Mar. 6, 1923. 1,447,204.

L. ESPENSCHIED.

PLURAL MODULATION AND DEMODULATION CIRCUITS.

ORIGINAL FILED SEPT. 30, 1919. 4 SHEETS—SHEET 1.

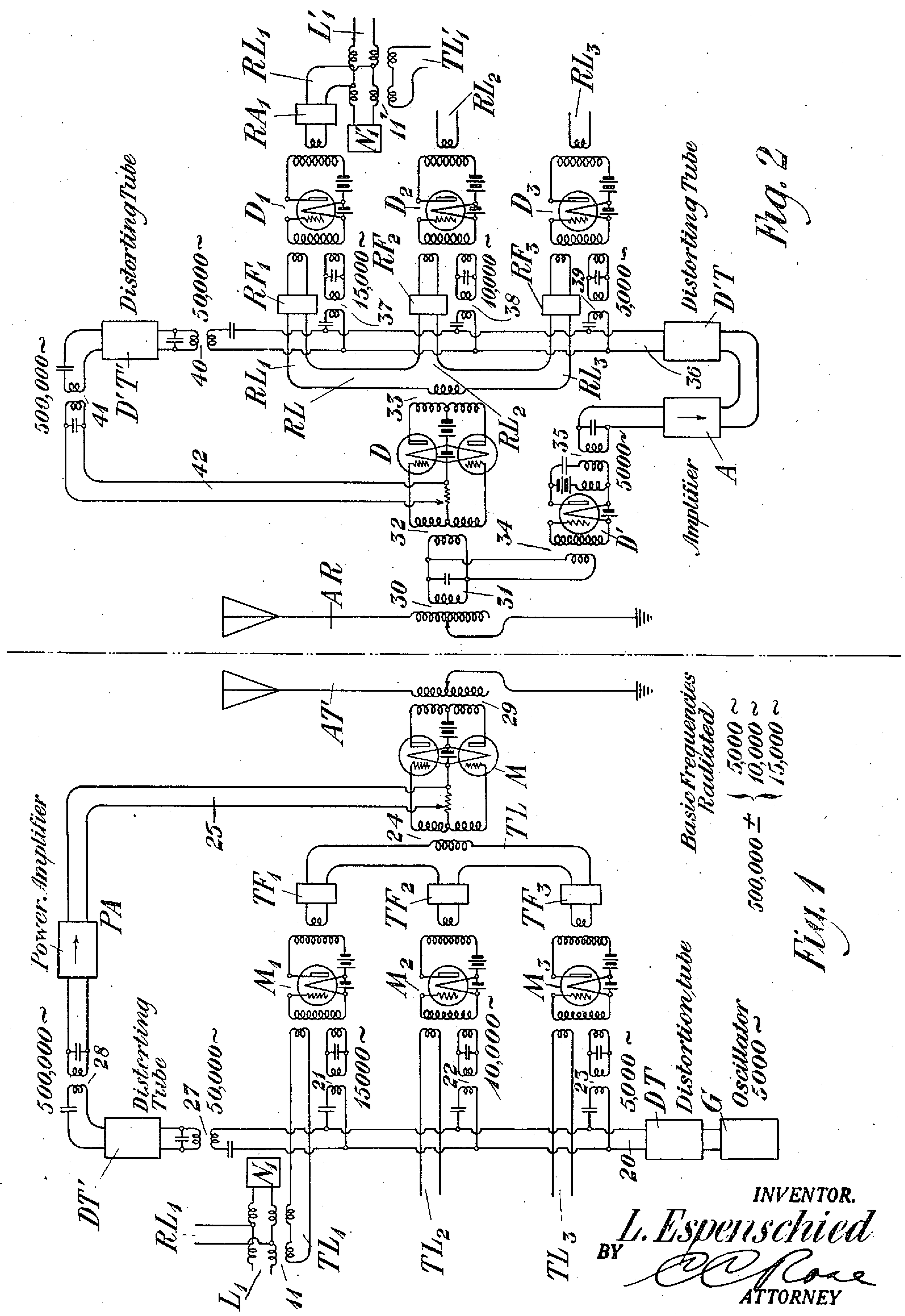

Fig. 2

Fig. 1

INVENTOR.

L. Espenschied

BY

ATTORNEY

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L. ESPENSCHIED.

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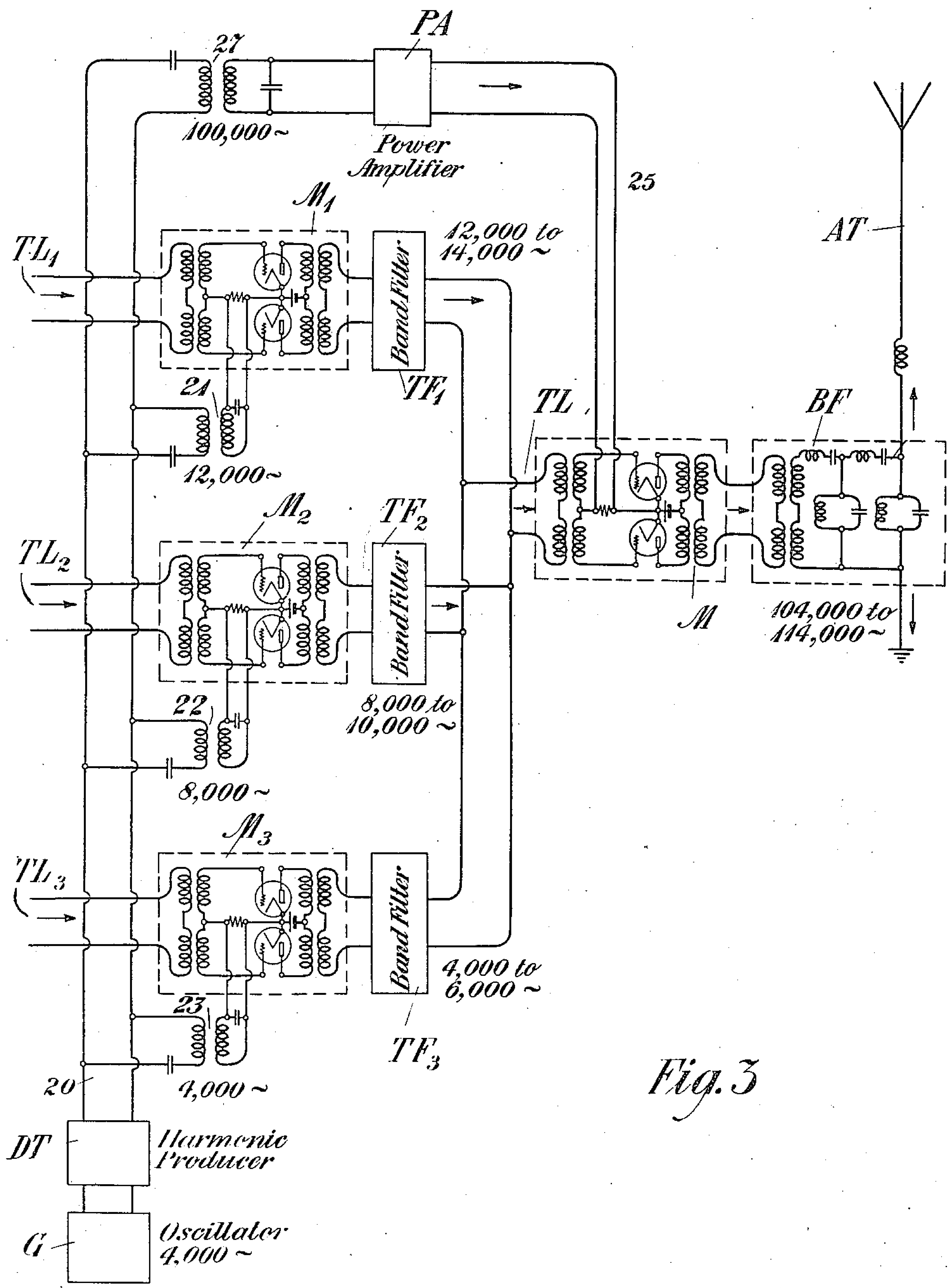

Fig. 3

INVENTOR.
L. Espenschied
BY
[signature]
ATTORNEY

Mar. 6, 1923. 1,447,204.

L. ESPENSCHIED.

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ORIGINAL FILED SEPT. 30, 1919. 4 SHEETS—SHEET 3.

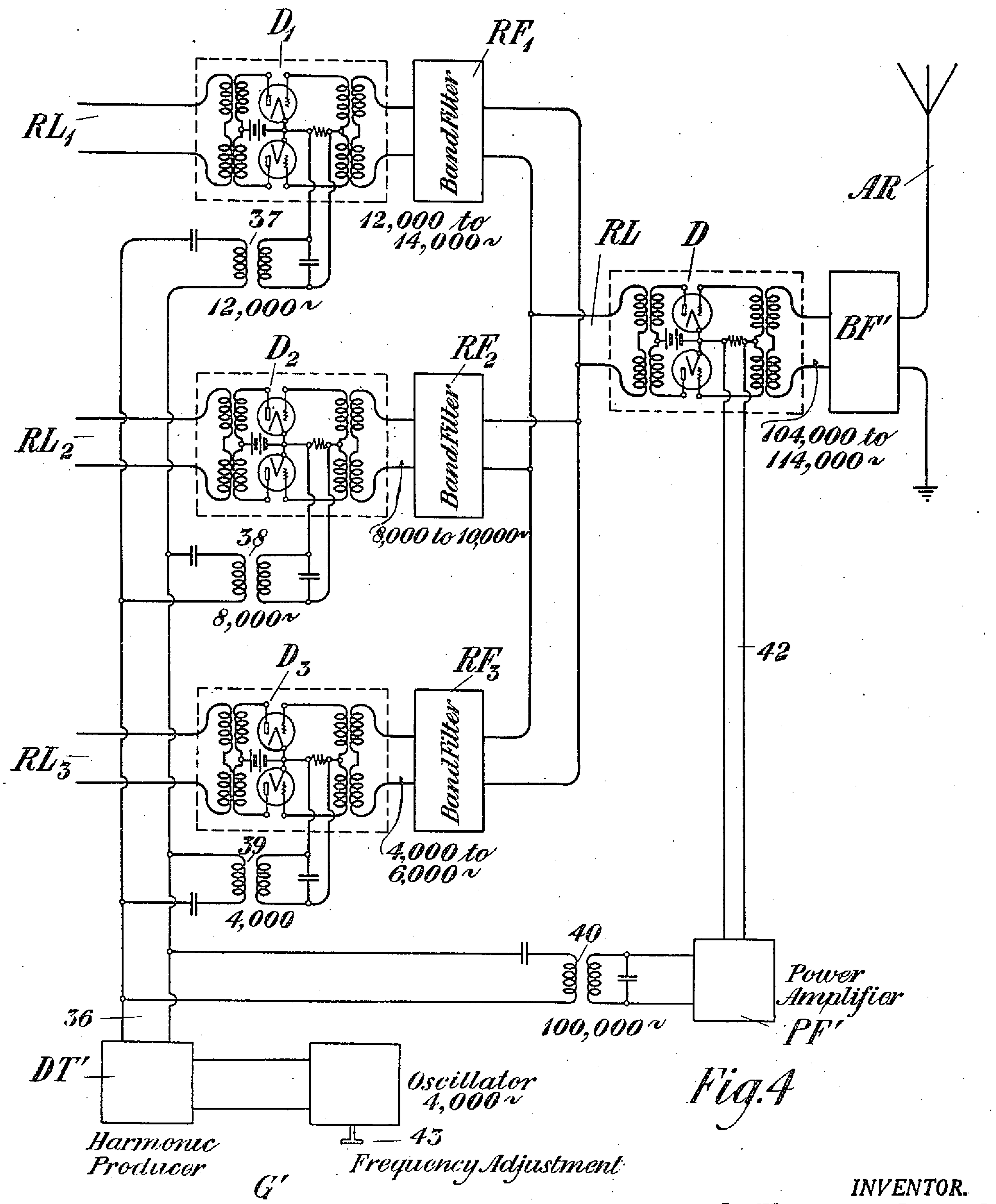

Fig. 4

INVENTOR.

L. Espenschied

BY C. C. Rose

ATTORNEY

Mar. 6, 1923. 1,447,204.

L. ESPENSCHIED.

PLURAL MODULATION AND DEMODULATION CIRCUITS.

ORIGINAL FILED SEPT. 30, 1919. 4 SHEETS—SHEET 4.

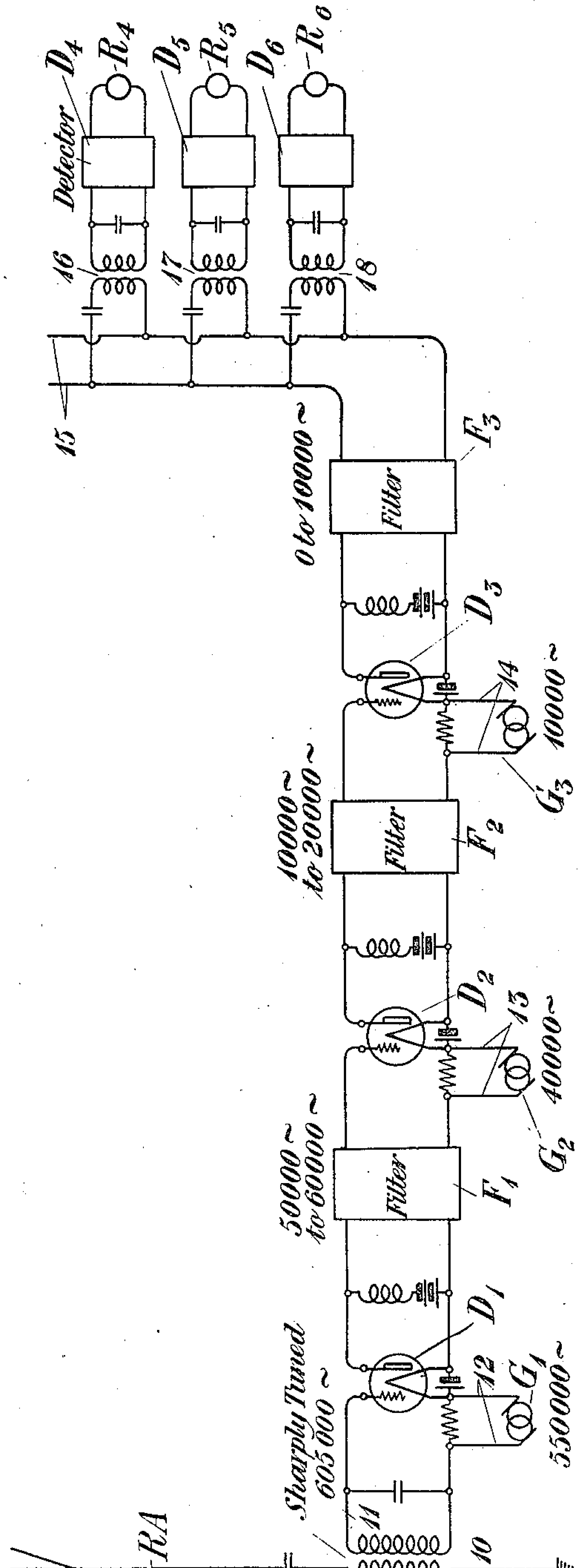

Fig. 5

INVENTOR
L. Espenschied
BY
C. C. Rose
ATTORNEY

Patented Mar. 6, 1923. 1,447,204

UNITED STATES PATENT OFFICE.

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

PLURAL MODULATION AND DEMODULATION CIRCUITS.

Application filed September 30, 1919, Serial No. 327,503. Renewed December 19, 1921. Serial No. 523,590.

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 and Demodulation Circuits, of which the following is a specification.

This invention relates to the transmission of signals and more particularly to systems for the multiplex transmission of radio signals.

One of the features of the invention resides in improved methods and means for securing selectivity between a plurality of signaling channels.

Another feature of the invention relates to methods and means whereby the interval between successive signaling channels may be reduced to a minimum.

Still another feature of the invention has reference to the provision of means and methods whereby the frequency intervals between signaling channels may be fixed or determined either at the transmitting station or receiving station, or both.

These features, together with other features of the invention more fully hereinafter appearing, are realized in a method of operation whereby multiplex channels are collected at the sending station and separated at the receiving station at frequencies which are low, compared with the frequencies used in actual transmission between stations. The essential principle underlying this method is that of a frequency step up and a frequency step down of a plurality of channels in common, in accordance with addition and subtraction of frequencies by modulation.

This general scheme involves at least two stages of modulation. Signaling currents of each of the multiplex circuits entering into the system are impressed upon the carrier currents of intermediate frequency and these carrier currents are collected upon a common circuit at this intermediate frequency. The frequency of the group is then stepped up to the transmission frequency by modulation with a carrier of the desired radio frequency. At the receiving end the process is reversed, the frequency being stepped down to the intermediate frequency level by subtracting the original radio frequency and the superposed channels are then separated by suitable selective circuits at the receiving frequency. Each channel is then detected individually and becomes a circuit of ordinary signaling frequency.

By performing the selecting and separating actions at a relatively low carrier frequency, instead of at the radio transmission frequency, an important advantage arises in connection with the design of selective circuits. For a given investment in the selective circuits far greater discrimination as measured in terms of frequency intervals rather than percentage of frequency range, can be obtained at low than at high frequecy.

A further advantage of a selective system of this type resides in the fact that it facilitates the suppression of one of the two side bands of modulation and thereby permits of reducing the width of the band of frequencies required to transmit the actual signal variations themselves. By thus reducing the width of the signaling bands, the channels may be more closely spaced and a larger number of channels obtained from the available frequency range.

A selective system of the type outlined above permits the communication channels to be placed so closely together in the radio frequency range as to practically require the use of some frequency control system for maintaining a rigid frequency spacing between channels and thereby preventing them from overlapping and interfering. The invention therefore contemplates generating a controlling frequency from which all other frequencies used in the system may be obtained. This may be done in several ways, for instance, there might be transmitted from the sending station a carrier frequency which is much more powerful than the side bands due to modulation, or the received carrier wave may be selectively amplified to the exclusion of the side bands. The first of these methods is not economical, while the second method is impractical, by reason of the difficulty of selecting the carrier at the high frequencies used in radio transmission. It is, however, feasible to select out the received carrier frequency from the side bands, if the separation takes place at a lower frequency level, as, for instance, after detection. It then becomes necessary to convert the component so selected as representing the carrier, back to the original high carrier frequency itself, so as to be enabled to employ it in demodulating received radio frequency channels.

Specifically it is proposed, therefore, to generate at the sending station a fundamental frequency and produce harmonics of this fundamental frequency. The lower harmonics are then used as carriers for the first step of modulation and a higher harmonic is used as the carrier for the second step of modulation. At the receiving station either of two things may be done: A fundamental frequency may be independently generated at the receiving station and harmonics may be produced from this fundamental, one of the higher harmonics being used for the first step of frequency translation and lower harmonics used for the final step of frequency translation. By this scheme all of the channels at each station are definitely tied together, since they are related to a fundamental frequency, and it is a matter of relatively simple adjustment to maintain the fundamental frequency at the sending and receiving station the same. An alternative expedient is to detect from the received band of frequencies the fundamental frequency generated at the sending station and produce from this frequency harmonics which may be used in the steps of demodulation, as above described. This expedient not only definitely ties together the frequencies of the various channels at the sending and receiving station, but also rigidly relates the frequencies of corresponding channels at the two stations.

The invention may now be more fully understood from the following detailed description when read in connection with the accompanying drawing, Figures 1 and 2 of which constitute circuit diagrams of a sending and receiving station, embodying one form of the invention, Figures 3 and 4 constitute diagrams of sending and receiving stations embodying another form of the invention, and Fig. 5 of which discloses apparatus for practicing a modification of the invention.

Referring to Figure 1, AT designates a transmitting antenna arrangement of any ordinary construction, while L_1 designates a low frequency signaling circuit, signals from which may be radiated from said antenna, after undergoing suitable frequency conversion. The signaling circuit L_1 is associated, through a balanced transformer 11, with a transmitting channel TL_1, while a corresponding receiving channel RL_1 is connected to the midpoints of the transformer windings. The apparatus associated with the receiving channel RL_1 is not illustrated, but may be understood from the corresponding receiving arrangement of a distant station, as illustrated in Figure 2. The channels TL_1 and RL_1 are rendered conjugate with respect to each other, by balancing the line L_1 by means of an artificial line or network N_1, in a well-known manner.

The channel TL_1 includes a modulator M_1 and a band filter TF_1. The modulator M_1 may be of any well-known type, but is illustrated as a vacuum tube modulator which is supplied with carrier current through a tuned circuit 21, in a manner more fully hereinafter described. The band filter TF_1 is of the general type disclosed in the U. S. patents to George A. Campbell, Nos. 1,227,113 and 1,227,114, issued May 22, 1917. This band filter is designed in accordance with the principles of said Campbell patent, to transmit the carrier frequency supplied to the modulator M_1 and one of the side bands resulting from modulation, but the other side band is preferably suppressed. The filter TF_1 connects the channel TL_1 to a common transmitting circuit TL.

The other channels, such as TL_2 and TL_3, corresponding to other signaling lines (not shown) are also connected to the common transmitting circuit TL through filters TF_2 and TF_3, respectively. The channels TL_2 and TL_3 also include modulators M_2 and M_3, which are supplied with carrier currents of different frequencies, through tuned circuits such as 22 and 23. The filters TF_2 and TF_3 are in general similar to the filter TF_1, but are designed to transmit the carrier frequency assigned to the channel, together with one of the side bands due to modulation, the other side band being preferably suppressed.

In order to provide the necessary carrier frequencies for the different channels, a source G is provided for generating a fundamental frequency. This source or generator may be of any type, such as, for instance, the well-known vacuum tube oscillator. The fundamental frequency generated may be any suitable frequency and for purposes of illustration is indicated on the drawing as being 5,000 cycles. Harmonic frequencies are obtained from this fundamental frequency, by means of a distorting tube arrangement DT. This distorting tube arrangement is of a well-known type and is fully set forth and described in the U. S. application of B. W. Kendall, Serial No. 139,530, filed December 29, 1916. The fundamental frequency and the various harmonics are supplied from the distorting tube DT to a common circuit 20, from which the desired carrier frequencies may be selected by means of the tuned circuits 21, 22 and 23, for application to the different modulators.

As illustrated, the fundamental frequency of 5,000 cycles is applied to the modulator M_3 and the first harmonic of 10,000 cycles to the modulator M_2 and the third harmonic of 15,000 cycles to the modulator M_1.

As the several carrier frequencies used in the first step of modulation are not sufficiently high for radio purposes, a common modulator M is provided for stepping up the several bands of frequencies impressed upon the common transmitting circuit TL. This modulator may be of any type, but is preferably a duplex vacuum tube modulator of the type illustrated in the U. S. application of John R. Carson, Serial No. 157,413, filed March 26, 1917, issued as Patent No. 1,343,307, dated June 15, 1920. The circuit TL is associated with the modulator M through a transformer 24. In order to supply carrier currents of the desired radio frequency to the modulator M, one of the higher harmonics of the fundamental frequency may be taken from the circuit 20 and supplied to the modulator M, over the circuit 25. As the carrier frequency desired for radio purposes may be quite high, and in the case illustrated is 500,000 cycles, which corresponds to the hundredth harmonic of the fundamental frequency, it is not practical to take this harmonic through the circuit 20 directly, consequently a lower harmonic such as the tenth harmonic, which corresponds to a frequency of 50,000 cycles, is selected by means of a tuned circuit 27 and is applied to an amplifying and distorting tube DT′, similar to the distorting tube DT, already referred to. This distorting tube produces amplified harmonics of the basic frequency 50,000 cycles, and the tenth harmonic corresponding to 500,000 cycles may then be selected by means of the tuned circuit 28. A power amplifier PA is provided for amplifying the selected harmonic which is then transmitted over the circuit 25 to the modulator M.

The modulator M is associated with the antenna AT, through a transformer 29. As a result of the second step of modulation, neglecting for the moment the side bands developed in the modulators M_1, M_2 and M_3, frequencies will appear in the output circuit of the modulator M, corresponding to 500,000 plus 5,000 cycles, 500,000 plus 10,000 cycles and 500,000 plus 15,000 cycles. Frequencies of 500,000 minus 5,000 cycles, 500,000 minus 10,000 cycles and 500,000 minus 15,000 cycles will also appear. In between these frequencies it will, of course, be understood that the frequencies corresponding to the side bands developed by the modulators M_1, M_2 and M_3 will appear. If it is desired to transmit both radio frequency side bands developed by the modulator M, the antenna AT will be tuned at the intermediate frequency between the two bands, which is 500,000 cycles. If, however, it is desired to radiate one side band in preference to the other, the antenna AT will be tuned to the average frequency of the side band to be radiated. If, for instance, the upper side band is to be radiated, the antenna should be tuned to about 510,000 cycles.

The receiving apparatus is illustrated in Figure 2, in which AR designates a receiving antenna at a distant station and L_1' a low frequency signaling circuit upon which the radio signals received by the antenna R may be impressed, after having undergone a suitable translation. A transmitting channel TL_1' is associated with the line L_1' through a transformer 11′. The apparatus associated with this channel is not illustrated, but it will be understood to be similar to that illustrated in Figure 1. A receiving channel RL_1 is connected to the midpoints of the windings of the transformer 11′ and the transmitting and receiving channels are rendered conjugate by balancing the line L_1' with an artificial line or network N_1'.

The receiving channel RL_1, together with the receiving channels RL_2 and RL_3 corresponding to other low frequency signaling lines, are connected to a common receiving circuit RL, through band filters RF_1 RF_2 and RF_3. These filters may be identical in construction with the corresponding filters TF_1, TF_2 and TF_3 of Figure 1. The receiving channels RL_1, RL_2 and RL_3 also include detectors D_1, D_2 and D_3. These detectors may be of any well-known type, but are preferably vacuum tube detectors. If desired, an amplifier such as RA_1 may be included in the output circuit of each detector, for amplifying the detected low frequency signals. This amplifier may be of any desired type, but is preferably a vacuum tube amplifier.

The receiving antenna AR is tuned to the same frequency as the transmitting antenna AT at the sending station and is coupled through a transformer 30 with a local oscillating circuit 31, tuned to the same frequency. The circuit 31 is connected through a transformer 32 with a common demodulator or detector D. This detector may be of any well-known type, but is preferably a balanced duplex vacuum tube detector of the general type illustrated in the U. S. application of John R. Carson, Serial No. 157,414, filed March 26, 1917, issued as Patent No. 1,343,308, dated June 15, 1920. The function of this detector is to step down the received band of radio frequencies to a point in the frequency spectrum corresponding to the first stage of modulation at the distant sending station. This result is accomplished by beating the received radio frequencies with a locally supplied carrier frequency corresponding to the frequency used in the last step of modulation at the distant sending station. In the case illustrated, this frequency is 500,000 cycles.

The detector D is associated with the common receiving circuit RL, through a transformer 33 and from this circuit the stepped down radio frequencies are supplied to the detectors D_1, D_2 and D_3, through the filters RF_1, RF_2, and RF_3. In order that these detectors may efficiently detect the low frequency signals from the band supplied thereto, it is desirable that the selected bands should be beaten with locally supplied homodyne frequencies corresponding to the carrier frequencies used in the first step of modulation at the distant sending station.

In order to supply these homodyne frequencies, as well as the beating frequency of 500,000 cycles to be used in the first step of demodulation, an ordinary vacuum tube detector D′ is associated through a transformer 34 with the oscillating circuit 31. The various frequencies in the received band, upon being impressed upon the detector D_1 react with each other in a well-known manner to produce in the output circuit of the detector frequencies corresponding to the sums and differences of the various frequencies. The high frequencies are of no utility and prominent among the low frequencies will be the fundamental frequency of 5,000 cycles. This will be apparent when it is considered that the three basic frequencies radiated from the distant sending station are 505,000, 510,000 and 515,000 cycles. The common difference between these frequencies is therefore 5,000 cycles. By means of a tuned circuit 35, associated with the detector D_1, the 5,000 cycle frequency may be selected from the various other frequencies resulting from the operation and detection. An amplifier A is provided for amplifying the selected fundamental frequency. A distorting tube arrangement D′T, similar to the distorting tube DT at the sending station, is provided for the purpose of producing harmonics of the fundamental frequency. The fundamental frequency, together with its various harmonics are supplied from the distorting tube D′T to the circuit 36, from which the desired homodyne frequencies may be supplied to the detectors D_1, D_2 and D_3 through tuned circuits 37, 38 and 39, respectively. In the case illustrated, these circuits will be tuned to 15,000 cycles, 10,000 cycles and 5,000 cycles respectively.

In order to provide the beating frequency for the detector D, a circuit 40 tuned to one of the higher harmonics of the fundamental frequency, such as the tenth harmonic, is associated with the circuit 36. The frequency of 50,000 cycles, selected by this harmonic is then impressed upon a second distorting tube arrangement D′T′, similar in character to the distorting tube arrangement DT′ at the distant sending station. This arrangement functions to produce harmonics of the 50,000 cycle frequency, of which the tenth harmonic corresponding to a frequency of 500,000 cycles may be selected by a tuned circuit 41. This frequency is then supplied to the detector D over a circuit 42.

Further details of the apparatus will be clear from the description of the operation, which is as follows: Low frequency signals incoming from circuits such as L_1, are impressed upon the transmitting channels TL_1, TL_2 and TL_3 and react in the modulators M_1, M_2 and M_3 with the carrier frequencies of 15,000, 10,000 and 5,000 cycles, to produce in the output circuit of the modulators carrier frequencies corresponding to the channels, together with side bands due to modulation. The filters TF_1, TF_2 and TF_3 then transmit one side band and the carrier frequency of each channel and suppress the other side band, the transmitted side bands and carrier frequencies being impressed upon the common transmitting circuit TL. By suppressing one side band for each channel, the channels may be spaced much closer together in the frequency spectrum.

The composite band of frequencies now appearing in the transmitting circuit TL are impressed through the transformer 24 upon the modulator M, to modulate the radio frequency of 500,000 cycles. This operation results in stepping the composite band appearing in the circuit TL up to a double band in the neighborhood of 500,000 cycles. Both side bands of this double band may be radiated, if desired, or the radiation of one side band may be minimized, depending upon the tuning of the radiating antenna AT, as already described. The radio frequency carrier current of 500,000 cycles is not transmitted as it is suppressed by the modulator M.

The frequencies radiated from the antenna AT are absorbed by the antenna AR at the distant receiving station of Figure 2 and are transmitted through the transformer 30 to the detectors D and D′. The detector D′ produces in its output circuit the fundamental frequency of 5,000 cycles, in the manner already described. This frequency is selected by means of a tuned circuit arrangement 35 and after being amplified by the amplifier A is passed through the distorting tube arrangement D_2′, thereby producing in the circuit 36 the fundamental frequency of 5,000 cycles, together with its various harmonics. The fundamental frequency and the second and third harmonics are supplied to the detectors D_3, D_2 and D_1, respectively, through the tuned circuits 39, 38 and 37, respectively. The tenth harmonic (50,000 cycles) is supplied through the tuned circuit 40 to the distorting arrangement D′T′, thereby producing harmonics of 50,000 cycles. The tenth harmonic of this frequency is 500,000 cycles and this frequency is supplied through the tuned circuit 41 and over the circuit 42 to the detector D. By beating the received radio band with this frequency in the detector D, the frequency differences will appear in the common receiving circuit RL, while the sums of the frequencies will also appear in the output circuit of the detector. These may be neglected, as they will be tuned out. As a result of this operation the same composite band of frequencies appears in the circuit RL as was superposed upon the transmitting circuit TL at the distant sending station, as a result of the first step of modulation.

The several bands making up this composite band will be selected by the filters RF_1, RF_2 and RF_3 and impressed upon the detectors D_1, D_2 and D_3. The individual bands will react in the detectors with the corresponding homodyne frequencies, 15,000 cycles, 10,000 cycles and 5,000 cycles, respectively, so that low frequency currents corresponding to the original low frequency signals will appear in the output circuits of the detectors and after amplification by amplifiers such as the amplifier RA_1, will be transmitted to the signaling lines, such as the line L_1'.

A modified arrangement is diclosed in Figures 3 and 4, in which the feature of tying together corresponding channels at the sending and receiving stations is eliminated, the frequency spacing between the channels being fixed, however, by developing the carrier frequencies at each station from a fundamental frequency.

Referring to Figure 3, which illustrates the transmitting arrangement, the apparatus is in general similar to that of Figure 1. For purposes of illustration, however, the frequencies used are indicated as being different from those used in Figure 1. Thus the frequency generated by the oscillator G is indicated as 4,000 cycles and the first and second harmonics supplied to the transmitting channels TL_2 and TL_1 are therefore 8,000 and 12,000 cycles respectively. Since, in accordance with this scheme, the fundamental frequency of 4,000 cycles will not be detected at the receiving station, it is unnecessary to transmit the carrier frequencies involved in the first modulation. The modulators M_1, M_2 and M_3 are therefore of the duplex vacuum tube type disclosed in the U. S. application of John R. Carson, Serial No. 157,413, already referred to.

In order to supply the proper radio carrier frequency to the common modulator M, in this instance the twenty fifth harmonic is selected by a tuned circuit 27 and this frequency (100,000 cycles) is supplied to the modulator M over the circuit 25. Preferably a power amplifier PA should be provided in the circuit 25 for amplifying this harmonic.

The band filters TF_1, TF_2 and TF_3 may be arranged to suppress one side band, preferably the lower band. The basic carrier frequency of each channel will be suppressed by the modulator. If, therefore, it be assumed that the signals transmitted over the low frequency lines are ordinary telephonic currents ranging from zero to 2,000 cycles in frequency, the band transmitted by the filter TF_1 will be 12,000 to 14,000 cycles, that transmitted by the filter TF_2 will be 8,000 to 10,000 cycles and that transmitted by the filter TF_3 will be 4,000 to 6,000 cycles, consequently the composite band supplied to the common transmitting circuit TL will be 10,000 cycles in width and extend from 4,000 cycles to 14,000 cycles. The modulator M, after modulating the radio frequency of 100,000 cycles in accordance with this composite band, will produce in its output circuit two side bands extending from 104,000 to 114,000 cycles and from 96,000 down to 86,000 cycles. The carrier frequency of 100,000 cycles will be suppressed by the modulator M, as before, and the band filter BF may be arranged to suppress the lower of the two bands, so that frequencies from 104,000 to 114,000 cycles will be radiated.

At the receiving station shown in Figure 4, a band filter BF′ similar in all respects to the band filter BF will be provided between the antenna AR and the demodulator D. As the fundamental frequency is not to be detected at the receiving station, the detector corresponding to the detector D′ of Figure 2 will be omitted. A generator G′ is provided instead, for generating the fundamental frequency. This generator may be of any well-known type, but is preferably a vacuum tube oscillator similar to the oscillator G of Figure 3. This oscillator is provided, however, with suitable means schematically indicated at 43, for adjusting its frequency in order to maintain the frequency generated in synchronism with that generated by the oscillator G at the sending station. The frequency adjusting means may control capacity or inductance in the frequency determining circuit of the oscillator. A harmonic producer D′T, similar to that shown in Figure 3, is provided for producing harmonics of the fundamental frequency (4,000 cycles). The first, second and third harmonics are supplied to the detectors D_3, D_2 and D_1, respectively, through tuned circuits 39, 38 and 37.

The detectors D_1, D_2 and D_3 are herein illustrated as being duplex vacuum tube detectors of the general type disclosed in the

U. S. application of John R. Carson, Serial No. 157,414, already referred to. The filters RF_1, RF_2 and RF_3 will be in all respects similar to the corresponding filters TF_1, TF_2 and TF_3 at the sending station, and will transmit the same band of frequencies.

In order to supply the proper homodyne frequency to the detector D for the first step of demodulation, a tuned circuit 40 is provided to select the twenty fifth harmonic from the circuit 36 and impress it over the circuit 42 upon the demodulator D. A power amplifier PF′ may be included in the circuit 42, for amplifying the homodyne frequency which should be of large power as compared with the received frequency.

Further details of the apparatus will now be clear from a description of the operation, which is as follows: Low frequency signals admitted to the channels TL_1, TL_2 and TL_3 are impressed upon the modulators M_1, M_2 and M_3, thereby modulating carrier frequencies of 12,000 cycles, 8,000 cycles and 4,000 cycles respectively, which are supplied from the harmonic producer DT. The modulators M_1, M_2 and M_3 suppress the carrier frequency and the filters TF_1, TF_2 and TF_3 suppress the lower side band of each channel, while transmitting the upper side bands. The several transmitted side bands are collected in a common transmitting circuit TL and impressed upon the common modulator M, which modulates the frequency of 100,000 cycles supplied over the circuit 25, in accordance with the frequencies contained in the composite side band transmitted to the circuit TL. The carrier frequency of 100,000 cycles is suppressed by the modulator M and the lower side band resulting from the second step of demodulation is suppressed by the filter BF, while the upper band ranging from 104,000 to 114,000 cycles is transmitted to the antenna for radiation to the distant receiving station.

At the distant receiving station the generator G′ is adjusted until it generates the same basic frequency as the generator G at the sending station. The received band of radio frequencies absorbed by the antenna AR is passed through the filter BF′ to the demodulator D. The frequency of 100,000 cycles impressed upon the demodulator from the circuit 42 reacts with the received band of frequencies to produce sum and difference frequencies in its output circuit. The high frequencies corresponding to the sum of the modulating and modulated frequencies are of no utility and will be suppressed by the band filters, owing to their high frequency. The band of frequencies corresponding to the difference between the modulating and modulated frequencies will be a composite band of frequencies ranging from 4,000 to 14,000 cycles. The individual signal bands making up this composite band will be selected by means of the filters RF_1, RF_2 and RF_3 into corresponding receiving channels RL_1, RL_2 and RL_3 and impressed upon the detectors D_1, D_2 and D_3, respectively. These bands, it will be noted, correspond to the bands resulting from the first step of modulation at the distant sending station and by reacting with the carrier frequencies assigned to the channels will result in the production of low frequency signaling currents in the output circuits of the detectors corresponding to the signaling currents originating at the sending station.

It will be observed that since all of the carrier frequencies involved at either the sending or receiving station are multiples of a fundamental frequency, the frequency spacing of the channels at either station and the correspondence of the frequency of similar channels at the two stations may be maintained fixed by the simple expedient of maintaining a proper adjustment of the oscillator producing the fundamental frequency at each station.

As has already been pointed out, one of the advantages of the arrangement of applicant's invention resides in the fact that by employing a plurality of steps of modulation and demodulation and by suppressing one of the side bands and the carrier, it is possible to space the channels in a multiplex system much closer than would be otherwise possible. The suppression of the carrier and one of the side bands for each step of modulation, and particularly the former, gives rise to another advantage, namely, a great saving in the amount of power which it is necessary to radiate in order to obtain a given signal at the receiving station. For example, it may be shown that where two steps of modulation are employed and only a single channel system is provided, it will be necessary to radiate, under certain circumstances, 19 times as much energy where the carrier and both side bands are transmitted as where but a single side band is transmitted. In the case of three channels, it may be shown that, under certain circumstances, 153 times as much energy will be radiated where the carrier and both side bands are transmitted In order to understand this more clearly, let it be assumed that there are to be two steps of modulation, and that in the first step of modulation the amplitude of each side frequency where the signal is a simple singing note, is a. If we have complete modulation, that is, a modulation in which when the signal wave is positive the instantaneous amplitude of the carrier is twice the normal amplitude and when the wave is negative the instantaneous amplitude is zero, the carrier employed in the first step of modulation must have an amplitude of $2a$. This follows at once when it is considered that the two side waves of amplitude a, when added to each other, must be equal in amplitude and opposite in sign to the carrier. Consequently, we will have in the output of the modulator a carrier of amplitude $2a$, an upper side frequency of amplitude a, and a lower side frequency of amplitude a. Since the energy is proportional to the square of the amplitude, the total energy represented by these three components will be proportional to $4a^2$ in the case of the carrier component and a^2 in the case of each side frequency component, making a total energy proportional to $6a^2$. If only one side frequency is radiated and the carrier and other side frequency be suppressed at this stage, the energy transmitted will be proportional to a^2.

If now we consider that all three components are passed on to the next step of modulation and are used to modulate another carrier, it will be seen that the output of the modulator at the second stage will have a component corresponding to the second stage carrier, a lower side band including the components corresponding to the first stage carrier and each of the side frequencies resulting from the first step of modulation, and an upper side band also containing components corresponding to the first stage carrier and each of the side frequencies resulting from the first step of modulation. In other words, there will be seven components. Now let us suppose that at a given instant all of the side components are in phase and of the same polarity, and that their amplitude has not been increased over that which existed in the fierst stage of moddulation. If we add the amplitudes of the six components other than the carirer, the total amplitude will be $8a$, so that in order to obtain complete modulation, the second stage carrier would have to have an amplitude of $8a$. If all of the energy is to be radiated, the energy corresponding to the second stage carrier would be proportional to $64a^2$, that corresponding to the three frequencies in the lower side band to $6a^2$, and that corresponding to the three frequencies in the upper side band would also be $6a^2$, making a total of $76a^2$. If only one side frequency had been transmitted after the first stage of modulation and this side frequency would have an amplitude of a, we would have at the second stage only a carrier frequency and upper and lower side frequencies corresponding to the side frequency transmitted from the first stage. If we suppress the carrier and one of these side frequencies, only a side frequency corresponding to the original signal and having an amplitude a, would be present, and the energy radiated would be proportional to a^2. The signal produced in this case at the receiving station would be only $\frac{1}{4}$ as great as that produced in the case where all of the components were transmitted in both stages, for the reason that the four side frequencies appearing in the last stage would correspond to the original signal and the energy of all four of these frequencies would be combined at the receiver. Taking this into account, it is at once apparent that in order to obtain a signal of the same strength in the case where only a single side frequency is finally radiated, as compared with the case where all of the frequencies are radiated, it would only be necessary to radiate $\frac{1}{19}$ of the power required in the latter case. This shows at once that an immense saving in power results from the suppression of the carrier at all stages of modulation in a plural modulation system, and a smaller but an appreciable saving results from the suppression of one of the side bands.

Considering now the case where three channels are transmitted and two steps of modulation are provided, it will be clear that in the output of the second stage there will be a component corresponding to the second stage carrier, a lower side band including three components corresponding to the three first stage carriers and two frequencies associated with each of these three frequencies, one frequency of each pair corresponding to one side frequency at the first stage and the other frequency of the pair corresponding to the other side frequency. There will also be an upper side band containing corresponding components, so that altogether there will be nineteen components. Assuming complete modulation in the first stage, each component corresponding to a first stage carrier will have an amplitude of twice the component corresponding to the signal. The sum of the amplitudes of all of the carriers in the two side bands of the second stage, there being altogether six carriers, will be $12a$. The amplitudes of the twelve side frequencies involved will also total $12a$. If, at a given instant all of these frequencies should be in phase and of the same sign, the total amplitude would be $24a$ and it would be necessary that the second stage carrier have an amplitude of $24a$ in order to have complete modulation. In practice, of course, the probability that all of these frequencies would be in phase and of the same sign at the same instant might not be great enough to warrant providing a carrier sufficient to accommodate all of them. In other words, as an engineering proposition, it might be better to provide a carrier of some smaller amplitude than would be required for perfect modulation and permit a small amount of distortion, which would result from an insufficient carrier. However, the second stage carrier would, in the case of three channels, necessarily have to have an amplitude considerably greater than the amplitude $8a$ required in the case of the single channel, and for perfect operation, its amplitude, as above stated, should be $24a$. Assuming that the amplitude be taken as the latter figure, the energy radiated in case all components are transmitted, would be proportional to $576a^2$ in the case of the second stage carrier, $18a^2$ in the case of the nine frequencies in the lower side band, and $18a^2$ in the case of the nine frequencies in the upper side band, making a total of $612a^2$. If we divide 612 by 4 to take into account the fact that where both side bands are radiated, the signal will be 4 times as strong in the case of double demodulation as where but a single side band is radiated, we see that it will be necessary to radiate 153 times as much power where all components are transmitted as would be the case where but a single side band is transmitted for each stage. Practically, as above stated, this figure might be reduced by using a carrier at the second stage of less amplitude than $24a$ and putting up with a certain amount of distortion. It is safe to say, however, that it would be necessary to radiate much more than 19 times the energy in the one case than in the other, and for perfection of operation, it would be necessary to radiate 153 times as much energy.

The suppression of the carrier particularly, and to a lesser extent the suppression of one of the side bands for each stage of modulation, is then a very important factor from the standpoint of energy saving as well as from the standpoint of close spacing of the channels. This is especially important where, as is usually the case, the energy is to be amplified before radiation, as it will be necessary to provide an amplifier which would handle 153 times as much energy in the one case as in the other under the conditions considered in connection with three channels. It is important to note that each time a channel is added, the energy radiated increases by an amount greater than a simple multiplication of the energy required for a single channel by the total number of channels.

As a further development of the method involved in this invention the successive steps of demodulation may be increased as will be clear from the following concrete statement of the method illustrated in Fig. 5. Let it be assumed that at a given station it is desired to select all frequencies lying between 600,000 and 610,000 cycles and to exclude all frequencies lying outside of that range. If the selection were to be made by the ordinary methods of discrimination now practised in the radio art this would involve excluding such frequencies as 599,500 cycles 610,500 cycles, which would be practically impossible. It is therefore proposed to impress the various received frequencies upon a circuit tuned sharply to about 605,000 cycles, which, it will be noted, is practically the mean of the limiting frequencies of the desired band. Since the desired band is relatively narrow as compared with the range of frequencies extending from zero up to the desired frequency, this step would give practically uniform reception for the frequencies between 600,000 and 610,000 cycles and decreasing reception for other frequencies. Such a circuit might, for example, give only ten per cent reception of current of 550,000 cycles.

The next step of the method involves beating the various frequencies with a locally supplied frequency for the purpose of stepping down the frequency of the desired band. The locally supplied frequency should be chosen as close as possible to the desired band and should be sufficiently below said band, so that frequencies resulting from the reaction of the local frequency with the undesired frequencies will, if they fall within the limits of the band resulting from the reaction of the desired frequencies with the locally supplied frequency, be practically negligible amplitude. For instance, assuming that a frequency of 550,000 cycles be used for beating the received frequencies, this would reduce the desired frequencies to a band between 50,000 and 60,000 cycles, which would be transmitted to the next circuit through a band filter. Although frequencies between 50,000 cycles and 60,000 cycles would also be produced by the reaction of the locally supplied 550,000 cycle currents with received currents in the range between 500,000 and 490,000 cycles, since the last mentioned band of frequencies is quite distant from the frequency to which the first circuit is tuned, the resultant frequencies between 50,000 and 60,000 cycles will be of very small amplitude as compared with frequencies within the same range resulting from the stepping down of the desired band of frequencies.

After stepping down the desired band of frequencies and filtering in the manner just described, the resultant band may be again stepped down by beating with locally supplied currents of a lower frequency which should be chosen with regard to the same considerations as stated in connection with the first step of lowering frequency. If it be assumed for purposes of illustration, that the second locally supplied frequency be 40,000 cycles, its reaction with the selected band would reduce the frequencies of said band to the range between 10,000 and 20,000 cycles. This range would then again be passed through a band filter.

The process may be continued as many times as may be necessary to pick out the high frequencies desired. In the case supposed, probably a third stepping down of the frequency would be sufficient. For instance, if the band between 10,000 and 20,000 cycles is beaten with a locally supplied frequency of 10,000 cycles, the currents will then lie in the frequency range from zero to 10,000 cycles and interfering currents would be eliminated.

A form of apparatus for carrying out the method is illustrated in Fig. 5. Referring to said figure, RA designates a receiving antenna of ordinary construction, which is coupled through a transformer 10 with a tuned circuit 11. Where, for instance, the desired band of frequencies lies between 600,000 and 610,000 cycles, the antenna and the circuit 11 may both be tuned to 605,000 cycles. A vacuum tube demodulator D_1 of a well-known type, is arranged with its input circuit connected to the tuned circuit 11 and a local beating frequency may be impressed upon said input circuit by means of a connection 12 leading to a generator G_1 which supplies a frequency of 550,000 cycles, for instance. A demodulator of this type, as is well known, produces in its output circuit frequencies corresponding to the sums and differences of the frequencies applied to its input circuit, consequently a frequency band between 50,000 cycles and 60,000 cycles will appear in its output circuit, corresponding to the reaction of the locally supplied frequency of 550,000 cycles with the desired received frequency band ranging from 600,000 to 610,000 cycles.

A band filter F_1 is connected with the output circuit of the demodulator D_1. This filter may be of the type disclosed in the U. S. patents to George A. Campbell, Nos. 1,227,113 and 1,227,114, issued May 22, 1917. The filter should be designed in accordance with the principles of said Campbell patents, so as to freely transmit frequencies lying between 50,000 and 60,000 cycles, while suppressing frequencies lying without these limits.

A second demodulator D_2, similar in type to the demodulator D_1, has its input circuit associated with the filter F_1. Low beating oscillations may be supplied over a circuit 13 from a generator G_2 to the input circuit of the demodulator D_2. As a result of these connections the output circuit of the demodulator will supply a frequency band lying between 10,000 cycles and 20,000 cycles, said band corresponding to the band passed by the filter F_1 stepped down to a lower position in the frequency spectrum. A filter F_2, in general similar to the filter F_1, but having a free transmission range between 10,000 and 20,000 cycles, is associated with the output circuit of the demodulator D_2 for selecting this band of frequencies.

A third demodulator D_3 has its input circuit associated with the filter F_2 and is supplied over a circuit 14 with local oscillations from a generator G_3. The frequency of these oscillations may be, for instance, 10,000 cycles. The action of this demodulator will step the band passed by the filter F_2 down to a range from zero to 10,000 cycles in the frequency spectrum. A filter F_3 of the Campbell type may be provided for selecting this band to the exclusion of the other band.

The desired band of frequencies now appears in the circuit 15 as a band lying between zero and 10,000 cycles. The desired individual frequencies or groups of frequencies may be selected from this band by tuned circuits such as 16, 17 and 18 and may be impressed upon the circuits of detectors such as D_4, D_5 and D_6 of any well known character. These detectors function to detect the selected frequencies so that they may actuate the receiving devices such as R_4, R_5 and R_6 of any well known type.

Obviously the converse of the method just described may be employed at the sending stations so that a larger number of steps of modulations may be used. Furthermore it will be understood that the frequencies hereinbefore described are merely illustrative and may be varied in practice as conditions may require.

It will also be understood that the details of the methods herein set forth may be varied and 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 radio signaling, which consists in receiving a band of radio frequencies, detecting from said band a fundamental frequency, producing harmonics of said fundamental frequency, selecting one of the higher harmonics, beating the band of radio frequencies with the selected harmonic, thereby producing a band of frequencies equal to the difference in frequency between said harmonic and the radio band, selecting frequencies from the resultant band into receiving circuits and detecting from the selected frequencies low frequency signals.

2. The method of radio signaling, which consists in generating a fundamental frequency, producing harmonics thereof, modulating certain of the harmonics in accordance with low frequency signals, modulating a higher harmonic in accordance with the resultant modulated frequencies, thereby producing a band of radio frequencies, transmitting said band to a receiving station, detecting from said band said fundamental frequency, producing harmonics of said fundamental frequency, beating the re-

ceived band with one of the higher harmonics, thereby stepping down the band in frequency, selecting frequencies from said band, and beating the selected frequencies with different lower harmonics, thereby detecting low frequency signals.

3. The method of radio signaling, which consists in generating a fundamental frequency, producing harmonics thereof, modulating said harmonics in accordance with low frequency signals, thereby producing a band of frequencies, producing the same fundamental frequency at a receiving station, producing harmonics of said fundamental frequency at said station, selecting at said station the modulated harmonics produced at the transmitting station, and beating the selected frequencies with corresponding harmonics, thereby detecting low frequency signals.

4. The method of radio signaling, which consists in generating at a transmitting station a fundamental frequency, producing harmonics of said frequency, modulating certain of said harmonics in accordance with low frequency signals, modulating another harmonic in accordance with the resultant modulated frequencies, thereby producing a band of radio frequencies for transmission, receiving said band at a receiving station, producing at said station a frequency corresponding to said fundamental frequency, producing harmonics of said frequency, beating the received band with one of the higher harmonics, thereby stepping the band down in the frequency spectrum, selecting frequencies from the stepped down band, and beating the selected frequencies with lower harmonics, thereby detecting low frequency signals.

5. The method of radio signaling, which consists in modulating a plurality of closely spaced carrier frequencies in accordance with low frequency signals, suppressing one side band of each of the resultant modulated bands so as to prevent interference with the unsuppressed band of the adjacent channel, modulating another frequency with each of the unsuppressed bands, suppressing the lower side band of the resulting band, transmitting the unsuppressed band, receiving said band at a distant receiving station, beating the received band with suitable frequency, in order to lower the band in the frequency spectrum, selecting from the band thus stepped down, bands corresponding to the side bands which were not suppressed at the transmitting station, and detecting from said bands low frequency signals.

6. In a radio signaling system, means to receive a band of radio frequencies, a common demodulator upon which said band may be impressed, means to supply a beating frequency to said band, whereby the received band will be stepped down in frequency, means to select from the band thus stepped down a plurality of smaller bands, a demodulator for each of the selected bands, means to supply a beating frequency to each of said bands, whereby low frequency signals may be detected from the selected bands.

7. In a radio signaling system, means to generate a fundamental frequency, means to produce harmonics of said fundamental frequency, means to modulate certain of said harmonics in accordance with low frequency signals, means to modulate another harmonic by means of the frequencies resulting from the first modulation, and means to transmit the band of frequencies resulting from the second modulation.

8. In a radio signaling system, means to receive a band of radio frequencies, means to produce a fundamental frequency, means to set up harmonics of said fundamental frequency, means to beat the received band of radio frequencies by one of said harmonics, thereby stepping the band down in the frequency spectrum, means to select smaller bands from the band thus stepped down, and means to beat the selected bands with other of said harmonics, thereby detecting low frequency signals.

9. In a radio signaling system, means to generate a fundamental frequency at a transmitting station, means to produce harmonics of said fundamental frequency, means to modulate certain of said harmonics in accordance with low frequency signals, means to modulate another harmonic in accordance with the modulated harmonics, means to transmit to a distant receiving station the band of frequencies resultant from said last mentioned modulation, means to produce at said receiving station a fundamental frequency corresponding to the frequency generated at the sending station, means to produce harmonics of said frequency, means to beat the received band of frequencies with one of said harmonics, thereby stepping the band down in the frequency spectrum, means to select smaller frequency bands from the band thus stepped down, and means to beat the selected bands with other of said harmonics, thereby detecting low frequency signals.

10. In a signaling system, means to generate at a sending station a fundamental frequency, means to produce harmonics thereof, means to modulate certain of said harmonics in accordance with low frequency signals, means to modulate another harmonic in accordance with the modulated harmonics, means to transmit the resultant band of frequencies to a distant receiving station, means at said receiving station to detect from said band of frequencies said fundamental frequency, means to produce harmonics of said fundamental frequencies at said receiving station, means to beat the

received band of frequencies with one of said harmonics, thereby stepping the band down in the frequency spectrum, means to select from the band thus stepped down smaller bands of frequencies, and means to beat the selected bands of frequencies with other of said harmonics, thereby detecting low frequency signals.

11. The method of selecting frequencies from a band of radio frequencies which consists in beating the band of radio frequencies with another frequency so chosen as to produce a side band of corresponding width and having a lower position in the frequency spectrum, selecting individual bands of the frequency band thus stepped down and beating each individual band with another frequency to detect signals therefrom.

12. The method of selecting frequencies from a band of radio frequencies which consists in beating the band with another frequency to produce a side band of the same width but having a lower position in the frequency spectrum, and selecting from the band thus stepped down individual frequency bands without distorting frequencies in the individual bands.

13. The method of selecting frequencies from a band of radio frequencies which consists in beating the band with another frequency to produce a side band of the same width but having a lower position in the frequency spectrum, selecting from the band thus stepped down individual frequency bands without distorting frequencies in the individual bands, and detecting signals from the individually selected bands.

14. The method of reducing the energy transmitted in a system employing a plurality of steps of modulation, which consists in suppressing the carrier before transmission after each step of modulation, and transmitting only the side bands.

15. The method of reducing the energy transmitted in a system employing a plurality of steps of modulation, which consists in suppressing the carrier and one side band before transmission after each step of modulation, and transmitting only one side band for each step.

16. The method of reducing the energy transmitted in a multiplex system employing a plurality of steps of modulation, which consists in suppressing the carrier before transmission after each step of modulation for each channel, and transmitting only the side bands of each channel.

17. The method of reducing the energy transmitted in a multiplex system employing a plurality of steps of modulation, which consists in suppressing the carrier and one side band before transmission after each step of modulation for each channel, and transmitting only one side band for each step of modulation in each channel.

18. In a signaling system employing a plurality of steps of modulation, means associated with each modulation stage for suppressing the carrier before transmission to the next stage, whereby the energy appearing in the output of the last stage will be reduced.

19. In a signaling system employing a plurality of steps of modulation, means associated with each modulation stage for suppressing the carrier frequency employed at that stage, and means associated with each stage of modulation for suppressing one side band resulting from the modulation at that stage, whereby only energy corresponding to one side band will appear in the last stage.

20. In a multiplex signaling system employing a plurality of stages of modulation, means associated with each stage of modulation for each channel for suppressing the carrier frequency before transmission to the succeeding stage, whereby the energy in the output of the last stage of each channel will be reduced.

21. In a multiplex signaling system employing a plurality of stages of modulation, means associated with each stage of modulation for each channel for suppressing the carrier frequency employed at that stage, and means associated with each stage of modulation for each channel for suppressing one side band resulting from the modulation at that stage, whereby only the energy corresponding to one side band for each channel will appear in the output of the last stage.

22. The method of radio signaling, which consists in receiving a band of radio frequencies, obtaining from said band a controlling frequency, producing other frequencies determined by said controlling frequency, selecting one of the frequencies produced, beating the band of radio frequencies with the selected frequency, thereby producing a band of frequencies equal to the difference in frequency between the selected frequency and the radio band, selecting frequencies from the resultant band into receiving circuits, and detecting from the resultant frequencies low frequency signals.

23. The method of radio signaling, which consists in generating a controlling frequency, producing other frequencies determined by said controlling frequency, modulating certain of the produced frequencies in accordance with low frequency signals, modulating another produced frequency in accordance with the resultant modulated frequencies, thereby producing a band of radio frequencies, transmitting said band to a receiving station, obtaining from said band the controlling frequency, producing other frequencies determined by said controlling frequency corresponding to the fre-

quencies produced from the controlling frequency at the transmitting station, beating the received band with one of the frequencies produced at the receiving station, thereby stepping down the band in frequency, selecting frequencies from said band and beating the selected frequencies with other of the frequencies produced at the receiving station, thereby detecting low frequency signals.

24. The method of radio signaling, which consists in generating a controlling frequency, producing other frequencies determined thereby, modulating said produced frequencies in accordance with low frequency signals, thereby producing a band of frequencies, producing the same controlling frequency at a receiving station, producing other frequencies at the receiving station determined by said controlling frequency and corresponding to the frequencies produced from the controlling frequency at the transmitting station, selecting at the receiving station modulated frequencies transmitted from the transmitting station, and beating the selected modulated frequencies with the frequencies produced at the receiving station under the control of the controlling frequency, thereby detecting low frequency signals.

25. The method of radio signaling, which consists in generating at a transmitting station a controlling frequency, producing other frequencies at the transmitting station determined by said controlling frequency, modulating certain of said produced frequencies in accordance with low frequency signals, modulating another of said produced frequencies in accordance with the resultant modulated frequencies, thereby producing a band of radio frequencies for transmission, receiving said band at a receiving station, producing at said receiving station a frequency corresponding to the controlling frequency generated at the transmitting station, producing at the receiving station other frequencies determined by said controlling frequency, beating the received band with one of said other frequencies, thereby stepping the band down in the frequency spectrum, selecting frequencies from the stepped-down band, and beating the selected frequencies with the remaining frequencies produced under the control of the controlling frequency, thereby detecting low frequency signals.

26. In a radio signaling system, means to generate a controlling frequency, means to produce other frequencies determined by said controlling frequency, means to modulate certain of said other frequencies in accordance with low frequency signals, means to modulate another of said frequencies by means of the frequencies resulting from the first modulation, and means to transmit the band of frequencies resulting from the second modulation.

27. In a radio signaling system, means to receive a band of radio frequencies, means to produce a controlling frequency, means to obtain other frequencies determined by said controlling frequency, means to beat the received band of radio frequencies by one of said last mentioned frequencies, thereby stepping the band down in the frequency spectrum, means to select smaller bands from the band thus stepped-down, and means to beat the selected bands with other of the frequencies produced under the control of the controlling frequency, thereby detecting low frequency signals.

28. In a radio signaling system, means to generate a controlling frequency at a transmitting station, means to produce other frequencies determined by said controlling frequency, means to modulate certain of said other frequencies in accordance with low frequency signals, means to modulate another of said frequencies in accordance with the modulated frequencies, means to transmit to a distant receiving station a band of frequencies resulting from the last mentioned modulation, means to produce at said receiving station a controlling frequency corresponding to the controlling frequency generated at the transmitting station, means to obtain other frequencies from said controlling frequency and corresponding to the frequencies obtained from the controlling frequency at the sending station, means to beat the received band of frequencies with one of the frequencies produced at the receiving station, thereby stepping the band down in the frequency spectrum, means to select smaller frequency bands from the band thus stepped down, and means to beat the selected bands with other of the frequencies produced at the receiving station, thereby detecting low frequency signals.

29. In a radio signaling system, means to generate at a sending station a controlling frequency, means to produce other frequencies determined thereby, means to modulate certain of said other frequencies in accordance with low frequency signals, means to modulate another of said frequencies in accordance with the modulated frequencies, means to transmit the resultant band of frequencies to a distant receiving station, means at said receiving station to obtain from said band of frequencies said controlling frequency, means to produce at said receiving station other frequencies determined by said controlling frequency, means to beat the received band of frequencies with one of said other frequencies produced at the receiving station, thereby stepping the band down in the frequency spectrum, means to select from the band thus stepped-down smaller bands of frequencies, and

means to beat the selected bands of frequencies with other of the frequencies produced at the receiving station, thereby detecting low frequency signals.

30. The method of radio signaling, which consists in generating a fundamental frequency, producing harmonics thereof, modulating certain of the harmonics in accordance with low frequency signals, modulating a higher harmonic in accordance with the resultant modulated frequencies, thereby producing a band of radio frequencies, and radiating the band of radio frequencies thus produced.

31. The method of radio signaling, which consists in generating a controlling frequency, producing other frequencies determined by said controlling frequency, modulating certain of said other frequencies in accordance with low frequency signals, modulating another of said frequencies in accordance with the resultant modulated frequencies, thereby producing a band of radio frequencies, and radiating the band of radio frequencies thus produced.

32. The method of radio signaling, which consists in modulating a plurality of carrier frequencies in accordance with low frequency signals, suppressing the carrier frequency component from each of the resultant frequency bands, modulating another frequency with each of the bands, and suppressing from the final resultant band the component corresponding to the carrier frequency employed in the last mentioned step of modulation.

33. The method of radio signaling, which consists in modulating a plurality of carrier frequencies in accordance with low frequency signals, suppressing one side band and the carrier frequency component from each of the resultant modulated bands, modulating another carrier frequency with each of the unsuppressed bands, and suppressing one of the side bands and the carrier component from the band produced by the last mentioned step of modulation.

34. The method of radio signaling, which consists in modulating a plurality of carrier frequencies in accordance with low frequency signals, suppressing the carrier component from each of the resultant modulated bands, modulating another carrier frequency of each of the unsuppressed bands, suppressing the carrier component corresponding to said last mentioned carrier frequency from the band resulting from said last mentioned step of modulation, transmitting a band of frequencies including at least one of the side bands involved in the last step of modulation, receiving said band at a distant receiving station, beating the received band with a suitable frequency in order to lower the band in the frequency spectrum, selecting from the band thus stepped-down bands corresponding to those resulting from the first step of modulation at the transmitting station, and detecting from said bands low frequency signals.

35. The method of radio signaling, which consists in modulating a plurality of carrier frequencies in accordance with low frequency signals, suppressing one side band and the carrier component from each of the resultant modulated bands, modulating another carrier frequency with each of the unsuppressed bands, suppressing the carrier frequency and one side band of the resultant band, transmitting the unsuppressed band, receiving said band at a distant receiving station, beating the received band with a suitable frequency in order to lower the band in the frequency spectrum, selecting from the band thus stepped-down bands corresponding to the side bands which were not suppressed at the transmitting station, and detecting from said bands low frequency signals.

36. A radio receiving system comprising means for receiving a plurality of bands of signaling oscillations, means for supplying other oscillations of a definite frequency, a demodulating device for combining said bands of oscillations with other oscillations to produce a plurality of oscillations corresponding to said signaling oscillations but reduced in frequency by the amount of the frequency of said other oscillations, a plurality of detectors, and a plurality of band pass filters for selecting from said last mentioned oscillations a plurality of bands corresponding to individual signals and supplying them to said detectors, respectively.

In testimony whereof, I have signed my name to this specification this 29th day of September, 1919.

LLOYD ESPENSCHIED.