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Gaya et al.

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(54) **FREQUENCY AND PATTERN RECONFIGURABLE SEGMENTED PATCH ANTENNA FOR WiMAX APPLICATIONS**

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(51) **Int. Cl.**
H01Q 9/04 (2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 9/0442*** (2013.01)

(58) **Field of Classification Search**
CPC .. H01Q 9/0442; H01Q 9/0407; H01Q 13/085; H01Q 13/10; H01Q 19/005; H01Q 21/065
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2007/0216594 A1* 9/2007 Uno H01Q 19/30 343/770
2019/0006766 A1 1/2019 Yonei et al.
2019/0260115 A1 8/2019 Tehran et al.
2021/0005975 A1* 1/2021 Hussain H01Q 21/28

FOREIGN PATENT DOCUMENTS

CN 102904022 A * 1/2013 .... H01Q 1/246
CN 105826667 A 8/2016
CN 110611163 A 12/2019
EP 2117078 A1 * 11/2009 .... H01Q 21/08

OTHER PUBLICATIONS

Panusa, et al. ; Quad Band H-slot Microstrip Patch Antenna for WiMAX Application ; International Journal of Computer Applications, vol. 103, No. 12 ; Oct. 2014 ; 3 Pages.

* cited by examiner

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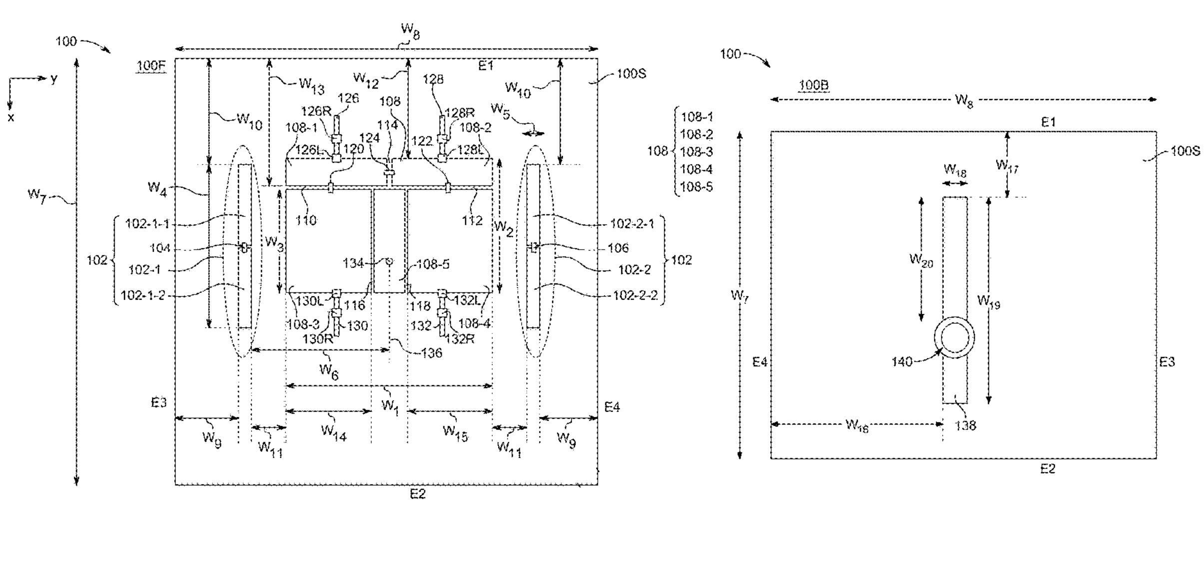
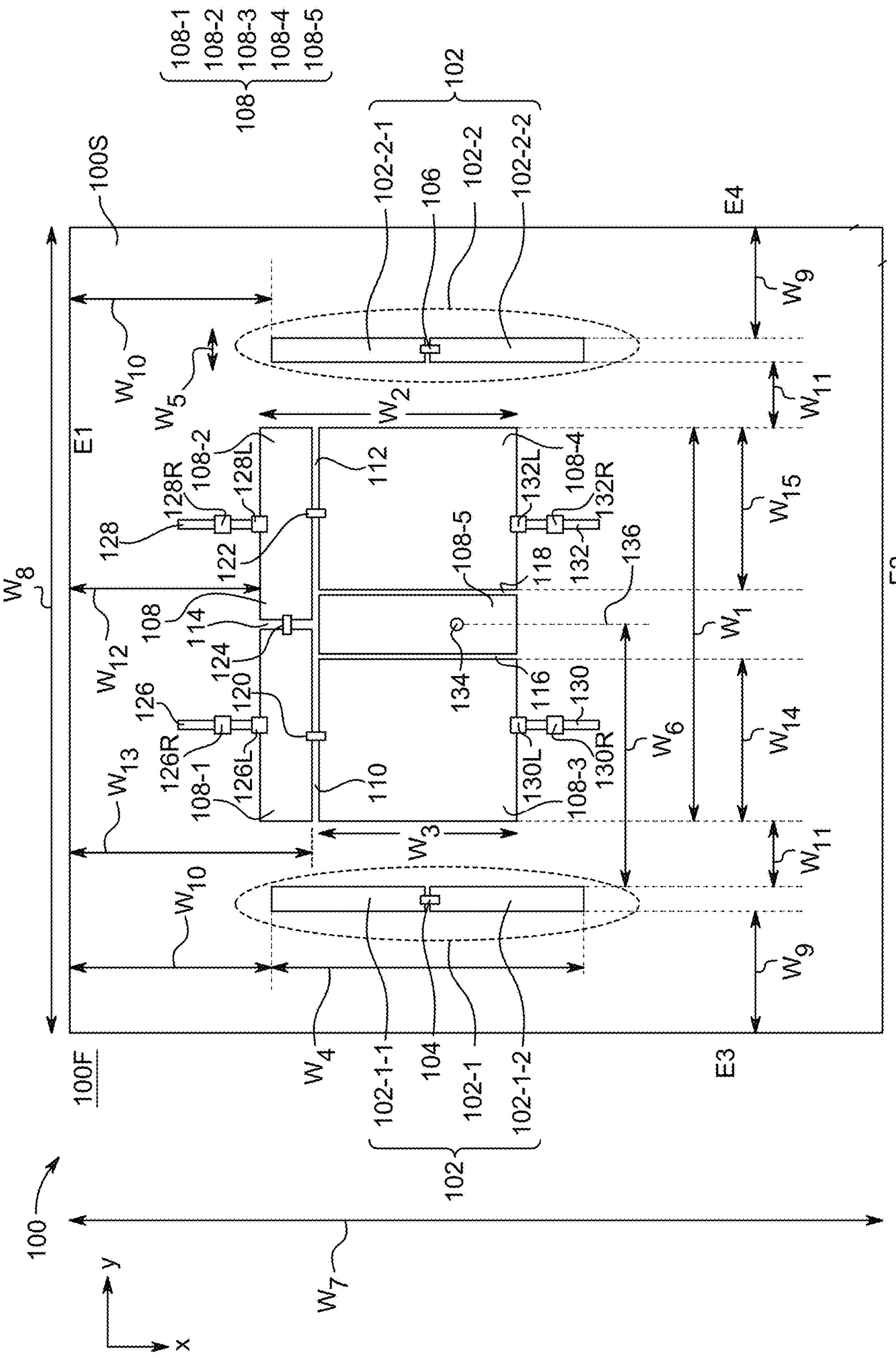
(57) **ABSTRACT**

A segmented patch antenna is described. The segmented patch antenna comprises two rectangular parasitic elements. Each parasitic element comprises an integrated diode. The segmented patch antenna further comprises a main rectangular patch segment. The main rectangular patch segment comprises 3 slots, 2 slits and 3 diodes, respectively. The segmented patch antenna is suitable for use in multiple frequencies between 4.1 GHz and 5.7 GHz inclusive and configurable to operate in 12 independent modes.

20 Claims, 17 Drawing Sheets

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100S
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102-2
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108-2
108-3
108-4
108-5
110
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114
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118
120
122
124
126
126L
126R
128
128L
128R
130
130L
130R
132
132L
132R
134
136
E1
E2
E3
E4
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
W11
W12
W13
W14
W15
x
y

FIG. 1A

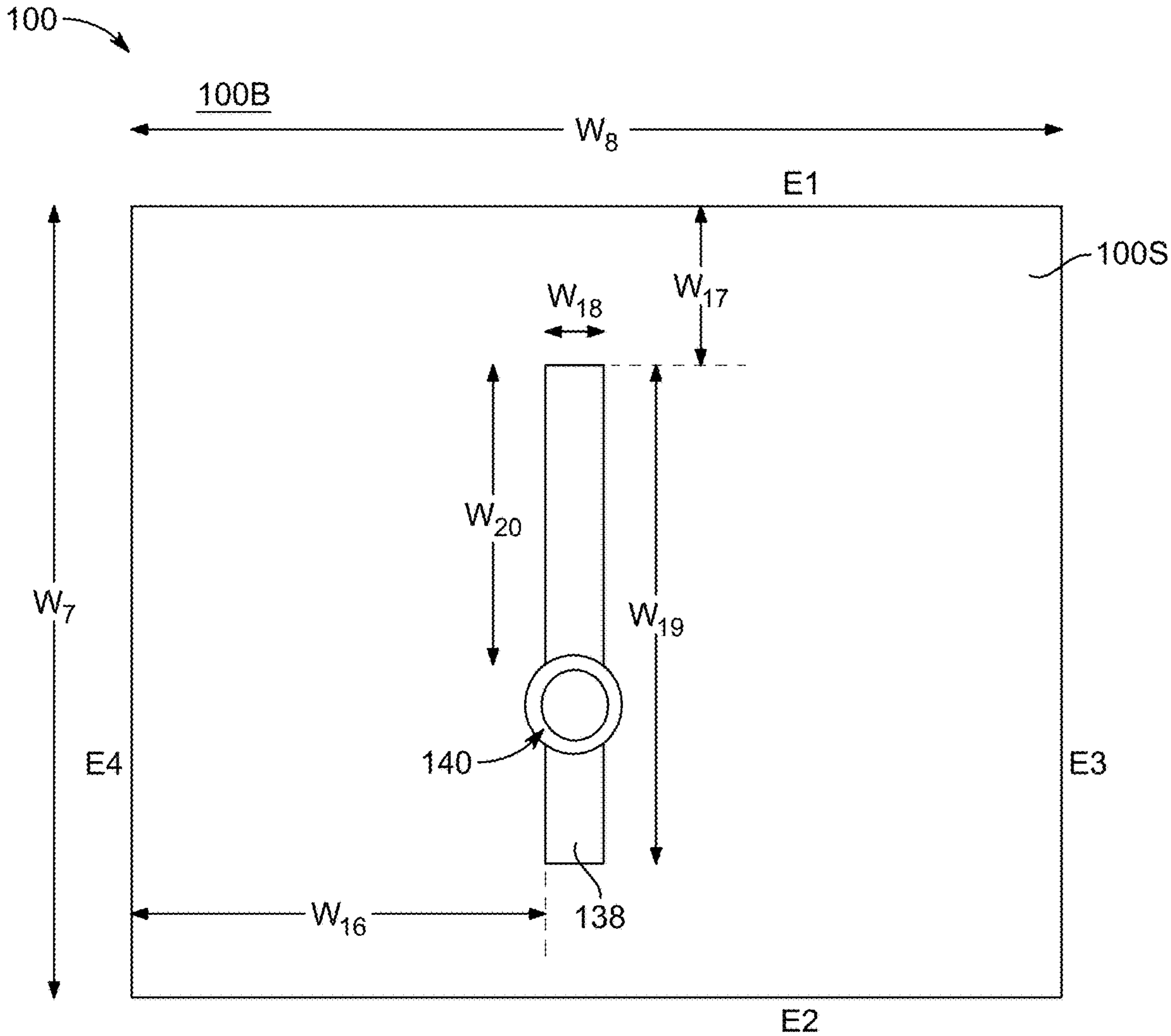
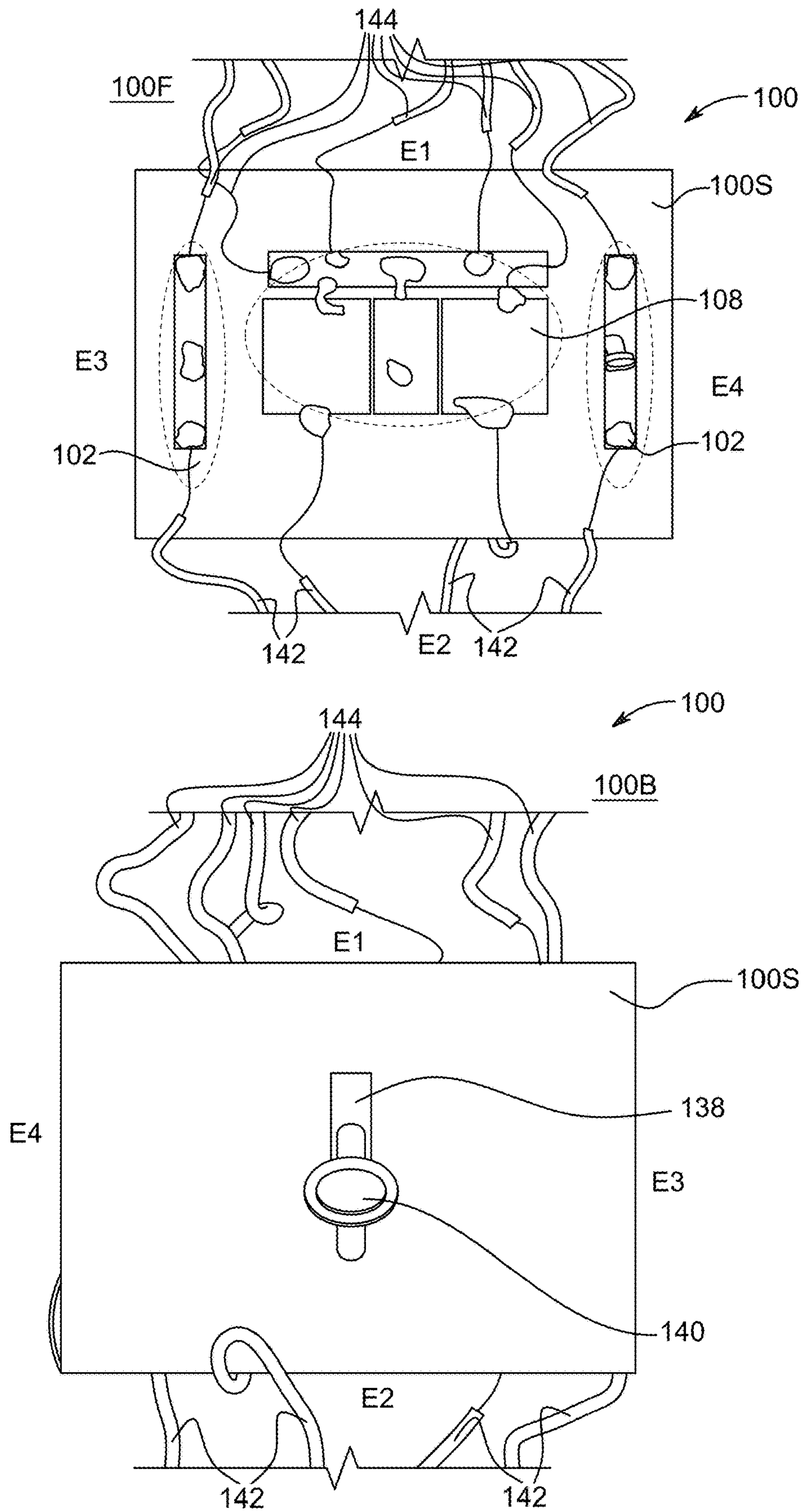


FIG. 1B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100F
100
E1
100S
108
E3
E4
102
102
142
E2
142
100
144
100B
E1
100S
138
E4
E3
140
E2
142
142

FIG. 1C

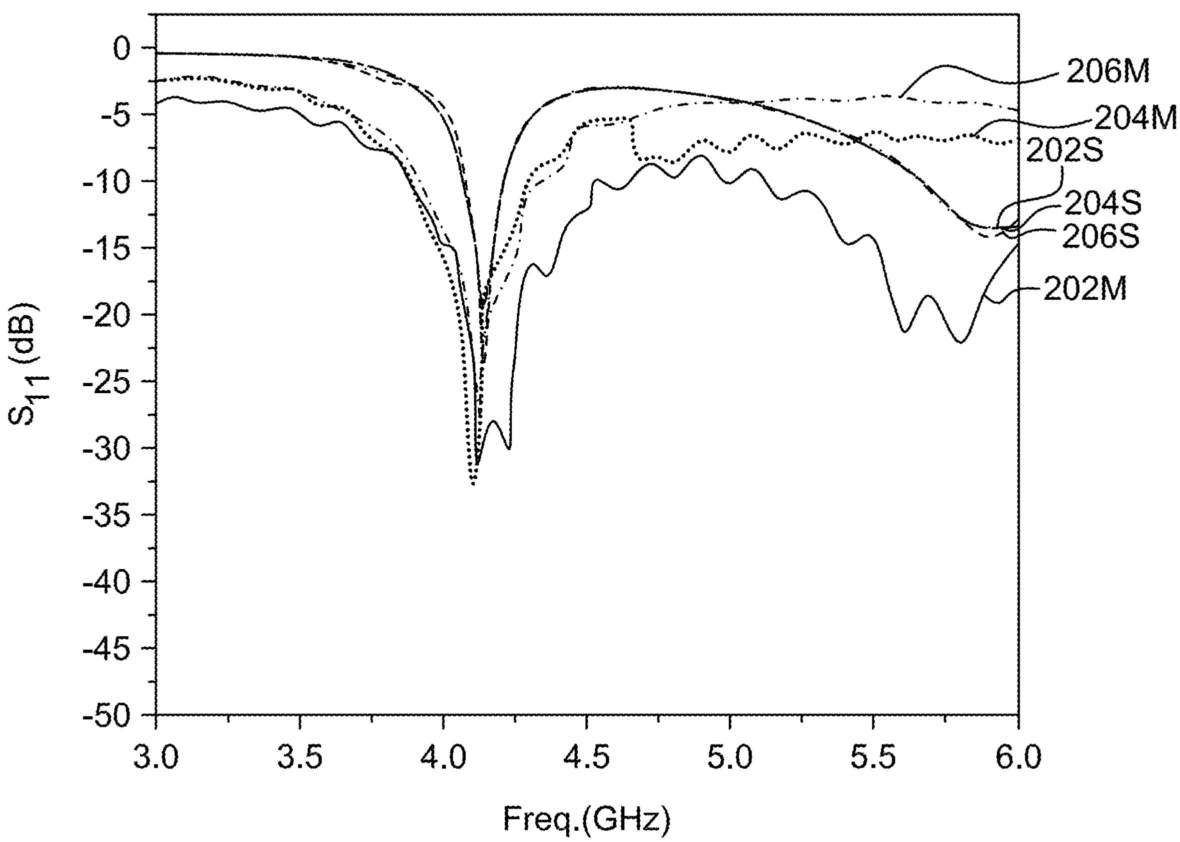

206M
204M
202S
204S
206S
202M
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
S_{11} (dB)
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Freq.(GHz)

FIG. 2A

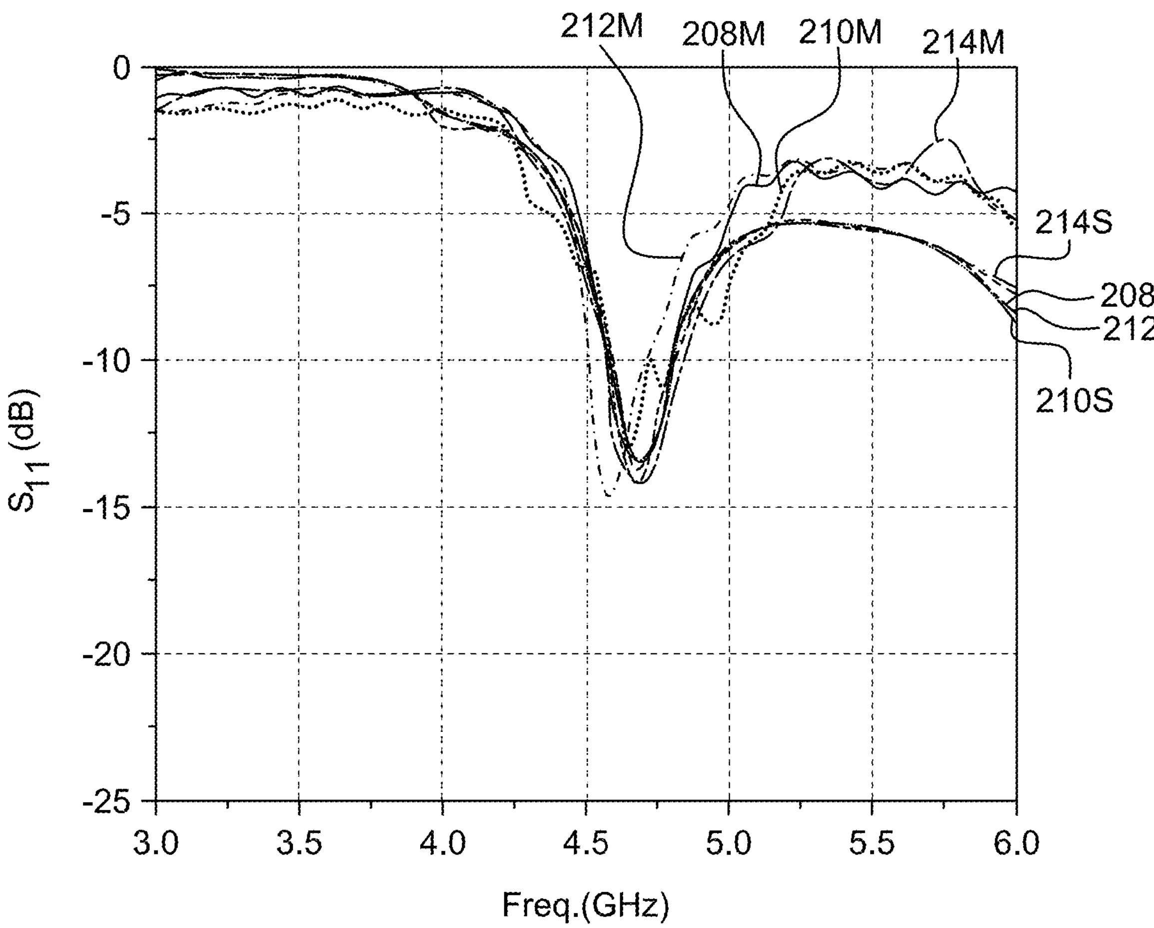
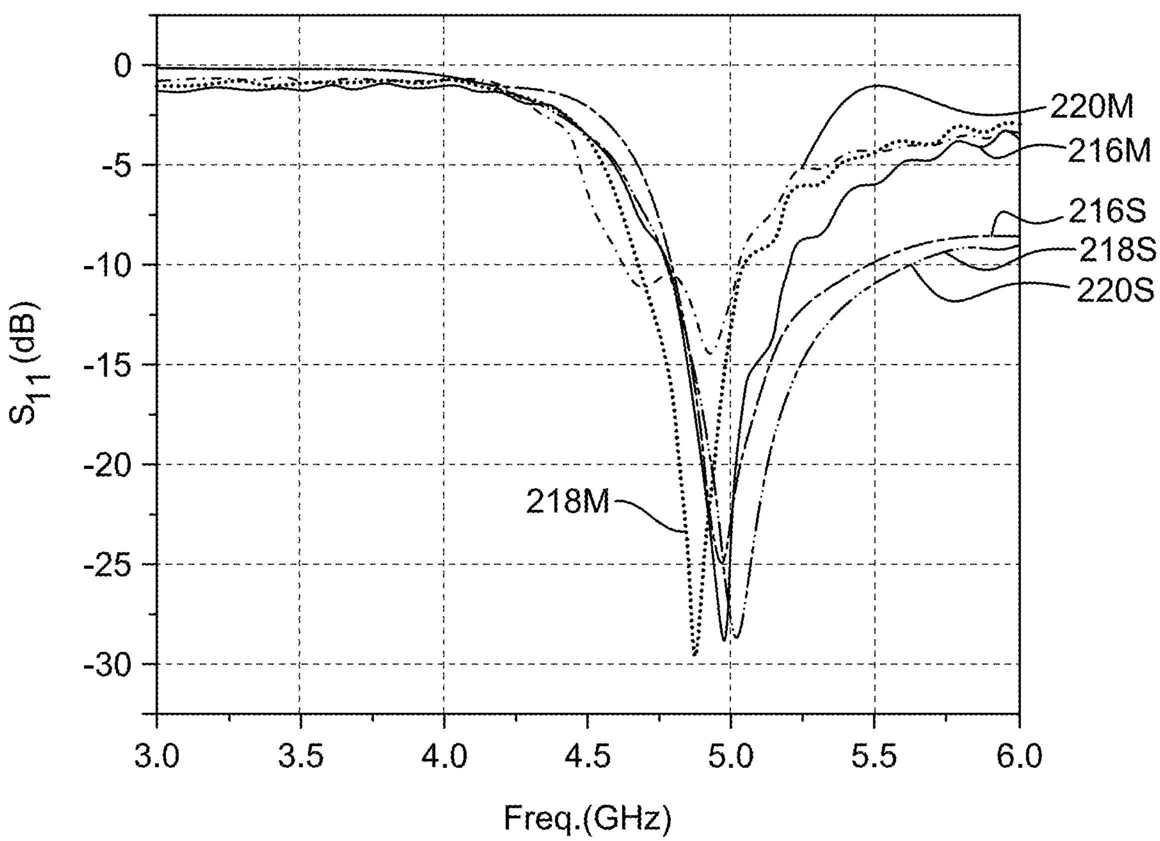
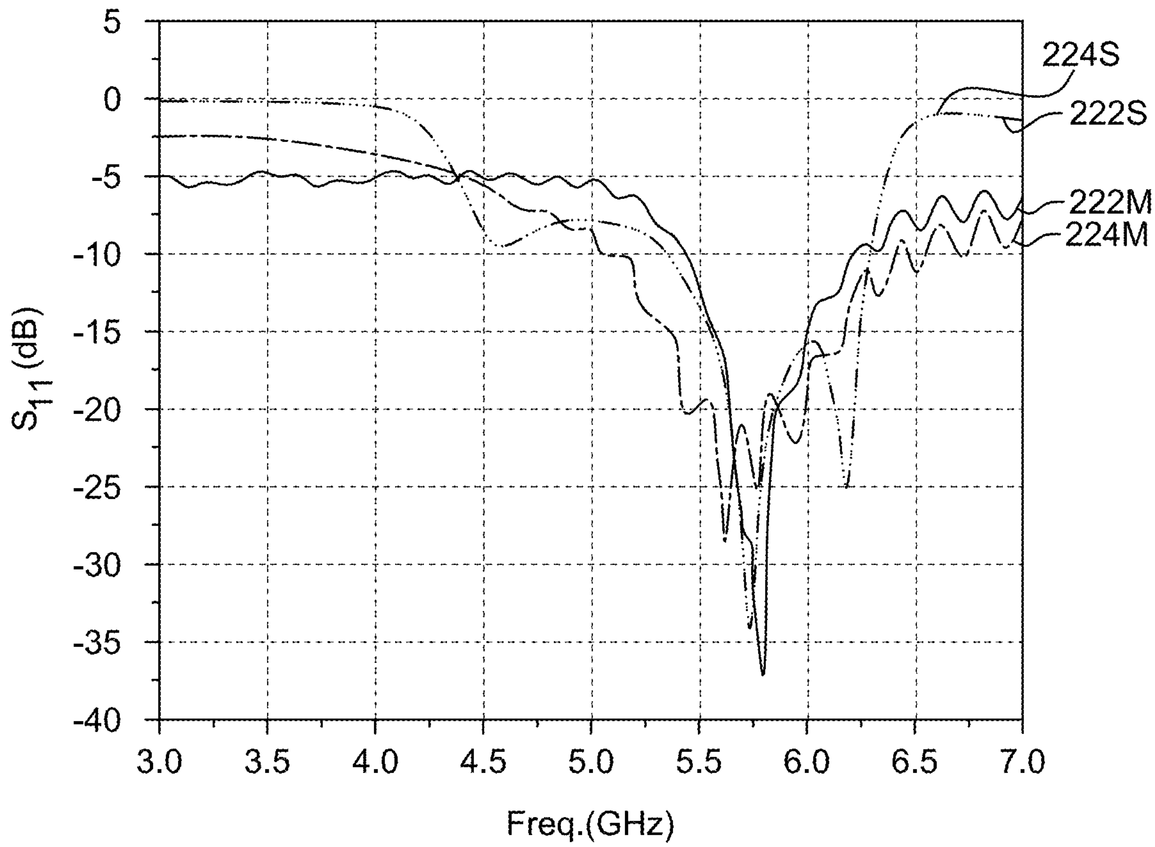

212M
208M
210M
214M
214S
208S
212S
210S
0
-5
-10
-15
-20
-25
S_{11} (dB)
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Freq.(GHz)

FIG. 2B



220M
216M
216S
218S
220S
218M
0
-5
-10
-15
-20
-25
-30
S11 (dB)
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Freq.(GHz)

FIG. 2C



5
0
-5
-10
-15
-20
-25
-30
-35
-40
S11 (dB)
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Freq.(GHz)
224S
222S
222M
224M

FIG. 2D

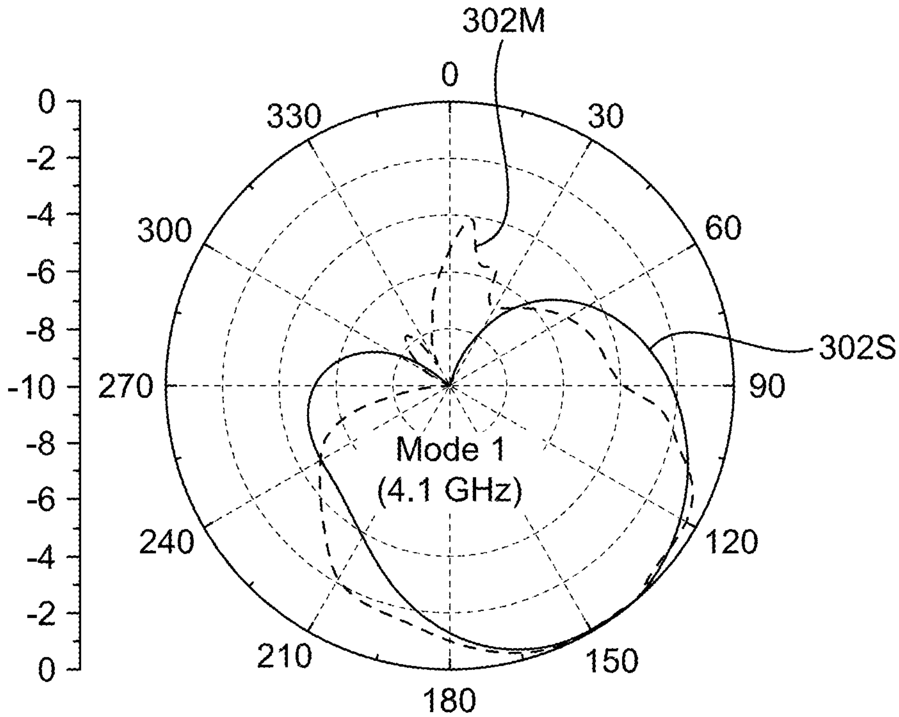

302M
302S
0
30
60
90
120
150
180
210
240
270
300
330
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
Mode 1
(4.1 GHz)

FIG. 3A

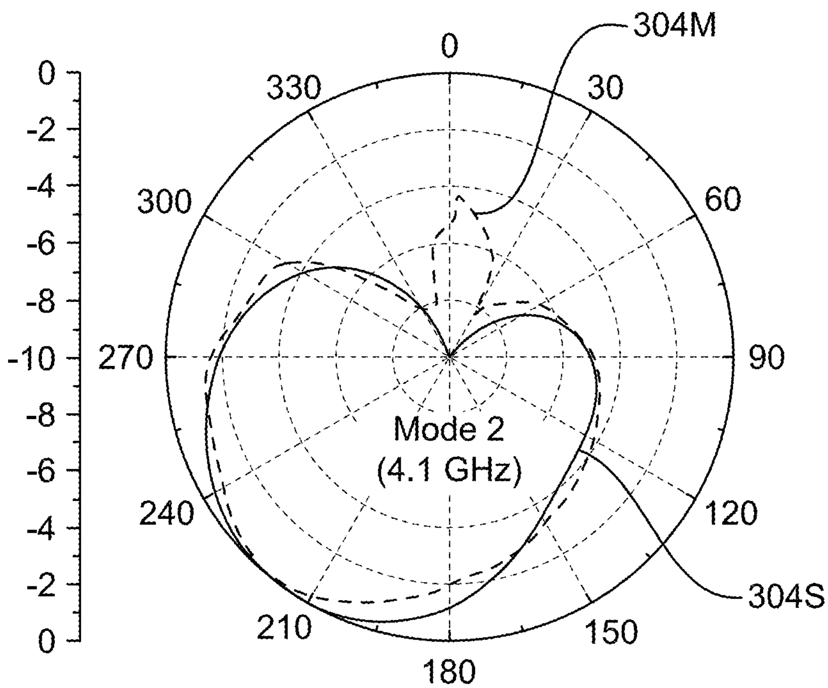

304M
304S
0
30
60
90
120
150
180
210
240
270
300
330
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
Mode 2
(4.1 GHz)

FIG. 3B

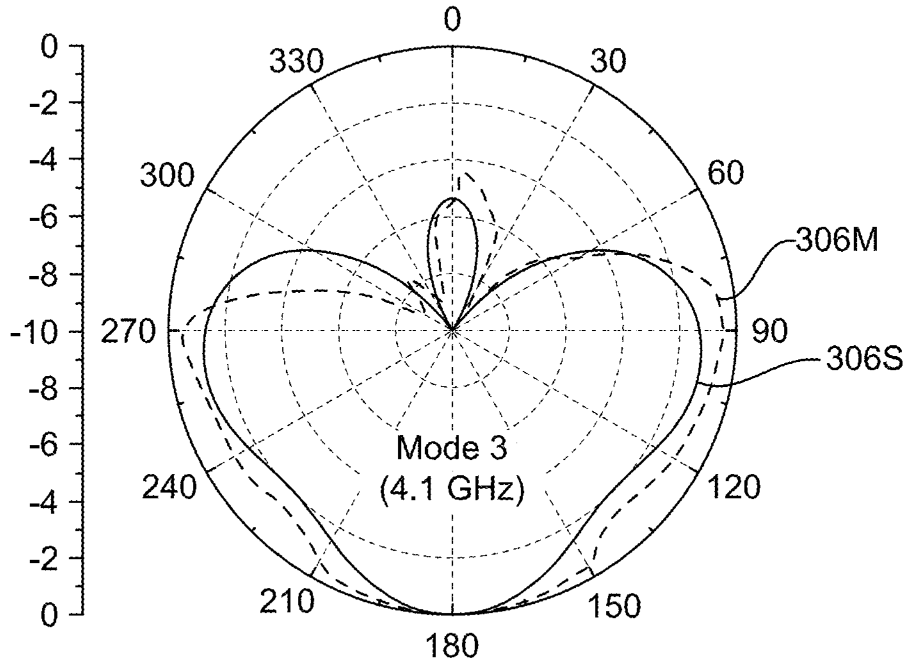

0
330
30
300
60
270
90
240
120
210
150
180
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
306M
306S
Mode 3
(4.1 GHz)

FIG. 3C

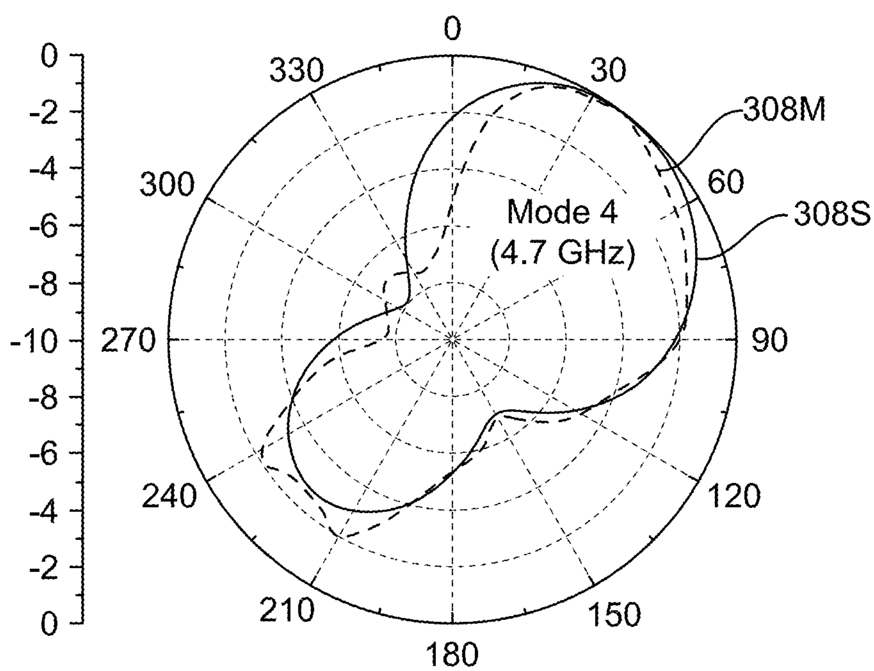

0
330
30
300
60
270
90
240
120
210
150
180
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
308M
308S
Mode 4
(4.7 GHz)

FIG. 3D

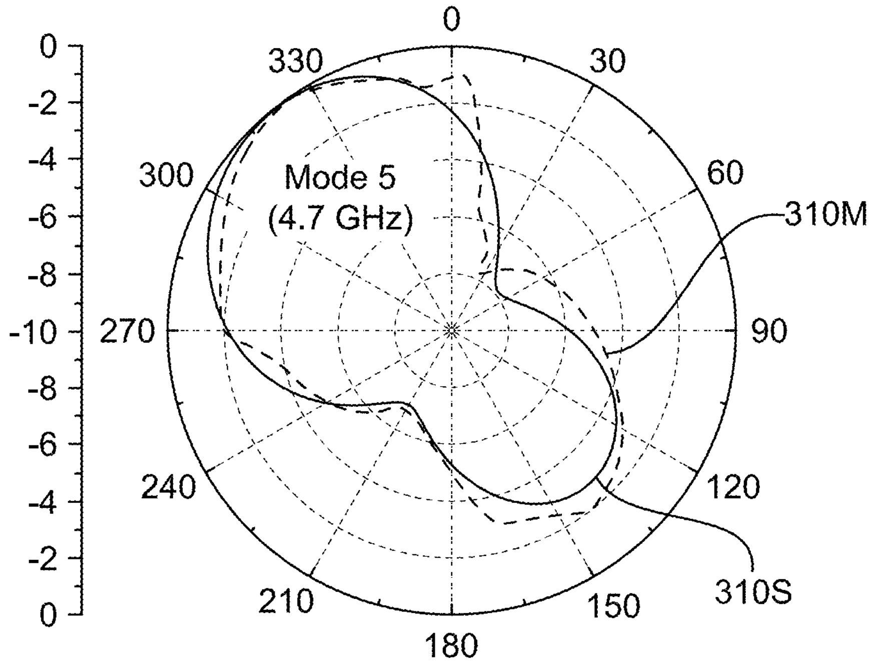

0
330
30
300
60
270
90
240
120
210
150
180
Mode 5
(4.7 GHz)
310M
310S
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0

FIG. 3E

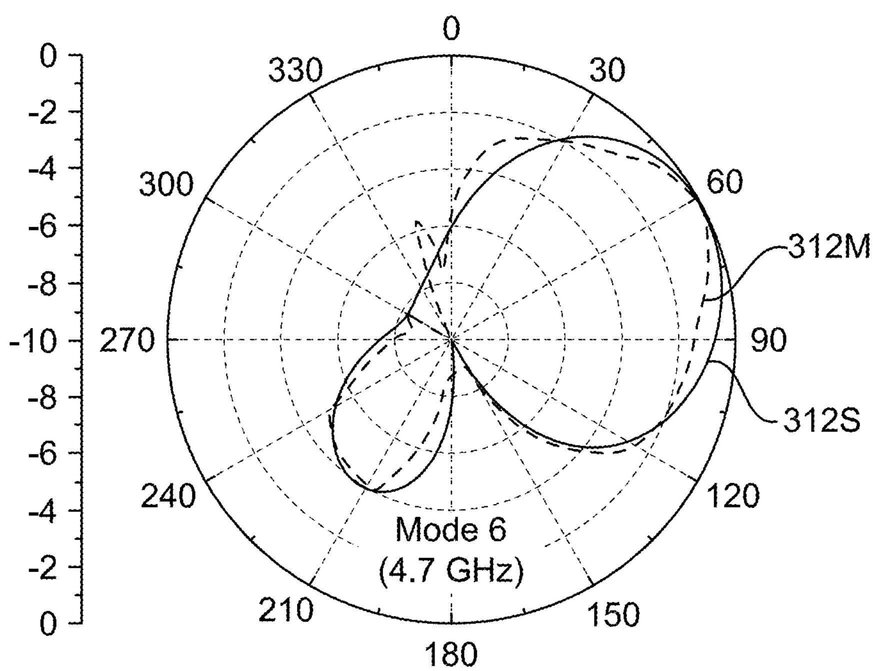

0
330
30
300
60
270
90
240
120
210
150
180
Mode 6
(4.7 GHz)
312M
312S
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0

FIG. 3F

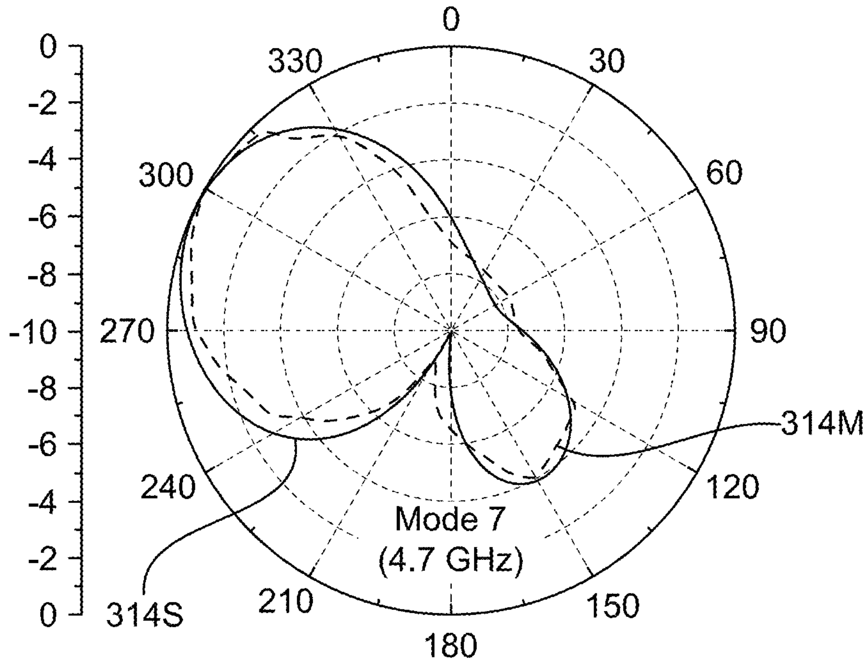

0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
0
30
60
90
120
150
180
210
240
270
300
330
Mode 7
(4.7 GHz)
314M
314S

FIG. 3G

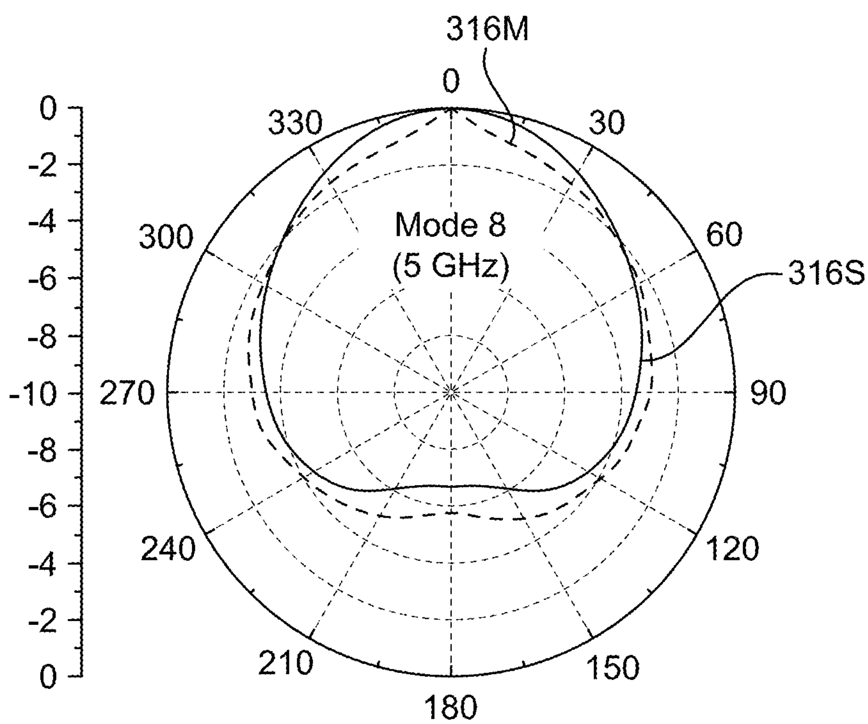
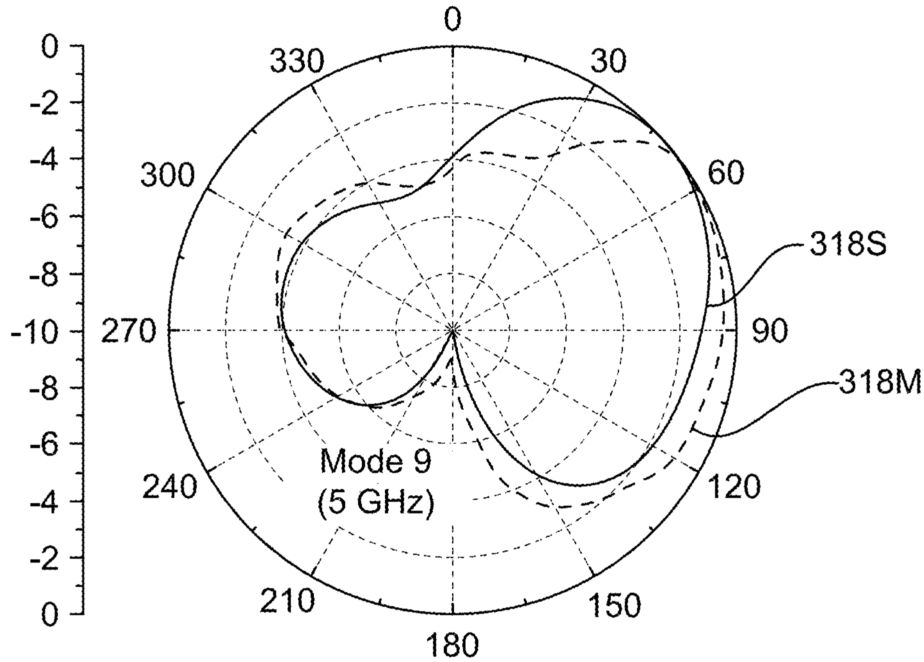
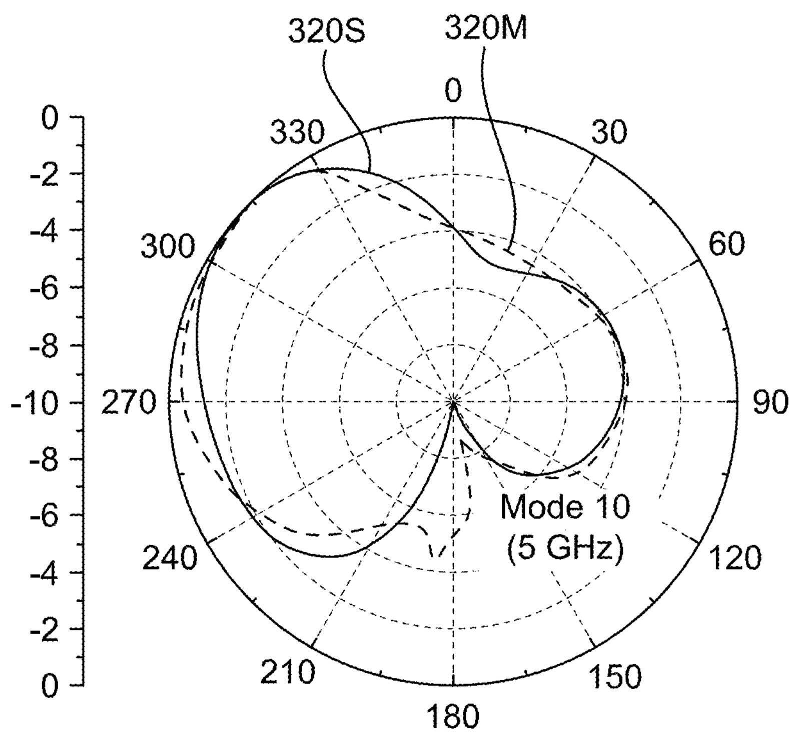

316M
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
0
30
60
90
120
150
180
210
240
270
300
330
Mode 8
(5 GHz)
316S

FIG. 3H



0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
0
30
60
90
120
150
180
210
240
270
300
330
318S
318M
Mode 9
(5 GHz)

FIG. 3I



320S
320M
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
0
30
60
90
120
150
180
210
240
270
300
330
Mode 10
(5 GHz)

FIG. 3J

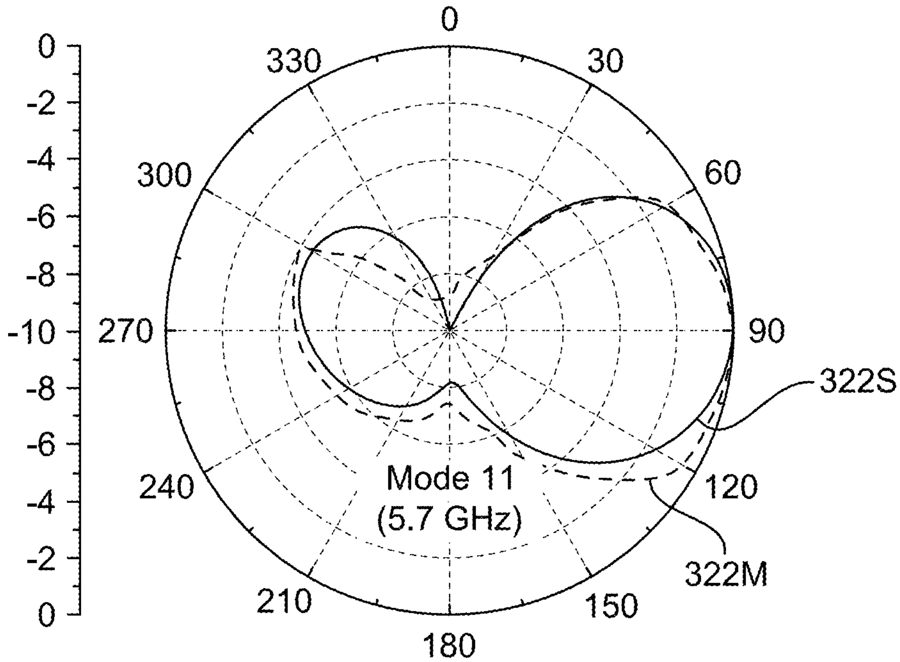

0
330
30
300
60
270
90
240
120
210
150
180
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
Mode 11
(5.7 GHz)
322S
322M

FIG. 3K

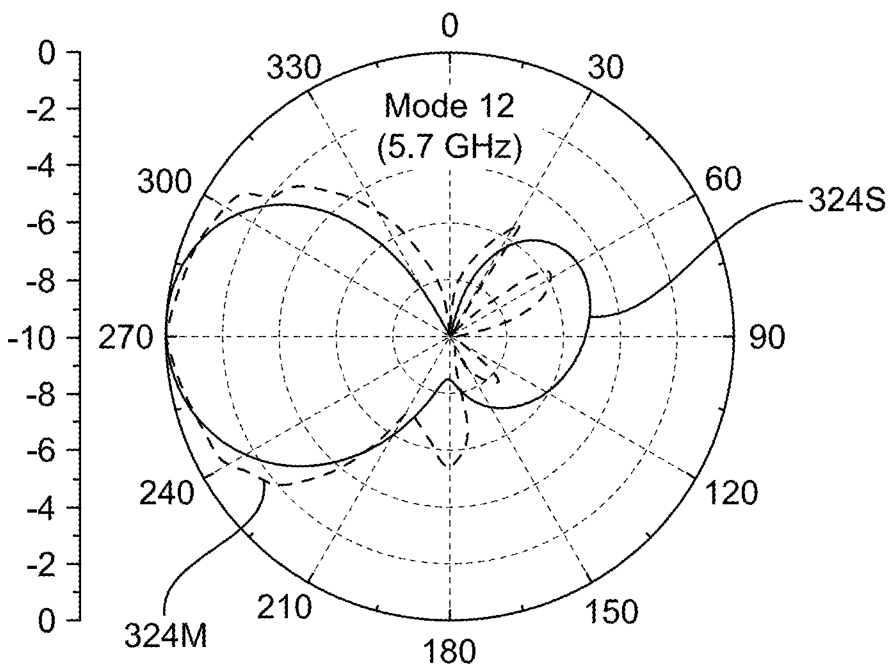

0
330
30
300
60
270
90
240
120
210
150
180
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
Mode 12
(5.7 GHz)
324S
324M

FIG. 3L

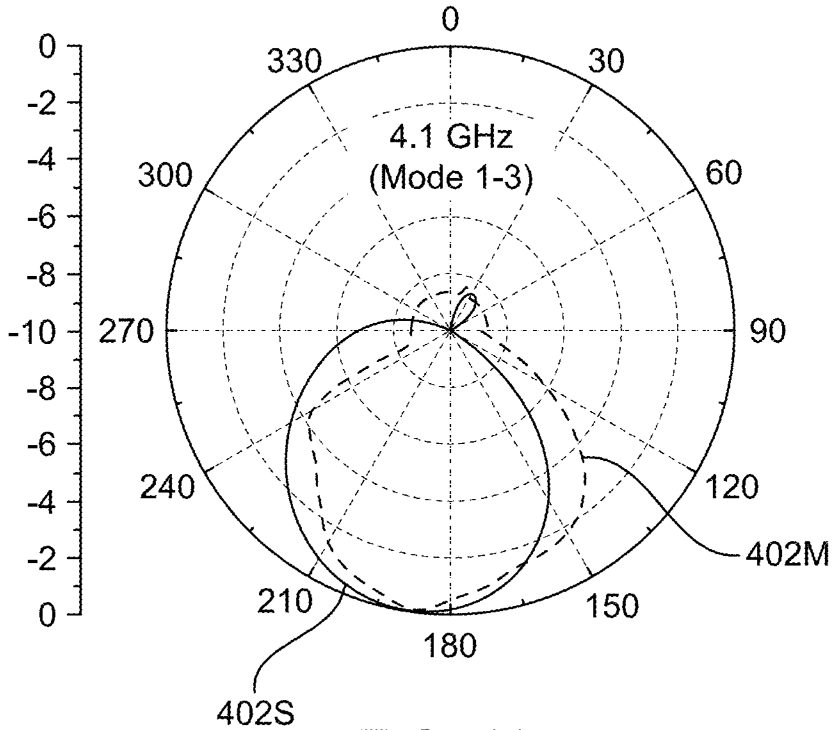

0
330
30
300
60
270
90
240
120
210
150
180
4.1 GHz
(Mode 1-3)
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
402M
402S

FIG. 4A

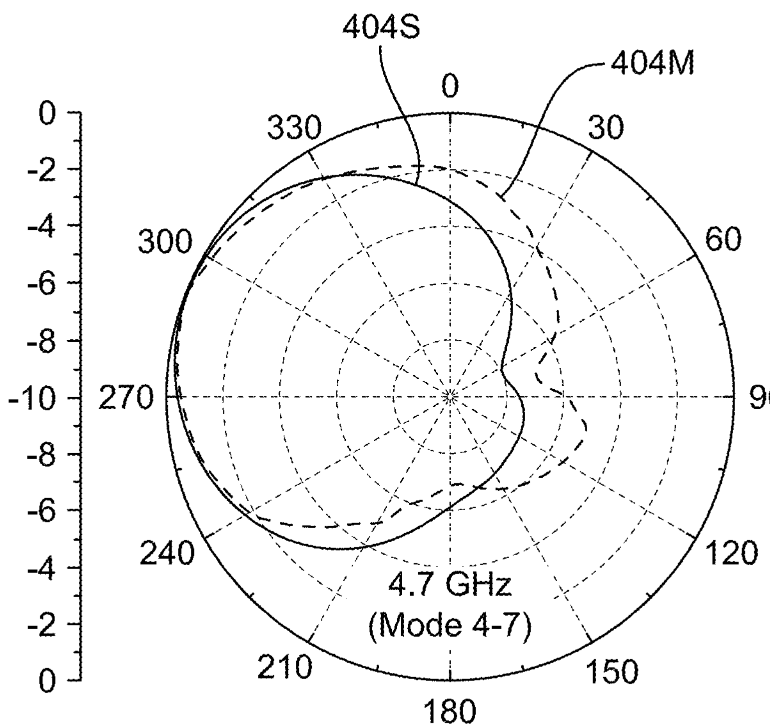

404S
404M
0
330
30
300
60
270
90
240
120
210
150
180
4.7 GHz
(Mode 4-7)
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0

FIG. 4B

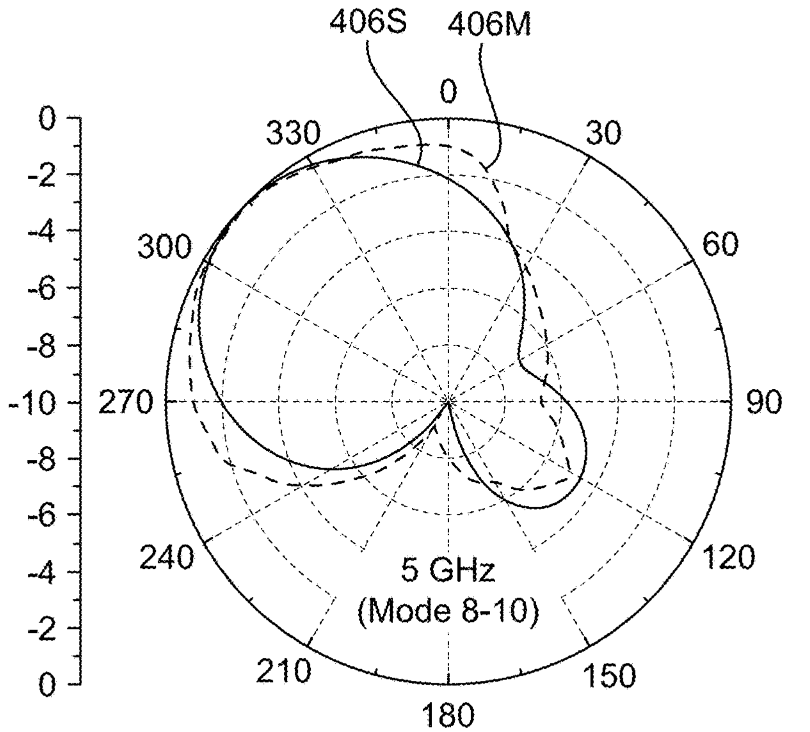

406S
406M
0
330
30
300
60
270
90
240
120
210
150
180
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0
5 GHz
(Mode 8-10)

FIG. 4C

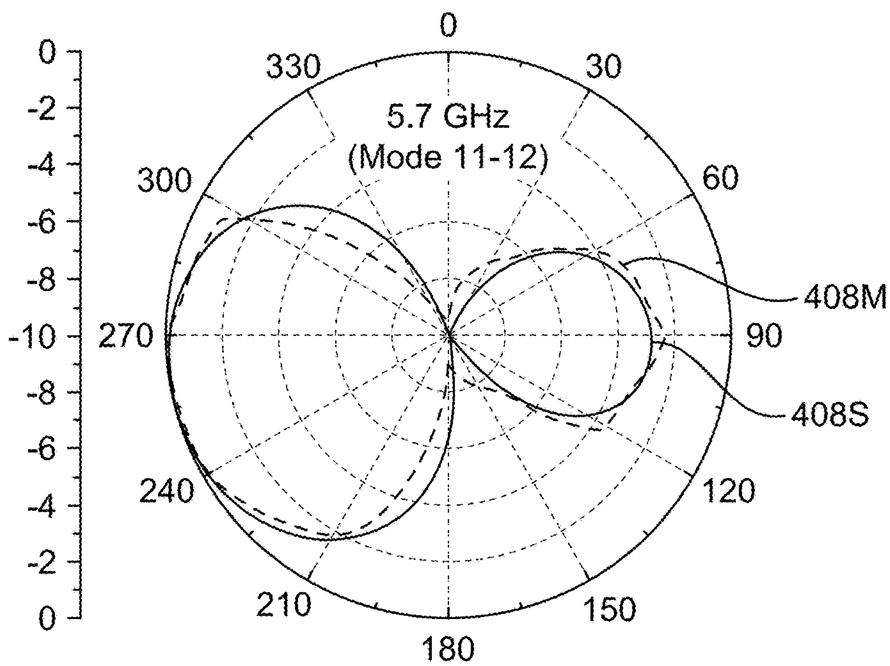

0
330
30
300
60
270
90
240
120
210
150
180
5.7 GHz
(Mode 11-12)
408M
408S
0
-2
-4
-6
-8
-10
-8
-6
-4
-2
0

FIG. 4D

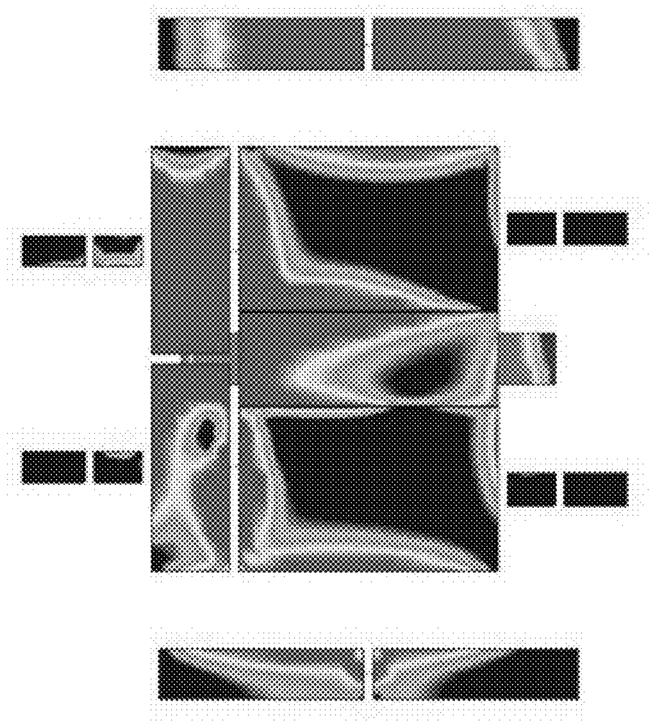
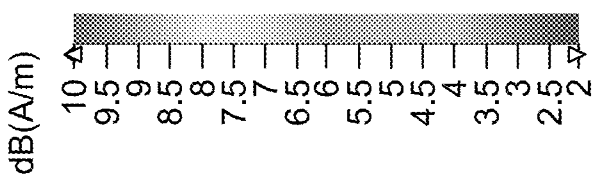


FIG. 5B



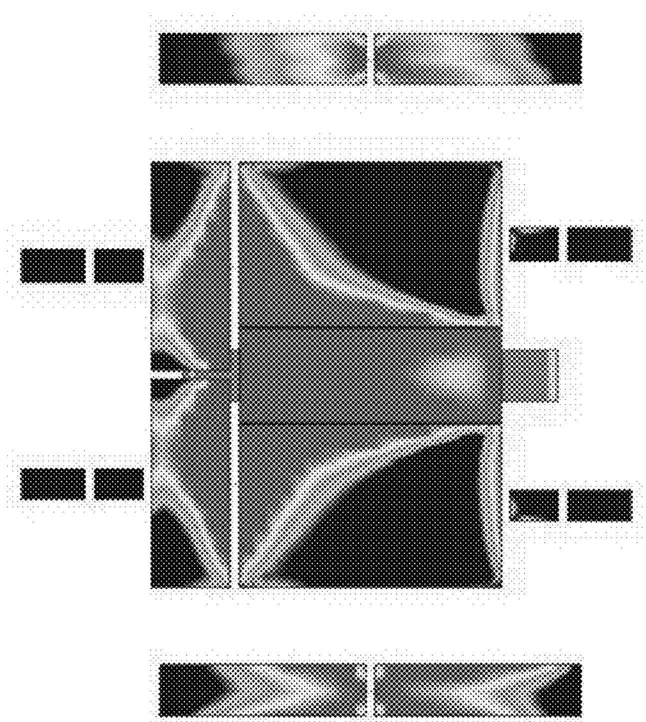


FIG. 5A

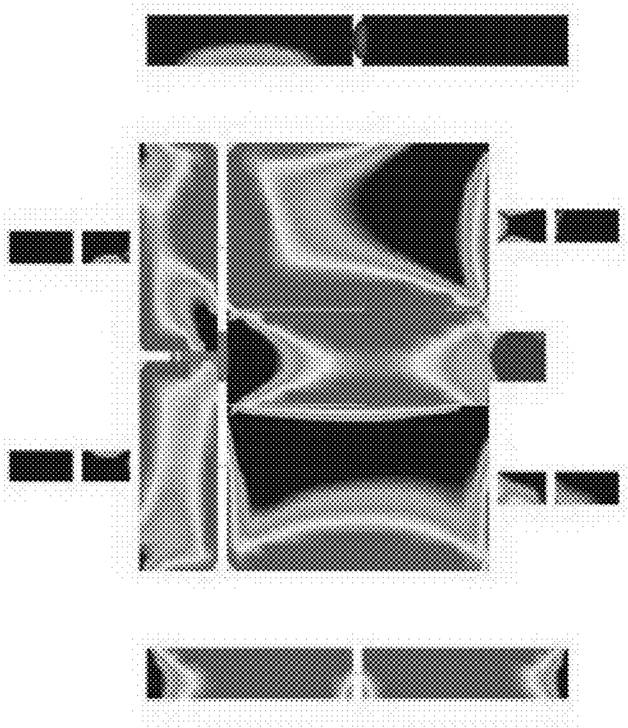
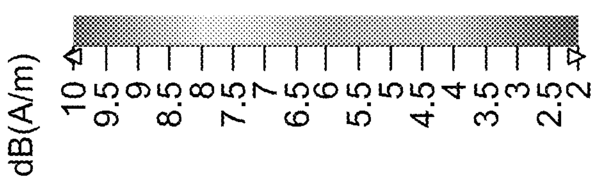


FIG. 5D



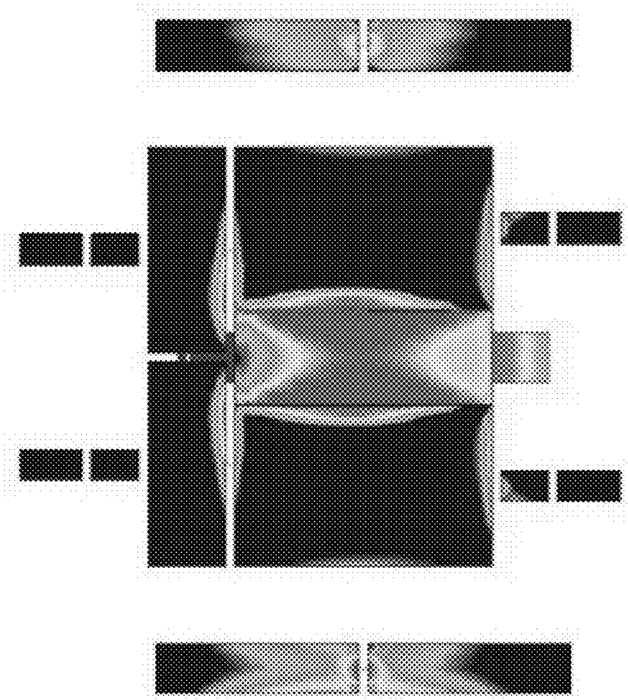


FIG. 5C

FREQUENCY AND PATTERN RECONFIGURABLE SEGMENTED PATCH ANTENNA FOR WiMAX APPLICATIONS

BACKGROUND

Technical Field

The present disclosure is directed to a reconfigurable patch antenna, and more particularly relates to a frequency and pattern reconfigurable segmented patch antenna for WiMAX applications.

Description of Related Art

The "background" description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description which may not otherwise qualify as prior art at the time of filing, are neither expressly or impliedly admitted as prior art against the present invention.

WiMAX, also known as worldwide interoperability for microwave access, is a broadband wireless technology that is effective for providing wireless data transmission over long distances in a variety of ways, for example, from point-to-point link to full mobile cellular type access. WiMAX can provide high-speed data communication with an ability to maintain dedicated links, broadband connectivity and VoIP services. WiMAX is based on a broadband wireless access standard set by the Institute of Electrical and Electronics Engineers (IEEE 802.16) that acts as an alternative to cable and DSL. WiMAX is increasingly appearing as a promising option of wireless replacement for wired broadband. Range is important factor for WiMAX technology because a single WiMAX tower can connect to other WiMAX towers through a line-of-sight microwave link.

Patch antennas have the capability to reconfigure frequency bands and radiation patterns and have attracted interest for wireless applications. Patch antennas are useful for operating in more than one frequency band. In a patch antenna, frequency reconfigurability is achieved by varying the length of the antenna using a PIN diode. Also, radiation pattern reconfigurability is achieved with a use of parasitic elements.

Patch antennas for frequency and radiation pattern reconfigurability have been reported in the literature. For example, a rhombus-shaped patch radiator with integrated 6 PIN diodes was shown to provide 5.2 GHz and 8.8 GHZ at two different radiating patterns, i.e., −45°/45° at 2 modes with 2 bands [see Y. P. Selvam, L. Elumalai, M. G. N. Alsath, M. Kanagasabai, S. Subbaraj, and S. Kingsly, "Novel frequency- and pattern-reconfigurable rhombic patch antenna with switchable polarization," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 1639-1642, 2017]. Here, the mode refers to the direction the antenna could direct its beam or radiation pattern. In another example, a patch antenna includes 5 PIN diodes placed to realize two frequency bands operating at 2.4 and 5.4 GHz at two different beam patterns, i.e., 2 modes with 2 bands [see P. K. Li, Z. H. Shao, Q. Wang, and Y. J. Cheng, "Frequency- and pattern reconfigurable antenna for multistandard wireless applications," IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 333-336, 2015]. In another example, a patch antenna includes 8 PIN diodes loaded on a radiating patch to achieve 1.9 and 2.4 GHz resonance, with 2 omnidirectional switching beams at each resonance frequency, i.e., 4 modes

with 2 bands, wherein the frequency and pattern reconfigurability is achieved by two shorting screws placed symmetrically and asymmetrically to modify the radiating elements [see S. Y. Z. Zhu, P. Wang and P. Gao, "A flexible frequency and pattern reconfigurable antenna for wireless systems," Progress In Electromagnetics Research Letters, vol. 76, pp. 63-70, 2018]. Other patch antenna configurations have been reported in the art. For example, a microstrip patch antenna with 2 varactor diodes achieves 3 resonant frequency bands from 2.68-3.51 GHz with a broadside and monopole-like radiation patterns, that is, 2 modes with 3 bands. [see N. Nguyen-Trong, L. Hall, and C. Fumeaux, "A frequency- and pattern reconfigurable center-shorted microstrip antenna," IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 1955-1958, 2016]. In another example, the removal of two slits from a rectangular patch antenna has been reported in the art that couples with 4 PIN diodes. The antenna permits 4 operating frequencies at 4.5, 4.8, 5.2, 5.8 GHZ, and 3 different radiation pattern, i.e., 3 modes with 4 bands. [see Y. P. Selvam, M. Kanagasabai, M. G. N. Alsath, S. Velan, S. Kingsly, S. Subbaraj, Y. V. Ramana Rao, R. Srinivasan, A. K. Varadhan, and M. Karuppiah, "A low-profile frequency- and pattern-reconfigurable antenna," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 3047-3050, 2017.] In another example, a patch antenna provides 6 different radiation patterns at frequency bands of 2.6 GHz and 3.5 GHz by using 6 pin diodes over an aperture-coupled stacked microstrip array antenna. The antenna provides 6 mode with 2 bands. Frequency and radiation pattern reconfigurability was achieved by changing the lengths of the feedline and radiating elements. [see N. Ramli, M. T. Ali, M. T. Islam, A. L. Yusof, and S. Muhamud-Kayat, "Aperture-coupled frequency and patterns reconfigurable microstrip stacked array antenna," IEEE Transactions on Antennas and Propagation, vol. 63, no. 3, pp. 1067-1074, March 2015]. In another example, 2 varactor diodes are integrated with loaded stubs on 2 patch antenna array antennas has also been disclosed in the art. By changing the bias voltages of the varactor diodes, 3 tuning range of 2.15, 2.27, 2.38 GHz and also 3 radiation pattern angles at each tuning frequency were achieved, thus making the antenna work in 9 different modes with 3 frequency band. [see S. N. M. Zainarry, N. Nguyen-Trong, and C. Fumeaux, "A frequency and pattern-reconfigurable two-element array antenna," IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 4, pp. 617-620, April 2018].

Each of the aforementioned antennas suffer from one or more drawbacks hindering their adoption. For example, aforementioned patch antennas designs could achieve up to 9 operational modes with 3 frequency bands with the help of 2 switches having small or no differences in the resonance frequencies, thus making the frequencies not completely independent and less operationally useful. Also, some designs in which high frequency reconfigurabily is achieved, that is, more number of supported frequency bands, the number of modes supported by the antenna are less, thus limiting the radiation pattern of the antenna. Also, most conventional patch antennas include a high number of switches to achieve high frequency reconfigurability which in turn impacts the cost of the antenna. Conventional patch antennas are large and when configured to smaller size provide 7 or less operational modes. If the number of switches is increased to achieve high frequency reconfigurability, the antenna may fail to provide a greater number of radiation patterns or modes of operation.

Therefore, it is an object of the present disclosure to provide a highly compact patch antenna design that is capable of providing high frequency reconfigurability, that is, more resonating bands along with high number of operational modes and corresponding radiation patterns, with a decreased number of switches that is useful in WiMax applications in multipath environment.

SUMMARY

In an exemplary embodiment, a frequency and pattern reconfigurable segmented patch antenna for WiMAX applications is described herein. The segmented patch antenna includes two rectangular parasitic elements. Each parasitic element comprises an integrated diode. The segmented patch antenna includes a main rectangular patch segment. The main rectangular patch segment includes 3 slots, 2 slits and 3 diodes. The segmented patch antenna is suitable for use in multiple frequencies between 4.1 GHz and 5.7 GHz inclusive and configurable to operate in 12 independent modes.

In another exemplary embodiment, the segmented patch antenna further includes 4 biasing lines having length and width of each biasing line between 7 and 8 mm and between 1 and 3 mm, respectively.

In another exemplary embodiment, each of the 4 biasing lines further include a limiting resistor and a choke inductor.

In another exemplary embodiment, the main rectangular patch segment has one edge of length between 26 and 28 mm and a second edge of length between 21 and 23 mm.

In another exemplary embodiment, the slots are of width 0.6 mm (±0.1 mm). and the slits are no larger than 0.1 (±0.01) mm.

In another exemplary embodiment, each of the two rectangular parasitic elements have one dimension between 26 and 28 mm and another dimension between 2.5 and 3.5 mm.

In another exemplary embodiment, the rectangular parasitic elements are located at one quarter wavelength from the center on each side of the main patch segment wherein an average of quarter wavelengths of each frequency is used to calculate the location of the parasitic elements.

In another exemplary embodiment, the rectangular parasitic elements are located between 18 and 19 mm from the center of the main rectangular patch segment.

In another exemplary embodiment, each of the two rectangular parasitic elements are separated into two sections by pin diodes D1 and D2.

In another exemplary embodiment, a length of the rectangular parasitic elements is configurable by turning on or off the diodes.

In another exemplary embodiment, the parasitic elements are reconfigurable to act as a reflector or as a director according to the settings of the diodes and the Yagi-Uda principle. [see Y. Mushiake, "A theoretical analysis of the multi-element end-fire array with particular reference to the yagi-uda antenna," IRE Transactions on Antennas and Propagation, vol, 4, no. 3, pp. 441-444, July 1956 for more details of the Yagi-Uda principle]

In another exemplary embodiment, three pin diodes D3, D4 and D5 are integrated on the 3 slots of the main rectangular patch segment in order to vary the length of the main rectangular patch thereby varying the length of the resonance frequency of the segmented patch antenna.

In another exemplary embodiment, the segmented patch antenna supports at least 4 frequency bands.

In another exemplary embodiment, the segmented patch antenna is reconfigurable to 12 independent modes.

In another exemplary embodiment, the segmented patch antenna has efficiency of at least 92% while configured to transmit at 5 GHz.

In another exemplary embodiment, the segmented patch antenna operates with average gain of 3 dBi throughout the 12 independent modes.

In another exemplary embodiment, the segmented patch antenna operates with average efficiency of 77%, throughout the 12 independent modes.

In another exemplary embodiment, a back view of the segmented patch antenna includes a partial ground with one dimension between 2.5 and 3.5 mm and a second dimension between 22 and 25 mm.

In another exemplary embodiment, the back view of the segmented patch antenna further includes a coaxial feed that is placed between 10 and 12 mm from a top of the partial ground.

In another exemplary embodiment, the area of the segmented patch antenna is less than 55×55 mm^2.

The foregoing general description of the illustrative embodiments and the following detailed description thereof are merely exemplary aspects of the teachings of this disclosure and are not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of this disclosure and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. **1**A illustrates a front side of a frequency and pattern reconfigurable segmented patch antenna for WiMax applications, according to certain embodiments.

FIG. **1**B illustrates a back side of a frequency and pattern reconfigurable segmented patch antenna, according to certain embodiments.

FIG. **1**C illustrates a prototype model of the frequency and pattern reconfigurable segmented patch antenna including a front side and a back side, according to certain embodiments.

FIG. **2**A illustrates plurality of curves for simulated as well as measured reflection coefficients for a first, second and a third independent operational modes of the frequency and pattern reconfigurable segmented patch antenna, according to certain embodiments.

FIG. **2**B illustrates plurality of curves for a simulated as well as measured reflection coefficients for a fourth, fifth, sixth and a seventh independent operational modes of the frequency and pattern reconfigurable segmented patch antenna, according to certain embodiments.

FIG. **2**C illustrates plurality of curves for simulated as well as measured reflection coefficients for an eighth, ninth and a tenth independent operational modes of the frequency and pattern reconfigurable segmented patch antenna, according to certain embodiments.

FIG. **2**D illustrates plurality of curves for a simulated as well as measured reflection coefficients for an eleventh and twelfth independent operational modes of the frequency and pattern reconfigurable segmented patch antenna, according to certain embodiments.

FIG. **3**A is a graph illustrating simulated radiation pattern and a measured radiation pattern at a first mode, according to certain embodiments.

FIG. **3**B is a graph illustrating simulated radiation pattern and a measured radiation pattern at a second mode, according to certain embodiments.

FIG. 3C is a graph illustrating simulated radiation pattern and a measured radiation pattern at a third mode, according to certain embodiments.

FIG. 3D is a graph illustrating simulated radiation pattern and a measured radiation pattern at a fourth mode, according to certain embodiments.

FIG. 3E is a graph illustrating simulated radiation pattern and a measured radiation pattern at a fifth mode, according to certain embodiments.

FIG. 3F is a graph illustrating simulated radiation pattern and a measured radiation pattern at a sixth mode, according to certain embodiments.

FIG. 3G is a graph illustrating simulated radiation pattern and a measured radiation pattern at a seventh mode, according to certain embodiments.

FIG. 3H is a graph illustrating simulated radiation pattern and a measured radiation pattern at an eight mode, according to certain embodiments.

FIG. 3I is a graph illustrating simulated radiation pattern and a measured radiation pattern at an ninth mode, according to certain embodiments.

FIG. 3J is a graph illustrating simulated radiation pattern and a measured radiation pattern at a tenth mode, according to certain embodiments.

FIG. 3K is a graph illustrating simulated radiation pattern and a measured radiation pattern at an eleventh mode, according to certain embodiments.

FIG. 3L is a graph illustrating simulated radiation pattern and a measured radiation pattern at a twelfth mode, according to certain embodiments.

FIG. 4A is a graph illustrating simulated radiation pattern and a measured radiation pattern in the first mode, the second mode, and the third mode, according to certain embodiments.

FIG. 4B is a graph illustrating simulated radiation pattern and a measured radiation pattern in the fourth mode, the fifth mode, the sixth mode and the seventh mode, according to certain embodiments.

FIG. 4C is a graph illustrating simulated radiation pattern and a measured radiation pattern in the eighth mode, the ninth mode and the tenth mode, according to certain embodiments.

FIG. 4D is a graph illustrating simulated radiation pattern and a measured radiation pattern in the eleventh mode and the twelfth mode, according to certain embodiments.

FIG. 5A illustrates a simulated surface current of the SPA at the third mode, according to certain embodiments.

FIG. 5B illustrates a simulated surface current of the SPA at the fourth mode, according to certain embodiments.

FIG. 5C illustrates a simulated surface current of the SPA at the eight mode, according to certain embodiments.

FIG. 5D illustrates a simulated surface current of the SPA at the twelfth mode, according to certain embodiments.

DETAILED DESCRIPTION

In the drawings, like reference numerals designate identical or corresponding parts throughout the several views. Further, as used herein, the words "a," "an" and the like generally carry a meaning of "one or more," unless stated otherwise.

Furthermore, the terms "approximately," "approximate," "about," and similar terms generally refer to ranges that include the identified value within a margin of 20%, 10%, or preferably 5%, and any values therebetween.

Aspects of this disclosure are directed to a frequency and pattern reconfigurable segmented patch antenna (SPA) for WiMAX Applications. The SPA has a compact and conformal antenna design, employing 5 switches that permit 12 operational modes with better bandwidth, average gain, and efficiency of 3 dBi and 77%, respectively, throughout the twelve operational modes. The SPA includes a radiating patch with three incorporated slots and two slits. Three PIN diodes are integrated on the three slots to vary a length of the radiating patch to permit frequency reconfiguration at 4.1 GHz, 4.7 GHz, 5.0 GHz, and 5.7 GHz, preferably ±0.1 GHz or ±0.5 GHz, that is, four frequency bands. The two slits are also incorporated in order to independently bias the three diodes. Two parasitic elements are configured to act as either a reflector or a director, each placed at a quarter wavelength based upon an average of quarter wavelengths of each frequency that the SPA **100** may be configured according to the Yagi-Uda principle. The SPA exhibits large number of switchable modes at four resonance frequency bands with relatively large gain and efficiency throughout all the modes, making the disclosed antenna an excellent candidate for WiMAX applications.

Accordingly, embodiments of the present disclosure relate to a frequency and pattern reconfigurable segmented patch antenna (SPA) **100** for WiMAX Applications. As shown in FIG. **1**A and **1**B, the SPA **100** includes two rectangular parasitic elements **102**, that is, a first rectangular parasitic element **102-1** and a second rectangular parasitic element **102-2**. The first rectangular parasitic element **102-1** and the second rectangular parasitic element **102-2** are integrated with a first diode **104** and a second diode **106**, respectively. The SPA **100** further includes a main rectangular patch segment **108**. The main rectangular patch segment **108** includes three slots, that is, a first slot **110**, a second slot **112** and a third slot **114**. The main rectangular patch segment **108** includes two slits, that is, a first slit **116** and a second slit **118**. The main rectangular patch segment **108** further includes three PIN diodes, that is, a third diode **120**, a fourth diode **122**, and a fifth diode **124** integrated into the first slot **110**, the second slot **112** and the third slot **114**, respectively. Based upon working of plurality of diodes (the first diode **104** and the second diode **106**) and the parasitic elements (the first rectangular parasitic element **102-1** and the second rectangular parasitic element **102-2**). The diodes are integrated into the three slots to vary the length of the entire patch in order to enable the frequency reconfiguration. This enables the SPA **100** suitable for use in multiple frequencies between 4.1 GHz and 5.7 GHz inclusive and configurable to operate in twelve independent modes. The details of the designed SPA **100** are illustrated in FIG. **1**A and FIG. **1**B.

FIG. **1**A illustrates a front side **100**F of a frequency and pattern reconfigurable segmented patch antenna (or simply referred to as an SPA **100**) for WiMAX applications, according to an embodiment of the present disclosure. The front side **100**F may refer to a top side or front view or top view of the SPA **100**. (top side, front side, front view or top view are used interchangeably in the present disclosure). The front side **100**F of the SPA **100** may include at least four edges, that is, a first edge E_1, a second edge E_2, a third edge E_3, and a fourth edge E_4. The first edge E_1 is preferably parallel to the second edge E_2, and the third edge E_3 is preferably parallel to the fourth edge E_4. Also, the third edge E_3 and the fourth edge E_4 may be perpendicular to the first edge E_1 and the second edge E_2. In an embodiment, edges E_3 and E_2 may not be perpendicular to each other. For example, the edge E_3 may be at an angle of 80-89 degrees to the edge E_2. Similarly, edges E_1 and E_4 may have angle of around 80-89 degrees therebetween. The SPA **100** also includes a back side **100**B (also referred to as back view

100B) that refers to a bottom side or back view or a bottom view of the SPA **100**. (back side, bottom side, back view or bottom view or used interchangeably in the present disclosure). The back side **100**B of the SPA **100** is described in detail in FIG. **1**B.

The front side **100**F and the back side **100**B are separated by a substrate **100**S over which the components of the SPA **100** are integrated. In an embodiment, the substrate **100**S is made up of a dielectric material. The dielectric material may be selected from a group containing an FR-4 PCB, a PTFE material, Rogers RO4350 or Rogers RT5880 substrate and such substrates. In some examples, the substrate **100**S is selected as Rogers RT5880 of dielectric constant value 2.2+/−0.2, preferable +/−0.1 and loss tangent 0.0009 and height 1.572 mm. The selection of the dielectric material is not limited to the group, and any other known material may be selected to act as a base material for designing an electronic circuit of the SPA **100**. Also, length and width of the substrate **100**S is W_8 unit along Y axis and W_7 unit along X axis, respectively. In some examples, $W_7=W_8=50$ mm or less (±5 mm, preferably ±2 mm). Accordingly, the total volume of the SPA **100** is 50 mm (±5 mm, preferably ±2 mm)×50 mm (±5 mm, preferably ±2 mm)×1.572 (±0.1 mm, preferably +0.05 mm) or less than or equal to 55×55×1.672 mm^3 in volume.

The front side **100**F of the SPA **100** includes two rectangular parasitic elements **102**, that is, the first rectangular parasitic element **102-1** and the second rectangular parasitic element **102-2**. The rectangular parasitic element **102** refers to a conductive sheet, such as an etched metallic sheet disposed over the substrate **100**S located at the front side **100**F of the SPA **100**. The length and the width of each of the rectangular parasitic element **102**, that is, the first rectangular parasitic element **102-1** and the second rectangular parasitic element **102-2**, is W_4 unit along X axis and W_5 unit along Y axis. In an example, a length of the rectangular parasitic element **102**, that is, W_4 is 26.7 mm or can be between 26 mm and 28 mm. Also, as an example, the width of the rectangular parasitic element **102**, can be, $W_5=3.2$ mm (±0.4 mm). Also, the first rectangular parasitic element **102-1** is located at W_9 units from the third edge E_3 and W_{10} units from the first edge E_1. Similarly, the second rectangular parasitic elements **102-2** is also located at a distance of W_9 units from the fourth edge E_4 and W_{10} units from the first edge E_1. In an example, W_9 is equal to 7.4 mm (±0.7 mm) and W_{10} is equal to 15.65 mm (±1.5 mm).

The first rectangular parasitic element **102-1** is separated into two sections, that is, a first section **102-1-1** and a second section **102-1-2**. Each section has a length equal to $W_4/2$ units along X axis. In order to create the section on each rectangular parasitic element **102**, the disposed first rectangular parasitic element The pair of parasitic elements are etched out, through any known metal etching process such as a chemical or wet etching process, at a distance $W_{10}+W_4/2$ units from the first edge E_1, in the X axis direction. Etching out the metallic sheet divides the first rectangular parasitic elements **102-1** into two equal parts. The parts are thus, for example, referred to as the first section **102-1-1** and the second section **102-1-2**, respectively. The first diode **104** is electrically connected to the first section **102-1-1** and the second section **102-1-2**. For example, a first terminal (not shown) of the first diode **104** is connected (e.g., soldered) to the first section **102-1-1**, and a second terminal (not shown) of the first diode **104** is soldered to the second section **102-1-2**. The electrical arrangement therefore establishes an electrical connection between the first section **102-1-1** and the second section **102-1-2** through the first diode **104**. The electrical connection so established is utilized to either increase or decrease the length of the first rectangular parasitic elements **102-1**. Accordingly, the length of the first rectangular parasitic elements **102-1** is configurable by turning on or off the first diode **104**. Based upon a bias setting of the first diode **104**, that is, turning on or off the first diode **104**, as well as based upon the Yagi-Uda principle, the first rectangular parasitic element **102-1** is reconfigurable to either function as a reflector or a director of the SPA **100**.

The second rectangular parasitic elements **102-2** is also separated into two sections, that is, a third section **102-2-1** and a fourth section **102-2-2**. Each section has a length equal to $W_4/2$ units along the X axis. Through the etching process, the second rectangular parasitic elements **102-2** is divided into two equal parts. The parts are thus referred to as the third section **102-2-1** and the fourth section **102-2-2**, respectively. Also, a second diode **106** is electrically connected to the third section **102-2-1** and the fourth section **102-2-2**. For example, a first terminal (not shown) of the second diode **106** is soldered to the third section **102-2-1**, and a second terminal (not shown) of the second diode **106** is soldered to the second section **102-2-2**. The electrical arrangement therefore establishes an electrical connection in between the third section **102-2-1** and the fourth section **102-2-2** through the second diode **106**. The electrical connection so established is utilized to either decrease or increase a length of the second rectangular parasitic elements **102-2**. Accordingly, the length of the second rectangular parasitic elements **102-2** is configurable by turning on or off the second diode **106**. Therefore, based upon a bias setting of the second diode **106**, that is, turning on or off the second diode **106**, as well as based upon the Yagi-Uda principle the second rectangular parasitic element **102-1** is also reconfigurable to either function as a director or a reflector of the SPA **100**.

The front side **100**F of the SPA **100** includes the main rectangular patch segment **108**. The main rectangular patch segment **108** refers to another conductive sheet, such as a metallic sheet disposed over the substrate **100**S located at the front side **100**F of the SPA **100**. The length and the width of the main rectangular patch segment **108** W_1 unit along the Y axis and W_2 unit along the Y axis. In an example, the length of the main rectangular patch segment **108**, that is; $W_1=26.9$ mm (±1 mm) Also, as an example, the width of the main rectangular patch segment **108**, that is, is $W_2=22.1$ mm (±2 mm) Also, the main rectangular patch segment **108** is located at a distance of W_{12} units from the first edge E_1. In an example, W_{12} is equal to 17.95 (±1.8 mm).

The main rectangular patch segment **108** includes at least three slots, that is, the first slot **110**, the second slot **112** and the third slot **114**. In order to create the first slot **110** on the main rectangular patch segment **108**, the disposed main rectangular patch segment **108** is etched out, through any known metal etching process such as a chemical or wet etching process, at a distance of W_{13} unit from the first edge E_1, along the X axis till the distance of $W_1/2$ unit. Etching out the main rectangular patch segment **108** therefore creates the first slot **110** of length $W_1/2$ units at a distance of $W_9+W_5+W_{11}$ unit from the third edge E_3 along the Y-axis, and W_{13} units from the first edge E_1 along the X-axis direction. Similarly, in order to create the second slot **112** on the main rectangular patch segment **108**, the disposed main rectangular patch segment **108** is etched out at a distance of W_{13} unit from the first edge E_1, along the X-axis till the distance of $W_1/2$ unit, opposite to the first slot **110**. Etching out the main rectangular patch segment **108** therefore creates the second slot **112** of length $W_1/2$ units at a distance of $W_9+W_5+W_{11}$ unit from the fourth edge E_4 along the Y-axis and W_{13} units from the first edge E_1 along the X-axis. Accordingly, the first slot **110** and the second slot **112** appear as a continuation of a slot of length W_1 unit at a distance of W_{13} units from the first edge along the Y-axis direction. The first slot **110** and the second slot **112** have a distance of $W_1/2$ units each. In order to create the third slot **114** on the main rectangular patch segment **108**, the disposed main rectangular patch segment **108** is etched out vertically in a downward direction at a distance of W_{12} units from the first edge E_1 and at a mid-point of the main rectangular patch segment **108**. Etching out the main rectangular patch segment **108** creates the third slot **114** of length W_2-W_3 units at a distance of W_{12} units from the first edge E_1 in vertically downward direction towards the X-axis. Accordingly, the third slot **114** touches the first slot **110** and the second slot **112**. The first slot **110**, the second slot **112** and the third slot **114** have a width between 0.5 mm and 0.7 mm. In an embodiment, each slot has a width equal to 0.6 mm (±0.1 mm) Creating of the first slot **110** and the third slot **114** cuts the main rectangular patch segment **108** into a first part **108-1**. Similarly, creation of the second slot **112** and the third slot **114** cuts the main rectangular patch segment **108** into a second part **108-2**.

The main rectangular patch segment **108** further includes at least two slits, for example the first slit **116** and the second slit **118**. In order to create the first slit **116** on the main rectangular patch segment **108**, the disposed main rectangular patch segment **108** is etched out at a distance of W_{13} unit from the first edge E_1, and the first slit **116** is located in vertical direction at a distance of $W_9+W_5+W_{11}+W_{14}$ units from the third edge E_3. Etching out the main rectangular patch segment **108** therefore creates the first slit **116** of length W_3 units at a distance of $W_9+W_5+W_{11}+W_{14}$ units from the third edge E_3 and W_{13} units from the first edge E_1. Similarly, in order to create the second slit **118** on the main rectangular patch segment **108**, the disposed main rectangular patch segment **108** is etched out at a distance of W_{13} unit from the first edge E_1, and the second slit **118** is located in a vertical direction at a distance of $W_9+W_5+W_{11}+W_{15}$ units from the fourth edge E_4. Etching out the main rectangular patch segment **108** creates the second slit **118** of length W_3 units at a distance of $W_9+W_5+W_{11}+W_{15}$ units from the fourth edge E_4 and W_{13} units from the first edge E_1. Also, the first slit **116** touches and is perpendicular to the first slot **110** and the second slit **118** touches and is perpendicular to the second slot **112**. In an embodiment, the first slit **116** and the second slit **118** has a thickness no larger than 0.1 mm (±0.01 mm). Therefore, there is almost no effect of the slits on the resonance frequency of the SPA **100**, since 0.1 mm (±0.01 mm) is a smallest possible value required for fabrication. Creating the first slit **116** with the first slot **110** divides the main rectangular patch segment **108** into a third part **108-3**. Similarly, creating of the second slit **118** with the second slot **112** cuts the main rectangular patch segment **108** into a fourth part **108-4**. Also, an area of the main rectangular patch segment **108** illustrated in between the first slit **116** and the second slit **118** represents a fifth part **108-5** of the main rectangular patch segment **108**. Accordingly, the combination of three slots and two slits over the main rectangular patch segment **108** cuts the main rectangular patch segment: **108** into five parts.

The main rectangular patch segment **108** includes at least three diodes, that is, the third diode **120**, the fourth diode **122** and the fifth diode **124**. The third diode **120** is electrically connected to the first part **108-1** and the third part **108-3**. For example, a first terminal (not shown) of the third diode **120** is soldered to the first part **108-1** and a second terminal (not shown) of the third diode **120** is soldered to the third part **108-3**. Similarly, the fourth diode **122** is electrically connected to the second part **108-2** and the fourth part **108-4**. For example, a first terminal (not shown) of the fourth diode **122** is soldered to the second part **108-2** and a second terminal (not shown) of the fourth diode **122** is soldered to the fourth part **108-4**. Also, the fifth diode **124** is electrically connected in between the first part **108-1** and the second part **108-2**. For example, a first terminal (not shown) of the fifth diode **124** is soldered to the first part **108-1** and a second terminal (not shown) of the fifth diode **124** is soldered to the second part **108-2**. Accordingly, three diode arrangements establish an electrical connection in between the first part **108-1**, the second part **108-2**, the third part **108-3** and the fourth part **108-4**. The electrical connection established is utilized to either increase or decrease or vary a length of main rectangular patch segment **108**. Accordingly, the main rectangular patch segment **108** is viewed as a segmented patch as a result of the first slot **110**, the second slot **112** and the third slot **114**. Also, due to the presence of two slits: the first slit **116** and the second slit **118**, the third diode **120** and the fourth diode **122** can be biased independently and also avoid any physical connection. Accordingly, the length of the main rectangular patch segment **108** is configurable by turning on or off the three diodes. As such, the three diodes integrated on the three slots of the main rectangular patch segment **108** are configured to vary the length of the main rectangular patch segment **108**. Varying the length of the main rectangular patch segment **108** therefore varies the length and consequently the resonance frequency of the SPA **100**. Therefore, based on bias settings of the each of the three diodes, that is, turning on or off, the length of the main rectangular patch segment **108** is also reconfigurable.

The main rectangular patch segment **108** further includes a feed point **134** over the fifth part **108-5** of the main rectangular patch segment **108**. The feed point **134** is located at a mid-location of the main rectangular patch segment **108**, that is, at a distance of $W_9+W_5+W_{11}+W_1/2$ from the third edge E_3. In another example, an imaginary axis **136** may be considered that bisects the main rectangular patch segment **108** into two equal parts. Each part, thus formed, has length of $W_1/2$ units. The feed point **134** may be located at the bisecting location, that is, over the imaginary axis **136**. In some examples, the position of the feed point **134** may be anywhere over the imaginary axis **136** within the fifth part **108-5**. One terminal of the feed point **134** may be soldered over the fifth part **108-5** of the main rectangular patch segment **108**. Another terminal of the feed point **134** is electrically connected to the back side **100**B of the SPA **100** that electrically couples a partial ground (not shown here) located at the back side **100**B of the SPA **100**. For example, a hole (not shown) may be created over the fifth part **108-5** as well as over the substrate **100**S immediately below the hole of the fifth part **108-5**. The hole (not shown) thus acts as a via (not shown) that opens at the back side **100**B of the SPA **100**. At the back side **100**B, the via (not shown) couples to the partial ground **138**. Accordingly, through soldering, an electrical connection may be established between the fifth part **108-5** at the front side **100**F and the partial ground **138** at the back side **100**B through the via (not shown) in the substrate **100**S. Details of the partial ground is discussed in the FIG. **1**B.

In an embodiment, the rectangular parasitic elements **102** are located at a distance of W_6 units from the imaginary axis **136** on either side of the main rectangular patch segment **108**. For example, the first rectangular parasitic element **102-1** is located at a distance of W_6 units towards the third edge E_3 and the second rectangular parasitic element **102-2** is symmetrically located at a distance of W_6 units towards the fourth edge E_3, respectively, from the imaginary axis **136**. The location of the rectangular parasitic elements **102** with respect to the main rectangular patch segment **108** may depend upon an average of quarter wavelengths of each frequency that the SPA **100** is designed for. Based upon the average value of the resonating frequency, a quarter wavelength value may be calculated based on the relationship between the frequency and wavelength. Accordingly, the location of the rectangular parasitic element **102** is computed based upon the average of quarter wavelength of each frequency. In an embodiment, the length W_6 is equal to 18.4 mm (±1.0 mm or preferably ±0.5 mm). The distance W_6 is almost equal to one quarter wavelength from the imaginary axis **136** on each side of the main rectangular patch segment **108**. In another embodiment, the distance between the rectangular parasitic elements **102** and the main rectangular patch segment **108** is equal to W_{11} units.

The front side **100**F of the SPA **100** includes at least four biasing lines. The biasing line refers to a metallic strip disposed over the substrate **100**S for biasing the three diodes over the main rectangular patch segment **108**. For example, a first biasing line **126** including a first limiting resistor **126**R and a first choke inductor **126**L is electrically soldered to the first part **108-1** of the main rectangular patch segment **108**. Similarly, a second biasing line **128** including a second limiting resistor **128**R and a second choke inductor **128**L is electrically soldered to the second part **108-2** of the main rectangular patch segment **108**. Also, a third biasing line **130** including a third limiting resistor **130**R and a third choke inductor **130**L is electrically soldered to the third part **108-3** of the main rectangular patch segment **108**. In the same way, a fourth biasing line **132** including a fourth limiting resistor **132**R and a fourth choke inductor **132**L is electrically soldered to the fourth part **108-4** of the main rectangular patch segment **108**. In an embodiment, a length of each of biasing line is in between 7 and 8 mm and width is in between 1 and 3 mm. For example, each biasing line may have length of 7.6 mm and width of 2 mm. Adding the biasing lines ensure the radiation characteristics of the SPA **100** are not distorted. Also, as an example, value of each limiting resistor and each choke inductor are selected as 500M Ω and 68 nH, respectively. The limiting resistor in each biasing line limits the biasing current through the diodes in the main rectangular patch segment **108**, since the diodes could be biased at no more than 0.7V. Also, the choke inductors in each biasing line isolates the RF signals from the DC supply such as a battery.

FIG. **1**B illustrates a back side **100**B of a frequency and pattern reconfigurable segmented patch antenna **100** for WiMAX applications, according to an embodiment of the present disclosure. The back side **100**B may refer to a back view or bottom view of the SPA **100**. The back side **100**B includes a partial ground **138**. The partial ground **138** also refers to a metallic strip disposed over the substrate **100**S at the back side **100**B of the SPA **100**. The partial ground **138** is located at a distance of W_{16} units from the fourth edge E_4 and W_{17} units from the first edge E_1. The partial ground **138** includes one dimension of length equal to W_{18} units and a second dimension of length equal to W_{19} units. The one dimension refers to the width of the partial ground **138** and the second dimension refers to the length of the partial ground **138**. In an embodiment, the width of the one dimension, that is, W_{18} of the partial ground **138** is 3 mm (±0.5 mm). For example, the length W_{18}=3.18 mm. The length of the second dimension of the partial ground **138** is 23.5 mm (±1.5 mm). For example, W_{19}=23.74 mm. Also, a coaxial feed **140** is placed over the partial ground **138**. In an embodiment, the coaxial feed **140** is placed at a distance of W_{20} units from top of the partial ground **138** or at a distance of W_{20}+W_{17} units from the first edge E_1. The distance W_{20} may equal 11 mm (±1.0 mm) such as 11.11 mm or any value within 10 and 12 mm. The partial ground **138** has a minimal effect over the tilting angles of the SPA **100**. The feed point **134** (shown in FIG. **1**A) is electrically connected to the coaxial feed **140**. For example, through soldering, the coaxial feed **140** over the partial ground **138** electrically and mechanical connects the feed point **134** over the fifth part **108-5** of the main rectangular patch segment **108**, through the via (not shown) in the substrate **100**S.

FIG. **1**C illustrates a prototype model of the frequency and pattern reconfigurable segmented patch antenna **100**, including a front side **100**F (left of FIG. **1**C) and a back side **100**B (right side of FIG. **1**C), according to aspects of the present disclosure. The SPA **100** and all four edges, that is, the first edge E_1, the second edge E_2, the third edge E_3, and the fourth edge E_4, are illustrated in each diagram. A view of back side **100**B is obtained when the front side **100**F is rotated 180° with respect to the fourth edge E_4. Additionally, a view of the back side **100**B is also obtained when the front side **100**F is rotated 180° with respect to the third edge E_4. The diagram shows the location of the rectangular parasitic elements **102** and main rectangular patch segment **108** over the substrate **100**S. The diagram also shows a plurality of electrical wires **142** and **144** of the rectangular parasitic elements **102** and the main rectangular patch segment **108** for biasing the diodes of the SPA **100**. The back side **100**B illustrates the location of the partial ground **138** and the coaxial feed **140** over the partial ground **138** above the substrate **100**S.

With reference to FIG. **1**A, FIG. **1**B and FIG. IC, the operation of the frequency and pattern reconfigurable segmented patch antenna **100** is described. In order to bias one or more diodes, that is, the first diode **104**, the second diode **106**, the third diode **120**, the fourth diode **122** and the fifth diode **124** of the SPA **100**, an electronic device (not shown), for example, may be electrically coupled to the SPA **100**. For example, the electronic device (not shown) may have an electrical connection with the wires **142** and **144** of the biasing lines **126**, **128**, **130** and **132** of the SPA **100**. Connecting the electronic device (not shown) with the SPA **100** aids in automatic switching of the plurality of diodes On or Off connected with the biasing lines, based upon the requirement of the frequency reconfiguration as well as radiation pattern reconfiguration in the desired direction. In an embodiment, switching of the diodes may be done manually. For example, an electronic circuit (not shown) comprising a plurality of logic gates may be electrically coupled with the wires **142** and **144** of the SPA **100**. Based upon the requirement of the frequency reconfiguration as well as radiation pattern reconfiguration in the desired direction, the logic gates may be manually operated to either turn On or Off all or some of the diodes of the SPA **100**. Also, the signal that is to be radiated through the SPA **100** in the space is applied at the coaxial feed **140**.

The parasitic elements **102** are configured to act as a reflector or as a director according to bias settings of the diodes and the Yagi-Uda principle. According to the Yagi-Uda principle, an element, when placed at quarter wavelength from the center of the main radiating element, act as a reflector or director depending on the length of the element. Based on the Yagi-Uda principle, the reflector is configured to reflect all the radiated beams of the radiating element towards the director whenever the length of the reflector is more compared to the director, whereas the director is configured to concentrate the radiation beam. In the design of SPA **100**, the main rectangular patch segment **108** acts as the main radiating element or a driving element, the first rectangular parasitic element **102-1** act as a first element and the second rectangular parasitic element **102-2** acts as a second element. The first element and the second element are configured to act either as a director or a reflector or vice versa. Both elements are placed at a quarter wavelength W_6 units from the main rectangular patch segment **108**. When the first diode **104** is turned 'On' and the second diode **106** is turned 'Off', the first section **102-1-1** and the second section **102-1-2** function as an element of length W_4 units. The first rectangular parasitic element **102-1** thus acts as a reflector element, whereas the second rectangular parasitic element **102-2** acts as the director. On the other hand, when the first diode **104** is turned 'Off' and the second diode is turned 'On', the first section **102-1-1** and the second section **102-1-2** function as an element of length $W_4/2$ units or less, whereas the third section **102-2-1** and the fourth section **102-2-2** acts an element of length W_4 units. The first rectangular parasitic element **102-1** thus acts as a director element, whereas the second rectangular parasitic element **102-1** acts as a reflector element. The pattern reconfiguration in any direction is thus achieved since the surface current distribution of the SPA **100** is altered based upon the setting of all five diodes.

Plurality of the operating modes of the SPA **100** is now described in detail.

First mode settings: The first diode **104** is set to '1', the second diode **106** is set to '0', the third diode **120** is set to '1', the fourth diode **122** is set to '1', and the fifth diode **124** is set to '1'. Based on the settings, the first rectangular parasitic element **102-1** acts as a reflector and the second rectangular parasitic element **102-2** acts as a director as the length of the first rectangular parasitic element **102-1** is more compared to the second rectangular parasitic element **102-2**. The SPA **100** resonates at 4.1 GHz. Also, the SPA **100** radiates at 143 degree of radiation angle.

Second mode settings: The first diode **104** is set to '0', the second diode **106** is set to '1', the third diode **120** is set to '1', the fourth diode **122** is set to '1', and the fifth diode **124** is set to '1'. Based on the settings, the first rectangular parasitic element **102-1** acts as a director and the second rectangular parasitic element **102-2** acts as a reflector as the length of the second rectangular parasitic element **102-2** is increased compared to the first rectangular parasitic element **102-1**. The SPA **100** resonates at 4.1 GHz. According to the settings, the SPA **100** radiates at −143 degrees of radiation angle.

Third mode settings: The first diode **104** is set to '1', the second diode **106** is set to '1', the third diode **120** is set to '1', the fourth diode **122** is set to '1', and the fifth diode **124** is set to '1'. Based on the settings the first rectangular parasitic element **102-1** as well as the second rectangular parasitic element **102-2** have the same element length and none of them acts either as a director or a reflector. The SPA **100** resonates at 4.1 GHz. Based on settings, the SPA **100** radiates at 180 degrees of radiation angle.

Fourth mode settings: The first diode **104** is set to '1', the second diode **106** is set to '1', the third diode **120** is set to '1', the fourth diode **122** is set to '0', and the fifth diode **124** is set to '1'. As a result of the setting, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** becomes shorter since one of the diode, (the fourth diode in this case) is set as off. Accordingly, the resonance frequency of the SPA **100** increases to 4.7 GHz. Also, the first rectangular parasitic element **102-1** as well as the second rectangular parasitic element **102-2** have the same element length and none of them acts either as a director or a reflector. Further, the SPA **100** radiates at a radiation angle of 38 degree.

Fifth mode settings: The first diode **104** is set to '1', the second diode **106** is set to '1', the third diode **120** is set to '0', the fourth diode **122** is set to '1', and the fifth diode **124** is set to '1'. Based on the settings, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** becomes shorter since one of the diode, (the third diode in this case) is set as off. The SPA **100** resonates at the resonance frequency of 4.7 GHz. Also, the first rectangular parasitic element **102-1** as well as the second rectangular parasitic element **102-2** have the same element length and none of them acts either as a director or a reflector. Further, the SPA **100** radiates at a radiation angle of −38 degrees.

Sixth mode settings: The first diode **104** is set to '1', the second diode **106** is set to '0', the third diode **120** is set to '1', the fourth diode **122** is set to '0', and the fifth diode **124** is set to '1'. According to the settings, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** becomes shorter since one of the diode, (the third diode in this case) is set as off. Also, the second rectangular parasitic element **102-2** acts as a reflector and the first rectangular parasitic element **102-1** acts as a director as the length of the second rectangular parasitic element **102-2** is increased compared to the first rectangular parasitic element **102-1**. Accordingly, based upon the setting of all fives diodes, the SPA. **100** resonates at the resonance frequency of 4.7 GHz with 63 degree of radiation angle.

Seventh mode settings: The first diode **104** is set to '0', the second diode **106** is set to '1', the third diode **120** is set to '0', the fourth diode **122** is set to '1', and the fifth diode **124** is set to '1'. According to the settings, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** becomes shorter since one of the diode, (the fourth diode in this case) is set as off. Also, the first rectangular parasitic element **102-1** acts as a reflector and the second rectangular parasitic element **102-2** acts as a director as the length of the first rectangular parasitic element **102-1** is increased compared to the second rectangular parasitic element **102-2**. Accordingly, based upon the setting of all fives diodes, the SPA **100** resonates at the resonance frequency of 4.7 GHz with −63 degree of radiation angle.

Eighth mode settings: The first diode **104** is set to '1', the second diode **106** is set to '1', the third diode **120** is set to '0', the fourth diode **122** is set to '0', and the fifth diode **124** is set to '0'. According to the settings, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** becomes even more shorter since two of the diode, (the third diode and the fourth diode in this case) is set as off. Also, the first rectangular parasitic element **102-1** as well as the second rectangular parasitic element **102-2** have the same element length and none of them acts either as a director or a reflector. Accordingly, based upon the setting of all fives diodes, the SPA **100** now resonates at the resonance frequency of 5 GHz with 0 degree of radiation angle.

Ninth mode settings: The first diode **104** is set to '1', the second diode **106** is set to '0', the third diode **120** is set to '0', the fourth diode **122** is set to '0', and the fifth diode **124** is set to '0'. According to the settings, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** is as same as in the case of eighth mode. Also, the first rectangular parasitic element **102-1** acts as a reflector and the second rectangular parasitic element **102-2** acts as a director as the length of the first rectangular parasitic element **102-1** is increased compared to the second rectangular parasitic element **102-2**. Accordingly, based upon the setting of all fives diodes, the SPA **100** resonates at the resonance frequency of 5 GHz with 50 degree of radiation angle.

Tenth mode settings: The first diode **104** is set to '0', the second diode **106** is set to '1', the third diode **120** is set to '0', the fourth diode **122** is set to '0', and the fifth diode **124** is set to '0'. According to the settings, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** is as same as in the case of eighth mode or 9. Also, the first rectangular parasitic element **102-1** as well as the second rectangular parasitic element **102-2** have the same element length and none of them acts either as a director or a reflector. Accordingly, based upon the setting of all fives diodes, the SPA **100** resonates at the resonance frequency of 5 GHz with −50 degree angle of radiation.

Eleventh mode settings: The first diode **104** is set to '0', the second diode **106** is set to '0', the third diode **120** is set to '1', the fourth diode **122** is set to '0', and the fifth diode **124** is set to '1'. According to the settings, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** is even shorter compared to previous cases. Also, the first rectangular parasitic element **102-1** as well as the second rectangular parasitic element **102-2** have the same element length and none of them acts either as a director or a reflector. Accordingly, based upon the setting of all fives diodes, the SPA **100** now resonates at the resonance frequency of 5.7 GHz with 90 degree angle of radiation.

Twelfth mode settings: The first diode **104** is set to '0', the second diode **106** is set to '0', the third diode **120** is set to '0', the fourth diode **122** is set to '1', and the fifth diode **124** is set to '1'. According to the settings, the length of the radiating element, that is, the main rectangular patch segment **108** of the SPA **100** is same as the previous cases. Also, the first rectangular parasitic element **102-1** as well as the second rectangular parasitic element **102-2** have the same element length and none of them acts either as a director or a reflector. Accordingly, based upon the setting of all fives diodes, the SPA **100** resonates at the resonance frequency of 5.7 GHz with −90 degree angle of radiation.

Based upon the setting of all five diodes and the arrangement of the patch and the parasitic element, multiple frequencies between 4.1 GHz and 5.7 GHz, that is, 4.7 GHz and 5 GHz are radiated through the SPA **100**. Accordingly, the SPA **100** radiates over at least 4 different resonance frequency bands, that is, 4.1 GHz, 4.7 GHz, S GHz, and 5.7 GHz with twelve different independent operating modes to reconfigure the direction of the radiation beam pattern through the SPA **100**.

FIG. **2**A illustrates a plurality of curves for a simulated reflection coefficient S_{11} as well as measured reflection coefficients S_{11} for the first three independent operational modes of the SPA **100**, according to an embodiment of the present disclosure. The first three independent mode refers to a first mode, a second mode and a third mode. S_{11} (in dB) denotes the amount of input power reflected from the SPA **100** when a signal is applied at the input port, that is, at the feed point **134**. The reflection coefficient is also known as a return loss of the SPA **100**. In an example, if S_{11}=0 dB then all the power is reflected from the SPA **100**, and nothing is radiated. The SPA **100** is biased through the first biasing line **126**, the second biasing line **128**, the third biasing line **130** and the fourth biasing line **132** for biasing the main rectangular patch segment **108**, along with biasing the rectangular parasitic element **102**. The signal is applied at the feed point **134**. Curves **202**S and **202**M accordingly illustrate a simulated reflection coefficients S_{11} and a measured reflection coefficients S_{11} for the first mode, respectively. Curves **204**S and **204**M illustrate a simulated reflection coefficients S_{11} and a measured reflection coefficients S_{11} for the second mode, respectively. Curves **206**S and **206**M illustrate a simulated reflection coefficients S_{11} and a measured reflection coefficients S_{11} for the third mode, respectively. Based on the simulated reflection coefficients and the measured reflection coefficients using the plurality of curves, the SPA **100** appears to resonate at the resonating frequency approximately equal to 4.1 GHz.

FIG. **2**B illustrates a plurality of curves for a simulated reflection coefficient S_{11} as well as measured reflection coefficients S_{11} for the next four independent operational modes of the SPA **100**, according to an embodiment of the present disclosure. The next four independent mode refers to a fourth mode, a fifth mode, a sixth mode and a seventh mode. Curves **208**S and **208**M accordingly illustrate simulated reflection coefficients S_{11} and measured reflection coefficients S_{11} for the fourth mode, respectively. Curves **210**S and **210**M shows simulated reflection coefficients S_{11} and measured reflection coefficients S_{11} for the fifth mode, respectively. Curves **212**S and **212**M illustrate a simulated reflection coefficients S_{11} and a measured reflection coefficients S_{11} for the sixth mode, respectively. Curves **214**S and **214**M illustrate a simulated reflection coefficients S_{11} and measured reflection coefficients S_{11} for the seventh mode, respectively. Based on the simulated reflection coefficients and the measured reflection coefficients using the plurality of curves, the SPA **100** appears to resonate at the resonating frequency approximately equal to 4.7 GHz.

FIG. **2**C illustrates a plurality of curves for simulated reflection coefficient S_{11} as well as measured reflection coefficients S_{11} for the next three independent operational modes of the SPA **100**, according to an embodiment of the present disclosure. The next three independent mode refers to an eighth mode, a ninth mode and a tenth mode. Curves **216**S and **216**M accordingly illustrate simulated reflection coefficients S_{11} and measured reflection coefficients S_{11} for the eight mode, respectively. Curves **218**S and **218**M illustrate simulated reflection coefficients S_{11} and a measured reflection coefficients S_{11} for the ninth mode, respectively. Curves **220**S and **220**M illustrate simulated reflection coefficients S_{11} and measured reflection coefficients S_{11} for the tenth mode, respectively. Based upon the simulated reflection coefficients and the measured reflection coefficients using the plurality of curves, the SPA **100** appears to resonate at the resonating frequency approximately equal to 5 GHz.

FIG. **2**D illustrates a plurality of curves for a simulated reflection coefficient S_{11} as well as measured reflection coefficients S_{11} for the next two independent operational modes of the SPA **100**, according to an embodiment of the present disclosure. The next two independent mode refers to an eleventh mode, a twelfth mode. Curves **222**S and **222**M accordingly illustrate simulated reflection coefficients S_{11} and measured reflection coefficients S_{11} for the eleventh mode, respectively. Curves **224**S and **224**M illustrate simulated reflection coefficients S_{11} and measured reflection coefficients S_{11} for the twelfth mode, respectively. Based upon the simulated reflection coefficients and the measured reflection coefficients using the plurality of curves, the SPA **100** appears to resonate at the resonating frequency approximately equal to 5.7 GHz.

With reference to FIG. **2**A, FIG. **2**B, FIG. **2**C and FIG. **2**D, the SPA **100** operates at twelve independent operational modes. By varying the electrical length using the third diode **120**, the fourth diode **122**, and the fifth diode **124** on the main rectangular patch segment **108**, the SPA **100** is configured to achieve at least four different resonant frequencies of 4.1 GHz, 4.7 GHz, 5 GHz, and 5.7 GHz with measured impedance bandwidths of 16.8%, 10.5%, 15.4% and 12.8%, respectively. It was observed that the simulated and measured results agree considerably. Also, the relatively large bandwidth in all twelve modes is due to the presence of the first slot **110**, the second slot **112** and the third slot **114** as well as the first slit **116** and the second slit **118** on the main rectangular patch segment **108**. Accordingly, the current path is increased in the main rectangular patch segment **108** that supports in creating more resonances and increasing the bandwidth.

FIG. **3** illustrates a measured and a simulated radiation pattern of the SPA **100** in the H-Plane or X-Y plane for all twelve modes, according to an embodiment of the present disclosure. As such, FIG. **3**A illustrates a curve **302**S for simulated radiation pattern and a curve **302**M for the measured radiation pattern in the first mode, that is, when all diodes are turned on, except the second diode **106**. It was experimentally observed that the first mode radiates the radiation beam towards +143 degree in X-Y plane. FIG. **3**B illustrates a curve **304**S for simulated radiation pattern and a curve **304**M for the measured radiation pattern in the second mode, that is, when all diodes are turned on, except the first diode **104**. The SPA **100** radiates the radiation beam towards −143 degrees in X-Y plane. FIG. **3**C illustrates a curve **306**S for simulated radiation pattern and a curve **306**M for the measured radiation pattern in the third mode, that is, when all diodes are turned On. The SPA **100** radiates the radiation beam towards +180 degree in X-Y plane. Based on the simulated and measured curves in FIG. **3**A, FIG. **3**B and FIG. **3**C, the SPA **100** was experimentally observed to resonate at 4.1 GHz. FIG. **3**D illustrates a curve **308**S for the simulated radiation pattern and a curve **308**M for the measured radiation pattern in the fourth mode, that is, when all diodes are turned on, except the fourth diode **122**. The SPA **100** radiates the radiation beam towards +38 degree in X-Y plane. FIG. **3**E illustrates a curve **310**S for the simulated radiation pattern and a curve **310**M for the measured radiation pattern in the fifth mode, that is, when all diodes are turned on, except the third diode **120**. The SPA **100** radiates the radiation beam towards −38 degree in X-Y plane. FIG. **3**F illustrates a curve **312**S for simulated radiation pattern and a curve **312**M for the measured radiation pattern in the sixth mode, that is, when all diodes are turned on, except the first diode **104** and the third diode **120**. The SPA **100** radiates the radiation beam towards +63 degree in X-Y plane. FIG. **3**G illustrates a curve **314**S for simulated radiation pattern and a curve **314**M for the measured radiation pattern in the seventh mode, that is, when all diodes are turned on, except the second diode **106** and the fourth diode **122**. The SPA **100** radiates the radiation beam towards −63 degrees in X-Y plane. Based on the simulated and measured curves in FIG. **3**D, FIG. **3**E, FIG. **3**F, and FIG. **3**G the SPA **100** was experimentally observed to resonate at 4.7 GHz. FIG. **3**H illustrates a curve **316**S for simulated radiation pattern and a curve **316**M for the measured radiation pattern in an eighth mode, that is, when all diodes are turned on, except the third diode **120** and the fourth diode **122**. The SPA **100** radiates the radiation beam towards 0 degree in X-Y plane. FIG. **3**I illustrates a curve **318**S for simulated radiation pattern and a curve **318**M for the measured radiation pattern in a ninth mode, that is, when all diodes are turned on, except the second diode **106**, the third diode **120** and the fourth diode **122**. The SPA **100** radiates the radiation beam towards +50 degree in X-Y plane. FIG. **3**J illustrates a curve **320**S for simulated radiation pattern and a curve **320**M for the measured radiation pattern in a tenth mode, that is, when all diodes are turned off, except the second diode **106**. The SPA **100** radiates the radiation beam towards −50 degree in X-Y plane. Based on the simulated and measured curves in FIG. **3**H, FIG. **3**I, and FIG. **3**J, the SPA **100** was experimentally observed to resonate at 5 GHz. FIG. **3**K illustrates a curve **322**S for simulated radiation pattern and a curve **322**M for the measured radiation pattern in an eleventh mode, that is, when all diodes are off, except the third diode **120** and the fifth diode **124**. The SPA **100** radiates the radiation beam towards +90 degree in X-Y plane. FIG. **3**L illustrates a curve **324**S for simulated radiation pattern and a curve **324**M for the measured radiation pattern in a twelfth mode, that is, when all diodes are off, except the fourth diode **122** and the fifth diode **124**. The SPA **100** radiates the radiation beam towards +90 degree in X-Y plane. Based on the simulated and measured curves in FIG. **3**K and FIG. **3**L, the SPA **100** was experimentally observed to resonate at 5.7 GHz. The simulated and measured radiation patterns in H-planes almost superimpose each other. The minor differences in between the curves of the simulated and measured radiation patterns may be due to non-inclusion of the actual loss characteristics of the inductors, resistors, and capacitors while fabricating the SPA **100**. Besides, soldering the diodes may result in some fabrication tolerances.

FIG. **4** illustrates a measured and simulated radiation pattern of the SPA **100** in the E-Plane or X-Z plane for all twelve modes. As such, FIG. **4**A illustrates a curve **402**S for simulated radiation pattern and a curve **402**M for the measured radiation pattern in the first mode, the second mode, and the third mode. The switching angle was experimentally observed to be inclined at +82 degree in X-Z plane for all three modes whenever the SPA **100** resonates at 4.1 GHz. FIG. **4**B illustrates a curve **404**S for the simulated radiation pattern and a curve **404**M for the measured radiation pattern in the fourth mode, the fifth mode, the sixth mode and the seventh mode. The switching angle was experimentally observed to be inclined at −67 degree in X-Z plane for all four modes whenever the SPA **00** resonates at 4.7 GHz. FIG. **4**C illustrates a curve **406**S for simulated radiation pattern and a curve **406**M for the measured radiation pattern in the eighth mode, the ninth mode and the tenth mode. The switching angle was experimentally observed to be inclined at −47 degree in X-Z plane for all three modes whenever the SPA **100** resonates at 5 GHz. FIG. **4**D illustrates a curve **408**S for simulated radiation pattern and a curve **408**M for the measured radiation pattern in the eleventh mode and the twelfth mode. The switching angle was experimentally observed to be inclined at −105 degree in X-Z plane for all three modes whenever the SPA **100** resonates at 5 GHz. Unlike FIG. **3**A-FIG. **3**L wherein twelve different beam tiles were observed in X-Y plane, only 4 beam tilts were observed in X-Z plane in FIG. **4**A-FIG. **4**D. The simulated and measured radiation patterns in E-planes also superimpose each other. The minor differences in between the curves of the simulated and measured radiation patterns may be due to non-inclusion of the actual loss characteristics of the inductors, resistors and capacitors while fabricating the SPA **100**.

FIG. **5** illustrates a diagram to demonstrate a mechanism of the pattern reconfiguration based upon the surface current distributions of the SPA **100**, according to an embodiment of the present disclosure. As such FIG. SA illustrates a simulated surface current of the SPA **100** at mode 3. The diagram illustrates a surface current distribution when all the diodes are switched ON. High reflection is observed from the top of the SPA **100** as a result of an increase in the length of the main rectangular patch segment **108** at the top, hence, serving as reflector to divert all the radiations towards the lower hemisphere. Accordingly, the switching state diode of the permits an end fire (180 degree) beam tilt. FIG. **5**B illustrates a simulated surface current of the SPA **100** at mode 4. When the fourth diode **122** is OFF, reflection occurs towards the right direction, making most of the surface currents gravitate towards the right, at an angle of 38 degree. FIG. **5**C illustrates a simulated surface current of the SPA **100** at eighth mode. When the third diode **120** and the fourth diode **122** are switched OFF, most of the current moves in the broadside direction (0 degree) since only the two parasitic lines act as reflector. FIG. **5**D illustrates a simulated surface current of the SPA **100** at twelfth mode. The SPA **100** is reflected towards the left when the fourth diode **122** and the fifth diode **124** are switched ON while the other diodes are OFF. This is because the right part of the SPA **100** now acts as a reflector, and therefore, diverts most of the currents towards the left.

Based upon FIG. **1**, FIG. **2**, FIG. **3**, FIG. **4**, and FIG. **5**, Table I summarizes all twelve independent modes and the frequency reconfiguration of the SPA **100** whereas Table II shows the performance of the SPA **100**. The SPA **100** permits to operate twelve different switching modes depending on the ON or OFF states of all five diodes. The efficiency of the SPA **100** was obtained by the inventors based upon the simulated model of the SPA as well as based upon the prototype model of the SPA **100**. The frequency of the SPA **100** is reconfigurable in four resonating bands. The simulated efficiency of the SPA ranges between 44.5%-95%, while the measured efficiency ranges between 42%-92%. Also, the inventors determined the simulated and measured gain to range between 1.97-4.3 dB and 1.7-4.2 dB, respectively. The measured efficiency and gain exhibit slight decrease because of the fabrication tolerances and the actual values of the inductors, resistors and capacitors used while fabricating the SPA **100**. Also, the radiation pattern is reconfigurable in twelve different operating modes. Lowest efficiency (42%) of the SPA **100** was seen at 4.1 GHz resonance band whereas the highest efficiency (92%) of the SPA **100** is seen when the SPA **100** is configured to transmit at 5 GHz or the resonance frequency is 5 GHz. At resonance frequencies of 4.7 GHz and 5.7 GHz, the SPA **100** radiates with 78% and 88% efficiency, respectively. Moreover, throughout the twelve operating modes, the SPA **100** exhibits a relatively large common bandwidth as a result of the 3 slots and 2 slits. Based upon the overall efficiency of the SPA **100** at all twelve different operating modes at four different resonating bands, the measured efficiency of the SPA **100** was experimentally obtained by the inventors as 77%, throughout the twelve independent modes.

TABLE I

Operating modes of the proposed SPA antenna

Modes	Diodes D_1	D_2	D_3	D_4	D_5	Resonant Freq (GHz)	Scan Angles (°)
1	1	0	1	1	1	4.1	+143
2	0	1	1	1	1		−143
3	1	1	1	1	1		+180
4	1	1	1	0	1	4.7	+38
5	1	1	0	1	1		−38
6	1	0	1	0	1		+63
7	0	1	0	1	1		−63
8	1	1	0	0	0	5.0	0
9	1	0	0	0	0		+50
10	0	1	0	0	0		−50
11	0	0	1	0	1	5.7	+90
12	0	0	0	1	1		−90

TABLE II

Performance of the proposed SPA

Frequency	Modes	Scan angle	Efficiency (Simu./Meas.) (%)	Gain (Simu./Meas.) (dB)	Common bandwidth (%)
4.1 GHz	1	143°	44.5/42	2.34/2.2	4.7
	2	−143°	44.5/42	2.34/2.2	
	3	180°	45/42	1.97/1.7	
4.7 GHz	4	38°	81/78	3.32/3.4	5.3
	5	−38°	81/78	3.32/3.4	
	6	63°	81/78	3.81/3.7	
	7	−63°	81/78	3.81/3.7	
5.0 GHz	8	0°	95/92	3.8/3.7	5.0
	9	50°	95/92	4.3/4.2	
	10	−50°	95/92	4.3/4.2	
5.7 GHz	11	90°	89/88	3.8/3.9	13.9
	12	−50°	89/88	3.8/3.9	

Table III shows the comparison of the SPA **100** with the antenna developed in prior art. The SPA **100** operates with an average gain of 3 dBi throughout the twelve independent modes based upon the simulated as well as prototype model of the SPA **100**. Also, the average bandwidth of 13.9 GHz was obtained through the SPA **100** by the inventors based upon the experimental calculations. Moreover, the area of the SPA **100** is 50 mm (±5 mm, preferably ±2 mm)×50 mm (±5 mm, preferably ±2 mm) or less than 55×55 mm^2. It is obvious that the SPA **100** has a simple antenna size, more operational modes, better average efficiency, moderately average gain, and comparatively better average bandwidth compared to all the antennas developed in the prior art. This makes the SPA **100** a viable choice for WiMAX applications.

TABLE III

Comparison between the SPA of the present disclosure and conventional patch antennas.

Year/Ref	Antenna size (mm^2)	No. of operational modes	Resonance Freq. (GHz)	No. of Switches	Average Efficiency (%)	Average Gain (dB)	Average Bandwidth (%)
2014[1]	130 × 160	9	1.82, 1.93, 2.1	14	85	4.6	8.3
2017[2]	40 × 40	8	2.95, 3.76, 4, 5.1	2 mech. sw.	71	4.27	6
2016[3]	85 × 85	6	2.68, 3, 3.51	2 varactors	67	4.05	—
2015[4]	45.8 × 80	4	2.4, 5.4	5	65.5	2.6	19.05
2017[5]	50 × 50	7	4.5, 4.8, 5.2, 5.8	4	80	3.57	2.6
2015[6]	120 × 120	6	2.6, 3.5	12	95.6	9.07	3.8
2018[7]	151.5 × 160.9	9	2.15, 2.27, 2.38	2 varactors	64	7.1	1.5
2018[8]	50 × 60	4	5.2, 5.8	6	84	2.75	3.55
Present Disclosure	50 × 50	12	4.1, 4.7, 5.0, 5.7	5	76.75	3.0	13.9

References for Table III

1. H. A. Majid, M. K. A. Rahim, M. R. Hamid, and M. F. Ismail, "Frequency and pattern reconfigurable slot antenna," IEEE Transactions on Antennas and Propagation, vol. 62, no. 10, pp. 5339-5343, October 2014.
2. A. Boukarkar, X. Q. Lin, Y. Jiang, and X. F. Yang, "A compact frequency-reconfigurable 36-states patch antenna for wireless applications," IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 7, pp. 1349-1353; July 2018.
3. N. Nguyen-Trong, L. Hall, and C. Fumeaux, "A frequency- and pattern reconfigurable center-shorted microstrip antenna," IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 1955-1958, 2016.
4. P. K. Li, Z. H. Shao, Q. Wang, and Y. J. Cheng. "Frequency- and pattern reconfigurable antenna for multi standard wireless applications," IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 333-336, 2015.
5. Y. P. Selvam, M. Kanagasabai, M. G. N. Alsath, S. Velari, S. Kingsly, S. Subbaraj, Y. V. Ramana Rao, R. Srinivasan, A. K. Varadhan, and M. Karuppiah, "A low-profile frequency- and pattern-reconfigurable antenna," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 3047-3050, 2017.
6. N. Ramli, M. T. Ali, M. T. Islam, A. L. Yusof, and S. Muhamud-Kayat, "Aperture-coupled frequency and patterns reconfigurable microstrip stacked array antenna," IEEE Transactions on Antennas and Propagation, vol. 63, no. 3, pp. 1067-1074, March 2015.
7. S. N. M. Zainatry, N. Nguyen-Trong, and C. Fumeaux, "A frequency and pattern-reconfigurable two-element array antenna," IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 4, pp. 617-620, April 2018.
8. Y. P. Selvam, L. Elumalai, M. G. N. Alsath, M. Kanagasabai, S. Subbaraj, and S. Kingsly, "Novel frequency- and pattern-reconfigurable rhombic patch antenna with switchable polarization," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 1639-1642, 2017.

Embodiments of the disclosure are illustrated with respect to FIG. **1**-FIG. **5**. The embodiments describe a segmented patch antenna (SPA) for a WiMAX related application. The SPA **100** includes two rectangular parasitic elements **102**, wherein each parasitic element comprising an integrated diode. The SPA **100** further includes a main rectangular patch segment **108**. The main rectangular patch segment **108** comprising 3 slots, 2 slits and 3 diodes. The SPA **100** is suitable for use in multiple frequencies between 4.1 GHz and 5.7 GHZ inclusive and configurable to operate in 12 independent modes

In an aspect, the SPA **100** further includes four biasing lines, that is, the first biasing line **126**, the second biasing line **128**, the third biasing line **130** and the fourth biasing line **132**, each of length 6 mm (±1.0 mm). and width 2 mm (±1.0 mm).

In an aspect, the four biasing lines each include a limiting resistor (that is, the first limiting resistor **126**R, the second limiting resistor **128**R, the third limiting resistor **130**R and the fourth limiting resistor **132**R) and a choke inductor (that is, the first choke inductor **126**L, the second choke inductor **128**L, the third choke inductor **130**L and the fourth choke inductor **132**L).

In an aspect, the SPA **100** supports at least four frequency bands.

In an aspect, the SPA **100** is reconfigurable to 12 independent modes.

In an aspect, the SPA **100** has efficiency of at least 92% while configured to transmit at 5 GHz.

In an aspect, the SPA **100** operates with average gain of 3 dBi throughout the twelve independent modes.

In an aspect, the SPA **100** operates with average efficiency of 77%, throughout the 12 independent modes.

In an aspect, the SPA **100** includes a back view **100**B wherein the back view **100**B includes a partial ground **138** with one dimension 3 mm (±0.5 mm). and a second dimension 23.5 mm (±1.5 mm).

In an aspect, the back view **100**B further includes a coaxial feed **140** that is placed between 11 mm (±1.0 mm).mm from the top of the partial ground **138**.

In an aspect, the SPA **100** is less than 50 mm (±5.0 mm).×50 mm(±5.0 mm). in area.

To this end, the present disclosure describes a compact frequency and pattern reconfigurable segmented path antenna (SPA). The SPA includes 2 slits, 3 slot and 3 integrated PIN diodes in the slots to increase or decrease the length of the main rectangular patch segment in order to perform frequency reconfiguration. The SPA further includes two integrated diodes in the rectangular parasitic element in order to achieve pattern reconfiguration using the Yagi-Uda principle. The SPA therefore exhibits twelve operational modes in four frequency band merely by using five PIN diodes. Further, the SPA has a miniaturized structure having size less than 55×55 mm^2. The SPA is simple to manufacture that makes the SPA best suited for WiMAX related applications.

Obviously, numerous modifications and variations of the present disclosure will be apparent to the person skilled in the art in light of the above description. For example, the shape of the main rectangular patch segment and the parasitic element may be circular, semi-circular, or triangular. Also, the length and width of the main rectangular patch segment and the parasitic element may have a certain tolerance value compared to the values used in the present disclosure. It is therefore to be understood that within the scope of the appended claims, the disclosure may be practiced otherwise than as specifically described herein.

The invention claimed is:

1. A segmented patch antenna, comprising:

a substrate having a top side and a bottom side, wherein the top side comprises a conductive sheet disposed over the substrate, the conductive sheet comprising a main rectangular patch segment,

the main rectangular patch segment comprising:

a first slot, a second slot, a third slot, a first slit, a second slit, and 3 diodes,

wherein the diodes are connected across each of the slots,

wherein the first slit is connected to and perpendicular to the first slot and the second slit is connected to and perpendicular to the second slot, and

wherein the top side of the segmented patch antenna further comprises two rectangular parasitic elements each parasitic element further having an additional integrated diode,

wherein the segmented patch antenna is configurable to operate in **12** independent modes by turning on or off the diodes.

2. The segmented patch antenna of claim **1**, further comprising **4** biasing lines, each of length between 7 and 8 mm and width between 1 and 3 mm.

3. The segmented patch antenna of claim **2**, wherein each of the 4 biasing lines include a limiting resistor and a choke inductor.

4. The segmented patch antenna of claim **1**, wherein the main rectangular patch segment has one edge of length between 26 and 28 mm and a second edge of length between 21 and 23 mm.

5. The segmented patch antenna of claim **1**, wherein the slots are of width no larger than 0.7 mm and the slits are no larger than 0.11 mm.

6. The segmented patch antenna of claim **1**, wherein each of the two rectangular parasitic elements have one dimension between 26 and 28 mm and another dimension between 2.5 and 3.5 mm.

7. The segmented patch antenna of claim **1**, wherein the rectangular parasitic elements are located at one quarter wavelength from the center on each side of the main patch segment wherein an average of quarter wavelengths of each frequency is used to calculate the location of the parasitic elements.

8. The segmented patch antenna of claim **1**, wherein the rectangular parasitic elements are located between 18 and 19 mm from the center of the main rectangular patch segment.

9. The segmented patch antenna of claim **1**, wherein each of the two rectangular parasitic elements are separated into two sections by pin diodes D1 and D2.

10. The segmented patch antenna of claim **9**, wherein a length of the rectangular parasitic elements is configurable by turning on or off the diodes.

11. The segmented patch antenna of claim **9**, wherein the parasitic elements are reconfigurable to act as a reflector or as a director according to settings of the diodes and a Yagi-Uda principle.

12. The segmented patch antenna of claim **1**, wherein three pin diodes D3, D4 and D5 are integrated on the 3 slots of the main rectangular patch segment in order to vary a length of the main rectangular patch thereby varying a resonance frequency of the antenna.

13. The segmented patch antenna of claim **1**, which supports at least 4 frequency bands between 4.1 GHz and 5.7 GHz inclusive.

14. The segmented patch antenna of claim **1** wherein the substrate has a dielectric constant value less than or equal to 2.4.

15. The segmented patch antenna of claim **1**, with efficiency of at least 92% while configured to transmit at 5 GHz.

16. The segmented patch antenna of claim **1** that operates with average gain of 3 dBi throughout the 12 independent modes.

17. The segmented patch antenna of claim **1** that operates with average efficiency of 77%, throughout the 12 independent modes.

18. The segmented patch antenna of claim **1**, wherein the bottom side comprises a partial ground with one dimension between 2.5 and 3.5 mm and a second dimension between 22 and 25 mm.

19. The segmented patch antenna of claim **18**, which further comprises a coaxial feed disposed 10-12 mm from a top of the partial ground.

20. The segmented patch antenna of claim **1**, wherein the top side of the segmented patch antenna is less than 55×55 mm^2 in area.

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