June 3, 1969 B. ARFIN ETAL 3,448,326

TWT WITH CLOVERLEAF SLOW-WAVE CIRCUIT HAVING SPECIALLY SHAPED COUPLING SLOTS

Filed Dec. 8, 1966 Sheet 1 of 2

FIG. 1

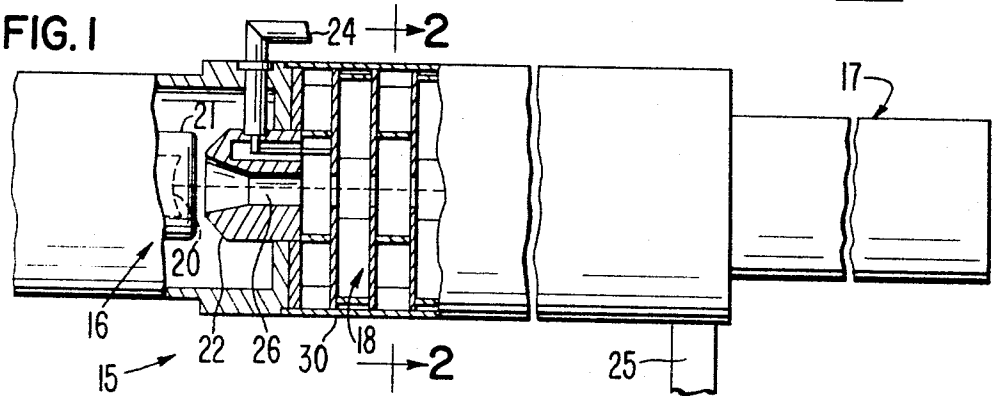


FIG. 2

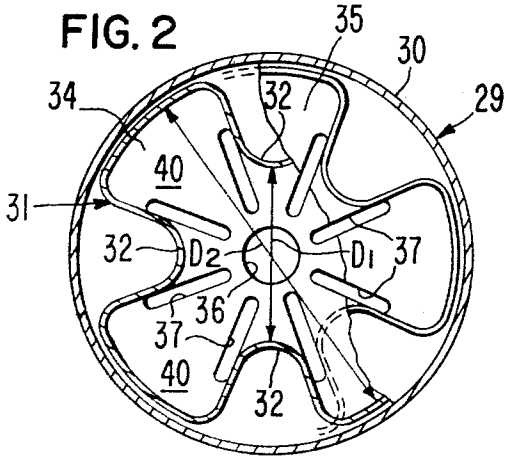
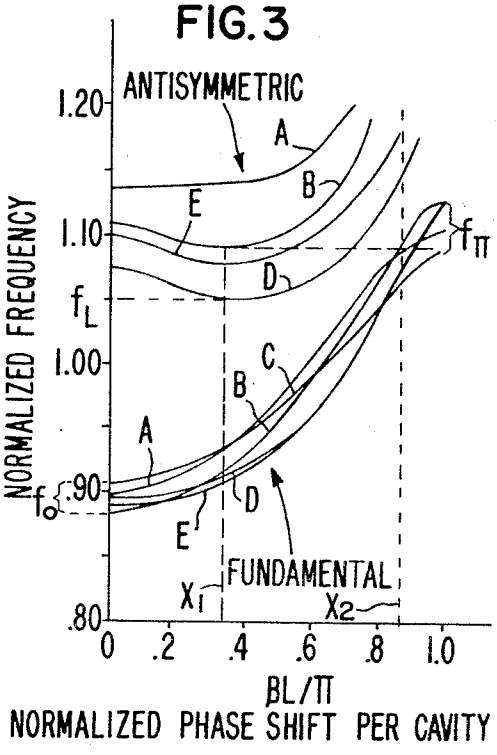


FIG. 3



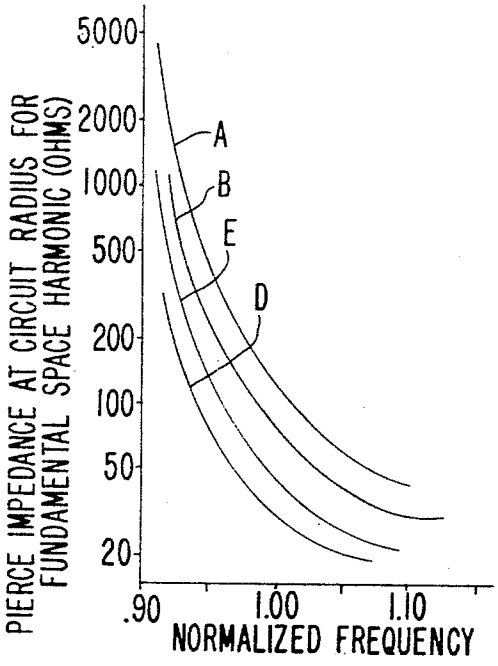


FIG. 4

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FIG. 5

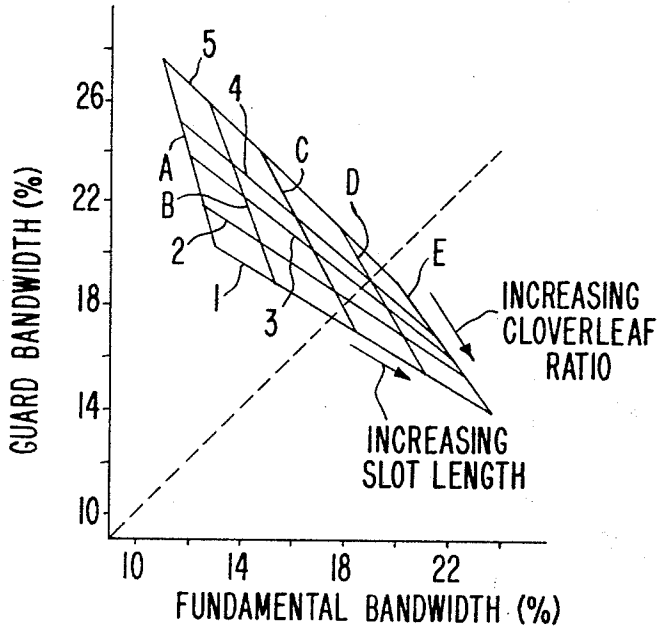


FIG. 6

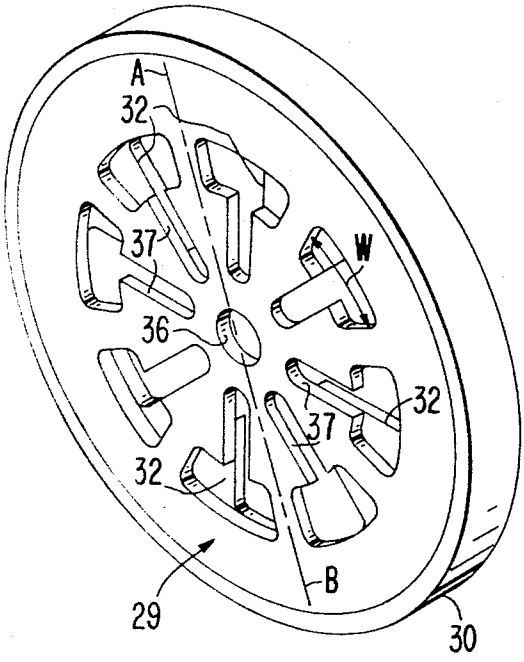
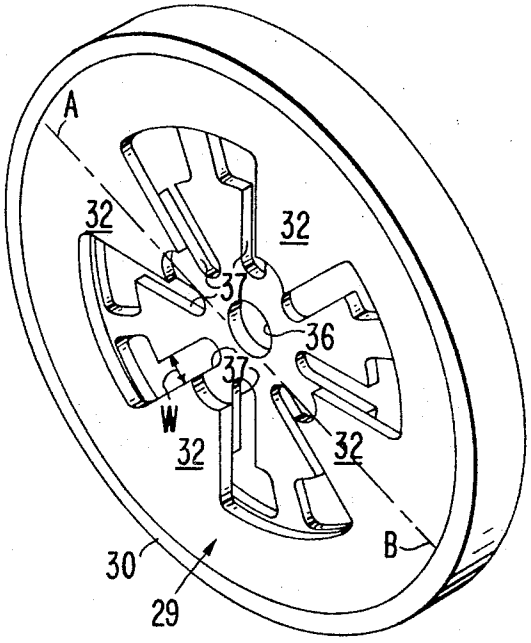


FIG. 7



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3,448,326

TWT WITH CLOVERLEAF SLOW-WAVE CIRCUIT HAVING SPECIALLY SHAPED COUPLING SLOTS

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U.S. Cl. 315—3.5 3 Claims

ABSTRACT OF THE DISCLOSURE

Coupling between adjacent cloverleaf cavities is provided by several radially spaced slots, each in the shape of a T as shown in FIG. 6. The T-shaped slots permit the use of increased thickness in the cavity end walls for high power capability while substantially preventing the loss of bandwidth which normally accompanies increases in end wall thickness.

This invention relates in general to the field of high frequency velocity modulated electron discharge devices incorporating coupled cavity slow-wave circuits of the cloverleaf type and more particularly to means for improving the bandwidth and power level capabilities of such devices without substantial degradation of interaction impedance.

Traveling wave tubes of both the conventional and hybrid (staggered tuned klystron inputs) types which utilize a cloverleaf type of slow-wave interaction circuit have found increased applications in microwave systems requiring large power levels (both average and peak) with good bandwidth, e.g., >10%. The teachings of the present invention are directed to increasing the average power levels while simultaneously increasing the operating bandwidth for S-band operation and any other regions of the microwave spectrum where the devices of the present invention are applicably scaled for operation.

The basic approach to increasing the average power capability of an ordinary cloverleaf slow-wave circuit is (1) to increase the thickness of the coupling plates and thus increase the thermal conduction properties; (2) to move the coupling slots radially outward from the beam coupling aperture to permit heat removal by the utilization of suitable water channels and/or increased thermal conductance to the outer peripheral regions of the circuit. However these measures have the undesirable effect of reducing the circuit interaction impedance as well as reducing the circuit cold bandwidth. In order to regain the lost bandwidth, the radial length and width of the coupling slots can be increased and the diameter (see e.g. D_1 in FIG. 2) between circuit nose or fingers can be decreased. However, these approaches have the undesirable effects of decreasing the circuit interaction impedance and also moving the anti-symmetric mode down in frequency and thus causing it to overlap the operating band of the fundamental mode.

By deforming the coupling slots into a T-shape by azimuthal enlargement of the outer peripheral slot dimensions it is possible to regain the bandwidth in cloverleaf circuits having increased plate thickness without substantial degradation of the circuit impedance or overlapping of the operating band.

It is therefore an object of the present invention to provide an improved high frequency electron discharge device of the traveling wave type.

A feature of the present invention is the provision of a high frequency electron discharge device incorporating a cloverleaf slow-wave interaction circuit with coupling slots in the end plates characterized by having larger

azimuthal dimensions at the outer slot radius than at the inner slot radius.

Another feature of the present invention is the provision of a high frequency electron discharge device incorporating a cloverleaf slow-wave interaction circuit with T-shaped coupling slots in the end plates.

These and other features and advantages of the present invention will become more apparent upon a perusal of the following specification taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a fragmentary longitudinal view, partly cut away, of a high frequency electron discharge device incorporating the teachings of the present invention,

FIG. 2 is a sectional view of a typical prior art cloverleaf slow-wave circuit cavity,

FIG. 3 is an ω–β diagram for a cloverleaf circuit showing the effects of modifying certain circuit parameters,

FIG. 4 is an illustrative graphical portrayal of impedance vs. frequency for a cloverleaf circuit showing the effects of modifying certain parameters,

FIG. 5 is a graphical plot of guard bandwidth defined as

$$\left(\frac{(f_L-f_0)}{\frac{1}{2}(f_\pi+f_0)}\times 100\right)$$

as shown e.g. in FIG. 3 where f_L is the lowest antisymmetric mode frequency and f_0 and f_π are the zero and π-points of the fundamental mode vs. fundamental bandwidth defined as

$$\left(\frac{(f_\pi-f_0)}{\frac{1}{2}(f_\pi+f_0)}\times 100\right)$$

for a cloverleaf circuit showing the effects of modifying certain circuit parameters.

FIGS. 6 and 7 are perspective views of both sides of a typical cloverleaf circuit section with T-shaped coupling slots.

Turning now to FIG. 1, there is shown a high frequency electron discharge device **15** incorporating a coupled cavity slow-wave circuit of the cloverleaf type. The device **15** is representative of both the conventional and hybrid types although particularly directed to the former. See, for example, U.S. Patent No. 3,233,139 by M. Chodorow and U.S. Patent No. 3,289,032, filed Dec. 30, 1963, by R. Rubert et al. and issued Nov. 29, 1966, both of which are assigned to the same assignee as the present invention for examples of coupled cavity traveling wave high frequency electron discharge devices of the conventional type and hybrid types incorporating cloverleaf slow-wave circuit sections. Briefly, the device **15** includes an electron beam forming and projecting means **16** disposed at the upstream end portion of the device and electron beam collector means **17** disposed at the downstream end portion of the device. Intermediate the upstream and downstream end portions a coupled cavity slow-wave circuit portion **18** of the cloverleaf type is disposed to provide interaction between the beam and the circuit in a manner well known in the art. The beam forming and projecting means **16** includes an electron gun with cathode emission surface **20**, focusing electrode **21** and accelerating anode **22** as shown. The gun region is separated from the circuit region via drift tube **26**. The shell **30** forms an evacuated enclosure for the device. Input coupler **24** feeds RF energy to be amplified to the input region of the circuit **18** and amplified RF energy is extracted via any conventional coupling mechanism, e.g., waveguide **25**. It is to be understood that the input section of the circuit **18** may be a klystron section for hybrid operation, e.g., as taught in the aforementioned U.S. Patent No. 3,289,032. The in-

put coupler can be a waveguide type instead of the coax coupler shown in FIG. 1.

Turning now to FIG. 2, there is depicted a typical prior art cloverleaf cavity section **29** disposed in a shell **30** which includes a sinuous four element sidewall portion **31** including the four 90° space rotated finger or nose sections **32**, slotted end wall plates **34, 35** having a central beam coupling aperture **36** and eight radially oriented coupling slots **37** provide wave coupling between adjacent cavities. Adjacent cavities are space rotated 45° relative to each other and provide negative mutual inductive coupling and good forward wave fundamental bandwidth in a manner well known in the art. A portion of sinuous side wall **31** for the next cavity section illustrates this as shown in FIG. 2. The cloverleaf cavity thus defines the four leaf sections **40** defined as above. The diameter or distance between nose or finger portions of the cloverleaf circuit is denoted D_1 and the diameter or distance between leaf peripheral wall portions is denoted D_2. It is to be noted that the terminology cloverleaf is not to be restricted to a 4 leaf or finger embodiment since 2, 6, 8, 10 etc. finger cloverleaf circuits are within the confines of the teachings of the present invention. The slot enlargement teachings of the present invention are equally applicable to said deviations and the terminology cloverleaf includes same.

As discussed above, attempts to increase the operating power level capabilities of a cloverleaf type of circuit have involved increasing the coupling plate thickness dimensions with resultant effects of reduction in circuit interaction impedance. Curve A in FIG. 4 is for a plate thickness of 6% of a periodic length L; curve B in FIG. 4 is for a plate thickness of 21% of a periodic length L; curve D in FIG. 4 is for a plate thickness of 30% of a periodic length L. The effects on circuit fundamental cold bandwidth of increasing the plate thickness dimensions are shown in the normalized ω–β plots in FIG. 3 where curve A represents a normal cloverleaf circuit with 6% of periodic length L plate thickness, curve B represents a normal cloverleaf circuit with 21% of periodic length L plate thickness, curve C represents a normal cloverleaf circuit with 30% of the periodic length L plate thickness with the coupling slots moved radially outward without increasing their dimensions; curve D represents a normal cloverleaf circuit with 30% of periodic length L plate thicknesses with the slots enlarged radially and azimuthally; curve E represents the same condition as for curve D except with the slots modified to a T-shape configuration as shown in FIGS. 6 and 7.

Generally speaking most cloverleaf circuits will have an operating bandwidth within the $\beta L/\pi$ region falling within X_1 to X_2 as shown in FIG. 3. It is evident from examination of FIG. 3 that curve D representative of the 30% plate thickness case with bandwidth regained by slot enlargement is highly undesirable from both an interaction impedance standpoint (see FIG. 4, curve D) and from a guard bandwidth standpoint as shown by the lowering of the anti-symmetric mode into an overlap condition with respect to the fundamental mode due to the slot enlargement.

The anti-symmetric mode overlap with the fundamental mode is undesirable for one reason because it introduces an element of doubt into the meaning of cold test measurements since it is difficult to determine the mode being observed. It is unlikely that there will be any beam-to-circuit interaction since the mode is anti-symmetrically disposed with respect to the beam axis resulting in zero net interaction. The main problem with the anti-symmetric mode is in impedance matching where the waveguide comes into the side of the leaf and may excite either mode. In FIG. 3 curves D and E have most of their fundamental bandwidth at high values of $\beta L/\pi$. Also from FIG. 3 it can be seen that a high value of $\beta L/\pi$ corresponds to a high value of frequency. From FIG. 4 it can be seen that a high value of frequency corresponds to a low value of interaction impedance. A curve that has most of its bandwidth at a lower value of $\beta L/\pi$ will have better impedance characteristics. A is such a curve.

One can attempt to increase the guard bandwidth by increasing the diameter D_1 between noses and thus reducing the cloverleaf ratio D_2/D_1 which as seen in FIG. 5 produces an increased guard bandwidth. However, this approach causes a reduction in fundamental bandwidth. The curves in FIG. 5 are plots of guard bandwidth as a function of fundamental bandwidth with slot length and cloverleaf ratio as parameters. The dotted line represents a division between overlap and non-overlap between anti-symmetric and fundamental modes. Regions above the dotted line are non-overlap or desirable conditions. Regions below the dotted line are overlap or undesirable conditions. The curves are plotted for a slot width=plate thickness=30% of L. The numbered lines **1, 2, 3, 4, 5** indicate constant cloverleaf ratio D_2/D_1 while the lettered lines A, B, C, D, E indicate constant slot lengths. It is seen that for a constant cloverleaf ratio as the slot length is increased to increase fundamental bandwidth the guard bandwidth is decreased. It is also seen that increasing D_2 relative to D_1 to increase D_2/D_1 results in increased fundamental bandwidth but decreased guard bandwidth. Similarly if D_1 is reduced relative to D_2 to increase D_2/D_1 the fundamental bandwidth is increased but again the guard bandwidth is decreased.

Turning now to FIGS. 6 and 7 there is depicted a novel type of cloverleaf circuit which overcomes certain of the above-indicated deficiencies and permits the cloverleaf circuit to handle high powers at increased bandwidths. By enlarging the outer radial (azimuthal or width) dimensions of the coupling slots **37** relative to the inner radial width dimensions it is possible to obtain broad bandwidth yet high power cloverleaf circuits (increased plate thickness) while still retaining good interaction impedance in the operating band. This is seen upon examination of the impedance plots in FIG. 4 where curve E represents a T-shaped slot with 30% plate thickness and curve D a typical prior art slot as shown in FIG. 2 with 30% plate thickness. The impedance is considerably enhanced without increasing the length of the slot dimensions to the detriment of circuit guard bandwidth as shown in FIGS. 4 and 5. As shown in FIG. 3 curve E represents the case where the T-shaped slots are used with a 30% thick plate as opposed to curves C and D which either decrease D_1 to the detriment of guard bandwidth as shown in FIG. 5 or increase slot length to the detriment of guard bandwidth as also shown in FIG. 5 to obtain increased fundamental bandwidth. Instead the T-shaped slots of the present invention produce an improved fundamental bandwidth without as radical degradation of guard bandwidth as the other approaches. Although the preferred embodiment depicts T-shaped slots as shown in FIGS. 6 and 7 it is to be understood that deviations of the enlarged regions from a rectangle shape to shapes such as ovals, circles, squares, etc., are within the scope of the present invention.

As shown in FIGS. 6 and 7, the coupling slots **37** are azimuthally enlarged at the outer radial portions. Since each adjacent cloverleaf cavity is space rotated 45° relative to the next cavity the finger or nose regions **32** will overlap half of each T-shaped slot. Since FIG. 6 is simply a perspective view of the back side of the cavity section **29** of FIG. 7 this can be seen by simply visually joining the two cavities along the lines denoted A–B. The cavity sections can be machined out of a solid metal block, e.g., copper or made in parts.

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 high frequency electron discharge device of the velocity modulation type including a coupled cavity type of slow-wave circuit disposed along the device axis, means for generating and directing an electron beam along the device axis disposed at the upstream end portion thereof, beam collector means disposed at the downstream end portion of said device, said coupled cavity slow-wave circuit including a plurality of cloverleaf cavities each bounded by a pair of end walls having central beam coupling apertures and a plurality of radially directed coupling slots therein, said cavities including radially directed finger members therein, said radially directed coupling slots in at least one of said plurality of cloverleaf cavities being wider at their outer radial end portion than at their inner radial end portion.

2. The device defined in claim 1 wherein said slots are T-shaped.

3. The device defined in claim 2 wherein the fingers in an adjacent cavity section overlap a portion of each of said T-shaped slots.

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U.S. Cl. X.R.

315—39.3; 333—31