

Jan. 29, 1957

J. A. MORTON

2,779,891

HIGH FREQUENCY AMPLIFIER

Filed Jan. 27, 1951

4 Sheets-Sheet 1

FIG. 1

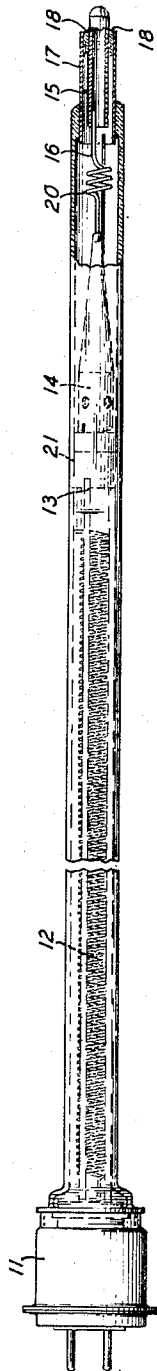
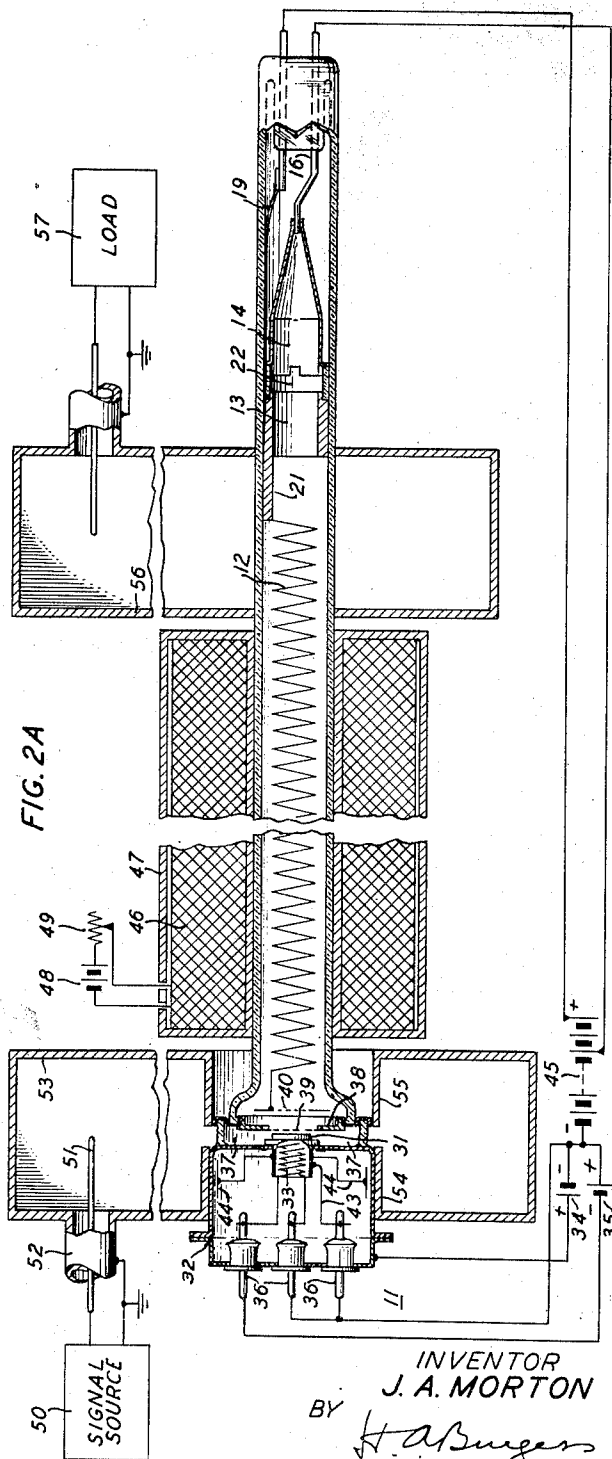


FIG. 2A



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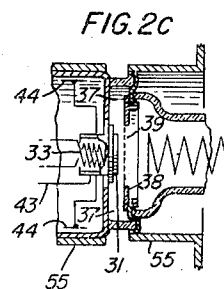
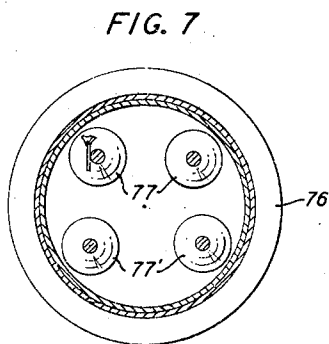
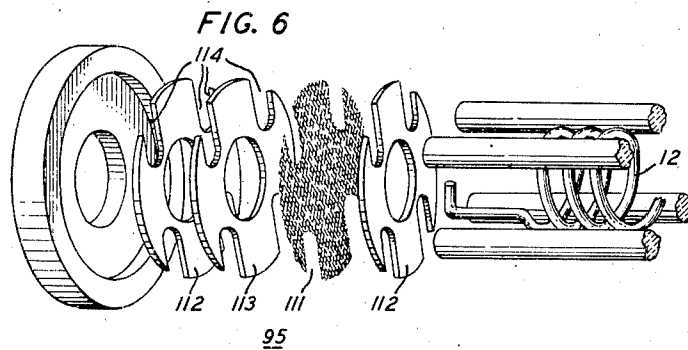
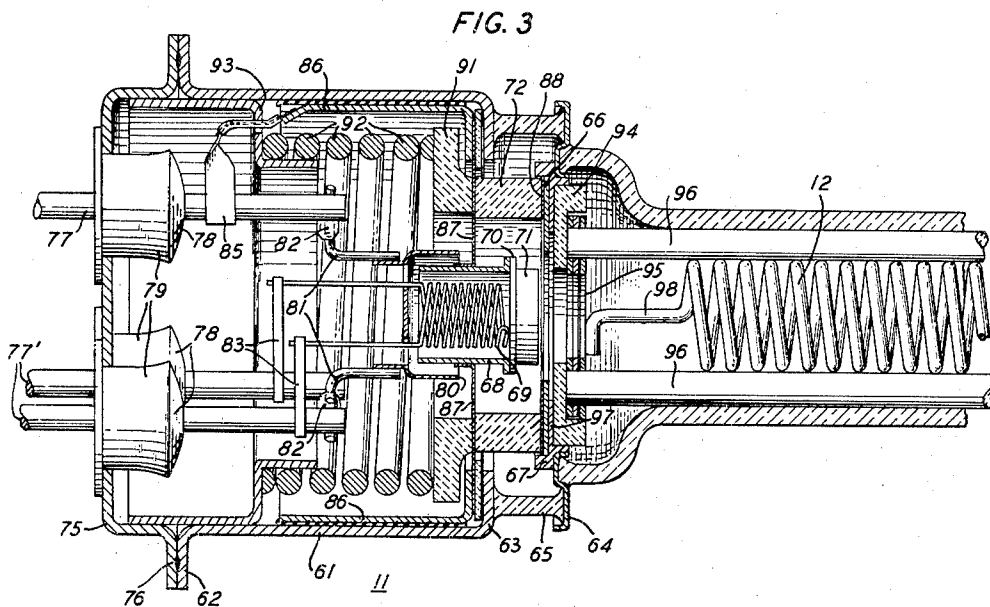
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4 Sheets-Sheet 2



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FIG. 2B

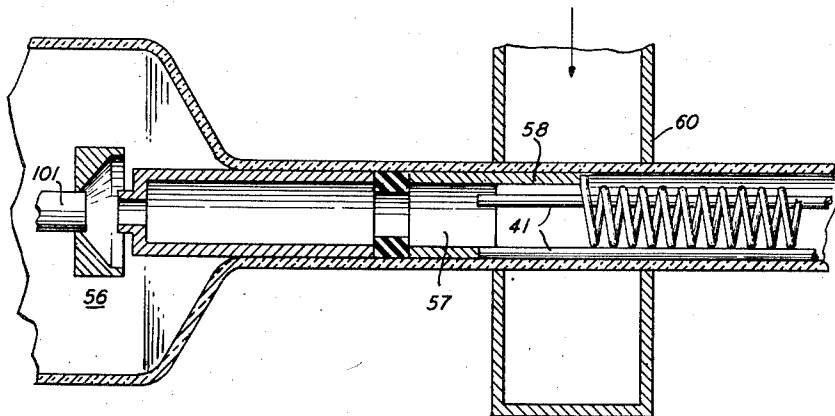


FIG. 4A

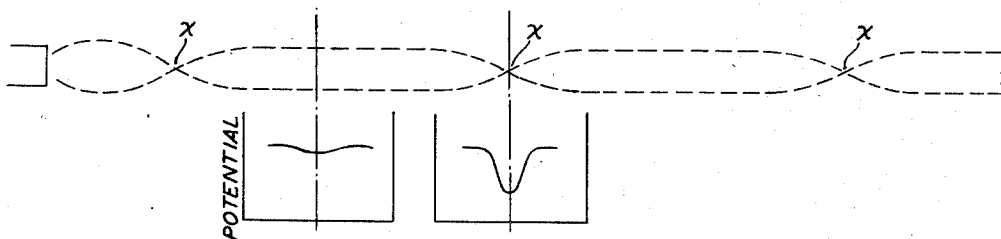


FIG. 4B



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FIG. 5A

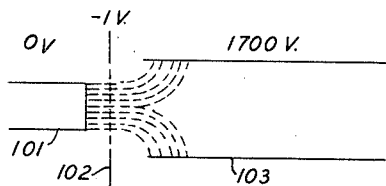


FIG. 5B

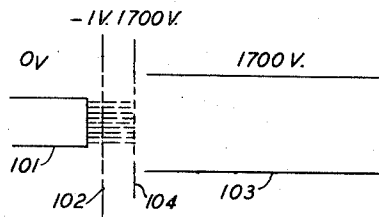


FIG. 8

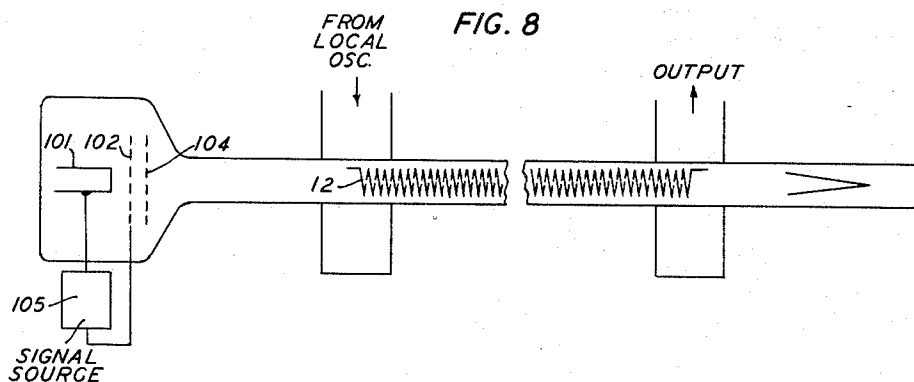
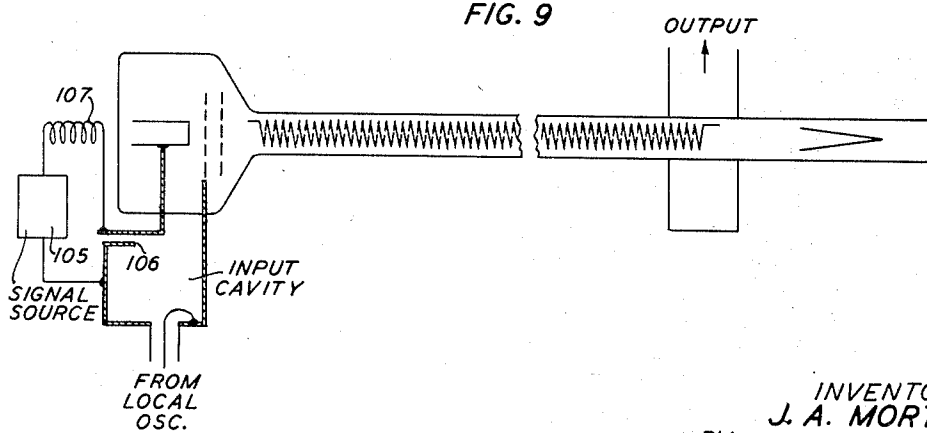


FIG. 9



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2,779,891

HIGH FREQUENCY AMPLIFIER

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Application January 27, 1951, Serial No. 208,203

12 Claims. (Cl. 315—3.5)

This invention relates to high frequency electron discharge devices and particularly to those devices wherein a stream of electrons is projected along a portion of wave transmission path several wavelengths or more long such that the electron stream may interact with the electric field of a high frequency wave transmitted along the path causing the high frequency wave to be amplified.

It is an object of this invention to increase the signal-to-noise ratio of such a device.

It is also an object of the invention to launch an electron stream in a traveling-wave type tube with a very small transit angle between the gun cathode and the helix.

Another object of the invention is to increase the gain of such an amplifier.

It is a further object of this invention to maintain broad band widths in such an amplifier while decreasing the noise generated therein.

Another object of this invention is to prevent formation of noise producing plasma within such a device by eliminating the potential pockets along the electron beam.

Another object of the invention is to combine features of microwave triodes with those of traveling wave tubes so that benefits of both devices may be realized in a single unit.

In devices of the type described above which are now known as traveling wave tubes, it is well known that the phase velocity of the high frequency wave must be approximately equal to the average velocity of the electron stream in order that there will be an appreciable energy transfer. The phase velocity of a high frequency wave in air will be of the order of the speed of light while the velocity of the electrons emitted by an electron gun having a beam voltage on the order of 1500 volts will be about one-thirteenth the speed of light.

In traveling wave tubes of the type described in a copending application Serial No. 704,858, filed October 22, 1946, by J. R. Pierce (United States Patent No. 2,602,148, issued July 1, 1952), synchronous velocities are approximated by causing the high frequency or traveling waves to follow a helical transmission path of the proper pitch while the trajectory of the electron stream is a path adjacent and parallel to the longitudinal axis of the helical path. A series of cylindrical support rods of any suitable insulator material which will not introduce excessive loss or capacitance in the tube are used to position the helix in the glass envelope in order to facilitate projection of the electron stream along the length of the coil without great loss of electrons to the coil conductor.

It has been found that traveling wave tubes tend to have relatively low signal-to-noise ratio due to sources of noise within the tube. In attempting to determine what these sources are it has been discovered that in a tube such as described in the Pierce application the transit angle between the electron emitter and the helix and the random capture of current from the beam is such that the electron beam enters the helix as almost pure shot noise before it receives the signal modulation.

Another source of noise has been discovered to be ion

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oscillations in plasma which form within the tube, particularly in the region of deep potential pockets.

A further source of noise has been traced by applicant to the variable pressure and hence variable contact resistance and capacitance with which the loss coated ceramic rods of a tube as disclosed in the Pierce application are held in contact with the helix. Techniques are disclosed in my copending application Serial No. 208,204, filed January 27, 1951, for the construction of a unitary helix assembly whereby the ceramic rods are held in rigid contact with the helix by glaze applied thereto. Loss material is applied about the circumference of a center portion of the entire assembly. Since the glaze insulates the rods from the helix, the effect of contact resistance is substantially eliminated; capacitance between the wires and support rods is also made uniform. A higher loss per unit length over which loss material is applied is also obtained by using these techniques so that the loss-free interaction region is increased, resulting in a higher gain for the same total length of helix.

In traveling wave tubes it has been necessary to make special provision for preventing self-sustaining oscillations which may result from waves reflected from the output section due to an imperfect impedance match of the helix to the output section. One method as disclosed in my aforementioned copending application applies a coating of high loss conductive material such as aquadag over the center portion of the helix assembly. In addition to attenuating reflected waves this coating of loss material also promotes isolation of the input and output sections of the amplifier and therefore tends to limit disturbances due to reflection therebetween.

Fluctuations in an electron stream as it leaves the electron emissive surface are largely velocity fluctuations but as is known, these fluctuations become density or convection current fluctuations at some finite transit angle from the cathode and at some point they approach pure shot noise. Applicant has utilized this concept to achieve a high signal-to-noise ratio by launching an electron beam down a helix with a small transit angle between gun cathode and helix so that the noise effect of the beam is substantially below the level of pure shot noise. In one embodiment, described below, the signal is impressed on the stream in the region preceding the helix where the noise is greatly reduced by space charge suppression and a small transit angle. This region is just the cathode-grid input of a microwave triode having a high transconductance so that both signal and noise are amplified by the gain in the region preceding the helix before noise due to transit time or random capture effect enter the stream. The helix then simply adds more gain and the original signal-to-noise ratio of the space charge region is preserved if the gain preceding the helix is adequate.

A structure in accordance with the invention whereby an electron stream may be launched with a small transit angle with provisions for impressing a signal to be amplified upon the stream before it enters the helix is obtained by combining a microwave triode input section, i. e., the cathode and grid sections, with a traveling wave tube. The helix replaces the anode of the triode so that the transit angle of the electron stream from the triode cathode as it enters the helix is extremely small, particularly in comparison with conventional traveling wave tubes of the prior art. The transit angle is also small relative to the transit angle required for velocity fluctuations from the cathode to reach the level of pure shot noise convection current fluctuations and in fact locates the helix input in the region of or as close as possible to the potential minimum just in front of the cathode. This region resulting from space charge is well known and is illustrated for example in "Electronics" by J. Millman and S. Seely, McGraw-Hill, 1941, at page 223. The input

signal modulates the beam convection current in the cathode-grid region and the output amplified signal is taken from the far end of the helix as from conventional traveling wave tubes. A collimating grid may be added to the helix input to insure a parallel sided beam so as to reduce noise due to plasma ion oscillation.

The combination of a triode and a traveling wave tube in accordance with the invention is herein called a "hybrid" tube. One feature of a hybrid tube is that the overall gain is greater than that of a conventional traveling wave tube of the same helix and beam dimensions due to the transconductance of the region preceding the helix in which the signal is impressed on the electron beam. Further, the bandwidth of the device is greater than that of a similar microwave triode since in the latter, the bandwidth is limited by the output section and in the hybrid tube, this section is replaced by the broad band helix.

Other features and objects of the invention may be better understood by reference to the following detailed description when read in accordance with the following drawings, in which:

Fig. 1 is a pictorial representation of a hybrid tube of the type described herein in detail;

Fig. 2A is a cross section view of the device including an input and an output circuit and showing particularly the general relation of the electrodes in the device;

Fig. 2B illustrates in diagram only the input section of a prior art traveling-wave tube;

Fig. 2C illustrates a modification of the input section of Fig. 2A to show the relation of the electrodes when the collimating grid is not included;

Fig. 3 is an enlarged cross section view of the input section of the device of Fig. 1, showing the detailed assembly when the collimating grid is included;

Figs. 4A and 4B compare, in a pictorial manner, electron beams with and without crossover;

Figs. 5A and 5B illustrate by diagram the collimating grid feature of the present invention;

Fig. 6 is an exploded perspective view of the collimating grid 95 of Fig. 3 and its immediately adjacent structure;

Fig. 7 is a pictorial view of the base of the device of Figs. 1 and 3; and

Figs. 8 and 9 illustrate, partly in diagram, features of the invention as applied to devices employed as modulators.

Gain

In general waves may be excited on a helix by any one or combinations of three mechanisms. These mechanisms are the following:

(a) By injecting an electron stream whose convection current is signal modulated;

(b) By injecting an electron stream whose velocity is modulated; and

(c) By applying an A. C. signal field to the beginning of the helix and injecting an unmodulated electron stream.

In any of these situations when the electron stream velocity is in synchronism with the helix wave various amounts of four different waves are excited in the system comprised of the helix and electron stream. There is one backward traveling wave and three forward traveling waves. The three forward waves are as follows:

1. A growing wave traveling slightly slower than the beam direct current velocity;

2. A decaying wave traveling slightly slower than the beam velocity; and

3. A constant amplitude wave traveling slightly faster than the beam direct current velocity.

In the ensuing discussion attention will be focused only on the increasing wave, assuming the reflected backward wave is eliminated in actual practice by perfect output termination or by loss. The other two forward waves will be neglected on the basis that if useful gain is to be achieved, the tube will be sufficiently long so that the

growing wave will be many times greater than the other two in the output region of the helix.

When all three methods of wave launching are used, the voltage amplitude squared of the growing wave at length L along the helix is given by:

$$|\bar{V}_1(L)|^2 = \frac{1}{9} \epsilon^{\sqrt{3\beta CL}} |\bar{V}_s + v_s' + q_s'|^2$$

where:

$$\beta = \frac{\omega}{u_0};$$

u_0 = direct current beam velocity;

$$C^2 = \left(\frac{K_1 I_0}{8V_0} \right)^{2/3}$$

where:

K_1 is the helix impedance;

I_0 is the direct current beam current;

V_0 is the direct current beam voltage;

$\bar{V}_s$ is the complex magnitude of the alternating current voltage applied to the beginning of the helix;

v_s' is the complex magnitude of the alternating current velocity modulation of the beam at the beginning of the helix; and

q_s' is the complex magnitude of the alternating current convection current in the electron beam at the beginning of the helix.

In the conventional traveling wave tube, in so far as signal modulations are concerned, $v_s' = q_s' = 0$, and the signal is applied only as a voltage $\bar{V}_s$ to the beginning of the helix.

In such a case, the maximum available gain becomes

$$\Gamma_T = \frac{1}{9} \epsilon^{2\sqrt{3\beta CL}} = \frac{1}{9} \epsilon^{2\sqrt{3} \pi CN}$$

where:

Γ_T is the gain of a conventional traveling wave tube, and N is the length of the lossless helix-electron stream interaction space in wavelengths.

This reduces, in decibel, to

$$\Gamma_T(\text{db}) = 9.54 + 47.3 CN$$

In one manner of operating the hybrid tube, when the transit angles in the spaces between grid and helix are very short, and when the helix is shorted at its input, then, $v_s' = \bar{V}_s = 0$ and the maximum available gain becomes

$$\Gamma_H = \left(\frac{1}{4} g_m R_0^{2/3} K_1^{1/3} \right) \left(\frac{1}{9} \epsilon^{2\pi\sqrt{3} CN} \right)$$

where:

Γ_H is the gain of a hybrid tube;

g_m is the transconductance of the cathode-grid region; and

$$R_0 = \frac{V_0}{I_0}$$

and will be termed the beam impedance; or

$$\Gamma_H(\text{db}) = 10 \log_{10} \left(\frac{g_m R_0^{2/3} K_1^{1/3}}{4} \right) - 9.54 + 47.3 CN$$

Hence:

$$\frac{\Gamma_H}{\Gamma_T} = \frac{1}{4} g_m R_0^{2/3} K_1^{1/3}$$

or

$$\Gamma_H(\text{db}) - \Gamma_T(\text{db}) = 10 \log_{10} \left(\frac{g_m R_0^{2/3} K_1^{1/3}}{4} \right)$$

The maximum available gain of the hybrid tube is thus greater than the maximum available gain of the conventional traveling wave tube by an amount which is a function of the transconductance, the beam impedance and

the helix impedance. In a typical experimental traveling wave tube, the helix had the following parameters:

$K_1=100$ ohms
 $V_0=1600$ volts
 $I_0=12 \times 10^{-3}$ amperes
 so that

$$R_0 = \frac{1600000}{12} = 133,000 \text{ ohms}$$

Thus:

$$\begin{aligned} \frac{\Gamma_H}{\Gamma_T} &= \frac{R_0^{2/3} K_1^{1/3}}{4} g_m \\ &= \frac{(133,000)^{2/3} (100)^{1/3}}{4} g_m \\ &= \frac{2.56 \times 10^3 \times 4.64}{4} g_m \\ &= 2.98 \times 10^3 g_m \\ &\approx 3000 g_m \end{aligned}$$

For a typical close spaced triode of the type used for an input section of the hybrid tube,

$$g_m = 50,000 \times 10^{-6} = 5 \times 10^{-2} \text{ (for } I_0 = 30 \text{ ma.)}$$

Therefore,

$$\frac{\Gamma_H}{\Gamma_T} = 3000 \times 5 \times 10^{-2} = 150 \text{ (about 21.7 db)}$$

In an actual test of these principles a helix which normally operates at 12 to 15 milliamperes in a conventional traveling wave tube was connected to a close spaced triode input section. In this particular case it was possible to operate with a beam current of only 5 to 7 milliamperes with correspondingly lower transconductances (of the order of 15000×10^{-6}). However, the hybrid tube had a gain of 30 decibels whereas, normally, the same helix operated in the traveling wave tube mode with voltage launching would have 17-20 decibels gain.

Bandwidth

Whenever one transmission system with a given field configuration is matched into another of different field configuration, local distortions of the field in the region of transition must be set up. These distortions can be resolved into other higher order field modes than the principal modes of either of the two transmission systems and as such they are primarily local in nature and do not propagate well into either transmission system. They do, however, represent stored energy and as such can be represented as lumped capacitances shunted across the principal modes of the two adjoining systems.

Let us represent the effect of such wave transforming discontinuities as effective capacitances lumped across the various significant electron stream interaction spaces.

Because the helix-to-wave-guide transformation may be made as gradual as we please and since the helix impedance is itself low, we may usually make the bandwidth of a helix-to-wave-guide transformation much broader than can be achieved in the input gap of a hybrid tube where we have the sudden discontinuity of the cathode-grid gap capacitance and conductance.

If we define the band of an amplifier $B_A(X)$ as that interval within which the voltage gain is within a factor of

$$\frac{1}{X}$$

times the maximum gain, then:

$$\left| \frac{\Gamma_\omega}{\Gamma_{\omega_0}} \right| \geq \frac{1}{X}$$

defines $B_A(X)$; where:

Γ_{ω_0} is the gain at the band center; and
 Γ_ω is the gain at a frequency removed from the band center.

Analogously, if we define the band of a simple anti-resonant circuit as $B_c(n)$, then:

$$\frac{Y_c(\omega_0)}{Y_c(\omega)} \geq \frac{1}{n} \text{ defines } B_c(n)$$

where:

5 $Y_c(\omega_0)$ is the admittance at the band center of the circuit alone; and

$Y_c(\omega)$ is the admittance at a frequency removed from the band center.

10 It follows, therefore, that

$$B_c(n) = \frac{G_c}{2\pi C_c} \sqrt{n^2 - 1}$$

where:

15 G_c is the circuit conductance; and
 C_c is the effective circuit capacitance.

Since amplifier gain is inversely proportional to the product of the input and output circuit admittances, $n_1 n_2 = X$. Two important cases are to be here considered.

20 (a) The band is equally shaped by the input and output as in the conventional traveling wave tube in which case input and output Q's are equal and

$$\frac{G_{1T}}{C_{1T}} = \frac{G_{2T}}{C_{2T}} = \frac{G_T}{C_T}$$

25

where:

$G_T = \frac{1}{K_1}$ and is the helix conductance; and,

30 C_T is the discontinuity capacitance associated with the field transformation from helix to wave guide.

Therefore:

$$n^2 = X$$

35

and

$$B_T(A) = \frac{1}{2\pi} \frac{G_T}{C_T} \sqrt{X + 1}$$

40

where $B_T(A)$ is the bandwidth of the traveling wave tube.

For $X=2$ at the 6 db down points:

$$B_T(A) = \frac{1}{2\pi} \frac{G_T}{C_T}$$

45

(b) The band is shaped only by the input; this is the case of the hybrid tube. Then, $Q_2 \gg Q_1$ and $X = n_2^2$ so that

$$B_H(A) = \frac{1}{2\pi} \frac{G_{1H}}{C_{1H}} \sqrt{X^2 - 1}$$

50

where:

G_{1H} is the input conductance of the hybrid tube at the electron stream; and

$C_{1H} = C_{11} + C_{p1}$ and is the total input capacitance at the

55

same point

where:

C_{11} is the gap capacitance; and,

C_{p1} is the effective capacitance of the matching resonator; and

60

$B_H(A)$ is the bandwidth of the hybrid tube.

At the 6 decibel down points, $X=2$ so that

$$B_H(A) = \frac{1}{2\pi} \frac{G_{1H}}{C_{1H}} \sqrt{3}$$

65

In a specific hybrid tube of the type described below, using a close spaced triode input section, it was not possible at 4000 megacycles to tune on the first mode since it exists inside the tube. The total effective input capacitance was thus very large and in an actual case the input bandwidth was measured to be about 500 megacycles corresponding to an input capacitance of about 58 micro-microfarads for the case in which

$$G_{1H} = 2g_m = 2 \times 50,000 \times 10^{-6} \text{ mhos}$$

75 By designing the input section of the hybrid tube so as to

permit resonating at the first node inside the envelope, the bandwidth may be raised to the order of 1000 megacycles which is also a typical value for conventional traveling wave tube.

In general, however, the straight traveling wave tube can achieve something of the order of twice the bandwidth of the best hybrid tube with about the same amount of design effort. This sacrifice in bandwidth will in many applications be warranted in view of the increased gain and decreased noise and in further view of the fact that even the narrower bandwidth of 500 megacycles represents a very broad band.

Noise figure

In the conventional traveling wave tube, assuming noise to be introduced only by fluctuating convection currents on the entering electron stream, the noise figure is given as

$$F = 1 + 2\gamma^2 \left(\frac{eV_0}{kT} \right) C = 1 + 80\gamma^2 V_0 C$$

where γ^2 is the space charge noise reduction factor.

For the case in which the transit angle is very large or where there is temperature limitation, $\gamma^2=1$ and we have pure shot noise. Then:

$$F_T = 1 + 80 V_0 C$$

Substituting typical values, viz. $V_0=1600$ volts and $C=.025$, gives $F=3201$ or about 35 decibel.

Actually, it is reasonable to suppose that γ^2 may be as small as 0.1 in which case the noise figure calculates out to be about 25 decibels and some traveling wave tubes have been measured that are almost this good.

In the hybrid tube, under the assumptions of:

- very short transit angles in the cathode-grid and grid-helix regions;
- no partition noise before the stream reaches the helix; and
- high transconductance so that we may neglect the effect of any velocity modulation in the input space,

we may write the theoretical minimum noise figure F_H for the hybrid tube as

$$F_H = 1 + 6(4-\pi) \frac{T_c}{T}$$

where:

T_c =cathode temperature in degrees Kelvin, and,
 T =temperature of input termination.

Typical values are $T_c=1020$, $T=290$,

giving $F_H=20$ or about 13 decibels or about one-half the number of decibels to be expected from a good traveling wave tube.

Actually, this is essentially the same noise figure to be expected from a close spaced triode under the same assumptions. Actual close spaced triodes have been measured with noise figures between 14 and 18 decibels. Any input passive loading would degrade the noise figure of both triode and hybrid alike so that 13 decibels actually represents a minimum figure.

For a detailed consideration of the equations relating to traveling wave tubes, reference may be had to a book entitled "Traveling Wave Tubes" by J. R. Pierce, Van Nostrand, 1950. For a consideration of the equations relating to close spaced triodes, reference may be had to an article entitled "Design factors of the Bell Telephone Laboratories 1553 triode" by R. M. Ryder and applicant, appearing in the Bell System Technical Journal for October 1950 at page 496.

Illustrative embodiments

The major components of a hybrid tube embodying principles of the invention may be seen by referring to Fig. 1. The tube there shown has an input section 11 comprising the cathode and grid sections of a micro-

wave triode, a wave interaction path comprising the helix 12 through which an electron stream is directed and along which a signal wave to be amplified is propagated, an output coupler 13, and a collector 14 for the electron stream. The input section 11 is enclosed in a metallic housing and the helix 12 is surrounded by a glass envelope and the entire structure is evacuated. Direct current coupling with which to apply bias voltages to the collector 14 and helix 12 is provided by an inner metallic sleeve member 15 connected to the collector 14 by means of a lead 16, and an outer metallic sleeve member 17 insulated from the inner member 16 by the glaze material 18 and connected to the helix 12 by an insulated conductor 19 which may be seen by reference to Fig. 2A and the coupler 13. A few loops 20 are provided in the lead 16 to serve both as a radio frequency choke and as a spring to assist in holding the collector 14 in position.

Means by which an input signal may be applied to and an output signal taken from a tube of the type shown in Fig. 1 may be seen by reference to Fig. 2A. An electron emissive cathode 31 is housed in cylinder 32 and a heating coil 33 is located within the hollow portion of the cathode cylinder. Biasing potentials from batteries 34 and 35 are applied to the cathode 31 and heater 33 by the socket pins 36 which extend through the base of the cathode housing cylinder 32. An input cavity 37 is formed by the top of the cathode housing cylinder 32 and a plate 38 having a central aperture which houses the control grid 39. The circular side walls of the cavity 37 are composed of a vitreous material such as glass which is substantially transparent to microwaves. The cathode 31 and control grid 39, together with a collimating grid 40 whose unique utility will be described below, form an electron gun assembly. The helix 12 and collector 14 are biased highly positive, for example, on the order of 1500 volts, with respect to the cathode by battery 45, so that an electron stream flows from the cathode 31 to the collector centrally along the longitudinal axis of the helix. Focusing of the beam is aided by a magnetic coil 46 housed in a cylindrical non-magnetic shield 47 which is concentric with the elongated portion of the tube which houses the helix 12. Direct current is supplied to the focusing coil 46 by battery 48 and is adjustable by means of a potentiometer 49.

Microwave signals to be amplified from a source 50 are launched by means of the antenna-like extension 51 of the central conductor of the coaxial cable 52 in the rectangular wave guide 53. The tube 11 extends through the guide 53 at a point substantially a quarter of a wavelength from the lower closed end with the tube axis normal to the broad faces of the rectangular guide. A pair of annular flanges 54 and 55 extend inward from either face of the guide flush with the outer surface of the cathode housing cylinder 32 and with the circular edge of the apertured plate 38 which mounts the control grid. At their farthestmost extent into the guide 53, the ends of flanges 54 and 55 are flush with the top of cylinder 32 and the left face of plate 38, respectively. The electromagnetic waves in the guide 53 induce standing waves in the input cavity 37 which modulate the electron stream convection current passing therethrough. As the stream enters the region within the helix, the variations in the stream cause a radio frequency wave corresponding to the input signal from the source 50 to be launched and impressed upon the helix. The signal wave travels along the helix with a longitudinal phase velocity component substantially equal to the average electron velocity, the pitch of the helix being proper, and interaction between the stream and the longitudinal electric field components of the wave causes the wave to grow in amplitude until it reaches the far end of the helix 12. At this point, the antenna-like extension 21 of coupler 13 couples the amplified wave into an output rectangular wave guide 56 and thence to a load 57.

By way of comparing the transit angles and methods of signal input with conventional traveling wave tubes there are shown in Fig. 2B the major components of a traveling wave tube of the type disclosed in the book and

applications of J. R. Pierce mentioned above. These comprise the electron gun assembly 56, the input coupler 57 having an antenna-like extension 58 to which is welded the end of the helix 59 an input wave guide 60, and helix support rods 41. With such a tube the transit angle is of necessity sufficiently large so that the beam enters the helix as substantially pure shot noise.

Referring now to Fig. 3, the input section 11 of the device of Fig. 1 utilizes techniques disclosed in Patent 2,502,530, dated April 4, 1950, of which I am a joint inventor together with R. L. Vance to effect a small transit angle between the electron source and the helical transmission line. Therein is disclosed a space discharge device comprising a cathode, one or more grids, and an anode, capable of operating at ultra-high frequencies. For example, such a device employing one grid, and known as a close spaced triode, has been found at an operating frequency on the order of 4000 megacycles to have a bandwidth of from 100 to 200 megacycles and a gain of approximately 9 decibels. In this patent it is pointed out that extremely small electrode spacings, for example of the order of $\frac{1}{2}$ to 1 mil between cathode and grid and of the order of 5 to 10 mils between grid and anode, are achieved whereby electron transit times are minimized and high transconductance and good signal-to-noise ratio and band width are obtained. A close spaced triode is also described in the Bell System Technical Journal article mentioned above and one of such devices is known commercially as the Western Electric 416A.

The device disclosed in the latter articles is characterized by input and output sections of relatively low and high "Q's" respectively so that the bandwidth is limited chiefly in the output section. The present invention replaces the anode and output section of a close spaced triode with a helical transmission line of a traveling wave tube. Helices have relatively unlimited bandwidths at ultra-high frequencies so that the bandwidth of the combination or hybrid tube is that of the input section which in specific embodiments tested was found to be on the order of 500 megacycles.

The cathode-grid section illustrated in Fig. 3 is similar to a great extent to the close spaced triode disclosed in Patents 2,455,381, dated December 7, 1948, to J. A. Morton and L. J. Speck, 2,502,531, dated April 4, 1950, to J. A. Morton and R. M. Ryder, and also 2,527,127, dated October 24, 1950, to R. S. Gormley, C. Maggs and L. F. Moose. The detailed description in these patents, as well as the techniques and methods disclosed by them are hereby incorporated in the present disclosure and will be described but briefly herein by way of illustration.

The container of the input section comprises a cylindrical metallic shell 61 provided with an outer flange 62 at one end and an inner flange 63 at the other. A control grid terminal ring 64 is mounted on the flange 63 by a vitreous spacer 65 hermetically sealed between the parallel facing surfaces of the ring 64 and the flange 63 of the shell. A conductive path to the planar control grid 66 is by way of the circular grid connector 67.

The cathode assembly is precision fabricated to insure positive parallelism with the wires of the grid and maintain close spacing thereto on the order of $\frac{1}{2}$ mil. The cathode assembly comprises a metallic sleeve member 68 both to enclose the cathode heater element 69 and to support the rigid metallic discs 70 and 71. The disc 71 provides a stable flat surface for the electron emissive coating applied thereto.

About the sleeve member 68 and coaxial therewith is an annular spacer ring 72 of ceramic material. The spacer ring is maintained in substantially coplanar relation with the emissive surface of the cathode 71 by support members, not shown, which are attached about the periphery of the sleeve member 68 and extend to slots provided in the spacer ring 72.

The stem closure is a dished metallic member 75 with

a plurality of apertures in the base portion and a peripheral flange 76 to correspond to the flange 62 of the shell 61. The flanges 62 and 76 are ring sealed to form a strong tight joint between the shell and stem. Terminal pins 77 and 77' extend through the apertures in the base member and are supported therein by glass beads 78 which are hermetically sealed to the pins and to the metallic eyelets 79. Two of the pins 77' support a heater shield 80 coaxially mounted about the shield member 68 by means of the support members 81 joined to and insulated from the pins 77' by the glass beads 82. These two pins 77' also provide a conductive path for the heater element 69 to its supply 35, indicated schematically in Fig. 2, by means of the conductor strips 83.

A low frequency coupling connection is provided from the other pin 77 to the cathode by means of a conducting strip 85, a cylindrical condenser can 86, and a cathode connector ring 87 which is in contact with the sleeve member 68. A high frequency coupling for the active cathode surface is provided by the condenser can 86 and shell 61 to an external circuit. In Fig. 2 the low frequency connection to the cathode is indicated by the lead 43 and the high frequency connection by the members 44.

To insure accurate parallel relation between the wires of the control grid 66 and the active surface of the cathode by a definite spacing on the order of $\frac{1}{2}$ mil, a spacer shim comprising a ring-like wafer 88 is inserted between the ceramic spacer ring 72 and the frame of the control grid 66. (As previously explained, the ceramic ring 72 is in a substantially coplanar relation with the emissive surface of the cathode element 71.)

Holding the cathode connector ring 87 in proper position and coaxial with the spacer ring 72 is a second ceramic ring 91. A helical spring 92 is seated in the metallic spring support 93 which is welded to the shell 61 and the stem closure 75. The spring presses against the ring 91, forcing all components towards the grid connector ring 67 and the dished ceramic ring 94 which mounts the collimating grid 95 and the helix support rods 96. All elements are thus held in accurate relation by the spring 92 during the operating life of the device.

The collimating grid 95, which will be described hereinafter in detail with particular reference to Fig. 6 is spaced from and maintained in parallel relation with the control grid 66 by means of the inner flange 97 of the control grid connector 67 and the ceramic piece 94. The helix 12 is welded directly to the frame of the collimating grid 95 and is matched thereto by a distortion 98 of the helix. Referring to Figs. 1 and 2, the helical transmission line 12 is matched to the output wave guide by means of the conductive coupler ring 13 which has an antenna portion 21 welded to the helix. The conical collector 14 for the electrons of the electron beam is insulated from the coupler 13 by a ceramic ring 22.

It has previously been mentioned that ion oscillations in plasma within the tube are a source of noise. Oscillations of this type are described in detail in an article entitled "Oscillations in ionized gases" by Tonks and Langmuir in the Physical Review, volume 33, second series, 1929. Briefly, molecules of gas which remain in the tube after evacuation or which enter later due to an imperfect seal or which are subsequently liberated from the parts by electron bombardment and heating drift into the region of the electron beam where they are ionized. These ions are trapped in the depressed potential along the beam due to the electron space charge. A beam subject to cross-over will have maximum current density at a cross-over point. As shown by the cross-sectional potential diagrams of Fig. 4A, the deepest potential pocket will therefore exist at the cross-over points due to the more intense space charge in these regions. Hence the density of positive ions in the region of the electron beam will be greatest at the cross-over points.

If there are enough molecules in the tube, the beam

will eventually become a plasma in which densities of ions and electrons are equal and the total space charge will be zero. As described in greater detail by Tonks and Langmuir, such a medium is capable of supporting oscillations of the ions due to random displacement. These oscillations have been found to appear as sidebands of the signal wave and as little as 10 decibel down from the signal. Such sidebands will not only distort the signal but will also interfere with close space frequency multiplexing.

There are several ways to prevent such oscillations. One way, largely theoretical, is to obtain a perfect vacuum, or at least one so hard that the few molecules of gas remaining in the tube will not be able to ionize and form a plasma capable of supporting ion oscillations. Another is to reduce the voltages and the length of the electron beam so that the ionization rate will be decreased. A further method, as disclosed in my copending application Serial No. 136,206, filed December 31, 1949 (United States Patent 2,692,351, issued October 19, 1954), is to sweep the positive ions away from the region of the electron stream so that plasma will not form.

Another method and a method with which the present invention is concerned is to prevent the formation of deep potential pockets along the electron beam by using a parallel-sided beam. In the absence of density modulation such a beam if perfectly collimated as shown in Fig. 4B will have a substantially uniform electron density along its length. The beam therefore will not give rise to the potential pockets.

It is, of course, possible to launch a collimated beam by the use of a carefully designed electron gun. The present invention, however, is concerned with the use of an auxiliary grid to collimate the beam.

With only a cathode 101, control grid 102, and helix 103 as represented diagrammatically in Fig. 5A and which, for example, are at 0, -1 and +1700 volts potential respectively, the electric field will have a configuration as illustrated by the dashed field lines. Due to the steep potential gradient between the planar control grid and the cylindrical helix, the field is distorted about the helix input, and a beam launched through such a field configuration will be subject to cross-over.

If another planar grid 104 is inserted between the helix and the control grid and maintained at approximately the same potential as the helix, the field will not be distorted but will appear as shown in Fig. 5B. The steep potential gradient is now between the coplanar grids where the electric field line will be substantially straight, and, since the helix 103 and the collimating grid 104 are at the same potential there will be no distorting field at the helix input so that the electrons emitted from the cathode will tend to be propagated in a parallel-sided beam.

With reference now to Figs. 3 and 6, a grid 95 to collimate the electron stream is interposed between the control grid 66 and the helix 12. The grid 95 comprises a tungsten mesh 111 held between two discs 112 of conducting material. The conducting discs are welded together, the welding being aided by a third disc 113 of suitable material, and the helix 12 is welded to the completed grid assembly as is more fully disclosed in the first of my aforementioned applications. The grid 95 and helix 12 are thus maintained at the same potential so as to produce the field configuration of Fig. 5B and consequently a parallel-sided beam.

The completed grid assembly 95 fits about the support rods 96 by means of the slots 114 provided in the grid frame and is seated in the ceramic cup 94 which insulates the collimating grid from the control grid connector 67.

It may be seen that the hybrid tube structure is especially adapted to the use of a collimating grid and that its compact assembly is not disturbed by the addition of such a grid, if desired. As has been indicated, the collimating grid is not essential to the operation of the tube as an amplifier. Therefore, if the additional noise reduction

to be had with use of the collimating grid is not necessary or desired, that grid may be omitted from the structure and the input section of Fig. 2A would then be as illustrated in Fig. 2C. It may be noted that the collimating grid 40 of Fig. 2A does not appear in Fig. 2C so that the turns of the helix 12 in Fig. 2C are immediately adjacent to the control grid 39 rather than to an interposed collimating grid as shown in Fig. 2A. Also, without a collimating grid the assembly 95 of Figs. 3 and 6 will not be required.

Fig. 8 illustrates a suggested modification of a hybrid tube when used as a modulator. The modulating signal is applied to the control grid 102 from a source 105 as previously described, but the helix 12 is moved away from the electron source so that the beating oscillator signal may be launched down the helix as in the traveling wave tubes of the prior art (see Fig. 2B). Such an arrangement, of course, entails a sacrifice of signal-to-noise ratio due to the increased transit angle between the cathode 101 and helix 12.

The modulator suggested in Fig. 9 makes no sacrifice in signal-to-noise ratio, but, due to the added capacitance 106 in the input circuit, the bandwidth is decreased. The capacitance 106 isolates the local oscillator from the signal source 105 and is resonated at the signal frequency by the inductance 107.

These and many other modifications will readily occur to one skilled in the art and the fact that the invention has been described as relating to a specific embodiment should not limit the appended claims.

Wherever in the description or claims the expression "immediately adjacent" is used it is to be understood to mean that two objects so described have nothing comparable to either between (or separating) them. For instance, when two electrodes are immediately adjacent, the space between them is electrode free.

What is claimed is:

1. A high frequency space discharge device comprising a cathode having a plane face, a planar grid member, means for spacing the plane face of said cathode and said planar grid in aligned parallel manner, means defining an input cavity which includes the gap between said cathode face and said grid member, a wave transmission path comprising an elongated helix having one end immediately adjacent said grid member and coaxially aligned with said cathode and grid member and capable of producing an alternating electromagnetic field in an interaction space substantially contiguous with said grid member for interacting with an electron stream from said cathode, and an electron collector at the end of the helix remote from said cathode.

2. A high frequency electron discharge device comprising a wave transmission path, said path comprising an elongated helix, means to propagate a stream of electrons along a path adjacent and parallel to the longitudinal axis of said helix comprising an electron emissive cathode at one end of said helix and an electron collector at the other end of said helix, a first planar grid member interposed between and coaxially aligned with said cathode and said helix, a second planar grid member interposed between and aligned with said first grid member and said helix to collimate the electron stream entering the helix, said stream characterized by a region of potential minimum resulting from the effect of space charge in the vicinity of said cathode, and supporting means holding the end of said helix nearer said cathode immediately adjacent to said second grid member and as close as possible to said potential minimum.

3. An electron discharge device comprising a source of electrons having a plane face, a first planar grid member, a second planar grid member, farther removed from said source than said first grid member, means spacing said face of the source and said planar grid members in aligned parallel manner, means defining an elongated wave transmission interaction path having one

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end located immediately adjacent to said second grid member whereby the electrons from said source are collimated immediately before reaching the wave interaction path and the electron transit angle from said source to said path end is substantially less than the minimum transit angle necessary for random fluctuations in an electron stream proceeding from said source to said wave interaction path to reach pure shot noise, and a collector of electrons located at the end of said wave interaction path remote from said source.

4. A high frequency space discharge device having an input section comprising a cathode member having a planar emissive face, a first planar grid member adjacent the face of said cathode, a second planar grid member adjacent said first grid member, means to insulate said second grid member from said first grid member, means spacing said cathode face and said grid members in aligned parallel relation, and means defining an input cavity which includes the gap between said cathode face and said first grid, an electrical wave transmission path comprising an elongated helix having one end immediately adjacent to and connected to said second grid member, means coaxially aligning said cathode, said grid members and said helix and an electron collector at the end of said helix remote from said cathode.

5. The combination in accordance with claim 4 and a plurality of support rods longitudinally disposed about the outer surface of said helix and seated at one end in said second grid member.

6. An electron discharge device comprising a source of electrons having a plane face, a first planar grid member adjacent said face, a second planar grid member adjacent said first grid member, means to insulate said second grid member from said first grid member, an elongated wave transmission path connected at one end to said second grid member, a collector of electrons located at the other end of said path, means spacing said face and said grids in aligned parallel relation, said transmission path end being located immediately adjacent to said second grid member whereby the electron transit angle between said source and said transmission path end is substantially less than the transit angle required for convection current fluctuations in the electron stream emanating from said source to reach the level of pure shot noise, and means to modulate said stream before it reaches said wave transmission path.

7. The combination in accordance with claim 6 wherein said last-named means comprise means defining a cavity resonator which includes at least a portion of the gap between said source and said first grid member, and means responsive to a signal to be amplified to induce standing waves in said cavity.

8. A high frequency space discharge device comprising a helical transmission line, means to cause a stream of electrons to be propagated along a path parallel and adjacent to the longitudinal axis of said helical line, said means comprising a cathode, a control grid, and a collimating grid, said collimating grid positioned immediately adjacent to one end of said helical line and transverse to said axis, said helical line connected directly to said collimating grid, and means comprising an input cavity resonator which includes the gap between said cathode and said control grid to modulate said stream.

9. A space discharge device for amplifying high frequency signal waves comprising a transmission line at least several wavelengths long, said line comprising a helix of uniform pitch along the greater portion of its length, means to cause a stream of electrons to be propagated along a path adjacent and parallel to the longitudinal axis of said helix, said means comprising a source of electrons, a control grid adjacent thereto, and a collimating grid interposed between said control grid and one

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end of said helix immediately adjacent to said end of helix, said control grid and said collimating grid in aligned parallel relation and coaxial with said helix, and means to modulate said stream as it traverses the space between said source and said control grid.

10. An electron discharge device comprising a first support member having a plane seating surface, a cathode mounted by said support member and having a face coplanar with said surface, a second support member having a plane seating surface, a first planar grid member, a second planar grid member seated in said second support member, means spacing said cathode face, said first grid member and said second grid member from each other in aligned parallel relation comprising spacer means between said grid member and the seating surfaces of said first and said second support members, means separate from said first and second support members locking said support members against said spacer means, a transmission line at least several wavelengths long immediately adjacent to and connected directly to said second planar grid, said line comprising a helix which has a substantially uniform pitch along a greater portion of its length, support means to mount said helix coaxially with said cathode and said grids, said support means comprising a plurality of rods of insulating material spaced symmetrically about said helix in a longitudinal manner and held in firm contact therewith, and electron collector means adjacent to the end of said helix remote from said second grid.

11. An electron discharge device comprising a helical transmission line at least several wavelengths long rigidly supported by a plurality of support rods spaced about said helix in a longitudinal manner, means to cause a stream of electrons to be propagated along a path adjacent and parallel to the longitudinal axis of said helix, said means comprising a cathode, a first plane grid, and a second plane grid each axially displaced from said helix, with said second grid immediately adjacent to said helix, said cathode having a plane face, said face and said first and second grids in aligned parallel relation and means to space said cathode and said grids from each other in accurate relative positions, and electron collector means at the other end of said helix from said cathode and said grids.

12. A high frequency space discharge device comprising a cathode having a plane face, a planar grid member, means for spacing the plane face of said cathode and said planar grid in aligned parallel manner, means defining an input cavity which includes the gap between said cathode face and said grid member, said cavity being the sole means for impressing signal wave energy from an external signal source on an electron beam from said cathode, an elongated helix coaxially aligned with said cathode and grid member and having one end adjacent the grid member for defining a beam interaction space which is substantially contiguous with said grid member, and an electron collector at the end of the helix remote from said cathode.

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