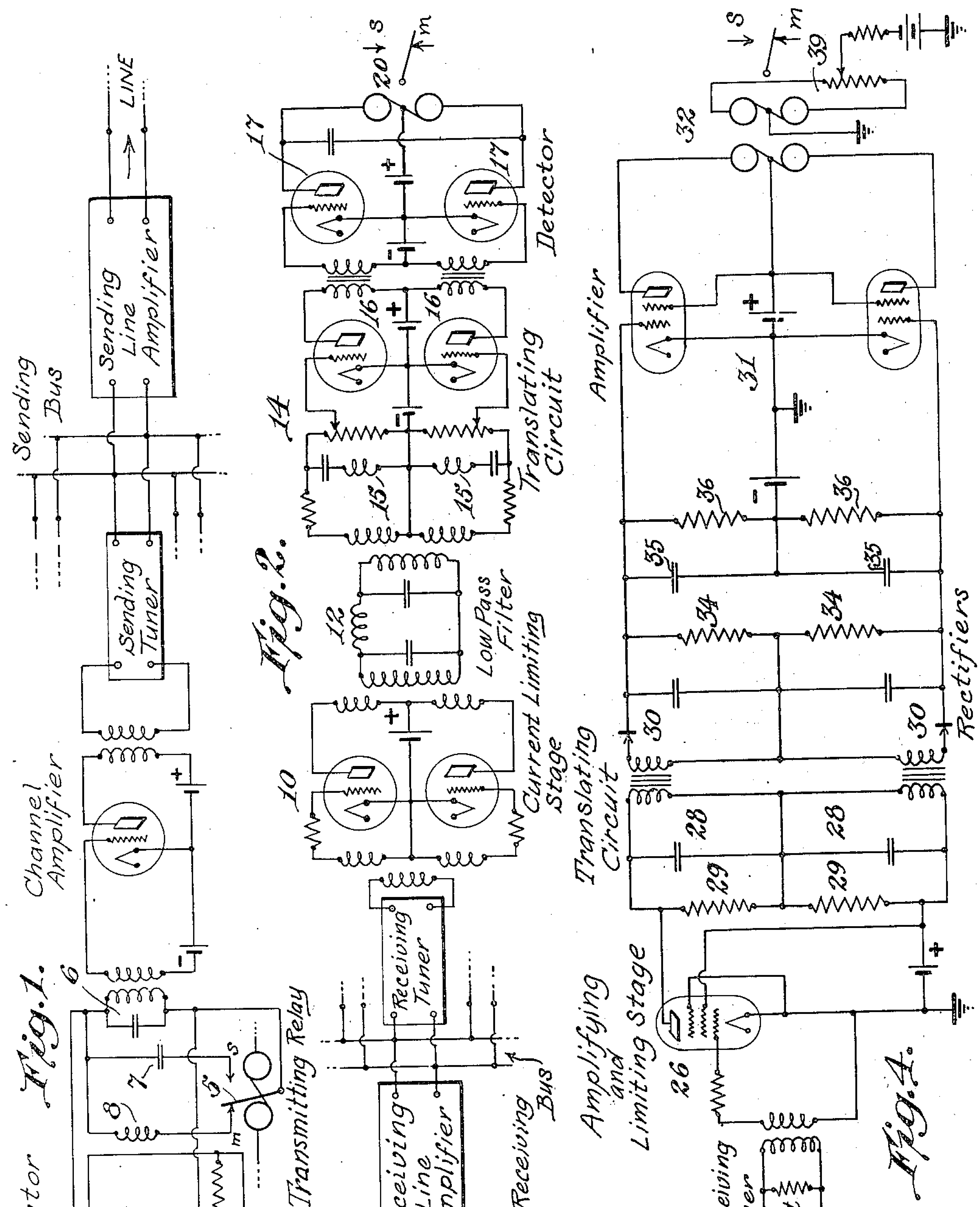
July 28, 1942. J. E. BOUGHTWOOD 2,291,369

POLAR CARRIER TELEGRAPH SYSTEM

Filed Nov. 21, 1941 3 Sheets-Sheet 1



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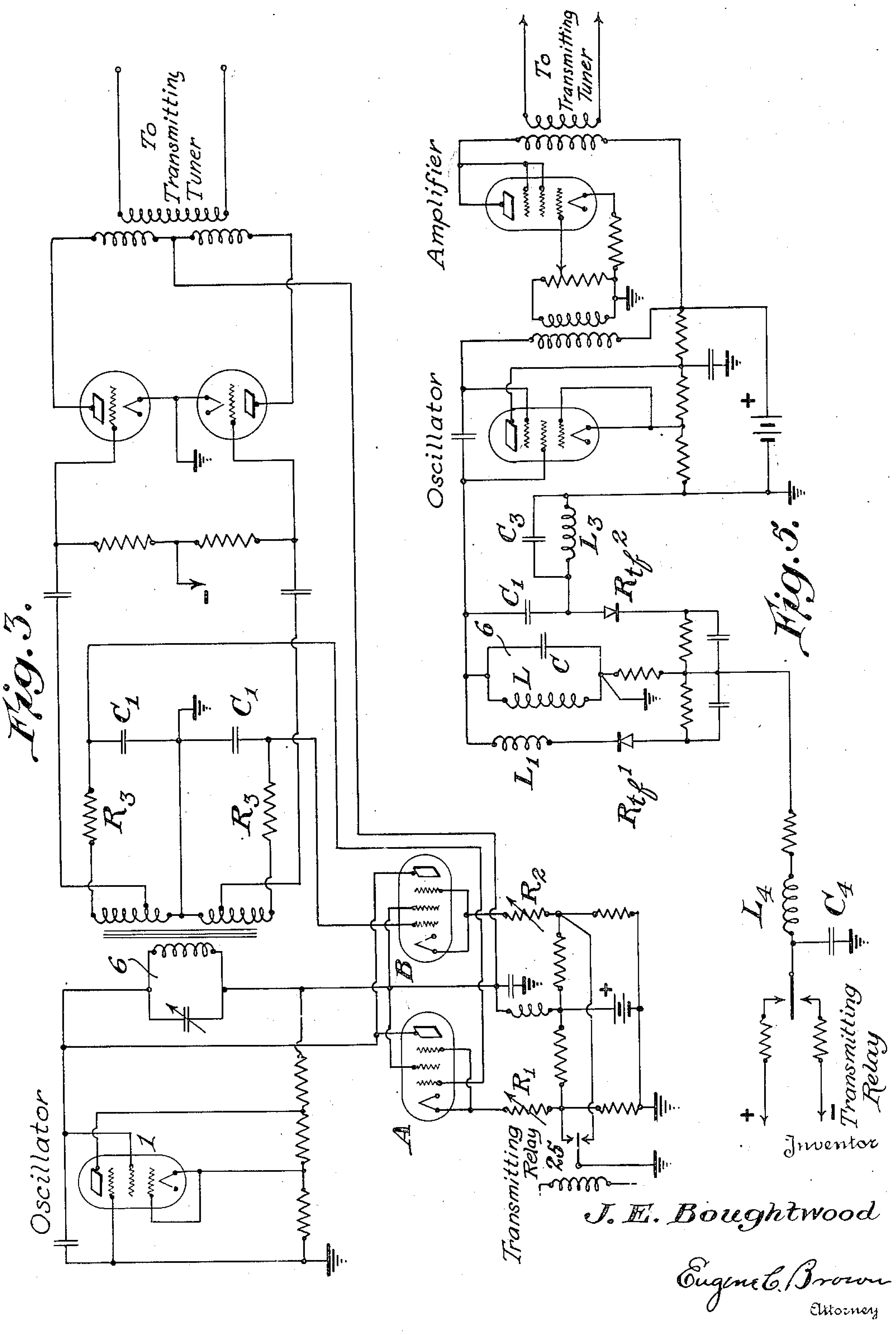

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POLAR CARRIER TELEGRAPH SYSTEM

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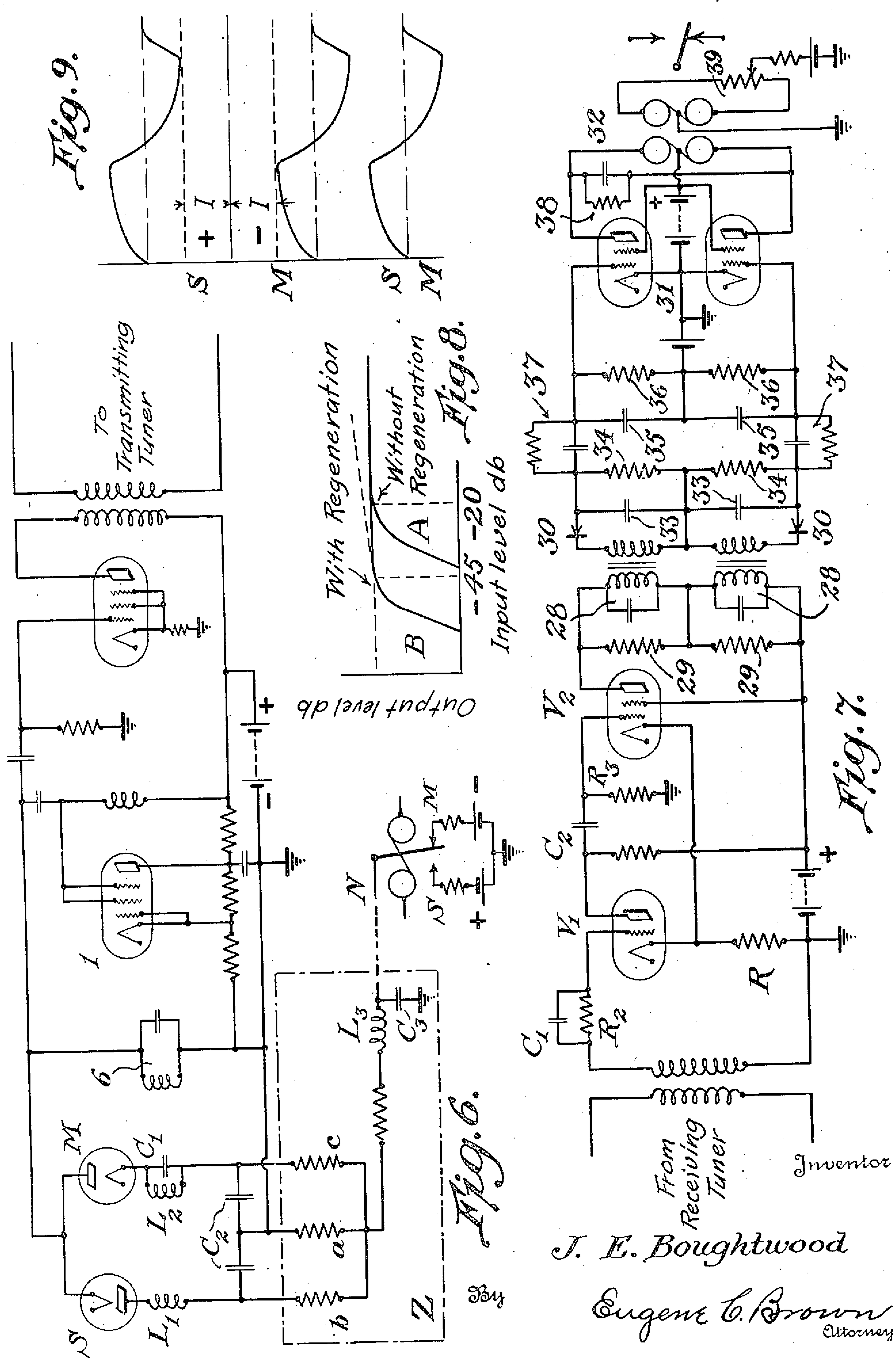

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UNITED STATES PATENT OFFICE

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POLAR CARRIER TELEGRAPH SYSTEM

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21 Claims. (Cl. 178—66)

This invention relates to systems of transmission in which carrier currents are employed for the transmission of telegraph signals and more particularly to improvements in polar carrier frequency systems employing separate frequencies for the "marking" and "spacing" signals. This application is a continuation in part of my prior application Serial Number 307,717, filed December 5, 1939.

Telegraph transmission by the carrier frequency method is usually accomplished by opening and closing the circuit of a carrier frequency generator at the transmitting end to send the spacing and marking signals respectively. At the receiving end the rectified carrier current operates a relay to produce the marking signal while the absence of current denotes a spacing signal. On occasion this relation between opening and closing of the circuit and marking and spacing may be reversed.

While a high degree of transmission efficiency may be secured by means of this elemental system, the signals are subject to bias as a result of variations in the level of the received signal. As a means of avoiding this difficulty it has been proposed to secure the equivalent of polar telegraph signals by employing separate frequencies for the marking and spacing signals, respectively, thus the receiving relay is operated positively by an incoming carrier subjected to the same line condition during both the marking and the spacing periods. Various arrangements have been developed for accomplishing this system of transmission.

The objects of the invention are as follows: To eliminate bias heretofore existing in the signals of polar carrier systems; to increase the efficiency of polar telegraph systems; to modulate the frequency of a carrier current in accordance with a telegraph signal of preferred shape; to cause the slow and smooth translation of the frequency generated by an oscillator between two values corresponding to marking and spacing telegraph signals; to gradually introduce inductance and capacity into the frequency determining circuit of an oscillator; to provide a regenerative limiting amplifier; to provide a differentiating circuit for coupling a discriminating circuit for polar telegraph signals to a balanced amplifier. Other objects will appear from the following detailed description.

The polar carrier channel disclosed herein while incorporating the usual features of such systems also embodies novel features for controlling the mode of transition between the marking and spacing frequencies whereby the carrier signal possesses a single set of characteristic frequency modulation products the essentials of which are encompassed within the 180 cycle band width.

As a consequence of these improvements it has been possible to operate a polar carrier channel within the 180 cycle band which is available when carrier frequencies are spaced at 300 cycle intervals, at the same high speeds which may be attained with single frequency working under favorable conditions. It is thus possible to introduce the improved features of my invention into existing carrier systems without loss of message capacity and with the gain of the advantages above outlined.

The invention is illustrated schematically in the accompanying drawings in which Figures 1 and 2 show respectively transmitting and receiving circuits; Figures 3, 5 and 6 show other improvements in transmitting circuits; Figures 4 and 7 illustrate further arrangements of receiving circuits; Figures 8 and 9 are illustrative diagrams explanatory of certain operations of the receiver shown in Fig. 7.

The transmitting circuit comprises an oscillator illustrated as of the dynatron type although any oscillator capable of rapid frequency change may be employed. In variable oscillator type transmitters it has been customary to employ a single contact relay which when open, permitted the oscillator to generate a "spacing" frequency and when closed so altered the frequency determining circuit as to cause the oscillator to produce a different frequency for "marking." It can be seen that with the single contact circuit the relay travel time is added to the spacing period to produce a spacing bias, which must be eliminated by relay adjustment at the receiving end. The transmitter of the type disclosed herein overcomes that difficulty by adjusting the oscillator to generate normally a frequency located midway between the marking and spacing frequency and then positively shifting the oscillator frequency to the marking and spacing values.

Referring to Fig. 1, the normal frequency of the oscillator circuit of the tube 1 is determined by the values of the condenser and the inductance of the frequency determining circuit 6. The frequency of the oscillator is then shifted from the normal or intermediate frequency to marking or spacing frequency as the armature or tongue 5 of the transmitting relay operates between its two contacts. Thus when the armature engages its spacing contact, the oscillator tuning circuit 6, is shunted by the capacity 7, thereby causing the oscillator to operate at spacing frequency; and when the armature is shifted to its marking contact, the tuning circuit 6 is shunted by the inductance 8, thereby causing the oscillator to operate at marking frequency. With this system the generated frequency shifts from marking through an intermediate frequency to spacing and vice versa to produce signals of equal length. This feature has been found to contribute prominently to the attainment of high speeds while retaining close spacing of the two signaling frequencies. Not only then are the marking and spacing periods symmetrical, but the transition of frequency from the one to the other is accomplished in two half steps thus achieving in some degree a controlled and gradual change between the two frequencies. However, signals from such a transmitter when received and demodulated into the original telegraph signals still show a slight fortuitous signal loss. A probable reason for this loss is as follows:

It is well known in frequency modulated transmission systems that when the modulation index,

$$m=\frac{\text{deviation frequency}}{\text{signal frequency}}$$

is in the neighborhood of unity, the side band components are limited to a very small number with the energy principally concentrated in the first component which is situated a distance from the carrier equal to the signaling frequency. Consequently, if a high speed telegraph signal, approaching the deviation frequency in value, contains only its fundamental component, the side bands will be as just defined with the more distant components virtually absent. On the other hand, if a square top telegraph signal were used with its infinite series of components there would be numerous additional side band frequencies distantly spaced from the carrier. Not only would a large portion of this side band energy be outside the available transmission band and thus be suppressed in the transmitting filter, but the energy relationships between the carrier and the side band frequencies which are contained within the available band would not be such as to provide the best signal shape after demodulation. However, where the signal is confined to substantially a single frequency component not only is most of the energy preserved and transmitted but the essential relationships between side bands and carrier are retained to provide a signal which upon demodulation substantially duplicates the original.

The signaling frequency waves pass through the usual channel amplifier and sending tuner to the sending bus for the various channels and from thence via the sending line amplifier to line in the manner well understood.

In order that the full benefit of polar operation may be secured, the proper type of receiving equipment must be utilized. Figure 2 shows schematically one form of receiving terminal. The signals of the carrier system after amplification, are selected by a channel tuner in the conventional manner and passed to the translating circuit via a limiting device 10, of the push-pull type, and harmonic suppressing filter 12. The translation circuit 14, comprises two series resonant circuits 15, tuned to the lower and higher signaling frequencies respectively, and sufficiently damped to eliminate amplitude distortion. The voltage across each circuit being a function of the instantaneous carrier frequency, there is produced an amplitude envelope proportional to the frequency envelope of the modulated signal. Thus when the carrier voltage across one tuned circuit is a maximum, the voltage across the other is a minimum and vice versa. These voltages are separately amplified at 16, detected at 17 and applied differentially to the receiving relay 20. Thus the receiving relay is actuated by polar D. C. telegraph signals, similar in form and character to those operating the transmitting relay at the distant station.

The double translation circuit shown and the method of transmission employed, permit the entire system to be operated on a polar basis with the advantages pertaining thereto. In addition, the limiting device 10, permits the receiving relay 20, to operate at its most efficient current level regardless of the received carrier level. Bias free operation is still possible on carrier levels below the limiter range, since in any polar system both marking and spacing signals are similarly reduced in level by line changes or other fortuitous circumstances.

Another type of transmitter shown in Fig. 3, employs a different method for varying the oscillator frequency. The oscillator may be identical with that of Figure 1, but instead of employing a supplemental inductance and capacity to obtain the required frequency deviation, these reactances are secured synthetically through the functioning of a pair of vacuum tubes. It is well known that a thermionic tube may be made to act as a reactance if its grid voltage is derived from and is in phase quadrature with its plate voltage. The magnitude of this reactance is a function of tube gain and can be controlled by the grid bias voltage. Thus by alternately shunting the oscillator tuned circuit with a pair of vacuum tubes having properly coupled plate and grid circuits, it is possible to have one tube act as a capacity and the other as an inductance to shift the frequency of the oscillator to thereby produce marking and spacing signals.

The functioning of this transmitter will now be described in greater detail. The cathode-anode circuits of the two tubes A and B are connected effectively in parallel with the frequency determining tuned circuit 6, of the oscillator 1. It is apparent that output voltages from the oscillator are applied to the grids of these two tubes through the two identical phase shifting circuits R_3 and C_1 and that the output voltage from the tubes A and B, operating in parallel, is returned to the oscillator tuned circuit. The phase shifting networks are so adjusted that the grid voltages of the two tubes A and B, while 180° apart, are each displaced substantially 90° from the voltage across the oscillator tuned circuit 6. Under these circumstances tube A which receives the leading grid voltage, functions as an inductance, while tube B, which receives the lagging voltage, appears as a capacity. Depending then upon which tube is functioning, the frequency of the oscillator may be shifted between its marking and spacing values by alternately paralyzing the tubes A and B. The control grids of the two tubes are connected to ground and the cathodes are connected to a positive potential via the self bias resistance R_1 and R_2 and the signal shaping circuits M and N. The positive cathode potential is sufficient to render the tubes inoperative. The contacts of the transmitting relay 25 are arranged to substitute ground for this positive potential and thus restore the grid-cathode potential to an appropriate operating value. The tubes A and B therefore function alternately in response to the operation of the marking and spacing contacts respectively of the transmitting relay 25, to vary the period of the tuned circuit 6. In consequence, marking and spacing frequencies respectively are generated and transmitted to line.

Figure 5 illustrates another modification of the transmitter wherein the supplementary inductance L_1 and capacity C_1 employed to change the frequency of the oscillation circuit of the tube 1, are connected to the main frequency determining circuit 6 via rectifier elements Rtf^1 and Rtf^2 whose conductivity may be controlled by the application of biasing potentials.

When the transmitting relay is connected to negative battery to send a "spacing" signal, the rectifier Rtf^1 is biased thereby so that it is effectively open circuited and hence inductance L_1 has no effect upon the oscillator frequency. Simultaneously, however, the rectifier Rtf^2 is rendered conductive so that the capacity C_1 forms a shunt to the tuned circuit 6, thus causing a spacing (low) frequency signal to be transmitted. The inductance L_3 shunted by condenser C_3, provides a path to ground for the required polarizing current through the rectifier Rtf^2.

Likewise when the transmitting relay is connected to positive battery for the purpose of sending a "marking" signal, the rectifier element Rtf^2 is biased to effectively open the circuit therethrough, so that the capacity C_1 is ineffective. At this time the polarizing current from positive battery via a path through L_1 and L in series, causes the rectifier Rtf^1 to become conductive so that the supplementary inductance L_1 effectively shunts the tuned circuit 6, whereby a "marking" (high) frequency is transmitted.

In this transmitter provision is made for causing the transition from the marking to the spacing frequency to be carried out smoothly and slowly. This is effected by means of a shaping network L_4C_4 located in the sending leg which causes the controlling potential applied to the rectifiers to rise gradually and smoothly. The sharp corners of a square top signal are eliminated so that the modulated signal is largely limited to its fundamental component, the higher harmonics being absent. Thus a true frequency modulation is provided. The carrier signal possesses a single set of characteristic frequency modulation products the essentials of which may be encompassed within the 180 cycle band width designed to operate with carrier frequencies spaced 300 cycles apart. It is therefore possible to substitute such a channel for an existing amplitude modulated channel, utilizing the same frequency space and filters, and to operate at the same or an even higher speed while gaining the advantages of polar carrier operation and frequency modulation described herein.

Another modification of my transmitter is shown in Fig. 6. The oscillator 1 is illustrated as of a particular type but other types of oscillators capable of rapid frequency change will serve as well.

This oscillator is coupled by any suitable form of coupling to one or more amplifying stages as needed for applying the modulated carrier current telegraph signals to line. The oscillator is adjusted by means of the anti-resonant circuit 6 to generate a carrier frequency located at the center of the assigned channel band. To produce the marking and spacing signals, the frequency of the oscillator is varied by like amounts upward and downward from the center frequency by alternately connecting in parallel with the tuned circuit 6, auxiliary reactance elements L_1 and C_1. This switching operation is accomplished by means of the rectifier devices S and M under control of the telegraph signals. The inductance L_1 is chosen with respect to the inductance of circuit 6, so that the inductance of the two in parallel causes an increase in the natural period of the oscillating system equal to the desired frequency deviation. Likewise the condenser C_1 and the inductance L_2 in combination, are similarly chosen with respect to the condenser of circuit 6 to produce a like decrease in frequency. The inductance L_2 furnishes a direct current by-pass around the condenser C_1 while the large condensers C_2 provide a carrier frequency by-pass to ground.

The function of the elements contained within the area Z is to alter the received direct current telegraph signal to the shape which has been found particularly desirable in the production of frequency modulated carrier telegraph signals and to control the conductivity of the marking and spacing rectifiers S and M alternately in accordance with the shape of these telegraph signals. The square top telegraph reversals received over the line N from any suitable form of transmitter of polar signals are given a smoothly rounded form by the inductance L_3 and the condenser C_3 in combination and flow thence to ground through the resistance *a*. The potential developed across this resistance is applied equally to the two rectifiers S and M through the rather high value resistances *b* and *c*, respectively. If, for example, a spacing or positive signal is being received, the resistance of the rectifier S is reduced from infinity down to substantially zero to gradually introduce inductance in parallel with the tuned circuit 6 up to the full value of the inductance coil L_1 at a rate determined by the smoothly rounded form of the telegraph signals. The generated carrier frequency will then have shifted upward in exact accordance with this change in tuning by an amount equal to the predetermined deviation frequency. Similarly, application of a marking signal will cause the gradual introduction of the effective capacity of the C_1L_2 combination in parallel with the tuned circuit up to the full value of the combination to cause a like downward shifting of the generated carrier frequency. It should be noted that the signal potential which renders one rectifier conductive to introduce the desired reactance element, at the same time renders the other rectifier non-conductive at the same time-rate to remove the other reactance element. This simultaneous introduction and withdrawal of the mutually opposing reactance elements in parallel with the circuit 6 causes relatively slow and smooth transition of the oscillator frequency between the marking and spacing values as determined by the shape of the modulating signals. It should be understood that although there will be some loss in efficiency, the action of the two rectifiers need not be simultaneous but that the introduction of the one may follow the withdrawal of the other. The function of resistances *b* and *c* is to prevent short circuiting of the resistance *a* through the rectifier which is at the moment conducting and thus reducing to zero the opposing potential which maintains the other rectifier in the non-conducting condition.

The conducting function of the two rectifiers in alternately connecting the auxiliary reactances into the tuned circuit may best be understood by considering them as variable resistance devices upon which is impressed the continuous carrier current voltage generated by the oscillator and appearing across the terminals of circuit 6 and having a frequency determined by the circuit 6. Assume, as before, that a positive potential is applied over the telegraph line to cause a current to flow through the resistance *b*, the inductance L_1 and the rectifier S, and thence to ground via the circuit 6. Under this condition rectifier S will have low resistance and will pass a direct current upon which is superimposed the carrier current generated by the oscillator. The inductance L_1 is now effectively in parallel with the inductance of tuned circuit 6 and will cause an increase in the generated frequency. The direct current component should be adjusted to exceed in value the highest possible peak value of the alternating carrier current so that the carrier current may flow freely through the rectifier without clipping of the peaks, except briefly during the period of reversal. By thus providing an excess conductivity for the rectifiers, ordinary variations in the amplitude of the received telegraph current will not influence the frequency deviation. While the rectifier S is conducting, the rectifier M is non-conducting by virtue of the equal positive potential applied to its cathode, thus opening the circuit of the C_1L_2 combination. In like manner, to send a marking signal an energizing negative potential is applied to the rectifier M to render it conductive and connect the combination C_1L_2 in parallel with the tuned circuit 6 to cause a decrease in the generated frequency. At the same time the negative potential imparts a very high resistance to rectifier S and thus effectively removes inductance L_1 from the circuit.

A particular property of the transmitter above described is the slow and smooth transition between the marking and spacing frequencies. This is contributed to by several factors, including the shaping elements L_3 and C_3 and the low decrement of the tuned circuit 6. It is by virtue of this slow transition that a true frequency modulation with a single orderly set of characteristic side bands of preferred disposition is obtained. As a consequence, the signal energy is contained within a range of useful frequencies sufficiently small to be contained within a narrow channel space, and extraneous frequencies which might cause interference in adjacent channels are substantially absent.

A small amount of amplitude modulation of the carrier signal envelope occurs at the moment of reversal, due to partial conductivity of the two rectifiers at this instant when the polarizing potential is in the neighborhood of zero. This effect is slight and since it is a reverse type of distortion to that which occurs in the transmitting filter, these two serve to effectively neutralize each other. If necessary, such distortion could be completely eliminated by means of transmitting limiting devices.

The rectifying devices in the transmitters of Figs. 5 and 6, are energized by the exciting telegraph potential which exceeds the maximum alternating current potential impressed upon the rectifiers so that their operating impedance to the carrier current is constant. As a consequence the constants of the oscillating circuits are entirely independent of variations in the exciting potentials received over the telegraph line.

Figure 4 illustrates a circuit arrangement at the receiving end which greatly aids in the superior performance of my telegraph system. In this receiver direct detection is accomplished by means of the discriminating circuits and the differential polar relay and is not dependent upon a synchronized demodulating frequency, as in certain prior systems and which is always a source of trouble.

The translation circuit comprises two parallel resonant circuits 28, in series, tuned respectively to the lower and higher signaling frequencies and having resonant impedances, small compared to the tube impedance. The resistances 29 provide sufficient damping to prevent distortion effects. Harmonics created by the limiting action of the tube 26, are effectively short-circuited by the low impedance of the translation circuits at the higher frequencies and they thus appear only to a negligible extent. As a result the harmonic suppressing filter indicated at 12 in Figure 2, can be eliminated.

The output voltages of the tuned circuits are detected at 30, the marking and spacing signals flowing separately through their associated resistance 34, across which the potential is of constant maximum value, reversing in sign as the carrier is modulated by the transmitter and is applied differentially to the grids of the push-pull amplifier 31. The resistances 36 and the condensers 35 serve to establish the potentials of the grids of the amplifier tubes with respect to ground. The amplified voltage is applied differentially to the receiving relay 32. A biasing circuit is indicated at 39 to compensate for minor asymmetries of the transmitting and receiving systems.

The above described receiver illustrated in Fig. 4 employs a single stage amplifier which functions as a combined amplifier and limiter. This receiver is satisfactory where the signals are received at a substantial level or when a common receiving amplifier for all channels precedes the channel receivers. In Figure 7 I have shown a modification of the receiver which employs a regenerative limiting amplifier of high gain in receiving terminals for frequency modulated carrier telegraph channels which are intended to operate on lines or circuits where the received levels are very low. The arrangement disclosed in Figure 7 effectively combines the two functions of amplifying and limiting in a single two-stage amplifier in such a manner that very high gain is secured along with perfectly effective limiting of the output current as the input level varies over a very wide range.

The limiting amplifier is embodied in a two-stage resistance coupled thermionic amplifier employing preferably for the first stage a triode and for the second stage a screen grid tube. A type of tube in which both the stages are included within a single glass or metal envelope has been found to operate very satisfactorily while making for economy in consumption of space and power. In the first stage, tube V_1, includes in series with its grid a resistance R_2 of comparatively high value shunted by a small condenser C_1. With such a resistance of suitable value the amplifying action of the tube remains approximately linear up to a certain limiting value of input voltage, but above this value the positive half waves of the input signal will cause a space current to flow in the grid-cathode circuit to produce an IR drop across the resistance R_2 in such direction as to make the grid more negative, thus reducing the amplification of the tube. As the input level increases the grid potential is progressively depressed in a negative direction until a balance is reached between the energizing input potential and the paralyzing bias potential. At this point, which is governed by the value of the resistance, the output level tends to become constant.

A single stage limiter operating in this fashion might provide a gain of 20 db. That is, it would lift an input signal say from a level of —20 db. to zero db. with effective limiting at the zero level. However, if the input level dropped below —20 db., the output level would not reach the desired constant limited value. Accordingly, in previously designed limiting amplifiers it has been necessary to provide pre-amplification sufficient to insure this overloading of the limiting stages. The present device comprises an organization of two tubes constituting a unitary limiter and high gain amplifier which will provide a constant output working level of adequate value for operating the discriminating or other detecting circuits while receiving extremely low input levels. Very high gain is secured by means of regeneration between the output and input stages so that even very low input levels may be amplified above the level where limiting action occurs. This regeneration is accomplished by means of the resistance R which is common to the cathodes and grids of both tubes. The current from the cathode of tube V_2 flows through this resistance to produce a potential drop thereacross which is in phase with and so augments the input voltage to tube V_1. By this regenerative action the gain of the amplifier as a whole is tremendously increased over the mere aggregate gain of the two tubes taken separately. It is possible, therefore, to extend the lower operating limits of the amplifier to exceedingly low levels while maintaining a constant output at a relatively high level.

The combination of the two tubes V_1 and V_2 without regeneration provides a limiting action as indicated in Curve A of Fig. 8. At relatively low levels the amplifying action of tubes V_1 and V_2 is substantially linear but at a certain desired higher level dependent upon choice of values for the resistance R_2 and the condenser C_1 the output tends to become constant. By virtue of the added amplification caused by the regenerative action of the tube V_2, however, the amplifier will reach to a much lower level as indicated by the Curve B while still producing a saturated output. Through the lower portion of this curve the action is again substantially linear and the feedback voltage is proportional to the signal input or output levels. However, the signal input voltage although very small is augmented by the feedback voltage to quickly reach a point where limiting action takes place, and since the output is constant the feedback remains constant. A substantially stable condition now obtains, the feedback furnishing the greater part of the energizing potential while the signaling potential remains just large enough to maintain control and prevent oscillation. In case the action of tube V_1 alone is insufficient to give a perfectly constant output level a supplemental limiting action may be obtained by proper choice of the values of the resistance R_3 and the condenser C_2 in the grid circuit of tube V_2. By this means the dotted portion of the curve of Fig. 8 may be rendered horizontal as indicated.

It can be seen that the cathode current of each tube in flowing through the resistance R impresses a degenerative potential upon its own grid. These degenerative effects, however, are so much smaller than the regenerative effect produced by the cathode current of tube V_2 upon the grid of the tube V_1 that they are entirely overcome. The amount of regeneration secured is dependent upon the value of the resistance R. This resistance should be large enough to provide a large degree of feedback, approximately 90% of the voltage on the grid of tube V_1, but the feedback should not be so large that any tendency toward oscillation would not be effectively suppressed with the signal at the lowest received level to be expected.

This amplifier while exceedingly simple and brief in its design provides a very large gain for the two stages yet with perfect stability and with constant limitation of output level at a value sufficiently high for the operation of the discriminating and detecting circuits. It functions very satisfactorily, therefore, in the reception of incoming signals at exceedingly low levels in frequency modulated telegraph channels of the type described.

After amplification the frequency modulated telegraph signals are applied to the translating circuit, comprising the two anti-resonant circuits **28** and the rectifiers **30** which discriminate between the marking and spacing frequencies. The two resonant circuits **28** are separately tuned, one to the marking frequency and one to the spacing frequency, their outputs being applied separately to the two rectifiers **30**. Resistances **29** provide damping for the tuned circuits for the prevention of amplitude distortion effects which tend to accompany sharp tuning. The circuits **28** are designed to have low impedance to the harmonics of the carrier frequencies which are normally present as a consequence of the limiting or distorting action of the preceding amplifier so that these harmonics are effectively by-passed. This expedient renders unnecessary the use of the low pass filter **12** illustrated in Fig. 2. After rectification the marking and spacing signals flow separately through their associated resistance **34** the potential across which is applied differentially to the grids of the push-pull amplifier **31**. The resistances **34** perform the unique function of removing the large direct current component of the demodulated signal voltage which occurs as a consequence of the imperfect separating action of the discriminating circuits **28**. Since these tuned circuits are rather broadly tuned and the marking and spacing carrier frequencies are spaced relatively close to each other, the momentary received current is not confined to the appropriate rectifier but an appreciable portion flows also through the inactive rectifier and in effect opposes the useful signal current. This spurious current is continuously present in both of the resistances **34** but flows in opposite directions so that no potential from this cause appears across the outer terminals of the resistances to be impressed upon the amplifier **31**. The amplified voltage is applied differentially to the receiving relay **32**. The condensers **33** serve to by-pass the A. C. component of the rectified carrier while the resistances **36** and the condensers **35** serve to establish the potentials of the grids of the amplifier tubes with respect to ground.

The two resistance shunted condenser combinations 37, 37 have been inserted to correct the small amount of characteristic distortion which commonly occurs in carrier telegraph channels of restricted band width. The effect of these devices may be supplemented if desired by the similar combination 38 shown in shunt to the relay 32.

Referring to Figure 9, the current in the two rectifiers is represented by the two upper curves in which the quantities +I and −I represent the continuously flowing direct current upon which is superimposed the useful spacing and marking signals. If the junction of the two resistances 34 was grounded and the potentials occurring across their outer terminals were applied directly to the amplifier, this direct current component would be impressed upon the grids and a large but useless direct current would be present in the coils of the relay in the plate circuit. To avoid the necessity for providing oversize vacuum tubes to handle this large current and also the excess heating of the relay, the resistances 34 were provided to perform a differentiation between the outputs of the two rectifiers whereby the D. C. component is suppressed, leaving only the marking and spacing telegraph signals illustrated in the final curve of Figure 9.

I have illustrated and described several circuit arrangements of transmitters and receivers embodying the features of my polar telegraph system but it will be evident to engineers that various modifications may be made to suit varying conditions within the scope of my invention defined in the accompanying claims.

I claim:

1. In a carrier wave transmission channel, the method of transmitting bias free signals which comprises introducing auxiliary inductive reactance and auxiliary capacity reactance alternatively into the frequency determining circuit of an oscillatory source which normally operates at a definite frequency in amount sufficient to invariably change its frequency to an equal degree above or below its normal frequency.

2. In a carrier wave transmission channel wherein the frequency of a carrier wave generated by an oscillator is varied in accordance with direct current polar telegraph signals, a frequency determining tuned circuit in association with the oscillator, and means for shifting the oscillator frequency to the marking or to the spacing frequency comprising means controlled by the polar signals to shunt the tuned circuit with an inductance or with a capacity dependent upon the polarity of the signal.

3. A carrier wave channel in which the frequency of a carrier wave is varied in opposite directions to produce marking and spacing signals respectively, an oscillator having a series-connected frequency determining circuit normally tuned to a frequency intermediate to the frequencies of the marking and spacing signals, frequency determining elements having equal and opposite reactance characteristics connected to said circuit, means to impress polar signals upon said circuit and means to render one or the other element ineffective upon the application of positive or negative polarities respectively.

4. In a carrier wave channel as set forth in claim 3, a network operating to shape the square topped polar signals to provide a smooth transition from marking to spacing frequency and vice versa.

5. In a carrier wave transmission channel wherein the carrier wave generated by an oscillator is varied in accordance with direct current marking and spacing telegraph signals to produce marking and spacing frequencies, a translating circuit for distinguishing said marking and spacing frequencies comprising a transformer having a center tapped secondary, separate resonant circuits tuned respectively to the marking and spacing frequencies connected across each half of said secondary, and damping means in each resonant circuit to eliminate amplitude distortion effects.

6. In a carrier wave transmission channel wherein the carrier wave generated by an oscillator is varied by marking and spacing telegraph signals to produce corresponding marking and spacing frequencies, a translating circuit comprising an amplifying tube which tends to generate harmonics, two damped parallel resonant circuits connected in series in the output circuit of said tube and tuned to the marking and spacing frequencies respectively for distinguishing said marking and spacing telegraph signals, said parallel resonant circuits having relatively low impedance at high frequencies for shunting the harmonics generated in said amplifying tube.

7. A receiving system for distinguishing and indicating two slightly separated frequencies representing marking and spacing telegraph signals comprising an amplifying tube having current limiting and harmonic producing properties, two damped parallel resonant circuits having low impedance at high frequencies connected in series with the output of said tube for distinguishing said marking and spacing signals and for shunting said harmonics, and separate rectifying and relay circuits for indicating said signals, symmetrically associated with said resonant circuits respectively.

8. In a carrier current telegraph transmitter, an oscillator having a natural frequency determined by a frequency determining element, two auxiliary reactances connectively associated with said element, and means responsive to unidirectional marking and spacing signal currents for alternately connecting said reactances to said element to thereby produce marking and spacing carrier telegraph signals by increasing or decreasing said oscillator frequency.

9. In a carrier current telegraph transmitter, an oscillator having a natural frequency determined by a frequency determining element, two auxiliary reactances connectively associated with said element, and high impedance devices whose conductivity is responsive to polarized signals connected in circuit respectively with said reactances for alternately connecting said reactances to said element to produce marking and spacing carrier telegraph signals by increasing or decreasing said oscillator frequency.

10. In a carrier wave telegraph channel for permitting operation on a polar basis throughout its extent with unbiased signals, a signal producing transmitting means comprising an oscillator having a natural frequency determined by a frequency determining element, two auxiliary reactances connectively associated with said element, and high impedance devices whose conductivity is responsive to polarized signals connected in circuit respectively with said reactances for alternately joining said reactances to said element to produce marking and spacing carrier telegraph signals by increasing or decreasing said oscillator frequency, and receiving means for maintaining the unbiased signals free from harmonics and substantially at the most

efficient current levels regardless of the received carrier level, comprising an amplifying tube having current limiting and harmonic producing properties, two damped parallel resonant circuits having low impedance at high frequencies connected in series with the output of said tube for distinguishing said marking and spacing signals and shunting said harmonics, and separate rectifying and relay circuits for indicating said signals, symmetrically associated with said resonant circuits respectively.

11. A telegraph system comprising a transmitting device for producing marking and spacing signals permuted in accordance with each character or other information to be transmitted, means including an oscillator and an associated oscillating circuit tuned to normally generate an alternating current having a predetermined frequency in the carrier spectrum, a plurality of impedance means selectively connectable to said tuned circuit, a plurality of means connected to said impedance means respectively for disabling the impedance means to prevent them from changing the tuning of the tuned circuit, and means controlled by said transmitting device for controlling said disabling means to cause said impedance means to be operatively connected alternately to said tuned circuit to cause said oscillator to generate marking and spacing signaling currents of two different frequencies respectively spaced equidistantly above and below said normally generated frequency, said signaling frequencies being unvarying irrespective of the speed at which the marking and spacing signals are transmitted, receiving means responsive to said signaling frequencies, means in the receiving means for translating the signaling frequencies into unidirectional signal currents, and means comprising a differential circuit responsive to said translated signal currents for producing marking and spacing signals corresponding to the signals produced by said transmitting device.

12. A telegraph system comprising a transmitting device for producing marking and spacing telegraph signals representative of each character or other item of information to be transmitted, means including an oscillator and an associated oscillating circuit tuned for normally generating an alternating current having a predetermined frequency in the carrier spectrum, an inductive reactance device, a capacitive reactance device, and means controlled by said transmitting device for selectively connecting said inductive and capacitive reactance devices to said tuned circuit to cause said oscillator to generate marking and spacing signaling currents of two different frequencies respectively spaced equidistantly above and below said normally generated frequency, said signaling frequencies being unvarying irrespective of the speed at which the marking and spacing signals are transmitted, receiving means responsive to said signaling frequencies, means in the receiving means for translating the signaling frequencies into unidirectional signal currents, and means comprising a differential circuit responsive to said translated signal currents for producing marking and spacing signals corresponding to the signals produced by said transmitting device.

13. A telegraph system comprising a transmitting device for producing marking and spacing telegraph signals representative of each character or other item of information to be transmitted, means including an oscillator and an associated oscillating circuit tuned to normally generate an alternating current having a predetermined frequency in the carrier spectrum, a plurality of impedance means each operatively connected to said tuned circuit to change the constants thereof for causing the oscillator to generate marking and spacing signaling currents of two different frequencies respectively above and below said normally generated frequency, a plurality of potential-controlled unidirectional current conducting devices respectively in circuit with said impedance means and each arranged to operatively connect its associated impedance means with said tuned circuit to produce said marking and spacing signaling currents of different frequencies, and means controlled by said transmitting device for selectively applying biasing potentials respectively to said unidirectional current conducting devices, whereby to send a marking signal one of said unidirectional currents conducting devices only will permit its associated impedance means to be operatively connected to the tuned circuit and to send a spacing signal, the other of said unidirectional currents conducting devices only will permit its associated impedance means to be operatively connected to said tuned circuit.

14. A telegraph system comprising a transmitting device for producing marking and spacing telegraph signals representative of each character or other item of information to be transmitted, means including an oscillator comprising a thermionic tube and a tuned circuit including an inductive reactance and a capacitive reactance connected to the control electrode of said thermionic tube for normally generating an alternating current having a predetermined frequency in the carrier spectrum, a plurality of impedance means each operatively connective to said tuned circuit to change the constants thereof for causing the oscillator to generate marking and spacing signaling currents of two different frequencies respectively above and below said normally generated frequency, a potential-controlled rectifier connected in series with one of said impedance means, another potential-controlled rectifier connected in series with another of said impedance means, said rectifiers being oppositely poled in said series circuits so that when either of said series circuits is operatively connected to said tuned circuit, the other of said series circuits is disabled relative to said tuned circuit, and means controlled by said transmitting device for selectively applying opposing biasing potentials respectively to said rectifiers, whereby to send a marking signal one of said rectifiers only will permit its associated series circuit to be operatively connected to the tuned circuit and to send a spacing signal the other of said rectifiers only will permit the series circuit with which it is associated to be operatively connected to said tuned circuit.

15. A telegraph system comprising a transmitting device for producing marking and spacing telegraph signals representative of each character or other item of information to be transmitted, means including an oscillator comprising a thermionic tube and a tuned circuit including a first inductive reactance and a first capacitive reactance connected to the control electrode of said thermionic tube for normally generating an alternating current having a predetermined frequency in the carrier spectrum, a second inductive reactance and a second capacitive reactance each connectable in shunt with said tuned circuit for causing the oscillator to generate marking

and spacing signaling currents of two different frequencies respectively above and below said normally generated frequency, a potential-controlled rectifier connected in series with said second inductive reactance and another potential-controlled rectifier connected in series with said second capacitive reactance, said rectifiers being oppositely poled in said series circuits so that when either of said series circuits is operatively connected in shunt with said tuned circuit, the other of said series circuits is open relative to said tuned circuit, and means controlled by said transmitting device for selectively applying opposing biasing potentials respectively to said rectifiers whereby to send a marking signal one of said rectifiers only will permit its associated series circuit to be operatively connected in shunt with the tuned circuit and to permit a spacing signal the other of said rectifiers only will permit the series circuit with which it is associated to be operatively connected in shunt with said tuned circuit.

16. A telegraph system comprising a transmitting device for producing marking and spacing telegraph signals representative of each character or other item of information to be transmitted, means including an oscillator and an associated oscillating circuit tuned for normally generating an alternating current having a predetermined frequency in the carrier spectrum, a plurality of impedance means each operatively connective to said tuned circuit to change the constants thereof for causing the oscillator to generate marking and spacing signaling currents of two different frequencies respectively above and below said normally generated frequency, a plurality of potential-controlled unidirectional current conducting devices respectively in circuit with said impedance means and each arranged to operatively connect its associated impedance means with said tuned circuit to produce said marking and spacing signaling currents of different frequencies, means including a biasing circuit controlled by said transmitting device for selectively applying biasing potentials respectively to said unidirectional current conducting devices whereby to send a marking signal one of said unidirectional current conducting devices only will permit its associated impedance means to be operatively connected to the tuned circuit and to send a spacing signal the other of said unidirectional current conducting devices only will permit its associated impedance means to be operatively connected to said tuned circuit, and impedance means in said biasing circuit for insuring smooth transition from either of the signaling frequencies to the other.

17. A telegraph system comprising a transmitting device for producing marking and spacing telegraph signals representative of each character or other item of information to be transmitted, means including an oscillator and an associated oscillating circuit tuned for normally generating an alternating current having a predetermined frequency in the carrier spectrum, means controlled by said transmitting device for selectively changing the constants of said tuned circuit to cause the oscillator to generate marking and spacing signaling currents of two different frequencies respectively spaced equidistantly above and below said normally generated frequency, receiving means comprising a high impedance thermionic tube responsive to said signaling frequencies for amplifying the signals, the character of said tube being such as to cause the signaling currents in the plate circuit of the tube to be maintained at a substantially constant level, two resonant circuits connected in series with the plate circuit of said tube and tuned respectively to the marking and spacing frequencies, each of said resonant circuits having a low impedance whereby distortion produced in the amplifying tube is by-passed, detecting devices associated with said tuned circuits for producing unidirectional potentials representative of said original marking and spacing signals, a balanced amplifier connected to said detecting devices, and a differential relay connected to said amplifier for reproducing the original marking and spacing signals.

18. A telegraph system comprising a transmitting device for producing marking and spacing telegraph signals representative of each character or other item of information to be transmitted, means including an oscillator and an associated oscillating circuit tuned for normally generating an alternating current having a predetermined frequency in the carrier spectrum, a plurality of impedance means each operatively connectable to said tuned circuit to change the constants thereof for causing the oscillator to generate marking and spacing signaling currents of two different frequencies respectively above and below said normally generated frequency, a plurality of potential-controlled unidirectional current conducting devices respectively in circuit with said impedance means and each arranged to operatively connect its associated impedance means with said tuned circuit to produce said marking and spacing signaling currents of different frequencies, means controlled by said transmitting device for selectively applying biasing potentials respectively to said unidirectional current conducting devices whereby to send a marking signal one of said unidirectional current conducting devices only will permit its associated impedance means to be operatively connected to the tuned circuit and to send a spacing signal the other of said unidirectional current conducting devices only will permit its associated impedance means to be operatively connected to said tuned circuit, receiving means comprising a high impedance thermionic tube responsive to said signaling frequencies for amplifying the signals, the character of said tube being such as to cause the signaling currents in the plate circuit of the tube to be maintained at a substantially constant level, two resonant circuits connected in series with the plate circuit of said tube and tuned respectively to the marking and spacing frequencies, each of said resonant circuits having a low impedance to by-pass distortion produced in the amplifying detecting devices associated with said tuned circuit for producing unidirectional potentials representative of said original marking and spacing signals and a balanced amplifier operatively connected to said detecting devices, and a differential relay connected to said amplifier for reproducing said original marking and spacing signals.

19. In a transmitter of carrier telegraph signals, an oscillator adapted to generate a median frequency under control of a frequency determining element, means connected in parallel with said frequency determining element for shifting the frequency of said oscillator equidistantly upward or downward from said median frequency to represent marking and spacing signals, comprising a first vacuum tube and a second vacuum tube, both of said tubes having cath-

ode, anode, and control grid elements, the grids of said tubes being coupled to their plate circuits through 90° phase shifting networks to produce a leading current in the grid circuit of said first vacuum tube and a lagging current in the grid circuit of said second vacuum tube, and means for alternately paralyzing said tubes in accordance with marking and spacing telegraph signals to cause said first tube to increase the frequency of said oscillator to send a marking signal and said second tube to decrease the frequency of said oscillator to send a spacing signal.

20. In a carrier wave transmission channel a transmitter comprising an oscillator adapted to generate a carrier current whose frequency is determined by a frequency determining circuit, auxiliary inductance and capacity reactances arranged to be alternately associated with said frequency determining circuit by means of oppositely polarized conducting devices for the purpose of shifting the frequency of said oscillator upward or downward to represent marking or spacing signals respectively, said polarized devices being connected to a transmitter of polar telegraph signals via an impedance network whereby equal potentials are applied to the two oppositely polarized devices to render them alternately conducting and non-conducting in paired sequence.

21. In a carrier wave transmission channel for two element signals a transmitter comprising an oscillator adapted to generate a carrier current of median frequency as determined by a frequency determining circuit, auxiliary inductance and capacity reactances arranged to be alternately associated with said frequency determining circuit by means of oppositely polarized conducting devices for the puropse of shifting the frequency of said oscillator upward or downward from said median frequency to represent said two element signals, said polarized devices being connected to a source of direct current signals via an impedance network whereby equal potentials are applied to the two polarized devices to render them alternately conducting and non-conducting in paired sequences for the purpose of cyclically shifting the oscillator between the two signaling frequencies.

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