(12) UK Patent (19) GB (11) 2592955 (13) B

(45) Date of B Publication 24.08.2022

(54) Title of the Invention: Cable system

(51) INT CL: ***H01B 7/00*** (2006.01) ***H01B 7/02*** (2006.01) ***H01B 9/00*** (2006.01) ***H01B 11/22*** (2006.01) ***H01R 9/22*** (2006.01) ***H02G 1/08*** (2006.01) ***H02G 3/04*** (2006.01)

(21) Application No: **2003556.4**

(22) Date of Filing: **11.03.2020**

(43) Date of A Publication **15.09.2021**

(56) Documents Cited:
EP 2804449 A1
JP 2018125311 A
US 20170309370 A1
US 20110192632 A1

(58) Field of Search:
As for published application 2592955 A viz:
INT CL **H01B**
Other: **WPI, EPODOC, Patent Fulltext**
updated as appropriate

Additional Fields
Other: **None**

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GB 2592955 B

Figure 1 – System Schematic

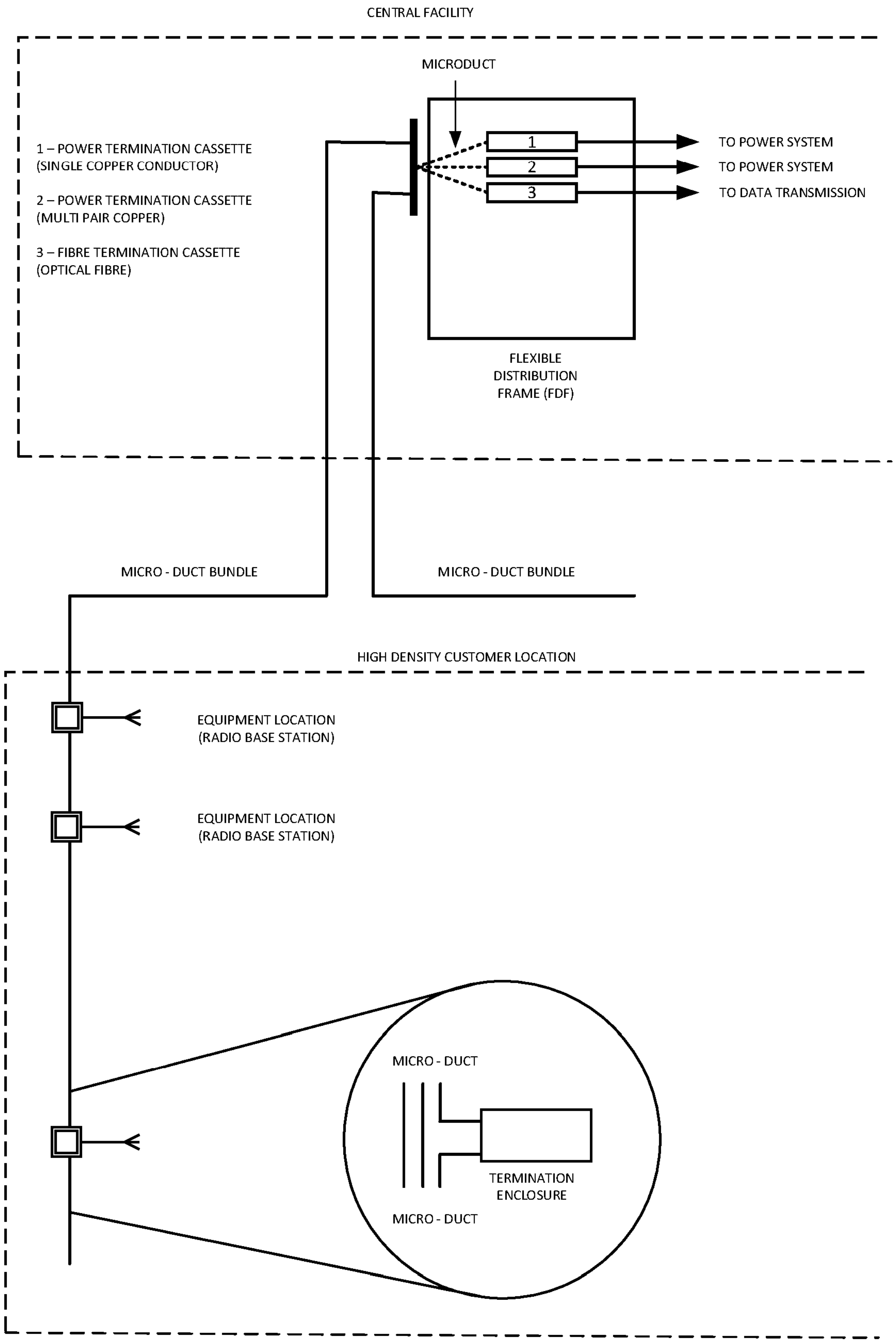


Figure 2 – Free Standing FDF Showing Discrete Positions For Micro Duct Terminations

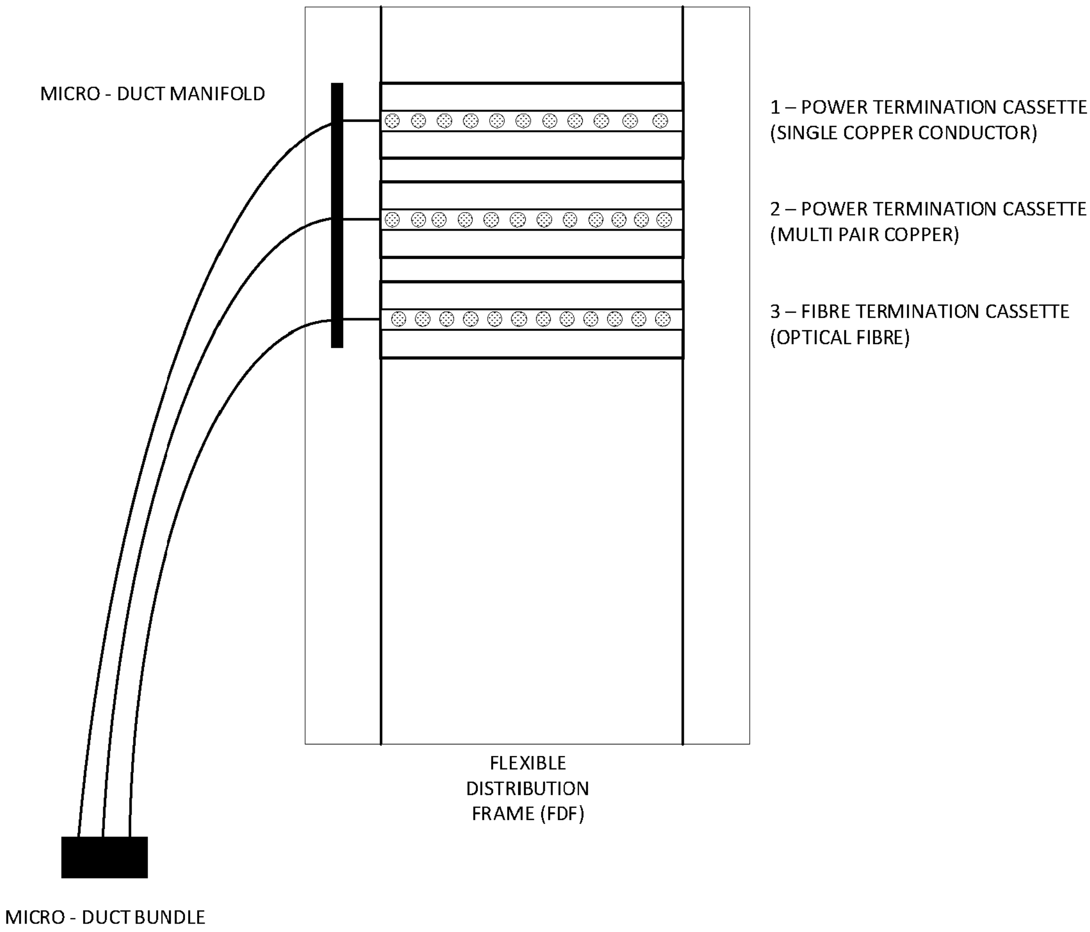
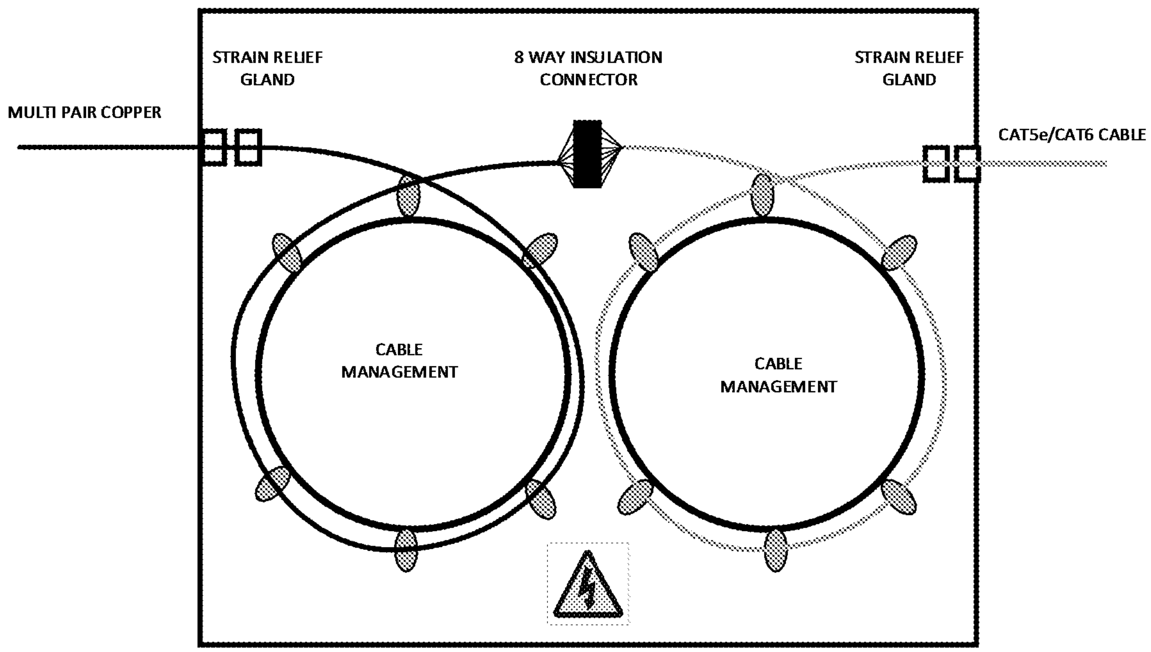
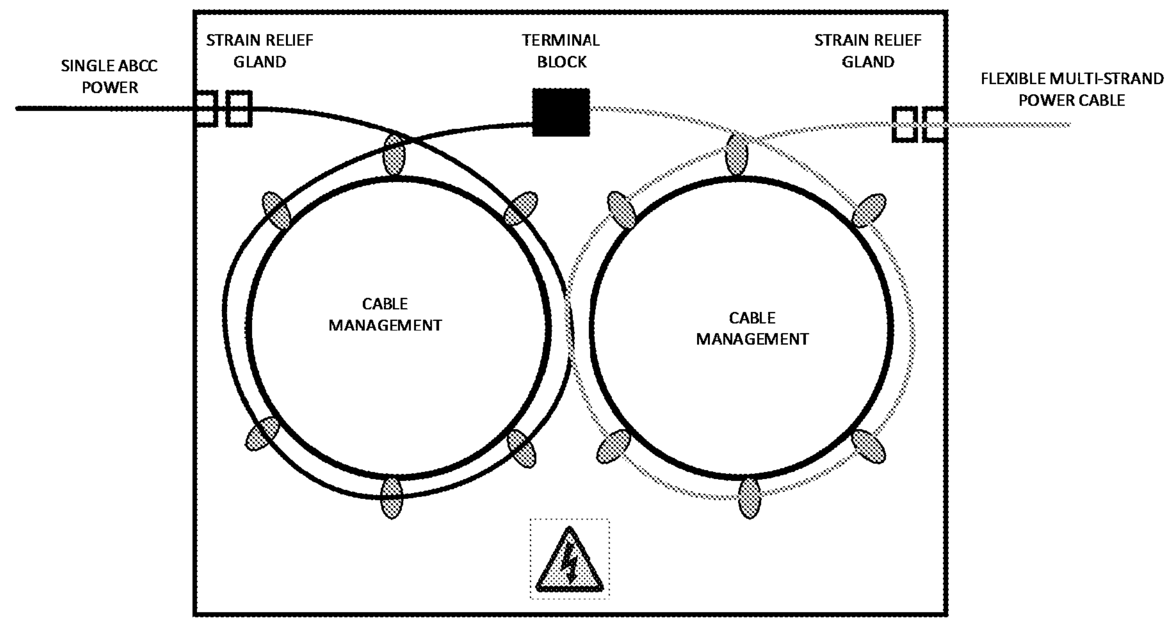


Figure 3 - Multiple Copper Conductor Termination Cassette



POWER TERMINATION CASSETTE
MULTI PAIR COPPER

Figure 4 – Single Copper Conductor Termination Cassette



POWER TERMINATION CASSETTE
SINGLE COPPER CONDUCTOR

Figure 5 – Example design – Landways 29.1

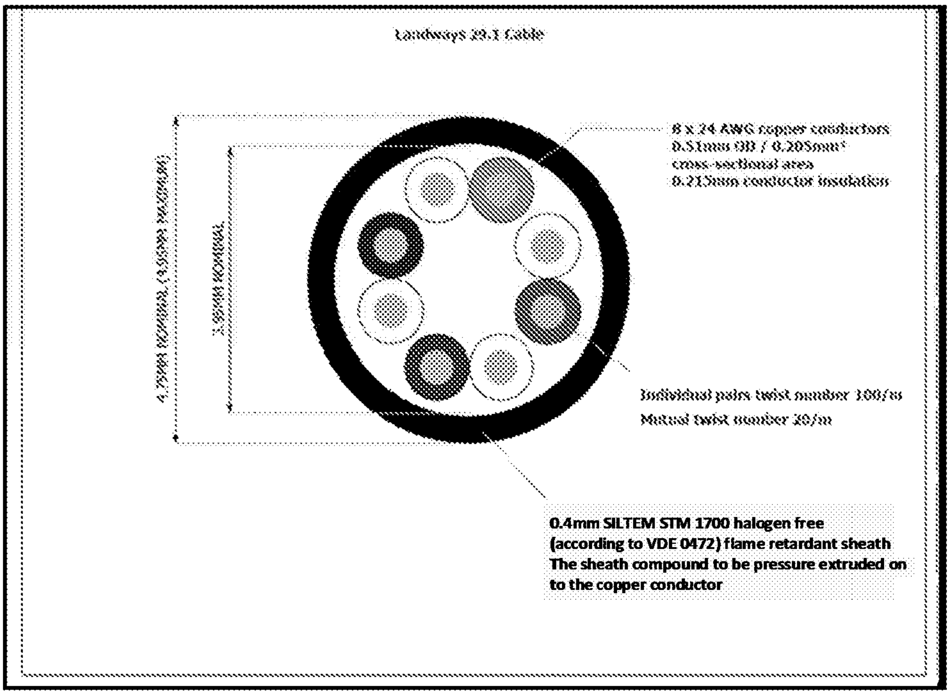


Figure 6 – Example design Landways 29.2

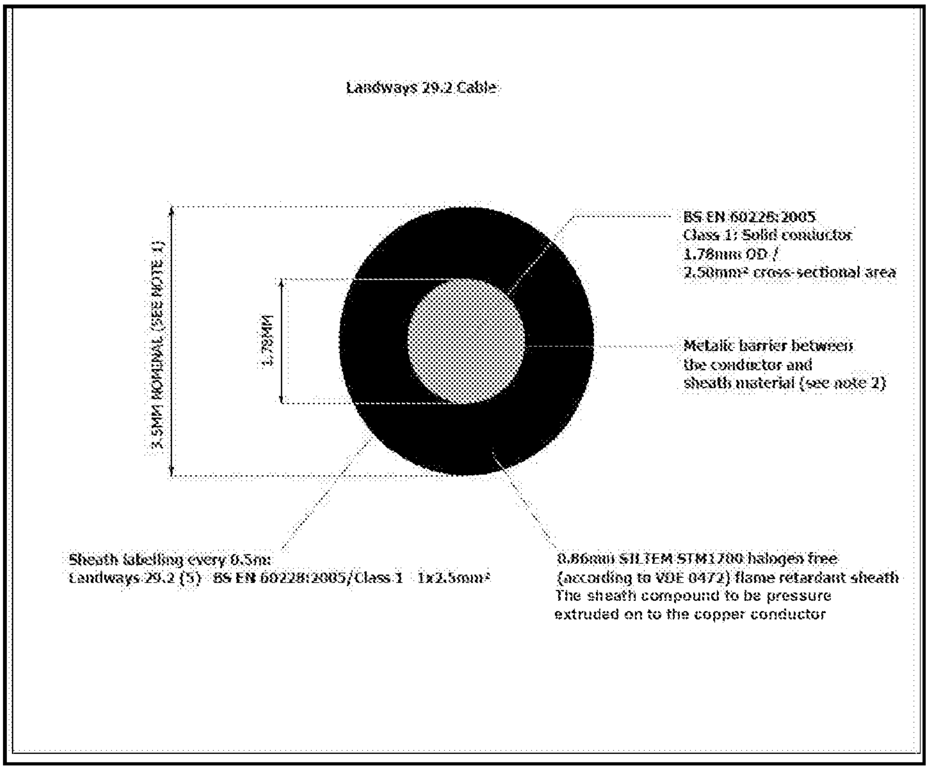


Figure 7 – Test circuit

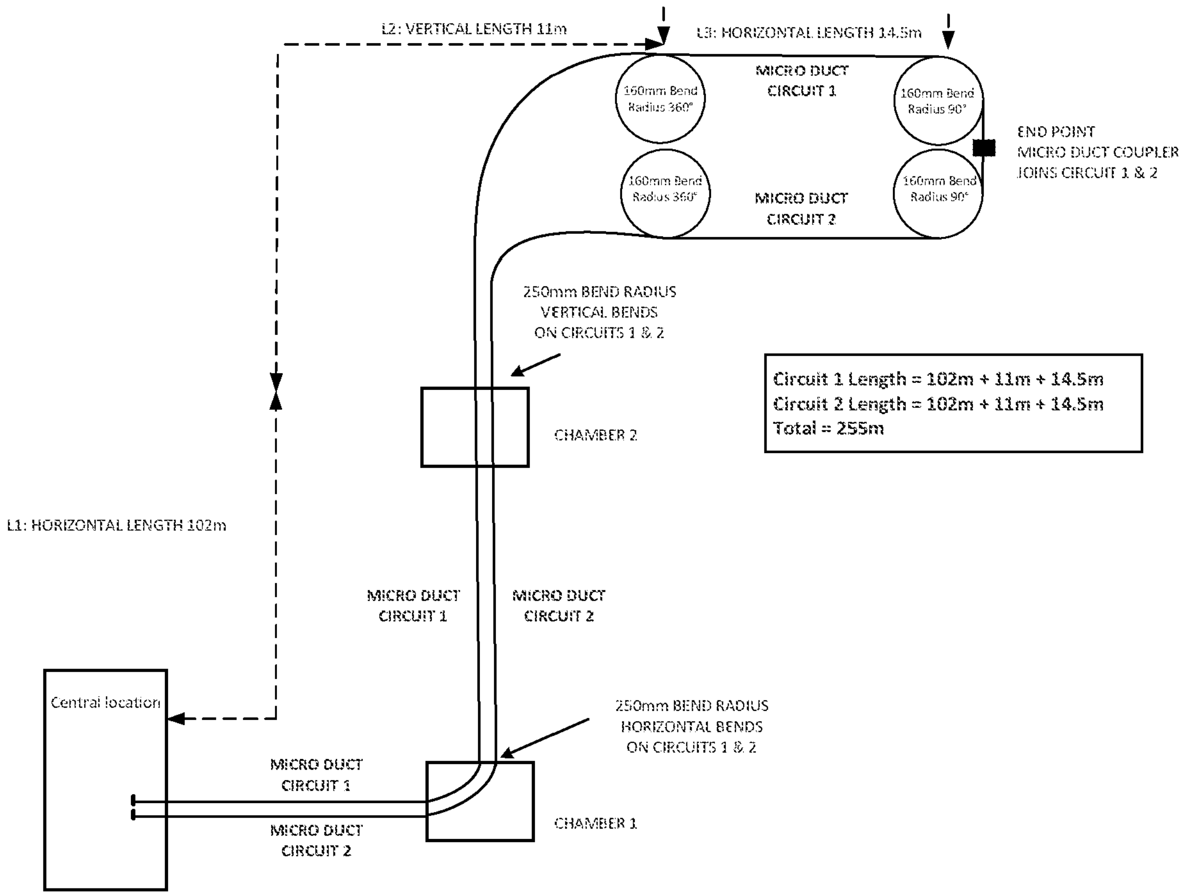


Figure 8 – Effect of stiffness on pushing / blowing performance

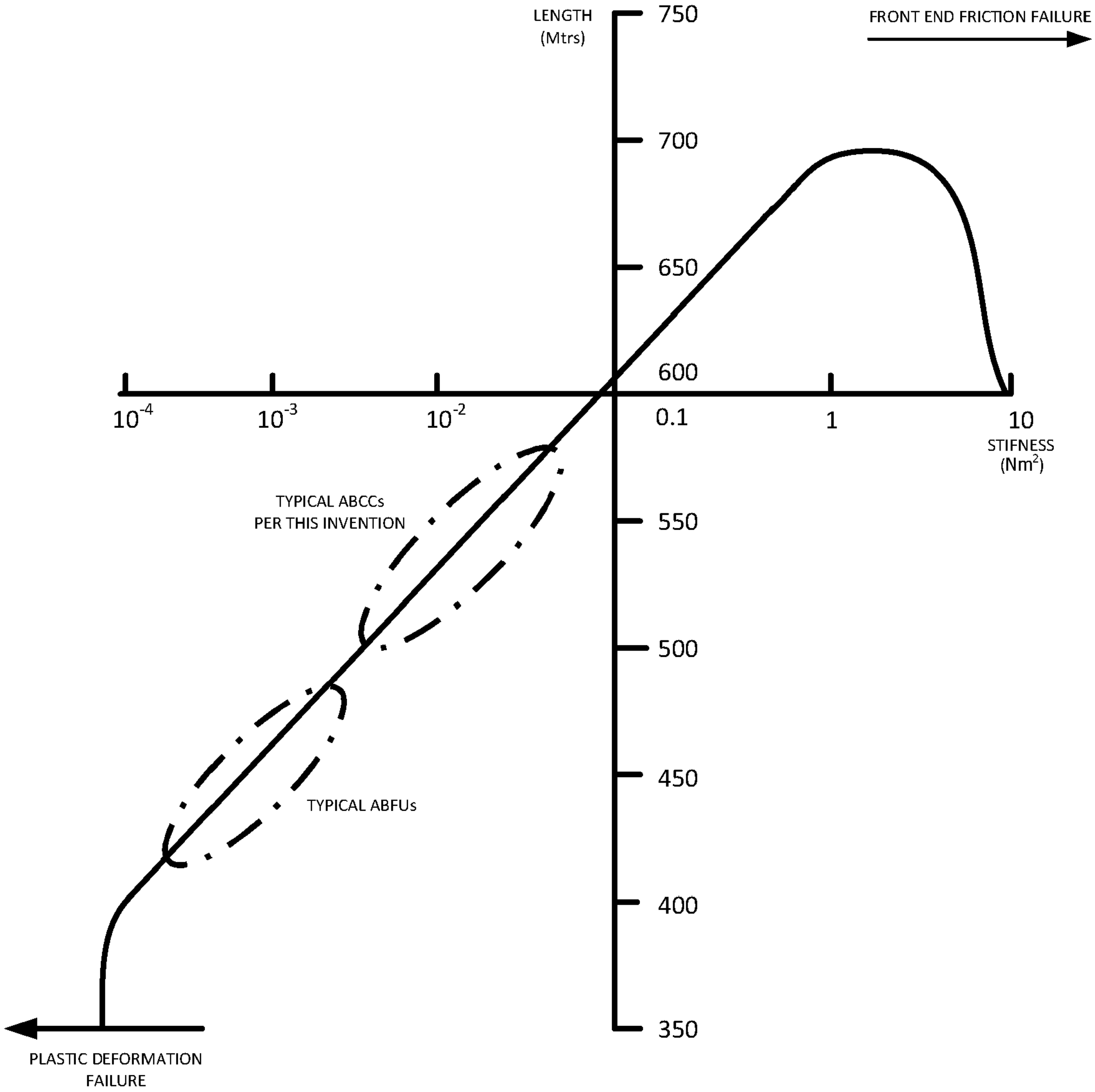


Figure 9 Three Point Bending Method to Determine Stiffness ('B' or 'EI')

The three point bend test (Figure 1) is a classical experiment in mechanics, used to measure the Young's modulus of a material in the shape of a beam. The beam, of length L, rests on two roller supports and is subject to a concentrated load P at its centre.

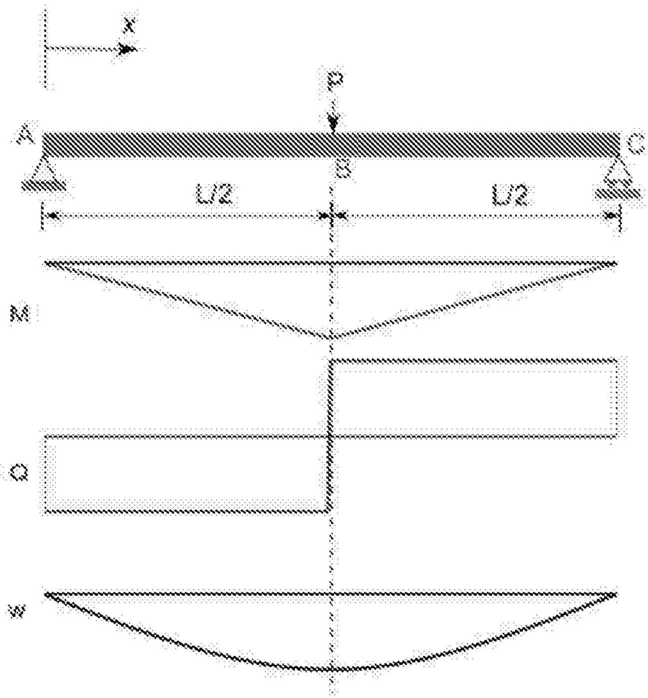


Figure 1: Schematic of the three point bend test (top), with graphs of bending moment M, shear Q and deflection w. Figure reproduced from http://commons.wikimedia.org/wiki/File:SimpSuppBeamPointLoad.svg.

It can be shown (see, for example, the *Cambridge University Engineering Department Structures Data Book*) that the deflection w_0 at the centre of the beam is

$$w_0 = \frac{PL^3}{48EI} \quad (1)$$

where E is the Young's modulus. I is the second moment of area defined by

$$I = \frac{a^3 b}{12} \quad (2)$$

where a is the beam's depth and b is the beam's width. By measuring the central deflection w_0 and the applied force P, and knowing the geometry of the beam and the experimental apparatus, it is possible to calculate the Young's modulus of the material.

CABLE SYSTEM

The present invention relates to cable systems, in particular a cable system that integrates optical fibre and copper media, a copper cable suitable for use in the cable system and installations employing the cable system.

Introduction

Optical fibre is acknowledged as a superior medium for the conveyance of both digital and analogue signals when compared to copper. However, copper is acknowledged as superior for the conveyance of power. As more and more devices situated at ever higher densities require optical fibres connections, the question of how to efficiently deliver power to the devices at the ends of those fibres becomes more pressing.

A good example of this is radio transceivers, in the form of public (4G and 5G) or private (WiFi) small cells, which are increasingly required throughout buildings and high-density open spaces. Each require both optical fibre and power. Whilst these can be delivered using separate infrastructures, there are considerable benefits in terms of efficiency, deployment speed, and security of supply, in delivering both media in an integrated manner.

The integration of both optical fibre and copper media within a single cable has been suggested for example in CN107068252 (A). However, should a change in specification of one of these occur (for example the power supply is upgraded to require larger conductors, or the optical fibre to a new generation), then both must be changed. This will lead to higher than necessary cost, and a (temporary) cessation of service to the customer.

In addition, power and optical fibre communications cables are usually routed to different locations at either one or both ends of the system. Where a combined power and communications cable is used it can be inconvenient for both to be too closely coupled at the origin and destination, since different skilled persons may be needed to handle each media type. Termination practices are very different for optical fibres and copper conductors – for example copper conductors lend themselves to intermediate connection without breaking the conductor (whereas optical fibres do not) and termination is made much more complex where both are combined in the same cable.

The installation of optical fibres into microducts (being tubes of typically less than 20mm outside diameter) has been accepted practice for over a decade and is a highly efficient method of deployment. GB2241121 illustrates one known example of optical fibre microducts.

The installation of large copper power cables in conventional ducts (greater than 20mm outside diameter) using floating (in particular to assist with pushing and/or pulling) has been proposed, but not widely adopted (see G. Plumettaz, J. Heinonen, “High voltage energy cables go underground – how to improve installation efficiency”, Proc. 58th IWCS (2009) 169-174). Floating systems require the provision and normally wastage of large volumes of water and is generally considered more suitable for very large and heavy products.

US2005258410 and CN104810106 describe approaches to blowing-in optical fibres.

Statement of Invention

Aspects of the present invention are based on a recognition that it would be beneficial to install, by blowing and/or pushing, copper cables of sufficient size for the supply of:

a) significant levels of power (e.g. above 100W and as high as 1500W), and

b) Lower levels (e.g. up to 100W) of power with the option to also convey ethernet data signals

into the same microducts designed for the installation (by blowing and/or pushing) of optical fibre, alongside such fibres, over significant distances (typically up to 1000m).

Were this possible, it would deliver a very efficient way to integrate the delivery of both power and signals.

According to the present invention, there is provided a cable for power distribution and/or data transmission, the cable comprising:

a core comprising one or more copper conductors; and

a sheath surrounding the core, the sheath being formed from a polymer having a tensile modulus of at least 1.5GPa;

wherein the outside diameter of the sheath is no more than 13.5mm; and the stiffness of the cable is at least 0.01 Nm^2.

The proposed construction, with a relatively large diameter, relatively high modulus sheath bound tightly around the copper core, can result in a cable that can be readily blown and pushed through a microduct without deforming, despite copper conductors' tendency to plastically deform under axial compressive loads. In effect, this is the reverse of a typical optical fibre, where it tends to be the bundle of fibres in the core of the cable that provide the desired stiffness, with the sheath adding very little.

In some embodiments, the outside diameter of the sheath is at least 4.5mm.

In some embodiments, the cable includes a barrier layer around the core, between the core and the sheath. The barrier layer can be formed from a tape either wound spirally or applied longitudinally around the core.

In some embodiments, the cable includes an electrical insulating sleeve around the or each copper conductor.

In some embodiments, the core comprises a plurality of twisted copper conductor pairs.

In some embodiments, the outer surface of the sheath has a coefficient of friction of 0.3 or less.

In some embodiments, the sheath is fire retardant.

In some embodiments, the tensile modulus of the polymer from which the sheath is formed is at least 2GPa.

In some embodiments, the stiffness of the cable is in the range 0.01 to 0.1 Nm2.

In some embodiments, the power transmission capacity of the cable is at least 70W and in other embodiments at least 100W.

The skilled person will appreciate that the features described and defined in connection with the the invention and the embodiments thereof described above can be combined in any combination, regardless of whether the specific combination is expressly mentioned herein. Thus, all such combinations are considered to be made available to the skilled person.

Detailed description

So that the invention may be more readily understood, and so that further features thereof may be appreciated, embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 schematically illustrates a cable system with which cables in accordance with an embodiment of the invention can be used;

Figure 2 illustrates a flexible distribution frame, which can be used with the system of fig. 1;

Figure 3 illustrates a multiple copper conductor termination cassette for use with the distribution frame of fig. 2;

Figure 4 illustrates a single copper conductor termination cassette for use with the distribution frame of fig. 2;

Figure 5 shows a schematic cross-sectional view of a copper cable in accordance with an embodiment of the present invention, having multiple twisted pairs of copper conductors;

Figure 6 shows a schematic cross-sectional view of a copper cable in accordance with another embodiment of the present invention, having a single copper conductor;

Figure 7 illustrates a test circuit used to test cable blowing of a single copper conductor;

Figure 8 is a graph showing cable stiffness on pushing vs blowing performance; and

Figure 9 explains the method used to measure cable stiffness.

As noted above, one general aim of the present invention is to enable copper cables having relatively high power transmission capacity and/or that afford Ethernet data transmission (with or without power), to be installed into the same microducts designed for the installation (by blowing and/or pushing) of optical fibre, alongside such cables (but not within the same individual ducts), over significant distances (typically up to 1000m).

Until now, this has not been thought possible as the physical characteristics of cables with sufficient copper content (1.64mm^2 in the case of gigabit ethernet requiring category 5 or 6 cables, and much higher in the case of single conductor cables, typically up to 5.6mm^2) have not been suitable for blowing/pushing. In particular, relatively large forces must be applied to progress a cable through a microduct, and existing cables are insufficiently stiff and deform plastically under even the modest pushing forces.

As an example, a variety of standard designs of Category 5e data cables, of outside diameters between 4.7mm and 4.85mm were tested using pushing / blowing into a 7/5.5mm microduct. The maximum distance achieved before the cable plastically deformed was 8m, making such an installation of very limited practical use.

Fig. 1 schematically illustrates a cable system. In this example, the system is for cabling in a building, in which there is a requirement for a high density of both power supply and data transmission to multiple radio transmitters.

The system uses bundles of microducts (e.g. from 2 to 24 microducts in each bundle). Each microduct can be from 5/3.5 mm (OD/ID) to 20/15 mm.

The bundle of microducts, can be of any suitable construction, including known examples already used for blown/pushed optical fibres. One suitable microduct arrangement that can be used is as described in GB2241121.

Optical fibres and copper conductor cables are air-blown into the microducts. The optical fibres in this example are packaged as Air-Blown optical Fibre Units (ABFUs), examples of which are readily available and well known to the skilled person. The copper conductor cables used in this example are termed Air-Blown-Copper Cables (ABCCs) (being either multi-pair or single conductor). These copper cables may be cables in accordance with the invention, as exemplified below. In some cases, further microducts of other sizes may be added for population with either further ABFUs or further ABCCs.

The system also includes a Flexible Distribution Frame (FDF) situated at the end of each bundle. In the FDF, each microduct is terminated on either:

a) an optical fibre termination cassette (which may be of a well-known type);
b) a multi-pair copper cable termination cassette; or
c) a single (or dual) conductor copper cable termination cassette.

Advantageously, as separating a bundle of microducts into its constituent individual ducts can be simply performed while leaving the media inside the microduct undisturbed, microducts can be flexibly assigned to different types of cassettes as required.

More specifically, in the case where large numbers of microducts are to be terminated (typically 9+), a free-standing closed rack or open frame structure of a type commonly used as an Optical Distribution Frame (ODF) is preferably used. Within the rack/frame each microduct is routed to a discrete position for termination, e.g. a specific shelf or splice tray.

Alternatively, a non-free-standing termination enclosure of a type similar to those commonly used as an optical fibre termination enclosure can be used, performing the same function, but typically for lower numbers of microducts (e.g. 2 – 8).

Figure 2 illustrates an example of a flexible distribution frame that can be used in the system of fig. 1 to terminate optical fibres, multi-pair copper cables and single copper cables.

The fibre and power termination shelf compartment is configured to allow installation of multiple fibre and power termination shelves to hold cassettes at which the ABFUs and ABPCCs are terminated. They also provide the facility to connect patching and jumper cables in a conventional manner.

In some examples, the shelves are segregated by function, for example one or more for optical fibre termination, one or more for multi-pair copper termination, and one or more for single conductor copper termination. This has the advantage that different operational and / or safety constraints as may exist in each media type (for example bend radius management for fibre and electrical safety required when copper conductors are energised), can be accommodated in each shelf.

It is also possible for shelves to be mixed, in which case the required or desired operational and safety constraints can be addressed at the cassette level.

The cassettes can be provided as trays mounted at discrete positions on shelves and are adapted to enable the termination and/or connection of multiple optical fibres or copper conductors.

In some embodiments, the type and position of cassettes may be interchanged or the cassettes replaced to reconfigure the distribution frame.

Each shelf in the distribution frame may hold one or more cassettes.

The optical fibre termination cassette can be of a well-known type.

An example design of multi-pair copper termination cassette is shown in Figure 3, in this example for connecting the end of a multi-pair copper cable to a CAT5e/CAT6 cable. The multi-pair copper cable enters the cassette from one side through strain relief gland and the CAT5e/CAT6 cable (or patch cord) exits from the opposite side of the cassette, also through a strain relief gland. The cable ends are connected to one another through an 8-way insulation displacement connector. The cassette includes a cable management arrangement within which spare cable can be stowed within the cassette.

An example design of single conductor copper termination cassette is shown in Figure 4, in this example for connecting the end of a single conductor copper cable to a flexible multi-strand power cable. The configuration of the cassette is largely the same as the cassette illustrated in fig. 3, with the two cable ends being connected in this case with a terminal block.

A particularly advantageous and unique feature of this approach is that each microduct can be individually assigned and re-assigned between the three media types (optical, multi-pair copper, single copper) and the corresponding cassettes can be easily changed to correspond with the function assigned.

Figures 5 and 6 illustrate copper conductor cables in accordance with embodiments of the invention. Before looking at these examples, it is useful to make some general observations about the new cables proposed here.

In designing optical fibre micro-cables, it is well understood that there is a range of stiffness over which acceptable pushing / blowing performance can be achieved. If the cable is too stiff, the pushing force required to be applied for it deflect from its axis to navigate bends will be too high and it will jam. However, if the cable is not stiff enough, the pushing force applied, particularly in the early stage of the installation operation will cause it to plastically deform and ‘buckle’, either before entry or within the microducts. An illustration of these behaviours for various B (stiffness) factors (as measured in accordance with the process described in fig. 9) is shown in figure 8.

In the case of optical fibres and especially small ‘fibre units’ (as defined in IEC 60794-5), the desired stiffness is achieved by creating a high stiffness inner core assembly of optical fibres, tightly bound together, counterbalanced by a much lower stiffness sheath. The composite stiffness is obtained using the parallel axis theorem. The parallel axis theorem sums the product of the tensile modulus and second moment of area of each component materials in an object, allowing for the distance of each element from the object's neutral axis. This means that components furthest from the neutral axis (ie 'outermost') contribute most, proportionally, to the 'B' value for the object as a whole.

The stiffness of a cable is easily measured by the 'Three Point Bending Method', shown in Figure 9.

In the case of the present invention, the objective is to create a copper conductor cable with the optimum properties for installation. The inner conductors are stiff (due to the high Tensile Modulus of copper) but are prone to 'plastic' deformation under compressive loads so that they buckle and remain in a deformed, 'bent' configuration. This is detrimental to installation as it creates additional, unwanted friction with the microduct side wall.

In embodiments of the first aspect of the present invention, the sheath is designed to be of sufficient tensile modulus, thickness and position to overcome the unwanted, buckling behaviour of the copper conductors by forming a tight jacket that constrains the copper core. Typically, the tensile modulus of the sheath material is in the range 1.5GPa to 2.5GPa, preferably at least 2GPa or higher, and the thickness is in the range 0.2 – 2mm, preferably higher than 0.4mm.

In some embodiments, the composite stiffness of the cable (i.e. copper core(s) surrounded by the tightly bound sheath) is 0.01 to 0.1Nm^2 (as measured in accordance with the method of Figure 9).

The sheath may be made, in some embodiments, of a polymer with a relatively low co-efficient of friction, for example a Coefficient of (dynamic) Friction of 0.3 or less, or more preferably 0.2 or less, reducing the force required to be applied and further enhancing its performance.

In embodiments of this aspect of the invention, the sheath material preferably also has an Elongation at Break of at least 10% and more preferably at least 15% to ensure the finished cable can be bent during handling and installation.

In some embodiments, the sheath is made of a material which exhibits excellent fire retardant, low smoke and zero halogen performance, giving significant safety benefits.

This is especially important for indoor uses, where standards often dictate cables with fire retardant properties. For example, preferred materials will typically have a high Oxygen Index, for example exceeding 40, a UL 94 V0 rating at low thickness (e.g 1.5mm) and should not melt before approximately 300C and, in doing so, produce minimal or no burning droplets.

In embodiments the sheath material is preferably extrudable using conventional cable manufacturing processes.

Examples of suitable sheath materials include polymer materials satisfying the above noted criteria, for example Polyetherimide ('PEI') polymers. PEI-siloxane copolymers are thought to be particularly suitable, one example being SILTEM™ STM1700 supplied by SABIC.

The inner copper conductor or conductor pair(s) can be engineered to a broad range of electrical performance specifications, including IEC/ISO11801 for communications and/or power (generally in the form of ‘Power over Ethernet’) and EN50525 for power only.

Two alternative designs of such cables are shown in figures 5 and 6.

Figure 5 illustrates, in cross-section, a copper cable having multiple twisted pairs of copper conductors. Each of the copper conductors has an insulator around it. The conductors are then twisted together in pairs, in this example with 100 twists per metre. In this exemplary cable, there are 4 twisted pairs and these 4 pairs are themselves all twisted together with 20 twists per metre to form the core of the cable. A PEI-siloxane copolymer (e.g. SILTEM™ STM1700) sheath is then extruded around the core. As seen in fig. 5, the resulting cable has an outside diameter of 4.75mm.

Figure 6 illustrates, in cross-section, a copper cable having a single copper conductor. The conductor is surrounded by a PEI-siloxane copolymer (e.g. SILTEM™ STM1700) sheath. The resultant cable in this example has an outside nominal diameter of 3.5mm.

The cables have been tested using the test circuit in figure 7. The circuit contains bends as tight as 60mm radius, as would be found inside commercial and domestic buildings.

The performance of the cables, when installed using air pressure of 15 bar, based on experiments using the test circuit, was:

Conductor size / duct	Blown Distance	Time	Installation Rate
1.78mmOD copper conductor as shown in Figure 6 5.5/7mm microduct	255m	5.44 min	47m/min

The features disclosed in the foregoing description, or in the following claims, or in the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for obtaining the disclosed results, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the exemplary embodiments of the invention set forth above are considered to be illustrative and not limiting. Various changes to the described embodiments may be made without departing from the scope of the invention.

For the avoidance of any doubt, any theoretical explanations provided herein are provided for the purposes of improving the understanding of a reader. The inventors do not wish to be bound by any of these theoretical explanations.

Any section headings used herein are for organizational purposes only and are not to be construed as limiting the subject matter described.

Throughout this specification, including the claims which follow, unless the context requires otherwise, the word “comprise” and “include”, and variations such as “comprises”, “comprising”, and “including” will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

It must be noted that, as used in the specification and the appended claims, the singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise. Ranges may be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, another embodiment includes from the one particular value and/or to the other particular value.

Similarly, when values are expressed as approximations, by the use of the antecedent "about," it will be understood that the particular value forms another embodiment. The term "about" in relation to a numerical value is optional and means for example +/- 10%.

CLAIMS

1. A cable for power distribution and/or data transmission, the cable comprising:

a core comprising one or more copper conductors; and

a sheath surrounding the core, the sheath being formed from a polymer having a tensile modulus of at least 1.5GPa;

wherein the outside diameter of the sheath is no more than 13.5mm; and

the stiffness of the cable is at least 0.01 Nm^2.

2. A cable according to claim 1, wherein the outside diameter of the sheath is at least 3.5mm.

3. A cable according to claim 1 or claim 2, comprising a barrier layer around the core, between the core and the sheath.

4. A cable according to claim 3, wherein the barrier layer is formed from a tape wound spirally around the core or applied longitudinally around the core.

5. A cable according to any one of the preceding claims, comprising an electrical insulating sleeve around the or each copper conductor.

6. A cable according to any one of the preceding claims, wherein the core comprises a plurality of twisted copper conductor pairs.

7. A cable according to any one of the preceding claims, wherein the outer surface of the sheath has a coefficient of friction of 0.3 or less.

8. A cable according to any one of the preceding claims, wherein the sheath is fire retardant.

9. A cable according to any one of the preceding claims, wherein the tensile modulus of the polymer from which the sheath is formed is at least 2GPa.

10. A cable according to any one of the preceding claims, wherein the stiffness of the cable is in the range 0.01 to 0.1 Nm^2.

11. A cable according to any one of the preceding claims, wherein the power transmission capacity of the cable is at least 70W.