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DIODE OSCILLATOR

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FIG. 1

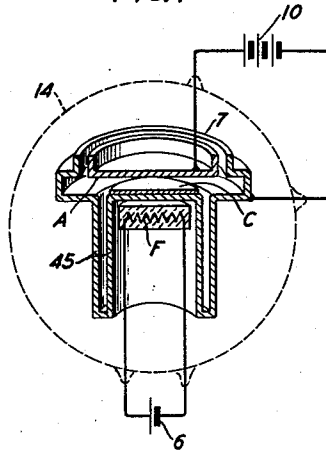
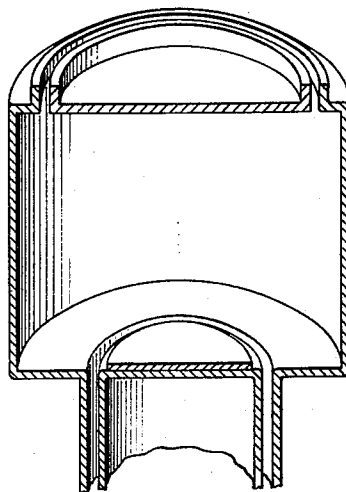


FIG. 2



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DIODE OSCILLATOR

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Original application July 31, 1937, Serial No.
156,647, now Patent No. 2,190,668, dated Feb-
ruary 20, 1940. Divided and this application
February 17, 1940, Serial No. 319,415

7 Claims. (Cl. 250—36)

This invention relates to oscillators where the wave-lengths contemplated may be as short as 10 centimeters and under when desired, therefore extending to a wave-length range in which, before the advent of the principle here utilized, it has been impracticable to operate. More specifically, the invention relates to what are known in the ultra-short wave art as "diode oscillators" and therefore to the configuration of two electrodes in an evacuated space and the relative mechanical and electrical design of an associated resonating system whereby the organization as a whole is adapted to generate stable waves of the type above indicated.

This application is a division of copending application Serial No. 156,647, filed July 31, 1937, now Patent 2,190,668, issued February 20, 1940.

It is believed that applicant's invention illustrates a maturity of development of diode oscillators not heretofore approximated in the art. The uniqueness and distinctive character of his invention results from his having been able to combine an electron discharge with low-loss circuit configurations and to analyze the prior art circuits and provide quantitative electrical and mechanical dimensions, configurations, etc. as above, so as to be able to predetermine the characteristics of operation of his oscillator.

Accordingly, the principal object of the invention is to provide a stable frequency oscillator capable of generating waves of the order of 10 centimeters and less long.

Subsidiary objects of the invention are to improve the operational characteristics of pre-existing diode oscillators to the extent of providing greater frequency stability, increased energy output and better modulation, and to improve their structures in the interest of increased facility of manufacture, longer life, and adaptability, by extension of the principle to variant alternative forms, to a greater variety of uses.

An object of the invention specific to the species of the parent application here to be disclosed, namely, that illustrated by Fig. 6 of said parent application, is the utilization of an associated resonating system, as characterized in the opening paragraph of this specification, having the characteristics of a wave guide, to the extent that the two electrodes which give the name to the invention are effectively the terminal elements of such a wave guide, this specific form of resonating system being alternative to other forms of resonating systems and cavity resonators disclosed in the parent application and having the specific advantages which char-

acterize generally the use of a wave guide in whatever environment it may be used.

The use, such as above, of the two terms "resonant wave guide" and "cavity resonator" is not to be construed as indicating a fundamental distinction between them for practically either may with propriety be substituted for the other in the language of the specification and appended claims. Cavity resonators may take various shapes and one is that of a section of wave guide which is made short or is partitioned off from the balance of a long guide so that it has resonant properties. The more general term "cavity resonator" is often applied to cavity type structures not obviously in the form of a portion of wave guide or other distinctively named device. However, a resonant wave guide may not necessarily appear to be of the cavity type. This is exemplified by a relatively short wave guide with open ends. It is apparent that all resonant circuits whether of the cavity type termed cavity resonator, a resonant wave guide, a tuned Lecher system, a tuned coaxial line or a combination of lumped inductance and capacity may function similarly in an electric circuit. The wave guide or cavity type of structure possesses several advantages over other forms of resonant circuit, among which are: that radiation is more readily controlled or prevented and that the conducting material is more favorably distributed to minimize circuit resistance.

The order of wave-length within the contemplation of the present invention is such as effectively to annul the operation of the regenerative principle on which most electron discharge oscillators have depended in the past. Neither is the ultra-short wave diode principle analagous to that underlying the operation of negative resistances of the common arc, or the ionized discharge, or the secondary emission type, nor may such prior art types of negative resistance be utilized for the short wave-lengths here in mind. Still further, the principle of the invention is not strictly comparable even with those of the so-called Barkhausen and magnetron oscillators or their variants and derivatives although such types of oscillators perhaps most nearly approximate that of the invention as to order of wave-lengths generated. In a certain aspect of the invention, a diode oscillator of the invention could be thought of as the end product of a radical evolution beginning with the Barkhausen oscillator and involving an avoidance of the usual negative plate thereof and a violent reorganization of the resultant two electrodes and the elec-

trical and mechanical dimensions of their immediately associated structures.

More specifically, the diode oscillator of the invention comprises two electrodes in an evacuated space, the negative resistance imputed to the space therebetween being a function of certain precise conditions affecting the electrodes. For instance, there must be a uniform flow of electrons from one such electrode, which simulates to that extent the function of the usual electron tube cathode, to the other electrode on which a positive potential is impressed relatively to the cathode in order to promote this flow, said positive electrode therefore simulating the usual electron tube anode. The requisite uniformity of electron flow requires practically that the emitting surface of the cathode be smooth and relatively extensive as distinguished from, for example, a small filamentary cathode associated with a planar anode. This ultimately means that the cathode must have a shape of the same type as that of the anode, both constituting regular, smooth, relatively flat surfaces. To promote further the uniform flow, the anode surface should be very closely equidistant at all points from that of the cathode, that is, the two surfaces should be uniformly spaced.

Concomitantly with the above purely structural requisites there must be the condition, brought about by the appropriate relative design of said structure and the potentials applied thereto, that the transit time of the electrons between the two electrodes is approximately 5, 9, 13, 17, etc. quarter-cycles of the high frequency current which it is intended to produce.

A negative resistance being provided by the satisfaction of the above considerations, a self-contained, or self-excited oscillator results from the further extension of the principle to the design of a cooperating external circuit and structure. For instance, the interelectrode space, above cited as the negative resistance, strictly partakes of the electrical characteristics of a circuit constituted by a negative resistance and a capacitance in series; therefore, the perpetuation of the oscillations implied by the negative resistance, per se, requires that this capacitance be constituted a part of a series resonant circuit the resistance of which, that is, the positive resistance of which, is less than the negative resistance imputed to the electrode space.

The consummation of the invention, therefore, results from the design of an inductive reactance so electrically dimensioned as to resonate with the interelectrode capacitance and which is almost wholly devoid of resistance. The inductor of said reactance, because of this necessary condition, that is, because of its very high ratio of reactance to resistance at the oscillation frequency which ratio is sometimes denominated "Q", tends to be very distinctive not only in its design but also in its physical appearance. In the form of the invention here to be disclosed, the diode electrodes are constituted by the uniformly spaced opposed end surfaces of a closed hollow disc-like structure, the remaining structure of which is constituted by the connecting side wall of the disc. The structure is here characterized as "disc-like," consistently with the specific illustration, Fig. 6 of the parent application. However, the axial length of the disc, that is, the uniform spacing of the electrodes, is not critical except as it must conform with the physical laws prescribing the transit time to be enunciated a little later. Therefore such axial

length might be such as to change the appearance of the structure from disc-like to that more nearly approaching an electrical conduit or rigid transmission line and therefore a conventionalized "wave guide." Regardless of the spacing or the precise configuration, the structure does have the electrical characteristic of a wave guide so that, to all intent and purposes the invention, according to this species, is a diode oscillator in which the electrodes constitute the terminal elements of the wave guide, the wave guide providing the requisite resonating system.

In the broadest aspect of the invention, an electron stream flows through an evacuated region in a conducting cavity (effectively a wave guide) which is resonant at the desired frequency, and the electron speed is such that the time which is required for the electrons to traverse the wave guide is approximately $1\frac{1}{4}$, $2\frac{1}{4}$, $3\frac{1}{4}$, etc. cycles.

Other features of the invention are illustrated in the accompanying drawings in which:

Fig. 1 is a duplicate of Fig. 6 of the parent application and illustrates, partially diagrammatically and in section, the above characterized embodiment of the invention as expressed in a diode oscillator of the type in which the resonating system comprises effectively a resonant wave guide with the diode electrodes constituting the opposed end surfaces whereby the electrons traverse the wave guide in a direction parallel to its axis; and

Fig. 2 is an alternative disclosure of the wave guide portion of the structure of Fig. 1 extended in an axial direction to indicate that, without any change in essential function or structure, the resonating system may have relative dimensions more nearly approximating the conventional idea of a wave guide although, as has been indicated, there is nothing in the theory or application of wave guides limiting its relative dimensions in any way. For the above indicated reasons this Fig. 2 distinctly does not constitute new matter or affect the characterization as above of this application as a division of the parent application from which Fig. 1 has been bodily taken.

The general method of attack in the development of a diode within which a negative resistance occurs, and the relative development of associated circuits and structure so as to perpetuate the oscillations implied by the negative resistance involves, as a first step, the finding of the power generated by the negative resistance, assuming an arbitrary magnitude for the high frequency current through it, and then the computing of the power dissipated in all of the positive resistances of the system by the currents flowing through them. For the production of oscillations this latter power must, of course, be less than the former. There are other necessary conditions and necessary steps in the development.

Preliminarily to a detailed description of the species of invention here to be disclosed, and in order to simplify the disclosure and economize the bulk of its presentation it will be related to such parts of the parent application as apply to the fundamental aspects of diode oscillators without regard to a particular species and also to the type of diode oscillator here disclosed and also disclosed in several other specific forms in the parent application, namely, the plane electrode type. This type has been denominated in the parent case by the term "plane electrode," as distinguished, for instance, from the "cylindrical

electrode" species, although as is evident from the parent application disclosure, it is not so important that the electrodes individually be "plane" as it is that they should be uniformly spaced. The electrodes in the present disclosed species, constituting opposed end surfaces of a resonant wave guide structure, do not have to be other than uniformly spaced, although the simplest expression of the principle of uniform spacing is a system of parallel plane electrodes. Fig. 1 of the parent application is one instance of this plane electrode type of diode oscillator and the analysis used in the parent application, as illustrative of diode oscillators as a whole, while for convenience adapted for this particular type of diode, is applicable to the like type of diode oscillator here disclosed except as will be indicated later and therefore need not be repeated here except in summary.

It has been found that a uniform stream of electrons moving between two equidistant or uniformly spaced surfaces, one of which is an effective cathode element and the other an effective anode element, may exhibit the property of negative resistance within a series of high frequency bands. An essential condition has been pointed out in the statement of invention having to do with a critical value of transit time in terms of the cycle time of the resultant generated wave. This property has been used by applicant for the production of oscillations having a wave-length of the order of 10 centimeters and is suitable for the production of considerably shorter or longer waves.

Between these two surfaces, constituting the diode electrodes, there is, of course, a capacitance besides the negative resistance above described, the value of this capacitance being determined by the dimensions and spacing of the electrodes. The existence of the negative resistance implies the possibility of developing oscillations, it being further required therefore that there be a co-operating inductance effectively constituting with the capacitance between said electrodes a tuned or resonant circuit. This circuit would, of course, tend to have some resistance but it must be sufficiently small as not to annul the effective negative resistance of the diode space. The matter of so constituting this effective inductance so as to have this attribute and to cooperate in the constitution of an effective tuned circuit of the requisite high frequency, is a matter of considerable difficulty. The inductance tends to assume the characteristics of a rigid tank or capsule structure; in the particular species to be here disclosed, it has more nearly the form of a hollow disc or resonant wave guide. As has been pointed out it has all of the electrical characteristics of such a wave guide or wave guide section, which it is in fact. While ideally, the resultant structure is completely closed, so as to avoid wastage of energy by radiation into space, for practical reasons there must be a division to enable a difference of potential to be set up between portions of the structure constituting the diode electrodes. By particular design the effect of so breaking the continuity of the physical structure may be minimized or, as in certain species of the invention not to be disclosed herein, an output circuit may be provided to receive the energy of the diode oscillator alternatively to the radiation of energy from the openings implied by such break in the continuity.

The complete analysis of the plane electrode diode oscillator leading up to the determination

of the requisite physical and electrical dimensions of the diode oscillator is given in the parent application. Accordingly it will not be repeated in this application except, as above indicated, when occasion is offered to qualify it to the extent of making it specifically applicable to the particular type of diode oscillator disclosed and claimed in this application. The detailed description of this species will now be undertaken.

Fig. 1 shows diagrammatically a form of parallel plane diode which, as a class, may be considered distinctive from the class to which belong the modifications illustrated by the early numbered figures of the parent application (which, however, belong to the same broad class of diode oscillators) in that there is less of an appearance, but not less of an actuality, of an effective resonant circuit or cavity comprising the electrodes and their immediately associated structure. This class of diode oscillator has sometimes been denominated "disc diode oscillator," signifying that in their simple forms these diode oscillators consist merely of two parallel discs, one of which constitutes the electron emitting cathode and the other the anode. As before, the electron discharge occurs between the cathode surface C and the opposing anode surface A, so that there exists a negative resistance in series with a capacitance between the two surfaces. This impedance configuration is continuous for each and every element of area of the electron discharge and, taken in conjunction with the impedance properties which the surfaces themselves present to tangential current flow, forms the admittance and impedance elements of an electrical transmission line, having in this instance extension in two dimensions as distinguished from the more familiar transmission line having its extension in one dimension only. In Fig. 1 the significance of the structure of the various other parts is believed to be obvious from a consideration of the specification of the parent application, except as to be pointed out.

Fig. 2 is introduced into this drawing as tending to show the proportions of the structure above denominated "disc" may be varied without violation of any teaching of the invention. In this figure there is reproduced, without labeling, the disc structure of Fig. 1 extended in axial length to approximate the appearance of a wave guide as the public tends to mentally picture such wave guide. The two figures taken together therefore indicate the complete independence from rigid limitations of physical proportions within the limitations imposed by theoretical considerations that have been pointed out. As a matter of fact these theoretical considerations may very easily make possible a structure having the approximate proportions of those shown in this Fig. 2. The details of both figures will now be explained, with particular reference to Fig. 1 because the labeling is confined thereto.

What is here termed "disc" or "wave guide" is constituted by the above described cathode and anode surfaces. Necessarily, the diameters of these two surfaces are equal, although there is nothing very critical governing this relation. When the diameter of the discs is a certain proportion of the free-space wave-length λ , the discs themselves, in view of the extended properties of transmission lines in two dimensions as described in the above paragraph, constitute a resonant system and determine the oscillation frequency. In the specific example illustrated

in this Fig. 1, the disc diameter is determined by the root of the Bessel function

$$J_0\left(\frac{2\pi r}{\lambda}\right)=0$$

which here replaces Equation 1 of the parent application for the tuning relation, so that the diameter may be either 0.766, 1.757, 2.755, etc. times the wave-length. A table which shows the first 12 roots of J_0 is given on page 286 of "Fourier's Series and Spherical Harmonics" by W. E. Byerly, Ginn and Co. 1893. It is quite practicable to employ open-circuited discs instead of the near short-circuited discs disclosed in Fig. 1, as by using the structure comprising effectively merely the opposed cathode and anode members, by use of a slightly different Bessel function to determine the diameter in terms of wave-length, but in this case the radiation must be confined by a wave guide or other shielding shell, as otherwise the radiation resistance may be so high as to stop oscillations. Because the losses are relatively smaller for small discs the diameter, in the form as shown in Fig. 1, is usually made 0.766 times the wave-length.

It is noted that the gap 7, which effectively conductively isolates the cathode and anode shown in Fig. 1, is remote from the rim of the capsule or disc and is therefore located where the lines of force are substantially perpendicular to the gap, so that only a small amount of radiation can escape.

Another distinctive feature of the diode oscillator of Fig. 1 is the half wave-length line constituted by the structure 45 which surrounds the emitting cathode surface. This insures that only the coated portion of the lower disc operates at high temperature and hence that electron emission can take place only in the region intended so that the electron stream tends to possess the uniform characteristics that are favorable to the production of stable diode oscillations. The purpose of making the line exactly a half wave-length long, rather than some other dimension in terms of wave-length is to prevent this line from introducing reactance into the circuit and thereby upsetting the resonance calculations based on the disc diameters. This is in accordance with now well-known theory of transmission lines of this order of length. Some resistance is unavoidably introduced into the circuit by the line, but can be reduced by making the emitting surface as large in diameter as possible. This has the twofold advantage of reducing the resistance which is introduced by the half wave line, the introduced resistance, as is well known, being less when the diameter ratio of a concentric line is nearly unity, and increasing the drive from the electrons.

In the disc diode of Fig. 1, the design formulas, (6) to (11) of the parent specification naturally require modification because of the obvious extensiveness of the dimensions in Fig. 1 in comparison with the free-space wave-length. As those who are used to dealing with the solution of the fundamental field equations as applied to cylindrical structures may readily verify, the oscillation conditions for the structure of Fig. 1 are given by the equation

$$|r_p| > 0.00233 \sqrt{\mu\sigma\lambda^2} J_2\left(\frac{\beta\sigma}{\beta c}\right) \left[\frac{J_1^2(\beta a)}{J_0^2(\beta c) + J_1^2(\beta c)} \right] \left[1 + \frac{\lambda c}{2a^2} \frac{J_1^2(\beta c)}{J_1^2(\beta a)} \right]$$

where a is the disc radius, c is the cathode radius, 75

β is $2\pi/\lambda$, and J_0 and J_1 are the usual Bessel functions of zero and first order, respectively, as defined on page 219 in the Byerly reference given above, all dimensions being in centimeters. The quantity $|r_p|$ is merely the magnitude of the negative resistance, Equation 6 of the parent specification, reckoned per unit area, namely,

$$|r_p| = 1.4\lambda^2 I_0 10^{-3} \left(\frac{4n+1}{5} \right)$$

In the first above equation the resistance introduced by the half-wave line in Fig. 1 is represented by the second term within the last pair of brackets and may become the dominating loss. This, of course, suggests immediately the omission of the line, and in cases where cathode heating power is not an important practical item, the half-wave line may well be omitted, as its function is merely that of confining the heat to the coated portion of the lower disc in Fig. 1. In the equation no allowance has been made for radiation resistance which may perform the function of a load resistance, and should then be proportioned to absorb the maximum power.

These algebraic relations apply particularly to the structure of the approximate geometry of Fig. 1, and under the restriction that the axial height (that is the height along the electron discharge path) of the cavity is small compared with the wave length. As explained above, this is not necessarily so, and in Fig. 2 which is drawn to emphasize the more general shape, a simple relation expresses the total electron current needed to produce oscillations. Thus, letting I_T represent this total electron current in amperes, and h represent the axial height in centimeters, and disregarding losses in the cathode coaxial sleeve, and assuming the entire structure to be composed of metallic conducting material at the same temperature, we have the following convenient expression:

$$I_T > \frac{200}{10^3} \left(\frac{5}{4n+1} \right) \left(\frac{1+2.62 \frac{h}{\lambda}}{\sqrt{\lambda}} \right) \sqrt{\mu I_T}$$

What is claimed is:

1. A diode oscillator comprising two uniformly spaced plane surfaces in an evacuated space and at least in part constituting cathode and anode elements, said surfaces also in effect constituting the opposed end surfaces of a cavity resonator otherwise constituted by a connecting single cylindrical surface, means insulatingly dividing said resonator whereby a difference of potential may be maintained between said cathode and anode elements, said end surfaces of the resonator being so dimensioned that it tends to resonate at such a periodicity that the electron transit time between said end surfaces in relation to said periodicity is appropriate to produce negative resistance between said end surfaces, the positive resistance therebetween being less than said negative resistance.

2. The diode oscillator specified in claim 1 in which said diode surfaces are circular and each has a diameter determined by a root of the Bessel function

$$J_0\left(\frac{2\pi r}{\lambda}\right)=0$$

3. A diode oscillator comprising a cavity resonator of a single cylinder form, uniformly spaced, opposed, planar end closure elements for said resonator, and means electrically segregating desired portions of said end members from the re-

maintaining portions thereof and further means constituting said segregated portions the cathode and anode elements of a diode oscillator.

4. The diode oscillator specified in claim 3 in which the means for segregating the anode electrode from the remaining portion of the corresponding end element is, in electrical effect, a closed gap extending through said end element and remote from the edge thereof where the lines of force are substantially perpendicular to the gap, whereby to minimize radiation.

5. The diode oscillator specified in claim 3 in which the means for segregating the cathode element from the remaining portion of the corresponding resonator end element comprises a closed gap extending through said end element, the portions of said end element separated by said gap being connected by an effective half wave-length transmission line.

6. A diode oscillator comprising a cylindrical surface bounded by plane end surfaces normal to the generatrix of said surface, means constituting said end surfaces at least in part cathode and anode surfaces, whereby said end surfaces with the cylindrical connecting surface constitute a resonant wave guide structure, means enclosing said structure in an evacuated space, means in-

cludingly dividing said wave guide structure whereby a difference of potential may be maintained between said cathode and anode surfaces, said wave guide end surfaces being so dimensioned that the wave guide tends to resonate at such a periodicity that the electron transit time between said surfaces in relation to said periodicity is appropriate to produce negative resistance between said surfaces, the positive resistance of the wave guide structure being less than said negative resistance.

7. A diode oscillator comprising two conductive elements each in turn comprising at least in part a planar portion uniformly spaced from the corresponding portion of the other said element, means constituting said planar portions, at least in part, anode and cathode elements, said planar portions being so dimensioned with reference to a desired frequency, exclusively of all other dimensions, that the resultant structure tends to resonate at such a periodicity that the electron transit time between said anode and cathode elements in relation to said periodicity is appropriate to produce negative resistance therebetween, the positive resistance therebetween being less than said negative resistance.

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