M. I. PUPIN AND E. H. ARMSTRONG.

RADIORECEIVING SYSTEM HAVING HIGH SELECTIVITY.

APPLICATION FILED DEC. 18, 1917. RENEWED MAY 27, 1921.

1,416,061. Patented May 16, 1922.

2 SHEETS—SHEET 1.

Fig.1.

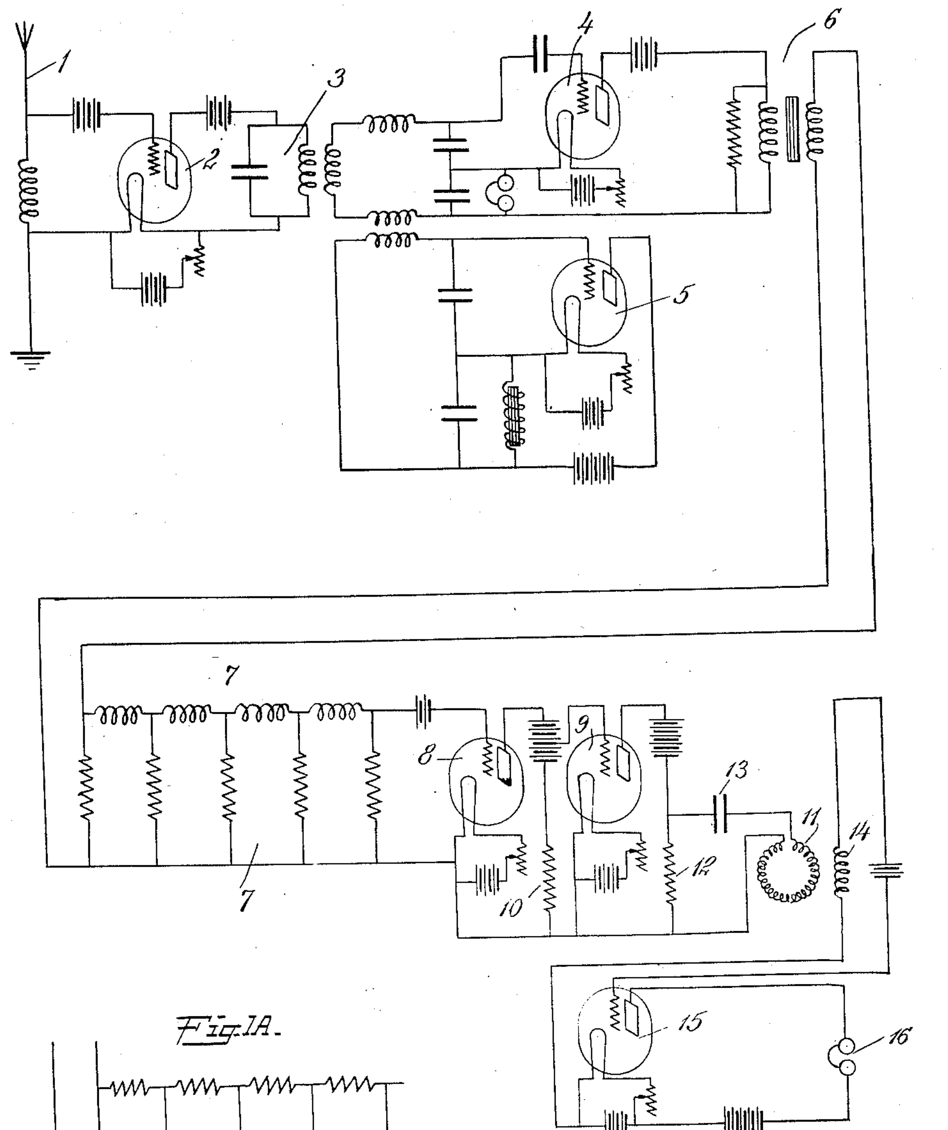
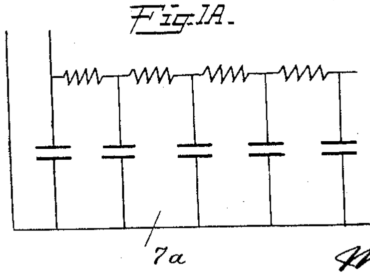


Fig.1A.



Inventors

Michael I. Pupin, Edwin H. Armstrong

By their Attorneys

Pennie Davis Marvin & Edmonds

M. I. PUPIN AND E. H. ARMSTRONG.

RADIORECEIVING SYSTEM HAVING HIGH SELECTIVITY.

APPLICATION FILED DEC. 18, 1917. RENEWED MAY 27, 1921

1,416,061. Patented May 16, 1922.

2 SHEETS—SHEET 2.

Fig. 2.

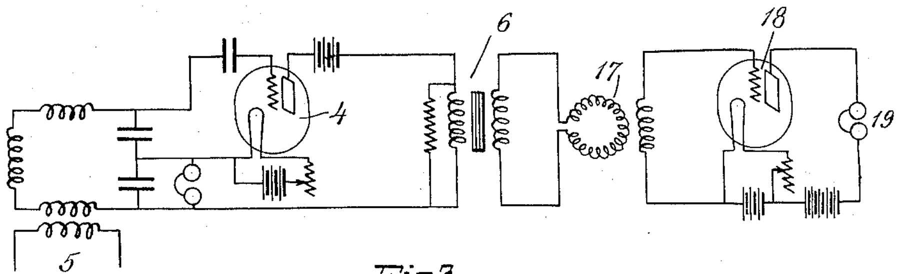


Fig. 3.

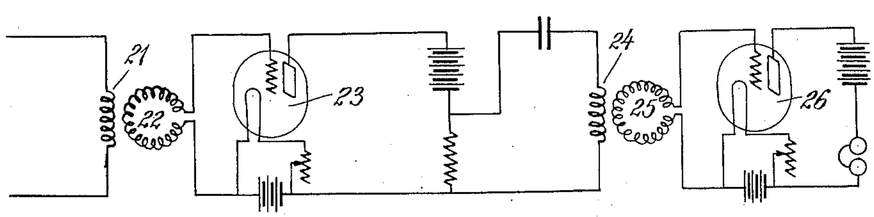
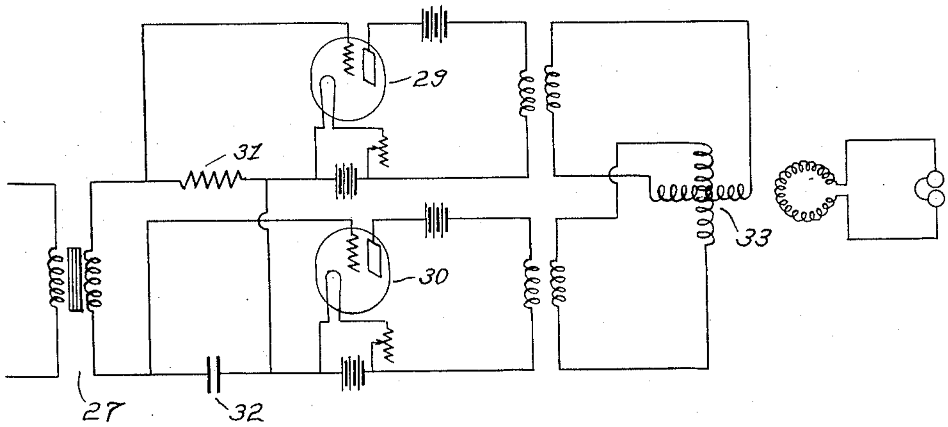


Fig. 4.



Inventor

Michael I. Pupin, Edwin H. Armstrong

By their Attorneys

Pennie Davis Marvin Edwards

UNITED STATES PATENT OFFICE.

MICHAEL I. PUPIN, OF NORFOLK, CONNECTICUT, AND EDWIN H. ARMSTRONG, OF YONKERS, NEW YORK.

RADIORECEIVING SYSTEM HAVING HIGH SELECTIVITY.

1,416,061. Specification of Letters Patent. **Patented May 16, 1922.**

Application filed December 18, 1917, Serial No. 207,659. Renewed May 27, 1921. Serial No. 473,044.

To all whom it may concern:

Be it known that we, MICHAEL I. PUPIN, a citizen of the United States, residing in Norfolk, county of Litchfield, State of Connecticut, and EDWIN H. ARMSTRONG, a citizen of the United States, residing in Yonkers, county of Westchester, State of New York, have invented certain new and useful Improvements in Radioreceiving Systems Having High Selectivity; and we do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

The object of the invention is to provide, for radio transmission purposes, a receiving system of extremely high selectivity. To this end we here propose to deal with the low or audio frequency current variations or pulsations in the receiving system; it being understood that the arrangement of the present invention may be used in conjunction with, and as a supplement to, any known or subsequently discovered selectivity-increasing means applicable to the high or radio frequency oscillations in such systems.

Primarily the purpose of the present invention is attained by developing a receiving system in which the current variations or pulsations in the detector circuit are reduced to a very low frequency, for the purpose of separating them effectually from all disturbing influences (including natural atmospheric disturbances as well as artificial radio disturbances originating at the sending stations of other systems), and are subsequently multiplied or augmented in frequency to bring them well within the range of audibility.

Important secondary features of novelty are employed, firstly, to permit a certain degree of variation in the radio frequency signals transmitted by the sending station, which variation is to be expected, and is perhaps unavoidable, in the present state of the art; and, secondly, to take advantage, in connection with the multiplying or augmenting of the frequency of the impulses above referred to, of physiological characteristics of the human ear which enable an operator to detect pulsations having certain musical characteristics, even when such pulsations are accompanied by undesirable disturbances of considerable amplitude.

The particular nature of the invention, and the principles involved therein, will be more clearly understood from the following description of radio receiving systems illustrated in the accompanying drawings; but it will be understood that these principles may be embodied in circuit arrangements other than those specifically illustrated.

In these drawings, Fig. 1 illustrates a radio receiving system in which the several features of the invention may be fully embodied; Fig. 1^A represents a substitute form of wave filter; Fig. 2 illustrates a receiving system in which the novel features of the invention are only partially embodied; Fig. 3 illustrates a portion of a receiving system particularly designed to take advantage of the physiological characteristics of the human ear above referred to, and Fig. 4 illustrates a possible substitute for the arrangement of Fig. 3.

In the receiving system illustrated in Fig. 1, there is associated with the antenna 1 a high frequency amplifier 2 of the electron-relay type, now well known to the art, and which produces in the resonant circuit 3 amplified radio frequency oscillations of the same form as the received oscillations. This circuit is coupled to the input circuit of a regenerative amplifier and detector or rectifier 4, which is of the character disclosed in the United States Patent No. 1,113,149, of October 6, 1914, and which is now entirely familiar to those skilled in the art. Likewise coupled to the input circuit of the regenerative amplifier and detector 4, is an electron-relay 5 associated with regenerative circuits of the type above referred to, the input and output circuits of this relay being so tuned and coupled as to generate continuous oscillations of radio frequency. As a result of this arrangement of circuits, the received radio frequency oscillations may be combined with the locally produced radio frequency oscillations in accordance with the heterodyne principle, to produce beats. It has heretofore been customary, in radio receiving systems of this character, to produce in this way beats of audible frequency (usually of about one thousand cycles per second), which, impressed upon the grid of the electron-relay 4, produce, by virtue of the rectifying action of that relay, variations of like frequency in the output circuit, which circuit is commonly connected directly or inductively with the reeciving telephones. We have found that by decreasing the beat frequency to about 100 cycles per second and passing these low frequency pulsations of distinct individuality through a wave filter designed to pass such frequencies, and, preferably, all lower frequencies, but to attenuate and suppress frequencies of substantially higher range, as frequencies of 200 or over, it is possible to increase greatly the selectivity of the receiving system. This will be understood if we consider, as an example, a signal frequency of 30,000 cycles combined with a locally produced frequency of 29,000 to create beats of 1,000 cycles. In this case, the system is responsive to frequencies in the neighborhood of 28,000 and 30,000 cycles, since 28,000 cycles will also combine with the 29,000 cycles to produce beats of 1,000 cycles. Thus, generally, the frequency band to which the system is responsive has a width at least equal to twice the beat frequency. By reducing the beat frequency, selectivity is correspondingly increased, provided steps are taken to suppress the higher frequencies. To this end the frequency of the locally generated oscillations produced in the generator 5, is so chosen, with respect to the frequency of the received oscillations, as to produce a beat frequency in the neighborhood of 100 cycles per second, so that the rectified pulsations in the output circuit of the relay 4 are of that frequency. These low frequency pulsations are transmitted through an iron core transformer 6 to the wave filter 7 consisting of a plurality of units, each of which comprises an inductance shunted by a resistance, as shown. We have employed for this purpose four units, in each of which the inductance is of the order of 25 henries and the shunted resistance of the order of 50,000 ohms. The wave filter is connected to the grid of a low frequency amplifier 8.

It is particularly to be noted that the wave filter above described is made up of aperiodic units which cannot give rise to periodic oscillations, as would be the case if each unit contained both inductance and capacity of sufficient amount to give to the unit a natural period of oscillation of its own. This is particularly important in a receiving system of the character described employed in radio signaling in any case where considerable atmospheric disturbances are encountered, for the reason that atmospheric disturbances representing large amounts of energy would give rise, in a filter containing periodic elements, to periodic oscillations in the filter units, which oscillations would interfere with the intended separation of the signaling oscillations from all disturbing influences. While we have shown here, for the purpose of passing the low frequency oscillations and excluding the high frequency oscillations, an aperiodic wave filter of which each element consists of a series inductance and a shunt resistance, it will be understood by those familiar with the principles of wave filters that a like result may be attained by an aperiodic filter of which each element consists of a series resistance and a hunt capacity as indicated by the reference numeral 7^a in Fig. 1^A.

Where the receiving system is intended for the reception of relatively weak long distance signals, and inasmuch as the signals are further weakened in the frequency transformation hereinafter described, it is advisable to employ two sets of amplfiers, one before and one after the transformation of frequency, and these amplifiers may be of any desired number connected in cascade, as is well konwn. We have here shown, for amplification prior to frequency transformation, a second amplifier 9, in addition to the amplifier 8.

It will be understood that pulsations of a frequency in the neighborhood of 100 cycles are not audible in a telephone circuit unless they are of great strength, and for the purpose of restoring the musical quality of the signal, we pass the pulsations through a frequency transformer consisting of an induction motor 11, the rotor of which is connected across the high resistance 12 in the plate circuit of the last amplifier, a condenser 13 being inserted in the connection leading to the rotor winding for the purpose of blocking off the continuous current of the plate circuit from the rotor and thereby preventing a continuous tone in the receivers. It is well known that when an alternating electromotive force is impressed on the primary of a single-phase induction generator, two frequencies are set up in the secondary winding, whether this winding is open or closed. If the winding is closed, these two frequencies react on the primary winding setting up therein other frequencies, which in turn react on the secondary, and so on, producing an infinite series of frequencies. If, however, the secondary winding is open, no current flows therein and hence there is no reaction of the secondary upon the primary, and the only frequencies produced are those originally arising in the secondary winding. These frequencies will be, respectively, the original frequency of the rotor plus the impressed frequency, and the original frequency of the rotor minus the impressed frequency. For example, if the speed frequency of the rotor is 1,000 cycles, and the frequency of the pulsations impressed upon the rotor is 100, then the frequencies in the secondary of the frequency transformer will be, respectively, 1100 and 900.

These two frequencies may be led off efficiently by connecting the terminals of the secondary winding to the input circuit of an electron-relay. The resistance from grid to filament is practically infinite, and the secondary remains, in effect, open circuited. In the present case, the secondary 14 is connected to the input circuit of the audio frequency amplifier 15 with the result that pulsations of 1100 cycles and 900 cycles are produced in the output circuit of the relay 15 containing the telephones 16.

Although it is of great importance to make use of the above-described wave filter, if the highest selectivity is to be attained, both with respect to atmospheric disturbances and with respect to signals from other stations, yet it will be obvious that a substantial improvement in selectivity, as compared with the systems now used, may be attained without using the wave filter. Such an arrangement is shown in Fig. 2, where the tube 4 produces, as before, pulsations of low frequency in the output circuit and these low frequency pulsations are transmitted by the transformer 6 to the primary circuit of the frequency transformer 17, the secondary of which is connected to the amplifier 18 in the output circuit of which the telephones 19 are included.

In making use of the frequency transformer in the manner above described, it has been found that the relative amplitudes and frequencies of the two currents in the secondary circuit are very important factors in determining the readableness of the signal through interfering disturbances. The amplitude, as well as the frequency, of the secondary currents depends on the relation between the original impressed frequency and the frequency speed of rotation. In the present case, the amplitudes of the two secondary currents will be practically equal, and, as has been pointed out, the frequencies are equal respectively to the frequency speed of rotation plus the impressed frequency and the frequency speed of rotation minus the impressed frequency. It has been found that when the numerical values of these two frequencies have some simple musical relation, corresponding to one of the simple fundamental intervals of the diatonic scale (such as the octave 1 to 2, the perfect fifth 2 to 3, the perfect fourth 3 to 4, the major third 4 to 5, etc.), there is produced in the telephones a compound tone of distinct individuality which is easily recognizable even in the presence of disturbing noises representing considerable energy. Particularly, we have had the best results when the numerical values of these two frequencies in the secondary of the frequency transformer correspond to a perfect fifth, that is, have the relation of 2 to 3. The effect of adopting this musical relation between the two frequencies is marked, and adds greatly to the readability of the signal. It is well known that received signals, when used to produce a single pure tone in the telephones, as is the common practice, are most readable when the frequency of the pulsations is in the neighborhood of 1,000 cycles per second, and we have found that we get the best results when the apparatus is so arranged that the two notes produced in the telephones have respectively a frequency of approximately 1200 cycles per second and a frequency of approximately 800 cycles per second. That is, when the two frequencies have a ratio to one another of 2 to 3, and differ by an equal amount (200 cycles) from the best frequency for single tone reception. Two tones differing thus in frequency are most easily produced in the secondary of the frequency transformer by driving the rotor of the transformer at a speed frequency of 1,000 and impressing upon the primary pulsations having a frequency of 200 cycles per second. As will be understood, the tube 4 of Figs. 1 and 2 may be adjusted to produce pulsations of that frequency, and these pulsations may be transmitted in the manner described, through the wave filter to the frequency transformer. We find, however, that a modification of the wave filter to make it suitable for 200 cycles, instead of 100 cycles, as in Fig. 1, is objectionable, since it also permits the transmission of interfering disturbances to a considerable degree. For that reason we prefer to transmit the pulsations through the wave filter at a frequency of approximately 100 cycles and then raise this frequency to 200 cycles before the pulsations pass to the frequency transformer which produces the two frequencies supplied to the telephones. This can best be done in the manner indicated in Fig. 3. In this figure the coil 21 is the primary of an induction generator, which may be supposed to be connected, as is the primary 11 in Fig. 1, to the end of the wave filter, so as to receive the pulsations having a frequency of 100 cycles, and amplified to any desired extent by means of low frequency amplifiers such as 8 and 9. In this case, the primary winding 21 is the stator of the induction generator, while in Fig. 3 the primary winding was the rotor, but it will be understood that the stator and the rotor are completely interchangeable whenever used in accordance with this invention. The secondary 22 of this generator is connected to the input circuit of the amplifier 23 which in turn is connected to the primary 24 of a second frequency transformer, the secondary 25 of which is connected to the input circuit of the amplifier 26, which supplies energy to the telephones. If we assume that the frequency of the pulsations in the primary 21 is 100, and we desire to raise that frequency to 200 by means of the first induction generator, then the rotor of this generator will be driven at a frequency of 100. The secondary currents will have a frequency of 0 and 200, respectively. That is, the secondary will deliver but one current of frequency of 200 cycles per second. This current gives rise to pulsations in the output circuit of the tube 23 having a frequency of 200 cycles. These pulsations are impressed upon the primary 24 of the second induction generator, the rotor of which is driven at a frequency speed of 1,000, and this produces in the input circuit of the amplifier 26, and consequently in its output circuit and in the telephones, pulsations of 800 cycles and 1200 cycles, thus giving the desired musical interval.

If, for any reason, it is desired that the frequency augmenter shall produce a simple tone within the range of good audibility, instead of the compound tone referred to above, we make use of the arrangement illustrated in Fig. 4. Here the low frequency pulsations are impressed, by the transformer 27, upon a phase-splitting arrangement consisting of two electron-relays 29 and 30 connected, respectively, across a resistance 31 and a condenser 32, the resistance and the condenser offering equal impedance to impulses of the frequency to be augmented. The split-phase currents produced in the output circuits of the relays are impressed upon two primary windings of the induction generator 33 at right angles to one another, and upon rotation of the rotor there will be produced in the secondary and in the telephone circuit connected thereto, current impulses of a frequency equal to the speed frequency of rotation of plus or minus the impressed frequency, depending upon the direction in which the rotor is driven.

While we have referred herein to a frequency of 100 cycles per second, as being an appropriate low frequency established by the interaction of the received signal impulses upon the receiving system, and we have likewise referred to a frequency of 1000 cycles per second as the best mean frequency for the impulses in the telephone circuit, it will be understood that our invention is not limited to those frequencies. It may be said generally that the low frequency to be established for the above described purposes of increasing the selectivity should be as low as practicable. The lower, the better. It is necessary, however, to take into consideration the variations in frequency of the transmitted signal impulses, which variations are necessarily incident to the present methods of generating the transmitted wave trains, and it is also necessary to take into consideration the difficulties in transforming low frequency impulses, and other practical considerations which lead to the adoption of a frequency in the neighborhood of 100 cycles per second as the preferable one, under existing conditions. So also, the frequency of 1000 cycles, which we have taken as the best frequency for the rotor of the frequency augmenter, is that which under existing conditions has been found to give the most readable signals. It will, of course, be understood, that whatever frequency is chosen for the rotor of the frequency augmenter, the frequency of the signal impulses should preferably be so related to it as to produce the desired musical interval between the two notes in the telephone circuit.

In the foregoing specification, and in the claims, we refer to telephones, as the means for rendering audible the final current pulsations in the detector circuit, but it will be understood that any other suitable means for rendering the signal audible or visible may be used as a substitute for the telephones, and wherever the expression is used we intend it to include not only the commonly employed telephones but all equivalents thereof.

What we claim is:

1. A radio-receiving system having means interacting with the received oscillations to produce current pulsations of a frequency below the range of good audibility, in combination with a frequency-augmenter upon which the low frequency pulsations are impressed to produce higher frequency pulsations within the range of good audibility, and a telephone connected to the high frequency side of the frequency-augmenter, whereby the received signal impulses produce audible sounds.

2. A radio-receiving system having means interacting with the received oscillations to produce two series of current pulsations of frequencies within the range of good audibility and so related that the ratio of the two frequencies corresponds to a simple musical interval, and a tephone circuit upon which the current pulsations are impressed to produce a compound harmonious tone.

3. A radio-receiving system having means interacting with the received oscillations to produce two series of current pulsations of frequencies within the range of good audibility and so related that the ratio of the two frequencies corresponds to a perfect fifth on the diatonic scale, and a telephone circuit upon which the current pulsations are impressed to produce a compound harmonious tone.

4. A radio-receiving system having means interacting with the received oscillations to produce current pulsations of a frequency below the range of good audibility, in combination with a frequency-augmenter upon which the low frequency pulsations are impressed, the said augmenter being adapted to produce, when excited by the said low frequency pulsations, two series of current

pulsations of higher frequency within the range of good audibility, and a telephone connected to the high frequency side of the frequency-augmenter, whereby the received signal impulses produce a compound harmonious tone in the telephone.

5. A radio-receiving system having means interacting with the received oscillations to produce current pulsations of a frequency below the range of good audibility, a wave filter through which the said pulsations are passed to separate them from disturbing pulsations of higher frequency, a frequency-augmenter upon which the filtered low frequency pulsations are impressed to produce higher frequency pulsations within the range of good audibility, and a telephone connected to the high frequency side of the frequency-augmenter, whereby the received signal impulses produce audible sounds.

6. A radio-receiving system having means interacting with the received oscillations to produce current pulsations of a frequency below the range of good audibility, an aperiodic wave filter through which the said pulsations are passed to separate them from disturbing pulsations of higher frequency, a frequency-augmenter upon which the filtered low frequency pulsations are impressed to produce higher frequency pulsations within the range of good audibility, and a telephone connected to the high frequency side of the frequency-augmenter, whereby the received signal impulses produce audible sounds.

7. A radio-receiving system having a receiving antenna in combination with means for converting the high frequency oscillations of the incoming energy to low frequency oscillations, an aperiodic oscillation filter interposed between said means and an indicating device, said filter having a high attenuation constant for high frequency oscillations and a low attenuation constant for low frequency oscillations, whereby low frequency oscillations are passed to the indicating device and high frequency oscillations are excluded without giving rise to periodic oscillations in the filter.

8. A radio-signalling system comprising means for combining locally generated high frequency oscillations with the energy of an incoming signal to produce oscillations of a very low frequency, means for attenuating and extinguishing any remaining undesirable high frequency oscillations, a frequency augmenter upon which the low frequency oscillations are impressed, and means for indicating said augmented oscillations whereby audible sounds corresponding to the signal are produced.

9. A radio receiving system having a receiving antenna in combination with means for converting the high frequency oscillations of the incoming energy to low frequency oscillations, an aperiodic wave filter interposed between said means and a frequency augmenter, and an indicating device for indicating said augmented oscillations, said filter having a high attenuation constant for high frequency oscillations and a low attenuation constant for low frequency oscillations, whereby low frequency oscillations are passed to the frequency augmenter and the indicating device, and high frequency oscillations are excluded without giving rise to periodic oscillations in the filter.

10. A radio-signaling system comprising means for converting the high frequency oscillations of the incoming energy to low frequency oscillations, a frequency augmenter, and means for producing and impressing split-phase currents of the low frequency oscillations upon said augmenter.

11. The combination in a radio receiving system of normally inoperative means for producing high frequency oscillations at the receiving station, means for receiving continuous high frequency signalling waves and means actuated by received high frequency signalling waves for setting into operation said means for producing high frequency oscillations at the receiving station and thereby producing high frequency oscillations of the same frequency as the received waves, means for producing by the high frequency oscillations locally produced a current which changes at a frequency below audibility and means actuated by said current of a frequency below audibility for producing a desired indication of signals.

In testimony whereof we affix our signatures.

MICHAEL I. PUPIN.
EDWIN H. ARMSTRONG.