Oct. 13, 1942. P. H. SMITH 2,298,428

TRANSMISSION LINE

Filed Aug. 19, 1939

FIG. 1

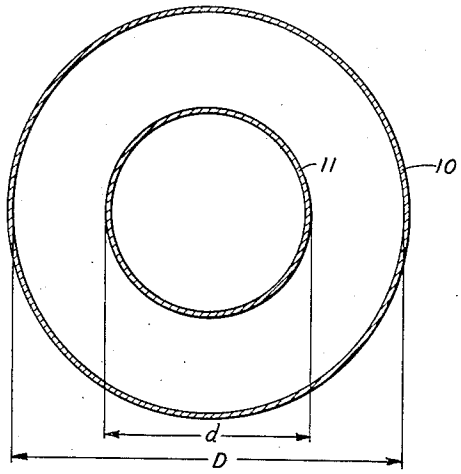


FIG. 2

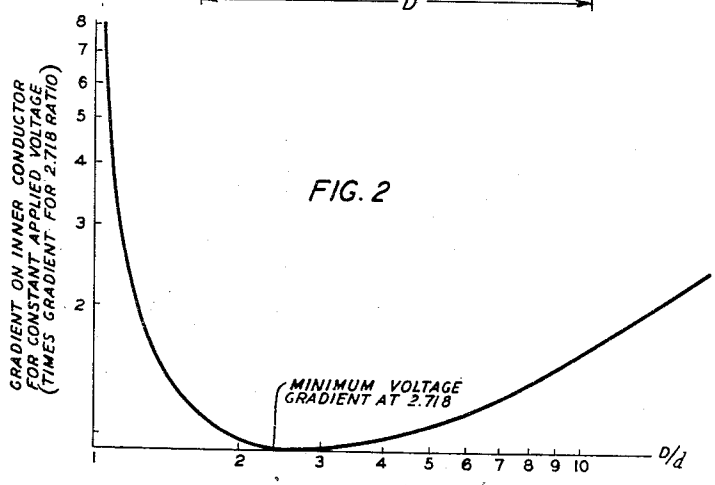
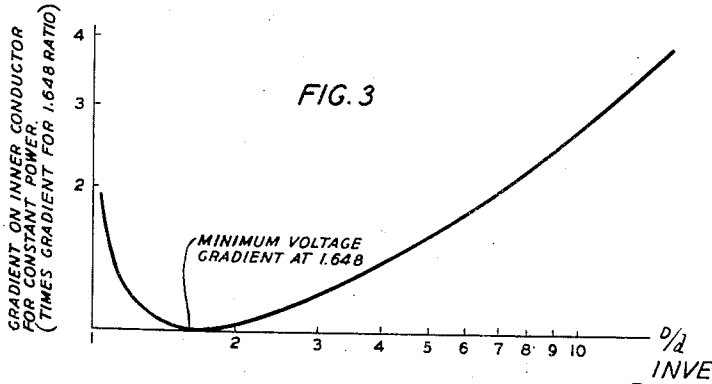


FIG. 3



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TRANSMISSION LINE

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4 Claims. (Cl. 178—44)

This invention relates to conductor lines for the transmission of high frequency electrical energy, and more particularly to such lines in which the conductors are in concentric relation.

When either a solid or hollow cylindrical conductor is provided with an external return conductor comprising a hollow cylindrical conductor concentrically arranged with respect thereto and both inner and outer conductors are separated by a dielectric consisting largely of air or other gaseous medium, there is thus formed a line that possesses desirable characteristics for broad band signaling transmission. Such transmission line is disclosed in the patent of L. Espenschied et al., No. 1,835,031 granted December 8, 1931. It is one characteristic of this line that at high frequencies the current tends to flow at the outer surface of the inner conductor and at the inner surface of the outer conductor so that when a voltage is applied to the line to effect such current flow the relation between the sizes of the two conductors is vitally important in so far as flash-over therebetween is concerned. This invention involves the discovery that for a given size of outer conductor there is an optimum size of inner conductor for use therewith so that a voltage applied to such line, as it is transmitting a predetermined amount of power, will have minimum tendency to cause flash-over between the conductors.

It is an object of the invention to obtain substantially maximum economy in a concentric conductor line transmitting a predetermined amount of power thereover.

It is another object of the invention to provide substantially maximum power carrying capability for a concentric conductor transmission line having a given size of outer conductor.

It is a further object of the invention to minimize the tendency for flash-over in a concentric conductor transmission line having a given size of outer conductor and over which a predetermined amount of power is to be transmitted.

As the most economical type of a concentric conductor line for the transmission of a predetermined amount of power is one in which the outside diameter of the outer conductor is as small as possible, it is the practice to determine the size of this conductor as the initial consideration in the design of such transmission line. Thereafter, the size of the inner conductor is determined.

In accordance with this invention the determination of the size of the inner conductor is such as to observe an optimum ratio between the inner diameter of the outer conductor and the outer diameter of the inner conductor so that the voltage applied across the conductors would have a minimum tendency to cause flashover therebetween. The observance of this optimum diameter ratio also provides substantially maximum power carrying capability for the transmission line.

The invention will be readily understood from the following description when taken together with the accompanying drawing in which:

Fig. 1 shows a cross-section of a concentric conductor; and

Figs. 2 and 3 are curves illustrating the operation of Fig. 1 under certain conditions.

Referring to Fig. 1, a hollow outer conductor 10 of suitable electrical conducting material is mounted concentrically with respect to an inner cylindrical electrical conductor 11 which may be either a hollow or solid structure so as to constitute a high frequency transmission system in which high frequency signaling currents flow in one direction along the inner surface of the outer conductor and in an opposite direction along the outer surface of the inner conductor as preferably disclosed in the patent to L. Espenschied et al., supra. It is to be understood that insulators for spacing the conductors may be of the type shown in the patent of L. Espenschied et al., supra; or of the type illustrated in my copending application, Serial No. 197,765 filed March 24, 1938, now Patent No. 2,216,893, issued Oct. 8, 1940; or other suitable type.

The determination of the diameter of the outer conductor of such line is usually influenced by practical considerations among which is that of economics. This aspect is of prime importance, particularly in the design of concentric conductor lines in which the outer conductor has an outside diameter of the order of six inches, as the cost of copper is an important factor. The most economical design for a concentric conductor transmission line required to transmit a predetermined amount of power is ordinarily one that embodies an outer conductor having the smallest possible outside diameter, as the major portion of the cost of such line is involved in the outer conductor.

Supplementing the above is the outstanding factor of voltage gradient at the surface of the inner conductor which gradient tends to cause flash-over between the inner and outer conductors when a critical value thereof is attained. Such flash-over is undesirable as it interrupts

transmission and may deleteriously affect both conductors and insulators.

According to this invention it has been found that, assuming the selection of an outer conductor having a certain inner diameter, there is an optimum ratio of 1.648 to 1 between the inner diameter of the outer conductor and the outer diameter of the inner conductor which optimum ratio effects a minimum voltage gradient at the outer surface of the inner conductor for a predetermined power input to the concentric conductor line. This means that the voltage applied across the conductors under such conditions will have minimum tendency to cause flash-over therebetween. It is to be understood that such concentric conductor transmission line is terminated in its characteristic impedance.

Minimum voltage gradient for predetermined applied voltage, diameter ratio=e=2.718 to 1

From the standpoint of minimum tendency to flash-over between the inner and outer conductors of a concentric conductor transmission line for a predetermined input voltage thereto and in which the inner diameter of the outer conductor possesses a predetermined value, the optimum conductor diameter ratio between outer and inner conductors is $e=2.718$ to 1, which corresponds to a characteristic impedance of 60.0 ohms. This is determined by minimizing the formula for the voltage gradient at the surface of the inner conductor where flash-over first occurs. The following equation gives the gradient at the surface of the inner conductor:

$$g=\frac{2E}{d\log_e\frac{D}{d}}\text{ volts/cm.} \qquad (1)$$

in which D is the inside diameter of the outer conductor, d is the outside diameter of the inner conductor, and E is the voltage applied across the two conductors. This equation may be found in Dielectric Phenomena in High Voltage Engineering, second edition, by F. W. Peek, Jr., at page 28.

This may be readily understood by referring to Fig. 2 which shows for a constant applied voltage the minimum voltage gradient on the outer surface of the inner conductor occurs for a conductor diameter ratio $e=2.718$ to 1; that the voltage gradient increases sharply for ratios less than 2.718 and increases gradually for ratios greater than 2.718.

Minimum voltage gradient for a predetermined power transmitted, diameter ratio=$\sqrt{e}$=1.648 to 1

Consequently, from the standpoint of maximum power capability of a concentric conductor transmission line the optimum ratio between the inner diameter of the outer conductor and the outer diameter of the inner conductor is $\sqrt{e}=1.648$ to 1, which ratio corresponds to a characteristic impedance of 30.0 ohms. This is due to the fact that as the conductor diameter ratio is being reduced the characteristic impedance is also being reduced which impedance reduction in turn serves to reduce the voltage impressed on the line for a predetermined power applied thereto. Therefore, even though the gradient for a predetermined voltage is increasing the applied voltage is at first decreasing more rapidly than such increases. Eventually, however, the rate at which the gradient increases, as the conductor diameter ratio is being reduced, occurs more rapidly than the rate at which the applied voltage is decreasing. The minimum gradient for a predetermined power, therefore, occurs at a lower conductor diameter ratio than the minimum gradient for the predetermined voltage, and is shown in Fig. 3. In the latter it is seen that the voltage gradient increases sharply for ratios less than 1.648 and increases gradually for ratios greater than 1.648.

The applied voltage across a transmission line terminated in its characteristic impedance is

$$E=\sqrt{PZ_0}\text{ volts} \qquad (2)$$

in which P is power in watts, but

$$Z_0=60\log_e\frac{D}{d} \qquad (3)$$

substituting this value for Z_0 into (2)

$$E=\sqrt{60P}\ \sqrt{\log_e\frac{D}{d}}\text{ volts} \qquad (4)$$

The gradient (g) at the surface of the inner conductor for a predetermined applied voltage is given by Equation 1. Substituting the above equivalent for E, Equation 4, in Equation 1, the following expression for the gradient at the surface of the inner conductor for a predetermined power is obtained:

$$g=\frac{2\sqrt{60P}}{d\sqrt{\log_e\frac{D}{d}}}\text{ volts/cm.} \qquad (5)$$

The conductor diameter ratio which permits maximum power transmission for a minimum gradient is obtained by minimizing Equation 5 with respect to the ratio D/d in the following manner:

Let

$$2\sqrt{60P}=K$$

and

$$\frac{D}{d}=x$$

then

$$g=\frac{K}{d\sqrt{\log_e x}}$$

$$=\frac{K}{D}(x)(\log_e x)^{-\frac{1}{2}}$$

$$\frac{dg}{dx}=\frac{K}{D}\left[x\left(-\frac{1}{2}\right)\frac{(\log_e x)^{-\frac{1}{2}}}{x}+(\log_e x)^{-\frac{1}{2}}\right]=$$

$$\frac{K}{D}(\log_e x)^{-\frac{1}{2}}\left[-\frac{1}{2}(\log_e x)^{-1}+1\right]$$

for minimum gradient

$$\frac{dg}{dx}=0$$

$$\frac{1}{2\log_e x}=1$$

$$\log_e x=\frac{1}{2}$$

$$e^{\frac{1}{2}}=x \qquad (6)$$

$$x=\sqrt{e}=1.648 \qquad (7)$$

$$\frac{D}{d}=\sqrt{e}=1.648 \qquad (8)$$

Thus, when the diameter ratio of a concentric conductor line shown in Fig. 1 approximates that

indicated in Equation 8 there will be substantially minimum voltage gradient on the outer surface of the inner conductor as a predetermined power is being transmitted over the line. This means that the line is provided with maximum power carrying capability as the voltage applied to the line would have a minimum tendency to cause flash-over between the conductors thereof. Such tendency represents the usual power carrying limitation of a high frequency concentric transmission line having air or inert gas as a dielectric at atmospheric pressure.

It is to be understood that while the invention is disclosed with reference to high frequency signaling systems, it is not necessarily limited thereto as it is also applicable with equal facility to power transmission systems of either direct or alternating-current type.

What is claimed is:

1. A concentric conductor transmission line comprising outer and inner cylindrical electrical conductors arranged concentrically so that one serves as a return path for the other, the ratio of the inner diameter of the outer conductor to outer diameter of the inner conductor being of the order of 1.65 to 1 to obtain maximum economy of conductor material in said line for transmitting a predetermined amount of power thereover.

2. A concentric conductor transmission line comprising outer and inner cylindrical electrical conductors arranged concentrically so that one serves as a return for the other, the ratio of the inner diameter of a given outer conductor to the outer diameter of the inner conductor being of the order of 1.65 to 1 to determine substantially maximum power carrying capability of the line.

3. A concentric conductor transmission line comprising outer and inner cylindrical electrical conductors arranged concentrically so that one serves as a return path for the other and insulated from each other by a dielectric that is largely gaseous, the ratio of the inner diameter of a given outer conductor and the outer diameter of the inner conductor being such value that the characteristic impedance of the line is approximately 30 ohms.

4. A concentric conductor transmission line comprising outer and inner cylindrical electrical conductors arranged concentrically so that one serves as a return path for the other, the ratio of the inner diameter of a given outer conductor to the outer diameter of the inner conductor being approximately 1.65 to 1 so that the voltage applied to the line will have substantially minimum tendency to cause flash-over between the conductors as a predetermined amount of power is being transmitted over the line.

PHILLIP H. SMITH.