

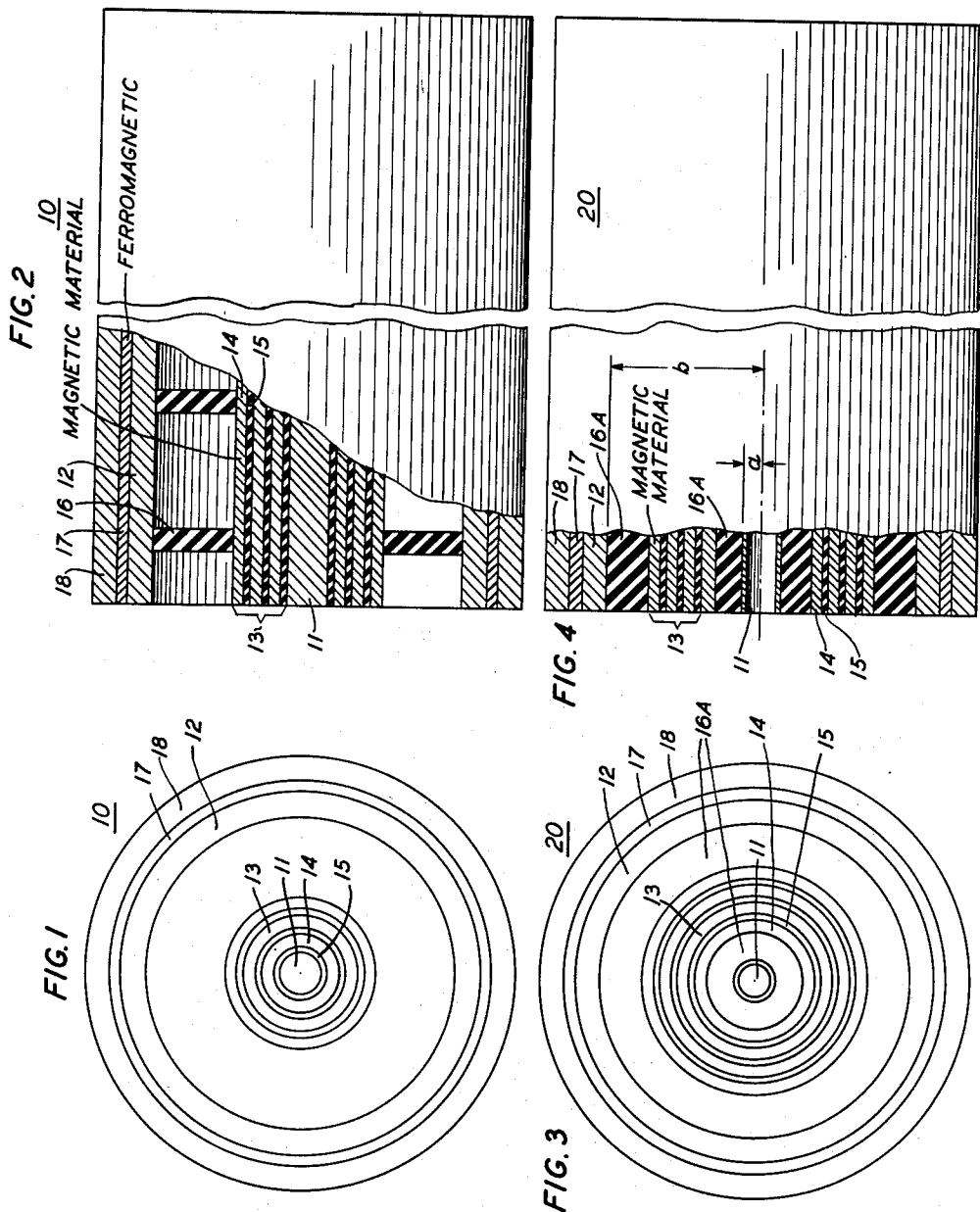
April 3, 1956

J. G. KREER, JR

2,740,834

MAGNETICALLY LOADED ELECTRICAL CONDUCTORS

Filed June 29, 1951



INVENTOR
J. G. KREER, JR.

BY

Hugh S. Wentz
ATTORNEY

1

2,740,834

MAGNETICALLY LOADED ELECTRICAL CONDUCTORS

John G. Kreer, Jr., Bloomfield, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application June 29, 1951, Serial No. 234,359

5 Claims. (Cl. 178-45)

This invention relates to electrical conductors and more specifically to the loading of coaxial cables.

It is an object of this invention to reduce the attenuation of cables and particularly to effect such improvement by magnetic loading.

It has long been known that the attenuation of a conventional type cable can be reduced by loading by the use of magnetic material. Loading raises the impedance and reduces the velocity at the same time that it reduces the attenuation. In fact, if the result of loading is to increase the impedance by a factor X, the velocity and attenuation are divided by X. Accordingly, loading affords an opportunity to reduce attenuation at the expense of a lower speed of propagation.

In many situations, such as, for example, in systems propagating television signals, a reduced speed of transmission would not represent any significant disadvantages. However, as a practical matter, because of the broad band, the loading would need to be continuous. Moreover, by the same token, eddy current losses and heating due to longitudinal currents in the ferromagnetic loading material become more serious the higher the frequency. As a consequence, even in the case of coaxial cables used for television transmission, it has not been the practice to use continuous loading because these ferromagnetic losses would offset the advantages of the reduced attenuation accompanying the loading. In fact, with present material in conventional methods for continuously loading a cable, these ferromagnetic losses would be so large that the net attenuation would be even greater than if the cable had not been loaded.

These disadvantages are overcome by an arrangement of continuously loading in which a stack of thin, insulated layers of magnetic material is placed within the coaxial conductor between the inner and outer conductors. Preferably the stack is symmetrically located with respect to the neutral plane in the cable. This stack, for example, can be composed of thin concentric iron cylinders or laminations insulated from one another by polystyrene or any other suitable insulating material. The eddy current losses are reduced to any desired extent by making the thickness of the iron cylinders very thin; for example, each lamination is many times (for example 10, 100 or even 1000 times) smaller than the appropriate skin depth of the material.

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 cable in accordance with the invention in which the space between the inner and outer conductors includes a stack of insulated laminations of a material of high permeability;

Fig. 2 is a longitudinal view, with portions broken away, of the composite conductor of Fig. 1;

Fig. 3 is an end view of a modification of the structure shown in Fig. 1 in which the stack between the inner and

2

outer conductor is symmetrically positioned with respect to the neutral cylinder of the cable; and

Fig. 4 is a longitudinal view, with portions broken away, of the arrangement of Fig. 3.

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 an inner conductor 11 (which may be either solid or tubular), an outer conductor 12 coaxially positioned with respect to the inner conductor 11, and a stack 13 between the inner and outer conductors formed of a multiplicity of very thin laminations 14 of magnetic material separated by thin layers 15 of insulating material. Each 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 thickness δ is given by the expression

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

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 and 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

$$\frac{l}{e} = 0.3679 \dots$$

times their amplitude at the surface of the slab. For a more complete description of the behavior of currents and fields in stacks of insulated thin conducting members, reference is made to a copending application of A. M. Clogston, Serial No. 214,393, filed March 7, 1951, and for a description of stacks employing magnetic material as the conducting material reference is made to another copending application of A. M. Clogston, Serial No. 234,350, filed June 29, 1951.

The stack 13 may be positioned within the conductor 10 by any suitable means, such as by the use of insulating spacers 16 placed at any convenient interval within the conductor or by using solid dielectric material, such as polyethylene foam, on one or both sides of the stack 13 (as in Fig. 4).

Preferably the stack 13 satisfies the condition

$$\bar{\mu}_1 \bar{\epsilon}_1 = \epsilon_2 \mu_2 \left(\frac{\mu_0}{\mu_2} + \frac{W}{t} \right) \quad (2)$$

where μ_1 is the average permeability of the complete medium between the inner and outer conductors 11 and 12 in henries per meter, $\bar{\epsilon}_1$ is the average dielectric constant of the same medium in farads per meter, μ_2 is the permeability of the metal laminae 14 in henries per meter, ϵ_2 is the dielectric constant of the insulating material between the laminae 14 in farads per meter, μ_0 is the permeability of free space in henries per meter, W is the thickness of one of the metal laminae 14 in meters, and t is the thickness of an insulating lamina 15 in meters. Both the magnetic and insulating laminae are made very thin and an optimum thickness for certain structures of this general type is that in which each insulating lamina is from one-half to one-third the thickness of a magnetic lamina. The magnetic conducting members 14 may be of any suitable material of high permeability, such as, for example, iron or permendur. The insulating layers 15 may be of any suitable material, such as polystyrene, while the spacers 16 or the solid dielectric material 16A may be of polystyrene, polyethylene or any other suitable material having the dielectric constant to produce the relationship represented by Equation 2.

3

Surrounding the outer conductor 12 are suitable ferromagnetic and copper cylinders 17 and 18, respectively, which, in conjunction with the outer conductor 12, provide an adequate shield.

Reference will now be made to Figs. 3 and 4 which show a modification of the structure shown in Figs. 1 and 2. Elements which are similar in the two structures have been given the same reference characters. On difference between the two structures has already been pointed out; that is, instead of the insulating spacer 16, an extruded polyethylene or polystyrene foam is used to position the stack 13. Another important difference is that the stack 13 is located within the member 16A in such a position that the stack is in a neutral cylinder, that is, it is in the region of low longitudinal electric field. This minimizes the dissipation due to current flow. The radius of the neutral cylinder can be represented by the following equation:

$$r_0 = \frac{a}{a+b} \frac{b}{a+b} \quad (3)$$

where r_0 is the radius of the neutral cylinder (the middle of the stack 13), a is the inner radius of the dielectric cylinder 16A, and b is the outer radius of the cylinder 16A. It is obvious that either the spaced discs 16 or the solid insulation 16A may be used in either case (Fig. 2 or Fig. 4) to support the various laminated magnetic structures involved.

In the arrangements of this invention, the magnetic loading of a coaxial cable produces a very substantial and highly desirable transmission improvement, especially in the transmission of television signals over a land or marine coaxial cable.

It is obvious that the invention is not restricted to the specific forms of composite conductors shown as clearly other modifications of the embodiments disclosed can be made without departing from the scope of the invention as indicated in the claims.

What is claimed is:

1. A composite elongated electromagnetic wave conductor comprising an elongated inner conductor, an outer conductor surrounding the inner conductor, and means for decreasing the attenuation of waves along said wave conductor, said means including a multiplicity of continuously extending magnetic conducting layers insulated from one another coaxially arranged with respect to the inner conductor in the space between the two con-

4

ductors, each of said magnetic layers having a dimension in a direction substantially transverse to the direction of wave propagation down the length thereof which is small compared with its appropriate skin depth at the highest frequency of electromagnetic wave to be propagated.

2. The combination of elements as in claim 1 in further combination with dielectric spacers for separating said outer conductor from the outer one of said magnetic layers.

3. The combination of elements as in claim 1 in further combination with a continuous length of dielectric material between said outer conductor and said outer one of said magnetic layers.

4. The combination of elements as in claim 1 in further combination with a continuous length of dielectric material between said outer conductor and said outer one of said magnetic layers, and also between the inner one of said magnetic layers and said inner conductor.

5. A composite elongated electromagnetic wave conductor for propagating waves having a longitudinal component of electric field which undergoes a reversal in direction across the conductor, said conductor comprising an elongated inner conductor, an outer conductor surrounding the inner conductor, and means for decreasing the attenuation of waves along said wave conductor, said means including a multiplicity of continuously extending magnetic conducting layers coaxially arranged with respect to the inner conductor in the spaces between the two conductors, each of said magnetic layers having a dimension in a direction substantially transverse to the direction of wave propagation down the length thereof which is small compared with its appropriate skin depth at the highest frequency of electromagnetic wave to be propagated, said magnetic layers being placed substantially in the region where the component of electric field in the axial direction is a minimum.

References Cited in the file of this patent

UNITED STATES PATENTS

1,701,278	Silbermann	Feb. 5, 1929
1,903,975	Buckley	Apr. 18, 1933
2,228,798	Wassermann	Jan. 14, 1941
2,433,181	White	Dec. 23, 1947
2,511,610	Wheeler	June 13, 1950