June 3, 1969 E. J. COOK 3,448,331

COMPOSITE COAXIAL COUPLING DEVICE AND COAXIAL WINDOW

Filed July 19, 1966 Sheet 1 of 3

FIG. 1

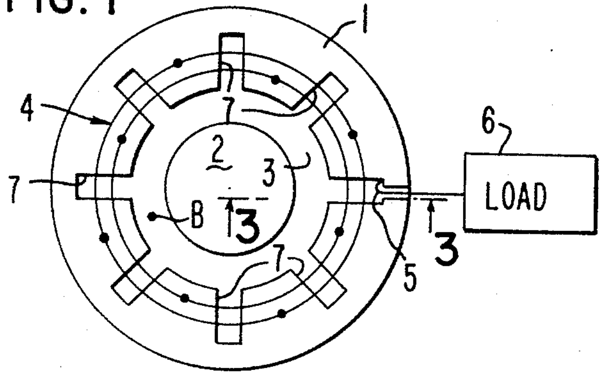


FIG. 2

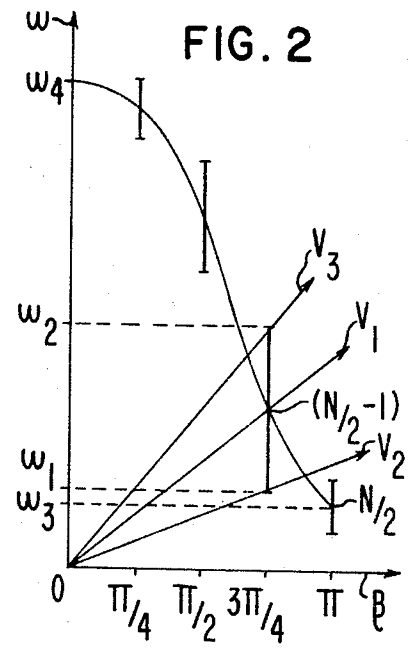
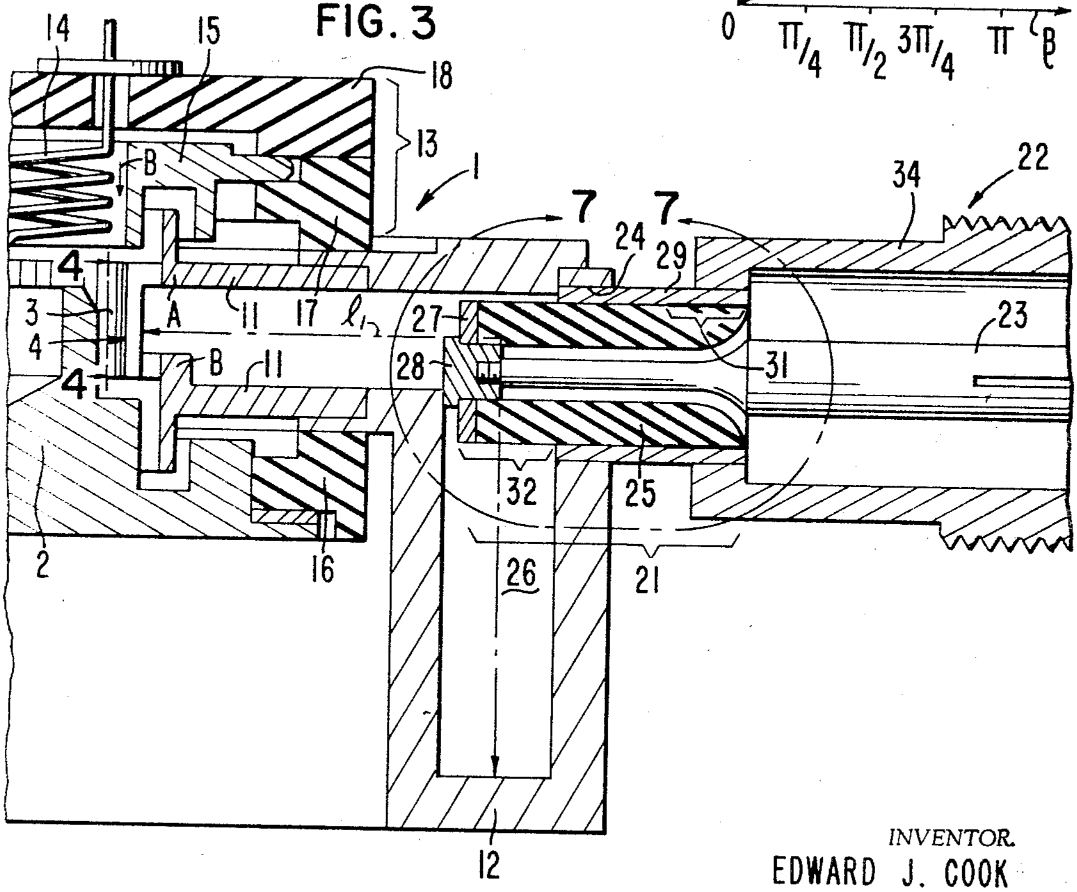


FIG. 3



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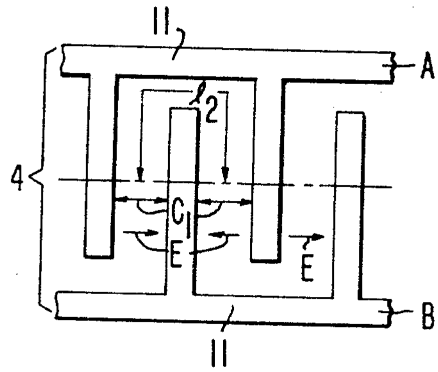

FIG. 4

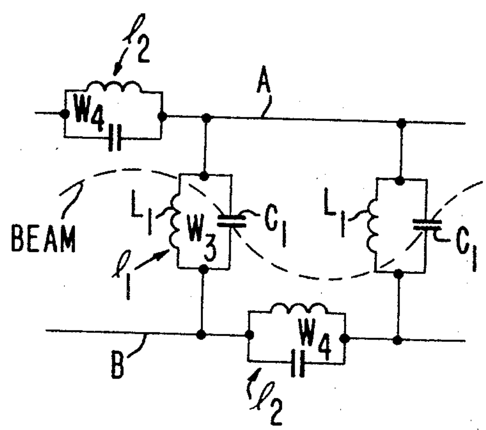

FIG. 5

FIG. 6

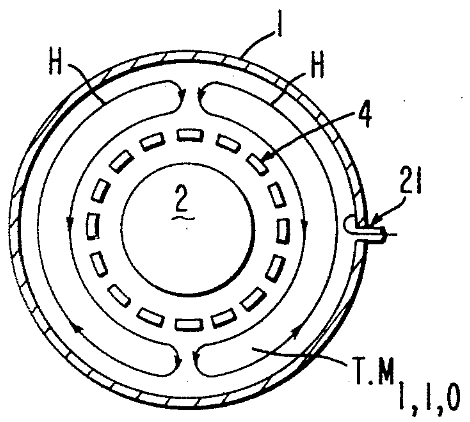

FIG. 7

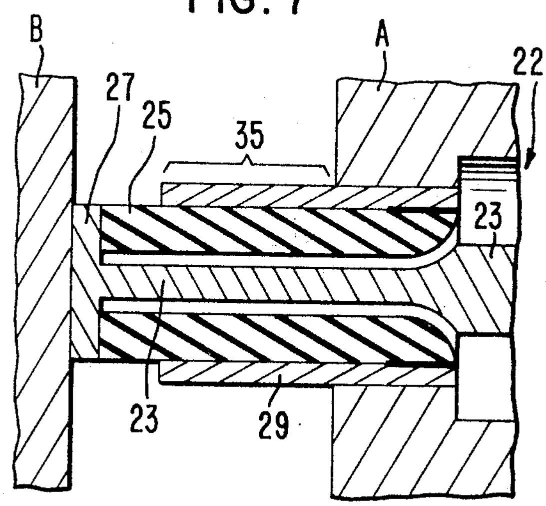

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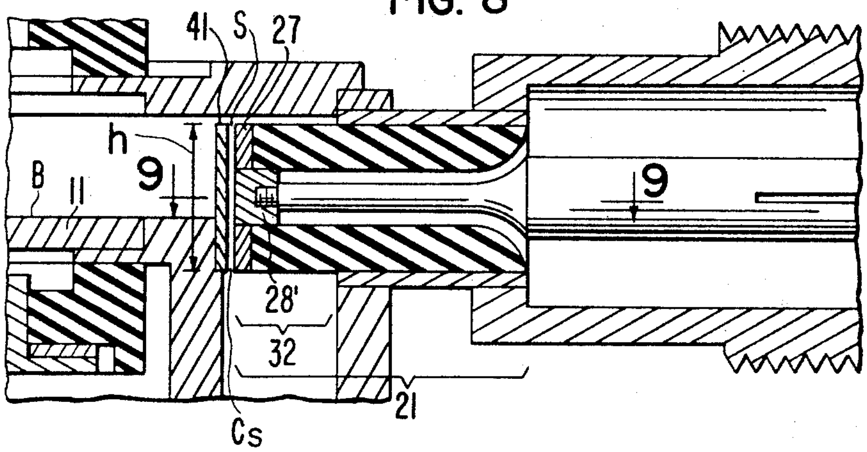
FIG. 8



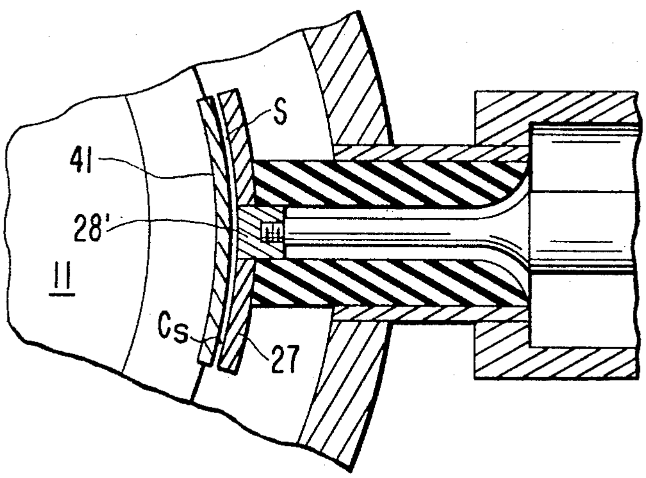


FIG. 9

FIG. 10

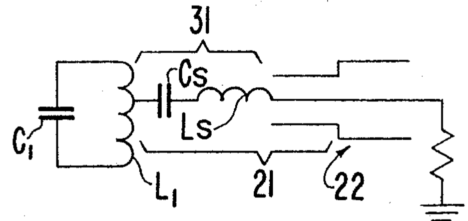
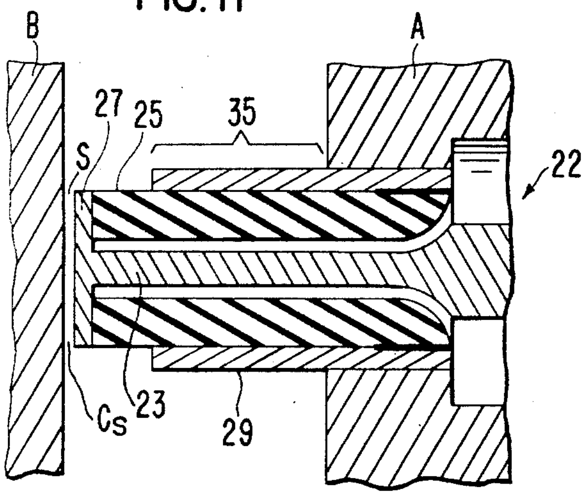


FIG. 11



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COMPOSITE COAXIAL COUPLING DEVICE AND COAXIAL WINDOW

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Continuation-in-part of application Ser. No. 525,455, Feb. 7, 1966. This application July 19, 1966, Ser. No. 574,271
Int. Cl. H01j *25/50;* H03h *7/38;* H01p *1/00*
U.S. Cl. 315—39.53 8 Claims

ABSTRACT OF THE DISCLOSURE

A composite coaxial coupling device and coaxial wave permeable window for microwave structures including microwave tubes is disclosed. The coaxial coupling device and window includes an inner conductor portion which projects into a field containing a region of space defined between a pair of conductors. A dielectric wave permeable window member coaxially surrounds the inner conductor and projects into the field containing region of space. In one embodiment, the field containing region of space is defined by a wave supporting structure having a radial line portion and a coaxial portion with the outer wall of the coaxial portion apertured for passage of the center conductor of the coupler and wherein a portion of one wall of the radial portion of the line forms an overlying outer conductor extension portion for a coaxial coupling device to load the coaxial coupler to maintain the characteristic impedance to obtain a broadband match. In another embodiment of the present invention, a coupling capacitor structure is disposed at the inner end of the inner conductor of the coaxial line, whereby the capacitor structure balances out a small series inductive reactance of the inwardly projecting portion of the coaxial line to provide a reflectionless window.

The present invention is a continuation-in-part of parent application Ser. No. 525,455, filed Feb. 7, 1966 now abandoned and assigned to the same assignee as the present invention.

Heretofore, composite coaxial line coupling devices and R.F. coaxial line windows have been used. However, in these prior devices, the window typically took the form of a ceramic or glass disk or bead disposed across the coaxial line at its entrance into the inductor of the circuit, usually a cavity resonator, to which the center conductor portion was connected or coupled. In such a device, the window introduces an impedance mismatch in the coaxial line which makes it unsuited for broadband coupling applications where wave reflections from the coupling device are to be avoided over a very broad frequencey range, for example, of 4 to 14 gc.

In the present invention, a composite coaxial coupling device and coaxial window is provided which is essentially reflectionless over the aforementioned frequency range. The broadband characteristic is attributable to utilizing a frame member and a portion of the window as integral portions of the coaxial line coupling device, whereby the distance betwen the anode circuit and the window are reduced to a minimum to obtain broadband operation.

The principal object of the present invention is to provide an improved composite coaxial coupling device and window for a coaxial line and tubes using same, whereby improved broadband performance characteristics are obtained.

One feature of the present invention is the provision of a composite coaxial line coupling means and cylindrical dielectric window wherein the window surrounds the center conductor of a coaxial line and projects with the center conductor into the region of the circuit to be coupled to the line with an extension of the outer conductor of the coaxial line disposed adjacent the inwardly projecting cylindrical window member to maintain its characteristic impedance whereby reflections are avoided over a broadband.

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Another feature of the present invention is the same as the preceding feature including the provision of a disk shaped frame member portion sealing the center conductor of the coaxial line to the inwardly projecting cylindrical window at its inner end, and wherein the frame member is closely spaced and coupled to a conductor portion disposed opposite to the conductor portion through which the coaxial line projects, whereby the impedance match is enhanced.

Another feature of the present invention is the same as one or more of the preceding features wherein the outer end of the cylindrical window is sealed over an axially coextensive region to a coaxially disposed cylindrical frame member which surrounds the cylindrical window, and which cylindrical frame forms a substantial length of the outer conductor of the coaxial line.

Another feature of the present invention is the same as any one or more of the preceding features wherein the composite window and coaxial coupling means is used for coupling wave energy from a voltage tunable magnetron to a load.

Another feature of the present invention is the same as any one or more of the preceding features wherein the center conductor of the coaxial line, which projects into the region of the circuit to be coupled, is capacitively coupled to the circuit at its inner end portion; whereby the capacitance serves to resonate a series inductance of the protruding center conductor of the coaxial line to better the impedance match between the coaxial line and the circuit being coupled.

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:

FIG. 1 is a schematic transverse sectional view of a magnetron oscillator coupled to a load,

FIG. 2 is an ω–β diagram showing the disperson characteristics for a voltage tunable magnetron,

FIG. 3 is a longitudinal sectional view of a magnetron incorporating features of the present invention. The view being similar to that as taken along line **3—3** in the direction of the arrows of FIG. 1.

FIG. 4 is an enlarged front view of an interdigital line magnetron interaction circuit similar to that as seen by a view taken along line **4—4** of FIG. 3 in the direction of the arrows,

FIG. 5 is a schematic equivalent circuit diagram for the interdigital magnetron interaction circuit of FIG. 3,

FIG. 6 is a transverse schematic circuit diagram for the tube of FIG. 3,

FIG. 7 is an enlarged sectional detailed view of an alternative embodiment of the present invention as delineated by lines **7—7** of FIG. 3,

FIG. 8 is an alternative embodiment of a portion of the structure of FIG. 3 delineated by line **8—8**,

FIG. 9 is a transverse sectional view of a portion of the structure of FIG. 8 taken along line **9—9** in the direction of the arrows,

FIG. 10 is a schematic equivalent circuit diagram for the output coupling circuit of FIGS. 8 and 9, and

FIG. 11 is an alternative embodiment of the structure of FIG. 7.

Referring now to FIG. 1 there is shown in schematic form a voltage tunable magnetron. More specifically, the magnetron includes an anode structure **1** coaxially surrounding a cathode electrode **2** and defining, in an annular region therebetween, a magnetron interaction region **3**. The anode **1** is provided with a suitable fundamental backward wave periodic wave circuit **4** formed therein facing the cathode **2** for interaction with the electrons of an electron stream in the magnetron interaction region **3**. In operation suitable operating potentials are applied between cathode **2** and anode **1** in the presence of an axially directed magnetic field B in the magnetron interaction region **3** for cumulative interaction with the electron stream to produce an output signal. The output signal is extracted from the circuit **4** via suitable coupling means **5** and fed to a load **6**. The voltage tunable magnetron will oscillate at a frequency determined by the circuit **4** and by the voltage between the cathode **2** and the anode **1**. The frequency range over which the tube may be tuned depends upon the loaded Q of the periodic circuit **4**. Circuit **4** may be loaded by heavily coupling the circuit **4** to the load **6** or the circuit may be provided with internal resistance to lower its load Q.

Referring now to FIG. 2 there is shown a dispersion characteristic for a typical fundamental backward wave circuit. When the circuit **4** is re-entrant, such that wave energy can travel in a continuous path around the circuit, the dispersion characteristic becomes discontinuous in the sense that a number of resonant modes of oscillation are produced corresponding to an integral number of full wavelengths of wave energy travel around the circuit **4**. Typically, there will be $N/2$ number of resonant modes established where N is the number of periodic elements taken around the circuit **4**. Thus, if a circuit has 8 slot resonators as depicted in FIG. 1, there will be $N/2$ or 4 resonant modes of oscillation established at equal intervals of β or phase shift per period of the circuit. Heretofore, it has been the practice to operate on the π mode designated $N/2$ on the diagram. However, in the tube incorporating the output coupling feature of the present invention, the $(N/2\text{-}1)$ mode is used, which, for a given operating frequency band, permits the anode circuit **4** to have larger dimensions and thus greater power handling capability than would be attainable if the tube was designed for operation on the π mode. Thus, the tube is operable over an electronic bandwidth from ω_1 to ω_2 corresponding to synchronous beam voltages of V_2 to V_3 as shown in the diagram of FIG. 2. However, in order to obtain such a wide tuning range, the circuit **4** must be heavily loaded such that the loaded Q of the anode circuit is on the order of 15 to 20. If the coupling to the load does not provide a good match between the load and the tube, the tuning range of the tube will be drastically affected. Any reflection introduced in the coupling between the load and the tube diminishes the coupling thereby raising the Q of the anode circuit **4** and reducing its tunable bandwidth. Thus, a reflectionless match between the anode circuit **4** and the load is desired for maximum tunable bandwidth.

Referring now to FIG. 3, there is shown in longitudinal section a voltage tunable magnetron incorporating the output coupling circuit of the present invention. More specifically, the tube includes an anode **1** having a crown supported interdigital type anode circuit **4** essentially as shown in FIG. 4. The interdigital anode circuit **4** is crown supported by a pair of annular plates **11** which include radial portions followed by axial directed portions and which are closed at their outer ends by end wall **12**. The anode circuit coaxially surrounds a cold cathode sole electrode **2** operated at cathode potential. An annular magnetron interaction region **3** is defined between the interdigital circuit **4** and the axially coextensive portion of the cathode electrode **2**. An electron gun **13** is disposed at the opposite end of the tube from the cold cathode electrode **2** and includes a helical filamentary emitter **14** surrounded by an injector electrode **15** operating at a substantially lower potential than the anode circuit **4** whereby the electrons are axially injected into the magnetron interaction region **3** under the confining effect of the axial magnetic field B.

The vacuum envelope for the tube is defined by several annular members sealed together in a vacuum tight manner at their abutting surfaces. The cathode sole **2** is sealed to an annular ceramic insulator **16** which in turn is sealed to the lower conductor plate **11** of the anode. Lower plate **11** is also sealed in a vacuum tight manner to the other plate **11** via the intermediary of the coaxial axially extending wall portions and the end closing wall **12**. The upper side of the upper annular anode plate **11** is sealed to another insulating ring **17** as of alumina which is in turn sealed to end enclosing plate member **18** as of ceramic.

The equivalent circuit for the anode circuit **4** is shown in FIG. 5. The circuit is essentially a two wire transmission line with series loading in the two conductors A and B formed by the quarter wave slot resonators formed between adjacent fingers in each of the lines. This can be readily seen by reference to FIG. 4 wherein one of the plates **11** is designated as A and the opposed plate **11** is designated as B. The upper cutoff frequency of the circuit is formed when the slot resonators formed in the interdigitated conductors A and B become resonant. This corresponds to a length l_2 between successive interaction regions of a half wavelength and a finger length of nearly a half wavelength. On the ω–β diagram this upper cutoff frequency is ω_4 and for the tube of FIG. 3 this frequency is selected to be approximately 70 gc. corresponding to a finger length of approximately 0.084″.

The low frequency cutoff of this circuit ω_3 corresponds to a resonance of the shunt elements L_1 and C_1 formed by the folded radial quarter wave cavity having a length designated l_1 in FIG. 3 and capacitively loaded by the capacitance C_1 between adjacent fingers of the interdigital line. In the tube of FIG. 3 l_1 is selected such that the resonant frequency of the π mode corresponding to ω_3 is approximately 4 gc. With this low frequency cutoff, substantial mode separation is obtained between the $(N/2\text{-}1)$ operating mode at 856 to 9.6 gc. and the adjacent π mode. The electron stream in the magnetron interaction region **3** successively cumulatively interacts with the electric field E between adjacent fingers which corresponds to the capacitive voltages developed across capacitors C_1 in FIG. 5.

At the operating $(N/2\text{-}1)$ mode the shunt cavity resonator portion of the circuit formed by the shorted folded section of radial transmission line, defined by annular radial and axial plates **11** as closed by end wall **12**, operates in the TM_{110} mode. This mode pattern is shown in FIG. 6.

The output signal is coupled out of the cavity via coaxial coupling means **21** which couples across a portion of the shunt inductor L_1.

More specifically, a coaxial line **22** is coupled to a load, not shown, and in the embodiments of FIGS. 3 and 7 has its center conductor **23** conductively connected to the inner conductor plate **11** of the crown supported interdigital line by passing through an aperture **24** in the outer wall **11**. A cylindrical dielectric window member as of alumina ceramic **25** coaxially surrounds the conductor **23** and projects inwardly of the vacuum envelope into the region of space **26** defined between the two conductor portions **11**. A disk shaped metallic frame member **27** as of copper plated molybdenum is brazed to the end of the inner end of the cylindrical window member **25** in a vacuum tight manner. The frame member **27** is centrally apertured and is brazed to a molybdenum plug **28** which in turn is brazed to conductor portion B of the cavity. Plug **28** is centrally bored and tapped to receive the center conductor **23** threaded therein. The outer end of the cylindrical window **25** is brazed to a coaxially surrounding sleeve **29** as of nickel over an annular axially coextensive brazed region **31** to form a vacuum tight seal therebetween. Sleeve **29** forms the outer conductor of the coaxial line segment, which includes the window member **25** and the sleeve **29** and is in turn brazed in a vacuum tight manner at its inner end to the apertured wall **24** of conductor **11**.

The cylindrical window member **25** is closely spaced to the radial conductor portion **11** such as to maintain its characteristic 50Ω impedance for that portion of its length which projects into the cavity **26**. This closely spaced outer conductor region is designated as **32** and assures a reflectionless coupling to the fields of the cavity by maintaining the characteristic impedance of the line **23** into the point of connection between plug **28** and conductor **11**. An externally threaded miniature coaxial connector adapter **34** is soldered over the outer end of the sleeve **29** to facilitate connection of the coaxial line **23** to a standard 50Ω miniature coaxial line.

By designing the window assembly **21** such that it presents substantially the same characteristic impedance, i.e. 50Ω as the miniature coaxial line into the point where it is connected to the inner conductor **11** there is assured a reflectionless connection between the circuit **4** and the load resistance of the load **6**, not shown in FIG. 3, whereby the circuit is heavily loaded by the load and its Q reduced to approximately 15–20 for broadband operation.

Referring now to FIG. 7 there is shown an alternative embodiment of the present invention wherein the closely spaced conductor region **32** has been replaced by a continuation formed by an inward extension of the sleeve **29** designated at **35**. Thus, as in the embodiment of FIG. 3, the window segment **25** maintains the characteristic 50Ω impedance into the point of connection of the inner conductor **23** to the axially directed portion of plate **11** via the intermediary of frame member **27**.

Referring now to FIGS. 8–11 there is shown an alternative embodiment of the present invention. It has been found that in the output coupling arrangements of FIGS. 3 and 7, that the center conductor segment of the coaxial line **21**, which projects into the circuit being coupled to, has associated therewith a small amount of series inductance L_s, see FIG. 10. This inductance L_s presents a small reactance to the slow wave circuit **4** which tends to shift the operating frequency of the tube and to slightly decouple the load from the tube **1**.

This small series industance L_s is balanced out in the embodiments of FIGS. 8–11 by capacitively coupling the inner end of the center conductor **23** to conductor B of the slow wave circuit **4**. The series capacitance of the coupling capacitor C_s is series resonated at the frequency of the tube with the series inductance L_s. Due to the heavy coupling of the circuit **4** to the 50Ω load the Q of the series resonant coaxial coupling circuit, as coupled to the slow wave circuit **4**, is so low that the pass band of the series resonant coupling circuit is much wider than the electrically tunable band of the tube on the operating (N/2-1) mode.

The apparatus of FIGS. 8–11 is essentially identical to the apparatus of FIGS. 3 and 7 except for the provision of the coupling capacitor C_s provided at the inner end of the center conductor **23**. More particularly, in the structure of FIGS. 8 and 9 the plug **28** is terminated flush with a circumferentially enlarged window frame member **27**. A conductive tab **41** as of copper is brazed to conductor B such as to provide a portion facing the frame member **27** which is substantially of the same dimensions as the window frame member **27**. The frame member **27** is then slightly spaced from the tab **41** to form the series coupling capacitor structure C_s.

In a typical example of the capacitive coupling structure the tab **41** is made to have a circumferential extent of about 0.250″, a thickness of 0.030″, and a height h of about 0.100″. The spacing s between the opposed faces of the tab **41** and the end of the frame **27** is dimensioned for series resonance at the center of the pass band of the tube **1** and typically falls within the range of 0.015″ to 0.030″.

Referring now to FIG. 11 this structure is essentially identical to the structure of FIG. 7 except that the window frame member **27′** is terminated short of the opposed conductor B by a slight spacing s to form the series coupling capacitor C_s. The spacing s typically falls within the range of 0.015″ to 0.030″.

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 shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A composite coaxial line coupling device and gas tight wave permeable window assembly including, an evacuated wave supporting region of space defined between a pair of conductive portions defining a section of wave supporting structure having a radial line portion and a coaxial axially directed portion and containing fields to be coupled to a coaxial line, means forming a coaxial line having inner and outer conductor portions for coupling to the fields of said field containing region of space and having a certain characteristic impedance, the outer wall of said coaxial portion of said section of wave supporting structure being apertured for passage of said inner conductor of said coaxial line therethrough for coupling to the other conductor portion of said wave supporting structure, means forming a wave permeable dielectric window member coaxially surrounding said inner conductor and projecting into said field containing region of space, means at the inner end of said window for sealing said window member to said inner conductor, means forming an extension of said outer conductor of said coaxial line formed by a portion of one wall of said radial portion of said wave supporting structure disposed overlying an axially coextensive region of the inwardly projecting portion of said dielectric window member for loading same to maintain the characteristic impedance of the inwardly projecting portion of said coaxial line means, whereby reflections of wave energy from said window are minimized.

2. The apparatus according to claim **1** wherein said wave supporting region of space is a portion of a microwave periodic circuit, and including means for producing a stream of charged particles adjacent said periodic circuit for cumulative interaction with the fields thereof for producing an output signal which is coupled from said circuit to a load via said coaxial line.

3. The apparatus according to claim **2** wherein said periodic circuit and said particle stream producing means are portions of a voltage tunable magnetron.

4. The apparatus according to claim **4** wherein said periodic circuit is heavily coupled to the load for loading the periodic circuit and reducing the Q thereof for broadbanding said voltage tunable magnetron.

5. The apparatus according to claim **1** wherein said dielectric window member is a ceramic cylinder.

6. The apparatus according to claim **1** wherein said means for sealing the inner end of said window member to said center conductor comprises an annular metallic frame member.

7. The apparatus according to claim **3** wherein said evacuated wave supporting region of space is contained withinin radial cavity resonator resonant in the TM_{110} mode at the output signal frequency.

8. A composite coaxial line coupling device gas tight wave permeable window assembly including, an evacuated wave supporting region of space defined between a pair of conductive portions and containing fields to be coupled to a coaxial line, means forming a coaxial line having an inner and outer conductor for coupling to the fields of said field containing region of space and having a certain characteristic impedance, said inner conductor passing through an aperture in one of said field supporting conductor portions and being coupled to the other conductor portion, means forming a wave permeable dielectric window member coaxially surrounding said inner conductor and projecting into said field containing region of space, means at the inner end of said window for sealing said window member to said inner conductor, means forming an extension of said outer conductor of said coaxial line disposed overlying an axially coextensixe region of the inwardly projecting portion of said dielectric window member for loading same to maintain the characteristic impedance of the inwardly projecting portion of said coaxial line means, and means forming a coupling capacitor structure disposed at the inner end of said inner conductor of said coaxial line means for coupling said inner conductor of said coaxial line means to said other conductor portion which is being coupled to said coaxial line, whereby said capacitor structure balances out a small

series inductive reactance of the inwardly projecting portion of said coaxial line to provide a reflectionless window assembly.

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U.S. Cl. X.R.

315—39.63, 362; 333—33, 98