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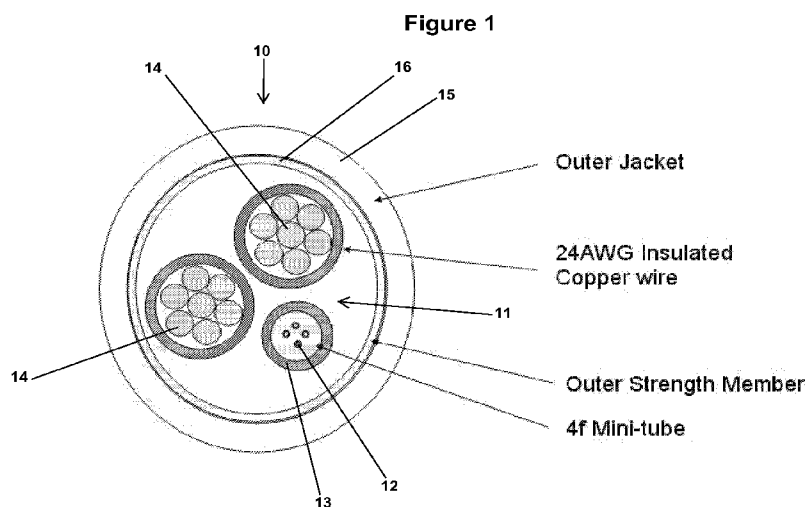
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(54) Title: OPTICAL-FIBER INTERCONNECT CABLE



(57) Abstract: An Optical - fiber interconnect cable (10) includes one or more optical fibres (12) and one or more electrical conductors (14) surrounded by an outer jacket. The optical fibers (12), such a multimode optical fibers, are typically enclosed within a flexible polimeric tube (13) to form a flexible subunit.

OPTICAL-FIBER INTERCONNECT CABLE

CROSS-REFERENCE TO PRIORITY APPLICATIONS

[0001] This U.S. nonprovisional application claims the benefit of U.S. Patent Application Ser. No. 61/444,960 for an *Optical-Fiber Interconnect Cable* (filed February 21, 2011) and U.S. Patent Application Ser. No. 61/515,532 for an *Optical-Fiber Interconnect Cable* (filed August 5, 2011), each of which is hereby incorporated by reference in its entirety.

FIELD OF INVENTION

[0002] The present invention relates to optical-fiber interconnect cables.

BACKGROUND

[0003] As compared with traditional wire-based networks, optical-fiber communication networks are capable of transmitting significantly more information at significantly higher speeds. Optical fibers, therefore, are being increasingly employed in communication networks. Optical data-transmission elements are also being increasingly integrated into computers, computer systems, and other electronic devices.

[0004] Various kinds of interconnect cables, such as USB cables, have been used to connect computers to peripheral devices. Conventional interconnect cables, however, do not support optical data transmission.

[0005] With the expansion of optical communications into and between computers and peripheral devices, a need exists for an optical-fiber interconnect cable that can facilitate optical data transmission.

SUMMARY

[0006] In one aspect, the present invention embraces an optical fiber interconnect cable. The interconnect cable typically includes a flexible subunit, which typically has one or more optical fibers (*e.g.*, multimode fibers) enclosed within a flexible polymeric tube. The flexible polymeric tube typically has a Young's modulus of less than about 100 MPa. The interconnect cable typically includes one or more high-conductivity conductors. An outer jacket surrounds the flexible subunit and the high-conductivity conductors. The outer jacket typically has a Young's modulus of less than about 150 MPa.

BRIEF DESCRIPTION OF THE DRAWING

[0007] Figure 1 schematically depicts a cross-sectional view of an optical-fiber interconnect cable in accordance with the present invention.

[0008] Figure 2 is a photograph of an exemplary, prototypical optical-fiber interconnect cable in accordance with the present invention.

[0009] Figure 3 is a photograph depicting an interconnect cable undergoing the pinch test in accordance with the present invention.

DETAILED DESCRIPTION

[0010] In one aspect, the present invention embraces an optical-fiber interconnect cable.

[0011] In this regard, Figure 1 depicts an exemplary optical-fiber interconnect cable 10 in accordance with the present invention. The optical-fiber interconnect cable 10 typically includes at least one flexible subunit 11 (*e.g.*, a flextube), which usually has one or more (*e.g.*, two to four) optical fibers 12 surrounded by a flexible polymeric tube 13 (*i.e.*, a flextube). For instance, the flexible subunit 11 may include at least six optical fibers 12 (*e.g.*, twelve optical fibers) surrounded by a flexible polymeric tube 13.

[0012] Typically, the optical-fiber interconnect cable 10 also includes one or more insulated high-conductivity conductors 14 (*e.g.*, electrical conductors). As depicted in Figure 1, an outer jacket 15 typically encloses the flexible subunit 11 and the insulated high-conductivity conductors 14. In some embodiments, the optical-fiber interconnect cable 10 may also have a strength member 16 (*e.g.*, strength yarns positioned within the outer jacket's central space).

[0013] In this regard, an exemplary optical-fiber interconnect cable according to the present invention typically employs high-conductivity conductors (*e.g.*, electrical conductors), optical conductors, and strength yarns to achieve a dry filled core. In a typical embodiment, the strength yarns mostly fill the free space around the electrical conductors and flexible subunits that enclose optical conductors (*i.e.*, the portion of the outer jacket's central space not otherwise occupied by the electrical conductors and the optical conductors). More typically, along the length of an optical-fiber interconnect cable, the strength yarns substantially fill the free space around the electrical conductors and flexible subunits that enclose optical conductors.

[0014] Those having ordinary skill in the art will appreciate that the concept of strength yarns filling free space within the outer jacket's central space is not intended to mean that substantially no voids exists between adjacent strength yarns. Rather, this concept is intended to convey the idea that the strength yarns are more or less present in the form of a fiberfill.

[0015] Figure 2, which is a photograph depicting a prototypical optical-fiber interconnect cable according to the present invention, illustrates this concept (*e.g.*, longitudinal strength yarns substantially filling the free space around the electrical conductors and the flexible sheathing element, which encloses optical conductors). In particular, the strength yarns shown in Figure 2 not only improve the cable's tensile strength and crush resistance, but also provide lateral

protection for the optical conductors (*e.g.*, by limiting the lateral movement of the flexible subunit).

[0016] The optical-fiber interconnect cable 10 is typically designed so that the bending radius is self-limiting in order to prevent violation of the minimum optical-fiber bending radius (*i.e.*, the minimum bending radius possessed by the constituent optical fibers). For example, the constituent components of the interconnect cable (*e.g.*, the electrical conductors and surrounding outer jacket) may enhance the cable's mechanical properties, thereby preventing excessive bending of the optical-fiber interconnect cable that might cause undesirable optical attenuation. Indeed, mechanical properties of the cable can be modified to achieve desirable self-limiting bending characteristics. Exemplary mechanical properties include, without limitation, (*i*) cable thickness (*e.g.*, diameter), (*ii*) cable stiffness, and (*iii*) fill ratio of the cable core. As will be appreciated by those having ordinary skill in the art, the characteristics of the cable's constituent elements will determine the resulting bending properties of the optical-fiber interconnect cable.

[0017] As noted, the optical-fiber interconnect cable 10 typically includes at least one flexible subunit 11. In an exemplary embodiment, the flexible subunit 11 includes one or more multimode optical fibers (*e.g.*, conventional optical multimode fibers with a 50-micron core, such as OM2 multimode fibers, that comply with the ITU-T G.651.1 recommendations). Exemplary multimode optical fibers that may be employed include MaxCapTM multimode optical fibers (OM2+, OM3, or OM4) commercially available from Draka (Claremont, North Carolina).

[0018] By way of further example, the flexible subunit 11 may include bend-insensitive multimode optical fibers, such as MaxCapTM-BB-OMx multimode optical fibers commercially available from Draka (Claremont, North Carolina). In this regard, bend-insensitive multimode optical fibers typically have macrobending losses of (*i*) no more than 0.1 dB at a wavelength of 850 nanometers for a winding of two turns around a spool with a bending radius of 15 millimeters and (*ii*) no more than 0.3 dB at a wavelength of 1300 nanometers for a winding of two turns around a spool with a bending radius of 15 millimeters.

[0019] In contrast, in accordance with the ITU-T G.651.1 recommendations, standard multimode optical fibers, have macrobending losses of (*i*) no more than 1 dB at a wavelength of 850 nanometers for a winding of two turns around a spool with a bending radius of 15 millimeters and (*ii*) no more than 1 dB at a wavelength of 1300 nanometers for a winding of

two turns around a spool with a bending radius of 15 millimeters. Moreover, as measured using a winding of two turns around a spool with a bending radius of 15 millimeters, such standard multimode optical fibers typically have macrobending losses of (i) greater than 0.1 dB, more typically greater than 0.2 dB (e.g., 0.3 dB or more), at a wavelength of 850 nanometers and (ii) greater than 0.3 dB, more typically greater than 0.4 dB (e.g., 0.5 dB or more), at a wavelength of 1300 nanometers.

[0020] Multimode optical fibers are advantageous, because their relatively large core diameter facilitates easy connectorization. Accordingly, it is within the scope of the present invention to employ multimode optical fibers having enlarged core diameters (e.g., 62.5 microns or greater), such as between about 70 microns and 100 microns (e.g., about 80 microns). An exemplary multimode optical fiber having an enlarged core diameter is disclosed in commonly assigned U.S. Patent Application No. 61/511,672 for a *Multimode Optical Fiber with Improved Bend Resistance*, filed July 26, 2011, (Molin *et al.*). In particular, U.S. Patent Application No. 61/511,672 discloses a trench-assisted multimode optical fiber having improved bend resistance. Another exemplary multimode optical fiber having an enlarged core diameter is disclosed in U.S. Patent Application Publication No. 2010/0220966 A1.

[0021] In an alternative embodiment, the flexible subunit 11 includes a plurality of conventional standard single-mode fibers (SSMF). Suitable single-mode optical fibers (e.g., enhanced single-mode fibers (ESMF)) that are compliant with the ITU-T G.652.D recommendations are commercially available, for instance, from Draka (Claremont, North Carolina).

[0022] In yet another alternative embodiment, the flexible subunit 11 includes a plurality of bend-insensitive single-mode optical fibers. Bend-insensitive single-mode optical fibers, which are less susceptible to attenuation (e.g., caused by microbending or macrobending), are commercially available from Draka (Claremont, North Carolina) under the trade name BendBright®. BendBright® optical fibers are compliant with the ITU-T G.652.D recommendations. That said, it is within the scope of the present invention to employ a bend-insensitive glass fiber that meets the ITU-T G.657.A recommendations (e.g., the ITU-T G.657.A1 (November 2009) and the ITU-T G.657.A2 (November 2009) subcategories) and/or the ITU-T G.657.B recommendations (e.g., the ITU-T G.657.B2 (November 2009) and the ITU-T G.657.B3 (November 2009) subcategories).

[0023] In this regard, particularly outstanding bend-insensitive single-mode glass fibers for use in the present invention are commercially available from Draka (Claremont, North Carolina) under the trade name BendBrightXS®. BendBrightXS® optical fibers are not only compliant with both the ITU-T G.652.D and ITU-T G.657.A/B recommendations but also demonstrate significant improvement with respect to both macrobending and microbending. As compared with such bend-insensitive single-mode optical fibers, conventional single-mode optical fibers typically do not comply with either the ITU-T G.657.A recommendations or the ITU-T G.657.B recommendations, but do typically comply with the ITU-T G.652 recommendations (*e.g.*, the ITU-T G.652.D recommendations).

[0024] As set forth in commonly assigned International Patent Application Publication No. WO 2009/062131 A1 for a *Microbend Resistant Optical Fiber* and U.S. Patent Application Publication No. US 2009/0175583 for a *Microbend-Resistant Optical Fiber*, pairing a bend-insensitive glass fiber (*e.g.*, Draka's single-mode glass fibers available under the trade name BendBrightXS®) and a primary coating having very low modulus achieves optical fibers having exceptionally low losses (*e.g.*, reductions in microbend sensitivity of at least 10x as compared with a single-mode fiber employing a conventional coating system).

[0025] The optical fibers deployed in the flexible subunit 11 may employ the optical-fiber coatings disclosed in International Patent Application Publication No. WO 2009/062131 A1 and U.S. Patent Application Publication No. US 2009/0175583 with either single-mode optical fibers or multimode optical fibers.

[0026] Optical fibers typically have an outer diameter of between about 235 microns and 265 microns, although the use of optical fibers having smaller diameters is within the scope of the present invention.

[0027] By way of example, the component glass fiber may have an outer diameter of about 125 microns. With respect to the optical fiber's surrounding coating layers, the primary coating may have an outer diameter of between about 175 microns and 195 microns (*i.e.*, a primary coating thickness of between about 25 microns and 35 microns) and the secondary coating may have an outer diameter of between about 235 microns and 265 microns (*i.e.*, a secondary coating thickness of between about 20 microns and 45 microns). At least one of the coating layers — typically the secondary coating — may be colored and/or possess other markings to help identify

individual fibers. Optionally, the optical fiber may include an outermost ink layer, which is typically between two and ten microns.

[0028] In one alternative embodiment, an optical fiber may possess a reduced diameter (*e.g.*, an outermost diameter between about 150 microns and 230 microns). In this alternative optical fiber configuration, the thickness of the primary coating and/or secondary coating is reduced, while the diameter of the component glass fiber is maintained at about 125 microns.

[0029] By way of example, in such exemplary embodiments the primary coating layer may have an outer diameter of between about 135 microns and about 175 microns (*e.g.*, about 160 microns), typically less than 165 microns (*e.g.*, between about 135 microns and 150 microns) and usually more than 140 microns (*e.g.*, between about 145 microns and 155 microns, such as about 150 microns). Moreover, in such exemplary embodiments the secondary coating layer may have an outer diameter of between about 150 microns and about 230 microns (*e.g.*, more than about 165 microns, such as 190–210 microns or so), typically between about 180 microns and 200 microns. In other words, the total diameter of the optical fiber is reduced to less than about 230 microns (*e.g.*, between about 195 microns and 205 microns, and especially about 200 microns).

[0030] In another alternative embodiment, the diameter of the component glass fiber may be reduced to less than 125 microns (*e.g.*, between about 60 microns and 120 microns), perhaps between about 70 microns and 115 microns (*e.g.*, about 80–110 microns). This may be achieved, for instance, by reducing the thickness of one or more cladding layers. As compared with the prior alternative embodiment, (*i*) the total diameter of the optical fiber may be reduced (*i.e.*, the thickness of the primary and secondary coatings are maintained in accordance with the prior alternative embodiment) or (*ii*) the respective thicknesses of the primary and/or secondary coatings may be increased relative to the prior alternative embodiment (*e.g.*, such that the total diameter of the optical fiber might be maintained).

[0031] By way of illustration, with respect to the former, a component glass fiber having a diameter of between about 90 and 100 microns might be combined with a primary coating layer having an outer diameter of between about 110 microns and 150 microns (*e.g.*, about 125 microns) and a secondary coating layer having an outer diameter of between about 130 microns and 190 microns (*e.g.*, about 155 microns). With respect to the latter, a component glass fiber having a diameter of between about 90 and 100 microns might be combined with a

primary coating layer having an outer diameter of between about 120 microns and 140 microns (*e.g.*, about 130 microns) and a secondary coating layer having an outer diameter of between about 160 microns and 230 microns (*e.g.*, about 195–200 microns).

[0032] Figure 1 depicts the optical fibers 12 being enclosed within a flexible polymeric tube 13. The optical fibers 12 may be bundled or stranded within the flexible polymeric tube 13. Typically, the flexible polymeric tube 13 is formed from a polymeric material having a Young's modulus (*e.g.*, at 25°C) of less than about 300 megapascals (MPa), typically less than about 200 MPa (*e.g.*, 50 MPa to 150 MPa), and more typically less than about 100 MPa. To achieve a Young's modulus less than about 100 MPa (*e.g.*, less than about 80 MPa), the flexible polymeric tube 13 may be formed from a thermoplastic copolyester elastomer, such as Hytrel® HTR8351, which is commercially available from DuPont.

[0033] That said, other materials having a suitable Young's modulus may be employed. In this regard, the flexible polymeric tube 13 may be formed from Santoprene®, which is a mixture of EPDM rubber and polypropylene. Santoprene® is commercially available from Exxon Mobile.

[0034] Mechanical properties of suitable materials for the flexible polymeric tube (*i.e.*, the flextube) are shown in Table 1 (below):

Table 1

Material	Tensile Strength (MPa)	Percent Elongation	Modulus (MPa)
Santoprene 201-87	11	818	83
Hytrel HTR8351NC020	10	160	25

[0035] By way of further example, the flexible polymeric tube 13 may be formed from a material having a Young's modulus of between about 10 MPa and 90 MPa (*e.g.*, 25 MPa to 75 MPa). In some embodiments, the flexible polymeric tube 13 may be formed from a material having a Young's modulus greater than about 50 MPa. In other embodiments, the flexible polymeric tube 13 may be formed from a material having a Young's modulus less than 50 MPa (*e.g.*, about 17 MPa), such as between about 20 MPa and 40 MPa (*e.g.*, between about 25 MPa and 30 MPa).

[0036] The flexible polymeric tube 13 typically has an outer diameter of less than one millimeter. In a typical embodiment, the flexible polymeric tube has an inner diameter of about 600 microns and an outer diameter of about 800 microns.

[0037] The insulated, high-conductivity conductors 14 may be used to provide power to a device connected to the optical-fiber interconnect cable 10. In this regard, Figure 1 depicts the optical-fiber interconnect cable 10 having two insulated high-conductivity conductors 14, which would typically be designated for V_{BUS} and ground electrical connections. Typically, the conductors 14 are copper, although other high-conductivity metals (*e.g.*, aluminum, silver, or gold) or metal alloys may be employed as an alternative to copper. Those having ordinary skill will appreciate that the high-conductivity conductors can be stranded or solid.

[0038] In an exemplary embodiment, each conductor 14 may be 24 AWG (America Wire Gauge) in size (*i.e.*, having a cross-sectional area of 404 circular mils). That said, those of ordinary skill in the art will appreciate that the size of the high-conductivity conductors 14 will depend upon the desired current-carrying capacity of the interconnect cable 10. Indeed, because the current carrying capacity of the interconnect cable 10 depends upon the cross sectional area of the high-conductivity conductors 14, greater current-carrying capacity needs typically require larger diameter high-conductivity conductors. Additionally, as will be appreciated by those having ordinary skill in the art, the maximum specified distance for device power transfer is limited by the wire gauge of the high-conductivity conductors 14.

[0039] Each conductor 14 is typically insulated. Each conductor 14 may be insulated with a material such as LDPE or LLDPE insulation, a chemically cross-linked polyolefin, cross-linked polyethylene, halogen-free ethylene propylene rubber, a low-smoke halogen-free insulation compound, or polyvinyl chloride (PVC).

[0040] The high-conductivity conductors 14 may be stranded about each other to form a twisted pair. Moreover, the flexible subunit 11 may be stranded about the high-conductivity conductors 14 (*e.g.*, stranded about a twisted pair of electrical conductors that are centrally positioned within the interconnect cable). This stranding can be accomplished helically in one direction, known as “S” or “Z” stranding, or via Reverse Oscillated Lay stranding, known as “S-Z” stranding. Stranding the flexible subunit about a centrally positioned twisted pair might reduce optical fiber strain when cable stress occurs during installation and use.

[0041] Alternatively, the flexible subunit 11 and/or the high-conductivity conductors 14 may be freely positioned within the interconnect cable 10. For example, the flexible subunit may not be intentionally stranded or arranged around a twisted pair in a particular manner, but rather may run substantially parallel to the electrical conductors or to the twisted pair.

[0042] It is within the scope of the present invention to position the high-conductivity conductors 14 within the cable's central space so as to define a preferential bending plane. For instance, the high-conductivity conductors 14 may be arranged diametrically opposite one another within the cable core (or even slightly off-axis with respect to the cable diameter) to facilitate the definition of a favored bending axis.

[0043] In one embodiment, the optical-fiber interconnect cable includes a strength member 16. The strength member 16 may include high-strength yarns (*e.g.*, aramid yarns) positioned parallel or wrapped (*e.g.*, contrahelically) around the flexible subunit 11 and the high-conductivity conductors 14. As will be understood by those having ordinary skill in the art, such strength yarns provide tensile strength and crush resistance to the interconnect cable.

[0044] The optical-fiber interconnect cable according to the present invention may include yarns, nonwovens, fabrics (*e.g.*, tapes), foams, or other materials containing water-swellaable material and/or coated with water-swellaable materials (*e.g.*, including super absorbent polymers (SAPs), such as SAP powder) to provide water blocking. For instance, the strength member 16 may include high-strength yarns that are coated with water-swellaable material, such as SAP powder.

[0045] An outer jacket 15 encloses the flexible subunit 11, the high-conductivity conductors 14, and the strength member 16. Typically, the outer jacket 15 is formed predominately of polyolefin(s), such as polyethylene (*e.g.*, LDPE, LLDPE, or HDPE) or polypropylene, including fluorinated polyolefins, polyesters (*e.g.*, polybutylene terephthalate), polyamides (*e.g.*, nylon), ethylene-vinyl acetate (EVA), polyvinyl chloride (PVC), as well as other polymeric materials and blends. The polymeric materials may include a curable composition (*e.g.*, a UV-curable material) or a thermoplastic material, such as a low-smoke zero-halogen (LSZH) thermoplastic material.

[0046] In a more typical embodiment, the outer jacket 15 may be predominately formed from a halogen-free flame-retardant (HFFR) compound. For example, the outer jacket may be formed from ECCOH® 6638, which is commercially available from PolyOne Corporation.

ECCOH® 6638 is a halogen-free flame-retardant (HFFR) compound that includes polyethylene, EVA, halogen-free flame retardants, and other additives. Other exemplary HFFR compounds include ECCOH® 6150, which is commercially available from PolyOne Corporation, and MEGOLON® HF 1876, MEGOLON® S545, MEGOLON® S380, and MEGOLON® HF 8142, which are commercially available from Alpha Gary Corporation.

[0047] Even more typically, the outer jacket 15 may be predominately formed from a low-modulus HFFR compound. A low-modulus HFFR compound typically has a Young's modulus (*e.g.*, at 25°C) of less than about 150 megapascals (MPa) (*e.g.*, between about 50 MPa and 150 MPa), such as less than about 100 MPa (*e.g.*, less than about 80 MPa). Exemplary low-modulus HFFR compounds include ECCOH® 5549 and ECCOH® 5924, which are commercially available from PolyOne Corporation. It has been found that low-modulus HFFR compounds demonstrate robust bend performance and minimal plastic deformation.

[0048] Accordingly, the polymeric materials used to form the outer jacket 15 may contain additives, such as nucleating agents, flame-retardants, smoke-retardants, antioxidants, UV absorbers, and/or plasticizers. For example, the outer jacket 15 may include a material that provides high temperature resistance and chemical resistance (*e.g.*, an aromatic material or polysulfone material).

[0049] In this regard, the outer jacket 15 typically has a fire-resistance rating of at least about VW-1. In other words, the outer jacket typically is able to pass the UL VW-1 Vertical-Wire Flame Test (UL 1581). Moreover, the outer-jacket material may have a riser flame rating and/or a plenum flame rating. In addition, the optical-fiber interconnect cable 10 may itself have a riser rating with respect to cable fire resistance.

[0050] The outer jacket 15 typically possesses a circular cross section. That said, it is within the scope of the present invention to employ an outer jacket possessing non-circular shapes (*e.g.*, an oval or a trapezoidal cross-section) or even somewhat irregular shapes.

[0051] The outer diameter of the outer jacket 15 is typically less than about 5 millimeters (*e.g.*, about 4.8 millimeters). In one embodiment, the outer jacket 15 has an outer diameter of about 4 millimeters. In other embodiments, the outer jacket 15 has an outer diameter of less than 4 millimeters (*e.g.*, 3.7 millimeters), such as less than 3.5 millimeters (*e.g.*, 3.0 millimeters or less).

[0052] The optical-fiber interconnect cable 10 may be pre-connectorized for final use. For instance, a specific length of the cable includes a connector at each of its ends. Each connector typically includes one or more mechanical interference features that ensure proper polarization and alignment of all connections, thereby ensuring that no damage occurs to the optical connections or the electrical connections during insertion and removal of the connector. Each connector typically includes an upstream element and a downstream element (*e.g.*, USB-like features). In addition, the connector may include stress-relief elements designed to prevent kinking at the connector-cable interface that could damage optical fibers or electrical conductors.

* * *

[0053] An optical-fiber interconnect cable in accordance with the present invention may be subjected to a pinch test as depicted in Figure 3. During the pinch test an interconnect cable is folded over itself so that the two cable portions on either side of the fold are substantially parallel to one another, thereby creating a pinch in the interconnect cable. The resulting folded cable has a maximum diameter of about twice the cable's normal diameter. At the pinch point, the cable is flattened and has a diameter less than its normal diameter. Although the cable has a reduced diameter at and near the pinch point, the remainder of the cable retains its normal diameter. The cable is held in this pinched state for about 10 minutes. After 10 minutes have elapsed and while the cable is held in the pinched state, the attenuation of the optical fibers in the cable is measured (*e.g.*, at room temperature).

[0054] The pinch test has been performed on an interconnect cable having an outer diameter of 4.8 millimeters and an inner diameter of 3.1 millimeters. The cable jacket was formed from ECCOH® 5924 HFFR compound. The cable included a flextube formed from Santoprene® 201-87 thermoplastic elastomer, which had an outer diameter of 0.9 millimeter and an inner diameter of 0.65 millimeter. The interconnect cable was folded over itself in a steel tube having an inner diameter of about 10 millimeters. At the pinch point, the cable had a diameter of about 3.2 millimeters. At the conclusion of the pinch test, the interconnect cable was straightened and returned to its original dimension with no cable discoloration, cable damage, or fiber damage.

[0055] One tested interconnect cable included 80-micron core multimode optical fibers lacking a trench. At a wavelength of 850 nanometers, these trench-free multimode optical fibers have macrobending losses of (i) no more than 0.5 dB for a winding of two turns around a spool with a bending radius of 15 millimeters and (ii) no more than 1.0 dB for a winding of two turns

around a spool with a bending radius of 7.5 millimeters. During the pinch test, these trench-free multimode optical fibers contained within this interconnect cable experienced attenuation added losses of about 0.518 dB at a wavelength of 850 nanometers.

[0056] Another tested interconnect cable included trench-assisted multimode optical fibers having an 80-micron core (*e.g.*, as disclosed in commonly assigned U.S. Patent Application No. 61/511,672). At a wavelength of 850 nanometers, these trench-assisted multimode optical fibers have macrobending losses of (*i*) no more than 0.3 dB for a winding of two turns around a spool with a bending radius of 5 millimeters and/or (*ii*) no more than 0.5 dB for a winding of one turn around a spool with a bending radius of 3 millimeters. During the pinch test, these trench-assisted multimode optical fibers contained within this interconnect cable experienced attenuation added losses of about 0.227 dB at 850 nanometers.

[0057] Accordingly, during the pinch test the present interconnect cables typically have attenuation added losses of less than about 0.5 dB, more typically less than about 0.3 dB (*e.g.*, less than about 0.25 dB).

* * *

[0058] In the specification and/or figures, typical embodiments of the invention have been disclosed. The present invention is not limited to such exemplary embodiments. The use of the term “and/or” includes any and all combinations of one or more of the associated listed items. The figures are schematic representations and so are not necessarily drawn to scale. Unless otherwise noted, specific terms have been used in a generic and descriptive sense and not for purposes of limitation.

CLAIMS

1. An optical-fiber interconnect cable, comprising:
a flexible subunit, said flexible subunit comprising one or more optical fibers enclosed within a flexible polymeric tube;
one or more high-conductivity conductors; and
an outer jacket surrounding said flexible subunit and said high-conductivity conductors.
2. The optical-fiber interconnect cable according to Claim 1, wherein said flexible subunit comprises a plurality of multimode optical fibers.
3. The optical-fiber interconnect cable according to Claim 1, wherein said flexible subunit comprises a plurality of bend-insensitive multimode optical fibers.
4. The optical-fiber interconnect cable according to Claim 3, wherein, for two turns around a bending radius of 15 millimeters, said bend-insensitive multimode optical fibers have macrobending losses of (i) 0.1 dB or less at a wavelength of 850 nanometers and (ii) 0.3 dB or less at a wavelength of 1300 nanometers.
5. The optical-fiber interconnect cable according to Claim 3, wherein, in accordance with the pinch test, said bend-insensitive multimode optical fibers have attenuation added losses of less than 0.3 dB at 850 nanometers.
6. The optical-fiber interconnect cable according to Claim 1, wherein said flexible subunit comprises a plurality of trench-assisted multimode optical fibers having a core diameter of about 80 microns.

7. The optical-fiber interconnect cable according to Claim 6, wherein, in accordance with the pinch test, said trench-assisted multimode optical fibers have attenuation added losses of less than 0.5 dB at 850 nanometers.

8. The optical-fiber interconnect cable according to Claim 6, wherein, in accordance with the pinch test, said trench-assisted multimode optical fibers have attenuation added losses of less than 0.25 dB at 850 nanometers.

9. The optical-fiber interconnect cable according to any one of the preceding claims, wherein said flexible polymeric tube has an outer diameter of less than about one millimeter.

10. The optical-fiber interconnect cable according to any one of the preceding claims, comprising a strength member positioned within said outer jacket.

11. The optical-fiber interconnect cable according to Claim 10, wherein said strength member comprises aramid yarns (*i*) surrounding said flexible subunit and said high-conductivity conductors and (*ii*) substantially filling the remaining central space defined by said outer jacket.

12. The optical-fiber interconnect cable according to any one of the preceding claims, wherein said outer jacket comprises a halogen-free, flame-retardant compound.

13. The optical-fiber interconnect cable according to any one of the preceding claims, wherein said outer jacket has VW-1 fire resistance in accordance with the UL VW-1 Vertical-Wire Flame Test (UL 1581).

14. The optical-fiber interconnect cable according to any one of the preceding claims, wherein said outer jacket has an outer diameter of less than about 5 millimeters.

15. The optical-fiber interconnect cable according to any one of the preceding claims, comprising a connector with stress relief at the connector-cable interface.

16. The optical-fiber interconnect cable according to any one of the preceding claims, comprising a connector that includes a mechanical interference device to facilitate reliable insertion and removal without damage to either said optical conductors or said high-conductivity conductors.

17. The optical-fiber interconnect cable according to any one of the preceding claims, wherein a specific length of the cable is pre-connectorized.

18. The optical-fiber interconnect cable according to any one of Claims 1–17, wherein said flexible polymeric tube has a Young's modulus at 25°C of less than about 300 MPa.

19. The optical-fiber interconnect cable according to any one of Claims 1–17, wherein said flexible polymeric tube has a Young's modulus at 25°C of less than about 200 MPa.

20. The optical-fiber interconnect cable according to any one of Claims 1–17, wherein said flexible polymeric tube has a Young's modulus at 25°C of between about 25 MPa and 75 MPa.

21. The optical-fiber interconnect cable according to any one of Claims 1–17, wherein said flexible polymeric tube has a Young's modulus at 25°C of between about 20 MPa and 40 MPa.

22. The optical-fiber interconnect cable according to any one of Claims 1–21, wherein said outer jacket has a Young's modulus at 25°C of less than about 150 MPa.

23. The optical-fiber interconnect cable according to any one of Claims 1–21, wherein said outer jacket has a Young's modulus at 25°C of less than about 80 MPa.

24. An optical-fiber interconnect cable, comprising:

an outer jacket surrounding a dry filled core, the dry filled core including (i) a plurality of optical fibers enclosed within a flextube, (ii) a plurality of electrical conductors, and (iii) strength yarns substantially filling the remaining free space within the outer jacket.

25. The optical-fiber interconnect cable according to Claim 24, wherein the dry filled core includes a plurality of trench-assisted multimode optical fibers having a core diameter of about 80 microns.

26. The optical-fiber interconnect cable according to Claim 25, wherein, in accordance with the pinch test, said trench-assisted multimode optical fibers have attenuation added losses of less than 0.5 dB at 850 nanometers.

Figure 1

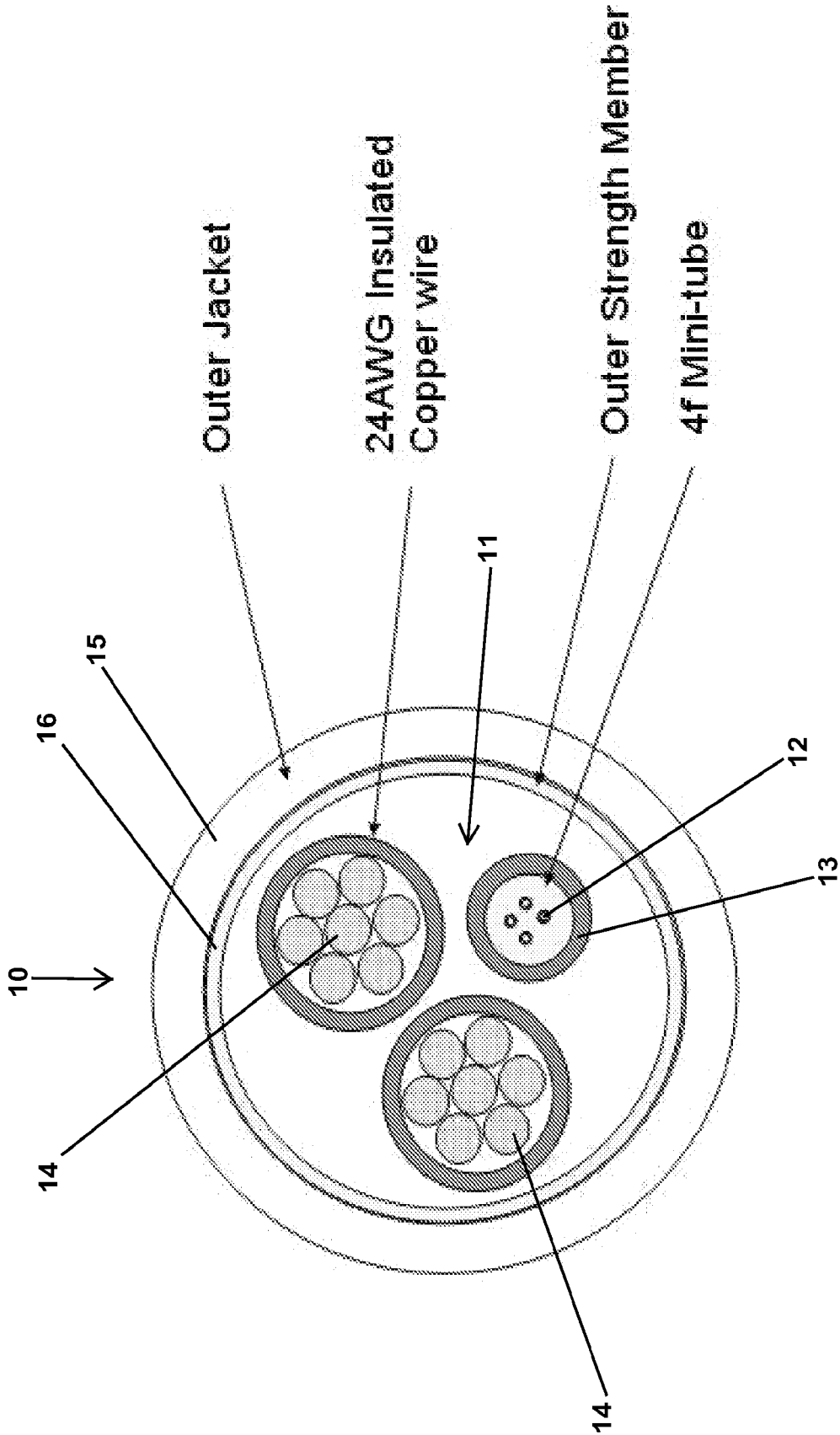


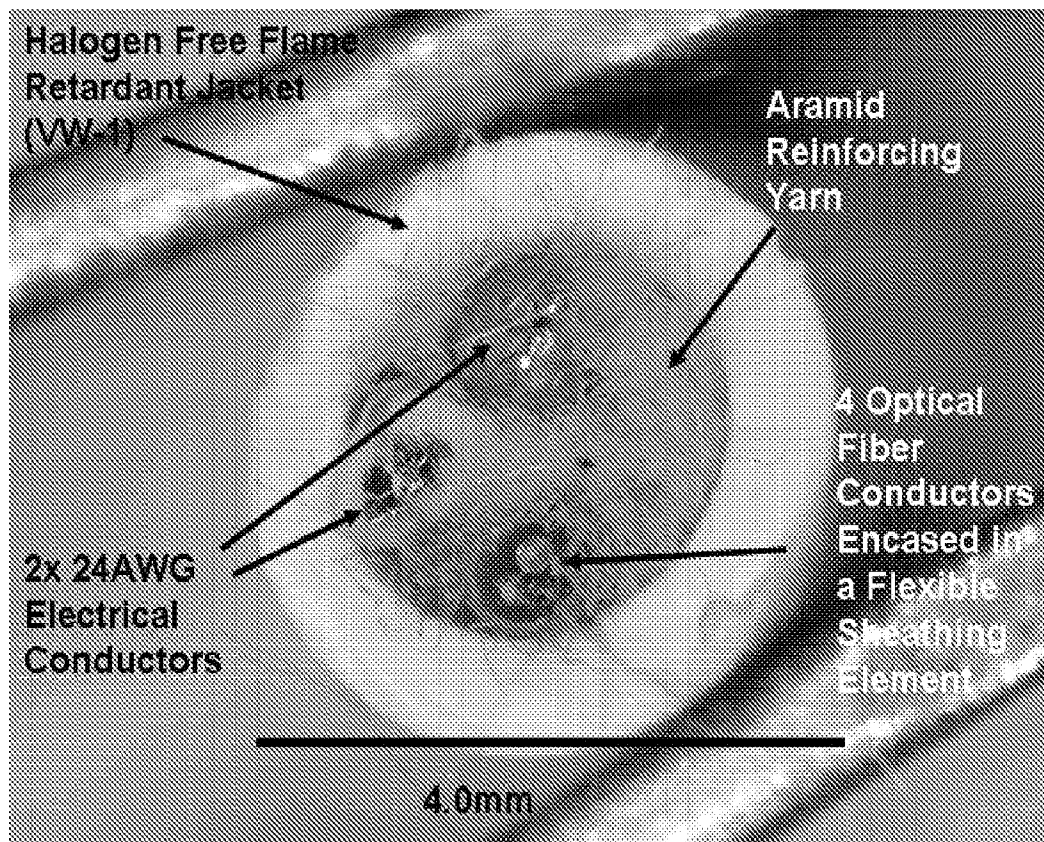
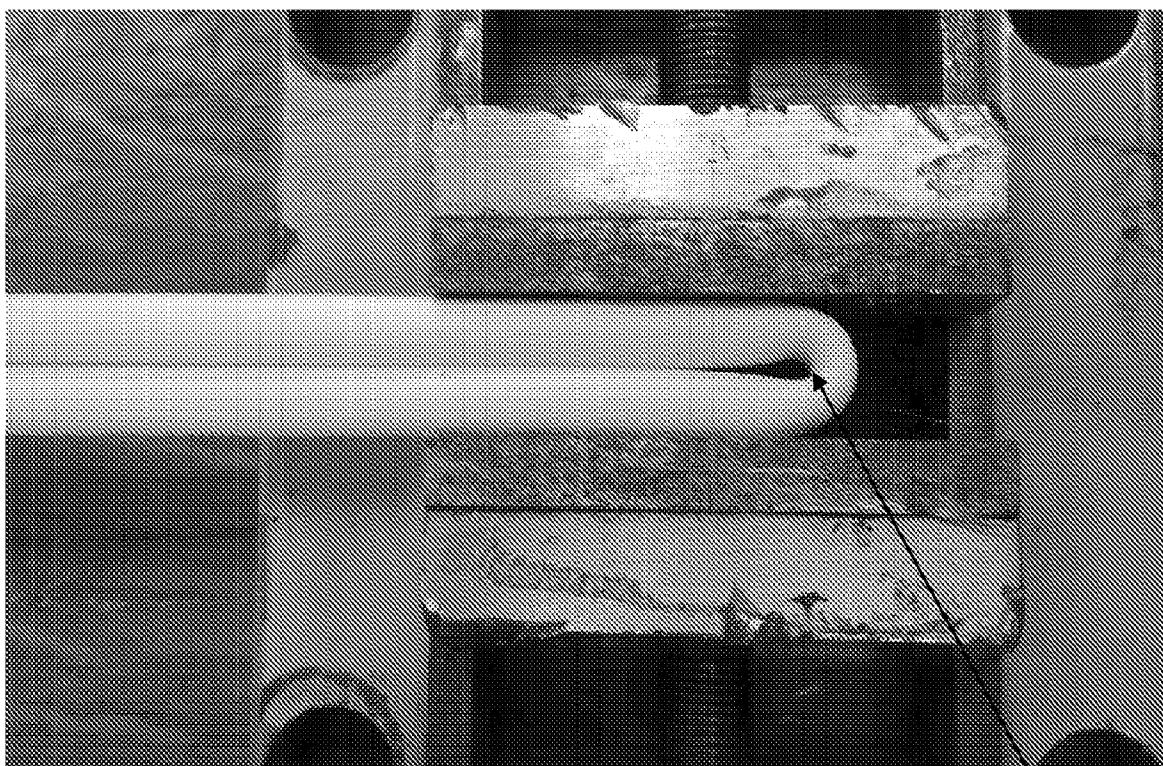
Figure 2

Figure 3



Pinch Point

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/025918

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B6/44
ADD.

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)
G02B

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 practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 651 081 A (BLEW DOUGLAS J [US] ET AL) 22 July 1997 (1997-07-22)	1,9-11, 14,24
Y	abstract column 4, lines 1-20 column 5, lines 41-44 figures 1,4	2-8,12, 13, 15-23, 25,26
Y	----- WO 2010/093888 A2 (CORNING CABLE SYS LLC [US]; BICKHAM SCOTT R [US]; HALL RADAWAN [US]; L) 19 August 2010 (2010-08-19) abstract claim 4 paragraph [0025] figure 1	2-8,25, 26
Y	----- US 4 575 184 A (UENO KEIJI [JP] ET AL) 11 March 1986 (1986-03-11) abstract ----- -/-	12,13



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

13 June 2012

Date of mailing of the international search report

21/06/2012

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/025918

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DE 93 02 981 U1 (KABEL RHEYDT AG) 22 April 1993 (1993-04-22) page 2, lines 11-17 -----	15-17
Y	GB 2 177 231 A (FUJIKURA LTD FUJIKURA LTD [JP]) 14 January 1987 (1987-01-14) claim 2 -----	18-23

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/025918

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5651081	A	22-07-1997	AU 2649195 A 05-01-1996
		US 5469523 A 21-11-1995	
		US 5651081 A 22-07-1997	
		WO 9534838 A1 21-12-1995	
WO 2010093888	A2	19-08-2010	AU 2010213627 A1 15-09-2011
		CN 102349008 A 08-02-2012	
		EP 2396685 A2 21-12-2011	
		US 2011305420 A1 15-12-2011	
		WO 2010093888 A2 19-08-2010	
US 4575184	A	11-03-1986	JP 59226413 A 19-12-1984
		US 4575184 A 11-03-1986	
DE 9302981	U1	22-04-1993	NONE
GB 2177231	A	14-01-1987	AU 593775 B2 22-02-1990
		AU 4780385 A 22-01-1987	
		BR 8505090 A 17-02-1987	
		CA 1254414 A1 23-05-1989	
		CN 85108068 A 24-12-1986	
		DE 3535827 A1 08-01-1987	
		GB 2177231 A 14-01-1987	
		JP 1706167 C 27-10-1992	
		JP 3075966 B 04-12-1991	
		JP 62002412 A 08-01-1987	
		US 4723832 A 09-02-1988	