Dec. 26, 1933. E. H. ARMSTRONG 1,941,069

RADIOSIGNALING

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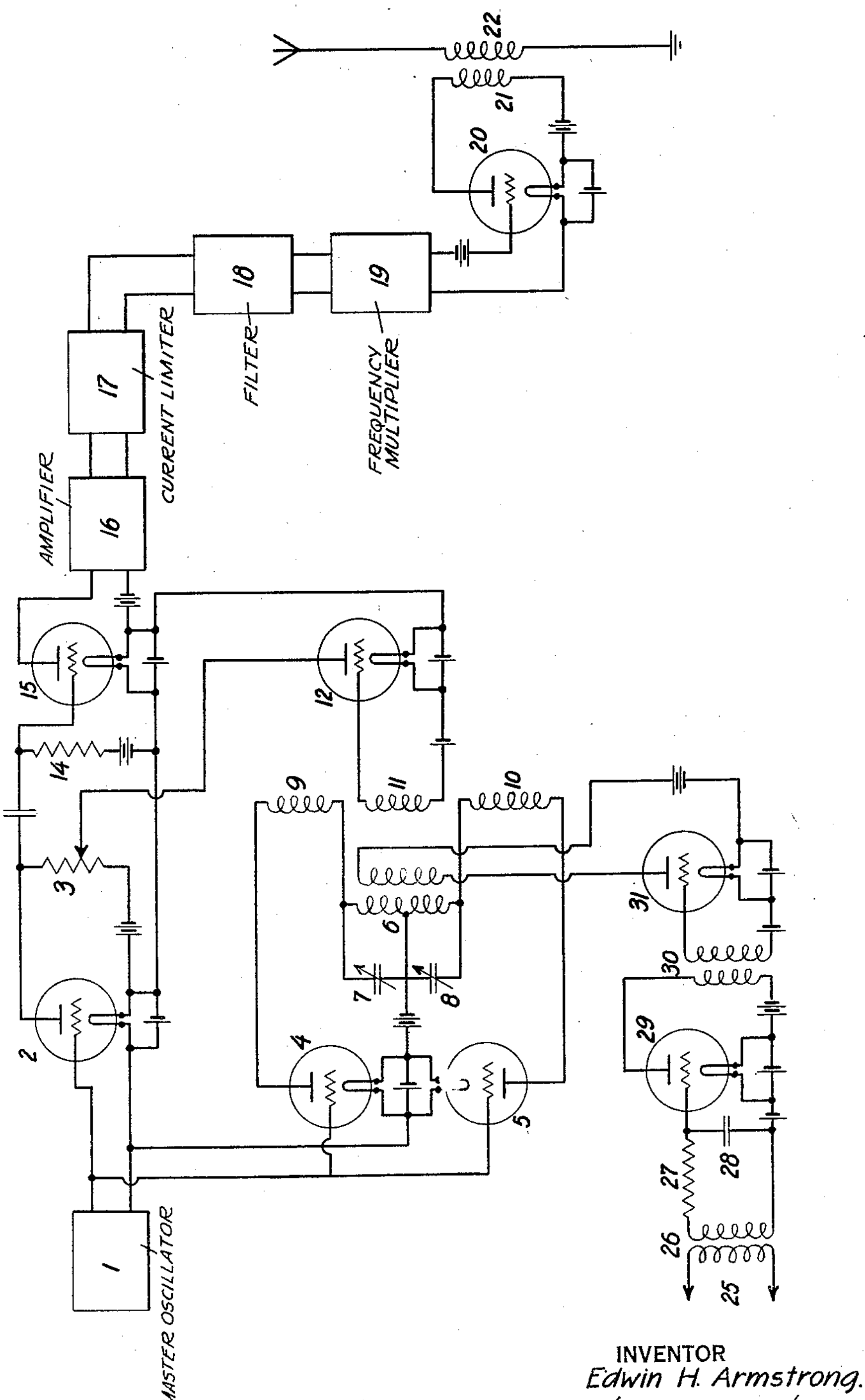
Fig. 1.

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RADIOSIGNALING

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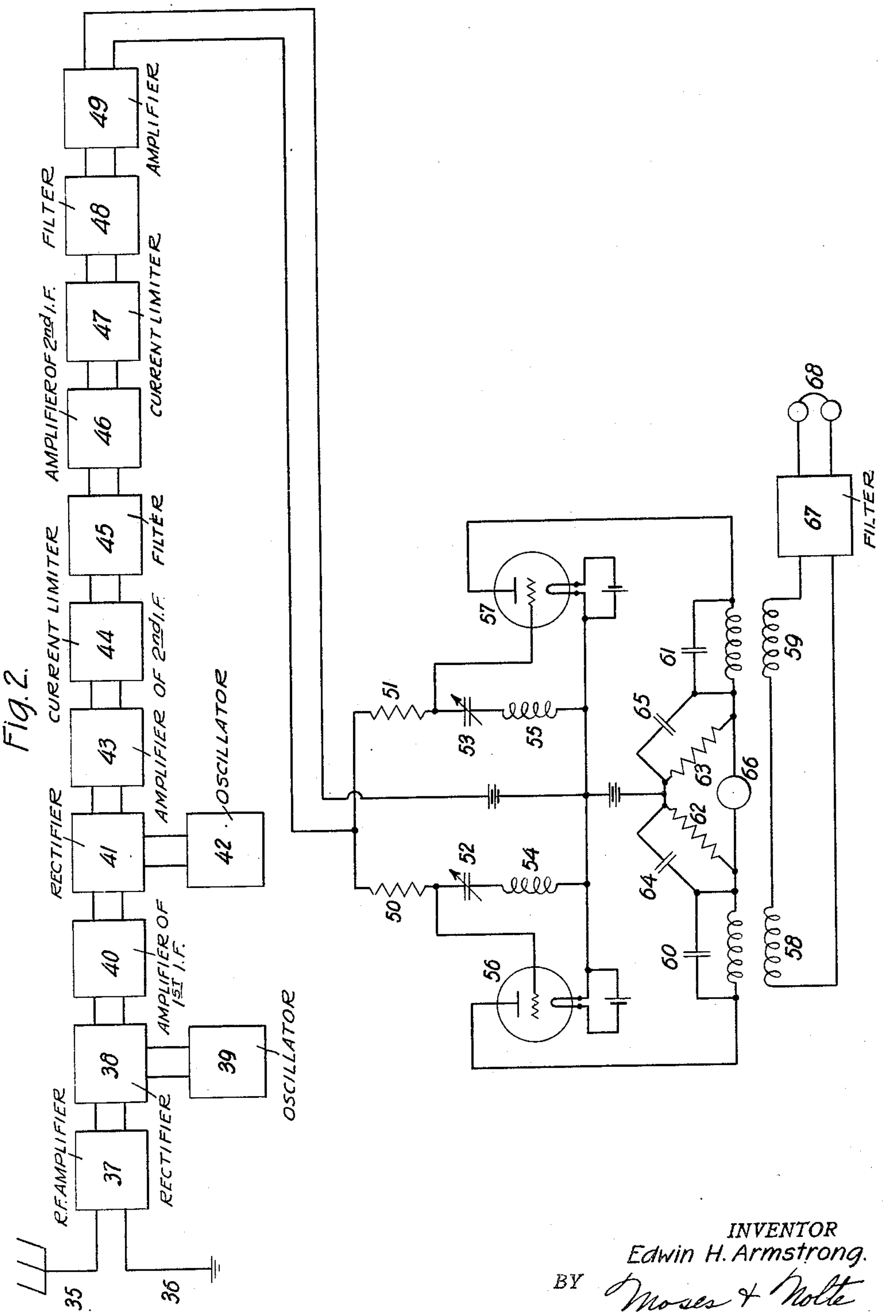


Fig. 2.

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Fig. 3.

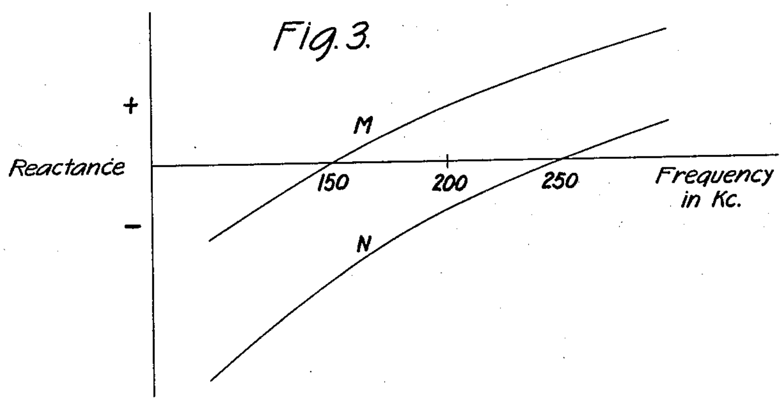



Fig. 4.

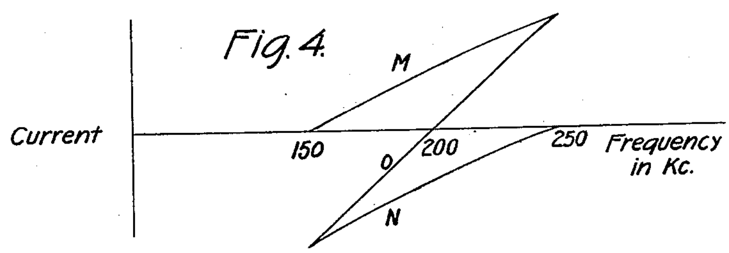
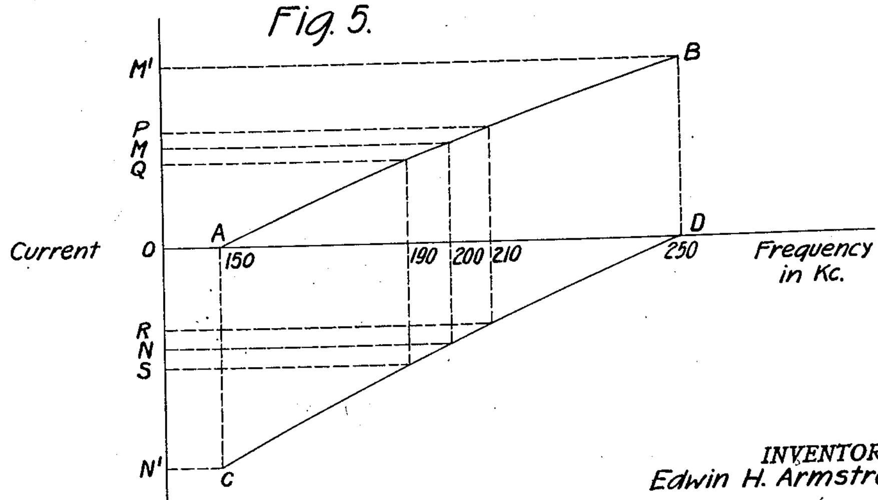



Fig. 5.

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Patented Dec. 26, 1933 1,941,069

# UNITED STATES PATENT OFFICE

1,941,069

## RADIOSIGNALING

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Application January 24, 1933. Serial No. 653,237

2 Claims. (Cl. 250—2)

This invention relates to a method of increasing the distance of transmission which may be covered in radio signaling with very short waves.

It is well known that waves of the order of ten meters or lower are limited in the distance of transmission by tube noise alone as the amount of static in that part of the spectrum is negligible.

That is, the electrical disturbances which are created in the first tube in a chain of vacuum tube amplifiers, when amplified by the chain and supplied to the detector are great enough to mask the effect of the signal when it falls below a certain level.

There is described herein a method of overcoming this type of disturbance by the use of frequency modulation in a particular way, so that it may be very greatly decreased with consequent increase in the distance over which communication may be maintained. In order to fully understand the nature of this invention, it is necessary to consider the characteristic of the disturbance and the present state of the art of receiving weak signals.

The nature of the disturbance, which is due mainly to the irregularities of the electron emission from the filaments of the vacuum tubes, is that of a spectrum, containing all frequencies, and as is well known it manifests itself in the telephone by a high pitched hiss, the frequencies composing which run from some low value to above audibility. The combination of all the irregularities of emission produces a spectrum of radio frequency currents which consists of irregular variations in amplitude and also, as I have found, in frequency, so that the hiss is heard in a frequency modulation receiver as well as in the ordinary type of receiver for amplitude modulated waves. This occurs even when the amplitude modulations of the disturbing currents are eliminated by current limiting or by some equivalent process.

It is the practice in designing amplitude modulated receivers to design the width of the selective system to be equal to twice the frequency of the modulation to be received and in voice transmission or the transmission of music this runs between 10,000 cycles and 15,000 cycles.

In frequency modulation, while there is no practice, the experimentation has proceeded along the same lines, the width in this case being somewhat greater than in the amplitude modulated case in order to allow for the deviation in frequency.

That is, the ordinary width dependent on the modulation frequency is increased by an amount dependent on the frequency deviation. These band widths have always been kept down to as low a value as possible because the amount of static which is received is proportional to the width of the band and hence after providing for the signal there is no advantage in going further. This applies both to amplitude and frequency modulated waves.

Where, however, there is no static and the sole disturbance is tube noise a different situation occurs. It is still true in the case of amplitude modulation that the band width should be approximately twice the frequency of modulation and no greater. It is not true in the case of frequency modulation.

I have discovered that by imparting a greater swing to the frequency of the transmitted wave than can exist in the disturbances due to tube irregularities and providing means for selecting these large swings of frequency which are at the same time substantially not responsive to the lesser swings due to the tube disturbances or to the variations in amplitude due to these disturbances, that a very great improvement in transmission can be produced.

Referring now to the figures which form a part of this specification, Fig. 1 illustrates the general arrangement of the transmitter, Fig. 2 the arrangement of the receiver and Figs. 3, 4 and 5 the characteristics of reception of the arrangement of Fig. 2.

In Fig. 1 is shown a modulating system similar in principle to that described in my application filed of even date herewith. Here 1 represents a constant frequency oscillator, 2 an amplifier of the output of this oscillator with a resistance 3 in its plate circuit which is small in comparison with the impedance of the tube. 4 and 5 are likewise amplifiers of the current produced by the master oscillator 1. 6 is a transformer for differentially modulating the plate voltages of the tubes 4 and 5 by the signaling current which is applied to the primary of the transformer through the amplifying system 26, 29, 31. 7 and 8 are condensers shunting the two halves of the secondary of the transformer 6, and 9 and 10 are inductances whose impedance for the frequency of the oscillator is small compared to the impedance of the tubes 4 and 5. 11 is a small inductance whose natural frequency is high compared to the frequency of the oscillator. It is coupled differentially to the coils 9 and 10. 12 is an amplifier for amplifying the outputs of the tubes 4 and 5. Its plate is connected as shown to an adjustable point in the resistance of the plate circuit of the amplifier 2. The combined outputs of the tubes 2 and 12 are supplied to an amplifier 15, 16 whose output passes through a current limiter 17, filter 18 and to a frequency multiplier 19 of many stages, power amplifier 20 and antenna 22. 27, 28 represents a correction system for impressing on the input of the amplifier 29 a voltage inversely proportional to the frequency of modulation which is applied at 25.

Referring now to Fig. 2 which represents a receiving system, 35, 36 represent the antenna system. 37 represents an amplifier for the frequency of the received wave. 38 represents a rectifier and 39 an oscillator for heterodyning the output of the amplifier 37 to a lower value which is amplified in the amplifier 40. 41, 42 represents a rectifier and oscillator for heterodyning the output of the amplifier 40 down to a still lower intermediate frequency and 43 represents an amplifier for this second intermediate frequency. 44 represents a current limiter supplied by the output of the amplifier 43. 45 is a filter through which the output of the current limiter 44 is passed. 46 is a second amplifier similar to the amplifier 43 and 47 is a current limiter for limiting the output of this amplifier. 48 is a filter for the output of the second current limiter 47. 49 is an amplifier for amplifying the limited and filtered output of the amplifier 46. The output of the amplifier 49 is delivered to a selective system consisting of two branch circuits 50, 52, 54 and 51, 53, 55 which are connected respectively to the inputs of the two detectors 56, 57. The plate circuits of these detectors contain transformers 58, 59 which are connected so as to respond cumulatively for frequency variations, but differentially for amplitude variations. 66 is a meter connected across the bridge formed by the resistances 62, 63 for the purpose of indicating the balance point. 60, 61 and 64, 65 are the usual by-pass condensers. 67 is a filter for the purpose of excluding frequencies above the range of the signaling frequencies and 68 is the telephone receiver.

The general characteristics of detection are illustrated in Figs. 3 and 4. Fig. 3 illustrates the reactance characteristics of the capacity inductance combinations 52, 54 and 53, 55. Characteristic values are taken for a swing of 100,000 cycles between the limits of 150,000 and 250,000 cycles respectively. In this figure M represents the reactance characteristic of 52, 54 which is made non-reactive for 150,000 cycles and N the reactance characteristic of 53, 55 which is made non-reactive for 250,000 cycles.

Fig. 4 illustrates the rectified or plate currents through the resistances 62 and 63 as shown by M and N, and O represents the current through the indicating instrument 66 in the balanced arm of the bridge. The output of the two transformers 58 and 59 are proportional to the current changes indicated by O. Fig. 5 illustrates the action of the system with respect to disturbances and will be referred to in detail later.

In principle the operation of the transmitter is similar to that described in my application previously referred to except that in the present arrangement the number of frequency multipliers is increased to an extent which gives a swing many times greater than the audible frequency range.

In the receiver the same general method of operation regarding the signal occurs as is described in my pending application Serial No. 192,320, filed May 18, 1927 for Radio telephone signaling. That is, the method of translating the radio frequency currents of variable frequency into currents of audible frequency which is shown in that specification is employed. However, because of the design of the selective system which is used in the present system the operation of the receiver is quite different from that described in the preceding application.

Because of the extremely complicated detecting action occurring in this system which results in the cumulative detection of signal and the differential detection of the disturbances originating in the tubes and the fact that some phases of the operation are obscure even to those skilled in the art it is necessary to deal with an explanation of the matter in great detail.

As already stated it is the standard practice in receiving amplitude modulated waves to design the receiving apparatus to have a frequency band width of admittance slightly greater than twice the frequency of modulation which it is desired to receive. This practice is used because it has been found that the amount of energy received from atmospheric disturbances varied directly as the width of the frequency band passed by the receiver and hence there was a disadvantage in making the band any wider than that necessary to pass the signal.

In the use of frequency modulation, while there is no practice, experimental work on ordinary commercial frequencies where there are atmospheric disturbances has shown the same general rule to be applicable except that the receiver must be designed to pass a somewhat greater band width than the amplitude modulated receiver, (assuming the same frequency of modulation). That is, the band width must be twice the frequency of modulation, plus the frequency swing or deviation.

On wave lengths below ten meters, however, atmospheric disturbances practically cease to exist, or in any event become of negligible amount compared to tube noise, and the limit of reception is then determined by tube noise or the disturbances which arise usually in the first tube in the receiving system.

The interference manifests itself as a steady hiss in the telephones or speaker and it is quite disturbing even when its amplitude is small compared with the amplitude of the signal. Electrically it is practically a continuous spectrum. In this it differs from static in that static is an extremely irregular spectrum in which, because of its discontinuous character, the peaks may be commensurate with or greater than the signal before serious disturbance occurs.

In order to understand the operation of this system with respect to a continuous spectrum of substantially constant amplitude it is necessary to analyze carefully what occurs in an ordinary receiver for amplitude modulated waves which is admitting a broad band of frequencies (several times that necessary to pass the frequency of modulation) at a wave length where tube disturbances are the predominating factor. Suppose for example the width of the receiver band is 100,000 cycles. Now when no signal carrier is being received the energy that is received thruout this band is uniformly rectified by the detector to produce a response which manifests itself as a continuous hissing tone. All parts of the spectrum within the 100,000 cycle band contribute to the response which is heard in the telephone receiver. Now suppose an unmodulated carrier is received which is of the same order of magnitude or greater than the tube disturbances. Under these circumstances the action changes and two things occur. One is that because of the presence of the carrier an increase in efficiency of detection occurs. The nature of this phenomena is well understood in the art. A technical explanation of it may be found in the Proceedings of the Institute of Radio Engineers for April 1917, where it was first described by me. The other is that the energy which is capable of producing an audible response is narrowed down from a band of 100,000 cycles in width and confined to the band which lies within the audible range on either side of the carrier. As a practical matter this may be taken to be 10,000 cycles above and 10,000 cycles below the carrier, so that the effect of the receipt of the unmodulated carrier is to narrow down the band from which the tube disturbances will produce an audible response. While the tube disturbances in the rest of the band are passed by the receiver as before and are rectified by the detector the currents resulting from this rectification have a frequency above audibility and are therefore not audible in the telephone receiver. Although the energy which is now able to produce an audible response is limited to that within a band only one-fifth as wide as before, it does not follow that the response in the telephones is correspondingly reduced. In general it is somewhat increased, since the presence of the signal carrier produces an increase in the efficiency of rectification which more than makes up for the narrowing of the band, although if the voltage applied to the detector is sufficient and the detector is substantially linear there is relatively little difference in the audible response.

In the above considerations it has been assumed that there is no current limiting. With current limiting an additional effect occurs. The presence of the carrier raises the amplitude level beyond the limiting value so that a large part of the fluctuations in amplitude created by tube disturbances are wiped out, leaving only the variations in frequency created by this type of disturbance.

Now with this conception in mind examine the action of a balanced amplitude receiver for frequency modulated waves having the characteristics illustrated in Fig. 5. This characteristic is the same as that illustrated in Fig. 4 but it is shown in Fig. 5 in greater detail. Assume for the moment that the signal is not being modulated and that a steady carrier of 200,000 cycles is being transmitted.

The only components of this spectrum from 150,000 cycles to 250,000 cycles which can at any one time by reason of amplitude modulation produce a really audible noise with the carrier in either of the two detectors are those components lying within, say, 10,000 cycles on either side of the signaling frequency, wherever that may happen to be. If we assume for the moment that the signal is not being modulated and a steady frequency of 200,000 cycles is being transmitted, then only the disturbances between 190,000 cycles and 210,000 cycles can produce any current which is of a really audible character.

An examination of Fig. 5 wil show that the reactance at 200,000 cycles on curve AB is equal to the reactance at the same frequency on curve CD. Hence the voltages impressed on each detector will be equal and the rectified currents will also be equal. As previously shown the only part of the band which is capable of producing an audible response due to amplitude variations are those frequencies lying between 190,000 and 210,000 cycles per second. It will be observed that between these ranges there is relatively little difference between the reactances on either side and that therefore insofar as the amplitude variations which remain after limiting are concerned the voltages impressed on the two detectors are substantially balanced. The difference between the voltages OM and ON represents approximately the response which will be heard in the telephones due to amplitude variations, and as these can be made substantially equal those amplitude variations which pass the current limiter are cancelled out.

As regards frequency variations produced by currents lying within the range capable of producing audible response, that is, from 190 to 210 kilocycles the action is cumulative. The response on the side represented by the curve AB is equal to OP—OQ or PQ and on the side represented by CD the response is equal to OS—OR or SR. Since the two detector outputs are connected cumulatively for frequency variations the total response is the sum of the two or PQ+SR.

As regards the signal, however, by reason of its frequency swing over the range from 150 kilocycles to 250 kilocycles the voltages impressed on the detectors vary from zero to OM′ on one side and from zero to ON′ on the other side. The total response is, therefore, proportional to the sum of OM′ and ON′ and the improvement in signal to hiss ratio is apparent.

While the above explanation shows the fundamental reason for the improvement obtained by this method its quantitative result must not be taken too literally since it has been assumed that the range 190 to 210 is the limit of the band which represents the sole source of the audible hiss. This is not strictly true since there are certain second order effects. But while there is no strict line which can be drawn, the extent of the swings of frequency due to tube disturbances which can produce audible disturbing response does not apear to be much greater than the value of the example given. It follows therefore that by increasing the variation of frequency of the transmitted wave to values greater than those indicated in the figures a still greater improvement in signal to noise ratio can be obtained. I find this to be so and also that it is readily practicable on the shorter wave lengths.

As a consequence of this method of signaling it now becomes possible to open up ranges of wave lengths and to operate over distances which were quite impossible with the methods previously known.

Based on measurements made with the system illustrated in Figs. 1 and 2 with a frequency swing of 100,000 cycles and a transmission frequency of 50,000,000 cycles (6 meters) the disturbances were reduced by this method to less than 1% of the energy of the disturbances in an ordinary amplitude modulated transmitter of equal power. For the purpose of completing the disclosure and to enable those skilled in the art to practice the invention the following added description of the systems of Figs. 1 and 2 used in these tests are here given. The initial frequency or the frequency of the master oscillator in the transmitter was of the order of 50,000 cycles. Ten stages of frequency doubling was employed. The tuned circuits in these stages were suitably broadened by the introduction of resistance to accommodate the wide variation of frequency. On account of this the selectivity of the doubler circuits for other frequencies is reduced so that push-pull circuits to eliminates the fundamental of the preceding stage are employed. In the phase shifting system coils 9 and 10 have an inductance of 5.4 mil henrys and coil 11 an inductance of 9.6 mil henrys. Condensers 7 and 8 have a capacity of .002 mfds. In the correction system the value of the resistance 27 is 150,000 ohms and the value of the capacity 28 is .2 mfds.

In the receiving system the amplifier represented by 37 consisted of three stages of tuned circuit coupled amplification at 50,000,000 cycles. This was heterodyned down by the rectifier, oscillator combination 38, 39 to about 6,000,000 cycles and amplified by the four stage transformer coupled amplifier 40. The output of this amplifier was heterodyned down by the rectifier, oscillator combination 41, 42 to 200,000 cycles. This current was then amplified by a five stage resistance coupled amplifier arranged to be flat from 150,000 cycles to 250,000 cycles by the proper choice of plate resistances, grid condensers and grid leak resistances. The output of this amplifier is supplied to a current limiter consisting of a screen grid tube operated at less than normal plate and screen grid voltages. This makes an effective current limiter provided sufficient excitation is applied to the grid and for that reason the large number of stages in the 200,000 cycle amplifier is used. I have discovered, however, that a repetition of the process of amplification and current limiting is very advantageous and therefore a second resistance coupled amplifier 46 and a second current limiter 47 similar respectively to the amplifier 43 and current limiter 44 is used. The reason for this is that the action of a current limiter is such that while it eliminates amplitude variations at the frequency of the carrier it does not eliminate the variations in amplitude produced by the interaction of other frequencies within the band of the receiver. While these are second order effects they are appreciable and are best dealt with by the use of a second or third current limiting system. The amplifier 49 consists of a couple of stages of resistance coupled amplification for the purpose of raising the voltage applied to the grids of detectors 56, 57 (which are biased to cutoff) to a sufficient level to secure straight line rectification. The resistances 50, 51 are of the order of 15,000 to 20,000 ohms and the inductance, capacity combinations 52, 54 and 53, 55 are suitably chosen, one to be non-reactive slightly below 150,000 cycles and the other to be non-reactive slightly above 250,000 cycles, and to have, respectively, the same arithmetic value of reactance at 200,000 cycles.

I have described what I believe to be the best embodiment of my invention. I do not wish, however, to be confined to the embodiment shown, but what I desire to cover by Letters Patent is set forth in the appended claims.

I claim:

1. The method of eliminating in radio signaling disturbances having the nature of a spectrum, which consists in producing a variation in frequency of the wave to be transmitted substantially greater in extent than the frequency range of good audibility, transmitting such wave, receiving the wave and amplifying the received currents, substantially eliminating amplitude variations so as to minimize the noise caused by the amplitude variations due to the disturbances, translating the frequency variations of the received signal into amplitude variations by a selective system which is fully responsive to the wide variations of the signal, but substantially not responsive to the lesser variations in frequency of the spectrum of the disturbances to be eliminated.

2. A system for eliminating in radio signaling disturbances having the nature of a spectrum, comprising means at the transmitter for producing a variation in frequency of the wave to be transmitted, substantially greater in extent than the frequency range of good audibility, means at the receiver for amplifying the received currents, current limiting means for substantially eliminating amplitude variations, and a detector system for translating the frequency variations of the received signal into amplitude variations, said system being fully responsive to the wide variations of the signal but substantially not responsive to the lesser variations in frequency of the spectrum of the disturbances to be eliminated nor to variations in amplitude of said disturbances.

EDWIN H. ARMSTRONG.