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High Gain Ultra-Wideband Parabolic Reflector Antenna Design Using Printed LPDA Antenna Feed

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Abstract

Reflector antennas with log periodic dipole array (LPDA) feeds are ideal for applications that demand high gain, broadband operation. However, when the phase center of the LPDA is not fixed, mismatches at the focal point cause degradation and large ripple in gain. To overcome these issues, a printed LPDA is optimized for minimal phase center variation as a reflector antenna feed. The antenna is designed to operate at 1-19 GHz frequency band with voltage standing wave ratio (VSWR) less than 3.0 and minimum gain of 17 dBi. Reflector size can be increased for further improvement in gain. Designed antenna parameters, radiation patterns, and aperture efficiencies over frequencies are presented and compared to previous studies.

Keywords: Log periodic dipole array; UWB; reflector antenna; parabolic reflector; high gain; direction finding; electronic intelligence.

1. Introduction

High gain, broadband antennas play a vital role in electronic intelligence systems [1], multimode radars [2], satellite communication and broadcasting services [3-5]. One particular broadband antenna is log periodic dipole array (LPDA) which consists of logarithmically scaled half wavelength dipoles. LPDA provides acceptable gain for most of the ultra-wideband applications. However, if higher gain is needed, LPDA alone becomes inadequate.

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Moreover, wire dipole form of LPDA has large antenna form factor which precludes its usage in space-constrained applications. When LPDA is printed on substrate, a low profile version can be easily obtained. The antenna size can be further reduced by increasing the thickness or relative permittivity of the substrate.

One of the most design challenges in using LPDA as a reflector antenna feed is obtaining a stable input port matching with minimal change in phase center [6-8]. Fluctuating phase center over the frequency range causes shifts in focal point of the reflector antenna, which, in turn, affects attainable gain and aperture efficiency, and degraded voltage standing wave ratio (VSWR).

One of the first studies in which parabolic reflectors were fed by LPDA was reported in [9], where the optimum value of the focal length to diameter ratio of reflector was targeted. The effect of LPDA structure and the phase center change on gain was observed. Parabolic reflector fed with an LPDA at 1-7 GHz frequency band was shown in [10], where the ratio of focal length to diameter was 0.4. It is evident in many of these prior works that phase center fluctuation greatly influences antenna gain, and more importantly, its radiation pattern. To minimize phase center variation, LPDA and reflector design was optimized together in [11], however, it was realized that further parameters such as side-lobe level (SLL) and half power bandwidth (HPBW) were also needed to be considered in the optimization.

In this study, firstly printed LPDA is designed and optimized for the optimum broadband phase center, low return loss, stable HPBW and uniform gain in the desired frequency band. Then, designed printed LPDA is used as prime-focus feed to increase the gain with attention to SLL, front-to-back ratio, return loss, and HPBW. When the LPDA is in front of the reflector antenna, VSWR of the LPDA slightly deteriorates due to the near field coupling and defocusing effect. This is minimized with the optimization of LPDA and reflector geometry. In Section 2, we present LPDA and reflector antenna design. In Section 3, simulation results using CST Microwave Studio [12] are detailed. Conclusions are given in the final Section.

2. Design of the Antenna

2.1. Design of LPDA

The design follows the basic approach presented in [13-14]. The length of the smallest and largest dipole is inversely proportional to maximum and the minimum frequency. After calculating the first and the last dipole of the structure, other dimensions are calculated using geometrical scaling factor (τ) as shown in the following,

$$\tau = \frac{l_m}{l_{m+1}} = \frac{s_m}{s_{m+1}} = \frac{w_m}{w_{m+1}} \qquad (1)$$

The dimensions of the antenna are shown in Figure 1. The width of the dipole and spacing between elements also change logarithmically as the length of dipoles. The angle shown in the figure is fixed because the lengths of the dipoles decrease with scaling factor as,

$$\tan\alpha = \frac{(l_{m+1} - l_m)/2}{s} \qquad (2)$$

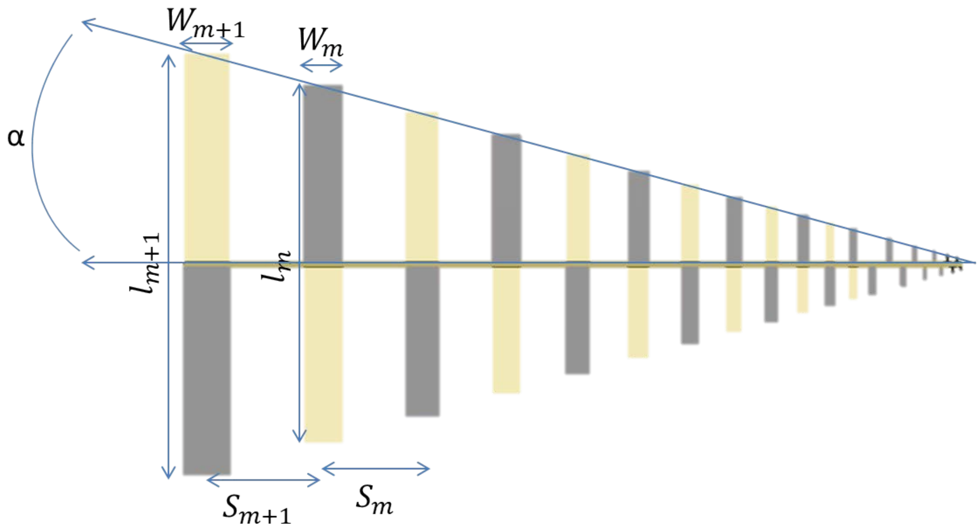

Figure 1: LPDA structure (gray: top side, yellow: bottom side).

The number of dipoles affects positively the bandwidth and the gain, but the size of the antenna grows. LPDA antenna is fed near the shortest dipole. The line feed on both sides of substrate has 50 ohm impedance.

Rogers 5880 dielectric substrate is selected for the printed LPDA. Relative permittivity of this substrate is 2.2 and its thickness is 0.762 mm. The lengths of the largest and the smallest dipoles are 177 mm and 5.11 mm, respectively. The minimum dipole width is chosen 0.5 mm. Optimal geometrical scaling factor of this design is selected as 0.85 and α is 15.16 degree. So the total size of the LPDA which has 23 half wavelength dipoles is 218 mm x 350.66 mm x 0.62 mm. Optimized printed LPDA structure is shown in Figure 2.

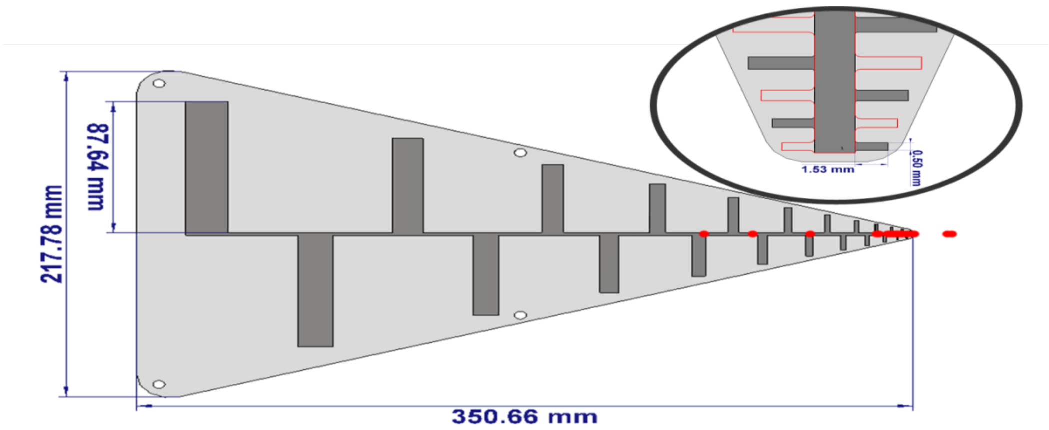

Figure 2: Designed LPDA dimensions (Red points from left to right shows phase centers from 1 GHz to 19 GHz with 1 GHz separation).

Fractional bandwidth of this LPDA is %180, and has more than 500 MHz frequency band to qualify for ultra-wideband description. The main disadvantage of UWB antennas is that the phase centers are variable. Therefore, it is difficult to use them as a feed for reflector antenna systems. Hence, one of the most important parameters in optimizing the antenna is the stabilization of phase centers.

LPDA antenna is designed and simulated using CST Microwave Studio [12]. Quad-core Xeon processor with 64 GB RAM workstation is used for 3D electromagnetic simulations.

2.2. Prime focus parabolic reflector design

Center focus parabolic reflector antenna is the most commonly used type of reflector antenna. Parabolic reflector can be initially designed using physical optics [6-8]. The reflector is designed using the following relations,

$$\tan\varphi_o = \frac{D/2}{F-H} \qquad (2)$$

$$2.F = R + R.cos\varphi \qquad (3)$$

$$F = \frac{D^2}{16.H} \qquad (4)$$

where F is the focal length, D is the diameter of paraboloid, H is depth of the reflector and φ_o is half horizontal angle of the reflector (Figure 3). For a paraboloid with depth H and diameter D in an x-y plane, the geometric relations become as flows:

$$y = a.x^2 \qquad a = \frac{H}{(D/2)^2} \qquad (5)$$

where x-axis varies from 0 to $D/2$. It is clear that when x is $D/2$, y will become H. The dimensions of the reflector can be formulated using the f / D ratio alternatively as,

$$\varphi_o = 2tan^{-1}(\frac{1}{4.(f/D)}) \quad . \qquad (6)$$

As f / D ratio increases, the depth of the reflector decreases.

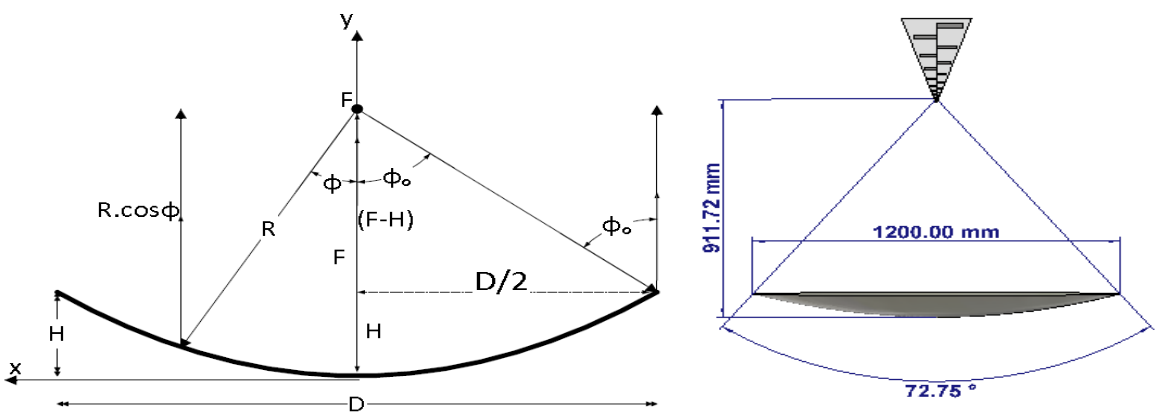

Figure 3: General geometry of the parabolic reflector antenna and the parabolic reflector fed by LPDA (F=911.72 mm, D=1200 mm and $2\varphi_o$=72.75 degree)

The designed parabolic reflector antenna is also shown in Figure 3. Diameter of the reflector is 1.2m and its focal length is 0.91m. So f/D ratio is 0.76 and the subtended angle of this reflector is 72.75 degrees.

2.3. Reflector feed

The HPBW distribution of the feeding antenna and its reflection on the reflector surface is important for high gain low cross polarization. Subtended angle of the reflector and HPBW of the feed antenna must be compatible. It is more important that the phase center is stable for all frequency bands when the feeder antenna is placed at the focal point. However, phase losses usually occur at the frequency extremes of the band. At higher frequencies, phase center variation relative to wavelength becomes large and attention must be paid at the optimization at these frequencies of the target band.

3. Simulation results

3.1. Results of LPDA

LPDA is simulated in free space first. Return loss appears to be almost less than -10 dB in the range of 0.7-19 GHz. VSWR of the designed antenna is under 2 at the desired band (1-19 GHz). Return loss and VSWR results are shown in Figure 4.

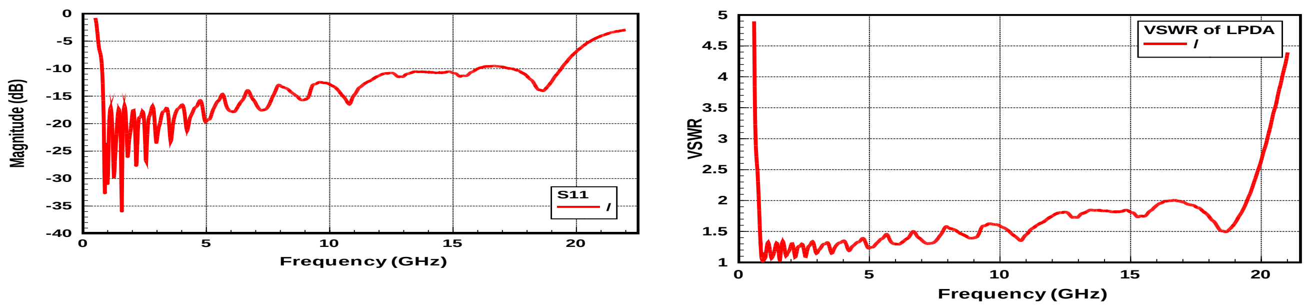

Figure 4: Return loss (left) and VSWR (right) of the LPDA.

Gain of the LPDA is shown in Figure 5. It varies between 8.03 – 8.8 dBi, and is very stable from 1 GHz to 19 GHz. The gain attains greatest value at 2 GHz and smallest value at 15 GHz.

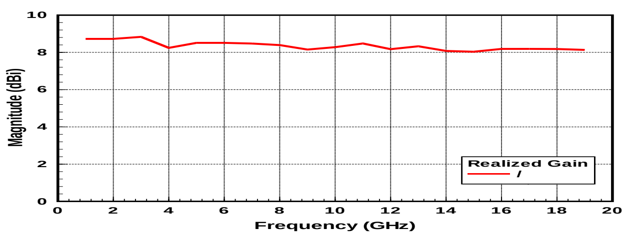

Figure 5: Main lobe gain of the LPDA.

Half power beam width (HPBW) of the antenna is shown in the Figure 6. The straight line indicates the HPBW along theta (E-plane), whereas dashed line indicates phi-axis (H-plane). HPBW on E-plane does not change much over the target frequency band, which makes it suitable for a reflector feed.

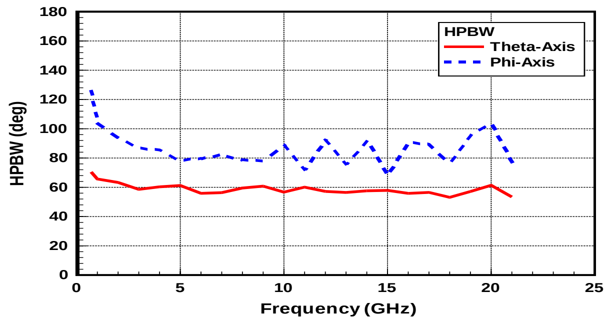

Figure6: Half power band width (HPBW) of the LPDA.

Gain pattern of the LPDA are shown in Figure 7.

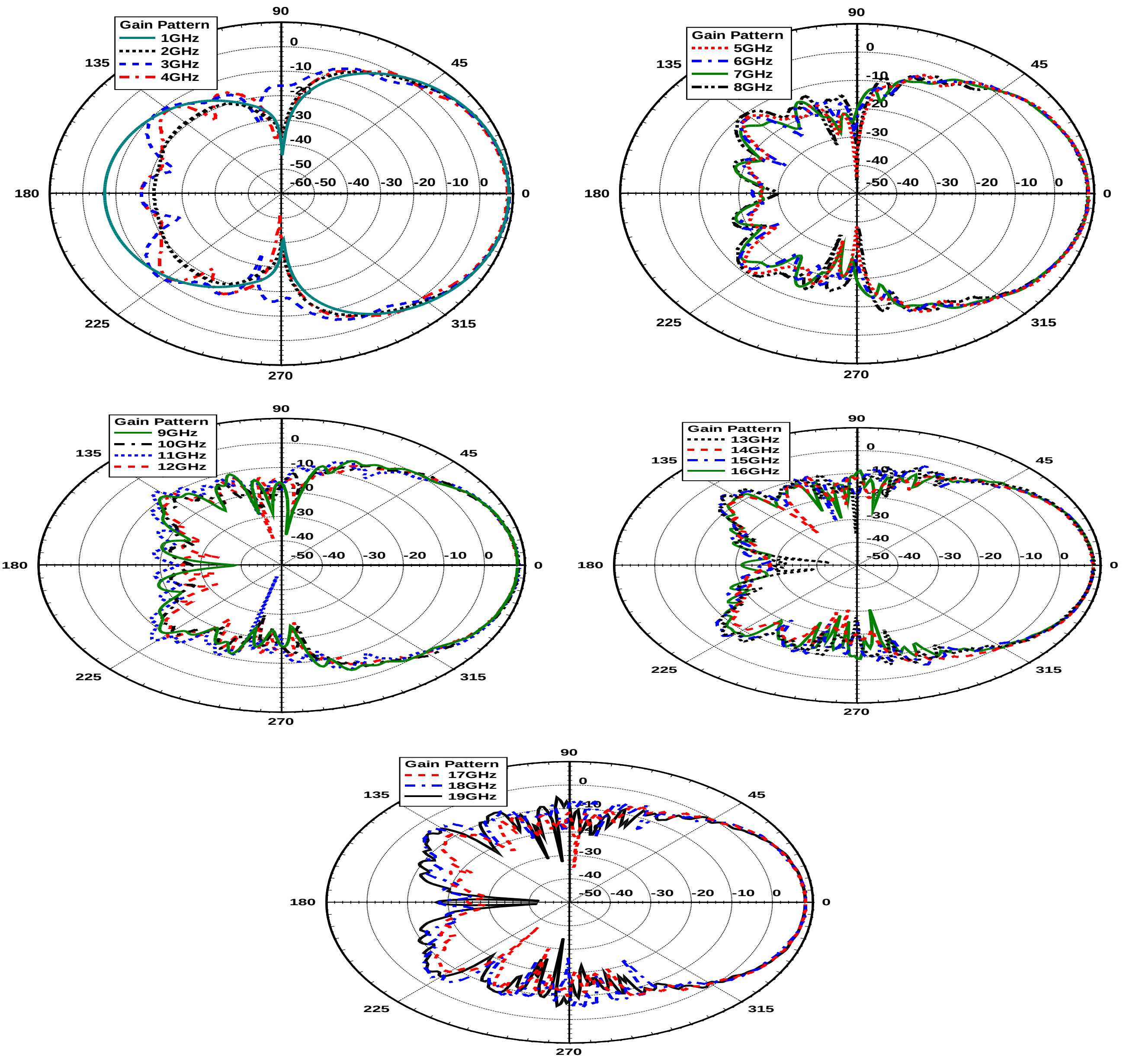

Figure 7: Gain patterns of the LPDA.

3.2. Results of parabolic reflector feeding by LPDA

When parabolic reflector antenna is fed by LPDA, the return loss of the LPDA changed due to near field coupling with the reflector. VSWR values are given in Figure 8 with and without reflector. VSWR value is below 3 in the range of 1-18 GHz and below 3.6 at 19 GHz. These VSWR values are acceptable when considering the bandwidth and gain.

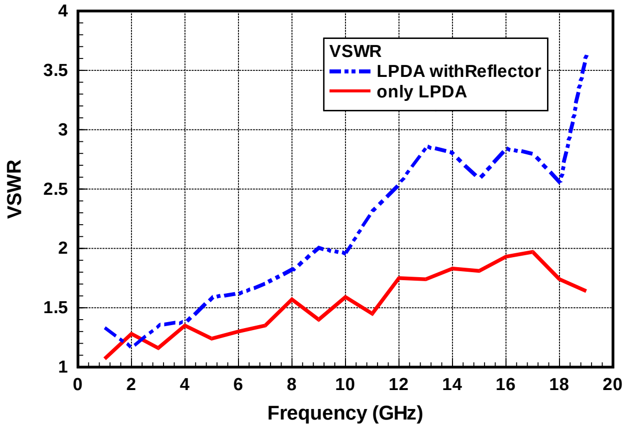

Figure 8: VSWR of LPDA without the reflector (red straight line) and with the reflector (blue dotted line).

Realized gain, front to back ratio (F/B) and side lobe level (SLL) of the total system are shown in the Figure 9. Gain is always increasing with frequency. The lowest gain is 17.37 dBi at 1 GHz and the highest gain is 41.74 dBi at 19 GHz. The SLL is almost below -20 dB. The SLL and front to back ratio is also better at higher frequencies.

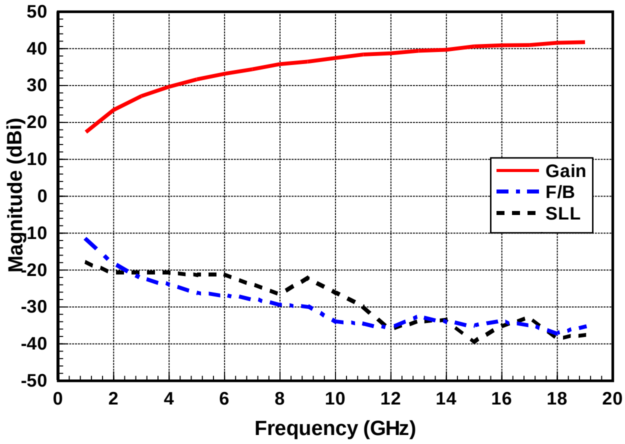

Figure 8: Realized gain at main lobe, front to back ratio (F/B), and side lobe level (SLL) of the reflector antenna fed with LDPA.

HPBW of the antenna is displayed in Figure 9. HPBW changes from 15.68 to 0.85 degree with increasing frequency as expected.

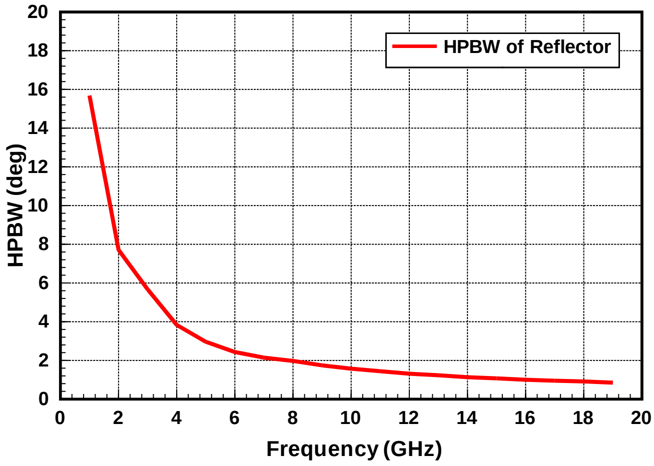

Figure 9: HPBW of reflector antenna

The realized gain patterns of the reflector antenna system are presented in Figure 10.

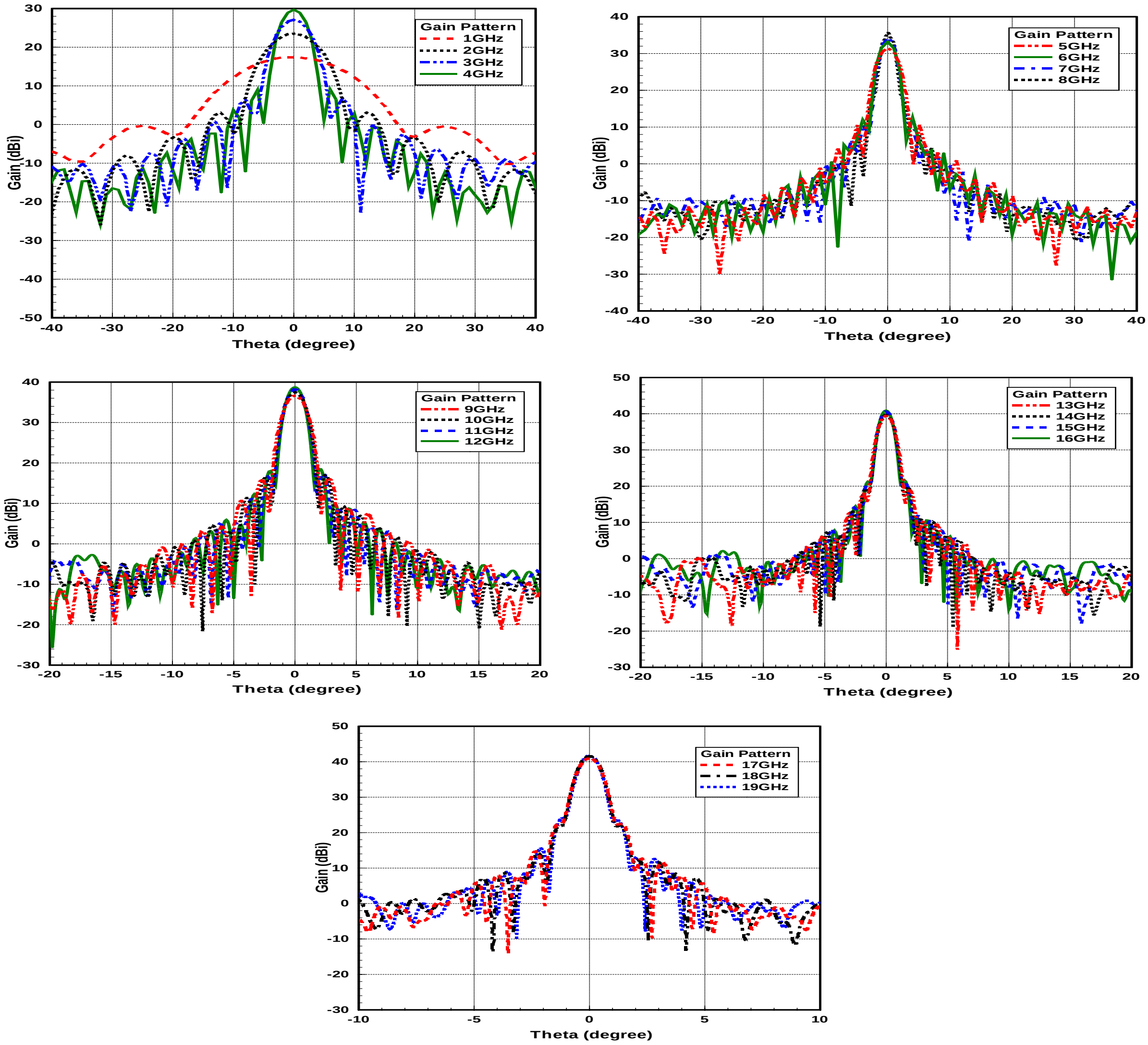

Figure 10: Gain patterns of the reflector antenna system.

Obtained antenna performances were compared with previously designed antennas in the Table 1. VSWR values of previous studies are omitted in Table 1, but peak gain along with HPBW and aperture efficiencies are compared. The reflector diameter, naturally, plays a critical role in gain and HPBW values, but focal orientation and design of LPDA definitely improved key antenna parameters.

Table 1: Comparison of antenna specifications with previous studies.

Antennas	Frequency (GHz)	Gain (dBi)	HPBW (degree)	Reflector Diameter (m)	Aperture Efficiency
This study	1 – 19	17.37 – 41.74	15.68 – 0.85	1.2	0.35 – 0.26
[11]	1 – 18	17.4 – 41.5	14.7 – 0.9	1.2	0.35 – 0.28
[15]	1 – 18	15 – 35	25 – 2	1.2	0.20 – 0.06
[16]	1 – 18	20 – 45	12 – 0.6	1.8	0.28 – 0.27

4. Conclusion

High gain broadband antenna system was designed using an LPDA feed to a1.2 m diameter parabolic reflector. This LPDA-fed reflector system operates at 1-19 GHz frequency band. Compared to previous studies, the design achieves higher aperture efficiency, hence better gain. Main limitation of the study is that it is purely simulation based and the results should be experimentally corroborated. The antenna can be readily used in direction finding and electronic intelligence systems.

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