Jan. 1, 1929. 1,697,650

L. A. HAZELTINE

SYSTEM OF RADIOCOMMUNICATION

Filed Nov. 1, 1917

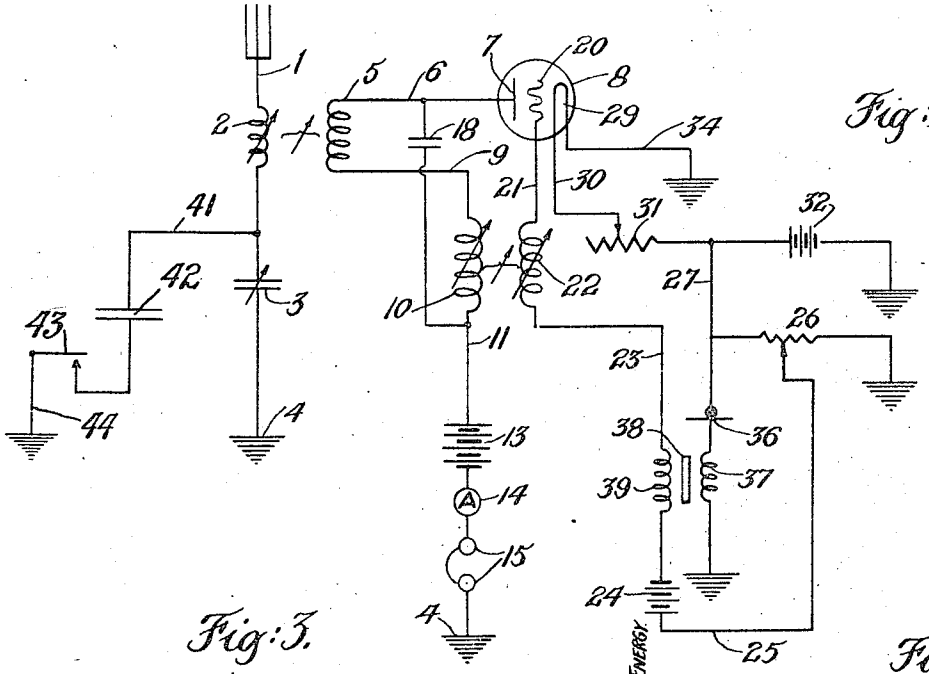


Fig. 1.

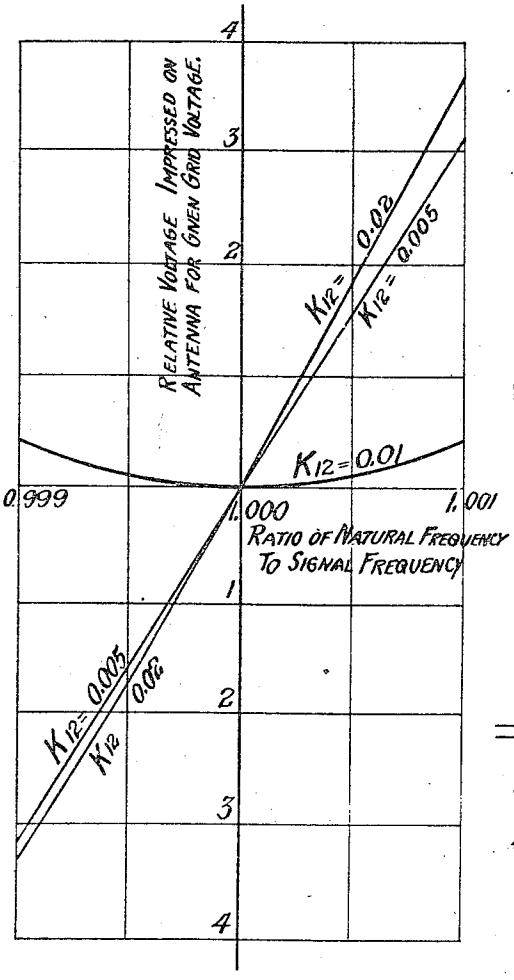


Fig. 3.

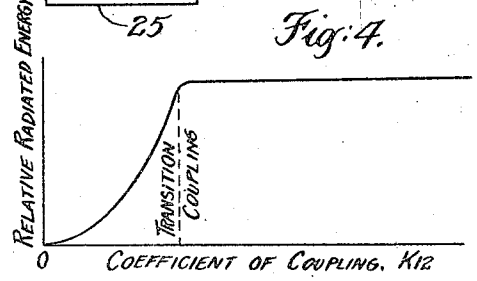


Fig. 4.

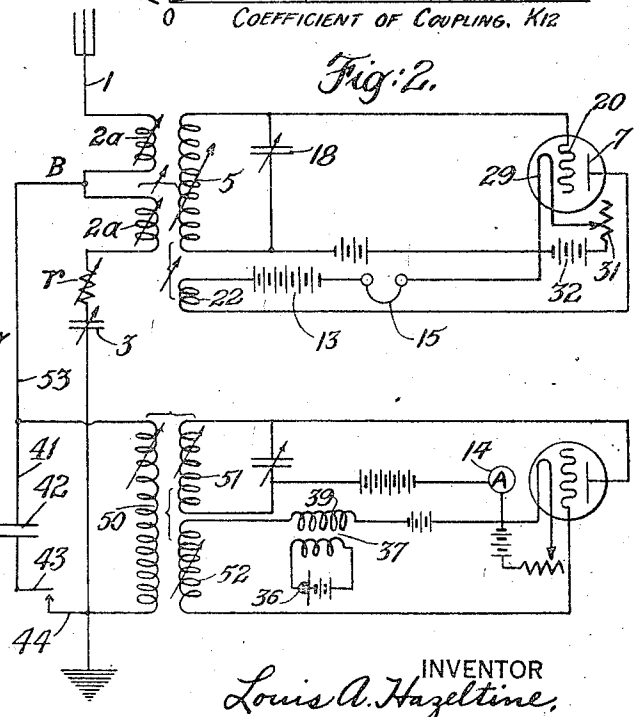


Fig. 2.

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UNITED STATES PATENT OFFICE.

LOUIS ALAN HAZELTINE, OF HOBOKEN, NEW JERSEY, ASSIGNOR, BY MESNE ASSIGNMENTS, TO WARE RADIO, INC., A CORPORATION OF DELAWARE.

SYSTEM OF RADIOCOMMUNICATION.

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This invention relates to radio communication, and more particularly to oscillating audion circuits such as are used in receiving or transmitting intelligence either by speaking telephone or by telegraph.

In radio telephony and telegraphy it is usual to employ one set of apparatus for transmitting and another set for receiving at each station. This is done because with the ordinary arrangements of receiving apparatus a comparatively large amount of incoming energy is required to give easily audible response, and this requires that the transmitting apparatus deliver more output than could be obtained from an audion which is suited for receiving. Thus a large audion or other radio-frequency generator is used for transmitting and a small audion or other detector is used for receiving.

In receiving sustained-wave telegraphic signals by the heterodyne or beats method, it is necessary to have a local oscillation of a slightly different frequency from that of the incoming oscillation and it is usual to employ an audion both to produce this local oscillation and to act as the detector. It has been recognized that in this use of the audion its sensitiveness as a detector is improved by its being in the oscillating condition; but application of this principle to radiotelephony presents special difficulties, which have not heretofore been overcome.

I have discovered that it is feasible to use an oscillating audion as a detector in radiotelephony, by employing methods and apparatus hereinafter described. By reason of the superior sensitiveness of the oscillating audion as a detector, I am thereby enabled to use a less powerful generator at the transmitting station, with the very desirable result that under suitable circumstances the same audion may be used both for transmitting and for receiving. I have also discovered that this apparatus and some of the methods are advantageously applied to radiotelegraphy, with the same result of decreasing the required transmitting power.

Fundamentally the method of two-way radiotelephonic communication with a single oscillating audion at each station consists in operating these audions in synchronism. If the audions are not in synchronism, a beat note will be produced, or a distortion of the voice tones, if the beat note be outside the audible range, causing the voice to be unintelligible. I have discovered that two audions may be operated in synchronism when connected in distant radio stations and that the extremely small energy transmitted from one station to the other is sufficient to hold them in synchronism even when the strength of the oscillation varies due to the voice vibrations.

In radio receiving apparatus employing an oscillating audion operating in synchronism with the incoming signal oscillation, it is desirable that the audion be able to readily change its freqency by small amounts so as to accommodate itself to accidental changes in the incoming frequency. I have discovered that audion receiving circuits of a certain general type and having certain numerical relations between the circuit constants have the property that the oscillation produced by the audion will readily change its frequency with changes in the frequency of the oscillation impressed on the antenna so as to keep the two oscillations in synchronism. This type of circuit and the necessary relation is given below.

The receiving system consists of two tuned circuits, an antenna circuit in which the incoming signal oscillation is impressed, and a local circuit connected or coupled to the audion. The audion may be connected to the local circuit in any of the various ways commonly known that will produce oscillations, but must either not be coupled to the antenna circuit at all, or else coupled very loosely thereto. The antenna and local circuits may be coupled together by any of the methods commonly used, as mutual inductance, common self-inductance, or common capacity.

If the coupling between the antenna and local circuits is closer than a certain transition value, the frequency of oscillation will suddenly change by a finite amount when the natural frequency of one of these circuits is gradually changed and passed through the value for the other circuit. If, on the other hand, the coupling is looser than this transition value, the frequency of oscillation will change only gradually when the natural frequency of one of the circuits is changed. I have discovered that this particular condition of transition

coupling is peculiarly valuable in radio receiving systems in that it permits the synchronous operation referred to above.

In the accompanying drawing,

Figure 1 is a diagram of a sending and receiving system,

Figure 2 is a diagram of a modified system adapted for long distance operation,

Figure 3 is a diagram showing the saving in power by transition coupling, and

Figure 4 is a diagram showing the variation in radiation of energy with different values of coupling.

In Figure 1, 1 is the antenna or external circuit containing the variable self-inductance coil 2 for tuning, and the variable series capacity 3, connected to ground 4. Variably coupled to the self-inductance 2 is a coil 5, having one terminal connected by wire 6 to the plate 7 of an audion or other suitable relay device 8. The variable coupling of these coils may be attained by pivoting one coil relatively to the other so that their axes can be varied in their relative relation.

By audion is meant any evacuated vessel having one hot and one or more cold electrodes and acting as a relay, whereby a relatively small alternating voltage supplied between one cold electrode and the hot electrode, produces a relatively large alternating current and voltage in a circuit or circuits connected between the other cold electrode or electrodes and the hot electrode. As commonly used, the audion has a rectifying action in addition to this relay or amplifying action, but for the purposes of this invention, a separate rectifier or detector may be employed if desired.

The other terminal of coil 5 is connected by wire 9 to self inductance 10, which is variable as shown for tuning this local circuit. The other terminal of coil 10 is connected by wire 11 to the positive terminal of plate battery 13. The negative side of the battery is connected to ground through the ammeter or other suitable current indicator 14 and the telephone receivers 15. 18 is a capacity connected between wires 6 and 11 around coil 10 to be used in case the inherent capacity of the audion and connected apparatus is insufficient to make the local circuit resonant.

The circuit of grid 20 is connected by wire 21 to inductance 22 which is variably coupled to inductance 10, constituting a variable grid coupling, then by wire 23 to adjustable grid battery 24, then by wire 25 to grid potentiometer 26, and by ground and wire 34 to filament 29. By varying battery 24, the strength of oscillation is varied, and the potentiometer 26 gives fine control of the grid potential, coarse control being obtained by varying the number of cells in battery 24. 32 is the heating battery connected to filament 29 through resistance 31, wire 30, and by wire 34 to ground.

It has been found that this conductive connection of the grid 20 to the filament 29 through the battery 24 and potentiometer 26 for adjusting its average potential is conducive to stability of the audion and hence to greater freedom from impulsive interference than is possible when a stopping condenser is used in series with the grid, as has been common practice heretofore. This is of great importance in the satisfactory operation of a two-way system, where the average potential of the grid is adjusted to give a powerful transmitted oscillation while effectively retaining the detecting property of the audion.

It has also been found that the arrangement of the oscillating circuit so that the alternating part of the plate potential is relatively large compared with the alternating part of the grid potential, attained in Fig. 1 by tuning the plate circuit by the condenser 18 instead of tuning the grid circuit, as has been common practice heretofore, permits oscillations of relatively large power to be generated, while effectively retaining the detecting property of the audion.

In operating to receive signals, the audion is most sensitive as a detector when it is oscillating independently of the received signal, which is necessary in the heterodyne reception of sustained waves. When an audion is oscillating however, certain limitations are imposed, which vary for different forms of signals to be received, as in radio telephony, or radio telegraphy with damped waves, or radiotelegraphy with sustained waves. This invention is applicable for all of these purposes and presents distinct and novel advantages over methods and systems heretofore proposed.

To determine experimentally when the coupling has the desired transition value, the natural frequency of one of the coupled circuits is continually varied through the tuning point (i. e., the point at which the two circuits have the same natural frequency), as by varying capacity 3 in the antenna circuit; and the main coupling 5, 2, is slowly decreased. As long as the coupling exceeds the transition value, at the instant when the tuning point is passed a momentary beat note or click will be heard in the telephone receivers 15 connected in the plate circuit and at the same time ammeter 14 connected in the plate circuit will show a sudden jump. When the coupling is loosened so that the click or beat note and the jump in the ammeter reading just disappear, transition coupling has been attained. This procedure is the same no matter what form of coupling or what audion connection is employed, so long as the connections are of the type described above.

Mathematically there is a definite and simple relation between the transition coupling and the other constants of the circuit and this

is that the "coefficient of coupling" should equal the "power factor" of the antenna circuit. By "coefficient of coupling" with mutually inductive coupling is meant the quantity,

$$k_{12} = \frac{M_{12}}{\sqrt{L_1 L_2}}$$

where M_{12} is the mutual inductance between the antenna and local circuits, whose self-inductances are L_2 and L_1 respectively. By "power factor" is meant the quantity,

$$p_2 = r_2 \sqrt{\frac{C_2}{L_2}}$$

where r_2 is the resistance and C_2 the capacity of the antenna circuit. With other forms of coupling the coefficient of coupling is expressed by other formulas, but its significance would generally be apparent to one familiar with the theory of coupled circuits; and it should still be adjusted to equal the power factor, either exactly or with an insignificant difference.

The curves of Fig. 3 give the relation of the voltage in the antenna required to maintain synchronous operation, plotted against the relative natural frequency for which the receiving system is adjusted, for a power factor p_2 of the antenna circuit equal to 0.01, and for the three cases: (*a*) of transition coupling, marked "$k_{12}=0.01$"; (*b*) of a coupling of twice the transition value, marked "$k_{12}=0.02$"; and (*c*) of a coupling of one half the transition value, marked "$k_{12}=0.005$". These curves show for example that if the natural frequency is out of adjustment by 1/20 of 1% (points at 0.9995 and 1.0005) the voltage in the antenna that will just maintain synchronous operation is about 15 times as great for $k_{12}=0.005$, and about 17 times as great for $k_{12}=0.02$, as for the transition value, $k_{12}=0.01$.

Similar conditions arise in receiving damped wave telegraphic signals. Damped waves are emitted in groups by the sending station, these groups ordinarily recurring at a frequency within the audible range. In the receiving apparatus the current of each group is rectified and passed through telephone receivers which respond with a musical tone having the group frequency. It is found in practice that an independent oscillation in the receiving apparatus will cause the received signals to be louder, but the musical note will be lost, and the signals thereby become less readable in the presence of disturbances, such as are caused by strays. The reason for this is that the local oscillation does not combine with successive signal groups in the same phase, but sometimes adds to and sometimes subtracts from the signal oscillation, and in varying amounts. This effect is similar in its general characteristics to radiotelephony receiving with the two oscillations out of synchronism, and is obviated to a considerable degree by the same receiving circuits and relation between the circuit constants. Thus with circuits of the type previously described (of which Fig. 1 is an example) and adjusted for transition coupling, the local oscillation can readily change slightly in frequency and so can accommodate itself to changes in phase of the successive groups. In this way the local oscillation will add to all (or nearly all) of the groups and will greatly amplify them without destroying their regular periodic character which gives the desired musical tone.

Even in cases where it is not found possible to attain this synchronizing action, it will be found desirable to adjust the antenna coupling to the transition value, the audion being also adjusted so as to be on the verge of oscillating, because the selectivity and sensitiveness will then be greatest. The curves of Fig. 3 for this case represent the relative antenna voltages required for a given response in the telephone receivers, and show this to be the least (when the local circuit is very nearly in tune with the signal) for transition coupling. With the audion oscillating the same remarks apply to receiving sustained wave signals, especially of short wave-length.

Transition coupling is advantageous when it is desired to employ loosely coupled circuits in transmitting sustained waves produced by an audion. For if closer coupling is employed, the oscillation, having two natural frequencies, is likely to suddenly change from one to the other due to any disturbance, thus causing great inconvenience; and, on the other hand, if looser coupling is employed, a smaller proportion of the output of the audion is radiated from the antenna. This is illustrated by the curve of Fig. 4 showing the relative energy radiated with different values of coupling, assuming the current in the local circuit to remain constant. It will be seen that no increase of radiated energy occurs when the coupling is made closer than the transition value, but that a rapid decrease occurs when the coupling is looser.

In radiotelephone sending, a microphone transmitter 36 is inserted between wire 27 and the ground, and having its primary coil 37 on core 38 inductively related to secondary 39 located between wire 23 and battery 24. In order to vary the frequency for radio telegraph sending by the compensating wave method, a condenser 42 is connected by wire 41, to a key 43, which is connected to ground by wire 44.

For long distance communication it is preferable to weaken the oscillation at the receiving end and strengthen that at the sending end, which by reason of the transition coupling at each end helps to maintain synchronous operation, and gives greater sensitiveness at the receiving end. Variation of the

strength of oscillation is effected, as above described, by varying the grid battery 24, or by varying mutual induction between coils 10 and 22 of Fig. 1. Any resulting slight change in tuning can be compensated for by changing the main tuning, or by special automatic compensation to be adjusted by trial, such as a variable capacity, or one connected in or out of circuit simultaneously with changes in the battery.

For long distance two-way telephonic communication without changes in adjustment, the modification shown in Figure 2 may be used, employing a receiving and a sending audion at each station, or any other high-frequency generator, or arc in place of the sending audion. In such case the high-frequency sending source should preferably be so connected as not to affect the receiving audion at that station. This is effected by balancing the antenna capacity, inductance and resistance on both sides of point B by the condenser 3, lower coil 2^a and non-inductive resistance r, respectively and causing the mutual induction between the antenna and local circuits to be equally divided between coil 5 and the two coils 2^a. This insures that the oscillations caused by sending from transmitter 36 will be transmitted through the inductive coupling of coils 50, 51, 52, and wire 53 to the point B and thence to the antenna 1 without affecting the receiving audion and the receivers 15. This figure also shows the grid and plate circuits interchanged in the receiving audion, which makes no difference in the results obtained with this invention, and is equally applicable to Figure 1.

From the foregoing description, it will be understood that the method of synchronous operation by transition coupling, and the circuits herein selected as examples, are of decided advantage in radio communication, not only in cutting down interference, but in increasing the range with a given power, or requiring less power for a given range. Portable outfits embodying this invention have extremely small dimensions and light weight and have many advantages for military and field work, as where quick communication may be desired between moving outposts and a central station.

What is claimed, is:

1. A radio telephone system having at a station radiating and collecting means, a single means for producing oscillations in said radiating means and amplifying collected oscillations, means for detecting the collected oscillations, and means for varying the radiated oscillations by voice modulation, said oscillation producing means being continuously in action.

2. A radio telephone system having at a station a single radiating and collecting element, a single means for producing oscillations in said radiating means and amplifying collected oscillations, means for detecting the collected oscillations, and means for varying the radiated oscillations by voice modulation, said oscillation producing means being continuously in action.

3. A radio telephone system employing at each of two stations an audion generating outgoing oscillations to be received and amplified by the other audion and receiving and amplifying incoming oscillations from the other station, and sending and receiving means at each station operable at will with the same circuit adjustments.

4. A radio telephone system employing at each of two stations an audion generating outgoing oscillations to be received and amplified by the other audion and receiving and amplifying incoming oscillations from the other station, each audion comprising a heated element, and two cold elements so connected in their circuits as to generate oscillations of relatively large power without substantially impairing the detection of incoming oscillations, and sending and receiving means at each station operable at will with the same circuit adjustments.

5. A radio communicating system having at a station a single radiating and collecting element, an audion for producing oscillations in said radiating element and amplifying collected oscillations, the grid of said audion being conductively connected to the filament through circuit means for adjusting its average potential, means for detecting the collected oscillations, and means for varying the radiated oscillations to transmit intelligence.

6. A radio communicating system having at a station a single radiating and collecting element, an audion for producing oscillations in said radiating element and amplifying collected oscillations, the grid of said audion being conductively connected to the filament through circuit means of low audio frequency impedance for adjusting its average potential, means for detecting the collected oscillations, and means for varying the radiated oscillations to transmit intelligence.

7. A radio communicating system having at a station a single radiating and collecting element, an audion for producing oscillations in said radiating element and amplifying collected oscillations, the grid of said audion being conductively connected to the filament through circuit means for maintaining the average potential of the grid negative and for adjusting said potential, means for detecting the collected oscillations, and means for varying the radiated oscillations to transmit intelligence.

8. A radio communication system having at a station a single radiating and collecting element, an audion for producing oscillations in said radiating element and amplifying collected oscillations, the grid of said audion being conductively connected to the

filament through a battery for maintaining the average potential of the grid negative and a potentiometer for finely adjusting said potential, means for detecting the collected oscillations, and means for varying the radiated oscillations to transmit intelligence.

9. The method of attaining synchronism between a free electric oscillation produced in one circuit by a source of continuous electric oscillations and a forced oscillation impressed on a second circuit, which comprises tuning said circuits to the forced oscillation and coupling said circuits in such manner that the coefficient of coupling is substantially equal to the power factor of the second circuit.

10. Apparatus for producing or amplifying electric oscillations comprising a device capable of producing electric oscillations, a circuit in which oscillations are generated by said device, and a second circuit in tune with the first circuit and coupled therewith in such manner that the coefficient of coupling is approximately equal to the power factor of the second circuit.

11. Apparatus for producing or amplifying electric oscillations comprising a device capable of producing electric oscillations, a local circuit in which oscillations are generated by said device, and an antenna circuit in tune with the local circuit and coupled therewith in such manner that the coefficient of coupling is approximately equal to the power factor of the antenna circuit.

12. Apparatus for producing or amplifying electric oscillations comprising an audion capable of producing electric oscillations, a local circuit in which oscillations are generated by the audion, an antenna circuit coupled with the local circuit in such manner that the coefficient of coupling is approximately equal to the power factor of the antenna circuit, and means for varying the natural frequency of these two circuits while keeping in tune with each other.

13. Apparatus for relaying electric impulses comprising a local circuit, means for impressing oscillations thereon, and a tuned antenna circuit coupled to said local circuit in such manner that the coefficient of coupling is approximately equal to the power factor of the antenna circuit.

14. Apparatus for radiotelephone receiving comprising a tuned receiving circuit containing an oscillating audion tuned in synchronism with the incoming signal, said circuit being coupled to the antenna circuit in such manner that the coefficient of coupling substantially equals the power factor of the antenna circuit, and a telephone receiver in the circuit of the audion.

15. Apparatus for radiotelephone receiving comprising a tuned receiving circuit containing an oscillating audion tuned in synchronism with the incoming signal, said circuit being coupled to the antenna circuit in such manner that the coefficient of coupling substantially equals the power factor of the antenna circuit, and a telephone receiver in the plate circuit of the audion.

16. Apparatus for radiotelephone receiving comprising a tuned receiving circuit containing an oscillating audion having a hot and two cold electrodes, an antenna circuit coupled to said receiving circuit in such manner that the coefficient of coupling substantially equals the power factor of the antenna circuit, a telephone receiver in the circuit of one of said cold electrodes, and means for controlling the strength of oscillation.

17. Apparatus for radiotelephone receiving comprising a tuned receiving circuit containing an oscillating audion having a hot and two cold electrodes, an antenna circuit coupled to the receiving circuit in such manner that the coefficient of coupling substantially equals the power factor of the antenna circuit, a telephone receiver in the circuit of one of said cold electrodes, and a variable coupling between the circuits of said cold electrodes for controlling the strength of oscillation.

18. Apparatus for radiotelephone receiving and sending comprising a tuned circuit containing an oscillating audion having a hot and two cold electrodes, an antenna circuit coupled to said local circuit in such manner that the coefficient of coupling substantially equals the power factor of the antenna circuit, a telephone receiver connected in circuit with one of said cold electrodes, and a telephone transmitter connected in circuit with the other cold electrode.

19. Apparatus for radio receiving and sending with the same adjustment comprising an antenna circuit, a locally oscillating circuit coupled thereto containing a single evacuated vessel having a hot and two cold electrodes, the circuit of one of said cold electrodes oscillating in synchronism with said antenna circuit and containing a receiver, and the circuit of the other cold electrode containing means for varying the oscillations radiated by the antenna to transmit intelligence.

20. Apparatus for radio receiving and sending comprising a tuned circuit containing an oscillating audion having a hot and two cold electrodes, an antenna circuit coupled to said local circuit in such manner that the coefficient of coupling substantially equals the power factor of the antenna circuit, a receiver connected to one of said cold electrodes, a transmitter connected to the other of said cold electrode, and means for varying the strength of oscillation.

21. Apparatus for radio receiving and sending comprising a tuned circuit containing an oscillating audion having a hot and two cold electrodes, a tuned antenna circuit

coupled to said local circuit in such manner that the coefficient of coupling substantially equals the power factor of the antenna circuit, a receiver connected to one of said cold electrodes, a transmitter connected to the other of said cold electrodes, and a variable coupling between the circuits of said cold electrodes for varying the strength of oscillation.

22. Apparatus for radiotelephone voice receiving comprising an antenna circuit receiving incoming signals, a locally oscillating receiving circuit coupled thereto in such manner that the coefficient of coupling is substantially equal to the power factor of the antenna circuit and oscillating in synchronism with the incoming signal, and a telephone receiver connected to said oscillating receiving circuit.

23. Apparatus for radio communication comprising an antenna circuit, an evacuated vessel having a hot and two cold electrodes, an oscillating tuned local circuit containing one of said cold electrodes and coupled to said antenna circuit in such manner that the coefficient of coupling is substantially equal to the power factor of the antenna circuit, receiving means and means for varying the radiated oscillations in sending.

24. In radiotelephony, means for radiating and collecting energy in the form of electromagnetic waves, a single means for producing oscillations in said radiating means in synchronism with the collected radiations and amplifying the same, a telephone for receiving the amplified synchronous received oscillations, and a telephone transmitter for varying the radiated oscillations whereby to receive and transmit speech in duplex without change in circuit adjustments.

25. In a station for radio telephony the combination of a source of continuous oscillation, means modulating said oscillation by voice control for transmission, means combining said oscillation with an incoming voice modulated signal oscillation, and means responsive to the combined oscillations for detection.

Signed at Hoboken, in the county of Hudson and State of New Jersey, this twenty-seventh day of October, A. D. 1917.

LOUIS ALAN HAZELTINE.