

ANTENNA SYSTEM

Field of the Invention

The present invention relates in general to the field of telecommunications and more particularly to an antenna system.

5 Background of the Invention

As mobile telecommunications standards evolve, time is required to adapt existing infrastructure in multiple areas to accommodate new standards. For example, frequency coverage for fifth-generation new radio (5G-NR) sub-6GHz is much wider as compared to that for existing fourth-generation long-term evolution (4G/LTE) and utilizes
10 a Multiple-Input-Multiple-Output (MIMO) antenna configuration. It would therefore be desirable to provide an antenna system that is easily tunable to accommodate evolving telecommunications standards.

Summary of the Invention

Accordingly, in a first aspect, the present invention provides an antenna system.
15 The antenna system includes one or more antenna boards and a ground board. Each of the one or more antenna boards includes a first substrate having a plurality of openings and a planar antenna on the first substrate. The ground board includes a second substrate having a plurality of protrusions on one or more edges of the second substrate, the protrusions being received in corresponding openings of the first substrate of the one
20 or more antenna boards, a ground plane on the second substrate, and a plurality of antenna elements on the second substrate, the antenna elements being configured to electrically connect the planar antenna of the one or more antenna boards to the ground plane.

Other aspects and advantages of the invention will become apparent from the
25 following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIGS. 1A through 1C are schematic diagrams illustrating an antenna system in accordance with an embodiment of the present invention;

FIG. 2 is a schematic diagram illustrating an antenna system in accordance with another embodiment of the present invention;

FIG. 3 is a graph of a reflection coefficient of an antenna system in accordance with an embodiment of the present invention across a frequency spectrum;

FIG. 4 is a graph of total efficiency of an antenna system in accordance with an embodiment of the present invention across a frequency spectrum;

FIG. 5 is a graph of peak gain of an antenna system in accordance with an embodiment of the present invention across a frequency spectrum;

FIGS. 6A and 6B illustrate radiation patterns of an antenna system in accordance with an embodiment of the present invention at a frequency of 698 megahertz (MHz); and

FIGS. 7A and 7B illustrate radiation patterns of an antenna system in accordance with an embodiment of the present invention at a frequency of 5900 MHz.

Detailed Description of Exemplary Embodiments

The detailed description set forth below in connection with the appended drawings is intended as a description of presently preferred embodiments of the invention, and is not intended to represent the only forms in which the present invention may be practiced. It is to be understood that the same or equivalent functions may be accomplished by different embodiments that are intended to be encompassed within the scope of the invention. In the drawings, like numerals are used to indicate like elements throughout.

The term "antenna element" as used herein refers to a component of an antenna system that is involved in signal transmission or reception and/or contributes to antenna performance in some way.

5 The term "about" as used herein refers to both numbers in a range of numerals and is also used to indicate that a value includes the standard deviation of error for the device or method being employed to determine the value. The term "about" as used herein can allow for a degree of variability in a value or range, for example, within 10%, within 5%, or within 1 % of a stated value or of a stated limit of a range.

Referring now to FIGS. 1A through 1C, an antenna system 10 is shown. The
10 antenna system 10 includes an antenna board 12 and a ground board or reference ground board 14. The antenna board 12 includes a first substrate 16 having a plurality of openings 18 and a planar antenna 20 on the first substrate 16. The ground board 14 includes a second substrate 22 having a plurality of protrusions 24 on an edge of the second substrate 22, the protrusions 24 being received in corresponding openings 18 of
15 the first substrate 16 of the antenna board 12, a ground plane 26 on the second substrate 22, and a plurality of antenna elements 28 on the second substrate 22, the antenna elements 28 being configured to electrically connect the planar antenna 20 of the antenna board 12 to the ground plane 26.

In the embodiment shown, two (2) rows of openings 18 are provided to allow
20 different mounting or orientation options. Different mounting or orientation options provide greater flexibility in achieving best matching between the antenna elements 28 and the planar antenna 20 for best performance. Additionally, having an upper row and a lower row also provides additional options for mounting the antenna board 12 for different enclosure heights.

25 The antenna elements 28 provide tuning connections for connecting the planar antenna 20 of the antenna board 12 to the reference ground 26 of the reference ground board 14 and thereby a tunable broadband frequency response.

The antenna elements 28 may include a plurality of traces 30 on the second substrate 22, each of the traces 30 extending between the planar antenna 20 and the
30 ground plane 26. The traces 30 connect the antenna board 12 and the reference ground

board 14 to form a signal conduction path. The traces 30 connecting the antenna board 12 and the reference ground board 14 may be tuned to achieve a required broadband frequency response in the radio-frequency spectrum; the size and length of the traces 30 may be adjusted to create a desired coupling between gaps 32 separating each of the
5 traces 30. The traces 30 may be printed circuit board (PCB) traces. As will be appreciated by those of ordinary skill in the art, the traces 30 are not limited by number, dimensions and placement position on the second substrate 22. In one or more alternative embodiments, fewer or more traces 30 with different sizes, gaps therebetween and/or placement positions may be employed. Individual trace dimensions
10 such as, for example, trace width and/or trace length, determine inductance and spacing between the traces 30 determines coupling effect.

The antenna elements 28 may further include a plurality of first electrical connections 34 electrically connecting the traces 30 to corresponding ones of a plurality of first contact pads or connection pads 36 on the planar antenna 20 and/or a plurality of
15 second electrical connections 38 electrically connecting the traces 30 to corresponding ones of a plurality of second contact pads 40 on the ground plane 26. The first and second electrical connections 34 and 38 may be solder connections. The first contact pads 36 may be located at multiple locations on the planar antenna 20 depending on tuning requirements for best performance of the antenna system 10. The number of the
20 first contact pads 36 on the planar antenna 20 may be independent of the number of traces 30. One of the second contact pads 40 at any location may serve as a signal excitation port and one or more remaining second contact pads 40 may serve as a current return path. A better match between the signal excitation port and the planar antenna 20 improves overall performance with higher return loss, wide resonance
25 bandwidth and reduced reflected feeding power, thereby achieving high radiated efficiency.

The antenna elements 28 may further include a plurality of first passive components 42 provided between and electrically connecting adjacent ones of the traces 30 at a first end of the traces 30 adjacent the planar antenna 20 and/or a plurality of
30 second passive components 44 provided between and connecting adjacent ones of the traces 30 at a second end of the traces 30 adjacent the ground plane 26. Advantageously, the first passive components 42 adjacent the planar antenna 20 provide

an impedance match between an overall tuning element at the first end of the PCB traces 30 to the antenna structure 20 and the second passive components 44 adjacent the ground plane 26 provide an impedance match between an overall tuning element at the second end of the PCB traces 30 to the ground plane 26. Each of the first passive components 42 and/or the second passive components 44 may be a capacitor, an inductor or a resistor. Combinations of the traces 30 together with the first and second passive components 42 and 44 determine an effective coefficient performance of the frequency response. The first and second passive components 42 and 44 may form part of the current return path. As will be appreciated by those of ordinary skill in the art, the present invention is not limited by the number of first and second passive components 42 and 44 employed and the first passive components 42 and the second passive components 44 may be provided independently of each other depending on design requirements.

As can be seen from FIG. 1A, the antenna board 12 is connected to the ground board or reference ground board 14 at a right angle for a desired feeding and grounding location. The right angle serves both mechanical and electrical purposes. Firstly, having a right-angle connection with a PCB board reduces a length of the antenna system 10. Secondly, with the right-angle connection, the antenna element 28 may be connected to an inner or central portion of the planar antenna structure 20. With inner or central connection, an optimized excitation location for the planar antenna 20 is provided and hence impedance matching between the ground plane 26, the antenna elements 28 and planar antenna 20 may be improved.

The planar antenna 20 may be a slot antenna. The slot antenna may include a first slot 46 extending along a length of the planar antenna 20 adjacent to the antenna elements 28 and/or a second slot 48 extending from the first slot 46 to an edge of the planar antenna 20. The first and second slots 46 and 48 provide separate structures on the planar antenna 20, each of the structures introducing additional resonance at different frequencies, thereby providing wideband frequency response coverage. Accordingly, the first and second slots 46 and 48 of the planar antenna structure 20 may be used to generate frequency response coverage at low (between about 600 megahertz (MHz) and about 960 MHz), mid (between about 1,400 MHz and about 2,800 MHz) and

high (between about 3,000 MHz and about 6,000 MHz) frequencies of a radio-frequency spectrum.

Due to high current density along edges of the first and second slots 46 and 48, variations in slot length and width may be used to enhance frequency bandwidth — a horizontal length L_{S1} of the first slot 46 determining a resonance frequency of interest, a vertical length L_{S2} of the second slot 48 determining a bandwidth of the frequency of interest, and a first slot width or gap W_{S1} and/or a second slot width or gap W_{S2} determining coupling between an opposite trace 30 which allows for bandwidth enhancement at the frequency of interest. Accordingly, the length and width of the first and second slots 46 and 48 may be varied to define multiple resonance modes on the first substrate 16. The first slot 46 may have a first slot length L_{S1} of between about 28 millimetres (mm) and about 44 mm and/or a first slot width or gap W_{S1} of between about 0.2 mm and about 0.7 mm. The second slot 48 may have a second slot length L_{S2} of between about 6 mm and about 11 mm and/or a second slot width or gap W_{S2} of between about 0.2 mm and about 0.7 mm. Further advantageously, in the embodiment shown, the first and second slots 46 and 48 define a slot having a specific gap in-between, the gap size providing additional coupling between the first and second slots 46 and 48 to further enhance multiband frequency response of the planar antenna structure 20.

The first and second substrates 16 and 22 may be dielectric substrates made of commercially available laminate material with a dielectric constant of about 4.0 such as, for example, FR-4, Rogers or RT/Duroid. In an exemplary embodiment, the second substrate 22 may have a length L of about 120 millimetres (mm), a width W of about 60 mm and a thickness T of about 1.6 mm. In alternative embodiments, the second substrate 22 may be of different dimensions depending on overall board design requirements.

As can be seen from FIG. 1B, the antenna board 12 engages with the ground board 14 when the protrusions 24 of the ground board 14 are inserted into the corresponding openings 18 of the antenna board 12. Advantageously, such an arrangement confers mechanical rigidity to the antenna system 10.

The antenna system 10 be used to provide a tunable, Multiple-Input-Multiple-Output (MIMO) planar slot antenna capable of providing a tunable broadband frequency response.

Referring now to FIG. 2, an antenna system 100 in a Multiple-Input-Multiple-Output (MIMO) configuration is shown. The antenna system 100 includes a plurality of antenna boards 12 and a ground board 14. Each of the antenna boards 12 includes a first substrate 16 having a plurality of openings 18 and a planar antenna 20 on the first substrate 16. The ground board 14 includes a second substrate 22 having a plurality of protrusions (not shown) on a plurality of edges of the second substrate 22, the protrusions being received in corresponding openings 18 of the first substrate 16 of the antenna boards 12, a ground plane 26 on the second substrate 22, and a plurality of antenna elements 28 on the second substrate 22, the antenna elements 28 being configured to electrically connect the planar antenna 20 of the antenna boards 12 to the ground plane 26.

The present embodiment differs from the previous embodiment in that there are multiple antenna boards 12 attached to the ground board 14. As can be seen from FIG. 2, the multiple antenna boards 12 may be attached at different locations of the ground plane board 14. Each antenna board 12 and corresponding set of antenna elements XX may be identical or different depending on antenna board design and location relative to the ground board 14. Advantageously, this allows the antenna system 100 to be used in a MIMO application. In the MIMO configuration, the antenna boards 12 may be mirror image designs depending on location and performance of the antenna system 100. The antenna boards 12 may be duplicated on all multiple sides of the reference ground board 14 for 2 x 2, 4 x 4 or other multiple MIMO configurations. In the present embodiment, multiple antenna boards 12 are duplicated and placed at a number of locations around the MIMO reference ground board 14 with feed and ground tuning elements 28 at each antenna section. The antenna feed and ground tuning elements 28 may be duplicated on multiple sides on the reference ground board 14 for each antenna board 12 for tuning of individual wideband resonant frequency modes. Each antenna section may have its own passive components 42 and 44 connected to a dedicated antenna 16, the passive components 38 being used to connect the MIMO reference ground board 14 to each of the antenna boards 12.

Example

The antenna system 10 of FIGS. 1A through 1C was simulated and its performance was verified using full-wave electromagnetics Computer-Aided Design (CAD) simulation tools, specifically, CST Microwave Studio. The simulation results are
5 described below with reference to FIGS. 3 through 7B.

Referring now to FIG. 3, reflection coefficient or return loss in decibels (dB) of the antenna system 10 was simulated across a frequency spectrum of from about 0.6 GHz to about 6 GHz to cover both fourth-generation long-term evolution (4G/LTE) and fifth-generation new radio (5G-NR) sub-6GHz bands. The simulation results show that typical
10 reflection coefficient ranges of from 6 dB to 15 dB over the frequency spectrum is achievable, meeting the minimum requirement of 6 dB in industrial practice.

Referring now to FIG. 4, efficiency in percentage (%) of the antenna system 10 was simulated across a frequency spectrum of from about 0.6 GHz to about 6 GHz. The simulation results show that a minimum of 40% efficiency across the bands is
15 achievable, meeting the minimum requirement of 40% according to an industrial standard.

Referring now to FIG. 5, a graph of peak gain of the antenna system 10 against frequency is shown. As can be seen from FIG. 5, a gain of 0.5 to 4 decibels-isotropic (dBi) is observed across the long-term evolution (LTE) bands and a peak gain of 6 dBi
20 was observed across the 5G-NR sub-6GHz bands.

Referring now to FIG. 6A, a two-dimensional radiation pattern plot in the YZ plane of realized gain against angular theta angles with phi angle fixed at 90 degrees (°) and frequency targeted at 698 MHz overlapping with the antenna system 10 is shown.

Referring now to FIG. 6B, a three-dimensional radiation pattern plot of realized
25 gain targeted at 698 MHz overlapping with antenna system 10 is shown. The donut structure of the radiation pattern shown in FIG. 6B demonstrates that the antenna system 10 contains the characteristics of a dipole antenna.

Referring now to FIG. 7A, a two-dimensional radiation pattern plot in the YZ plane of realized gain against angular theta angles with phi angle fixed at 90 degrees (°) and frequency targeted at 5900 MHz overlapping with the antenna system 10 is shown.

Referring now to FIG. 7B, a three-dimensional radiation pattern plot of realized
5 gain targeted at 5900 MHz overlapping with the antenna system 10 is shown.

The simulation results demonstrate that the antenna system 10 is able to achieve good wideband performance across the frequency spectrum of from 600 MHz to 6000 MHz and also yields high peak gain ranges from 4 to 6 dBi.

As is evident from the foregoing discussion, the present invention provides a
10 wideband antenna system with multiband capability and high gain. Advantageously, the wideband antenna system of the present invention may serve as a bridging channel between existing and new wireless telecommunications standards. For example, the wideband antenna system of the present invention may be compatible with evolving fifth-generation new radio (5G-NR) sub-6GHz technology and at the same time, serve as a
15 bridging channel for existing fourth-generation long-term evolution (4G/LTE) technology in Artificial Intelligence (AI), machine learning, Internet-of-Things (IoT), Machine-to-Machine (M2M) in wireless communications, medical and real-time transportation monitoring. Further advantageously, the antenna system of the present invention is easily tunable based on any antenna location placement and PCB board size for MIMO
20 applications. The tunable antenna system of the present invention is also able to cover a required wideband frequency response with good performance.

While preferred embodiments of the invention have been described, it will be clear that the invention is not limited to the described embodiments only. Numerous modifications, changes, variations, substitutions and equivalents will be apparent to
25 those skilled in the art without departing from the scope of the invention as described in the claims.

Further, unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise", "comprising" and the like are to be construed in an inclusive as opposed to an exclusive or exhaustive sense; that is to say, in the sense of
30 "including, but not limited to".

CLAIMS

1. An antenna system, comprising:
one or more antenna boards, each of the one or more antenna boards
5 comprising:
a first substrate having a plurality of openings, and
a planar antenna on the first substrate; and
a ground board comprising:
a second substrate having a plurality of protrusions on one or more edges
10 of the second substrate, wherein the protrusions are received in corresponding
openings of the first substrate of the one or more antenna boards,
a ground plane on the second substrate, and
a plurality of antenna elements on the second substrate, the antenna
elements being configured to electrically connect the planar antenna of the one or
15 more antenna boards to the ground plane.
2. The antenna system according to claim 1, wherein each of the one or more
antenna boards is connected to the ground board at a right angle.
- 20 3. The antenna system according to claim 1 or 2, wherein the planar antenna
comprises a slot antenna.
4. The antenna system according to claim 3, wherein the slot antenna comprises a
first slot extending along a length of the planar antenna adjacent to the antenna
25 elements.
5. The antenna system according to claim 4, wherein the first slot has a first slot
length of between about 28 millimetres (mm) and about 44 mm.
- 30 6. The antenna system according to claim 4 or 5, wherein the first slot has a first slot
width of between about 0.2 mm and about 0.7 mm.

7. The antenna system according to any one of claims 4 to 6, wherein the slot antenna further comprises a second slot extending from the first slot to an edge of the planar antenna.
- 5 8. The antenna system according to claim 7, wherein the second slot has a second slot length of between about 6 mm and about 11 mm.
9. The antenna system according to claim 7 or 8, wherein the second slot has a second slot width of between about 0.2 mm and about 0.7 mm.
- 10 10. The antenna system according to any one of the preceding claims, wherein the antenna elements comprise a plurality of traces on the second substrate, each of the traces extending between the planar antenna and the ground plane.
- 15 11. The antenna system according to claim 10, wherein the antenna elements further comprise a plurality of first electrical connections electrically connecting the traces to corresponding ones of a plurality of first contact pads on the planar antenna.
12. The antenna system according to claim 10 or 11, wherein the antenna elements
20 further comprise a plurality of second electrical connections electrically connecting the traces to corresponding ones of a plurality of second contact pads on the ground plane.
13. The antenna system according to any one of claims 10 to 12, wherein the antenna elements further comprise a plurality of first passive components provided
25 between and electrically connecting adjacent ones of the traces at a first end of the traces adjacent the planar antenna.
14. The antenna system according to any one of claims 10 to 13, wherein the antenna elements further comprise a plurality of second passive components provided
30 between and connecting adjacent ones of the traces at a second end of the traces adjacent the ground plane.

15. The antenna system according to claim 13 or 14, wherein each of the first passive components and/or the second passive components is selected from a group consisting of a capacitor, an inductor and a resistor.
- 5 16. The antenna system according to any one of the preceding claims, comprising a plurality of antenna boards attached to the ground board in a Multiple-Input-Multiple-Output (MIMO) configuration.