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2,420,342

HIGH FREQUENCY CONTINUOUS AMPLIFIER

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FIG. 1

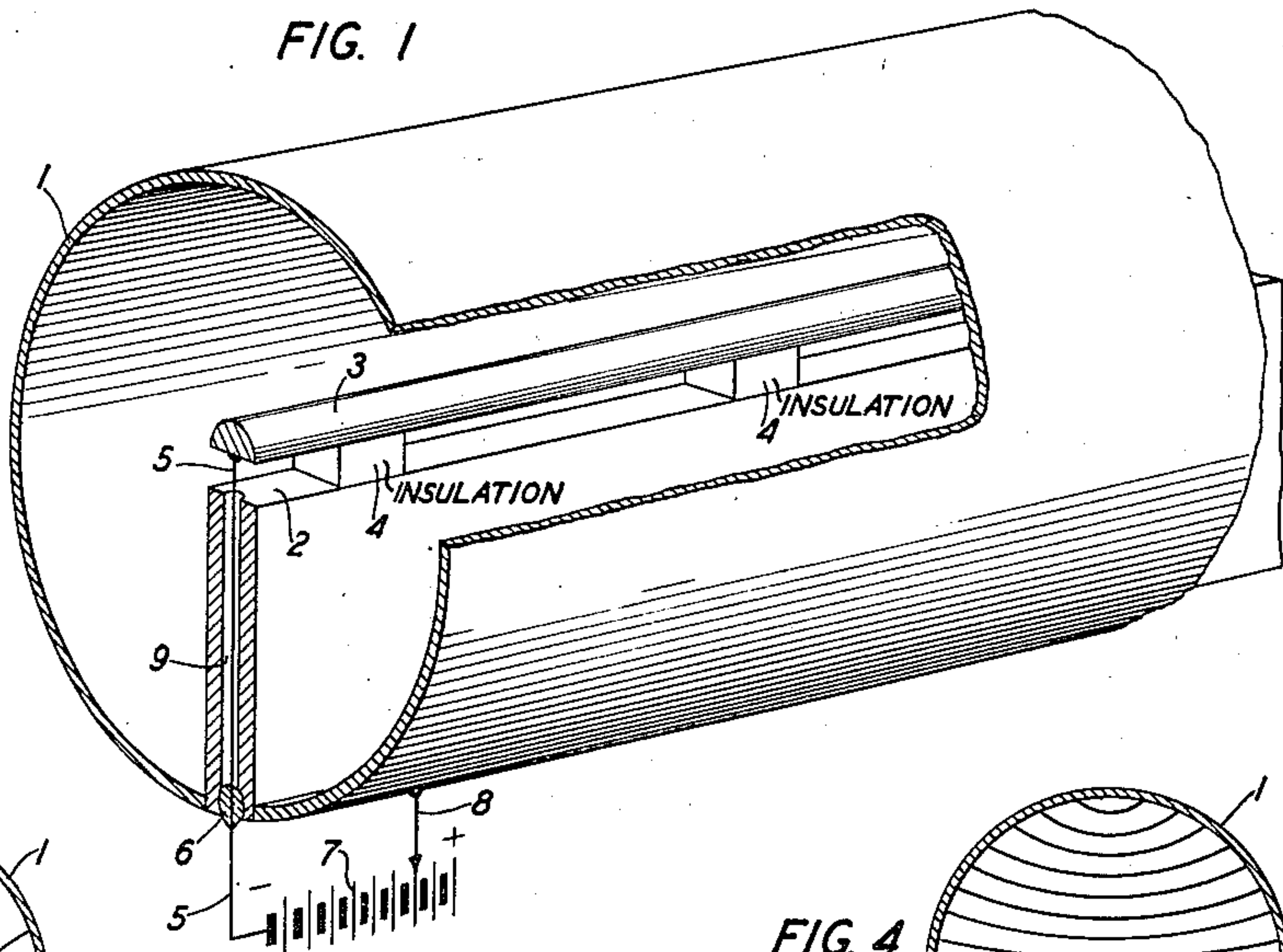


FIG. 2

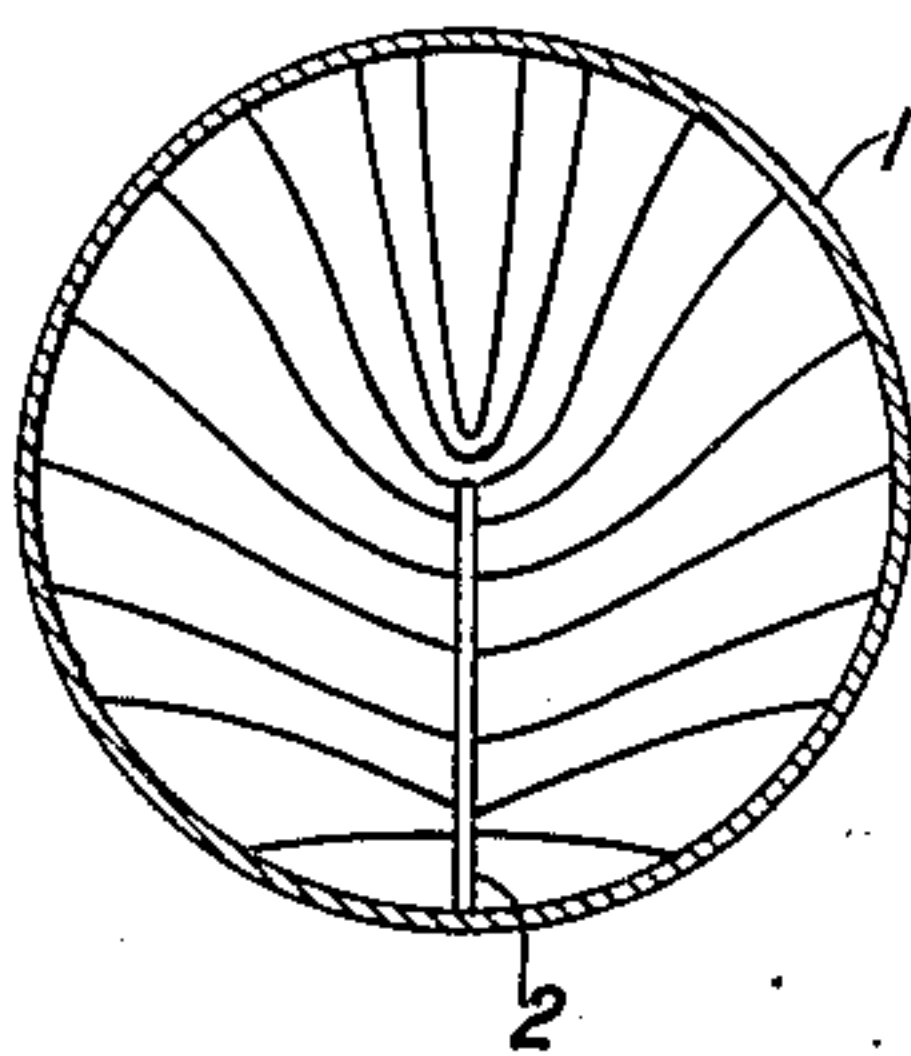


FIG. 4

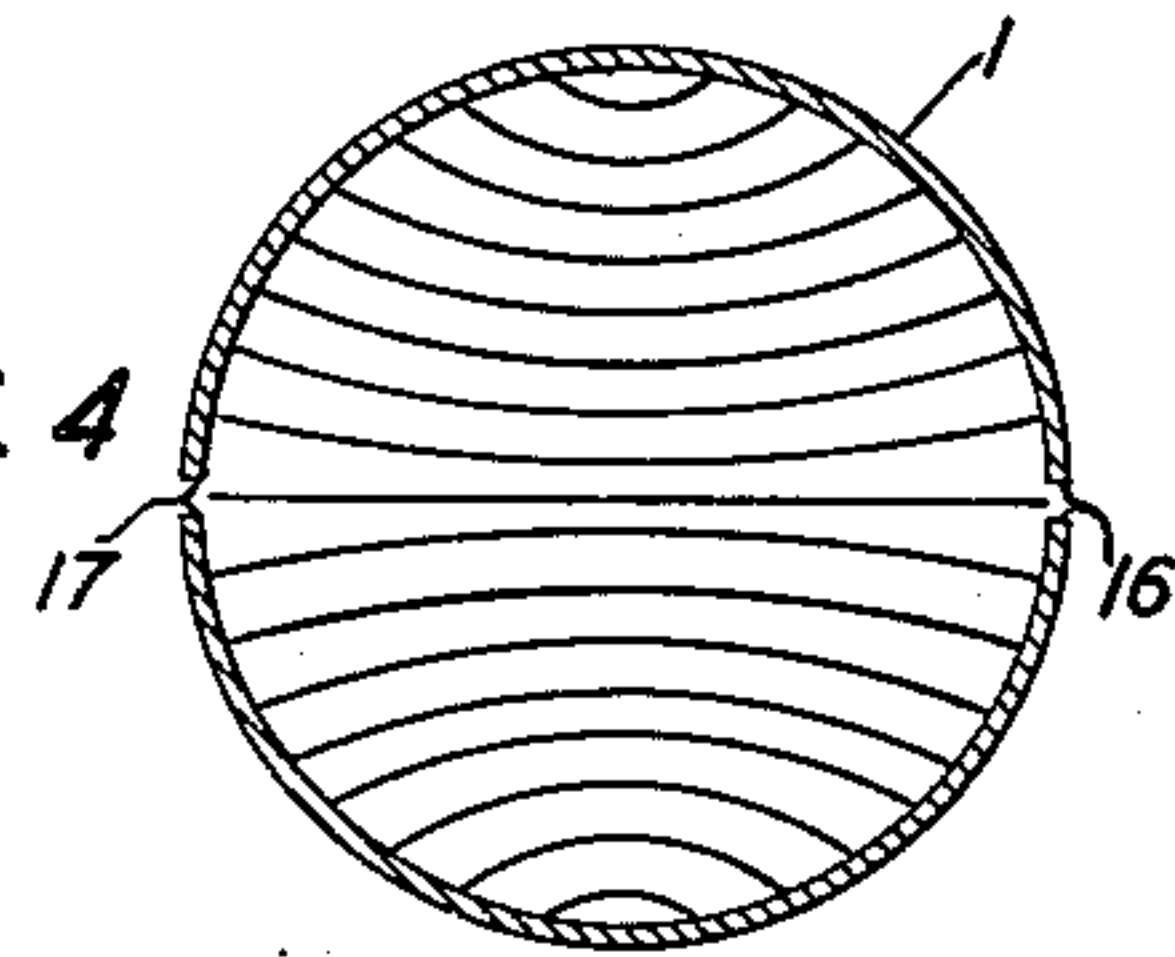
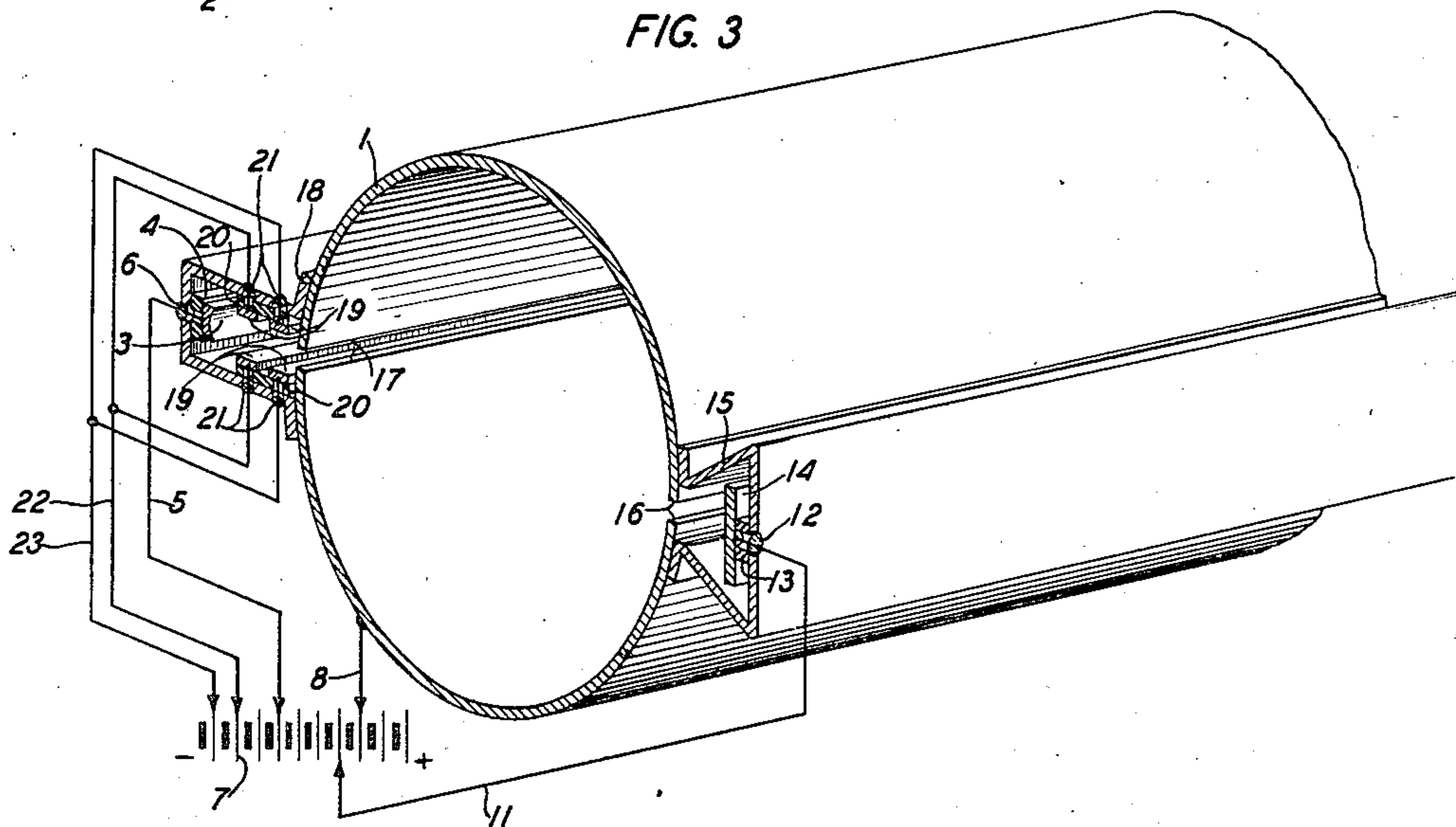


FIG. 3



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HIGH FREQUENCY CONTINUOUS
AMPLIFIER

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9 Claims. (Cl. 178-44)

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This invention relates to high frequency transmission systems and particularly to such systems incorporating amplifiers to compensate for transmission losses.

An object of the invention is to provide such a transmission system in which amplification means is distributed uniformly along a considerable portion of the transmission path.

Another object is to provide a transmission system in which the energy level is maintained substantially the same over a considerable portion of the transmission path.

Another object is to provide a transmission system in which the energy loss is relatively low.

Another object is to provide a transmission system having a high degree of immunity from extraneous noise.

In the transmission of electrical energy, loss is encountered which tends to reduce the energy level as the distance from the energy source along the transmission path is increased. A usual way of compensating for such loss is to insert amplifiers along the path at suitable intervals. Each of these amplifiers serves to raise the energy level from the attenuated level at the point where it is inserted to a higher level for transmission to the next amplifier position. The amplifiers are generally spaced so that the attenuated energy level is not so low as to be masked by extraneous electrical disturbances and at the same time so that the energy level at the output of the amplifier is not excessive. Compromises to reduce the number of amplifiers required may result in deterioration of the over-all transmission due to the variations in energy level along the transmission path.

Such deterioration is avoided in a system according to this invention because the energy level may be maintained nearly constant along the transmission path. This is achieved by distributing the amplifying means continuously along the path so that energy is added to compensate for attenuation continuously rather than at separate points between which there may be considerable attenuation. In typical embodiments this is accomplished by utilizing a cathode coextensive with a wave guide transmission system and causing the electron emission therefrom all along its length to contribute electrical energy to that being transmitted.

Since energy is added to the system continuously along its length the energy level need nowhere exceed the minimum required for satisfactory transmission as determined by noise or other limiting factors. It is necessary for stabil-

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ity that the total gain of the system be less than zero or that there be some loss. The level will therefore decrease slowly along the system and be slightly lower at the receiving end than at the transmitting end. As the energy level may be a minimum the energy loss in the system will be a minimum. Therefore the power required of the amplifying means will be a minimum and less than would be required from a series of spaced amplifiers.

Since the "continuous" amplifier of this invention has no sense of direction it functions to reduce the attenuation of energy transmitted through the system in either direction. Also, the transmission characteristic of the system apart from attenuation is not sensibly affected by the introduction of the amplifying feature.

In order to accomplish the desired amplification by the transfer of energy from the electrons emitted along the length of the transmission system advantage is taken of the fact that when a stream of electrons is passed through an alternating electric field in the direction of the lines of force such that the time required for an electron to pass through the field is approximately equal to the period of any number of cycles plus one-quarter cycle of the field there is a transfer of energy from the electron stream to the field. An exposition concerning the transfer of energy from the electron stream under this condition appears in United States Patent 2,190,668 issued February 20, 1940, to F. B. Llewellyn. In that patent it is shown that a stream of electrons moving in a high frequency electric field between two equidistant surfaces or planes exhibits the property of negative resistance within a series of frequency bands and that this property may be used for the production of high frequency energy through the transfer of energy from the electron stream to the electric field. In order that the energy (corresponding to the negative resistance) be produced at the desired frequency it is only necessary that the electron transit time be properly correlated to that frequency. It is shown that the negative resistance is exhibited when the transit time of the electrons through the field is a period between that of 1 and $1\frac{1}{2}$ or 2 and $2\frac{1}{2}$ or 3 and $3\frac{1}{2}$, etc., cycles of the high frequency field and is a maximum when the transit time is approximately the period of $1\frac{1}{4}$ or $2\frac{1}{4}$ or $3\frac{1}{4}$, etc., cycles. The magnitude of the negative resistance and therefore of the generated high frequency energy varies with the magnitude of the electron current and also with the degree to which the transit time is adjusted

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to the period for maximum negative resistance. It is specified that the path of the electron stream in the field should be between two equidistant surfaces or planes so that the transit time of all the electrons will be substantially the same.

The invention will be understood more completely from the following description and the associated drawings of which:

Fig. 1 illustrates one embodiment of the invention in a wave guide transmission system;

Fig. 2 illustrates the type of electric field within the guide of Fig. 1;

Fig. 3 shows another embodiment of the invention in a wave guide transmission system of a different type from the showing of Fig. 1; and

Fig. 4 illustrates the type of electric field within the guide of Fig. 3.

The general principles underlying the transmission of electrical energy along a dielectric guide within a sheath of conducting material is well known and in the embodiments illustrated by the above figures the dielectric material consists of the space within the sheath or shell which is evacuated to permit the passage of electrons.

For a description of wave guides and their operation and particularly to certain pertinent features, reference is made to United States Patents 2,129,712 issued September 13, 1938, to G. C. Southworth and 2,199,083 issued April 30, 1940, to S. A. Schelkunoff. A comprehensive discussion of the subject appears in an article "Hyper-frequency wave guides," by G. C. Southworth in Bell System Technical Journal, vol. 15, pages 284-309, April 1936.

In Fig. 1, 1 represents the conducting shell of a cylindrical wave guide extending indefinitely in both directions from the transverse section shown and serving as a medium for the transmission of high frequency electrical energy between points external to the figure; 2 is a septum of conducting material extending longitudinally along the guide and radially from near the center of the guide to the shell 1. Supported by the septum 2 on insulators 4 is a cold emission cathode 3 which extends along the length of the guide in the approximate center thereof. This cathode may be a conductor coated with active material or may be any other arrangement capable of the desired electron emission. A hot cathode may be substituted for the cold cathode shown, in which case it will of course be necessary to provide means for heating the cathode. Insulators 4 will of course be spaced along the entire length of the cathode to support it insulated from the septum 2. Potential source 7 is connected to the shell 1 by lead 8 and to the cathode 3 by lead 5 passing through the insulating seal 6 and the radial hole 9 in the septum 2. The space within the wave guide is evacuated and the shell 1 is maintained positive with respect to the cathode 3 so that electrons flow from the cathode in radial directions to the shell.

Potential sources such as 7 may be provided at suitable intervals along the guide to maintain a flow of electrons between the cathode 3 and the shell 1 uniformly or as desired along the length of the cathode.

In operation as an amplifier it is necessary that energy be transferred from the electrons to the energy being transmitted along the wave guide and as previously stated this is accomplished through interaction between the electrons and the electric field associated with the transmitted energy. For such interaction it is necessary that the electrons have a component of velocity in the

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direction of the lines of force of the electric field. Since the electrons follow radial paths from the cathode, lines of force of the electric field in the guide should follow similar paths which they do as indicated in the diagram of Fig. 2. This figure indicates the lines of force, the shell of the guide and the septum. It will be noted that the electric field is substantially radial over the region through which the electrons flow. The high frequency excitation of the guide by which means energy is transmitted must therefore be such that the electric field produced is of this type. The above-mentioned Schelkunoff patent (2,199,083) shows a form of wave guide with a septum introduced for the purpose of obtaining certain transmission characteristics and also shows methods of excitation in Figs. 3 and 5 which produce the type of transverse electric field pictured in Fig. 2. The applicant's "continuous amplifier" arrangement with the cathode supported in the center of the guide by the septum as shown in Fig. 1 is well adapted to this type of guide comprising a radial septum.

If the septum is dispensed with and the cathode supported in some other suitable manner along the center of the shell 1 and insulated from it, the system becomes the equivalent of a coaxial line incorporating the invention. It would then be necessary to connect the cathode to the source 7 at the end of the line to prevent interference with the electric field which would be radial in all directions from the cathode between it and the shell.

It has been mentioned above that the path of the electron stream in the electric field should be between two equidistant surfaces or planes so that the transit time of all the electrons will be substantially the same. It will be observed that this condition exists in Fig. 1 as the paths are radial from the center of the guide to the concentric conducting shell. (A similar condition of equal transit times exists in the showing of Fig. 3 where the planes of the slots in opposite sides of the shell where the electrons respectively enter and leave the alternating electric field are substantially parallel.)

In operation the direct potential applied between the cathode 3 and the anode or shell of the guide from source 7 is adjusted so that the electron transit time will be substantially the period of a whole number of cycles plus $\frac{1}{4}$ cycle of the energy being transmitted along the guide or as near that period as is required to produce the desired amount of negative resistance or in other words to produce the desired amount of high frequency energy to supplement that being transmitted. Operating as an amplifier it is of course desired to produce only enough high frequency energy to compensate for the attenuation of the wave guide, avoiding an excess which would produce undesired self-oscillation.

Fig. 3 shows an embodiment of the invention in which the cathode is placed outside of the wave guide and the electrons are directed through longitudinal slots in the shell diametrically across the guide and collected external to it on the opposite side.

For this arrangement the excitation of the wave guide should be such as to produce a transverse electric field of the type shown in Fig. 4. This figure indicates the shell of the guide and the direction of the diametric electric lines of force with respect to the slots in the shell through which the electron stream is projected. This type of field corresponds to that illustrated in

Figs. 9 and 9a of the Southworth patent (2,129,712) previously referred to.

In Fig. 3 (as in Fig. 1), 1 is the conducting shell of a cylindrical wave guide extending indefinitely in both directions from the transverse section shown and serving as a medium for the transmission of high frequency electrical energy between points external to the figure, and 3 is a cold cathode extending along the length of the guide and supported on a series of insulators such as 4. As mentioned in connection with Fig. 1, a hot cathode with suitable heating means may be substituted for the cold cathode. Under the influence of potential source 7 electrons pass from the cathode 3 across the guide through the aligned longitudinal slots 17 and 16 and are collected at the collector 14 or on member 15. Collector 14 which is supported on a series of insulators such as 13 may be held at a somewhat lower potential than member 15 or the guide shell 1 by means of the connection through lead 11 to the potential source 7 so as to retard electrons approaching it and cause the slower ones to be collected on member 15.

Members 15 and 18 bridge the slots 16 and 17 respectively, supporting the shell 1 and enclosing the space within so that it may be evacuated to permit the passage of electrons from the cathode 3. Insulating seals such as 6 and the four designated 21 in member 18 and the one designated 12 in member 15 may be provided at intervals along the length of the guide to permit the passage of leads such as 5, 22, 23 and 11 from suitable potential sources such as 7 to the various electrodes 3, 19 and 14.

The electrodes 19 extend along the length of the guide on each side of the path of the electron stream and serve to focus the stream to facilitate its passage through the slots 17 and 16. These electrodes are supported on insulators such as 20 and are maintained negative with respect to the cathode 3 by the leads 22 and 23 from potential source 7. The branches from leads 22 and 23 pass through the insulating seals 21 to the electrodes 19.

In operation, electrons from the cathode 3 are focused by the electrodes 19, pass through slot 17 into the wave guide through the electric field in the space of the wave guide, leave that field by passing through slot 16 then are collected, either by the electrode 14 or on the inner surface 15 depending upon the velocity with which they leave the guide and the potential of the electrode 14. The potential applied to the shell 1 through lead 8 is adjusted so that the electron transit time through the field in the guide between slots 17 and 16 is approximately the period of a whole number of cycles plus $\frac{1}{4}$ cycle of the field or as near thereto as required to obtain the desired transfer of high frequency energy from the electron stream to the field as explained in connection with Fig. 1.

The invention is applicable to systems employing other types of transmission than those illustrated and described. For instance it is applicable to any wave guide arrangement where the mode of the transmitted wave is such that there is a transverse electric field with which an electron stream may interact along the length of the guide. It is only necessary to arrange the longitudinal electrodes appropriately with respect to a component of the transverse electric field. Likewise, the invention is not limited to wave guide systems. It may be applied to coaxial

and parallel conductor transmission systems by providing appropriate electron discharge means.

Since, therefore, the invention is applicable to many different types of transmission systems with many different configurations of the electric field associated therewith, it is not intended that the invention is limited to the embodiments illustrated and described, but only by the appended claims.

What is claimed is:

1. The method of reducing the attenuation of a high frequency electrical transmission path which comprises producing electrons substantially uniformly along a substantial length of the path and along said length of path projecting said electrons at a uniform rate transversely to the path through the high frequency electric field produced by transmitted energy and distributed along the length of the path, and adjusting the electron transit time through the field to be such that the transmitted energy is greater than it is without the presence of the electrons.

2. The method of reducing the attenuation of a high frequency electrical transmission path which comprises producing electrons substantially uniformly along a substantial length of the path and along said length of path projecting said electrons at a uniform rate transversely to the path through the electric field produced by transmitted energy and distributed along the length of the path, and adjusting the electron transit time through the said electric field to be approximately $1\frac{1}{4}$, $2\frac{1}{4}$, $3\frac{1}{4}$, etc., cycles of the field.

3. In combination, a hollow wave guide extending between two remote points capable of supporting a high frequency field therein for the transmission of energy therethrough in either direction, an electron emitting cathode extending along the length of the guide for a substantial distance, means for projecting electrons from the cathode in a direction transverse to the length of the guide and along a substantial length of the guide through at least a portion of the high frequency electric field therein and such that the transit time of the electrons through the high frequency field substantially equals the period of any whole number of cycles plus $\frac{1}{4}$ cycle of the high frequency field.

4. In combination, a hollow wave guide capable of transmitting electric wave energy therethrough in either direction along its length extending between two remote points, and means for projecting a steady stream of electrons through space within the guide in a direction transverse to the length of the guide and substantially continuously along a substantial proportion of the length of the guide between the said points.

5. A hollow wave guide capable of supporting an electric field within it for the transmission of high frequency electrical energy along its length in either direction, a cathode coextensive along the length of the guide, and means for projecting electrons from the cathode transversely across space within the guide with a transit time such that the attenuation to the high frequency energy is reduced.

6. A hollow cylindrical wave guide capable of supporting within it a high frequency electric field for the transmission of high frequency energy along its length in either direction, a cathode coextensive along the axis of the guide, and means for projecting electrons from the cathode transversely across space within the guide along a substantial length thereof with a transit time

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such that if the guide is excited for high frequency transmission high frequency energy is transferred from the electrons to the transmission energy.

7. A hollow wave guide capable of supporting within it a high frequency electric field for the transmission of high frequency energy along its length, a cathode coextensive along the guide but external to it, and means for projecting electrons from the cathode transversely across space within the guide along a substantial length thereof with a transit time such that if the guide is excited for high frequency transmission high frequency energy is transferred from the electrons to the transmission energy.

8. A hollow wave guide capable of supporting within it a high frequency electric field for the transmission of high frequency energy along its length in either direction, a cathode coextensive along the guide and located within the guide, and means for projecting electrons from the cathode transversely across space within the guide along a substantial length thereof with a transit time such that if the guide is excited for high frequency transmission high frequency energy is transferred from the electrons to the transmission energy.

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9. A high frequency wave transmission path comprising a single hollow wave guide capable of transmitting high frequency wave energy in either direction along its length, a cathode extending along the length of the guide for a substantial distance, and means for projecting a steady stream of electrons from the cathode transversely across the space within the guide with a transit time such that if the guide is energized for high frequency transmission high frequency energy is transferred from the electron stream to the transmission energy throughout the said substantial distance along the guide length.

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