United States Patent [19]

Hiramatsu

[11] **3,886,397**

[45] **May 27, 1975**

[54] **HYBRID SLOW WAVE CIRCUIT**

[75] Inventor: **Yukio Hiramatsu**, Los Altos, Calif.

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

[22] Filed: **Jan. 10, 1974**

[21] Appl. No.: **432,380**

[52] **U.S. Cl.** ..... **315/3.6**; 315/3.5; 315/39.3; 333/31 A

[51] **Int. Cl.**..... **H01j 23/24**; H01j 25/34

[58] **Field of Search**..... 315/3.5, 3.6, 39.3; 333/31 A

[56] **References Cited**

UNITED STATES PATENTS

2,927,832	3/1960	Marchese	315/3.6
3,181,024	4/1965	Sensiper	315/39.3 X
3,508,108	4/1970	Salisbury	315/39.3 X
3,527,976	9/1970	Thal, Jr.	315/3.6
3,715,616	2/1973	Elfe, Jr.	315/3.5

Primary Examiner—James W. Lawrence
Assistant Examiner—Marvin Nussbaum
Attorney, Agent, or Firm—Stanley Z. Cole; D. R. Pressman; J. D. Slobod

[57] **ABSTRACT**

A slow wave circuit of a microwave tube includes a wide band helix-type slow wave circuit, such as a comb-supported ring bar (CSRB) circuit, followed by a coupled cavity slow wave output circuit in direct microwave coupling relationship with the CSRB circuit.

1 Claim, 6 Drawing Figures

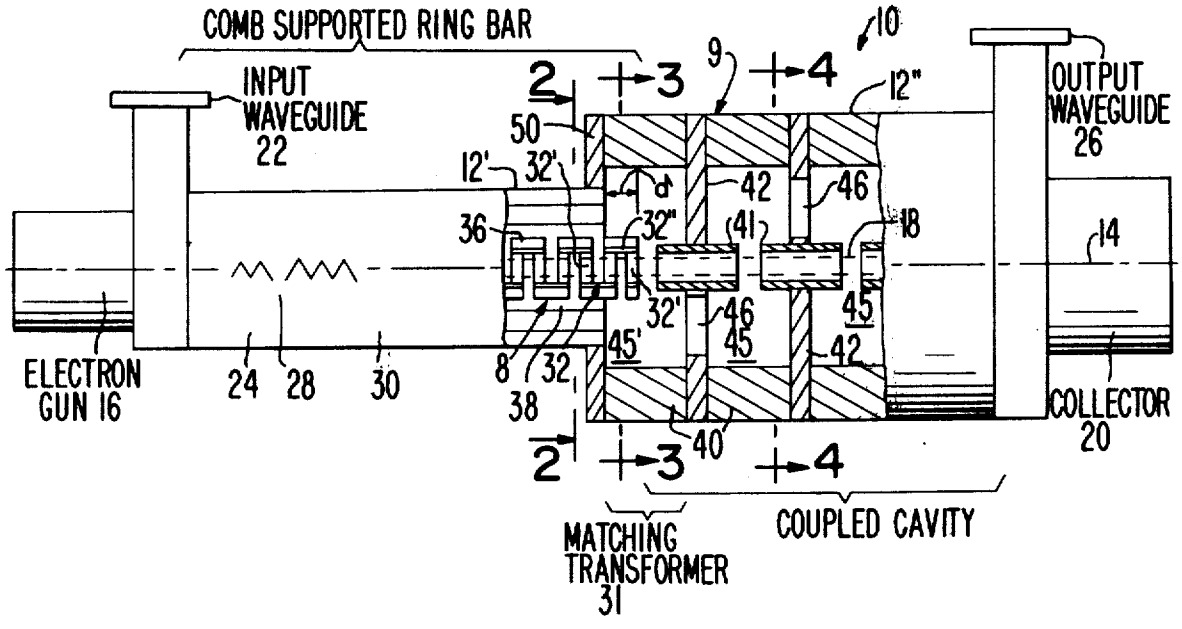


FIG. 1

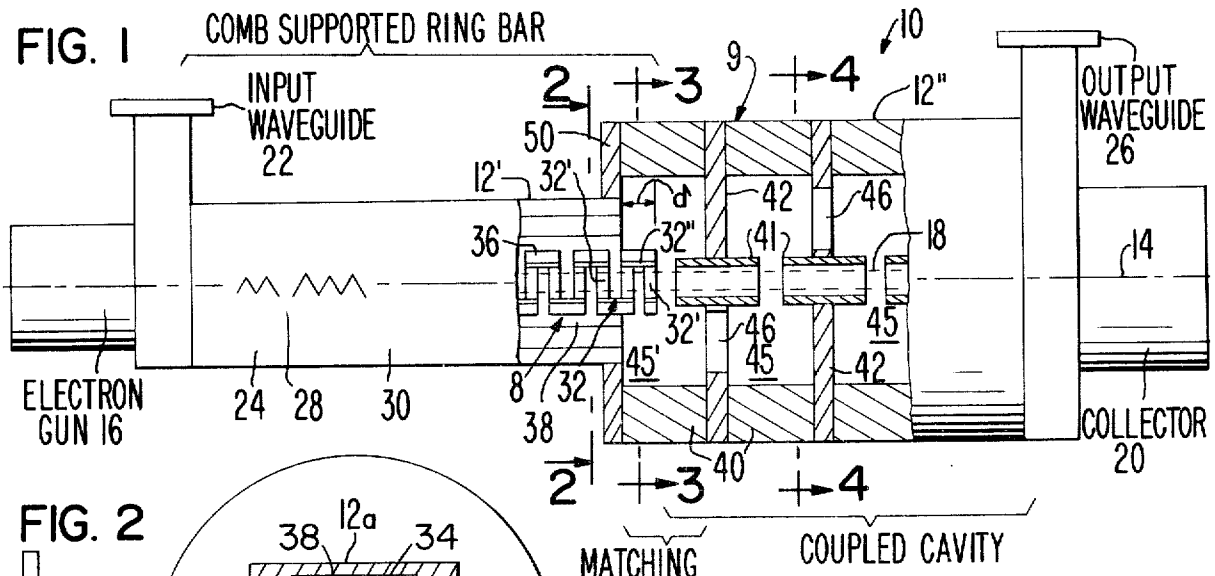


FIG. 2

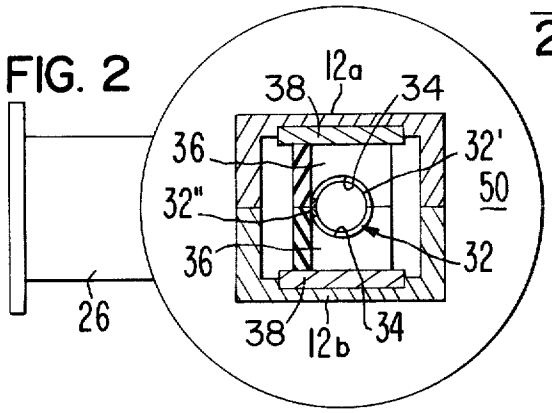


FIG. 3

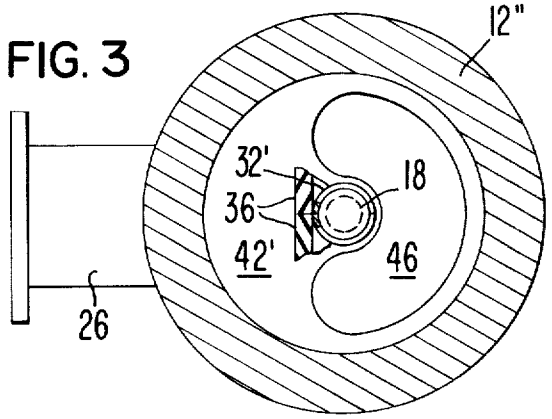


FIG. 4

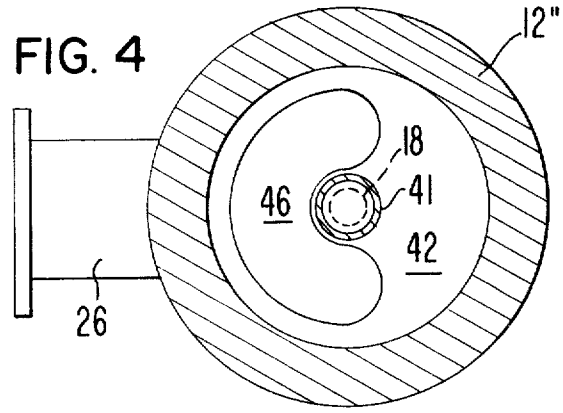


FIG. 5

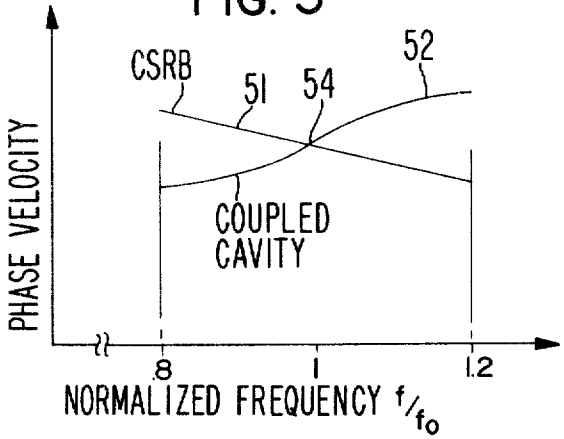
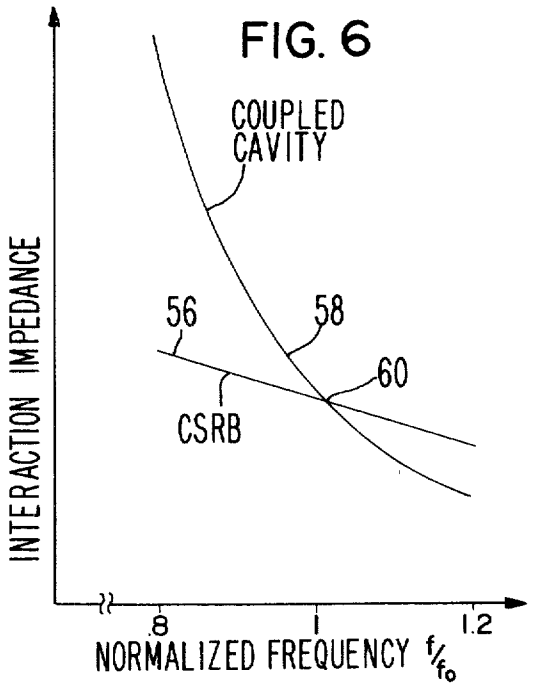


FIG. 6



HYBRID SLOW WAVE CIRCUIT

FIELD OF THE INVENTION

The present invention relates to slow wave structures of the type for interacting microwave energy with an electron beam. In its particular aspects, the invention relates to a slow wave structure comprising the combination of a helix-type slow wave circuit and a coupled cavity slow wave circuit.

BACKGROUND OF THE INVENTION

Travelling wave tubes (TWT's) employing coupled cavity slow wave structures have been employed in high output power, relatively narrow bandwidth applications while wider bandwidth helix-type travelling wave tubes have been relegated to relatively low output power applications.

In response to demands for TWT's with both high output power and wide bandwidth, attempts have been made to increase the bandwidth of coupled cavity tubes. These attempts have been met by serious problems of tube band edge oscillations which have required extraordinary oscillation suppression techniques. Also, in response to such demands, efforts were made to increase the output power of helix-type TWT's. These efforts resulted in the development of the dielectric comb-supported ring bar (CSRB) circuit. Present travelling wave tubes employing CSRB helix-type slow wave structures have efficiencies and consequently output power significantly less than that of coupled cavity travelling wave tubes.

Heretofore, it has been known that the efficiency and output power of a TWT are strongly dependent on the circuit loss in the output part of the tube. For example, structures to provide losses within coupled cavity slow wave structures for band edge oscillation suppression purposes have not been coupled to and near the tube output part.

Because coupled cavity structures have lower loss than helix-type structures higher efficiencies and output powers are attained with the former than with the latter.

OBJECTS OF THE INVENTION

It is an object of the present invention to provide a new and improved slow wave structure for achieving combinations of efficiency and bandwidth generally not heretofore possible.

It is a further object of the present invention to provide a new and improved travelling wave tube with both high bandwidth and high output power capability.

It is yet another object of the invention to provide a new and improved slow wave structure which can be easily optimized in terms of bandwidth and efficiency for given applications.

It is still another object of the present invention to provide a wide band travelling wave tube with a rugged slow wave structure.

SUMMARY OF THE INVENTION

According to the teachings of the present invention, a single microwave tube employs a slow wave structure comprising a hybrid combination of slow wave circuit types. In particular, a main part of the slow wave structure is a helix-type circuit. This main part is followed by an aligned short coupled cavity output section.

Since the output power and efficiency of a TWT are primarily determined by the characteristics of the slow wave structure at the output portion of the tube, the resultant hybrid tube has a bandwidth approaching that of a helix-type tube and efficiency and output power capabilities approaching those of coupled cavity tubes.

To achieve these results the helix-type and coupled cavity slow wave circuits are directly coupled in microwave energy exchange relationship, with each being designed according to known criteria to have comparable phase velocities and interaction impedance to achieve a broadband, high output power hybrid TWT. It is desirable in some applications to provide a more narrow band coupled cavity output section characterized by higher interaction impedance than the helix-type circuit. In such applications, the output power capability of the hybrid tube is further increased at the expense of bandwidth. The combined, diverse TWT slow wave structures permit certain trade-offs enabling the design of microwave tubes which are optimally tailored for various specific applications. For example, the diverse slow wave circuits can be combined to achieve a bandwidth intermediate the capabilities of helix-type and coupled cavity-type tubes at the highest efficiency presently possible.

The hybrid microwave tube of the invention is more rugged than conventional helix-type TWT's since the coupled cavity output section is considerably more resistant to burn out failures caused by high power microwave propagation than is a helix-type circuit.

In general it is necessary to match the characteristic wave impedance of the helix-type and coupled cavity circuits. In particular, when the helix-type circuit is a CSRB circuit, matching of the characteristic impedances of the two circuits is provided by an impedance transformer section comprising a first generally open cavity of the coupled cavity circuit. The ring bar circuit protrudes into the open cavity and is aligned with the drift tubes of the coupled cavity circuit.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a schematic, top view of one embodiment of a travelling wave tube of the invention, with a portion broken away in cross-section;

FIGS. **2, 3** and **4** are cross-sectional views respectively taken along the lines **2—2, 3—3** and **4—4** of FIG. **1**;

FIG. **5** is a plot of phase velocity versus normalized frequency; and

FIG. **6** is a plot of interaction impedance versus normalized frequency.

DETAILED DESCRIPTION OF THE DRAWING

Referring to FIG. **1**, a composite or hybrid slow wave structure comprising a helix-type slow wave circuit **8**, preferably a comb-supported ring bar circuit, and a coupled cavity circuit **9** are incorporated into a single microwave travelling wave tube **10**. Electrically conducting, axially aligned joined barrel portions **12'** and **12''** house the respective slow wave circuits **8** and **9** that are generally directed along the barrel longitudinal

axis **14**. A conventional electron gun **16** at one end of tube **10** provides means for forming and launching or projecting a beam of electrons **18** over an elongated beam path comprising the barrel longitudinal axis **14**. Beam **18** propagates through aligned circuits **8** and **9** to a beam collector **20** which dissipates and collects the energy of the electron beam. The helix-type and coupled cavity slow wave circuits **8** and **9** provide progressive microwave interaction with electron beam **18**. The coupled cavity slow wave circuit **9** forms an output or high power section which further amplifies microwave power received from the helix-type circuit **8**. As is usual, there is provided around the exterior of tube **10** a focusing magnet means (not shown) for producing an axial magnetic field along the beam path to confine the beam to a small cross-section.

The microwave tube **10** further comprises an input waveguide **22** for coupling microwave energy to be amplified into a first portion **24** of the helix-type circuit **8** and an output waveguide **26** for extracting amplified microwave energy from the coupled cavity circuit. The input and output waveguides **22** and **26** are coupled to the respective slow wave circuits **8** and **9** in the usual manner employed in helix-type TWT's on the one hand and coupled cavity TWT's on the other. The helix-type circuit **8** also includes a conventional sever **28** between a first helix-type portion **24** and a second helix-type portion **30**. As is well known, sever **28** allows only electron beam coupling between portions **24** and **30** to obviate backward wave oscillations.

In the first portion **24** electron beam **18** is current density modulated to induce microwave energy in second portion **30**. By progressive interaction with the electron beam **18**, a growing wave of microwave energy is formed in the second portion **30**. The growing wave advances longitudinally and directly impinges upon the coupled cavity slow wave circuit **9** in a matching transformer section **31**, forming a part of both circuits **8** and **9**. The wave continues to grow in amplitude in coupled cavity circuit **9** until it is extracted at output waveguide **26** at the end of the circuit **9**.

The helix-type slow wave circuit **8** may for the purposes of the invention advantageously be any helix-derived circuit, but is preferably for high bandwidth, high output power applications, a comb-supported ring bar (CSRB) circuit. Because of the relatively high power handling capabilities of a CSRB circuit in comparison with a simple helix circuit, the coupled cavity circuit can comprise fewer cavities when preceded by a CSRB circuit because less additional power gain is required of the coupled cavity circuit for a given application. With only a few cavities, such as two or three, in the coupled cavity circuit **9**, the possibility of tube band edge oscillations is minimized.

The CSRB slow wave circuit is generally of the type disclosed in U.S. Pat. Nos. 3,505,730 and 3,508,108, assigned to the same assignee as the present invention, which patents were respectively issued on Apr. 14 and 17, 1970. Referring to FIGS. **1** and **2** herein, the CSRB circuit **8** is a topologically equivalent ring and bar helix-derived circuit including a pair of opposed meander line portions **32** disposed in transverse registration upon concave cylindrical trough surfaces **34** of a pair of serpentine-shaped ceramic insulator support structures **36**, as of alumina or beryllia ceramic.

The opposed meander line portions **32**, formed of electrically conductive sheet metal, are adhesively secured to trough surfaces **34** of support structures **36** to form rings **32'** that alternate with longitudinally directed bars **32''**. Barrel portion **12'**, surrounding CSRB circuit **8**, has a rectangular cross-section and is longitudinally split in half to form two registered opposed halves **12***a* and **12***b*. The support structures **36** are secured to the barrel halves **12***a* and **12***b* by brazing the support structures to a pair of flat intermediate slab members **38** having a coefficient of expansion matching that of the support structures; one material suitable for members **38** is a copper impregnated tungsten matrix. The intermediate members **38** are then brazed to barrel halves **12***a* and **12***b*, and the barrel halves **12***a* and **12***b* are thereafter brazed together.

With reference to FIGS. **1**, **3** and **4**, the coupled cavity circuit **9** comprises a plurality of axially aligned tubular cavity interior defining tubes **40** interleaved with axially aligned, cylindrical, centrally apertured cavity end wall discs **42**. Axially aligned drift tubes **41** within which the electron beam **18** passes, are brazed in the center of end wall discs **42**. Interleaved tubes **40** and discs **42**, which are copper, are brazed together whereby the outer diameter of the tubes and discs forms the circular barrel portion **12''** which houses the coupled cavity circuit **9**. The electron beam **18** passes through the aligned drift tubes **41** of the end wall discs **42** to interact with microwave energy in each cavity **45**. Kidney-shaped coupling slots **46** are provided in the end wall discs **42** for coupling microwave energy between successive cavities **45**. Slots **46** and cavities **45** have resonant respective frequencies that are chosen according to well known techniques for broadbanding the coupled cavity circuit. Discs **42** are preferably oriented so that successive coupling slots **46** are staggered, alternating between radially opposite sides of the axis **14**.

The axially aligned barrel portions **12'** and **12''** are joined via a metal adaptor plate **50**. Plate **50** has a circular periphery matching and brazed to the outside of barrel portion **12''**, as well as a centrally located rectangular aperture receiving and having edges brazed to the barrel portion **12'**. By bonding barrel portions **12'** and **12''** to the edges of the aperture and outer periphery of plate **50** a radially stepped, barrel cross-section is provided.

Adaptor plate **50** forms an end wall of the first cavity section **45'** of coupled cavity circuit **45**. The last ring **32'** of the ring bar circuit, approximately of the same transverse dimensions as the drift tubes **41**, protrudes past adaptor plate **50** into the first cavity **45'** a sufficient distance *d* to form an impedancae transformer section in the first cavity **45'** for matching the characteristics wave impedances of the slow wave circuits **8** and **9**. The radial and axial dimensions defining the interior of the first cavity **45'** may also be adjusted for matching the two circuits **8** and **9**.

When it is desired to provide increased output power or efficiency with respect to conventional helix-type TWT's while paying a minimum penalty in bandwidth, the coupled cavity output section **9** is designed according to well known techniques to have interaction impedance and phase velocity characteristics comparable to those of helix-type circuit **8**. FIGS. **5** and **6**. respectively indicate the general form of the phase velocity and interaction impedance characteristics of the CSRB and wide band coupled cavity slow wave structures **8** and **9**. With reference to FIG. **4**, the CSRB phase veloc-

ity curve **51** is a generally decreasing function of frequency while the coupled cavity phase velocity curve **52** is a generally increasing function of frequency. By choosing the various dimensional parameters of the slow wave circuits according to well known techniques, the curves **51** and **52** can be made to cross at a point **54** which is approximately at the center frequency, f_o, of tube operation to provide comparable phase velocities throughout the tube bandwidth, as of from $0.8\,f_o$ to $1.2\,f_o$. Similarly, in FIG. **5** the CSRB and coupled cavity structures **8** and **9** respectively have interaction impedance curves **56** and **58** that can, by appropriate choice of slow wave circuit parameters, simultaneously be made to cross at a point **60** approximately at the center frequency of tube operation, f_o, thereby providing comparable interaction impedances for the two different slow wave circuits. It is estimated that in such a design, the output power of the overall tube may be increased by at least a factor of two with only a slight decrease in overall bandwidth.

When it is desired to trade excess bandwidth in the helix-type CSRB for even more increased overall output power or efficiency, the coupled cavity circuit may be provided with significantly higher interaction impedance than curve **58** over a narrower range of frequency.

Having described one preferred embodiment of the invention, it should be apparent that numerous modifications are possible within its spirit and scope. Thus it is intended that this embodiment be interpreted as illustrative and not in a limiting scope.

What is claimed is:

1. A device for progressively interacting microwave energy with an electron beam comprising:

a. means for projecting a beam of electrons over an elongted beam path;

b. a ring and bar slow wave circuit disposed along said beam path in enegy exchange relationship with said beam;

c. a coupled cavity slow wave circuit disposed along said beam path downstream of said ring and bar circuit and in energy exchange relationship with said beam;

d. said ring and bar circuit being in direct microwave energy exchange relationship with said coupled cavity circuit by protruding into a first cavity of said coupled cavity circuit.

* * * * *