METHOD OF AND APPARATUS FOR RECEIVING HIGH FREQUENCY OSCILLATIONS

Filed Feb. 8, 1926 3 Sheets-Sheet 1

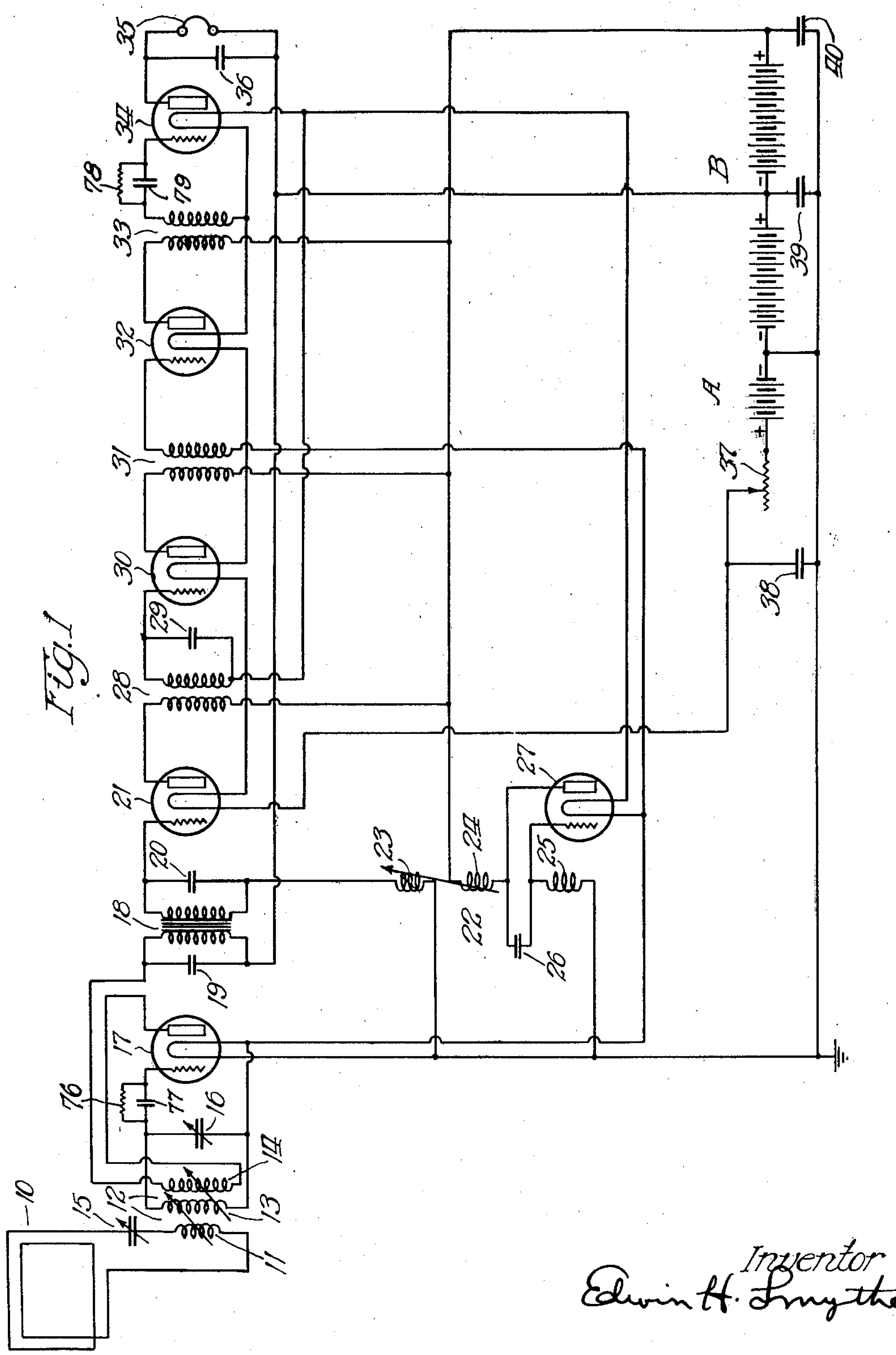

Fig. 1

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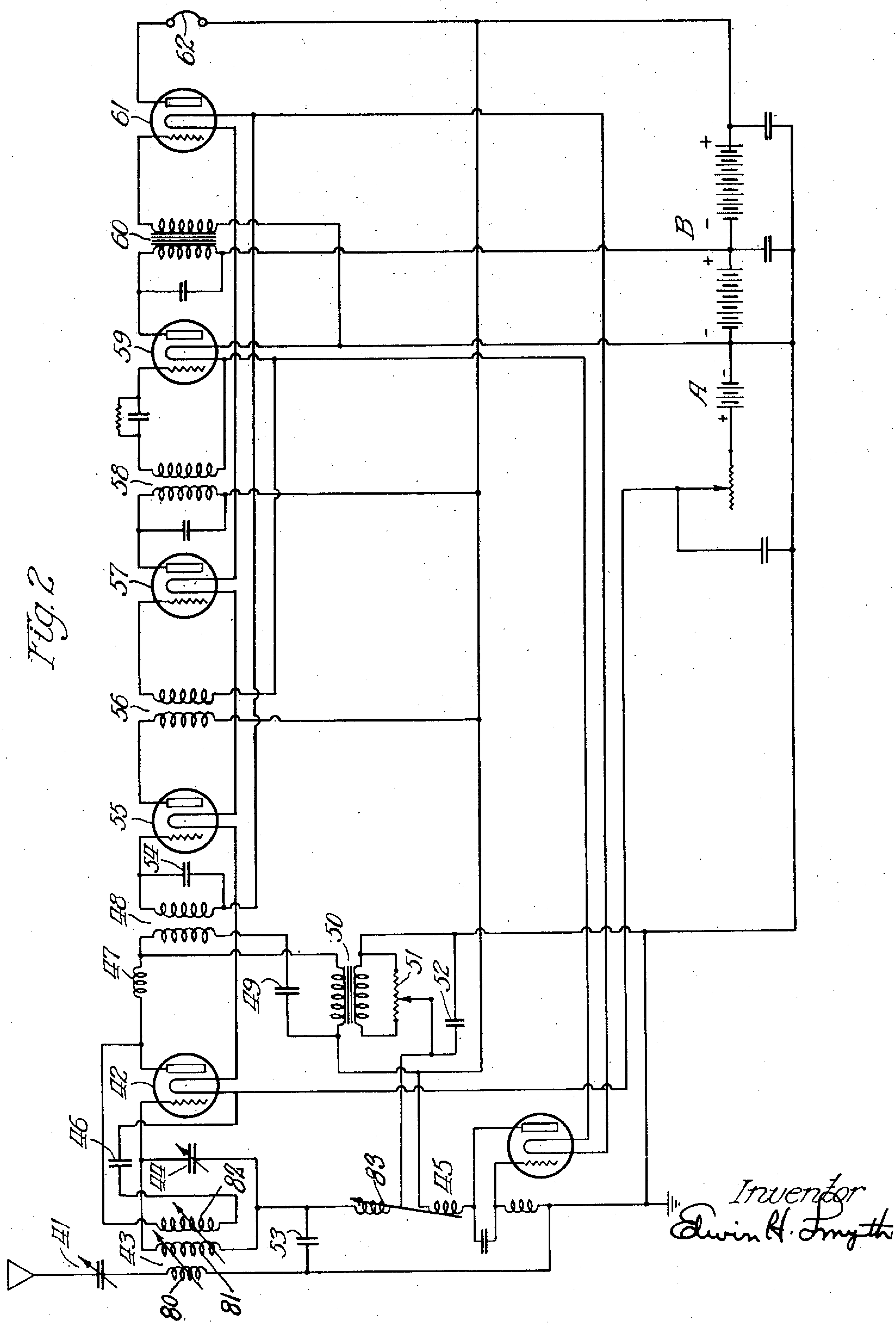

Fig. 2

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Fig. 3

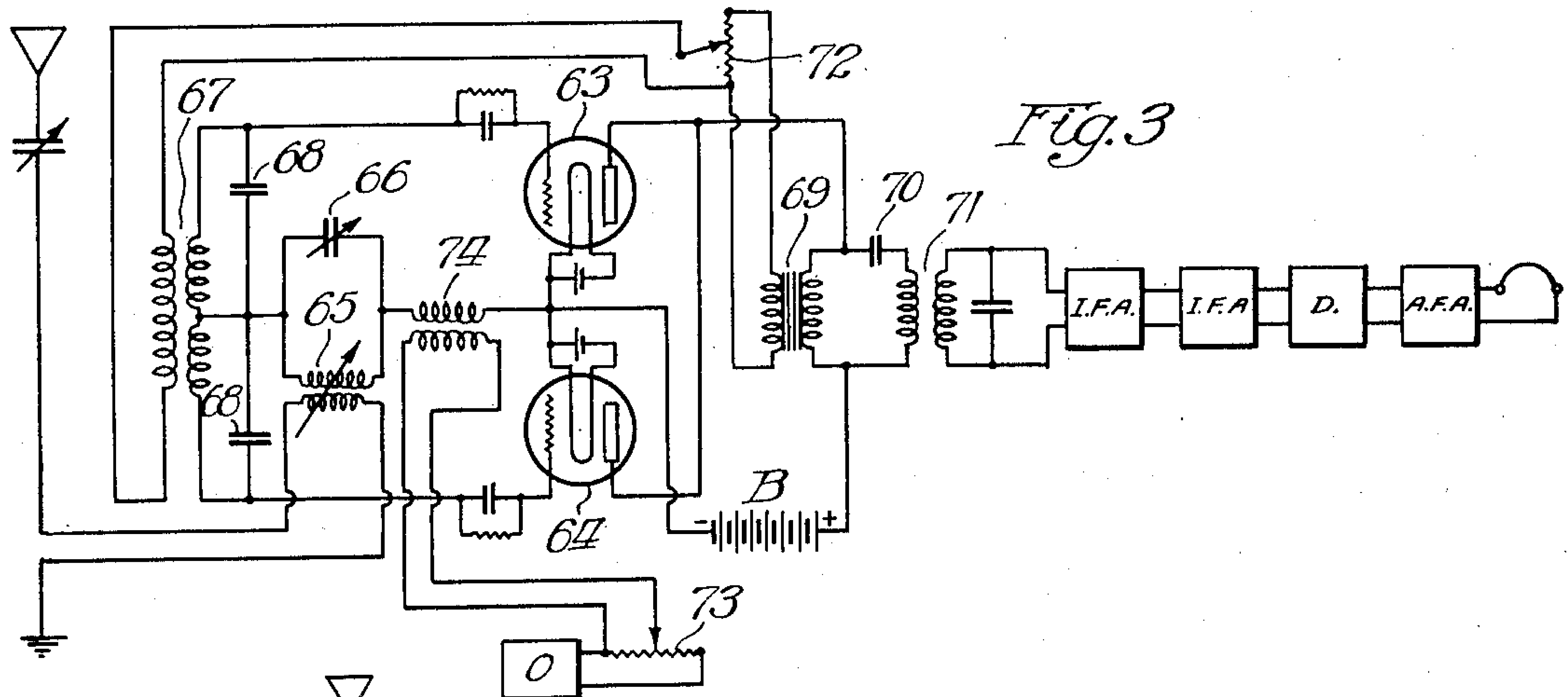


Fig. 4

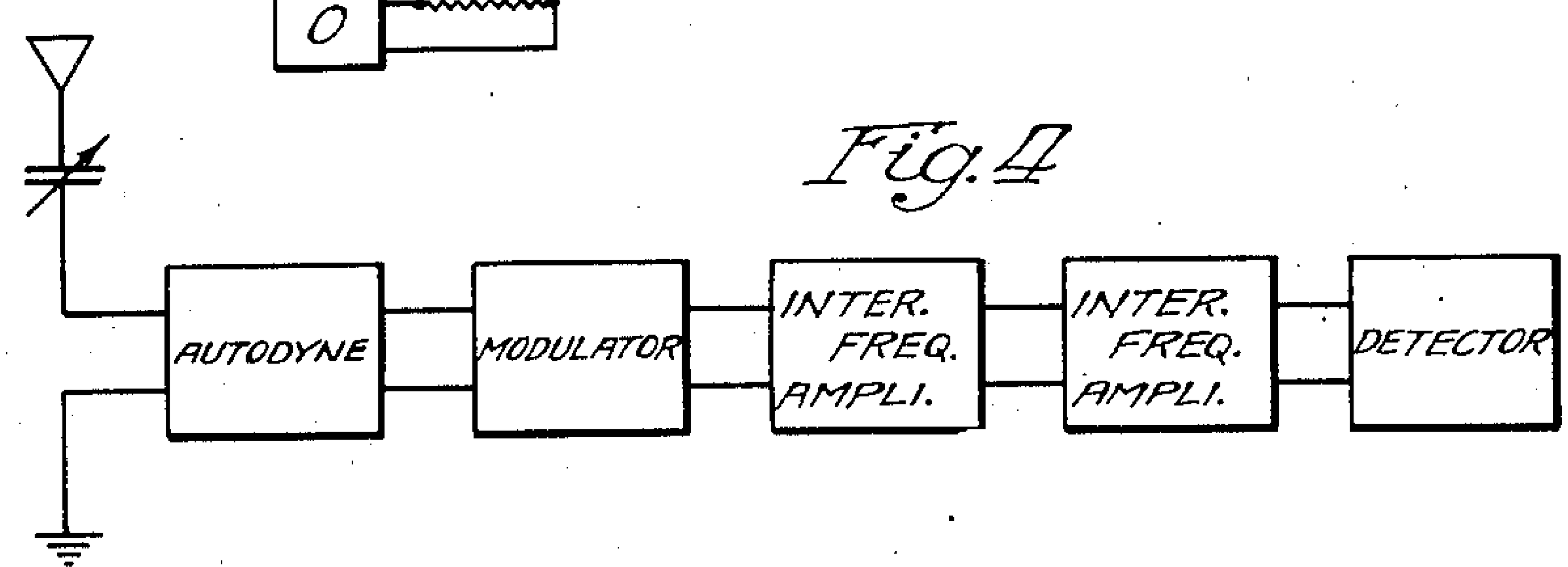


Fig. 5

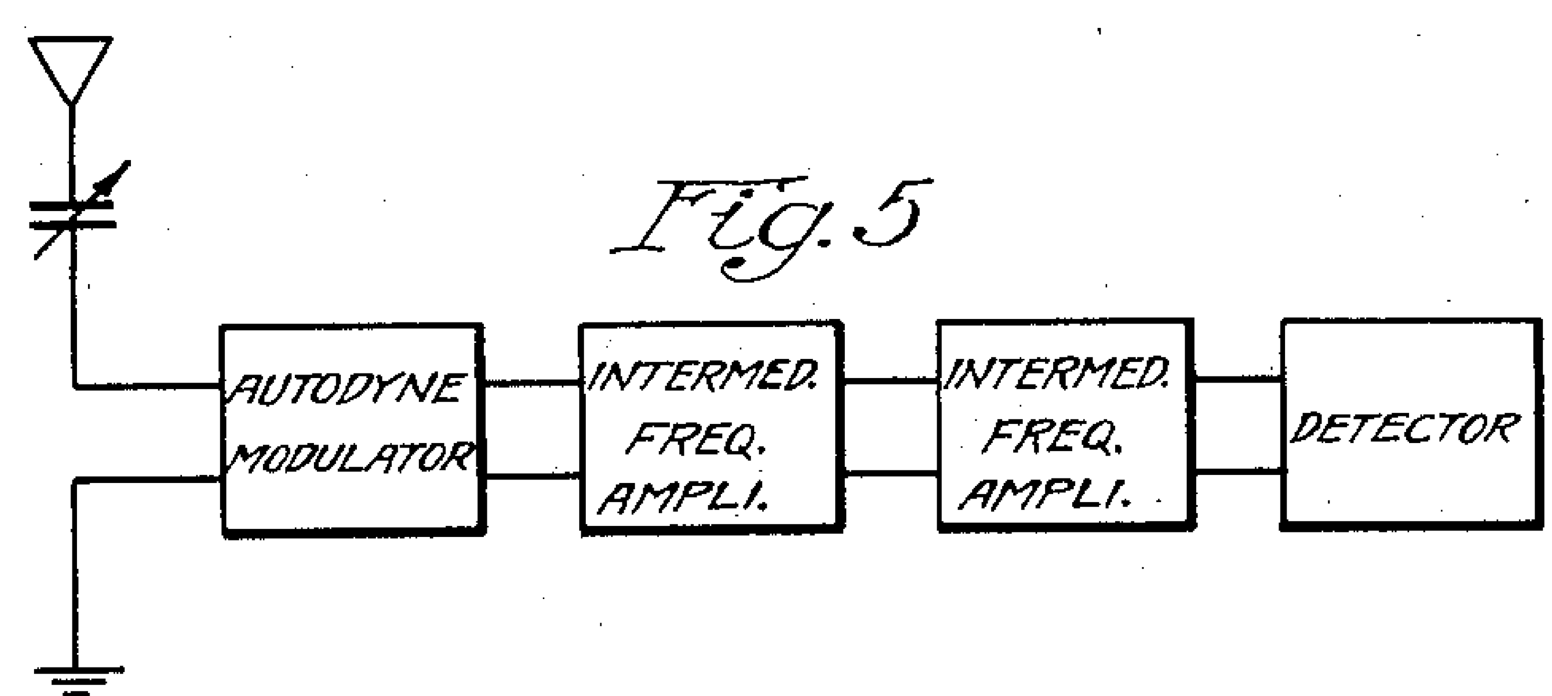
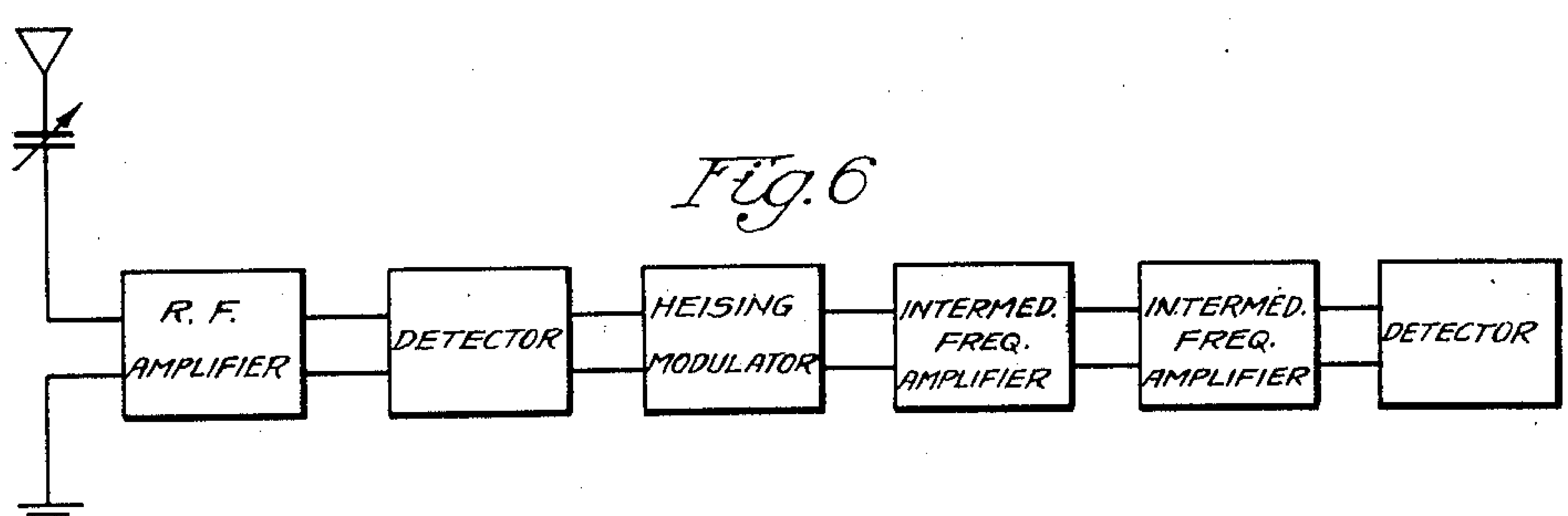


Fig. 6



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UNITED STATES PATENT OFFICE

1,924,628

METHOD OF AND APPARATUS FOR RECEIVING HIGH FREQUENCY OSCILLATIONS

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Application February 8, 1926. Serial No. 86,811

10 Claims. (Cl. 250—20)

This invention relates to a method of and apparatus for receiving high frequency oscillations such as are employed in connection with radio telephony and radio telegraphy, and particularly in connection with systems of this sort employing continuous or sustained oscillations. In such systems it is customary to superpose upon the continuous oscillations radiated from the transmitting station, modulations produced by the operation of a telephone transmitter or by a telegraph key. The modulated oscillations which reach the receiving station are greatly attenuated, and in order that they may be made effective to bring about the operation of the responsive or signal indicating devices at the receiving station it is ordinarily necessary that their energy shall be amplified.

There are inherent difficulties attendant upon the amplification of the received energy, either before or after the modulating component of the high frequency oscillations is separated out by the usual detecting or rectifying process. When the amplification is effected at the high frequency of the received oscillations a practical limit is imposed upon it by the inherent couplings and reactions which exist between different parts of the circuits and apparatus, these effects being greatly augmented at the high frequencies which are ordinarily employed in radio communication. When the amplification is effected at frequencies such as are ordinarily used in the modulation of the high frequency radiated wave, that is, at the so-called audio frequencies, not only are the detected modulating frequencies of the received wave amplified, but also such locally produced disturbances as "tube noises" and the like, so that the practical limit of audio frequency amplification is speedily reached.

In systems of reception based upon the heterodyne and superheterodyne principles, amplification is effected at an intermediate frequency, this intermediate frequency being produced by interaction between the received high frequency wave and a locally generated wave that is also a high frequency wave differing in frequency from the received wave by an amount equal to the frequency at which the intermediate amplification is to be effected. The high frequency of this locally generated wave is such as to make it a good radiator of energy; and to avoid such radiation of the energy of the locally generated wave, which may objectionably affect the operation of neighboring receiving sets, it is customary to restrict the use of the heterodyne receiver to sets employing loop antennæ for the interception of the received high frequency waves. Furthermore, the heterodyne principle has the objectionable feature of complicating the station selecting operation due to the fact that each station appears at two positions on the dial of the local oscillator tuning condenser. In the method and organization of the present invention all of the advantages of amplification at a readily amplifiable intermediate frequency are retained, while at the same time the complications due to the appearance of each station at two points on the tuning dial are avoided, and the use of an open or ordinary antenna is made possible by the employment of a locally generated oscillation having a frequency such that it may be communicated to the antenna without giving rise to disturbance in neighboring receiving sets.

Generally stated, the present invention contemplates the selective reception of the modulated high frequency oscillations, the rectification of the selected oscillations to separate out the modulating component, the raising of the separated component by modulation with a locally generated wave to an intermediate frequency having a value that permits ready amplification, the amplifying of the modulated intermediate frequency wave to such a degree as may be desired, and the separation of the modulating component from the amplified intermediate frequency wave by rectification or detection. Furthermore, the present invention relates to the provision of an improved organization whereby the various steps in the above recited process of reception and amplification may be effectively carried out, and wherein certain of the parts or units of the organization are employed to effect two or more of the steps in the sequence of operation.

The invention will be explained in connection with the accompanying drawings, which illustrate certain preferred and typical organizations whereby the desired mode of operation may be realized. In the representative circuit organizations illustrated in the accompanying drawings, Fig. 1 shows diagrammatically a radio receiving system wherein the received high frequency modulated wave is intercepted by a loop antenna, demodulated, the modulating component combined with a locally generated intermediate frequency wave, amplified at the intermediate frequency, and detected to produce the signal indication; Fig. 2 shows a modification in which an open or ordinary antenna is employed instead of a loop, and in which the demodulation of the received high frequency oscillations and the subsequent combining of the modulating components and the locally generated intermediate frequency oscillations are effected in a single modulating device; Fig. 3 shows a further modification in which an ordinary antenna is employed for intercepting the received high frequency waves, and the first detection of the modulating components and their recombination with the locally generated intermediate frequencies are accomplished in a modulating device of a type which is adapted to prevent reamplification of certain of the frequencies that are applied to it; and Figs. 4, 5 and 6 indicate in skeleton form further modifications in the application of the principles of the invention.

Referring to the organization illustrated in Fig. 1, the modulated high frequency oscillations from the distant station are received upon the loop antenna 10, which includes in its circuit the antenna winding 11 of the coupler or radio frequency transformer 12, and also the variable antenna tuning condenser 15. The radio frequency transformer 12 also includes the secondary winding 13 and the feed back winding or tickler coil 14, and the coupling relation between the three coils of the radio frequency transformer 12 is preferably made variable as indicated. Preferably the antenna coil 11 consists of only a few turns and is loosely coupled with the secondary coil or winding 13. The terminals of the secondary coil 13 are connected with the terminals of the variable tuning condenser 16, and one of the terminals of this resonant tuning circuit is connected with the grid of the thermionic detector tube 17 by way of the usual grid leak 76 and condenser 77, while the other terminal is connected with the positive terminal of the filament of the detector tube 17.

The plate of detector tube 17 is connected with the intermediate positive pole of the B battery by way of the tickler coil 14, and the primary winding of audio frequency transformer 18 shunted by a high frequency by-pass condenser 19. The secondary winding of the audio frequency transformer 18 is shunted by an intermediate frequency by-pass condenser 20, and one terminal is connected with the grid of the modulator tube 21 while the other terminal is connected through the pick up coil 23 of intermediate frequency oscillator 22 to the negative pole of the A battery. The grid of the intermediate frequency oscillator tube 27 is connected through winding 25 with the negative pole of the A battery while the plate of the oscillator tube is connected through winding 24 with the high potential positive pole of the B battery. The oscillator condenser 26 is connected between the terminals of the windings 24 and 25 that extend to the plate and grid respectively of oscillator tube 27, and the oscillatory circuit thus constituted is inductively coupled with the pick up coil 23, the coupling being made variable so that the amount of energy communicated to its associated circuit by the pick up coil 23 may be regulated and controlled.

The plate of modulator tube 21 is connected with the high potential positive pole of the B battery by way of the primary winding of intermediate frequency transformer 28, and the secondary winding of transformer 28 has shunted across its terminals a filter condenser 29 which operates to make the intermediate frequency transformer selective of the intermediate frequency and its modulating side bands. One terminal of this selective circuit is connected with the grid of intermediate frequency amplifier tube 30 while the other terminal is connected with the series filament circuit of the tubes at such a point as to give the grid of intermediate frequency amplifier tube 30 the proper potential with respect to the associated filament.

The plate of intermediate frequency amplifier tube 30 is connected with the high potential positive pole of the B battery by way of the primary winding of intermediate frequency transformer 31, and the secondary winding is included in a circuit which extends from the grid of intermediate frequency amplifier tube 32 to a point on the series filament circuit which gives the grid of tube 32 its proper operating potential. The plate of tube 32 is connected with the high potential positive pole of the B battery through the primary winding of intermediate frequency transformer 33, and the secondary winding of this transformer has one terminal connected with the grid of detector tube 34 through the usual grid leak 78 and condenser 79, while the other terminal of the secondary winding of the transformer 33 is connected to the positive terminal of the filament of the associated detector tube 34. The plate of detector tube 34 is connected with the intermediate positive pole of the B battery through the head telephones 35 or other receiving device, while the condenser 36 serves to by-pass around the telephone receiver the high frequencies appearing in the plate circuit of detector tube 34.

In the particular embodiment of the invention illustrated in Fig. 1 the filaments of the tubes are connected in series across the terminals of the A battery, with a rheostat 37 included for controlling the current flow in the series filament circuit. This series arrangement of the tube filaments, which is one that is known in the art, affords a convenient means for securing the proper potential relation between each filament and the grid of the corresponding tube. The condensers 38, 39 and 40 are condensers of relatively large capacity for reducing the impedance to the flow of alternating or oscillatory currents in the paths that are common to various parts of the circuit organization.

The operation of the organization illustrated in Fig. 1 is as follows:

The received modulated high frequency waves cause the flow of corresponding oscillatory currents in the circuit of the loop antenna 10, the loop circuit being tuned to the frequency of the particular station desired by the variable tuning condenser 15, and the energy of the selected high frequency wave being transferred to the grid circuit of the detector tube 17 by the inductive coupling existing between the primary winding 11 and secondary winding 13 of the coupling coil 12. Additional selectivity with respect to the frequency that is to be received is obtained by means of the variable condenser 16 of the resonant grid circuit. The detector 17 operates in the usual way to detect and separate out the modulating component of the received high frequency wave, this low frequency modulating component flowing through the primary winding of audio frequency transformer 18 while the amplified modulated high frequency oscillations flow in the circuit that includes the tickler coil 14 and the high frequency by-pass 19. By properly adjusting the coupling of the tickler coil 14 with the grid coil 13, the action is adjusted to secure maximum regenerative effect with a corresponding amplification of the audio frequency modulating components that flow in the primary winding of audio frequency transformer 18.

The audio frequency components stepped up in potential appear in the secondary winding of the audio frequency transformer 18 and are applied to the grid of modulator tube 21 in combination with the intermediate frequency oscillations generated by the oscillator 22. The constants of the oscillator 22 may be so adjusted as to produce a frequency that is above audibility and is low enough to avoid the difficulties incident to the amplification of such frequencies as lie in the ordinary radio frequency range. A frequency of, say, 50,000 cycles per second is a convenient frequency to employ, although other frequencies lying within the range of the superaudible and subradio frequencies may be used.

As a result of the modulating action of tube 21, there appears in the output circuit of the tube the intermediate frequency of the oscillator with its upper and lower side bands resulting from the intermodulation with the audio frequencies, and also a component consisting of amplified and unmodulated intermediate frequency. The proportion of the modulated and unmodulated intermediate frequency components may be regulated to give the best results by an adjustment of the oscillator pick up coil 23.

The intermediate frequency oscillation and its accompanying modulated wave are communicated through the intermediate frequency transformer 28 to the intermediate frequency amplifier tube 30 where amplification takes place, and thence through the intermediate transformer 31 to the intermediate frequency amplifier tube 32 where there is further amplification, the amplified intermediate frequency oscillations finally being communicated through the intermediate frequency transformer 33 to the input circuit of detector tube 34. The characteristics of the transformers 28, 31 and 33 and the filter condenser 29 are so chosen as best to adapt the circuit in which they are included for the transmission of a frequency band based upon the intermediate frequency which the oscillator 22 has been adjusted to generate. In the detector tube 34 the intermediate frequency with its accompanying modulating side bands are demodulated to produce in the output circuit of the detector tube the audio or modulating frequencies, the high frequency products of demodulation being by-passed by way of the condenser 36.

The intermediate frequency oscillator and also the devices included in the stages of intermediate frequency amplification are adjusted for the production and transmission of the same intermediate frequency, and when the rate of oscillation of the intermediate frequency has been chosen the setting of the oscillator for the production of this frequency is maintained, and is not varied for each particular high frequency modulated wave that is being received. The adjustment of the receiving system is thus simpler than in the case of a superheterodyne receiver.

Referring now to the modification illustrated in Fig. 2, the antenna is tuned to the desired frequency by the variable condenser 41, and the high frequency oscillatory current flowing in the antenna circuit sets up a corresponding flow in the grid circuit of tube 42 through the medium of the coupling existing between the antenna coil 80 and the grid coil 81 of transformer 43. This coupling is made variable, as indicated, and the grid coil is shunted by variable condenser 44 in order that the grid circuit may be made resonant to the same frequency to which the antenna circuit has been made selective.

The tube 42 acts as a regenerative amplifying and detecting tube, and also operates to modulate together the detected low or audio frequency components of the received radio frequency wave and an intermediate frequency generated by the intermediate frequency oscillator 45. The regenerative action of the tube 42 with respect to the modulated radio frequency wave is by virtue of the feed back connection from the plate circuit of the tube by way of the tickler coil 82 of transformer 43 and condenser 46 to the filament of the tube. The condenser 46 is of such capacity that the path in which it is included offers low impedance to the passage of radio frequency currents and high impedance to the passage of intermediate frequency and audio frequency currents. The radio frequency currents are prevented from being diverted into other branches of the plate circuit by the interposition of the radio frequency choke coil 47. The coupling of the tickler coil with the grid circuit winding of transformer 43 is made variable, as indicated.

In consequence of the detecting action of tube 42, the audio frequency components of the modulated high frequency wave appear in the plate circuit of the tube. These audio frequency currents pass freely through the radio frequency choke coil 47, are diverted from the branch including the primary winding of intermediate frequency transformer 48 and condenser 49, on account of the constants of this path being such as to make the path of high impedance to audio frequency currents and of low impedance to intermediate frequency currents, and pass through the primary winding of audio frequency transformer 50. The corresponding audio frequency currents which appear in the secondary winding of transformer 50 are communicated to a circuit including a potentiometer 51 and a pick up coil 83 of the intermediate frequency oscillator 45, this circuit also including the secondary winding 81 of transformer 43 and tuning condenser 44, and terminating at the grid of tube 42. Consequently the detected audio frequency current and the intermediate frequency carrier are applied to the input circuit of tube 42, are modulated together and the products of modulation appear in the output circuit of the tube. By adjusting the potentiometer 51 and the variable pick up coil 83 of oscillator 45 the amounts of audio frequency and intermediate frequency current applied to the grid circuit may be correctly proportioned. The condenser 52 acts as a by-pass for the intermediate frequencies around the impedance of the secondary winding of audio frequency transformer 50 and its potentiometer 51, and the condenser 53 serves as a by-pass for the radio frequency current around the impedance of that part of the grid circuit including the pick up coil 83 of oscillator 45 and the secondary winding and potentiometer of audio frequency transformer 50.

The intermediate frequency oscillations with their audio frequency side bands that now appear in the output circuit of tube 42 pass through the radio frequency choke coil 47 and the intermediate frequency low impedance path including the primary winding of intermediate frequency transformer 48 and condenser 49, being diverted from the path including the primary winding of audio frequency transformer 50 on account of its high impedance to intermediate frequency oscillations. There is also present in the output circuit of tube 42 reamplified audio frequency currents; but these currents are prevented from "singing" around the circuit by the proper adjustment of potentiometer 51 and the oscillator pick up coil.

The intermediate frequency oscillations modulated with the audio frequency side bands are repeated into the secondary winding of intermediate frequency transformer 43, which is provided with a filter condenser 54 to make the circuit selective of the particular band of frequencies that it is desired to transmit. Thence the modulated intermediate frequency oscillations pass through the intermediate frequency amplifying stages including amplifying tubes 55 and 57 and intermediate frequency transformers 56 and 58 to the circuits of detector tube 59 where the audio frequency components of the modulated intermediate frequency oscillations are detected and communicated to the telephone or receiving device 62 after passing through the audio frequency transformer 60 and audio frequency amplifying tube 61. In other respects the circuit of Fig. 2 corresponds with that of Fig. 1 and need not be described in detail.

In the modification illustrated in Fig. 3 use is made of the principles of the balanced modulator or detector, the type employed being generally that disclosed in United States patent to Hartley No. 1,419,562 issued June 13, 1922. The reflex connections of this balanced modulator are also generally of the nature of those disclosed in the application of Farrington and Smythe, Serial No. 654,104 filed July 27, 1923, altered in such a way as to provide for the complete demodulation of the received modulated radio frequency wave and the remodulation of the audio frequency components into an intermediate frequency carrier in the same modulating device. In the modified form of the invention illustrated in Fig. 3 the particular modulated high frequency oscillations that it is desired to receive are selected and applied to the common branch of the input circuits of modulator tubes 63 and 64 through the medium of the input transformer 65, the secondary circuit of which is tuned by the variable condenser 66. The modulated high frequency oscillations are applied in the same phase to the grids of the modulator tubes 63 and 64 by way of the two input circuits each of which includes one of the two secondary windings of the transformer 67 shunted by their respective balancing and by-pass condensers 68, and each of which includes the customary grid leak and condenser; or, if desired, the modulating action of the balanced tubes may be secured by maintaining the grids of the tubes at the proper negative potential with respect to their filaments by means of a C battery or otherwise.

As both the tubes 63 and 64 are operating in the same phase, the detected audio frequency components of the modulated wave are additive in the common output circuit of the tubes. These audio frequency components flow through the primary winding of audio frequency transformer 69, being diverted from the parallel branch including condenser 70 and primary winding of intermediate frequency transformer 71 on account of the high impedance of this branch to audio frequency currents, and are reproduced in the secondary winding of the audio frequency transformer 69. From the secondary winding the audio frequency currents flow to the primary winding of transformer 67, being controlled in their magnitude by the potentiometer 72. The secondary winding of transformer 67 is so connected in the input circuit of the balanced modulator tube 63 and 64 that the repeated audio frequency currents are applied in opposite phase to the grids of the two tubes. At the same time intermediate frequency oscillations generated by the intermediate frequency oscillator 0 and controlled in magnitude by the potentiometer 73 are applied to the common branch of the divided input circuit by way of the transformer 74. As a result the products of intermodulation between the audio frequency currents applied through transformer 67 and the intermediate frequency current appear additively in the common output circuit of the two tubes, while the amplified audio frequencies applied through transformer 67, appearing in opposite phase in the output circuit of the two tubes, are completely neutralized and suppressed. The two tubes operating in the same phase with respect to the intermediate carrier frequency, this frequency also appears in the common output circuit of the tubes and accompanies the audio frequency side bands of the intermediate frequency wave through the intermediate frequency amplifiers that are represented by the squares marked IFA. The intermediate frequency and its side bands are demodulated in the detector D, and after amplification of the audio frequencies in the audio frequency amplifier AFA, these frequencies are passed to the receiving apparatus.

The invention herein disclosed may be practiced in a variety of forms, and other of these forms are indicated in skeleton in Figs. 4, 5 and 6. In the form illustrated in Fig. 4, the received high frequency modulated wave is applied to the input circuit of a self-heterodyne or autodyne receiver, which, however, is adjusted to continuously generate oscillations of a relatively low or intermediate frequency. Consequently there are present in the output circuit of the autodyne these continuous intermediate frequencies together with the audio frequencies resulting from the demodulation of the received high frequency wave in the modulating oscillator. These frequencies are selected and passed to the modulator, which is shown next in the series of designated squares, and in this modulator the audio frequencies and the intermediate frequency are modulated together. After this the intermediate frequency with its audio frequency side bands are passed through the two intermediate frequency amplifiers that are indicated, to the detector, where final demodulation takes place.

In the form illustrated in Fig. 5 the autodyne is reflexed to act also as a modulator to recombine the intermediate frequencies which it generates with the audio frequencies which are set free from the modulated high frequency wave by virtue of the detecting properties of the autodyne, the recombined and intermodulated intermediate and audio frequencies appearing in the output circuit and being passed through two stages of intermediate frequency amplification to the detector.

In the modification illustrated in Fig. 6, one stage of radio frequency amplification precedes the detection of the audio frequency components of the received high frequency oscillations. From the detector the audio frequencies, either with or without further amplification pass into the input circuit of a modulator of the well-known Heising type where they are modulated with a carrier wave of intermediate frequency within the readily amplifiable range. After modulation, the modulated intermediate frequencies pass through one or more stages of intermediate frequency amplification to the detector.

The present invention, as described above, makes it possible to translate received modulated radio frequency waves in a radio frequency channel into readily amplifiable intermediate frequency waves in an intermediate frequency channel and to prevent undesired reactions between waves in the radio frequency and intermediate frequency channels by interposing a low frequency channel therebetween. Difficulties experienced in superheterodyne systems from reactions between the high frequency and intermediate frequency circuits are thus avoided. Further advantages of the present invention are that the frequency of the local oscillations may be easily adjusted without critical operations and the initial adjustment of the oscillator frequency serves for all received wave frequencies. The invention also provides a method different from that of the superheterodyne system for attaining advantageous results heretofore obtainable only with the superheterodyne system.

It will be understood that in the various modifications of the invention illustrated and described, the amount of amplification at the high frequency, intermediate frequency and low or audio frequency levels may be provided as desired to produce the best operation of the system under varying conditions with respect to the nature and amount of the received energy and the nature and amount of energy required to be made available in the audio frequency responsive device.

The invention claimed is:

1. The method of amplifying high frequency electrical wave energy which comprises translating said high frequency wave energy into low frequency waves, supplying intermediate frequency waves having materially less tendency to radiate than said high frequency waves, modulating said intermediate frequency waves with said low frequency waves, amplifying the resulting modulated intermediate frequency waves, and translating said amplified intermediate frequency waves into low frequency waves of amplified energy.

2. The method of amplifying high frequency electrical wave energy modulated in accordance with low frequency modulating waves, which comprises reproducing said low frequency modulating waves by rectification of said high frequency wave energy, supplying readily amplifiable intermediate frequency waves, modulating said intermediate frequency waves with said low frequency waves, amplifying said modulated intermediate frequency waves, and reproducing said modulating waves with amplified energy by rectification of said amplified intermediate frequency waves.

3. The method of indirectly amplifying the modulating wave with which an incoming modulated high frequency electric wave has been modulated, which comprises reproducing said modulating wave by demodulating said high frequency wave, supplying a readily amplifiable wave of frequency above the audible range, but too low to permit of substantial radiation, modulating said intermediate frequency wave with said reproduced wave, and amplifying said last modulated wave.

4. The method of amplifying received high frequency electrical wave energy and of minimizing the introduction of disturbances, which method comprises producing low frequency waves of amplified energy under the control of said high frequency wave energy for obtaining a part of the desired amplification, supplying intermediate frequency waves, modulating said intermediate frequency waves with said low frequency waves of amplified energy to produce modulated intermediate frequency waves of amplified energy, and amplifying said modulated intermediate frequency waves for obtaining the remaining part of the desired amplification.

5. The method of translating signal wave energy of high frequency into signal waves of intermediate frequency and of preventing undesirable reactions between said signal wave energy of high frequency and said corresponding signal waves of intermediate frequency, said method consisting in translating said signal wave energy of high frequency into signal waves of low frequency before translation into said intermediate frequency waves, and then producing said intermediate frequency waves by translation from said low frequency waves.

6. In a system for receiving high frequency waves, means for translating incoming high frequency waves into low frequency waves, a source of intermediate frequency waves, the frequency of said intermediate frequency waves being so low and said system being so designed that substantially no intermediate frequency waves are radiated, means whereby said low frequency waves modulate said intermediate frequency waves, means for amplifying said modulated intermediate frequency waves, and means for translating the resulting amplified intermediate frequency waves into amplified low frequency waves.

7. In a system for receiving high frequency waves, a modulator, means whereby high frequency waves modulated in accordance with low frequency waves are selectively transmitted to said modulator, a local source of super-audible, non-radiating intermediate frequency waves, said modulator being adapted to demodulate said high frequency waves to reproduce said low frequency waves and to modulate intermediate frequency waves from said source with said reproduced low frequency waves, means for amplifying the resulting modulated intermediate frequency waves, and means for utilizing the resulting amplified intermediate frequency waves.

8. In a radio receiving system, means for selectively receiving audio frequency modulated radio frequency waves, a source of intermediate frequency waves, the frequency of said intermediate frequency waves being so low and said system being so designed that substantially no intermediate frequency waves are radiated, a modulator whereby the selected radio frequency waves are demodulated to reproduce the audio frequency modulating waves and whereby said intermediate frequency waves are modulated with said reproduced audio frequency waves, an amplifier for said modulated intermediate frequency waves, and a demodulator for said amplified intermediate frequency waves for reproducing said audio frequency waves with amplified energy.

9. In a wave receiving system, a thermionic modulating device having input and output circuits, means for impressing a received signal modulated high frequency wave upon said input circuit, a local intermediate frequency wave source, means for impressing upon said input

circuit the wave from said local source together with the detected signals present in said output circuit, a thermionic intermediate frequency amplifier coupled with said modulating device, and a detector coupled with said intermediate frequency amplifier whereby the amplified intermediate frequency waves are demodulated to reproduce amplified signals.

10. A radio receiving system including an antenna adapted effectively to receive modulated high frequency waves, a source of waves of an intermediate frequency below the effective frequency receiving or radiating range of said antenna, means coupled to said antenna for demodulating the received high frequency waves to produce low frequency waves and for modulating waves from said source with said low frequency waves, means for selecting the resulting modulated waves, and means for amplifying the selected waves and demodulating the amplified waves for reproducing said low frequency waves with amplified energy.

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