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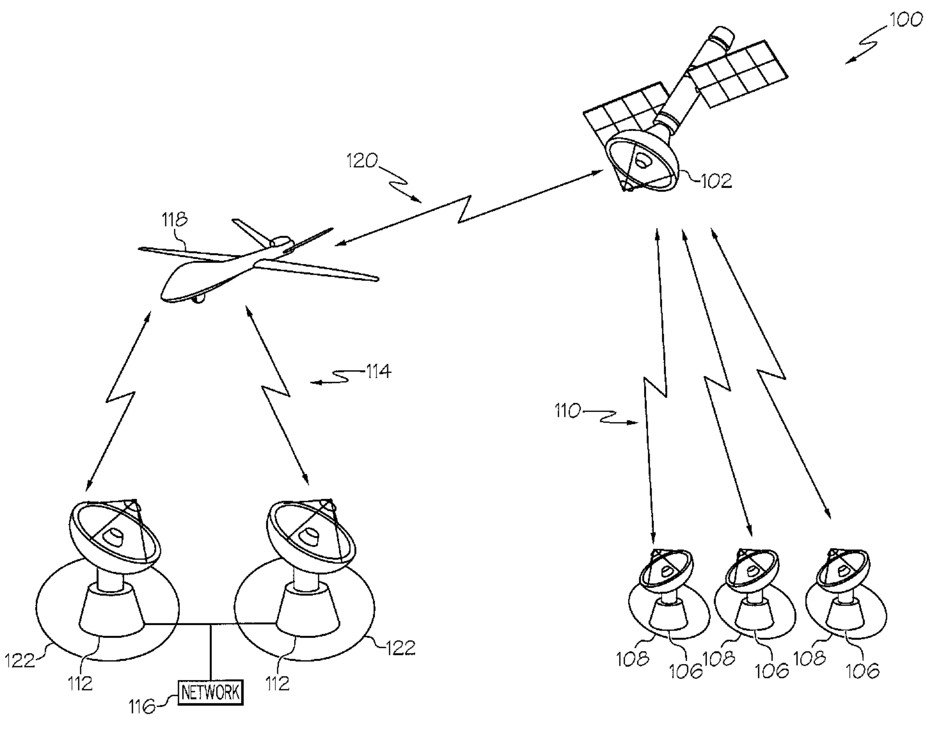

(57) Abrégé/Abstract:
A satellite communication system may include a communication satellite orbiting Earth, a user terminal in radio communication with the communication satellite through a user link, a communication relay apparatus operating at an altitude of approximately 65,000 feet and in optical communication with the communication satellite through a feeder link, and a gateway station in radio communication with the communication relay apparatus through a gateway link.

ABSTRACT

A satellite communication system may include a communication satellite orbiting Earth, a user terminal in radio communication with the communication satellite through a user link, a communication relay apparatus operating at an altitude of approximately **65**,**000** feet and in optical communication with the communication satellite through a feeder link, and a gateway station in radio communication with the communication relay apparatus through a gateway link.

SATELLITE COMMUNICATION SYSTEM

FIELD

The present disclosure is generally related to satellite communications and, more particularly, to a satellite communications system utilizing an optical relay link for communication between a satellite and a ground station.

BACKGROUND

High-throughput satellites ("HTS") provide significantly more throughput than conventional fixed-satellite service satellites ("FSS") over the same orbital spectrum. The significant increase in capacity is achieved by high level frequency re-use and spot beam technology, which enables frequency re-use across multiple narrowly focused spot beams (usually in the order of hundreds of kilometers), such as in cellular networks. However, as the demand for satellite communications continues to increase, there continues to be a need for satellites configured to provide increased throughput. Due to this ever-increasing need for bandwidth and the limitations of the radio frequency ("RF") spectrum, increasing numbers of gateway ground stations distributed over larger regions are required, which may place gateway ground stations in undesirable geographic locations.

Accordingly, those skilled in the art continue with research and development efforts in the field of high-throughput satellite communications.

SUMMARY

In one example, the disclosed satellite communication system may include a communication satellite orbiting Earth, a user terminal in radio communication with the communication satellite through a user link, a communication relay apparatus in optical communication with the communication satellite through a feeder link, and gateway stations in radio communication with the communication relay apparatus through a gateway link.

In another example, the disclosed satellite communication relay apparatus may include a radio frequency terminal to transmit and receive radio frequency communication signals to and from a gateway station over a gateway link, and an optical terminal to transmit and receive optical communication signals to and from a communication satellite over a feeder link.

In yet another example, the disclosed method for providing satellite communication may include the steps of: (**1**) generating a user link for a first radio communication between a communication satellite and a user terminal, (**2**) generating a feeder link for an optical communication between the communication satellite and a communication relay apparatus, the communication relay apparatus operating at an altitude of between approximately **39,000** feet and approximately **180,000** feet, and (**3**) generating a gateway link for a second radio communication between the communication relay apparatus and a gateway station.

In accordance with one disclosed aspect there is provided a satellite communication system. The system includes a communication satellite orbiting Earth, a user terminal in radio communication with the communication satellite through a user link, and a communication relay apparatus in optical communication with the communication satellite through a feeder link. The system also includes a plurality of gateway stations in radio communication with the communication relay apparatus through a gateway link. A signal processor of the communication relay apparatus is configured to convert optical signals received by the communication relay apparatus through the feeder link into radio frequency communication signals, form a plurality of spot beams that include the radio frequency communication signals each spot beam being formed to correspond to a specific frequency range that depends on re-use factors. The signal processor is also configured to route portions of the radio frequency communication signals that correspond to each particular one of the plurality of gateway stations to a corresponding one of the plurality of spot beams, and combine a plurality of gateway uplink radio frequency communication signals, received through the gateway link from the plurality of gateway stations, into a single optical signal.

The user link may include a radio frequency communication signal.

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The radio frequency communication signal of the user link may include an operating frequency between approximately 1 GHz and approximately 40 GHz.

The gateway link may include a radio frequency communication signal.

The radio frequency communication signal of the gateway link may include at least one of an operating frequency between approximately 12 GHz and approximately 18 GHz, and an operating frequency between approximately 19 GHz and approximately 31 GHz.

The feeder link may include an optical communication signal.

The communication relay apparatus may be configured to operate at an altitude of between 39,000 feet and 180,000 feet.

The communication relay apparatus may include an unmanned aerial vehicle.

The communication relay apparatus may include a radio frequency terminal to transmit and receive radio frequency communication signals over the gateway link, and an optical terminal to transmit and receive optical communication signals over the feeder link.

The radio frequency terminal transmits a gateway downlink radio frequency communication signal to the gateway station, and the radio frequency terminal may receive a gateway uplink radio frequency communication signal from the gateway station.

The optical terminal may transmit a feeder uplink optical communication signal to the communication satellite, and the optical terminal may receive a feeder downlink optical communication signal from the communication satellite.

The signal processor may convert the feeder downlink optical communication signal to the gateway downlink radio frequency communication signal, and the signal processor may convert the gateway uplink radio frequency communication signal to the feeder uplink optical communication signal.

The signal processor may convert the single optical signal to the feeder uplink optical communication signal.

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In accordance with another disclosed aspect there is provided an unmanned aircraft used in a satellite communications network including an airframe, a control unit operable to control flight of the unmanned aircraft along a predetermined flight path, and a radio frequency terminal to transmit and receive radio frequency communication signals to and from a plurality of gateway stations. The unmanned aircraft also includes an optical terminal to transmit and receive optical communication signals to and from a communication satellite in Earth orbit, and a signal processor coupled to the radio frequency terminal and the optical terminal. The signal processor is operable to process the radio frequency communication signals and the optical communication signals and further operable to transmit the radio frequency communication signals in the form of a plurality of spot beams. Each one of the plurality of spot beams covers a corresponding one of the plurality of gateway stations and has a frequency selected for a corresponding one of the plurality of gateway stations. Each spot beam is formed to correspond to a specific frequency range that depends on re-use factors.

The radio frequency terminal may transmit a gateway downlink radio frequency communication signal to each one of the plurality of gateway stations, the radio frequency terminal receiving a gateway uplink radio frequency communication signal from each one of the plurality of gateway stations, the optical terminal transmitting a feeder uplink optical communication signal to the communication satellite, and the optical terminal receiving a feeder downlink optical communication signal from the communication satellite.

The signal processor may include a signal converter operable to convert the feeder downlink optical communication signal to the gateway downlink radio frequency communication signal and to convert the gateway uplink radio frequency communication signal to the feeder uplink optical communication signal, and a beam former operable to form the plurality of spot beams, each including the gateway downlink radio frequency communication signal having an operating frequency selected for a corresponding one of the plurality of gateway stations.

The unmanned aircraft may operate at an altitude of between approximately 39,000 feet and approximately 180,000 feet.

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In accordance with another disclosed aspect there is provided a method for providing satellite communication. The method involves generating a user link for a first radio communication between a communication satellite and a user terminal, and generating a feeder link for an optical communication between the communication satellite and a communication relay apparatus, the communication relay apparatus operating at an altitude of between approximately 39,000 feet and approximately 180,000 feet. The method also involves generating a gateway link for a second radio communication between the communication relay apparatus and a plurality of gateway stations. At a signal processor of the communication relay apparatus, the method further involves converting optical signals received by the communication relay apparatus through the feeder link into radio frequency communication signals, and forming a plurality of spot beams that include the radio frequency communication signals, each spot beam being formed to correspond to a specific frequency range that depends on re-use factors. The method also involves routing portions of the radio frequency communication signals that correspond to each particular one of the plurality of gateway stations to a corresponding one of the plurality of spot beams, and combining a plurality of gateway uplink radio frequency communication signals, received through the gateway link from the plurality of gateway stations, into a single optical signal.

Other examples of the disclosed system, apparatus and method will become apparent from the following detailed description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. **1** is a schematic illustration of one example of the disclosed satellite communication system;

Fig. **2** is a schematic illustration of one example of the disclosed satellite communication system;

Fig. **3** is a schematic illustration of one example of the disclosed satellite communication system;

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Fig. **4** is a schematic block diagram of one example if the disclosed communication satellite of the satellite communication system;

Fig. **5** is a schematic block diagram of one example of the disclosed communications relay apparatus of the satellite communication system;

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Fig. **6** is a flow diagram of one example of the disclosed method for providing satellite communications;

Fig. **7** is a block diagram of aircraft production and service methodology; and

Fig. **8** is a schematic illustration of an aircraft.

DETAILED DESCRIPTION

The following detailed description refers to the accompanying drawings, which illustrate specific examples described by the disclosure. Other examples having different structures and operations do not depart from the scope of the present disclosure. Like reference numerals may refer to the same feature, element, component or characteristic in the different drawings.

Reference herein to "example," "one example," "another example," or similar language means that one or more feature, structure, element, component or characteristic described in connection with the example is included in at least one embodiment or implementation. Thus, the phrases "in one example," "as one example," and similar language throughout the present disclosure may, but do not necessarily, refer to the same example. Further, the subject matter characterizing any one example may, but does not necessarily, include the subject matter characterizing any other example.

Illustrative, non-exhaustive examples, which may be, but are not necessarily, claimed, of the subject matter according the present disclosure are provided below.

Referring to Fig. **1**, one example of satellite communications system, generally referred to as system **100**, is disclosed. System **100** may also be referred to as a satellite communications network. System **100** includes at least one communications satellite, generally referred to as satellite **102**, orbiting Earth (not explicitly illustrated). System **100** also includes at least one gateway hub **122** and at least one user area **108**. As illustrated in Fig. **2**, in one example, a plurality of satellites **102** form satellite array **104**.

Satellite **102** may be any object in any elliptical orbit and configured to transmit and/or receive communications to and from Earth. As one example, satellite **102** may be in geostationary orbit. As another example, satellite **102** may be geosynchronous orbit. As another example, satellite **102** may be in Molniya orbit.

System **100** may be particularly well suited and beneficial for satellite **102** in High Earth orbit ("HEO") (e.g., at an altitude above approximately **35,000** kilometers (**22,000** miles)). However, system **100** may also be used with satellite **102** in other types of orbits, for example, Low Earth orbit ("LEO") (e.g., at an altitude below approximately **2,000** kilometers (**1,200** miles)) or Medium Earth orbit ("MEO") (e.g., at an altitude between approximately **2,000** kilometers and **35,000** kilometers).

As one specific, non-limiting example, satellite **102** may be a high-throughput satellite ("HTS"). As one non-limiting example, satellite **102** may be configured to transmit and/or receive radio waves covering a microwave frequency range between approximately **1.0** GHz and approximately **90** GHz.

In one example, gateway hub **122** includes at least one gateway station **112** (also commonly referred to as a ground station or teleport). Gateway station **112** may include one or more transmitting and/or receiving antennas used to communicate with satellite **102** (or satellite array **104**) (Fig. **2**). As one general example, gateway hub **122** may be one or more of audio, video, and/or data service providers. As one example, gateway hub **122** may be an Internet service provider. As one example, gateway hub **122** may be a telephone, voice, and/or data service. As one example, gateway hub **122** may be a television, video, and/or audio broadcaster.

Gateway stations **112** may be coupled to terrestrial network **116**. As one example, network **116** may include a telecommunications network, such as the Internet. Thus, gateways stations **112** may provide connectivity between user terminals **106** and network **116** through satellite **102** and communications relay apparatus **118**.

While not explicitly illustrated, each gateway station **112** may include or be connected to a gateway station controller that controls the communication of signals over gateway hub **122**. The gateway station controller may include a processor, a storage device (e.g., a memory), an input device, and/or a display. The gateway controller may be remotely located with or co-located with (e.g., integral to) gateway station **112**.

In one example, user area **108** defines a geographic area that includes a plurality of user terminals **106** that can communicate with satellite **102** (only one user terminal is shown within each user area for clarity of illustration). As one example, user area **108** may represent a footprint of a radiated spot beam from satellite **102** to Earth's surface. The spot beam may include a predetermined signal strength (e.g., power) so that it will cover only a limited geographic area on Earth, represented by user area **108**.

Each one of user terminals (also referred to herein as user terminal **106**) includes one or more transmitting and/or receiving antennas used to communicate with satellite **102**. User terminal **106** may include any communications device used by an end user (e.g., an audio, video, or data communications device). Thus, the audio, video, and/or data service provider may service user terminals **106** located within user area **108**.

While not explicitly illustrated in Figs. **1** and **2**, in another example, user area **108** may also include one or more terrestrial communication network sites or towers. The communication network site may include one or more transmitting and/or receiving antennas used to communicate with satellite **102** and user terminals **106**. In other words, the communication network site may serve as a terrestrial communications link or relay between satellite **102** and user terminals **106** and/or among user terminals **106**.

While not explicitly illustrated, each user terminal **106** may include or be connected to a user terminal controller that controls the communication of signals over user area **108**. The user terminal controller may include a processor, a storage device (e.g., a memory), an input device, and/or a display. The user terminal controller may be remotely located with or co-located with (e.g., integral to) user terminal **106**.

In one example, system **100** also includes at least one communications relay apparatus, generally referred to as apparatus **118**. Apparatus **118** serves as a communications link, node, or relay between satellite **102** and one or more gateway stations **112**. In other words, apparatus **118** may serve one or more gateway hubs **122**.

In one example, apparatus **118** is a mobile platform capable of operating at a high altitude. Generally, the operating altitude of apparatus **118** may be above any atmospheric interference. As one example, apparatus **118** may operate at an altitude of between approximately **39,000** feet (**12** km) and approximately **180,000** feet (**55** km) (e.g., stratosphere). As another example, apparatus may operate at an altitude of between **55,000** feet (**16** km) and approximately **164,000** feet (**50** km). As another example, apparatus **118** may operate at an altitude of approximately **65,000** feet (**20** km). As yet another example, apparatus **118** may operate at an altitude of at least approximately **65,000** feet (**20** km). As one example, apparatus **118** may be an unmanned aerial vehicle ("UAV"). Apparatus **118** may fly in a predetermined flight path over a given geographic area on Earth, such as over one or more gateway hubs **122**. Apparatus **118** may be capable of flying for long periods of time (e.g., for several months) at the operating altitude. As one example, apparatus **118** may be a solar-powered electric UAV.

Referring to Fig. 1, satellite **102** communicates with user terminals **106** (e.g., either directly or via the terrestrial communication network site). Satellite **102** may be configured to transmit and/or receive radio frequency ("RF") communication signals to and from user terminals **106**. Similarly, user terminals **106** may be configured to transmit and/or receive RF communication signals to and from satellite **102**. Any RF communication signals between satellite **102** and user terminals **106** are referred to herein as user links **110**. Thus, user links **110** are RF (RF communication) links. Each user terminal **106** may receive the RF communication signal within an associated spot beam of a multiple spot beam pattern (not explicitly illustrated) radiated from satellite **102**. The multiple spot beam pattern may re-use frequencies across multiple narrowly focused spot beams defining user areas **108** (e.g., in the order of hundreds of kilometers).

Satellite **102** also communicates with apparatus **118**. Satellite **102** may be configured to transmit and/or receive optical communication signals to and from apparatus **118**. Similarly, apparatus **118** may be configured to transmit and/or receive optical communications signals to and from satellite **102**. Any optical communication signals between satellite **102** and apparatus **118** are referred to herein as feeder links **120**. Thus, feeder links **120** are optical (optical communication) links.

Apparatus **118** communicates with gateway stations **112**. Apparatus **118** may be configured to transmit and/or receive RF communication signals to and from gateway station **112**. Similarly, gateway station **112** may be configured to transmit and/or receive RF communication signals to and from apparatus **118**. Any RF communication signals between apparatus **118** and gateway station **112** are referred to herein as gateway links **114**. Thus, gateway links **114** are RF (RF communication) links.

Referring to Fig. **3**, and with reference to Figs. **1** and **2**, satellite **102** and apparatus **118** are configured to provide two-way communication between each one of user areas **108** (e.g., user terminals **106**) and each one of gateway hubs **122** (e.g., gateway stations **112**). As one example, and as illustrated in Fig. **3**, user area **108** transmits user uplink **110**a (e.g., a user uplink signal) as an RF signal (also referred to as a user uplink radio frequency communication signal) to satellite **102**. Satellite **102** transmits feeder downlink **120**b (e.g., a retransmission of the user uplink signal) as an optical signal (also referred to as a feeder downlink optical communication signal) to apparatus **118**. Apparatus **118** then transmits gateway downlink **114**b (e.g., another retransmission of the user uplink signal) as an RF signal (also referred to as a gateway downlink radio frequency communication signal) to gateway station **112**.

Similarly, as one example, gateway station **112** transmits gateway uplink **114**a (e.g., a gateway uplink signal) as an RF signal (also referred to as a gateway uplink radio frequency communication signal) to apparatus **118**. Apparatus **118** transmits feeder uplink signal **120**a (e.g., a retransmission of the gateway uplink signal) as an optical signal (also referred to as a feeder uplink optical communication signal) to satellite **102**. Satellite **102** then transmits user downlink **110**b (e.g., another retransmission of the gateway uplink signal) as an RF signal (also referred to as a user downlink radio frequency communication signal) to user terminal **106**.

In one example implementation, user link **110** (e.g., user uplink **110**a and/or user downlink **110**b) may operate in a frequency range (e.g., an operating frequency or range of operating frequencies) of between approximately **1** GHz and approximately **40** GHz. In another example implementation, user link **110** (e.g., user uplink **110**a and/or user downlink **110**b) may operate in a frequency range (e.g., an operating frequency or range of operating frequencies) of between approximately **20** GHz and approximately **40** GHz (e.g., the K band). In another example implementation, user link **110** (e.g., user uplink **110**a and/or user downlink **110**b) may operate in a frequency range of between approximately **19.0** GHz and approximately **31** GHz (e.g., the Ka band). In another example implementation, user link **110** (e.g., user uplink **110**a and/or user downlink **110**b) may operate in a frequency range of between approximately **12** GHz and approximately **18** GHz (e.g., the Ku band). In still other example implementations, user link **110** (e.g., user uplink **110**a and/or user downlink **110**b) may operate in various other frequency ranges, for example, between approximately **8** GHz and approximately **12** GHz (e.g., the X band), between approximately **500** MHz and approximately **1000** MHz (e.g., the C band), between approximately **1** GHz and approximately **2** GHz (e.g., the L band), etc.

In one example implementation, gateway link **114** (e.g., gateway uplink **114**a and/or gateway downlink **114**b) may operate in a frequency range of between approximately **12** GHz and approximately **18** GHz (e.g., the Ku band). In another example implementation, gateway link **114** (e.g., gateway uplink **114**a and/or gateway downlink **114**b) may operate in a frequency range of between approximately **19** GHz and approximately **31** GHz (e.g., the Ka band). In still other example implementations, gateway link **114** (e.g., gateway uplink **114**a and/or gateway downlink **114**b) may operate in various other frequency ranges.

In one example implementation, feeder link **120** (e.g., feeder uplink **120**a and/or feeder downlink **120**b) may operate in a frequency range of between approximately **100** THz and approximately **400** THz. In other example implementations, feeder link **120** (e.g., feeder uplink **120**a and/or feeder downlink **120**b) may operate in various other frequency ranges.

Referring to Fig. **4**, and with reference to Fig. **3**, in one example, satellite **102** includes satellite RF terminal **124** configured to transmit and/or receive RF communication signals (e.g., user link **110**) to and from user terminals **106**. As one example, satellite RF terminal **124** may include satellite transmitting antenna **126** configured to transmit RF signals and satellite receiving antenna **128** configured to receive RF signals. As one example, satellite RF terminal **124** (e.g., satellite transmitting antenna **126** and/or satellite receiving antenna **128**) may be a phased-array antenna. As one example, satellite RF terminal **124** may include a high-gain antenna for communication with user terminals **106** over user link **110**. While satellite RF terminal **124** is illustrated as having an individual satellite transmitting antenna and satellite receiving antenna, in another example, satellite RF terminal **124** may have a single satellite antenna capable of both transmitting and receiving RF signals.

In one example, satellite **102** includes satellite optical terminal **130** configured to transmit and/or receive optical communication signals (e.g., feeder link **120**) to and from apparatus **118**. As one example, satellite optical terminal **130** may include satellite optical transmitter **132** configured to transmit optical signals from satellite **102** and satellite optical receiver **134** configured to receive optical signals from apparatus **118**. While satellite optical terminal **130** is illustrated as having an individual satellite optical transmitter and satellite optical receiver, in another example, satellite optical terminal **130** may have a single satellite transmitter/receiver capable of both transmitting and receiving optical signals.

Referring to Fig. **4**, and with reference to Fig. **3**, in one example, satellite **102** includes satellite signal processor **136** configured to process the communication signals transmitted and/or received by satellite **102**. As one example, satellite signal processor **136** may (may be configured to) convert RF signals to optical signals and/or optical signals to RF signals.

As one example, RF signals that are received by satellite RF terminal **124** through user link **110** (e.g., user uplink **110**a) include data destined for retransmission to gateway station

112 via apparatus **118**. The RF signals are routed through satellite signal processor **136** where they are converted into optical signals and transmitted to apparatus **118** through feeder link **120** (e.g., feeder downlink **120**b).

As one example, optical signals that are received by satellite optical terminal **130** through feeder link **120** (e.g., feeder uplink **120**a) include data destined for retransmission to user terminal **106**. The optical signals are routed through satellite signal processor **136** where they are converted into RF signals and transmitted to user terminals **106** through user link **110** (e.g., user downlink **110**b).

As one example, satellite signal processor **136** may (may be configured to) combine multiple (e.g., a plurality of) RF signals received through user link **110**, for example, from the plurality of user terminals **106**, into a single optical signal.

As one example, satellite signal processor **136** may (may be configured to) amplify the RF signal and/or the optical signal transmitted and/or received by satellite **102**.

As one example, satellite signal processor **136** may (may be configured to) filter the RF signal and/or the optical signal transmitted and/or received by satellite **102**.

As one example, satellite signal processor **136** may (may be configured to) form one or more spot beams (defining one or more user areas **108**) that includes the RF signal transmitted by satellite **102**. As one example, satellite signal processor **136** may route a portion of the RF signal that corresponds to a particular user area **108** to a particular spot beam corresponding to that user area **108**. As one example, satellite signal processor **136** may form each spot beam to correspond to a specific frequency range that depends, for example, of the total bandwidth, channel bandwidth, and/or re-use factors.

Therefore, as one example, satellite signal processor **136** may include satellite signal converter **138**, satellite signal combiner **140**, satellite signal amplifier **142**, satellite signal filter **144**, and/or satellite beam former **146**. Satellite signal processor **136** may include hardware, software, or a combination thereof configured to facilitate the functions described above. While not explicitly illustrated, satellite signal processor **136** may include a processor, a storage device (e.g., a memory), an input device, and/or a display. Satellite signal processor **136** may also include other components not expressly illustrated.

Referring to Fig. **5**, and with reference to Fig. **3**, in one example, apparatus **118** includes apparatus RF terminal **148** configured to transmit and/or receive RF communication signals (e.g., gateway link **114**) to and from gateway station **112**. As one example, apparatus RF terminal **148** may include apparatus transmitting antenna **150** configured to transmit RF signals and apparatus receiving antenna **152** configured to receive RF signals. As one example, apparatus RF terminal **148** (e.g., apparatus transmitting antenna **150** and/or apparatus receiving antenna **152**) may be a phased-array antenna. While apparatus RF terminal **148** is illustrated as having an individual apparatus transmitting antenna and apparatus receiving antenna, in another example, apparatus RF terminal **148** may have a single apparatus antenna capable of both transmitting and receiving RF signals.

In one example, apparatus **118** includes apparatus optical terminal **154** configured to transmit and/or receive optical communication signals (e.g., feeder link **120**) to and from satellite **102**. As one example, apparatus optical terminal **154** may include apparatus optical transmitter **156** configured to transmit optical signals from apparatus **118** and apparatus optical receiver **158** configured to receive optical signals from satellite **102**. While apparatus optical terminal **154** is illustrated as having an individual apparatus optical transmitter and apparatus optical receiver, in another example, apparatus optical terminal **154** may have a single apparatus transmitter/receiver capable of both transmitting and receiving optical signals.

Referring to Fig. **5**, and with reference to Fig. **3**, in one example, apparatus **118** includes apparatus signal processor **160** configured to process the communication signals transmitted and/or received by apparatus **118**. As one example, apparatus signal processor **160** may (may be configured to) convert RF signals to optical signals and/or optical signals to RF signals. As one example, apparatus signal processor **160** may convert the feeder downlink optical communication signal to the gateway downlink radio frequency communication signal.

As one example, RF signals that are received by apparatus RF terminal **148** through gateway link **114** (e.g., gateway uplink **114**a) include data destined for retransmission to user terminals **106** via satellite **102**. The RF signals are routed through apparatus signal processor **160** where they are converted into optical signals and transmitted to satellite **102** through feeder link **120** (e.g., feeder uplink **120**a). As one example, apparatus signal processor **260** may convert the gateway uplink radio frequency communication signal to the feeder uplink optical communication signal.

As one example, optical signals that are received by apparatus optical terminal **154** through feeder link **120** (e.g., feeder downlink **120**b) include data destined for retransmission to gateway station **112**. The optical signals are routed through apparatus signal processor **160** where they are converted into RF signals and transmitted to gateway station **112** through gateway link **114** (e.g., gateway downlink **114**b).

In one example, apparatus **118** may include a single apparatus RF terminal **148** capable of communicating with one or more gateway stations **112** (as illustrated in Fig. **5**). In another example (not explicitly illustrated), apparatus **118** may include more than one apparatus RF terminal **148**, each one being capable of communicating with a particular gateway station **112**.

As one example, apparatus signal processor **160** may (may be configured to) combine multiple (e.g., a plurality of) RF signals received through gateway link **114**, for example, from the plurality of gateway stations **112**, into a single optical signal.

As one example, apparatus signal processor **160** may (may be configured to) amplify the RF signal and/or the optical signal transmitted and/or received by apparatus **118**.

As one example, apparatus signal processor **160** may (may be configured to) filter the RF signal and/or the optical signal transmitted and/or received by apparatus **118**.

As one example, apparatus signal processor **160** may (may be configured to) form one or more spot beams **174** (Fig. **3**) (defining one or more gateway hubs **122**) that includes the RF signal transmitted by apparatus **118**. As one example, apparatus signal processor **160** may route a portion of the RF signal that corresponds to a particular gateways station **112** to a particular spot beam **174** corresponding to that gateway hub **122**. As one example, apparatus signal processor **160** may form each spot beam **174** to correspond to a specific frequency range that depends, for example, of the total bandwidth, channel bandwidth, and/or re-use factors.

Therefore, as one example, apparatus signal processor **160** may include apparatus signal converter **162**, apparatus signal combiner **164**, apparatus signal amplifier **166**, apparatus signal filter **168**, and/or apparatus beam former **170**. Apparatus signal processor **160** may include hardware, software, or a combination thereof configured to facilitate the functions described above. While not explicitly illustrated, apparatus signal processor **160** may include a processor, a storage device (e.g., a memory), an input device, and/or a display. Apparatus signal processor **160** may also include other components not expressly illustrated.

Referring to Fig. **5**, in one example, apparatus **118** may include control unit **172**. Control unit **172** may (may be configured to) provide command and control to apparatus **118**. As non-limiting examples, control unit **172** may control the flight path of apparatus **118**, the flight duration of apparatus **118**, the altitude of apparatus **118**, with which one or more gateway stations apparatus **118** communicates, with which one or more satellites apparatus **118** communicates, and the like. Control unit **172** may include hardware, software, or a combination thereof configured to facilitate the functions described above. While not explicitly illustrated, control unit may include a processor, a storage device (e.g., a memory), an input device, and/or a display.

Referring to Figs. **1** and **2**, the disclosed system **100** may be implemented in a variety of different ways. As one example, and as illustrated in Fig. **1**, system **100** may include one satellite **102** optically coupled to one apparatus **118**. As one example, and as illustrated in Fig. **2**, system **100** may include a plurality of satellites **102** optically coupled to one apparatus

118. As another example, and as illustrated in Fig. **2**, system **100** may include a plurality of satellites **102** optically coupled to a plurality of apparatuses **118**.

Referring to Fig. **6**, and with reference to Figs. **1–5**, one example of method, generally designated **200**, is disclosed. Method **200** is one example implementation of a method for providing satellite communications, for example utilizing the disclosed system **100**. Modifications, additions, or omissions may be made to method **200** without departing from the scope of the present disclosure. Method **200** may include more, fewer, or other steps. Additionally, steps may be performed in any suitable order.

In one example implementation, method **200** includes the step of generating user link **110** for a first radio communication (e.g., a radio frequency communication signal) between communication satellite **102** and one or more user terminals **106**, as shown at block **202**.

In one example implementation, method **200** includes the step of generating feeder link **120** for an optical communication (e.g., an optical communication signal) between communication satellite **102** and communication relay apparatus **118**, as shown at block **204**. In one example, communication relay apparatus **118** may operate at an altitude of between approximately **39,000** feet (**12** km) and approximately **180,000** feet (e.g., **55** km), for example, approximately (e.g., at least) **65,000** feet (**20** km).

In one example implementation, method **200** includes the step of generating gateway link **114** for a second radio communication (e.g., a radio frequency communication signal) between communication relay apparatus **118** and one or more gateway stations **112**, as shown at block **206**.

Unless otherwise indicated, the terms "first," "second," etc. are used herein merely as labels, and are not intended to impose ordinal, positional, or hierarchical requirements on the items to which these terms refer. Moreover, reference to a “second” item does not require or preclude the existence of lower-numbered item (e.g., a “first” item) and/or a higher-numbered item (e.g., a “third” item).

Accordingly, the disclosed system **100** provides a communication signal relay between satellite **102** and one or more gateway stations **112** via feeder link **120** (optical link) between satellite **102** and apparatus **118** and gateway link **114** (RF link) between apparatus **118** and gateway stations **112**. By utilizing apparatus **118** to split the communication signal between satellite **102** and gateway station **112**, system **100** is capable of increasing communication efficiency. Feeder link **120** (e.g., optical communication link) may provide significantly greater available bandwidth, provide higher data transfer rates, and improve link efficiency as compared to standard RF communication link between a communication satellite and a gateway station.

Further, with apparatus **118** operating at a sufficiently high altitude (e.g., above any atmospheric interference), the effect of weather and atmosphere on feeder link **120** is reduced, if not eliminated. Further, gateway link **114** (e.g., RF communication link) generated at apparatus **118** (e.g., at high altitude) may not be affected by weather and atmosphere and the RF spectrum may be re-used more efficiently by allowing gateway stations **112** to be located in a closer spatial relationship. Thus, the combination of feeder link **120** between satellite **102** and apparatus **118** and gateway link **114** between apparatus **118** and gateway station **112** may be capable of carrying the capacity of all of user link **110** from all user terminals **106**.

Even further, apparatus **118** may perform one or more tasks and/or functions that would typically be performed on satellite **102** including, but not limited to, complete or partial beam forming, signal processing, and the like.

Examples of the disclosed apparatus **118** may be described in the context of aircraft manufacturing and service method **1100** as shown in Fig. **7** and aircraft **1200** as shown in Fig. **8**. Aircraft **1200** may be one example of apparatus **118** (e.g., a UAV).

During pre-production, the illustrative method **1100** may include specification and design, as shown at block **1102**, of aircraft **1200**, which may include design of apparatus RF terminal **148**, apparatus optical terminal **154**, and/or apparatus signal processor **160**, and material procurement, as shown at block **1104**. During production, component and subassembly manufacturing, as shown at block **1106**, and system integration, as shown at block **1108**, of aircraft **1200** may take place. Apparatus RF terminal **148**, apparatus optical terminal **154**, and/or apparatus signal processor **160** as described herein may be incorporated as a portion of the production, component and subassembly manufacturing step (block **1106**) and/or as a portion of the system integration (block **1108**). Thereafter, aircraft **1200** may go through certification and delivery, as shown block **1110**, to be placed in service, as shown at block **1112**. While in service, aircraft **1200** may be scheduled for routine maintenance and service, as shown at block **1114**. Routine maintenance and service may include modification, reconfiguration, refurbishment, etc. of one or more systems of aircraft **1200**.

Each of the processes of illustrative method **1100** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in Fig. **8**, aircraft **1200** produced by illustrative method **1100** may include airframe **1202**, and a plurality of high-level systems **1204** and interior **1206**. Examples of high-level systems **1204** include one or more of propulsion system **1208**, electrical system **1210**, hydraulic system **1212** and/or environmental system **1214**. Any number of other systems may be included.

The apparatus shown or described herein may be employed during any one or more of the stages of the manufacturing and service method **1100**. For example, components or subassemblies corresponding to component and subassembly manufacturing (block **1106**) may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **1200** is in service (block **1112**). Also, one or more examples of the apparatus may be employed during production stages (blocks **1108** and **1110**). Similarly, one or more examples of the apparatus may be utilized, for example and without limitation, while aircraft **1200** is in service (block **1112**) and during maintenance and service stage (block

1114).Although various examples of the disclosed system, apparatus, and method have been shown and described, modifications may occur to those skilled in the art upon reading the specification. The present application includes such modifications and is limited only by the scope of the claims.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A satellite communication system comprising:

a communication satellite orbiting Earth;

a user terminal in radio communication with said communication satellite through a user link;

a communication relay apparatus in optical communication with said communication satellite through a feeder link; and

a plurality of gateway stations in radio communication with said communication relay apparatus through a gateway link;

wherein a signal processor of the communication relay apparatus is configured to:

convert optical signals received by the communication relay apparatus through the feeder link into radio frequency communication signals;

form a plurality of spot beams that include the radio frequency communication signals, wherein each spot beam is formed to correspond to a specific frequency range that depends on re-use factors;

route portions of the radio frequency communication signals that correspond to each particular one of the plurality of gateway stations to a corresponding one of the plurality of spot beams; and

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combine a plurality of gateway uplink radio frequency communication signals, received through the gateway link from the plurality of gateway stations, into a single optical signal.

2. The system of Claim **1** wherein said user link comprises a radio frequency communication signal.

3. The system of Claim **2** wherein said radio frequency communication signal of said user link comprises an operating frequency between approximately **1** GHz and approximately **40** GHz.

4. The system of any one of Claims **1** – **3** wherein said gateway link comprises a radio frequency communication signal.

5. The system of Claim **4** wherein said radio frequency communication signal of said gateway link comprises at least one of an operating frequency between approximately **12** GHz and approximately **18** GHz, and an operating frequency between approximately **19** GHz and approximately **31** GHz.

6. The system of any one of Claims **1** – **5** wherein said feeder link comprises an optical communication signal.

7. The system of Claim **6** wherein said communication relay apparatus operates at an altitude of between approximately 39,000 feet and approximately 180,000 feet.

8. The system of any one of Claims **1** – **7** wherein said communication relay apparatus comprises an unmanned aerial vehicle.

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9. The system of any one of Claims **6 – 8** wherein said communication relay apparatus comprises:

a radio frequency terminal to transmit and receive radio frequency communication signals over said gateway link; and

an optical terminal to transmit and receive optical communication signals over said feeder link.

10. The system of Claim **9** wherein said radio frequency terminal transmits a gateway downlink radio frequency communication signal to said gateway station, and wherein said radio frequency terminal receives a gateway uplink radio frequency communication signal from said gateway station.

11. The system of Claim **10** wherein said optical terminal transmits a feeder uplink optical communication signal to said communication satellite, and wherein said optical terminal receives a feeder downlink optical communication signal from said communication satellite.

12. The system of Claim **11** wherein said communication relay apparatus further comprises a signal processor, wherein said signal processor converts said feeder downlink optical communication signal to said gateway downlink radio frequency communication signal, and wherein said signal processor converts said gateway uplink radio frequency communication signal to said feeder uplink optical communication signal.

13. The system of Claim **12** wherein said signal processor converts said single optical signal to said feeder uplink optical communication signal.

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14. An unmanned aircraft used in a satellite communications network said unmanned aircraft comprising:

an airframe;

a control unit operable to control flight of said unmanned aircraft along a predetermined flight path;

a radio frequency terminal to transmit and receive radio frequency communication signals to and from a plurality of gateway stations;

an optical terminal to transmit and receive optical communication signals to and from a communication satellite in Earth orbit; and

a signal processor coupled to said radio frequency terminal and said optical terminal, said signal processor being operable to process said radio frequency communication signals and said optical communication signals and further operable to transmit said radio frequency communication signals in the form of a plurality of spot beams, wherein each one of said plurality of spot beams covers a corresponding one of said plurality of gateway stations and has a frequency selected for a corresponding one of said plurality of gateway stations, wherein each spot beam is formed to correspond to a specific frequency range that depends on re-use factors.

15. The unmanned aircraft of Claim **14** wherein:

said radio frequency terminal transmits a gateway downlink radio frequency communication signal to each one of said plurality of gateway stations,

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said radio frequency terminal receives a gateway uplink radio frequency communication signal from each one of said plurality of gateway stations,

said optical terminal transmits a feeder uplink optical communication signal to said communication satellite, and

said optical terminal receives a feeder downlink optical communication signal from said communication satellite.

16. The unmanned aircraft of Claim **15** wherein said signal processor comprises:

a signal converter operable to convert said feeder downlink optical communication signal to said gateway downlink radio frequency communication signal and to

convert said gateway uplink radio frequency communication signal to said feeder uplink optical communication signal; and

a beam former operable to form said plurality of spot beams, each comprising said gateway downlink radio frequency communication signal having an operating frequency selected for a corresponding one of said plurality of gateway stations.

17. The unmanned aircraft of any one of Claims **14** – **16** wherein said unmanned aircraft operates at an altitude of between approximately 39,000 feet and approximately 180,000 feet.

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18. A method for providing satellite communication, said method comprising:

generating a user link for a first radio communication between a communication satellite and a user terminal;

generating a feeder link for an optical communication between said communication satellite and a communication relay apparatus, said communication relay apparatus operating at an altitude of between approximately 39,000 feet and approximately 180,000 feet; and

generating a gateway link for a second radio communication between said communication relay apparatus and a plurality of gateway stations;

wherein, at a signal processor of the communication relay apparatus, the method further comprises:

converting optical signals received by the communication relay apparatus through the feeder link into radio frequency communication signals;

forming a plurality of spot beams that include the radio frequency communication signals, wherein each spot beam is formed to correspond to a specific frequency range that depends on re-use factors;

routing portions of the radio frequency communication signals that correspond to each particular one of the plurality of gateway stations to a corresponding one of the plurality of spot beams; and

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combining a plurality of gateway uplink radio frequency communication signals, received through the gateway link from the plurality of gateway stations, into a single optical signal.

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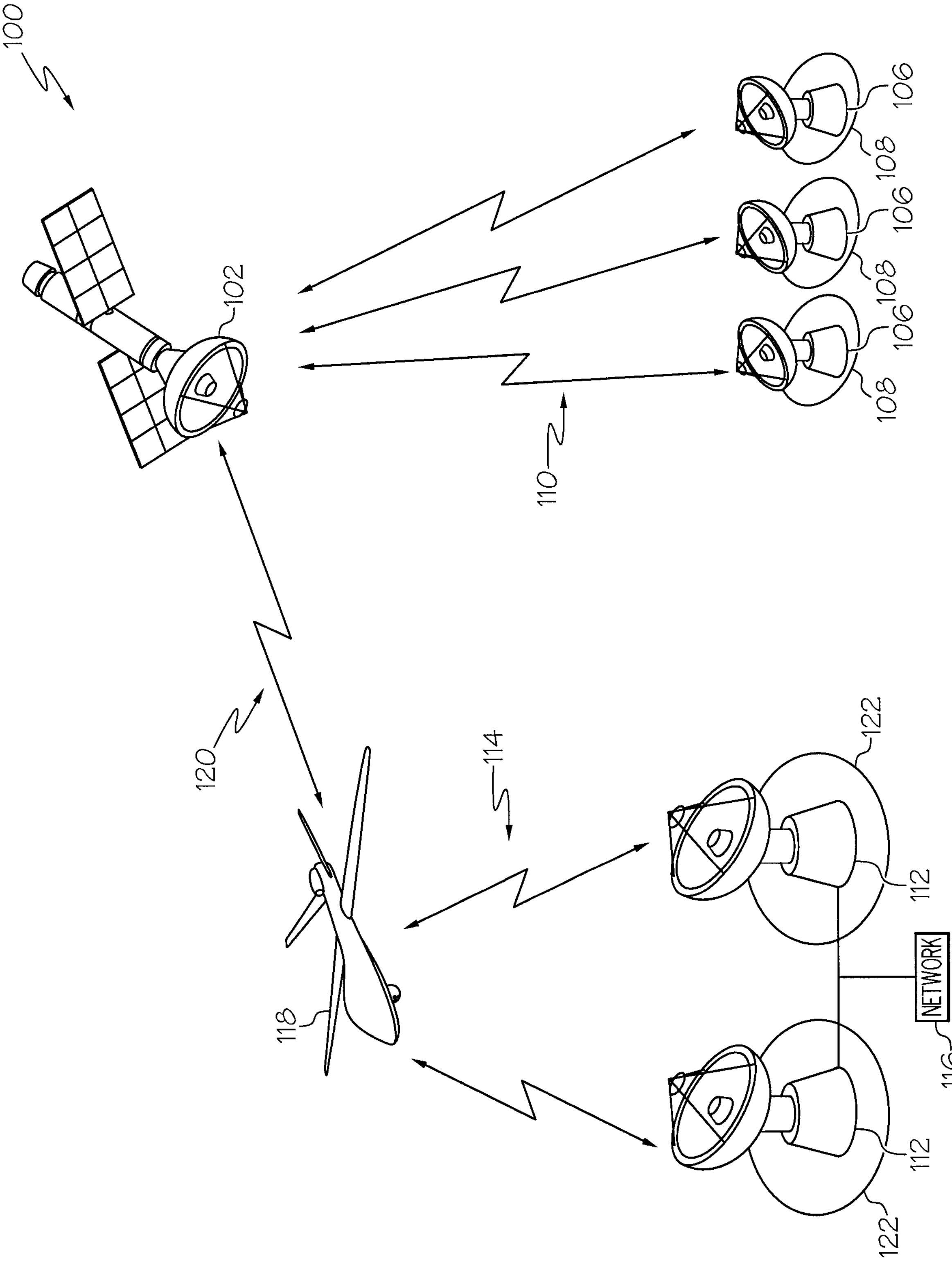

100
102
106
108
106
108
106
108
110
120
114
118
122
112
112
122
NETWORK
116

FIG. 1

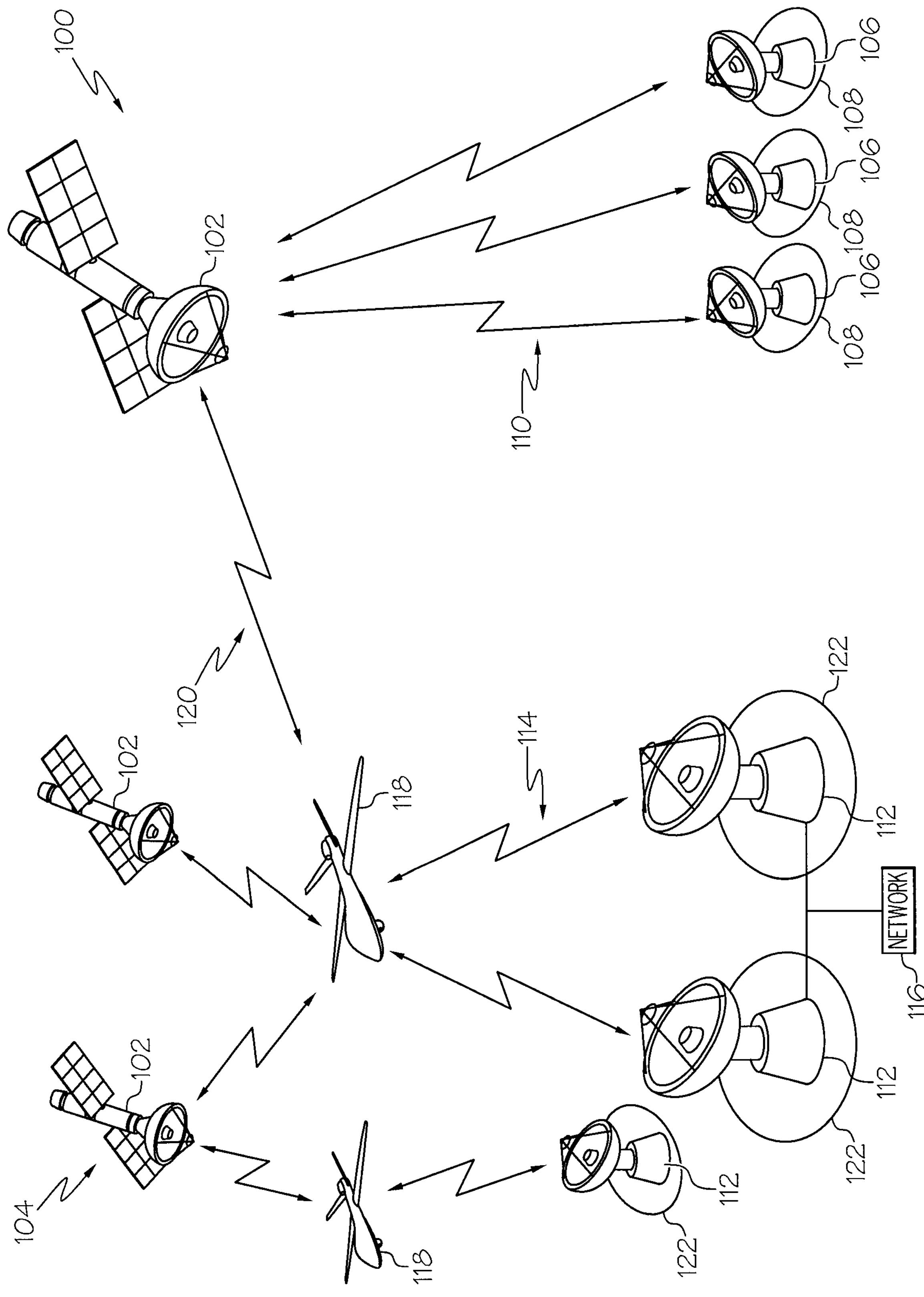


FIG. 2

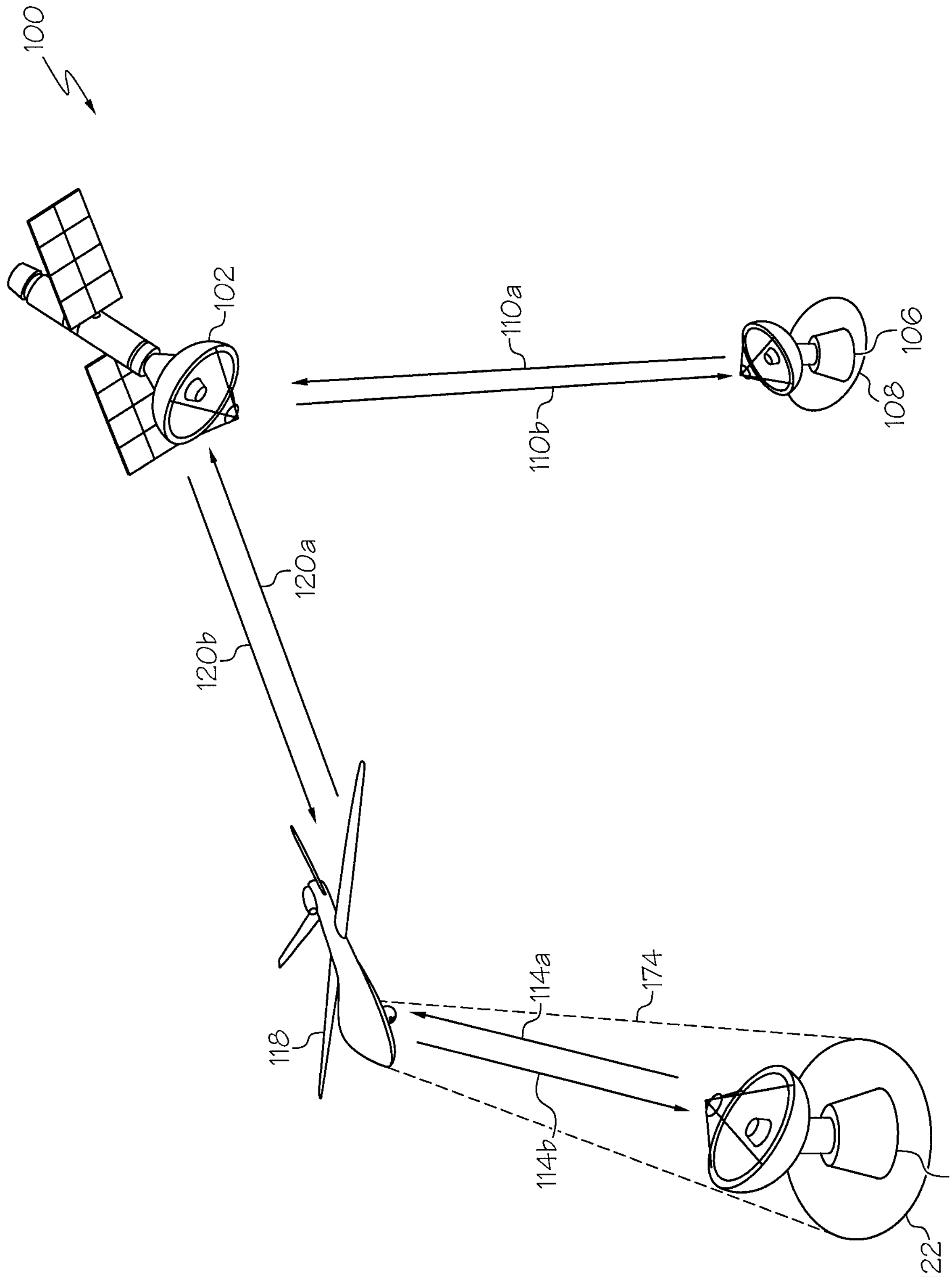


FIG. 3

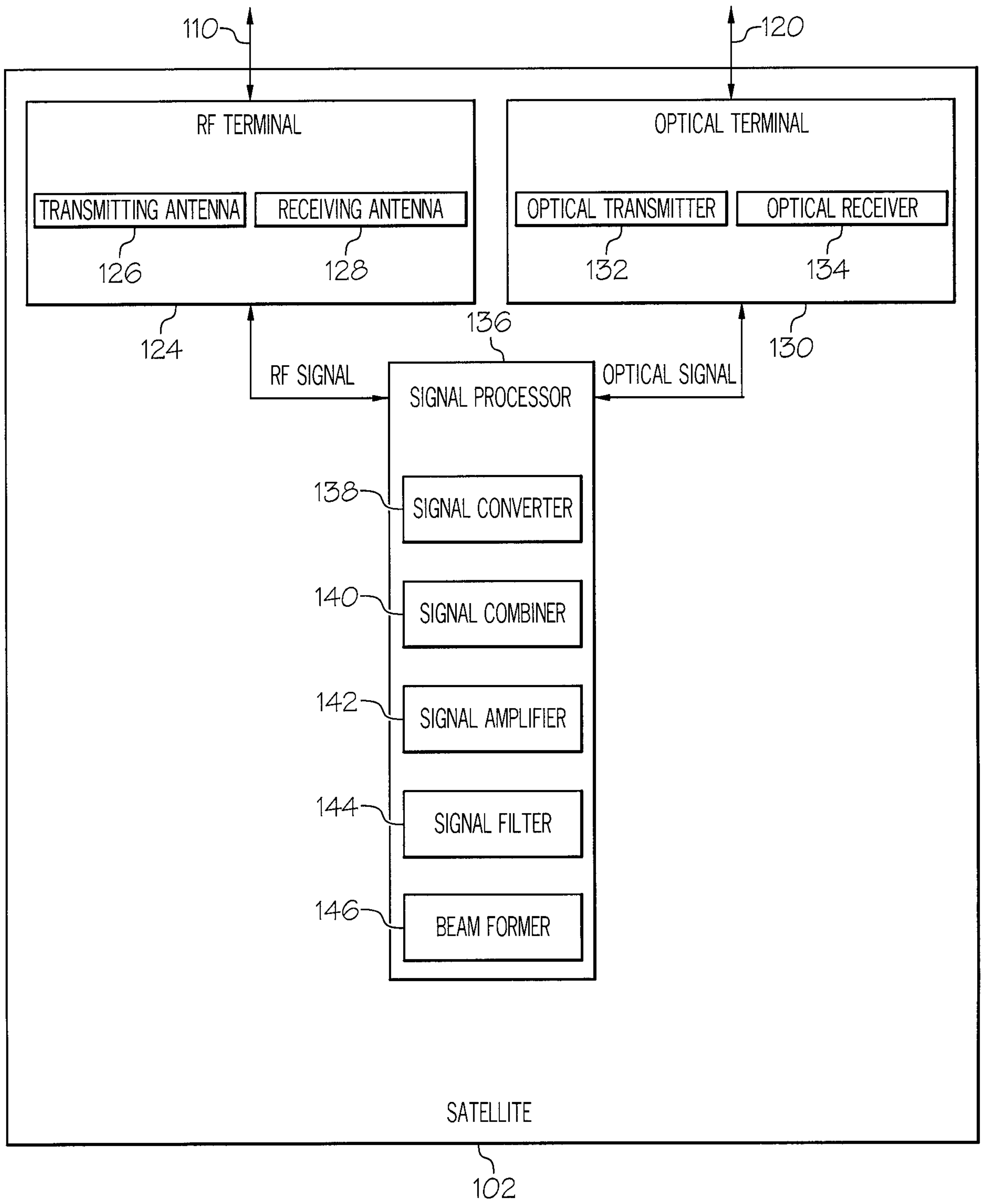

110
120
RF TERMINAL
TRANSMITTING ANTENNA
RECEIVING ANTENNA
126
128
124
OPTICAL TERMINAL
OPTICAL TRANSMITTER
OPTICAL RECEIVER
132
134
130
136
RF SIGNAL
OPTICAL SIGNAL
SIGNAL PROCESSOR
138
SIGNAL CONVERTER
140
SIGNAL COMBINER
142
SIGNAL AMPLIFIER
144
SIGNAL FILTER
146
BEAM FORMER
SATELLITE
102

FIG. 4

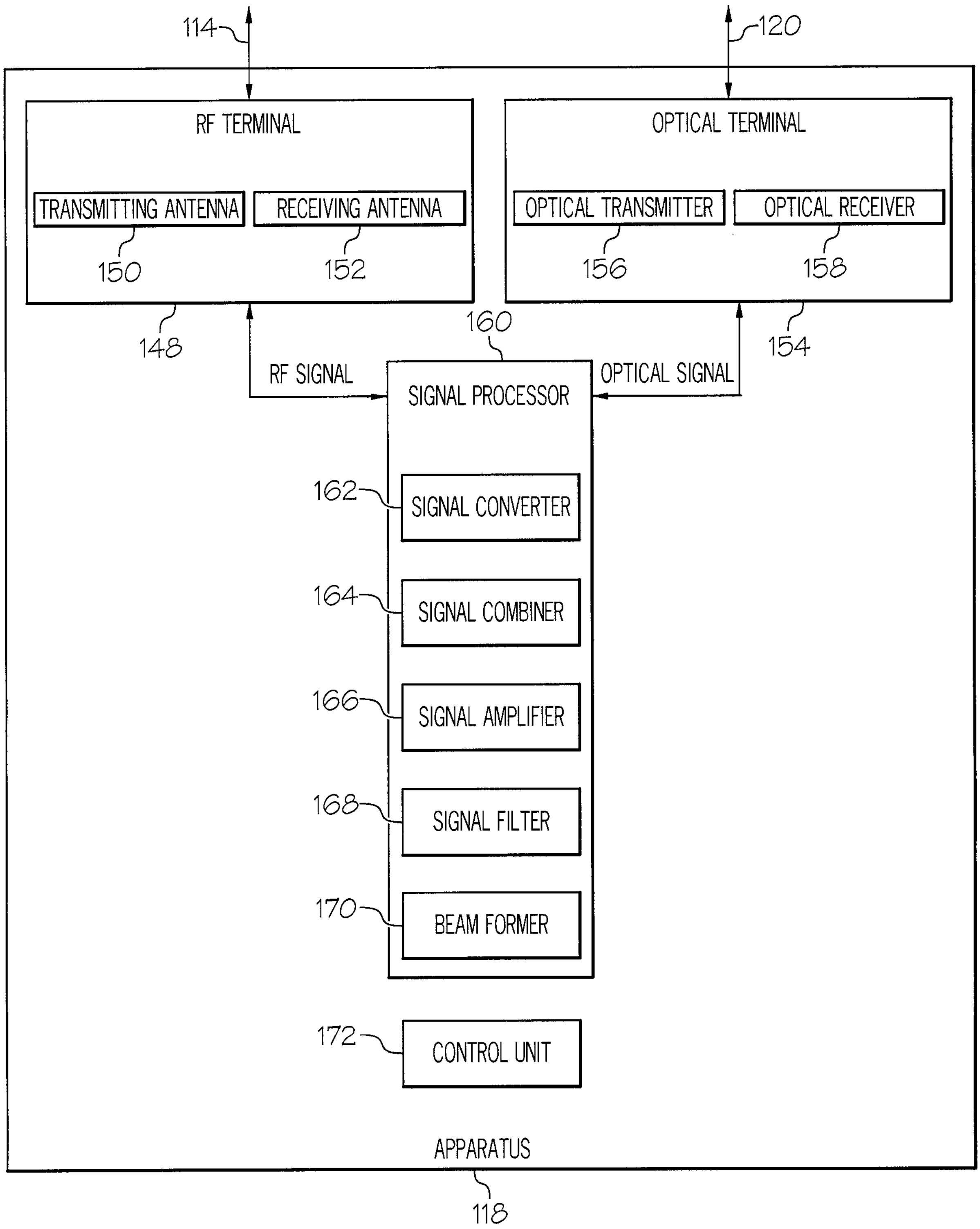

114
120
RF TERMINAL
TRANSMITTING ANTENNA
RECEIVING ANTENNA
150
152
OPTICAL TERMINAL
OPTICAL TRANSMITTER
OPTICAL RECEIVER
156
158
148
160
154
RF SIGNAL
SIGNAL PROCESSOR
OPTICAL SIGNAL
162
SIGNAL CONVERTER
164
SIGNAL COMBINER
166
SIGNAL AMPLIFIER
168
SIGNAL FILTER
170
BEAM FORMER
172
CONTROL UNIT
APPARATUS
118

FIG. 5

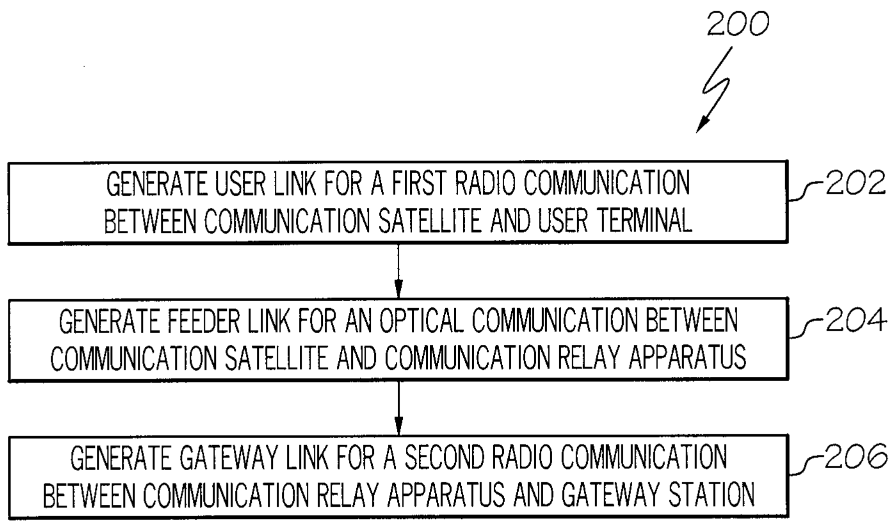

200
GENERATE USER LINK FOR A FIRST RADIO COMMUNICATION BETWEEN COMMUNICATION SATELLITE AND USER TERMINAL
202
GENERATE FEEDER LINK FOR AN OPTICAL COMMUNICATION BETWEEN COMMUNICATION SATELLITE AND COMMUNICATION RELAY APPARATUS
204
GENERATE GATEWAY LINK FOR A SECOND RADIO COMMUNICATION BETWEEN COMMUNICATION RELAY APPARATUS AND GATEWAY STATION
206

FIG. 6

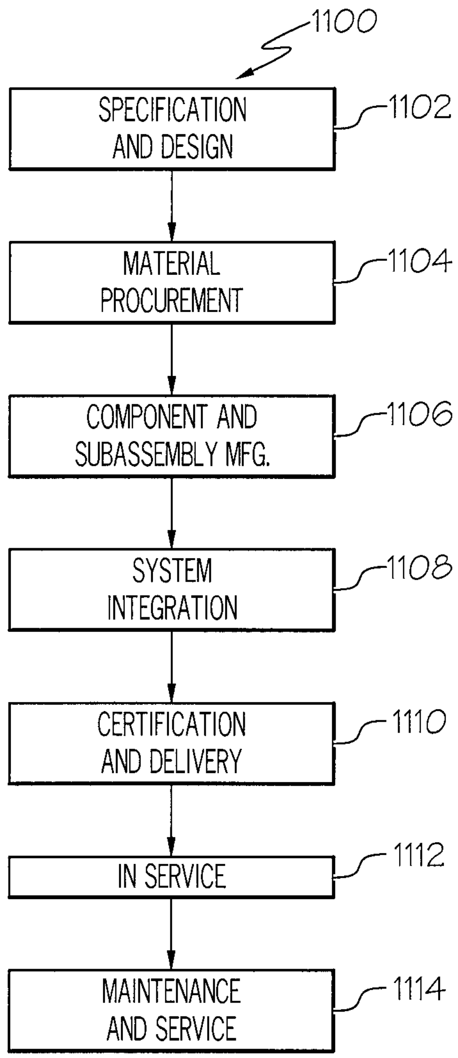

1100
SPECIFICATION AND DESIGN
1102
MATERIAL PROCUREMENT
1104
COMPONENT AND SUBASSEMBLY MFG.
1106
SYSTEM INTEGRATION
1108
CERTIFICATION AND DELIVERY
1110
IN SERVICE
1112
MAINTENANCE AND SERVICE
1114

FIG. 7

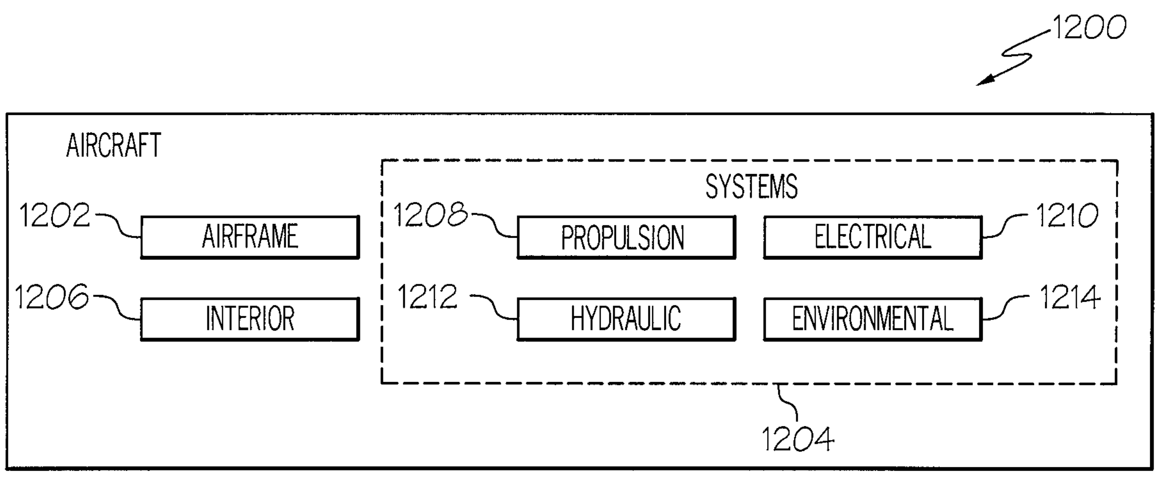
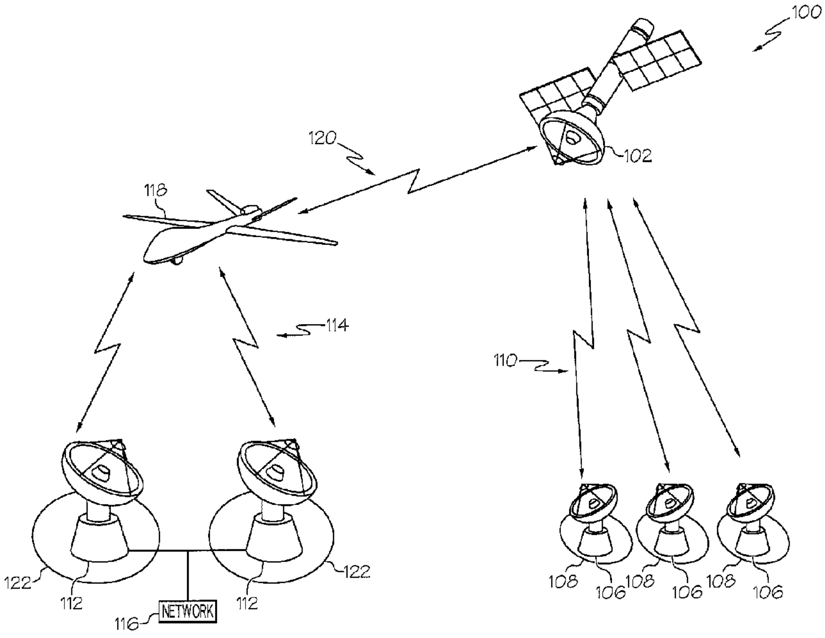

1200
AIRCRAFT
1202
AIRFRAME
1206
INTERIOR
SYSTEMS
1208
PROPULSION
ELECTRICAL
1210
1212
HYDRAULIC
ENVIRONMENTAL
1214
1204

FIG. 8


100
102
120
118
114
110
122
112
NETWORK
116
112
122
108
106
108
106
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106