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SHIELDED DIELECTRIC WAVE GUIDES

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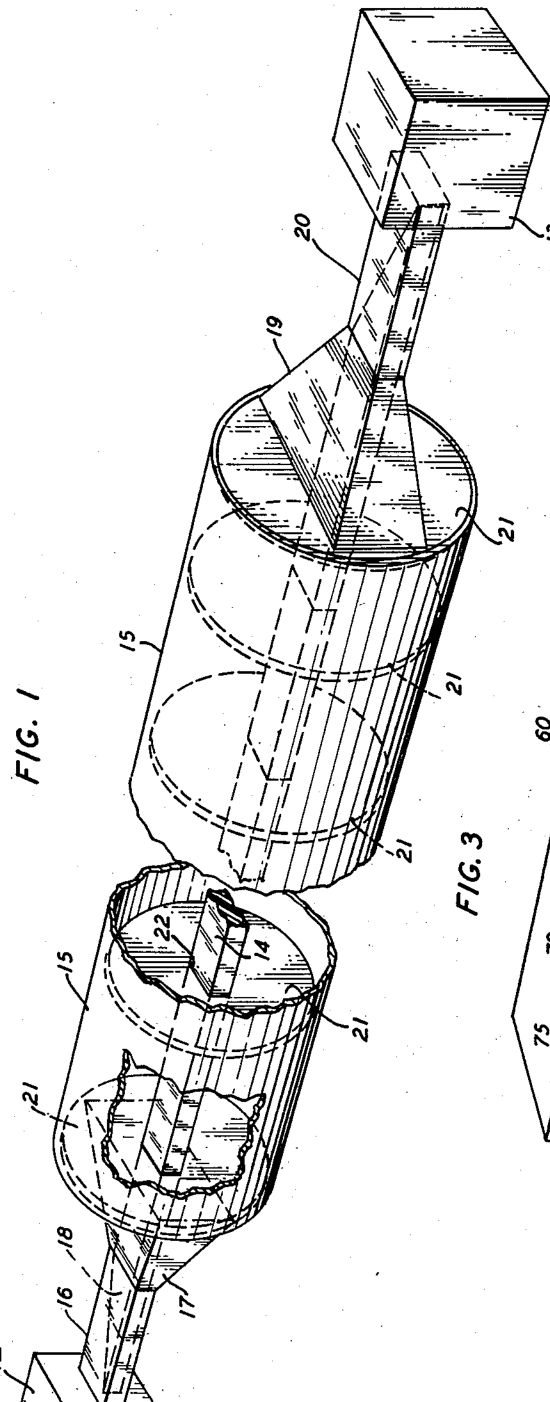

FIG. 1

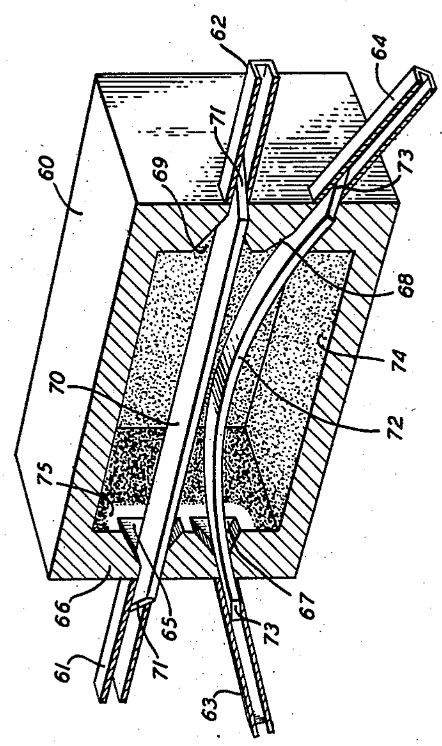

FIG. 3

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FIG. 2

WAVELENGTH	GUIDE DIMENSIONS AND POLARIZATION	RADIUS OF FIELD AND MINIMUM RADIUS OF SHELL	LOSS Db/FT.
.25"	.142" × .056", E	0.4"	1.0
.25"	.142" × .056", E	0.8"	.27
.25"	.114" × .038", E	1.5"	.045
.25"	.096" × .032", E	3.0"	.007
.50"	.156" × .095", E	1.5"	.05
.50"	.155" × .086", E	4.0"	.05
.50"	.155" × .086", E	7.0"	.025

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SHIELDED DIELECTRIC WAVE GUIDES

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3 Claims. (Cl. 333—95)

This invention is a continuation in part of my copending application Serial No. 274,313, filed March 1, 1952, now Patent No. 2,794,959, and relates to microwave transmission systems and more particularly to the transmission of electromagnetic wave energy having wavelengths of several millimeters along dielectric transmission lines having no conductive shields.

In said copending application it is disclosed how electromagnetic wave energy may be guided along a transmission medium consisting solely of dielectric material, in other words, an unshielded or all-dielectric media as opposed to the more well known transmission media of the types in which a longitudinal conductive shield is placed to immediately surround the dielectric material. Investigation has indicated that the guiding effect is retained when using a very thin dielectric rod only a fraction of a wavelength in diameter. When launched upon such a rod in the proper mode, a great portion of the energy is conveyed in a field surrounding the dielectric material and therefore is not subject to its losses. For this reason the transmission attenuation of a thin all-dielectric guide may be made very low.

In the past it has been found necessary in many applications to surround the dielectric guide by a conductive metal shell, spaced from the dielectric guide at a sufficient distance so that the low-loss characteristic of the guide is maintained. The principal functions of this shell are to provide a more or less rigid support for the guide, to protect the guide from mechanical influences and at the same time to shield the guide from electrical interference, such as crosstalk with other systems. It has been found, however, that the conventional conductive shell acts as a very large conductively bounded wave guide supporting its own spurious modes. Slight discontinuities that produce coupling between the modes supported by the dielectric guide and the conductive guide modes result in undesired spurious resonances.

It is therefore an object of the present invention to shield and protect a dielectric wave guide of the unshielded type from outside influences and at the same time prevent and suppress the generation of spurious modes by the shielding means.

This object is accomplished in the embodiments to be described hereinafter by making the shell surrounding an unshielded dielectric transmission medium of high resistance material. The material is located sufficiently removed from the dielectric so that it intercepts a negligible part of the electric field of the energy conveyed by the dielectric. Thus this energy is propagated substantially unaffected by the presence of the shell. The spurious modes, however, have electric field patterns that induce current components in the shell and are dissipated by the high resistance thereof. Likewise, all extraneous and interfering outside fields are also dissipated in the material. In the embodiment of the invention disclosed in the parent application hereof, these principles are applied to a relatively short line comprising the coupled

paths of an all-dielectric directional coupler. These principles are extended in the added embodiments hereof to a transmission medium of considerable length.

As used in the present specification and claims, the term "shield" is intended to mean the conductive boundary of a wave transmission path that actually forms a part of the propagating media. In this sense it includes the conductive portion of the conventional hollow pipe wave guide which may be regarded as a column of dielectric material, usually air, immediately surrounded by a conductive shield. The term "shell" will be reserved to mean a boundary sufficiently distant from the propagation media as to have little or no effect upon the propagation of energy. The terms "unshielded wave guide" or "all-dielectric wave guide" are intended to mean a rod or column of material having a different, and generally a greater, dielectric constant than its immediate surroundings. They are intended to exclude those propagation media which comprise a column of dielectric material closely surrounded by a conductive "shield" but are not intended to exclude a media in which a "shell" is located at a substantial distance from the boundary between the high dielectric media and the low dielectric media.

These and other objects, the nature of the present invention and its advantages and features, will appear more fully upon consideration of the several illustrative embodiments now to be described in connection with the accompanying drawings in which:

Fig. 1 is a pictorial representation of a microwave system in which two electromagnetic wave devices are interconnected by a transmission line having a resistive shell in accordance with the invention;

Fig. 2 is a table showing the relationship of the several dimensional parameters of embodiments of the invention; and

Fig. 3 represents an all-dielectric directional coupler shielded in accordance with the invention.

Referring more specifically to Fig. 1, it will be seen how a dielectric guide in accordance with the invention may be used to connect two electromagnetic wave devices **12** and **13** which may be a source of wave energy and a load, respectively. This connection comprises an elongated member **14** of dielectric material having a shell **15** extending substantially the length of member **14**.

The body of member **14** is made of a nonconductive material having a dielectric constant substantially different from the atmosphere surrounding it which may be air, any other gas, or vacuum, and therefore having a phase velocity for wave energy substantially different from the phase velocity of the wave energy in that atmosphere. By way of example, the synthetic plastic materials, polystyrene, polyethylene, Teflon and laminated polyflex, have proved satisfactory, to mention only several specific materials.

The transverse cross section of member **14** is ovoid, i. e., is provided with different orthogonal dimensions in any given cross section so that the phase velocity of dominant wave energy polarized parallel to one of these dimensions is substantially different from the phase velocity of dominant wave energy polarized orthogonally thereto. It has been found that this sort of cross section maintains the polarization of the wave launched upon it and substantially aids in reducing the tendency for it to couple into the orthogonal polarization as fully described in the abovementioned copending application. As illustrated by way of specific example in Fig. 1, member **14** is of rectangular cross section having a longer transverse dimension of several times the shorter transverse dimension thereof. However, oblong or elliptical cross sections may be used and are preferable with long slender guides since these cross sections are easier to make by presently known methods of manufacture, such as by extruding.

To couple the wave energy from device **12** and to launch it in the proper mode upon guide **14**, a transducer of conductively bounded components is employed. This transducer comprises a rectangular wave guide **16** which has one end coupled to device **12** according to conventional practice so that a dominant transverse electric or TE_{10} mode is excited within guide **16**. The other end of guide **16** is flared out into a rectangular horn **17** which has its wide and narrow mouth dimensions extending parallel to the wide and narrow dimensions of guide **16**. One end of guide **14** is pushed through the horn to extend several wavelengths into guide **16**. The match between guide **14** and guide **16** is improved by providing a taper **18**, extending along several wavelengths of the portion of guide **14** within guide **16**. A similar arrangement comprising horn **19** and rectangular guide **20**, which may be identical to horn **17** and guide **16**, respectively, is provided at the other end of guide **14** to couple it to device **13**. Thus the dominant mode wave energy in guide **16** is launched upon guide **14** with an electric field pattern which resembles the field pattern of the mode in the metallic shielded guide **16**.

Shell **15** comprises a tubular member of high resistance material supported coaxially around guide **14** by separators **21** consisting of very thin plate-like partitions of material having a dielectric constant substantially equal to that of the atmosphere within shell **15**. For example, a material such as polyfoam may be used if this atmosphere is air. Apertures **22** are provided at the center of each separator **21** through which guide **14** may pass. For the purposes of the present invention, the ordinarily relative term "high resistance" will be taken specifically to mean the resistance of a material having a resistivity of greater than 15×10^{-6} ohm centimeters at 20 degrees centigrade. Within this category are the metallic materials commonly used in heating elements in electrical appliances such as constantan, Nichrome and Climax. Shell **15** can also be made of non-metallic materials such as high carbon Bakelite or other synthetic resin of high electrical dissipation properties. In an experimental model it has been found that commercial plywood of high resin content operated satisfactorily. As opposed to these materials of "high resistance" are the metallic substances of "low resistance" conventionally recognized as being good conductors of electrical energy, and the insulators recognized as being nonconductors or dielectric materials. It should be noted, however, that shell **15** may be made of a base material of either low resistance or nonconductive that is coated on at least the inside surface by a high resistance material, such as carbon black or Aquadag.

The cross sectional shape of shell **15** is determined by mechanical considerations more than from electrical considerations. As illustrated, this shape is circular but it may readily be square or rectangular depending upon the most suitable shape to fabricate from the particular material used.

Regardless of shape, the minimum cross sectional dimension of shell **15** is dependent upon the cross sectional dimensions of guide **14** and upon the frequency of the wave energy to be conducted thereby. In general shell **15** should be spaced away from guide **14** by a distance at least as large as the extent of the major portion of the field of the energy propagated by guide **14** so that the resistive material of shell **15** will intercept only a negligible portion of this electric field. As the cross section of guide **14** is made smaller and, more particularly, as the dimension thereof parallel to the electric vector is decreased, obtaining thereby a smaller loss, the extent of the field out away from the axis of the guide increases. The precise relationship varies in accordance with a very complicated formula and the exact dimensions for a given embodiment are best obtained on an empirical basis. However, the table shown in Fig. 2 gives representative measured values to afford some comparison of magnitudes. In Fig. 2, the cross sectional dimensions of the dielectric member are given for a particular polarization represented by the vector E for a given wavelength. The radius of the field extent, which is the minimum dimension of the shell cross section, is given and also the transmission loss in decibels per foot is indicated. It will be noted that in all cases for a desirable loss, the maximum dimension of the guide should be a small fraction of a wavelength and the radius of the shell should be at least several wavelengths.

With these relative dimensions, the desired mode on the dielectric guide **14** is propagated with a small amount of attenuation. However, substantially all spurious modes that could be supported in a conductive guide of the same cross sectional dimensions as shell **15** induce either longitudinal or circumferential current components in the material of the shell. These modes are dissipated by the high resistance material of shell **15** before they can propagate.

Having thus disclosed how the principles of the invention may be applied to a transmission line of substantial length, it may now be considered how similar principles may be applied to guided wave devices of shorter length. Referring therefore to Fig. 3, a directional coupler of the type described in the above identified parent application hereof is shown in which two all-dielectric transmission paths are located adjacent to each other so that the fields surrounding each path interact. The directional coupler of Fig. 3 comprises a hollow metal structure **60** forming a chamber having four metal wave guide terminals **61, 62, 63** and **64**. Guides **61** and **62** open from opposite walls of the chamber and are axially aligned. Guides **63** and **64** open from opposite walls of the chamber and are each substantially directed toward a common point on the axis of guides **61** and **62**. Each of the four guides terminates in a horn, the interior surface area and shape of which may be similar to that of horn **17** of Fig. 1. For example, guide **61** may terminate at the apex of a pyramidal-shaped depression **65** integrally machined in the interior wall **66** of structure **60**. Similar horns or depressions **67, 68** and **69** are provided for guides **62, 63, 64**, respectively, each of which is symmetrically arranged about the axis of its associated guide, and are provided for launching dielectric waves within the chamber. An all-dielectric wave guide **70** having tapers **71** at each of its ends passes through chamber **60** with one end thereof pushed within guide **61** and horn **65** and the other end within guide **62** and horn **69**. A second all-dielectric guide **72**, having the same cross sectional dimensions as guide **70** and having tapers **73** at each of its ends, passes in a smoothly curved arch through chamber **60**, the center portion of the arch being contiguous to the center portion of guide **70**. One end of guide **72** is pushed within guide **63** and horn **67**, and the other end within guide **64** and horn **68**. As illustrated on Fig. 6, guides **70** and **72** are coupled in the electric plane, but it should be noted that the guides **70** and **72** may also be coupled in the magnetic plane. The tapers **71** and **73** at the ends of the dielectric guides **70** and **72** afford a good match between the dielectric guides and the metallic guide sections **61, 62** and **63, 64**, respectively. It is thus possible to move either end of dielectric guide **72** along the terminating metallic wave guides **63** or **64** without influencing the transmission of wave energy between guide **63** and guide **72** or between guide **64** and guide **72**. Consequently, if the dimensions of chamber **60** are chosen so that dielectric guide **72** is approximately the correct distance from dielectric guide **70**, fine adjustment in this spacing and consequent fine adjustment of the coupling factor between guides **70** and **72** can be easily made by moving either end of guide **72** along its metal launching wave guides **63** or **64**. Such motion will cause guide **72** to move closer or farther away from guide **70** and thus alter the coupling factor between guides **70** and **72** so as to produce any desired power transmission from guide **72** to guide **70** in accordance with the principles already defined. In order to avoid resonance effects within chamber **60**, the interior surfaces thereof are lined with an absorbing material **74** which may be, for example, a coating of carbon material, with the exception of a portion of the interior surfaces in the vicinity of dielectric guides **70** and **72** and particularly in the area surrounding the launching horns **65**, **67**, **68** and **69** as represented for example by area **75** surrounding horns **65** and **67**. This area **75** should be large enough so that the resistive material **74** will not intercept any appreciable part of the wave energy normally propagated along guides **70** or **72**.

In all cases it is understood that the above described arrangements are illustrative of a small number of the many possible specific embodiments which can represent applications of the principles of the invention. Numerous and varied other arrangements can readily be devised in accordance with these principles by those skilled in the are without departing from the spirit and scope of the invention.

What is claimed is:

1. In an electromagnetic wave transmission system, a wave guiding path comprising an elongated member of dielectric material enclosed within a shell of material having a resistivity of at least 15×10^{-6} ohm centimeters, and means at each end of said path for launching an electromagnetic wave of a given wavelength upon said path in a first electric field pattern that resembles the electric field of the dominant mode in a hollow conductor wave guide but which is guided exclusively by said member, said dielectric member having a maximum cross sectional dimension that is a small fraction of said wavelength whereby the field of said wave is extended into the space surrounding said member, said shell having a minimum cross sectional dimension that is at

least a plurality of said wavelengths to intercept a negligible portion of said extended electric field, said shell substantially dissipating wave energy in electrical patterns other than said first pattern that induce current components in said shell.

2. A wave guiding path for electromagnetic wave energy comprising a strip-like member of nonconductive material having a dielectric constant substantially greater than unity, the transverse cross sectional dimensions of said member being small compared to the wavelength of the highest frequency wave to be transmitted therealong, said member being surrounded by a layer of matter having a dielectric constant substantially equal to unity, the thickness of said layer being large compared to said wavelength, and a shell of material having a resistivity of at least 15×10^{-6} ohm centimeters surrounding said layer.

3. In an electromagnetic wave transmission system, an elongated enclosure at least the inside surface of which is formed of a material having a resistivity of at least 15×10^{-6} ohm centimeters dissipative for electromagnetic wave energy, said enclosure having a minimum inside transverse dimension of several wavelengths of said energy, a plurality of thin partitions extending transversely within said enclosure, said partitions being made of material having a dielectric constant close to unity and each having an aperture extending through its thickness, and a slender rod of material having a dielectric constant substantially greater than unity extending through said apertures.

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