Design of a High-gain Antenna System for MM-wave Full-duplex Communication

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***Abstract*—Advanced antenna designs are crucial for millimeter-wave (mmWave) 5&6G communication to support higher data rates, lower latency, and reduced power consumption. These demands can be partially met through wideband antenna arrays, while full-duplex radios further enhance spectral efficiency by enabling simultaneous transmission and reception in the same band. This paper proposes a patch antenna array architecture for full-duplex mmWave applications, which can significantly mitigate self-interference at the antenna stage. The array achieves broadside symmetrical radiation patterns and exhibits exceptional isolation characteristics, making it well-suited for mmWave full-duplex operation. Simulation results demonstrate a gain of circa 17.5 dB, self-interference (SI) isolation less than -55 dB reaching to -85 dB between the transmit (Tx) and receive (Rx) ports, and mutual coupling (MC) level below -10 dB reaching to -16.5 dB within the Tx and the sampling (Rs) port, across the 26–27 GHz band. Additionally, the proposed design achieves a radiation efficiency of approximately 90%.**

***Index Terms*—Antenna arrays, Full-duplex radios, mmWave, Self-interference cancellation, Patch antenna, High isolation, 5/6G communications.**

I. INTRODUCTION

The rapid evolution of wireless communication has fueled the demand for higher data rates, increased capacity, and lower latency, driving the development of 5&6G technology. In this regard, a key advancement can be in the area of full-duplex radios in the mmWave spectrum. These radios enable simultaneous transmission and reception over the same frequency band, significantly enhancing spectral efficiency and making it a crucial component of next-generation wireless networks.

A comprehensive overview of full-duplex wireless communication is presented in [1], outlining its potential benefits and the technical challenges that must be addressed to achieve effective operation. Among these challenges, the SI is a critical issue, as the transmitted signal can interfere with the received signal, degrading system performance. Various SI cancellation techniques have been explored, involving both analog and digital processing stages, including mitigation strategies at the antenna level, as discussed in [2].

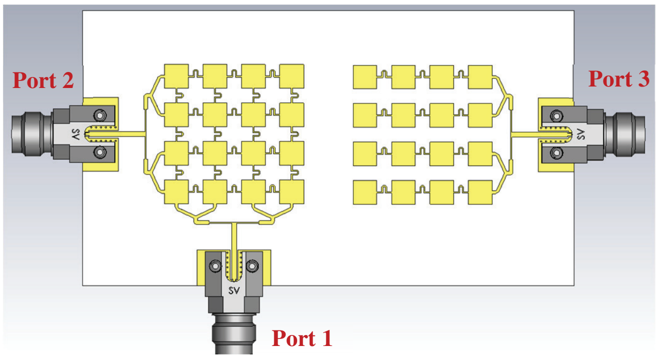


Fig. 1. Structure of the proposed full-duplex array.

At the antenna stage, the key design considerations for reducing self-interference include polarization and isolation between the Tx and Rx antennas. Indeed, higher isolation at the antenna level reduces the complexity of SI cancellation in subsequent processing stages. In low microwave frequency full-duplex systems, planar antennas integrated on the same substrate typically achieve around 35 dB of isolation. However, this isolation significantly diminishes at higher frequencies, presenting a major challenge in SI cancellation in mmWave full-duplex systems. To overcome this limitation while maintaining a compact form factor and energy-efficient operation, high-gain antennas are essential for mmWave full-duplex radios. Planar antenna arrays, seamlessly integrable with transceiver circuits, can offer a promising solution. The choice of antennas or array elements varies based on application requirements. For instance, a two-rectangular spiral antenna system with Electromagnetic Band Gap (EBG) structures [3] has been developed to enhance the performance of a 3.2 GHz full-duplex system originally operated with square patch antennas [2]. In contrast, for mmWave full-duplex communication systems, potential antennas (although not deployed yet) are wideband patch antenna arrays [4], ultra-wideband spiral antennas with circular polarization [5]-[6], and V-band leaky-wave antennas utilizing surface-integrated waveguides (SIW) [7]. These antennas have complex designs but can offer promising features for achieving the stringent gain and isolation requirements of mmWave full-duplex radios.

In this work, a low-profile transceiver antenna array consisting of square patches is proposed for mmWave applications, as shown in Fig. 1. The design consists of two separate 16-element (4×4) arrays—one dedicated solely to reception (Rx) and the other for sampling (Rs) and transmission (Tx). A well-optimized feeding structure is implemented to achieve impedance matching, while λg/2 coupling lines are incorporated between the elements to direct the beam in the right direction.

In this paper, Section II outlines the design of the antenna array, Section III presents the simulation results and analyses, and Section V covers the conclusion.

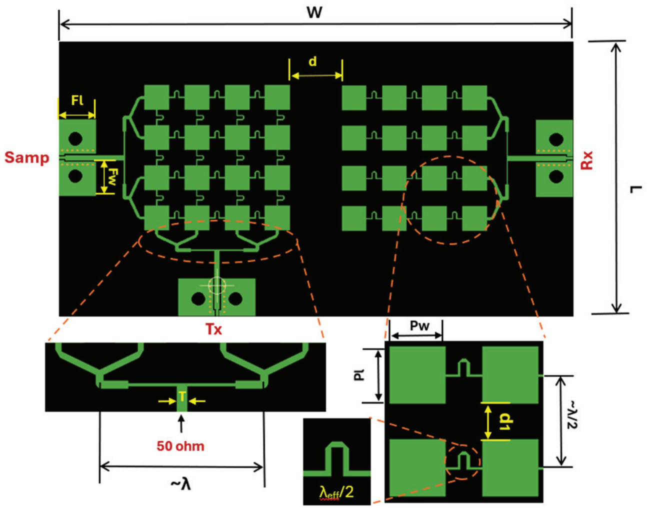


Fig. 2. Dimensions of the proposed full-duplex antenna.

II. Design of Full Duplex Antenna Arrays

The proposed antenna system consists of two separate antenna arrays, designed specifically for full-duplex operation. The design focuses on achieving high gain and high isolation. In this design, each array has 4x4 rectangular patches, as shown in Fig. 1. Simulations were conducted using CST Microwave Studio to evaluate the performance of the design.

The geometrical shapes and dimensions of the proposed arrays are displayed in Fig. 2 and Table 1. The radiating square patches are on Rogers RT/Duroid 5880 substrate (with a dielectric constant of $\varepsilon r = 2.2$ and a loss tangent of $\tan\delta = 0.0009$). The copper thickness of the ground plane and the patches is 17 µm. The substrate dimensions are 75 mm × 42 mm × 0.254 mm. The choice of substrate thickness (0.254 mm) is to minimize the surface wave coupling between elements at mmWave frequencies. The patches are of equal length and width to maintain a symmetric structure, making the array well-suited for full-duplex operation.

Each patch element is connected to its neighboring elements through a $\lambda_g/2$ coupling line (providing a 180-deg phase shift), implemented using a 100 Ω impedance microstrip. These high-impedance lines play a crucial role in mitigating cross-coupling effects among the array elements. To achieve high gain and low side lobe levels, the elements are spaced at approximately half a wavelength ($\lambda_o/2$) from center to center. Additionally, to ensure high isolation between the two arrays, the separation distance was found to be 7.7 mm.

As shown in Fig. 2, the left array of the design includes two 50 Ω ports. In a full-duplex system, one of these ports is used for transmission (Tx), while the other captures the sampled signal (Rs) from the transmitter. The Rx port is on the right array and arranged such that the transmit and receive signals maintain orthogonal polarization for enhancing isolation between Tx and Rx. The two arrays exhibit linear polarization.

TABLE I
THE STRUCTURAL PARAMETERS OF THE PROPOSED DESIGN

Symbol	Quantity	Value (mm)
W	Width of substrate	75
L	Length of substrate	42
Pl	Length of patch	3.7
Pw	Width of patch	3.7
d1	Separation distance between patches	2.25
Fl	Pad length for connector	5.59
Fw	Pad width for connector	5.17
T	50 Ω feeding port width	0.78
d	Separation distance between the two arrays	7.7

III. Simulation Results

For an effective full-duplex design, maintaining a good impedance matching and high isolation performance across a desired frequency range are essential, and these were considered in the proposed design. Simulated return losses (S11, S22, and S33) presented in Fig. 3 suggest that all ports achieve a return loss bandwidth of approximately 12.3%, ensuring stable performance across a 5/6G operating band. Fig. 4 presents the simulation results for mutual coupling (S21) between the Tx and Rs ports, as well as isolation (S23) between the Tx and Rx ports. The mutual coupling ranges from approximately -10 to -16.5 dB, while the isolation achieves an impressive -55 to -85 dB within the 26–27 GHz range. Notably, the isolation result is particularly very impressive compared to previous research records, highlighting the effectiveness of the proposed design in minimizing self-interference at the antenna stage over a wideband.

Fig. 5 illustrates the realized Tx gain across the 26–27 GHz range, reaching approximately 17.5 dBi. It also depicts the simulated total efficiency, which remains consistently high, approximately 90%, across the same frequency range. Figs. 6, 7, and 8 present the normalized radiation patterns at 26 GHz, 26.5 GHz, and 27 GHz in both the E-plane and H-plane. They indicate that the radiation pattern is broadside with no noticeable tilt over the band, confirming the antenna stability and optimal performance. The side-lobe levels remain well-controlled and between -12.5 dB and -13.4 dB over the frequency range, ensuring efficient radiation characteristics and minimal interference. The 3D radiation pattern for Tx of the proposed structure at 26.5 GHz is illustrated in Fig. 9.

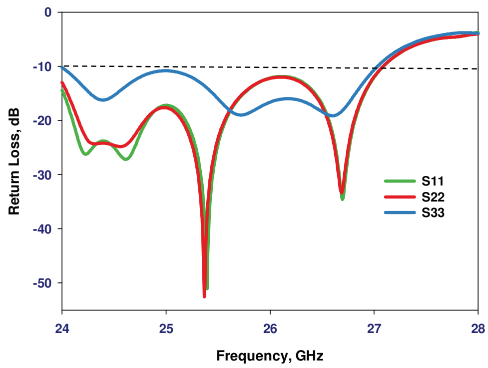


Fig.3. Return losses at the three different ports as a function of frequency for the proposed design.

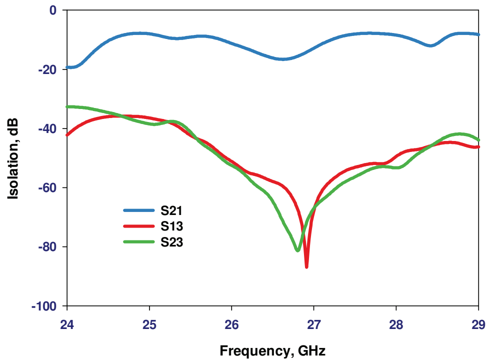


Fig.4. Simulated isolation and mutual coupling of the array.

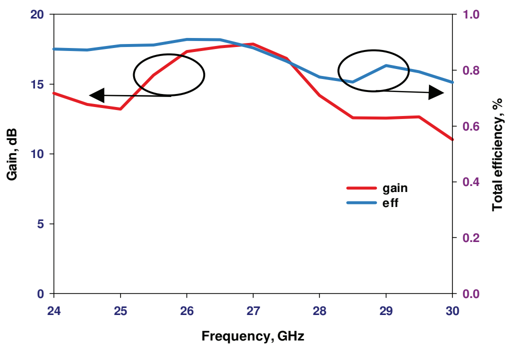
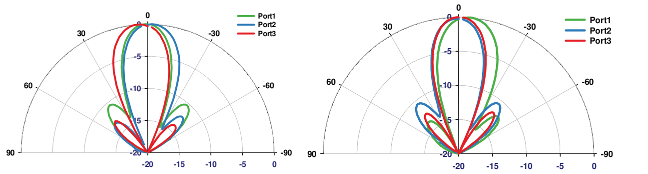
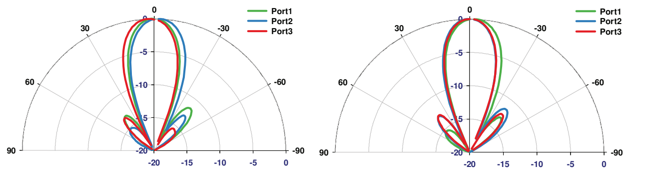


Fig.5. Simulated gain and radiation efficiency for the array.



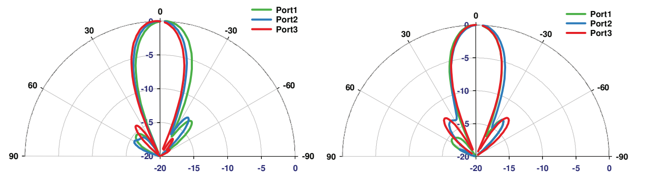
(a) (b)

Fig.6. Simulated normalized radiation patterns at 26GHz: (a) E-plane and (b) H-plane.



(a) (b)

Fig.7. Simulated normalized radiation patterns at 26.5GHz: (a) E-plane and (b) H-plane



(a) (b)

Fig.8. Simulated normalized radiation patterns at 27GHz: (a) E-plane and (b) H-plane.

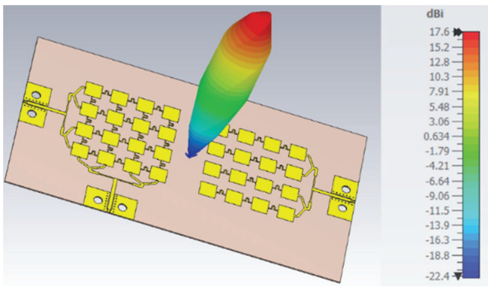


Fig.9. 3D radiation pattern of the Tx antenna for the proposed structure at 26.5 GHz.

IV. CONCLUSION

A patch antenna array system for the mmWave full-duplex communication system is proposed. It is designed to achieve high isolation for efficient self-interference mitigation between Tx and Rx at the antenna stage. The antenna system has a broadside symmetrical radiation pattern with side lobes less than -12.5 dB. Simulation results demonstrate a realized gain of 17.5 dBi, self-interference isolation less than -55 dB reaching -85 dB, and mutual coupling below -10 dB reaching -16.5 dB, all across the 26–27 GHz band for the antenna system, which exhibits 90% radiation efficiency. Future work will focus on experimental validation and integration of the antenna system with a full-duplex transceiver.

V. ACKNOWLEDGEMENT

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