A 28 GHz Beam-Switching Yagi-Uda Array Using Rotman Lens for 5G Wireless Communications

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***Abstract*—A modified Rotman lens feeding an antipodal Yagi-Uda antenna array is designed and fabricated for 5G wireless communications. The 28 GHz band is selected in this work as the center frequency, which is a potential band for 5G millimeter-wave communications. The measured reflection coefficients of the beam ports of the Rotman lens cover at least 3 GHz bandwidth, while the Yagi-Uda antenna has 3.7 GHz bandwidth. The Rotman Lens is designed to have five directions covering 45^o symmetrically, while transmitting or receiving signal does not have more than 1 dB drop in its power level. By employing antipodal dipole antennas in dummy ports, the excessive EM waves are absorbed very well in the desired band. The simulated gain of the antenna array varies from 8.3 dBi to 8.7 dBi when the input signal is switched from the first to the fifth port at the 28 GHz frequency.**

***Index Terms*—Rotman Lens, 5G communications, Yagi-Uda antenna, beam-steering, millimeter-wave.**

I. INTRODUCTION

To accommodate higher data rates, and deliver a higher quality of service to users 5G wireless system is the main subject of research and development in RF fields and communications the millimeter-wave frequency spectrum is chosen to employ its higher unspecified bandwidths and its unique specifications [1], while it has higher path loss considering the Friis equation in comparison to microwave. Therefore, consistent network coverage can be achieved in 5G communications when the base stations have a cell radius of 200 meter [2], which needs more base stations in each area in comparison to previous communications generations. As a result, the base stations should be low-cost to be practical and commercial. In this regard, a millimeter-wave frequency band such as 28 GHz has become a prominent candidate supporting a desired high data rate [3].

Different beam-steering methods can be hired in base stations. As such applications needs fast beam-steering, the candidates should use electronic scanning. For instance, by means of phase-shifters, a phased array antenna can be implemented; however, this solution in costly and the phase shifters and feeding network increase the complexity of the system. An alternative solution which is easy to implement and low-cost and covers the broadside direction is the Rotman lens. The Rotman lens can be exploited to feed the antenna array as its multi-input multi-output characteristic (MIMO) and symmetry [4].

In this paper, a modified Rotman Lens feeding an array of antipodal Yagi-Uda antennas was designed and fabricated for 28 GHz as the center frequency. The main beam is designed to steer $\pm20^o$, while covering 45^o of the angular space.

II. ROTMAN LENS

The Rotman lens consists of N input ports, named beam ports, L dummy ports, and M array ports. In each Rotman lens, reflections from the sidewalls and dummy ports, seriously affect the amplitude and phase distribution of the radiation at each antenna [4]. A low-cost solution for this problem is employing antennas covering the whole required bandwidth in dummy ports. The only issue is the radiation of the mentioned antennas in the dummy ports, which should not affect the radiation of the main antennas. The solution for this issue is separating these radiations from the main antennas, and absorbing the excessive waves by means of typical absorbers.

The Rotman lens is designed to have 5 beam ports to support beam-pointing to $-20^o, -10^o, 0^o, 10^o, 20^o$ directions, 8 dummy ports, to alleviate the wave reflections towards the lens and 5 antenna ports, to feed the antenna array. The Rotman lens and antennas are designed and fabricated using an 8 mil RO4003 substrate with $\varepsilon_r = 3.55$ and $\tan\ \delta = 27\times10^{-4}$. The Rotman lens was designed to have at least 3 GHz bandwidth about 28 GHz in each beam ports.

III. ANTENNAS

The designed antennas are shown in Fig. 1 and their parameters are mentioned in Table I. The antipodal Yagi-Uda antenna was designed to have 3.7 GHz bandwidth about the center frequency, and 8 dBi gain in 28 GHz. In addition, an antipodal dipole antenna was designed to cover all of the Yagi-Uda antenna bandwidth, to be used as matched loads in dummy ports to provide the lowest wave reflection in the desired bandwidth.

TABLE I
ANTENNAS PARAMETERS

w_1	$0.5(mm)$	L_1	$2.1(mm)$	d_1	$1.7(mm)$	w_{line}	$0.34(mm)$
w_2	$0.4(mm)$	L_2	$2.9(mm)$	d_2	$1.2(mm)$	w_a	$0.48(mm)$
w_3	$0.4(mm)$	L_3	$2.5(mm)$	d_3	$0.8(mm)$	L_a	$2.1(mm)$
w_4	$0.4(mm)$	L_4	$2.3(mm)$	d_4	$0.8(mm)$	d_a	$1(mm)$
w_5	$0.4(mm)$	L_5	$2.1(mm)$	d_5	$0.8(mm)$		

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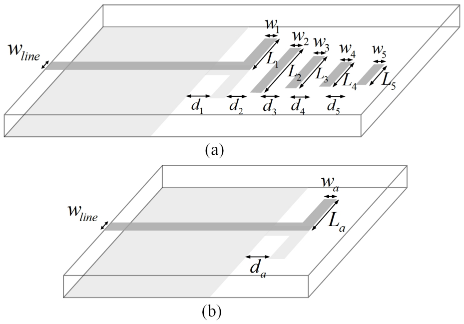

Fig. 1. (a) Antipodal Yagi-Uda antenna, (b) antipodal dipole antenna.

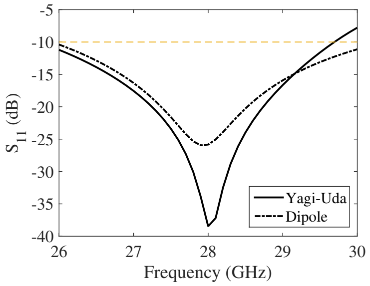

Fig. 2. Simulated S_{11} of the antipodal Yagi-Uda and dipole antenna.

The reflection coefficients (S_{11}) of the designed antipodal Yagi-Uda and dipole antennas are depicted in Fig. 2, which shows that the antipodal Yagi-Uda antenna and the antipodal dipole antenna has 3.7 GHz, and more than 4 GHz impedance bandwidth about the center frequency, respectively.

The main antennas are placed in an antenna array with $0.6\ \lambda_0$ spacing ($\lambda_0 = 10.7mm$). As the main beam is designed to steer $\pm 20^o$, this element spacing reduces the antenna beam-width to the desired beam-width, and does not lead to any grating lobe in the visible region of the array.

IV. RESULTS

The Rotman lens was designed to cover 45^o symmetrically about the broadside. The main beam directions and their angular spacings are designed to transmit or receive signals with no more than 1 dB drop from their relative peak in each direction. Therefore, during the beam-steering, the main beam completely covers the required angular space, which can be easily scaled to 360^o for covering the whole space in a base station. The radiation patterns are drawn in Fig. 3, when exciting each beam port solely.

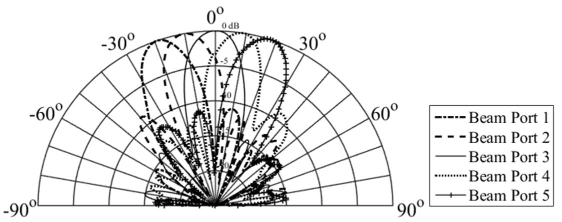

Fig. 3. Simulated radiation patterns of the Rotman lens corresponding to exciting each beam port separately.

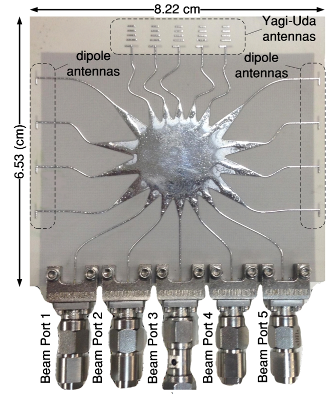

Fig. 4. Fabricated Rotman lens feeding Yagi-Uda antenna array.

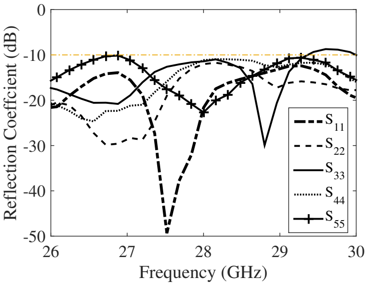

Fig. 5. Measured reflection coefficients of the beam ports of the Rotman lens.

The fabricated structure is shown in Fig. 4. The measured reflection coefficients of the beam ports are plotted in Fig. 5, which shows that each port has at least 3 GHz bandwidth about 28 GHz.The simulated realized gain of the array varies from 8.3 dBi to 8.7 dBi while the beam ports are switched.

V. CONCLUSION

In this paper, a low-cost Rotman lens feeding a Yagi-Uda antenna array was designed and fabricated for 5G communications applications in 28 GHz. The main beam covers 45^o symmetrically about the broadside by means of switching the five beam ports, while the transmitted or received signal does not face more than 1 dB drop in its power level.

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