

April 16, 1940.

A. P. KING

2,197,123

GUIDED WAVE TRANSMISSION

Filed June 18, 1937

2 Sheets-Sheet 1

FIG 1

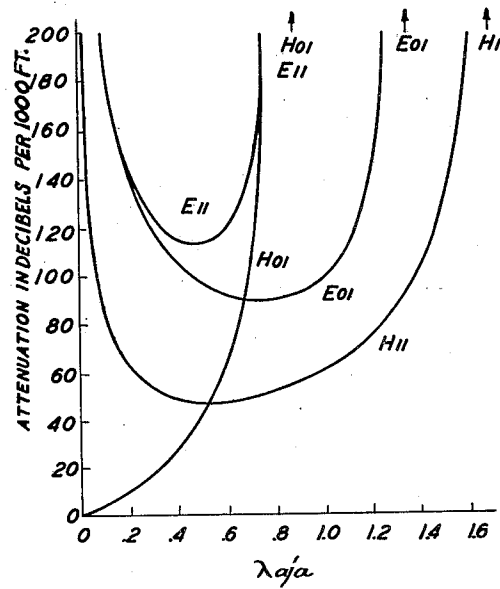
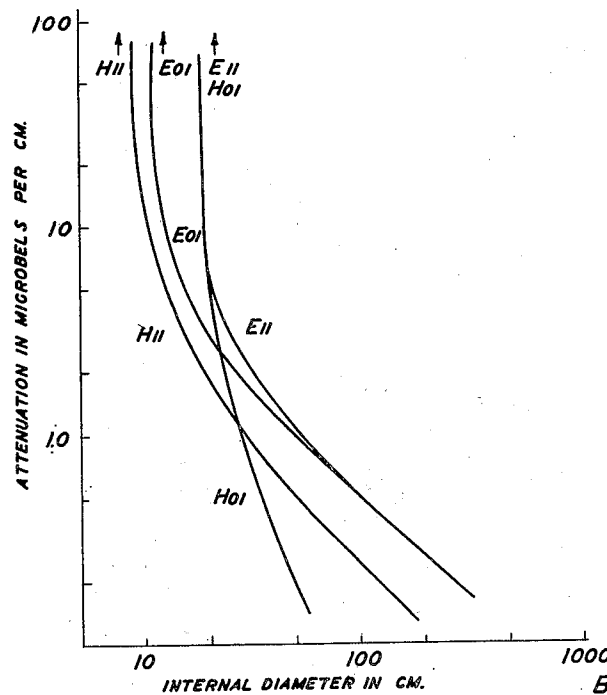


FIG 2



INVENTOR
A. P. KING

BY *H. A. Burgess*
ATTORNEY

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2 Sheets-Sheet 2

FIG. 3

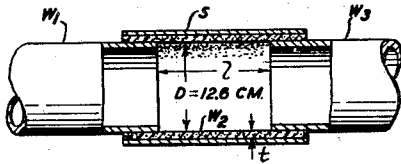


FIG. 4

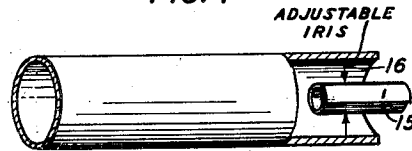


FIG. 5

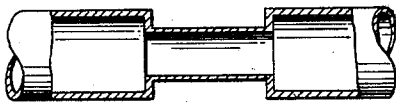


FIG. 6

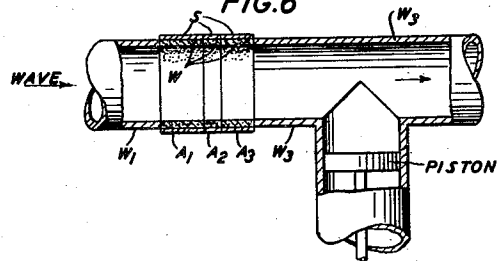


FIG. 7

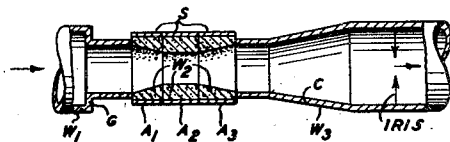


FIG. 8

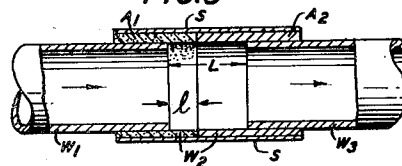


FIG. 9

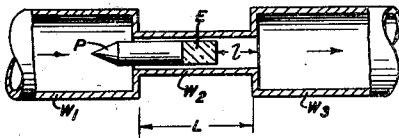


FIG. 10

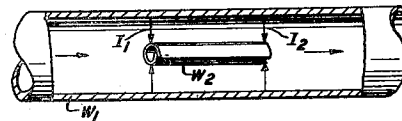


FIG. 11

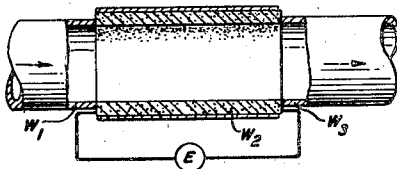
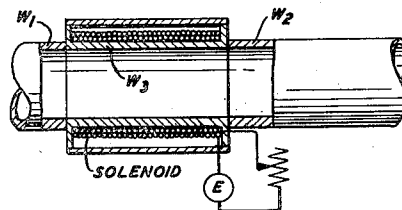


FIG. 12



INVENTOR
A. P. KING
BY *H. A. Burgess*
ATTORNEY

UNITED STATES PATENT OFFICE

2,197,123

GUIDED WAVE TRANSMISSION

Archie P. King, Red Bank, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application June 18, 1937, Serial No. 148,879

12 Claims. (Cl. 178-44)

This invention relates to electromagnetic wave attenuators and more particularly to attenuators for use in a system for dielectrically guided waves.

Dielectric guide systems of various kinds have been described in some detail heretofore in such applications for Letters Patent as those of G. C. Southworth which issued on September 13, 1938 as U. S. Patents No. 2,129,711 and No. 2,129,712 and that of S. A. Schelkunoff which issued on February 21, 1939, as U. S. Patent No. 2,147,717, and in the papers by J. R. Carson *et al.* and Schelkunoff appearing in the April 1936 issue of the Bell System Technical Journal. The dielectric guide itself has taken a wide variety of forms, but typical of guides disclosed heretofore is one consisting of a rod of dielectric material and another consisting essentially of a metallic pipe containing a solid or gaseous dielectric medium.

A form of dielectric guide that lends itself well to the purposes in hand is one consisting of a metallic pipe, evacuated or filled with air, and it is in terms of such a guide that my invention will be described. It is to be understood, however, that this is for illustrative purposes only and that the invention is not to be limited to this specific form of guide.

Dielectrically guided wave transmission as disclosed in the applications and publication cited above, is unique in several respects. In the first place it is evident that the provision of separate conducting paths for the go-and-return flow of conduction current is not an essential characteristic whereas in conventional guided wave systems known heretofore it is. Secondly, in each instance it has been observed that the guide presents the attenuation characteristic of a high-pass filter, that is, there is a certain critical or cut-off frequency separating the propagation range from a lower frequency range of zero or highly attenuated transmission. Moreover, it has been found that the critical frequency and the phase velocity of dielectrically guided waves are both functions of the transverse dimensions of the guide.

Dielectrically guided waves are capable of transmission in an indefinitely large number of forms or types, each type being distinguished by the characteristic spacial distribution and interrelation of the component electric and magnetic fields comprising the waves.

Although as noted, there are an indefinite number of types of dielectrically guided waves, it has been found that they fall into either of

two broad classes. In the one class, assuming now for the sake of simplicity that the guide is in the form of a metallic pipe, the electric component of the wave is transverse to the pipe and at no point does it have a longitudinal component excepting as the pipe is not quite a perfect conductor. The magnetic component, on the other hand, has both transverse and longitudinal components. This class will be designated as "transverse electric" waves or TE waves. In the other class, the magnetic component is transverse to the pipe and at no point does it have a longitudinal component, but the electric component has in general both transverse and longitudinal components. This class will be designated as "transverse magnetic" waves or TM waves.

The various possible types of dielectrically guided waves in each of these two classes may be identified and distinguished from each other by their order and by their mode of propagation. The order of the wave is determined by the manner in which the field intensity varies circumferentially around the axis of the guide, whereas the mode is determined by the manner of its variation with distance from the axis of the guide. Reference is made here to the Schelkunoff application, *supra*, for a more complete discussion of this matter of mode and order. The usual convention is herein adopted of designating a TE wave by H_{nm} , where n represents the order and m the mode. Similarly a TM wave of the n th order and m th mode will be represented by E_{nm} .

The purpose of this invention is that of providing suitable attenuating devices for wave guide systems carrying one or another of the different types of dielectrically guided waves described above. More specifically the purpose of the invention is to provide a series attenuating device as distinguished from a shunt attenuating device for such systems. Still a further purpose is to provide attenuators which may be continuously adjustable to yield any desired degree of attenuation. Other purposes will appear presently.

The invention will be better understood by reference to the following specification and the accompanying drawings in which:

Figs. 1 and 2 are curves showing certain characteristics of wave guides; and

Figs. 3 to 12 show various forms of attenuators for carrying out my invention.

Referring more specifically to Fig. 1, there are shown the attenuation curves of the four principal types of dielectrically guided waves as a func-

tion of the ratio of the operating free space wave-length λ_a to the internal diameter d of the guiding structure. The values are calculated for a cylindrical copper guide with air dielectric, and the critical ratios corresponding to the cut-off frequencies are indicated by the arrows. In Fig. 2 the curves of Fig. 1 are redrawn to show the relation between attenuation and diameter at a constant wave-length $\lambda_a=15$ centimeters, the curves for convenience being plotted on a logarithmic scale.

Fig. 2 indicates that the attenuation per centimeter length of guide is extremely low except near cut-off. The transmission loss can be increased, however, by increasing the wall resistivity of the wave guide and an important part of my invention resides in the use of this fact. For a wave guide as ordinarily used, with a metallic wall and a diameter not too near the cut-off, attenuations of the order of 10^{-2} and 10^{-4} decibels per centimeter prevail. Since the rate of attenuation is thus very low, it would require a section of guide of inconveniently great length to produce an appreciable loss. To obtain transmission losses of from 0.1 to 10 decibels per centimeter and thus to realize substantial transmission losses in an attenuator of moderate length, is an object of this invention.

Fig. 3 shows a form of attenuator which is adapted for a large variety of types of dielectrically guided waves such, for specific example, as an H_{11} wave. Mounted between two highly conducting guide sections, W_1 and W_3 , is the high resistance section W_2 . The length l of this cylinder exposed to the passing wave is adjustable by sliding W_3 longitudinally, thus varying the amount of attenuation. The resistance section may consist of a large variety of resistance elements such, for example, as a piece of blotting paper impregnated with colloidal graphite. With such a system a wave propagated through the guide will suffer loss of power at a fairly high rate while passing through the section W_2 .

In such a section of attenuator there may be a tendency for the wave proper to leak out through the high resistance wall. This leakage may be considered as part of the attenuation. On the other hand, any such leakage is frequently undesirable because of the external effects produced. It may be very materially reduced by applying an external sheath S of copper foil although this will have a tendency to reduce the attenuation proper, because of the preference of the wave to travel along the low resistance sheath. However, by increasing the thickness of the resistance element, as by using several layers of impregnated blotting paper, the leakage factor can be largely reduced without excessive reduction of the attenuating factor. As a general proposition it may be stated that high conductivity attenuator walls will require thin-walled sheaths and low conductivity attenuator walls will require thick-walled sheaths to reduce the external field to a desired low value.

The attenuations referred to above can, I find, be increased by a reduction in the diameter of the power absorbing section of the line. Thus, in a particular instance, for a wave-length of fifteen centimeters a decrease in the diameter from 12.6 centimeters to 10 centimeters increased the attenuation per unit length by a factor of 2.5 whereas a decrease to nine centimeters diameter increased the attenuation by a factor of 6. This may be readily understood by reference to the attenuation curves of Fig. 1 and the principle

involved is one applicable to my invention which will be disclosed in further detail in this specification.

It is to be noted that the presence of a high resistivity guide section may set up a substantial reflected wave. This is in part due to the change in characteristic impedance of that section of the line represented by the attenuator, for such characteristic impedance is dependent to some extent on the resistance of the guide section. For this reason it will frequently be desirable to make the resistivity of the guide of a value which will not represent too large a departure in impedance characteristic from that of the main portion of the guide and then to use a longer length of attenuator section to obtain the desired attenuation. Or again the large change in characteristic impedance may be avoided by a change in the diameter of the attenuator portion of the guide.

In this method of wave propagation it is convenient to speak of the critical diameter of a guide, where the critical diameter is defined as the smallest diameter which will permit the propagation of a wave of a given type and length in a perfectly conducting guide. Such critical diameters may be readily obtained from the curves of Fig. 1 for those types of waves which are there represented.

Where the material comprising a pipe guide is not a substantially perfect conductor, transmission does not entirely cease when the wave frequency or the pipe diameter is reduced below the critical frequency or critical diameter, respectively, as hereinbefore defined, so that a smaller guide than indicated by theoretical cut-off may transmit a wave. The effect, I find, becomes more pronounced as the resistivity of the hollow conductor wall increases and the corresponding attenuation curve near the cut-off becomes appreciably less sharp. I make use of this feature in the manner shown in Fig. 4, in which a thin piece of metal such as phosphor-bronze may be rolled into a tube 15 and held centrally in the main tube by a metallic adjustable iris 16. As the diameter of the tube 15 is decreased by means of the iris 16, one approaches more closely to the cut-off value for this tube, the attenuation rising quite rapidly but not so rapidly as indicated by the curves of Fig. 1. Over a reasonably wide range the change in attenuation is substantial. Thus I have found it feasible to obtain in this manner attenuations as high as 5 decibels per centimeter.

Further control of the attenuation may be obtained by suitable choice of material so far as its resistivity or other physical properties are concerned. Thus if the pipe 15 of Fig. 4 is to be of fixed diameter, as shown in Fig. 5, then this pipe may be chosen of one material or another. I find, for example, that iron, because of its permeability, exhibits a higher attenuation than tubes of non-permeable materials of comparable resistivity.

As a further illustration of the modes of application of my invention it is to be noted that a desired value of attenuation may be obtained from a plurality of units of fixed attenuating characteristics. Thus in Fig. 6 the attenuator consists of three sections, A_1 , A_2 and A_3 . From an assortment of such elements and by combining them in the manner indicated, a large number of values may be obtained. In the event of impedance discontinuity due to such element one may provide an adjustable side chamber or an

equivalent iris, these serving as reactive elements to cancel any impedance discontinuity or to vary the amount of attenuation. The resistivity, thickness and diameter of the elements may be constant as shown in Fig. 6 or they may vary as shown in Fig. 7, to maintain characteristic impedance. In such cases also the resistivity may vary radially or longitudinally, or the thickness, length, diameter and resistivity may vary in any desired manner. Furthermore, the diameter of the attenuating section may be either above or below the theoretical cut-off value. Using a reduced diameter section of guide to produce increased loss, as in Fig. 7, one may make a connection either with the tapered joint as at C or an abrupt joint as at G. The kind of joint employed will be largely dependent upon the operating conditions. Obviously also external sheaths S shown in Fig. 6 and Fig. 7 may be used.

An attenuator which makes use of the adjustment of length to introduce the desired loss is shown in Fig. 8. Here the attenuating section W_2 is mounted between two guides fixed in position and separated by the gap L. The attenuator comprises two sections of guide one portion A_1 being of high loss and the other portion A_2 being highly conductive. The amount of attenuation is adjusted by sliding W_2 longitudinally over the connecting guides thus varying the length l of the high loss section exposed to the waves.

Here again the resistivity of A_1 may be constant or may vary radially or longitudinally, or may be varied with thickness and the thickness of the wall may vary longitudinally. An external sheath S may be used if desired.

Fig. 9 illustrates a means of attenuation adjustment with a guide section W_2 operated at a frequency below the cut-off frequency. Sliding in the section W_2 and of approximately the same length is an adjustable dielectric rod or plug E. The dielectric constant of the rod is sufficiently high so that the portion of W_2 containing the dielectric will be above cut-off and will thus propagate the wave with relatively low attenuation. For the unoccupied portion, however, the attenuation is high. If W_2 is of constant diameter or cross-section the attenuation inserted in the circuit is proportional to l , which is that section of W_2 with air dielectric. One or both ends of the dielectric may be specially shaped as indicated by P to reduce distortion or impedance discontinuity. This adjustable feature may obviously be used with additional sections of W_2 or in conjunction with the attenuator of Fig. 7 to provide an extended range of attenuation.

In Fig. 10 there is shown an attenuator making use of a guide length of continuously variable cross-sectional area. This type, which has been previously described in a somewhat simplified form in Fig. 4, consists of a variable diameter tube W_2 and the adjustable irises I_1 and I_2 . The tube W_2 is a thin flexible metallic sheath rolled into a cylindrical tube whose spring tension tends to unwind or extend the diameter of the tube. This tension makes the tube conform to and follow the openings of the adjustable irises. I_1 and I_2 may be geared together and adjusted so that W_2 is cylindrical or conical. Obviously this scheme may be extended to guides of rectangular cross-section whose area could readily be changed by varying the spacing between opposite sides.

Fig. 11 indicates a method of varying the power transmission in an attenuator by means of a guide material whose resistivity may be altered by passage of electric current or whose permeabil-

ity may be changed by passage of magnetic current. Among the materials susceptible to change in resistivity are thyrite, boron, silver sulphide, copper oxide, etc. If W_2 is the resistive section the current flow may be longitudinal or circumferential, or both.

Fig. 12 shows a method for varying the permeability of a magnetic material used as an attenuator section. This may be accomplished by means of a solenoid wound over the permeable part and coaxial with the guide. The permeability of W_2 can be varied by changing the current flow through the coil. The efficiency of the magnetic circuit may, of course, be increased by using a closed magnetic circuit as shown.

It is to be understood that any suitable reacting elements such as a side-chamber or iris may be used to compensate the reactance or impedance discontinuities in any of these attenuators.

While the invention has been described thus far in terms of one or more series absorbing elements, it is to be understood that one may combine them in various ways with shunt absorbing elements, such as those described in the pending application of A. E. Bowen, Serial No. 148,839, filed of even date herewith.

What is claimed is:

1. In an electrical transmission system, a shielded transmission structure for propagating ultra-high frequency waves with low attenuation, an attenuator comprising a short length of conductive pipe electrically interposed in tandem relation in said transmission structure for the transmission of said waves in the form of dielectrically guided waves, the transverse dimensions of said pipe being so related to the frequency of said waves that said frequency is at least approximately the cut-off frequency of said pipe whereby the energy of said waves is in part dissipated in the form of heat in said attenuator and the rate of attenuation in said pipe is large compared with that in said transmission structure.

2. In a dielectric wave guide system, an attenuator for dielectrically guided waves comprising a section of guide of adjustable loss value, said section comprising a sleeve adapted to slide over the ends of two adjacent guide sections, the portion of the sleeve which is exposed to the passing wave being capable of adjustment, the inner face of said sleeve comprising resistance material so distributed that a variable amount thereof can be exposed by effecting said adjustment.

3. In a dielectric wave guide system, an attenuator for dielectrically guided waves comprising a section of guide of adjustable loss value, said section comprising a sleeve to slide over two adjacent guide sections, the sleeve having one portion of high loss value and the other of low loss value.

4. In a dielectric wave guide system, an attenuator for dielectrically guided waves, an attenuator comprising a section of guide of adjustable loss value, said section comprising a sleeve to slide over two adjacent guide sections, the sleeve having one portion of high loss value and the other of low loss value and being adapted to slide longitudinally to expose a greater or smaller portion of the high loss section to the passing wave.

5. In combination, a hollow metallic pipe constituting a guide for the transmission of dielectrically guided waves, an attenuator interposed in said guide comprising a pipe section having a high rate of attenuation, said pipe section

being composed of a resistive material for dissipating the energy of said waves passing through it, and means for adjustably controlling the resistivity of said material whereby the attenuation introduced by said pipe section can be regulated.

6. In a dielectric wave guide system, an attenuator for dielectrically guided waves comprising a section of high loss guide, said section comprising a material the resistivity of which is a function of temperature, and means for adjustably controlling the temperature of said material whereby the loss introduced by said attenuator can be regulated.

7. A wave guide comprising a metallic pipe, means for transmitting dielectrically guided waves therethrough, and an attenuator for said waves comprising a short section of said pipe a transverse dimension of which is so related to the frequency of said waves that said dimension lies between the value for cut-off and the value at which transmission ceases, whereby said waves are transmitted through said attenuator but with reduced amplitude.

8. A combination in accordance with claim 7 comprising a body of dielectric material having a dielectric constant greater than unity and adapted to be advanced into said section of pipe.

9. A system comprising a metallic pipe for the transmission of dielectrically guided waves and a device interposed in said pipe comprising a pipe-like section having a high rate of attenuation for said waves, the total amount of attenuation introduced by said device being dependent on (a) the length of said section, (b) the resistivity of the material comprising it, (c) its transverse di-

mensions and (d) the dielectric coefficient of the dielectric medium contained within it, and means for changing at least one of the parameters (a), (b), (c), (d), whereby the total attenuation introduced by said device is changed.

10. In a system for the transmission of dielectrically guided waves, a wave guide comprising a metallic pipe, and a variable attenuator comprising a section of said pipe at least a portion of the wall of which comprises material of high resistivity and means for adjusting the amount of said material that is exposed to waves transmitted through said pipe, whereby said waves proceed beyond said attenuator with reduced amplitude.

11. In combination with a metallic pipe for the transmission of dielectrically guided waves, a localized device comprising material of high resistivity disposed in the path of said waves for attenuating them and means for adjustably controlling the resistivity of said material whereby to adjust the attenuation suffered by said waves.

12. In a wave guide comprising a metallic pipe containing a dielectric medium for the transmission of dielectrically guided waves, a variable attenuator comprising a section of said pipe including means for adjustably fixing the transmission cut-off frequency of at least a portion thereof, the frequency of said waves being approximately said cut-off frequency whereby a change in the latter effects a disproportionately large change in the amplitude of the waves transmitted through said attenuator.