July 17, 1951 R. A. DEHN 2,561,184

TRANSMISSION LINE ATTENUATOR

Filed Sept. 18, 1948

Fig. 1.

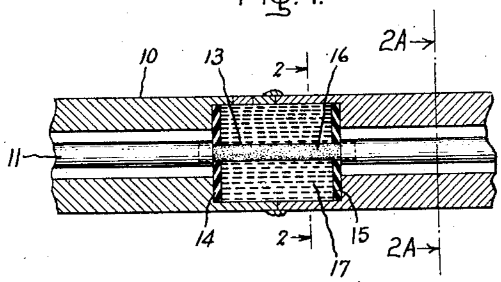


Fig. 2A.

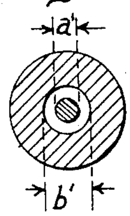


Fig. 2.

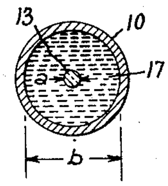


Fig. 4.

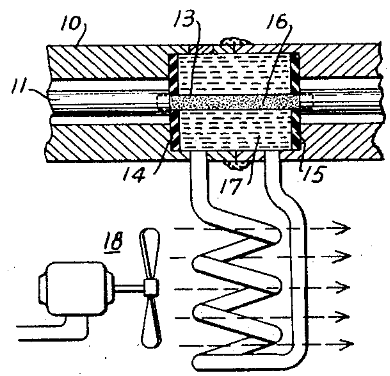
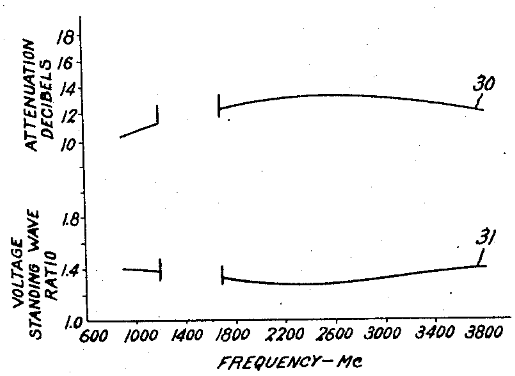


Fig. 3.



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Patented July 17, 1951

2,561,184

UNITED STATES PATENT OFFICE

2,561,184

TRANSMISSION LINE ATTENUATOR

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Application September 18, 1948, Serial No. 49,974

3 Claims. (Cl. 178—44)

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This invention relates generally to electrical attenuators, and more particularly to high frequency attenuators of the type designed for insertion in a coaxial transmission line.

In general, an attenuator should reduce the amount of energy transmitted past the point where it is inserted in a system, without altering the amount of energy arriving at that point. In low frequency systems, an attenuator is generally a circuit having lumped constants which are selected to give the attentuator the required characteristic impedance and the desired attenuation. In high frequency or microwave systems, it is not practical to employ such a circuit for an attenuator, because the physical dimensions of the elements of the attenuator would be too small. Accordingly, attenuators at high frequencies are more commonly made of sections of transmission lines having distributed constants. These are constructed to have high attenuation factors through the use of conductors or dielectrics causing high distributed losses.

If an attenuator, which is inserted in a transmission line, is to reduce the amount of energy transmitted without altering the amount received, it must act as an absorber of energy and must not reflect any energy. To function in such a manner, the attenuator must have a characteristic impedance substantially equal to the characteristic impedance of the transmission line in which it is inserted. As is well-known, if the characteristic impedance of the attenuator differs from that of the line, there will be a reflection of energy at the input of the attenuator. The reflected energy will return to the source of the received energy and will affect the current to voltage ratio at the source, or in other words, it will have the highly undesirable effect of changing the impedance which the transmission line presents at the source.

Two types of attenuators for insertion in high frequency coaxial transmission lines have heretofore been in common use. The first type consists of a section of coaxial line in which the inner conductor has been replaced by a resistive rod of approximately the same dimensions. The second type of attenuator consists of a section of transmission line in which a high loss dielectric has been inserted between the inner and outer conductor to replace the air which is normally present. Both of these attenuators suffer from the difficulty of having a characteristic impedance which varies with frequency. Although such attenuators are used in transmission lines, they operate effectively only at the frequency for which they have been designed. At any other frequency, a matching transformer is required to transform the characteristic impedance of the

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attenuator to that of the line. It is thus apparent that the usefulness of these two types of attenuators is limited.

The principal object of my invention is to provide a high frequency transmission line attenuator which will have a characteristic impedance and an attenuation substantially independent of frequency throughout its operating range.

Another object of my invention is to provide a high frequency transmission line attenuator having a construction essentially suited to dissipate a large amount of energy.

A further object of my invention is to provide an attenuator for insertion in a high frequency transmission line which provides a very high attenuation and a very low reflection factor in a smaller physical construction than heretofore possible.

For additional objects and advantages, and for a better understanding of the invention, attention is now directed to the following description and accompanying drawing, and also to the appended claims in which the features of the invention believed to be novel are particularly pointed out.

In the drawing, Fig. 1 is a longitudinal sectional view of a coaxial attenuator embodying my invention; Fig. 2 is a cross-sectional view of the attenuator of Fig. 1 at section **2—2**, illustrating certain of the dimensions utilized in mathematical equations; Fig. 2A is a similar cross-sectional view at section **2A—2A**; Fig. 3 represents certain operating characteristics of the apparatus of Fig. 1; and Fig. 4 is a longitudinal sectional view of a modification of the attenuator of Fig. 1.

My invention is based on the adaptation to microwave frequencies of certain principles, well-known in the telephone and low frequency arts, for insuring a distortionless transmission line. In the description of these physical principles, the significance of the symbols employed is as follows:

For the transmission line electrical characteristics:

Z_0=characteristic impedance in ohms.
α=attenuation in nepers/meter.
Z=impedance in ohms/meter.
Y=admittance in mhos/meter.
L=inductance in henrys/meter.
R=resistance in ohms/meter.
C=capacitance in farads/meter.
G=conductance in mhos/meter.

For the transmission line dimensions:

a=outer diameter of inner conductor.
b=inner diameter of outer conductor.

For the line dielectric:

ϵ_1=dielectric constant in farads/meter.
μ_1=permeability in henrys/meter.
σ_1=conductivity in mhos.

General:

f=frequency of operation in cycles per second.
$\omega=2\pi f$=angular frequency in radians per second.
$1n$=natural logarithm.

The characteristic impedance of a line is defined as the ratio of current to voltage in a wave traveling along the line in one direction. For a transverse electromagnetic wave, which is the type used at present in all commercial power and low frequency system, the characteristic impedance of a line is given by the equation:

$$Z=\sqrt{\frac{Z}{Y}}=\sqrt{\frac{R+j\omega L}{G+j\omega C}} \qquad \text{(I)}$$

Since the term ω enters this equation, it follows that the characteristic impedance will in general depend upon the frequency of operation. The attenuation of the line will be given by the following equation:

$$\alpha+\tfrac{1}{2}\left(\frac{R}{Z_0}+GZ_0\right) \qquad \text{(II)}$$

Since the characteristic impedance also enters this equation, the attenuation will similarly vary with frequency. By making the phase angle of the impedance Z equal to that of the admittance Y, which can be achieved by choosing the characteristics of the transmission line so that $LG=RC$, the term ω is eliminated and the equation reduced simply to the ideal line equation:

$$Z_0=\sqrt{\frac{L}{C}} \qquad \text{(III)}$$

This principle has been utilized in telephone transmission lines and cables to reduce the distortion inherent in certain types of telephone lines. For instance in a telephone cable, the inductive reactance L instead of being very large in comparison with R, as it is at micro-wave frequencies, is of a proportional magnitude, whereas ωC is generally very much larger than G. The solution then has commonly consisted of connecting lumped inductances in series with the line at critical points along its length, and in the telephone art, this practice is known as loading a line.

At micro-wave frequencies, the inductive and capacitive reactive terms of the characteristic impedance equation are so large in comparison with the resistive and conductive terms, that the latter are generally neglected. Accordingly, at micro-wave frequencies, the characteristic impedance equation reduces to that of the ideal line Equation III.

The high frequency transmission line attenuators which have been used heretofore, provide attenuation by increasing either R or G. If either R or G is increased individually, or without any attempt to maintain a definite proportion, the term ω will be present in the characteristic impedance equation. In accordance with my invention, the attenuator is constructed to maintain $LG=RC$ so that the frequency does not enter the characteristic impedance equation. The following equations determine the capacitance, inductance, and conductance of the line per unit length:

$$C=\frac{2\pi\epsilon_1}{1n\left(\frac{b}{a}\right)} \text{ farads/meter} \qquad \text{(IV)}$$

$$L=\frac{\mu_1}{2\pi}1n\left(\frac{b}{a}\right) \text{ henrys/meter} \qquad \text{(V)}$$

$$G=\frac{Z\pi\sigma_1}{1n\left(\frac{b}{a}\right)} \text{ mhos/meter} \qquad \text{(VI)}$$

An inspection of these equations will reveal that all three of the above line characteristics are dependent both upon the ratio of the diameters of the coaxial conductors and upon the characteristics of the dielectric. If now either the inner or the outer conductor of a coaxial line is made of a material which has a high resistivity so as to increase R, the ratio $LG=RC$ could be achieved by employing a dielectric having a high conductivity and the same dielectric constant as was used before. In practice, however, dielectrics having a higher conductivity, in general have a higher dielectric constant. Accordingly, to maintain the characteristic impedance constant, the capacitance per unit length of the line must be reduced, and this is achieved by increasing the ratio of diameters

$$\frac{b}{a}$$

either by increasing the size of the outer conductor or by decreasing the size of the inner conductor.

Referring now to the drawing, Fig. 1 illustrates an attenuator embodying my invention in accordance with these principles. The assembly consists of an outer conductor **10** along the axis of which an inner conductor **11** is disposed. Two dielectric spacers **14** and **15**, cemented to both the inner and outer conductors, provide a small chamber hermetically sealed from the remainder of the structure. The inner conductor **11** does not project through this chamber but instead is terminated at both spacers, and a glass rod **13** is bonded to the ends. The glass rod is coated with a suitable metallic coating **16** of relatively high resistance, such as a thin platinum film, for example, which makes contact with the inner conductor **11** at both ends. The resistance of the inner conductor, in a typical construction of an attenuator in accordance with my invention, would be of the same order of magnitude as the inductive reactance of the line. The space between the glass rod and the outer conductor inside the chamber is filled with a suitable dielectric material **17**. For example, glycerine is suitable for the purpose because it has a comparative high conductivity at micro-wave frequencies and its dielectric constant is not too high. However, the dielectric constant of glycerine is higher than that of air. Accordingly, to maintain the characteristic impedance in the chamber equal to that in the end portions, the diameter of the glass rod **13** is reduced from that of the inner conductor **11**, while that of the outer conductor is increased, as shown in Fig. 2 and Fig. 2A. The choice of dielectric determines the exact value of the resistance of the inner conductor. For instance, with glycerine as the dielectric, the ratio

$$\frac{R}{\omega L}$$

would be approximately 0.5 at a frequency of 1000 megacycles per second, and the resistance R would be calculated therefrom.

Other substances besides glycerine may be used as a dielectric for the purposes of this invention. Ethylene glycol and various solutions of inorganic compounds have been found effective for different applications. Also a wide choice of substances is available for providing an increased resistive component R in the attenuator. A resistive paint consisting of silver and graphite powder with a resin binder can be employed, as also a straight carbon rod in certain circumstances. In general, however, it is preferable to use a liquid dielectric having a high thermal conductivity. This insures that the heat generated in the inner conductor and in the dielectric is rapidly conducted to the outside conductor. Thereafter, it is an easy matter to provide adequate cooling for the outer conductor either by means of a forced air current or by means of a water jacket surrounding it. This permits the dissipation of large amounts of power in an attenuator of small physical size without overheating either the inner conductor or the dielectric. Also, as shown in the modification of Fig. 4, the liquid dielectric may be circulated between the attenuator chamber and a conventional heat exchanger unit **18**. This further increases the power capabilities and the rating of the attenuator.

In a particular construction of an attenuator embodying my invention, which was of the form shown in Fig. 1 and designed for use in the frequency range from 1800 to 3800 megacycles, the dimensions and the characteristics of the more important elements employed were as follows:

Outer coaxial conductor **10**: silver-plated brass
  Inner diameter b': 0.198 inch
  Inner diameter b: 0.412 inch
Inner coaxial conductor **11**: copper
  Diameter a': 0.086 inch
Dielectric washers **14**, **15**: polystyrene, cemented in place
  Thickness: 0.030 inch
Resistive element **13**: Pyrex glass, coated with platinum to yield 140 ohms per inch resistance and bonded to the inner coaxial conductor at both ends
  Length: 0.55 inch
  Diameter a: 0.060 inch
Dielectric 17: chemically pure glycerine

Referring to Fig. 3, curves **30** and **31** represent respectively the attenuation and the voltage standing wave ratio obtained on test with this particular construction of a coaxial attenuator embodying my invention. These results were obtained by inserting the attenuator in a standard 50 ohm coaxial line terminated in 50 ohm load. The curves illustrate that the variation in attenuation was less than 10% over a two-to-one frequency band. The curves also show a very low variation in reflection over this broad band of frequencies. This construction illustrates the high attenuation achieved in a very small structure. The actual length of the attenuating section was approximately ⅝ inch and at attenuation in excess of 13 decibels was achieved. This amounts to an attenuation of approximately 8 decibels per centimeter of line length. The board band attenuators employed in the art, at present, are often 10 times as long to obtain an equivalent attenuation with the same low reflection coefficient.

While a specific embodiment has been shown and described, and certain illustrative values have been given, it will, of course, be understood

that various modifications may be made without departing from the invention. The appended claims are, therefore, intended to cover any modifications which are within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A coaxial section having an input and an output for connection respectively to a source and to a receiver of electromagnetic energy, said section comprising an outer conductor, an inner conductor, and a dielectric medium between them, said inner conductor being a non-conductive rod coated with a thin film of conducting material having a relatively high resistance in comparison with that of said inner conductor, said dielectric being a liquid with a relatively high conductivity in comparison to that of air whereby the amount of energy transmitted to said receiver at said output is substantially less than the amount received from said source at said input and the amount reflected at said section is substantially constant over a wide range of operating frequencies.

2. A coaxial attenuator comprising an outer conductor and an inner conductor, said inner conductor being replaced through a portion of said attentuator by a non-conducting rod, a pair of dielectric washers mounted at both ends of said portion and arranged to hermetically seal said portion, said non-conductive rod being coated with a high resistive film bonded at both ends to said inner conductor, a dielectric comprising a glycerine solution inserted in the empty spaces of said portion.

3. A coaxial transmission attenuator adapted for insertion between an ultra-high frequency source and load and capable of providing substantially reflectionless absorption of energy over a very wide band of frequencies lying above 500 megacycles per second, said wide band including at least a two-to-one range of frequencies, comprising a tubular outer sheath and an inner coaxial conductor adapted to be interposed in a transmission line interconnecting said source and load, said inner conductor comprising a high resistance material providing a high resistance R per unit length of line and having a very small effective cross-sectional area for currents of said frequencies so as to maintain said resistance substantially constant over said wide band, and a dielectric medium interposed between said sheath and inner conductor providing substantially uniform high values of shunt conductance G and of shunt capacitance C per unit length of line as compared to air, said attenuator also having a series inductance L per unit length of line which is substantially uniform over said wide band, said resistance, conductance, capacitance and inductance being proportioned substantially to maintain the relationship $LG=CR$ at all frequencies within said wide band.

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