Jan. 26, 1954 R. S. BAILEY 2,667,597

VELOCITY MODULATED ELECTRON DISCHARGE DEVICE

Filed June 14, 1948

2 Sheets-Sheet 1

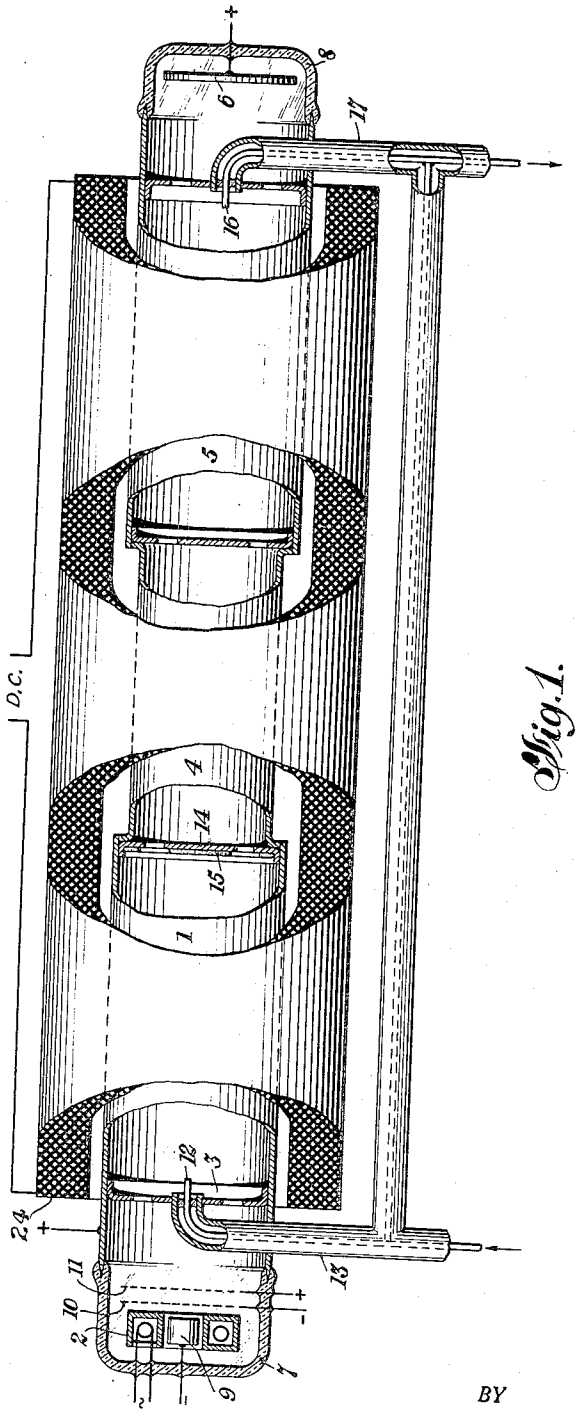


Fig. 1.

INVENTOR.
ROBERT S. BAILEY

BY

R. P. Morris

ATTORNEY

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Fig. 2.

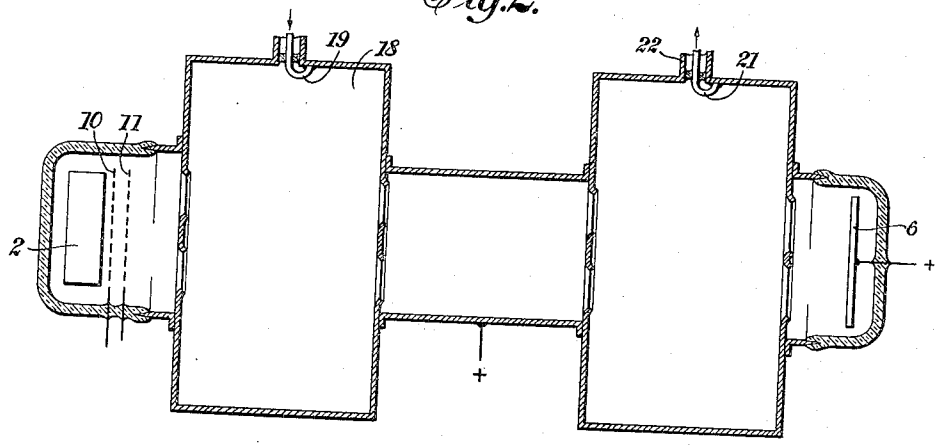
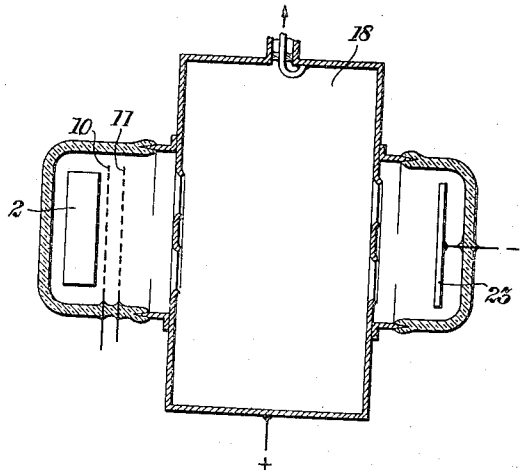


Fig. 3.



INVENTOR.
ROBERT S. BAILEY

BY

R. P. Morris

ATTORNEY

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VELOCITY MODULATED ELECTRON DISCHARGE DEVICE

Robert S. Bailey, New York, N. Y., assignor to International Standard Electric Corporation, New York, N. Y., a corporation of Delaware

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1 Claim. (Cl. 315—3)

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My invention relates to electron discharge devices and is particularly directed to improvements in construction and methods of operation of devices of the velocity-modulated types.

In the conventional velocity-modulated microwave generator, a beam of electrons is projected through aligned windows in opposite sides of a cavity resonator, the time phase of the electrons in the windows with respect to the electric fields at the windows being adjusted so that the electrons are bunched. Undulating energy may then be extracted from the electron bunches when passing through the windows of a second and similar cavity resonator or when returned to the first cavity by a negatively charged reflector or so-called reflex electrode. In such generators the principal mode of operation contemplated consists of straight longitudinal movement of the electrons through a cylindrical cavity resonator with the walls of the cavity resonator through which the beam passes always 180 degrees out of phase, the single frequency of operation being fixed primarily by the dimensions of the cavity. The wave length, operating in the conventional longitudinal mode, appears to be a function primarily of the radius, r, for a cylindrical cavity resonator and is approximately equal to $2.61r$.

The object of my invention is improved apparatus and methods for generating and/or amplifying microwaves.

A more specific object of my invention is means for increasing the operating frequency of a velocity-modulated electron discharge device with a cavity resonator of a given physical size.

A still more specific object of my invention is a velocity-modulated electron discharge device employing cylindrical cavity resonators the operating wave length of which is less than $2.61r$, where r is the radius of the cavity resonator of the device.

These and other objects are achieved in a structure of my invention comprising, essentially, a cylindrical wave guide of such length and diameter that there may be excited therein oscillations of a higher order and frequency than that of the longitudinal mode of the conventional velocity-modulating cavity resonator. If, for example, oscillations of the transverse electric mode, designated as the $TE_{0,1,1}$ mode, are established

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in my wave guide, a resonant frequency corresponding to a wave length of approximately one half the wave length in the longitudinal mode may be obtained. In the $TE_{0,1,1}$ mode of the cavity resonator or the corresponding mode $TE_{0,1}$ of the wave guide, the electric field appears as circular lines of force in planes transverse to the axis of the wave guide and substantially concentric therewith so that electrons entering one end of the wave guide are propelled by an alternating electric field in a spiral path to the opposite end. The potentials within the wave guide will bunch the electrons and thereafter energy at the mode frequency may be extracted from the bunches in a catcher or debuncher cavity.

The above-mentioned and other objects and features of my invention and the manner of attaining them will become more apparent and the invention itself will be best understood, by reference to the following description of preferred embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 shows a longitudinal one-half section of one of said embodiments, and

Fig. 2 shows a longitudinal one-half section of another embodiment of my invention, and

Fig. 3 shows still another embodiment of my invention involving a reflex principle.

In Fig. 1, a velocity-modulated electron discharge device is shown, the device being adapted for either generation or amplification of oscillations in the low centimeter range. At 1 is a cylindrical wave guide, the radius of the wave guide being chosen large enough to accommodate the lowest frequency, or longest wave length, expected to be amplified or generated in the device. At one end of the wave guide, preferably exteriorly thereof, is placed a cathode 2 in axial alignment with the annular window 3 in the end plate of the guide. Extending from the other end of the wave guide is the drift tube 4, the aligned catcher or debuncher cavity structure 5, and the reflector electrode 6. The walls of the wave guide, drift tube, cavity structure and the glass bulbs 7 and 8 are placed end to end and may be hermetically joined so that the enclosed space may be evacuated.

The particular cathode shown comprises an annular sleeve, is indirectly heated, and is placed concentric with the center line of the wave guide

structures. The side of the cathode annulus facing the wave guide is flattened and coated with electron emissive material. A non-emitting plate 9 is positioned in the center of the cathode annulus. The window 3 in the wave guide, also annular in shape, is approximately coextensive with the emitting portion of the cathode. Control grid 10 and accelerating and focusing grid 11, diagrammatically shown in Fig. 1, are placed in front of the cathode and accelerate and direct a tubular stream of electrons through the window 3. Magnetic focusing may be used, if desired.

An antenna 12 to excite oscillations in the wave guide is positioned at or near the cathode end and may comprise a loop, or probe of the proper length, depending upon the position of the antenna and the mode of oscillations to be established in the wave guide. The antenna shown is a probe and is energized through the coaxial cable 13 which may be connected to an independent source of oscillations to be amplified or to the catcher cavity for feed back energy and self-sustained oscillations. It is important that the excitation of the cavity be accomplished in such a way, well known to the art, that circular electric field lines be obtained in a plane transverse to the axis of the cavity.

In operation as an amplifier, the desired waves are applied to the antenna. Assume that the applied waves have a length less than $2.61r$, where r is the wave guide radius, and that the antenna is a probe at the center of the end plate of the wave guide as shown, then, oscillation in the transverse electric mode, $TE_{0,1}$, will travel lengthwise of the wave guide. Such oscillations comprise circumferential electric lines in planes transverse to the wave guide traveling lengthwise of the wave guide at the group velocity Vg. Then, electrons projected into such an oscillatory field at a velocity near that of Vg will spiral helically about the center line of the wave guide and will travel along the wave guide, through the annular window 14 and into the drift tube 4. The alternating field potential within the wave guide will velocity modulate the electrons and bunch them along the spiral path and electrons passing from the second annular window 14 continue bunching in the drift tube.

Accordingly, the final result of my invention is a helical stream of bunched electrons with a buch frequency corresponding to wave lengths much shorter than the wave length possible in cavity resonators of conventional velocity modulators. Calculations show that in the $TE_{0,1}$ mode, the waves that can be amplified may be of any length shorter than the cut-off wave length of $1.64r$ and that with a wave guide having a radius of 1 centimeter, the wave length may be 1.64 centimeters or less. Such frequencies are not possible with conventional velocity-modulated tubes of similar dimensions.

To prevent reflections and standing waves in the wave guide, the output end may be coated with a layer 15 of resistance material, such as carbon, of such depth and composition as to have a resistance equal to the characteristic impedance of the wave guide.

For extracting the radio frequency energy from the bunched electrons a wave guide 5 similar in size and shape to the buncher 1 is preferred, so that the boundary condition may be similar and the broad-band characteristics of the buncher wave guide preserved.

Electrons emerging from the outer end of the debuncher wave guide 5 are absorbed and removed by the collecting electrode 6, and oscillatory energy is picked up by the probe 16 at the output end of the debuncher cavity and conducted away through the coaxial cable 17. A portion of this energy may be fed regeneratively to the buncher wave guide for sustained ocillations or for increased amplifier gain. If the feedback circuit is frequency selective, the resonant frequency of the feedback circuit may determine the operating frequency of the device.

In Fig. 2 is shown another velocity modulated electron discharge device of my invention. Where wave guides several wave lengths long are not desired and where narrow band or fixed frequency operation is desired, yet where the high frequency of wave guide modes are necessary, the device of Fig. 2 may be used. Here the wave guide 18 is but a half guide wave length long and is operable, in its fundamental mode, with a transverse electric field, designated $TE_{0,1,1}$. The loop 19 in the side of the wave guide will excite such a mode. The resonant wave length, λ res. of the shortened cavity is

$$\lambda \text{ res} = \frac{2L}{\sqrt{1+\left(\frac{2L}{1.64r}\right)^2}}$$

where L is the length and r is the radius of the resonant wave guide or cavity resonator. The electric field here also appears as circular lines of force in planes perpendicular to and concentric with the axis of the cavity. Electrons from cathode 2 projected into the cavity at about the group velocity will travel helically and bunch circumferentially. Drift space 4 allows continued bunching, and cavity 20 dimensioned for $TE_{0,1,1}$ oscillations, is phased to receive and extract high frequency energy from the bunches. The output circuit may comprise a loop 21 in the side of the cavity on the end of a coaxial cable 22. Electrode 6 collects the spent electrons.

Alternatively, the high frequency energy from the bunched electrons may be derived by returning the bunches to and into the opening in the buncher cavity. As shown in Fig. 3 a reflector electrode 23 with the proper negative potential is placed across the electron trajectory for reversing the direction of electron flow and returning the electron bunches to the cavity 18 in phase with the oscillations in the cavity.

In each of the embodiments disclosed, a longitudinal magnetostatic field may be employed to keep the electrons in their proper orbits. One specific suggestion for application of magnetic focusing to my cavity resonator or wave guide oscillators is shown in Fig. 1 where a direct current coil 24 is telescoped over the wave guides or resonators to establish magnetic lines substantially parallel to the axis thereof. Signals imposed on the magnetic field would, conveniently, amplitude and/or frequency modulate the high frequencies of the device.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention.

I claim:

An electron discharge device comprising a wave guide, said wave guide being a plurality of guide wave lengths long, an antenna in said wave guide for establishing electromagnetic oscillations in said wave guide of a frequency above the cut-off frequency of said wave guide, windows in opposite ends of said wave guide offset laterally with

respect to the longitudinal axis of said guide, an electron source at one end of said wave guide to release a stream of electrons into one window and hence to and through the other window, a drift tube and a catcher cavity aligned with said other window.

ROBERT S. BAILEY.

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