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[21] Appl. No. 817,355
[22] Filed Apr. 18, 1969
[45] Patented Sept. 7, 1971
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[54] HIGH Q MICROWAVE CAVITY
6 Claims, 6 Drawing Figs.

[52] U.S. Cl. 333/73 W,
333/31, 333/81 B, 333/98, 333/33, 333/83,
333/95
[51] Int. Cl. H03h 9/00
[50] Field of Search. 333/73 C,
73 W, 34, 81 B, 95, 97

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ABSTRACT: A low loss microwave transmission structure composed of a section of waveguide within which is concentrically placed an array (one or more) of cylindrical sections of dielectric material with relative dielectric constant greater than four, spaced away from the walls by a significant fraction of the radius (at least of the order of 10 percent) and possessing appreciable discontinuities. In the dielectric loaded sections electromagnetic radiation is propagated primarily within the dielectric so that the losses observed are mainly a function of the dielectric material and are, to first order, insensitive to the wall composition or condition. In this most general form the structure can be synthesized as a low loss filter or equalizer. When operated at frequencies at which the unloaded waveguide is below cutoff a high-Q cavity can be formed. A single section cavity of this type has been used to measure the Q of the low loss high dielectric constant dielectrics. A particularly simple and easily adjustable coaxial input and output structure is available which couples strongly to the cylindrically symmetric TM_{01} mode, all other propagating modes being greatly disfavored.

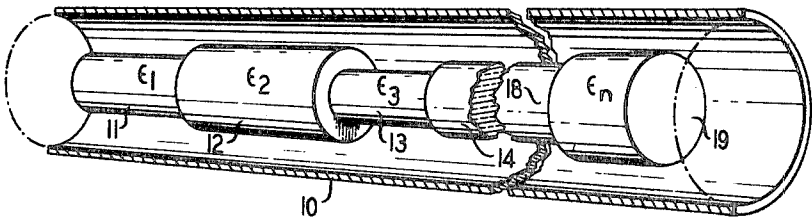


FIG. 1

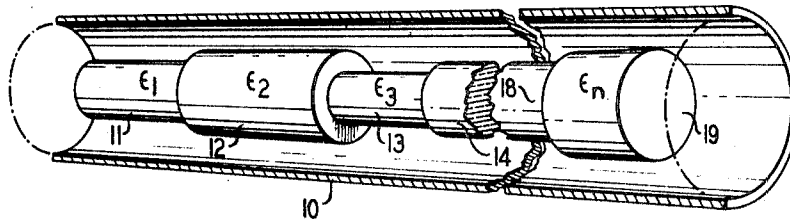
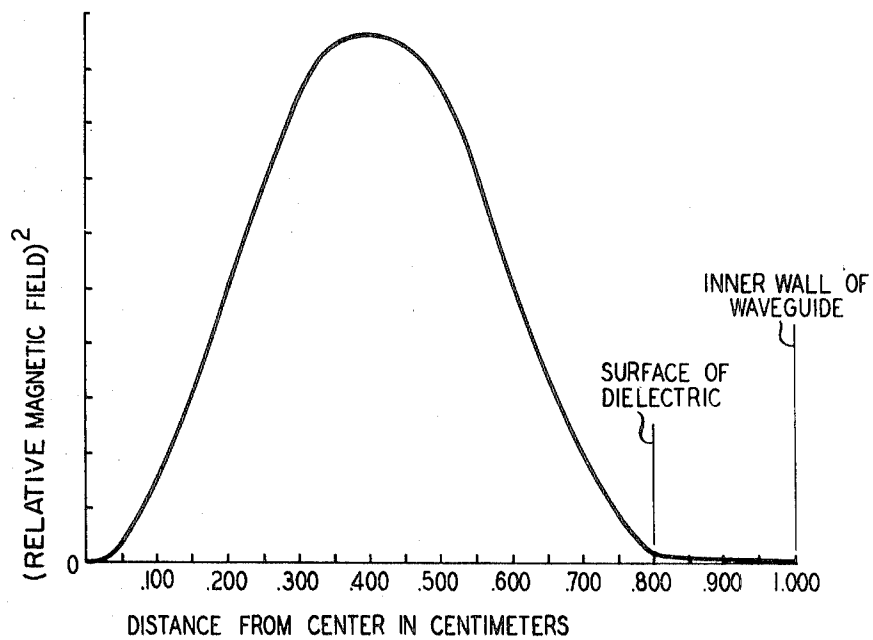


FIG. 2



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FIG. 3

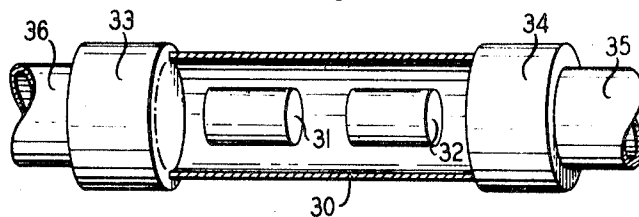


FIG. 4

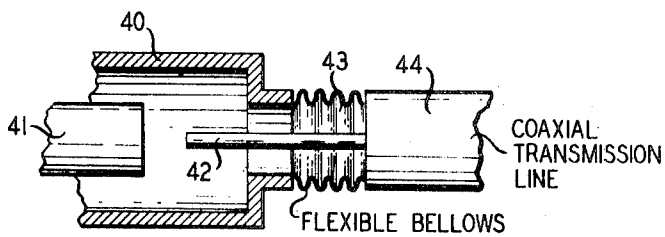


FIG. 5

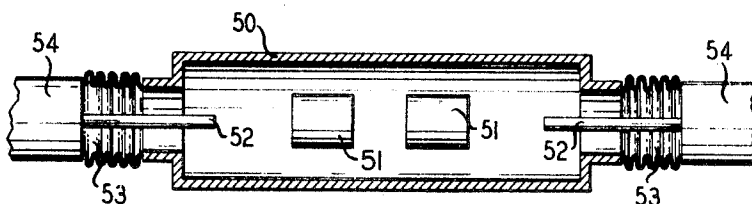
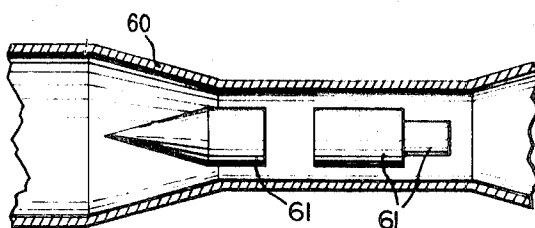


FIG. 6



HIGH Q MICROWAVE CAVITY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The disclosure treats dielectrically loaded circular waveguide devices capable of low loss signal processing such as filtering and equalizing. Also treated is the testing of low loss high dielectric constant dielectric materials.

2. Description of the Prior Art

The synthesis of reactive transmission networks with predetermined transmission and reflection properties is an old and well-known art. Such devices are used, for instance, as filters and equalizers in communication systems. In various frequency ranges, the specific embodiments take on widely varying forms. At lower frequencies, the elements used are lumped capacitors and inductors. In other frequency ranges one can use lengths of transmission line and discontinuities in the transmission line as the elements of the synthesis. The discontinuities can be either lumped reactive elements such as capacitors and inductors or points at which a transmission medium of one characteristic impedance is joined to a transmission medium of another characteristic impedance. The latter method is used at microwave frequencies, for instance, to form coaxial quarter wave transformers. This disclosure bears on that part of the art which considers the transmission of electromagnetic radiation through waveguide structures. The synthesis of waveguide structures with predetermined transmission and reflection characteristics is likewise an old and much practiced art. Within this art are filter networks composed of lengths and waveguide within which are placed sections of dielectric material of varying length and dielectric constant either fully or partially filling the guide. The placing of sections of dielectric within waveguide is also a standard method for the testing of the properties of the dielectric material.

The limitations inherent in the prior art include energy dissipation in the waveguide wall due to the finite conductivity of the wall material. This dissipation is a function of the wall material and as such leads to the dependence of the device properties on the wall material and the condition of the wall (e.g. the wall temperature). Most previously used structures which include dielectric loading have the dielectric placed immediately adjacent to the wall so that expansion and contraction of the wall with temperature can cause significant performance variations due to large variations of the small air space. Another problem often met is the transmission of spurious modes generated at the junction between the device and the external system.

A class of devices which bears a superficial resemblance to that disclosed here is the class of gyromagnetic devices making use of the Faraday rotation in longitudinally magnetized rods of ferrite within circular waveguide [Fox et al. Bell System Technical Journal (Jan. 1955) p. 5 (especially pp. 22-28)]. In this ferrite art, however, the very discontinuities which form the basis of the filter network synthesis disclosed here are anathema to the ferrite devices. In fact the microwave ferrite art includes many techniques, such as the inclusion of long tapered ends on the ferrite rods, for the diminution of such discontinuities (C. L. Hogan 2,768,354 and E. A. Ohm 2,963,668).

Summary of the Invention

The device disclosed here comprises a section of circular waveguide within which is concentrically disposed one or more right circular cylinders of dielectric material with dielectric constant greater than approximately four and spaced away from the wall by a distance at least of the order of 10 percent of the guide radius. If the conditions indicated above are met, the energy of the electromagnetic wave is confined primarily within the dielectric material. If dielectric materials are used which possess low intrinsic loss, a low loss structure is

produced, since a relatively small amount of the transmitted field contacts the waveguide wall. Such devices can be designed by an appropriate synthesis procedure, using the discontinuities between sections, to form signal processing networks, such as filters or equalizers.

Useful device classes include the operation of such a device at a frequency at which one or more of the loaded sections are in a cutoff condition. Since the fields in a cutoff section are exponentially decreasing, these cutoff sections can be entirely free from dielectric. A test fixture for the measurement of the loss properties of dielectric materials has been constructed using a single cylinder of dielectric material and operating with the unloaded ends in a cutoff condition. This forms a high Q resonator. All device classes disclosed here share the property that they can be observed in reflection as well as in transmission. Thus, useful devices can be envisioned which are connected to the external system at only one end, the other end being suitably terminated.

However, the above considerations hold for all propagating modes if transformation to a coaxial geometry is necessary and transmission is the TM_{01} mode a simple and efficient transducer is produced by introducing a probe which is coaxial to the waveguide. The transformation from the waveguide to the coaxial geometry takes place with very little spurious mode generation because of the great similarity between the TM_{01} and the coaxial field geometries.

Brief Description of the Drawing

FIG. 1 is a partially sectioned perspective view of a general transmission structure, within the scope of the disclosure, containing an array of dielectric cylinders of varying dielectric constant, length and diameter;

FIG. 2 is a curve, derived by calculation, showing the square of the magnetic field (ordinate) as a function of the distance from the axis of the structure (abscissa) for the situation in which a cylinder of radius 0.8 centimeter of the material of relative dielectric constant 10 is situated within a waveguide of radius one centimeter and the transmitted radiation is 10^{10} Hz.;

FIG. 3 is a partially sectioned perspective view of a two-section high Q band-pass filter;

FIG. 4 is a partially sectioned plane view of a transducer from a waveguide to a coaxial geometry including a length of flexible bellows between the outer conductor of the coaxial cable and the waveguide for easy adjustment of probe penetration;

FIG. 5 is a partially sectioned plane view of an exemplary cavity incorporating the transducer of FIG. 4; and

FIG. 6 is a partially sectioned plane view of a device incorporating a tapered transformer section between a device of the disclosed class and an external waveguide system.

Definition of Some Important Terms

Loaded

In this disclosure *loaded* implies *containing*. A section of the waveguide which is "dielectrically loaded," contains a cylinder of dielectric material.

Cutoff

In this disclosure *cutoff* implies a nonpropagating condition. A general expression representing a wave propagating in the z direction is

$A = A_0 e^{i(\omega t - kz)}$; where ω is the angular frequency of the wave and k is the propagation constant.

When the transmission is taking place in a waveguide structure there exists a frequency, dependent upon the particular waveguide geometry and known as the "cutoff frequency," below which the propagation constant, k , becomes imaginary. Below this frequency the above expression becomes

$A = A_0 e^{i\omega t} e^{-|k|z}$, which represents an exponentially decaying wave. The wave, then is decreasing in the z direction and not freely propagating. "Below cutoff" implies operation at a frequency such that the wave is exponentially decaying.

Detailed Description of the Invention

1. General Considerations

FIG. 1 shows a general structure of this class comprising a portion of a circular waveguide 10 within which is concentrically disposed an array of dielectric cylinders 11, 12, 13, 14, 18, 19, each having a different dielectric constant, diameter and length. Each of the cylinders should have a relative dielectric constant at least of the order of four and be spaced away from the waveguide wall by a least of the order of 10 percent of the waveguide radius. In addition the space between the dielectric cylinders and the metallic wall must be below cutoff in the transverse direction. If these conditions are met the electromagnetic energy is largely confined within the dielectric cylinder and any effects due to the metallic wall are small.

A complete device would also include means for introducing electromagnetic radiation 33 and 34. Such means might be the simple junction to a circular waveguide wherein the external system has caused electromagnetic radiation to be propagated, a tapered transformation section 60, a more complex transducer such as the coaxial probe 42 to be described below or any other transducer known in the art. A device of this general class can be designed to perform reactive functions such as filtering and equalization by suitable choice of cylinder length, diameter and dielectric constant. The change of diameter and dielectric constant from one section to the next must be such as to produce a significant discontinuity. It is considered that if the product of the cylinder diameter and the square root of the dielectric constant changes by less than ten percent within a distance equal to one quarter of the cylinder diameter the discontinuity will not be significant and a marginally useful device will be produced.

2. Choice of Structure Parameters

The teaching of this disclosure comprises the following qualitative picture: The electromagnetic energy is largely confined within the dielectric cylinder; since the space between the cylinder and the wall is transversely cut off, the fields decrease exponentially away from the cylinder decreasing to a low value at the wall; since only this small field contacts the wall, effects (such as loss) due to the wall are minimal. Thus, one must include enough dielectric material to contain a major part of the field energy yet not allow the cylinder to approach the wall too closely.

A solution of Maxwell's equation for this geometry yields more specific information concerning the choice of optimum parameters. For every set of physical parameters (dielectric constant and frequency of operation) an optimum set of geometric parameters (waveguide diameter and cylinder diameter) can be determined. For material near the low end of the acceptable range, the choice of optimum parameters is important for the realization of improved performance.

With a material having a dielectric constant of 4 and a dissipation factor of 2×10^{-5} and with propagation in the TM_{01} mode there is as much dissipation in the walls of the waveguide as there is within the dielectric material at the optimum geometry so that the improvements afforded by this construction becomes marginal for materials of dielectric constant less than 4.

For dielectric materials of relative dielectric constant of the order of 10 or greater, the field energy is well contained within the dielectric and a choice of the ratio between the diameters of the cylinder and the waveguide is not critical as long as the restrictions mentioned above are observed. Typical structures operating at 10^{10} Hz. have a diameter ratio of 0.8 and a waveguide diameter of 2 centimeters. The magnetic field distribution within such a device containing a dielectric material with a relative dielectric constant of 10 is illustrated in FIG. 2. These solutions can be extended to other frequencies by realizing that, in the low loss regime, Maxwell's equations scale with frequency so long as all elements of the structure are scaled properly.

Since the walls of the waveguide contribute in only a minor way to the properties of devices of the disclosed class, the device properties are relatively insensitive to the composition

or conditions of the waveguide walls. The wall material can then be chosen for properties other than high conductivity (e.g. structural strength, corrosion resistance or thermal stability). In addition the variation of metallic conductivity with temperature becomes unimportant.

3. Use of Cutoff Sections

A section of waveguide which is cut off represents a greater discontinuity than the junction between two different dielectrics. If cutoff sections are included in the structure, transmission characteristics can be synthesized which vary much more rapidly with frequency. Typical structures using cutoff sections are high Q band-pass filters. The cutoff sections can be entirely free from dielectric material and not significantly increase the loss of the structure because of the exponential decrease of field strength within the cutoff region. The absence of material in the cutoff section allows the easy variation of the coupling between adjacent dielectric sections.

FIG. 3 shows a typical structure which is a two-section band-pass filter. This filter can be designed to have either a maximally flat or Chebishev response. The spacing between the ends of the dielectric cylinders 31, 32 and the structures which couple to the device 33, 34 is chosen to give the required energy coupling to the external circuit 35, 36.

4. Tapered Transformer Input

When a device of the disclosed type is adjoined to an external waveguide system it may be necessary to minimize the junction discontinuity. This can be done, for instance, by the inclusion of a tapered transformer section having a tapered dielectric cylinder 61 for impedance matching and filtering such as is depicted in FIG. 6.

5. Coaxial Probe

When it is required to transform to a coaxial geometry the use of the TM_{01} mode is particularly advantageous. The simple introduction of a probe 42 coaxial to the waveguide 40, as illustrated in FIG. 4, forms a transducer which produces no coupling to noncylindrically symmetric modes and very little coupling to any modes other than TM_{01} because of the great similarity between the TM_{01} and the coaxial field geometry.

This figure also shows that the probe penetration can be easily adjusted by the inclusion of a flexible bellows 43 between the waveguide and the outer conductor of the external coaxial transmission line 44.

6. Dielectric Loss Test Fixture

The teaching of this disclosure has allowed the construction of a test fixture (see FIG. 5) for the measurement of the dielectric loss of high dielectric constant material, comprising a circular waveguide structure 50 with a single dielectric cylinder 51 (FIG. 5 illustrates a more complex device containing two spaced cylinders 51) and two coaxial transducers 52, 53, and 54 operated at a frequency for which the waveguide is cut off outside of the dielectrically loaded section. This test fixture is significantly better than the structures reported in W. B. Westphal, Tech. Rep. 182, Lab. for Insulation Research, M.I.T., Oct. 1963 and S. B. Cohn et al. IEEE Transaction MTT-1409 (Sept. 1966) which are considered to be representative of the prior art. By considering a material having a dielectric constant of 10 and a dissipation of 2×10^{-5} one can derive a figure of merit for this structure. A meaningful figure of merit is the ratio of dielectric loss to metal wall loss expressed as Q_R/Q_D where Q_R characterizes cavity Q in the presence of wall losses only and Q_D represents a similar quantity for the dielectric losses. For the cavity and material described above, this figure of merit has a value of 24 showing that the effect of wall loss is very small.

7. The Composition of the Ambient

All of the discussions above have assumed that all spaces outside of the dielectric cylinders are filled by vacuum or a gaseous medium whose relative dielectric constant is close to one. However, all of the above considerations hold if the said spaces are filled by some other dielectric material so long as its dielectric constant is at least four times lower than the smallest dielectric constant of the dielectric cylinders.

What we claim is:

1. An electromagnetic wave conducting structure comprising:

- a. a portion of circular electrically conductive waveguide;
- b. at least two right circular cylindrical sections of a dielectric material, which are not resonant at a frequency of intended use, concentrically disposed therein; and
- c. means for launching into said portion of circular waveguide an electromagnetic wave of such frequency that said wave decays essentially exponentially in a radial direction in the space between said cylindrical sections and said waveguide, said means terminating at least one end of said portion of circular waveguide characterized in that the said cylinders are spaced away from the wall of the said waveguide by at least of the order of 10 percent of the waveguide radius, that the relative dielectric constants of the said cylinders are at least of the order of four and that the structure contains discontinuities of magnitude such that the product of each dielectric cylinder diameter and the square root of its dielectric constant

changes from one section to the next by more than 10 percent within a distance equal to one quarter of the cylinder diameter.

2. A device of claim 1 in which said means for launching is a structure comprising a coaxial probe jointed to the center conductor of a coaxial transmission line whose outer conductor is electrically joined to the said waveguide.

3. A device of claim 1 including at least one section cut off in the direction of propagation for the mode employed.

4. A device of claim 2 wherein the said outer conductor is joined to the said waveguide wall by means of a flexible metallic bellows.

5. A device of claim 1 wherein at least one of said cylindrical sections is terminated, at least at one end, by a tapered transformer section comprising a tapered section of dielectric material.

6. A device of claim 1 in which said electromagnetic wave is in the TM_{01} mode.

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