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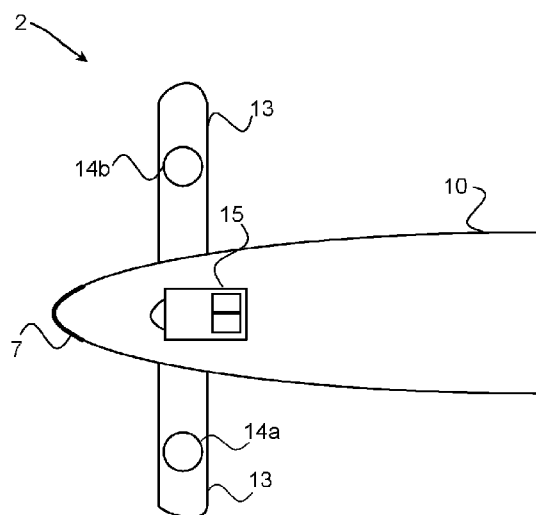


Figure 6a

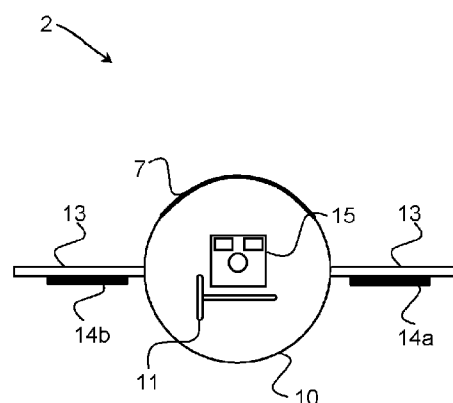


Figure 6b

(57) Abstract: The present invention provides a communication apparatus for a high altitude long endurance aircraft. The communication apparatus comprises: a housing; at least one radio disposed inside the housing; and a laser transmitter and/or receiver electrically coupled to the radio. The present invention also provides a high altitude long endurance aircraft having the communication apparatus and a method of communicating using the same.

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COMMUNICATION APPARATUS**FIELD OF THE INVENTION**

The present invention relates to a communication apparatus for a high altitude
5 long endurance aircraft. Furthermore, the present invention relates to a high
altitude long endurance aircraft having the communication apparatus and a
method of communicating using the same.

BACKGROUND

10 High altitude long endurance (HALE) unmanned aircraft have been devised.
These typically have long wingspans and low drag to improve their ability to
operate efficiently for weeks or months at altitudes in excess of 15km.
Unmanned vehicles, specifically unmanned aircraft, typically require control
input from a terminal such as a ground station. There is also typically a
15 requirement to transmit data generated by the unmanned vehicle to another
asset for processing and/or use. Particularly in a military or border patrol
context, these assets or ground stations may be displaced relatively far from the
aircraft in the horizontal plane either due to geography or threat actors. Typical
prior art antenna systems for receiving control signals or transmitting data have
20 relatively high power requirements and/or have relatively poor aerodynamic
properties, which is not suitable for a high altitude long endurance aircraft.

It would therefore be advantageous to provide a low-power communication
system with increased range and low aerodynamic drag, for enabling an
25 unmanned vehicle to be controllable remotely or transmitting imagery.

SUMMARY

According to an aspect of the present invention, there is provided a
communication apparatus for a high altitude long endurance aircraft, the
30 communication apparatus comprising:

- a housing;
- at least one radio disposed inside the housing; and
- a laser transmitter and/or receiver electrically coupled to the radio.

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The communication apparatus may comprise a rotatable mounting, wherein the laser transmitter is coupled to the rotatable mounting. The rotatable mounting may have a plurality of axes of rotation, such that the laser transmitter can be
5 adjusted in elevation and azimuth.

The communication apparatus may comprise a processor configured to determine a bearing from the communication apparatus to a recipient entity and control the rotatable mounting to point the laser transmitter towards the recipient
10 entity, such that data can be transmitted by the at least one radio to the recipient entity. The recipient entity may be ground station or a high altitude long endurance aircraft.

The housing may comprise a window arranged in the path of a laser beam
15 emitted when the laser transmitter is activated, wherein the window is transparent to the wavelength of the laser beam.

The communication apparatus may comprise at least one directional antenna and/or at least one omnidirectional antenna coupled to the at least one radio.
20

The at least one directional antenna may be coupled to a bottom surface of the housing. At least a portion of the bottom surface of the housing may be planar and the at least one directional antenna may be coupled to the planar portion.

25 The at least one omnidirectional antenna may extend from the bottom surface of the housing.

The communication apparatus may comprise at least one wing extending from one or both sides of the housing, and the bottom surface of the at least one
30 wing may comprise the at least one directional antenna and/or the at least one omnidirectional antenna.

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The omnidirectional antenna may be coupled to an end of the at least one wing.
The laser receiver may be coupled to the at least one wing.

The communication apparatus may comprise at least one motor for retracting
5 the at least one wing into the housing or extending the at least one wing from
the housing.

The at least one omnidirectional antenna may be a dipole antenna.

10 The at least one directional antenna may comprise a dynamically phased array
or a patch antenna.

The at least one radio may comprise:

a first radio electrically coupled to the laser transmitter and/or receiver;
15 and
one or both of:
a second radio electrically coupled to the at least one omnidirectional
antenna; and
a third radio electrically coupled to the at least one directional antenna,
20 wherein the processor is configured to select the first radio, the second
radio or the third radio for transmitting data to the recipient entity.

The processor may be arranged to receive positional and/or signal propagation
data and to select the first radio, second radio or third radio to transmit data to
25 the recipient entity based on the positional and/or signal propagation data. The
signal propagation data may comprise terrain data or weather data.

The processor may be arranged to receive data relating to the bandwidth
requirements of the data to be transmitted to the recipient entity and to select
30 the first radio, second radio or third radio to transmit the data based on a link
budget.

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The communication apparatus may comprise at least two directional antennas and at least two omnidirectional antennas arranged in a Multiple In Multiple Out [MIMO] configuration.

- 5 The communication apparatus may comprise coupling means for attaching the communication apparatus to a high altitude long endurance aircraft.

The communication apparatus may further comprise an imaging system disposed within the housing, and the housing may comprise an aperture
10 arranged within the field of view of the imaging system and transparent to a detection frequency of the imaging system.

According to a second aspect of the present invention, there is provided a high altitude long endurance aircraft comprising a communication apparatus
15 according to the first aspect.

According to a third aspect of the present invention, there is provided a method of communicating using a high altitude long endurance aircraft according to the second aspect, comprising determining the position of a recipient entity relative
20 to the communication apparatus, determining a bearing to the recipient entity and controlling the rotatable mount to point the laser transmitter towards the recipient entity.

The method may comprise determining the range to a recipient entity and
25 selecting the first radio, second radio or the third radio to transmit data to the recipient entity based on the determined range.

The method may comprise receiving signal propagation data and selecting the first radio, second radio or the third radio to transmit data to the recipient entity
30 based on the signal propagation data.

The method may comprise receiving data relating to the bandwidth requirements of data to be transmitted and selecting the first radio, the second

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radio or the third radio to transmit the data to the recipient entity based on a link budget.

The method may comprise retracting the at least one wing when the directional
5 or omnidirectional antenna attached thereto is not in use.

It will be appreciated that features described in relation to one aspect of the present invention can be incorporated into other aspects of the present invention. For example, an apparatus of the invention can incorporate any of
10 the features described in this disclosure with reference to a method, and vice versa. Moreover, additional embodiments and aspects will be apparent from the following description, drawings, and claims. As can be appreciated from the foregoing and following description, each and every feature described herein, and each and every combination of two or more of such features, and each and
15 every combination of one or more values defining a range, are included within the present disclosure provided that the features included in such a combination are not mutually inconsistent. In addition, any feature or combination of features or any value(s) defining a range may be specifically excluded from any embodiment of the present disclosure.

20

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings.

25 Figure 1 is a perspective view of an unmanned aircraft;
Figure 2a is a plan view of a communication module according to a first embodiment;
Figure 2b is a frontal view of a communication module according to the first embodiment;
30 Figure 3 is a system diagram showing components of the communication module;
Figure 4 is a system diagram showing an example of a use of the communication module;

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Figure 5 is a system diagram showing an example of a use of the communication module;

Figure 6a is a plan view of a communication module according to a second embodiment;

- 5 Figure 6b is a frontal view of a communication module according to the second embodiment; and

Figure 7 is a flowchart showing a method of operating a communication module according to an embodiment.

- 10 For convenience and economy, the same reference numerals are used in different figures to label identical or similar elements.

DETAILED DESCRIPTION

- Embodiments herein generally relate to a communication module, particularly
15 for use on an unmanned high-altitude long-endurance (HALE) aircraft as shown in Figure 1. The communication module includes a laser transmitter (i.e. a laser emitter), and in some embodiments additional directional or omnidirectional antennas for when communication using a laser transmitter is not optimal or possible.

20

The invention will now be explained in more detail with reference to the drawings.

- An aircraft 100, specifically an unmanned HALE aeroplane, is shown in Figure
25 1. While an unmanned HALE aeroplane is illustrated, it would be readily appreciated that the present invention is applicable to other types of aircraft 100, such as high altitude balloons or airships. The aircraft 100 includes a wing member 6 having a wing span of about 35 metres and a relatively narrow chord (i.e. of the order 1 metre). The wing member 6 is coupled to a fuselage 4. To
30 aerodynamically balance the aircraft 100, tail surfaces 8 are coupled to the rear of the fuselage 4.

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A communication module 2 is coupled to the front of the fuselage 4, i.e. the nose of the aircraft 100. The communication module 2 may be coupled to the front of the fuselage 4 by an attachment point. The attachment point may comprise a protrusion for insertion into an aperture. For example, the front of
5 the fuselage 4 may comprise a protrusion, such as a pin, which pushes through an aperture on the rear of the communication module 2. The attachment point may comprise a spring-loaded quick release mechanism, for example. In alternative embodiments, the communication module 2 may be coupled to a different part of the aircraft 100, such as the tail or ventral fuselage 4. The
10 communication module 2 is interchangeable according to the present embodiment. In other words, the communication module 2 is detachable such that a different type of payload can be added to the aircraft 100 to reconfigure the aircraft 100 for a different purpose. In other embodiments, the communication module 2 is fixed. In other words, the communication module 2
15 may be integrated with and/or distributed throughout the aircraft 100.

Various physical configurations of the communication module 2 are shown in more detail in Figures 2a, 2b, 6a, and 6b. The system architecture will be described in more detail with reference to Figure 3.. Identical features have the
20 same reference numerals throughout the Figures, and description of like features will not be repeated when describing the various illustrated embodiments.

The communication module 2 includes a combination of directional antennas
25 14a, 14b and omnidirectional antennas 12a,12b. In the embodiment illustrated in Figures 2a and 2b, the directional antennas 14a,14b are coupled to the underside of a housing 10. The directional antennas 14a,14b are shaped to fit the underside of the housing 10. In a preferred embodiment, the underside of the housing 10 is flattened (i.e. planar), which tends to improve the downward
30 projection of the directional antennas' emission pattern. The omnidirectional antennas 12a,12b protrude through apertures in the wall of the housing 10. In alternative embodiments, the omnidirectional antennas 12a,12b are fixed to the housing 10.

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The housing 10 also includes a laser transmitter 15a (i.e. emitter). The housing 10 includes at least one laser receiver 15b (i.e. sensor) disposed on its outside surface. The laser transmitter 15a and laser receiver 15b may be integrated to
5 provide a laser transceiver 15, as illustrated in Figures 6a and 6b. Alternatively, laser receivers 15b may be distributed throughout the communication module 2 or aircraft 100. The communication module 2 may include any number of laser receiver 15b, with more receivers 15b increasing the likelihood of a communication link being maintained. In another embodiment, the
10 communication module 2 does not have a laser receiving capability, and so may comprise only a laser transmitter 15a.

The laser transmitter 15a and receivers 15b are coupled to a radio 19, shown in Figure 3. The radio 19 is configured to convert (i.e. encode or module) an
15 electrical signal into an encoded optical signal for emission by the laser transmitter 15a. The radio 19 may also be configured to convert (i.e. decode or demodulate) a received optical signal into an electrical signal that can be processed by a controller 17.

20 The laser transmitter 15a is illustrated as being disposed inside the housing 10. In order for a signal to reach a recipient entity from the laser transmitter 15a, a transparent window 7 is disposed in the surface (i.e. skin) of the housing 10. The window 7 is disposed in front of the laser transmitter 15a. The window 7 is transparent to the wavelength of the laser beam emitted by the laser transmitter
25 15a. The window 7 may be transparent in the optical or infrared spectrum, for example. A typical laser transmitter 15a has a wavelength of about 650nm. In Figure 2b, the window 7 is illustrated as being disposed on the upper surface of the housing 10, which would allow the aircraft 100 to communicate with other aircraft or satellites operating above it. However, in other embodiments, the
30 window 7 may also or alternatively be disposed on the underside of the housing 10 to enable communication with ground assets, for example a ground station 200.

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In alternative embodiments, the laser transmitter 15a is mounted on the outside surface of the housing 10. The laser transmitter 15a may be disposed in a blister, or fairing, on the outside surface of the housing 10.

- 5 The laser transmitter 15a is coupled to the housing 10 by way of a mounting 11. The mounting 11 may be arranged to rotate in azimuth and/or in elevation, such that the laser transmitter 15a can be aimed at a recipient entity without having to change the heading of the aircraft 100. The mounting 11 may be a gimbal mounting. The mounting may be controlled by the controller 17. The controller
- 10 17 may use feedback from the recipient entity to determine if the laser transmitter 15a is pointing directly at a receiver of the recipient entity. Alternatively, the controller 17 may use an imaging system 9 to determine the direction to a recipient entity. Alternatively again, the controller 17 may receive coordinates of the recipient entity either from a memory (i.e. coordinates may be
- 15 pre-stored), or through another communication means, such as the directional or omnidirectional antennas 12,14.

In an alternative embodiment, the laser transmitter 15a is fixed. Here, the controller 17 is used to generate control signals to control the aircraft 100 to

20 change heading such that the laser transmitter 15a points at a receiver of the recipient entity.

The housing 10 is aerodynamically shaped. The housing 10 has fixings for attaching to the front of the fuselage 4. The fixings are, for example, screw

25 points or clips. In alternative embodiments, the housing 10 itself is part of the fuselage 4.

Figures 6a and 6b illustrate two views of another embodiment of the communication module 2. Here, the housing 10 comprises wings 13 extending

30 from either side. The wings 13 are aerofoil shaped, such that they provide lift without substantially increasing drag. In further embodiments, the wings 13 are substantially flat on the bottom and/or stop surfaces. While one set of wings 13

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is illustrated, the housing 10 may have further similar protrusions along its length to increase the surface area available for locating antennas.

Here, instead of on the underside of the housing 10, one directional antenna 14
5 is disposed on the underside of each wing 13. The directional antennas
14a, 14b may be etched, engraved or otherwise attached to each wing 13.
Here, the omnidirectional antennas 12 are omitted. In another embodiment, the
wings 13 comprise the omnidirectional antennas 12, but here the directional
antennas 14 are omitted.

10

In another embodiment, two omnidirectional antennas 12a, 12b are disposed on
the underside of the housing 10, making an acute angle with respect to each
other. The omnidirectional antennas 12a, 12b may be arranged in parallel to
each other, and at right angles to the plane of the housing 10. By attaching the
15 omnidirectional antennas 12a, 12b to a flat surface, a null zone tends to be
reduced.

In an alternative embodiment, the omnidirectional antennas 12a, 12b may be
attached to the wings 13, while the directional antennas 14a, 14b are attached
20 or disposed on the underside of the housing 10 as shown in Figures 2a and 2b.

The wings 13 may be retractable to the inside of the housing 13 when not in use
(for example, when an antenna 12, 14) is not needed for transmission or
reception) to reduce the effect of drag on the aircraft 100. A motor may be
25 disposed inside the housing 10 to drive the wings 13 to retract or extend. In
alternative embodiments, the wings 13 are fixed.

While a plurality of directional antennas 14a, 14b and omnidirectional antennas
12a, 12b are present in Figures 2a, 2b, 6a, and 6b, this is for illustrative
30 purposes only. In other embodiments, there may only be a single directional
antenna 14a and/or a single omnidirectional antenna 12a. Alternatively, there
may be more than two directional antennas 14a, 14b and/or more than two
omnidirectional antennas 12a, 12b. The use of a plurality of antennas

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12a, 12b, 14a, 14b within each communication node (defined here as a radio and antenna combination or radio and laser transmitter/receiver combination) provides the advantages of a Multiple In Multiple Out (MIMO) configuration. Here, error bitrate is reduced and link budget tends to be optimised, and
5 therefore signal to noise ratio is improved. For example, one omnidirectional antenna may extend from the front of the housing 10, one omnidirectional antenna may extend from the rear of the housing 10, and an omnidirectional antenna may extend from either side of the housing 10 to optimise the MIMO effect.

10

In the illustrated embodiments, the directional antennas 14a, 14b comprise patch antennas. These are relatively thin planar conductive members having patterns etched thereon. The patch antennas are attached to the housing 10 or wings 13 of the communication module 2 by glue. The glue is suitable for use
15 at low temperatures. For example, at 20,000 metres above sea level, the ambient temperature can drop to about -56.5 degrees Celsius. Alternatively, the patch antennas may be riveted, screwed or otherwise affixed to the housing 10 or wings 13. The patch antennas are conformal with the housing 10, which is itself conformal with the fuselage 4.

20

On HALE aircraft 100, particularly those optimised for low aerodynamic resistance (or drag), it is disadvantageous to provide antennas in dome-like fairings, or to provide satellite dishes. Low-profile antennas, such as patch
25 antennas, tend to reduce drag. Furthermore, conventional monopole or dipole antennas, when arranged substantially parallel with the main transverse plane of the aircraft 100 tend to emit electromagnetic energy sideways rather than downwards. Further, conventional monopole or dipole antennas tend to be more sensitive to electromagnetic energy in the horizontal plane.

In further embodiments, the communication module 2 includes at least one
30 dynamic phased array. For example, the communication module 2 may include a dynamic phased array disposed on either side of the housing 10. Further, the communication module 2 may include a dynamic phased array at least on the front (i.e. distal part) of the housing. The dynamic phased array(s) can be used

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to steer an RF beam pattern, for example such that the peak of the energy distribution is centred on a recipient entity. The dynamic phased arrays(s) are directional in nature, but as the direction of pointing can be adjusted, they may be used in lieu of or in addition to the omnidirectional antennas 12a,12b.

5

In addition to the directional antennas 14a,14b and omnidirectional antennas 12a,12b, the communication module 2 may include an imaging system 9. The imaging system 9 includes a camera. The camera is for example an optical camera. The camera may alternatively or additionally be configured to detect
10 infrared, ultraviolet, microwave or x-ray emission, for example, to detect objects or map an area. The imaging system 9 may be a hyperspectral imaging system. The communication module 2 includes a window transparent to the observing spectrum of the camera and arranged such that the camera can observe the environment outside the aircraft 100. The window may be the
15 same window 7 disposed in front of the laser transmitter 15a. The camera may be disposed on a gimbal such that the aircraft 100 can bank or pitch up or down without the field of view of the camera moving significantly.

The communication module 2 is a self-contained module having a processor 17.
20 The processor 17 is configured to control the components of the communication module 2. The processor 17 may receive information about the location of a receiving entity, for example the ground station 200 or another aircraft 100, and in some embodiments the location of the aircraft 100. The processor 17 then uses the location data to determine the bearing from the communication module
25 2 to the recipient entity. The processor 17 can then control the mounting 11 or the aircraft 100 such that the laser transmitter 15a is pointed towards the recipient entity. The processor 17, in some embodiments, may use the imaging system 9 to determine the location of, or bearing to, the recipient entity. The processor 17 may calculate the range to the recipient entity and select an
30 appropriate radio and/or antenna type for transmitting a signal to the recipient entity based on the range.

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Further, the processor 17 receives signal propagation data. This may include data from the imaging system 9, such as the presence of clouds or precipitation. The signal propagation data may include weather data received from a satellite, aircraft or ground station. The signal propagation data may include terrain
5 mapping data. The signal propagation data may be pre-stored or received during flight.

The processor 17 can then select between the radio 16 coupled to the omnidirectional antennas 12a,12b, the radio 18 coupled to the directional
10 antennas 14a,14b or the radio 19 coupled to the laser transmitter 15a for transmitting the data recipient entity, depending on which of their associated antennas 12a,12b,14a,14b are within range, or whether the signal propagation data indicates that one communication node is better than another in the current circumstances. For example, the presence of clouds may prohibit the use of
15 the laser transmitter 15a, while a recipient entity being directly beneath the communication module 2 may prohibit use of the omnidirectional antennas 12.

The processor 17 may also determine that the aircraft 100 needs to be moved (for example moved closer to the recipient entity, or controlled or change pitch,
20 bank or yaw) in order for a reliable communication link to be made and/or maintained. The processor 17 may make use of terrain, weather or other environmental data that affects signal propagation to determine which communication node to use or how to move the aircraft 100. The processor 17 may also perform switching to ensure optimal bandwidth utilisation across all of
25 the communication nodes. The processor 17 may be used to control the motor for extending or retracting the wings 13 described with reference to Figures 6a and 6b, depending on whether the antennas fixed thereto are in use or will be used.

30 The processor 17 may take any suitable form. For instance, it may be a microcontroller, plural microcontrollers, or plural processors.

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Each type of transceiving element (i.e. omnidirectional antenna 12, directional antenna 14 or laser transmitter/receiver 15) has associated therewith a radio 16,18,19. The respective radio 16,18,19 converts (or encodes or modulates) the information to be transmitted into a signal for transmission through a
5 respective transceiving element. Further, the radios 16,18,19 convert (or decode or demodulate) received signals into information usable by the processor 17. The radios 16,18 coupled to the antennas 12,14 operate according to any communication standard known to the skilled person. For example, they may for example be 3G, 4G, or 5G radios. The radios 16,18 may
10 be Frequency Modulated (FM) radios. The radios 16,18,19 may encrypt the signals to be transmitted, or decrypt received signals.

Signals received by the radios 16,18,19 from off-board the aircraft 100 are processed by the processor 17 to determine their content and what action to
15 perform in response. For example, control signals received from a ground station 200 are determined to be control signals and are directed to the aircraft's main avionics system for actuation of the various control surfaces and/or propulsion systems. In some embodiments, the processor 17 is configured to actuate the control surfaces and/or propulsion systems in response to receiving
20 a control signal. The processor 17 may determine the type of signal being received, or the content of the signal, by decoding a packet header.

Where the communication module 2 includes an imaging system 9, the communication module 2 may include a storage means for storing images or
25 video. The storage means may act as a buffer while the images or video are being processed and transmitted to another entity. The processor 17 is used to control the imaging system 9 and perform data analysis and processing. In alternative embodiments, particularly where the communication module 2 is distributed throughout the aircraft 100, the communication module 2 may use
30 the aircraft's main avionics system to perform data analysis and processing. The processor 17 may determine when it is a suitable time to transmit the processed images or video. For example, the processor 17 may determine an EMCON restriction is in place and that a non-essential transmission should not

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be made. Further, the processor 17 may determine when the antennas 12,14 and/or laser transmitter 15a are likely to be within range of an intended recipient entity, or when a reliable communications link is likely to be made, and control the radio 16,18,19 to only transmit when the intended recipient entity is likely to
5 be within range or if the reliable communications link is likely to be made.

Alternatively or additionally to an imaging system 9, the communication module 2 may include a telemetry system. The telemetry system may be, for example, for monitoring weather patterns or magnetic field strength. The telemetry
10 system may include a LIDAR, RADAR, hyperspectral imaging system, x-ray emission sensor, air particle sampler, pitot tube, or any other known sensing system. Here, the processor 17 processes telemetry data and controls a radio 16,18,19 to transmit the processed telemetry data to an off-board entity, such as a ground station 200, mobile ground unit 300 such as a soldier, or another
15 aircraft 100.

While the radios 16,18,19 and processor 17 are depicted as being separate entities in Figure 3, in other embodiments, they may be software modules within a single hardware device. Furthermore, in some embodiments, the directional
20 antenna(s) 14 and omnidirectional antenna(s) 12 are coupled to the same radio 16,18. Therefore, the processor 17 may select only between the radio 19 coupled to the laser transmitter 15a and the radio 16,18 coupled to the various antennas to transmit data to a recipient entity. In some embodiments, where both antenna types are coupled to the same radio 16,18, there is a switch for
25 selecting which antenna type (i.e. directional or omnidirectional) to use, or the signal may be transmitted through both the directional antenna(s) 14 and omnidirectional antenna(s) 12 simultaneously.

The communication module 2 may include a power source for powering the
30 processor 17 and other electronic components of the communication module 2, such as the imaging system 9 and radios 16,18,19 and other optional features. Alternatively, the communication module 2 may draw power from the aircraft 100. Here, the communication module 2 may comprise a power supply for

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converting the voltage and/or current delivered by the aircraft 100 to a voltage and/or current demanded by the radios 16, 18, 19 and processor 17.

The components within the communication module 2 are coupled together as indicated by the straight lines in Figure 3. These indicate low-latency wired connections.

The unmanned aircraft 100 is controllable remotely from a ground station 200, shown in Figures 3 and 4. The ground station 200 includes a man/machine interface 24 for providing information regarding the current state of the aircraft 100 to a user. The man/machine interface 24 includes a user input such as a keyboard, mouse and/or joystick to enable the user to provide means for the user to control the aircraft 100.

A processor 26 is used to process data received from a transceiver node, for example to determine the type of data. The transceiver node includes a long range antenna 20 and radio 22. The transceiver node may include a laser transmitter and receiver alternatively or additionally to the long range antenna 20. The radio 22 converts a received signal (e.g. RF or optical) into a format that can be processed by the processor 26. Further, the processor 26 converts input received from the user into a control signal to be transmitted via the radio 22 to the aircraft 100. The signals for controlling the aircraft 100 are transmitted with a bitrate of the order 30 to 40mb/s. However, it would be appreciated that transmissions with increased bitrate, for example up to 100mb/s, might be necessary but transmitting large amounts of data, such as video data, quickly.

Figure 4 demonstrates how an aircraft 100 having the communication module 2 may be used in practice. The Figure is not to scale. The aircraft 100 is operating at an altitude of about 20km. The aircraft 100 is in communication with a mobile ground asset 300, such as military vehicle patrolling a country's border. The aircraft 100 transmits a signal 40 to the ground asset 300 containing data such as a live surveillance video feed of the area. Further, the aircraft 100 is in communication with a ground station 200, which is laterally

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displaced from the aircraft 100 further than the ground asset 300. The ground station 200 transmits control signals 50 to the aircraft 100.

The communication module 2 coupled to the aircraft 100 includes a directional
5 antenna 14a, an omnidirectional antenna 12a and a laser transmitter 15a.
Here, the directional antenna 14a is a patch antenna. The omnidirectional
antenna 12a is a dipole, but may alternatively be a monopole. The field of view
of the patch antenna is represented by the dashed line. Here, a cone making
an angle of 45 degrees with the vertical projects beneath the aircraft 100 from
10 the patch antenna. The patch antenna projects a circle of coverage 20 on the
ground with a radius of about 20km. The dipole antenna has greater horizontal
range than the patch antenna, since the patch antenna is most sensitive a
relatively small area in the downwards direction and transmits its energy in that
relatively small area. The dipole antenna projects most of its energy
15 horizontally (this is not shown in the Figures), but some energy is directed in a
downwards cone. The downward field of view of the dipole antenna is
represented by the cone having the dots and dashes. The field of view of the
dipole antenna is a cone making an angle of about 60 degrees with the vertical.
The maximum horizontal range of dipole antenna is about 40km. The dipole
20 antenna projects a toroid of coverage 30 on the ground, the circle of coverage
20 of the patch antenna falling inside the inner part of the toroid 30.

The directional antennas 14a, 4b concentrate their energy on a relatively small
and defined area, which makes them efficient at communicating with assets,
25 e.g. mobile ground asset 300, in that particular area. Meanwhile, the
omnidirectional antennas 12a,12b, distribute their energy in a relatively planar
disk, the plane of the disk being substantially parallel with the transverse plane
of the aircraft 100. Some energy from the omnidirectional antennas 12a,12b
does reach the ground, as shown in Figure 4. While boosting power to the
30 omnidirectional antennas 14a,14b will increase their range, on HALE aircraft
this is not viable due to limited resources.

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Where the bottom surface of the communication module 2 comprises the window 7, and the laser transmitter 15a is adjustable to point downwards, the laser transmitter 15a may be used to transmit signals to the ground-based recipient entities (ground asset 300 and ground station 200). Further, while
5 signals may be transmitted from the communication module 2 to the ground-based recipient entities 200,300 using the antennas 12,14, signals may be received by the communication module 2 from the ground-based entities through the laser receiver 15b.

10 Figure 5 demonstrates another embodiment of an aircraft 100 having the communication module 2 being used in practice. It is not to scale. Here, an aircraft 100a acts as a communications relay, or node, in a Mobile Ad-hoc Network (MANET). While a single aircraft 100a is shown performing the function of a relay, in practice there may be any number of aircraft 100 in the
15 MANET acting as relays for each other.

In other words, the nodes (radio 16,18 and antennas 12a,12b,14a,14b or radio 19 and laser transmitter 15a and receiver 15b) in aircraft 100a,100b equipped with the communication module 2 can operate as nodes within a larger MANET.
20 These nodes are a self-constructing, self-healing decentralised network of nodes which act as mobile routers to all other traffic on the network. Advantageously, the communication module 2 provides communication to users in remote locations without pre-existing network infrastructure. This MANET system can easily be extended to an arbitrary number of platforms, each having
25 the communication module 2.

It is normal in a military context for administrative or non-combat personnel to operate far from an area of operations, such as a checkpoint or border. Therefore, an aircraft 100b on station over that area of operations would not be
30 within communication range of a ground station 200 having intelligence analysts and flight controllers etc.

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Figure 5 shows an aircraft 100b operating in the intelligence-gathering role. Here, the aircraft 100b is using an imaging system 9 to video an area of border. The aircraft 100b is operating at an altitude of about 20km. The imaging system 9 projects a cone toward the ground, and has a circular field of view 40. An
5 adversary vehicle 400 is detected within the field of view 40 of the imaging system 9.

As the aircraft 100b is out of communication range with the ground station 200, or where there is terrain blocking the line of sight between the aircraft 100b and
10 ground station 200, it is unable to directly receive control signals. Further, the video generated by the imaging system 9 may not be received by the ground station 200 if transmitted. However, as the omnidirectional antennas 12a,12b predominantly distribute their energy in the transverse plane of the aircraft 100b, signals 50 transmitted by these antennas 12a,12b may be received by
15 another aircraft 100a at a similar altitude acting as a relay. Further, the signals 50 may be transmitted between the aircraft 100a,100b using a laser transmitter 15a and receiver 15b.

The relay aircraft 100a is then able to communicate signals 40 to the ground
20 station 200 using one of the omnidirectional antennas 12a,12b, directional antennas 14a,14b or the laser transmitter 15a.

Using an aircraft 100a as the relay tends to provide the advantage that the relay aircraft 100a can also be used as the intelligence gathering aircraft 100b. In
25 other words, additional specialist assets are not required to form the MANET. The relay aircraft 100a, of which there may be many operating in a chain, could be positioned over another part of the area of operations, for example an area of the border closer to the ground station 200. These relay aircraft 100a can then themselves be used to gather intelligence data, which is transmitted to
30 other aircraft in the chain for relay.

A method of operating a communication module 2 according to an embodiment will now be described with reference to Figure 7. Here, in a first step, step 700,

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signal propagation data and location data is received by the processor 17. This may include GPS data relating to the aircraft 100 having the communication module 2 and the recipient entity 100a,200,300, coordinates (e.g. grid reference), range to the recipient entity 100a,200,300, bearing to the recipient
5 entity 100a,200,300, altitude of the aircraft 100b and recipient entity 100a, weather patterns, sensor obscuration (e.g. indicating cloud cover), humidity, air density, air temperature, precipitation, or received signal strength, for example. The signal propagation data and location data may be received from a storage module (i.e. a memory), from a sensor on the aircraft 100, or from a signal
10 receiver 12,14,15b.

It would be appreciated that in some embodiments, only location data is received by the processor 17. Here, range and bearing to a recipient entity 100a,200,300 are calculated (if they are not part of the received location data)
15 and used to determine which communication node to use (i.e. the laser transmitter 15a and radio 19 combination or the antenna 12,14 and radio 16,18 combination) to transmit data to the recipient entity 100a,200,300. The range may be calculated using trigonometry. For example, if the bearing to a recipient entity 100a,200,300 is known, and the relative altitudes of the recipient entity
20 100a,200,300 and aircraft 100 are known, the maximum separation distance can be calculated. Alternatively, if the coordinates in three-dimensional space of the aircraft 100 and recipient entity 100a,200,300 are known, these can be subtracted from each other to give a separation distance.

25 In another embodiment, only signal propagation data is received. Here, only signal propagation information is used to determine which communication node to use to transmit data to the recipient entity 100a,200,300. For example, in this embodiment, the decision over whether to use the laser transmitter 15a or an antenna 12,14 to transmit data may be made based only on whether the
30 recipient entity 100a,200,300 is too opaque (i.e. dense cloud cover) for a laser beam to be received by it.

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The embodiment illustrated in Figure 7 assumes that the processor 17 is only selecting either a communication node having an antenna 12,14 or a communication node having a laser transmitter 15a. This may be because there is only one type of antenna 12,14 present on the aircraft 100, or because
5 both types of antenna 12,14 are used simultaneously. In another embodiment, where there are different types of antennas (i.e. directional and omnidirectional) present on the communication module 2, the algorithm used by the processor 17 to select a communication node further includes selecting which of these antenna systems (i.e. nodes) to use.

10

For example, as explained with reference to Figure 4, the omnidirectional antenna(s) 14 and associated radio 18 or directional antenna(s) 12 and associated radio 16 may be selected based on the range to the recipient entity 100a,200,300. In other words, where the range to the recipient entity
15 100a,200,300 is greater than a threshold, the omnidirectional antenna 12 is selected. However, where the range to the recipient entity 100a,200,300 is less than the threshold, the directional antenna 14 is selected (if the bearing to the recipient entity 100a,200,300 is such that the recipient entity 100a,200,300 is within the field of regard of the directional antenna 14).

20

If the range to the recipient entity 100a,200,300 is not greater than a threshold, it is determined whether or not the recipient entity 100a,200,300 is within the field of regard of the directional antenna 14. For example, the recipient entity 100a may be another aircraft flying very close to the aircraft 100, but if it is not
25 directly beneath the aircraft 100 then the directional antennas 14 will not be effective in transmitting data to it as they are on the underside of the communication module 2 and have a relatively narrow field of regard. The communication node having the directional antenna 14 is selected for transmitting data if the recipient entity 100a,200,300 is within the field of regard
30 of the directional antenna 14.

A further factor in the communication node selection process carried out by the processor 17 may include a link budget or bandwidth availability. For example,

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the directional antenna 14 is preferable over the omnidirectional antenna 12 where a high data transfer rate is required. Therefore, it may be preferable to wait until the communication node having the directional antenna 14 is in range of the recipient entity 100a,200,300 or to move the aircraft 100 such that it is
5 within range instead of selecting to transmit using the communication node having the omnidirectional antenna 12.

In step 702, the received signal propagation data is used to determine if there clear line of sight to the recipient entity 100a,200,300 in wavelength of the laser
10 beam emitted by the laser transmitter 15a. If the recipient entity 100a,200,300 is obscured or is likely to become obscured (based on predicted weather patterns), a communication node having an antenna 12,14 is selected to be used to transmit data to the recipient entity 100a,200,300 in step 704.
Determining whether there is a clear line of sight may also comprise
15 determining the relative positions of the recipient entity 100a,200,300 and communication module 2 using the received location data. For example, if the recipient entity 100a,200,300 is behind the aircraft 100 having the communication module 2, then the laser transmitter 15a cannot be pointed at the recipient entity 100a,200,300 because the aircraft 100 will be in the way or
20 because the mounting 11 is not capable of achieving the required angle.

In step 706, the location data is used to determine the relative velocities of the communication module 2 and the recipient entity 100a,200,300. If it is determined that it is likely that the recipient entity 100a,200,300 is going to
25 move out of the field of regard of the laser transmitter 15a, or if the mounting 11 cannot respond quickly enough to account for the changing relative positions of the communication module 2 and recipient entity 100a,200,300, then a communication node having an antenna 12,14 is selected to transmit the data in step 708.

30

If the processor 17 determines that there is a clear line of sight to a recipient entity 100a,200,300, and it determines that it is likely to retain a target lock on that recipient entity 100a,200,300, then the processor 17 selects the

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communication node having the laser transmitter 15a for transmitting data to it in step 710. Otherwise, a communication node having an antenna 12,14 is selected to transmit the data in steps 704 and 708.

- 5 In a further embodiment, steps 702 and 706 occur in reverse order.

Where, in the foregoing description, integers or elements are mentioned that have known, obvious, or foreseeable equivalents, then such equivalents are herein incorporated as if individually set forth. Reference should be made to the
10 claims for determining the true scope of the present disclosure, which should be construed so as to encompass any such equivalents. It will also be appreciated by the reader that integers or features of the disclosure that are described as optional do not limit the scope of the independent claims. Moreover, it is to be understood that such optional integers or features, while of possible benefit in
15 some embodiments of the disclosure, may not be desirable, and can therefore be absent, in other embodiments.

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CLAIMS

1. A communication apparatus for a high altitude long endurance aircraft,
the communication apparatus comprising:
 - a housing;
 - 5 at least one radio disposed inside the housing; and
 - a laser transmitter and/or receiver electrically coupled to the radio.
2. The communication apparatus according to claim 1, comprising a
rotatable mounting, wherein the laser transmitter is coupled to the rotatable
10 mounting.
3. The communication apparatus according to claim 2, comprising a
processor configured to determine a bearing from the communication apparatus
to a recipient entity and control the rotatable mounting to point the laser
15 transmitter towards the recipient entity, such that data can be transmitted by the
at least one radio to the recipient entity.
4. The communication apparatus according to any one of the preceding
claims, wherein the housing comprises a window arranged in the path of a laser
20 beam emitted when the laser transmitter is activated, wherein the window is
transparent to the frequency of the laser beam.
5. The communication apparatus according to any one of the preceding
claims, comprising at least one directional antenna and/or at least one
25 omnidirectional antenna coupled to the at least one radio.
6. The communication apparatus according to claim 5, wherein the at least
one directional antenna is coupled to a bottom surface of the housing.
- 30 7. The communication apparatus according to claim 6, wherein at least a
portion of the bottom surface of the housing is planar and wherein the at least
one directional antenna is coupled to the planar portion.

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8. The communication apparatus according to any one of claims 5 to 7, wherein the at least one omnidirectional antenna extends from the bottom surface of the housing.
- 5 9. The communication apparatus according to claim 5, comprising at least one wing extending from one or both sides of the housing, wherein the bottom surface of the at least one wing comprises the at least one directional antenna and/or the at least one omnidirectional antenna.
- 10 10. The communication apparatus according to claim 9, wherein the laser receiver is coupled to the at least one wing.
11. The communication apparatus according to claim 9 or claim 10, comprising at least one motor for retracting the at least one wing into the
15 housing or extending the at least one wing from the housing.
12. The communication apparatus according to any one of claims 5 to 11, wherein the at least one omnidirectional antenna is a dipole antenna.
- 20 13. The communication apparatus according to any one of claims 5 to 12, wherein the at least one directional antenna comprises a dynamically phased array or a patch antenna.
14. The communication apparatus according to any one of claims 5 to 13,
25 wherein the at least one radio comprises:
a first radio electrically coupled to the laser transmitter and/or receiver;
and
one or both of:
a second radio electrically coupled to the at least one omnidirectional
30 antenna; and
a third radio electrically coupled to the at least one directional antenna,
wherein the processor is configured to select the first radio, the second radio or the third radio for transmitting data to the recipient entity.

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15. The communication apparatus according to claim 14, wherein the processor is arranged to receive positional and/or signal propagation data and to select the first radio, second radio or third radio to transmit data to the
5 recipient entity based on the positional and/or signal propagation data.

16. The communication apparatus according to claim 14, wherein the processor is arranged to receive data relating to the bandwidth requirements of the data to be transmitted to the recipient entity and to select the first radio,
10 second radio or third radio to transmit the data based on a link budget.

17. The communication apparatus according to any one of claims 5 to 16, comprising at least two directional antennas and at least two omnidirectional antennas arranged in a Multiple In Multiple Out [MIMO] configuration.

15

18. The communication apparatus according to any one of the preceding claims, comprising coupling means for attaching the communication apparatus to a high altitude long endurance aircraft.

20 19. The communication apparatus according to any one of the preceding claims, further comprising an imaging system disposed within the housing, wherein the housing comprises an aperture arranged within the field of view of the imaging system and transparent to a detection frequency of the imaging system.

25

20. A high altitude long endurance aircraft comprising a communication apparatus according to any one of the preceding claims.

21. A method of communicating using a high altitude long endurance aircraft
30 according to claim 20, comprising determining the position of a recipient entity relative to the communication apparatus, determining a bearing to the recipient entity and controlling the rotatable mount to point the laser transmitter towards the recipient entity.

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22. The method according to claim 21, comprising determining the range to a recipient entity and selecting the first radio, second radio or the third radio to transmit data to the recipient entity based on the determined range.

5

23. The method according to claim 21, comprising receiving signal propagation data and selecting the first radio, second radio or the third radio to transmit data to the recipient entity based on the signal propagation data.

10 24. The method according to claim 21, comprising receiving data relating to the bandwidth requirements of data to be transmitted and selecting the first radio, the second radio or the third radio to transmit the data to the recipient entity based on a link budget.

15 25. The method according to any one of claims 21 to 24, comprising retracting the at least one wing when the directional or omnidirectional antenna attached thereto is not in use.

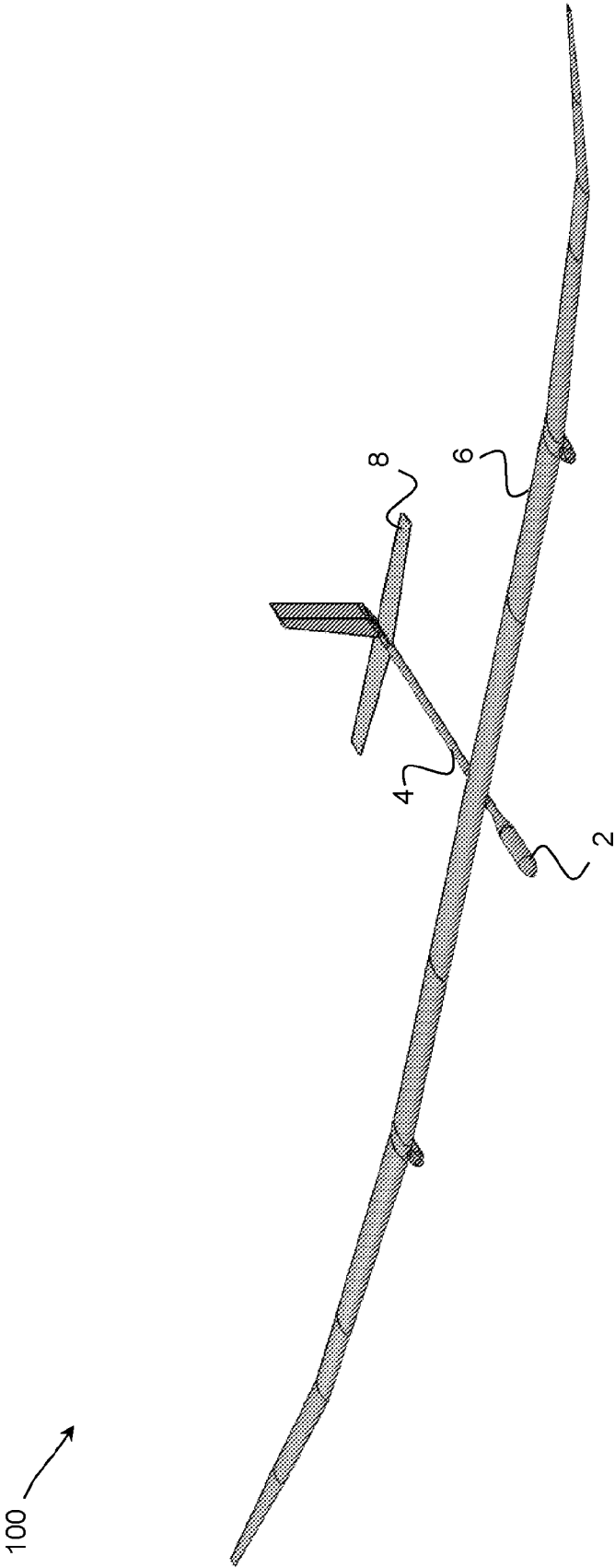


Figure 1

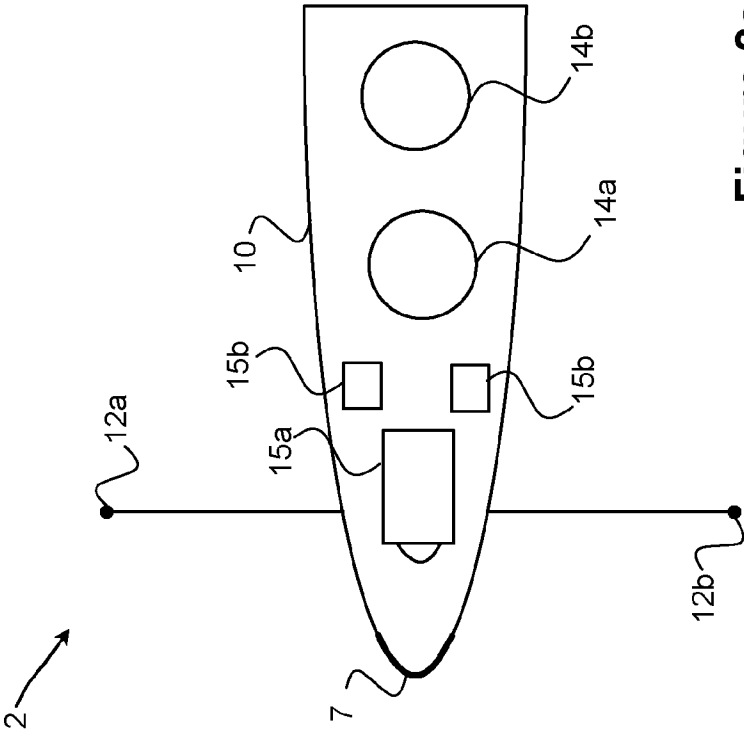


Figure 2a

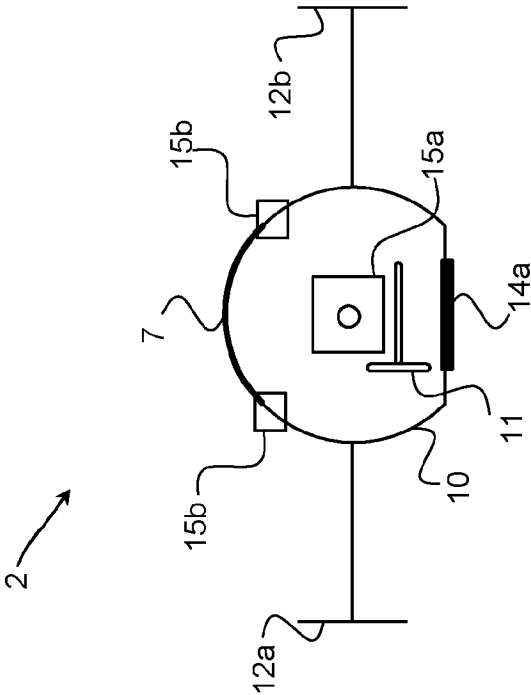


Figure 2b

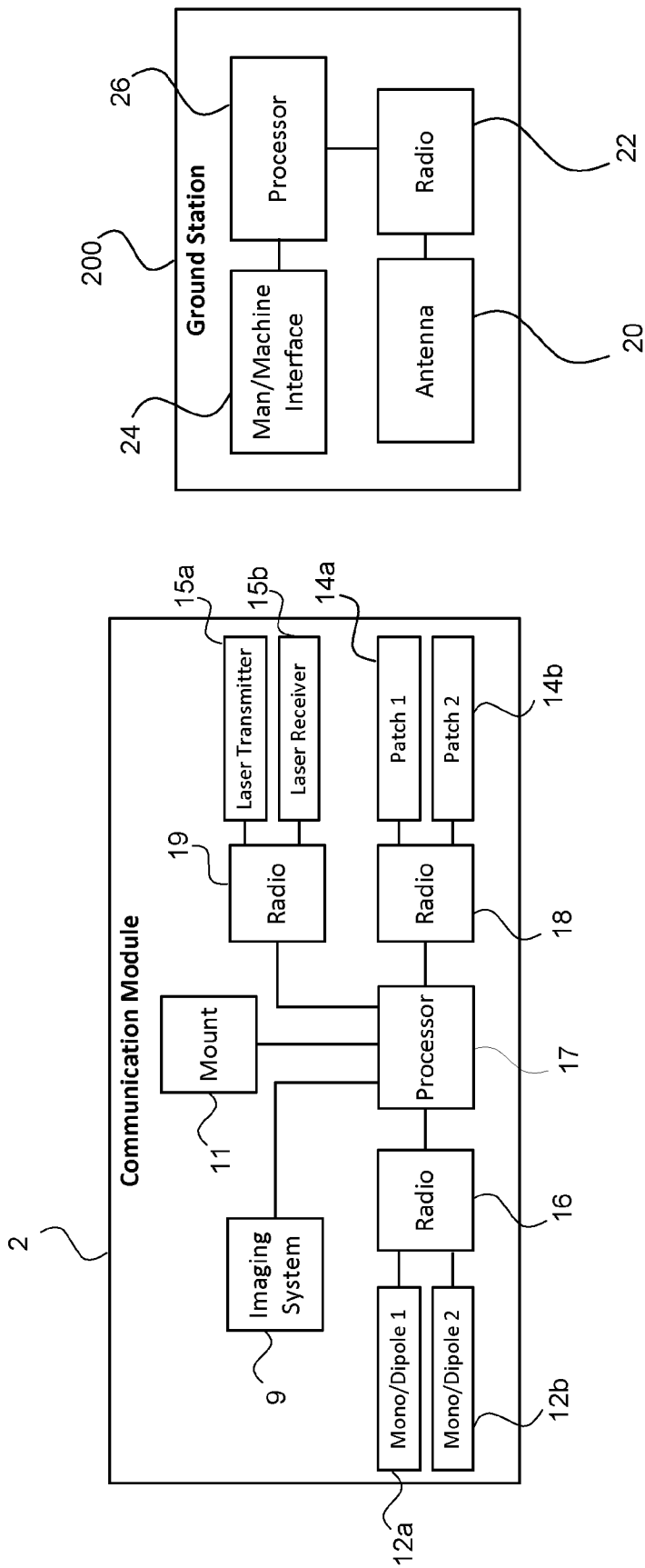


Figure 3

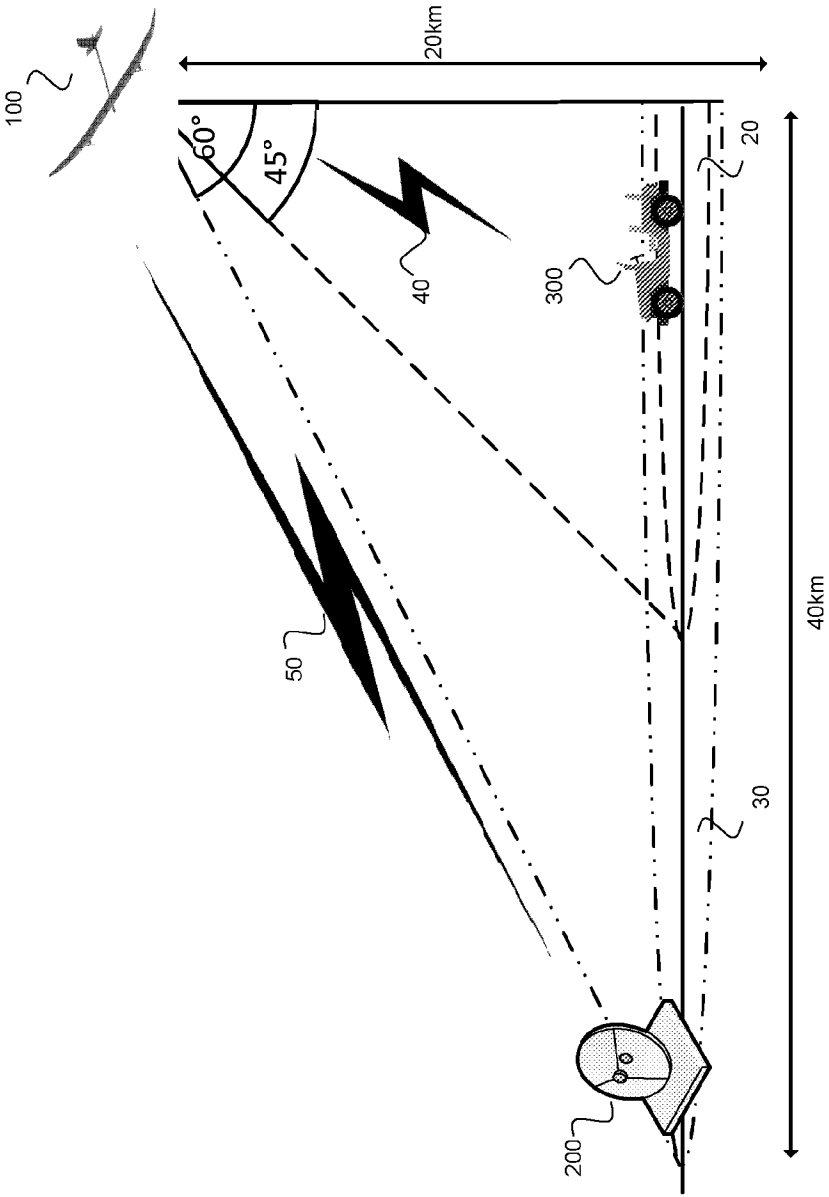


Figure 4

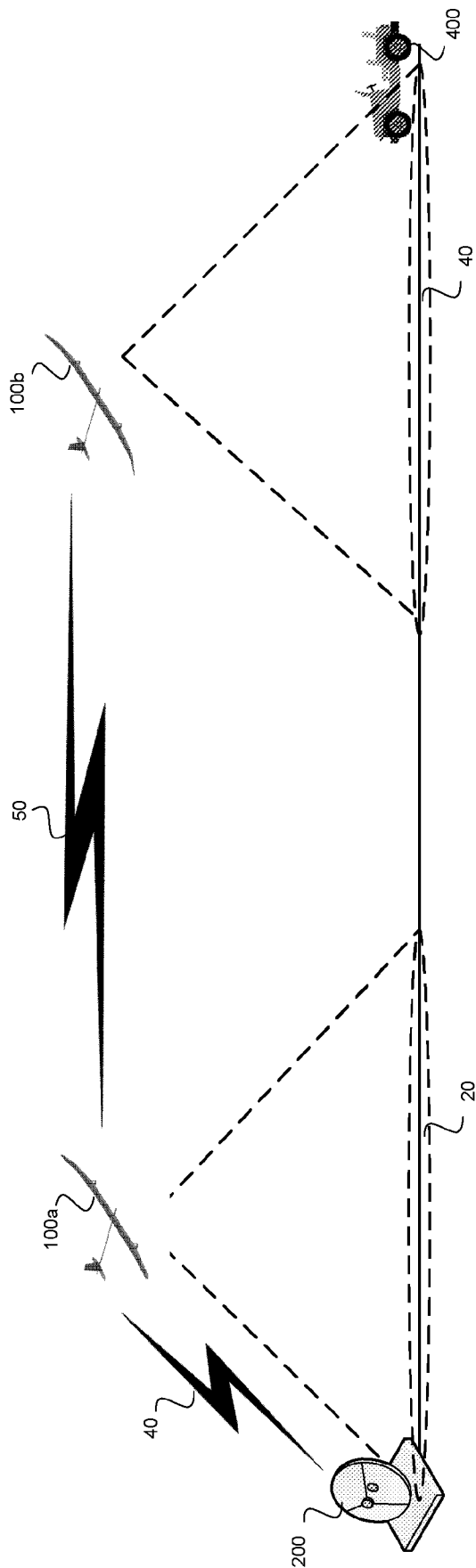


Figure 5

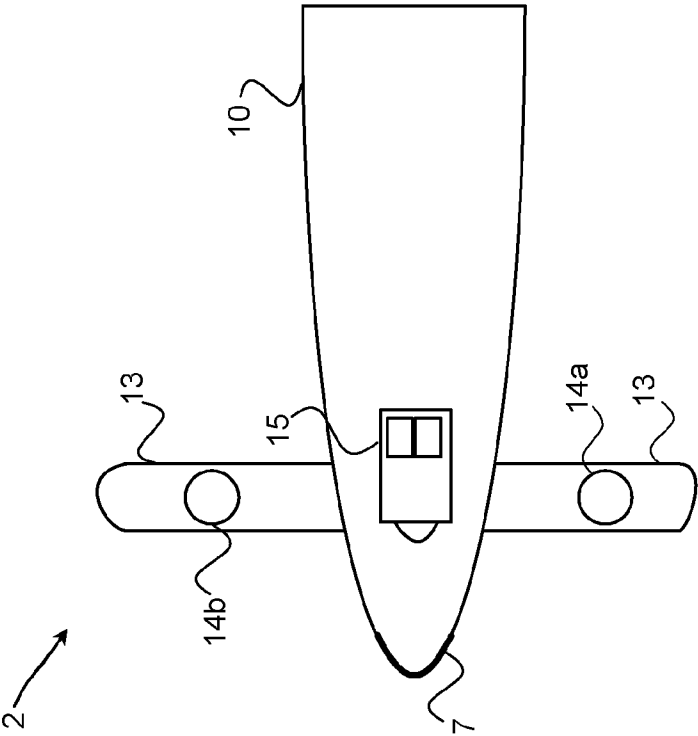


Figure 6a

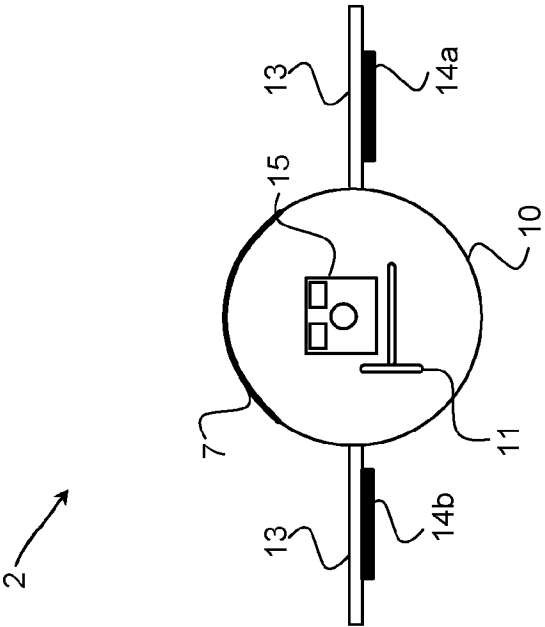


Figure 6b

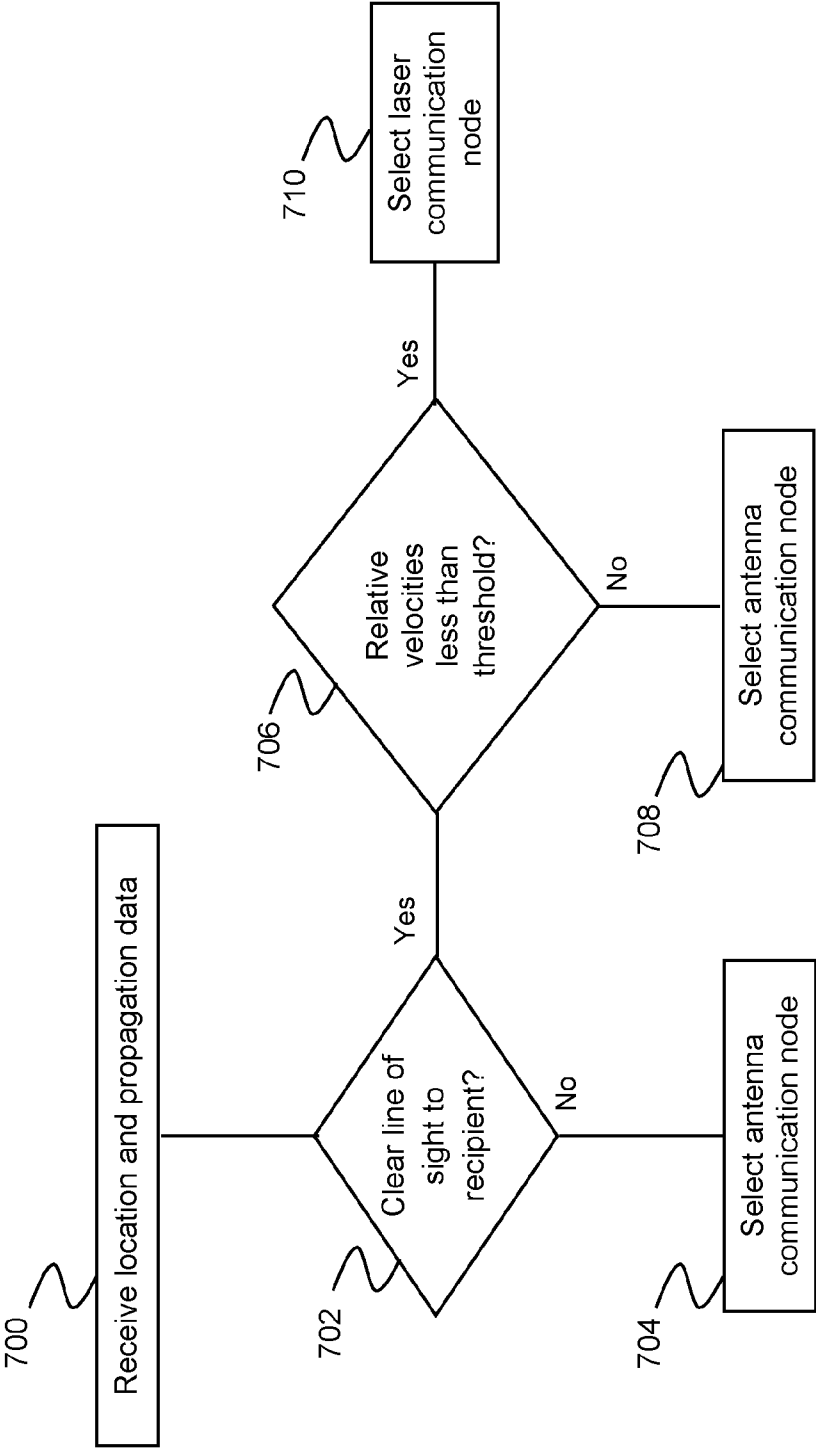


Figure 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/052505

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/185
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)
H04B

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

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

EPO-Internal, WPI Data

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Y	columns 8,14; figures 1-4,5a,5b -----	10
X	WO 2011/075707 A1 (AEROVIRONMENT INC [US]; RIOS EDWARD OSCAR [US]) 23 June 2011 (2011-06-23) pages 5,7-9,10; figures 1,3-6 -----	1,2,5-7, 18,20,21
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Y	paragraphs [0091] - [0097]; figure 14 -----	10
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-/-		



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

29 October 2019

Date of mailing of the international search report

07/11/2019

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/052505

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

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International application No

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