

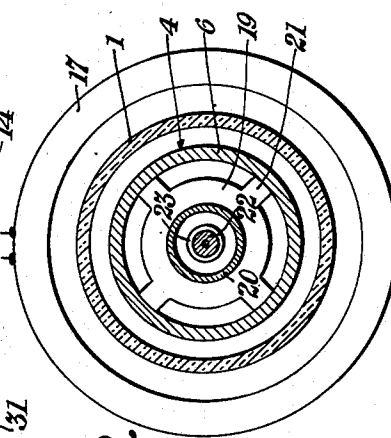
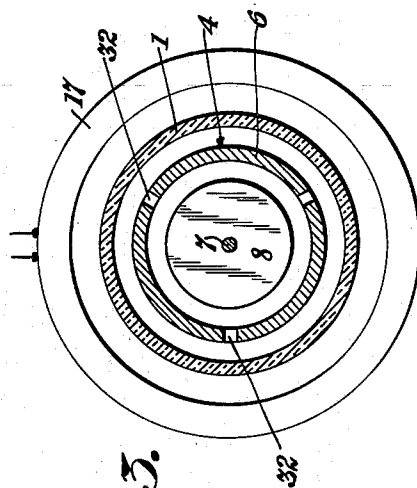
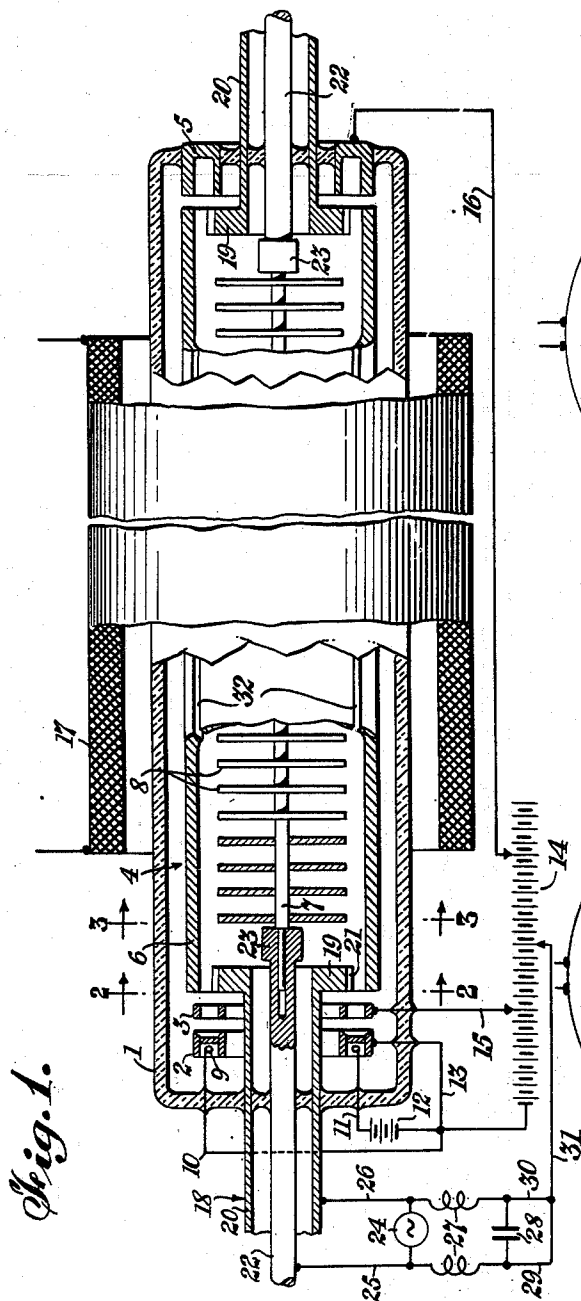
June 23, 1953

G. C. DEWEY
TRAVELING WAVE TUBE

2,643,353

Filed Nov. 4, 1948

3 Sheets-Sheet 1



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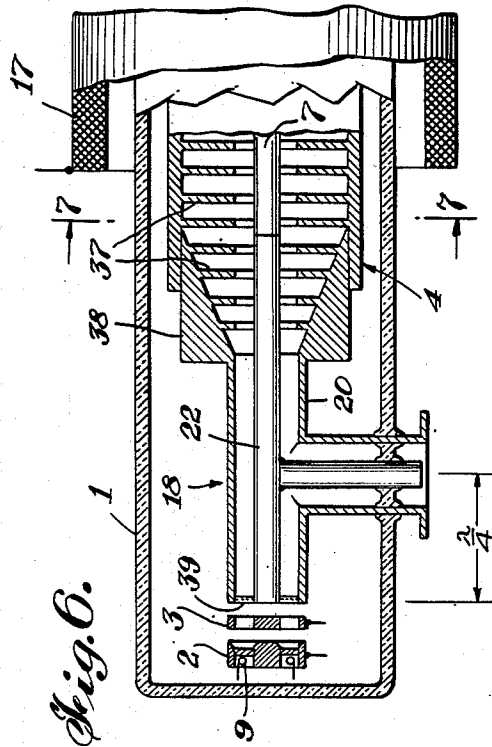
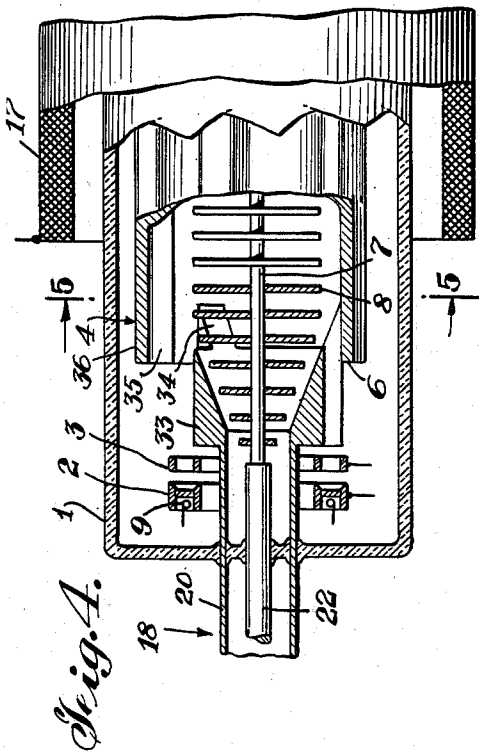
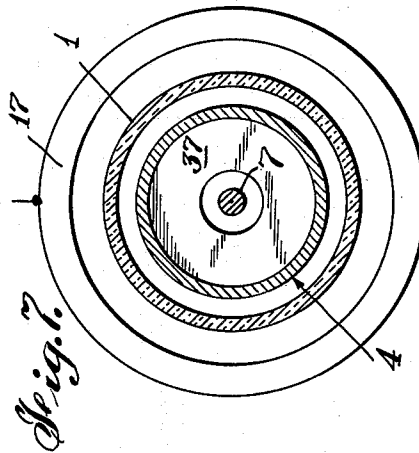
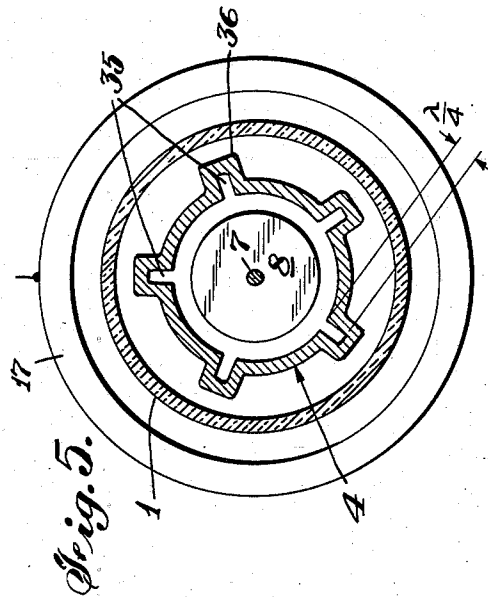
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3 Sheets-Sheet 2



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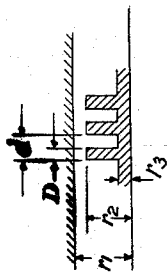
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Fig. 12.



$r_2 = 1.2 \text{ CM}$
 $r_3 = .4 \text{ CM}$
 $\frac{D}{d} = .135 \text{ CM}$
 $d = .15 \text{ CM}$

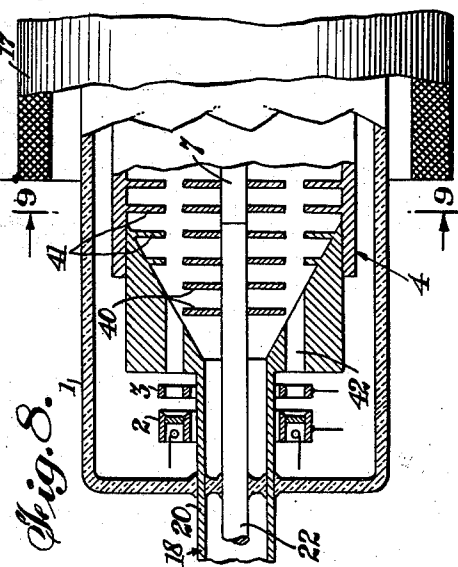
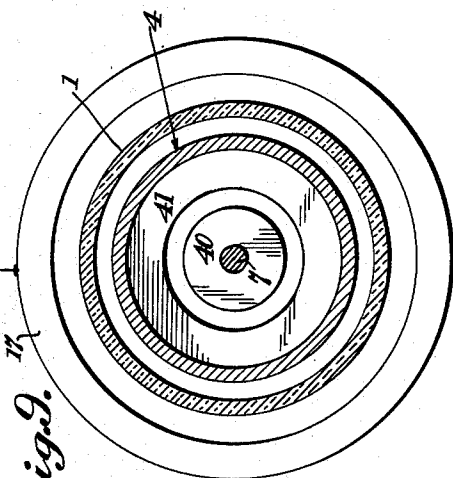


Fig. 11.

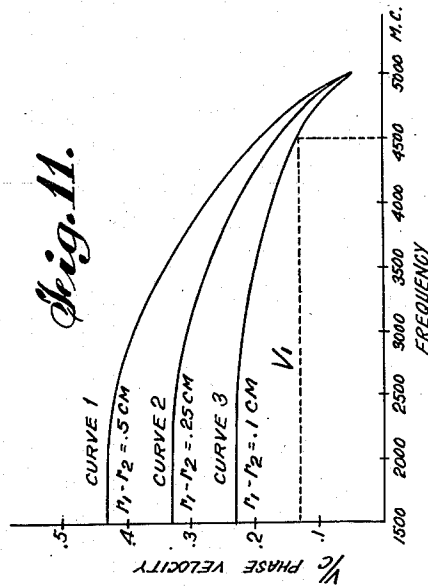
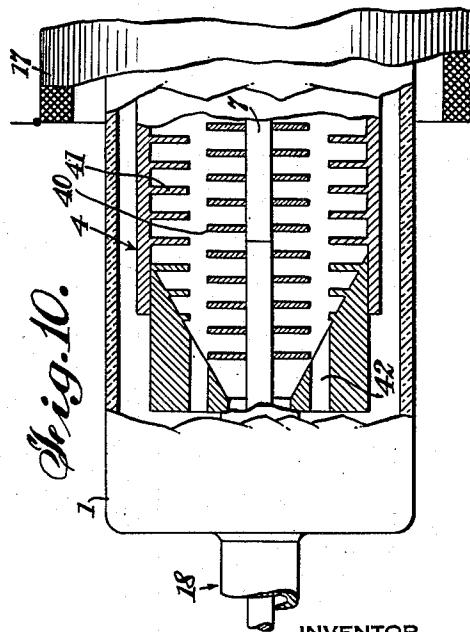


Fig. 10.



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2,643,353

TRAVELING WAVE TUBE

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12 Claims. (Cl. 315-3)

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This invention relates to amplifiers of the travelling wave type and has for its object the production of a more efficient amplifier having a very high power output.

Travelling wave tubes, known generally to the art today, consist of a tightly wound helix down which an electromagnetic wave can propagate. The phase velocity of propagation of the electromagnetic wave along the axis of the helix is small compared to the velocity of light. An electron beam source is arranged to direct a stream of electrons axially through the helix. When the velocity of the electrons in the stream is slightly greater than the phase velocity of the wave, part of the kinetic energy of the electrons is converted into radio frequency energy and the electromagnetic wave propagated in the direction of the electron stream is amplified.

The efficiency of the travelling wave tube of the helical type is low and the power output is limited. The amount of total kinetic energy converted to radio frequency energy is a small fraction of the total kinetic energy in the beam. The magnitude of the fraction is determined primarily by the ratio of the wave impedance along the helix to the electron beam impedance. This impedance ratio must be large in the first place because the efficiency of the travelling wave tube is low if, for a given radio frequency power input, the field produced inside the helix has a weak axial electric field component. In the second place it must be large since it is desired to have a large beam current for a given beam voltage and hence a small beam impedance.

As mentioned above, the power output of the travelling wave tube is directly related to the maximum kinetic energy of the electron beam, e. g. to the product of the beam voltage and the beam current.

The beam voltage is limited by two factors. In the first place, the larger the beam voltage is, the higher the beam velocity must be and hence the higher the phase velocity along the helix. This implies a longer helix for comparable gain, and, therefore, a more difficult tube to construct. In the second place there is a practical limitation on the maximum beam voltage at which a useful tube may operate.

The beam current is limited primarily by the size of the helix which, in turn, is limited by the operating wavelength. The maximum diameter for a 5000 megacycle per second tube is of the order of half a centimeter. The beam diameter must be less than half a centimeter. This, in turn, limits the size of the beam source and hence

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the beam current. Furthermore the maximum beam current density is limited by the space charge effects of a beam of small diameter for a given beam voltage limited as discussed above. The beam will tend to spread. The space charge limitation is made very stringent by the necessity of keeping the beam velocity quite uniform along its length so as to maintain synchronism with the wave velocity.

In the helical type tube there are other unavoidable sources of loss and inefficiency. There are extensive dielectric losses in the necessary insulating supports for the helix. These supports are generally located in a region in which the radio frequency field is strong and, as the field is increased, cause trouble as a result of overheating. Dielectric losses also occur in the glass envelope and the envelope causes further trouble as a result of secondary electron bombardment from a high energy beam.

The object of my invention is to provide a travelling wave amplifier tube which will overcome, in part, the above-mentioned difficulties and which will be efficient and capable of furnishing a large power output.

A further object of this invention is to provide a travelling wave amplifier tube which will be frequency selective by variation of the beam velocity.

It is another object of the invention to provide means for eliminating any undesired modes or reducing their effect in the operation of the travelling wave tube as an amplifier.

A further object of this invention is to increase the bandwidth of periodic waveguide travelling wave tubes.

A further object of this invention is to provide an amplifier with built in terminals which provide a good match to the apparatus to be connected to the travelling wave tube.

These and other objects of the invention are accomplished by providing a travelling wave tube having a structure comprising inner and outer conductors, the inner conductor, or outer conductor, or both being finned with a plurality of baffles. The spaces between said baffles are very small and the space between the edges of the baffle plates and the outer conductor also is very small.

In place of the helix or other waveguide structures proposed for travelling wave tubes, I use a coaxial transmission line operating in a dominant mode where the phase velocity is reduced to a small value compared to the velocity of light. Said reduction is obtained by placing a plurality

of baffles on the inner conductor or outer conductor or both. An annular electron beam is projected along the axis of the tube in the gap between inner conductor structure and outer conductor structure. A feature of this invention lies in the use of the small gaps between the edges of the baffles and the outer conductor to give a greater bandwidth, that is, less variation of phase velocity for a given change in frequency.

The above mentioned and other features and objects of this 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 an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a cross sectional view partly in elevation of a travelling wave tube showing features of the invention;

Fig. 2 is a section view taken on line 2—2 of Fig. 1;

Fig. 3 is a section view taken on line 3—3 of Fig. 1;

Fig. 4 is a section view of part of the tube partly cut away showing another means for matching the tube to the input;

Fig. 5 is a section view taken on line 5—5 of Fig. 4, showing another embodiment of the slotted structure;

Fig. 6 is a cross section view of part of the amplifier tube showing the baffle plates attached to the outer conductor;

Fig. 7 is a section view taken on line 7—7 of Fig. 6;

Fig. 8 is a section view of the amplifier tube showing another embodiment of the invention wherein baffle plates are provided for both inner and outer conductors;

Fig. 9 is a section view taken on line 9—9 of Fig. 8;

Fig. 10 is a section view of the amplifier tube showing a still further embodiment of the invention wherein baffle plates on the inner and outer conductors are in staggered relationship;

Fig. 11 is a graph showing the phase velocity of a typical embodiment of the invention divided by the velocity of light plotted as ordinate and frequency plotted as abscissa; and

Fig. 12 identifies the dimensions of a specific embodiment referred to in Fig. 11.

The tube of this invention is generally illustrated in Fig. 1. An envelope 1 encloses an electron gun 2, focusing electrode 3, cylindrical coaxial waveguide 4 and collector electrode 5 arranged from end to end of the tube. Extending through the cylinder or wall 6, which forms an outer conductor, is an axial conducting shaft 7 which serves as an inner conductor. Arranged uniformly on said shaft is a plurality of plain conducting discs or baffles 8.

At one end of the tube, inside the envelope there is positioned a ring shaped electron gun 2 which is indirectly heated by coil 9, leads 10 and 11 thereto being connected across a voltage source 12. The lead 13 from the electron gun is connected to the negative side of a high tension source 14. Lead 15 from focusing electrode 3 is connected to a low voltage point of said high tension source. Lead line 16 from collector electrode 5 is connected to a high voltage point of said high tension source. This is done so that the uncovered portion of the kinetic energy of the beam does not necessarily appear as dissipated power at the collector electrode. A solenoid 17 is arranged around the outer conductor for sup-

plying a magnetic field parallel to the path of the beam between the gun and the collector electrode.

The coaxial travelling wave tube is coupled to coaxial input line 18 which extends through the end of tube 1, by means of a spider 19 which establishes contact between outer conductor 6 of the tube and the outer conductor 20 of the input line by means of projections 21. The gaps between said projections are arranged to allow the electron beam from the electron gun 2 to be projected through the tube. The inner conductor 7 of the tube is coupled to the inner conductor 22 of the coaxial input line by means of a slug 23, the dimensions of which are so chosen that the combined transformation effect of the changes in diameter and the length of the slug gives a good impedance match over a broad band. The radial transformation in the first change in diameter compensates for the rapid change in impedance of the finned inner conductor amplifier tube as the frequency approaches the cut-off frequency. The matching structure at the output end of the tube is similar to that described for the input end, the corresponding elements being indicated by similar reference numerals.

The coaxial input line is provided with a high frequency signal from source 24 through leads 25 and 26. Said source is coupled to a median point on the direct current source 14 by means of choke coils 27, bypass condenser 28 and leads 29, 30 and 31.

There is also provided in the outer conductor 6 a plurality of longitudinal slots 32 which are cut radially through the outer conductor for the purpose of eliminating undesired modes or reducing their effect in the operation of the travelling wave tube as an amplifier. These slot means are arranged for suppression of angle dependent modes in the periodic structure. The principal interfering mode is an H_{11} -like mode, that has a $\cos \phi$ angular dependence. Such a mode must have circumferential currents in the outer conductor. A means of suppressing this mode or any similar mode with $\cos m\phi$ (where m is any integer) angular dependence is to cut $2m-1$ slots in the outer conductor and thereby couple the circumferential current to space where it will be attenuated by radiation.

The spacing of baffles 8 from each other and the outer conductor has been greatly exaggerated in the drawings but in actuality said spacing is very small, with the distance between the respective baffles being substantially the order of the distance between the outer circumference of said baffles and the inner circumference of said outer conductor. The distance d , which is the space occupied by one baffle and one gap (between baffles), is very much smaller than λ_g , the guide wavelength of the highest frequency to be amplified. Since λ_g is smaller than λ_0 , which is the natural free space wavelength, then d is very much smaller than λ_0 . The distance d is generally of the order of $\lambda_g/4$ or smaller.

An alternative method of coupling the travelling wave tube to the coaxial input line is shown in Fig. 4 where inner conductor 7 is directly connected to the inner conductor of the coaxial input line while the outer conductor 6 of the tube is coupled to the outer conductor of the coaxial input line by means of a ring 33 having a tapered inside diameter. Said ring has a plurality of projections 34 which establish contact with outer conductor 6 and which are spaced

apart so as to allow the electron beam emitted by electron gun 2 to pass through the tube. It is seen that, in effect, the outer conductor of the tube is tapered out to the final diameter of the coaxial input line and that the diameter of the baffles 8 is also gradually tapered out to the final size to fit within the input section. The exact form of the taper can be chosen in such a manner as to make the impedance change per section a constant and thereby obtain a better match over a wider band. If the tapered section is n baffles long and the total transformation ratio is

$$M = \frac{Z(\text{coax})}{Z(\text{finned inner conductor tube})}$$

then the impedance change per section is

$$\frac{Z_n}{Z_{n-1}} = (1 - \sqrt[n]{M})$$

The impedance of each section may be calculated by well known means.

Fig. 5 is a section view taken on line 5—5 of Fig. 4 and shows another embodiment, where slots 35 in the outer conductor 6 are covered by extensions 36 integral with the structure of said outer conductor. In this embodiment the slots should be about a quarter of a wavelength deep so as to be substantially anti-resonant, to suppress interfering angle dependent modes.

Figs. 6 and 7 show a further embodiment of the present invention wherein baffle plates 37 are fixed to the outer conductor instead of to the inner conductor 7 which extends through central apertures of said plates. The dimensions of the outer conductor 6 are reduced by means of ring 38 in contact with said outer conductor and having a tapered inside diameter and baffle plates of reduced outside diameter. The diameter of the baffle apertures is constant throughout the coupling ring 38.

Also the coaxial input line is shown positioned normal to the longitudinal axis of the coaxial amplifier tube and connected thereto a quarter wavelength from the end of the inner conductor. The grid 39 is provided for the purpose of short-circuiting the inner and the outer conductor of the coaxial tube. Said grid is apertured to permit the passage of the electron beam there-through.

Figs. 8 and 9 show a still further embodiment of the present invention wherein baffles 40 and 41 are provided both on the inner conductor and outer conductor respectively, while the connector ring has an aperture 42 to provide passage for the electron beam emitted by electron gun 2. The structure shown in Fig. 8 provides a strong electric field at the edges of the inner and outer baffles adjacent to the electron beam. The distance between the outer circumference of the baffles positioned on the inner conductor and the inner circumference of the baffles positioned on the outer conductor is small compared to the diameter of the baffles on the inner conductor.

Fig. 10 shows another embodiment of the present invention wherein baffles 40 and 41 are provided on both the inner and outer conductors of the coaxial amplifier tube, but the respective baffles are positioned in a staggered relationship, on the inner and outer conductors, thereby providing a more uniform electric field. Here, too, the distance between the edges of the inner and outer baffles, respectively, is small compared to the diameter of the inner baffles.

The operation of the device is as follows. In

Fig. 3 an ultra high frequency wave is fed into the coaxial transmission line 18 and is coupled to the cylindrical coaxial waveguide 4 by the coupling device 23. The wave propagating along the waveguide 4 is modified by the effective radial slots comprised by the space between adjacent baffles, so as to slow down the phase velocity of the wave and to produce a substantial longitudinal electric field at the edges of the baffles. It was found by matching the wave configuration in the gap between the outer conductor and the baffle edges to the TEM-like mode in the effective radial slots that the phase velocity of the wave propagating along the structure is greatly reduced compared to the velocity of light, at frequencies near the antiresonance of the radial slots. It was also found the phase velocity in the waveguide 4 was greatly reduced compared to the velocity of light at frequencies not near the antiresonance of the effective radial slots provided that the gap between the outer conductor and the baffle edges is small.

Fig. 11 is a graph showing the phase velocity divided by the velocity of light plotted as ordinate, and the frequency plotted as abscissa for a specific embodiment. The dimensions of the structure are identified in Figure 12, where r_1 is the radius of the outer conductor, r_2 is the radius of the baffle edges and r_3 is the radius of the inner conductor shaft. D is the thickness of the baffles and d is the thickness of one baffle plus the length of one effective radial slot. D is substantially smaller than $\lambda g/4$. In curve one of Fig. 11 indicating the phase velocity for a large radial gap $r_1 - r_2$, it is seen that the slowing down of the wave is not pronounced except near the antiresonance of the slots occurring approximately at 5000 mc./s. Curve three of Fig. 11 shows the phase velocity for a small radial gap $r_1 - r_2$ and the slowing of the phase velocity is very pronounced giving a slow wave at frequencies far from the antiresonance of the slots. The dimensions indicated in Figs. 11 and 12 are chosen for a typical operating device in the region of 7.5 centimeters free space wavelength.

An electron beam is directed axially through radial gap $r_1 - r_2$ at a velocity near that of the phase velocity of the guide and it interacts with the wave in a manner similar to that of a helix type tube. This results in the wave which propagates out through the output coaxial transmission line being amplified. The axial electric field components of the axially propagating wave is strongest adjacent the baffle edges and the hollow electron beam is focused as close to the aforesaid baffles as possible, or it may fill the entire gap $r_1 - r_2$.

For certain frequency ranges the amplifier can be made frequency selective. The electron beam accelerating voltage placed on the resonator is adjustable and is given a value such that the electrons in the beam move at a velocity v_1 on curve 3, Fig. 11 the value of which is such that an axial phase velocity of the same value lies in a region in which the axial phase velocity varies sharply with frequency. Then if a wide band of frequencies is applied through input coaxial transmission line 18, only the waves of frequency close to the frequency f_1 will be amplified since only these waves will have an axial phase velocity close to that of the electron beam.

It will be appreciated by those skilled in the art that coaxial wave guides with different baffle means may be used for slowing up the wave. While I have described my invention with refer-

ence to particular embodiments, it is not intended to be limited thereto but only as defined in the appended claims.

What is claimed is:

1. A travelling wave amplifier comprising an electron gun and a collector electrode defining an electron beam path therebetween, a wave guide comprising a cylindrical wall conductor coaxial with and surrounding said path for propagating an electromagnetic wave along said beam path in the direction from said gun to said collector electrode, an inner conductor positioned axially within said wall, conducting baffles positioned uniformly on at least one of said conductors and arranged within the space defined by the conductors for causing the wave to propagate more slowly than the velocity of light and substantially with the velocity of electrons in said beam, said cylindrical wall conductor containing a plurality of longitudinal slots for the suppression of angle dependent modes, said slots being cut radially through said wall.

2. An amplifier according to claim 1 further comprising an input coaxial transmission line and an output coaxial transmission line coupled to respective ends of said amplifier.

3. Amplifier according to claim 1 further comprising impedance matching means interconnecting said inner conductor of the amplifier to the respective inner conductors of said input and output lines by means of a slug, the dimensions of which are chosen to provide a good match over a broad band, said wall being connected to the outer conductors of the respective lines by means of a ring having apertures to permit the projection of the electron beam therethrough.

4. Amplifier according to claim 1 further comprising a solenoid coaxially positioned about said cylindrical wall conductor for producing a magnetic field parallel to the beam path for focussing said beam.

5. Amplifier according to claim 4 wherein the distance between said baffles is substantially smaller than the guide wavelength in the amplifier.

6. Amplifier according to claim 5 wherein the distance between the outer circumference of the baffles and the inner circumference of said wall conductor is substantially the order of the distance occupied by the gap between said baffles and the thickness of one baffle.

7. Amplifier according to claim 6 wherein said

baffles are positioned upon said inner conductor and the distance between the outer circumference of the baffles and the inner circumference of said wall is small compared to the diameter of said wall.

8. Amplifier according to claim 7 wherein the distance between the outer circumference of said baffles and the inner circumference of said wall is small compared to the diameter of said baffles.

9. Amplifier according to claim 8 wherein the outer conductor of said amplifier is coupled to the outer conductor of the input line by means of a ring having a tapered inner circumference, the inner conductor of said amplifier being directly coupled to the inner conductor of said input line, the baffles surrounded by said ring being graduated in size to conform to the inside diameter of said ring.

10. Amplifier according to claim 9 further comprising apertured baffle plates attached to the inner circumference of said wall, said apertured baffles surrounding corresponding baffles attached to said inner conductor.

11. Amplifier according to claim 10 wherein the distance between the outer circumference of said baffles positioned on the inner conductor and the inner circumference of said baffles positioned on said wall is small compared to the diameter of said baffles on the inner conductor.

12. Amplifier according to claim 11 wherein said apertured baffles are in staggered relationship to the baffles positioned upon the inner conductor.

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