

Comparing Two Feed Techniques for Exciting High-Gain mmWave Lens Antenna

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Abstract—Two planar feeds, a microstrip patch antenna and a printed square loop antenna, are used as primary radiators for illumination of a lens antenna for operation within 26 – 27 GHz band. In isolation, the patch antenna exhibits a gain of 6.9 dBi and fractional impedance bandwidth of 3.7%, while the loop-fed design to a gain of 6.5 dBi and 1.3% bandwidth, both satisfying the –10 dB matching criterion. When these planar antennas are integrated with a spherically shaped dielectric lens, the peak realized gain of the lens antenna is 14.4 dBi for the patch and 13.4 dBi for the loop-fed excitation with corresponding radiation efficiencies of approximately 90% and 79%. The results demonstrate the impact of the radiation patterns of the feeds on lens illumination and provide design guidance for compact high-gain mmWave dielectric lens antennas for 5G and future wireless applications.

Keywords: Dielectric Lens antenna, Microstrip Patch Antenna, Loop antenna, Feed technique, mmWave.

I. INTRODUCTION

The emergence of millimeter-wave communication represents a major advance in wireless communication technology, providing exceptionally high bandwidths and meeting the massive data requirements of contemporary applications [1], [2]. Among mmWave bands, 26–28 GHz is extensively allocated for mobile and fixed wireless applications, motivating antenna designs that can simultaneously achieve high gain, wide bandwidth, and a compact form factor [2]. A principal challenge at mmWave frequencies is overcoming the inherently high free-space path loss, which necessitates antenna systems with significant directivity and efficiency [3]. Dielectric lens antennas have been widely studied for this purpose, transforming near spherical wavefronts from a primary feed into quasi-planar wavefronts, hence providing high directivity without resorting to arrays requiring complex feed networks [4], [5], [6].

Dielectric lens antennas have a long application history in microwave and mmWave systems, originally explored for reflector-like performance with simpler physical structures [4], [7]. Recent advances in materials and fabrication, including 3D printed and graded-index (GRIN) lenses, have produced compact, low-loss lenses for mmWave applications [5], [8]. Works on flat and curved dielectric lenses demonstrate improved field collimation, higher aperture efficiency, and wideband performance when they are matched with appropriate feeds [5], [6], [9]. In addition, a lens may be integrated with

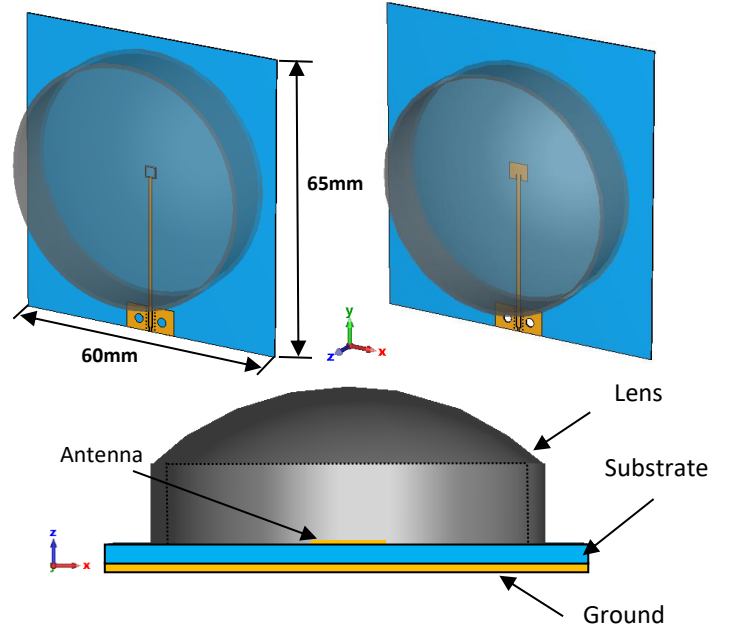


Figure 1. Structure of the proposed lens antenna excited by (a) microstrip patch antenna feed, (b) square loop antenna feed, and (c) a side view of it.

planar arrays in beam-steering applications for base-station and radar systems [10], [11].

While the dielectric lens plays a dominant role in gain enhancement and beam shaping, the characteristics of the feed antenna critically influence the overall antenna performance through lens illumination. The radiation properties of a feed such as near/far-field distribution, polarization, and radiation pattern directly affect impedance matching, sidelobe levels, and radiation efficiency of the integrated lens system [4], [12]. Planar feed antennas including microstrip patch antennas are particularly attractive at mmWave frequencies for their low profile and ease of fabrication and integration, however, they often exhibit limited bandwidth and non-uniform aperture illumination [13]. Alternative planar feed structures, such as microstrip loop and slot radiators produce distinct field distributions that may offer different trade-offs between bandwidth, efficiency, and illumination uniformity.

Despite the importance of the feed–lens interaction, most existing work focuses on lens design methodologies and advanced lens topologies, with relatively few studies offering a systematic comparison of planar feed types in dielectric lens

systems at mmWave bands. To address this gap, this paper presents a comparative simulation-based investigation of two planar feeds — a microstrip patch and a printed square loop — integrated with a spherical dielectric lens at its focal plane for the 26–27 GHz band. To this end, we evaluate the impedance bandwidth, realized gain, radiation efficiency, and radiation characteristics, providing insight into the impact of the feeds on the performance of the lens antenna for compact high-gain mmWave applications.

II. ANTENNA AND DIELECTRIC LENS DESIGN

A. Patch and Loop antenna

Two planar feed configurations are investigated to study their interaction with a dielectric lens and the resulting impact on radiation performance. The first configuration shown in Fig. 2(a) employs a conventional microstrip patch antenna, while the second one shown in Fig. 2(b) utilizes a printed square loop antenna. Both antennas are designed for a center frequency of 26.5 GHz and implemented on Rogers RT/duroid 5880 substrate ($\epsilon_r = 2.2$, $\tan\delta = 0.0009$) with a thickness of 0.254 mm and a substrate footprint of 60×65 mm². The fully copper-plated bottom layer serves as the ground plane.

Both antennas are excited by a 50 Ω microstrip feed line. The radiation from the microstrip patch antenna primarily arises from fringing electric fields at the patch edges. In contrast, the square loop antenna designed with an effective side length of approximately $\lambda_{\text{eff}}/4$ behaves as a magnetic-type radiator due to circulating currents that generate a magnetic dipole moment normal to the loop plane. This fundamental difference in radiation mechanisms produces distinct near-field distributions and interaction behaviors with the dielectric lens. Simulated results without the dielectric lens indicate that both planar feeds achieve satisfactory impedance matching and broadside radiation at 26.5 GHz. In terms of return losses, the patch antenna exhibits a $|S_{11}| \sim -10$ dB over 3.1% bandwidth, while the square loop antenna has a narrower bandwidth of 1.2%, Fig. 3, which can be attributed to the close proximity of the ground plane to the loop. As illustrated in Fig. 4, the radiation performance in the $\phi = 0^\circ$ and $\phi = 90^\circ$ planes shows that the patch antenna achieves a peak realized gain of 6.9 dBi, while the square loop antenna exhibits a slightly lower gain of 6.5 dBi. The efficiencies obtained for these two planar antennas are 89% and 75%, respectively. The optimized geometrical parameters of excitation antennas and the dielectric lens are summarized in Table I.

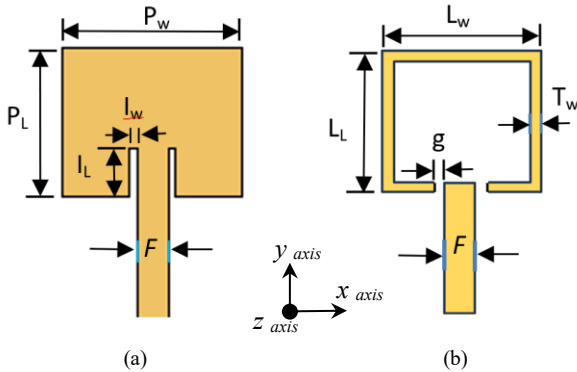


Figure 2. Designed planar feed antennas: (a) microstrip patch antenna, and (b) printed square loop antenna.

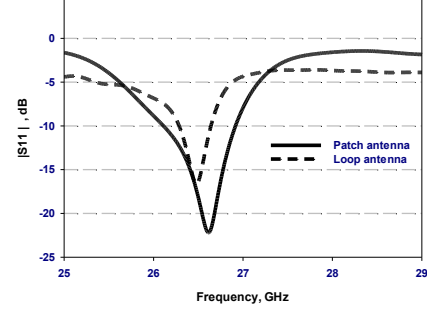


Figure 3. Simulated $|S_{11}|$ of patch- and loop-antennas without dielectric-lens antennas.

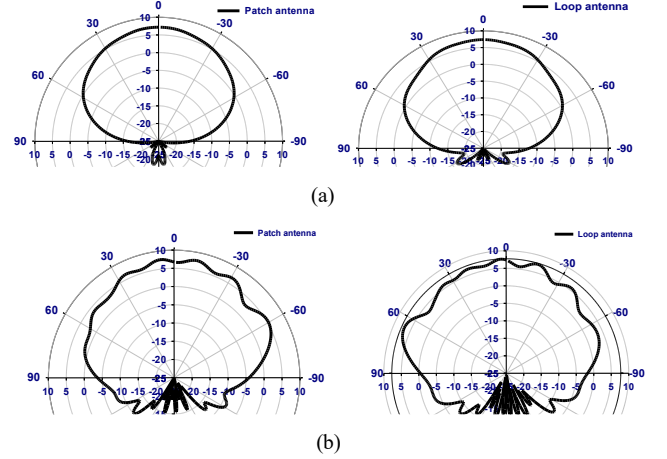


Figure 4. Simulated 2D radiation patterns at (a) $\phi = 0^\circ$ and (b) $\phi = 90^\circ$ for both feed configurations without dielectric lens antennas at 26.5 GHz.

B. Dielectric Lens antenna

The dielectric lens which is a sector of a solid sphere, is assembled directly above the radiating planar antennas. The lens assembly is considered to be 3D printed using an available low-loss dielectric material with a relative permittivity of $\epsilon_{\text{lens}} = 2.8$ and $\tan\delta \sim 0.0$. Its cross-section is shown in red in Fig. 5. It consists of two parts: the lens portion with a thickness of L_{h1} , and a support portion of a height of L_{h2} with a wall thickness of 2 mm. This hollow lens design reduces weight and dielectric losses while maintaining the ability of the lens to collimate the radiated waves. Its primary function is to transform the near-spherical wavefronts radiated by the feed antenna placed at the lens focal plane into quasi-planar wavefronts at the aperture, thereby increasing the effective aperture area and improving the directivity.

The achievable gain with the lens is approximated by [14]:

$$G \approx \eta \frac{4\pi A_{\text{eff}}}{\lambda_0^2} \quad (1)$$

where A_{eff} is the effective aperture area, and η is the aperture efficiency, both dependent on several factors including the material losses and the aperture field phase and magnitude distribution. Considering just the aperture size, (1) predicts the lens maximum gain to be about 20 dB provided that ideal

conditions are assumed for phase and amplitude, losses etc [14]. The lens thickness, support thickness, and spacing relative to the feed antennas are optimized through full-wave simulations to maximize aperture illumination and gain.

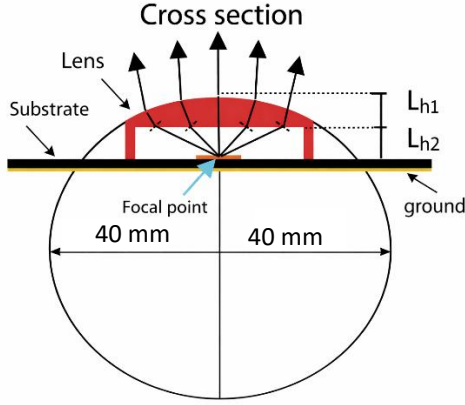


Figure 5. Illustrating the structural configuration of the dielectric lens antenna.

TABLE I. THE STRUCTURAL PARAMETERS OF THE PROPOSED DESIGN.

Symbol	Value (mm)	Symbol	Value (mm)	Symbol	Value (mm)
P_W	4.47	P_L	3.67	F	0.78
T_W	0.23	L_W	2.57	L_L	2.57
L_{h1}	11.4	L_{h2}	8.6	L_{h2}	8.6
l_L	1.2	l_w	0.02	g	0.01

III. PERFORMANCE OF LENS ANTENNA WITH DIFFERENT EXCITATIONS

A comparative study of the lens antenna excited by the patch antenna and by the loop antenna is accomplished using CST Studio Suite. The excitation antenna is located symmetrically about the focal point of the lens. In this analysis of return losses, realized gains, radiation efficiencies, and radiation characteristics were evaluated within the 26–27 GHz band. The reflection coefficients are shown in Fig. 6, where the patch-fed lens antenna exhibits a wider $|S_{11}| = -10$ dB fractional impedance bandwidth of circa 3.7% as compared to the loop-fed configuration providing a narrower bandwidth of about 1.3%. These bandwidths are close to those in Fig. 3 for the excitation antennas in isolation, hence, the presence of the lens has not affected the fields of the exciters for a significant amount.

The peak gain and radiation efficiency predicted are summarized in Fig. 7. The patch-fed lens antenna achieves a maximum gain of 14.4 dBi with an average radiation efficiency of approximately 90%. In comparison, the loop-fed design attains a slightly lower peak gain of 13.4 dBi and a reduced efficiency of around 79%. This latter reduction can be attributed to loop conductor losses and the radiation from the capacitive feed coupling. In both excitation cases, the gains are about 6 dB lower than the maximum ideal lens gain of 20 dB.

Fig. 8 shows the normalized radiation patterns in the principal planes ($\phi = 0^\circ$ and $\phi = 90^\circ$) at the center frequency, 26.5 GHz. Both antenna configurations exhibit highly directive broadside patterns with well-defined main lobes, low side lobes, and good symmetry, confirming effective wave collimation by the dielectric lens. For the patch-fed lens antenna, sidelobe levels obtained are -18.9 dB and -14.6 dB in $\phi = 0^\circ$ and $\phi = 90^\circ$ planes, respectively. The radiation from the loop-fed lens shows higher sidelobe levels of -16.7 dB and -10 dB in the same planes. These differences are mainly due to the distinct aperture field distributions on the lens produced by the two feed geometries. Finally, the 3D radiation patterns of the lens are shown in Fig. 9 to visualize the effects of the feeds, validating the gain enhancement and the different side lobes associated with overall structure in each case.

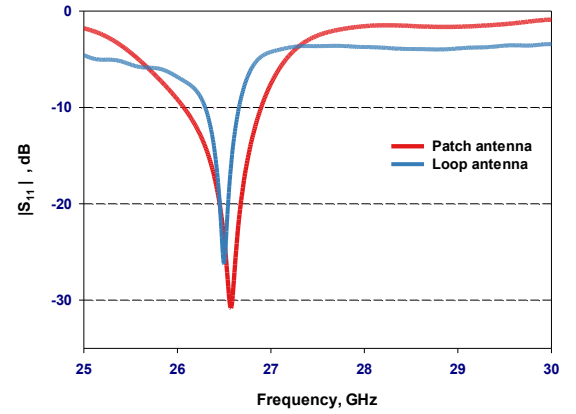


Figure 6. Simulated $|S_{11}|$ of patch- and loop-fed dielectric-lens antennas.

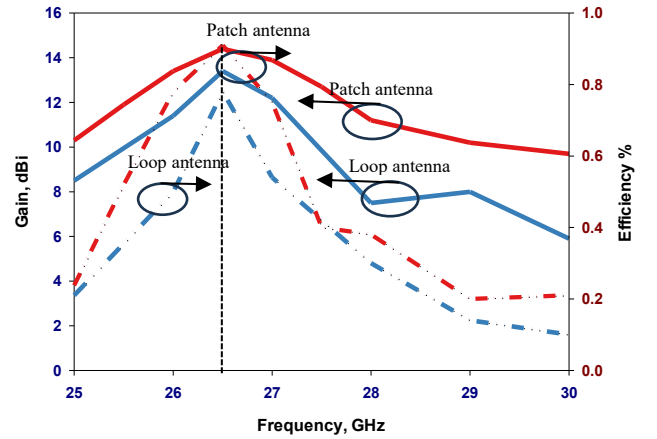


Figure 7. Simulated peak realized gains and radiation efficiencies of patch- and loop-fed dielectric lens antennas.

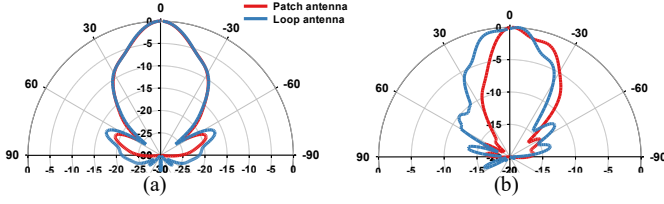


Figure 8. Simulated normalized 2D radiation patterns at (a) $\phi = 0^\circ$ and (b) $\phi = 90^\circ$ for both feed configurations at 26.5 GHz.

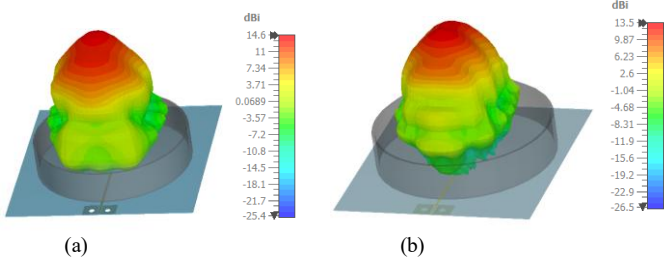


Figure 9. 3D radiation patterns of the dielectric lens antenna at 26.5 GHz for (a) patch-antenna feeding and (b) loop-antenna feeding the lens.

IV. CONCLUSION

A comparative study of patch- and loop-fed dielectric lens antennas operating in the 26–27 GHz band was presented. The patch-fed configuration achieved wider impedance bandwidth, higher radiation efficiency, and approximately 1 dB higher peak realized gain than the loop-fed design. Differences in radiation characteristics and sidelobe levels were attributed to the different lens illumination by the two feeding techniques. These results provide useful guidance for selecting planar feeds for compact high-gain mmWave lens antenna applications.

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