June 18, 1946. A. L. SAMUEL 2,402,184

ULTRA-HIGH FREQUENCY ELECTRONIC DEVICE CONTAINED WITHIN A WAVE GUIDE

Filed May 3, 1941 3 Sheets-Sheet 1

FIG. 1

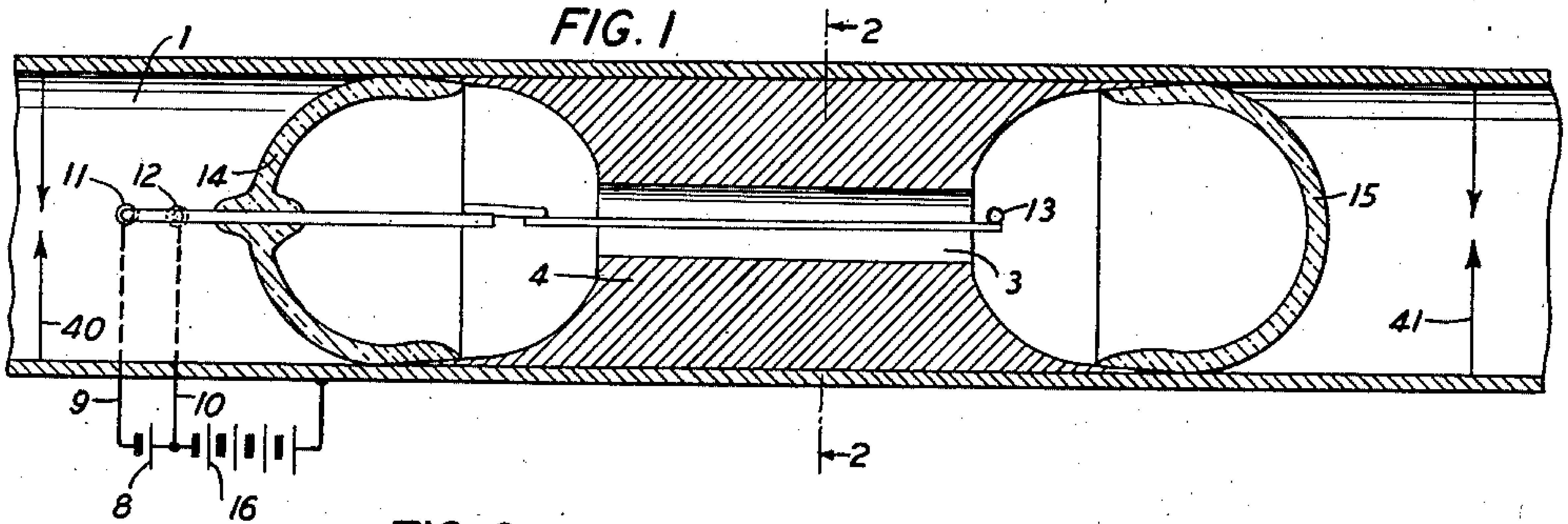


FIG. 2

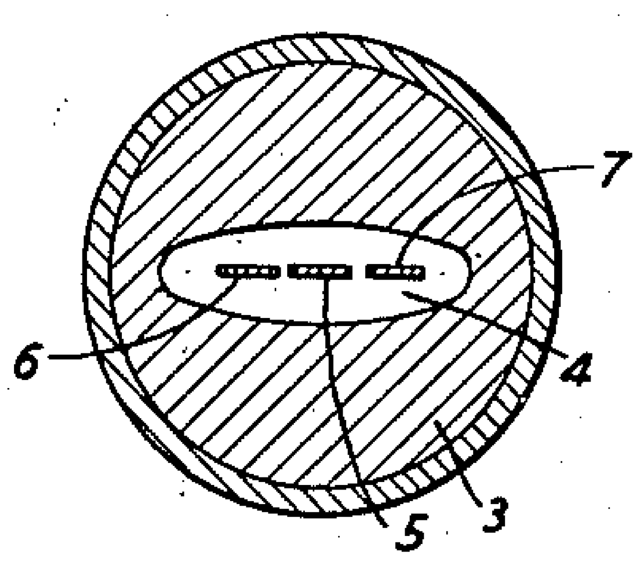


FIG. 3

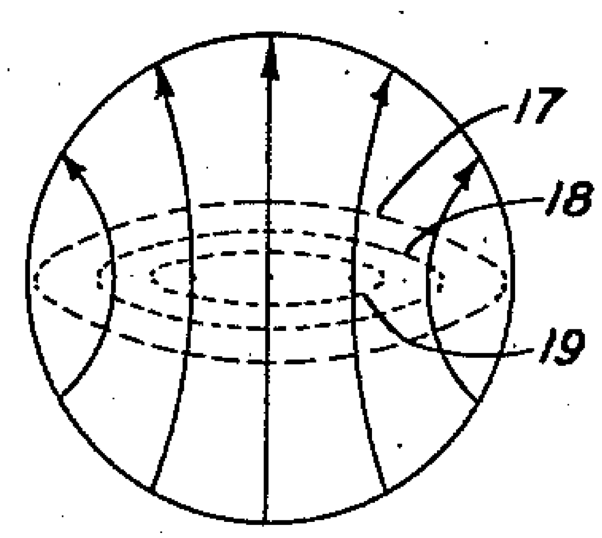


FIG. 5

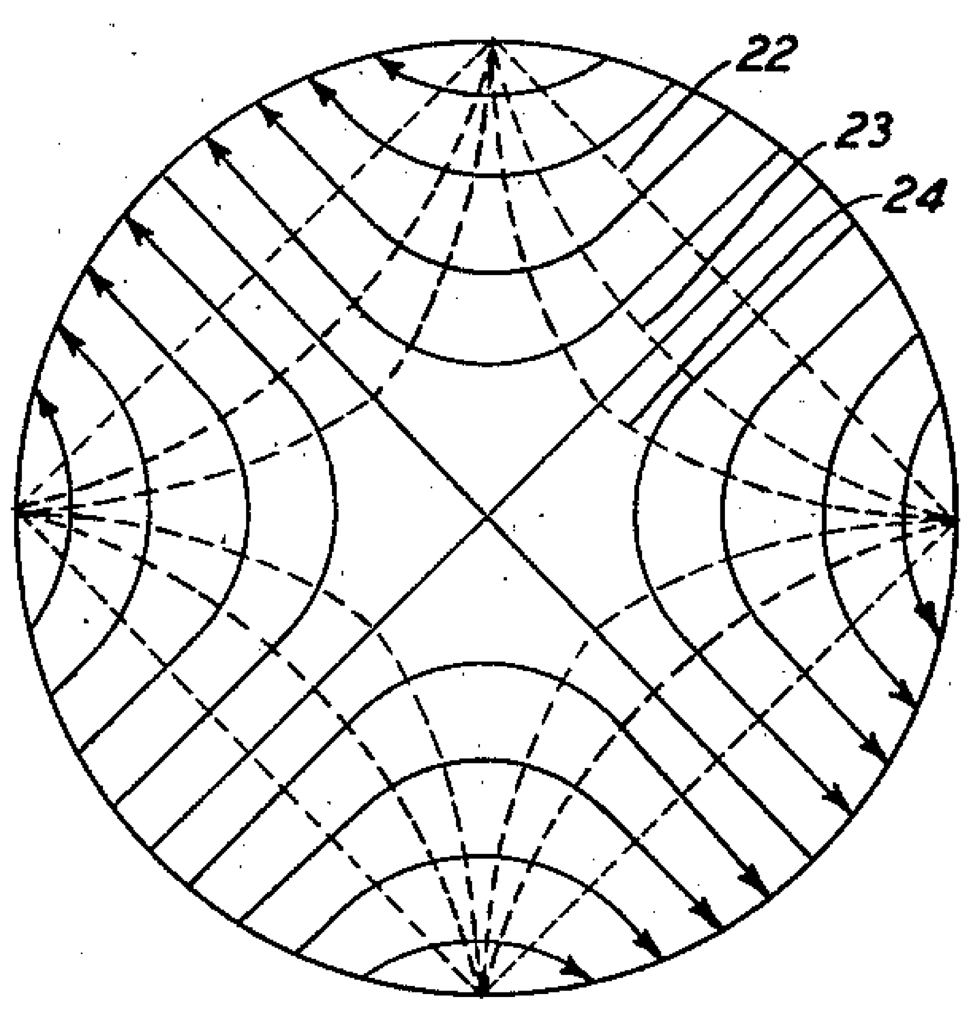
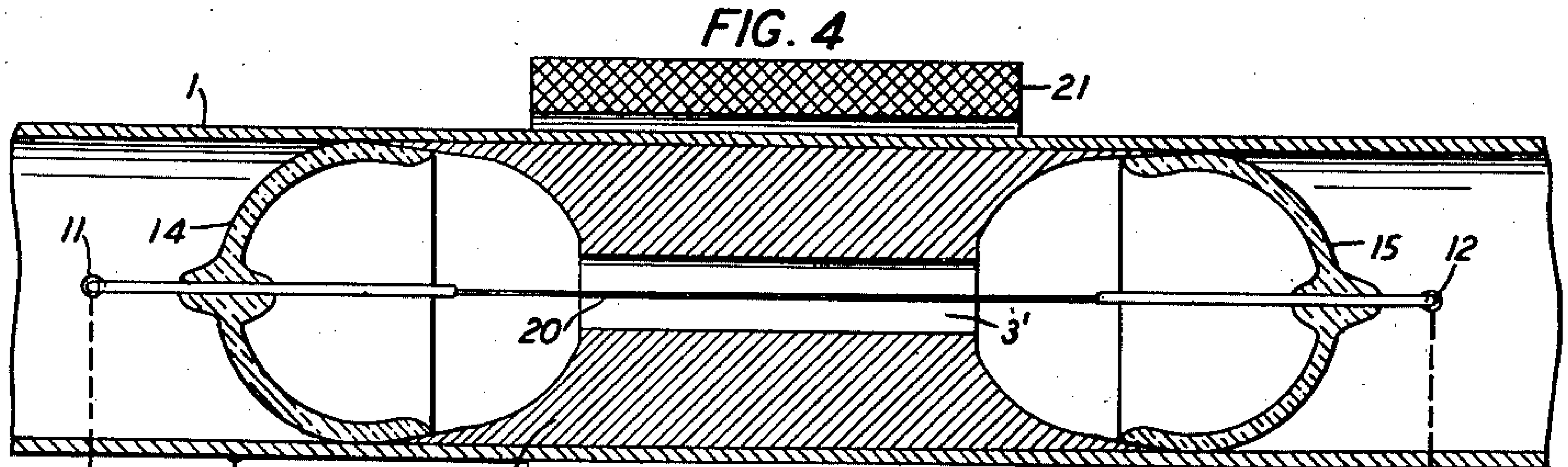


FIG. 4



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ULTRA-HIGH FREQUENCY ELECTRONIC DEVICE CONTAINED WITHIN A WAVE GUIDE

Filed May 3, 1941 3 Sheets-Sheet 2

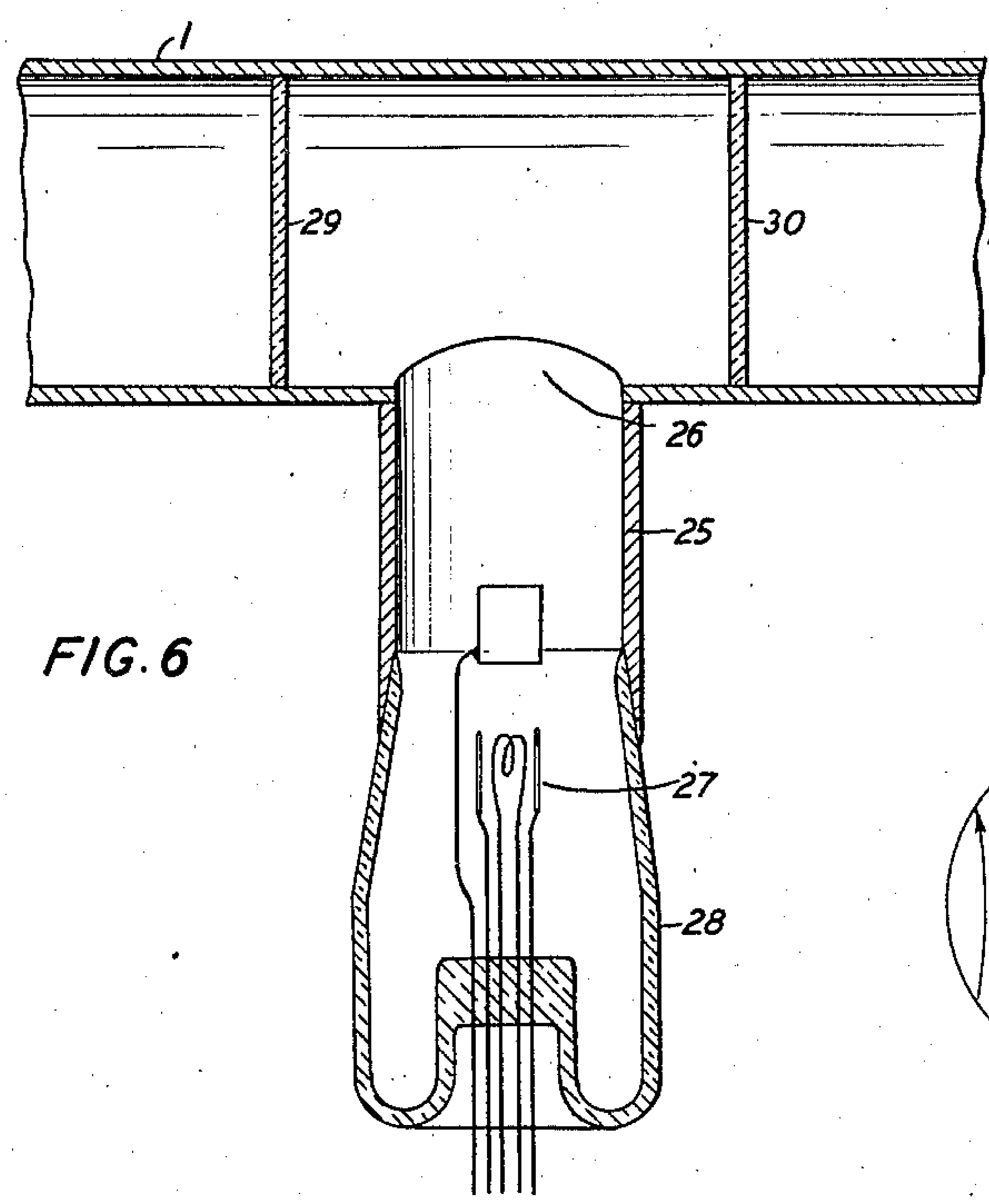


FIG. 6

FIG. 7

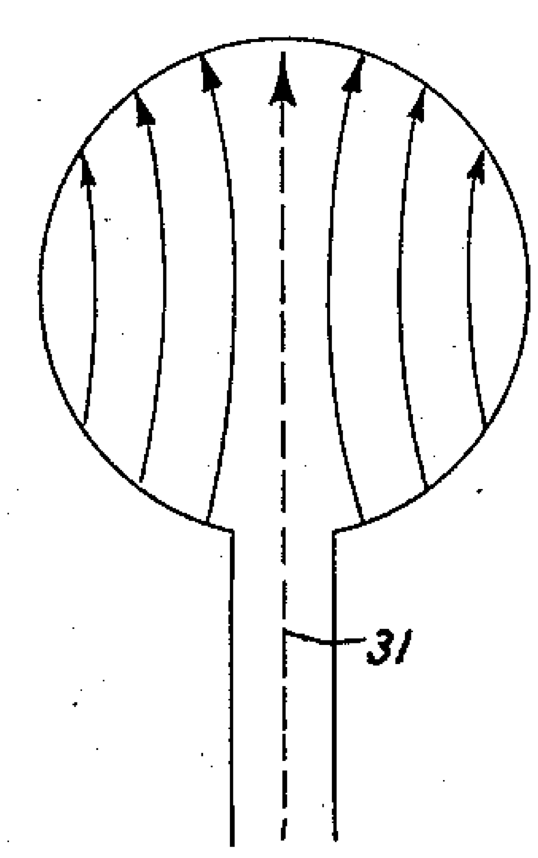
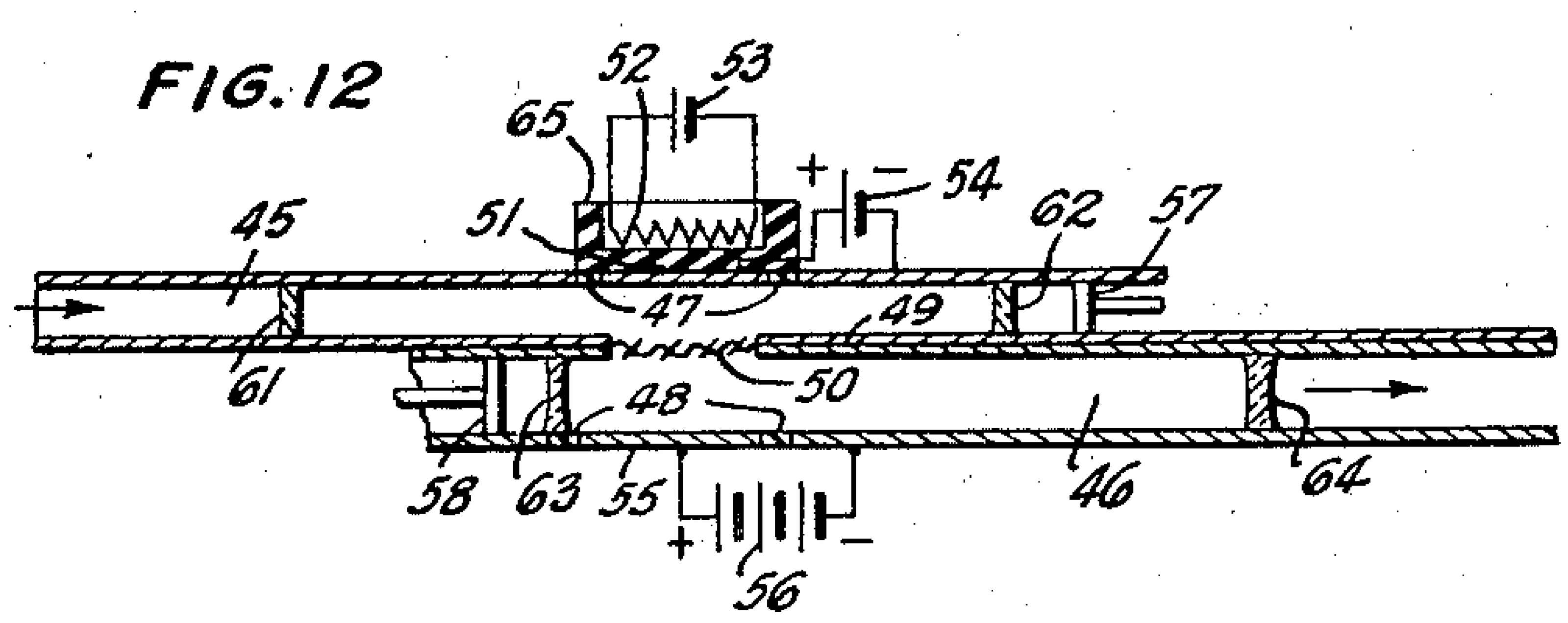


FIG. 12



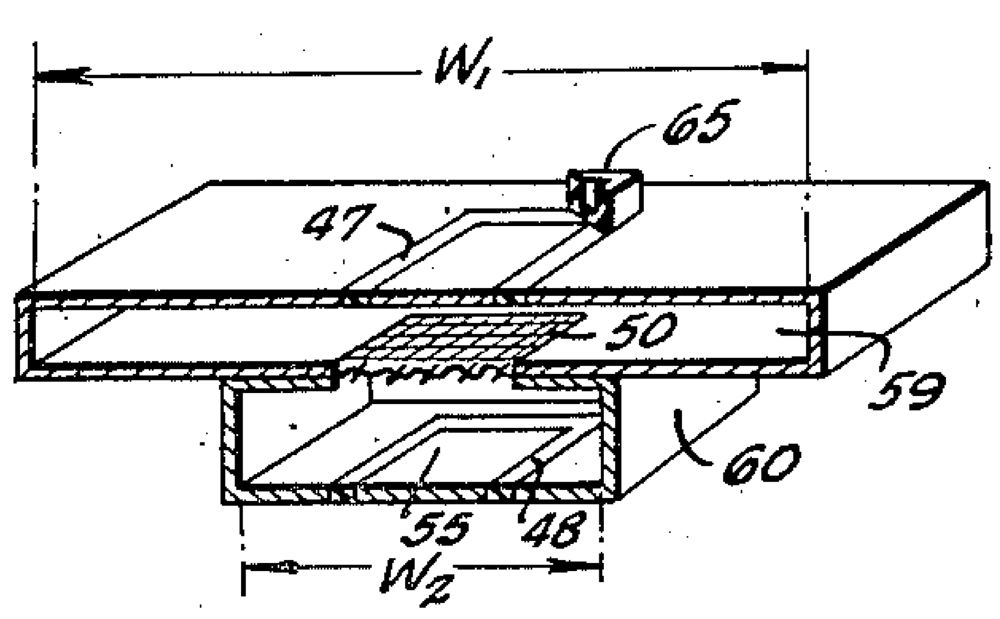


FIG. 13

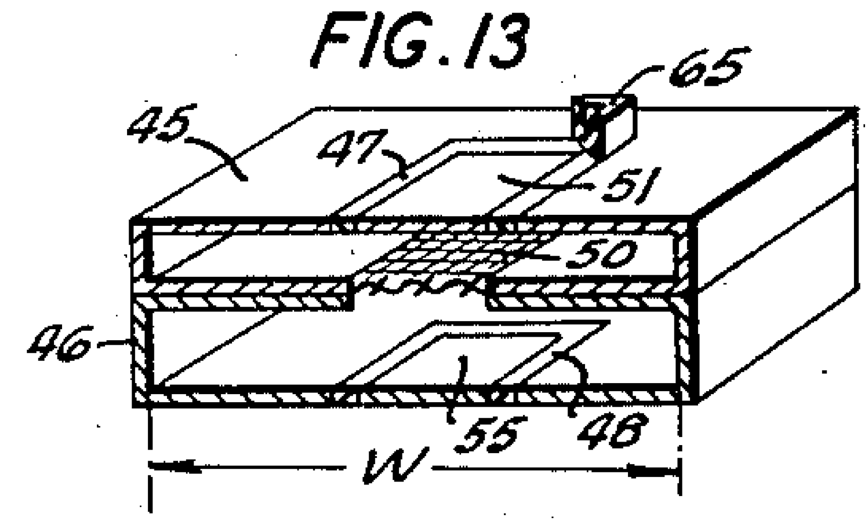


FIG. 14

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FIG. 8

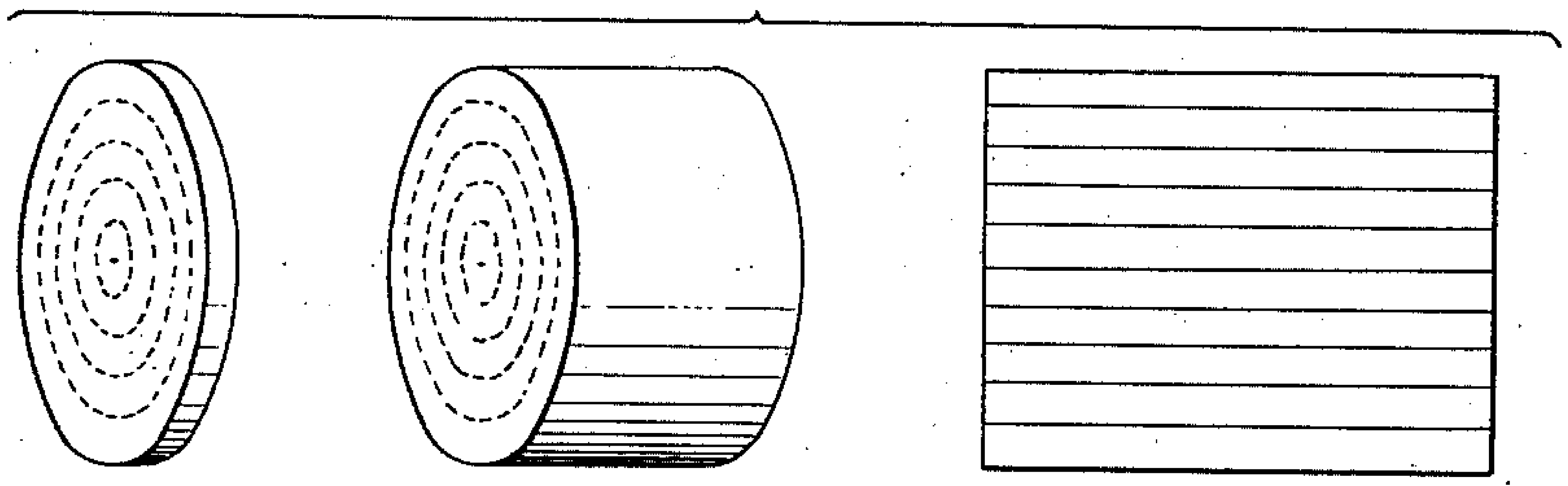


FIG. 9

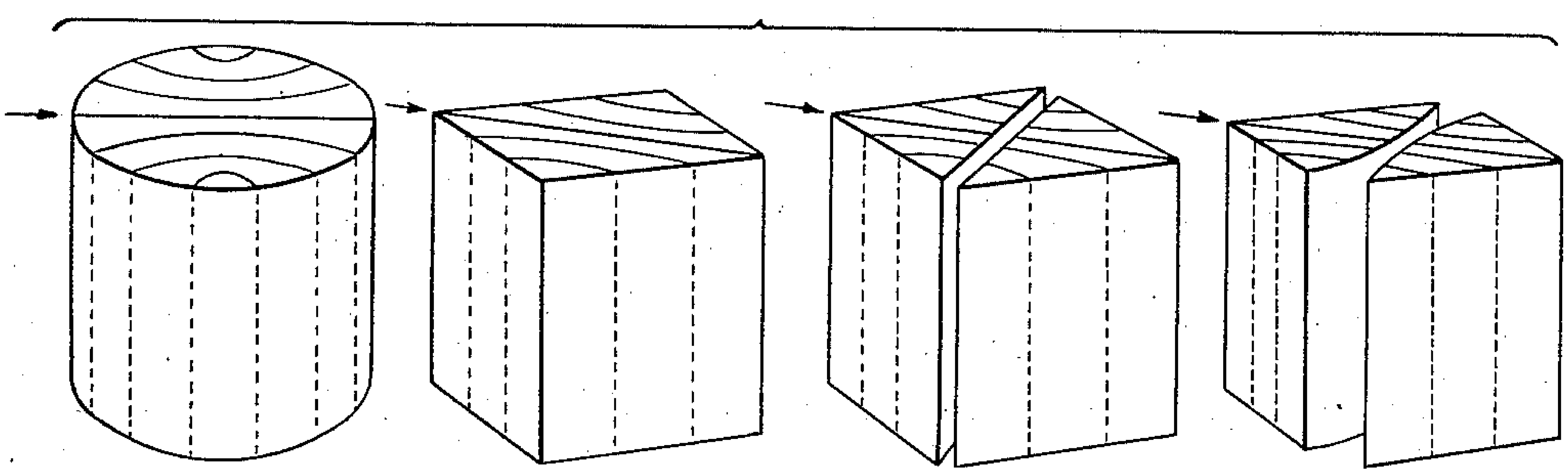


FIG. 10

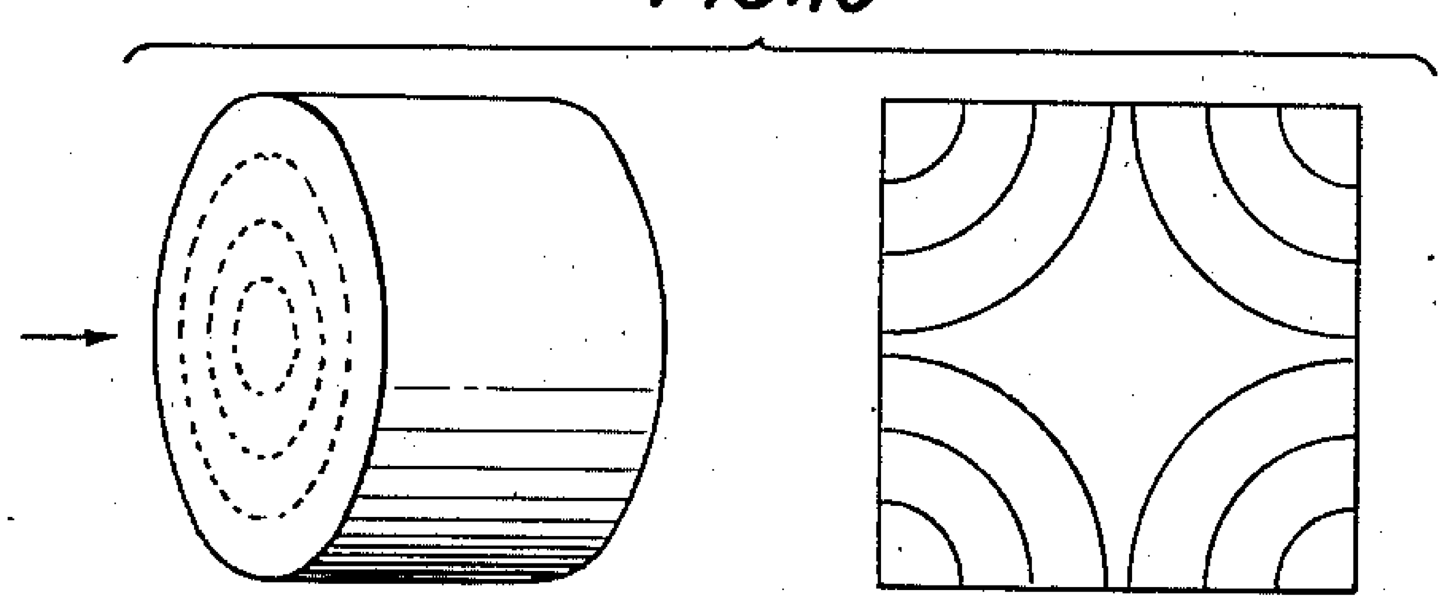
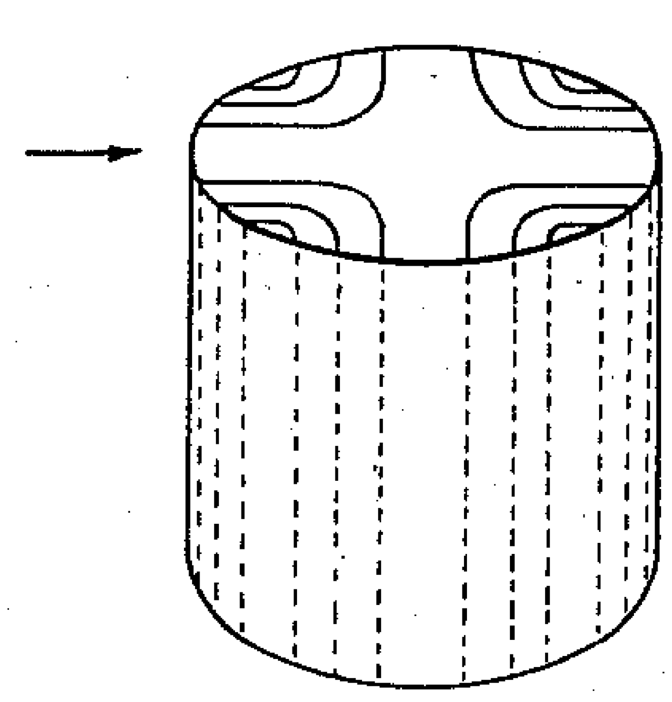


FIG. 11



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Patented June 18, 1946

2,402,184

UNITED STATES PATENT OFFICE

2,402,184

ULTRA HIGH FREQUENCY ELECTRONIC DEVICE CONTAINED WITHIN WAVE GUIDES

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Application May 3, 1941, Serial No. 391,658

5 Claims. (Cl. 178—44)

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This invention relates to methods of and apparatus for utilizing the interaction between electron streams and electromagnetic waves within wave guides.

An object of the invention is to increase the efficiency of coupling of electronic energizing systems to wave guides.

Another object of the invention is to cause a section of a wave guide to serve as a negative resistance with respect to waves traversing it, whereby the wave guide section may function as an amplifier.

An additional object of the invention is to increase the effective wave-length inside a wave guide by virtue of the properties of the guide in the frequency range near its cut-off frequency.

A feature of the invention lies in the incorporation of an electronic device such as an amplifier entirely within the compass of the wave guide. The device so incorporated is protected by the wall of the wave guide and if the wall is of conductive material, the device is shielded thereby from incoming or outgoing radiations.

Another feature of the invention is the use of an electron stream of increased cross-sectional area such as may be supplied from a linearly extended cathode. By constricting the inner cavity of the wave guide immediately surrounding the cathode, advantage is taken of the natural variation of the velocity of wave propagations in a wave guide operating near the cut-off frequency of the guide, which velocity may greatly exceed the free-space velocity of waves at the operating frequency. In accordance with this feature of the invention, a cathode may be extended through a length of several free-space wave-lengths and still occupy a length only a quarter wave-length or less relative to the waves inside the guide.

Another feature of the invention is the placing of the cathode structure and connecting leads substantially within an equipotential plane with respect to the electromagnetic field in the adjacent portion of the wave guide.

While the main advantages of the above features will immediately be evident to those familiar with the ultra-high frequency technique, it should be noted that the feature involving a linearly extended cathode is of particular importance in increasing the power capacity of electronic devices at the higher frequencies. Usually the power capacity of an ultra-high frequency system is limited by the diminutiveness of such of its physical dimensions as are necessarily not much greater than the free-space wave-lengths

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employed. When a narrow beam or pencil of electrons is employed for energy interaction with the system, the amount of power which can be handled may be uneconomically small at the higher frequencies. In accordance with the present invention, a sheet of electrons may be employed instead of a beam or pencil thereof. To avoid difficulties due to phase and amplitude differences in the electromagnetic wave from point to point along the length of the electron sheet, the stream is preferably limited to the order of a quarter wave-length in the direction of its linear extension. By placing the electron stream in a restricted section of wave guide where the velocity of wave propagation is several times the free-space velocity, the actual length of the cathode may be extended to several times what it would be if it were operating upon a wave in free space or in an unmodified section of the wave guide. The restricted section of the guide may be connected to the adjacent unmodified portion either by a transition section to minimize reflections or through an apertured partition or coupling iris to secure an optimum impedance transformation, or through any other suitable coupling means, or by a combination of such means.

In the drawings:

Figs. 1 and 2 show, respectively, a longitudinal and a transverse section of a wave guide containing the elements of a diode oscillator in a constricted portion of the guide;

Fig. 3 is a diagram useful in explaining the reason for the particular design of cross section shown in Fig. 2;

Fig. 4 shows a longitudinal section of a magnetron oscillator embedded in a restricted section of a wave guide;

Fig. 5 is a diagram useful in selecting appropriate designs for the cross-sectional configuration of the device shown in Fig. 4;

Fig. 6 shows an arrangement for projecting an electron stream into a wave guide through a side opening;

Fig. 7 is a diagram useful in explaining the operation of the arrangement of Fig. 6;

Figs. 8, 9, 10 and 11 show various shapes of wave guides and appropriate types of electromagnetic field distributions which may be advantageously used in connection with electronic energization;

Figs. 12 and 13 show, respectively, a longitudinal and a transverse section of an arrangement for coupling two wave guides through an electronic amplifier; and

Fig. 14 is a cross-sectional view of an arrangement whereby a wave of fundamental frequency in one wave guide may be utilized to set up a wave of a higher or harmonic frequency in a wave guide of smaller dimensions.

Referring to Figs. 1 and 2, a wave guide 1 is shown comprising a tube of conductive material, circular in cross section, and filled with a dielectric substance, for example atmospheric air. The wave guide 1 is shown broken off at the ends but it may actually be a section of a guide of any desired length, for example, connecting two distant points for the transmission of electromagnetic waves from one to the other or may be coupled to such a system by means of an iris. A constricted portion 3 is formed of conductive material at 4, as, for example, by thickening of the walls. The particular shape of the hollow space 3, which is formed within the thickened walls, is preferably determined in accordance with principles which will be discussed hereinafter. The transition between the constricted space and the unmodified wave guide is made gradual and preferably in accordance with the same general principles which determine the shaping of the space 3. In the diametral plane perpendicular to the paper in Fig. 1, shown more clearly by the sectional view in Fig. 2, there is located a filament such as a metallic ribbon 5 and a pair of similarly shaped ribbons 6 and 7 mounted edgewise with respect to the filament 5. The filament may be heated by current flowing from a battery 8 by way of leads 9 and 10 entering the wall of the guide 1 through small holes provided with insulating bushings 11 and 12, and thence through a pair of bent supporting rods, one of which is conductively connected with the filament 5 and the other of which is connected with one of the return leads 6 and 7, the latter being conductively joined at the far end in any suitable manner, as for example, by means of a connecting bar 13 to complete the filament circuit. To provide a vacuum chamber, both ends of the constricted section are sealed by means of glass or other suitable insulating closures 14 and 15 through one of which, 14, the filament heating leads may be hermetically sealed. The filament 5 is preferably made of highly resistive material and coated with a substance which gives copious electron emission, in accordance with well-known practice. The return leads 6 and 7 are preferably of highly conductive material, such as copper. The thickened wall portions 4 are conductively connected with the walls of the unmodified guide and may be integral therewith. The inner surface of the cavity 3 serves as an anode and is provided with a polarizing potential by means of a battery 16 or other suitable source preferably connected between one side of the filament circuit and the wall of the guide 1. Irises 40 and 41 may be employed to regulate the coupling to the main body of the guide.

In the operation of the system shown in Figs. 1 and 2 the elements in the evacuated chamber between the closures 14 and 15 function as a diode to provide a negative resistance effect in the manner of the diodes disclosed in U. S. Patent 2,190,668, issued February 20, 1940, to F. B. Llewellyn. The arrangement may be used as an oscillator to generate ultra-high frequency waves, in which case the waves will be transmitted along the wave guide in either direction. Alternatively, the device may be employed as an amplifier to reinforce a traveling wave as it passes the device. In either case, the closures 14 and 15 will have negligible effect in attenuating or distorting the wave as it passes. The device may also be used as a modulator or detector. As in the case of the Llewellyn type of diode, the transit time of electrons passing from the cathode to the anode is to be adjusted to a critical value depending upon the operating frequency in order to secure the desired negative resistance effect. The transit time may be adjusted by variation or proper selection of the voltage supplied by the battery 16. The transit time is preferably adjusted to one of the values of the expression $(n+\frac{1}{4})$ cycles of the operating frequency, where n is a positive integer.

The mode of propagation for which the above-described structure is primarily designed is that designated as an H_1 wave according to the notation employed in U. S. Patent 2,129,712, issued September 13, 1938, to G. C. Southworth. The H_1 type wave is depicted diagrammatically in Figs. 9 and 9a of the Southworth patent. In the wave of this kind the instantaneous configuration of the electric field is as shown approximately by the arrows in Fig. 3. Other types of wave propagation may be employed with suitable modification of the apparatus.

As above noted, the purpose of constricting the interior space of the wave guide at 3 is to produce a modified portion of guide, the cut-off frequency of which will be only slightly below the operating frequency of the system. One way to achieve this result would be to diminish the diameter of the cavity leaving it circular in shape. By this process the electric field would be considerably distorted from the configuration shown in Fig. 3 and as it is desirable to permit waves from the unmodified portion of the guide to traverse the constricted section without undue distortion, a shape of section for the constricted portion should be adopted which will, as little as possible, distort the electric field. For this purpose, a shape may be selected which is substantially in the form of an equipotential line or contour, cutting the lines of electric force everywhere at right angles. Curves of this sort are in the general nature of ellipses, a number of which are shown at 17, 18 and 19 in Fig. 3. The shape which has been employed in the arrangement of Figs. 1 and 2 is that of curve 18. In an elliptical wave guide, the cut-off frequency for the H_1 wave is determined by the length of the major axis of the ellipse. Accordingly, the major axis of the cross section of cavity 3 is made somewhat less than the diameter of the guide 1. In this way, the cut-off frequency of the elliptical section is brought closer to the operating frequency than is the case of the cut-off frequency in the unmodified portion of the guide 1. As a result, the velocity of propagation of the wave in the constricted section may be made greater than the velocity of propagation of the same wave in the unmodified guide by a factor of several times. The active length of the cathode is preferably made substantially equal to the length of the constricted section and this may be several free-space wave-lengths and at the same time the cathode will actually be short compared with the wave-length within the constricted guide, preferably a quarter wave-length or less. It will be evident that by this arrangement the cathode has been extended linearly and the area of the electron stream which can be usefully employed has been increased in substantially the same ratio.

Fig. 4 shows a modified system according to the same general principles employed in the system of Figs. 1 and 2, in this case arranged to operate as a magnetron rather than in the manner of the diode oscillator. In the arrangement of Fig. 4 the cathode comprises a wire or small rod **20** mounted substantially on the axis of the guide **1** and supported at either end by means of extensions which are hermetically sealed into and pass through the closures **14** and **15**. A magnetizing coil **21**, coaxial with the cathode **20** is provided to supply the field required for magnetron operation. This arrangement is particularly designed for a second order type of wave propagation, the electric field configuration for which is shown approximately by the arrows in Fig. 5, corresponding generally with Fig. 9b of the Southworth Patent 2,129,712, above cited. The thickened wall section **4'** of Fig. 4 encloses a cavity **3'** which may have a cross-sectional shape such as one of those represented by equipotential lines **22**, **23** and **24**, respectively, in Fig. 5.

The arrangement of Fig. 4 operates in essentially the same manner as a four-plate conventional magnetron, current flowing principally to four regions on the anode surface, which regions, however, need not be physically separated or insulated from one another. Due to the constricted cavity 3', the axial length of the elements may be long compared to the free-space wave-length in accordance with the same principle governing the case of the diode. As in the case of the arrangement of Figs. 1 and 2, the magnetron of Fig. 4 may be used as an oscillator, amplifier, modulator, etc.

An alternate arrangement for a diode in a wave guide is as shown in Fig. 6. This arrangement has the property of acting upon a traveling wave in a wave guide but does not make use of a constricted section nor of a linear cathode. The guide **1** is provided with a side tube **25** fastened over a hole **26** in the wall of the guide **1**. An electron gun, designated generally at **27**, enclosed in an insulating envelope **28** is affixed to the tube **25** by means of a suitable vacuum-tight seal, and the vacuum chamber is closed by means of insulating windows **29** and **30** which offer substantially no obstruction to the passage of electromagnetic waves along the guide **1**. A wave of the H_1 type is suitably employed, giving an electric field configuration as indicated diagrammatically in Fig. 7. The electron stream indicated by a dash-line arrow **31** is injected into the main guide **1** substantially in the principal direction of the electric field. The electrons of the stream **31** are accelerated by a suitable biasing potential between the cathode of the electron gun and the conductive walls of the guide **1**. By suitably controlling the transit time of electrons in traversing the interior of the guide **1**, the electron stream may be made to deliver energy to the electromagnetic field of the guide. Accordingly, the device may be employed as a negative resistance element to sustain the amplitude of a traveling wave passing along the guide. It will readily be appreciated that the arrangement may also be used as an oscillator or modulator.

The arrangements shown in Figs. 1, 2 and 6 are all characterized by an electron beam interacting with an electromagnetic field, the electric component of which is substantially at all times in the direction of the beam or in the reverse of that direction. It will be evident that there are many modes of oscillation in wave guides which will set up electric field configurations suitable for interaction with an electron beam in the manner above described. It will further be noted that the guide need not be a circular one but may be square or prismatic with a variety of different shapes, the main characteristic desired being that the electric field have a considerable region in which it consists essentially of parallel straight lines. A number of suitable wave guide sections with appropriate electric fields indicated are shown in Figs. 8, 9, 10 and 11.

Fig. 8 shows cylindrical guides supporting a wave of the E_0 type as in Figs. 6 and 6a in Southworth Patent 2,129,712.

Fig. 9 shows how the circular guide of Fig. 3 may be modified into various prismatic shapes, all of which will support essentially the same configuration of electrical waves as shown in Fig. 3. The modifications include a square guide in which the electron stream is suitably introduced in the direction of a diagonal of the square cross section, and a triangular guide in which the electron stream may be introduced either at the right angle corner or in the reverse direction so as to emerge from that corner. The last example in Fig. 9 is in the form of quarter sections of a cylindrical shape in which the electron beam may either enter or leave at the center of the circular arc. In all these examples the electron path is substantially parallel to the electric field.

Fig. 10 shows a field configuration generally similar to that shown in Fig. 5 but imposed upon a cylindrical guide transversely to the axis of the cylinder instead of longitudinally.

For comparison a cylindrical guide supporting a wave in the manner of Fig. 5 is shown in perspective in Fig. 11.

In Figs. 8, 9, 10 and 11 the direction of the axis of the electron stream is indicated by an arrow.

The electron stream in the form of a beam or pencil may be employed with any of the wave guides illustrated in Figs. 8, 9, 10 and 11 as well as in other configurations not shown. The arrangements of Figs. 9 and 11 are particularly well adapted, in addition, to the use of the extended linear cathode in connection with a constricted portion of a guide, in accordance with the principles set down in connection with the description of Figs. 1, 2 and 4.

Figs. 12 and 13 show longitudinal and transverse sections, respectively, partially diagrammatic, of a triode arrangement coupling two wave guides. The arrangement operates as an ordinary triode amplifier except that the cathode-grid space and the grid-anode space are isolated from each other by being included each in a separate wave guide interconnected only through the meshes of the grid. The arrangement is shown as an amplifier.

In Figs. 12 and 13, two partially overlapping wave guides **45** and **46** are shown with a common wall portion **49**. The guides are preferably rectangular in cross section and in the case of an amplifier both guides may well have the same transverse dimension or width W, as indicated in Fig. 13. In the common wall **49** there is situated an electron permeable region or grid **50** opposite which in the guide **45** is a thermionically active cathode section **51** insulated from the wall of the guide by insulation **47** or otherwise suitably mounted. Vacuum seals are provided, as at **61**, **62**, **63** and **64**. The cathode may be heated by an external heating element **52** insulated as at **65** and energized by a battery **53**. The cathode may be positively polarized with respect to the grid **50** by means of a polarizing battery 54. Opposite the grid 50 in the guide 46 may be mounted an anode 55 insulated from the wall of the guide by insulation 48 and polarized positively with respect to the grid 50 by means of a battery 56. Each of the batteries above mentioned may be replaced by any suitable source of direct current electromotive force. Adjustable pistons or reflectors 57 and 58 are provided for controlling the establishment of standing wave patterns. An incoming wave in the guide 45 serves to impress a control voltage between the cathode 51 and the grid 50 thereby producing a variable electron current in the region between the grid 50 and the anode 55, the variations of which current serve to set up amplified electromagnetic waves in the guide 46. The mode of operation of the device is generally similar to that described in U. S. Patent 2,153,728, issued April 11, 1939, to G. C. Southworth.

Fig. 14 is a cross-sectional view of a modification of the arrangement of Figs. 12 and 13 adapted for frequency conversion. In this arrangement the incoming wave guide, shown at the top, is of a suitable width (horizontal dimension) to support a wave of a desired fundamental frequency. The output wave guide, shown below, is narrower so that it will not support a wave of the fundamental frequency but it may be tuned to the harmonic frequency. The vertical dimensions of the respective guides in Figs. 12, 13 and 14 may be determined by the relative spacings desired between the grid and the cathode on the one hand and the anode on the other.

In Fig. 14 the wave guide for the fundamental frequency is designated 59 and the guide for the harmonic 60, the widths of the respective guides being W_1 and W_2.

The arrangement of Fig. 14 is claimed in my copending application Serial No. 461,517, filed October 10, 1942, assigned to the same assignee as the present application.

What is claimed is:

1. In an ultra-high frequency electronic device, a source of waves of a given operating frequency, a section of wave guide of such transverse dimensions as to have a cut-off frequency close to and slightly below said operating frequency, said wave guide section being so proportioned that its length is of the order of magnitude of a quarter wave-length referred to propagation of waves within said guide, but relatively great compared to the free-space wave-length corresponding to the operating frequency, a cathode with its active portion extending substantially the full length of said wave guide section, and means for causing an electron stream emitted from said cathode to effect energy interchange with electromagnetic waves from said source within said wave guide section.

2. In a system for effecting exchange of energy between an electron stream and an electromagnetic wave, a source of waves of given operating frequency, a wave guide, means in said guide to increase the speed of propagation of waves from said source therein over the speed of propagation of a wave of the same frequency in free space, thereby multiplying the wave-length in said guide compared to the free-space wave-length, and a source of an electron stream, said

source extending along and adjacent to the path of propagation of said wave within the confines of said speed increasing means in said guide, the length of said source in this extension being of the order of magnitude of a quarter wave-length referred to propagation within said speed increasing means and at the same time of the order of magnitude of several free-space wave-lengths.

3. In a system for energy interchange at ultra-high frequencies, a source of electromagnetic waves of a given operating frequency, a source of an electron stream, means for constraining waves from said first-mentioned source to traverse a restricted region in which the speed of propagation of the wave is increased with respect to the speed of propagation of a wave of the same frequency in free space, thereby multiplying the wave-length in said region compared to the free-space wave-length, said source of an electron stream being positioned within said region of increased speed of wave propagation and being extended in its dimensions along the path of propagation of said wave to a length which is of the order of magnitude of a quarter wave-length referred to propagation within said region of increased speed and at the same time of the order of magnitude of several free-space wave-lengths.

4. An extended length of wave guide, a source of waves of a given frequency freely transmitted by said guide, a section of reduced internal cross-sectional area in said guide having such dimensions as to have a cut-off frequency close to and slightly below said given operating frequency, said section of reduced area being so proportioned that its length is a fraction of a wave-length referred to the speed of wave propagation within said section and at the same time equal to several free-space wave-lengths of the operating frequency, and means for projecting electrons transversely to the guide within said section of reduced area along a substantial portion of the entire length of said section to effect energy interchange between electrons so projected and a wave of the operating frequency within said section.

5. In an ultra-high frequency transmission system, a wave guide designed for the propagation of an electromagnetic wave of a given field configuration, a portion of said guide being modified in internal dimensions to form a section of reduced internal diameter, the cross section at all points of said guide being such as to conform substantially with equipotential contours of the given field configuration to secure a section of increased speed and propagation without causing material distortion of the field configuration, and means for maintaining in said section of reduced internal diameter an electron stream having a dimension transverse to the direction of motion of the electrons which is substantially as great as the length of said reduced section, said means comprising a heated cathode located within the said section of reduced internal diameter, and said cathode having its electrical connections located substantially in a single equipotential plane of said given field configuration.

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