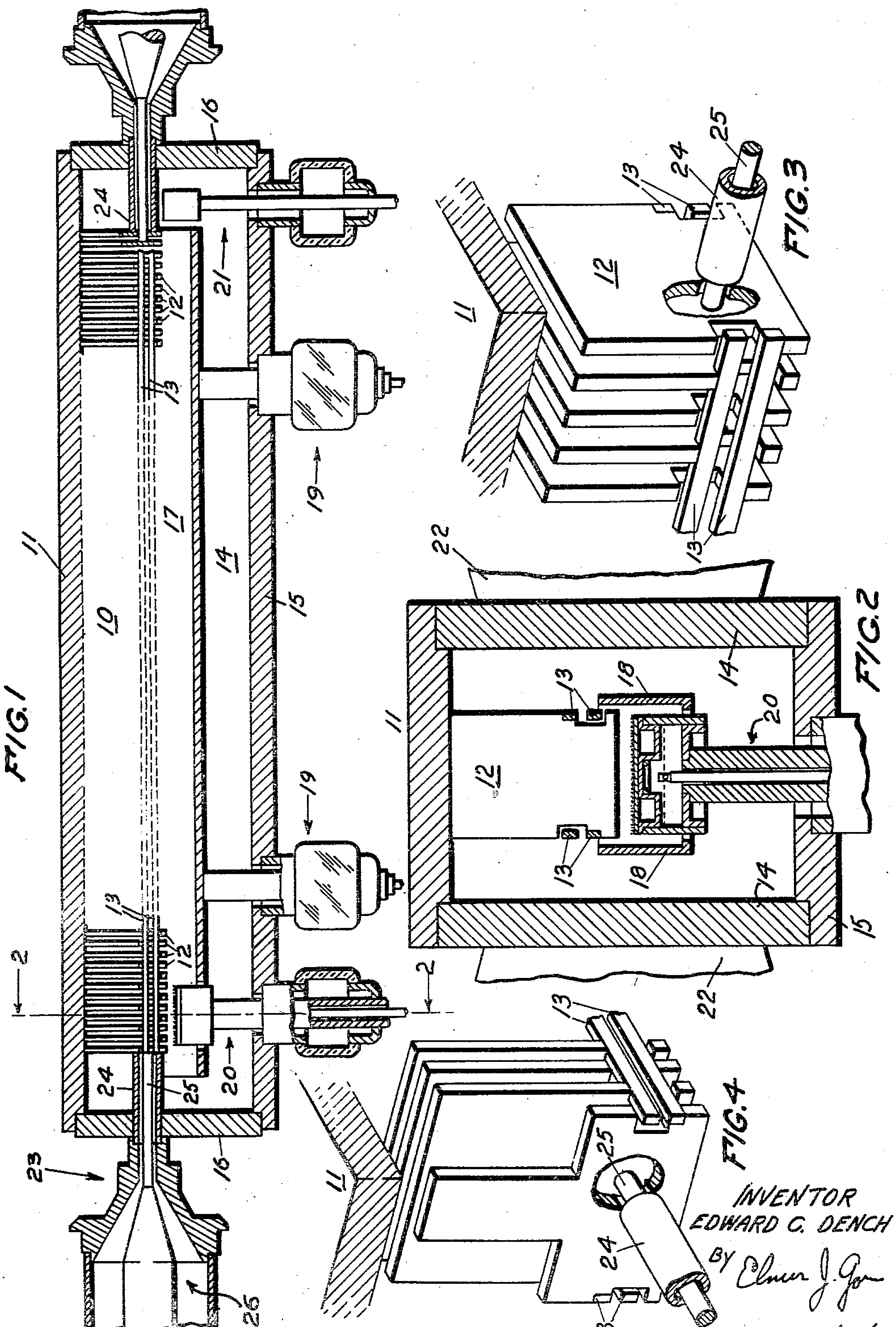
Sept. 2, 1958 | E. C. DENCH | 2,850,671

MAGNETRON AMPLIFIERS

Filed Jan. 24, 1952 | 2 Sheets-Sheet 1



INVENTOR
EDWARD C. DENCH
BY Elmer J. Gorn
ATTORNEY

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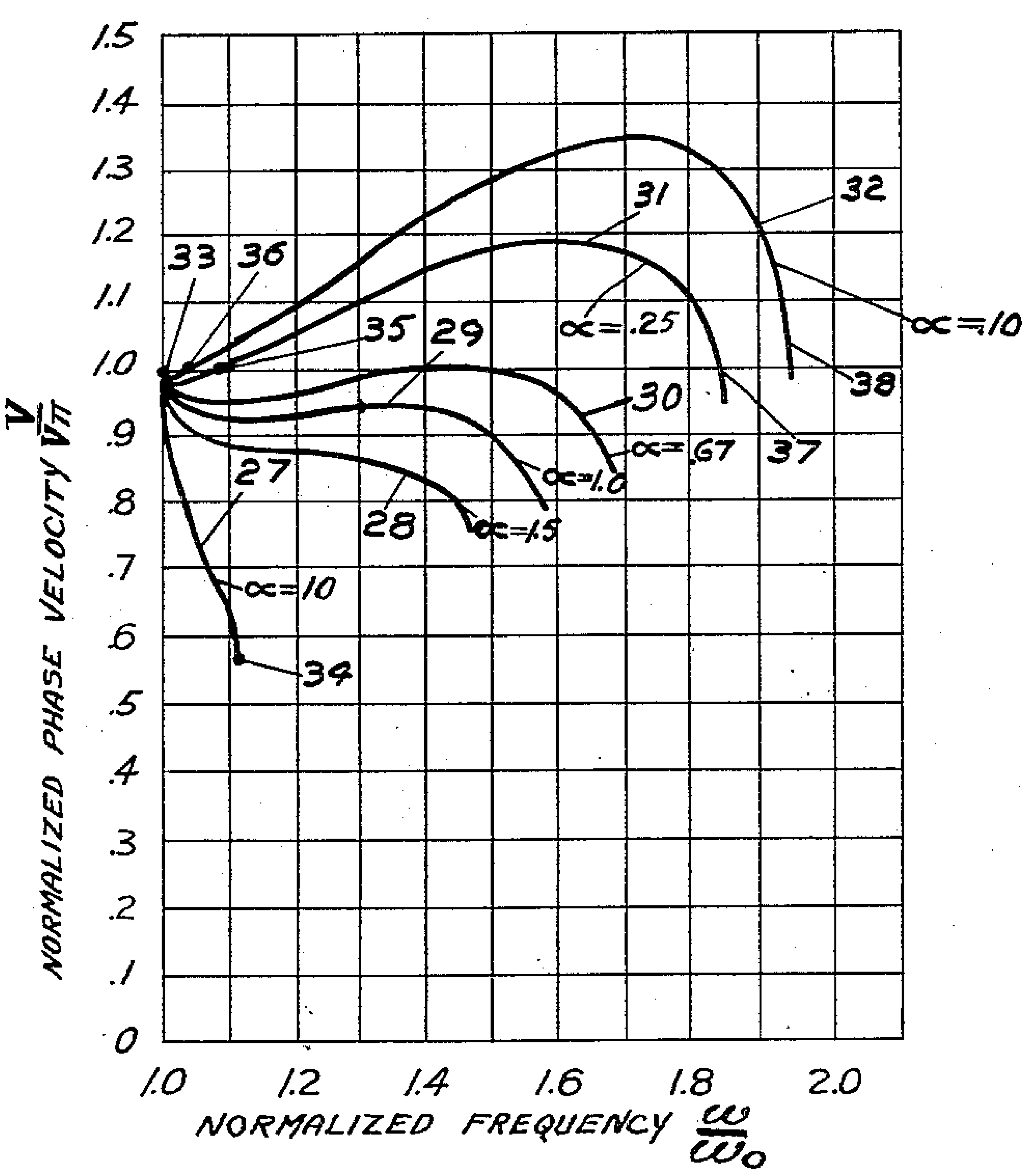

FIG. 5

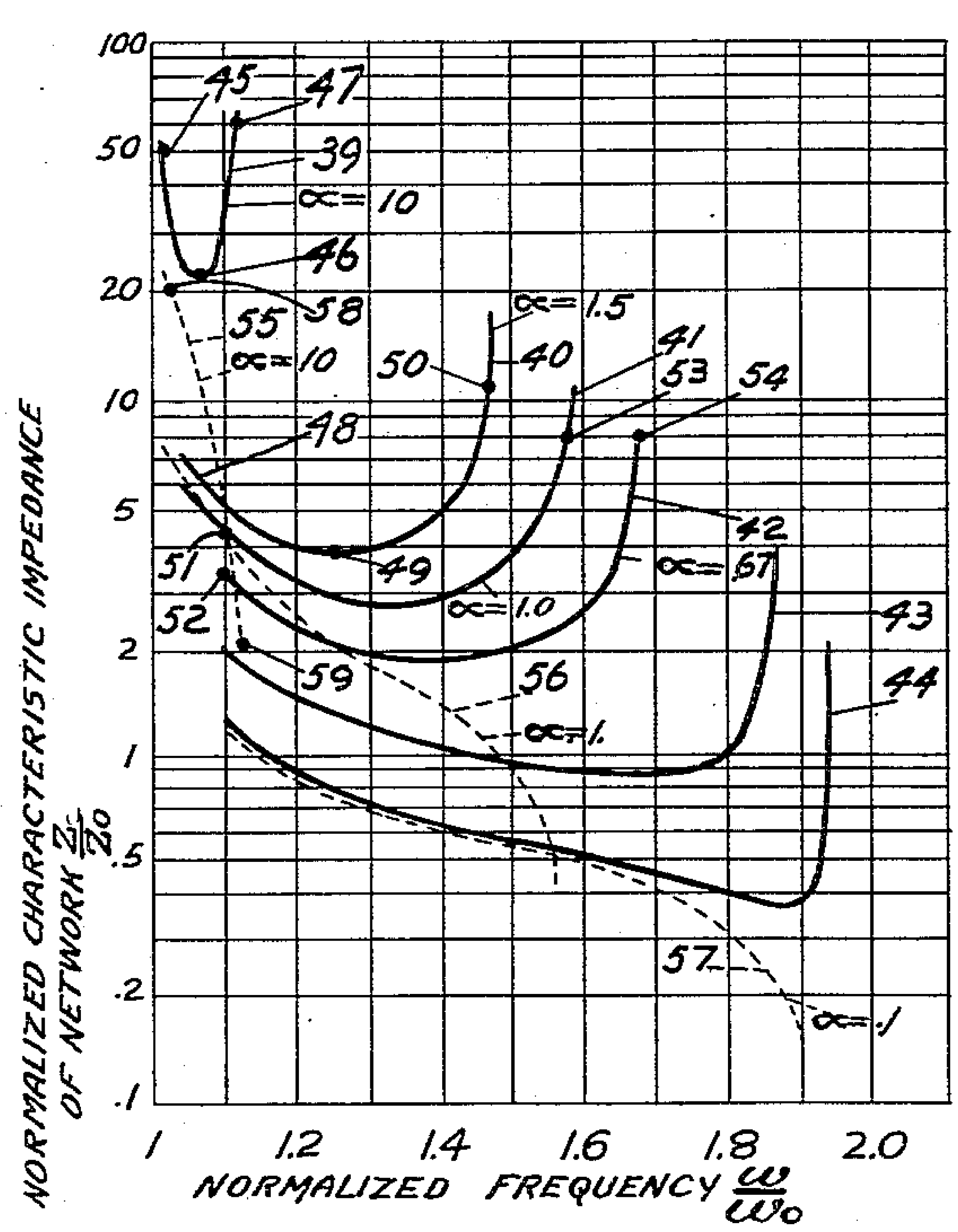

FIG. 6

INVENTOR
EDWARD C. DENCH
BY Elmer J. Gorn
ATTORNEY

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MAGNETRON AMPLIFIERS

Edward C. Dench, Needham, Mass., assignor to Raytheon Manufacturing Company, Newton, Mass., a corporation of Delaware

Application January 24, 1952, Serial No. 268,097

6 Claims. (Cl. 315—39.3)

This invention relates to electron discharge devices, and more particularly to devices of the magnetron amplifier type.

It has been found that magnetron amplifiers previously constructed had an undesirable tendency to oscillate when a sufficient voltage was applied to the device in the presence of a particular magnetic field to create conditions whereat amplification was possible. While the oscillations may be damped out by loading down the signal wave transmission structure, which makes up the anode, such loading also absorbs power from the amplified signal, hence reducing the afficiency and amplification factor of the device.

One source of oscillations is the operation of the discharge device under conditions whereat electrons move along paths adjacent the signal wave transmission network in the anode at velocities sufficient to produce π mode oscillations. The π mode oscillations encountered are similar to those generated in a conventional magnetron oscillator and are produced when adjacent anode members making up the signal wave transmission structure differ in phase by substantially π radians. These oscillations are the result of feedback within the signal wave transmission network, substantially independent of the terminations at the ends thereof, with each pair of adjacent anode members together with the space therebetween behaving as a substantially resonant cavity. Therefore such oscillations cannot be satisfactorily eliminated by adjustment of the impedance match at the signal input and output connections to the signal wave transmission network. Moreover, increasing the velocity of the electron stream substantially above the required velocity for oscillation at the π mode frequency will not always eliminate this source of oscillations since the transmission line at the π mode has an extremely high Q, and hence is coupled strongly enough to the electron stream to interact therewith sufficiently well to produce oscillations possibly by slowing down some of the electrons in the stream to velocities where more efficient interaction at the π mode frequency occurs.

This invention discloses a magnetron amplifier wherein the device may be operated in a region where amplification is possible but where oscillation at the π mode frequency is not probable. Briefly, this is accomplished by using in the anode structure a signal wave transmission network having a lower cutoff frequency, said anode structure being such that the phase velocity of a component of a signal traveling along said network at frequencies other than said cutoff frequency is slower than the phase velocity of said component at said cutoff frequency. The term lower cutoff frequency, as used throughout the specification and claims, is hereby defined as that frequency below which the desired component of the signal will not propagate along the transmission network and above which said component will propagate along said network.

Specifically, in the embodiment illustrated herein where a strapped anode structure is used, it has been found

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that α should be greater than .67 where α is a normalized design parameter determined from the formula

$$\alpha=\frac{\omega_0 L_s}{Zc} \qquad (1)$$

where

ω_0=the lower cutoff frequency,
L_s=the strap inductance encountered in one section or cavity of the anode structure, and
Z_C=the characteristic impedance of the cavity.

The reasons for the effect of the design parameter α on the ability of the transmission network to oscillate in the π mode will be demonstrated in greater detail presently.

This invention further discloses a novel method of coupling the input and output devices to the signal wave transmission network. Briefly, the coupling is accomplished by connecting the outer conductor of a coaxial line to the end anode member of the signal wave transmission network at a point adjacent the inner end of the anode member and substantially half way between the sets of straps. The central conductor of the coaxial line extends through an aperture in the end anode member spaced therefrom and is connected to the anode member adjacent the end anode member. Such a coupling device sees the signal wave transmission network substantially as a series of cascaded π section filters.

For the particular range of values of the design parameter α previously discussed, it has been found that the characteristic impedance of a transmission network analyzed as cascaded π section filters remains substantially constant over a wider range of frequencies than the same transmission network analyzed as a series of cascaded T section filters. Hence, an output coupling device which sees substantially π section filters in the transmission network may couple a constant impedance load to the transmission network with a better degree of match over a wider range of frequencies than can a coupling device, such as a connection to the straps, which sees substantially T sections in the transmission network.

Other and further objects and advantages of this invention will be apparent as the description thereof progresses, reference being had to the accompanying drawings wherein:

Fig. 1 illustrates a longitudinal cross-sectional view of an electron discharge device embodying this invention;

Fig. 2 illustrates a transverse cross-sectional view of the device shown in Fig. 1 taken along line 2—2 in Fig. 1;

Fig. 3 illustrates a partially broken away isometric view of the device shown in Fig. 1, illustrating the details of the input or output coupling devices;

Fig. 4 illustrates a partially broken away isometric view illustrating a further embodiment of an input or output coupling device which may be used in the device illustrated in Fig. 1;

Fig. 5 illustrates a graph showing the relationship between frequency and phase velocity of a component of a wave travelling in the signal wave transmission network used in the device of Fig. 1 for various values of the design parameter α; and

Fig. 6 illustrates a graph showing the relationship between the characteristic impedance of the signal wave transmission network used in the device shown in Fig. 1, and frequency for various values of the design parameter α when said transmission network is analyzed as a series of cascaded π section filters and when said transmission network is analyzed as a series of cascaded T section filters.

Referring now to Figs. 1, 2, 3 and 4, there is shown an electron discharge device comprising anode structure **10** which is fabricated to form a signal wave transmission network. Anode structure **10** comprises a backing support member **11** which is shown as a flat plate of conductive material such as copper. Extending downwardly from plate **11** is a plurality of anode members **12** which are shown here, for example, as substantially rectangular planar members. Anode members **12** are rigidly attached at their upper ends to support member **11** and are alternately connected at points on their edges adjacent their lower ends by conductive straps **13** according to well-known practice. Planar members **12** are positioned substantially perpendicular to support member **11** and to the conductive straps **13**.

The anode members **12** are positioned within a conductive evacuated envelope of which the support member **11** is a part. The envelope comprises side walls **14** attached to support member **11** and a lower wall **15**, sealed to side members **14**, and end walls **16** sealed to the ends of the box-like structure made up of members **11**, **14**, and **15**.

Positioned inside the envelope adjacent the lower ends of anode members **12** is a metallic trough-like member **17**, the bottom of said trough-like member being positioned parallel to the lower edges of anode members **12** and the sides **18** of trough-like member **17** extending upwardly to a point slightly above but spaced from the lower corners of anode members **12**. Trough **17** is supported by means of insulated supports **19** which provide electrical connection of trough **17** with circuits outside the envelops but which prevent electrical contact of trough **17** with the envelope or the anode structure **10**. Trough **17** and the insulated supports therefor are described in greater detail in my copending application, Serial No. 255,499, filed November 8, 1951, now Patent No. 2,809,328, dated October 8, 1957.

A cathode structure **20** is positioned adjacent one end of the signal wave transmission network made up of anode members **12** while a catcher electrode **21** is positioned adjacent the other end of said signal wave transmission network. The purpose of the cathode **20** is to emit electrons which, under the influence of the proper electrostatic and magnetic fields produced in the space between trough **17** and the lower ends of the anode members **12**, will move along paths adjacent thhe anode members **12** and, after amplifying any signal present in the network through interaction therewith, the electrons will impinge on the catcher electrode **21**. The particular details of the cathode **20** and catcher electrode **21**, as well as the support and electrical connections thereto, are described in greater detail in the aforesaid copending application. The magnetic field may be produced by means of a magnet which is connected to magnetic pole pieces **22**, positioned adjacent the external sides of side members **14**.

The anode members **12** do not extend all the way to the end members **16** but a space is left adjacent the end members **16** where the members **12** have been omitted. Signal coupling devices **23** are connected at each end to the signal wave transmission network made up of the anode members **12**. The coupling device **23** comprises a coaxial line having an outer conductor **24** sealed through end plate **16** and terminating in the end anode member **12** at a point substantially half way between the sets of straps **13** and adjacent the lower end of said anode member. Positioned inside conductor **24** and spaced therefrom is a central conductor **25** which extends through an aperture in the end anode member **12** spaced therefrom and is connected to the anode member adjacent the end anode member. Inner and outer conductors **24** and **25**, after passing outwardly through end plate **16**, have a tapered transition section **26** designed to match the impedance of the device being coupled to the signal wave transmission network to the impedance of said network. Thereafter, central conductor **25** is

insulatedly sealed to the outer conductor **24** by means of an insulating seal, not shown.

Referring now to Fig. 5, there is shown a graph illustrating the relationship between frequency and the phase velocity of a component of a wave traveling along the signal wave transmission network for various values of the design parameter α. This relationship may be calculated from a formula derived as follows: The signal wave transmission network is analyzed as a series of T section filters, one such section comprising the cavity formed by two parallel anode members **12** and the portions of the straps included therebetween. Such T sections are shown in copending application, Serial No. 66,249, filed December 20, 1948, by William C. Brown. One half of the strap inductance is positioned in each of the horizontal arms of the T and has an impedance equal to $j\omega L_s$ where ω is any frequency applied to the network. The vertical arm of the T represents the impedance of the cavity connected across the straps, said impedance being given by the formula

$$jZ_c \tan \beta l$$

where

Z_c=the characteristic impedance of the cavity,

$$\beta=\frac{2\pi l}{\lambda}$$

l=the effective length of the cavity, and
λ=the wavelength at said frequency.

The phase velocity of a component of the wave travelling along the signal wave transmission network is given by the formula

$$V=\frac{\omega\Delta}{\pi+\theta} \quad (2)$$

where

Δ=the length of a network section and
θ=phase shift per network section.

At the lower cutoff,

Thus

$$V\pi=\frac{\omega_0\Delta}{\pi} \quad (3)$$

and

$$V/V\pi=\frac{\omega}{\omega_0}\left\{\frac{\pi}{\pi+\theta}\right\} \quad (4)$$

where ω_0=the cutoff frequency in radians.

θ must now be found in terms of the design parameters. From network theory

$$\theta=\cos^{-1}\frac{Z_{11}}{Z_{12}} \quad (5)$$

where

$$Z_{11}=j\omega L_s+jZ_c \tan \beta l \quad (6)$$

$$Z_{12}=jZ_c \tan \beta l \quad (7)$$

Thus

$$\theta=\cos^{-1}\left\{1+\frac{\omega L_s}{Z_c \tan \beta l}\right\} \quad (8)$$

$$\theta=\cos^{-1}\left\{1+\frac{\omega}{\omega_0}\frac{\alpha}{\tan \beta l}\right\} \quad (9)$$

where

$$\alpha=\frac{\omega_0 L_c}{Z_c} \quad (9a)$$

but

$$\beta=\frac{2\pi l}{\lambda} \quad (10)$$

At lower cutoff

$$l=\frac{\lambda_0}{4}$$

So

$$\beta=\frac{2\pi}{4}\frac{\lambda_0}{\lambda}=\frac{\pi}{2}\frac{\omega}{\omega_0} \quad (11)$$

Thus

$$\theta=\cos^{-1}\left\{1+\frac{\omega}{\omega_0}\frac{\alpha}{\tan\frac{\pi}{2}\frac{\omega}{\omega_0}}\right\} \quad (12)$$

θ is calculated for values of ω/ω_0 from $\theta=0$ to $\theta=\pi$ (i. e. over the pass band) for various values of α. Using these values of θ, the values of $V/V\pi$ are then computed; the results are plotted in the graph illustrated in Fig. 5.

The normalized phase velocity

$$\frac{V}{V\pi}$$

is plotted along the axis of ordinates while the normalized frequency

$$\frac{\omega}{\omega_0}$$

is plotted along the axis of abscissae. Curves are plotted for values for α of 10, 1.5, 1, .67, .25, and .10 and are indicated by curves **27**, **28**, **29**, **30**, **31**, and **32**, respectively. At the π mode frequency indicated as a normalized frequency

$$\frac{\omega}{\omega_0}$$

of 1 on the graph, the normalized phase velocity is unity for all of the curves as is indicated by point **33** on the graph. As the frequency is increased, the curves **27** through **32** diverge with all the curves initially extending downwardly from point **33**. The curve **27** indicating a design parameter α of 10 continues sharply downward until it reaches a normalized phase velocity of approximately .56 at a normalized frequency of approximately 1.11 as indicated by point **34** on the graph. Curves **28** and **29** level off for a short period at normalized phase velocities of approximately .88 and .92, respectively, over a frequency range extending from the normalized frequency of 1.1 to substantially 1.3 and 1.1 to 1.4, respectively. These curves then again veer downward. Curve **30** after extending downward from point **33**, as frequency is increased, levels off and turns upward to again reach a normalized phase velocity of 1 at a normalized frequency of approximately 1.4 after which it again veers downward as frequency is increased. Curves **31** and **32** after extending downwardly from point **33**, as frequency is increased, veer upwardly again and exceed the normalized phase velocity of 1 at normalized frequencies in excess of 1.08 and 1.04, respectively, as is indicated by point **35** and point **36**, respectively. The curves **31** and **32** extend upwardly to normalized phase velocity maximums of approximately 1.19 and 1.35, respectively, at normalized frequencies of approximately 1.6 and 1.7, respectively. The curves **31** and **32** then veer downwardly and again reach normalized phase velocities of 1 at frequencies of around 1.85 and 1.94, respectively, as indicated by point **37** and **38**, respectively.

Thus, it may be that for values of the design parameter α greater than .67, the transmission network will transmit waves at all frequencies within the pass band at phase velocities which are less than the phase velocity of the lower cutoff or π mode frequency. With such an anode structure, the velocity of the electrons directed past the anode members may be adjusted by adjustment of the anode voltage to a value which is below the phase velocity of the π mode. It has been found that under these conditions oscillations will not occur at the π mode frequency. If values of α which were less than .67 were used, the voltage required would have to be very close to or above the voltage required to produce electron velocities equal to the phase velocity of a wave at the π mode frequency, and under these conditions oscillations at the π mode frequency would probably occur if the tube were not highly damped, for example, by the insertion of excessive amounts of lossy material.

In addition, it may be noted that curves **28** and **29** are relatively flat over a wide range of frequencies, for example, between the normalized frequencies of 1.1 and 1.4 or 1.5 and hence the anode voltage may be adjusted to a value which will produce electron velocities at the phase velocities of the waves in the signal wave transmission structure over this range of frequencies where values of α within this range are used, thereby insuring substantially the same degree of interaction between the electron stream and the waves, and hence the same gain for the electron discharge device over this range of frequencies. The curves **36** and **38** which rise above a normalized phase velocity of 1, on the other hand, are not flat over any substantial portion thereof and hence the gain of an amplifier tube operating on these curves, even if oscillations could be prevented, would vary considerably with frequency.

Referring now to Fig. 6, there is shown a graph illustrating the relationship between the characteristic impedance of the signal wave transmission network and frequency for various values of the normalized design parameter α when the network is analyzed as a series of cascaded **T** section filters and when the network is analyzed as a series of cascaded π section filters. Plotted along the axis of ordinates is the normalized characteristic impedance of the network Z/Z_0 where Z_0 is a characteristic impedance of the network. Plotted along the axis of abscissae is the normalized frequency

$$\frac{\omega}{\omega_0}$$

The curves illustrating analysis of the signal wave transmission network as a series of cascaded π sections are shown in solid lines for values of α equal to 10, 1.5, .67, .25 and .1 as are illustrated by curves **39**, **40**, **41**, **42**, **43**, and **44**, respectively.

The curve **39** has a normalized impedance of 50 at a normalized frequency of approximately 1.01 as is indicated by point **45**. As frequency is increased, it drops rapidly to a minimum normalized impedance of approximately 22 at a normalized frequency of 1.06 as is indicated by point **46** and thereafter rises rapidly to a normalized characteristic impedance value in excess of 60 at a frequency of approximately 1.11 as is indicated by point **47**. The curve **40** has a normalized impedance of 7 at a normalized frequency of 1.05 as is indicated by point **48** and falls gradually to a minimum along a curved line to a normalized impedance of approximately 4 at a normalized frequency in the range between 1.2 and 1.3 as is indicated at point **49** and thereafter rises gradually to a normalized impedance in excess of 10 at a normalized frequency of 1.47 as is indicated by point **50**. This curve has a relatively constant normalized impedance, for example, within a difference of 1 over a frequency range from 1.1 to 1.4 and hence would present conditions allowing good input and output matching to the network over this range of frequencies. Reference to curve **28** in Fig. 5 which is for the same value of α indicates that this range of frequencies could be used to amplify with electron velocities on the order of 85 percent of the velocity required for π mode operation.

Similarly, curves **41** and **42** in Fig. 6 are relatively gradual, having normalized characteristic impedance of approximately 4.2 and 3.3, respectively, for a normalized frequency of 1.1 as is indicated by point **51** and point **52**, respectively. These curves gradually fall to minimums at normalized impedances on the order of approximately 3 and 2, respectively, at frequencies within the range from 1.2 to 1.4, then rise gradually to normalized impedances in excess of 8 at normalized frequencies of approximately 1.58 and 1.67, respectively, as is indicated by point 53 and point 54, respectively. Since these curves are relatively flat over a wide range of frequencies, and reference to Fig. 5 shows that for these values of α amplification is practical without risking oscillation at the π mode, design of an electron discharge device and output coupling structure for this range of values of α, namely $\alpha=.67$ to $\alpha=1.5$, is feasible. Curves 43 and 44 are also relatively flat over wide ranges but reference to Fig. 5 indicates that for these values of α the required electron velocity is greater, for most of the frequencies, than that necessary for π mode oscillation, and hence oscillation from this source is possible. Therefore, design of a tube within this range of values is considerably less desirable than design of a tube using α within the range of .67 to 1.5.

There is also illustrated in Fig. 6 curves 55, 56 and 57 indicated at dotted lines representing analysis of the transmission line as a series of cascaded T sections for values of 10, 1, and .1, respectively. The curve 55 has a normalized characteristic impedance of 20 at a normalized frequency of 1.02 as is indicated by point 58 and drops rapidly as frequency is increased to a normalized characteristic impedance of 2 at a normalized frequency of 1.12 as is indicated by point 59. Similarly, curves 56 and 57 vary quite rapidly with frequency, and hence good impedance match over a wide range of frequencies to either input or output loads is not possible. Thus, it may be seen that when the input and output coupling devices see the signal wave transmission network substantially as a series of cascaded π section filters, the impedance to which the external loads must be matched remains constant over a wider range of frequencies than is possible when the coupling device sees T section filters. Since this is accomplished by a coupling structure wherein the coaxial line is connected between adjacent anode members, it may be seen that distinct advantages flow from this structure over the results which can be obtained, for example, by coupling directly to the straps.

Referring now to Fig. 4, there is shown a further modification of this coupling structure wherein the coaxial line is connected to the end anode member and anode member adjacent said end anode member similar to that described in connection with Figs. 1 through 3. However, the end anode member is made narrower in that portion which extends from a region just above the straps back to the support member 11. As a result, the end section of the transmission line more closely resembles a true π section.

This completes the description of the particular embodiments of the invention illustrated herein. However, many modifications thereof will be apparent to persons skilled in the art. For example, the device may be made in arcuate or circular form rather than in the linear form shown. The anode structure is not limited to the particular structure illustrated herein but the principle of design disclosed herein may be applied to various types of anode structure such as helixes, unstrapped anode members, or strapped interdigital anode structures. Furthermore, various structures for forming the electron beam and for directing the electrons along paths adjacent the signal wave transmission network may be used. Accordingly, it is desired that this invention be not limited by the particular details of the embodiments described herein except as defined by the appended claims.

What is claimed is:

1. A traveling wave tube comprising an electron source and a collector electrode defining therebetween a path of electron flow, a wave retardation structure positioned along said path, said retardation structure comprising a plurality of vanes alternately connected by conductive straps, means for coupling signal transmission apparatus to said retardation structure comprising a two conductor line having one of its conductors connected to a terminal vane of said retardation structure and having its other conductor electrically connected to the adjacent vane.

2. A traveling wave tube comprising an electron source and a collector electrode defining therebetween a path of electron flow, a wave retardation structure positioned along said path, said structure comprising a plurality of aligned vanes depending from a common conductor, and signal coupling means for connecting signal transmission apparatus to said wave retardation structure comprising a coaxial line having its outer conductor connected to a terminal vane of said structure, said terminal vane having an aperture therein permitting passage of the inner conductor of said coaxial line, and said inner conductor projecting through said aperture and being connected to the adjacent vane.

3. A traveling wave tube comprising an electron source and a collector electrode defining therebetween a path of electron flow, a wave retardation structure positioned along said path, said structure comprising a plurality of aligned vanes depending from a common conductor and conductive straps connected to alternate vanes whereby to form two sets of strapped vanes, and means for coupling signal transmission apparatus to said retardation structure comprising a coaxial line having its outer conductor connected to a terminal vane having an aperture therein permitting passage of the inner conductor of said coaxial line, and said inner conductor extending through said aperture and being connected to the adjacent vane.

4. A traveling wave amplifier tube comprising an electron source and a collector electrode defining therebetween a path of electron flow, a wave retardation structure positioned along said path, said structure comprising a plurality of aligned vanes and conductive straps connecting alternate vanes, said structure being dimensioned so that

$$\frac{\omega_0 L_s}{Z_c}$$

is greater than .67.

Where

ω_0 is the cutoff frequency in radians of said structure,
L_s is the strap inductance of a section of said structure, and
Z_c is the characteristic impedance of a cavity section of said structure.

5. A traveling wave amplifier tube comprising an electron source and a collector electrode defining therebetween a path of electron flow, a wave retardation structure positioned along said path, said retardation structure comprising a plurality of aligned vanes depending from a common conductor and conductive straps connected to alternate vanes of said structure, said structure being dimensioned so that

$$\frac{\omega_0 L_s}{Z_c}$$

is greater than .67.

Where

ω_0=the cutoff frequency of said structure in radians,
L_s=the inductance of the straps of a section of said structure, and
Z_c=the characteristic impedance of a cavity section of said structure.

6. A traveling wave amplifier tube comprising an electron source and a collector electrode defining therebetween a path of electron flow, a wave retardation structure positioned adjacent said path, said structure comprising a plurality of aligned vanes and conductive straps connecting alternate vanes, said structure being dimensioned so that

$$\frac{\omega_0 L_s}{Z_c}$$

is greater than .67.

Where

ω_0 is the cutoff frequency in radians of said structure,
L_s is the strap inductance of a section of said structure,
Z_c is the characteristic impedance of a cavity section of said structure,

and means for directing electrons from said source along said path of velocities below the velocity required to cause said tube to operate in its π mode.

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UNITED STATES PATENT OFFICE

Certificate of Correction

Patent No. 2,850,671 September 2, 1958

Edward C. Dench

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 26, for "afficiency" read —efficiency—; column 3, line 30, for "envelops" read —envelope—; line 44, for "thhe" read —the—; column 4, line 40, after "cutoff," add —$\theta=0$ and $V=V_x$—; column 6, line 68, for "impedance" read —impedances—; column 9, line 8, for "path of" read —path at—.

Signed and sealed this 25th day of November 1958.

[SEAL]

Attest:
KARL H. AXLINE,
Attesting Officer.

ROBERT C. WATSON,
Commissioner of Patents.