Jan. 5, 1937. W. VAN B. ROBERTS 2,067,021

MEANS FOR CONVERTING ELECTRICAL ENERGY INTO ACOUSTICAL ENERGY

Filed Dec. 12, 1929

Fig. 1

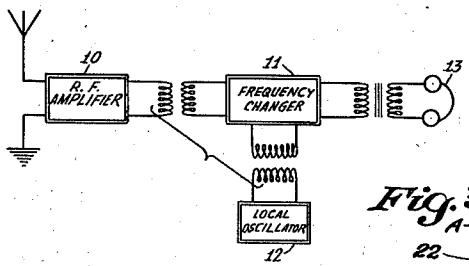


Fig. 3

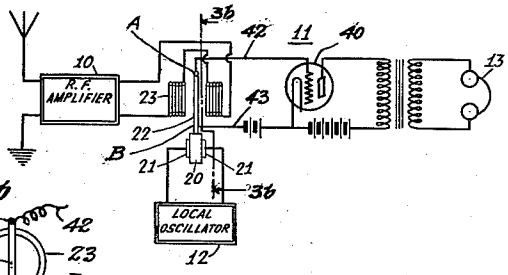


Fig. 3b

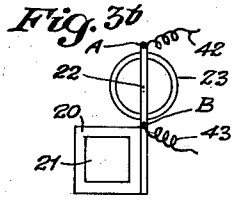


Fig. 2

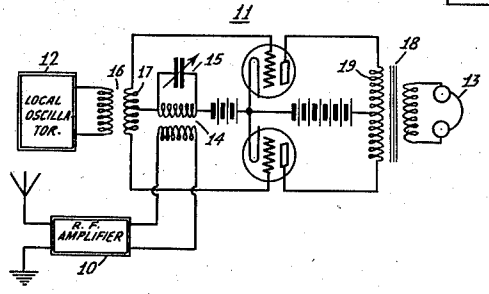


Fig. 3a

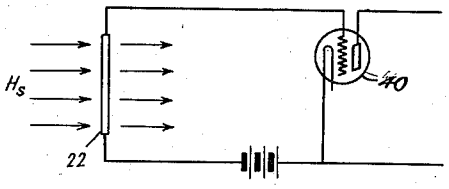


Fig. 4

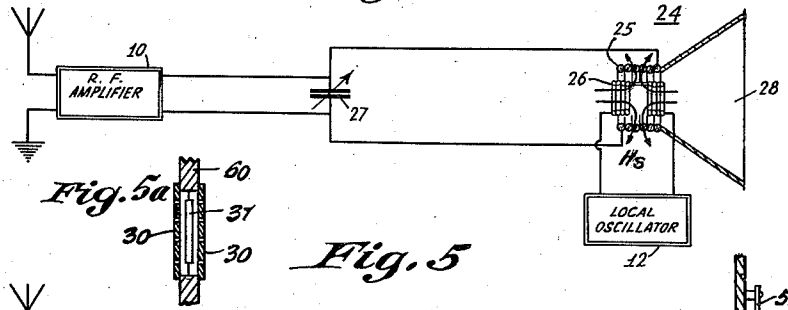


Fig. 5a

Fig. 5

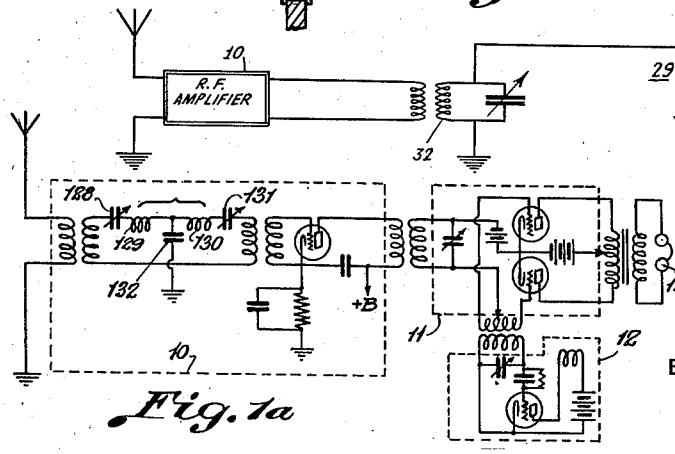


Fig. 4a

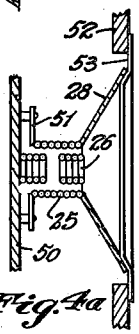


Fig. 1a

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UNITED STATES PATENT OFFICE

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MEANS FOR CONVERTING ELECTRICAL ENERGY INTO ACOUSTICAL ENERGY

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Application December 12, 1929, Serial No. 413,458

7 Claims. (Cl. 250—22)

This invention relates to means for converting electrical energy into acoustical energy which has a frequency different from the frequency of the electrical energy by a controllable amount. More particularly, this invention relates to means for combining locally generated energy of constant amplitude with received energy in the form of a modulated radio frequency, in a manner such that energy of the same or a different form and having a frequency different from the frequency of the received energy by a controllable amount, is obtained.

The primary object of this invention is to provide means for obtaining audible sound waves from modulated radio frequency signals without the possibility of interference from signals of other than the desired wave length.

Another object of this invention is to provide an improved selecting system for receiving radio signals which functions so that the ear is used as the frequency selecting device, instead of the usual means such as tuned circuits or electrical acoustic or mechanical filters.

Another object of this invention is to provide means for receiving radio signals which functions so that the output whether electrical, mechanical or otherwise, is proportional to the product of the input and a heterodyne, and which also functions so that it does not have in its output any term proportional to an even power of the input.

Another object of this invention is to provide a radio receiving system for converting electrical energy at a modulated radio frequency into either electrical energy or acoustical energy at two frequencies only, namely the sum of the radio and heterodyne frequencies and their difference.

Another object of this invention is to provide a radio receiving system in which a plurality of modulated radio frequency signals are combined with a heterodyne frequency in a manner such that the output energy contains frequencies equal to the difference between the heterodyne frequency and each of the radio frequencies and does not contain any audio currents of frequency independent of the signal carrier frequencies.

Another object of this invention is to provide means for receiving radio signals which functions by changing the frequency of a band of frequencies, the frequency of the carrier of the desired signal being changed to zero, while the frequencies of the undesired carriers are not.

Another object of this invention is to provide a system for receiving radio frequency signals which does not employ tuned circuits as the frequency selecting means, or which uses them only as a secondary form of frequency selecting means.

Another object of this invention is to provide a radio receiving system which does not use a detector having a term in its ouput which is proportional to the square of the input.

Another object of this invention is to provide a radio receiving system which does not use audio frequency amplifiers.

Another object of this invention is to use a sound reproducer such as a bilateral electrostatic loudspeaker, as a frequency changing device.

Still further objects of the invention will become apparent upon reading the following specification in connection with the accompanying drawing which illustrates diagrammatically several approved forms of my invention.

The broad objects of my invention are attained by receiving and amplifying a plurality of modulated high frequency signals and by combining them in a suitable frequency changing device with locally generated energy which has the same frequency as the frequency of the carrier wave of the modulated high frequency signal it is desired to receive. The frequency changing device is of a nature such that its output is proportional to the product of the desired signal input and the locally generated energy. Furthermore, the frequency changing device is of a nature such that the energy in its output does not contain a term proportional to the square of the input.

In one form of my invention the modulated high frequency signals are combined in the frequency changing device with locally generated energy which is in the form of electrical oscillations and the frequency changing device is of a nature such that the energy in its output is also in the form of electrical oscillation.

In another form of my invention the modulated high frequency signals are combined in the frequency changing device with locally generated energy which is in the form of mechanical vibrations and the frequency changing device is of a nature such that the energy in its output is in the form of an alternating voltage.

In still another form of my invention, the modulated high frequency signals are combined in the frequency changing device with locally generated energy which is in the form of electrical oscillations and the frequency changing device is of a nature such that the energy in its output is in the form of mechanical vibrations.

Still other types of frequency changing devices may be designed to combine the modulated high frequency signals with locally generated energy of the same or different form, to obtain an energy output in the form of electrical, mechanical or still some different form of energy, without departing from the spirit of my invention.

Referring more particularly to the drawing:

Fig. 1 illustrates diagrammatically a radio receiving system according to the broad principles of my invention;

Fig. 1*a* illustrates approved circuits for the different portions of radio receiving systems of Fig. 1.

Fig. 2 illustrates an approved form of my invention including the details of a frequency changing device in which the locally generated energy is supplied in the form of electrical oscillations and in which the energy in the output of the frequency changing device is also in the form of electrical oscillations;

Fig. 3 illustrates diagrammatically a modification of my invention in which the locally generated energy is supplied to the frequency changing device in the form of mechanical vibrations and in which the frequency changing device is of a nature such that the energy in its output is in the form of an alternating voltage;

Fig. 3*a* illustrates a detail of the frequency changing device illustrated in Fig. 3;

Fig. 3*b* illustrates a sectional view along the section line 3*b*—3*b* of Fig. 3.

Fig. 4 illustrates diagrammatically another modification of my invention in which the locally generated energy is supplied to the frequency changing device in the form of electrical oscillations and in which the energy in the output of the frequency changing device is in the form of mechanical vibrations;

Fig. 4*a* illustrates approved constructional details of one of the elements of Fig. 4.

Fig. 5 illustrates diagrammatically still another modification of my invention in which the locally generated energy is supplied to the frequency changing device in the form of electrical oscillations and in which the energy in the output of the frequency changing device is in the form of mechanical vibrations; and

Fig. 5*a* illustrates in more detail one of the elements of Fig. 5.

In Fig. 1 a radio frequency amplifier is indicated diagrammatically by reference numeral 10. This radio frequency amplifier may be of any well known type and may include an antenna circuit and one or more radio frequency amplifying stages connected in cascade. The amplifying stages may be untuned, tuned to a band of frequencies, or provided with any well known means for tuning them to a particular frequency. While untuned stages are preferably used in connection with my invention the system will operate equally well if either tuned or untuned stages of radio frequency amplification are used.

The radio frequency amplifier 10 is coupled in any well known manner to a frequency changing device indicated diagrammatically at 11. A local oscillator 12 is also coupled to the frequency changing device 11, in any well known manner. The output of the frequency changing device is coupled by means of a suitable audio frequency transformer to an acoustic device such as a loudspeaker or a pair of headphones 13.

The local oscillator may be of any well known type and it is tuned to the frequency of the carrier wave of the modulated high frequency signal it is desired to receive. It is usually desirable to provide some means for locking the local oscillator in step with the desired carrier wave, so that the frequency of the locally generated energy will always be the same as the frequency of the carrier wave.

The frequency changing device may vary in nature as pointed out hereinafter according to the form of the locally generated energy supplied thereto and according to the form of the energy which it is desired to obtain in the output of the device. The frequency changing device, however, must always be of a nature such that its output is proportional to the product of the signal input and the locally generated input. The frequency changing device must also be of a nature such that the energy in its output does not contain terms proportional to the square of the signal input. In other words the frequency changing device must act as a "straight line device" and must not act as "square law detector."

Fig. 1*a* shows an approved form of the radio frequency amplifier 10 and an approved form of the local oscillator 12. The figure also shows a frequency changer 11 of the type illustrated in more detail in Fig. 2, and described hereinafter.

The radio frequency amplifier 10 of Fig. 1*a* is of the type adapted to amplify a selected band of frequencies. It consists essentially of a band pass filter and an amplifying tube. The band pass filter which includes the two adjustable condensers 128 and 131, and the two mutually coupled inductances 129 and 130, and the mutual capacity 132 is shown and described in applicant's copending application S. N. 133,283 filed September 2, 1926. In Fig. 11 of said copending application elements indicated in Fig. 1*a* by reference characters 128 to 132, are indicated by reference characters 28 to 32 inclusive.

The local oscillator 12 of Fig. 1*a* is similar to the oscillator shown and described in the patent to De Forest 1,507,016. As oscillating circuits of this type are well known in the art, it is not believed necessary to describe the circuit in detail.

Fig. 2 illustrates the details of an approved form of a frequency changing device which meets with the requirements of my invention. In this figure the modulated high frequency signals are received and amplified by the radio frequency amplifier 10. The amplifier 10 is coupled to the frequency changing device 11 by means of transformer 14 the secondary winding of which forms a part of the tuning circuit 15. The locally generated energy is supplied to the frequency changing device 11 in the form of electrical oscillations from the local oscillator 12 which is coupled to the frequency changing device 11 by means of a transformer 16 having a secondary winding 17. The acoustic device 13 is connected to the output of the frequency changing device 11 through a suitable audio frequency transformer 18 having a primary winding 19.

The frequency changing device 11 in this particular modification, comprises a pair of thermionic valves arranged in push-pull fashion. That is, the filaments of the valves have a common connection, the grids are connected together through the winding 17 the mid point of which is connected to the filaments through a biasing battery and in this case through the tuned circuit 15, and the plates are connected together through winding 19 the mid point of which is connected through a B battery to the filaments.

The energy from the radio frequency amplifier 10 is supplied to the push-pull circuit, however, in a somewhat different manner from when the circuit is used as an amplifier. In this particular case the tuned circuit 15 is connected in the common portion of the input circuits of both valves and the local oscillator is coupled to the winding 17 half of which is included in the input circuit of each valve. With this arrangement the incoming signal will impress the same potential upon the grids of both valves at the same instant and the corresponding plate current for each valve flowing in half of the inductance 19

will balance out the plate current of the other valve flowing in the other half of inductance 19. As a result no energy will be transferred through the transformer 18 to the acoustic device 13.

However, when the local oscillator is coupled to the winding 17 and tuned to the frequency of the carrier wave, potentials of opposite phase will be impressed upon the grids of the two valves and oppositely phased beat frequency currents will be obtained in the two halves of winding 19 which act cumulatively upon the acoustic device 13. Other beat frequencies due to interfering stations will also be present in the winding 19 but they will not be detected by the ear if the carrier waves are separated by say 10 kilocycles. As the frequency changing device does not have the characteristics of the ordinary detector the modulations of these other carrier waves will not be present in the winding 19. It is also possible to interchange the positions of the signal and heterodyne inputs.

In order to explain this fundamental feature of the invention in detail, suppose the desired signal produces an input to the frequency changer which we will call $A \cos Pt + a \cos (P+Q)t + a \cos (P-Q)t$ where A is a constant determined by the carrier strength, $P/2\pi$ is the carrier frequency, $Q/2\pi$ is a typical audio modulation frequency, and a is the amplitude of the typical "side frequency". Similarly, an interfering signal would produce $B \cos P't + b \cos (P'+Q')t + b \cos (P'-Q')t$. The heterodyne is of the form H cos Pt where H is constant, and the heterodyne is not added to the signal and interfering input, but is applied by way of a different path.

Since the fundamental requirement of the frequency changer is that its output is proportional to the product of the input and heterodyne, and not to any even power of the input, the output will be proportional to—

$$A \cos Pt + a \cos (P+Q)t + a \cos (P-Q)t + B \cos P't + b \cos (P'+Q')t + b \cos (P'-Q')t \text{ times } H \cos Pt.$$

Multiplying out, this reduces to a sum of terms of the following frequencies:

Zero——which is inaudible;

$2P/2\pi$——which is inaudible being a radio frequency;

$P+(P+Q)/2\pi$——which is inaudible being a radio frequency;

$P+(P-Q)/2\pi$——which is inaudible being a radio frequency;

$P+P'/2\pi$——which is inaudible being a radio frequency;

$P+(P'+Q')/2\pi$——which is inaudible being a radio frequency;

$P+(P'-Q')/2\pi$——which is inaudible being a radio frequency;

$P-(P-Q)/2\pi=Q/2\pi$——which is the desired modulation frequency;

$(P+Q)-P/2\pi=Q/2\pi$——which is the desired modulation frequency;

$P-(P'-Q)/2\pi$——which is inaudible if the carrier fresuencies $P/2\pi$ and $P'/2\pi$ are separated by more than the limits of audibility, as they should be for any type of reception, and

$(P'+Q')-P/2\pi$——which is inaudible for the same reason.

Thus the result is that the carrier frequencies of all signals are reduced by a like subtractive amount, the amount being such that the carrier frequency of the desired signal is reduced to zero and the desired signal thus rendered audible, while other signals remain in the form of modulated high frequency currents and hence remain inaudible.

In Fig. 3 a still different type of frequency changing device is illustrated. In this modification the locally generated energy supplied to the frequency changing device is in the form of mechanical vibrations and the energy in the output of the frequency changing device is in the form of oscillations of potential.

The modulated high frequency signals are received and amplified by the radio frequency amplifier 10 just as in the other modification. The locally generated energy is first obtained as electrical oscillations from the local oscillator 12. The electrical oscillations are changed to mechanical vibrations by any suitable means such as a piezo electric crystal 20 which is provided with electrodes 21 connected to the output of the local oscillator 12. The piezo electric crystal is secured in a suitable manner such as by cementing to the vibratile element 22. It is to be understood, however, that any other means may be provided for mechanically vibrating the member 22 at the desired frequency.

The element 22 consists of a strip of suitable conducting material such as copper or aluminum. Leads 42 and 43 from the points A and B on the conductor, which are preferably near the ends thereof, supply energy to the cathode-grid circuit of a suitable amplifying device 40. The ouput of this amplifier is connected through an audio frequency transformer to the acoustic device 13.

The conductor 22 is positioned in the magnetic field (see Fig. 3*a*) which is set up by the coil 23 connected to the output of the radio frequency amplifier. The conductor 22 is connected to the piezo electric crystal 20 in such a manner that it vibrates in said magnetic field H_s at right angles to the lines of force thereof.

Referring to Fig. 3*b* which indicates diagrammatically a section through coil 23 along the section line 3*b*—3*b* of Fig. 3, the conductor 22 is vibrated from left to right. Vibration of the conductor 22 at right angles to the field of the coil 23 sets up an electromotive force in the conductor, the magnitude of which is the product of the velocity of motion in the conductor times the field strength. As the magnetic field H_s has an alternating component comprising the modulated carrier wave it is desired to receive and as the conductor 22 is vibrated at the frequency of the carrier wave to be received, a potential is set up in the conductor corresponding to the modulation of the modulated carrier wave. The potential difference which exists between the points A and B on the conductor 22 as a result of the electromotive force set up therein, is applied across the input electrodes of tube 40. The voltage from tube 40 is converted into sound by means of the sound reproducer 13.

Fig. 4 illustrates a modification of the frequency changing device in which the locally generated enrgy is supplied in the form of electrical oscillations and the energy in the output of the frequency changing device is in the form of mechanical vibrations.

In this modification the modulated carrier waves are received and amplified by the radio frequency amplifier 10 in the usual manner and

the local energy is again generated in the form of electrical oscillations by the local oscillator 12. The frequency changing device and the acoustic device are combined into a single device 24. This device preferably comprises a movable coil 25 energized from the radio frequency amplifier 10 and a stationary coil 26 energized from the local oscillator 12. A tuning condenser 27 may be connected in parallel with the coil 25 to increase the current therein, if desired. A sound wave producing member which may be in the form of a conical diaphragm 28, is mechanically connected to the moving coil 25 to vibrate therewith. The coils 25 and 26 are arranged so that the magnetic field H_s from the two sections of coil 26, is substantially at right angles to, and cuts the turns of coil 25. In this respect the alternating field H_s of the acoustic device 24 is similar to the constant field of the well known electromagnetic loudspeaker. In both instances the magnetic field is substantially at right angles to the turns of the moving coil.

When the coil 25 is supplied with modulated high frequency signals from the radio frequency amplifier 10 and the coil 26 is supplied with the electrical oscillations at the same frequency as the frequency of the signal it is desired to receive, the moving coil 25 and the diaphragm 28 attached thereto will move in accordance with the modulations of the desired signals, as explained before.

In Fig. 4*a* means are shown for rigidly supporting the stationary coil 26 and flexibly supporting the moving coil 25. Any suitable supporting member 50 may be used for supporting the stationary coil 26. The moving coil 25 is supported by any suitable type of spider member 51 in the well known manner. The peripheral edge of the diaphragm 28 which is physically secure to the moving coil 25 to vibrate therewith, is supported from any supporting means 52 by suitable supporting means 53 which may be, for example, an annular rim of cloth or other flexible material. The spider member for supporting the moving diaphragm and the flexible member for supporting the peripheral edge of the diaphragm are well known in the art.

The device will operate equally well if the coil 26 is supported for movement and connected with the diaphragm 28 and if the coil 25 is held in place by suitable supporting means.

Fig. 5 illustrates still another modification of my invention. In this modification the frequency changing device and the sound reproducer are again combined and the arrangement is such that the signal and the locally generated energy are supplied to the frequency changing device in the form of electrical potential oscillations and the energy in the output is in the form of mechanical vibrations.

The modulated carrier waves are received and amplified by radio frequency amplifier 10 and the electric oscillations supplied to the combined frequency changing device and acoustic device 29 are generated by the local oscillator 12 in the usual manner.

In this particular modification the combined frequency changing device and acoustic device comprises a bilateral electrostatic sound reproducer. This type of electrostatic sound reproducer comprises a pair of perforated fixed plates 30 and a movable plate 31 electrostatically balanced there between. The high biasing potential usually applied in sound reproducers of this type between the two outer fixed plates and the inner plate is replaced by radio frequency voltage.

In using a bilateral electrostatic sound reproducer as a combined frequency selecting device and sound reproducer, the modulated carrier waves from the radio frequency amplifier 10 are applied between the movable plate 31 and the fixed plates 30. In an approved construction the radio frequency amplifier 10 is coupled to a tuned circuit 32, one side of which is directly connected to the movable plate and the other side of which is connected, through the ground, to the intermediate point of an inductance 33 which is connected between the two fixed plates 30. The local oscillations are supplied to the bilateral device by coupling the local oscillator 12 to the inductance 33 which is connected between the two fixed plates. The device will operate equally well, however, if the heterodyne and signal are interchanged, i. e., if the local oscillations are impressed between the fixed plates 30 and movable plate 31 and the amplified radio frequency variations are impressed between the two fixed plates 30.

When the local oscillator is tuned to the frequency of the desired carrier wave, the electrostatic balance between the fixed plates and the movable plate is disturbed and the movable plate will be vibrated at frequencies corresponding to the modulations of the desired signal as explained before.

As shown in Fig. 5*a* the two outer stationary plates 30 may be secured to suitable supporting means 60 having an opening therein in which the plate 31 is mounted for vibration. The plate 31 may be mounted within the opening by any suitable flexible supporting means such as an annular rim of material extending from the peripheral edge of the plate to the member 60. Sound waves set up by movement of the plate 31 pass through perforations in the fixed plates 30. Bilateral electrostatic speakers of this type are well known in the prior art.

It is to be understood that in all the modifications described hereinbefore, a tuned radio frequency amplifier may be used if desired. It is not necessary that the amplifier be tuned, as the selecting of the desired carrier frequency does not depend upon the tuning of a radio frequency circuit but upon the action of the ear.

It is also to be understood that while reasonably good results can be obtained by simply tuning the local oscillator to the frequency of the desired carrier wave, in some instances it may be found desirable to lock the local oscillator in step with the carrier wave so that small variations in the frequency of the carrier wave will immediately result in a corresponding change in the oscillator frequency, and also so that the local oscillator cannot of its own accord vary from the frequency of the carrier wave. I have found that the local oscillator will lock itself in step with the desired carrier if a little of the latter is impressed upon the oscillator. There are various other methods of locking the local oscillator in step with the carrier wave but as these methods have no bearing on the present invention, they will not be described in detail herein.

Finally it is to be understood that various modifications can be made to the frequency changing device and to the manner of supplying energy thereto and obtaining energy therefrom, without departing from the spirit of the present invention. For this reason it is desired to point out that the present invention is not to be limited

to the particular structure of the modifications shown and described, but only by the scope of the appended claims.

I claim:

1. A radio receiving system comprising a radio frequency amplifier for providing a modulated high frequency signal, means for providing locally derived energy in the form of mechanical vibrations, and a frequency changing device for combining the energy of said modulated high frequency signal with the energy of said mechanical vibrations to obtain an output energy in the form of electrical oscillations corresponding to the modulation of said modulated high frequency signal.

2. A radio receiving system comprising an untuned radio frequency amplifier for providing a plurality of modulated high frequency signals, means for providing locally generated energy in the form of mechanical vibrations at the frequency of a desired one of said plurality of signals, and a frequency changing device for combining the energy of said plurality of modulated high frequency signals with the energy of said mechanical vibrations to obtain an output energy in the form of electrical oscillations corresponding to the modulation of the desired one of said plurality of signals.

3. A radio receiving system comprising means for providing a magnetic field from a modulated high frequency signal, a conductor of electrical energy, means for mechanically vibrating said conductor in said field at right angles to said field, said conductor being vibrated at the frequency of said high frequency signal, and acoustic device, and means for transferring a potential proportional to the electromotive force set up in said conductor to said acoustic device.

4. A radio receiving system comprising means for providing a magnetic field from a plurality of modulated high frequency signals, an electrical conductor, means for mechanically vibrating said conductor in said field at right angles to said field, said conductor being vibrated at the frequency of one of said high frequency signals, an acoustic device, and means for transferring energy corresponding to the electromotive force set up in said conductor to said acoustic device.

5. A radio receiving system comprising a radio frequency amplifier for providing a modulated high frequency signal, means associated with said amplifier for providing a magnetic field corresponding to said modulated high frequency signal, an electrical conductor positioned in said magnetic field, means for mechanically vibrating said conductor at right angles to said field whereby an electromotive force is set up in said conductor, an acoustic device, and means for transferring electrical energy corresponding to said electromotive force from said conductor to said acoustic device.

6. A radio receiving system comprising an untuned radio frequency amplifier for receiving and amplifying a plurality of modulated high frequency signals, means for providing a magnetic field corresponding to said plurality of modulated high frequency signals, an elongated conductor positioned in said field and extending substantially at right angles thereto, means for mechanically vibrating said conductor in said field at right angles to said field and at the same frequency as the frequency of a desired one of said signals, whereby an electromotive force is set up in said conductor, an amplifier of electrical energy, means for transferring the electrical energy corresponding to the electromotive force set up in said conductor to said amplifying means, and an acoustic device coupled to said amplifying means.

7. A radio receiving system comprising high frequency amplifying apparatus for amplifying modulated carrier waves to obtain amplified electrical variations, apparatus for producing constant frequency electrical variations, means for combining the constant frequency electrical variations with electrical variations from said high frequency amplifying apparatus and for producing sound waves therefrom corresponding to the modulation of one of the modulated carrier waves amplified by said high frequency amplifying apparatus, said means including a piezo electric crystal device upon which certain of said electrical variations are impressed.

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