IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

COMMSCOPE TECHNOLOGIES LLC	)	
	)	C.A. No.
Plaintiff,	)	
	)	**JURY TRIAL DEMANDED**
v.	)	
	)	
ROSENBERGER SITE SOLUTIONS, LLC; ROSENBERGER ASIA PACIFIC ELECTRONIC CO., LTD.; ROSENBERGER TECHNOLOGIES (KUNSHAN) CO. LTD.	)	
	)	
Defendants.	)	

COMPLAINT FOR PATENT INFRINGEMENT

Plaintiff CommScope Technologies LLC ("CommScope") brings this action against Defendants Rosenberger Site Solutions, LLC ("Rosenberger SSL"), Rosenberger Asia Pacific Electronic Co., Ltd. ("Rosenberger AP"); and Rosenberger Technologies (Kunshan) Co., Ltd. ("Rosenberger China") (collectively "Rosenberger" or "Defendants") and alleges as follows:

Nature of the Case

1. This is an action for patent infringement of seven patents: (1) United States Patent No. 7,358,922 ("the '922 patent"), (2) United States Patent No. 7,535,430 ("the '430 patent"), (3) United States Patent No. 9,698,486 ("the '486 patent"), (4) United States Patent No. 9,831,548 ("the '548 patent"), (5) United States Patent No. 10,439,285 ("the '285 patent"), (6) United States Patent No. 10,498,035 ("the '035 patent"); and (7)

United States Patent No. 10,547,110 ("the '110 patent"). These patents (collectively the "patents-in-suit") relate to base station antenna systems used in mobile phone networks.

2. Defendants have been making, using, importing, selling and/or offering for sale antennas that infringe the patents-in-suit. Plaintiff CommScope seeks damages and an injunction against any further infringement of its patents by Rosenberger.

Parties

3. CommScope, formerly known as Andrew LLC, is a Delaware company, headquartered in Hickory, North Carolina. Together with its affiliated companies, CommScope designs, manufactures, and sells telecommunications products and equipment around the world. CommScope's innovative products are used to build network infrastructures that enable wired and wireless communications. For example, CommScope designs and manufactures a wide range of innovative base station antennas (BSAs) for wireless outdoor networks to support wireless communications, such as cellular telephone communications. CommScope protects its investment in research and development of innovative antenna systems by filing and obtaining patents on its innovations, including the patents-in-suit.

4. Upon information and belief, Defendant Rosenberger SSL is a Delaware company with headquarters at 102 Dupont Drive, Lake Charles, Louisiana 70607. Rosenberger SSL is part of a multinational conglomerate ("the Rosenberger family") that competes with CommScope in the sale of telecommunications equipment, including BSAs.

5. Upon information and belief, Defendant Rosenberger AP is a Chinese entity with a place of business at No. 3, Anxiang Road, Block B, Tianzhu Airport Industrial Zone, Beijing 101300, China. It is a part of the Rosenberger family and is majority owned by the German parent company of the Rosenberger family.

6. Upon information and belief, Defendant Rosenberger China is a Chinese entity with a place of business at No. 6, Shenan Road, Dianshanhu Town, Kunshan Jiangsu, Province 215345, China. It is a part of the Rosenberger family and is owned by Rosenberger AP.

Jurisdiction

7. This action arises under the Patent Act, 35 U.S.C. § 271 *et seq*.

8. This Court has subject matter jurisdiction under 28 U.S.C. §§ 1331 and 1338(a).

9. This Court has personal jurisdiction over Rosenberger. Upon information and belief, Defendant Rosenberger SSL is incorporated in Delaware, while Defendants Rosenberger AP and Rosenberger China are incorporated in China.

10. Venue is proper in this district under 28 U.S.C. §§ 1391 and 1400(b). As set forth above, Rosenberger SSL is a Delaware corporation. Under 28 U.S.C. § 1391(c)(3) Rosenberger AP and Rosenberger China are not resident in the U.S. and may be sued in any district.

Background and Patents-in-Suit

11. The subject matter of this complaint relates to BSAs. BSAs are typically used to wirelessly communicate with mobile communication devices (cell phones) within

a desired coverage area. Such antennas are commonly positioned in elevated positions atop cell towers or buildings to provide mobile phone service to an area near the antenna. The antennas transmit and/or receive radio waves to communicate wirelessly with cell phones or other wireless devices.

12. CommScope is a recognized innovator in the field of base station antenna systems. Employees of CommScope, and the companies CommScope has acquired, have developed many inventions for base station antennas, including the inventions in the patents-in-suit.

13. CommScope is the owner of the entire right, title and interest in and to the ‘922 patent, which duly and legally issued on April 15, 2008. The ‘922 patent is entitled “Directed Dipole Antenna.” A copy of the ‘922 patent is attached as Exhibit A.

14. CommScope is the owner of the entire right, title, and interest in and to the ‘430 patent, which duly and legally issued on May 19, 2009. The ‘430 patent is entitled “Directed Dipole Antenna Having Improved Sector Power Ratio (SPR)” and is a continuation of the ‘922 patent. A copy of the ‘430 patent is attached as Exhibit B.

15. CommScope is the owner of the entire right, title, and interest in and to U.S. Patent No. 9,698,486 (“the ‘486 patent”), which duly and legally issued on July 4, 2017. The ‘486 patent is entitled “Low Common Mode Resonance Multiband Radiating Array.” A copy of the ‘486 patent is attached as Exhibit C.

16. CommScope is the owner of the entire right, title, and interest in and to U.S. Patent No. 9,831,548 (“the ‘548 patent”), which duly and legally issued on

November 28, 2017. The ‘548 patent is entitled “Dual-Beam Sector Antenna and Array.” A copy of the ‘548 patent is attached as Exhibit D.

17. CommScope is the owner of the entire right, title, and interest in and to U.S. Patent No. 10,439,285 (“the ‘285 patent”), which duly and legally issued on October 8, 2019. The ‘285 patent is entitled “Cloaked Low Band Elements for Multiband Radiating Arrays.” A copy of the ‘285 patent is attached as Exhibit E.

18. CommScope is the owner of the entire right, title and interest in and to U.S. Patent No. 10,498,035 (“the ‘035 patent), which duly and legally issued on December 3, 2019. The ‘035 patent is entitled “Cloaked Low Band Elements for Multiband Radiating Arrays” and is a continuation of the ‘285 patent. A copy of the ‘035 patent is attached as Exhibit F.

19. CommScope is the owner of the entire right, title and interest in and to U.S. Patent No. 10,547,110 (“the ‘110 patent), which duly and legally issued on January 28, 2020. The ‘110 patent is entitled “Cloaked Low Band Elements for Multiband Radiating Arrays” and is a continuation of the ‘035 patent. A copy of the ‘110 patent is attached as Exhibit G.

Rosenberger’s Infringing Products and Its Copying of CommScope’s Patented Technology

20. Rosenberger has committed acts of patent infringement by making, using, selling, offering for sale, and/or importing into the United States its base station antennas including at least the following antenna models:

BA-AIO3O3T3T3VFX65F-06;

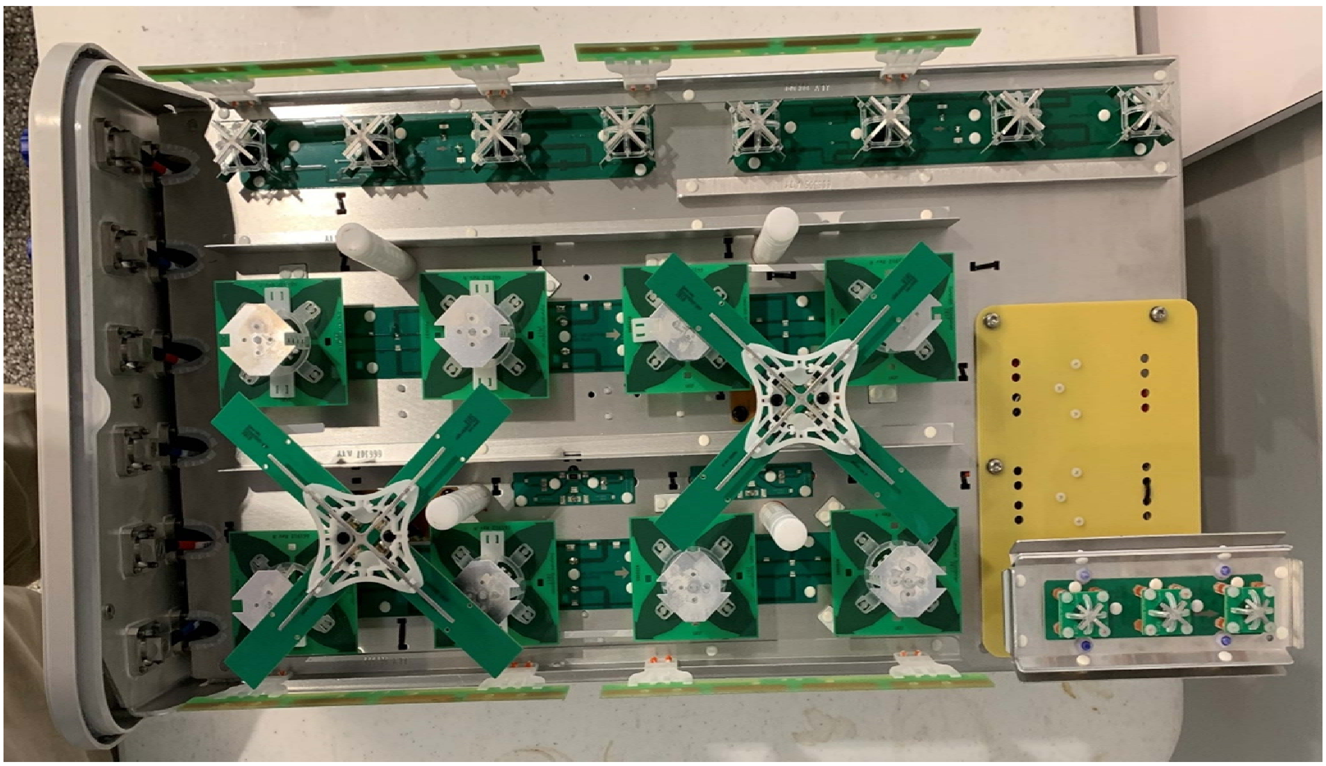
BA-AIO3O3T3T3VJX65F-06;

BA-O3O3T3T3VFX65F-06;

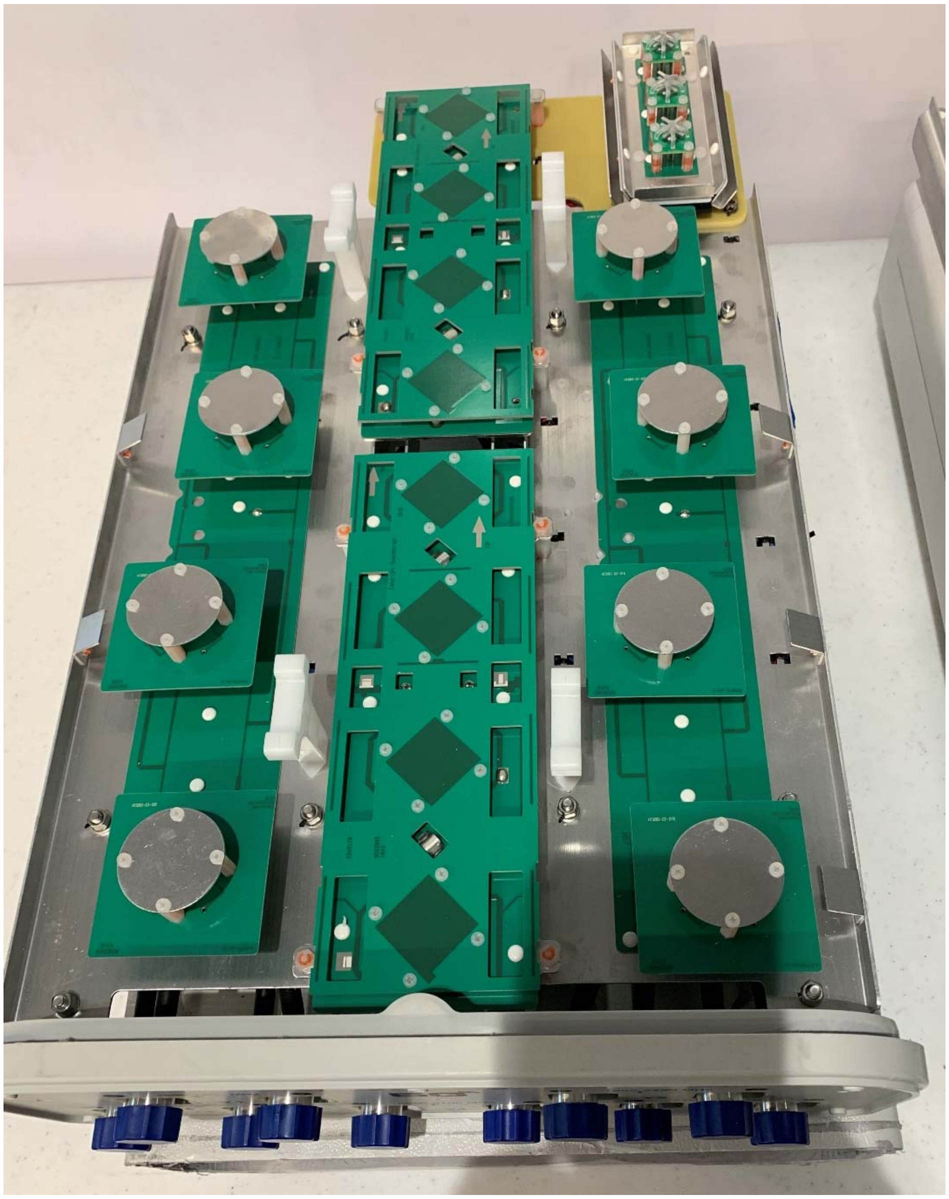
BA-A5A54O7X65V-01; and

MB-A64O9X65V-01

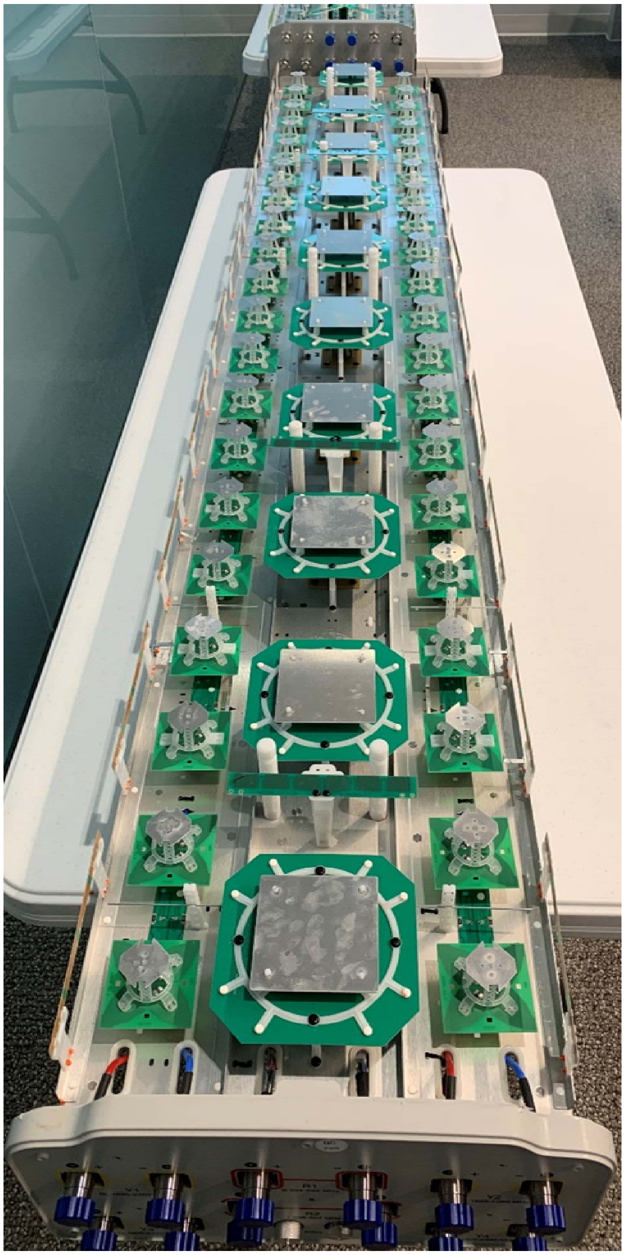
21. Shown below is a photograph of internal components of Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06, which is also representative of the relevant internal components of BA-AIO3O3T3T3VJX65F-06.



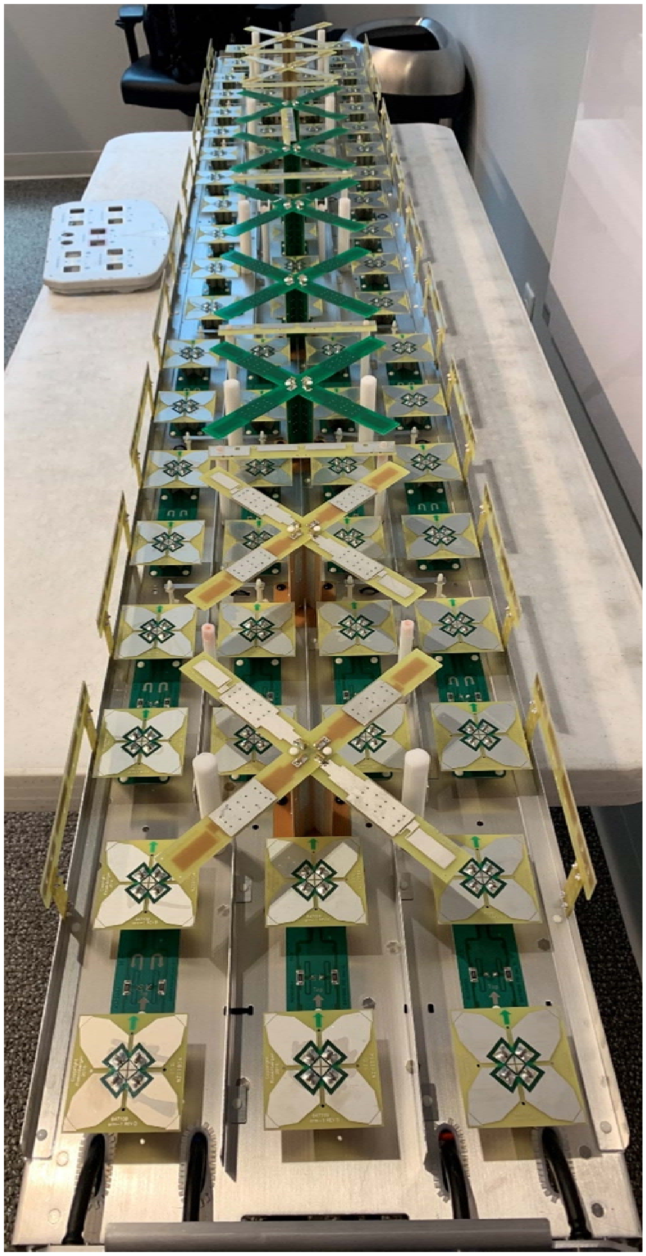
22. Shown below is a photograph of internal components of Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06.



23. Shown below is a photograph of internal components of Rosenberger antenna model no. BA-A5A54O7X65V-01.



24. Shown below is a photograph of internal components of Rosenberger antenna model no. MB-A64O9X65V-01.



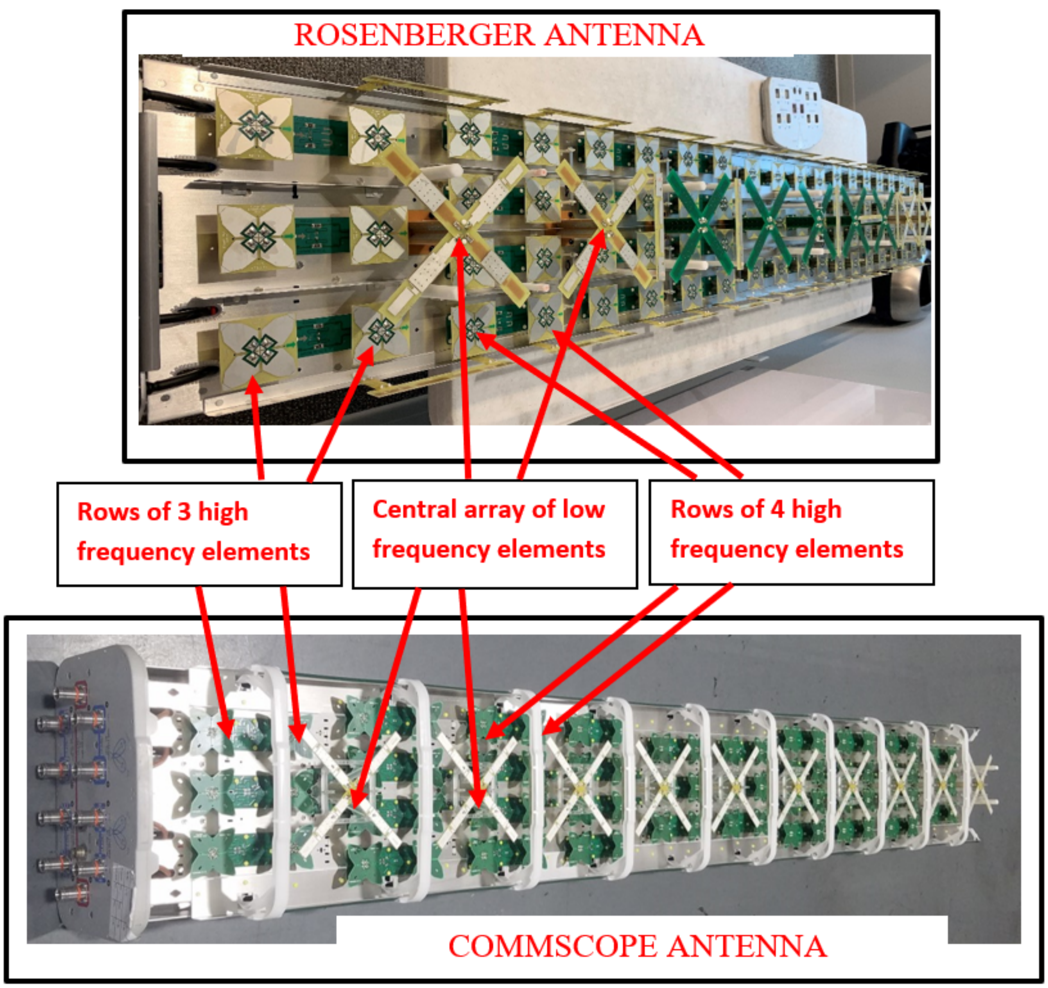
25. Upon information and belief, Rosenberger has been making, using, importing, offering for sale, and/or selling the antenna models identified above in the United States.

26. Rosenberger has engaged in a campaign of hiring CommScope's employees, and has successfully hired away more than a dozen of CommScope's employees who worked on CommScope's BSAs. The CommScope ex-employees include managers, supervisors and the former lead R&D manager of CommScope's Chinese business unit with responsibility for BSAs. They include mechanical engineers and radio frequency (RF) engineers, all of whom were familiar with all aspects of CommScope's BSAs, including design files and engineering drawings. They were also familiar with CommScope's intellectual property, including the patents CommScope had obtained to protect the designs of its BSAs. In the U.S., Rosenberger SSL has also employed former CommScope employees in leadership roles.

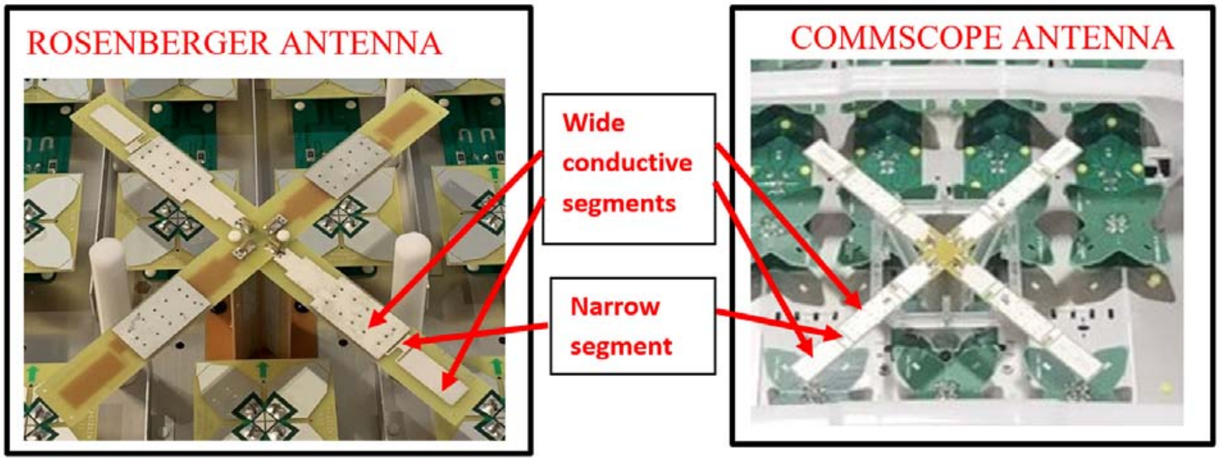
27. Rosenberger developed and marketed its infringing products after hiring away these CommScope employees who were intimately familiar with CommScope's BSA products and BSA innovations. Upon information and belief, these ex-CommScope employees knew that CommScope protects such products and innovations through patent protection.

28. Several patented features of CommScope's BSAs appeared in Rosenberger products after hiring CommScope's ex-employees. For example, while employed at CommScope, Yang Zhongcao worked on CommScope's twin beam antennas, which are covered by CommScope's '548 patent. Within less than a year after he left CommScope for Rosenberger, Rosenberger was marketing a twin beam antenna that uses CommScope's patented technology.

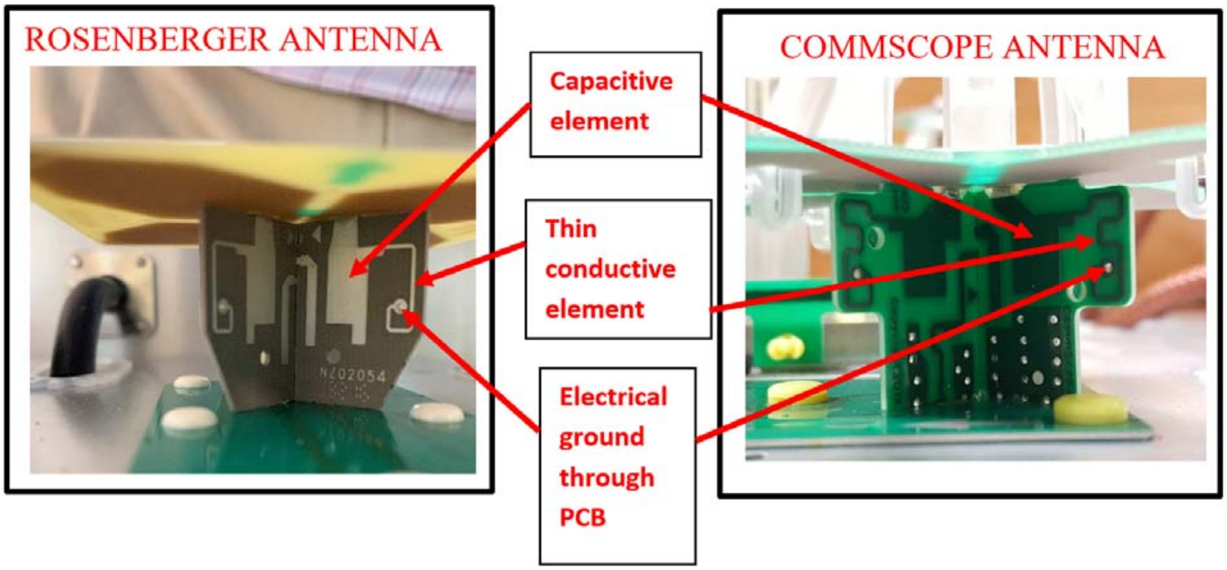
29. Commscope's twin beam antenna model no. R2HH-6533CR5 is an antenna that uses a central array of low frequency radiating elements for generating a beam of low frequency band radiation and an array of high frequency radiating elements that generates two beams of high frequency band radiation. The array of high frequency radiating elements includes rows of three or four elements in a distinctive pattern using rows of three and four radiating elements. A side-by-side comparison of the Rosenberger antenna model no. MB-A64O9X65V-01 (upper photo) with the CommScope twin beam antenna (lower photo) shows that these features have been copied over from CommScope's design to the Rosenberger antenna.



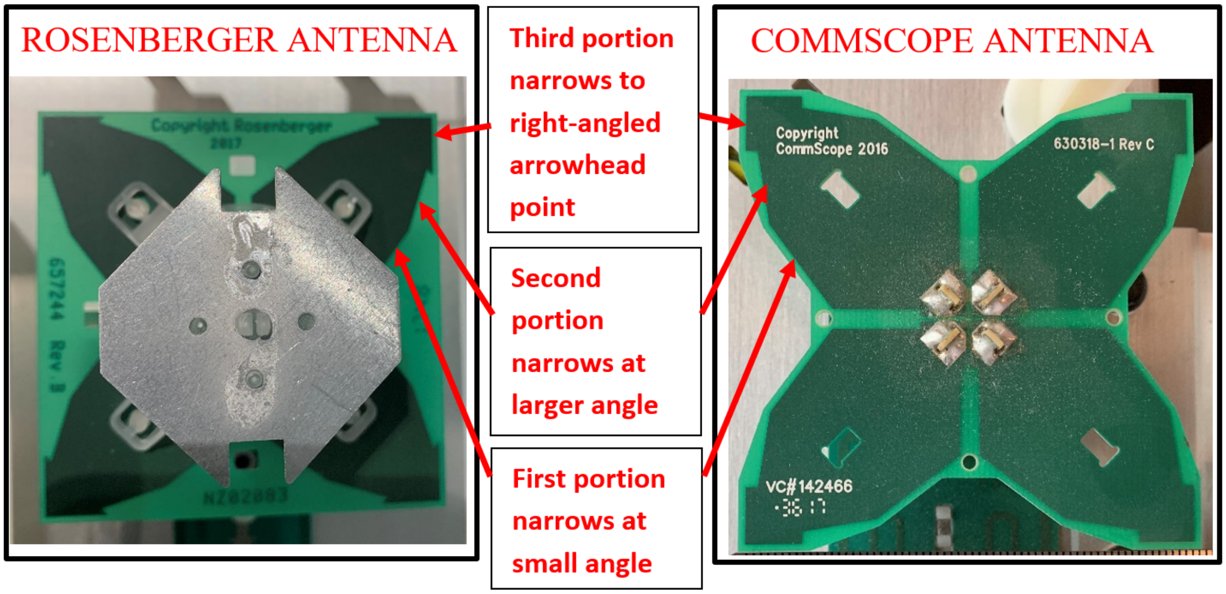
30. A comparison of the low frequency radiating elements of these two antennas shows that the design of the low frequency radiator in the CommScope antenna (right photo), in which the dipole leg is formed of wide conductive segments separated by narrow segments, has been copied over to the Rosenberger antenna (left photo).



31. A comparison of the high frequency radiating elements of these two antennas shows that multiple features have been copied. In both the CommScope and Rosenberger antennas, the high frequency radiating elements are crossed dipoles formed on etched printed circuit board (PCB) sitting atop a stalk made of two interlocking PCBs. The interlocking PCBs are provided with electrical circuitry to allow the radio frequency signal being radiated to reach the dipole. The electrical circuitry on the stalk includes a capacitive element coupled via a thin conductive element to an electrical ground through the PCB. The Rosenberger MB-A64O9X65V-01 antenna (left photo) includes these features, which have been copied from the CommScope antenna (right photo). These features are also replicated in other Rosenberger antennas, including the BA-A5A54O7X65V-01.



Another feature copied by Rosenberger is the shape of the crossed dipole elements on the PCB. CommScope developed a low profile dipole design in which the arms of the crossed dipole are formed in a metallization on a PCB, having a distinctive shape. Each arm extends from a central feed point to a maximum width and then narrows via a three narrowing portions, having linear sides, to a point. The narrowing portions narrow at different angles: the first narrowing portion narrows at a small angle, the second narrowing portion narrows at a larger angle, and the third narrowing portion narrows to a right-angled arrowhead point. The CommScope crossed dipole (right photo) has a 2016 copyright notice. The Rosenberger crossed dipole (left photo) has a 2017 copyright notice.



32. Rosenberger's copied crossed dipole design is used across multiple antennas, including BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01.

33. These similarities between CommScope's and Rosenberger's antennas are not coincidence and show that Rosenberger has copied CommScope's products, including patented features of CommScope's products.

Count 1

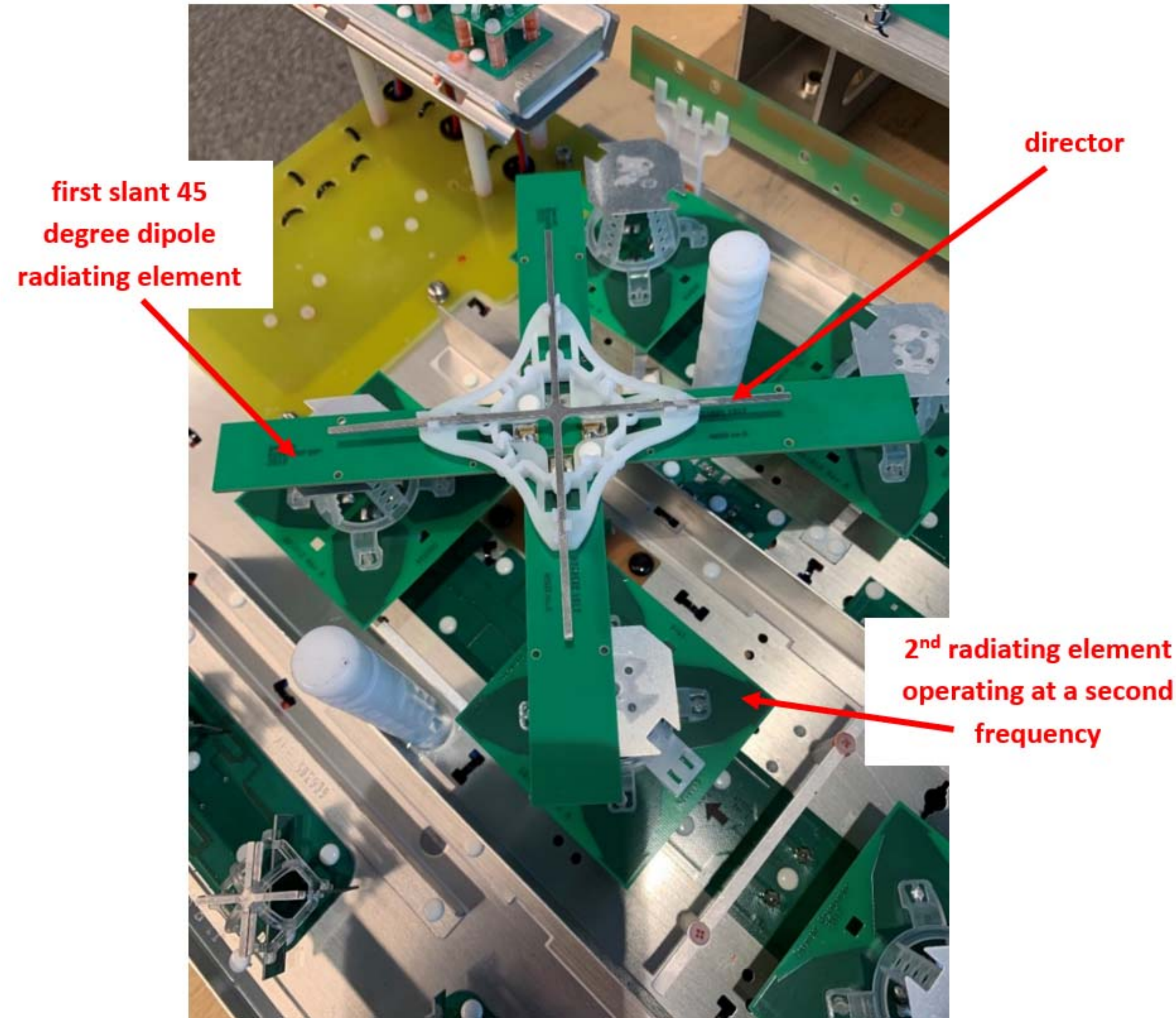
<u>Claim for Patent Infringement of U.S. Patent No. 7358,922</u>

34. CommScope incorporates by reference each of the paragraphs above as it fully states herein.

35. By its activities related to making, using, selling, offering for sale, and/or importing in or into the United States its base station antennas, including for example and without limitation its antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-

AIO3O3T3T3VJX65F-06, and BA-O3O3T3T3VFX65F-06, Rosenberger has infringed at least claim 27 of the ‘922 patent.

36. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06:



37. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

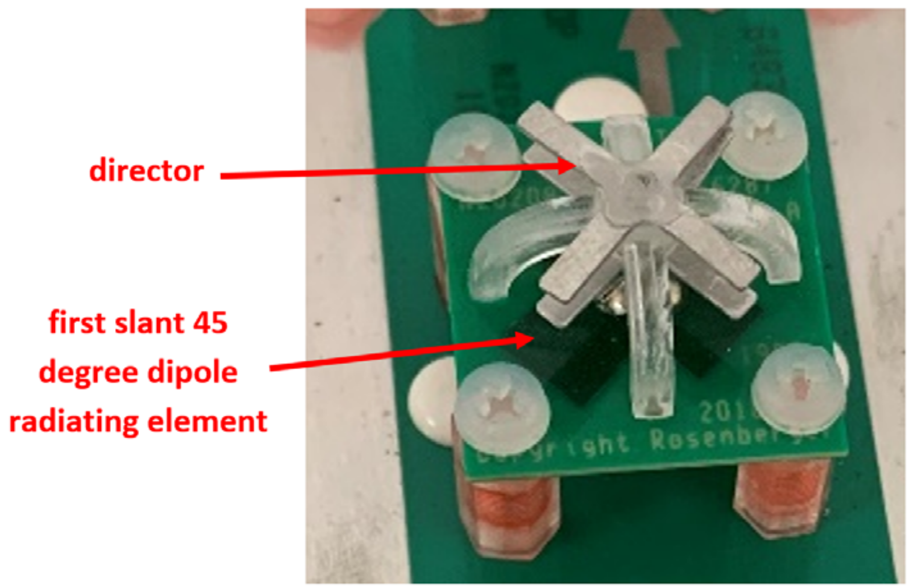
38. Claim 27 of the ‘922 patent is as follows:

27. A dual-band antenna, comprising:

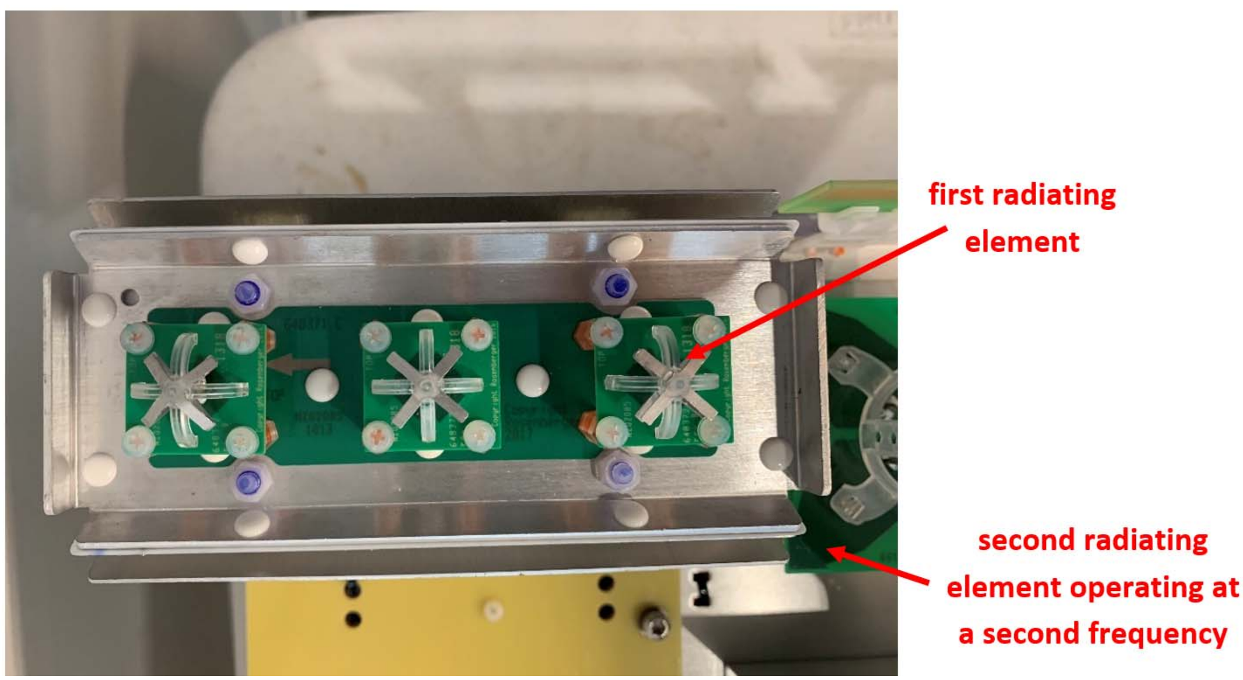
> a first slant 45-degree dipole radiating element adapted to generate a first beam at a first frequency
> a first director disposed proximate the first radiating element adapted to improve a Sector Power Ratio of the beam while maintaining an equivalent 3 dB beamwidth; and
> a second radiating element disposed proximate the first radiating element and adapted to generate a second beam at a second frequency.

39. With respect to claim 27, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 include an antenna comprising a slant 45 degree dipole radiating element adapted to first beam at a first frequency. As indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also comprise a first director disposed proximate the first radiating element. The first director improves the Sector Power Ratio (SPR) of the beam while maintaining an equivalent 3 dB beamwidth. As further indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also comprise a second radiating element disposed proximate the first radiating element, that is adapted to generate a second beam at a second frequency.

40. The radiating element, marked as “slant 45 degree dipole radiating element” in the photograph above, is one of the radiating elements for the antenna’s lowest RF band. Claim 27 can also be read on other radiating elements for other RF bands. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06, including a first radiating element for the antenna’s highest RF band and a director.



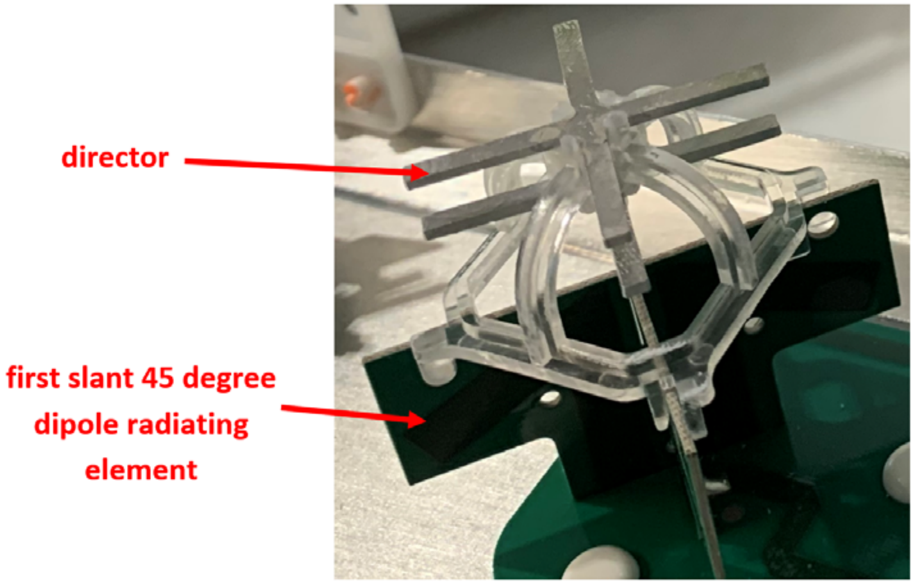
41. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06, showing a second radiating element, adapted to generate a second beam at a second frequency, is proximate the first radiating element.



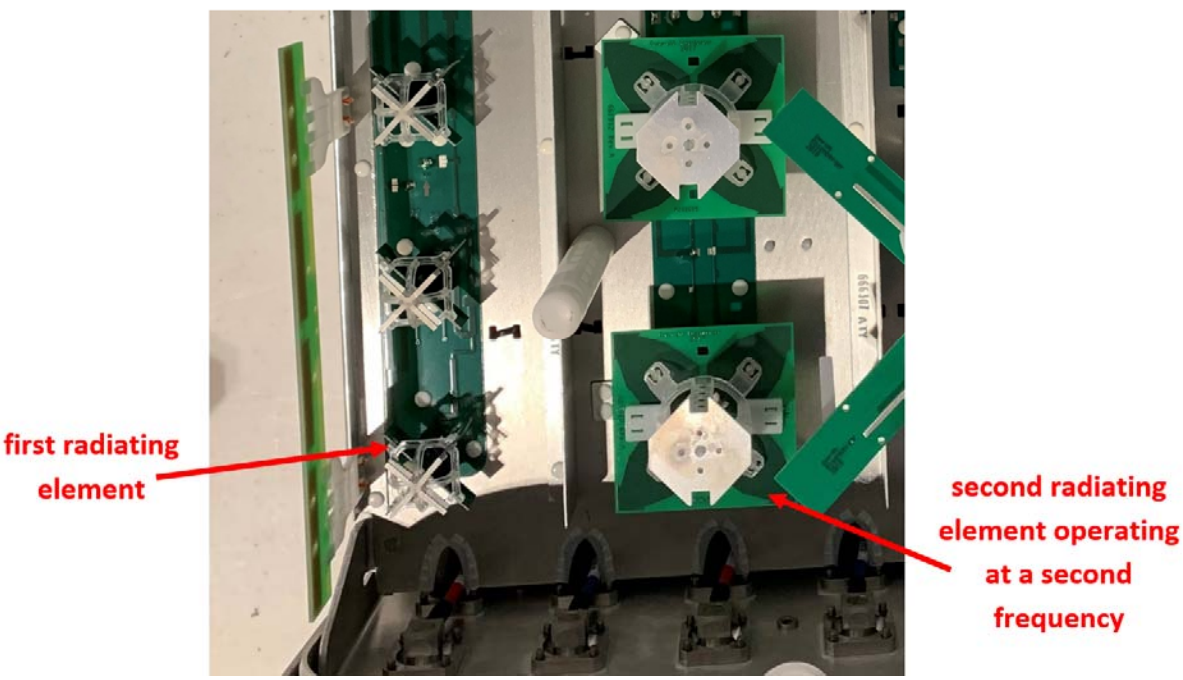
42. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

43. With respect to claim 27, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 include a highest frequency antenna that comprises a first slant 45 degree dipole radiating element adapted to generate a first beam at a first frequency and a first director proximate the first radiating element to improve an SPR of the beam while maintaining an equivalent 3 dB beamwidth. Furthermore, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also include a second radiating element disposed proximate the first radiating element and adapted to generate a second beam at a second frequency.

44. Claim 27 can also be read on the radiating elements of the second highest RF band of Rosenberger's antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06, including a radiating element for the antenna's second highest RF band and a director.



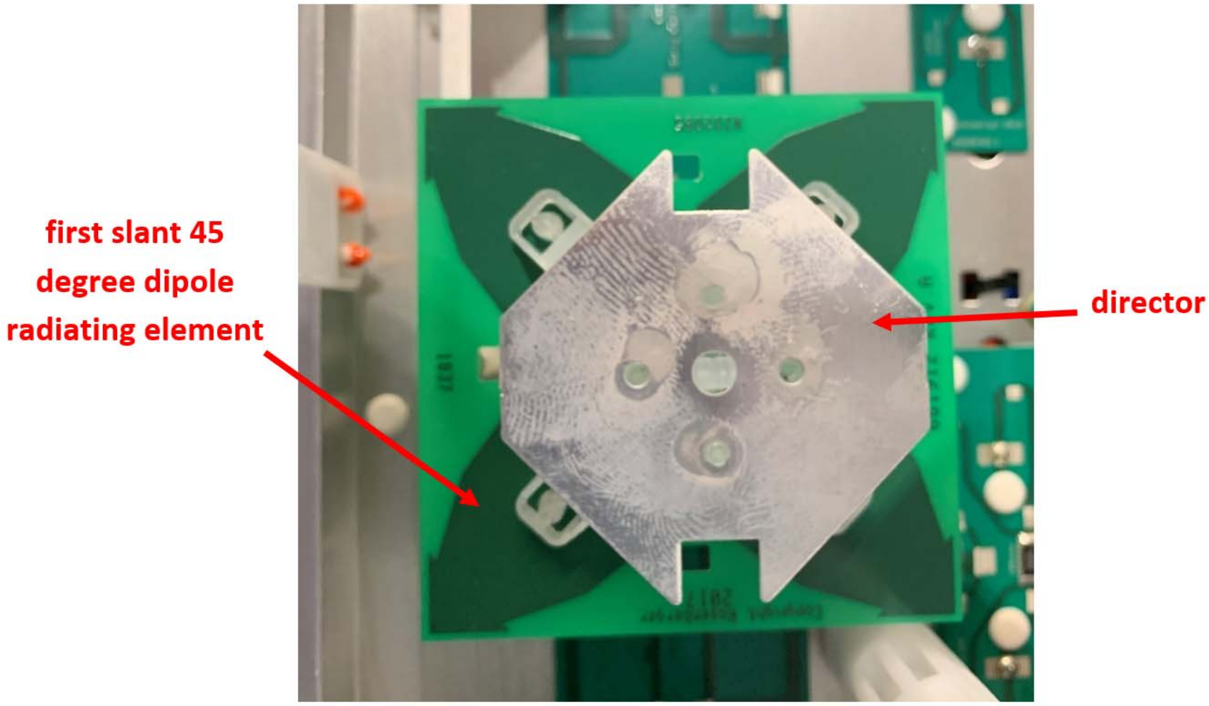
45. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06, showing a second radiator, proximate the first radiator, that is adapted to generate a second beam at a second frequency.



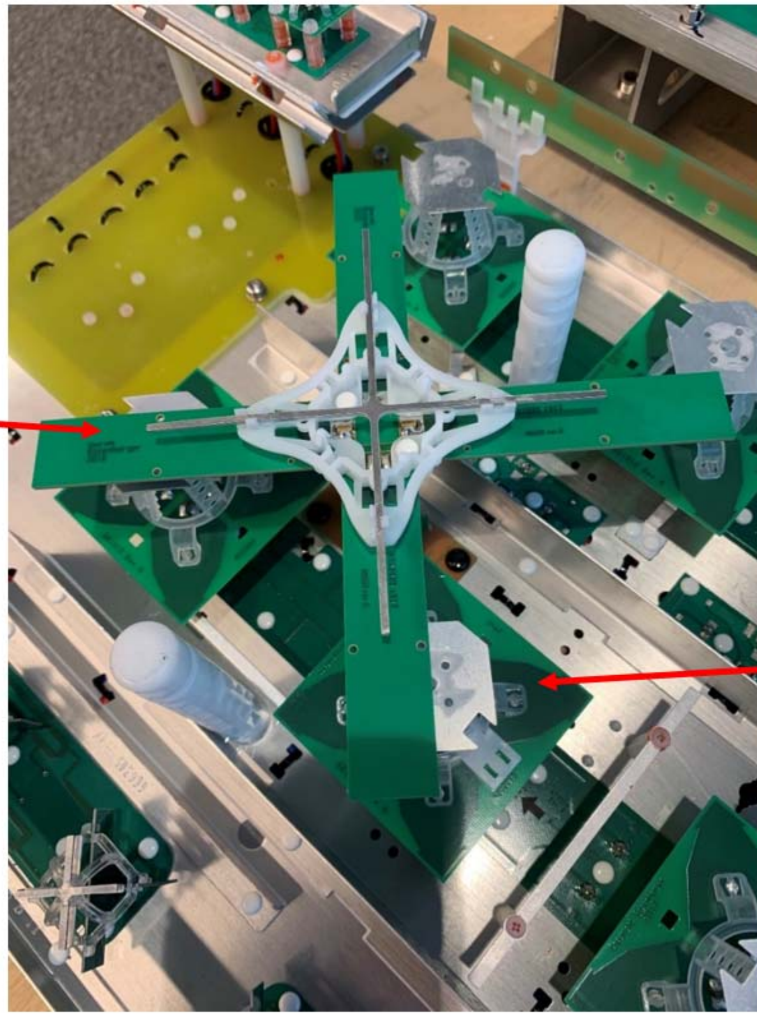
46. Rosenberger antenna model BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

47. With respect to claim 27, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 include a second highest frequency antenna that comprises a first slant 45 degree dipole radiating element adapted to generate a first beam at a first frequency and a first director proximate the first radiating element to improve an SPR of the beam while maintaining an equivalent 3 dB beamwidth. Furthermore, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also include a second radiating element, disposed proximate the first radiating element, that is adapted to generate a second beam at a second frequency.

48. Claim 27 can also be read on the radiating elements of the second lowest RF band of Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 antennas. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06, including a radiating element for the antenna's second lowest RF band and a director.



49. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06, showing a second radiator, proximate the first radiator, that is adapted to generate a second beam at a second frequency.

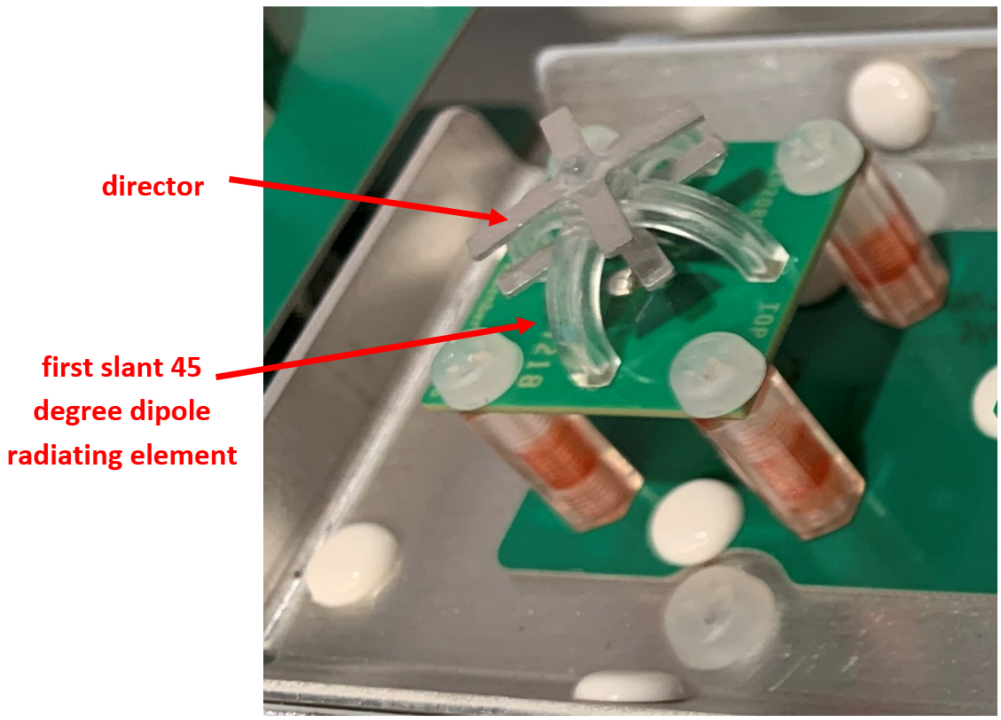


50. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

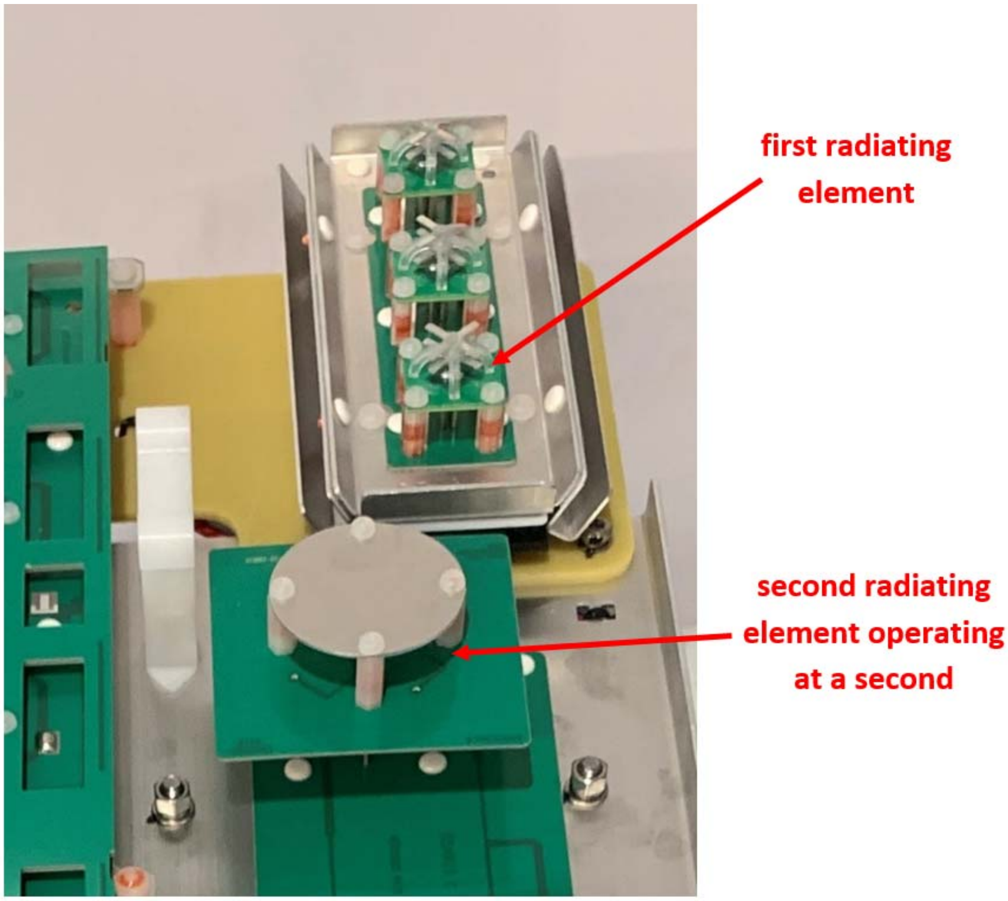
51. With respect to claim 27, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 include a second lowest frequency antenna that comprises a first slant 45 degree dipole radiating element adapted to generate a first beam at a first frequency and a first director proximate the first radiating element to improve an SPR of the beam while maintaining an equivalent 3 dB beamwidth. Furthermore, as indicated above, Rosenberger antenna model nos. BA-

AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also include a second radiating element, disposed proximate the first radiating element, that is adapted to generate a second beam at a second frequency.

52. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06 showing a first slant 45 degree dipole radiating element adapted to generate a first beam at a first frequency, and a first director disposed proximate the first radiating element to improve the SPR while maintaining an equivalent 3 dB beamwidth.



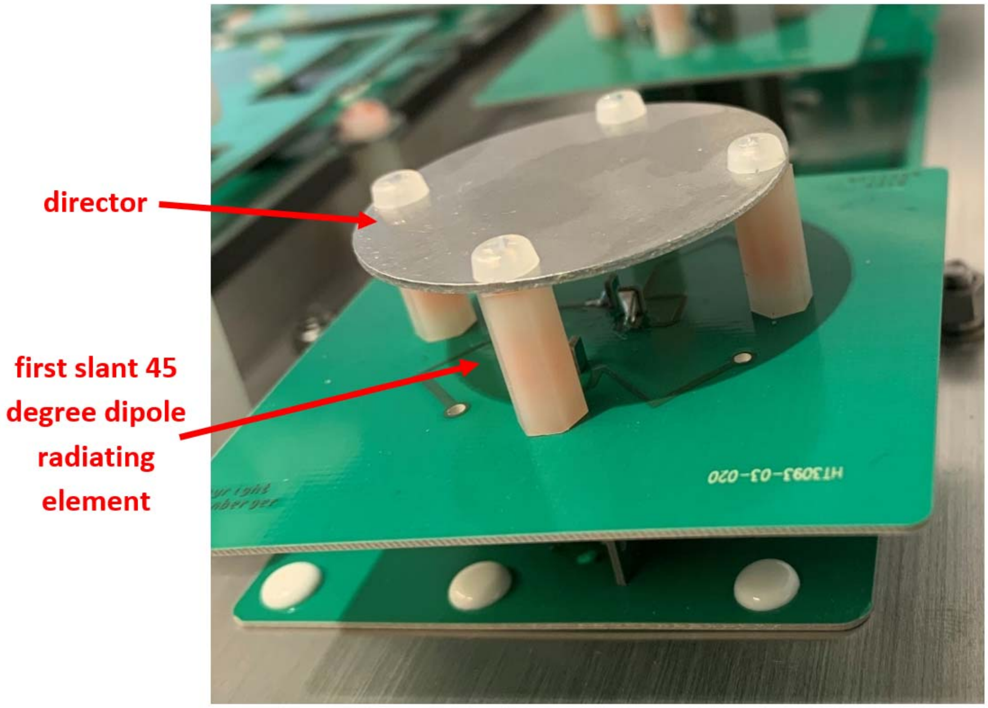
53. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06 showing a second radiating element adapted to generate a second beam at a second frequency and which is disposed proximate the first radiator.



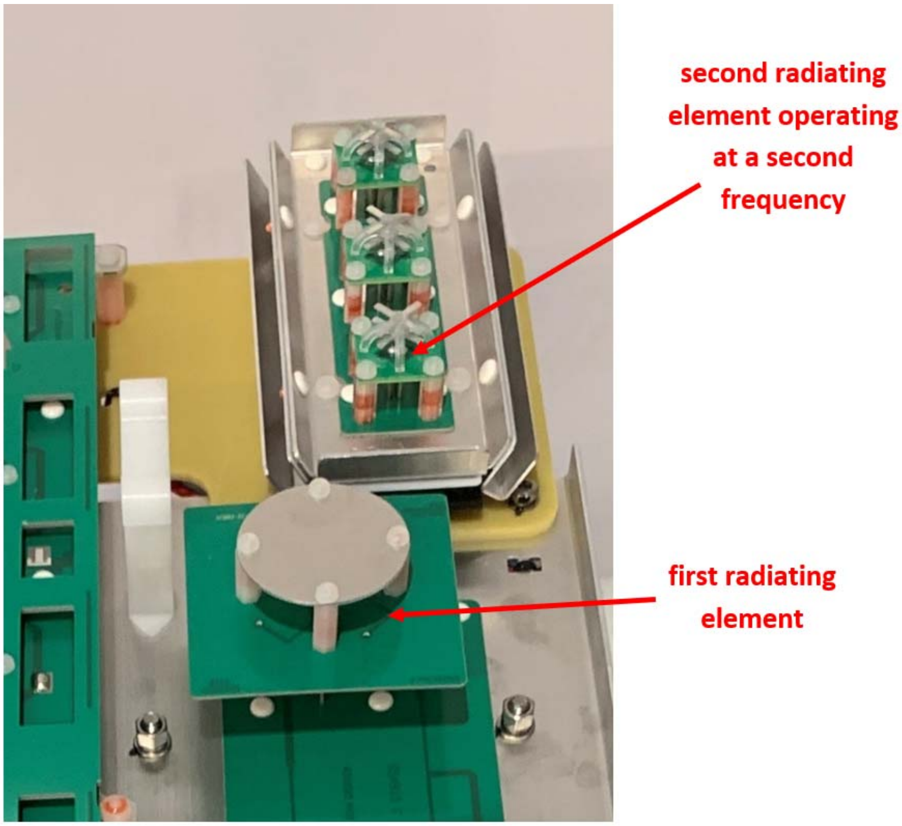
54. With respect to claim 27, as indicated above, Rosenberger model no. BA-O3O3T3T3VFX65F-06 includes an antenna that comprises a first slant 45 degree dipole radiating element adapted to generate a first beam at a first frequency and a first director proximate the first radiating element to improve an SPR of the beam while maintaining an equivalent 3 dB beamwidth. Furthermore, as indicated above, Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06 also includes a second radiating element disposed proximate the first radiating element and adapted to generate a second beam at a second frequency.

55. The radiating element, marked as "first slant 45 degree dipole radiating element" for Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06 above is one of

the radiating elements of the highest RF band. This antenna is capable of operating in three different RF bands, each of which uses its own unique set of radiating elements. Claim 27 can also be read on other radiating elements for the middle of the three RF bands. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06, showing a first radiating element for the antenna's middle RF band, and a director.



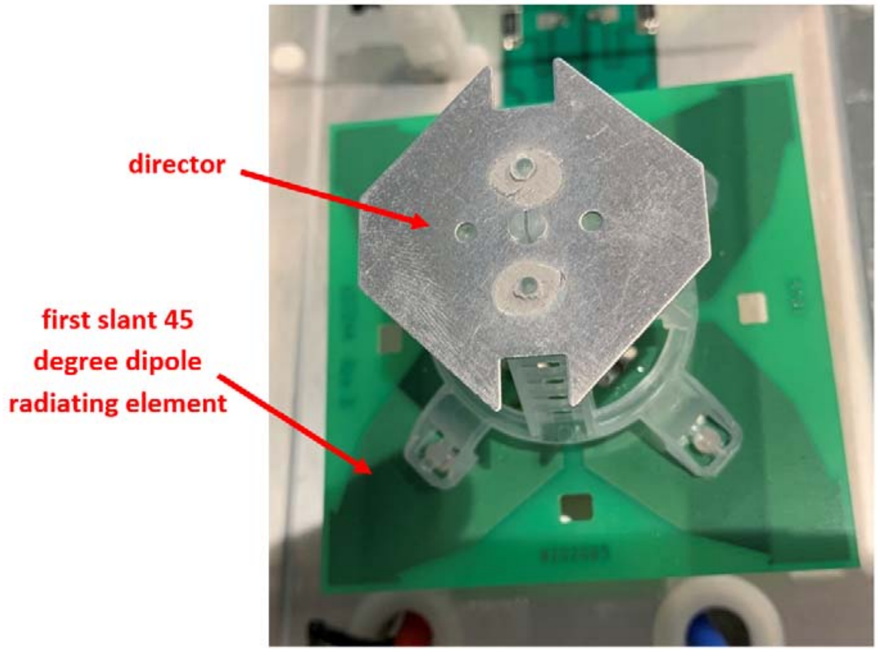
56. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06, showing a second radiator, adapted to generate a beam at a second frequency, disposed proximate the first radiating element.



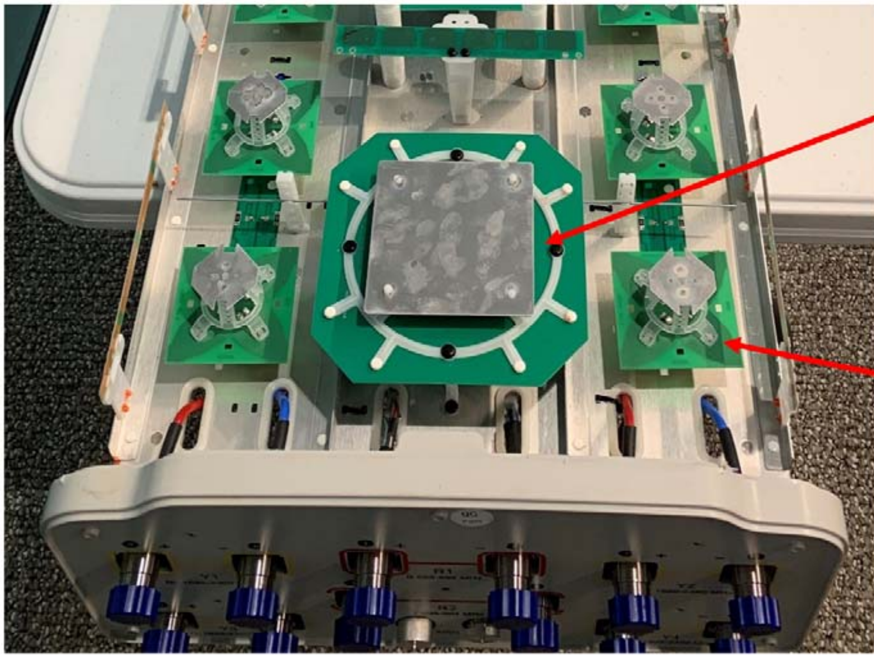
57. With respect to claim 27, as indicated above, Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06 includes an antenna operating in the middle RF band that comprises a first slant 45 degree dipole radiating element adapted to generate a first beam at a first frequency and a first director proximate the first radiating element to improve an SPR of the beam while maintaining an equivalent 3 dB beamwidth. Furthermore, as indicated above, Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06 also includes a second radiating element disposed proximate the first radiating element and adapted to generate a second beam at a second frequency.

58. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-A5A54O7X65V-01 antenna array, showing a first slant 45 degree dipole radiating element adapted to generate a first beam at a first

frequency, and a first director disposed proximate the first radiating element to improve the SPR while maintaining an equivalent 3 dB beamwidth.



59. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-A5A54O7X65V-01, showing a second radiator, adapted to generate a beam at a second frequency, disposed proximate the first radiating element.



60. With respect to claim 27, as indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 includes an antenna that comprises a first slant 45 degree dipole radiating element adapted to generate a first beam at a first frequency and a first director proximate the first radiating element to improve an SPR of the beam while maintaining an equivalent 3 dB beamwidth. Furthermore, as indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 also includes a second radiating element disposed proximate the first radiating element and adapted to generate a second beam at a second frequency.

61. Therefore, Rosenberger directly infringes, literally and under the doctrine of equivalents, claims of the '922 patent including, for example and without limitation, claim 27, through its making, using, selling, offering for sale, and/or importing of, for example and without limitation, its antenna model nos. BA-AIO3O3T3T3VFX65F-06,

BA-AIO3O3T3T3VJX65F-06, BA-O3O3T3T3VFX65F-06, and BA-A5A54O7X65V-01.

62. Rosenberger also indirectly infringes claims of the ‘922 patent, including, for example, and without limitation, claim 27. Operators of Rosenberger's antenna directly infringe at least some claims of the ‘922 patent. At least as of the filing of this complaint, Rosenberger knows its products are especially made or especially adapted for use in an infringement.

63. Rosenberger products include features that are not staple articles of commerce suitable for substantial non-infringing uses. For example, there is no substantial use for these antennas that does not infringe the ‘922 patent. The intended, normal use of Rosenberger antennas results in infringement. Rosenberger products are a material part of the invention of the ‘922 patent.

64. CommScope has been damaged by Rosenberger's infringement of the ‘922 patent and will continue to be damaged in the future unless Rosenberger is enjoined from infringing the ‘922 patent.

65. CommScope has satisfied the notice and/or marking provisions of 35 U.S.C. § 287.

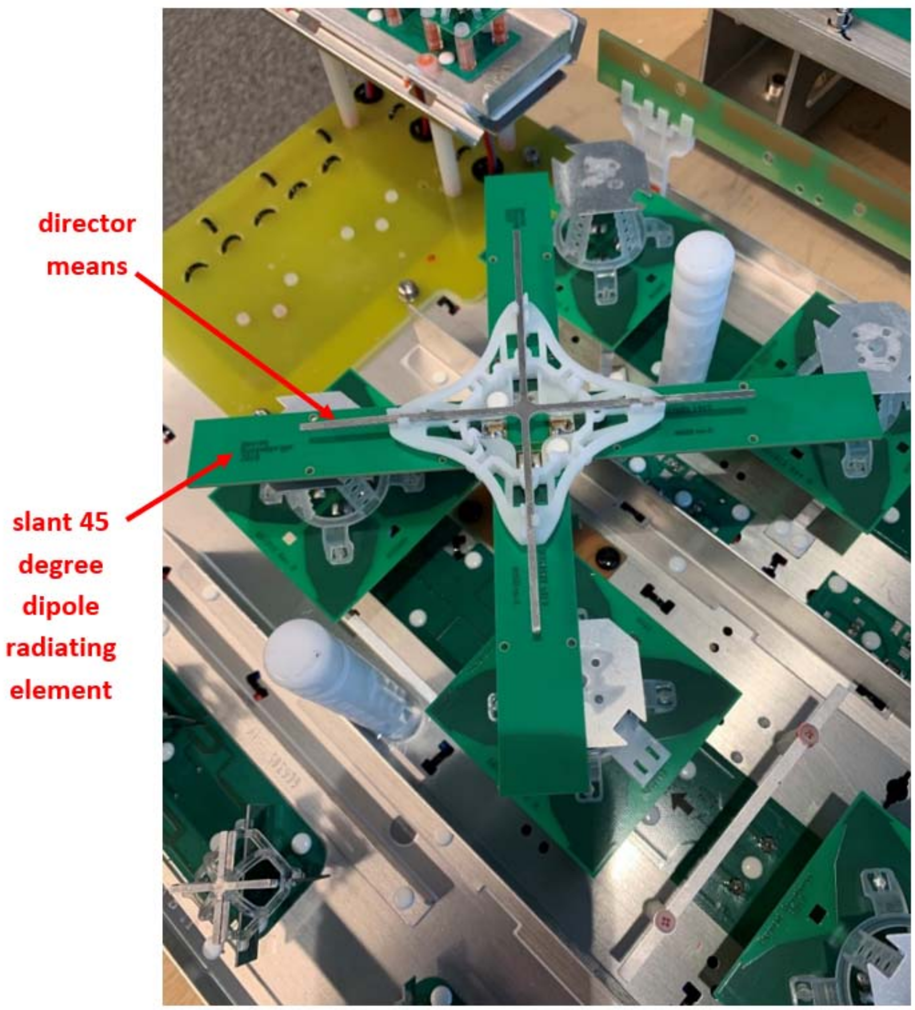
Count 2

Claim for Patent Infringement of U.S. Patent No. 7,535,430

66. CommScope incorporates by reference each of the paragraphs above as if fully stated herein.

67. By its activities related to making, using, selling, offering for sale, and/or importing in or into the United States its base station antennas, including for example and without limitation its antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06, and BA-O3O3T3T3VFX65F-06, Rosenberger has infringed at least claim 20 of the '430 patent.

68. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06:



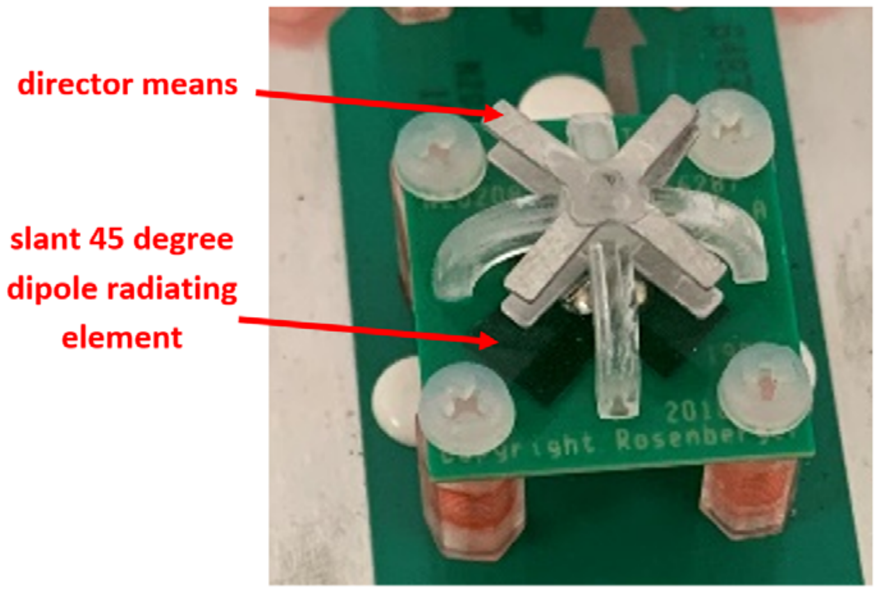
69. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

70. Claim 20 of the '430 patent recites as follows:

> 20. An antenna, comprising:
>
> a slant 45 degree dipole radiating element adapted to generate a beam; and
>
> director means disposed proximate the slant 45 degree dipole radiating element for directing the beam.

71. With respect to claim 20, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 include an antenna comprising a slant 45 degree dipole radiating element adapted to generate a beam. As indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also comprise director means proximate the slant 45 degree dipole radiating element for directing the beam.

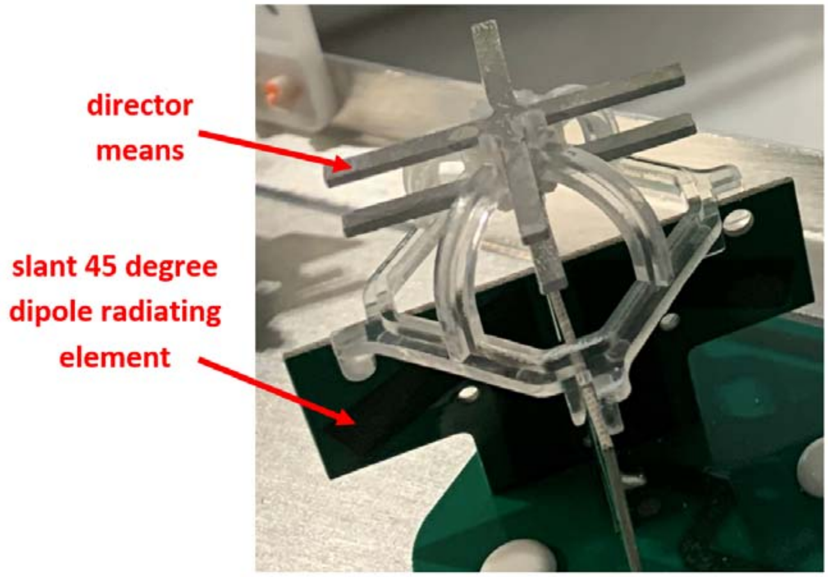
72. The radiating element, marked as "slant 45 degree dipole radiating element" in the photograph above, is one of the radiating elements for the antenna's lowest RF band. Claim 20 can also be read on the radiating elements of the highest RF band of Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06, including a radiating element for the antenna's highest RF band.



73. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

74. With respect to claim 20, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 include a highest frequency antenna that comprises a slant 45 degree dipole radiating element adapted to generate a beam. As indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also comprise director means proximate the slant 45 degree dipole radiating element for directing the beam.

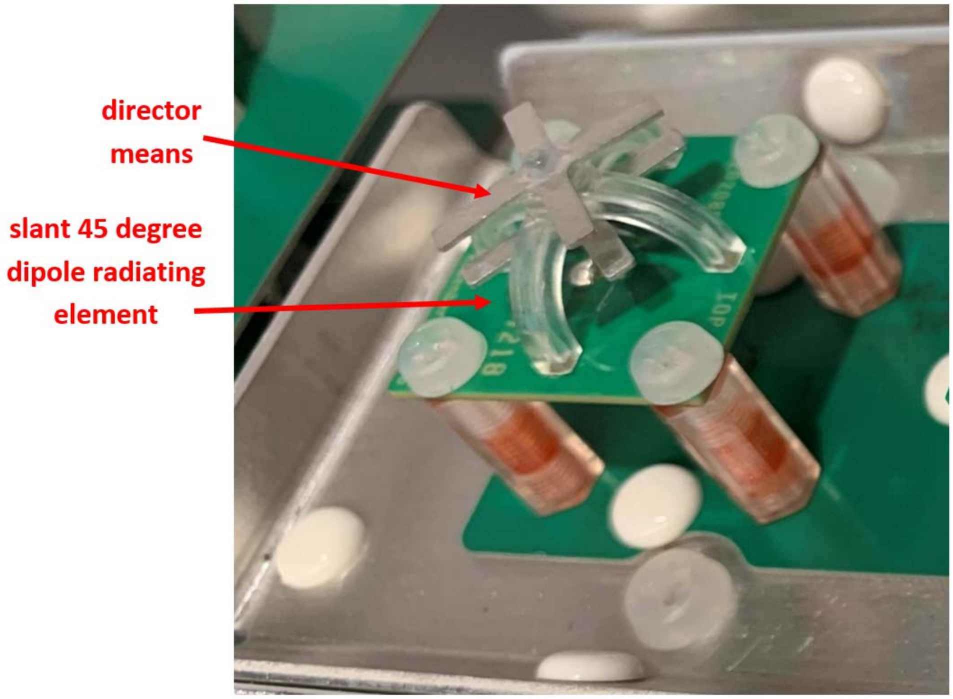
75. Claim 20 can also be read on the radiating elements of the second highest RF band of Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06, including a radiating element for the antenna's second highest RF band.



76. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

77. With respect to claim 20, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 include a second highest frequency antenna that comprises a slant 45 degree dipole radiating element adapted to generate a beam. As indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also comprise director means proximate the slant 45 degree dipole radiating element for directing the beam.

78. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06.



79. With respect to claim 20, as indicated above, Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06 includes an antenna comprising a slant 45 degree dipole radiating element adapted to generate a beam. As indicated above, Rosenberger antenna model no. BA-O3O3T3T3VFX65F-06 also comprises director means disposed proximate the slant 45 degree dipole radiating element for directing the beam.

80. Therefore, Rosenberger directly infringes, literally and under the doctrine of equivalents, claims of the ‘430 patent including, for example and without limitation, claim 20, through its making, using, selling, offering for sale, and/or importing of, for example and without limitation, its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, and BA-O3O3T3T3VFX65F-06.

81. Rosenberger also indirectly infringes claims of the ‘430 patent, including, for example, and without limitation, claim 20. Operators of Rosenberger antennas

directly infringe at least some claims of the '430 patent. At least as of the filing of this complaint, Rosenberger knows its products are especially made or especially adapted for use in an infringement.

82. Rosenberger products include features that are not staple articles of commerce suitable for substantial non-infringing uses. For example, there is no substantial use for the antennas that does not infringe the '430 patent. The intended, normal use of Rosenberger antennas results in infringement. Rosenberger products are a material part of the invention of the '430 patent.

83. CommScope has been damaged by Rosenberger's infringement of the '430 patent and will continue to be damaged in the future unless Rosenberger is enjoined from infringing the '430 patent.

84. CommScope has satisfied the notice and/or marking provisions of 35 U.S.C. § 287.

Count 3

Claim for Patent Infringement of U.S. Patent No. 9,698,486

85. CommScope incorporates by reference each of the paragraphs above as if fully stated herein.

86. By its activities related to making, using, selling, offering for sale, and/or importing in or into the United States its base station antennas, including for example and without limitation its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01, Rosenberger has infringed at least claim 14 of the '486 patent.

87. Claim 14 of the ‘486 patent is as follows:

14. A higher band radiating element for a multiband antenna having at least higher band elements and lower band elements, comprising:

a first dipole arm;

a second dipole arm;

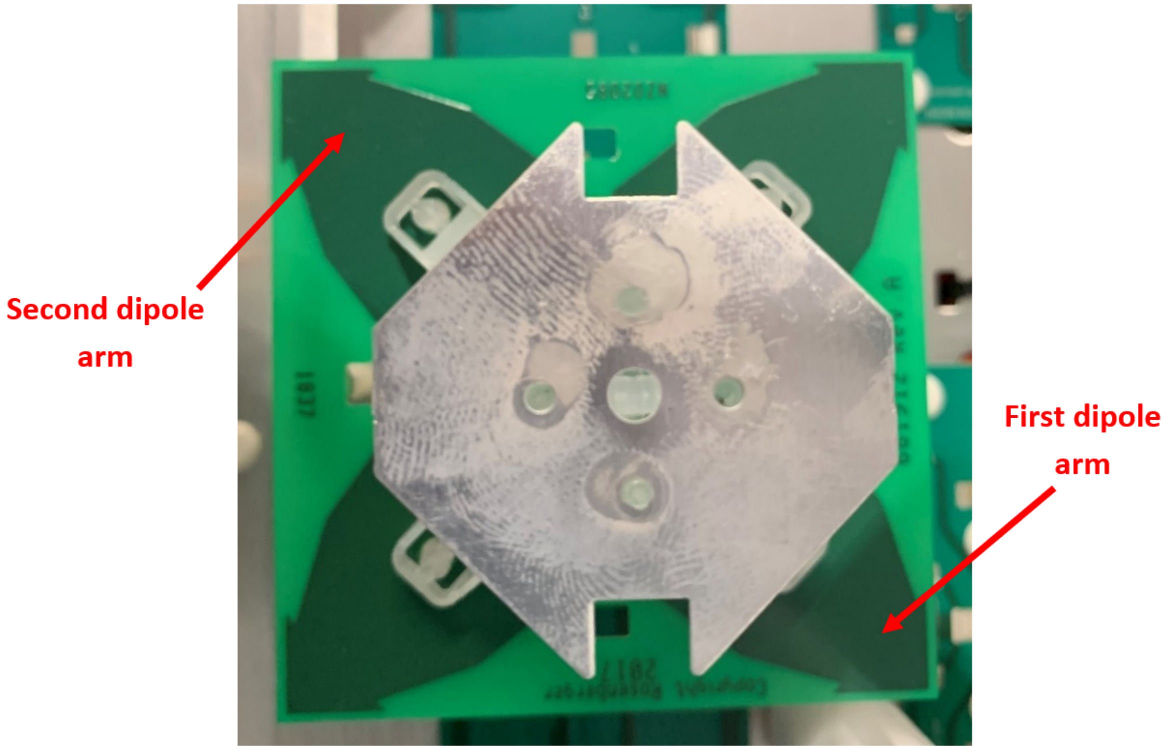
a feedboard having a balun and first and second matching circuits coupled to the balun, the first matching circuit being coupled to the first dipole arm and the second matching circuit being coupled to the second dipole arm,

the first matching circuit comprising a first stalk that is coupled to the balun and a first capacitor coupled between the first stalk and the first dipole arm, and

the second matching circuit comprising a second stalk that is coupled to the balun and a second capacitor coupled between the second stalk and the second dipole arm,

wherein the first matching circuit further comprises a common mode tuning circuit that provides a direct current path from a first node that is between the first capacitor and the first dipole arm to ground.

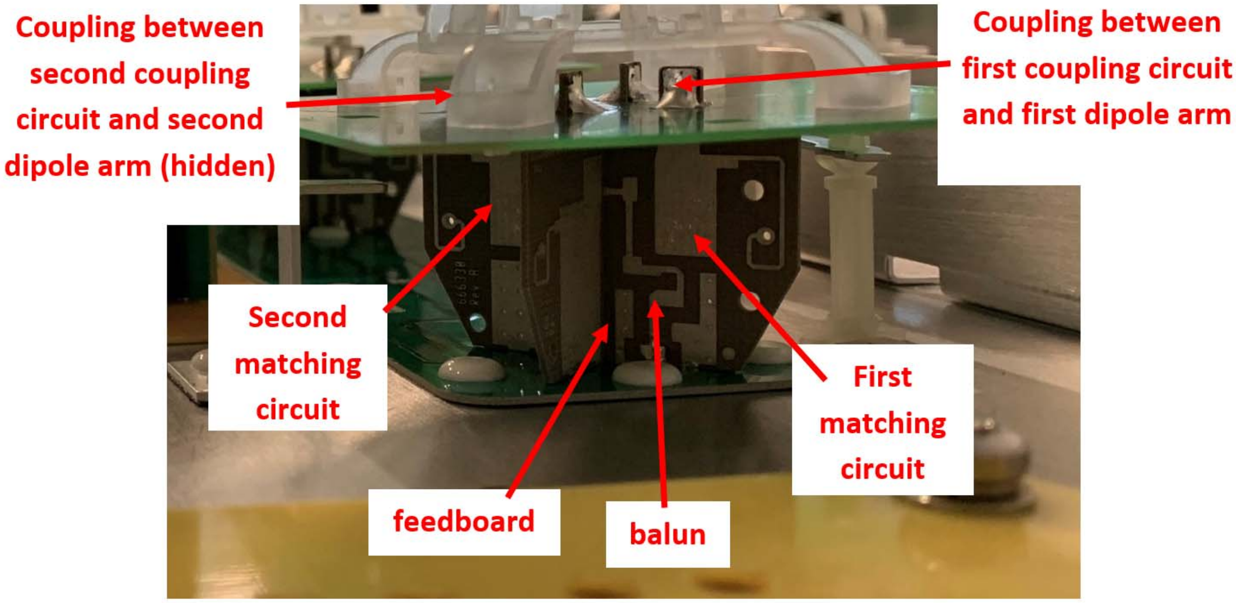
88. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06:



89. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

90. With respect to claim 14, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 are antennas comprising a higher band radiating element that comprises a first dipole arm and a second dipole arm.

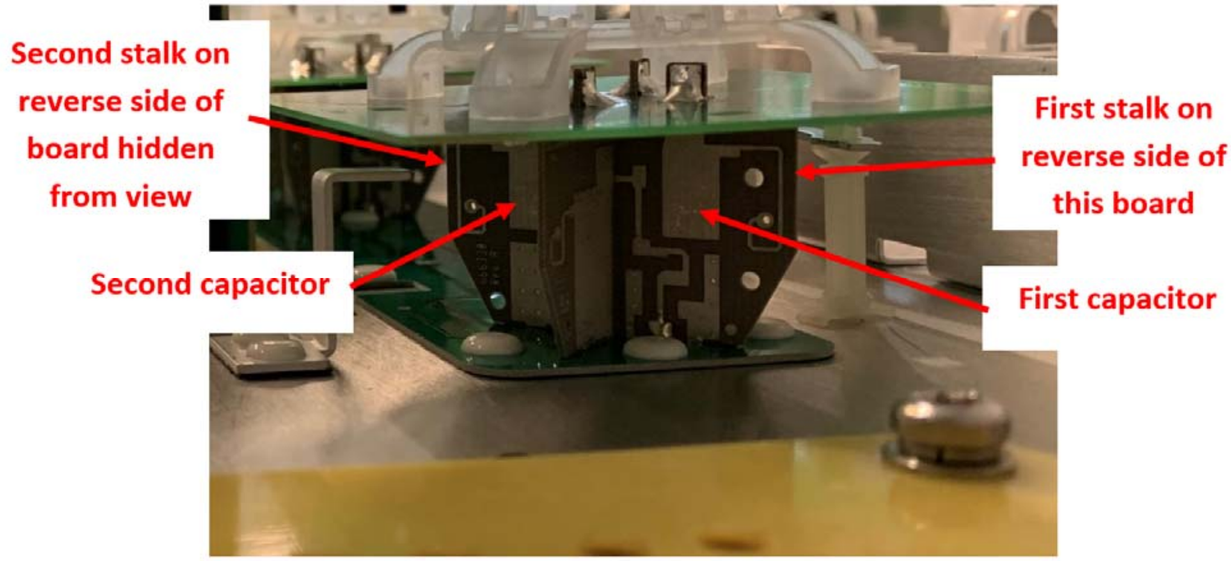
91. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06:



92. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

93. With respect to claim 14, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 comprise a feedboard having a balun and first and second matching circuits coupled to the balun, the first matching circuit being coupled to the first dipole arm and the second matching circuit being coupled to the second dipole arm.

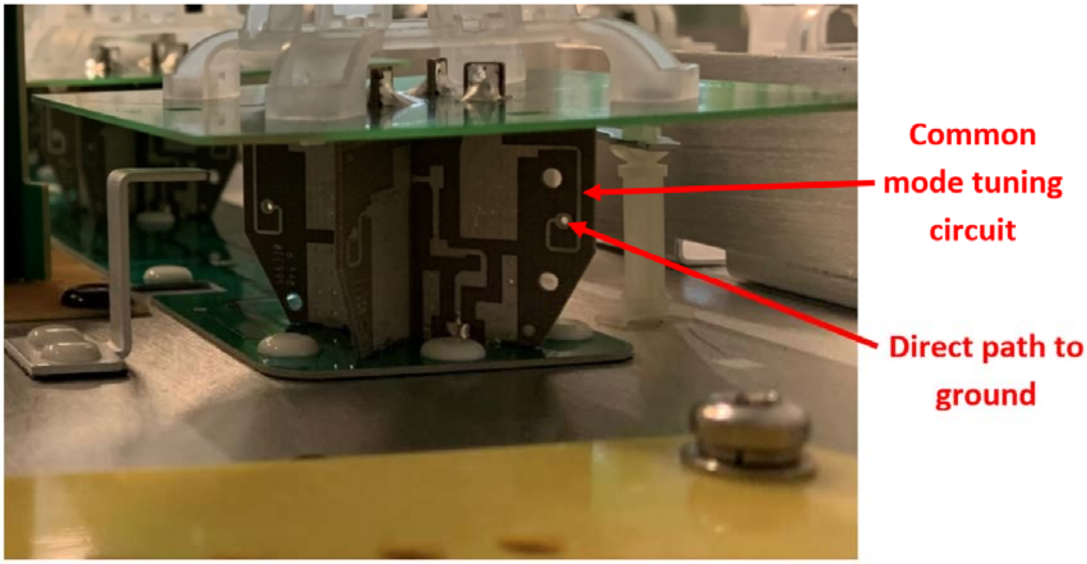
94. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06:



95. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

96. With respect to claim 14, as indicated above, in Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 the first matching circuit comprises a first stalk that is coupled to the balun and a first capacitor coupled between the first stalk and the first dipole arm, and the second matching circuit comprising a second stalk that is coupled to the balun and a second capacitor coupled between the second stalk and the second dipole arm.

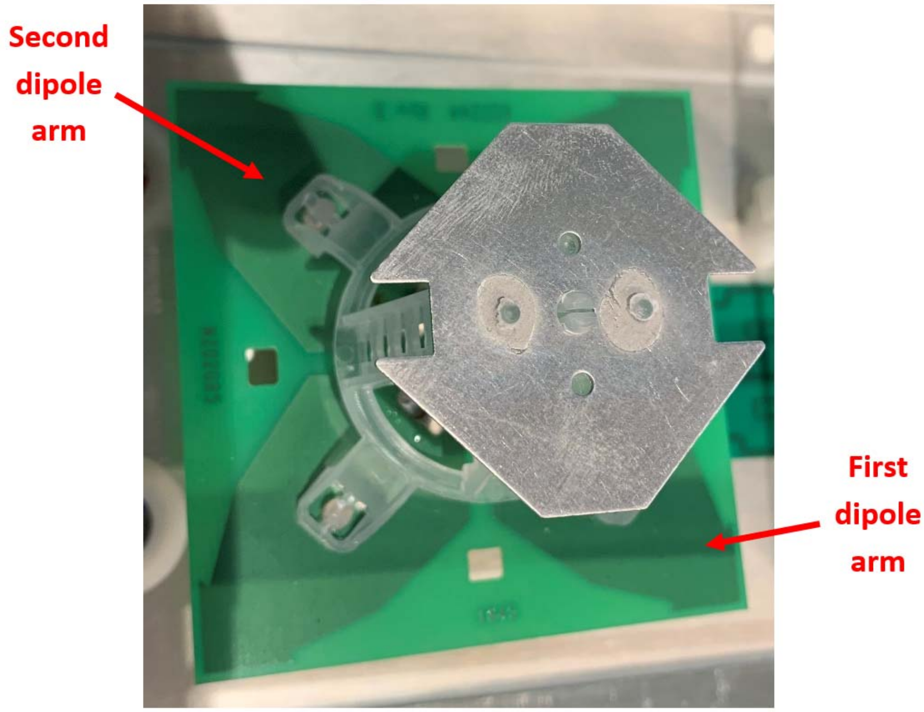
97. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06:



98. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those shown above.

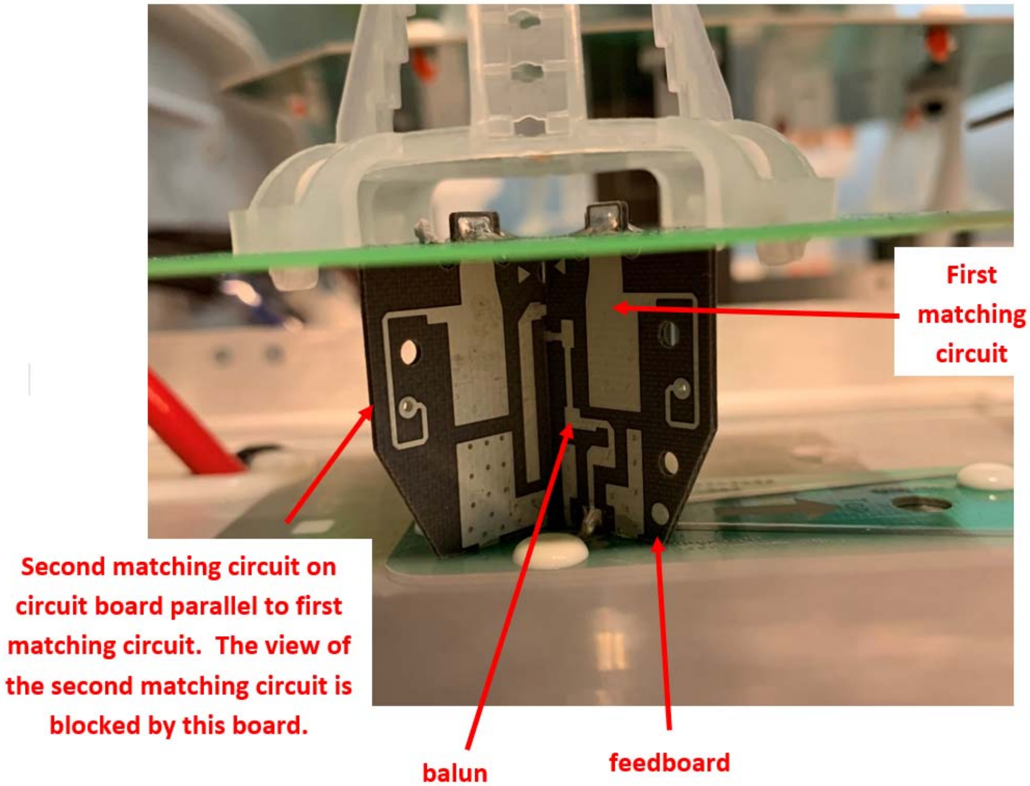
99. As indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 also comprise a common mode tuning circuit that provides a direct current path from a first node that is between the first capacitor and the first dipole to ground.

100. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-A5A54O7X65V-01:



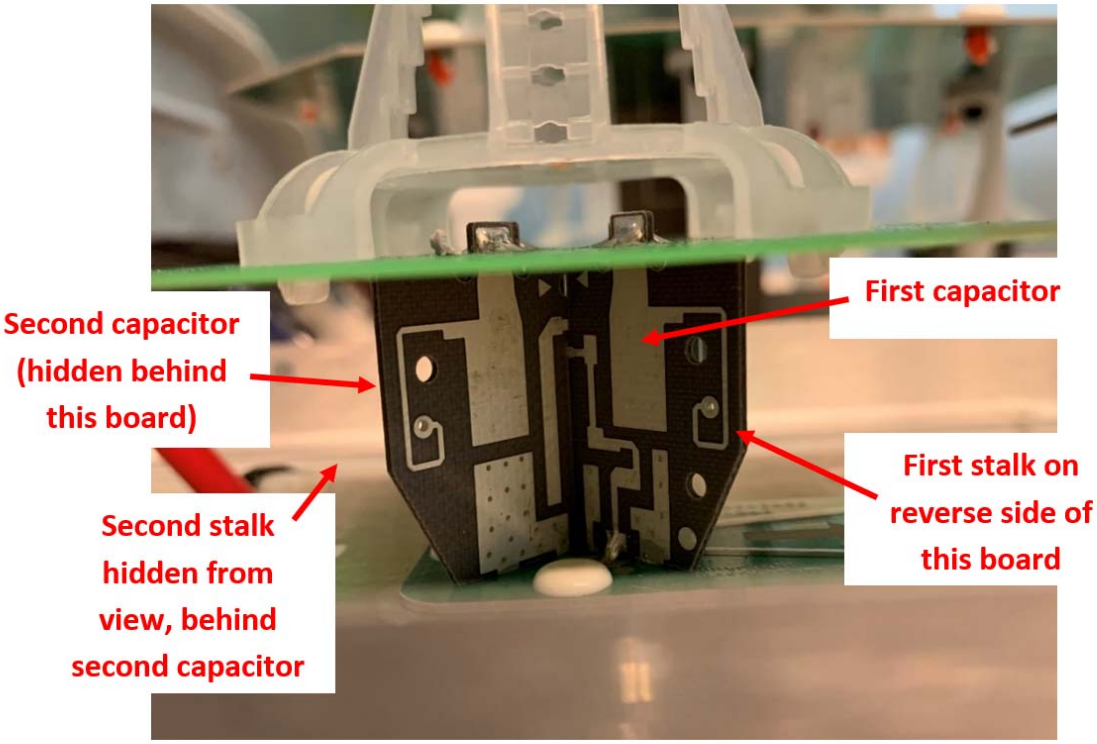
101. With respect to claim 14, as indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 is an antenna comprising a higher band radiating element that comprises a first dipole arm and a second dipole arm.

102. Shown below is another annotated photograph of the same interior component of Rosenberger antenna model no. BA-A5A54O7X65V-01:



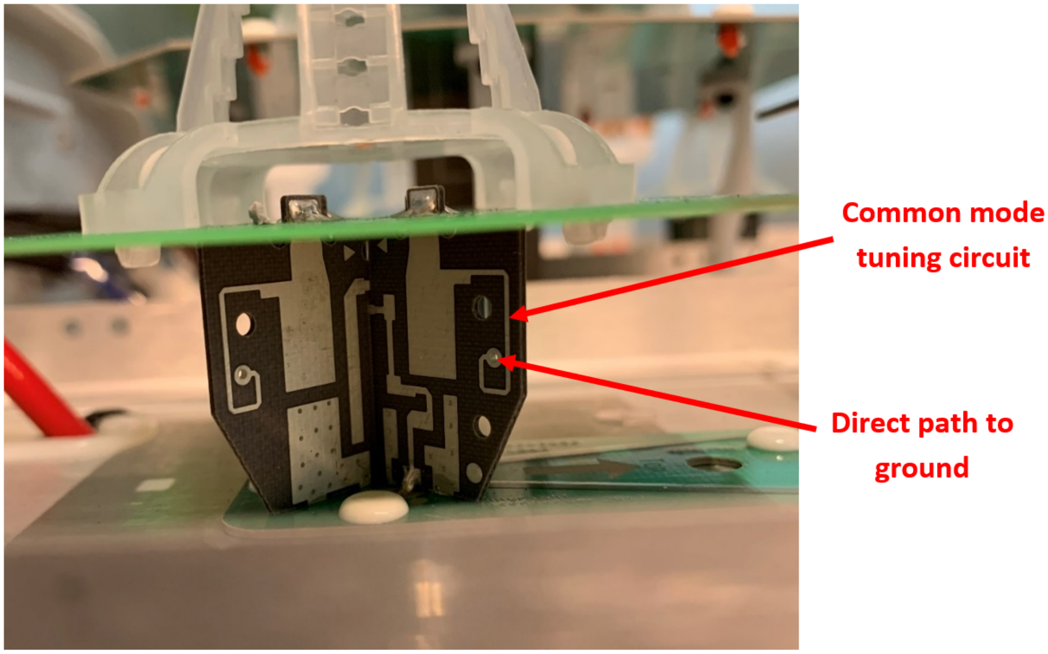
103. As indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 comprises a feedboard having a balun and first and second matching circuits coupled to the balun, the first matching circuit being coupled to the first dipole arm and the second matching circuit being coupled to the second dipole arm.

104. Shown below is another annotated photograph of the same interior component of Rosenberger antenna model no. BA-A5A54O7X65V-01:



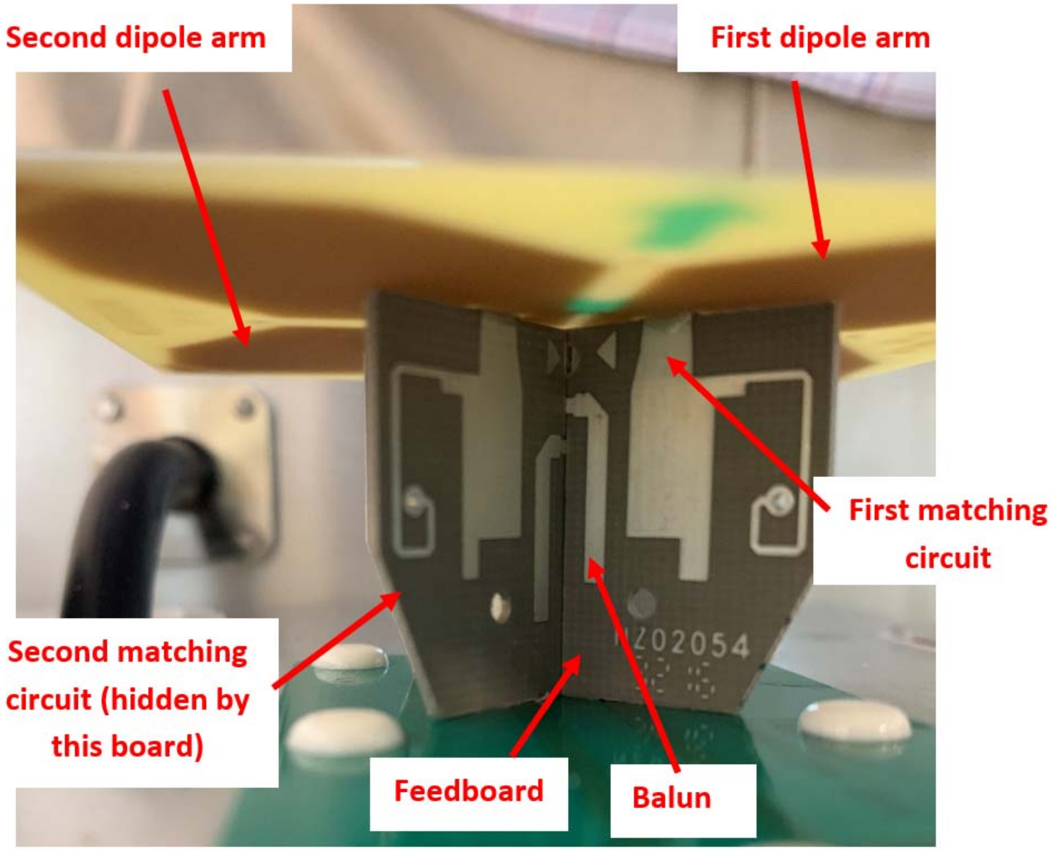
105. As indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-has the first matching circuit comprising a first stalk that is coupled to the balun and a first capacitor coupled between the first stalk and the first dipole arm, and the second matching circuit comprising a second stalk that is coupled to the balun and a second capacitor coupled between the second stalk and the second dipole arm.

106. Shown below is another annotated photograph of the same interior component of Rosenberger antenna model no. BA-A5A54O7X65V-01.



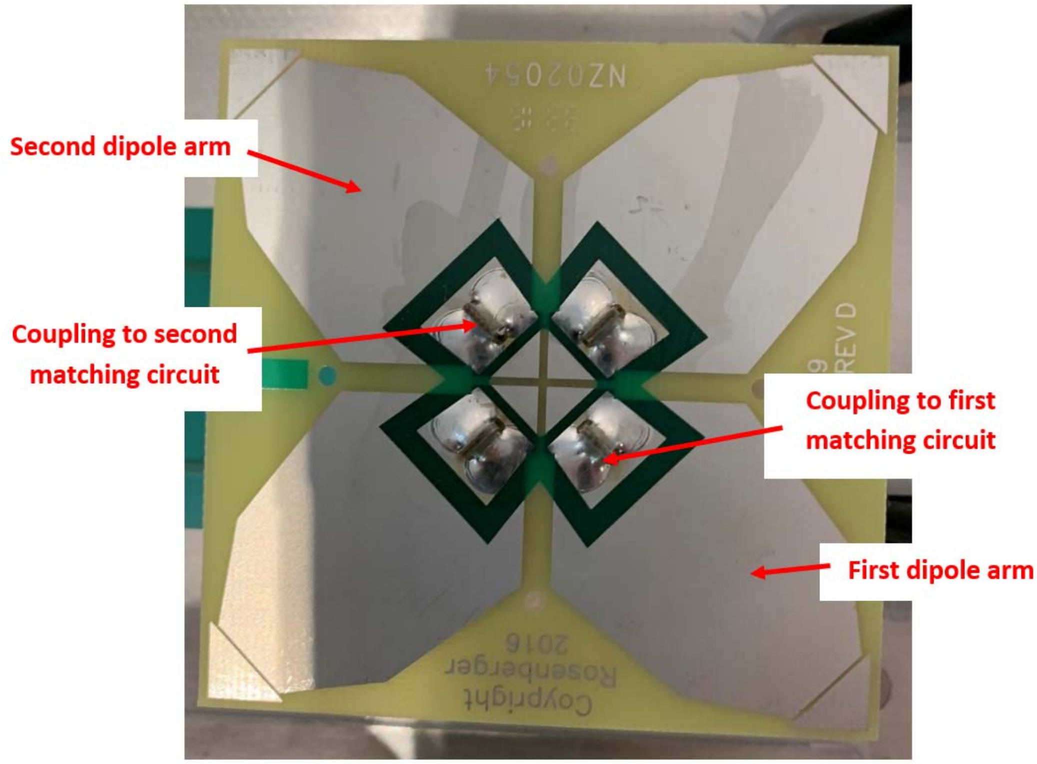
107. As indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 also comprises a common mode tuning circuit that provides a direct current path from a first node that is between the first capacitor and the first dipole to ground.

108. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. MB-A64O9X65V-01.



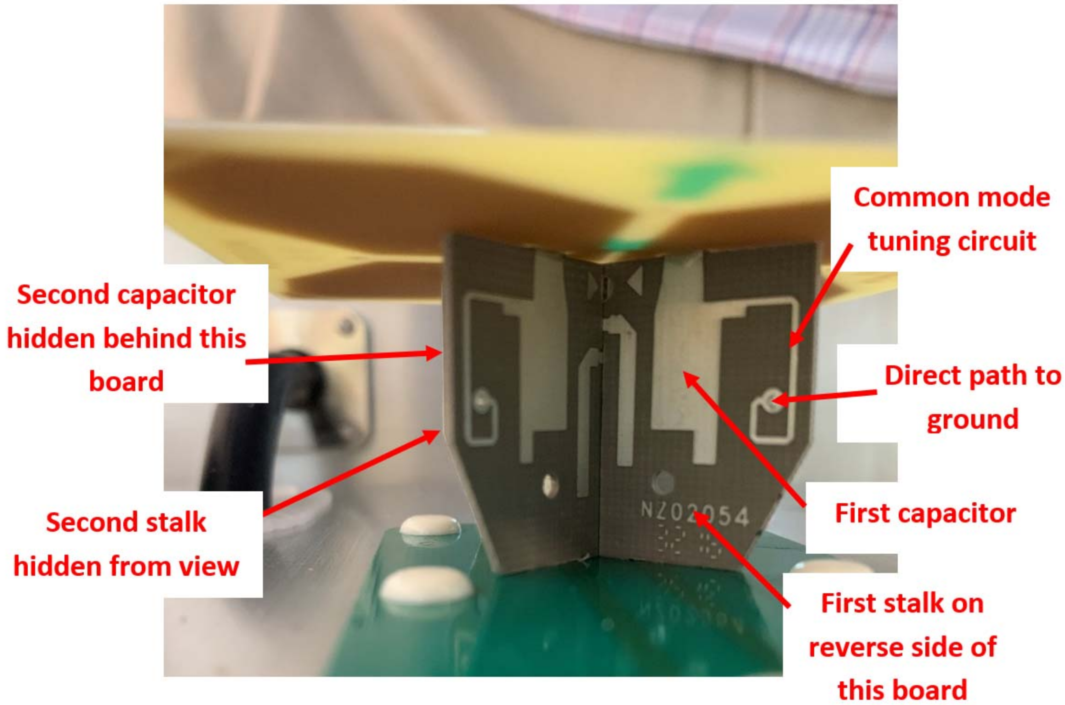
109. With respect to claim 14, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 is an antenna comprising a higher band radiating element that comprises a first dipole arm and a second dipole arm and comprises a feedboard having a balun and first and second matching circuits coupled to the balun,

110. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. MB-A64O9X65V-01.



111. With respect to claim 14, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 includes the first matching circuit being coupled to the first dipole arm and the second matching circuit being coupled to the second dipole arm.

112. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. MB-A64O9X65V-01.



113. With respect to claim 14, as indicated above, in Rosenberger antenna model no. MB-A64O9X65V-01 the first matching circuit comprising a first stalk that is coupled to the balun and a first capacitor coupled between the first stalk and the first dipole arm, and the second matching circuit comprising a second stalk that is coupled to the balun and a second capacitor coupled between the second stalk and the second dipole arm. Furthermore, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 also comprises a common mode tuning circuit that provides a direct current path from a first node that is between the first capacitor and the first dipole to ground.

114. Therefore, Rosenberger directly infringes, literally and under the doctrine of equivalents, claims of the ‘486 patent, including, for example, and without limitation, claim 14, through its making, using, selling, offering for sale, and/or importing of, for

example and without limitation, its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01.

115. Rosenberger also indirectly infringes claims of the ‘486 patent, including, for example, and without limitation, claim 14. Operators of Rosenberger antennas directly infringe at least some claims of the ‘486 patent. At least as of the filing of this complaint, Rosenberger knows its products are especially made or especially adapted for use in an infringement.

116. Rosenberger products include features that are not staple articles of commerce suitable for substantial non-infringing uses. For example, there is no substantial use for the antennas that does not infringe the ‘486 patent. The intended, normal use of Rosenberger antennas results in infringement. Rosenberger products are a material part of the invention of the ‘486 patent.

117. CommScope has been damaged by Rosenberger’s infringement of the ‘486 patent and will continue to be damaged in the future unless Rosenberger is enjoined from infringing the ‘486 patent.

118. CommScope has satisfied the notice and/or marking provisions of 35 U.S.C. § 287.

<u>Count 4</u>

Claim for Patent Infringement of U.S. Patent No. 9,831,548

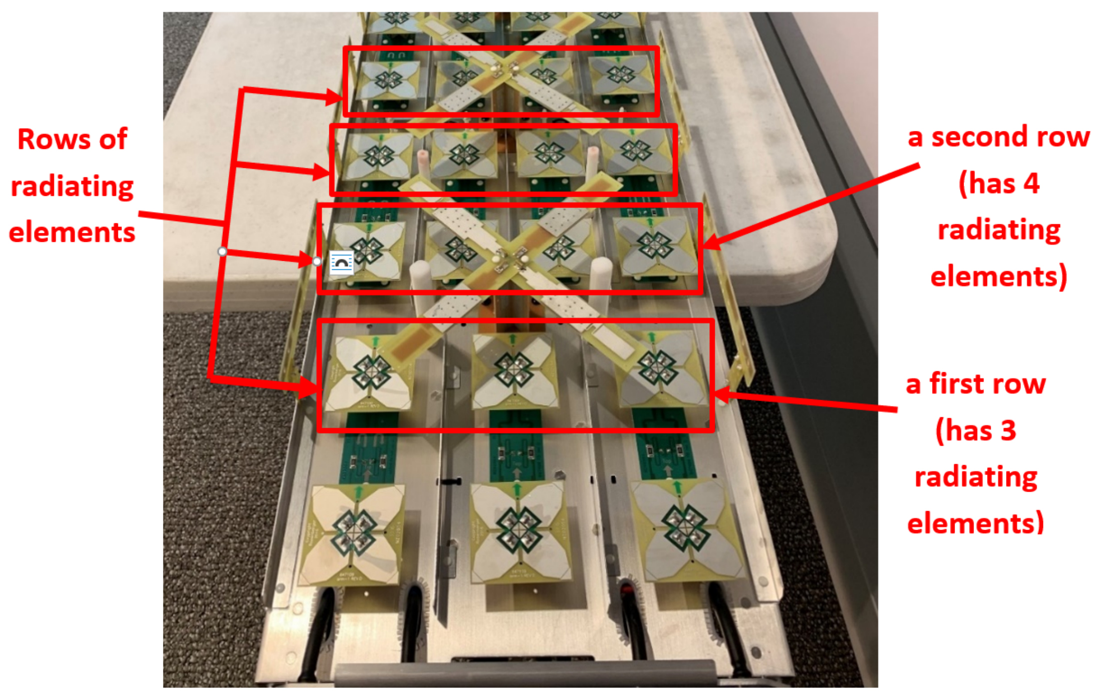
119. CommScope incorporates by reference each of the paragraphs above as if fully stated herein.

120. By its activities related to making, using, selling, offering for sale, and/or importing in or into the United States its base station antennas, including for example and without limitation its antenna model no. MB-A64O9X65V-01, Rosenberger has infringed at least claim 1 of the '548 patent.

121. Claim 1 of the '548 patent recites:

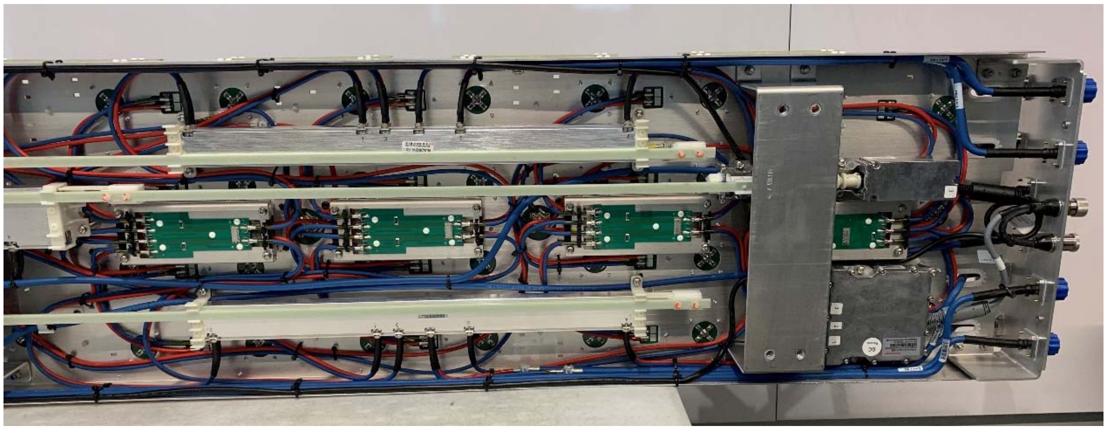
> 1. A multi-beam cellular communication antenna, comprising:
>
> an antenna array having a plurality of rows of radiating elements, wherein a first of the rows includes at least two radiating elements and a second of the rows includes at least three radiating elements and has a different number of radiating elements than the first of the rows; and
>
> an antenna feed network that is configured to couple at least a first input signal and a second input signal to all of the radiating elements of the antenna array.

122. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. MB-A64O9X65V-01:



123. With respect to claim 1, as indicated above, Rosenberger model no. MB-A64O9X65V-01 is a multi-beam cellular communication antenna that includes an antenna array having a plurality of rows of radiating elements. As indicated above, in Rosenberger antenna model no. MB-A64O9X65V-01 a first of the rows includes at least two radiating elements (indicated as having three elements in photo above), and a second of the rows includes at least three radiating elements and has a different number of radiating elements than the first of the rows (indicated as having four elements in the photo above).

124. Shown below is another photograph of interior components of Rosenberger antenna model no. MB-A64O9X65V-01, showing feed network components generally arranged on the underside of the reflector.



125. With respect to claim 1, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 also comprises a feed network that is configured to couple at least a

first input signal and a second input signal to all of the radiating elements of the antenna array.

126. Therefore, Rosenberger directly infringes, literally and under the doctrine of equivalents, claims of the '548 patent, including, for example, and without limitation, claim 1, through its making, using, selling, offering for sale, and/or importing of, for example and without limitation, its antenna model no. MB-A64O9X65V-01.

127. Rosenberger also indirectly infringes claims of the '548 patent, including, for example, and without limitation, claim 1. Operators of Rosenberger antennas directly infringe at least some claims of the '548 patent. Upon information and belief, at least as of the filing of this complaint, Rosenberger knows its products are especially made or especially adapted for use in an infringement.

128. Rosenberger products include features that are not staple articles of commerce suitable for substantial non-infringing uses. For example, there is no substantial use for the antennas that does not infringe the '548 patent. The intended, normal use of Rosenberger antennas results in infringement. Rosenberger products are a material part of the invention of the '548 patent.

129. CommScope has been damaged by Rosenberger's infringement of the '548 patent and will continue to be damaged in the future unless Rosenberger is enjoined from infringing the '548 patent.

130. CommScope has satisfied the notice and/or marking provisions of 35 U.S.C. § 287.

Count 5

Claim for Patent Infringement of U.S. Patent No. 10,439,285

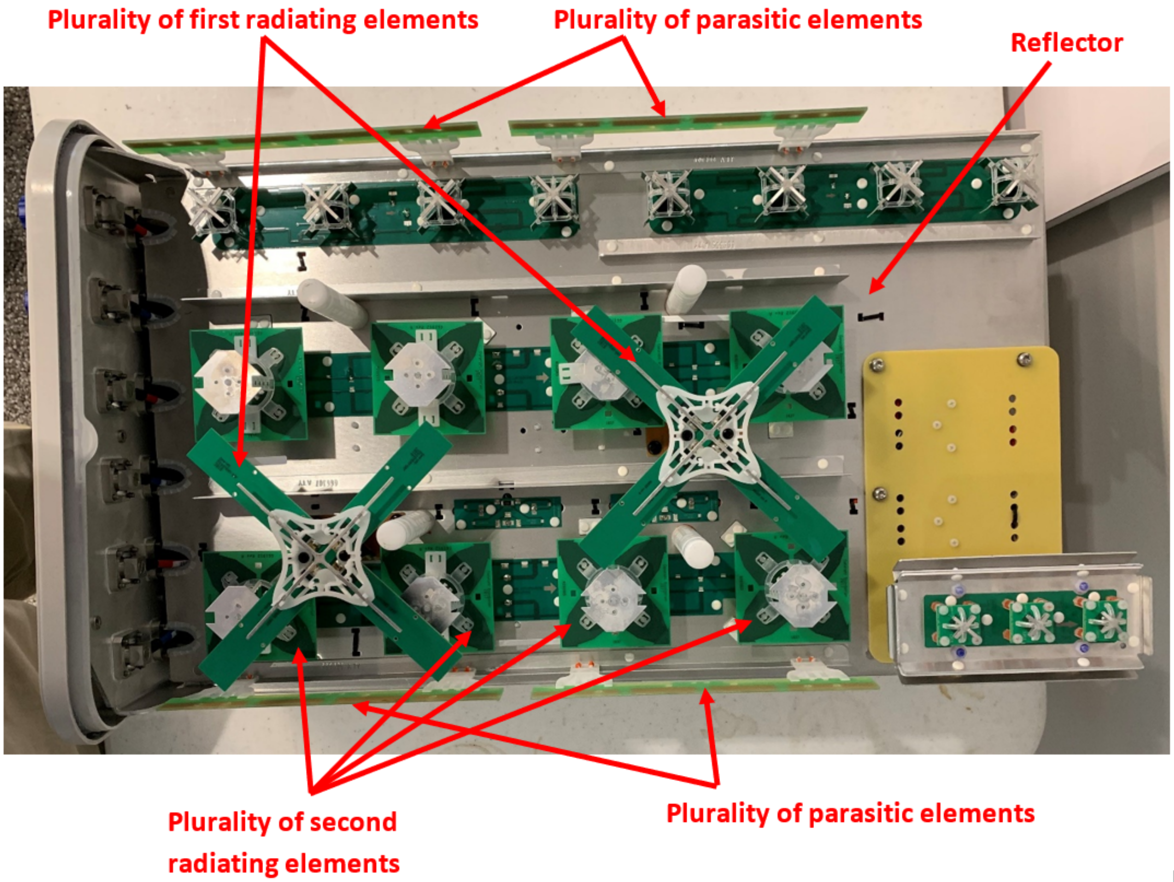
131. CommScope incorporates by reference each of the paragraphs above as if fully stated herein.

132. By its activities related to making, using, selling, offering for sale, and/or importing in or into the United States its base station antennas, including for example and without limitation its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01, Rosenberger has infringed at least claim 27 of the '285 patent.

133. Claim 27 of the '285 patent is as follows:

> 27. A multiband antenna comprising:
> a reflector;
> a plurality of first radiating elements that are configured to operate in a first frequency band and that extend forwardly from the reflector;
> a plurality of second radiating elements that are configured to operate in a second frequency band that is higher than the first frequency band, the second radiating elements extending forwardly from the reflector; and
> a plurality of parasitic elements that extend forwardly from the reflector, wherein a first of the plurality of parasitic elements comprises a plurality of conductive segments coupled in series by a plurality of inductors.

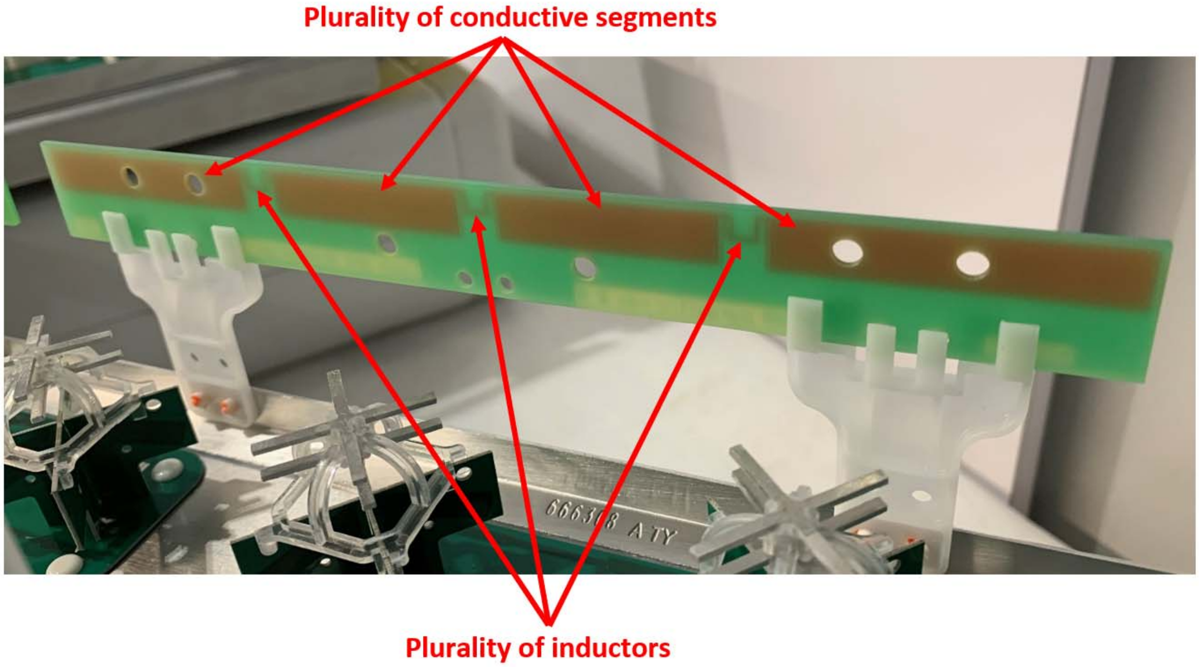
134. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06.



135. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those annotated above.

136. With respect to claim 27, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 are antennas comprising a reflector, a plurality of first radiating elements extending forwardly from the reflector, a plurality of second radiating elements configured to operate in a second frequency higher than the first frequency band, and that extend forwardly from the reflector, and a plurality of parasitic elements that extend forwardly from the reflector.

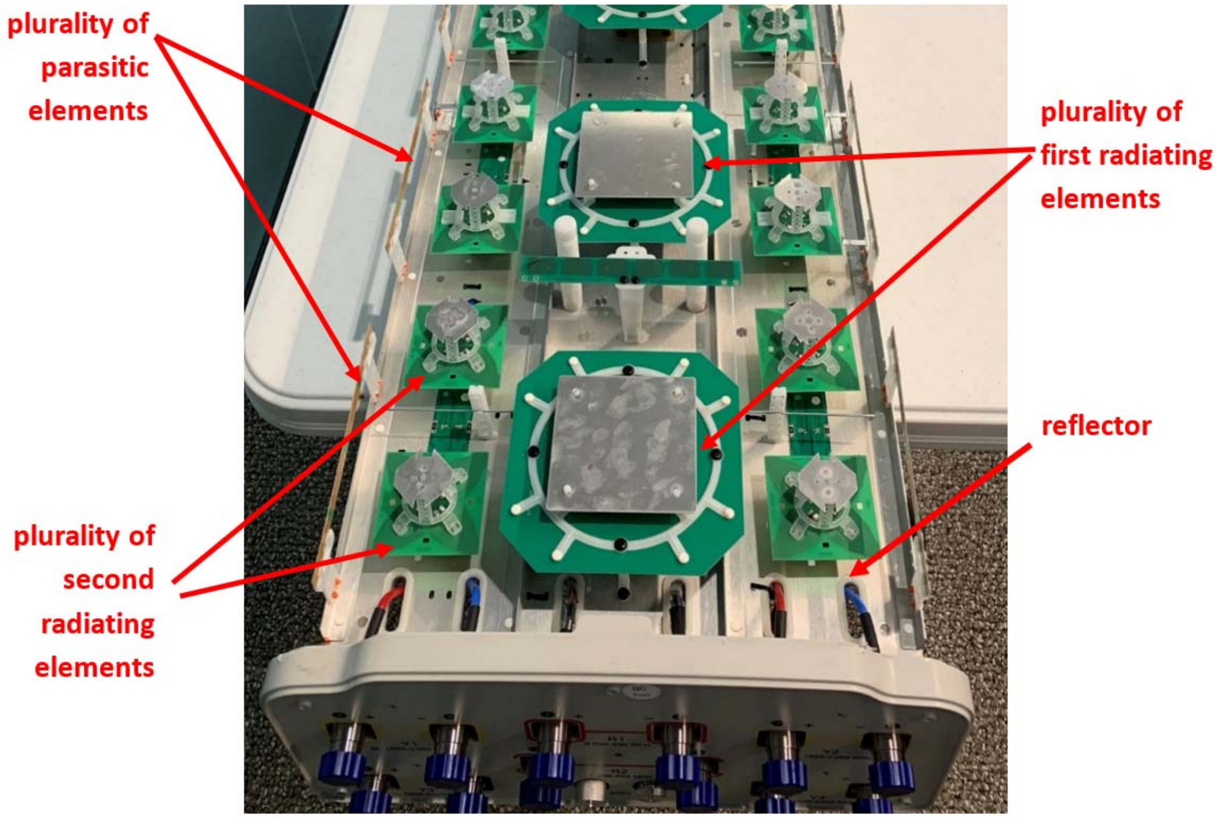
137. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06.



138. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those annotated above.

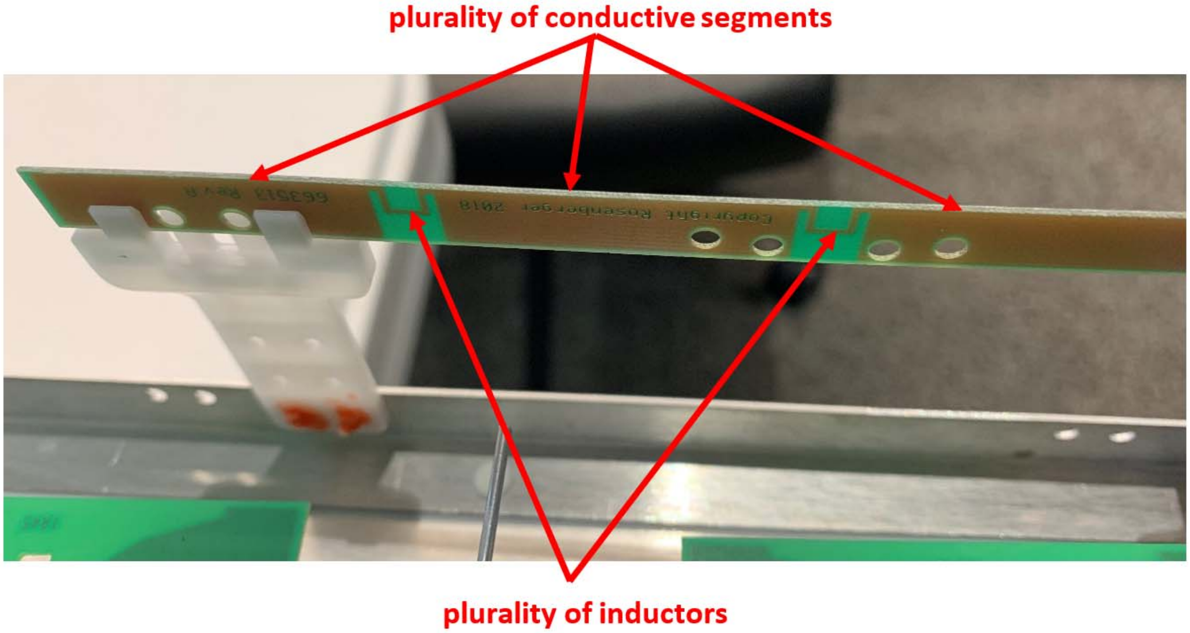
139. With respect to claim 27, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 are antennas that include a first parasitic element that comprises a plurality of conductive segments couples in series by a plurality of inductors.

140. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-A5A54O7X65V-01.



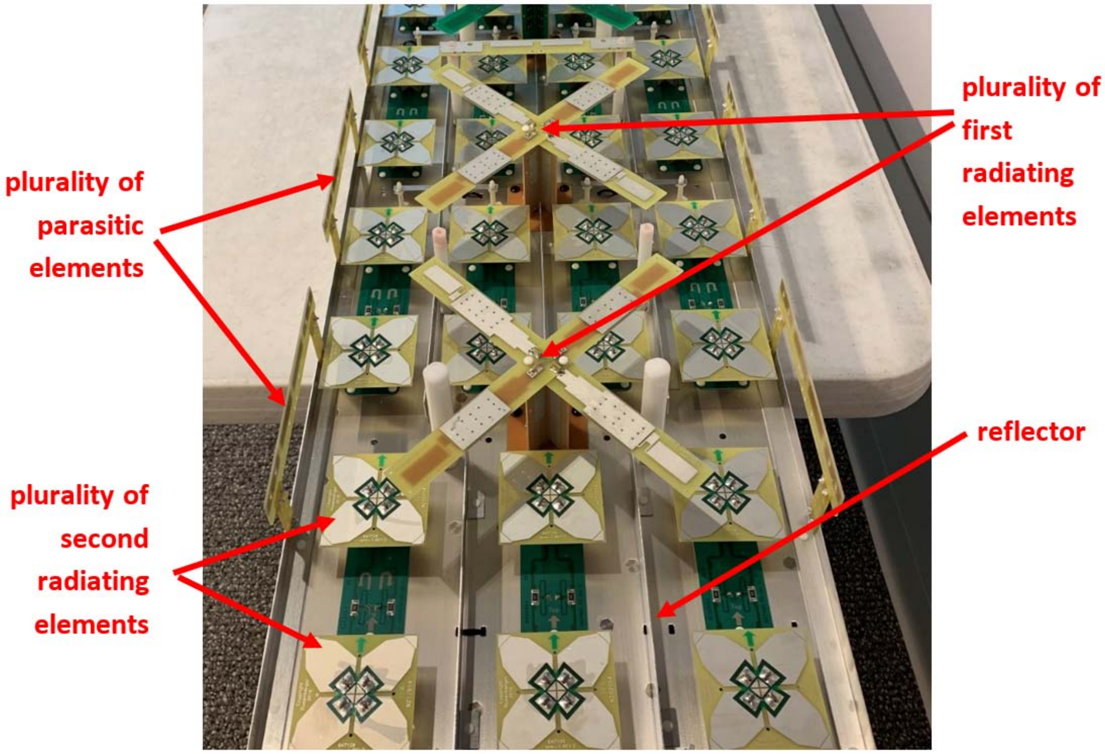
141. With respect to claim 27, as indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 comprises a reflector, a plurality of first radiating elements extending forwardly from the reflector, a plurality of second radiating elements configured to operate in a second frequency higher than the first frequency band, and that extend forwardly from the reflector, and a plurality of parasitic elements that extend forwardly from the reflector.

142. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-A5A54O7X65V-01.



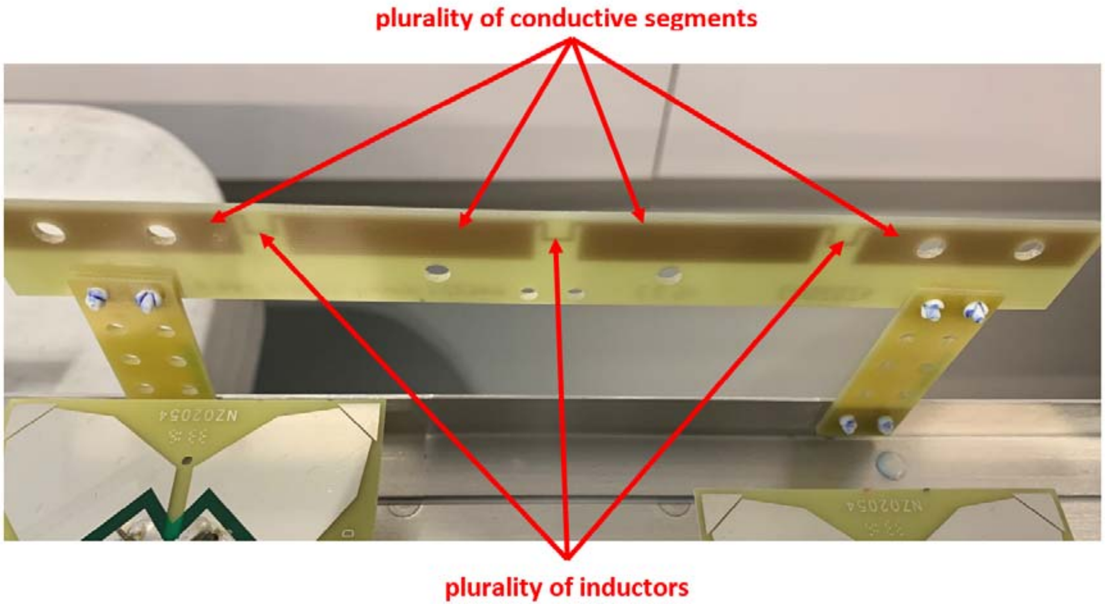
143. With respect to claim 27, as indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 includes a first parasitic element that comprises a plurality of conductive segments couples in series by a plurality of inductors.

144. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. MB-A64O9X65V-01 antenna.



145. With respect to claim 27, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 comprises a reflector, a plurality of first radiating elements extending forwardly from the reflector, a plurality of second radiating elements configured to operate in a second frequency higher than the first frequency band, and that extend forwardly from the reflector, and a plurality of parasitic elements that extend forwardly from the reflector.

146. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. MB-A64O9X65V-01.



147. With respect to claim 27, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 includes a first parasitic element that comprises a plurality of conductive segments couples in series by a plurality of inductors.

148. Therefore, Rosenberger directly infringes, literally and under the doctrine of equivalents, claims of the '285 patent, including, for example and without limitation, claim 27, through its making, using, selling, offering for sale, and/or importing of, for example and without limitation, its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01.

149. Rosenberger also indirectly infringes claims of the '285 patent, including, for example, and without limitation, claim 27. Operators of Rosenberger antennas directly infringe at least some claims of the '285 patent. At least as of the filing of this complaint, Rosenberger knows its products are especially made or especially adapted for use in an infringement.

150. Rosenberger products include features that are not staple articles of commerce suitable for substantial non-infringing uses. For example, there is no substantial use for the antennas that does not infringe the '285 patent. The intended, normal use of Rosenberger antennas results in infringement. Rosenberger products are a material part of the invention of the '285 patent.

151. CommScope has been damaged by Rosenberger's infringement of the '285 patent and will continue to be damaged in the future unless Rosenberger is enjoined from infringing the '285 patent.

152. CommScope has satisfied the notice and/or marking provisions of 35 U.S.C. § 287.

Count 6

Claim for Patent Infringement of U.S. Patent No. 10,498,035

153. CommScope incorporates by reference each of the paragraphs above as if fully stated herein.

154. By its activities related to making, using, selling, offering for sale, and/or importing in or into the United States its base station antennas, including for example and without limitation its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01, Rosenberger has infringed at least claim 10 of the '035 patent.

155. Claim 10 of the '035 patent is as follows:

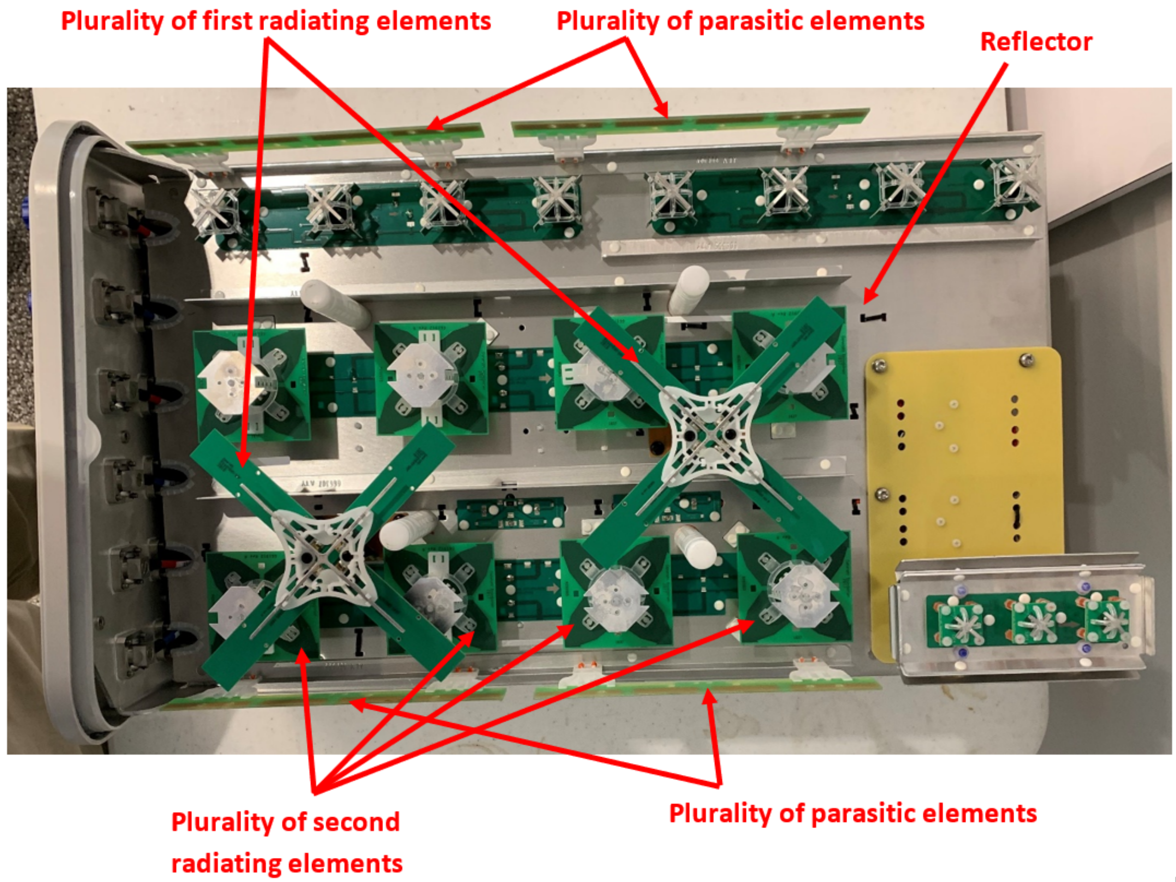
10. A multiband antenna comprising: a reflector;

a plurality of first radiating elements that are configured to operate in a first frequency band and that extend forwardly from the reflector;

a plurality of second radiating elements that are configured to operate in a second frequency band that is higher than the first frequency band, the second radiating elements extending forwardly from the reflector; and

a plurality of parasitic elements that extend forwardly from the reflector, wherein a first of the plurality of parasitic elements comprises a plurality of elements that are configured to have a high impedance that attenuates current in the first of the plurality of parasitic elements in the second frequency band and have a low impedance that passes current in the first of the plurality of parasitic elements in the first frequency band.

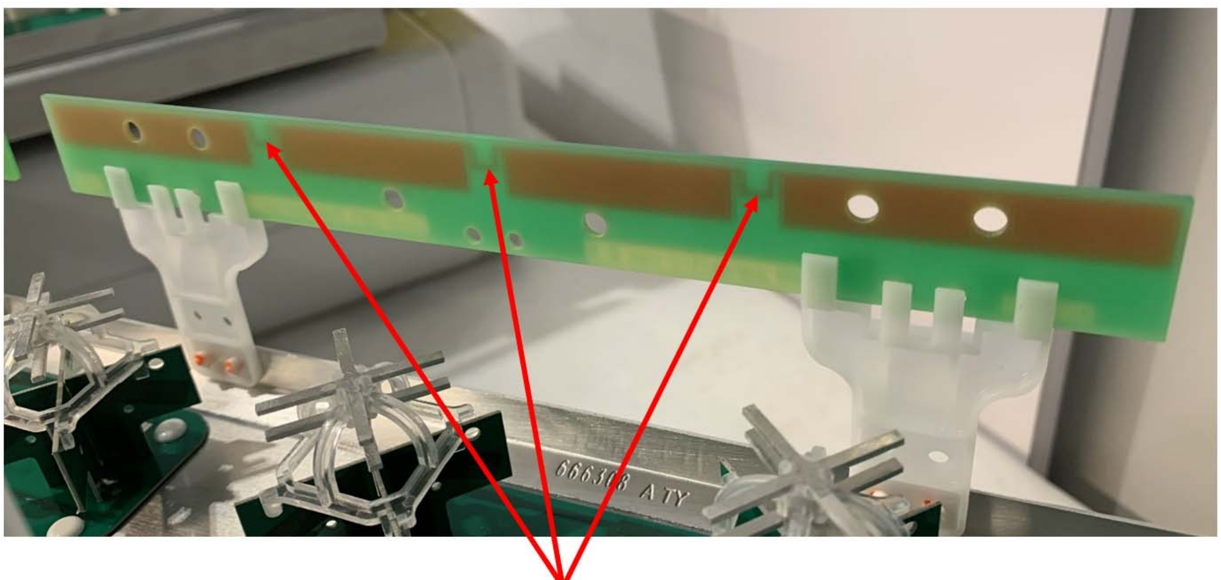
156. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06.



157. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those annotated above.

158. With respect to claim 10, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 are antennas comprising a reflector, a plurality of first radiating elements extending forwardly from the reflector, a plurality of second radiating elements configured to operate in a second frequency higher than the first frequency band, and that extend forwardly from the reflector, and a plurality of parasitic elements that extend forwardly from the reflector.

159. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06.



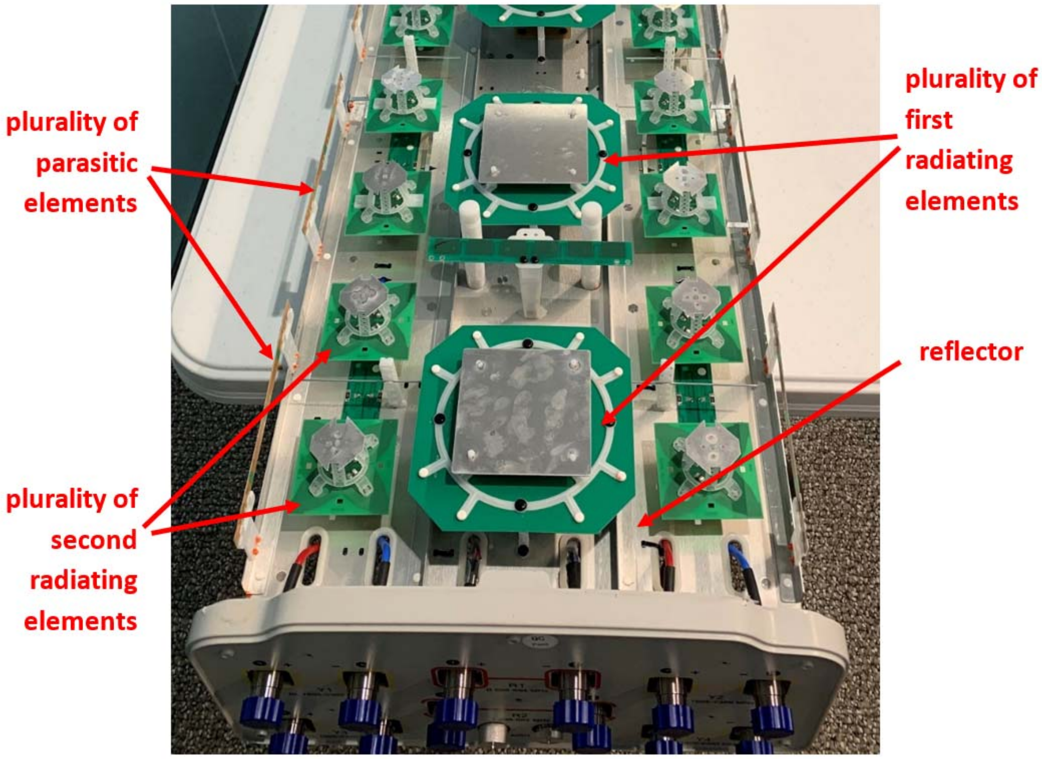
Elements having high impedance at the second frequency band and low impedance at the first frequency band

160. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those annotated above.

161. With respect to claim 10, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 are antennas that include elements that are configured to have a high impedance that attenuates current in

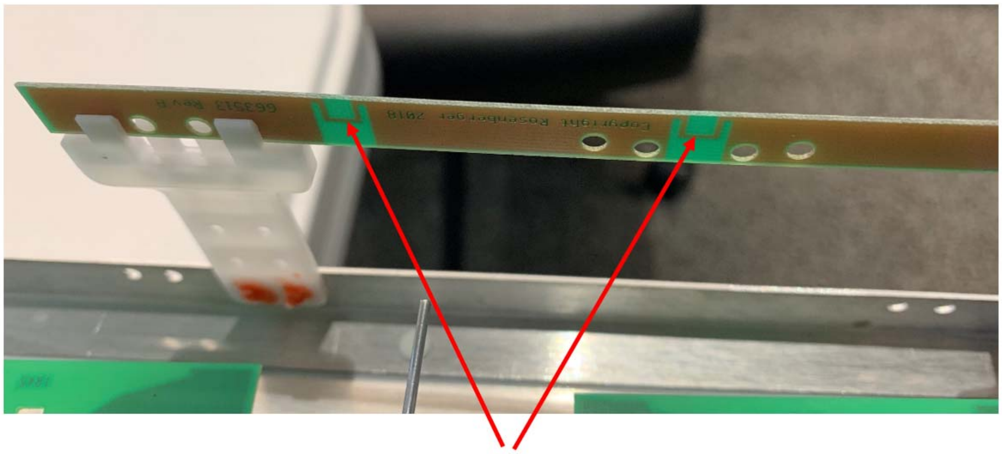
the first of the plurality of parasitic elements in the second frequency band and have a low impedance that passes current in the first of the plurality of parasitic elements in the first frequency band.

162. Shown below is an annotated photograph of interior components of Rosenberger model no. BA-A5A54O7X65V-01.



163. With respect to claim 10, as indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 comprises a reflector, a plurality of first radiating elements extending forwardly from the reflector, a plurality of second radiating elements configured to operate in a second frequency higher than the first frequency band, and that extend forwardly from the reflector, and a plurality of parasitic elements that extend forwardly from the reflector.

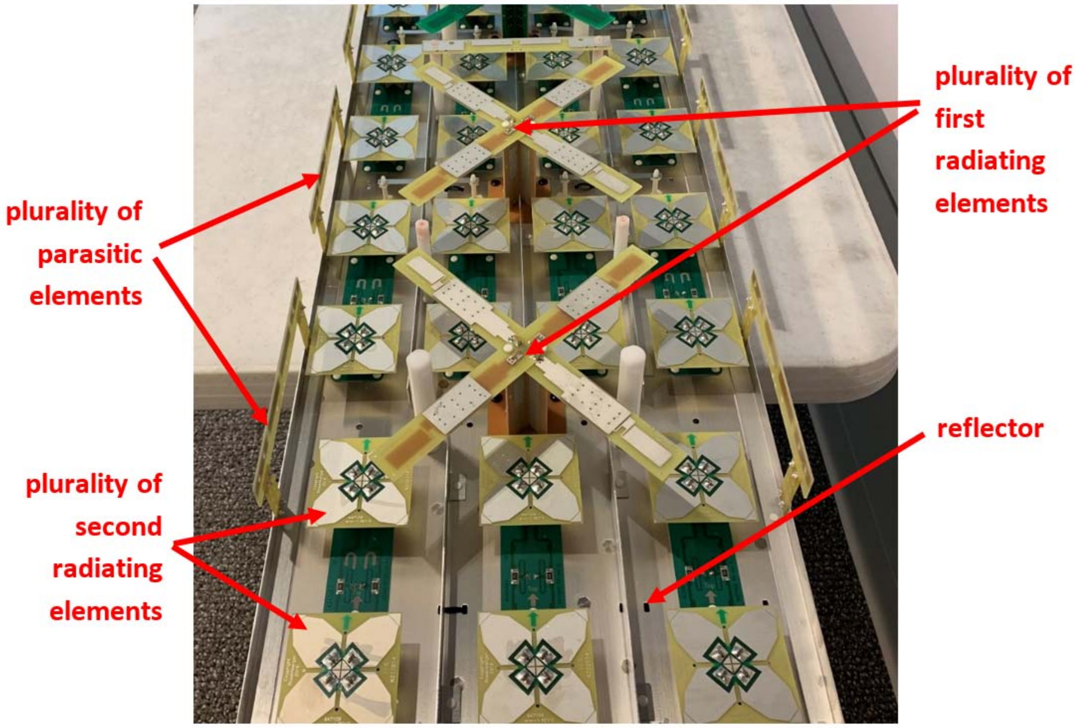
164. Shown below is another annotated photograph of interior components of Rosenberger antenna model no. BA-A5A54O7X65V-01.



Elements having high impedance at the second frequency band and low impedance at the first frequency band

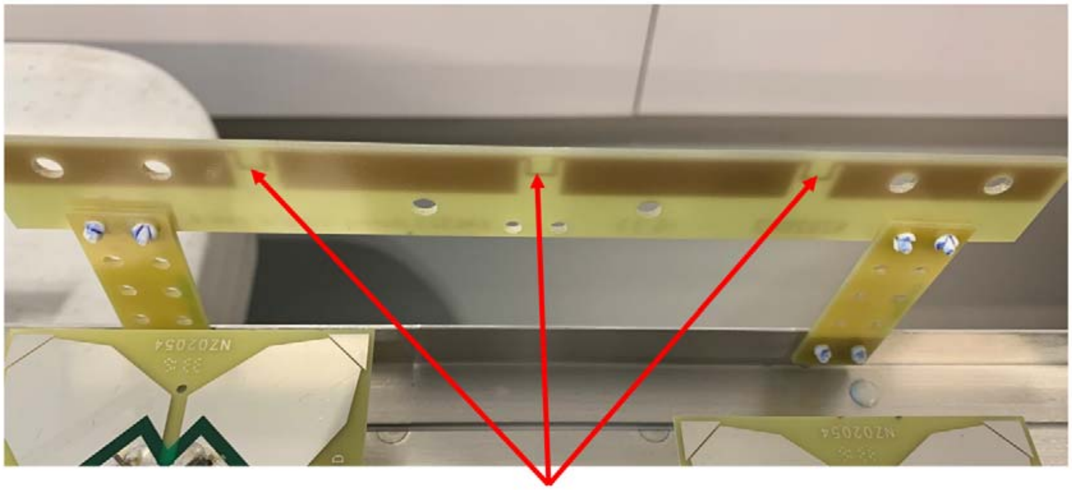
165. With respect to claim 10, as indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 includes a first parasitic element that includes elements that are configured to have a high impedance that attenuates current in the first of the plurality of parasitic elements in the second frequency band and have a low impedance that passes current in the first of the plurality of parasitic elements in the first frequency band.

166. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. MB-A64O9X65V-01.



167. With respect to claim 10, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 comprises a reflector, a plurality of first radiating elements extending forwardly from the reflector, a plurality of second radiating elements configured to operate in a second frequency higher than the first frequency band, and that extend forwardly from the reflector, and a plurality of parasitic elements that extend forwardly from the reflector.

168. Shown below is another annotated photograph of interior components of Rosenberger antenna model no._MB-A64O9X65V-01.



Elements having high impedance at the second frequency band and low impedance at the first frequency band

169. With respect to claim 10, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 includes a first parasitic element that includes elements that are configured to have a high impedance that attenuates current in the first of the plurality of parasitic elements in the second frequency band and have a low impedance that passes current in the first of the plurality of parasitic elements in the first frequency band.

170. Therefore, Rosenberger directly infringes, literally and under the doctrine of equivalents, claims of the ‘035 patent, including, for example and without limitation, claim 10, through its making, using, selling, offering for sale, and/or importing of, for example and without limitation, its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01.

171. Rosenberger also indirectly infringes claims of the ‘035 patent, including, for example, and without limitation, claim 10. Operators of Rosenberger antennas directly infringe at least some claims of the ‘035 patent. At least as of the filing of this

complaint, Rosenberger knows its products are especially made or especially adapted for use in an infringement.

172. Rosenberger products include features that are not staple articles of commerce suitable for substantial non-infringing uses. For example, there is no substantial use for the antennas that does not infringe the ‘035 patent. The intended, normal use of Rosenberger antennas results in infringement. Rosenberger products are a material part of the invention of the ‘035 patent.

173. CommScope has been damaged by Rosenberger’s infringement of the ‘035 patent and will continue to be damaged in the future unless Rosenberger is enjoined from infringing the ‘035 patent.

174. CommScope has satisfied the notice and/or marking provisions of 35 U.S.C. § 287.

Count 7

Claim for Patent Infringement of U.S. Patent No. 10,547,110

175. CommScope incorporates by reference each of the paragraphs above as if fully stated herein.

176. By its activities related to making, using, selling, offering for sale, and/or importing in or into the United States its base station antennas, including for example and without limitation its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01, Rosenberger has infringed at least claim 1 of the ‘110 patent.

177. Claim 1 of the ‘110 patent is as follows:

1. A multiband antenna comprising:

a reflector that has a longitudinal axis;

a first column of high band radiating elements that are configured to operate in a first operational frequency band mounted on the reflector, the first column of high band radiating elements extending in parallel to the longitudinal axis of the reflector;

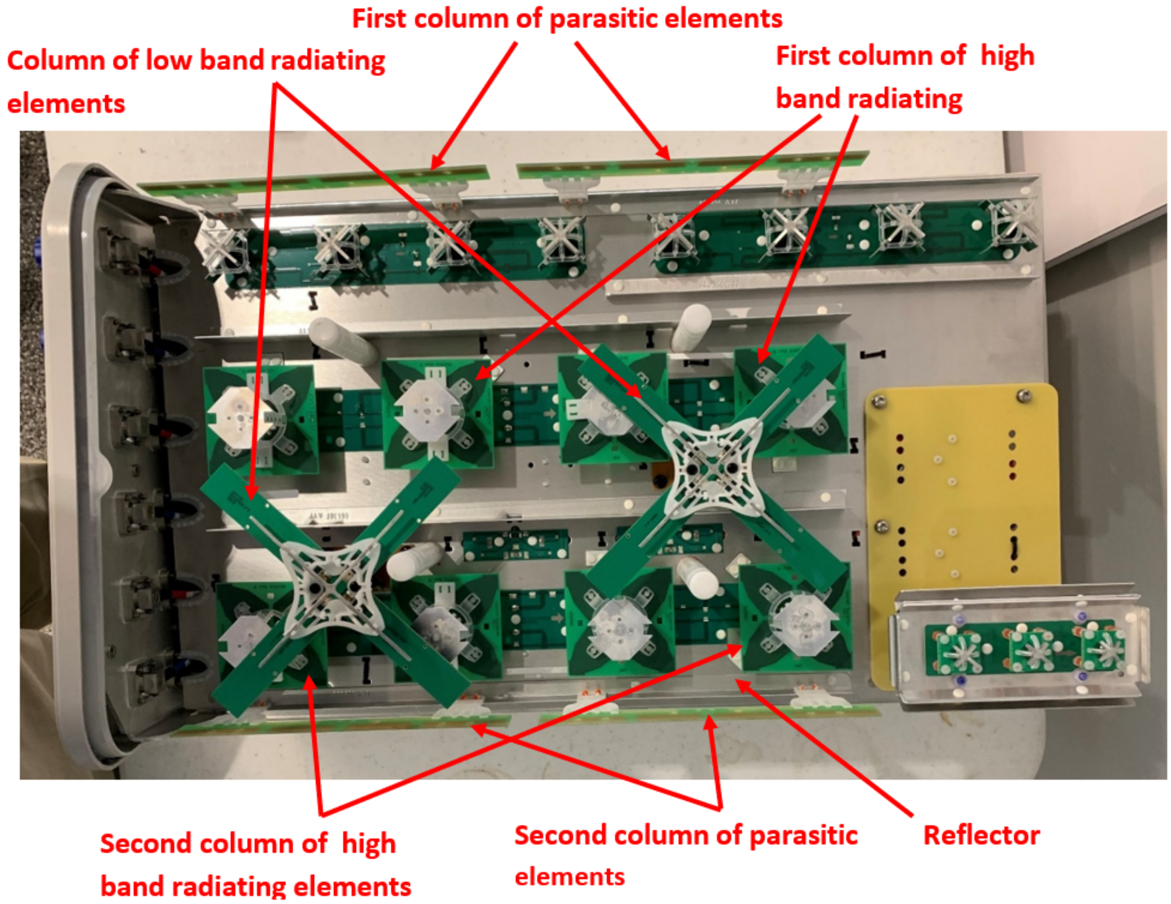
a second column of high band radiating elements that are configured to operate in the first operational frequency band mounted on the reflector, the second column of high band radiating elements extending in parallel to the longitudinal axis of the reflector;

a first column of low band radiating elements that are configured to operate in a second operational frequency band mounted on the reflector, the second operational frequency band being at frequencies that are lower than frequencies of the first operational frequency band, the first column of low band radiating elements extending in parallel to the longitudinal axis of the reflector between the first column of high band radiating elements and the second column of high band radiating elements;

a first column of parasitic elements extending in parallel to the longitudinal axis of the reflector such that the first column of high band radiating elements is between the first column of parasitic elements and the first column of low band radiating elements, and

a second column of parasitic elements extending in parallel to the longitudinal axis of the reflector such that the second column of high band radiating elements is between the second column of parasitic elements and the first column of low band radiating elements.

178. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-AIO3O3T3T3VFX65F-06.

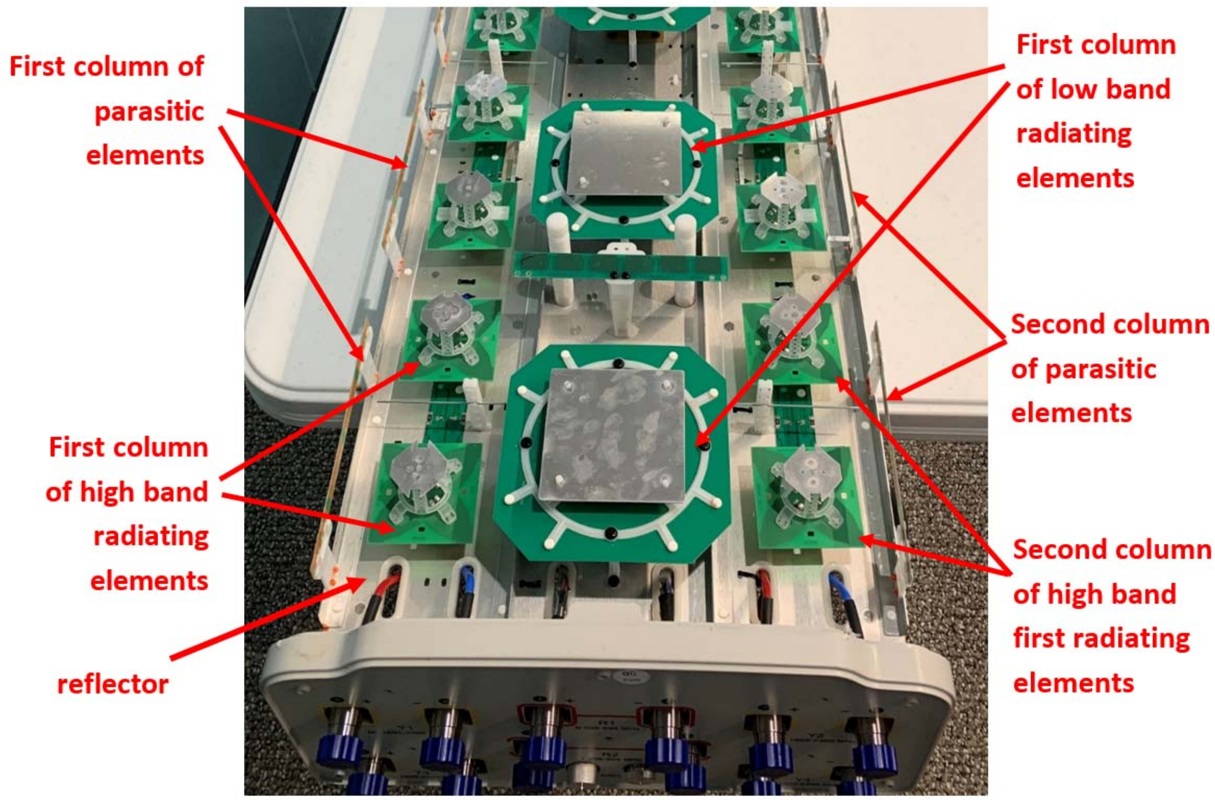


179. Rosenberger antenna model no. BA-AIO3O3T3T3VJX65F-06 contains the same elements as those annotated above.

180. With respect to claim 1, as indicated above, Rosenberger antenna model nos. BA-AIO3O3T3T3VFX65F-06 and BA-AIO3O3T3T3VJX65F-06 are antennas comprising a reflector, a first column of high band radiating elements configured to operate in a first operational frequency band, a second column of high band radiating elements configured to operate in a first operational frequency band, a first column of low band radiating elements configured to operate in a second operational frequency band, a first column of parasitic elements with the first column of high band radiating

elements between the first column of parasitic elements and the first column of low band radiating elements, and a second column of parasitic elements with the second column of high band radiating elements between the second column of parasitic elements and the first column of low band radiating elements.

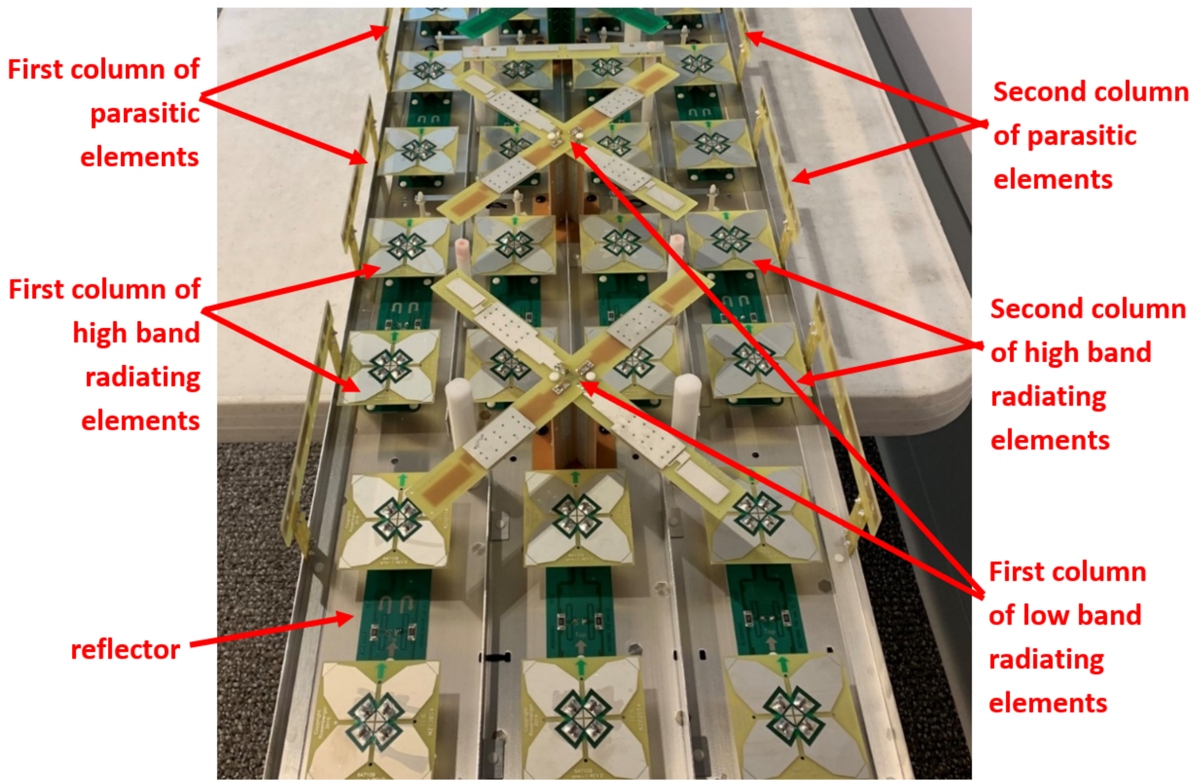
181. Shown below is an annotated photograph of interior components of Rosenberger antenna model no. BA-A5A54O7X65V-01.



182. With respect to claim 1, as indicated above, Rosenberger antenna model no. BA-A5A54O7X65V-01 comprises a reflector, a first column of high band radiating elements configured to operate in a first operational frequency band, a second column of high band radiating elements configured to operate in a first operational frequency band, a first column of low band radiating elements configured to operate in a second

operational frequency band, a first column of parasitic elements with the first column of high band radiating elements between the first column of parasitic elements and the first column of low band radiating elements, and a second column of parasitic elements with the second column of high band radiating elements between the second column of parasitic elements and the first column of low band radiating elements.

183. Shown below is an annotated photograph of interior components of Rosenberger antenna model MB-A64O9X65V-01.



184. With respect to claim 1, as indicated above, Rosenberger antenna model no. MB-A64O9X65V-01 comprises a reflector, a first column of high band radiating elements configured to operate in a first operational frequency band, a second column of high band radiating elements configured to operate in a first operational frequency band,

a first column of low band radiating elements configured to operate in a second operational frequency band, a first column of parasitic elements with the first column of high band radiating elements between the first column of parasitic elements and the first column of low band radiating elements, and a second column of parasitic elements with the second column of high band radiating elements between the second column of parasitic elements and the first column of low band radiating elements.

185. Therefore, Rosenberger directly infringes, literally and under the doctrine of equivalents, claims of the '110 patent, including, for example and without limitation, claim 1, through its making, using, selling, offering for sale, and/or importing of, for example and without limitation, its antenna model nos. BA-AIO3O3T3T3VFX65F-06, BA-AIO3O3T3T3VJX65F-06, BA-A5A54O7X65V-01, and MB-A64O9X65V-01.

186. Rosenberger also indirectly infringes claims of the '110 patent, including, for example, and without limitation, claim 1. Operators of Rosenberger antennas directly infringe at least some claims of the '110 patent. At least as of the filing of this complaint, Rosenberger knows its products are especially made or especially adapted for use in an infringement.

187. Rosenberger products include features that are not staple articles of commerce suitable for substantial non-infringing uses. For example, there is no substantial use for the antennas that does not infringe the '110 patent. The intended, normal use of Rosenberger antennas results in infringement. Rosenberger products are a material part of the invention of the '110 patent.

188. CommScope has been damaged by Rosenberger's infringement of the '110 patent and will continue to be damaged in the future unless Rosenberger is enjoined from infringing the '110 patent.

189. CommScope has satisfied the notice and/or marking provisions of 35 U.S.C. § 287.

Willful Infringement

190. CommScope incorporates by reference each of the paragraphs above as if fully stated herein.

191. Rosenberger is aware of CommScope's patents and has at least been willfully blind to infringement of the patents-in-suit.

192. Over the period starting around 2014 to present day, Rosenberger has engaged in a campaign of hiring CommScope's employees, and has successfully hired away more than a dozen of CommScope's employees who worked on CommScope's BSAs. The CommScope ex-employees include managers, supervisors and the former lead R&D manager of CommScope's Chinese business unit with responsibility for BSAs. They include mechanical engineers and radio frequency (RF) engineers, all of whom were familiar with all aspects of CommScope's BSAs, including design files and engineering drawings. They were also familiar with CommScope's intellectual property, including the patents CommScope had obtained to protect the designs of its BSAs. In the U.S., Rosenberger SSL has also employed former CommScope employees in leadership roles.

193. Rosenberger developed and marketed its infringing products after hiring away these CommScope employees who were intimately familiar with CommScope's BSA products and BSA innovations. Upon information and belief, these ex-CommScope employees knew that CommScope protects such products and innovations through patent protection.

194. Rosenberger's concerted campaign of hiring CommScope's employees to gain access to CommScope's antenna designs has resulted in Rosenberger producing antennas that include many features copied from CommScope, including patented features.

195. Upon information and belief, Rosenberger improperly used the knowledge of CommScope's ex-employees to develop key aspects of its BSA products, including the features identified as infringing the patents-in-suit, with full knowledge or willful blindness that CommScope's products are patent-protected and that copying CommScope's products would result in patent infringement.

196. Rosenberger's infringement occurred with knowledge and/or objective recklessness and this has been and will continue to be willful and deliberate. Rosenberger's willful and deliberate infringement entitles CommScope to enhanced damages under 35 U.S.C. § 285.

<u>Prayer for Relief</u>

CommScope respectfully requests the following relief:

A. a judgment that Rosenberger has infringed the ‘922 patent, ‘430 patent, the ‘486 patent, the ‘548 patent, the ‘285 patent, the ‘035 patent, and the ‘110 patent;

B. a judgment that infringement of the 922 patent, ‘430 patent, the ‘486 patent, the ‘548 patent, the ‘285 patent, the ‘035 patent, and/or the ‘110 patent has been willful;

C. a permanent injunction enjoining and restraining Defendant Rosenberger, its officers, directors, agents, servants, employees, attorneys and all persons in active concert or participation with them from infringing the ‘922 patent, ‘430 patent, the ‘486 patent, the ‘548 patent, the ‘285 patent, the ‘035 patent, and the ‘110 patent;

D. a judgment and order requiring Rosenberger to pay all appropriate damages under 35 U.S.C. §284, including prejudgment and post-judgment interest, and including increased damages;

E. a judgment and order requiring Rosenberger to pay all costs of this action, including all disbursements and attorney fees, if this case is found to be exceptional as provided by 35 U.S.C. §285; and

F. such other and further relief that this Court may deem just and equitable.

Demand for a Jury Trial

Pursuant to Rule 38 of the Federal Rules of Civil Procedure, CommScope demands a trial by jury of all issues so triable.

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Dated: August 10, 2020

EXHIBIT A

US007358922B2

(12) **United States Patent**
Le et al.

(10) **Patent No.: US 7,358,922 B2**
(45) **Date of Patent: *Apr. 15, 2008**

(54) **DIRECTED DIPOLE ANTENNA**

(75) Inventors: **Kevin Le**, Arlington, TX (US); **Louis J. Meyer**, Shady Shores, TX (US); **Pete Bisiules**, LaGrange Park, IL (US)

(73) Assignee: **CommScope, Inc. of North Carolina**, Hickory, NC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 225 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **11/104,986**

(22) Filed: **Apr. 13, 2005**

(65) **Prior Publication Data**

US 2005/0179610 A1 Aug. 18, 2005

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/737,214, filed on Dec. 16, 2003, now Pat. No. 6,924,776, and a continuation-in-part of application No. 10/703,331, filed on Nov. 7, 2003, and a continuation-in-part of application No. 10/390,487, filed on Mar. 17, 2003.

(60) Provisional application No. 60/577,138, filed on Jun. 4, 2004, provisional application No. 60/484,688, filed on Jul. 3, 2003, provisional application No. 60/482,689, filed on Jun. 26, 2003, provisional application No. 60/433,352, filed on Dec. 13, 2002.

(51) **Int. Cl.**
H01Q 21/26 (2006.01)
H01Q 21/00 (2006.01)
H01Q 1/48 (2006.01)

(52) **U.S. Cl.** **343/797**; 343/810; 343/846

(58) **Field of Classification Search** 343/793, 343/797, 810–820, 846
See application file for complete search history.

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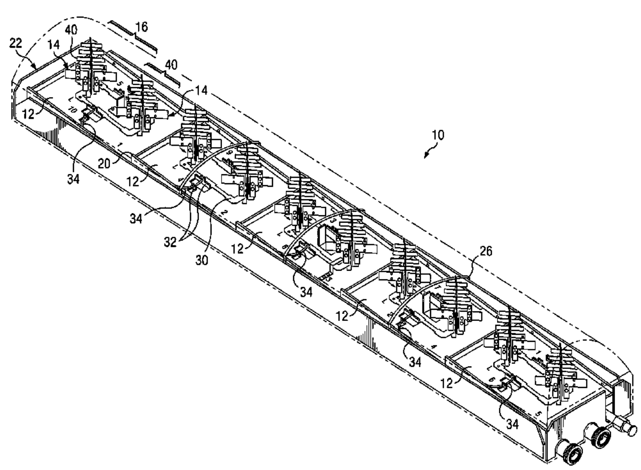
Primary Examiner—Shih-Chao Chen
(74) *Attorney, Agent, or Firm*—Jackson Walker LLP; Robert C. Klinger

(57) **ABSTRACT**

A dual polarized variable beam tilt antenna having a superior Sector Power Ratio (SPR). The antenna may have slant 45 degree dipole radiating elements including directors, and may be disposed on a plurality of tilted element trays to orient an antenna boresight downtilt. The directors may be disposed above or about the respective dipole radiating elements. The antenna has a beam front-to-side ratio exceeding 20 dB, a horizontal beam front-to-back ratio exceeding 40 dB, a high-roll off, and is operable over an expanded frequency range.

47 Claims, 11 Drawing Sheets



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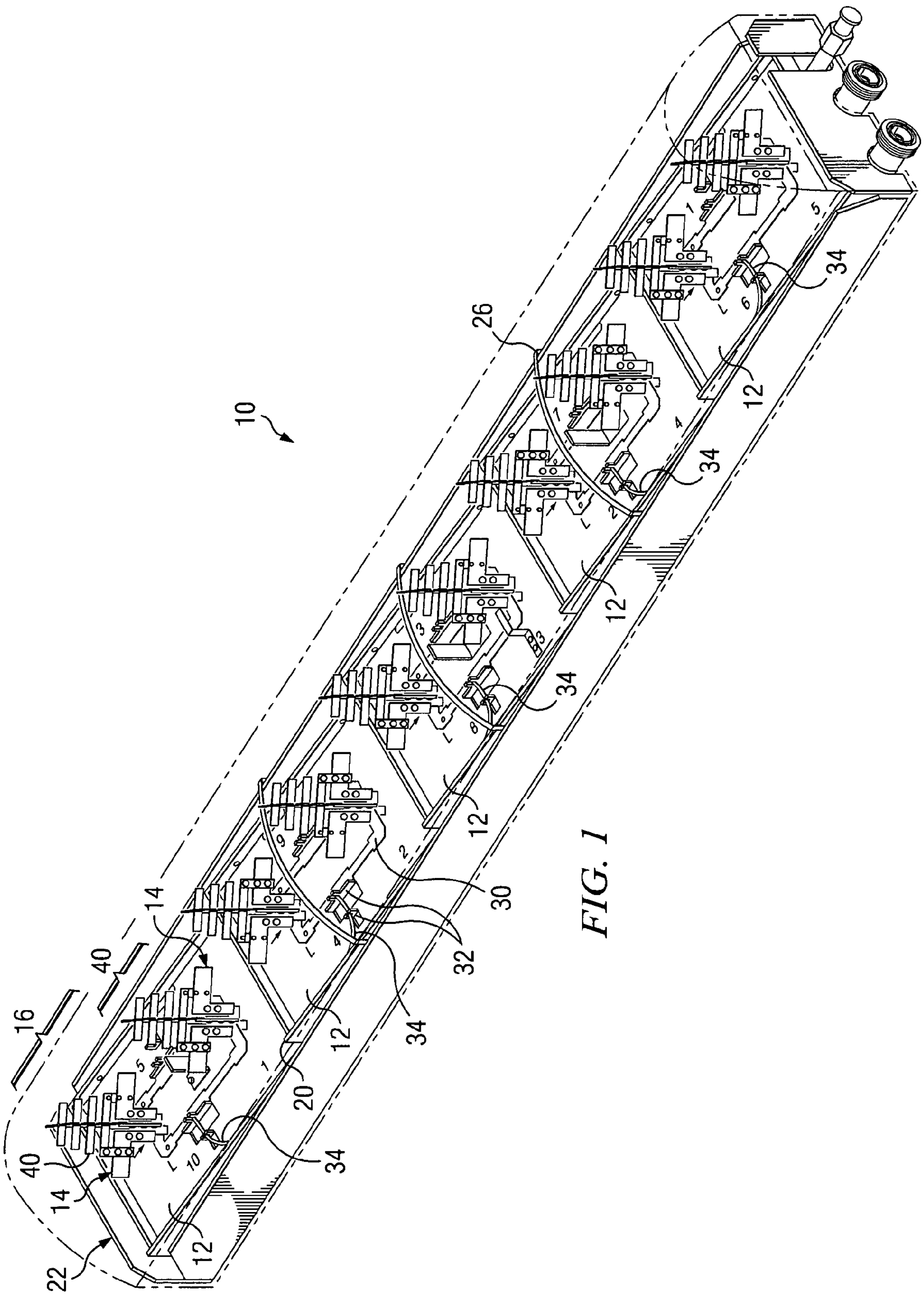


FIG. 1

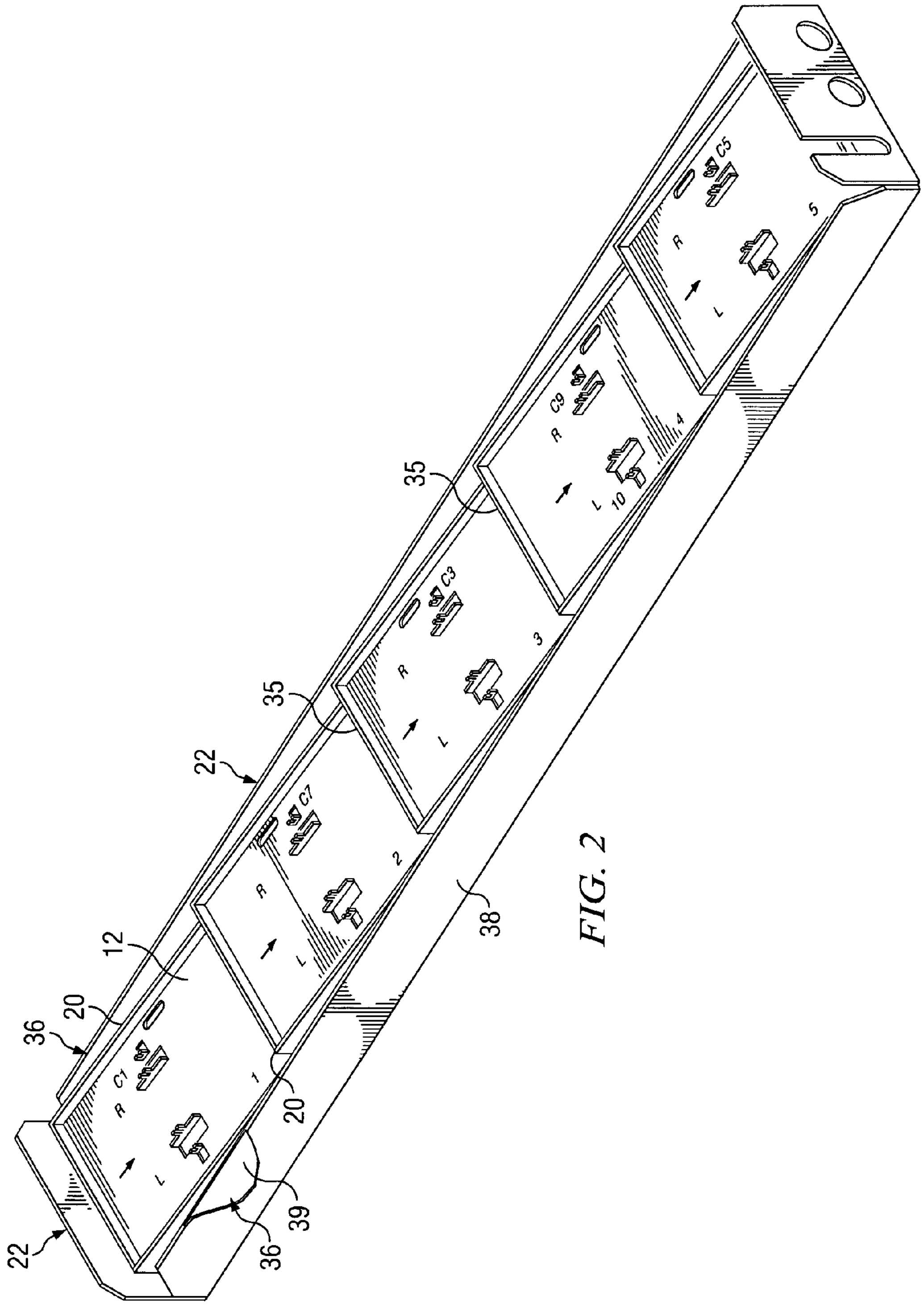


FIG. 2

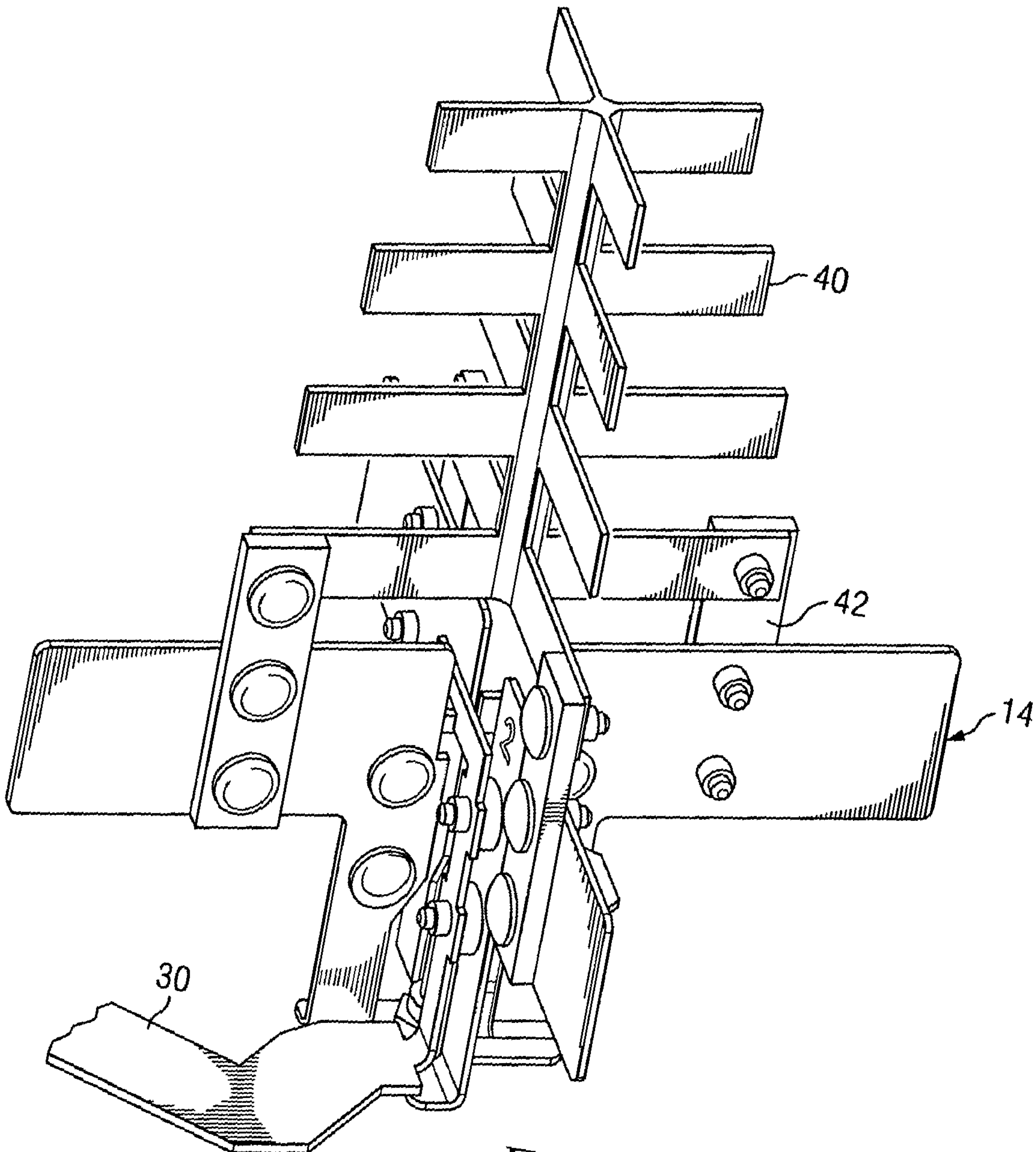


FIG. 3

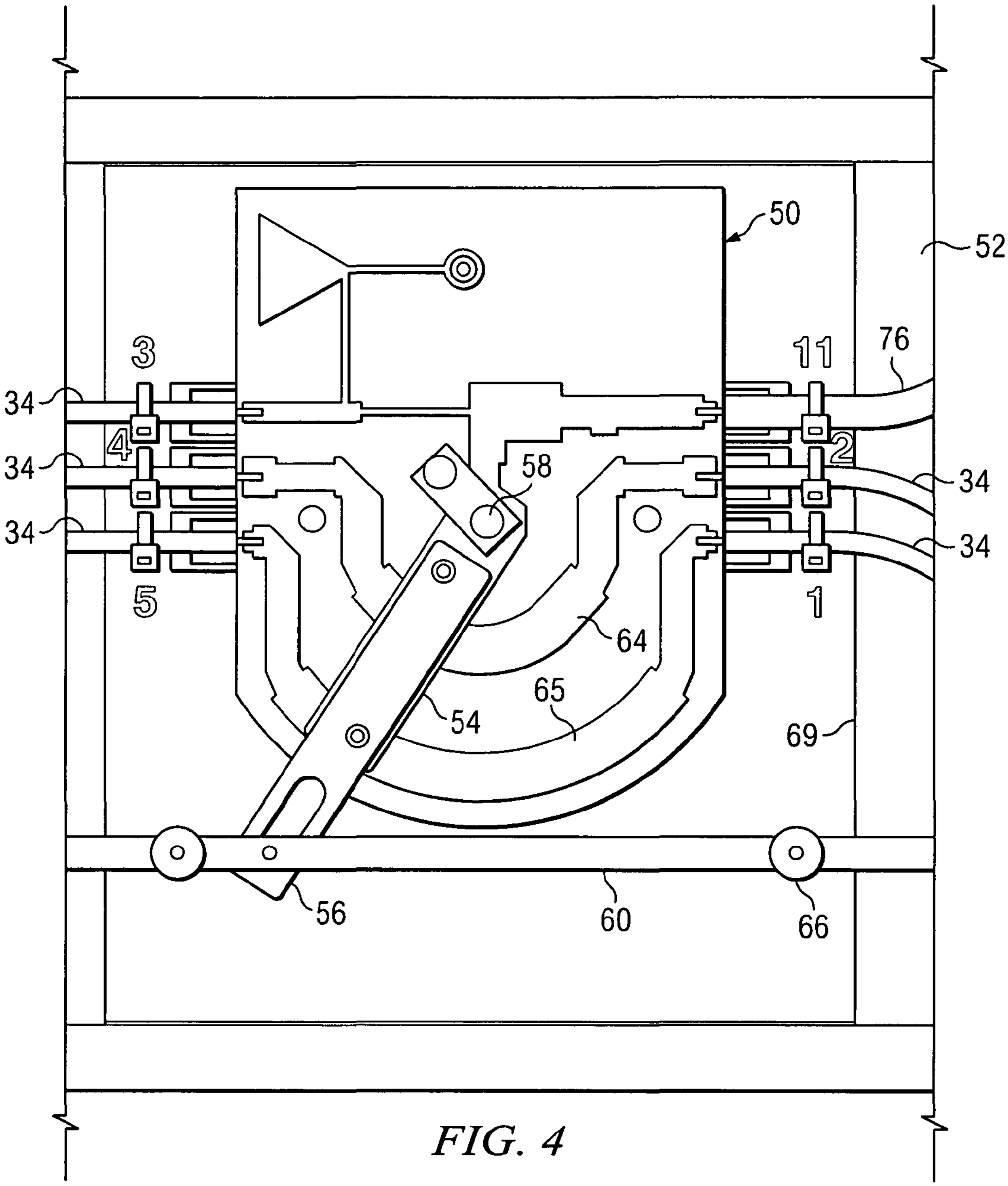


FIG. 4

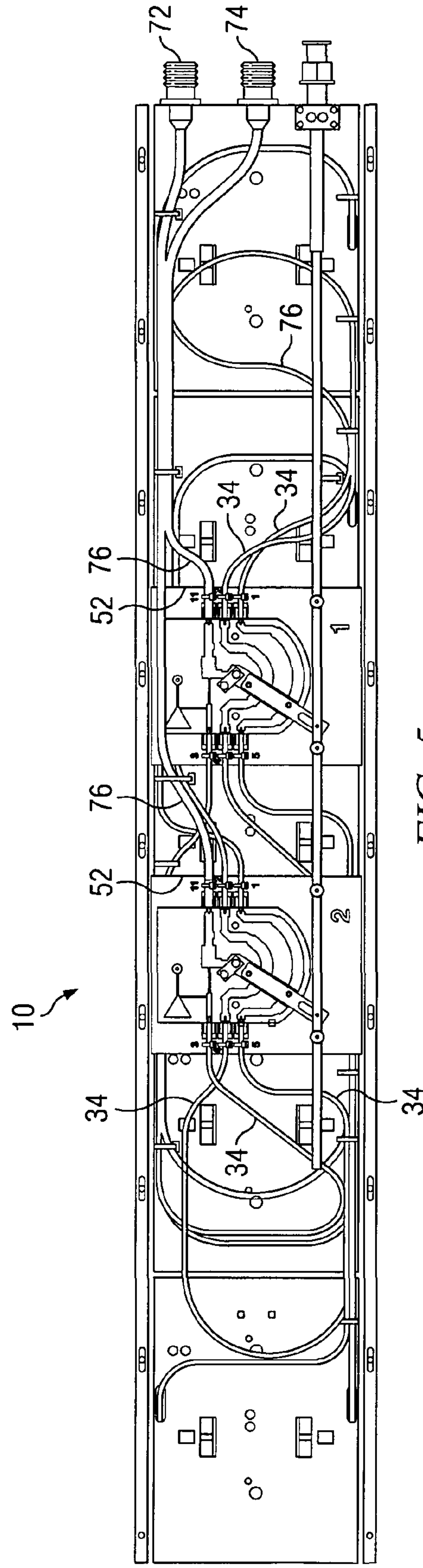


FIG. 5

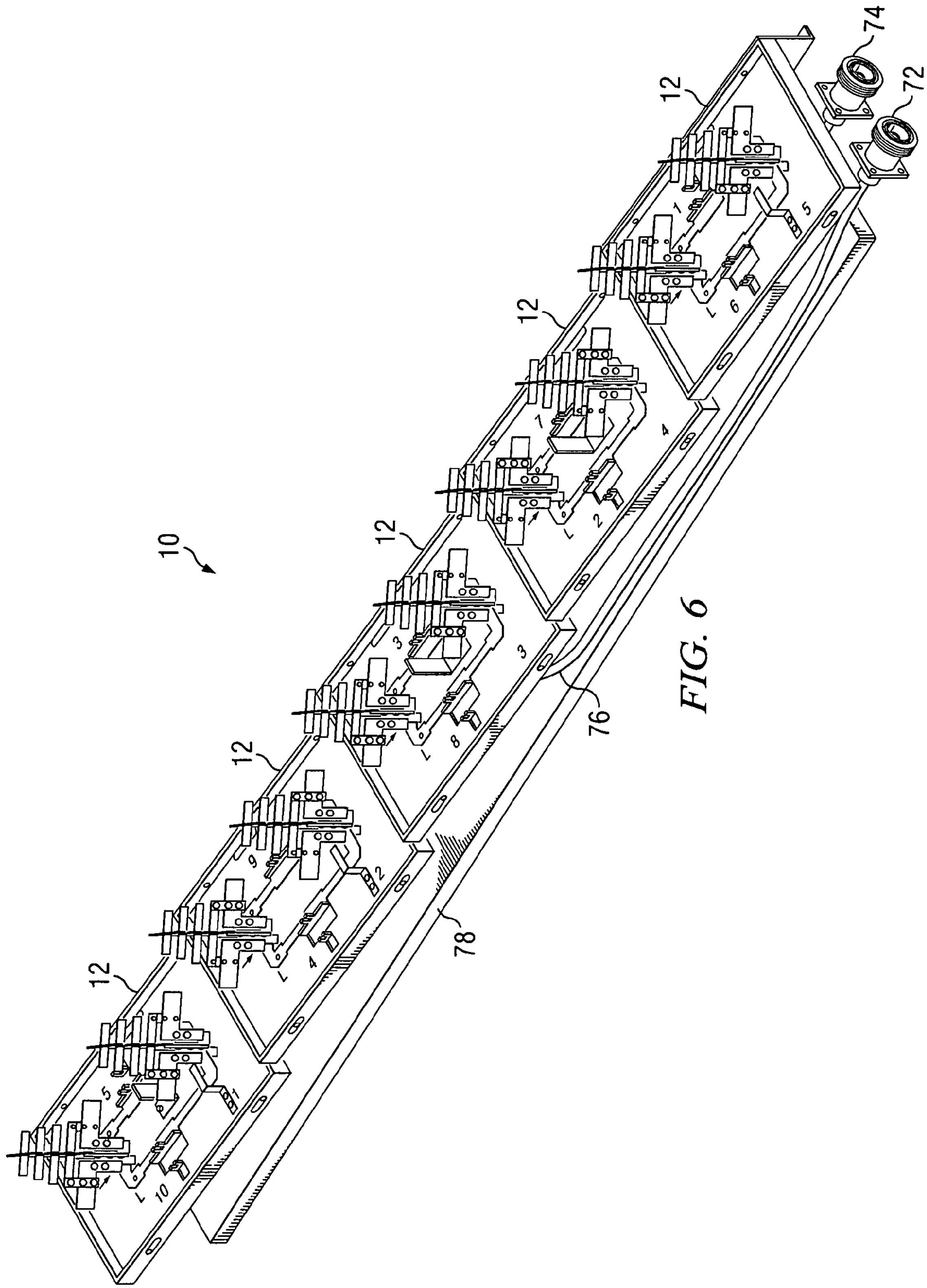
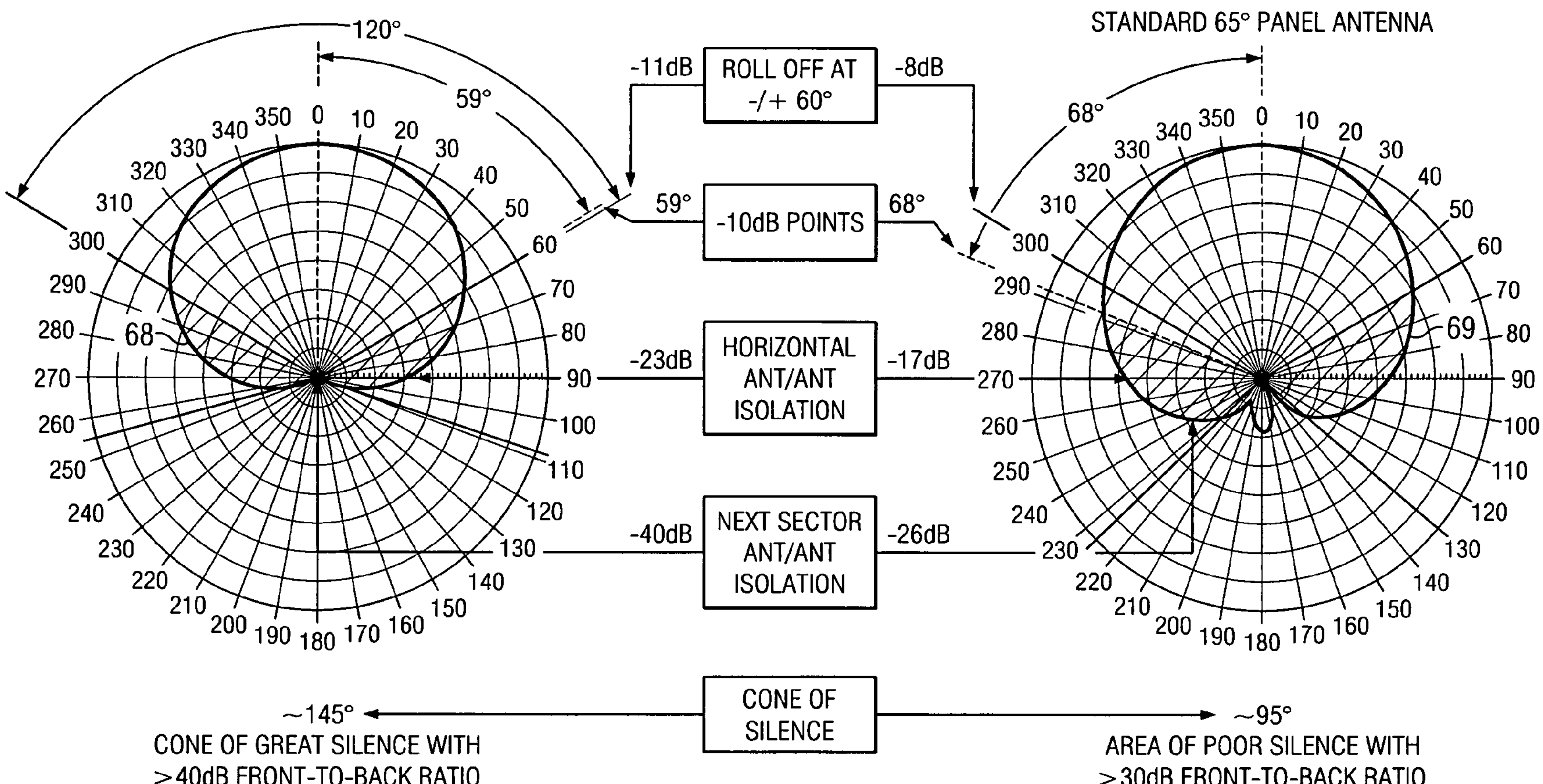


FIG. 6



STANDARD 65° PANEL ANTENNA
120°
59°
68°
-11dB
ROLL OFF AT -/+ 60°
-8dB
59°
-10dB POINTS
68°
68
69
-23dB
HORIZONTAL ANT/ANT ISOLATION
-17dB
-40dB
NEXT SECTOR ANT/ANT ISOLATION
-26dB
CONE OF SILENCE
~145°
CONE OF GREAT SILENCE WITH
>40dB FRONT-TO-BACK RATIO
~95°
AREA OF POOR SILENCE WITH
>30dB FRONT-TO-BACK RATIO

FIG. 7

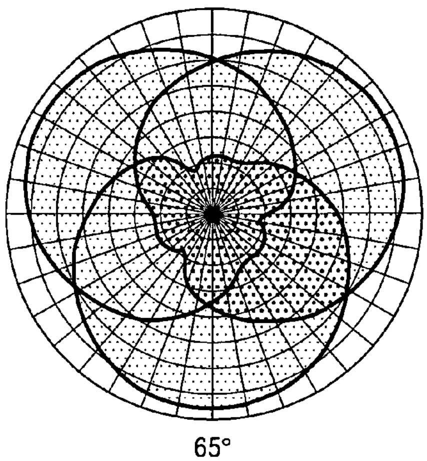


FIG. 8A

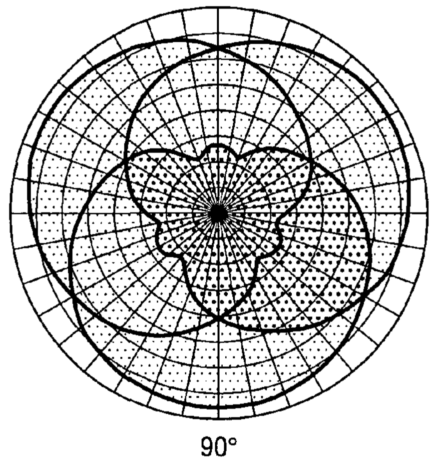


FIG. 8B

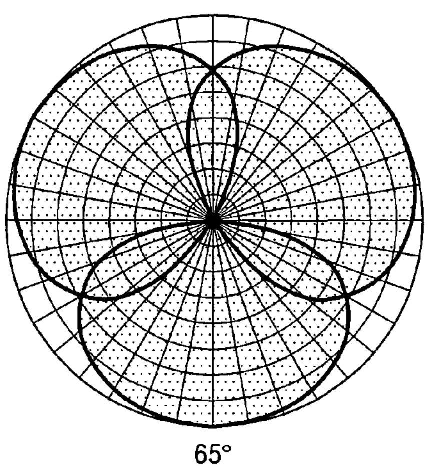


FIG. 9A

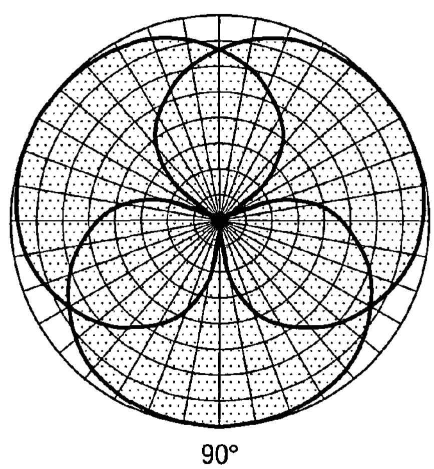


FIG. 9B

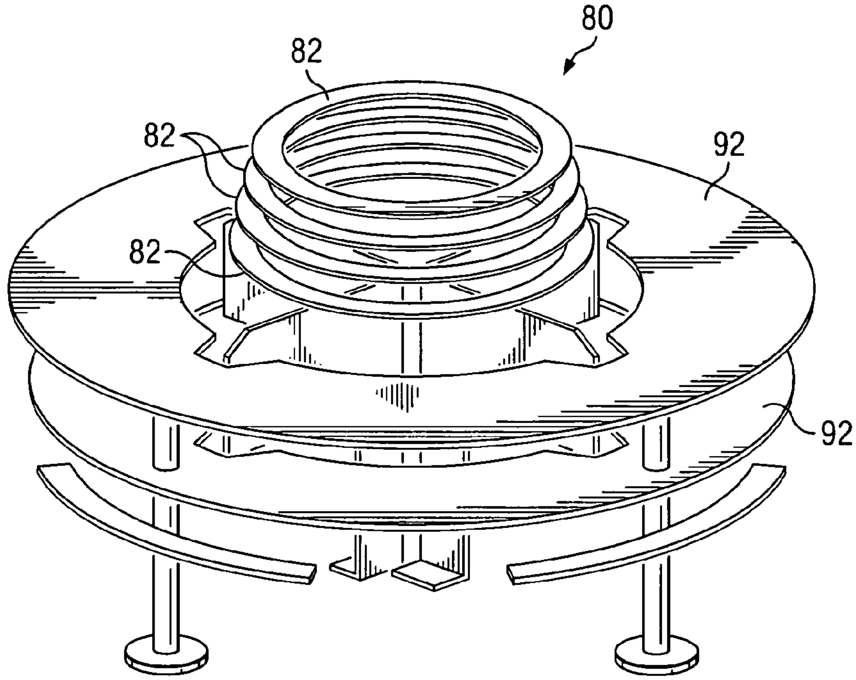


FIG. 10

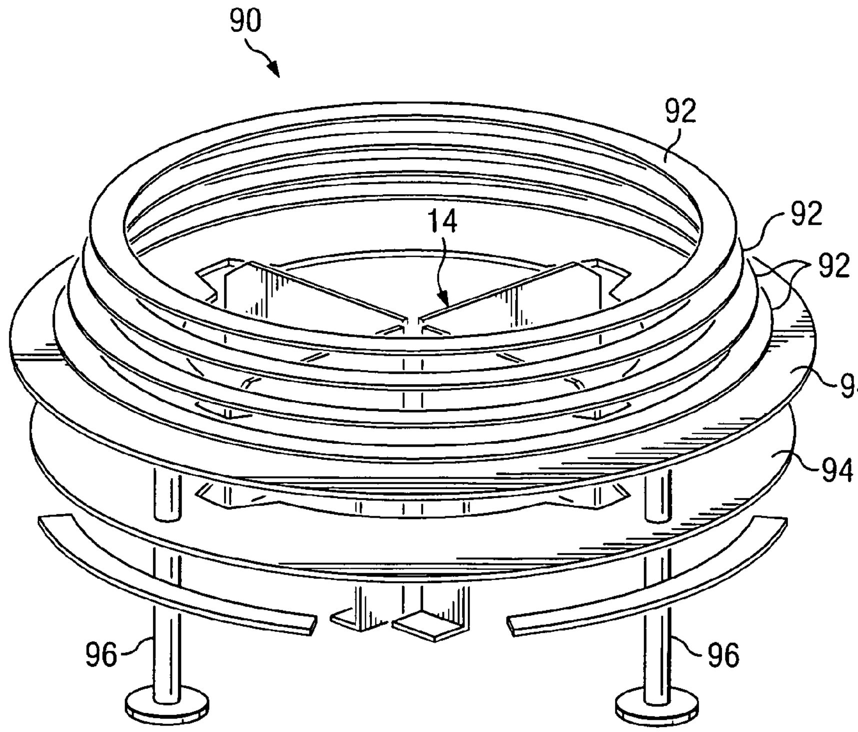


FIG. 11

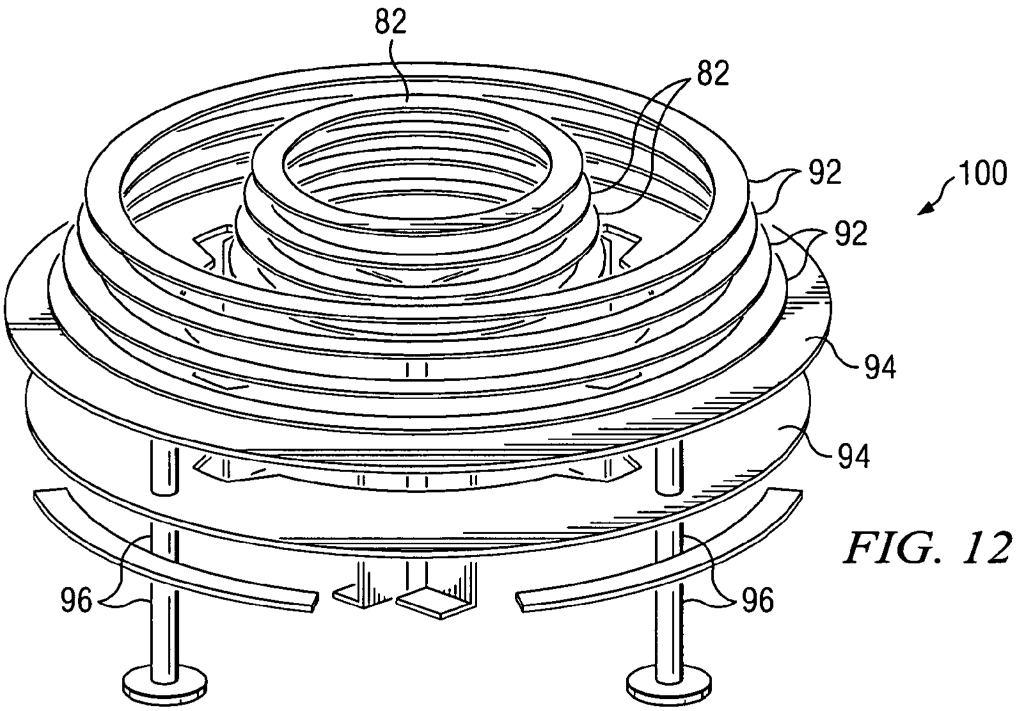


FIG. 12

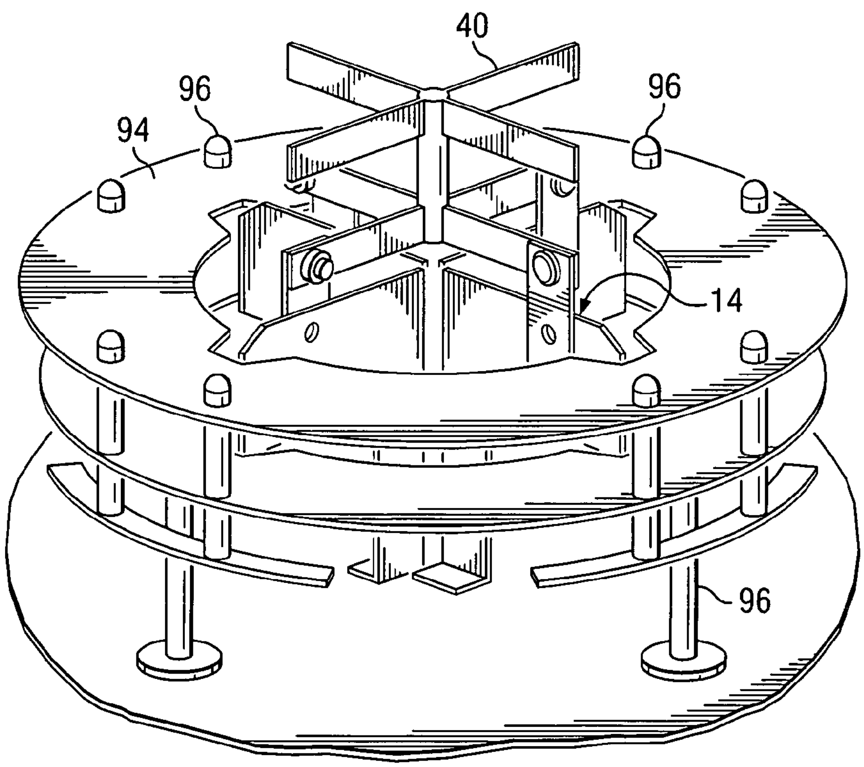


FIG. 14

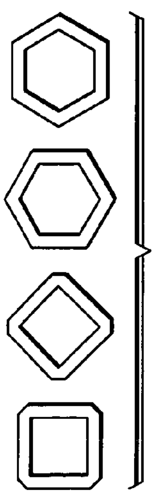


FIG. 13

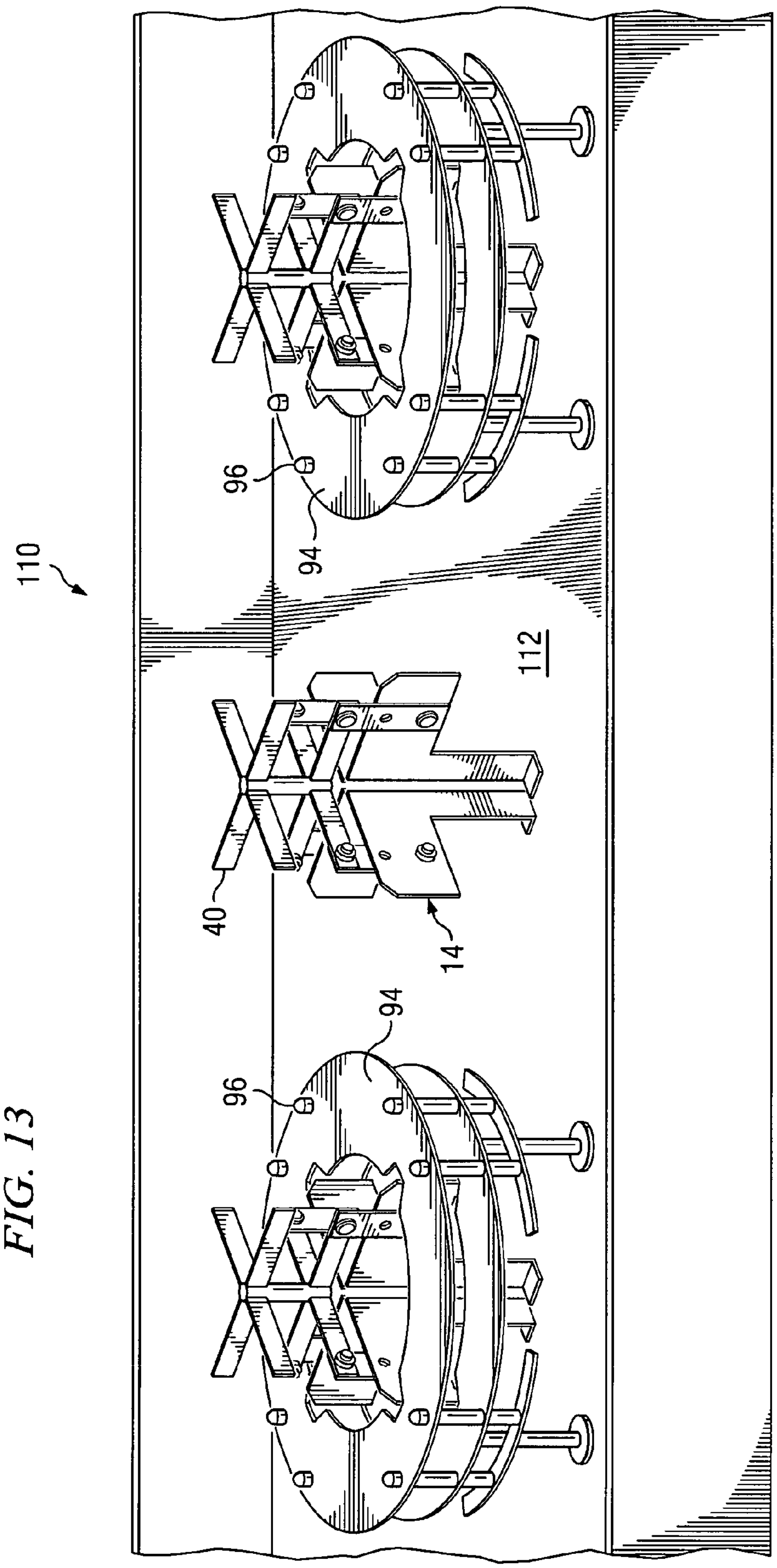


FIG. 15

DIRECTED DIPOLE ANTENNA

CLAIM OF PRIORITY

This application claims priority of U.S. Provisional Application Ser. No. 60/577,138 entitled "Antenna" filed Jun. 4, 2004, and is a Continuation-in-Part (CIP) of U.S. patent application Ser. No. 10/737,214 filed Dec. 16, 2003 now U. S. Pat. No. 6,924,776, entitled "Wideband Dual Polarized Base Station Antenna Offering Optimized Horizontal Beam Radiation Patterns And Variable Vertical Beam Tilt", which application claims priority of U.S. Provisional Patent Application Ser. No. 60/484,688 entitled "Balun Antenna With Beam Director" filed Jul. 3, 2003, and is also a Continuation-in-Part of U.S. patent application Ser. No. 10/703,331 filed Nov. 7, 2003, entitled "Antenna Element, Feed Probe, Dielectric Spacer, Antenna and Method of Communicating with a Plurality of Devices", which application claims priority of U.S. Provisional Patent Application Ser. No. 60/482,689 entitled "Antenna Element, Multiband Antenna, and Method of Communicating with a Plurality of Devices" filed Jun. 26, 2003, and is a Continuation-in-Part (CIP) of U.S. patent application Ser. No. 10/390,487 filed Mar. 17, 2003, entitled "Folded Dipole Antenna, Coaxial to Microstrip Transition, and Retaining Element, and claims the benefit of priority from U.S. Provisional Patent Application Ser. No. 60/433,352, filed on Dec. 13, 2002.

BACKGROUND OF THE INVENTION

Wireless mobile communication networks continue to be deployed and improved upon given the increased traffic demands on the networks, the expanded coverage areas for service and the new systems being deployed. Cellular type communication systems derive their name in that a plurality of antenna systems, each serving a sector or area commonly referred to as a cell, are implemented to effect coverage for a larger service area. The collective cells make up the total service area for a particular wireless communication network.

Serving each cell is an antenna array and associated switches connecting the cell into the overall communication network. Typically, the antenna array is divided into sectors, where each antenna serves a respective sector. For instance, three antennas of an antenna system may serve three sectors, each having a range of coverage of about 120°. These antennas are typically vertically polarized and have some degree of downtilt such that the radiation pattern of the antenna is directed slightly downwardly towards the mobile handsets used by the customers. This desired downtilt is often a function of terrain and other geographical features. However, the optimum value of downtilt is not always predictable prior to actual installation and testing. Thus, there is always the need for custom setting of each antenna downtilt upon installation of the actual antenna. Typically, high capacity cellular type systems can require re-optimization during a 24 hour period. In addition, customers want antennas with the highest gain for a given size and with very little intermodulation (IM). Thus, the customer can dictate which antenna is best for a given network implementation.

It is a further objective of the invention to provide a dual polarized antenna having improved directivity and providing improved sector isolation to realize an improved Sector Power Ratio (SPR).

It is an objective of the present invention to provide a dual polarized antenna array having optimized horizontal plane radiation patterns. One objective is to provide a radiation pattern having at least a 20 dB horizontal beam front-to-side ratio, at least a 40 dB horizontal beam front-to-back ratio, and improved roll-off.

It is another objective of the invention to provide an antenna array with optimized cross polarization performance with a minimum of 10 dB co-pol to cross-pol ratio in a 120 degree horizontal sector.

It is another objective of the invention to provide an antenna array with a horizontal pattern beamwidth of 50° to 75°.

It is another objective of the invention to provide an antenna array with minimized intermodulation.

It is an objective of the invention to provide a dual polarized antenna array capable of operating over an expanded frequency range.

It is a further objective of the invention to provide a dual polarized antenna array capable of producing adjustable vertical plane radiation patterns.

It is another objective of the invention to provide an antenna with enhanced port to port isolation of at least 30 dB.

It is further object of the invention to provide an inexpensive antenna.

These and other objectives of the invention are provided by an improved antenna array for transmitting and receiving electromagnetic waves with +45° and −45° linear polarizations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a dual polarized antenna according to a first preferred embodiment of the present invention;

FIG. **2** is a perspective view of a multi-level groundplane structure with a broadband slant **45** cross dipole radiating element removed therefrom, and a tray cutaway to illustrate a tilting of the groundplanes and an RF absorber in a RF choke;

FIG. **3** is a perspective view of N cross-shaped directors supported above the dipole radiating element;

FIG. **4** is a backside view of one element tray illustrating a microstrip phase shifter design employed to feed each pair of the cross dipole radiating elements;

FIG. **5** is a backside view of the dual polarized antenna illustrating the cable feed network, each microstrip phase shifter feeding one of the other dual polarized antennas;

FIG. **6** is a perspective view of the dual polarized antenna including an RF absorber functioning to dissipate RF radiation from the phase shifter microstriplines, and preventing the RF current cross coupling;

FIG. **7** is a graph depicting the high roll-off radiation pattern achieved by the present invention, as compared to a typical cross dipole antenna radiation pattern;

FIGS. **8**A and **8**B are graphs depicting the beam patterns in a three sector site utilizing standard panel antennas;

FIGS. **9**A and **9**B are graphs depicting the beam patterns in a three sector site utilizing antennas according to the present invention;

FIG. **10** is a perspective view of another embodiment of the invention including dual-band radiating elements;

FIG. **11** is a perspective view of the embodiment shown in FIG. **10** having director rings disposed over one of the radiating elements;

FIG. **12** is a perspective view of an embodiment of the invention having director rings disposed over each of the radiating elements;

FIG. **13** is a view of various suitable configurations of directors;

FIG. **14** is a close-up view of a dual-band antenna; and

FIG. **15** depicts an array of dual-band and single-band dipole radiating elements.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **1**, there is generally shown at **10** a wideband dual polarized base station antenna having an optimized horizontal radiation pattern and also having a variable vertical beam tilt. Antenna **10** is seen to include a plurality of element trays **12** having disposed thereon broadband slant **45** cross dipole (x-dipole) radiating elements **14** arranged in dipole pairs **16**. Each of the element trays **12** is tilted and arranged in a "fallen domino" arrangement and supported by a pair of tray supports **20**. The integrated element trays **12** and tray supports **20** are secured upon and within an external tray **22** such that there is a gap laterally defined between the tray supports **20** and the sidewalls of tray **22**, as shown in FIG. **1** and FIG. **2**. Each tray element **12** has an upper surface defining a groundplane for the respective dipole pair **16**, and has a respective air dielectric micro stripline **30** spaced thereabove and feeding each of the dipole radiating elements **14** of dipole pairs **16**, as shown. A plurality of electrically conductive arched straps **26** are secured between the sidewalls of tray **22** to provide both rigidity of the antenna **10**, and also to improve isolation between dipole radiating elements **14**.

As shown, a pair of cable supports **32** extend above each tray element **12**. Supports **32** support a respective low IM RF connection cables **34** from a cable **76** to the air dielectric micro stripline **30** and to microstrip feed network defined on a printed circuit board **50** adhered therebelow, as will be discussed in more detail shortly with reference to FIG. **4**.

Referring now to FIG. **2**, there is shown a perspective view of the element trays **12** with the sidewall of one tray support **20** and tray **22** partially cut away to reveal the tilted tray elements **12** configured in the "fallen domino" arrangement. Each tray element **12** is arranged in a this "fallen domino" arrangement so as to orient the respective dipole radiating element **14** pattern boresight at a predetermined downtilt, which may, for example, be the midpoint of the array adjustable tilt range. The desired maximum beam squint level of antenna **10** in this example is consistent with about 4° downtilt off of mechanical boresight, instead of about 8° off of mechanical boresight as would be the case without the tilt of the element trays **12**. According to the present invention, maximum horizontal beam squint levels have been reduced to about 5° over conventional approaches, which is very acceptable considering the antenna's wide operating bandwidth and tilt range.

Still referring to FIG. **2**, there is illustrated that the tray supports **20** are separated from the respective adjacent sidewalls of tray **22** by an elongated gap defining an RF choke **36** therebetween. This choke **36** created by physical geometry advantageously reduces the RF current that flows on the backside of the external tray **22**. The reduction of induced currents on the backside of the external tray **22** directly reduces radiation in the rear direction. The critical design criteria of this RF choke **36** involved in maximizing the radiation front-to-back ratio includes the height of the folded up sidewalls **38** of external tray **22**, the height of the tray supports **20**, and the RF choke **36** between the tray supports **20** and the sidewall lips **38** of tray **22**. The RF choke **36** is preferably lambda /4 of the radiating element **14** center frequency, and the RF choke **36** has a narrow bandwidth which is frequency dependent because of internal reflection cancellation in the air dielectric, the choke bandwidth being about 22 percent of the center frequency.

According to a further embodiment of the present invention, an RF absorber **39** may be added into the RF choke **36** to make the RF choke less frequency dependent, and thus create a more broadband RF choke. The RF absorber **39** preferably contains a high percentage of carbon that slows and dissipates any RF reflection wave from effecting the main beam radiation produced by the cross dipole antenna **12**. The slant 45 degree cross dipole antenna **14**, as shown, produces a cross polarized main beam radiation at a ±-45 degree orientation, each beam having a horizontal component and a vertical component. The cross polarization is good when these components are uniform and equal in magnitude in 360 degrees. For the panel antenna **10** shown in FIG. **1** with the linearly arranged cross dipoles **14**, the horizontal component of each beam orientation rolls off faster than the vertical component. This means that the vertical beamwidth is broader than the horizontal beamwidth for each beam orientation, and the vertical components travel along the edge of the respective trays **12** more than the horizontal components. Because the thin metal trays **12** have limited surface area, the surface currents thereon are less likely to reflect the horizontal components back to the main beam radiation. In contrast, along the edges of the respective trays **12** the stair cased baffles **35** have to contain many of the vertical component vector currents. Advantageously, by adding the RF absorber **39** into the RF choke **36**, the vertical components of each beam orientation are minimized from reflecting back into the main beam radiation of the cross dipole **14**. As such, cross dipoles **14** are not provided with a reflector behind them.

A dual polarized variable beam tilt antenna having a superior Sector Power Ratio (SPR). The antenna may have slant 45 degree dipole radiating elements including directors, and may be disposed on a plurality of tilted element trays to orient an antenna boresight downtilt. The directors may be disposed above or about the respective dipole radiating elements. The antenna has a beam front-to-side ratio exceeding 20 dB, a horizontal beam front-to-back ratio exceeding 40 dB, a high-roll off, and is operable over an expanded frequency range.

Preferably, the element trays **12** are fabricated from brass alloy and are treated with a tin plating finish for solderability. The primary function of the element trays is to support the radiating element **14** in a specific orientation, as shown. This orientation provides more optimally balanced vertical and horizontal beam patterns for both ports of the antenna **10**. This orientation also provides improved isolation between each port. Additionally, the element trays **12** provide an RF grounding point at the coaxial cable/airstrip interface.

The tray supports are preferably fabricated from aluminum alloy. The primary function of the tray supports is to support the five element trays **12** in a specific orientation that minimizes horizontal pattern beam squint.

The external tray **22** is preferably fabricated from a thicker stock of aluminum alloy than element trays **12**, and is preferably treated with an alodine coating to prevent corrosion due to external environment conditions. A primary functions of the external tray **22** is to support the internal array components. A secondary function is to focus the radiated RF power toward the forward sector of the antenna

10 by minimizing radiation toward the back, thereby maximizing the radiation pattern front-to-back ratio, as already discussed.

Referring now to FIG. **3** there is depicted one radiator element **14** having N laterally extending parasitic broadband cross dipole directors **40** disposed above the radiating element **14** and fed by the airstrip feed network **30**, as shown. N is 1, 2, 3, 4 . . . , where N is shown to equal 4 in this embodiment. The upper laterally extending members of parasitic broadband cross dipole director **40** are preferably uniformly spaced from one another, with the upper members preferably having a shorter length, as shown for bandwidth broadening. The lower members of director **40** are more closely spaced from the radiating element **14**, so as to properly couple the RF energy to the director in a manner that provides pattern enhancement while maintaining an efficient impedance match such that substantially no gain is realized by the director **40**, unlike a Yagi-Uda antenna having a reflector and spaced elements each creating gain. Advantageously, rather than realized gain, an improved pattern rolloff is achieved beyond the 3 dB beamwidth of the radiation pattern while maintaining a similar 3 dB beamwidth. Preferably, the upper elements of directors **40** are spaced about 0.033 lambda (center frequency) from one another, with the lower director elements spaced from the radiating element **14** about 0.025 lambda by parasitic **42** (lambda being the wavelength of the center frequency of the radiating element **14** design).

Referring now to FIG. **4** there is shown one low loss printed circuit board (PCB) **50** having disposed thereon a microstrip capacitive phase shifter system generally shown at **52**. The low loss PCB **50** is secured to the backside of the respective element tray **12**. Microstrip capacitive phase shifter system **52** is coupled to and feeds the opposing respective pair of radiating elements **14** via the respective cables **34**.

As shown in FIG. **4**, each microstrip phase shifter system **52** comprises a phase shifter wiper arm **56** having secured thereunder a dielectric member **54** which is arcuately adjustable about a pivot point **58** by a respective shifter rod **60**. Shifter rod **60** is longitudinally adjustable by a remote handle (not shown) so as to selectively position the phase shifter wiper arm **56** and the respective dielectric **54** across a pair of arcuate feedline portions **62** and **64** to adjust the phase velocity conducting therethrough. Shifter rod **60** is secured to, but spaced above, PCB **50** by a pair of non-conductive standoffs **66**. The low loss coaxial cables **34** are employed as the main transmission media providing electrical connection between the phase shifter system **52** and the radiating elements **14**. Gain performance is optimized by closely controlling the phase and amplitude distribution across the radiating elements **14** of antenna **10**. The very stable phase shifter design shown in FIG. **4** achieves this control.

Referring now to FIG. **5**, there is shown the backside of the antenna **10** illustrating the cable feed network, each microstrip phase shifter system **52** feeding one of the other polarized antennas **14**. Input **72** is referred as port I and is the input for the −45 polarized Slant, and input **74** is the port II input for the +45 polarized Slant. Cables **76** are the feed lines coupled to one respective phase shifter system **52**, as shown in FIG. **4**. The outputs of phase shifter system **52**, depicted as outputs **1**-**5**, indicate the dipole pair **16** that is fed by the respective output of the phase shifter **52** system.

Referring now to FIG. **6**, there is shown antenna **10** further including an RF absorber **78** positioned under each of the element trays **12**, behind antenna **10**, that functions to

dissipate any rearward RF radiation from the phase shifter microstrip lines, and preventing RF current from coupling between phase shifters systems **52**.

Referring now to FIG. **7**, there is generally shown at **68** the high roll-off and front-to-back ratio radiation pattern achieved by antenna **10** according to the present invention, as compared to a standard 65° panel antenna having a dipole radiation pattern shown at **69**. This high roll-off radiation pattern **68** is a significant improvement over the typical dipole radiation pattern **69**. The horizontal beam width still holds at approximately 65 degree at the 3 dB point.

Further, the design of the radiating elements **14** with directors **40** provides dramatic improvements in the antenna's horizontal beam radiation pattern, "where the Front-to-Side levels are shown to be 23 dB in FIG. **7**. Conventional, cross dipole radiating elements produce a horizontal beam radiation pattern with about a 17 dB front-to-side ratio, as shown in FIG. **7**. According to the present invention, the broadband parasitic directors **40** integrated above the radiating elements **14** advantageously improve the antenna front-to-side ratio by up to 10 dB, and is shown as 6 dB delta in the example of FIG. **7**. This improved front-to-side ratio effect is referred to as a "high roll-off" design. In this embodiment, radiating elements **14** and cross dipole directors **40** advantageously maintain an approximately 65 degree horizontal beamwidth at the antenna's 3 dB point, unlike any conventional Yagi-Uda antenna having more directors to get more gain and thus reducing the horizontal beamwidth.

Still referring to FIG. **7**, there is shown the excellent front-to-back ratio of antenna **10**. As shown, panel antenna **10** has a substantially reduced backside lobe, thus achieving a front-to-back ratio of about 40 dB. Moreover, antenna **10** has a next sector antenna/antenna isolation of about 40 dB, as compared to 26 dB for the standard 65° panel antenna. As can also be appreciated in FIG. **7**, with the significant reduction of a rear lobe, a 120° sector interference free zone is provided behind the radiation lobe, referred to in the present invention as the "cone of silence".

Referring now to FIGS. **8**A and **8**B, there is shown several advantages of the present invention when employed in a three sector site. FIG. **8**A depicts standard 65° flat panel antennas used in a three sector site, and FIG. **8**B depicts standard 90° panel antennas used in a three sector site. The significant overlap of these antenna radiation patterns creates imperfect sectorization that presents opportunities for increased softer hand-offs, interfering signals, dropped calls, and reduced capacity.

Referring now to FIGS. **9**A and **9**B, there is shown technical advantages of the present invention utilizing a 65° panel antenna and a 90° panel antenna, respectively according to the present invention, employed in a three sector site. With respect to FIG. **9**A, there is depicted significantly reduced overlap of the antenna radiation lobes, thus realizing a much smaller hand-off area. This leads to dramatic call quality improvement, and further, a 5-10% site capacity enhancement.

Referring back to FIG. **7**, the undesired lobe extending beyond the 120° sector of radiation creates overlap with adjacent antenna radiation patterns, as shown in FIG. **8**A-**8**B and FIG. **9**A-**9**B. The undesired power delivered in the lobe outside of the 120° forward sector edges, as compared to that desired power delivered inside this 120° sector, defines what is referred to as the Sector Power Ratio (SPR). Advantageously, the present invention achieves a SPR being less than 2%, where the SPR is defined by the following equation:

$$SPR(\%) = \frac{\sum_{60}^{300} P \text{ Undesired}}{\sum_{300}^{60} P \text{ Desired}} \times 100$$

This SPR is a significant improvement over standard panel antennas, and is one measure of depicting the technical advantages of the present invention. The directors **40** are impedance matched at 90 ohms, although limitation to this impedance is not inferred, to the micro stripline **30**. The radiating elements **14** and the cross dipole directors **40** have mutual instantaneous electromagnetic coupling which generate with source impedance at 90 ohm and source voltage of a matching network. Many other system level performance benefits are afforded by incorporation of this high roll-off antenna design, including improved soft handoff capabilities, reduced co-site channel interference and increased base station system capacity due to increased sector-to-sector rejection.

Referring now to FIG. **10**, there is shown another preferred embodiment of the invention seen to comprise a band, dualpol antenna **80** including one slant **45** crossed dipole radiating element **14** and a slant **45** microstrip Annular Ring (MAR) radiator **94** encircling said dipole, as will be described shortly in reference to FIG. **11**. In this embodiment, antenna **80** includes N annular (ring-like) directors **82** disposed above the radiating element **14**, where N=1, 2, 3, 4 . . . . The N directors **82** are configured as vertically spaced parallel polygon-shaped members, shown as concentric rings, although limitation to this geometry of directors **82** is not to be inferred. Other geometric configurations of the directors may be utilized as shown in FIG. **13**.

The ring directors **82** react with the corresponding dipole radiating element **14** to enhance the front-to-side ratio of antenna **10** with improved rolloff. The ring directors **82** are preferably uniformly spaced above the corresponding x-dipole radiating element **14**, with the ascending ring directors **82** having a continually smaller circumference. The ring directors **82** maintain a relatively close spacing with one another being separated by electrically non-conductive spacers, not shown, preferably being spaced less than 0.15 lambda (lambda being the wavelength of the center frequency of the antenna design). Additionally, the grouping of ring directors **82** maintain a relatively close spacing between the bottommost director **82** and the top of the corresponding dipole radiating element **14**, preferably less than 0.15 lambda. There are a variety of methods to build the set of planar directors **82**, such as molded forms and electrically insulating clips.

The set of stacked ring directors **82** may also consist of rings of equal circumference while maintaining similar performance of improved roll-off leading to an improved SPR with the previously stated system benefits while maintaining a similar 3 dB beamwidth.

Referring now to FIG. **11**, there is shown at **90** a dual-band antenna including a set of director rings **92** disposed above a stacked Microstrip Annular Ring (MAR) radiator **94**. In this view, there are four feedprobes **96** (2 balanced feed pairs) arranged in pairs feeding dual orthogonal polarizations of the MAR radiator **94**. The directors **92** in this embodiment of the invention are thin rings stacked above the respective MAR radiator **94**, as shown. Advantageously, this dual-band antenna **90** also has improved element pattern roll-off beyond the 3 dB beamwidth thus increasing the SPR while maintaining an equivalent 3 dB beamwidth.

Referring now to FIG. **12**, there is shown a dual-band antenna **100** having ring directors **82** and **92**. The ring directors **92** above the MAR radiator **94** also interact with the x-dipole radiating element **14** and provide some additional beamshaping for the x-dipole radiating element, including improved roll-off of the main beam outside of the 3 dB beamwidth as well as improved front-to-back radiation leading to an improved SPR and the system benefits previously mentioned while maintaining a similar 3 dB beamwidth.

Both the MAR radiator element **94** and the x-dipole radiating element **14** have respective ring directors thereabove. The ring directors **82** for the x-dipole radiating element **14** are also concentric to the ring directors **92** for the MAR radiator **94**. The same benefits as discussed earlier for the directors are applicable here as well per frequency band (i.e. improved roll-off beyond the 3 dB beamwidth and front-to-back ratio leading to improved SPR.

Referring now to FIG. **13**, there is shown other suitable geometrical configurations of directors **82** and **92**, and limitation to a circular ring-like director is not to be inferred. A circle is considered to be an infinitely sided polygon where the term polygon is used in the appending claims.

Referring now to FIG. **14** , there is shown a close-up view of dual band antenna **80** having cross shaped directors **40** extending over the radiating element **14**, and the MAR radiator **94** without the associated annular director.

Referring now to FIG. **15**, there is shown a panel antenna **110** having an array of radiating elements **14**, each having cross directors **40**, alternately provided with the MAR radiators **94**, each disposed over common groundplane **112**. The advantages of this design include an improved H-plane pattern for the higher frequency radiating element in a dualband topology. The improved H-plane pattern provides improved roll-off beyond the 3 dB beamwidth and improved front-to-back ratio. The improved roll-off additionally provides a slight decoupling of the radiators depending on the number of directors incorporated due to lower levels of side and back radiation.

Though the invention has been described with respect to a specific preferred embodiment, many variations and modifications will become apparent to those skilled in the art upon reading the present application. It is therefore the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.

We claim:

1. An antenna, comprising:

at least one slant 45 degree dipole radiating element adapted to generate a beam; and

at least one director disposed proximate the at least one dipole radiating element adapted to improve a Sector Power Ratio (SPR) of the beam while maintaining an equivalent 3 dB beamwidth, wherein the director has at least 2 members, wherein the members are cross-shaped members parallel to the slant 45 degree dipole radiating element in the vertical direction.

2. The antenna as specified in claim **1** wherein the antenna has a Sector Power Ratio of less than 10%.

3. The antenna as specified in claim **2** wherein the antenna has a Sector Power Ratio of less than 5%.

4. The antenna as specified in claim **3** wherein the antenna has a Sector Power Ratio of less than 2%.

5. The antenna as specified in claim **1** comprising at least 2 of the directors.

6. The antenna as specified in claim **5** wherein said at least 2 of the directors are parallel to one another.

7. The antenna as specified in claim **5** wherein at least some of the directors are uniformly spaced from one another.

8. The antenna as specified in claim **7** wherein one of the directors is spaced closer to the radiating element than an adjacent said director.

9. The antenna as specified in claim **1** wherein the radiating element is a cross dipole radiating element.

10. The antenna as specified in claim **1** wherein the members have different lengths and form a tapered director.

11. The antenna as specified in claim **1** wherein the antenna has a front-to-side ratio of at least 20 dB.

12. The antenna as specified in claim **1** wherein the antenna has a front-to-back ratio of at least 40 dB.

13. An antenna, comprising:

at least one slant 45 degree dipole radiating element adapted to generate a beam;

at least one director disposed proximate the at least one dipole radiating element adapted to improve a Sector Power Ratio (SPR) of the beam while maintaining an equivalent 3 dB beamwidth, wherein the at least one director comprises a polygon shaped ring.

14. The antenna as specified in claim **13**, further comprising a plurality of the polygon shaped rings disposed over the radiating element.

15. The antenna as specified in claim **14** wherein the polygon shaped rings are concentric.

16. The antenna as specified in claim **15** wherein the polygon shaped rings have a common diameter.

17. The antenna as specified in claim **15** wherein the polygon shaped rings have different diameters and form a tapered director.

18. An antenna, comprising:

a plurality of tilted groundplanes configured in a "fallen-domino" arrangement; and

a plurality of dipole radiating elements disposed above the groundplanes and configured such that the dipole radiating elements define a boresight downtilt.

19. The antenna as specified in claim **18** wherein the antenna has a beam downtilt, further comprising a feed network coupled to the plurality of dipole radiating elements and adapted to selectively adjust the antenna beam downtilt.

20. The antenna as specified in claim **19** wherein the boresight downtilt is defined at approximately a midpoint of an overall beam downtilt.

21. The antenna as specified in claim **20** wherein the groundplanes are disposed a fixed distance from one another.

22. The antenna as specified in claim **19** wherein the dipole radiating elements are grouped in pairs, wherein at least one said pair is defined on each of the groundplanes.

23. An antenna comprising a radiating element disposed over a tray having a backside and having at least one groundplane disposed above the tray, the tray having a side wall spaced from the groundplanes and defining a gap therebetween; and

wherein the gap forms a RF choke configured to reduce RF current flowing in the backside of the tray.

24. The antenna as specified in claim **23** further comprising an RF absorber disposed in the RF choke.

25. The antenna as specified in claim **23** wherein a height of the tray sidewall is configured to increase a front-to-back ratio of the antenna.

26. An antenna comprising a radiating element disposed over a tray having a backside and having at least one groundplane disposed above the tray, the tray having a side wall spaced from the groundplanes and defining a gap therebetween; and

further comprising an RF absorber disposed behind the groundplanes adapted to reduce RF current coupling between the groundplanes.

27. A dual-band antenna, comprising:

a first slant 45 degree dipole radiating element adapted to generate a first beam at a first frequency;

a first director disposed proximate the first radiating element adapted to improve a Sector Power Ratio of the beam while maintaining an equivalent 3 dB beamwidth; and

a second radiating element disposed proximate the first radiating element and adapted to generate a second beam at a second frequency.

28. The dual-band antenna as specified in claim **27**, further comprising a second director disposed proximate the second radiating element adapted to improve the Sector Power Ratio of the second beam while maintaining an equivalent 3 dB beamwidth.

29. The dual-band antenna as specified in claim **28** wherein the first director comprises at least two members.

30. The dual-band antenna as specified in claim **29** wherein the second director comprises at least two members.

31. The dual-band antenna as specified in claim **30** wherein the first and second directors are disposed over the respective first and second radiating elements.

32. The dual-band antenna as specified in claim **28** wherein the second director comprises at least one polygon-shaped member.

33. The dual-band antenna as specified in claim **27** wherein the second radiating element comprises a slant 45 degree microstrip annular ring radiating element.

34. The dual-band antenna as specified in claim **27** wherein the first radiating element comprises a cross-shaped radiator.

35. The dual-band antenna as specified in claim **34** wherein the second radiating element comprises a polygon-shaped radiator.

36. The dual-band antenna as specified in claim **35** wherein the first director comprises a plurality of the cross-shaped members.

37. The dual-band antenna as specified in claim **35** wherein the second director comprises a plurality of the polygon-shaped members.

38. The dual-band antenna as specified in claim **27** wherein the first director comprises at least one cross-shaped member.

39. The dual-band antenna as specified in claim **27** wherein the second radiating element encompasses the first radiating element.

40. The dual-band antenna as specified in claim **39** wherein the first radiating element comprises a cross-shaped dipole radiating element.

41. The dual-band antenna as specified in claim **39** wherein the second radiating element comprises a polygon.

42. An antenna, comprising:

a slant 45 degree dipole radiating element adapted to generate a beam; and

director means for directing the beam, wherein the director means includes at least one cross-shaped member parallel to the slant 45 degree radiating element.

43. The antenna as specified in claim **42** wherein the director means establishes a Sector Power Ratio of the beam being less than 10%.

44. The antenna as specified in claim **42** wherein the director means establishes a Sector Power Ratio of the beam being less than 5%.

45. The antenna as specified in claim **42** wherein the director means establishes a Sector Power Ratio of the beam being less than 2%.

46. The antenna as specified in claim **42** wherein the director means establishes a front-to-back ratio of the beam of at least about 40 dB.

47. The antenna as specified in claim **42** wherein the director means establishes a front-to-side ratio of the beam of at least about 20 dB.

* * * * *

EXHIBIT B

US007535430B2

(12) **United States Patent**
Le et al.

(10) **Patent No.: US 7,535,430 B2**
(45) **Date of Patent: *May 19, 2009**

(54) **DIRECTED DIPOLE ANTENNA HAVING IMPROVED SECTOR POWER RATIO (SPR)**

(75) Inventors: **Kevin Le**, Arlington, TX (US); **Louis J. Meyer**, Shady Shores, TX (US); **Pete Bisiules**, LaGrange Park, IL (US)

(73) Assignee: **Andrew LLC**, Hickory, NC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **11/999,679**

(22) Filed: **Dec. 6, 2007**

(65) **Prior Publication Data**

US 2008/0088521 A1 Apr. 17, 2008

Related U.S. Application Data

(63) Continuation of application No. 11/104,986, filed on Apr. 13, 2005, now Pat. No. 7,358,922, and a continuation-in-part of application No. 10/737,214, filed on Dec. 16, 2003, now Pat. No. 6,924,776, and a continuation-in-part of application No. 10/703,331, filed on Nov. 7, 2003, now Pat. No. 7,283,101.

(60) Provisional application No. 60/577,138, filed on Jun. 4, 2004, provisional application No. 60/484,688, filed on Jul. 3, 2003, provisional application No. 60/482,689, filed on Jun. 26, 2003.

(51) **Int. Cl.**
H01Q 21/26 (2006.01)
H01Q 21/00 (2006.01)
H01Q 19/10 (2006.01)

(52) **U.S. Cl.** **343/797**; 343/810; 343/818

(58) **Field of Classification Search** 343/793, 343/797, 810–820, 846
See application file for complete search history.

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7,358,922	B2 *	4/2008	Le et al.	343/797

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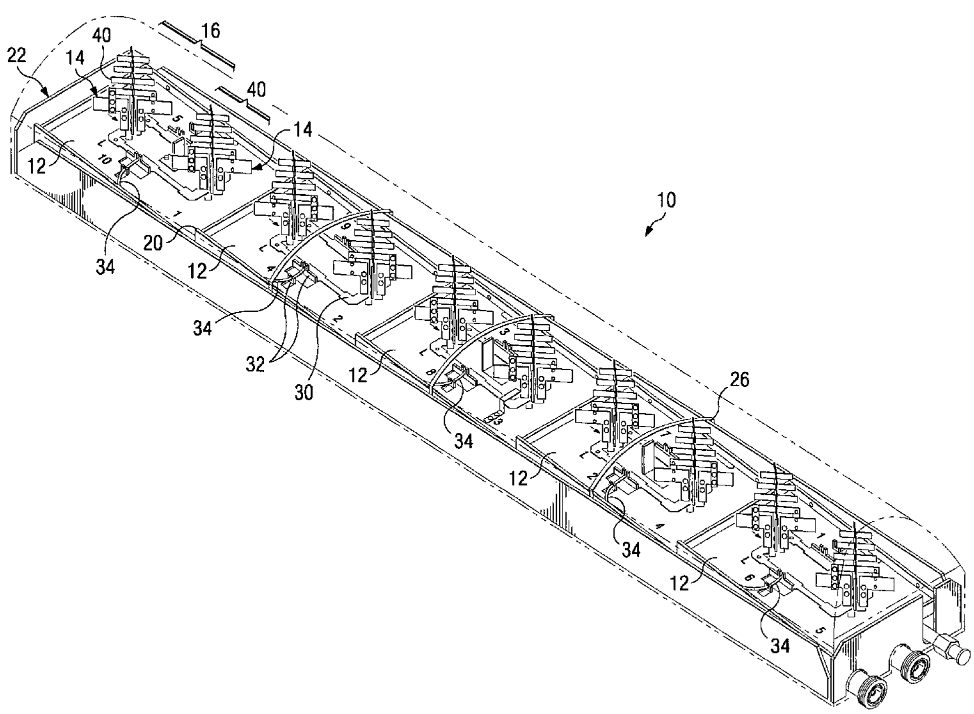
Primary Examiner—Shih-Chao Chen
(74) *Attorney, Agent, or Firm*—Robert C. Klinger

(57) **ABSTRACT**

A dual polarized variable beam tilt antenna having a superior Sector Power Ratio (SPR). The antenna may have slant 45 degree dipole radiating elements including directors, and may be disposed on a plurality of tilted element trays to orient an antenna boresight downtilt. The directors may be disposed above or about the respective dipole radiating elements. The antenna has a beam front-to-side ratio exceeding 20 dB, a horizontal beam front-to-back ratio exceeding 40 dB, a high-roll off, and is operable over an expanded frequency range.

25 Claims, 11 Drawing Sheets



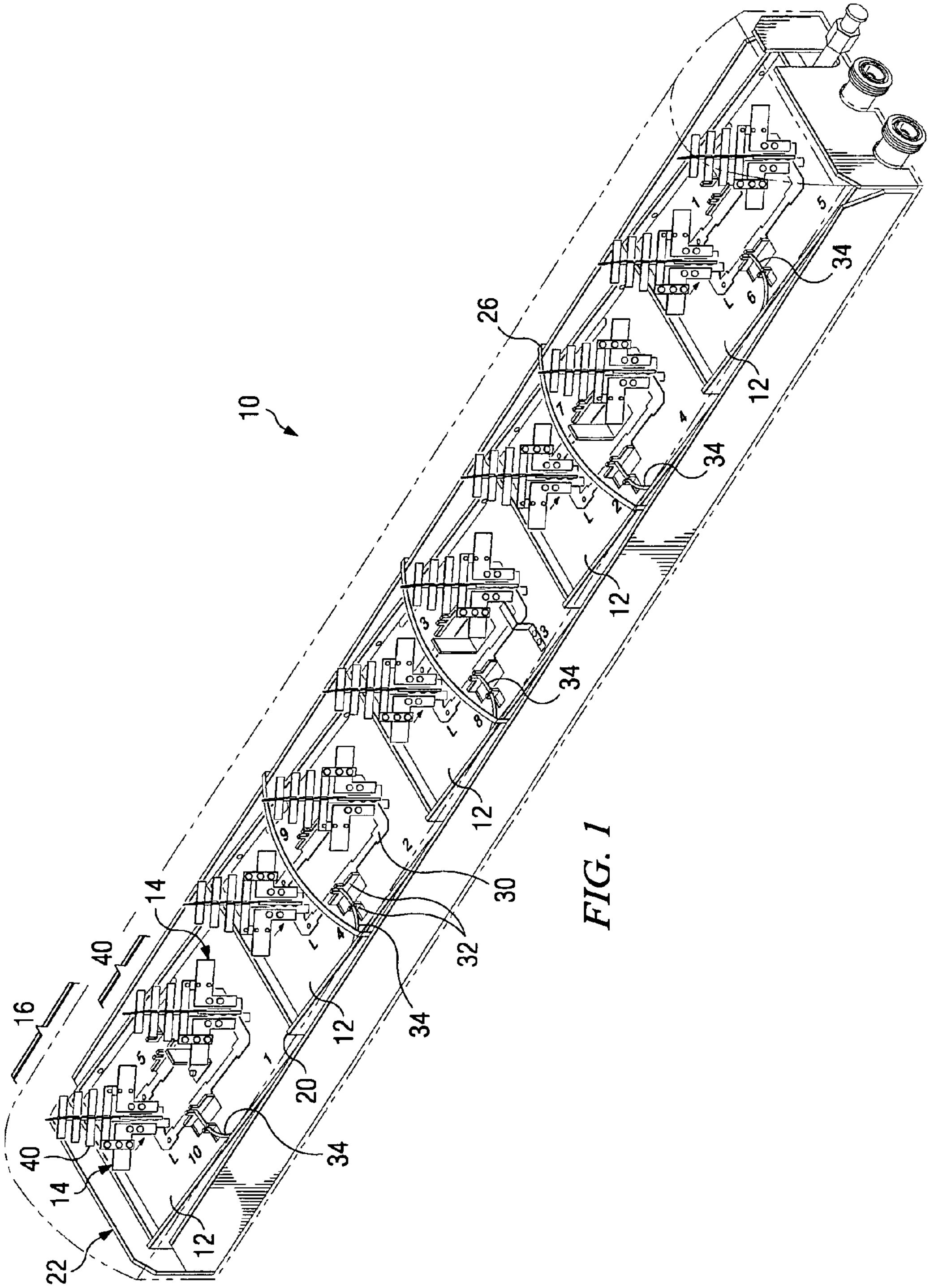


FIG. 1

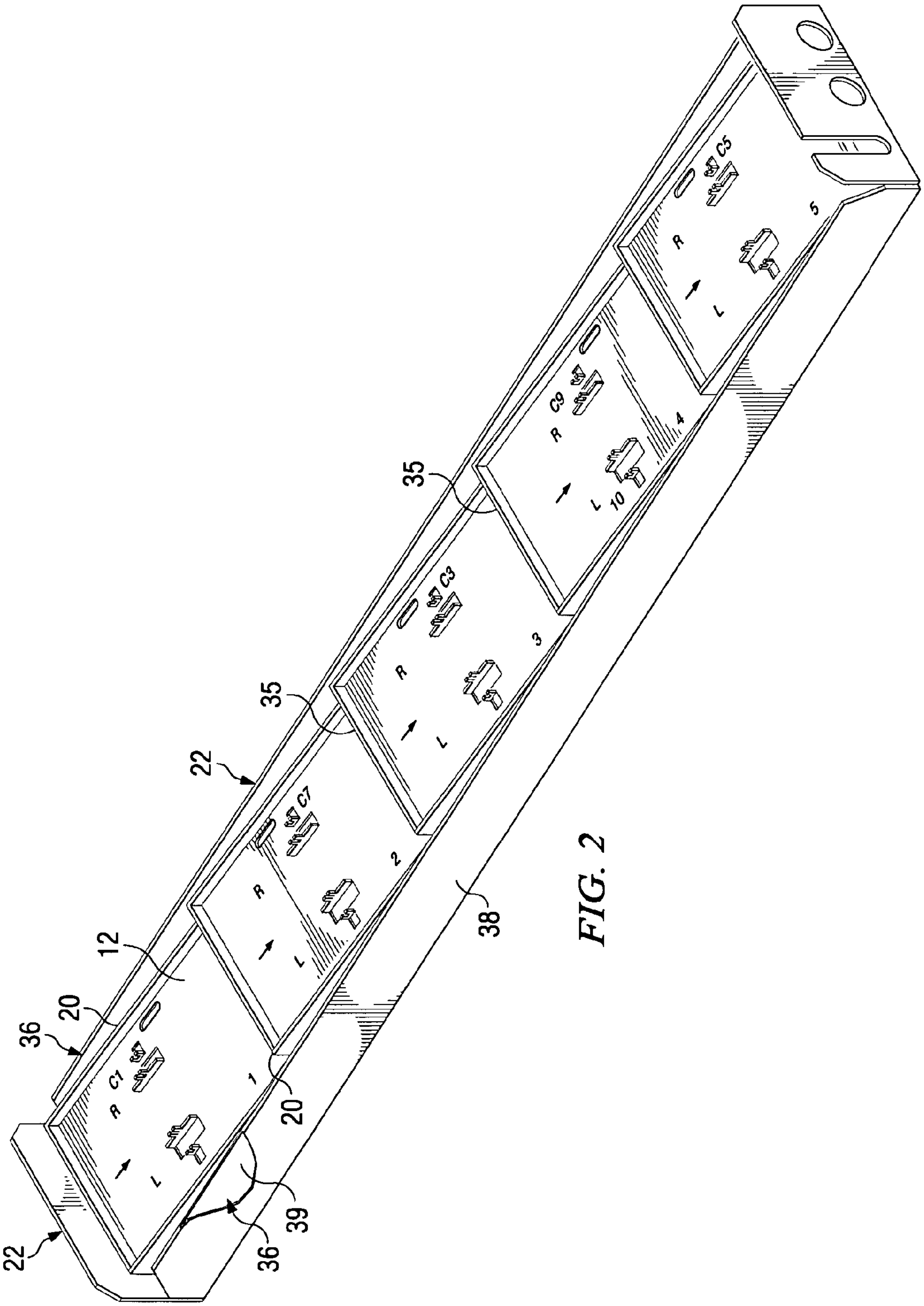


FIG. 2

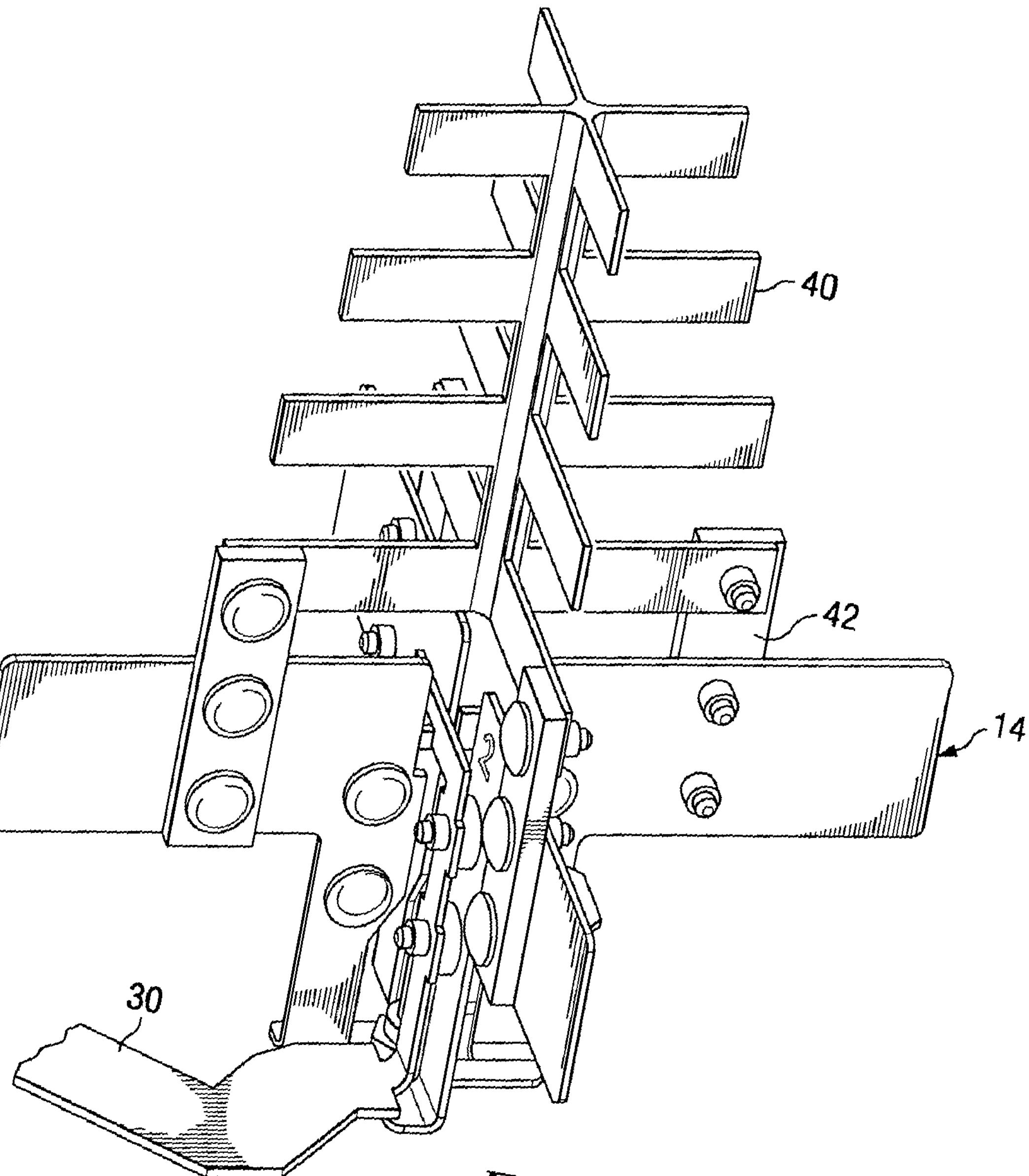


FIG. 3

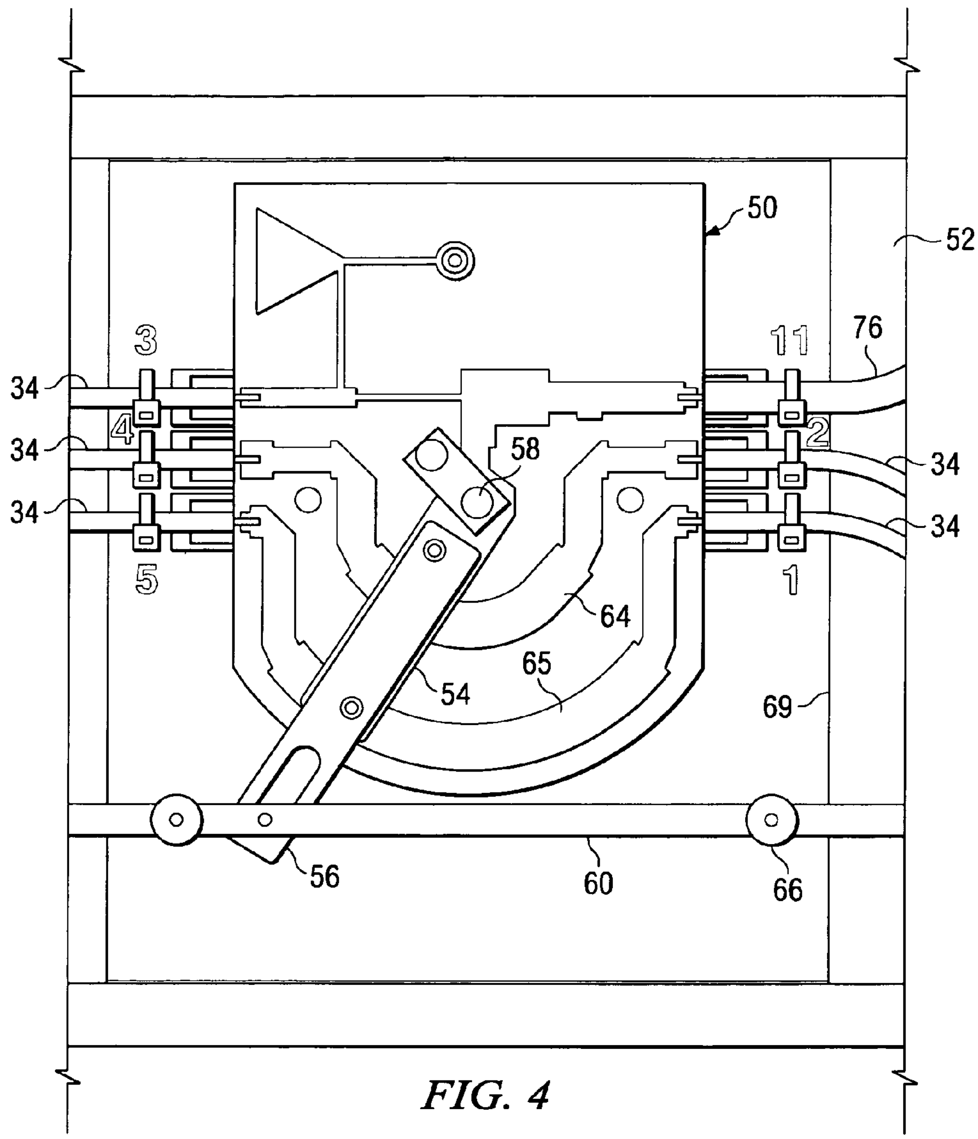


FIG. 4

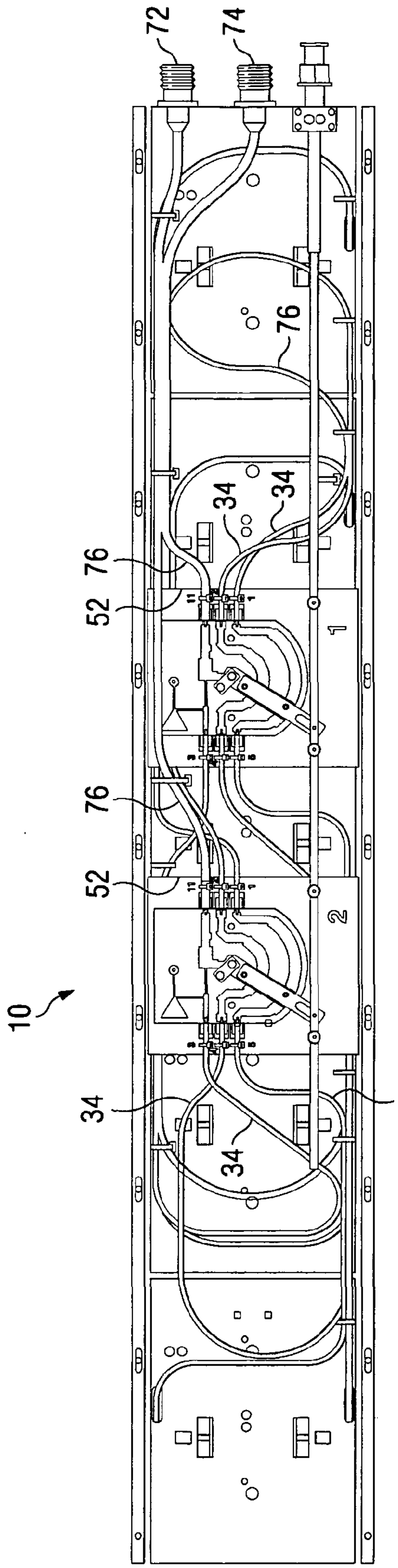


FIG. 5

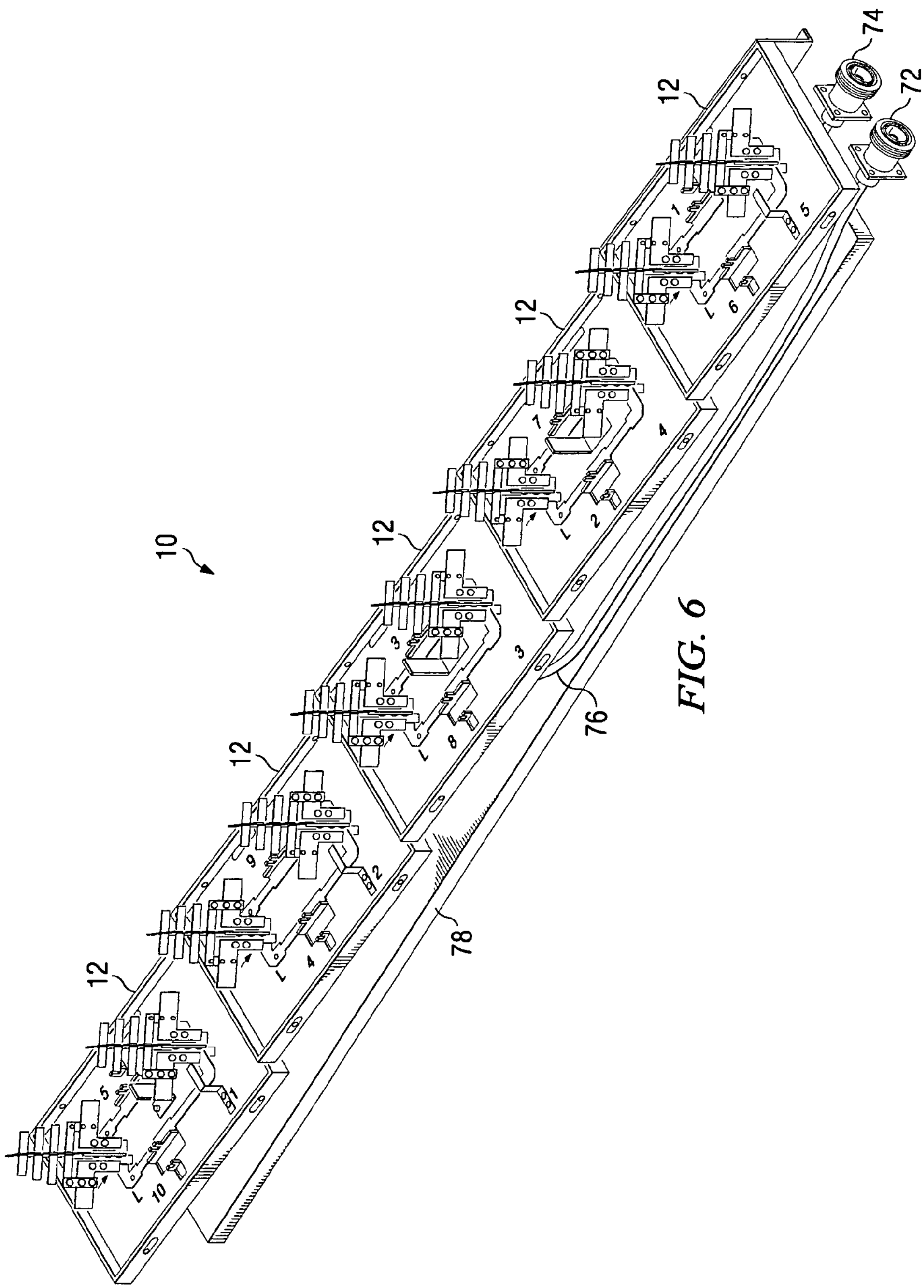


FIG. 6

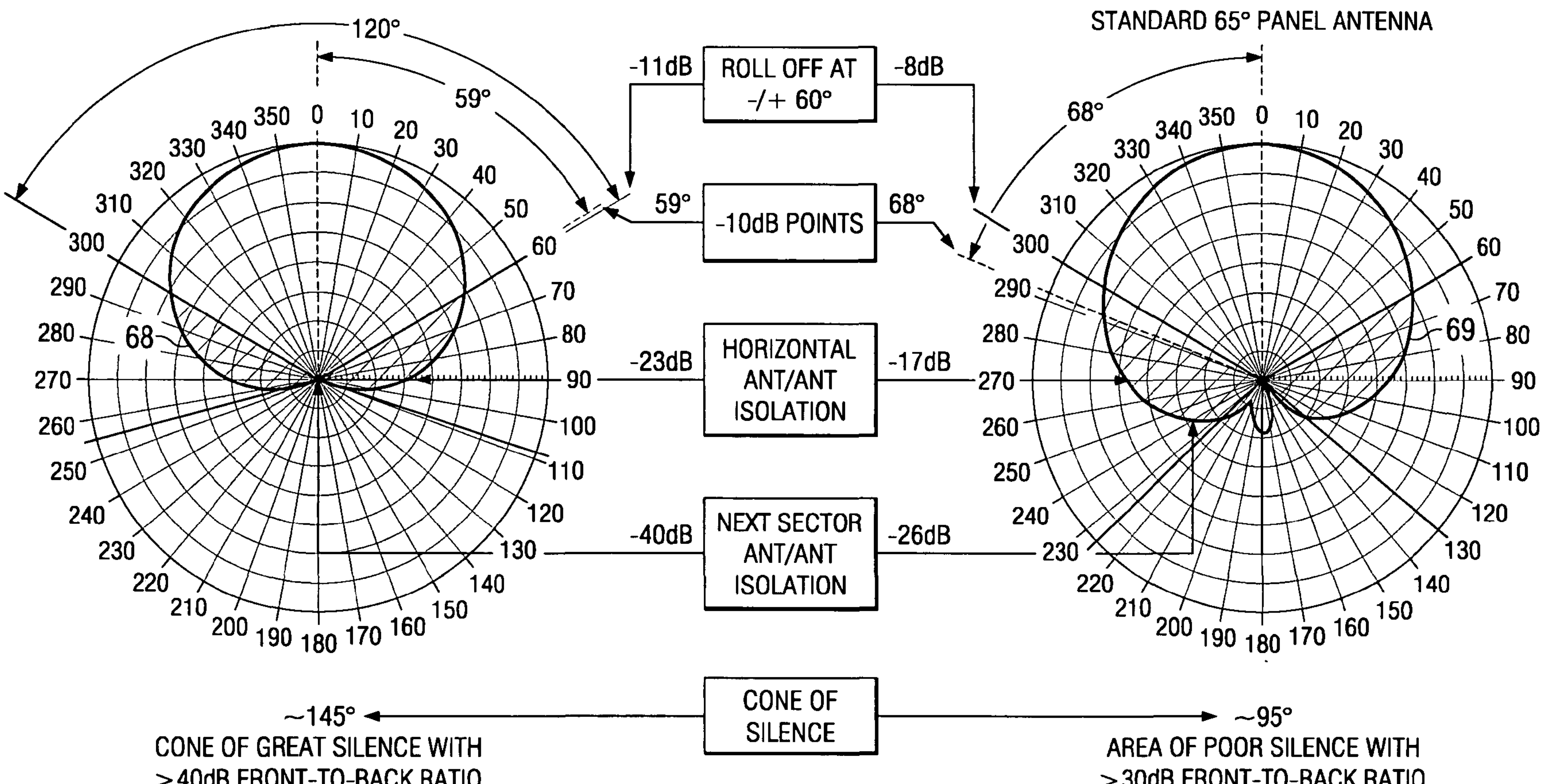
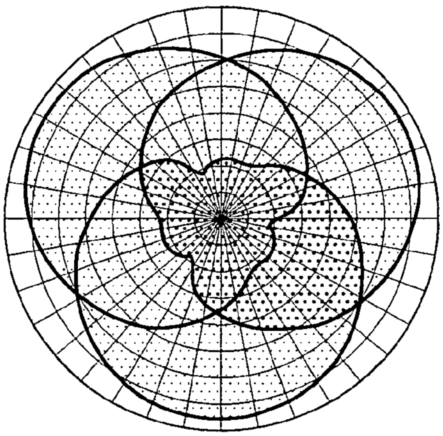
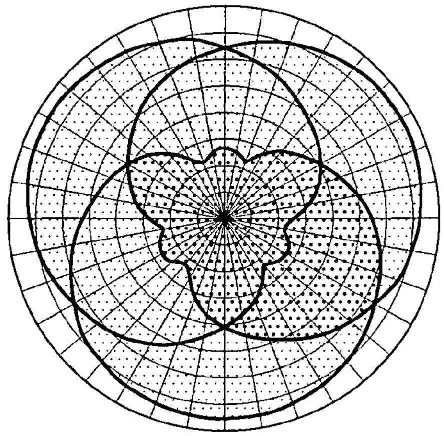

120°
59°
STANDARD 65° PANEL ANTENNA
68°
-11dB
ROLL OFF AT -/+ 60°
-8dB
59°
-10dB POINTS
68°
68
69
-23dB
HORIZONTAL ANT/ANT ISOLATION
-17dB
-40dB
NEXT SECTOR ANT/ANT ISOLATION
-26dB
CONE OF SILENCE
~145°
CONE OF GREAT SILENCE WITH >40dB FRONT-TO-BACK RATIO
~95°
AREA OF POOR SILENCE WITH >30dB FRONT-TO-BACK RATIO

FIG. 7



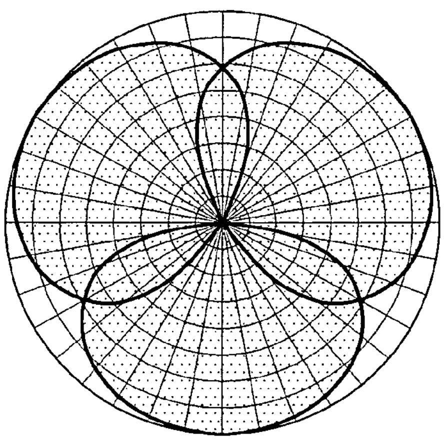
65°

FIG. 8A



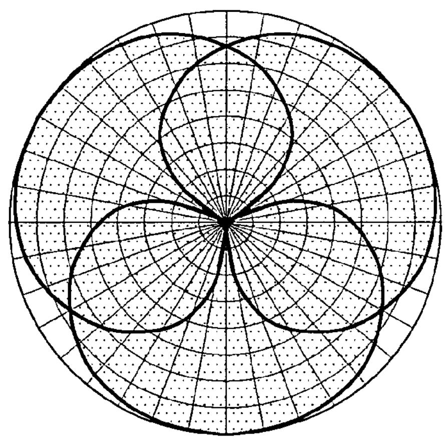
90°

FIG. 8B



65°

FIG. 9A



90°

FIG. 9B

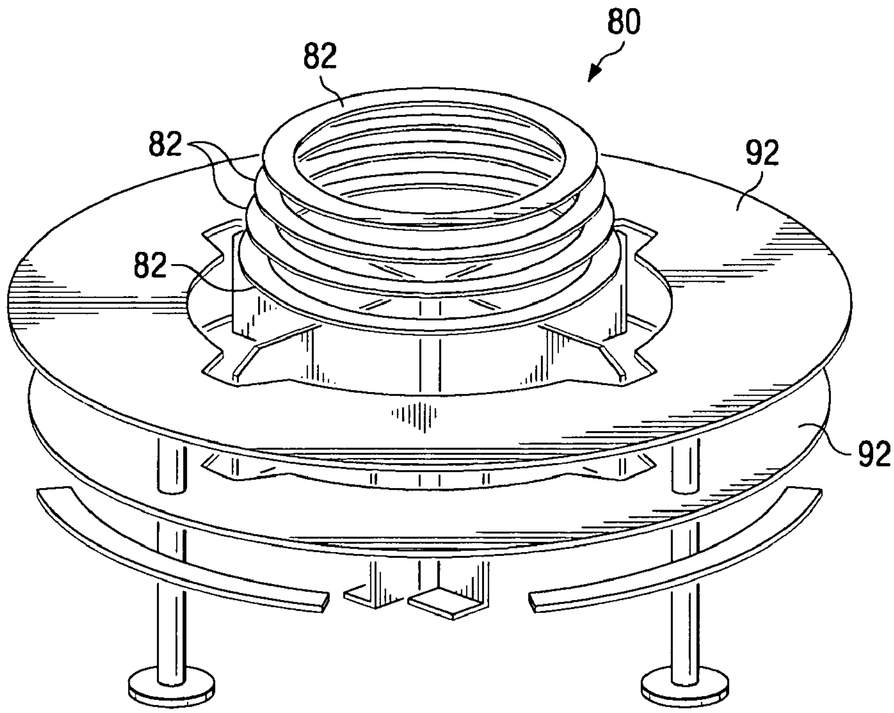


FIG. 10

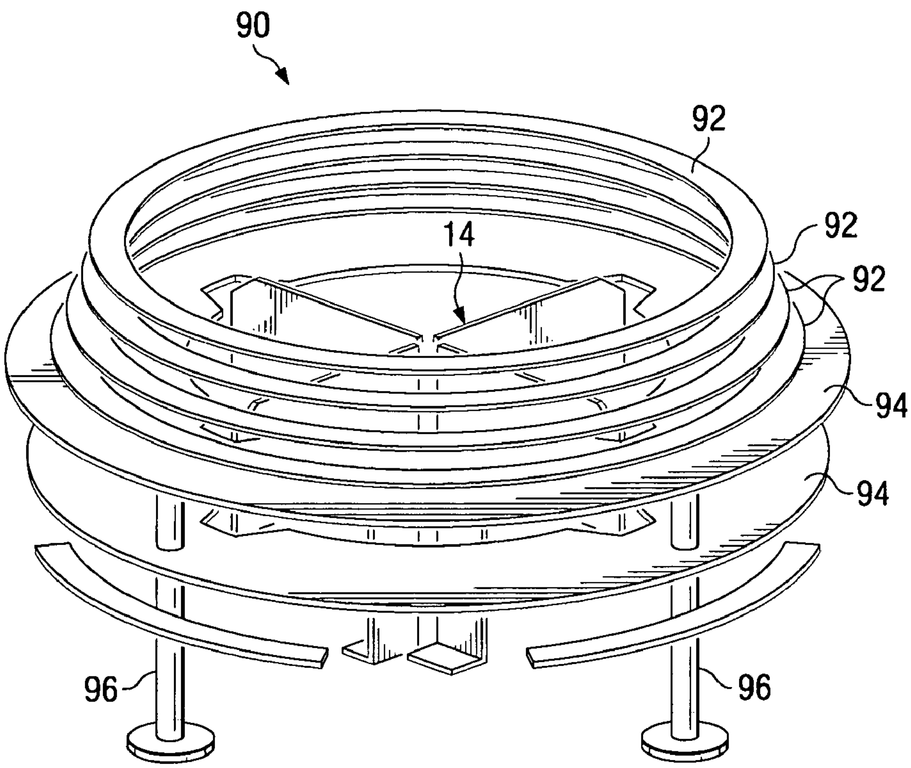


FIG. 11

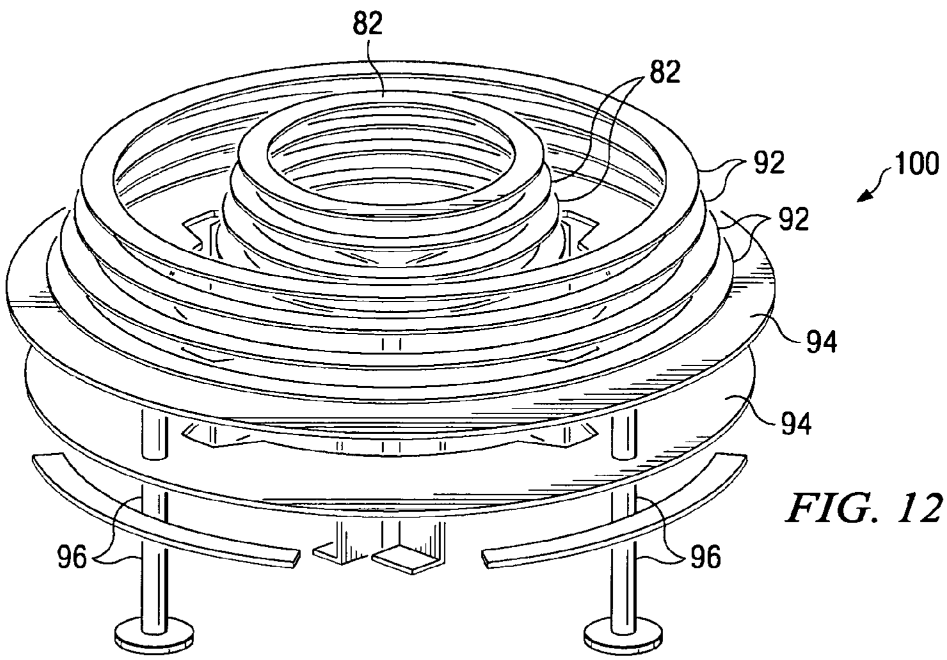


FIG. 12

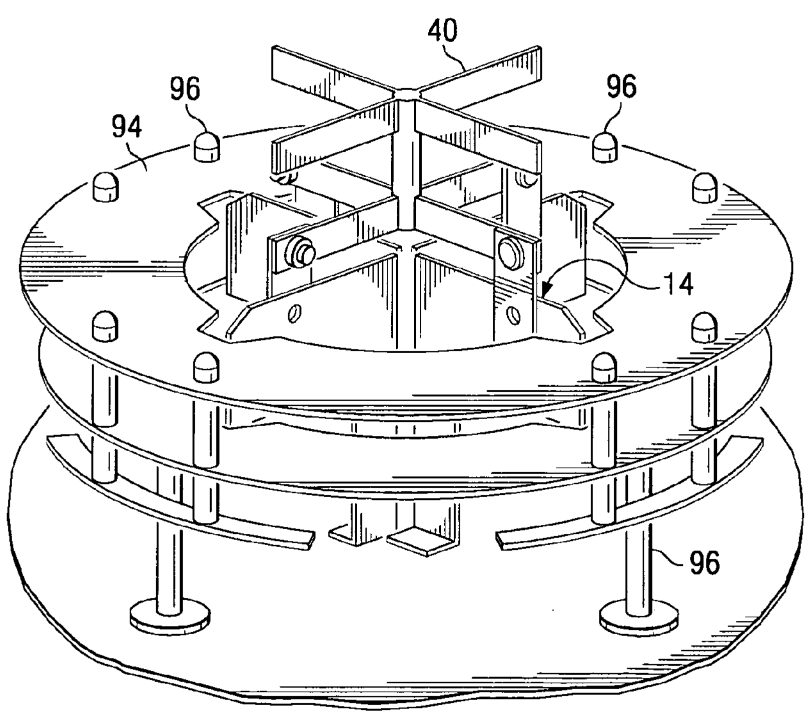


FIG. 14

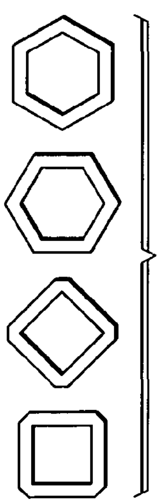


FIG. 13

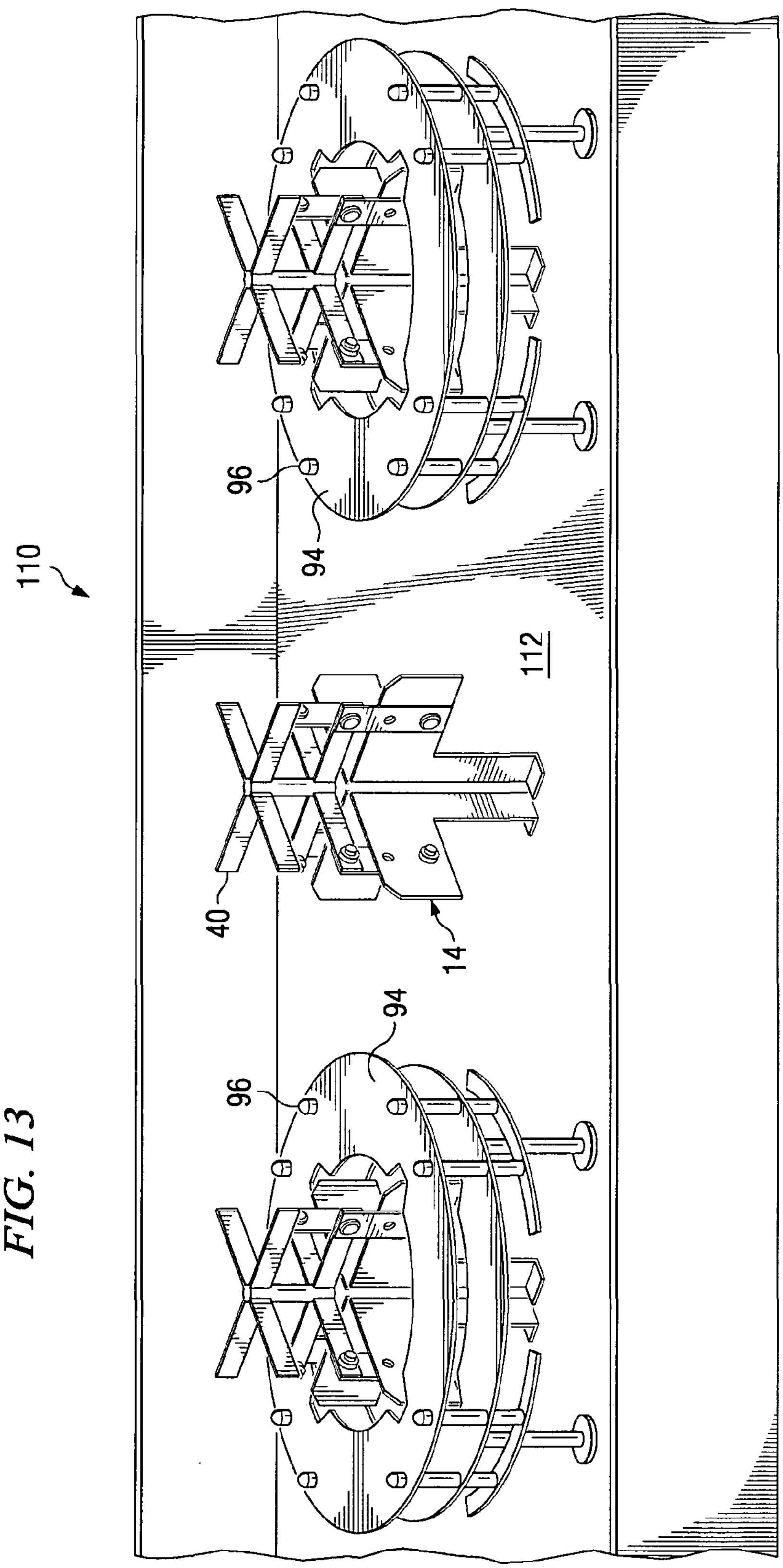


FIG. 15

DIRECTED DIPOLE ANTENNA HAVING IMPROVED SECTOR POWER RATIO (SPR)

CLAIM OF PRIORITY

This application is a continuation of U.S. patent application Ser. No. 11/104,986 entitled DIRECTED DIPOLE ANTENNA filed Apr. 13, 2005, now U.S. Pat. No. 7,358,922 which claims priority of U.S. Provisional Application Ser. No. 60/577,138 entitled "Antenna" filed Jun. 4, 2004, and is a Continuation-in-Part (CIP) of U.S. patent application Ser. No. 10/737,214 filed Dec. 16, 2003, now U.S. Pat. No. 6,924,776 entitled "Wideband Dual Polarized Base Station Antenna Offering Optimized Horizontal Beam Radiation Patterns And Variable Vertical Beam Tilt", which application claims priority of U.S. Provisional Patent Application Ser. No. 60/484,688 entitled "Balun Antenna With Beam Director" filed Jul. 3, 2003, and is also a Continuation-in-Part of U.S. patent application Ser. No. 10/703,331 filed Nov. 7, 2003, now U.S. Pat. No. 7,283,101 entitled "Antenna Element, Feed Probe, Dielectric Spacer, Antenna and Method of Communicating with a Plurality of Devices", which application claims priority of U.S. Provisional Patent Application Ser. No. 60/482,689 entitled "Antenna Element, Multiband Antenna, and Method of Communicating with a Plurality of Devices" filed Jun. 26, 2003.

FIELD OF THE INVENTION

The present invention is related to the field of antennas, and more particularly to antennas having dipole radiating elements utilized in wireless communication systems.

BACKGROUND OF THE INVENTION

Wireless mobile communication networks continue to be deployed and improved upon given the increased traffic demands on the networks, the expanded coverage areas for service and the new systems being deployed. Cellular type communication systems derive their name in that a plurality of antenna systems, each serving a sector or area commonly referred to as a cell, are implemented to effect coverage for a larger service area. The collective cells make up the total service area for a particular wireless communication network.

Serving each cell is an antenna array and associated switches connecting the cell into the overall communication network. Typically, the antenna array is divided into sectors, where each antenna serves a respective sector. For instance, three antennas of an antenna system may serve three sectors, each having a range of coverage of about 120°. These antennas are typically vertically polarized and have some degree of downtilt such that the radiation pattern of the antenna is directed slightly downwardly towards the mobile handsets used by the customers. This desired downtilt is often a function of terrain and other geographical features. However, the optimum value of downtilt is not always predictable prior to actual installation and testing. Thus, there is always the need for custom setting of each antenna downtilt upon installation of the actual antenna. Typically, high capacity cellular type systems can require re-optimization during a 24 hour period. In addition, customers want antennas with the highest gain for a given size and with very little intermodulation (IM). Thus, the customer can dictate which antenna is best for a given network implementation.

It is a further objective of the invention to provide a dual polarized antenna having improved directivity and providing improved sector isolation to realize an improved Sector Power Ratio (SPR).

It is an objective of the present invention to provide a dual polarized antenna array having optimized horizontal plane radiation patterns. One objective is to provide a radiation pattern having at least a 20 dB horizontal beam front-to-side ratio, at least a 40 dB horizontal beam front-to-back ratio, and improved roll-off.

It is another objective of the invention to provide an antenna array with optimized cross polarization performance with a minimum of 10 dB co-pol to cross-pol ratio in a 120 degree horizontal sector.

It is another objective of the invention to provide an antenna array with a horizontal pattern beamwidth of 50° to 75°.

It is another objective of the invention to provide an antenna array with minimized intermodulation.

It is an objective of the invention to provide a dual polarized antenna array capable of operating over an expanded frequency range.

It is a further objective of the invention to provide a dual polarized antenna array capable of producing adjustable vertical plane radiation patterns.

It is another objective of the invention to provide an antenna with enhanced port to port isolation of at least 30 dB.

It is further object of the invention to provide an inexpensive antenna.

These and other objectives of the invention are provided by an improved antenna array for transmitting and receiving electromagnetic waves with +45° and −45° linear polarizations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a dual polarized antenna according to a first preferred embodiment of the present invention;

FIG. **2** is a perspective view of a multi-level groundplane structure with a broadband slant 45 cross dipole radiating element removed therefrom, and a tray cutaway to illustrate a tilting of the groundplanes and an RF absorber in a RF choke;

FIG. **3** is a perspective view of N cross-shaped directors supported above the dipole radiating element;

FIG. **4** is a backside view of one element tray illustrating a microstrip phase shifter design employed to feed each pair of the cross dipole radiating elements;

FIG. **5** is a backside view of the dual polarized antenna illustrating the cable feed network, each microstrip phase shifter feeding one of the other dual polarized antennas;

FIG. **6** is a perspective view of the dual polarized antenna including an RF absorber functioning to dissipate RF radiation from the phase shifter microstriplines, and preventing the RF current cross coupling;

FIG. **7** is a graph depicting the high roll-off radiation pattern achieved by the present invention, as compared to a typical cross dipole antenna radiation pattern;

FIGS. **8**A and **8**B are graphs depicting the beam patterns in a three sector site utilizing standard panel antennas;

FIGS. **9**A and **9**B are graphs depicting the beam patterns in a three sector site utilizing antennas according to the present invention;

FIG. **10** is a perspective view of another embodiment of the invention including dual-band radiating elements;

FIG. **11** is a perspective view of the embodiment shown in FIG. **10** having director rings disposed over one of the radiating elements;

FIG. **12** is a perspective view of an embodiment of the invention having director rings disposed over each of the radiating elements;

FIG. **13** is a view of various suitable configurations of directors;

FIG. **14** is a close-up view of a dual-band antenna; and

FIG. **15** depicts an array of dual-band and single-band dipole radiating elements.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **1**, there is generally shown at **10** a wideband dual polarized base station antenna having an optimized horizontal radiation pattern and also having a variable vertical beam tilt. Antenna **10** is seen to include a plurality of element trays **12** having disposed thereon broadband slant 45 cross dipole (x-dipole) radiating elements **14** arranged in dipole pairs **16**. Each of the element trays **12** is tilted and arranged in a "fallen domino" arrangement and supported by a pair of tray supports **20**. The integrated element trays **12** and tray supports **20** are secured upon and within an external tray **22** such that there is a gap laterally defined between the tray supports **20** and the sidewalls of tray **22**, as shown in FIG. **1** and FIG. **2**. Each tray element **12** has an upper surface defining a groundplane for the respective dipole pair **16**, and has a respective air dielectric micro stripline **30** spaced thereabove and feeding each of the dipole radiating elements **14** of dipole pairs **16**, as shown. A plurality of electrically conductive arched straps **26** are secured between the sidewalls of tray **22** to provide both rigidity of the antenna **10**, and also to improve isolation between dipole radiating elements **14**.

As shown, a pair of cable supports **32** extend above each tray element **12**. Supports **32** support a respective low IM RF connection cables **34** from a cable **76** to the air dielectric micro stripline **30** and to microstrip feed network defined on a printed circuit board **50** adhered therebelow, as will be discussed in more detail shortly with reference to FIG. **4**.

Referring now to FIG. **2**, there is shown a perspective view of the element trays **12** with the sidewall of one tray support **20** and tray **22** partially cut away to reveal the tilted tray elements **12** configured in the "fallen domino" arrangement. Each tray element **12** is arranged in a this "fallen domino" arrangement so as to orient the respective dipole radiating element **14** pattern boresight at a predetermined downtilt, which may, for example, be the midpoint of the array adjustable tilt range. The desired maximum beam squint level of antenna **10** in this example is consistent with about 4° downtilt off of mechanical boresight, instead of about 8° off of mechanical boresight as would be the case without the tilt of the element trays **12**. According to the present invention, maximum horizontal beam squint levels have been reduced to about 5° over conventional approaches, which is very acceptable considering the antenna's wide operating bandwidth and tilt range.

Still referring to FIG. **2**, there is illustrated that the tray supports **20** are separated from the respective adjacent sidewalls of tray **22** by an elongated gap defining an RF choke **36** therebetween. This choke **36** created by physical geometry advantageously reduces the RF current that flows on the backside of the external tray **22**. The reduction of induced currents on the backside of the external tray **22** directly reduces radiation in the rear direction. The critical design criteria of this RF choke **36** involved in maximizing the radiation front-to-back ratio includes the height of the folded up sidewalls **38** of external tray **22**, the height of the tray supports **20**, and the RF choke **36** between the tray supports **20** and the sidewall lips **38** of tray **22**. The RF choke **36** is preferably lambda/4 of the radiating element **14** center frequency, and the RF choke **36** has a narrow bandwidth which is frequency dependent because of internal reflection cancellation in the air dielectric, the choke bandwidth being about 22 percent of the center frequency.

According to a further embodiment of the present invention, an RF absorber **39** may be added into the RF choke **36** to make the RF choke less frequency dependent, and thus create a more broadband RF choke. The RF absorber **39** preferably contains a high percentage of carbon that slows and dissipates any RF reflection wave from effecting the main beam radiation produced by the cross dipole antenna **12**. The slant 45 cross dipole antenna **14**, as shown, produces a cross polarized main beam radiation at a +/−45 degree orientation, each beam having a horizontal component and a vertical component. The cross polarization is good when these components are uniform and equal in magnitude in 360 degrees. For the panel antenna **10** shown in FIG. **1** with the linearly arranged cross dipoles **14**, the horizontal component of each beam orientation rolls off faster than the vertical component. This means that the vertical beamwidth is broader than the horizontal beamwidth for each beam orientation, and the vertical components travel along the edge of the respective trays **12** more than the horizontal components. Because the thin metal trays **12** have limited surface area, the surface currents thereon are less likely to reflect the horizontal components back to the main beam radiation. In contrast, along the edges of the respective trays **12** the stair cased baffles **35** have to contain many of the vertical component vector currents. Advantageously, by adding the RF absorber **39** into the RF choke **36**, the vertical components of each beam orientation are minimized from reflecting back into the main beam radiation of the cross dipole **14**. As such, cross dipoles **14** are not provided with a reflector behind them.

Preferably, the element trays **12** are fabricated from brass alloy and are treated with a tin plating finish for solderability. The primary function of the element trays is to support the radiating element **14** in a specific orientation, as shown. This orientation provides more optimally balanced vertical and horizontal beam patterns for both ports of the antenna **10**. This orientation also provides improved isolation between each port. Additionally, the element trays **12** provide an RF grounding point at the coaxial cable/airstrip interface.

The tray supports are preferably fabricated from aluminum alloy. The primary function of the tray supports is to support the five element trays **12** in a specific orientation that minimizes horizontal pattern beam squint.

The external tray **22** is preferably fabricated from a thicker stock of aluminum alloy than element trays **12**, and is preferably treated with an alodine coating to prevent corrosion due to external environment conditions. A primary functions of the external tray **22** is to support the internal array components. A secondary function is to focus the radiated RF power toward the forward sector of the antenna **10** by minimizing radiation toward the back, thereby maximizing the radiation pattern front-to-back ratio, as already discussed.

Referring now to FIG. **3** there is depicted one radiator element **14** having N laterally extending parasitic broadband cross dipole directors **40** disposed above the radiating element **14** and fed by the airstrip feed network **30**, as shown. N is 1, 2, 3, 4 . . . , where N is shown to equal 4 in this embodiment. The upper laterally extending members of parasitic broadband cross dipole director **40** are preferably uniformly spaced from one another, with the upper members preferably having a shorter length, as shown for bandwidth broadening. The lower members of director **40** are more closely spaced from the radiating element **14**, so as to properly couple the RF energy to the director in a manner that provides pattern enhancement while maintaining an efficient impedance match such that substantially no gain is realized by the director **40**, unlike a Yagi-Uda antenna having a reflector and spaced elements each creating gain. Advantageously, rather than realized gain, an improved pattern rolloff is achieved beyond the 3 dB beamwidth of the radiation pattern while maintaining a similar 3 dB beamwidth. Preferably, the upper elements of directors **40** are spaced about 0.033 lambda (center frequency) from one another, with the lower director elements spaced from the radiating element **14** about 0.025 lambda by parasitic **42** (lambda being the wavelength of the center frequency of the radiating element **14** design).

Referring now to FIG. **4** there is shown one low loss printed circuit board (PCB) **50** having disposed thereon a microstrip capacitive phase shifter system generally shown at **52**. The low loss PCB **50** is secured to the backside of the respective element tray **12**. Microstrip capacitive phase shifter system **52** is coupled to and feeds the opposing respective pair of radiating elements **14** via the respective cables **34**.

As shown in FIG. **4**, each microstrip phase shifter system **52** comprises a phase shifter wiper arm **56** having secured thereunder a dielectric member **54** which is arcuately adjustable about a pivot point **58** by a respective shifter rod **60**. Shifter rod **60** is longitudinally adjustable by a remote handle (not shown) so as to selectively position the phase shifter wiper arm **56** and the respective dielectric **54** across a pair of arcuate feedline portions **62** and **64** to adjust the phase velocity conducting therethrough. Shifter rod **60** is secured to, but spaced above, PCB **50** by a pair of non-conductive standoffs **66**. The low loss coaxial cables **34** are employed as the main transmission media providing electrical connection between the phase shifter system **52** and the radiating elements **14**. Gain performance is optimized by closely controlling the phase and amplitude distribution across the radiating elements **14** of antenna **10**. The very stable phase shifter design shown in FIG. **4** achieves this control.

Referring now to FIG. **5**, there is shown the backside of the antenna **10** illustrating the cable feed network, each microstrip phase shifter system **52** feeding one of the other polarized antennas **14**. Input **72** is referred as port I and is the input for the −45 polarized Slant, and input **74** is the port II input for the +45 polarized Slant. Cables **76** are the feed lines coupled to one respective phase shifter system **52**, as shown in FIG. **4**. The outputs of phase shifter system **52**, depicted as outputs **1**-**5**, indicate the dipole pair **16** that is fed by the respective output of the phase shifter **52** system.

Referring now to FIG. **6**, there is shown antenna **10** further including an RF absorber **78** positioned under each of the element trays **12**, behind antenna **10**, that functions to dissipate any rearward RF radiation from the phase shifter microstrip lines, and preventing RF current from coupling between phase shifters systems **52**.

Referring now to FIG. **7**, there is generally shown at **68** the high roll-off and front-to-back ratio radiation pattern achieved by antenna **10** according to the present invention, as compared to a standard 65° panel antenna having a dipole radiation pattern shown at **69**. This high roll-off radiation pattern **68** is a significant improvement over the typical dipole radiation pattern **69**. The horizontal beam width still holds at approximately 65 degree at the 3 dB point.

Further, the design of the radiating elements **14** with directors **40** provides dramatic improvements in the antenna's horizontal beam radiation pattern, "where the Front-to-Side levels are shown to be 23 dB in FIG. **7**. Conventional, cross dipole radiating elements produce a horizontal beam radiation pattern with about a 17 dB front-to-side ratio, as shown in FIG. **7**. According to the present invention, the broadband parasitic directors **40** integrated above the radiating elements **14** advantageously improve the antenna front-to-side ratio by up to 10 dB, and is shown as 6 dB delta in the example of FIG. **7**. This improved front-to-side ratio effect is referred to as a "high roll-off" design. In this embodiment, radiating elements **14** and cross dipole directors **40** advantageously maintain an approximately 65 degree horizontal beamwidth at the antenna's 3 dB point, unlike any conventional Yagi-Uda antenna having more directors to get more gain and thus reducing the horizontal beamwidth.

Still referring to FIG. **7**, there is shown the excellent front-to-back ratio of antenna **10**. As shown, panel antenna **10** has a substantially reduced backside lobe, thus achieving a front-to-back ratio of about 40 dB. Moreover, antenna **10** has a next sector antenna/antenna isolation of about 40 dB, as compared to 26 dB for the standard 65° panel antenna. As can also be appreciated in FIG. **7**, with the significant reduction of a rear lobe, a 120° sector interference free zone is provided behind the radiation lobe, referred to in the present invention as the "cone of silence".

Referring now to FIGS. **8**A and **8**B, there is shown several advantages of the present invention when employed in a three sector site. FIG. **8**A depicts standard 65° flat panel antennas used in a three sector site, and FIG. **8**B depicts standard 90° panel antennas used in a three sector site. The significant overlap of these antenna radiation patterns creates imperfect sectorization that presents opportunities for increased softer hand-offs, interfering signals, dropped calls, and reduced capacity.

Referring now to FIGS. **9**A and **9**B, there is shown technical advantages of the present invention utilizing a 65° panel antenna and a 90° panel antenna, respectively according to the present invention, employed in a three sector site. With respect to FIG. **9**A, there is depicted significantly reduced overlap of the antenna radiation lobes, thus realizing a much smaller hand-off area. This leads to dramatic call quality improvement, and further, a 5-10% site capacity enhancement.

Referring back to FIG. **7**, the undesired lobe extending beyond the 120° sector of radiation creates overlap with adjacent antenna radiation patterns, as shown in FIG. **8**A-**8**B and FIG. **9**A-**9**B. The undesired power delivered in the lobe outside of the 120° forward sector edges, as compared to that desired power delivered inside this 120° sector, defines what is referred to as the Sector Power Ratio (SPR). Advantageously, the present invention achieves a SPR being less than 2%, where the SPR is defined by the following equation:

$$SPR(\%) = \frac{\sum_{60}^{300} P \text{ Undesired}}{\sum_{300}^{60} P \text{ Desired}} \times 100$$

This SPR is a significant improvement over standard panel antennas, and is one measure of depicting the technical advantages of the present invention. The directors **40** are impedance matched at 90 ohms, although limitation to this impedance is not inferred, to the micro stripline **30**. The radiating elements **14** and the cross dipole directors **40** have mutual instantaneous electromagnetic coupling which generate with source impedance at 90 ohm and source voltage of a matching network. Many other system level performance benefits are afforded by incorporation of this high roll-off antenna design, including improved soft handoff capabilities, reduced co-site channel interference and increased base station system capacity due to increased sector-to-sector rejection.

Referring now to FIG. **10**, there is shown another preferred embodiment of the invention seen to comprise a band, dualpol antenna **80** including one slant 45 crossed dipole radiating element **14** and a slant 45 microstrip Annular Ring (MAR) radiator **94** encircling said dipole, as will be described shortly in reference to FIG. **11**. In this embodiment, antenna **80** includes N annular (ring-like) directors **82** disposed above the radiating element **14**, where N=1, 2, 3, 4 . . . . The N directors **82** are configured as vertically spaced parallel polygon-shaped members, shown as concentric rings, although limitation to this geometry of directors **82** is not to be inferred. Other geometric configurations of the directors may be utilized as shown in FIG. **13**.

The ring directors **82** react with the corresponding dipole radiating element **14** to enhance the front-to-side ratio of antenna **10** with improved rolloff. The ring directors **82** are preferably uniformly spaced above the corresponding x-dipole radiating element **14**, with the ascending ring directors **82** having a continually smaller circumference. The ring directors **82** maintain a relatively close spacing with one another being separated by electrically non-conductive spacers, not shown, preferably being spaced less than 0.15 lambda (lambda being the wavelength of the center frequency of the antenna design). Additionally, the grouping of ring directors **82** maintain a relatively close spacing between the bottom-most director **82** and the top of the corresponding dipole radiating element **14**, preferably less than 0.15 lambda. There are a variety of methods to build the set of planar directors **82**, such as molded forms and electrically insulating clips.

The set of stacked ring directors **82** may also consist of rings of equal circumference while maintaining similar performance of improved roll-off leading to an improved SPR with the previously stated system benefits while maintaining a similar 3 dB beamwidth.

Referring now to FIG. **11**, there is shown at **90** a dual-band antenna including a set of director rings **92** disposed above a stacked Microstrip Annular Ring (MAR) radiator **94**. In this view, there are four feedprobes **96** (2 balanced feed pairs) arranged in pairs feeding dual orthogonal polarizations of the MAR radiator **94**. The directors **92** in this embodiment of the invention are thin rings stacked above the respective MAR radiator **94**, as shown. Advantageously, this dual-band antenna **90** also has improved element pattern roll-off beyond the 3 dB beamwidth thus increasing the SPR while maintaining an equivalent 3 dB beamwidth.

Referring now to FIG. **12**, there is shown a dual-band antenna **100** having ring directors **82** and **92**. The ring directors **92** above the MAR radiator **94** also interact with the x-dipole radiating element **14** and provide some additional beamshaping for the x-dipole radiating element, including improved roll-off of the main beam outside of the 3 dB beamwidth as well as improved front-to-back radiation leading to an improved SPR and the system benefits previously mentioned while maintaining a similar 3 dB beamwidth.

Both the MAR radiator element **94** and the x-dipole radiating element **14** have respective ring directors thereabove. The ring directors **82** for the x-dipole radiating element **14** are also concentric to the ring directors **92** for the MAR radiator **94**. The same benefits as discussed earlier for the directors are applicable here as well per frequency band (i.e. improved roll-off beyond the 3 dB beamwidth and front-to-back ratio leading to improved SPR.

Referring now to FIG. **13**, there is shown other suitable geometrical configurations of directors **82** and **92**, and limitation to a circular ring-like director is not to be inferred. A circle is considered to be an infinitely sided polygon where the term polygon is used in the appending claims.

Referring now to FIG. **14**, there is shown a close-up view of dual band antenna **80** having cross shaped directors **40** extending over the radiating element **14**, and the MAR radiator **94** without the associated annular director.

Referring now to FIG. **15**, there is shown a panel antenna **110** having an array of radiating elements **14**, each having cross directors **40**, alternately provided with the MAR radiators **94**, each disposed over common groundplane **112**. The advantages of this design include an improved H-plane pattern for the higher frequency radiating element in a dualband topology. The improved H-plane pattern provides improved roll-off beyond the 3 dB beamwidth and improved front-to-back ratio. The improved roll-off additionally provides a slight decoupling of the radiators depending on the number of directors incorporated due to lower levels of side and back radiation.

Though the invention has been described with respect to a specific preferred embodiment, many variations and modifications will become apparent to those skilled in the art upon reading the present application. It is therefore the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.

We claim:

1. An antenna, comprising:

at least one slant 45 degree dipole radiating element adapted to generate a beam; and

at least one director disposed proximate the at least one slant 45 degree dipole radiating element adapted to improve a Sector Power Ratio (SPR) of the beam while maintaining an equivalent 3 dB beamwidth.

2. The antenna as specified in claim **1** wherein the antenna has a Sector Power Ratio of less than 10%.

3. The antenna as specified in claim **2** wherein the antenna has a Sector Power Ratio of less than 5%.

4. The antenna as specified in claim **3** wherein the antenna has a Sector Power Ratio of less than 2%.

5. The antenna as specified in claim **1** comprising at least 2 of the directors.

6. The antenna as specified in claim **5** wherein said at least 2 of the directors are parallel to one another.

7. The antenna as specified in claim **5** wherein at least some of the directors are uniformly spaced from one another.

8. The antenna as specified in claim **7** wherein one of the directors is spaced closer to the radiating element than an adjacent said director.

9. The antenna as specified in claim **1** wherein the radiating element is a cross dipole radiating element.

10. The antenna as specified in claim **9** wherein the director has at least 2 members.

11. The antenna as specified in claim **10** wherein the members are cross-shaped members parallel to the cross dipole radiating element in the vertical direction.

12. The antenna as specified in claim **1** wherein the at least one director comprises a polygon shaped ring.

13. The antenna as specified in claim **12**, further comprising a plurality of the polygon shaped rings disposed over the radiating element.

14. The antenna as specified in claim **13** wherein the polygon shaped rings are concentric.

15. The antenna as specified in claim **14** wherein the polygon shaped rings have a common diameter.

16. The antenna as specified in claim **14** wherein the polygon shaped rings have different diameters and form a tapered director.

17. The antenna as specified in claim **10** wherein the members have different lengths and form a tapered director.

18. The antenna as specified in claim **1** wherein the antenna has a front--to-side ratio of at least 20 dB.

19. The antenna as specified in claim **1** wherein the antenna has a front--to-back ratio of at least 40 dB.

20. An antenna, comprising:

a slant 45 degree dipole radiating element adapted to generate a beam; and

director means disposed proximate the slant 45 degree dipole radiating element for directing the beam.

21. The antenna as specified in claim **20** wherein the director means establishes a Sector Power Ratio of the beam being less than 10%.

22. The antenna as specified in claim **20** wherein the director means establishes a Sector Power Ratio of the beam being less than 5%.

23. The antenna as specified in claim **20** wherein the director means establishes a Sector Power Ratio of the beam being less than 2%.

24. The antenna as specified in claim **20** wherein the director means establishes a front-to-back ratio of the beam of at least about 40 dB.

25. The antenna as specified in claim **20** wherein the director means establishes a front-to-side ratio of the beam of at least about 20 dB.

* * * * *

EXHIBIT C

US009698486B2

(12) **United States Patent**
Shooshtari et al.

(10) **Patent No.: US 9,698,486 B2**
(45) **Date of Patent: Jul. 4, 2017**

(54) **LOW COMMON MODE RESONANCE MULTIBAND RADIATING ARRAY**

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(73) Assignee: **CommScope Technologies LLC**, Hickory, NC (US)

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§ 371 (c)(1),
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(87) PCT Pub. No.: **WO2016/114810**
PCT Pub. Date: **Jul. 21, 2016**

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Related U.S. Application Data

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(51) **Int. Cl.**
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H01Q 9/28 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01Q 9/285*** (2013.01); ***H01Q 1/50*** (2013.01); ***H01Q 1/521*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01Q 1/50; H01Q 9/285; H01Q 1/521; H01Q 21/062
(Continued)

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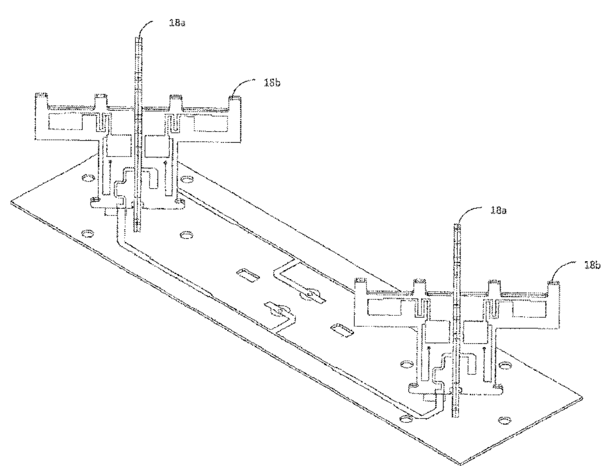
Primary Examiner — Huedung Mancuso
(74) *Attorney, Agent, or Firm* — Myers Bigel, P.A.

(57) **ABSTRACT**

A higher band radiating element for use in a multiband antenna includes first and second dipole arms supported by a feedboard. The feedboard includes first and second matching circuits, each comprising a capacitor-inductor-capacitor (CLC) matching circuit. The matching circuit further includes a CM tuning circuit connecting a portion of the matching circuit to ground via a microstrip trace selected to pass lower band currents while blocking higher band currents. The CM tuning circuit moves the common mode resonance of the higher band support PCB down below the operating frequency of additional, lower band radiating elements present in the multiband antenna, which is preferable to moving the common mode resonance above the lower band frequencies.

19 Claims, 9 Drawing Sheets



(51) **Int. Cl.**
H01Q 1/52 (2006.01)
H01Q 21/06 (2006.01)
H01Q 1/24 (2006.01)
H01Q 1/38 (2006.01)
H01Q 21/26 (2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 21/062*** (2013.01); *H01Q 1/246* (2013.01); *H01Q 1/38* (2013.01); *H01Q 21/26* (2013.01)

(58) **Field of Classification Search**
USPC 343/793
See application file for complete search history.

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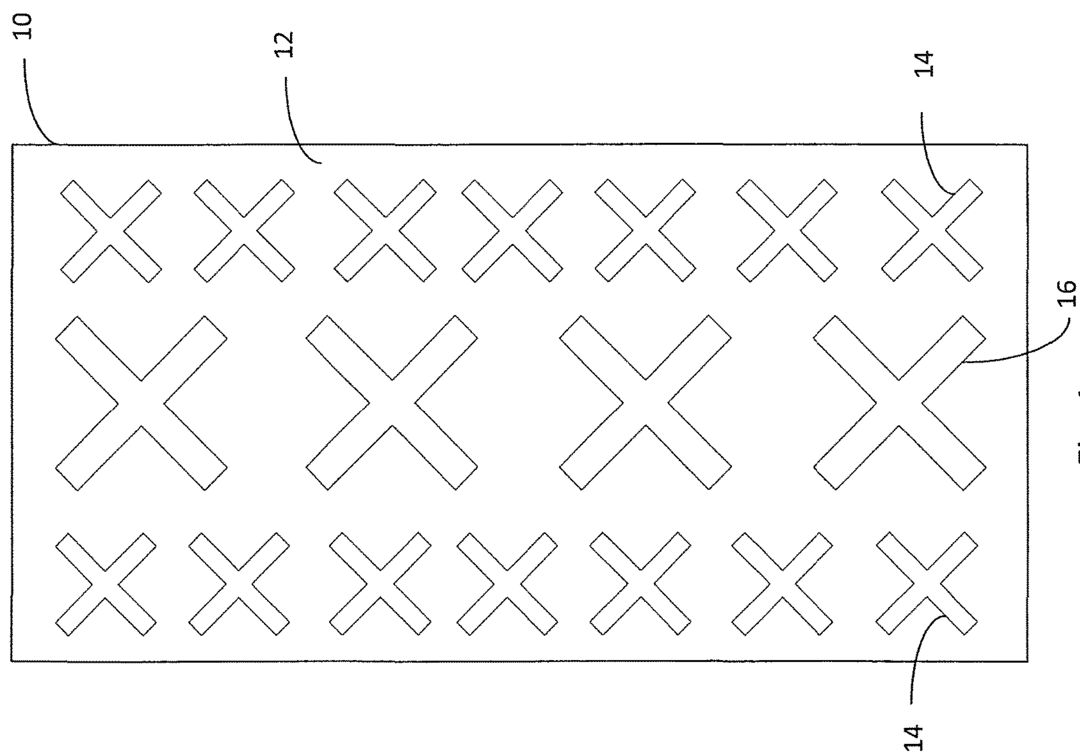

Fig. 1

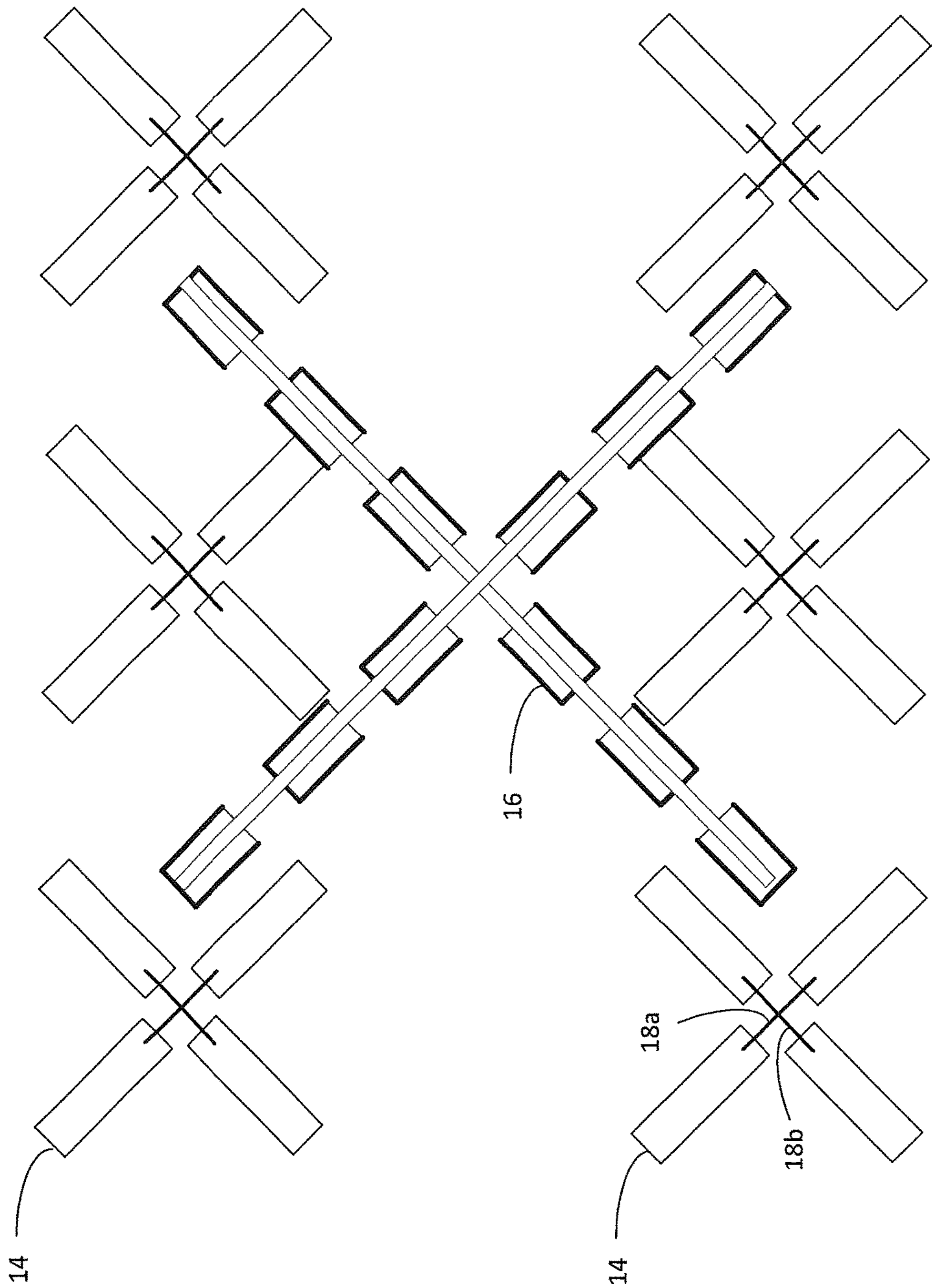

Fig. 2

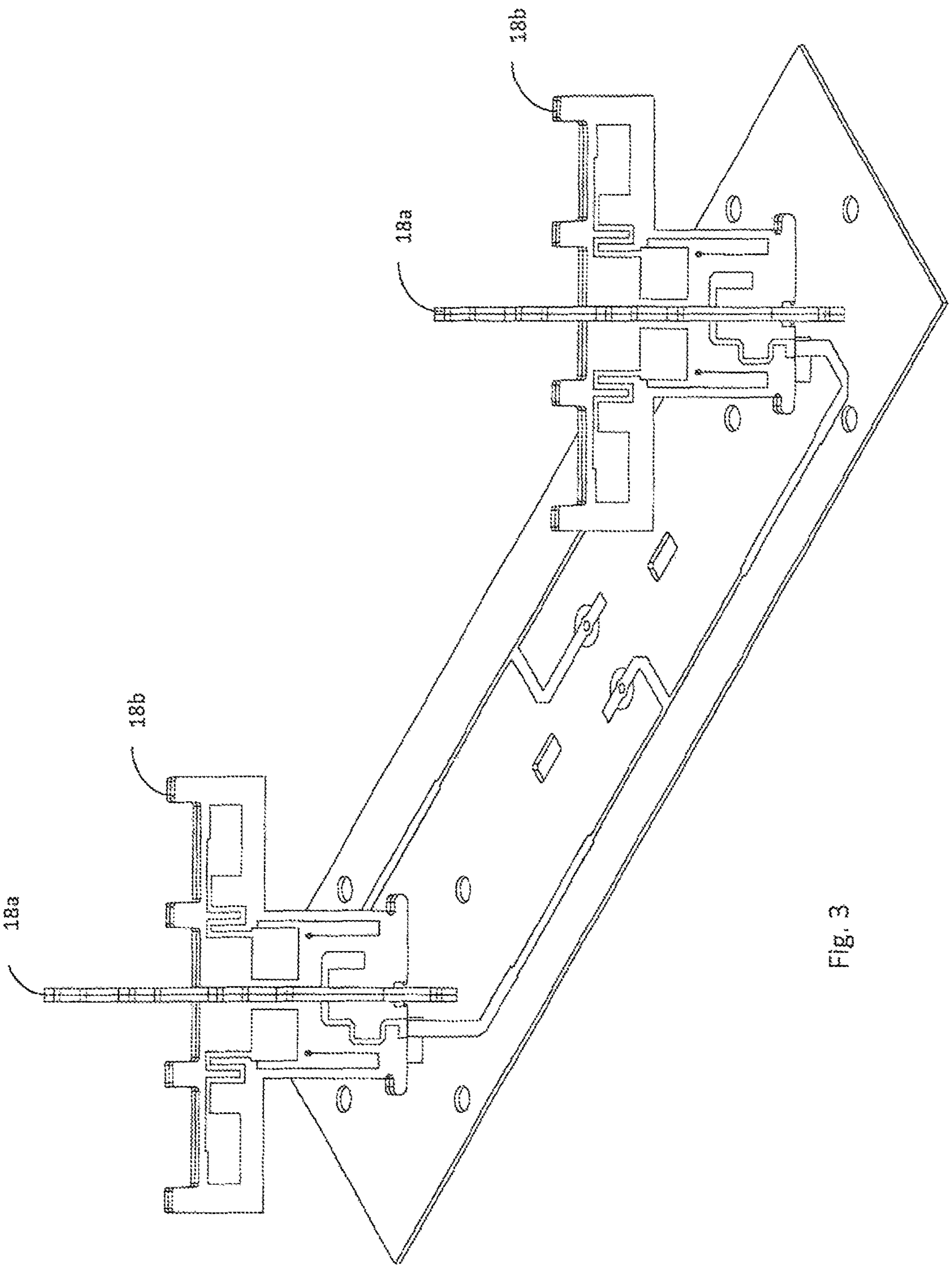

Fig. 3

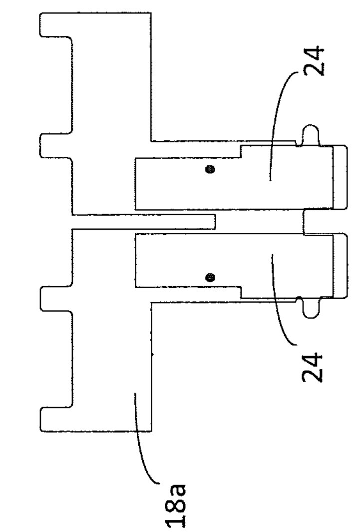

Fig. 4b

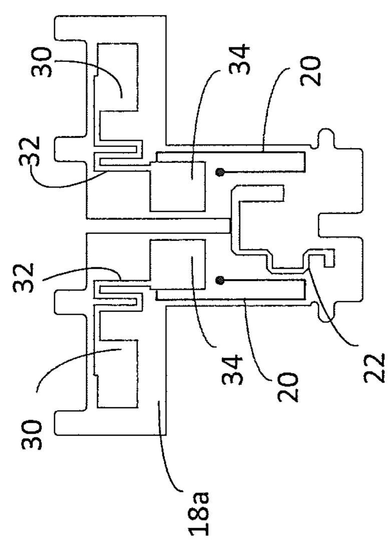

Fig. 4a

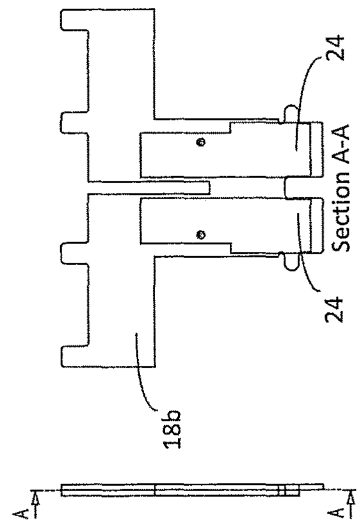

Fig. 5b

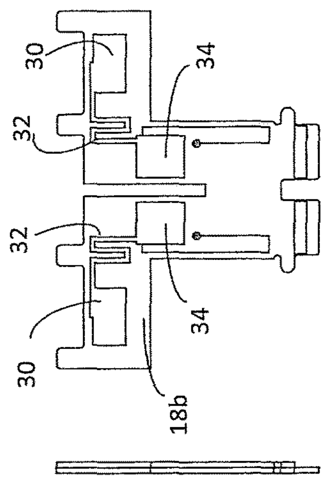

Fig. 5c

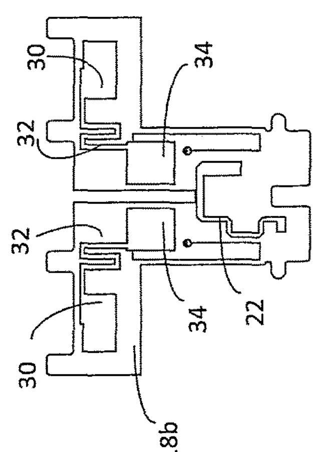

Fig. 5a

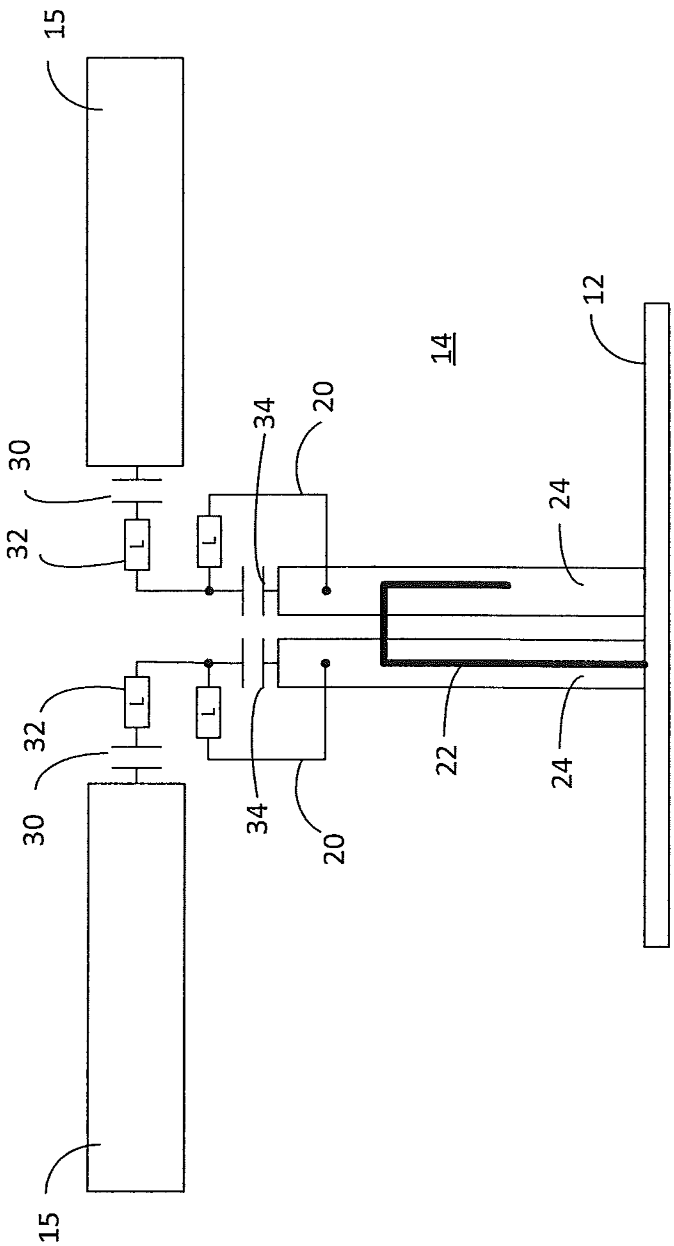

Fig. 6

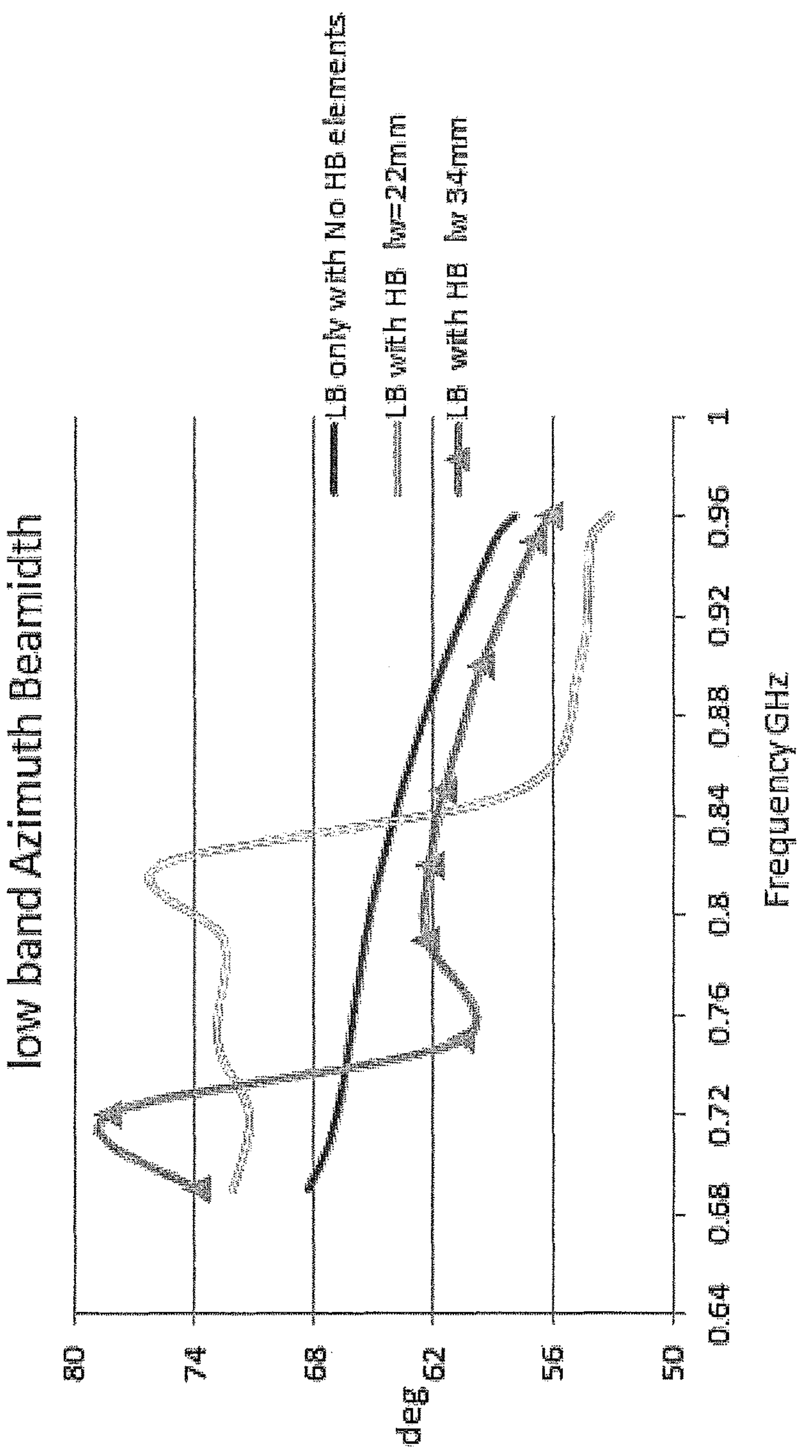
low band Azimuth Beamidth
LB only with No HB elements
LB with HB lw=22mm
LB with HB lw 34mm
80
74
68
62
56
50
deg
0.64
0.68
0.72
0.76
0.8
0.84
0.88
0.92
0.96
1
Frequency GHz

Fig. 7

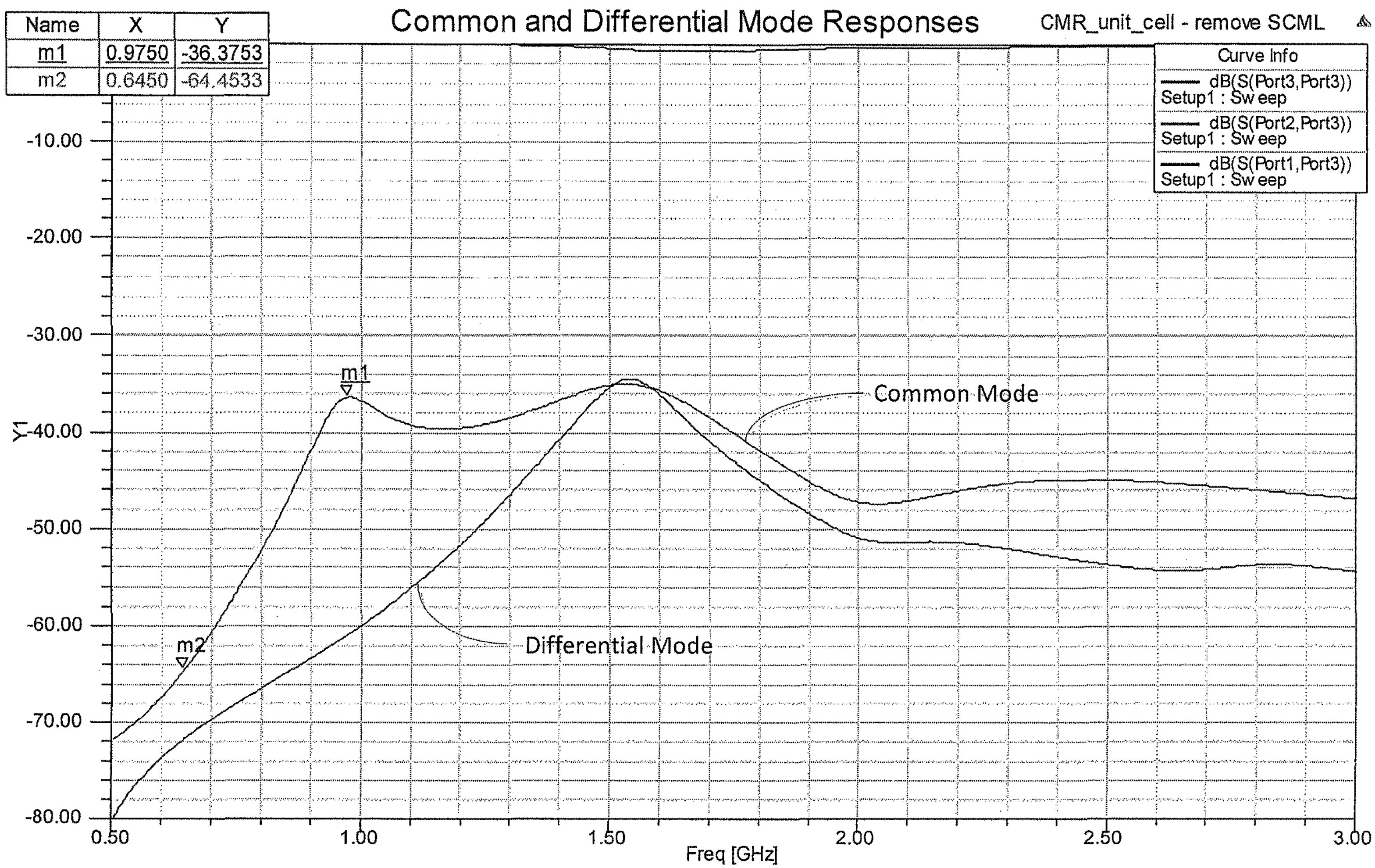
Name X Y
m1 0.9750 -36.3753
m2 0.6450 -64.4533
Common and Differential Mode Responses
CMR_unit_cell - remove SCML
Curve Info
dB(S(Port3,Port3))
Setup1 : Sweep
dB(S(Port2,Port3))
Setup1 : Sweep
dB(S(Port1,Port3))
Setup1 : Sweep
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
Y1
m1
m2
Common Mode
Differential Mode
0.50
1.00
1.50
2.00
2.50
3.00
Freq [GHz]

Fig. 8

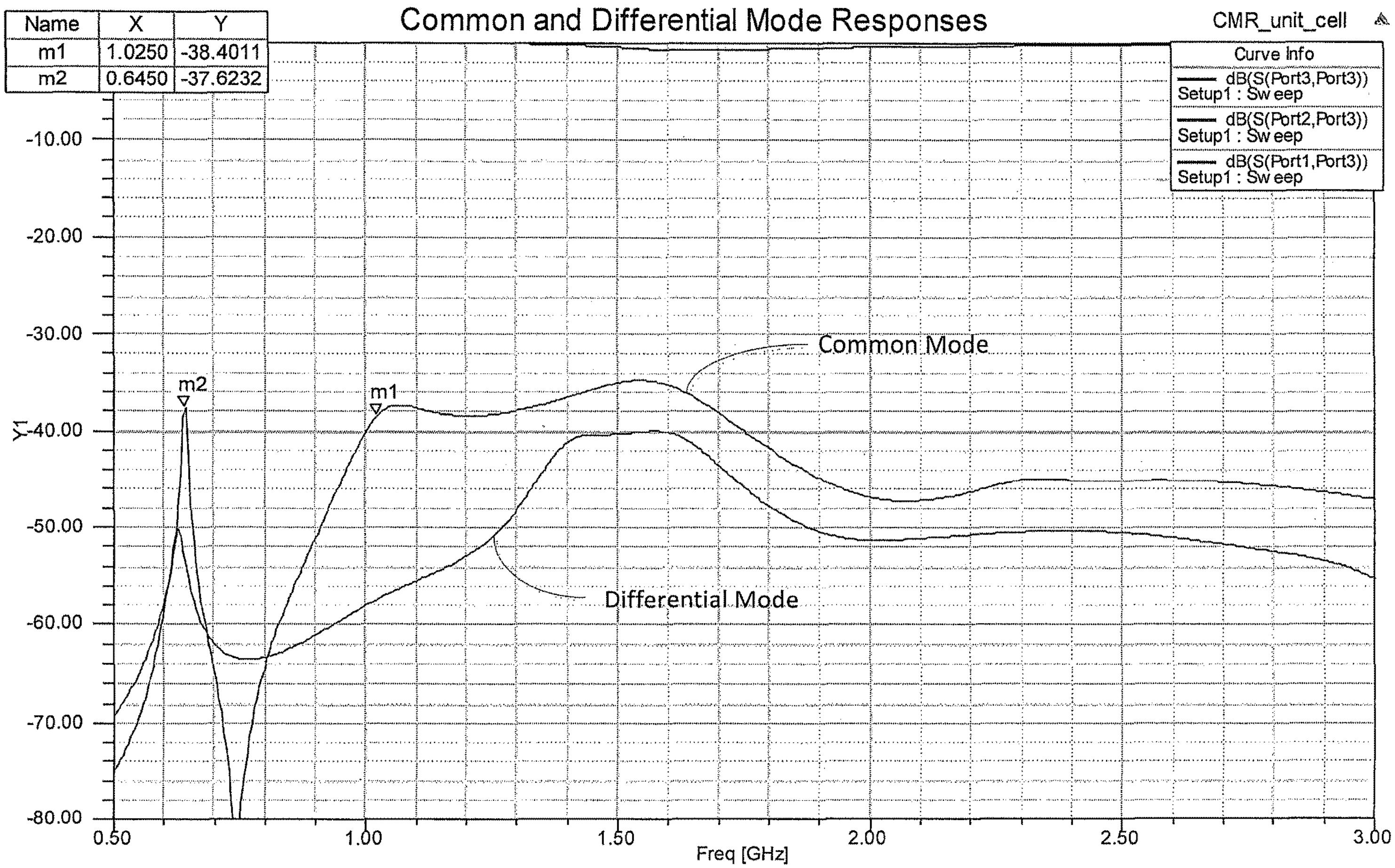
Name
X
Y
m1
1.0250
-38.4011
m2
0.6450
-37.6232
Common and Differential Mode Responses
CMR_unit_cell
Curve Info
dB(S(Port3,Port3))
Setup1 : Sw eep
dB(S(Port2,Port3))
Setup1 : Sw eep
dB(S(Port1,Port3))
Setup1 : Sw eep
Common Mode
Differential Mode
m1
m2
Y1
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
0.50
1.00
1.50
2.00
2.50
3.00
Freq [GHz]

Fig. 9

LOW COMMON MODE RESONANCE MULTIBAND RADIATING ARRAY

This application claims priority to and incorporates by reference U.S. Provisional Patent Application No. 62/103,799, filed Jan. 15, 2015 and titled "Low Common Mode Resonance Multiband Radiating Array"

BACKGROUND

Multiband antennas for wireless voice and data communications are known. For example, common frequency bands for GSM services include GSM900 and GSM1800. A low band of frequencies in a multiband antenna may comprise a GSM900 band, which operates at 880-960 MHz. The low band may also include Digital Dividend spectrum, which operates at 790-862 MHz. Further, it may also cover the 700 MHz spectrum at 698-793 MHz. Ultra wide band antennas may cover all of these bands.

A high band of a multiband antenna may comprise a GSM1800 band, which operates in the frequency range of 1710-1880 MHZ. A high band may also include, for example, the UMTS band, which operates at 1920-2170 MHz. Additional bands may comprise LTE2.6, which operates at 2.5-2.7 GHz and WiMax, which operates at 3.4-3.8 GHz. Ultra wide band antennas may cover combinations of these bands.

When a dipole element is employed as a radiating element, it is common to design the dipole so that its first resonant frequency is in the desired frequency band. To achieve this, the dipole arms are about one quarter wavelength, and the two dipole arms together are about one half the wavelength of the desired band. These are commonly known as "half-wave" dipoles.

However, in multiband antennas, the radiation patterns for a lower frequency band can be distorted by resonances that develop in radiating elements that are designed to radiate at a higher frequency band, typically 2 to 3 times higher in frequency. For example, the GSM1800 band is approximately twice the frequency of the GSM900 band.

There are two modes of distortion that are typically seen, Common Mode resonance and Differential Mode resonance Common Mode (CM) resonance occurs when a portion of the higher band radiating element structure resonates as if it were a one quarter wave monopole at low band frequencies. For example, when the higher band radiating element comprises a dipole element coupled to a feed network with an associated matching circuit, the combination of a high band dipole arm and associated matching circuit may resonate at the low band frequency. This may cause undesirable distortion of low band radiating patterns.

For example, low band elements, in the absence of high band elements, may have a half power beam width (HPBW) of approximately 65 degrees. However, when high band elements are combined with low band elements on the same multi-band antenna, Common Mode resonance of the low band signal onto the high band elements may cause an undesirable broadening of the HPBW to 75-80 degrees.

Approaches for reducing CM resonance include adjusting the dimensions of a high band element to move the CM resonance up or down to move it out of band of the low band element. In one example, the high band radiators are effectively shortened in length at low band frequencies by including capacitive elements in the feed, thereby tuning the CM resonance to a higher frequency and out of band. See, for example, U.S. Provisional Application Ser. No. 61/987,791, the disclosure of which is incorporated by reference.

While this approach is cost-effective, tuning the CM resonance above the low band often results in an undesirable broadening of the azimuth beamwidth of the low band pattern.

Another approach for reducing CM resonance is to increase the length of the stalk of a high band element by locating it in a "moat". A hole is cut into the reflector around the vertical stalks of the radiating element. A conductive well is inserted into the hole and the stalk is extended to the bottom of the well. This lengthens the stalk, which lowers the resonance of the CM, allowing it to be moved out of band, while at the same time keeping the dipole arms approximately ¼ wavelength above the reflector. See, U.S. patent application Ser. No. 14/479,102, the disclosure of which is incorporated by reference. While this approach desirably tunes the CM resonance down and below the low band, it requires more space and entails extra complexity and manufacturing cost.

SUMMARY

According to one aspect of the present invention, a higher band radiating element for use in a multiband antenna includes first and second dipole arms supported by a feedboard. Each dipole arm has a capacitive coupling area. The feedboard includes a balun and first and second matching circuits coupled to the balun. The first matching circuit is capacitively coupled to the first dipole arm and the second matching circuit is capacitively coupled to the second dipole arm. The first and second matching circuits each comprise a capacitor-inductor-capacitor (CLC) matching circuit having, in series, a stalk, coupled to the balun, a first capacitive element, an inductor, and a second capacitive element, the second capacitive element being coupled to a dipole arm. The feed circuit further includes a CM tuning circuit connecting the first capacitive element and the inductor to the stalk. The CM tuning circuit may comprise a microstrip line providing a DC connection to the stalk and having a length selected to appear as a high impedance at an operating frequency of the radiating element. The CM tuning circuit moves the common mode resonance of the support PCB down below the operating frequency of additional, lower band radiating elements present in the multiband antenna, which is preferable to moving the common mode resonance above the lower band frequencies. The capacitive elements may be selected to block out-of-band induced currents while passing in-band currents.

The capacitors of the CLC matching circuits may be shared across different components. For example, the first capacitive element and an area of the stalk may provide the parallel plates of a capacitor, and the feedboard PCB substrate may provide the dielectric of the capacitor. The second capacitive element may combine with the capacitive coupling area of the dipole arm to provide the second capacitor.

The radiating element may comprise a cross dipole radiating element. In one example, the multiband antenna comprises a dual band antenna having high band radiating elements and low band radiating elements. The high band radiating elements have a first operational frequency band within a range of about 1710 MHz-2700 MHz, and the low band radiating elements have a second operational frequency band within a range of about 698 MHz-960 MHz. In such an example, the common mode tuning circuit is dimensioned to pass low band current and block high band current.

In another example, a multiband antenna, may include a first array of first radiating elements having a first operational frequency band and a second array of second radiating

elements having a second operational frequency band. The second operational frequency band is higher than the first operational frequency band, and often a multiple of the first operational frequency band. The second radiating elements further comprising first and second dipole arms, each dipole arm having a capacitive coupling area, and a feedboard having a balun and first and second matching circuits coupled to the balun. The first matching circuit is coupled to the first dipole arm and the second matching circuit is coupled to the second dipole arm. The first and second matching circuits each include, in series, a stalk, coupled to the balun, a first capacitive element, an inductor, and a second capacitive element, the second capacitive element being associated with one of the first and second dipole arms. Each matching circuit further includes a common mode tuning circuit connecting the first capacitive element and the inductor to the stalk, the common mode tuning circuit comprising a microstrip line dimensional to short any induced low band currents to the stalk without substantially affecting high band currents.

The first operational frequency band comprises a mobile communications low band and the second operational frequency band comprises a mobile communications high band. For example, the first operational frequency band may located within an approximate range of 698 MHz to 960 MHz, and the second operational frequency band may located within an approximate range of 1710 MHz to 2170 MHz.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view of a panel antenna having arrays of high band radiating elements and low band radiating elements.

FIG. **2** is a diagram of a low band radiating element and a plurality of high band radiating elements.

FIG. **3** is an isometric view of a sub-array of high band radiating element feedboards according to one aspect of the present invention.

FIGS. **4***a* and **4***b* illustrate one example of layers of metallization according to another aspect of the present invention.

FIGS. **5***a*-**5***c* illustrate another example of layers of metallization according to another aspect of the present invention.

FIG. **6** is a schematic diagram of a radiating element dipole and feed circuit of the elements illustrated in FIGS. **3**, **4***a*-**4***b*, and **5***a*-**5***c*.

FIG. **7** is a graph showing improved azimuth beamwidth performance due to the present invention.

FIG. **8** is a graph illustrating typical common mode and differential mode performance.

FIG. **9** is a graph illustrating improved common mode and differential mode performance due to the present invention.

DESCRIPTION OF THE INVENTION

FIG. **1** schematically diagrams a dual band antenna **10**. The dual band antenna **10** includes a reflector **12**, arrays of high band radiating elements **14**, and an array of low band radiating elements **16** interspersed with the high band elements. The high band radiating element **14** and low band element **16** may each comprise a cross dipole. Other radiating elements may be used, such as dipole squares, patch elements, single dipoles, etc. The present invention is not limited to dual band antennas, and may be used in any multiband application where higher band radiating elements and lower band radiating elements are present.

FIG. **2** illustrated the dual band antenna of FIG. **1** in more detail. The low band element **16** may optionally include a chokes on the dipole arms **17** to reduce undesirable interference from the low band elements on the high band radiation pattern. See, e.g., PCT/CN2012/087300, which is incorporated by reference. The dipole arms **15** of the high band element **14** may be supported over the reflector **12** by feed boards **18**.

The high band radiating elements **14** may be arranged in a sub-array. For example, referring to FIG. **3**, feed boards **18** are arranged on a backplane with a portion of a feed network to create a sub array.

Referring to FIGS. **4***a* and **4***b*, a first example of a feed board **18***a* for a high band radiating element **14** according to one aspect of the present invention is illustrated. In this example, the stalk traces capacitively couple signals from the feed network to the dipole arms of radiating elements **14**.

In the example of FIGS. **4***a* and **4***b*, two metallization layers of a feed board **18***a* are illustrated. These metallization layers are on opposite sides of a printed circuit board substrate. A first layer is illustrated in FIG. **4***a* and a second layer is illustrated in FIG. **4***b*. The first layers implements CM tuning circuits **20**, hook balun **22**, first capacitor sections **34**, inductive elements **32**, and second capacitor sections **30**. The second layer implements stalks **24**.

Another example of a feed board including CM tuning circuits **20** is illustrated in FIGS. **5***a*-**5***c*. In this example, similar CLC and CM tuning circuits are employed, but are implemented on three layers of metallization. A first outer layer is illustrated in FIG. **5***a*, an inner layer is illustrated in FIG. **5***b*, and a second outer layer is illustrated in FIG. **5***c*. The middle layer implements the stalks **24**. The first and second outer layers implement the CM tuning circuits **20**, first capacitor sections **34**, inductive elements **32**, and second capacitor sections **30**. Additionally, the first outer layer implements hook balun **22**.

A schematic diagram of a high band radiating element **14** according to either of the examples of FIGS. **4***a*-**4***b* and FIGS. **5***a*-**5***c* is illustrated in FIG. **6**. Hook balun **22** couples with stalks **24** through the substrate of feed board **18** to transform a Radio Frequency (RF) signal in transmit direction from single-ended to balanced. (In the receive direction, the balun couples from balanced to unbalanced signals.) Stalks **24** propagate the balanced signals toward the dipole arms **15**. First capacitor sections **34** capacitively couple to the stalks **24** through the substrate of feed board **18**. Inductive traces **32** connect first capacitor sections **34** to second capacitor sections **30**. Second capacitor sections **30** capacitively couple the RF signals to the dipole arms **15**. The first capacitor section **34** is introduced to couple capacitively from the stalks **24** to the inductive sections **32** at high band frequencies where the dipole is desired to operate and acts to help block some of the low band currents from getting to the inductor sections **32**.

CM tuning circuits **20** provide a direct current (DC) path from first capacitor sections **34** to stalks **24** though a microstrip line and plated through-hole. Because stalks **24** are connected to ground at their lower-most edge, CM tuning circuits **20** provide a DC path to ground. The CM tuning circuits **20**, in combination with capacitor sections **34**, are preferably configured to act differently at low band and high band frequencies, and to suppress CM resonance at low band frequencies. The impedance of the CM tuning circuits **20** may be adjusted by varying a length and width of the metallic trace, and/or locating the CM tuning circuits over or to the side of a ground plane (e.g., stalk) on an opposite side of a layer of PCB substrate.

For example, CM tuning circuit **20** may comprise a narrow, high impedance microstrip line having length lw. The CM tuning circuit **20** may be dimensioned with a length to appear as a high impedance element at high band RF frequencies where it connects to capacitor section **34** near inductive section **32**. However, the electrical length of 20 inversely proportional to frequency, and appears electrically shorter and lower in impedance at low band frequencies where it connects to capacitor section **34**. With the addition of CM tuning circuit **20**, the main path for any induced low band current is through the CM tuning circuit **20**, because the first capacitor section **34** acts as a high impedance at low band frequencies. The narrow, high impedance microstrip may affect the high band CLC match and radiation pattern only at high band wavelengths close to lw=nλ/2, where n may be any integer. The length lw may therefore be selected such that CM tuning circuit **20** does not adversely affect high band signals.

Referring to FIG. **8**, a plot of CM resonance versus frequency is illustrated. In the case of FIG. **8**, the high band radiating element is a dipole with a CLC feed circuit, but no CM tuning circuit **20**. There is considerable CM resonance in the band between 790 MHz and 960 MHz. FIG. **9** shows a similar plot of CM resonance, but in this case the high band radiating element is a dipole with a CLC feed circuit and CM tuning circuit **20**. CM resonance is considerably reduced at low band frequencies, with a deep notch between 700 MHz and 800 MHz and a CM resonance below 700 MHz.

The CM tuning circuit **20** may be configured to move the CM resonance down below the low band frequency range. The CM resonance of the high band radiating element structure may be shifted by adjusting the length of the CM tuning circuit **20**. In particular, the CM resonance may be shifted lower by increasing length lw.

For example, referring to FIG. **7**, three plots of low band beamwidth versus frequency are shown. In a first case, the low band radiating element, in the absence of any high band radiating element, has a beamwidth of 58-65 degrees in at low band frequencies. In a second case, a high band element with a CM tuning circuit **20** having a length lw=22 mm is included. The beamwidth undesirably widens to more than 74 degrees at about 840 MHz, which is within the low band. The widening of the beamwidth is due to the CM resonance in the high band radiating element. This in-band CM resonance may also cause additional beam pattern distortions, such as large azimuth beam squint and poor Front/Back ratios. Also, in this second case, the beamwidth is much better above the CM resonance frequency (less than 60 degrees) than below the CM resonance frequency (more than 70 degrees), illustrating the benefit of tuning the CM resonance frequency to down below the low band.

In a third case, a high band element with a CM tuning circuit **20** having a length lw=34 mm is included. In this case, the CM resonance is indicated where the beamwidth widens to almost 80 degrees, which is at about 720 MHz. This is well below 760 MHz, which is outside the lower end of the low band frequency range. Advantageously, the beamwidth of the low band radiating elements is about 62 degrees, which is an improvement over techniques that tune the CM resonance frequency to be above the low band range, and the HB radiators of the present invention do not require expensive and bulky moats. A length lw=34 mm also has very little effect on the high band pattern and impedance matching. Other lengths for lw may also be utilized. For example, a length lw=65 mm moves the CM resonance down to 640 MHz.

In another example of the present invention, the place where the CM tuning circuit **20** connects to the feed stalk may be varied to move CM resonance lower and out of band without detuning the high band radiating element. This solution is advantageous when a desired length lw of the CM tuning circuit **20** degrades or detunes the high band dipole. For example, applying the equation lw=nλ/2, a length lw=65 mm (as in the above example) may affect high band CLC match and radiation pattern at 2300 MHz. If 2300 MHz is within the operational band of the high band element, a different length **1***w* may be selected to achieve good higher band performance. Significantly, the high band impedance of CM tuning circuit **20** depends solely on length lw, whereas the common mode responds is dependent on the total length of the signal path from second capacitor section **30** to stalk **24**. Accordingly, the CM tuning circuit **20** attachment point may be adjusted closer to or further away from the second capacitor section **30** to adjust overall length of the CM tuning circuit **20** and to move the CM resonance back to the desired frequency.

In view of the many possible embodiments to which the principles of the disclosed invention may be applied, it should be recognized that the illustrated embodiments are only preferred examples of the invention and should not be taken as limiting the scope of the invention. Rather, the scope of the invention is defined by the following claims. We therefore claim as our invention all that comes within the scope of these claims.

What is claimed is:

1. A higher band radiating element for a multiband antenna having at least higher band elements and lower band elements, comprising:

a. first and second dipole arms, each dipole arm having a capacitive coupling area; and

b. a feedboard having a balun and first and second matching circuits coupled to the balun, the first matching circuit being coupled to the first dipole arm and the second matching circuit being coupled to the second dipole arm, the first and second matching circuits each comprising in series:

1. a stalk, coupled to the balun,
2. a first capacitive element;
3. an inductor; and
4. a second capacitive element, the second capacitive element being coupled to a dipole arm;

each matching circuit further comprising a common mode tuning circuit connecting the first capacitive element and the inductor to the stalk to move the common mode resonance of the matching circuits to a frequency below the lower band frequency.

2. The higher band radiating element of claim **1**, wherein the common mode tuning circuit further comprises a microstrip line providing a DC connection to the stalk and having a length selected such that it appears as a high impedance at an operating frequency of the higher band radiating element.

3. The higher band radiating element of claim **2**, wherein the common mode tuning circuit has a length selected such that it appears as a relatively low impedance at the operating frequency of the lower band radiating element.

4. The higher band radiating element of claim **1**, wherein the first capacitive element and an area of the stalk comprise parallel plates of a capacitor and the feedboard substrate comprises a dielectric of a capacitor.

5. The higher band radiating element of claim **1**, wherein the second capacitive element and dipole arm capacitive coupling area combine to form a capacitor that blocks out of band currents.

6. The higher band radiating element of claim **1**, wherein the radiating element further comprises a cross dipole radiating element.

7. The higher band radiating element of claim **1**, wherein the higher band radiating element further comprises a high band radiating element of a dual-band array.

8. The higher band radiating element of claim **1**, wherein the higher band radiating element has a first operational frequency band within a range of about 1710 MHz-2700 MHz, and each lower band radiating element has a second operational frequency band within a range of about 698 MHz-960 MHz.

9. The radiating element of claim **8**, wherein the common mode tuning circuit has a length selected to pass low band current and block high band current.

10. The higher band radiating element of claim **1**, wherein the common mode tuning circuit has a length such that it does not de-tune the higher band radiating element.

11. The multiband antenna of claim **10**, wherein the first operational frequency band comprises a mobile communications low band and the second operational frequency band comprises a mobile communications high band.

12. The multiband antenna of claim **10**, wherein the first operational frequency band is located within an approximate range of 698 MHz to 960 MHz, and the second operational frequency band is located within an approximate range of 1710 MHz to 2170 MHz.

13. A multiband antenna, comprising:

a. a first array of first radiating elements having a first operational frequency band; and

b. a second array of second radiating elements having a second operational frequency band, the second operational frequency band being higher than the first operational frequency band, the second radiating elements further comprising: a. first and second dipole arms, each dipole arm having a capacitive coupling area; and b. a feedboard having a balun and first and second matching circuits coupled to the balun, the first matching circuit being coupled to the first dipole arm and the second matching circuit being coupled to the second dipole arm, the first and second matching circuits each comprising in series:

1. a stalk, coupled to the balun,
2. a first capacitive element;
3. an inductor; and
4. a second capacitive element, the second capacitive element being associated with one of the first and second dipole arms,

each matching circuit further comprising a common mode tuning circuit connecting the first capacitive element and the inductor to the stalk, the common mode tuning circuit comprising a microstrip line dimensioned to short any induced low band currents to the stalk without substantially affecting high band currents, thereby moving common mode resonance down below the second operational frequency band.

14. A higher band radiating element for a multiband antenna having at least higher band elements and lower band elements, comprising:

a first dipole arm;

a second dipole arm;

a feedboard having a balun and first and second matching circuits coupled to the balun, the first matching circuit being coupled to the first dipole arm and the second matching circuit being coupled to the second dipole arm, the first matching circuit comprising a first stalk that is coupled to the balun and a first capacitor coupled between the first stalk and the first dipole arm, and the second matching circuit comprising a second stalk that is coupled to the balun and a second capacitor coupled between the second stalk and the second dipole arm,

wherein the first matching circuit further comprises a common mode tuning circuit that provides a direct current path from a first node that is between the first capacitor and the first dipole arm to ground.

15. The higher band radiating element of claim **14**, wherein the first matching circuit further includes a third capacitor coupled in series between the first capacitor and the first dipole arm, wherein the first node is located between the first and third capacitors.

16. The higher band radiating element of claim **14**, wherein the common mode tuning circuit comprises a transmission line connecting the first node to the stalk, and wherein a length of the transmission line is selected such that it appears as a high impedance at an operating frequency of the higher band radiating element.

17. The higher band radiating element of claim **16**, wherein the length of the transmission line is further selected such that it appears as a relatively low impedance at the operating frequency of the lower band radiating element.

18. The higher band radiating element of claim **14**, wherein the first matching circuit is further configured to move the common mode resonance of the matching circuits to a frequency below the operating frequency of the lower band radiating element.

19. The higher band radiating element of claim **15**, wherein the first matching circuit further includes a first inductor in series between the first capacitor and the third capacitor and a second inductor in series between the second capacitor and the fourth capacitor.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,698,486 B2
APPLICATION NO. : 14/768398
DATED : July 4, 2017
INVENTOR(S) : Shooshtari et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 6, Line 14: delete “different length 1*w* may” and insert -- different length *lw* may --

Signed and Sealed this
Sixteenth Day of January, 2018

Joseph Matal

Joseph Matal
Performing the Functions and Duties of the
Under Secretary of Commerce for Intellectual Property and
Director of the United States Patent and Trademark Office

EXHIBIT D

US009831548B2

(12) **United States Patent**
Timofeev et al.

(10) **Patent No.: US 9,831,548 B2**
(45) **Date of Patent: Nov. 28, 2017**

(54) **DUAL-BEAM SECTOR ANTENNA AND ARRAY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1021 days.

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H01Q 3/26 (2006.01)
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CPC ***H01Q 3/26*** (2013.01); ***H01Q 1/246*** (2013.01); ***H01Q 3/30*** (2013.01); ***H01Q 25/002*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01Q 3/26; H01Q 3/263; H01Q 3/267; H01Q 3/28; H01Q 3/30; H01Q 3/40; H01Q 25/002; H01Q 25/02
(Continued)

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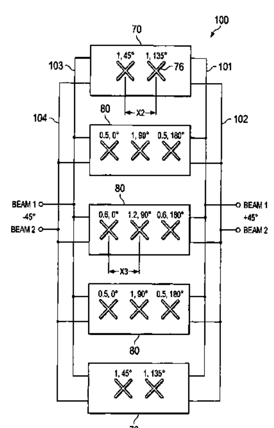
Primary Examiner — Chuong P Nguyen
(74) *Attorney, Agent, or Firm* — Myers Bigel, P.A.

(57) **ABSTRACT**

A low sidelobe beam forming method and dual-beam antenna schematic are disclosed, which may preferably be used for 3-sector and 6-sector cellular communication system. Complete antenna combines 2-, 3- or -4 columns dual-beam sub-arrays (modules) with improved beam-forming network (BFN). The modules may be used as part of an array, or as an independent 2-beam antenna. By integrating different types of modules to form a complete array, the present invention provides an improved dual-beam antenna with improved azimuth sidelobe suppression in a wide frequency band of operation, with improved coverage of a
(Continued)



desired cellular sector and with less interference being created with other cells. Advantageously, a better cell efficiency is realized with up to 95% of the radiated power being directed in a desired cellular sector.

20 Claims, 10 Drawing Sheets

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See application file for complete search history.

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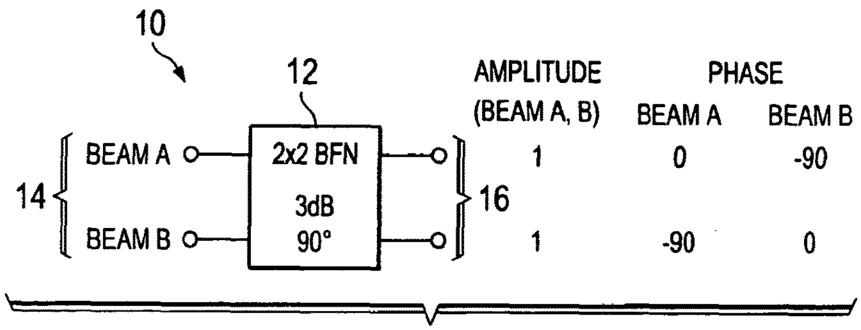


FIG. 1A
(PRIOR ART)

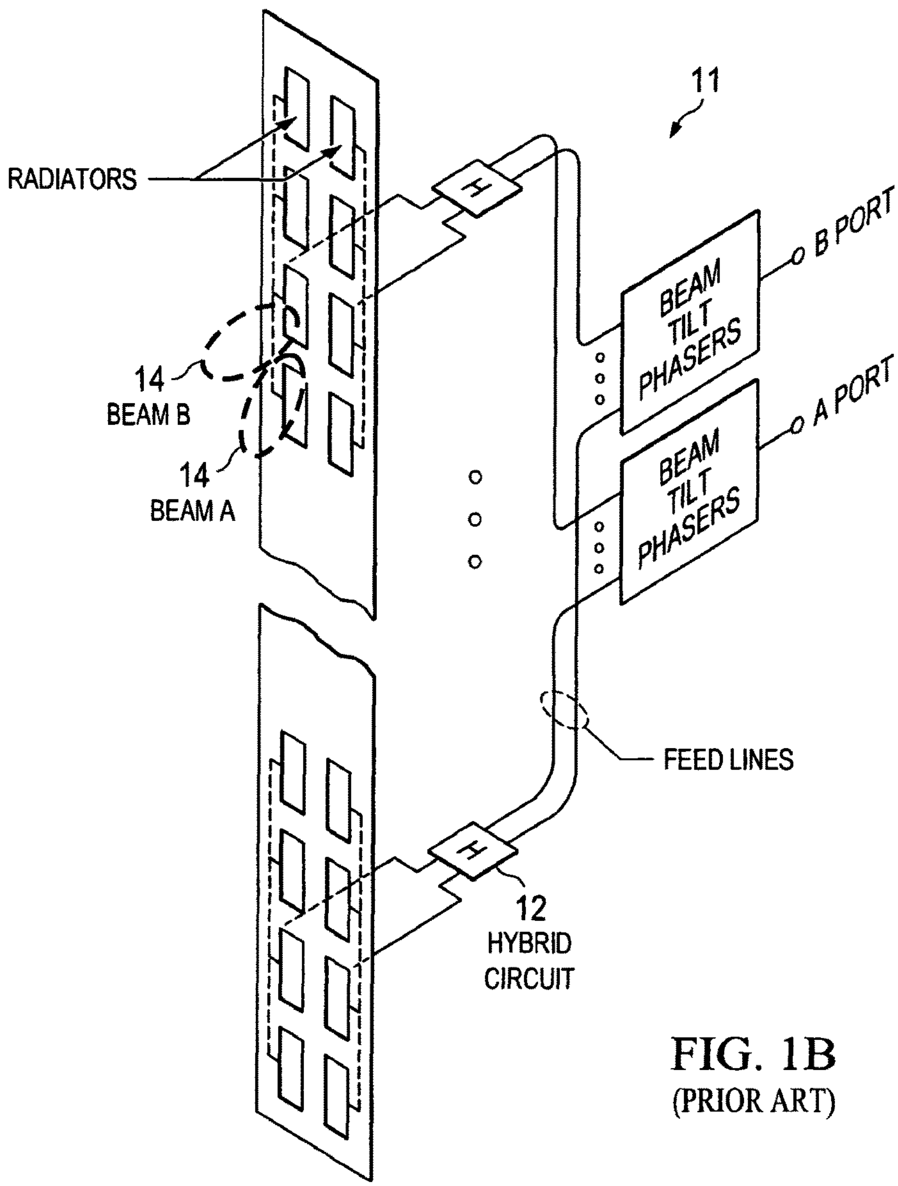


FIG. 1B
(PRIOR ART)

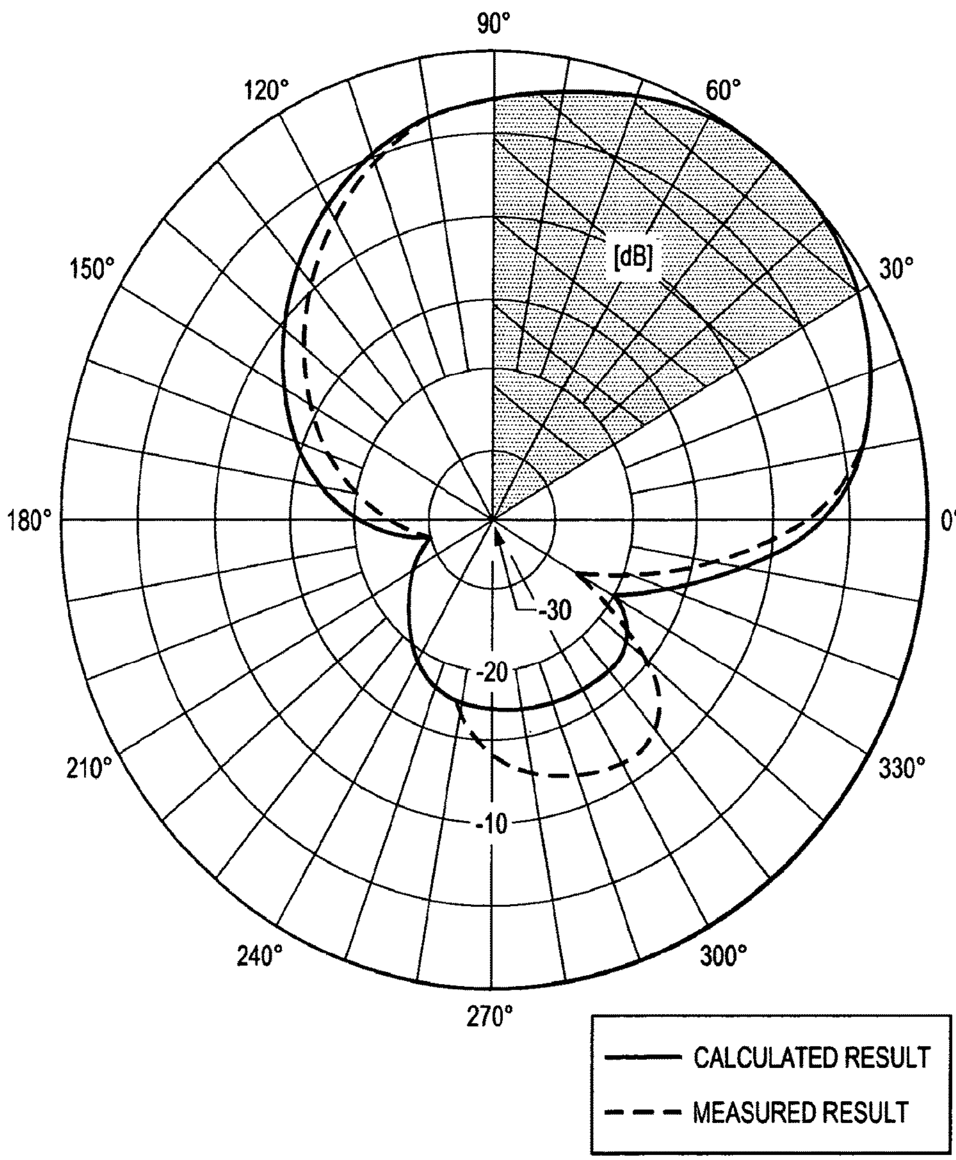


FIG. 1C
(PRIOR ART)

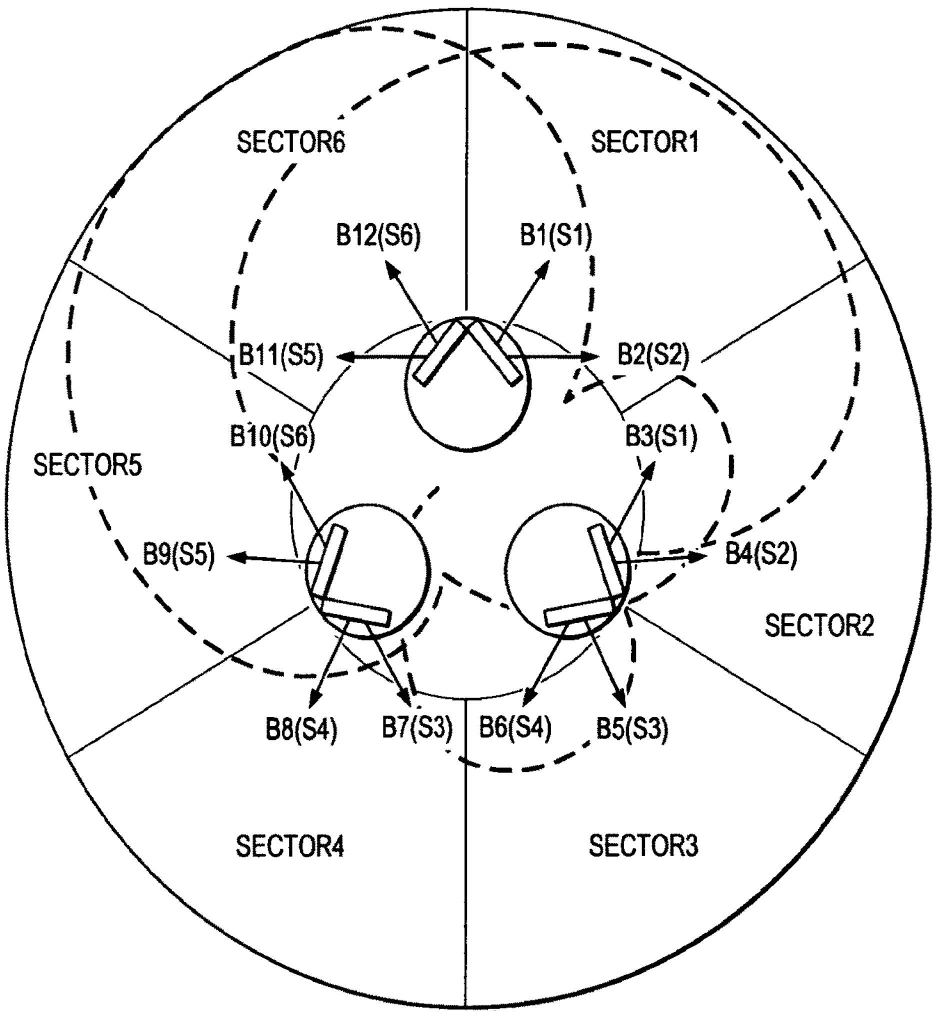


FIG. 1D
(PRIOR ART)

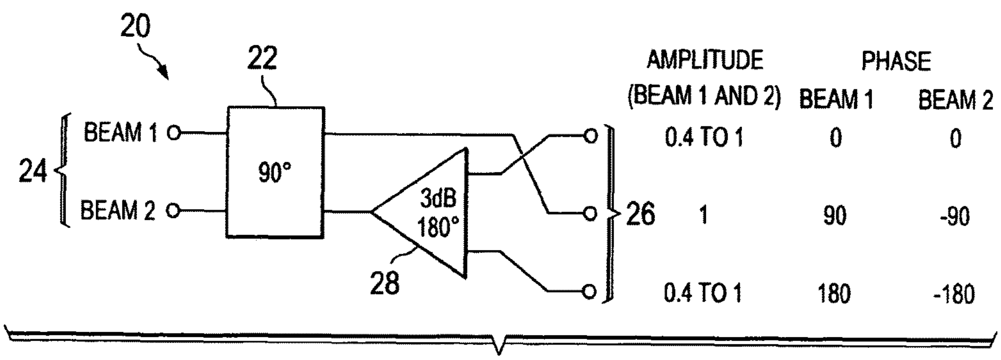


FIG. 2A

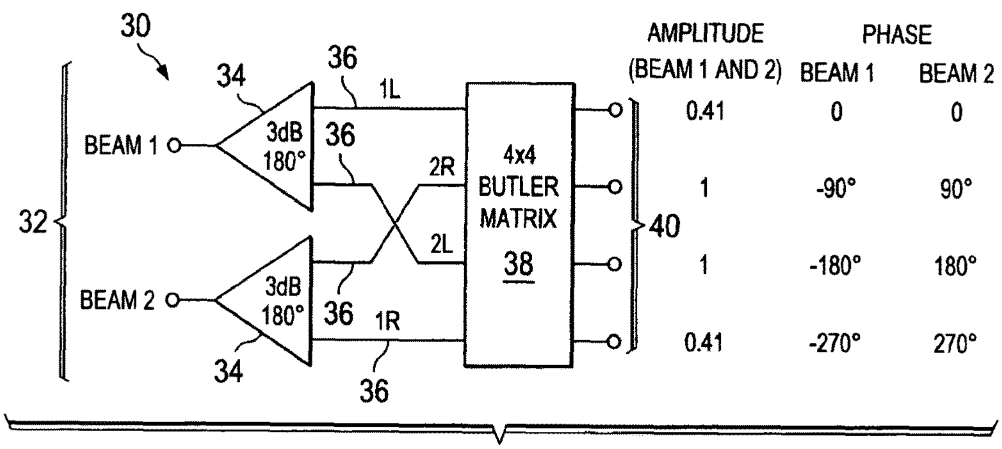


FIG. 2B

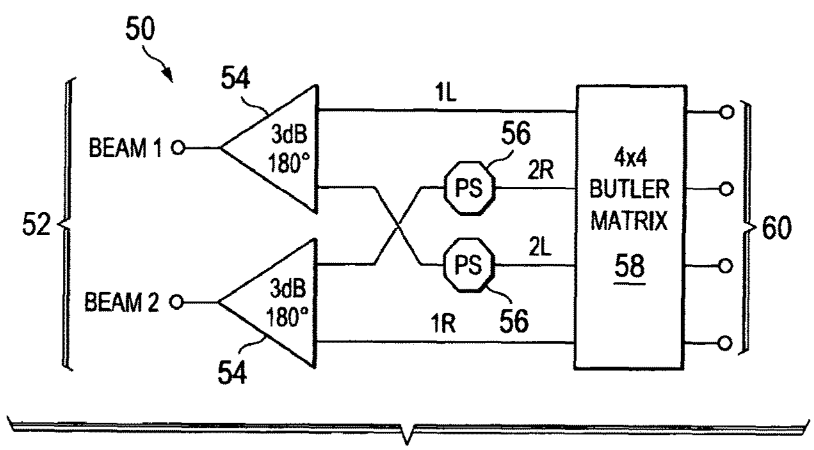


FIG. 2C

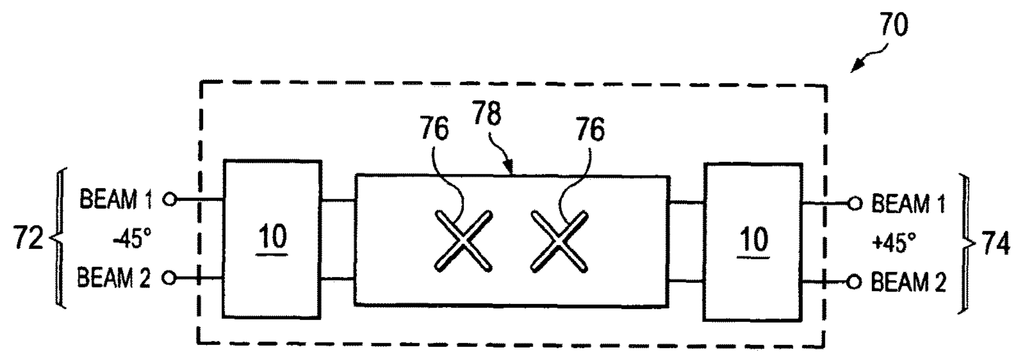


FIG. 3

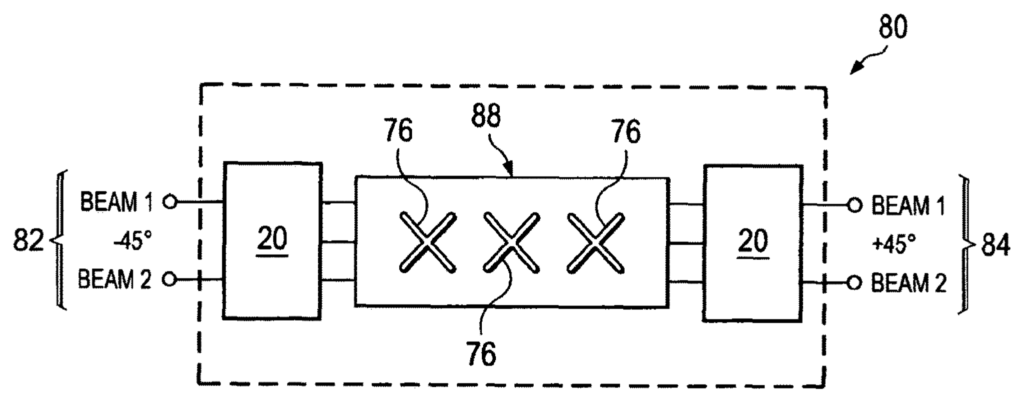


FIG. 4

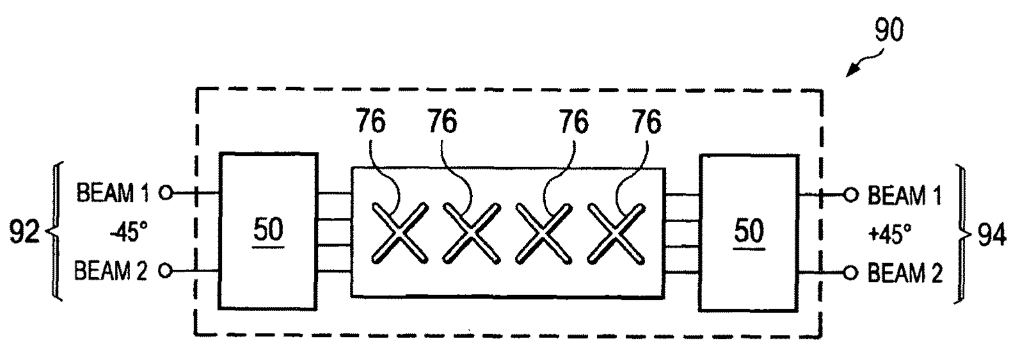


FIG. 5

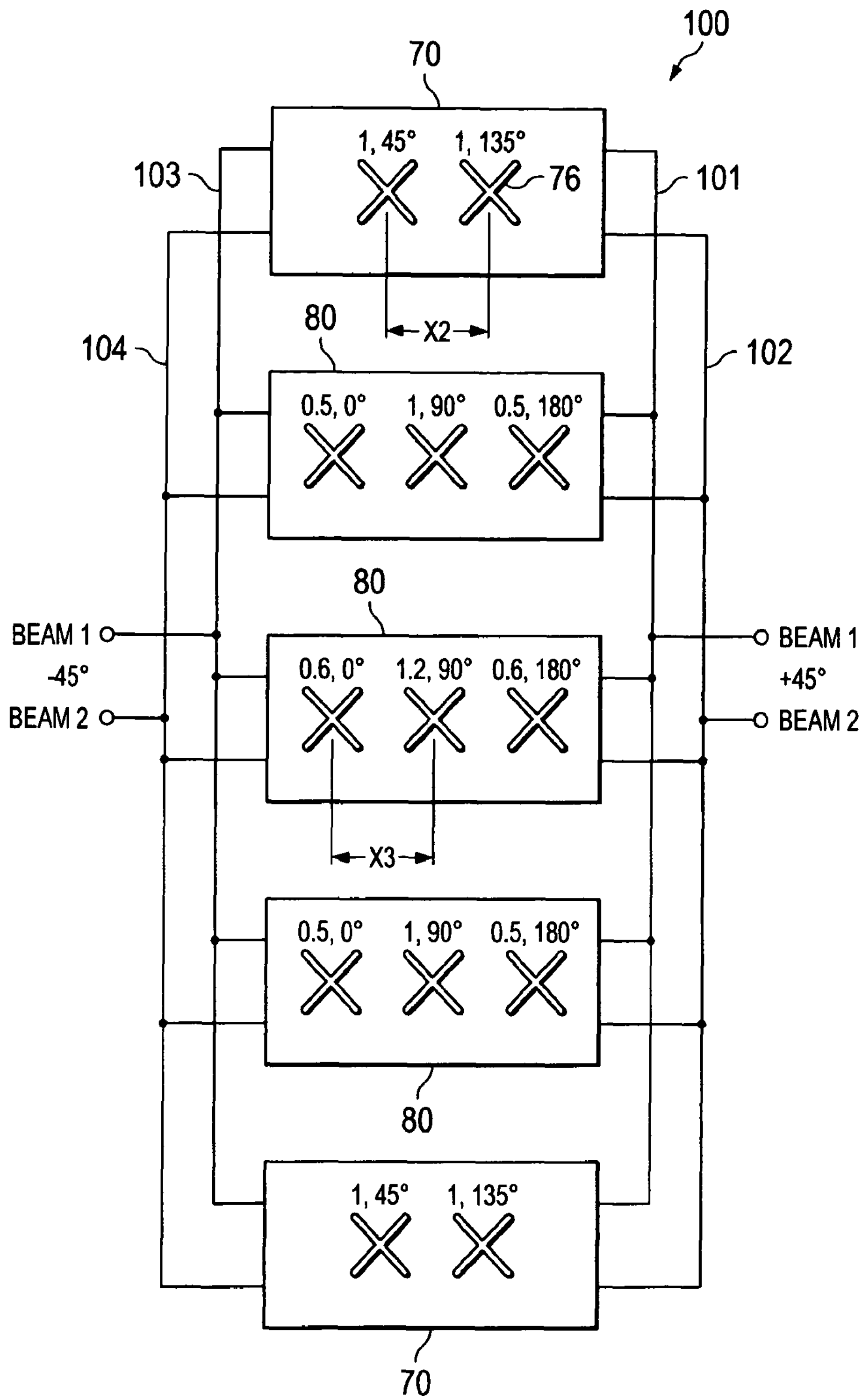

100
70
1, 45°
1, 135°
76
103
101
80
X2
104
102
0.5, 0°
1, 90°
0.5, 180°
80
BEAM 1
-45°
BEAM 2
0.6, 0°
1.2, 90°
0.6, 180°
BEAM 1
+45°
BEAM 2
X3
0.5, 0°
1, 90°
0.5, 180°
80
1, 45°
1, 135°
70

FIG. 6

FIG. 7A

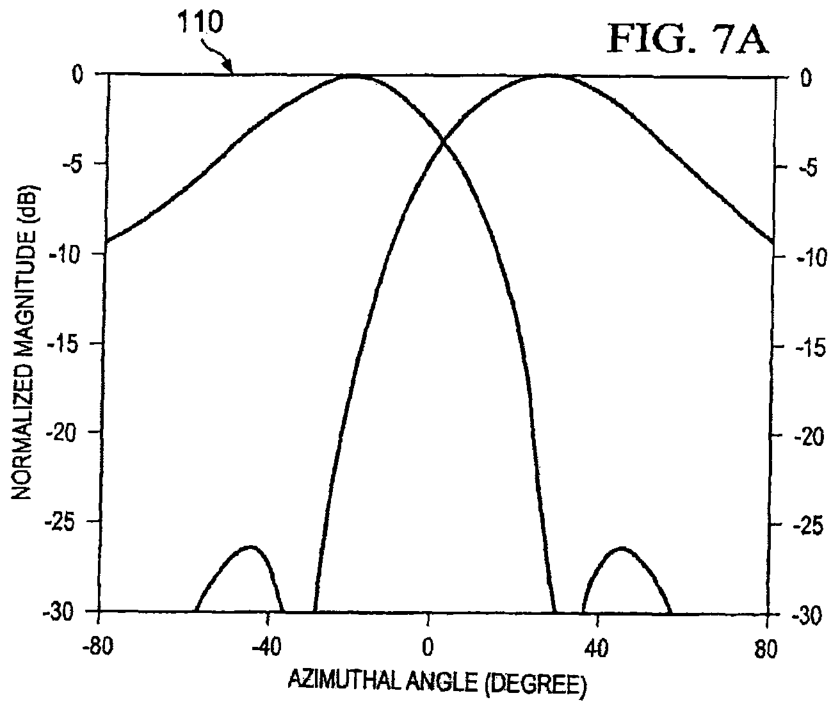
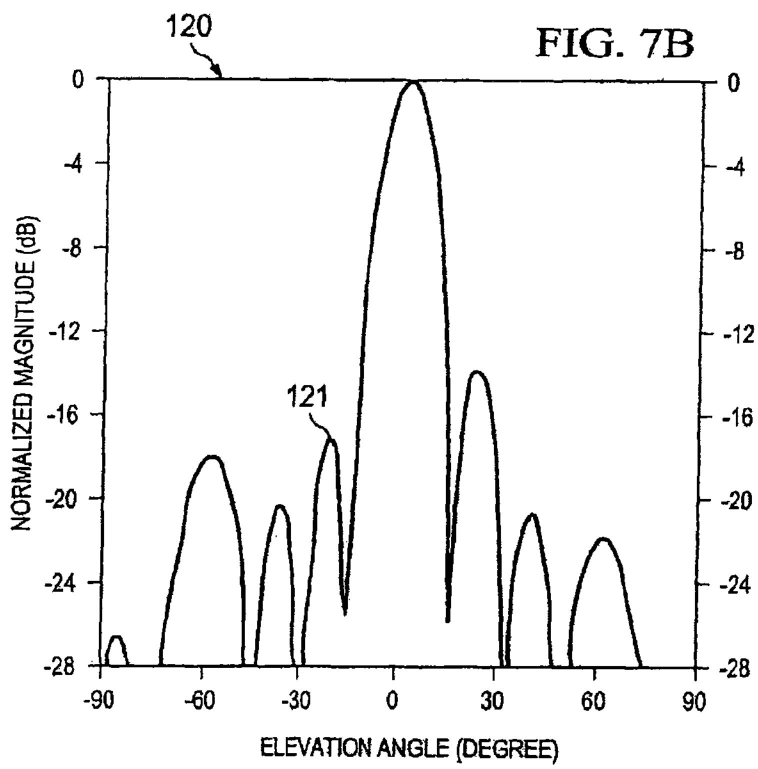

110
NORMALIZED MAGNITUDE (dB)
0
-5
-10
-15
-20
-25
-30
-80
-40
0
40
80
AZIMUTHAL ANGLE (DEGREE)

FIG. 7B


120
121
NORMALIZED MAGNITUDE (dB)
0
-4
-8
-12
-16
-20
-24
-28
-90
-60
-30
0
30
60
90
ELEVATION ANGLE (DEGREE)

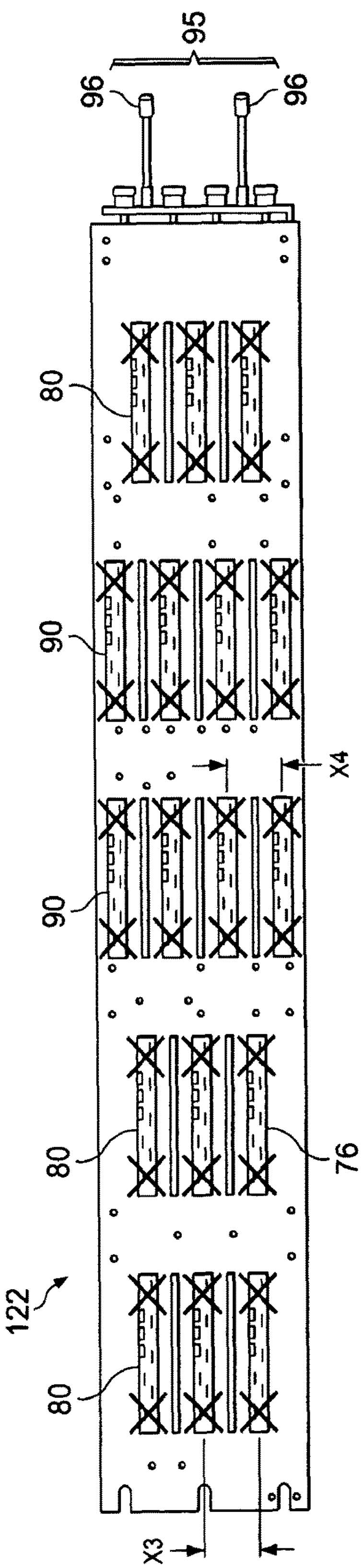

95
96
96
80
90
90
80
76
122
80
X4
X3

FIG. 8A

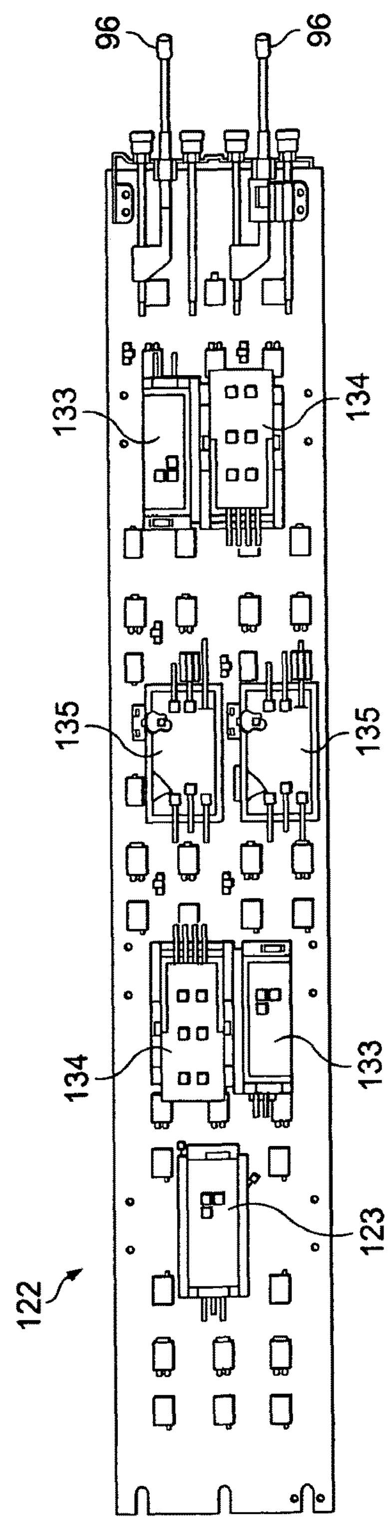

96
96
133
134
135
135
134
133
123
122

FIG. 8B

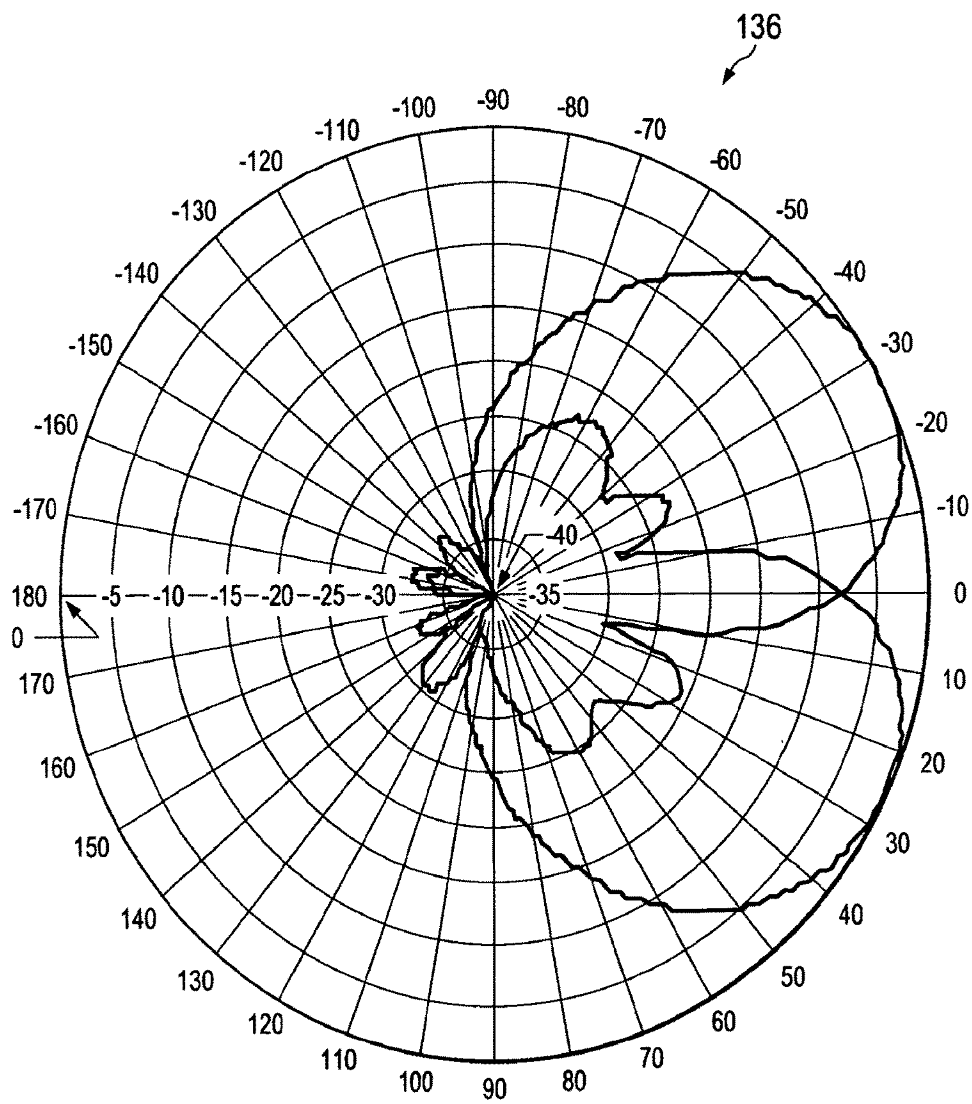
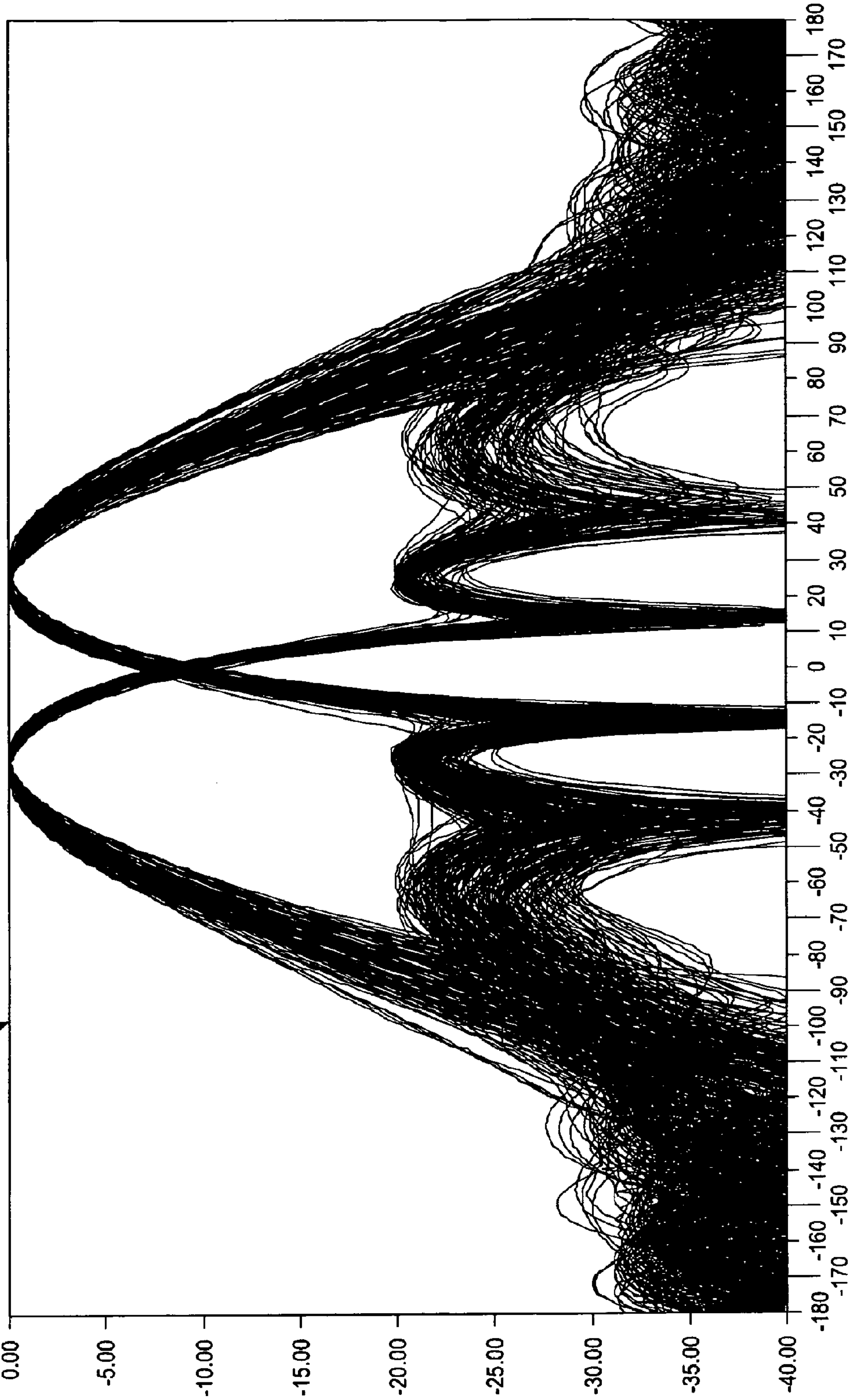

136
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
0
-170
-160
-150
-140
-130
-120
-110
-100
-5
-10
-15
-20
-25
-30
-35
-40

FIG. 9

FIG. 10

140


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00

DUAL-BEAM SECTOR ANTENNA AND ARRAY

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a 35 U.S.C. §371 national stage application of PCT International Application No. PCT/US2009/006061, filed Nov. 12, 2009, which itself claims priority of Provisional Application U.S. Ser. No. 61/199,840 filed on Nov. 19, 2008 entitled Dual-Beam Antenna Array, the teaching of which are incorporated herein. The disclosure and content of both of which are incorporated herein by reference in their entireties. The above-referenced PCT International Application was published in the English language as International Publication No. WO2010/059786 A1 on May 27, 2010.

FIELD OF THE INVENTION

The present invention is generally related to radio communications, and more particularly to multi-beam antennas utilized in cellular communication systems.

BACKGROUND OF THE INVENTION

Cellular communication systems derive their name from the fact that areas of communication coverage are mapped into cells. Each such cell is provided with one or more antennas configured to provide two-way radio/RF communication with mobile subscribers geographically positioned within that given cell. One or more antennas may serve the cell, where multiple antennas commonly utilized and each are configured to serve a sector of the cell. Typically, these plurality of sector antennas are configured on a tower, with the radiation beam(s) being generated by each antenna directed outwardly to serve the respective cell.

In a common 3-sector cellular configuration, each sector antenna usually has a 65° 3 dB azimuth beamwidth (AzBW). In another configuration, 6-sector cells may also be employed to increase system capacity. In such a 6-sector cell configuration, each sector antenna may have a 33° or 45° AzBW as they are the most common for 6-sector applications. However, the use of 6 of these antennas on a tower, where each antenna is typically two times wider than the common 65° AzBW antenna used in 3-sector systems, is not compact, and is more expensive.

Dual-beam antennas (or multi-beam antennas) may be used to reduce the number of antennas on the tower. The key of multi-beam antennas is a beamforming network (BFN). A schematic of a prior art dual-beam antenna is shown in FIG. **1**A and FIG. **1**B. Antenna **11** employs a 2×2 BFN **10** having a 3 dB 90° hybrid coupler shown at **12** and forms both beams A and B in azimuth plane at signal ports **14**. (2×2 BFN means a BFN creating 2 beams by using 2 columns). The two radiator coupling ports **16** are connected to antenna elements also referred to as radiators, and the two ports **14** are coupled to the phase shifting network, which is providing elevation beam tilt (see FIG. **1**B). The main drawback of this prior art antenna as shown in FIG. **1**C is that more than 50% of the radiated power is wasted and directed outside of the desired 60° sector for a 6-sector application, and the azimuth beams are too wide (150°@−10 dB level), creating interference with other sectors, as shown in FIG. **1**D. Moreover, the low gain, and the large backlobe (about −11 dB), is not acceptable for modern systems due to high interference generated by one antenna into the unintended cells. Another drawback is vertical polarization is used and no polarization diversity.

In other dual-beam prior art solutions, such as shown in U.S. Patent application U.S. 2009/0096702 A1, there is shown a 3 column array, but which array also still generates very high sidelobes, about −9 dB.

Therefore, there is a need for an improved dual-beam antenna with improved azimuth sidelobe suppression in a wide frequency band of operation, having improved gain, and which generates less interference with other sectors and better coverage of desired sector.

SUMMARY OF INVENTION

The present invention achieves technical advantages by integrating different dual-beam antenna modules into an antenna array. The key of these modules (sub-arrays) is an improved beam forming network (BFN). The modules may advantageously be used as part of an array, or as an independent antenna. A combination of 2×2, 2×3 and 2×4 BFNs in a complete array allows optimizing amplitude and phase distribution for both beams. So, by integrating different types of modules to form a complete array, the present invention provides an improved dual-beam antenna with improved azimuth sidelobe suppression in a wide frequency band of operation, with improved coverage of a desired cellular sector and with less interference being created with other cells. Advantageously, a better cell efficiency is realized with up to 95% of the radiated power being directed in a desired sector. The antenna beams' shape is optimized and adjustable, together with a very low sidelobes/backlobes.

In one aspect of the present invention, an antenna is achieved by utilizing a M×N BFN, such as a 2×3 BFN for a 3 column array and a 2×4 BFN for a 4 column array, where M≠N.

In another aspect of the invention, 2 column, 3 column, and 4 column radiator modules may be created, such as a 2×2, 2×3, and 2×4 modules. Each module can have one or more dual-polarized radiators in a given column. These modules can be used as part of an array, or as an independent antenna.

In another aspect of the invention, a combination of 2×2 and 2×3 radiator modules are used to create a dual-beam antenna with about 35 to 55° AzBW and with low sidelobes/backlobes for both beams.

In another aspect of the invention, a combination of 2×3 and 2×4 radiator modules are integrated to create a dual-beam antenna with about 25 to 45° AzBW with low sidelobes/backlobes for both beams.

In another aspect of the invention, a combination of 2×2, 2×3 and 2×4 radiator modules are utilized to create a dual-beam antenna with about 25 to 45° AzBW with very low sidelobes/backlobes for both beams in azimuth and the elevation plane.

In another aspect of the invention, a combination of 2×2 and 2×4 radiator modules can be utilized to create a dual-beam antenna.

All antenna configurations can operate in receive or transmit mode.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A, **1**B, **1**C and **1**D shows a conventional dual-beam antenna with a conventional 2×2 BFN;

FIG. **2**A shows a 2×3 BFN according to one embodiment of the present invention which forms 2 beams with 3 columns of radiators;

FIG. **2**B is a schematic diagram of a 2×4 BFN, which forms 2 beams with 4 columns of radiators, including the associated phase and amplitude distribution for both beams;

FIG. **2**C is a schematic diagram of a 2×4 BFN, which forms 2 beams with 4 columns of radiators, and further provided with phase shifters allowing slightly different AzBW between beams and configured for use in cell sector optimization;

FIG. **3** illustrates how the BFNs of FIG. **1**A can be advantageously combined in a dual polarized 2 column antenna module;

FIG. **4** shows how the BFN of FIG. **2**A can be combined in a dual polarized 3 column antenna module;

FIG. **5** shows how the BFNs of FIG. **2**B or FIG. **2**C can be combined in dual polarized 4 column antenna module;

FIG. **6** shows one preferred antenna configuration employing the modular approach for 2 beams each having a 45° AzBW, as well as the amplitude and phase distribution for the beams as shown near the radiators;

FIG. **7**A and FIG. **7**B show the synthesized beam pattern in azimuth and elevation planes utilizing the antenna configuration shown in FIG. **6**;

FIGS. **8**A and **8**B depicts a practical dual-beam antenna configuration when using 2×3 and 2×4 modules; and

FIGS. **9-10** show the measured radiation patterns with low sidelobes for the configuration shown in FIG. **8**A and FIG. **8**B.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **2**A, there is shown one preferred embodiment comprising a bidirectional 2×3 BFN at **20** configured to form 2 beams with 3 columns of radiators, where the two beams are formed at signal ports **24**. A 90° hybrid coupler **22** is provided, and may or may not be a 3 dB coupler. Advantageously, by variation of the splitting coefficient of the 90° hybrid coupler **22**, different amplitude distributions of the beams can be obtained for radiator coupling ports **26**: from uniform (1-1-1) to heavy tapered (0.4-1-0.4). With equal splitting (3 dB coupler) 0.7-1-0.7 amplitudes are provided. So, the 2×3 BFN **20** offers a degree of design flexibility, allowing the creation of different beam shapes and sidelobe levels. The 90° hybrid coupler **22** may be a branch line coupler, Lange coupler, or coupled line coupler. The wide band solution for a 180° equal splitter **28** can be a Wilkinson divider with a 180° Shiffman phase shifter. However, other dividers can be used if desired, such as a rat-race 180° coupler or 90° hybrids with additional phase shift. In FIG. **2**A, the amplitude and phase distribution on radiator coupling ports **26** for both beams Beam 1 and Beam 2 are shown to the right. Each of the 3 radiator coupling ports **26** can be connected to one radiator or to a column of radiators, as dipoles, slots, patches etc. Radiators in column can be a vertical line or slightly offset (staggered column).

FIG. **2**B is a schematic diagram of a bidirectional 2×4 BFN **30** according to another preferred embodiment of the present invention, which is configured to form 2 beams with 4 columns of radiators and using a standard Butler matrix 38 as one of the components. The 180° equal splitter **34** is the same as the splitter **28** described above. The phase and amplitudes for both beams Beam 1 and Beam 2 are shown in the right hand portion of the figure. Each of 4 radiator coupling ports **40** can be connected to one radiator or to column of radiators, as dipoles, slots, patches etc. Radiators in column can stay in vertical line or to be slightly offset (staggered column).

FIG. **2**C is a schematic diagram of another embodiment comprising a bidirectional 2×4 BFN at **50**, which is configured to form 2 beams with 4 columns of radiators. BFN **50** is a modified version of the 2×4 BFN **30** shown in FIG. **2**B, and includes two phase shifters **56** feeding a standard 4×4 Butler Matrix 58. By changing the phase of the phase shifters **56**, a slightly different AzBW between beams can be selected (together with adjustable beam position) for cell sector optimization. One or both phase shifters **56** may be utilized as desired.

The improved BFNs **20**, **30**, **50** can be used separately (BFN **20** for a 3 column 2-beam antenna and BFN **30**, **50** for 4 column 2-beam antennas). But the most beneficial way to employ them is the modular approach, i.e. combinations of the BFN modules with different number of columns/different BFNs in the same antenna array, as will be described below.

FIG. **3** shows a dual-polarized 2 column antenna module with 2×2 BFN's generally shown at **70**. 2×2 BFN **10** is the same as shown in FIG. **1**A. This 2×2 antenna module **70** includes a first 2×2 BFN **10** forming beams with −45° polarization, and a second 2×2 BFN **10** forming beams with +45° polarization, as shown. Each column of radiators **76** has at least one dual polarized radiator, for example, a crossed dipole.

FIG. **4** shows a dual-polarized 3 column antenna module with 2×3 BFN's generally shown at **80**. 2×3 BFN **20** is the same as shown in FIG. **2**A. This 2×3 antenna module **80** includes a first 2×3 BFN **20** forming beams with −45° polarization, and a second 2×3 BFN **20** forming beams with +45° polarization, as shown. Each column of radiators **76** has at least one dual polarized radiator, for example, a crossed dipole.

FIG. **5** shows a dual-polarized 4 column antenna module with 2×4 BFN's generally shown at **90**. 2×4 BFN **50** is the same as shown in FIG. **2**C. This 2×4 antenna module **80** includes a first 2×4 BFN **50** forming beams with −45° polarization, and a second 2×4 BFN **50** forming beams with +45° polarization, as shown. Each column of radiators **76** has at least one dual polarized radiator, for example, a crossed dipole.

Below, in FIGS. **6-10**, the new modular method of dual-beam forming will be illustrated for antennas with 45 and 33 deg., as the most desirable for 5-sector and 6-sector applications.

Referring now to FIG. **6**, there is generally shown at **100** a dual polarized antenna array for two beams each with a 45° AzBW. The respective amplitudes and phase for one of the beams is shown near the respective radiators **76**. The antenna configuration **100** is seen to have 3 2×3 modules **80** is and two 2×2 modules **70**. Modules are connected with four vertical dividers **101**, **102**, **103**, **104**, having 4 ports which are related to 2 beams with +45° polarization and 2 beams with −45° polarization), as shown in FIG. **6**. The horizontal spacing between radiators columns **76** in module **80** is X3, and the horizontal spacing between radiators in module **70** is X2. Preferably, dimension X3 is less than dimension X2, X3<X2. However, in some applications, dimension X3 may equal dimension X2, X3=X2, or even X3>X2, depending on the desired radiation pattern. Usually the spacings X2 and X3 are close to half wavelength (λ/2), and adjustment of the spacings provides adjustment of the resulting AzBW. The splitting coefficient of coupler **22** was selected at 3.5 dB to get low Az sidelobes and high beam cross-over level of 3.5 dB.

Referring to FIG. **7**A, there is shown at **110** a simulated azimuth patterns for both of the beams provided by the antenna **100** shown in FIG. **6**, with X3=X2=0.46λ and 2 crossed dipoles in each column **76**, separated by 0.87λ As shown, each azimuth pattern has an associated sidelobe that is at least −27 dB below the associated main beam with beam cross-over level of −3.5 dB. Advantageously, the present invention is configured to provide a radiation pattern with low sidelobes in both planes. As shown in FIG. **7**B, the low level of upper sidelobes **121** is achieved also in the elevation plane (<−17 dB, which exceeds the industry standard of <−15 dB). As it can be seen in FIG. **6**, the amplitude distribution and the low sidelobes in both planes are achieved with small amplitude taper loss of 0.37 dB. So, by selection of a number of 2×2 and 2×3 modules, distance X2 and X3 together with the splitting coefficient of coupler **22**, a desirable AzBW together with desirable level of sidelobes is achieved. Vertical dividers **101**,**102**,**103**,**104** can be combined with phase shifters for elevation beam tilting.

FIG. **8**A depicts a practical dual-beam antenna configuration for a 33° AzBW, when viewed from the radiation side of the antenna array, which has three (3) 3-column radiator modules **80** and two (2) 4-column modules **90**. Each column **76** has 2 crossed dipoles. Four ports **95** are associated with 2 beams with +45 degree polarization and 2 beams with −45 degree polarization.

FIG. **8**B shows antenna **122** when viewing the antenna from the back side, where 2×3 BFN **133** and 2×4 BFN **134** are located together with associated phase shifters/dividers **135**. Phase shifters/dividers **135**, mechanically controlled by rods **96**, provide antenna **130** with independently selectable down tilt for both beams.

FIG. **9** is a graph depicting the azimuth dual-beam patterns for the antenna array **122** shown in FIG. **8**A, **8**B, measured at 1950 MHz and having 33 deg. AzBW.

Referring to FIG. **10**, there is shown at **140** the dual beam azimuth patterns for the antenna array **122** of FIG. **8**A, **8**B, measured in the frequency band 1700-2200 MHZ. As one can see from FIGS. **9** and **10**, low side lobe level (<20 dB) is achieved in very wide (25%) frequency band. The Elevation pattern has low sidelobes, too (<−18 dB).

As can be appreciated in FIGS. **9** and **10**, up to about 95% of the radiated power for each main beam, Beam 1 and Beam 2, is directed in the desired sector, with only about 5% of the radiated energy being lost in the sidelobes and main beam portions outside the sector, which significantly reduces interference when utilized in a sectored wireless cell. Moreover, the overall physical dimensions of the antenna **122** are significantly reduced from the conventional 6-sector antennas, allowing for a more compact design, and allowing these sector antennas **122** to be conveniently mounted on antenna towers. Three (3) of the antennas **122** (instead of six antennas in a conventional design) may be conveniently configured on an antenna tower to serve the complete cell, with very little interference between cells, and with the majority of the radiated power being directed into the intended sectors of the cell.

For instance, the physical dimensions of 2-beam antenna **122** in FIG. **8**A, **8**B are 1.3×0.3 m, the same as dimensions of conventional single beam antenna with 33 deg. AzBW.

In other designs based on the modular approach of the present invention, other dual-beam antennas having a different AzBW may be achieved, such as a 25, 35, 45 or 55 degree AzBW, which can be required for different applications. For example, 55 and 45 degree antennas can be used for 4 and 5 sector cellular systems. In each of these configurations, by the combination of the 2×2, 2×3 and 2×4 modules, and the associated spacing X2, X3 and X4 between the radiator columns (as shown in FIGS. **6** and **8**A), the desired AzBW can be achieved with very low sidelobes and also adjustable beam tilt. Also, the splitting coefficient of coupler **22** provides another degree of freedom for pattern optimization. In the result, the present invention allows to reduce azimuth sidelobes by 10-15 dB in comparison with prior art.

Though the invention has been described with respect to a specific preferred embodiment, many variations and modifications will become apparent to those skilled in the art upon reading the present application. For example, the invention can be applicable for radar multi-beam antennas. The intention is therefore that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.

What is claimed is:

1. A multi-beam cellular communication antenna, comprising:

an antenna array having a plurality of rows of radiating elements, wherein a first of the rows includes at least two radiating elements and a second of the rows includes at least three radiating elements and has a different number of radiating elements than the first of the rows; and

an antenna feed network that is configured to couple at least a first input signal and a second input signal to all of the radiating elements of the antenna array.

2. The multi-beam cellular communication antenna of claim **1**, wherein the antenna array is configured to generate a first beam that points in a first direction responsive to the first input signal and to generate a second beam that points in a second direction responsive to the second input signal.

3. The multi-beam cellular communication antenna of claim **2**, wherein the first beam covers a first sector of a cell of a wireless communication system and the second beam covers a second sector of the cell.

4. The multi-beam cellular communication antenna of claim **2**, wherein the first of the rows includes a total of three radiating elements and the second of the rows includes a total of four radiating elements.

5. The multi-beam cellular communication antenna of claim **4**, wherein a third of the rows includes a total of four radiating elements and a fourth of the rows includes a total of three radiating elements.

6. The multi-beam cellular communication antenna of claim **5**, wherein the second and third of the rows are between the first and fourth of the rows.

7. The multi-beam cellular communication antenna of claim **5**, wherein ones of the radiating elements in the first of the rows are aligned in a column direction that is perpendicular to a row direction with respective ones of the radiating elements in the fourth of the rows and ones of the radiating elements in the second of the rows are aligned in the column direction with respective ones of the radiating elements in the third of the rows.

8. The multi-beam cellular communication antenna of claim **4**, wherein the antenna feed network comprises a 2×3 beamforming network that couples the first and second input signals to the first of the rows, a 2×4 beamforming network that couples the first and second input signals to the second of the rows, a first power divider that couples the first input signal to the 2×3 beamforming network and to the 2×4 beamforming network, and a second power divider that couples the second input signal to the 2×3 beamforming network and to the 2×4 beamforming network.

9. The multi-beam cellular communication antenna of claim **8**, wherein the 2×3 beamforming network comprises a 90° hybrid coupler and a 180° splitter.

10. The multi-beam cellular communication antenna of claim **8**, wherein the 2×4 beamforming network comprises a pair of 180° 3 dB splitters and a 4×4 Butler matrix.

11. The multi-beam cellular communication antenna of claim **10**, wherein the 2×4 beamforming network further comprises at least one phase shifter interposed between each of the 180° 3 dB splitters and the 4×4 Butler matrix.

12. The multi-beam cellular communication antenna of claim **1**, wherein a first distance between two adjacent radiating elements in the first of the rows is greater than a second distance between two adjacent radiating elements in the second of the rows.

13. A multi-beam cellular communication antenna, comprising:

a plurality of first subarrays that are spaced apart from each other along a column direction, each of the first subarrays comprising M radiating elements that are spaced apart from each other along a row direction that is perpendicular to the column direction and comprising a 2×M beamforming network that is configured to couple first and second input signals to all of the radiating elements of the respective first subarray;

a plurality of second subarrays that are spaced apart from each other and from the first subarrays along the column direction, each of the second subarrays comprising N radiating elements that are spaced apart from each other along the row direction, N being not equal to M, and comprising a 2×N beamforming network that is configured to couple the first and second input signals to all of the radiating elements of the respective second subarray; and

a power distribution network configured to provide both of the first and second input signals to the respective 2×M beamforming network of each of the first subarrays and to the respective 2×N beamforming network of each of the second subarrays.

14. The multi-beam cellular communication antenna of claim **13**, wherein the multi-beam cellular communication antenna is configured to generate a first beam that points in a first direction responsive to the first input signal and to generate a second beam that points in a second direction responsive to the second input signal.

15. The multi-beam cellular communication antenna of claim **13**, wherein M=3 and N=4.

16. The multi-beam cellular communication antenna of claim **13**, wherein the M radiating elements of each of the first subarrays comprise a respective first row of M radiating elements and wherein each of the first subarrays comprise a second row of M radiating elements, and

wherein the N radiating elements of each of the second subarrays comprise a respective first row of N radiating elements and wherein each of the second subarrays comprise a second row of N radiating elements.

17. The multi-beam cellular communication antenna of claim **13**, wherein the plurality of second subarrays are arranged between two of the plurality of first subarrays in the column direction.

18. A multi-beam cellular communication antenna, comprising:

a first plurality of rows of dual polarized radiating elements, each of the rows in the first plurality of rows including a total of three dual polarized radiating elements that are arranged in a row direction;

a second plurality of rows of dual polarized radiating elements, each of the rows in the second plurality of rows including a total of four dual polarized radiating elements that are arranged in the row direction;

a plurality of first beamforming networks, each of which is configured to provide respective output signals to each of the radiating elements of a respective one of the first plurality of rows, each of the output signals of each of the plurality of first beamforming networks being based on a first input signal and based on a second input signal;

a plurality of second beamforming networks, each of which is configured to provide respective output signals to each of the radiating elements of a respective one of the second plurality of rows, each of the output signals of each of the plurality of second beamforming networks being based on the first input signal and the second input signal;

a plurality of third beamforming networks, each of which is configured to provide respective output signals to each of the radiating elements of a respective one of the first plurality of rows, each of the output signals of each of the plurality of third beamforming networks being based on a third input signal and based on a fourth input signal; and

a plurality of fourth beamforming networks, each of which is configured to provide respective output signals to each of the radiating elements of a respective one of the second plurality of rows, each of the output signals of each of the plurality of fourth beamforming networks being based on the third input signal and the fourth input signal,

wherein the plurality of first beamforming networks and the plurality of second beamforming networks together form a first beam in a first direction and a second beam in a second direction, and

wherein the plurality of third beamforming networks and the plurality of fourth beamforming networks together form a third beam in the first direction and a fourth beam in the second direction.

19. The multi-beam cellular communication antenna of claim **18**, wherein the first and second beams are configured to have a polarization that is 90° apart from a polarization of the third and fourth beams.

20. The multi-beam cellular communication antenna of claim **18**,

wherein the output signals of the first and second beamforming networks are provided to each of radiating elements of a first subarray of radiating elements, the first subarray of radiating elements comprising the first row and comprising a third row of three dual polarized radiating elements arranged in the row direction, the third row being spaced apart from the first row in a column direction that is perpendicular to the row direction, and

wherein the output signals of the third and fourth beamforming networks are provided to each of radiating elements of a second subarray of radiating elements, the second subarray of radiating elements comprising the second row and comprising a fourth row of four dual polarized radiating elements arranged in the row direction, the fourth row being spaced apart from the second row in the column direction.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,831,548 B2
APPLICATION NO. : 13/127592
DATED : November 28, 2017
INVENTOR(S) : Timofeev et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 1, Line 17: Please correct International Publication No. “WO2010/059786 A1” to read -- WO2010/059186 A1 --

Column 5, Line 7: Please correct “by 0.87λ As” to read -- by 0.8λ. As --

Signed and Sealed this
First Day of May, 2018

Andrei Iancu
Director of the United States Patent and Trademark Office

EXHIBIT E

US010439285B2

(12) **United States Patent**
Isik et al.

(10) **Patent No.: US 10,439,285 B2**
(45) **Date of Patent: Oct. 8, 2019**

(54) **CLOAKED LOW BAND ELEMENTS FOR MULTIBAND RADIATING ARRAYS**

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(73) Assignee: **CommScope Technologies LLC**, Hickory, NC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/517,906**

(22) PCT Filed: **Aug. 6, 2015**

(86) PCT No.: **PCT/US2015/044020**

§ 371 (c)(1),
(2) Date: **Apr. 7, 2017**

(87) PCT Pub. No.: **WO2016/081036**

PCT Pub. Date: **May 26, 2016**

(65) **Prior Publication Data**

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Related U.S. Application Data

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H01Q 21/12 (2006.01)
H01Q 5/49 (2015.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01Q 5/49*** (2015.01); ***H01Q 1/24*** (2013.01); ***H01Q 1/523*** (2013.01); ***H01Q 9/16*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC .. H01Q 1/52; H01Q 1/24; H01Q 9/16; H01Q 19/10; H01Q 5/49; H01Q 21/06; H01Q 21/30; H01Q 25/00
(Continued)

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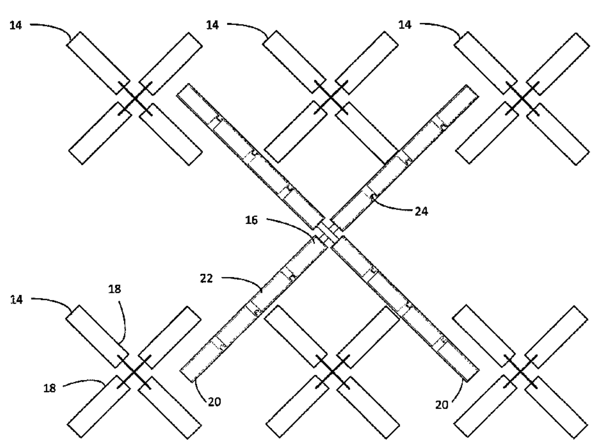
Primary Examiner — Joseph J Lauture
(74) *Attorney, Agent, or Firm* — Myers Bigel, P.A.

(57) **ABSTRACT**

A multiband antenna, having a reflector, and a first array of first radiating elements having a first operational frequency band, the first radiating elements being a plurality of dipole arms, each dipole arm including a plurality of conductive segments coupled in series by a plurality of inductive elements; and a second array of second radiating elements having a second operational frequency band, wherein the plurality of conductive segments each have a length less
(Continued)



than one-half wavelength at the second operational frequency band.

37 Claims, 5 Drawing Sheets

(51) **Int. Cl.**

H01Q 1/24	(2006.01)
H01Q 1/52	(2006.01)
H01Q 9/16	(2006.01)
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H01Q 21/26	(2006.01)
H01Q 21/06	(2006.01)
H01Q 25/00	(2006.01)
H01Q 21/30	(2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 19/108*** (2013.01); ***H01Q 21/062*** (2013.01); ***H01Q 21/26*** (2013.01); *H01Q 1/246* (2013.01); *H01Q 21/06* (2013.01); *H01Q 21/30* (2013.01); *H01Q 25/00* (2013.01); *H01Q 25/001* (2013.01)

(58) **Field of Classification Search**
USPC 343/815, 722, 702, 810, 893, 876, 725
See application file for complete search history.

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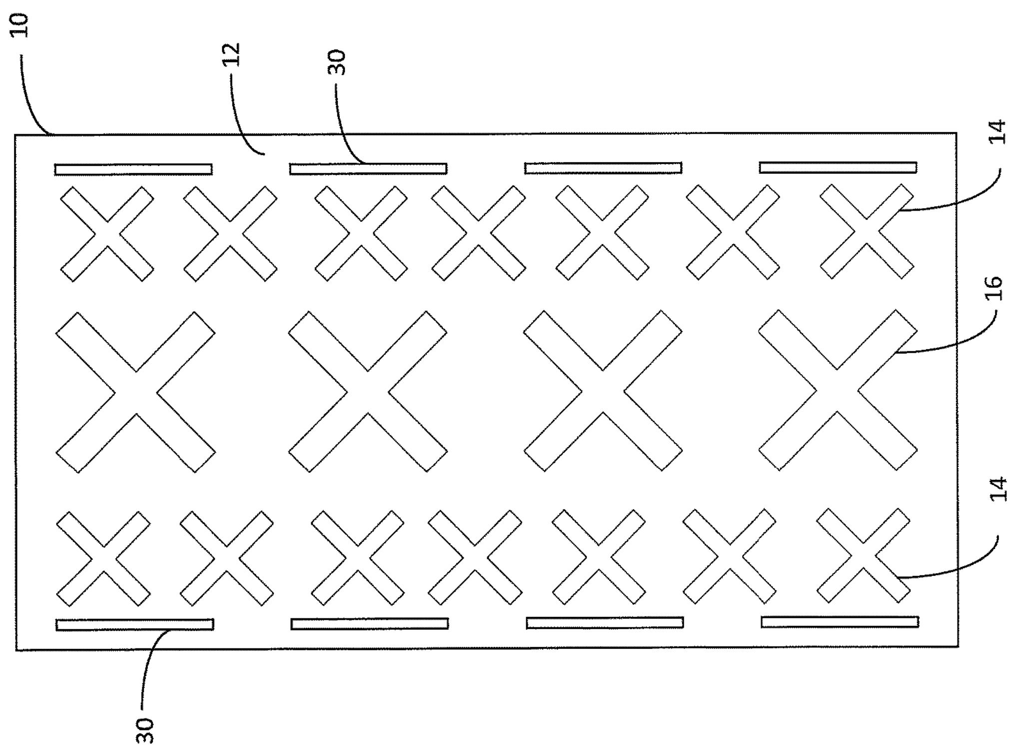

Fig. 1

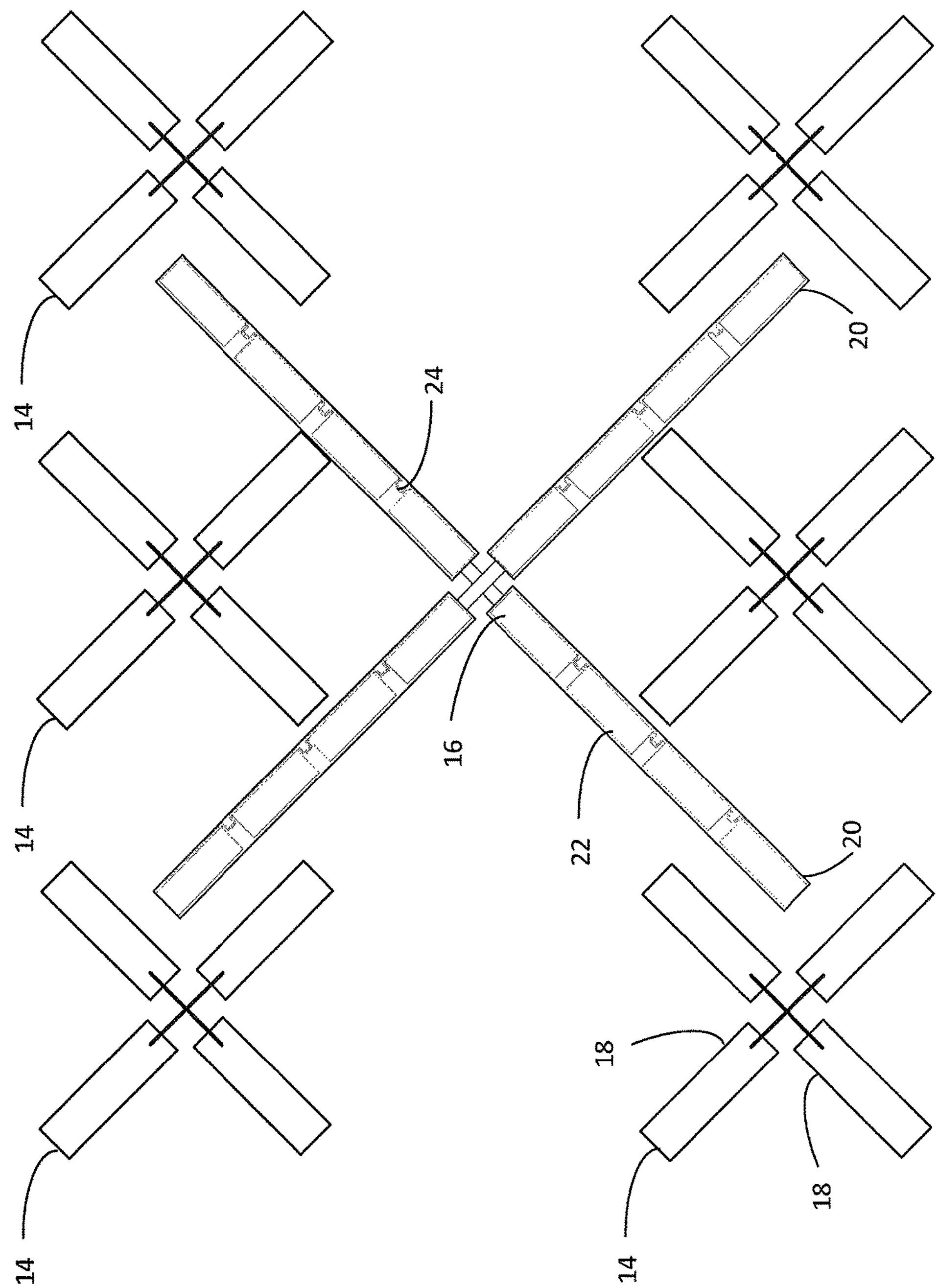

Fig. 2

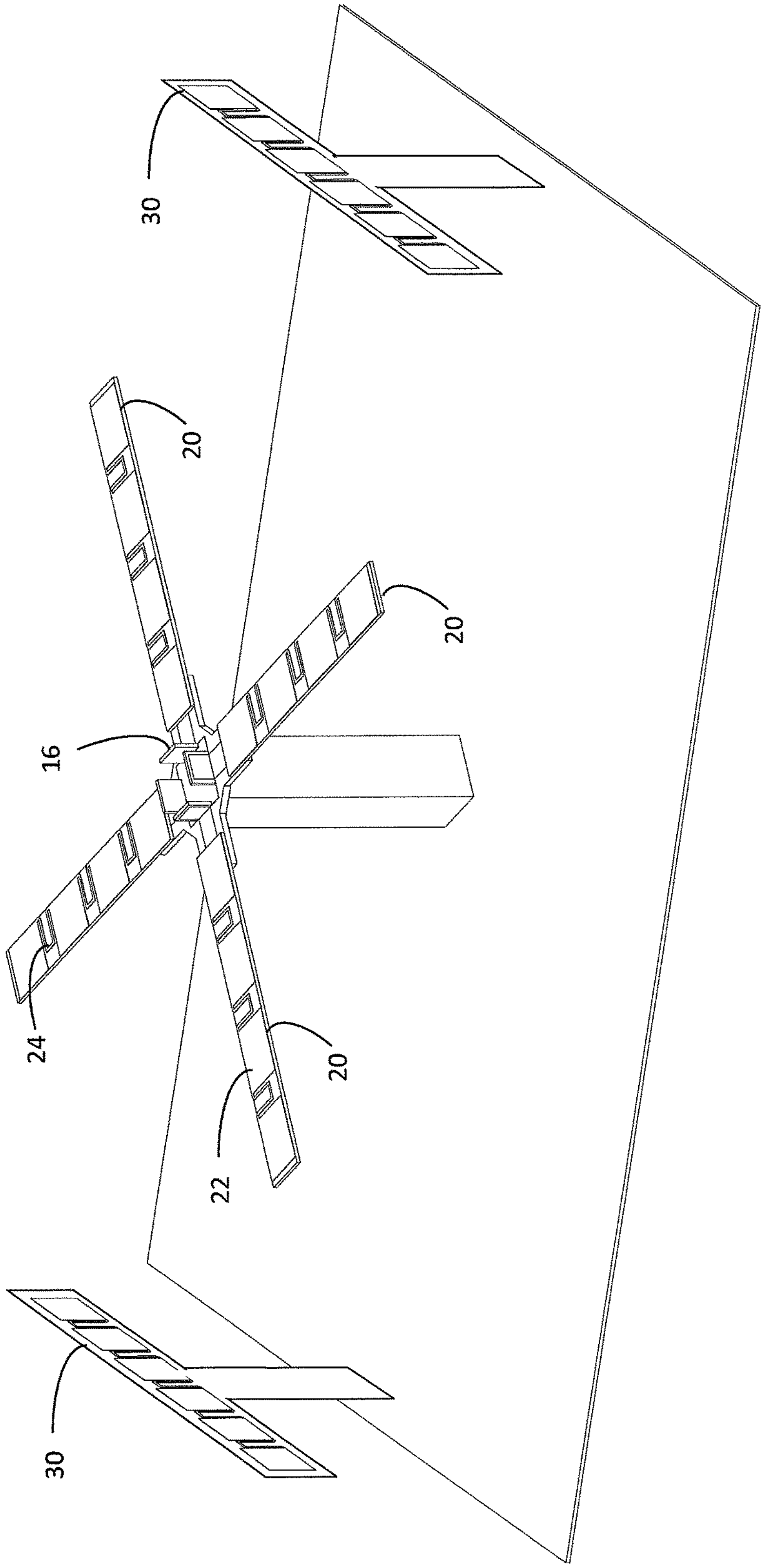

Fig. 3

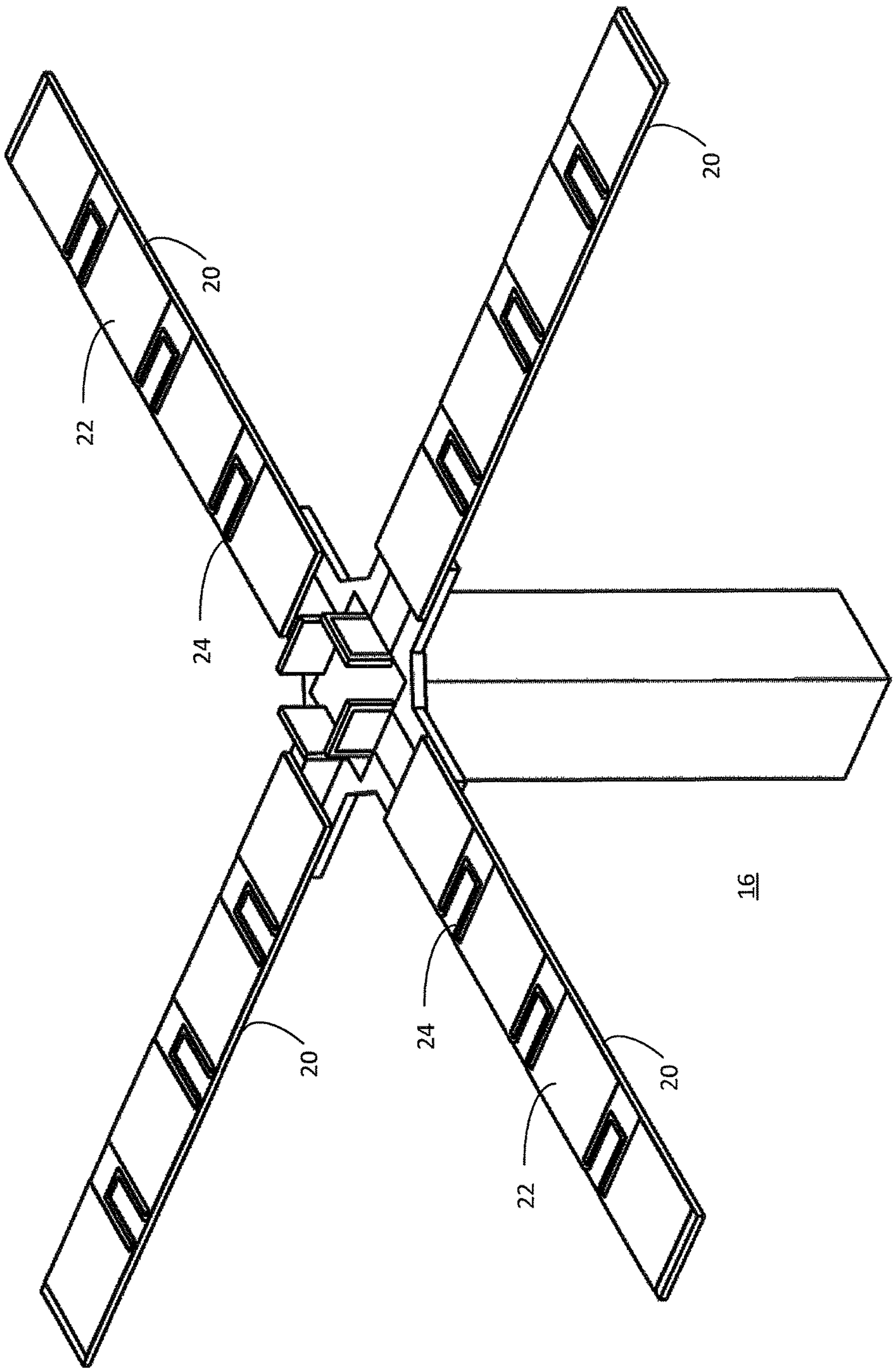

Fig. 4

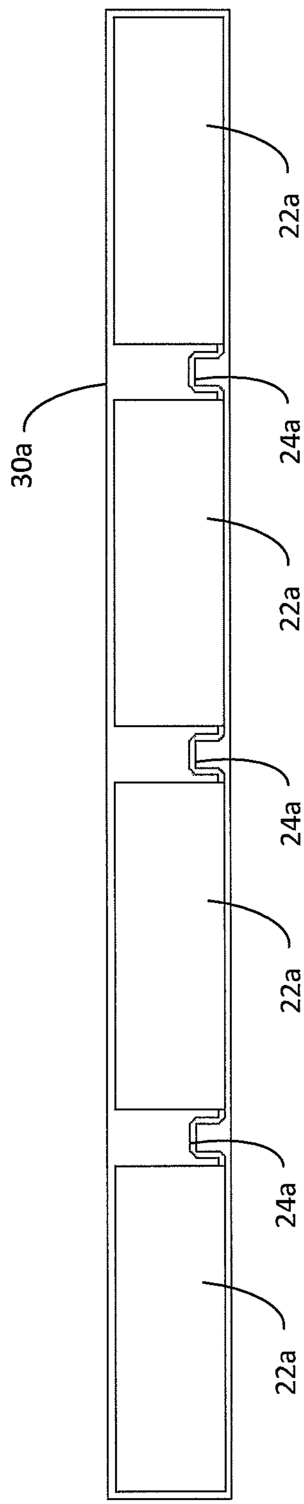
22a
30a
24a
22a
24a
22a
24a
22a

Fig. 5

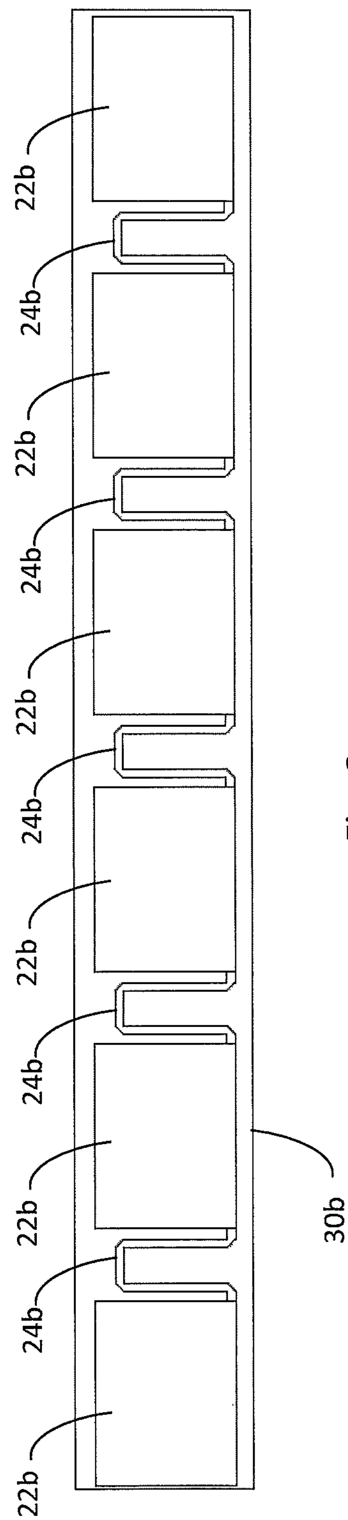
22b
24b
22b
24b
22b
24b
22b
24b
22b
30b
24b
22b

Fig. 6

CLOAKED LOW BAND ELEMENTS FOR MULTIBAND RADIATING ARRAYS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a 35 U.S.C. § 371 national stage application of PCT International Application No. PCT/US2015/044020, filed Aug. 6, 2015, which itself claims priority to U.S. Provisional Patent Application No. 62/081,358, filed Nov. 18, 2014, the disclosure and content of both of which are incorporated by reference herein in their entireties. The above-referenced PCT International Application was published in the English language as International Publication No. WO 2016/081036 A1 on May 26, 2016.

FIELD OF THE INVENTION

This invention relates to wide-band multi-band antennas with interspersed radiating elements intended for cellular base station use. In particular, the invention relates to radiating elements intended for a low frequency band when interspersed with radiating elements intended for a high frequency band. This invention is aimed at minimizing the effect of the low-band dipole arms, and/or parasitic elements if used, on the radio frequency radiation from the high-band elements.

BACKGROUND

Undesirable interactions may occur between radiating elements of different frequency bands in multi band interspersed antennas. For example, in some cellular antenna applications, the low band is 694-960 MHz and the high band is 1695-2690 MHz. Undesirable interaction between these bands may occur when a portion of the lower frequency band radiating structure resonates at the wavelength of the higher frequency band. For instance, in multiband antennas where a higher frequency band is a multiple of a frequency of a lower frequency band, there is a probability that the low band radiating element, or some component or part of it, will be resonant in some part of the high band frequency range. This type of interaction may cause a scattering of high band signals by the low band elements. As a result, perturbations in radiation patterns, variation in azimuth beam width, beam squint, high cross polar radiation and skirts in radiation patterns are observed in the high band.

SUMMARY

In one aspect of the present invention, a low band radiating element for use in a multiband antenna having at least a high band operational frequency and a low band operational frequency is provided. The low band element comprises a first dipole element having a first polarization and comprising a first pair of dipole arms and a second dipole element having a second polarization and comprising a second pair of dipole arms oriented at approximately 90 degrees to the first pair of dipole arms. Each dipole arm includes a plurality of conductive segments, each having a length less than one-half wavelength at the high band operational frequency, coupled in series by a plurality of inductive elements, having an impedance selected to attenuate high band currents while passing low band currents in the dipole arms. The inductive elements are selected to appear

as high impedance elements at the high band operational frequency and as lower impedance elements at the low band operational frequency.

In another aspect of the present invention, a multiband antenna is provided. The multiband antenna includes a reflector, a first array of first radiating elements and a second array of second radiating elements. The first radiating elements have a first operational frequency band and the second radiating elements have a second operational frequency band. The first radiating elements include two or more dipole arms. Each dipole arm includes a plurality of conductive segments coupled in series by a plurality of inductive elements. The conductive segments each have a length less than one-half wavelength at the second operational frequency band. The first radiating elements may comprise single dipole elements or cross dipole elements.

The inductive elements are typically selected to appear as high impedance elements at the second operational frequency band and as lower impedance elements at the first operational frequency band. The first operational frequency band typically comprises a low band of the multiband antenna and the second operational frequency band typically comprises a high band of the multiband antenna.

In another aspect of the present invention, parasitic elements may be included on the multiband antenna to shape low band beam characteristics. For example, the parasitic elements may have an overall length selected to shape beam patterns in the first operational frequency band, and comprise conductive segments coupled in series with inductive elements selected to reduce interaction between the parasitic elements and radiation at the second operational frequency band. The conductive segments of the parasitic elements may also have a length of less than one half wave length at the second operational frequency band.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an antenna according to one aspect of the present invention.

FIG. **2** is a plan view of a portion of an antenna array according to another aspect of the present invention.

FIG. **3** is an isometric view of a low band radiating element and parasitic elements according to another aspect of the present invention.

FIG. **4** is a more detailed view of the low band radiating element of FIG. **3**.

FIG. **5** is a first example of a parasitic element according to another aspect of the present invention.

FIG. **6** is a second example of a parasitic element accordingly to another aspect of the present invention.

DESCRIPTION OF THE INVENTION

FIG. **1** schematically diagrams a dual band antenna **10**. The dual band antenna **10** includes a reflector **12**, an array of high band radiating elements **14** and an array of low band radiating elements **16**. Optionally, parasitic elements **30** may be included to shape azimuth beam width of the low band elements. Multiband radiating arrays of this type commonly include vertical columns of high band and low band elements spaced at pre-determined intervals. See, for example, U.S. patent application Ser. No. 13/827,190, now U.S. Pat. No. 9,276,329 to Jones et al., which is incorporated by reference.

FIG. **2** schematically illustrates a portion of a wide band dual band antenna **10** including features of a low band radiating element **16** according to one aspect of the present invention. High band radiating elements **14** may comprise any conventional crossed dipole element, and may include first and second dipole arms **18**. Other known high band elements may be used. The low band radiating element **16** also comprises a crossed dipole element, and includes first and second dipole arms **20**. In this example, each dipole arm **20** includes a plurality of conductive segments **22** coupled in series by inductors **24**.

The low band radiating element **16** may be advantageously used in multi-band dual-polarization cellular base-station antenna. At least two bands comprise low and high bands suitable for cellular communications. As used herein, "low band" refers to a lower frequency band, such as 694-960 MHz, and "high band" refers to a higher frequency band, such as 1695 MHz-2690 MHz. The present invention is not limited to these particular bands, and may be used in other multi-band configurations. A "low band radiator" refers to a radiator for such a lower frequency band, and a "high band radiator" refers to a radiator for such a higher frequency band. A "dual band" antenna is a multi-band antenna that comprises the low and high bands referred to throughout this disclosure.

Referring to FIG. **3**, a low band radiating element **16** and a pair of parasitic elements **30** are illustrated mounted on reflector **12**. In one aspect of the present invention, parasitic elements **30** are aligned to be approximately parallel to a longitudinal dimension of reflector **12** to help shape the beam width of the pattern. In another aspect of the invention, the parasitic elements may be aligned perpendicular to a longitudinal axis of the reflector **12** to help reduce coupling between the elements. The low band radiating element **16** is illustrated in more detail in FIG. **4**. Low band radiating element **16** includes a plurality of dipole arms **20**. The dipole arms **20** may be one half wave length long. The low band dipole arms **20** include a plurality of conductive segments **22**. The conductive segments **22** have a length of less than one-half wavelength at the high band frequencies. For example, the wavelength of a radio wave at 2690 MHz is about 11 cm, and one-half wavelength at 2690 MHz would be about 5.6 cm. In the illustrated example, four segments **22** are included, which results in a segment length of less than 5 cm, which is shorter than one-half wavelength at the upper end of the high band frequency range. The conductive segments **22** are connected in series with inductors **24**. The inductors **24** are configured to have relatively low impedance at low band frequencies and relatively higher impedance at high band frequencies.

In the examples of FIGS. **2** and **3**, the dipole arms **20**, including conductive segments **22** and inductors **24**, may be fabricated as copper metallization on a non-conductive substrate using, for example, conventional printed circuit board fabrication techniques. In this example, the narrow metallization tracks connecting the conductive segments **22** comprise the inductors **24**. In other aspect of the invention, the inductors **24** may be implemented as discrete components.

At low band frequencies, the impedance of the inductors **24** connecting the conductive segments **22** is sufficiently low to enable the low band currents continue to flow between conductive segments **22**. At high band frequencies, however, the impedance is much higher due to the series inductors **24**, which reduces high band frequency current flow between the conductive segments **22**. Also, keeping each of the conductive segments **22** to less than one half wavelength at high band frequencies reduces undesired interaction between the conductive segments **22** and the high band radio frequency (RF) signals. Therefore, the low band radiating elements **16** of the present invention reduce and/or attenuate any induced current from high band RF radiation from high band radiating elements **14**, and any undesirable scattering of the high band signals by the low band dipole arms **20** is minimized. The low band dipole is effectively electrically invisible, or "cloaked," at high band frequencies.

As illustrated in FIG. **3**, the low band radiating elements **16** having cloaked dipole arms **20** may be used in combination with cloaked parasitic elements **30**. However, either cloaked structure may also be used independently of the other. Referring to FIGS. **1** and **3**, parasitic elements **30** may be located on either side of the driven low band radiating element **16** to control the azimuth beam width. To make the overall low band radiation pattern narrower, the current in the parasitic element **30** should be more or less in phase with the current in the driven low band radiating element **16**. However, as with driven radiating elements, inadvertent resonance at high band frequencies by low band parasitic elements may distort high band radiation patterns.

A first example of a cloaked low band parasitic element **30***a* is illustrated in FIG. **5**. The segmentation of the parasitic elements may be accomplished in the same way as the segmentation of the dipole arms in FIG. **4**. For example, parasitic element **30***a* includes four conductive segments **22***a* coupled by three inductors **24***a*. A second example of a cloaked low band parasitic element **30***b* is illustrated in FIG. **6**. Parasitic element **30***b* includes six conductive segments **22***b* coupled by five inductors **24***b*. Relative to parasitic element **30***a*, the conductive segments **22***b* are shorter than the conductive segments **22***a*, and the inductor traces **24***b* are longer than the inductor traces **24***a*.

At high band frequencies, the inductors **24***a*, **24***b* appear to be high impedance elements which reduce current flow between the conductive segments **22***a*, **22***b*, respectively. Therefore the effect of the low band parasitic elements **30** scattering of the high band signals is minimized. However, at low band, the distributed inductive loading along the parasitic element **30** tunes the phase of the low band current, thereby giving some control over the low band azimuth beam width.

In a multiband antenna according to one aspect of the present invention described above, the dipole radiating element **16** and parasitic elements **30** are configured for low band operation. However, the invention is not limited to low band operation, the invention is contemplated to be employed in additional embodiments where driven and/or passive elements are intended to operate at one frequency band, and be unaffected by RF radiation from active radiating elements in other frequency bands. The exemplary low band radiating element **16** also comprises a cross-dipole radiating element. Other aspects of the invention may utilize a single dipole radiating element if only one polarization is required.

What is claimed is:

1. A multiband antenna, comprising:

a reflector;

a first array of first radiating elements having a first operational frequency band, the first radiating elements comprising a plurality of dipole arms, each dipole arm including a plurality of conductive segments coupled in series by a plurality of inductive elements comprising planar inductive traces; and

a second array of second radiating elements having a second operational frequency band;

wherein the plurality of conductive segments each have a length less than one-half wavelength at the second operational frequency band.

2. The multiband antenna of claim 1, wherein the inductive elements are configured to have a high impedance that attenuates currents in the dipole arms in the second operational frequency band and have a low impedance that passes currents in the dipole arms in at the first operational frequency band.

3. The multiband antenna of claim 1, wherein the first operational frequency band comprises a low band of the multiband antenna and the second operational frequency band comprises a high band of the multiband antenna.

4. The multiband antenna of claim 3, further comprising a parasitic element mounted adjacent a first of the first radiating elements, the parasitic element comprising a plurality of conductive elements coupled in series by a plurality of inductive elements, wherein the inductive elements of the parasitic element are distributed along the parasitic element to tune a phase of a low band current in the parasitic element.

5. The multiband antenna of claim 1, further comprising a plurality of parasitic elements that are adjacent sides of the reflector, wherein the parasitic elements comprise conductive segments coupled in series with inductive elements selected to reduce interaction between the parasitic elements and radiation at the second operational frequency band.

6. The multiband antenna of claim 1,

wherein the first and second operational frequency bands comprise first and second cellular frequency bands, respectively,

wherein the first radiating elements comprise a plurality of crossed dipole elements, respectively, and

wherein each dipole arm includes three inductive elements.

7. A multiband cellular base station antenna, comprising:

a reflector;

a first array of first radiating elements that are configured for operation in a first operational frequency band of the multiband cellular base station antenna, the first radiating elements comprising a plurality of dipole arms, each dipole arm including a plurality of conductive segments that are formed on a planar, non-conductive substrate, the conductive segments coupled in series by a plurality of inductive elements that comprise narrow metallization tracks formed on the planar, non-conductive substrate; and

a second array of second radiating elements that are configured for operation in a second operational frequency band of the multiband cellular base station antenna;

wherein each of the plurality of conductive segments has a length that is less than one-half of a wavelength at the second operational frequency band.

8. The multiband cellular base station antenna of claim 7, further comprising a plurality of parasitic elements, wherein the parasitic elements comprise alternating conductive segments and inductive elements that are coupled together in series.

9. The multiband cellular base station antenna of claim 8, wherein each of the conductive segments of at least one of the parasitic elements has a length less than one half wavelength at the second operational frequency band.

10. The multiband cellular base station antenna of claim 7, further comprising a plurality of parasitic elements, wherein at least some of the parasitic elements are positioned adjacent the second array of second radiating elements.

11. The multiband cellular base station antenna of claim 7, further comprising a plurality of parasitic elements that are adjacent sides of the reflector, wherein the parasitic elements each have an overall length and position that is selected to reduce coupling between opposite polarization dipole elements in the first operational frequency band.

12. The multiband cellular base station antenna of claim 7, further comprising a plurality of parasitic elements, wherein a first of the first radiating elements is positioned between first and second of the parasitic elements.

13. The multiband cellular base station antenna of claim 12, wherein the first parasitic element is on a first side of the reflector and is aligned to be approximately parallel to a longitudinal dimension of the reflector and the second parasitic element is on a second side of the reflector and aligned to be approximately parallel to the longitudinal dimension of the reflector, and the first of the first radiating elements is positioned along a transverse axis connecting the first and second parasitic elements.

14. The multiband cellular base station antenna of claim 13, wherein the first and second parasitic elements each comprise alternating conductive segments and inductive elements that are coupled together in series.

15. The multiband cellular base station antenna of claim 12, wherein the first and second parasitic elements are aligned to be perpendicular to a longitudinal dimension of the reflector.

16. The multiband cellular base station antenna of claim 7, wherein the first operational frequency band comprises a cellular low band of the multiband cellular base station antenna and the second operational frequency band comprises a cellular high band of the multiband cellular base station antenna,

wherein the inductive elements are fewer in number than the conductive segments on at least some of the dipole arms,

wherein at least one of the inductive elements on each dipole arm comprises a copper metallization track that connects two adjacent ones of the conductive segments, wherein a length of the copper metallization track exceeds a length of a gap between the two adjacent ones of the conductive segments.

17. The multiband cellular base station antenna of claim 7, wherein at least one of the inductive elements on each dipole arm comprises a copper metallization track that connects two adjacent ones of the conductive segments, wherein a length of the copper metallization track exceeds a length of a gap between the two adjacent ones of the conductive segments.

18. The multiband cellular base station antenna of claim 7, further comprising a parasitic element mounted adjacent a first of the first radiating elements,

wherein the first operational frequency band comprises a cellular low band of the multiband cellular base station antenna and the second operational frequency band comprises a cellular high band of the multiband cellular base station antenna,

wherein the parasitic element comprises a plurality of conductive segments coupled in series by a plurality of inductive elements,

wherein each of the plurality of conductive segments of the parasitic element has a length that is less than one-half of a wavelength at the second operational frequency band,

wherein the conductive segments and inductive elements of the parasitic element comprise copper metallization on a non-conductive substrate.

19. The multiband cellular base station antenna of claim 7, wherein at least two of the inductive elements comprise respective U-shaped metallization tracks.

20. The multiband cellular base station antenna of claim **7**, wherein a first of the inductive elements on a first of the dipole arms is between first and second of the conductive segments, and the first of the inductive elements comprises a copper metallization track that has sections that extend in multiple directions, wherein a combined length of the sections exceeds respective widths of the first and second conductive segments in a transverse direction that is perpendicular to a longitudinal direction of the first of the dipole arms.

21. The multiband cellular base station antenna of claim **7**, wherein a first of the conductive segments on a first of the dipole arms has a first length in a longitudinal direction of the first of the dipole arms, the first length exceeding a length of a gap between the first of the conductive segments and a second of the conductive segments on the first of the dipole arms that is adjacent the first of the conductive segments.

22. The multiband cellular base station antenna of claim **7**, further comprising a parasitic element mounted adjacent a first of the first radiating elements, wherein the parasitic element is configured so that current in the parasitic element is substantially in phase with current in the first of the first radiating elements.

23. The multiband cellular base station antenna of claim **7**, wherein the first radiating elements comprise a plurality of crossed dipole elements, respectively.

24. The multiband cellular base station antenna of claim **7**, wherein each dipole arm includes three inductive elements.

25. The multiband cellular base station antenna of claim **24**,

wherein a first of the three inductive elements couples a first and a second of the plurality of conductive segments in series,

wherein a second of the three inductive elements couples a third and the second of the plurality of conductive segments in series, and

wherein a third of the three inductive elements couples a fourth and the third of the plurality of conductive segments in series.

26. The multiband cellular base station antenna of claim **7**, wherein the length of each of the plurality of conductive segments is less than 5 cm.

27. A multiband antenna comprising:

a reflector;

a plurality of first radiating elements that are configured to operate in a first frequency band and that extend forwardly from the reflector;

a plurality of second radiating elements that are configured to operate in a second frequency band that is higher than the first frequency band, the second radiating elements extending forwardly from the reflector; and

a plurality of parasitic elements that extend forwardly from the reflector,

wherein a first of the plurality of parasitic elements comprises a plurality of conductive segments coupled in series by a plurality of inductors.

28. The multiband antenna of claim **27**, wherein each of the plurality of parasitic elements comprises a plurality of conductive segments coupled in series by a plurality of inductors.

29. The multiband antenna of claim **28**, wherein the plurality of parasitic elements comprises a first set of parasitic elements that extend approximately parallel to a longitudinal dimension of the reflector and a second set of parasitic elements that are aligned to be perpendicular to the longitudinal dimension of the reflector.

30. The multiband antenna of claim **27**, further comprising a plurality of conductive segments coupled in series by a plurality of inductors on a first of the plurality of first radiating elements.

31. The multiband antenna of claim **27**, wherein the plurality of first radiating elements comprises a plurality of crossed dipole elements, respectively, and

wherein the first and second frequency bands comprise first and second cellular frequency bands, respectively.

32. The multiband antenna of claim **31**,

wherein a first of the plurality of crossed dipole elements is between a first pair of the plurality of parasitic elements,

wherein a second of the plurality of crossed dipole elements is between a second pair of the plurality of parasitic elements, and

wherein a first parasitic element of the first pair of the plurality of parasitic elements is aligned with a first parasitic element of the second pair of the plurality of parasitic elements along a longitudinal dimension of the reflector, and a second parasitic element of the first pair of the plurality of parasitic elements is aligned with a second parasitic element of the second pair of the plurality of parasitic elements along the longitudinal dimension of the reflector.

33. The multiband antenna of claim **27**,

wherein the plurality of parasitic elements comprises a first column of parasitic elements extending longitudinally along a first side of the reflector and a second column of parasitic elements extending longitudinally along a second side of the reflector, and

wherein the plurality of first radiating elements and the plurality of second radiating elements are between the first and second columns of parasitic elements.

34. The multiband antenna of claim **33**,

wherein the plurality of first radiating elements comprises a vertical column of low band radiating elements at a center of the reflector,

wherein the plurality of second radiating elements comprises a plurality of vertical columns of high band radiating elements, and

wherein the first and second columns of parasitic elements are adjacent first and second edges, respectively, of the reflector.

35. The multiband antenna of claim **27**, wherein at least some of the inductors comprise U-shaped metallization tracks.

36. The multiband antenna of claim **27**, wherein the first of the plurality of parasitic elements is configured so that current in the first of the plurality of parasitic elements is substantially in phase with current in a first of the first radiating elements.

37. The multiband antenna of claim **27**, wherein the plurality of first radiating elements comprises a column of low band crossed dipole radiating elements that extend along a longitudinal dimension of the reflector,

wherein the plurality of second radiating elements comprises a plurality of columns of high band radiating elements that each extend along the longitudinal dimension of the reflector,

wherein the first of the plurality of parasitic elements is adjacent a side edge of the reflector,

wherein the plurality of conductive segments comprises a first plurality of conductive segments the multiband antenna further comprising a plurality of conductive segments coupled in series by a plurality of inductors on a first of the plurality of first radiating elements, and wherein the first and second pluralities of conductive segments comprise conductive segments that each have a length that is less than one-half of a wavelength at the second frequency band.

* * * * *

EXHIBIT F

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(12) **United States Patent**
Isik et al.

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(45) **Date of Patent: Dec. 3, 2019**

(54) **CLOAKED LOW BAND ELEMENTS FOR MULTIBAND RADIATING ARRAYS**

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(73) Assignee: **CommScope Technologies LLC**, Hickory, NC (US)

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(22) Filed: **Feb. 15, 2019**

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H01Q 5/49 (2015.01)
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(52) **U.S. Cl.**
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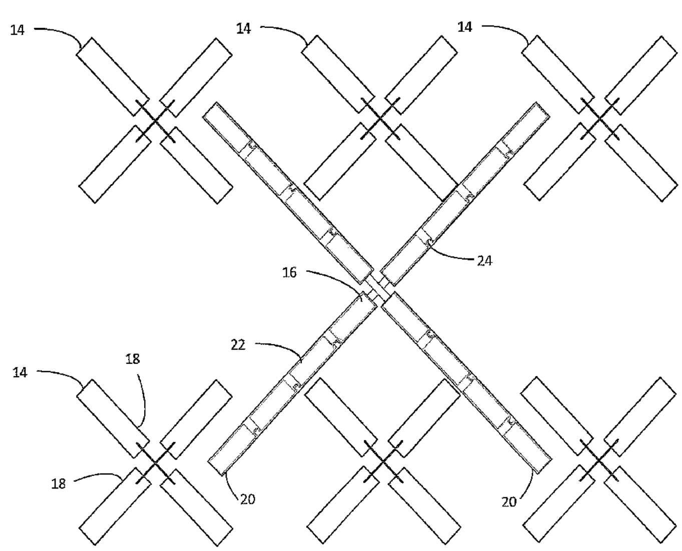
Primary Examiner — Joseph J Lauture
(74) *Attorney, Agent, or Firm* — Myers Bigel, P.A.

(57) **ABSTRACT**

A multiband antenna, having a reflector, and a first array of first radiating elements having a first operational frequency band, the first radiating elements being a plurality of dipole arms, each dipole arm including a plurality of conductive segments coupled in series by a plurality of inductive elements; and a second array of second radiating elements having a second operational frequency band, wherein the plurality of conductive segments each have a length less than one-half wavelength at the second operational frequency band.

23 Claims, 5 Drawing Sheets



(51) **Int. Cl.**

H01Q 1/52	(2006.01)
H01Q 9/16	(2006.01)
H01Q 19/10	(2006.01)
H01Q 21/06	(2006.01)
H01Q 21/26	(2006.01)
H01Q 1/24	(2006.01)
H01Q 25/00	(2006.01)
H01Q 21/30	(2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 19/108*** (2013.01); ***H01Q 21/062*** (2013.01); ***H01Q 21/26*** (2013.01); *H01Q 1/246* (2013.01); *H01Q 1/52* (2013.01); *H01Q 19/10* (2013.01); *H01Q 21/06* (2013.01); *H01Q 21/30* (2013.01); *H01Q 25/00* (2013.01); *H01Q 25/001* (2013.01)

(58) **Field of Classification Search**
USPC 343/815, 722, 702, 810, 893, 725; 33/876
See application file for complete search history.

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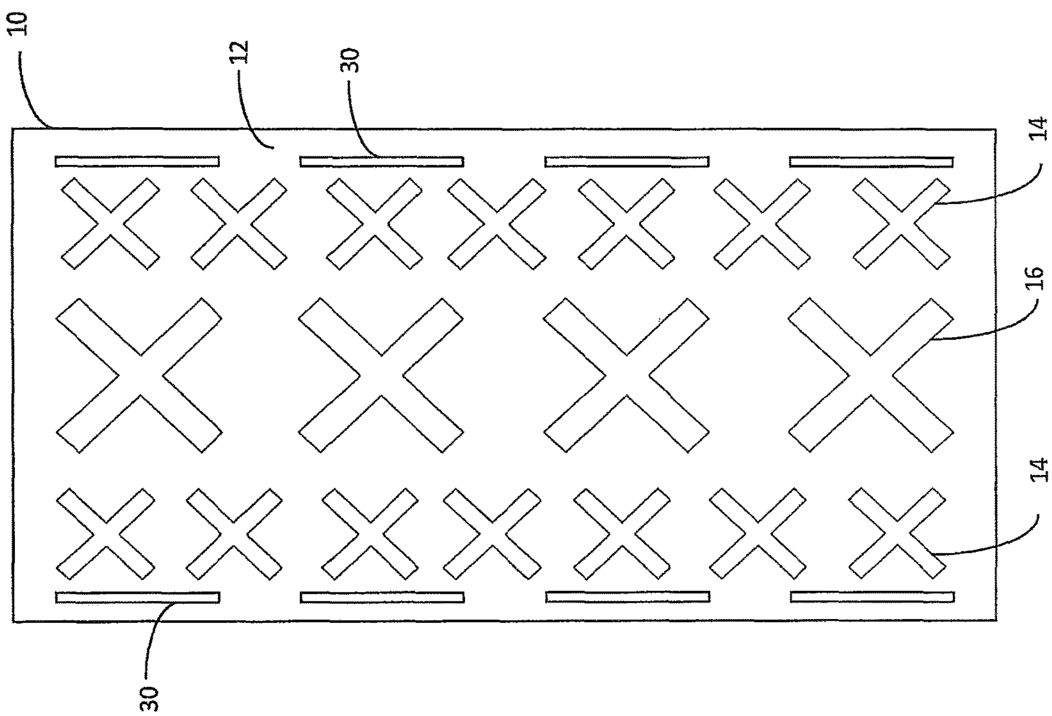

Fig. 1

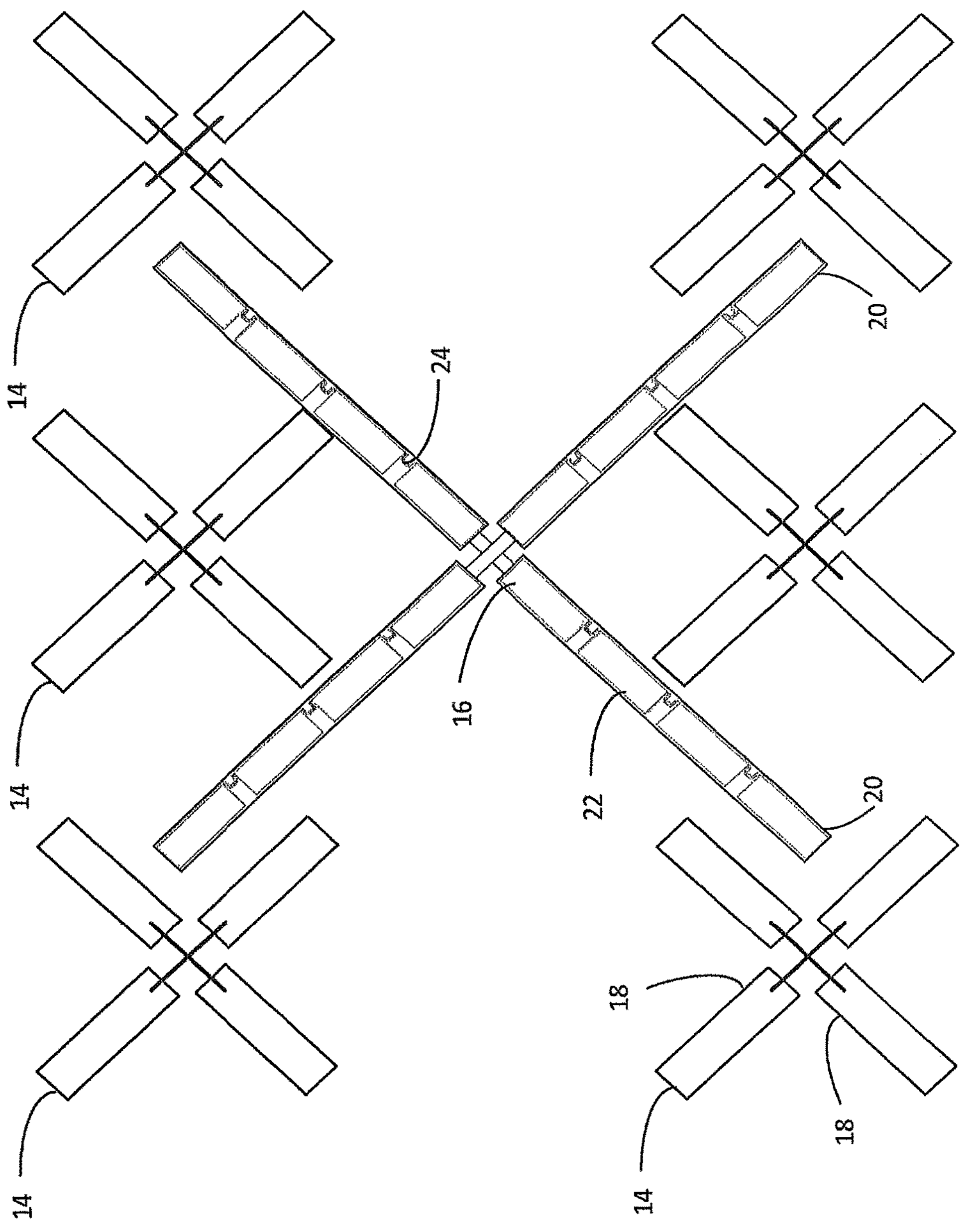

Fig. 2

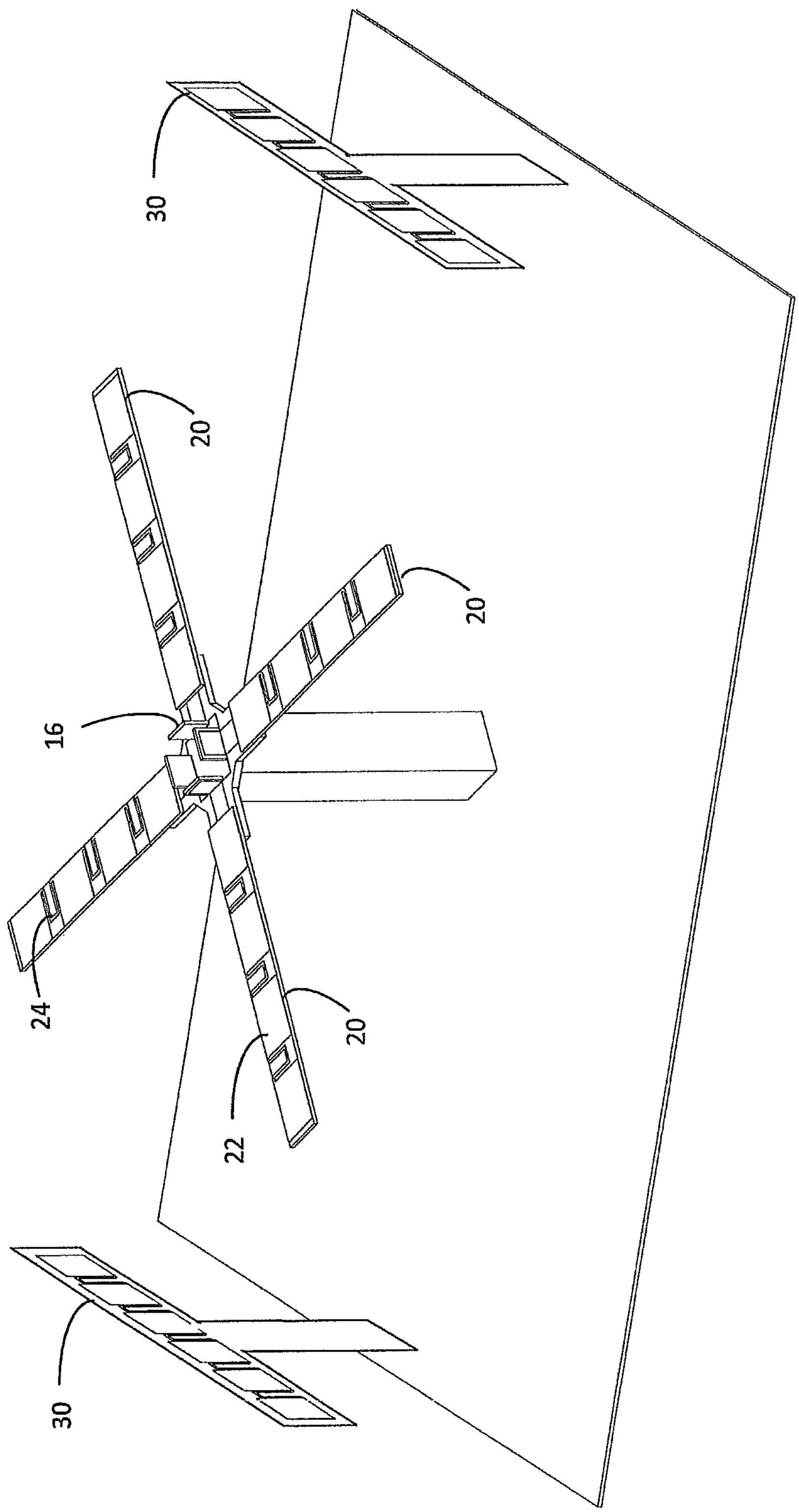

Fig. 3

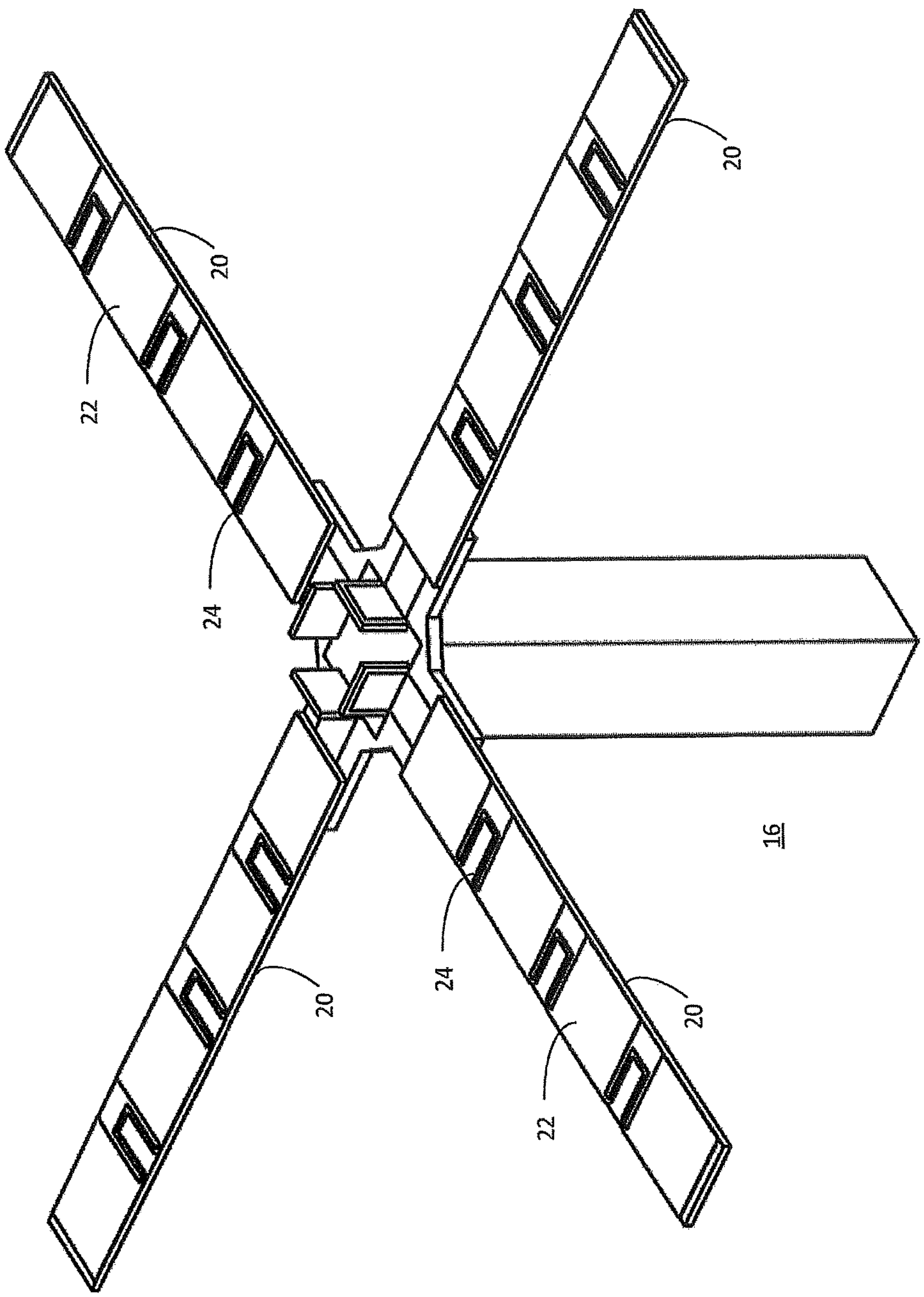

Fig. 4

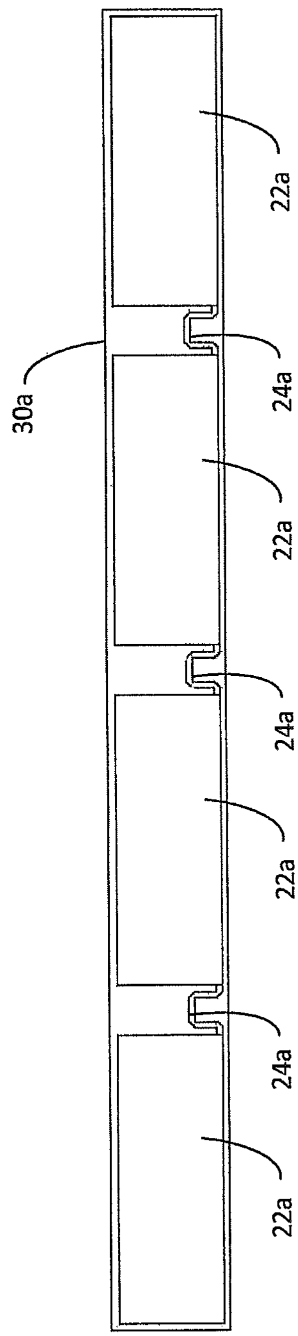
22a
30a
24a
22a
24a
22a
24a
22a

Fig. 5

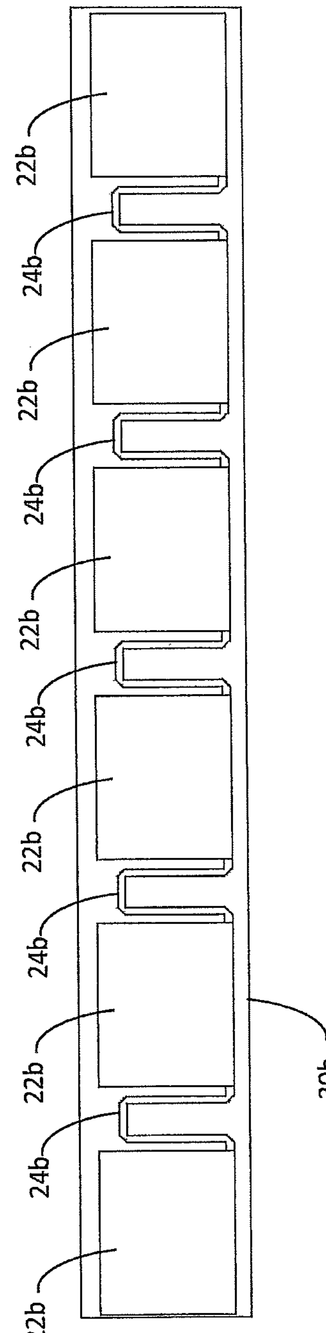
22b
24b
22b
24b
22b
24b
22b
24b
22b
24b
22b
30b

Fig. 6

CLOAKED LOW BAND ELEMENTS FOR MULTIBAND RADIATING ARRAYS

The present application is a continuation application of and claims priority from U.S. patent application Ser. No. 15/517,906, filed Apr. 7, 2017, which is a 35 U.S.C. § 371 national stage application of PCT International Application No. PCT/US2015/044020, filed Aug. 6, 2015, which itself claims priority to U.S. Provisional Patent Application No. 62/081,358, filed Nov. 18, 2014, the disclosure and content of both of which are incorporated by reference herein in their entireties. The above-referenced PCT International Application was published in the English language as International Publication No. WO 2016/081036 A1 on May 26, 2016.

FIELD OF THE INVENTION

This invention relates to wide-band multi-band antennas with interspersed radiating elements intended for cellular base station use. In particular, the invention relates to radiating elements intended for a low frequency band when interspersed with radiating elements intended for a high frequency band. This invention is aimed at minimizing the effect of the low-band dipole arms, and/or parasitic elements if used, on the radio frequency radiation from the high-band elements.

BACKGROUND

Undesirable interactions may occur between radiating elements of different frequency bands in multi band interspersed antennas. For example, in some cellular antenna applications, the low band is 694-960 MHz and the high band is 1695-2690 MHz. Undesirable interaction between these bands may occur when a portion of the lower frequency band radiating structure resonates at the wavelength of the higher frequency band. For instance, in multiband antennas where a higher frequency band is a multiple of a frequency of a lower frequency band, there is a probability that the low band radiating element, or some component or part of it, will be resonant in some part of the high band frequency range. This type of interaction may cause a scattering of high band signals by the low band elements. As a result, perturbations in radiation patterns, variation in azimuth beam width, beam squint, high cross polar radiation and skirts in radiation patterns are observed in the high band.

SUMMARY

In one aspect of the present invention, a low band radiating element for use in a multiband antenna having at least a high band operational frequency and a low band operational frequency is provided. The low band element comprises a first dipole element having a first polarization and comprising a first pair of dipole arms and a second dipole element having a second polarization and comprising a second pair of dipole arms oriented at approximately 90 degrees to the first pair of dipole arms. Each dipole arm includes a plurality of conductive segments, each having a length less than one-half wavelength at the high band operational frequency, coupled in series by a plurality of inductive elements, having an impedance selected to attenuate high band currents while passing low band currents in the dipole arms. The inductive elements are selected to appear as high impedance elements at the high band operational frequency and as lower impedance elements at the low band operational frequency.

In another aspect of the present invention, a multiband antenna is provided. The multiband antenna includes a reflector, a first array of first radiating elements and a second array of second radiating elements. The first radiating elements have a first operational frequency band and the second radiating elements have a second operational frequency band. The first radiating elements include two or more dipole arms. Each dipole arm includes a plurality of conductive segments coupled in series by a plurality of inductive elements. The conductive segments each have a length less than one-half wavelength at the second operational frequency band. The first radiating elements may comprise single dipole elements or cross dipole elements.

The inductive elements are typically selected to appear as high impedance elements at the second operational frequency band and as lower impedance elements at the first operational frequency band. The first operational frequency band typically comprises a low band of the multiband antenna and the second operational frequency band typically comprises a high band of the multiband antenna.

In another aspect of the present invention, parasitic elements may be included on the multiband antenna to shape low band beam characteristics. For example, the parasitic elements may have an overall length selected to shape beam patterns in the first operational frequency band, and comprise conductive segments coupled in series with inductive elements selected to reduce interaction between the parasitic elements and radiation at the second operational frequency band. The conductive segments of the parasitic elements may also have a length of less than one half wave length at the second operational frequency band.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an antenna according to one aspect of the present invention.

FIG. **2** is a plan view of a portion of an antenna array according to another aspect of the present invention.

FIG. **3** is an isometric view of a low band radiating element and parasitic elements according to another aspect of the present invention.

FIG. **4** is a more detailed view of the low band radiating element of FIG. **3**.

FIG. **5** is a first example of a parasitic element according to another aspect of the present invention.

FIG. **6** is a second example of a parasitic element accordingly to another aspect of the present invention.

DESCRIPTION OF THE INVENTION

FIG. **1** schematically diagrams a dual band antenna **10**. The dual band antenna **10** includes a reflector **12**, an array of high band radiating elements **14** and an array of low band radiating elements **16**. Optionally, parasitic elements **30** may be included to shape azimuth beam width of the low band elements. Multiband radiating arrays of this type commonly include vertical columns of high band and low band elements spaced at pre-determined intervals See, for example, U.S. patent application Ser. No. 13/827,190, now U.S. Pat. No. 9,276,329 to Jones et al., which is incorporated by reference.

FIG. **2** schematically illustrates a portion of a wide band dual band antenna **10** including features of a low band radiating element **16** according to one aspect of the present invention. High band radiating elements **14** may comprise any conventional crossed dipole element, and may include first and second dipole arms **18**. Other known high band elements may be used. The low band radiating element **16** also comprises a crossed dipole element, and includes first and second dipole arms **20**. In this example, each dipole arm **20** includes a plurality of conductive segments **22** coupled in series by inductors **24**.

The low band radiating element **16** may be advantageously used in multi-band dual-polarization cellular base-station antenna. At least two bands comprise low and high bands suitable for cellular communications. As used herein, "low band" refers to a lower frequency band, such as 694-960 MHz, and "high band" refers to a higher frequency band, such as 1695 MHz-2690 MHz. The present invention is not limited to these particular bands, and may be used in other multi-band configurations. A "low band radiator" refers to a radiator for such a lower frequency band, and a "high band radiator" refers to a radiator for such a higher frequency band. A "dual band" antenna is a multi-band antenna that comprises the low and high bands referred to throughout this disclosure.

Referring to FIG. **3**, a low band radiating element **16** and a pair of parasitic elements **30** are illustrated mounted on reflector **12**. In one aspect of the present invention, parasitic elements **30** are aligned to be approximately parallel to a longitudinal dimension of reflector **12** to help shape the beam width of the pattern. In another aspect of the invention, the parasitic elements may be aligned perpendicular to a longitudinal axis of the reflector **12** to help reduce coupling between the elements. The low band radiating element **16** is illustrated in more detail in FIG. **4**. Low band radiating element **16** includes a plurality of dipole arms **20**. The dipole arms **20** may be one half wave length long. The low band dipole arms **20** include a plurality of conductive segments **22**. The conductive segments **22** have a length of less than one-half wavelength at the high band frequencies. For example, the wavelength of a radio wave at 2690 MHz is about 11 em, and one-half wavelength at 2690 MHz would be about 5.6 em. In the illustrated example, four segments **22** are included, which results in a segment length of less than 5 em, which is shorter than one-half wavelength at the upper end of the high band frequency range. The conductive segments **22** are connected in series with inductors **24**. The inductors **24** are configured to have relatively low impedance at low band frequencies and relatively higher impedance at high band frequencies.

In the examples of FIGS. **2** and **3**, the dipole arms **20**, including conductive segments **22** and inductors **24**, may be fabricated as copper metallization on a non-conductive substrate using, for example, conventional printed circuit board fabrication techniques. In this example, the narrow metallization tracks connecting the conductive segments **22** comprise the inductors **24**.

In other aspect of the invention, the inductors **24** may be implemented as discrete components.

At low band frequencies, the impedance of the inductors **24** connecting the conductive segments **22** is sufficiently low to enable the low band currents continue to flow between conductive segments **22**. At high band frequencies, however, the impedance is much higher due to the series inductors **24**, which reduces high band frequency current flow between the conductive segments **22**. Also, keeping each of the conductive segments **22** to less than one half wavelength at high band frequencies reduces undesired interaction between the conductive segments **22** and the high band radio frequency (RF) signals. Therefore, the low band radiating elements **16** of the present invention reduce and/or attenuate any induced current from high band RF radiation from high band radiating elements **14**, and any undesirable scattering of the high

band signals by the low band dipole arms **20** is minimized. The low band dipole is effectively electrically invisible, or "cloaked," at high band frequencies.

As illustrated in FIG. **3**, the low band radiating elements **16** having cloaked dipole arms **20** may be used in combination with cloaked parasitic elements **30**. However, either cloaked structure may also be used independently of the other. Referring to FIGS. **1** and **3**, parasitic elements **30** may be located on either side of the driven low band radiating element **16** to control the azimuth beam width. To make the overall low band radiation pattern narrower, the current in the parasitic element **30** should be more or less in phase with the current in the driven low band radiating element **16**. However, as with driven radiating elements, inadvertent resonance at high band frequencies by low band parasitic elements may distort high band radiation patterns.

A first example of a cloaked low band parasitic element **30*a*** is illustrated in FIG. **5**. The segmentation of the parasitic elements may be accomplished in the same way as the segmentation of the dipole arms in FIG. **4**. For example, parasitic element **30*a*** includes four conductive segments **22*a*** coupled by three inductors **24*a***. A second example of a cloaked low band parasitic element **30*b*** is illustrated in FIG. **6**. Parasitic element **30*b*** includes six conductive segments **22*b*** coupled by five inductors **24*b***. Relative to parasitic element **30*a***, the conductive segments **22*b*** are shorter than the conductive segments **22*a***, and the inductor traces **24*b*** are longer than the inductor traces **24*a***.

At high band frequencies, the inductors **24*a***, **24*b*** appear to be high impedance elements which reduce current flow between the conductive segments **22*a***, **22*b***, respectively. Therefore the effect of the low band parasitic elements **30** scattering of the high band signals is minimized. However, at low band, the distributed inductive loading along the parasitic element **30** tunes the phase of the low band current, thereby giving some control over the low band azimuth beam width.

In a multiband antenna according to one aspect of the present invention described above, the dipole radiating element **16** and parasitic elements **30** are configured for low band operation. However, the invention is not limited to low band operation, the invention is contemplated to be employed in additional embodiments where driven and/or passive elements are intended to operate at one frequency band, and be unaffected by RF radiation from active radiating elements in other frequency bands. The exemplary low band radiating element **16** also comprises a cross-dipole radiating element. Other aspects of the invention may utilize a single dipole radiating element if only one polarization is required.

What is claimed is:

1. A multiband cellular base station antenna comprising:

a reflector;

a first array of first radiating elements that are configured to operate in a first operational frequency band of the multiband cellular base station antenna, each of the first radiating elements including a plurality of dipole arms that are configured to have a high impedance that attenuates currents in a second operational frequency band of the multiband cellular base station antenna and to have a low impedance that passes currents in the first operational frequency band;

a second array of second radiating elements that are configured to operate in the second operational frequency band; and

a plurality of parasitic elements,

wherein a first of the plurality of parasitic elements comprises a plurality of elements that are configured to have a high impedance that attenuates current in the first of the plurality of parasitic elements in the second operational frequency band and have a low impedance that passes current in the first of the plurality of parasitic elements in the first operational frequency band.

2. The multiband cellular base station antenna of claim **1**, wherein the plurality of parasitic elements are adjacent sides of the reflector.

3. The multiband cellular base station antenna of claim **2**, wherein at least some of the parasitic elements are positioned adjacent the second array of second radiating elements.

4. The multiband cellular base station antenna of claim **2**, wherein the parasitic elements each have an overall length and position that is selected to reduce coupling between opposite polarization radiators of the first radiating elements.

5. The multiband cellular base station antenna of claim **1**, wherein a first of the first radiating elements is positioned between the first of the parasitic elements and a second of the parasitic elements.

6. The multiband cellular base station antenna of claim **5**, wherein the first of the parasitic elements is on a first side of the reflector and is aligned to be approximately parallel to a longitudinal dimension of the reflector and the second of the parasitic elements is on a second side of the reflector and aligned to be approximately parallel to the longitudinal dimension of the reflector, and the first of the first radiating elements is positioned along a transverse axis connecting the first and the second of the parasitic elements.

7. The multiband cellular base station antenna of claim **5**, wherein the first of the parasitic elements and the second of the parasitic elements are aligned to be perpendicular to a longitudinal dimension of the reflector.

8. The multiband cellular base station antenna of claim **5**, wherein the first of the parasitic elements is configured so that current in the first of the parasitic elements is substantially in phase with current in the first of the first radiating elements.

9. The multiband cellular base station antenna of claim **1**, wherein the first of the parasitic elements is mounted adjacent a first of the first radiating elements, wherein the first operational frequency band comprises a low band of the multiband cellular base station antenna and the second operational frequency band comprises a high band of the multiband cellular base station antenna.

10. A multiband antenna comprising:

a reflector;

a plurality of first radiating elements that are configured to operate in a first frequency band and that extend forwardly from the reflector;

a plurality of second radiating elements that are configured to operate in a second frequency band that is higher than the first frequency band, the second radiating elements extending forwardly from the reflector; and

a plurality of parasitic elements that extend forwardly from the reflector,

wherein a first of the plurality of parasitic elements comprises a plurality of elements that are configured to have a high impedance that attenuates current in the first of the plurality of parasitic elements in the second frequency band and have a low impedance that passes current in the first of the plurality of parasitic elements in the first frequency band.

11. The multiband antenna of claim **10**, wherein the plurality of first radiating elements comprises a plurality of crossed dipole elements, respectively.

12. The multiband antenna of claim **11**,

wherein a first of the plurality of crossed dipole elements is between a first pair of the plurality of parasitic elements,

wherein a second of the plurality of crossed dipole elements is between a second pair of the plurality of parasitic elements, and

wherein a first parasitic element of the first pair of the plurality of parasitic elements is aligned with a first parasitic element of the second pair of the plurality of parasitic elements along a longitudinal dimension of the reflector, and a second parasitic element of the first pair of the plurality of parasitic elements is aligned with a second parasitic element of the second pair of the plurality of parasitic elements along the longitudinal dimension of the reflector.

13. The multiband antenna of claim **10**,

wherein the plurality of parasitic elements comprises a first column of parasitic elements extending longitudinally along a first side of the reflector and a second column of parasitic elements extending longitudinally along a second side of the reflector, and

wherein the plurality of first radiating elements and the plurality of second radiating elements are between the first and second columns of parasitic elements.

14. The multiband antenna of claim **13**,

wherein the plurality of first radiating elements comprises a vertical column of low band radiating elements at a center of the reflector,

wherein the plurality of second radiating elements comprises a plurality of vertical columns of high band radiating elements, and

wherein the first and second columns of parasitic elements are adjacent first and second edges, respectively, of the reflector.

15. The multiband antenna of claim **10**, wherein the plurality of parasitic elements comprises a first set of parasitic elements that extend approximately parallel to a longitudinal dimension of the reflector and a second set of parasitic elements that are aligned to be perpendicular to the longitudinal dimension of the reflector.

16. The multiband antenna of claim **10**, wherein the first of the plurality of parasitic elements is configured so that the current in the first of the plurality of parasitic elements is substantially in phase with current in a first of the plurality of first radiating elements in the first frequency band.

17. The multiband antenna of claim **10**,

wherein the plurality of first radiating elements comprises a column of low band crossed dipole radiating elements that extend along a longitudinal dimension of the reflector,

wherein the plurality of second radiating elements comprises a plurality of columns of high band radiating elements that each extend along the longitudinal dimension of the reflector, and

wherein the first of the plurality of parasitic elements is adjacent a side edge of the reflector.

18. A multiband antenna, comprising:

a first array of first radiating elements having a first operational frequency band, the first radiating elements comprising a plurality of dipole arms, each dipole arm including a plurality of conductive segments and a plurality of inductive elements, wherein, for each dipole arm, a respective one of the inductive elements is electrically positioned between each pair of adjacent conductive segments, and wherein a first of the inductive elements comprises a metallization track that has sections that extend in multiple directions; and

a second array of second radiating elements having a second operational frequency band;

wherein the plurality of conductive segments each have a length less than one-half wavelength at the second operational frequency band.

19. The multiband antenna of claim **18**, wherein the inductive elements are configured to have a high impedance that attenuates currents in the dipole arms in the second operational frequency band and have a low impedance that passes currents in the dipole arms in the first operational frequency band.

20. The multiband antenna of claim **18**, wherein the conductive segments and the inductive elements comprise copper metallization on a non-conductive substrate, and wherein the first radiating elements each comprise a crossed dipole radiating element.

21. The multiband antenna of claim **18**, wherein the metallization track has a U-shape.

22. The multiband antenna of claim **18**, wherein the first of the inductive elements is in a first gap that is between first and second of the conductive segments that are adjacent each other, and wherein a length of the metallization track exceeds a length of the first gap.

23. The multiband antenna of claim **18**, wherein the first and second operational frequency bands comprise first and second cellular frequency bands, respectively.

* * * * *

EXHIBIT G

US010547110B1

(12) **United States Patent**
Isik et al.

(10) **Patent No.: US 10,547,110 B1**
(45) **Date of Patent: Jan. 28, 2020**

(54) **CLOAKED LOW BAND ELEMENTS FOR MULTIBAND RADIATING ARRAYS**

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(73) Assignee: **CommScope Technologies LLC**, Hickory, NC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/655,479**

(22) Filed: **Oct. 17, 2019**

Related U.S. Application Data

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(Continued)

(51) **Int. Cl.**
H01Q 21/12 (2006.01)
H01Q 5/49 (2015.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01Q 5/49*** (2015.01); ***H01Q 1/24*** (2013.01); ***H01Q 1/523*** (2013.01); ***H01Q 9/16*** (2013.01); ***H01Q 19/108*** (2013.01); ***H01Q 21/062*** (2013.01); ***H01Q 21/26*** (2013.01); *H01Q 1/246* (2013.01); *H01Q 1/52* (2013.01); *H01Q 19/10* (2013.01); *H01Q 21/06* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC .. H01Q 1/52; H01Q 9/16; H01Q 1/24; H01Q 19/10; H01Q 5/49; H01Q 21/06; H01Q 21/30; H01Q 25/00
USPC 343/815, 722, 702, 810, 893, 876, 725
See application file for complete search history.

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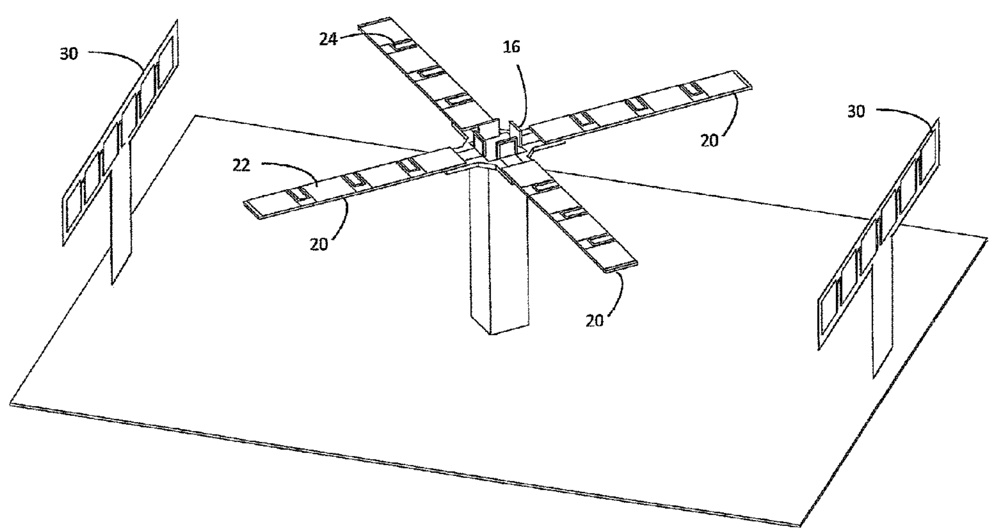
Primary Examiner — Joseph J Lauture
(74) *Attorney, Agent, or Firm* — Myers Bigel, P.A.

(57) **ABSTRACT**

A multiband antenna, having a reflector, and a first array of first radiating elements having a first operational frequency band, the first radiating elements being a plurality of dipole arms, each dipole arm including a plurality of conductive segments coupled in series by a plurality of inductive elements; and a second array of second radiating elements having a second operational frequency band, wherein the plurality of conductive segments each have a length less than one-half wavelength at the second operational frequency band.

19 Claims, 5 Drawing Sheets



Related U.S. Application Data

No. 15/517,906, filed as application No. PCT/US2015/044020 on Aug. 6, 2015, now Pat. No. 10,439,285.

(60) Provisional application No. 62/081,358, filed on Nov. 18, 2014.

(51) **Int. Cl.**

H01Q 1/52	(2006.01)
H01Q 9/16	(2006.01)
H01Q 19/10	(2006.01)
H01Q 21/06	(2006.01)
H01Q 21/26	(2006.01)
H01Q 1/24	(2006.01)
H01Q 25/00	(2006.01)
H01Q 21/30	(2006.01)

(52) **U.S. Cl.**

CPC *H01Q 21/30* (2013.01); *H01Q 25/00* (2013.01); *H01Q 25/001* (2013.01)

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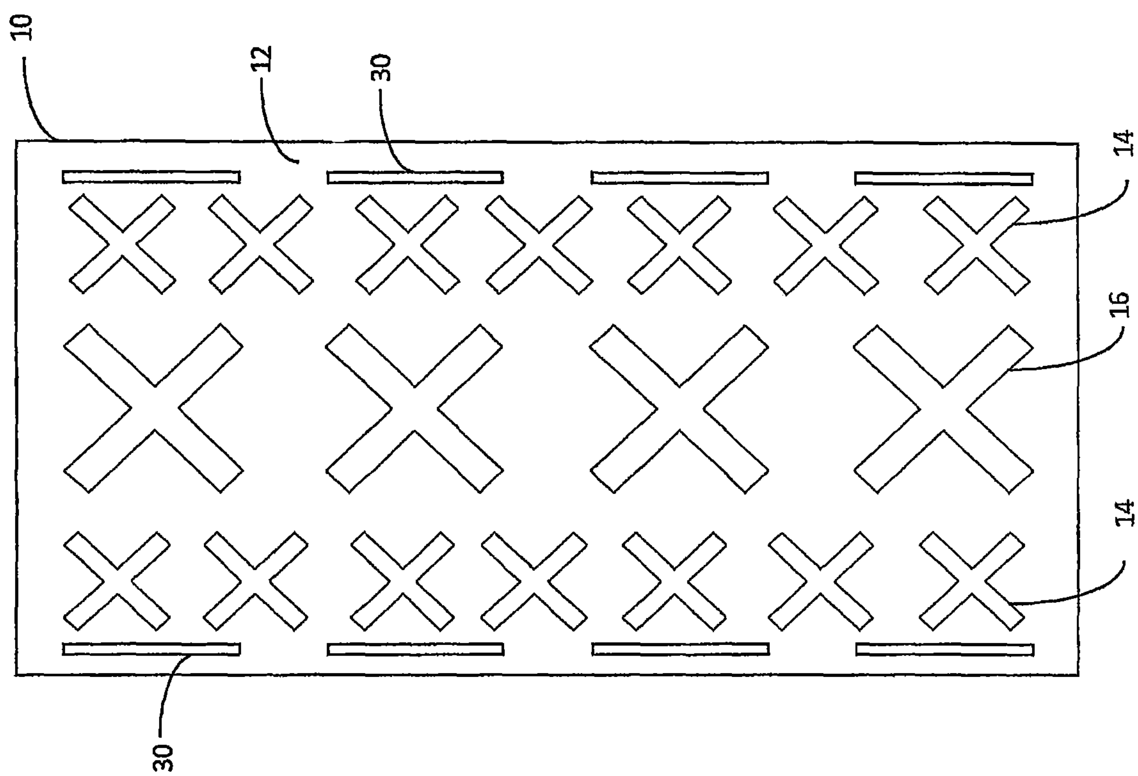

Fig. 1

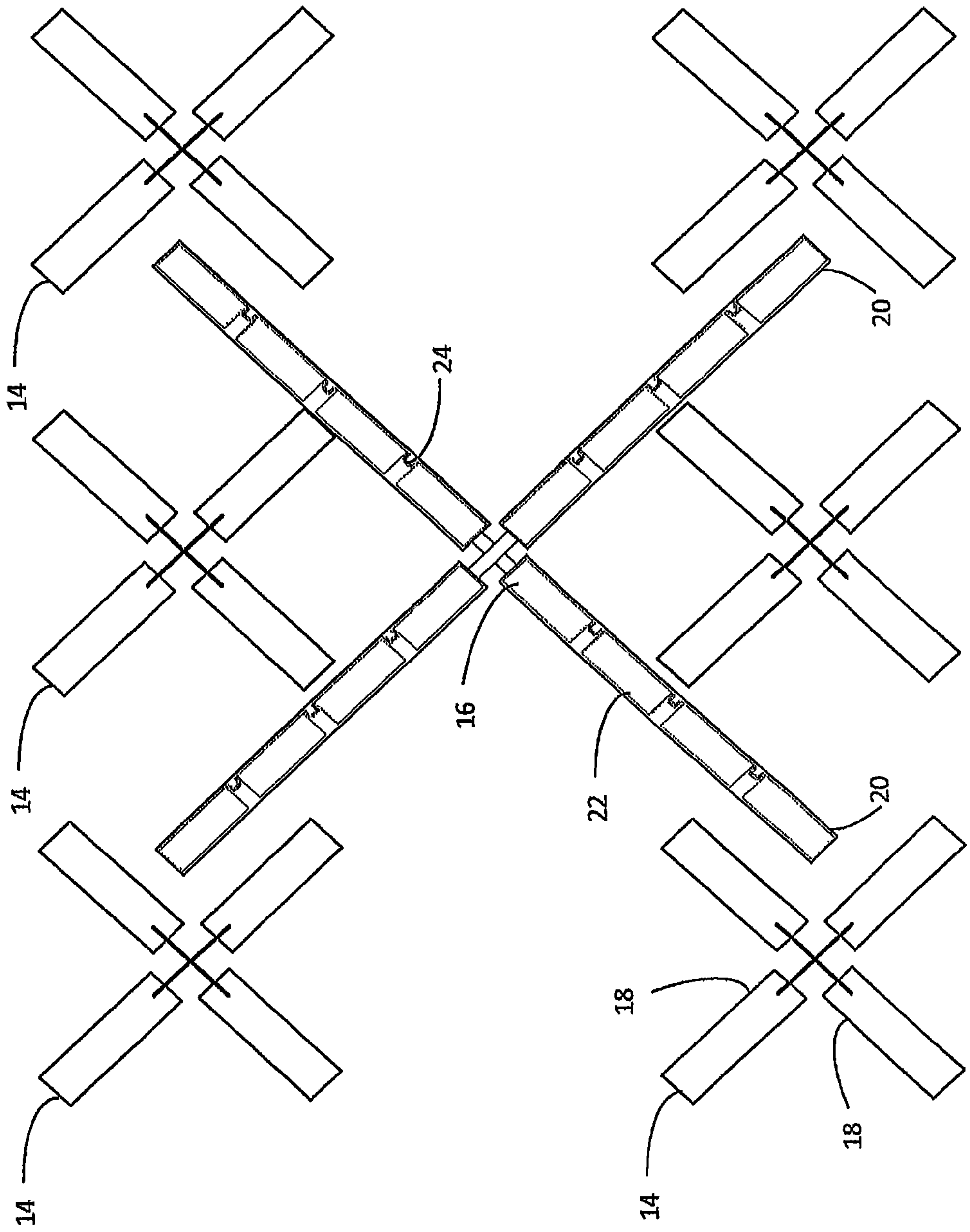

Fig. 2

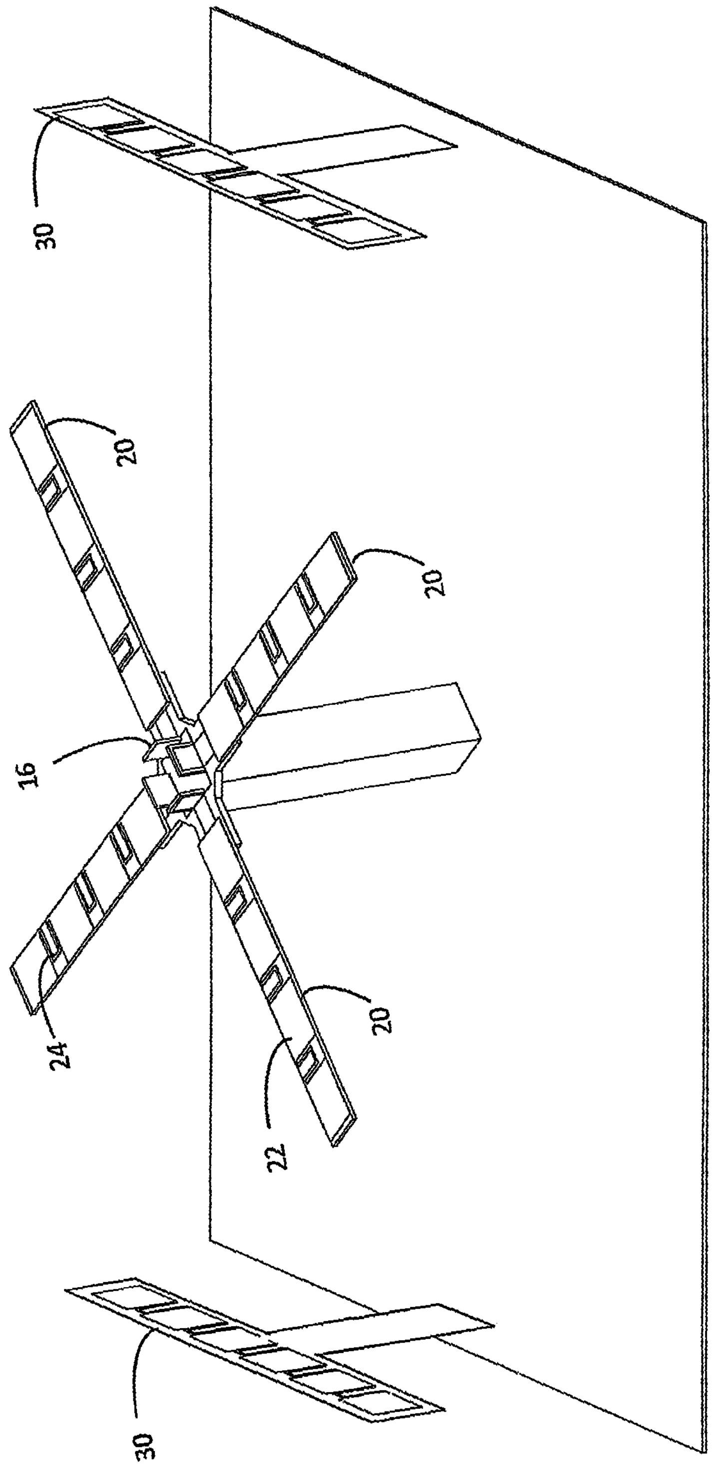

Fig. 3

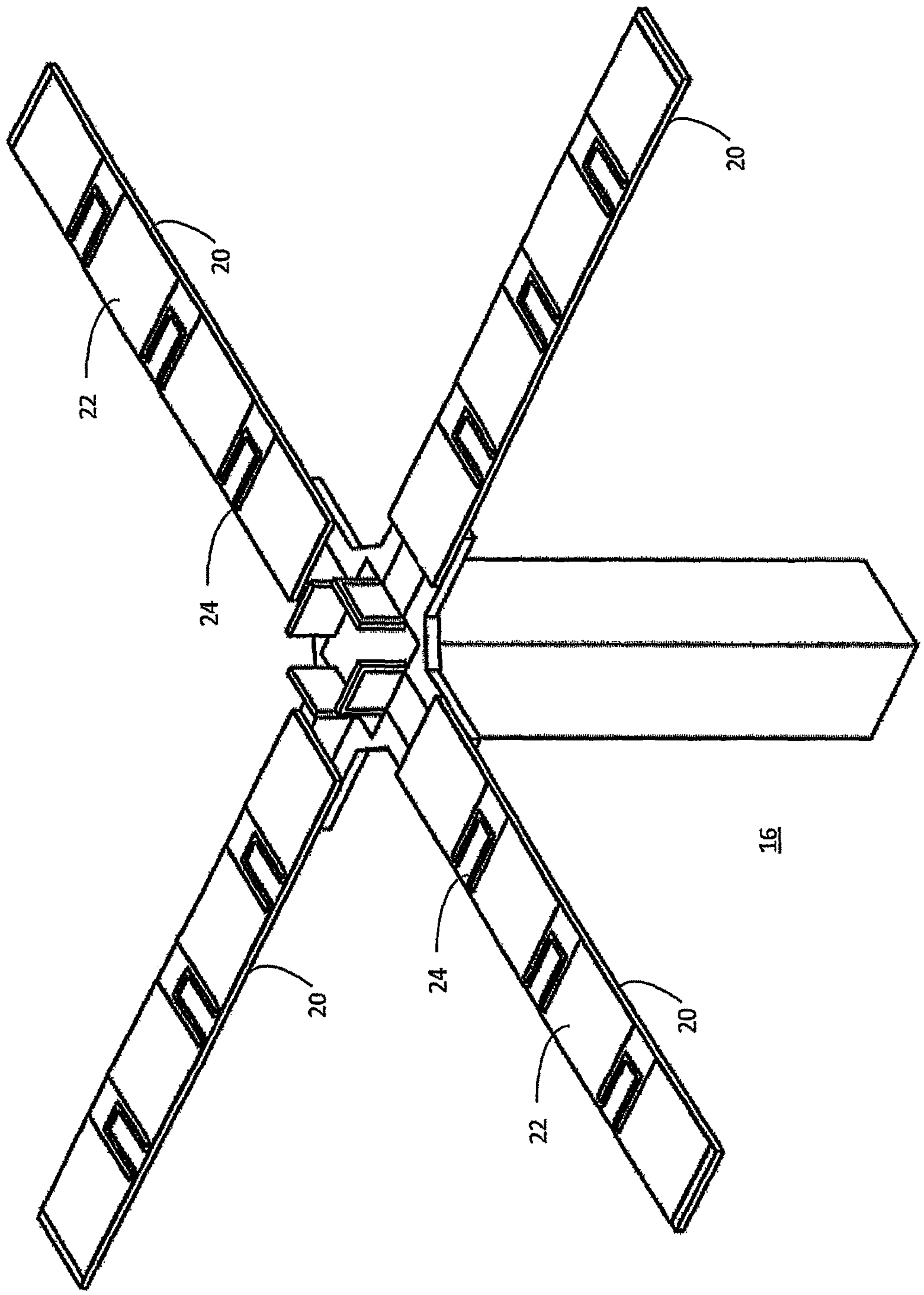

Fig. 4

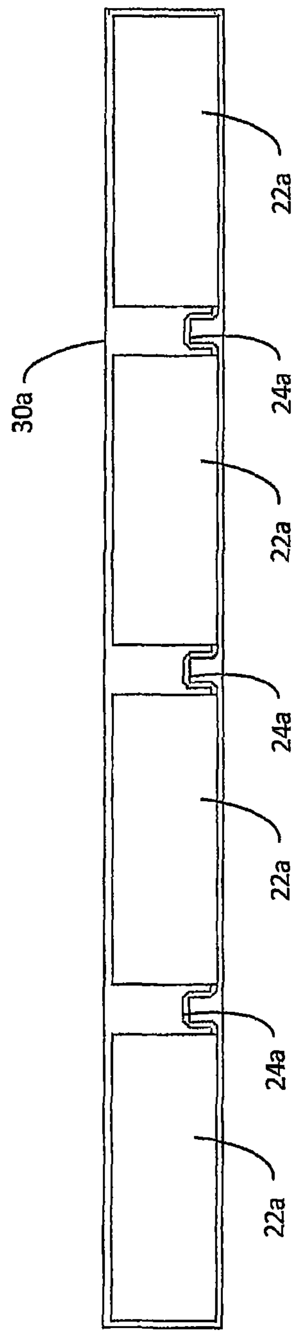
22a
24a
22a
24a
22a
24a
22a
30a

Fig. 5

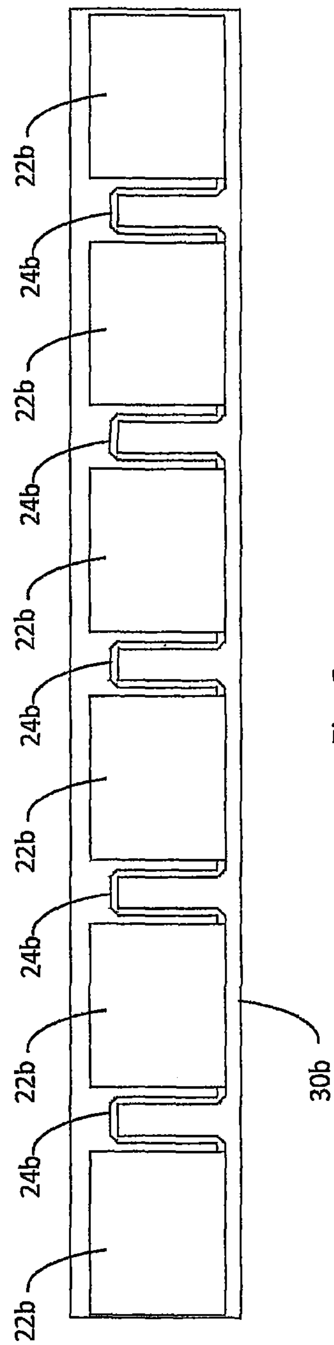
22b
24b
22b
24b
22b
24b
22b
24b
22b
24b
22b
30b

Fig. 6

CLOAKED LOW BAND ELEMENTS FOR MULTIBAND RADIATING ARRAYS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation application of and claims priority from U.S. patent application Ser. No. 16/277,044, filed Feb. 15, 2019, which is a continuation of U.S. patent application Ser. No. 15/517,906, filed Apr. 7, 2017, which is a 35 U.S.C. § 371 national stage application of PCT International Application No. PCT/US2015/044020, filed Aug. 6, 2015, which itself claims priority to U.S. Provisional Patent Application No. 62/081,358, filed Nov. 18, 2014, the disclosure and content of each of the above applications is incorporated by reference herein. The above-referenced PCT International Application was published in the English language as International Publication No. WO 2016/081036 A1 on May 26, 2016.

FIELD OF THE INVENTION

This invention relates to wide-band multi-band antennas with interspersed radiating elements intended for cellular base station use. In particular, the invention relates to radiating elements intended for a low frequency band when interspersed with radiating elements intended for a high frequency band. This invention is aimed at minimizing the effect of the low-band dipole arms, and/or parasitic elements if used, on the radio frequency radiation from the high-band elements.

BACKGROUND

Undesirable interactions may occur between radiating elements of different frequency bands in multi band interspersed antennas. For example, in some cellular antenna applications, the low band is 694-960 MHz and the high band is 1695-2690 MHz. Undesirable interaction between these bands may occur when a portion of the lower frequency band radiating structure resonates at the wavelength of the higher frequency band. For instance, in multiband antennas where a higher frequency band is a multiple of a frequency of a lower frequency band, there is a probability that the low band radiating element, or some component or part of it, will be resonant in some part of the high band frequency range. This type of interaction may cause a scattering of high band signals by the low band elements. As a result, perturbations in radiation patterns, variation in azimuth beam width, beam squint, high cross polar radiation and skirts in radiation patterns are observed in the high band.

SUMMARY

In one aspect of the present invention, a low band radiating element for use in a multiband antenna having at least a high band operational frequency and a low band operational frequency is provided. The low band element comprises a first dipole element having a first polarization and comprising a first pair of dipole arms and a second dipole element having a second polarization and comprising a second pair of dipole arms oriented at approximately 90 degrees to the first pair of dipole arms. Each dipole arm includes a plurality of conductive segments, each having a length less than one-half wavelength at the high band operational frequency, coupled in series by a plurality of inductive elements, having an impedance selected to attenuate high band currents while passing low band currents in the dipole arms. The inductive elements are selected to appear as high impedance elements at the high band operational frequency and as lower impedance elements at the low band operational frequency.

In another aspect of the present invention, a multiband antenna is provided. The multiband antenna includes a reflector, a first array of first radiating elements and a second array of second radiating elements. The first radiating elements have a first operational frequency band and the second radiating elements have a second operational frequency band. The first radiating elements include two or more dipole arms. Each dipole arm includes a plurality of conductive segments coupled in series by a plurality of inductive elements. The conductive segments each have a length less than one-half wavelength at the second operational frequency band. The first radiating elements may comprise single dipole elements or cross dipole elements.

The inductive elements are typically selected to appear as high impedance elements at the second operational frequency band and as lower impedance elements at the first operational frequency band. The first operational frequency band typically comprises a low band of the multiband antenna and the second operational frequency band typically comprises a high band of the multiband antenna.

In another aspect of the present invention, parasitic elements may be included on the multiband antenna to shape low band beam characteristics. For example, the parasitic elements may have an overall length selected to shape beam patterns in the first operational frequency band, and comprise conductive segments coupled in series with inductive elements selected to reduce interaction between the parasitic elements and radiation at the second operational frequency band. The conductive segments of the parasitic elements may also have a length of less than one half wave length at the second operational frequency band.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an antenna according to one aspect of the present invention.

FIG. **2** is a plan view of a portion of an antenna array according to another aspect of the present invention.

FIG. **3** is an isometric view of a low band radiating element and parasitic elements according to another aspect of the present invention.

FIG. **4** is a more detailed view of the low band radiating element of FIG. **3**.

FIG. **5** is a first example of a parasitic element according to another aspect of the present invention.

FIG. **6** is a second example of a parasitic element accordingly to another aspect of the present invention.

DESCRIPTION OF THE INVENTION

FIG. **1** schematically diagrams a dual band antenna **10**. The dual band antenna **10** includes a reflector **12**, an array of high band radiating elements **14** and an array of low band radiating elements **16**. Optionally, parasitic elements **30** may be included to shape azimuth beam width of the low band elements. Multiband radiating arrays of this type commonly include vertical columns of high band and low band elements spaced at pre-determined intervals See, for example, U.S. patent application Ser. No. 13/827,190, now U.S. Pat. No. 9,276,329 to Jones et al., which is incorporated by reference.

FIG. **2** schematically illustrates a portion of a wide band dual band antenna **10** including features of a low band radiating element **16** according to one aspect of the present invention. High band radiating elements **14** may comprise any conventional crossed dipole element, and may include first and second dipole arms **18**. Other known high band elements may be used. The low band radiating element **16** also comprises a crossed dipole element, and includes first and second dipole arms **20**. In this example, each dipole arm **20** includes a plurality of conductive segments **22** coupled in series by inductors **24**.

The low band radiating element **16** may be advantageously used in multi-band dual-polarization cellular base-station antenna. At least two bands comprise low and high bands suitable for cellular communications. As used herein, "low band" refers to a lower frequency band, such as 694-960 MHz, and "high band" refers to a higher frequency band, such as 1695 MHz-2690 MHz. The present invention is not limited to these particular bands, and may be used in other multi-band configurations. A "low band radiator" refers to a radiator for such a lower frequency band, and a "high band radiator" refers to a radiator for such a higher frequency band. A "dual band" antenna is a multi-band antenna that comprises the low and high bands referred to throughout this disclosure.

Referring to FIG. **3**, a low band radiating element **16** and a pair of parasitic elements **30** are illustrated mounted on reflector **12**. In one aspect of the present invention, parasitic elements **30** are aligned to be approximately parallel to a longitudinal dimension of reflector **12** to help shape the beam width of the pattern. In another aspect of the invention, the parasitic elements may be aligned perpendicular to a longitudinal axis of the reflector **12** to help reduce coupling between the elements. The low band radiating element **16** is illustrated in more detail in FIG. **4**. Low band radiating element **16** includes a plurality of dipole arms **20**. The dipole arms **20** may be one half wave length long. The low band dipole arms **20** include a plurality of conductive segments **22**. The conductive segments **22** have a length of less than one-half wavelength at the high band frequencies. For example, the wavelength of a radio wave at 2690 MHz is about 11 cm, and one-halfwavelength at 2690 MHz would be about 5.6 cm. In the illustrated example, four segments **22** are included, which results in a segment length of less than 5 cm, which is shorter than one-half wavelength at the upper end of the high band frequency range. The conductive segments **22** are connected in series with inductors **24**. The inductors **24** are configured to have relatively low impedance at low band frequencies and relatively higher impedance at high band frequencies.

In the examples of FIGS. **2** and **3**, the dipole arms **20**, including conductive segments **22** and inductors **24**, may be fabricated as copper metallization on a non-conductive substrate using, for example, conventional printed circuit board fabrication techniques. In this example, the narrow metallization tracks connecting the conductive segments **22** comprise the inductors **24**. In other aspect of the invention, the inductors **24** may be implemented as discrete components.

At low band frequencies, the impedance of the inductors **24** connecting the conductive segments **22** is sufficiently low to enable the low band currents continue to flow between conductive segments **22**. At high band frequencies, however, the impedance is much higher due to the series inductors **24**, which reduces high band frequency current flow between the conductive segments **22**. Also, keeping each of the conductive segments **22** to less than one half wavelength at high band frequencies reduces undesired interaction between the conductive segments **22** and the high band radio frequency (RF) signals. Therefore, the low band radiating elements **16** of the present invention reduce and/or attenuate any induced current from high band RF radiation from high band radiating elements **14**, and any undesirable scattering of the high band signals by the low band dipole arms **20** is minimized. The low band dipole is effectively electrically invisible, or "cloaked," at high band frequencies.

As illustrated in FIG. **3**, the low band radiating elements **16** having cloaked dipole arms **20** may be used in combination with cloaked parasitic elements **30**. However, either cloaked structure may also be used independently of the other. Referring to FIGS. **1** and **3**, parasitic elements **30** may be located on either side of the driven low band radiating element **16** to control the azimuth beam width. To make the overall low band radiation pattern narrower, the current in the parasitic element **30** should be more or less in phase with the current in the driven low band radiating element **16**. However, as with driven radiating elements, inadvertent resonance at high band frequencies by low band parasitic elements may distort high band radiation patterns.

A first example of a cloaked low band parasitic element **30***a* is illustrated in FIG. **5**. The segmentation of the parasitic elements may be accomplished in the same way as the segmentation of the dipole arms in FIG. **4**. For example, parasitic element **30***a* includes four conductive segments **22***a* coupled by three inductors **24***a*. A second example of a cloaked low band parasitic element **30***b* is illustrated in FIG. **6**. Parasitic element **30***b* includes six conductive segments **22***b* coupled by five inductors **24***b*. Relative to parasitic element **30***a*, the conductive segments **22***b* are shorter than the conductive segments **22***a*, and the inductor traces **24***b* are longer than the inductor traces **24***a*.

At high band frequencies, the inductors **24***a*, **24***b* appear to be high impedance elements which reduce current flow between the conductive segments **22***a*, **22***b*, respectively. Therefore the effect of the low band parasitic elements **30** scattering of the high band signals is minimized. However, at low band, the distributed inductive loading along the parasitic element **30** tunes the phase of the low band current, thereby giving some control over the low band azimuth beam width.

In a multiband antenna according to one aspect of the present invention described above, the dipole radiating element **16** and parasitic elements **30** are configured for low band operation. However, the invention is not limited to low band operation, the invention is contemplated to be employed in additional embodiments where driven and/or passive elements are intended to operate at one frequency band, and be unaffected by RF radiation from active radiating elements in other frequency bands. The exemplary low band radiating element **16** also comprises a cross-dipole radiating element. Other aspects of the invention may utilize a single dipole radiating element if only one polarization is required.

What is claimed is:

1. A multiband antenna comprising:

a reflector that has a longitudinal axis;

a first column of high band radiating elements that are configured to operate in a first operational frequency band mounted on the reflector, the first column of high band radiating elements extending in parallel to the longitudinal axis of the reflector;

a second column of high band radiating elements that are configured to operate in the first operational frequency band mounted on the reflector, the second column of high band radiating elements extending in parallel to the longitudinal axis of the reflector;

a first column of low band radiating elements that are configured to operate in a second operational frequency band mounted on the reflector, the second operational frequency band being at frequencies that are lower than frequencies of the first operational frequency band, the first column of low band radiating elements extending in parallel to the longitudinal axis of the reflector between the first column of high band radiating elements and the second column of high band radiating elements;

a first column of parasitic elements extending in parallel to the longitudinal axis of the reflector such that the first column of high band radiating elements is between the first column of parasitic elements and the first column of low band radiating elements, and

a second column of parasitic elements extending in parallel to the longitudinal axis of the reflector such that the second column of high band radiating elements is between the second column of parasitic elements and the first column of low band radiating elements.

2. The multiband antenna of claim **1**, wherein currents induced in the parasitic elements in the first and second columns of parasitic elements are configured to be substantially in phase with currents in the low band radiating elements.

3. The multiband antenna of claim **1**, wherein each low band radiating element comprises a crossed dipole radiating element that includes first and second dipole elements, each dipole element including first and second dipole arms.

4. The multiband antenna of claim **3**, wherein at least some of the parasitic elements have an overall length and position that is selected to reduce coupling between the first and second dipole elements of the low band radiating elements.

5. The multiband antenna of claim **3**, wherein each dipole arm comprises copper metallization on a dielectric substrate.

6. The multiband antenna of claim **3**, wherein the first dipole element of each low band radiating element is oriented at approximately 90° from the second dipole element of each low band radiating element.

7. The multiband antenna of claim **1**, wherein each low band radiating element comprises a crossed dipole radiating element.

8. The multiband antenna of claim **1**, wherein the first operational frequency band is the 1695-2690 MHz frequency band and the second operational frequency band is the 694-960 MHz frequency band.

9. The multiband antenna of claim **1**, wherein the first column of parasitic elements is adjacent a first edge of the reflector and the second column of parasitic elements is adjacent a second edge of the reflector.

10. The multiband antenna of claim **1**, wherein a first of the parasitic elements that is in the first column of parasitic elements is aligned to be approximately parallel to the longitudinal axis of the reflector, and a second of the parasitic elements that is in the second column of parasitic elements is aligned to be approximately parallel to the longitudinal axis of the reflector, and a first of the low band radiating elements is positioned along a transverse axis connecting the first and the second of the parasitic elements.

11. The multiband antenna of claim **1**, wherein the first column of low band radiating elements extends along a center of the reflector.

12. The multiband antenna of claim **1**, wherein the multiband antenna is a cellular base station antenna.

13. The multiband antenna of claim **1**, wherein the parasitic elements in the first and second columns of parasitic elements are configured to shape a beam generated by the first column of low band radiating elements.

14. The multiband antenna of claim **1**, wherein a number of parasitic elements in each of the first and second columns of parasitic elements is the same as a number of low band radiating element in the first column of low band radiating elements.

15. A multiband antenna comprising:

a reflector that has a longitudinal axis;

a first column of high band radiating elements that are configured to operate in a first operational frequency band mounted on the reflector, the first column of high band radiating elements extending in parallel to the longitudinal axis of the reflector;

a second column of high band radiating elements that are configured to operate in the first operational frequency band mounted on the reflector, the second column of high band radiating elements extending in parallel to the longitudinal axis of the reflector;

a first column of low band radiating elements that are configured to operate in a second operational frequency band mounted on the reflector, the second operational frequency band being at frequencies that are lower than frequencies of the first operational frequency band, the first column of low band radiating elements extending in parallel to the longitudinal axis of the reflector between the first column of high band radiating elements and the second column of high band radiating elements;

a first column of parasitic elements extending in parallel to the longitudinal axis of the reflector such that the first column of high band radiating elements is between the first column of parasitic elements and the first column of low band radiating elements, and

a second column of parasitic elements extending in parallel to the longitudinal axis of the reflector such that the second column of high band radiating elements is between the second column of parasitic elements and the first column of low band radiating elements,

wherein each low band radiating element comprises a cross dipole radiating element that includes first and second dipole elements, each dipole element including first and second dipole arms,

wherein each dipole arm comprises copper metallization on a dielectric substrate,

wherein the first operational frequency band is the 1695-2690 MHz frequency band and the second operational frequency band is the 694-960 MHz frequency band, and

wherein the first column of parasitic elements is adjacent a first side of the reflector and the second column of parasitic elements is adjacent a second side of the reflector.

16. The multiband antenna of claim **15**, wherein the column of low band radiating elements extends along a center of the reflector.

17. The multiband antenna of claim **16**, wherein the multiband antenna is a cellular base station antenna.

18. The multiband antenna of claim **17**, wherein the first dipole element of each low band radiating element is oriented at approximately 90° from the second dipole element of each low band radiating element.

19. The multiband antenna of claim **18**, wherein the parasitic elements in the first and second columns of parasitic elements are configured to shape a beam generated by the first column of low band radiating elements.

* * * * *

JS 44 (Rev. 09/19)

CIVIL COVER SHEET

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. *(SEE INSTRUCTIONS ON NEXT PAGE OF THIS FORM.)*

I. (a) PLAINTIFFS
COMMSCOPE TECHNOLOGIES LLC

(b) County of Residence of First Listed Plaintiff ______
(EXCEPT IN U.S. PLAINTIFF CASES)

(c) Attorneys *(Firm Name, Address, and Telephone Number)*
Kelly E. Farnan, Richards, Layton & Finger, P.A.
920 N. King Street Wilmington, DE 19801 (302) 651-7700

DEFENDANTS
ROSENBERGER SITE SOLUTIONS, LLC; ROSENBERGER ASIA PACIFIC ELECTRONIC CO., LTD.; ROSENBERGER TECHNOLOGIES (KUNSHAN) CO. LTD.

County of Residence of First Listed Defendant ______
(IN U.S. PLAINTIFF CASES ONLY)
NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE TRACT OF LAND INVOLVED.

Attorneys *(If Known)*

II. BASIS OF JURISDICTION *(Place an "X" in One Box Only)*

- ❒ 1 U.S. Government Plaintiff
- ☒ 3 Federal Question *(U.S. Government Not a Party)*
- ❒ 2 U.S. Government Defendant
- ❒ 4 Diversity *(Indicate Citizenship of Parties in Item III)*

III. CITIZENSHIP OF PRINCIPAL PARTIES *(Place an "X" in One Box for Plaintiff and One Box for Defendant)*

(For Diversity Cases Only)

	PTF	DEF		PTF	DEF
Citizen of This State	❒ 1	❒ 1	Incorporated *or* Principal Place of Business In This State	❒ 4	❒ 4
Citizen of Another State	❒ 2	❒ 2	Incorporated *and* Principal Place of Business In Another State	❒ 5	❒ 5
Citizen or Subject of a Foreign Country	❒ 3	❒ 3	Foreign Nation	❒ 6	❒ 6

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- ❒ 153 Recovery of Overpayment of Veteran's Benefits
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- ❒ 190 Other Contract
- ❒ 195 Contract Product Liability
- ❒ 196 Franchise

REAL PROPERTY
- ❒ 210 Land Condemnation
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- ❒ 230 Rent Lease & Ejectment
- ❒ 240 Torts to Land
- ❒ 245 Tort Product Liability
- ❒ 290 All Other Real Property

TORTS

PERSONAL INJURY
- ❒ 310 Airplane
- ❒ 315 Airplane Product Liability
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- ❒ 330 Federal Employers' Liability
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- ❒ 345 Marine Product Liability
- ❒ 350 Motor Vehicle
- ❒ 355 Motor Vehicle Product Liability
- ❒ 360 Other Personal Injury
- ❒ 362 Personal Injury - Medical Malpractice

PERSONAL INJURY
- ❒ 365 Personal Injury - Product Liability
- ❒ 367 Health Care/ Pharmaceutical Personal Injury Product Liability
- ❒ 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
- ❒ 370 Other Fraud
- ❒ 371 Truth in Lending
- ❒ 380 Other Personal Property Damage
- ❒ 385 Property Damage Product Liability

CIVIL RIGHTS
- ❒ 440 Other Civil Rights
- ❒ 441 Voting
- ❒ 442 Employment
- ❒ 443 Housing/ Accommodations
- ❒ 445 Amer. w/Disabilities - Employment
- ❒ 446 Amer. w/Disabilities - Other
- ❒ 448 Education

PRISONER PETITIONS

Habeas Corpus:
- ❒ 463 Alien Detainee
- ❒ 510 Motions to Vacate Sentence
- ❒ 530 General
- ❒ 535 Death Penalty

Other:
- ❒ 540 Mandamus & Other
- ❒ 550 Civil Rights
- ❒ 555 Prison Condition
- ❒ 560 Civil Detainee - Conditions of Confinement

FORFEITURE/PENALTY
- ❒ 625 Drug Related Seizure of Property 21 USC 881
- ❒ 690 Other

LABOR
- ❒ 710 Fair Labor Standards Act
- ❒ 720 Labor/Management Relations
- ❒ 740 Railway Labor Act
- ❒ 751 Family and Medical Leave Act
- ❒ 790 Other Labor Litigation
- ❒ 791 Employee Retirement Income Security Act

IMMIGRATION
- ❒ 462 Naturalization Application
- ❒ 465 Other Immigration Actions

BANKRUPTCY
- ❒ 422 Appeal 28 USC 158
- ❒ 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
- ❒ 820 Copyrights
- ☒ 830 Patent
- ❒ 835 Patent - Abbreviated New Drug Application
- ❒ 840 Trademark

SOCIAL SECURITY
- ❒ 861 HIA (1395ff)
- ❒ 862 Black Lung (923)
- ❒ 863 DIWC/DIWW (405(g))
- ❒ 864 SSID Title XVI
- ❒ 865 RSI (405(g))

FEDERAL TAX SUITS
- ❒ 870 Taxes (U.S. Plaintiff or Defendant)
- ❒ 871 IRS—Third Party 26 USC 7609

OTHER STATUTES
- ❒ 375 False Claims Act
- ❒ 376 Qui Tam (31 USC 3729(a))
- ❒ 400 State Reapportionment
- ❒ 410 Antitrust
- ❒ 430 Banks and Banking
- ❒ 450 Commerce
- ❒ 460 Deportation
- ❒ 470 Racketeer Influenced and Corrupt Organizations
- ❒ 480 Consumer Credit (15 USC 1681 or 1692)
- ❒ 485 Telephone Consumer Protection Act
- ❒ 490 Cable/Sat TV
- ❒ 850 Securities/Commodities/ Exchange
- ❒ 890 Other Statutory Actions
- ❒ 891 Agricultural Acts
- ❒ 893 Environmental Matters
- ❒ 895 Freedom of Information Act
- ❒ 896 Arbitration
- ❒ 899 Administrative Procedure Act/Review or Appeal of Agency Decision
- ❒ 950 Constitutionality of State Statutes

V. ORIGIN *(Place an "X" in One Box Only)*

☒ 1 Original Proceeding ❒ 2 Removed from State Court ❒ 3 Remanded from Appellate Court ❒ 4 Reinstated or Reopened ❒ 5 Transferred from Another District *(specify)* ❒ 6 Multidistrict Litigation - Transfer ❒ 8 Multidistrict Litigation - Direct File

VI. CAUSE OF ACTION

Cite the U.S. Civil Statute under which you are filing ***(Do not cite jurisdictional statutes unless diversity)***:
35 U.S.C. § 271 et seq.

Brief description of cause:
Patent Infringement

VII. REQUESTED IN COMPLAINT:

❒ CHECK IF THIS IS A **CLASS ACTION** UNDER RULE 23, F.R.Cv.P.

DEMAND $

CHECK YES only if demanded in complaint:
JURY DEMAND: ☒ Yes ❒ No

VIII. RELATED CASE(S) IF ANY

(See instructions): JUDGE ______ DOCKET NUMBER ______

DATE
8/10/2020

SIGNATURE OF ATTORNEY OF RECORD
/s/ Kelly E. Farnan

FOR OFFICE USE ONLY

RECEIPT # ______ AMOUNT ______ APPLYING IFP ______ JUDGE ______ MAG. JUDGE ______

INSTRUCTIONS FOR ATTORNEYS COMPLETING CIVIL COVER SHEET FORM JS 44

Authority For Civil Cover Sheet

The JS 44 civil cover sheet and the information contained herein neither replaces nor supplements the filings and service of pleading or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. Consequently, a civil cover sheet is submitted to the Clerk of Court for each civil complaint filed. The attorney filing a case should complete the form as follows:

I.(a) **Plaintiffs-Defendants.** Enter names (last, first, middle initial) of plaintiff and defendant. If the plaintiff or defendant is a government agency, use only the full name or standard abbreviations. If the plaintiff or defendant is an official within a government agency, identify first the agency and then the official, giving both name and title.

(b) **County of Residence.** For each civil case filed, except U.S. plaintiff cases, enter the name of the county where the first listed plaintiff resides at the time of filing. In U.S. plaintiff cases, enter the name of the county in which the first listed defendant resides at the time of filing. (NOTE: In land condemnation cases, the county of residence of the "defendant" is the location of the tract of land involved.)

(c) **Attorneys.** Enter the firm name, address, telephone number, and attorney of record. If there are several attorneys, list them on an attachment, noting in this section "(see attachment)".

II. **Jurisdiction.** The basis of jurisdiction is set forth under Rule 8(a), F.R.Cv.P., which requires that jurisdictions be shown in pleadings. Place an "X" in one of the boxes. If there is more than one basis of jurisdiction, precedence is given in the order shown below.
United States plaintiff. (1) Jurisdiction based on 28 U.S.C. 1345 and 1348. Suits by agencies and officers of the United States are included here.
United States defendant. (2) When the plaintiff is suing the United States, its officers or agencies, place an "X" in this box.
Federal question. (3) This refers to suits under 28 U.S.C. 1331, where jurisdiction arises under the Constitution of the United States, an amendment to the Constitution, an act of Congress or a treaty of the United States. In cases where the U.S. is a party, the U.S. plaintiff or defendant code takes precedence, and box 1 or 2 should be marked.
Diversity of citizenship. (4) This refers to suits under 28 U.S.C. 1332, where parties are citizens of different states. When Box 4 is checked, the citizenship of the different parties must be checked**.** (See Section III below**; NOTE: federal question actions take precedence over diversity cases.**)

III. **Residence (citizenship) of Principal Parties.** This section of the JS 44 is to be completed if diversity of citizenship was indicated above. Mark this section for each principal party.

IV. **Nature of Suit.** Place an "X" in the appropriate box. If there are multiple nature of suit codes associated with the case, pick the nature of suit code that is most applicable. Click here for: Nature of Suit Code Descriptions.

V. **Origin.** Place an "X" in one of the seven boxes.
Original Proceedings. (1) Cases which originate in the United States district courts.
Removed from State Court. (2) Proceedings initiated in state courts may be removed to the district courts under Title 28 U.S.C., Section 1441.
Remanded from Appellate Court. (3) Check this box for cases remanded to the district court for further action. Use the date of remand as the filing date.
Reinstated or Reopened. (4) Check this box for cases reinstated or reopened in the district court. Use the reopening date as the filing date.
Transferred from Another District. (5) For cases transferred under Title 28 U.S.C. Section 1404(a). Do not use this for within district transfers or multidistrict litigation transfers.
Multidistrict Litigation – Transfer. (6) Check this box when a multidistrict case is transferred into the district under authority of Title 28 U.S.C. Section 1407.
Multidistrict Litigation – Direct File. (8) Check this box when a multidistrict case is filed in the same district as the Master MDL docket.
PLEASE NOTE THAT THERE IS NOT AN ORIGIN CODE 7. Origin Code 7 was used for historical records and is no longer relevant due to changes in statue.

VI. **Cause of Action.** Report the civil statute directly related to the cause of action and give a brief description of the cause. **Do not cite jurisdictional statutes unless diversity.** Example: U.S. Civil Statute: 47 USC 553 Brief Description: Unauthorized reception of cable service

VII. **Requested in Complaint.** Class Action. Place an "X" in this box if you are filing a class action under Rule 23, F.R.Cv.P.
Demand. In this space enter the actual dollar amount being demanded or indicate other demand, such as a preliminary injunction.
Jury Demand. Check the appropriate box to indicate whether or not a jury is being demanded.

VIII. **Related Cases.** This section of the JS 44 is used to reference related pending cases, if any. If there are related pending cases, insert the docket numbers and the corresponding judge names for such cases.

Date and Attorney Signature. Date and sign the civil cover sheet.