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TRANSMISSION LINE ATTENUATORS FOR HIGH POWER

Filed Dec. 14, 1964 2 Sheets-Sheet 1

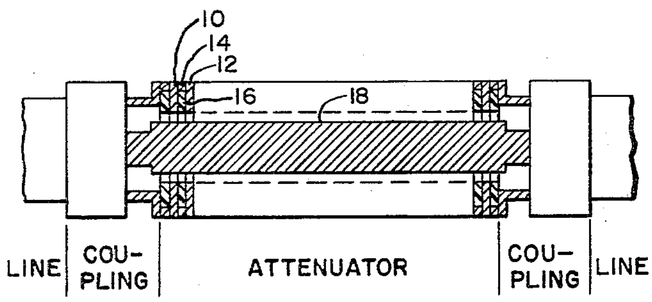

FIG. 1

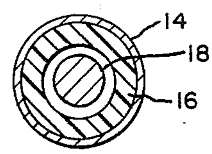

FIG. 2

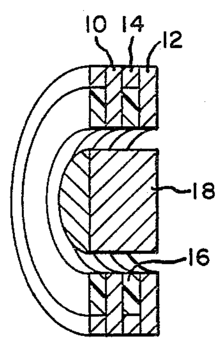

FIG. 3

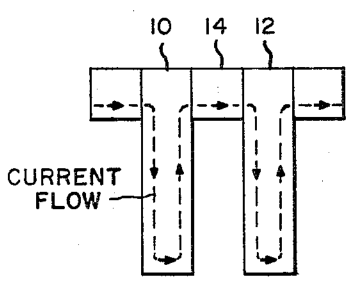

FIG. 4

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TRANSMISSION LINE ATTENUATORS FOR HIGH POWER

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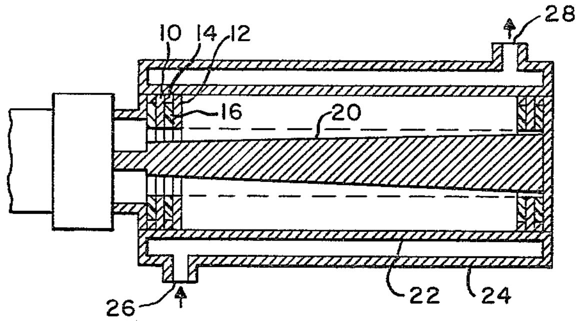

FIG. 5

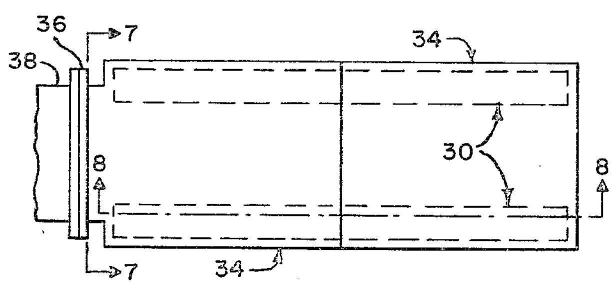

FIG. 6

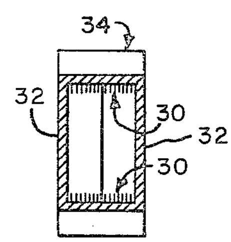

FIG. 7

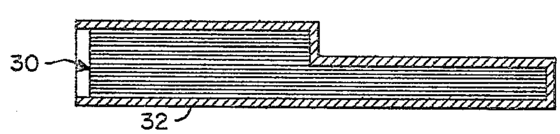

FIG. 8

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TRANSMISSION LINE ATTENUATORS FOR HIGH POWER

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16 Claims. (Cl. 333—81)

This invention relates to attenuators and terminations for use with transmission lines for electromagnetic waves. "Attenuator" will be used as a generic term with a "termination" being considered an attenuator wherein it is intended that all incident power shall be absorbed. More particularly, this invention pertains to high power attenuators using the surface resistance of metallic sheets to provide power handling capabilities of the order of 100 times as great as prior art attenuators of comparable size.

Objects of this invention are to provide attenuators and terminations for transmission lines, such as coaxial cable and waveguide, for example, which permit high power handling capacity for given size or small size for given power capacity, or both.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description, taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings,

FIG. 1 shows an attenuator constructed in accordance with the invention which is bisected longitudinally to show inner construction;

FIG. 2 is a cross-sectional view of the complete attenuator of FIG. 1;

FIG. 3 is an oblique sectional view of a small portion of the FIG. 1 attenuator;

FIG. 4 is a drawing useful in describing the operation of the FIG. 1 attenuator;

FIG. 5 shows a termination with a stepped inner conductor for impedance matching; and

FIGS. 6, 7, and 8 are three views of a waveguide termination using spaced parallel metal plates to form the side walls of the waveguide.

Referring now to FIG. 1, there is shown a bisected view of an attenuator coupled to a coaxial transmission line. The coupling between the attenuator and the coaxial line is shown schematically and any suitable connector can be used to allow coupling to the connector at the end of the transmission line. FIG. 2 is a cross-sectional view of the complete attenuator showing the symmetrical coaxial construction, and FIG. 3 is an expanded, rotated view showing greater detail.

As shown in FIG. 3, this attenuator in accordance with the invention includes a plurality of spaced metallic sheets, of which iron washers **10** and **12** are typical. The iron washers **10** and **12** are in common electrical contact at the outer edges due to the inclusion of the narrow conductive band **14** which bridges the space between the washers **10** and **12**. The central portions of the washers **10** and **12** are spaced and noncontacting, and the space between the washers **10** and **12** is shown as being filled by dielectric washer **16**. Iron washers **10** and **12** and dielectric washer **16** are typical of the large number of similar components included in the complete attenuator of FIG. 1.

As further shown in FIG. 3, both the iron washers **10** and **12** and the dielectric washer **16** have central openings in the center portions of the washers. The holes in all of the washers are centered along the central axis of the attenuator, and are therefore coaxial as shown in FIG. 2. Also included is a central conductor **18**, positioned coaxially within the holes in the washers to form a symmetrical coaxial transmission line.

The additional specific details of construction do not directly involve the basic concept of the present invention. As one example, the conductive band **14** may be a raised rim constructed integrally with washer **10** or **12** and the attenuator shown in FIG. 1 may be put into a close-fitting metallic cylinder and end caps screwed onto this cylinder to hold all the washers together for good electrical and thermal conductivity. The end caps may form part of coaxial connectors used for connection to a transmission line. Another approach is to assemble the metal washers, such as **10** and **12**, and the dielectric washers, such as **16**, on a central mandrel and then cause solder to flow into the space between the edges of washers **10** and **12** to form bridging sections, such as **14**. Once the present invention is understood, such details can be supplied by workers skilled in this art.

In operation, an electromagnetic wave to be attenuated is coupled into the end of the FIG. 1 attenuator. As is well known, currents will be caused to flow in both the outer and inner conductors. The present invention operates by absorbing power from the current in the outer conductor by converting said current to heat which is dissipated. As long as the thickness of the washers **10** and **12** is a few (more than two) times as great as the skin depth of current in the metal in the operating frequency range, the current in the outer conductor will be made to follow a long zigzag path to get from one end of the attenuator to the other. Thus, as indicated in the simplified sketch of FIG. 4, this current must flow along the surface of washer **10**, out to the washer **14**, back in again along the surface of the next washer **12**, etc., throughout the full length of the attenuator.

The total attenuation produced will, of course, depend on the surface resistance of the path which the current is made to travel and the characteristic impedance of the coaxial transmission line. Therefore, in accordance with the invention, washers **10** and **12** are most desirably constructed of material having high electrical surface resistance and, at the same time, high thermal conductivity. Applicants have discovered that iron is an especially useful material for this purpose. The magnetic properties of iron are helpful in this application because the high permeability of iron increases the electrical surface resistance of the washer, but not the thermal resistance. Nonmagnetic alloys could also be used to obtain the high resistance needed, but higher resistance in a metal is usually associated with higher thermal resistance and, therefore, lower power capacity as limited by the heating permissible. A magnetic material thus overcomes this limitation and provides high surface resistance with high thermal conductivity.

The high thermal conductivity of the complete attenuator is a very important feature of the present invention. The metal washers **10** and **12** in FIG. 3 are the elements in which the heat is introduced by the dissipation of electromagnetic energy. These same elements physically extend to the outer circumference of the attenuator without interruption or discontinuity. Therefore, as heat is generated, it is rapidly conducted outward where such heat can be very rapidly removed by the use of cooling fins, cooling water flowing through a surrounding jacket, etc. The provision of such external cooling means is well known and need not be discussed in detail. One example will be dealt with briefly in connection with FIG. 5.

Use of the dielectric washers such as **16** is optional, according to the requirements of physical strength, cost, etc. Obviously, for very thin metal washers, dielectric washers may be needed to provide physical rigidity. For extremely high power, the temperature rise may require the use of dielectric washers constructed of mica or ceramic. The inclusion or exclusion of the dielectric washers is thus not a factor which can be specified for all possible applications, and is, therefore, best left to the designer facing a particular application.

Referring now to FIG. 5, there is shown a longitudinal bisected view of a termination for a coaxial transmission line. The same reference numerals as in FIG. 1 have been used where appropriate. As shown, the construction is basically the same as for the attenuator of FIGS. 1–3, except that, since this termination is designed to totally dissipate an input electromagnetic wave, there is no output port. It will be appreciated that, since perfection is not attainable, there will always be some reflection coefficient or standing-wave ratio associated with this device, and the best that can be accomplished is substantially total dissipation of an input wave. In order to improve impedance matching in the FIG. 5 termination, the center conductor **20** is tapered so that the spacing between the washers **10**, **12**, etc., and the center conductor **20** varies. As shown, the complete active termination is a half-wave long, all such measurements in this specification being specified on the basis of a compromise wavelength chosen within the intended operating frequency range of the device. The actual dimensions of the washers are chosen so that the zigzag path length, times the unit surface resistance, provides a total resistance sufficient to totally dissipate an input wave.

As shown, the FIG. 5 termination has been constructed so as to be very nearly matched to the line over a very wide frequency band (such as a ratio of 4 to 1). The washers in the outer conductor are designed to present a value of total surface resistance equal to the line impedance, then the inner conductor is tapered gradually to maintain at every point a match to the line impedance at that point. This taper is arrived at using known transmission line impedance calculating techniques, and the required taper is close to the exponential form approximated in FIG. 5. This principle could obtain a perfect match down to zero frequency, except that the surface resistance varies slowly with frequency. Therefore, a close match can be obtained to the extent of the best compromise over any specified band. In other attenuators, the center conductor may incorporate stepped quarter-wave sections of different diameter in place of the taper as shown. The provision of stepped impedance matching sections is well known.

Also included in FIG. 5 is a surrounding hollow jacket having an inner wall **22**, in good thermal contact with the outer circumferences of all the metal elements **10**, **12**, **14**, etc., a spaced outer wall **24**, an input port **26**, and an output port **28**. As shown, the walls **22** and **24** are formed integrally with bridging end sections so that an annular circumferential chamber is formed around the complete termination. In operation, a cooling fluid such as water can be circulated through the chamber, via ports **26** and **28**, to provide rapid heat removal. Cooling fluid chambers, fins to permit cooling by air convection, or other arrangements for removing heat can be provided for use with all attenuators constructed in accordance with the invention.

FIGS. 6, 7, and 8 are three views of a termination for use with rectangular waveguide. As shown, iron sheets **30** in stacked spaced relation form the narrow side walls of a waveguide section. These sheets have their main surfaces parallel to the broad walls **32**, and the outer extremities of the sheets are in common electrical contact at **34**. As shown, the active portion of the termination is a half-wavelength long, and a quarter-wavelength section of diminished height is provided for impedance matching purposes. At **36** is shown a standard waveguide flange permitting coupling to a standard rectangular waveguide section **38**.

As is well known in waveguide theory, transmission of electromagnetic waves in waveguide causes current to flow vertically in the side walls of the waveguide. With construction such as shown in FIGS. 6, 7, and 8, such currents are made to travel a long zigzag path similar to that described with reference to FIGS. 1–4. Dissipation of energy results from providing a long path in material, like iron, having a high surface resistance. It will be understood that the well-established principles of transmission line and waveguide theory and practice are applicable and quarter-wave stepped sections, tapered sections, etc., for impedance matching can be provided by persons skilled in the art using such established principles.

A termination constructed in accordance with the invention and resembling FIG. 5 was built and successfully tested. Such termination had the following dimensions and provided the test results listed below:

Length	4 inches.
Washer material	Iron.
Spacer material	Mica.
Washer inner diameter	½ inch.
Washer outer diameter	⅞ inch.
Washer thickness	0.002 inch.
Spacer thickness	0.002 inch.
Peak power	30 kw.
Average power	1 kw.
Frequency	1,300 mc. per second.
VSWR	Less than 1.3.
Washer permeability	Approx. 50.
Washer skin depth	Approx. 0.1 micron or 4 microinches.

In accordance with the present invention, energy dissipation is accomplished directly in iron sheets for example. The major significance of this fact is that high power capability results from the combination of good thermal conduction and high permissible operating temperatures. Thus, the power rating per unit size is increased greatly over prior designs which were of limited power rating, due primarily to the inability to provide an unbroken path of high heat conductivity directly to the outside of an attenuator.

While there has been described what is, at present, considered to be the preferred embodiment of the present invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention; and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An attenuator comprising:

a plurality of spaced iron sheets in common electrical contact at the outer edges with the central portions spaced and noncontacting and having openings in the central portions cooperating to permit propagation of electromagnetic waves;

the attenuator being so constructed and arranged that currents associated with such waves are made to travel a long zigzag path along the surface of each sheet out to the common contact, back in again along the surface of the next sheet, etc., and the surface resistance encountered along said path dissipates energy while the resulting heat is conducted away through the sheets.

2. An attenuator in accordance with claim **1** which includes an adequate number of sheets to provide a current path with a total surface resistance sufficient to substantially totally dissipate an electromagnetic wave coupled to said attenuator, whereby such wave will be terminated.

3. An attenuator in accordance with claim **1**, wherein said sheets are constructed of iron having high permeability and high thermal conductivity and the thickness of each iron sheet is more than two times the skin depth of current in the operating frequency range.

4. An attenuator comprising:

a plurality of laterally spaced circular iron washers in common electrical contact at the outer circumference with the central portions spaced and noncontacting and having coaxial central openings cooperating to permit propagation of electromagnetic waves;

the attenuator being so constructed and arranged that currents associated with such waves are made to travel a long zigzag path along the surface of each washer, out to the common contact, back in again along the surface of the next washer, etc., and the surface resistance encountered along said path dissipates energy while the resulting heat is conducted away radially through the washers.

5. An attenuator in accordance with claim 4 which additionally comprises a central conductor coaxial with said central openings to form a coaxial transmission line attenuator.

6. An attenuator in accordance with claim 5, wherein said washers are constructed of iron having high permeability and high thermal conductivity, and the thickness of each washer is more than two times the skin depth of current in the operating frequency range.

7. An attenuator in accordance with claim 5, wherein the spaces between said iron washers are filled by dielectric washers having central openings similar to the openings in the metallic washers.

8. An attenuator in accordance with claim 5, wherein the spacing between the center conductor and the iron washers is exponentially tapered for providing impedance matching.

9. A coaxial transmission line termination comprising:

a plurality of laterally spaced iron washers with metallic bridging sections at the outer circumferences effectively forming a continuous metallic cylinder surrounding the central portions of the washers which are spaced and noncontacting and have coaxial openings cooperating to permit propagation of electromagnetic waves, the thickness of the iron washers being more than two times the skin depth of current in the operating frequency range;

a central conductor passing through said central openings coaxially;

the termination being so constructed and arranged that when electromagnetic waves are coupled to the termination, the resulting current in the outer conductor is made to travel a long zigzag path along the surface of each washer out to the circumferential bridging sections, back in again along the surface of the next washer, etc., and the surface resistance encountered along said path is sufficient to substantially totally dissipate said waves.

10. A termination in accordance with claim 9, wherein the spaces between said iron washers are filled by dielectric washers having central openings similar to the openings in the iron washers.

11. A termination in accordance with claim 9, wherein the spacing between the center conductor and the iron washers varies for providing impedance matching.

12. A waveguide attenuator comprising:

a plurality of spaced iron sheets whose main surfaces are parallel to the direction of propagation with the outer extremeties of the sheets in common electrical contact and the inner portions noncontacting and cooperating to define a waveguide permitting an electromagnetic wave to propagate in the space bounded by the inner edges of the sheets;

the attenuator being so constructed and arranged that currents associated with waves propagating in said attenuator are made to travel a long zigzag path along the surface of each sheet out to the common contact, back in again along the surface of the next sheet, etc., and the surface resistance encountered along said path dissipates energy.

13. A waveguide attenuator for use with rectangular waveguide comprising:

a waveguide section wherein each narrow wall of the waveguide comprises a plurality of spaced iron sheets whose main surfaces are parallel to the broad walls of the waveguide with the outer extremeties of the sheets in common electrical contact and the inner portions spaced and noncontacting, the metal sheets of the two narrow walls cooperating to form a waveguide permitting electromagnetic waves to propagate in the space bounded by the broad walls of the waveguide and the inner edges of the metal sheets;

the attenuator being so constructed and arranged that currents associated with waves propagating in said attenuator are made to travel a long zigzag path along the surface of each sheet, out to the common contact, back in again along the surface of the next sheet, etc., and the surface resistance encountered along said path dissipates energy.

14. An attenuator in accordance with claim 13, which includes an adequate number of sheets to provide a current path with a total surface resistance sufficient to substantially totally dissipate an electromagnetic wave coupled to said attenuator, whereby such wave will be terminated.

15. An attenuator in accordance with claim 13, wherein said sheets are constructed of iron having high permeability and high termal conductivity, and the thickness of each iron sheet is more than two times the skin depth of current in the operating frequency range.

16. An attenuator in accordance with claim 13, wherein said waveguide defined by the inner edges of the metal sheets diminishes in height along the direction of propagation for providing impedance matching.

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