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(54) Title: A MULTI-NETWORK TELEMATICS DEVICE WITH MULTIPLE ANTENNAS

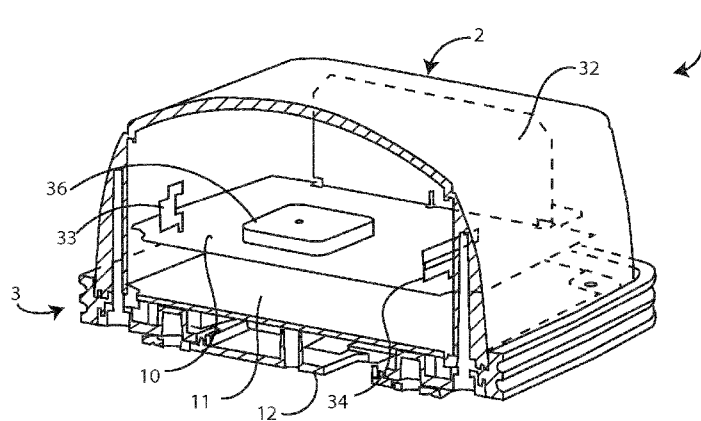


Fig.3

(57) Abstract: A telematics device has an antenna unit (1) housing enclosing various antennas (31-36) and an electronic control circuit (11). There is a link (301) to an external power supply (300). The housing encloses multiple substrates (10, 11) in a multi-tier arrangement, including at least one antenna substrate (10) supporting antennas (31-36) and a control substrate (11) supporting an electronic control circuit for the antennas. There is also a base plate (12) and a domed plastics cover (2) sealed to the base plate. The base plate (12) is of metal material, for heat conduction out of the housing. The cover (2) and the base plate (12) are joined at their edges by a peripheral rim (3) which interconnects them to seal the housing, and internally contributes to support of the control board, and also conducts heat to its outer surface.



“A Multi-Network Telematics Device with Multiple Antennas”INTRODUCTION5 Field of the Invention

The invention relates to telematics devices with multiple antennas.

Prior Art Discussion

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Prior telematics devices of this particular type comprise antennas which are externally connected to the device, and comprise housings and cabling which are bulky and liable to being vandalized. Special care must be taken to mount them so that they maintain good RF performance. Also, as the antennas are exposed they are vulnerable to the environment and may degrade quickly.

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EP1744470 (Delphi Technologies) describes an antenna system in which an antenna element is on a ground plane which is capacitively coupled to a vehicle surface. EP2317603 (Delphi Technologies) describes a module with a multi-antenna arrangement. EP1146593 (NEC) describes a phased array antenna with a multi-layer structure and a metal plate or metal enclosure enclosing the sides. US2006/0043585 (Sukegawa et al) describes a semiconductor device with substrates and interposers bonded by bumps, the substrates supporting electronic components and communication units. US2010/0134376 (Margomenos) describes an antenna substrate with impedance matched transitions between sides for interconnection of an RF circuit and an antenna.

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An object of the invention is to achieve a telematics device which is more compact and reliable, while achieving optimum operation of antennas when they are mounted in close proximity, such as for a vehicle.

30 SUMMARY OF THE INVENTION

According to the invention, there is provided a telematics device comprising:

an antenna unit comprising:

a plurality of antennas mounted on a substrate,

an electronic control circuit on a substrate, and
a housing enclosing and supporting said antenna substrate and said control circuit
substrate in a multi-tier arrangement, said housing including an RF transparent
cover and a base,

5 wherein the antennas are supported in a manner exposed to the housing cover, and
the control circuit substrate is spaced apart from the antenna substrate on a side
opposed to the housing cover, and
a power supply connected to the control circuit.

10 In one embodiment, the base is at least partly of metal material, for heat conduction out of the
housing.

In one embodiment, the housing comprises a metal rim, and the base and the housing cover are
sealed to the metal rim in which the metal rim extends around at least some of the periphery of
15 adjoining edges of the cover and the base, said metal rim having an external exposed surface.

In one embodiment, the rim comprises ribs along its external surface.

In one embodiment, the rim comprises an internal inwardly-directed support for supporting
20 and/or acting as a spacer for the control and antenna substrates.

In one embodiment, the rim comprises internal lugs for connection to spacer pillars for
supporting the antenna substrate above the control substrate, and said lugs also support the
control circuit substrate.

25 In one embodiment, said antenna substrate comprises an antenna ground plane.

In one embodiment, said ground plane is at least 20mm from the base or any other metal
component.

30 In one embodiment, the system comprises a common ground plane for the antennas on the
antenna substrate and for electronic components on the control substrate.

In one embodiment, the antennas are linked by cables or by board-to-board connectors to the control circuit.

5 In one embodiment, the antenna substrate supports at least two cellular antennas mounted perpendicularly to the antenna ground plane and on opposite sides of the substrate on the same substrate face adjacent substrate edges for maximum separation.

In one embodiment, said antennas are substantially parallel, and have a PIFA (planar inverted-F antenna) structure.

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In one embodiment, said cellular antennas are located on the antenna substrate at opposed sides of said substrate along the longest dimension.

15 In one embodiment, separation of the cellular antennas along the antenna ground plane is at least 80 mm.

In one embodiment, at least one cellular antenna comprises a lower band resonance trace beginning from a feeding point and extends parallel to the antenna substrate and then away from the substrate towards a top middle region, and an upper band resonance trace extending in the
20 opposite direction parallel to the substrate and then upwardly towards an upper central location.

In one embodiment, said cellular antennas are perpendicular to the antenna substrate and are parallel to each other.

25 In one embodiment, the antenna substrate supports at least two WiFi antennas in spaced-apart relationship on opposite sides of the substrate on the same face of the substrate.

In one embodiment, the antenna substrate is of generally rectangular shape in plan, and the cellular antennas are adjacent opposed short edges and the WiFi antennas are adjacent opposed
30 long edges.

In one embodiment, each WiFi antenna is a PIFA type antenna, and has a feeding path from a bottom location to top, with a left hand side trace resonant WiFi lower bands mode and a right hand side small part resonant WiFi upper bands mode.

In one embodiment, the antenna substrate supports at least one positioning patch antenna and at least one satellite patch antenna.

- 5 In one embodiment, said antennas are at a location spaced-apart from all edges of the substrate, close to a central location of the antenna substrate.

In one embodiment, at least one of said antennas is a ceramic patch antenna with a low axial ratio, preferably less than 5.

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In one embodiment, said antennas are mutually offset with respect to both orthogonal axes on the plane of the antenna ground plane.

- 15 In one embodiment, the patch antennas are in the plane of the antenna substrate and the antenna ground plane, and are mounted between both cellular antennas on opposed sides of the patch antennas in a first direction, and both Wi-Fi antennas on opposed sides of the patch antennas in a second direction orthogonal to said first direction.

- 20 In one embodiment, there is a gap of at least 10mm between each cellular antenna and each WiFi antenna from the housing cover.

- 25 In one embodiment, the power supply is external of the antenna unit and comprises a physically separate unit, connected to the antenna unit by power supply cables, an interface for connection to a vehicle battery, and an interface for connection to a vehicle ground.

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In one embodiment, the base comprises a metal rim and a metal plate within the rim.

In one embodiment, the control circuit comprises a planar shield over a processor, and a cover shield over said planar shield.

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In another aspect, the invention provides an antenna unit comprising:

a plurality of antennas mounted on a substrate,
an electronic control circuit on a substrate, and

5 a housing enclosing and supporting said antenna substrate and said control circuit substrate in a multi-tier arrangement, said housing including an RF transparent cover and a base, wherein the antennas are supported in a manner exposed to the housing cover, and the control substrate is spaced apart from the antenna substrate on a side opposed to the housing cover.

Additional Statements

10 According to the invention, there is provided a data router comprising an antenna unit comprising a plurality of antennas and an electronic control circuit. There is a power supply for the control circuit, and the power supply may be external to the antenna unit.

15 In one embodiment, the antenna unit comprises a housing enclosing said plurality of antennas and said control circuit.

In one embodiment, the housing supports a plurality of substrates in a multi-tier arrangement, including at least one antenna substrate supporting a plurality of antennas and a control substrate supporting an electronic control circuit for the antennas.

20 In one embodiment, the housing comprises a base plate and a domed plastics cover sealed to the base plate.

In one embodiment, the base plate is of metal material, for heat conduction out of the housing.

25 In one embodiment, the base plate and the housing cover are sealed to a rim extending around the periphery of adjoining edges of the cover and the base plate.

In one embodiment, the rim has an external, exposed, surface.

30 In one embodiment, the rim is of metal for heat conduction. In one embodiment, the rim comprises ribs along its external surface. In one embodiment, the rim comprises an internal inwardly-directed support for supporting and/or acting as a spacer for substrates within the housing. In one embodiment, the rim comprises internal lugs for connection to spacer pillars for

supporting the antenna substrate above the control substrate. In one embodiment, said lugs also support the control circuit substrate.

In one embodiment, the router comprises a common ground plane for the antennas and electronic components on different substrates. In one embodiment, the antennas are linked by cables to the control circuit. The ground plan continuity may be provided by one or more cables linking the antenna and control circuit boards.

In one embodiment, the antenna unit comprises an upper antenna substrate and a lower control circuit substrate in spaced-apart relationship.

In one embodiment, the antenna substrate supports at least two cellular antennas mounted on opposite sides of the substrate adjacent the substrate edges for maximum separation. In one embodiment, said antennas are substantially parallel.

In one embodiment, the antennas have a PIFA (planar inverted-F antenna) structure.

In one embodiment, at least one cellular antenna comprises a lower band resonance patch trace beginning from a feeding point and extends parallel to the antenna substrate and then away from the substrate towards a top middle region, and an upper band resonance patch extending in the opposite direction parallel to the substrate and then upwardly towards an upper central location.

In one embodiment, a gap between said traces sets required impedance matching.

In one embodiment, the antenna substrate supports at least two WiFi antennas in spaced-apart relationship, in one embodiment perpendicular to the cellular antennas, and in one embodiment on opposite sides of the substrate.

In one embodiment, the WiFi antennas have a smaller separation than the cellular antennas, and in one embodiment, the antenna substrate is of generally rectangular shape in plan, and the cellular antennas are adjacent opposed short edges and the WiFi antennas are adjacent opposed long edges.

In one embodiment, each WiFi antenna is a PIFA type antenna, and has a feeding path from a bottom location to top, with a left hand side trace resonant WiFi lower bands mode and a right hand side small part resonant WiFi upper bands mode.

- 5 In one embodiment, the antenna substrate supports at least one positioning patch antenna.

In one embodiment, antenna is at a location spaced-apart from all edges of the substrate, close to a central location of the antenna substrate.

- 10 In one embodiment, at least one of said antennas is a ceramic patch antenna with a low axial ratio, preferably less than 5.

In one embodiment, said patch antennas include a satellite L-band antenna and/or a GNSS (Global Navigation Satellite System) antenna.

- 15 In one embodiment, the or each patch antenna is in the plane of the antenna substrate, and said cellular and/or WiFi antennas are perpendicular to said substrate.

- 20 In one embodiment, the control circuit includes components on a circuit board, and a sub-system with at least a modem.

- In one embodiment, the external power supply comprises a physically separate unit, connected to the antenna unit by power supply cables, an interface for connection to a vehicle battery, and an interface for connection to a vehicle ground.

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DETAILED DESCRIPTION OF THE INVENTION

Brief Description of the Drawings

- 30 The invention will be more clearly understood from the following description of some embodiments thereof, given by way of example only with reference to the accompanying drawings in which:-

Fig. 1 is a side view of an antenna unit part of a multi-network telematics device of the invention, including a multi-antenna assembly and a control circuit, Fig. 2 is a perspective view with some internal components visible underneath the cover, and Fig. 3 vertical cut-away perspective view across the narrow dimension;

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Fig. 4 is a perspective view showing the control circuit being mounted to a heat sink rim;

Fig. 5 is a perspective view of an antenna board;

10 Fig. 5 is a perspective view showing coaxial cable interconnections between the antenna board and the control board, Fig. 6 is a plan view showing relative positioning of the antennas on the antenna board, and Fig. 7 is a view showing signal connection of the antennas to the control circuit;

15 Fig. 8 is a set of views showing an antenna with transverse brackets used to secure the cellular antenna to the antenna board,

Fig. 9 shows side and plan views of a WiFi antenna of the router;

20 Fig. 10 is an exploded view of the housing, the control board, the antenna board, and an outer seal;

Fig. 11 is a diagram showing the power architecture of the control board, Fig. 12 is a block diagram of the control board, and Fig. 13 is a block diagram of a system-on-module (SoM) on which the router's main CPU operates in one example; and

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Figs. 14 and 15 are diagrams showing power supply components of the device, which feed power to the antenna unit;

30 Fig. 16 is set of S11 plots of the cellular antennas, showing good impedance match of the antennas to 50 Ohm across the band of interest of about 2500 MHz to 3400Mhz;

Fig. 17 shows efficiencies for the two cellular antennas in the main frequency bands of interest;

Fig. 18 shows peak gain for this frequency range, in which it will be seen that the two cellular antennas track well together;

5 Fig. 19 is an S11 plot for the WiFi antennas, efficiencies are shown in Fig. 20, and peak gains in Fig. 21;

Fig. 22 is an S11 plot for the GNSS patch antenna, Fig. 23 shows its efficiency, and Fig. 24 shows its peak gain;

10 Fig. 25 is an S11 plot for the satellite antenna, Fig. 26 shows efficiency, and Fig. 27 shows peak gain

Fig. 28 is a set of plan and side views of an alternative heat sink part of a housing;

15 Figs. 29 and 30 show assembly of the heat sink to the remainder of the housing;

Fig. 31 shows assembly of an antenna board above a circuit board onto the heat sink; and

20 Figs. 32 and 33 are perspective views showing a circuit board module of the router.

Description of the Embodiments

Referring to Figs. 1 to 15 a multi-network telemetrics device or “data router” has an antenna unit
25 1 which is primarily for vehicular mounting, but can be mounted at fixed locations, and is suited to outdoor mounting as it is weather-proof. The antenna unit 1 part of the system is suitable for external mounting and houses a number of different antennas. The antenna unit 1 has an s domed housing cover 2 enclosing, together with a base, both antennas and electronic circuits in a multi-tier arrangement. An antenna board 10 is mounted at the highest level, exposed to the
30 cover 2 and beneath this is mounted a control board 11 electrically connected to the antenna board, and both of which are entirely enclosed in the enclosure 2.

Advantageously, the antennas on the board 10 have radiation access via the plastics housing cover 2, and very close proximate links to the control electronic components on the board 11

underneath. The fact that the antennas are exposed to the cover 2 without any barrier helps to achieve excellent radiation efficiency, which is very advantageous for optimal radiated power and sensitivity and a reliable communications link. This is augmented by proximity of the antennas to the control circuit, with very little loss in transmission between them, less than 1dB compared to typical losses of many dB from external cabled antennas. Also, advantageously, the antennas have their own common ground plane shorted to but physically separate from the control circuit board ground plane, being above the level of the control circuit. The antenna board is connected to the main router circuit board by Nylon column stand-offs but the shielding of the co-axial cables connecting the antenna board elements and the main router board radio modules have a common earth connection and are electrically at a common ground potential i.e. the ground planes connect via the shielding on the co-axial cables. The relatively long top groundplane for the antenna board provides for improved radiation efficiency for the monopole antennas in this configuration and enhanced shielding from radiation emissions coming from the control circuit board below.

As shown in Figs. 2, 3 and 4 the control board 11 is affixed to a metal rim heat sink 3 having a ribbed outer surface 3(b). The heat sink 3 presents an accessible thermal interface, dissipating the thermal energy generated by the Ohmic heating of the electronic components when the router is operating.

The housing cover 2 is of ASA plastics material, being weather and UV-resistant. The rim 3 is of metal and so it acts as a heat sink for transfer of heat from the electronic components to the surrounding air. This heat transfer route is via the rim seal, which is of metal material.

We have found that a plastics housing cover over a multi-tier arrangement of antennas exposed to the cover and electronic circuit boards underneath with a heat-dissipating metal rim provides an optimum performance of radiation communication, electronic control, housing rigidity, and heat dissipation. This is achieved while enclosing all active components in a weather-proof enclosure. Because the rim is below the level of the antennas' ground plane, it does not interfere with radiation efficiency of the antennas.

As is described in more detail below, the antenna board 10 has the same ground plane for all antennas, with the main electronic components including the CPU located underneath the antenna board 10, on the control board 11. The connection point between the individual

antennas and the respective radio modules on the control board 11 is provided by short high-grade coaxial cables 40, as shown in Fig. 7. This avoids cable loss, with the antennas and the electronic components being close together.

- 5 In another embodiment, at least one connection is by way of a board-to-board connection, rather than cable. In another embodiment, the electronic control circuits and related components can be placed on the other side of the board from the antenna elements, or in between the antenna elements on the same side of the board.
- 10 The control board 11 connects directly to the heat sink rim 3 (Fig. 3), and the antenna board 10 connects to the control board 11 and the rim 3 at lugs 3(a) via spacer pillars, not shown. The top cover 2 covers the control board 11 and the antenna assembly 11 and the entire unit is enclosed by screwing a base plate 12 to the top cover via screw holes in the heat-sink rim.
- 15 The heat-sink rim 3 has grooves which receive the top cover 2 and the base cover 12. These grooves are filled with a liquid gasket material. This provides an excellent seal between the housing cover 2 and the base 12 (being resistant even to power hoses washing the vehicle on which the assembled device is mounted). The sealing rim 3 has external ribs extending along its length, and internally, it acts as a spacer between the control board – antenna board assembly.
- 20 This bridges the control board – antenna board to the base, providing excellent structural integrity and also heat conduction towards ambient.

Mounting of the control board 11 to the rim 3 is shown in more detail in Fig. 4; it is seated on inwardly-directed lugs 3(a) and is fixed to these lugs by metal fasteners.

- 25 The antenna board 10 has six different antenna elements inside the router enclosure 2/12. There are two LTE band cellular antennas 31 and 32, two WiFi dual bands antennas 33 and 34, one GNSS patch antenna 36, and one Satellite L-bands 1621MHz path antenna 35. In one embodiment, at least one of said antennas is a ceramic patch antenna with a low axial ratio, preferably less than 5 for improved satellite signal reception and better accuracy of positioning.
- 30

In more detail, the antenna board 10 supports two parallel vertical plate wide-band cellular (2G/3G/4G) antennas operating from 698MHz to 2700MHz 31 and 32 on opposite sides of the board 10, with a maximum separation. The antennas are a monopole PIFA type. We have found

that they operate optimally at the edges of ground-planes, maximum separation gives maximum isolation distance, and they are connected to the antenna board common ground-plane. The height and dimensions of the antennas ensure maximum radiation efficiency of the antennas and a good broad-band impedance match. The location of the antennas on the edge of the antenna board 10 also allows for direct clearance from the plane of the underlying metal structure of the control board 11.

The two monopole WiFi antennas 33 and 34 are on opposite sides of the board 10 in the narrow dimension. Again, location has been chosen to achieve maximum isolation between all antenna elements 31-36 on the antenna board.

The GNSS patch antenna 36 is of planar rectangular shape and is mounted at a location offset from the centre of the board 10, and adjacent to this there is the satellite navigation patch antenna 35, of larger rectangular block configuration. Placing the patch antennas at generally central locations improves radiation pattern homogeneity and lowers axial ratio, to improve the signal reception and transmission characteristics of satellite communications and navigation systems.

Referring to Fig. 6 the separations of the various antennas are shown. The two patch antennas 35 and 36 are closer to each other (13.45 mm) than to the LTE cellular antennas 31 and 32 and to the WiFi antennas 33 and 34. The separation of the antennas 31 and 32 is about 88mm, which is the maximum possible for the housing. In general, this may be different depending on the housing configuration, but it is preferred in any event that it is greater than 80mm in order to achieve more than 12dB isolation. It is well understood that increased isolation leads to improved bandwidth in MIMO systems. Also, it is preferred that the separation of each patch antenna 35 and 36 along the ground plane is at least 20mm, in this case 21mm and 26mm, to have adequate isolation and reduction in radiation pattern degradation.

Advantageously the patch antennas 35 and 36 are offset from each other in the orthogonal directions in the plane of the ground plane. This helps to increase the isolation between the two patches. Also, there is a minimum separation of a patch antenna from an antenna perpendicular to the ground plane of 16.7mm, and more generally this is preferably greater than 15mm to achieve greater isolation of over 10dB.

Advantageously, all antennas are at least 20mm from any metal component, to reduce to a minimum reduction in radiation efficiency and distortion of the radiation pattern. This is primarily achieved because of the multi-tier arrangement, keeping them separated by at least this from the rim 3.

5

All antennas are connected to the co-axial connectors by 50 Ohm co-planar waveguides. The location and routing of the co-planar waveguides has been carefully chosen to provide a correct 50 Ohm wide-band match, while also reducing signal loss and potential interference with other transmission lines.

10

In more detail, the antenna unit 1 may be regarded as a multi-radio data router and telematics device which incorporates a multi-network antenna assembly 31-36, the electronic control board 10 and a single IP69K rated outdoor enclosure 2. The device simultaneously provides data connectivity to multiple wireless networks for use in fixed and mobile data applications. The combined antenna circuit board assembly, control board and enclosure arrangement is particularly advantageous.

15

By providing all of the antennas 31-36 in one assembly the requirement to provide multiple external antenna mountings is negated, hence the associated signal loss over external cable runs is significantly reduced. It also reduces the potential for electronic noise to enter the system since the transmission lines are much reduced in length due to proximity of the control board 11 to the antenna board 10. In addition to the improvement in signal loss, this antenna unit configuration reduces the installation time and cost associated with deployment on vehicles or on other equipment, reducing the time taken to install from hours to just minutes in some cases. Also, the proximity of the antennas to the control board achieves at least a 2dB saving compared to a situation where they are separated by say 1m.

20

25

As all of the antennas are located together within a single assembly, this arrangement provides for integration of the associated radio electronics within the same enclosure (connected to the antenna board 10 using the coaxial cable assemblies 40). This allows the data router electronics and antennas to be deployed together in a single enclosure which can be mounted externally on vehicles or buildings. The enclosure has been designed to be mounted externally whereby the radiation paths for the internal antennas are minimally affected by interference from the sheet metal of vehicles, equipment, or walls. This is because the antennas operate on their own antenna

30

board ground-plane, and the housing structure maintains minimum clearance levels of at least 20mm from the antennas to the surrounding environment due to the cover, rim, base, antenna board, and control board configuration.

- 5 The metal heat-sink 12 onto which the control board 11 is mounted dissipates heat from the electronic components 41 on the control board 11 to the rim 3, and there is of course also direct heat transfer from the control board 11 to the rim 3 via the lugs 3(a). This ensures that the control components are maintained at a temperature below 65° in the vast majority of conditions.
- 10 The antenna board 10 and the control board 11 interconnect within the enclosure 2 and share the same ground plane. This improves the radiation efficiency at lower frequencies. Metal standoffs or pillar spacers are screwed into heat sink rim lugs 3(a) through plated holes in the control board 11. The antenna board 10 is mounted to the standoffs with metal screws through the plated holes. This connection methodology is simple and serves to extend the ground plane.

- 15 Because the control board 11 mounts directly to the metal heat sink base plate 12, the heat sink is an intrinsic part of the enclosure, and the device as a whole is air cooled through the thermal coupling of the control board 11. The control board 11 screws directly to the heat sink 12 with application of thermally-conductive paste for enhanced heat transfer, and the antenna board 10 connects to the control board 11.
- 20

- By placing the various components in the same enclosure, transmission lines are minimized, particularly between the antenna assembly board and the control board 10. The co-axial feed points on the antenna board 11 are placed near the end feed point of the respective antenna board
- 25 10. The antenna board 10 then connects directly to the control board 11 via co-axial cables 40. When the co-axial cables 40 are connected the antenna assembly 10 is screwed onto the control board 11.

- When the assembly is affixed to the control board silicone sealant is placed within the grooves of
- 30 the heat sink rim 3 and the enclosure top is placed into the heat sink plate 12.

Referring to Fig. 10, a neoprene sealing gasket 60 and an outer rubberized seal 7 are mounted below the metal base plate 12. By assembling the router with these gaskets and by placing silicon

sealant at sub-assembly intersection points the enclosure offers an ingress protection for dust and moisture to IP69K standard.

Referring especially to Figs. 4 to 9, all of the antenna features below are combined on the same assembly.

Cellular Antennas (Figs. 6 and 8):

Two antennas 31 and 32 are provided for 2G/3G/4G cellular service to support high-performance 1x2 or 2x2 MISO/MIMO UMTS and LTE. Both antennas support UMTS/LTE Bands 1-5, 8, 12, 13, 25, 26, and 17. Their frequencies can also support all worldwide GSM, CDMA bands. The antennas 31 and 32 have a PIFA structure. An LTE lower band resonance trace beginning from feeding point 31(b) goes right and then extends to the middle-top of a PCB. This path generates the mode to cover from 698MHz to 960MHz. An upper band resonance trace starts from the feeding point 31(b) and goes left to middle top. This path generates the mode covering 1710MHz to 2690MHz. The gap between lower and upper mode trace pattern affects two modes impedance matching. Through adjustment of this gap there is better impedance matching in both LTE lower and upper bands mode. The LTE MIMO1 32 and MIMO2 31 antennas have the same antenna pattern.

Wi-Fi Antennas (Fig. 9):

The two antennas 33 and 34 are provided for Wi-Fi to support high-performance 2x2 MIMO (Multiple Input Multiple Output). Each antenna supports both the 2.4GHz and 5GHz ISM bands (2400 - 2485MHz and 4900 - 5850MHz, respectively). Each antenna 33 and 34 is a PIFA type antenna, and the material is stamped brass. Antenna feeding is from left bottom 33(b) to top, left hand side trace resonant WiFi lower bands mode, right hand side small part resonant WiFi upper bands mode. Through the short to ground point, the antenna impedance matching can be optimized. Advantageously, the Wi-Fi antennas 33 and 34 are offset with respect to each other in the longitudinal direction, and they have separations of 13.17mm from the cover. These aspects help to achieve an omnidirectional pattern and increased isolation. The separation from the cover is preferably at least 10mm to achieve this benefit.

L-band (Satellite) Antenna 35:

The antenna dimension is 35*35*3mm, it's a patch type antenna. Through silver pattern adjusting, the antenna can have resonant modes to cover Satellite L-Band 1621MHz. The area in

the plane of the ground plane is large enough for high efficiency, optimum peak gain, and low axial ratio.

GNSS Antenna 36:

- 5 The antenna dimension is 25*25*4mm, it's a patch type antenna. Through the silver pattern adjusting, the antenna can have two separate resonant modes to cover GPS 1575.42MHz and GLONASS 1602MHz, respectively. Again the area achieves desired efficiency peak gain and axial ratio. These aspects are augmented for both of the patch antennas because they are offset in the orthogonal directions.

10

The size and positioning of the antenna elements 31-36 on the antenna assembly board 10 are advantageous. The antenna 31-36 positioning results in multiplying the capacity of the individual radio frequencies for the relevant band using pairs of transmit and receive antennas to exploit multipath propagation (Wi-Fi and Cellular antennas).

15

The cellular antennas 31 and 32 provide 2x2 MIMO LTE with fall-back to 3G and 2G, operating on US frequency bands

- LTE 2,4,5,6,12,13,17,18,19
- UMTS 850, AWS, 1900, 2100
- 20 – GSM 850, 1900
- The antennas are more than 40% efficient at US operator LTE bands, ensuring certification approval. Some efficiency graph should be shown of each antenna system.

And EU frequency bands

- 25 – LTE (Long Term Evolution) 1,3,5,7,8,20
- UMTS (Universal Mobile Telephony System) 850, 900, 2100
- GSM 900, 1800

The arrangement of the antennas optimizes radiation patterns including polarization to achieve a low envelope correlation co-efficient (ECC) between the two antennas. This implementation achieves below 0.4 ECC, thus increasing bandwidth capacity.

30

The cellular antenna board 10 is anchored by transverse brackets 85 shown in Fig. 8 which provide additional support to the antenna board 10 by retaining it in a fixed perpendicular position.

The MIMO (Multiple-in Multiple-out) Wi-Fi dual antennas 33 and 34 provide wireless communication to IEEE 802.11n (Wi-Fi) and IEEE 802.11ac (Wi-Fi) standards. The assembly also provides Wi-Fi: 802.11a/b/g connectivity.

5 Each antenna is effective at 2.4 Ghz and 5.8 Ghz. Effective MIMO implementation requires separation of the antennas and optimizing MIMO antennas individual radiation patterns including polarization to achieve a low envelope correlation co-efficient (ECC) between the two antennas. This implementation achieves below 0.4 ECC, thus increasing bandwidth capacity.

10 The control board 11 supports a circuit (Figs. 11 to 13) including a Cortex A9 based i.MX6 processor from Freescale is at the centre of the SoM produced by Variscite. The ZRM 500 router utilizes the following on-module components provided by a SOM (system on module) 50 including.

- 15 – Freescale i.MX6
 - UARTs (universal asynchronous receiver/transmitter)
 - I2C (inter integrated circuit)
 - USB (universal serial bus)
 - PCIe (peripheral component interface)
- 20 • SDIO (secure digital input/output)
- GPIO (general purpose input/output)
- Freescale PMIC (power management IC) (provides the power rails to the processor)
- Ethernet PHY (physical layer)
- DDR (double data rate)

25 Memory
NAND (logical NOT AND) Storage

Sub-system components 50 (shown in Fig. 13) on the control board 11 are controlled based on their individual interface,

- An Iridium 9603™ modem, the GNSS receiver and the external RJ50 configuration
- 30 interface are connected to the core system via one of the four serial interface (UART) available on the SOM
- A cellular modem is controlled via the USB host on the SOM
- A Wi-Fi module is controlled via the PCIe interface

- An Ethernet connection is presented via the PHY (10/100/1000), and integrated Ethernet controller on the i.MX6™
- Indicator LEDS are controlled via an I²C interface as well as GPIO
- Power conditioning circuitry, external power gating, SIM muxing, and input monitoring are also managed with GPIO

The sub-system 50 shown in Fig. 13 includes a System on Module – Variscite i.MX6 SOM™. The SOM is an i.MX 6 multi core ARM Cortex-A9™ CPU device running at 800Mhz. The functional temperature range of the SOM is between -40 to 85 °C which renders it suitable for deployment in an outdoor grade router enclosure.

The SOM 50 is responsible for managing the connected hardware resources, specifically the Wi-Fi, Cellular, GNSS and L-Band modules. The SOM runs on OpenWrt operating system based on the Linux kernel which is primarily used on embedded devices to route network traffic.

The main components of the operating system are,

- The Linux kernel
- OpenWRT - The application level framework for network routing
- UCI (Universal Configuration Interface), which is used for managing all configuration
- LuCI, the web based user interface

The Linux Kernel manages applications while the daemons constitute the background processes running to manage the sub-system inter-operation.

Power Architecture (Control Board 11, Fig. 11)

Within the router unit 1 the incoming power injector voltage is dropped from the 8 to 32VDC input range to the following rails through a series of regulators.

- 5V (Iridium Modem)
- 4.2V (Cellular)
- 3.3V (SOM, WiFi, IO)
- 3.3V Low Noise (GPS)

The architecture diagram is as shown in Fig. 11:

The SOM, WiFi, and Satellite modules were chosen to be powered directly from switching supplies because they all have internal regulators, isolating their internal operation from the switching noise of these supplies. The performance of the Cellular and GPS modules is directly related to the noise on their supplies. In all cases appropriate power decoupling and RF
5 bypassing will be used to ensure the lowest possible noise figures.

Satellite – Iridium 9603™

The Iridium 9603 Short Burst Data modem is an L-band satellite transceiver.

Its key features for implementation in the ZRM 500 router are:

- 10 – 5V operation
- Global short burst data operation
- Small (31.5 x 29.6 x 8.10mm) dimensions
- -30 to +70C operation
- Mounting holes for PCB retention
- 15 – 3.3V UART (Universal Asynchronous Receiver/Transmitter) interface
- Power control

The Iridium modem is used for critical data communications. In situations where cellular and WiFi connections are not available, the Iridium modem is still capable of reporting status,
20 location, and any other small format data back to the client.

The satellite communication provided by the system will be used primarily to send tracking and system status data back to the pilot partner's vehicular management systems and also to a management server. This data will provide system operating information and alarm data. The
25 router sends this data over satellite, with all other streamed IP data being sent over the terrestrial networks.

The GNSS receiver equipped on the router will receive GNSS data and generate the appropriate latitude and longitude location data: this location data will accompany all dataset transmissions
30 from the router for location reference and time sync purposes. When the Iridium radio is transmitting the GNSS receiver is switched out to ensure the receiver is not overloaded.

WiFi – Azurewave AW-CH397

The Azurewave AW-CH397 is a WiFi a/b/g/n/ac SIP LGA module integrating a Marvell 88W8897 core and diplexers on the front-end. Its key features for implementation in the ZRM 500 router are:

- 3.3V Operation
- 5 – 2x2 MIMO (multiple input multiple output) capability
- 802.11 a/b/g/n/ac capability
- Small (12.3 x 10.0 x 1mm) dimensions
- -20 to +85C operation
- SDIO and PCIe interfaces

10

The SOMs SDIO3.0 and PCIe 2 interfaces are both capable of transferring data at or near the modules maximum theoretical link speed, making them both suitable for high-performance desired in the ZRM 500 router.

15 Cellular– uBlox TOBY L2XX™

The uBlox TOBY L2XX™ devices are multi-band LTE/HSPA+/GPRS cellular modules in US and EU variants in an LGA package. Its key features for implementation in the ZRM 500 router are:

- 4.4V-3.3V Operation
- 20 – 2x2 MIMO capability
- 4G LTE with 3G/2G fallback
- Small (24.8 x 35.6 x 2.6 mm) dimensions
- -40 to +85C operation
- US and EU footprint compatible variants
- 25 – USB interface

The SOMs USB2.0 host interface will be utilized to connect to the TOBY L2XX and is capable of realizing the full throughput of LTE Cat 4. Two u.FL connectors will be used to connect the antenna ports of the module to the antenna board. For configuration a 2-wire interface will be
 30 connected to the module. This interface requires level shifting between 3.3V and 1.8V. The 1.8V rail is generated by the cellular module. In order to support two SIM sockets an analogue 4PDT switch will be utilized to switch VSIM, SIM_CLK< SIM_RST, and SIM_IO to two different low profile latching SIM card holders.

GNSS – uBlox MAX-M8

The uBlox TOBY MAX-M8 module is a concurrent GNSS module supporting GPS, GLONASS, and Beidou. Its key features for implementation in the ZRM 500 router are:

- 3.3V Operation
- 5 – -167dBm tracking sensitivity
- Small (9.7 x 10.1 x 2.5 mm) dimensions
- -40 to +85C operation
- Serial Interface
- Low-cost

10

The SOM will communicate with the uBlox module with over a 2-wire serial interface running at 3.3V. An LNA amplifier will be utilized to maximize receive sensitivity and general performance of the GNSS device. Dual stage SAW filters will also be used to further isolate the GNSS signals from other radiated frequencies. A u.FL connector will connect the GNSS RF
15 input to the antenna board. A separate LDO will be used to provide the GPS with an extremely low noise power supply input.

The power injector

This is shown in Figs. 14 and 15. A power injector unit 300 is connected by co-ax cables 301 to
20 the antenna unit 1, and power is derived from a battery 302, and there are links 303 to vehicle ground. The nominal input voltage of the system is 24V and it will have an input range suitable for future compatibility. This input voltage is buck regulated and distributed either directly to system components or to LDOs when noise performance is critical.

25 The power injector galvanically isolates the vehicular power supply from the router. It also provides isolation from load dump conditions.

Performance of the various antennas is illustrated in the plots of Figs. 16 to 27. Fig. 16 plots return loss (S11) for the cellular antennas 31 and 32 in the main frequency bands of interest,
30 1600 MHz to 2000 MHz giving best performance. Also, there is excellent isolation for large parts of the frequency spectrum, with very little inter-antenna coupling. These plots show that the performance comfortably achieves a target of less than -5dB for the antennas, and less than -12dB for isolation.

As shown in Figs. 17 and 18, for these two antennas the efficiency and peak gain parameters track each other closely in the main bands of interest.

Also, for the WiFi antennas 33 and 34, as shown in Fig. 19 the performance is best between about 4600 and 5200 MHz. Again, as shown in Figs. 21 and 22 the efficiency and peak gain parameters track each other closely. These plots show that there is a response of below -10dB for the antennas, and less than -12dB for isolation. Also, the efficiency is very good, greater than 50%.

Figs. 22 to 24 show that for the GNSS patch antenna there is markedly good performance in the band of about 1550 to 1625 MHz. Again in the relevant band the gain is less than -12dB. The efficiency is greater than 50%, the peak gain is greater than 3dBi across the band.

The satellite patch antenna has, as shown in Figs. 25 to 27, a narrower band for optimum performance. In this case it is about 1600 to 1650 MHz. The loss figure is less than -10dB, the efficiency is greater than 50%.

Referring to Figs. 28 to 33 an alternative antenna unit 500 comprises a base 501 incorporating a rim akin to the rim 3, but also a metal plate 503 within the rim. It therefore acts as both a base and a heat sink and rim to support the multi-tier substrates. The plate 503 includes a boss 506 for power and data cables 518, and an access opening 505 for a SIM (subscriber identity module) card. The opening is covered by a rectangular plate cover 517, which is sealed in place with a gasket 516. A rubber (neoprene in this example) backing sheet 530 may also be applied to the outside surface of the plate 503, as shown in Fig. 30.

Figs. 31 to 33 show mounting of the circuit board 540 in this embodiment, and component layout and internal RF shield positioning. The circuit board 540 has a VarisiteTM metal RF shield 542 above which is mounted a metal screen shield 543 in the shape of a cover.

It will be appreciated that the performance characteristics are excellent despite the fact that the antennas are mounted in close proximity to each other in a weatherproof enclosure.

It is particularly advantageous that the antenna units 1 and 500 have a thermally conductive metallic segment (3, 501, 503) that forms a part of an otherwise RF transparent sealed enclosure while also serving as a rigid permanent mounting apparatus for the enclosure.

5 Another major advantage is that the ground of the antenna PCB (10, 550) combines with the structure and spacing of the metal (3, 501, 503) of the lower part of the enclosure to form a shield. By placing the antennas on the opposite side of the antenna substrate from the parallel bottom circuit substrate the device is able to utilize the combination of the antenna substrate and enclosure to form a symbiotic complementary shielding system.

10

The multi-antenna substrate has a intentionally controlled spacing from the parallel circuit substrate so as to be anti-resonant at the wavelengths of the identified radios.

15 The invention is not limited to the embodiments described but may be varied in construction and detail. For example, the power supply may be mounted internally within the antenna unit, and if so is preferably below the control board, furthest from the antennas. Instead of having a socket for a conventional SIM (Subscriber Identity Module), SIM functionality may be provided on a SIM IC, providing “provisioning on the go”.

20 The antenna unit may have a round, square, or any other shape in plan.

The antenna board may be connected electronically to the control board by board-to-board connectors, the elements of the control board may also be directly placed amongst the antenna board or directly on opposite side. Also, the antennas may be supported on multiple substrates,
25 as may be the control circuit. In such a case, the antenna substrates may be co-planar and may be linked electrically.

Other wireless technologies such as AM/FM, 5G, mmwave, DSRC, UWB location system also can be included in this device.

30

Claims

1. A telematics device comprising:
an antenna unit (1) comprising:
 - 5 a plurality of antennas (31-36) mounted on a substrate (10),
an electronic control circuit (11) on a substrate, and
a housing (2, 3, 12) enclosing and supporting said antenna substrate (10) and said
control circuit substrate (11) in a multi-tier arrangement, said housing including
an RF transparent cover (20) and a base (12),
 - 10 wherein the antennas (31-36) are supported in a manner exposed to the housing cover (2,
520), and the control circuit substrate (11, 550) is spaced apart from the antenna substrate
on a side opposed to the housing cover (2), and
a power supply (300) connected to the control circuit (1).
- 15 2. A telematics device as claimed in claim 1, wherein the base (12, 503) is at least partly of
metal material, for heat conduction out of the housing.
3. A telematics device as claimed in claim 2, wherein the housing comprises a metal rim,
and the base (12, 503) and the housing cover (2, 520) are sealed to the metal rim (3, 501)
20 in which the metal rim extends around at least some of the periphery of adjoining edges
of the cover and the base, said metal rim (3) having an external exposed surface (3(b)).
4. A data router as claimed in claim 3, wherein the rim comprises ribs (3(b)) along its
external surface.
- 25 5. A telematics device as claimed in either of claims 3 or 4, wherein the rim comprises an
internal inwardly-directed support (3(a), 502) for supporting and/or acting as a spacer for
the control and antenna substrates.
- 30 6. A telematics device as claimed in claim 5, wherein the rim comprises internal lugs for
connection to spacer pillars (85) for supporting the antenna substrate (10, 520) above the
control substrate, and said lugs also support the control circuit substrate.

7. A telematics device as claimed in any preceding claim, wherein said antenna substrate comprises an antenna ground plane.
- 5 8. A telematics device as claimed in claim 7, wherein said ground plane is at least 20mm from the base or any other metal component.
9. A telematics device as claimed in any preceding claim, wherein the system comprises a common ground plane for the antennas (31-36) on the antenna substrate (10) and for electronic components on the control substrate (11).
- 10 10. A telematics device as claimed in any preceding claim, wherein the antennas (31-36) are linked by cables (40) or by board-to-board connectors to the control circuit (11).
11. A telematics device as claimed in any preceding claim, wherein the antenna substrate
15 (10) supports at least two cellular antennas (31, 32) mounted perpendicularly to the antenna ground plane and on opposite sides of the substrate on the same substrate face adjacent substrate edges for maximum separation.
12. A telematics device as claimed in claim 11, wherein said antennas are substantially
20 parallel, and have a PIFA (planar inverted-F antenna) structure.
13. A telematics device as claimed in claims 11 or 12, wherein said cellular antenna are located on the antenna substrate at opposed sides of said substrate along the longest dimension.
- 25 14. A telematics device as claimed in claim 13, wherein separation of the cellular antennas along the antenna ground plane is at least 80 mm.
- 30 15. A telematics device as claimed in any of claims 11 to 14, wherein at least one cellular antenna comprises a lower band resonance trace beginning from a feeding point (31(b)) and extends parallel to the antenna substrate (10) and then away from the substrate towards a top middle region, and an upper band resonance trace extending in the opposite direction parallel to the substrate (10) and then upwardly towards an upper central location.

16. A telematics device as claimed in any of claims 11 to 15, wherein said cellular antennas are perpendicular to the antenna substrate and are parallel to each other.
- 5 17. A telematics device as claimed in any preceding claim, wherein the antenna substrate (10) supports at least two WiFi antennas (33, 34) in spaced-apart relationship on opposite sides of the substrate on the same face of the substrate.
- 10 18. A telematics device as claimed in claim 17, wherein the antenna substrate (10) is of generally rectangular shape in plan, and the cellular antennas are adjacent opposed short edges and the WiFi antennas are adjacent opposed long edges.
- 15 19. A telematics device as claimed in claims 17 or 18, wherein each WiFi antenna (33, 34) is a PIFA type antenna, and has a feeding path from a bottom location (33(b)) to top, with a left hand side trace resonant WiFi lower bands mode and a right hand side small part resonant WiFi upper bands mode.
- 20 20. A telematics device as claimed in any preceding claim, wherein the antenna substrate (10) supports at least one positioning patch antenna and at least one satellite patch antenna.
21. A telematics device as claimed in claim 20, wherein said antennas are at a location spaced-apart from all edges of the substrate, close to a central location of the antenna substrate..
- 25 22. A telematics device as claimed in claims 20 or 21, wherein at least one of said antennas is a ceramic patch antenna with a low axial ratio, preferably less than 5.
- 30 23. A telematics device as claimed in any of claims 20 to 22, wherein said antennas are mutually offset with respect to both orthogonal axes on the plane of the antenna ground plane.
24. A telematics device as claimed in any of claims 20 to 23, wherein the patch antennas are in the plane of the antenna substrate and the antenna ground plane, and are mounted between both cellular antennas on opposed sides of the patch antennas in a first direction,

and both Wi-Fi antennas on opposed sides of the patch antennas in a second direction orthogonal to said first direction.

25. A telematics device as claimed in claim 24, wherein there is a gap of at least 10mm
5 between each cellular antenna and each WiFi antenna from the housing cover.
26. A data router as claimed in any preceding claim, wherein the power supply is external of
the antenna unit and comprises a physically separate unit (300), connected to the antenna
unit by power supply cables (301), an interface for connection to a vehicle battery, and an
10 interface for connection to a vehicle ground.
27. A telematics device as claimed in any preceding claim, wherein the base comprises a
metal rim and a metal plate within the rim.
- 15 28. A telematics device as claimed in any preceding claim, wherein the control circuit
comprises a planar shield over a processor, and a cover shield over said planar shield.
29. A telematics device antenna unit (1) comprising:
a plurality of antennas (31-36) mounted on a substrate (10),
20 an electronic control circuit (11) on a substrate, and
a housing (2, 3, 12) enclosing and supporting said antenna substrate (10) and said
control circuit substrate (11) in a multi-tier arrangement, said housing including
an RF transparent cover (20) and a base (12),
wherein the antennas (31-36) are supported in a manner exposed to the housing
25 cover (2, 520), and the control substrate (11, 550) is spaced apart from the antenna
substrate on a side opposed to the housing cover (2).

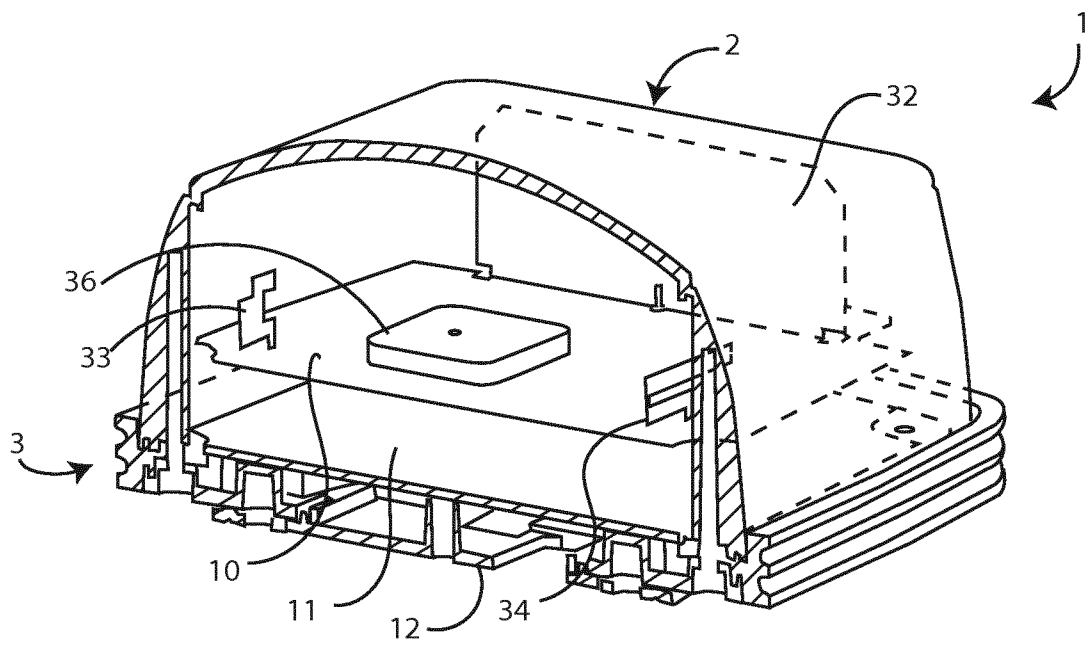
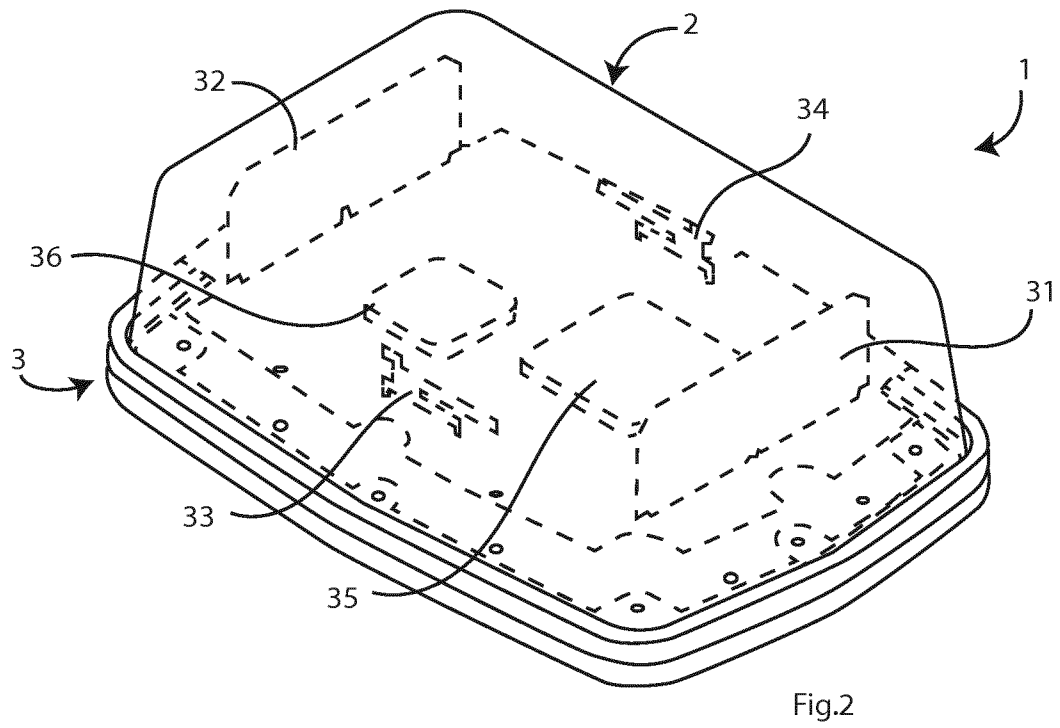
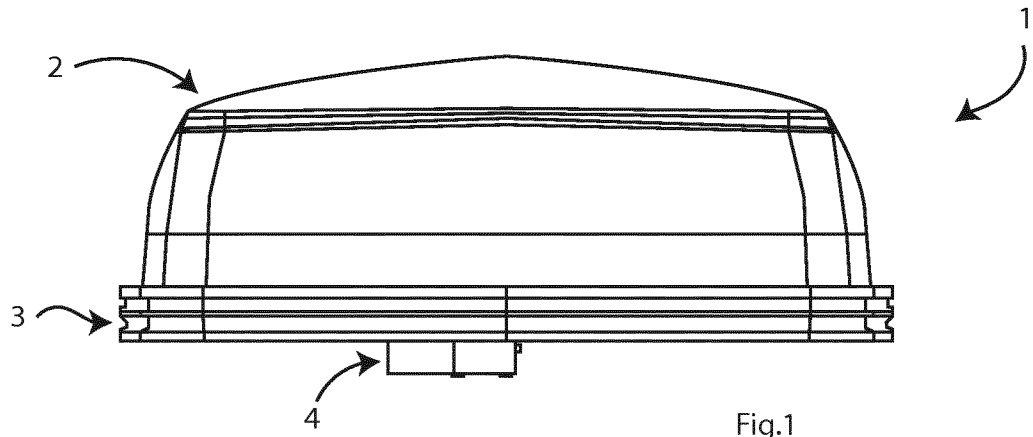


Fig.3

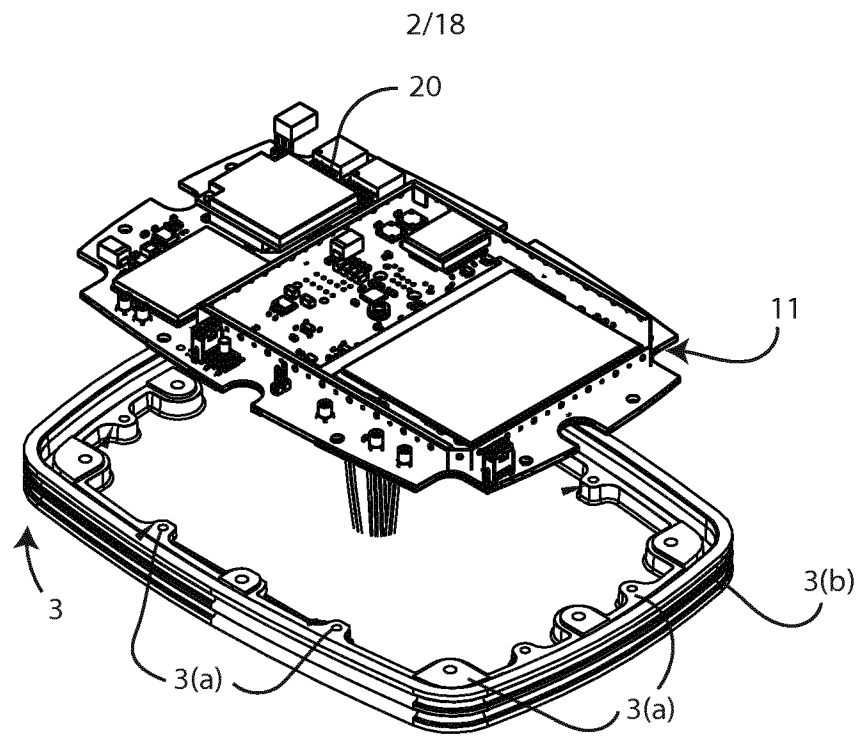


Fig.4

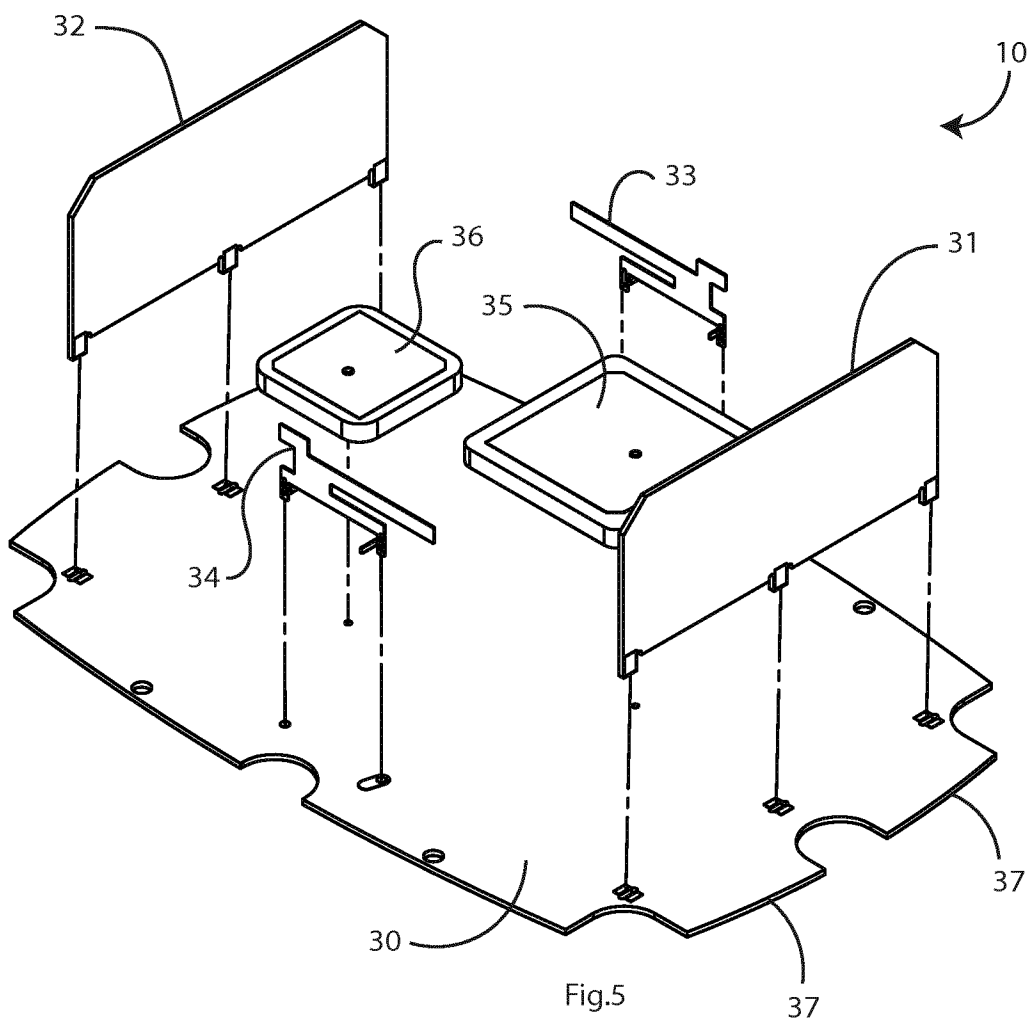


Fig.5

3/18

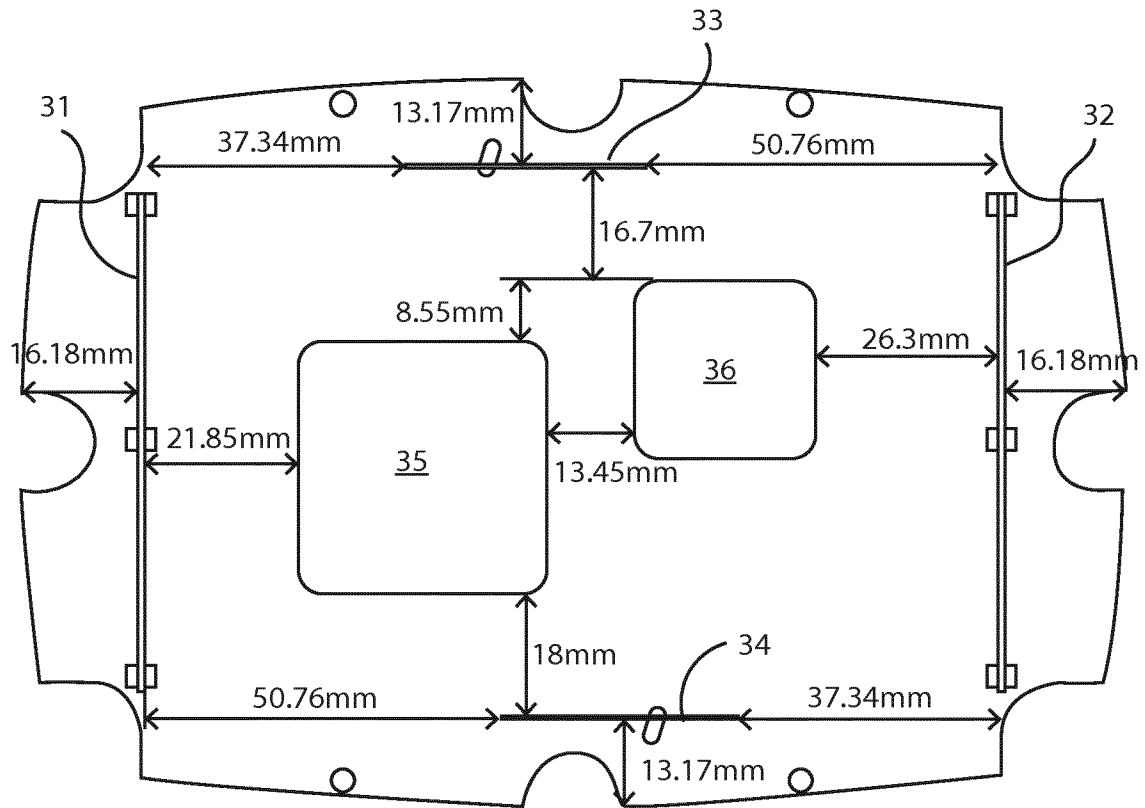


Fig.6

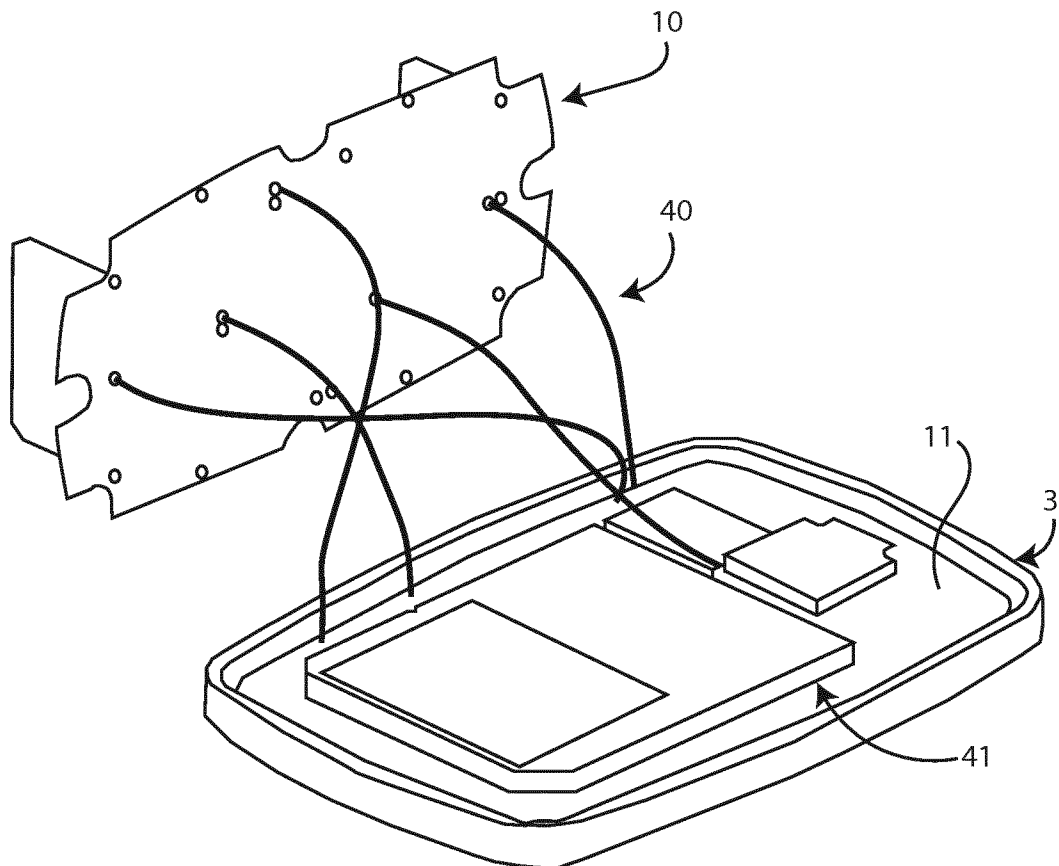


Fig.7

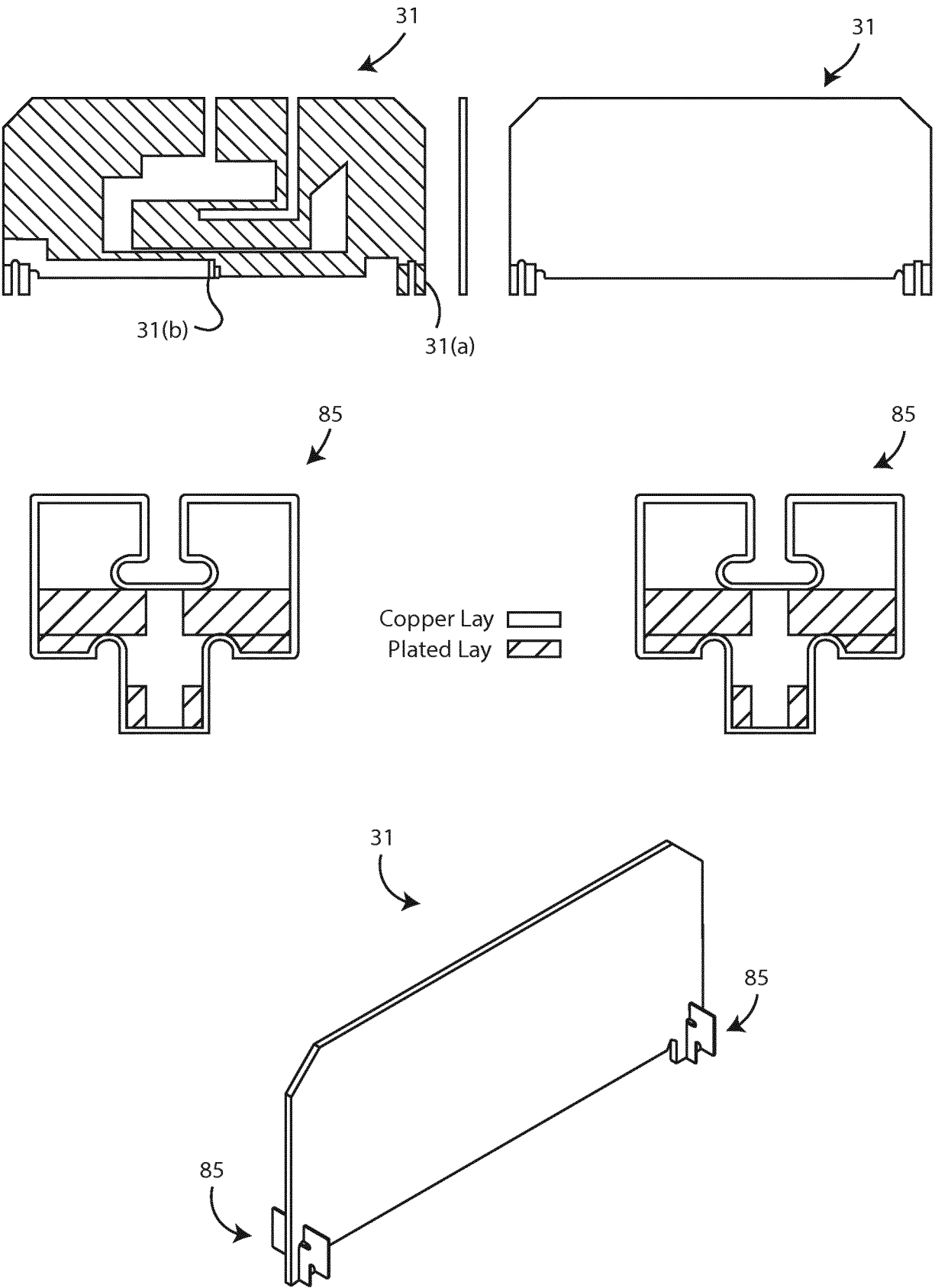


Fig.8

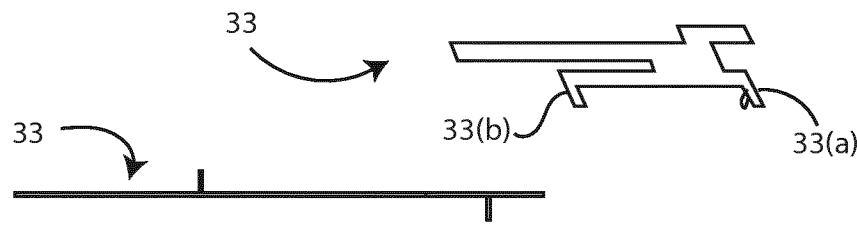


Fig.9

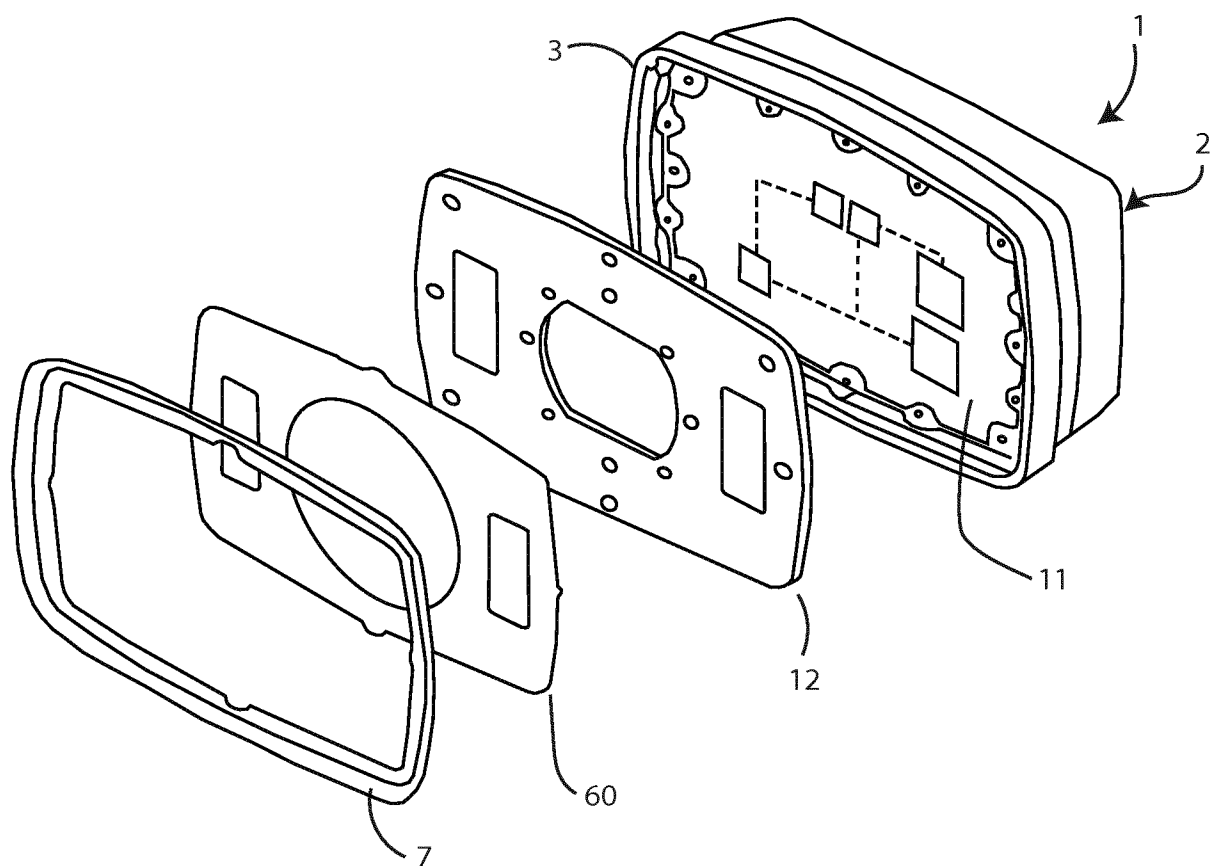


Fig.10

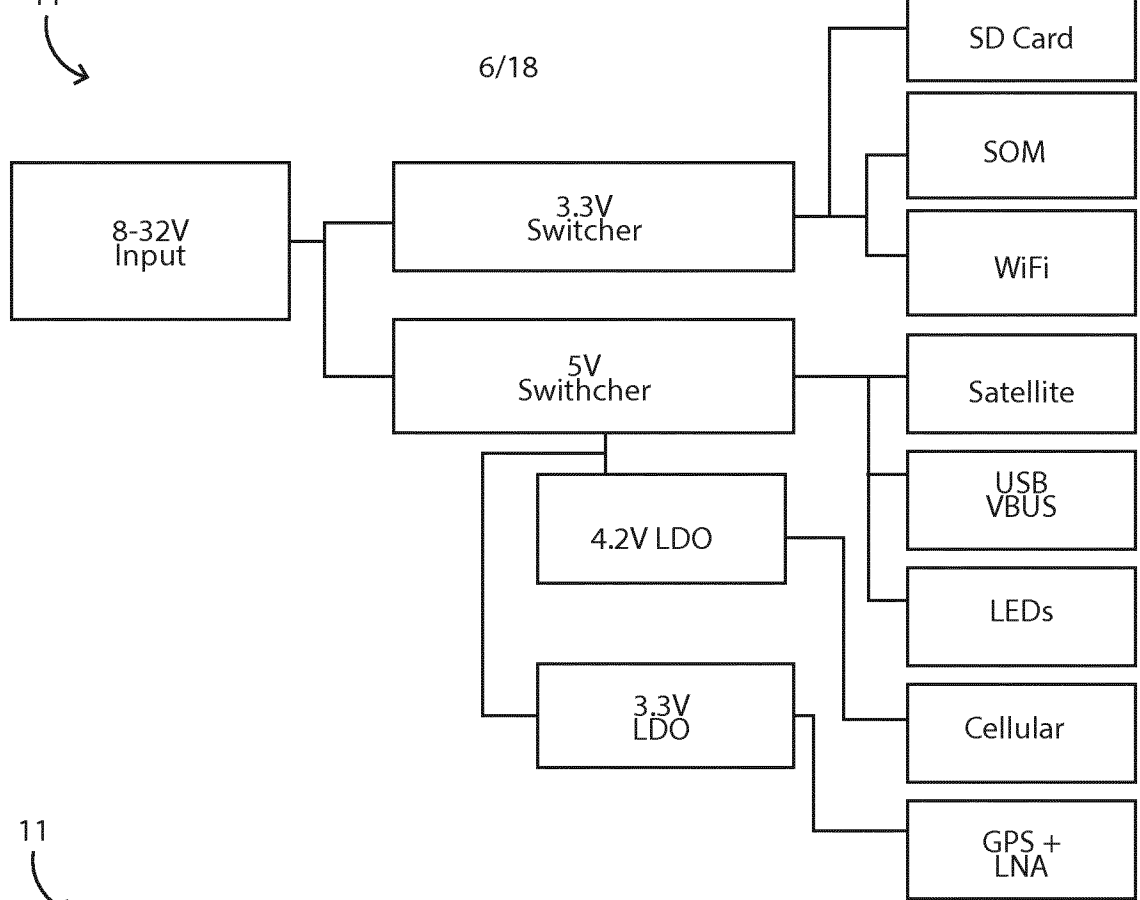


Fig.11

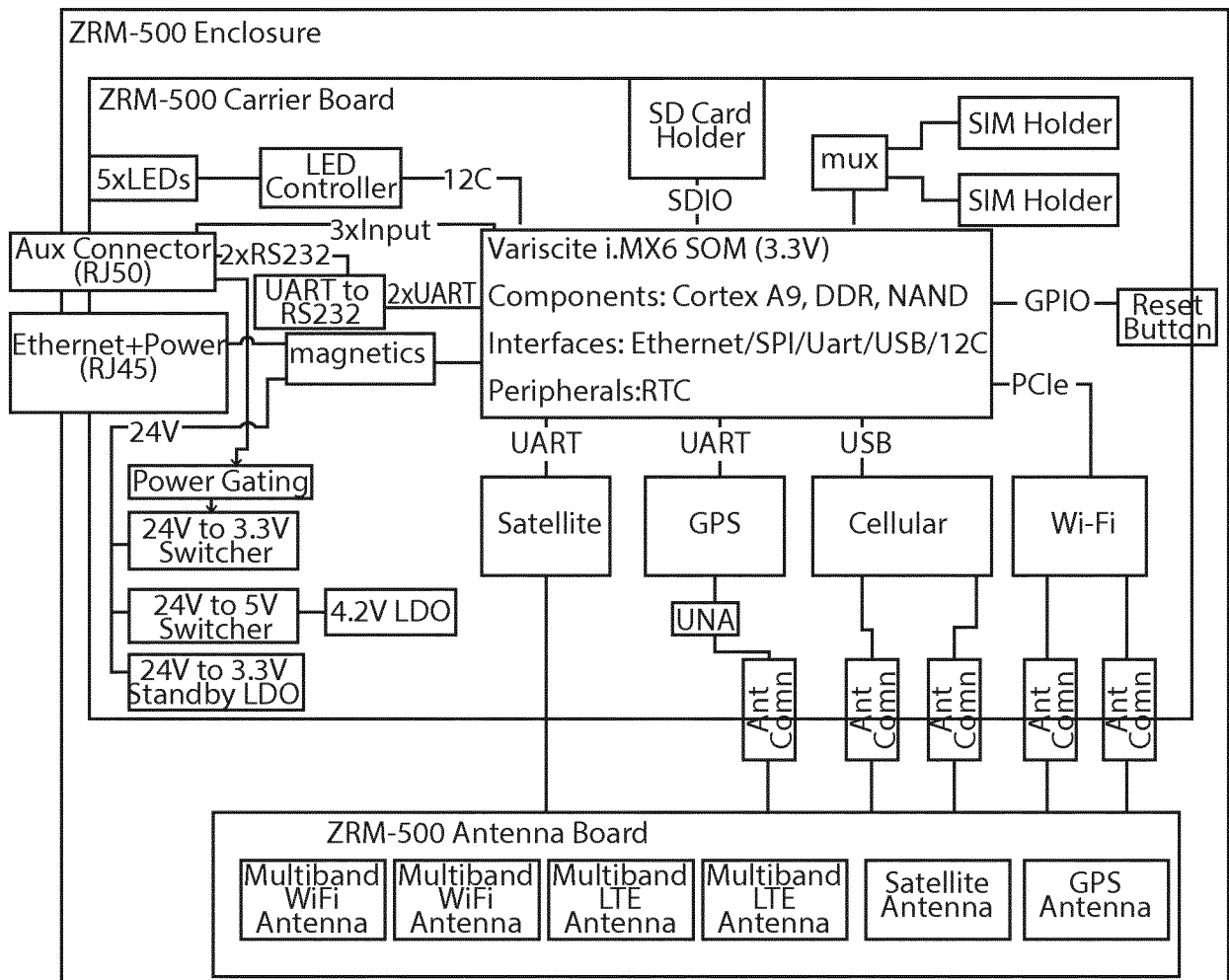


Fig.12

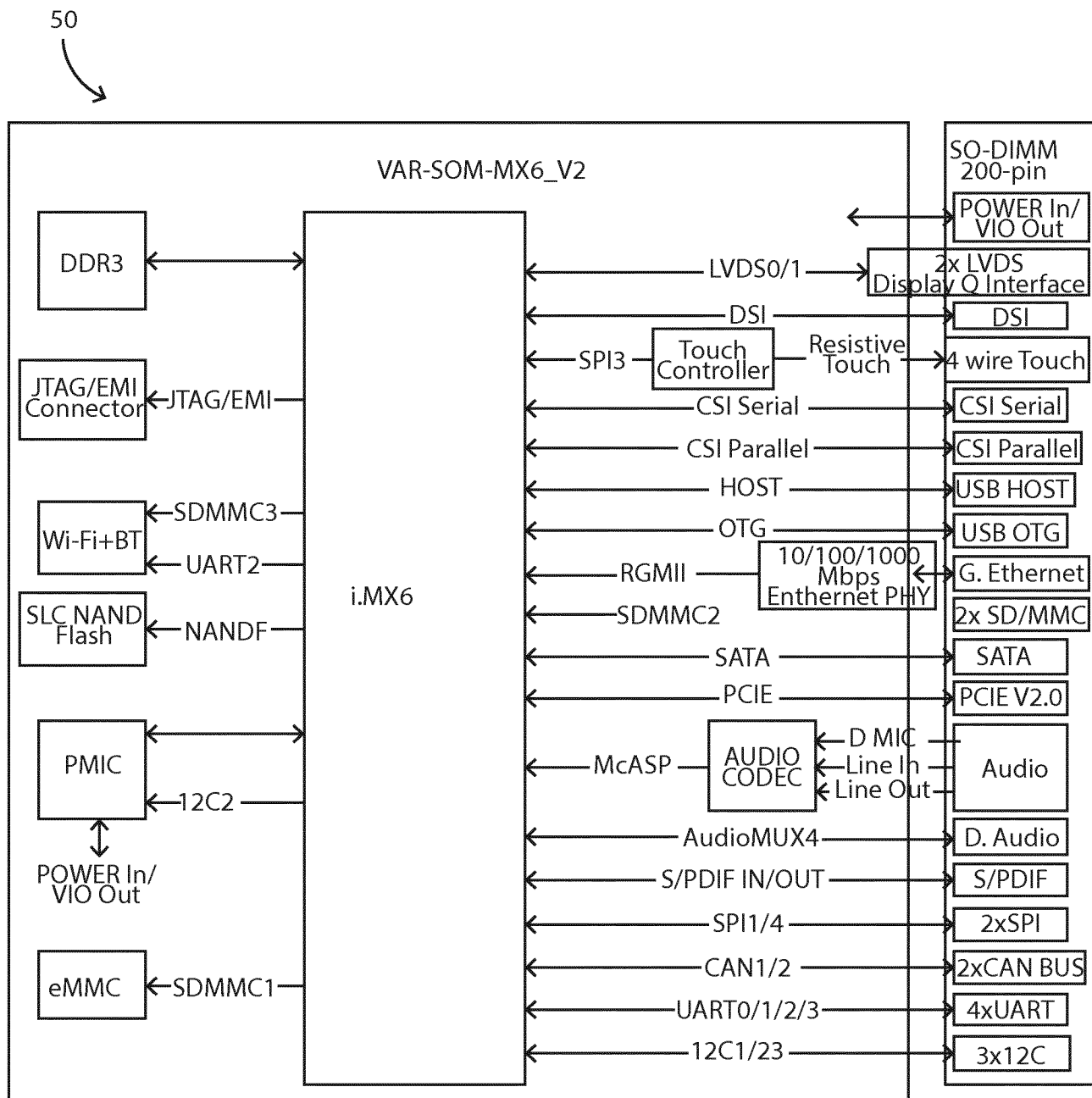
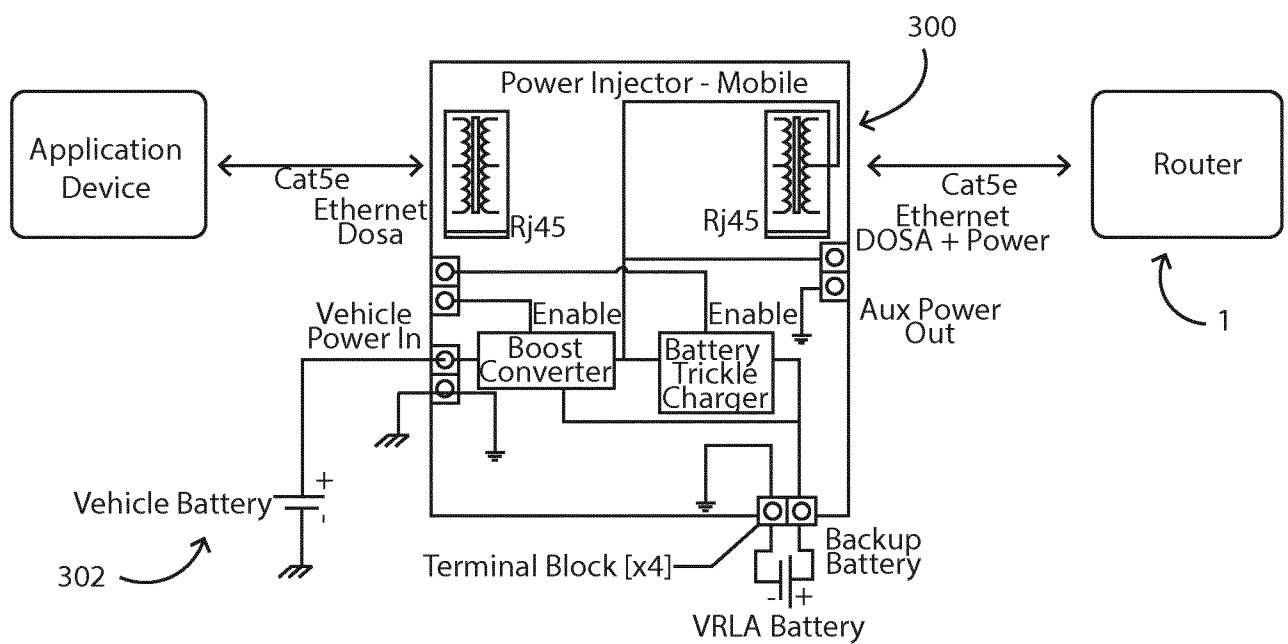
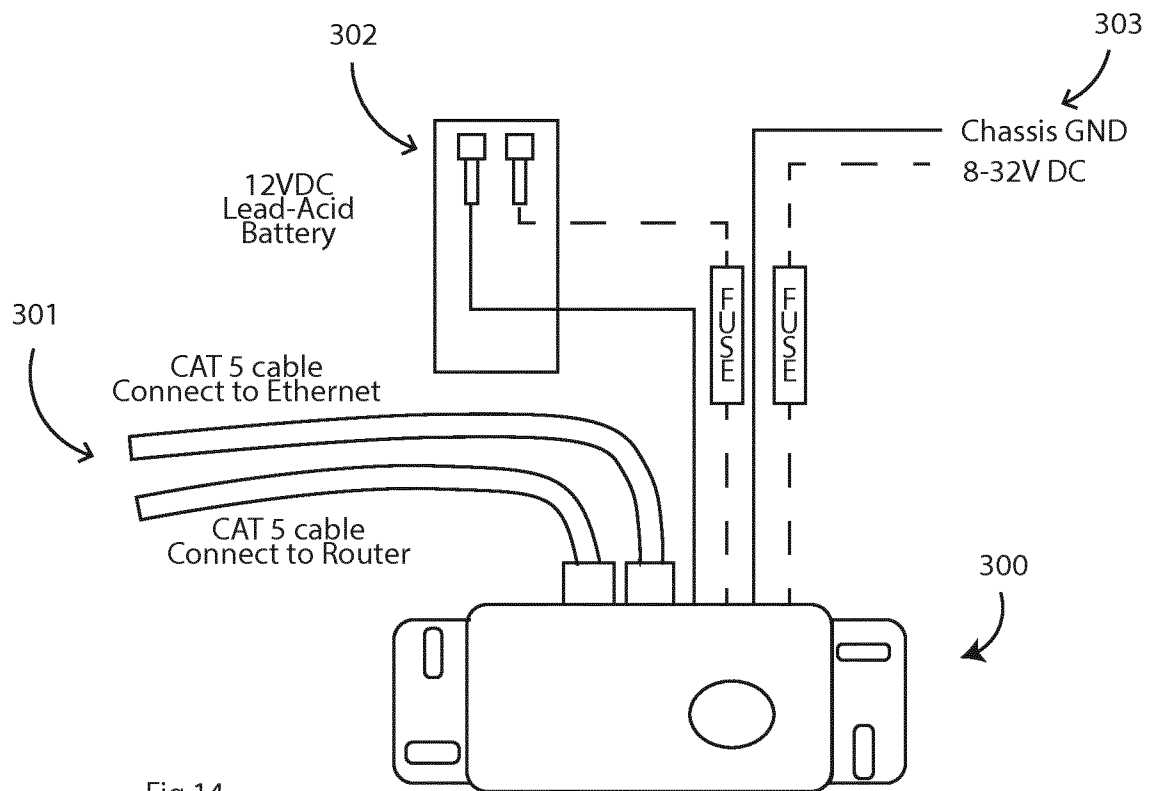


Fig.13



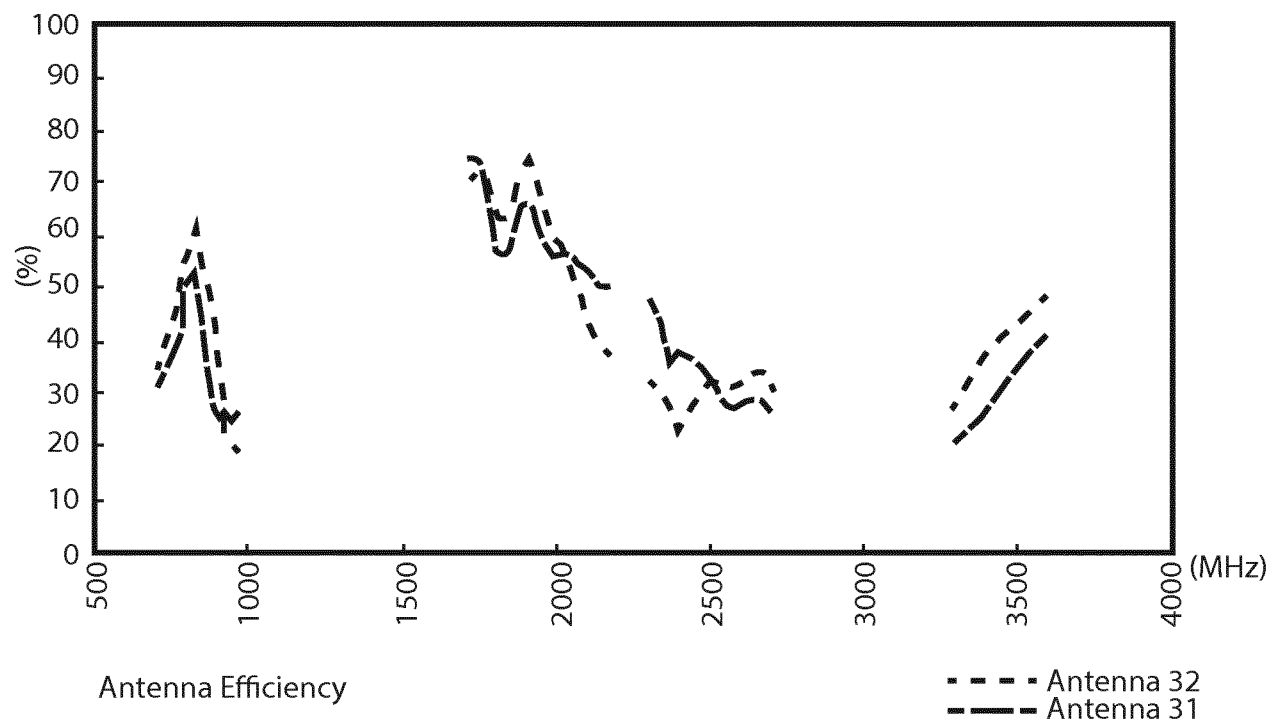
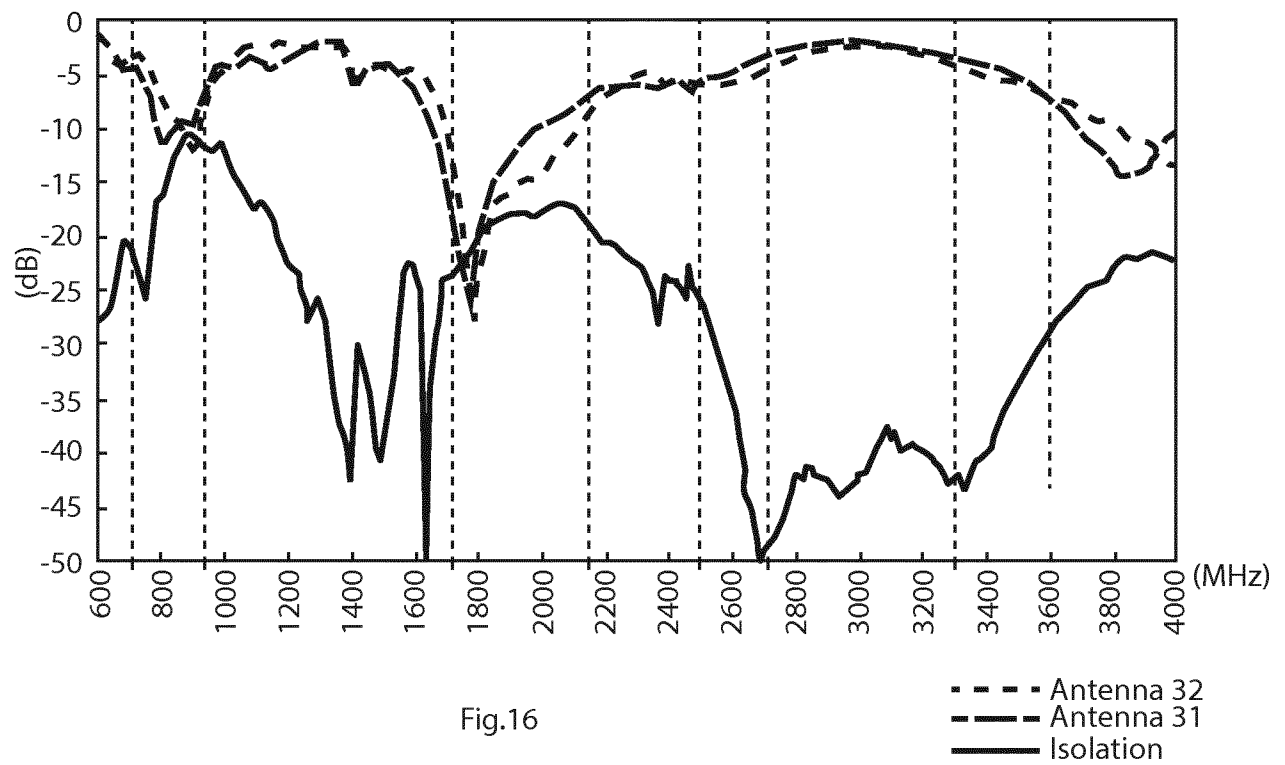


Fig.17

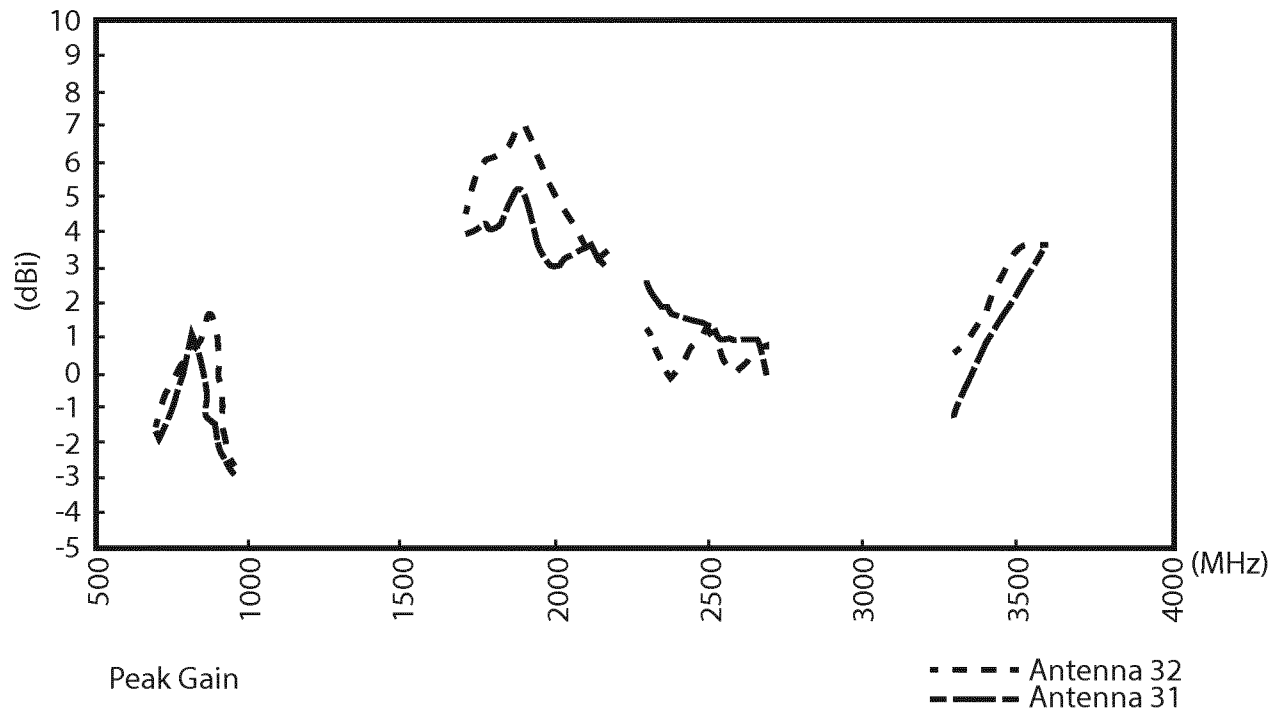


Fig.18

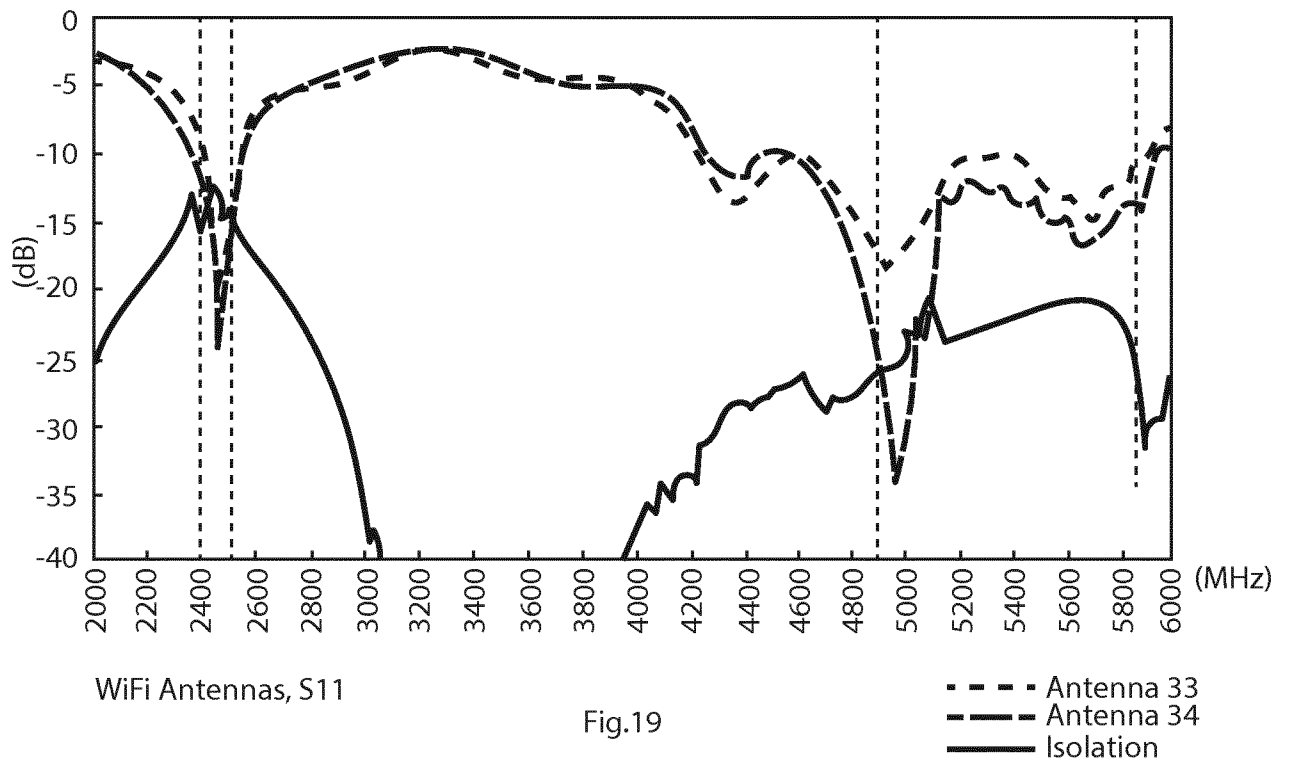
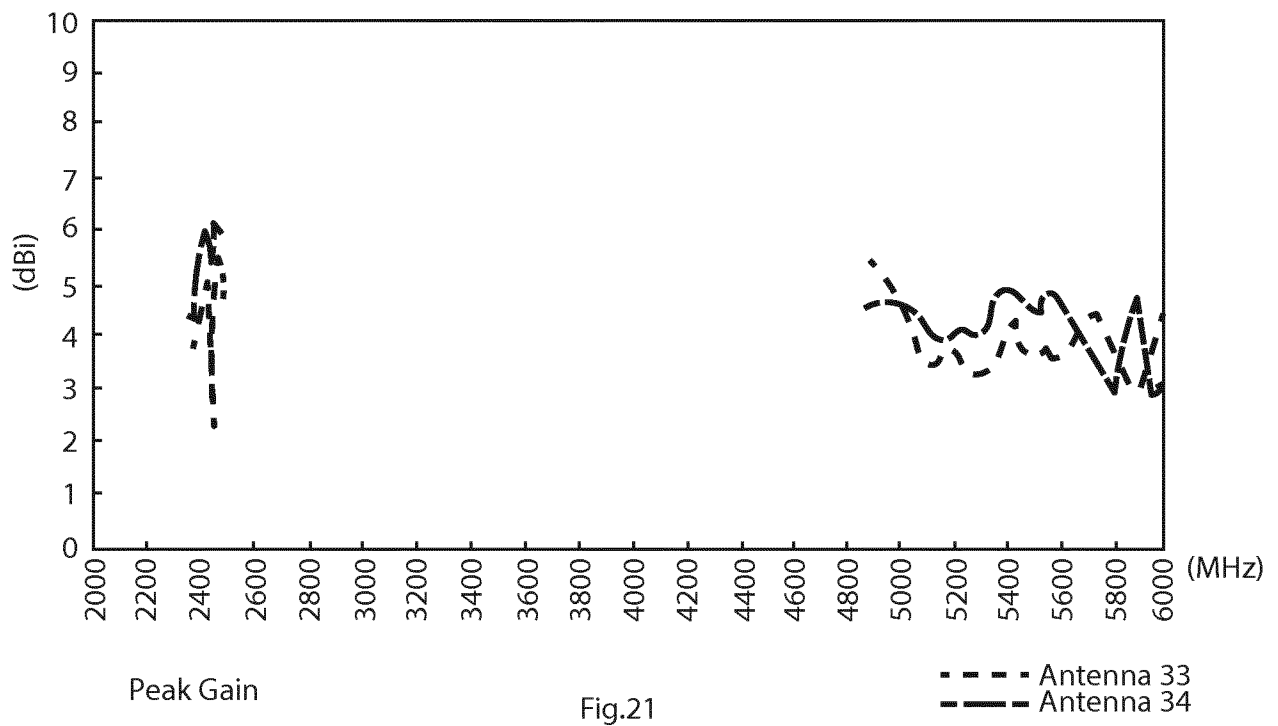
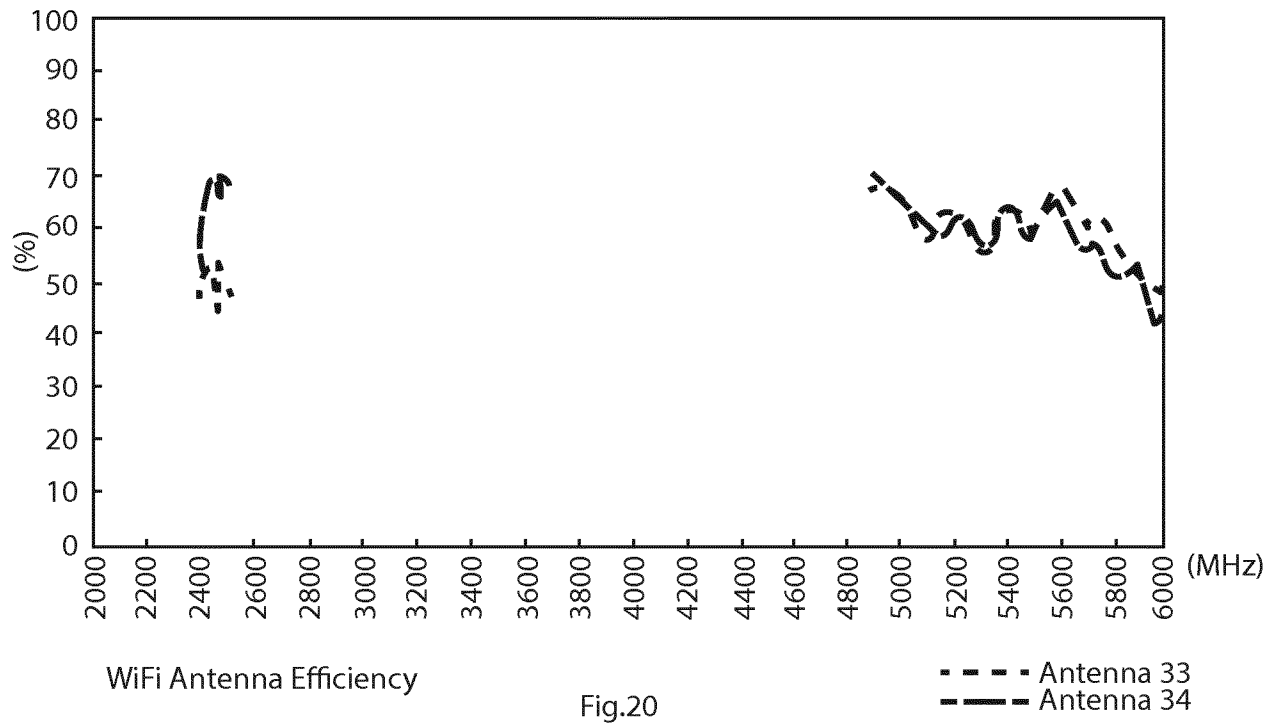


Fig.19



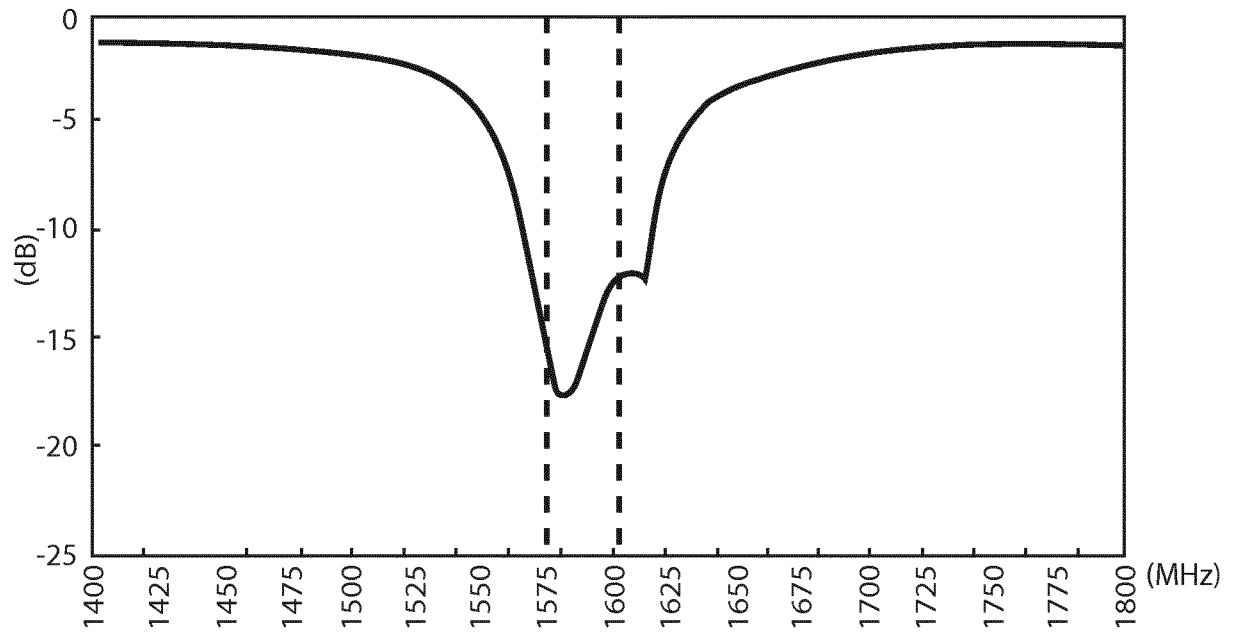
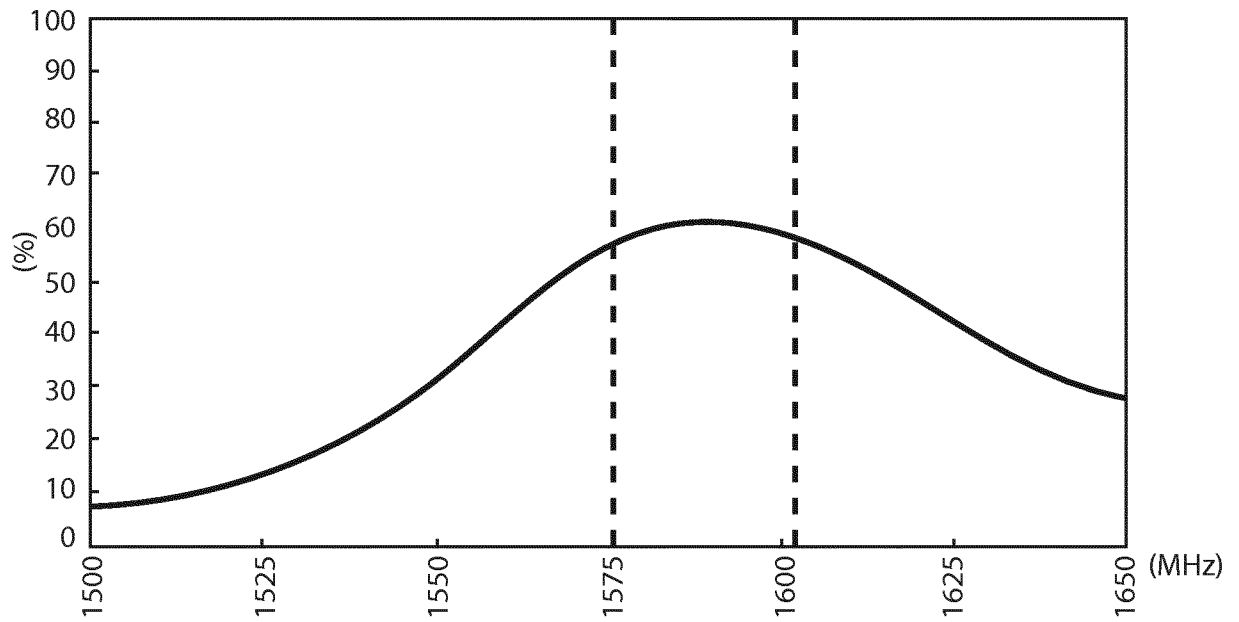
GNSS Patch Antenna 36, S_{11} ,

Fig.22



GNSS patch antenna Efficiency,

Fig.23

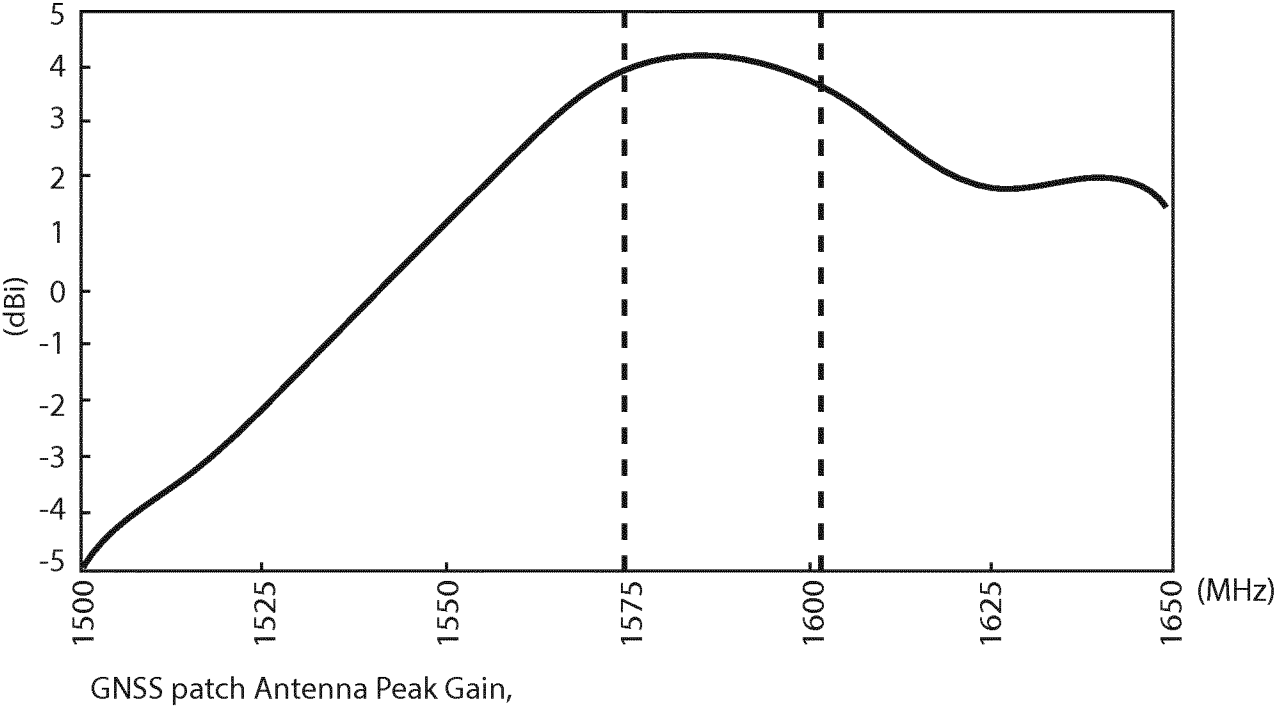
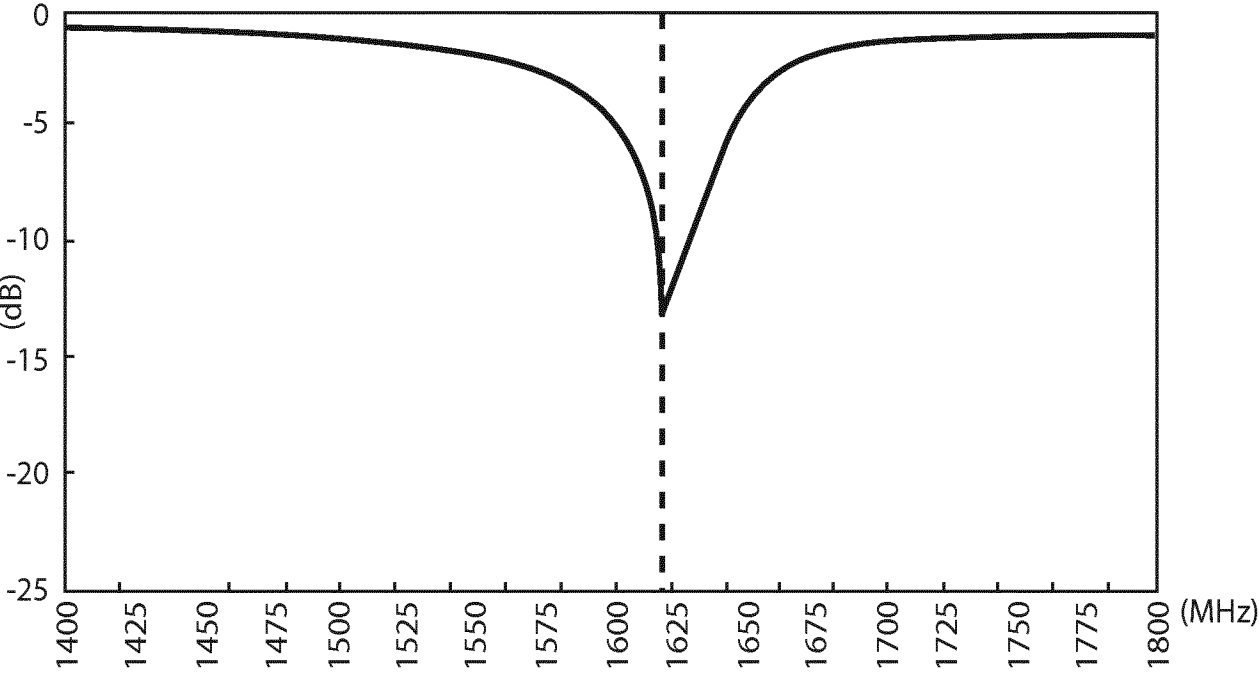
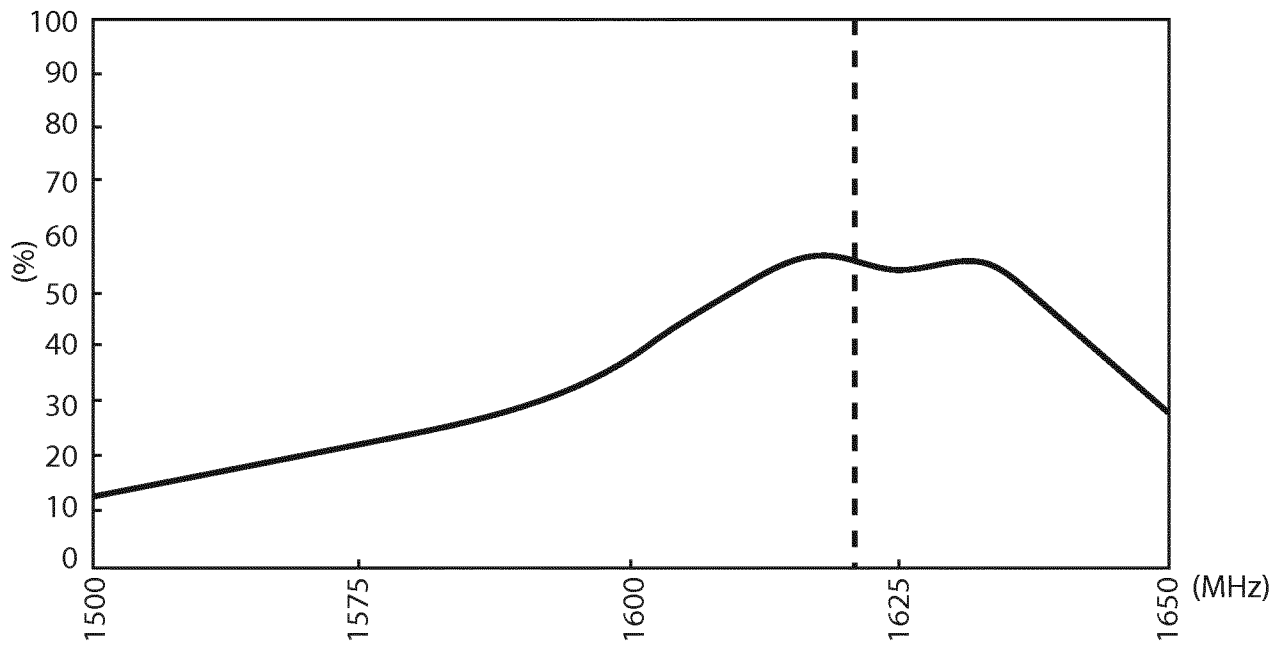


Fig.24

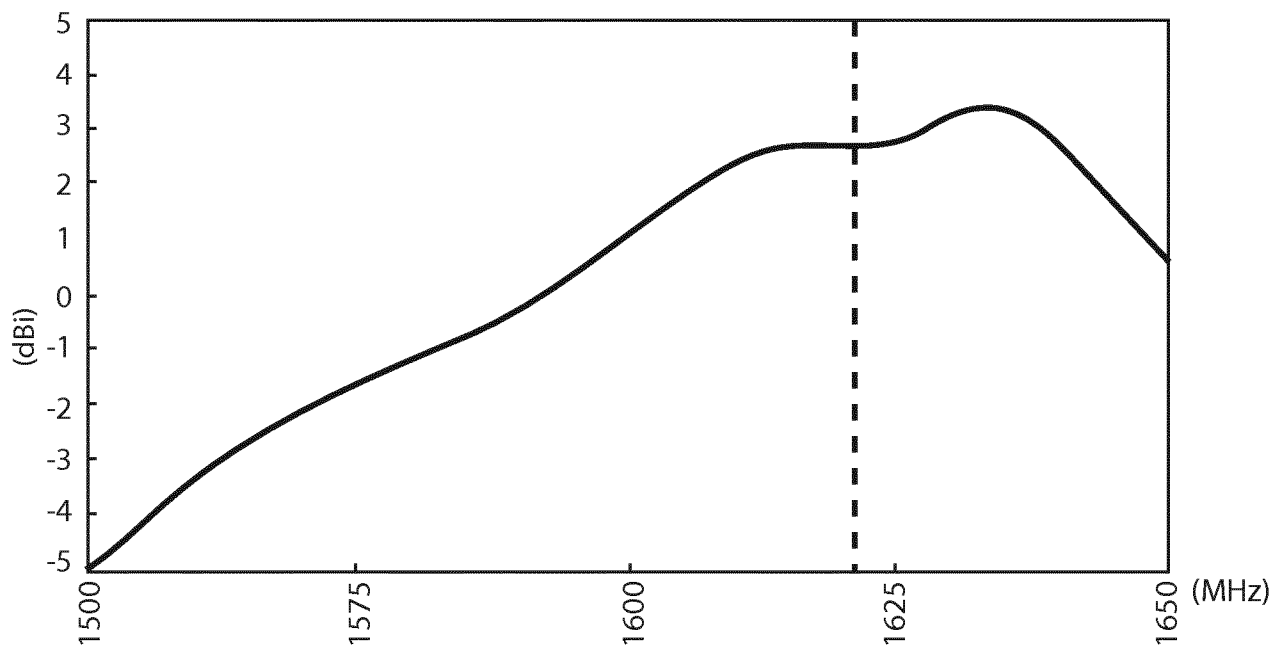


Satellite L-Band Antennas 35, S11, Fig.25



Satellite Antenna 35 Efficiency

Fig.26



Satellite Antenna 35 Peak Gain

Fig.27

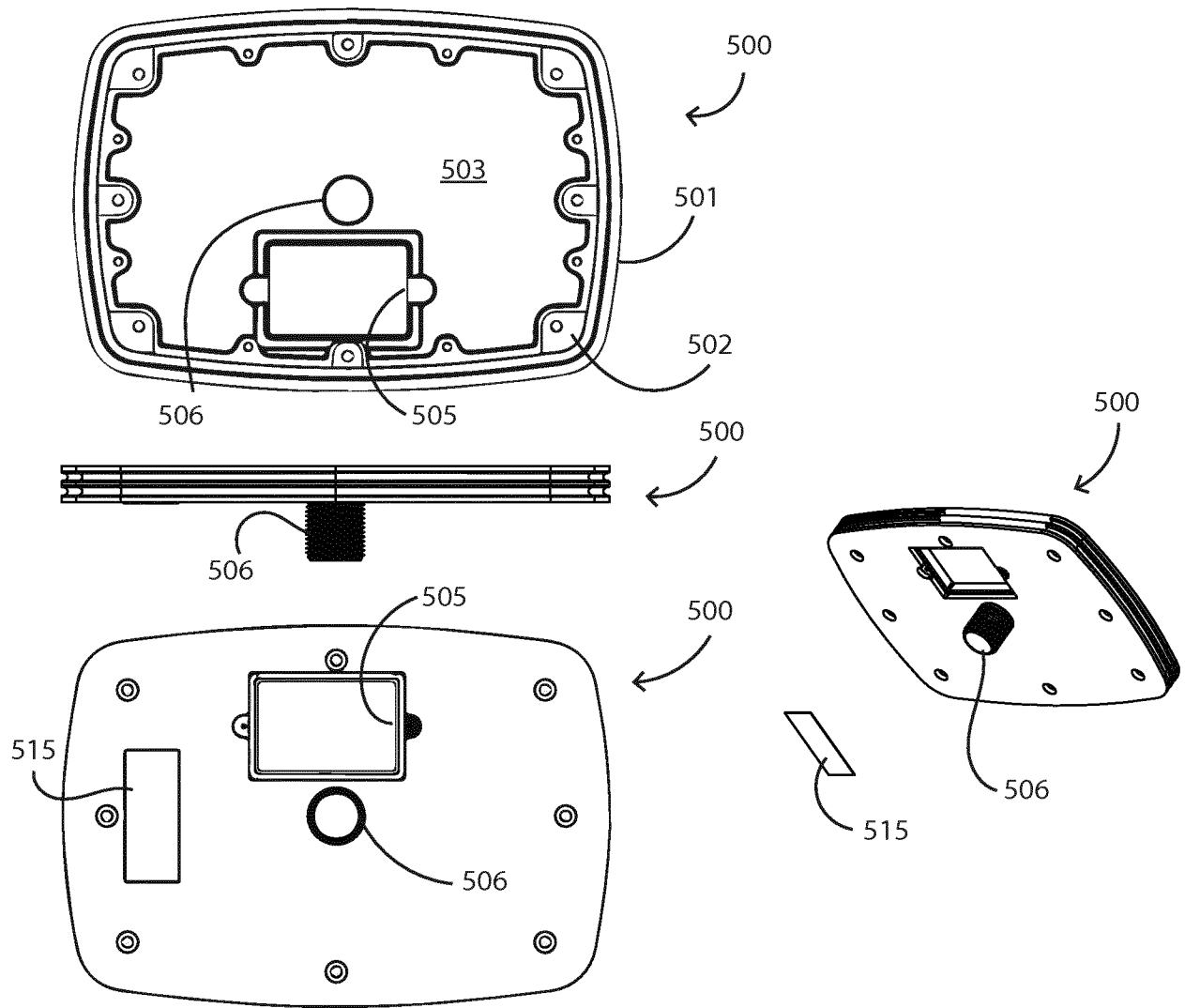


Fig.28

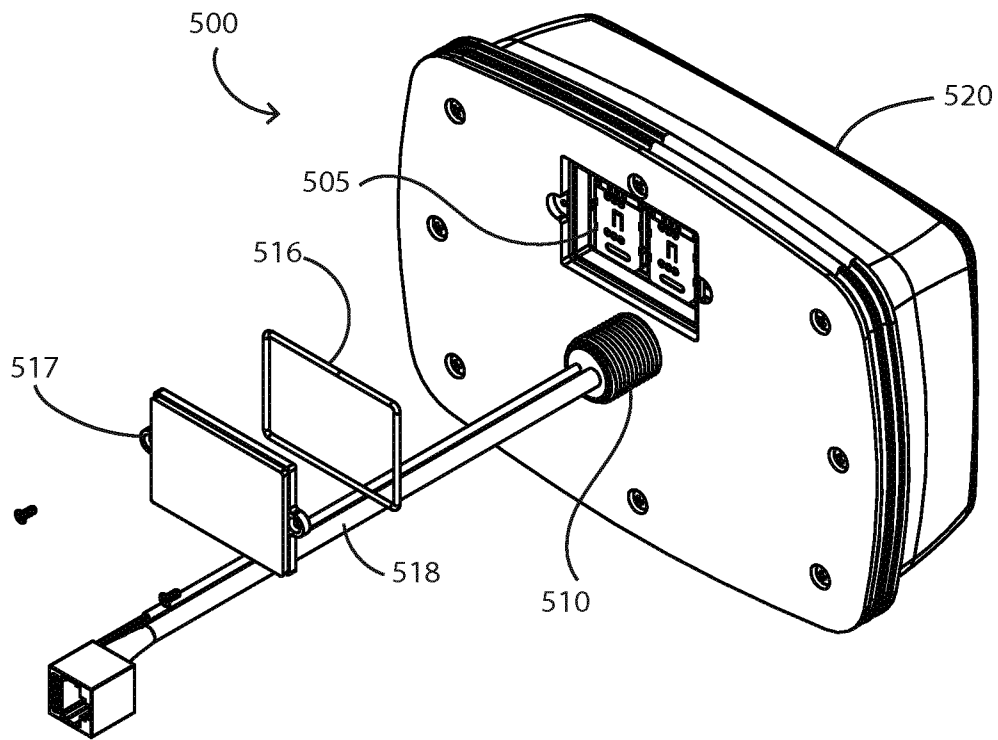


Fig.29

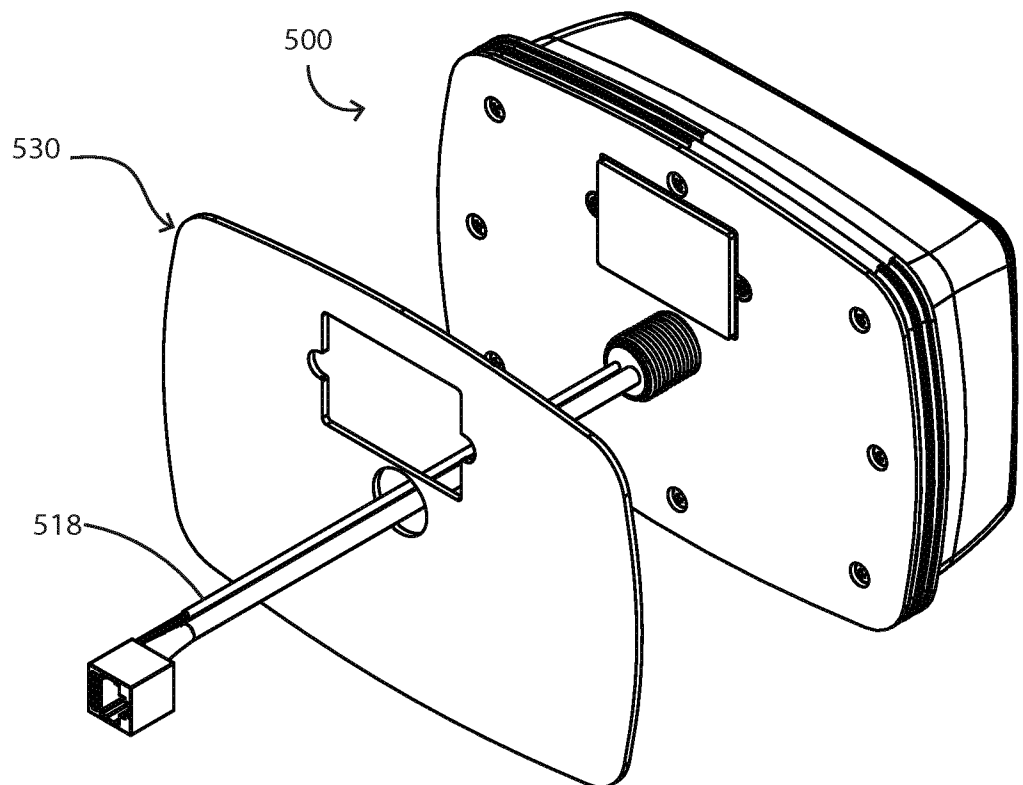


Fig.30

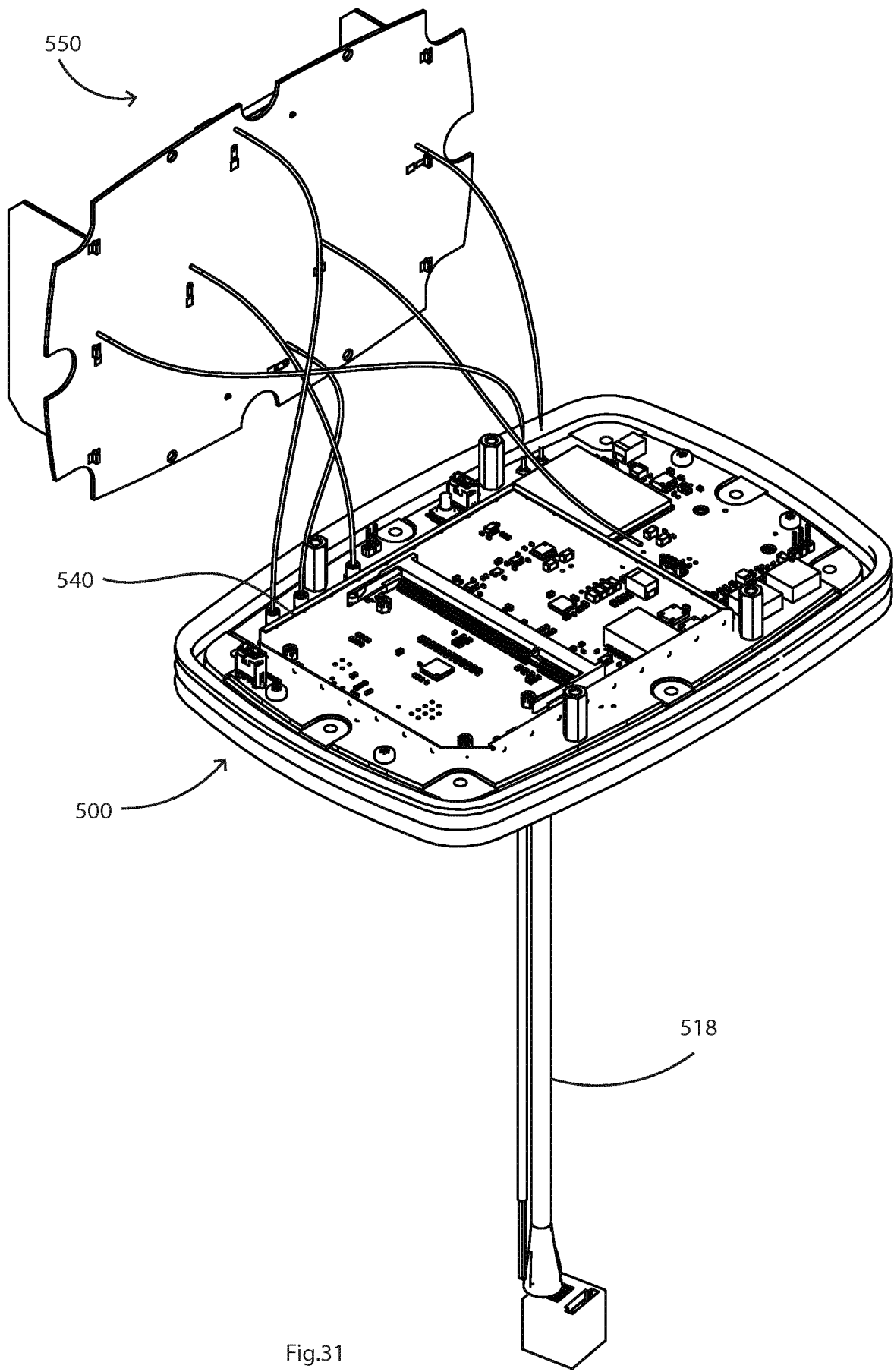


Fig.31

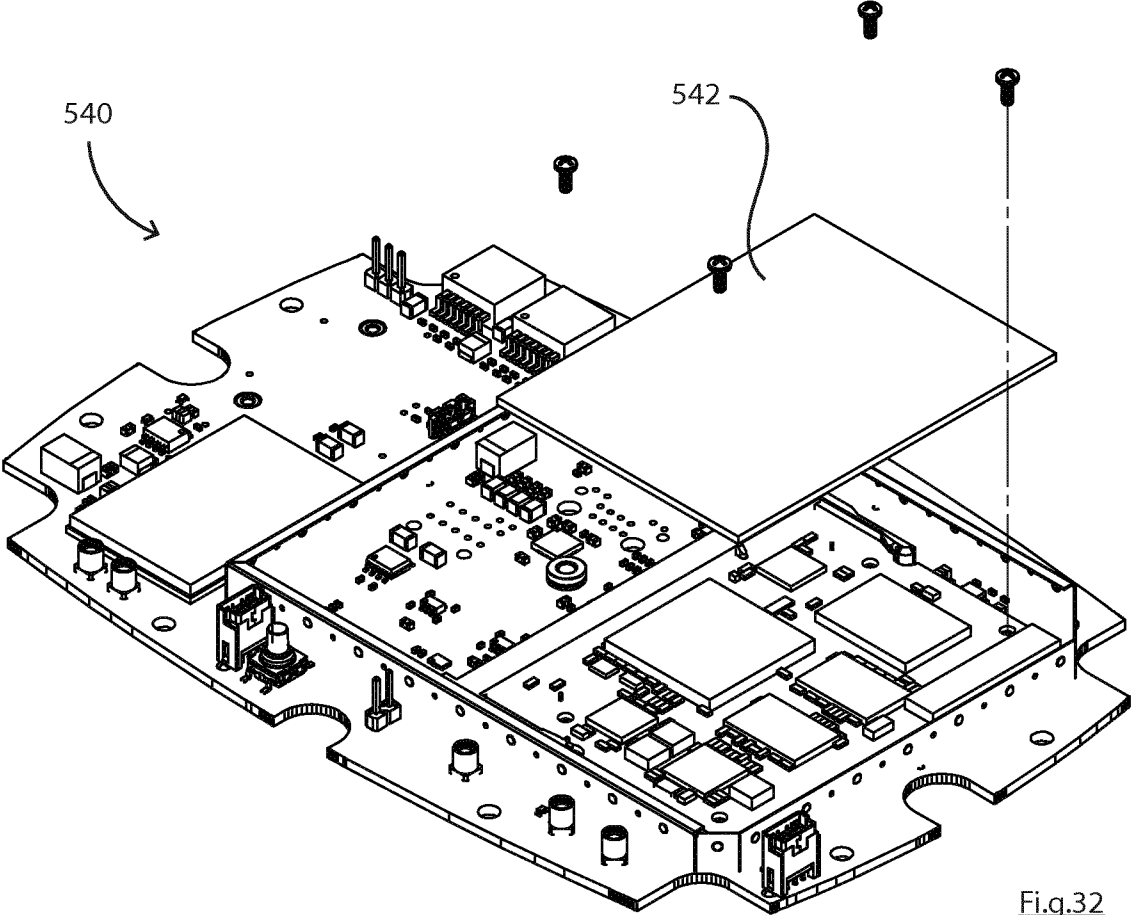


Fig. 32

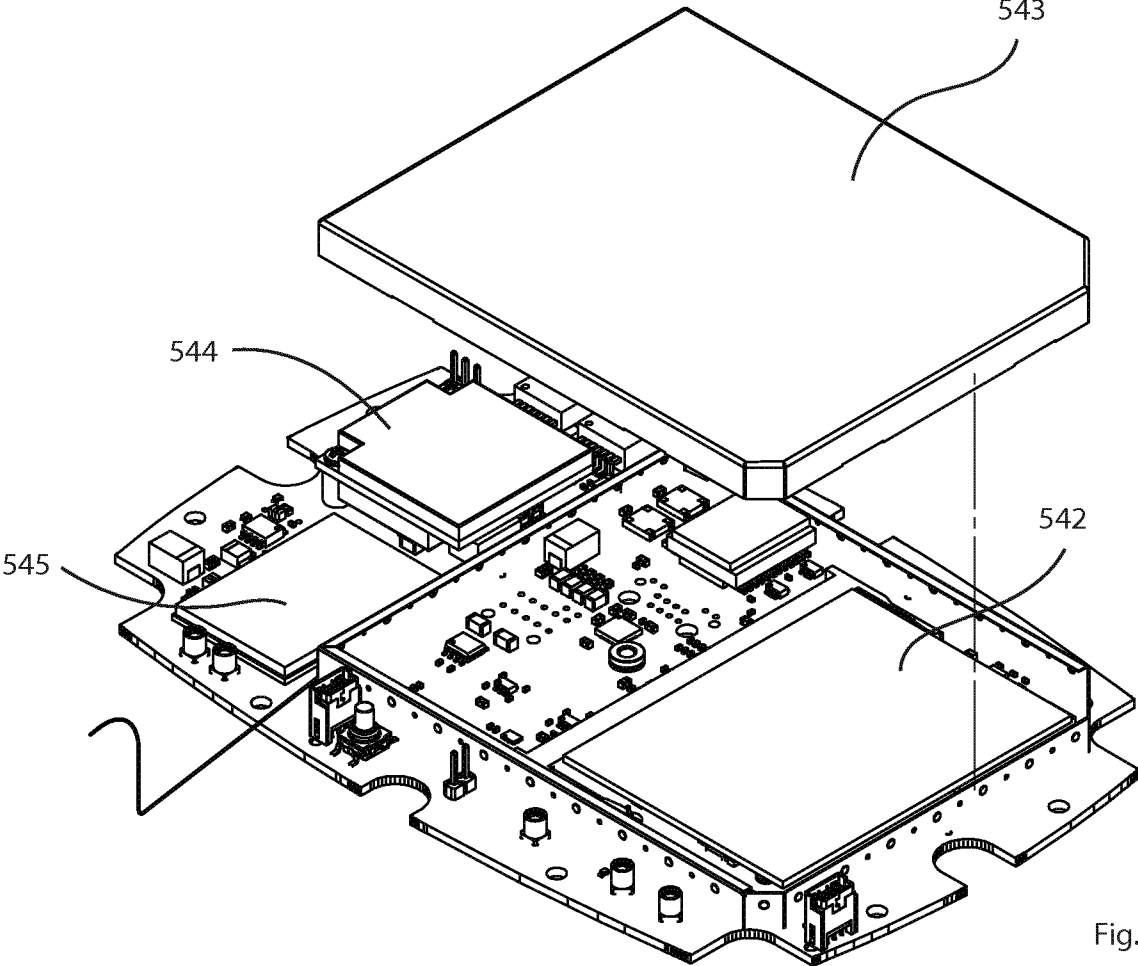


Fig. 33

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/075976

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	H01Q1/02 H01Q9/42	H01Q1/32 H01Q21/28
	H01Q1/42	H01Q1/52
		H01Q9/04
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) H01Q		
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		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/197998 A1 (GOVINDASAMY GURURAJ [US] ET AL) 17 July 2014 (2014-07-17) paragraphs [0013], [0025] - [0032]; figures 2,3,4 -----	1-19, 27-29
X	US 2013/222201 A1 (MA ZHENGXIANG [US] ET AL) 29 August 2013 (2013-08-29) paragraphs [0026], [0027]; figure 2 -----	1-10, 27-29
X	WO 2013/090783 A1 (LAIRD TECHNOLOGIES INC [US]) 20 June 2013 (2013-06-20) paragraphs [0005], [0007], [0011], [0030] - [0042]; figures 1,2,4 -----	1,2, 7-26,29
A	US 2005/219131 A1 (HAIDACHER FLORIAN [DE] ET AL) 6 October 2005 (2005-10-06) paragraphs [0003], [0024] - [0030], [0034]; figure 1 -----	1-29
☐ 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 18 January 2017		Date of mailing of the international search report 25/01/2017
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 Moumen, Abderrahim

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/075976

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014197998	A1	17-07-2014	NONE
US 2013222201	A1	29-08-2013	CN 104145372 A 12-11-2014
		EP 2812948 A1 17-12-2014	
		US 2013222201 A1 29-08-2013	
		US 2013225222 A1 29-08-2013	
		US 2016268694 A1 15-09-2016	
		WO 2013123907 A1 29-08-2013	
		WO 2013123916 A1 29-08-2013	
WO 2013090783	A1	20-06-2013	CN 104115329 A 22-10-2014
		EP 2792020 A1 22-10-2014	
		US 2014292593 A1 02-10-2014	
		WO 2013090783 A1 20-06-2013	
US 2005219131	A1	06-10-2005	AT 352108 T 15-02-2007
		DE 10330087 B3 20-01-2005	
		EP 1616367 A1 18-01-2006	
		ES 2279388 T3 16-08-2007	
		JP 4260186 B2 30-04-2009	
		JP 2009514253 A 02-04-2009	
		US 2005219131 A1 06-10-2005	
		WO 2005004280 A1 13-01-2005	