Jan. 20, 1959 G. PAPP 2,870,374

MICROWAVE ELECTRON DISCHARGE TUBES

Filed May 26, 1954 4 Sheets-Sheet 1

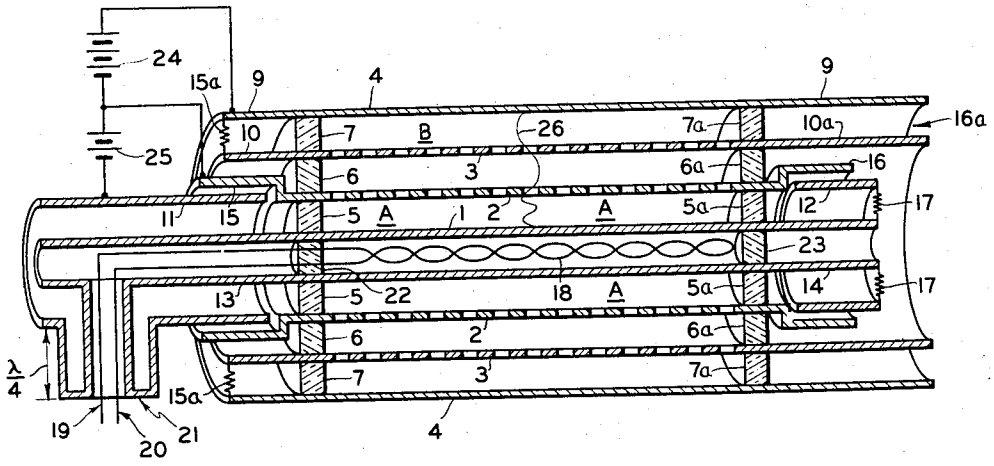


FIG.1

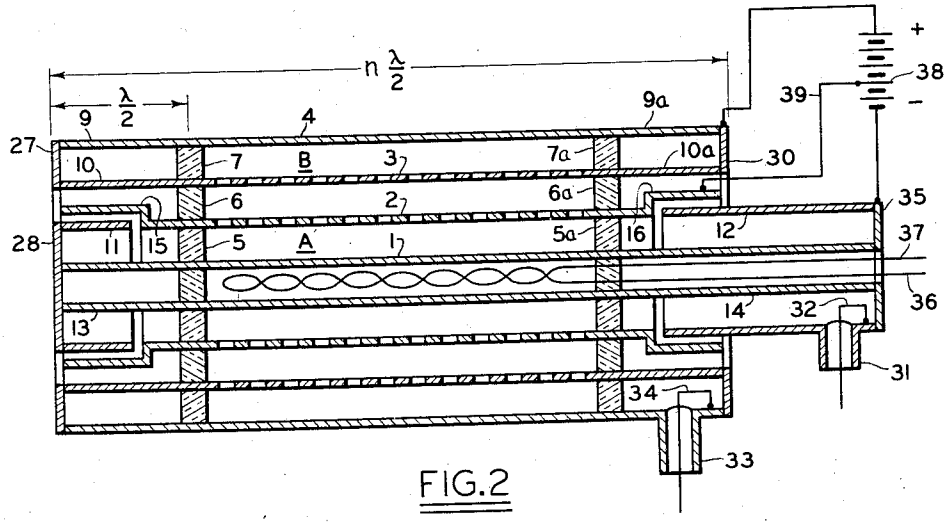


FIG.2

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MICROWAVE ELECTRON DISCHARGE TUBES

Filed May 26, 1954 4 Sheets-Sheet 2

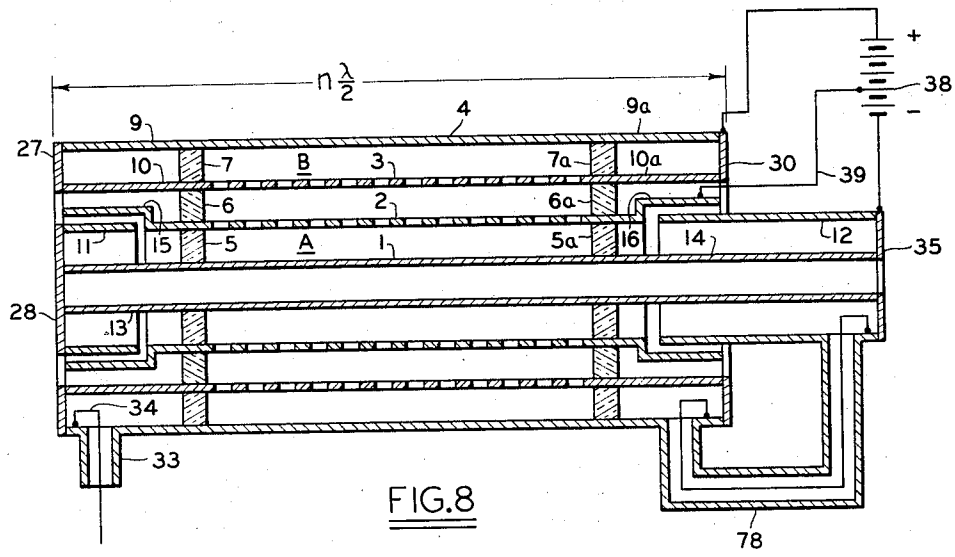
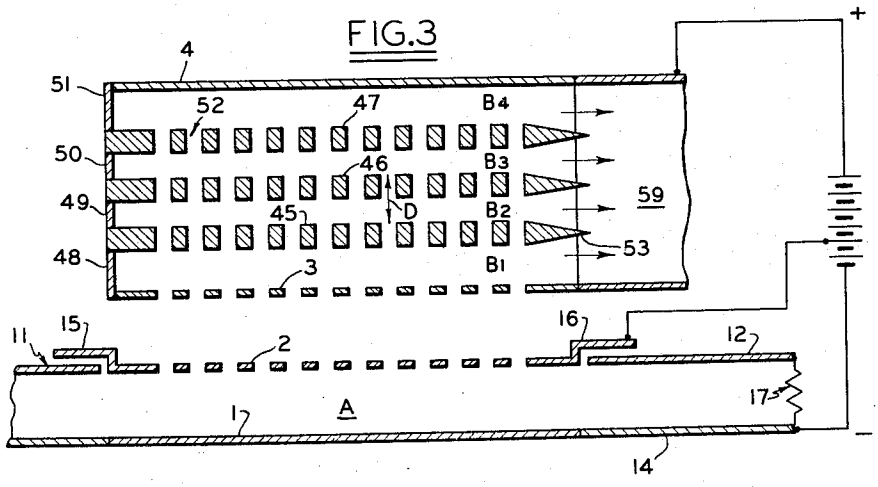


FIG.8

FIG.3



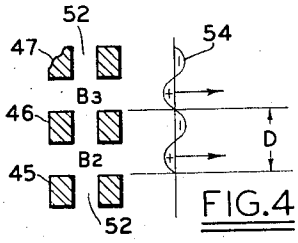


FIG.4

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MICROWAVE ELECTRON DISCHARGE TUBES

Filed May 26, 1954 4 Sheets-Sheet 3

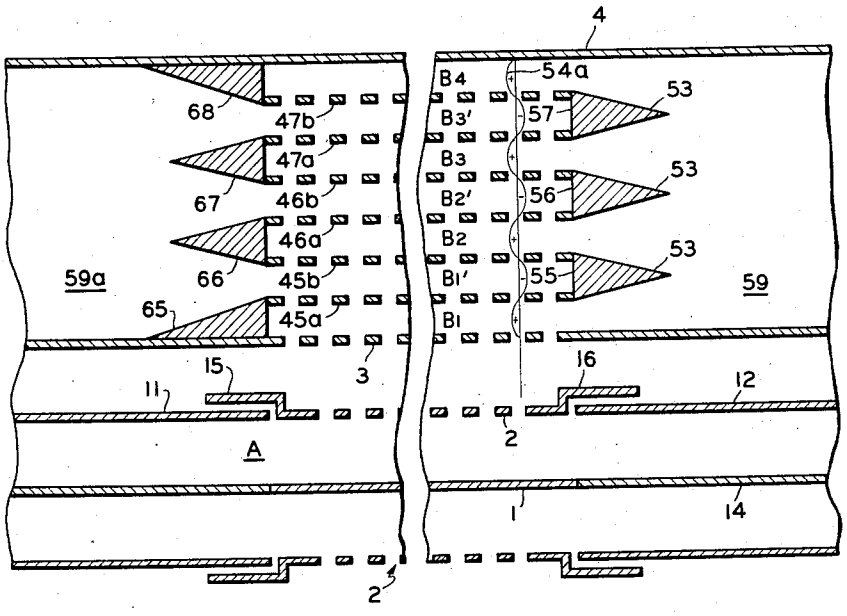


FIG.5

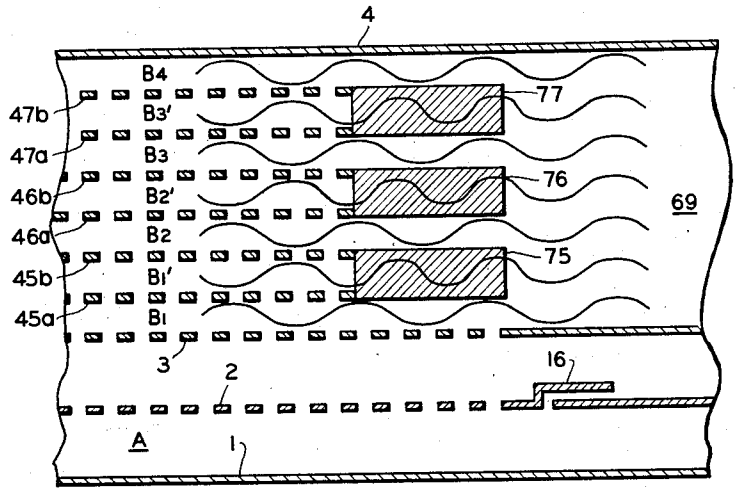


FIG.6

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MICROWAVE ELECTRON DISCHARGE TUBES

Filed May 26, 1954 4 Sheets-Sheet 4

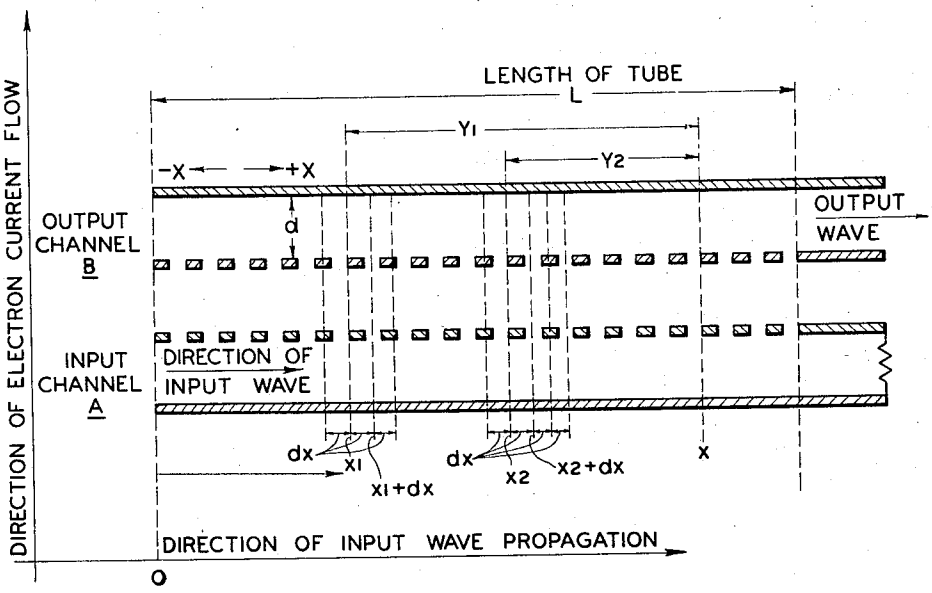


FIG.7

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MICROWAVE ELECTRON DISCHARGE TUBES

George Papp, Fort Wayne, Ind., assignor to International Telephone and Telegraph Corporation

Application May 26, 1954, Serial No. 432,376

11 Claims. (Cl. 315—39)

The present invention relates to extremely high frequency electron discharge devices, commonly characterized as microwave electron discharge tubes.

Numerous electron discharge devices have heretofore been devised for generating and utilizing high and ultra-high frequencies. In the design and fabrication of these devices, the time of travel of the electrons as they move from the cathode to the anode, commonly referred to as the transit time, as well as the effect of inter-electrode capacities, constitute limitations in generating and handling appreciable quantities of power. Electron transit time, in certain known electron discharge devices, serves to determine exactly the physical spacing between the various electrodes, such spacing being in the order of fractions of a millimeter for the microwave frequencies with which this invention is concerned. It has been found also that the shunting effect of the inter-electrode capacities limits the operating frequency range as well as use of known techniques for modulating the electron current flowing from cathode to anode. Other limiting factors in the design of microwave tubes are well known to the art.

Recognizing, therefore, that serious limitations now obtain in the art, the present invention comprehends the utilization of the wave propagation limitations in an electron discharge device for producing and handling greater quantities of power than has heretofore been possible in the microwave frequency range.

It is therefore an object of this invention to provide an electron discharge device which may be used in the microwave frequency range to either generate or amplify signals of relatively high power.

It is another object of this invention to provide a microwave discharge device which utilizes the effects of electron discharge current flowing from the cathode to the anode to generate a multiplicity of incremental signals which may be collected in phase to amplify a given input signal.

It is yet another object of this invention to provide an electron discharge device capable of amplifying microwave frequency signals.

It is still another object of this invention to provide an electron discharge device for use in the microwave range of frequencies, which is not limited in operation by discontinuities such as lumped tube constants or capacitive circuit losses.

Other objects will become apparent as the description proceeds.

In accordance with the present invention there is provided a high vacuum electron discharge comprising an anode member of conducting material. A cathode or electron-emissive member is mounted in parallel spaced relation with the anode member and is separated therefrom by at least one grid-like electrode also made of conductive material. Means are employed for modulating the flow of electrons from the cathode to the anode. In this arrangement, the grid-like element is spaced from

the anode member a distance dependent upon the electron transit time, which distance is preferably equal to one-half of the product of the period (in seconds) of the input high frequency signal times the velocity of the electrons impinging on the anode member (in centimeters per second). The cathode element extends in the direction of the input signal wave propagation while the electron stream flows transversely to such direction. An output section extends also in the direction of the input signal wave propagation with the means for modulating the stream being interposed between the anode and cathode.

For a better understanding of this invention, reference is made to the following description, taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawings:

Fig. 1 is an axial section in diagram form of one embodiment of this invention;

Fig. 2 is an axial section of another embodiment;

Fig. 3 is a partial axial section similar to Fig. 1 showing still another embodiment of this invention;

Fig. 4 is an enlarged fragmental section of the embodiment of Fig. 3;

Fig. 5 is a partial sectional view of yet another embodiment of this invention;

Fig. 6 is a partial section of a further embodiment similar to the one of Fig. 5;

Fig. 7 is a graph used in explaining the operation of this invention; and

Fig. 8 is another embodiment shown in longitudinal section which is similar to Fig. 2.

With reference to Fig. 1, an evacuated electron discharge device of cylindrical form is comprised of a straight elongated cathode 1 which extends in the direction of input signal wave propagation, an input grid 2 surrounding the cathode 1, an accelerating grid 3 radially spaced from the grid 2, and an anode 4 coaxially supported about the grid 3. These various tube electrodes are maintained in rigid radial relation by means of suitable annular glass or the like spacers, spacers 5 and 5*a* separating the cathode from the input grid 2, spacers 6 and 6*a* separating the two grids, and spacers 7 and 7*a* separating the grid 3 from the anode 4.

The grids 2 and 3 may be composed of ordinary conductive screen or reticulate sheeting formed to a suitable tubular shape, the exact composition of these grids not being critical except for the fact that they be constructed of conductive material and be provided with openings in radial registry through which electrons may flow from the cathode to the anode.

In the arrangement of Fig. 1, the electron discharge device is contained essentially between the axially spaced arrangement of spacers 5, 5*a*; 6, 6*a*; and 7, 7*a*; however, in order to obtain optimum operating characteristics, each of the aforedescribed tube elements are extended axially in opposite directions.

The opposite extensions of the anode 4 are indicated by the reference numerals 9 and 9*a* respectively, the corresponding extensions of the grid 3 by the reference numerals 10 and 10*a*, the extensions of the grid 2 by numerals 11 and 12, respectively, and the extensions of the cathode 1 by the reference numerals 13 and 14, respectively. All of these extensions are made of conductive material and may comprise sections of suitable metal tubing. As will be explained more fully herewith, the extensions 11 and 13 constitute the outer and inner conductors, respectively, of a coaxial signal input line of conventional design.

The cathode 1, grid 3, and anode 4 are conductively connected to their respective extensions; however, the

grid 2 is capacitively coupled to its extensions 11 and 12 by means of conventional stepped diameter concentric line chokes 15 and 16 preferably made a quarter of a wave length long and surrounding the respective ends of the extensions 11 and 12. These high frequency chokes are well known to the art and serve as conductors of microwave signals and as open circuits to the passage of direct current.

The grid 3 and anode 4 actually serve as the inner and outer conductors of a coaxial line or signal output channel B. The extensions 9 and 10 at the input side of the tube may be terminated in the usual manner by a resistor or resistor annulus 15*a* having a value equal to the characteristic impedance of the line. The right-hand or signal output end of this line, generally indicated by the reference numeral 16*a*, is open for utilization of the output signal.

The right-hand end of the coaxial line 12, 14 (channel A) is similarly terminated by a resistor 17, preferably of annular shape, having a resistance equal to the characteristic impedance of that line.

The cylindrical space within the end partitions 5, 6, 7, and 5*a*, 6*a*, 7*a*, respectively, and the anode 4 is evacuated in a manner well known to the art.

The cathode 1 is thermionically emissive and may be composed of any of the well known materials suitable for use in heated cathodes. In the present instance, the cathode is tubular and interiorly receives a filament 18 having leads 19 and 20 which are passed through the cathode wall 13 and brought out of the assembly by means of a conventional shorted quarter-wave line 21 suitably connected into the input line 11, 13. The opposite ends of the cathode are hermetically sealed by means of the two insulating plugs 22 and 23 for evacuating the space occupied by the filament. Other methods of bringing the filament leads 19 and 20 out of the assembly, which do not disturb the operating characteristics of the tube, will occur to persons skilled in the art.

Operating potentials are supplied by the two batteries 24 and 25 of 400 volts and 30 volts, for example, respectively. The two batteries are connected in series with the positive terminal of battery 24 leading to the anode 4 and the negative terminal to the grid 2. The negative terminal of the battery 25 is connected to the extension 11 to supply negative voltage to the cathode, the conductive connection being provided by the shorted quarter-wave line 21.

In operation, electrons emitted by the cathode 1 will flow through the grids 2 and 3 and be collected by the anode 4 thereby providing a space discharge current which may be detected in the external circuitry of the tube by any suitable means.

In further describing this invention, it is convenient to consider the tube assembly as comprising two coaxial lines, the line comprised of the outer conductor 2 and the inner conductor 1 serving as the signal input line, referred to also as Channel A, and the line comprised of the inner conductor 3 and the outer conductor 4 constituting the output line, Channel B. In the complete assembly illustrated, the input line 1, 2 includes the extensions 13, 14 and 11, 12 respectively so that a signal applied to the coaxial extensions 11 and 13 will be conducted through the tube and be absorbed by the terminating resistor 17.

As the input signal is fed to the input line 11, 13, an electric field, modulated in accordance with the signal, is set up between the cathode and grid 2, which field modulates the electron flow, and since this field varies progressively along the length of the line, such electron flow will be correspondingly affected along the tube length.

The tube may be of considerable length in comparison with the wave length of the operating frequency. The input signal proceeds as a wave through the tube and so modulates every axially successive incremental section of the tube. Every such section of the tube may therefore be regarded as a separate amplifier tube and may be designed to produce optimum amplification which may be less than unity.

Since every axial section is excited in successive order, the generated signals leave the respective axial sections in the same order, each of these signals propagating down the line independently of each other. As will be explained more fully hereinafter, the incremental, generated signals are all eventually collected in the same phase for producing an amplified signal.

The potential on the grid 3 and anode 4 being much higher than that coupled to the input grid 2, electron flow will be directed and accelerated toward the grid 3 and the anode 4. Since the potential difference between the grid 3 and anode 4 is zero, the velocity of the electrons flowing in the radial space between the grid 3 and anode 4 will be substantially uniform.

From this explanation it will be seen that at any instant of time, at a selected axial position in the tube, the intensity of the electron current flowing from the cathode will bear a value corresponding to the intensity of the modulating electric field between the conductors 1 and 2. The electron current will be oscillating with the frequency of the microwave signal, and since it proceeds toward the anode, it will have a wave-like configuration in radial direction of a wave length equal to the distance which an electron travels during one period of the signal input. This "electron wave length" may be expressed in the following terms: $We=Tv$, where "T" equals the period in seconds of the input signal, and "v" equals the velocity of the electrons in centimeters per second. The distance between the cathode and anode corresponds to a number of electron wave lengths, and the spacing between the grid 3 and anode 4 may be of plural wave lengths, but is preferably designed equal to a half wave length.

A typical wave instantaneously occurring between the cathode and anode is represented by the wave form 26 in Fig. 1 which may be considered as occurring in a cross-sectional plane at the selected axial point in the tube.

The signal induced in the output channel between elements 3 and 4 by the cross-sectional electron beam will propagate along the channel in opposite directions. It may be shown that the components generated in different cross sections of the tube travelling toward the output end are all in phase and additive while those directed toward the left are out of phase and consequently their sum is of a negligible magnitude. Leftward components from the axial points of contribution spaced a quarter wave-length apart cancel each other, consequently there will be no leftward wave in a tube of a multiple of half wave lengths long.

Thus, if the incremental currents induced in the coaxial line 3, 4 are collected at the end of the tube 16*a*, the resultant total current will have a relatively high value, and when this current is multiplied by the characteristic impedance of the transmission line 3, 4, it is seen that a signal voltage having a value many times that of an input signal voltage is produced, and this amplified signal voltage may be coupled from the coaxial line 3, 4 by any suitable utilizing means well known to the art.

Keeping the foregoing explanation in mind, and making particular reference to Fig. 7, the long tube may be regarded as being comprised of a continuous succession of short tubes indicated in the figure by the dashed radial lines spaced a distance "dx" apart. The input signal wave proceeding along the input channel "A" may be represented by the formula

$$E(x,t)=E_1 \sin w\left(t-\frac{x}{c_1}\right)$$

where E (x,t) is the high frequency electric field intensity at point "X" at instant "t,"

"E_1" is the amplitude of the field intensity,

$$"w"=2\pi.f=\frac{2\pi}{T}$$

where "f" is the frequency and

$$T=\frac{1}{f}$$

the period of high frequency, and

"c_1" is the wave velocity in channel A.

This wave modulates the transverse electron current in every section "dx" of the long tube. The modulated current traverses the grid-anode space (channel B) and generates an elementary signal "dV" in that section of channel B.

Selecting a particular section at point "x_1" of the tube, the modulated current flowing to the anode in that section will be

$$d_1=I_1dx\sin\left[w\left(t-\frac{x_1}{c_1}\right)+S\right]$$

where "I_1" is the amplitude of the total current, i. e., the sum of the convection and the displacement currents in a one centimeter long section of the tube. It can be shown, that

I_1 can be expressed in the form

$$I_1=i_1\sin\frac{\frac{d}{\pi We}}{\frac{d}{\pi We}}$$

where "i_1" is the corresponding amplitude of the electron (convection) current; "d" is the distance between electrodes 3 and 4, and

"We" is the "electron wave length,"
We=T.v defined above;

"S" is a phase constant being dependent upon operating conditions, being the same however at every section of the tube.

This current dI generates a signal voltage

$$dV=Z_0dI=Z_0Idx\sin\left[w\left(t-\frac{x_1}{c_1}\right)+S\right]$$

where Z_0 is the characteristic impedance of the line 3, 4.

This signal induced in channel B will propagate as an electric wave, half of the signal travelling toward the right ("$+X$" direction) and the other half travelling left (in the "$-X$" direction).

The wave component in the "$+X$" direction will have the form

$$dV_1=Adx\sin\left[w\left(t-\frac{x_1}{c_1}-\frac{y_1}{c_2}\right)+S\right]$$

where
$A=\frac{1}{2}ZI_1$.
"y" is the distance travelled in channel B, which at point X is
$y_1=X-x_1$
and
c_2 is the wave velocity in channel B.

The effect producing the signal in the tube length between x_1 and (x_1+dx) as derived in the foregoing, may now be envisaged as occurring in every incremental tube length, e. g., between x_2 and (x_2+dx). Here the wave

$$dV_2=Adx\sin\left[w\left(t-\frac{x_2}{c_1}-\frac{y_2}{c_2}\right)+S\right]$$

will be generated, where

$$y_2=X-x_2$$

All of these elementary signals "dV" will propagate independently of each other since the transmission thereof is a linear function.

If the tube design is such as to produce equal wave velocity in both channels "A" and "B," i. e., $c_1=c_2=c$., which is satisfied e. g. automatically by the TEM mode of transmission, the phase of all signal components "dV" at point X will be

$$w\left(t-\frac{x_1}{c_1}-\frac{y_1}{c_2}\right)+S=$$

$$w\left(t-\frac{x_1}{c}-\frac{X-x_1}{c}\right)+S=w\left(t-\frac{X}{c}\right)+S$$

independent of the place of the signal generation x_1, x_2, etc.

Therefore, at the output end of the tube, X="L" all of the signal contributions will arrive in the same phase adding to a summated value

$$V=dv_1=\int_0^L Adx\sin\left[w\left(t-\frac{L}{c}\right)+S\right]=$$

$$LA\sin\left[w\left(t-\frac{L}{c}\right)+S\right]$$

From the foregoing it will be seen that the incremental generated signals dV of the respective sections "dx" may be of small magnitude but "V" can be appreciably greater than the input signal by making the tube sufficiently long.

Insofar as the leftward signal components

$$dV=Adx\sin\left[w\left(t-\frac{x_1}{c_1}+\frac{y_1}{c_2}\right)+S\right]=$$

$$Adx\sin w\left(t\frac{X}{c}-\frac{2x_1}{c}\right)+S$$

are concerned, each will arrive at a selected point X in a phase dependent upon the generating position x_1, so that the sum of the incremental signals

$$\Sigma dV$$

will always be limited to a negligibly small value. The summation will equal zero at the left or input end if the tube is an integral number of half wavelengths long. In this case the left end of channel B may be terminated by a short circuit or left open as desired without affecting the operation of the tube. Generally, however, a termination by means of a resistance **15***a* will serve the best because no signal reflection will occur at any frequency.

From the foregoing explanation, for optimum results as is well known the spacing between the grid 3 and anode 4 should equal one half the "electron wave length."

In considering further embodiments of this invention, and for convenient reference purposes, the embodiment of Fig. 1 may be characterized as a non-resonant tube. The second embodiment of this invention is shown in Fig. 2, and in contrast to the former may be regarded as a resonant tube. This tube is very similar in construction to the tube of Fig. 1, in which case like numerals will represent like parts.

Since in order to obtain a relatively high degree of amplification in the tube of Fig. 1, it is necessary that this tube be of considerable length, the amplification factor being directly proportional to the tube length. However it becomes of practical importance to reduce the length of the tube and yet obtain a given useful factor of amplification. The overall length of the tube of Fig. 2 is made equal to a small integral number of half wavelengths of the operating frequency. The spacers **5**, **6** and **7** at the left end and the spacers **5***a*, **6***a* and **7***a* on the right end are spaced inwardly from the respective ends a distance approximately equal to a half wavelength of the operating frequency to locate them at voltage node points. The left end of the coaxial line constituted by the inner and outer conductors **3** and **4**, respectively, is terminated by means of an annular shorting disk **27**. Similarly, the left end of the coaxial line **11**, **13**, is terminated by a shorting disk **28**. An annular

terminating disk 30 is conductively affixed to the right ends of the conductors 9a and 10a for terminating the line 3, 4 while a similar disk 35 terminates the right-hand end of line 12, 14. A signal input connection is made to the line represented by the reference numerals 12 and 14 by means of the coaxial connector 31 having an inner conductor which terminates in a loop 32 suitably conductively secured to the inner periphery of the outer line conductor 12. A similar coaxial connection 33 is coupled to the coaxial line 3, 4 and is comprised of an inner conductor also terminated by the loop 34 secured to the conductor 4 as shown.

The signal input circuit for this tube is the coaxial line represented by the inner and outer conductors 14 and 12, respectively. This input line is terminated on the right end by means of an annular disk 35 at a location which will produce the desired resonant effect to be explained more fully hereinafter. As in the embodiment of Fig. 1, the cathode 1 is thermionically emissive and is provided with a suitable heating filament interiorly thereof having leads 36 and 37 projecting from the right end of the hollow cathode extension 14 as shown.

A source of operating potential, indicated as the battery 38, which provides, for example, a potential of 400 volts, has its positive terminal connected to the terminating disk 30 for supplying the same positive potential to the grid 3 and anode 4, and its negative terminal connected to the shorting disk 35 for providing a direct current connection to the cathode 1. The input grid 2 has a connection 39 leading to a terminal on the battery 38 which supplies, for example, 30 volts of positive polarity.

As explained previously, the overall length of the tube and its extensions is made equal to an integral number of half wavelengths of the tube operating frequency. This being true, the wave of the signal introduced by means of the connector 31 and lead 32 to the tube input channel between the conductors 12 and 14 and cathode 1 and grid 2 will travel from right to left through this channel until it is reflected by the terminating disk 28. By making the distance between the terminating disks 28 and 35 equal to an integral number of half wavelengths, standing waves will be produced in this input channel. This input line being resonant, the input signal will build up by using the proper input connection to a value limited only by the electrical attenuation and absorption characteristic of the coaxial line itself. The ultimate amplitude of this resonant signal, will, of course, be many times greater than the amplitude of the input signal introduced at the right end by the connector 31.

The intense modulating field now set up between the cathode 1 and grid 2, increases the intensity of the modulated part of the electron current for a given axial section of tube over that which was obtained in the case of the tube of Fig. 1. As in the case of Fig. 1, incremental signals will be induced in the channel B and will add in phase to produce an amplified wave which travels down the channel between the grid 3 and anode 4 until it is reflected by the terminating disk 27 like the input signal at the terminating disk 28. The phase relationship of the signals in channels B and A, respectively, after the reflection, is the same as it was previous to the reflection, so the amplification of the generated signal "V" in channel B will increase further as it would in a long tube which does not utilize reflection. The same has to be said of the reflections at the terminating disks 30 and 35 if they are properly positioned, the distance between the respective terminating disks (27, 30) and (28, 35) being an integral number of half wavelengths at the operating frequency.

From the description, it is evident that this "resonant tube" is equivalent in its operation to an infinitely long amplifier tube, having the advantage of increased current modulation and consequently increased signal generation in the elementary sections of the tube as was described above.

From the foregoing it will be seen that the resonant tube of Fig. 2 may be of much shorter length than the tube of Fig. 1 for a given factor of amplification.

Another embodiment of this invention which utilizes the principles of the foregoing is illustrated in Figs. 3 and 4. The principal difference in construction between this embodiment and the one of Fig. 2 resides in the fact that this embodiment does not utilize reflected or standing waves to produce a high initial modulation of the electron current in the region of the cathode 1 and the grid 2, but instead employs the concept of providing a multiplicity of coaxial output channels, such as the one contained between the grid 3 and the anode 4. The signals of all of the output channels are added in phase to obtain an amplified signal. In this embodiment, like numerals will again indicate like parts.

As in the first-described embodiment, this tube may be several wavelengths long at the tube operating frequency, and comprises the basic coaxial electrodes 1, 2 and 3 which serve the same purpose and function in substantially the same manner as in the tube of Fig. 1.

Coaxially arranged with respect to the electrodes 1, 2 and 3 are a plurality of radially outwardly spaced grid electrodes bearing the reference numerals 45, 46 and 47, respectively, which define signal channels B1, B2, B3 and B4, respectively.

An anode 4 coaxially surrounds these latter mentioned electrodes. All of these electrodes are preferably rigid or self-supporting in construction and are maintained in their separated relationship by means of glass or the like spacers of the type described in connection with the preceding embodiments. On the left end of this tube assembly, the spacers may consist of annular resistance elements 48, 49, 50 and 51 which are interposed between the electrodes 3, 45, 46, 47, and 4, respectively. The values of these respective resistances are made equal to the characteristic impedances of the respective transmission lines embracing the spacers, an example of this being that the spacer 48 has a resistance value equal to the characteristic of impedance of the coaxial line 3, 45. Each of the electrodes 45, 46, and 47 is made of a suitable conducting material having cross-sectional thickness which makes it self-supporting, the tubular member comprising this material being provided with a multiplicity of radial openings or perforations 52 all arranged in radial registry. The electrons emitted by the cathode 1, will, therefore, find a radial path to the anode through these various openings 52.

The right-hand ends of the electrodes 45, 46 and 47 are tapered in cross section as at 53 for a purpose which will become apparent hereinafter. As seen more clearly in Fig. 4, the respective adjacent electrodes 45, 46 and 47 are made such that the outer peripheries of the adjacent electrodes will be spaced apart a distance equal to one electron wave length. This spacing is represented by the letter "D."

For purposes of convenient explanation, this tube of Fig. 3 may be considered as comprising a multiplicity of the tubes of Fig. 1. The annular space between the grid 3 and anode 4 of Fig. 1 characterized as output channel B, corresponds to the annular space between the grid 3 and electrode 45 of Fig. 3, denominated channel B1. Similarly, the spaces between succeeding electrodes may be considered as constituting additional channels B2, B3, and B4. In each one of these channels a signal is produced in exact phase conformity with the signals produced in the remaining channels, whereby all of the signals may be collected in additive relation.

With reference to Fig. 4, a microwave signal fed to the input section 1, 2 of the tube, will produce a flow of electron current to the anode, via the openings 52, which may be characterized by the waveform 54 (Fig. 4). From the application of this waveform 54, to the tube

geometry, a graphic illustration of the phase relation of the electron current traversing the respective channels between the electrodes 3, 45, 46, 47, and 4 is obtained. It will be noted that exact phase conformity prevails in these channels so that the individual electric fields produced will, at any axial location in the tube, be directed in a common direction. Like the spacing of the electrodes 3, 45, 46, 47, 4 is prescribed to give exactly the same phase relationship in the channels between them, the thickness of these electrodes are selected to give optimum signal generation in each of the channels. The resultant signals proceeding down the respective channels B1, B2, B3 and B4 are at any given instant, radially of the tube, in exact phase relation, and since they travel toward the right emanate from the flaring mouth provided by the tapered end sections 53, a signal will be accumulated in the annular space 59 contained between the right-hand ends of the grid 3 and the anode 4 which will have a value equal to the sum of the values of the individual output signals. The anode 4 and grid 3 may now be considered as a coaxial transmission line for coupling the amplified signal to a suitable load.

As will now be obvious, any number of electrodes or channels may be utilized to obtain an amplified signal, and the tube may be made to any suitable length. Theoretically, the more channels used or the longer the tube is made, the higher will be the gain factor of the tube.

By use of the multiple channels or zones of this embodiment shown in Fig. 3, the same magnitude of output signal as produced by the embodiment of Fig. 1 of given length may be obtained by a tube of shorter length.

A possible modification as shown in Fig. 5, of the embodiment of Figs. 3 and 4, resides in fabricating each of the various electrodes 45, 46, and 47 of two cylinders 45*a* and 45*b*, 46*a* and 46*b* and 47*a* and 47*b*, respectively, of spaced apart screen material. In this construction, in addition to channels B1, B2, B3 and B4 formed between electrodes 3 and 45*a*, 45*b* and 46*a*, 46*b* and 47*a*, and 47*b* and 4, respectively, which correspond in every respect to the channels of Fig. 3 which bear the same reference symbols, additional channels B1', B2' and B3' are provided as shown.

Electrons (represented graphically by wave 54*a*) passing through the openings of the grids generate waves travelling toward the right with increasing amplitude in all of these channels. The waves in B1, B2, B3 and B4, as in the case of Fig. 3, will be in exact phase, and in the channels B1', B2' and B3' will be in opposite phase conformity.

By closing channels B1', B2' and B3' with annular metal rings 55, 56 and 57, which are extended by the tapered metal segments 53, the waves generated in channels B1, B2, B3 and B4 can be collected in the line 59, between cylinders 3 and 4 exactly as described in connection with Fig. 3. The waves generated in channels B1', B2' B3' and arriving at the shorting disks 55, 56, 57 respectively, will be reflected, and will propagate leftward through the tube. If at the left end, channels B1, B2, B3 and B4 are shorted by the tapered annular metal disks 65, 66, 67 and 68 and amplified signal can be produced in the same manner in the left end of the tube in cavity 59*a*, formed between electrodes 3 and 4.

Fig. 6 illustrates a still further embodiment of the invention. It is built similar to the tube of Fig. 5, except that channels B1', B2', and B3' are not shorted at the right end. Instead dielectric cylinders 75, 76, 77 are inserted in these channels, which diminish the propagation velocity of the waves in the plugged portions of the respective channels. If the lengths of these plugs 75, 76, 77 are properly selected, so that the travel time of the wave is lengthened by one half period, the waves of all the channels, as they enter the cavity 69, will be in additive phase.

The phase shifting rings 75, 76 and 77 may be fabricated of any suitable dielectric material and to any suitable dimension which will provide the desired phase transformation for bringing the wave generated in all of the channels into proper phase relationship. A graphic representation of what happens in the various channels is indicated in the figure by a train of sine waves in the respective channels. It will readily be appreciated that by shifting the phase of the intermediate channels, practically the entire radial space of the tube is utilized for generating the amplified signal. This feature enables the shortening of the tube for a given value of amplified signal in comparison with the tube shown in Fig. 3.

While all of the foregoing embodiments have been described in connection with amplification of a microwave signal, it will be readily understood by a person skilled in the art that each of these embodiments may be modified slightly to achieve sustained oscillation thereby providing microwave oscillators. This is accomplished, as shown in Fig. 8, by feeding a small quantity of the amplified signal back into the input channel between the cathode and the adjacent grid 2. A suitable coaxial line 78 or cavity connection interconnecting the input and output channels of the respective tubes may be utilized for feeding a signal from the output channel to the input channel for achieving sustained oscillations. It is understood as well that this connection between the output and input channels may be more closely coupled. Such is the case, for example, in reflex klystrons or in magnetrons, where the two channels are the same. Following the motion of the electrons, it is possible in the case of reflex klystrons to separate in time the two different actions between the electron beam and this only channel, these being the same actions as were attributed above to the channels A and B, while this distinction is not possible any more in the case of magnetrons.

In any event, regardless of whether the general idea of this invention is incorporated in a true amplifier or in an oscillator, the signal contributions of the various incremental sections of the tube are collected "in phase" to produce the ultimate output signal.

While there has been described what, at present, is considered the preferred embodiments of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and therefore, it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An electron discharge device for use in the utilization of microwave frequency signals comprising signal input and signal output channels arranged respectively for signal propagation in the same direction, said input channel being constituted by an elongated coaxial line having inner and outer conductors, the inner conductor serving as a cathode and emitting electrons throughout its length, the outer conductor being radially perforated therethrough throughout its length, the output channel being constituted by a second elongated coaxial line having inner and outer conductors supported in spaced coaxial relation to the first-mentioned coaxial line, the inner conductor of said second line being radially perforated throughout its length to provide paths for electron flow from said first line, the outer conductor of said second line serving as an anode throughout its length so that the microwave signal voltage applied to said input channel is propagated in said first coaxial line and modulates said electrons emitted from said cathode in every axially successive incremental section thereof thereby providing axially incremental signals in said second coaxial line which add in phase to provide an amplified signal in said output channel.

2. The device of claim 1 including means for electrically insulating the input and output lines from each other, and a unidirectional voltage source connected to impress the same relatively high positive potential on said

inner and outer conductors of said second coaxial line, a relatively lower positive potential on said outer conductor of said first coaxial line, and the lowest potential on said inner conductor of said first coaxial line.

3. The device of claim 1 in which the inner and outer conductors of said second coaxial line are spaced apart by one half the electron wavelength of said device.

4. The device of claim 1 in which the opposite ends of the coaxial lines are shorted respectively and said coaxial lines respectively have lengths which are an integral number of half wavelengths of the signal frequency so that said lines are respectively resonant at said frequency.

5. An electron discharge device for use in the utilization of microwave frequency signals comprising: signal input and signal output channels arranged respectively for signal propagation in the same direction, said input channel being constituted by an elongated coaxial line having inner and outer conductors, with said inner conductor serving as a cathode, said output channel being constituted by a second elongated coaxial line having inner and outer conductors disposed in spaced coaxial relation to said input line with said outer conductor serving as an anode, and means cooperating with said input and output lines defining an axially extending evacuated electron discharge zone between said cathode and said anode, said outer conductor of said input line and said inner conductor of said output line being respectively radially perforated throughout their lengths and said cathode being arranged for electron emission throughout its length in said zone whereby a microwave signal voltage applied to said input channel is propagated in said first coaxial line and modulates said electrons emitted by said cathode in every axially successive incremental section thereof thereby providing axially incremental signals in said second coaxial line which add in phase to provide an amplified signal in said output channel.

6. An electron discharge device for use in the utilization of microwave frequency signals comprising: signal input and output channels arranged respectively for signal propagation in the same direction, said input channel being constituted by an elongated coaxial line having inner and outer conductors with said inner conductor serving as a cathode, said output channel being constituted by a second elongated coaxial line and having inner and outer conductors disposed in spaced coaxial relation to said input line with said outer conductor serving as an anode, first spacing means for radially spacing and supporting said input and output line conductors, and second spacing means for radially spacing and supporting said input and output line conductors and axially spaced from said first spacing means to define an evacuated electron discharge zone therewith between said cathode and said anode, said outer conductor of said input line and said inner conductor of said output line being respectively radially perforated throughout their lengths in said zone, said cathode being arranged for electron emission throughout its length in said zone and the inner and outer conductors of said second coaxial line being spaced apart by one-half the electron wavelength of said device whereby a microwave signal voltage applied to said input channel is propagated in said first coaxial line and modulates said electrons emitted from said cathode and every axially successive incremental section thereof thereby providing axially incremental signals in said second coaxial line which add in phase to provide an amplified signal in said output channel.

7. The device of claim 6 in which the opposite ends of said input and output lines are respectively shorted and said input and output lines extending a distance of approximately one-half the wavelength of the signal frequency respectively beyond said first and second spacing means and respectively having over-all lengths which are an integral number of one-half wavelengths of the signal frequency so that said input and output lines are respectively resonant at said frequency.

8. An electron discharge device for use in the utilization of microwave frequency signals comprising an input signal channel constituted by an elongated length of coaxial line having inner and outer conductors, the inner conductor serving as a cathode and emitting electrons throughout its length and the outer conductor having a plurality of openings therethrough throughout its length to provide a plurality of radial paths for the flow of electrons therethrough, and a plurality of coaxial output signal channels coaxially surrounding said input channel and being comprised of a plurality of radially spaced tubular electrodes which are all, with the exception of the outermost electrode, provided with a plurality of radial openings throughout their lengths for passing the aforementioned flow of electrons, said electrodes being radially spaced apart a distance which will place the outer peripheral surfaces of adjacent electrodes a full wave length of electron flow apart, said electrodes further providing coaxial channels interiorly thereof so that the microwave signal applied to said input channel is propagated in said first coaxial line and modulates said electrons emitted from said cathode in every axially successive incremental section thereof thereby providing axially incremental signals in said output signal channels, the same respective ends of said interior channels being furnished with phase-shifting means whereby the signals generated in all channels will adjust into additive phase relation, the innermost and outermost of said electrodes serving as the inner and outer conductors respectively of an elongated output coaxial line and extending axially beyond the ends of said phase-shifting means to provide a collection cavity in which the signals produced by the individual output channels may be added in phase to produce an amplified output signal in said cavity, said output coaxial line being arranged to propagate the output signal in the same direction as the propagation of the input signal in the input signal channel.

9. An electron discharge device for use in the utilization of microwave frequency signals comprising an input signal channel constituted by an elongated length of coaxial line having inner and outer conductors, the inner conductor serving as a cathode and emitting electrons throughout its length and the outer conductor having a plurality of openings therethrough throughout its length to provide a plurality of radial paths for the flow of electrons therethrough, and a plurality of radially spaced coaxial output signal channels coaxially surrounding said input channel and being comprised of a plurality of radially spaced tubular electrodes provided with a plurality of radial openings throughout their lengths for passing the aforementioned flow of electrons so that the microwave signal applied to said input channel is propagated in said first coaxial line and modulates said electrons emitted from said cathode in every axially successive incremental section thereof thereby providing axially incremental signals in said output signal channels, adjacent electrodes being radially spaced apart a distance which will serve to produce signals in all output channels which are in phase, the same ends of said output channels being terminated by impedances having values equal to the characteristic impedances of the respective output channels, the ends of said electrodes remote from the last-mentioned impedances being tapered to provide channel openings of axially progressive width, the innermost and outermost of said electrodes serving as the inner and outer conductors respectively of an elongated output coaxial line and extending axially beyond the ends of said tapered ends to provide a collection cavity in which the signals produced by the individual output channels may be added in phase to produce an amplified output signal in said cavity, said output coaxial line being arranged for propagation of said output signal in the same direction as the propagation of the input signal in the input signal channel.

10. An electron discharge device for use in the utilization of microwave frequency signals comprising an

input signal channel constituted by an elongated length of coaxial line having inner and outer conductors, the inner conductor serving as a cathode and emitting electrons throughout its length and the outer conductor having a plurality of openings therethrough throughout its length to provide a plurality of radial paths for the flow of electrons therethrough, and a plurality of radially spaced coaxial output signal channels coaxially surrounding said input channel and being comprised of a plurality of radially spaced tubular electrodes provided with a plurality of radial openings throughout their lengths for passing the aforementioned flow of electrons so that the microwave signal applied to said input channel is propagated in said first coaxial line and modulates said electrons emitted from said cathode in every axially successive incremental section thereof thereby providing axially incremental signals in said output channels, said electrodes being radially spaced apart a distance which will place the outer peripheral surfaces of adjacent electrodes a full wavelength of electron flow apart, adjacent electrodes being radially spaced apart a distance which will serve to produce signal in all output channels which are in phase, the same ends of said output channels being terminated by annular shaped impedance members having impedance value corresponding to the characteristic impedance of the respective output channel, the opposite ends of said output channels being open, the innermost and outermost of said electrodes serving as the inner and outer conductors respectively of an elongated output coaxial line and extending axially beyond the open ends of said output channels to provide a collection cavity in which the signal produced by the individual output channels may be added in phase to produce an amplified output signal in said cavity, and a coaxial connection coupled to the cavity conductors for conducting the amplified signal therefrom and with propagation in the same direction as the propagation of the input signal in said input channel.

11. An electron discharge device for use in the utilization of microwave frequency signals comprising an input signal channel which extends in the direction of signal propagation, said channel being defined by two elongated spaced conductors, one of which being electron emissive throughout its length and the other of which being pervious to the passage of electron flow throughout its length, said electron flow being transverse to the direction of signal propagation, a plurality of output channels disposed in progressive spaced relation from said input channel and extending parallel to the direction of said signal propagation, said output channels being separated by a plurality of conductive members which are pervious to said electron flow throughout their lengths so that the microwave signal applied to said input channel is propagated in said first coaxial line and modulates said electrons emitted from said cathode in every axially successive incremental section thereof thereby providing axially incremental signals in said output channels, said conductive members being spaced apart a distance which provides for the generation of a signal in each output channel in response to said electron flow thereacross whereby the generated signals in one series of alternate channels are in exact phase relation and the generated signals in the other series of alternate channels are in phase with each other but opposite to the signals of said one series of channels, first means disposed at the same ends of series of said alternate channels to facilitate collection of all signals therefrom which are in phase, and second means disposed at the other ends of said other series of alternate channels to facilitate collection of all signals therefrom which are in phase.

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