

Dual-Polarized 2x2 Element Sub-Array at 15 GHz with High Port Isolation

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Abstract— This paper presents simulation results of a dual-polarized 2x2 element sub-array antenna element at 15 GHz center frequency. The basic idea is to use two waveguides one on the other to excite the orthogonal polarizations by using radiating slots. Above the slots, 4 parasitic patches are set to a form of 2x2 element sub-array. Antenna presents -10 dB impedance bandwidth from 14.3 to 15.6 GHz with better than 68 dB isolation between the excitation ports. At the aforementioned bandwidth, the total efficiency is better than -0.7 dB (>85%). Antenna shows very good polarization properties and difference between ϕ , θ components is greater than 45 dB. Also the radiation patterns and surface current distributions at 15 GHz center frequency are presented and compared.

Index Terms—5G, antenna array, full duplex, mm-waves.

I. INTRODUCTION

Over the past few years, the world has seen a significant increase in the use of smart-phones for data-intensive applications such as Internet access, online gaming and video streaming, and 1000-fold growth in wireless data transfer is expected by 2020 [1]. The growth in the mobile communications is leading towards a fully connected network society. To face this challenge, the key component is the fifth generation (5G) radio access technology. 5G is the new generation of radio systems and network architecture that will deliver extreme broadband, ultra-robust, low latency connectivity and massive networking. In order to fulfill the demands for the long-term multi-Gbps data rates, the future wireless systems need to expand transmission bandwidths and operate at the higher frequencies [2].

Since the existing mobile and wireless systems are mostly operating at the frequencies below 6 GHz, the knowledge of frequencies beyond this has become important. Requirements for increasing data rate and better signal quality drives the research in wireless communication technology towards exploration of multiple input-multiple output (MIMO) systems for 5G networks.

Related to the antenna design aspects, different parameters need to be taken into account. These include things like electrical performance such as impedance matching, antenna port isolation, polarization properties, radiation pattern, and total efficiency. Other things to

consider are thermal and mechanical performances such as connections and/or interconnections between elements in the antenna structure and substrates which are related to the physical size and manufacturability of the antenna. When frequencies increase, the manufacturing tolerances also become more important.

These aspects might be in conflict with each other: for example, electrical performance might require structures that are not mechanically viable. Solutions to this area have been presented by researchers, giving answers concerning wide bandwidth and high isolation [3]–[5], physical size [6] and simple manufacturing process [7].

Many patents exist concerning dual polarized antennas, examples being those in [8]–[11]. However, higher frequencies issue new challenges and will thus result in further research work, followed by patents.

In this work, simulation results of a dual-polarized 2x2 element sub-array antenna element at 15 GHz center frequency are presented. The antenna structure relates to [11] but instead of separating a single feed to four dual-polarized slots, the structure is simplified by using four parasitic patches. Thus, the patches can be easily, for example laminated, above the cross shaped feed slot to simplify the manufacturing process.

II. DUAL-POLARIZED ANTENNA STRUCTURE

Fig. 1 presents the dual-polarized antenna structure and the coordinate system studied in this paper. Notice, that the coordinate system is the same for every drawing in Fig. 1 but that the scale of the structure varies to present it in better way.

The antenna structure is implemented so that there are two waveguides (WG) one on the other. As it can be seen, the lower waveguide (Fig. 1(a)) has a horizontal slot to create linearly polarized radiation. The upper waveguide in Fig. 1(b) presents the dual-polarized orthogonal feeding with cross shaped slot, as presented in [12]. Waveguide cross section is presented in Fig. 1(c), and both lower and upper waveguides have the same dimensions. To increase directivity of the antenna, a ground plane is placed to the same level as the cross shaped slot, as shown in (Fig. 1(d)).

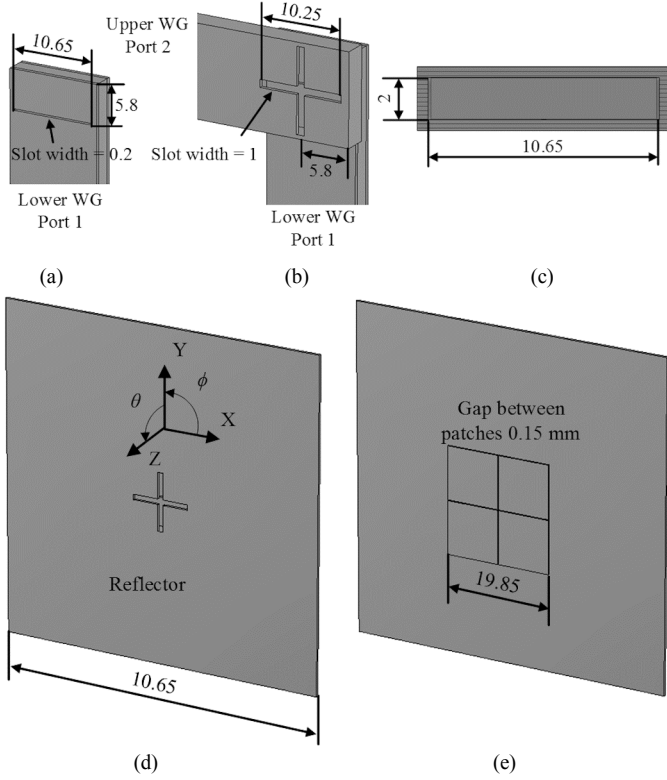


Fig. 1. Dual-polarized slot antenna structure where (a) presents the lower waveguide (WG) for linear polarization, (b) the upper waveguide where orthogonal polarizations are combined to one dual-polarized cross, (c) the same cross section of the lower and upper waveguides, (d) size of the reflector with the coordinate system, and (e) the parasitic patch 3.7 mm above the reflector with air isolation. Dimensions in the figure are presented in mm.

Finally, parasitic patches are brought in 3.7 mm height from the ground plane. The substrate used between the patches and ground plane is air ($\epsilon = 1$). The waveguides are excited with a waveguide port and CST Microwave Studio is used as a simulation tool.

III. SIMULATION RESULTS

This section presents the simulation results of the antenna structure presented in Section II. First, the S -parameters of the dual-polarized structure with parasitic patches are presented for both polarizations. Second, the surface current distributions and the radiation properties of the parasitic patches are shown in terms of θ and ϕ polarization, total efficiency and radiation patterns. The surface currents and radiation patterns are presented at 15 GHz center frequency.

A. S -parameters

Fig. 2 presents the simulated S -parameters. The antenna structure shows -10 dB impedance matching from 14.3 GHz to 15.6 GHz which corresponds to 8.7% relative impedance bandwidth with approximately 15 GHz the center frequency.

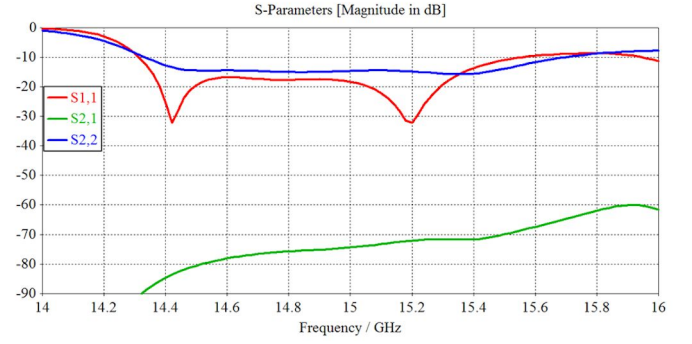


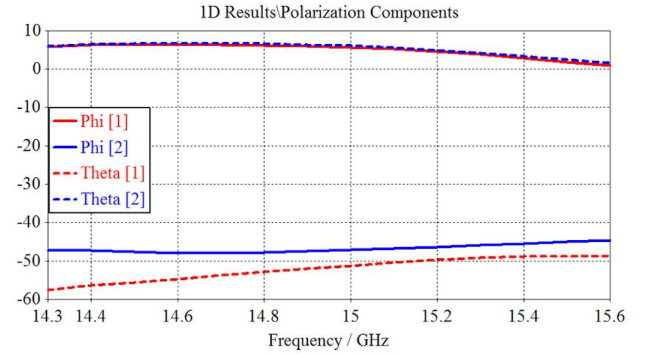
Fig. 2. Simulated S -parameters of the antenna structure.

At the -10 dB impedance bandwidth, the isolation between the antenna ports is better than 68 dB predicting good polarization properties. It is good to notice here that the results are simulated and measured results can show lower isolation like 40 dB would be much closer with prototyping.

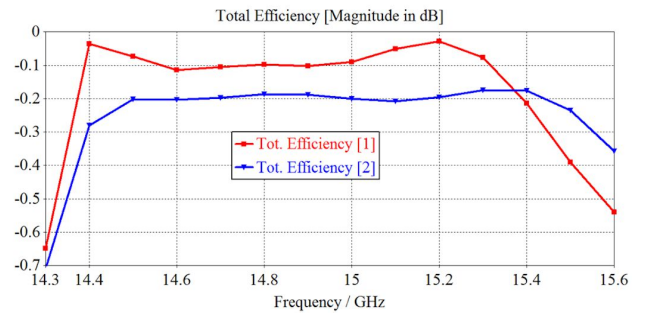
B. Radiation Properties and Surface Current Distributions

Fig. 3 presents the simulated polarization components (ϕ , θ) and the total efficiency of both antenna ports. As it can be observed Fig. 3(a), the difference between the same polarization components of the different antenna ports is greater than 45 dB. As it was discussed in the previous section, the isolation between the antenna ports predicted very good polarization purity which can be well seen in Fig. 3(a).

Fig. 3(b) presents the simulated total efficiency over the -10 dB impedance bandwidth. The total efficiency is presented here to show how well the antenna structure radiates over the studied frequency range.



(a)



(b)

Fig. 3. Simulated (a) ϕ and θ polarization components and (b) total efficiency of the both antenna ports 1 and 2.

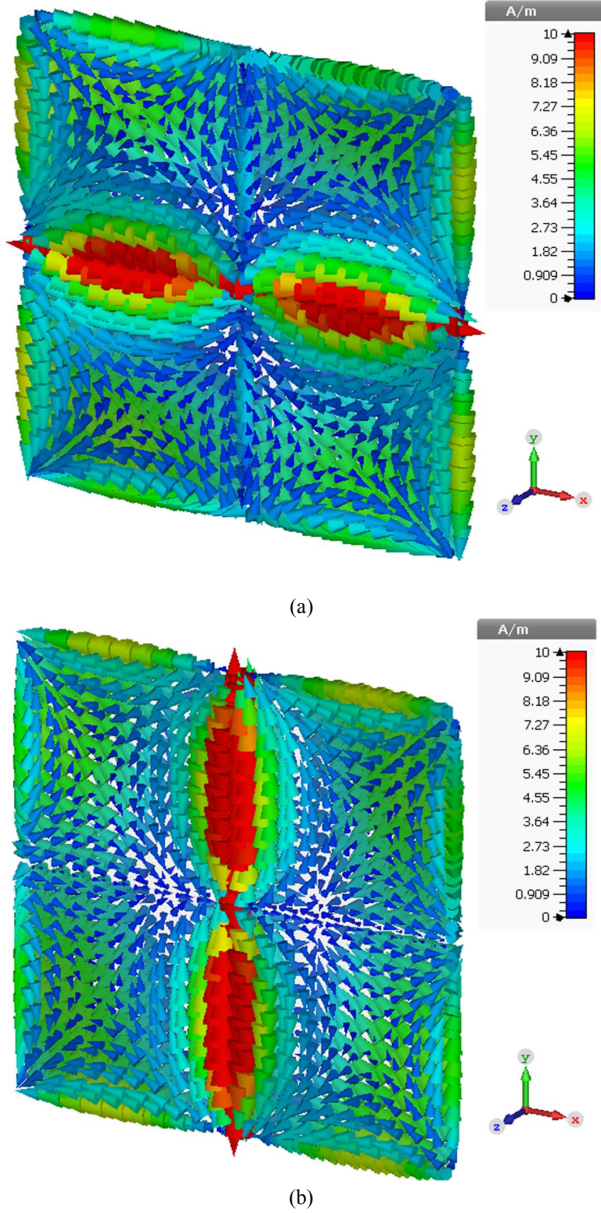


Fig. 4. Simulated surface current distributions at 15 GHz of the excitation (a) Port 1 and (b) Port 2.

The total efficiency is the total power radiated over a sphere, related to the power incident on the antenna port. The total efficiency is better than -0.7 dB ($> 85\%$) over the studied frequency bandwidth, which is 14.3 GHz-15.6 GHz.

Fig. 4 presents the simulated surface current distributions at 15 GHz center frequency. As it can be clearly seen, the polarization of the Port 1 (Fig. 4(a)) is vertically polarized. On the other hand, the polarization of Port 2 in Fig. 4(b) is orthogonal to the Port 1, and, thus horizontally polarized.

The strong currents (red color) in the middle of the antenna structure are cancelling each other as they propagate in opposite directions. Thus, the vertical currents of Port 1 on

the edges of the patches and the horizontal currents of Port 2 are reinforcing each other by creating linear polarization.

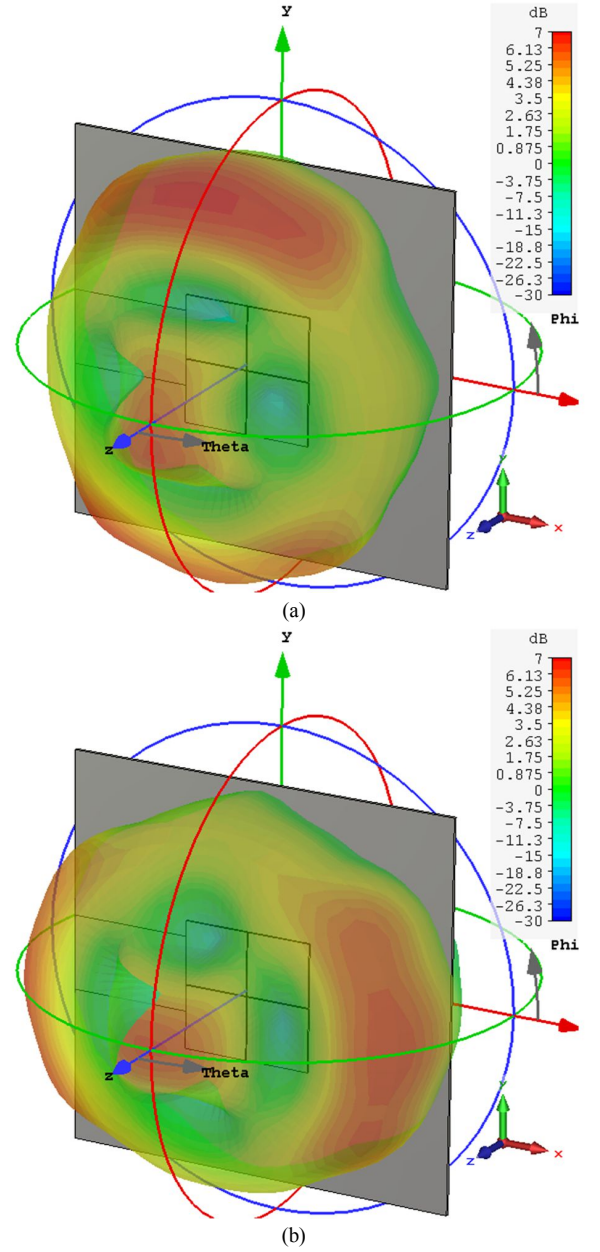


Fig. 5. Simulated 3D radiation patterns at 15 GHz of the excitation (a) Port 1 and (b) Port 2.

When considering the radiation patterns in Fig. 5, the linear currents can be observed in the amplitude of the radiation. Reinforcement of the currents are easily seen in the middle of the patterns ($\theta = 0^\circ$).

It is good to notice that as only the surface currents of the patches are presented, the radiation properties also counts the ground plane. The effect of the ground plane can be seen in the radiation in the direction of $\theta \pm 45^\circ$.

IV. CONCLUSIONS

The paper presented a dual-polarized antenna structure at 15 GHz center frequency. Antenna was implemented in such form that one signal was split into four element sub-arrays. The antenna was fed by using wave guides and a basic radiator was a slot. The antenna structure was formed by using parasitic patch elements as radiators over the slot. The number of elements in the sub-array was four in a shape of 2x2 matrix. Antenna presented good impedance matching and port isolation over the 14.3-15.6 GHz bandwidth. At the same bandwidth, antenna radiated well in terms of total efficiency and directivity. The structure was studied based on simulation results.

As a conclusion, the high isolation properties between the antenna ports are corresponding to a very good polarization properties and the antenna can be considered to be used for example in a full-duplex system. On the other hand, the good impedance matching and high total efficiency are predicting good overall performance of the antenna structure in a future 5G wireless telecommunication systems.

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