substrate 12. Each radiating element 26 can be implemented as a patch antenna (e.g., a round or rectangular patch antenna element). Each antenna element module 8 can be adhered (mounted) on a top surface 34 of the multi-layer substrate 10. In some examples, each antenna element module 8 can include a feedline extending through the dielectric substrate 12 that couples (e.g., a direct connection, passively coupled, etc.) the IC chip 18 with the feed 20. Moreover, each feed 20 of FIG. 1 can be a single feed, such that there is an equal number of IC chips 18 and feeds 20 across the phased array antenna 2. Alternatively, each feed 20 of FIG. 1 can be a plurality of feeds, such as a pair of orthogonally arranged slots, wherein each IC chip 18 can include multiple circuits for individually adjusting signals communicated between the feed 20 and the IC chip 18.

[48] For purposes of simplification of explanation, the terms "top" and "bottom" are employed throughout this disclosure to denote opposing surfaces in a selected orientation. Similarly, the terms "upper" and "lower" are employed to denote relative positions in the selected orientation. Further, the terms "underlying" and "overlay" (as well as derivative words) are employed to denote a relative position of two adjacent surfaces or elements in the selected orientation. In fact, the examples used throughout this disclosure denote one selected orientation. However, in the described examples, the selected orientation is arbitrary, and other orientations are possible (e.g., upside down, rotated by 90 degrees, etc.) within the scope of the present disclosure.

[49] The multi-layer substrate 10 can include a BFN circuit 40. The BFN circuit 40 can be formed on a layer (or layers) of the multi-layer substrate 10. In some examples, the BFN circuit 40 can be formed on an interior layer of the multi-layer substrate 10. In other examples, the BFN circuit 40 can be formed on an exterior layer, such as a top layer or bottom layer. As described herein, the BFN circuit 40 operates as a combiner and/or divider circuit that combines and/or divides signals in-phase. In some examples, the BFN circuit 40 can be a passive circuit. As used herein, the term "passive circuit" indicates that the BFN circuit 40 can include circuit components, (e.g., resistive traces, capacitors and/or inductors) ~~that~~ that are not supplied power from a power supply. The BFN circuit 40 can be in electrical communication with the IC chip ~~14~~ 18 of each antenna element module 8.

[50] The local system 4 can include a controller 38 that can control an operating mode of the phased array antenna 2. As one example, the controller 38 can be implemented as a microcontroller with embedded instructions. In another example, the controller 38 can be implemented as a computing device with a processing unit (e.g., one or more processor cores) that executes machine code stored in a non-transitory memory. In some examples, the controller 38 can provide control signals via control lines (not shown) to the IC chips 18, wherein such control signals cause the IC chips 18 to set an amplitude and/or phase adjustment level of signals communicated between the BFN circuit 40 and the feeds 20 of the antenna element modules 8. That is, the controller 38 can control the signal adjustment of the IC chips 18. Additionally or alternatively, in

some examples, the controller 38 can provide control signals to the IC chips 18 that cause the phased array antenna 2 to operate in a receiving mode or in a transmitting mode. Additionally, for purposes of simplification of explanation, in examples described herein, the controller 38 also provides power signals to the IC chips 18 of the antenna element modules 8. However, in other examples, other sources can provide power for the IC chips ~~14~~ 18.

[51] In operation, in some examples, the phased array antenna 2 architecture can be designed to operate exclusively in the receiving mode or the transmitting mode. In other examples, as described herein, the phased array antenna 2 architecture can be designed to operate in half-duplex mode or polarization duplex mode, wherein the phased array antenna 2 switches between the receiving mode and the transmitting mode. In still other examples, the phased array antenna 2 architecture can be designed to operate in a frequency division multiplexing mode, such that the phased array antenna 2 can operate in the receiving mode and the transmitting mode concurrently.

[52] In the receiving mode, electromagnetic (EM) signals can be received from the remote system 6 by the radiating elements 26 on each of the plurality of antenna element modules 8, or some subset thereof. The radiating elements 26 can couple the received EM signals through the air gap 30 and to a corresponding feed 20. The corresponding feed 20 can convert the received EM signals into electrical signals and provide the electrical signals to a corresponding IC chip 18 of a respective antenna element module 8. Each corresponding IC chip 18 can include circuitry that can adjust the received electrical signals to output an element signal. In particular, each IC chip ~~14~~ 18 can amplify, filter and/or phase shift the received electrical signals to form the element signal.

[53] Moreover, different IC chips 18 can provide different levels and types of adjustment. For example, a first IC chip 18 of a first antenna element module 8 can amplify the received signal with a first gain and/or phase shift the received electrical signals by a first phase shift. Additionally, a second IC chip ~~14~~ 18 of a second antenna element module 8 can amplify the received electrical signals with a second gain and/or phase shift the received electrical signals by a second phase shift. In this manner, the plurality of element signals output by the IC chips 18 can have specific properties to facilitate combination by the BFN circuit 40.

[54] Each of the element signals output by the IC chips 18 can be provided to the BFN circuit 40. The BFN circuit 40 can combine the element signals to form a received beam signal. The received beam signal can be provided to the local system 4 through a connection port that can be located at a bottom surface 41 of the multi-layer substrate 10, or other location. The local system 4 can process (e.g., demodulate) the received beam signal and consume decoded data.

[55] The BFN circuit 40 can be implemented with stages of combiner/divider circuits 42, illustrated in FIG. 1 as split lines. In the example illustrated in FIG. 1, there are three (3) such stages, but in other examples, there can be more stages or fewer stages (as few as one (1) stage) of combiner/divider circuits 42. Each combiner/divider circuit 42 can be implemented as a power

combiner/divider circuit, such as a Wilkinson power divider, a hybrid coupler, a directional coupler, or any other circuit that can combine and/or divide signals. Each combiner/divider circuit 42 can combine or divide signals passing through the BFN circuit 40. For instance, when used for receiving, signals communicated between the IC chips ~~14~~ 18 and the local system 4 can be combined by each stage of the combiner/divider circuits 42. Additionally or alternatively, when used for transmitting, signals communicated from the local system 4 to the IC chips ~~14~~ 18 can be divided by each stage of the combiner/divider circuit 42 of the BFN circuit 40. As some examples, the BFN circuit 40 can combine the element signals in-phase or out of phase. Additionally or alternatively, the BFN circuit 40 can combine the element signals equally or unequally. In general, the architecture of the BFN circuit 40 can be designed for nearly any form of signal combining and/or dividing.

[56] In the transmitting mode, the local system 4 can provide a transmit beam signal to the BFN circuit 40 that is intended to be transmitted to the remote system 6. The BFN circuit 40 divides the transmit beam signal to form a plurality of divided signals, which are referred to as element signals. The element signals can be provided to the IC chips 18 of the antenna element modules 8. Each IC chip 18 can adjust (e.g., amplify, filter and/or phase shift) a received element signal, and outputs an adjusted signal for a corresponding feed 20. In the transmitting mode, each IC chip 18 can be configured to provide a different level of adjustment than the adjustment in the receiving mode, including examples where the phased array antenna 2 operates in the receiving mode and the transmitting mode concurrently. For example, a given IC chip 18 can provide a different level of gain, a different phase shift and/or a different passband in the transmitting mode than in the receiving mode.

[57] The feed 20 of each antenna element module 8 can convert the adjusted element signal provided by the corresponding IC chip 14 into an EM signal that is provided through the air gap 30 toward the corresponding radiating element 26. Each radiating element 26 can couple the transmitted EM signal into free space, such that the transmitted EM signal is superimposed with the transmissions of the other antenna element modules 8 to form a beam of the transmit beam signal that propagates through the free space to the remote system 6, as indicated by an arrow 44. The remote system 6 can demodulate the received transmit beam signal and process resulting data. The phased array antenna 2 can be designed such that the transmit signals constructively and destructively interfere to produce the beam of the transmit beam signal with a radiation pattern having desired properties (e.g., a desired direction of maximum gain, and/or polarization). Additionally, in some examples, the adjustment (e.g., amplification and/or phase shift) by the plurality of IC chips 18 of each antenna element module 8 can be controllable by the controller 38 to couple the beam of the transmit beam signal in a desired direction. In examples where the phased array antenna 2 is designed to operate in the receiving mode and the transmitting mode, bi-directional wireless communication between the remote system 6 and the local system 4 can be established. Alternatively, in examples where the phased array antenna 2 is designed operate in only the receiving mode or only the

transmitting mode, unidirectional wireless communication between the remote system 6 and the local system 4 can be established.

[58] By implementing the phased array antenna 2 of FIG. 1, a relatively simple, low cost phased array antenna can be fabricated. In particular, the antenna element modules 8 can be fabricated separately from the multi-layer substrate 10, and mounted on the multi-layer substrate 10. Moreover, as explained herein in detail, the antenna element modules 8 can be fabricated as an array of antenna element modules that can be singulated and adhered to the top surface 34 of the multi-layer substrate 10.

[59] Furthermore, the antenna element modules 8 can be fabricated with a relatively simple and low cost process. For example, the antenna packages 22 can be formed with an injection molding or a thermo molding process. In an example where the antenna packages 22 can be formed with injection molding, the plastic antenna carrier 24 of a given antenna package 22 can be formed with injection of a first polymer (e.g., a first type of plastic) into a mold that can include a cavity shaped for the radiating element 26. Subsequently, a second polymer (e.g., a second type of plastic) can be injected to the cavity of plastic antenna carrier 24 to form the ~~antenna package 22~~ radiating element 26. Additionally, the IC chip 18 can be attached to the lower surface 14 of the dielectric substrate 12. The antenna package 22 can subsequently be adhered to the top surface of the dielectric substrate 12.

[60] Additionally, by implementing the IC chips 18 in the antenna element modules 8, the need for IC chips within the BFN circuit 40 and/or the bottom surface 41 of the multi-layer substrate 10 is obviated, thereby reducing the complexity of the BFN circuit 40. For example, inclusion of the IC chips 18 in the antenna element modules 8, avoids printed circuit board (PCB) complexities arising from routing a received signal through the multi-layer substrate 10 to an IC chip mounted on an opposing (bottom) surface, and then to the BFN circuit 40 for combining. Further still, including both the feed 20 and the radiating element 26 increases directivity and gain of the phased array antenna 2.

[61] FIG. 2 is a perspective view of an example phased array antenna 50 with a split-level architecture for transmitting and/or receiving EM signals such as RF signals. FIG. 3 is an exploded diagram of the phased array antenna 50. FIGS. 2 and 3 employ the same reference numbers to denote the same structure. Moreover, unless noted otherwise, reference to elements of the phased array antenna 50 applies to both FIGS. 2 and 3. The phased array antenna 50 of FIGS. 2 and 3 can be employed to implement the phased array antenna 2 of FIG. 1.

[62] In some examples, the phased array antenna 50 can be fabricated as modules and assembled. In particular, the phased array antenna 50 can include N number of antenna element modules 52 (only some of which are labeled in detail in FIGS. 1 and 2) mounted on a multi-layer substrate 54. Each antenna element module 52 can include a dielectric substrate 56 with an upper