

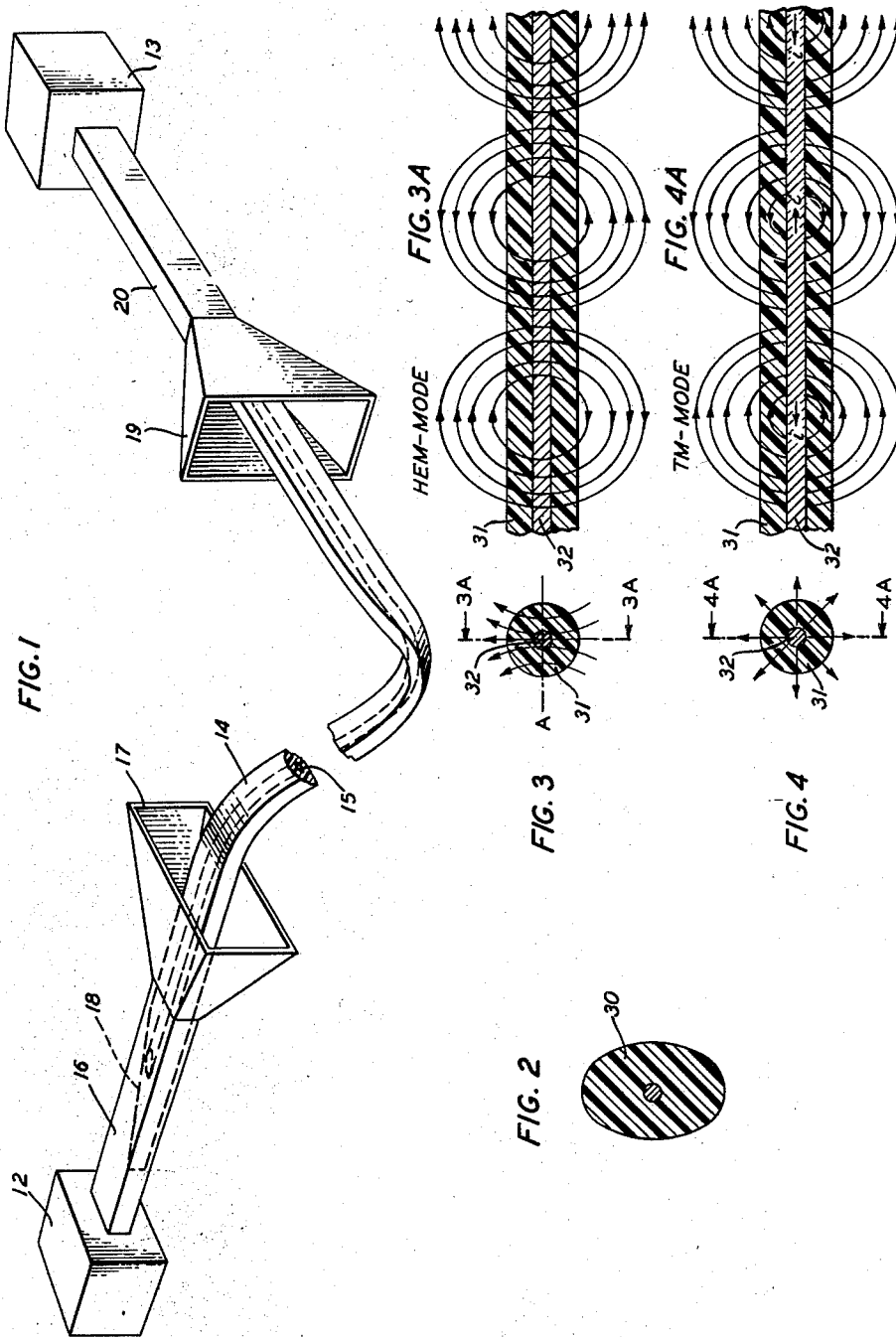
Aug. 26, 1958

A. G. FOX

2,849,692

DIELECTRIC GUIDE FOR ELECTROMAGNETIC WAVES

Filed Aug. 18, 1954



INVENTOR
A. G. FOX
BY *Ray M. Potter, Jr.*
ATTORNEY

1

2,849,692

DIELECTRIC GUIDE FOR ELECTROMAGNETIC WAVES

Arthur G. Fox, Rumson, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application August 18, 1954, Serial No. 450,626

6 Claims. (Cl. 333—95)

This invention 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 applicant's copending application, Serial No. 274,313, filed March 1, 1952, now U. S. Patent 2,794,959, issued June 4, 1957, it is taught that electromagnetic wave energy may be guided along a transmission medium consisting solely of dielectric material, in other words, an all-dielectric media as opposed to the more well-known transmission media of the types either in which a longitudinal conductive shield is placed to surround the dielectric material or in which a conductive axial core is provided within 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. A great portion of the energy when launched upon such a rod in the proper mode 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. However, transmission applications of these guides have been substantially limited to experimental installations because of the physical weakness of the material forming the guide. Not only is it subject to fracture by sharp bends or kinks or by sudden changes of strain, but even a constantly applied force, for example, due to the weight of a self-supported vertical run of the guide, tends to stretch and deform the guide. This deformation may increase mode degeneration and radiation losses. Rigid mountings for supporting the guide will overcome this limitation to some extent but such supports destroy the flexibility and simplicity of the unshielded transmission system which are among its most useful attributes.

It is therefore an object of the invention to add strength to an unshielded dielectric transmission media while maintaining its flexibility and simplicity.

It is another object of the invention to transmit a desired mode of propagation along an unshielded transmission medium which medium at the same time dissipates and prevents transmission of undesired modes of propagation.

These objects are accomplished in the embodiment to be described hereinafter by transmitting wave energy in a mode, the field pattern of which resembles the dominant transverse electric mode in a conductively shielded rectangular wave guide, along an unshielded dielectric guide having a central metallic core of resistive material. Since the field of this wave does not tend to induce longitudinal current components running along the core, the wave energy is propagated substantially unaffected by the presence of the resistive core. The metal core, however, adds substantial mechanical strength to the guide. On the other hand, a predominant spurious wave into which the desired wave tends to degenerate is transverse magnetic, with a field pattern resembling the dominant mode of coaxial transmission lines. This spurious wave produces

2

longitudinal currents in the resistive core that cause dissipation of the wave energy.

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 millimeter wavelength microwave system in which two electromagnetic wave devices are interconnected along a curving path by a transmission line having a resistive core in accordance with the invention;

Fig. 2 represents an alternative cross section for the transmission line of Fig. 1;

Figs. 3 and 3A represent the electric field pattern of the desired mode of transmission on a transmission line of the type employed by the present invention; and

Figs. 4 and 4A represent the electric field pattern of a spurious wave which is dissipated by the transmission line of the present invention.

Fig. 1 illustrates how a dielectric guide in accordance with the invention is used to connect two electromagnetic wave devices 12 and 13 which may be a source and a load, respectively. This connection may be one that requires a curving path and perhaps some freedom of movement between devices 12 and 13. At the lower frequencies such a connection might have been made by a conventional coaxial line or by one of the well-known corrugated or vertebra types of wave guide connections, but inasmuch as the present apparatus is contemplated as operating in the wavelength range of several millimeters, these well-known connectors are not satisfactory. In accordance with the present invention, therefore, this connection is made by an elongated member 14 of dielectric material, having a metallic core 15 of high resistance material extending substantially the length of member 14, and having no external conductive shield.

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 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 degenerate into other modes as fully described in the above-mentioned 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, such as the cross section of guide 30 represented in the alternative cross-sectional view of Fig. 2, may be used if the lengths of the major axis are different. Long slender guides of the latter cross sections are easier to make by presently known methods of manufacture such as by extruding.

Core 15 comprises an axially imbedded wire-like member that is surrounded by or circumferentially sheathed within the dielectric and runs substantially the entire length of member 14. Core 15 can be characterized as a

3

"dissipative conductor" and is made of a high resistance material. 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 about 15×10^{-6} ohm centimeters at 20 degrees centigrade. Within this category are the commercially available resistance wires commonly used as heating elements in electrical appliances, such as constantan, Nichrome and Climax wire. Also within this category are the conductive materials bismuth, bronze, copper-manganese, gallium, German silver, Monel metal, osmium, and most of the alloy steels. Opposed to this group of high resistance materials are the "low resistance" materials commonly recognized as being good conductors of electrical energy having resistivities below 15×10^{-6} ohm centimeters at 20 degrees centigrade. This group includes such materials as copper, brass, aluminum, gold, silver, cadmium, chromium, iron, molybdenum and zinc.

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 respectively. 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 TE_{10} mode in guide 16 is launched as a "dominant hybrid" wave upon dielectric guide 14. This wave is the lowest order hybrid electromagnetic wave that may be supported by the dielectric guide and that has an electric field pattern which closely resembles the field pattern of the dominant TE wave in a hollow metal tube wave guide. The electric field pattern of such a wave is shown in Figs. 3 and 3A to be discussed in detail hereinafter. For the purposes of the present specification, this wave will be referred to as the "dominant hybrid electromagnetic mode" which will be abbreviated as the "HEM₁ mode." As the cross-sectional dimensions of the dielectric guide are reduced, a major portion of the wave power of this mode will be forced into the surrounding space. In order to keep the attenuation low for this mode, therefore, it is preferable to use a very slender dielectric member for guide 14 such that the maximum cross-sectional dimension thereof is a small fraction of a wavelength of the highest frequency to be transmitted.

Any discontinuity along guide 14 produces a tendency for the HEM₁ mode to couple with and degenerate into another mode on guide 14. This new mode resembles both the mode in a coaxial transmission line and the TM_{01} mode in a hollow round metal wave guide and has predominantly transverse magnetic lines of force and radial electric lines of force in a given cross section. This field pattern is more fully disclosed hereinafter in connection with Figs. 4 and 4A. For the purposes of this specification, this new mode will be referred to as the lowest order "transverse magnetic mode" or "TM₁ mode." Its nature is fully considered in a paper entitled "Single-conductor surface-wave transmission lines," by Georg Goubau in the Proceedings of the Institute of Radio Engineers, volume 39, No. 6, June 1951, pages 619-624.

Referring therefore to Figs. 3 and 3A, and 4 and 4A, the electrical field patterns of the HEM₁ and TM₁ modes are illustrated, respectively. To simplify the illustration

4

of the field patterns and the comparison to be made between them, the transmission medium of Figs. 3 and 4 is illustrated as having a dielectric portion 31 and a resistive core 32 which are round in cross section, even though as noted above it is preferable to employ an ovoid cross section. However, the field pattern on the ovoid cross sections does not differ qualitatively from those shown in Figs. 3, 3A, 4 and 4A.

From Figs. 3 and 3A it will be seen that the electric field of the HEM₁ mode forms closed loops that lie substantially in curved surfaces that pass in the vicinity of the dielectric portion 31. These surfaces are substantially normal to the same plane through the axis of the line (represented at A on Fig. 3) and tend to fan out in the space farthest away from the axis of the line. In the vicinity of core 32, these loops have no component parallel with the longitudinal axis of the core, but rather extend transversely across the core. Thus no longitudinal current components are produced to flow along core 32. This particular mode is guided only by the dielectric portion 31 with substantially no interference from core 32. Measurements have indicated that the presence of the core perturbs the HEM₁ mode only slightly and adds but very little to its electric losses. Thus the presence of the core adds physical strength to the dielectric guide, allows the guide to be more nearly self-supporting, and allows it to be bent smoothly and with ready flexibility around gradual curves.

From Figs. 4 and 4A it will be seen that the electric field of the TM₁ mode forms radially extending loops each of which terminate upon the core 32. In order to complete the continuity of each loop, longitudinal return currents i must flow through core 32. These currents cause dissipation of energy by the resistive material of the core with the result that the TM₁ mode and all other modes similarly producing substantial longitudinal currents are rapidly attenuated. Since it is a fundamental of coupled transmission lines that one wave will not easily couple with or degenerate into a second wave which is highly attenuated, the tendency of the HEM₁ mode to degenerate into the TM₁ mode is substantially reduced.

As used in the present specification and claims, the term "shield" is restricted to mean the conductive boundary of a wave transmission path that actually forms a part of the propagation media and substantially influences the propagated wave. In this sense it includes the conductive portion of the conventional hollow pipe wave guide. Therefore, the terms "dielectric wave guide" or "unshielded guide" are intended to mean a rod or column of material having a different and generally a greater dielectric constant than its immediate surroundings not closely surrounded by a conductive shield. However, it is understood that these terms are not intended to exclude structures which are provided with a boundary, conductive or otherwise, located at a sufficient distance from the boundary between the high and low dielectric constant media to have little or no effect on the propagation of the desired wave along the dielectric portion of the guide.

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

What is claimed is:

1. In combination, first and second electro-magnetic wave devices, an elongated member of dielectric material connecting said devices, said member being unsheathed whereby a substantial portion of wave power is conveyed in a field surrounding said member, and a metallic core of high resistance material extending substantially the length of said member to dissipate wave energy which produces longitudinal currents in said core.

5

2. In an electromagnetic wave transmission system, a waveguiding path comprising a wire-like element enclosed within a sheath of material having a high dielectric constant, and means at each end of said path for launching an electromagnetic wave upon said path in an electric field pattern having continuous loops which extend transversely through said sheath and through and around said wire, said wire being resistive to substantially dissipate wave energy in electrical field patterns having loops which terminate upon said wire.

3. In combination, first and second electromagnetic wave devices, an elongated member of nonconductive material connecting said devices, said member having different orthogonal transverse dimensions in any given cross section and being unsheathed with the outside surface thereof exposed to the atmosphere surrounding said member and having a dielectric constant substantially different from that of said atmosphere, means interposed between an end of said member and each of said devices for launching an electromagnetic wave upon said member in an electric field pattern having continuous loops which extend transversely through said member, a metallic wire-like element extending through substantially the center of the cross section of said member, said wire being highly resistive to substantially dissipate wave energy having field patterns that are different from the field patterns launched by said means in that said different patterns have electric field loops which terminate upon said wire.

4. In combination, first and second electro-magnetic

6

wave devices, an elongated member of dielectric material connecting said devices, means for coupling one of said devices to said member to launch waves therein in the hybrid electromagnetic mode, means coupling the other of said devices to said member to abstract energy therefrom, and means extending along said member to couple to and dissipate waves propagating therein the transverse magnetic mode.

5. In an electromagnetic wave transmission system, a source of electromagnetic energy, an elongated member of dielectric material, means for launching waves from said source for propagation along said member in the hybrid electromagnetic mode, and means extending along said member to couple with and dissipate electromagnetic waves of the transverse magnetic mode.

6. In an electromagnetic wave transmission system, a source of electromagnetic energy, an elongated member of dielectric material, means for launching waves from said source for propagation along said member in the hybrid electromagnetic mode, and a strength member of dissipative material positioned in and extending along said dielectric member to couple with and dissipate waves traveling along said dielectric member in the transverse magnetic mode.

References Cited in the file of this patent

UNITED STATES PATENTS

2,058,619	Peters	Oct. 27, 1936
2,548,467	Crise	Apr. 10, 1951