Feb. 11, 1969 G. K. FARNEY 3,427,495

DUAL HELIX COUPLED PERIODIC CIRCUITS AND TUBES USING SAME

Filed Dec. 15, 1965 Sheet 1 of 2

FIG.1
PRIOR ART

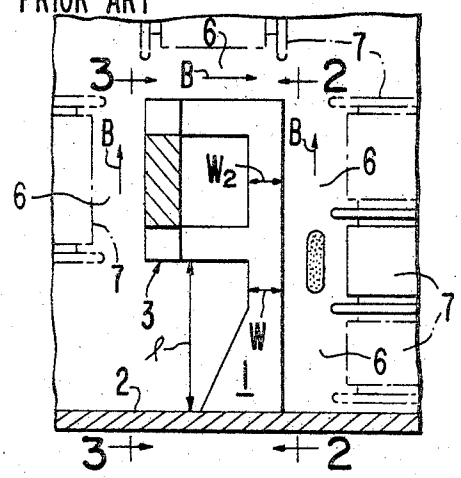


FIG.2
PRIOR ART

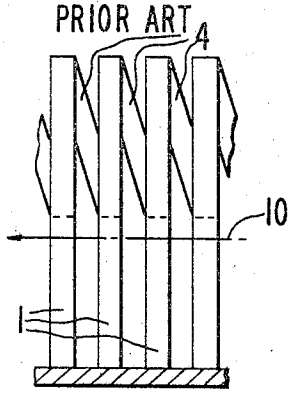
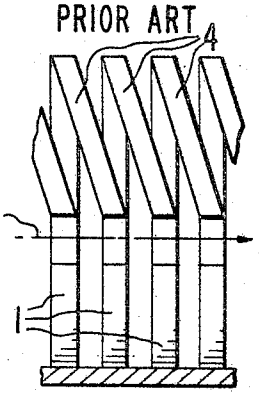


FIG.3
PRIOR ART



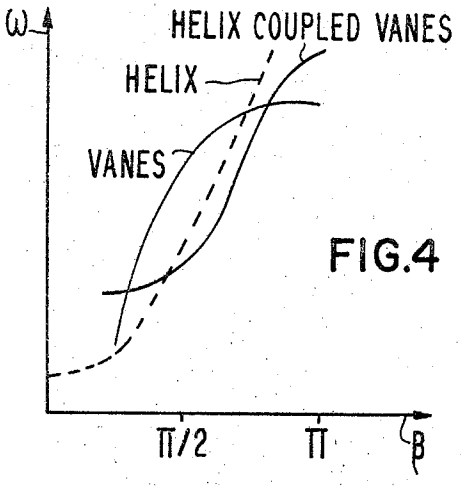
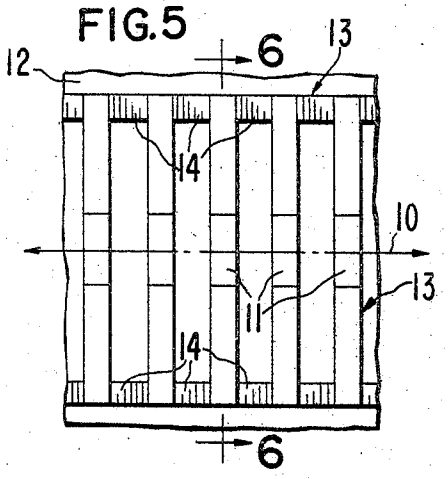


FIG.4

FIG.5



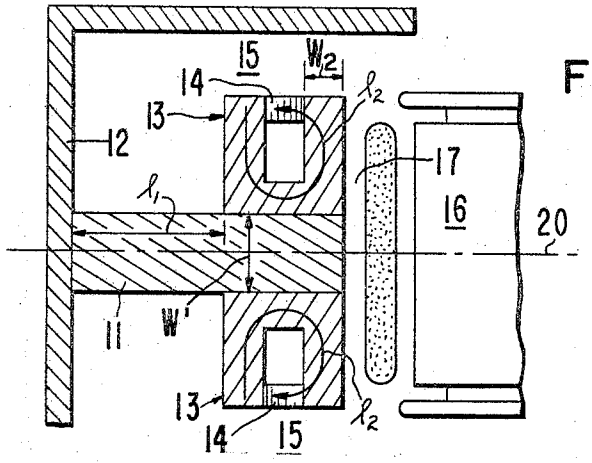


FIG.6

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DUAL HELIX COUPLED PERIODIC CIRCUITS AND TUBES USING SAME

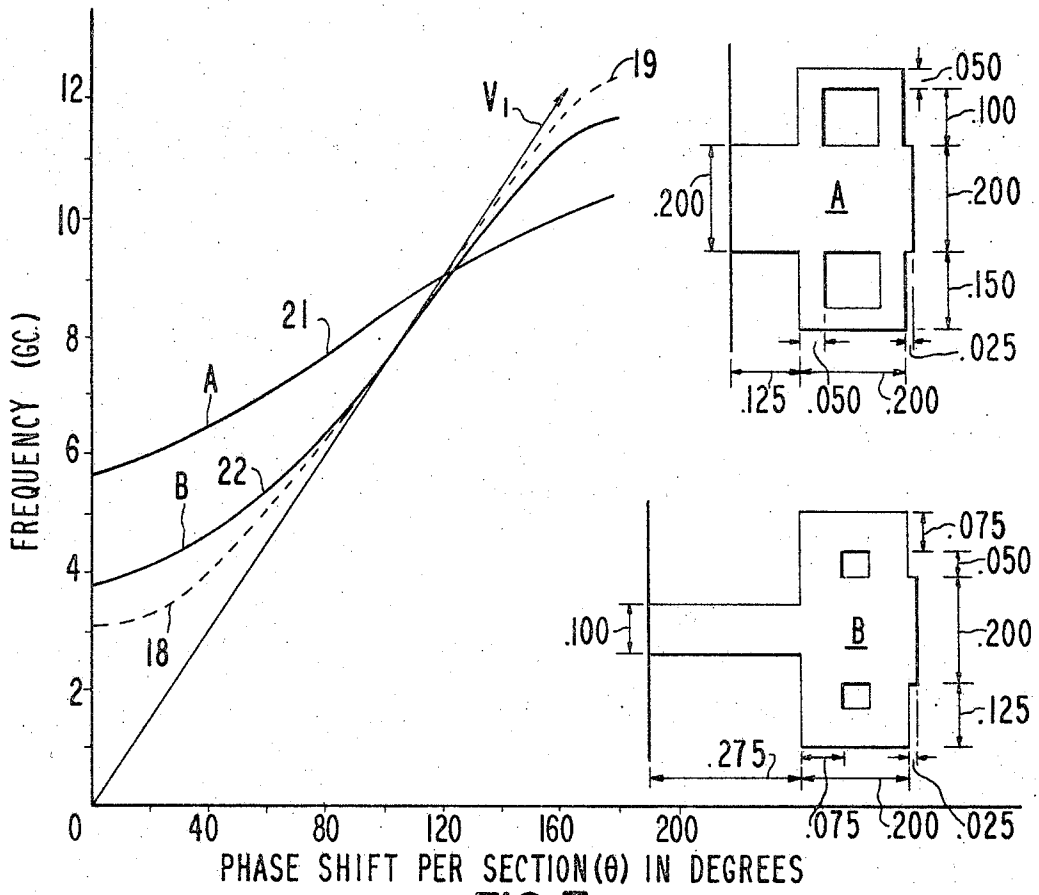


FIG. 7

FIG. 8

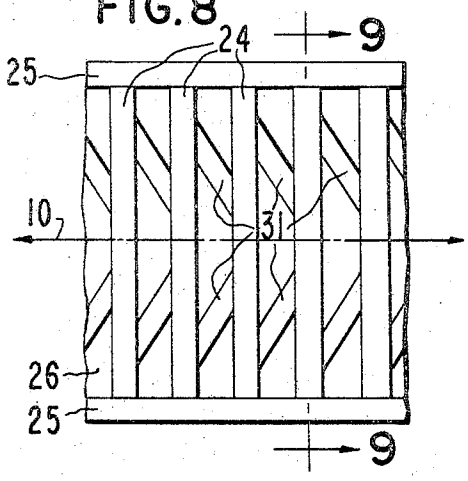
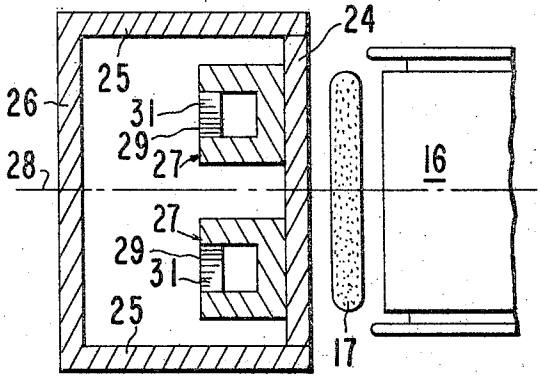


FIG. 9



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DUAL HELIX COUPLED PERIODIC CIRCUITS AND TUBES USING SAME

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U.S. Cl. 315—3.5 7 Claims
Int. Cl. H01j 25/34

ABSTRACT OF THE DISCLOSURE

A microwave tube is disclosed. The tube includes a periodic slow wave circuit formed by an array of vanes or bars coupled together by means of a pair of helices. The helices have their axes transversely displaced and they are each directed along the line of circuit development of the slow wave circuit. A cathode electrode produces a stream of electrons adajcent the array of helix coupled periodic vanes or bars for cumulative electronic interaction with the electromagnetic fields of the vanes or bars to produce output microwave energy. The helices are preferably wound with opposite senses of rotation and located on opposite sides of a plane of symmetry of the vanes or bars to prevent excitation of certain undesired modes of propagation.

Heretofore, in copending U.S. application, Ser. No. 454,140, now issued as U.S. Patent 3,387,170, and assigned to the same assignee as the present invention, it has been taught that the bandwidth of a periodic vane or bar circuit may be enhanced, in the forward wave fundamental space harmonic mode of operation, by coupling the vanes or bars together by means of a relatively low characteristic impedance helix; i.e., having an impedance comparable to that of the vane or bar circuit. While such a circuit has improved bandwidth, mechanical strength, and thermal capacity, which are all requisites for good microwave periodic interaction circuits, a need exists for further enhancement in the electrical, mechanical and thermal properties of the helix coupled circuit.

In the present invention there are provided novel helix coupled periodic circuits having improved electrical, mechanical and thermal properties by employing a plurality of helices coupled to common elements of the periodic circuit, for example, vanes or bars. The plural helices are preferably located on opposite sides of a plane of symmetry passing through the coupled members of the array and arranged to advance in the direction of the circuit with opposite senses of rotation, i.e., contrawound, whereby certain undesired modes of oscillation are prevented from being supported on the coupled common elements.

The principal object of the present invention is the provision of an improved plural helix coupled periodic circuit and tubes using same.

One feature of the present invention is the provision of a pair of helices coupled to a common array of elements of a periodic circuit for improving one or more of the thermal or electrical or mechanical properties of the circuit.

Another feature of the present invention is the same as the preceding wherein the common coupled elements of the periodic circuit are either vane or bar members.

Another feature of the present invention is the same as any one or more of the preceding wherein the plural helices include a pair of helices disposed on opposite sides of a plane of symmetry of the coupled periodic elements with the helices advancing in the direction of circuit development with opposite sense of rotation, whereby certain undesired modes of oscillation of the periodic elements are suppressed.

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 transverse line diagram of a prior art helix coupled vane circuit,

FIG. 2 is a view of the structure of FIG. 1 taken along line 2—2 in the direction of the arrows,

FIG. 3 is a view of the structure of FIG. 1 taken along line 3—3 in the direction of the arrows,

FIG. 4 is an ω versus β diagram showing the dispersion characteristics of a helix circuit, a vane circuit, and a helix coupled vane circuit,

FIG. 5 is a side elevational schematic line diagram of a dual helix coupled vane circuit embodying features of the present invention,

FIG. 6 is a transverse sectional view of the structure of FIG. 5 taken along line 6—6 in the direction of the arrows,

FIG. 7 is a frequency versus phase shift per section (ω versus β) diagram showing the measured dispersion characteristics for the dual helix coupled vane circuits shown in the inserts A and B,

FIG. 8 is a fragmentary elevational line diagram of a dual helix coupled bar circuit embodying features of the present invention, and

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

Referring now to FIGS. 1–3, there is shown the prior art helix coupled vane circuit. More specifically, an array of vanes 1, defining a line of circuit development 10, are carried at one end from a conductive wall 2 such that the vanes project outwardly therefrom. A helix 3 is connected to the end of the vanes 1 with the axis of the helix directed along the direction of the array of vanes 1. The vanes 1 have a length l, which is on the order of a quarter-wavelength long and for wide band operation the width of the vanes W is preferably comparable to the width W_2 of the conductor forming the helix 3. The helix 3 is conveniently made by slotting a relatively thick walled tube of rectangular cross-section through three sides of the tube leaving one side uncut. The uncut side is then slotted with an array of diagonal cuts with the member defined between adjacent diagonal cuts serving to couple one turn of the helix to the next. Electronic interaction may be had with the fields of the composite helix coupled vane circuit along the sides of the helix or along the sides of the vanes as indicated by 6 in FIG. 1. In FIG. 1 the interaction regions 6 are defined by the regions of space between the composite helix coupled vane circuit and the cathode electrodes 7 which are schematically shown.

The helix coupled vane circuit of FIG. 1 combines the thermal advantages of the vane circuit with the broad band characteristics of the helix to obtain a composite interaction circuit having lower bandwidth than a high impedance helix and higher bandwidth than a vane circuit with a thermal capacity of that of a vane circuit. The dispersion characteristics for a high impedance helix, helix coupled vane circuit and vane circuit are shown in FIG. 4.

Referring now to FIGS. 5 and 6, there is shown the dual helix coupled vane circuit of the present invention. More specifically, an array of vane members 11 as of copper is carried from a conductive wall member 12 as of copper with the vanes 11 projecting outwardly from the wall. A pair of helices 13 as of copper are coupled to the vanes 11 at their side edges, and preferably near the ends, said helices extending in the direction of the array of vanes 11. The helices 13 are preferably made of rec-

tangular cross-section having three side portions thereof in the plane of the vane and including a diagonal leg portion **14** extending to the adjacent turn of the helix. The diagonal members **14** are preferably formed by slotting the side of a tube which is remote from the ends of the vanes with an array of diagonal slots to define the diagonally directed members **14** between adjacent slots. The helices **13** on opposite sides of the vanes **11** thus are dimensioned and arranged to have the same pitch and furthermore are arranged such that one of the helices advances along the circuit in a clockwise direction while the other helix on the opposite side of the vanes **11** advances along the circuit in the counterclockwise direction. In this manner, currents flowing out the vane and into the helices flow in the same direction near the ends of the vanes **11**. With the sense of rotation of the helices arranged as aforesaid (contrawound) the current flowing in one helix does not tend to cancel the current flowing in the other helix. Moreover, this leads to a symmetrical flow of current in the vane **11** and helices **13** which is desirable for preventing excitation of certain undesired modes of resonance associated with the end spaces of the circuit designated as **15** on the drawing.

The dual helix coupled vane circuit of FIGS. 5 and 6 is preferably used in crossed-field type M tubes such as, for example, magnetrons either of the circular or linear type, wherein the circuit serves as the anode to collect the beam. Thus the electrons which interact the fields of the circuit may approach close to the circuit for increased interaction. This is desired since the circuit has a relatively low interaction impedance. Thus, the helix coupled circuit of FIGS. 5 and 6 is preferably arranged for interaction with a stream of electrons **17** in an interaction region defined between the circuit and a cathode emitter **16** or a cathode electrode which may be of the nonemitting type. For broadband operation, it is desirable that the width of the conductor W_2 forming the helix **13** be comparable to one-half the width, W', of the vane members **11**. Increasing the length of the vane, l_1, lowers the low frequency cutoff of the circuit as indicated by the dotted lines **18** of FIG. 7, whereas decreasing the length of the helical circuit between adjacent turns, l_2, raises the high frequency cutoff as indicated by the dotted line **19** as of FIG. 7.

The advantage of the dual helix coupled vane circuit over the single helix coupled vane circuit of FIG. 1 is that the electronic interaction area has been substantially increased compared to that of circuit of FIG. 1 thereby permitting more power output for a given power density on the interaction circuit. In addition the symmetry of the circuit, with the helices **13** symmetrically placed about a plane indicated by line **20** passing through the axial center of the vane members, leads to better control of spurious modes encountered in the end regions **15** of the circuit. Furthermore, the provision of dual helices coupled to the vanes **11**, rather than a single helix, gives greater mechanical strength to the composite circuit. Also dual helices permit the vane members **11** to be twice as wide as the similar vane member for a single helix coupled circuit, thereby substantially improving the thermal capacity of the dual helix coupled vane circuit by allowing improved cooling to the back wall **12**.

Measured dispersion characteristics for the circuits of FIGS. 5 and 6 are shown in FIG. 7. More particularly, curve **21** shows the dispersion characteristic for the dual helix coupled vane circuit having dimensions as shown in insert A. This circuit readily yields a 10% electronic bandwidth at X-band and a practical synchronous voltage as is indicated by line V_1. The dispersion characteristic for the X-band circuit of insert B, having dimensions as indicated, readily yields an electronic bandwidth on the order of 1 octave from 5 gc. to 11 gc. Thus it is seen that the dual helix coupled vane circuit leads to a relatively rugged circuit having relatively high thermal capacity and having substantial electronic bandwidth. Such circuits are especially desirable for wide band amplifiers.

Referring now to FIGS. 8 and 9, there is shown an alternative embodiment of the present invention. More particularly, the circuit shown is a dual helix coupled bar circuit. The circuit comprises an array of conductive bar members **24** as of copper shorted at their ends by a pair of conductors **25** as of copper which may extend back to and include the back wall **26** of the circuit. A pair of helices **27** as of copper are joined to the bars **24** intermediate their length and extend along the line of circuit development defined by the array of bars. The helices **27** are preferably located symmetrically above and below a center plane **28** bisecting the centers of the bars **24**. As in the previous example the helices should be formed with the same pitch but with opposite sense of rotation taken in the direction along the array of bars. In this manner coupling currents flowing in the helices **27** do not excite certain undesired modes of resonance associated with nonsymmetric current flow in the circuit including the bars **24**.

The helices **27** may be centrally disposed of the bars **26** with their mutually opposing side edges in substantial contacting relationship or they may be substantially spaced apart of the bars **24** but preferably more centrally located than near the ends of said bars. As before, the helices **27** are preferably made by brazing a pair of relatively thick walled tubes to the back sides of the bars **24**, said tubes having rectangular cross-section. The tubes are then slotted through three sides from the side abutting the bars **24** leaving a remaining unslotted wall **29**. The unslotted wall is then slotted with an array of diagonally directed slots leaving a diagonally directed conductive member **31** interconnecting adjacent turns of the helix.

The dual helix coupled bar circuit of FIGS. 8 and 9 has the advantage over the dual helix coupled vane circuit of providing increased interaction area as the bars **24** may be substantially longer than the interaction area of the vane circuit of FIGS. 5 and 6 for a given frequency. In addition, the dual helix coupled bar circuit of FIGS. 8 and 9 provides a mechanically more rigid structure than a single helix coupled bar circuit due to the fact that adjacent bars are tied together by means of two helices rather than a single helix. Furthermore, as aforementioned the symmetry of the dual helix coupled bar circuit prevents setting up of certain undesired modes of resonance associated with nonsymmetrical current distribution as may be encountered with a single helix coupled bar circuit.

Since many changes can be made in the above constructions and apparently widely different embodiments 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. In a microwave tube having a certain operating band of frequencies, means forming an array of coupled periodic conductive elements arranged along a line of circuit development, said conductive elements of said array including an array of elongated conductive member portions with adjacent member portion short circuited together at one end for microwave energy of a frequency within the operating band of frequencies of the tube to define a periodic slow wave circuit, the improvement comprising, means forming a pair of helices, said helices being connected to said elongated conductive member portions in regions removed from their short circuited end portions for coupling said conductive members, said helices having their axes transversely displaced and directed along the line of circuit development of said slow wave circuit, means for producing a stream of electrons adjacent said array of helix coupled periodic elements for cumulative electronic interaction with the electromagnetic

fields of said conductive member portions to produce output microwave energy.

2. The apparatus according to claim 1 wherein said helices advance along the direction of circuit development with opposite senses of rotation.

3. The apparatus according to claim 2 wherein said array of coupled conductive member portions comprise an array of vanes shorted at the base ends thereof and being open at the tip portions thereof.

4. The apparatus according to claim 2 wherein said array of conductive member portions comprise an array of bars shorted at the opposite ends thereof.

5. The apparatus according to claim 2 wherein said helices are connected to adjacent periodic elements of said array of periodic elements.

6. The apparatus according to claim 2 wherein said helices are symmetrically located on opposite sides of a plane of symmetry of said array of coupled periodic elements.

7. The apparatus according to claim 3 wherein said helices are located on opposite side edges of said vanes nearer to the tip portions of said vanes than the base portions of said vanes.

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U.S. Cl. X.R.

315—3.6; 333—31