Jan. 19, 1937.

R. A. HEISING

2,068,324

SHORT WAVE ELECTRON TUBE CIRCUIT

Filed Feb. 19, 1936

FIG. 1

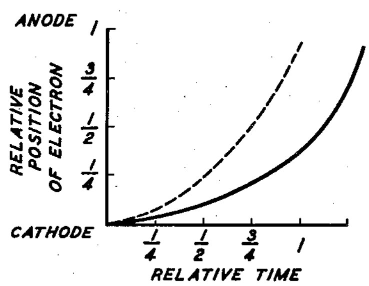


FIG. 2

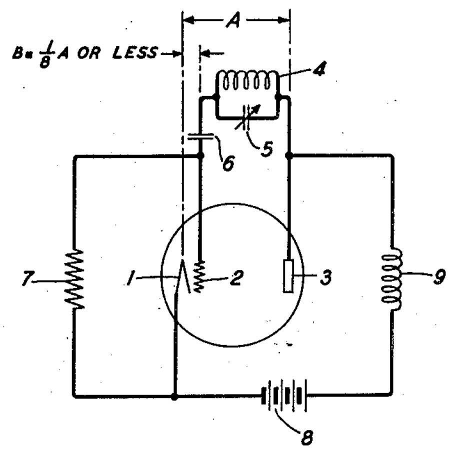


FIG. 3

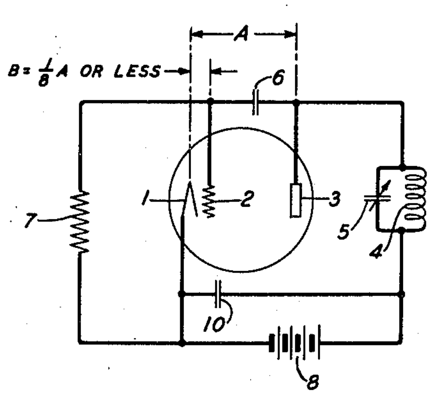
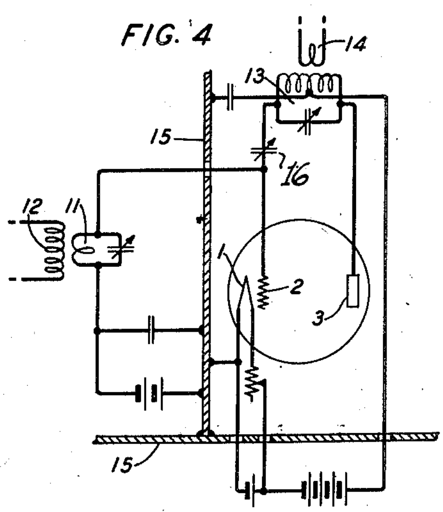


FIG. 4



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SHORT-WAVE ELECTRON TUBE CIRCUIT

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10 Claims. (Cl. 250—36)

This invention relates to short-wave, or ultra-short-wave circuits, each employing an electron tube having the usual cathode, control electrode and anode, these three electrodes being electrically conditioned to cause the tube to function in the conventional manner characteristic of an electron tube amplifier or repeater.

This application embodies all of the subject-matter, both as to specification and drawing, of a pending application of the same inventor, Serial No. 18,119 filed April 25, 1935, together with additional subject-matter specific to an amplifier tube circuit as exemplified in Fig. 4 to be described.

More specifically the invention relates to a special conditioning of the tube structure, as by a super-threshold ratio of spacings of electrodes, to enable the tube to repeat or amplify the ultra-short waves impressed on its input either from the outside, or regeneratively from its output circuit as in the instance of a regenerative oscillator, while avoiding the complicating to and fro or transition effect on the electrons tending to result at these high frequencies where the transit time of the electrons from the cathode to the anode is comparable with the periodicity of said impressed waves.

To enable such a tube to perpetuate the oscillations presumed initially to be impressed on its input circuit, and therefore between the control electrode and cathode, so as to produce self-sustained oscillations, it is necessary according to one well-known mode of operation to insure a regenerative feed-back from the output circuit to the input circuit in such manner that the phase of the alternating potential between the control electrode and cathode is 180 degrees displaced from the corresponding potential between the anode and cathode. This necessary condition results from the phase characteristics of the tube treated as an amplifier of the initial impulse impressed on the input circuit and the treatment of the tube and associated circuits as a means for perpetually and cyclically repeating this effect without discontinuity or systematic variation of function or effect from one cycle to a consecutive cycle.

Such an oscillation generating circuit, to which generic class the systems of the present invention belong, is known generally as of the regenerative type, obvious examples of which are the well-known Hartley and Colpitts oscillator circuits disclosed in, respectively, U. S. Patents 1,356,763, October 26, 1920 and 1,624,537, April 12, 1927. The principle may be operative in a quite different manner than those disclosed in the Hartley and Colpitts patents, as is instanced by a circuit to be disclosed in the present application. This generic type of oscillation generating circuit is to be distinguished from, for example, the negative resistance or dynatron type and the Barkhausen or Barkhausen-Kurtz type, the latter being adapted for the generation of exceedingly short waves in fact usually considerably shorter than may be generated by other types of oscillation generating circuits.

In the region of the frequency spectrum corresponding to what is ordinarily thought of as ultra-short waves, where the waves are almost as short as those for which the Barkhausen type of oscillator is well adapted, it is possible to generate oscillations as in accordance with the regenerative principle only with an attendant difficulty on account of complications due to phase lag of electrons in their flight from the cathode to the anode. That is, within the marginal range of frequencies where the periodicity of the generated wave is comparable with the transit time of electrons from cathode to anode, account must be taken of this transit time and therefore, which amounts to the same thing, of the difference in phase at cathode and anode which is a measure of this transit time. While advantage can be taken of this phase lag, to cause it to simulate, to a certain extent, the desired relative phase relations necessary for regeneration as exemplified by the Hartley and Colpitts principles, and as will be disclosed in detail later in this specification, this expedient does not provide a perfect solution partly by reason of the fact that there is no necessary correspondence between the desired wave-length and the transit time.

I have discovered that the time, expressed in parts of a cycle, for an electron to move from the cathode past the grid is of paramount importance in determining the amplification to be secured at very high frequencies, and is many times as important as the transit time from the cathode to the anode. The problem is therefore to enable the control electrode to exert its control over the electrons employed while insuring that the electrons, or as many of them as possible, are outside of the zone of influence before the phase of the control electrode potential reverses so as to tend to actuate the electrons in a reverse direction. The lack of a solution of this problem means that the electrons tend to have impressed on them at one point at least in their flight to-and-fro stresses which are inconsistent with the ideal of a smooth and systematically controlled flight.

The effect is somewhat like that resulting from an attempt to force vibrations in an electric circuit, or its mechanical analog, by impressing a wave the periodicity of which is different from its natural period of vibration.

The above considerations have been made specific to a regenerative oscillator. Of course, the principle is equally applicable to an amplifier of like waves, the tube receiving and translating any wave presented to it quite impartially as to its source of origin as between an outside impressing source or the network itself which includes the tube.

The failure to solve this problem in the past has imposed a lower limit on the wave-length of waves that may be generated by the regenerative type of electron tube oscillator or repeated by an amplifier. It is accordingly an object of the invention to enable an electron tube oscillator of the regenerative type to generate shorter waves, that is, waves of greater frequency, than has heretofore been possible or to enable an electron tube amplifier to similarly effectively amplify or repeat waves of this order of frequency.

A specific object of the invention is to avoid the tendency of the control electrode of an electron tube used as a translating device, that is, in either an amplifying circuit or in a regenerative type oscillator circuit, where the periodicity of the generated wave is comparable with the transit time, to induce a near discontinuity in the electron flight with its concomitant damping or like effect.

The theory of operation of an electron tube repeater, without regard to its particular circuit environment, that is, without regard, for example, as to whether it is used in an amplifier or an oscillator circuit, contemplates that the electrons emitted from the cathode arrive substantially instantaneously at the anode. This condition clearly is not satisfied, as a matter of relative values, with these marginal wave-lengths. It is an object of the invention to obviate, or compensate for, this incompatability or inconsistency.

The above objects are achieved by utilizing an electron tube in which the control electrode is positioned relatively much closer to the cathode than in the case of tubes of prior oscillators of the same generic type. That is, the control electrode is not spaced a quarter or more of the distance to the anode, but as close as one-eighth or one-sixteenth of this distance or, in other words, it is placed, with a given cathode-anode spacing, as close to the cathode as is mechanically feasible. With this geometry of tube the electrons can get past the control electrode quicker and in larger number before the control electrode potential reverses its phase, than it would if positioned more remotely from the cathode. This is the closest practical approach to the ideal of causing the control electrode to exert its effect on the emission of the cathode during an instant of time and having the electrons otherwise independent of any potential except those on the anode.

In another aspect, the invention relates to a continuity of circuit, rather than to a novel aspect of a circuit as supported by the use of the special tube of the invention. That is, it relates to an oscillator circuit, whether or not this particular type of tube is used, in which the regenerative principle operates on account of a substantial phase reversal due to the phase retardation measured by the transit time, this transit time being comparatively large for the order of frequency concerned. This is the unconventional type of regenerative oscillator circuit that has been referred to before in contra-distinction to the generic type represented by the Hartley and Colpitts oscillator circuits in which the requisite reversal of phase is a matter of electrical relations in the network which is coupled to the electron tube and particularly coupled to the control electrode and anode of the tube. A regenerative circuit of this type is inherently more simple than those of other types, among other advantages. This type of regenerative circuit is well adapted for use with the particular tube of the invention. The principle of the invention, as it relates to the effect of the relatively small control electrode-cathode spacing is applicable in the same way as in connection with more conventional regenerative oscillator circuits.

The invention and the features thereof will be understood more clearly and fully from the following detailed description when taken with the accompanying drawing in which:

Fig. 1 is an acceleration diagram intended to show the especial significance of the positioning of the control electrode relatively to the cathode and anode on account of the law of movement of the electrons in their flight from the cathode to the anode;

Figs. 2 and 3 illustrate two forms of circuit, of which that of Fig. 2 is quite conventional, adaptable for the use of the particular tube arrangement which gives significance to the operation of the oscillator circuit, although the same circuits could be used with conventional types of tubes; and

Fig. 4 illustrates a form of amplifier circuit which utilizes the principle of the invention.

Referring now to the drawing, the dash line in Fig. 1 represents the sequential positions that an electron would take in its flight from the cathode to the anode. Specifically, it is a curve plotted against time and distance as coordinates, in terms of the time required to arrive at the anode and the distance thereto, and responding to the familiar equation of motion

$$S=\frac{1}{2}at^2$$

wherein S represents space or distance, a represents the constant of acceleration and t represents the elapsed time. This assumes plane parallel anode and cathode, as the acceleration is not constant if they are not plane parallel. This simple example is used to explain the principles underlying the invention but the principles are applicable to all forms of anodes and cathodes.

It is customary in most tubes of the prior art, as used in oscillation generating circuits and elsewhere, to position the control electrode between one-fourth and one-half the distance from the cathode to the anode. Inspection of this dash curve will indicate that if the control electrode is one-fourth the distance from cathode to anode, and the control electrode does not distort the potential distribution between the cathode and anode, one-half the time required for an electron to pass from the cathode to the anode is occupied in moving past the control electrode.

If the control electrode is positioned further than one-fourth the distance to the anode a greater proportional time, about 71 per cent of the time for one-half the distance, is required for the electron to move to the anode is occupied in getting past the grid.

In other words, with conventional electron tube arrangements, if an oscillation generator employing such a tube is operated at frequencies such that an appreciable part of a cycle is required for the electron to reach the anode, a large part of this transit time, which is very significant in the operation of the oscillator, is occupied in getting the electron past the control electrode. The control electrode is the element, of the three tube elements, which is designed to play the dominant part in conditioning the electrons to move or not to move, or to qualify the movement in a significant way. If too much of the cycle time is occupied in getting an electron past the control electrode, the control electrode potential may reverse phase in this part of the cycle and tend to stop the electron and cause it to return thereby reducing the amount of amplifier current between anode and cathode, or it may decelerate the electron in such a way that when it gets past the control electrode and consequently arrives at the anode it will be incorrect in phase with relation to the anode potential with a resultant power loss instead of gain.

If the control electrode has a negative bias as is customary, or even no bias, with respect to the cathode, the control electrode tends to distort the potential distribution curve, otherwise indicated by the dash curve, so as to emphasize still more the significance of control electrode-cathode spacing. Such a curve is indicated by the whole line curve below the dash line curve in Fig. 1, this curve being a theoretical curve plotted between distance and time, as before, where the control electrode is now at a potential lower than the potential which would occur at its position in space due to potential difference between the cathode and anode. This curve shows that with the control electrode one-quarter the distance to the anode, the time required for an electron to pass the control electrode is now increased considerably as compared with the situation not implying a distortion due to the control electrode potential. Specifically, the curve indicates a 50 per cent increase in time for reaching the anode and 100 per cent increase or thereabouts for passing the control electrode, this indicating not only a proportionally increased liability of an electron being subjected to to-and-fro forces during its passage across to the control electrode, but also in an increase in its time of flight to the anode. The potential of the control electrode and its position relatively to the cathode and anode may therefore both be expected to have a very serious effect upon the performance of the electron tube at ultra-high frequencies or at frequencies which are marginal with respect to regenerative type oscillator circuits.

What would be desired ideally is that the control electrode should be capable of exerting its effect instantly after the initiation of flight of the electrons from the cathode and that the electrons thereafter be independent of any potentials except those impressed on the anode. The closest approximation to this ideal, with the use of electron tubes generally conforming to practical possibilities of manufacture and design, would result from placing the control electrode as close to the cathode as is mechanically possible, and especially from having the ratio of control electrode distance to anode distance as small as one-eighth or one-sixteenth or even smaller as compared with the conventional spacing of perhaps one-fourth. In that case the electrons can get past the control electrode considerably quicker and a larger number which leave the cathode when the control electrode potential becomes positive will have a chance to move past the control electrode before its potential moves sufficiently in the reverse direction to stop them or appreciably decelerate them.

Fig. 2 represents a conventional regenerative type of oscillator circuit as adapted for ultra-short waves and employing an electron tube having the desirable geometry of elements pointed out in the above paragraph. The figure does not presume to show a particular structural design of tube to satisfy the desired conditions, that is, the tube showing is diagrammatic and is intended only to indicate the order of the relative spacing of the three elements. An oscillator circuit of this kind, by reason of the inclusion of a tube of this kind, has been operated to generate waves of much shorter length than have been found possible with the use of ordinary tubes, for the same anode-cathode spacing.

The circuit is generally of the Colpitts type, the control electrode-cathode and anode-cathode capacitances replacing the capacitances of physical condensers ordinarily used in the Colpitts oscillator as designed to generate longer waves. The tuned circuit comprising inductance **4** and condenser **5** effectively connected directly between the control electrode **2** and anode **3**, since condenser **6** is a blocking condenser and therefore interposes substantially no impedance to alternating current, has an effective inductive reactance at the generated frequency and therefore simulates the usual inductance coil connected between the control electrode and anode of the Colpitts type of oscillator. The control electrode is given a slight negative bias by reason of the leak resistance **7** connected between the control electrode **2** and cathode **1** as in accordance with the well understood principle. The anode **3** is excited, in a conventional manner, by continuous current source **8** through choke coil **9**. This choke coil prevents the flow of alternating current, generated by the system as a whole, from flowing in the anode exciting circuit, the blocking condenser **6** similarly preventing the continuous exciting current from flowing through the coil **4** and affecting the electrical conditions in the input circuit of the tube. Of course, the generation of electrical waves by this circuit represents a conversion of energy from direct current energy, as represented by prime source **8**, into the eventual alternating current, or wave, energy. Although the characteristic frequency of the circuit is a function jointly of all of the impedances in the alternating current path, practically it is determined principally by the resonant frequency of the tuned circuit **4—5**. Because the control electrode and anode are effectively tapped into a common oscillating current network, and at opposite ends of a reactance therein, the requisite relative reversal of phase at the control electrode is easily achieved by this circuit.

Fig. 3 represents an alternative form of oscillator circuit, with which the tube of the invention is adapted to be used. When the tube of the invention is used in this circuit its effectiveness and principle of operation is substantially the same as when used otherwise, especially as when used in the more conventional circuit of Fig. 2. In this Fig. 3 circuit similar reference numerals are used to indicate elements having similar functions as in the circuit of Fig. 2. A notable distinction is that in the circuit of Fig. 3 no impedance is imputed to the control electrode-cathode circuit to the extent of affecting the operation of the circuit as a wave generator, the only alternating current network being that comprising inductance 4 and condenser 5. The control electrode 2 is separated from this tuned circuit, which is the frequency determining circuit of the oscillator, only by condenser 6 and therefore partakes of the phase of the anode.

The necessary relative oppositeness of phase of the control electrode and anode potentials, for regenerative oscillators of the prior art has usually presumed that the phase relations generally are not complicated by imputing a finite comparable transit time. This would be true of all oscillator circuits except the ultra-short-wave oscillators of the present consideration. Actually, however, what is of significance, phasially, is the relative phases of the anode and the phase of the fed-back wave as repeated back to the anode. In the present instance there is the necessary phase oppositeness at this point on account of the phase lag due to transit time of the electrons, the transit time being an appreciable part of a cycle. In the instance of the circuit of this Fig. 3, the ultimate, necessary, phase relations are a matter of very careful design of the circuit as a whole with relation to the transit time rather than being an inherent characteristic of the circuit as in the instance of the Fig. 2 circuit. In the operation of the Fig. 3 circuit, when the anode potential moves in a positive direction the control electrode potential moves in a likewise direction and in approximately the same phase. Electrons leave the cathode and very quickly pass the control electrode whereupon the potential of both control electrode and anode move in the reverse direction and the electrons reach the anode at a later part of the cycle.

Fig. 4 illustrates an application of the invention to an ultra-high frequency amplifier. The tube elements are identified similarly as in Figs. 2 and 3. The circuit generally is similar to said circuits of Figs. 2 and 3, especially Fig. 2, differing principally as to the derivation of the impressed wave. In a quite logical point of view the amplifier circuit of this Fig. 4 could be treated as a separately excited oscillator as distinguished from the self-excited oscillators of Figs. 2 and 3. In the circuit of Fig. 4 the wave is impressed on the input circuit of the tube, through the resonant selecting or accentuating circuit 11 from a source diagrammatically indicated by reference numeral 12. As is obvious the impression of the wave need not be through the intermediation of the transformer shown, this being merely representative of a typical type of coupling means. The output wave may similarly be derived from the amplifier tube through resonant circuit 13, which is similar in structure and function to the resonant circuit 11, and impressed on the utilization circuit 14.

Because of the difficulty of insuring the necessary absence of coupling between the output and input circuits, which might radically affect the function of the circuit as a whole as an amplifier, conductive shield means 15 may be used as shown. This means might well have the form of copper sheets. The use of this means in the present instance is made especially necessary because of the order of frequency concerned which imposes extraordinary coupling hazards on the circuit. The effect could equally well be secured by enclosing either the input circuit or the output circuit together with the tube in a shield box. To further promote the desired complete absence of coupling, the lead wires from the resonant circuit 13 to the tube, and likewise that portion of the lead wires between resonant circuit 11 and the tube which is on the tube side of the vertical shield means 15, should be made as short as possible. Furthermore, the loop formed by these lead wires connected to resonant circuit 13 (and similarly as to any other putative loop circuits, although the one mentioned is probably of the most importance) should be so physically composed relative to associated circuits as to have as near zero mutual inductance with respect thereto as is practicable. The condenser 16 is for the purpose of neutralizing the control electrode-anode capacitance as in accordance with conventional practice.

In an oscillator circuit of the invention which was demonstrated experimentally to be effective, a linear filament .0085 inch in diameter with cylindrical control electrode and anode of .0625 inch and 1 inch diameters respectively were used, so that the input electrode spacing was about one-seventeenth the output electrode spacing. An anode-cathode potential difference of 900 volts was used and the tuning was variously adjusted to generate waves of 68, 75 and 80 centimeters length, these values corresponding, respectively, to about 440, 400 and 350 megacycles. There is reason to think that the circuit would be effective, either as an amplifier or as an oscillator not only throughout this range but at considerably higher frequencies, perhaps throughout the present known Barkhausen range of frequencies. The principle would, of course, be effective below the above-tried frequency range but, because of the lesser need therein, not so uniquely effective as in the ranges specified.

Although certain specific embodiments of this invention have been shown and described, it will be understood, of course, that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electron tube circuit comprising an electron tube having a cathode, an anode, and a control electrode, and means for impressing between the control electrode and cathode of said tube a wave the periodicity of which is comparable with the electron transit time from cathode to anode, the control electrode-cathode spacing in said tube being as small as possible consistently with mechanical stability and adequate electrical insulation at all times.

2. An electron tube circuit comprising an electron tube having input and output electrodes including a cathode element common to said sets of electrodes, and means for impressing on the input electrodes a wave the periodicity of which is comparable with the electron transit time between the output electrodes, the spacing between said input electrodes being less than one-eighth the spacing between said output electrodes.

3. An electron tube amplifier circuit comprising an electron tube having a cathode, an anode, and a control electrode, and means for impressing between the control electrode and cathode of said tube a wave, the periodicity of which is comparable with the electron transit time from cathode to anode, the control electrode-cathode spacing in said tube being as small as possible consistently with mechanical stability and adequate electrical insulation at all times.

4. An electron tube amplifier circuit comprising an electron tube having input and output electrodes including a cathode element common

to said sets of electrodes, and means for impressing on the input electrodes a wave the periodicity of which is comparable with the electron transit time between the output electrodes, the spacing between said input electrodes being less than one-eighth the spacing between said output electrodes.

5. An electron tube oscillation generator of the regenerative type comprising an electron tube having a cathode, an anode and a control electrode, and a resonant circuit connected in frequency determining relation to the remaining elements of the generator and so electrically dimensioned that the periodicity of the generated oscillations is comparable with the electron transit time from cathode to anode, the control electrode-cathode spacing in the electron tube being as small as possible consistently with mechanical stability and adequate electrical insulation at all times.

6. A regenerative type electron tube oscillator comprising an electron tube having coupled input and output electrodes including a cathode element common to said sets of electrodes, and a resonant circuit connected in frequency determining relation to the remaining elements of the oscillator the natural periodicity of oscillations in which is comparable with the electron transit time between the output electrodes, the spacing between said input electrodes being less than one-eighth the spacing between said output electrodes.

7. A regenerative type of electron tube oscillator comprising an electron tube having a cathode, an anode and a control electrode, means for impressing a positive potential on the anode relatively to the cathode, means for impressing a potential on said control electrode relatively to the cathode which potential is lower than that which would occur at its position in space on account of the potential difference between said anode and cathode, and means regeneratively coupling said cathode, anode and control electrode to enable the circuit as a whole to generate oscillations, said coupling means being so electrically dismensioned that the periodicity of the generated oscillations is comparable with the transit time of electrons from cathode to anode and the cathode-control electrode spacing being less than one-eighth of the cathode-anode spacing.

8. The oscillator circuit specified in the next preceding claim in which the control electrode is positioned as close to the cathode as is physically possible consistent with mechanical stability and adequate electrical insulation at all times.

9. A regenerative type electron tube oscillator comprising an electron tube having a cathode, anode and control electrode, a substantially reactionless input circuit connected to said cathode and control electrode, a resonantly vibratory frequency determining output circuit connected to said cathode and anode, and coupling means between said output and input circuits whereby the alternating potentials at the control electrode and anode are of substantially the same phase, the oscillator frequency as a function of the electrical dimensions of said frequency determining circuit being such, in relation to the electron transit time from cathode to anode that the phase of the control electrode potentials as translated to the anode by taking account of the phase lag due to transit time is in opposition to the phase of the anode potentials impressed cyclically thereon from the frequency determining circuit.

10. The oscillator specified in the next preceding claim in which the control electrode is spaced from the cathode a distance less than one-eighth the corresponding spacing of cathode and anode.

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