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Antenna Arrays for Full-Duplex Systems

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Abstract—The 5G technology necessitates the advancement in antenna technology to meet the demands of higher data rates, lower latency and lower power consumption. In wideband mm-wave 5G, these can be partly achieved using wideband antenna arrays. The capacity of the 5G communication can be further enhanced by the use of full-duplex radios. In this paper, a full-duplex transceiver antenna array with planar architecture for 28 GHz 5G NR FR2 n258 (27.5-28.35 GHz) band is proposed. In this design, the array gain is about 17 dB at 27.5 GHz/28 GHz and has a significant isolation (over 33 dB) across the band. This is a highly desirable isolation for the overall reduction of the self interference at the RF stage of wideband mm-wave 5G full-duplex radios.

Keywords — Antenna arrays, Full-duplex radios, 5G NR FR2, Self interference cancellation.

I. INTRODUCTION

The growing demand for high-speed wireless communication, increased capacity and lower latency has driven the development of 5G technology. Amongst the various innovations outstanding is the development of antenna arrays for full-duplex radios in the 5G NR FR2 (28 GHz) band to enhance spectral efficiency by allowing simultaneous transmission and reception over the same frequency channel. A comprehensive overview of full-duplex wireless communication is given in [1], highlighting the potential benefits and emphasizing the key technical challenges, such as self-interference, which must be mitigated to achieve effective full-duplex operation. Self-interference is a significant problem in full-duplex communication, where the transmitted signal can interfere with the received signal. Normally self-interference suppression involves the use of analogue and digital technique in the receiver chain including the antenna stage as presented in [2]. To reduce the self-interference in the antenna stage, crucial factors are polarisation and isolation of the receive and transmit antennas. In the antenna stage, the higher the isolation, the lower would be the effort to suppress the self-interference in the rest of a full-duplex radio. For typical low frequency full-duplex radios, the isolation between the receive and transmit antenna of planar type using the same substrate is about 35 dB, but this figure significantly decreases with frequency.

To reduce power unit size and power cost (due to free-space and environmental losses), the use of high gain antennas for mm-wave full-duplex radios would be necessary. Planar array antennas easily integrated with the transceiver circuits are suitable for the purpose where the array element can have various topologies depending on the applications. For example, the rectangular spiral antenna with

Electromagnetic Band Gap (EBG) can be used as the array element to enhance the performance of full-duplex systems. Two such antennas (one for the transmitter and one for the receiver) located in proximity of each other in a 3.2 GHz system have provided about 31 dB isolation [3].

Further, although not yet tested in a full-duplex radio system, one can use high gain ultra-wideband spiral antenna configuration designed for circular polarization [4]-[5], or the V-band leaky wave antenna with a surface integrated waveguide (SIW) [6] to meet the high gain specification in mm-wave full-duplex radios.

In this paper, initial results on a new transceiver antenna array proposed and designed for 28 GHz 5G FR2 n2b1 (27.5-28.35 GHz) band are presented. This planar array consists of 16 (4x4) elements and includes square patches fed/connected by high impedance lines. The topology of the feed is borrowed from an earlier work on a 3.2 GHz full-duplex radio, rendering its antenna orthogonal linear polarization [2]. The paper is organized as follow: Section II describes the design of the array. The simulation results are discussed in section III.

II. DESIGN OF 4X4 ARRAY

The proposed antenna array is shown in Fig. 1. It consists of 4x4 rectangular patches. In this design, the length and width of the patches are made equal to have a symmetric structure suitable for full-duplex radio. The array is designed on Rogers RT/duroid 5880 with the thickness of $h = 0.2$ mm and dielectric constant is $\epsilon_r = 2.2$. This selection of the substrate ensures only some small coupling between elements due to surface waves at the 28 GHz band. The thickness of the copper cladding of the substrate is 0.017 mm. The length and width of the elements are 3.6 mm which is half the wavelength in the substrate along the patch at 28 GHz. In this array, every element/patch in the array is connected to its neighbouring elements with high impedance microstrip lines of impedance about 200 Ohm close to the input impedance of the patches at the resonant frequency of 28 GHz. The width of the lines $W1 = 0.25$ mm and their lengths are about $\lambda_g/2$ (in the substrate along the lines) at 28 GHz. To get a high gain and low side lobes out of the array, the elements are separated by less than a wavelength (between 8 mm and 10 mm). Hence, the connecting lines must be meandered to be accommodated between patches. In this configuration, the high impedance lines can also help to mitigate the cross couplings amongst the array elements. As shown in Fig. 1, the array has two ports. In a full-duplex system, the transmitter feeds one of the ports and the other port takes the

received signal to the receiver. Since the ports and the connecting lines are orthogonally located with respect to the patches, the received and transmit signals are orthogonal in polarization, noting that the polarization of the patches are linear. From the architecture of the antenna, it is easy to observe that the array elements get the feed at equal phase. The ports in the array are rotationally symmetric, hence the role of these ports can be interchanged without altering the performance. The various dimensions of the array are listed in Table 1 from which it can be inferred that the receive and transmit ports have 50Ω impedance.

TABLE 1. DIMENSIONS OF VARIOUS PARAMETERS OF THE ARRAY

Parameter	Value (mm)	Parameter	Value (mm)
L	3.36	W2	0.25
W	3.36	W3	0.3
W1	0.25	W4	0.8

In the following section the performance of the antenna is investigated using CST Microwave Studio.

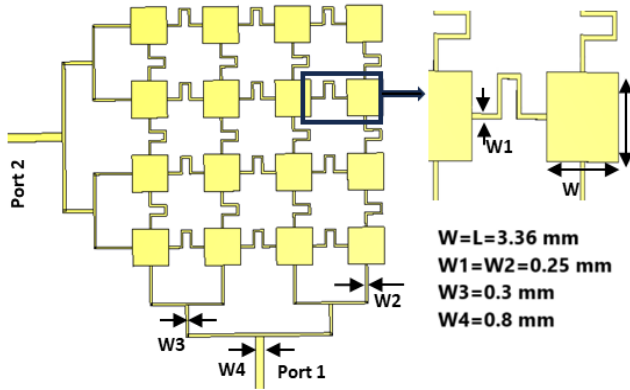


Fig. 1 Proposed 4x4 patch antenna array designed for 28 GHz 5G NR FR2.

III. SIMULATION RESULTS OF ARRAY

The designed array shown in Fig. 1 is simulated using the CST Microwave Studio software in the frequency range of 26-30 GHz. The both ports have an impedance of 50 Ohm. The array is fed at port 1. The magnitudes of S_{11} and S_{21} of the array obtained from the simulations are shown in Fig. 2. As the antenna is rotationally symmetric, S_{21} and S_{12} giving the isolation between the ports and S_{11} and S_{22} representing the return losses at the two ports are identical. As seen in Fig. 2, the return-loss and isolation are 25 dB and 35 dB respectively at 28 GHz. The simulated directivity of the antenna array at 27.5 GHz/28 GHz is close to 17 dBi as shown in Fig. 3 and Fig. 4, respectively.

Further, as can be seen in Fig. 2, the antenna array covers the 28 GHz n258 band (27.5-28.35 GHz) considering the -10 dB reflection coefficient criteria. Over this band, the isolation between transmit and receiver ports are large and better than 33 dB. Indeed, around 27.6 GHz, it peaks to 48 dB.

In Fig. 5 where the gain over the band is plotted, one can infer that it varies by less than 0.5 dB from that at 28 GHz. The drop in the gain from low side of the band to its high side can be attributed to the losses in the high impedance lines and power coupling to unwanted radiations. The radiation pattern across the band observed to be very similar to that at 28 GHz with a few degrees tilt in the beam direction

The array structure is simulated in the CST studio and the simulated results are shown in Fig. 6. The return loss for both the ports is identical.

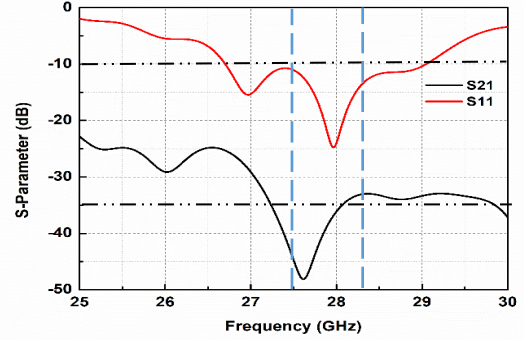


Fig. 2. Magnitude of S-parameters of the antenna array: S_{11} and S_{21}

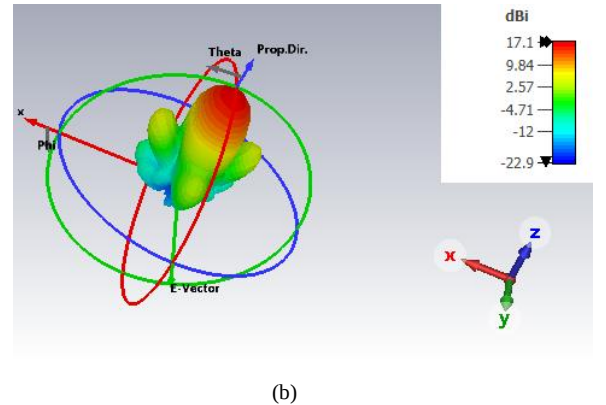
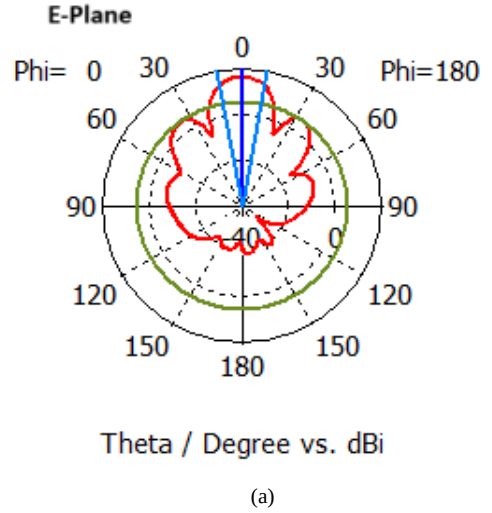
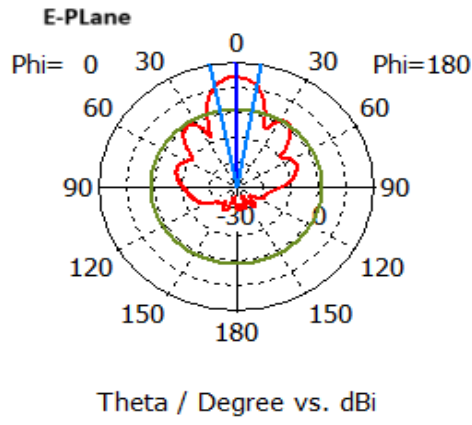
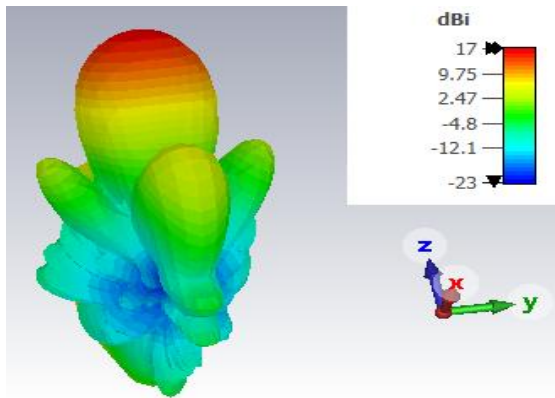


Fig. 3 (a) 2D radiation pattern (b) 3D radiation pattern of the proposed antenna array at 27.5 GHz.



(a)



(b)

Fig. 4 (a) 2D radiation pattern (b) 3D radiation pattern of the proposed antenna array at 28 GHz.

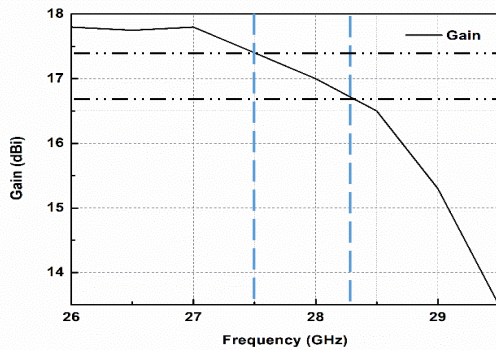


Fig. 5 Simulated gain of the proposed 4x4 Antenna array.

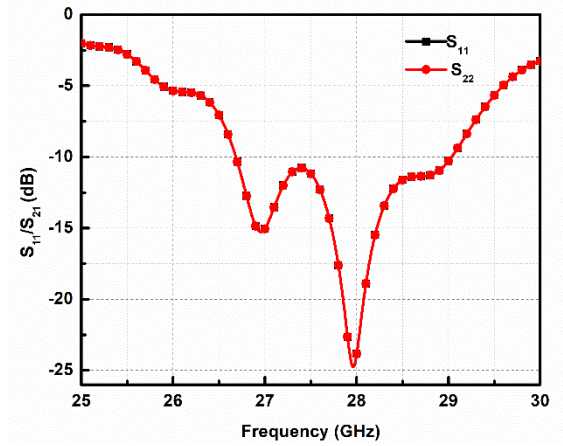


Fig. 6. Simulated Return loss of the array (S_{11} and S_{22}) of port 1 and port 2.

IV. CONCLUSION

The design of a planar antenna array suitable for broadband mm-wave full-duplex radio system is covered. It is specifically designed for application in a 28 GHz 5G NR FR2 n261 (27.5-28.35 GHz) band. Simulations show that it can provide a gain of about 17 ± 0.5 dBi and a better than 33 dB isolation between the receive and transmit ports. This array can be integrated with the trans-receiver system, but the integrating the array with the full-duplex transceivers involves challenges related to signal routing, impedance matching, and thermal management

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