M. CHODOROW

COAXIAL CAVITY SLOW WAVE STRUCTURE WITH NEGATIVE MUTUAL INDUCTIVE COUPLING

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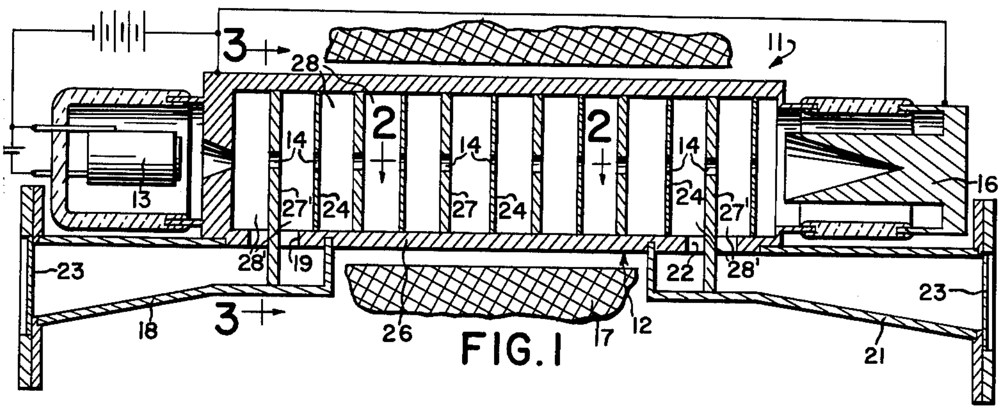


FIG.1

FIG.2a

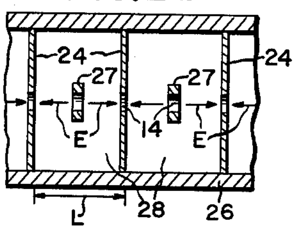


FIG.2b

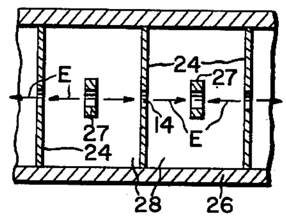
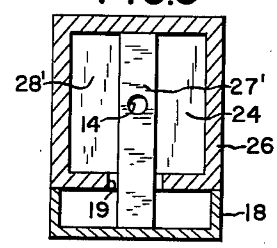


FIG.3



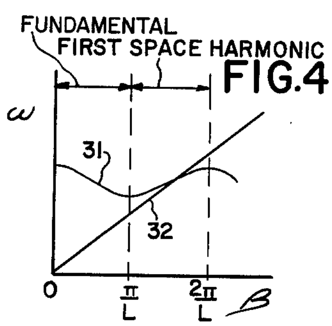


FIG.4

FIG.5a

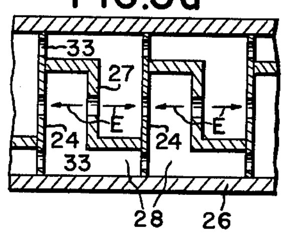
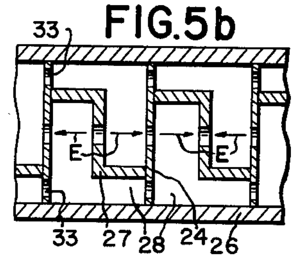


FIG.5b



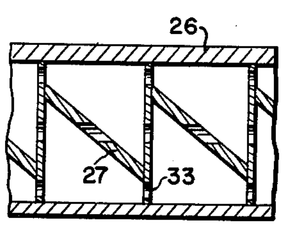


FIG.6

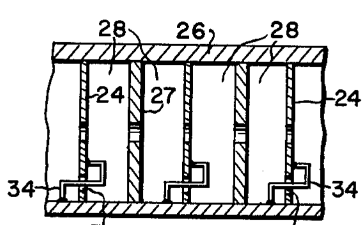


FIG.7

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COAXIAL CAVITY SLOW WAVE STRUCTURE WITH NEGATIVE MUTUAL INDUCTIVE COUPLING

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This invention relates in general to high frequency apparatus, more particularly, to a periodic slow wave structure having novel resonating sections in the apparatus, and to the method of providing mutual coupling between sections of the slow wave structure.

Loaded waveguides or transmission lines are used as wave propagating circuits for traveling wave tubes. These devices are of the filter type circuits consisting of waveguides with some sort of periodic loading to slow down the wave phase velocity to that of the electrons in the beam. This type of structure is more rugged, dissipates more heat, and is more easily manufactured than the helix type structure. The usual sort of periodic loading for a waveguide consisted of dividing the waveguide into sections by transverse walls to form a series of cavity resonators and the sections are coupled together either capacitively or inductively or both. If the sections are coupled by both capacitive and inductive coupling, the inductive coupling must be negative and therefore aid the capacitive coupling in making the group velocity of the wave positive for the fundamental space component or harmonic. But a structure that has a group velocity positive for the fundamental space component must interact with a higher-energy beam than a structure which has the group velocity of the wave positive in the first space harmonic component. Up to now, traveling wave tubes were preferably operated on the fundamental space component of the wave propagating structure than on the first space harmonic component because the amplitude of the interacting fundamental space component was larger than the amplitude of first or higher space harmonics which higher amplitude means that better interaction is obtained between the wave and the beam.

The principal object of the invention is to provide in high frequency apparatus a novel resonating section having improved characteristics of its propagating wave in its first space harmonic.

One feature of the present invention is the provision of a periodic wave-propagating structure having a series of cavity resonator sections disposed in an axis with a conducting bar disposed substantially transversely within each section and terminating on opposite axially parallel cavity walls.

Another feature of the invention is the provision of a periodic wave-propagating structure having a series of cavity resonator sections disposed in an axis with a conducting bar disposed substantially transversely within each section and terminating on opposite axially transverse common walls.

Another feature of the present invention is the provision of a high frequency electron discharge device incorporating coaxial cavities for a slow wave interaction circuit, said coaxial cavities being provided with negative mutual inductive coupling means.

Another feature of the invention is the provision of the addition of inductive coupling slots disposed near the outer region of the transverse common wall between two adjacent cavities and the conducting bar which terminates on the common walls is disposed inwardly of inductive coupling slots.

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Still another feature of the invention is the provision of negative mutual inductive coupling between adjacent coaxial cavities such as to perturb the π mode of the circuit formed by the cavities.

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

FIG. 1 is a longitudinal section view of a typical traveling wave tube incorporating the novel slow wave structure.

FIGS. 2*a* and 2*b* are fragmentary sectional views of the traveling wave tube of FIG. 1 taken on line 2—2 in the direction of the arrows, with FIG. 2*a* showing the "0" mode of operation and FIG. 2*b* showing the π mode of operation.

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

FIG. 4 is a Brillouin diagram for the slow wave structure as shown in FIG. 1.

FIGS. 5*a* and 5*b* are fragmentary longitudinal sectional views of another embodiment of the slow wave structure of FIG. 1 having improved coupling with FIG. 5*a* showing the "0" mode of operation and FIG. 5*b* showing the π mode of operation.

FIG. 6 is a fragmentary longitudinal sectional view of still another embodiment of the slow wave structure.

FIG. 7 is a fragmentary sectional view of still a further embodiment of the slow wave structure.

Although the present invention will be explained as it is applied to a traveling wave tube, the present invention has application to many different devices including backward wave oscillators, linear accelerators, microwave filters and velocity modulation devices.

Referring now to the drawings and to FIG. 1 in particular there is shown a traveling wave tube amplifier **11** utilizing the novel periodic slow wave structure **12**. An electron gun assembly **13** provides a beam of electrons which passes axially through a series of space displaced aligned apertures **14** in the slow wave structure **12**. A collector assembly **16** is provided at the terminating end of the slow wave structure and serves to collect the electrons of the beam at the terminating end of the beam path and dissipates the power therein while a focusing electrical coil **17** surrounds the slow wave structure **12** to provide a magnetic field to confine the electrons to a prescribed beam path thereby minimizing electron interception within the slow wave structure.

An input waveguide section **18** is coupled by a coupling aperture **19** into the slow wave structure **12** and transmits low amplitude high frequency electromagnetic wave signals to the slow wave structure **12**. The wave signals are propagated along the slow wave structure **12** wherein energy is delivered by the beam to the wave signals thereby increasing the amplitude of the wave signals.

An output waveguide section **21** receives the amplified signals through another coupling aperture **22** and propagates it to a load (not shown). Suitable vacuum tight wave permeable windows **23** are placed in the waveguide sections **18** and **21** forming a part of the vacuum envelope of the tube.

The slow wave structure **12** includes a series of apertured transverse common walls **24** disposed within a substantial rectangular tube **26** and between two transverse walls **24** are disposed apertured transverse bars **27**. In essence two adjacent transverse walls, the transverse bar or inner conductor **27** between the two walls, and the rectangular tube or outer conductor **26** provide a length of coaxial line shorted at its ends to form cavities **28** (FIG. 2). The cavities **28** are aligned so that the transverse bar is disposed substantially perpendicular to the beam and preferably parallel to each other as shown. To increase the coupling between the waveguides **18** and **21** and the slow wave structure, the bars **27'** (FIG. 3) in the first and last cavities **28'** protrude outwardly of the resonators **28'** through apertures **19** and **22** respectively into the adjacent waveguide and terminates on a wall therein.

Referring to FIGS. 2*a* and 2*b* the dominant modes of oscillation of the structure are shown. Each cavity **28** formed by two transverse walls **24** have the bar **27** disposed substantially midway between the two walls **24** and the electrical field therein will be either pointed towards the bar **27** or away from the bar **27**. Thus when the electric field in each cavity **28** points away from the bar **28** as shown by arrows E in FIG. 2*a*, this phenomenon will be known as the "0" mode of operation. When the electric field in each cavity is reversed in direction to the electric field in its adjacent cavity, as shown again by the arrows E in FIG. 2*b*, it will be known as the π mode of operation.

The slow wave structure **12** has a Brillouin diagram as shown in FIG. 4 wherein the abscissa is the propagation constant β and the ordinate is the frequency ω. The π mode of operation by definition has a propagation constant of π/L wherein L is the distance between corresponding points of adjacent cavities **28**. The sinusoidal curve **31**, shown in the diagram, has maximum and minimum peaks representing the cutoff frequency of the structure and these peaks occur at modes 0, π, 2π, 3π, etc. respectively because the cavities **28** are capacitively coupled through apertures **14** of walls **24** and the capacitance of the cavities are perturbed in 0, 2π, etc., modes and are not perturbed in the π mode causing the frequency to go up in the 0, 2π, etc. modes and remains the same in the π, 3π, etc. modes. The slope at any point of the sinusoidal curve **31** represents the instantaneous group velocity of the wave traveling through the structure **12**. The slope of any straight line **32** emanating from the origin 0 and intersects the sinusoidal curve **31** represents the phase velocity of the traveling wave and the particular line **32** shown is the phase velocity at ¾ of the operating cycle. The closer the electron velocity of the beam approaches the phase velocity of the traveling wave, the interaction between the wave and the beam becomes more efficient, and also when the phase velocity approaches the group velocity the bandwidth of the traveling wave amplifier becomes broader. This structure is operated so that the time the electron takes to travel from the same point between adjacent cavities **28** is approximately three-quarters of a cycle of the operating frequency of the apparatus and the time the electron takes to travel to one point on one side of one bar **28** to a corresponding point on the other side of the same bar is approximately equal to one-half a cycle of the operating frequency of the tube. This can conveniently be accomplished by making the bar thicker than a common wall between the cavities thereby controlling the length of travel of the electron as it goes between corresponding points of opposite sides of the bar **27** within the same cavity and between corresponding points in adjacent cavities. The half cycle from one side of the cavity bar to the other side of the cavity bar and a three-quarter cycle between corresponding points with two adjacent cavities are compatible requirements in the first space harmonic component of FIG. 4. The interacting first space harmonic will have a large amplitude and electrons will see electric fields practically all the time rather than spend useless time in a drift tube.

This structure has a drawback that the central hole in the common wall does not give enough coupling between the two cavities and therefore the bandwidth is limited. If one puts a hole in the common wall between cavities and near the periphery of the common wall that is near the end of the coaxial cavity **28**, such a hole will produce

magnetic or inductive coupling between adjacent cavities but of the wrong kind namely for the 0 mode, the frequency would go down because the inductance of the cavities is increased. The inductance of the cavities increases in the 0 mode and not in the π mode because in the 0 mode the current on either side of the wall flows in the same direction and therefore must flow around the hole over a greater path but in the π mode the current on either side of the wall flows in opposite directions and therefore flows through the hole to the other side over substantially the same length path as if the hole was not there. In the embodiment shown in FIGS 5*a* and 5*b* the electrostatic field lines E as in the structure of FIG. 1 point away from the bar **27** in the 0 mode (FIG. 5*a*) and in the π mode (FIG. 5*b*) the lines point toward the bar in every other cavity **28**. The bars **27** are made to terminate on opposite common walls **24**, leaving enough room between the bar **27** and walls of the tube **26** to provide a coupling aperture **33** in walls **24**. In the 0 mode the magnetic field line H points into the paper on the lower periphery of the tube **26** (as viewed in the drawing) for each cavity **28** and out of the paper on the upper periphery as denoted by small crosses (+) and dots (·) respectively. The inductance of the cavities in the 0 mode does not increase in this case and the frequency is not perturbed, but the inductance of the cavites **28** are increased in the π mode as can be seen in FIG. 5*b* in that the magnetic field lines (+) and (·) point in opposite directions on either side of the aperture **33**. This coupling concept between adjacent cavities in which the inductance of the cavity is increased in the π mode of operation is referred to as negative mutual inductive coupling.

Negative mutual coupling between cavities **28** which have a center conducting bar **27** may also be obtained by alternate embodiments. FIG. 6 shows a variation in the shape of the bars **27** in that they are inclined to the beam axis. FIG. 7 shows still another embodiment wherein adjacent cavities are coupled through an inverted coupling loop **34** which extends through a small hole **35** in walls **24**. In each of these embodiments the inductance of the cavities is increased in the π mode but not in the 0 mode.

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 slow wave circuit capable of supporting traveling electromagnetic wave energy thereon, comprising, cavity resonator means forming at least two cavity resonators successively disposed along and defining an axis of propagation for said electromagnetic wave energy, said cavity resonator means being physically oriented with respect to said axis to substantially align at least a portion of the in-phase mode of operation electric field lines within said cavity resonator means with said axis, a conducting bar disposed within each of said cavity resonators and crossing said axis, and negative mutual inductive coupling means communicating between said cavity resonators.

2. The apparatus according to claim 1, wherein said cavity resonator means include a conducting transverse common wall member separating adjacent cavity resonators, one of said conducting bars disposed within each of said cavity resonators, said negative mutual inductive coupling means communicating between adjacent cavity resonators through inductive apertures provided in said common wall, said apertures being offset with respect to said axis.

3. The apparatus according to claim 2 wherein said axis is substantially a straight line forming the axis of

the slow wave circuit, and wherein said conducting wall members and said conducting bars have apertures therein, said apertures being aligned along said axis.

4. The apparatus according to claim 3 wherein said successive cavity resonators have substantially equal dimensions.

5. The apparatus according to claim 4 wherein an electron beam is provided to pass through said axially aligned apertures, and wherein the axial distance between corresponding points of adjacent cavity resonators corresponds to the distance that an electron in said beam takes to travel in three-quarters of a cycle of the operating frequency of the apparatus, and the length between corresponding points on opposite sides of said conducting bar within the same cavity is equal to the distance that said electron takes to travel in one-half cycle of said operating frequency.

6. A high frequency slow wave circuit adapted and arranged to support traveling electromagnetic wave energy thereon comprising at least two resonant sections successively arranged along and defining an axis of propagation for said traveling electromagnetic wave energy, a conducting wall member separating adjacent resonant sections, said sections being physically oriented with repect to said axis to substantially align at least a portion of the in-phase mode-of-operation electric field lines within said sections with said axis, a conducting bar disposed within each of said sections and crossing said axis, and negative mutual inductive coupling means intercoupling said at least two resonant sections, said negative mutual inductive coupling means comprising an aperture in said wall members with the ends of each of said bars being terminated on opposite wall members of each section.

7. The apparatus according to claim 6 wherein said negative mutual inductive coupling means further include the said aperture in said wall member being disposed on the remote side of said bar from said axis.

8. A slow wave circuit for high frequency traveling electromagnetic wave energy comprising, a plurality of coupled coaxial cavity resonators disposed along and defining an axis of propagation for said traveling electromagnetic wave energy, inductive coupling means between at least two adjacent coaxial cavity resonators of said plurality of coupled coaxial cavity resonators, said coaxial cavity resonators being defined by spaced conductive walls disposed along said axis, the center conductors of at least two adjacent coaxial cavity resonators of said plurality of coaxial cavity resonators being a conductive bar disposed within each said coaxial cavity resonator, said bars being disposed within each of said cavity resonators with respect to said inductive coupling means so as to cause perturbation of the π mode of operation of said cavity resonators while substantially unaffecting the 0 mode of operation of said cavity resonators.

9. A slow-wave circuit for high frequency electromagnetic waves comprising, a plurality of coupled coaxial cavity resonators, said coaxial cavity resonators each having an inner conductor disposed within an outer conductor, said coaxial cavity resonators, having negative mutual inductive coupling means between adjacent coaxial cavity resonators, said plurality of coupled coaxial cavity resonators being coupled together in a manner such as to support traveling electromagnetic wave energy emanating from a source of traveling electromagnetic wave energy coupled to said plurality of coupled coaxial cavity resonators forming said slow wave circuit, said plurality of coupled coaxial cavity resonators forming said slow wave circuit being further coupled together in a manner such that an electron beam can be directed through said plurality of coupled coaxial cavity resonators in a manner such that an energy exchange between traveling electromagnetic wave energy supported on said slow wave circuit and an electron beam directed through said slow wave circuit can occur.

10. A high frequency slow wave circuit adapted and arranged to support electromagnetic traveling wave energy thereon comprising, a plurality of coaxial cavities, said coaxial cavities each having an inner conductor disposed within an outer conductor, said coaxial cavities being successively arranged along and defining an axis of propagation for said electromagnetic traveling wave energy and negative mutual inductive coupling means electrically coupling at least two adjacent coaxial cavities of said plurality of coaxial cavities whereby the π mode of operation is perturbed thus lowering the frequency at the π mode of operation.

11. The slow-wave structure of claim 9 wherein the outer conductors of said coaxial cavities are partially defined by spaced conducting walls having axially aligned apertures therein and the center conductors of said coaxial cavities being conducting bars having axially aligned apertures therein.

12. The slow-wave structure of claim 10 wherein the outer conductors of said coaxial cavities are partially defined by spaced conducting walls having apertures therein and the center conductors of said coaxial cavities being conducting bars having apertures therein.

13. The slow-wave structure of claim 11 wherein said conducting bars are conductively connected to said spaced conductive walls partially defining each of said cavities.

14. The slow-wave structure of claim 12 wherein said conducting bars are conductively connected to said spaced conductive walls partially defining each of said cavities.

15. The slow-wave structure of claim 11 wherein at least two adjacent coaxial cavities of said plurality of coaxial cavities are coupled by means of an inverted coupling loop extending through an aperture in said conducting wall between said at least two adjacent coaxial cavities.

16. The slow-wave structure of claim 12 wherein at least two adjacent coaxial cavities of said plurality of coaxial cavities are coupled by means of an inverted coupling loop extending through an aperture in said conducting wall between said at least two adjacent coaxial cavities.

17. A high frequency slow-wave structure comprising a plurality of coupled cavity resonators disposed along an elongated axis, said cavity resonators being defined by spaced conductive walls transversely oriented with respect to said elongated axis, said conductive walls having both axial and axially displaced apertures therein, said resonators having conductive bars disposed therein, each of said conductive bars having an axial aperture therein, said axial apertures in said conducting walls and said bars being aligned along said elongated axis, said conductive bars and said axially displaced apertures in said conducting walls being so oriented whereby π mode currents in said conductive walls are displaced around said axially displaced apertures in said conductive walls thus increasing the inductance for the π mode of operation and resulting in a lowering of the frequency for the π mode of operation.

18. A high-frequency slow-wave structure adapted and arranged to support electromagnetic traveling wave energy comprising, a plurality of successively coupled coaxial cavity resonators said coaxial cavity resonators having an inner conductor disposed within an outer conductor, at least two adjacent ones of said plurality of coaxial cavity resonators having negative mutual inductive coupling means therebetween whereby π mode currents in common walls which partially define said adjacent coaxial cavity resonators are perturbed and thereby caused to flow around apertures within said common walls thus lengthening the current paths for π mode currents in said walls.

19. A high frequency electron discharge device comprising an electron gun, slow wave circuit and collector assembly operatively connected to form a traveling wave tube, said slow wave circuit comprising, a plurality of

successively coupled coaxial cavity resonators, said coaxial cavity resonators having an inner conductor disposed within an outer conductor, at least two adjacent coaxial cavities of said plurality of coupled coaxial cavity resonators being intercoupled by negative mutual inductive coupling means.

20. A high frequency slow wave circuit adapted and arranged to support traveling electromagnetic wave energy thereon including resonator means forming at least two coaxial cavity resonators successively arranged along and defining an axis of propagation for said traveling electromagnetic wave energy and wherein said axis is substantially a straight line forming the axis of the slow wave circuit, said resonator means being physically oriented with respect to said axis to substantially align at least a portion of the in-phase mode of operation electric field lines within said means with said axis, the center conductor of each of said coaxial cavity resonators having an axially aligned aperture therein disposed within each of said coaxial cavity resonators and crossing said axis, means for coupling high frequency electromagnetic wave energy into and out of said resonator means, said resonator means being partially defined by transverse conducting walls having axially aligned apertures therein, and negative mutual inductive coupling means intercoupling said at least two adjacent coaxial cavity resonators whereby the cut-off frequency in the π mode of operation is lowered without substantially perturbing the 0 mode cut-off frequency.

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