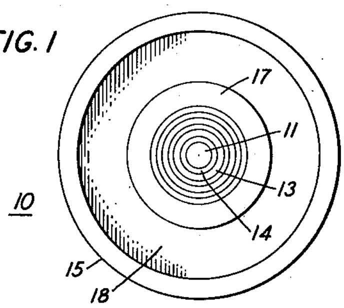
June 25, 1957 A. M. CLOGSTON 2,797,394

ELECTRICAL CONDUCTOR HAVING COMPOSITE
CENTRAL DIELECTRIC MEMBER
Original Filed March 7, 1951

FIG. 1



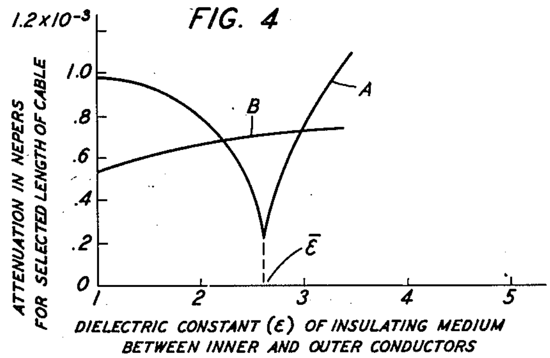


FIG. 2

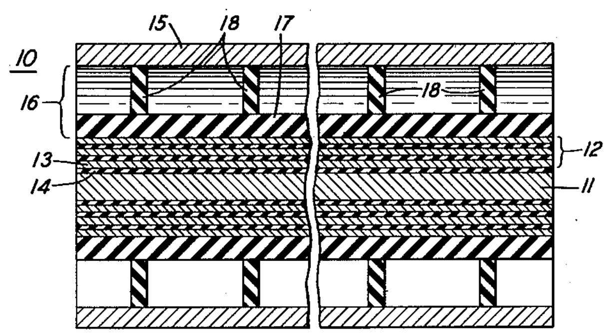


FIG. 3

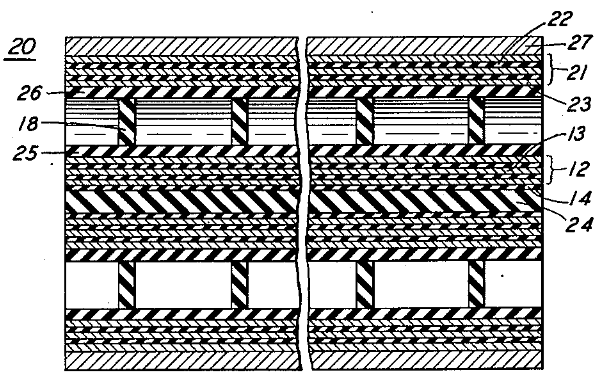


FIG. 5

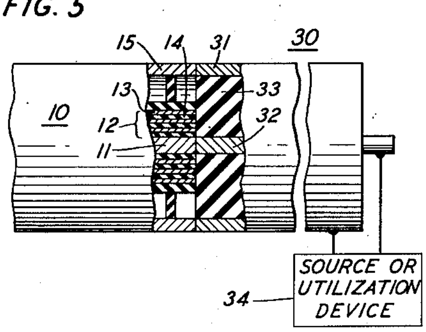
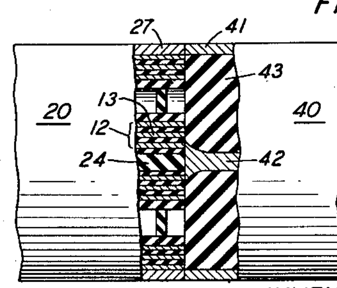


FIG. 6



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1

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ELECTRICAL CONDUCTOR HAVING COMPOSITE CENTRAL DIELECTRIC MEMBER

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Original application March 7, 1951, Serial No. 214,393, now Patent No. 2,769,148, dated October 30, 1956. Divided and this application April 1, 1952, Serial No. 279,809

2 Claims. (Cl. 333—96)

This invention relates to electrical conductors and more specifically to composite conductors formed of a pair of coaxially positioned conducting members separated by an intermediate dielectric member, at least one of the pair being a composite of many insulated conductors.

This application is a division of application Serial No. 214,393, filed March 7, 1951, which issued as U. S. Patent 2,769,148 on October 30, 1956.

It is an object of this invention to improve the current distribution in conductors of the above-mentioned type and particularly to effect such improvement by the novel construction of the intermediate dielectric member.

Due to the phenomenon known as "skin effect," at high frequencies the current distribution through a conductor is not uniform. Consider, for example, the case of a two-conductor coaxial line to which are applied waves of increasing frequency. At zero and sufficiently low frequencies the currents in the conductors are substantially uniformly distributed throughout and the resistance of the conductors and hence the conductor loss in the line is at a minimum. With increasing frequency, the current distribution changes so that the current density is a maximum at the inner surface of the outer conductor and at the outer surface of the inner conductor and decreases into the material at a rate depending on the frequency and the material. In the example given, the current density may be negligible at the other surface of each conductor. From another point of view, the electromagnetic field between the two conductors (where the useful power is transmitted) penetrates into the conductors with a field intensity decreasing with distance. Thus the current density (or field) in each conductor is associated with a power loss that is a function of the distribution of current density (or field) across the thickness of the conductor.

In the copending parent application identified above, there are disclosed a number of composite conductors, each of which comprises a multiplicity of insulated conducting elements of such number, dimensions, and disposition relative to each other and to the orientation of the electromagnetic wave being propagated therein as to achieve a more favorable distribution of current and field within the conducting material. In these composite conductors the power loss associated with skin effect in electrical conductors is greatly reduced.

Applying the principles of the invention of the parent application to the case of the two-conductor coaxial line, one or both of the conductors is formed of a multiplicity of thin metal laminations insulated from one another by layers of insulating material, the smallest dimension of the laminations being in the direction perpendicular to both the direction of wave propagation and the magnetic vector. Each metal lamination is many times (for example 10, 100 or even 1000 times) smaller than the factor δ which is called one skin thickness or one skin depth. The distance δ is given by the expression

$$\delta=\sqrt{\frac{1}{\pi f\mu\sigma}} \qquad (1)$$

2

where δ is expressed in meters, f is the frequency in cycles per second, μ is the permeability of the metal in henries per meter, and σ is the conductivity in mhos per meter. The factor δ measures the distance in which the current or field penetrating into a slab of the metal many times δ in thickness will decrease by one neper; i. e., their amplitude will become equal to $1/e=0.3679\ldots$ times their amplitude at the surface of the slab. It is pointed out in the parent application that when a conductor has such a laminated structure, a wave propagating along the conductor at a velocity in the neighborhood of a certain critical value will penetrate further into the conductor (or completely through it) than it would penetrate into a solid conductor of the same material, resulting in a more uniform current distribution in the laminated conductor and consequently lower losses. The critical velocity for the type of structure just described in determined by the thickness of the metal and insulating laminae and the dielectric constant of the insulating laminae in the composite conductors. The critical velocity can be maintained by making the dielectric constant of the main dielectric, that is, the dielectric material intermediate the two coaxial conductors one or both of which may be composite conductors, equal to

$$\epsilon_1=\epsilon_2\left(1+\frac{w}{t}\right) \qquad (2)$$

where ϵ_1 is the dielectric constant of the main dielectric element between the two conductors in farads per meter, ϵ_2 is the dielectric constant of the insulating material between the laminae of the conductors in farads per meter, w is the thickness of one of the metal laminae in meters, and t is the thickness of an insulating layer in meters. The insulating layers are also made very thin and an optimum thickness for certain types of structures in accordance with the invention is that in which each insulating layer is one-half of the thickness of a metal lamina.

For long cables of the type just described, the main dielectric member preferably is of a dielectric of the proper dielectric constant to give optimum velocity of propagation and which completely fills the space between the two coaxially arranged conductors. However, it is sometimes not practical to maintain the rather accurate controls necessary to provide the exact dielectric constant required. The present invention, in one of its more important aspects, relates to a structure of the composite conductor type in which the intermediate or main dielectric member does not take up all the space between the coaxial conductors. By way of example, it can be formed of one or more hollow dielectric cylinders surrounding the inner composite conductor but taking only part of the space between the two conductors, and a multiplicity of dielectric spacers associated with the dielectric cylinder or cylinders. By varying the number and/or positions of the cylinders and spacers, the dielectric constant of the over-all main dielectric member can be adjusted to the required value. This invention will be described first with reference to the case where there is only one laminated conductor and an unlaminated one coaxial therewith, and second, in the case of two laminated coaxial conductors.

The invention will be more readily understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof, in which:

Fig. 1 is an end view of a coaxial transmission line in accordance with the invention, the inner conductor of the line comprising a multiplicity of metal laminations insulated from one another and the inner and outer conductors being separated by a composite dielectric member;

Fig. 2 is a longitudinal cross-sectional view of a section of cable of the type shown in Fig. 1;

Fig. 3 is a longitudinal cross-sectional view of a modification of the conductor of Figs. 1 and 2;

Fig. 4 is a graph of attenuation vs. dielectric constant of the insulating medium between the inner and outer conductors of (A) a coaxial cable of the type shown in Fig. 1 and (B) a coaxial cable of a conventional type;

Fig. 5 illustrates a method of terminating coaxial cables of the types shown in Figs. 2 and 3 where each of these cables has a metallic core; and

Fig. 6 shows a method of terminating the same types of coaxial cables in the cases where the inner core is of dielectric material.

Referring more particularly to the drawings, Figs. 1 and 2 show, by way of example, a conductor **10** in accordance with the invention, Fig. 1 being an end view and Fig. 2 being a longitudinal view. The conductor **10** comprises a central core **11** (which may be either of metal or dielectric material but which by way of example has been shown as of metal), an inner composite conductor or stack **12** formed of many laminations of conducting material **13** spaced by laminations of insulating material **14**, and an outer conductor **15** separated from the inner conductor **12** by a composite intermediate dielectric member **16**. The dielectric member **16** comprises an inner dielectric cylinder **17** and a plurality of dielectric spacers **18** between the members **17** and **15**.

As discussed in the above-mentioned parent application, each of the conducting layers **13** is made thin compared to its appropriate skin depth (δ). The insulating layers **14** are also preferably but not necessarily of comparable thinness with the conducting layers. Examples of satisfactory materials are: conductors—copper, silver and aluminum; insulators—polyethylene, polystyrene, quartz and polyfoam. The inner conductor **12** has 10 or 100 or more conducting layers **13** while the outer conductor **15** in the embodiment of Fig. 2 is a solid cylinder. Since there are a large number of insulating and conducting layers in the stack **12**, it makes no difference whether the first or last layers of the stack is of conducting or of insulating material.

The improvement forming the present invention is based on the novel construction of the intermediate dielectric member **16**. Since dielectric members **17** and **18** take up only part of the annular space between the stack **12** and the conductor **15**, a material can be used which has a higher dielectric constant than that used in the composite conductor employing a main dielectric member completely filling the space between the two coaxial conductors and still have an over-all dielectric constant for the entire annular space which is of the proper value to produce a velocity of propagation which matches that in the stack and thus satisfy the so-called "Clogston condition" represented by Equation 2 given above. The cylinder **17** and the discs **18** can be of a material which has a relatively high dielectric constant and still have an average dielectric constant which can be varied between values of one and over three, as shown in the curves in Fig. 4.

Fig. 4 compares the attenuation of a selected length of a line of the type shown in Fig. 2 (curve A) with that of a conventional line (curve B) having a solid inner conductor of the same diameter, as the dielectric constant of the insulating material between the inner and outer conductors is varied by changing the number and spacing of the discs **18**. The attenuation of the conductor **10** is seen to reach a minimum at $\bar{\epsilon}=\bar{\epsilon}$ where $\bar{\epsilon}$ has the value given by the following equation

$$\bar{\epsilon}=\epsilon_2\,(1+w/t) \tag{3}$$

The similarity between this equation and Equation 2 is obvious. This minimum value of attenuation at $\bar{\epsilon}$ is much less than that of the conventional coaxial conductor. Even for values of ϵ appreciably different than $\bar{\epsilon}$ (as shown in Fig. 4), the conductor **10** has advantages over the conventional coaxial cable.

Fig. 3 is a longitudinal view of another embodiment of the invention. In this embodiment, a stack **21** replaces the outer solid cylinder **15** of the arrangement of Fig. 2. This stack can be similar to the stack **12** and be made up of multiplicity of alternately arranged insulating and conducting laminae **22** and **23**, respectively. The inner core **24** can be either of metal or of dielectric material but, by way of example, it is being shown as a dielectric member. While one dielectric cylinder may be used surrounding the inner stack **12** (corresponding to the cylinder **17** of Fig. 2), the arrangement of Fig. 3 comprises two dielectric cylinders **25** and **26** between which are placed the dielectric spacers **18**. Obviously any number of dielectric cylinders in the intermediate space between the stacks **12** and **21** can be used. A shield **27** of any suitable metal surrounds the outer stack **21**. The members **25**, **26** and **18** are chosen and spaced so that the over-all dielectric constant within the entire inner space between the stacks **12** and **21** has the value represented by Equation 3 above.

Figs. 5 and 6 show forms of terminations used with the conductor structures shown in Figs. 2 and 3. In each case there is the problem of connecting one end of a composite conductor to another conductor in such a way that there are the fewest possible impedance discontinuities or mismatches at the joint, although generally this condition is not a critical one. In certain cases, however, it may be necessary to provide a very low loss cable of great length and with many intervening joints. It obviously would be advantageous to minimize mismatch and accompanying mode conversion at the joints.

In the arrangement of Fig. 5, a cable such as cable **10** of Fig. 2 (or a cable **20** of Fig. 3 with an inner core of metal) has its end positioned against an end of cable **30** of the coaxial type having an outer conductor **31** and an inner conductor **32**, the space between the conductors for a short interval being filled with dielectric material **33**. The outside diameter of the cable **30** is chosen to be substantially the same as that of the cable **10** so that the conductor **15** butts against and is connected to the outer conductor **31** and the core **11** butts against and is connected to the inner conductor **32**. By means of this connection, a mismatch between the cable **10** and the cable **30** is prevented or kept at a minimum. The cable **30** can be connected at its other end to a source of energy or other utilization device **34**.

Fig. 6 shows a connection between a conductor **20** of the type shown in Fig. 3 (or a conductor **10** of Fig. 2 with an inner core of non-metallic material) and a terminating cable **40**. The outer conductor **41** butts against and is connected to the outer sheath **27** of the cable **20** while the inner conductor **42** of the conductor **40** butts against the dielectric core **24** of the cable **20**. Dielectric material **43** is placed between the conductors **41** and **42** for a short distance. Since the dielectric core is not of metallic material, the end of the inner conductor **42** flares out so that it contacts at least the inner one of the metal laminations **13** of the stack **12**. Alternatively, the inner conductor **42** can have a diameter large enough to contact at least the inner one of the metal laminations **13**, in which case a flared end is not necessary. In both cables **30** and **40**, the dielectric members **33** and **43** are chosen so that in each case it has approximately the same dielectric constant as that of the composite dielectric member in the composite conductor **10** or **20** to which it is connected.

It is obvious that many changes can be made in the embodiments described above. The various embodiments and the modifications thereof described herein are meant to be exemplary only and they do not by any means comprise a complete list of conductors to which the present invention is applicable and it is obvious that others can be devised by one skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a medium for the transmission of high frequency electromagnetic waves comprising two coaxially arranged conductors spaced apart, at least one of said conductors comprising a stack of concentric thin-walled conducting cylinders separated by layers of insulation, the space between said conductors having a plurality of spaced dielectric members, the dielectric members having a dielectric constant and being spaced in a manner such that the average dielectric constant e of the space between the two conductors is given substantially by the following equation

$$e=e_1\left(1+\frac{w}{t}\right)$$

where e_1 is the dielectric constant of the insulating layers, t is the thickness of an insulating layer, and w is the thickness of one of said conducting cylinders.

2. In combination, a medium for the transmission of high frequency electromagnetic waves comprising two coaxially arranged conductors spaced apart, at least one of said conductors comprising a stack of concentric thin-walled conducting cylinders separated by layers of insulation, the space between said conductors having a plurality of spaced dielectric members, the dielectric members having a dielectric constant and being spaced in a manner such that the average dielectric constant e of the space between the two conductors is given substantially by the following equation

$$e=e_1\left(1+\frac{w}{t}\right)$$

where e_1 is the dielectric constant of the insulating layers, t is the thickness of an insulating layer, and w is the thickness of one of said conducting cylinders, and means for applying an electromagnetic wave to said transmission medium.

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