Research Article

Double Meander Dipole Antenna Array with Enhanced Bandwidth and Gain

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In this paper, a new design of high gain and wide bandwidth microstrip patch antenna array containing double meander dipole structure is proposed. Two in-phase resonant frequencies in the Ku-band (12–18 GHz) could be achieved in the double meander dipole array structure, which lead to enhance impedance bandwidth without costing extra design section. Besides, further enhanced gain of 2 dBi of the array over the entire operating frequency range has been achieved by introducing a double-layer substrate technique. The proposed antenna has been fabricated using the E33 model LPKF prototyping PCB machine. The measurement results have been performed, and they are in very good agreement with the simulation results. The measured −10 dB impedance bandwidth indicates that the array provides a very wide bandwidth which is around 30% at the center frequency of 15.5 GHz. A stable gain with a peak value of 10 dBi is achieved over the operating frequency range. The E- and H-plane radiation patterns are simulated, and a very low sidelobe level is predicted. The proposed antenna is simple and has relatively low-profile, and it could be a good candidate for millimeter wave communications.

1. Introduction

High gain, wide bandwidth, and compactness are the primary features of antennas which are of interest in many modern wireless applications [1, 2]. Parabolic dish antennas, which have high gain and are relatively large bandwidth antennas, were commonly used in the Ku-band satellite communication systems [3]. However, they are less desirable for millimeter wave applications because of their curvature shape and bulky size. Due to their flexibility in design and lightness in weight, microstrip patch structures have been widely focused in the antenna design [4–7]. A linear active microstrip patch array is utilized to feed a lens antenna in order to improve the antenna gain and the power amplification capability for the Ka-band satellite communication

system [8]. The Eggcup-type of lens with a 2 × 2 microstrip patch array is also presented in [9] to design a larger and high-gain microstrip array with a more compactness layout. The truncated edge of the microstrip element with an L-shaped branch of a 4 × 4 array is presented in [10] to improve the gain and widen the bandwidth. A new architecture of a compact Psi-shaped microstrip antenna is imprinted on Rogers RT/Duroid 5880 materials in [11] for Ku-band satellite applications. Also, two 2 × 1 microstrip arrays with energy band gap structure [12] and defected ground structure [13] were investigated in order to suppress the back lobes of the pattern, eliminate the higher harmonic modes, and enhance the array bandwidth. It should be addressed that the losses yielded in the feeding network of microstrip arrays are considered as one of the main

drawbacks, particularly at millimeter wave frequencies which are significant [14].

Inherently, microstrip patch antennas are considered as narrow bandwidth antennas due to their feed network. Many efforts to enhance the antenna bandwidth were reported in the literature. A very large bandwidth U-shaped slot antenna, which is placed on a conventional microstrip substrate, was reported in [7]. A three element nonuniform rectangular microstrip patch array, which is fed via a rectangular aperture from beneath, is placed on a Teflon substrate with a dielectric constant of 2.1 [15]. Such feed technique has improved the antenna bandwidth significantly. Recently, filtering antenna array technique has become an interesting approach to control the bandwidth of the microstrip antenna arrays using the bandpass (BPF) filter theory [16–19]. The main challenge during the implementation of this technique is the dimensional optimizations of the employed resonators in the antenna arrays to avoid phase interference from resonators and generate constructive radiation patterns.

In this paper, a compact meander dipole (MD) based on two integrated in-phase microstrip resonator structure shown in Figure 1 is proposed. Conventionally, a rectangular microstrip patch antenna produces a single resonant frequency at the operating frequency band of interest. However, because of the two in-phase microstrip resonators structures, the proposed MD shape produces two resonant frequencies without costing any extra structure or size. It should be mentioned that the genetic algorithm optimization feature in the computer simulation technology (CST) studio [20] is utilized and implemented on the physical dimensions of the MD structure. This is to adjust and bring the two resonant frequencies close to the edges of the frequency band of interest and then enlarge the antenna bandwidth. More details are given in Section 2. On the other hand, an extra substrate layer is introduced and placed beneath the original substrate in order to reflect the radiated power in the backside and then improve the antenna gain. Such improvement can be depicted in Section 3.

2. The Proposed Antenna Design

A single MD is designed and modeled using the CST studio as shown in Figure 1. Instead of a conventional rectangular microstrip patch, the MD is introduced which is based on two integrated microstrip resonators as colored in yellow as shown in Figure 1. This is to manipulate the resonant frequencies of the resonators and then enlarge the bandwidth the antenna as discussed in Section 1. The substrate layer is created utilizing RT Duroid 5880 LZ with a thickness of 3.127 mm and a dielectric constant (ε_r) of 1.96. Each element of the MD is modeled originally from the integration of two microstrip resonators. The knowledge regarding the integration of resonators given in [19] has been taken into account in this work. The optimum dimensions of the proposed single MD antenna are presented in Table 1.

To improve the gain, the design of a two-element antenna array is proposed here. The proposed arrays are based on the two MD structures as shown in Figure 2. The
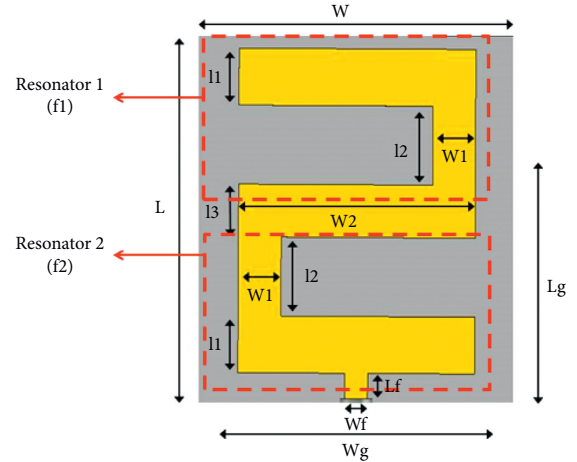

Figure 1: The structure of the proposed meander dipole antenna.

Table 1: Designed antenna parameters.

Parameters	Value (mm)	Parameters	Value (mm)
W	23.45	l1	3.618
L	23.45	w1	3.149
Wg	21.44	l2	5.03
Lg	15.41	w2	17.42
Wf	2	l3	3.35
Lf	1.943		

dimensions of the MDs are optimized with the aid of the CST in a way that the two resonant frequencies ($f1 = 14.5$ GHz; $f2 = 16.5$ GHz) around the operating center frequency edges. On the top layer of the substrate, the two MD elements with the feeding network are printed. It is worth mentioned that the feeding network is optimized in order to have minimum reflection coefficient to the input port and has negligible influence on the S_{11} response of the array. The substrate is made from the RT Duroid 5880 LZ with the relative permittivity 1.96 and thickness of 3.175 mm. The other side of the substrate is the ground layer with 29.5 mm × 80 mm size. To further improve the array gain, another substrate layer is introduced which has the same characteristics as the first substrate as shown in Figure 2(b). This is to reflect the radiated power back to the main radiation side and hence improve the array gain. The physical dimensions of the MD structure and the array are summarized in Table 2.

3. Simulation Results

The simulated return loss of the single MD antenna over the Ku frequency band is shown in Figure 3. It can be seen that the return loss of the antenna is below −10 dB between 10.2 and 17.2 GHz. The fractional bandwidth (FBW) is 50% at the center frequency (13.6 GHz) which is extremely large; this is because of having two obvious resonant frequencies at 11.5 GHz and 15.5 GHz.

The simulated reflection coefficient ($S11$) of the two-element MD microstrip array is shown in Figure 4. Similar to
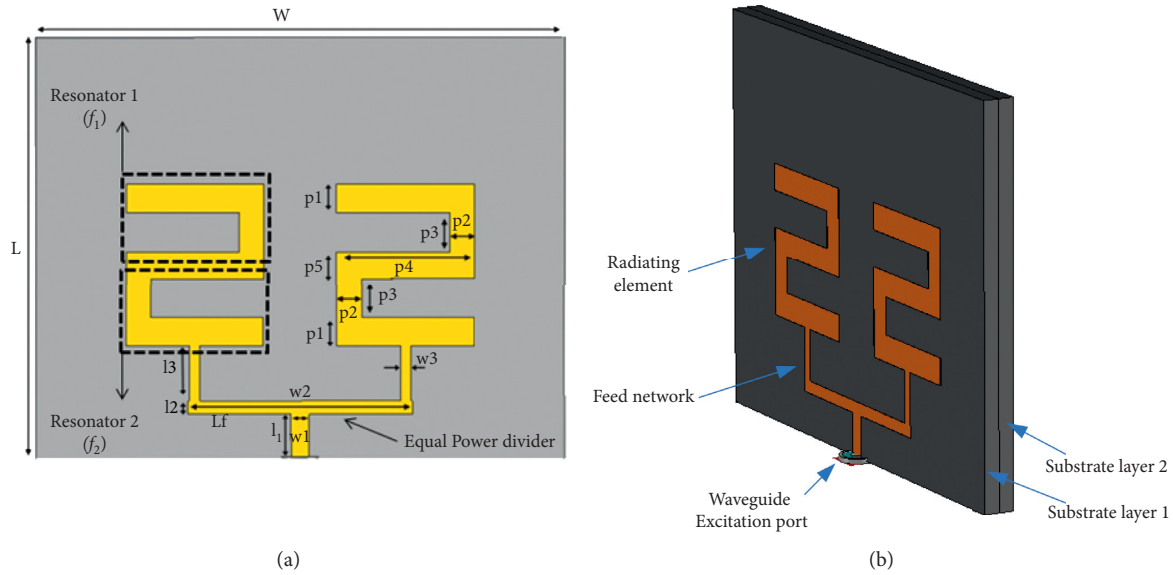
(a)

(b)

FIGURE 2: Layout of the proposed two-element MD array with (a) the physical parameters label and (b) substrate position.

TABLE 2: Proposed array antenna parameters.

Parameters	Value (mm)	Parameters	Value (mm)
W	100	L2	2.5
L	80	L3	10.4
Gw	80	P1	5.4
Gl	29.5	P2	4.7
W1	3.4	P3	7.5
W2	42.4	P4	26
W3	2	P5	5
L1	8.5		
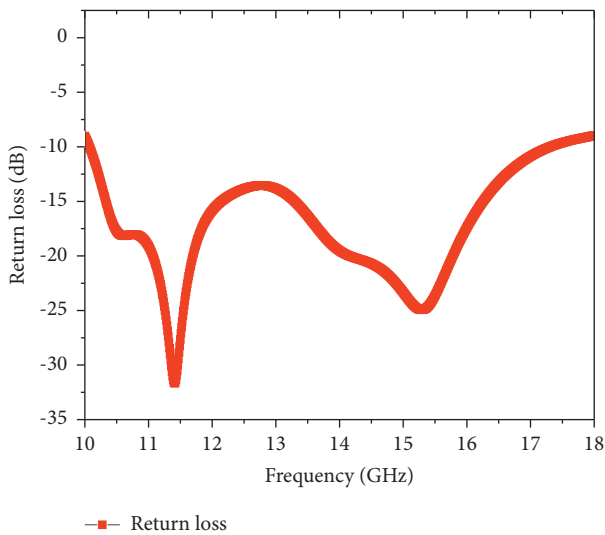
FIGURE 3: The return loss response of the single MD antenna.

FIGURE 4: The proposed S_{11} antenna response.

the single MD antenna, two obvious resonant frequencies ($f1$, $f2$) are depicted at 14.5 GHz and 16.5 GHz. The 10 dB impedance bandwidth is more than 30%. To the best
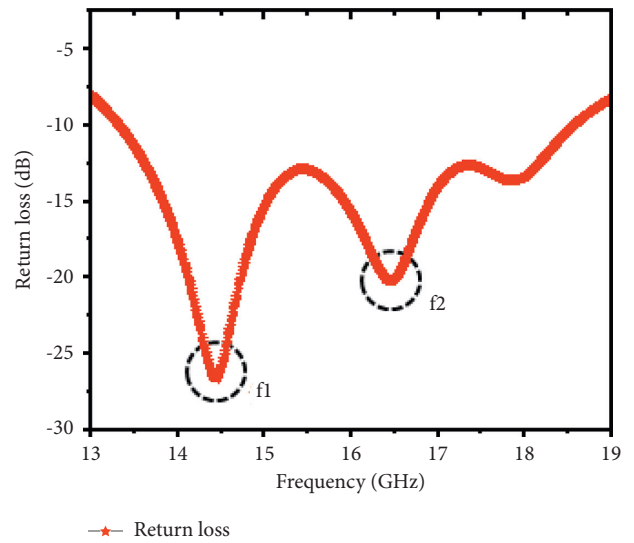
knowledge of the authors, such achievement of large bandwidth for such low-profile structure has not been reported in the literature. Both of the presented designs have stable realized gains over the entire operating frequencies, as can be seen in Figure 5. Looking the frequency range of interest, the realized gain of the single MD design fluctuates from 6 to 8.2 dBi.

As shown in Figure 5, the MD array gain with a single substrate layer has a peak gain around 7.9 dBi at 13.3 GHz. Adding the second substrate layer allows a 2 dBi gain improvement over the entire operating frequency band as can be noticed in Figure 5. It is fundamental that when an antenna system is fed, the radiating elements try to launch as much the input power to free space as possible. However, due to the mismatch issue and radiator bandwidth
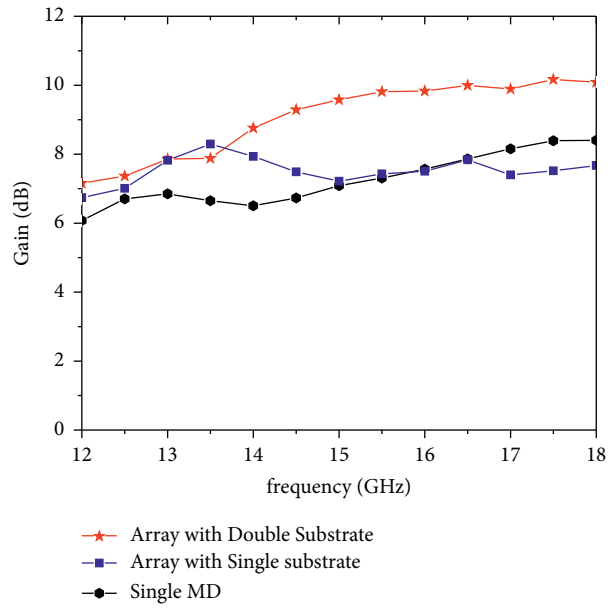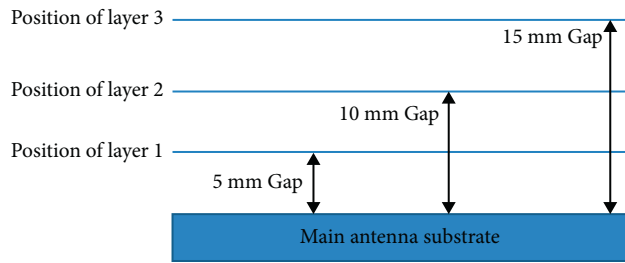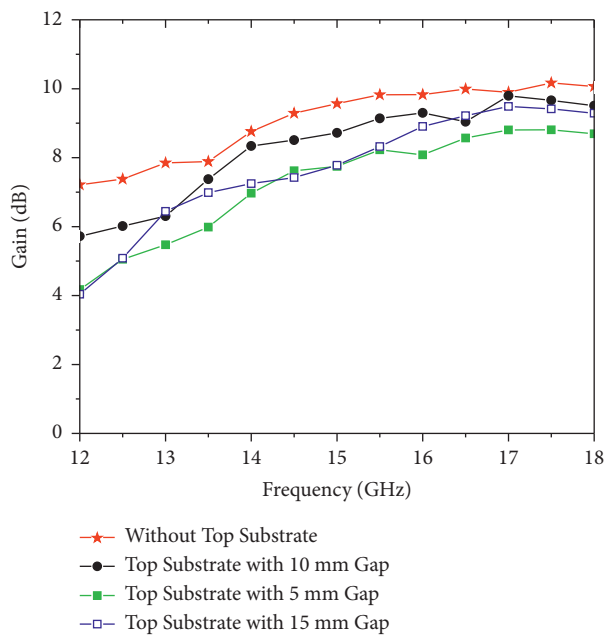
FIGURE 5: The antenna gain with the effect of the 2nd substrate.

(a)

(b)

FIGURE 6: (a) The effect of top substrate on the antenna gain and (b) position of three substrate layers.

constrains, all the inserted input power may not be radiated and may be stored in the reactive region the antenna. Some of the power may also reflect to the input port. Thus, when a structure like what we named second layer in this paper is added to the antenna, it could lead to the backside radiation, nonradiated power, and stored power in the reactive region to be redirected to the radiation side of the two MD array. Therefore, this could increase the radiation intensity and eventually increase the gain of the antenna.

Further, investigation has been conducted on the proposed antenna regarding the addition of more substrate layers. It has been concluded that if we place another substrate layer over the main one depending on the relative permittivity parameter, the transmission signal would be degraded. To confirm this claim, the top substrate has been added to the structure with three different gaps. The result shows that the realized gain decreased with existence of the top substrate, and its impact has been reduced with increasing the gap distance as shown in Figure 6.

The defected ground plane in the MD array plays an important role in improving the antenna realized gain as illustrated in Figure 7. The ground plate size has been
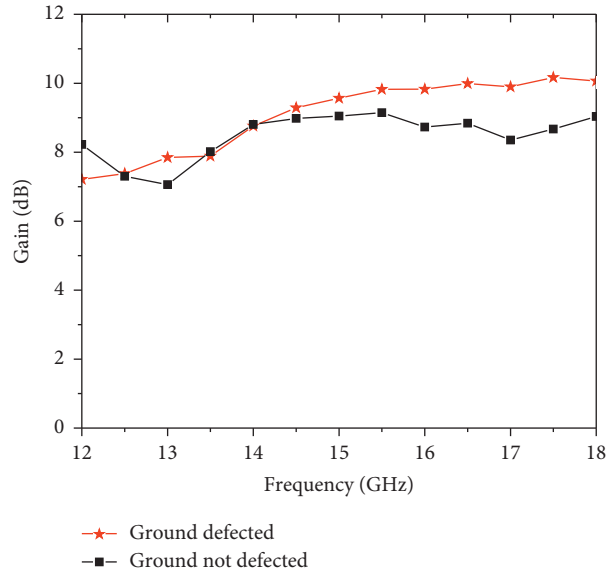
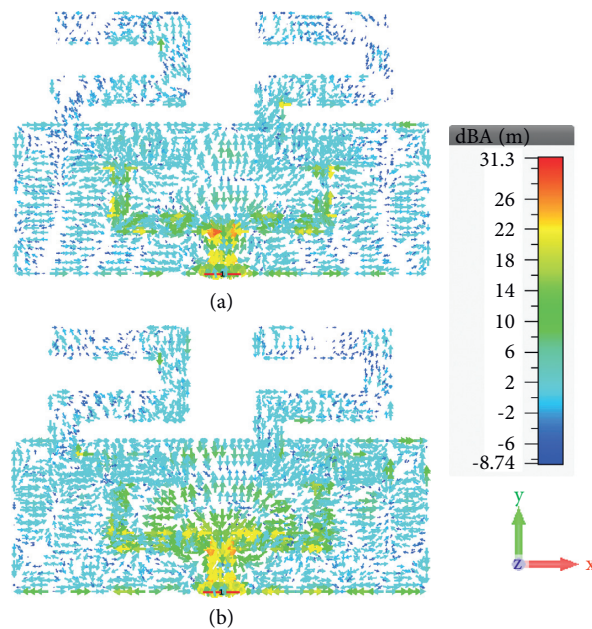FIGURE 7: Effect of the defect ground plane on the proposed design.

FIGURE 8: Proposed structure with current view distribution at the resonance frequencies: (a) 14.5 GHz; (b) 16.5 GHz.

optimized to achieve a high and stable realized gain over the operating frequency ranges.

The current distribution of the antenna is presented in Figure 8. It can be observed that the current is strengthened around the feeding line and the MD structure, especially at the lower part of lower resonators.

The radiation patterns of the array at the center frequency of 15.5 GHz are illustrated in Figure 9. The E-plane radiation pattern is well shaped, while the H-plane experiences asymmetrical properties with a shifted main lobe toward 30°–60°. This could be due to asymmetrical ground plane around the feeding network in the bottom layer and phase variation between the two MD elements.

4. Fabrication and Measurements

To validate the simulation results, the proposed meander dipole microstrip array has been fabricated using E33 model LPKF prototyping PCB machine as shown in Figure 10. The substrates were made of the RT Duroid 5880 with the relative permittivity of 2.2 and thickness of 3.175 mm. After the fabrication, the 50-ohm SMA connector has been soldered to the feeding line and ground plane of the structure in order to connect to the PNA-L Agilent vector network analyzer (VNA) as can be depicted in Figure 10(b). The measured S_{11} is found to agree quite well with the simulation2 results as compared in Figure 11. There is a small operating frequency

(a)   (b)
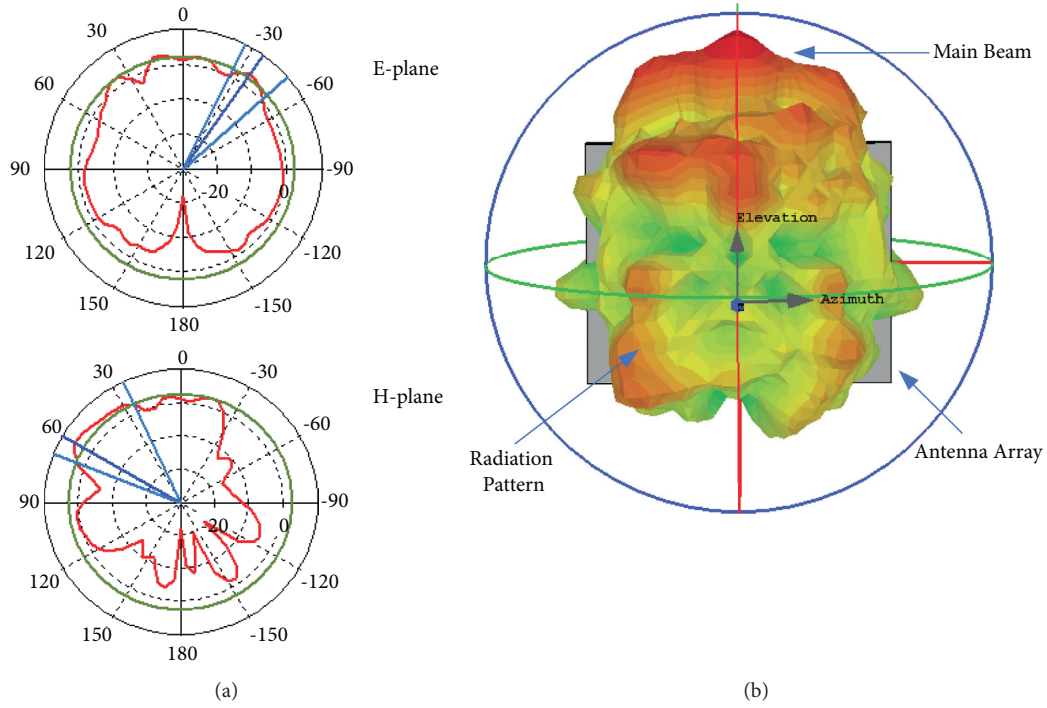
FIGURE 9: The antenna radiation patterns at the operating center frequency of 15.5 GHz: (a) polar radiation pattern; (b) 3D radiation pattern.
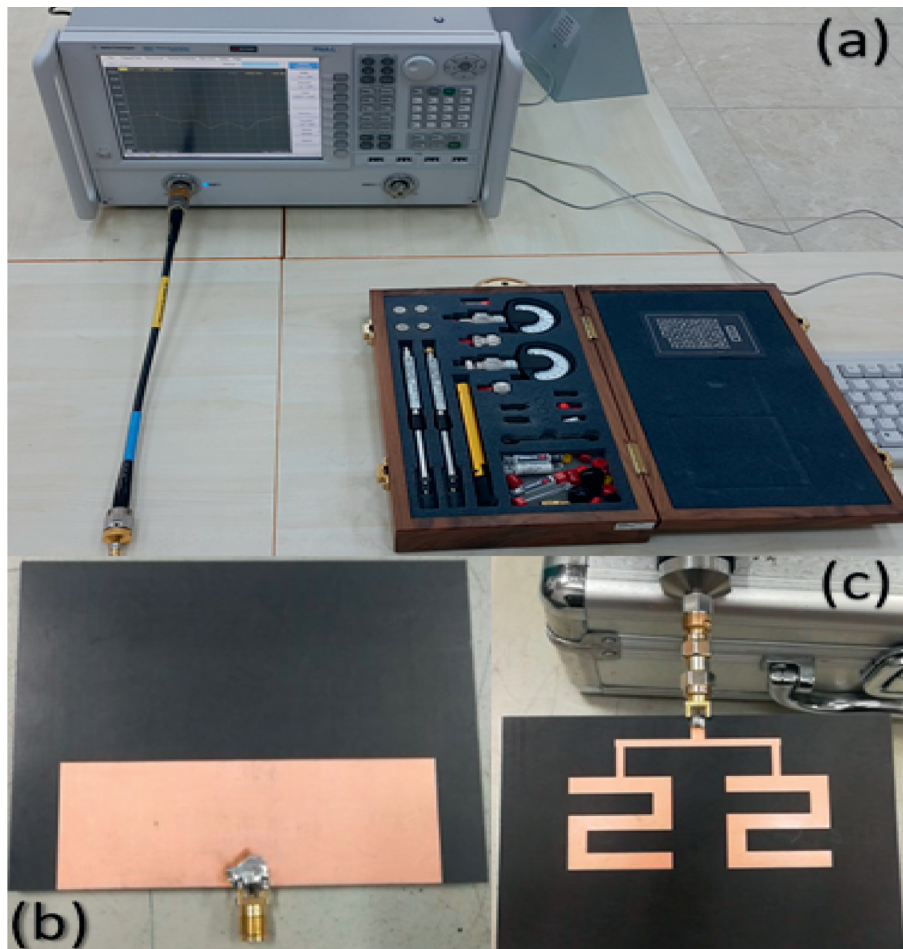

FIGURE 10: Photograph of a fabricated proposed meander dipole: (a) experimental set up; (b) back view; (c) fabricated antenna connecting to VNA.
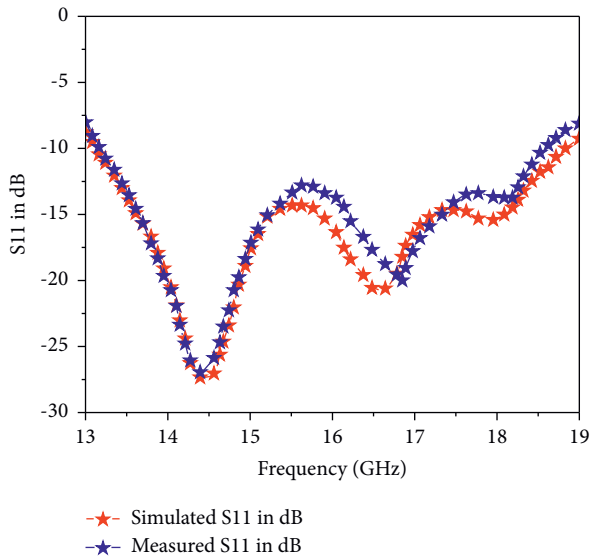
FIGURE 11: Comparison measured and simulated return loss of the proposed antenna.
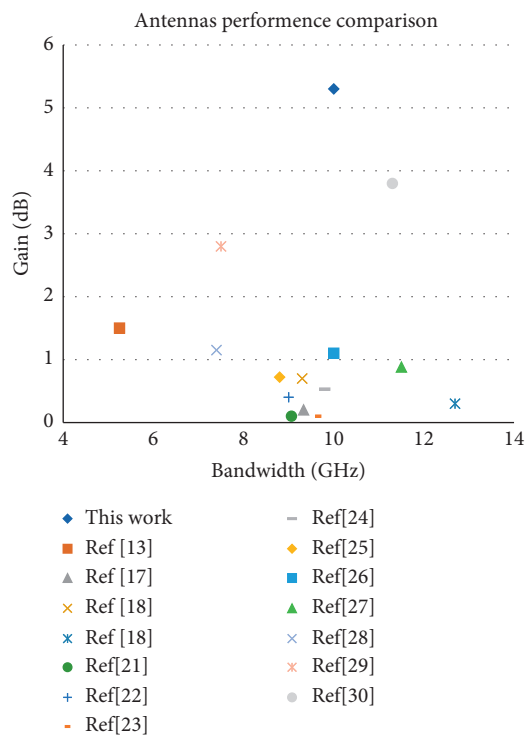

FIGURE 12: Comparison between the proposed design and other published works in terms of gain and bandwidth [21–30].

shift observed to the right-hand side of Figure 11, which could be due to the fabrication tolerance.

It is important to note that usually there exists a tradeoff between the gain and bandwidth improvement in antenna design. Therefore, it remains a challenging task to design an antenna with high gain, wide bandwidth, and keeping the antenna structure as simple as possible. For this purpose, the proposed antenna design is compared with the published designed antennas for the millimeter wave technologies in order to evaluate the achievements of the proposed antennas, and comparision results are summarized in Figure 12. Obviously, 5.2 GHz bandwidth with 10 dB peak gain of proposed double meander dipole antenna array with low-profile structure could be achieved. The evaluation is conducted based on the important parameters including bandwidth and maximum gain.

5. Conclusion

In this paper, a new design of high gain and wide bandwidth planar array printed microstrip patch antennas has been presented. The design of the array was based on symmetrical mender dipole shapes with two resonators. The main theme was to improve the bandwidth by introducing a novel MD structure instead of the conventional square patch. The MD shapes behave as resonators which have been optimized in such way that they provide wider bandwidth. In addition, a double substrate layer technique was presented to enhance the antenna gain. The simulated and measured array responses (i.e., results) agreed well with each other. The obtained results show that 30% impedance bandwidth was achieved over the frequency range of 13.3–18.5 GHz with the peak gain of 10 dB. Therefore, it is believed that the design could be of interest to millimeter wave applications.

Data Availability

No data were used to support this study.

Disclosure

The funder had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

H. N. A., R. H. M., and B. A. K. conceptualized the study; R. H. M. and Y. I. A. contributed to methodology; H. N. A. and B. A. K. provided the software; R. H. M and Y. I. A. validated the study; H. N. A., R. H. M., and B. A. K. were responsible for formal analysis; H. N. A. investigated the study; R. H. M. was responsible for resources; H. N. A. was responsible data curation; H. N. A. and B. A. K. prepared the original draft; Y. I. A., H. L., and M. K. reviewed and edited the manuscript; H. N. A. and R. H. M. visualized the study; M. K. and H. L. supervised the study; M. K. and H. L. were responsible for project administration; H. L. was responsible for funding acquisition.

Acknowledgments

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