June 8, 1948. E. G. LINDER 2,443,109

SUPER HIGH FREQUENCY ATTENUATOR

Filed May 1, 1943

Fig. 1.

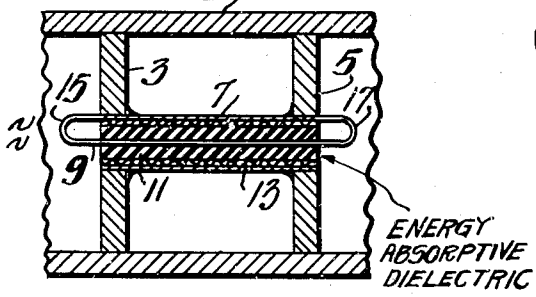


Fig. 5.

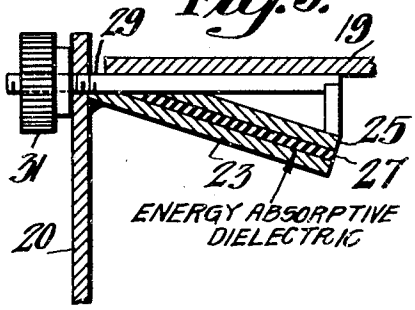


Fig. 2.

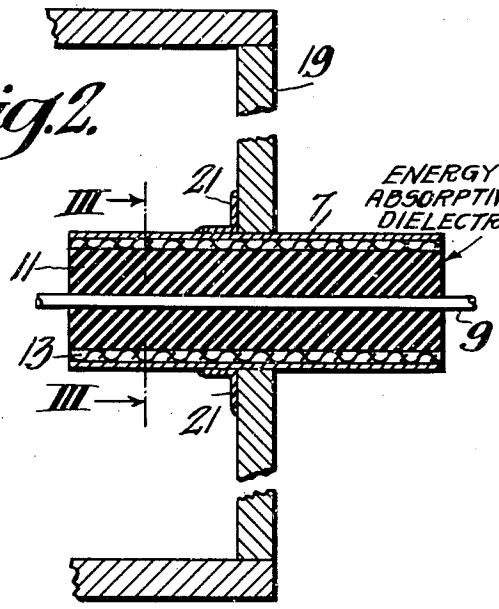


Fig. 3.

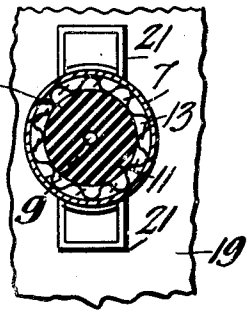


Fig. 4.

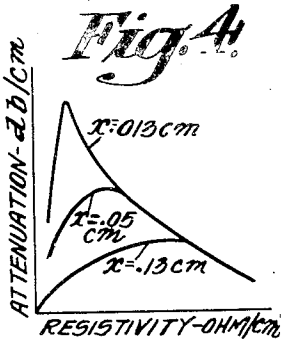
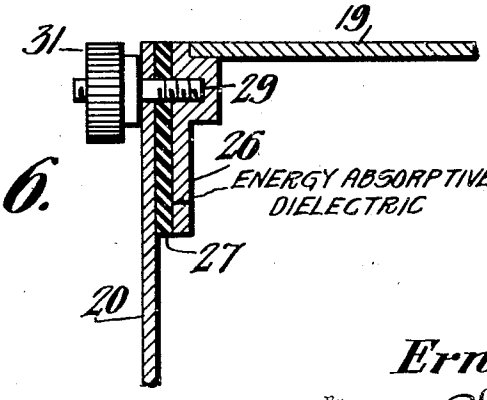


Fig. 6.



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Patented June 8, 1948

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UNITED STATES PATENT OFFICE

2,443,109

SUPER HIGH FREQUENCY ATTENUATOR

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Application May 1, 1943, Serial No. 485,357

2 Claims. (Cl. 178—44)

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This invention relates generally to super-high frequency attenuators, and more particularly to attenuators of a type employing semi-conductive plastic materials as dielectrics in the super-high frequency field. The term "super-high frequency" is used to cover approximately 3,000,000 kilocycles to 30,000,000 kilocycles. The invention provides an efficient and economical means for obtaining predetermined attenuation of super-high frequency energy in wave guides or concentric transmission lines, as well as an effective means for preventing leakage of super-high frequency energy through openings in shielding enclosures therefor.

A convenient form of attenuator for a wave guide comprises a short section of concentric line inserted within the guide. The line should preferably include coupling loops at each end thereof to provide suitable coupling and impedance matching to the wave guide.

The concentric line section preferably includes a central conductor separated from the outer concentric conductor by a dielectric comprising energy absorptive material such, for example, as conductive rubber of relatively low D.-C. resistivity. High direct current insulation may be provided conveniently by separating the high loss dielectric from the outer conductor by a relatively thin layer of varnished cambric or other low conductivity material.

The attenuation characteristics of a filter of the type described heretofore may be readily calculated for energy absorptive materials of known D.-C. resistivity and dielectric constant. The specific super-high frequency resistivity of the particular energy absorptive material employed may be computed from the propagation function.

$$\gamma=\sqrt{(R+j\omega L)(G+j\omega C)} \qquad (1)$$

where R is the series resistance, L is the series inductance, G is the shunt conductance, and C is the shunt capacitance, all per unit length. In the present case R is always negligibly small, and in the case of the lower resistivity dielectric materials, C also is small compared to G. Hence,

$$\gamma=\alpha+j\beta=\sqrt{j\omega LG}$$

where α is the attenuation and β is the phase constant. Since

$$\sqrt{j}=\frac{1+j}{\sqrt{2}}$$

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this becomes

$$\alpha=(1+j)\sqrt{\frac{\omega LG}{2}}$$

and

$$\alpha=\sqrt{\frac{\omega LG}{2}} \qquad (2)$$

For concentric lines

$$L=\frac{\mu}{2\pi}\ln\frac{b}{a}$$

where the units are in the MKS system, a and b are the inner and outer radii, respectively, and μ is the permeability. Also

$$G=\frac{2\pi}{\rho\ln\frac{b}{a}}$$

Inserting these expressions in (2) yields

$$\alpha=\sqrt{\frac{\mu\omega}{2\rho}} \qquad (3)$$

This is identical with the expression for the attenuation of a plane wave in a medium of sufficiently high conductivity so that

$$\frac{1}{\rho\epsilon\omega}\gg 1$$

where ϵ is the permittivity (see Slater, Microwave Transmission, page 111). In the present case this condition is adequately met. Hence, Formula 3 may be applied here to both the concentric line and wave guide measurements.

The same calculations apply to an attenuator comprising a simple plug or diaphragm of energy absorptive material inserted within a wave guide using the H_{01} mode of transmission.

For an energy absorption material comprising a conductive synthetic rubber such as neoprene, having sufficient carbon content, such as acetylene black, to provide a D.-C. resistivity of the order of 5 ohm-centimeters, a convenient concentric line type filter may be constructed to provide an attenuation of the order of 90 decibels per centimeter, and to provide a D.-C. insulation effective for at least 12,000 volts. By way of example, the diameter of the outer conductor may be approximately .6 centimeter while that of the inner conductor may be of the order of .1 centimeter.

A typical formula for conductive rubber having a resistivity of the order of 5 ohm-centimeters is:

	Parts
Neoprene GN	100.00
Latac	.50
Extra light cal. mag	4.00
Shawinigin black	80.00
Cumar P–25	10.00
Neozone D	2.00
Zinc oxide	10.00
Total	206.50

Cured 45/290° F.

If an energy absorptive material of the same general type, but having a D.-C. resistivity of the order of 200 ohm-centimeters, is employed, an attenuation of the order of 3 decibels per centimeter may be readily provided with a line having an outer conductor diameter of .9 centimeter and an inner conductor diameter of .15 centimeter. The foregoing calculations are based upon the assumption that the input and output elements of the attenuator are properly matched to the wave guide. In actual practice, such filter sections would probably be mismatched intentionally, thereby providing attenuations higher than the calculated values.

Such filters may be employed for providing effective attenuation of super-high frequency energy in power leads to super-high frequency apparatus, by utilizing the power lead as the central conductor of a short section of concentric line which includes energy absorptive material of the type described heretofore. Similarly, the energy absorptive material, such as the conductive synthetic rubber described heretofore, may be employed in the form of gaskets to prevent leakage of super-high frequency energy through openings in shielding enclosures.

Among the objects of the invention is to provide an improved method of and means for attenuating super-high frequency energy. Another object is to provide an improved method of and means for preventing leakage of super-high frequency energy through openings in shielding enclosures therefor. A further object is to provide an improved attenuator for super-high frequency energy in power leads to super-high frequency apparatus. Another object is to provide an improved super-high frequency attenuator comprising a concentric line section which includes a dielectric of relatively low D.-C. resistivity and relatively high energy absorptive characteristics at super-high frequencies. Another object of the invention is to provide an improved attenuator for super-high frequencies which provides relatively uniform attenuation over a wide band of frequencies. A still further object of the invention is to provide an improved means for sealing apertures or joints in super-high frequency shielding enclosures.

The invention will be described in further detail by reference to the accompanying drawing, of which Figure 1 is a cross-sectional view of one embodiment of the invention, Figure 2 is a cross-sectional view of a second embodiment thereof, Figure 3 is the section III—III of Fig. 2, Figure 4 is a family of graphs illustrative of the invention, and Figures 5 and 6 are modifications of a third embodiment of the invention. Similar reference numerals are applied to similar elements throughout the drawing.

Fig. 1 includes a wave guide 1 having metallic aperture devices 3, 5 transversely disposed therein and separated axially a distance predetermined by the calculated length of the attenuator. A cylindrical outer conductor 7 connects the apertures of the conductive aperture devices 3, 5 and is supported thereby substantially coaxially with the axis of the wave guide 1. An inner conductor 9 is disposed substantially coaxially with the outer conductor 7 and is separated therefrom by an energy absorptive dielectric 11 and a relatively thin layer of D.-C. insulating material 13 such, for example, as varnished cambric. The ends of the inner conductor 9 are terminated in coupling loops 15, 17 which are connected, respectively, to the ends of the outer cylindrical conductor 7. If desired, the characteristics of the coupling loops 15, 17 may be selected to provide desired impedance matching with the wave guide 1 at the operating frequency. The lengths and diameters of the inner and outer conductors 9, 7, respectively, and the characteristics of the dielectric materials 11, 13 may be readily calculated from the formulae discussed heretofore, to provide desired attenuation at the selected operating frequency.

Figs. 2 and 3 illustrate attenuators of the general type described in connection with Fig. 1, which may be employed to attenuate effectively super-high frequency currents on, for example, a power conductor 9 which enters a shielding enclosure 19. The concentric line section consists of the power conductor 9 and an outer cylindrical conductor 7, separated by an energy absorptive dielectric 11 and a D.-C. insulating dielectric 13. The outer cylindrical conductor 7 may be fastened to the shielding enclosure 19 by means of brackets 21 which are preferably soldered to the cylindrical conductor 7 and the shielding enclosure 19.

Optimum values of resistivity will obtain for filters of predetermined proportions and characteristics. This feature may be explained as follows:

If the resistivity of the semi-conductive rubber is sufficiently low that considerable current flows longitudinally on its surface, it may then be regarded as the inner conductor of the transmission line. This condition obtains when the effective skin thickness becomes less than the radius of the rubber. The filter may then be regarded as a low impedance line having a good dielectric (e. g., the varnished cambric insulation). The attenuation a_2 may be determined by the conventional formula:

$$a_2=\frac{R}{2Z_0}=\frac{\sqrt{\mu\omega\rho k}}{1080x} \tag{4}$$

where k is the dielectric constant of the varnished cambric, $\mu=4\pi 10^{-9}$ henries per centimeter, $\omega=2\pi f$, ρ is the resistivity, and x is the thickness of the varnished cambric or other insulation.

If the resistivity of the rubber is high, so that $\omega C \angle\angle G$, then

$$a_1=\sqrt{\frac{\omega LG}{2}}=\sqrt{\frac{\mu\omega}{2\rho}} \tag{5}$$

Equations 4 and 5 represent two limiting cases. In Equation 4, the attenuation increases with the resistivity ρ, whereas in Equation 5 it decreases. Hence the maximum attenuation may be determined approximately by the intersection of the two curves. The optimum value of resistivity may be found by equating Equations 4 and 5, whereby

$$\rho \text{ opt.}=\frac{765x}{\sqrt{k}} \tag{6}$$

Fig. 4 shows theoretical curves of the relations between attenuation and resistivity in filters of the type described which employ three different thicknesses of varnished cambric insulation having a dielectric constant equal to 4.

Fig. 5 illustrates a convenient method of employing energy absorptive material to prevent leakage of super-high frequency energy around the edges of a door in a shielding enclosure for super-high frequency apparatus. An enclosure **19** is provided with a door or cover **20** having a tapered edge **23** which fits a complementarily tapered jamb **25** at the aperture of the shielding enclosure **19**. Energy absorptive material **27** is inserted in the aperture between the tapered portions **23**, **25** of the door and jamb, respectively. Due to the tapered form of the door and jamb, the effective length of the attenuator may be relatively large in comparison to the cross-sectional area of the aperture in the shielding enclosure.

A bolt **29**, fastened to the shielding enclosure **19**, extends through a hole in the door **20**. The door **20** may be secured in a closed position by means of a nut **31** threaded to the end of the bolt **29** extending through the door. As many bolts and nuts as desired may be disposed at regular intervals around the edge of the door. Due to the relatively long energy absorbing path in the dielectric **27**, between the tapered portions **23**, **25** of the door and jamb, there will be relatively low energy leakage along the bolt **29** between the door **20** and the jamb **25**. Preferably all joints between the tapered portion **25** and the body of the shielding enclosure **19** should be soldered to eliminate energy leakage around the gasket.

A modification of the super-high frequency gasket is illustrated in Fig. 6. In this arrangement a shielding enclosure **19** includes a door frame **26** extending well into the door opening in the enclosure **19**. The door **20** abuts against the door frame **26** and is separated therefrom by a gasket of super-high frequency energy absorptive material **27**. A bolt **29** is secured to the door frame **26** and extends through a suitable aperture in the door. The door may be retained in a closed position by means of a nut **31** threaded to the portion of the bolt **29** extending through the door. This modification has the distinct advantage that the door frame **26** must necessarily extend well into the door aperture in order to provide a gasket as effective as that described for the tapered door frame of the modification shown in Fig. 5. However, where space is not an important consideration, either modification may be employed to advantage.

It should be understood that the highly conductive rubber employed as a dielectric or energy absorber in the various super-high frequency attenuators described heretofore may be similarly employed to prevent leakage of super-high frequency energy around rotating or movable shafts extending into various other types of enclosures. Various modifications and embodiments thereof are disclosed and claimed in a copending U. S. application of George L. Fernsler, Serial Number 485,012, filed April 29, 1943, assigned to the same assignee.

I claim as my invention:

1. An attenuator for super-high frequency energy comprising a transmission line including two conductors, a leakage path for said energy including a first dielectric having a predetermined proportion of energy absorptive material, and a second dielectric interposed between said first dielectric and one of the conductors of said line, characterized by the relation

$$\rho=\frac{765x}{\sqrt{k}}$$

where ρ is the resistivity of the first dielectric, x is the thickness of the second dielectric, and k is the dielectric constant of the second dielectric.

2. An attenuator for super-high frequency energy including a predetermined length of coaxial transmission line having a first solid dielectric including a predetermined proportion of energy absorptive material, a second dielectric interposed between said first dielectric and one of the conductors of said line, the resistivity of said first dielectric being a value just sufficiently high effectively to prevent substantial current "skin effect" thereon adjacent to the surface of said second dielectric in contact therewith, and a pair of coupling loops each terminating a different one of the ends of said line.

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