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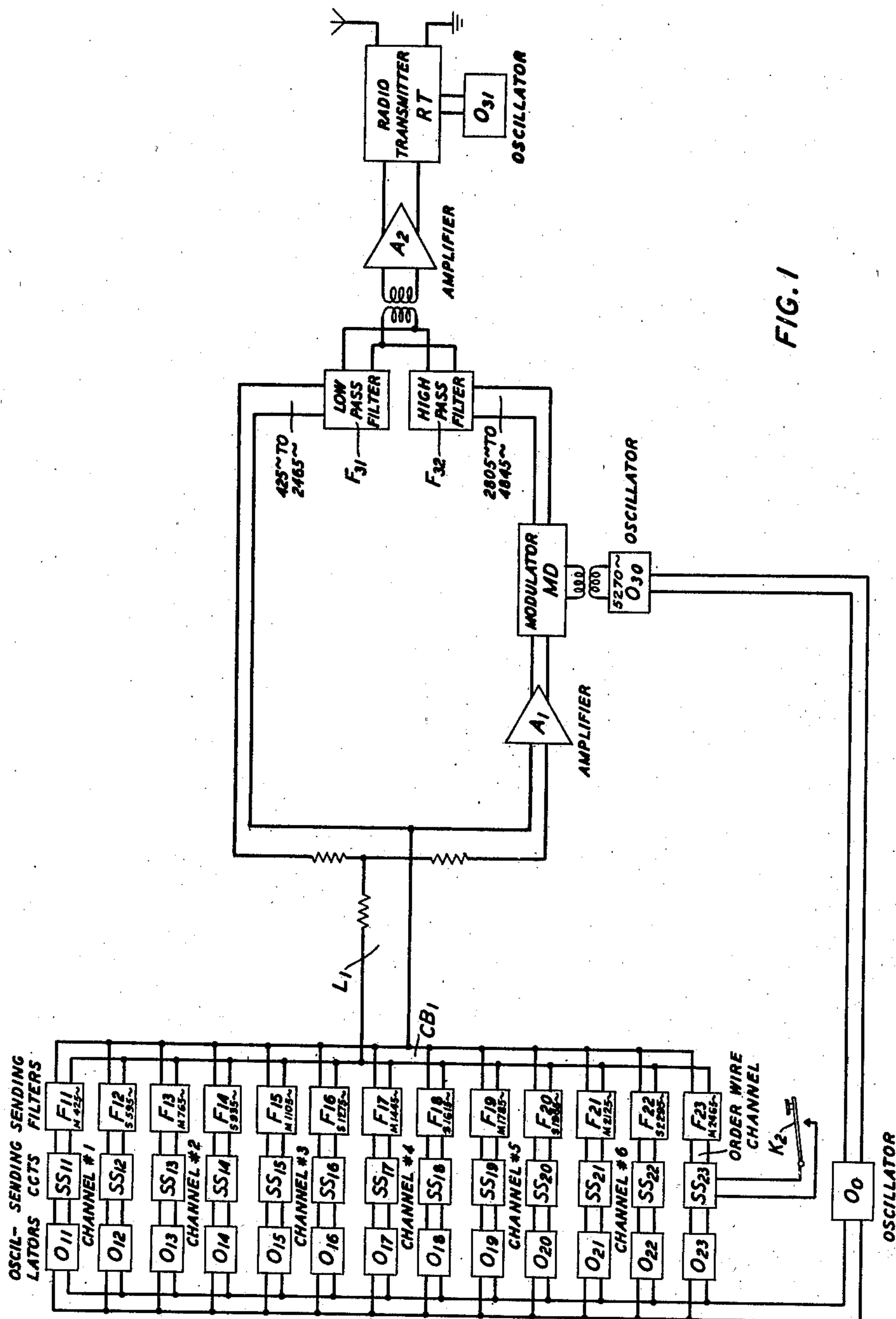
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2,407,684

RADIO COMMUNICATION SYSTEM

Filed Dec. 1, 1944

4 Sheets-Sheet 1



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RADIO COMMUNICATION SYSTEM

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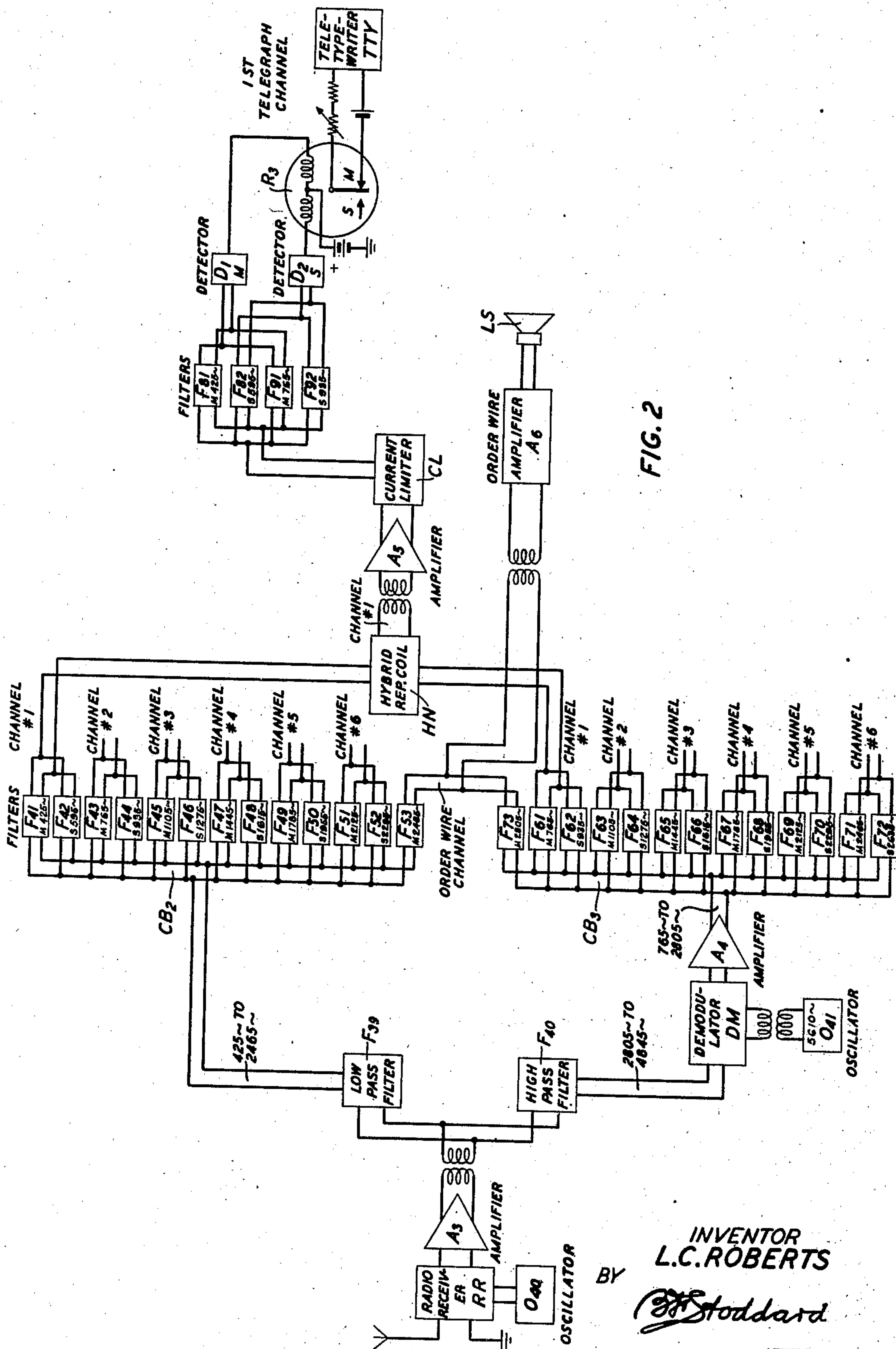


FIG. 2

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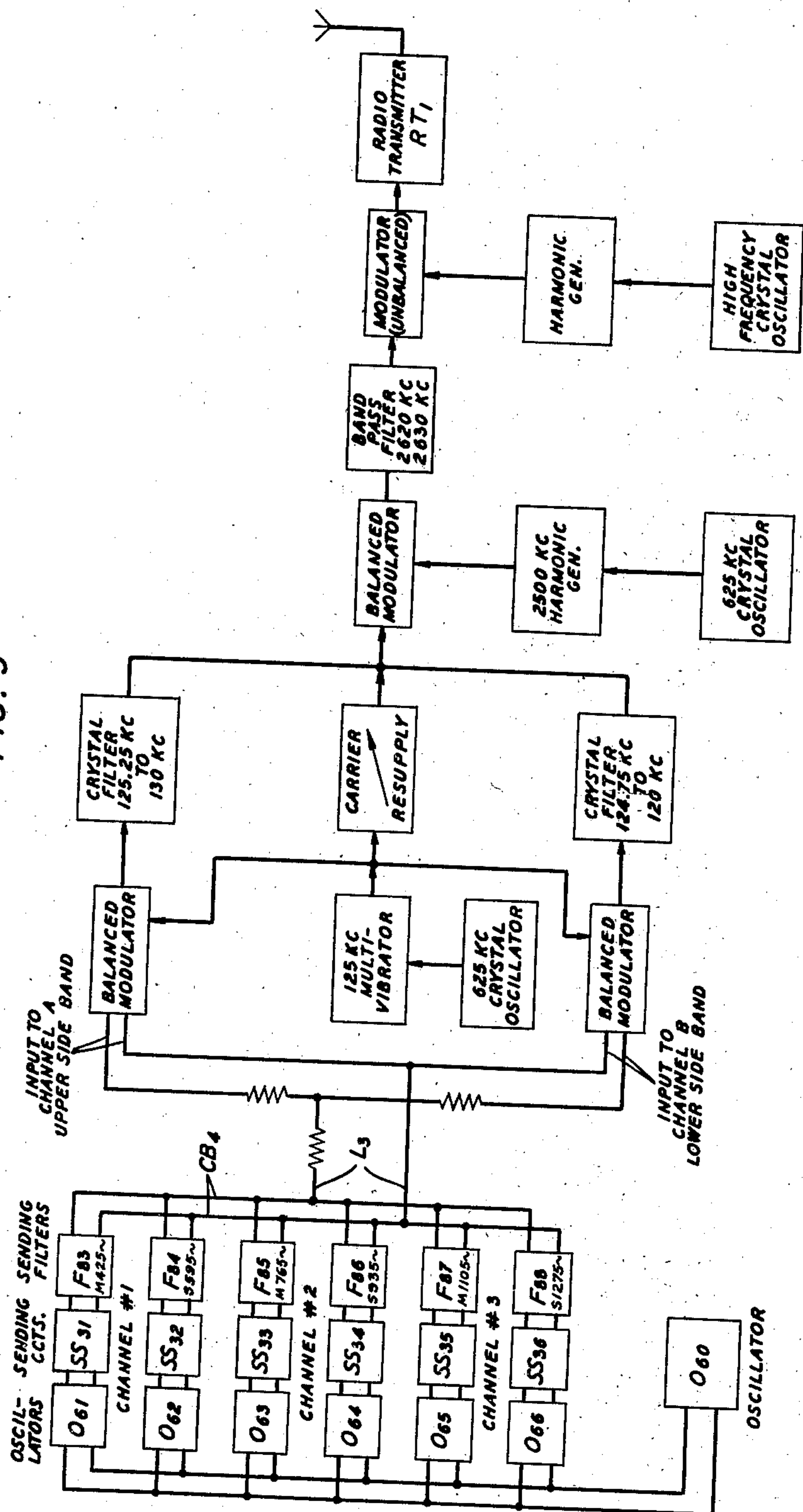
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FIG. 3



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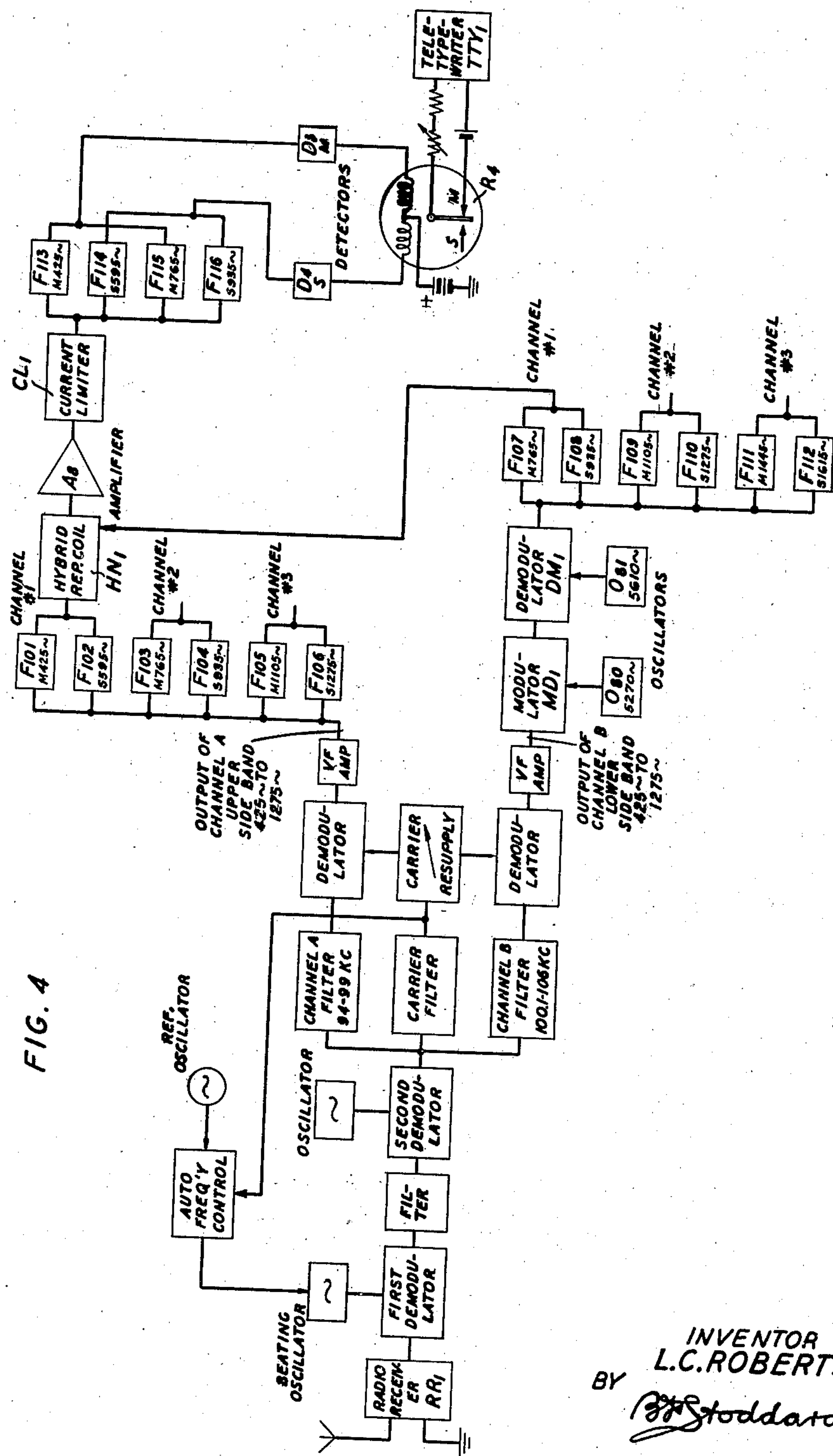


FIG. 4

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RADIO COMMUNICATION SYSTEM

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7 Claims. (Cl. 250—9)

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This invention relates to radio communication systems and, more particularly, to receiving circuits for frequency modulation radio telegraph systems employing frequency diversity principles of operation.

It is well known that, in operating radio telegraph communication systems, errors in the reception and recording of telegraph signals are apt to occur due to various causes, such as fading. It has been proposed heretofore to reduce the occurrence of such errors by employing a form of frequency modulation transmission in which the frequency of the carrier wave energy is modulated to one value for marking telegraph signals and to another value for spacing telegraph signals. This type of frequency modulation communication is commonly known as two-tone radio telegraph communication. It has also been proposed heretofore to reduce further the occurrence of such errors by employing various diversity methods of transmission and reception, such as frequency diversity. The principles of frequency diversity radio communication can be applied to the transmission of telegraph signals by employing double modulation to produce practically simultaneously carrier wave energy of two discrete frequencies for each marking signal that is to be transmitted and, at another time, to produce substantially simultaneously carrier wave energy of two other discrete frequencies for each spacing signal. These four waves usually have equal amplitudes.

After this carrier wave energy has been transmitted through space and has been received at a receiving station, it can be observed that the two waves representing each signal do not always have equal amplitudes. This is due chiefly to selective fading which, at times, may be so severe as to cause one of the waves to disappear momentarily. When this occurs, it will often be found that noise currents will produce errors in the recording of the signals. In order to avoid such errors, it is desirable to discriminate against the weaker of the two waves representing each signal. This can be accomplished by passing both waves simultaneously through one current limiter which will discriminate in favor of the wave of greater amplitude. Thus, the current limiter acts, in effect, as a selector of the wave having the greater amplitude.

If a current limiter should be used for this purpose in a double modulation frequency diversity radio telegraph system, then there would be a need for special means at the receiving station to demodulate the received carrier wave energy

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in such a manner as to produce demodulation products suitable for enabling the current limiter to perform its selecting function effectively. The need for such special demodulating means would be particularly urgent if the principles described above should be applied to a multiplex radio telegraph system having a number of frequency diversity channels for the transmission of radio telegraph signals because of the difficulties inherent in the selection of the proper wave energies to be applied to the current limiter.

Accordingly, it is an object of this invention to provide a radio receiving system with special means for demodulating received frequency diversity signals.

It is also an object of the invention to provide a radio receiving system with improved means for reducing the frequency separation between received frequency diversity signals.

A further object of the invention is to provide a radio receiving system with improved means for preparing received frequency diversity signals for selection as to amplitude.

These and other objects of the invention are accomplished in a double modulation frequency diversity radio receiving system by employing a first demodulator to reduce the received radio frequency signals to lower frequencies. These lower frequencies contain both sets of double modulation frequency diversity signals, one set having a higher order of frequencies than the other. These two sets of diversity signals are separated by connecting the output of the demodulator through an amplifier to a two-path parallel circuit having a low-pass filter in one path for passing one set of the diversity signals and a high-pass filter in the other path for passing the other set of diversity signals. In accordance with the principles of this invention, the output of the high-pass filter is connected to a second demodulator which further reduces the frequencies of this second set of diversity signals by shifting them by a heterodyne process to positions in the frequency spectrum closer to, but different from, the positions of the corresponding diversity signals in the first set.

The output of the low-pass filter is supplied to a first plurality of narrow band-pass filters connected in parallel for separating the two-tone signals in this path. Similarly, the output of the second demodulator is connected to a second plurality of parallel narrow band-pass filters for separating the two-tone signals in this path. The separated signal waves in the first path are supplied jointly with the separated signal waves

in the second path to a current limiter which discriminates in favor of the diversity signal wave of greater amplitude. After passing through the current limiter, the signal waves pass through a third plurality of parallel narrow band-pass filters which separate the two-tone diversity signals. The filtered signal waves are then delivered to a detecting circuit which supplies the rectified signaling energy to a recording device, such as a teletypewriter.

When the principles of the invention are applied to multiplex transmission of double modulation frequency diversity radio telegraph signals, each signaling channel is assigned currents of four different frequencies, two for marking signals and two for spacing signals. Since each multiplex channel must be provided with four different narrow band-pass filters at the receiving station for separating its four demodulated signal waves, it can be understood that in the case of a system having a large number of multiplex channels some difficulty may be encountered in supplying the receiving station with the necessary number and type of narrow band-pass filters. If the frequency spacing between the diversity signals is large, then the frequencies of some of the signals would be too high for standard narrow band-pass filters and it would be necessary to design and manufacture special filters. On the other hand, if one set of diversity signals is demodulated to the same frequency levels as its corresponding set of diversity signals, then signals might occasionally be canceled by out-of-phase diversity currents having the same frequency. Therefore, the principles of the invention are particularly useful when applied to a multiplex system having a large number of channels as the demodulated diversity signals are brought within the range of standard narrow band-pass filters while, at the same time, retaining sufficient frequency separations to prevent cancelation by out-of-phase currents.

In another embodiment of the invention frequency diversity transmission is effected by connecting in parallel the input circuits of a twin single sideband transmission system and by transmitting each signal simultaneously over the two sidebands. At the receiving end of this system, the frequencies of the signals received over one sideband are shifted, after demodulation, to positions in the frequency spectrum different from those of the corresponding signals received over the other sideband.

These and other features of the invention are more fully explained in connection with the following detailed description of the invention with reference to the drawings in which:

Fig. 1 represents a double modulation frequency diversity multiplex radio telegraph transmitting system;

Fig. 2 illustrates the invention applied to a radio receiving system for receiving signals transmitted by the radio transmitting system of Fig. 1;

Fig. 3 illustrates another radio transmitting system for transmitting frequency diversity signal waves; and

Fig. 4 shows the manner in which the invention is applied to a radio receiving system for use with the transmitting system of Fig. 3.

In Fig. 1, a base frequency oscillator O_0 generates wave energy having a low frequency, such as 85 cycles, which is supplied to a plurality of controlled oscillators O_{11} to O_{23} , inclusive, connected in parallel. As is indicated in Fig. 1, the outputs of the controlled oscillators are connected

to the telegraph sending circuits SS_{11} to SS_{23} , inclusive. The resulting signal waves are filtered by a plurality of narrow band-pass filters F_{11} to F_{23} , inclusive, having their outputs connected to a common bus CB_1 which, in turn, is connected to a line L_1 .

The controlled oscillators O_{11} to O_{23} , inclusive, are of any suitable construction, such as a plurality of sine-wave generators or multivibrators, for producing different harmonics of the base frequency of oscillator O_0 . The harmonic frequency generated by each controlled oscillator is passed by its associated narrow band-pass filter. As is indicated in the filters shown in Fig. 1, the harmonic frequencies extend from 425 cycles up to 2465 cycles. Each pair of controlled oscillators supplies one two-tone telegraph channel, as is also indicated in Fig. 1, except that oscillator O_{23} separately supplies a special order wire channel. The sending circuits SS_{11} to SS_{22} , inclusive, are of any appropriate design that will selectively, in accordance with marking and spacing telegraph signals, permit only one harmonic frequency to be transmitted over one telegraph channel at any given instant. For example, considering only channel 1 for the sake of simplicity, its telegraph sending circuits could comprise means for short-circuiting the outputs of oscillators O_{11} and O_{12} alternatively in accordance with marking and spacing telegraph signals from any suitable source, such as a keying circuit. This would cause wave energy of the marking frequency of 425 cycles generated by oscillator O_{11} to be supplied to filter F_{11} and would alternatively cause wave energy of the spacing frequency of 595 cycles generated by oscillator O_{12} to be supplied to filter F_{12} . Since the oscillator O_{23} supplies a special order circuit, its sending circuit SS_{23} may comprise means, such as a key K_2 , for simply interrupting the wave energy from oscillator O_{23} in accordance with marking and spacing telegraph signals. It is to be understood that the invention is not limited to signaling frequencies which are in harmonic relation as other signaling frequencies may be used.

The line L_1 delivers the output currents from all the channels to a channel shifting circuit having two parallel paths. The upper path contains a low-pass filter F_{31} which passes all the channel output currents extending over a frequency range from 425 cycles to 2465 cycles. The lower path supplies the channel output currents through an amplifier A_1 to a modulator MD which is also supplied with wave energy of 5270 cycles generated by an oscillator O_{30} controlled by the base frequency oscillator O_0 . The modulator MD functions as a channel shifter to elevate the frequency of each of the channel output currents. Thus, the marking frequency of 425 cycles from oscillator O_{11} is elevated or shifted to 4845 cycles, the spacing frequency of 595 cycles from oscillator O_{12} is shifted to 4675 cycles, and the frequencies of the wave energies generated by oscillators O_{13} to O_{23} , inclusive, are likewise elevated to values representing the difference between their original values and 5270 cycles. The modulator MD has its output connected to a high-pass filter F_{32} which passes the lower modulation products having a frequency range from 2805 cycles to 4845 cycles. The outputs of filters F_{31} and F_{32} are jointly amplified by an amplifier A_2 and are then applied to a radio transmitter RT where they are combined with radio frequency carrier wave energy supplied by an oscillator O_{31} . Either double sideband or single sideband suppressed

carrier transmission may be used. In this manner, frequency diversity transmission is obtained by transmitting each telegraph signal over carrier wave energy of two discrete frequencies which are different from the frequencies used for carrying the other signals.

When these double modulation frequency diversity signals are received at the receiving system shown in Fig. 2, they are all converted to low frequency currents by a radio receiver RR which is supplied with wave energy from an oscillator O₄₀ for demodulation purposes, the frequency of the wave energy generated by oscillator O₄₀ being the same as that produced by oscillator O₃₁ at the transmitting station. The demodulated signals are amplified by an amplifier A₃ and are then supplied to two parallel filters F₃₉ and F₄₀ which separate the two groups of diversity signals. Filter F₃₉ is a low-pass filter designed to pass that group of diversity signals which has frequencies extending from 425 cycles to 2465 cycles whereas filter F₄₀ is a high-pass filter designed to pass the other group of diversity signals having frequencies extending from 2805 cycles to 4845 cycles.

The output circuit of filter F₃₉ is connected by means of a common bus CB₂ to the input circuit of each of a plurality of narrow band-pass filters F₄₁ to F₅₃, inclusive. Each of these filters has a pass-band which is different from those of the other filters in this group. Since, as is indicated in the drawings, the pass-bands of this group of filters are the same as those of the filters F₁₁ to F₂₃, inclusive, at the transmitting station shown in Fig. 1, the multiplex two-tone signals in the first diversity group will accordingly be separated from each other. Thus, filter F₄₁ will pass the marking frequency of 425 cycles from channel No. 1, filter F₄₂ will pass the spacing frequency of 595 cycles from channel No. 1, filter F₄₃ will pass the marking frequency of 765 cycles from channel No. 2, filter F₄₄ will pass the spacing frequency of 935 cycles from channel No. 2, etc. The output circuits of filters F₄₁ and F₄₂ are jointly connected to a hybrid coil repeating network HN. Similarly, the output circuits of the marking and spacing filters for each of the other channels in this diversity group are likewise jointly connected to other individual hybrid coil repeating networks, although, for the sake of simplicity, these networks have not been shown in the drawings.

The wave energies passed by filter F₄₀ are delivered to a demodulator DM which is supplied with wave energy having a frequency of 5610 cycles generated by an oscillator O₄₁. It should be noted that, since the frequency of the waves produced by oscillator O₄₁ is 340 cycles higher than the frequency of the waves generated by oscillator O₃₀, the output wave energies produced by the heterodyning function of the demodulator DM will have frequencies that are higher than the frequencies of the signals applied to the modulator MD. For example, a wave of 765 cycles in the output circuit of the demodulator DM will correspond to a marking signal of 425 cycles from filter F₁₁. In other words, the output of the demodulator DM will comprise a plurality of signal waves each of which is 340 cycles higher than its corresponding original frequency.

The output currents from the demodulator DM are amplified by an amplifier A₄ and are then supplied to the input circuits of a plurality of narrow band-pass filters F₆₁ to F₇₃, inclusive, by means of a common bus CB₃. Each of these

filters has a pass-band different from the others for separating the multiplex two-tone signals in this diversity group. For example, the marking signal wave of 425 cycles in channel No. 1 will be raised to 765 cycles by the demodulator DM and will be passed by filter F₆₁ while the spacing signal wave of 595 cycles in channel No. 1 will be raised to 935 cycles and will be passed by filter F₆₂.

The output circuits of filters F₆₁ and F₆₂ are jointly connected to the hybrid coil repeating network HN. Similarly, the output circuits of the marking and spacing filters for each of the other channels in this diversity group are jointly connected to their corresponding hybrid coil repeating networks mentioned above. In this way, the hybrid coil repeating network associated with each channel will be supplied with two marking waves of two discrete frequencies and alternatively with two spacing waves of two other discrete frequencies.

The diversity signal waves of channel No. 1 are jointly delivered by the hybrid coil repeating network HN to an amplifier A₅ which has its output circuit connected to a current limiter CL. The two diversity signals thus applied at any one time to the current limiter CL will ordinarily, whether they be marking signals or spacing signals, not have the same amplitude because one of them is usually more attenuated by selective fading than the other. As is well known, when currents of two different frequencies and different amplitudes pass simultaneously through a current limiter, the limiter has the property of discriminating in favor of the current of higher level, the weaker current producing only a slight frequency modulation of the stronger. Thus, the current limiter CL acts, in effect, as a selector of the wave having the greater amplitude.

The output circuit of the current limiter CL is connected in parallel to four narrow band-pass filters F₈₁, F₈₂, F₉₁ and F₉₂. Filters F₈₁ and F₈₂ are similar to filters F₄₁ and F₄₂ in that their respective pass-bands will pass the marking frequency of 425 cycles and the spacing frequency of 595 cycles, respectively, as is indicated in Fig. 2. Filters F₉₁ and F₉₂ are similar to filters F₆₁ and F₆₂ in that their respective pass-bands will pass the marking frequency of 765 cycles and the spacing frequency of 935 cycles, respectively, from the other diversity component of channel No. 1.

The two marking diversity signals passed by filters F₈₁ and F₉₁ are jointly supplied to the marking detector D₁ and the two spacing diversity signals passed by filters F₈₂ and F₉₂ are jointly supplied to the spacing detector D₂. The rectified marking signals from the detector D₁ are delivered to one winding of a polarized relay R₃ and the rectified spacing signals from the detector D₂ are supplied to another winding of relay R₃. The armature of relay R₃ will therefore be operated alternatively between its marking and spacing contacts in accordance with the marking and spacing signals detected respectively by detectors D₁ and D₂. This operation of the armature of relay R₃ alternatively opens and closes an input circuit of any suitable design leading to a receiving teletypewriter TTY which records the telegraph signals transmitted over channel No. 1.

The diversity signals transmitted over the other channels are delivered by the hybrid coil repeating networks associated with those channels to other individual current limiters connected to similar detecting circuits supplying other receiving teletypewriters.

Since the signals transmitted over the order wire channel are of the interrupted current type, the diversity wave energies representing marking signals in this channel are selected by the narrow band-pass filters F_{53} and F_{73} , filter F_{53} being designed to pass waves having a frequency of 2465 cycles and filter F_{73} passing waves of 2805 cycles. The currents passed by filters F_{53} and F_{73} are jointly supplied to an amplifier A_6 which has its output circuit connected to a loud-speaker LS.

It should be noted that, in order to reduce interchannel interference and to minimize the effect of intermodulation between the two frequencies of each signal, a special frequency allocation has been employed. This comprises using odd harmonics of the base frequency supplied by oscillator O_0 which, in this case, is 85 cycles. Calling this base frequency n cycles, each signal may then be said to be transmitted simultaneously over two frequencies, one being Kn where K is an odd integer and the other being $mn - Kn$ when m is an even integer that is larger than the odd integer represented by K . For example, the frequency passed by filter F_{11} is 425 cycles which is five times the base frequency of 85 cycles. Its corresponding diversity frequency is 4845 cycles which is 62 times 85 cycles, or 5270 cycles which is the frequency of oscillator O_{30} , minus 425 cycles which is the value of Kn . The value of m remains constant but a different odd integer is used for K in the case of each signaling circuit. At the receiver, optimum results are obtained by choosing a frequency of $m+4$ times n for the frequency of the oscillator O_{41} which would be, in this case, $62+4$ times n , or 66 times 85 cycles, resulting in 5610 cycles.

It is to be understood that the principles and features of operation of the invention are not limited to the specific circuits described above, but may be applied to various other embodiments. For example, another transmitting system for transmitting frequency diversity signals is shown in Fig. 3 in which frequency diversity is obtained by connecting in parallel the input circuits of a twin single sideband transmitting circuit. In Fig. 3, a base frequency oscillator O_{60} generates wave energy having a low frequency, such as 85 cycles, which is supplied to a plurality of controlled oscillators O_{61} to O_{66} , inclusive, connected in parallel and having their outputs connected respectively to the sending circuits SS_{31} to SS_{36} , inclusive. The resulting signal waves are filtered by a plurality of narrow band-pass filters F_{83} to F_{88} , inclusive, having their outputs connected to a common bus CB_4 . The common bus CB_4 , in turn, is connected by a line L_3 to a twin single sideband transmitting system having the input circuits to its two sideband circuits connected in parallel as shown in Fig. 3. Thus, each signal is sent over both channel A and channel B simultaneously through the various units of the twin channel transmitting system which is of the type described in Patent 2,179,106 granted November 7, 1939, to C. C. Taylor and S. B. Wright. The disclosure of this Taylor-Wright patent is incorporated herein by reference as a part of this specification. The operation of this twin single sideband transmitting system is well known and requires no explanation here. It is sufficient to state that each signal is impressed upon each of the twin single sidebands practically simultaneously and is radiated through space over waves of two different frequencies.

A receiving system is shown in Fig. 4 for re-

ceiving the multiplex frequency diversity two-tone radio telegraph signals transmitted by the system of Fig. 3. The radio frequency portion of the receiving system of Fig. 4 is similar in both design and operation to that disclosed in the above-mentioned Taylor-Wright patent and therefore need not be described here other than to state that the received radio frequency signals are demodulated, filtered, and delivered to the outputs of channels A and B. As is indicated in Fig. 4, the corresponding signal frequencies in both channels A and B are the same after the two different carrier sidebands have been reduced to voice frequencies by demodulation. Since the corresponding signal waves in channels A and B would usually not be in phase, they might cancel each other if they were applied to the same detector. It is therefore advisable to shift the frequencies of the signals received over one of the channels to avoid the necessity of providing another set of detectors and limiters.

This is accomplished by connecting the output of channel B to a modulator MD_1 which is also provided with wave energy of 5270 cycles generated by an oscillator O_{80} . The modulator MD_1 functions as a frequency changer and elevates the frequency of each of the signal waves in the output of channel B. This modulator contains a low-pass filter in its output which prevents frequencies exceeding about 5000 cycles from entering the demodulator DM_1 . These elevated signal frequencies are then supplied to a demodulator DM_1 which is also provided with wave energy of 5610 cycles generated by an oscillator O_{81} . Since the frequency of the wave energy produced by oscillator O_{81} is 340 cycles higher than the frequency of the waves generated by oscillator O_{80} , the output of the demodulator DM_1 will comprise a plurality of signal waves each of which is 340 cycles higher than the corresponding signal wave in the output of channel A.

The two-tone diversity signals in channel A are separated by means of a plurality of narrow band-pass filters F_{101} to F_{106} , inclusive. Similarly, the signal waves in channel B are separated by another plurality of narrow band-pass filters F_{107} to F_{112} , inclusive. As the design and operation of the equipment in this portion of the receiving system of Fig. 4 is similar to that explained above in connection with the description of the operation of the receiving system shown in Fig. 2, no additional description is required. In brief, the output circuits of the narrow band-pass filters are connected to hybrid coil repeating networks individual to each pair of diversity channels. Each hybrid coil repeating network, such as the network HN_1 , has its output circuit connected through an amplifier to a current limiter. The output circuit of each current limiter, such as the limiter CL_1 , is connected in parallel to four narrow band-pass filters, such as the filters F_{113} to F_{116} , inclusive, which separate the two-tone diversity signals. The signal waves are then delivered alternatively to marking and spacing detecting circuits, such as the detectors D_3 and D_4 , which control the operation of their associated receiving teletypewriters, such as the teletypewriter TTY₁.

What is claimed is:

1. A radio communication system comprising in combination means for producing and transmitting frequency diversity signals having frequency separations between corresponding diversity signals, a receiving station having a single antenna for receiving said signals, common de-

modulating means for demodulating all of the received signals, means for preparing said demodulated signals for selection on the basis of their amplitudes, said means including first filtering means for separating one group of the frequency diversity signals, second filtering means for separating another group of the frequency diversity signals, and means for reducing the frequency separations between corresponding diversity signals, said last-mentioned means comprising special demodulating means for shifting the frequencies of the signals in one of said groups to positions in the frequency spectrum nearer to but different from the frequencies of the corresponding signals in the other of said groups.

2. In a frequency diversity radio communication system including means for producing, transmitting, and receiving a plurality of sets of frequency diversity signals having relatively wide frequency separations between corresponding diversity signals, the method of reducing said frequency separations which comprises separating the different sets of diversity signals, heterodyning one of said sets of diversity signals, and selecting from the products of the heterodyning process currents having positions in the frequency spectrum narrowly separated from the corresponding diversity signals in another of said sets of diversity signals.

3. A radio communication system comprising in combination means for producing and transmitting multiplex double modulation frequency diversity two-tone radio telegraph signal waves having relatively wide frequency separations between corresponding diversity signals, a receiving station having a single antenna for receiving said signals, common demodulating means for demodulating all of the signals received by said antenna, means for preparing the received diversity signals for selection in respect to their amplitudes, said means including first filtering means for selecting one set of said multiplex double modulation two-tone signals, second filtering means for selecting the other set of multiplex double modulation two-tone signals, a first plurality of parallel connected narrow band-pass filters for separating the multiplex two-tone signals passed by said first filtering means, heterodyne means for shifting the frequencies of the multiplex double modulation two-tone signals passed by said second filtering means to positions in the frequency spectrum that are relatively narrowly separated from their corresponding diversity signals passed by the first filtering means, a second plurality of parallel connected narrow band-pass filters for separating the frequency shifted multiplex double modulation two-tone signals, and means for separately discriminating between each pair of multiplex diversity signal waves in favor of the signal wave of greater amplitude.

4. A multichannel radio communication system having a transmitting station including a plurality of voice frequency signals having fre-

quencies that are odd harmonics of a base frequency of n cycles, a common radio transmitter for simultaneously transmitting each voice frequency signal over current having a frequency of Kn cycles where K is an odd integer different for each signal and also over current having a frequency of $(mn-Kn)$ cycles where m is an even integer larger than K , a receiving station having means for receiving and demodulating said signals, said receiving station also having additional demodulating means for further demodulating the signals transmitted over the frequency of $(mn-Kn)$ cycles with a frequency of $(m+4)n$ cycles, and means for jointly examining the resulting demodulated signals in respect to their amplitudes.

5. A radio communication system comprising in combination means for producing and transmitting two groups of frequency diversity signals having frequency separations between the corresponding diversity signals of each group, a receiving station having a single antenna for receiving said signals, demodulating means for demodulating the received signals, additional demodulating means for shifting the frequencies of the demodulated signals in one of said diversity groups, and means for jointly examining the signals in both diversity groups in respect to their amplitudes.

6. A radio communication system comprising in combination means for producing and transmitting two groups of frequency diversity signals having frequency separations between the corresponding diversity signals of each group, a receiving station having a single antenna for receiving said signals, demodulating means for demodulating the received signals, frequency shifting means for shifting the frequencies of the demodulated signals in one of said diversity groups, said frequency shifting means including a modulator supplied with current of a first frequency and a demodulator supplied with current of a second frequency, said second frequency being higher than said first frequency, and means for jointly examining the signals in both diversity groups in respect to their amplitudes.

7. A radio communication system comprising in combination means for producing signals, said system having twin single sideband transmitting circuits of different frequencies, each of said circuits including an input circuit, frequency diversity transmitting means for transmitting each signal over both of said twin single sideband transmitting circuits simultaneously, said transmitting means including means for connecting said input circuits in parallel, receiving means for receiving and demodulating said signals, frequency shifting means for shifting the frequencies of the demodulated signals received over one of the twin single sideband transmitting circuits, and means for jointly examining said frequency shifted signals together with the corresponding diversity signals received over the other twin single sideband transmitting circuit.

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