Title of the Invention: High altitude platform

INT CL: B64B 1/50 (2006.01)  D07B 1/14 (2006.01)  H04B 7/185 (2006.01)

Application No: 1202072.3
Date of Filing: 20.10.2010
Date Lodged: 07.02.2012

Priority Data:
(31) 1012864  (32) 30.07.2010  (33) GB
(31) 1015807  (32) 21.09.2010  (33) GB

Divided from Application No 1017685.7 under section 15(9) of the Patents Act 1977

Date of A Publication 04.07.2012

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Documents Cited:
GB 1191322 A  US 20100101833 A
US 20020167702 A

Field of Search:
As for published application 2486993 A viz:
INT CL B64B, B64C, D07B, H04B
Other: Online: WPI, EPDOC & selected English language full text databases updated as appropriate
Figure 10
Title: High Altitude Platform

Technical field

The invention relates to high altitude platforms, particularly for delivering information services at altitude, including telecommunications, observation and positioning services.

Background to the invention

High altitude platforms, e.g. situated from 10 to 25 km altitude, have been proposed for a wide variety of applications. One area of growing interest is in providing information services from such arrangements such as telecommunications, positioning and observation capabilities including high speed internet, e-mail, telephony, televisual services, video-on-demand, global positioning.

Compared with satellites, high altitude platforms have several advantages, primarily because the distance from a transmitter to a receiver on Earth can be much less, with geostationary satellites typically at 40,000 km altitude and around 1000 km altitude for a low Earth orbit satellite.

This relative nearness of high altitude platforms can result in much stronger signals and avoid the expense of rocket launches as well as providing shorter development times.

US 7,046,934 discloses a high altitude balloon for delivering information services in conjunction with a satellite.

However, there are numerous and significant technical challenges to providing a reliable commercial information service from a high altitude platform. A key problem is maintaining the stability of such a platform, which will be subject to winds which
can be highly fluctuating and of very high speeds. In particular, many information services require accurate directional transmissions which are difficult to deliver from a platform subject to the high winds present at such altitudes.

Furthermore the power available locally at altitude is generally restricted to a few kW, ruling out engineering solutions involving high powered devices.

Therefore, further improvements in this area would be highly desirable.

**Summary of the invention**

The invention relates to an apparatus for providing high altitude services, comprising a platform at an elevated location, the platform being tethered to a substantially ground level location, wherein the tether is coated with a hydrophobic material.

Thus, if any liquid forms on the surface of the tether it will generally not form continuous pathways, thus preventing the possibility of an electrical pathway forming. Additionally, other potentially problematic situations may be avoided by preventing the formation of ice on the tether which can promote aerodynamic instability in particular in the case of non-circular tethers.
The engineering challenges involved in such an arrangement are significant. However, with careful design of the apparatus it can be achieved, as will be discussed below.

Typically the elevated location will be at an altitude of from 5,000 m to 30,000 m, preferably from 10,000 m to 25,000 m, more preferably from 15,000 m to 25,000 m. This provides sufficient altitude to deliver information services over a wide area whilst not being so high as to present insurmountable engineering challenges. In a preferred embodiment, the elevated location is in the stratosphere, preferably just above or at the tropopause, where side winds are much less severe.

The substantially ground-level location is typically at or very near to the land or sea surface of Earth, e.g. within 1000 m, preferably within 100 m of a land or sea surface. In one preferred embodiment, the apparatus comprises a ship to which is coupled the tether.

In a preferred embodiment the apparatus comprises one or more balloons or dirigibles at the elevated location, to provide the lift necessary to keep the apparatus at the elevated location. Such a one or more balloon or dirigible is therefore preferably capable of providing a lifting force of at least 5.0 metric tonnes, more preferably at least 10.0 metric tonnes, and possibly at least 25 metric tonnes.

In order to provide such lift, any balloons preferably have a total volume of from 60,000 m$^3$ to 2,000,000 m$^3$.

Such a balloon or dirigible can be spherical but is preferably non-spherical or ellipsoidal in shape. This provides a more aerodynamic shape, which helps reduce wind forces.
It has been further discovered that such a tether may preferably have a non-circular cross-section to reduce horizontal drag whilst maintaining vertical strength and pressure containment for the conduit.

Horizontal drag on the tether is a significant problem as it could cause the tether to move to a more horizontal orientation, thus lowering the altitude of the platform to below that of the desired elevated location, a problem that can be described as blow-over. This can be exacerbated if the platform enters a region of higher wind speeds which could lead to a catastrophic failure due to excess wind loads.

Thus, preferably the tether has a non-circular cross-section.

Such a tether can be characterised by the aspect ratio of the cross-section, i.e. the ratio of the length of sides of a rectangle which just contains the cross-section. Aspect ratios of from 1.5 to 20.0 are preferred.

The tether may comprise reinforcing cables so as to provide sufficient strength to the tether. In one preferred embodiment, the tether comprises more than one cable, each being parallel to each other. In this way cables with a
circular cross-section can produce a tether according to the invention having a non-circular cross-section. Further cables can be included which may also be aligned with the other cables to produce an elongate cross-sectional tether. For example a tether comprising from 1 to 10 cables is preferred.

As is well-known in the art, a circular cross-section tether would always present the same area to the air irrespective of any twisting action in the tether. However a tether with a non-circular cross-section has the potential to expose a variable area to the flowing air according to the rotated state of the tether.

However, one problem with long non-circular cross-section tethers is that they tend to expose their maximum area to flowing air, rather than expose their minimum area. This is because such tethers will generally have a low torsional stiffness and align themselves in the flowing air with the minimum strain energy thereby putting the long axis at right angles to the flow direction unless regularly oriented by, for example, vanes.

Thus, their natural tendency to present an increased area can increase the forces on the tether due to flowing air. It is therefore desirable to take steps to ensure that the non-circular cross-section tether tends to expose a minimum area to flowing air.

It has now been surprisingly found that such non-circular cross-section tethers can be made to expose their minimum area to flowing air even though they may have low torsional stiffness.

Such tethers are thus typically elongate in their cross-section, having two well-defined ends to the elongate cross-section. The two ends can be referred to as the leading edge and trailing edge respectively. The leading edge is typically rounded and is intended to be at the most upstream point of air flowing over the tether. Likewise the trailing edge is intended to be the most downstream point of flowing air. The distance from the most upstream point of the tether to the most downstream point on the tether in a given cross-section, is referred to as the chord length of the tether at that cross-section.
When air flows over such a tether, it creates forces on the tether. At any given time there is a notional point within the cross-section of the tether about which the sum of all the moments induced by such forces, cancel each other out. Such a point is referred to herein as the centre of aerodynamic pressure.

Because of the length of the tether it will generally have a low torsional stiffness. It has been surprisingly found that if the centre of mass of the tether at a given cross-section is nearer to the leading edge of the tether than is the centre of aerodynamic pressure, then the tether will find its most stable arrangement to be when it exposes its minimum area to the flowing air, even though the stored strain energy may not be a minimum.

In other words, the centre of mass is preferably nearer to the leading edge than is the centre of aerodynamic pressure in use.

It is typically the case that for an elongate cross-section of tether positioned to expose its minimum area to the flowing air, the centre of aerodynamic pressure will be near to one-quarter the chord length from the leading edge. Thus, in order to ensure that the centre of mass is closer to the leading edge than is the centre of aerodynamic pressure, particular steps need to be taken.

For example, the shape of the tether cross-section is preferably a tear-drop shape, e.g. similar to a helicopter rotor cross-section. However, this alone will not ensure that the centre of mass is sufficiently close to the leading edge. Thus, typically the material density of the tether is greater near to the leading edge than it is in the centre and near to the trailing edge.

Such variation in material density may be gradual or sudden. It may even involve dislocations where other materials, such as optical fibre cables and reinforcing cables, pass through the tether. However, any variation in material density together with variations in shape together provide the centre of mass being suitably positioned within the tether.
Thus, preferably the centre of mass of the tether is less than 25% of the chord length from the leading edge. More preferably it is less than 24% of the chord length from the leading edge. Typically it will be from 10% to 24%, more preferably from 15% to 24% of chord length from the leading edge.

Naturally, as the tether connects the substantially ground-level location to the platform it will carry a tension force. It has been surprisingly found that improvements in tether stability can be achieved if the centre of tension is nearer to the leading edge than is the centre of aerodynamic pressure in use.

It has been found that if the centre of tension is downstream of the centre of aerodynamic pressure, the tether may be prone to twisting so that the longitudinal axis inclines at a large angle to any wind. Once this process begins, more and more of the length of the tether will assume this altitude, potentially giving higher wind loads than if the tether is pointed in the wind.

The centre of tension is that point in a cross-section of tether about which all the moments established by the tension forces (which are directed normal to the plane of the cross-section) carried by the tether in that cross-section add up to zero.

Thus preferably the centre of tension of the tether is less than 25% of the chord length from the leading edge. More preferably it is less than 24% of the chord length from the leading edge. Typically it will be from 10% to 24%, more preferably from 15 to 24% of chord length from the leading edge.

It has been surprisingly found that improvements in tether stability can be achieved if the centre of shear is nearer to the leading edge than is the centre of aerodynamic pressure in use.

The centre of shear is the point in the cross-section of the tether through which, if a notional force is applied in the plane of the cross-section, causes no rotational forces
on the tether. In other words the force applied results in pure deflection of the tether without any rotation thereof.

Thus preferably the centre of shear of the tether is less than 25% of the chord length from the leading edge. More preferably it is less than 24% of the chord length from the leading edge. Typically it will be from 10% to 24%, more preferably from 15 to 24% of chord length from the leading edge.

It has also been found that is may be optimally desirable that that the centres of mass, tension and shear are in close proximity to each other, whilst remaining nearer to the leading edge than the centre of aerodynamic pressure. Thus the centres of mass, tension and shear are preferably within a region of less than 10% of the chord length, preferably less than 5%. On occasion it is possible that one or two of these centres may be further away from the leading edge than the centre of aerodynamic pressure, but not all three if a dynamically stable system with low drag is to be achieved.

In a preferred embodiment the tether may comprise a series of vanes or aerofoils to provide lift to the tether from horizontal or near horizontal winds. The tether may also comprise fins which may be powered to provide active control.

Alternatively or additionally, the tether may comprise a plurality of flags located along the length of the conduit. Such flags have been found to prevent flutter of the non-circular cross-sectional tether.

In a preferred embodiment, the apparatus comprises a gyroscopic and/or gravitational stabilisation means. Such an apparatus can act to maintain a fixed attitude in the atmosphere. This enables transmissions directed from the apparatus through the atmosphere and to the Earth’s surface. Without such a stabilisation
means, the movement of the apparatus would make directional transmissions more difficult.

The platform preferably comprises information services apparatus. For example, the apparatus may comprise electromagnetic transmitters and/or receivers for delivering telecommunication services to the surface of the Earth.

In a preferred embodiment, the tether also comprises an optic fibre cable from the substantially ground level location to the elevated location to transmit and receive high bit rates to transmitters/receivers at the elevated location. From the substantially ground level location the optical fibre can be linked to ground-based centres of communication by optical fibre. In the case when the substantially ground level location is a ship, then it is desirable to arrange for an optic fibre cable to travel from the mainland under the sea to a buoy, connected by an optical fibre or other means to the ship. Communication to and from the ship can then be transmitted by optic fibre via the sub-sea optic fibre cable.
The tether and platform according to the invention may also be susceptible to lightning strikes. Such strikes can be very hazardous, particularly if a fuel fluid is passing through a conduit in the tether. Thus, preferably the conduit is non-electrically conducting. This can be achieved, for example, by ensuring that any metal components of the tether are broken every so often, e.g. every few metres, to break any electrical pathway. Alternatively the conduit may be essentially free of electrically conductive elements.

Whilst the conduit is preferably non-electrically conductive, the tether itself may be non-electrically conductive too or alternatively may comprise a lightning strike conductor electrically connecting the substantially ground level location to the
platform. Thus, any lightning strikes would be carried by the conductor and not influence the non-conductive conduit.

It is also preferable if the tether comprises a moveable vehicle which is operable to inspect the tether for damage, possibly make minor repairs and providing a de-icing capability.

As such high altitude platforms will generally be located in the vicinity of human population areas, consideration with respect to aircraft safety and regulations must also be given. One such safety consideration is the requirement that the tether contain a multitude of lights which may operate continuously or intermittently, in order to alert aeroplane pilots of the presence of the tether.
However, providing lights and providing sufficient power along the length of the tether can involve significant weight increases, which in general are to be avoided. Thus, a system which can provide such lighting without significant additional weight would be highly desirable.

Thus, preferably the tether comprises an optic fibre cable at least substantially from the substantially ground level location to the platform, the optic fibre cable comprising a plurality of couplers spaced along the length of the optic fibre cable, each coupler adapted to divert a fraction of the light in the optic fibre cable and direct it to a respective light emission means.

Typically the light emission means comprises a collimator and may, for example, comprise one or more lenses, some mirrors or diffraction gratings (either conventional or holographic).

The light transmitted along the optic fibre cable is preferably intermittent, in order to provide a flashing light effect at the respective light emissions means.

In a preferred embodiment the light emission means are evenly spaced apart. Spacing between the light emission means can be from 50 to 200 m.

Thus, such a tether may comprise from 20 to 200 such light emitting means. Thus, the amount of light diverted by each coupler is preferably in the range of from 0.5 to 5.0 % of the light in the optic fibre at that point.

The optic fibre in this embodiment is typically a different optic fibre employed for conveying optical signals for use with information services apparatus according to other aspects of the invention.

Such an arrangement is low weight, compact, can present little additional wind resistance and involves no local power requirements, thus simplifying the apparatus required.
Any of the features disclosed herein may be combined with any other feature to provide embodiments according to the invention.

The invention will now be illustrated, by way of example and with reference to the following figures, in which:

Figure 1 is a schematic representation of an apparatus according to the invention.

Figure 2 is a sectional plan view through the cross-section of a tether for use with apparatus according to the present invention.

Figure 3 is a sectional plan view through the cross-section of another tether for use with apparatus according to the present invention.

Figure 4 is a perspective view of a section through another tether for use with apparatus according to the present invention.

Figure 5 is a perspective view of a section through another tether for use with apparatus according to the present invention.

Figure 6 is a perspective view of a section of another tether for use with apparatus according to the present invention.

Figure 7 is a perspective view of a section of another tether for use with apparatus according to the present invention.

Figure 8 is a perspective view of a section of another tether for use with apparatus according to the present invention.

Figure 9 is a schematic representation of elements of an apparatus according to the present invention.
Figure 10 is a sectional view through a cross-section of a tether according to the present invention.

Figure 11 is a schematic representation of a further apparatus according to the present invention.

Figure 12 is a schematic representation of a light emission means for use with a tether according to the present invention.

Turning to the figures, Figure 1 shows an apparatus according to the invention comprising a high altitude platform 4 supported by a balloon 3 and a tether 2. The tether is attached to a ship 1 located at sea level, being a ground level location.

The platform 4 comprises an electrical generator in the form of a fuel cell, although it could be a gas engine, jet engine or a diesel engine and the like.

The platform 4 also comprises a variety of information services apparatus, such as internal antennas, multi networks for wireless internet, a 700 horn antennae to supply 1 to 20 km diameter cells, television transmitters, GPS transmitters, aircraft warning systems, e.g. radar reflectors and light strobes.

The tether 2 comprises a Kevlar™ pipe with a 15 mm outside diameter and 12 mm inside diameter made of composite material with a PTFE liner. The pipe is reinforced by four additional Kevlar™ cables of 15 mm diameter to provide a cross-section to the tether which is non-circular.

Balloon 3 is 600,000 cubic metres capacity of ellipsoid shape with a horizontal diameter of 158 m and a vertical height of 46 m and is filled with helium to support the platform 4 which weighs 8 metric tonnes.

The ship 1 comprises a store of hydrogen, and optionally a hydrogen generation plant, and can pressurise the hydrogen to 350 bar pressure by two high pressure compressors (not shown) so that it can flow up the tether to the platform 4. Once the hydrogen
arrives at the platform it passes to the fuel cell, whereupon electrical energy is
generated at altitude. The electrical energy produced is typically from 100 to 10,000
kW, e.g. 1000 kW, and is more than enough to provide high strength signals for use
with the information services apparatus.

Figure 2 shows a cross-section through a portion of the tether 2 used in Figure 1. The
tether 2 comprises a conduit 6 which carries the fuel fluid, e.g. hydrogen. It is
strengthened by a wall 8 of composite material.

Also provided are four strengthening cables 10 which do not carry fuel fluid but are
there to lend strength to the tether. Also provided is a tail portion 12 and a fin portion
14 attached to tail portion 12 by a ring or actuator 16. The tether is surrounded by a
skin 18 to maintain integrity of the tether 2. The elongate nature of the cross-section
helps to reduce horizontal drag induced by high cross-winds. The actuator 16 may be
operable to provide active control to prevent adverse tether movement.

Figure 3 shows a cross-section through a portion of another tether 20 for use with the
present invention. Tether 20 comprises a fuel conduit 22 embedded in a non-circular
composite material 24. Also provided is a fin 26 attached to tether 20 by ring or
actuator 28. The actuator 28 may be operable to provide active control to prevent
adverse tether movement.

Figure 4 shows a view of a portion of another tether 30 for use with the present
invention. Shown is a central conduit 32 carrying fuel fluid surrounded on each side
by two strengthening cables 34.

Also provided is a vane 36 which acts to provide lift to the tether when high lateral
winds flow past the tether. This helps to prevent blow over of the platform.

Figure 5 shows a view of a portion of another tether 40 for use with the present
invention. Shown is a central conduit 42 for carrying fuel fluid surrounded on each
side by two strengthening cables 44.
Also provided is a vane 46 attached to a strengthening cable 44 by links 48 and spring 50. In use, vane 46 provides lift to the tether 40 when strong lateral winds flow past the tether.

Figure 6 shows another form of lifting vanes being wound onto the tether. The diameter of the vanes 52 may be from 0.2 to 10 mm, but is typically around 1mm, with 4mm vertical spacing. The winding may or may not be continuous along the length of the tether. Preferably the winding is present between 7000 m and 13000 m altitude.

Figure 7 shows a further means of construction with the vanes 55 being interlaced with the tether cables.

Figure 8 shows a view of a portion of another tether 58 for use with the present invention. The tether comprises a flag 57 attached to the tether by a coil 59 and holes 60 in the flag. The flag could alternatively be a simple wire to prevent flutter of the non-circular cross-section of tether in high winds.

Figure 9 shows more detail of the fuel management system and the platform shown in figure 1. Shown is a hydrogen pressurisation system within a spool 64 at the ground level location, conduit 65 and platform 79.

The pressurisation system within a spool 64 comprises a low pressure slip seal 62, through which the hydrogen passes to a compressor 63 prior to the hydrogen flowing up the conduit 65 in the tether.

Once at the platform 79, the conduit enters an upper spool 68 with a let down valve 66. In another embodiment the spool 68 may be omitted. The hydrogen then flows to past a slip seal 67 into the fuel cell made up of an anode 69, a membrane 70 and a cathode 71. Atmospheric air 73 is compressed in compressor 74 passed through dehumidifier 75 before entering the cathode 71. Water is expelled via outlet 72.
Power from the fuel cell drives a motor 78 which in turn drives the compressor 74. Other uses of the power are the payload electronics 76 supplying transmitters 77 as well as any platform stabilisers (not shown).

Figure 10 shows a section through a tether according to the present invention. The tether comprises a skin 84 which contains two optical fibre cable bundles 86 and two conduits or cables 88. The cross-section is non-circular and elongate with an aspect ratio of about 4. In use, air flows from left to right, defining a leading edge 90 and a trailing edge 91. Also defined is the chord length 92 and the chord width 93. At 90 and 91 there are small optical fibres providing an external light source.

The cross-section is filled at the leading edge with aramid 94 and the remainder filled with low density foam 95. The relative densities of the elements of the cross-section through the tether are such that the centre of mass is provided along line 96, and being symmetric close to the chord line.

As air flows from the leading edge to the trailing edge, the centre of aerodynamic pressure is located on line 97. As the centre of mass 96 is nearer the leading edge 90 than is the centre of aerodynamic pressure 97, the arrangement shown is stable. Thus the design of tether exposes its minimum area to the flowing air and thus experiencing minimised wind resistance.

Figure 11 shows an apparatus 100 according to the invention comprising a balloon or dirigible 102 connected to a base station (not shown) by a tether 106. The tether comprises an optic fibre cable 108 travelling from an intermittent light source 104 to the balloon or dirigible 102.

Spaced along the optic fibre 108 is a plurality of lights 110, 112 with lights 114 around the balloon or dirigible 102. As shown in more detail, optic fibre cable 108 enters a coupler 116 which diverts a fraction of the light in the optic fibre to light 110 and 112. The majority of the light remains in the optic fibre and travels to the next pair of lights, where the same process is carried out. At the balloon or dirigible 102 the remaining light is diverted equally to the lights 114.
Thus, safety lights are provided in a lightweight, compact and low wind resistance form.

Figure 12 shows in detail the operation of a coupler 116 to provide light emission. Light from the optic cable 108 enters the coupler 116, whereupon a fraction of light 108a is diverted and directed to grating 118. The majority of the light passes through the coupler 116 and is not diverted. The diverted light exits the grating 118 and is directed onto reflective cone 120 which reflects the light in a wide angle to provide the light emission means. Other methods of distributing the diverted light to provide the light emission means can be readily conceived of.
Claims

1. An apparatus for providing high altitude services, comprising a platform at an elevated location, the platform being tethered to a substantially ground level location, wherein the tether is coated with a hydrophobic material.

2. An apparatus according to claim 1, wherein the elevated location is at an altitude of from 5,000 m to 30,000 m, preferably from 10,000 m to 25,000 m, more preferably from 15,000 m to 25,000 m.

3. An apparatus according to claim 1 or claim 2, which comprises one or more balloons or dirigibles at the elevated location.

4. An apparatus according to claim 3, wherein such a one or more balloon or dirigible is capable of providing a lifting force of at least 5.0 metric tonnes, preferably at least 10 metric tonnes, more preferably at least 25 metric tonnes.

5. An apparatus according to any one of the preceding claims, wherein the tether has a non-circular cross-section.

6. An apparatus according to claim 5, wherein the tether has a cross-section with an aspect ratio of from 1.5 to 20.0.

7. An apparatus according to claim 5 or 6, which, when air flows past the tether from a leading edge to a trailing edge, has a cross-section with its centre of mass nearer to the leading edge than is the centre of aerodynamic pressure.

8. An apparatus according to any one of claims 5 to 7, which, when air flows past the tether from a leading edge to a trailing edge, the tether has a cross-section with its centre of mass less than 25% of the chord length from the leading edge, preferably from 15% to 24% of the chord length from the leading edge.
9. An apparatus according to any one of claims 5 to 8, which, when air flows past the tether from a leading edge to a trailing edge, has a cross-section with its centre of tension nearer to the leading edge than is the centre of aerodynamic pressure.

10. An apparatus according to any one of claims 5 to 9, which, when air flows passed the tether from a leading edge to a trailing edge, the tether has a cross-section with its centre of tension less than 25% of the chord length from the leading edge, preferably from 15 to 24% of the chord length from the leading edge.

11. An apparatus according to any one of claims 5 to 10, which, when air flows past the tether from a leading edge to a trailing edge, has a cross-section with its centre of shear nearer to the leading edge than is the centre of aerodynamic pressure.

12. An apparatus according to any one of claims 5 to 11, which, when air flows passed the tether from a leading edge to a trailing edge, the tether has a cross-section with its centre of shear less than 25% of the chord length from the leading edge, preferably from 15 to 24% of the chord length from the leading edge.

13. An apparatus according to any one of claims 5 to 12, wherein the centres of mass, tension and shear are within a region of less than 10% of the chord length, preferably less than 5%.

14. An apparatus according to any one of the preceding claims, wherein the tether comprises a series of vanes or aerofoils to provide lift to the tether from horizontal winds.

15. An apparatus according to any one of claims 5 to 14, wherein the tether comprises a plurality of flags along its length.

16. An apparatus according to any one of the preceding claims, wherein the platform comprises a gyroscopic and/or a gravitational stabilisation means.
17. An apparatus according to any one of the preceding claims, wherein the platform comprises information services apparatus.

18. An apparatus according to any one of the preceding claims, wherein the tether comprises an optic fibre cable from the substantially ground level location to the elevated location.

19. An apparatus according to any one of the preceding claims, wherein the tether comprises a lightning strike conductor providing an electrical connection between the substantially ground level location to the platform.

20. An apparatus according to any one of the preceding claims, wherein the tether comprises an optical fibre cable at least substantially from the substantially ground level location to the platform, the optical fibre cable comprising a plurality of couplers spaced along the length of the optical fibre cable, each coupler adapted to divert a fraction of the light in the optical fibre cable and direct it to a respective light emission means.

21. An apparatus according to claim 20 wherein the light emission means comprise a collimator.

22. An apparatus according to claim 20 or 21 wherein the light emission means are spaced apart by from 50m to 200m.

23. An apparatus according to any one of claims 20 to 22, wherein the tether comprises from 20 to 200 light emission means.