

[72] Inventors **George Bahder**
Edison;
Carlos Katz, Bayonne, both of, N.J.
 [21] Appl. No. **862,353**
 [22] Filed **Sept. 30, 1969**
 [45] Patented **July 20, 1971**
 [73] Assignee **General Cable Corporation**
New York, N.Y.

2,992,425	7/1961	Pratt.....	174/35 X
3,080,446	3/1963	Volk.....	174/25
3,160,702	12/1964	Lapsley.....	174/32
3,179,904	4/1965	Paulsen.....	174/36 X
3,339,007	8/1967	Blodgett.....	174/25
3,413,405	11/1968	Myers.....	174/36
3,484,532	12/1969	Anderson.....	174/36

FOREIGN PATENTS

870,953	6/1961	Great Britain.....	174/36
880,658	4/1943	France	174/36

Primary Examiner—Lewis H. Myers

Assistant Examiner—A. T. Grimley

Attorney—Sandoe, Hoppood & Calimafde

[54] **PIPE-TYPE CABLE SYSTEMS WITH REDUCED AC LOSSES**

16 Claims, 12 Drawing Figs.

[52] U.S. Cl..... **174/36,**
174/26, 174/108, 174/113, 336/218

[51] Int. Cl..... **H01b 9/02**

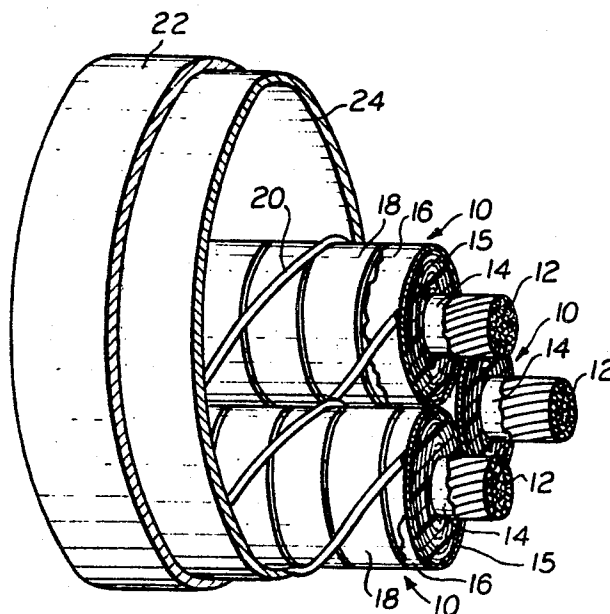
[50] Field of Search..... **174/24, 25,**
26, 32, 35, 36, 102, 103, 105, 106, 108, 109, 113,
117.1; 336/218

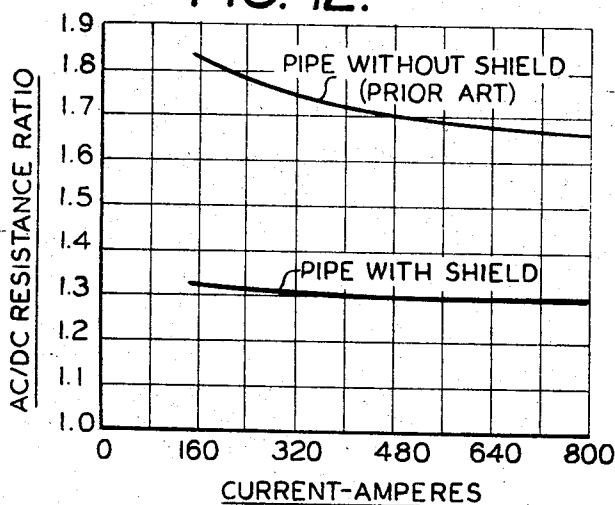
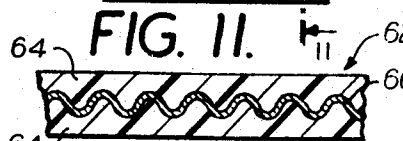
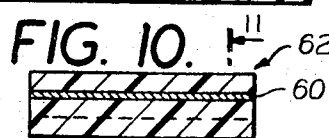
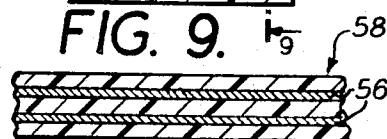
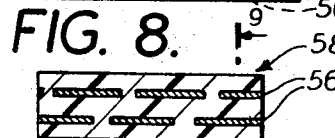
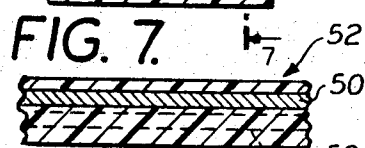
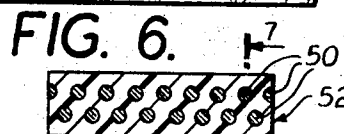
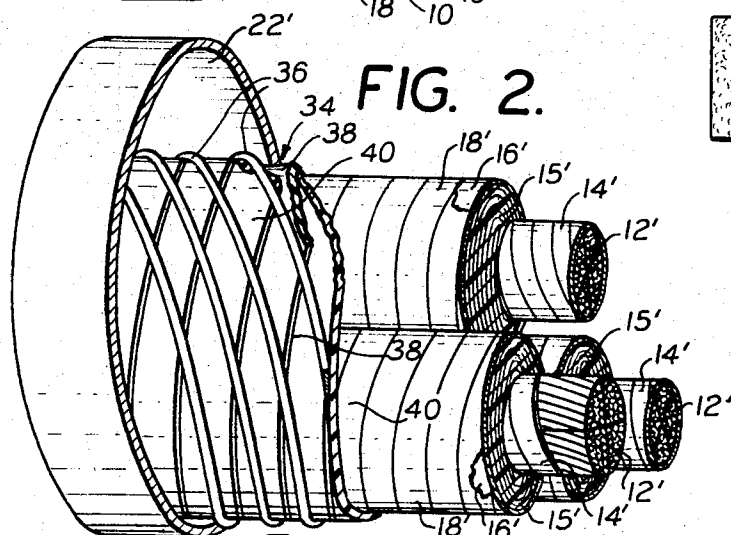
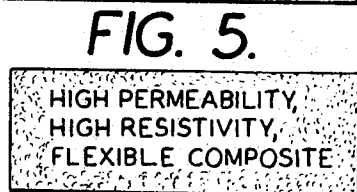
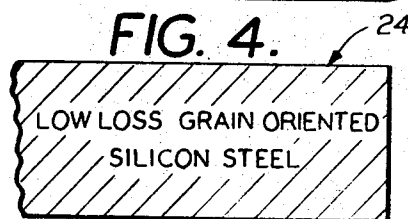
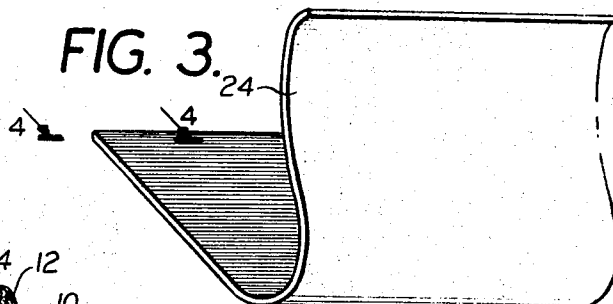
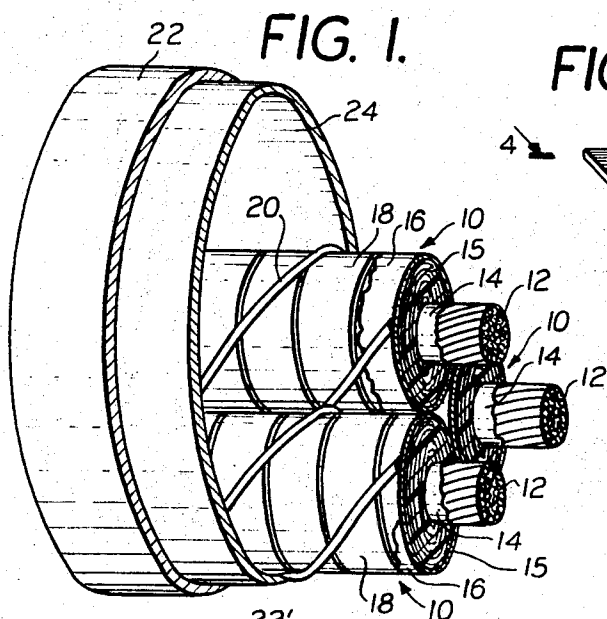
[56] **References Cited**

UNITED STATES PATENTS

2,665,328 1/1954 Atkinson et al..... **174/25**

ABSTRACT: A magnetic, low-loss liner in a metal pipe reduces the AC loss of high-voltage electrical cable enclosed within the pipe; or the cable in the pipe can be wrapped with a sheet or tapes of the magnetic low-loss material. Tapes used for the purpose can be plastic with suitable metal, such as ferromagnetic material of high permeability distributed through the plastic.





INVENTORS
 George Balder & Carlos Katz
 BY *James H. Haggood*
 & *Calvin M. de*
 ATTORNEYS.

PIPE-TYPE CABLE SYSTEMS WITH REDUCED AC LOSSES

BACKGROUND AND SUMMARY OF THE INVENTION

This invention relates to high-pressure pipe-type cables installed in metallic-type pipes, such as a steel pipe. These cables operate at high pressure of oil or gas and are used for underground and submarine transmission of electric power at high and extra high voltages. In particular, the present invention relates to pipe-type cable systems with reduced AC losses.

The use of steel pipes as an enclosure for the three-phase cable system increases and distorts the magnetic field in the conductors, causing a relatively large increase in the conductor's AC resistance over the corresponding values for the cables placed in air. In addition to the increase in conductor AC resistance, big losses are originated in the pipe due to eddy currents and hysteresis. For instance, in a three-phase, 345 kV, HPOF cable system having segmental copper conductors with a 2000 MCM cross section, the total losses in pipe, with the conductors arranged in a triangular formation, are increased about 35 percent with respect to the losses measured in air and with the conductors arranged in cradle formation this increase is about 50 percent of the corresponding values in air.

Several attempts have been made in the past to reduce the increase in AC resistance due to the use of steel pipes in high-pressure cable systems. The following methods were proposed to reduce the AC losses in pipe-type cables:

1. The use of pipes made of a different material than steel.
2. The use of magnetic pipes provided with a section of nonmagnetic material, or a section having longitudinal slits (U. S. Pat. No. 2,718,542) or provided with circumferential slits (U.S. Pat. No. 2,787,651).
3. The use of a pipe lined with a "magnetic field trap" (U.S. Pat. No. 3,160,702).

Considerations made in the past indicated that losses at 60 Hz could not be reduced over those attainable with steel pipes, by using pipes made of any available nonmagnetic metal of reasonable low price. Tests made using nonferrous materials such as Everdur pipe (6.5 percent conductivity of copper) and aluminum pipe (61 percent conductivity of copper) and aluminum pipe (61 percent conductivity of copper) gave AC resistance of the same order of magnitude as obtained with steel pipes.

U. S. Pat. No. 2,718,542 "Electric Cable Systems" describes the use of a magnetic pipe having a small longitudinal section of nonmagnetic material and/or suggests the use of a pipe made of magnetic material provided with numerous longitudinal slits. U.S. Pat. No. 2,787,651, "Electric Cable Systems" suggests the use of a pipe made of magnetic material provided with numerous circumferential, or a helical slit. These methods provide only a very slight reduction in the AC losses, much below the value which might be interesting from the practical point of view. This is due to the fact that the major portion of the losses are caused by eddy currents and the proposed methods give only a small reduction of these currents.

U.S. Pat. No. 3,160,702, "Alternating Current Pipe Cable System with Magnetic Field Trap" discloses the use of a pipe lining material made of a dielectric resin and having dispersed in it a magnetic material. Such pipe lining creates an insulation layer between the cables and the pipe and consequently the cable is insulated from the pipe. The use of such a pipe appears to be dangerous for the cable system in case of lightning, and switching surges, and in case of ground faults which cause overvoltages. Under overvoltage conditions the lining material may break through, causing arcing which destroy the cable shield and subsequently, the cable insulation.

With the invention described in this specification, the AC losses in pipe-type cable systems can be substantially reduced without increasing the susceptibility of the system to overvolt-

ages. For this purpose the cables installed in the pipe must be surrounded with a layer of special magnetic material. The surrounding layer should cover at least three-quarters, but preferably more, of the cable assembly circumference and must have the following properties:

1. The reluctance of the layer along the circumference should be lower than 5×10^7 1/H per foot of cable.
2. The 4 resistance in the longitudinal direction should be higher than 10^{14} ohms per foot of cable.
3. The electrical resistance in the radial direction should be less than 1 ohm per foot of cable.

With this invention at least 23 percent of the power loss, when transmitting AC can be saved; or the line-current-carrying capacity can be increased accordingly.

Other objects features and advantages of the invention will appear or be pointed out as the description proceeds.

BRIEF DESCRIPTION OF DRAWING

In the drawing, forming a part hereof, in which like reference characters indicate corresponding parts in all the views:

FIG. 1 is a diagrammatic view showing electric cables enclosed within a pipe and provided with a special magnetic shield, in accordance with this invention;

FIG. 2 is a modification of the construction shown in FIG. 1 with the special magnetic shield made a part of the cable;

FIG. 3 is a diagrammatic view showing material from which the special magnetic shield can be made;

FIG. 4 is a greatly enlarged sectional view of the line 4-4 of FIG. 3;

FIG. 5 is a view similar to FIG. 4 but showing a modified construction of the special magnetic shield material;

FIG. 6 is a sectional view showing another form of material for the special magnetic shield;

FIG. 7 is a sectional view taken on the line 7-7 of FIG. 6;

FIG. 8 is a view similar to FIG. 6 but showing still another modification of the invention;

FIG. 9 is a sectional view taken on the line 9-9 of FIG. 8;

FIG. 10 is a sectional view similar to FIGS. 6 and 8 but showing still another modification of the invention;

FIG. 11 is a sectional view taken on the line 11-11 of FIG. 10; and

FIG. 12 is a graph showing one set of new results obtained with this invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 shows electrical cables 10 of conventional construction and each of which comprises a center conductor 12, a conductor shield 14, insulation 15, an insulation shield 16, overlying moisture protection tapes 18 and skid wires 20. These cables 10 carry three-phase power and they are enclosed in a metal pipe 22, usually a steel pipe.

In order to reduce the alternating current power losses, the metal pipe 22 has a special magnetic liner 24. This liner provides a magnetic shield inside the pipe 22. The liner 24 is made of material having high permeability and low loss. The magnetic shield can be a metal alloy, as will be explained in connection with the other figures.

When used as a liner for the pipe 22, the magnetic shield 24 preferably covers the entire inside surface of the pipe, but this is not essential. For good results, however, the shield 24 should extend around at least three-quarters of the circumference of the pipe. The shield 24 reduces the magnetic flux in the pipe 22 and thereby decreases the AC losses. On the other hand, the high longitudinal resistivity of the shield 24 prevents high losses within the shield.

In describing the special magnetic shields of this invention as having high permeability and low loss, these terms are to be understood as designating the relation between the magnetic flux density at a point in a material to the magnetic intensity at the same point, and the reluctance and resistance characteristics described above. In describing the magnetic shield as

being made of a metal alloy, the term "alloy" is used in a special broad sense to include not only true alloys of metals but also metal in powdered form dispersed throughout a plastic matrix or metal encapsulated in plastic tapes or sheets, as will be described in connection with FIGS. 5—11.

With the construction shown in FIG. 1, this invention requires no change in the design of the cables. In the construction which will be described in connection with FIG. 2, special cable is used which does not require the insertion of the liner 24 into the pipe because the liner is made a part of the cable itself and is, therefore, conveniently pulled into the pipe with the cable.

FIG. 3 shows a section of the metal sheet before it is inserted into the pipe 22 of FIG. 1. The sheet is preferably a strip having a width substantially equal to the inside circumference of the pipe in which it is to be used. This particular sheet is a low-loss, grain-oriented silicon steel, as indicated by the cross section shown in FIG. 4.

The low-loss, high-permeability metal can also be manufactured into a pipe with an outside diameter equivalent to the inside diameter of the pipe 22 and factory installed in the pipe 22.

If the material used for the special magnetic shield is sufficiently flexible it can be wrapped as a sheet around the group of cables; but to make this more practical with cables that have to be pulled into long lengths of pipe 22, a cable of special construction is used.

FIG. 2 shows such a special cable. Corresponding parts are indicated by the same reference characters as in FIG. 1 but with a prime appended. The individual shielded and insulated conductors of FIG. 2 are wrapped in a special magnetic shield 34 which is formed by tapes wound helically, preferably with overlapping convolutions, around the insulated and shielded conductors to form a composite cable. Skid wires 36 are wound over the special magnetic shield 34.

If the resistivity of a tape 38 used for the magnetic shield 34 would otherwise be too high, it is intercalated with another tape 40 which may be nonmagnetic or magnetic material but which has good electrical and thermal conduction properties. Copper or aluminum are appropriate for the tape 40. With this intercalated construction, fault currents or overvoltages can be easily dissipated to ground.

If the special cable construction shown in FIG. 2 is not commercially available, the wrapping of the tapes 38 and 40 and the application of the skid wires 36 can be done in the field at the time the cables are to be pulled into the pipe 22'.

FIGS. 1 and 2 show the conductors 12 and 12', respectively, in a triangular configuration. The invention can be used with cables in a cradle configuration or in any other configuration but because the triangular configuration in a cable system has lower losses, it is more efficient for use with this invention.

FIG. 5 shows a cross section of a tape made of plastic material having ferromagnetic material dispersed through the plastic. The ferromagnetic material can be metal or synthetic; and it should have a very fine powdery appearance before being mixed. Magnetic materials such as polycrystalline ceramics used in the manufacture of ferrites, containing iron, oxygen and one or more of the following metals: copper, nickel, zinc, cadmium, magnesium, manganese, or others providing the characteristics of magnetic ferrites, are appropriate for this invention.

FIGS. 6 and 7 show a special construction in which a low-loss magnetic material in the form of rods 50 are imbedded or encapsulated in a plastic tape 52. These rods 50 are disposed in two rows with the rods in one row staggered in relation to the rods of the other row. The rods preferably extend in the direction of the length of the tape 52 and in the construction shown, the rods 50 are of the same diameter.

The rods 50 are parallel to one another and are spaced from one another. It is desirable to have the diameters of the rods at least one row greater than the spacing of the rods of the other row so that the projections of the rods on the top and bottom surfaces of the tape cover the entire area of these surfaces.

FIGS. 8 and 9 show a modified construction in which plates 56 are substituted for the rods 50. These plates have widths greater than the spacing between them and they are staggered so that the projections of the plates cover the entire areas of the top and bottom surfaces of the tape 58. As shown, the plates 56 provide substantially a double layer of metal in the tape 58.

FIGS. 10 and 11 show another construction in which a sheet or tape of metal 60 is of continuous extent throughout the length and breadth of a tape 62. This metal 60 is a low-loss magnetic metal, as in the case of the rods and plates of FIGS. 6—9, and its flexibility is increased by having it corrugated with the corrugations extending transversely of the length of the tape, and preferably at right angles to the length of the tape. The metal 60 is coated on both sides with plastic 64.

The magnetic low-loss metal alloys and the flexible combination or composite magnetic materials previously described, can be used in the form of pipes, sheets, tapes, strips or any other form suitable for the proposed application. The materials can be used in single or multiple layers, they can be plain or embossed, they can be coated or not coated. In the case where they are used in the form of tapes, they may be applied butt and if the thickness allows, overlapped. The magnetic shield materials to be used in the described systems have to be able to: withstand the mechanical stresses, which may be developed during installation or service life of the cables without breaks or tears; they have to be compatible with the oils (natural or synthetic) used in cable installations; and they have to be able to withstand the cable service temperatures. Some high polymer materials, such as polytetrafluoroethylene, hexafluoropropylene, polyethylene terephthalate, polypropylene, polycarbonate and others are appropriate for use as encapsulating materials; however, any other materials providing the above characteristics could be used for this application. The combination or composite material can be irradiated to improve the memory and thermal characteristics of the plastic.

In cases where the tape used for the special magnetic shield has electrical resistance which is otherwise too high, the insulation shield can be connected to the metallic pipe by a continuous strip of highly conductive material applied intercalated with the magnetic shield material. It should be understood that the low-loss magnetic materials used for the special magnetic shield of this invention can be applied in either single or multiple layers; and that the material can be plain or embossed and coated or not coated, as conditions warrant.

FIG. 12 is a graph showing new results obtained with this invention, as compared with the results obtained by the prior art.

FIG. 12 allows the comparison of two sets of AC/DC resistance ratios measured at various currents on an assembly of three cables in a triangular configuration. In both cases, the same 10 inches ID steel pipe was used. The upper curve indicates AC/DC resistance ratios for the cables installed in the pipe without a magnetic shield (present practice). The lower curve indicates AC/DC resistance ratios for the same cables installed using the high-permeability, relatively high-resistivity screen in accordance with one of the variations of the disclosure (wrapped as illustrated in FIG. 2). The pipe used for these tests is similar to that used by an electric utility for the installation of 345 kV, HPOF cables. The high-permeability material used in this particular case consisted of a grain-oriented silicon steel tape, 2 inches wide, 14 mil thick, insulated with an inorganic coating. This material had a relative magnetic permeability (μ) of about 6000 at a flux density of 50 gauss and a resistivity of 50 microhm-centimeter.

FIG. 12 gives the AC/DC resistance ratios; which are practically independent of the current. For any given current the AC/DC ratio is equal to the ratio of watts loss when carrying alternating-current to the watts loss when carrying direct-current.

Further tests indicate that by using other variations of these methods, considerable savings in electric power or increase in

current-carrying capacities can be obtained. As an example, following are a few of the results of measurements made at 800 amps. with the cables in a triangular configuration in the previously described steel pipe:

Cable Assembly:	AC/DC Resistance Ratios
1. In a steel pipe as presently used	1.66
2. In a steel pipe lined with a high permeability silicon steel, except for a longitudinal strip 1 inch wide	1.45
3. In a steel pipe lined with a high permeability silicon steel (100 percent coverage)	1.42
4. In a steel pipe with the three cables wrapped in a sheet of high permeability silicon steel	1.42

It was found that with the cables and conditions used during these tests, an increase in the thickness of the silicon steel above the 14 mils used would not produce any further significant decrease in the AC/DC resistance ratios of this cable system.

The preferred embodiments of the invention have been illustrated and described and they are defined in the appended claims.

We claim

1. An electrical cable system for transmitting alternating-current when the cable is enclosed in a pipe, including a group of individually insulated conductors extending side by side, and a special magnetic shield surrounding at least three-quarters of the circumference of the group, the shield being made of material having high permeability and low loss, the magnetic shield having a reluctance along its circumference lower than 5×10^7 1/H per foot of the cable system, an electrical resistance in the direction of the length of the cable system higher than 10^{14} ohms per foot of the cable system, and an electrical resistance in the direction of the radius of the cable system greater than 1 ohm per foot of the cable system.
2. The electrical cable system described in claim 1 characterized by the magnetic shield having a reluctance along its circumference lower than 5×10^7 1/H per foot of the cable system, an electrical resistance in the direction of the length of the cable system higher than 10^{14} ohms per foot of the cable system, and an electrical resistance in the direction of the radius of the cable system greater than 1 ohm per foot of the cable system.
3. The electrical cable system described in claim 1 characterized by the special magnetic shield being wrapped around the outside of the group of insulated conductors, and a skid wire over the outside of the shield.
4. The electrical cable system described in claim 1 characterized by the individual conductors being wrapped together by the special magnetic shield.
5. The electrical cable system described in claim 1 characterized by there being three conductors in the group and each of which has a conductor shield, an insulating layer over the conductor shield, an insulation shield covering the outside of the insulation, moisture protection means outside of the insulation shield, the special magnetic shield extending around the full circumference of the group of conductors outside of the moisture protection means, and a skid wire over the outside of the special magnetic shield.
6. The electrical cable system described in claim 5 charac-

terized by the special magnetic shield comprising tapes made of plastic material with metal distributed through the plastic, the metal distribution including metal that is oriented so that the projections thereof on the inner surface of the tape cover the entire inner surface thereof.

7. The electrical cable system described in claim 4 characterized by the special magnetic shield being a helically wound layer of flexible tape made of plastic material having two rows of flexible rods therein with the rods extending lengthwise of the tape and with the rods of one row in staggered relation to the rods of the other row, all of the rods being generally parallel to one another and the rods of each row being spaced from one another transversely of the tape, and the rods of one row being of a diameter greater than the spacing of the rods of the other row.

8. The electrical cable system described in claim 4 characterized by the special magnetic shield being a helically wound layer of flexible tape made of plastic material having two rows of plates therein with the plates extending lengthwise of the tape and with the plates of one row in staggered relation to the plates of the other row, all of the plates being generally parallel to one another and the plates of each row being spaced from one another transversely of the tape, the plates of one row being of a width greater than the spacing of the plates of the other row.

9. The electrical cable system described in claim 4 characterized by the special magnetic shield being a helically wound layer of flexible tape made of plastic material having ferromagnetic material dispersed throughout the plastic.

10. The electrical cable system described in claim 4 characterized by the special magnetic shield being made of flexible magnetic tape.

11. The electrical cable system described in claim 10 characterized by the magnetic tape being intercalated with metal tape.

12. The electrical cable system described in claim 4 characterized by the special magnetic shield being a helically wound layer of flexible metal tape with the metal corrugated and the corrugations extending transversely of the tape, and with layers of plastic bonded to the surfaces of the corrugated metal.

13. The electrical cable system described in claim 4 characterized by the special magnetic shield being made of flexible magnetic tape, a metal pipe in which the cable is enclosed, and a continuous strip of highly conductive metal connecting the shield to the pipe in which the cable is enclosed.

14. The electrical cable system described in claim 1 characterized by a metal pipe in which the cable is enclosed, the special magnetic shield being a liner in the pipe in contact with the inside surface of the pipe and extending around substantially the entire circumferential extent of said surface.

15. An electrical cable system enclosure including a metal pipe, and a liner in the pipe made of metal having higher permeability and lower loss than the metal pipe the liner having a reluctance along its circumference lower than 5×10^7 1/H per foot of the cable system, an electrical resistance in the direction of the length of the cable system higher than 10^{14} ohms per foot of the cable system, and an electrical resistance in the direction of the radius of the cable system greater than 1 ohm per foot of the cable system.

16. The electrical cable system enclosure described in claim 15 characterized by the liner being an inner pipe enclosed in the first pipe.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,594,492 Dated July 20, 1971

Inventor(s) George Bahder et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, lines 44 and 45, cancel "an aluminum pipe (61% conductivity of copper)"; Column 2, line 8, "4" should read -- electrical --. Column 2, line 11, Column 5, lines 37 and 44 and Column 6, line 57,

" 10^{14} ", each occurrence, should read -- 10^{-4} --.

Signed and sealed this 1st day of August 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents