United States Patent [19]

Scott

[11] **3,755,706**

[45] **Aug. 28, 1973**

[54] **MINIATURIZED TRAVELING WAVE TUBE**

[75] Inventor: **Allan W. Scott**, Los Alto, Calif.

[73] Assignee: **Varian Associates**, Palo Alto, Calif.

[22] Filed: **Mar. 20, 1972**

[21] Appl. No.: **236,299**

[52] **U.S. Cl.** **315/3.5,** 315/5.35, 335/210, 335/296

[51] **Int. Cl.** **H01j 25/34**

[58] **Field of Search** 315/3.5, 5.35; 335/210, 296

[56] **References Cited**

UNITED STATES PATENTS

3,509,504	4/1970	Joannais	315/3.5 X
2,843,775	7/1958	Yasuda	315/3.5 X
3,398,315	8/1968	Washburn	315/5.35 X
3,215,906	11/1965	Taber	315/3.5

Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Saxfield Chatmon, Jr.
Attorney—Stanley Z. Cole et al.

[57] **ABSTRACT**

A microwave beam tube operating above 4GHz is miniaturized by designing the electron gun to produce an electron beam having a microperveance within the range of 0.8 to 2.2. A periodic permanent magnet beam focusing structure is provided which employs ring-shaped permanent magnets having a coercive force in excess of 2,000 gauss, whereby the length, size, and weight of the tube, for a given gain and output power, are reduced substantially.

7 Claims, 6 Drawing Figures

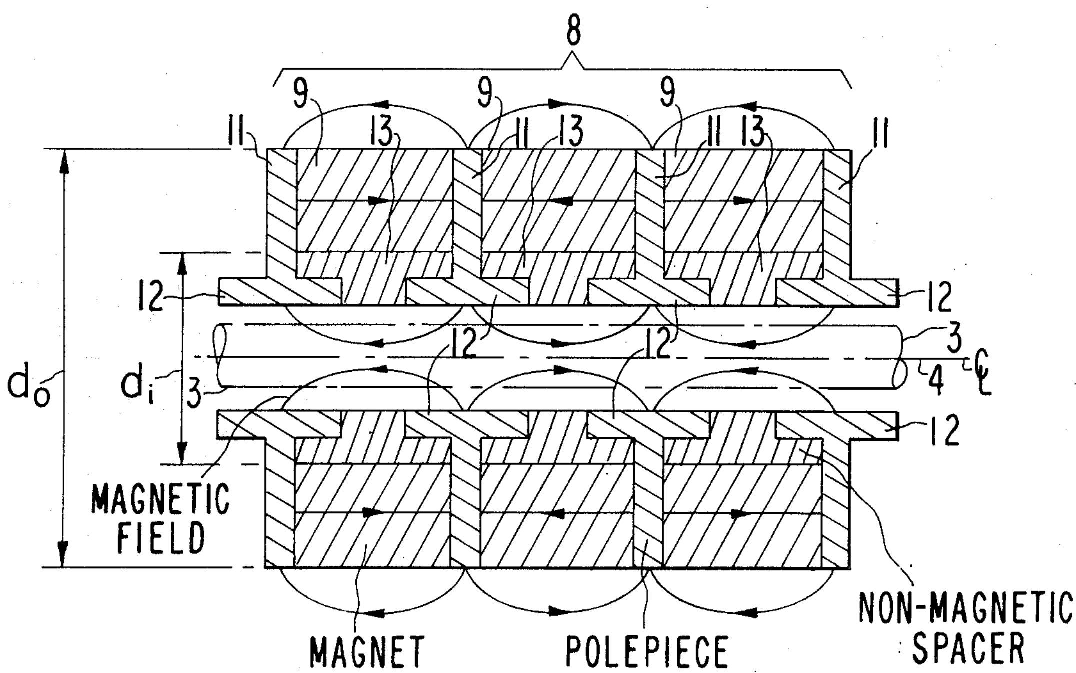


FIG. 1

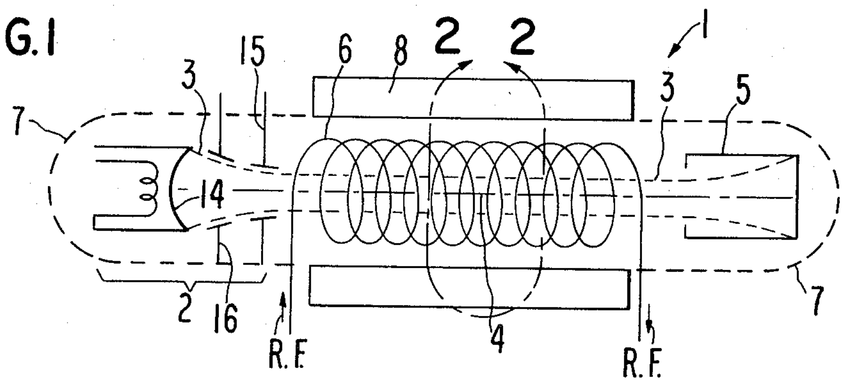


FIG. 2

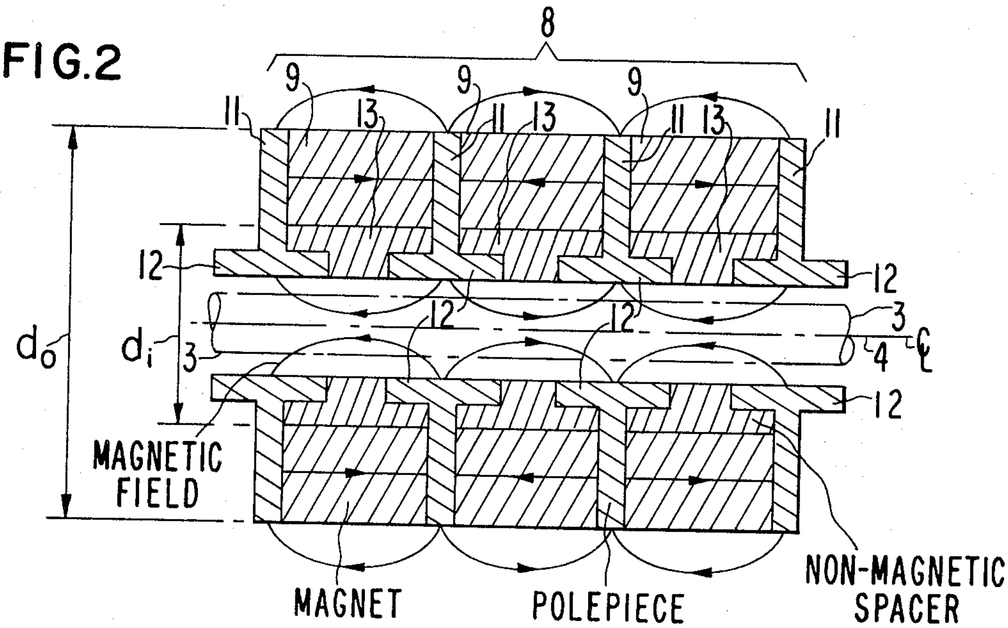


FIG. 3

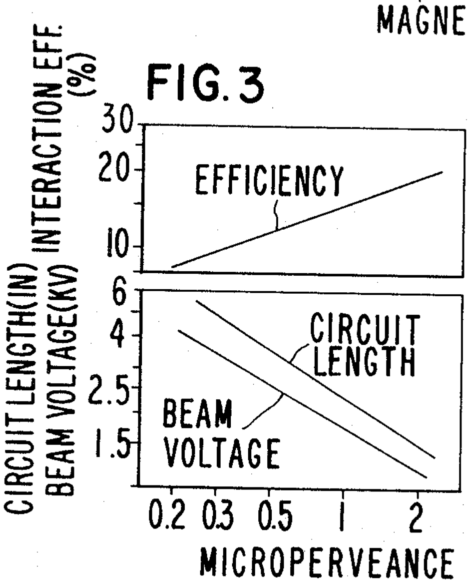


FIG. 4

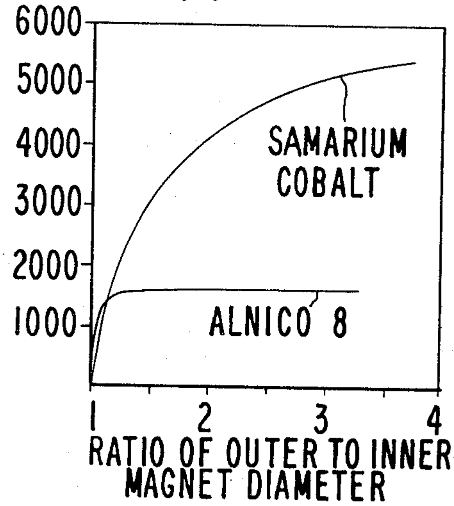


FIG. 5

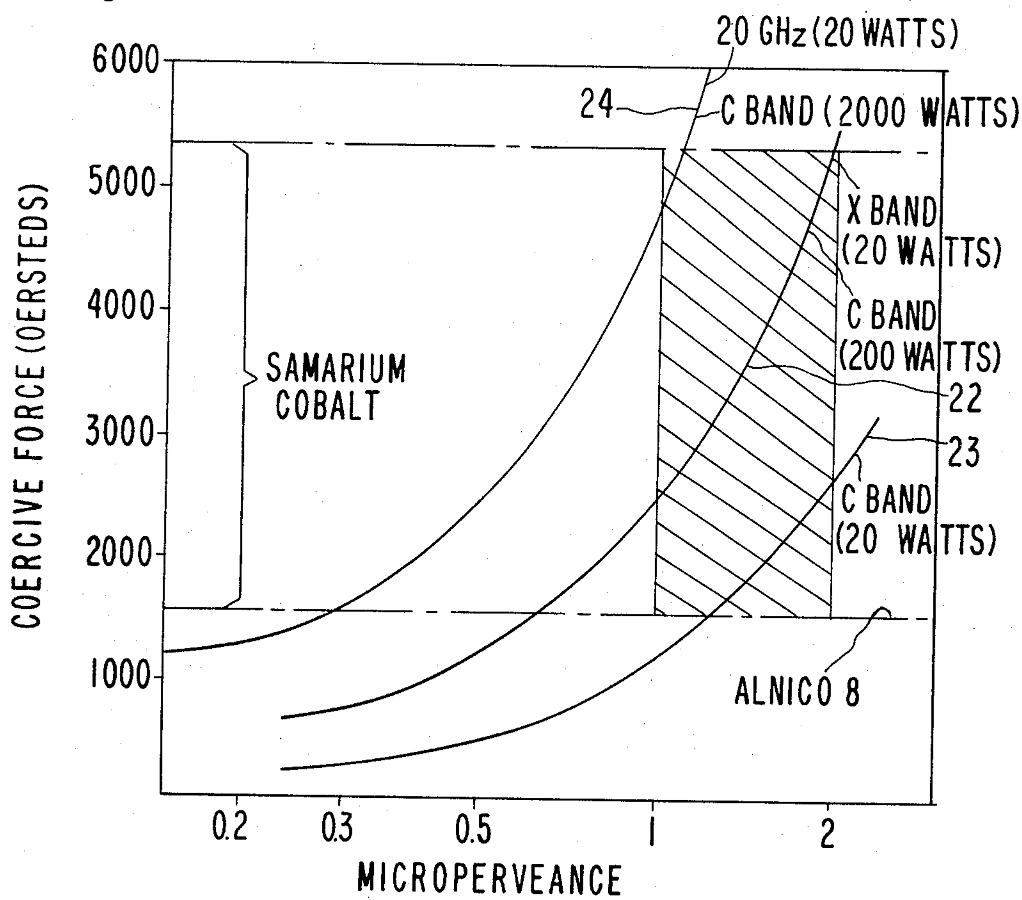
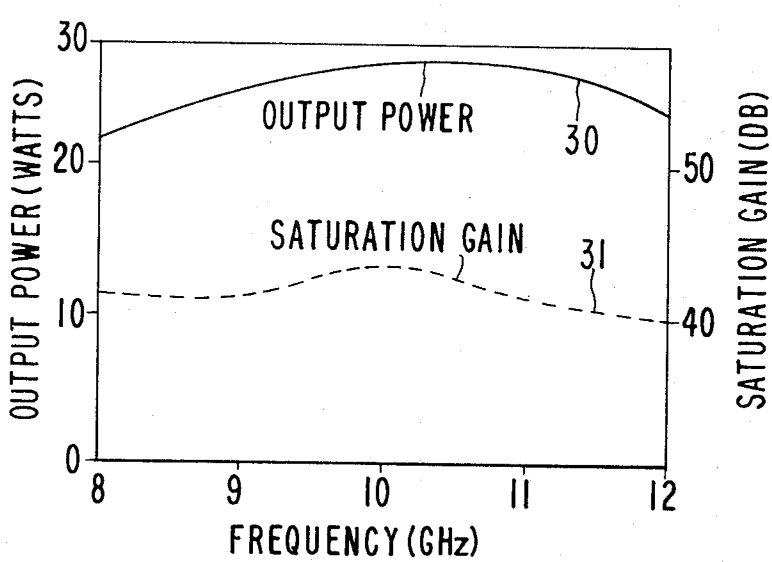

20 GHz (20 WATTS)
24
C BAND (2000 WATTS)
X BAND (20 WATTS)
C BAND (200 WATTS)
22
23
C BAND (20 WATTS)
SAMARIUM COBALT
ALNICO 8
COERCIVE FORCE (OERSTEDS)
6000
5000
4000
3000
2000
1000
0.2
0.3
0.5
1
2
MICROPERVEANCE

FIG. 6


OUTPUT POWER
30
SATURATION GAIN
31
OUTPUT POWER (WATTS)
SATURATION GAIN (DB)
30
20
10
0
50
40
8
9
10
11
12
FREQUENCY (GHz)

MINIATURIZED TRAVELING WAVE TUBE

DESCRIPTION OF THE PRIOR ART

Heretofore, periodic permanent magnet focused traveling wave tubes operating above 4GHz have been built utilizing samarium cobalt ring magnets or other high coercive force (2,000 to 6,000 oersteds) ring magnets. However, in these prior designs, the magnets of high coercive force were merely employed in conjunction with increased anode voltage to increase the focused beam power of the tube without redesigning the electron optics of the tube to utilize a higher perveance beam.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved miniaturized microwave beam tube.

In one feature of the present invention, the electron gun is designed to produce a beam of electrons having a microperveance within the range of 0.8 to 2.2. Periodic ring-shaped permanent magnets having a coercive force in excess of 2,000 oersteds are employed around the beam path for developing a periodic beam focusing magnetic field path, such focusing field within the beam having a peak intensity in excess of 2,000 gauss, whereby the size of the tube can be substantially decreased and the efficiency of the tube substantially improved for microwave interaction at a frequency above 4GHz.

In another feature of the present invention, the ring-shaped permanent magnets are made of a rare earth cobalt material wherein the rare earth component is selected from the group consisting of Y, Sc, La, Ce, Pr, Nd, Sm, Eu, Gd, Eb, Dy, Ho, Er, Tm, Yb, and Lu.

In another feature of the present invention, the ring magnets have a ratio of outside diameter to inside diameter falling within the range of 1.3 to 3.0.

In another feature of the present invention, the microwave tube is designed for a power output of less than 100 watts c.w. (continuous wave).

In another feature of the present invention, the microwave energy developed is centered at a frequency above 8GHz.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic longitudinal sectional line diagram of a microwave tube incorporating features of the present invention,

FIG. 2 is an enlarged detailed view of a portion of the structure of FIG. 1 delineated by line 2—2,

FIG. 3 is a plot of circuit length in inches, beam voltage in KV, and interaction efficiency in percent, all vs. microperveance of the beam for an X-band 20 watt c.w. traveling wave tube,

FIG. 4 is a plot of coercive force in oersteds vs. ratio of outer to inner diameter for an Alnico 8 ring-shaped permanent magnet and a similar magnet made of samarium cobalt,

FIG. 5 is a plot of coercive force in oersteds vs. microperveance of the beam depicting the beam focusing ranges for Alnico 8 and samarium cobalt for various tube designs, including a C-band traveling wave tube operating at various output powers, and for 20 watt c.w. traveling wave tubes at X-band and 20 GHz, and

FIG. 6 is a plot of output power in watts and saturation gain in db vs. frequency in GHz for the 20 watt c.w. X-band traveling wave tube of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown a traveling wave amplifier tube 1 incorporating features of the present invention. The microwave traveling wave tube 1 includes an electron gun assembly 2 for forming and projecting a beam of electrons 3 over an elongated beam path 4 to a beam collector structure 5 disposed at the terminal end of the beam path 4.

A microwave circuit 6, such as a tape helix slow wave circuit, is disposed intermediate the gun 2 and the collector 5 along the beam path 4 for cumulative electromagnetic interaction with the beam 3 for amplifying microwave energy applied to the upstream end of the microwave circuit 6 to produce an amplified microwave signal extracted from a downstream end of the circuit 6 by a suitable output RF coupling means.

A conventional evacuated envelope structure 7, shown in dotted lines, encloses the electron gun, slow wave circuit 6 and collector 5. A periodic permanent magnet beam focus structure 8 is disposed surrounding the beam path 4 intermediate the gun 2 and collector 5 for focusing the electron beam 3 through the microwave circuit 6.

Referring now to FIG. 2, the beam focus magnetic structure 8 is shown in greater detail. The periodic permanent magnet focus structure 8 includes a series of ring-shaped permanent magnets 9 made of a permanent magnet material having a coercive force preferably higher than 2,000 oersteds. Examples of such permanent magnet material includes the rare earth cobalt magnet materials wherein the rare earth component of the magnet is selected from the group consisting of Y, Sc, La, Ce, Pr, Nb, Sm, Eu, Gd, Tb, Dy, Ho, Er, Pm, Yb, and Lu. Such rare earth cobalt magnet materials are disclosed and claimed in copending U.S. application Ser. No. 164,066 of L. R. Falce filed July 19, 1971 and assigned to the same assignee as the present invention. In ring-shaped magnets the peak magnetic field intensity H, produced on the axis of the magnet, for focusing the beam 3, is approximately equal to the coercive force of the magnet material.

Adjacent ring magnets 9 are spaced by ring-shaped magnetic pole plates 11, as of iron, having inner annular flange portions 12. The pole pieces 11 are spaced apart by metallic annular non-magnetic spacers 13. The annular pole pieces 11 and spacers 13 are brazed together at their adjoining faces to form the hollow cylindrical vacuum tight envelope 7 of the tube 1. The ring-shaped magnets 9 are preferably axially cut to form two half ring members which are then slipped over the envelope 7 and retained, by retaining rings, not shown, between the pole pieces 11.

The helical slow wave circuit 6, not shown in FIG. 2, is supported in the conventional manner via three longitudinally directed ceramic support rods, as of boron nitrate, spaced at 120° intervals around the outside of the helix. An interference fit is obtained between the helix, the helix support rods, and the inside cylindrical bore of the envelope 7, formed by the inside surface of the annular pole piece flanges 12 and the non-magnetic spacer 13 to facilitate thermal conduction from the helix 6 to the envelope 7.

Referring again to FIG. 1, the electron gun 2 is designed with a microperveance in the range of 0.8 to 2.2, where microperveance is defined as the beam current divided by the 3/2 power of the beam voltage. Microperveance is a convenient parameter because the required magnetic focus field is proportional to the square root of the microperveance. In a typical example, the microperveance of the electron gun 2 is 1.0, the area convergence of the spherically concave cathode emitter 14 and anode is 13.5 to 1, which gives a cathode loading of 2 amps per square centimeter. The cathode emitter 14 is preferably a dispenser cathode. The diameter of the cathode button for a 20 watt X-band tube is 0.0845 inch and its spherical radius is 0.086 inch.

The electron gun 2 includes a centrally apertured anode 15 through which the electron beam 3 is projected into the region of the slow wave circuit 6 and periodic permanent magnet structure 8. The electron gun 2 has a modulating anode 16 such that the tube 1 can be operated under dual mode conditions, i.e., pulsed or c.w. The cathode 14, modulating anode 16, and anode 15 are stacked between ceramic cylinders, not shown, of 0.342 inch O.D. and 0.254 I.D. to reduce the diameter of the gun 2 to be compatable with the miniature periodic permanent magnet structure 8.

Heretofore, 20 watt X-band traveling wave tubes have been designed employing Alnico 8 ring-shaped permanent magnets for focusing the beam. Alnico 8 has a maximum coercive force of approximately 1,500 oersteds; this limits the design of the gun to approximately a microperveance of 0.6 as shown in FIG. 5. As a consequence, the prior art tube had a relatively low efficiency (on the order of 12 percent, as indicated in FIG. 3), required a beam voltage of approximately 2.5 KV, and had an overall circuit length of approximately 3.75 inches.

In the present invention, a higher coercive force magnet material is utilized, such as samarium cobalt, which has the coercive force in oersteds vs. ratio of outer to inner magnet diameter d_o/d_i shown by curve 21 of FIG. 4. By selecting the ratio of outer diameter to inner diameter of the magnetic rings 9 to be approximately 1.5, a coercive force in oersteds of approximately 3,000 is obtained. When stabilized for thermal effects at 2,500 oersteds, this yields a peak axial magnetic beam focusing field intensity within the beam of approximately 2,250 gauss. This then permits a gun microperveance of 1.0 for an X-band 20 watt tube as shown by curve 22 of FIG. 5.

By utilizing a microperveance of 1.0, the beam voltage is reduced to approximately 1,750 volts, the circuit length is reduced to approximately 2.3 inches, and the efficiency of the tube is increased to approximately 15 percent. However, by designing the electron gun 2 with a higher microperveance of 2.0, the beam voltage can be reduced to approximately 1,250 volts, the circuit length reduced to approximately 1.5 inches, and the efficiency increased to approximately 20 percent for an X-band traveling wave tube operating with a power output of approximately 20 watt c.w. and employing periodic permanent magnets having a coercive force of approximately 5,500 oersteds as shown in FIGS. 3 and 5.

Thus, the use of rare earth cobalt magnets, having a relatively high coercive force as illustrated by samarium cobalt in FIG. 5, permits use of tubes utilizing electron guns having microperveances in the range of 1.0 to 2.0. This allows either increasing the power output of the tube at a given frequency, such as C-band, as indicated by the C-band curves 22, 23 and 24 or the design of microwave tubes utilizing a gun 2 having a microperveance in the range of 1.0 to 2.0 at higher frequency ranges than were heretofore achievable. For example, Alnico 8 could not have been used for focusing a 1.0 to 2.0 microperveance electron beam for a 20 watt tube at X-band. The maximum microperveance that could be employed with such a magnetic material was 0.6.

Since the magnetic field required to focus an electron beam depends directly on the square root of the beam microperveance and inversely on the beam diameter, the greater the microperveance, the greater the required magnetic field. Since beam diameter is inversely proportional to the frequency of the tube, the required focusing field increases directly with frequency. The higher the frequency range of the tube, the greater the required focusing field for a given microperveance.

This is roughly illustrated by curves 22, 23 and 24 of FIG. 5 where the C-band curve for 2,000 watts corresponds roughly to the curve for a 20GHz tube at 20 watts c.w. An X-band tube to produce 20 watts c.w. corresponds roughly to a C-band tube producing 200 watts c.w., and a C-band 20 watt curve corresponds roughly to an X-band 2 watt curve.

In a 20 watt X-band tube of the present invention, the output performance of the tube is shown in FIG. 6. The c.w. power output, as illustrated by curve 30, is greater than 20 watts over the range of 8 to 12GHz and the saturated gain, curve 31, is greater than 40db over the range of 8 to 12GHz. The tube has an overall size that permits it to fit inside a standard X-band waveguide so that the outer diameter of the magnets was less than 0.4 inch; the magnet outer to inner diameter ratio is 1.5, with the magnet coercive force being 2,500 oersteds after temperature stabilization. This permitted focusing of a beam with a microperveance of 1.0. The weight of the tube, with the focusing magnet, was 3 ounces; its overall size was 0.35 inch by 0.75 inch by 5.0 inches. The tube had an overall efficiency including heater power of 20 percent.

The miniaturization of medium power traveling wave tubes by the use of rare earth cobalt magnets, such as samarium cobalt, is applicable throughout the C, X and Ku-band frequency ranges. At lower frequencies, conventional magnets have always been strong enough, and existing tubes have already achieved their minimum size.

Octave bandwidth is readily available from the miniaturized tubes of the present invention. Miniaturization can be effectively applied at c.w. power levels from milliwatts up to 50 watts and at peak power levels up to a few hundred watts.

Although the present invention has been described thus far for focusing the beam of a traveling wave tube, it is also applicable in general to other linear beam tubes, such as backward wave oscillators, klystrons, and the like.

What is claimed is:

1. In a miniaturized periodic permanent magnet focused microwave beam tube, means for forming and

projecting a beam of electrons of a microperveance within the range of 0.8 to 2.2 over an elongated beam path, microwave circuit means disposed along said beam path in microwave energy exchanging relation with the beam for cumulative electron interaction with the beam to develop microwave energy on said microwave circuit, such developed microwave energy being of a frequency above 4GHz, periodic ring-shaped axially polarized permanent magnet means having a coercive force in excess of 2,000 oersteds and disposed coaxially of and along said beam path for developing a periodic magnetic beam focusing field of an intensity within the beam path in excess of 2,000 gauss for focusing the electron beam through said microwave circuit.

2. The apparatus of claim **1** wherein said microwave circuit means is a slow wave circuit.

3. The apparatus of claim **1** wherein said ring-shaped permanent magnets are made of a rare earth cobalt material wherein the rare earth material component is selected from the group consisting of, Y, Sc, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

4. The apparatus of claim **1** wherein said ring magnets have a ratio of outer diameter to inner diameter falling in the range between 1.3 and 3.0.

5. The apparatus of claim **1** including means for extracting the developed microwave energy from said microwave circuit as output microwave power, and wherein the output microwave power is in a range less than 100 watts c.w.

6. The apparatus of claim **1** wherein said microwave energy developed on said circuit is centered at a frequency above 8GHz.

7. The apparatus of claim **1** wherein said microwave circuit is a helix slow wave circuit.

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