April 17, 1951 T. M. FERRILL, JR 2,548,881

HIGH-FREQUENCY ATTENUATING APPARATUS

Filed Feb. 24, 1945 3 Sheets-Sheet 1

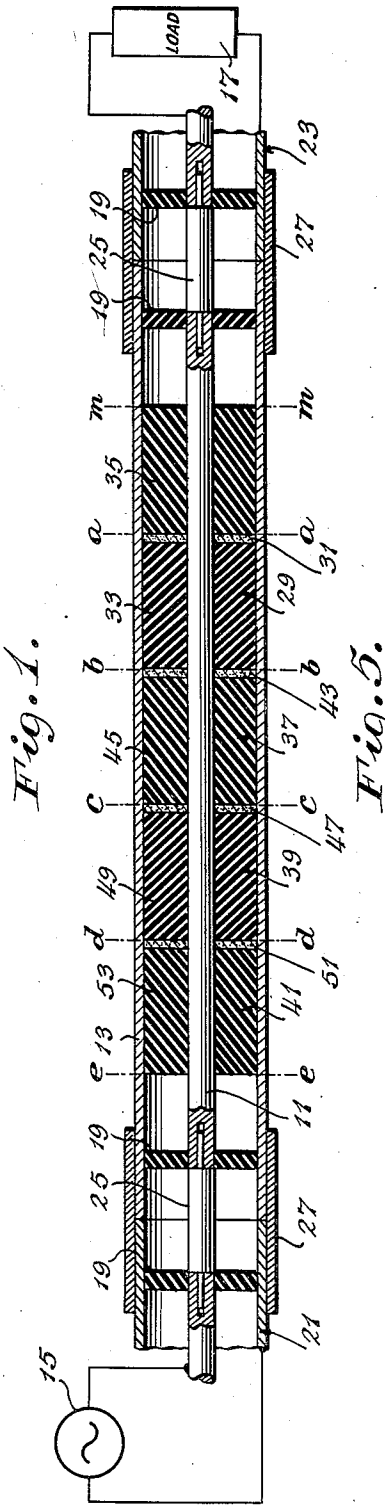


Fig. 1.

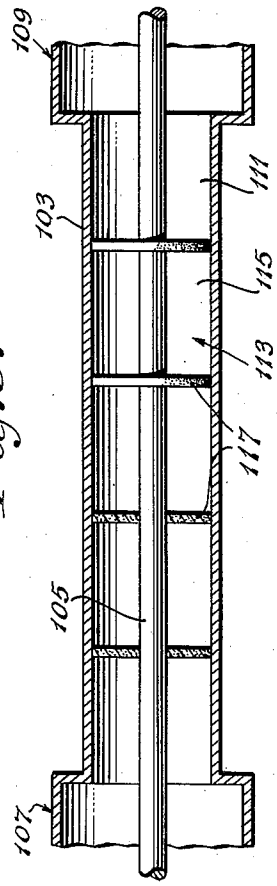


Fig. 5.

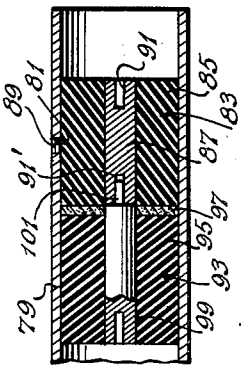


Fig. 4.

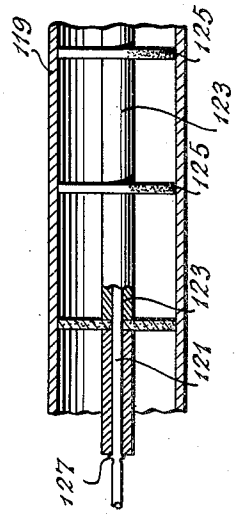


Fig. 6.

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HIGH-FREQUENCY ATTENUATING APPARATUS

Filed Feb. 24, 1945 3 Sheets-Sheet 2

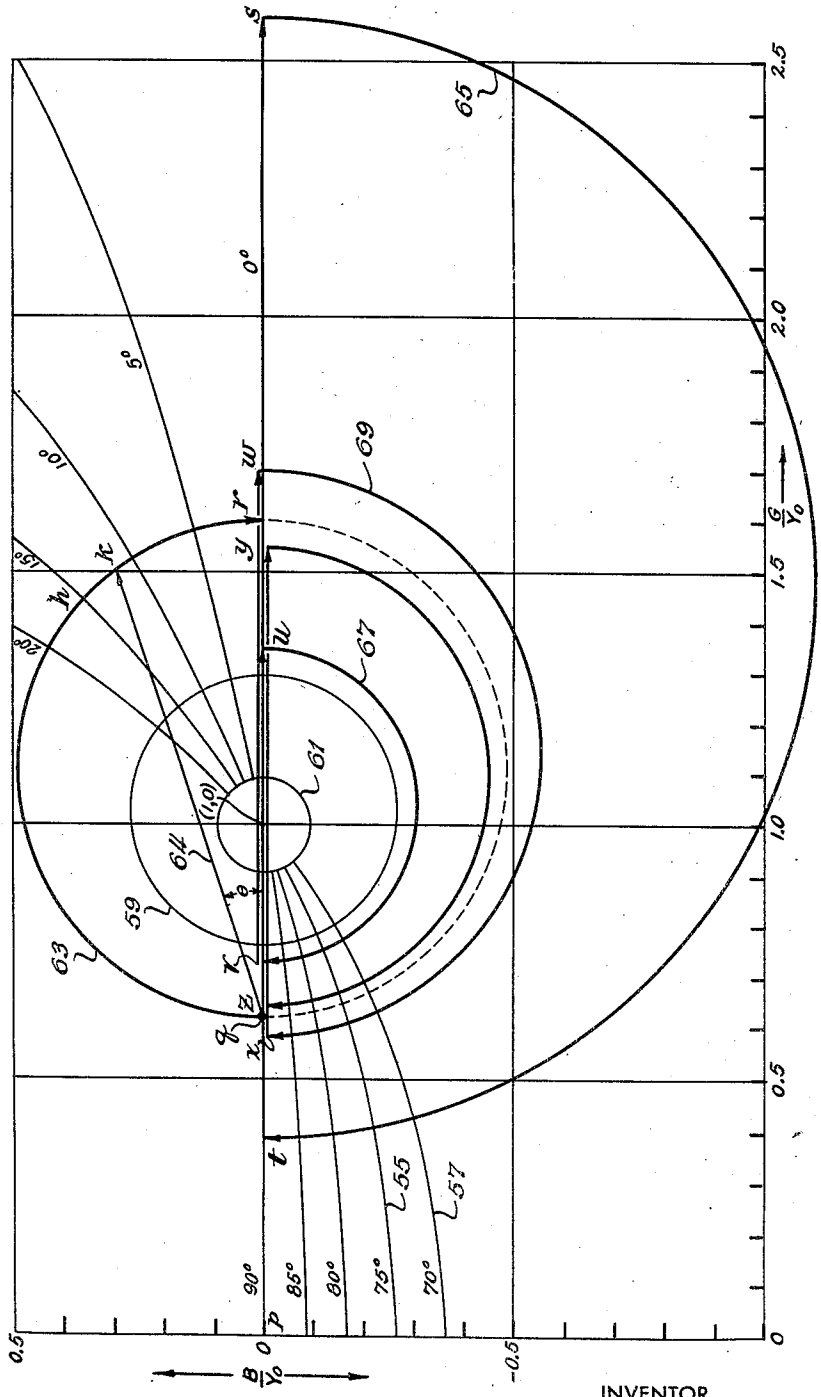


Fig. 2.

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HIGH-FREQUENCY ATTENUATING APPARATUS

Filed Feb. 24, 1945 3 Sheets-Sheet 3

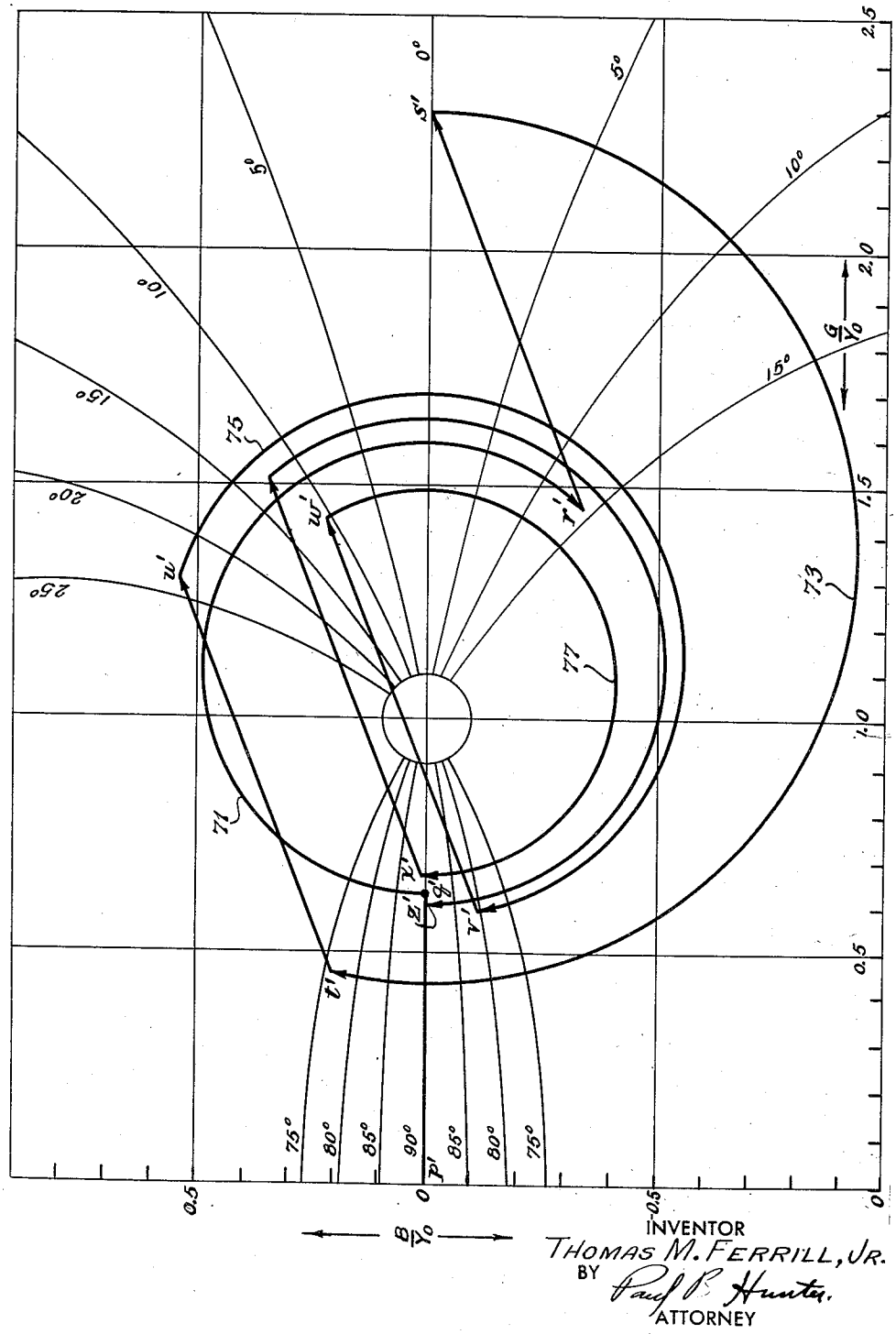


Fig. 3.

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Patented Apr. 17, 1951 2,548,881

UNITED STATES PATENT OFFICE

2,548,881

HIGH-FREQUENCY ATTENUATING APPARATUS

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Application February 24, 1945, Serial No. 579,559

14 Claims. (Cl. 178—44)

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The present invention relates to devices for attenuating high frequency electromagnetic energy, and especially to devices adapted for use in energy conducting systems such as concentric transmission lines or wave guides.

Attenuating devices of a type generally similar to that herein contained have been known heretofore and have been provided in a wide variety of forms. Typical of the prior devices is one consisting of one or more high loss dissipator elements arranged, with or without associated dielectric bodies, in a suitable energy conductor to attenuate, by a predetermined amount, the energy transmitted through the conductor from a so-called sending or source end to what is known as the receiving or load end.

For most efficient operation of many types of attenuating devices, special provision is made to properly match the impedance of said devices to that of the sending and/or receiving portions of the system coupled thereto in order to avoid the production of undesirable wave reflections and standing waves and the well-known harmful effects attendant thereto.

It is also desirable to provide attenuating devices which are completely symmetrical with respect to the impedance offered thereby relative to the characteristic impedance of the portions of the system coupled thereto, as viewed from either end of said device. This kind of symmetry is desirable because completely symmetrical attenuating devices may be coupled in either sense to a source and a load without effecting impedance mismatch.

Another feature to be desired in attenuating devices is adjustability, whereby the components of said devices may be altered, at will, to accommodate the requirements of a particular use. Furthermore, for the sake of economy and simplicity, it is desirable that a certain prescribed operating range of attenuation be made available in fixed, small-valued steps which may be introduced into or withdrawn from the device with a minimum of effort and disturbance of the existing impedance conditions.

As viewed in one of its broader aspects, a principal feature of this invention lies in the provision of attenuating devices wherein uniformly spaced dissipator elements are provided, each of said elements having a similar transformer section associated therewith to produce a symmetrical, multi-unit attenuator adapted to match the impedance of high frequency apparatus coupled to said devices.

Still another desirable feature lies in the provision of impedance transformer sections comprised of solid dielectric bodies to which dissipator elements may be attached, said bodies serving the purpose of providing additional mechanical support for said elements as well as for providing for the transformation of the characteristic impedance of the portion of the conductor containing the dielectric body to that of the air-dielectric portion of said conductor. Furthermore, if the dissipator element is not purely resistive, but instead, is appreciably reactive as well, the length of the solid dielectric bodies may be changed to compensate for this reactance.

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Still another feature of the present invention is to provide attenuating devices wherein similar air-filled transformer sections are associated with each of a series of attenuating elements, said air-filled transformer sections being so constituted with respect to the dimensions thereof that they may be used interchangeably with solid dielectric-filled transformer sections of equivalent electrical length.

In accordance with the present invention, there is provided an attenuating device which not only possesses the above specified desirable features, but which is further characterized by the fact that a certain, predetermined amount of attenuation is obtainable by the use of separable attenuating units consisting of identical dissipator elements and identical impedance transformer sections. Such units may, at will, be inserted into or withdrawn from the device to introduce or subtract predetermined, small-valued fractions of the total attenuation range; that is, to introduce or subtract predetermined small increments of attenuation as measured in decibels or similar units. If it is required to produce a unit producing an attenuation increment of a value different from the predetermined value adopted, the use of solid dielectric bodies may be partially or completely eliminated and the dimensions of the conductor, which forms part of the attenuating device, may be correspondingly altered to compensate for the change in impedance caused by the change in the amount of the solid dielectric used.

The improved attenuating device of the present invention stems largely from the discovery that, by extending the length of the conductor forming part of the device beyond the terminal dissipator elements therein, through a distance equal to the interval between a pair of adjacent dissipator elements, it is possible to construct a

multisection, completely symmetrical attenuator wherein there are utilized identical dissipator elements, while retaining desirable impedance matching properties. Thus, the necessity, common to all types of prior art attenuating devices, of selecting certain unequal attenuator elements to be used in constructing a device of desired characteristics and of correctly positioning said unequal elements relative to each other has here been completely eliminated. Instead, I can now standardize the single-valued dissipator element and transformer section employed, and thus prefabricate, by mass production methods, attenuating units of identical characteristics, any number of which may be used together to obtain substantially any desired amount of attenuation.

Accordingly, it is an object of the present invention to provide new and improved attenuating devices wherein special provision is made for matching the impedance of the attenuator to the impedance of the portions of the system coupled thereto.

It is another object of the present invention to provide attenuating devices wherein substantially equal increments of attenuation may be obtained by the addition of identical attenuating units in step-by-step fashion.

It is still another object of the present invention to provide attenuating devices which may be fabricated as a multisection, continuous impedance, symmetrical attenuator having broadband frequency characteristics.

Still another object of the present invention lies in the provision of attenuating devices which are mechanically rugged, and at the same time, are of relatively simplified construction and economical to produce by mass production methods.

A still further object of the present invention is to provide a symmetrical attenuating device which has desirable impedance matching properties and is suitable for yielding small fractions of attenuation.

The present 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 same 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.

Other objects and advantages will be apparent from the following detailed specification taken in connection with the accompanying drawing wherein the invention is embodied in concrete form.

In the drawing,

Fig. 1 is a longitudinal cross-sectional view of one form of attenuating device, in accordance with the present invention;

Figs. 2 and 3 are admittance diagrams useful in explaining the theory of operation of the device of Fig. 1; and Figs. 4, 5 and 6 are longitudinal cross-sectional views of modified forms of attenuating devices.

Referring now to the drawing, and particularly Fig. 1, there is disclosed a section of concentric or coaxial transmission line having an inner conductor 11 and an outer conductor 13 extending between a source of high frequency energy 15 and a high frequency load 17. The conductors 11, 13 are maintained in fixed concentric relation by insulating supports or spacers 19. The line section is adapted to be joined at either end to other lines, such as lines 21, 23, and for this purpose, the spacers 19 are so disposed that when the adjoining lines 21, 23 are placed in abutment with line section 11, 13, as shown, the spacers are separated by a distance electrically equivalent to one-quarter of the operating wavelength in free space, in order to substantially eliminate disturbing reflections due to discontinuities at the dielectric and conducting junctions. To avoid damaging the structure during handling, the inner conductor 11 is terminated slightly interiorly of the outer conductor 13 and a smooth joint between the inner conductor 11 and those of the lines 21, 23 is made by means of a joining member 25, as here shown. The abutting outer conductors are joined and connected by a snugly fitted outer sleeve 27 positioned so as to overlap the adjacent ends of the outer conductors.

To attenuate the high frequency electromagnetic energy conducted along the line 21 from source 15 toward line 11, 13, a plurality of identical admittance units, here shown as four in number, are provided in the line 11, 13. Typical of said units is admittance unit 29 which extends between lines *a*—*a* and *b*—*b* and consists of a relatively thin dissipator element 31 and an impedance transformer section, here shown as a solid dielectric body 33 of electrical length equal to one-quarter of the operating wavelength, to which element 31 may be permanently attached in any suitable manner. A suitable form for the element 31 has been found to comprise a relatively thin layer of resistive material, such as carbon or other semi-conducting material which may easily be adjoined to or deposited on the solid dielectric body 33. It is to be noted, however, that the present invention is not restricted to this form of dissipator, since many other forms may be used. A suitable form of solid dielectric body may be formed of the insulating material known as polystyrene, although here again any equivalent dielectric material may be utilized without departing from the spirit of the invention. Suitable values of the admittance of dissipator element 31 and the length of body 33 may be determined in a manner to be hereinafter described.

It may be shown that an attenuation of a constant predetermined amount substantially equal to 3.7 decibels is obtained when a single polystyrene body 33 of dielectric constant $\epsilon=2.56$ is used with a single dissipator element 31 characterized by a ratio of reactance to resistance equal to 0.4. Any desired number of composite admittance units similar to unit 29 may be added, in tandem, in the line 11, 13 to produce a corresponding integral multiple of 3.7 decibels attenuation. However, the form of attenuator thus produced is asymmetric, yielding impedance match between attenuator and line coupled thereto only when connected in one energy transmission direction or sense and yielding a gross mismatch when reversed in position in the same circuit.

To overcome the asymmetry referred to above, I add a primary impedance transformer section, which in the embodiment of Fig. 1 is a solid dielectric body 35, positioned in the line 11, 13 next adjacent the dissipator element 31 of the unit 29. Body 35 is entirely similar to body 33 distinguishing therefrom only by the fact that no dissipator element is fixedly attached thereto. Also, additional units, such as 37, 39 and 41 extend-

ing respectively between lines *b*—*b* and *c*—*c*, *c*—*c* and *d*—*d*, and *d*—*d* and *e*—*e* may be arranged in cascade, as shown, for a purpose to be hereinafter described in detail. Units **37**, **39** and **41** are like unit **29** and comprise dissipator elements **43**, **47** and **51**, and impedance transformer sections such as solid dielectric bodies **45**, **49** and **53**. All the dissipator elements employed are of mutually identical characteristics, and are preferably purely resistive, although dissipator elements having some reactance may also be used. All the impedance transformer sections are of mutually identical characteristics and these sections may be of any solid, liquid, or gaseous dielectric material suitable for use in high frequency operation.

Having thus described the basic structural aspects of one form of the present invention, it is proposed in the following analysis to describe the operation thereof in detail. For this purpose, a concrete illustrative example will be considered specifying a particular type of dissipator element which may be used with a particular type of impedance transforming section. It should, however, be clearly understood that the specification herein of particular types of dissipator and impedance transforming section is merely for the purpose of explanation, and that the scope of the invention should not be limited thereby, since other types of dissipator elements and transformer sections may be employed with equally desirable results.

In the following analysis, let it be assumed that the load **17** has an admittance Y_L, and is coupled to the air-filled transmission line **23** of admittance Y_a, and that Y_a is equal to Y_L. In general, the admittance Y_a of the line **23** may or may not be matched to the admittance Y_L of the load **17**, and if there is no match, e. g., if Y_a is different from Y_L, one is then confronted with a mismatch at the junction of line **23** and load **17**, which may or may not be crucial. In such a case, however, the attenuating device of line **11**, **13** is presented with a resultant or joint admittance Y_r whose value is determined by the values of Y_a and Y_L and it is to this resultant admittance Y_r that the attenuating device delivers energy from source **15**. In the particular instance of Y_a equal to Y_L (so that Y_a also equals Y_r) clearly, when the admittance Y_0 of the attenuating device is matched to the line **23**, it is also matched to the load **17**. In either event, however, whether Y_a is equal to or different from Y_L, the attenuating device may be matched to the admittance Y_r presented thereto, from without, and its construction and/or operation is entirely independent of the condition of match or of mismatch, experienced elsewhere in the system. Hence, the foregoing assumption that Y_a is equal to Y_L should not be construed as a limitation imposed on the present invention, but merely as a further simplification adopted purely to facilitate the analysis of the following example.

Consider, then, the case of an attenuating device having admittance transformer sections of polystyrene characterized by a dielectric constant, ϵ_0 of 2.56 such as obtains at an operating frequency of 3000 megacycles, corresponding to a free space wavelength λ_0 of 10 centimeters, and dissipator elements preliminarily assumed to be purely resistive. A similar case, but one wherein dissipator elements having generally reactive properties, will be considered next following the analysis of the purely resistive dissipator example.

The operation of the attenuating device described above may be more clearly understood through study of the admittance circle diagram shown in Fig. 2. Such circle diagrams are widely used for simple graphical analysis of transmission line behavior. Complete detailed descriptions of the nature and use of such diagrams may be found on pages 22 through 33 of the book "Microwave Transmission" of J. C. Slater, first edition, 1942, McGraw-Hill Book Company, New York, and on pages 689 through 693 of an article entitled "Graphical solution of voltage and current distribution and impedance of transmission lines" by R. C. Paine, in the Proceedings of the Institute of Radio Engineers, volume 32, November 1944. Since the use of the admittance circle diagram is so well established, the repetition here of a full description thereof is believed to be unnecessary.

The circle diagram may be employed, generally, for analyses of the change of impedance or admittance of a load produced by a transmission line section, with respect to the electrical length of the section and the ratio of the receiving end impedance or admittance to the characteristic impedance or admittance of the transmission line section. For the present purpose, however, it is convenient to consider the characteristics of the circuit elements in terms of admittance Y, susceptance B and conductance G rather than impedance, reactance and resistance, although precisely the same results may be obtained regardless of which set of elements is considered.

Thus, in Fig. 2, the axis of ordinates represents the susceptance B while the axis of abscissae represents the conductance G, both the susceptance and the conductance being normalized with respect to the characteristic admittance Y_0 of the transmission line whose characteristics are to be investigated. Superimposed on the rectangular coordinate graph there is a first series of circles having centers on the axis of ordinates, each of these circles intersecting the axis of abscissae at the point (1, 0) and representing constant electrical distance, βl, in degrees, along the transmission line. Portions of two such constant βl circles are shown at **55**, **57**. A second series of circles, having centers on the axis of abscissae, are provided mutually orthogonal with said first series of circles and surrounding the point (1, 0) on the axis of abscissae. Each of said second series of circles intersects the axis of abscissae at mutually reciprocal points. Two such circles are shown at **59** and **61** by way of illustration.

A simple illustrative example will serve to demonstrate the properties of the latter series of circles in relation to the rectangular coordinate system. If the point (1, 0) is taken to represent the characteristic admittance of any transmission line and if the line is terminated in an admittance relative to said characteristic admittance corresponding to the arbitrary point *h*, different from the said characteristic admittance of the line, then, as the length of the line is varied, the sending end admittance assumes values according to points on the circle **63** on which said point *h* lies. For each 180 electrical degrees of line added, one complete traverse around circle **63** is made.

Then, for an attenuating device of the character hereinabove specified, the ratio,

$$\frac{Y_a}{Y_0}$$

of admittance of the air-filled line to the admittance of the solid dielectric-filled line is equal to

$$\frac{\sqrt{\epsilon_a}}{\sqrt{\epsilon_0}}=\frac{1}{\sqrt{\epsilon_0}}=\frac{1}{\sqrt{2.56}}=0.625$$

which ϵ_a is the dielectric constant of air (substantially equal to unity). The ratio

$$\frac{Y_a}{Y_0}=0.625$$

is then taken as determinative of the length of a vector *pq*, extending between the points (0, 0) and (0.625, 0) of the rectangular coordinate system, and representing the conductance of load **17** (equal to the characteristic admittance of air-filled line **23**) in relation to the characteristic admittance Y_0 of the solid dielectric filled section of line **11**, **13**. It is this conductance that is "seen" looking toward the load **17** from the line *m*—*m* of Fig. 1.

To determine the value of the admittance of the dissipator to be employed and the electrical length of the dielectric body or admittance transformer section associated therewith, one needs only to select from the said second series of circles the one which passes through the point on the axis of the abscissae corresponding to

$$\left(\frac{Y_a}{Y_0}, 0\right) \text{ or } (0.625, 0)$$

here labelled *q* and its reciprocal

$$\left(\frac{Y_0}{Y_a}\right) \text{ or } (1.6, 0)$$

here labelled *r*. For the assumed case, this circle is readily observed to be circle **63** the upper half of which is shown as a solid line. A vector drawn from the point *q* as origin and terminating on the circle **63** then has a magnitude equal to the desired value of the dissipator admittance of purely conductive character. The impedance transforming section is then chosen as 90 electrical degrees in length.

In the general case, e. g., when the dissipator is characterized by a complex admittance, the vector corresponding to the dissipator admittance is drawn from the origin *q*, in a sense determined by the ratio of susceptance to conductance

$$\frac{B}{G}$$

defining a certain admittance angle, θ, of the dissipator. Such a vector is shown at **64** making an angle θ with the axis of abscissae defined by

$$\theta=\tan^{-1}\frac{B}{G}$$

and terminating on circle **63** in point *k*. The length of the vector *qk* is determinative of the desired value of complex dissipator admittance. The length of transformer section, expressed in equivalent electrical degrees, required (1) to compensate for the susceptive component of said dissipator admittance and (2) to additionally effect an admittance transformation sufficient to produce matched admittances, is read from the same circle **63** by proceeding in a clockwise direction along said circle **63** from point *k* to point *q*. The length of arc thus traversed corresponds to an electrical length, βl, which for the illustrative example corresponding to vector *qk* is approximately equal to 101°. Of this length, about 11° serve to compensate for the susceptive admittance of the dissipator while the remaining 90° serve to transform the admittance to produce a matched condition.

In a relatively simple idealized case, such as the one to be considered in the example immediately following, the dissipator is assumed to be a pure conductance having zero susceptive component. In this case, the dissipator vector is drawn from point *q* defining an angle $\theta=0$ with respect to an axis of abscissae and terminating at the point *r* on said circle **63**. Hence, the vector *qr* is the diameter of the admittance circle **63** and the required admittance of the dissipator is thereby determined. The required length of transformer section is, in this simplified case, exactly equal to 90 electrical degrees, as may be seen by proceeding along said circle **63** from point *r* to point *q*.

The effect of the quarter-wavelength dielectric body **35** on the admittance seen looking into the load from points within the body **35** successively removed from the line *m*—*m* (Fig. 1) is represented by the semicircle **63** of which the origin coincides with the terminus of vector *pq* (0.625, 0) and which extends, through 90 electrical degrees (180° of arc in the diagram), to a point *r* on the abscissa axis corresponding to

$$\frac{1}{0.625} \text{ or } 1.6$$

The vector $pr=pq+qr$ represents the admittance seen looking toward the load **17** from line *a*—*a* (Fig. 1) which, it will be observed, is fairly large as compared with the admittance in air of the transmission line.

The effect on the admittance produced by dissipator **31** is to produce a mismatch of admittances with respect to transmission line **21** which is even greater than that caused by body **35**. The magnitude of the conductance added by dissipator **31** (here assumed to be purely conductive) is represented in the circle diagram by vector *rs* whose magnitude is determined in the manner hereinabove described and is equal to *qr*. The admittance transformation effected by the dielectric-filled transformer section **33** is shown by the semicircle **65** extending between the terminus *s* of vector *ps* and a point *t* on the axis of abscissae corresponding to a very small admittance value. Conductive admittance element **43** then adds the influence of its admittance which has the effect of increasing the admittance proportionately to the conductance of element **43** and this admittance change is indicated by the vector *tu* also equal to vector *qr*. The dielectric section **45** transforms the admittance via the semicircle **67** to a value corresponding to the point *v*, which, it will be observed, approaches the starting admittance represented by the vector *pq*. It may also be noted, at this point, that the addition to the primary impedance transformer section, comprising the solid dielectric body **35** of the two identical admittance units **29**, **37** yields a resulting admittance *pv* which, relative to the starting admittance *pq*, represents a mismatch of only approximately 15%. It will be apparent, from the following analysis, that the successive addition of units **39** and **41** renders the percentage mismatch smaller and smaller, yielding a value which is negligible for most practical purposes.

As the point of view shifts farther from the load, as by the addition of units **39** and **41**, it is seen that the conductance of element **47** changes the admittance by an amount represented by the vector *vw* (also equal to *qr*). It is to be understood that all the horizontally disposed vectors

are colinear with the axis of abscissae (since it was assumed, for the present analysis, that all the dissipator elements are purely conductive, having zero suspective component). To avoid confusion, however, vector *vw*, since it overlies to a considerable extent the vectors *qr* and *tu*, is drawn parallel to and slightly displaced from the axis of abscissae.

The dielectric transformer body **49** transforms the admittance, in a manner indicated by the semicircle **69**, from the point *w* to point *x*, representing an admittance which is a mismatch relative to the starting admittance of approximately 7%. This percentage mismatch may be reduced to approximately 3% by the addition of unit **41** of which the dissipator element **51** changes the admittance from that represented by the point *x* to a value represented by the point *y*, whence the admittance is transformed by body **53** to a value *z*, very close to starting point *q*.

It is readily seen from the foregoing analysis that as the number of identical units is increased, the percentage mismatch approaches zero, although, for most practical purposes a mismatch of 3% may be considered the equivalent of a perfect match.

That the attenuator of Fig. 1 is symmetrical is obvious by inspection, for it is clear that if the positions of the source **15** and the load **17** were interchanged and the foregoing analysis were applied starting at the end adjacent the new position of the source **15**, the resulting circle diagram would be identical with that shown in Fig. 2.

To determine the amount of attenuation introduced by each unit of the attenuator it is only necessary to compare the conductance of load **17**, as seen through the solid dielectric body **35** with the sum of the conductances of the dissipator element and of the load. Thus, the ratio of the energy passed to the load **17** to the total energy received per admittance unit may be taken as the attenuation per admittance unit.

In the foregoing example, the conductance of the load is $0.625Y_0$. As seen through the quarter-wave dielectric body transformer section **35** (at *a*—*a*) this conductance looks like a conductance of $1.6Y_0$ as indicated by the point *r* of the circle diagram. For unit **29**, the total conductance consisting of the conductance of the element **31** and that of the load **17** is seen from the circle diagram to be equal to $2.6Y_0$. Hence, the relative attenuation for unit **29** is

$$\frac{1.6Y_0}{2.6Y_0}=0.617$$

corresponding to 2.1 decibels. Similarly, the relative attenuation introduced by element **43** is calculated by obtaining the quotient of the conductance of the load as seen from the line *b*—*b* and the total conductance corresponding to dissipator element **43**. Inspection of the circle diagram reveals that the relative attenuation for element **43** is thus,

$$\frac{0.38Y_0}{1.36Y_0}=0.27$$

corresponding to 5.6 decibels. The relative attenuations corresponding to elements **47** and **51** may be calculated in a similar manner, and these will be found to be, respectively, 3.6 and 4.2 decibels. In the foregoing relative attenuation calculations, all the attenuation introduced by the device is considered to be caused by the dissipator element concerned since the solid dielectric bodies are practically lossless.

Furthermore, it will be apparent that, as the number of attenuator units is increased beyond two, the attenuation per unit approaches a constant value approximately equal to 3.75 decibels. The over-all attenuation for an attenuator section comprising any number of identical units is simply the sum of the relative attenuations of the individual units. Thus, it may be seen that I have here described a symmetrical attenuating device having admittance matching characteristics wherein a desired attenuation may be obtained by the addition of a predetermined member of identical units, each one of which, beyond an initial preliminary set of two such units, provides substantially equal increments of attenuation.

In the above discussion, attenuators comprising purely resistive dissipators have been considered. Actually, at very high frequencies, a dissipator comprised of compressed or deposited carbon particles, which is a common attenuating resistive material, is likely to have a complex impedance rather than a pure resistance. At a frequency of 3000 megacycles, corresponding to a free-space wavelength λ of 10 centimeters, for example, certain samples of dissipators have been found to have appreciable capacitative reactance. In actual tests, some have been found to have a ratio of susceptance to conductance

$$\frac{B}{G}$$

of 0.4. When such a dissipator is provided in each of the above-described admittance units, the length of the solid dielectric body transformer section is suitably altered from the 90° effective electrical length, as explained above, in order to provide compensation for the susceptive component of the dissipator element.

Fig. 3 shows an admittance circle diagram useful for analysis of the attenuator wherein the dissipators are again of mutually identical characteristics but which now have complex impedances of a magnitude determined as hereinabove described. In the following example, it will again be assumed that the solid dielectric bodies are of polystyrene having a dielectric constant $\epsilon=2.56$ at $\lambda=10$ centimeters. However, here the equivalent electrical length of the dielectric body is suitably increased to compensate for the susceptive components of the complex admittance dissipators.

The point *q'* is located, as in the above analysis for ordinate O and abscissa 0.625, defining the vector *p'q'* which represents the conductance of load **17** (again assumed to be equal to the characteristic admittance of air-filled transmission line **23**) in relation to the characteristic admittance, Y_0, of the solid dielectric-filled section of line **11**, **13**. As mentioned above, the dissipators employed in this example are characterized by a ratio,

$$\frac{B}{G}$$

of susceptance to conductance of 0.4. The admittance angle, θ, of such a dissipator is the angle whose tangent equals 0.4, or angle $\theta=21.8°$.

Thus, as the observational viewpoint recedes from the load end of primary transformer body **35**, or, from line *m*—*m* (Fig. 1) to the line *a*—*a*, the admittance varies as indicated by the arc **71** (Fig. 3) from an admittance represented by the point *q'* to a complex admittance represented by the point *r'*, spaced an electrical distance,

βl=104° from point q'. From the point r', a vector $r's'$ is drawn oriented at an angle 21.8° with respect to the axis of abscissae and extending for a distance proportional to the predetermined complex admittance of dissipator **31** (equal to qk of Fig. 2) to the point s'. This point s', it will be noted necessarily lies on the axis of abscissae, since as mentioned hereinabove, the length of body **35** is preselected to compensate for the susceptive admittance of dissipator **31**. Dielectric body **33** of unit **29** introduces a further admittance transformation of 104 electrical degrees, as indicated by arc **73**, to point t' whence the element **43** and body **45** of unit **37** carry the admittance via vector $t'u'$ and arc **75**, respectively, to a complex admittance represented by point v', which affords a relatively good match with the starting admittance represented by q'. For a considerably better match, unit **39** may be added, the dissipator **47** of which carries the admittance along the vector $v'w'$ to the point w', whence the body **49** effects an admittance transformation from point w' along arc **77** to point x' of which the admittance is very nearly that of point q'. Finally by a similar process of continued attenuation and transformation the attenuation element **51** and transformer section **53** of unit **41** carry the admittance from point x' to point z', whereat the admittance differs from that of the air-filled line **23**, matched thereto, by a negligible amount.

By means of an analysis similar to the foregoing, it has been found that admittance-matching characteristics of my attenuating device is virtually unaffected by a shift in the operating frequency by as much as 4% above or below the normal operating frequency. For an analysis of the effect produced by a shift of, say 4% below 3000 megacycles, one needs only to reduce the electrical length of the solid dielectric transformer sections by a proportionate amount and then follow through the investigation as hereinabove described in detail.

Fig. 4 illustrates a convenient manner of utilizing prefabricated standardized dissipator units and primary transformer sections which are especially adapted for mass production assembling of the attenuator device of Fig. 1. As shown in Fig. 4, a section of hollow cylindrical conductor **79** of suitable length and inside diameter is provided with a tapped opening **81** near one end of its side wall.

A prefabricated primary solid dielectric transformer section **83** is adapted to be positioned in said hollow conductor **79**, this transformer section **83** comprising a cylindrical dielectric body **85** of predetermined equivalent electrical length and an axially disposed inner conducting rod **87** having a length equal to that of the body **85** and preferably heat molded in said body to insure uniform contact therewith. The transformer section **83** may be removably retained within said hollow conductor **79** by means of a set screw **89** in the tapped opening **81**. For detachably connecting the inner conducting rod **87** to a joining member such as that shown at **25** in Fig. 1, the end of said rod **87** is drilled axially to provide socket **91** in which the turned-down end of joining member **25** is adapted to be snugly received.

A prefabricated admittance unit **93** is adapted to be positioned adjacent said primary transformer section **83** in the hollow conductor **79**, said admittance unit **93** comprising a cylindrical dielectric body **95** of predetermined equivalent electrical length and a dissipator element **97** having predetermined admittance characteristics and fixedly attached to one end of said body **95**. An inner conducting rod **99** is coaxially disposed within said dielectric body **95** and said dissipator element **97**, one end of said rod **99** being flushed with the free end of said dielectric body **95**, while the other end of the rod **99** extends somewhat beyond the free end of the dissipator element **97**. The rod **99** is preferably heat molded in the composite dielectric body and dissipator element to insure uniform contact therewith. For detachably connecting admittance unit **93** to the primary transformer section **83**, the extended end of conducting rod **99** adjacent the dissipator element **97** is turned down to provide a pin **101** which is adapted to fit snugly in a socket **91'** provided at the end of rod **87** adjacent unit **93**. The other end of rod **99** is drilled to receive a similar pin of an adjoining unit or of a joining member. As many additional units similar to unit **93** may be provided, as desired, to produce a symmetrical attenuator having a desired amount of attenuation, as hereinbefore described in connection with the device of Fig. 1.

While the admittance transformer sections of the completely symmetrical attenuator devices, hereinbefore described, are disclosed and described as comprising solid dielectric-filled portions of coaxial transmission line, it is to be understood that other types of transformer sections may be suitably employed with satisfactory results. Figs. 5 and 6 show two alternative forms of my device wherein air-filled transmission line sections are utilized as admittance transformers. Thus, in Fig. 5 the attenuator device comprises a section of coaxial transmission line having an outer conductor **103** and an inner conductor **105**, said line section being joined at either end to other lines, such as lines **107**, **109**, for the purpose of attenuating, by a predetermined amount, the high frequency energy transfer between said lines **107** and **109**, and of effecting good admittance match between said line section **103**, **105** and said adjoining lines **107**, **109**.

As described above, in connection with the admittance circle diagrams of Figs. 2 and 3, explanatory of the operation of the device of Fig. 1, the points q (Fig. 2) and q' (Fig. 3) are determined in view of the value of the ratio

$$\frac{Y_a}{Y_0}$$

of the admittance of the air-filled line to the admittance of the solid dielectric-filled portion of the line. It is known that the admittance Y_0 of the solid dielectric-filled portion of the line is a function of the nature of the dielectric material within the line and also of the ratio of the diameters of the conductors comprising the line. Thus, for a given value, Y_a, of the admittance of the air-filled line or load, the value of Y_0 required to satisfy the condition set above may be obtained by changing the dielectric material in the line or by a corresponding change in the diametral ratio of the conductors of said line, or both. Hence, in the device of Fig. 5, air-filled primary transformer section **111** replaces solid dielectric-filled primary transformer section **35** (Fig. 1) and admittance units, such as unit **113**, comprising air-filled transformer section **115**, and dissipator element **117** replace the attenuator units, such as unit **29** of Fig. 1. To compensate for the change in admittance produced by substituting air for the solid dielectric in the line section **103**, **105**, the ratio of the di-

ameter of the outer conductor 103 to the diameter of the inner conductor 105 is correspondingly decreased relative to the diametral ratios of the conductors of lines 107, 109. As in the case of the solid dielectric-filled attenuator, as many additional air-filled admittance units, as desired, may be employed to produce a device of substantially any desired amount of attenuation without impairing the symmetry characteristics thereof.

It will be understood that, while the attenuator formed of line section 103, 105 is shown in Fig. 5 as integral with or permanently connected to lines 107, 109, said section 103, 105, may if desired, be detachably connected to the lines 107, 109 as by the joining members 25 and the outer sleeves 27 of Fig. 1. Obviously, the outer sleeves 27 would, in this case, be formed to conform with the altered dimensions of conductor 103.

Fig. 6 is a fragmentary showing illustrating an attenuating device of similar characteristics to that of Fig. 5, wherein the altered diametral ratio is achieved by increasing the diameter of the inner conductor throughout the length of the attenuator while maintaining the outer conductor diameter unchanged. Thus, as shown, the attenuator section comprises an outer conductor 119 and an inner conductor 121 suitably positioned coaxially with respect to said outer conductor 119. To increase the effective diameter of the inner conductor throughout the length of the attenuator, thereby decreasing the diametral ratio of outer to inner conductor, I provide tubular conducting members 123 slideable over the inner conductor 121 and adapted to be positioned between adjacent pairs of dissipator elements 125.

To aid in the proper assembling of the device, the inner conductor 121 may be preliminarily crimped as at 127 to provide a stop against which the first one of said members 123 may be positioned when said member is slipped down over the conductor 121. Thereafter, a dissipator disc 125 is slipped into position and retained therein by the following tubular member 123, as shown. Successive sets comprising tubular member 123 and dissipator disc 125 may be added, as desired, to construct an attenuator of substantially any attenuation.

It will be obvious from the foregoing descriptions that attenuating devices of similar general characteristics may be constructed by combining the teachings of Figs. 1 and 4 and Figs. 5 and 6. That is to say, virtually any desired attenuation characteristics may be obtained in an attenuating device by selecting a dielectric material (solid or gaseous) of a given dielectric constant ϵ, and by so altering the diametral ratio either by changing the diameter of the outer conductor or by changing the diameter of the inner conductor, or both, as to yield an admittance characteristic, Y_0, according to said desired attenuation.

Although the above description of the attenuating devices was based on the employment of coaxial transmission lines for the attenuator and the conducting means coupled thereto, it is to be noted that the invention need not be so restricted. In place of the coaxial lines illustrated and described, other types of hollow conductors, such as air-filled or solid dielectric-filled wave guides or parallel wire transmission lines, may be utilized with entirely similar results.

In the foregoing description, the term "high frequency conductor" has been used in a manner which is intended to denote, generally, hollow or dielectric-filled coaxial line conductors and wave guides and parallel wire transmission lines. Hence, the appended claims should be read and interpreted in the light of the broader meaning of the term.

As 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. An electromagnetic wave energy conducting system comprising conductor means adapted to propagate high-frequency wave energy therealong, said conductor means having a characteristic admittance; means for attenuating the energy being propagated by said conductor means, said attenuating means comprising a plurality of disc-shaped admittance elements spaced along said conductor means at equal electrical intervals of the order of one-quarter the wavelength of the propagated energy, each of said disc-shaped elements being disposed in shunt with said conductor means, and means for transforming said characteristic admittance of said conductor means along with said admittance elements to a selected value, said transforming means including a plurality of solid dielectric bodies, each of said solid dielectric bodies being disposed between each pair of opposed faces of adjacent disc-shaped admittance elements and completely filling the space therebetween; and two additional solid dielectric bodies positioned adjacent each of the terminal faces of the end disc-shaped admittance elements respectively.

2. In an electromagnetic wave energy conducting system comprising conductor means adapted to propagate wave energy therealong to a load and having a characteristic admittance; the combination with said conductor means of means for attenuating the energy being delivered to said load, said means comprising at least three dissipator elements disposed in parallel spaced relation along said conductor means at equal electrical intervals substantially equal to one-quarter wavelength of the propagated waves, and means for matching said characteristic admittance to said load, said admittance matching means comprising a solid dielectric body disposed between each of the opposed faces of adjacent dissipator elements and completely filling the space therebetween; and an additional solid dielectric body positioned adjacent each of the outward faces of the end dissipator elements.

3. In an electromagnetic wave energy conducting system comprising a concentric transmission line terminated in a load; the combination with said concentric transmission line of means for attenuating by a predetermined amount the energy being delivered to said load, said means comprising a plurality of shunt admittance units supported in juxtaposition along said line, each of said units including a disc-shaped dissipative element extending radially between the inner and outer conductors of said concentric transmission line, and an adjacent solid dielectric admittance-transforming body, each of said elements being disposed along said line at equal electrical intervals of the order of one-quarter wavelength of

the delivered wave energy, each of said admittance-transforming bodies being disposed between each pair of opposed faces of adjacent disc-shaped dissipative elements and completely filling the space therebetween; and an additional solid dielectric body positioned adjacent the outward face of the dissipative element nearest said load, said additional solid dielectric body extending along said line a distance equal to said intervals beyond the end one of said disc-shaped dissipative element.

4. A transmission line attenuator for delivering energy to a load having a first admittance, comprising a transmission line section coupled to said load and having a characteristic admittance different from said first admittance, and a plurality of dissipative elements in shunt with said transmission line section spaced at equal electrical intervals therealong of the order of one quarter wave length of the delivered energy wave, the magnitudes of the impedances of said dissipative elements being substantially equal, said transmission line section extending by a distance equal to said intervals beyond the end ones of said dissipative elements for presenting an attenuator input admittance equal to said first admittance.

5. A concentric transmission line attenuator for delivering electromagnetic wave energy to a load having a first admittance, comprising a transmission line section coupled to said load and having a characteristic admittance different from said first admittance, and at least three equal dissipator elements in shunt with said transmission line section spaced therealong at equal electrical intervals of the order of one-quarter of the wavelength of said wave energy, said transmission line section extending by a distance equal to said electrical intervals beyond the end ones of said dissipator elements for presenting an attenuator input admittance equal to said first admittance.

6. A concentric transmission line attenuator for delivering electromagnetic wave energy to a load having a first admittance, comprising a transmission line section coupled to said load and having a characteristic admittance different from said first admittance, and means for presenting an attenuator input admittance equal to said first admittance comprising a plurality of admittance units supported in juxtaposed relation with each other and in shunt with said transmission line section, each of said units including a dissipative part and an admittance transforming part associated therewith, said admittance transforming part having a length substantially equal to one quarter wavelength of said wave energy, said transmission line section extending by a distance equal to the length of one of said admittance transforming parts beyond the end one of said dissipative parts nearest said load.

7. The attenuator defined in claim 6 wherein said dissipative part is an energy-absorbing disc, and said admittance transforming part is a solid dielectric body attached to said disc.

8. The attenuator defined in claim 6 wherein said transmission line section is coupled to a load by way of a further transmission line section having concentric inner and outer conductors, and said dissipative part is an energy-absorbing disc and said admittance transforming part is an air-filled section of diametral ratio less by a predetermined amount than the diametral ratio of said further transmission line section.

9. An energy conducting system comprising a first transmission line section having a first characteristic admittance, a second transmission line secton coupled to said first line section and having a second and uniform characteristic admittance, and attenuating means in said second transmission line section for dissipating a predetermined fraction of high frequency energy conducted through said second line section toward said first line section and for presenting to said first line section an admittance substantially equal to said first characteristic admittance, said attenuating means comprising at least three equal dissipator elements having appreciable admittance effectively in shunt with the admittance of said second line section and spaced at equal electrical intervals therealong substantially equal to one-quarter of the wavelength of the high frequency energy conducted therethrough, admittance transforming means for transforming the admittance of an adjacent dissipator element and disposed between each pair of adjacent dissipator elements and completely filling the space therebetween, and additional admittance transforming means adjoining the terminal ones of said elements, said additional admittance transforming means extending a distance equal to said intervals beyond the end ones of said dissipator elements, whereby a substantially matched admittance condition is provided between said first characteristic admittance and the input of said second transmission line section.

10. An energy conducting system comprising a first coaxial transmission line section having a first characteristic admittance, a second coaxial transmission line section coupled to said first coaxial line section and having a second characteristic admittance, and attenuating means in said second line section for dissipating a predetermined fraction of high frequency energy conducted through said second line section toward said first line section and for presenting to said first line section an admittance substantially equal to said first characteristic admittance, said attenuating means comprising a plurality of dissipator elements having appreciable admittance effectively in shunt with the admittance of said second line section and spaced at equal electrical intervals therealong of the order of one quarter of the wavelength of the high frequency energy conducted therethrough, said second line section extending by a distance equal to said intervals beyond the end ones of said dissipator elements and having a diametral ratio of outer conductor diameter to inner conductor diameter different from that of said first line section for transforming the admittance seen at the input of said second transmission line section to a value substantially equal to said first characteristic admittance.

11. The system defined in claim 10 wherein the diameter of the outer conductor of said second line section is substantially less than the diameter of the outer conductor of said first line section and the space between successive dissipator elements is air-filled.

12. The system defined in claim 10 wherein the diameter of the inner conductor of said second line section is substantially greater than the diameter of the inner conductor of said first line section and the space between successive dissipator elements is air-filled.

13. Symmetrical high frequency wave energy attenuator apparatus comprising a coaxial transmission line section, at least three equal dissipative elements spaced at equal quarter-wavelength intervals along said transmission line sec-

tion, dielectric means between adjacent pairs of said elements and completely filling the space therebetween, and additional dielectric means disposed exteriorly of the terminal ones of said elements and extending beyond said terminal elements by a distance equal to said intervals.

14. In a preformed attenuator device adapted to be coupled to a load and including a hollow conductor, a plurality of dissipator elements, a like plurality plus one of admittance-transformer dielectric bodies of electrical length substantially equal to one-quarter of the operating wavelength positioned in said conductor in sequence therealong, with each of said dissipator elements located between successive dielectric bodies, a plurality of conducting members, each of said conducting members being centrally disposed within a respective one of said dielectric bodies, and means associated with said conducting members

for detachably interconnecting said conducting members, said dissipator elements and said dielectric bodies being disposed electrically in shunt with the coaxial transmission line formed by said hollow conductor and said conducting members.

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