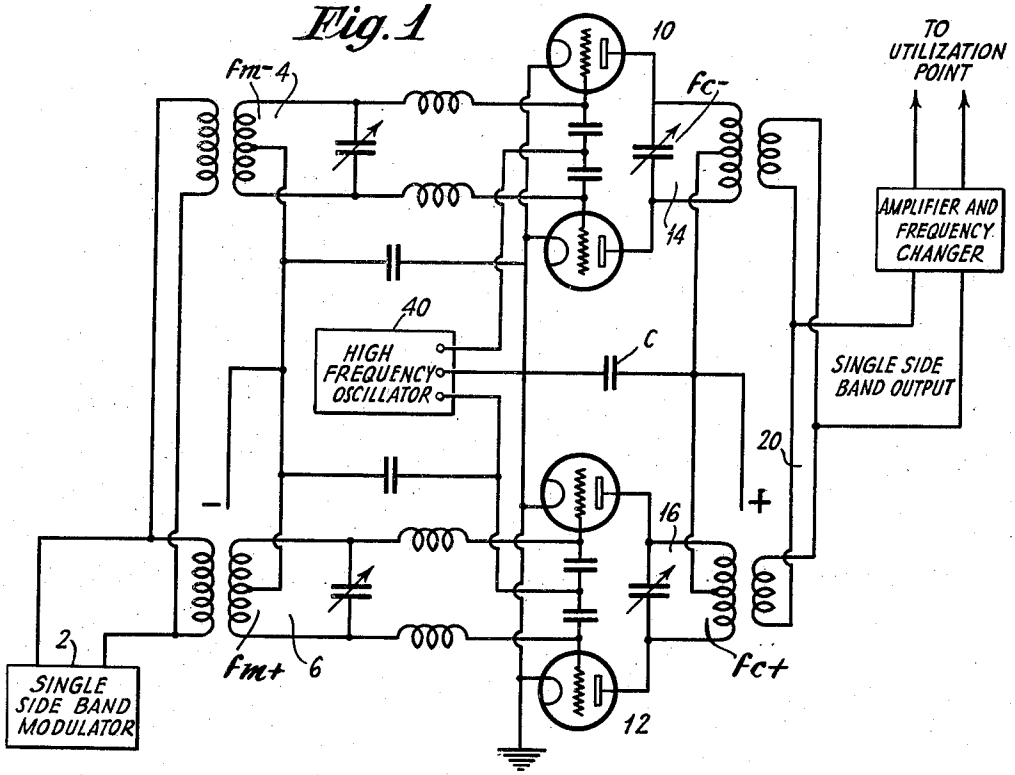

Fig. 1a

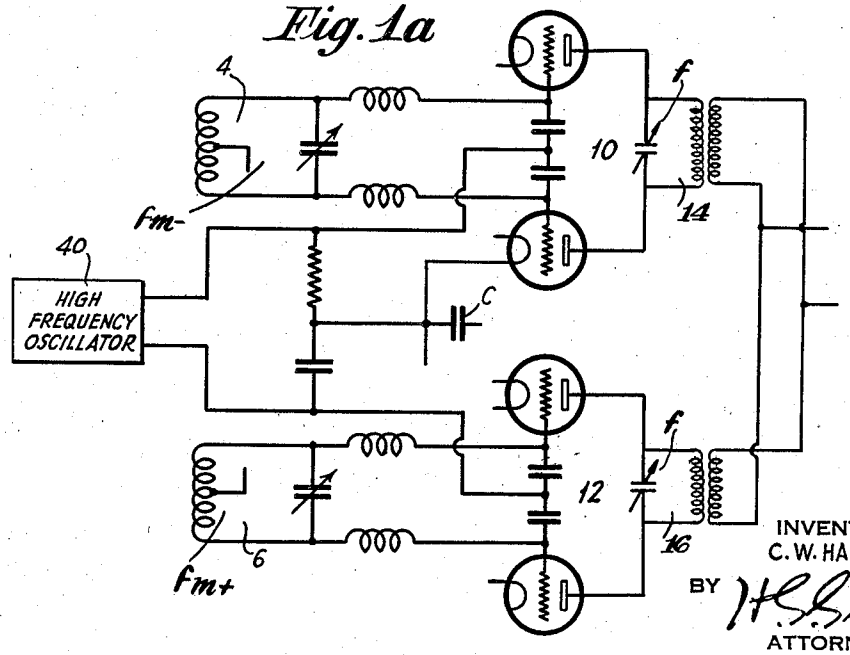

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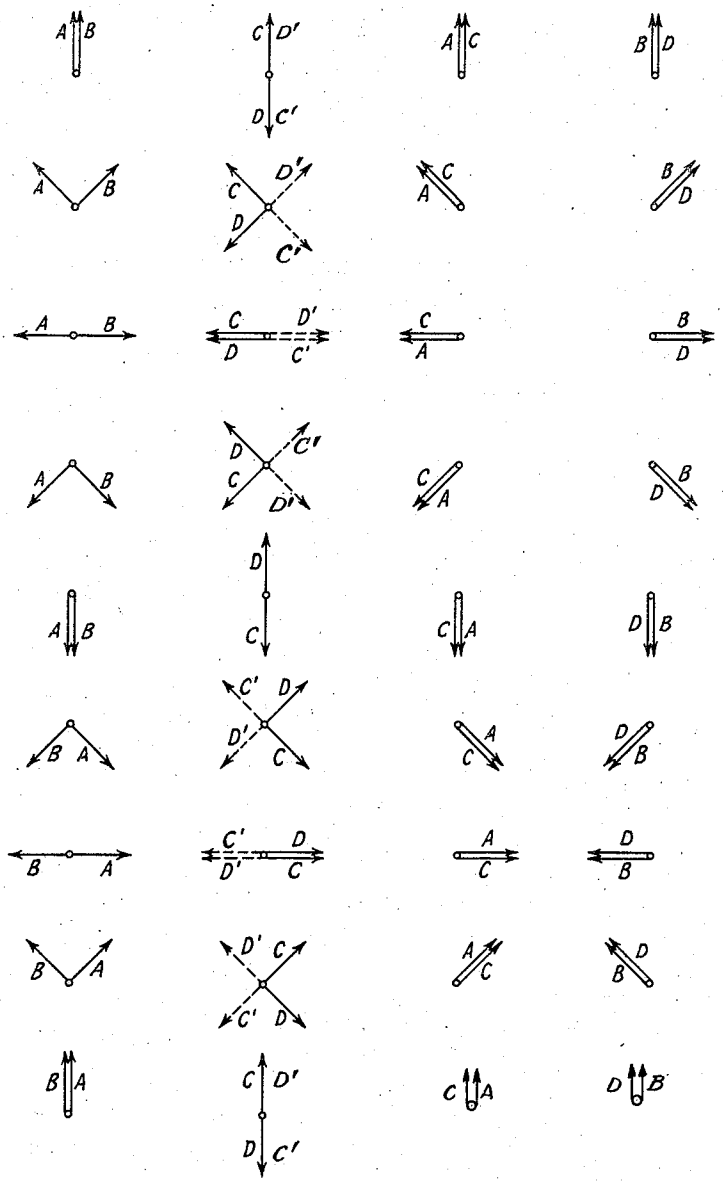
Fig. 2



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Patented June 27, 1939 2,163,680

UNITED STATES PATENT OFFICE

2,163,680

SINGLE SIDE BAND MODULATION

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Application April 3, 1936, Serial No. 72,503
Renewed November 25, 1938

11 Claims. (Cl. 179—171)

This invention concerns a new method of and means for adding the frequencies of radio frequency energies modulated and unmodulated to accomplish the same purpose as the balanced modulator and filters used in a single sideband radio telephone or multiplex telegraph system. The advantage in this invention resides in the ability of the new method and circuits to balance out the undesired sideband so that the necessity for sharp discrimination between sidebands in filter circuits is no longer necessary. The method makes it possible to use much larger differences between carrier and modulating frequencies and so reduces the number of cascaded single sideband modulators which would otherwise be required to produce a flat response in single sideband output, over a range equal to the modulation frequency band, at very high frequencies. The principle upon which the invention is based is that two sets of side frequencies or sidebands, produced in two balanced modulators by modulating currents 90° different in phase, when combined into a single circuit have such phase relations that one pair of sidebands add to produce a useful output while the other two sidebands oppose one another and substantially balance out. The carrier is suppressed by the action of the balanced modulators.

In single sideband modulation systems such as those in use at the present time, it is necessary to have a relatively small frequency ratio between the carrier energy and the modulating energy in order that the percentage frequency difference between sidebands in the output of a balanced modulator may be sufficiently great to allow filter circuits to discriminate between them. This is no great handicap where signals are to be transmitted at low radio frequencies. However, as the transmission frequency is increased, the percentage spacing between sidebands in the modulators must be made less and less and when very high radio frequencies are used it is necessary to use three or more modulators in order that the filters may discriminate between the sidebands in each modulator. I have described a way for reducing this difficulty, through the use of improved filters, in my United States applications, Serial #203,901 filed July 7, 1927, Patent No. 2,005,083, dated June 18, 1935, and Serial #564,770, filed September 24, 1931, Patent No. 2,000,387, dated May 14, 1935. By the use of the invention to be described here, the suppression of undesired sidebands may be still further improved and in some cases the invention will make possible the construction of satisfactory single sideband modulator systems for use at relatively high frequencies without the use of mechanical oscillating filters, which, up to the present time at least, are difficult and expensive to construct.

This invention is not applicable at the present time to the first stage of a single sideband modulator in a telephone transmitter because no method is available for converting single phase voice frequency currents into two currents having the phase of all frequency components differing by 90°. However, it can be applied to modulators used for handling multiplex carrier current circuits and, in telephony, to the second or any succeeding modulator where the voice frequency currents occupy a relatively small percentage band at the input frequency.

In describing my invention reference will be made to the attached drawings in which,

Figure 1 illustrates the primary elements of a modulator circuit arranged in accordance with my invention. In this circuit filament heating leads and sources are omitted for simplicity as are plate potential sources. In practice, additional elements not shown but well known in the art, may be added to the circuit,

Figure 1*a* illustrates a modification of the arrangement of Figure 1, while

Figure 2 is a series of vector diagrams denoting the relations of the modulated wave components in portions of the circuit of Figure 1. Figure 2 serves to illustrate the manner in which my novel method is carried out and in particular how it is carried out on the circuit of Figure 1.

In describing in detail one method of applying my invention, reference is made to Figure 1 of the drawings. In this figure I have shown two balanced modulators **10** and **12** so connected that their outputs **14** and **16** are combined into a single circuit **20**. The balanced modulators are supplied with phase opposed carrier energy from a high frequency oscillator **40**. At the same time both balanced modulators are supplied with modulating energy which is taken from the output of any single sideband modulator. That is to say, a sideband resulting from the modulation of a carrier wave in any manner is supplied from a modulator **2** to the two circuits **4** and **6** and is applied to the two modulators **10** and **12** with a phase difference of 90°. In the circuits shown in Figure 1 I obtain this phase difference by detuning the two input circuits **4** and **6** connected with the modulators **10** and **12** in opposite directions (relative to the mean side band frequency) as indicated by $fm+$ and $fm-$, so that the currents set up by said side band frequencies are

made to lead and lag 45° respectively. When the balanced modulators 10 and 12 are excited in phase quadrature as described above the output circuits 14 and 16 of each pair of tubes will contain two sidebands but the carrier energies will be balanced out. In order to complete the phase shift necessary for the elimination of one sideband the output circuits must be detuned relative to the carrier frequency in the same manner as the input circuits as indicated by $fc+$ and $fc-$, so that the phase of the output currents of each pair of modulator tubes are shifted in phase by 90° with respect to the phase of currents in the output of the other pair of modulator tubes. This gives in the mixing circuit 20, four side band energy components, the carrier having been balanced out. The relation of the four side bands is shown in Figure 2.

I could accomplish the phase shifting by employing artificial lines in the input and output circuits of the modulators, by using radiogoniometers or any other known phase shifting devices.

Under the conditions described the two balanced modulators 10 and 12 each have outputs containing two sidebands, one above and one below the carrier frequency by amounts equal to the frequencies of the modulating energies from the first modulator. Keeping in mind the well known phase relations of currents in ordinary balanced modulators, it will be noted that, when two side frequency currents add together to produce a maximum resultant instantaneous output from modulator 10, then at this same instant, because of the 90° phase relation between input modulating currents, the corresponding two side frequency currents in the output of modulator 16 are opposed to give zero instantaneous resultant output. Also at this same instant, since the carrier input to the two modulators is 180° different in phase it can be shown that the natural phase relations between equal side frequency currents in the outputs of the two modulators are 90° different in phase. By shifting the phase of output current from one modulator plus 45°, and by shifting the phase of output current from the other modulator minus 45°, a total relative phase shift of 90°, we may bring the upper side frequency currents in phase and the lower side frequency currents 180° out of phase or vice versa.

To illustrate the manner in which the side frequency currents add up to produce single sideband output I have made up a series of vector diagrams which appear in Figure 2. In this figure the first or left hand row of vector diagrams represents successive phase positions of two side frequencies from the output of one modulator, say 10, during a complete cycle of the modulating energy, as it appears in output circuit 20. The two vectors A—B represent the two side frequencies corresponding to any one modulating frequency. Vector A represents the upper side frequency and vector B the lower side frequency. With these assumptions, the relative rotations or time positions of the vectors at various successive positions of a cycle of the modulating energy are as shown. In the second column of vector diagrams I have shown the phase relations of the two side frequencies produced by the same modulating frequency in the output to circuit 20 from the other modulator 16. In this diagram, vector C represents the upper side frequency and vector D the lower side frequency. A comparison between the two sets of vector diagrams will at once indicate that vectors B and D rotate in the same direction and are always opposite one another in polarity so that when the two sets of side frequencies are combined into the one circuit 20 with the phase relations shown, they cancel one another out and have a zero resultant. At the same time, vectors A and C rotate in the same direction but are always additive and consequently will produce an output in the output circuit corresponding to their sum.

If the phase of the modulating frequency or the polarity of the connections from the output of one modulator were reversed, the polarities of the two side frequencies represented in the vector diagrams would be reversed. This is represented by the dotted vectors C' D' in the second column of vector diagrams. With the polarity of the side frequencies reversed it will be at once apparent that instead of vectors B and D cancelling out, it will now be vectors A and C which oppose, while vectors B and D add to give the useful output. Consequently, by choosing the polarity of input to either of the modulators or the polarity of output, we may determine which of the upper or lower sidebands appears in the output of the modulator.

Since the phase shifting circuits are not quite perfect in that the relative amplitude of the modulating energy delivered to the two modulators varies somewhat with frequency, it will be evident that the value of the sidebands delivered by the two modulators is not perfectly constant over a considerable frequency band and, consequently, the suppression of the undesired sideband will not be absolutely perfect. For this reason I would expect in some cases, to use filters with this new type of modulator but since the modulator itself gives a large amount of discrimination between the side frequencies, the characteristics of the filters may be either less perfect or the modulator may be operated at a higher output frequency than would be possible with previously known types of modulators. Since the lowest modulating frequencies produce sidebands nearest together in the output of the modulator, these sidebands are separated by means of filter circuits with greater difficulty than the sidebands produced by the higher modulating frequencies. Consequently, I would expect to adjust the relative amplitudes of carrier and modulating energy to the two modulators for obtaining a perfect balance at the lowest modulating frequencies and to depend more upon the filters to discriminate between sidebands produced by the higher modulating frequencies.

I have shown in Figure 1 only one of many possible detail arrangements for carrying out the fundamental idea of this invention. The circuits shown may be modified in many ways. For example, the modulating energy may be applied to any electrode of the tube and the same statement applies with respect to the carrier excitation energy. The three element tubes shown may be replaced with tubes having four or more electrodes if desired and the additional electrodes may have modulating or carrier energy applied to them if desired. Another possible modification is that instead of combining the outputs of the two modulators by coupling a single circuit to both modulator outputs, it may be found desirable to use amplification after each modulator before combining the two sets of side frequencies. Single stage amplifiers used for this purpose are commonly called coupling tubes and have the advantage that they would prevent reaction of one modulator upon another.

It will, of course, be understood that the modulator which I have described may be used not only as part of a radio transmitter but it may also be used for wire line communication as well. In carrier current telephony and multiplex telegraphy over wire circuits, some of the most expensive parts of equipment required are the filters used for discriminating between sidebands. It is quite possible that the new circuit which has been described can be applied to some wire circuits in a manner to bring about economies.

As a further simplification and improvement I may alter the arrangement of Figure 1 by supplying the two balanced modulators with carrier excitation which is displaced 90° in phase instead of 0 or 180°. This 90° phase relation can be obtained by use of a phase splitting circuit **9, 11** connected, as shown in Figure 1*a*, to **40** and to the grids of the tubes of balanced modulators **10** and **12**. When I do this it is no longer necessary to produce a phase shift of 90° in the outputs from the modulators. In this case, output of one sideband or the other may be obtained by simply combining the output currents from the modulators with one polarity or the other, without phase shifting.

It should also be understood that my system may be used to produce an output including the carrier, as well as a single sideband due to modulation, by omitting one tube from each of the modulators in Figure 1. Likewise my system may be applied with any other carrier passing or suppressing modulators including all forms of amplitude modulators, phase modulators and frequency modulators. In other words, the modulators **10** and **12** and the carrier oscillator **40** of Figure 1 may be replaced with any known forms of modulators and carrier sources and the object of my invention may still be achieved. Of course, the single sideband output may be amplified in power by all the known means. Also it may be increased or decreased in frequency by further modulation or heterodyne devices or it may in some cases, be frequency multiplied or frequency divided according to the needs and objects of the equipment to which my invention is applied.

It may further be noted that 90° phase relation between the input modulating currents and the 90° shift in output currents or carrier input currents, are not essential since an undesired side frequency or band of frequencies may always be substantially balanced out so long as there is any phase difference between the input modulating currents to the two modulators. The 90° relations described are best, however, for obtaining maximum output for the desired side frequency or band of frequencies.

I claim:

1. The method of signalling which includes the steps of, producing a phase quadrature relation between two portions of signal modulated wave energy, producing a phase opposed relation between two portions of oscillator energy of carrier wave frequency, superposing each of said first named portions on a different one of said last named portions producing a phase quarature relation between the energies resulting from said last step and combining the resultants.

2. The combination with a signal modulated wave energy source of a source of high frequency oscillations, two balanced modulator systems, each consisting of a pair of electron discharge tubes, circuits tuned to the opposite sides of the mean frequency of the wave energy of said source for applying signal modulated wave energy from said source substantially in phase quadrature to control electrodes of the tubes in each pair, circuits for applying the high frequency oscillations substantially in phase opposition to control electrodes of the tubes of each pair, a combining circuit coupled to the output electrodes of said tubes to derive modulation components therefrom, and means in said combining circuit for producing substantially 90° phase displacement between the modulation components from each pair of tubes.

3. The combination with a signal modulated wave source, of a source of high frequency oscillations, two balanced modulator systems, each consisting of a pair of tubes, a detuned circuit for applying signal modulated carrier energy substantially in phase opposition to the input electrodes of one pair of tubes, a detuned circuit for applying signal modulated wave energy of different phase from said source substantially in phase opposition to the input electrodes of the tubes of said other pair of tubes, said circuits being detuned in different directions with respect to the mean frequency of said signal modulated energy means for applying high frequency oscillations in phase to the input electrodes of the tubes of each pair, and output circuits detuned in opposite directions with respect to the frequency of said high frequency oscillator coupled to the output electrodes of said tubes.

4. In a modulation system a pair of balanced modulators each having symmetrical electron systems including input electrodes and output electrodes, circuits connected with the input electrodes of each system, a circuit for applying signal modulated waves to said circuits, means in each of said first named circuits for detuning the same in opposite directions relative to the mean frequency of said signal modulated waves, a source of carrier frequency oscillations, circuits applying said carrier frequency oscillations to the input electrodes of both of said electron systems, output circuits connecting the output electrodes of each of said systems in push-pull relation, means for detuning said output circuits in opposite directions relative to the mean frequency of said oscillations, and a circuit coupled with each of said output circuits.

5. Modulating means including means for suppressing modulation components resulting from modulation of a carrier wave including a pair of modulating devices each having symmetrical electron systems including input electrodes and output electrodes, tuned circuits connecting the input electrodes of each system, means for applying signal modulated waves to said tuned circuits, a source of carrier frequency oscillations to be modulated, means for applying said carrier frequency oscillations in phase to the input electrodes of one of said electron systems and in phase to the input electrodes of the other electron systems, output circuits in which modulated wave energy flows connecting the output electrodes of each of said systems in push-pull relation, means for detuning said output circuits in opposite directions with respect to the mean frequency of said oscillations to produce substantially a phase quadrature relation between the modulated wave energies in said output circuits, and a combining circuit coupled with each of said output circuits.

6. In a single sideband modulation system, a pair of balanced modulators each having electron systems including input electrodes and output electrodes, circuits connected with the input electrodes of each system, means for applying

signal modulated waves to said circuits, means in each of said circuits for detuning the same in opposite directions relative to the means frequency of said signal modulated waves, a source of oscillations of carrier wave frequency, circuits applying oscillations from said source to the input electrodes of both of said electron systems, the oscillations applied to the input electrodes of one of said systems being displaced in phase relative to the oscillations applied to the input electrodes of the other systems, output circuits connecting the output electrodes of each of said systems together, means in each of said output circuits for detuning the same in opposite directions relative to the mean frequency of said oscillations of carrier wave frequency, and a combining circuit coupled to each of said output circuits.

7. The method of producing a single sideband in a carrier system by means of wave energy of carrier frequency and sideband energy resulting from modulation of oscillatory energy by signal potentials which includes the steps of, producing out of phase components characteristic of the sideband energy, producing components characteristic of said carrier wave energy which differ in phase by an amount different than the phase displacement of said out of phase sideband components, modulating one wave energy characteristic component by one sideband energy characteristic component, modulating the other wave energy characteristic by the other sideband characteristic component, and phase displacing and combining the two resultants obtained by so modulating the said two wave energy characteristic components by the sideband characteristic components.

8. The method of single side band signalling by means of signal modulated wave energy and wave energy of carrier wave frequency which includes the steps of, producing substantially a phase quadrature relation between voltages characteristic of the said signal modulated wave energy, producing voltages of substantially like phase characteristic of the wave energy of carrier wave frequency, superimposing one of said first produced voltages on one of said second produced voltages and the other of said first produced voltages on the other of said second produced voltages, to produce two resultant voltages, relatively phase displacing said resultant voltages and combining the displaced resultant voltages.

9. The combination with a signal modulated wave energy source of a source of oscillatory wave energy of carrier frequency, a pair of balanced modulator systems, each system consisting of a pair of electron discharge tubes each having control electrodes and output electrodes, circuits tuned to opposite sides of the mean frequency of the wave energy of said source for applying signal modulated wave energy from said source substantially in phase quadrature to corresponding control electrodes of the tubes in each pair, means for applying the high frequency oscillations substantially in phase to corresponding control electrodes of the tubes of the pair of tubes, a combining circuit coupled to the output electrodes of the tubes, and means in said combining circuit for producing a substantially 90 degree phase displacement between the modulation components from each pair of tubes appearing in said combining circuit.

10. The method of producing a single sideband in a carrier system by means of wave energy of carrier frequency and sideband energy resulting from modulation of oscillatory energy by signal potentials which includes the steps of, producing out of phase components characteristic of the sideband energy, producing components characteristic of said carrier wave energy, modulating one wave energy characteristic component by one sideband energy characteristic component, modulating the other wave energy characteristic component by the other sideband characteristic component, and phase displacing and combining the two resultants obtained by so modulating the said two wave energy characteristic components by the sideband characteristic components.

11. The method of signalling which comprises the steps of, producing a 90 degree phase relation between two portions of modulating frequency power, producing a 0 or 180 degree phase relation between two portions of carrier frequency power, applying one portion of modulating frequency power and one portion of carrier frequency power to each of two modulators, shifting the relative phase relations of output power from the two modulators by 90 degrees and then combining output power from the two modulators in a common circuit.

CLARENCE W. HANSELL.