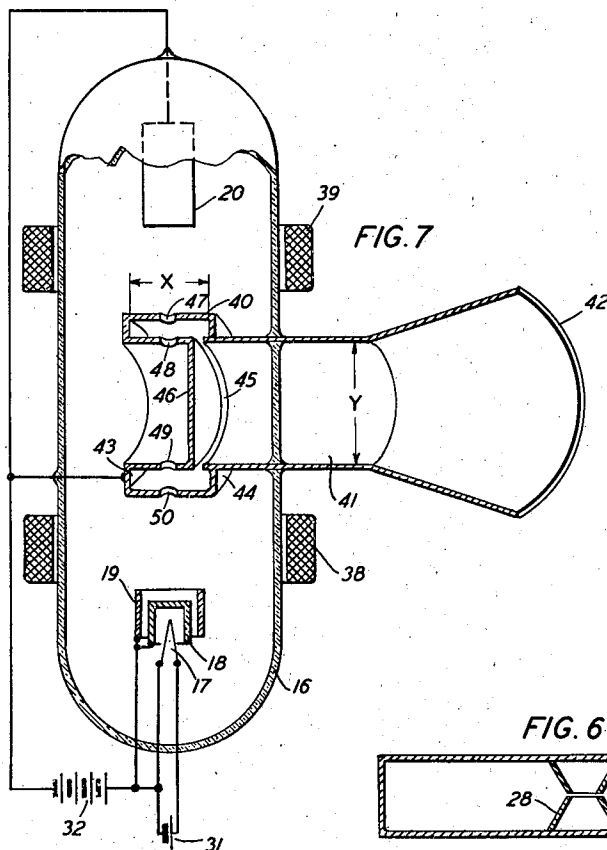
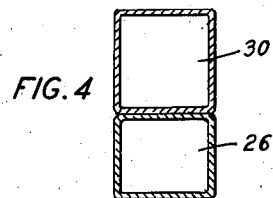
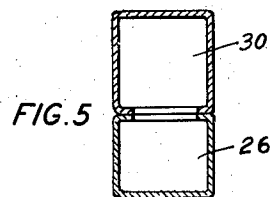
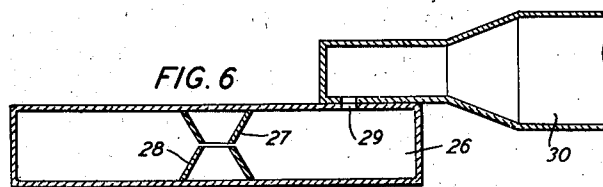
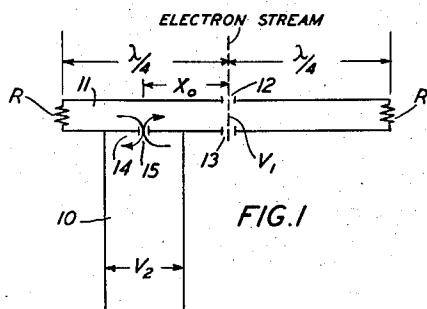
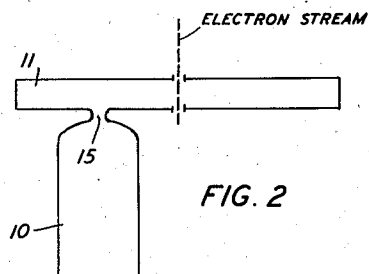


Feb. 5, 1946.

J. R. PIERCE
BEAM RESONATOR TUBE
Filed April 9, 1941

2,394,008

2 Sheets-Sheet 1



INVENTOR
J. R. PIERCE
BY
Franklin Mohr
ATTORNEY

Feb. 5, 1946.

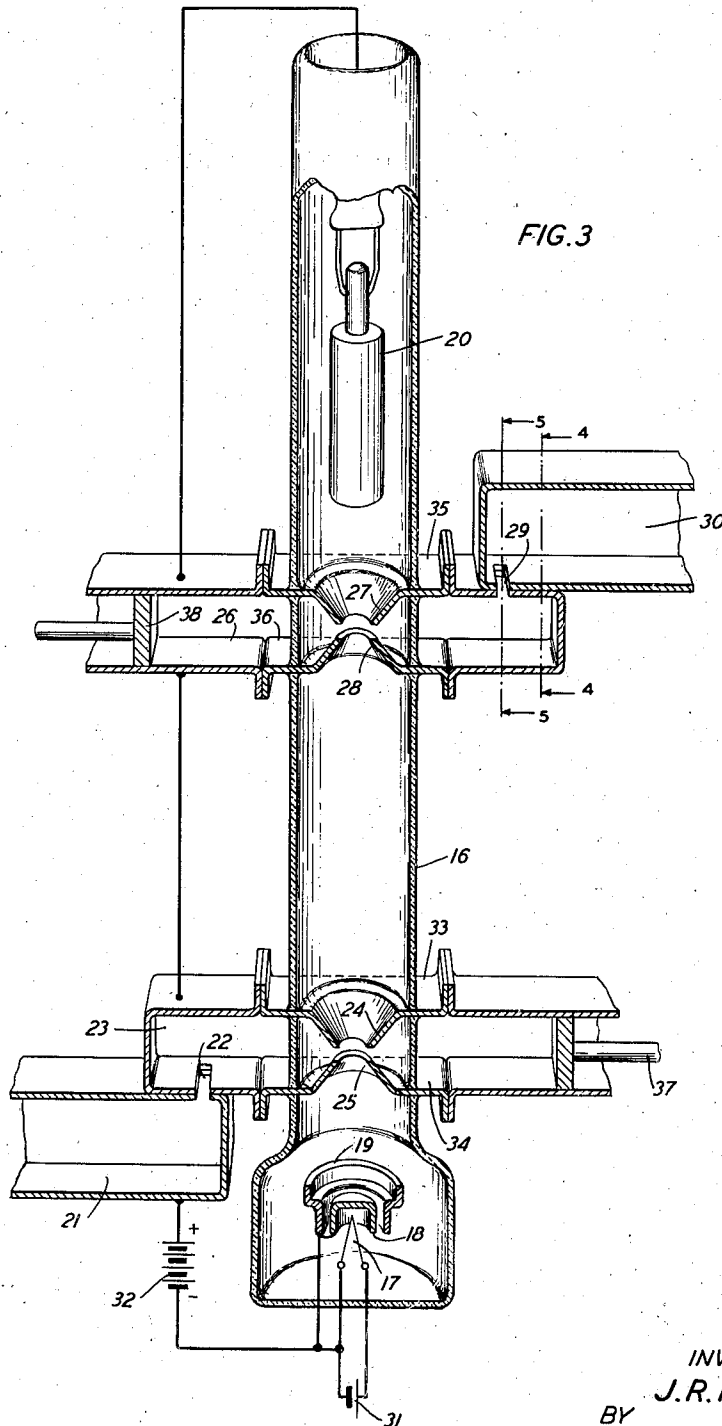
J. R. PIERCE

2,394,008

BEAM RESONATOR TUBE

Filed April 9, 1941

2 Sheets-Sheet 2



INVENTOR
J. R. PIERCE
BY
Franklin Mohr
ATTORNEY

UNITED STATES PATENT OFFICE

2,394,008

BEAM RESONATOR TUBE

John R. Pierce, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application April 9, 1941, Serial No. 387,602

7 Claims. (Cl. 250—27.5)

This invention relates to arrangements for coupling an ultra-high frequency wave guide with an electron stream through a resonator to form an improved system for effecting velocity variations or some other change in the characteristic of the electron stream in response to electromagnetic energy transmitted by the wave guide from an electrically distant source or for supplying high frequency energy from the modulated electron stream to the wave guide for transmission to a load device of any suitable kind.

The invention is particularly applicable to wave guides and resonators of a type comprising a conductive boundary surface, usually of metal, surrounding a space or cavity filled with a dielectric, which latter may consist of air.

In accordance with the invention, the wave guide and the resonator have a portion of their boundaries in common and have their interior spaces coupled together by means of a slit or similar aperture which is located at a position intermediate between the ends of the resonator, the exact position being determined by the desired value of the impedance looking into the resonator, it generally being desirable to match the impedance of the resonator with that of the wave guide at the point of coupling. In addition to the coupling slit above described, the resonator is provided with a plurality of aligned apertures through which the electron stream may be projected, usually transversely to the longitudinal axis of the resonator.

It is usually convenient to make the resonator comprise a section of wave guide one-half wavelength long with conductive closures at both ends. The natural oscillations of which such a resonator is capable will then produce a maximum intensity of electric field midway between the ends, at which point the electron stream may be advantageously introduced. In order that the transit time of the electrons in passing through the resonator may be no more than a small portion of the periodic time of the oscillations, the resonator should be relatively thin transversely to its longitudinal axis. A thin wave guide of suitable dimensions for this purpose will be of relatively low characteristic impedance, the value of the characteristic impedance being determined by the ratio, in an electrically long wave guide, of the voltage appearing across the guide to the current flowing in its walls. For conveying power to or from the resonator at high frequencies with low losses, a wave guide of the kind hereinbefore mentioned forms a suitable transmission me-

dium. For best transmission efficiency in the wave guide, the ratio of voltage appearing across the guide to current flowing in the walls should be high. In other words, the resonator should be a guide of low characteristic impedance and the transmission device should be a guide of high characteristic impedance. In a wave guide of high characteristic impedance in contrast to a guide of low characteristic impedance, the walls will be relatively far apart. The problem to which the present invention is directed is to couple the different size wave guides together in an efficient manner while at the same time providing access and suitable physical arrangements for introducing the electron stream at the midpoint of the resonator. A direct connection of one guide into the other, as for example by placing an open end of the smaller guide over a hole of equal size in the wall of the larger guide will not suffice, for in that case the electric field intensity developed in the guide of low characteristic impedance is small and the coupling is inefficient. As hereinbefore mentioned, the position of the coupling aperture along the length of the resonator may be determined so as to provide within wide limits any desired impedance looking into the resonator. Thus impedance matching between the transmitting wave guide and the resonator may be achieved.

A feature of the invention is an ultra-high frequency oscillator employing a section of concentric conductor transmission line as a resonator and coupled to a hollow cylindrical transmitting wave guide having substantially the same diameter as the inner conductor of the concentric line and forming substantially an extension of the said inner conductor. In this case the coupling between the resonator and the wave guide takes place through an annular slit communicating between their interior portions.

In the drawings:

Figs. 1 and 2 are diagrammatic representations of a resonator coupled to a transmission guide, with the place of introduction of the electron stream indicated;

Fig. 3 is a perspective view partially in cross-section showing an electron beam tube provided with input and output resonators coupled respectively to receiving and transmitting wave guides in accordance with the invention;

Figs. 4 and 5 are cross-sectional views taken at lines 4 and 5, respectively, in Fig. 3;

Fig. 6 shows an alternative form of coupling between a resonator and wave guide; and

Fig. 7 is a perspective view partly in cross section of an ultra-high frequency generator or projector embodying the invention.

In Fig. 1, 10 is a wave guide of high characteristic impedance and 11 a resonator of low characteristic impedance. The two structures are represented as having different thicknesses in the plane of the paper and may be of the same or different dimensions in the direction perpendicular to the paper. The resonator 11 has a total length $\lambda/2$ where λ represents the wavelength peculiar to the operating frequency under the conditions existing in the interior of the resonator. Aligned apertures 12 and 13 are provided for the passage of an electron stream or beam midway between the ends of the resonator, which will be the position of a voltage anti-node. A common boundary or wall between the resonator and wave guide is indicated at 14 and contains a slit 15 extending in the direction perpendicular to the plane of the drawing and providing a coupling between the interior spaces of the guide and resonator in a manner described in British Patent 507,473, complete specification accepted June 14, 1939. As indicated by arrows in Fig. 1 herewith, and according to the principles set forth in the British patent, the coupling between the resonator and the wave guide is such that a portion of the surface current of the wave guide will flow over the edge of the slit into the resonator as a source of current therein and conversely a portion of the surface current in the resonator will flow into the wave guide.

The value of the impedance looking into the resonator through the coupling slit may be arrived at approximately in the following manner. The resonator may be regarded as made up of two transmission lines having their input terminals connected in series. The shorter of the two line sections has a length of

$$\frac{\lambda}{4} - x_0$$

and the longer section has a length

$$\frac{\lambda}{4} + x_0$$

A sufficiently close approximation for practical purposes will be obtained by assuming the transmission lines to be non-dissipative but allowing for the dissipation which is actually present by supposing two equal resistors R to be inserted at the ends of the resonator, respectively, as indicated schematically in Fig. 1. The characteristic impedance of the line 11 will be designated K_1 , while the characteristic impedance of the line 10 will be designated K_2 , the line 10 having the higher characteristic impedance.

From the well-known theory of transmission lines working at high frequencies, the sending-end impedance Z_{11} of a line of length L , characteristic impedance K_1 and terminated in a resistance R is as follows:

$$Z_{11} = K_1 \frac{\frac{R}{K_1} + j \tan \frac{2\pi L}{\lambda}}{1 + j \frac{R}{K_1} \tan \frac{2\pi L}{\lambda}} \quad (1)$$

The two sections of line 11 in question are so related that their lengths add up to

$$\frac{\lambda}{2}$$

with the result that the trigonometric tangents

for the two line sections always have equal numerical values and opposite signs regardless of the particular value of x_0 . For the shorter line section, the value of

$$\tan \frac{2\pi L}{\lambda}$$

is

$$\cot \frac{2\pi x_0}{\lambda}$$

and for the longer line section the value is

$$-\cot \frac{2\pi x_0}{\lambda}$$

Substituting first one of these values and then the other for the tangent terms in Equation 1, two expressions are obtainable which when added together give the combined impedance of the two line sections with their inputs connected in series, the result being

$$Z = K_1 \left[\frac{\frac{R}{K_1} + j \cot \frac{2\pi x_0}{\lambda}}{1 + j \frac{R}{K_1} \cot \frac{2\pi x_0}{\lambda}} + \frac{\frac{R}{K_1} - j \cot \frac{2\pi x_0}{\lambda}}{1 - j \cot \frac{2\pi x_0}{\lambda}} \right] \quad (2)$$

By simple algebraic and trigonometric manipulation, Equation 2 may be reduced to the following form:

$$Z = \frac{\frac{2K_1^2}{R}}{1 - \left(1 - \frac{K_1^2}{R^2}\right) \sin^2 \left(\frac{2\pi x_0}{\lambda}\right)} \quad (3)$$

Equation 3 shows the combined impedance of the sections to be purely resistive, and determines the value of the resistance as a function of x_0 for a resonator with given values of K_1 , λ and R . It will be readily observed that the value of Z may be varied over an extended range by varying x_0 . For example, if x_0 is made to equal 0, the impedance Z comes out

$$\frac{2K_1^2}{R}$$

which will be very high in the case of a line having low dissipation as represented by the value of R . On the other hand, if x_0 is made equal to

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

the value of Z comes out $2R$, which will be very small for small values of R . Intermediate values of x_0 will give intermediate values of Z . If then, x_0 is adjusted so that $Z = K_2$, the line of high characteristic impedance will be perfectly terminated, and in practice a substantial impedance match may be obtained by proper adjustment of the value of x_0 .

Considering now the relative values of the voltage V_1 , appearing across the resonator 11, and the voltage V_2 present in the line of high characteristic impedance, it is convenient to consider the power relations which hold in the presence of a substantial impedance match. The power P_2 flowing in line 10 is

$$P_2 = \frac{V_2^2}{K_2} \quad (4)$$

The power dissipated in the two resistances R together is

$$P_R = 2I_2^2 R \quad (5)$$

where I_R is the current flowing in the resistances. As the center of line 11 is distance

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

from either resistor R , the voltage at the center of the resonator will be

$$V_1 = K_1 I_R \quad (6)$$

From (5) and (6)

$$P_R = \frac{2V_1^2 R}{K_1^2} \quad (7)$$

Equating the power flowing through the line 10 as given by Equation 4 with the power dissipated in the resistances as given by Equation 7 enables the desired voltage ratio to be obtained as follows:

$$\frac{V_1}{V_2} = \sqrt{\frac{K_1^2}{2K_2 R}} \quad (8)$$

It will be evident from inspection of Equation 8 that when the impedances looking in the two directions at the junction are matched, the ratio V_1/V_2 can be made large even if K_1 is small and K_2 is large, provided R is sufficiently small. Equation 8 indicates the highest possible voltage ratio in terms of K_1 , K_2 and R , and Equation 3 determines how far from the center of line 11, the slit 15 should be placed in order to attain the maximum voltage ratio. Representative values for a practical case would be

Impedance	Value
K_1	Ohms
K_2	40
R	160
	0.05

The tabulated values give a voltage step-up ratio of ten times.

Fig. 2 shows diagrammatically a modification of the arrangement of Fig. 1 in which a smoother physical termination of line 10 is provided and the slit 15 is shown with rounded edges, the resistances R being omitted.

Fig. 3 shows a vacuum tube amplifier of the electron velocity variation type provided with resonators each coupled to the electron stream and coupled respectively to an incoming and an outgoing wave guide in accordance with the invention. An evacuated insulating envelope 16 is shown containing in its lower portion a heating filament 17, an electron emitting cathode 18 and a collimating electrode 19, the elements 17, 18 and 19 forming an electron gun of known construction. At the upper end of the envelope 16 is shown a target or electron collector 20. The particular form of electron gun, target and envelope employed are not essential to the invention, there being many other suitable forms known to the art.

An incoming wave guide 21 is coupled by means of a slit 22 with a resonator 23. The guide 21 and resonator 23 have conductive walls, preferably metallic, for example, copper, and are conductively connected with electrodes 24 and 25. The electrodes have the form of conical frusta with aligned apertures through which the electron beam from the electron gun is arranged to pass. A second resonator 26 having similar electrodes 27 and 28, apertured for the passage of the electron beam, is coupled through a slit 29 with an outgoing wave guide 30.

The filament 17 may be heated by a battery 31 or other suitable source. The collimating electrode 19 is conductively connected to the cathode 18 and may also be connected to one side of the filament 17. The cathode 18 is also conductively connected to the negative terminal of an accelerating battery 32 or other suitable source. The positive terminal of the battery 32 is conductively connected to the metallic system of wave guide 21 and resonator 23, the metallic system of resonator 26 and wave guide 30, and to the electron target 20. However, other suitable biasing or accelerating arrangements may be provided instead. The electrodes 24, 25, 27 and 28 are metallically joined to or form a part of plates 33, 34, 35 and 36, respectively, which plates are hermetically sealed to and extend through the walls of the envelope 16. The plates 33 and 34 form a part of the conductive resonator 23 and the plates 35 and 36 are part of the resonator 26. The plates and other parts of each resonator may be welded together or joined conductively in any other suitable manner. Adjustable pistons 37 and 38 are provided for tuning resonators 23 and 26, respectively.

It will be noted that the coupling slit 22 is so placed that it extends transversely to the longitudinal axes both on the wave guide 21 and the resonator 23. The slit 29 is likewise transverse to the longitudinal axes of resonator 26 and wave guide 30. In each case the slit is preferably placed near the closed end of the wave guide. The position of the slit with respect to the center of the resonator in each case is determined in accordance with Equation 3 to secure a desired value of impedance looking into the resonator.

The system of Fig. 3 operates in a manner well known in its general aspects. With the electron beam properly collimated and adjusted so as to pass through the apertures in the electrodes 24, 25, 27 and 28 and strike the target 20, the arrangement may be used, for example, to amplify ultra-high frequency waves supplied through the wave guide 21. The guide 21 is preferably designed to transmit electromagnetic waves of a type which will produce longitudinal surface currents near the closed end of the guide 21. These currents will flow with a vertical component in the end wall of the guide but will also flow over the edge of the slit 22 into the interior of resonator 23 in a manner such as was explained above in connection with Fig. 1. The resonator 23 is preferably adjusted to resonate at the frequency of the incoming wave by adjusting the piston 37. With the proper adjustments, an alternating voltage at the operating frequency is impressed between the electrodes 24 and 25 and reacts with the electron stream to produce a variation in the velocities of the electrons passing between the electrodes. A substantially field-free drift space is provided between electrode 24 and electrode 28 within which the electrons of the stream, having been differentiated from each other by their velocities, tend to group themselves in bunches. The bunched electrons in passing between the electrodes 27 and 28 tend to set up oscillations in resonator 26, particularly when the latter is tuned by means of the piston 38 to the operating frequency. The resonator 26 is coupled with the outgoing wave guide 30 by means of the slit 29 in the same manner as has been described above in connection with the slit 22. As is well known in the art, the wave sup-

plied to wave guide 30 may develop a considerably greater amplitude than that of the incoming wave in guide 21, the device thus being characterized as an amplifier.

Fig. 4 shows a cross-sectional view of the resonator 26 and wave guide 30 at the line 4-4 in Fig. 3 and indicates that the resonator and wave guide may have the same horizontal dimensions and different vertical dimensions, although different horizontal dimensions might also be used if desired.

Fig. 5 shows a cross-sectional view taken through the slit 29 at the line 5-5 in Fig. 3.

Fig. 6 shows a possible variation in the termination of the wave guide 30 wherein the wave guide is tapered down to the same size and cross-sectional area as the resonator 26 and the slit 29 couples the resonator with the wave guide at a place where the cross-sectional areas are the same.

Fig. 7 shows an adaptation of the coupling arrangement of the invention to the case of an oscillator employing a concentric cylindrical resonator and a cylindrical outgoing wave guide. The electron gun elements 17, 18 and 19 are similar to those shown in Fig. 3 and the envelope 16 contains in addition to the electron gun, the target 20 as shown in Fig. 3. The batteries 31 and 32 are provided here also. Additional collimating means in the form of magnetizing coils 38 and 39 may be used if desired. A resonator 40 is joined conductively to a transmission line or wave guide 41 which in turn opens into a projector or horn 42 for radiating electromagnetic waves. The resonator 40 comprises outer and inner concentric conductive cylinders closed at both ends by conductive end plates 43 and 44, respectively. The wave guide 41 is bounded by a cylindrical wall which is a continuation of the inner cylindrical boundary of resonator 40. The coupling slit between the resonator and the wave guide comprises the annular space 45 between the end of the wave guide 41 and a disc 46. Apertures 47, 48, 49 and 50 are provided for the passage of the electron beam through and beyond the resonator 40. The guide 41 is hermetically sealed to and extends through the walls of the envelope 16.

The effective length X of the resonator is preferably a half wave-length of the operating frequency. The diameter Y of the wave guide 41 is preferably designed to be in the neighborhood of eight-tenths of the wave-length of the operating frequency in order that it may support electromagnetic waves of the operating frequency, it being well known that the diameter of a wave guide of this type will set a lower limit to the frequency of the electromagnetic wave which may be maintained and transmitted through the guide.

The system of Fig. 7 will operate as an oscillator provided the initial velocity of the electrons in the electron beam is adjusted so that the electron transit time between electrode 49 and electrode 48 is of such a value that electrons bunched as a result of velocity variations acquired between electrodes 50 and 49 will arrive in the proper phase to supply energy to the electromagnetic field within the resonator 40 and thus sustain oscillations in the resonator. Thus adjusted, the arrangement will generate electromagnetic waves of ultra-high frequency which will pass through the annular slit 45 into the wave guide 41 and then into the projector 42 from which they will be launched into space. The waves may,

of course, be conducted by means of the wave guide 41 to any suitable load circuit instead of being radiated by means of the projector.

What is claimed is:

1. An ultra-high frequency system comprising a hollow resonator with conductive walls, a pair of which walls being relatively close together, a hollow conductive wave guide with walls relatively far apart in comparison with the minimum wall spacing of said resonator, said resonator and said wave guide partially overlapping longitudinally and having a portion of their boundaries in common, said common boundary portion containing a slit interconnecting the interiors of said wave guide and said resonator through said common boundary at a point intermediate between the extremities of said resonator, said resonator having aligned apertures in a non-common portion of the boundary in a line parallel to the smallest internal dimension of said resonator, said apertures establishing a passageway through the said resonator, and means for directing and maintaining an electron stream through said aligned apertures.

2. An ultra-high frequency system comprising a hollow cylindrical wave guide and a concentric cylindrical transmission line section, said line section being substantially half a wave-length long at a predetermined operating frequency, the outer diameter of the wave guide being substantially equal to the outer diameter of the inner conductor of the line section, said wave guide and line section being coaxial, said line section being short-circuited and closed at both ends, said wave guide extending interiorly into said line section for a portion of the length of the section and terminating therein in a conductive disc, said wave guide having an annular slit constituting a coupling for electromagnetic waves between the interconductor space of the line section and the interior of the wave guide, said slit being located near the closed end of said wave guide, and said line section having a plurality of aligned apertures midway between the ends thereof providing a passage entirely through both conductors of the line section transversely to the common axis of said line section and wave guide, and means for directing an electron stream through said aligned apertures.

3. An ultra-high frequency system comprising a hollow cylindrical wave guide and a concentric cylindrical transmission line section, said line section being substantially half a wave-length long at a predetermined operating frequency, the outer diameter of the wave guide being substantially equal to the outer diameter of the inner conductor of the line section, said wave guide and line section being coaxial, said line section being short-circuited and closed at both ends, said wave guide extending interiorly into said line section for a portion of the length of the section, a conductive disc opposite the end of the said inwardly extending wave guide and spaced therefrom, the space therebetween defining an annular slit constituting a coupling for electromagnetic waves between the interconductor space of the line section and the interior of the wave guide, and said line section having a plurality of aligned apertures midway between the ends thereof providing a passage entirely through both conductors of the line section transversely to the common axis of said line section and wave guide, and means for directing an electron stream through said aligned apertures.

4. An ultra-high frequency electronic device

comprising a first wave guide of extended length and rectangular cross section with conductive walls, a second rectangular wave guide with conductive walls, a pair of which walls are close together in comparison with the walls of said first wave guide, said second wave guide partially overlapping and being in conductive connection with said first wave guide, said first wave guide being closed by a conductive short-circuiting member at the end near said second wave guide, said second wave guide being closed at both ends by short-circuiting members and having a length substantially a half wave-length for electromagnetic waves of a predetermined operating frequency, said second wave guide being provided with apertured electrodes forming a gap substantially in the center of said half wave-length, said overlapping portions of said wave guides containing a coupling slit interconnecting the interiors of said wave guides in said overlapping region at a position intermediate between said gap and one end of said second wave guide, and means for passing an electron stream between said electrodes through the apertures therein.

5. An ultra-high frequency electronic device comprising a relatively thin rectangular wave guide short-circuited at both ends to form a half wave resonator at a predetermined operating frequency, a pair of apertured electrodes formed substantially at the center of said resonator, means for passing an electron stream through the apertures in said electrodes, an extended relatively thick rectangular wave guide closed at the near end by a short-circuiting member, said two wave guides overlapping longitudinally and being placed in conductive contact in said overlapping region, said overlapping and contacting region containing a slit providing a coupling for electromagnetic waves in said respective wave guides, said slit being located intermediate between the middle and one end of said resonating wave guide.

6. An ultra-high frequency electronic device comprising an evacuated envelope of insulating material, means for maintaining an electron beam

within said envelope, a pair of conductive plates each having an apertured electrode conductively attached thereto and said plates being hermetically sealed into and extending through the walls of said envelope, conductive members attached to said plates and forming a half wave resonator of rectangular cross section for electromagnetic waves of a predetermined frequency, said resonator being partly within and partly without said envelope, an extended wave guide having conductive walls one of which is in conductive contact with the walls of said resonator at a position intermediate between the middle and one end of said resonator, said walls being spaced apart materially farther than are said pair of conductive plates, the walls of said resonator and of said wave guide in conductive contact being provided with a slit intercommunicating between the interior portions of said resonator and said wave guide.

7. An ultra-high frequency electronic device comprising an evacuated insulating envelope, a pair of parallel conductive plates, each plate having an apertured electrode attached thereto and both plates being hermetically sealed into and through the walls of said envelope, additional conductive plates external to said envelope and conductively connected with said plates and forming a rectangular shaped resonator for electromagnetic waves of a predetermined operating frequency, said resonator being extended symmetrically on both sides of said electrodes, a rectangular wave guide with conductive walls one of which walls overlaps said resonator longitudinally and makes conductive contact therewith, said resonator and wave guide being provided with an intercommunicating slit in the overlapping region at a position intermediate between the middle and one end of said resonator, and means for maintaining an electron beam within said envelope and passing through the apertures in the electrodes of said resonator.

JOHN R. PIERCE.