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J. V. HUPCEY

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ATTENUATING APPARATUS FOR HIGH-FREQUENCY ENERGY

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Fig. 1.

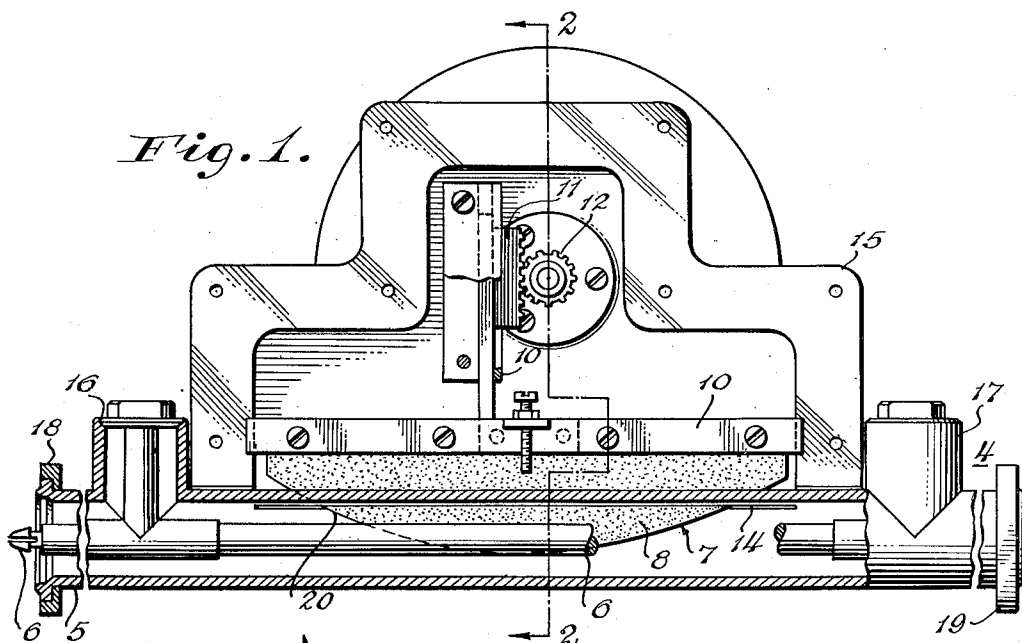


Fig. 2.

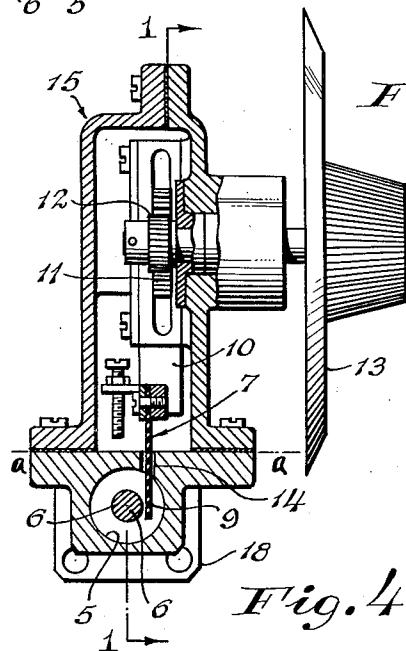


Fig. 4.

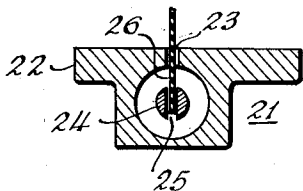


Fig. 3.

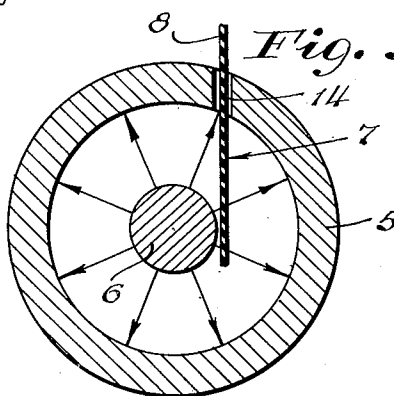
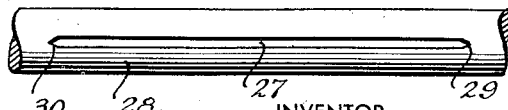


Fig. 5.



Fig. 6.



INVENTOR
JOSEPH V. HUPCEY
BY *Paul B. Hunter*
ATTORNEY

UNITED STATES PATENT OFFICE

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ATTENUATING APPARATUS FOR HIGH-FREQUENCY ENERGY

Joseph V. Hupcey, West Hempstead, N. Y., assignor to The Sperry Corporation, a corporation of Delaware

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8 Claims. (Cl. 178-44)

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The present invention relates to improvements in attenuating apparatus for ultra-high-frequency energy.

Ultra-high-frequency energy (that is, energy of wavelengths of one meter or shorter) is generally conducted by means of a hollow conductor of either the coaxial line or wave guide type of construction. For measuring and testing purposes, there is a need for simple apparatus that can be interposed along the hollow conductor to attenuate the energy in the conductor (that is, to reduce its energy level) by adjustable and known amounts. One known kind of apparatus makes use of a wave guide and a rounded card of resistive material inserted to an adjustable degree into the wave guide, in the portion of the electromagnetic field within the guide having the greatest voltage gradient.

It would be desirable to have similar simple attenuating apparatus for coaxial lines. In a coaxial line, operating in the conventional transverse electromagnetic (TEM) mode, the electric field is radial with respect to the inner conductor. However, radial insertion of a resistance card with a rounded edge permits only a small area of the resistance card to be put in the high intensity portion of the field (which is close to the inner conductor) even at maximum insertion, because the amount of insertion is limited by the presence of the inner conductor. Therefore, even at maximum insertion, there is a very limited amount of attenuation.

Accordingly, it is an object of the present invention to provide simple attenuating apparatus for high frequency energy in coaxial lines that overcomes the above defects and effects comparatively high amounts of attenuation.

Another object is to provide simple attenuating apparatus for high frequency energy in coaxial lines that minimizes energy reflections, while effecting comparatively high amounts of attenuation.

Yet another object is to provide simple variable attenuating apparatus for high frequency energy in coaxial lines that minimizes variation in reflected energy with variation in attenuation, while permitting a comparatively large maximum value of attenuation.

A further object is to provide simple attenuating apparatus for high frequency energy in transmission lines having inner and outer conductors that provide minimum variation of reflected energy with variation in frequency of the applied energy, while permitting comparatively large amounts of attenuation, and which is useful over a wide range of frequencies.

A further object is to provide variable coaxial line attenuating apparatus that provides a substantially linear relation between insertion of attenuating material into the coaxial line and amount of attenuation effected by the attenuating material.

The invention in another of its aspects relates to novel features of the instrumentalities described herein for achieving the principal objects of the invention and to novel principles employed in those instrumentalities, whether or not these features and principles are used for the said principal objects or in the said field.

A further object of the invention is to provide improved apparatus and instrumentalities embodying novel features and principles, adapted for use in realizing the above objects and also adapted for use in other fields.

These and other objects are achieved by the provision of attenuating apparatus that comprises a section of a coaxial transmission line and means for inserting a card of resistive material into and through the high intensity field close to the inner conductor. In one form of the invention, there is provided a section of coaxial line and a resistance card, with a rounded edge, inserted substantially tangentially to the inner conductor. In another form of the invention, there is provided a section of coaxial line with an inner conductor having a slot therein and a resistance card with a rounded edge, passing through the slot. It is thus made possible to pass a substantial amount of the resistive material into and through the high intensity part of the field, thereby securing a wide range of attenuation. At the same time the construction of the present invention minimizes energy reflection; minimizes variations in the amount of energy reflection with variation of amount of attenuation; minimizes variation of amount of energy reflection with variation of the frequency of the energy; and provides an approximate linear relation between amount of insertion of the resistance into the transmission line and decibels of attenuation produced.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawings wherein:

Fig. 1 is an elevation view, with some parts in cross-section, of one form of the invention;

Fig. 2 is an elevation view, partly in cross-section, taken along line 2-2 of Fig. 1.

Fig. 3 is a view in cross-section, to an enlarged scale, of the coaxial line of Fig. 1, showing the electric field lines in the conventional transverse electromagnetic (TEM) mode of operation and

the relation of the resistance card to both the field lines and the inner conductor;

Fig. 4 is a fragmentary elevation view in cross-section of another embodiment showing a modification of the apparatus below line *a-a* of Fig. 2;

Fig. 5 is a fragmentary plan view of the inner conductor of the apparatus of Fig. 4, showing the rectangular configuration of the slot in the inner conductor; and

Fig. 6 is a similar view showing a modification of the configuration of the slot of Fig. 5.

Referring to Figs. 1, 2 and 3, the apparatus embodying the present invention includes a section of coaxial line 4 comprising an outer conductor 5 and an inner conductor 6. A resistance card 7 formed of attenuating material upon a non-conductive carrier, such as provided by a resistive coating 8 upon a flat laminated Bakelite base or carrier 9, is carried on a guide member 10 connected to a rack 11, and passes through an axial slot 14 in outer conductor 5. The rack 11 engages a pinion 12 that is operable by a knob 13 to adjust the amount of insertion of the resistance card 7 through slot 14. The path of the insertion is along a non-diametric chord that is displaced a small distance, such as of the order of .005 inch, from the inner conductor 5, as shown in Figs. 2 and 3. It is thus substantially tangential to the inner conductor. A shielding enclosure 15 is placed about the rack 11, pinion 12, and slot 14 to prevent electromagnetic energy from radiating into space from coaxial line 4. Also included in the apparatus are conventional one-quarter-wavelength stub supports 16 and 17 for supporting inner conductor 6 coaxially of outer conductor 5, and suitable coupling means 18 and 19 for connecting the apparatus to other circuit elements.

When resistance card 7 is inserted into the coaxial line 4, the shunt conductance per unit length of the portion of line 4 containing the card 7 is increased by an amount dependent upon the degree of insertion. Because of this increase in shunt conductance, the attenuation effected by that section of the coaxial line 4 is increased, and desirable attenuating action is produced.

The edge 20 of the resistance card is rounded in order to minimize reflections of energy by the resistance card. Because of the rounded edge 20, the shunt conductance per unit length of the transmission line 4 is gradually increased along its axis from the shunt conductance of the line in advance of the resistance card to the point where the increase of shunt conductance effected by the resistance card 7 is maximum and then is gradually decreased from that maximum point to the shunt conductance of the line 4 beyond the resistance card 7. Thus, there is no abrupt change in unit shunt conductance along the axis of the line 4 and, therefore, energy reflection by the resistance card 7 is minimized.

The characteristic impedance of a coaxial line is a function of the shunt conductance per unit length of line, as can be seen from the formula

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

where

Z_0 = characteristic impedance of the line

R = series resistance per unit length

L = series inductance per unit length

G = shunt conductance per unit length

C = shunt capacitance per unit length

$\omega = 2\pi$ times the frequency (F) of operation.

In the section of line 4 in which the shunt conductance per unit length of line 4 is gradually increased, the characteristic impedance of infinitesimal lengths of the section is gradually decreased as the shunt conductance is gradually increased. Accordingly, it may be said that the section of resistance card 7 that produces a gradually increasing shunt conductance per unit length of line 4 along the axis of line 4, also produces a gradually decreasing characteristic impedance along the axis.

In the transverse electromagnetic (TEM) mode of propagation of energy along line 4, the intensity of the electric component of the electromagnetic field decreases with increase of radial distance from the inner conductor. As it can be seen in Fig. 1, which shows the apparatus in a position for a large amount of attenuation, a comparatively large area of the card 7 is close to the inner conductor 6 in that position. Being close to the inner conductor 6, this comparatively large area of resistance card is in the high intensity field, and, therefore, produces a large amount of attenuation.

The path of the insertion of the resistance card 7 may be substantially tangential to the inner conductor. In this form at maximum insertion, a large area of the resistance card would also be in the high intensity field close to the inner conductor. This would result, however, in physical contact between the resistance card 7 and inner conductor 6, and in an undesirable rubbing action between the two during adjustment of the card 7 by knob 13. It is advisable, therefore, to have the resistance card 7 as close as possible to inner conductor 6 without actual contact in order that it may be in high intensity field.

In actual use, a variable attenuator of the type shown in Figs. 1-3 was connected between a matched load and a source of super-high frequency energy, variable in wavelength from 5.0 to 7.2 cm. A standing wave detector was connected between the source and the variable attenuator, and power-measuring apparatus was connected to the matched load to measure the power delivered to the load. The inner diameter of the outer conductor of the coaxial line was .561 inch and the outer diameter of the inner conductor was .250 inch. The resistance card was formed of material having a resistance of 200 ohms per square, i. e., any square of the material has a resistance of 200 ohms, as measured from edge to edge, regardless of the dimensions of the square. The rounded edge was an arc of a circle of 4 inch radius. Standing waves between the source and the attenuator apparatus were measured for various degrees of insertion of the card and for various wavelengths over the wavelength band of 5.0 to 7.2 cms.

It was found that the average of the voltage standing wave ratios was less than 1.112 for wavelengths from 5.0 to 6.3 cms. and less than 1.25 for wavelengths 6.4 cm. to 7.2 cm. The maximum attenuation effected over the same band of frequencies varied only 2.5 decibels. It was also found that there was an approximately linear relationship between attenuation in decibels and degree of insertion of the resistance card 7 into the line 4.

It will be understood that the values just given represent only one set of operating conditions, and many other values and dimensions of the parts of the structure may be used. Thus, other values of resistance cards may be used. Generally, it may be stated that higher values of re-

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sistance produce smaller maximum amounts of attenuation, while causing lower standing wave ratios; and, conversely, lower values of resistance produce larger values of attenuation while causing higher standing wave ratios.

In the modification shown in Fig. 4, the attenuating card 26, similar to card 7, is inserted radially into the electric field. It will be understood that the structure shown in Fig. 4 is intended to replace that portion of Fig. 2 which is below line *a-a* thereof. The advantage of wide range of attenuation found in the embodiment of Figs. 1-3 is present here also.

In Fig. 4, coaxial line 21 comprises an outer conductor 22, having an axial slot 23 therein, and an inner conductor 24 having a rectangular axial slot 25 preferably diametrically therein, as shown in Fig. 5. The attenuating material, in the form of resistance card 26 having a rounded profile as in Figs. 1-3, is inserted through the slot 23 in the outer conductor 22 along a path passing through the slot 25 in the inner conductor 24. For small values of attenuation, card 26 is inserted only slightly into slot 23, and its lower edge remains out of slot 25. For higher values of attenuation, card 26 is inserted further through slot 23, even into slot 25. For maximum attenuation, card 26 extends substantially fully across a diameter of outer conductor 22.

As in Figs. 1-3, a comparatively large area of the resistance card 26 may thus be positioned in the high intensity portions of the field close to the inner conductor, at maximum insertion. Therefore, a comparatively large amount of attenuation is obtainable in this form of the invention, also. This variable attenuator was connected to the auxiliary apparatus described above in the tests of the embodiment of Figs. 1-3. The results showed that voltage standing wave ratios fluctuated between higher upper and lower limits than with the embodiments of Figs. 1-3, for the same frequency and attenuation ranges.

Referring to Fig. 6, there is shown a modification of the apparatus of Figs. 4 and 5. In this form, a slot 27 of substantially rectangular shape is formed in inner conductor 28, but its ends 29 and 30 are tapered axially. Because of the taper, there is a more gradual change in characteristic impedance between the coaxial line section before the slot and the line section containing the slot; and also between the latter section and the line section beyond the slot. This serves further to reduce standing wave ratios in the system.

I have therefore provided simple attenuating apparatus for high frequency energy in coaxial transmission lines that produces comparatively large maximum amounts of attenuation with only minimum amounts of energy reflection and with maximum band-width.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. High frequency apparatus comprising a transmission line having an inner conductor with an opening therein and an outer conductor with an opening therein, attenuating means, and means for adjustably inserting said attenuating means into said line through said opening in the

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outer conductor and along a path passing through said opening in said inner conductor.

2. Apparatus as in claim 1 wherein the opening in said inner conductor has a tapered portion at each end of the opening.

3. Apparatus for adjustably attenuating high frequency energy comprising a high frequency transmission line including an outer conductor and an inner conductor, said outer conductor having a longitudinal opening therein, a resistance card with a rounded edge and comprising a non-conductive base and a resistive coating on said base, and means for slidably adjusting said resistance card into said transmission line through said opening and in a plane substantially tangential to said inner conductor.

4. Apparatus for adjustably attenuating high frequency energy comprising a high frequency transmission line including an outer conductor with an opening therein and an inner conductor with an opening therein, a resistance card with a rounded edge and comprising a non-conductive base and a resistive coating on said base, and means for adjustably sliding said resistance card into the transmission line through the opening in said outer conductor and in a plane passing through both said opening in the outer conductor and said opening in the inner conductor.

5. High frequency apparatus comprising a transmission line having an inner and an outer conductor, a card-shaped resistance element, and means for inserting a portion of said resistance element into a longitudinal slot in said transmission line a distance transverse to the longitudinal axis of the transmission line which is greater than the distance between said inner and outer conductors, the longitudinal axis of said resistance element being coextensive with the longitudinal axis of said transmission line.

6. The apparatus of claim 5 wherein the portion of said card-shaped resistance element which is inserted into said transmission line has a rounded edge.

7. The apparatus of claim 5 wherein said resistance element is inserted into said transmission line along a plane which is substantially tangential to said inner conductor.

8. The apparatus of claim 5 wherein said longitudinal slot comprises aligned slots in said inner and outer conductors and said resistance element is inserted into said transmission line along a diametrical plane which passes through said slots.

JOSEPH V. HUPCEY.

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