



- (51) International Patent Classification:
G02B 6/44 (2006.01)
- (21) International Application Number:
PCT/US2014/042731
- (22) International Filing Date:
17 June 2014 (17.06.2014)
- (25) Filing Language: English
- (26) Publication Language: English
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- (81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: CENTRAL-TUBE OPTICAL-FIBER CABLE

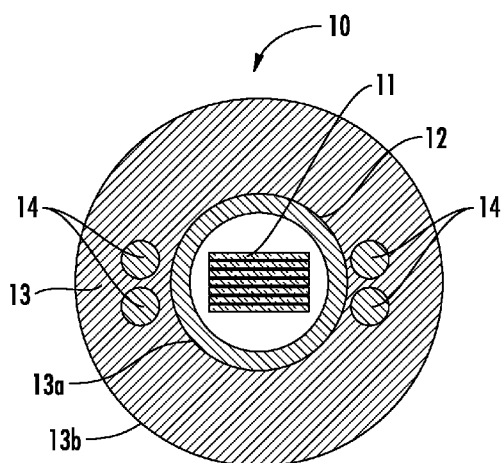


FIG. 1

(57) Abstract: The present invention relates to optical-fiber cables, such as ribbon-in-central-tube optical-fiber cables. An exemplary optical-fiber cable includes a central buffer tube that encloses optical fiber elements (e.g., ribbonized or non-ribbonized optical fibers) and a surrounding cable jacket in which radial strength members are substantially embedded.

CENTRAL-TUBE OPTICAL-FIBER CABLE

FIELD OF THE INVENTION

[0001] The present invention relates to optical-fiber cables, particularly ribbon-in-central-tube optical-fiber cables.

BACKGROUND

[0002] Optical fibers provide advantages over conventional communication lines. As compared with traditional wire-based networks, optical-fiber communication networks can transmit significantly more information at significantly higher speeds. Optical fibers, therefore, are being increasingly employed in communication networks.

[0003] Optical fibers are typically grouped in optical-fiber cables, such as central loose-tube cables. Such optical-fiber cables sometimes include rigid, outer strength members to help the optical-fiber cables withstand the mechanical stresses that occur during installation and thereafter as a result of thermal expansion and contraction. For example, optical-fiber cables should be able to withstand conditions of use over a wide temperature range, such as between about -20°C and 50°C . Indeed, it is desirable for optical-fiber cables to be able to withstand an even wider temperature range, such as between about -40°C and 70°C . The inclusion of rigid, outer strength members, however, not only increases the size of optical-fiber cables but also provides another route for water to spread (*e.g.*, flood or otherwise flow) along the length of the cables.

[0004] Accordingly, a need exists for a central-tube optical-fiber cable having satisfactory flexibility and strength, while maintaining acceptable optical-fiber attenuation.

SUMMARY

[0005] Accordingly, in one aspect, the present invention embraces an optical-fiber cable having a central buffer tube that encloses optical fiber elements (*e.g.*, ribbonized or non-ribbonized optical fibers) and a surrounding cable jacket. Two groups of rigid, radial strength members (*e.g.*, four strength members having the same diameter D_{sm} and being grouped in pairs) are substantially embedded within the cable jacket. The two groups of rigid strength members (*e.g.*, glass-reinforced-plastic rods) are positioned substantially diametrically opposite each other.

[0006] In one embodiment, the optical-fiber cable includes two pairs of two adjacent strength members, the respective adjacent strength members being spaced from one another by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$ (*e.g.*, $0.4D_{sm}$ and $0.8D_{sm}$).

[0007] In another embodiment, strength members (*e.g.*, two pairs of two strength members) are acentrically positioned toward the cable jacket's inner wall, either fully or partially embedded with the cable jacket.

[0008] In yet another embodiment, two pairs of adjacent strength members having a diameter D_{sm} are spaced from the cable jacket's inner wall by a distance of less than $0.25D_{sm}$. For example, four fully embedded strength members having a diameter D_{sm} are positioned between $0.05 D_{sm}$ and $0.1 D_{sm}$ from the cable jacket's inner wall.

[0009] In yet another embodiment, none of the strength members has more than 20 percent of its surface area exposed through the cable jacket's inner wall and none of the strength members is exposed through the cable jacket's outer wall. For example, each of four partially embedded strength members exposes between 1 percent and 5 percent of its surface area through the cable jacket's inner wall.

[0010] The foregoing illustrative summary, as well as other exemplary objectives and/or advantages of the invention, and the manner in which the same are accomplished, are further explained within the following detailed description and its accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figures 1–5 schematically depict cross-sectional views of optical-fiber cables according to exemplary embodiments of the present invention.

DETAILED DESCRIPTION

[0012] In one aspect, the present invention embraces an optical-fiber cable.

[0013] In this regard, Figures 1–5 each schematically depict an exemplary optical-fiber cable 10 in accordance with the present invention. The optical-fiber cable 10 includes a central, polymeric buffer tube 12 that defines a central, annular space. Optical fibers 11 (*e.g.*, optical-fiber ribbons) are positioned within the polymeric buffer tube's annular space. A cable jacket 13 encloses the optical fibers 11 and the surrounding polymeric buffer tube 12. In some typical embodiments like those depicted in Figures 1–3, the cable jacket 13 surrounds the buffer tube 12 so there is essentially no free space between the cable jacket 13 and the buffer tube 12 (*e.g.*, the cable jacket 13 is extruded around the buffer tube 12).

[0014] In other embodiments like those depicted in Figures 4–5, optional water-blocking elements 15 (*e.g.*, water-swellaable yarns and/or water-swellaable tapes) may be positioned between the buffer tube 12 and the surrounding cable jacket 13. Typically, there is little, if any, free space between a water-blocking element 15 and either the cable jacket 13 or the buffer tube 12 (*i.e.*, the cable jacket 13 tightly surrounds the water-blocking element 15). Alternatively, a thixotropic material 16 (not depicted) or other water-blocking substance might replace the water-blocking elements 15 depicted in Figures 4–5. Optional water-blocking elements 15 (*e.g.*, water-swellaable yarns and/or water-swellaable tapes) or a thixotropic material 16 (*e.g.*, as depicted in Figure 3) may be included within the central, annular space defined by the buffer tube 12.

[0015] At least four rigid strength members 14 are substantially embedded in the cable jacket 13. The rigid strength members 14 may be either fully embedded in the cable jacket 13, as depicted in Figure 1, or partially embedded in the cable jacket 13, as depicted in Figure 5. In some embodiments like those depicted in Figures 2–4, the rigid strength members 14 are thinly covered by a polymeric layer of the material that forms the cable jacket 13 (*e.g.*, a polymeric skin) or are just slightly exposed through the inner wall 13a of the cable jacket 13. The rigid strength members 14 are typically not positioned to bulge from or otherwise be exposed through the outer wall 13b of the cable jacket 13.

[0016] Those having ordinary skill in the art will appreciate that this configuration of strength members 14 (*e.g.*, as depicted in Figures 1–5) can facilitate access to the optical-fiber cable 10. As depicted in Figures 4–5, one or more rip cords 17 may be positioned between the buffer tube 12 and the surrounding cable jacket 13. A rip cord 17 is

typically positioned near the strength members 14, where there is less jacketing material to access and open, thereby facilitating buffer-tube access.

[0017] Typically, the strength members 14 have the same diameter D_{sm} and are configured in two groups of two. The first and second groups of two strength members 14 are positioned substantially diametrically opposite one another, such as depicted in Figures 1–5. For example, a first group of two adjacent, rigid strength members 14, each having a diameter D_{sm} , is substantially embedded within the cable jacket 13. Exemplary rigid strength members are glass-reinforced-plastic strength members having a diameter of between about 0.6 millimeter and 2.6 millimeters (*e.g.*, a diameter of 1.6 millimeters). These first two rigid strength members 14 are typically spaced from one another by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$, such as more than $0.35D_{sm}$ or less than $1.0D_{sm}$ (*e.g.*, less than $0.75D_{sm}$, such as between about $0.35D_{sm}$ and $0.5D_{sm}$). A second group of two adjacent, rigid strength members 14, each having a diameter D_{sm} , is substantially embedded within the cable jacket 13. These second two rigid strength members 14 are likewise spaced from one another by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$, such as more than $0.35D_{sm}$ or less than $1.0D_{sm}$ (*e.g.*, less than $0.75D_{sm}$, such as between about $0.35D_{sm}$ and $0.5D_{sm}$).

[0018] As depicted in each of Figures 1–5, the rigid strength members 14 are acentrically positioned toward the cable jacket's inner wall (*i.e.*, the strength members 14 are biased toward the center of the optical-fiber cable). Typically, the first and second groups of rigid strength members 14 are partially or fully embedded in the cable jacket 13 (*i.e.*, substantially embedded in the cable jacket 13) such that none of the strength members has more than one third of its surface area (*i.e.*, 120 degrees or less of a circular strength member's circumference) exposed through the cable jacket's inner wall 13a. More typically, the first and second groups of rigid strength members 14 are partially or fully embedded in the cable jacket 13 (*i.e.*, substantially embedded in the cable jacket 13) such that none of the strength members has more than 20 percent of its surface area (*e.g.*, 60 degrees or less of a circular strength member's circumference) exposed through the cable jacket's inner wall 13a. As noted, none of the strength members 14 typically has any of its surface area exposed through the cable jacket's outer wall 13b.

[0019] In some embodiments, such as depicted in Figure 5, in which both the first and second groups of rigid strength members 14 are partially embedded in the cable jacket 13, each of the strength members has between 2 percent and 15 percent (*e.g.*, between 5 percent and 10 percent) of its surface area exposed through the cable jacket's inner wall 13a.

[0020] Where both the first and second groups of rigid strength members 14 are fully embedded in the cable jacket 13, each of the strength members is typically spaced from the cable jacket's inner wall 13a by a distance of less than $0.25D_{sm}$, such as less than $0.15D_{sm}$ (*e.g.*, less than $0.05D_{sm}$ as depicted in Figures 2–4).

[0021] The rigid strength members 14 are typically glass-reinforced-plastic rods (*i.e.*, GRP strength members). Glass, which has excellent fire resistance, typically accounts for at least 70 weight percent of these reinforcing materials, with a polymeric component accounting for the remainder. The glass-reinforced-plastic strength members 14 are typically sufficiently tacky to reduce slippage as embedded within the cable jacket 13 while allowing removal during field operations requiring optical-fiber access. Alternatively, smooth, non-tacky glass-reinforced-plastic strength members 14 may be embedded within or otherwise glued to the cable jacket 13.

[0022] In some embodiments, the rigid strength members 14 might include metal rods (*e.g.*, steel strength members), but these are conductive and so are typically disfavored for unarmored optical-fiber cables.

* * *

[0023] Optical-fiber cables were tested to evaluate the spacing between adjacent pairs of glass-reinforced-plastic strength members. In particular, bend testing was performed in accordance with Telcordia Technologies generic requirements for “Low- and High-Temperature Cable Bend” (Section 6.5.3) as set forth in GR-20-CORE (Issue 3, May 2008), which itself references ICEA 640 (Section 7.21), FOTP-37 and other sections of GR-20-CORE (Issue 3, May 2008), namely “Cable Testing” (Section 6.5.2). GR-20-CORE (Issue 3, May 2008), ICEA 640 (Section 7.21), and FOTP-37 are hereby incorporated by reference in their entirety.

[0024] Each of the tested optical-fiber cables had a ribbon-in-central-tube design including 432 ribbonized optical fibers within a central, polymeric buffer tube. The optical-fiber ribbons and the surrounding polymeric buffer tube were enclosed in an unarmored cable jacket in which two pairs of two glass-reinforced-plastic strength members were embedded (*i.e.*, four embedded strength members). Each glass-reinforced-plastic strength member had a diameter of 1.6 millimeters, and the two groups of glass-reinforced-plastic strength members were positioned diametrically opposite from one another. Each tested ribbon-in-central-tube optical-fiber cable had a diameter of less than

20 millimeters. In accordance with GR-20-CORE (Issue 3, May 2008), each glass-reinforced-plastic strength member was covered externally by at least 0.5 millimeter of jacketing material (*e.g.*, at least 0.85 millimeter of jacketing material). Adjacent glass-reinforced-plastic strength members were positioned relative to one another in the cable jacketing at three discrete spacings: 0 millimeter (Comparative Table 1), 2.9 millimeters (Comparative Table 2), and 0.65 millimeter (Table 3). The basic configuration of the tested ribbon-in-central-tube optical-fiber cables is illustrated in Figure 1, albeit with no strength-member gap between the comparative optical-fiber cable reported in Table 1.

Table 1 (comparative)

strength-member spacing (mm)	temperature	results	P/F
0.0	+60C (1 hr)	0 strength-member breaks observed during/after bending (rolled method)	P

[0025] The tested ribbon-in-central-tube optical-fiber cable reported in Table 1 was a control optical-fiber cable. It has been observed that placing two glass-reinforced-plastic strength members contiguously adjacent to one another can reduce cable diameter while maintaining satisfactory cable strength. It has also been observed, however, that such an optical-fiber design allows unacceptable water intrusion and migration via passageways between the contiguously adjacent strength members (*e.g.*, near the central buffer tube).

Table 2 (comparative)

strength-member spacing (mm)	temperature	results	P/F
2.9	+60C (18 hrs)	4 strength-member breaks observed during/after bending	F
2.9	+23C	2 strength-member breaks observed during/after bending	F

[0026] The tested, comparative ribbon-in-central-tube optical-fiber cables reported in Table 2 displayed unacceptable strength as evidenced by strength-member breakage. Spacing adjacent glass-reinforced-plastic strength members by a distance of about $1.8D_{sm}$ (*i.e.*, a 2.9-millimeter strength-member gap divided by the strength-member diameter D_{sm} of 1.6 millimeters) proved to be unsatisfactory.

[0027] Without being bound to any theory, it is thought that if strength members are placed too far from the optical-fiber cable's neutral axis, bending can cause one adjacent rigid strength member to be under tension and the other adjacent rigid strength member to be under compression, leading to strength-member failure. Glass-reinforced-plastic rods (*e.g.*, E-glass rods) can shatter during rigorous bending, especially at extreme temperatures.

Table 3

strength-member spacing (mm)	temperature	results	P/F
0.65	+23C	0 strength-member breaks observed during/after bending (rolled method)	P
0.65	+60C (70 hrs)	0 strength-member breaks observed during/after bending (single ended / cinched method)	P
0.65	+60C (70 hrs)	0 strength-member breaks observed during/after bending (single ended / cinched method)	P
0.65	+60C (70 hrs)	0 strength-member breaks observed during/after bending (single ended / cinched method)	P

[0028] The tested, exemplary ribbon-in-central-tube optical-fiber cables reported in Table 3 demonstrated satisfactory strength (*e.g.*, compression resistance and tensile strength), while precluding possible water passageways between each pair of adjacent strength members. Spacing adjacent glass-reinforced-plastic strength members by a distance of about $0.4D_{sm}$ (*i.e.*, a 0.65-millimeter strength-member gap divided by the strength-member diameter D_{sm} of 1.6 millimeters) proved to be satisfactory.

* * *

[0029] As will be known by those having ordinary skill in the art, the central buffer tube is typically formed from thermoplastic material(s), such as polyolefins (*e.g.*, polyethylene or polypropylene, such as high-density polyethylene), including fluorinated polyolefins. The central buffer tube may also be formed from polyester, such as polybutylene terephthalate (PBT), nucleated polybutylene terephthalate, or low-shrink polybutylene terephthalate; nylon, such as polyamide 12 (PA12), amorphous polyamide 12, or polyamide 11; polyvinyl chloride (PVC); halogen-free flame retardant materials (HFRR); urethane polymers, such as urethane acrylates; and/or blends of these and other polymeric materials. In general, the central buffer tube may be formed of one or more layers. The layers may be homogeneous or include mixtures or blends of various materials within each

layer. In this context, the buffer tube may be extruded (*e.g.*, an extruded polymeric material) or pultruded (*e.g.*, a pultruded, fiber-reinforced plastic). By way of example, the buffer tube may include a material to provide high temperature and chemical resistance (*e.g.*, an aromatic material or polysulfone material).

[0030] Although buffer tubes typically have a circular cross section, buffer tubes alternatively may have an irregular or non-circular shape (*e.g.*, an oval or trapezoidal cross-section, or a substantially circular cross-section with one or more flat spots).

[0031] The cable jacket is likewise typically formed from thermoplastic material(s), such as polyolefins (*e.g.*, polyethylene or polypropylene, such as medium-density or high-density polyethylene). The cable jacket may also be formed from polyvinyl chloride (PVC), polyamides (*e.g.*, nylon), polyester (*e.g.*, PBT), fluorinated plastics (*e.g.*, perfluorethylene propylene, polyvinyl fluoride, or polyvinylidene difluoride), and ethylene vinyl acetate. The cable jacket is typically extruded over the buffer tube and any water-blocking elements (*e.g.*, a water-swellaable tape). The cable jacket and/or buffer tube materials may also contain other additives, such as nucleating agents, flame-retardants, smoke-retardants, antioxidants, UV absorbers, and/or plasticizers.

[0032] The cable jacket may be a single sheath formed from a dielectric material (*e.g.*, non-conducting polymers), with or without supplemental structural components that may be used to improve the protection (*e.g.*, from rodents) and strength provided by the cable jacket. One or more layers of metallic (*e.g.*, steel) tape along with one or more dielectric sheathing may form an armored cable jacket. In addition, aramid, fiberglass, or polyester yarns may be employed under the various sheathing materials (*e.g.*, between the cable jacket and the buffer tube), and/or ripcords may be positioned, for example, within the cable jacket.

[0033] Similar to buffer tubes, the cable jacket typically has a circular cross section, but the cable jacket alternatively may have an irregular or non-circular shape (*e.g.*, an oval, trapezoidal, or flat cross-section).

* * *

[0034] As noted, passive elements may be placed within the central buffer tube's annular space or outside the central buffer tube between its exterior wall and the cable jacket's interior wall. For example, 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) may be employed to provide water blocking and/or to couple the optical fibers to the surrounding buffer tube and/or cable jacket (*e.g.*, via adhesion, friction, and/or compression). For example, a dry water-blocking tape or yarn may at least partially fill the polymeric buffer tube's annular space, and/or a dry water-blocking tape or yarn may be positioned between the central buffer tube and the surrounding cable jacket. Exemplary water-swellaable elements are disclosed in commonly assigned U.S. Patent No. 7,515,795, which is hereby incorporated by reference in its entirety.

[0035] Moreover, an adhesive (*e.g.*, a hot-melt adhesive or curable adhesive, such as a silicone acrylate cross-linked by exposure to actinic radiation) may be provided on one or more passive elements (*e.g.*, water-swellaable material) to bond the passive elements to the central buffer tube. An adhesive material may also be used to bond the water-swellaable element to optical fibers within the central buffer tube. Exemplary arrangements of such elements are disclosed in commonly assigned U.S. Patent No. 7,599,589, which is hereby incorporated by reference in its entirety.

[0036] The central buffer tube may also include within its annular space a thixotropic composition (*e.g.*, grease or grease-like gels) between the optical fibers and the buffer tube's interior wall. For example, at least partially filling the free space inside the buffer tube with water-blocking, petroleum-based filling grease helps to block the ingress of water. Further, the thixotropic filling grease mechanically (*i.e.*, viscously) couples the optical fibers to the surrounding buffer tube. That said, such thixotropic filling greases are relatively heavy and messy, thereby hindering connection and splicing operations. Thus, in some cable embodiments the optical fibers may be deployed in dry cable structures (*i.e.*, a grease-free buffer tube).

* * *

[0037] The optical-fiber cables according to the present invention may contain either multimode optical fibers or single-mode optical fibers.

[0038] The optical fibers are typically configured as optical-fiber ribbons positioned within central buffer tube's annular space. In this regard, multiple optical fibers as disclosed herein may be sandwiched, encapsulated, and/or edge bonded to form an optical-fiber ribbon. Optical-fiber ribbons can be divisible into subunits (*e.g.*, a twelve-fiber ribbon that is splittable into six-fiber subunits). Moreover, a plurality of such optical-fiber ribbons may be aggregated to form a ribbon stack, which can have various sizes and shapes.

[0039] For example, it is possible to form a rectangular ribbon stack or a ribbon stack in which the uppermost and lowermost optical-fiber ribbons have fewer optical fibers than those toward the center of the stack. This construction may be useful to increase the density of optical elements (*e.g.*, optical fibers) within the present buffer tube.

[0040] A rectangular ribbon stack may be formed with or without a central twist (*i.e.*, a "primary twist"). Those having ordinary skill in the art will appreciate that a ribbon stack is typically manufactured with rotational twist to allow the tube or cable to bend without placing excessive mechanical stress on the optical fibers during winding, installation, and use. In a structural variation, a twisted (or untwisted) rectangular ribbon stack may be further formed into a coil-like configuration (*e.g.*, a helix) or a wave-like configuration (*e.g.*, a sinusoid). In other words, the ribbon stack may possess regular "secondary" deformations.

[0041] Alternatively, the optical fibers may be configured as non-ribbonized optical fibers, such as optical-fiber bundles or as discrete optical fibers loosely positioned within central buffer tube's annular space. For example, bundles of optical fibers can be stranded (*e.g.*, SZ, S, or Z stranded) and then bundled together using binders (*e.g.*, helically or contra-helically wrapped binder yarns or binder tapes) to form an optical-fiber bundle. In exemplary embodiments of the present optical-fiber cable, several optical-fiber bundles may be positioned within the central buffer tube's annular space.

[0042] In one embodiment, the optical fibers employed in the present optical-fiber cables may be 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 Prysmian Group (Claremont, North Carolina, USA). The ITU-T G.652 (November 2009)

recommendations and each of its attributes (*i.e.*, A, B, C, and D) are hereby incorporated by reference in their entirety.

[0043] In another embodiment, bend-insensitive single-mode optical fibers may be employed in the optical-fiber cables according to the present invention. Bend-insensitive optical fibers are less susceptible to attenuation (*e.g.*, caused by microbending or macrobending). Exemplary single-mode glass fibers for use in the present optical-fiber cables are commercially available from Prysmian Group (Claremont, North Carolina, USA) under the trade name BendBright®, which is 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). In this regard, the ITU-T G.657.A1 (November 2009) subcategory fully encompasses the former ITU-T G.657.A (December 2006) category, and the ITU-T G.657.B2 (November 2009) subcategory fully encompasses the former ITU-T G.657.B (December 2006) category. The ITU-T G.657.A/B recommendations are hereby incorporated by reference in their entirety.

[0044] In this regard, exemplary bend-insensitive single-mode glass fibers for use in the present invention are commercially available from Prysmian Group (Claremont, North Carolina, USA) under the trade names BendBrightXS® and BendBright-Elite™. BendBrightXS® optical fibers and BendBright-Elite™ 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).

[0045] As set forth in commonly assigned U.S. Patent No. 8,265,442, U.S. Patent No. 8,145,027, U.S. Patent No. 8,385,705, and International Patent Application Publication No. WO 2009/062131 A1, pairing a bend-insensitive glass fiber (*e.g.*, Prysmian Group's single-mode glass fibers available under the trade name BendBright^{XS}®) 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

optical fiber employing a conventional coating system). The optical-fiber cables according to the present invention may employ the optical-fiber coatings disclosed in U.S. Patent No. 8,265,442, U.S. Patent No. 8,145,027, U.S. Patent No. 8,385,705, and International Patent Application Publication No. WO 2009/062131 A1, which are hereby incorporated by reference in their entirety, with either single-mode optical fibers or multimode optical fibers.

[0046] The optical fibers employed with the present optical-fiber cables may also comply with the IEC 60793 and IEC 60794 standards, which are hereby incorporated by reference in their entirety.

[0047] In another embodiment, the optical fibers employed in the present optical-fiber cables are conventional multimode optical fibers having a 50-micron core (*e.g.*, OM2 multimode optical fibers) and complying with the ITU-T G.651.1 recommendations. The ITU-T G.651.1 (July 2007) recommendations are hereby incorporated by reference in their entirety. Exemplary multimode optical fibers that may be employed include MaxCapTM multimode optical fibers (OM2+, OM3, or OM4), which are commercially available from Prysmian Group (Claremont, North Carolina, USA).

[0048] Alternatively, the present optical-fiber cables may include bend-insensitive multimode optical fibers, such as MaxCapTM-BB-OMx multimode optical fibers, which are commercially available from Prysmian Group (Claremont, North Carolina, USA). 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.

[0049] In contrast, conventional multimode optical fibers, in accordance with the ITU-T G.651.1 recommendations, 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, conventional 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.

[0050] Whether ribbonized or not, optical fibers typically have an outer diameter of between about 235 microns and 265 microns, although using optical fibers having a smaller diameter may be employed in the present optical-fiber cables.

[0051] 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). Optionally, the optical fiber may include an outermost ink layer, which is typically between two and ten microns.

* * *

[0052] 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 cable, comprising:

a polymeric buffer tube defining an annular space, and a plurality of optical fibers positioned within the polymeric buffer tube's annular space;

a cable jacket surrounding the polymeric buffer tube and the plurality of optical fibers positioned within the polymeric buffer tube's annular space, the cable jacket defining an inner wall and an outer wall;

a first group of two adjacent, rigid strength members substantially embedded within the cable jacket, the first two rigid strength members (*i*) each having a diameter D_{sm} and (*ii*) being spaced from one another by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$; and

a second group of two adjacent, rigid strength members substantially embedded within the cable jacket, the second two rigid strength members (*i*) each having a diameter D_{sm} and (*ii*) being spaced from one another by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$, wherein the second group of two strength members is positioned substantially diametrically opposite the first group of two strength members.

2. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that the first two strength members are spaced from one another by a distance of between $0.35 D_{sm}$ and $1.0 D_{sm}$; and

the second group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that the second two strength members are spaced from one another by a distance of between $0.35D_{sm}$ and $1.0D_{sm}$.

3. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that each of the first two strength members is acentrically positioned toward the cable jacket's inner wall; and

the second group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that each of the second two strength members is acentrically positioned toward the cable jacket's inner wall.

4. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is fully embedded within the cable jacket such that each of the first two strength members is acentrically positioned toward the cable jacket's inner wall; and

the second group of two adjacent, rigid strength members is fully embedded within the cable jacket such that each of the second two strength members is acentrically positioned toward the cable jacket's inner wall.

5. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is fully embedded within the cable jacket such that each of the first two strength members is spaced from the cable jacket's inner wall by a distance of less than $0.25D_{sm}$; and

the second group of two adjacent, rigid strength members is fully embedded within the cable jacket such that each of the second two strength members is spaced from the cable jacket's inner wall by a distance of less than $0.25D_{sm}$.

6. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is fully embedded within the cable jacket such that each of the first two strength members is spaced from the cable jacket's inner wall by a distance of less than $0.15D_{sm}$; and

the second group of two adjacent, rigid strength members is fully embedded within the cable jacket such that each of the second two strength members is spaced from the cable jacket's inner wall by a distance of less than $0.15D_{sm}$.

7. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is fully embedded within the cable jacket such that each of the first two strength members is spaced from the cable jacket's inner wall by a distance of less than $0.05D_{sm}$; and

the second group of two adjacent, rigid strength members is fully embedded within the cable jacket such that each of the second two strength members is spaced from the cable jacket's inner wall by a distance of less than $0.05D_{sm}$.

8. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that (i) neither of the first two strength members has more than 20 percent of its surface area exposed through the cable jacket's inner wall and (ii) neither of the first two strength members is exposed through the cable jacket's outer wall; and

the second group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that (i) neither of the second two strength members has more than 20 percent of its surface area exposed through the cable jacket's inner wall and (ii) neither of the second two strength members is exposed through the cable jacket's outer wall.

9. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that (i) each of the first two strength members has between 2 percent and 15 percent of its surface area exposed through the cable jacket's inner wall and (ii) neither of the first two strength members is exposed through the cable jacket's outer wall; and

the second group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that (i) each of the second two strength members has between 2 percent and 15 percent of its surface area exposed through the cable jacket's inner wall and (ii) neither of the second two strength members is exposed through the cable jacket's outer wall.

10. The optical-fiber cable according to Claim 1, wherein:

the first group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that (i) each of the first two strength members has between 5 percent and 10 percent of its surface area exposed through the cable jacket's inner wall and (ii) neither of the first two strength members is exposed through the cable jacket's outer wall; and

the second group of two adjacent, rigid strength members is substantially embedded within the cable jacket such that (i) each of the second two strength members has between 5 percent and 10 percent of its surface area exposed through the cable jacket's inner wall and (ii) neither of the second two strength members is exposed through the cable jacket's outer wall.

11. The optical-fiber cable according to any one of Claims 1–10, wherein:

each of the first two rigid strength members has a diameter D_{sm} of between 0.6 millimeter and 2.6 millimeters; and

each of the second two rigid strength members has a diameter D_{sm} of between 0.6 millimeter and 2.6 millimeters.

12. The optical-fiber cable according to any one of Claims 1–10, wherein both the first and second groups of rigid strength members consist of glass-reinforced-plastic strength members.

13. The optical-fiber cable according to any one of Claims 1–10, wherein the plurality of optical fibers are configured as optical-fiber ribbons positioned within polymeric buffer tube's annular space.

14. The optical-fiber cable according to Claim 13, wherein the optical-fiber ribbons are configured as an optical-fiber ribbon stack positioned within the polymeric buffer tube's annular space.

15. The optical-fiber cable according to any one of Claims 1–10, wherein the plurality of optical fibers are configured as optical-fiber bundles positioned within the polymeric buffer tube's annular space.

16. The optical-fiber cable according to any one of Claims 1–10, wherein the plurality of optical fibers comprise single-mode optical fibers.

17. The optical-fiber cable according to any one of Claims 1–10, wherein the plurality of optical fibers comprise single-mode optical fibers that comply with the ITU-T G.657.A recommendations and/or the ITU-T G.657.B recommendations.

18. The optical-fiber cable according to any one of Claims 1–10, wherein the plurality of optical fibers comprise multimode optical fibers.

19. The optical-fiber cable according to any one of Claims 1–10, wherein the plurality of optical fibers comprise multimode optical fibers that comply with the ITU-T G.651.1 recommendations.

20. The optical-fiber cable according to any one of Claims 1–10, comprising a thixotropic composition at least partially filling the polymeric buffer tube's annular space.

21. The optical-fiber cable according to any one of Claims 1–10, comprising a dry water-blocking tape or yarn at least partially filling the polymeric buffer tube's annular space.

22. The optical-fiber cable according to any one of Claims 1–10, comprising a dry water-blocking tape or yarn positioned between the polymeric buffer tube and the surrounding cable jacket.

23. An optical-fiber cable, comprising:

a plurality of optical fibers;

a polymeric buffer tube defining an annular space, the polymeric buffer tube enclosing the plurality of optical fibers within its annular space;

a cable jacket surrounding the polymeric buffer tube and the plurality of optical fibers positioned within the polymeric buffer tube's annular space, the cable jacket defining an inner wall and an outer wall;

a first group of two adjacent, glass-reinforced-plastic strength members fully embedded within the cable jacket such that each of the first two glass-reinforced-plastic strength members is acentrically positioned toward the cable jacket's inner wall, the first two glass-reinforced-plastic strength members (i) each having a diameter D_{sm} , (ii) being spaced from one another by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$, and (iii) being spaced from the cable jacket's inner wall by a distance of less than $0.25D_{sm}$; and

a second group of two adjacent, glass-reinforced-plastic strength members fully embedded within the cable jacket such that each of the second two glass-reinforced-plastic strength members is acentrically positioned toward the cable jacket's inner wall, the second two glass-reinforced-plastic strength members (i) each having a diameter D_{sm} , (ii) being spaced from one another by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$, and (iii) being spaced from the cable jacket's inner wall by a distance of less than $0.25D_{sm}$, wherein the second group of two glass-reinforced-plastic strength members is positioned substantially diametrically opposite the first group of two glass-reinforced-plastic strength members.

24. The optical-fiber cable according to Claim 23, wherein:

the first two glass-reinforced-plastic strength members are spaced from one another by a distance of between $0.35D_{sm}$ and $1.0D_{sm}$; and

the second two glass-reinforced-plastic strength members are spaced from one another by a distance of between $0.35D_{sm}$ and $1.0D_{sm}$.

25. The optical-fiber cable according to either Claim 23 or Claim 24, wherein:

each of the first two glass-reinforced-plastic strength members is spaced from the cable jacket's inner wall by a distance of less than $0.15D_{sm}$; and

each of the second two glass-reinforced-plastic strength members is spaced from the cable jacket's inner wall by a distance of less than $0.15D_{sm}$.

26. The optical-fiber cable according to either Claim 23 or Claim 24, wherein:

each of the first two glass-reinforced-plastic strength members is spaced from the cable jacket's inner wall by a distance of less than $0.05D_{sm}$; and

each of the second two glass-reinforced-plastic strength members is spaced from the cable jacket's inner wall by a distance of less than $0.05D_{sm}$.

27. The optical-fiber cable according to any one of Claims 23–26, wherein:

each of the first two glass-reinforced-plastic strength members has a diameter D_{sm} of between 0.6 millimeter and 2.6 millimeters; and

each of the second two glass-reinforced-plastic strength members has a diameter D_{sm} of between 0.6 millimeter and 2.6 millimeters.

28. The optical-fiber cable according to any one of Claims 23–27, wherein the plurality of optical fibers are configured as optical-fiber ribbons positioned within the polymeric buffer tube's annular space.

29. The optical-fiber cable according to any one of Claims 23–27, wherein the plurality of optical fibers are configured as optical-fiber bundles positioned within the polymeric buffer tube's annular space.

30. An optical-fiber cable, comprising:

a plurality of optical fibers;

a polymeric buffer tube defining an annular space, the polymeric buffer tube enclosing the plurality of optical fibers within its annular space;

a cable jacket surrounding the polymeric buffer tube and the plurality of optical fibers positioned within the polymeric buffer tube's annular space, the cable jacket defining an inner wall and an outer wall;

a first group of two adjacent, glass-reinforced-plastic strength members partially embedded within the cable jacket such that each of the first two glass-reinforced-plastic strength members is acentrically positioned toward the cable jacket's inner wall, wherein each of the first two glass-reinforced-plastic strength members (i) has a diameter D_{sm} and (ii) is spaced from the other by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$, and wherein (iii) neither of the first two glass-reinforced-plastic strength members has more than 20 percent of its surface area exposed through the cable jacket's inner wall and (iv) neither of the first two glass-reinforced-plastic strength members is exposed through the cable jacket's outer wall; and

a second group of two adjacent, glass-reinforced-plastic strength members partially embedded within the cable jacket such that each of the second two glass-reinforced-plastic strength members is acentrically positioned toward the cable jacket's inner wall, wherein each of the second two glass-reinforced-plastic strength members (i) has a diameter D_{sm} and (ii) is spaced from the other by a distance of between $0.25D_{sm}$ and $1.25D_{sm}$, wherein (iii) neither of the second two glass-reinforced-plastic strength members has more than 20 percent of its surface area exposed through the cable jacket's inner wall and (iv) neither of the second two glass-reinforced-plastic strength members is exposed through the cable jacket's outer wall, and wherein the second group of two glass-reinforced-plastic strength members is positioned substantially diametrically opposite the first group of two glass-reinforced-plastic strength members.

31. The optical-fiber cable according to Claim 30, wherein:

the first two glass-reinforced-plastic strength members are spaced from one another by a distance of between $0.35 D_{sm}$ and $1.0 D_{sm}$; and

the second two glass-reinforced-plastic strength members are spaced from one another by a distance of between $0.35 D_{sm}$ and $1.0 D_{sm}$.

32. The optical-fiber cable according to either Claim 30 or Claim 31, wherein:

each of the first two glass-reinforced-plastic strength members has between 2 percent and 15 percent of its surface area exposed through the cable jacket's inner wall; and

each of the second two glass-reinforced-plastic strength members has between 2 percent and 15 percent of its surface area exposed through the cable jacket's inner wall.

33. The optical-fiber cable according to either Claim 30 or Claim 31, wherein:

each of the first two glass-reinforced-plastic strength members has between 5 percent and 10 percent of its surface area exposed through the cable jacket's inner wall; and

each of the second two glass-reinforced-plastic strength members has between 5 percent and 10 percent of its surface area exposed through the cable jacket's inner wall.

34. The optical-fiber cable according to any one of Claims 30–33, wherein:

each of the first two glass-reinforced-plastic strength members has a diameter D_{sm} of between 0.6 millimeter and 2.6 millimeters; and

each of the second two glass-reinforced-plastic strength members has a diameter D_{sm} of between 0.6 millimeter and 2.6 millimeters.

35. The optical-fiber cable according to any one of Claims 30–34, wherein the plurality of optical fibers are configured as optical-fiber ribbons positioned within the polymeric buffer tube's annular space.

36. The optical-fiber cable according to any one of Claims 30–34, wherein the plurality of optical fibers are configured as optical-fiber bundles positioned within the polymeric buffer tube's annular space.

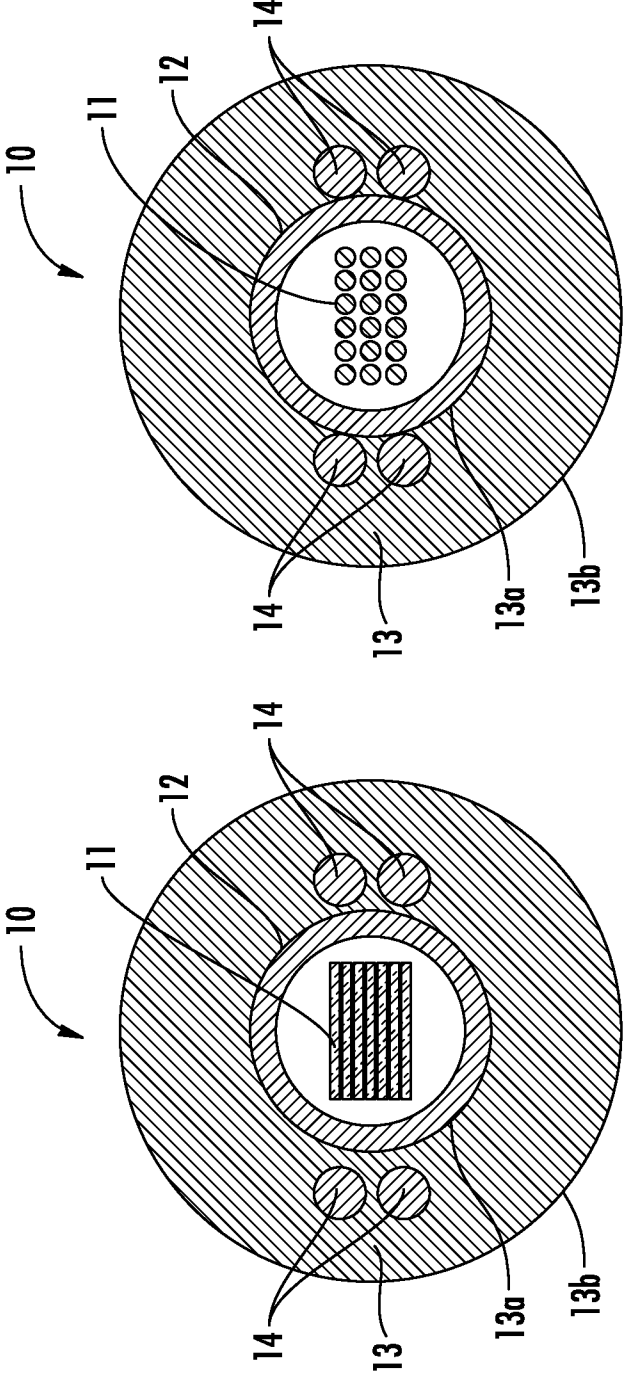


FIG. 2

FIG. 1

2/2

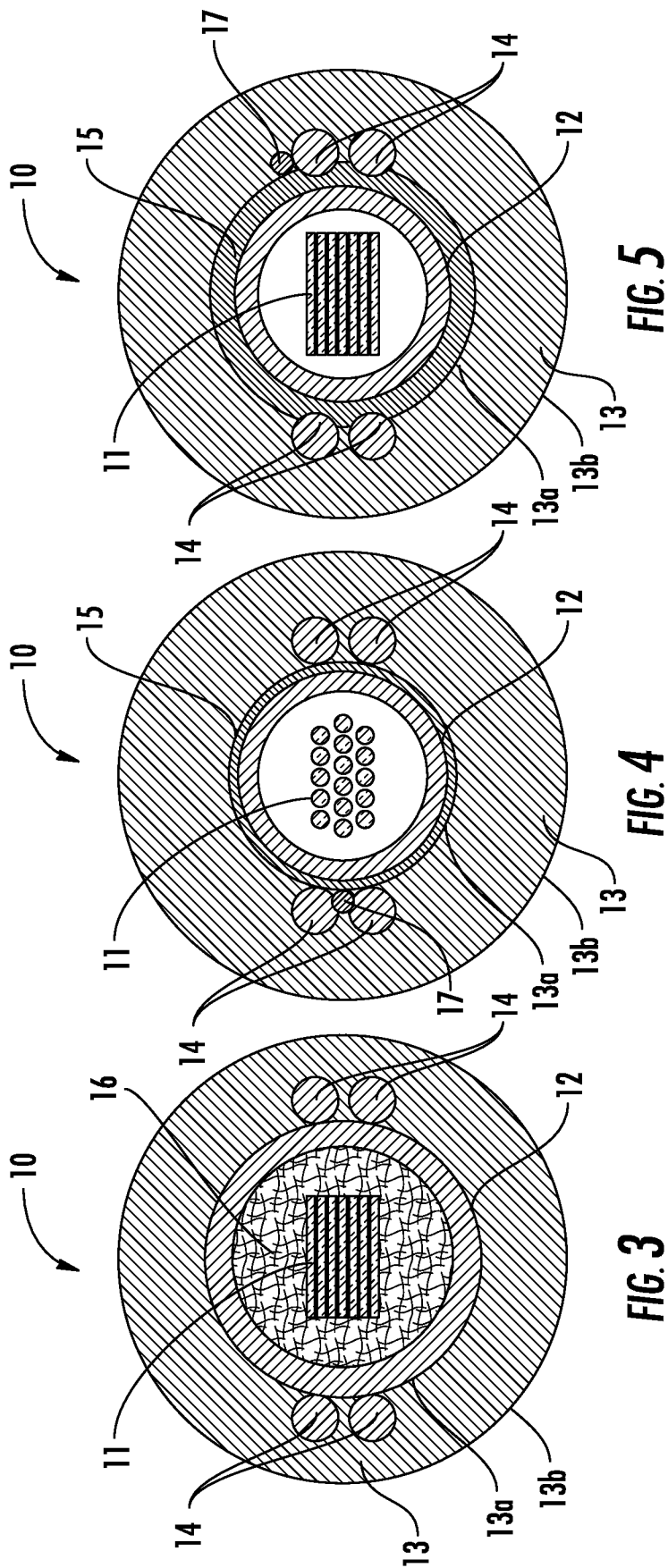


FIG. 3

FIG. 4

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/042731

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)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	column 8, line 23 - line 31; figure 5	11, 13-22, 27-29, 34-36
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Y	paragraph [0012]; figure 5	9-11, 13-22, 27, 28, 32-36
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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

26 August 2014

Date of mailing of the international search report

19/09/2014

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/042731

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	paragraph [0012] - paragraph [0018]; figures 4,5	9-11, 13-22, 27-29, 32-36

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International application No

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