

L. ESPENSCHIED.
PLURAL MODULATION SYSTEM.
APPLICATION FILED MAR. 18, 1920.

1,361,522.

Patented Dec. 7, 1920.

2 SHEETS—SHEET 1.

Fig. 1

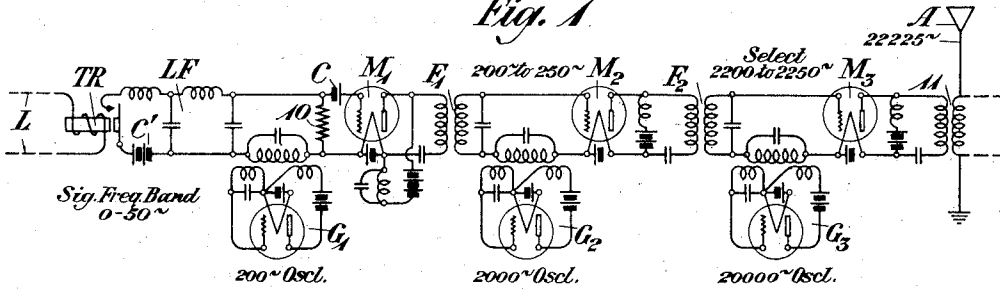


Fig. 2

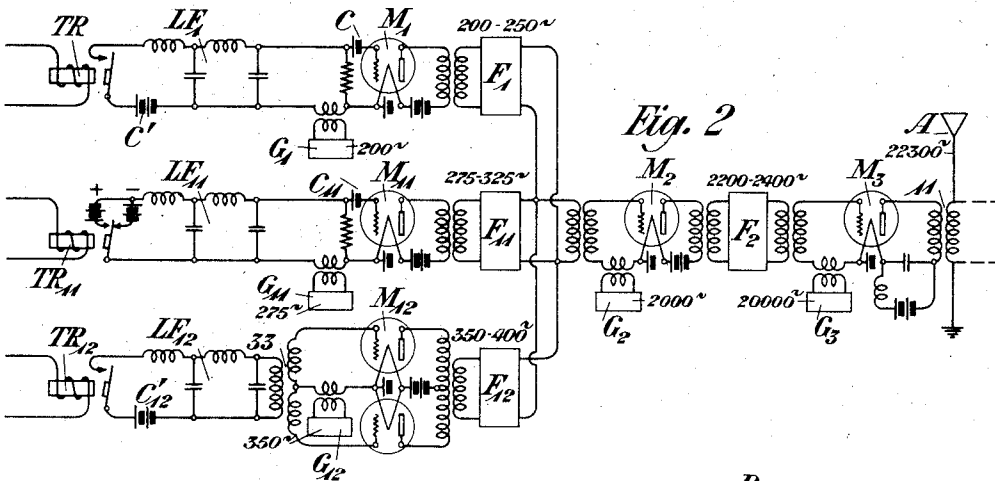
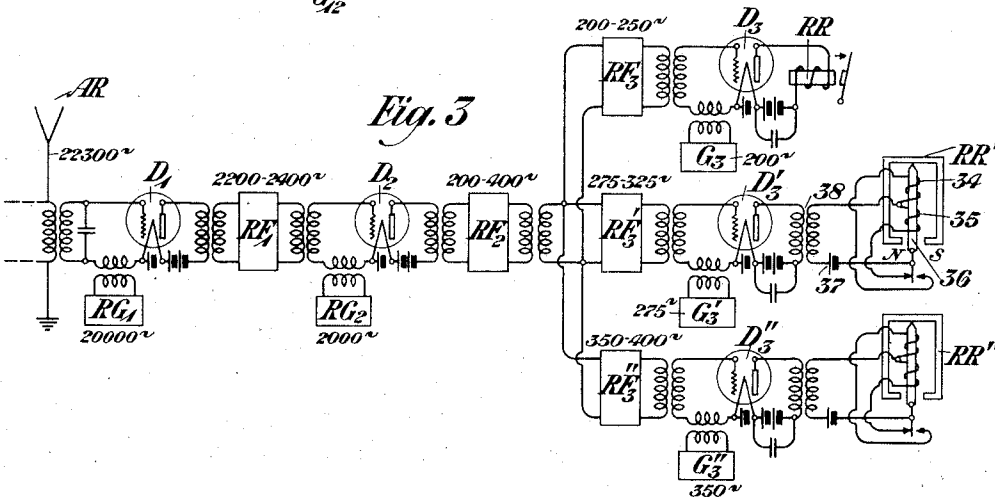


Fig. 3

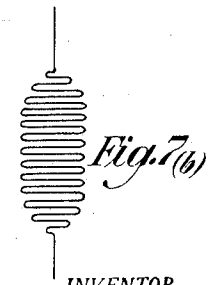
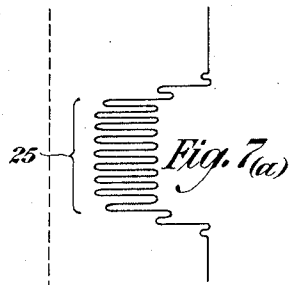
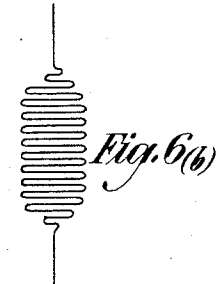
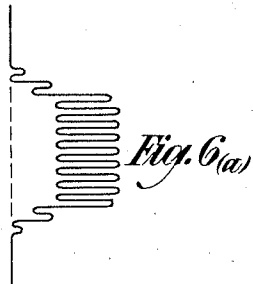
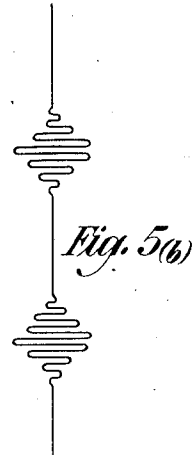
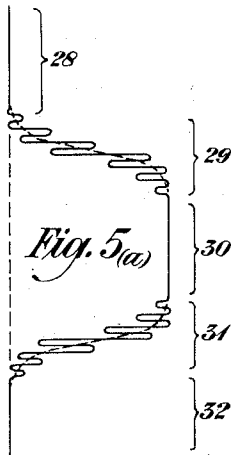
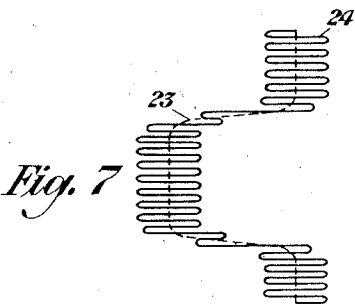
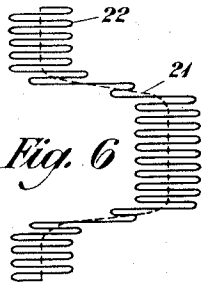
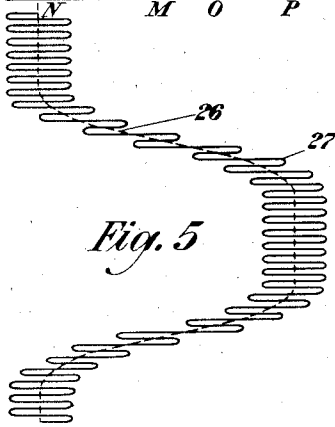
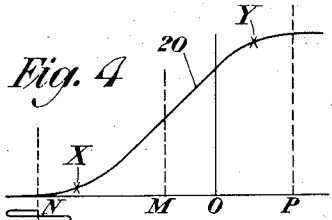


INVENTOR.
L. Espenschied
BY *g. v. 408*
ATTORNEY

1,361,522.

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2 SHEETS—SHEET 2.



INVENTOR.
L. Espenschied
BY *gryor*
ATTORNEY

UNITED STATES PATENT OFFICE.

LLOYD ESPENSCHIED, OF QUEENS, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

PLURAL MODULATION SYSTEM.

1,361,522.

Specification of Letters Patent.

Patented Dec. 7, 1920.

Application filed March 18, 1920. Serial No. 366,802.

To all whom it may concern:

Be it known that I, LLOYD ESPENSCHIED, residing at Queens, in the county of Queens and State of New York, have invented certain Improvements in Plural Modulation Systems, of which the following is a specification.

This invention relates to the transmission of telegraph signals and more particularly to transmission of telegraph signals by so-called carrier currents.

One of the objects of this invention is to narrow the band of frequencies employed in transmitting telegraph signals by carrier waves in a system in which modulation takes place by a plurality of steps.

Another object of the invention is to suppress the transmission of carrier waves during certain signaling conditions, by taking advantage of the property of a vacuum tube whereby when operated upon any non-amplifying portion of its characteristic it will function to practically prevent the transmission of carrier currents supplied thereto.

Another object of the invention is to provide for the transmission of signals formed by direct current pulses by suppressing the transmission of carrier waves during the steady state condition of the pulses and only transmitting carrier waves during the change from one steady state to another.

A further object of the invention is to suppress, in a system for translating so-called direct current signals into carrier waves, the direct current component of the signal and transmit only the alternating current component.

Other and further objects of the invention will be clear, from the following description when read in connection with the appended drawing, in which Figures 1 and 2 represent circuit diagrams of two forms of transmitting arrangements which may be employed in connection with the invention, Fig. 3 of which is a diagram of a receiving arrangement to be used in connection with the transmitting circuit of Fig. 2, and Figs. 4, 5, 5^a, 5^b, 6, 6^a, 6^b, 7, 7^a and 7^b are curves illustrating the operation of the modulator employed.

Referring to Fig. 1, L designates a transmitting circuit over which telegraph or other direct current signals may be transmitted. The circuit L terminates in a trans-

mitting relay, TR, which controls the application of potential from a battery C' to the grid of a modulator M₁ of the well known vacuum tube type. A grid battery C is connected between the filament and grid of the modulator M₁, through a resistance 10, thereby giving the grid a normal potential, so as to cause the tube to operate upon a desired part of its characteristic curve, in a manner more fully described hereinafter.

In order to narrow the band of frequencies involved in the transmission of ordinary direct current signals such, for instance, as telegraph signals, a filter LF is included in the input circuit of the modulator, as indicated. This filter is preferably a low pass filter of the type disclosed in the United States Patents to George A. Campbell, Nos. 1,227,113 and 1,227,114, issued May 22, 1917. An ordinary direct current signal having a sharp wave form and recurring at a frequency of say 50 cycles per second actually represents a frequency band of considerable width and the impressed wave may be analyzed in accordance with Fourier's theorem into a series of harmonics of the fundamental frequency of say 50 cycles. In order to transmit the signal it is not necessary to transmit all of these harmonics, the extent to which they may be eliminated being dependent, among other things, upon the type of receiver employed, a wave-recording type of receiver, such as the photographic or siphon recorder, for instance, requiring a less sharp wave and, therefore, the transmission of fewer harmonics than a relay type of receiver. Consequently, by properly designing the filter LF as to its upper cut-off frequency, all of the harmonics above a given frequency may be eliminated, thereby narrowing the band of frequencies which it is necessary to transmit in order to reproduce the signal. It will always be necessary to transmit at least the fundamental or dot frequency, so that the limit to which this expedient may be extended will be to eliminate all of the harmonics and retain simply the fundamental.

The modulator M₁ may be supplied with carrier waves from a suitable source G₁, which is illustrated as being a vacuum tube oscillator. The frequency of this source should not be too high as compared with the frequency to be transmitted through the

filter LF, for the reason that the side bands resulting from modulation should be separated by a sufficient amount relative to the carrier frequency to permit of the selection of one side band to the exclusion of the other.

In order to select one of the side bands, say the upper side band appearing in the output circuit of the modulator M_1 , a filtering arrangement F_1 is included between the modulator M_1 and the next translating element of the circuit. This filter may be, for instance, a fairly sharply tuned circuit capable of transmitting frequencies between 200 and 250 cycles, where the highest frequency employed in the signaling operation is 50 cycles. A modulator, M_2 , of vacuum tube or other well known type, is included in the circuit beyond the filter F_1 and is supplied with carrier waves from a source G_2 . This modulator serves to modulate the carrier waves from the source G_2 , in accordance with the band of frequencies selected by the filter F_1 , thereby stepping up the selected band in frequency. A filter F_2 , which may be similar in construction to the filter F_1 , is included in the circuit beyond the modulator M_2 to select the upper side band in preference to the lower side band. By designing this filter to transmit a band between 2200 and 2250 cycles, for instance, both the carrier frequency of 2,000 cycles and the lower side band extending from 1750 to 1800 cycles will be spaced from the upper side band a sufficient distance to be substantially suppressed.

In order to still further step up the frequency, an additional modulator, M_3 , may be provided, said modulator being supplied with carrier waves of a still higher frequency from the source G_3 . The frequency of this source is illustrated as being 20,000 cycles. The output circuit of the modulator M_3 is coupled through a transformer 11 to a transmitting antenna A, and in order to select the upper side band appearing in the output circuit of the modulator M_3 to the exclusion of the carrier frequency and the lower side band, the antenna A and the output circuit of the modulator M_3 may be tuned so as to readily transmit frequencies in the neighborhood of 22,200 to 22,250 cycles.

The modulators M_2 and M_3 operate in the usual and well understood manner. The modulator M_1 , however, is adjusted to transmit the carrier frequency applied thereto only under certain conditions. The operation of this modulator may be understood by referring to the curves in Figs. 4 to 7^b, inclusive. In Fig. 4 curve 20 indicates the characteristic curve of a three-element vacuum tube, that is a curve representing the variation of plate current with applied grid potential. In this curve positive grid voltages

are plotted as abscissæ to the right of the vertical axis O and negative grid voltages are plotted as abscissæ to the left of the axis O, while the corresponding current values are plotted as ordinates. It will be seen that as the negative grid voltage is increased the plate current decreases until it becomes zero in the neighborhood of the vertical line N. As the grid voltages increase in a positive direction to the right of the axis O it will also be seen that the current increases until a voltage in the neighborhood of the vertical line P is reached. Beyond this point further increase in voltage results in no further increase in the current and the current remains constant at this value, which is known as a saturation value. The points X and Y upon the curve 20 are known as the knees of the curve, the former being usually called the lower knee and the latter being the upper knee. The portion of the curve between the points X and Y is its amplifying portion and variations in grid potential over this part of the curve result in corresponding variations in the plate current, so that if the tube is working over this part of the curve carrier waves will be transmitted. The two flat parts of the curve beyond the points X and Y, however, represent portions of the characteristic curve in which the tube is practically unresponsive to potential variations, since the output current is constant at either zero or its saturation value. If the tube is operating upon either one of these two portions of its characteristic it will not transmit carrier waves.

If now the battery C of the modulator M_1 in Fig. 1 be given such a value as to bring the grid potential to the point designated by the dotted line M, the normal adjustment of the tube will be about the midpoint of its amplifying characteristic. If, with the grid potential thus adjusted, an alternating potential of carrier frequency be impressed upon the grid, a corresponding variation in the plate current will occur, so that carrier waves will be transmitted. Suppose now the battery C' of Fig. 1, which is controlled by the transmitting relay TR is connected to the grid circuit and is so adjusted that its potential when superposed upon that of the battery C will bring the grid potential to the point N, if an alternating potential be superposed upon this grid potential it will be observed that no variation in current flow will take place in the plate circuit, since over this portion of the characteristic no current flow takes place. When the potential of the battery C' is removed by the action of the relay TR, the grid potential will be shifted to the point M, where, as already pointed out, transmission of carrier waves will take place.

The variation in grid potential with time, corresponding to the opening and closing of

the circuit of the battery C' at the relay TR in response to signals is indicated by the dotted line curve 21 of Fig. 6 and the superposed alternating potential from the source G_1 is indicated at the curve 22 of Fig. 6. These curves are plotted on the same scale as Fig. 4, grid potentials being plotted as abscissæ and time being plotted as ordinates. The corresponding plate current is indicated in Fig. 6^a, which is likewise plotted on the same scale as Fig. 4, ordinates representing time and the plate current being plotted as abscissæ. By causing this current to flow through the primary of a carrier frequency transformer the alternating carrier current component will appear in the secondary circuit, this alternating component being indicated by the curve in Fig. 6^b. It will be observed from the curves of Fig. 6^a and Fig. 6^b that no current is transmitted when the tube is working on the flat part of the curve, but that carrier waves are transmitted when its operation is shifted to the amplifying portion of its characteristic, as indicated in Fig. 6.

Substantially similar results may be secured by so adjusting the battery C' to operate upon the portion of the curve to the right of the point Y. Upon this part of the curve the plate current remains steady at its saturation value, but when the potential of the battery C' is removed by the transmitting relay the operation is shifted to the amplifying portion of the curve and carrier waves are transmitted. The variation in potential, due to opening and closing the circuit of the battery C' , will now be as indicated by the dotted line curve 23 of Fig. 7 and the superposed alternating current potential is indicated by the curve 24. The corresponding plate current is indicated in Fig. 7^a, where it will be noted that the plate current is steady while the grid potential varies about an axis in the neighborhood of the vertical line P of Fig. 4, but is decreased to a pulsating value at 25 when the battery C' is disconnected and the tube operates on the amplifying portion of its characteristic. The alternating carrier current component is indicated in Fig. 7^b.

The transmitting relay TR may be operated on either an open circuit or a closed circuit basis. As above described, carrier waves are transmitted when the relay TR operates to open the circuit of the battery C' and the carrier waves are suppressed when the circuit of the battery is closed. Exactly the opposite effect may be produced by suitably proportioning the batteries C and C' . If, for example, the battery C is so adjusted as to bring the normal grid potential to the point N in Fig. 4 and the battery C' is oppositely poled and so adjusted that when it is connected in circuit the grid potential is brought to the point M, then it

will be observed that carrier transmission takes place as in Figs. 6, 6^a and 6^b, when the circuit of the battery C' is closed. Likewise, if the battery C is adjusted to bring the normal grid potential to the point P and the battery C' is then oppositely poled and so adjusted that when included in circuit the grid potential is brought to the point M, carrier transmission will only take place when the battery C' is in circuit, as indicated in the curves 7, 7^a, and 7^b.

In general, the operation of the circuit of Fig. 1 is as follows: Telegraph signals from the circuit L operate the transmitting relay TR to produce sharply defined pulses in the circuit of the battery C' . Due to the action of the filter LF, however, the upper harmonics of the fundamental frequency of the signals are eliminated, so that the signals transmitted to the grid circuit appear as curved pulses which in the limiting case may involve merely the fundamental frequency. These pulses produce potential changes in the grid circuit, which results in shifting its operation to different points of the characteristic, as indicated by the curves 21, and 23 of Figs. 6 and 7, respectively, so that carrier waves are alternately transmitted and suppressed, depending upon whether the pulse shifts the operation of the tube to the amplifying or non-amplifying portion of its characteristic. In the output circuit of the modulator M_1 upper and lower side bands appear, the upper band ranging from say 200 to 250 cycles and the lower side band from 150 to 200 cycles. The upper side band may be selected by the filter F_1 and transmitted to the modulator M_2 , where it modulates oscillations of say 2,000 cycles from the source G_2 . Upper and lower side bands again appear in the output circuit of the modulator M_2 , the upper being selected by the filter F_2 and transmitted to the modulator M_3 . Here again modulation of a frequency of say 20,000 cycles from the source G_2 occurs and the upper side band is selected by the antenna A for transmission. Instead of the antenna A an ordinary wire transmission line may be used, as indicated in dotted lines. The filters F_2 and F_3 , in selecting in each instance the upper side band, also operate to suppress the carrier frequencies as well as the lower side bands.

Fig. 2 illustrates the invention as applied to a multiplex circuit. The apparatus for the second and third steps of modulation in this figure may be the same as in Fig. 1, although the filter F_2 is illustrated as being a band filter of the Campbell type above referred to. The input circuit of the modulator M_2 is provided with three incoming branches, including filters F_{11} , F_{12} and F_{13} . These filters may be tuned circuits, but are preferably filters of the Campbell type, each

so proportioned and adjusted as to transmit a proper band of frequencies. The transmitting relay TR, filter LF₁, modulator M₁ and source G₁ associated with the first channel are identical with corresponding apparatus of Fig. 1 and the frequency assigned to this channel may be the same as that assigned to the channel of Fig. 1, so that the filter F₁ should be designed to pass a band lying between 200 and 250 cycles. The relatively low carrier frequency assigned to the second channel should be somewhat different from that assigned to the first channel and is illustrated as being 275 cycles, the frequency of the generator G₁₁. Assuming that the signaling frequency is the same as that of Fig. 1, say 50 cycles per second, the filter F₁₁ should be designed to transmit a band from 275 to 325 cycles. In a similar manner the generator G₁₂ of the third channel may have a frequency of 350 cycles and the filter F₁₂ pass a band from 350 to 400 cycles.

The second channel of Fig. 2 differs somewhat from the first channel and is so arranged that carrier waves are only transmitted during the change from one steady state to the other. For this purpose the transmitting relay TR₁₁ is arranged to connect either one or the other of two batteries of opposite polarity to the grid circuit of the modulator M₁₁.

The operation of the modulator M₁₁ under these circumstances may be understood by reference to the diagrams in Figs. 4, 5, 5^a and 5^b. As described in connection with Fig. 1, the battery C₁₁ of the modulator M₁₁ is so poled and adjusted as to bring the normal grid potential to the intermediate point M. One of the batteries under control of the relay TR₁₁, when connected in the grid circuit, then shifts the resultant grid potential to the point P, while the other battery is so poled and adjusted as to shift the grid potential to the point N.

Let us suppose now that the transmitting relay TR₁₁ has its armature so thrown as to bring about the last mentioned result. The carrier waves from the source G₁₁ will not be transmitted, as the plate current will remain at zero. This will be clear from Figs. 5 and 5^a. In Fig. 5 the dotted line curve 26 indicates the slow speed changes in grid potential, due to the action of the transmitting relay TR₁₁, while 27 is a plot of the superposed high frequency potential from the source G₁₁. Turning now to the curve of Fig. 5^a, it will be seen that in the part 28 of the curve the current remains zero, regardless of the high frequency variation in potential indicated in Fig. 5. As soon, however, as the relay TR₁₁ operates to connect in the other battery, so that the grid potential will be as indicated at P in Fig. 4, the tube will momentarily operate over

the amplifying portion 20 of its characteristic, during the period of change-over, as indicated at 29 in Fig. 5^a. When the change-over is completed, however, and the steady state again reached, the current will remain at the saturation value, as indicated at 30 in Fig. 5^a. Upon another reversal of the grid battery under the control of the relay TR₁₁, the tube momentarily passes over the amplifying portion of its characteristic, so that high frequency pulsations again occur, as indicated at 31 of Fig. 5^a. Upon reaching the initial steady state condition, however, the current remains zero and no high frequency is transmitted. The alternating carrier current component of the pulsating current indicated in the curve of Fig. 5^a is shown in Fig. 5^b and, as indicated, consists of a short train of high frequency impulses corresponding to each change in polarity produced by the transmitting relay. In each instance, as soon as the change-over is completed and the steady state condition reached, regardless of whether the potential of the grid be as indicated at N or P, the alternating current will cease.

By the arrangement just described the carrier wave is only transmitting during the change-over and is not transmitted during the steady state of the low frequency signal. The same result may be secured by means of the arrangement shown in connection with the third transmitting channel, in which the modulator M₁₂ is of the duplex vacuum tube type illustrated and described in the U. S. application of John R. Carson, Serial No. 157,413, filed March 15, 1917. Such a duplex vacuum tube arrangement normally suppresses the carrier by reason of the fact that the carrier source G₁₂ is connected to the common branch of the two similar input circuits. The signaling battery C'₁₂ is connected in a local circuit including the filter LF₁₂, which local circuit is inductively connected to the modulator M₁₂ through a transformer 33. The transformer 33 suppresses the direct current component of the low frequency signal, so that the steady state condition produces no effect upon the modulator M₁₂. Upon either closing or opening the circuit of the battery C'₁₂, however, one alteration is induced through the transformer 33 and unbalances the modulator circuit, so that a brief train of high frequency waves from the source G₁₂ is transmitted.

The receiving apparatus for use in connection with the transmitting systems of Figs. 1 and 2 may be as illustrated in Fig. 3 in which AR designates a receiving antenna, D₁ a demodulator or detector supplied with modulating oscillations from a source RG₁ and D₂ designates a second demodulator or detector supplied with modulating currents from a source RG₂. RF₁

designates a filter which may be, for instance, of the Campbell type, said filter being inserted between the demodulators D_1 and D_2 . This filter is designed to suppress the upper side band resulting from the first step of demodulation and freely transmit the lower side band. The width of the lower side band will, of course, be sufficient to accommodate the desired number of channels to be received and the illustration given the filter is arranged to transmit a band lying between 2200 and 2400 cycles. A similar filter RF_2 is included in the output circuit of the second demodulator, D_2 , to eliminate the upper side band and transmit the lower side band resulting from the second step of demodulation. After the composite band has been passed through this filter, the several bands making up the composite band may be separated by means of filters RF_3 , RF_3' and RF_3'' in the individual receiving channels. For instance, the filter RF_3 may select a band lying between 200 and 250 cycles, this band being impressed upon a receiving detector D_3 supplied with detecting current from a source G_3 and having an ordinary receiving relay RR in its output circuit. The filter RF_3' may select a band between 275 and 325 cycles, this band being impressed upon a detector D_3' supplied with a detecting frequency from a source G_3' . In a similar manner the filter RF_3'' may select a frequency between 350 and 400 cycles, this band being impressed upon a demodulator D_3'' , which is supplied with a detecting frequency from a source G_3'' .

The operation of the receiving circuit of Fig. 3 when used in connection with the transmitting circuit of Fig. 1 may be as follows: Let it be assumed that the maximum low frequency signal transmitted by the relays TR , TR_{11} , etc., in Fig. 2, will not exceed 50 cycles per second, in the first channel the modulator M_1 will produce two side bands on either side of 200 cycles, of which the upper side band from 200 to 250 cycles may be selected by the filter F_1 . In the second channel, the modulator M_{11} will produce two side bands on either side of the carrier frequency of 275 cycles and the upper side band from 275 to 325 cycles may be selected by the filter F_{11} . In the third channel the modulator M_{12} will produce side bands on either side of the carrier frequency of 350 cycles and the upper side band from 350 to 400 cycles may be selected by the filter F_{12} . These several bands now coalesce and form a single band extending from 200 to 400 cycles, this band being impressed upon the modulator M_2 . As a result, the new carrier frequency of 2,000 cycles, as well as two side bands, the lower of which extends from 1800 cycles to 1800 cycles and the upper of which extends from 2200

cycles to 2400 cycles, appear in the output circuit of the modulator M_2 . The lower side band and the carrier frequency of 2,000 cycles are suppressed and the upper side band is transmitted by the filter F_2 . The transmitted side band is then impressed upon the modulator M_3 , so that upper and lower side bands are again produced. The lower side band extends from 17,600 to 17,800 cycles, while the upper side band extends from 22,200 to 22,400 cycles. By tuning the antenna to the average frequency of the upper band, say 22,300 cycles, the upper band will be readily radiated, while the carrier frequency of 20,000 cycles of the lower side band may be substantially eliminated.

The radiated band extending from 22,200 to 22,400 cycles is now received by the receiving antenna AR , which is tuned to the intermediate frequency and the received band is modulated by a frequency of 20,000 cycles supplied to the detector D_1 from the source RG_1 . The lower side band resulting from this operation extending from 2200 cycles to 2400 cycles may be selected by means of the filter RF_1 and impressed upon the detector D_2 , where a modulating action with the frequency of 2000 cycles takes place. This results in a further step down in frequency, the lower side band extending from 200 to 400 cycles being selected by the filter RF_2 . The several bands making up this composite low frequency band are selected by means of filters RF_3 , RF_3' and RF_3'' , each being designed to pass the band indicated, and the selected bands are again modulated with frequencies of 200 cycles, 275 cycles and 350 cycles, respectively, in the detecting apparatus D_3 , D_3' and D_3'' , so that low frequency currents corresponding to the original signaling currents result.

Since the modulating apparatus of the second and third channels of Figs. 2 and 3 only transmit carrier waves to represent the change-over from one steady state to the other, it is necessary to provide a special form of signal receiving relay for the corresponding receiving channels, in order that the receiving apparatus will discriminate between a change from positive to negative and a change from negative to positive, both of these changes being represented by the transmission of the brief train of high frequency waves. Such a receiving relay is indicated at RR' and RR'' in Fig. 3. Relay RR' is a polarized relay having two windings, 34 and 35. Normally the armature 36 of the relay will rest on one of its contacts, so that current may flow through one of the windings, say 35, from the battery 37. The battery 37 is of low potential and merely supplies enough current to hold the armature against the pole of the relay to which it is shifted. Suppose now a train of waves representing a change-over from positive to

negative is being received, the detector D_3 will translate this brief train of waves into a pulse of current flowing in its output circuit. This pulse will pass through the transformer 38, producing a pulse of current through the winding 35 in a direction opposite to that produced from the battery 37. This pulse of current is of considerable strength and therefore tends to throw the armature 36 to the opposite contact of the relay. The pulse being of momentary duration has now ceased and a current from the battery 37 flows through the other winding 34, in such a direction as to hold the armature against the opposite contact. If now a second train of waves corresponding to a change-over from negative to positive is received, an exactly similar pulse of current will appear in the output circuit of the detector D_3 . Owing to the shifted connections of the relay RR' , however, this pulse now flows through the winding 34 of the relay and being of greater strength and opposite in direction from the current flowing from the battery 37, shifts the armature of the relay back to its original position. Thus it will be seen that since changes from negative to positive always succeed changes from positive to negative, in regular order, the relay RR' will in effect discriminate between the two kinds of changes, since, in response to a pulse of current, it will first produce one action and then in response to a similar pulse of the same character will produce another action.

The receiving apparatus of the first channel of Fig. 3 may be used in connection with the transmitting apparatus of Fig. 1 or in connection with the transmitting apparatus of the first channel of Fig. 2. The receiving apparatus associated with the other two channels of Fig. 3 can only be used in connection with the second and third transmitting channels of Fig. 2. The several frequencies referred to in the preceding description are to be understood as being merely illustrative, a wide variation in the frequencies used being possible in actual practice.

It will further 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. The method of translating low frequency telegraph currents into high frequency carrier currents for carrier current transmission, which consists in curbing the low frequency telegraph impulses to eliminate therefrom the higher harmonics, thereby narrowing the band of low frequencies representing the telegraph signal, and then stepping up the frequency of the resultant

currents by successive steps of modulation with carrier currents.

2. The method of translating low frequency currents into high frequency carrier currents for carrier current transmission, which consists in passing the low frequency telegraph currents through a filter to eliminate the higher harmonics, then raising the frequency of the resultant currents by successive steps of modulation.

3. In a signaling system, means for producing telegraph impulses, a filter for eliminating the higher harmonics from said telegraph impulses, and a plurality of modulating devices, one working into the other and each supplied with carrier current whereby, upon the application of the currents transmitted through the filter to the first modulating device of the series, such low frequency currents will be raised to a desired carrier frequency by a plurality of steps.

4. The method of transmitting telegraphic impulses by means of carrier waves, which consists in supplying carrier waves to a vacuum tube so adjusted that under a certain condition of operation the tube will work upon a non-amplifying part of its characteristic curve which lies outside of one of the two knees thereof, thereby substantially preventing the transmission of carrier waves, and causing by means of telegraph impulses such a change in the adjustment of the tube as to cause it to operate upon the amplifying part of its characteristic, thereby transmitting carrier waves.

5. The method of transmitting telegraphic impulses by means of carrier waves, which consists in impressing carrier waves upon a vacuum tube so adjusted that normally it operates upon a non-amplifying, flat portion of its characteristic curve lying beyond one of the knees of said curve, so that normally carrier currents will not be transmitted, and in disturbing the normal adjustment of the tube by means of telegraphic impulses so that the tube operates upon the amplifying portion of its characteristic curve to transmit carrier currents.

6. The method of modulating carrier currents in accordance with telegraphic impulses through the agency of a vacuum tube comprising a heated filament, a grid and plate electrodes, which consists in maintaining under certain conditions such an adjustment of the grid potential that the tube operates upon a non-amplifying substantially flat portion of its characteristic curve, impressing carrier currents upon the tube, and varying the grid potential in accordance with telegraphic impulses to cause the tube to operate at certain times upon the amplifying portion of its characteristic wire, whereby the transmission of carrier waves will be permitted when the wire is operated upon the amplifying portion of its charac-

teristic and will be substantially prevented from operating on the non-amplifying portion thereof.

7. In a signaling system, a vacuum tube modulator, means to supply carrier waves thereto, said tube having its circuits so adjusted that the tube normally operates upon a non-amplifying portion of its characteristic beyond one of the knees thereof, whereby the transmission of carrier waves is substantially prevented, and means to disturb the adjustment of said tube by the action of telegraphic impulses, so that the tube works upon the amplifying portion of its characteristic, thereby transmitting carrier waves.

8. In a telegraph signaling system, a vacuum tube modulator having a filament grid and plate electrode, means to supply carrier waves to said tube, the grid potential of the tube being normally so adjusted that it operates upon a non-amplifying substantially flat portion of its characteristic curve, thereby substantially preventing the transmission of carrier waves, means responsive to telegraph impulses to vary the potential of the grid, so that the tube operates upon the amplifying portion of its characteristic, thereby transmitting carrier waves.

9. The method of translating direct current pulses into carrier waves, which consists in transmitting carrier waves during the period that the direct current pulse is undergoing a change, while suppressing the transmission of carrier waves during the constant portion of the pulse.

10. The method of translating direct current pulses into carrier waves, which consists in impressing carrier waves upon a modulating device so organized that during the application of substantially constant potential thereto carrier waves will not be transmitted, while carrier waves will be transmitted during a change in the applied potential, and in applying direct current pulses to said device to produce changes in the applied potential, thereby permitting the transmission of carrier waves during such changes only.

11. The method of translating direct current pulses into carrier waves, which consists in impressing the direct current pulses upon a vacuum tube modulator so adjusted that during one steady state of the pulses the tube will operate upon a non-amplifying portion of its characteristic lying beyond one knee of the curve, while during another steady state condition of the pulses, the tube will operate upon a non-amplifying portion of its characteristic lying beyond the other knee of the curve, and in impressing carrier waves upon said tube whereby during either steady state condition of the applied pulses substantially no transmission of carrier waves will take place, while during the transition from one steady state to the other, the

tube will pass through the amplifying portion of its characteristic with consequent transmission of carrier waves.

12. The method of translating direct current pulses into carrier waves, which consists in applying potentials corresponding to said pulses to the grid circuit of a vacuum tube modulator comprising filament grid and plate electrodes, said tube being so adjusted that the potential on its grid during one steady state condition of the applied pulses will be such that the tube operates on a non-amplifying part of its characteristic beyond one knee of the curve, while during the other steady state condition of the pulses, the potential on the grid will be such that the tube operates on a non-amplifying portion of its characteristic lying beyond the other knee of the curve, and in applying carrier waves to said tube, whereby during either steady state condition of the pulses, substantially no transmission of carrier waves takes place, but during the transition from one steady state condition to the other, a change in the potential of the grid takes place which causes the tube to pass through the amplifying portion of its curves, thereby transmitting carrier waves during such transition.

13. In a signaling system, a vacuum tube modulator having grid filament and plate electrodes, a source of carrier waves therefor, means to apply potentials to said grid corresponding to direct current pulses, the tube being so adjusted and the potential applied during one steady state condition of the direct current pulses being such that the tube operates on a non-amplifying portion of its characteristic beyond one of the knees of the curve, and the potential corresponding to the other steady state condition of the pulses being such that the tube operates on a non-amplifying portion of its characteristic beyond the other knee of the curve, whereby carrier waves are substantially suppressed during the steady state periods, and are transmitted only during the transition from one steady state to the other.

14. In a multiplex telegraph system, a plurality of carrier channels, means to apply telegraphic impulses to said channels, filtering means in each channel for eliminating the higher harmonics of the impulses, thereby narrowing the band of frequencies representing the telegraph signals, means in each channel to modulate relatively low carrier frequencies in accordance with the telegraphic pulses passed through said filtering means, and means to raise the resultant carrier waves to a higher frequency by a plurality of subsequent modulating steps.

In testimony whereof I have signed my name to this specification this 16th day of March 1920.

LLOYD ESPENSCHIED.