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(54) **MM-WAVE PHASED ARRAY ANTENNA AND SYSTEM INTEGRATION ON SEMI-FLEX PACKAGING**

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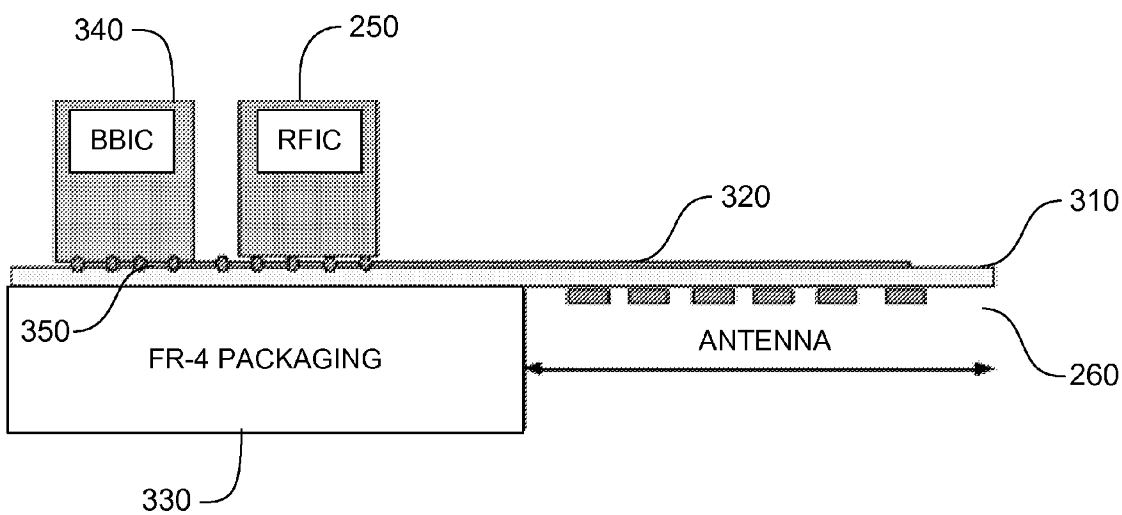
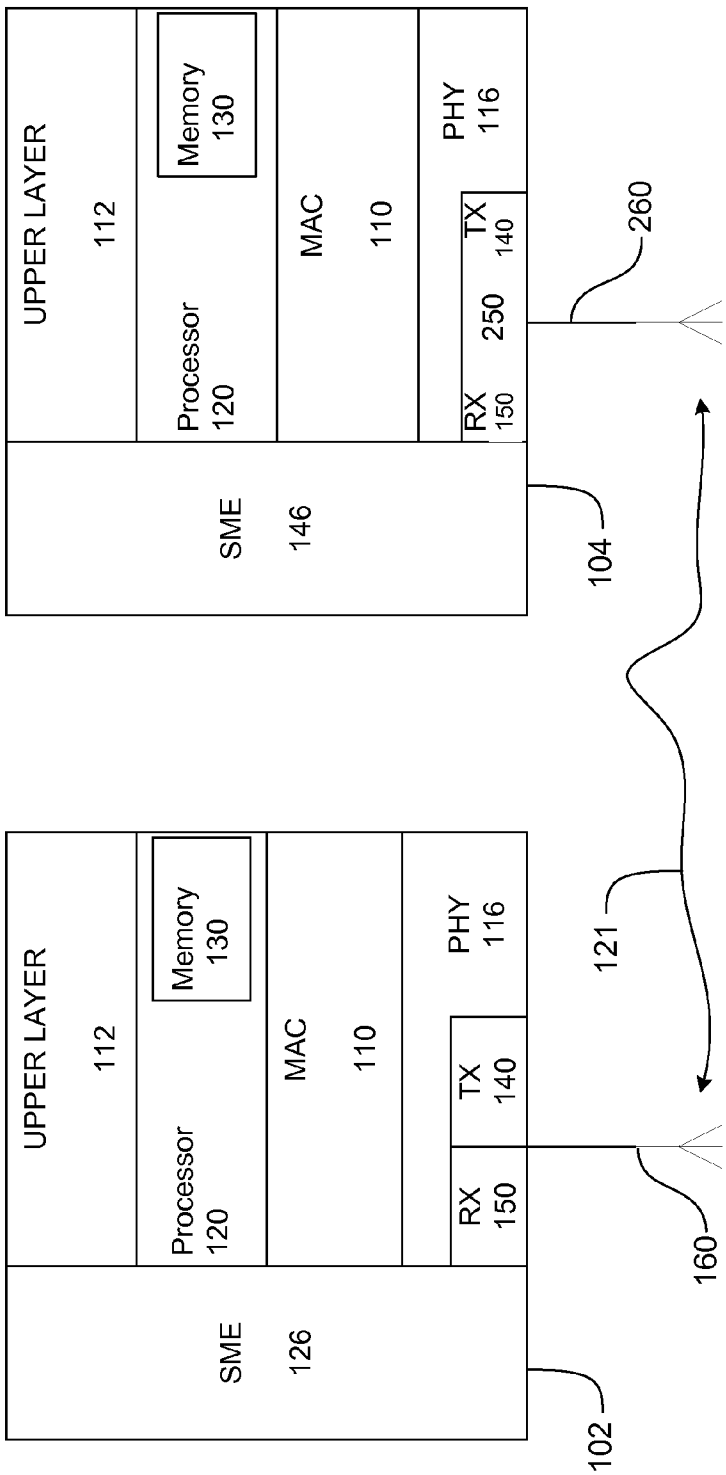
(57) **ABSTRACT**

Embodiments of wireless antenna array systems to achieve three-dimensional beam coverage are described herein. Disclosed is an integrated multiple phased antenna array on a flexible substrate with one RFIC. In this way the module can be molded onto the contour of a platform such as a notebook or a hub of the personal area network or local area network. The multiple phased array can be 3D bent in a compact size to fit into thin mobile platforms. Different array antennas or antennas radiate in different spherical directions with beam scanning capabilities while driven simultaneously by one RFIC chip.

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Memory
130
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121
UPPER LAYER
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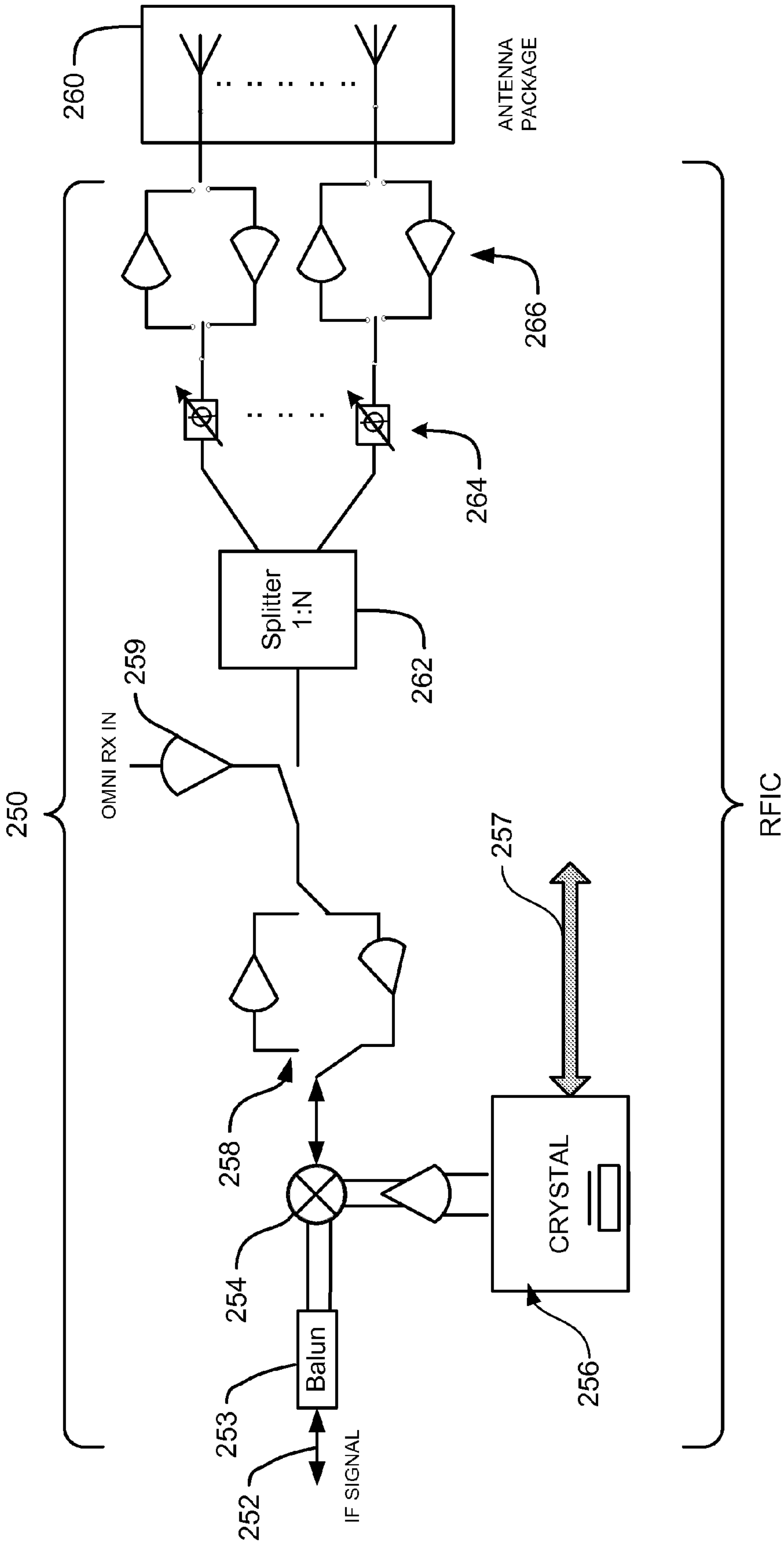
FIG. 1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250
OMNI RX IN
259
Splitter 1:N
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264
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Balun
253
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IF SIGNAL
CRYSTAL
256
257
RFIC

FIG. 2

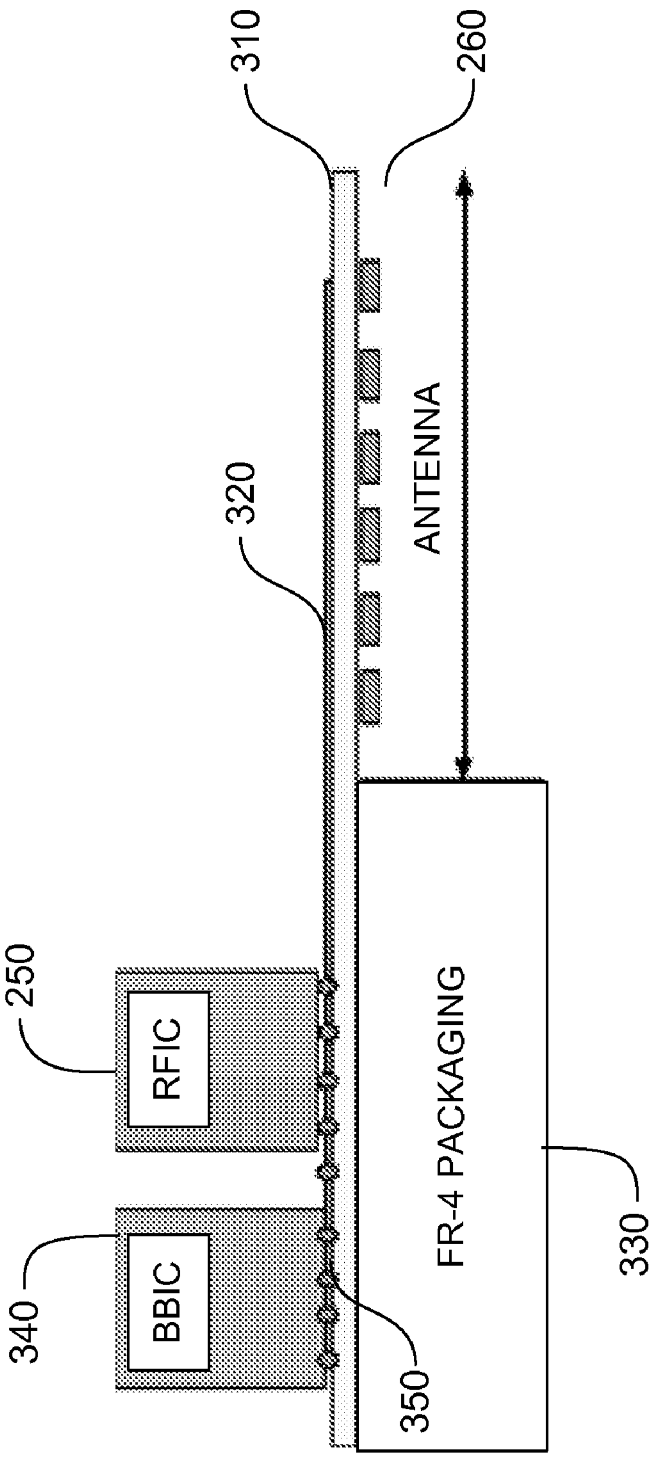

FIG. 3

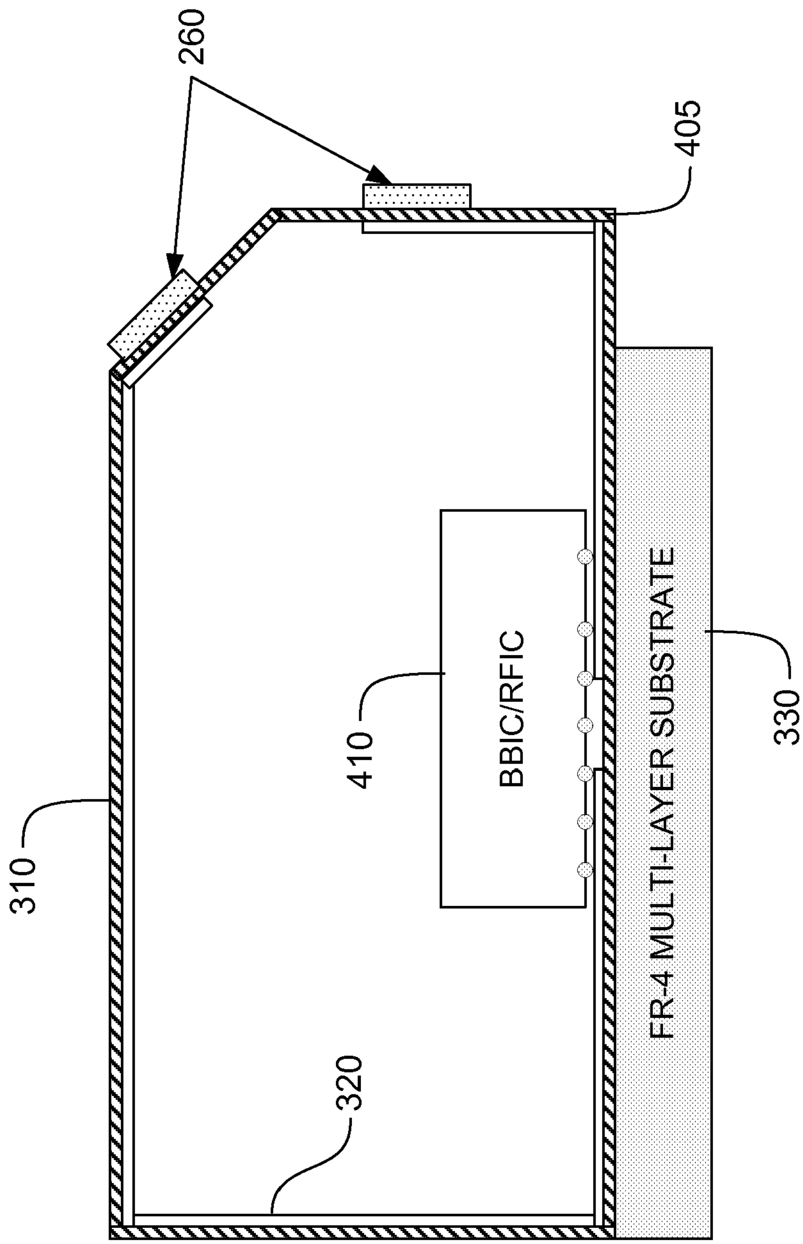

FIG. 4

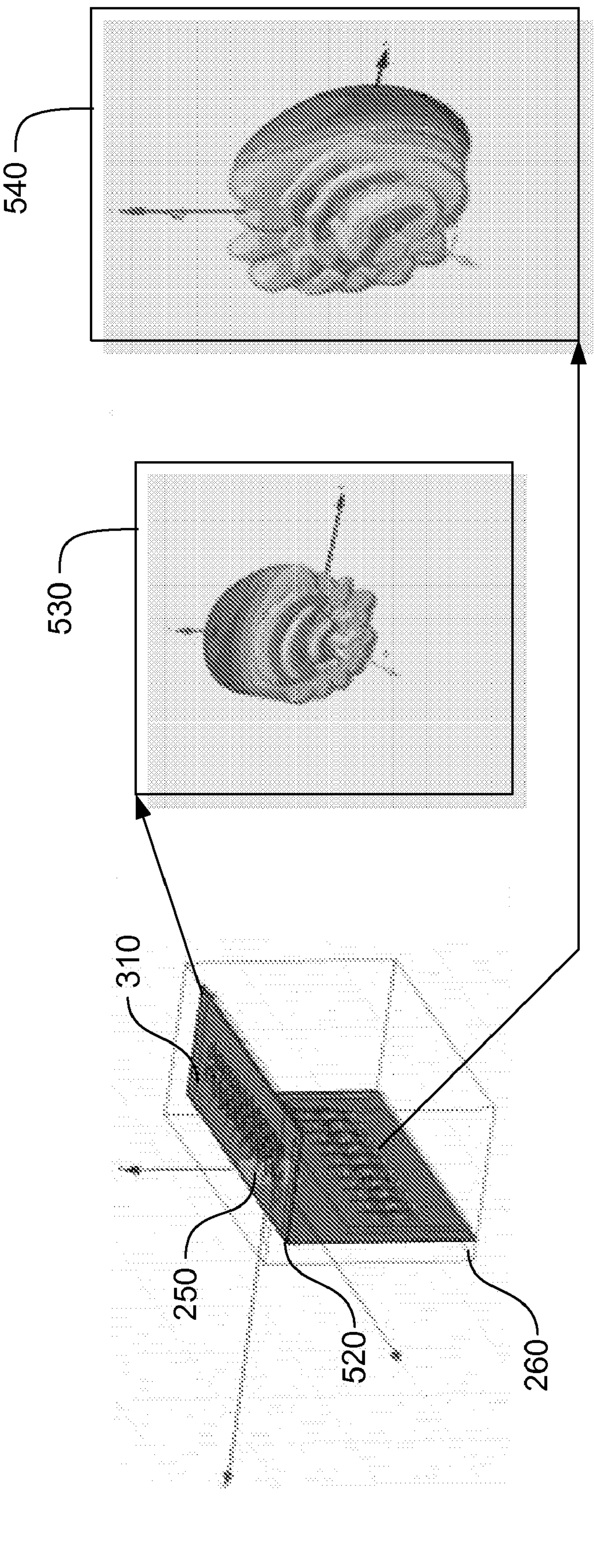

FIG. 5

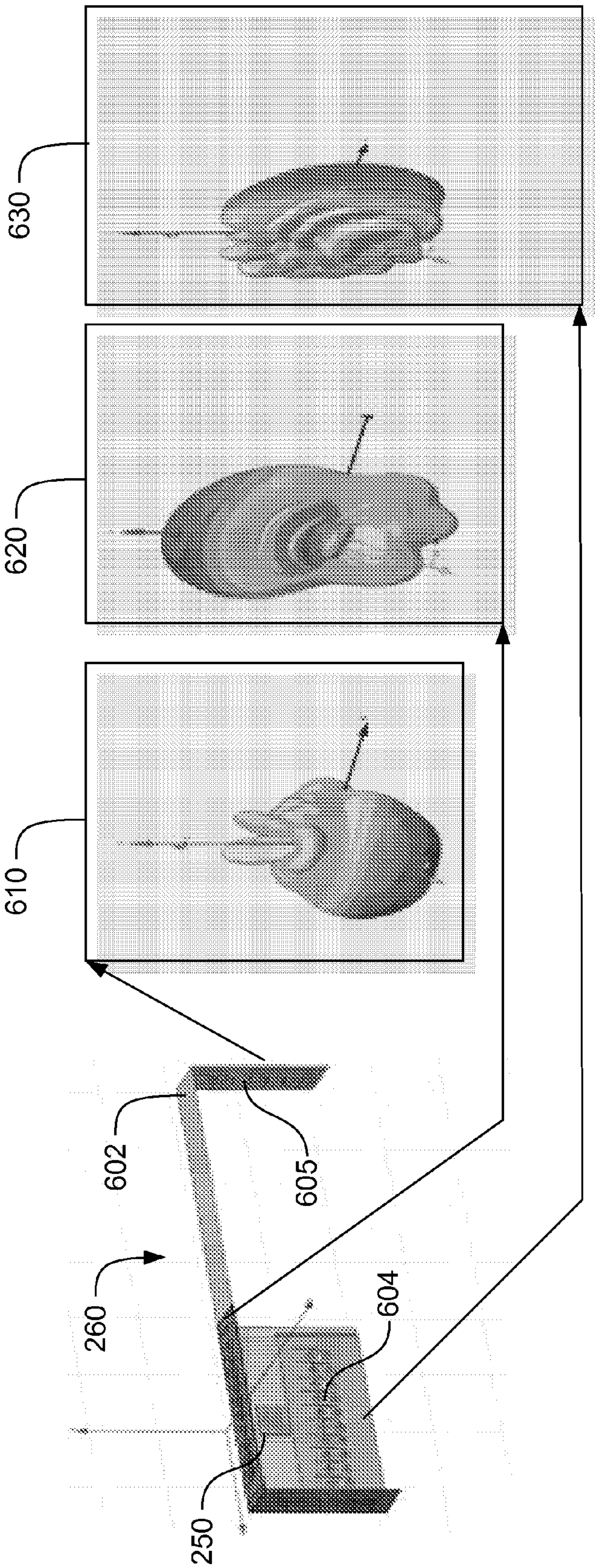

FIG. 6

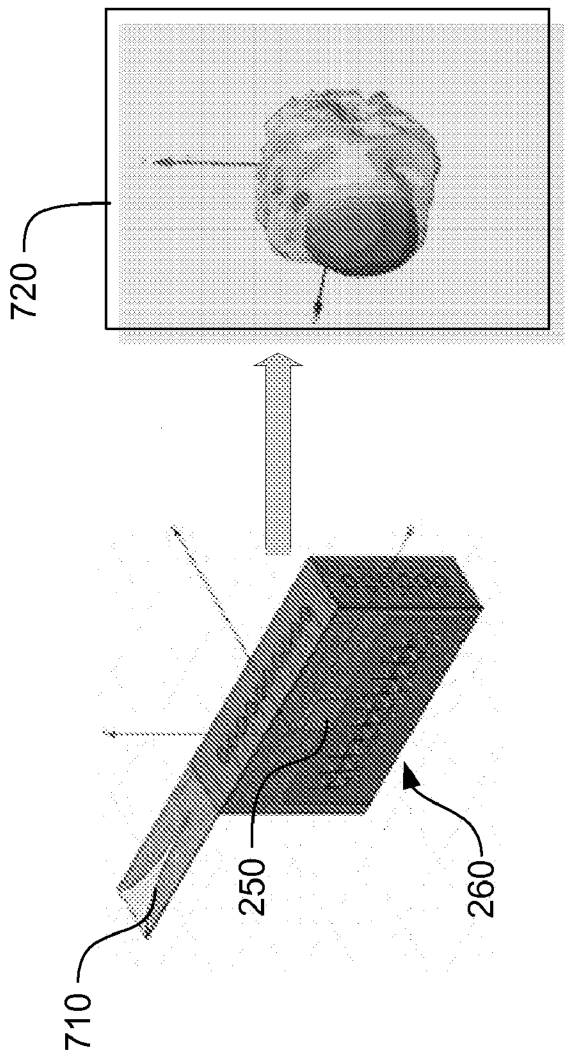

FIG. 7

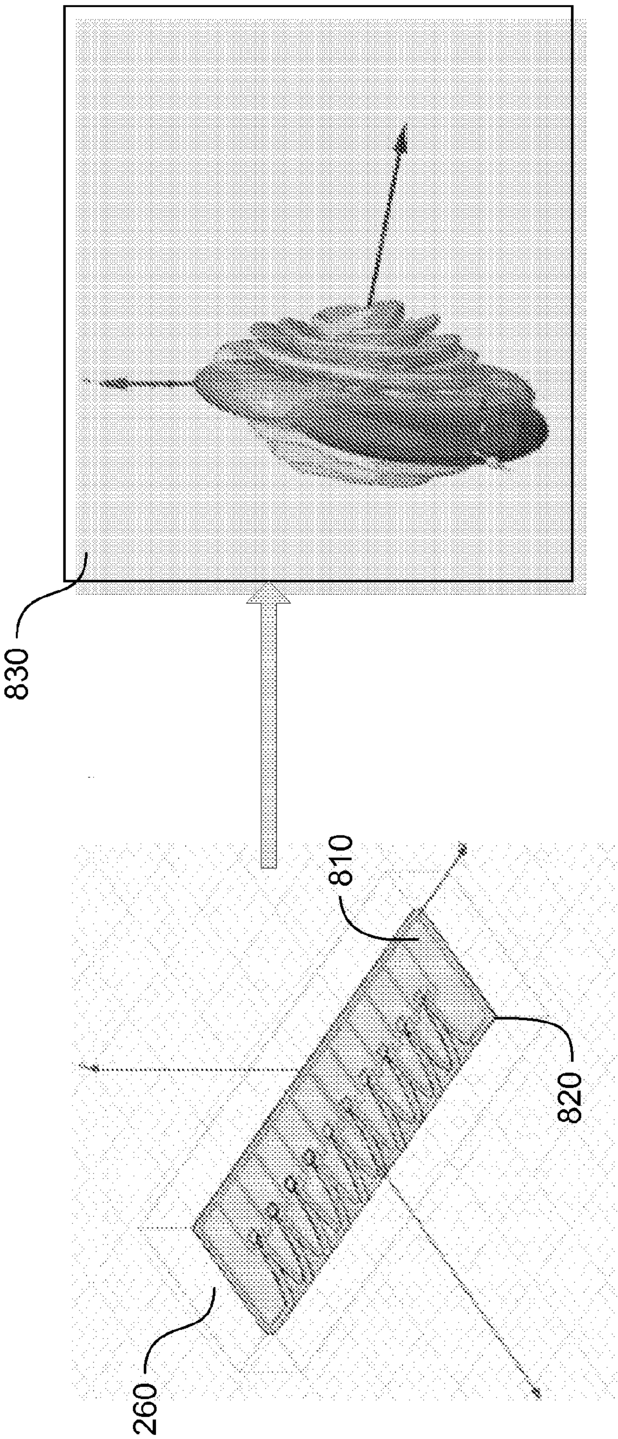

FIG. 8

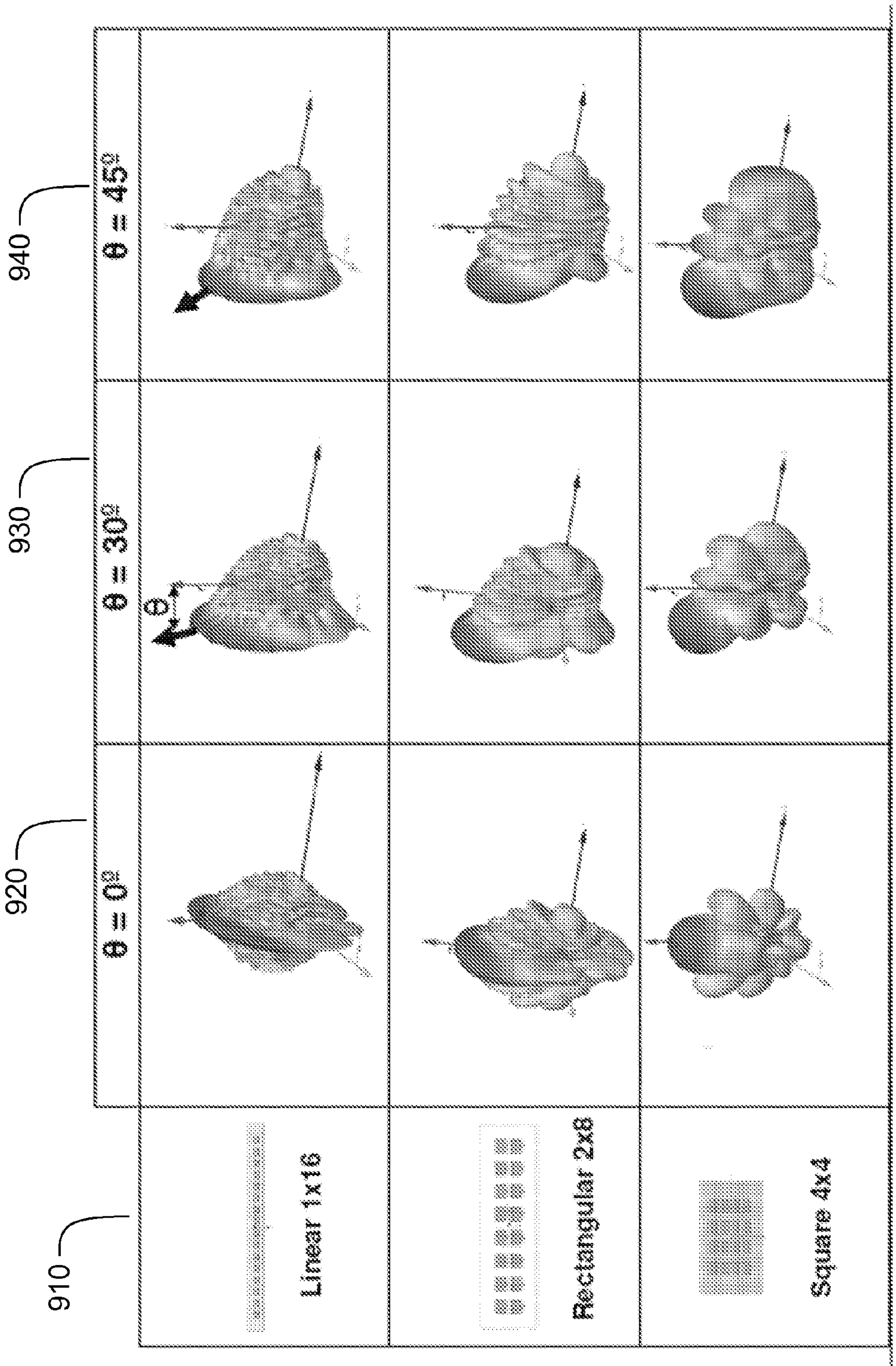
910
920
930
940
θ = 0º
θ = 30º
θ = 45º
θ
Linear 1x16
Rectangular 2x8
Square 4x4

FIG. 9

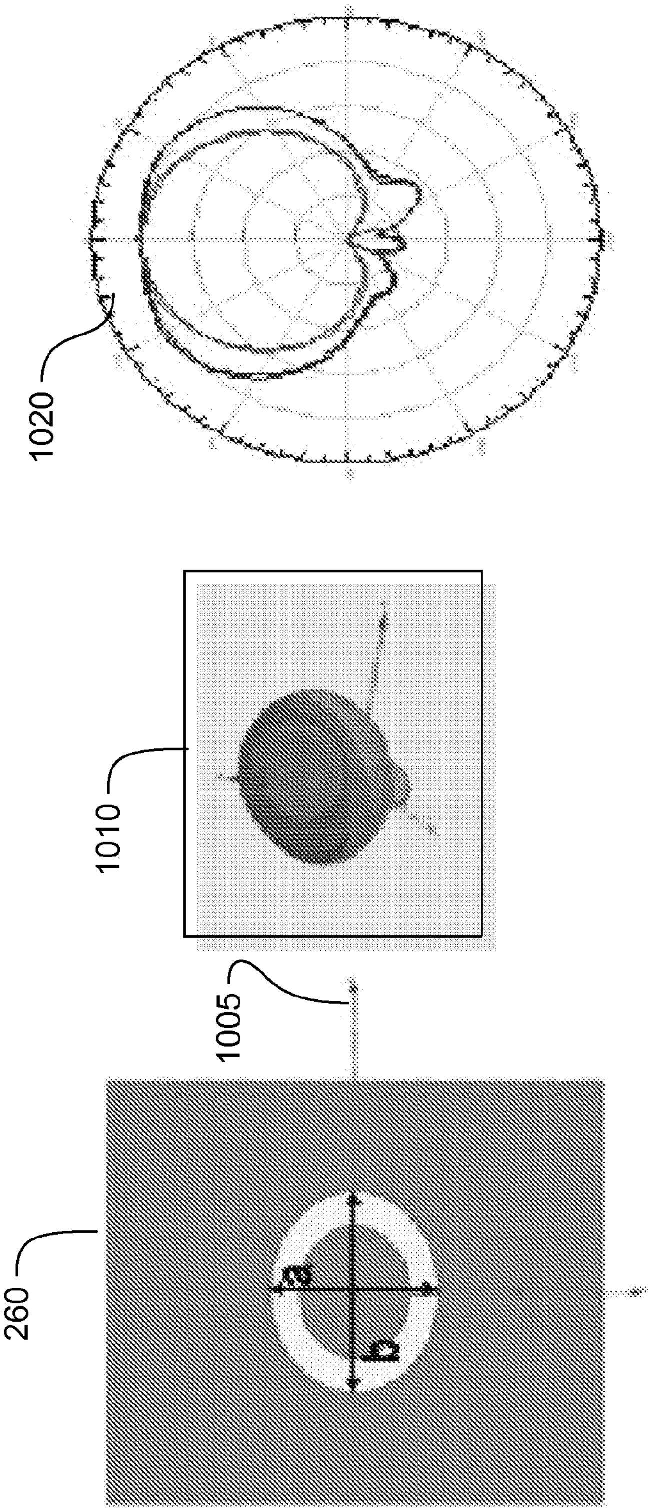

FIG. 10

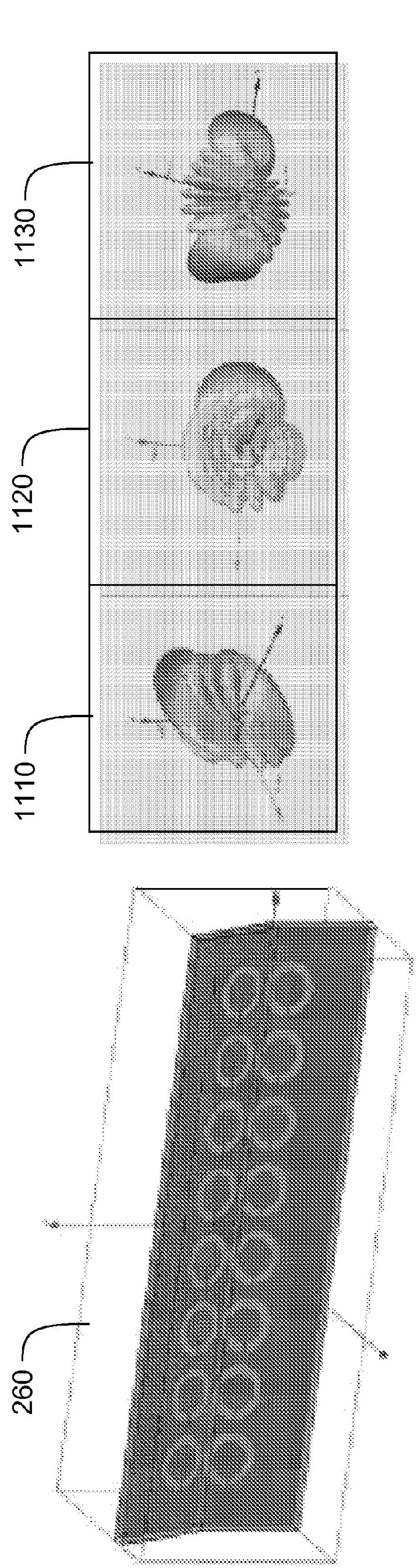

FIG. 11

MM-WAVE PHASED ARRAY ANTENNA AND SYSTEM INTEGRATION ON SEMI-FLEX PACKAGING

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 61/452,754, entitled "ANTENNA ARCHITECTURE, ANTENNA SYSTEM AND A METHOD THEREOF," filed Mar. 15, 2011, the entire disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] 1. Field of the Disclosed Embodiments

[0003] The present invention relates generally to mm-wave receivers and transmitters in general and particularly to an integrated mm-wave device that employs a phased array.

[0004] 2. Introduction

[0005] In recent years, the operating frequency of commercial communications and radar applications has also increased towards the upper end of the radio frequency spectrum, including operation at mm wavelengths. With the silicon chip assuming greater functionality at higher frequencies in a smaller area at a lower cost, it is becoming economically feasible to manufacture high-frequency wideband ICs for both commercial and consumer electronic applications. High-frequency wideband IC applications now include millimeter (mm) wave applications such as short range communications at 24 GHz and 60 GHz and automotive radar at 24 GHz and 77 GHz.

[0006] Technological developments permit digitization and compression of large amounts of voice, video, imaging, and data information. The need to transfer data between devices in wireless mobile radio communication requires reception of an accurate data stream at a high data rate. It would be advantageous to provide antennas that allow radios, especially wireless mobile devices, to handle the increased capacity while providing an improved quality that achieves antenna coverage in both azimuth and elevation. It would also be advantageous to provide mobile internet devices and/or access points with a smaller form factor that incorporates integrated, compact, high performance antennas.

DETAILED DESCRIPTION OF THE DISCLOSED EMBODIMENTS

[0007] The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

[0008] FIG. **1** is a block diagram illustrating devices using extremely high frequency radio signals to communicate in a wireless network in accordance to an embodiment;

[0009] FIG. **2** is a block diagram of an N element mm-wave transceiver RFIC architecture in accordance to an embodiment;

[0010] FIG. **3** is an illustration of a conformal antenna module using semi-flex packaging with flexible layers on the top for antenna integration and FR-4 packaging below in accordance to an embodiment;

[0011] FIG. **4** is an illustration mm-wave phased antenna array on flexible substrate is integrated with BBIC/RFIC on standard FR-4 stackup in accordance to an embodiment;

[0012] FIG. **5** is an illustration of an antenna module consisting of a 2×8 rectangular array on the top and a 2×8 rectangular array to provide top and front area beam scan coverage in accordance to an embodiment;

[0013] FIG. **6** is an illustration of a 3D phased antenna array wrapping to provide top, side, and front spatial coverage in accordance to an embodiment;

[0014] FIG. **7** is an illustration of a 3D phased antenna array wrapping with an attached single high gain antenna to provide top, side, and front spatial coverage in accordance to an embodiment;

[0015] FIG. **8** shows a pair of co-linear mm-wave taper slot antenna array (2×8) and associated radiation pattern in accordance to an embodiment;

[0016] FIG. **9** illustrates the relationship between phased array antenna configuration and scan angle in accordance to an embodiment;

[0017] FIG. **10** shows a slot loop antenna and associated radiation pattern in accordance to an embodiment; and

[0018] FIG. **11** shows a phased antenna array (2×8) bent slightly up to provide a desired coverage and the array's scanning radiation pattern for mm-wave applications in accordance to an embodiment.

[0019] The term PBSS control point (PCP) as used herein, is defined as a station (STA) that operates as a control point of the mmWave network.

[0020] The term access point (AP) as used herein, is defined as any entity that has STA functionality and provides access to the distribution services, via the wireless medium (WM) for associated STAs.

[0021] The term wireless network controller as used herein, is defined as a station that's operates as PCP and/or as AP of the wireless network.

[0022] The term directional band (DBand) as used herein is defined as any frequency band wherein the Channel starting frequency is above 45 GHz.

[0023] The term DBand STA as used herein is defined as a STA whose radio transmitter is operating on a channel that is within the DBand.

[0024] The term personal basic service set (PBSS) as used herein is defined as a basic service set (BSS) which forms an ad hoc self-contained network, operates in the DBand, includes one PBSS control point (PCP), and in which access to a distribution system (DS) is not present but an intra-PBSS forwarding service is optionally present.

[0025] The term scheduled service period (SP) as used herein is scheduled by a quality of service (QoS) AP or a PCP. Scheduled SPs may start at fixed intervals of time, if desired.

[0026] The terms "traffic" and/or "traffic stream(s)" as used herein, are defined as a data flow and/or stream between wireless devices such as STAs. The term "session" as used herein is defined as state information kept or stored in a pair of stations that have an established a direct physical link (e.g., excludes forwarding); the state information may describe or define the session.

[0027] The term "wireless device" as used herein includes, for example, a device capable of wireless communication, a communication device capable of wireless communication, a communication station capable of wireless communication, a portable or non-portable device capable of wireless communication, or the like. In some embodiments, a wireless device may be or may include a peripheral device that is integrated with a computer, or a peripheral device that is attached to a computer. In some embodiments, the term "wireless device" may optionally include a wireless service

[0028] The embodiments of the invention described herein may include an active conformal phased array antenna module for 60 GHz Wireless personal area network and/or a wireless local area network (WPAN/WLAN) communication systems. The design approach described here is guided by the need to deploy as few active antenna modules at 60 GHz as possible on a platform to get full, or pseudo-omni coverage with low cost and low power consumption in high volume manufacture production.

[0029] An exemplary embodiment of the invention may include a notebook, and/or notebook platform, which is assumed to be the hub of the personal area network or local area network, although the scope of the invention is not limited in this respect. Embodiments of the invention may be equally applied to handheld, tablet and any other communication device, if desired.

[0030] Although the scope of the present invention is not limited in this respect, the best approach with the given technology for cost reduction may be to have a number of antennas printed on to a single thin conformal (flexible) package material that may be molded onto the contour of the platform while driven with a single radio frequency integrated circuit (RFIC) chip, if desired.

[0031] For example, to print a number of phased array or fixed antennas onto a single material flexible substrate may enable different array antennas and/or other types of antennas to radiate in different spherical directions with beam scanning capabilities while driven simultaneously by a single RFIC chip. Implemented the digital signal processing algorithms within the RFIC chip may enable seamless beam scanning across different orthogonal directions. In this approach, the single mm-wave module has capability to provide complete quasi-omni coverage in all the directions. The only requirement is that one region of the platform needs to be rugged enough to accommodate the flip chip attachment of the RFIC to the platform and to allow porting of all of the digital/bias and RF low intermediate frequency (IF) frequency signals as well as cable ports and/or solder landing pads to accommodate attachment of external cabling. For example, the RFIC may include an integrated mm-wave transceiver and the phase array antenna may include a conformal antenna.

[0032] It should be understood that the present invention may be used in a variety of applications. Although the present invention is not limited in this respect, the circuits and techniques disclosed herein may be used in many apparatuses such as stations of a radio system. Stations intended to be included within the scope of the present invention include, by way of example only, WLAN stations, wireless personal network (WPAN), and the like.

[0033] Types of WPAN stations intended to be within the scope of the present invention include, although are not limited to, stations capable of operating as a multi-band stations, stations capable of operating as PCP, stations capable of operating as an AP, stations capable of operating as DBand stations, mobile stations, access points, stations for receiving and transmitting spread spectrum signals such as, for example, Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS), Complementary Code Keying (CCK), Orthogonal Frequency-Division Multiplexing (OFDM) and the like.

[0034] Additional features and advantages of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the disclosure. The features and advantages of the disclosure may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features of the present disclosure will become more fully apparent from the following description and appended claims, or may be learned by the practice of the disclosure as set forth herein.

[0035] Various embodiments of the disclosure are discussed in detail below. While specific implementations are discussed, it should be understood that this is done for illustration purposes only. A person skilled in the relevant art will recognize that other components and configurations may be used without parting from the spirit and scope of the disclosure.

[0036] Although embodiments of the invention are not limited in this regard, discussions utilizing terms such as, for example, "processing," "computing," "calculating," "determining," "applying," "receiving," "establishing", "analyzing", "checking", or the like, may refer to operation(s) and/or process(es) of a computer, a computing platform, a computing system, or other electronic computing device, that manipulate and/or transform data represented as physical (e.g., electronic) quantities within the computer's registers and/or memories into other data similarly represented as physical quantities within the computer's registers and/or memories or other information storage medium that may store instructions to perform operations and/or processes.

[0037] Although embodiments of the invention are not limited in this regard, the terms "plurality" and "a plurality" as used herein may include, for example, "multiple" or "two or more". The terms "plurality" or "a plurality" may be used throughout the specification to describe two or more components, devices, elements, units, parameters, or the like. For example, "a plurality of resistors" may include two or more resistors. The term coupled as used herein, is defined as operably connected in any desired form for example, mechanically, electronically, digitally, directly, by software, by hardware and the like.

[0038] FIG. **1** is a schematic block diagram of a wireless communication system **100** in accordance to an embodiment. The system **100** comprises a pair of multi-band capable stations **102** and **104** such as peer Quality of Service (QSTAs) stations. Although only two stations (STAs) are shown for simplicity, the invention is not limited to any particular number of STAs. Using the first multi-band capable station **102** as an example, each STA includes a station management entity (SME) **126** and **146** having a MAC interface (not shown) for transceiving primitives, a processor **120** to convert between primitives and MAC frames, and a physical layer interface (not shown) to transceive primitive-converted MAC frames. A physical layer (PHY) entity **116** has a MAC interface (not shown) to transceive MAC frames and a physical layer interface on line (not shown) connected to a peer STA PHY entity such as STA **104** to transceive physical layer communications.

[0039] Typically, the PHY entities (**116** in STA **102** and **104**) communicate via a wireless link represented by reference designator **121** through antenna **160** (STA **102**) and antenna **260** (STA **104**) comprising antennas printed on to a single thin conformal (flexible) package material that can be molded onto the contour of the platform while driven with one RFIC **250** which in association with the antenna array perform the function of transmitter **140** and receiver **150**. Antenna **160** or **260** may include an internal and/or external RF antenna, for example, a dipole antenna, a monopole antenna, an omni-directional antenna, an end fed antenna, a circularly polarized antenna, a micro-strip antenna, a diversity antenna, or any other type of antenna suitable for transmitting and/or receiving wireless communication signals, blocks, frames, transmission streams, packets, messages and/or data. In some embodiments, station **110** may include for example one or more processors **120**, one or more memory units **130**, one or more transmitters **140**, one or more receivers **150**, and one or more antennas **160** or **260**. Station **110** may further include other suitable hardware components and/or software components. While the RFIC **250** and antenna **260** are shown as discrete components it is contemplated that these devices can be integrated into a single substrate and that other components can be added or remove without affecting the functionality of the devices. Additionally, the RFIC **250** may include an integrated mm-wave transceiver and the antenna **260** may include a conformal antenna. Implementing digital signal processing algorithms within the RFIC **250** enables seamless a single mm-wave module to provide complete quasi-omni coverage in all the directions.

[0040] Processor **120** may include, for example, a Central Processing Unit (CPU), a Digital Signal Processor (DSP), a microprocessor, a controller, a chip, a microchip, an Integrated Circuit (IC), or any other suitable multi-purpose or specific processor or controller. Processor **120** may, for example, process data received by station **102**, and/or process data intended for transmission by station **102**.

[0041] Memory unit **130** may include, for example, a Random Access Memory (RAM), a Read Only Memory (ROM), a Dynamic RAM (DRAM), a Synchronous DRAM (SD-RAM), a Flash memory, a volatile memory, a non-volatile memory, a cache memory, a buffer, a short term memory unit, a long term memory unit, or other suitable memory units or storage units Memory unit **130** may, for example, store data received by station **104**, and/or store data intended for transmission by station **102** and/or store instructions for carrying out the operation of station **102** including for example embodiments of a method described herein.

[0042] Transmitter **140**, may include, for example, a wireless Radio Frequency (RF) transmitter able to transmit RF signals, e.g., through antenna **160**, and may be capable of transmitting a signal generated by for example a Multi-Stream Multi-Band Orthogonal Frequency Division Modulation (MSMB OFDM) system in accordance with some embodiments of the present invention. Transmitter **140** may be implemented using for example a transmitter, a transceiver, or a transmitter-receiver, or one or more units able to perform separate or integrated functions of transmitting and/or receiving wireless communication signals, blocks, frames, transmission streams, packets, messages and/or data. One approach to system implementation can include a split module topology where baseband signals (IF Signal) are modulated onto an IF carrier in a module that may be physically remote from the antenna module platform consisting of circuitry and antennas. The IF signal from the baseband module is then ported to one or more conformal antenna modules via cabling, and then up-converted to the desired frequency such as 60 GHz by a radio frequency circuit that is integrated in the conformal antenna module. The upconverted 60 GHz signal is then split N times by splitter to drive N on-chip transceivers such as the plurality of mm-wave antennas on a substrate. Each transceiver is bidirectional containing a phase shifter **264** and low noise amplifier (LNA) and/or power amplifier (PA) **266** like shown in FIG. **2**.

[0043] Receiver **150** may include, for example, a wireless Radio Frequency (RF) receiver able to receive RF signals, e.g., through antenna **160**, and may be capable of receiving a signal generated by for example a Multi-Stream Multi-Band Orthogonal Frequency Division Modulation (MSMB OFDM) system in accordance with some embodiments of the present invention. Receiver **150** may be implemented using for example a receiver, transceiver, or a transmitter-receiver, or one or more units able to perform separate or integrated functions of receiving and/or transmitting/receiving wireless communication signals, blocks, frames, transmission streams, packets, messages and/or data.

[0044] FIG. **2** is a block diagram of N element mm-wave transceiver RFIC architecture in accordance to an embodiment. Each of the N transceivers may be connected to an antenna element **260** in the N-element phased array antenna. In one exemplary embodiment the antenna module comprises a plurality of mm-wave antennas (N=32) with a 2 GHz baseband signal that is modulated such as onto a 12 GHz carrier in a remote module like a baseband integrated circuit (BBIC). The 12 GHz modulated signal may arrive to the conformal antenna module and ported in the Si CMOS RFIC **250** at the IF Signal IN/OUT port such as port **252** of the RFIC shown in the block diagram of RFIC **250**.

[0045] According to the exemplary embodiment in transmitter (TX) or receiver (RX) mode, the single-ended 12 GHz modulated signal at port **252** may be upconverted/downconverted to 60 GHz in the passive bidirectional mixer **254**. The signal then passes through a bidirectional amplifier **258** and is split N times at splitter **262**. The phase of the signal is then controlled by a phase shifter **262** and passes through a PA/LNA **266** in TX/RX modes, respectively. The signal then passes into the package material with integrated antenna via a flip bump. An oscillator **256** generates an output signal that is fed to the passive bidirectional mixer **254** to upconvert/downconvert the IF signal at port **252**. The oscillator **256** has an input/output port **257** to provide a sample output signal at the same frequency as the upconverted signal (60 GHZ) or to receive a signal from an external source such as a control signal. The oscillator (crystal) **256** can be in a different package due to its sensitivity to temperature variance. A balun circuit such as balun **253** may be used to balance signals between circuits. Also, omni RX input signals can be further amplified through an amplifier circuit such as amplifier **259**.

[0046] FIG. **3** is an illustration of a conformal antenna module using semi-flex packaging with flexible layers on the top for antenna integration and FR-4 packaging below in accordance to an embodiment. An RFIC **250** flip chip launched on conformal mm-wave antenna modules is shown. The Figure illustrates the Direct Chip Attachment (DCA) for RFIC **250** and BBIC **340** on a hybrid laminate module (semi-flex packaging) substrate **310** such as PCIe card module, but it could also be only an RFIC integrated on the module with IF interface as descript in previous paragraphs concerning FIG. **1**. The RFIC **250** or BBIC **340** chips are flip-chip landed **350** on conformal antenna module with die area routing. The antenna module **260** is built on top layer of the laminate packaging. While shown as a single layer it may not be limited to single layer and may be multiple flexible top layers. The top flexible layer may use low tangent loss material to achieve lowest mm-wave loss and best mm-wave antenna performance. There are various flexible material substrate **310** which may be implemented on the top layers, such as, liquid crystal polymer (LCP) such as Ultralam3000, polyimide, Teflon, Low Temperature Co-fired Ceramic, alumina, antenna grade core materials and laminates, duroid, high-resistivity silicon or one or more other suitable substrates for mm-wave applications. Under the die area, a standard FR-4 laminate **330** is positioned below the flexible layers for digital/power/ground routing that are not critical mm-wave RF signals and achieve lowest manufacture cost. The RFIC **259** circuit is anchored to a bottom substrate such as a glass fiber board like FR-4 packaging so that one region of the platform (flexible substrate **310**) is rugged enough to accommodate the flip chip attachment of the RFIC to the platform and to allow porting of all of the digital/bias and RF low intermediate frequency (IF) frequency signals as well as cable ports and/or solder landing pads to accommodate attachment of external cabling. The RFIC **250** can also be anchored by other substrates selected from a group consisting of printed circuit board (PCB), temperature-resistant glass fiber board (FR-5), ceramic substrate, metal-core PCB (MCPCB), direct copper bonded (DCB) substrate, metal composite board, copper-coated aluminum board, and aluminum board.

[0047] In this design approach, the mm-wave phased array antenna or other any other antenna designs may be conformal to provide flexibility to fit in any mobile platform such as a notebook or mobile device and preserve best electromagnetic performance in term of gain, bandwidth and scan-ability. An antenna element is traditionally controlled by its own active device. However, the active devices used in controlling the antenna elements can be expensive, and in some cases may even require one or more stages of amplifiers. Even when the active devices are relatively inexpensive, the system may require a large digital memory to support a large set of field of views (FOVs). For a phased array system having a single controller, an issue is the signal delay in the routing **320** between the different antenna array element arms. To minimize delays the routing **320** is maintained substantially equal distant to control group delay for broadband beam pattern stability. The length of the line is chosen so that the antenna element will be excited in-phase with the rest of the antenna elements or when receiving signals from a communicating device so that signals would substantially arrive at the RFIC **250** at the same time. Depending on the topology, this requires transmission line meandering to equalize the delay between the different arms in the package.

[0048] FIG. **4** is an illustration mm-wave phased antenna array on flexible substrate is integrated with BBIC/RFIC on standard FR-4 stackup in accordance to an embodiment. According to another embodiment a phased antenna array implementation is provided. Since the slot loop antenna array design is on a single layer dielectric substrate, it can be implemented with an extended low cost flexible layer combined with low cost FR-4 board/HDI (high density interconnect) technology **330** for RFIC/BBIC **410** routing **320** as shown. The phased antenna array may be bent into different configurations such as bent **405** to be vertical for spatial coverage and still preserve compact size. The whole mm-wave phased antenna array including the integrated packaging and ICs can take the shape of a compact form factor. The phased antenna array may also be designed by splitting half of the array on each side of a flexible substrate and finally bent together on the platform as shown in FIG. **4**. In this way there is easy trace routing and it also minimizes antenna element coupling by feeding traces as shown with respect to routing **320**. The top half of the phased antenna array is bent slightly up to provide coverage on the top that may not be achieved with conventional phased array designs.

[0049] There are many antenna array designs which may be implemented to provide broad spatial beam scan coverage. The following figures, FIGS. **5-11**, demonstrate many different antenna array configurations to provide different spatial directivity gain and spatial coverage. It is noted that the mm-wave antenna designs and configuration are not limited the illustrations shown below. Depending on the platform and application, it may be implemented in many other ways to utilize the conformal antenna module.

[0050] FIG. **5** is an illustration of an antenna module consisting of a 2×8 rectangular array on the top and a 2×8 rectangular array on the front to provide top and front area beam scan coverage in accordance to an embodiment. The two 2×8 rectangular arrays provide equal gain and coverage to the top and front as shown in top beam **430** and front area beam **440** scan coverage. This topology can be implemented in a laptop lid or base to provide spatial coverage away from the users. The RFIC **250** chip is shown on the upper part of the antenna module near the bent region **420** which separates the rectangular arrays. The arrays could be further modified by having a single row array (1×8) and adding a row to the front array (3×8). In this topology, the top scan has same coverage with about 2 dB array gain degradation. But since mm-wave application may be used in indoor environment. The space coverage from the modified device may be less than (L.T.) three meter range. On the other hand, the front coverage is increased by using the additional elements rectangular array to achieve higher gain.

[0051] FIG. **6** is an illustration of a 3D phased antenna array wrapping to provide top, side, and front spatial coverage in accordance to an embodiment. The embodiment in FIG. **6** integrates multiple phased antenna arrays on a flexible substrate with a single RFIC. In this way the module may be molded onto the contour of the platform such as a laptop or notebook computer. The multiple phased arrays may be 3D bent in a compact size to fit into thin mobile platform. This embodiment provides a solution to integration RFIC with phased antenna array and delivers quasi-omni mm-wave spatial coverage. In order to achieve complete three dimensions spatial coverage, the illustrated antenna configuration may be used, if desired. Illustrated are four sub-arrays, a 2×8 rectangular array **604** to provide spatial coverage in the front **630**, a 1×8 linear array **602** to provide spatial coverage to the top area **620**, and two liner 1×4 arrays **605** to provide coverage at short range on two sides **610**. Using laptop as example, due to the camera and microphone placement in the center of the lid, one of the side linear array has much longer trace routing and higher path loss on mm-wave trace. Even though, it still may provide array gains (about 5-6 dB) incorporate longer trace loss. It may provide coverage on the near by side device communication link. And also the other end of communication link device may have much higher antenna gain (about 10-15 dB) to enhance coverage area. It is also may be implemented with a single high gain antenna on the right to overcome the blockage from lid electronics placed in the center of the laptop lid. The scan top **620**, scan front **630**, and scan size 610 spatial coverages are shown.

[0052] FIG. **7** is an illustration of a 3D phased antenna array wrapping with an attached single high gain antenna to provide top, side, and front spatial coverage in accordance to an embodiment. A Taper Slot antenna (TSA) is illustrated with its scan side **720** spatial coverage. The single high gain antenna **710** may be yagi, periodic antenna or any other high gain antenna designs. Due to use single high gain antenna **710**, there is no scan capability to that side, but with fixed directional gain. The single high gain antenna also needs to overcome the lid center electronics blockage as well. In all the designs, edge dummy antenna elements placed on the edge of the antenna array designs may be included. The purpose of the edge dummy antenna element is to stabilize antenna array bandwidth and frequency coverage as beam scan to different angles. Those edge dummy antenna element are terminated with load resistor.

[0053] FIG. **8** shows a pair of co-linear mm-wave taper slot antenna array (2×8) and associated radiation pattern in accordance to an embodiment. This embodiment places the linear phased antenna arrays on the top **810** and bottom **820** layer of the packaging design. The inter two linear array spacing may be less than five hundred microns (500 μm). The linear phased array antenna placement is not limited to the top **810** and bottom **820** layer of the packaging design. When more than two linear arrays are required, they may also be placed on top and bottom layers of the board for instance, and the module can be placed in the middle of the mobile platform base along height dimension. An example of the co-linear 2×8 Taper slot endfire array antenna is illustrated. As is shown, the antenna element design is not limited to taper slot antennas and it may also be Yagi, folded dipole, bending dipole/monopole design and the like. This methodology may use 180 offset feeding to achieve higher isolation and enable dense antenna array placement. As shown in element mm-wave TSA array radiation pattern **830**, the N element (16) dense mm-wave array delivers an increase in array antenna gain (≧15 dBi). To extend the design concept, there are multiple array antenna designs which may be integrated with one RFIC and deliver quasi-omni spatial coverage.

[0054] Currently, planar end-fire array antennas are either a single linear array or implemented into a 3D structure. The single linear array antenna has higher packaging path loss and is harder to implement for large numbers of array elements. The 3D array structure is bulky, expensive and hard to fit into a mobile platform. This embodiment allows multiple linear arrays to stack up in a thin planar packaging. In this way, a high density integration may be achieved.

[0055] According to embodiments of the invention, the antenna may include implements of two linear arrays in a thin planar packaging structure and may use 180 phase offset method to minimize crosstalk and allow dense integration. It allows more than one of linear array integrates in a dense thin packaging multiple layer structure.

[0056] Embodiments of the invention may deliver a compact mm-wave array antenna design and RFIC integration as well as providing high gain for directional adaptive beam forming. This invention enables a thin planar packaging integration for mm-wave array antenna that other method may not provide.

[0057] Alternatively, but not limited to, endfire radiation pattern antenna arrays may only provide azimuth coverage on the horizontal plane, but no coverage on the broadside. For example, laptops and other mobile devices that require multiple phased antenna arrays on the platform cost, size and platform implementation are the major constraints to enabling 60 GHz technology. According to some embodiments of the invention, in order to solve the above described problems, embodiments of the invention may provide a single flexible dielectric substrate slot loop antenna array which provides complete half sphere spatial coverage for mobile devices and provides greater than eleven gigahertz (>11 GHz) bandwidth coverage for worldwide 60 GHz technology deployment. For example, the mm-wave antenna element design may replace a conventional broadside radiation pattern antenna element, a slot loop antenna forms a magnetic loop which is equivalent to an electrical dipole like shown in FIG. **10**. By tuning the loop two edge length ratio (a/b), a broader radiation pattern is achieved. The slot loop antenna design may be circular or rectangular.

[0058] FIG. **9** illustrates the relationship between phased array antenna configuration and scan angle in accordance to an embodiment. Phased Array Antenna Configuration **910** and radiation patterns at zero degrees)(0°) **920**, thirty degrees)(30°) **930**, and forty five degrees)(45°) **940**. Implementing tilting radiation pattern antenna element in the antenna array as shown, the rectangular mm-wave antenna element (2×8) provide 10 dBi gain at 90 degree and 15 dBi at broadside. If using two antenna arrays on two edges of a laptop or mobile device, it will have the complete front and side of coverage. As can be seen from the patterns the linear 1×16 array provides interference mitigation along YZ, but has sensitivity to movement. The 2×8 array is a compromise between interference mitigation and sensitivity to movement. The 4×4 array is less sensitive to movement but is not as strong in interference mitigation.

[0059] FIG. **10** shows a slot loop antenna and associated radiation pattern in accordance to an embodiment. According to another embodiment of the invention, a slot loop antenna **260** may provide both a broadside radiation pattern **1010** and close to a half sphere omni radiation pattern along xz plane **1020** as shown. The broader radiation pattern along xz plane **1020** may provide a broad beam scanning range 180 degrees long x axis **1005**. The mm-wave slot loop antenna design uses single layer dielectric to simplify the structure with a separate metal to eliminate the back radiation. The return loss is below (<10 dB) across 55-66 GHz and provides greater (>11 GHz) bandwidth coverage for worldwide 60 GHz technology deployment. According to this embodiment, the slot loop antenna array may also be immune to mutual coupling. This provides better performance in antenna array beam scanning. The slot loop antenna could be tilted to change the gain in a particular direction. For example, antenna design on a planar surface may provide 45 degree titled beam. The rectangular slot loop antenna backed by ground plane with offset stripline feeding achieved **45** tilting beam. The tuning in two edge ratio (a/b) and open slot gap will achieve 45 degree tilting beam pattern. Broad antenna bandwidth can be achieved (range of 55-64 GHz) with peak gain (range of 4 dB-8 dB). The mm-wave antenna element design can use low loss polytetrafluoroethylene (PTFE) substrate material that is used in standard FR-4 manufacture process.

[0060] FIG. **11** shows a phased antenna array (2×8) bent slightly up to provide a desired coverage and the array's scanning radiation pattern for mm-wave applications in accordance to an embodiment. The top half of the phased antenna array **260** is bent slightly up to provide coverage on the top **1110** that may not be achieved with conventional phased array designs like rectangular array (2×8) shown in FIG. **9**. Due to the small angle of bending on the top half antenna array **260**, those antenna elements still provide radiation gain to the front of antenna array. This array has can achieve increases in gain (about 15-17 dB) in the front area along Y axis **1120**. The individual antenna element has close to omni radiation pattern along Y axis. Therefore, it also provides side radiation pattern coverage **1130**. The conformal single layer flexible mm-wave phased antenna array is very easy to be implemented in mobile platforms such as the laptop lid. It may be held in place with a simple clip on the lid wall of the mobile platform.

[0061] Although the above description may contain specific details, they should not be construed as limiting the claims in any way. Other configurations of the described embodiments of the disclosure are part of the scope of this disclosure. For example, the principles of the disclosure may be applied to each individual user where each user may individually deploy such a system. This enables each user to utilize the benefits of the disclosure even if any one of the large number of possible applications do not need the functionality described herein. In other words, there may be multiple instances of the components each processing the content in various possible ways. It does not necessarily need to be one system used by all end users. Accordingly, the appended claims and their legal equivalents should only define the disclosure, rather than any specific examples given.

We claim:

1. A millimeter-wave (mm-wave) communications device, comprising:
 an antenna module comprising a plurality of mm-wave antennas on a substrate, wherein the substrate can be molded or bent to radiate in different spherical directions; and
 an integrated circuit on the substrate connected to the plurality of mm-wave antennas through a transmission line;
 wherein the integrated circuit is configured to communicate using mm-wave signals.

2. The millimeter-wave communications device of claim **1**, wherein the integrated circuit is selected from a group consisting of radio frequency integrated circuit (RFIC), baseband integrated circuit (BBIC), or a combination thereof.

3. The millimeter-wave communications device of claim **2**, wherein the transmission line connecting the plurality of mm-wave antennas is routed to equalize delays in the antenna module.

4. The millimeter-wave communications device of claim **2**, wherein the RFIC comprises a splitter to combine signals directed from the plurality of mm-wave antennas and to divide a signal into a plurality of signals to drive the antenna module.

5. The millimeter-wave communications device of claim **4**, wherein the integrated circuit is attached to the substrate by a technique selected from chip and wire assembly, chip-on-board assembly, or flip-chip assembly.

6. The millimeter-wave communications device of claim **5**, wherein the substrate is made from a material selected from a group consisting of liquid crystal polymer, Teflon, Low Temperature Co-fired Ceramic, alumina, antenna grade core materials and laminates, duroid, high-resistivity silicon or one or more other suitable substrates for mm-wave applications.

7. The millimeter-wave communications device of claim **6**, wherein the integrated circuit is anchored to a lower layer substrate selected from a group consisting of printed circuit board (PCB), glass fiber board (FR-4), temperature-resistant glass fiber board (FR-5), ceramic substrate, metal-core PCB (MCPCB), direct copper bonded (DCB) substrate, metal composite board, copper-coated aluminum board, and aluminum board.

8. A communication system adapted to be installed in an electronic device to communicate with other electronic devices comprising:
 an interface adapted to transfer and to receive signals at a first frequency from an antenna module; and
 the antenna module comprising:
  at least one antenna array comprising a plurality of mm-wave antennas on a substrate, wherein the substrate can be molded or bent to radiate in different spherical directions;
  an integrated circuit on the substrate connected to the plurality of mm-wave antennas through a transmission line;
  wherein the integrated circuit is configured to exchange signals between the interface and the antenna module, and to communicate with other electronic devices using mm-wave signals.

9. The communication system of claim **8**, wherein the integrated circuit is a radio frequency integrated circuit (RFIC) and wherein the interface is baseband integrated circuit (BBIC).

10. The communication system of claim **9**, wherein the transmission line connecting the plurality of mm-wave antennas is routed to equalize delays in the at least one antenna array.

11. The communication system of claim **9**, wherein the RFIC comprises a splitter to combine signals directed from the plurality of mm-wave antennas and to divide a signal into a plurality of signals to drive the plurality of mm-wave antennas.

12. The communication system of claim **11**, wherein the integrated circuit is attached to the substrate by a technique selected from chip and wire assembly, chip-on-board assembly, or flip-chip assembly.

13. The communication system of claim **12**, wherein the substrate is made from a material selected from a group consisting of liquid crystal polymer, Teflon, Low Temperature Co-fired Ceramic, alumina, antenna grade core materials and laminates, duroid, high-resistivity silicon or one or more other suitable substrates for mm-wave applications.

14. The communication system of claim **13**, wherein the integrated circuit is anchored to a lower layer substrate selected from a group consisting of printed circuit board (PCB), glass fiber board (FR-4), temperature-resistant glass fiber board (FR-5), ceramic substrate, metal-core PCB (MCPCB), direct copper bonded (DCB) substrate, metal composite board, copper-coated aluminum board, and aluminum board.

15. A multipoint wireless communications device installed in an electronic device to communicate with other electronic devices comprising:
 a flexible substrate comprising an antenna module with a plurality of mm-wave antennas, wherein the flexible substrate comprises a pliable material that can be configured to alter the radiation pattern of the antenna array module; and
 an integrated circuit on the flexible substrate connected to the plurality of mm-wave antennas through a transmission line;
 wherein the integrated circuit is configured to communicate using mm-wave signals.

16. The multipoint wireless communications device of claim **15**, wherein the integrated circuit is selected from a group consisting of radio frequency integrated circuit (RFIC), baseband integrated circuit (BBIC), or a combination thereof.

17. The multipoint wireless communications device of claim **16**, wherein the transmission line connecting the plurality of mm-wave antennas is routed to equalize delays in the antenna array.

18. The multipoint wireless communications device of claim **16**, wherein the RFIC comprises a splitter to combine signals directed from the plurality of mm-wave antennas and to divide a signal into a plurality of signals to drive the antenna array.

19. The multipoint wireless communications device of claim **18**, wherein the integrated circuit is attached to the substrate by a technique selected from chip and wire assembly, chip-on-board assembly, or flip-chip assembly.

20. The multipoint wireless communications device of claim **19**, wherein the substrate is made from a material selected from a group consisting of liquid crystal polymer, Teflon, Low Temperature Co-fired Ceramic, alumina, antenna grade core materials and laminates, duroid, high-resistivity silicon or one or more other suitable substrates for mm-wave applications.

21. The multipoint wireless communications device of claim **20**, wherein the integrated circuit is anchored to a lower layer substrate selected from a group consisting of printed circuit board (PCB), glass fiber board (FR-4), temperature-resistant glass fiber board (FR-5), ceramic substrate, metal-core PCB (MCPCB), direct copper bonded (DCB) substrate, metal composite board, copper-coated aluminum board, and aluminum board.

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