United States Patent [19]

Garuts

[11] E **Re. 29,018**

[45] **Reissued Oct. 26, 1976**

[54] **CONTINUOUSLY VARIABLE RESISTANCE ATTENUATOR USING LOSSY TRANSMISSION LINE AND HAVING CONSTANT SIGNAL TRANSIT TIME**

[75] Inventor: **Valdis E. Garuts**, Beaverton, Oreg.

[73] Assignee: **Tektronix, Inc.**, Beaverton, Oreg.

[22] Filed: **June 9, 1975**

[21] Appl. No.: **585,014**

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: **3,740,676**
Issued: **June 19, 1973**
Appl. No.: **239,375**
Filed: **Mar. 29, 1972**

U.S. Applications:

[63] Continuation of Ser. No. 85,678, Oct. 30, 1970.

[52] **U.S. Cl.** .... **333/81 A;** 323/94 R; 338/216

[51] **Int. Cl.**[2] **H01P 1/22**

[58] **Field of Search** .... 333/81 R, 81 A; 338/150, 216; 323/74, 81, 94, 96

[56] **References Cited**

UNITED STATES PATENTS

1,613,423	1/1927	Wegel	333/81 R X
2,517,180	8/1950	Davis	333/81 A
2,536,501	1/1951	Hood et al.	333/81 R
2,539,352	1/1951	Hewlett	333/81 R X
2,909,736	10/1959	Sommers et al.	333/81 A
3,657,688	4/1972	Casey et al.	338/150

FOREIGN PATENTS OR APPLICATIONS

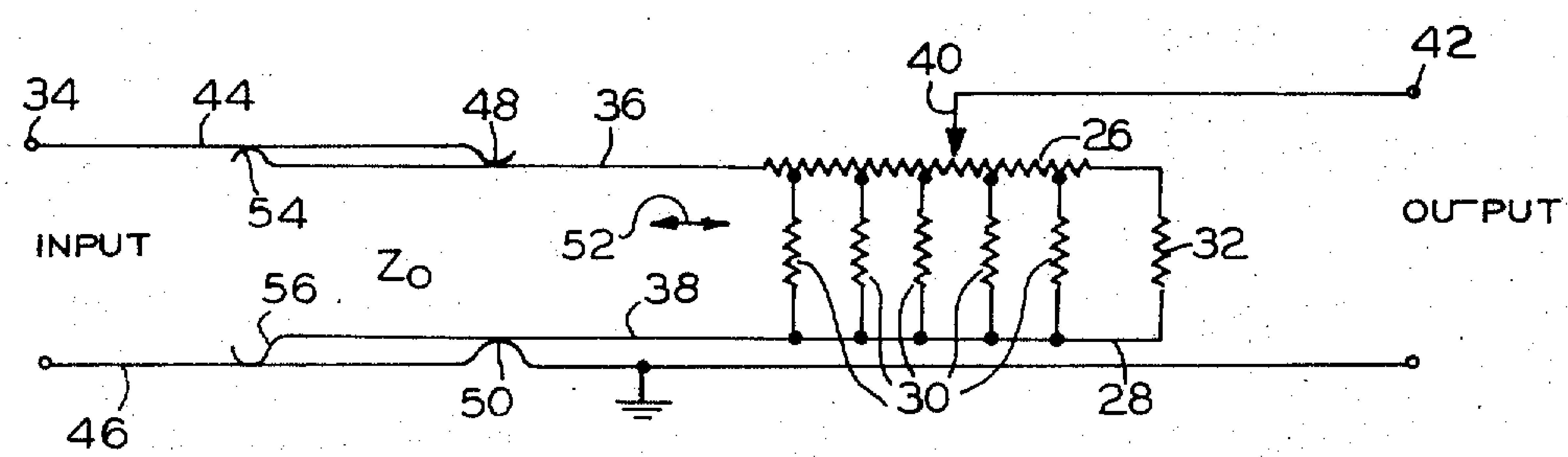
804,747	11/1958	United Kingdom	333/81 R

Primary Examiner—Paul L. Gensler
Attorney, Agent, or Firm—Kenneth M. Durk

[57] **ABSTRACT**

A continuously variable resistance attenuator is described in which the signal conductor of a distortionless lossy transmission line is employed as an attenuation resistance uniformly distributed along such line, and the connection of an output contact is moved along such signal conductor to change the attenuator setting. The transmission line has a plurality of separate shunt resistors of equal value extending between the signal conductor and the ground conductor of the line and uniformly distributed along the line to provide a lossy line of uniform characteristic impedance. The input end of such lossy line is connected to a non-lossy line of the same characteristic impedance, and its other end is terminated in a termination resistor equal to such characteristic impedance. In one embodiment, the lossy transmission line is moved relative to a fixed input contact and a fixed output contact to provide a constant transit time for the signal to pass through the attenuator, due to the fixed distance between such contacts and to reduce the size of the contacts for improved high frequency response. The input contact is provided by a fixed portion of the non-lossy line which engages its movable portion attached to the lossy line to provide a transmission line stretcher of variable length.

16 Claims, 5 Drawing Figures



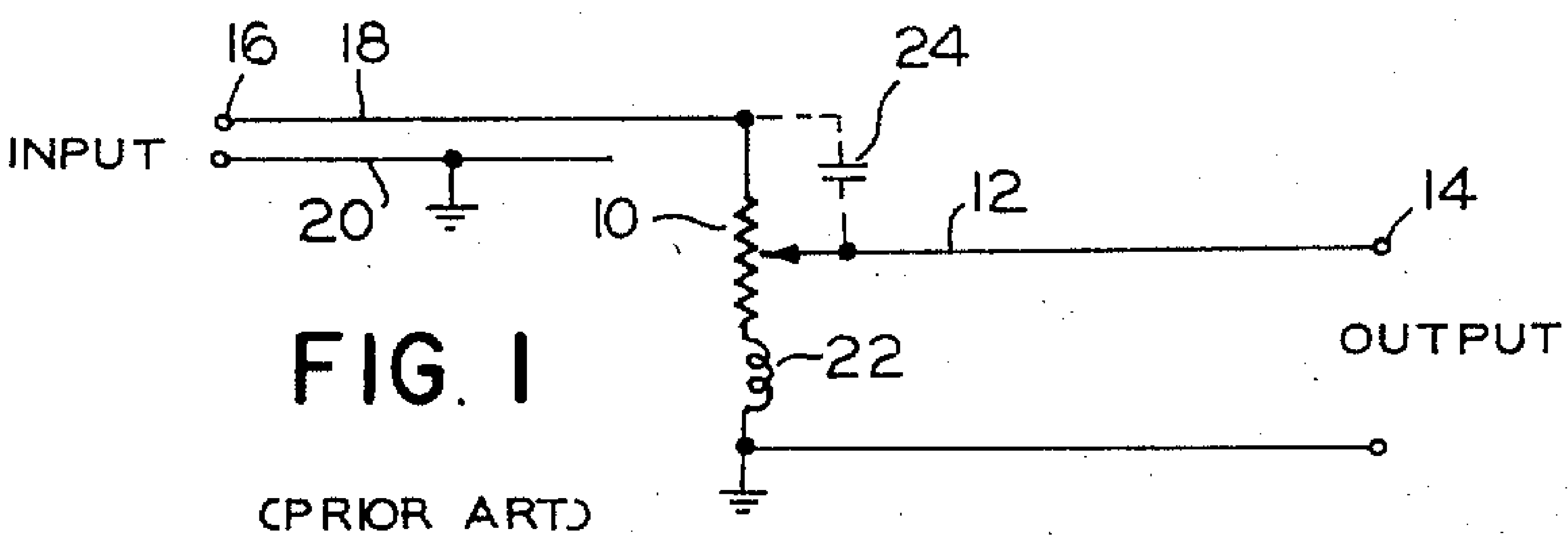


FIG. 1
(PRIOR ART)

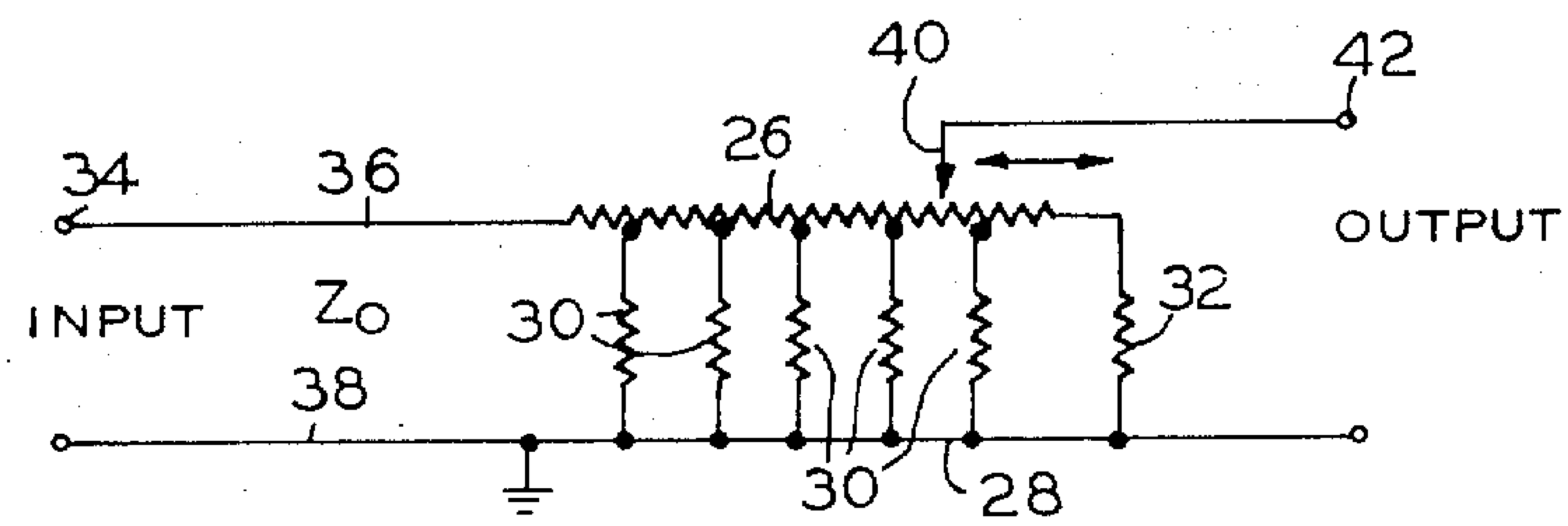


FIG. 2

FIG. 3

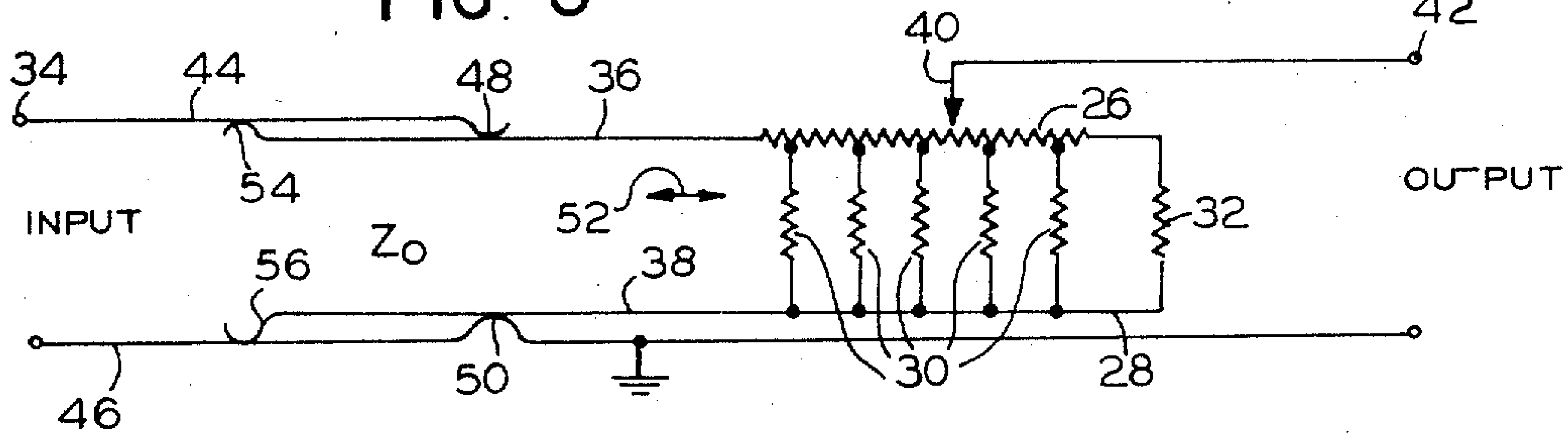
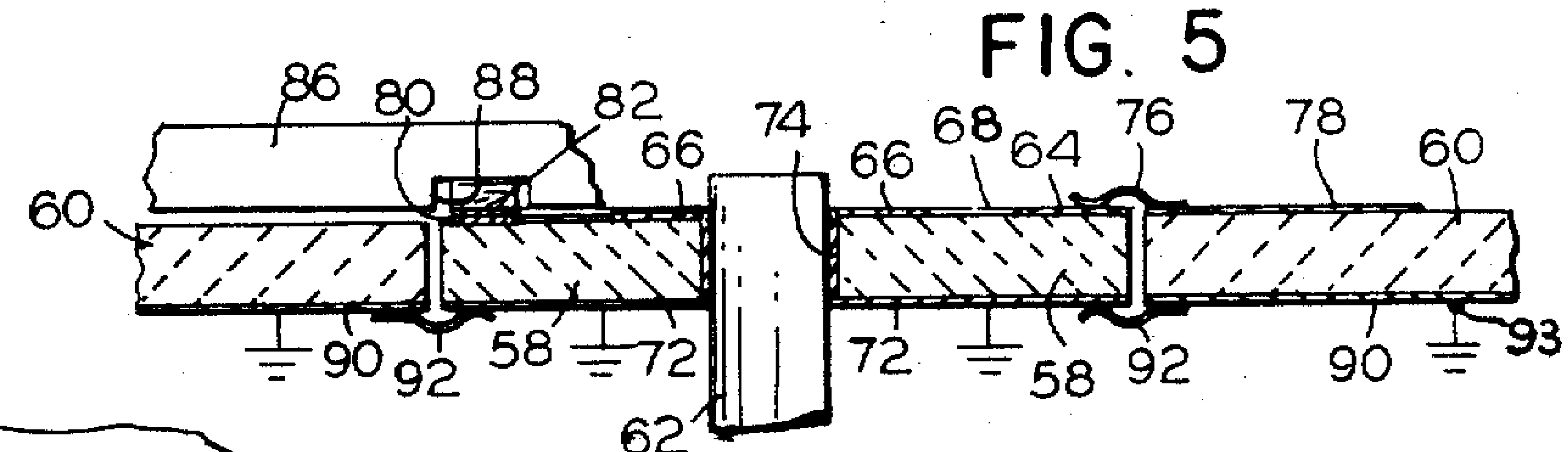


FIG. 5



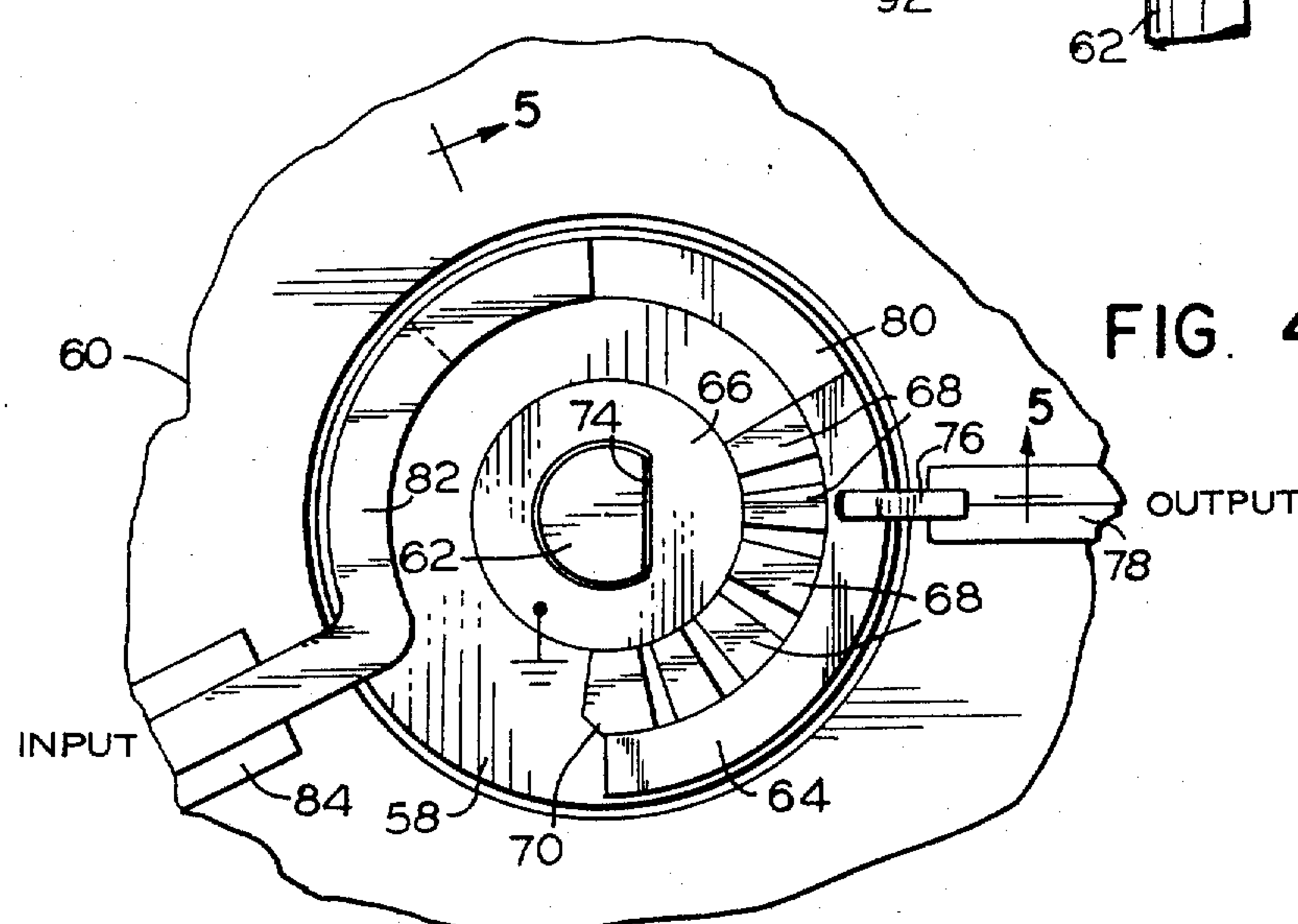


FIG. 4

VALDIS E. GARUTS
INVENTOR
BY
BUCKHORN, BLORE, KLARQUIST & SPARKMAN
ATTORNEYS

CONTINUOUSLY VARIABLE RESISTANCE ATTENUATOR USING LOSSY TRANSMISSION LINE AND HAVING CONSTANT SIGNAL TRANSIT TIME

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This is a continuation of application Ser. No. 85,678 filed Oct. 30, 1970.

BACKGROUND OF THE INVENTION

The subject matter of the present invention relates generally to continuously variable resistance attenuators of wide band frequency response and, in particular, to such an attenuator employing a lossy distortionless transmission line with its signal conductor providing an attenuation resistance uniformly distributed along such line which is engaged by the output contact of the attenuator for movement relative to change the attenuator setting. The lossy transmission line includes a plurality of separate shunt resistors of equal value connected between the signal conductor and a ground conductor and uniformly distributed along the transmission line. The shunt resistors have a total parallel value per unit length equal to the square of the characteristic impedance divided by the resistance per unit length of the signal conductor to provide the line with a uniform characteristic impedance. A termination resistor equal to the characteristic impedance of the line is connected to the output end thereof to prevent signal reflections.

The attenuator of the present invention has a greater high frequency response than previous continuously variable resistance attenuators including that shown in U.S. Pat. No. 3,157,846 of B. O. Weinschel. In addition it has a larger attenuation range within such frequency response. The present attenuator also has the advantage that it can be employed to terminate a transmission line since the lossy transmission line forming such attenuator has a constant input impedance equal to its characteristic impedance regardless of the attenuation setting of the output contact. Furthermore, the output impedance of the attenuator at such output contact is constant and equal to one-half of the characteristic impedance under such circumstances.

One embodiment of the attenuator of the present invention employs a movable lossy transmission line section and fixed input and output contacts so that the signal transit time between such contacts does not change with adjustments in the setting of the attenuator. In addition, this enables the size of the contacts to be minimized, thereby further increasing the high frequency response due to the resulting reduction of the inductance and capacitance associated with such contacts.

The present attenuator may be employed in place of any continuously variable resistance attenuator including potentiometers. However, the present attenuator is especially useful when employed in the vertical amplifier of a cathode ray oscilloscope having a wide band frequency response from DC to several hundred megahertz.

It is, therefore, one object of the present invention to provide improved continuously variable resistance attenuator having a wider frequency band width.

Another object of the invention is to provide such an attenuator in which a distortionless lossy transmission line is employed whose signal conductor forms an attenuation resistance uniformly distributed along its length and the output contact of the attenuator engages such signal conductor for movement relative thereto, and includes a plurality of separate shunt resistors uniformly spaced along the line to provide such line with a uniform characteristic impedance.

An additional object is to provide such an attenuator whose input impedance remains constant for different attenuation settings.

A further object is to provide such an attenuator having a constant output impedance at its output contact.

Still another object of the invention is to provide such an attenuator in which the lossy transmission line section is moved while the input contact and the output contact remain fixed in order to provide a constant signal transit time between such contacts in spite of changes in the attenuator setting.

A still further object of the invention is to provide such an attenuator with an extremely compact, rugged structure by providing the movable lossy transmission line as a resistance coating on a rotor plate of insulating material surrounded by a stator plate of insulating material on which the fixed input and output contacts are provided.

BRIEF DESCRIPTION OF DRAWINGS

Other objects and advantages of the present invention will be apparent from the following detailed description of certain preferred embodiments thereof and from the attached drawings of which:

FIG. **1** is a schematic diagram of a prior art variable resistance attenuator;

FIG. **2** is a schematic diagram of one embodiment of the variable resistance attenuator of the present invention;

FIG. **3** is a schematic diagram of another embodiment of the attenuator of the present invention having fixed input and output contacts;

FIG. **4** is a plan view of an attenuator made in accordance with the embodiment of FIG. **3**; and

FIG. **5** is a sectional view taken along the line **5**–**5** of FIG. **4**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in FIG. **1**, prior art attenuators include a continuously variable resistance potentiometer **10** having its movable contact **12** connected to an output terminal **14.** One end terminal of the potentiometer **10** is grounded while its other end terminal is connected to a signal source at the input terminal **16** of the attenuator through the signal conductor **18** of a transmission line. The transmission line includes a ground conductor **20** uniformly spaced from the signal conductor **18** to provide such line with a uniform characteristic impedance. This transmission line **18, 20** enables the signal source connected to input terminal **16** to be positioned remotely from the attenuator potentiometer **10** and such potentiometer also forms as the termination resistor for such transmission line.

The attenuator of FIG. **1** includes a series lead inductance **22** connected between one end of the potentiometer **10** and ground, and a stray capacitance **24** connected between the input end of the potentiometer **10** and movable contact **12**, which both cause distortion. Thus, at high frequencies, the stray capacitor **24** shunts the signal current around the attenuation resistance **10** while the lead inductance **22** prevents the signal current from flowing to ground so that practically no attenuation of the signal is achieved at high frequencies. As a result, attenuation varies greatly with the frequency of the input signal at high frequencies and is not related to the setting of the movable contact **12** on potentiometer **10.** Of course, this also prevents the attenuator from properly terminating the transmission line **18, 20** in its characteristic impedance which results in signal reflections causing distortion of the input signal.

As shown in FIG. **2,** one embodiment of the present invention includes a distortionless lossy transmission line formed by a signal conductor **26** having an attenuation resistance uniformly distributed along its length, a ground conductor **28,** and a plurality of separate shunt resistors **30** connected between such signal conductor and such ground conductor. The shunt resistors **30** are uniformly spaced along signal conductor **26** and of the same resistance value $[n(Z_o)^2,/R]$ where Z_o is the characteristic impedance of the transmission line **26, 23,** n is the number of shunt resistors per unit length of such line, and R is the resistance per unit length of the signal conductor **26.** Thus, in one embodiment when $Z_o = 50$ ohms and five shunt resistors **30** were employed, a total resistance of 50 ohms was used for the signal conductor **26** to provide $R = 50/5 = 10$ ohms per unit length and the value of each shunt resistor $(Z_o)^2/R = (50)^2/10 = 250$ ohms.

The output end of the signal conductor **26** is connected through a termination resistor **32** to the ground conductor **28.** Such termination resistor having a resistance equal to the characteristic impedance of the transmission line.

The input end of the attenuation resistance **26** is connected to an input terminal **34** through the signal conductor **36** of another transmission line. Thus, the signal conductor **36** is uniformly spaced from a ground conductor **38** to form a non-lossy type transmission line of uniform characteristic impedance Z_o, equal to the characteristic impedance of the lossy line **26, 28, 30.** A movable contact **40** slides along the attenuation resistance forming the signal conductors **26** of the lossy transmission line to change the attenuator setting, and is connected to an output terminal **42.** The continuously variable resistance attenuator of FIG. **2** has the advantage over the prior art attenuator of FIG. **1** that the input impedance of such attenuator is constant regardless of changes in the setting of the movable contact **40** if a high impedance is connected to output terminal **42.** Thus, under such conditions the attenuator terminates the transmission line **36, 38** in its characteristic impedance at all attenuator settings. In addition, the lead inductance and stray capacitance of the attenuation element is a part of a transmission line so that they do not distort the signal traveling along such line. Therefore, the high frequency response of the attenuator is greatly increased.

The lossy transmission line of FIG. **2** may be made of any length by varying the size of the attenuation resistance of signal conduct **26,** to change the attenuation range. Thus, the size of the attenuation resistance **26** does not limit the high frequency response, so that it can be made large enough to avoid any mechanical problems and to enable more accurate adjustment of the movable contact. In addition, the output impedance of the attenuator seen at output terminal **42** is constant regardless of the setting of the movable contact **40** providing that the input end **34** of the transmission line **36** and **38** is terminated in its characteristic impedance Z_o. The constant output impedance at output terminal **42** is then equal to $Z_o/2$.

The embodiment of FIG. **2** has two problems. First, since the distance between the movable contact **40** and the input terminal **34** of the attenuator varies with changes in the setting of such movable contact, the transit time of an input signal through such attenuator also changes. Second, a long movable contact **40** must be employed when the attenuation resistance of the signal conductor **26** is of any appreciable length and the resulting increase in the lead inductance and capacitance to ground of such movable contact limits the high frequency response of the attenuator.

The first problem may be overcome and the second problem greatly reduced by employing the embodiment of FIG. **3.** In this embodiment, the lossy transmission line section is movable while the input contact and the output contact are both fixed. Since the embodiment of FIG. **3** is similar to that of FIG. **2,** the same reference symbols have been employed to designate like parts and only the differences will be described. Thus, the output contact **40** is fixed and engages the attenuation resistance of the signal conductor **26** of the movable lossy transmission line section while the non-lossy transmission line **36, 38** is connected to the input terminal through a transmission line "stretcher" including a signal conductor **44** and a ground conductor **46.** The signal conductor **44** and the ground conductor **46** of the "stretcher" are provided with fixed contacts **48** and **50,** respectively, for engagement with signal conductor **36** and ground conductor **38** which are moved in the direction of the double headed arrow **52.** Signal conductor **36** and ground conductor **38** may also be provided with sliding contacts **54** and **56,** respectively, for engagement with signal conductor **44** and ground conductor **46** of the stretcher to provide good electrical contact. Thus, it can be seen that a variable length transmission line section of uniform characteristic impedance is formed by signal conductors **44** and **36** and ground conductors **46** and **38,** whose length varies with the movement with the attenuator element **26.** Since the distance between the input terminal **34** and the output contact **40** remains constant regardless of changes in the setting of such contact on the attenuation resistance **26,** an input signal is always transmitted from input terminal **34** to output terminal **42** with the same constant transit time. In addition, since the output contact **40** is fixed, it can be made of an extremely small size, thereby reducing its series inductance and shunt capacitance to ground to a minimum and increasing the high frequency response of the attenuator.

As shown in FIGS. **4** and **5,** the attenuator of FIG. **3** may be provided as coatings of resistance material and conductive material on a rotor plate **58** and a stator plate **60** of insulating material, such as aluminum oxide ceramic. The rotor plate **58** is provided with a central aperture through which a control shaft **62** extends for rotation of such rotor plate relative to the fixed stator plate **60.** The rotor **58** has an arcuate resistance strip **64** coated thereon to provide the attenuation resistance of signal conductor **26** in FIG. **3.** An annular conductive layer **66** of low sheet resistance is coated on the rotor in the area surrounding its central opening and radially spaced inwardly from resistive coating **64.** This conductive layer **66** forms the ground conductors **28** and **38** of FIG. **3.** Five radially spaced resistance areas **68** are coated on the rotor plate **58** extending like spokes between coatings **66** and **64,** such resistance areas corresponding to shunt resistors **30** of FIG. **3.** The attenuation resistance **64** has a value of 50 ohms uniformly distributed along the length of such layer. The shunt resistors **68** are uniformly spaced along the attenuation resistance **64** and have substantially the same value of, for example, 250 ohms each when five shunt resistors are employed. A resistance area **70** equal to the 50 ohms characteristic impedance of the lossy transmission line and corresponding to the termination resistor **32** of FIG. **3,** is coated on the rotor member **58** extending radially between the end of layer **64** and **66.** The number of shunt resistors **30** of FIGS. **2** and **3** and resistive areas **68** of FIG. **4** can be increased if their resistance is also increased to provide the same characteristic impedance. For example with ten shunt resistors, the attenuation resistance per unit length R = 50/10 = 5 and the shunt resistance R_s, is given by [R_2] $R_s = (Z_o)^2/R = (50)^2/5 = 2{,}500/5 = 500$ ohms.

The conductive layer **66** is connected to a ground plane coating **72** on the back side of the stator through a conductive layer **74** on the inner surface of the central aperture of the stator member as shown in FIG. **5.** A spring contact member **76** is fixedly attached at one end to a conductive strip **78** on the stator member **60.** The spring contact **76** corresponds to output contact **40** of FIG. **3** and its free end engages the resistive layer **64** for sliding movement thereon during rotation of the rotor member **58.**

An arcuate conductive strip **80** is coated on the rotor plate **58** with one end overlapping the input end of the resistance layer **64.** This conductive strip **80** functions as the signal conductor **36** of FIG. **3,** while the grounded conductive layer **66** functions as the ground conductor **38** of the non-lossy transmission line. An arcuate spring member **82** corresponding to signal conductor **44** of FIG. **3** is fixedly attached at one end to a conductive strip **84** on the stator member **60.** Of course the conductive layer **66** provides the ground conductor **46** of FIG. **3** and in combination with the spring member **82** forms the "stretcher" transmission line section. The spring member **82** has the same radius of curvature as the conductive strip **80** and is positioned to overlap conductive area **80** with its free end in engagement therewith for sliding contact during rotation of the rotor member **58.** As shown in FIG. **5,** a contact pressure plate **86** of insulating material such as aluminum oxide ceramic or the acetal resin plastic sold under the trademark "DELRIN," is positioned on the opposite side of the spring member **82** and is provided with an arcuate notch **88** containing such spring member. The pressure plate **86** holds the spring member **82** in contact with the conductive area **80** during rotation of the rotor **58** as shown in FIG. **5.** It should be noted that the pressure plate **86** has been broken away from FIG. **4** for purposes of clarity, and the rotation of rotor **58** is limited to an angle of about 90° by suitable stops (not shown).

The ground plane coating **72** on the rotor **58** is connected to a similar ground plane **90** formed by a coating of conductive material on the stator through a plurality of spring contacts **92** as shown in FIG. **5.** The stator ground plane **90** is electrically connected to ground through a fixed connection **93.**

It will be obviously to those having ordinary skill in the art that many changes may be made in the above described preferred embodiment of the present invention without departing from the spirit of the invention. Thus, the input and output terminals can be reversed and a signal source connected to the input terminal **42** through a non-lossy transmission line (not shown) having a uniform characteristic impedance equal to one half the characteristic impedance of the lossy line **26, 28.** Therefore, the scope of the present invention should only be determined by the following claims.

I claim:

1. A variable resistance attenuator of wide frequency bandwidth comprising:

first transmission line means of substantially uniform characteristic impedance including a signal conductor and a ground conductor forming a lossy transmission line, said signal conductor being of resistance material to provide an attenuation resistance distributed substantially uniformly along the length of said signal conductor, and a plurality of separate shunt resistors of substantially the same resistance connected between said signal conductor and said ground conductor and spaced substantially uniformly along the length of said signal conductor;

first signal coupling means connected to one end of said signal conductor through a first connection;

second signal coupling means connected to said signal conductor through a second connection;

control means for moving said second connection along the attenuation resistance of said signal conductor to vary the attenuation setting; said control means moving the first transmission line means to change the attenuator setting of said second connection while maintaining the same electrical signal path length between said first connection and said second connection.

2. An attenuator in accordance with claim **1** in which the second connection includes a fixed contact engaging the attenuation resistance and the first connection includes another fixed contact coupled to said one end of said first line, said first transmission line means being moved relative to said fixed contacts to change the attentuator setting so that the distance between said fixed contacts remains the same for different attenuator settings.

3. An attenuator in accordance with claim **2** in which the first signal coupling means includes a second transmission line of substantially uniform characteristic impedance equal to that of said first transmission line means, and including a signal conductor and a ground conductor insulated from each other to provide a non-lossy second line and connected, respectively, to the signal conductor and the ground conductor of the first transmission line.

4. An attenuator in accordance with claim **3** in which the second transmission line is formed in two separate sections joined by said first connection, one of said sections being fixed in position and the other of said sections being attached to the first transmission line for movement therewith to change the length of said second line.

5. An attenuator in accordance with claim **4** in which said one section of said second line has its signal conductor forming the fixed contact of said first connection which is in engagement with the signal conductor of said other section of said second line.

6. An attenuator in accordance with claim **2** in which the first transmission line means is formed by a rotor member of insulating material with the signal conductor forming said attenuation resistance, the ground conductor, and said shunt resistors provided as layers on said rotor member, and in which the fixed contacts are provided on a stator member of insulating material and connected to separate conductive regions on said stator member so that rotation of said rotor member causes the second connection to move along the attenuation resistance of the signal conductor layer.

7. An attenuator in accordance with claim **6** in which the first signal coupling means includes a second transmission line of non-lossy type having a substantially uniform characteristic impedance equal to that of the first transmission line means and formed of two separate sections including one section provided on the stator member and another section provided on the rotor member, said one section having a signal conductor forming the fixed contact of said first connection which engages the signal conductor of the other section.

8. An attenuator in accordance with claim **7** in which the signal conductor of said other section is provided by a conductive layer of said rotor connected to said one end of the first transmission line means for movement therewith on the rotor member.

9. An attenuator in accordance with claim **6** in which the rotor member is an annular plate mounted in a hole in another plate forming the stator member, and the shunt resistor layers extend radially outward from the ground conductor layer to the signal conductor layer which are coated on the same side of said rotor plate.

10. An attenuator in accordance with claim **7** which also includes a termination resistor equal to said characteristic impedance provided as a layer on the stator plate between the other end of the signal conductor and the ground conductor.

11. A variable resistance attenuator of wide frequency bandwidth comprising:

first transmission line means of substantially uniform characteristic impedance including signal conductor means and ground conductor means forming a lossy transmission line, said signal conductor means being of resistance material to provide an attenuation resistance distributed along a length of said signal conductor means and separate shunt conductance means connected between said signal conductor means and said ground conductor means and distributed along the length of said signal conductor means in proportion to said attenuation resistance;

first signal coupling means connected to one end of said signal conductor means through first connection means;

second signal coupling means connected to said signal conductor means through second connection means;

control means for moving said second connection means along said attenuation resistance of said signal conductor means to vary the attenuation setting, said control means moving said first transmission line means to change the attenuator setting of said second connection means while maintaining the same electrical signal path between said first connection means and said second connection means.

12. A variable resistance attenuator according to claim **11** wherein said separate shunt conductance means comprises a plurality of separate shunt resistance means.

13. A variable resistance attenuator of wide frequency bandwidth comprising:

first transmission line means of substantially uniform characteristic impedance including first signal conductor means and first ground conductor means defining a lossy transmission line, said signal conductor means being of resistance material to provide an attenuation resistance distributed along a length of said signal conductor means and separate shunt conductance means connected between said signal conductor means and said ground conductor means and distributed along the length of said signal conductor means in proportion to said attenuation resistance;

second transmission line means of substantially uniform characteristic impedance equal to that of said first transmission line means and including second signal conductor means and second ground conductor means defining a non-lossy transmission line; first signal coupling means including first connection means connecting said first signal coupling means to said first signal conductor means;

second signal coupling means including second connection means connecting said second signal coupling means to said second signal conductor means; and

control means for moving said first and second transmission line means relative to one another to change the attenuator setting of said first connection means while maintaining the same electrical signal path length between said first and second connection means.

14. A variable resistance attenuator according to claim **13** wherein said second signal coupling means defines third transmission line means including third signal conductor means connected to said first signal conductor means and third ground conductor means connected to said first ground conductor means defining another non-lossy transmission line.

15. A variable resistance attenuator according to claim **14** wherein said separate shunt conductance means comprises a plurality of separate shunt resistance means.

16. A variable resistance attenuator, comprising:

transmission line means of substantially uniform characteristic impedance including signal conductor and ground conductor means disposed on a support member and forming a lossy transmission line, said signal conductor means having resistance film material to provide an attenuation resistance distributed along a length of said signal conductor means and defining series resistance means and including shunt resistance means extending away from said series resistance means to provide electrical connection to said ground conductor means;

means coupled between said transmission line means and an input connector device for electrically connecting said transmission lines means and said input connector device together;

means coupled between said transmission line means and an output connector device for electrically connecting said transmission line means and said output connector device together; and

means for moving both said means and said support member relative to one another to change the attenuation value of the attenuator while maintaining the same electrical path length between both said connector devices.

* * * * *