Nov. 2, 1937. J. G. CHAFFEE 2,097,514

ELECTRON DISCHARGE SYSTEM FOR ULTRASHORT WAVES

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FIG. 2

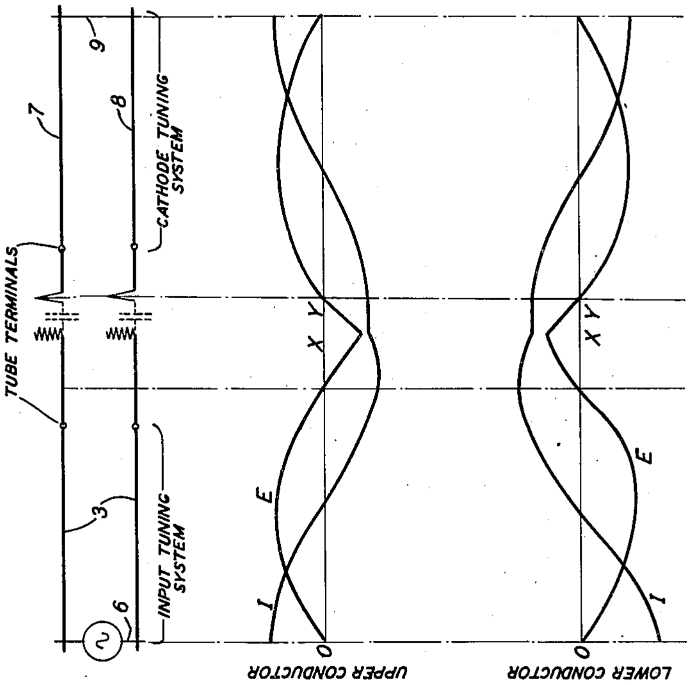


FIG. 1

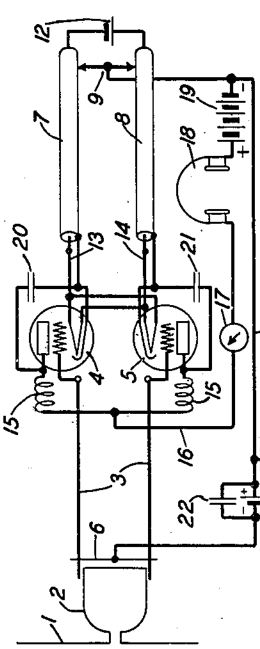
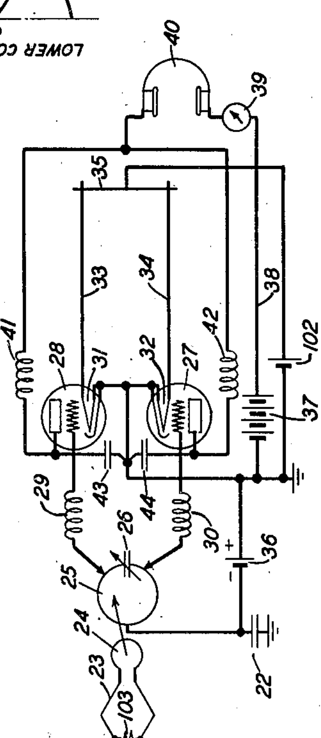


FIG. 3



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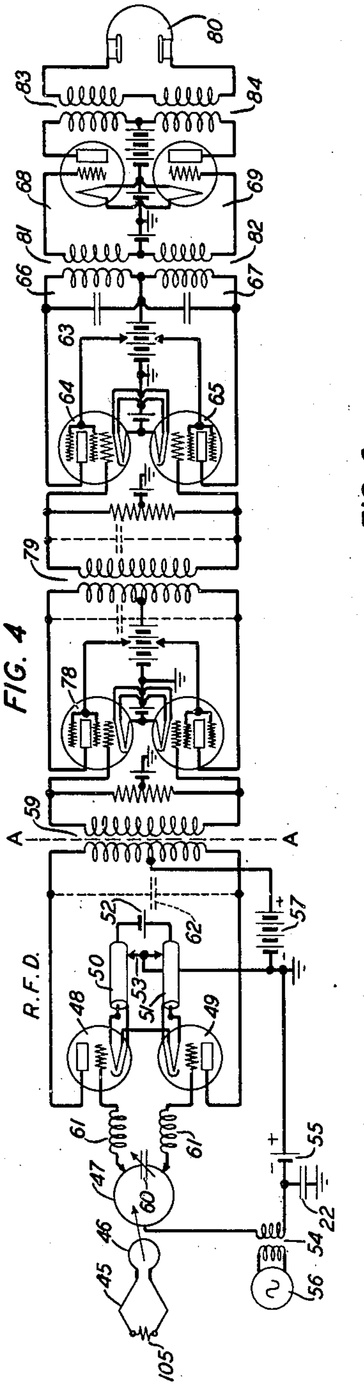

FIG. 4

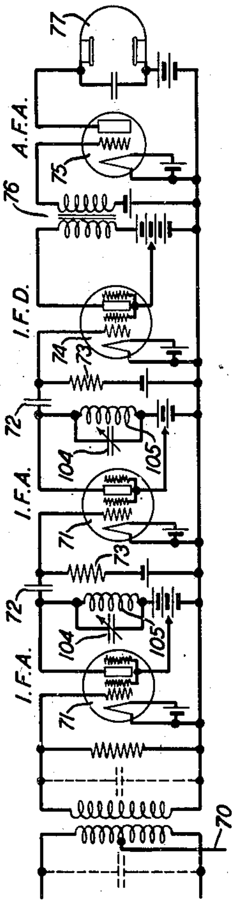

FIG. 6

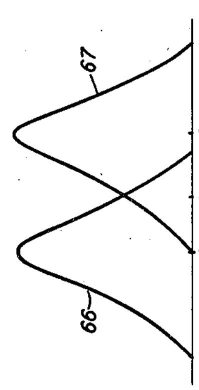

FIG. 5

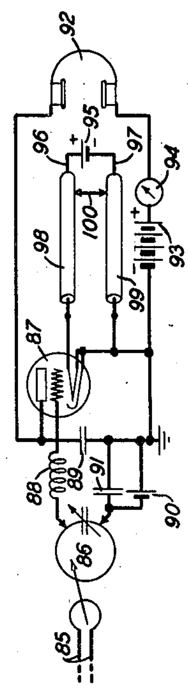

FIG. 7

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ELECTRON DISCHARGE SYSTEM FOR ULTRASHORT WAVES

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Application October 10, 1935, Serial No. 44,321

8 Claims. (Cl. 250—20)

This invention relates to high frequency electronic apparatus and more particularly to electron discharge systems for ultra-short waves.

An object of the invention is to improve the efficiency of electron discharge detectors or amplifiers operating at wave-lengths of the order of 60 centimeters or less, by providing a more effective transfer of driving voltage from the tuned systems associated with the input circuits of these devices to the control elements of the devices.

At the longer wave-lengths in common use, the input impedance of such electron discharge devices is usually very great and they may, therefore, be connected directly to tuned circuits presenting a high anti-resonant impedance without substantially affecting the response of the tuned circuits except in so far as a slight change in tuning may be necessary. Furthermore, such voltage as appears across the input terminals of the electron discharge device is identical with that which actuates the control element of the electron discharge device.

The phenomenon of active grid loss of electron discharge devices operating at high frequencies is considered at page 1018 of an article entitled "The Determination of Dielectric Properties at Very High Frequencies", Aug. 1934 Proceedings of Institute of Radio Engineers, Vol. 22, No. 8. At wave-lengths below about one meter the input impedance of electron discharge devices even when operated so that the grid draws no current becomes comparatively low, due both to the presence of considerable active grid loss and to the decrease in the reactance of the capacities within the structure of the tube itself. As a result, the input impedance may become such that it will exert a very great influence upon the tuning system connected to the input terminals and may seriously reduce both the voltage step-up and the selectivity of the input circuit. Furthermore, the combination of the inductance of the leads within the electron discharge tube and the capacities between the leads assumes sufficient importance at wave-lengths of the order of half a meter so that the actual tube elements become considerably removed, electrically, from the available terminals of the tubes, and there may result a very great difference between the terminal voltages delivered by the tuning system and that which actuates the elements of the tube. A still further effect, usually negligible at the lower frequencies, is the comparatively high coupling, presumably capacitative in nature, existing between the control element and the cathode, with the result that the system associated with the cathode can exert a profound influence upon the performance of the system.

Thus it will be seen that for efficient operation of detectors or repeaters at ultra-high frequencies, it is necessary to take all of these factors into consideration and to provide means for impressing the greatest driving voltage, not upon the available terminals of the electron discharge device, but upon the elements themselves. This involves the proper matching of the terminal impedance of the electron discharge device to that of the input tuning system and the setting up of a voltage distribution throughout the system which impresses a maximum driving voltage upon the control elements.

Since the input impedance of electron discharge devices at ultra-high frequencies can become quite low, and may contain a very appreciable reactive component, it is usually impracticable to connect the input terminals of such a device directly across a tuned selective circuit since (1) the reactance added across the tuning element of the tuning system may make it impossible to restore resonance in the system as a whole, and (2) the resistive component may be of sufficiently low value to destroy the selective properties and the voltage step-up obtainable in the tuning system alone. Ideally, the input impedance of the discharge device should be matched to that of the tuning system. This condition may be approached by inserting between the input to the discharge device and the output terminals of the tuning system a length of Lecher system so proportioned that it effectively transforms the terminal impedance of the discharge device into a pure resistance of sufficient magnitude to approach that of the tuning system. Such a Lecher system would be a fraction of a wave-length in extent and as such might occupy considerable space. In accordance with one feature of the invention, essentially the same result is secured by using in lieu of the Lecher system a pair of inductances of such value that together with their self and mutual capacity, they will have the same electrical characteristics as that of the Lecher system which they are to replace.

The inductance reactance presented by the input terminal leads at wave-lengths less than a meter is sufficient to cause the expenditure of a portion of the driving electromotive force upon these leads. Accordingly, there is a loss of electromotive force which, in single tube elements, is manifested between the cathode and the junction point of the input and output circuits and which in balanced or push-pull circuits is effective between the two cathodes. This loss reduces the desired grid to cathode electromotive force and the inductive reactance may also change the phase of the resulting grid to cathode electromotive force. Not only does this cathode lead electromotive force represent a direct loss but it also sets up circulating high frequency oscillations in the cathode heating circuit. The reactance of the cathode heating circuit accordingly becomes a factor which may strongly affect the efficiency of the electron discharge device. According to another feature of the invention, the cathode heating circuit is so tuned as to constitute with the input circuit and the tube a standing wave system having a large potential difference between the points to which the two input electrodes are connected. Moreover, if the input circuit and the cathode heating circuit operating together as a standing wave system are each provided with means for changing their effective wave-lengths or terminal reflecting points they may be varied simultaneously to cause the standing wave system to move effectively in one direction or the other so as to bring the potential antinodes of the system at the two input electrodes.

In the drawings:

Fig. 1 illustrates an ultra-short wave receiving system having an electronic detector, the input circuit and cathode heating circuit of which together constitute a standing wave system;

Fig. 2 is a graph indicating current and electromotive force distribution in the resonance circuits of Fig. 1;

Fig. 3 illustrates a modification of the circuit of Fig. 1 in which the input resonant circuit is associated with the input leads of the electron discharge device through impedance transformers;

Fig. 4 shows a schematic circuit diagram of a superheterodyne receiver for frequency modulated waves;

Fig. 5 illustrates graphs of the selective characteristics of the intermediate frequency selecting circuit of Fig. 4;

Fig. 6 shows a circuit diagram of a superheterodyne receiver for receiving amplitude modulated waves, and

Fig. 7 shows a simple detector circuit in which the principles of the invention are applied to a single tube circuit.

Referring to Fig. 1, an antenna 1 of any well-known type is associated through a coupling circuit 2 with a Lecher circuit 3. Electron discharge devices 4 and 5 each provided with a cathode, an anode, an impedance control element and a cathode heating element have their impedance control elements connected to the Lecher circuit 3 in push-pull fashion. A sliding contact tuning element 6 is provided to tune the Lecher circuit in well-known manner. The effective length of the Lecher conductor may accordingly be so adjusted that in conjunction with the grid lead it will constitute a circuit in which a maximum driving electromotive force may be developed between the grid and cathode.

The cathodes are respectively connected to the outer tubular conductors 7 and 8 of a pair of coaxial conductor elements which together constitute a second Lecher circuit. A slidable tuning member 9 directly connecting conductors 7 and 8 is connected through lead 10 and grid biasing source 11 with tuning member 6 to complete a polarizing circuit for the impedance control elements with respect to their associated cathodes. The cathode heating elements are connected in parallel to a source of heating current 12 through the inner conductors 13 and 14, respectively, of the coaxial conductors. A space current path is provided for each of the electron discharge devices from their respective anodes, through high frequency chokes 15, common lead 16, indicating device 17, signal indicating device 18, space current source 19 to tuning element 9. High frequency by-pass condensers 20 and 21 connected directly between the anodes and cathodes of each of the electron discharge devices serve to effectively short-circuit the space current paths of those devices at the incoming short wave frequencies. A high frequency by-pass condenser 22 is also connected in shunt to grid bias source 11 the positive terminal of which is grounded as indicated in the drawings.

In operation, the circuit illustrated serves to receive ultra-short waves and to demodulate them to reproduce the audio frequency modulating current in the indicating device 18, of any well-known type, illustrated in the drawings as a telephone receiver. Applicant has discovered that both the input impedance of the electron discharge devices and the magnitude of the demodulated current of audio frequency to which they give rise, is influenced very markedly by the character of the loop circuit joining the cathode heating elements to the source of heating current. It has been found that by tuning this loop a very marked improvement in rectifying efficiency of the electronic apparatus is secured. The explanation for this appears to be that the grid and cathode in each tube are coupled by the grid cathode capacity with which is associated an effective resistance representing the active grid circuit loss equivalent. With a Lecher system or an electrically equivalent circuit connected between the grid terminals, the standing waves in this system continue in some fashion within the tube along the cathode and finally terminate at the slider on the cathode tuning system. While for any particular setting of the tuning slider 9 an optimum setting of the tuning slider 6 of the input circuit will be found, the greatest voltage will be developed between the grid and cathode when the current through the capacitance between the cathode and the grid is a maximum. For example, in tests with ultra-short wave oscillations of about 58 centimeters wave-length, it has been found that the cathode tuning system when adjusted to a length of about 24 centimeters measured from slider 9 to the cathode terminals will place the cathodes at very nearly a point of grid circuit current maximum. When both the cathode and grid system are constructed as Lecher circuits, adjustment of both tuning slider elements in effect moves the tube along a single tuning system until the most favorable potentials are developed on the grid.

In Fig. 2 the upper diagram shows in skeleton form the resonance system 6, 3, 7, 8 and 9 with the connected grids and cathodes of discharge devices 4 and 5. The source of the driving electromotive force may be regarded as introduced at the central point of element 6 as indicated diagrammatically in the drawings. The points marked tube terminals represent the external points accessible for making connections. The current and electromotive force distribution for the upper conductor 3, 7 are indicated respectively by the curves I and E in the second diagram and the corresponding conditions for the lower conductor 3, 8 are shown in the third diagram. Each set of curves has its own reference line and potentials are shown with respect to ground which is a plane midway between the upper and lower conductors and perpendicular to the paper. From these diagrams it is apparent that the current and potential distributions are in general sinusoidal except over the region XY which is the path through the capacity between the grid and cathode. In that particular region the current is constant while the potential drops rapidly to zero placing the two cathodes at the same potential. The importance of the tuning of the cathode system in bringing about this result will be readily appreciated. The current through the grid to cathode capacity, although somewhat less than the peak shown to the left, is the maximum that can be obtained and the potential difference between the grid and cathode is, accordingly, relatively high. In practice the input Lecher system will, in general, be somewhat in excess of a half wave-length for the reason that most tubes at wave-lengths of the order of 60 centimeters have an effective length from grid terminals to actual grid of nearly a quarter wave-length. Accordingly, it is desirable to operate with such a length of Lecher circuit that added to the grid terminal lead the entire circuit will have approximately a three-quarters wave-length at which, as is well-known, the impedance presented by the tuned driving circuit will be high.

Fig. 3 illustrates a modification of the circuit of Fig. 1 involving a rhombic antenna 23 having a terminating network 103 and associated by a coupling loop 24 with tuned loop input circuit 25 including variable condenser 26. It will, of course, be understood that any suitable type of ultra-short wave antenna may be employed in this circuit as well as in connection with the other circuits disclosed. Electronic apparatus comprising two electron discharge devices 27 and 28, each having a cathode, an anode, an impedance control element and a cathode heating element, all of well-known types, are associated with tuned input circuit 25 in push-pull fashion. The input impedance between the input terminals of the electron discharge apparatus is so unfavorable at the ultra-short wave frequencies involved as to seriously reduce the efficiency of the system when connected directly to points in the tuned input circuit. Applicant has discovered that this effect may be overcome by introducing into the lead connecting the grids or impedance control elements of the devices 27 and 28 to the tuned input circuit 25, inductances 29 and 30 which serve to transform the unfavorable grid circuit impedance to a value suitable for connecting directly across the tuned input circuit. In lieu of these inductances the lead might be extended in the form of a Lecher system to constitute a line a fraction of a wave-length long which would provide an impedance suitable for connecting the input terminals of the tube to the tuned input circuit. Inductances 29 and 30 accomplish the same result with an economy of space.

In order to enable nice adjustment of the coupling between the tuned input circuit and the path including the grid leads and the impedance transformers, the connections of the latter to the input circuit loop are preferably effected by variable or sliding taps. This enables compensation to be readily made for various operating conditions and is useful if tubes are to be replaced at any time by others of different input characteristics.

The cathode heating elements 31 and 32 are connected in parallel to source 102 of cathode heating current. It has been found that if the leads to elements 31 and 32 be extended in the form of parallel Lecher circuit conductors 33 and 34 as indicated, they may be tuned by a sliding tuning element 35 to increase the effective grid to cathode electromotive force in the same manner as has been described in connection with the circuit of Fig. 1. The grids of the two electron discharge devices are suitably biased by a source 36 connected between the cathode and a central point of the inductance of tuned input circuit 25. One terminal of source 36 is grounded and a high frequency by-pass condenser 22 is connected in shunt to the grid bias source in the same manner as in Fig. 1. Space current for the electron discharge devices is supplied by a source 37 in the space current path leading from the cathodes by way of source 37, conductor 38, current indicator 39, telephone receiver or other signal indicating device 40, to the junction point of the individual paths leading to the respective anodes through high frequency choke coils 41 and 42. As in the circuit of Fig. 1 by-pass paths including capacity elements 43 and 44 are provided to increase the efficiency of the electron discharge devices as demodulators. In practice, the circuit of Fig. 3 has demonstrated that for a certain driving electromotive force induced in circuit 25 the rectified current component corresponding to the demodulated waves may be increased from a magnitude of .3 milliampere for an untuned condition of the heating circuit to a magnitude in excess of three milliamperes when the heating circuit is tuned.

Fig. 4 shows a superheterodyne circuit for receiving frequency modulated ultra-short waves. Antenna 45, which may be of rhombic form, having a terminating network 105, is associated through the coupling circuit 46 with the tuned input circuit 47 to which electron devices 48 and 49 are connected in push-pull fashion as in the circuit of Fig. 3. Associated with the cathode and cathode heating elements are coaxial conductor elements 50 and 51 which as in the case of the circuit of Fig. 1 serve through their inner conductors to supply heating current to the cathode heating element from a source 52. The outer conductors connected directly to the cathode are associated with a tuning slider element 53. A grid biasing circuit is connected between a point in the tuned input circuit 47 and passes by way of secondary winding of transformer 54, polarizing source 55, slider 53 and conductor elements 50 and 51 to the cathodes. It will be appreciated that as in the case of Fig. 1, the capacitance between the inner and outer conductors of the two Lecher conductor elements is sufficient to effectively short-circuit any ultra-short wave frequency difference of potential between the cathode and its associated heating element. In other words, either of the cathodes or the cathode heating elements may be regarded from the standpoint of ultra-short wave as electrically connected to the tuned Lecher circuits constituted by coaxial conductors 50 and 51. This effect is further enhanced by the existence of considerable capacity which exists between the inner and outer conductors of 50 and 51 by virtue of the insulating material surrounding the inner conductors.

A local source 56 of ultra-high frequency oscillations is connected to the primary winding of transformer 54. It is customary in superheterodyne circuits that the frequency of the oscillations produced by the local source differ from that of the desired incoming wave by a suitable intermediate difference frequency so that as a result of the interaction of the incoming waves which are applied in opposite phase to the input electrodes of the electron discharge devices 48 and 49 and the local oscillations from source 56 which are applied in like phase to the electron discharge devices 48 and 49, there are produced intermediate frequency oscillations in the output circuit of the electron discharge devices which are frequency modulated in the same manner as the wave received on the antenna 45. Space current is supplied to electron discharge devices 48 and 49 from a source 57 connected between slider element 53 and the mid-point of the primary winding of transformer 59. The alternating current output circuit of the electron discharge devices passes by way of the primary winding of a transformer 59 from one anode to the other. The variable tuning capacity 60 and impedance transformers 61 correspond in every respect to the similar elements of the circuit of Fig. 2.

Transformer 59 may be so designed that its primary winding is tuned to the intermediate frequency by its distributed capacity together with the capacity of the associated tubes and leads in accordance with well-known practice in the art. The effective capacity of the windings under these conditions is indicated by the capacity element 62 shown in dotted lines. Transformer 59 serves to couple the electronic apparatus 48 and 49 to the input circuit of a band pass amplifier 78 of balanced type which has a "flat" characteristic within its transmission band so that it transmits the intermediate frequency waves with no discrimination between their different frequency components. Amplifier 78 is coupled by a transformer 79, similar to transformer 59, to the input circuit of a push-pull device 63 for converting the constant amplitude intermediate frequency waves with frequency modulations to variable amplitude intermediate frequency waves. The device 63 comprises two electron discharge devices 64 and 65 having input circuits connected in push-pull or balanced amplifier fashion through the secondary winding of transformer 79 and having tuned and uncoupled output circuits 66 and 67, one of which is resonant at a frequency considerably lower than the intermediate carrier frequency and the other of which is resonant at a frequency correspondingly higher than the intermediate carrier frequency. Graphs of the current frequency characteristics of these circuits are shown in Fig. 5 in which the resonant frequency of circuit 66 is indicated by f_1, the intermediate carrier frequency by f_0, and the resonant frequency of circuit 67 by f_2. Circuits 66 and 67 are coupled respectively to intermediate frequency detectors 68 and 69 by transformers 81 and 82 and the output circuits of the two detectors are coupled in opposition to the circuit of a telephone receiver or other signal indicator 80 by transformers 83 and 84. When the intermediate frequency wave applied to device 63 is of frequency f_0 the response of circuits 66 and 67, as may be seen from Fig. 5 will be equal. Consequently, detectors 68 and 69 will receive equal amplitude input currents and will yield equal audio frequency currents. These audio frequency currents differ in phase by 180° since they have been converted from frequency modulated to amplitude modulated waves by the sloping characteristics of circuits 66 and 67, which, over the region f_1 to f_2 in Fig. 4, have slopes of opposite sign. Hence, it is necessary to make use of a push-pull connection of output transformers 83 and 84 for securing speech currents in receivers 80. This function could also be performed by means of a single output transformer having a center tap on its primary side.

It is desirable, in the interest of noise reduction, that the frequencies f_1 and f_2 of the resonant circuits be rather widely separated. If that is the case the response of either at frequency f_0 will be represented by an ordinate which is relatively small. Accordingly, any noise which is introduced by interaction of disturbing extraneous electromotive forces with that of the local oscillator will be relatively small and the receiving instrument 80 will be relatively free from noise in the non-signaling intervals during pauses in modulation when the incoming carrier wave is of frequency f_0. When signaling is initiated the incoming carrier wave frequency will depart from f_0 toward f_1 or f_2 and the concomitant noise currents will rise. Since, however, the signal current rises with them and overrides them, the disturbance which they produce will not be particularly troublesome. By operating with the tunings of circuits 66 and 67 so widely separated that the ordinate at f_0 represents a magnitude of the order of 12 decibels lower than that of the peak ordinates at frequencies f_1 and f_2, a single channel system appears to be noticeably free from noise. With the resonance frequencies of the tuned circuits so widely separated the noise during pauses in modulation is reduced. With the same degree of modulation as before the fundamental output is also reduced but not to the same extent. If now the degree of modulation is increased so that the frequencies undergo such excursions as to again approach the peak or resonance frequencies the original level of fundamental output current may be obtained or at least approached. Greater distortion arising from the curvature of the tuned circuit characteristic will of course result. However, the use of the two tuned circuits in this manner will bring about cancellation of the even harmonics thus permitting this process to be carried farther with the same degree of distortion than would be possible with a single conversion circuit. It is even possible to operate with a greater separation of f_1 and f_2 than indicated and in some instances to the extent that the ordinate f_0 represents a magnitude 15 to 20 decibels below the magnitudes of the ordinates at f_1 and f_2. For multiplex operation, a similar advantage is not attained since even during the silent periods of one channel noise may be introduced by the operation of the other channels in changing the frequency and, moreover, since operation at a lower and hence more curved portion of the tuned circuit characteristic may introduce cross modulation between the various channels. Accordingly, for multiplex operation it is desirable to place the f_0 ordinate at about 5 or 6 decibels lower than the peak ordinates of the f_1 and f_2 frequencies.

While a tuned Lecher circuit might be employed in Fig. 4 in lieu of the tuned input circuit 47, the latter is advantageous in a superheterodyne system for the reason that it imposes a much smaller load upon the local oscillator 56. This is for the reason that the portions of the lumped tuned circuit traversed by the beating oscillations from the local oscillator are of very much shorter physical dimensions than are the conductors of an equivalent Lecher circuit.

Fig. 6 discloses a modification of the circuit of Fig. 4 adapted for use for receiving and demodulating amplitude modulated ultra-short waves. The receiving circuit of Fig. 6 may be identical with that of Fig. 4 up to the broken line A—A of Fig. 4. Intermediate frequency transformer 70, both windings of which may be self-tuned, is connected to the input circuit of intermediate frequency amplifier 71 having two similar stages, the output circuit of the latter of which is connected through a series capacity 72 and shunt resistance 73 with the input circuit of intermediate frequency detector 74. The inductance 104 and capacity 105 in the space current path of amplifier 71 constitute a loop tuned broadly to the intermediate carrier frequency. Audio frequency amplifier 75 is connected to the output of intermediate frequency detector 74 by transformer 76 and serves to impress amplified audio frequency signals upon the receiving device 77.

The operation of the circuit of Fig. 6 is similar to that of the circuit of Fig. 4 with the exception that no modulation converter is necessary since the incoming oscillations are modulated in accordance with amplitudes of the modulating signals.

Although in Figs. 1 to 6 inclusive, the invention has been disclosed in various circuits embodying balanced or push-pull translating circuits, it is not limited to circuits of that type. Fig. 7 discloses a simple single tube detector circuit in which the incoming circuit 85 is coupled to the tuned circuit 86 of an electron discharge detector 87. A resonance transformer 88 is included in the lead to the grid. A by-pass condenser 89 connects the plate and cathode and presents a low impedance path at incoming carrier wave frequencies. Grid polarizing source 90 and by-pass condenser 91 are provided in accordance with well-known practice. The low frequency signal currents produced as a result of the demodulating operation are indicated by a signal indicating instrument, for example, a telephone receiver 92 in the space current path in series with space current source 93 and current-indicating meter 94. The cathode heating element is supplied with heating current by a source 95 through the inner conductors 96 and 97 of the coaxial elements 98 and 99 which constitute a Lecher circuit that may be tuned by slider 100 as a half wave-length system to effectively short-circuit any impedance effect introduced in series with the grid and cathode by reason of the cathode heating circuit. If desired elements 98 and 99 may be omitted and tuning slider 100 connected directly across conductors 96 and 97. In that case a large capacity blocking condenser may be inserted in the tuning slider to prevent short-circuiting source 95.

In the various figures of the drawings the detector circuits are shown as comprising indirectly heated cathode tubes with the tuned Lecher circuit associated with the cathode heating circuit. It is to be understood that the circuits may also comprise ordinary directly heated three element tubes and that they may correspond in every respect to the circuits as shown except that the indirectly heated cathode would be omitted from the circuit diagrams and the unidirectional current circuit conductors leading from the cathodes to the grids and anodes and now shown connected to tuning sliders 9 and 53 in Figs. 1 and 4 would connect directly to a point between the filamentary cathodes instead of to the tuning sliders.

It is to be understood that the principles of the invention are in no wise limited to demodulating devices but are equally applicable to circuits of amplifiers or other electron discharge devices.

What is claimed is:

1. An ultra-short wave circuit comprising an electron discharge device having an anode, a cathode, and an impedance control element, means for polarizing said anode and said impedance control element, means for heating said cathode, a closed tuned loop, two leads connecting the loop to the impedance control element and cathode, at least one of said leads including a series reactance equivalent to a fractional wave-length line whereby the impedance presented at the driving terminals of said leads is effectively increased over that which would be presented by the path between the input electrodes, a tunable circuit connected to said cathode heating means, means for tuning said tunable circuit to cause the circuit, together with the cathode heating means, to simulate a short-circuited half-wave length path whereby the potential drop which the heating means tends to produce in the lead from the cathode to the closed tuned loop is eliminated thus permitting the full driving electromotive-force impressed through the series reactance of the leads to be effective between the cathode and the impedance control element, and an output path connected to the output electrodes.

2. An ultra-short wave transmission apparatus including an electron discharge device comprising a cathode, an anode and an impedance controlling element, an input circuit connected to said cathode and impedance controlling element, means for heating said cathode comprising a source of electrical energy and a circuit including said source and two leads connected thereto, and means for tuning said leads to cause said heating circuit to exhibit such a predetermined reactance at the frequency of the ultra-short waves to be transmitted as to cause the tuned leads to function as a short-circuited standing wave circuit of approximately one-half wave-length whereby the effect of cathode lead impedance is substantially eliminated.

3. In combination, two electron discharge devices, each having a cathode, an anode, means for heating the cathodes and an impedance control element, a tuned circuit, means connecting each of said control elements to said tuned circuit comprising control element leads, at least one of said leads including a series reactance equivalent to a fractional wave-length line whereby the impedance present at the driving terminals of said leads is effectively increased over that which would be presented by the path between the cathode and impedance controlling element, an output circuit connected between said anodes,

and a half wave-length Lecher circuit connected to the cathode heating means and short-circuited at its terminals remote from the connection of the cathode heating means.

4. In combination, two electron discharge devices, each having a cathode and an impedance control element, means for heating the cathode, an input circuit, leads connecting said input circuit to said impedance control element and said cathode in push-pull relation, lumped reactance connected in series with certain of said leads to increase the effective input impedance presented by the electron discharge devices to the input circuit, and means connected to said cathodes and cathode heating means to substantially eliminate any impedance introduced into the input circuit by the cathode heating means whereby the full electromotive force developed between the terminals of the impedance control elements is effective in producing impedance changes in said electron discharge devices.

5. A system for receiving frequency modulated waves comprising a receiving conductor, a local oscillator associated therewith, means for causing oscillations from the local oscillator to interact with waves received by the receiving conductor to produce intermediate frequency waves, a pair of differently tuned circuits which for equal impressed voltages each have a maximum response at their respective resonance frequencies of the order of 10 decibels greater than for an equal electromotive force at the frequency at which their responses are of the same magnitude, means for impressing the intermediate frequency waves upon the two tuned circuits and means for deriving from each tuned circuit a wave proportional to its response whereby an intermediate frequency wave having an amplitude modulation is produced.

6. A system according to claim 5 characterized in this that means are provided to detect each of the amplitude modulated intermediate frequency waves and to add the resultant detected waves.

7. A system for receiving frequency modulated waves comprising an incoming circuit upon which the waves may be impressed, a pair of differently tuned circuits connected to the input circuit which for equal impressed voltages each have a maximum response at their respective resonance frequencies of the order of 10 decibels greater than for an equal electromotive force at the frequency at which their responses are of the same magnitude, means for deriving from each tuned circuit a wave proportional to its response whereby waves having amplitude modulation are produced and means for detecting the amplitude modulated waves and combining their detected energy.

8. A system for receiving frequency modulated waves comprising a closed tuned circuit upon which the waves may be impressed, an electron discharge device having a cathode, an anode and an impedance control element, leads connecting the cathode and the impedance control element respectively to two points in the closed tuned circuit of substantially maximum electrical difference of potential, at least one of said leads including a series reactance equivalent to a fractional wave-length line at the frequency of the oscillations to which the tuned circuit is resonant whereby the impedance presented by the input circuit of the electron discharge device at the driving terminals of said leads is effectively increased over that which would be presented by the path between the cathode and impedance control element, and means for heating said cathode comprising a source of electrical energy and a circuit including said source and two conductors connected thereto, together with means for tuning said conductors to cause the heating circuit to function as a short-circuited standing wave path of approximately one-half wave-length whereby effective cathode lead impedance introduced by the heating circuit is substantially eliminated.

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