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IMPEDANCE-MATCHING DEVICE

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Fig. 1.

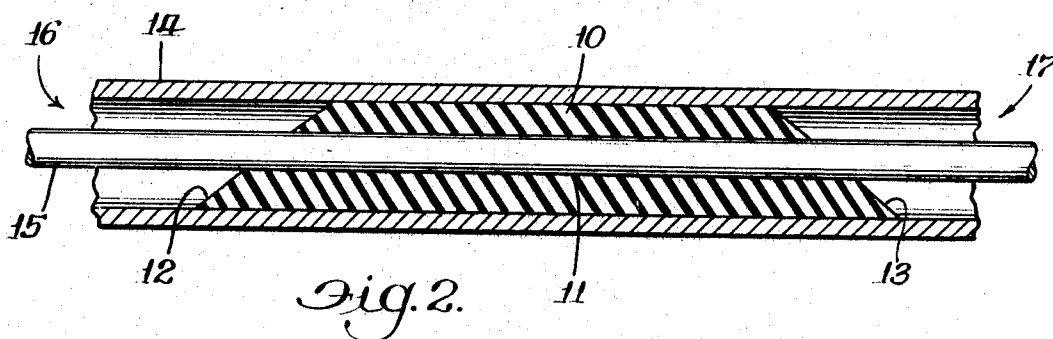
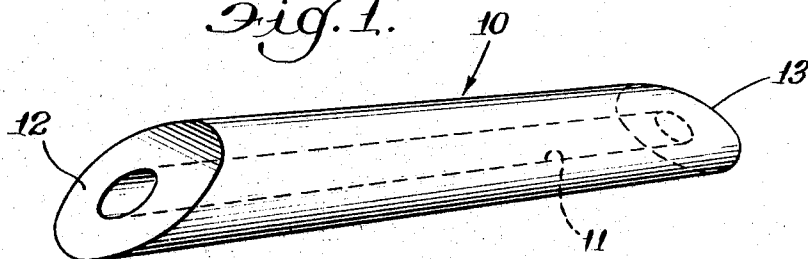


Fig. 2.

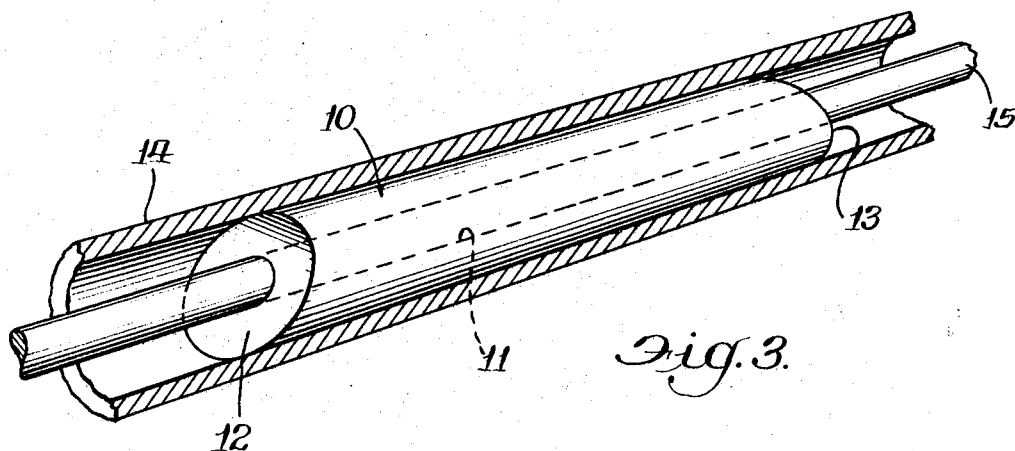


Fig. 3.

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IMPEDANCE-MATCHING DEVICE

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6 Claims

ABSTRACT OF THE DISCLOSURE

A broad-band impedance-matching device for coaxial transmission lines defining a beveled interface between the dielectric of the line and the dielectric of the matching device.

BACKGROUND

The present invention relates to an impedance-matching device; that is, a device for coupling electrical energy in the microwave region between two transmission lines having different characteristic impedances with a minimum of reflection.

A conventional transmission line or coaxial cable includes a cylindrical outer conductor, a center conductor coaxial therewith, and a dielectric separating the two.

When it is desired to couple microwave electrical energy from a coaxial cable having one dielectric material to a coaxial cable having a different dielectric material, a problem arises in matching the two cables to minimize the energy reflected at their interface. One conventional method of matching such cables is to design the geometry of the cables such that each cable has the same characteristic impedance. However, when the dielectric constants of the two dielectric materials are substantially different (such as water and air), the relative dimensions required of the outer conductors and center conductors of the matched cables become impractical.

A second way to match two such cables, is to construct the cables having two different characteristic impedances and then to insert an impedance matching device between the two cables to minimize reflections thereby increasing the energy coupled from one cable to the other. Such impedance-matching devices are frequency dependent, and often very difficult to design. Further, it is sometimes desired to have the outer conductors and center conductors of the two coaxial cables continuous, in which case the matching device must be designed to be inserted in the space between the center and outer conductors and engaging both of the dielectric materials.

One known device for matching coaxial cables having dielectric materials of substantially different dielectric constants and continuous center and outer conductors is a dielectric cone having an exponential taper and the same relative dielectric constant as one of the dielectric materials of the cables. The exponential taper extends into the other dielectric, and the dimensions of the taper are such as to provide a constant change in impedance per wave length. Such tapers are made of titanium dioxide, which after it is fired, is a very hard substance; hence, the tapers must be formed while the substance is in its chalky, prefired state, and allowances must be for shrinkage. Secondly, since it has been found to be impractical to mold the center conductor inside the titanium dioxide, a channel of the proper size must be formed in the extruding operation to provide for a center conductor. This operation makes for an impedance-matching device which is extremely difficult to manufacture.

SUMMARY

It has been found that a dielectric having the same transverse dimensions as the dielectric with which match-

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nig is desired may serve as a suitable impedance-matching device if the interface between the two dielectrics defines a surface inclined relative to a plane perpendicular to the axis of the cable. Hence, according to the instant invention, a wide-band impedance-matching device can be obtained by simply providing a beveled surface interfacing two dielectric materials of substantially different dielectric coefficients while maintaining the same outer-conductor to center-conductor ratio. In addition, by providing two such inclined surfaces, it is possible to couple microwave energy from a coaxial cable having, for instance, air as a dielectric material to a coaxial cable having water, or some other fluid, as the dielectric material without significant loss of energy due to reflection.

Other advantages to the instant invention will be obvious to persons skilled in the art from the following detailed description of a preferred embodiment together with the attached drawing in which identical reference numerals will refer to like parts in the various views.

THE DRAWING

FIG. 1 is a perspective view of a coaxial cable dielectric incorporating features of the present invention;

FIG. 2 is a side sectional view of a coaxial cable in which the dielectric of FIG. 1 is inserted; and

FIG. 3 is a partially-sectioned perspective view of the structure of FIG. 2.

DESCRIPTION

A coaxial cable is a well known device for transmitting high frequency electrical energy, and it consists of two concentric conductors separated at constant spacing by an electrical insulator or dielectric material. Such cables are generally circular in cross section such that the outer conductor has a cylindrical shape and the inner or center conductor lies along the axis of the cylindrical outer conductor; either conductor may be formed of strands or solid wire. The insulator may be air or any other dielectric material, for example, Teflon. When a coaxial cable has a uniform and constant cross section along its length, it is known to have a constant distributed impedance, called its characteristic impedance; and if it is terminated in a load having the same impedance as the cable, all of the electrical energy transmitted through the cable will be delivered to the load; that is, none of the electrical energy will be reflected back to the source. Such reflections, of course, are undesirable since they indicate an inefficient transfer of energy. In other words, the reflections carry power away from the load.

When the load has an impedance value different than the characteristic impedance of the cable, an impedance-matching device may be inserted between the two such that the cable sees an impedance equal to its characteristic impedance and energy is delivered to the load from an impedance value equal to the load impedance. No energy is dissipated in an ideal impedance-matching device.

The characteristic impedance of a coaxial cable may be determined from the physical constants of the cable as follows:

$$Z_0 = \frac{60}{\sqrt{\epsilon_0}} \ln \frac{b}{a}$$

where:

ϵ_0 is the relative dielectric constant of the insulator or dielectric material;

$\ln$ is the natural logarithm;

b is the inside diameter of the outer conductor; and a is the outside diameter of the center conductor.

A commonly-used figure of merit indicating the mismatch between a transmission system and its termination is the voltage standing wave ratio. The voltage standing

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wave ratio may be defined as the amplitude of the incident wave plus the amplitude of the reflective wave divided by the amplitude of the incident wave minus the amplitude of the reflected wave in volts. If there is no reflection, then the amplitude of the reflected wave is zero and the standing wave ratio is 1.0 indicating a perfect matching between transmission system and load. In general, the standing wave ratio is a function of frequency since usually both the transmission system and the load have some variation with frequency, and the standing wave ratio, if given as a constant, is only valid for a given frequency range.

A useful known circuit configuration for investigating impedance matching is a series circuit in which a source having a known output impedance is coupled into a transmission cable having a matching characteristic impedance. The source transmission cable is then connected to a transmission cable having an unknown or mismatching characteristic impedance. This latter transmission cable is then connected to a second transmission cable having a characteristic impedance equal to the characteristic impedance of the source transmission cable, and this latter transmission line is terminated in a load impedance equal to its characteristic impedance. Hence, the unknown or different characteristic impedance sees the same impedance at both of its ends.

Such a system will exhibit a voltage standing wave ratio which is a periodic function of frequency having a shape resembling a $\sin^2$ function. The standing wave ratio will be one at certain frequencies, indicating a perfect match only at these frequencies. The frequencies indicating an impedance match are those for which the unknown line is a multiple of one-half wave length of the propagating wave. When the unknown line is an odd multiple of quarter wave lengths, the voltage standing wave ratio will theoretically be five hundred.

The characteristics of the above-described series circuit configuration are well known, and it is commonly used to determine both the value of an impedance and the frequency dependency of a distributed impedance. Such a series configuration of characteristic impedances may also be used to determine the frequency response of matching devices by inserting the matching device between two transmission lines or coaxial cables having the same characteristic impedance, one of which is coupled to the source, and the other is terminated in its characteristic impedance. Suitable transmission lines can be obtained having characteristic impedances constant over a very wide frequency range. The measured standing wave ratio will be constant at one as long as the matching devices couples energy between the lines without reflection. Eventually, of course, one of the elements in the circuit will exhibit a frequency dependency which will reflect itself in a varying standing wave ratio as a function of frequency. As will be described in more detail below, such an experiment was performed to determine the frequency response of the matching device of the instant invention.

Turning now to the drawing, the matching device of the instant invention will be described. As shown, the matching device has been adapted for use with a coaxial cable having a circular cross section. Hence, in FIG. 1 is seen an insulator or dielectric of annular cross section and generally designated as 10, having a central aperture 11 and first and second beveled surfaces 12 and 13.

FIG. 2 shows a side sectional view of the dielectric 10 of FIG. 1 incorporated into a convention transmission cable. The cable has a cylindrical outer conductor 14 and a solid center conductor 15 lying along its axis. For convenience, the source end is indicated generally at 16, and the load end at 17. As is clearly seen in FIG. 2, the outer diameter of the dielectric 10 is constant and equal to the inner diameter of the outer conductor 14. Likewise, the diameter of the aperture 11 of the dielectric 10 is designed to accommodate the center conductor 15.

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It will be observed that the beveled surface 12 of the dielectric 10 is merely a planar surface inclined relative to a plane perpendicular to the axis of the center conductor 15. The beveled surface 13 of the dielectric 10 is similarly inclined, and it is noted that the relative disposition of the beveled surfaces 12 and 13 has no bearing on the matching characteristics of the device. In other words, the plane of the beveled surface 13 may be rotated out of symmetry with the plane of the beveled surface 12, or they may take the same angular disposition.

For convenience of illustration, and because the experiments described below were performed under these circumstances, the source end 16 of the coaxial cable is shown as having its dielectric as air. Hence, the interface between the dielectric material of the matching device and the dielectric material of the transmission cable is a planar surface inclined relative to a plane perpendicular to the axis of the center conductor 15. Further, it will be noted that the dielectric materials are contiguous longitudinally of the cable; that is, the dielectric of the cable is continuous with the dielectric of the matching device both at the source end and at the load end.

With the structure as described above, I have found that an extremely good impedance match may be obtained between two sections of continuous coaxial cable having dielectric materials of substantially different dielectric constants. In my experiments, I used as the dielectric material of the matching device, a commercially-available ceramic tube having a relative dielectric constant of approximately 80 with an outside diameter of three-eighths of an inch and an internal diameter of one-eighth inch. As supplied, the end surfaces of the ceramic tubing were perpendicular relative to its axis. The beveled or inclined surface was formed by simply cutting with a diamond edge saw. The inclined surface was cut to define an angle of about 40° with the plane perpendicular to the axis of the tubing.

A test was performed with a six inch test section of the impedance-matching dielectric inserted into a brass coaxial cable twelve inches long. The ends of the dielectric tube were planes perpendicular to the axis of the tube. (The characteristic impedance of the brass cable with air as the dielectric was measured to be sixty-six ohms, and with the ceramic dielectric, seven and two-tenths ohms.) One end of the cable was coupled to a 50 ohm cable which was terminated in a standard 50 ohm load; and the other end was supplied with a source cable having a characteristic impedance of 50 ohms. A conventional oscillator and slotted line were then connected in series with the source cable, and a VSWR meter coupled to the slotted line to measure the voltage standing wave ratio.

The voltage standing wave ratio was then measured as a function of frequency, and it was found that the voltage standing wave ratio varied from 1.3 to greater than 40 following the $\sin^2$ relationship indicated above wherein the nodes were separated by 110 megacycles.

As a second experiment, the six inch section of ceramic tubing was cut with a saw so that the plane of the cut was inclined at an angle of about 40° to the axis of the tubing. Changes were made in the brass test section so that without the ceramic tube inserted, the test circuit had a voltage standing wave ratio less than 1.2 over the frequency range of 280 megacycles to 6000 megacycles. (The minimum VSWR with the brass conductor and air dielectric previously had been 1.3, as noted above.) With the ceramic dielectric then inserted in the test section of the brass tube, the VSWR was found to be less than 1.4 over the entire frequency range of 280 megacycles to 6000 megacycles.

The same test was repeated with a section of ceramic dielectric ten and a half inches long, and the results were the same.

The length of the matching device, that is, the projection of the beveled surface on the axis of the ceramic tubing, was about one-half an inch long, indicating that an

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extremely simple and compact matching device could be constructed having a very wide frequency range.

A third experiment was performed in which a three inch segment of the center conductor internal of the ceramic dielectric was removed. This arrangement formed a wave guide, capable of transmitting a transverse magnetic wave if the source frequency was above 3,200 megacycles. In test, the structure thus constructed exhibited a very high standing wave ratio (above forty, the maximum registrable on the instrument used) until the frequency increased to 3,200 megacycles. Then the VSWR dropped to 1.4 at 3,300 megacycles and remained below 1.4 to the upper end of the frequency range of the oscillator which was 6000 megacycles, thereby indicating that the wave propagated through the dielectric section in a normal TEM transmission mode in the sections previously occupied by the center conductor.

In summary, the overall results of the various tests indicate that the ceramic dielectric without the beveled ends fits the classical transmission line theory by mismatching with the known cables. Secondly, with the beveled ends formed in the ceramic matching device, wherein the relative disposition of each beveled surface is independent of the other, a very good impedance match is obtained, and one which is continuous for a broad frequency spectrum. Finally, the wave propagating in the dielectric does so in a normal TEM coaxial mode.

Although the structure and dielectric material, as well as the inclination of the beveled surfaces described above, may be suitably changed depending upon the application, it is desired that all such modifications be covered as they are embraced within the spirit and scope of the appended claims.

What is claimed is:

1. An impedance-matching device for coupling to a coaxial cable having a center conductor, a dielectric body about said center conductor, and an outer conductor encompassing said dielectric body, comprising: a center conductor coupled to said cable center conductor, an outer conductor coupled to said cable outer conductor, and a dielectric body between said device center conductor and said device outer conductor, said device dielectric body being contiguous with said cable dielectric body and defining a first generally flat surface inclined relative to a plane perpendicular to the direction of elongation of said center conductor therebetween whereby electrical energy may be efficiently transmitted between said cable and said device.

2. The device of claim 1 wherein said coaxial cable is circular in cross section, said device center conductor is a continuation of said cable center conductor, and said device outer conductor is a continuation of said cable outer conductor, said device dielectric body defining an annular cross section and a second generally flat surface inclined relative to a plane perpendicular to the direction of elongation of said center conductor at an end opposite said first generally flat surface inclined relative to a plane perpendicular to the direction of elongation of said center conductor.

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3. The device of claim 1 wherein said device dielectric body is ceramic having a relative dielectric constant equal to that of a dielectric of a second coaxial cable.

4. In a coaxial cable impedance-matching device, a dielectric body adapted for encompassing a center conductor and defining an end generally flat surface inclined relative to a plane perpendicular to the direction of elongation of said center conductor for engaging a similar generally flat surface inclined relative to a plane perpendicular to the direction of elongation of said center conductor of the dielectric of said cable whereby coupling of microwave electrical energy is facilitated.

5. A device for matching impedances between a first coaxial cable having a center conductor, an outer conductor, and a first dielectric material, and a second coaxial cable having a center conductor, an outer conductor, and a second dielectric material different from said first dielectric material of said first cable comprising: a center conductor coupling the center conductor of said first cable with the center conductor of said second cable; an outer conductor coaxial with said device center conductor and coupling the outer conductor of said first cable with the outer conductor of said second cable; and a dielectric body between said device center conductor and said device outer conductor, said body defining a first generally flat surface inclined relative to a plane perpendicular to the direction of elongation of said center conductor contiguous with the dielectric of said first cable and a second generally flat interface surface inclined relative to a plane perpendicular to the direction of elongation of said center conductor contiguous with the dielectric of said second cable.

6. An impedance-matching device for a coaxial cable including a center conductor, a generally cylindrical outer conductor and a dielectric between said center and outer conductors and having an annular cross section, comprising a center conductor connected to the center conductor of said cable, a cylindrical outer conductor connected to the outer conductor of said cable and a dielectric body having an annular cross section and a substantially different dielectric constant than the dielectric of said cable, and defining a flat surface inclined relative to a plane perpendicular to the direction of elongation of said center conductor, said dielectric of said cable and said dielectric body of said device being contiguous along said inclined plane.

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