Oct. 19, 1937. F. B. LLEWELLYN 2,096,460

SPACE DISCHARGE APPARATUS

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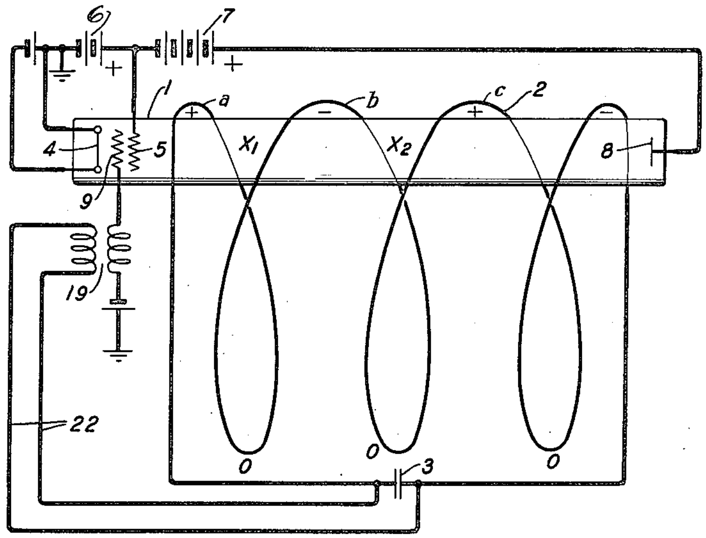

FIG. 1

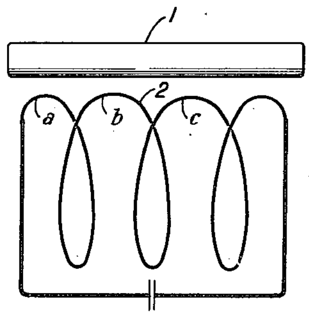

FIG. 1A

FIG. 2

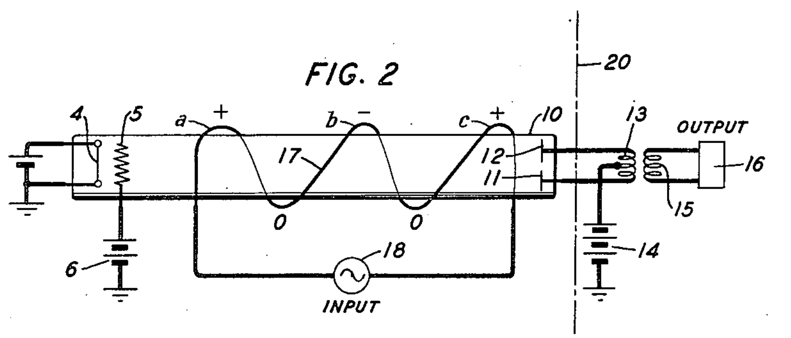

FIG. 2A

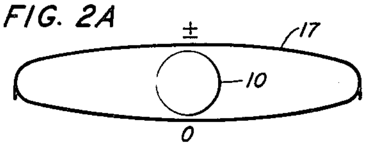

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FIG. 3

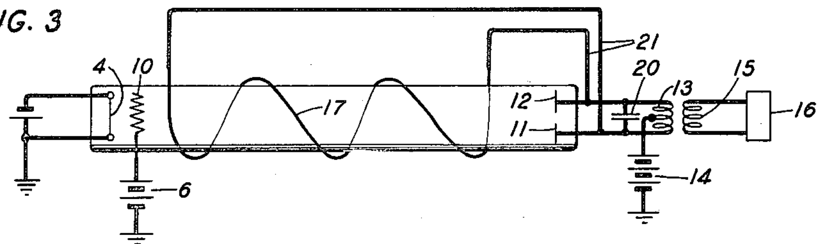


FIG. 4

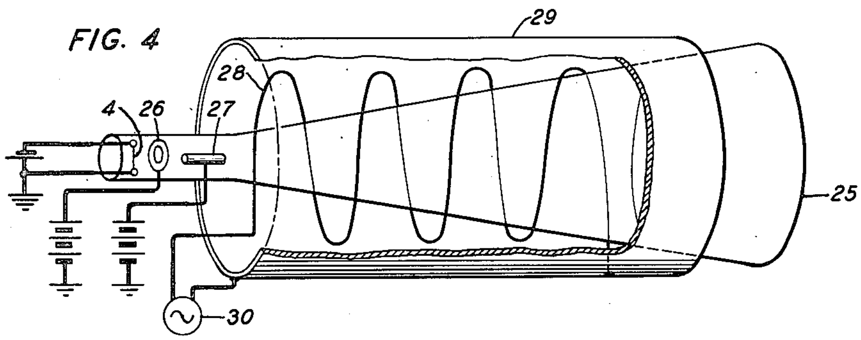


FIG. 5

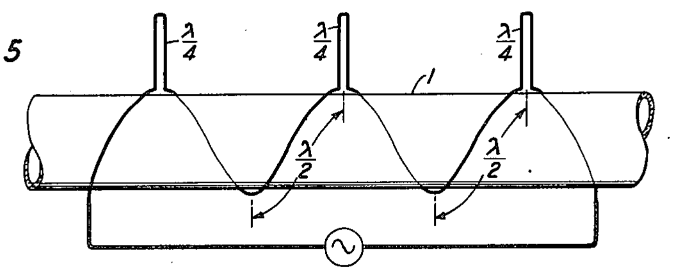


FIG. 6

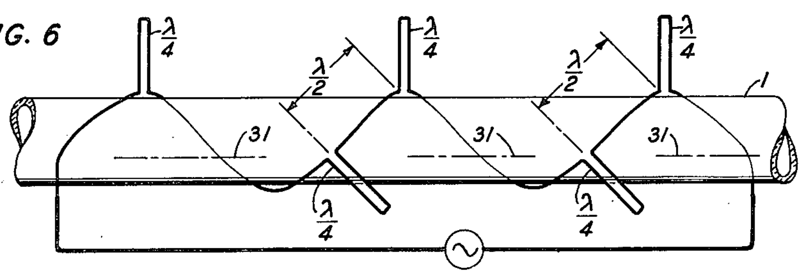
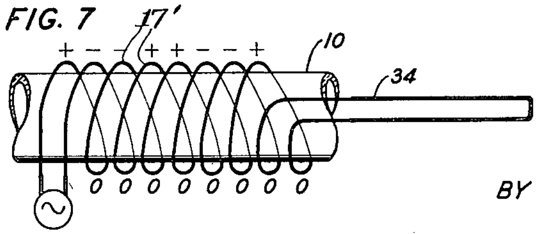


FIG. 7



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2,096,460

SPACE DISCHARGE APPARATUS

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Application January 23, 1936, Serial No. 60,403

5 Claims. (Cl. 250—36)

The present invention relates to ultra-high frequency circuits employing space discharge apparatus for amplification, oscillation production or kindred purposes.

A general object of the invention is to secure a useful cooperative relation between electrons traversing a given path at given velocity and an alternating current field along the path, the wave-length of which is suitably related to the electron velocity.

A further object is to produce an electric force which moves along with the electron and acts on the electron in the same direction at all times.

The useful cooperative relation may, as one example, be such that energy is delivered by the moving electrons to the circuit by which the alternating current field is produced. Conversely, the field may be used to exert forces on the electron stream for the purpose of producing amplified oscillations in a circuit in which the electron stream controls a current flow.

In one specific form of embodiment to be described, a cylindrical tube has electrodes for producing electron flow along its length and has a series of conducting surfaces spaced along the tube such that an electron traverses the distance from one conductor to the next in half a period of the oscillations that are being produced or utilized in the system. These conductors may be formed as the successive turns of a standing wave coil or may be so related to a standing wave coil that the phase reverses from each conductor to the next, considered along a line parallel to the axis of the tube. An electron entering the field of influence of the first conductor may, as one example, have such a phase relation as to impart an increment of energy to the standing wave circuit. The driving voltage on the tube sustains the velocity of the electron notwithstanding this delivery of some of its energy to the external circuit. By the time the electron has entered the field of influence of the next conductor of the standing wave circuit the phase relations have become identically the same as in the case of the first conductor and a further increment of energy is delivered to the external circuit. This action continues throughout the journey of the electron along the tube.

For amplification a somewhat converse action may be secured by causing the energy in the standing wave circuit to drive electrons alternately toward separate anodes and produce amplified oscillations in the circuit connected to these anodes.

The various objects and features of the invention will be more fully understood from the following detailed description of certain illustrative embodiments as shown in the accompanying drawings.

In the drawings:

Fig. 1 is a schematic diagram of a circuit embodying the invention in one form of oscillation generator;

Fig. 1A is an alternate form of the circuit of Fig. 1;

Fig. 2 is a similar diagram of the invention applied to an amplifier;

Fig. 2A is an end-view detail of Fig. 2;

Fig. 3 shows an alternative form of oscillation generator embodying the invention;

Fig. 4 shows the invention applied to an oscillograph tube; and

Figs. 5 to 7 show various winding modifications.

In Fig. 1 an evacuated tube **1** is provided with a cathode **4**, grid **5** biased positive by battery **6**, and anode **8** at still higher positive potential than the grid as determined by battery **7**. Coil **2** surrounds the tube **1** although it could be placed altogether or in part inside the tube if a suitable bias voltage were maintained on it. The coil may be self-tuned or tuned by a condenser **3**. The condenser **3** or coil **2** or both may constitute a radiator of waves produced by the circuit.

In operation, the grid and anode are given such voltages that electrons emitted at **4** travel down the tube toward the anode **8** at suitable velocity. Assume a transient in coil **2** of such frequency that the phase in adjacent turns *a* and *b* is opposite. An electron at x_1, between the turns experiences a retarding force and delivers an increment of energy to the coil in a direction to sustain the transient. With a proper spacing of turns relative to the electron velocity and frequency of oscillation of the circuit **2**, **3**, it is apparent that the phase between *b* and *c* when the electron passes the point x_2 may be such that a further increment of energy is abstracted from the electron by the coil **2** in a direction to sustain the transient. The condition for this to happen is that points *a* and *b* on coil **2** shall have opposite phase and that the distance between turns is equal to the distance traversed by the electron in half the period of oscillation of the circuit **2**, **3**. Under these conditions electrons entering the influence of the coil **2** a half cycle later than the one just described will be acted upon by accelerating forces; and hence will abstract energy from the transient and thus produce a tendency for it to die out. This tendency is counteracted, however, by the fact that the accelerating forces cause the electrons to speed up and hence catch up with the electrons from the preceding half cycle which are in the proper phase to deliver energy to the transient. The tendency to absorb energy may further be reduced by varying the relative number of electrons emitted during successive half cycles. This may be accomplished by coupling a portion of the energy from the coil 2 to a grid 9 provided with suitable bias potential. A means of doing this is shown at 19 as an inductive coupling to a grid from the output circuit by way of leads 22. This coupling and grid are optional. Whether or not this feed-back is employed, oscillations are produced in the circuit 2, 3 and can be utilized in any suitable way, as by coupling the circuit 2, 3 to a load or using it as a radiator.

The assumption made above that points *a* and *b* are at opposite phase is realized in the case where standing waves are produced in coil 2 with nodal points of potential at 0, 0. In any one turn, the voltage at all points above the point 0 in the figure is in the same phase but differs in amplitude along the wire, being a maximum at the uppermost point such as *a*. In the next turn at the same instant of time the field at all points above the point 0 in the figure is of opposite phase to that of the first turn, and so on.

In order that the electrons experience forces from the individual turns of the coil 2 rather than the mean effect of the coil as a whole, it is necessary that the shortest distance between the electron stream and a given turn shall be at most not much greater than the distance between turns. In Fig. 1 this is provided by making the glass envelope 1 of the tube as small in diameter as may be and by placing it as close to the periphery of the coil as possible. While Fig. 1 shows the tube located inside of the coil, this is a matter of convenience and the tube may optionally be positioned just outside rather than just inside of the coil, as indicated schematically in Fig. 1A, which shows the tube at 1 and the coil at 2.

In Fig. 2 a tube 10 is assumed similar to tube 1 except that it is provided with two anodes 11 and 12 connected to opposite ends of a primary winding 13, the center of which is connected to space voltage source 14. The secondary 15 leads to any suitable load 16. Elements 4, 5 and 6 may be the same as in Fig. 1. The winding 17 is in this figure an input coil connected to an input source 18 of ultra-high frequency waves to be amplified. The effective length of each turn of wire in the coil is half a wave-length and the spacing between turns is such that an electron requires half a period to traverse the distance from turn to turn. To accomplish this, the cross-section of the coil may be made elliptical in shape as shown in section in Fig. 2A where 10 represents the tube and 17 the coil. At a given instant, the potential distribution along the coil will be as shown by the (+) and (−) signs in Fig. 2.

Consider initially two electrons that started out at different times such that one of them has arrived at a point under *a* at the same instant that the other has reached a point under *b*, the potential distribution at that instant being as represented. The electron under *b* will be deflected (say) downward, while that under *a* will be deflected upward. A half period later the first electron will be under *c* which is then minus and will be further deflected downward. The second electron will, at that instant, have reached *b* which is then positive and will be further deflected upward. Each turn of the coil acts on these two electrons to augment their initial deflection in the same direction with the result that one is driven against anode 11 and the other against anode 12. From the course of these two electrons it is seen that in reality the electron stream is made to oscillate up and down at the frequency of the standing wave in coil 17 and to impinge alternately on the anodes 11 and 12, thus setting up an amplified output wave in the utilization circuit 15, 16. The output may be shielded from the input as indicated by shield 20 which may be considered as enclosing to a sufficient extent the part of the apparatus to the right or to the left of the line at which it is shown in the figure. Thus, an amplifier without feed-back is secured.

An apparatus similar to that of Fig. 2 but provided with feed-back for the generation of oscillations is shown in Fig. 3. In this figure the various elements of the circuit of Fig. 2 can be identified by the use of similar reference characters. The source of waves 18, is, however, omitted and in its stead the terminals of coil 17 are connected across the anodes by leads 21. A tuning condenser 20 may be used.

The operation is essentially the same as that of the Fig. 2 circuit, except that the wave producing the field in coil 17 is obtained from the output instead of from an external source. A transient in the output circuit or in coil 17 may be assumed to deflect electrons toward anode 11 or 12 and produce a current change in the anode circuit which is in a direction to sustain the transient and, because of the amplifying action, to augment the original transient effect. Oscillations, therefore, build up to a value determined by the gains and losses in the system as in the case of the usual oscillator.

In Fig. 4 the oscillograph tube 25 may be of usual type suitably rendered luminescent over its larger end and provided with the usual cathode 4, accelerating and concentrating electrodes 26, 27. Coil 28 surrounds the tube and may be shielded from external fields by copper cylinder 29 which may conveniently form one terminal of the coil. A similar shield can be used for the coils shown in Figs. 1, 2 and 3 if desired. In one case the coil 28 had a diameter of 4.5 inches and a distance between turns of 0.49 inch. The source 30 was an oscillator of 72 centimeter wave-length. Each turn of coil 28 was, therefore, half a wave-length. The spot at the center of the screen changed, upon application of the waves to coil 28 from source 30, to a straight line which became as long as 1½ inches even with the application of quite weak oscillations. Varying the strength of the applied oscillations varied the length of the image line. The anode-cathode voltage on the cathode-ray tube for the straight line pattern was 300 volts. Changing the voltage successively to 275 and to 250 produced a rotation of the image and changed it from a line to an ellipse of successively greater minor axis. The existence of the straight line pattern showed that at 300 volts potential the electron travel in half a period was the distance from one turn to the next. Standing waves were being produced with the nodal and anti-nodal points diametrically opposite each other on a diameter of the same angular position as the line pattern.

The condition stated in connection with Fig. 1 was that the wave in any one complete turn was in the same phase and that there was a phase reversal from turn to turn. In a coil wound as in Fig. 1, this condition imposes a limit on the diameter of coil and tube that can be used. Various expedients can, however, be employed to relieve this restriction. In Fig. 5, for example, a coil having a circumference equal to a whole wave-length is shown. The first half of a given turn carries a current of a given phase. At the end of the half turn a loop of half a wave-length is introduced so that the current of the opposite phase is carried in the loop. The other half-turn, therefore, carries current in the same phase as the first half-turn. By including one phase-reversing loop per turn, as shown, the phase in each turn is kept the same but is reversed from one turn to the next.

In Fig. 6, a similar construction is used except that each turn is one and a half wave-lengths in circumference. The broken line 31 is the line of potential nodes. Starting from this line and following around any complete turn, it will be seen that each third of the turn represents a half cycle of the same sign with the intervening two phase-reversing loops.

Fig. 7 shows a winding structure which is a modification of that shown in Fig. 2. Instead of winding the coil as a single wire as in the case of coil 17 of Fig. 2, the coil may consist of a pair of wires wound as a pair into a coil 17' and ending in a short-circuited Lecher wire 34. With this type of winding, the circumference of the coil is a half wave-length long (as in Fig. 2) but the distance an electron must travel to realize the action described with reference to Fig. 2 is twice the distance between turns. The distribution of potentials along the coil is as shown by the plus and minus signs.

With the examples that have been given of preferred forms of embodiment, various modifications will naturally suggest themselves to those skilled in the art, and it is intended that the invention is not to be limited to the specific forms disclosed but only by the scope of the claims.

What is claimed is:

1. The combination of a space discharge tube having a cathode, an anode and a source of anode voltage, of a coil surrounding the space traversed by electrons between the cathode and anode, and having its axis in the direction of the electron travel, means producing standing waves in said coil, the frequency of which is related to the coil dimensions such that alternate turns of the coil carry currents of opposite phase, and the spacing of coil turns being related to the electron velocity such that an electron travels the distance from one turn to the next in half a period of the waves in said coil.

2. The combination specified in claim 1, said tube having a pair of anodes spaced from each other at the end of the tube opposite the cathode, a work circuit differentially connected to said anodes, and a source of input waves connected to said coil.

3. The combination specified in claim 1, in which a pair of anodes is provided at the anode end of the tube, a work circuit differentially connected to said anodes, and a feed-back connection from said work anodes to said coil to enable the production of sustained oscillations.

4. The combination comprising an elongated tube having a cathode at one end and an anode at the opposite end, means including a source of potential for imparting velocity to electrons down the tube toward the anode, a coil surrounding the electron path within the tube, means producing standing waves in said coil of a wave-length to cause a turn-to-turn reversal of phase in the coil, and the distance between turns being related to the velocity of electrons in the tube to cause an electron to deliver energy to turn after turn of the coil in phase relation such as to tend to sustain the waves in the coil.

5. An amplifier comprising an elongated tube having a cathode near one end and anodes near the other end, means to impart velocity to the electrons down the tube toward the anodes, a coil surrounding the path of electron travel within the tube, a source of input waves connected to said coil, the frequency of said waves, the diameter of the coil, the spacing between turns and the electron velocity being all related such that a given electron in the electron stream is acted on similarly by each successive turn of the coil and the stream is deflected alternately to and away from one or more of said anodes, and an output circuit connected to said anodes.

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