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Pinel et al.

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(54) **MODULE, FILTER, AND ANTENNA TECHNOLOGY FOR MILLIMETER WAVES MULTI-GIGABITS WIRELESS SYSTEMS**

(75) Inventors: **Stephane Pinel**, Atlanta, GA (US); **Joy Laskar**, Marietta, GA (US)

(73) Assignee: **Georgia Tech Research Corporation**, Atlanta, GA (US)

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(51) **Int. Cl.**
H01Q 1/38 (2006.01)

(52) **U.S. Cl.** **343/700 MS**

(58) **Field of Classification Search** **343/700 MS,**
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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,552,798 A 9/1996 Dietrich et al.

(Continued)

FOREIGN PATENT DOCUMENTS

JP 08181452 A 7/1996

(Continued)

OTHER PUBLICATIONS

Murakami, Yasushi et al., "A Switchable Multi-Sector Antenna for Indoor Wireless LAN Systems in the 60-GHz Band", IEEE Transactions on Microwave Theory and Techniques, vol. 46, No. 6, Jun. 1998, pp. 841-843.

(Continued)

Primary Examiner—Hoang V Nguyen

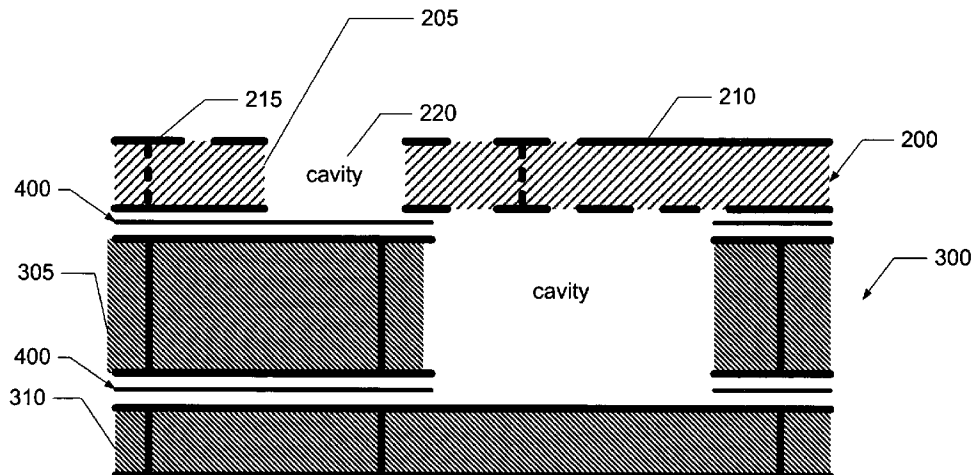
Assistant Examiner—Robert Karacsony

(74) *Attorney, Agent, or Firm*—Ryan A. Schmeider, Esq.; Seyed Kaveh E. Rashidi-Yazd, Esq.; Troutman Sanders LLP

(57) **ABSTRACT**

A method of fabricating an ultra-high frequency module is disclosed. The method includes providing a top layer; drilling the top layer; milling the top layer; providing a bottom; milling the bottom layer to define a bottom layer cavity; aligning the top layer and the bottom layer; and adhering the top layer to the bottom layer. The present invention also includes an ultra-high frequency module operating at ultra-high speeds having a top layer, the top layer defining a top layer cavity; a bottom layer, the bottom layer defining a bottom layer cavity; and an adhesive adhering both the top layer to the bottom layer, wherein the top layer and the bottom layer are formed from a large area panel of a printed circuit board.

15 Claims, 25 Drawing Sheets



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U.S. PATENT DOCUMENTS

5,888,627 A 3/1999 Nakatani
6,028,489 A 2/2000 Juang et al.
6,091,364 A 7/2000 Murakami et al.
6,091,373 A * 7/2000 Ragueneat 343/778
6,147,648 A * 11/2000 Granholm et al. 343/700 MS
6,275,191 B1 8/2001 Lesea et al.
6,320,543 B1 * 11/2001 Ohata et al. 343/700 MS
6,384,785 B1 * 5/2002 Kamogawa et al. ... 343/700 MS
6,836,247 B2 12/2004 Soutiaguine et al.
6,975,276 B2 * 12/2005 Brown 343/767
6,982,480 B2 * 1/2006 Shi 257/687
7,295,161 B2 * 11/2007 Gaucher et al. 343/700 MS

7,358,604 B2 * 4/2008 Heyen et al. 257/700
2002/0158722 A1 * 10/2002 Maruhashi et al. 333/246
2005/0195082 A1 * 9/2005 Morrison 340/539.26

FOREIGN PATENT DOCUMENTS

JP 2001260274 9/2001

OTHER PUBLICATIONS

Int'l Search Report and Written Opinion for related PCT Application No. PCT/US06/016826 dated May 1, 2007.
Supplementary European Examination Report dated Jun. 5, 2009 for related European application EP06752085.

* cited by examiner

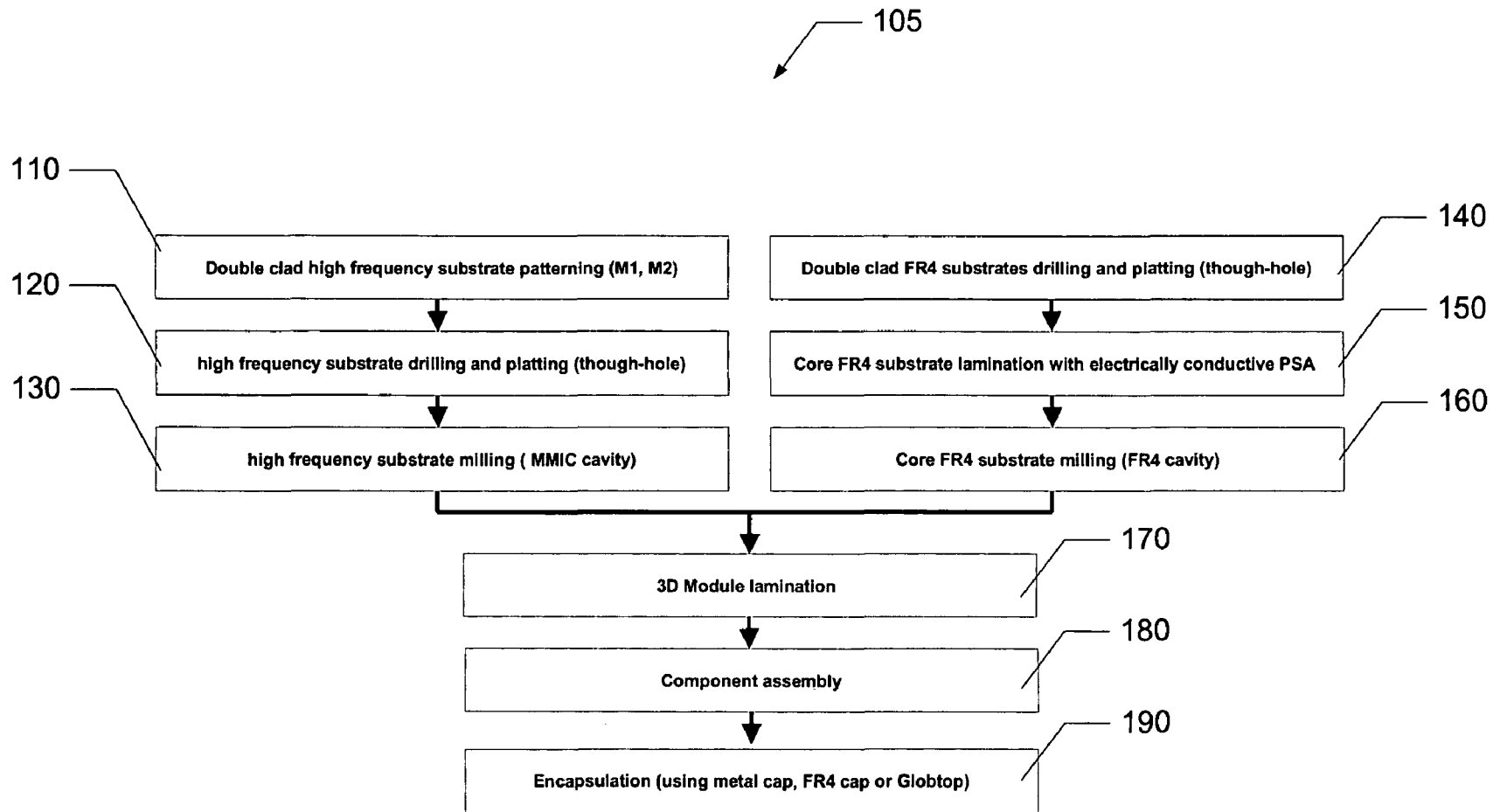


Fig. 1

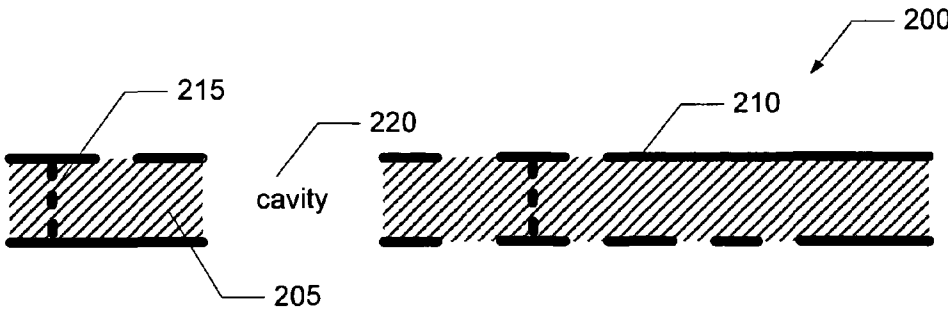


Fig. 2A

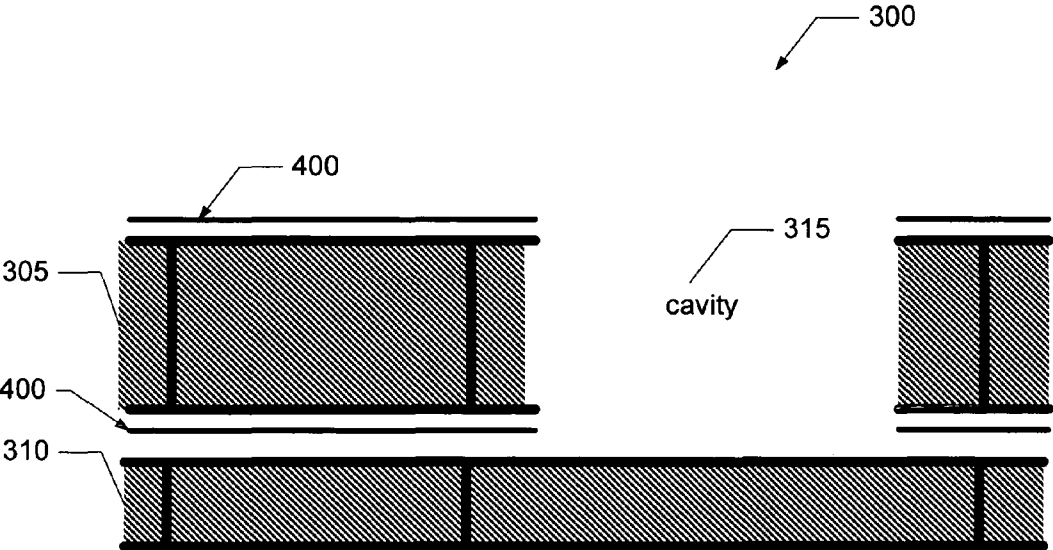


Fig. 2B

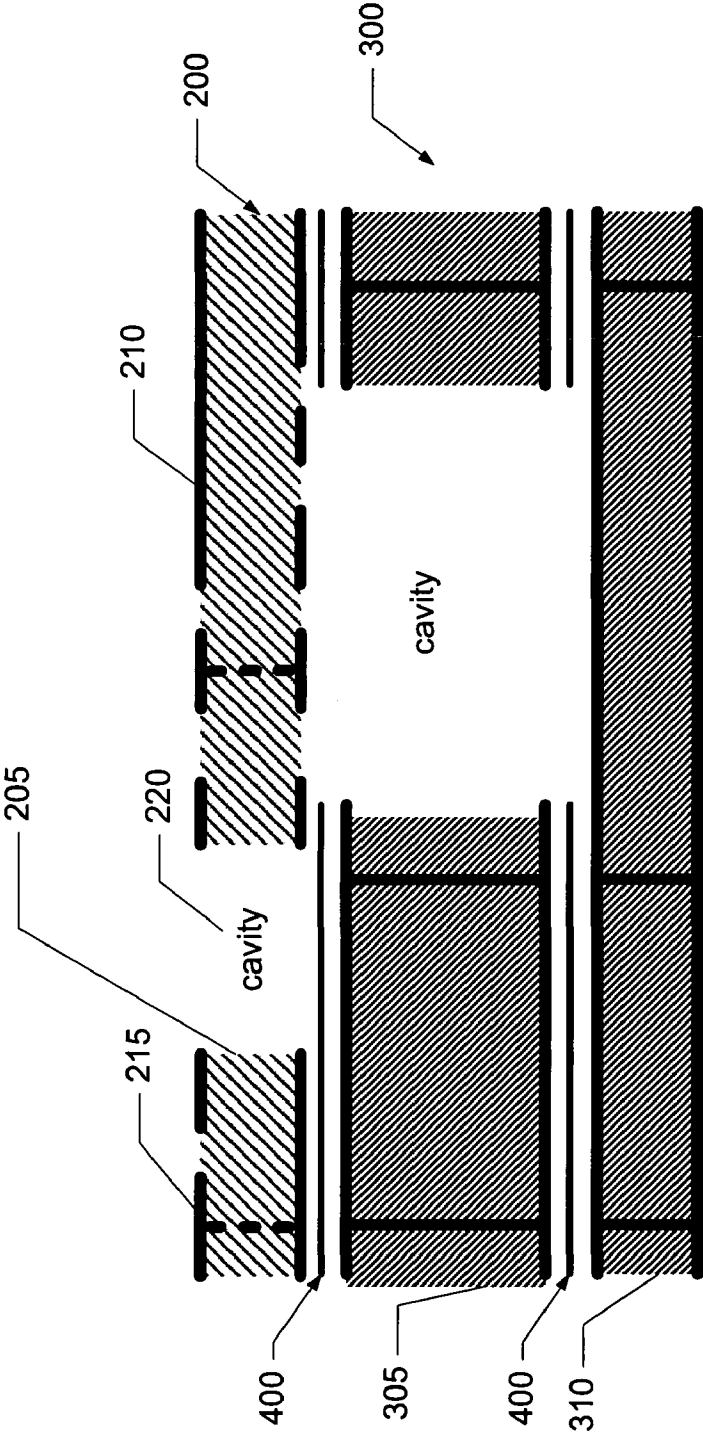


Fig. 3

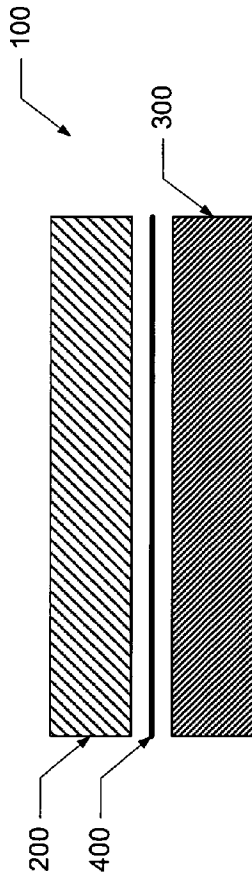


Fig. 4A

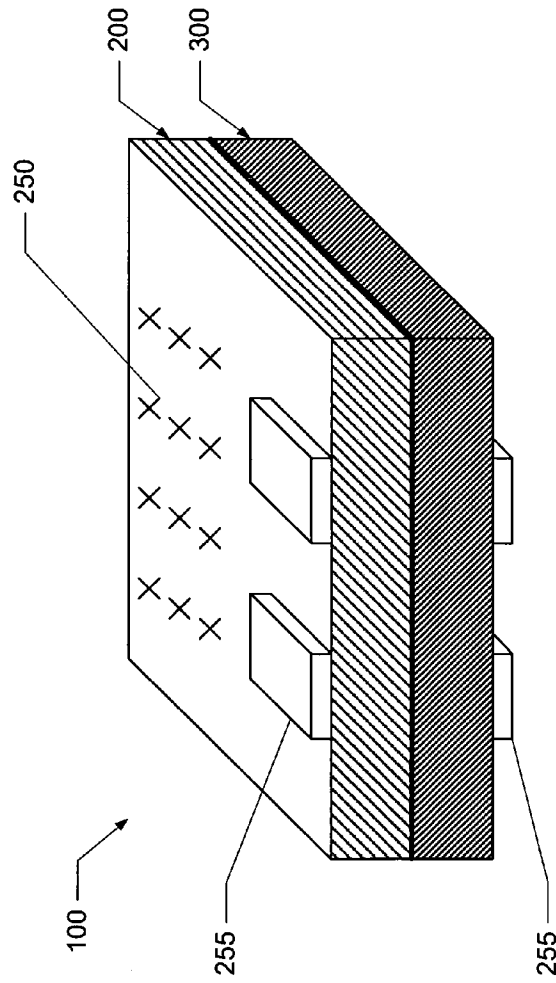


Fig. 4B

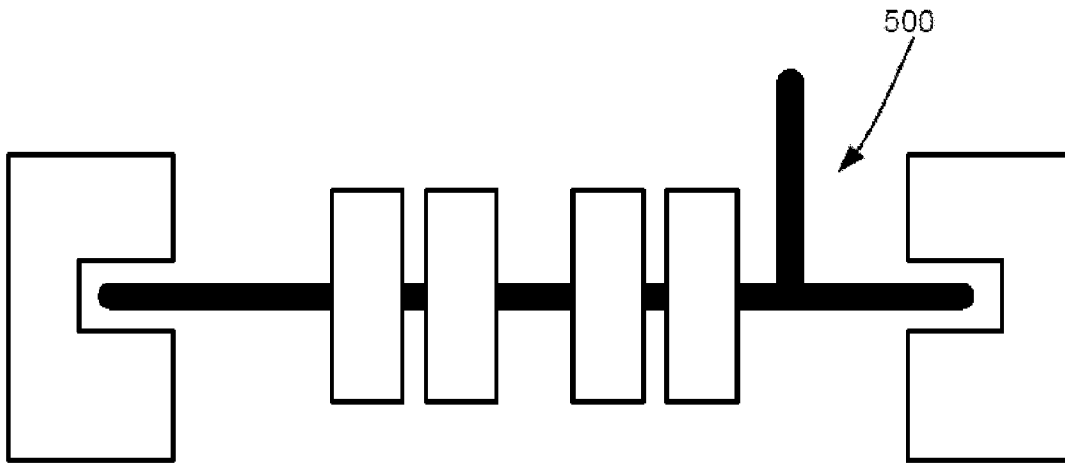


Fig. 5A

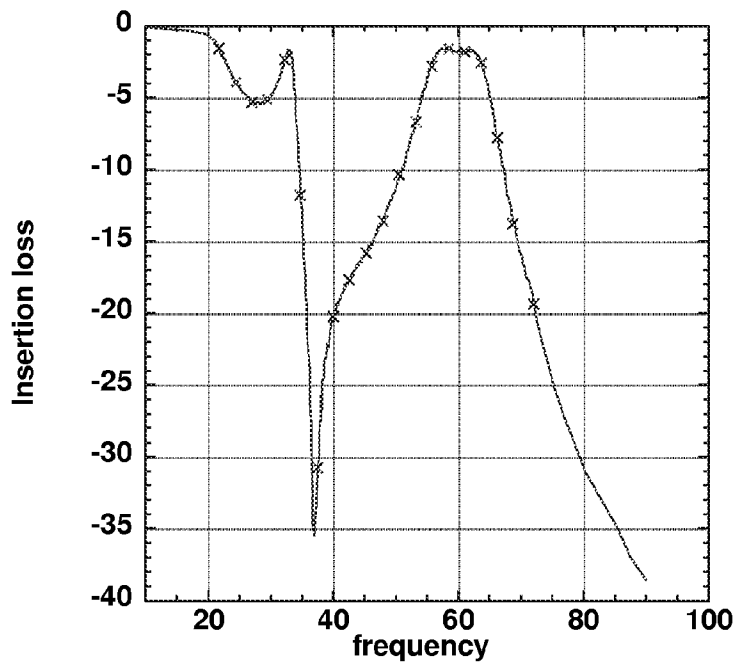


Fig. 5B

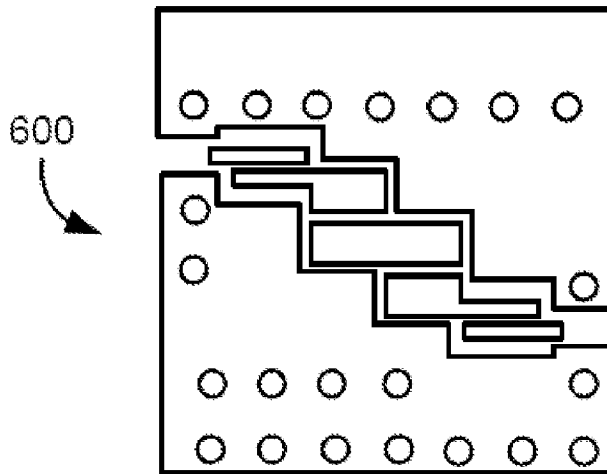


Fig. 6A

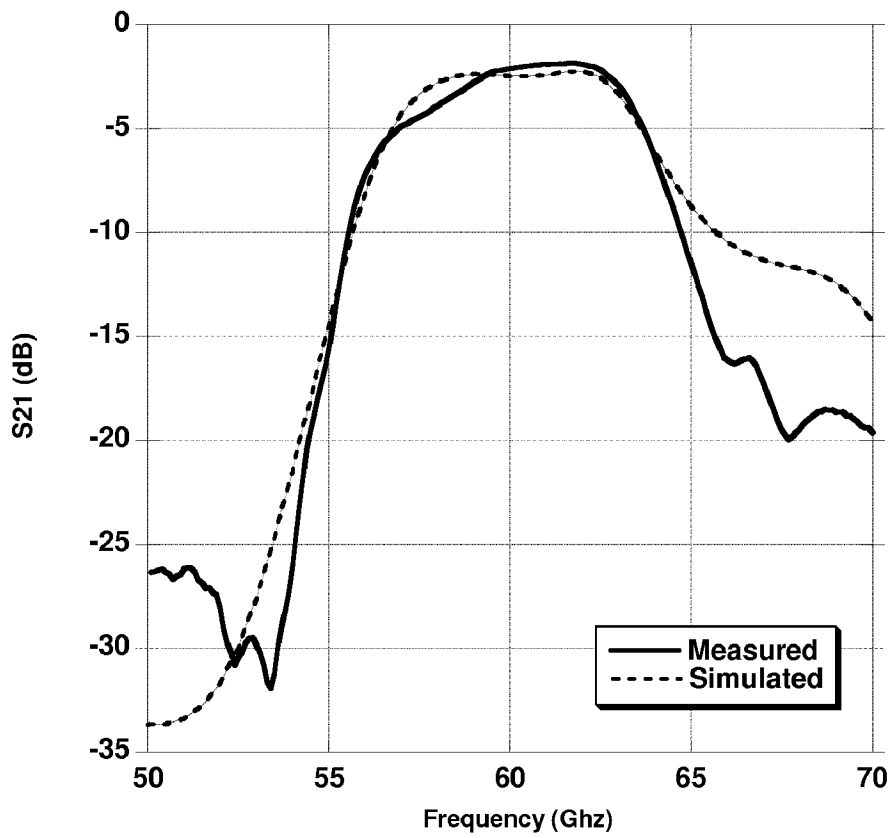


Fig. 6B

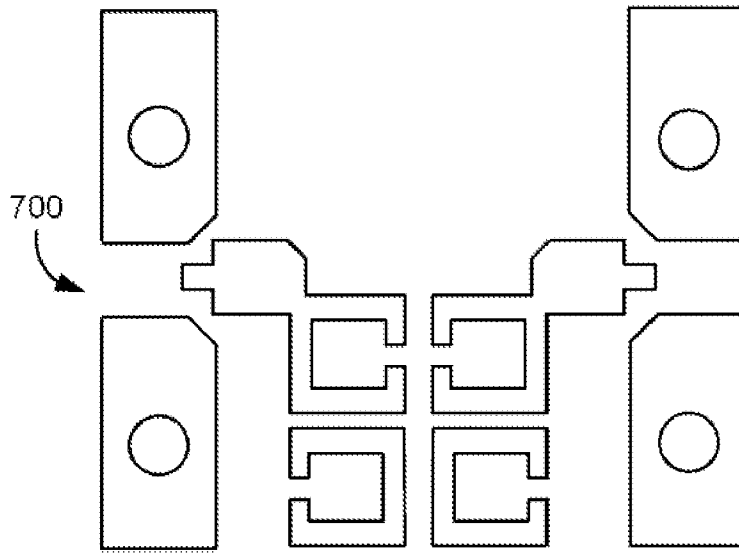


Fig. 7A

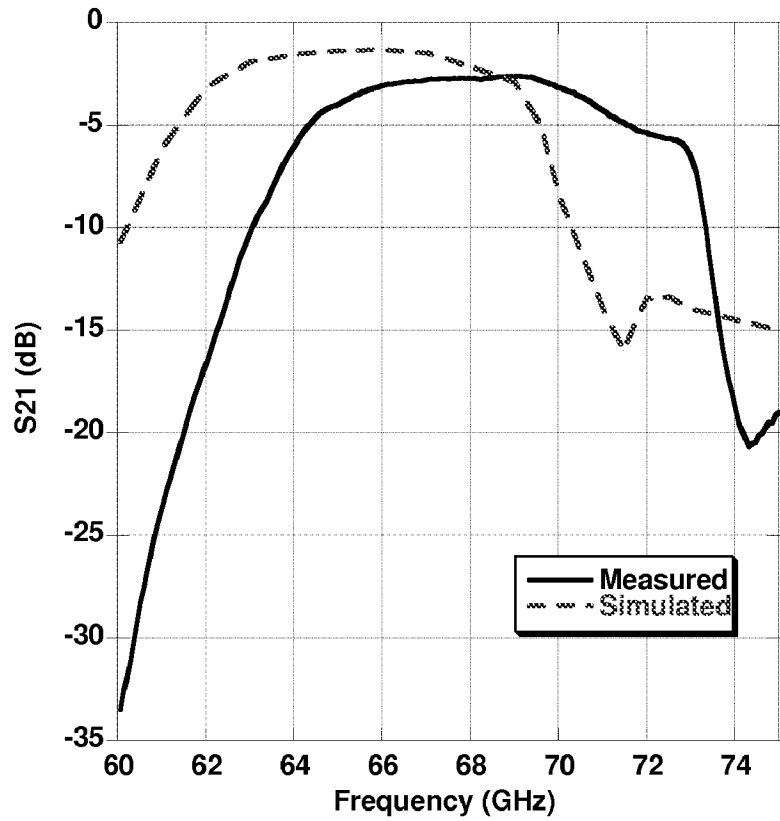


Fig. 7B

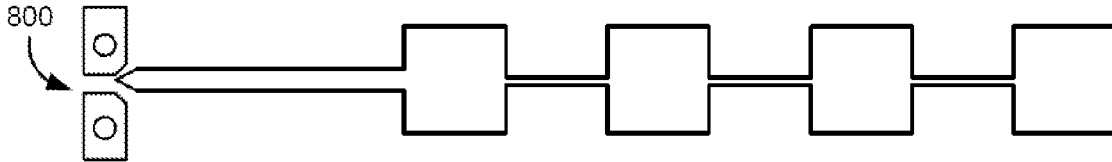


Fig. 8A

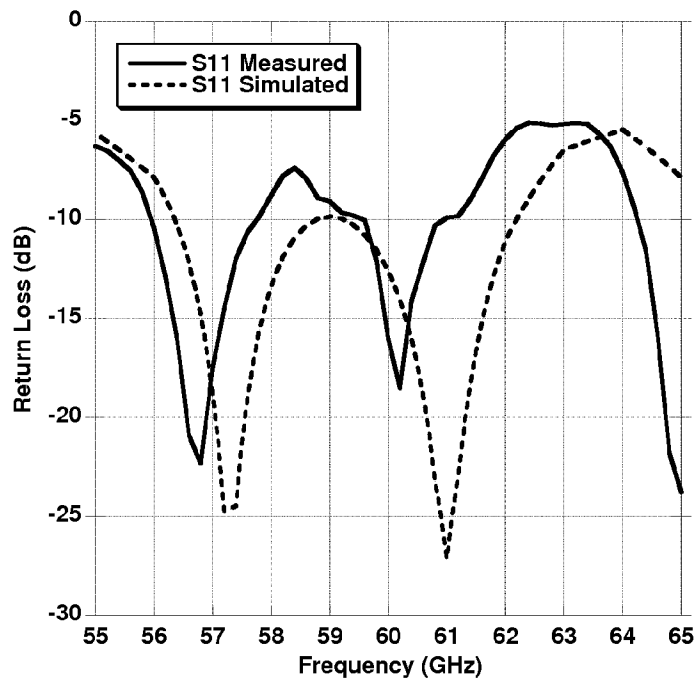


Fig. 8B

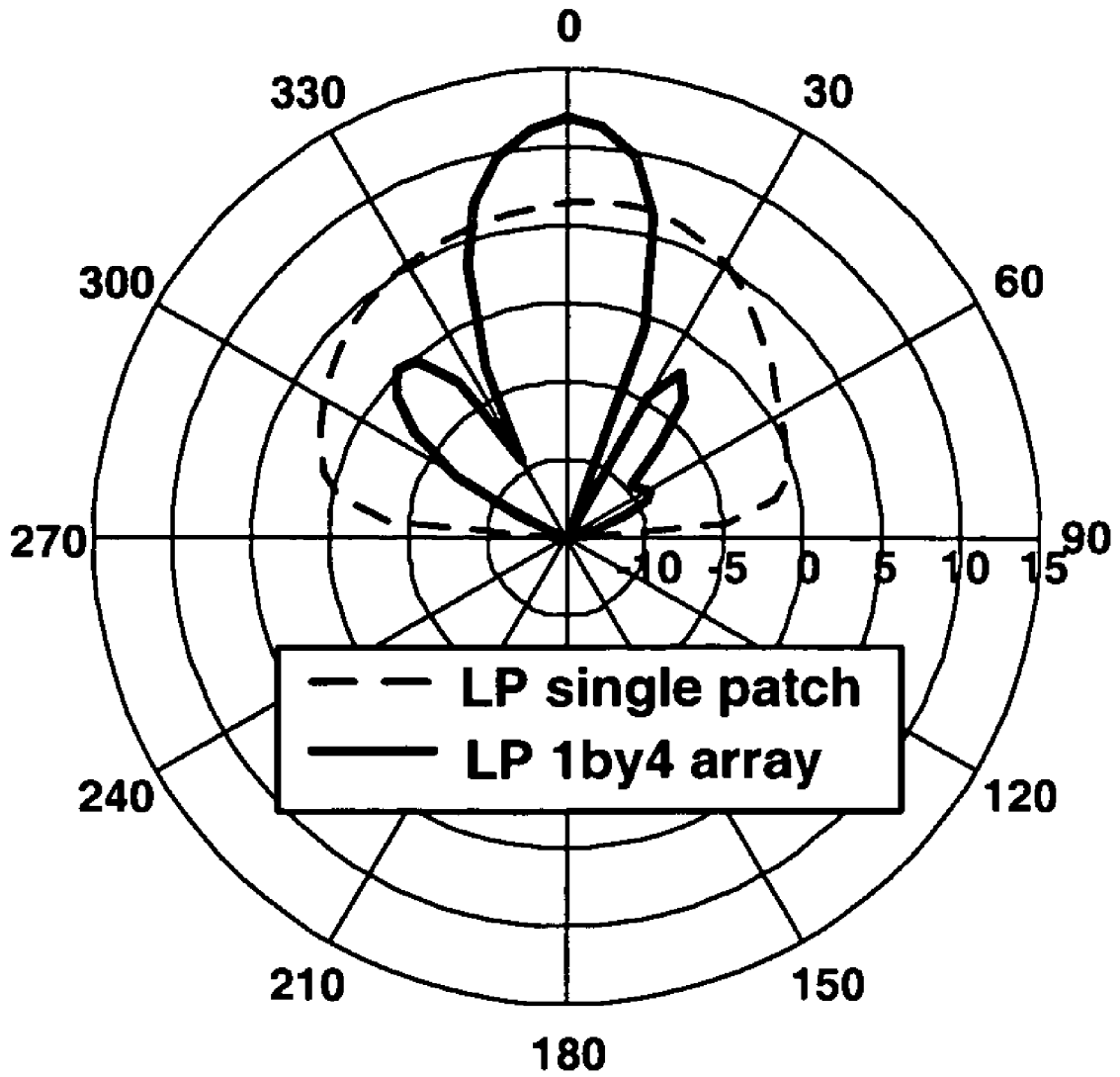


Fig. 8C

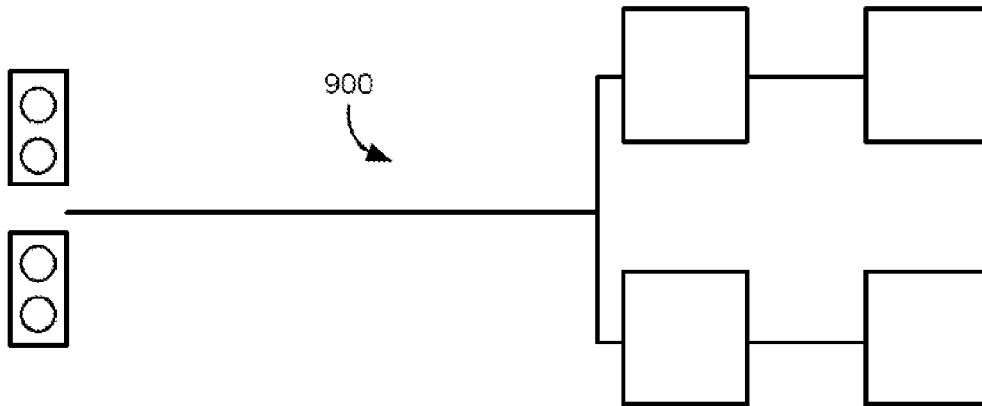


Fig. 9A

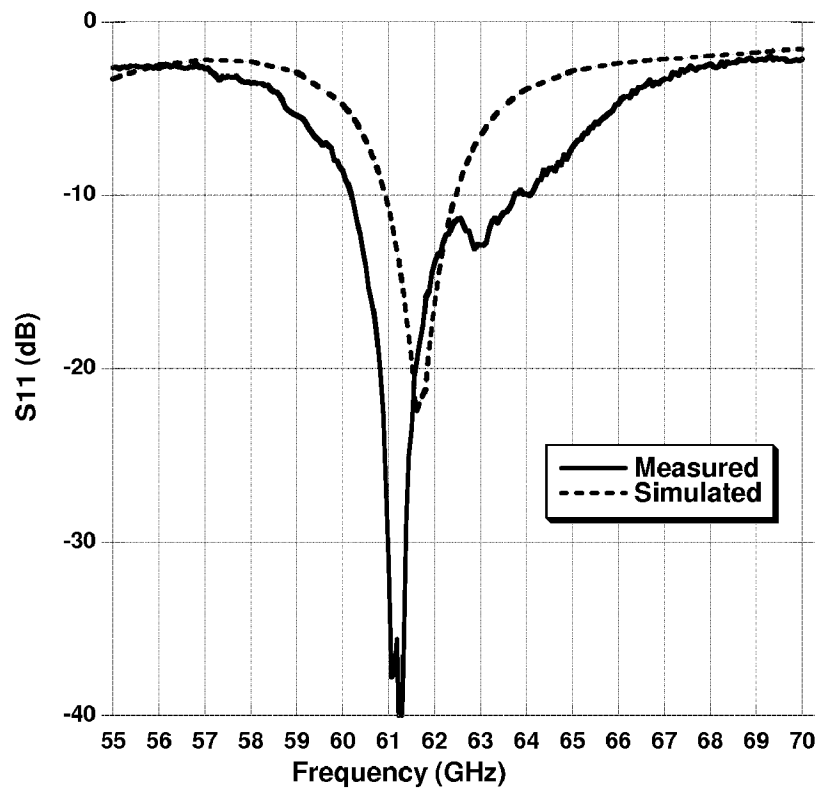


Fig. 9B

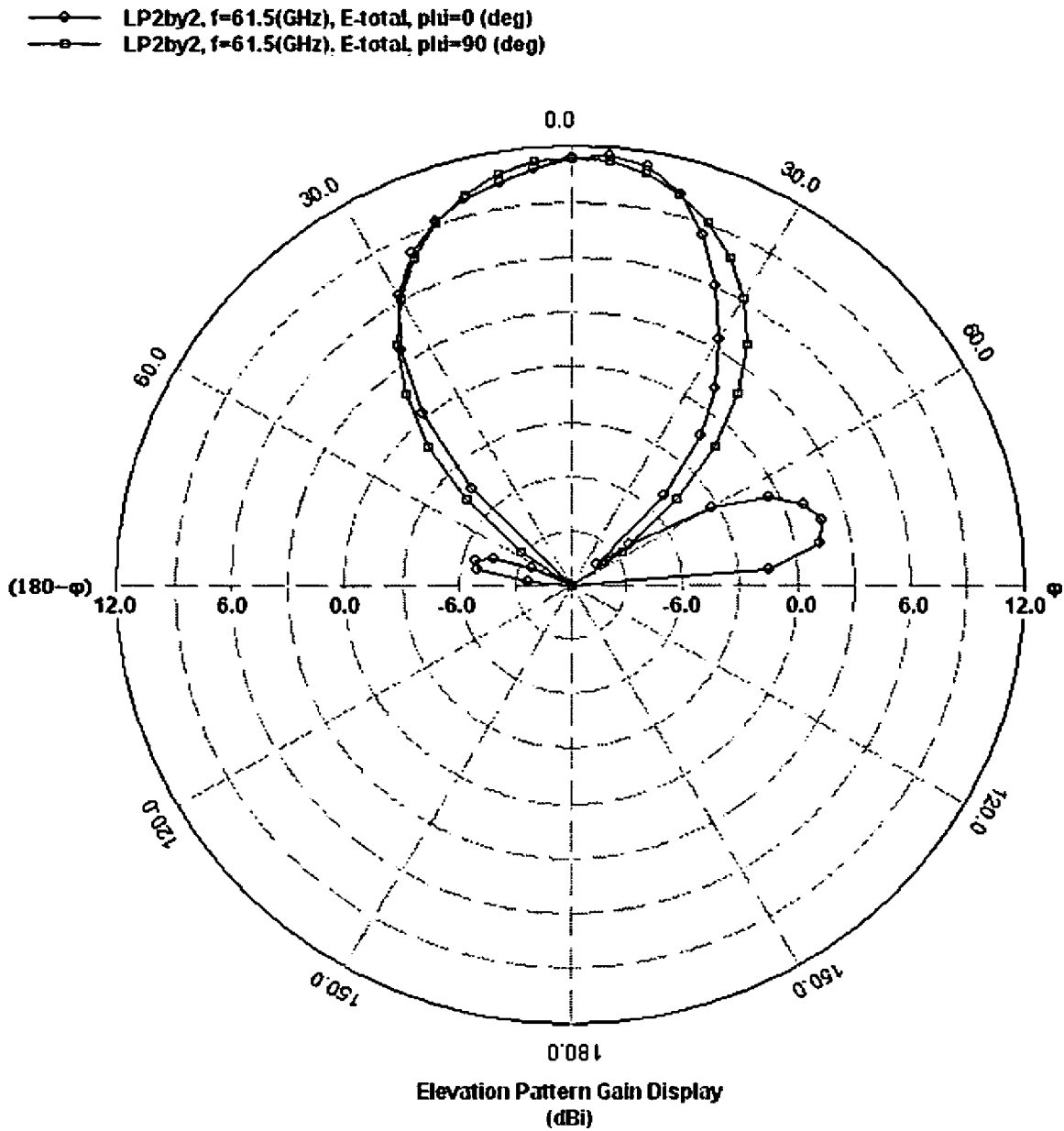


Fig. 9C

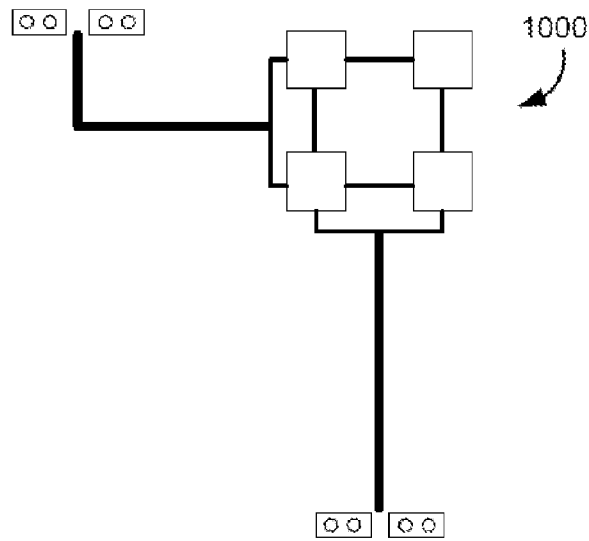


Fig. 10A

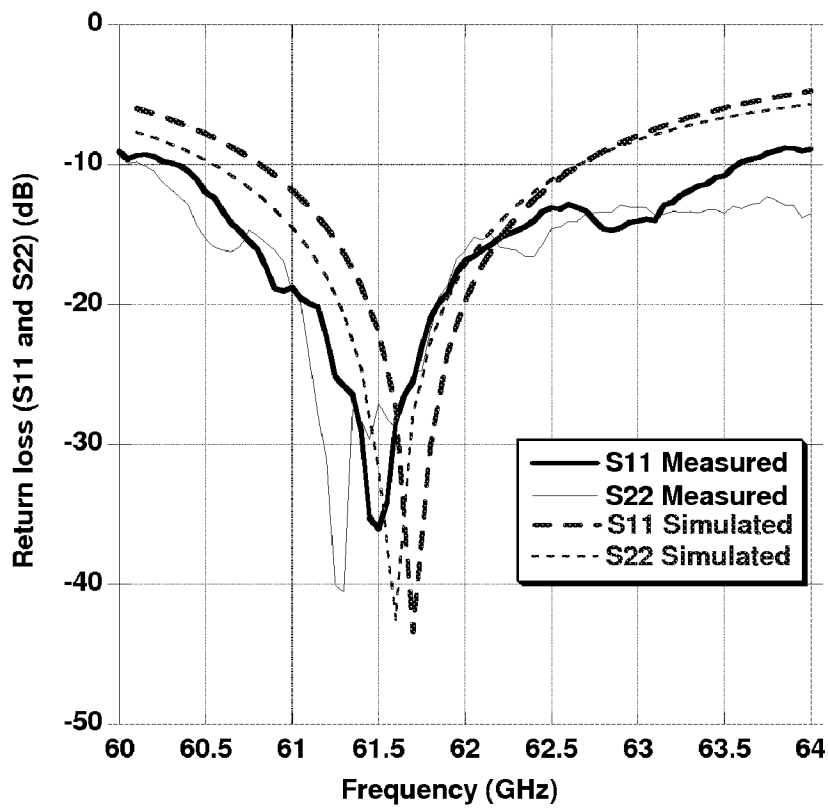


Fig. 10B

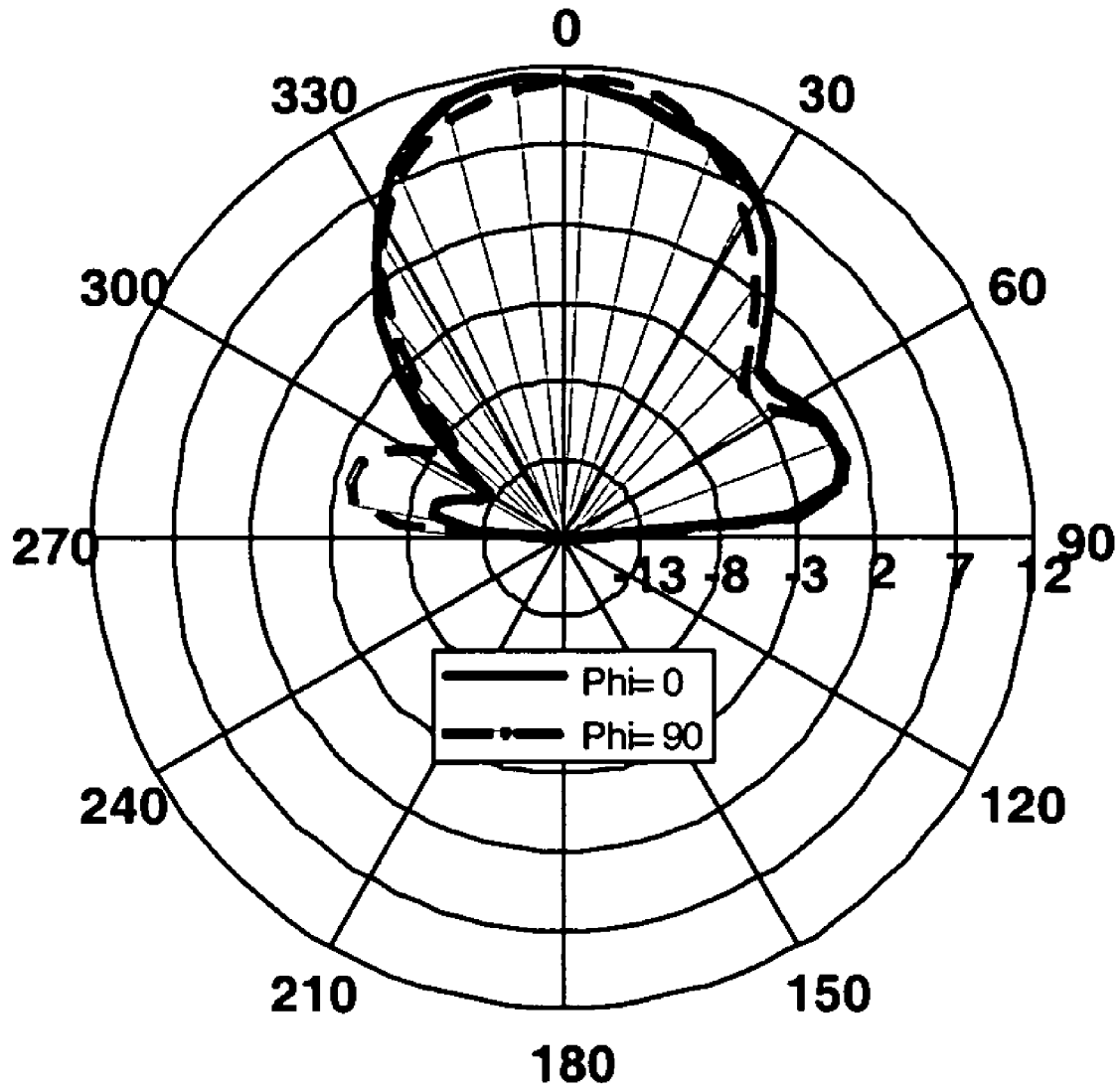


Fig. 10C

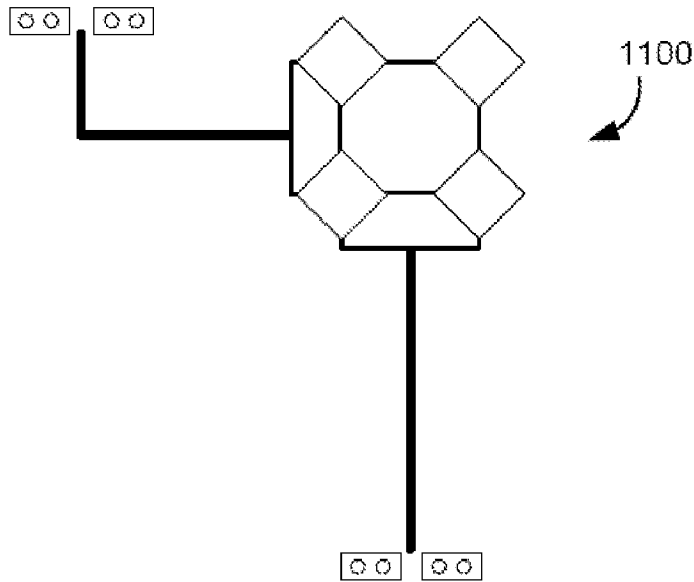


Fig. 11A

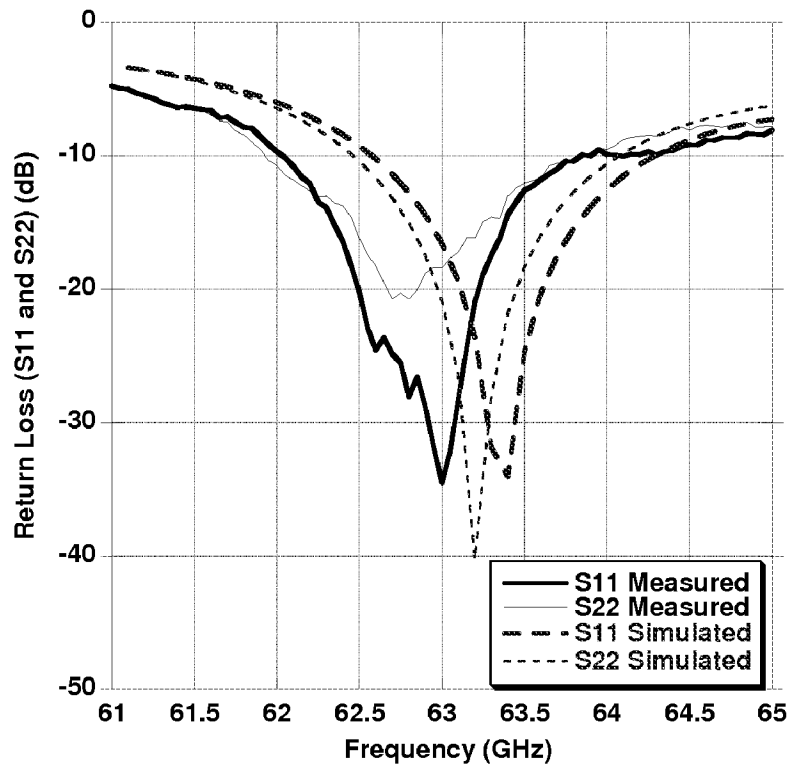


Fig. 11B

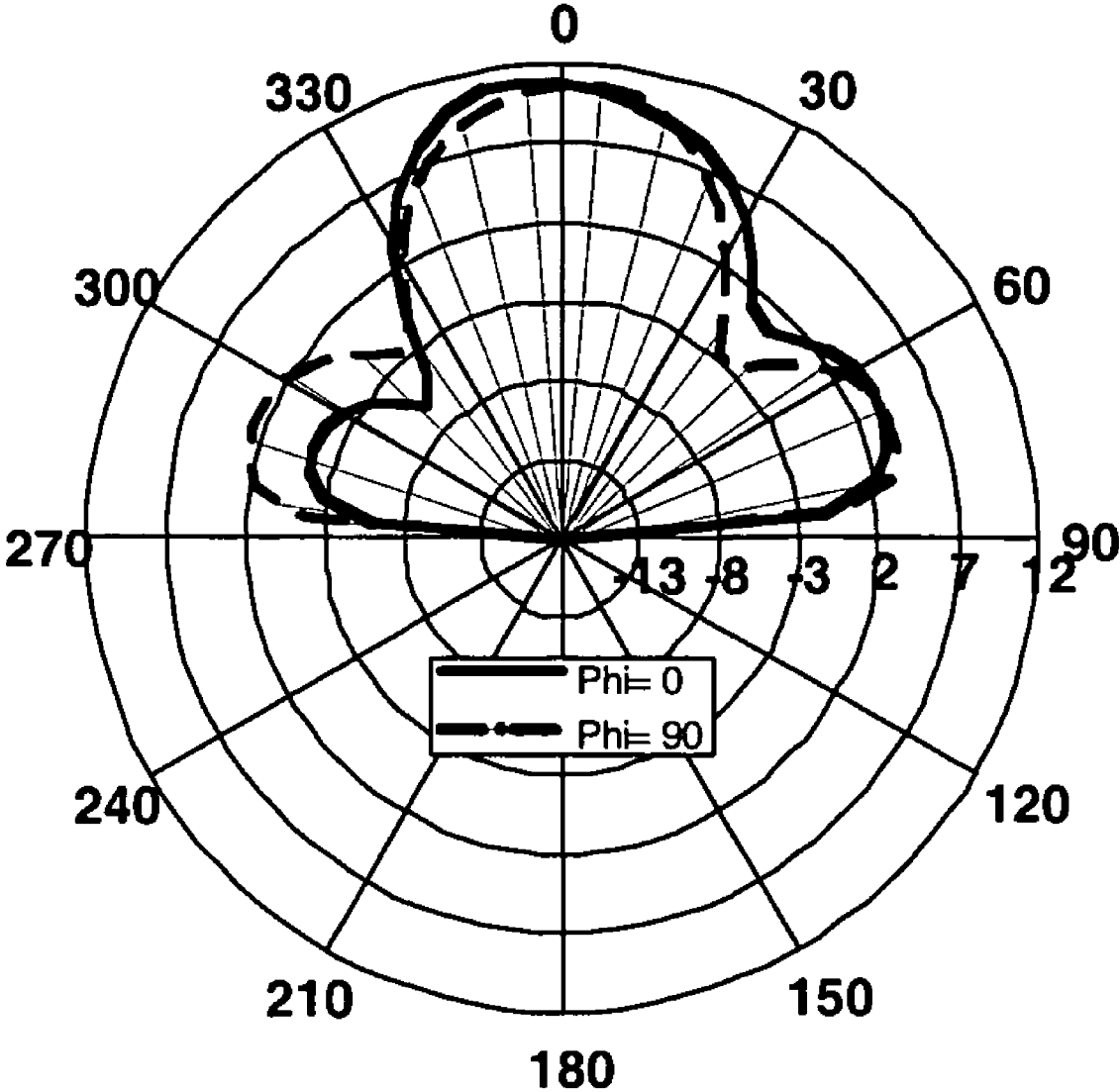


Fig. 11C

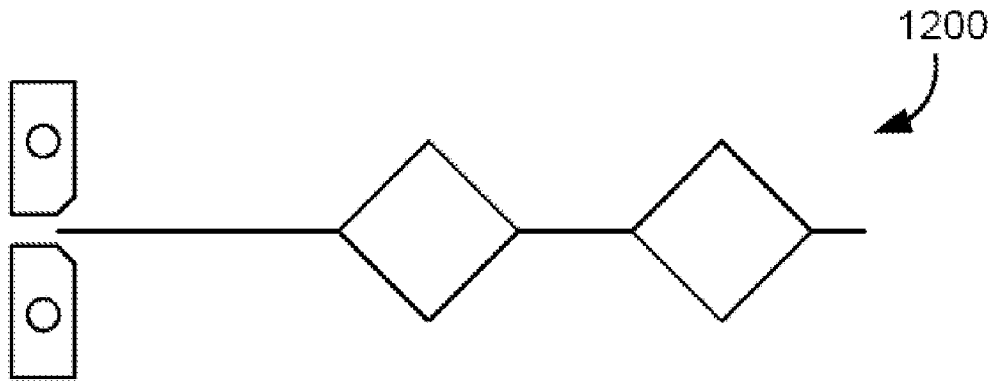


Fig. 12A

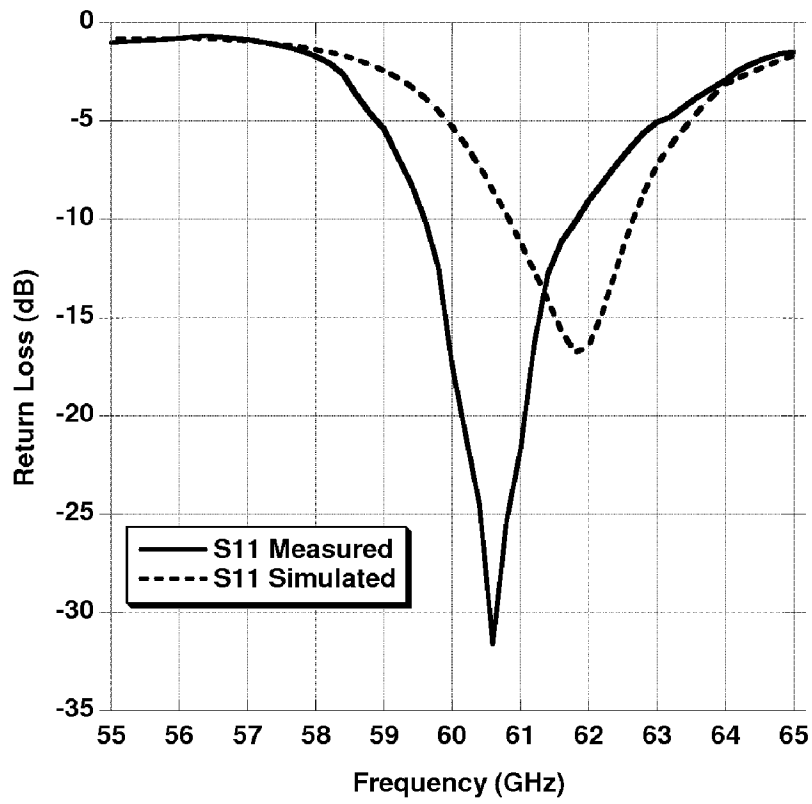


Fig. 12B

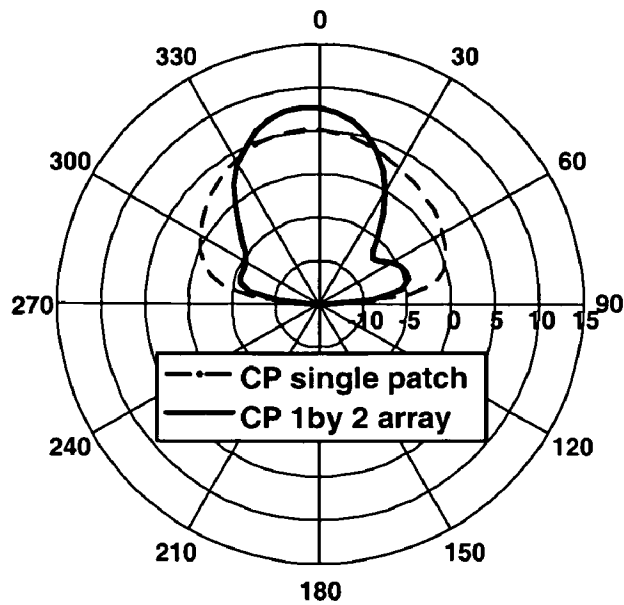


Fig. 12C

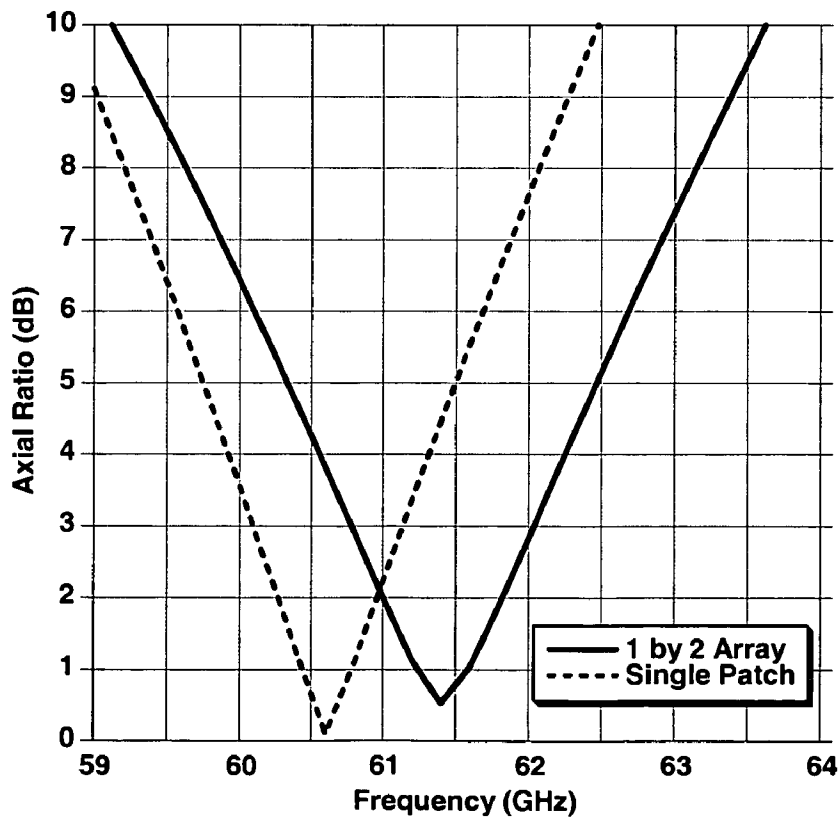


Fig. 12D

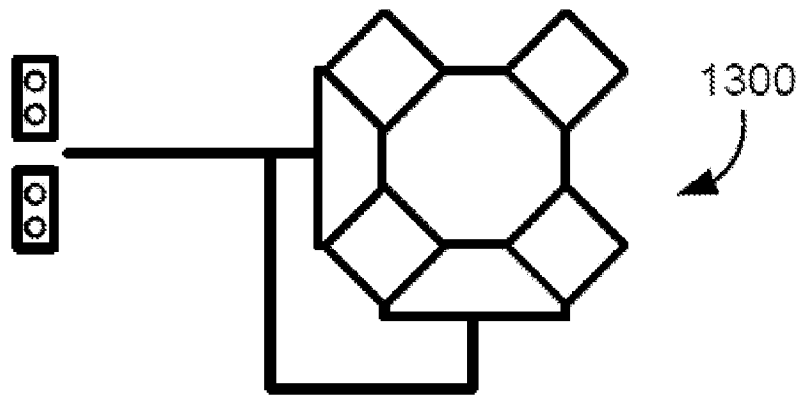


Fig. 13A

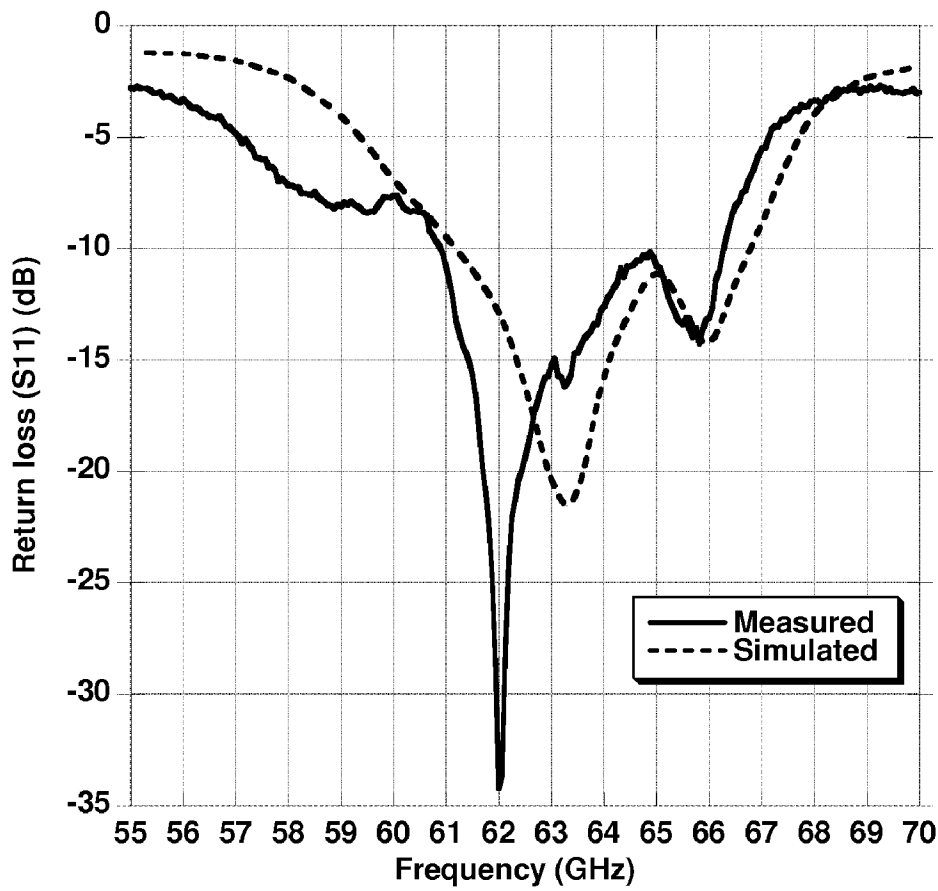


Fig. 13B

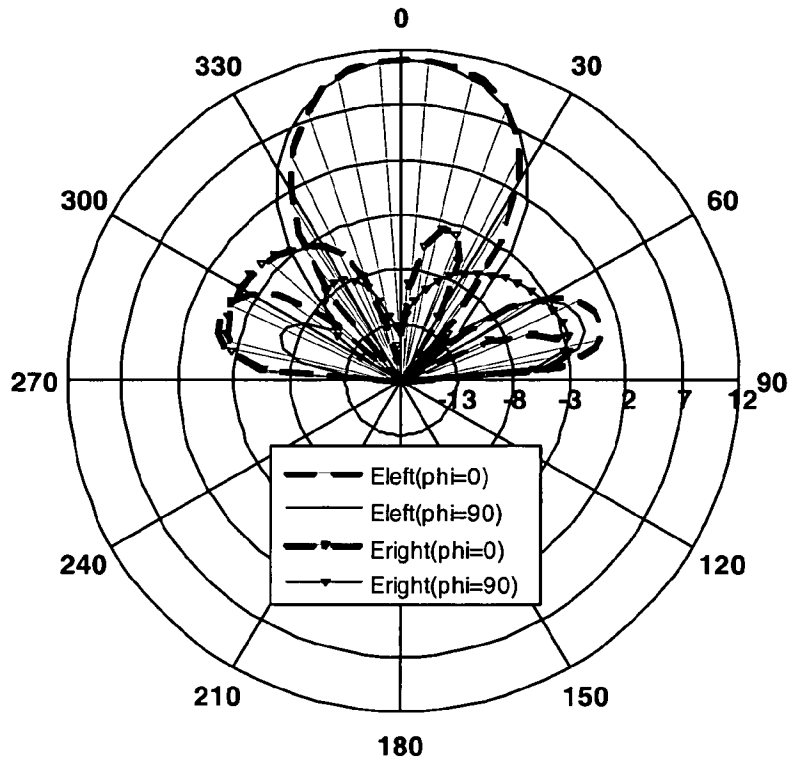


Fig. 13C

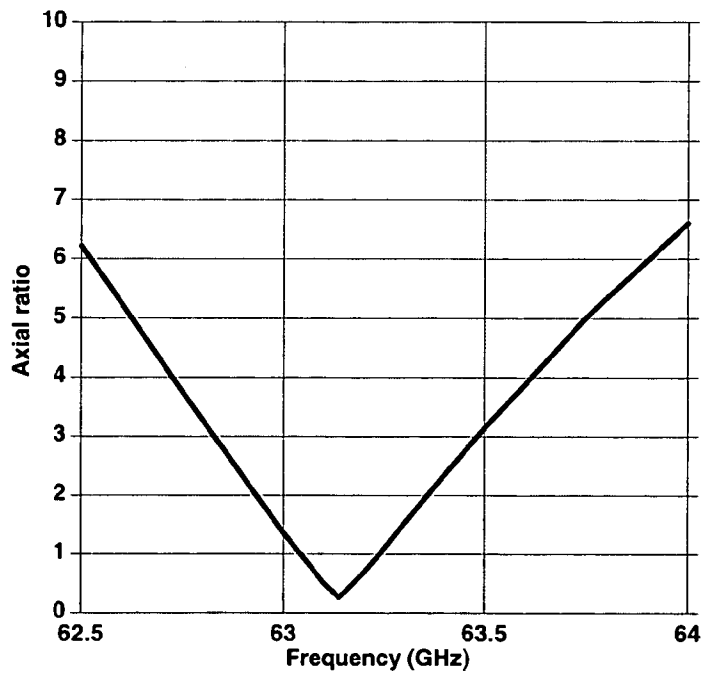


Fig. 13D

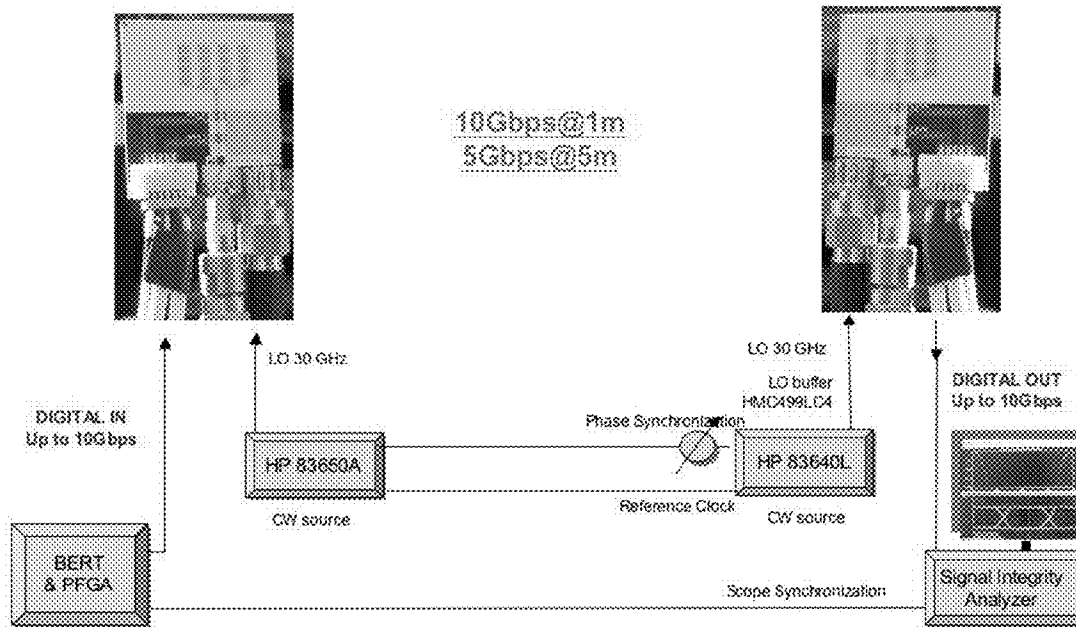


Fig. 14A

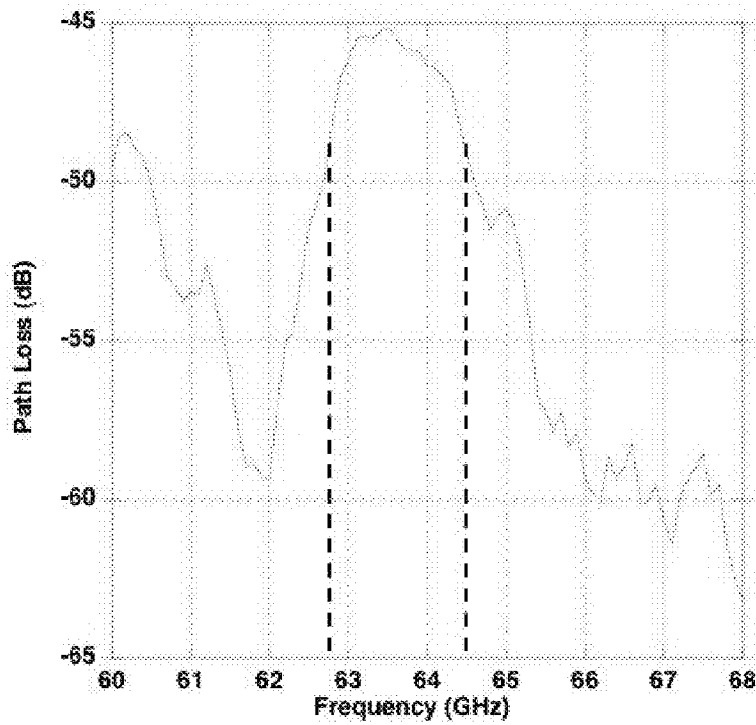


Fig. 14B

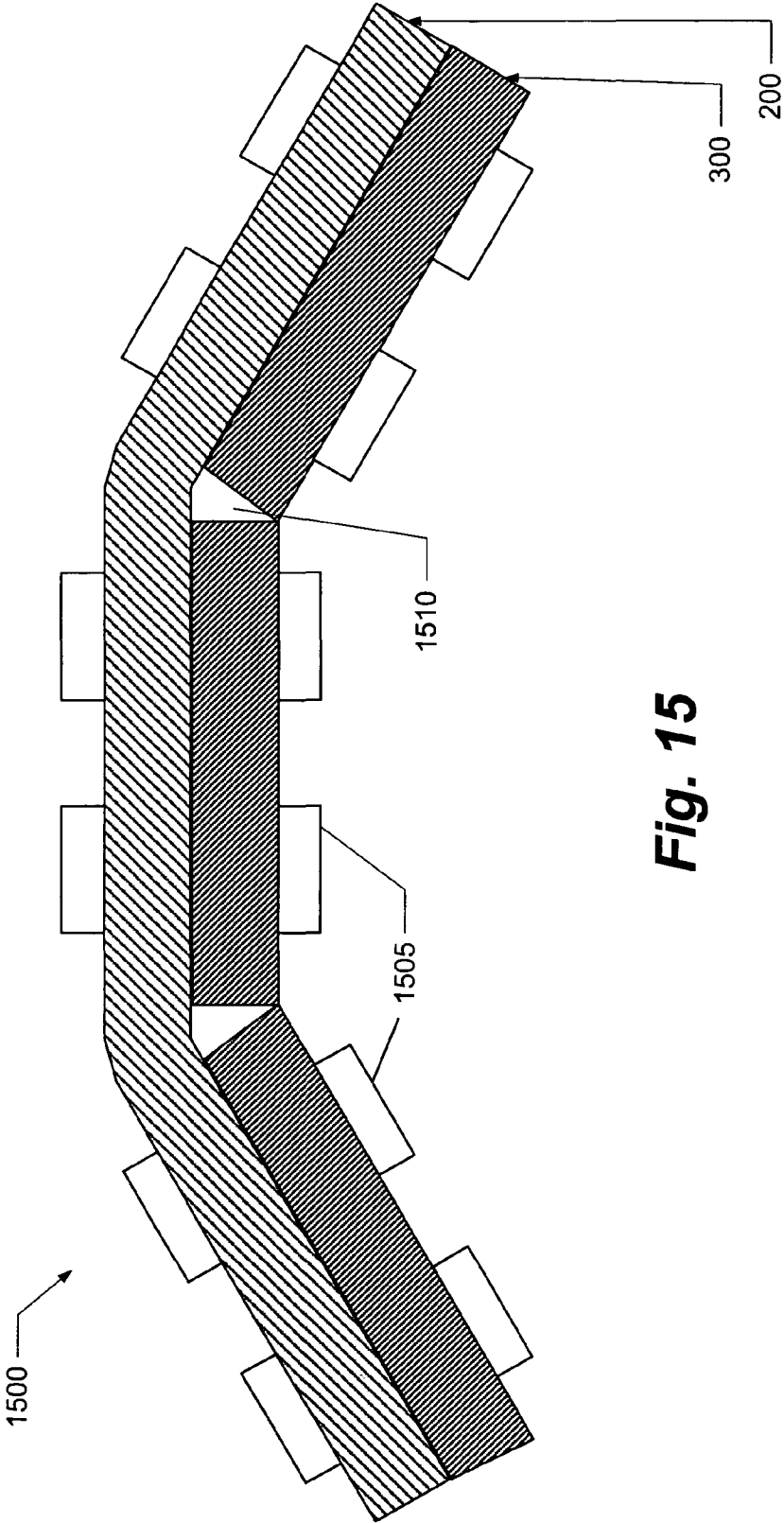
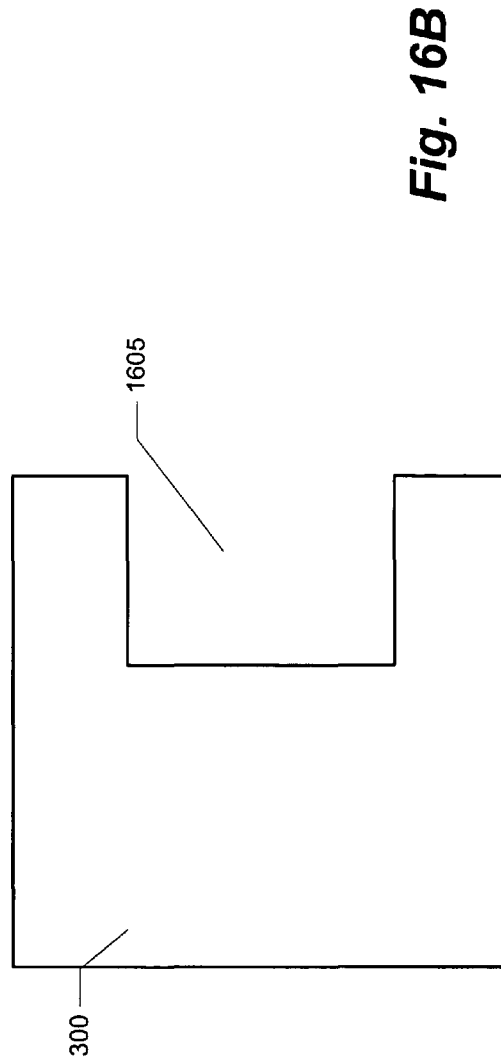
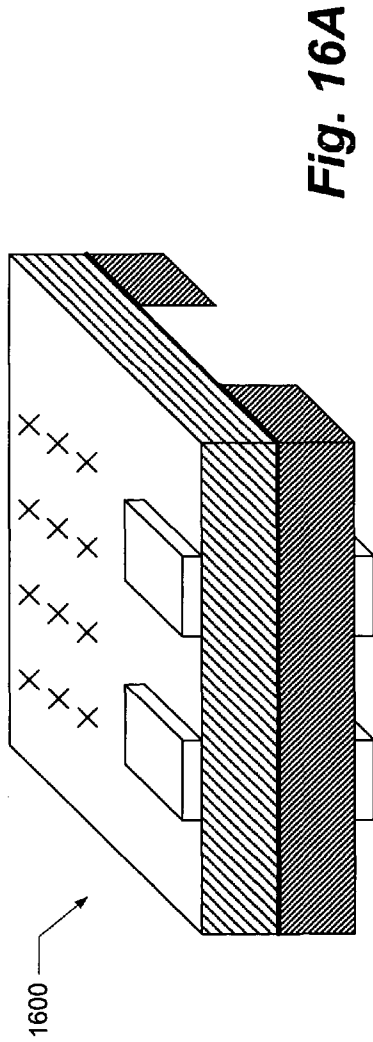


Fig. 15



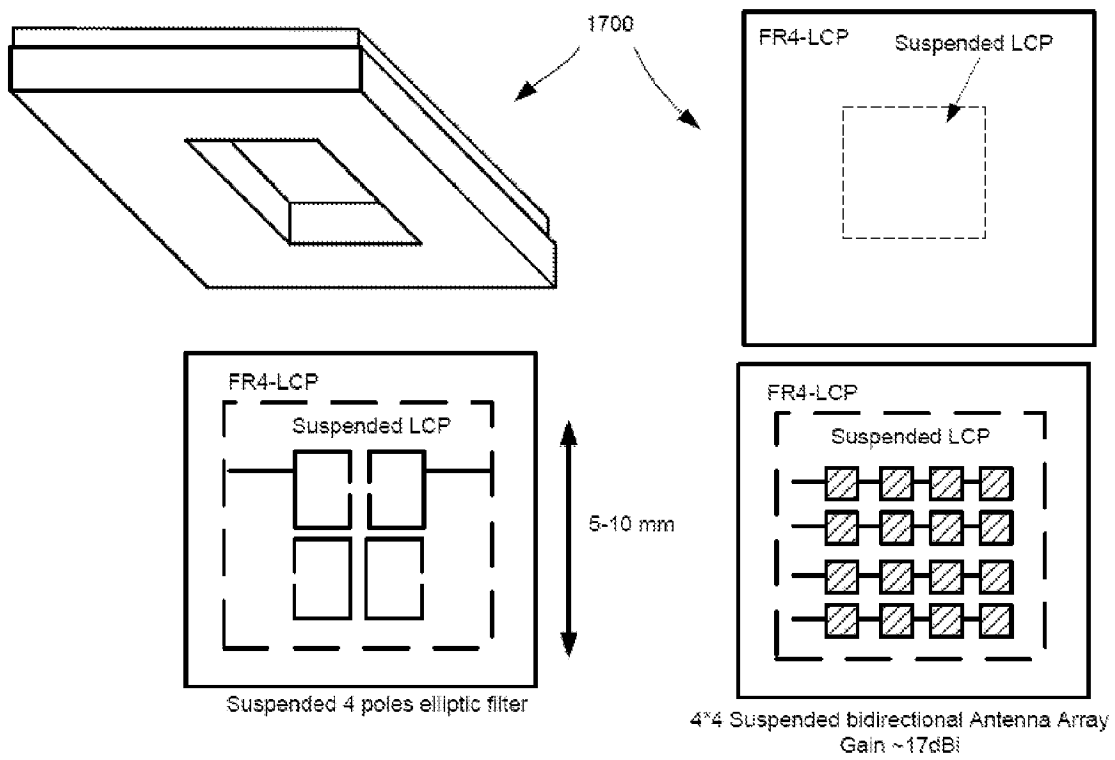


Fig. 17

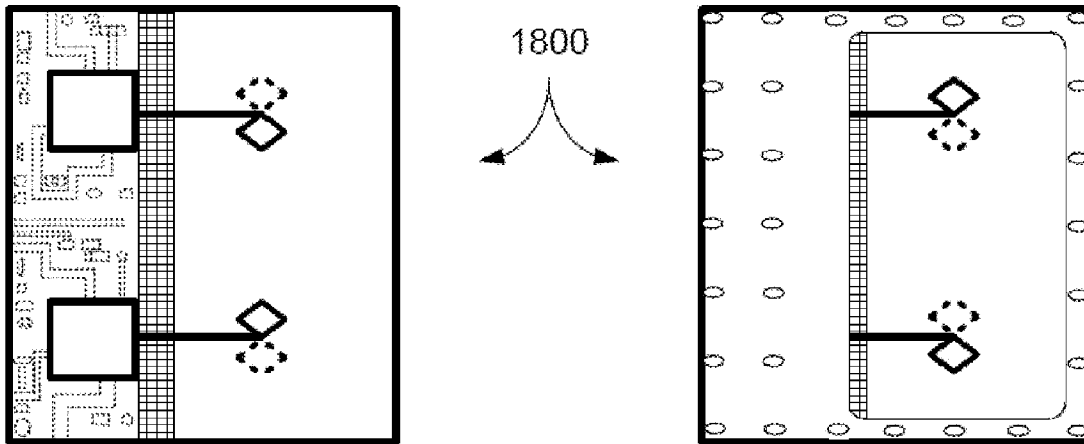


Fig. 18A

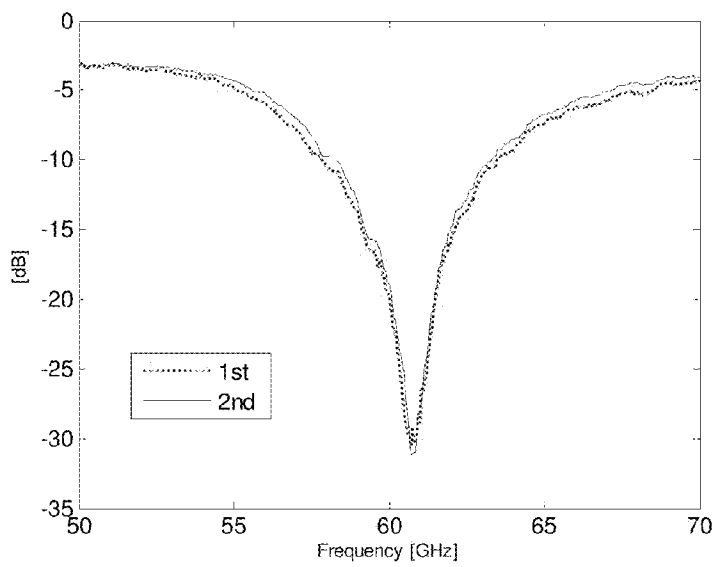


Fig. 18B

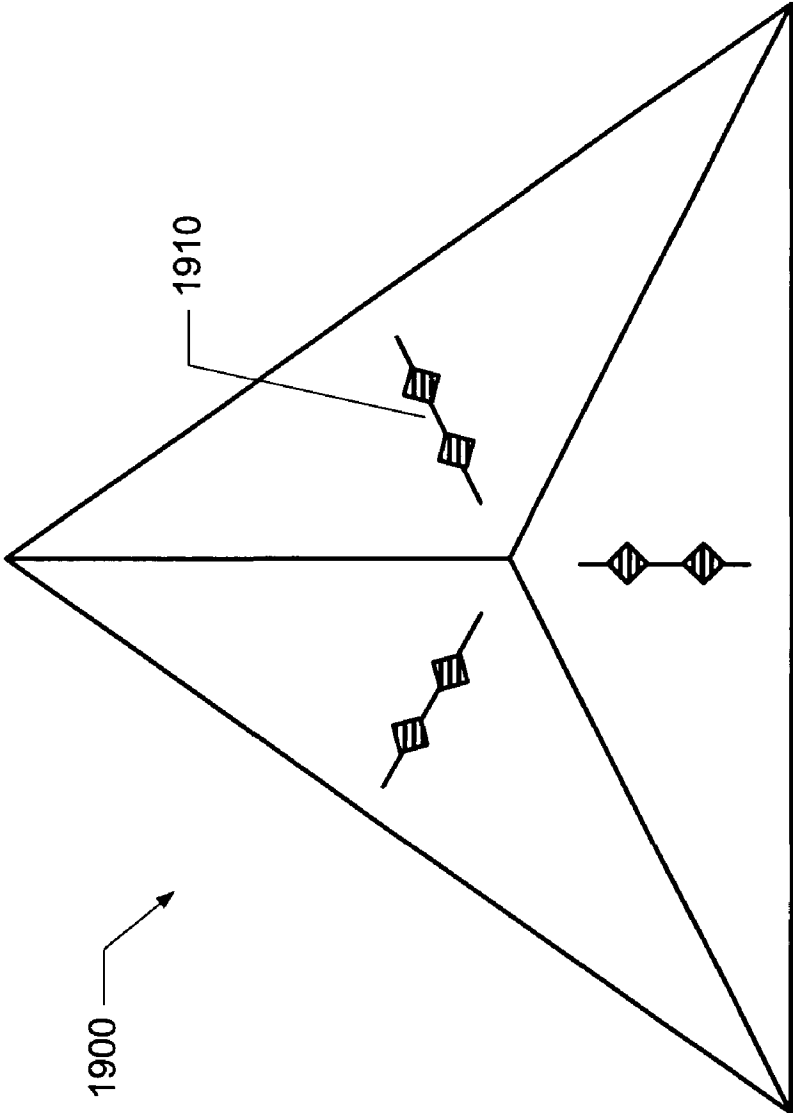


Fig. 19

**MODULE, FILTER, AND ANTENNA
TECHNOLOGY FOR MILLIMETER WAVES
MULTI-GIGABITS WIRELESS SYSTEMS**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application claims the benefit of U.S. Provisional Application Nos. 60/666,839 and 60/666,840, both filed 31 Mar. 2005, and U.S. Provisional Application Nos. 60/667,287, 60/667,312, 60/667,313, 60/667,375, 60/667,443, and 60/667,458, collectively filed 1 Apr. 2005, the entire contents and substance of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to communication networks and, more particularly, to improved packaging of high speed communication devices.

2. Description of Related Art

As the world becomes more reliant on electronic devices, and portable devices, the desire for faster and more convenient devices continues to increase. Accordingly, manufacturers and designers of such devices strive to create faster, easier to use, and more cost-effective devices to serve the needs of consumers.

Indeed, the demand for ultra-high data rate wireless communication has increased, in particular due to the emergence of many new multimedia applications. Due to some limitations in these high data rates, the needs for ultra-high speed personal area networking (PAN), and point-to-point or point-to-multipoint data links become vital.

Conventional wireless local area networks (WLAN), e.g., 802.11a, 802.11b, and 802.11g standards, are limited, in the best case, to a data rate of only 54 Mb/s. Other high speed wireless communications, such as ultra wide band (UWB) and multiple-input/multiple-output (MIMO) systems can extend the data rate to approximately 100 Mb/s.

To push through the gigabit per second (Gb/s) spectrum, either spectrum efficiency or the available bandwidth must be increased. Consequently, recent development of technologies and systems operating at the millimeter-wave (MMW) frequencies increases with this demand for more speed.

Fortunately, governments have made available several GHz (gigahertz) bandwidth unlicensed Instrumentation, Scientific, and Medical (ISM) bands in the 60 GHz spectrum. For instance, the United States, through the Federal Communications Commission (FCC), allocated 59-64 GHz for unlicensed applications in the United States. Likewise, Japan allocated 59-66 GHz for high speed data communications. Also, Europe allocated 59-62, 62-63, and 65-66 GHz for mobile broadband and WLAN communications. The availability of frequencies in this spectrum presents an opportunity for ultra-high speed, short-range wireless communications.

Unfortunately, the high cost of MMIC (monolithic micro-wave integrated circuit) chipsets and packaging devices operating at ultra-high frequencies and/or ultra-high speeds affects the number of consumers that can enjoy these advances in technology. Conventional solutions of MMW radios cost often several hundred, or even several thousand dollars. The high costs of MMW radios are due to high costs of material used, as well as costs associated with low volume fabrication, and assembly processes. Moreover, antennas for MMW radios are traditionally implemented using either

metallic horn antennas, or large planar array printed micro-strips, that are connected to a module, which further increase manufacturing costs.

Conventional MMW MMIC chipsets is based on PHEMT (pseudomorphic high electron mobility transistor), and a bulky metal housing. Additionally, MMW packaging can include a refined form of aluminum oxide—i.e., Alumina—or Teflon® based micro-strip substrates, thin film metallization, and coaxial or waveguide feed-through connectors.

Another approach to manufacturing passive devices for these high frequencies and high speeds includes the use of Low Temperature Co-Fired Ceramic (LTCC) multi-layer substrate as a platform for module integration. The LTCC substrate reduces the costs of materials, in comparison to those described above. Further cost reduction, however, is necessary for competitive high volume production.

The combination of CMOS (complementary metal-oxide semiconductor) and SiGe (Silicon Germanium) technologies with a low cost highly producible module technology, featuring low loss and embedded functionality, i.e., antennas, is required to enable a high volume commercial use of high frequency technologies, e.g., 60 GHz. Accordingly, antenna solutions are required for multi-gigabits indoor wireless communication in the MMW region.

What is needed, therefore, is an improved packaging of MMW radios, which lowers manufacturing and material costs. It is to such a method and device that that present invention is primarily detected.

BRIEF SUMMARY OF THE INVENTION

The present invention comprises a method of fabricating an ultra-high frequency module comprising: providing a top layer having a high frequency substrate; drilling the top layer to establish vertical vias in the top layer; milling the top layer to define a top layer cavity for receiving a chipset; providing a bottom layer comprising a reinforcement structure, the bottom layer having a double clad core and a bottom substrate; adhering the double clad core and the bottom substrate of the bottom layer together with an adhesive; milling the bottom layer to define a bottom layer cavity; aligning the top layer and the bottom layer; and adhering the top layer to the bottom layer with the adhesive.

The method of fabricating can further comprise assembling external components on a surface of the top layer and the bottom layer. Also, the method can enable the operation of the ultra-high frequency module at approximately 60 GHz.

The top layer can comprise liquid crystal polymer (LCP), and the bottom layer can comprise fire resistant 4 (FR4). The method of fabricating can further comprise integrating a printed filter and a filtered antenna into the module. Moreover, the method of fabricating can further comprise encapsulating the top layer and the bottom layer.

In a preferred embodiment, the method of fabricating can further include fabricating the top layer and the bottom layer on a large area panel of a printed circuit board, wherein the large area panel is approximately 12 inches by 18 inches or larger.

In a preferred embodiment, the adhesive is a pressure sensitive adhesive enabling room-temperature lamination, a solid electrical connection between connections, and an accurate alignment of the top layer and the bottom layer.

An ultra-high frequency module operating at ultra-high speeds is further disclosed. The module comprises: a top layer having a high frequency substrate, the top layer defining a top layer cavity; a bottom layer having a double clad core and a bottom substrate, the bottom layer defining a bottom layer

cavity; and an adhesive to adhere the top layer to the bottom layer, and to adhere the double clad core of the bottom layer and the bottom substrate of the bottom layer,

wherein the top layer and the bottom layer are fabricated on a large area panel of a printed circuit board.

The module can further comprise an antenna for communicating at approximately 60 gigaHertz (GHz), wherein the antenna is adapted to transmit data wireless at least 2.5 gigabits per second (Gb/s).

The antenna of the module can be selected from the group consisting of a 1 by 4 patch array antenna, a 2 by 2 series patch array antenna, a 2 by 2 dual edge patch array antenna, a 2 by 2 dual corner patch array antenna, a 4 by 4 array antenna, and a circularly polarized antenna.

The top layer of the module can comprise LCP and the bottom layer comprises FR4. Additionally, the top layer defines a cavity for receiving a monolithic microwave integrated circuit. The bottom layer preferably defines a cavity for receiving a printed antenna.

An ultra-high frequency multi-sector module comprising: a top layer comprising a high frequency substrate; a bottom layer comprising a sturdy and electric material; and an adhesive for connecting the top layer to the bottom layer, wherein at least two modules are connected to one another creating an angle therebetween enabling signals from different angles to be received by the multi-sector module. The multi-sector module can operate at frequency of approximately 60 GHz.

The top layer can comprise liquid crystal polymer and the bottom layer comprises fire resistant 4. The bottom layer can define a trench at the angle, wherein a portion of fire resistant 4 is omitted, and wherein the top layer is flexible enabling a bent shape of the multi-sector module. The multi-sector module can further comprise a pyramidal shape for covering 360 degrees in azimuth.

These and other objects, features and advantages of the present invention will become more apparent upon reading the following specification in conjunction with the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a flowchart of preferred fabrication steps of a module, in accordance with a preferred embodiment of the present invention.

FIG. 2A depicts a cross-section view of a top layer of the module, in accordance with a preferred embodiment of the present invention.

FIG. 2B depicts a cross-section view of a bottom layer of the module, in accordance with a preferred embodiment of the present invention.

FIG. 3 depicts a cross-section view of the module, illustrating the top layer and bottom layer combined to form the module, in accordance with a preferred embodiment of the present invention.

FIG. 4A depicts a cross-section view of the module, in accordance with a preferred embodiment of the present invention.

FIG. 4B depicts a perspective view of the module, in accordance with a preferred embodiment of the present invention.

FIG. 5A depicts a top view of a liquid crystal polymer planar series fed slotted patch filter, in accordance with a preferred embodiment of the present invention.

FIG. 5B depicts a graphical representation of the insertion loss versus frequency of the liquid crystal polymer planar series fed slotted patch filter, in accordance with a preferred embodiment of the present invention.

FIG. 6A depicts a top view of a liquid crystal polymer, backed co-planar wave (BCPW) filter, in accordance with a preferred embodiment of the present invention.

FIG. 6B depicts a graphical representation of the insertion loss versus frequency of the liquid crystal polymer BCPW filter, in accordance with a preferred embodiment of the present invention.

FIG. 7A depicts a top view of a liquid crystal polymer planar elliptic filter, in accordance with a preferred embodiment of the present invention.

FIG. 7B depicts a graphical representation of the insertion loss versus frequency of the liquid crystal polymer planar elliptic filter, in accordance with a preferred embodiment of the present invention.

FIG. 8A depicts a top view of a 1 by 4 patch array antenna, in accordance with a preferred embodiment of the present invention.

FIGS. 8B-8C depict graphical representations of the performance of the 1 by 4 patch array antenna, in accordance with preferred embodiments of the present invention.

FIG. 9A depicts a top view of a 2 by 2 series patch array antenna, in accordance with a preferred embodiment of the present invention.

FIGS. 9B-9C depict graphical representations of the performance of the 2 by 2 series patch array antenna, in accordance with preferred embodiments of the present invention.

FIG. 10A depicts a top view of a 2 by 2 dual edge patch array antenna, in accordance with a preferred embodiment of the present invention.

FIGS. 10B-10C depict graphical representations of the performance of the 2 by 2 dual edge patch array antenna, in accordance with a preferred embodiment of the present invention.

FIG. 11A depicts a top view of a 2 by 2 dual corner patch array antenna, in accordance with a preferred embodiment of the present invention.

FIGS. 11B-11C depict graphical representations of the performance of the 2 by 2 dual corner patch array antenna, in accordance with a preferred embodiment of the present invention.

FIG. 12A depicts a top view of a 1 by 2 circularly polarized antenna, in accordance with a preferred embodiment of the present invention.

FIGS. 12B-12D depict graphical representations of the performance of the 1 by 2 circularly polarized antenna, in accordance with a preferred embodiment of the present invention.

FIG. 13A depicts a top view of a 2 by 2 circularly polarized antenna, in accordance with a preferred embodiment of the present invention.

FIGS. 13B-13D depict graphical representations of the performance of the 2 by 2 circularly polarized antenna, in accordance with a preferred embodiment of the present invention.

FIG. 14A depicts a top view of a test environment of a 60 GHz multi-gigabit link, in accordance with a preferred embodiment of the present invention.

FIG. 14B depicts a measured power link of the test environment, in accordance with a preferred embodiment of the present invention.

FIG. 15 depicts a side view of an multi-sector module, in accordance with a preferred embodiment of the present invention.

FIG. 16A depicts a perspective view an end-fire millimeter wave antenna, in accordance with a preferred embodiment of the present invention.

FIG. 16B depicts a top view of a bottom layer of the end-fire millimeter wave antenna, in accordance with a preferred embodiment of the present invention.

FIG. 17 depicts a module having the bottom layer defining a cavity, in accordance with a preferred embodiment of the present invention.

FIG. 18A depicts views of a 60 GHz radio module, in accordance with a preferred embodiment of the present invention.

FIG. 18B depicts a graphical representation of the 60 GHz radio module, in accordance with a preferred embodiment of the present invention.

FIG. 19 depicts a pyramidal multi-sector antenna, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

To facilitate an understanding of the principles and features of the invention, it is explained hereinafter with reference to its implementation in an illustrative embodiment. In particular, the invention is described in the context of being a wireless module for operation at ultra-high frequencies and ultra-high data communication speeds.

The materials described as making up the various elements of the invention are intended to be illustrative and not restrictive. Many suitable materials that would perform the same or a similar function as the materials described herein are intended to be embraced within the scope of the invention. Such other materials not described herein can include, but are not limited to, for example, materials that are developed after the time of the development of the invention.

The present invention is a wireless module 100. The module 100 preferably includes a top layer 200, a bottom layer 300, and an adhesive 400 to connect the top layer 200 to the bottom layer 300.

The wireless module 100 can be adapted to receive/transmit ultra-high frequencies at ultra-high speeds. For instance, preferably the wireless module 100 can operate at approximately 60 GHz at approximately 10 Gb/s.

FIG. 1 depicts a flowchart of fabrication step of the module 100. A method 105 of fabricating the module 100 includes providing a top layer 200. The top layer 200 can comprise double-side patterning of a double-clad high frequency dielectric substrate 205 to define a passive millimeter-wave circuit 210 (i.e., interconnection, filter, and antenna).

Thus, the method 105 at 110, preferably, metallizing the circuit 210 having copper, wherein having a thickness between 9 to 18 microns. Moreover, gold plating of the circuit 210 is preferred for wire bonding, surface mounting, and additional protection.

Liquid Crystal Polymer (hereinafter "LCP") is a preferred high frequency substrate 205, and can comprise the top layer 200. The Rogers Corporation is a preferred manufacturer of LCP for the present invention. Hence, a preferred LCP is manufactured by the Rogers Corporation is RO3600. The thickness of the high frequency substrate 205—the LCP layer—can be in the range of 4 to 10 mils, depending on the material availability and design requirements.

More common materials, however, such as RO4003 or RO3003 (by happenstance, also manufactured by Rogers Corporation), or even other equivalent dielectric materials, can further be used for the top layer 200.

At 120, the method 105 further includes drilling and plating of the high frequency substrate 205 to realize a vertical via 215 of the top layer 200. Next, at 130, milling a cavity 220 can occur. The cavity 220 of the top layer 200 can host a MMIC (monolithic microwave integrated circuit) chipset (see FIG.

2A). In a preferred embodiment, the cavity 220 of the top layer 200 is sufficiently large enough to receive the MMIC chipset.

A bottom layer 200 can be provided. At 140, the method 105 of fabrication further comprises the step of drilling and plating of the bottom layer 300. The bottom layer 300 can comprise a double clad core 305 and a bottom substrate 310. Preferably, the bottom substrate 310 comprises FR4. FR4 is an abbreviation for Flame Resistant 4. FR4 is an epoxy material reinforced with a woven fiberglass mat, often used in the manufacturing of printed circuit boards (PCBs). Since FR4 is widely used to build high-end consumer and industrial electronic equipment, it is widely available and, hence, cost effective.

Preferably, at 150, the method 105 of fabricating further includes laminating both sides of the FR4 core substrate 310 using, preferably, an electrically conductive pressure sensitive adhesive 400. Indeed, 3M-9713 adhesive tape, manufactured by 3M®, can be used. Next, at 160, the method 105 further includes milling a cavity 315 in the FR4 core substrate 310 of the bottom layer 300. (See FIG. 2B).

At 170, the method 105 further can comprise aligning and laminating the high frequency substrate 205, the FR4 core 305, and the FR4 bottom substrate 310, i.e., the top layer 200 and the bottom layer 300. The use of the pressure sensitive adhesive 400 can enable room-temperature lamination, a good electrical connection between the three substrates (205, 305 and 310), as well as a good accuracy alignment of the layer. (See FIG. 3).

The preferred next step of the method 105, at 180, includes assembling components onto the module 100—i.e., both surface mounted and wire-bonded components. The appropriate depth of the cavity 220 into the high frequency substrate 205 allows for a very short wire-bonding length between the MMIC and the module 100. Finally, at 190, encapsulating can occur. Encapsulation can occur using a conventional device, such as using metal cap, FR4 based cap, globtop, and the like. The step of encapsulating can isolate, protect and enclose the module 100.

The method 105 and resulting module 105 topology can enable efficient and simultaneous integration of the MMIC, a printed filter, a printed antenna, and many other printed passive devices for millimeter-wave applications in a single fabrication large area (i.e., approximately 12 by 18 inches, and/or approximately 18 by 24 inches) printed wire board (PWB) process. The dimension range that is possible to fabricate the module can be compatible with design requirements for operating frequencies around approximately 60 GHz, i.e., approximately in the range of 54-66 GHz. Although, as one skilled in the art would recognize, the dimensions of the top layer 200 and bottom layer 300 can easily be altered to increase or decrease the frequency of the module 100.

The preferred topology of the module 100 can support a quasi-hermetic packaging solution for the MMIC. The topology can further enable integration of direct current and millimeter waves feed-through interconnection, planar filters, integrated waveguide filter, broadside, end-fire, reflector, bidirectional ultra-wide bandwidth linear, circular polarization antenna arrays, and the like.

FIG. 2A illustrates a cross-section view of the top layer 200 of the module. The top layer 200 can contain a high frequency substrate 205, preferably comprising LCP. Although, as described, and as one skilled in the art would recognize, other materials can be implemented. For example, the Rogers Corporation manufactures RO4003 and RO3003, which can be used in the top layer 200.

LCP offers a low-cost alternative for millimeter wave module implementation. Indeed, LCP combines uniquely outstanding microwave and mechanical performances at low cost, as well as in large area processing capabilities.

The thickness of the top layer **200** can be in the range of approximately 4 to 10 mils.

The cavity **220** of the top layer **200** can be adapted to receive the MMIC circuit, and thus the cavity **220** is preferably large enough to receive the MMIC circuit.

FIG. 2B illustrates a cross-section view of the bottom layer **300** of the module **100**. The bottom layer **300** preferably contains a stable and sturdy material. In a preferred embodiment, the bottom layer **300** includes FR4.

The thickness of the bottom layer **300** comprises the double clad core **305** and the bottom substrate **310**. The thickness of the double clad core **305** is in the range of approximately 35 to 45 mils. The thickness of the bottom substrate **310** is, preferably, in the range of approximately 15 to 25 mils.

The top layer **200** and the bottom layer **300** of the module **100** are preferably connected. The top layer **200** and the bottom layer **300** can be connected via an adhesive **400**. The adhesive **400** is preferably a pressure sensitive adhesive, such as 3M®'s 9713, which is an electrically conductive tape. Indeed, the 9713 tape is a pressure sensitive adhesive **400** transfer tape with isotropic electrical conductivity. Innovative conductive fibers of the 9713 extend above the adhesive **400**, ensuring a solid electrical connection between the substrates—in this case, between the top layer **200** and the bottom layer **300**. One skilled in the art would recognize that other materials can be implemented to connect the top layer **200** to the bottom layer **300** in the present invention.

The top layer **200** (preferably comprising LCP), the bottom layer **300** (preferably comprising FR4), and the adhesive **400** (preferably comprising 3M-9713) combine (collectively “the layers”) to provide a low cost packaging system for the module **100**. Moreover, the layers can be fabricated on a large area panel (approximately 12 by 18 inches or larger); thus, when manufactured in high quantities can further reduce cost. The module **100**, when complete can many sizes from 1 mm² to the whole size of the layers **200** and **300**.

FIG. 3 illustrates a cross section view of the module **100**, wherein the layers **200** and **300** are connected with the adhesive **400**.

FIG. 4A illustrates a cross section view of the module **100**, wherein the layers **200** and **300** are connected. FIG. 4B illustrates a perspective view of the module **100**. An antenna array **250** is shown on the top layer **200**. Additionally, a surface of the top layer **200**, or the bottom layer **300** can include components **255**. The components **255** can be surface mount or through-hole.

As illustrated in exemplary embodiments, efficient integration of printed filters on the module **100** have been validated by various examples, many exemplary embodiments are illustrated in FIGS. 5A-5B, 6A-6B and 7A-7B.

FIG. 5A illustrates a LCP planar series fed slotted patch filter **500**. In the series slotted patch filter **500**, the bandwidth is in the range of approximately 55 to 65 GHz. The resulting insertion loss is approximately -1.5 dB (decibels) at approximately 60 GHz. FIG. 5B illustrates a graphical representation of the performance of the series slotted patch filter **500**, wherein graphing an exemplary relationship of insertion loss versus frequency. Both measured and simulated representations are illustrated.

FIG. 6A illustrates a LCP BCPW (backed co-planar wave) filter **600**. In the LCP BCPW filter **600**, the bandwidth is in the range of approximately 57 to 64 GHz. The resulting insertion loss is approximately -1.85 dB at approximately 60.3 GHz.

FIG. 6B illustrates a graphical representation of the performance of the BCPW filter **600**, wherein graphing an exemplary relationship of insertion loss versus frequency. Both measured and simulated representations are illustrated.

FIG. 7A illustrates a LCP planar elliptic filter **700**. In the elliptic filter **700**, the bandwidth is in the range of approximately 64 to 72 GHz. The resulting insertion loss is approximately -2.6 dB at approximately 68 GHz. FIG. 7B illustrates a graphical representation of the performance of the elliptic filter **700**, wherein graphing the insertion loss versus frequency. Both measured and simulated representations are illustrated.

FIGS. 8A-8C, 9A-9B, 10A-10C, and 11A-11C illustrate exemplary results of a plurality of 60 GHz antenna array solutions integrated on LCP, including 1 by 2, 1 by 4, 1 by 6, 2 by 2, 2 by 4, and 4 by 4 array antenna designs. The fabricated antennas can be, preferably, implemented on 150 microns thick of LCP substrate. The targeted gain for these antennas has been determined to be above approximately 10 dBi, enabling a reliable 60 GHz link for WPAN (wireless personal area networking) applications.

The FIGS. 8A-8C, 9A-9C, 10A-10C, and 11A-11C illustrate examples of the linearly polarized antenna developed. Table I further summarizes these figures.

TABLE I

Summary of Linearly Polarized Antennas Array Performances			
Antenna Topology	Gain (dBi)	10 dB bandwidth GHz	Beam-width Azimuth/Elevation (Deg.)
1 by 4	12	1.5	60/15
2 by 2	11	~2	40/40
2 by 2 - dual edge fed	11	~2	40/40
2 by 2 - dual corner fed	11	~2	40/40

FIG. 8A illustrates a top view of a 1 by 4 patch array antenna **800**. FIGS. 8B and 8C illustrate graphical representations of exemplary performances of the 1 by 4 patch array antenna **800**; both FIGS. 8B and 8C illustrate measured and simulated results. FIG. 8B illustrates a graphical representation of return loss (dB) versus frequency (GHz). FIG. 8C, however, illustrates a graphical representation of the radiation path of the 1 by 4 patch array antenna **800**.

FIG. 9A illustrates a top view of a 2 by 2 series patch array antenna **900**. FIGS. 9B and 9C illustrate graphical presentations of exemplary performances of the 2 by 2 series patch array antenna **900**; both FIGS. 9B and 9C illustrate measured and simulated results. FIG. 9B illustrates a graphical representation of return loss (dB) versus frequency (GHz). FIG. 9C, however, illustrates a graphical representation of the radiation path of the 2 by 2 series patch array antenna **900**.

FIG. 10A illustrates a top view of a 2 by 2 dual edge patch array antenna **1000**. FIGS. 10B and 10C illustrate graphical presentations of exemplary performances of the 2 by 2 dual edge patch array antenna **1000**; both FIGS. 10B and 10C illustrate measured and simulated results. FIG. 10B illustrates a graphical representation of return loss (dB) versus frequency (GHz). FIG. 10C, however, illustrates a graphical representation of the radiation path of the 2 by 2 dual edge patch array antenna **1000**.

FIG. 11A illustrates a top view of a 2 by 2 dual corner patch array antenna **1100**. FIGS. 11B and 11C illustrate graphical presentations of an exemplary performance of the 2 by 2 dual corner patch array antenna **1100**; both FIGS. 11B and 11C illustrate measured and simulated results. FIG. 11B illustrates

a graphical representation of return loss (dB) versus frequency (GHz). FIG. 11C, however, illustrates a graphical representation of the radiation path of the 2 by 2 dual corner patch array antenna 1100.

FIGS. 12A-12D and 13A-13D illustrate examples of tested circularly polarized antennas, and graphical representations of simulated and measured characteristics of the antennas. These antennas exhibit a gain above approximately 10 dBi, having an input matching range from approximately 2 to 9 GHz, wherein providing a solution for multi-gigabit WPAN applications. In addition, the resulting axial ratio performance produces an ability to mitigate multi-path effect occurring in a WPAN scenario.

FIG. 12A illustrates a top view of a 1 by 2 array antenna 1200. FIG. 12B illustrates a graphical representation of the 1 by 2 array antenna 1200, wherein illustrating the measured and simulated results of return loss (dB) versus frequency (GHz). FIG. 12C illustrates a graphical representation of the radiation path of the 1 by 2 array antenna 1200. FIG. 12D illustrates a graphical representation of axial ratio (dB) versus frequency (GHz).

FIG. 13A illustrates a top view of a 2 by 2 array antenna 1300. FIG. 13B illustrates a graphical representation of the 2 by 2 array antenna 1300, wherein illustrating the measured and simulated results of return loss (dB) versus frequency (GHz). FIG. 13C illustrates a graphical representation of the radiation path of the 2 by 2 array antenna 1300. FIG. 13D illustrates a graphical representation of axial ratio (dB) versus frequency (GHz).

Table II further summarizes FIGS. 12A-12D and 13A-13D.

TABLE II

Summary of Circularly Polarized Antennas Array Performances				
Antenna Topology	Gain (dBi)	10 dB Bandwidth (GHz)	Beam-width Azimuth/Elevation (Deg.)	3 dB Axial Ratio Bandwidth (GHz)
1 by 2	9	~2	60/30	1
1 by 6	12	9	60/8	3.5
2 by 2	11	~5	40/40	0.75

FIG. 14A illustrates a test environment 1400 of performances of 60 GHz multi-gigabit links to validate exterior of channels. FIG. 14B illustrates the measured power link of the test environment 1400.

FIG. 14A depicts the test environment 1400 targeting a wireless data rate of approximately 2.5 Gb/s at a distance of approximately 3 to 5 meters. The approximately 60 GHz front-end module is implemented on a LCP substrate, using the building blocks described above. In a first phase, PHEMT (pseudomorphic high electron mobility transistor) commercial MMIC (monolithic microwave integrated circuit) can be used to validate the module integration concept. In a second phase, Silicon MMIC can be used.

FIG. 14A illustrates the operation of the test environment 1400. The bit error rate tester (BERT) 1405 provides a signal 1410 up to 2.5 Gb/s. This speed is preferably doubled, to 5 Gb/s using QPSK (Quadrature Phase Shift Keying) modulation, and quadrupled to 10 Gb/s using dual capacity QPSK modulation schemes. The signal 1410 can be filtered through a filter 1415. The signal then enters a first module 1420. A continuous wave signal generator 1425 is buffered into the first module 1420. Preferably, the continuous wave signal generator 1425 operates at 30 GHz and the use of sub-harmonic mixers enables 60 GHz mixing operations. The com-

posed signal is transmitted from the first module 1420. A second module 1430, approximately 50 centimeters to 5 meters from the first module 1420, receives the transmitted signal 1435 from the first module 1420. The signal from the first module 1420 is transmitted to the second module 1430 at up to 10 Gb/s, depending on the modulation and the use or double capacity transmission scheme. The transmitted signal 1435 is then filtered through a filter 1440 and then transmitted to the BERT 1405. The second module 1430, in addition, has an attached signal generator 1445 that is synchronized with the signal generator 1425 of the first module 1420.

FIG. 14B illustrates a graphical representation of a path loss (dB) versus frequency (GHz) result of the test environment. A power link measurement, performed with a transmitter omni-directional antenna, and a receiver having a 4 by 4 pencil beam antenna array, is illustrated. An approximately 2 GHz wireless channel is clearly open, centered at approximately 63.5 GHz.

FIG. 15 illustrates a multi-sector module 1500, or an angled module, utilizing multiple angles to receive and/or transmit from the module. Active components 1505 are also illustrated on a surface of the multi-sector module 1500. As a result of the multi-sector module 1500 design, at least one trench 1510 can be implemented in the FR4 core substrate (the bottom layer 300), before the lamination of the LCP layers (the top layer 200). Thus, a portion of the FR4 bottom substrate 310 is partially omitted. The FR4 layer provides stability to the multi-sector module 1500. The mechanical property of the LCP (the top layer 200) enables flexibility and thus enables the bent (or angled) shape of the multi-sector module 1500. Thus, the LCP can function as a high performance, low loss flexible interconnect that enables the easy and low cost fabrication of the multi-sector conformal module 1500. One of the advantages of this approach is to minimize the assembly works of a multi-sector system, wherein each element would be built separately.

The multi-sector module 1500 can enable a plurality of sectors, or modules, to be configured to enable the module 1500 to receive signals from different angles. Thus, the typical module is improved to receive a number of signals from a number of angles.

FIG. 16A illustrates an end-fire MMW antenna 1600. FIG. 16B illustrates a top view of the bottom layer 300. Referring to FIG. 16A, the bottom layer 300 defines a cavity 1605; this is defined in the FR4 core substrate (see FIG. 16B). The cavity 1605 of the bottom layer 300 is, preferably, created before the lamination of the top layer 200 (the LCP). Hence, the LCP can perform as a high performance low loss dielectric membrane. The end result can be an easy and low cost fabrication of end-fire Yagi antenna array.

Another embodiment of the present invention is shown in FIG. 17. FIG. 17 illustrates a module 1700, wherein a cavity 1705 is centered in the bottom layer 300. Accordingly, the bottom layer 300 can have a defined cavity 1705. Preferably, the cavity 1705 is created before the lamination of the LCP layers (the top layer 200). Hence, the LCP can perform as a high performance, low loss dielectric membrane, which enables easy and low cost fabrication of the suspended filter and bi-directional patch antenna array.

FIG. 18A illustrates a preferred topology for use as a 60 GHz radio module 1800 with integrated dual polarization, dual capacity antenna array for 10 Gb/s wireless link. FIG. 18B illustrates performance of the of the integrated dual polarization, dual capacity antenna array for 10 Gb/s wireless link.

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FIG. 19 illustrates a pyramidal multi-sector antenna 1900 for a 60 GHz wireless docking station. The pyramidal antenna 1900 can cover 360 degrees in azimuth. Each sector support a low to medium gain, single patch antenna or a 1 by 2 patch antenna array 1910, depending on the required/desired coverage. Further, linear or circular polarization can be used. In a preferred embodiment, the dimension of the pyramidal antenna 1900 is compatible with its integration, in a 1.8 by 1.8 by 1.8 cubic centimeters volume.

While the invention has been disclosed in its preferred forms, it will be apparent to those skilled in the art that many modifications, additions, and deletions can be made therein without departing from the spirit and scope of the invention and its equivalents, as set forth in the following claims.

We claim:

1. An ultra-high frequency module operating at ultra-high speeds comprising:
 - a top layer comprising a high frequency substrate and defining a top layer cavity;
 - a bottom layer comprising a double clad core and defining a bottom layer cavity;
 - an adhesive adhering the top layer to the bottom layer; and
 - a dual-capacity, dual-polarization antenna for communicating at approximately 60 GHz and at approximately 10 GB/s, the antenna suspended by the top layer above the bottom layer cavity,
 wherein the dual-capacity, dual-polarization antenna functions as a bidirectional antenna when the module is mounted on an unclad core; and
 - wherein the dual-capacity, dual-polarization antenna functions as a cavity-backed antenna when the module is mounted on a single or double clad core.
2. The module of claim 1, the dual capacity, dual polarization antenna comprising two or more antenna arrays.
3. The module of claim 1, wherein a monolithic microwave integrated circuit is positioned within the top layer cavity such that the monolithic microwave integrated circuit is flush with the top layer.
4. The module of claim 1, wherein the top layer comprises a high performance dielectric and the bottom layer comprises a high performance dielectric.
5. The module of claim 4, wherein the bottom layer comprises flame retardant 4 (FR4).
6. The module of claim 1, wherein the adhesive adhering the top layer to the bottom layer comprises an electrically conductive laminate.
7. An ultra-high frequency module operating at ultra-high speeds comprising:
 - a top layer comprising a high frequency substrate and defining a top layer cavity;
 - an integrated circuit positioned within the top layer cavity;
 - a bottom layer comprising a double clad core and defining a bottom layer cavity;

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an adhesive adhering the top layer to the bottom layer; and a dual-capacity, dual-polarization antenna for communicating at approximately 60 GHz and at approximately 10 GB/s, the antenna suspended by the top layer above the bottom layer cavity,

wherein the dual-capacity, dual-polarization antenna functions as a bidirectional antenna when the module is mounted on an unclad core; and wherein the dual-capacity, dual-polarization antenna functions as a cavity-backed antenna when the module is mounted on a single or double clad core.

8. The module of claim 7, wherein the top layer comprises a high performance dielectric and the bottom layer comprises a high performance dielectric.
9. The module of claim 7, wherein the bottom layer comprises flame retardant 4 (FR4).
10. The module of claim 7, wherein the adhesive adhering the top layer to the bottom layer comprises an electrically conductive laminate.
11. The module of claim 7, wherein the integrated circuit is connected directly to the dual-capacity, dual-polarization antenna.
12. An ultra-high frequency module operating at ultra-high speeds comprising:
 - a top layer comprising a high frequency substrate and defining a top layer cavity;
 - a monolithic microwave integrated circuit (MMIC) positioned within the top layer cavity such that the MMIC is flush with the top layer;
 - a bottom layer comprising a double clad core and defining a bottom layer cavity;
 - an adhesive adhering the top layer to the bottom layer; and
 - a dual-capacity, dual-polarization antenna for communicating at approximately 60 GHz and at approximately 10 GB/s, the antenna suspended by the top layer above the bottom layer cavity,
 wherein the MMIC is directly connected to the dual-capacity, dual-polarization antenna;
 - wherein the dual-capacity, dual-polarization antenna functions as a bidirectional antenna when the module is mounted on an unclad core; and
 - wherein the dual-capacity, dual-polarization antenna functions as a cavity-backed antenna when the module is mounted on a single or double clad core.
13. The module of claim 12, wherein the top layer comprises a high performance dielectric and the bottom layer comprises a high performance dielectric.
14. The module of claim 12, wherein the bottom layer comprises flame retardant 4 (FR4).
15. The module of claim 12, wherein the adhesive adhering the top layer to the bottom layer comprises an electrically conductive laminate.

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