United States Patent

James

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[45] **June 6, 1972**

[54] **COALESCED MODE COUPLED CAVITY SLOW WAVE TUBE**

[72] Inventor: **Bertram G. James**, Redwood City, Calif.

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

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[52] **U.S. Cl.** ....**315/3.5**, 315/3.6, 333/31 A, 330/42

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

[58] **Field of Search** ....315/3.5, 3.6, 39.3; 330/42; 333/31 A

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Primary Examiner—H. K. Saalbach
Assistant Examiner—Saxfield Chatmon, Jr.
Attorney—Stanley Z. Cole

[57] **ABSTRACT**

A coupled cavity coalesced mode slow wave tube is disclosed. In the tube, the slow wave circuit is formed by a succession of cavity resonators coupled together via the intermediary of coupling slots. The coupling slots are dimensioned or tuned to have a resonant frequency substantially at the upper band edge frequency of the cavity mode to coalesce the slot mode and the cavity mode frequencies at the band edge, thereby increasing the passband of the circuit. At least two sets of such coupling slots are provided throughout the circuit. Each set of such slots is disposed with their centers in substantial alignment with a line substantially parallel to the axis of the beam. Provision of the plural sets of slots substantially reduces the slot impedance of the circuit, thereby substantially increasing the operating bandwidth of the circuit as compared to a similar circuit employing only one set of in-line coupling slots.

5 Claims, 6 Drawing Figures

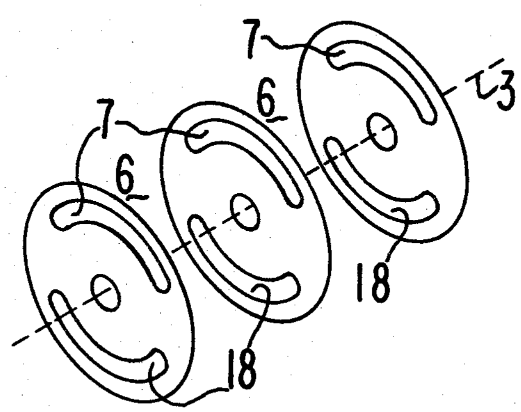


FIG. 1
PRIOR ART

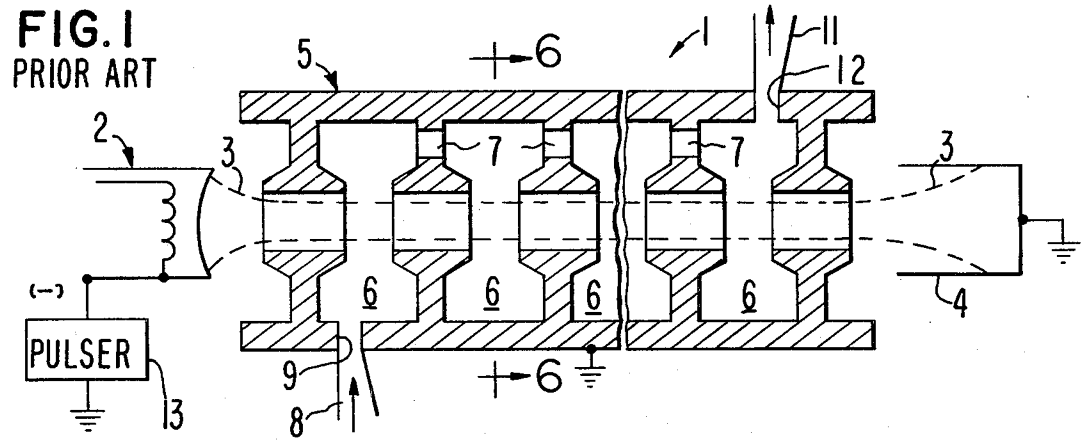


FIG. 2

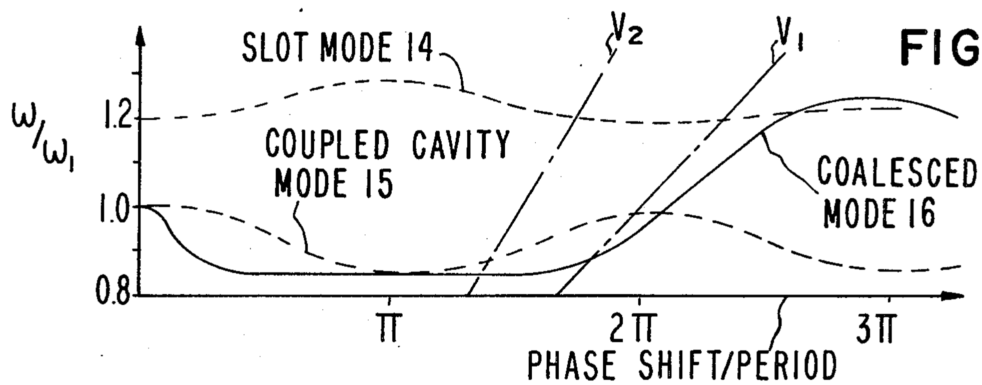
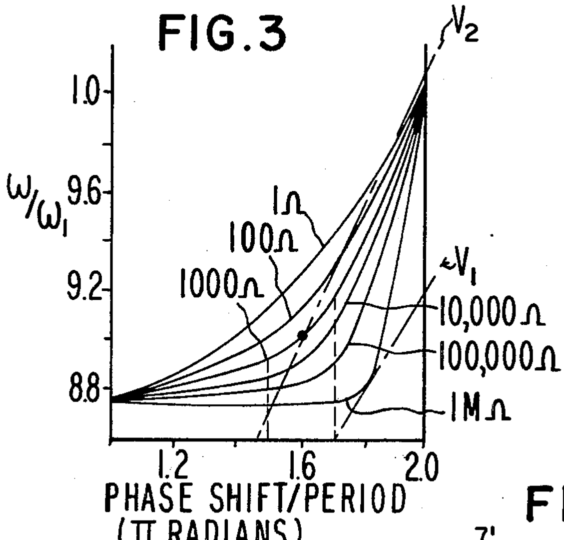


FIG. 3



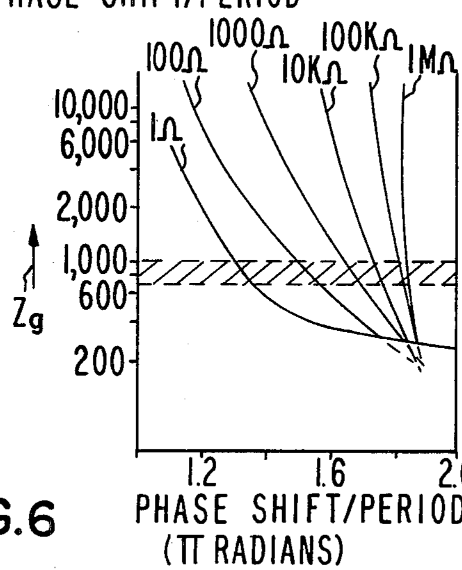


FIG. 4

FIG. 6

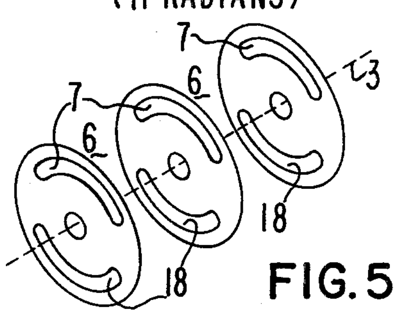
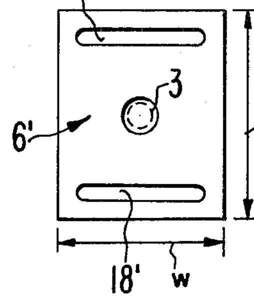


FIG. 5



INVENTOR.
BERTRAM G. JAMES
BY Stanley Z. Cole
ATTORNEY

COALESCED MODE COUPLED CAVITY SLOW WAVE TUBE

DESCRIPTION OF THE PRIOR ART

Heretofore, coupled cavity coalesced mode slow wave tubes have been built. In such prior art tubes, a single set of in-line coupling slots was provided for coupling the cavities of the circuit together to form a coupled cavity slow wave circuit. The coupling slots of the one set were each tuned to the upper band edge frequency of the cavity mode for coalescing the slot and cavity modes to increase the operating bandwidth of the tube. Such a slow wave tube is disclosed and claimed in copending U.S. patent application Ser. No. 69,198 filed Sept. 3, 1970 and assigned to the same assignee as the present invention.

One of the problems with this prior art tube has been that the operating bandwidth, at **16** GHz was only on the order of 3 percent. It is desirable to increase the bandwidth of the tube to a value substantially in excess of 3 percent, as of 10 percent.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved coupled cavity coalesced mode slow wave tube.

One feature of the present invention is the provision, in a coupled cavity coalesced mode slow wave tube, of at least two sets of in-line coupling slots for coupling together successive cavities of the slow wave circuit, whereby the slot impedance is substantially reduced as compared to a tube employing only one set of in-line coupling slots to substantially increase the operating bandwidth of the tube.

Another feature of the present invention is the same as the preceding feature wherein the two sets of in-line coupling slots lie on opposite sides of the beam.

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

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram, partly in block diagram form, partly in line diagram form, and partly in sectional view, depicting the prior art microwave tube,

FIG. 2 is an ω-β diagram depicting the passbands for the cavity mode, slot mode and coalesced cavity and slot mode circuits,

FIG. 3 is a plot of normalized frequency vs. phase shift per cavity depicting the dispersive characteristics of the in-line coalesced mode slow wave circuits for several slot impedances,

FIG. 4 is a plot of interaction gap impedance Z_g vs. phase shift per cavity depicting the characteristics for the coalesced mode circuit as a function of slot impedance,

FIG. 5 is a schematic perspective line diagram depicting the coupled cavity slow wave circuit of the present invention, and

FIG. 6 is a plan view of a cavity end wall for a coupled cavity circuit of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is shown a prior art microwave coupled cavity slow wave circuit tube **1**. In the microwave tube **1**, an electron gun **2** forms and projects a beam of electrons **3** over an elongated beam path to beam collector **4** disposed at the terminal end of the beam path **3**. The coupled cavity slow wave circuit **5** is disposed along the beam path intermediate the gun **2** and the collector **4** for cumulative electromagnetic interaction with the beam to produce a growing wave on the circuit which is extracted as an output signal.

The coupled cavity slow wave circuit **5** includes a plurality of cavity resonators **6** successively disposed along the beam path. Adjacent cavities **6** are coupled together via the intermediary of coupling slots **7** disposed in the common wall between the adjacent cavities. Input wave energy to be amplified is fed to the up-stream cavity **6** via an input waveguide **8** communicating with the up-stream cavity **6** via a coupling iris **9**. The wave energy coupled onto the slow wave circuit **5** propagates through the circuit for cumulative electromagnetic interaction with the beam to produce a growing wave on the circuit. The amplified wave energy is extracted from the down-stream end of the slow wave circuit **5** via output waveguide **11** coupled to the down-stream cavity **6** via the intermediary of output iris **12**. The output energy is coupled via waveguide **11** to a suitable load, such as an antenna, not shown. In a typical example, the slow wave circuit, collector, and anode of the gun are all operated at ground potential, whereas the cathode emitter of the gun **2** is pulsed or operated at a negative potential via a suitable power supply, such as pulser **13**, which supplies the beam voltage.

Referring now to FIG. **2** there is shown the dispersive characteristic for the coupled cavity coalesced mode slow wave circuit **5** of FIG. **1**. More particularly, the coupling slots **7** are each tuned for a frequency which is coincident with the upper band edge frequency of the coupled cavity mode of the circuit. In the coalesced mode circuit, the geometric centers of the coupling slots **7** are all in substantial axial alignment with a line parallel to the axis of and to one side of the beam path. In a typical example, the slot mode would have a dispersive characteristic as indicated by line **14** of FIG. **2**, whereas the coupled cavity mode would have a dispersive characteristic as indicated by line **15**. However, when the resonant frequency of the slots is caused to be coincident with the upper band edge frequency of the cavity mode, the two modes coalesce to form a composite coalesced mode, as shown by curve **16**.

The coalesced mode circuit has a much broader cold bandwidth, for the second space harmonic, than that of the noncoalesced coupled cavity circuit. In addition, undesired band edge oscillations that were heretofore encountered near the upper band edge frequency of the non-coalesced coupled cavity mode have been eliminated in the coalesced mode circuit.

Referring now to FIGS. **3** and **4**, the dispersive characteristic of the coalesced in-line slow wave circuit and the gap impedance characteristic of such circuits are shown as a function of the total slot impedance per cavity of the slow wave circuit. More particularly, FIG. **3** shows a family of dispersive characteristics for the coalesced in-line circuit with the slot impedance per cavity increasing from 1 ohm to 1 megaohms. In a typical microwave tube, the gap impedance can vary between 700 to 1,000 ohms and for wide bandwidth it is desirable to operate with as low a slot impedance per cavity as practical.

In the prior art coupled cavity coalesced mode circuit of FIG. **1** dimensioned for operating in the band of frequencies centered at about 35 GHz, the lowest practicable slot impedance per cavity was on the order of 1,000 ohms. It would be desirable to decrease the slot impedance per cavity substantially to obtain broader bandwidth for the circuit while maintaining as high a phase shift per cavity as possible in order to obtain a circuit with relatively high thermal capacity.

Accordingly, it has been found that by providing two sets of coupling slots running longitudinally of the tube that the slot impedance per cavity can be reduced by a factor of 4, i.e., from 1,000 to 240 ohms, thereby substantially increasing the bandwidth of the tube from approximately 3 percent to approximately 10 percent in the Ka band centered at 35 GHz. Each set of the coupling slots is in-line, i.e. geometric centers of the slots in opposite cavity end walls fall on a straight line which is generally parallel to the beam axis. One set of slots is positioned on one side of the beam and the other set of slots is positioned on the opposite side of the beam. This configuration is indicated in FIG. **5** where a first set of in-line coupling slots is indicated at **7** and the second set of in-line coupling slots is indicated at **18**.

Referring now to FIG. **6**, there is shown, in plan view, a common wall between adjacent coupled cavities **6'** with the coupling slots provided therein. In this embodiment, the cavities **6'** are of rectangular cross section as opposed to the circular cross section of FIG. **5** and the coupling slots **7'** and **18'** rectilinear as opposed to being curved in FIG. **5**. In a typical example of a coalesced mode coupled cavity circuit utilizing two sets of coupling slots for operation at 35 GHz and providing approximately 10 percent operating bandwidth, the coupling slots **7'** and **18'** are each 0.160 inch long with a height of 0.015 inch and the cavities **6'** have a height h of 0.216 inch and width w of 0.200 inch. The spacing between adjacent end walls, in the axially direction of the cavities **6'** is approximately 0.048 inch. Operation is obtained with a phase shift per cavity of approximately 1.5 to 1.6 π radians.

Although the coupled cavity in-line circuit of FIGS. **5** and **6** has been described as used for forward wave interaction in a traveling wave tube operating with a phase shift per period between 1.5π and 1.6π radians, it may also be used to advantage as the output circuit for a hybrid tube utilizing a succession of klystron buncher cavities followed by the in-line coupled cavity circuits of FIGS. **5** or **6** as the output circuit.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings are to be interpreted as illustrative not in a limiting sense.

What is claimed is:

1. In a microwave tube; means for projecting a beam of electrons over an elongated beam path; slow wave circuit means disposed along the beam path in electromagnetic energy exchanging relation with the beam; said slow wave circuit means including, an array of cavity resonators arranged along the beam path for successive electromagnetic interaction with the beam, adjacent ones of said cavity resonator having common end walls, an array of wave energy coupling slot means disposed in the common end walls of said cavity resonators for wave energy coupling together the array of cavity resonators to define a slow wave circuit having a cavity mode passband of frequencies associated with the coupled cavities and a slot mode passband of frequencies centered at a higher frequency than the cavity mode passband and associated with the array of slots, said slots being dimensioned to have a resonant frequency at substantially the upper band edge frequency of the cavity mode and the low frequency band edge of the slot mode for increasing the width of the passband of the composite slow wave circuit, THE IMPROVEMENT WHEREIN, said coupling slots are comprised of at least two sets of slots, each set of said slots being disposed in opposite end walls of each of said cavities with their geometric centers lying on one side of the beam path and falling substantially in a plane defined by the axis of the beam path and the centers of said coupling slots, whereby the total slot impedance for each coupled cavity is substantially reduced for substantially increasing the operating bandwidth of the tube compared to a tube using only one set of similar coupling slots.

2. The apparatus of claim **1** wherein each set of coupling slots has the geometric centers of the coupling slots positioned to be substantially on a straight line which is generally parallel to the beam axis and to one side of the beam axis.

3. The apparatus of claim **1** wherein said coupled cavity slow wave circuit means is a backward wave circuit for the fundamental space harmonic.

4. In a method for stabilized operation of a coupled cavity slow wave tube operating with cumulative electromagnetic interaction with the beam in the region of 1.0π to 2.0π radians of phase shift per period of the slow wave circuit the steps of, dimensioning the coupling slots between adjacent cavity resonators of the circuit to have a slot mode of resonance substantially at the upper band edge frequency of the cavity mode passband of the slow wave circuit to coalesce the low frequency passband edge of the slot mode with the upper passband edge of the cavity mode, thereby substantially increasing the width of the passband of the composite slow wave circuit and eliminating the stop band of frequencies between the cavity and slot modes of propagation, and positioning two sets of the coupling slots in opposite end walls of each of the coupled cavities with each set of coupling slots lying on opposite sides of the beam path and falling substantially in a plane defined by the axis of the beam and the geometric centers of the coupling slots.

5. The method of claim **4** including the step of, positioning the geometric centers of each set of coupling slots to lie substantially in a straight line generally parallel to the beam axis and to one side of the beam path.

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