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(71) Applicants and
(72) Inventors: **WHITESIDE, Michael, James** [GB/GB]; 11 Hill Crescent, Surbiton, Surrey KT5 8DT (GB). **GABLE, Daniel, Mark** [GB/GB]; Flat A, 34 Birchington Road, London NW6 4LJ (GB).

(74) Common Representative: **WHITESIDE, Michael, James**; 11 Hill Crescent, Surbiton, Surrey KT5 8DT (GB).

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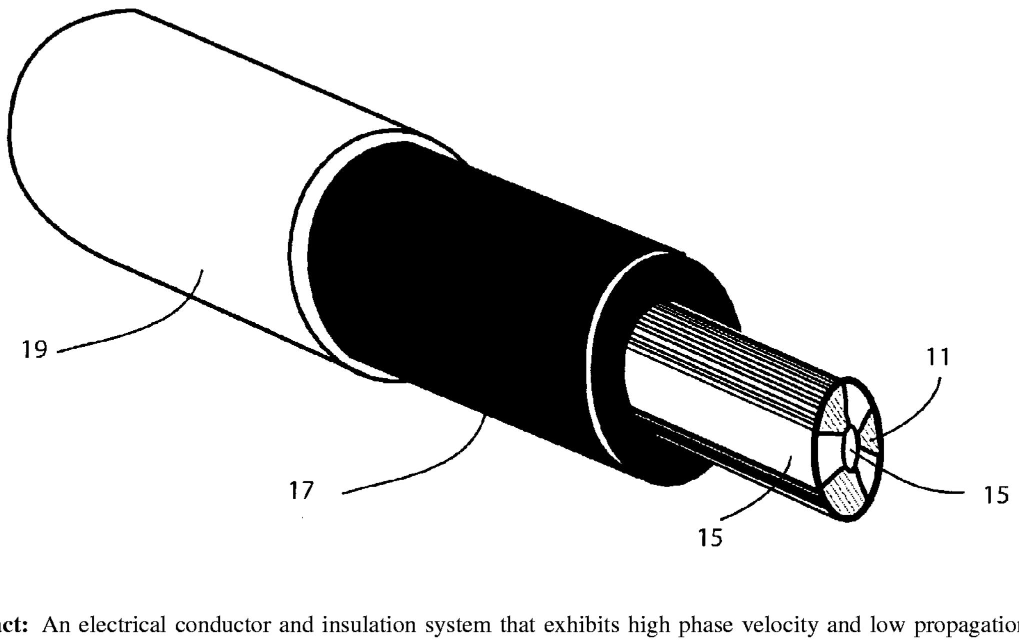
(54) Title: ELECTRICAL CABLE CONDUCTOR AND DUAL INSULATION SYSTEM



(57) Abstract: An electrical conductor and insulation system that exhibits high phase velocity and low propagation delay with improved direct current, low frequency and high frequency impedance characteristics for transmitting a broad frequency spectrum of signals for certain applications including, but not limited to, audio frequency and audio frequency harmonic loudspeaker signals. More specifically this invention relates to an electrical conductor and insulation system comprising a finely stranded conductor consisting of plated and non-plated strands, with a dual layer, low dissipation, low dielectric coefficient insulation in an arrangement such that said cable demonstrates low propagation delay with improved large signal current carrying capacity.

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Electrical cable conductor and dual insulation system

Technical Field

The present invention relates to a cable that exhibits high phase velocity and low propagation delay with improved direct current, low frequency and high frequency resistance for transmitting a broad frequency spectrum of signals for certain applications including, but not limited to, audio frequency and audio frequency harmonic loudspeaker signals.

More specifically this invention relates to a cable comprising a finely stranded conductor consisting of plated and non-plated strands, with a dual layer, low dissipation, low dielectric coefficient insulation in an arrangement such that said cable demonstrates low propagation delay with improved large signal current carrying capacity.

Background of the invention

The evolution of high fidelity audio reproduction has lead to an increase in the sophistication of audio playback systems that enable reproduction of acoustic detail to a far greater accuracy and clarity than has previously been attainable.

In order for the audio reproduction system components to work and interact together to provide the overall high level of performance of the audio reproduction system, the components such as, but not limited to, amplifiers and loudspeakers require interconnection cables that give electrical connectivity between them with minimal frequency related A.C. and D.C. electrical resistance, minimal reactive impedance, minimal distortion and minimal electrical parasitic influence on the currents and voltages that flow between the components.

The ability of the ear to detect relatively small phase and amplitude inaccuracies in audio signals and the effect this has on the perception of a sound source's position, sound field and the overall authenticity of the audio images generated from an audio reproduction system is surprisingly outstanding.

The commonly known Hass effect demonstrates how amplitude, relative timing and relative phase of the fundamental, harmonic and Fourier components of an audio signal provide the cues which the human brain interprets to construct spatial, positional and directional information with.

The three dimensional acoustic effect created by the human brain's interpretation of the relative amplitude, timing and phase of the fundamental, harmonic and Fourier components of a compound acoustic signal is often referred to as the 'sound stage', 'staging', 'image' or the 'sound field'.

The significance of fundamental, harmonic and Fourier component's relative amplitude, phase and timing in audio signal is demonstrated by the fact that many audio reproduction systems depend upon and manipulate these parameters to create and alter the apparent direction and position of sound sources and also to provide a spatial impression of the sound field. A signal with fundamental and harmonic components that are in accurate and correct phase position and amplitude proportion relative to each other is referred to as a phase and amplitude coherent signal.

Loss of stable and correct relative phase and amplitude relationship of audio signal fundamental frequencies and component harmonics and the introduction of phase delays in a signal, causes degradation of the audio spatial and directional information and its perceived authenticity. This is acutely apparent in highly accurate and sensitive modern audio reproduction systems where phase and amplitude related distortions are manifest as loss of the spatial information and alteration of the impression of the sound's three dimensional image and sound field. This is especially apparent when listening to sounds with subtle fundamental and harmonic component content that constitute the compound sound to create an acoustic image, for example, but not limited to, an orchestra or human voices.

Typically loss of phase and amplitude coherence of harmonics and Fourier components that are out of the basic 20Hz to 20kH audio band is manifest by loss of clarity and stability and natural authenticity of the sound, often being referred to as a 'hard' or 'indistinct' sound.

The undesired effects and indistinct soundstage caused by the phenomena of digital clock instability in digital audio reproductions systems, often referred to as Jitter, bears witness to how perceived sound is distorted by alteration of the relationship between harmonics and Fourier components that constitute an audio signal that occur at frequencies considerably higher than the basic 20Hz to 20kHz fundamental audio frequency band.

Loss of phase and amplitude coherence often results from lack of close electrical coupling of audio system components. For example reactive load components such as loudspeaker drivers and crossover networks need to be closely coupled to the controlling source driver, i.e. the amplifier. Resistance or impedance in this coupling introduces electrical damping, which diminishes the amplifier's control over the loudspeaker's component parts and diminishes the amplifier's ability to arrest vibrations and resonance in reactive load components. The damping introduced by resistance or impedance inherent in the coupling introduces phase delays to the signal that lead to loss of critical fundamental, harmonic and Fourier component phase and amplitude coherence.

It is thus desirable to minimise the undesirable effects of coupling between components in an audio reproduction system and to minimise any undesired electrical interaction between the components and the coupling medium itself. To achieve this, it is necessary to have an interconnection electric cable that exhibits high velocity ratio with low resistive and reactive impedances.

Therefore, an electrical cable is sought which electrically links equipment including, but not limited to, audio reproduction system components with minimal undesired effect on how the components work and interact together. The sought after cable is often referred to in the high fidelity audio media as being 'transparent' and being 'fast', meaning that electrically it has minimal capacitance, inductance and resistance and has a low propagation delay with high velocity ratio and exhibits minimal audio and high frequency energy dissipation in both conductor and insulation.

A prior art method of constructing the above described sought after cable has been to use stranded conductors in order to provide a large conductor surface area for improved 'skin effect' high frequency transmission conduction. A disadvantage of this method is that it is found to add 'parasitic' elements to the sound quality due to inter-strand reactions.

A prior art method to reduce the fore mentioned inter-strand reactions has been to insulate the individual strands of the conductors; this is often referred to as Litz wire. The disadvantage of this technique is that virtually all of the additional conductor surface area gained for 'skin effect' high frequency transmission is in immediate contact with insulation dielectric which, by the nature of dielectrics, increases the propagation delay of the cable. This is further accentuated as, typically, practical size restrictions and the small scale of the insulation required does not allow for the insulation to be formed with foamed material or by using other techniques that reduce undesired insulation dielectric effects.

Another prior art method for attaining low propagation delay is to provide a large surface area to enhance high frequency skin effect conduction by forming conductors into flat foil or ribbon form conductors and using these types of conductors in conjunction with an insulation system that offers low dielectric constant. This method has the disadvantage of providing a reduced total conductive cross sectional area relative to the conductive surface area when compared to other non-flat conductor types which results in an increased low frequency impedance relative to high frequency impedance. The effect of this is significant in audio signals because in such signals generally the majority of audio signal energy is transmitted at frequencies below 500 Hz, and so such high, low-frequency impedance relative to low, high-frequency impedance in an electrical conductor results in undesirable incoherent relative phase and amplitude effects.

A further disadvantage of this prior art is that the increased low frequency impedance relative to high frequency impedance undesirably affects the electrical damping factor between connected system components differently at lower frequencies than at high frequencies.

Another disadvantage of this prior art is the large flat surface of the cable offers a large electrically exposed surface for electromagnetic interference to be induced onto and transmitted from.

Another disadvantage of this prior art is that flat, foil and ribbon type cables cannot be successfully twisted together in groups in order reduce electromagnetic linked interference and transmission by way of phase cancellation.

Reduction of many of the undesirable effects that cable has on the way high fidelity audio system components interact is reduced by increased conductor conductivity. Copper is a commonly used material as it has one of the best conductivities of all metals and it is commonly available. The use of other materials with better conductivity than copper has not been commercially practicable because of the relative high cost of these rarer materials, particularly silver, which has the highest conductivity of all metals. Further, the improvement in overall conductivity of conductors formed wholly from silver instead of copper is very marginal relative to the cost differences, with copper having a relative conductivity of 100 and silver with a relative conductivity of approximately 106.

A prior art technique for improving high frequency conductivity of copper conductors is to plate the conductors with a lower resistivity conductor such as silver. A disadvantage of plating one conducting material with another is that the contact between the plated and plating conductor materials establishes an electrical junction that exhibits undesirable effects due to the transition from skin effect conduction in the plating surface to lower frequency conduction in the inner, plated material.

What is required is an electrical cable that can conduct high level loudspeaker currents and provide improved audio frequency and audio high frequency harmonic signal transmission with low propagation delays, minimal phase delays and minimal parasitic electrical interference.

It is an objective of the present invention to provide a conductor and insulation arrangement which eliminates the aforementioned deficiencies inherent in the cables of the prior art while providing improved transmission of high frequency audio signals and the harmonic components of such signals that may additionally be transmitted with high energy, low frequency audio signals.

It is another objective of the present invention to provide an electrical transmission cable which is capable of transmitting high power audio frequency and audio frequency harmonic signal currents more efficiently than cables of the prior art and with improved minimal electrical distortion and minimal electro-mechanical distortion.

It is another objective of the present invention to provide an electrical cable which is capable of transmitting audio frequency and audio frequency harmonic signal currents with stable and accurate relative phase and amplitude relationship between audio signal fundamental frequencies and component harmonics.

Summary of the Invention

The present invention therefore provides an electrical cable that comprises an electrical conductor and insulation system that has:

(a) an electrical conductor made up of a number of strands N where between 5 percent and 95 percent of the number N of said strands are plated in a material which has a relative conductivity of between 1.01 and 1.2 times higher than the conductor strand material that the plating is applied to, where N satisfies the formulae

$$N > 199 \times A$$

where the integer number N is the number of strands comprising the conductor, and A is total cross sectional conducting area of the conductor measured in square millimetres;
(b) a flexible, foamed electrical insulation layer formed around the conductor, said foamed electrical insulation layer being of a dielectric material which has a maximum dielectric constant of 3 which is foamed with a gas to have a minimum of 20% of said gas content; and
(c) a solid, flexible insulation layer that is formed around the said foamed insulating layer.

The conductors of the present invention are characterised by having fine strands of which a portion is plated with a higher conductivity material than the base material. In one preferred embodiment the strands are made from oxygen free copper and three strands out of every seven are plated in silver.

The insulation system of the present invention is characterised by a low dielectric constant and a low dissipation factor. The insulation system of the present invention comprises an inner foamed layer and a solid outer layer. In one preferred embodiment the inner insulation layer is made from polyethylene which is foamed with 25% nitrogen content and the outer insulation layer is made from solid polyethylene.

A plurality of the conductor and insulation system of the present invention may be used to construct a cable comprising a plurality of the said conductor and insulation system that can be twisted together or laid together in parallel and may also, but not necessarily, be contained within an overall sheath or jacket.

Brief description of the drawings

The present invention is illustrated to show examples, not to show limitations, in the figures of the accompanying drawing. In the drawing, the same reference numeral and sign refer to a similar element.
In the drawing:

FIGURE 1 shows a cross sectional representation of the conductor and insulation system according to a preferred embodiment of the present invention.

FIGURE 2 shows a perspective of the conductor and insulation system according to the preferred embodiment of the present invention.

FIGURE 3 shows a cross sectional representation of a cable comprising two conductors and insulation systems of the present invention contained in one jacket according to another preferred embodiment of the present invention.

FIGURE 4 shows a cross sectional representation of a cable comprising four conductors and insulation systems of the present invention contained in one jacket according to another preferred embodiment of the present invention.

Detailed description

Referring to FIG. 1, an electric cable according to a preferred embodiment of the present invention comprises an electric conductor made up of plated copper strands 11 that are twisted together and non-plated strands13 and 15 that are twisted together. In a preferred embodiment the strands are arranged and twisted into groups of either plated strands or non-plated strands. In a preferred embodiment the twisted groups of silver plated copper strands 11 and twisted groups of non-plated copper strands13 are laid up consecutively around a central twisted group of non-plated copper strands 15.

The stranding of the groups 11, 13 and 15 is uncommonly fine such that the concentration of surface electrical fields and current is diffused and distributed over the large surface area provided by the fine stranding so as to eliminate undesirable electrical inter strand reactions.

The stranding is made adequately fine such that the mass of each stand is very low so as to cause each strand to have a very high natural mechanical resonance that is damped by the twist and body of the conductor and insulation body so as to further diminish and render insignificant any undesirable electrical and mechanical inter-strand reactions.

Given that the number of strands, N, in a conductor must be increased by an inverse square function of the strand radii in order to maintain a constant overall cross sectional area, A, of the said conductor, as the conductor strand radii tend toward being very small, the field concentration on the surface area of each strand rapidly tends toward zero and the field pattern tends toward that of a solid conductor that has uniform conductivity at all frequencies.

In practice a suitable stranding is attained where the number of strands, N, exceeds the total conductor cross sectional area of the cable, A, measured in square millimetres by a factor of approximately 200;
that is to say; $N > 199 \times A$

In a preferred embodiment that has a total conductive cross sectional area A per conductor of between 1.0 and 6 square millimetres, the conduct bundles are made up of fine strands of typically 0.035mm radius. This strand size is as fine as is practical for reasons of cable termination and commercial availability.

The high frequency attenuation of a conducting cable pair is approximately given by the following equation:

$$\text{Attenuation} = 8.68\ (\ (R/2)\ C/L) + G/2)\ L/C)\ \text{dB}\ /100\text{m}$$

Where R = high frequency skin resistance in Ohms /100m, C= Capacitance in Farads /100m
L = Inductance in Henrys /100m and G = Conductance in Siemens /100m

The term (R/2) C/L is typically larger than the term (G/2)L/C, therefore in order to achieve minimal attenuation, minimal values of R, G and C are sought.

Referring to Fig. 1, a proportion of the conductor strands 11 are plated with a higher conductivity material than the inner bulk strand material. In a preferred embodiment the conductor strand groups 13 and 15 are made from copper and the conductor strand groups 11 are made from copper that is plated with silver.

The low resistance plating on the conductor strands 11 provides a reduction in high frequency resistance and thus a reduction in high frequency attenuation with better high frequency phase linearity and extended conduction to include higher frequencies.

The plating is of a conductivity and thickness to provide a low impedance path for the very high frequency harmonic and Fourier components of signal transmitted through the conductor. In a preferred embodiment the plated surface material is 30microns thick. In another preferred embodiment the plated surface material is 1.06 times more conductive than the material constituting the inner part of the strands 11, 13 and 15.

The proportion of the amount of plated strands 11 relative to the non plated strands 13 and 15 is selected to ensure a balance in the proportion of high frequency and lower frequency conducting media and to provide smooth transition of conduction of high frequencies flowing in the plated skin strand surfaces and the non-plated strand surfaces.

As is indicated in FIG. 1 a proportion less than 95% of the conductor strands are plated to provide a low impedance skin effect path for the higher Fourier components and frequencies whilst allowing simultaneous conduction to occur in the skin of the non-plated strands, thus causing a smooth and seamless transition of conduction between plated layer skin conduction and conduction in the skins of the non-plated strands and conduction in the bulk of the strands.

This arrangement electrically by-passes any non conductive or other boundary effects that occurs at the junction of the surface of the plating layer conductor material and surface of the plated strand conductive material. In a preferred embodiment a proportion of 47 % of the conductor strands is plated to provide a smooth transition between conduction in the plated surfaces and conduction in the non-plated surfaces and thus by-pass effects caused by the junction of the plating material and the strand material and thus eliminate any undesirable effects present in the zones where the plating is bonded to the strand.

Referring to FIG. 1, a preferred embodiment of the present invention, the conductor is insulated with an extrusion 17 of a foamed insulation material of low dielectric constant. With improvement of high frequency transmission and reduction in harmonic phase delay in a conductor, the high frequency Fourier harmonic propagation delay and dissipation caused by the dielectric constant of the insulation becomes more significant. The insulation material 17 is of low dielectric constant in order to reduce propagation delay and electrical energy dissipation in the cable.

One of the lowest dielectric constant insulation materials in common use for flexible cable is foamed polyethylene that is foamed with nitrogen. Referring to FIG. 1 the foamed dialectic layer 17 has a solid insulation layer 19 extruded over it to provide rigidity and protection for the foamed polyethylene layer. This dual layer insulation system is a well known arrangement and is often referred to as a 'dual insulation system' or a 'foam skin arrangement'.

In a preferred embodiment of the cable, the inner insulation layer 17 is made from foamed polyethylene that is foamed to contain between 25% and 35% air. In a preferred embodiment of the cable the outer insulation layer 19 is an extrusion made of the same polymer as the foamed layer so as cause the two insulation layers 17 and 19 to bond together during the extrusion process which aids the stripping of the cable in preparation for termination.

FIG 2 illustrates an example of a preferred embodiment of the present invention. Referring to FIG. 2, the cable conductor of the preferred embodiment described herein comprises three groups 11 of one hundred and fourteen, 0.035mm radius circular strands of copper that are plated with 10 microns of silver, and three groups 13 of one hundred and fourteen, 0.035mm radius circular strands of non-plated copper that are consecutively placed around a central group 15 of one hundred and fourteen, 0.035mm radius circular strands of non-plated copper. Thus the conductor of the preferred embodiment described herein comprises a total of seven hundred and ninety eight strands, of which approximately 43% are plated with silver.

Referring to FIG. 2, the cable conductor of the preferred embodiment is contained within an extrusion of foamed polyethylene insulation 17 which in this preferred embodiment is foamed with approximately 35% air content. Referring to FIG. 2, the foamed insulation layer 17 has a second insulation layer 19 extruded around it which in this preferred embodiment is made of solid polyethylene.

Referring to FIG 3 and FIG 4 a plurality of the present invention conductor and insulation arrangement can be laid up in a twisted or parallel fashion and sheathed with an overall jacket 21. In a preferred embodiment the sheath material 21 is made of a dissimilar material to the solid insulation layer 19 such that the jacket 21 is prevented from bonding to the insulation 19 which aids stripping of the cable. In a preferred embodiment the jacket material 21 is PVC and the insulation layer 19 is polyethylene.

The present invention is described in connection with what is presently considered to be the most practical and preferred embodiments. However, the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

Claims

1. An electrical cable that comprises an electrical conductor and insulation system that has:

(a) an electrical conductor made up of a number of strands N where between 5 percent and 95 percent of the number N of said strands are plated in a material which has a relative conductivity of between 1.01 and 1.2 times higher than the conductor strand material that the plating is applied to, where N satisfies the formulae

$N > 199 \times A$

where the integer number N is the number of strands comprising the conductor, and A is total cross sectional conducting area of the conductor measured in square millimetres;
(b) a flexible, foamed electrical insulation layer formed around the conductor, said foamed electrical insulation layer being of a dielectric material which has a maximum dielectric constant of 3 which is foamed with a gas to have a minimum of 20% of said gas content; and
(c) a solid, flexible insulation layer that is formed around the said foamed insulating layer.

2. A multiconductor cable comprising a plurality of the conductor and insulation system as defined by claim 1.

3. A multiconductor cable comprising a plurality of the conductor and insulation system as defined by claim 1 contained within an overall sheath.

4. A multiconductor cable comprising a conductor and insulation system as defined by claim 1 that is contained within a overall sheath.

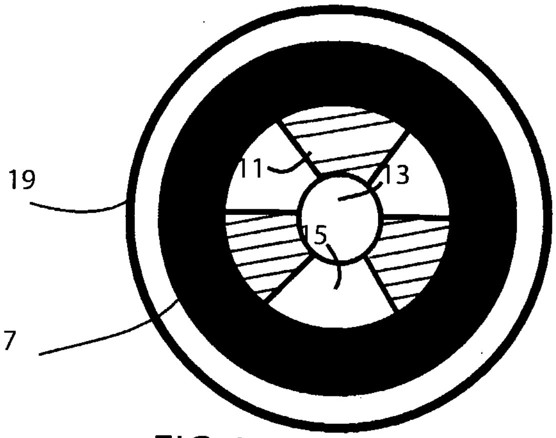

FIG. 1

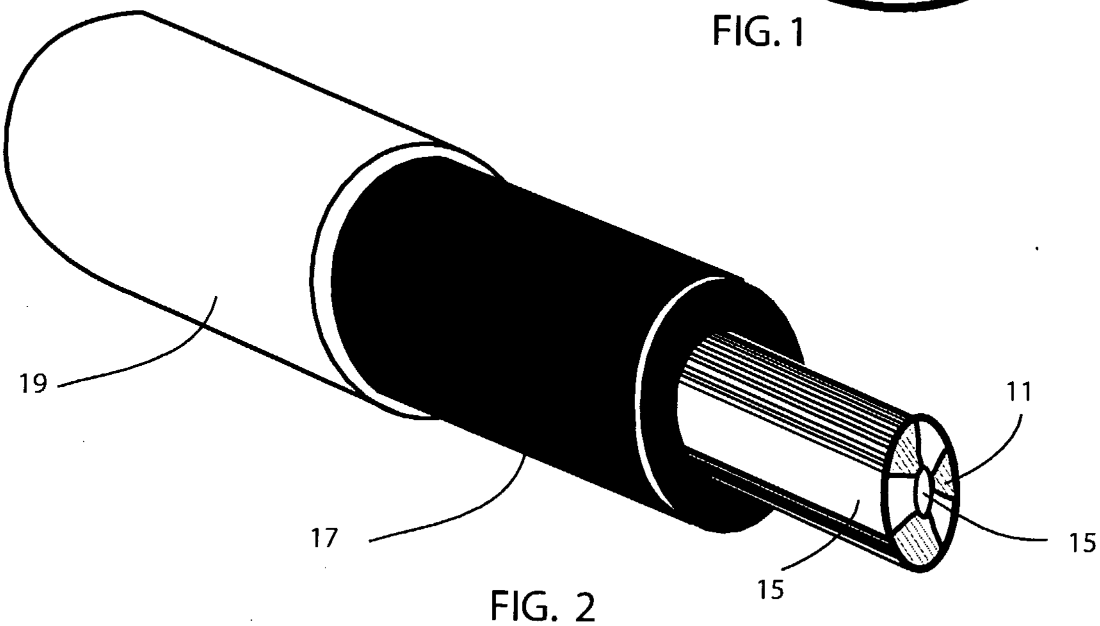

FIG. 2

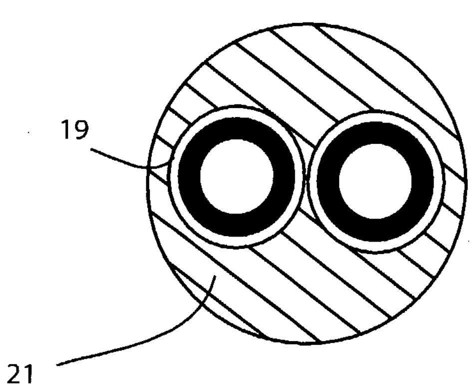

FIG. 3

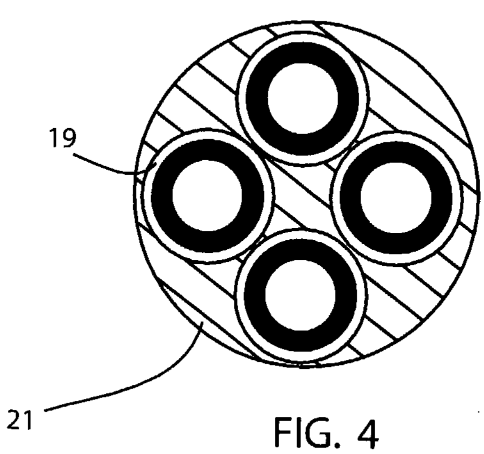

FIG. 4

INTERNATIONAL SEARCH REPORT

ıtional application No
/GB2005/003303

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01B11/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1 566 817 A (RICH ELECTRIC WIRE & CABLE CO., LTD) 24 August 2005 (2005-08-24) paragraph [0012]; figure 1 paragraph [0014] column 4, line 30 - line 42	1-4
Y	US 5 523 528 A (BESE ET AL) 4 June 1996 (1996-06-04) column 3, line 14 - line 28; figure 1	1-4

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 April 2006	09/05/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Salm, R

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INTERNATIONAL SEARCH REPORT

Information on patent family members

ıtional application No
/GB2005/003303

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 1566817	A	24-08-2005	NONE			
US 5523528	A	04-06-1996	AU	2263092	A	25-01-1993
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			WO	9300687	A1	07-01-1993