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A Compact CPW-FED curved patch antenna for UWB applications

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Abstract- Compact and miniaturization of the radiating elements for the ultra wide band (UWB) technology are the latest challenges of electromagnetic engineers. In this paper a novel inverted arc shaped radiating stub based coplanar waveguide fed microstrip patch antenna is proposed. The proposed geometry comprised of many degrees of freedom like arc length, ground plane dimensions and gap widths of the patch and the CPW feed. The effect of these dimensional properties on the characteristics of the proposed antenna are studied. The UWB features of the antenna are studied basing on the reports like return loss (S11), voltage standing wave ratio (VSWR) and radiation pattern.

Keywords- ultra wide band (UWB), planar micro strip patch antenna (PMPA), Coplanar waveguide feed,

1. Introduction

Modern wireless technology demands for a communication sub system that is capable of handling data at a rate of Mega bits per second to Giga bits per second. This in turn specifies the required wide frequency bandwidth which is called UWB. The wide frequency bandwidth facilitates for a wide channel capacity [1,2] which increases the rate of transmission. In addition to high speed capability, the UWB technology has an advantage of very low power consumption. This is due to the fact that the entire signal power is divided and distributed over wide discrete frequencies.

Earlier, the UWB technology suffered with the misconception that it potentially generates interference among several applications. This is due to the then poor technology to extract the wide band signal in strong interference conditions. The inclusion of Industrial Scientific and Medicine (ISM), Wireless Local Area Network (WLAN) and Wireless Fidelity (WiFi) to the unlicensed spectrum paved a path for communication industry to study the merits and implications of wider bandwidth communication. Due to tremendous growth of usage of these bands the FCC later declared the entire band of 7.5GHz between 3.1GHz to 10.6GHz for unlicensed UWB applications [3]. According to FCC, any signal that occupies a spectrum of 500MHz within the range of 3.1GHz-10.6GHz is called UWB.

The Antenna is one such communication sub system that is of prime importance. In order to blend with the demands of the UWB technology mentioned above, the embedded antenna should adopt some additional properties along with that a narrow band antenna possess. The significant increase in the applications in the UWB region have drawn attention of electromagnetic engineers to design antennas with a wide variety of geometries. However, the design of antennas with UWB compatibility have many challenges like wide bandwidth, exactly falling in the spectrum allocated by the FCC and radiation characteristics which are similar over the entire band of operation.

Considering these, many classical and advanced techniques are introduced in the due course of research in antennas for UWB technology. Most fundamental of such antenna geometry is a simple wire monopole. Spark gap radiators, which pioneered the radio technology during the early days of 1900, are considered as the first elements of this UWB technology [4]. Many antenna geometries emerged during later days have their design inspired by these systems. To name, some of them are Vivaldi [5], Bi-conical [6] and Log periodic [7] antennas. These antennas have excellent directional properties but suffer from large size which makes them unsuitable for indoor and portable applications. In addition log periodic and other frequency independent antennas observe severe dispersive and ringing effects. On the other hand, applications of the UWB technology are mostly need antennas which are compact, portable and conformal with good directional properties. In addition to these they significantly need to have radiation characteristics similar though out the entire range of spectrum. Most of the systems operating in the UWB region are simple which need the integrated radiating element also to be having similar structural characteristics and maintain low profile with the device. This has been a challenge and perhaps a limitation of UWB systems until the advent of the printing technology. Planar microstrip patch antennas (PMPA) are the potential candidates that evolved with this technology. Besides satisfying many features of UWB, the PMPAs also have ease of fabrication with low cost and doable to mass fabrication. In addition to these the PMPA are capable of handling any kind of geometry. The conducting patch over the substrate can be of Euclidean shape or fractal [8]. The geometry can be excited using a wide variety of feed systems like co-axial, strip line, microstrip line and CPW. Also multiresonant structures like 'E', 'U' or 'EU' can be easily carved on the patch.

Ultra wide band (UWB) antennas have paramount application in developing UWB technology and served for rapid growth of wireless technology. There are a wide variety of UWB antennas, among which slot antenna is a very important member. This type of antenna can take various configurations such as rectangle, circle, arc-shape, triangle, annular-ring and fractals like Koch, Hilbert or Sierpinski. Also various broadbanding techniques based on printed slot antennas are proposed and their performance is analyzed. Though a simple PMPA designed in [9] could produce excellent broadband characteristics covering the entire UWB range, unfortunately appear to be large in dimension which is inappropriate for certain applications. The CPW fed square slot antenna with tuning stub in [10] has clearly shown a wide bandwidth almost covering 58% of the UWB spectrum. Where as in [11] an improvement n bandwidth is obtained by using rectangular slot and modified stub. But, in none of the cases mentioned above have reported antennas which are capable of sweeping the entire UWB spectrum.

In this paper, such an attempt to achieve complete UWB in to the operating mode of the antenna is made. The simulated antenna validates the attempt to obtain wide bandwidth with analysis based on return loss and VSWR. A thorough analysis of the proposed geometry is possible with parametric analysis of the antenna. The analysis is divided in to several cases and each case one parameter is varied keeping the remaining parameters constant. This enables us to study the impact of the parameter on the UWB characteristics of the antenna.

2. Antenna Design

The geometry of the proposed UWB slot antenna is as shown in the Fig.1. The PMPA mentioned here has a conducting patch over an FR4 substrate of height 1.6mm. The substrate has a dielectric constant of 4.2. The substrate is square piece with dimensions 25mm X 25mm.

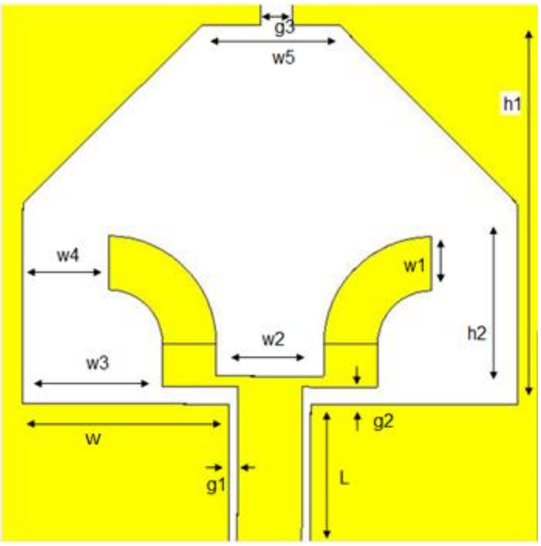


Fig.1: Proposed CPW fed PMPA

The geometry typically consists of two inverted arc shaped stubs projected in to the slot. The slot shape is modified hexagon. The base includes an angle of 90^0 with two sides on either edge. The remaining three sides are arranged to close the six sided slot. The three sides are well described by the length of the centre line (w5). A strip line with two gaps on either sides and projecting towards the slot area forms a CPW feed system. The ground plane is comprised two symmetrical structures running around the slot area inside to the square boundary. The two inverted arcs are facing back to back and initiate from the end point of the T shaped microstrip line and are separated by a gap.

3. Simulation and Optimization

The geometry is simulated using CST MW Studio. The geometry is designed using effective CAD tool embedded with the 3D Full wave Electromagnetic (EM) Simulation tool. The name, full wave is given as the tool is capable of analysing the geometry using all the three possible E and H fields. The designed CAD geometry is provided with all the required boundary conditions to depict the proposed PMPA. The antenna is now excited by establishing the port field conditions at the edge of the CPW structure. The EM simulation tool uses efficient Method of Moments (MoM) field solver engine to solve any complexed EM shapes. The MoM is a fast and accurate numerical technique. Hence the results obtained using this tool are accurate and close to that of the measured.

After completely describing the geometry in the EM tool with necessary boundary conditions, the immediate step is to tune and optimize the model. The main issue with any arbitrary or irregular shaped antennas is feed dimension description. The optimization tool is a versatile option in CST that makes this part of the antenna design convenient. The feed dimension includes the width and length of the strip line and width of the gap on either sides of the feed line that constitute CPW system. Running a parametric sweep with variables describing the dimensions of the microstrip line (L & w2) and the gap (g1). The field distribution and the port description are as shown in the Fig.2.

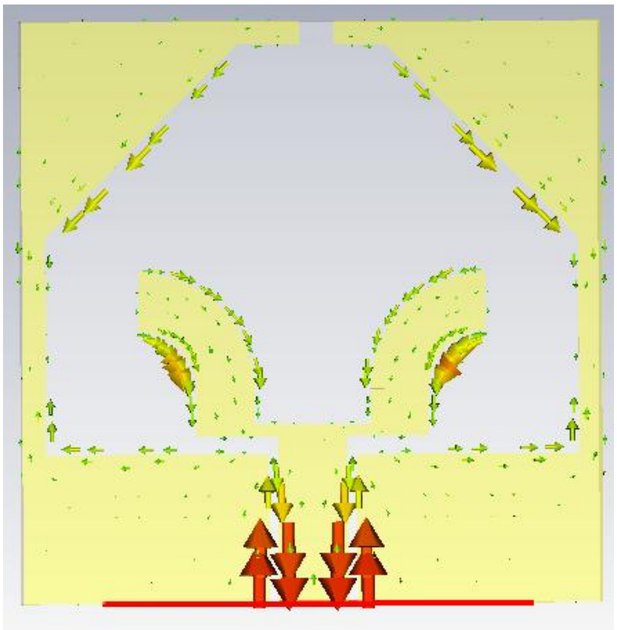


Fig.2: Port definition and current distribution

4. Results and Discussions

As discussed earlier the simulation experimentation is divided in to several cases to perform a parametric analysis of the antenna. For this the parameters diagonal distance (d), length of the feed line (L), width of the arc (w1), height of the arc (h2), width of the arc space (w6) and the width of the gap (w2) between the arc origination points on the 'T' line. The simulation is divided into six cases varying six parameters mentioned above with one parameter fixed to value mentioned in Table.1 in each case.

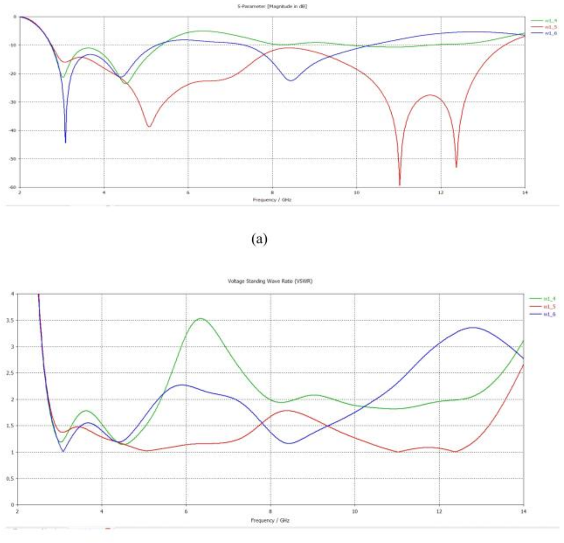
Table.1: Dimensions of the geometry

Dimension	Value (mm)
W1	2
W2	5
W3	7
W4	4
W5	4.2
g1	0.4
g2	0.8
g3	1
h1	14.4
h2	9
L	8

In all the cases reports like return loss (S11) and VSWR are generated to analyze the characteristics of the antenna. In all the cases the upper bound of the S11 is considered as -10dB. Similarly the upper bound of VSWR is 2. The region of the graph below this threshold value are considered to be resonant frequencies. The description and results pertaining to each case are mentioned as follows.

a) Case-1: 'L' varying

The dimension 'L' is varied from 5.4mm to 8.4mm with an incremental step of 1mm resulting in four variations. The variation of the S11 and VSWR with respect to frequency sweep is given in the Fig.3 (a) & (b). It can be analyzed from the plots that a wide range of frequencies have return loss value well below -10dB and the VSWR less than 2.



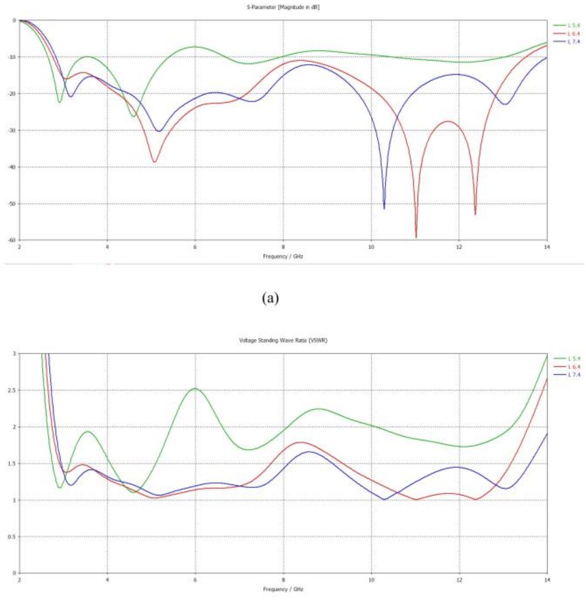
(a)

(b)

Fig.3. Frequency response of the proposed antenna with varying feed length 'L' in terms of (a) Return loss and (b) VSWR

b) Case-2: Varying 'w1'

The width of the arc is varied between 3mm to 6mm with a step size of 1mm keeping the remaining parameters at values specified in Table.1. For each step, the width of the arc is varied accordingly and the corresponding S11 and VSWR values are evaluated against frequency sweep. The respective frequency response curves are as shown in the Fig.4 (a) & (b).



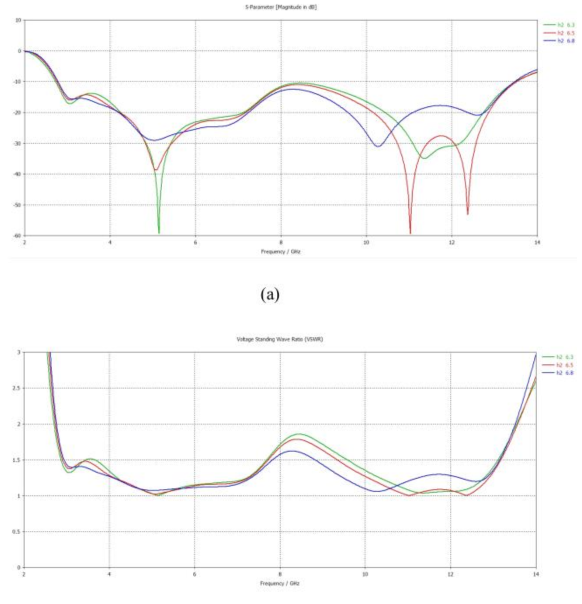
(a)

(b)

Fig.4. Frequency response of the proposed antenna with varying feed length 'w1' in terms of (a) Return loss and (b) VSWR

c) Case-3: Varying 'h2'

The frequency response of the geometry with varying arc height is studied in this case keeping the remaining parameter constant. The arc height h2 is varied with values 6.3mm, 6.5mm and 6.8mm. The corresponding curves pertaining to S11 and VSWR are plotted as shown in the Fig.5 (a) & (b).



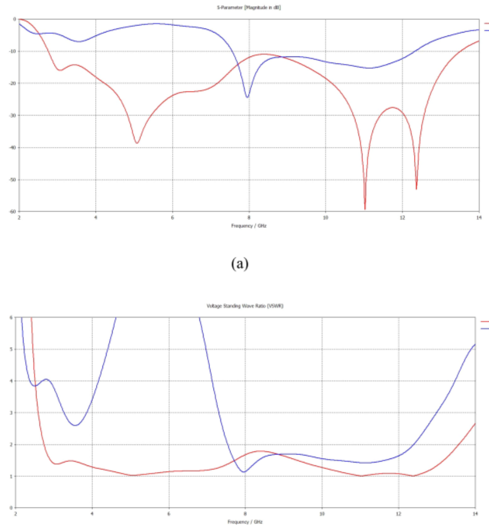
(a)

(b)

Fig.5. Frequency response of the proposed antenna with varying arc height 'h2' in terms of (a) Return loss and (b) VSWR

d) Case-4: Varying 'w6'

The arc space w6 is varied at a step size of 0.2mm from 2.3mm to 2.7mm. For each step the corresponding S11 and VSWR are as shown in the Fig.6 (a) & (b) respectively. It can be inferred from the plots that the resultant geometry for step have shown a wide bandwidth characteristics ranging in the UWB region.



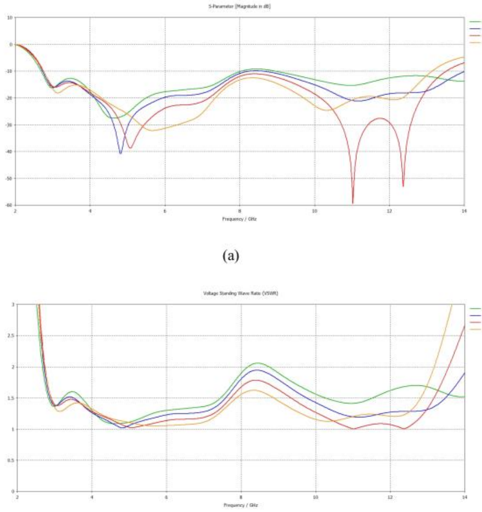
(a)

(b)

Fig.6. Frequency response of the proposed antenna with varying arc space 'w6' in terms of (a) Return loss and (b) VSWR

e) Case-5: Varying 'w2'

w2 represents the gap between back to back arranged inverted arc shaped strips mounted on the horizontal arm of the 'T' shaped microstrip line. This w2 is varied at a step size of 0.1mm from 3.3mm to 3.6mm. For each step the corresponding frequency response curves with respect to S11 and VSWR are plotted as shown in Fig.7 (a) & (b). The UWB characteristics can be read readily from these plots.



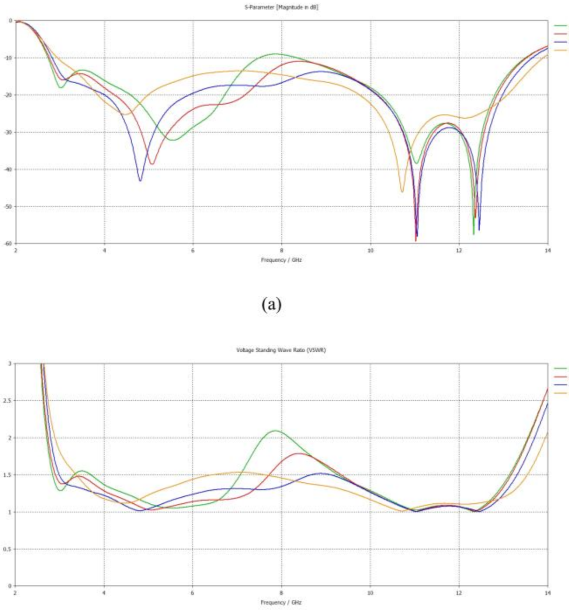
(a)

(b)

Fig.7. Frequency response of the proposed antenna with varying parameter 'w2' in terms of (a) Return loss and (b) VSWR.

f) Case-6: Varying'd'

diagonal length of the ground plane 'd' is varied from 6.28mm to 9.28mm with an interval of 1mm keeping the remaining parameters constant at values specified in table.1. Plots corresponding to S11 and VSWR for each step combination are as given in Fig.8 (a) & (b).



(a)

(b)

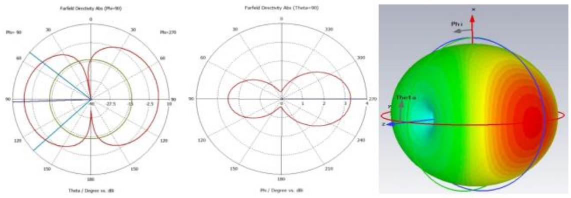
Fig.8. Frequency response of the proposed antenna with varying diagonal length 'd' in terms of (a) Return loss and (b) VSWR.

g) Radiation Patterns of simulated geometry

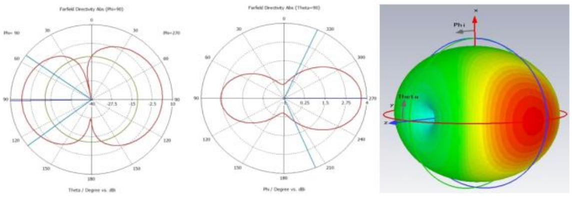
From Fig.3 through Fig.8 the S11 and the VSWR plots are used to gain the knowledge of the resonant frequencies and the resonant bandwidth of the antenna. In order to conclude the resonant characteristics of the radiating element the knowledge of the S11 and the VSWR are not sufficient. In such case, 2D and 3D radiation pattern plots are useful to verify the characteristics at the obtained resonant frequencies of selecting some frequency points from the resonant bandwidth and compare them with the template radiation patterns of a simple patch antenna. The radiation pattern at the resonant frequencies are supposed to have maximum radiation directed towards the patch side and minimum towards the ground side.

In this section radiation pattern plots drawn for the geometry with the optimized dimensions mentioned in the table 1. Resonant frequencies are selected as 3.5 GHz, 5 GHz, 7.5 GHz, 8 GHz 9.5 GHz and 12 GHz from the wide resonant bandwidth that is common in Fig.3 through Fig.8. Along with three dimensional radiation plots, two dimensional radiation plots for

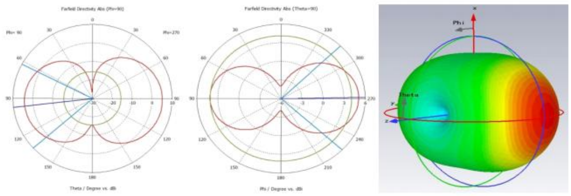
i) all elevation angles with azimuthal angle constant at 90^0
ii) all azimuthal angles with elevation angle constant at 90^0 are taken for analysis.



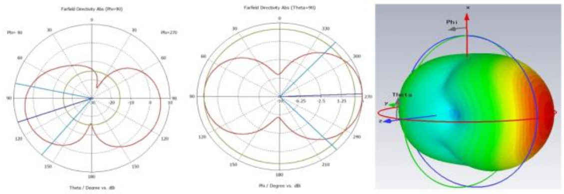
(a) Ø =90^0 at 3.5GHz (b) θ=90^0 at 3.5GHz (c)3D at 3.5GHz



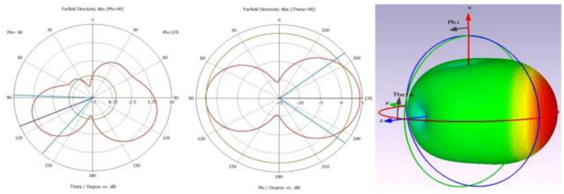
(c) Ø =90^0 at 5GHz (d) θ =90^0 at 5GHz (e)3D at 5GHz



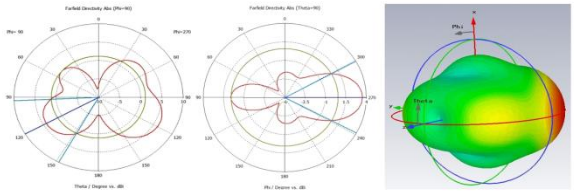
(f) Ø =90^0 at 7.5GHz (g) θ =90^0 at 7.5GHz (h)3D at 7.5GHz



(i) Ø =90^0 at 8GHz (j) θ =90^0 at 8GHz (k)3D at 8GHz



(l) Ø =90^0 at 9.5GHz (m) θ =90^0 at 9.5GHz (n)3D at 9.5GHz



(o) Ø =90^0 at 12GHz (p) θ =90^0 at 12GHz (q)3D at 12GHz

Fig.9: Radiation pattern diagrams for all θ and Ø =90^0, for all Ø and θ =90^0 and for all θ & Ø (3D) at 3.5 GHz, 5 GHz, 7.5 GHz, 9.5 GHz and 12 GHz.

h) Fabricated Prototype:

The fabricated prototype with the optimized parameters of the proposed antenna is as shown in the Fig.10. The measured return loss can be read from the network analyzer screenshot presented in the Fig.11.

Fig.10: Photograph and experimental setup of fabricated prototype

Start 2.000000000 GHz

S11
10.00dB/
0.00dB LogM
dB S11

> 1: 3.005000 GHz -9.4233 dB

Ch1: Start 2.00000 GHz Stop 15.0000 GHz

CH 1: S11 C 1-Port

Fig.11. Measured Frequency response of the prototype with respect to (a) Return Loss (S11).

It is clear from the above mentioned results that the measured results are in good agreement with the simulated results.

5. Conclusion

The arc shaped radiating stub is used in place of regular sharp edged L and T shaped stubs and the bandwidth characteristics are observed. An excellent bandwidth enhancement is verified with return loss (S11), VSWR and radiation pattern plots. A thorough parametric analysis is performed with the chosen physical dimensions of the stub and the radiating patch. The effect of each parameter on the bandwidth is analysed and presented. The curve structure in the arc shaped stub provided necessary current transferring path better than the sharp edged stubs and supported the fundamental mode operation. This results in maximizing the current density and further enhancing the gain characteristics. The fabricated prototype and the measured results are in good agreement with the simulated results.

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