March 16, 1954 R. WALLAUSCHEK 2,672,591

ULTRAHIGH-FREQUENCY ATTENUATOR WITH COAXIAL LINE INPUT AND OUTPUT

Filed Nov. 10, 1951

3 Sheets-Sheet 1

Fig. 1

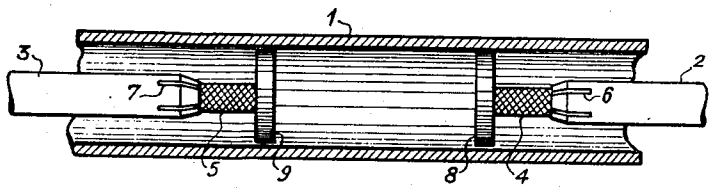


Fig. 2

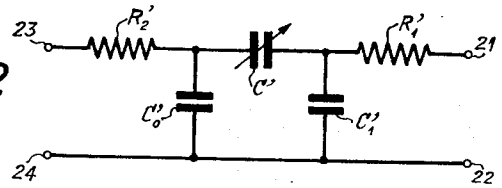


Fig. 3

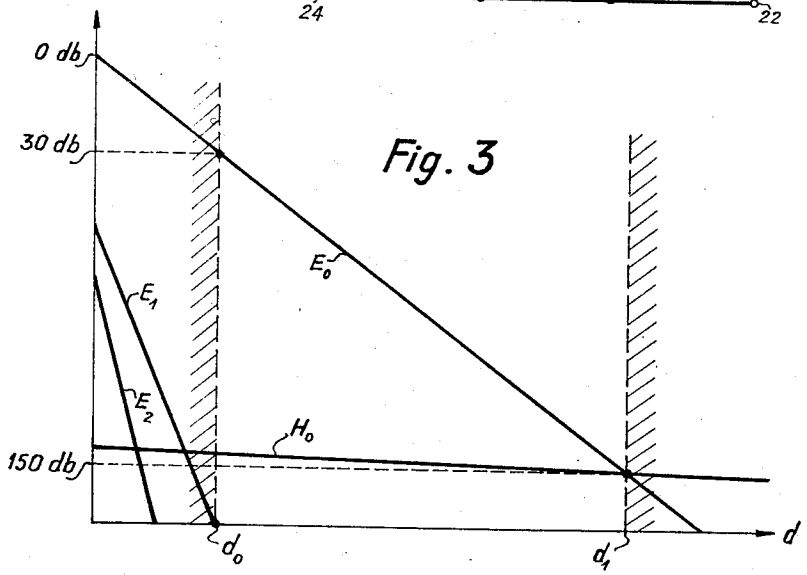
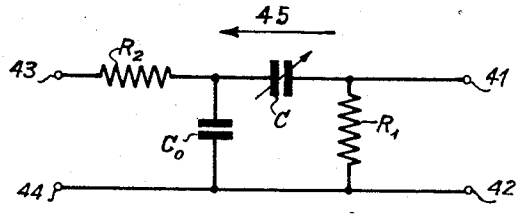


Fig. 4



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Fig. 5

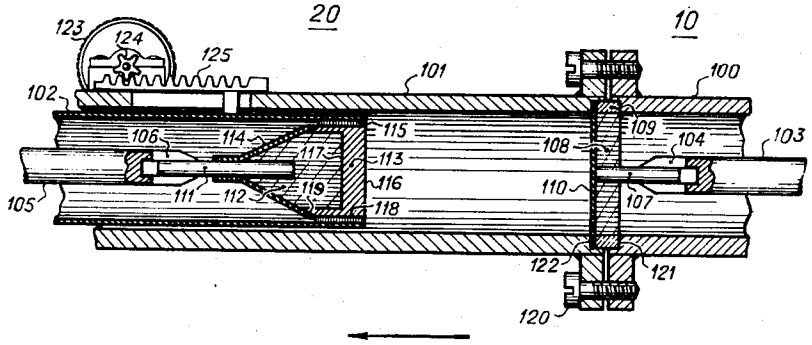
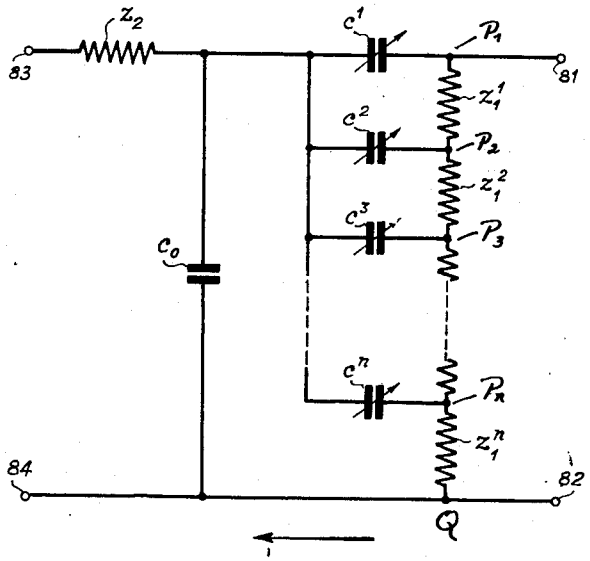


Fig. 8



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Fig. 6

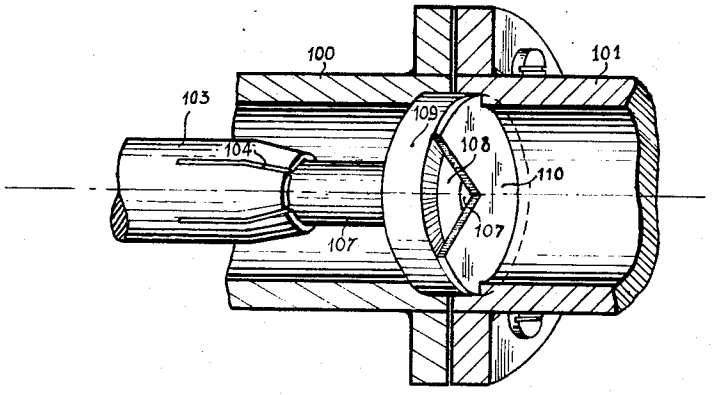
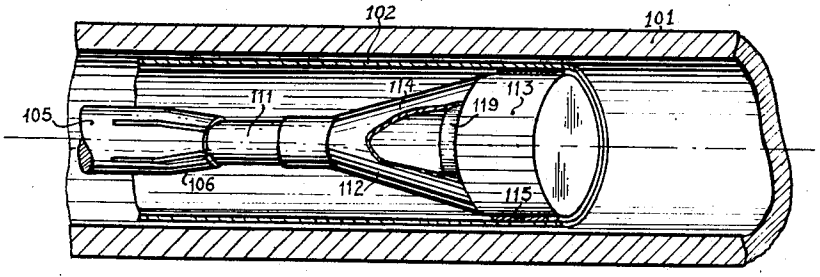


Fig. 7



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UNITED STATES PATENT OFFICE

2,672,591

ULTRAHIGH-FREQUENCY ATTENUATOR WITH COAXIAL LINE INPUT AND OUTPUT

Richard Wallauschek, Chromepet, Madras, India

Application November 10, 1951, Serial No. 255,861

Claims priority, application France November 18, 1950

4 Claims. (Cl. 333—81)

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My invention relates to a non-selective attenuator for ultra-high frequencies, matched on both sides with coaxial lines, and more specifically to an attenuator consisting of a length of a cylindrical wave guide of circular cross-section, working according to one of the type E modes, also called "TM" modes, i. e., "transverse magnetic," at frequencies lower than the cut-off frequency of travelling wave propagation.

Wave-guide attenuators of the prior art working at frequencies lower than the said cut-off frequency are known to belong to two main types.

Those of the first type utilize guides energized in an H (or "TM") mode (see for instance "Technique of Microwave Measurements" by Montgomery, Massachusetts Institute of Technology, 1947, page 685), more exactly in the H_0 mode. This mode being the least attenuated for a given length of guide, the energy contained in all the other modes rapidly becomes negligible, at least beyond a certain minimum length, compared with the energy transmitted in the H_0 mode. The attenuation may then be calculated as a function of distance according to an exponential law. These attenuators are in the shape of a guide having a sufficiently small cross-section, with which the input and output lines are coupled by suitable small loops adapted to energize especially the H_0 mode. The distance between the two loops is variable and allows adjustment of the attenuation. Attenuators of this type are electrically equivalent to the assembly of a transformer, the primary and secondary windings of which are constituted by the inductances of the two loops and of resistances in series with said inductances representing the loss resistances of the loops. The coupling between these primary and secondary windings varies as a function of the distance between the loops. These attenuators are frequency-selective owing to the properties of the loops, which depend on frequency.

Attenuators of the second type utilize guides energized in an E mode. As will be set forth in detail later on, these attenuators behave like capacitive voltage dividers, but, though superior to the above-described as regards non-selectivity, they offer certain drawbacks. The value of maximum attenuation attainable is limited by the existence of an H_0 mode, liable to be excited owing to inevitable constructional asymmetries and which, though at a much lower energy level than the predominating E_0 mode, benefits by a relative attenuation lower than that of the said E_0 mode and finally predominates over the latter beyond a certain length of guide. The value of minimum

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attenuation is fairly high since the full voltage of the input wave is not applied to the capacitive voltage divider. Finally, the matching of the attenuator with the impedances of its input and output lines is generally not satisfactory, which is particularly troublesome on the output side of the attenuator.

One object of my invention is to build an attenuator of the wave-guide type, working below the cut-off frequency of travelling wave propagation in an E mode and equivalent to a capacitive voltage divider combined with a resistance in shunt across its input and ensuring the necessary dissipation of energy and with a further resistance in series with its output, the latter determining the output impedance of the attenuator.

Another object of my invention is to obtain an attenuator in which the full voltage of the input wave is applied to the capacitive voltage divider.

Another object of my invention is to build an attenuator the output impedance of which very exactly matches the impedance of the coaxial output line.

Other objects and advantages of my attenuator will appear from the detailed description which will now be made, with reference to the appended drawings, wherein:

Figure 1 represents an attenuator of the prior art for ultra-high frequencies using a wave-guide energized in an E mode;

Figure 2 shows the electrical diagram equivalent to the attenuator of Figure 1;

Figure 3 shows the attenuation curve as a function of the length of guide, for the attenuator of Figure 1;

Figure 4 shows the electrical diagram of a high-frequency capacitive voltage divider using lumped elements.

Figure 5 shows an axial section of my attenuator;

Figures 6 and 7 respectively show, in perspective, the energizing portion and the receiving portion of my attenuator;

Figure 8 shows the electrical diagram equivalent to the attenuator of Figure 5.

Referring to Figure 1 which represents an attenuator of the prior art, excited in an E mode, 1 represents a guide with a circular cross-section, and 2 and 3 the inner conductors of the input and output coaxial lines, of which the wall 1 of the guide constitutes the outer conductor. At the ends of each one of the conductors 2 and 3 are respectively mounted series resistances 4 and 5 secured to said conductors by means of resilient clamps 6 and 7.

Each one of these resistances carries a metal disc (8 and 9 respectively), mounted perpendicularly to the axis of the tube 1 and exactly centered within the latter, with no direct contact and forming therewith a sufficiently large shunt capacity.

The equivalent diagram of the attenuator of Figure 1 is represented on Figure 2, wherein 21 and 22 are the input terminals and 23 and 24 the output terminals. The capacities C'_1 and C'_0, existing respectively between the discs 8 and 9 and the tube 1 are assumed to be sufficiently large so that their reactances may be neglected when compared with the values R'_1 and R'_2 of the resistances 4 and 5.

The input impedance of the attenuator is thus practically determined by R'_1 and it may be matched with the characteristic impedance of the coaxial input line. Similarly, the output impedance of the attenuator is practically determined by R'_2 and it may be matched with the characteristic impedance of the coaxial output line. The capacity C' is the capacity of the surfaces facing the discs 8 and 9 and it varies as a function of the distance between said surfaces.

The attenuation is practically independent of frequency, at least for frequencies sufficiently remote from the cut-off frequency of the guide and for not too small distances between the two discs. The attenuator is electrically symmetrical and may be used, in principle, in the two directions, that is 23—24 may be used as input terminals and 21—22 as output terminals.

Figure 3 shows, as a function of distance d between the discs 8 and 9 the relative attenuations of the E_0 mode (which predominates over the higher modes E_1 and E_2 also excited by the disc 8), and of the H_0 mode excited at a much lower level by the inevitable constructional asymmetries.

Between the distance d_0, beyond which the higher modes E_1 and E_2 become negligible and the distance d_1 beyond which the H_0 mode, which has a lower attenuation than the E_0 mode becomes predominant with respect to the latter, the attenuation can be calculated according to an exponential law as a function of distance. In general, such attenuators operate correctly between 30 and 150 db, approximately.

A drawback of these attenuators consists, as already stated, on the one hand in the existence of an upper limit of the possible attenuation, on the other hand in the relatively high value of their minimum attenuation (30 db), and finally in the fact that the matching with the impedances of the input and output lines is not sufficiently ensured by the series resistances R'_1 and R'_2, which is particularly troublesome at the output of the attenuator.

It will be further noted that, due to the presence of the series resistance R'_1, the whole input voltage is not applied to the terminals of the voltage divider consisting of the capacities C' and C'_0; hence an additional cause for the relatively high value of the minimum attenuation.

Figure 4 shows the diagram of an attenuator consisting of a capacitive voltage divider of a conventional type, for attenuating high frequency voltages. On Figure 4, 41 and 42 are the input terminals and 43 and 44 the output terminals. C_0 is a fixed capacity and C an adjustable capacity, the assembly of which forms the voltage divider. R_1 is a resistance dissipating the energy delivered by the high frequency energy source and R_2 is a suitably selected resistance

connected in series at the output of the attenuator and determining its output impedance. The attenuator, being a four-terminal non-symmetrical network can work correctly only in one direction, which is that indicated by the arrow 45.

The chief advantage of this type of attenuator resides in the fact that its attenuation does not depend on frequency to the extent to which the assumption of its equivalence to lumped elements (capacities and resistances) remains valid. If W_1 is the power available at the output from a generator connected with the terminals 41 and 42, and matched with R_1, the voltage at the input to the attenuator is:

$$V_1=\sqrt{W_1R_1}$$

The voltage at the terminals of C_0, assuming C to be smaller than C_0 and ωC much smaller than $1/R_1$ is:

$$V'=V_1\frac{C}{C+C_0}\approx V_1\frac{C}{C_0}=\frac{C}{C_0}\sqrt{R_1W_1}$$

The voltage at the output terminals 43—44 for a load matched to R_2 and assuming ωC_0 to be larger than $1/R_2$ is

$$V_2=\frac{V'}{2}$$

As a result, the ratio between the output power W_2 and the input power W_1 is expressed by:

$$\frac{W_2}{W_1}=\frac{V_2^2}{R_2W_1}=\frac{1}{4}\frac{R_1}{R_2}\left[\frac{C}{C_0}\right]^2 \qquad (1)$$

which shows that

$$\frac{W_2}{W_1}$$

does not depend on frequency.

The main object of the invention is to build an attenuator for ultra-high frequencies whose operation is more closely represented by a diagram consisting of lumped elements than is the case for the attenuator of Figure 1 and the diagram of Figure 2.

Referring to Figure 5, it will be seen that the attenuator comprises an energization portion designated as a whole by the reference numeral 10 and mounted inside a conducting tube comprised of two juxtaposed parts 100—101 and which constitute the wall of the guide and a receiving portion designated as a whole by the reference numeral 20 and mounted inside a conducting tube 102 sliding inside the tube 101.

The energizing portion of the attenuator comprises the parts 107, 108, 109 and 110.

107 is a cylindrical metal rod connected by one of its ends to the inner conductor 103 of the input coaxial line, by a spring clamp 104, and which goes through the center of a circular insulating disc 108 arranged in the plane of a cross-section perpendicular to the axis of the guide. The other or "far" end of the rod 107 has, as a terminal plane, the farther face of the disc 108. The outer conductor of the input coaxial line is constituted by 100.

The disc 108 has about the same diameter as the guides 100 and 101 and is surrounded by a metal ring 109 which is wedged into two shoulders 121 and 122 provided in the terminal surfaces of the tubes 100 and 101 on the inner side of said tubes. When the two tubes are connected by means of the screws 120, the ring 109 is wedged in the grooves. 109 is thus in electrical contact with 100 and 101, while, in the plane

common to the end of the rod 107 and to the farther face of the disc 108 and of the ring 109, there has been applied, by metallization, a homogeneous electrically resistant layer 110 the thickness of which is small with respect to the depth of penetration of high frequency currents due to the skin effect. The far end of 107 is in electrical contact with 110.

The receiving portion for the attenuated wave comprises the parts 111, 112, 113, 114 and 115.

Part 113 is a metal body having circular symmetry and in the shape of a pot, having an outer bottom 116, an inner bottom 117 and a cylindrical wall 118 the edge of which is bevelled, 119.

Inside part 113 is secured a cylindro-conical insulating support 112, the cylindrical portion of which enters the pot 113 and the conical portion of which extends the bevelled surface 119. This part 112 comprises a central hole entered by and securing a cylindrical metal rod 111 connected by a spring clamp 106 to the inner conductor 105 of the output coaxial line. The rod 111, therefore, is not in direct metallic contact with the metal pot 113.

On the conical surface of the insulating support 112, extended by the bevelled surface of the pot 113 there is applied, by metallization, a homogeneous electrically resistant layer 114, having a thickness of the same order as that of layer 110, and which also covers a very short length of the rod 111 at the place where said rod issues from the insulating support.

The diameter of the pot 113 is slightly less than the inner diameter of the tube 102 and the receiving assembly is centered and secured inside a metallic tube 102 by means of a thin annular insulating layer 115 intermediate between 102 and 113. Thus the metal parts 102 and 113 are not in direct contact but offer a certain electrical capacity between them. 102 constitutes the outer conductor of the output coaxial line.

The energizing assembly 107, 108, 109, 110 may, for example, be obtained by sealing a glass disc between a central metal rod and a concentrical metal ring, by lapping the common plane surface, opposite to the output side of the rod, and by applying a resistant layer by cathodic evaporation. One could also use a ceramic disc, bored at its center with an axial hole, secure in this hole, by means of putty, a metal rod whose end would be flush with one face of the disc, metallize a thick layer over the cylindrical portion of the disc to form a deposit playing the part of the ring and metallize a thin layer on the face of the disc which is flush with the end of the metal rod.

Similar embodiments may be used for the receiving assembly. The insulating layer 115 may be obtained by introducing between 102 and 113 a cement capable of drying in air or a plastic blue capable of being polymerized by heat.

The attenuator behaves electrically at its working frequencies like a guide length working below the cut-off frequency of travelling waves. The corresponding guide length then consists of the portion of the tube 101 comprised between the energizing and receiving portions. Due to the configuration of the electromagnetic field in the vicinity of the layer 110 the guide is almost exclusively energized in the E modes.

To adjust attenuation between the input and output of the attenuator, the tube 102 may be moved inside the tube 101 by means of a knurled knob 123, a pinion 124, and a rack 125 (or by any equivalent control system).

There is no drawback to having the tube 102 slide within the tube 101 with a fairly large clearance, as it is well known that in a guide energized at a frequency lower than the cut-off frequency of E modes, there is practically no current in the guide's metal wall. The quality of the contact between the tubes 101 and 102 practically plays no part in the value of the attenuation obtained.

The equivalent diagram of the attenuator of the invention is represented on Figure 8, wherein:

81—82 are the input terminals of the attenuator and 83—84 its output terminals.

The layer 110 of the energizing device may be represented by a number n of elementary resistances Z_1^1 to Z_1^n in series, the sum of which must be taken equal to Z_1, the characteristic impedance of the coaxial input line, each elementary resistance Z_1^1 to Z_1^n representing the resistance of an annular zone of the layer 110.

The capacity between the energizing surface of layer 110 and the receiving surface may be represented by a number n of elementary capacities C_i respectively corresponding to the various resistances Z_1^1 to Z_1^n, i being any integer number from 1 to n, the said elementary capacities each having one terminal connected to the junction point of two successive resistances, the other terminals being connected to one another. The capacity C_1, for instance, has one of its terminals connected with the junction point of resistances Z_1^1 and Z_1^2.

The diagram of Figure 8 represents perfectly the distributed nature of the coupling between the energizing system and the receiving surface.

The system of capacities C_1 to C_n forms, with the capacity C_0 between 102 and 103, a voltage divider. If the capacities C_1 to C_n are sufficiently small for their reactances to be negligible with respect to the resistances Z_1^1 to Z_1^n, which may be assumed to be true beyond a certain distance between the energizing and receiving surfaces, the rate of attenuation of the device practically no longer depends on frequency. In this case, the voltages between the connection points between resistances Z_1 depend only on the total applied voltage. If the elementary resistances Z_1 are assumed to be equal and the reactance of capacities C_1 to C_n very small relatively to nZ_1^1 the voltage between point Q and point P_1 of the set-up is:

$$U_{P_i}=\frac{n-i+1}{n}U_1$$

P_1 being the junction point between resistance Z_1^{i-1} and Q a point at a constant potential to which the last resistance Z_1^n is connected where U_1 is the input voltage, which, in the case of a generator with a power W_1, matched with R_1 is equal to $\sqrt{R_1 W_1}$.

The voltage transmitted to the terminals of C_0 through the capacity C_1 is:

$$U_i'=U_{P_i}\frac{C_i}{C_0+C_i}\approx\frac{n-i+1}{n}\frac{C_i}{C_0}U_1$$

Therefore, the sum of all the voltages superposed at the terminals of C_0 is

$$U'=\sum U_i'=U_1\frac{\sum_{i=1}^{n}\frac{n-i+1}{n}C_i}{C_0}$$

and the power W_2, available at the output terminals 83 and 84 of the attenuator is, assuming

the admittance of C_0 to be very large compared with

$$\frac{1}{R_2}$$

$$W_2=\frac{1}{4}\frac{U'^2}{R_2}=\frac{1}{4}\frac{R_1}{R_2}W_1\left[\frac{\sum_{i=1}^{n}\frac{n-i+1}{n}C_1}{C_0}\right]^2$$

Hence the value of the ratio

$$\frac{W_2}{W_1}$$

$$\frac{W_2}{W_1}=\frac{1}{4}\frac{R_1}{R_2}\left[\frac{\sum_{i=1}^{n}\frac{n-i+1}{n}C_1}{C_0}\right]^2 \qquad (2)$$

This expression is very similar to Formula 1 valid for the diagram of Figure 1. It shows the non-selectivity of the attenuator of the invention.

The restriction imposed for (2) to be valid, namely that the distance between the energizing and receiving surfaces be larger than a certain value, means, physically, that for too small distances, the contents in higher modes of the field excited in the guide depends on frequency. This fact does not constitute a drawback of the attentuator according to the present invention with respect to that of Figure 5 since in the latter, the existence of higher E modes already introduces a certain dependence between attenuation and frequency below a certain distance between the energizing and receiving surfaces, and since the difference in the contents of the field in higher modes practically introduces no additional drawback.

Experiments have shown that the novel attenuator makes it possible to obtain an attenuation which is practically independent of frequency above a certain minimum attenuation value, with a good matching of the impedances of the attenuator's output and of the output coaxial line and an input impedance sufficiently matched with that of the input coaxial line to ensure a satisfactory operation of the generator producing the energy to be attenuated. A comparison between the diagrams of Figures 4 and 8 further brings out the fact that the minimum attenuation is much lower than that of the previous attenuators since in the latter only a small fraction of the ultra-high frequency input voltage is applied to the voltage divider C'C'$_0$ (due to the presence of the series resistance R'$_1$) while, in the novel attenuator, the full ultra-high frequency voltage is applied to the voltage divider. In practice, due to this fact, the minimum attenuation may be lowered by 10 to 15 db with respect to that obtainable in prior systems.

I claim:

1. An attenuation device for ultra-high frequencies including a length of cylindrical wave guide of circular cross-section, working at a frequency below the cut-off frequency of propagation of travelling waves and adapted to be respectively connected at its input and at its output to input and to output coaxial lines and energized on its input side so as to develop an electromagnetic field of the type having a magnetic component transverse with respect to the axis of the said guide, comprising on its input side an energizing conducting surface set up inside and perpendicular to the axis of the guide and consisting of a homogeneous electrically resistant layer deposited on an insulating disc and connecting the central conductor of the said input coaxial line to the inner wall of the said guide which at the same time forms the outer conductor of the input coaxial line, the thickness and resistivity of said layer being such that its effective resistance measured between said inner and outer conductors be substantially equal to the characteristic impedance of said input coaxial line, and a receiving metal plate perpendicular to the axis of and set up inside a metal tube mounted inside the said guide and concentric therewith and electrically insulated from the said tube so as to form an electric capacity with the inner wall of the said tube the said plate being secured to a flared transition conductor consisting of a homogeneous electrically resistant layer deposited on an insulating support and connected at its larger end to the said plate and at its smaller end to the inner conductor of the said output coaxial line, the outer conductor of the said output line being formed by the said metal tube, and the effective resistance of said transition conductor measured between said receiving plate and said inner conductor of said output coaxial line being substantially equal to the characteristic impedance of said output coaxial line.

2. A device according to claim 1, wherein receiving plate, the conical or flared transition conductor and the central conductor of the coaxial output line are mounted inside the said metal tube which is slidingly movable inside the said guide, thereby to enable variations of the distance between the energizing and receiving surfaces and adjust the attenuation.

3. A device according to claim 1, wherein the energizing surface of the guide is made in the form of an insulating disc bored with an axial hole, through which passes a metal rod one end of which is flush with one face of the disc, and the other end of which is electrically connected to the central conductor of the input coaxial line, the said disc being surrounded with a metal ring fitting into a groove provided in the inner wall of the guide and coated, on the side flush with the rod, with a homogeneous electrically resistant layer in contact with the ring and with the said rod.

4. A device according to claim 1, wherein the receiving device is made of an insulating body comprising a flared or conical portion, mechanically secured, at its larger end, to a metal plate insulated from and forming an electric capacity with the inner wall of the said tube and, at its smaller end, to a metal rod arranged along the axis of the guide and electrically connected to the central conductor of the said output coaxial line, said flared or conical portion of the said insulating body serving as a support for a homogeneous electrically resistant layer in contact with said plate and said rod.

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