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2,879,318

SHIELD FOR ELECTRIC CURRENT APPARATUS

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FIG. 1

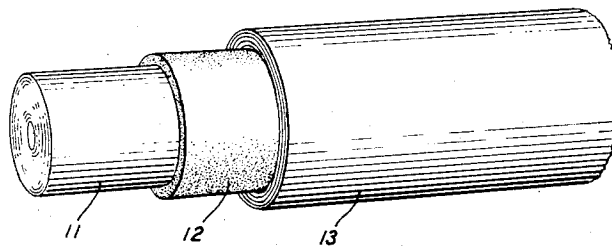


FIG. 2

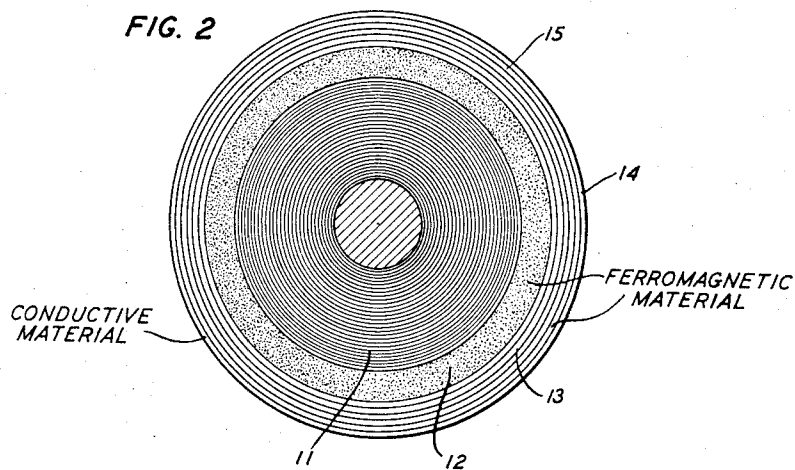


FIG. 3

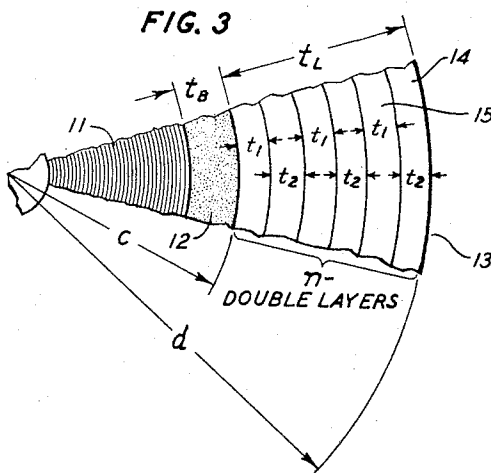
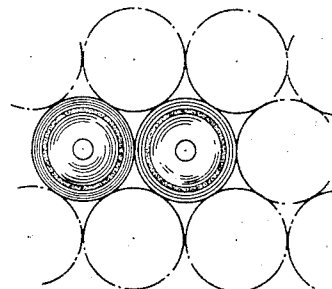


FIG. 4



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SHIELD FOR ELECTRIC CURRENT APPARATUS

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10 Claims. (Cl. 174—36)

This invention relates to shields for devices carrying electric currents and more particularly to shields of small cross section for attenuating and dissipating electromagnetic and electrostatic fields set up by high frequency currents.

It is an object of this invention to more effectively shield high frequency current carrying devices.

The extensive use of high frequency currents for transmission purposes and the development of compact circuit elements operating at high frequencies have created a demand for efficient and effective shielding means. This is especially true in the field of coaxial transmission lines such as, for example, the cable shown and described in the copending application of A. M. Clogston, Serial No. 214,393, filed March 7, 1951, now United States Patent 2,769,148, issued October 30, 1956, wherein there is disclosed a laminated transmission cable of small cross-sectional area operating at microwave frequencies and having superior broad band transmission characteristics. It is not only important that such devices should be effectively shielded so as to preserve their superior qualities and prevent interference with adjacent circuit elements, but it is also important that the shielding make efficient use of space commensurate with the space occupied by the shielded device in order to take complete advantage of the economies realized from the use of compact devices.

It is, therefore, a specific object of this invention to provide a high loss, high impedance, broad band shield of small cross-sectional area.

A further object of the invention is to provide a high loss, high impedance, broad band shield of small cross-sectional area for use with coaxial cables of the Clogston type.

The invention contemplates a composite shield for electromagnetic and electrostatic fields comprising an inner buffer shield and an outer laminated shield. The buffer shield presents a high impedance at the surface adjacent to the current carrying device and is of ferromagnetic material, for example, and the outer laminated shield presents a high loss per unit thickness and is constructed of alternate layers of materials having different intrinsic impedances. The buffer shield is preferably equal to or greater than the thickness of current penetration into a conductor of the same material at the lowest band frequency, which current penetration depth is hereinafter referred to as a classical skin thickness. Depending upon the specific materials used in the laminated shield there are optimum values for individual layer thicknesses and an optimum number of layer pairs. The ratio of the saturation magnetization to permeability of the materials in both shields must substantially meet lower limit requirements to provide adequate shielding throughout a given band of signal frequencies. Total shielding losses are attributable primarily to the insertion loss of the laminated shield, but it is also contributed to by simple attenuation losses in the buffer shield and by reflection losses at the buffer interfaces. One advantage of the present arrangement is that maximum shielding losses

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may be achieved over a broad band of frequencies with negligible effect on the operation of the circuit element being shielded and with only a small expenditure of space.

The invention, its objects and advantages, will be better understood by referring to the following descriptions and drawings forming a part thereof wherein:

Fig. 1 is a sectional view, in perspective, of a shield in accordance with the invention in combination with a laminated transmission line;

Fig. 2 is an end view of the arrangement of Fig. 1;

Fig. 3 is an enlarged section of the view of Fig. 2 showing the dimensions of the transmission line and composite shield; and

Fig. 4 is an end view of a plurality of the shielded transmission lines shown in Fig. 2 arranged adjacent to one another.

For the purposes of easier understanding, the relative dimensions of the structural members shown in the drawings are intentionally distorted.

Referring more specifically to Fig. 1, there is shown an exemplary embodiment of the invention including a laminated cable 11, which may be of the type disclosed in the aforementioned application of A. M. Clogston and a composite shield in accordance with the invention covering the outer surface of cable 11, comprising a buffer shield 12 and a laminated shield 13. The laminated shield 13, as shown in Fig. 2 and Fig. 3 consists of alternate layers of different materials. Not only does the composite shield have a high radial loss, but it also has characteristics so that the longitudinal attenuation constant of the cable is substantially unaffected by enclosing the cable within the shield. For practical purposes the change in cable attenuation for longitudinal transmission due to the presence of the shield should be small and typically not greater than one percent. To keep the change in cable attenuation at a minimum the buffer shield is of critical thickness and of a material having characteristics so that it presents a high impedance to the cable and thereby protects the cable from adjacent low impedance elements which would otherwise affect the operational characteristics of the cable. The laminated shield 13 consists of alternate layers 14 and 15 of two materials, each of a critical thickness, and of a determinate number of layer pairs having quite different intrinsic impedances. By using a laminated structure, the insertion loss is appreciably greater than the simple radial attenuation loss of a solid structure due primarily to the reflection losses contributed by the impedance mismatch at the interfaces of the layers. The critical conditions by which optimum shielding may be achieved are described below.

To achieve the desired high radial impedance for the composite shield the buffer shield 12 is preferably of a ferromagnetic material having a high permeability and low conductivity such as, for example, iron or Permalloy, and is of a thickness equal to or greater than a classical skin thickness at the lowest signal frequency carried by the cable 11. The buffer shield thickness t_b may be expressed as

$$t_b \geq \frac{1}{\sqrt{\pi f' \mu_b g_b}} \quad (1)$$

where f' is the lowest operating frequency, μ_b the permeability of the buffer material and g_b the buffer material conductivity.

For broad band use it is necessary to consider the resonant frequency of the ferromagnetic material in the buffer shield and its impedance at that frequency. The phenomena of ferromagnetic resonance is now fairly well understood and is discussed in detail, for example, in a paper by C. Kittel entitled "Theory of Ferromagnetic

Resonance Absorption" which was published in Physical Review, volume 73, for 1948, at page 155. For the purposes of the present invention, it is necessary only to state that this phenomena occurs when the frequency of the high frequency electromagnetic energy is such as to excite the ferromagnetic material causing the absorption of energy thereby. At this frequency, which is referred to as the "resonance frequency," the permeability of the material involved decreases to the value for a vacuum. The radial impedance of the buffer layer may be shown to be directly proportional to a function of the permeability and inversely proportional to the conductivity. Thus when ferromagnetic resonance occurs, the radial impedance is markedly reduced and approaches a lower limit. Accordingly, the ferromagnetic material is selected so that either the resonance occurs at a frequency above the highest band frequency carried by the cable or if resonance occurs within the frequency band the material will have a minimum impedance at the resonance frequency which is at least equal to the impedance found to be sufficient at the lowest band frequency. The first condition is substantially satisfied when:

$$\frac{B_{sb}}{\mu_b} \geq \frac{f'}{1.87 \times 10^6} \quad (2)$$

where B_{sb} is the saturation magnetization and μ_b the permeability of the buffer material, μ_v the permeability in a vacuum and f' the highest band frequency. The second condition is substantially satisfied when:

$$\left[\frac{B_{sb}}{\mu_b} \right]^2 \geq \frac{f'}{1.87 \times 10^6} \quad (3)$$

where f' is the lowest band frequency. The resonant frequency f_r at which ferromagnetic resonance occurs and the buffer material will undergo an impedance minimum is substantially:

$$f_r = 1.87 \times 10^6 \frac{B_{sb}}{\mu_b} \quad (4)$$

Since this frequency is determined in part by the permeability of the buffer layer, it follows that the material to be employed in the buffer layer or shield must be chosen both to obtain a desired radial impedance and to meet the requirements of Equations 2 and 3 set forth above. As f' , f'' and μ_v are in each instance fixed by conditions external to the buffer shield, it is evident that for the material chosen to meet the conditions established by Equations 2 or 3 the ratio of the saturation magnetization B_{sb} to the permeability μ_b will have a lower limit.

In the laminated shield 13 the layers 14 and 15 are chosen of materials having different intrinsic impedances so that high reflection losses will be effected. In addition, it is desirable that the product of the permeability and conductivity for each material be large in order to afford a high radial attenuation loss. Both of these conditions are satisfied by the use of one material having a permeability of μ_1 and conductivity g_1 and another material having a permeability μ_2 and g_2 so that:

$$\mu_1 \gg \mu_2 \quad (5)$$

$$g_1 \ll g_2 \quad (6)$$

While alternate layers of different ferromagnetic materials such as iron and Permalloy may be used, it was found in practice that best results are obtained with the use of alternate layers of conductive material other than ferromagnetic material such as copper and ferromagnetic material such as iron. In Fig. 2 and 3 layer 14 is of conductive material other than ferromagnetic and layer 15 is of ferromagnetic material.

The ratio of the thickness of the individual layers, the number of layer pairs and the thickness of the laminated shield are all critical values determined by the

constants of the materials used and the loss desired to be inserted by the laminated shield. For most effective radial shielding losses, it has been found that the optimum ratio θ of the thicknesses of the materials comprising each double layer is:

$$\theta = \frac{t_1}{t_1 + t_2} = \frac{1}{2} \frac{\mu_1 g_2 + \mu_2 g_1 - 2\mu_2 g_2}{\mu_1 g_2 + \mu_2 g_1 - \mu_1 g_1 - \mu_2 g_2} \quad (7)$$

where t_1 is the thickness of the material having a permeability μ_1 and conductivity g_1 and t_2 is the thickness of the other material as shown in Fig. 3. In practice where copper and iron were used θ was found to be equal to six-tenths. The thickness t_L of the laminated shield may be selected arbitrarily or determined by considering the radial attenuation loss L_L desired to be inserted by the laminated shield. In the latter case, the thickness of the laminated shield t_L may be expressed substantially as:

$$t_L = \frac{L_L - 20 \log_{10} \left[\frac{(Z_m + K)(Z_b + K)}{2K(Z_b + Z_m)} \right]}{8.686 K[g_1 \theta + g_2(1 - \theta)]} \quad (8)$$

where Z_m is the radial impedance at radius c of the buffer material and K is the iterative impedance of a chain of infinitesimally thin double layers of materials used in the laminated shield. It is clear that in the instance where two shielded cables are placed adjacent as shown in Fig. 4, Z_m will be equal to Z_b and Equation 8 will be modified accordingly.

The optimum number of double layers n required to produce maximum radial insertion loss is found to be:

$$n = t_L \sqrt{\pi f'(\mu_1 g_2 + \mu_2 g_1) \theta (1 - \theta)} \quad (9)$$

In practice where conditions were selected so that $t_L = 0.0073$ centimeter, $f' = 1$ megacycle per second and $f'' = 1000$ megacycles per second the optimum number of double layers w was found to be five.

As in the case of the buffer shield, consideration must be given to the resonant frequencies of the materials used in the laminated shield. Generally, the materials must be selected so that even at a resonant frequency for either of the materials the minimum required attenuation will be provided by the laminated shield. Hence, either both materials must be resonant above the highest band frequency or at least the low permeability material must be substantially non-resonant within the frequency band, in which case:

$$\frac{B_{s2}}{\mu_2} \geq \frac{f''}{1.87 \times 10^6} \quad (10)$$

and the impedance of the high permeability material is found to be expressed by the equation:

$$\frac{B_{s1}}{\mu_1} \geq \frac{L_L^2}{444 \times 10^6 (1 - \theta) 2\mu_2 g_2 t_L^2} \quad (11)$$

where B_{s2} and B_{s1} are each the saturation magnetization of the low permeability and high permeability materials respectively.

It is understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements might be derived by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A shield for a transmission line comprising an inner layer of ferromagnetic material characterized as having a high intrinsic impedance as compared to the corresponding property of said line and a contiguous outer layer of laminated materials characterized as having a high loss per unit thickness as compared to the corresponding loss of said inner layer and comprising plural pairs of laminations, one lamination of each pair having an intrinsic impedance differing from that of the other lamination of said pair.

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2. A shield for a transmission line comprising an inner casing of ferromagnetic material characterized as having a numerically high permeability as compared to the numerical value of conductivity of said material and a contiguous laminated outer casing characterized as having a high loss per unit thickness as compared to the corresponding loss of said inner casing and comprising plural pairs of laminations, one lamination of each pair having an intrinsic impedance differing from that of the other lamination of said pair.

3. A shield according to claim 2 wherein said laminated casing comprises alternate layers of first and second sheathing materials, said first material having a high permeability and a low conductivity as compared to the corresponding properties of said second material.

4. A shield according to claim 2, wherein said laminated casing comprises alternate layers of conductive materials, one set of alternate layers being of ferromagnetic material.

5. A composite shield for a transmission line carrying electromagnetic waves comprising an inner casing of ferromagnetic material, said casing being of substantially a classical skin thickness at the lowest frequency of said electromagnetic waves, and a contiguous outer casing of laminated construction comprising a plurality of double layers of conductive materials, one layer of each said double layer being of ferromagnetic material.

6. A composite shield for a transmission line carrying electromagnetic waves comprising an inner casing of ferromagnetic material and a contiguous outer casing of laminated construction comprising a plurality of double layers of conductive material, one layer of each said double layer being of ferromagnetic material and a layer of conductive material, the ratio θ of the thickness of said ferromagnetic material to the thickness of a double layer being given substantially by the equation:

$$\theta = \frac{1}{2} \frac{\mu_1 g_2 + \mu_2 g_1 - 2\mu_2 g_2}{\mu_1 g_2 + \mu_2 g_1 - \mu_1 g_1 - \mu_2 g_2}$$

in which μ_1 and g_1 are respectively the permeability and conductivity of said ferromagnetic material and μ_2 and g_2 are respectively the permeability and conductivity of said conductive material.

7. A composite shield according to claim 6 wherein the number of double layers is given substantially by the equation:

$$n = t_L \sqrt{\pi f' (\mu_1 g_2 + \mu_2 g_1) \theta (1 - \theta)}$$

in which n is the number of double layers, t_L is the

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thickness of said outer casing and f' is the lowest frequency of said electromagnetic waves.

8. A composite shield for transmission line carrying electromagnetic waves comprising an inner casing of ferromagnetic material characterized as having a high intrinsic impedance as compared to the corresponding property of said line and a contiguous outer casing of laminated materials characterized as having a high loss per unit thickness as compared to the corresponding losses of said inner layer, said ferromagnetic material having physical properties so that:

$$\left[\frac{B_{sb}}{\mu_v} \right]^2 \geq \frac{f'}{1.87 \times 10^6}$$

in which B_{sb} is the saturation magnetization and μ_b the permeability of said material, μ_v the permeability in a vacuum and f' the lowest electromagnetic wave frequency whereby said intrinsic impedance is maintained high over a broad band of frequencies.

9. A composite shield for a transmission line carrying a band of frequencies of electromagnetic waves comprising an inner casing of ferromagnetic material and a contiguous outer casing of laminated construction comprising alternate layers of ferromagnetic materials and forming plural pairs of laminations of unlike characteristics within each pair and conductive materials, said materials being chosen so as to be non-resonant over said band of frequencies.

10. A shield for a transmission line carrying electric currents comprising an inner core of high impedance material characterized as having a high permeability and a low conductivity as compared to the corresponding properties of said line and a contiguous outer core of laminated material characterized as having a high radial attenuation loss and a high reflection loss as compared to the corresponding losses of said inner core and comprising plural pairs of laminations, one lamination of each pair having an intrinsic impedance differing from that of the other lamination of said pair.

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