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S. G. TOMLIN

2,450,026

THERMIONIC DEVICE FOR USE WITH WAVE GUIDES

Filed Oct. 14, 1942

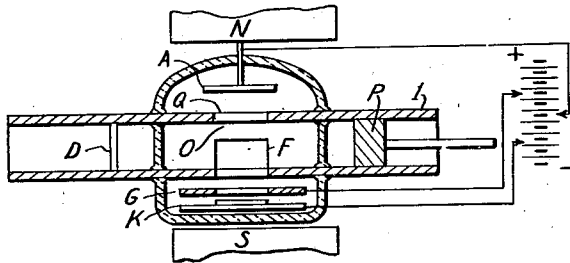


Fig. 1.

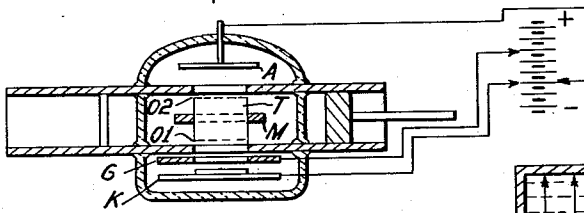


Fig. 2.

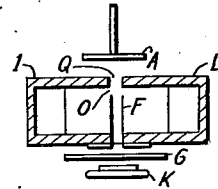


Fig. 1A.

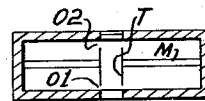


Fig. 2A.

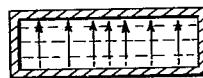


Fig. 2B.

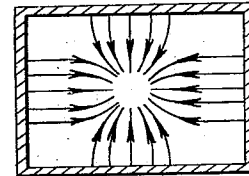


Fig. 3.

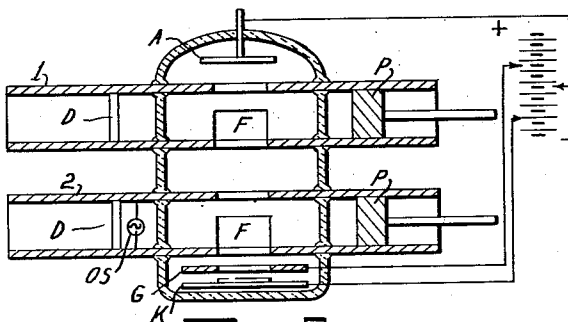


Fig. 5.

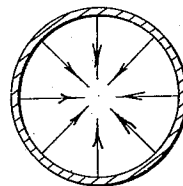


Fig. 4.

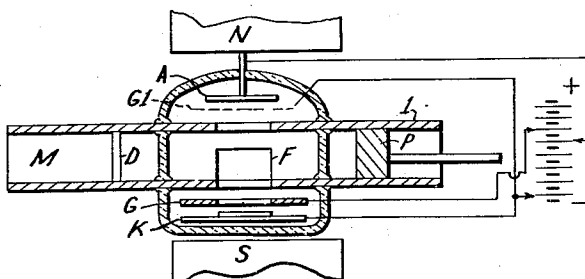


Fig. 6.

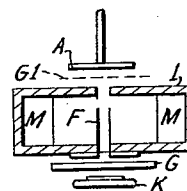


Fig. 7. INVENTOR

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THERMIONIC DEVICE FOR USE WITH
WAVE GUIDES

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8 Claims. (Cl. 250—27)

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The present invention relates to electronic dis-
charge apparatus for use with dielectric wave
guides.

Dielectric guide systems of various kinds have
been described in some detail heretofore in the
papers on Hyperfrequency wave guides by
J. R. Carson, Mead and Schelkunoff and by
G. C. Southworth, appearing in the April 1936
issue of the Bell System Technical Journal. The
dielectric guide itself has taken a wide variety
of forms, but typical of guides disclosed heretofore
is one consisting of a rod of dielectric material and
another consisting essentially of a metallic pipe
containing dielectric medium.

Dielectrically guided waves are capable of
transmission in an indefinitely large number of
forms or types, each type being distinguished by
the characteristic spacial distribution and inter-
relation of the component electric and magnetic
fields comprising the waves. Although as already
stated there are an indefinite number of types of
dielectrically guided waves, they fall into either
of two broad classes. In the one class, assuming
now for the sake of simplicity that the guide is in
the form of a metallic tube, the electric compo-
nent of the wave is transverse to the tube and at
no point does it have a longitudinal component
excepting as the tube is not quite a perfect con-
ductor. The magnetic component, on the other
hands, has both transverse and longitudinal com-
ponents. This class has been designated as trans-
verse electric waves or TE waves. In the other
class the magnetic component is transverse to
the tube and at no point does it have a longitudi-
nal component, but the electric component has in
general both transverse and longitudinal com-
ponents. This class has been designated as trans-
verse magnetic waves or TM waves.

The various possible types of dielectrically
guided waves in each of these two classes have
been identified and distinguished from each other
by their order and by their mode of propagation.
The order of the wave is determined by the
manner in which the field intensity varies circum-
ferentially around the axis of the guide whereas
the mode is determined by the manner of its
variation with radial distance from the axis of
the guide. The usual convention is herein
adopted of designating a TE wave by H_{nm} , where
 n represents the order and m the mode. Simi-
larly, a TM wave of the n th order and m th mode
will be represented by E_{nm} .

The object of the present invention is to pro-
vide arrangements for producing electromag-

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netic waves of ultra short wave length in and for
propagation along dielectric wave guides or for
receiving and amplifying and detecting such
waves.

Arrangements for producing ultra high fre-
quencies are known which consist of a space
resonator across which a beam of electrons is
directed at a voltage antinode so as to be acted
upon by the electric field within the chamber in
order to bunch or group the electrons, and at
another portion of the path the electrons give up
a portion of their energy to the field to maintain
oscillation. The velocity of the electrons, dimen-
sions of the space resonator and positions along
the electron path at which energy is absorbed and
given up, being appropriately selected.

Electron discharge apparatus for use with
dielectric wave guides according to the present
invention comprises a length of wave guide hav-
ing a reflector at one end whilst the electro-
magnetic waves may proceed through the other
end, and means for producing and directing a
beam of electrons across the guide in a direction
parallel to the electric field lines of force of the
electromagnetic waves and at a field antinode so
as to be velocity modulated by said field and
bunched.

In one embodiment of the invention, the beam
of electrons after traversing the guide in one
direction is reflected back from an electrode to
retraverse the guide and during the period be-
tween traversing the guide the electrons become
bunched and on the second traversal feed energy
to the guide.

In another embodiment, after the electrons
have traversed the guide for the bunching opera-
tion, said electrons are arranged to strike a sec-
ondary electron emission electrode and the sec-
ondary electron beam thus generated is directed
across the guide to give up energy to the guide.

In another embodiment, the guide is arranged
to receive electromagnetic waves and to reflect
said waves from said reflector to produce stand-
ing waves, and the velocity modulated and
bunched beam of electrons is collected, the elec-
trode potentials being such that the apparatus
works on a curved part of the output current
control voltage characteristic, whereby a rectified
output of the received electromagnetic waves
is obtained.

In another embodiment the guide is arranged
to receive electromagnetic waves which are re-
flected from the reflector in the guide to produce
standing waves within the guide and the elec-
tron beam is reflected back across the guide after

being velocity modulated so as to give up energy to said guide. The reflector is so adjusted that the reflected beam produces oscillations in the guide differing in frequency from the received waves by a desired intermediate frequency. The potential of the electrode towards which the electrons move after being velocity modulated are so adjusted that the apparatus works on a curved part of the output current-control voltage characteristic.

The invention will be better understood from the following description taken in conjunction with the accompanying drawings, in which

Fig. 1 shows schematically a plan view of one practical embodiment;

Fig. 1A shows an end view of the arrangement shown in Fig. 1;

Fig. 2 shows diagrammatically a plan view of another embodiment of the invention;

Fig. 2A shows an end view of the guide shown in Fig. 2;

Fig. 2B shows the electric field distribution in continuous line within the guide and equipotential lines are shown in broken line;

Fig. 3 shows the electric field distribution of an E11 wave in a guide of rectangular section;

Fig. 4 shows the electric field distribution of an E01 wave in a guide of circular section;

Fig. 5 shows diagrammatically a plan view of another embodiment.

Fig. 6 shows a modified form of the apparatus shown in Fig. 1 for use as a receiving arrangement with a wave guide system;

Fig. 7 is an end view of the arrangement shown in Fig. 6.

The invention will be described in terms of wave guides of rectangular section since the electromagnetic fields which can exist in these guides are somewhat simpler than in tubes of any other section. It is, however, to be understood that the use of guides of other sections, particularly of circular section is envisaged and that guides of rectangular section are described by way of illustration only.

Referring to Fig. 1, an H₀₁ wave is excited in a guide 1 of rectangular section by projecting a beam of electrons produced by an electric gun shown as cathode K and concentrating grid G through the wave guide 1 at a voltage or electric field antinode, in a direction parallel to the electric field and then reflecting the beam from a low potential electrode A back through the wave guide 1. If the reflecting electrode A has a sufficiently negative potential with respect to the cathode K of the electron gun nearly all electrons will be reflected and bunching will occur since the electron beam is velocity modulated on its forward journey. If now the transit time to and from the reflector A is suitably adjusted the bunches which are formed, will pass across the guide at such time as the electric field is able to absorb energy from them so that oscillations may be maintained.

Another mode of operation occurs if the reflector A is maintained at cathode potential. In this case those electrons which are accelerated on their way through the wave guide will be collected by the reflector A whereas those electrons which have lost energy on passing through the guide will be reflected and pass through it a second time and if transit times are suitably adjusted this second passage will occur when the direction of the electric field in the wave guide is such as to absorb energy from them. In this case the transit time from the modulating gap

0 to the reflector A and back to the gap should be $(n + \frac{1}{2})$ periods, n being an integer.

A third method of operation results from running the electrode A at a potential positive with respect to the cathode K in which case secondary electron emission may occur from the electrode A. If the potential of A is suitably adjusted the fast primary electrons striking A cause more secondary electrons to be emitted than the slow ones so that bunches of secondary electrons leave the electrode A and pass across the modulating gap 0 giving up energy to the wave guide provided transit times are suitably adjusted. It is necessary that the transit time from the modulating gap 0 to the secondary electron emitter A and back to the gap should be n periods. An alternative action involving secondary emission arises if the distance from gap 0 to the secondary electron emitter A is such that the primary electrons after velocity modulation, arrive in bunches at the secondary electron emitting surface. Then bunches of secondary electrons will leave the surface and on passing across the modulating gap 0 will give up energy to the guide, again provided that transit times are suitably adjusted.

In Fig. 1 essential details of the apparatus are shown diagrammatically. The wave guide 1 is a copper box of rectangular section which may be closed at one end only the other end being open as regards the electromagnetic waves to radiate energy therefrom. To produce a voltage or field antinode in the wave guide, one end is closed by a movable piston P which reflects the waves incident thereon to produce standing waves. In the end left open, a diaphragm D is necessary in order to reduce the radiation damping which may otherwise be excessive. Since the critical wavelength for the wave guide is twice the long side L of the rectangular section Fig. 1A, this dimension must be greater than half the wavelength to be generated. The short side of the rectangle should be made as large as possible since the losses in the guide increase rapidly as this dimension decreases. This dimension cannot be too great however because the fins F which have to be introduced to make the modulation gap 0 of such a size that the transit time of electrons crossing it should be small compared with a period of the oscillation, will have a great effect upon the characteristics of the guide. For a given value of the length of the short side a , and the wave length λ , the optimum value of b , the length of the long side of the rectangle, is given by

$$b^3 = a\lambda^2$$

provided $2b \ll \lambda$.

Another method of adjustment consists of compressing the guide so that the modulating gap width is altered, since this varies the capacitive loading due to the presence of the fins F.

The position of the aperture through which the electron beam is projected is at a voltage or electric field antinode and should therefore be at an odd number of quarter wavelengths from the closed end P or an even number from an open end D as regards the waves, this wavelength being the wavelength λ in the guide which differs from that in free space. To reduce losses the total length of the guide between the aperture Q and the reflecting end P should be a minimum. Since for small wavelengths the size of the aperture Q is limited, for it cannot be much longer than

$$\frac{\lambda}{4}$$

with any advantage, it may be desirable to have several apertures and cathodes.

In order to obtain a sufficiently intense beam of electrons it may be advantageous to mount the apparatus between the poles of a magnet NS as shown in Fig. 1 producing a field along the path of the beam.

In Fig. 2B the electric field distribution of the H_{01} wave is shown. Since the equipotential surfaces of this field are planes parallel to the side of the wave guide which determines its critical wave length, the introduction of a perfectly conducting plane M, Figures 2 and 2A, into the guide in this position would not alter the field distribution. Suppose this to be done and further suppose that a metal tube T is mounted on this plate M as shown in Figs. 2 and 2A. Now consider a beam of electrons projected across the guide through the metal tube T. The electrons will be velocity modulated at the first gap 01 assuming that a high frequency field already exists, and in traversing the metal tube T will become bunched so that if the transit time through the tube is suitably adjusted energy will be given up to the electromagnetic field at the second gap 02 and so maintain the oscillations.

In the known coaxial line type of resonator the electric fields across the gaps between the inner and outer conductors are at any instant opposite to one another whereas in the type of oscillator shown in Fig. 2 these fields are in the same direction. It follows then that the transit time through the drift tube T must differ in this case by half a period from the value appropriate to the coaxial line resonator. A transit time of either $\frac{3}{4}$ or $1\frac{1}{4}$ periods is therefore necessary for this type of wave guide oscillator. More generally the transit time through the drift tube T is $(n - \frac{1}{4})$ periods where n is a whole number.

Apart from this difference of the plate M and drift tube T inside the guide other points such as termination of the guide, methods of adjustment etc. have already been considered in connection with Figs. 1 and 1A.

In Fig. 3 is shown the electric field distribution of the E_{11} wave and in a rectangular guide tube, in Fig. 4 the electric field distribution of the E_{01} wave of a circular guide tube. It is clear from these diagrams that these waves could be excited in the appropriate guides in a manner exactly analogous to the excitation of the coaxial line resonator. Further since the field strength at the centre of the tube is zero it might be possible to dispense entirely with any fin, or drift tube system inside the wave guide.

In another arrangement for exciting $H_{0,1}$ waves in a rectangular wave guide a beam of electrons is projected across the wave guide parallel to the lines of electric force and at an antinode of the electric field. It is known that if the transit time of electrons crossing the field in the guide is $(n + \frac{1}{4})$ cycles of the oscillation to be excited, the system has a negative impedance and may therefore absorb energy from the beam thus maintaining the oscillating electromagnetic field. The structure of the apparatus is similar to that shown in Fig. 1, except that fins F may not be necessary since the gap width must now be much larger, preferably such as to make the transit time across it $1\frac{1}{4}$ periods of the required oscillation. The electron beam is finally collected on an electrode A maintained at the lowest possible potential consistent with collecting the whole of the beam.

A receiving arrangement according to the invention now to be described with reference to Figs. 6 and 7, is a straight forward detector.

Figs. 6 and 7 are similar to Figs. 1 and 2, the same references are given to like parts. The wave guide is open at one end which may be terminated in an electromagnetic horn M to increase the high frequency energy picked up by the wave guide.

A beam of electrons is projected across the wave guide past a modulating gap across which the transit time is small compared with a period of the oscillation to be received, this gap being at an antinode of the electric field. The incoming signal thus velocity modulates an electron beam. Beyond the modulating gap is placed an auxiliary grid structure G1 maintained at approximately cathode potential and beyond this is the collector electrode A maintained at a potential positive with respect to the cathode K. By biasing the auxiliary control grid G1 to a curved part of the collector current-grid voltage characteristic a rectified output is obtained in a manner analogous to triode anode bend detection.

Alternatively the auxiliary grid G1 may be omitted and then if the collector electrode A is biased to a curved part of the collector current-collector voltage characteristic detection results as before, the detected output being taken from the collector electrode A.

If the spacing between modulating gap and auxiliary grid G1 (or collector when this grid is omitted) is suitably adjusted electrons which are reflected back through the modulating gap may cause the wave guide to oscillate and since this oscillation may be in synchronism with the incoming carrier the detected output can be increased.

The apparatus illustrated in Figs. 6 and 7 can also be used as an autodyne frequency changer. In this case it may be necessary to have a diaphragm D at the neck of the horn in order to reduce radiation damping for the oscillations have to be produced by reflection of the electron beam from the auxiliary grid G1. The piston P is adjusted to produce standing waves corresponding to a frequency differing by the required intermediate frequency from that of the carrier which it is desired to receive. Then by adjustment of the beam velocity so that the necessary transit times are obtained the arrangement is set into oscillation by reflection of electrons from the auxiliary grid (or collector if this grid is omitted) which is maintained at approximately cathode potential at a point in the curved part of the collector current-grid voltage (or collector voltage in the absence of a grid) characteristic. If the intermediate frequency chosen is not too high the wave guide will be only slightly out of adjustment for the carrier and thus two fields of slightly different frequencies will exist in the wave guide so that the electric field across the modulating gap will be of the form $A \cos \omega_1 t + B \cos \omega_2 t$. Then owing to the non-linearity of the collector electrode current characteristic the collector electrode current will have an intermediate frequency component of the form $I \cos (\omega_1 - \omega_2) t$.

An improvement on the autodyne frequency changer hereinbefore described may be obtained as shown in Fig. 5 by providing two wave guides 1, 2 side by side across both of which an electron beam is projected at voltage antinodes. One of these guides 1 having an open end, with or without an electromagnetic horn, is adjusted to the incident carrier wave frequency and the second 2 is adjusted to the frequency of a local oscillator OS with which it is directly coupled. In this way the beam is velocity modulated by voltages $A \cos \omega_1 t$ and $B \cos \omega_2 t$ in series and again as a re-

sult of the non-linearity of the collector electrode voltage-output current characteristic an output current of the form $I \cos (\omega_1 - \omega_2)t$ is obtained.

Alternatively instead of using a separate local oscillator the second wave guide may be set in oscillation by reflection of electrons from an auxiliary grid such as G1 in Figs. 6 and 7.

What is claimed is:

1. Electron discharge apparatus for use with dielectric wave guides comprising a length of the wave guide open at one end a source of electromagnetic waves coupled to said open end, a reflector acting as a closure at the other end, means for producing standing waves in said guide, means for producing and directing a beam of electrons transversely across the guide at a point along the guide where a field antinode exists and where the direction of the electron beam is parallel to the electric field lines of force of the electromagnetic waves whereby the electrons in said beam are velocity modulated by said field and bunched in their passage across the guide there being openings transversely through said guide for the passage of said beam, means for bringing electrostatic charges to bear on said beam after passage through the guide and means to limit the space across said guide to at least one gap within which the electrons react with said field, so that the transit time of electrons crossing said gap is small compared with the period of oscillations.

2. Electron discharge apparatus as claimed in claim 1 wherein the means for bringing an electrostatic charge to bear on said beam comprises a reflector electrode whereby the said beam of electrons after traversing the guide in one direction is reflected back to retrace the guide and wherein the said means for limiting the space across said guide to at least one gap comprises fins within said guide adjacent said openings and parallel to said electric lines of force, said fins being shorter than the distance across said guide.

3. Electron discharge apparatus as claimed in claim 1 wherein the guide is arranged to receive electromagnetic waves and to reflect said waves from said reflector to produce standing waves in the guide and the velocity modulated and bunched beam of electrons is collected, said means for bringing electrostatic charges to bear on said beam being electrodes whose potentials are such that the apparatus works on a curved part of the output current versus control-voltage characteristic whereby a rectified output of the received electromagnetic waves is obtained.

4. Electron discharge apparatus as claimed in claim 1 wherein said means for bringing electrostatic charges to bear on said beam comprising a collecting electrode spaced from the wave guide at the end of the beam path remote from the beam generating means and an auxiliary grid provided between the collecting electrode and the wall of the wave guide and the potentials on said electrodes are adjusted so that the apparatus works on the curved part of the collector current-auxiliary grid voltage characteristic whereby a rectified output of electromagnetic waves received along said guide is obtained.

5. Electron discharge apparatus as claimed in claim 1 wherein said means for bringing electrostatic charges to bear on said beam comprising a collecting electrode spaced from the wave guide at the end of the beam path remote from the beam generating means and the width of the path tra-

versed by the electrons between the wall of the wave guide and the collecting electrode is so adjusted and the potential of the said collecting electrode is so adjusted that part of the electrons are reflected back across the guide and give up energy to the said electromagnetic waves received along said guide whereby the detected output is amplified.

6. Electron discharge apparatus as claimed in claim 1 wherein the guide is arranged to receive electromagnetic waves which reflected from said reflector produce standing waves within the guide, and said means for bringing electrostatic charges to bear on said beam comprising a reflecting electrode spaced from the wave guide at the end of the beam path remote from the beam regenerating means whereby the electron beam is reflected back across the guide after being velocity modulated so as to give up energy to said guide, the said reflector in said guide being so positioned that the reflected beam produces oscillations in said guide differing in frequency from the received waves by a desired intermediate frequency, the potential of the said reflecting electrode being so adjusted that the apparatus works on a curved part of the output current-reflecting electrode voltage characteristic.

7. Electron discharge apparatus as claimed in claim 1 for producing H₀₁ electromagnetic waves wherein the said means to limit the space across the guide to at least one gap comprises a metal tube supported by a conducting plane sheet arranged parallel to the equipotential lines in the guide, arranged with its longitudinal axis transversely of the guide so that the beam of electrons passes therethrough and leaving gaps between the ends of said tube and the guide walls, the transit time of the electrons and the dimensions of said metal tube being so adjusted that in crossing the first gap in their path the electrons absorb energy from the field and give up energy to the field at the second gap.

8. Electron discharge apparatus as claimed in claim 1 wherein the transit time of the electrons crossing the field in the guide is arranged to be $(n + \frac{1}{4})$ cycles of the oscillation to be excited where n is an integer.

STANLEY GORDON TOMLIN.

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Certificate of Correction

Patent No. 2,450,026

September 28, 1948

STANLEY GORDON TOMLIN

It is hereby certified that errors appear in the above numbered patent requiring correction as follows:

In the grant, line 14, strike out the words "of seventeen years"; same line, after "grant" insert *until August 29, 1961*; in the heading to the printed specification, line 9, before "8 Claims" insert the following—

Section 1, Public Law 690, August 8, 1946. Patent expires August 29, 1961;
and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 21st day of February, A. D. 1950.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.