United States Patent [19]

Kogo et al.

[11] **3,890,589**

[45]***June 17, 1975**

[54] **VARIABLE RESISTOR**

[75] Inventors: **Masanori Kogo; Hisashi Honda,** both of Tokyo, Japan

[73] Assignee: **Nippon Electric Company, Limited,** Tokyo, Japan

[*] Notice: The portion of the term of this patent subsequent to Sept. 18, 1990, has been disclaimed.

[22] Filed: **June 20, 1973**

[21] Appl. No.: **371,620**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 267,630, June 29, 1972, Pat. No. 3,760,322.

[30] **Foreign Application Priority Data**

June 30, 1971 Japan 46-48316

[52] **U.S. Cl.** ..... **338/89;** 338/137; 338/142; 338/150; 333/81 R

[51] **Int. Cl.**[2] **H01C 10/04;** H01C 10/26

[58] **Field of Search** ..... 338/89, 137, 138–142, 338/150; 333/81 R

[56] **References Cited**

UNITED STATES PATENTS

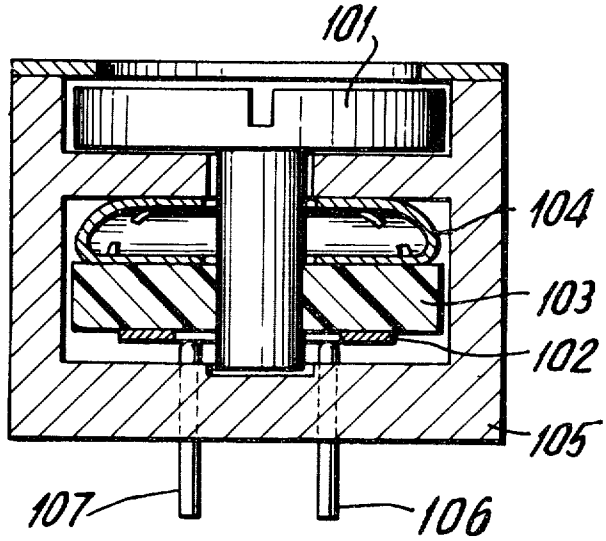
1,731,772	10/1929	Greenewalt	338/141 X
2,005,922	6/1935	Stoekle	338/140
2,096,027	10/1937	Bode	333/81 X
2,681,967	6/1954	Harrison et al.	338/89
2,798,140	7/1957	Kohring	338/137
2,854,643	9/1958	Wigan et al.	333/81
2,881,295	4/1959	Brown	338/137 X
3,657,688	4/1972	Casey et al.	338/150

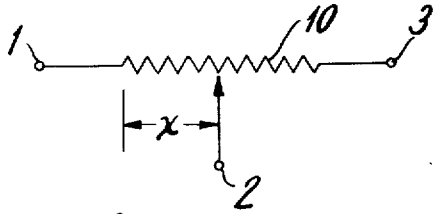
Primary Examiner—J. V. Truhe
Assistant Examiner—D. A. Tone
Attorney, Agent, or Firm—Hopgood, Calimafde, Kalil, Blaustein & Lieberman

[57] **ABSTRACT**

A resistive element has a gradient of resistivity extending along its length. It is held in slidable contact with two or more brushes spaced-apart from each other. The resistance between the brushes can be varied by changing their position relative to the resistive element and the gradient or resistivity. The resistive element may have an arcuate configuration and the relative position may be changed by rotating the element. Two such variable resistors having a logarithmic resistance gradient may be combined in a variable resistance attenuator.

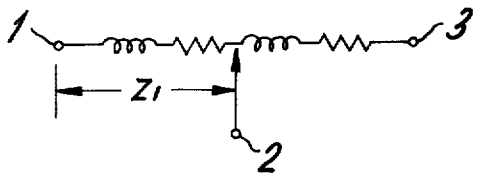
3 Claims, 13 Drawing Figures





(PRIOR ART)

FIG. 1a



(PRIOR ART)

FIG. 1b

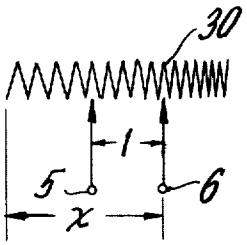


FIG. 2a

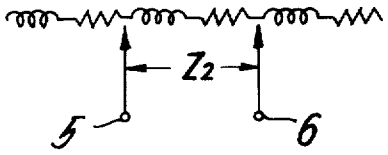


FIG. 2b

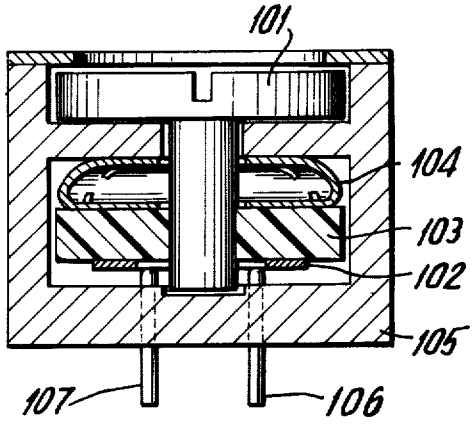


FIG. 3

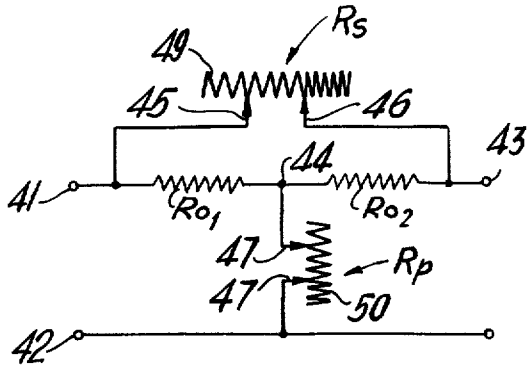


FIG. 4

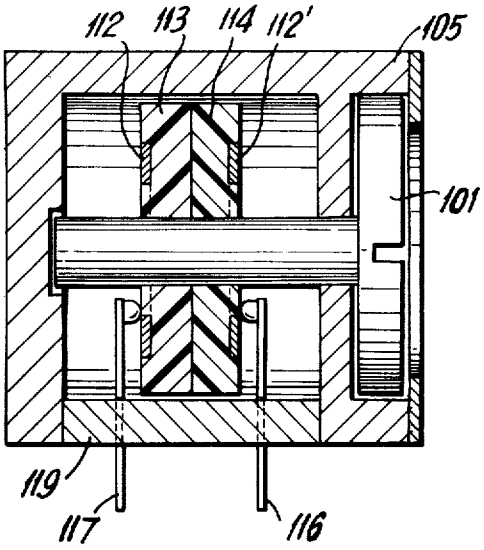


FIG. 5

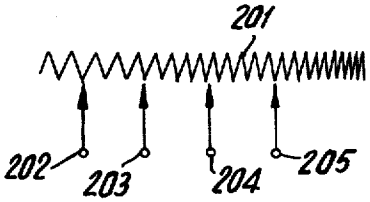


FIG. 6

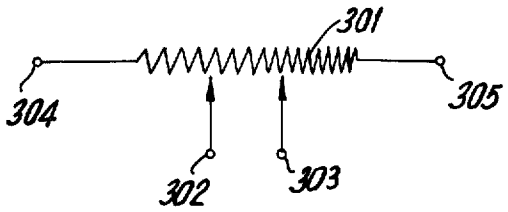
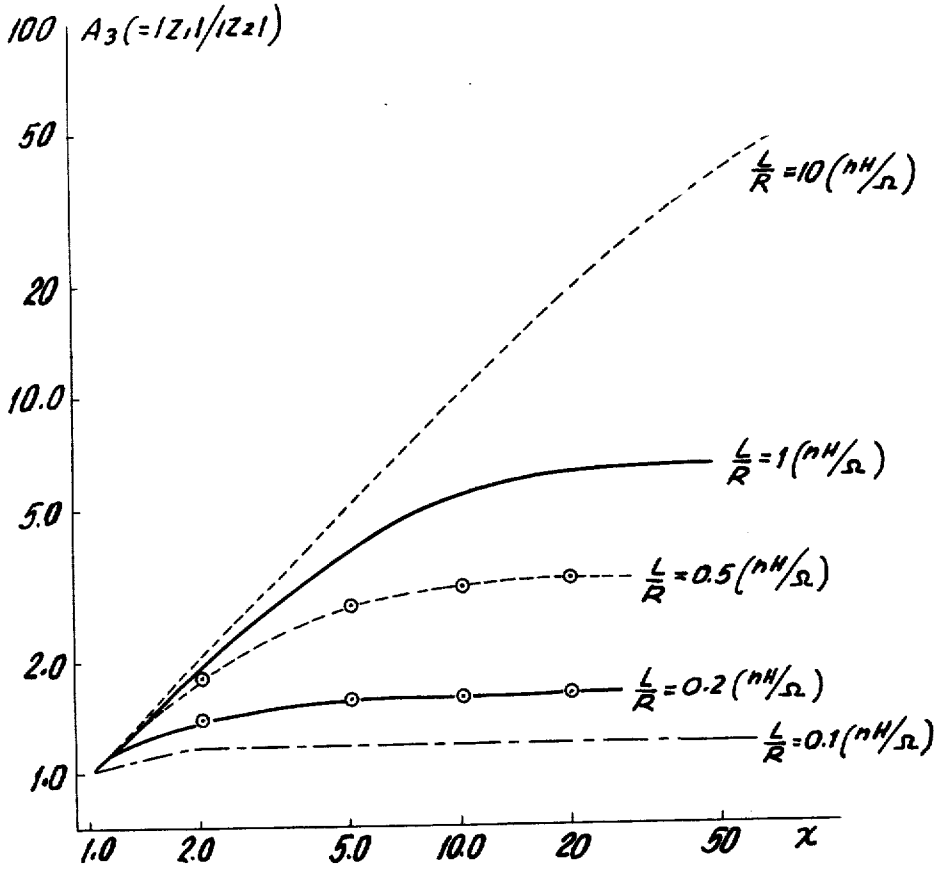
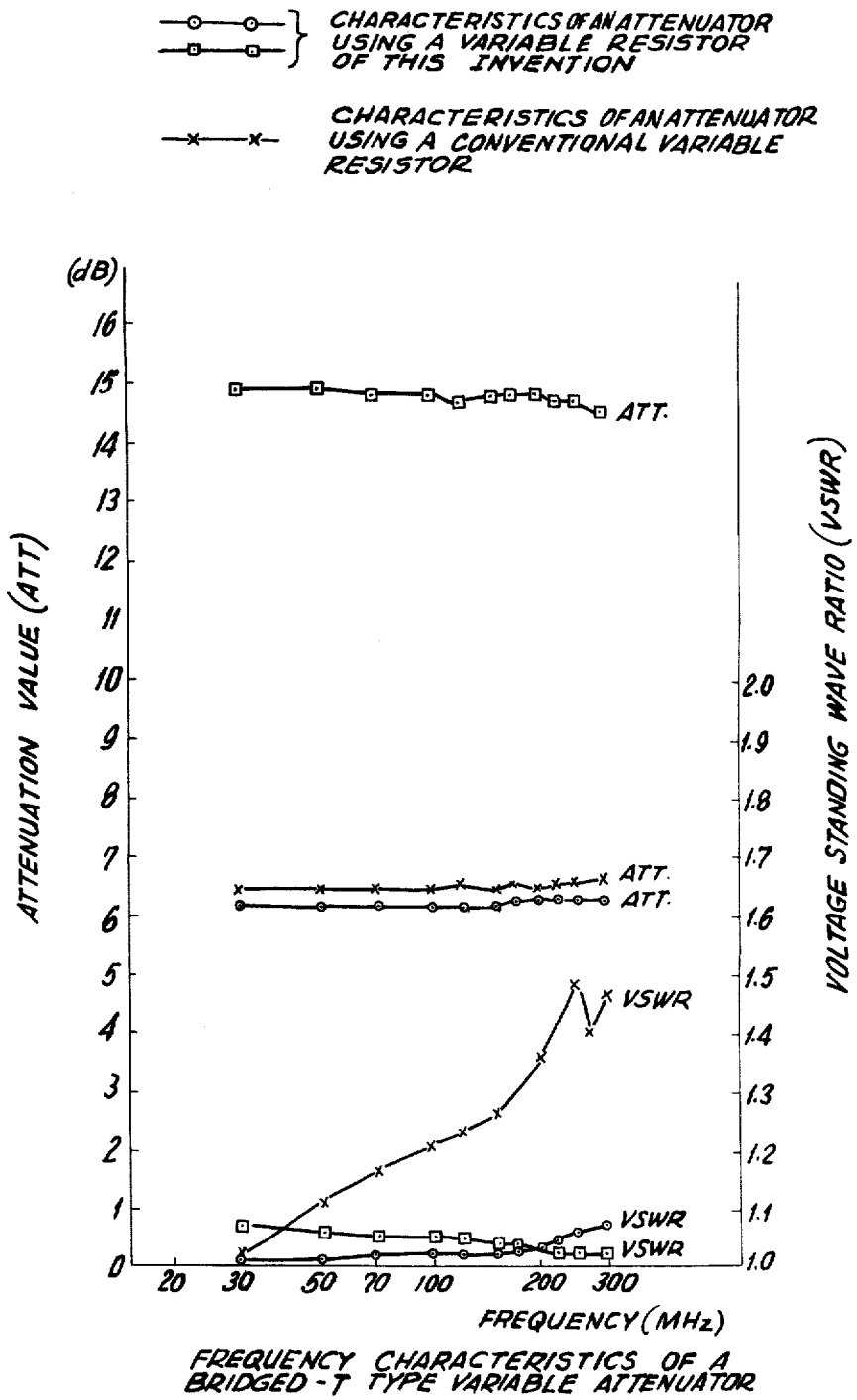


FIG. 7



VARIATION OF $A_3 (= |Z_1|/|Z_2|)$ WITH RESPECT TO THE LENGTH X (AT 100 MHz)

FIG. 8



FREQUENCY CHARACTERISTICS OF A BRIDGED-T TYPE VARIABLE ATTENUATOR

FIG. 9

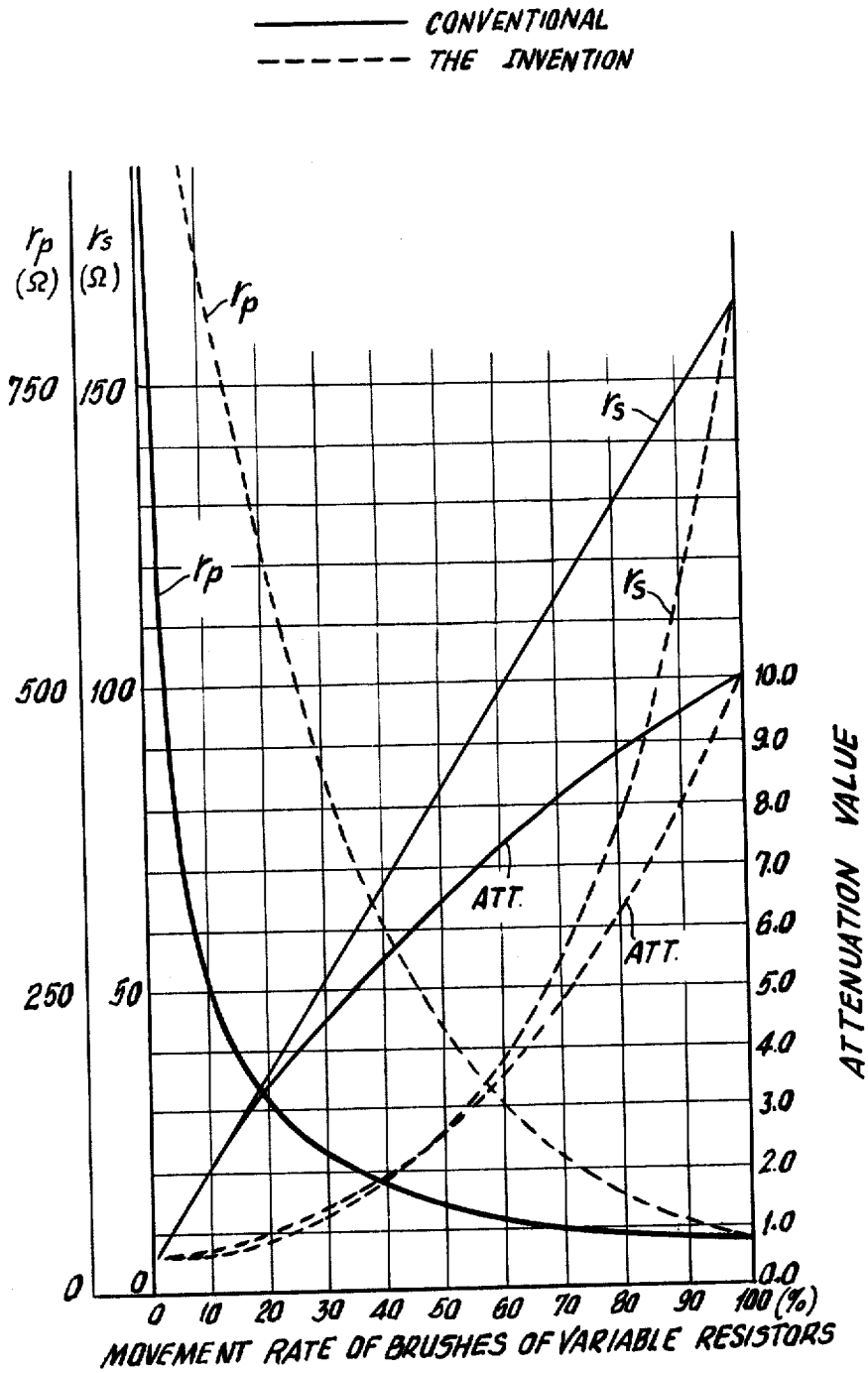

CONVENTIONAL
THE INVENTION
r_p (Ω)
r_s (Ω)
750
150
500
100
250
50
0
0
r_p
r_s
ATT.
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ATTENUATION VALUE
0 10 20 30 40 50 60 70 80 90 100 (%)
MOVEMENT RATE OF BRUSHES OF VARIABLE RESISTORS

FIG. 10

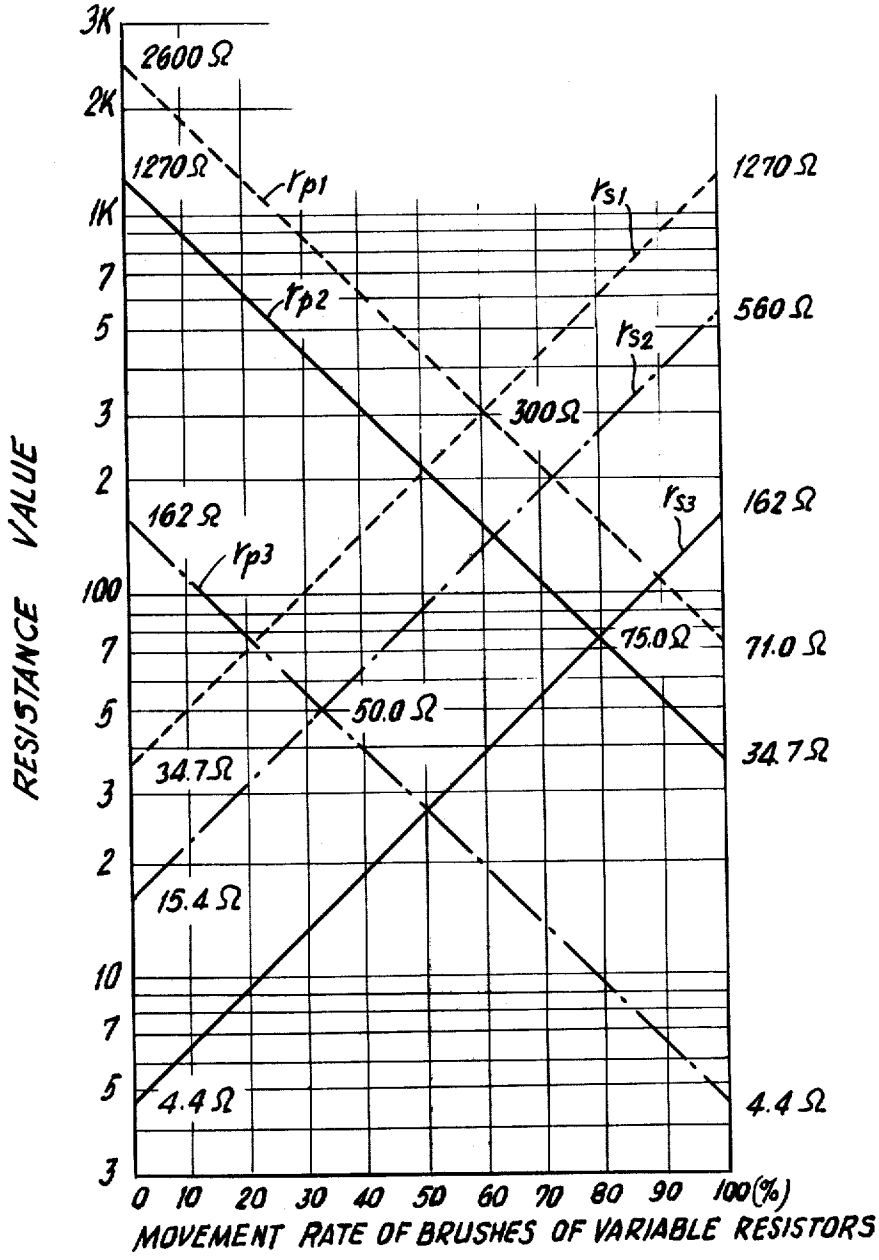

3K
2K
1K
7
5
3
2
100
7
5
3
2
10
7
5
3
2600 Ω
1270 Ω
r_{p1}
r_{p2}
r_{p3}
r_{s1}
r_{s2}
r_{s3}
300 Ω
162 Ω
75.0 Ω
50.0 Ω
34.7 Ω
15.4 Ω
4.4 Ω
1270 Ω
560 Ω
162 Ω
71.0 Ω
34.7 Ω
4.4 Ω
RESISTANCE VALUE
0 10 20 30 40 50 60 70 80 90 100(%)
MOVEMENT RATE OF BRUSHES OF VARIABLE RESISTORS

FIG. 11

VARIABLE RESISTOR

RELATED APPLICATIONS

This is a continuation-in-part of an application entitled "Variable Resistor" Ser. No. 267,630 filed June 29, 1972 now U.S. Pat. No. 3,760,322 and the benefit of the filing date of that application is claimed.

BACKGROUND OF THE INVENTION

This invention relates to a variable resistor for use in electrical circuits and, more specifically, to a variable resistor including a film of resistive material having a gradient of resistivity in a predetermined direction.

In a conventional variable resistor, terminals are provided at the ends of the resistive film and a brush is held in slidable contact with the film to provide a variable resistance between one of the terminals and the brush. The resistance then depends on the position of the brush with respect to the film.

One of the shortcomings of this type of variable resistor is that the inductance component appearing in parallel with the variable resistance undergoes a considerable change depending on the resistance selected. A principal object of the present invention is therefore to provide a variable resistor capable of resistance variation without causing a change in the inductance component.

SUMMARY OF THE INVENTION

The variable resistor of the present invention comprises a resistive element having a gradient of resistivity that varys in a predetermined manner along its length and at least two brushes separated by a predetermined interval and held in slidable contact between the resistive element. The desired gradient of resistivity can be given to the resistive element by tapering its width or gradually changing its composition. More than two slidable brushes may be used as required. When more than two brushes are used, a different variable resistance can be obtained across every two brushes. The brushes are interconnected so that the distance between them remains constant.

In the variable resistor of this invention, a desired variable resistance is provided between the slidable brushes, while maintaining the accompanying inductance component at a fixed value.

Another feature of the present invention is that the variable resistance never takes the value zero ohms. This contributes to the simplification of a circuit including a finite minimum resistance.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described with reference to the accompanying drawings, in which:

FIGS. **1***a* and *b* show equivalent circuits of a conventional variable resistor for the direct-current and extremely low frequency region and for the high frequency region, respectively;

FIGS. **2***a* and *b* show equivalent circuits of an embodiment of the invention for the direct-current and low frequency region and for the high frequency region, respectively;

FIG. **3** is a cross-sectional view of a first embodiment of the invention;

FIG. **4** shows a circuit diagram of a bridged-T type variable resistance attenuator to which this invention is applicable;

FIG. **5** shows a cross-sectional view of a second embodiment of this invention adapted to the attenuator of FIG. **4**;

FIG. **6** is an equivalent circuit of a third embodiment of the invention;

FIG. **7** is an equivalent circuit of a fourth embodiment of the invention;

FIG. **8** shows diagramatically, the impedance variation characteristics of the invention as compared to those of a conventional variable resistor;

FIG. **9** shows diagramatically, the frequency characteristics of the conventional bridged-T type variable attenuator and those of the attenuator of FIG. **4** in comparison with the second embodiment of the invention shown in FIG. **5**;

FIG. **10** shows diagramatically, the attenuation values of a conventional attenuator and the attenuator of FIG. **4** and the resistance values of variable resistors Rs and Rp used therein, as a function of the movement of brushes of the variable resistors; and

FIG. **11** shows diagramatically, the resistance variation of the variable resistors R*s* and R*p* which are used in the variable resistance attenuator of FIG. **4**, with respect to the movement of the brushes of the variable resistors.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1***a* shows an equivalent circuit for conventional variable resistor comprising a resistive film **10** having terminals **1** and **3** at its ends, and a slidable brush **2** operating in the low frequency range. The desired variable resistance is obtained between the brush **2** and the terminal **3.** The resistive film **10** has a uniform specific resistance, and its inductance component is proportional to the length, but negligibly small when a direct current or extremely low frequency signal is applied. Likewise, the capacitive component is also negligible. Generally, the impedance Z_1 between the terminals **1** and the brush **2** is given by:

$$Z_1 = xR + j\,w \times L \tag{1}$$

$$Z_1 = x\ \sqrt{R^2 + w^2L^2} \tag{2}$$

where R stands for the resistance per unit length of the resistive film **10**; L, for the inductance per unit length of the film **10**; x, for the length of the section of the film **10** lying between the terminal **1** and the brush **2**; and w, for the angular frequency. Differentiating Eq. (2) with respect to x and w,

$$d\,|\,Z_1\,|/dx = \sqrt{R^2 + w^2L^2} \tag{3}$$

$$d\,|\,Z_1\,|/dw = wL^2\,x/\sqrt{R^2 + w^2L^2} \tag{4}$$

From Eqs. (3) and (4), it is apparent that $|\,Z_1\,|$ increases linearly with each successive increment of the length x, and non-linearly with each successive increment of the angular frequency w.

The impedance Z_0 of an ideal variable resistor having neither a capacitance component nor an inductance component may be expressed as follows:

$$Z_0 = |\,Z_0\,| = xR \tag{5}$$

where resistive film is assumed to have a uniform specific resistance R. The ratio A_1 of $|\,Z_0\,|$ to $|\,Z_1\,|$ is given by:

-Continued

$$A_1 = \frac{|Z_1|}{|Z_0|} = \frac{x\sqrt{R^2+w^2+L^2}}{xR} = \sqrt{1+\frac{w^2L^2}{R^2}} \geqq 1 \quad (6)$$

More specifically, the absolute value of impedance is always larger in the conventional variable resistor than in the ideal variable resistor. Also, the larger the angular frequency w, or the smaller the specific resistance R of the resistive film, the greater the ratio A_1 of Eq. (6) becomes.

In other words, with the increase of the frequency, the impedance has a greater effect on the variable resistance, making the deviation from the ideal variable resistor greater. An equivalent circuit for a conventional variable resistor at high frequency is shown in FIG. 1*b*.

In the equivalent circuits of the variable resistor of the invention shown in FIGS. 2*a* and 2*b*, slidable brushes **5** and **6** are in contact with a resistive film **30**. The film **30** (resistive element) has a nonlinear gradient of resistivity with respect to its length. Two brushes **5** and **6**, spaced apart by a predetermined interval, are held in slidable contact with the resistive film **30**. The interval between the brushes and the nonlinear gradient in the resistivity of the film **30** are selected so that the resistance between the brushes **5** and **6** exhibits an increase in linear proportion to the lengthwise movement of the brushes. It will be appartent, however, that the invention is not limited to this resistive film arrangement. In general, the gradient may change continuously, linearly or nonlinearly. For simplicity in this explanation, it is assumed here that the incremental change in the gradient, in other words, the rate of the change of the resistivity of the film **30**, is in linear proportion to the position selected along its length.

Assuming that the distance from the lefthand end of the resistive film **30** to the brush **6** is x, the resistance therebetween is xR, and the spatial interval between the brushes **5** and **6** is unity, then the impedance Z_2 between the brushes **5** and **6** can be expressed as:

$$Z_2 = x\,R + j\,w\,L \quad (7)$$

$$|Z_2| = x\sqrt{R^2+\frac{w^2L^2}{X^2}} \quad (8)$$

where $x \geqq 1$ and the variables are the same as those in Eqs. (1) and (2). The ratio A_2 of the impedance $|Z_2|$ of the present variable resistor to the impedance $|Z_0|$ of the ideal variable resistor is given by:

$$A_2 = \frac{|Z_2|}{|Z_0|} = \sqrt{1+\left(\frac{wL}{xR}\right)^2} \quad (9)$$

where $x \geqq 1$.

As in the case of Eq. (6), Eq. (9) indicates that the impedance of the present variable resistor is always larger than that of the ideal variable resistor, and that the value of A_2 is increased with the increase in the angular frequency w. Also, as the resistance xR is increased, the present variable resistor approaches the ideal variable resistor in its characteristics.

Derived from Eqs. (2) and (3), the ratio A_3 of the absolute value of the impedance of the present variable resistor to that of the conventional one is given by:

$$A_3 = \frac{|Z_1|}{|Z_2|} = \frac{x\sqrt{R^2+w^2L^2}}{x\sqrt{R^2+w^2L^2/x^2}} = \sqrt{\frac{1+w^2L^2/R^2}{1+w^2L^2/x^2R^2}} \quad (10)$$

It follows that

$$A_3 \geqq 1.0 \quad (11)$$

where $x \geqq 1$.

In other words, in the range of $x \geqq 1.0$, the variable impedance Z_2 of the present variable resistor is smaller than that Z_1 of the conventional resistor and closer to that of the ideal resistor. FIG. **8** shows the value of A_3 given in Eq. (10) with respect to the length x.

In such a variable resistor, the resistance obtained across the brushes **5** and **6** cannot take the value zero ohms even under the state of unity thus maintaining a certain minimum resistance value. The variable resistor of this invention is therefore highly desirable for those circuits which require a minimum constant resistance.

Referring now to FIG. **3**, the first embodiment of the invention, an equivalent circuit of which is shown in FIG. **2**, two brushes **106** and **107** are attached to a cylindrical housing **105** and held in contact with an arcuate resistive film **102** attached to a disc-shaped base **103**. The film **102** may form a complete circle. The resistive film **102** has a nonlinear gradient of resistivity in the circumferential direction. This gradient is attained by tapering the thickness or the width of the film **102**. Alternatively, it may be attained by varying the composition of the material of which the film is made. By the expression gradient of resistivity it is meant that the resistance per unit length of the film varies in a predetermined manner as it is measured at different points along its length. The base **103** is pressed downwardly by a spring **104** thus permitting rotation under the control of a rotatable disc **101**. The desired variable resistance value is thus obtained between the brushes **106** and **107**, by changing the relative position of the brushes and the film **102**.

Referring now to FIG. **4**, a bridge-T type variable attenuator using the variable resistors of the present invention permits a variation in the attenuation depending on the selected resistance of two resistors R*s* and R*p*. A variable resistor Rs is connected across the input terminal **41** and the output terminal **43**, and two fixed resistors R*o* and Ro_2 are connected in parallel with the variable resistor R_S. A variable resistor R*p* is connected across the connection point **44** of the two fixed resistors R*o* and Ro_2, and the input-output common terminal **42**. In each of the variable resistors Rs and Rp, the interval between the brushes **45** and **46** (**47** and **48**) and the nonlinear gradient in the resistivity of the film **49** (**50**) are selected so that the resistance between the brushes **45** and **46** (**47** and **48**) exhibits an increase in logarithmic proportion to the lengthwise movement of the brushes **45** and **46** (**47** and **48**). Moreover, the variable resistors R*s* and R*p* are interlocked to operate so that when one resistance is increasing, the other is decreased. When conventional variable resistors are used in this attenuator, the voltage standing wave ratio (VSWR) is unavoidably increased with an increase in the frequency. This tends to cause an increase in the impedance Z_1.

Referring now to FIG. **5**, a second embodiment is shown which is adapted to the variable attenuator of

FIG. 4 and has a dual variable resistor which may be viewed as two separate variable resistors. Each of these variable resistors is the equivalent to one resistor of the circuit shown in FIG. 2. The dual variable resistor has two brushes **116** and **117** fixed to a base **119** which also serves as a cover. Two arcuate resistive films **112** and **112'** having nonlinear resistivity gradients are attached to bases **113** and **114** and kept in slidable contact with the brushes **116** and **117**. The resistive films **112** and **112'** are moved as a disc **101** on which the bases **113** and **114** are mounted is rotated. These elements are contained in a cylindrical housing **105** and a closure including a base **119**. A pair of brushes are provided for each of the resistive films **112** and **112'**.

With the dual variable resistor of FIG. 5 used as the resistors Rs and Rp of the bridged-T type variable attenuator of FIG. 4, the impedances of the resistors Rs and Rp exhibit virtually no change in the inductive components, as indicated by Eq. (7). Therefore, the voltage standing wave ratio (VSWR) can be kept unchanged as shown in FIG. 9, which illustrates two groups of curves showing the attenuation vs. frequency and the voltage standing wave ratio (VSWR) vs. frequency characteristics of the present variable attenuator as compared with those of a conventional variable-resistor-based attenuator.

In the bridged-T type variable attenuator of FIG. 4, the resistances r_s and r_p of the resistors R*s* and R*p* can be expressed as a function of the attenuation value ϵ as follows:

$$\left.\begin{aligned} r_s &= \epsilon\,(e^a - 1) \\ r_p &= \epsilon\,(e^a - 1)^{-1} \end{aligned}\right\} \quad (12)$$

where a is given in neper.

The zero attenuation value is achieved by making the resistance r_s and r_p zero and infinity, respectively. Conversely, infinite attenuation is achieved by making r_s and r_p inifinity and zero, respectively. Practically, however, these requirements cannot be met, because infinite impedance is difficult to achieve with a conventional variable resistor. This results in a residual attenuation which causes a high voltage standing wave ratio. Therefore, to achieve a satisfactorily low voltage standing wave ratio with the conventional device, at least one resistor must be in series with either Rs or Rp or both. In contrast, the variable resistor of the invention never takes the value zero ohms. This makes it possible to dispense with any additional resistance elements and consequently to simplify and miniatuarize the attenuator as a whole. This applies to any apparatus or device in which the present invention finds application.

Now, other advantages of the variable attenuator of FIG. 4 will be explained.

It is required for the purpose of inserting a bridged-T type variable resistance attenuator into a transmission line without changing the characteristics of the transmission line that resistors of the attenuator satisfy the following equation

$$r_s \times r_p = r_o^2 \quad (13)$$

where r_o stands for a resistance value of each fixed resistor R*o*. In general, an attenuation value of the bridge-T type attenuator is adjusted by changing the resistances r_s and r_p of the variable resistors R*s* and R*p*. Therefore, the above equation (13) should be satisfied regardless of the adjusted attenuation value, for the mention purpose. In order to meet equation (13), the conventional bridged-T type attenuator employs a variable resistor Rs of such a type that the resistance increases in linear proportion to the movement of the brushes and a variable resistor Rp of such a type that the resistance increases in inverse proportion. In such conventional attenuators, it is difficult to provide a variable resistor R*p* having the desired inverse resistance variation, because strict controls are needed for the area resistance and width of the resistance film thereof. Therefore, the yield and manufacturing efficiency are small, and the manufacturing cost is usually about two or three times higher than that of the variable resistor R*s* having a linear resistance variation. Also, since variable resistors R*s* and R*p* have different resistance variations, it is not possible to interchange the variable resistor R*s* with R*p* or vice versa, where attenuation value or characteristic impedance is changed.

In contrast, both the variable resistors Rs and Rp of the attenuator of FIG. 4 have a structure such that resistance increases or decreases in logarithmic proportion to the movement of brushes. Therefore, the variable resistors R*s* and R*p* can be interchanged, and, moreover, the attenuator of FIG. 4 always satisfies equation (13).

FIG. **10** shows the attenuation values (ATT) of a conventional attenuator and the attenuator of FIG. 4 and the resistance values of variable resistors Rs and Rp used in the conventional attenuator and in the attenuator of FIG. 4, all as a function of the movement of the brushes of the variable resistors R*s* and R*p*. As will be understood from FIG. **10**, the variable resistor R*p* having the logarithmic variation of the resistance value r_p (dotted line) has a smaller variation gradient of the resistance than that of the resistor having the reciprocal variation of the resistance value r_p (solid line). This reveals the ease of manufacture of the resistor R*p* of the invention.

In designing electronic equipment such as transmission equipment, it is preferable, to avoid the use of variable resistance attenuators. If the use of such attenuators is not avoidable, they should be used in a region where the attenuation value thereof is small. In this respect, as will be apparent from comparison of the ATT curves of FIG. **10**, the variable resistance attenuator of this invention is more suited for selecting a small attenuation value than the conventional attenuator. Hence the attenuator or this invention is suitable for use in transmission equipment.

FIG. **11** shows the resistance variation of the resistors R*s* and R*p* of the attenuator of this invention; the movement of the brushes of the variable resistors is presented along the abscissa and the resistance value is represented along the ordinate on a logarithmic scale to show the resistance values r_p and r_s of the variable resistors R*p* and R*s*. Both the resistances r_p and r_s are selected to vary logarithmically with respect to the movement of the brushes, but their variations are in opposite directions. Hence, in FIG. **11**, resistances r_p and r_s are shown as straight lines declining in opposite directions.

In FIG. **11**, three pairs of resistances r_{p1} and r_{s1}, r_{p2} and r_{s2}, and r_{p3} and r_{s3} are shown. However, for resistances r_p and r_s belonging to either the same pair or different pairs the value of $r_{pi} \times r_{sj}$ (both i and j stand for 1,2 or 3) is always equal to the second power of the resistance value at an intersection of the straight lines r_{pi} and r_{sj}. In effect, for a variable resistance attenuator having a characteristic impedance of 75 ohms (corresponding to r_o of equation 13), variable resistors R*s* and

Rp having resistance values r_{p2} and r_{s3}, respectively, may be selected. In the same way, for the characteristic impedance of 50 ohms, variable resistors Rs and Rp having resistance values r_{p3} and r_{s2}, respectively, may be selected, and for the characteristic impedance of 300 ohms, variable resistors Rs and Rp having respectively resistances r_{p1} and r_{s1} may be selected.

An additional advantage of the resistance attenuator of FIG. **4** is that one variable resistor may be used as either Rs or Rp. It can be pointed out as another advantage that one variable resistor can be used in a variable resistance attenuator having any characteristic impedance. These advantages are attributed to the fact that the variable resistors having a logarithmic resistance variation are used as both variable resistors Rs and Rp of the variable resistance attenuator. This allows mass production of variable resistance attenuators having one or more characteristics with fewer kinds of variable resistors and contributes to reduced losses.

Referring now to FIG. **6**, a third embodiment of this invention has four brushes **202, 203, 204,** and **205** spaced at predetermined intervals and held in slidable contact with a resistive film **201.** This variable resistor makes it possible to obtain two desired variable resistance values from one resistive film **201,** one from the brushes **202** and **203** and the other from the brushes **204** and **205.** In other words, a dual variable resistor can be constructed using one resistive film **201.** Brushes **203** and **204** may be connected to each other when these two brushes are to be at an equal potential. It will be apparent that more than four brushes can be used.

Referring now to FIG. **7**, the fourth embodiment of the invention includes a resistive film **301** having terminals **304** and **305** at its ends, respectively, and brushes **302** and **303** held in slidable contact with the resistive film **301** with a voltage is applied between the terminals **304** and **305,** the desired voltage is derived from the brushes **301** and **303.** In this variable resistor, the inductive component of the output impedance is small and constant. Therefore, the use of this variable resistor in a high frequency device will contribute substantially to better performance.

In the foregoing description, we have explained the present invention with reference to several exemplary embodiments and their application. However it will be apparent to those skilled in the art that other modifications are possible without departing from the spirit and scope of the invention.

We claim:

1. A variable resistance attenuator comprising an input terminal, an output terminal, a common terminal, a first variable resistor connected between said input terminal and said output terminal, first and second resistors connected in series between said input terminal and said output terminal, and a second variable resistor connected to the series connection between said first and second resistors and connected at its opposite terminal to said common terminal, said first and second variable resistors each comprising an electrically resistive element, the incremental resistance of which varies along its length, to form a gradient of resistivity, and two brushes spaced apart by a constant distance in slidable contact with each said resistive element, said gradient being such that the resistance between the brushes varies logarithmically, but the inductance between them remains substantially constant as they are moved with respect to the gradient.

2. A variable resistor comprising an electrically resistive element the incremental resistance of which varies along its length to form a gradient of resistivity, and two moveable brushes spaced apart by a fixed distance and in slidable contact with the resistive element, the resistive element providing a substantially constant inductance and a linearly variable resistance as the position of the brushes with respect to the gradient is varied.

3. A variable resistor comprising an electrically resistive element the incremental resistance of which varies along its length to form a gradient of resistivity, and two moveable brushes spaced apart by a fixed distance and in slidable contact with the resistive element, the resistive element providing a substantially constant inductance and a logarithmically variable resistance as the position of the brushes with respect to the gradient is varied.

* * * * *