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MICROWAVE SLOW WAVE DIELECTRIC STRUCTURE
AND ELECTRON TUBE UTILIZING SAME
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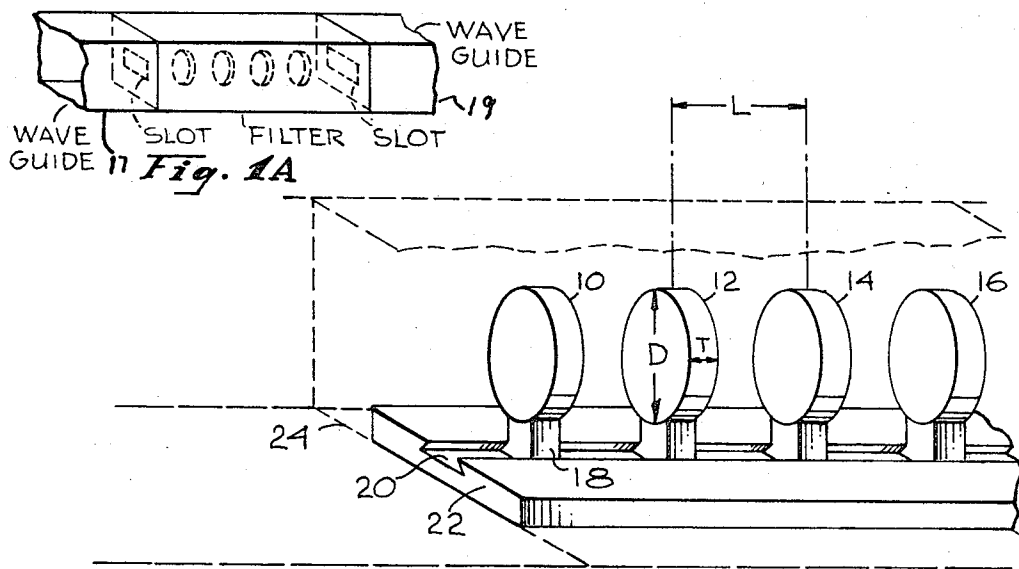


Fig. 1

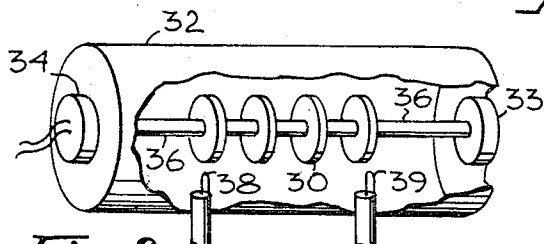


Fig. 2

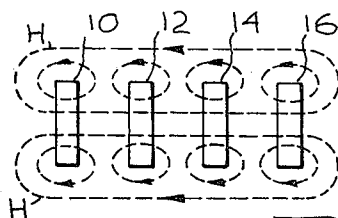


Fig. 3

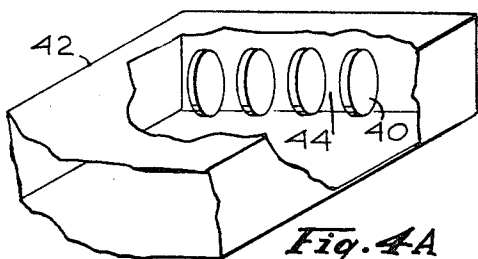


Fig. 4A

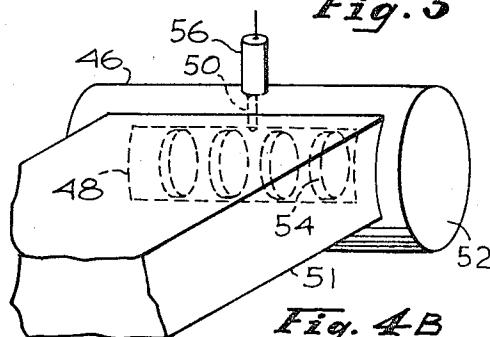


Fig. 4B

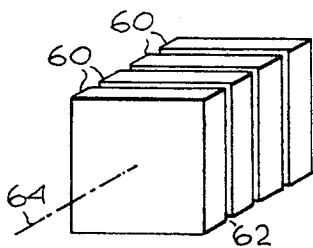


Fig. 5

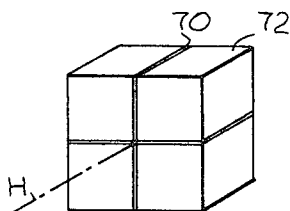


Fig. 6

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MICROWAVE SLOW WAVE DIELECTRIC STRUCTURE AND ELECTRON TUBE UTILIZING SAME

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14 Claims 10

ABSTRACT OF THE DISCLOSURE

A microwave slow wave structure is provided which comprises an array of high Q dielectric resonator elements within a shield or a waveguide, each of which may be circular in shape. The individual resonator elements are coupled together solely by their external magnetic fields. The degree of coupling is varied by the spacing of the array.

This invention relates to microwave circuits and more particularly to improved dielectric structures used at microwave frequencies.

Microwave slow-wave structures find utility in microwave circuits as bandpass or stop filters, delay lines, transducers, oscillator frequency controls, and in other capacities. Slow-wave structures may be installed in waveguides by providing discontinuities at proper spacings, such as by inserting irises at repeated distances of one-half the resonant wavelength. However, heretofore there have not been available compact, high Q resonators, sharp cut-off filters, and the like with bandpass characteristics which could easily be varied.

Accordingly, one object of the present invention is to provide slow-wave structures which are economical and compact, and which can be provided with any frequency characteristic within a broad range, more easily than could be provided with structures available heretofore.

Another object is to provide a low loss slow-wave system composed of a plurality of individual resonator elements, wherein selectivity or pass band of the system is varied by varying the spacing of the elements without changing the center frequency of the pass band.

Still another object of this invention is to provide a high Q resonator system composed of a plurality of individual resonator elements wherein the frequency of resonance of the system is varied by varying the spacing of the elements.

Yet another object is to provide a simple resonator which can be coupled to waveguides which propagate the TE₀₁ mode.

Still another object is to provide a simple means for obtaining purity of mode propagation of waves in structures composed of dielectric resonators.

The foregoing and other objects of the present invention are basically realized by a resonator structure comprising an array of high Q dielectric resonator elements, such as rutile (single crystal TiO₂) or strontium titanate, arranged in proximity to each other. The individual resonator elements are coupled together solely by the magnetic (H) fields external to them. The degree of coupling is varied by the spacing of the array. In what may be termed the "traveling wave" embodiment of the invention the center resonant frequency of the array is the resonant frequency of each element, and the width of the pass band varies inversely with the spacing of the elements. In what may be termed the composite resonator embodiment of the invention, the array of dielectric elements are suspended within a metal cylinder to form a resonator. The frequency of resonance, but not the band-

width can be varied by varying the spacing between the dielectric elements.

Tunnels can be provided in the elements without substantially degrading their resonant characteristics. Arrays with tunnels can be used to focus charged particles, by means of the axial magnetic fields threading the elements. In another application, the dielectric elements are doped near their axes with chromium ions or the like, to obtain a traveling wave maser.

The arrays serve not only to control frequency characteristics, but also to eliminate unwanted modes of propagation in these arrays, particularly modes other than the TE₀₁ mode. Mode purity is also achieved by providing a conductive "cage" about a dielectric, in an embodiment of the invention.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIGURE 1 is a perspective, partial sectional view of a resonator array constructed in accordance with the invention;

FIGURE 1A illustrates one mode of coupling a waveguide to the invention shown in FIGURE 1;

FIGURE 2 is a perspective partial sectional view of an embodiment of the invention employed to couple electromagnetic fields to a beam of particles;

FIGURE 3 is a representation of the array of FIGURE 1 showing the R.F. magnetic field lines present;

FIGURES 4A and 4B are perspective, partial views, of other embodiments of the invention, used as resonators;

FIGURE 5 is a perspective view of yet another embodiment of the invention, particularly useful in obtaining purity of mode in a dielectric resonator or traveling wave structure; and

FIGURE 6 is a perspective view of still another embodiment of the invention, which is useful for obtaining purity of mode in a dielectric resonator or traveling wave structure.

The embodiment of the invention, shown in FIGURE 1, comprises a plurality of cylindrical elements 10, 12, 14 and 16. Each element is constructed of a high Q, high ϵ' (relative dielectric constant, at least several times unity) material. When the material is an anisotropic crystalline material, there is often a preferred orientation of the crystalline axis with respect to the R.F. electric and magnetic fields. In the case of rutile, the preferred orientation is that in which the C-axis is aligned with the axis of the cylinder. Rutile is a preferred material here. The elements are mounted on supports 18 of a low dielectric-constant material, the supports being slidably mounted in a track 20 of a base 22, which is also constructed of a low dielectric-constant material. While in principle metal shields are not required where phase velocities less than C are of interest, the elements may be disposed within a shielding container 24. The elements are positioned at a uniform distance L from each other.

Electromagnetic waves propagating along the array of dielectric units should be in the TE₀₁ mode, usually important as the "low-loss" mode in circular guides. Magnetic field lines pass through the elements and couple them together, as represented by the lines "H" in FIGURE 3. The end elements couple to the H field of the waves in input and output waveguides (not shown).

The substantial separation of the elements 10, 12, 14 and 16 of the array results in the coupling being largely independent of the shape and orientation of the individual elements, e.g. the elements may be rectangular instead of cylindrical, or oriented with the axis not along that of

the array, or even each element may consist of a multiplicity of pieces of rutile. The parameters determining the characteristics of the array, to the first order, are the spacing L and the resonant frequency of each element in isolation. However, thin disks, such as those with thicknesses T less than one-fourth of the diameter D , are often preferable because of their circular symmetry and because their lowest resonant frequency is comfortably much lower than their next higher resonant frequency. While it is not essential to do so, it is usually convenient to orient the disks with their axis of symmetry parallel to the axis of the array, and in cases where the material is anisotropic, e.g. for rutile, to align the crystalline C -axis with the axis of the array.

The average or center resonant frequency of an array has been found to be approximately the resonant frequency of the individual elements, for all useful element spacings. However, the pass band varies inversely with the element spacing L , so that as L decreases, the bandwidth increases. The elements in the array of FIGURE 1 are supported to be movable toward and away from each other to vary the bandwidth. The coupling between elements is effective for separations L as great as twice the diameter D of the individual elements. Slow-wave structures have been constructed in accordance with this invention for S band operation, using rutile cylinders one-eighth inch in diameter and one-eighth inch thick, having resonant frequencies of 3200 megacycles and unloaded Q 's of approximately 10,000. The arrays were found to function as predicted, and to display positive dispersion i.e. a phase shift, from one end of the structure to the other, which increases with frequency, when the structure is considered as a traveling-wave structure.

FIGURE 1A shows how the embodiment of the invention shown in FIGURE 1 may be coupled to a waveguide 17, 19. Coupling is made via matching slots in end walls of the waveguide to the end discs 10, 16 of the array.

In another embodiment of the invention, illustrated in FIGURE 2 there is provided an array of resonator elements 30 each having a toroidal shape. The center holes of the elements are aligned. The arrangement is used to couple electromagnetic fields to a stream of particles passing through the center holes. These particles may be charged or uncharged. A cathode apparatus 34 (or a molecular oven) generates and propagates a beam of ions or electrons, for example, through an evacuated tube 36 which extends into the shield 32 and through the centers of the resonator elements 30, to a target 33. The material about the hole in each element may be doped with ferromagnetic material or with chromium ions.

When waves of a frequency within the band propagated by the array are coupled into and out of the array by means of the respective loops, 38, 39 which are effectively within the planes of the respective first and last elements, they set up large axial magnetic fields. These fields act upon the particles in the beam to provide focussing, bunching, deflection, population inversion, or other useful function, as is well known in the art.

In principle, metallic shields are not required about the dielectric array when wave velocities in it are less than c (the free space speed of light). It may be noted that this is one of the distinctions between the structures of the present invention and the heretofore known structure of a metallic waveguide periodically loaded with dielectric discs.

Thus far we have been concerned with a traveling-wave structure in which we couple into and out of the remote ends of the array. The coupling at the ends is matched, so that the behaviour of the structure is as if the array were infinite. Now, let us turn to an array which is not infinite in effect, and has no couplings limited to the end elements alone. If we couple to this finite array broadside, it can act as a single lumped resonator. Analogous to a few turns of a helix with shorted ends or

with open free ends. In practice it is found that the fields external to a single dielectric resonator whether or not composite as just depicted, sometimes contain components which can lead to a deterioration of Q by reason of radiation damping, unless the resonator is shielded by an electrically conductive enclosure.

As shown in FIGURE 4A, a group of resonator elements 40 are placed within and coupled to a waveguide 42. By reason of the location within the waveguide no further shielding is required. The back wall 44 of the waveguide is slidable within the guide walls forming a tuning piston. However, in some applications, e.g. where direct coupling to a coaxial cable is necessary, waveguide shielding may not be obtainable. Shielding can be obtained by enclosing the dielectric in a metal cylinder 46 as illustrated in FIGURE 4B. The cylinder 46 has an iris aperture 48 opening into the end of a waveguide 51 through which microwaves are propagated. Each end 52 of the cylinder is open to enable the entry of plastic or ceramic rods for manipulating the dielectric resonators 54, and to avoid spurious resonances of the metal cavity. A coaxial cable 56 extends through the side of the cylinder and has a loop 50 for coupling to the resonator. The composite resonator and shield can be used in connection with two coaxial cables instead of a waveguide and cable, by providing two coaxial cable loops. These are positioned near the center of the array of elements and loosely coupled thereto. Other configurations of waveguides, and/or coaxial cables for coupling energy to and from the composite resonator will be apparent to those skilled in the art, from the foregoing description. However, these are to be considered within the spirit of this invention and the scope of the claims herein.

While the array of resonator elements described finds utility as a composite microwave resonator, or as a pass or stop band filter, to separate propagated microwaves according to frequency, it also finds utility in regulating the mode of its own resonance. The TE_{016} or "magnetic dipolar" mode of a dielectric element, with the H field concentrated along the axis of the element, is often the most important mode used in connection with paramagnetic, ferromagnetic, hall-effect, and magnetostrictive specimens located near said axis. Other modes of dielectric resonance often "tune in" at frequencies close to that at which the TE_{016} mode creates an effect. In many applications it is desirable to eliminate the effects of all modes other than the TE_{016} mode. Positive suppression of unwanted modes is accomplished without substantial lowering of the Q of a dielectric element by employing as the entire resonator in a filter, or as each element of an array for traveling wave purposes, at least two of such elements 60 separated by small gaps 62 as illustrated in FIGURE 5. When thin air gaps, or films of low-loss, low- ϵ' dielectric, such as Mylar films, are inserted transverse to the axis of the array, modes with an E component parallel to the axis 64 of the array are detuned to a remote high frequency while the desired mode is not appreciably affected. This is due to the fact that E fields do not readily "jump" air gaps while H fields do.

Another arrangement for suppressing unwanted modes in any application utilizing one or more dielectric resonators is illustrated in FIGURE 6. It involves the placing of a cage 70 of thin, electrically conductive wire loops in meridional planes about the dielectric material 72, i.e. defining planes perpendicular to each other and parallel to the R.F. H field. A mode with H field lines tending to thread a loop is damped and detuned. The desired TE_{016} mode is not affected appreciably if the wires of the cage are very thin. The finite thickness of the wires somewhat decreases Q and the resonant wave length in the desired mode but the effect is very small where the wire thickness is less than about one-fiftieth the width of the resonant element.

While particular embodiments of the invention have been described herein, many variations and modifications

will be apparent to those skilled in the art. For example, arrays may be constructed with ferromagnetic resonator elements at their axes, or chromium doped dielectric materials may be used at the centers of the elements to provide traveling wave masers. Also, groups of arrays may be positioned beside each other for mutual interaction. Therefore, the invention should not be considered as limited by the particular embodiments described herein, but only by a just interpretation of the following claims.

What is claimed is:

1. A structure for use in a microwave system comprising:

a plurality of dielectric resonator elements, each comprising a cylinder of rutile having its crystalline C-axes aligned with its axes of symmetry, and the axes of symmetry of said plurality of dielectric elements being aligned with each other;

each element being resonant at a predetermined frequency; and

means for positioning said elements in an array relative to one another, with a predetermined spacing and in positions wherein radio frequency magnetic field lines of microwaves propagated by said microwave system pass through and between said resonator elements.

2. A structure as recited in claim 1 wherein each said element is spaced from an adjacent element by a relatively thin dielectric material of relatively low loss.

3. A structure as defined in claim 2 wherein the spacing of said elements is less than twice their diameters, whereby to assure coupling between the elements.

4. A structure as recited in claim 1 wherein said plurality of dielectric resonator elements are all resonant at substantially the same frequency; and

said structure includes means for applying microwave energy to a first of said array of resonator elements; and

means for deriving microwave energy from a last of said array of resonator elements.

5. A structure as recited in claim 1 wherein said plurality of dielectric resonator elements are all resonant at substantially the same frequency; and there is included means for applying microwave energy substantially simultaneously to said plurality of resonator elements from one side of said array.

6. A structure as defined in claim 1 wherein each of said elements has a toroidal shape with the central holes of said toroidal elements being aligned, said structure including:

means for applying microwave energy to said elements; and

particle generating means for directing a beam of particles through the holes in said elements;

means to couple said microwave energy to said beam of particles.

7. A structure as defined in claim 6 wherein the material surrounding the central holes of each of said toroidal elements is doped with ferromagnetic material.

8. A structure as defined in claim 6 wherein the material surrounding the central holes of each of said toroidal elements is doped with chromium ions.

9. A structure defined in claim 1 wherein said plurality of resonator elements includes at least three elements of disk-like shape, each having a thickness no more than one-fourth its diameter.

10. A structure for use in a microwave system comprising:

a plurality of dielectric resonator elements, each constructed of material having high Q microwave frequencies, each having a relative dielectric constant at least several times unity, and each being resonant at a predetermined frequency;

each element being enclosed in a cage of thin electrically conductive wire loops disposed in meridional planes about said dielectric material; and

means for positioning said elements in an array relative to one another, with a predetermined spacing and in positions wherein radio frequency magnetic lines of microwaves propagated by said microwave system pass through and between said resonator elements.

11. A microwave apparatus comprising a plurality of substantially identical disk-like elements constructed of a material characterized by a relatively high dielectric constant and high Q at microwave frequencies:

said plurality of disk-like elements being positioned spaced from one another with their axes in alignment, and having the same resonant frequency;

shield means forming an enclosure around said elements;

an opening in said shield means at an end of said shield means adjacent a first of said plurality of elements; and

means for applying microwave energy through said opening into said enclosure to said element at a predetermined frequency to the one of said elements at one end of said plurality of disk-like elements; and

there is included means for movably supporting said plurality of disk-like elements for enabling variation of the bandwidth of the frequencies which can be propagated from said first to the last of said plurality of elements inversely with the spacing between said plurality of elements.

12. A microwave apparatus comprising:

a plurality of substantially identical disk-like elements constructed of a material characterized by a relatively high dielectric constant and a high Q at microwave frequencies;

said plurality of disk-like elements being positioned spaced from one another with their axes in alignment and having the same resonant frequency;

shield means forming an enclosure around said elements; an opening in said shield means at the side of said shield means adjacent the center of said plurality of disk-like elements; and

means for applying microwave energy through said opening into said enclosure to said elements at a predetermined frequency substantially simultaneously to all of said disk-like elements; and

there is included means for movably supporting said plurality of disk-like elements for enabling variation of the frequency of resonance of said structure.

13. A microwave apparatus as recited in claim 12 wherein each element is spaced from an adjacent element by a relatively thin dielectric material of relatively low loss.

14. A microwave apparatus as recited in claim 12 wherein each element is enclosed in a cage of thin electrically conductive wire loops disposed in meridional planes about said dielectric material.

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U.S. Cl. X.R.

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