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(54) **VOLUMETRIC SCAN AUTOMOTIVE RADAR WITH END-FIRE ANTENNA ON PARTIALLY LAMINATED MULTI-LAYER PCB**

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G01S 13/93	(2006.01)
H01Q 21/06	(2006.01)
G01S 13/00	(2006.01)

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CPC ***H01Q 1/3233*** (2013.01); ***G01S 7/03*** (2013.01); ***G01S 13/931*** (2013.01); ***H01Q 1/3283*** (2013.01); ***H01Q 21/067*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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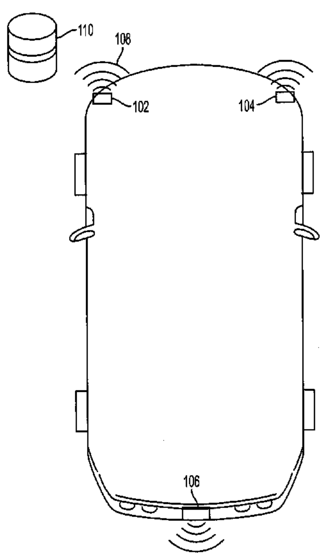
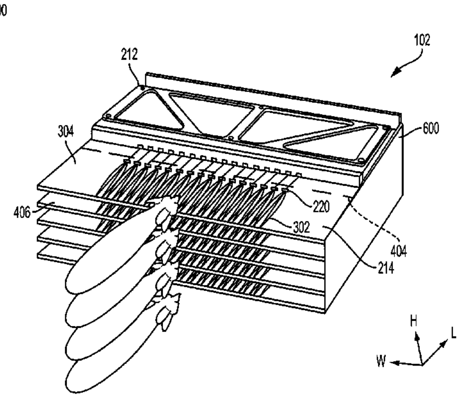
(57) **ABSTRACT**

A vehicular radar system includes a first printed circuit board (PCB) having a first material. The vehicular radar system also includes a plurality of end-fire antennas positioned on the first PCB. The vehicular radar system also includes a second PCB stacked on or under the first PCB and having a second material that has a greater rigidity than the first material. The vehicular radar system also includes a radio frequency integrated circuit (RFIC) coupled to the plurality of end-fire antennas and configured to control the plurality of end-fire antennas.

20 Claims, 7 Drawing Sheets





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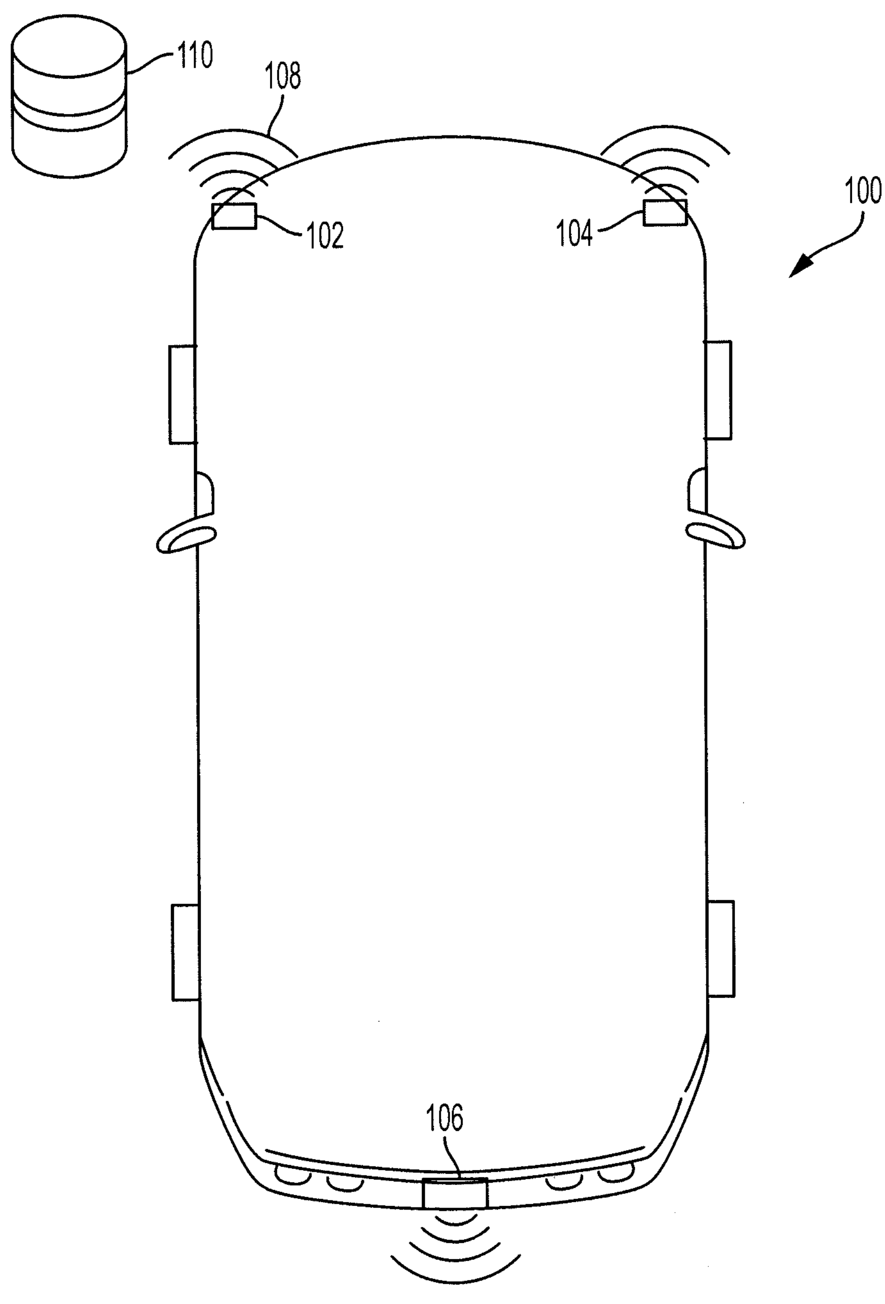

FIG. 1

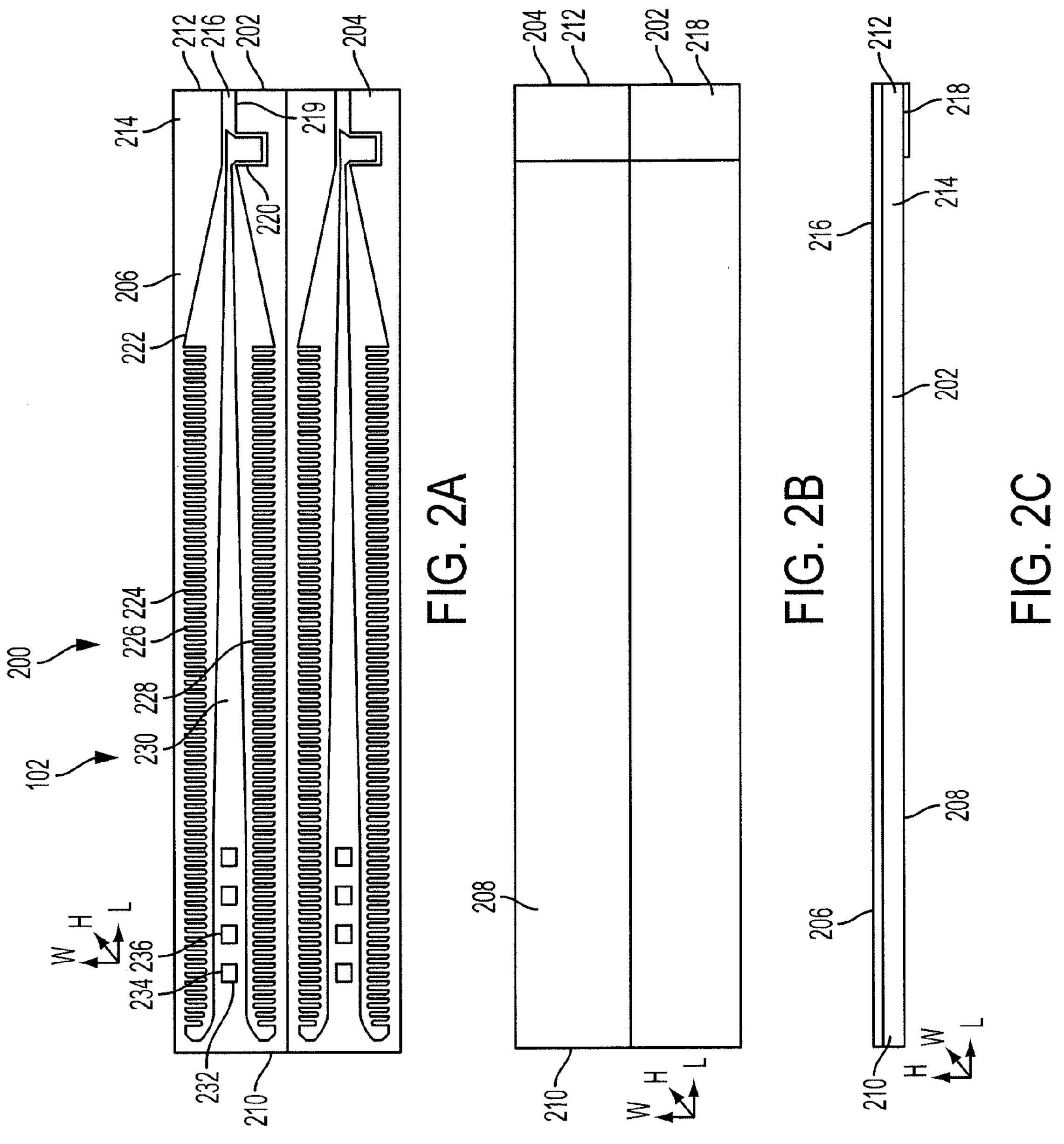

FIG. 2A

FIG. 2B

FIG. 2C

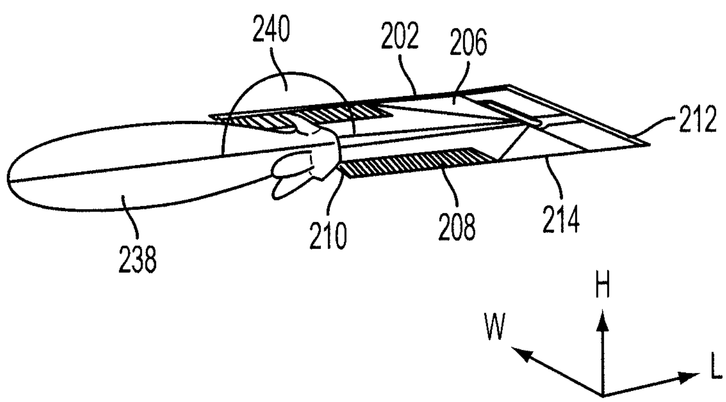

FIG. 2D

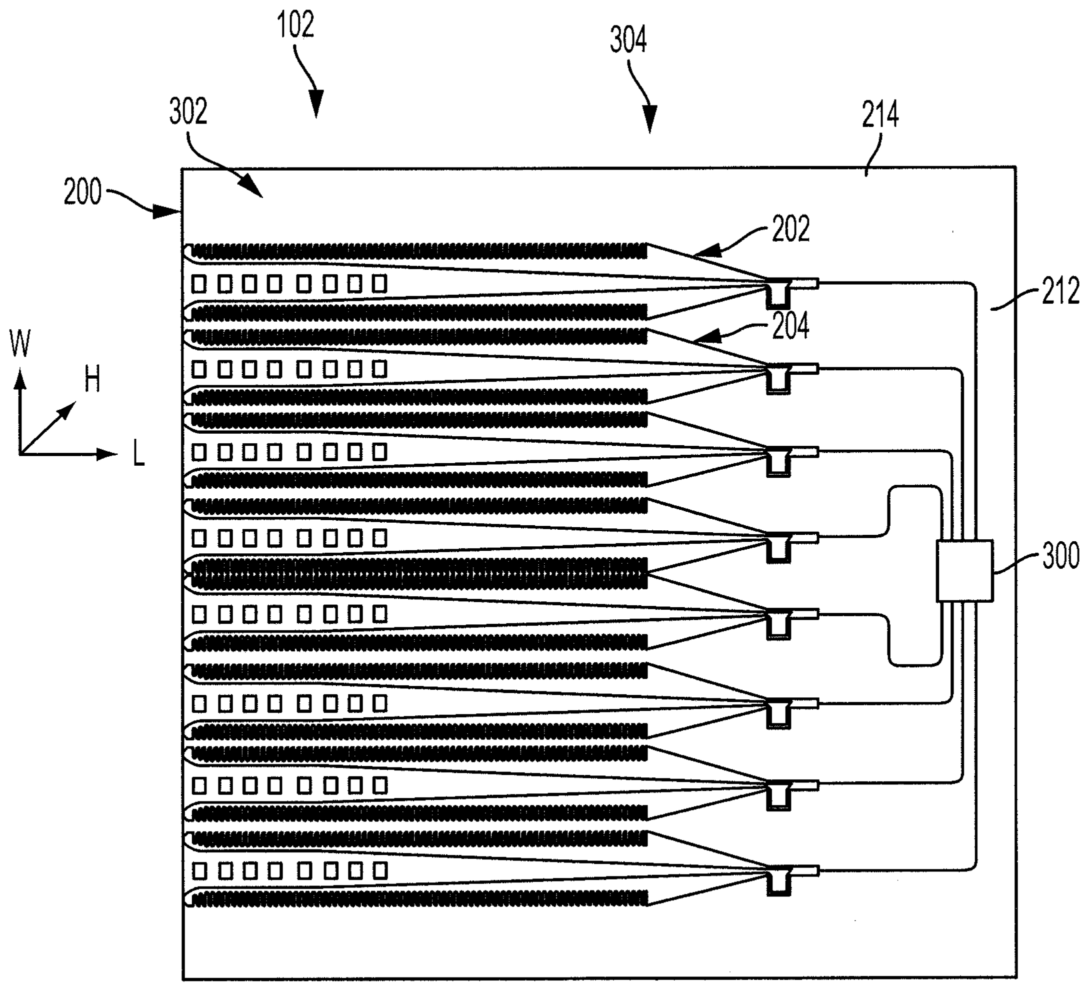

FIG. 3

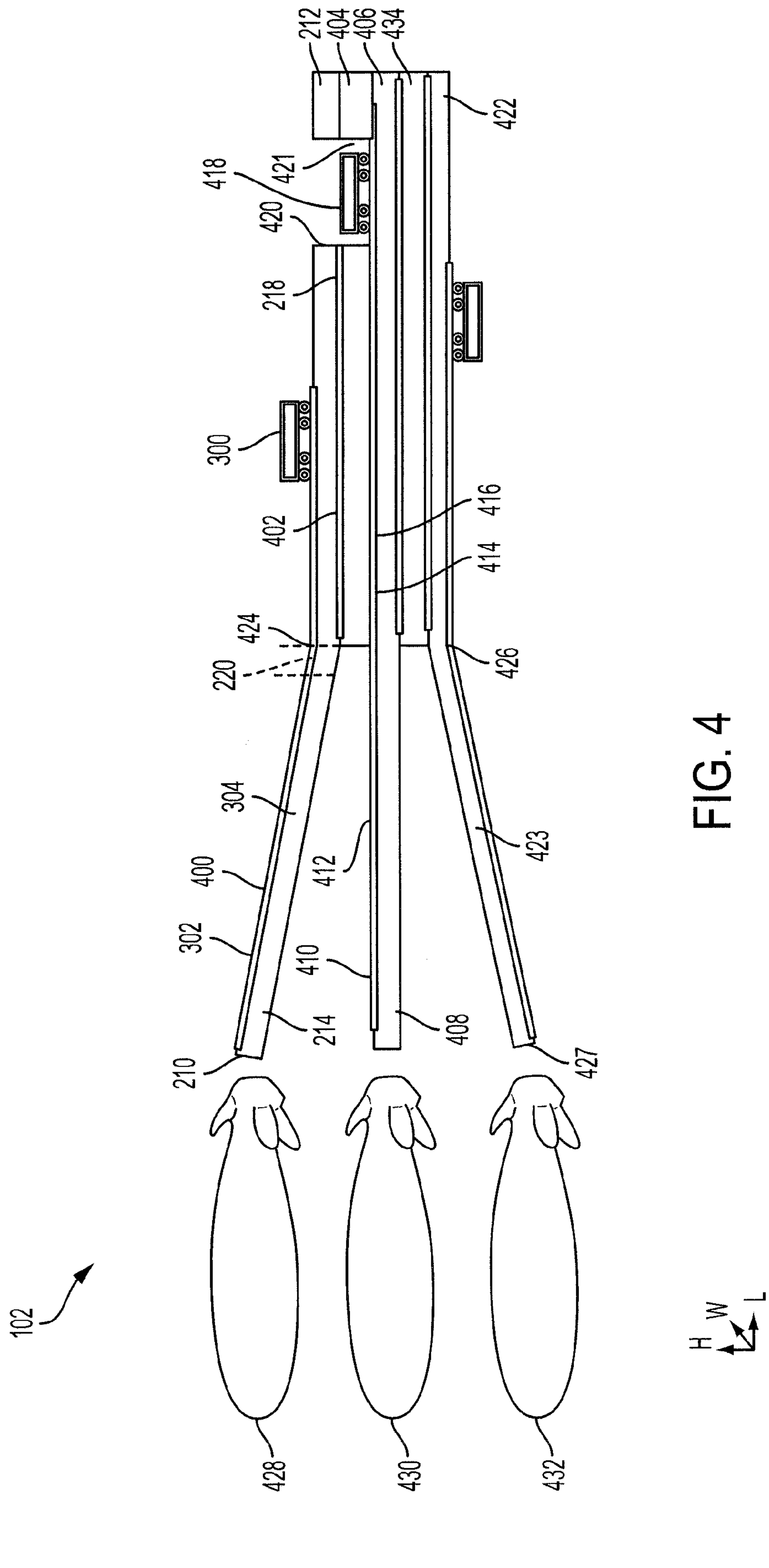
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FIG. 4

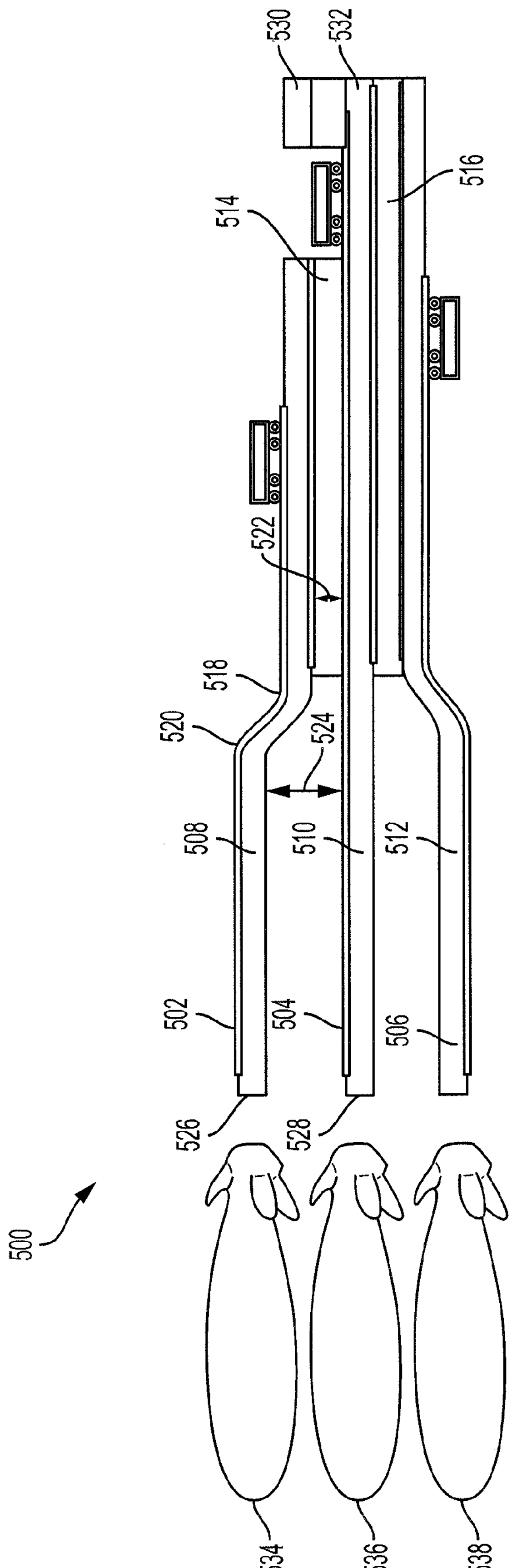
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FIG. 5

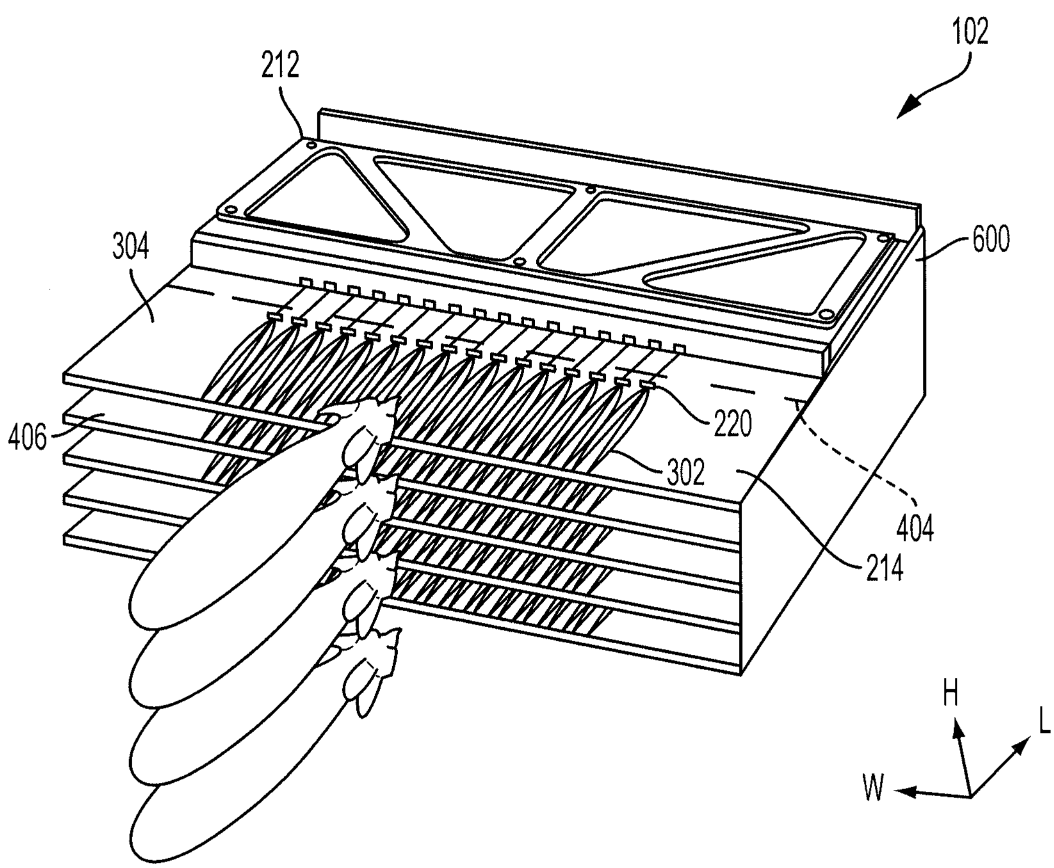

FIG. 6

VOLUMETRIC SCAN AUTOMOTIVE RADAR WITH END-FIRE ANTENNA ON PARTIALLY LAMINATED MULTI-LAYER PCB

BACKGROUND

1. Field

The present disclosure relates to vehicular radar systems and, in particular, to a vehicular radar system having high-frequency printed circuit boards with antennas and low-frequency printed circuit boards stacked between the high-frequency printed circuit boards for structurally supporting the high frequency printed circuit boards.

2. Description of the Related Art

Autonomous and semi-autonomous vehicle functions are increasing in use. For example, some vehicle manufacturers are currently designing fully autonomous and semi-autonomous vehicles that can drive themselves from a starting location to a destination location. Some other vehicles include collision avoidance features that may warn a driver and/or control operations of a vehicle when detected data indicates that the vehicle may collide with another object. Algorithms for these autonomous and semi-autonomous vehicle features are based on detection of objects in the vicinity of the vehicle, such as street signs, other vehicles, people, and the like.

Many vehicles incorporate radar systems to detect such objects. Vehicular radar systems transmit a radar signal having a frequency of about 80 gigahertz (GHz) through the air. The radar signal is reflected from a target and the reflected signals or waves are then received by the vehicular radar system. The characteristics of the reflected signals are analyzed by a processor or a controller to determine characteristics of the objects that reflected the signal, such as a size of the object, a distance between the object and the vehicle, or the like.

Vehicular radar systems include antennas that transmit the radar signals. Typically, the antennas include metal traces on a printed circuit board (PCB). In order to reduce interference with the high-frequency radar signals, it is desirable for the PCB to be made from certain materials and to be relatively thin. The relative thinness and the materials used for such a PCB result in the PCB being relatively flexible or malleable.

Thus, there is a need for systems and methods for increasing the rigidity of end-fire antennas used in vehicular radar systems.

SUMMARY

Described herein is a vehicular radar system. The vehicular radar system includes a first printed circuit board (PCB) having a first material. The vehicular radar system also includes a plurality of end-fire antennas positioned on the first PCB. The vehicular radar system also includes a second PCB stacked on or under the first PCB and having a second material that has a greater rigidity than the first material. The vehicular radar system also includes a radio frequency integrated circuit (RFIC) coupled to the plurality of end-fire antennas and designed to control the plurality of end-fire antennas.

Also described is a vehicular radar system. The vehicular radar system includes a first radar board having a first printed circuit board (PCB) made of a first material and having a chip connection end and a transmission end and a

first plurality of end-fire antennas. The vehicular radar system also includes a second radar board having a second PCB made of the first material and having a chip connection end and a transmission end and a second plurality of end-fire antennas. The vehicular radar system also includes a third PCB stacked between the first PCB and the second PCB and made of a second material that has a greater rigidity than the first material. The vehicular radar system also includes at least one radio frequency integrated circuit (RFIC) coupled to the first plurality of end-fire antennas and the second plurality of end-fire antennas and designed to control each of the first plurality of end-fire antennas and each of the second plurality of end-fire antennas.

Also described is a vehicular radar system. The vehicular radar system includes a first printed circuit board (PCB) having a chip connection end, a transmission end, a top, and a bottom. The vehicular radar system also includes a plurality of end-fire antennas positioned on the first PCB. Each of the plurality of end-fire antennas includes a ground structure positioned adjacent to the chip connection end of the first PCB on the bottom of the first PCB. Each of the plurality of end-fire antennas also includes a chip connection lead positioned adjacent to the chip connection end of the first PCB and electrically coupled to the RFIC. Each of the plurality of end-fire antennas also includes a balun positioned adjacent to the chip connection lead and configured to convert an unbalanced signal to a balanced signal or to convert a balanced signal to an unbalanced signal. Each of the plurality of end-fire antennas also includes a wave section having a first wave section and a second wave section separated by a space and configured to transmit a wireless radar signal. Each of the plurality of end-fire antennas also includes a tapered section positioned between the balun and the wave section and tapered towards the balun from the wave section. The vehicular radar system also includes a second PCB coupled to the top or the bottom of the first PCB, having a greater rigidity than the first PCB, and positioned between the balun of each of the plurality of end-fire antennas and the chip connection end of the first PCB. The vehicular radar system also includes a radio frequency integrated circuit (RFIC) coupled to the plurality of end-fire antennas and designed to control the plurality of end-fire antennas.

BRIEF DESCRIPTION OF THE DRAWINGS

Other systems, methods, features, and advantages of the present invention will be or will become apparent to one of ordinary skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present invention, and be protected by the accompanying claims. Component parts shown in the drawings are not necessarily to scale, and may be exaggerated to better illustrate the important features of the present invention. In the drawings, like reference numerals designate like parts throughout the different views, wherein:

FIG. **1** is a drawing of a vehicle having multiple vehicular radar systems for sensing objects in an environment of the vehicle according to an embodiment of the present invention;

FIG. **2A** is a drawing showing a top view of two end-fire antennas of an end-fire antenna array according to an embodiment of the present invention;

FIG. **2**B is a drawing showing a bottom view of the end-fire antenna array of FIG. **2**A according to an embodiment of the present invention;

FIG. **2**C is a drawing showing a side view of the end-fire antenna array of FIG. **2**A according to an embodiment of the present invention;

FIG. **2**D is a drawing illustrating a shape of a radar beam transmitted by one of the end-fire antennas of FIG. **2**A according to an embodiment of the present invention;

FIG. **3** is a drawing illustrating a two-dimensional radar board having the end-fire antenna array of FIG. **2**A and a radio frequency integrated circuit (RFIC) coupled to the end-fire antenna array according to an embodiment of the present invention;

FIG. **4** is a drawing illustrating a cross-section of a vehicular radar system including multiple two-dimensional radar boards and multiple relatively rigid low-frequency printed circuit boards stacked between the two-dimensional radar boards according to an embodiment of the present invention;

FIG. **5** is a drawing illustrating a cross-section of another vehicular radar system including multiple two-dimensional radar boards and multiple relatively rigid low-frequency printed circuit boards stacked between the two-dimensional radar boards according to an embodiment of the present invention; and

FIG. **6** is a drawing illustrating the vehicular radar system of FIG. **4** positioned within a housing according to an embodiment of the present invention.

DETAILED DESCRIPTION

The present invention provides systems for structurally supporting end-fire antennas of a vehicular radar system. The system includes relatively rigid low-frequency printed circuit boards (PCBs) stacked between or sandwiched between relatively flexible high-frequency PCBs. The system also includes multiple end-fire antennas positioned on each of the high frequency PCBs and a radio frequency integrated circuit (RFIC) positioned on each of the high-frequency PCBs. The high-frequency PCBs are designed to reduce interference of signals of the end-fire antennas and the RFIC. In order to reduce the interference, the high-frequency PCBs may be relatively thin and/or made from a relatively malleable material. Because the low-frequency PCBs do not transmit signals having radar frequencies, they may be designed to have a greater rigidity than the high-frequency PCBs. Thus, by stacking or sandwiching the low-frequency PCBs between the high-frequency PCBs, the low-frequency PCBs provide support for the relatively flexible high-frequency PCBs.

The PCBs of the vehicular radar system are stacked in such a way that the transmission ends of the high-frequency PCBs (where the signals are transmitted by the end fire antennas) are separated from the low-frequency PCBs. Due to the malleability of the high-frequency PCBs, the transmission ends of the high-frequency PCBs can be reshaped in such a way that the end-fire antennas transmit signals in a desired direction.

The systems described herein provide several benefits and advantages such as providing structural support for relatively flexible high-frequency PCBs that contain end-fire antennas and RFICs. This advantageously reduces the likelihood of damage to the high-frequency PCBs. Use of relatively rigid low-frequency PCBs to support the high frequency PCBs is advantageously less expensive and more compact than alternative support options such as housings designed to separately support each of the high frequency-PCBs. The separation of the transmission end of the high-frequency PCBs from the low-frequency PCBs advantageously allows the transmission ends of the high-frequency PCBs to be oriented in a desirable direction. This provides the benefit and advantage of allowing signals from the end-fire antennas to be transmitted in a desired direction, advantageously increasing an area that can be scanned by the vehicular radar system at any given time.

Turning to FIG. **1**, a vehicle **100** having radar sensing capabilities is shown. The vehicle **100** includes a first vehicular radar system **102**, a second vehicular radar system **104**, and a third vehicular radar system **106**. Each of the vehicular radar systems **102**, **104**, **106** may determine the location and characteristics of objects around the vehicle **100**. For example, the vehicular radar system **102** may transmit a signal or a beam **108**. The beam **108** may reflect off of an object **110** and propagate back towards the vehicular radar system **102**. The vehicular radar system **102** may receive the reflected signal and determine a location and characteristics of the object **110** based on the received reflected signal.

Turning to FIGS. **2**A, **2**B, and **2**C, a top view, a bottom view, and a side view, respectively, of an end-fire antenna array **200** are shown. The end-fire antenna array **200** may be included in the vehicular radar system **102**. An L-W-H axis is shown in various drawings to illustrate directions corresponding to a length, a width, and a height of the vehicular radar system **102**. Although features are described with reference to the length, the width, and the height, one skilled in the art will realize that the vehicular radar system **102** may be oriented in any direction such that, for example, a height may be referred to as a length and so forth.

The end-fire antenna array **200** has a plurality of end-fire antennas including a first end-fire antenna **202** and a second end-fire antenna **204**. In some embodiments, the antenna array **200** may include between 2 and 32 end-fire antennas.

The antenna array **200**, and thus the first antenna **202** and the second antenna **204**, has a top **206** and a bottom **208**. The tell is top and bottom are used for reference only. One skilled in the art will realize that the top **206** and the bottom **208** of the antenna array **200** may be oriented in any direction.

The first antenna **202** may include a metal **216** inside of or on a PCB **214**. The metal **216** may be, for example, a metal trace printed on the PCB **214**. The PCB **214** includes a transmission end **210** and a chip connection end **212**. The transmission end **210** is an end of the PCB **214** from which signals propagate into the atmosphere from the antenna array **200**. The chip connection end **212** of the PCB **214** is an end of the PCB **214** from which a signal propagates from an RFIC towards the first antenna **202**.

A signal from a controller, such as an RFIC designed to transmit signals in a radio frequency, may be received by the first antenna **202** at the chip connection end **212**. The signal may propagate through the first antenna **202** towards the transmission end **210**. From the transmission end, the signal may be wirelessly transmitted into the atmosphere in the longitudinal direction (i.e., in the negative L direction).

Similarly, a wireless signal (such as a signal reflected off of an object) may be received by the first antenna **202** at the transmission end **210** and may propagate through the first antenna **202** to the chip connection end **212**. The signal may then be received by the controller and analyzed by the controller to determine features of the object from which it was reflected.

The metal **216** of the first antenna **202** may include tin, gold, nickel, any other conductive metal, or any combination thereof. The metal **216** on the bottom **208** of the first antenna **202** may form a ground structure **218**. The ground structure **218** may be electrically isolated from the metal **216** on the top **206** of the first antenna **202** and may be connected to an electrical ground.

The metal **216** on the top **206** of the first antenna **202** may form an antenna structure including a chip connection lead **219**, a balun **220**, a tapered section **222**, and a wave section **224**. In some embodiments, the metal **216** on the top **206** of the first antenna **202** may also form one or more beam adjustment feature **232** including a first beam adjustment feature **234** and a second beam adjustment feature **236**. The first antenna **202** and the second antenna **204** may each be referred to as tapered slot end-fire antennas.

The chip connection lead **219** may be electronically connected to a controller, such as an RFIC, that controls operation of the antenna array **200**.

The balun **220** may function as a transformer and convert an unbalanced signal to a balanced signal and/or may convert a balanced signal to an unbalanced signal.

The tapered section **222** is tapered from the wave section **224** to the balun **220**. The converted signal may propagate through the tapered section **222** towards the wave section **224**.

The wave section **224** may include a first wave section **226** and a second wave section **228** separated by a space **230**. The design of the wave section **224** allows the signal propagating towards the transmission end **210** to continue to propagate beyond the wave section **224** in a wireless manner.

The beam adjustment features **232** may be included or adjusted to alter characteristics of a signal transmitted by the first antenna **202**. The beam adjustment features **232** may be positioned within the space **230**. The beam adjustment features **232** may have any shape such as the square shape that is shown, a triangular shape, a parallelogram shape, or the like. The beam adjustment features **232** may be electrically isolated from the other metal **216** on the top **206** of the first antenna **202** or may be in electrical contact with the other metal **216**.

Turning to FIG. **2**D, the first antenna **202** functions as an end-fire antenna because it transmits a signal or a beam **238** that propagates in a direction parallel to a longitudinal direction of the first antenna **202** (i.e., in the negative L direction). This is distinguished from a signal transmitted by a broadside antenna that propagates perpendicular to a longitudinal direction of an antenna (i.e., in the positive H direction).

Referring to FIGS. **2**A and **2**D, the beam adjustment features **232** may be varied to adjust characteristics of the beam **238**. For example, a quantity of the beam adjustment features **232**, a shape of the beam adjustment features **232**, and/or dimensions of the beam adjustment features **232** may be selected to achieve desirable characteristics of the beam **238**. In some embodiments, the quantity, the shape, and/or the dimensions of the beam adjustment features **232** may be selected in order for the beam **238** to form a desired angle **240** with the top **206** or the bottom **208** of the PCB **214**.

Returning reference to FIGS. **2**A, **2**B, and **2**C, bandwidths for automotive radar systems may be about 80 gigahertz (GHz), such as between 77 GHz and 79 GHz. Where used in this context, "about" refers to the referenced value plus or minus seven percent (7%). The end-fire antennas, including tapered slot end-fire antennas, provide desirable characteristics at these bandwidths. The end-fire antennas may be positioned adjacent to each other, as shown in FIG. **2**A, in order to form a beam that scans in two dimensions. Furthermore, because the signal propagates away from the antenna in the longitudinal direction, the end-fire antennas may be stacked on top of each other, allowing for a volumetric (three-dimensional) scan.

In order to obtain desirable antenna properties of signals having bandwidths in the automotive spectrum, the substrate of the antenna array **200** (i.e., the PCB **214**) may be relatively thin. For example, the first antenna **202** (including the PCB **214**) may have a height of 0.127 mm in the H direction, a width of 2.5 mm in the W direction, and a length of 10 mm to 30 mm in the L direction.

Turning now to FIG. **3**, the vehicular radar system **102** may include a two-dimensional radar board **304**. The two-dimensional radar board **304** may include the end-fire antenna array **200** that includes a plurality of end-fire antennas **302**. The two-dimensional radar board **304** may also include an RFIC **300**. The RFIC **300** may be connected to each of the plurality of end-fire antennas **302** of the end-fire antenna array **200**. The RFIC **300** may be connected to the PCB **214**, and thus the plurality of end-fire antennas **302**, in any of a variety of manners such as flipchip bonding, wire bonding, or the like.

The RFIC **300** may control operation of each of the plurality of end-fire antennas **302**. For example, the RFIC **300** may transmit a signal to each antenna of the plurality of end-fire antennas **302**, which in turn may be wirelessly transmitted by the corresponding antenna.

The RFIC **300** may control the plurality of end-fire antennas **302** to transmit one or more radar beams. For example, at least some of the signals transmitted by the RFIC **300** to each of the plurality of end-fire antennas **302** may have a different phase. When the signals have a different phase and are transmitted into the atmosphere, the combined signals form a radar beam.

When the beam reaches an object away from the two-dimensional radar board **304**, the beam may reflect from the object and travel towards the two-dimensional radar board **304**. The reflected beam may be received by the end-fire antennas **302** and/or other end-fire antennas and may be transmitted from the antennas to the RFIC **300**. The RFIC **300** may analyze the received beam that was reflected from the object and determine characteristics of the object based on the reflected beam.

Because the antennas **302** of the two-dimensional radar board **304** are positioned in a linear manner with respect to each other, the two-dimensional radar board **304** may scan in two dimensions. When two or more two-dimensional radar boards are stacked such that antennas are positioned in two directions with respect to each other, the radar boards may together scan in three dimensions.

Turning to FIG. **4**, additional features of the vehicular radar system **102** are shown. As described above, the vehicular radar system **102** includes the two-dimensional radar board **304** that has the PCB **214**, the plurality of end-fire antennas **302**, and the RFIC **300**. Metal traces **400** are positioned on a top of the PCB **214** and form the plurality of end-fire antennas **302** as well as connections between the end-fire antennas **302** and the RFIC **300**. Metal traces **402** are positioned on a bottom of the PCB **214** and may form the ground structure **218** of the plurality of end-fire antennas **302**.

As described above, the vehicular radar system **102** may transmit and receive signals having frequencies of about 80 GHz. Some printed circuit boards may have characteristics that interfere with signals having these relatively high frequencies. Thus, the PCB **214** must be made in such a way as to accommodate these relatively high frequency signals.

In order to reduce interference with signals from the plurality of end-fire antennas **302**, the PCB **214** may include any high frequency material compatible with millimeter wave signals, such as RO3003. In order to further reduce interference with the signals, the PCB **214** may be relatively thin. In that regard, the PCB **214** may have a height in the H direction of between 0.01 mm and 1 mm, between 0.05 mm and 0.5 mm, between 0.05 mm and 0.3 mm, or about 0.127 mm. The use of such materials in combination with the relatively small thickness of the PCB **214** may cause the PCB **214** to be relatively flexible or malleable, to have a relatively low rigidity, and to bend with relative ease.

It is undesirable for the PCB **214** of the two-dimensional radar board **304** to break or change shape during use. Thus, it is desirable to support at least a portion of the PCB **214** when the vehicular radar system **102** is assembled. A second PCB **404** may be coupled to the PCB **214** in order to support the PCB **214**. In particular, the second PCB **404** may be coupled to a bottom of the PCB **214** of the two-dimensional radar board **304**. For example, the second PCB **404** may be coupled to the PCB **214** via an adhesive, such as a hot melt adhesive, screws, rivets, solder, or the like. In some embodiments, the second PCB **404** may be coupled to the metal traces **402** on the bottom of the PCB **214**, may be coupled to a non-metallic surface on the bottom of the PCB **214**, or a combination of both.

In some embodiments, high-frequency signals from the plurality of end-fire antennas **302** and/or the RFIC **300** may not propagate along or through the second PCB **404**. In that regard, it is not necessary for the second PCB **404** to be capable of handling signals having frequencies near 80 GHz. Accordingly, the second PCB **404** may include different materials than the PCB **214** and may have a greater thickness than the first PCB **214**, allowing the second PCB **404** to be designed to have a greater rigidity than the first PCB **214**. For example, the material of the second PCB **404** may be selected to have a relatively high strength to provide structural support to the first PCB **214**, such as FR4. Likewise, the second PCB **404** may have a thickness in the H direction of between 0.01 mm and 5 mm, between 0.1 mm and 3 mm, between 0.1 mm and 1 mm, or the like.

In some embodiments, the second PCB **404** may be made of a material or combination of materials that has a greater rigidity than a material of the first PCB **214** of the two-dimensional radar board **304**. In some embodiments, the second PCB **404** may be made of a similar material as the first PCB **214** and may have a greater thickness than the first PCB **214**.

It is undesirable for the second PCB **404** to interfere with the signals transmitted by the plurality of end-fire antennas **302**. In order to reduce the likelihood of interference with the signals, the second PCB **404** may extend from the chip connection end **212** of the PCB **214** to a location between the chip connection end **212** and the transmission end **210**. In some embodiments, the second PCB **404** may extend from the chip connection end **212** to a location aligned with the balun **220** of the plurality of end-fire antennas **302** along the L direction. For example, the second PCB **404** may extend to a center of the balun **220**, an end of the balun **220** nearest the transmission end **210**, or an end of the balun **220** nearest the chip connection end **212**.

As described above, the two-dimensional radar board **304** can provide a two-dimensional scan of the environment. Multiple two-dimensional radar boards may be aligned with each other along the H direction in order to provide a volumetric scan of the environment. Thus, the vehicular radar system **102** includes multiple two-dimensional radar boards for detecting three-dimensional data regarding the environment.

In order to include multiple two-dimensional radar boards to the vehicular radar system **102**, a PCB having a higher rigidity than those of the two-dimensional radar boards may be stacked between, and coupled to, a pair of two-dimensional radar boards. For example, the second PCB **404** may be stacked between the first two-dimensional radar board **304** and a second two-dimensional radar board **406**. The PCB **404** may be coupled to a top of the second two-dimensional radar board **406** in a similar manner as it is coupled to the first two-dimensional radar board **304**. Similarly, another relatively rigid low-frequency PCB **434** may be coupled to a bottom of the second two-dimensional radar board **406** and a top of a third two-dimensional radar board **422**.

Each of the two-dimensional radar boards **406**, **422** may include similar features as the two-dimensional radar board **304**. For example, the second two-dimensional radar board **406** includes a PCB **408**, metal traces **410** on a top of the PCB **408**, metal traces **414** on a bottom of the PCB **408**, and an RFIC **418**. The metal traces **410** form a plurality of end-fire antennas **412** and connections between the end-fire antennas **412** and the RFIC **418**. The metal traces **414** may form ground structures **416** of the plurality of end-fire antennas **412**.

As shown, the RFIC **418** extends in the H direction from the PCB **408** of the second two-dimensional radar board **406**. In order to accommodate the RFIC **418** of the second two-dimensional radar board **406**, the PCB **214** of the first two-dimensional radar board **304** and the PCB **404** may each be designed to have a chip aperture. For example, the PCB **214** of the first two-dimensional radar board **304** includes a chip aperture **420** and the PCB **404** between the first two-dimensional radar board **304** and the second two-dimensional radar board **406** includes a chip aperture **421**. The chip apertures **420**, **421** provide a volume for receiving the RFIC **418** when the vehicular radar system **102** is assembled. In some embodiments, a vehicular radar system may include more than three two-dimensional radar boards such that PCBs at the outer end of the vehicular radar system include multiple chip apertures for receiving RFICs of multiple two-dimensional radar boards.

In some embodiments, it may be desirable for power or other relatively low frequency signals to be transmitted from one two-dimensional radar board to another two-dimensional radar board. For example, it may be desirable for a power signal to be transferred between the first two-dimensional radar board **304** and the second two-dimensional radar board **406**. Such low frequency signals can pass through the more rigid PCBs, such as the PCB **404**, with relatively low interference due to the low frequency of the signals as compared to the high frequency radar signals. Thus, in some embodiments, vias or through holes may exist in the low-frequency PCBs **404**, **434** for allowing low-frequency signals to be transferred between adjacent two-dimensional radar boards. For example, a power signal may transfer from the first two-dimensional radar board **304** to the second two-dimensional radar board **406** via a through hole or via (not shown) through the PCB **404**.

Because the PCBs of the two-dimensional radar boards **304**, **406**, **422** are relatively flexible, they may be formed to have a desired shape. For example, as shown in FIG. **4**, the PCB **214** of the first two-dimensional radar board **304** is bent at a location **424**. The PCB **214** is bent in such a way as to orient the transmission end **210** of the PCB **214** in a direction away from the PCB **408** of the second two-dimensional radar board **406**. By bending the PCB **214** in this manner, a radar beam **428** from the plurality of end-fire antennas **302** of the first two-dimensional radar board **304** may be oriented in a direction away from the second two-dimensional radar board **406**. Similarly, a PCB **423** of the third two-dimensional radar board **422** may be bent at a location **426** such that a transmission end **427** of the PCB **423** is oriented away from the second two-dimensional radar board **406**. This bending orients a radar beam **432** from the third two-dimensional radar board **422** in a direction away from the second two-dimensional radar board **406**.

By bending the PCB **214** and the PCB **423** to orient the radar beam **428** and the radar beam **432** away from the second two-dimensional radar board **406**, the radar beam **428** from the first two-dimensional radar board **304**, the radar beam **432** from the third two-dimensional radar board **422**, and a radar beam **430** from the second two-dimensional radar board **406** may scan a greater volume at any given time.

Turning now to FIG. **5**, another vehicular radar system **500** includes a first two-dimensional radar board **502**, a second two-dimensional radar board **504**, and a third two-dimensional radar board **506**. Each of the two-dimensional radar boards **502**, **504**, **506** may include similar features as the two-dimensional radar board **304** of FIG. **4**. The first two-dimensional radar board **502** includes a relatively high-frequency PCB **508**, the second two-dimensional radar board **504** includes a relatively high-frequency PCB **510**, and the third two-dimensional radar board **506** includes a relatively high-frequency PCB **512**.

The vehicular radar system **500** also includes a first relatively rigid low-frequency PCB **514** and a second relatively rigid low-frequency PCB **516**. The first relatively rigid PCB **514** is stacked between, and coupled to, the PCB **508** and the PCB **510**. The second relatively rigid PCB **516** is stacked between, and coupled to, the PCB **510** and the PCB **512**. In that regard, the vehicular radar system **500** is similar to the vehicular radar system **102** of FIG. **4**.

Unlike the vehicular radar system **102** of FIG. **4**, the PCB **508** of the first two-dimensional radar board **502** and the PCB **512** of the third two-dimensional radar board **506** are each bent at two locations instead of one. For example, the PCB **508** is bent at a first location **518** away from the second two-dimensional radar board **504**. The PCB **508** is bent again at a second location **520** to cause a transmission end **526** of the PCB **508** to become parallel to a transmission end **528** of the PCB **510**.

The effect of bending the PCB **508** in two locations increases a distance between the first two-dimensional radar board **502** and the second two-dimensional radar board **504** at the transmission ends **526**, **528**. For example, a distance **522** between the first two-dimensional radar board **502** and the second two-dimensional radar board **504** near the chip connection ends **530**, **532** of the PCBs **508**, **510** is less than a distance **524** between the first two-dimensional radar board **502** and the second two-dimensional radar board **504** near the transmission ends **526**, **528**.

Because the PCBs **508**, **512** are bent to increase separation from the second two-dimensional radar board **504**, radar beams **534**, **536**, **538** from the two-dimensional radar boards **502**, **504**, **506** have a greater separation and may scan a larger volume at any given time than without the increased separation.

Turning now to FIG. **6**, a housing **600** may be provided for the vehicular radar system **102**. The housing **600** may include any rigid or semi rigid material such as metal, plastic, or the like. The housing **600** may be used to retain each of the two-dimensional radar boards in a desired location and to protect components of each of the two-dimensional radar boards.

As shown, the housing **600** may at least partially enclose each of the two-dimensional radar boards including the first two-dimensional radar board **304** and the second two-dimensional radar board **406**. The housing **600** may also at least partially enclose each of the relatively rigid PCBs including the PCB **404**.

As with the relatively rigid low-frequency PCB **404**, the housing **600** may be designed in such a way as to reduce the likelihood of interference with the signals from the various antennas. For example, when the housing **600** is installed, the plurality of end-fire antennas of each of the two-dimensional radar boards may be exposed. In that regard, the housing **600** may be positioned towards the chip connection end **212** of the PCB **214** from the balun **220** of the plurality of end-fire antennas **302**.

Exemplary embodiments of the methods/systems have been disclosed in an illustrative style. Accordingly, the terminology employed throughout should be read in a non-limiting manner. Although minor modifications to the teachings herein will occur to those well versed in the art, it shall be understood that what is intended to be circumscribed within the scope of the patent warranted hereon are all such embodiments that reasonably fall within the scope of the advancement to the art hereby contributed, and that that scope shall not be restricted, except in light of the appended claims and their equivalents.

What is claimed is:

1. A vehicular radar system comprising:
- a first printed circuit board (PCB) having a first material;
- a plurality of end-fire antennas positioned on the first PCB;
- a second PCB stacked on or under the first PCB and having a second material that has a greater rigidity than the first material; and
- a radio frequency integrated circuit (RFIC) coupled to the plurality of end-fire antennas and configured to control the plurality of end-fire antennas.

2. The vehicular radar system of claim **1** wherein the first PCB has a chip connection end and a transmission end and wherein the second PCB is stacked on or under the first PCB between the chip connection end and a line parallel to and positioned between the chip connection end and the transmission end such that the transmission end of the first PCB is separated from the second PCB.

3. The vehicular radar system of claim **2** wherein the first PCB has a top and a bottom and each of the plurality of end-fire antennas includes:
- a ground structure positioned adjacent to the chip connection end of the first PCB on the bottom of the first PCB;
- a chip connection lead positioned adjacent to the chip connection end of the first PCB and electrically coupled to the RFIC;
- a balun positioned adjacent to the chip connection lead and configured to convert an unbalanced signal to a balanced signal or to convert a balanced signal to an unbalanced signal;
- a wave section having a first wave section and a second wave section separated by a space and configured to transmit a wireless radar signal; and
- a tapered section positioned between the balun and the wave section and tapered towards the balun from the wave section.

4. The vehicular radar system of claim 3 wherein the second PCB is coupled to the top or the bottom of the first PCB and positioned between the balun of each of the plurality of end-fire antennas and the chip connection end of the first PCB.

5. The vehicular radar system of claim 2 wherein the first material is malleable and a portion of the first PCB between the transmission end and the line is bent to orient the transmission end of the first PCB in a desired direction.

6. The vehicular radar system of claim 2 further comprising a housing at least partially enclosing the second PCB and a portion of the first PCB between the transmission end and the line.

7. The vehicular radar system of claim 1 wherein the first material includes RO3003 and the second material includes FR4.

8. The vehicular radar system of claim 1 wherein:
the first PCB has a top;
the RFIC is connected to the top of the first PCB; and
the second PCB is positioned on the top of the first PCB and defines a chip aperture for receiving the RFIC.

9. A vehicular radar system comprising:
a first radar board having:
a first printed circuit board (PCB) made of a first material and having a chip connection end and a transmission end, and
a first plurality of end-fire antennas;
a second radar board having:
a second PCB made of the first material and having a chip connection end and a transmission end, and
a second plurality of end-fire antennas;
a third PCB stacked between the first PCB and the second PCB and made of a second material that has a greater rigidity than the first material; and
at least one radio frequency integrated circuit (RFIC) coupled to the first plurality of end-fire antennas and the second plurality of end-fire antennas and configured to control each of the first plurality of end-fire antennas and each of the second plurality of end-fire antennas.

10. The vehicular radar system of claim 9 wherein the third PCB is stacked between the first PCB and the second PCB between the chip connection end and a line parallel to and positioned between the chip connection end and the transmission end such that the transmission end of the first PCB and the second PCB is separated from the third PCB.

11. The vehicular radar system of claim 10 wherein each of the first PCB and the second PCB has a top and a bottom and each of the first plurality of antennas and the second plurality of antennas includes:
a ground structure positioned adjacent to the chip connection end of the first PCB or the second PCB on the bottom of the first PCB or the second PCB;
a chip connection lead positioned adjacent to the chip connection end of the first PCB or the second PCB and electrically coupled to the RFIC;
a balun positioned adjacent to the chip connection lead and configured to convert an unbalanced signal to a balanced signal or to convert a balanced signal to an unbalanced signal;
a wave section having a first wave section and a second wave section separated by a space and configured to transmit a wireless radar signal; and
a tapered section positioned between the balun and the wave section and tapered towards the balun from the wave section.

12. The vehicular radar system of claim 11 wherein the third PCB is coupled to the bottom of the first PCB and the top of the second PCB and positioned between the balun of each of the first plurality of end-fire antennas and the second plurality of antennas and the chip connection end of the first PCB and the second PCB.

13. The vehicular radar system of claim 10 wherein the first material is malleable and a portion of the first PCB between the transmission end and the line is bent to orient the transmission end of the first PCB in a direction away from the second PCB.

14. The vehicular radar system of claim 10 wherein the first material is malleable and the first PCB is bent at a first location between the transmission end and the line to separate the first PCB from the second PCB and is bent at a second location between the transmission end and the first location to cause the transmission end of the first PCB to be parallel to the transmission end of the first PCB.

15. The vehicular radar system of claim 9 wherein:
the second PCB has a top;
one of the at least one RFIC is connected to the top of the second PCB;
the third PCB has a bottom coupled to the top of the second PCB and a top and defines a chip aperture for receiving the RFIC; and
the first PCB has a bottom coupled to the top of the third PCB and defines another chip aperture for receiving the RFIC.

16. A vehicular radar system comprising:
a first printed circuit board (PCB) having a chip connection end, a transmission end, a top, and a bottom;
a plurality of end-fire antennas positioned on the first PCB each having:
a ground structure positioned adjacent to the chip connection end of the first PCB on the bottom of the first PCB,
a chip connection lead positioned adjacent to the chip connection end of the first PCB and electrically coupled to the RFIC,
a balun positioned adjacent to the chip connection lead and configured to convert an unbalanced signal to a balanced signal or to convert a balanced signal to an unbalanced signal,
a wave section having a first wave section and a second wave section separated by a space and configured to transmit a wireless radar signal, and
a tapered section positioned between the balun and the wave section and tapered towards the balun from the wave section;
a second PCB coupled to the top or the bottom of the first PCB, having a greater rigidity than the first PCB, and positioned between the balun of each of the plurality of end-fire antennas and the chip connection end of the first PCB; and
a radio frequency integrated circuit (RFIC) coupled to the plurality of end-fire antennas and configured to control the plurality of end-fire antennas.

17. The vehicular radar system of claim 16 wherein the first PCB has a first material and the second PCB has a second material that has a greater rigidity than the first material.

18. The vehicular radar system of claim 16 further comprising a housing at least partially enclosing the second PCB and a portion of the first PCB between the balun of each of the plurality of end-fire antennas and the chip connection end of the first PCB.

19. The vehicular radar system of claim 16 wherein the first PCB is malleable and a portion of the first PCB between

the transmission end and the balun is bent to orient the transmission end of the first PCB in a desired direction.

20. The vehicular radar system of claim **16** wherein:

the first PCB has a top;

the RFIC is connected to the top of the first PCB; and

the second PCB is positioned on the top of the first PCB and defines a chip aperture for receiving the RFIC.

* * * * *