March 17, 1942. L. TONKS 2,276,806

HIGH FREQUENCY APPARATUS

Filed July 26, 1940 2 Sheets-Sheet 1

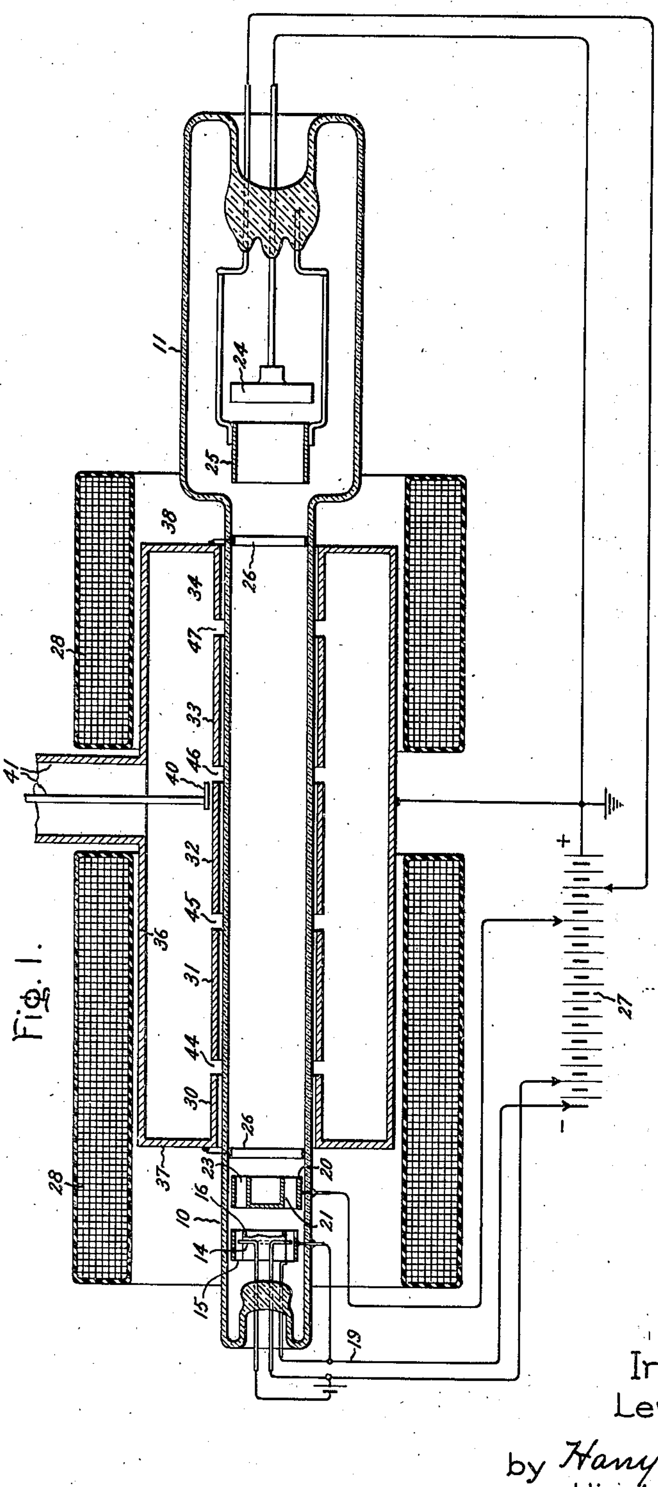

Fig. 1.

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Fig. 2.

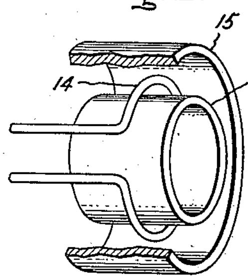


Fig. 3.

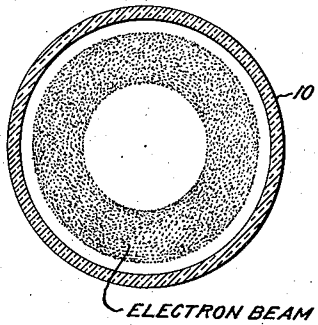


Fig. 4.

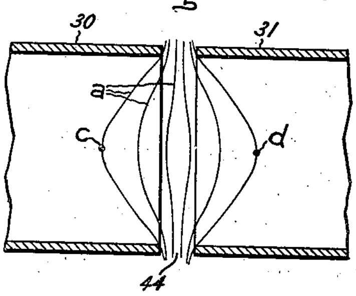


Fig. 5.

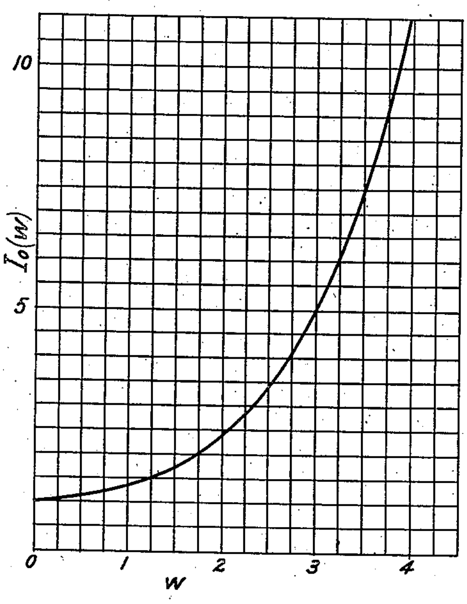
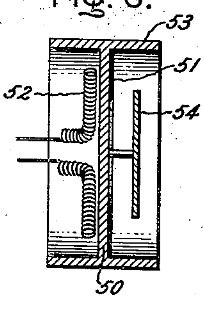


Fig. 6.



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2,276,806

UNITED STATES PATENT OFFICE

2,276,806

HIGH FREQUENCY APPARATUS

Lewi Tonks, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application July 26, 1940, Serial No. 347,744

2 Claims. (Cl. 250—27)

The invention described herein relates to high frequency apparatus and more particularly to improvements in electronic devices of the type in which high frequency effects are obtained by the use of a pencil-like beam of electrons projected through an evacuated space.

In application S. N. 211,123, filed June 1, 1938, and in application S. N. 276,172, filed May 27, 1939, Patent No. 2,222,902, November 26, 1940, both in the name of W. C. Hahn, various devices of the character above specified are described in which a concentrated beam of electrons is projected successively through a series of aligned tubular conductive members. The members referred to are mutually spaced to provide gaps between them, and potentials are impressed across the gaps in such fashion as to produce high frequency variations in the beam. By appropriate correlation of the dimensions of the members with the desired operating conditions of the system it is found possible with the arrangement referred to to produce amplification effects and other forms of energy conversion ordinarily very difficult of attainment at high frequencies. It is to this class of apparatus that my present invention especially pertains, and it is the purpose of the invention to improve the operation of such apparatus.

It is a more specific object of the invention to increase the effectiveness of cooperation of an electrode system such as that described in the preceding paragraph with the electron beam with which the electrodes coact. To this end it is proposed to provide means for increasing the relative electron density of the beam at its lateral boundaries; that is, at the region where the electrons are in closest proximity to the electrode structure. This may be done, for example, by the provision at the electron source of means for causing the beam to possess an annular cross-section. The advantages of such an arrangement and the reasons for them will be set forth in detail in the following.

The features which I desire to protect herein are pointed out with particularity in the appended claims. The invention itself, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the drawings, in which Fig. 1 represents a longitudinal section of an electronic device suitably embodying the invention; Fig. 2 is an enlarged view of the cathode of the device illustrated in Fig. 1; Fig. 3 illustrates the cross section of an electron stream produced by a cathode such as that shown in Fig. 2; Fig. 4 is a view useful in explaining the invention; Fig. 5 is a graphical representation, and Fig. 6 illustrates a modification of the cathode structure of the device of Fig. 1.

Referring particularly to Fig. 1, the invention is illustrated in connection wtih an electronic device adapted to be used as an oscillator at ultra high frequencies. The oscillator itself, apart from the particular improvement to be described herein, is the invention of W. C. Hahn and is fully disclosed and claimed by him in his aforesaid application S. N. 276,172.

The arrangement shown comprises an electron beam tube which includes an evacuated envelope having an elongated tubular portion 10. This portion, which is of uniform diameter throughout its length, connects at one end with an enlarged electrode-containing portion 11. The envelope may suitably consist of quartz or other low loss insulating material.

At the left end of the tubular envelope 10 there is provided an electron source comprising a directly heated filament 14 (Fig. 2) which is bent into a loop in a plane transverse to the axis of the envelope. The cathode loop is positioned in an annular space provided between two concentric cylindrical parts 15 and 16 which serve as focusing elements for confining the electrons emitted by the cathode to an annular beam. (This feature, which constitutes an important aspect of my invention, will be referred to in greater detail below.) The elements 15 and 16 may be biased a few volts positive or negative with respect to the cathode, as required to give the desired focusing action. The elements may either be connected to separate voltage sources or connected to a common source by a conductor 19 as shown in Fig. 1.

In order to accelerate the electrons emitted by the cathode 14 to a desired extent there is provided an accelerating electrode comprising a second pair of concentric cylinders which are respectively indicated by the numerals 20 and 21. These elements are sufficiently spaced from one another to provide an annular electron-permeable passage 23 between them and are jointly biased to a suitable positive potential, say several hundred volts. After its issuance from the passage 23, the beam is caused to pass through a region of fixed potential, the limits of which are defined by a pair of conducting rings 26.

At the right-hand end of the envelope, there is provided an anode 24 which serves to collect the electron beam after it has traversed the tubular envelope portion 10. A ring-like electrode

25 in the nature of a suppressor grid serves to prevent secondary electrons emitted by the anode 24 from returning to the discharge space. In operating the device the anode may be maintained at a potential one to several thousand volts above the cathode and the suppressor element 25 may be biased fifty to one hundred volts negative with respect to the anode. These potential relationships are established by means of a suitable voltage source, which is conventionally represented as a battery 27. In order to maintain the beam in focus during its passage along the axis of the envelope, one may employ magnetic focusing coils such as those which are indicated by the numeral 28.

The combination of elements so far described comprises means for projecting a unidirectional beam of electrons through the discharge envellope. Outside the envelope there is provided an electrode system for generating ultra-high frequency oscillations by reaction with the beam. The electrodes which make up this system include a series of sequentially arranged tubular conductive elements which surround the envelope and which are respectively numbered 30 to 34. These elements are concentrically enclosed by a one-piece tubular structure 36 which is terminally connected with the end ones of the elements by means of transversely extending annular parts 37 and 38.

It has been shown in the Hahn application S. N. 276,172, previously referred to, that an electrode system such as that described above may be made to develop self-sustained oscillations provided the electron transit time through the elements 30 to 34 is properly correlated to the desired frequency of operation of the oscillator and provided further, that the lumped capacitance existing across the various gaps which separate the elements is properly related to the distributed constants of the elements and the surrounding conductive shell 36. When the foregoing requirements are complied with the electrode structure acts as a resonant standing wave system which is maintained in excited condition by its reaction with the beam at the inter-electrode gaps. Power may be taken from the system for external utilization by the provision of a member 40 which is capacitively coupled to one of the electrode elements near its extremity and which is associated with a concentric conductor transmission line 41 appropriate for the transfer of high frequency energy. The mechanism by which self-sustained operation of the system described above is accomplished may be outlined briefly as follows:

Let it be assumed that the system is initially brought to an excited condition by some unspecified means. Under these conditions cyclically varying potentials appear across the various gaps 44 to 47 which respectively separate the elements 30 to 34. Consequently, electrons traversing the first of these gaps are variously effected in velocity depending upon the part of the voltage cycle at which they reach the gap. That is to say, electrons which reach the gap when the gradients across it are in such direction as to produce a retarding effect are decelerated, while other electrons, arriving at a different time, are accelerated. As a result, the portion of the beam leaving the gap is velocity modulated in the sense that it exhibits recurrent variations of electron velocity from point to point along its length.

In passing through the relatively field-free space which is provided within the confines of the electrode 31, a beam which is velocity modulated as above specified, will undergo certain changes in condition. Specifically, sorting or bunching of electrons will occur as a result of the tendency of the faster moving electrons to overtake those of lower velocity. As a result, by the time the stream reaches the gap 45 it will be characterized by recurrent irregularities in electron density. Moreover, for reasons which need not be elaborated here, the charge density variations thus produced may be of a higher order of magnitude than the velocity variations by which they are produced. As a consequence, a mechanism is provided by which energy may be supplied from the electron stream to the oscillating system at the gaps 45, 46 and 47 in such fashion as to sustain the oscillations of the system, this action being a result of the ability of the charge density modulated stream as it traverses the gaps to induce high frequency currents in the electrode elements. With a proper arrangement and correlation of the various parts it is readily possible to operate under such conditions that considerable power may be taken from the system by means of the coupling element 40 without damping the system below the point of stable operation.

It may be shown that satisfactory functioning of a system such as that described above requires that the period of electron dwell in the various regions of changing field shall be very small with respect to a complete cycle of the potential variation. In connection with an arrangement such as that illustrated in Fig. 1 this condition is well realized near the outer boundary of the electron stream where the extent of the electric field is definitely limited by the proximity of the electrode elements. However, near the center of the stream, where fringing of the field occurs, a considerable departure from optimum conditions may exist. This factor may be more clearly understood by reference to the illustration of Fig. 4, which shows in aproximate fashion the contour of the equipotential lines *a* which exist between two of the electrode elements, say, the elements 30 and 31. It will be seen that at and near the axis of the system the region in which definite potential gradients exist is quite long, so that the electron transit time therethrough may include an appreciable portion of a complete cycle of the potential variation. As a result, it is found that in so far as electrons projected along the axis of the electrode system are concerned, the possibility of obtaining effective coaction with the electrode system is substantially reduced. The reason for this may be seen in connection with a special case if we assume that the dimensions of the parts are such that the electron transit time between points *c* and *d* (Fig. 4) happens to correspond precisely to a complete cycle at the operating frequency. Under these conditions it will be readily understood that the acceleration imparted to an axially moving electron during one part of its travel through the constantly changing field is largely neutralized by the deceleration which the same electron experiences during the remainder of its travel. Consequently, the net result is that the electron velocity is only slightly changed—a condition directly opposite to that necessary for the occurrence of effective energy exchange between the electrons and the electrode system. On the other hand, an electron whose path lies close to the gap 44 between the elements 30 and 31 traverses the changing field in a fraction of a cycle and therefore experiences a large change in velocity.

An idea of the quantitative significance of the matters just referred to can be obtained from a consideration of the following approximate formula:

$$dv=\frac{-eV}{mv}\cdot\frac{I_0(2\pi x/(BL))}{I_0(2\pi a/(BL))} \qquad (1)$$

where e is the electronic charge, m is the electronic mass, v is the beam velocity, V is the signal on a gap, dv is the velocity modulation amplitude for electrons at the radial distance x from the tube axis, L is the free space wave length corresponding to the signal frequency, B is the ratio of beam velocity to light velocity, and a is the internal radius of the metal tube enclosing the beam space, so that $a-x$ is the closest approach of the electrons to the gap. $I_0(w)$ is a function whose behaviour is shown in Fig 5.

For comparison with Equation 1 it is to be noted that the maximum velocity modulation dv_m which is attainable in a gap is given by

$$dv_m=-\frac{eV}{mv} \qquad (2)$$

so that what may be called the efficacy of the gap in producing velocity modulation is

$$\frac{dv}{dv_m}=\frac{I_0(2\pi x/BL)}{I_0(2\pi a/BL)} \qquad (3)$$

For an electron grazing the enclosing tube ($x=a$), the gap efficacy is unity, that is, it induces the maximum velocity modulation. With respect to an electron which is appreciably displaced from the tube, the gap efficacy is obviously correspondingly less than unity.

As an illustration of the advantage of a hollow beam, suppose it is desired to use a 15 cm. (L) wave with a beam voltage of 10,000 volts ($B=1/5$) in a 1 cm. (a) radius conductor. Then

$$\frac{2\pi a}{BL}=2.1$$

$$I_0\left(\frac{2\pi a}{BL}\right)=2.4 \quad \text{(from Fig. 5)}$$

Substituting this value in Equation 3 it appears that the efficacy of the gap is 0.42 for an axial electron ($x=o$) and 0.69 for an electron displaced from the axis by a distance $0.7a$ (i. e. $x=0.7$). The ratio between these quantities

$$\left(\frac{.69}{.42}=1.64\right)$$

is indicative of the difference in effectiveness of reaction of the electrode structure on the two radially displaced electrons. In determining the overall effectiveness of the energy conversion system, this ratio factor should be squared since it must be taken into account both at the input and output gaps. Consequently, the effectiveness of the axial electron is only about one-third of that of the electron which is displaced from the axis of the tube by a distance equal to $0.7a$. As a result of these considerations, it may be said that the effectiveness of the electric fields in producing the desired energy conversion effects by reaction with the electron stream varies as an inverse function of the distance of the electrons acted upon from the boundary of the stream or, alternatively, from the inner surfaces of the electrode elements.

It might be thought that the objectionable aspects of the effects outlined in the foregoing might be overcome in connection with the usual form of electron beam device simply by increasing the total current in the beam so as to offset the fact that a portion of the stream is rather remote from the electrode elements. Actually this is not a desirable solution because it requires the expenditure of more energy in the cathode to give the larger electron current. Also, the relation between the electron beam and the high frequency exciting circuit is such as to require greater excitation of this circuit for increased values of beam current and a constant useful output of energy, thus resulting in reduced operating efficiency. In accordance with my present invention, however, more effective coaction between the components of the electron stream and the electrode structure is obtained by the provision of means for causing the electron density in the stream near its outer boundary to be materially greater than that at the center of the stream. One way of accomplishing this result has already been described and consists in the use of an electron source of such character as to produce an electron stream of annular cross section. Other means not involving the total elimination of electrons from the central portion of the beam may very well be used. In any case, the improvement realized is a function and consequence of bringing as large a proportion of the stream as possible into close proximity to the electrode elements by which modulation of the stream is produced.

One alternative form of cathode which may be advantageously used in some cases is illustrated in Fig. 6. As will be seen from this figure, the cathode comprises a conductive disk **50** which is provided on one surface thereof with an annular coating **51** of electron emissive material such as alkaline earth oxide or the like. The other side of the disk is heated in a region generally coextensive with the layer **51** by means of a coiled filamentary heater such as is shown at **52**. Focusing of the electrons emitted by the layer **51** in response to heating thereof is accomplished by means of a tubular conductive part **53** which concentrically bounds the disk **50** and by a circular element **54** which is somewhat displaced from the disk **50**. The elements **53** and **54** are at the same potential as the emitting surface and therefore tend to prevent inward or outward spreading of the electron stream as it is projected from the cathode. The annular character of the stream may be preserved during its passage along the axis of the envelope by the use of a magnetic field-producing system such as the coils **28** of Fig. 1.

While I have described the invention in connection with particular structural embodiments thereof, it will be understood that numerous modifications may be made by those skilled in the art, and I, therefore, aim in the appended claims to cover all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In high frequency apparatus, means for producing a compact stream of electrons, a high frequency electrode system wholly outside the path of the stream and comprising spaced conductive parts positioned in proximity to the outer boundary of the stream, high frequency means cooperating with the said electrode system to develop at the gaps between the said conductive parts cyclically varying electric fields which coact

with the stream to produce energy conversion effects representable as an inverse function of the radial distance between the electrons acted upon and the outer stream boundary, and means for maintaining the electron density in the stream greater near the outer boundary of the stream than at the center thereof.

2. In high frequency apparatus, means for producing an electron stream of compact outline, a high frequency electrode system wholly outside the path of the electron stream and comprising a plurality of axially aligned apertured conductive elements which are arranged to be successively traversed by the stream, the inwardly directed surfaces of the elements being relatively close to the outer boundary of the stream and the elements being mutually spaced to provide gaps between them, means cooperating with the said elements to develop at the said gaps cyclically varying electric fields which coact with the stream to produce energy conversion effects representable as an inverse function of the radial distance between the said surfaces of the elements and the electrons acted upon, and means associated with the source of the electron stream for causing the stream to be of annular cross-section.

LEWI TONKS.