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2,269,991

HIGH FREQUENCY TRANSMISSION LINE

Filed March 8, 1940

Fig. 1.

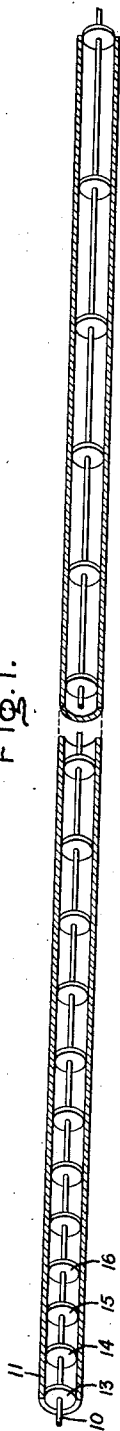


Fig. 2.

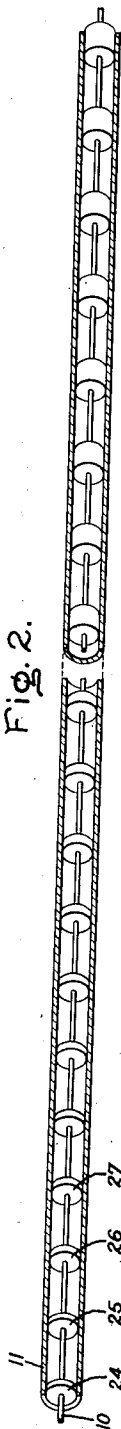


Fig. 3.

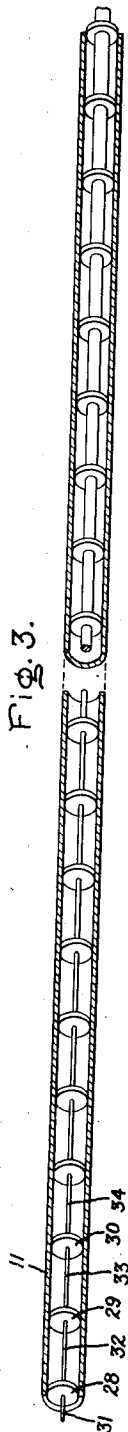


Fig. 4.

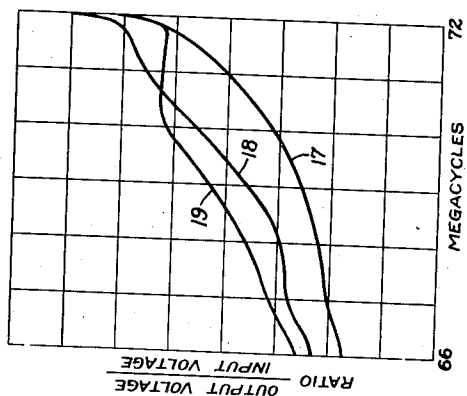


Fig. 5.

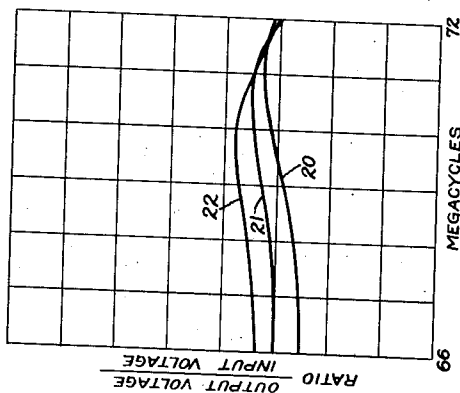
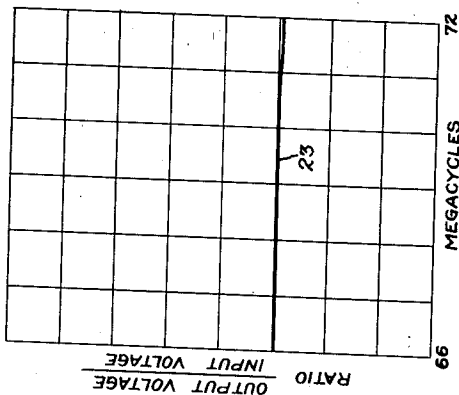


Fig. 6.



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UNITED STATES PATENT OFFICE

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HIGH FREQUENCY TRANSMISSION LINE

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12 Claims. (Cl. 178-44)

This invention relates to a high frequency transmission line and more particularly to an electric transmission line for conveying a high frequency wave covering a relatively wide range of frequencies between two points a considerable distance apart.

It is an object of my invention to provide a simple and easily constructed electric transmission line having improved transmission characteristics.

More particularly, an object of my invention is to provide a relatively long transmission line having inherent electric discontinuities therein and adapted to transmit a high frequency wave covering relatively wide range of frequencies with substantially equal amounts of attenuation in the wave at all transmitted frequencies.

The features of my invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Figs. 1, 2, and 3 represent three different embodiments of my invention; Fig. 4 represents certain electrical characteristics of apparatus similar to that shown in Fig. 1 before the application of my invention and in which the insulating disks were uniformly spaced along the cable, and Figs. 5 and 6 represent certain electrical characteristics of the embodiment of Fig. 1, which includes my invention, respectively before and after a certain final adjustment.

Referring to Fig. 1 there is shown a coaxial cable having a center conductor 10 of uniform cross section and a cylindrical conductor 11 coaxial therewith and of uniform inside diameter. Several insulating disks 13, 14, 15, 16, etc., are provided, these disks being centrally perforated to receive the conductor 10 snugly and being of such size as to fit closely within the cylindrical conductor 11. The insulating disks 13, 14, 15, 16, etc., are of uniform thickness and shape and are spaced along the conductor 10 in a manner to be explained later.

It has been found that when insulating disks, such as those shown in Fig. 1, are spaced uniformly within a coaxial cable, certain very harmful characteristics are produced within the transmission line, when it is employed to transmit a wave between two points at a considerable distance and when the wave covers a considerable range of frequencies. For example, such a line

usually has the characteristic that attenuation of a wave transmitted therethrough differs very greatly at various frequencies in the band to be transmitted. Such an electrical characteristic of a transmission line is very undesirable, and makes it useless in many situations.

In a particular instance, the characteristics of a coaxial cable 45 feet and $\frac{5}{8}$ inch long were measured, the insulating disks being spaced 20 inches apart. The ratio of the inside diameter of the outside cylindrical conductor to the outside diameter of the center conductor was 3.52. The susceptance of each insulating disk was 0.00114 mho and the conductance of each disk was 0.0000115 mho.

Fig. 4 illustrates the relation of the ratio of output voltage to input voltage with frequency, the ratio being plotted as ordinate and frequency in megacycles being plotted as abscissa. This relation was measured for the line just described as having equally spaced insulating disks over a frequency range from 66 to 72 megacycles. The three curves 17, 18, 19 represent this characteristic when the line was terminated respectively by resistances of 60.4 ohms, 71.8 ohms, and 79.8 ohms. These curves indicate that this coaxial line having equally spaced insulators cannot be terminated in a characteristic impedance within the frequency range of from 66 to 72 megacycles. From theoretical considerations it appears that the term "characteristic impedance" has, in fact, no meaning when applied to such a line.

It is believed that deleterious effects, such as are indicated by Fig. 4, arise by reason of cumulative reflections at certain frequencies from such electrical discontinuities in the line as equally spaced insulators, whose dielectric constant is considerably different than the air between the insulators. Other sorts of electrical discontinuities such as rough pipe joints produce the same effect.

I have found it possible to construct a coaxial line, having spaced insulating disks between the center and the outer cylindrical conductors, so that its transmission characteristic is constant over a wide frequency range. As is illustrated in Fig. 1, the insulating disks 13 and 14 are spaced apart a relatively small distance and the next pair of insulators are spaced apart a somewhat larger distance, whose ratio to the distance between the disks 13 and 14 is a certain value, which may for convenience be denoted as K. The distance between disks 15 and 16 is K times the distance between disks 14 and 15. Correspondingly, the distance between every pair of

adjacent disks in the cable is made K times the distance between the preceding pair of disks. The distances between the disks within the cable, when arranged in this manner, form a geometrical or logarithmical progression.

Tests were made of a cable substantially identical with the cable described above as tested with equally spaced insulators, except that its insulators were logarithmically spaced. This cable was 45 feet and $\frac{5}{8}$ inch long and the ratio of the inside diameter of the outside cylindrical conductor to the outside diameter of the center conductor was 4.0. The first two insulators 13 and 14 were spaced 30.65 inches apart. The value of K was 1.022, that is, each pair of insulating disks was spaced 1.022 times as far apart as the preceding pair of disks. The last pair of insulating disks was 39.89 inches apart. The same type of insulating disks were used as in the above described cable, so that their susceptance and conductance is the same.

Referring to Fig. 5, there is illustrated the improvement in the transmission characteristic which resulted in this geometrical or logarithmic spacing of the insulating disks. Curves 20, 21, and 22 represent respectively the relation between frequency and the ratio of output voltage to input voltage for a wave whose frequency varies between 66 and 72 megacycles. The three curves 20, 21, and 22 represent this characteristic when the line terminated respectively by a load of 62.3 ohms, 72.5 ohms, and 81.8 ohms. It is apparent that, while this cable could not be terminated in its characteristic impedance, a very great improvement in its transmission characteristic was made.

The small variation in the transmission characteristic indicated by the curves 20, 21, and 22 of Fig. 5 was actually found to be due, not to any defect in the geometrically increased spacing of the insulating disks, but was rather caused by a certain type of connection which was used at one end of the line to support the central conductor. Upon a change in this supporting insulator the transmission characteristic indicated by Fig. 6 was found in which curve 23 indicates that the ratio of output voltage to input voltage is substantially constant between 66 and 72 megacycles, when the line is terminated by its characteristic impedance. It is, therefore, apparent that by using a geometrically increased spacing between the insulating disks, rather than equal spacing therebetween, the transmission characteristic of the coaxial cable has been made substantially constant over a very wide range of frequencies.

It may be noted that the geometrically increased spacing of the line described and tested is such that the ratio of the greatest distance between any pair of insulating disks to the smallest distance between any pair of insulating disks is only about 1.3. A coaxial line has been constructed which is about 120 feet long, and in which the ratio of the spacing between insulating disks at one end of the line to the spacing between the insulating disks at the other end is about 4.0.

It is preferred that as great a ratio of spacing of the disks at one end of the spacing of the disks at the other end be used as is feasible, provided the longest spacing is not greater than a quarter wave length of a transmitted wave. The constancy of the transmission characteristic over wide frequency ranges is better as this ratio is larger up to this limit. Practical considera-

tions limit the amount to which the ratio may be increased, because of the need for support between the center conductor and the cylindrical outer conductor at that end of the cable where the disks are far apart and because of too great crowding of the disks at that end of the cable where they are near together.

In the design of this cable the number of insulators and the value of K may be readily determined by application of well known formulae for geometric progressions. Let a be the small distance between two adjacent insulators at one end of the cable, b be the large distance between two adjacent insulators at the other end, s be the total length of cable, n the number of spaces and $n+1$ be the number of insulators, and K the ratio b/a ; which is, as stated, preferably 4. If the sizes of the two conductors be known, b can be determined as the largest tolerable distance between two supports between the two conductors so as to allow no undesired sagging or movement between the two conductors. Of course, b should not be greater than a quarter wave length, if this distance is smaller than that allowable to provide proper support. Once b is chosen, a may be determined, and, knowing a , b , and s ; K and n may be found by the following formulae:

$$K = \frac{s-a}{s-b}$$

$$n = \frac{\log b/a}{\log K} + 1$$

Of course, the number of insulators determined by the formula will rarely be an even number. The nearest even number may be selected and accurate calculations made to find the exact values of K , a , and b corresponding thereto. To construct the cable itself, it is convenient to make a tabulation of the distances between every adjacent pair of insulators in order that the entire line may be easily assembled with the desired geometrically or logarithmically increased spacing.

The same result as obtained by geometrically or logarithmically spacing the insulators as in Fig. 1 may be obtained in other ways. Fig. 2 illustrates an embodiment of my invention in which the spacing between the insulators is constant while the thickness of the individual insulators is geometrically or logarithmically increased progressively from one end of the cable to the other. That is, an insulating disk 24 at one end of the cable formed by the center conductor 10 and the outer cylindrical conductor 11 is made of a certain thickness. The next insulating disk 25 is made slightly thicker in the ratio K . The third insulating disk 26 is made K times as thick as the insulating disk 25. Likewise the fourth disk 27 is made K times as thick as the disk 26, and etc.

The same theoretical considerations apply to this construction of coaxial line as to that illustrated in Fig. 1, and the same formulae apply provided that a and b denote respectively the thickness of the end insulators, and s denotes the total insulator thickness. It is, of course, necessary that the specific dielectric constant for the material used in all the insulating disks of my embodiment of Fig. 2 be the same. This is, of course, true for Fig. 1 as well.

Fig. 3 illustrates a third embodiment of my invention in which there is utilized a third way of producing a geometric or logarithmic change of an electrical characteristic progressively from

one end of a coaxial cable to the other. In this figure the outer cylindrical conductor 11 is provided with a plurality of insulating disks 28, 29, 30, etc. and a central conductor 31. Insulating disks throughout the line are equally spaced and of the same size. The central conductor 31 is given a logarithmically or geometrically increasing cross section between each pair of disks progressively from one end of the line to the other. For example, a section 32 of the conductor 31 between the disks 28 and 29 is made of rather small diameter m , a section 33 of the conductor 31 between the disks 29 and 30 is made of slightly larger diameter n . The ratio m/n is the ratio "K" mentioned above. The diameter of a section 34 of the conductor 31 between the disk 30 and the adjacent disk to the right is therefore K times the diameter of the section 33. The various sections of the conductor 31 between adjacent disks are progressively increased in the same way to the end of the line, as is illustrated.

It is wholly within the scope of this invention to use a combination of two or three of these progressively logarithmically increasing electrical characteristics to form a coaxial cable having a constant transmission characteristic. It is also within the scope of this invention to make a progressive logarithmic alteration in any electric characteristic of a coaxial cable, which may have repeated discontinuities therein such, for example, as a plurality of insulators. The invention is, of course, not limited to coaxial cables but may be applied to any two parallel conductors having inherent electric discontinuities. It is at present preferred to use a logarithmically varied spacing between similar insulating disks as the variable electric factor, because of the practical difficulties surrounding the construction of the insulating disks of different thickness or of a center conductor of varying diameter.

My invention is of greatest advantage when applied to a low loss transmission line, since damping, which is minimized in the insulators of such a line, does not tend to overshadow the electrical discontinuities represented by insulating disks or the like. It is a very important advantage of my invention that when a transmission line is constructed according thereto, deleterious electrical effects caused by junction boxes or the like, used at turns in the line, are minimized. It appears that this effect springs from the fact that a section of transmission line constructed according to my invention and placed between two junction boxes is unlike any other section in the same transmission line, so that reflections from any junction box are unlikely to be cumulative with respect to reflections from any other box. The adjustment of such junction boxes is greatly simplified.

While I have shown a particular embodiment of my invention, it will, of course, be understood that I do not wish to be limited thereto, since different modifications may be made both in the circuit arrangement and instrumentalities employed, and I aim by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electric transmission line for transmitting high frequency electric waves comprising a pair of juxtaposed conductors having supports introducing electrical discontinuities at spaced intervals along the length of at least one of said conductors, each portion of said line lying

between adjacent supports having uniform electrical characteristics throughout its length, the various successive portions of said line lying between adjacent discontinuities having electrical characteristics varying from one portion to another according to a logarithmic relationship.

2. An electric transmission line for transmitting high frequency electric waves comprising a pair of juxtaposed conductors, and a plurality of means spaced along said line for maintaining said conductors in fixed spaced relation, said means introducing electrical discontinuities along the length of at least one of said conductors, each portion of said line lying between adjacent ones of said means having uniform electrical characteristics throughout its length, the various successive portions of said line lying between adjacent ones of said means having electrical characteristics varying from one portion to another according to a logarithmic relationship.

3. An electric transmission line for transmitting high frequency electric waves comprising a pair of juxtaposed conductors, and a plurality of insulators spaced along said line for maintaining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, each portion of said line lying between adjacent insulators having uniform electrical characteristics throughout its length, the various successive portions of said line lying between adjacent insulators having electrical characteristics varying from one portion to another according to a logarithmic relationship.

4. An electric transmission line for transmitting high frequency electric waves comprising a pair of juxtaposed conductors, and a plurality of similar insulators spaced along said line for maintaining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, each portion of said line lying between adjacent insulators having uniform electrical characteristics throughout its length, the various successive portions of said line lying between adjacent insulators having electrical characteristics varying from one portion to another according to a logarithmic relationship.

5. An electric transmission line for transmitting high frequency electric waves comprising a pair of coaxial conductors, and a plurality of similar insulators spaced along said line for maintaining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, each portion of said line lying between adjacent insulators having uniform electrical characteristics throughout its length, the various successive portions of said line lying between adjacent insulators having electrical characteristics varying from one portion to another according to a logarithmic relationship.

6. An electric transmission line for transmitting high frequency electric waves comprising a pair of coaxial conductors, and a plurality of similar insulators spaced along said line for maintaining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, the distance between any two adjacent insulators and the distance between the preceding adjacent insulators having a constant ratio throughout the line different from unity.

7. An electric transmission line for transmitting high frequency electric waves comprising a

pair of juxtaposed conductors, and a plurality of insulators spaced along said line for maintaining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, the distance between any two adjacent insulators and the distance between the preceding adjacent insulators having a constant ratio throughout the line different from unity.

8. An electric transmission line for transmitting high frequency electric waves comprising a pair of juxtaposed conductors, and a plurality of insulators equally spaced along said line for maintaining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, the thickness of any insulator and the thickness of the adjacent insulator having a constant ratio throughout said line different from unity.

9. An electric transmission line for transmitting high frequency electric waves comprising a pair of juxtaposed conductors, and a plurality of insulators equally spaced along said line for maintaining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, each portion of said line lying between adjacent insulators having uniform electrical characteristics throughout its length, the various portions of said line lying between adjacent insulators having electrical characteristics varying from one portion to another according to a logarithmic relationship.

10. An electric transmission line for transmitting high frequency electric waves comprising a pair of juxtaposed conductors, and a plurality of insulators equally spaced along said line for main-

taining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, each portion of said line lying between adjacent insulators having uniform electrical characteristics throughout its length, the various portions of said line lying between adjacent insulators having the spacing between the conductors thereof varying from one portion to another according to a logarithmic relationship.

11. An electric transmission line for transmitting high frequency electric waves comprising a pair of coaxial conductors, and a plurality of similar insulators spaced along said line for maintaining said conductors in fixed spaced relation, said insulators introducing electrical discontinuities along the length of said line, each portion of said line lying between adjacent insulators having uniform electrical characteristics throughout its length, the various successive portions of said line lying between adjacent insulators having lengths varying from one portion to another according to a logarithmic relationship.

12. An electric transmission line for transmitting high frequency electric waves comprising a pair of juxtaposed conductors having electrical discontinuities at spaced intervals along the length of at least one of said conductors, each portion of said line lying between adjacent discontinuities having uniform electrical characteristics throughout its length, and the electrical characteristics of the various successive portions of said line varying from one portion to another according to a logarithmic relationship.

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