CLAIMS

What is claimed is:

1. An antenna array comprising:

a plurality of antenna cells positioned in a global coordinate system of the antenna array, wherein each of the plurality of antenna cells has a respective local coordinate system and comprises:

a radiating element having a predetermined angle of rotation defined in the global coordinate system; and

an antenna port coupled to the radiating element, the antenna port being positioned at a particular set of coordinates in the respective local coordinate system;

wherein the particular set of coordinates of the antenna port of each of the plurality of antenna cells are the same;

wherein the antenna port of each of the plurality of antenna cells comprises a via that is for coupling to a beam-forming network, BFN (200; 300; 500; 600; 800; 900; 1004; 1104); and

wherein the predetermined angle of rotation of the radiating element of a first antenna cell of the plurality of antenna cells is a first rotation angle in the global coordinate system, and the predetermined angle of rotation of the radiating element of a second antenna cell of the plurality of antenna cells is a second rotation angle in the global coordinate system, the second rotation angle different than the first rotation angle.

2. The antenna array of claim 1, wherein the antenna port of each of the plurality of antenna cells is a first antenna port and each of the plurality of antenna cells further comprises a second antenna port, the second antenna port being positioned at a second set of coordinates in the respective local coordinate system, wherein the second antenna port of each of the plurality of antenna cells is positioned at the same second set of coordinates in each respective local coordinate system.

3. The antenna array of claim 2, wherein the first antenna port and the second antenna port of each of the plurality of antenna cells are for ~~communicate~~ communicating signals that have a phase difference of 90 degrees.

4. The antenna array of any one of claims 1 - 3, wherein the second antenna cell is rotated in the global coordinate system relative to the first antenna cell.

5. The antenna array of claim 4, wherein the radiating element of the first antenna cell of the plurality of antenna cells has a first local predetermined angle of rotation in the local coordinate system of the first antenna cell and the radiating element of the second antenna cell of the plurality of antenna cells has a second local predetermined angle of rotation in the local coordinate system of the second antenna cell, the second local predetermined angle of rotation being offset from the first local predetermined angle of rotation by a predetermined angle in the local coordinate system of the first antenna cell and the local coordinate system of the second antenna cell.

6. The antenna array of any one of claims 1 - 5, wherein a third antenna cell of the plurality of antenna cells is rotated in the global coordinate system relative to the first antenna cell of the plurality of antenna cells and a radiating element of the third antenna cell and the radiating element of the first antenna cell are not rotated relative to each other in the global coordinate system.

~~7. The antenna array of any one of claims 1 - 6, wherein the antenna port of each of the plurality of antenna cells comprises a via that is coupled to a beam-forming network (BFN).~~

~~8. The antenna array of claim 7, wherein the BFN comprises a plurality of combiners/dividers that convert between an input/output signal and a plurality of sub-signals, wherein each of the plurality of sub-signals is communicated to an antenna port of a respective antenna cell of the plurality of antenna cells through an integrated circuit (IC) chip.~~

~~9~~7. The antenna array of any one of claims 1 - ~~8~~6, wherein the antenna port of each of the plurality of antenna cells is a signal interface for communicating signals between the antenna cell and an integrated circuit (IC) chip coupled to the~~a~~ beam-forming network (BFN).

~~10~~8. The antenna array of any one of claims 1 - ~~9~~7, wherein each of the plurality of antenna cells further comprises a feedline that couples a corresponding radiating element and antenna port of a respective antenna cell, wherein a length of each respective feedline of the plurality of antenna cells is the same.

~~11~~9. The antenna array of claim ~~10~~8, wherein a third antenna cell of the plurality of antenna cells is rotated in the global coordinate system relative to the first antenna cell of the plurality of antenna cells and a radiating element of the third antenna cell and the radiating element of the first antenna cell are not rotated relative to each other in the global coordinate system.

~~12~~10. The antenna array of one of claims 1 - ~~11~~9, wherein the particular set of coordinates for each of the plurality of antenna cells is located between a respective radiating element and a perimeter of a respective antenna cell.

~~13~~11. The antenna array of any one of claims 1 - ~~12~~10, further comprising a plurality of isolation vias, wherein a given isolation via of the plurality of isolation vias is shared between an antenna port of at least three of the plurality of antenna cells.

~~14. The antenna array of any one of claims 1 - 13, wherein the antenna port of each of the plurality of antenna cells is coupled to a beam-forming network (BFN) wherein the BFN comprises a plurality of beam forming stages, wherein each of the plurality of beam forming stages has a respective local coordinate system, and each of the plurality of beam forming stages has the same geometric shape in the respective local coordinate system; and~~

~~wherein a given beam forming stage of the plurality of beam forming stages has the same geometric shape as another beam forming stage of the plurality of beam forming stages, wherein the given beam forming stage and the other beam forming stage are the same stage, and the given beam forming stage is rotated in the global coordinate system relative to the other beam forming stage.~~

~~15~~12. The antenna array of any one of claims 1 - ~~14~~11, wherein the plurality of antenna cells are arranged in a plurality of groups of antenna cells each comprises a group rotation pattern that defines a predetermined angle of rotation in the global coordinate system for each radiating element in a respective group of antenna cells.

~~16~~13. The antenna array of claim ~~15~~12, wherein the group rotation pattern for adjacent groups of antenna cells is different.

~~17~~14. The antenna array of any one of claims 1 - ~~16~~13, wherein the radiating element of six of the plurality of antenna cells has a different angle of rotation in the global coordinate system.

15. The antenna array of any one of claims 1 - 14, wherein each of the plurality of antenna cells further comprises a feedline that couples a corresponding radiating element and antenna port of a respective antenna cell, wherein a length of each respective feedline of the plurality of antenna cells is the same, wherein, optionally, a third antenna cell of the plurality of antenna cells is rotated in the global coordinate system relative to the first antenna cell of the plurality of antenna cells and a radiating element of the third antenna cell and the radiating element of the first antenna cell are not rotated relative to each other in the global coordinate system.

1~~8~~6. A multi-layer printed circuit board (PCB) comprising:

~~A~~ a beam-forming layer having a plurality of traces that form a beam-forming network (BFN), wherein the beam-forming network is coupled to vias of a plurality of antenna ports ~~forming vias extending away from the beam-forming network (BFN)~~, and the BFN comprises:

a plurality of combiners/dividers that convert between an input/output signal and a plurality of sub-signals, wherein each of the plurality of sub-signals has an equal power and an array of phases, wherein each of the plurality of sub-signals is communicated to an antenna port of the plurality of antenna ports;

the antenna array of any of claims 1 - ~~1~~15~~a plurality of antenna cells being positioned in a global coordinate system of the multi-layered PCB to form a regular tiling pattern, wherein each of the plurality of antenna cells has a respective local coordinate system and comprises:~~

~~a radiating layer comprising a radiating element that has a predetermined angle of rotation in the global coordinate system~~; and

a feedline layer having a feedline that couples a corresponding antenna port of the plurality of antenna ports to the radiating element, wherein each antenna port intersects with the feedline layer at a particular set of coordinates in the respective local coordinate system~~;~~

~~wherein the particular set of coordinates for each of the plurality of antenna cells are the same; and~~

~~wherein the predetermined angle of rotation of the radiating element of a first antenna cell of the plurality of antenna cells is a first rotation angle in the global coordinate system, and the predetermined angle of rotation of the radiating element of a second antenna cell of the plurality of antenna cells is a second rotation angle in the global coordinate system, the second rotation angle different than the first rotation angle~~.

17~~9~~. The multi-layered PCB of claim ~~18~~16, wherein the plurality of combiners/dividers of the BFN are arranged in a plurality of beam forming stages, wherein each of the plurality of beam forming stages has a respective local coordinate system, and each of the plurality of beam forming stages has the same geometric shape in the respective local coordinate system; and

wherein a given beam forming stage of the plurality of beam forming stages has the same geometric shape as another beam forming stage of the plurality of beam forming stages, wherein the given beam forming stage and the another beam forming stage are the same stage, and the given beam forming stage is rotated in the global coordinate system relative to the another beam forming stage.

~~20~~18. The multi-layered PCB of ~~any one of~~ claim~~s~~ 1~~8~~7~~—19~~, wherein each of the plurality of beam forming stages correspond to a first circuit and a second circuit, wherein the first circuit and the second circuit amplify and phase shift a signal communicated between a respective beam forming stage~~s~~ and a corresponding radiating element of a respective antenna cell of the plurality of antenna cells.

~~21~~15~~9~~. The multi-layered PCB of any one of claims ~~18~~ 1~~2~~6 - ~~20~~18, when dependent on claim 2, wherein ~~the antenna port of each of the plurality of antenna cells is a first antenna port and each of the plurality of antenna cells further comprises a~~the second antenna port ~~that~~ intersects with the feedline layer at ~~a~~the second ~~particular~~ set of coordinates in the respective local coordinate system~~, and the second particular set of coordinates for each of the antenna cells are the same~~.

~~22~~20. The multi-layered PCB of claim ~~21~~19, wherein the first antenna port and the second antenna port of each of the plurality of antenna cells communicate signals that have a phase difference of 90 degrees.

~~23~~21. The multi-layered PCB of any one of claims ~~18~~ 16 – ~~22~~20, wherein a third antenna cell of the plurality of antenna cells is rotated in the global coordinate system relative to the first antenna cell of the plurality of antenna cells and a radiating element of the third antenna cell and the radiating element of the first antenna cell are not rotated relative to each other in the global coordinate system.

~~24~~22. The multi-layered PCB of any one of claims ~~18~~ 16 – ~~23~~21, wherein the particular set of coordinates for each of the plurality of antenna cells is located between a respective radiating element and a perimeter of a respective antenna cell.

~~25~~23. The multi-layered PCB of any one of claims ~~18~~ 16 – ~~24~~22, wherein the plurality of antenna cells are arranged in a plurality of groups of antenna cells each comprises a group rotation pattern that defines a predetermined angle of rotation in the global coordinate system for each radiating element in a respective group of antenna cells.

~~26~~24. The multi-layered PCB of claim ~~25~~23, wherein the group rotation pattern for adjacent groups of antenna cells is different.