Sept. 16, 1947. J. COLLARD 2,427,643

ATTENUATOR FOR ELECTRIC WAVES OF VERY SHORT LENGTH

Filed July 14, 1944 2 Sheets-Sheet 1

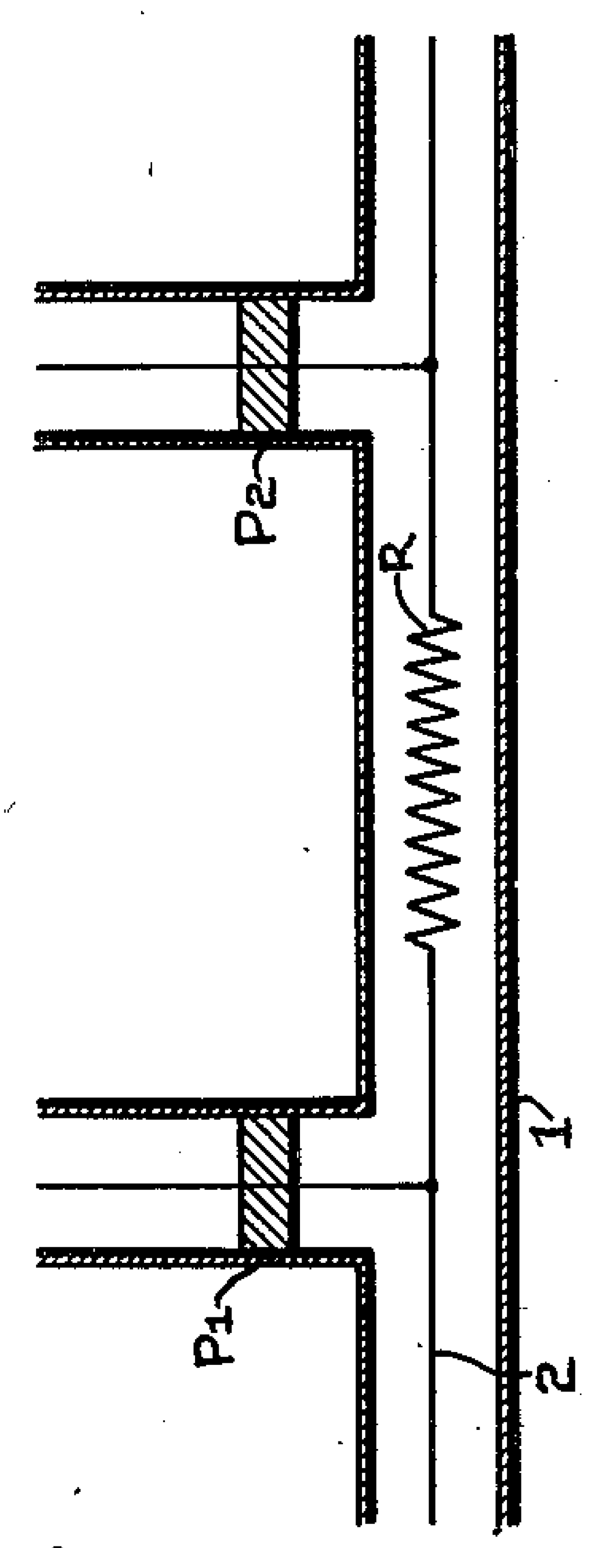

Fig. 1.

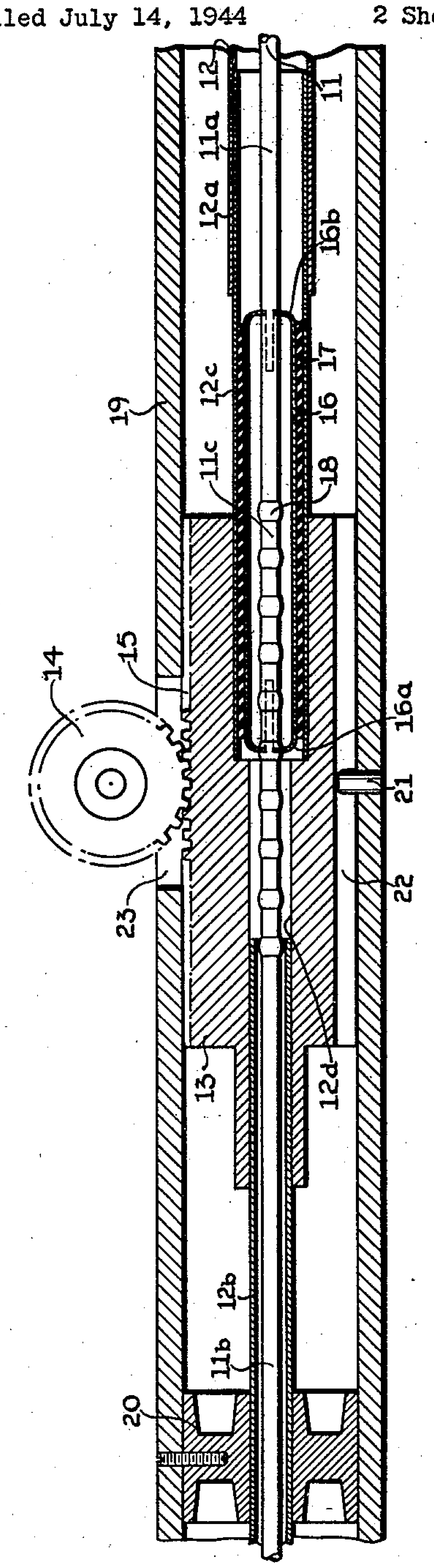

Fig. 2.

INVENTOR.
JOHN COLLARD.

BY H. S. Grover

ATTORNEY

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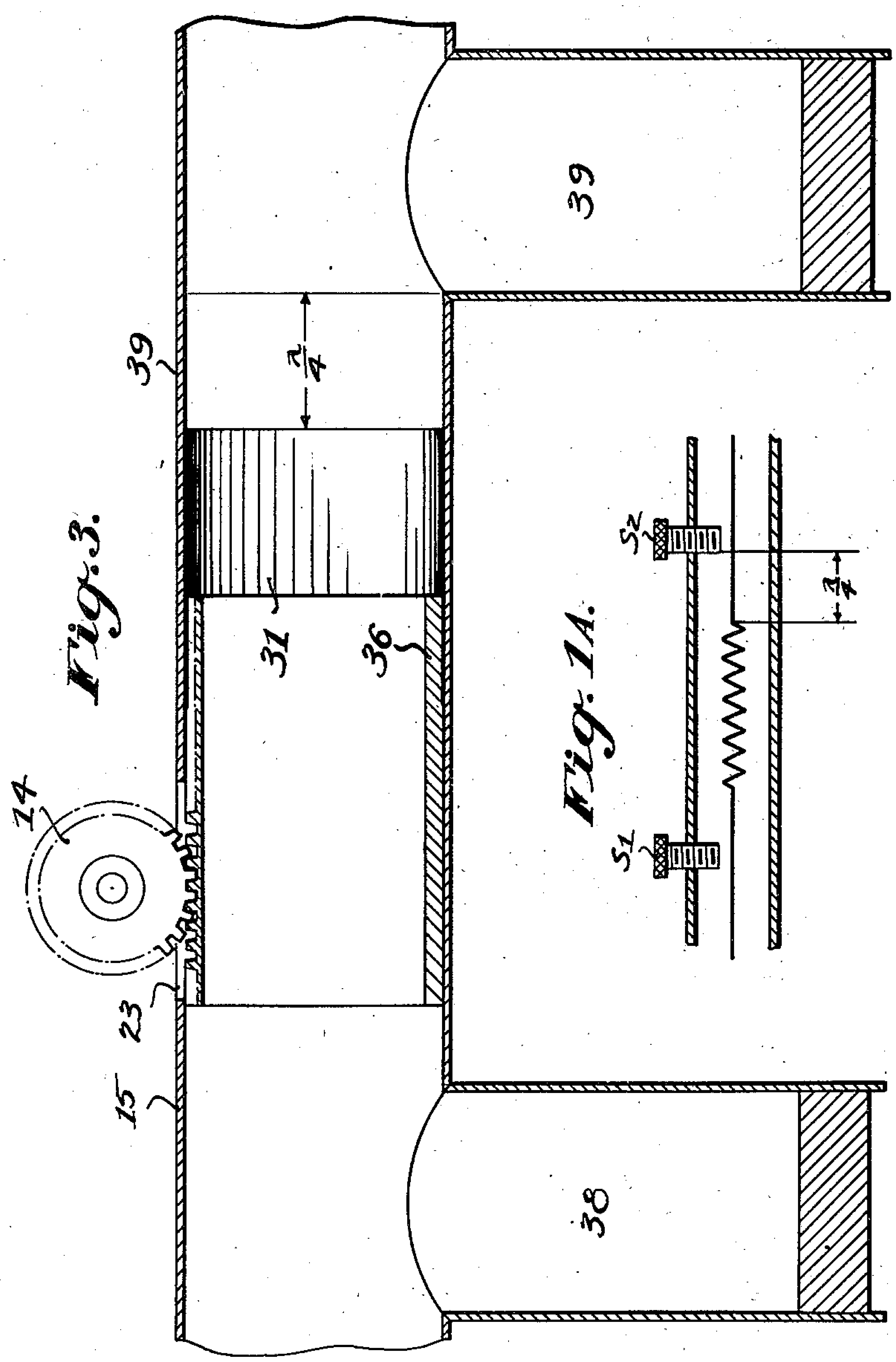

INVENTOR
JOHN COLLARD
BY H. S. Grover
ATTORNEY

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ATTENUATOR FOR ELECTRIC WAVES OF VERY SHORT LENGTH

John Collard, Hammersmith, London, England

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5 Claims. (Cl. 178—44)

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The present invention relates to attenuators for electric waves of very short length, for example, of the order of a few centimeters.

Known attenuators, when used for the attenuation of electric waves having wavelengths of the order mentioned, suffer from the drawback that in use they are either capacitative or inductive and introduce reactance into the circuit in which they are included instead of being purely resistive as are attenuators employed at longer wavelengths. Thus, the known attenuators employed for very short wavelengths introduce undesired reflection effects and do not act as true attenuators. As a consequence, the input impedance of these attenuators is variable for low losses and even when the loss is sufficient for the impedance to be substantially constant, the impedance is reactive. Since attenuators are usually required to have effectively a resistive impedance, it becomes necessary to insert a masking pad after them. Such a pad may consist of a length of cable having a loss of about 10 db. The impedance seen from the far end of the attenuator then looks approximately like the characteristic impedance of the cable so that the reactive impedance of the attenuator is masked. However, the use of a cable in this way is objectionable in that the cable is bulky and the constants of the cable in respect of the very short wavelengths involved are subject to variation so that reflection takes place at various points in the cable and the input impedance, instead of being a constant resistance, is variable with wavelength and has a reactive term. At long wavelengths, the difficulties above referred to can be overcome by using a resistance attenuator pad in the form of a π or T network, but such arrangements are not practicable with very short wavelengths.

The object of the present invention is to provide an attenuator pad for use with very short wavelengths of which the impedance is mainly resistive.

According to the present invention, an attenuator for electric waves of very short wavelength is provided, comprising a section of transmission lines having a resistance parameter of large value. In a preferred form of the invention the section of transmission line is constituted by a pair of conductors one of which consists of a highly resistive body, for example, the section of transmission line may be a coaxial line section of which the highly resistive body forms the inner conductor of the section. Preferably an attenuator in accordance with the invention is

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employed in combination with a pair of resistance devices disposed one at each end of the line section, one of said devices serving to provide the correct termination of the section and the other serving to neutralize the effect of reactance of the section as seen from the input end whereby the section can be inserted in a transmission line without causing reflection loss.

In order that the invention may be clearly understood and readily carried into effect, the same will now be described in detail with reference, by way of example, to the accompanying drawing in which

Figure 1 is an explanatory diagram referred to in describing a concentric line section in accordance with the invention, while Fig. 1*a* illustrates a modification of Fig. 1, and

Figure 2 is a longitudinal sectional view through a section of transmission line embodying the present invention and having an adjustable resistance parameter and Fig. 3 illustrates a modification of Fig. 2.

In carrying the invention into effect, an attenuator in accordance with the invention can be constituted by a coaxial line section represented in Figure 1 as having an outer conductor 1 and an inner conductor 2, of which the inner conductor is at least in part constituted by a resistor of high resistance, shown at R in Figure 1, this resistance presenting a substantially pure resistive impedance to very short waves. For example, the resistor may be of the chemical or solid carbon type, this being mounted in insulating relation in the outer conductor 1 of the line section. If the resistive portion of the inner conductor is constituted by a chemical resistor, then such resistor should not be of the kind in which a spiral groove is cut in the resistor to increase the value of its impedance as such resistor presents a reactance in respect of short waves.

The line section formed in the manner above described has a characteristic impedance Z_0 and propagation constant P which are given by the expressions

$$Z_0=\sqrt{\frac{R+j\omega L}{j\omega C}}$$

$$P=\sqrt{(R+j\omega L)j\omega C}$$

where R is the resistance per centimeter and L and C are, respectively, the inductance and capacity per centimeter of the coaxial section, and are the same as for the circuit which would be obtained by replacing the resistor R by an inner conductor of the same effective diameter and no resistance, and ω is the pulsatance of the wave to be attenuated. If Z_0 is the characteristic impedance of the resistanceless line section and λ is the wavelength and f the frequency of the waves to be attenuated, then

$$\frac{L}{C}=Z_0^2 \quad \text{and} \quad \omega\sqrt{LC}=\frac{2\pi}{\lambda}$$

Hence

$$L=\frac{Z_0}{\lambda f} \quad \text{and} \quad C=\frac{2\pi}{Z_0\omega\lambda}$$

Substituting these values in the expression for Z_0 and P and putting

$$x\pm jy=\sqrt{1-\frac{jR}{2\pi Z_0}}$$

we have

$$Z_0=(x+jy)$$

$$P=j\frac{2\pi}{\lambda}(x+jy)$$

If the coaxial line section formed by the resistor R and its outer conductor 1 is terminated by an impedance equal to the characteristic impedance of the line section, then the impedance seen from the input end of the line section will be Z_0. Furthermore, if a voltage V_1 is applied to the input end of this terminated coaxial circuit, then the voltage at the other end will be $V_2=V_1e^{-Pl}$ where l is the physical length of the coaxial line section. Thus, substituting for P in terms of x and y we have

$$V_2=V_1e^{\frac{2\pi yl}{\lambda}}.e^{-j\frac{2\pi xl}{\lambda}}$$

Hence the attenuation of the coaxial line section will be

$$20\log\frac{V_1}{V_2}=\frac{-40}{2.3}\,\frac{\pi yl}{\lambda}\text{ db}$$

Usually, the attenuator has to work between devices whose impedances are pure resistances, and in order to introduce no mismatch in the circuit due to the employment of the attenuator, it will be necessary to insert suitable reactance devices one at each end of the attenuator, for example, a reactance piston P_1 or P_2 may be connected in shunt to the line section at each end thereof. Thus, for example, if the attenuator is connected between two resistances of value M, the terminal reactance piston of the coaxial line section will serve to add in shunt to the following resistance M a reactance of such value as to provide an impedance of value Z_0 such that the line section will be correctly terminated while the piston at the input end of the concentric line section will serve to neutralize the reactive component of the impedance Z_0 of the concentric line section as seen from the resistance connected to the input end, so that only pure resistance is effective in the circuit. Thus, the attenuator in the form of a transmission line section can be included in the circuit without causing any reflection loss. If it is not necessary to match the impedance of the attenuator as seen from either end of the impedance to the rest of the circuit, then the reactance device at the appropriate end of the attenuator can be omitted.

In the case where the attenuator is required to work between resistances of value M, it can be shown that the reactance device at the terminating end must produce a reactance of jX across the following resistance such that

$$Z_0(x+jy)=\frac{M}{1+jM/X}$$

whence

$$M=\frac{Z_0(x^2+y^2)}{x} \quad \text{and} \quad X=M\frac{x}{y}$$

Solving for x and y and putting A equal to

$$\frac{-R\lambda}{2\pi Z_0}$$

it is found that

$$x^2=\frac{A^2}{2(-1+\sqrt{1+A^2})}$$

x being positive,

$$y^2=\frac{-1+\sqrt{1+A^2}}{2}$$

y being negative.

Thus, assuming it is desired to design an attenuator pad to have an attenuation of N db and to match a resistance termination of M, then the three variables l, R and Z_0 have to be so related as to satisfy the two equations

$$M=\frac{Z_0(x^2+y^2)}{x}$$

$$N=-\frac{40}{2.3}\,\frac{\pi yl}{\lambda}$$

Thus, one of the variables may be arbitrarily fixed, and in practice the length l of the resistance is usually fixed, leaving R and Z_0 to be determined. If l is known, then the value of y is given by

$$y=-\frac{2.3\lambda N}{40\pi l}$$

and also since $x^2-y^2=1$, the value x can be found. The value Z_0 is derived from

$$Z_0=\frac{xN}{x^2+y^2}$$

Moreover, the value of A is given by the equation

$$A=-\sqrt{(2y^2+1)-1}$$

and since

$$A=\frac{-R\lambda}{2\pi Z_0}$$

the value of R can be found. From the value of Z_0 and the outer diameter of the resistance, the inner diameter of the surrounding tube can be found. Thus, all the dimensions of the concentric line section can be determined.

In practice it is often found that the reactance X to be added at one terminal end of a coaxial line section employed as an attenuator in accordance with the invention can be produced by means of a small screw S_1 (Fig. 1*a*) to be threaded through an outer tube and making a capacity connection with the inner conductor of the line, and at the other end the inductive component, which must be provided to remove the reactive part of the impedance thus introduced can be constituted by a further screw S_2 similar to the first screw, but separated by a quarter of a wavelength from the end of the resistance in the concentric line section as indicated by the dimension λ_4 in Fig. 1*a*.

Figure 2 of the drawing is a longitudinal cross-sectional view through an embodiment of the invention in which the connection to the resistor section is made adjustable so that the effective length of the attenuator can be varied. The device shown in Figure 2 comprises a transmission line of the coaxial conductor type of which the central conductor 11 comprises end portions 11*a* and 11*b* formed of rod form conducting material such as brass joined by a section 11*c* constituted, for example, by a body of graphitic carbon bonded by a suitable binding material, the section 11*c* being sweated on to the inner ends of the sections 11*a* and 11*b*. The outer conductor 12 of the transmission line has fixed sections 12*a* and 12*b* of large and small diameter, respectively, there being a section 12*c* supported in a block 13 and arranged to slide into and out of the section 12*a* by actuation of a pinion 14 which engages a rack 15 on the block. The conductor 12 is completed through the block 13, which has a bore 12*d* which surrounds the conductor 11 and into which the section 12*b* of the conductor 12 is inserted. The block 13 is arranged to slide to and fro about the position shown in the drawing, the block moving to the left along the section 12*b* of the conductor 12 so as to withdraw the section 12*c* of the conductor 12 from the section 12*a* of the conductor or moving to the right to cause the section 12*c* to enter the section 12*a* and to withdraw the block 13 along the end of the section 12*b*.

Within the section 12*c* of the conductor 12 is a conducting sleeve 16 having resilient split ends 16*a* and 16*b*. The sleeve 16 is secured to the movable section 12*c* of the outer conductor 12 by means of an insulating sleeve 17 formed, for example, of polystyrene, the sleeve 16 being so positioned that as the block 13 is moved to and fro, the end 16*b* of the sleeve is carried along the resistor section 11*c*, the other end of the sleeve 16*a* engaging on the portion 11*a* of the inner conductor 11. Thus the sleeve 16 short circuits that part of the resistor section lying to the right of the end 16*b* within the sleeve and movement of the sleeve varies the effective resistance of the portion 11*c*. Consequently as the sleeve 16 is moved, the attenuation afforded by the line will also be varied.

The resistor section 11*c* has metal rings 18 with which the split end 16*b* of sleeve 16 contacts as the sleeve 16 is moved along the resistance section 11*c*. The rings 18 are made of slightly larger internal diameter than the carbon rod of which the section 11*c* is formed, the ring being slipped over the rod and compressed axially so as to be forced into recesses in the rod, the recesses being disposed so that after the assembly is complete, each section 11*c* between the successive rings produces an attenuation of 10 db. Thus, as the sleeve 16 is moved along the section 11*c* the attenuation is varied in steps of 10 db. If desired, the transmission line may also include a further resistance section or sections for affording adjustment of the attenuation in smaller or larger steps as desired.

The transmission line 11, 12 and the block 13 are mounted in a cylindrical housing 19 which may also be made of brass in which the block 13 has a sliding fit, the fixed sections 12*a* and 12*b* of the conductor 12 may be supported by annular metal supports such as that shown at 20 in the drawing. To maintain the block 13 in position for the rack 15 to be engaged by the pinion 14, the housing 19 carries a key pin 21 which engages in a key groove 22 provided in the block 13. The housing 19 is cut away at 23 to accommodate the pinion 14.

It will be appreciated that the inner conductor 11 is supported within the conductor 12 by virtue of the support afforded through the sliding sleeve 16 and the polystyrene sleeve 17 from the section 12*c* of the outer conductor, and also suitable insulating plugs not shown may be provided between the inner and outer conductors affording additional support for the inner conductor.

When the section shown in Figure 2 is connected in a transmission line, it will be appreciated that the effect of the mismatch due to the fact that the portion 12*a* of the outer conductor 12 has a different diameter from the portion 12*b* thereof, together with any reactances such as that arising from the sleeve 16 and its mounting can be eliminated by suitably choosing the value of the reactances afforded by the pistons P_1 and P_2 or similar devices provided in the transmission line as explained with reference to Figure 1 above.

While the invention has been described as embodied in a transmission line having a pair of conductors, it will be appreciated that it may also be incorporated in a transmission line such as a wave guide which includes only a single conductor through which the waves are conveyed. In this case, illustrated in Fig. 3, the single conductor may be formed so as to constitute an attenuator in accordance with the invention, for example the wave guide may be constituted by a hollow metal conductor 30 having a section of which the interior surface is coated with a high resistance layer 31, for example of carbon, for providing the desired high resistance parameter in the guide. The attenuation afforded by the aforesaid layer may be rendered variable by arranging a further conducting sleeve 36 to slide within the hollow conductor in contact with the highly resistive layer so as to short circuit the highly resistive layer to a variable extent thereby adjusting the value of the resistance parameter and hence the attenuation afforded by the guide. In Fig. 3 the inner conductor sleeve 36 is arranged to be moved by a rack and pinion arrangement 14, 15 operating through slot 23 similar to that shown and described with reference to Fig. 2. Similar parts in the two figures are given the same reference numerals. An attenuator formed in this manner may have a pair of reactance devices in the form of shunt guide sections 38, 39 disposed one on each end of the section having the high resistance parameter, one of said devices, 38, serving to provide the correct termination of the section, and the other, 39, serving to neutralize the effect of the reactance of the section as seen from the input end in a manner similar to that described in detail above with reference to Figure 1.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:

1. An attenuator for electromagnetic waves of very short wave length including at least one conductor having a high resistance portion interposed along the path of said waves, a conductive sleeve arranged to contact said high resistance portion and an adjacent portion of said conductor and means for varying the engagement of said sleeve with said high resistance portion whereby the effective series resistance of said portion is adjusted, said one conductor being the inner conductor of a coaxial transmission line, the outer tube of said line having a telescoping section insulatingly carrying said conductive sleeve.

2. An attenuator for electromagnetic waves of very short wave length including at least one conductor having a high resistance portion interposed along the path of said waves, a con-

ductive sleeve arranged to contact said high resistance portion and an adjacent portion of said conductor and means for varying the engagement of said sleeve with said high resistance portion whereby the effective series resistance of said portion is adjusted, said one conductor being the inner conductor of a coaxial transmission line, the outer tube of said line having a telescoping section insulatingly carrying said conductive sleeve, and shunt reactance means at each end of said high resistance portion.

3. An attenuator for electromagnetic waves of very short wave length including at least one conductor having a high resistance portion interposed along the path of said waves, a conductive sleeve arranged to contact said high resistance portion and an adjacent portion of said conductor and means for varying the engagement of said sleeve with said high resistance portion whereby the effective series resistance of said portion is adjusted, said one conductor being the inner conductor of a coaxial transmission line, the outer tube of said line having a telescoping section insulatingly carrying said conductive sleeve, and shunt reactance means at each end of said high resistance portion, said shunt reactance means being constituted by screws threaded through said outer tube and having their ends in capacity relation with the inner conductor of said line.

4. An attenuator for electromagnetic waves of very short wave length including at least one conductor having a high resistance portion interposed along the path of said waves, a conductive sleeve arranged to contact said high resistance portion and an adjacent portion of said conductor and means for varying the engagement of said sleeve with said high resistance portion whereby the effective series resistance of said portion is adjusted, said one conductor being the inner conductor of a coaxial transmission line, the outer tube of said line having a telescoping section insulatingly carrying said conductive sleeve, said high resistance portion being provided with low resistance contact sleeves adapted to be contacted by said movable sleeve.

5. An attenuator for electric waves of very short wave length including a coaxial transmission line having an outer tube and an inner conductor, a section of said outer tube having overlapping telescopic portions whereby one portion may be slid back and forth for a distance without disturbing the electric continuity of said outer tube, said inner conductor having a series connected high resistance portion substantially the same length as said distance, said one portion of said outer tube carrying, through an insulating support, a conductive sleeve surrounding, and in electrical contact, with one portion of said inner conductor and said high resistance portion whereby moving said one portion of said outer tube varies the resistance effectively included in series in said inner conductor.

JOHN COLLARD.

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