CLAIMS

1. Antenna apparatus (100, 100') comprising:

a first subassembly (110, 110') comprising a plurality of antenna elements (120); and

a second subassembly (150, 150') adhered to the first subassembly, the second subassembly comprising a plurality of components (160, 170, 180) of a beamforming network encapsulated within a molding material (152), and further comprising one or more interconnect layers (155) on the molding material to electrically couple the plurality of components of the beamforming network to the plurality of antenna elements,

wherein the plurality of components includes an input/output port (170), a combiner / divider network (180), and a plurality of integrated circuit (IC) chips (160) each electrically coupled to at least one of the antenna elements, wherein:

the input/output port routes a transmit radio frequency (RF) signal in a transmit direction to the combiner / divider network and/or routes a combined receive RF signal from the combiner / divider network in a receive direction;

the combiner / divider network is configured to divide the RF transmit signal into a plurality of divided transmit RF signals and/or combine a plurality of modified RF receive signals, each received from one of the IC chips, into the combined RF receive signal; and

each of the IC chips is configured to modify a respective one of the divided RF transmit signals to provide a modified RF transmit signal and output the same to the at least one antenna element coupled thereto and/or modify an RF receive signal provided from the at least one antenna element coupled thereto to provide one of the modified RF receive signals to the combiner / divider network.

2. The antenna apparatus (100, 100') of claim 1, wherein surfaces of the plurality of components of the beamforming network are co-planar with a surface of the molding material.

3. The antenna apparatus (100, 100') of claim 1, wherein the plurality of antenna elements are on a first surface of the first subassembly, and the first subassembly further comprises an array of vias directly connected to the plurality of antenna elements and extending to a second surface of the first subassembly, wherein the second subassembly is adhered to the second surface of the first subassembly.

4. The antenna apparatus (100, 100') of claim 1, wherein the plurality of components includes a plurality of amplifiers (60, 80) coupled to the plurality of antenna elements through a plurality of vias (Vs) within the one or more interconnect layers.

5. The antenna apparatus (100, 100') of claim 4, wherein an amplifier (60, 80) of the plurality of amplifiers is coupled to and underlies a corresponding antenna element of the plurality of antenna elements.

6. The antenna apparatus (100, 100') of claim 1, wherein the second subassembly further comprises one or more vias (190) coupled to the one or more interconnect layers and extending through the molding material to a surface of the second subassembly.

7. The antenna apparatus (100, 100') of claim 1, wherein at least one of the components is a transmission line (170) coupled to the one or more interconnect layers and extending through the molding material to a surface of the second subassembly.

8. The antenna apparatus (100, 100') of claim 1, wherein the first subassembly has a top surface and a bottom surface, the plurality of antenna elements are disposed at the top surface, and the first subassembly further comprising a ground plane (119) disposed at the bottom surface.

9. The antenna apparatus (100, 100') of claim 1, wherein each of the antenna elements is a patch antenna element having a body fed from a point directly underneath the body by a probe feed orthogonal to a major surface of the body.

10. The antenna apparatus (100, 100') of claim 1, wherein the first and second subassemblies are adhered to one another by at least a plurality of ground-signal-ground (GSG) solder connections (147s, 147g), each electrically connecting one of the antenna elements to signal and ground contacts on the one or more interconnect layers.

11. The antenna apparatus (100, 100') of claim 1, wherein each of the IC chips comprises at least one of: (i) a transmit amplifier and/or a transmit phase shifter, or (ii) a receive

amplifier and/or a receive phase shifter, to modify the divided RF transmit signal and/or the RF receive signal provided thereto.

12. The antenna apparatus (100, 100') of claim 1, wherein:

the input / output port is a coaxial transmission line extending from a first major surface of the second subassembly to a second, opposite major surface of the second subassembly; and

the combiner / divider network is composed of coplanar waveguide (184a, 184b, 184c) supported by a dielectric (185) disposed between the input / output port and the plurality of IC chips.

13. The antenna apparatus (100, 100') of claim 12, wherein the dielectric has a loss tangent lower than that of the molding material.

14. The antenna apparatus (100, 100') of claim 12, wherein:

the dielectric (185) is quartz and the molding material is a liquid crystal polymer; and

the first subassembly comprises a quartz substrate supporting the plurality of antenna elements.

15. The antenna apparatus (100, 100') of claim 1, wherein:

the components comprise a plurality of integrated circuit (IC) chips (160, 160') arranged in rows and columns of a two dimensional array, each IC chip spaced from one another in a row direction and in a column direction and each directly underlying and electrically connected to at least two probe feeds that connect at least two corresponding antenna elements to the respective IC chip.

16. The antenna apparatus (100, 100') of claim 1, wherein the components include a plurality of integrated circuit (IC) chips (160'), and the second subassembly comprises a plurality of heat spreader tabs (1102), each attached to a major surface of one of the IC chips.

17. The antenna apparatus (100, 100') of claim 16, wherein first major surfaces of each of the heat spreader tabs are attached to respective ones of the IC chips, and second, opposite major surfaces of the heat spreader tabs are exposed outside the molding material.

18. The antenna apparatus (100, 100') of claim 1, wherein the beamforming network and the antenna elements are configured to transmit and / or receive signals at millimeter wave frequencies.

19. The antenna apparatus (100, 100') of claim 1, wherein the plurality of antenna elements comprise at least sixteen antenna elements.

20. A method (600) of forming an antenna apparatus, comprising:

forming a first subassembly (S610) comprising a plurality of antenna elements;

encapsulating a plurality of beamforming components of a beamforming network within a molding material to form an embedded component structure (S610, 700, 1000);

forming one or more interconnect layers on the embedded component structure (S770), thereby forming a second subassembly; and

adhering and electrically connecting the first subassembly to the second subassembly so that the plurality of beamforming components are electrically coupled to the plurality of antenna elements (S620),

wherein said encapsulating a plurality of beamforming components comprises:

providing a carrier with adhesive foil adhered thereto (S710, S1010);

placing the plurality of beamforming components on a surface of the adhesive foil (S720);

applying the molding material in an uncured state around the beamforming components while placed on the adhesive foil surface (S730, S1030);

curing the molding material to form an interim structure (S730, S1040); and

removing the carrier and the adhesive foil from the interim structure to form the embedded component structure (S740, S1050),

wherein the plurality of beamforming components comprises a plurality of integrated circuit (IC) chips (160), a combiner / divider network formed within at least one transmission line section (180), and a coaxial feed-through transmission line (170), each placed on the surface of the adhesive foil prior to the application of the molding material.

21. The method (600) of claim 20, wherein said adhering and electrically connecting the first subassembly to the second subassembly comprises heating and cooling a plurality of ground-signal-ground (GSG) solder connections (147s, 147g) between respective signal pads (Ps) and ground pads (Pg) on each of the first and second subassemblies.

22. The method (600) of claim 20, wherein said forming one or more interconnect layers comprises forming a plurality of vias (Vs) completely through the one or more interconnect layers for direct electrical connection of at least some of the beamforming components to respective ones of the antenna elements when the first and second subassemblies are adhered and electrically connected to one another.

23. The method (600) of claim 20, further comprising forming a plurality of vias through the molding material after the curing thereof, for subsequent connection to at least one of the IC chips through the one or more interconnect layers (S760, S1070).

24. The method (600) of claim 20, further comprising:

attaching heat spreader tabs (1102) to respective major surfaces of at least some of the beamforming components prior to encapsulating the beamforming components (S1020).