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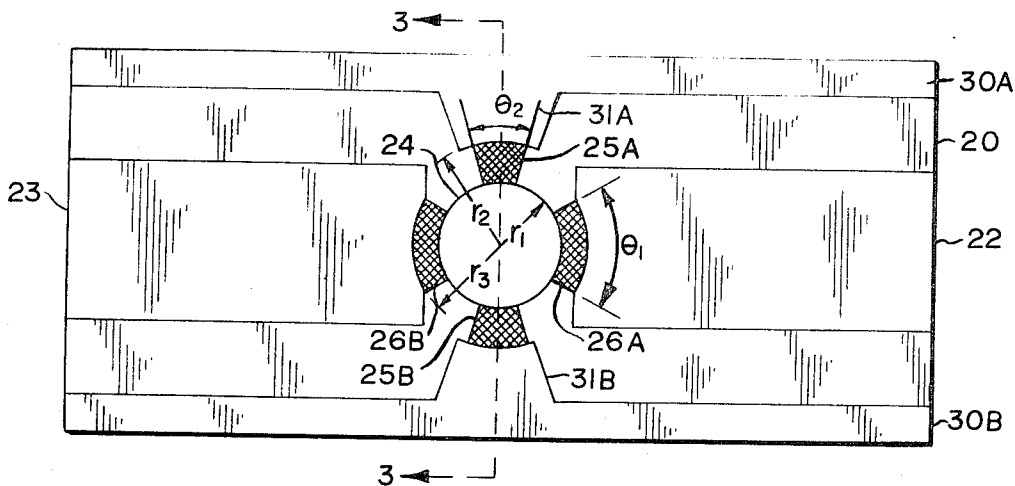
[54] **RESISTIVE FILM CARD ATTENUATOR FOR MICROWAVE FREQUENCIES**
10 Claims, 5 Drawing Figs.

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333/22, 333/34, 333/84, 338/216, 338/217,
338/309
[51] Int. Cl..... H01p 1/22,
H01p 1/26, H01c 7/00
[50] Field of Search..... 333/81 A,
84 M, 81, 84, 22; 338/216, 217, 142, 295, 309

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ABSTRACT: A microstrip attenuator includes a ground plane and a signal conductor supported on a dielectric material above the ground plane. The signal conductor is interrupted for a portion of its length. A circular conductor having a diameter less than the length of interruption is placed on the dielectric with its center at the center of the gap between the portions of the signal conductor. Resistive material of predetermined resistivity is deposited on the dielectric extending from the circular conductor to the edges of signal conductors. Each deposition defines a sector of a circle with the transverse extremities thereof extending radially from the circular conductor. The longitudinal extremities are determined by arcs extending from the center of the circular conductor to the conductors and the circular conductor periphery. Shunt resistive elements are formed by depositing material of predetermined resistivity on the dielectric extending from the circular conductor in a direction essentially transverse of the direction of propagation. Likewise, the shunt resistive configuration defines a sector of a circle extending from the circular conductor to a second conductor essentially maintained at ground plane potential.



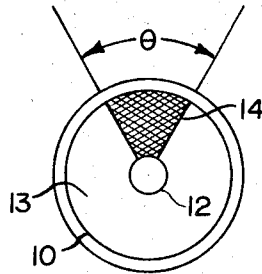


FIG. 1

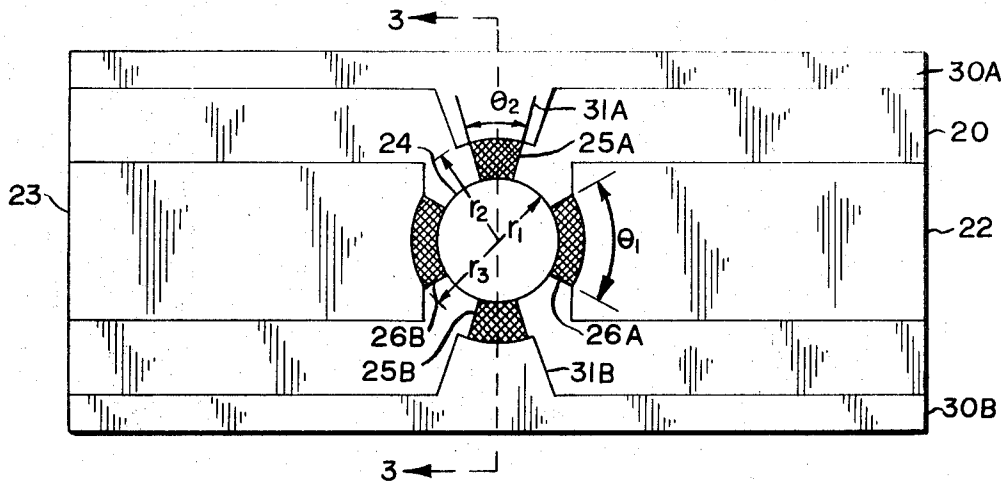


FIG. 2

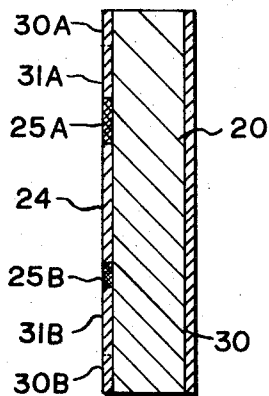


FIG. 3

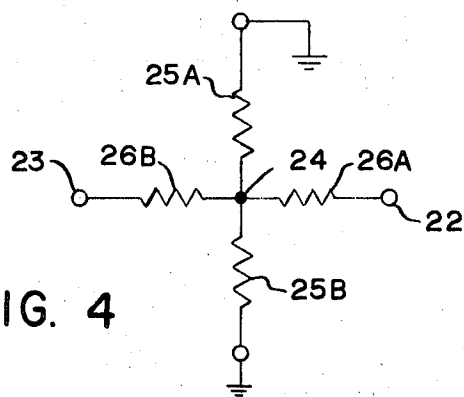


FIG. 4

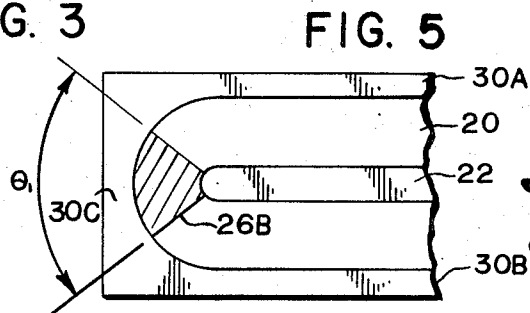


FIG. 5

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RESISTIVE FILM CARD ATTENUATOR FOR MICROWAVE FREQUENCIES

BACKGROUND OF INVENTION

The present invention relates in general to high frequency resistance and more particularly concerns novel broadband resistances with high electrical performance and small physical form which is relatively easy and inexpensive to fabricate in large and small quantities with uniformly high quality.

It is an important object of the invention to provide a broadband microwave resistive means.

It is an object of this invention to provide an improved resistive film attenuator having both series and shunt elements.

Another object of this invention is to provide an attenuator in which the individual resistive elements are susceptible to measurement by simple inexpensive devices, as for example by an ohm meter.

Another object of this invention is to provide a wide band attenuator having a substantially flat frequency response over a wide range of frequencies, for example from DC to 18 GHz.

It is another object of this invention to provide an attenuator in which the resistive elements have a length substantially less than a wavelength at the highest frequency of operation.

It is another object of this invention to provide an attenuator in which the criticality of uniform distribution of resistive materials is substantially diminished.

Another object of this invention is to provide an attenuator which may be adapted for use with a variety of dielectric materials to achieve high power carrying capability.

It is a further object of this invention to provide an attenuator which may function as a termination for other purposes.

A further object of the invention is to provide a broadband attenuator which is susceptible to operation at high microwave frequencies with a variety of connectors for coupling to external apparatus.

Another object of the invention is to provide an attenuator which may be integrally combined with other devices to form a microwave integrated circuit.

A further object of the invention is to provide an attenuator in which the values of the resistive elements are easily calculable.

Another object of the invention is to provide an attenuator which may be deposited upon a relatively thin dielectric card for use in coaxial, strip line or other TEM waveguide lines.

It is another object of this invention to provide an attenuator which is susceptible to sealed or unsealed operation and which is relatively easy and inexpensive to fabricate in large and small quantities with uniformly high quality.

It is another object of the invention to provide an attenuator capable of handling relatively large quantities of RF power while introducing relatively little reflection in the microwave frequencies of interest.

It is a further object of the invention to provide an attenuator which may be used with a variety of TEM waveguide configurations, as for example microstrip, strip line, or coaxial lines.

It is a further object of the invention to provide an attenuator in which the resistive elements may be deposited by thin or thick film techniques.

SUMMARY OF THE INVENTION

According to the invention, there is provided a TEM waveguide, as for example a microstrip transmission line. The signal conductor of the transmission line is supported by a dielectric material above a ground plane. The signal conductor is interrupted for a portion of its length, and a thin circular conductor having a diameter less than the interruption is placed upon the dielectric with its center at the center of the interruption. Resistive material is deposited upon the dielectric extending from the circular conductor to the respective signal conductor portions in a shape substantially defining an annular sector. The transverse portions of the resistive depositions are essentially determined by radii extending from the

center of the circular conductor to the inner conductor portions. The longitudinal extremities of the resistive deposition are determined by an arc having a center at the center of the circular conductor intercepting the signal conductor portions and the circular conductor periphery. Thus, series resistive elements are formed. Shunt resistive elements may be formed by depositing annular sectors of resistive material in a like manner with an axis essentially orthogonal to the direction of propagation. The shunt elements extend radially outward to a second conductor essentially maintained at the potential of the ground plane.

Numerous other features, objects and advantages of the invention will become apparent from the following specification when read in connection with the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a section view of a portion of a coaxial transmission line illustrating a shunt disc partially coated with resistive material;

FIG. 2 is a top view of an embodiment of the invention;

FIG. 3 is a section view through section 3-3 of FIG. 2;

FIG. 4 is a schematic circuit diagram further illustrating the invention; and

FIG. 5 is a top view of an embodiment of the resistive termination.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Corresponding reference symbols refer to corresponding elements throughout the drawings where applicable.

With reference now to the drawings and more particularly to FIG. 1 thereof, there is shown a cross section of a coaxial transmission line in which inner or signal conductor 12 is maintained coaxially within outer conductor 10. A disc of substrate 13 is interposed between inner conductor 12 and outer conductor 10 and coated for a portion of its area with resistive material 14. The area of resistive coating defines an annular sector and is essentially determined by the angle, theta, between radii extending from the center of the transmission line.

Referring now to FIG. 2, there is shown a top view of a microstrip transmission line attenuator according to the invention in which signal conductor portions 22 and 23 are supported by dielectric material 20. Dielectric material 20, in turn, is supported by a ground plane (not shown in FIG. 2). Circular conducting disc 24 (of radius r_1) is centered in the gap between signal conductor portions 22 and 23. Resistive material, as for example a thin layer of nichrome, is deposited upon dielectric 20 between conducting disc 24 and signal conductor portions 22 and 23, respectively to form series resistive arms. The resistive portion extends over annular sectors 26A and 26B, whose longitudinal dimensions are substantially determined by the periphery of disc 24 and an arc (of radius r_3) intercepting signal conductor portions 22 and 23, having a center at the center of disc 24. The transverse dimensions of sectors 26A and 26B are essentially determined by radii extending from the center of disc 24 and subtending an angle θ_1 .

The shunt resistive elements of the attenuator are formed by depositing resistive material on dielectric 20 in the form of annular sectors 25A and 25B. The transverse boundaries of sectors 25A and 25B are determined by the periphery of conducting disc 24 and an arc (of radius r_2) extending to tabs 31A and 31B coupled to conductors 30A and 30B. The radii have their center at the center of conducting disc 24. Conductors 30A and 30B are coupled to and essentially maintained at ground plane potential. The longitudinal boundaries of sectors 25A and 25B are determined by radii extending from the center of disc 24 and subtending an angle θ_2 . Preferably, a protective coating, as for example silicon oxide, is deposited over the resistive film annular sectors 25A, 25B, 26A and 26B to protect them from humidity and other environmental effects.

Referring now to FIG. 3 there is shown a sectional view taken along the parting plane 3-3 of FIG. 2. Disc 24 is shown mounted on dielectric 20, which in turn is supported by a ground plane member such as the cylindrical outer conductor of a coaxial line as in U.S. Pat. No. 3,157,846, or is mounted upon an adherent conductive sheet, such as the ground plane sheet 30. Conductors 30A and 30B and tabs 31A and 31B are coupled to ground plane 30. Resistive annular sectors 25A and 25B are shown interconnecting disc 24 with tabs 31A and 31B, respectively.

FIG. 4 is a schematic diagram in which the resistive annular sectors are represented as lumped resistive elements. Disc 24 is represented as the terminal interconnecting resistive elements 25A, 25B, 26A and 26B. From the figure it is easily seen that resistive elements 25A and 25B are maintained in parallel combination and form a TEE network in combination with series elements 26A and 26B.

Referring now to FIG. 5, there is shown a top view of a resistive termination in which one series element and the shunt elements have been eliminated. Signal conductor 22 is rounded at one of its ends in a manner similar to disc 24. Resistive element 26B again is formed as an annular sector having transverse boundaries determined by radii extending from the center of the rounded portion of signal conductor 22. The longitudinal boundaries of resistive element 26B are determined by the rounded portion of inner conductor 22 and arcuately shaped conductor 30C intercoupling conductors 30A and 30B, which are maintained at ground plane potential. Preferably, the arc of conductor 30C has its center at the center of the rounded portion of signal conductor 22. The radial boundaries of resistive element 26B subtend an angle θ_1 , which may be determined by the resistivity of the material and mechanical and electrical constraints.

Having described the embodiments and the physical arrangement of the circuit components, it is appropriate we consider the techniques and design criteria used. FIG. 1 illustrates a resistive annular sector in coaxial configuration. If the resistivity of the material deposited were that of free space, i.e. 377 ohms per square, then the resistance of the configuration would be (1) $R=120\pi/2\pi \ln B/A$

Where B equals the inner radius of the outer conductor and A equals the outer radius of the inner conductor. If a general resistivity, ρ is assumed and the annular sector defined, the resistance between the inner conductor, and the outer conductor may be defined as: (2) $R=360^\circ/\theta \rho/2\pi \ln B/A$

Where ρ is the resistivity in ohms per square and θ is the angle subtended by the annular sector of resistive material. Thus, the resistance between the two conductors will be determined by the respective diameters of the conducting material, the resistivity of the resistive deposition, and the angle subtended by the radii determining sector of resistive material.

In a specific embodiment of the invention, a 50 ohm 10 db. card attenuator was designed for insertion in a coaxial line. Copper signal conductors of width 0.082 inches and thickness 0.0002 inches were deposited on an alumina substrate material of width 0.206 inches. The alumina substrate had a thickness of 0.020 inches to achieve a 50 ohm characteristic impedance between the inner conductor and an outer conductor of 0.156 inches inner diameter. The shunt and series resistive elements, having a resistivity of 94.25 ohms per square, were deposited about a copper conducting disc, having a radius (r_1) of 0.032 inches. The longitudinal extremities of the series resistive annular sectors were determined by an arc of 0.0427 inches radius (r_3) extending from the center of the disc and intercepting the inner conductors for an angle of 60° (θ_1). The transverse extremities of the shunt elements were determined by an arc of 0.0474 inches radius (r_2) extending from the center of the disc. The shunt resistive annular sectors subtended an angle of 30° and contacted a tab extending radially inward toward the disc from the side ground planes. The side ground planes were likewise of copper material and placed 0.037 inches equidistant from the signal conductor and coupled to the outer conductor. Each side ground plane was

0.025 inches wide and was fitted with a tab extending 0.031 inches radially inward toward the shunt resistive element. Also, conventional type coaxial connectors may be employed to facilitate the connection of the card attenuator to a coaxial line in a manner comparable, for example, to that shown in FIG. 3 of U.S. Pat. No. 3,260,971 or FIG. 6 of U.S. Pat. No. 3,157,846.

The specific embodiment of the attenuator was designed with both longitudinal and transverse symmetry. Also, the resistivity of the shunt and series elements were equal. However, where mechanical or electrical fabrication problems dictate, the resistivity of the shunt and series elements may be unequal and the device may be asymmetrical.

The angles chosen for the series and shunt sector resistive elements were 60° and 30° , respectively. The choice of angles was arbitrary and elicited by convenience of fabrication and packaging. Virtually any angle may be used, provided the resistive configuration and electrical integrity of the device are not impaired.

The invention is illustrated as a bilateral attenuator. That is, the resistance seen looking into either inner conductor will be equal. But the invention is particularly adaptable to nonbilateral techniques. For example, where a lossy matching network is desired to couple two devices of different impedances, the series resistive elements may be unequal. In fact, one of the series resistive elements may be eliminated altogether. One of the inner conductors may extend to the centerline of the conducting disc and its extremity rounded to define one longitudinal boundary for the remaining series resistor element.

When the attenuation to be achieved is extremely small, the shunt element is usually designed to be quite large is resistance. For the limiting case, the shunt elements may be eliminated altogether.

The attenuator may be formed with the shunt elements extending outwardly to couple directly to parallel conductors maintained at ground potential. In a specific embodiment, conducting tabs extended inwardly from the conductors to define the boundaries for the shunt resistive developments. The invention works well in either configuration, the choice dictated by the area of deposition required for the correct resistance value. Moreover, the inwardly extending tabs may be used as matching elements, particularly at high frequencies.

One important feature of the invention is that the separation of resistive elements allows each element to be checked, as for example by DC ohmmeter, so that the correct value of attenuation is achieved.

Also, the resistive values of each of the elements may be adjusted by painting silver over small portions of the elements or scraping small portions of the resistive material from the surface of the dielectric, or any other means of adjusting resistance values.

Also, the invention may be adapted for use as a termination. A conductive layer may extend accurately from the longitudinal extremity of the output series resistor to the side ground planes, thereby shorting the signal conductor to the ground planes and forming an L-pad-type resistive termination. Preferably, however, the termination may take the form of FIG. 5 above.

The invention is illustrated in microstrip TEM waveguide configuration. The invention may also be constructed in strip line, coaxial line, or any other TEM waveguide. The particular application may make use of a dielectric card with the resistive elements deposited thereon.

Also, virtually any type of connectors may be used with proper interconnection to the signal conductors and outer of the transmission line. For example, the connectors on either end of the attenuator may be of the same type and sex, same type but different sex (thereby creating a feed through type device), or of different types and sexes of connectors.

The invention is illustrated with resistive elements in the shape of annular sectors. However, where it is desired to modify the dimensional aspects of the elements to accom-

moderate changes in impedance along the element, the transverse dimensions of the series elements may be determined by an exponential rather than radial taper. Likewise, the longitudinal dimensions of the shunt elements may be determined by an exponential rather than radial taper. In most cases, where there is a relatively short length of resistive element, an exponential taper will not be needed.

Where an exponential taper is desired, the specific exponent may depend upon the resistance per unit length, the distance from the extremity of the resistor and the characteristic impedance of the transmission line. The exponential tapers resulting thereby, preferably, do not vary greatly from radial tapers, so that ease of calculation of resistance value is not substantially impaired.

It is also preferred, although the invention is not limited thereby, that the longitudinal dimensions of the resistive elements do not exceed 0.1 wavelengths at the highest frequency of interest.

Other modifications and uses of and departures from the specific embodiments as described herein may be practiced by those skilled in the art without departing from the inventive concepts. Consequently, the invention is to be construed as embracing each and every novel feature and novel combination of features present in or possessed by the apparatus and techniques herein disclosed and limited solely by the spirit and scope of the appended claims.

What I claim is:

1. A microwave resistance comprising,

TEM waveguide means,

said TEM waveguide means including signal conductor means having a gap between portions thereof, and at least one reference conductor means,

insulating means within said TEM waveguide means,

a first resistive means supported by said insulating means in said gap coupled to one of said portions of said signal conductor means,

a first conducting means supported by said insulating means coupled to said first resistive means and positioned in said gap,

said first resistive means substantially defining an annular sector.

2. A microwave resistance in accordance with claim 1,

wherein said first conducting means includes relatively thin circular-shaped conducting means supported by said insulating means and positioned substantially in the center of said gap.

3. A microwave resistance in accordance with claim 2 and

further comprising second resistive means and second conducting means, said second conducting means being coupled to said reference conductor means,

said second resistive means supported by said insulating means and intercoupling said first conducting means with said second conducting means over an area substantially defining an annular sector extending from said first conducting means to said second conducting means.

4. A microwave resistance in accordance with claim 3, wherein said first and second resistive means include resistive areas of substantially equal resistivity.

5. A microwave resistance in accordance with claim 2 and further comprising,

a third resistive means supported by said insulating means in said gap coupled to the other of said portions of said signal conductor means and coupled to said first conducting means,

said third resistive means substantially defining an annular sector.

6. A microwave resistance in accordance with claim 3 and further comprising,

fourth resistive means and third conducting means, said third conducting means being coupled to said reference conductor means,

said fourth resistive means supported by said insulating means and intercoupling said first conducting means with said third conducting means over an area substantially defining an annular sector extending from said first conducting means to said third conducting means.

7. A microwave resistance in accordance with claim 6 and further comprising,

a third resistive means supported by said insulating means in said gap coupled to the other of said portions of said signal conductor means and coupled to said first conducting means,

said third resistive means substantially defining an annular sector.

8. A microwave resistance in accordance with claim 7, wherein said first and third resistive means include resistive areas of substantially equal resistivity.

9. A microwave resistance in accordance with claim 7, wherein the angular boundaries of said annular sectors are essentially determined by an exponential taper.

10. A microwave resistance in accordance with claim 2, wherein said first conducting means includes means conductively coupling with the other of said portions of said signal conductor means.