A High-Gain Quad-Band Shared Aperture Antenna for Integrated 5G Wireless Backhaul and Satellite Uplinks

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Abstract

This paper presents a compact quad-band multilayer antenna operating at 6 GHz, 8 GHz, 28 GHz, and 38 GHz, designed for point-to-point communication links. Utilizing aperture-sharing techniques, the antenna integrates a 2×2 dual-band slotted aperture-coupled microstrip patch array for the 6 GHz and 8 GHz bands with a dual-band slotted aperture-coupled element operating at 28 GHz and 38 GHz. The overall stack has a compact vertical profile with dimensions of $1.01\lambda\times 1.12\lambda\times 0.039\lambda$ (λ= free space wavelength at the lowest frequency). Full-wave simulations demonstrate excellent impedance matching and isolation between bands, with bandwidths of 1.3%, 0.6%, 7.18%, and 7.15% at 6 GHz, 8 GHz, 28 GHz, and 38 GHz, respectively. The antenna exhibits broadside gains of 11.54 dBi, 13.76 dBi, 10.47 dBi, and 8 dBi, with isolation levels exceeding 20 dB, 33 dB, 25 dB, and 40 dB at the respective bands.

1 Introduction

The rapid evolution of 5G, the emergence of 6G, and the expanding role of satellite connectivity necessitate the development of radio systems capable of operating across widely separate frequency bands using compact, high-gain, and multi-band antennas [1]. Integrating widely separated frequency antennas, such as those operating at sub-6 GHz (e.g., 6 GHz band) and millimeter-wave (mmWave) frequencies (e.g.,28 GHz, 38 GHz), within a single shared aperture is highly desirable for minimizing system complexity and reducing overall size and weight, as well as enabling seamless broadband connectivity across both short and long distances. Extensive research has been carried over for multi-band operation using shared aperture techniques including dual, tri, and quad-band or more [2] [3] [4]. Although traditional shared aperture designs often involve complex multilayer structures with air gaps or frequency-selective surfaces (FSS), resonant cavities, electromagnetic bandgap (EBG) structures, or artificial reflectors [5] [6] [7] [8], these approaches can significantly increase the antenna profile both horizontally and vertically, leading to fabrication complexity and potential mechanical instability. As a result, these approaches may not be suitable for applications where compactness and cost-effectiveness are critical.

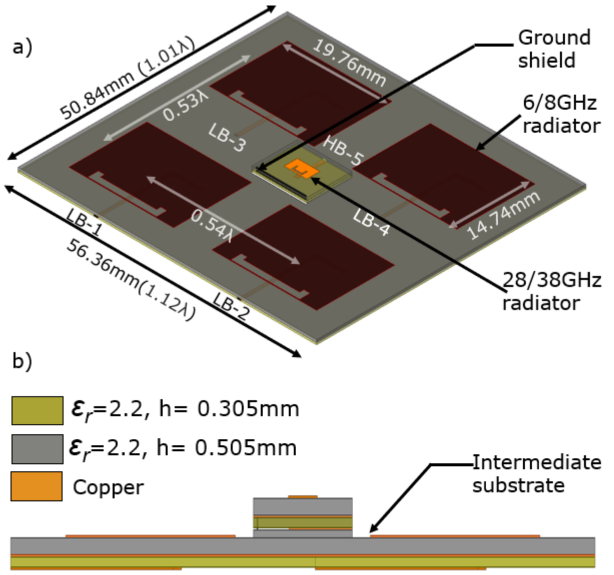

Figure 1. A Quad-band multilayer antenna operating at 6GHz, 8GHz, 28GHz and 38GHz: a) Isometric view, b) stack-up side view.

This paper addresses these challenges by bringing forward a novel quad-band shared aperture antenna that integrates a dual-dual band slotted aperture coupled patch antenna, operating at 6 GHz and 8GHz with a dual-band mmWave antenna operating at 28 GHz and 38GHz, as depicted in Fig. 1. The low-frequency antenna is a 2×2 dual-band slotted patch array with aperture-coupled feeding using a rectangular coupling slot. Preliminary simulations show high broadside gains of 11.54 dBi and 13.76 dBi with sufficient bandwidth at 6GHz and 8GHz bands, respectively. At the mmWave bands, a dual-band slotted aperture-coupled antenna is co-integrated with the 6/8 GHz array. The mmWave antenna achieves instantaneous bandwidths of 2.03 GHz and 2.8 GHz, with realized gains of 10.47dBi and 8dBi at 28GHz and 38GHz, respectively. While the broadside radiation pattern is satisfactory across all bands after using a ground shield in the shared aperture antenna, the beam for the 38 GHz band exhibits some non-uniformity due to potential interference and coupling effects which could be addressed by proper coupling reduction techniques.

2 Design of the Shared Aperture Antenna System

2.1 Low-Frequency Dual-band Antenna Array at 6 GHz and 8GHz

A 2×2 aperture coupled slotted patch antenna array is designed on a low-cost Rogers RT/Duroid 5880 laminate of dielectric constant of 2.2, loss tangent of 0.0009 with height of 0.508mm as antenna (upper) substrate and RO4003 material of dielectric constant 3.55, loss tangent of 0.0027 with height 0.305mm as feed substrate. The slotted patch radiator has a length and width of 14.8mm and 19.76mm, respectively. Using an inter-element spacing of 0.53λ, each the four elements of the array are fed by 50 Ω transmission line (labeled LB-1 to LB-4), as shown in Fig. 1.

2.2 28/38 GHz Dual Band Aperture Coupled Antenna

A 28 GHz/38 GHz dual-band, aperture-coupled antenna is designed and integrated with the lower-band antenna array. The 28/38GHz radiator design utilizes three substrate layers (top three layers in Fig. 1). The radiating element is printed on a 0.508mm thick RT/Duroid 5880 substrate (sub-1, relative dielectric constant = 2.2, loss tangent= 0.0009). The feed structure is designed on a 0.305mm thick RO4003 substrate (sub-2, relative dielectric constant = 3.55, loss tangent = 0.0027). A third, 0.252mm thick substrate (sub-3), identical to sub-1, is placed beneath the feed substrate to enhance isolation between the two antenna sections. The patch dimensions are 2.83mm $\times$ 4.24mm. A 0.68mm wide strip line, coupled through a rectangular slot, provides excitation.

2.3 Full-Wave Simulation of the Quad-Band Shared Aperture

Using a shared aperture technique, the low frequency and mmWave antennas are integrated into a five-layer antenna stack up with dimensions 56.36mm × 50.84mm × 1.91mm, as depicted in Fig. 1. Using full-wave simulations, we compute the reflection coefficient of the shared aperture antenna. As depicted in Fig. 2 (a-b), the antennas exhibit excellent matching at all four frequency bands. The lower two bands of the antenna operate with a 1.3% bandwidth at 6GHz, spanning from 5.97GHz to 6.03GHz, and a 0.58% bandwidth at 8GHz, spanning from 7.98GHz to 8.03GHz. The high bands operate with a 7.18% bandwidth at 28GHz, covering 27.5GHz to 29.25GHz, and 7.15% bandwidth at 38GHz, covering from 37.5GHz to 40.5GHz. The antenna system maintains very good isolation of greater than 20dB at all four bands, as depicted in Fig.3. More in detail, the isolation is greater than 20dB, 33dB, 30dB, and 40dB at 6GHz, 8GHz, 28GHz, and 38GHz bands, respectively. The antenna achieves a very good and unaffected radiation pattern at 6GHz, 8GHz, and 28 GHz, as depicted in Fig.4 (a,b).

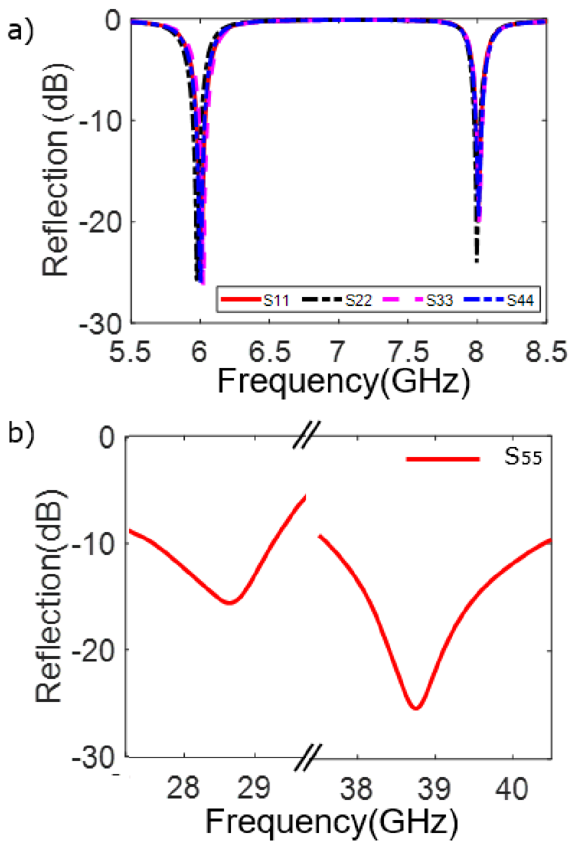

Figure 2. Full-wave simulation of the shared aperture antenna showing a) the active reflection coefficient of 6/8 GHz antenna, and b) the active reflection coefficient of 28/38GHz antenna.

For the 38GHz GHz band, the radiation pattern exhibits some inconsistencies due to the interference and couplings of multiple elements in a multilayer stacked structure and requires further optimization. Overall, the shared aperture antenna achieves a satisfactory high gain in the operating bands with a peak gain of 11.54 dBi, 13.76 dBi, 10.47 dBi, and 8 dBi at 6GHz, 8GHz, 28GHz, and 38GHz bands.

3 Conclusion

This paper presents a shared aperture design that integrates a dual-band (6/8 GHz) 2x2 slotted aperture-coupled array with a dual-band (28/38 GHz) slotted aperture-coupled antenna in a five-layer stack-up. The antenna's high-frequency ratio, high gain, and compact form factor make it well-suited for both long- and moderate-range point-to-point communication, as well as low-profile applications. Excellent impedance matching and good isolation are achieved across all bands, with a minimum isolation of 20 dB at 6 GHz, which can be further improved. The antenna exhibits satisfactory bandwidth and consistent gain performance. Minor variations in the high-frequency element's radiation pattern, caused by coupling in the stacked configuration, can be minimized through optimization. Further gain enhancement at the mmWave frequencies can be

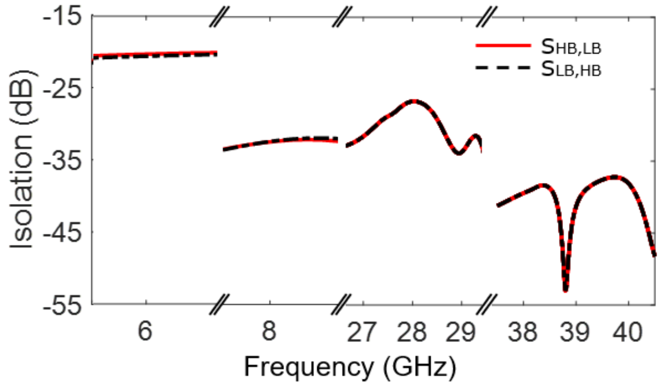

Figure 3. Full-wave simulation of the quad-band shared aperture stack-up showing the antenna isolation at 6GHz, 8GHz, 28GHz, and 38GHz.

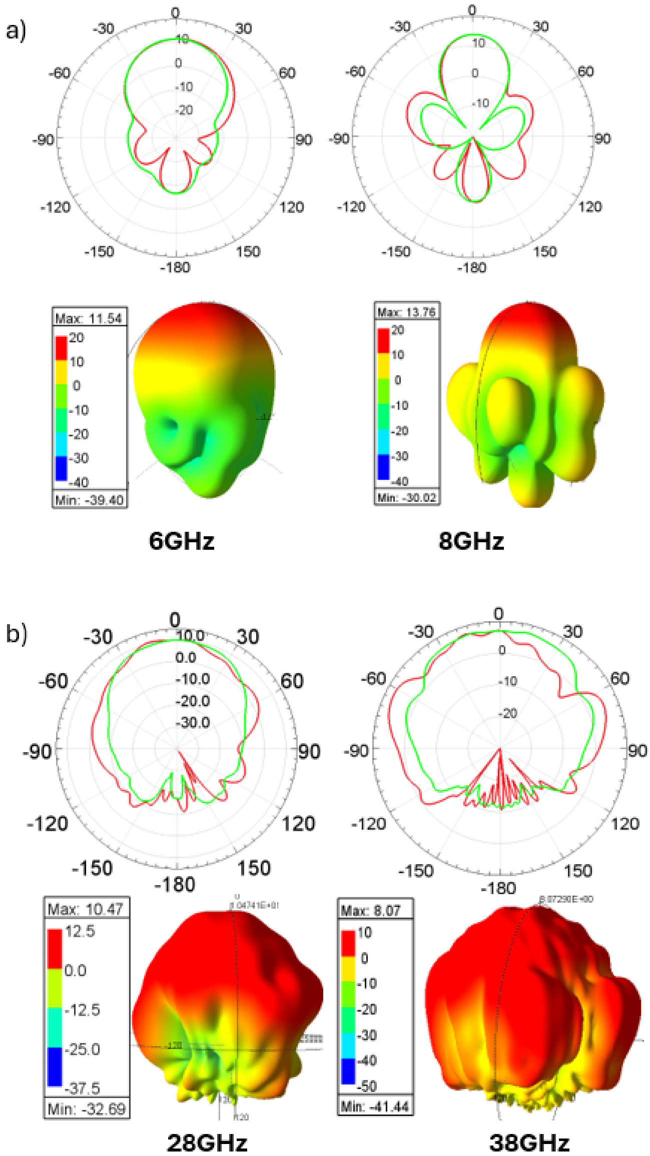

Figure 4. 2D and 3D radiation pattern of shared aperture antenna, showing a) 6GHz, 8GHz radiation, b) 28GHz, 38GHz radiation

achieved through array techniques or other advanced antenna design methodologies.

4 Acknowledgements

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