



(51) International Patent Classification:
H04B 7/185 (2006.01)

(21) International Application Number:
PCT/GB2019/052504

(22) International Filing Date:
09 September 2019 (09.09.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1900975.2 24 January 2019 (24.01.2019) GB
19275008.1 24 January 2019 (24.01.2019) EP

(71) Applicant: **BAE SYSTEMS PLC** [GB/GB]; 6 Carlton Gardens, London SW1Y 5AD (GB).

(72) Inventors: **WILLIAMS, Josh Matthieu**; Bae Systems, Grange Road, Christchurch Dorset BH23 4JE (GB). **MILLER, James Martin**; Bae Systems, Grange Road, Christchurch Dorset BH23 4JE (GB). **SALTER, Robert**

John; Bae Systems, Grange Road, Christchurch Dorset BH23 4JE (GB).

(74) Agent: **BAE SYSTEMS PLC, GROUP IP DEPT**; Farnborough Aerospace Centre, Farnborough Hampshire GU14 6YU (GB).

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

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,

(54) Title: COMMUNICATION APPARATUS

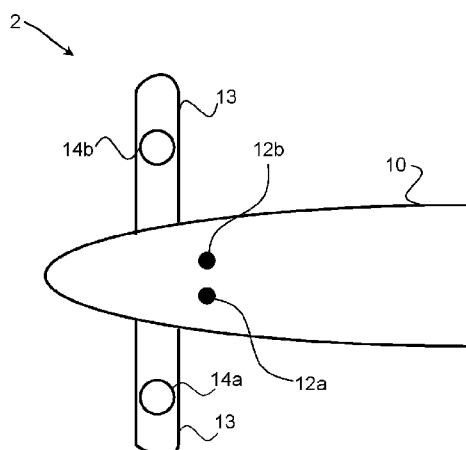


Figure 6a

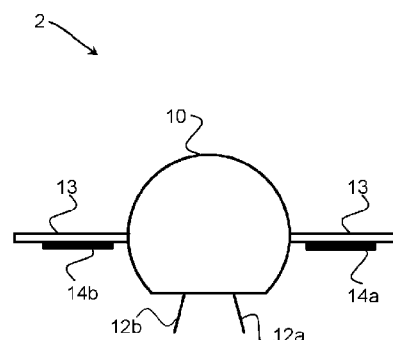


Figure 6b

(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; at least one omnidirectional antenna electrically coupled to the at least one radio; and at least one directional antenna electrically coupled to the at least one radio. The present invention also provides a high altitude long endurance aircraft having the communication apparatus and a method of communicating using the same.



TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

- *with international search report (Art. 21(3))*

- 1 -

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;

- 2 -

at least one omnidirectional antenna electrically coupled to the at least one radio; and

at least one directional antenna electrically coupled to the at least one radio.

5

Advantageously, the communication apparatus provides communication at increased range without a significant increase in power or weight requirements.

The housing may be aerodynamically-shaped.

10

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.

15 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. The bottom surface of the wing may comprise the at least one directional antenna and/or the at least one omnidirectional
20 antenna. The at least one directional antenna may extend from the bottom of the housing. The at least one omnidirectional antenna may extend from an end of the at least one wing. The at least one omnidirectional antenna may extend orthogonally from the at least one wing.

25 The communication apparatus may comprise at least one motor for retracting 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.

30 Alternatively, the omnidirectional antenna may be a monopole antenna. The at least one directional antenna may comprise a dynamically phased array or a patch antenna.

- 3 -

The communication apparatus may comprise:

- a first radio coupled to the at least one omnidirectional antenna;
 - a second radio coupled to the at least one directional antenna; and
 - a processor electrically coupled to the first radio and the second radio,
- 5 the processor being arranged to select the first radio or the second radio for transmitting data to a recipient entity.

The processor may be arranged to receive positional and/or signal propagation information relating to a recipient entity and the communication apparatus. The

10 processor may be arranged to select the first radio or the second radio to transmit data to the recipient entity based on the positional and/or signal propagation information. The processor may be arranged to generate control signals to move the high altitude long endurance aircraft closer to the recipient entity. Signal propagation information may include weather data or terrain data

15 relating to the atmosphere or terrain between the recipient entity and communication apparatus.

The processor may be arranged to receive data relating to the bandwidth requirements of data to be transmitted and to select the first radio or second

20 radio for transmission of the data based on a link budget.

The communication apparatus may comprise coupling means for attaching the communication apparatus to a high altitude long endurance aircraft. The coupling means may comprise a protrusion having an aperture for alignment

25 with an aperture on the high altitude long endurance aircraft. A pin or screw may be disposed in the apertures to couple the communication apparatus to the high altitude long endurance aircraft. Alternatively, the coupling means may comprise a protrusion for insertion into an aperture on the high altitude long endurance aircraft. Alternatively again, the coupling means may comprise an

30 aperture into which a protrusion on the high altitude long endurance aircraft is inserted.

- 4 -

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 further comprise 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.
- 10 According to a second aspect, there is provided a communication apparatus for a high altitude long endurance aircraft, the communication module comprising:
 an aerodynamically-shaped housing;
 at least one omnidirectional antenna electrically extending from the housing; and
15 at least one directional antenna electrically coupled to the housing.

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

20

- The communication apparatus may be coupled to a fuselage of the high altitude long endurance aircraft. Alternatively, the housing may comprise a fuselage of the high altitude long endurance aircraft. The high altitude long endurance aircraft may comprise a coupling means for attaching the communication
25 apparatus to the fuselage. The communication apparatus may be releasably attached to the fuselage.

- According to a fourth aspect of the present invention, there is provided a system comprising a plurality of high altitude long endurance aircraft according to the
30 third aspect, wherein a first of the plurality of aircraft is arranged to communicate with a second of the plurality of aircraft, and wherein the second of the plurality of aircraft is arranged to communicate with a ground station.

- 5 -

According to a fifth aspect of the present invention, there is provided a method of communicating using a high altitude long endurance aircraft according to the third aspect, the method comprising selecting from the first radio and the second radio to transmit data to a recipient entity.

5

The method may comprise receiving positional and/or signal propagation information relating to the recipient entity and the communication apparatus. The method may comprise using the positional information to determine the range to the recipient entity and selecting, using the determined range, the first
10 radio or the second radio to transmit data to the recipient entity. The method may comprise either:

generating control signals to move the high altitude long endurance aircraft closer to the recipient entity based on the received positional and/or signal propagation information; or

15 selecting the first or second radio to transmit data to the recipient entity based on the received positional and/or signal propagation information.

The method may comprise receiving data relating to the bandwidth requirements of data to be transmitted and selecting the first radio or the
20 second 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 or omnidirectional antenna attached thereto is not in use.

25 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 the features described in this disclosure with reference to a method, and vice versa. Moreover, additional embodiments and aspects will be apparent from
30 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 every combination of one or more values defining a range, are included within

- 6 -

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.

5

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.

- 10 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;
- 15 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;
Figure 5 is a system diagram showing an example of a use of the
- 20 communication module;
Figure 6a is a plan view of a communication module according to a second embodiment;
Figure 6b is a frontal view of a communication module according to the second embodiment;
- 25 Figure 7a is a plan view of a communication module according to a third embodiment;
Figure 7b is a frontal view of a communication module according to the third embodiment; and
Figure 8 is a flowchart showing a method of operating a communication module
- 30 according to an embodiment.
- For convenience and economy, the same reference numerals are used in different figures to label identical or similar elements.

- 7 -

DETAILED DESCRIPTION

Embodiments herein generally relate to a communication module, particularly for use on an unmanned high-altitude long-endurance (HALE) aircraft as shown in Figure 1. The communication module includes one or more patch antennas
5 for communication with assets on the ground in the relative vicinity of the aircraft, and one or more monopole or dipole antennas for relatively longer-range communication with other airborne or ground assets.

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

An aircraft 100, specifically a HALE unmanned aeroplane, is shown in Figure 1. While an unmanned HALE aeroplane 100 is shown here, it would be readily appreciated that the present invention is applicable to other types of aircraft,
15 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 aerodynamically balance the aircraft 100, tail surfaces 8 are coupled to the rear of the fuselage 4.

20 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
25 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
30 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

- 8 -

communication module 2 is fixed. In other words, the communication module 2 may be integrated with and/or distributed throughout the aircraft 100.

Various configurations of the communication module 2 are shown in more detail in Figures 2a, 2b, 6a, 6b, 7a and 7b. While the physical layout illustrated in each of these embodiments is different, the system architecture, as illustrated in Figure 3, may be the same or similar. Identical features have the 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 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 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.

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

- 9 -

Here, instead of on the underside of the housing 10, one directional antenna 14 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. 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 omnidirectional antennas 12a,12b to a flat surface, a null zone tends to be reduced.

10

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

15 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 disposed inside the housing 10 to drive the wings 13 to retract or extend. In alternative embodiments, the wings 13 are fixed.

20

Figures 7a and 7b illustrate two views of another embodiment of the communication module 2. The embodiment is similar to those described with respect to Figures 6a and 6b. Here, the housing 10 is curved on the underside to improve its aerodynamic properties. The directional antennas 14a,14b are disposed on the underside of the wings 13. A first omnidirectional antenna 12a is disposed on the tip of a wing 13 on one side of the communication module 2, and a second omnidirectional antenna 12b is disposed on the tip of a wing 13 disposed on the other side of the communication module 2. Electrical wiring for coupling the omnidirectional antennas 12a,12b to a radio on the inside of the housing 10 is disposed inside the wings 13.

30

The omnidirectional antennas 12a,12b are illustrated as being parallel to each other and orthogonal to the horizontal plane of the housing 2, however, in other

- 10 -

embodiments, they may be disposed at an angle relative to each other to improve EM transmission capability in the horizontal plane.

While a plurality of directional antennas 14a, 14b and omnidirectional antennas 5 12a, 12b are present in Figures 2a, 2b, 6a, 6b, 7a and 7b, this is for illustrative purposes only. In other embodiments, there may only be a single directional antenna 14a and 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 12a, 12b, 10 14a, 14b within each communication node (defined here as a radio and antenna 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 therefore signal to noise ratio is improved. For example, one omnidirectional antenna may extend from the front of the housing 10, one 15 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.

In the illustrated embodiments, the directional antennas 14a, 14b comprise 20 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 at low temperatures. For example, at 20,000 metres above sea level, the ambient temperature can drop to about -56.5 degrees Celsius. Alternatively, 25 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.

On HALE aircraft 100, particularly those optimised for low aerodynamic 30 resistance (or drag), it is disadvantageous to provide antennas in dome-like fairings, or to provide satellite dishes. Low-profile antennas, such as patch antennas, tend to reduce drag. Furthermore, conventional monopole or dipole antennas, when arranged substantially parallel with the main transverse plane

- 11 -

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.

- 5 In further embodiments, the communication module 2 includes at least one 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
- 10 to steer an RF beam pattern, for example such that the peak of the energy distribution is centred on a recipient node. 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.
- 15 In addition to the directional antennas 14a, 14b and omnidirectional antennas 12a, 12b, the communication module 2 may include an imaging system. The imaging system includes a camera. The camera is for example an optical camera. The camera may alternatively or additionally be configured to detect infrared, ultraviolet, microwave or x-ray emission, for example, to detect objects
- 20 or map an area. The imaging system may be a hyperspectral imaging system. The communication module 2 includes an aperture transparent to the observing spectrum of the camera and arranged such that the camera can observe the environment outside the aircraft 100. 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
- 25 of the camera moving significantly.

- The communication module 2 is a self-contained module having a processor 17. 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
- 30 receiving node, for example the ground station 200, and the location of the aircraft 100. Examples of location information include GPS data relating to the aircraft 100 having the communication module 2 and the recipient entity, coordinates (e.g. grid reference), range to the recipient entity, bearing to the

- 12 -

recipient entity, and altitude of the aircraft 100 and recipient entity. The processor 17 can then select between the radio 16 coupled to the omnidirectional antennas 12a, 12b or the radio 18 coupled to the directional antennas 14a, 14b for transmitting the information to be sent to the receiving
5 node, depending on which of their associated antennas 12a, 12b, 14a, 14b are within range. The processor 17 may also determine that the aircraft 100 needs to be moved (for example moved closer to the receiving node, or controlled or change pitch, 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
10 or other environmental information that affects signal propagation to determine which antenna 12a, 12b, 14a, 14b to use or how to move the aircraft 100. Examples of received signal propagation data includes weather patterns, sensor obscuration (e.g. indicating cloud cover), humidity, air density, air temperature, precipitation, and received signal strength. The processor 17 may
15 also perform switching to ensure optimal bandwidth utilisation across all of the antennas 12a, 12b, 14a, 14b. The processor 17 may be used to control the motor for extending or retracting the wings 13 described with reference to Figures 6a, 6b, 7a and 7b, depending on whether the antennas fixed thereto are in use or will be used.

20

The signal propagation information and location information may be received from a storage module (i.e. a memory), from a sensor on the aircraft 100, or from a signal receiver 12, 14.

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

Each type of antenna has associated therewith a radio 16, 18. The respective radio 16, 18 converts (or encodes or modules) the information to be transmitted
30 into a signal for transmission through a respective antenna 12a, 12b, 14a, 14b. Further, the radios 16, 18 convert (or decode or demodulate) received signals into information usable by the processor 17. The radios 16, 18 operate according to any communication standard known to the skilled person. For

- 13 -

example, they may for example be 3G, 4G, or 5G radios. The radios 16, 18 may be Frequency Modulated (FM) radios. The radios 16, 18 may encrypt the signals to be transmitted, or decrypt received signals.

- 5 Signals received by the radios 16, 18 from off-board the aircraft 100 are processed by the processor 17 to determine their content and what action to 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
- 10 propulsion systems. In some embodiments, the processor 17 is configured to actuate the control surfaces and/or propulsion systems in response to receiving 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.
- 15 Where the communication module 2 includes an imaging system, the communication module 2 may include a storage means for storing images or 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 and perform data analysis and processing. In
- 20 alternative embodiments, particularly where the communication module 2 is distributed throughout the aircraft 100, the communication module 2 may use 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
- 25 EMCON restriction is in place and that a non-essential transmission should not be made. Further, the processor 17 may determine when the antennas 12a, 12b, 14a, 14b 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 to only transmit when the intended recipient entity is likely to be within
- 30 range or if the reliable communications link is likely to be made.

Alternatively or additionally to an imaging system, the communication module 2 may include a telemetry system. The telemetry system may be, for example,

- 14 -

for monitoring weather patterns or magnetic field strength. The telemetry 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
5 16,18 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 aircraft 100.

While the radios 16, 18 and processor 17 are depicted as being separate
10 entities in Figure 3, in other embodiments, they may be software modules within a single hardware device. Furthermore, in some embodiments, the directional antenna(s) 14 and omnidirectional antenna(s) 12 are coupled to the same radio 16,18. Here, there may be a switch for selecting which antenna type (i.e.
15 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 processor 17 and other electronic components of the communication module 2,
20 such as the imaging system and radios 16,18 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 converting the voltage and/or current delivered by the aircraft 100 to a voltage and/or current demanded by the radios 16,18 and processor 17.

25

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.

30 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

- 15 -

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 radio 22 converts received data 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 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 antenna 14a and an omnidirectional antenna 12a. 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 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

- 16 -

downwards direction and transmits its energy in that relatively small area. The dipole antenna projects most of its energy 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 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.

10

The directional antennas 14a, 14b concentrate their energy on a relatively small and defined area, which makes them efficient at communicating with assets, 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 omnidirectional antennas 14a, 14b will increase their range, on HALE aircraft this is not viable due to limited resources.

20

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 MANET acting as relays for each other.

25

In other words, the nodes (radio 16, 18 and antennas 12a, 12b, 14a, 14b) in aircraft 100a, 100b equipped with the communication module 2 can operate as nodes within a larger MANET. 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

30

- 17 -

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 the communication module 2.

- 5 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 within communication range of a ground station 200 having intelligence analysts and flight controllers etc.

10

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

20

As the aircraft 100b is out of communication range with the ground station 200, it is unable to directly receive control signals. Further, the video generated by the imaging system 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 another aircraft 100a at a similar altitude acting as a relay.

25

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

30

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 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

- 18 -

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 other aircraft in the chain for relay.

5

A method of operating a communication module 2 will now be described with reference to Figure 8. Here, in a first step, step 800, signal propagation information and location information is received by the processor 17. This may include GPS data relating to the aircraft 100 having the communication module
10 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 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
15 signal propagation information and location information may be received from a storage module (i.e. a memory), from a sensor on the aircraft 100, or from a signal receiver 12,14.

It would be appreciated that in some embodiments, only location information is
20 received by the processor 17.

In step 802, the range to a recipient entity 100a,200,300 is calculated (if is not part of the received location information) and used to determine which communication node to use (i.e. the omnidirectional antenna 12 and radio 16
25 combination or the directional antenna 14 and radio 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 100a,200,300 and aircraft 100 are known, the maximum separation distance can be calculated.
30 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. As explained with reference to Figure 4, the omnidirectional antenna 12 has greater range than the directional

- 19 -

antenna 14 for the same power draw. Therefore, in step 804, if the range is greater than a threshold, for example about 28km in the illustrated embodiment, the communication node having the omnidirectional antenna 12 and radio 16 is selected for transmitting data to a recipient entity 100a,200,300. Alternatively in
5 step 804, the processor 17 may generate a control signal to move the aircraft 100 closer to the recipient entity or change the aircraft's attitude or angle of bank to strengthen a communication link.

If the range to the recipient entity 100a,200,300 is not greater than a threshold,
10 in step 806 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 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
15 communication module 2 and have a relatively narrow field of regard. In step 808, 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 of the directional antenna 14.

20 In step 810, the communication node having the omnidirectional antenna 12 is selected for transmitting data if the recipient entity 100a,200,300 is not within the field of regard of the directional antenna 14. Alternatively, in step 810, the aircraft 810 is moved (e.g. pitched or banked) such that the recipient entity 100a,200,300 is within the field of regard of the directional antenna 14.

25

A further factor in the antenna 12,14 selection process carried out by the processor 17 may include a link budget or bandwidth availability. For example, the directional antenna 14 is preferable where a high data transfer rate is required. Therefore, it may be preferable to wait until the communication node
30 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 within range instead of selecting to transmit using the communication node having the omnidirectional antenna 12.

- 20 -

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

5 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

10 some embodiments of the disclosure, may not be desirable, and can therefore be absent, in other embodiments.

- 21 -

CLAIMS

1. A communication apparatus for a high altitude long endurance aircraft, the communication module comprising:
 - a housing;
 - 5 at least one radio disposed inside the housing;
 - at least one omnidirectional antenna electrically coupled to the at least one radio; and
 - at least one directional antenna electrically coupled to the at least one radio.
- 10 2. The communication apparatus according to claim 1, wherein the at least one directional antenna is coupled to a bottom surface of the housing.
3. The communication apparatus according to claim 2, wherein at least a
15 portion of the bottom surface of the housing is planar and wherein the at least one directional antenna is coupled to the planar portion.
4. The communication apparatus according to any one of the preceding claims, wherein the at least one omnidirectional antenna extends from the
20 bottom surface of the housing.
5. The communication apparatus according to any one of the preceding claims, 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
25 least one directional antenna and/or the at least one omnidirectional antenna.
6. The communication apparatus according to claim 5, wherein the omnidirectional antenna is coupled to an end of the at least one wing.
- 30 7. The communication apparatus according to claim 5 or claim 6, comprising at least one motor for retracting the at least one wing into the housing or extending the at least one wing from the housing.

- 22 -

8. The communication apparatus according to any one of the preceding claims, wherein the at least one omnidirectional antenna is a dipole antenna.

9. The communication apparatus according to any one of the preceding
5 claims, wherein the at least one directional antenna comprises a dynamically phased array or a patch antenna.

10. The communication apparatus according to any one of the preceding claims, comprising:

10 a first radio electrically coupled to the at least one omnidirectional antenna;

a second radio electrically coupled to the at least one directional antenna; and

a processor electrically coupled to the first radio and the second radio,
15 the processor being arranged to select the first radio or the second radio for transmitting data to a recipient entity.

11. The communication apparatus according to claim 10, wherein the processor is arranged to receive positional and/or signal propagation
20 information relating to a recipient entity and the communication apparatus, and either:

to select the first radio or the second radio to transmit data to the recipient entity based on the positional and/or signal propagation information; or

to generate control signals to move the high altitude long endurance
25 aircraft closer to the recipient entity.

12. The communication apparatus according to claim 10 or claim 11, wherein the processor is arranged to receive data relating to the bandwidth requirements of data to be transmitted and to select the first radio or second
30 radio for transmission of the data based on a link budget.

- 23 -

13. 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.
- 5 14. The communication apparatus according to any one of the preceding claims, comprising at least two directional antennas and at least two omnidirectional antennas arranged in a Multiple In Multiple Out [MIMO] configuration.
- 10 15. 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.
- 15 16. A high altitude long endurance aircraft comprising a communication apparatus according to any one of the preceding claims.
17. The high altitude long endurance aircraft according to claim 16, wherein
20 the communication apparatus is coupled to a fuselage of the high altitude long endurance aircraft.
18. The high altitude long endurance aircraft according to claim 16, wherein the housing comprises a fuselage of the high altitude long endurance aircraft.
- 25 19. A system comprising a plurality of high altitude long endurance aircraft according to any one of claims 16 to 18, wherein a first of the plurality of aircraft is arranged to communicate with a second of the plurality of aircraft, and wherein the second of the plurality of aircraft is arranged to communicate with a
30 ground station.

- 24 -

20. A method of communicating using a high altitude long endurance aircraft according to any one of claims 16 to 18, the method comprising selecting the first radio and the second radio to transmit data to a recipient entity.

- 5 21. The method according to claim 20, comprising:
receiving positional and/or signal propagation information relating to the recipient entity and the communication apparatus; and
either generating control signals to move the high altitude long endurance aircraft closer to the recipient entity based on the received positional
10 and/or signal propagation information; or
selecting the first or second radio to transmit data to the recipient entity based on the received positional and/or signal propagation information.

22. The method according to claim 21, comprising using the received
15 positional information to determine the range to the recipient entity and selecting, using the determined range, the first radio or the second radio to transmit data to the recipient entity.

23. The method according to claim 20 or claim 21, comprising receiving data
20 relating to the bandwidth requirements of data to be transmitted and selecting the first radio or the second radio to transmit the data to the recipient entity based on a link budget.

24. The method according to any one of claims 20 to 23, comprising
25 retracting the at least one wing when the directional or omnidirectional antenna attached thereto is not in use.

1/8

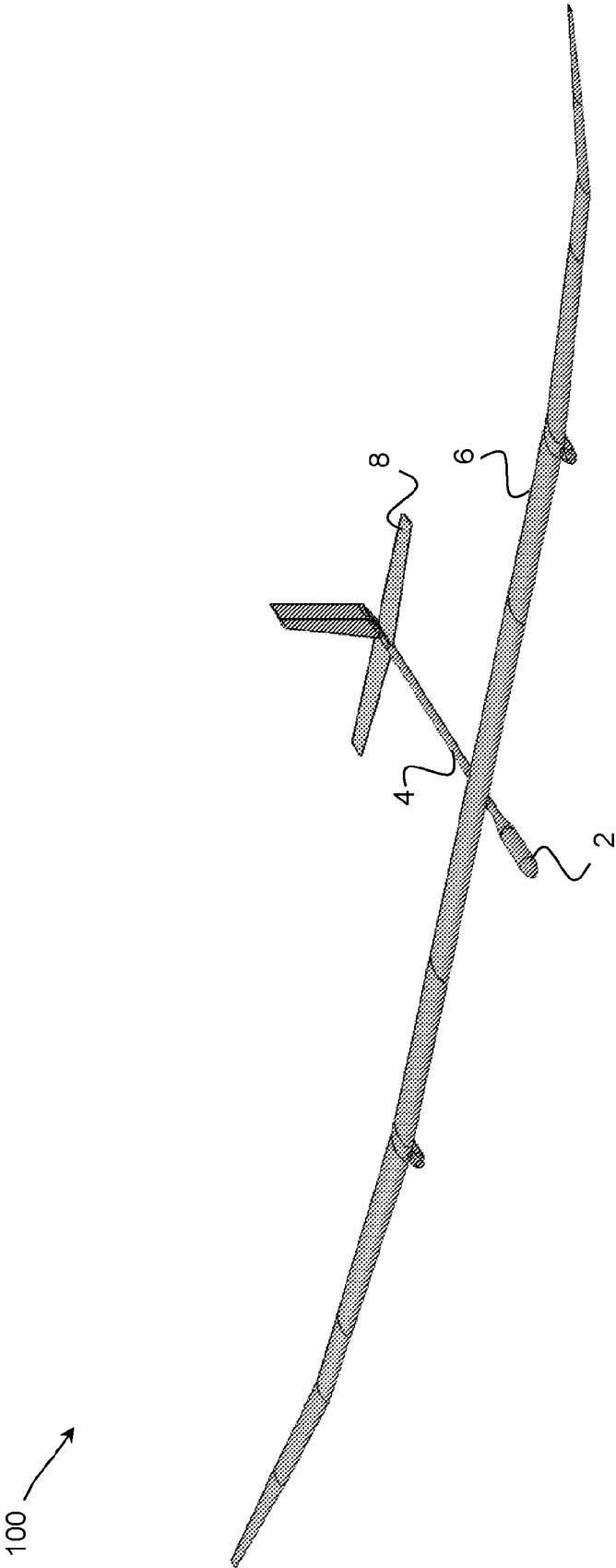


Figure 1

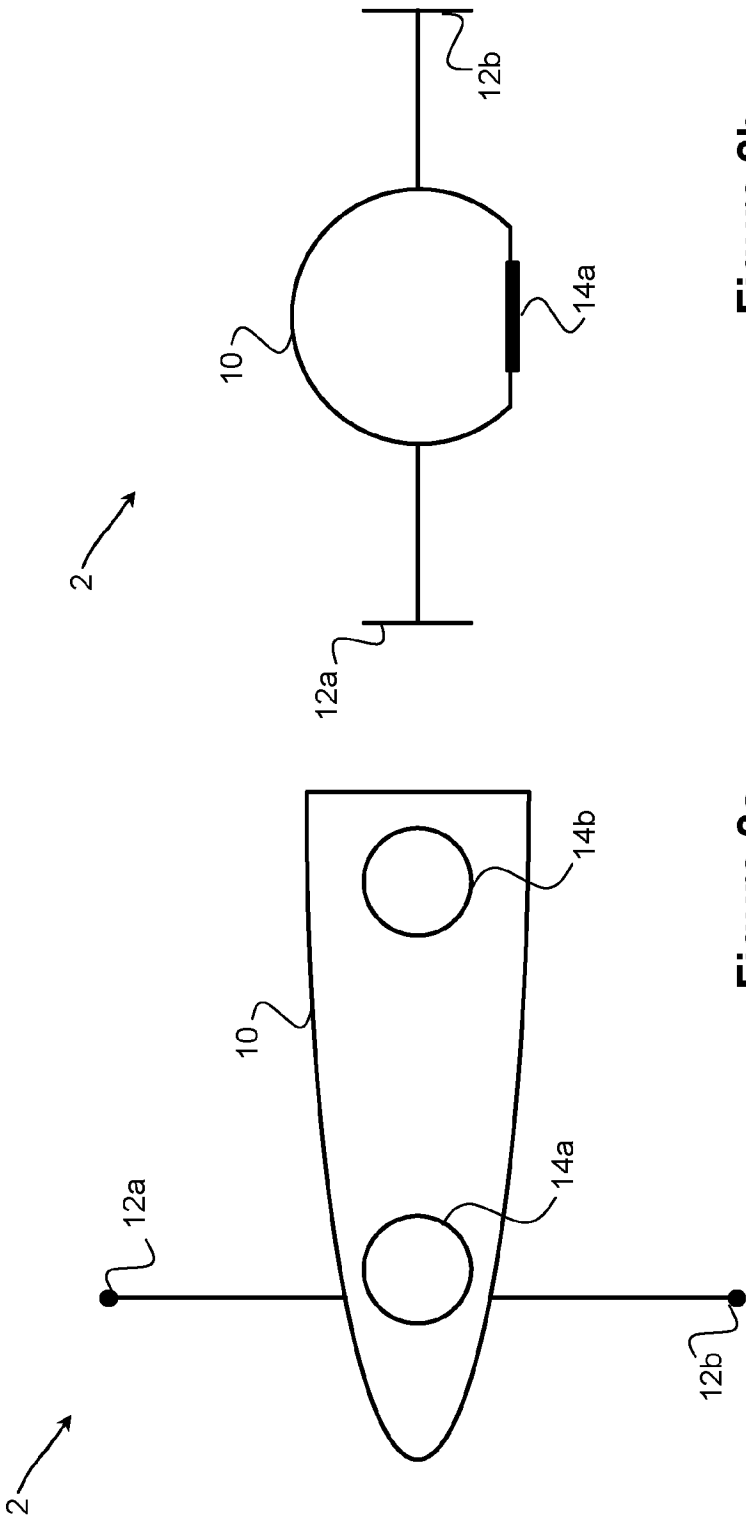


Figure 2b

Figure 2a

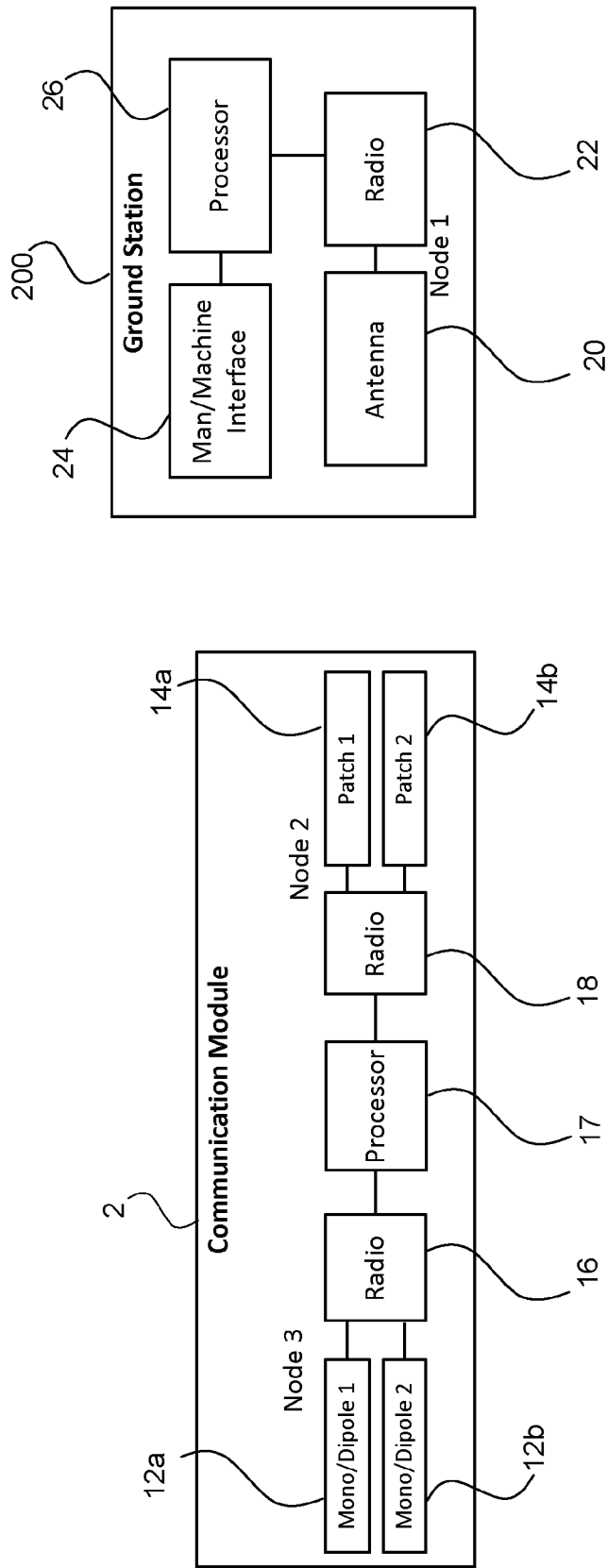


Figure 3

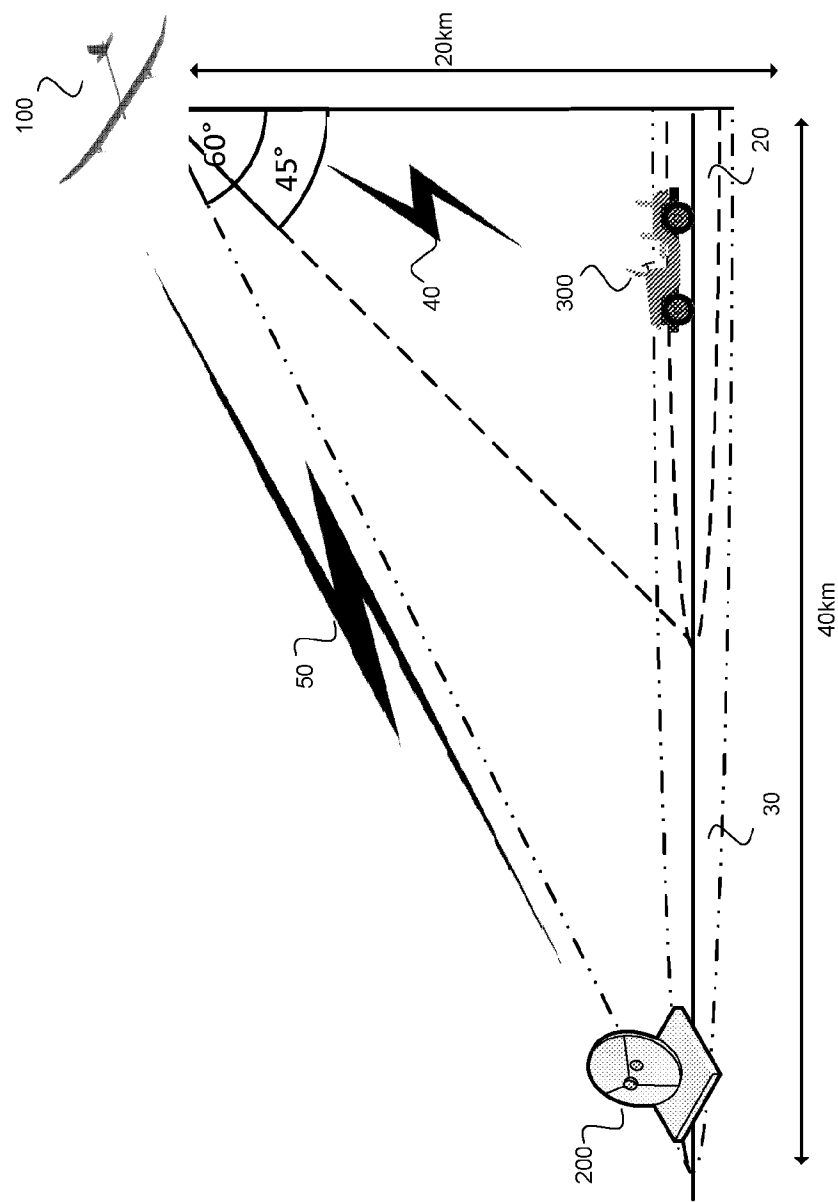


Figure 4

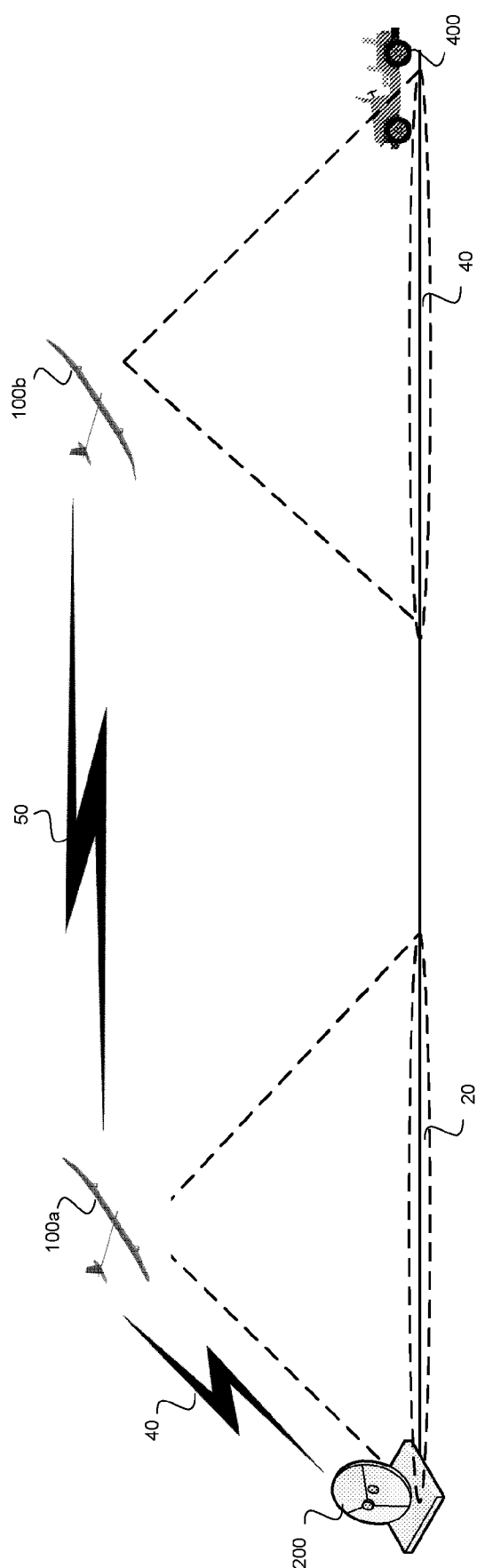


Figure 5

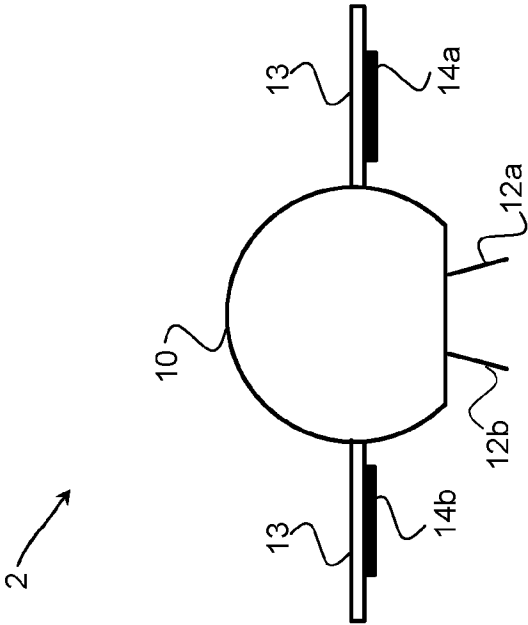


Figure 6b

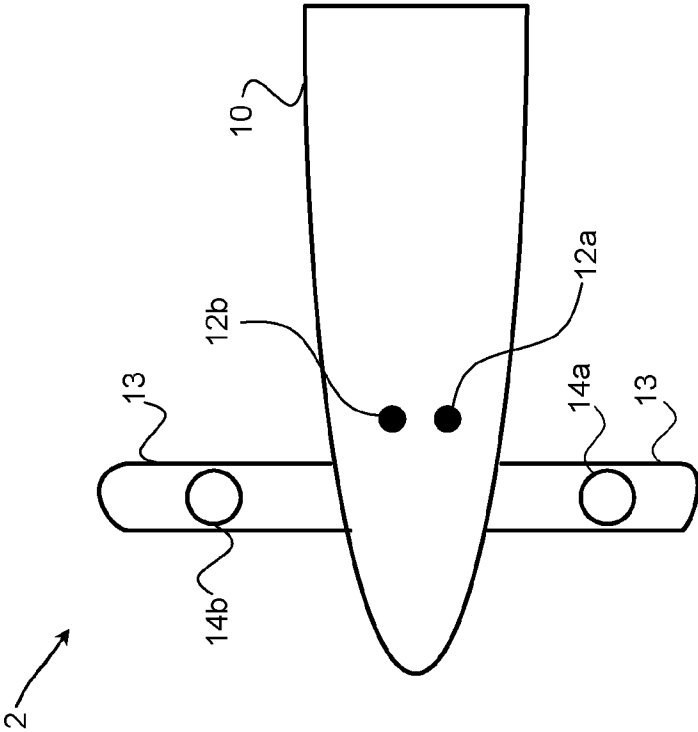


Figure 6a

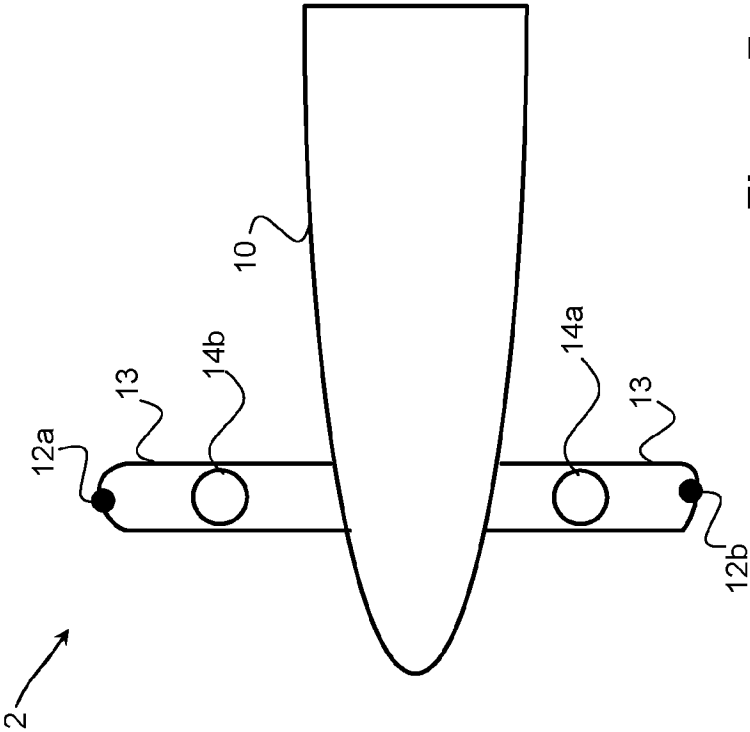


Figure 7a

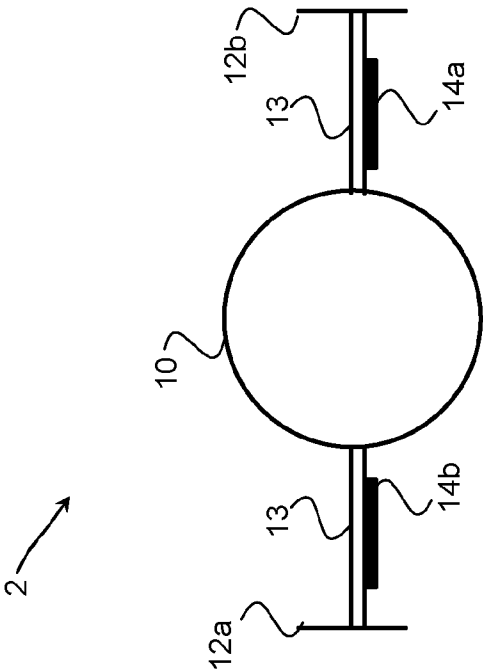


Figure 7b

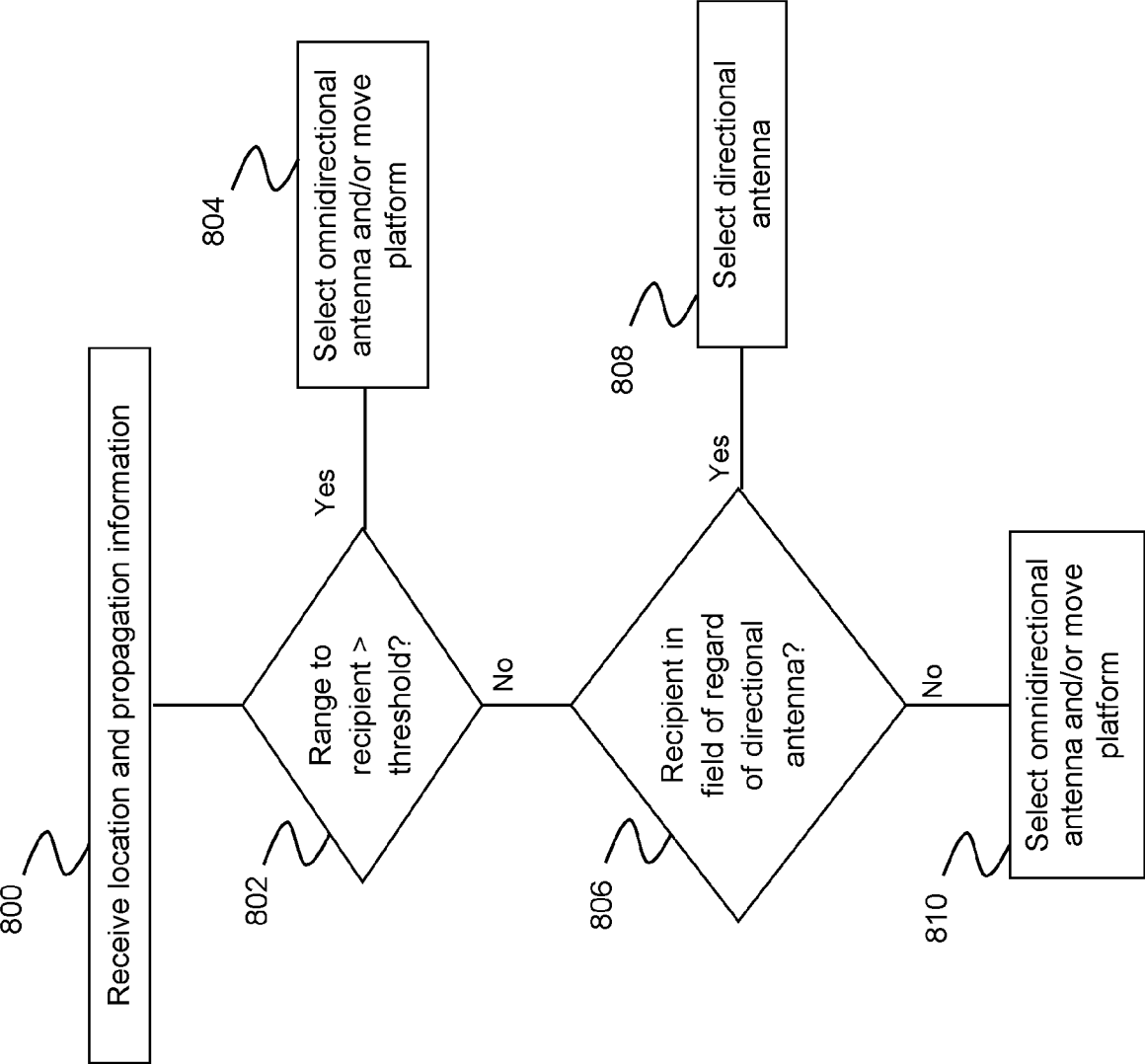


Figure 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/052504

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2017/025723 A1 (BAE SYSTEMS PLC [GB]) 16 February 2017 (2017-02-16) pages 13,14,28; figure 11 -----	1-14, 16-18, 20-24
X	US 9 836 049 B1 (TU HAOFENG [CN]) 5 December 2017 (2017-12-05) column 8; figures 1-5 -----	1-24
X	WO 2011/075707 A1 (AEROVIRONMENT INC [US]; RIOS EDWARD OSCAR [US]) 23 June 2011 (2011-06-23) pages 5,9,10; figure 1 -----	1,16-18, 20
A	GB 2 536 014 A (STRATOSPHERIC PLATFORMS LTD) 7 September 2016 (2016-09-07) pages 4-6,8,9; figures 1-4 ----- -/-	1,20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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

20 September 2019

Date of mailing of the international search report

27/09/2019

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Esbri, Oriol

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2019/052504

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 204 906 394 U (YANG SHANSHAN) 23 December 2015 (2015-12-23) pages 6-9 -----	1,20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2019/052504

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2017025723 A1	16-02-2017	EP 3335376 A1 US 2019028172 A1 WO 2017025723 A1	20-06-2018 24-01-2019 16-02-2017
US 9836049 B1	05-12-2017	CN 108615346 A EP 3399666 A1 US 9836049 B1	02-10-2018 07-11-2018 05-12-2017
WO 2011075707 A1	23-06-2011	AU 2010330766 A1 CN 102741655 A CN 106125094 A EP 2513600 A1 JP 2013515242 A KR 20120109563 A SG 182554 A1 SG 10201408310Q A US 2014195150 A1 US 2016311531 A1 US 2018086459 A1 WO 2011075707 A1	09-08-2012 17-10-2012 16-11-2016 24-10-2012 02-05-2013 08-10-2012 30-08-2012 29-01-2015 10-07-2014 27-10-2016 29-03-2018 23-06-2011
GB 2536014 A	07-09-2016	BR 112017018349 A2 CN 107567415 A EP 3265381 A1 GB 2536014 A US 2018053991 A1 WO 2016139465 A1	17-04-2018 09-01-2018 10-01-2018 07-09-2016 22-02-2018 09-09-2016
CN 204906394 U	23-12-2015	NONE	