5G Wideband Magneto-Electric Dipole Antenna Fed by a Single-Layer Corporate-Feed Network based on Ridge Gap Waveguide

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***Abstract*—This paper proposes a wideband magneto-electric (ME) dipole fed by a single-layer corporate-feed network based on the ridge gap waveguide (RGW) transmission line technology for 5G backhauling applications. The proposed antenna is composed of two layers. The top layer is the radiating layer that is composed of the 2×2 ME-dipole antenna element. The bottom layer is the corporate-feed network designed based on RGW. The proposed solution differs from the conventional solution where a slot antenna is fed by RGW and a cavity layer is to excite the radiating elements in order to provide a large spacing for the corporate-feed network in the design of the array antenna. Our new design allows for a smaller antenna volume as it excited the antenna directly by the RGW without the need of cavity layer. In addition, with the use of the ME-dipole radiating element, the bandwidth performance supported by the proposed design is larger as compared to the existing conventional designs. From the obtained simulation results, the proposed antenna produces $S_{11} \leq -10$ dB over $24-30$ GHz resulting in a 22% fractional bandwidth. The maximum directivity over the operating bandwidth of the simulated 2×2 ME-dipole antenna element is approximately 15.4 dBi. Thus, the proposed antenna is a good candidate for low profile fixed-beam applications.**

***Index Terms*—Fixed-beam antennas, gap-waveguide, metamaterial, Magneto-Electric Dipole, millimeter-wave.**

I. INTRODUCTION

raWireless communications have recently experienced a significant evolution due to the proliferation of new wireless applications such as the Internet of Things (IoT) and machine-to-machine communication (M2M). To support the huge demand of wireless data, the millimetre-wave (mmWave) band has been proposed to be used in 5G wireless communication systems [1]. However, the mmWave band experiences more significant propagation path loss as compared to the lower frequency bands [2]. Therefore, the antennas going to employ for 5G mmWave communication must produce a high-gain beam, a wide bandwidth and also be compact in size [2], [3]. A metallic waveguide-based antenna is usually preferred when designing a high-gain array antenna for mmWave. It experiences very low radiation losses and clearly avoids dielectric losses [4]–[6]. However, these antennas require good electrical contacts between the feeding and radiating layers which makes them very expensive to manufacture. An alternative solution is to utilize the substrate integrated waveguide (SIW) technologies for mmWave band antennas [7]–[9]. Nevertheless, the antenna array designs based on SIW still suffer from high losses due to the presence of the dielectric substrate and imperfect shielding due to the use of vias [8]. The gap waveguide (GW) technology was introduced about a decade ago to address the aforementioned issues [10]. The basic principle of the GW technology is based on the combination of the parallel-plate waveguide configuration and the semi-periodic artificial magnetic conductor (AMC) structure to control the direction of propagation of electromagnetic waves. The main advantage of the GW technology is the fact that no electric contact is required between the different metal blocks or metal layers while keeping low-loss performance. To this end, numerous array antennas have been developed based on the GW technology at different operating frequencies [11], [12]. To provide sufficient spacing for the corporate-feed networks and to achieve wideband performance, most of these antennas were excited through the cavity layer. Therefore, these antennas usually consist of at least 3 different metal layers: the corporate-feed network layer, the cavity layer and the radiating layer. However, the manufacturing costs and the design complexity is increased for these cavity-backed array antennas. Besides, in many applications, antenna arrays with a low volumetric profile are preferred. Therefore, to address these issues, a single layer feed array antenna is designed based on the series-feed network have been proposed [5], [6]. However, these antennas usually suffer from poor bandwidth performance, where the -10 dB bandwidth is usually less than 10%. Recently, few versions of the single-layer corporate-feed array antennas based on the GW technology have been successfully developed. The design proposed in [13] still suffers from the limited bandwidth performance where it only supports a -10 dB bandwidth of 5%. To resolve the poor bandwidth performance issue, [14] proposed to modify the conventional slot into a “8-shaped” slot achieving a bandwidth of around 17%. However, this is still insufficient to cover the whole potential mmWave band proposed for 5G systems at $24.25-29.5$ GHz. Untill to now, all these fully metallic GW based antennas have been developed using the conventional slot as the radiating element which limited the bandwidth performance of the GW based antennas. In this paper, we propose an alternative solution for the wideband single-layer corporate-feed array antenna based on the ridge gap-waveguide (RGW). Namely, we propose to employ the magneto-electric (ME) dipole as the radiating element fed by an RGW transmission line. From the simulated results, the proposed antenna provides a $S_{11} \leq -10$ dB over the $24-30$ GHz frequency band resulting in a 22% fractional bandwidth and the simulated gain is approximately 15.4 dBi. Our proposed solution allows the single-layer corporate-feed array antenna to have comparable bandwidth as the cavity-backed array antenna. Thus, this is a good option for applications requiring low volumetric profile antennas.

II. DESIGN OF THE RIDGE GAP WAVEGUIDE

As reported in [10], the design of the AMC pin plays an important role in determining the performance of the GW. The GW can only control the propagation of waves at certain a frequency band which is determined by the stopband created by AMC pin [10], [11]. In this work, we aim to design an antenna that operates within the $24-30$ GHz band. Thus, it is important to design AMC pins that support the stopband over this frequency band. Another important characteristic that needs to be taken into consideration is to ensure that the whole GW is only operating over a single-mode, the quasi-TEM mode. The design approach of the AMC pins and ridge is discussed in [10]. Fig. 1 illustrates the proposed RGW and its dispersion diagram. As it can be seen from the dispersion diagram, the proposed AMC pin provides a band-stop characteristic from $22-45$ GHz which covers nearly the whole K-band bandwidth. Therefore, it can be used to develop the feeding network for our proposed antenna.

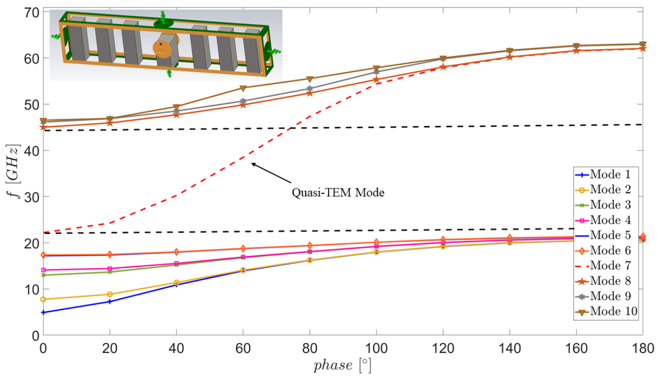

Fig. 1: Dispersion diagram for the proposed RGW. The red, dotted line represents the Quasi-TEM mode of the proposed RGW.

III. 2×2 ME DIPOLE

Fig 2 shows the proposed 2×2 ME-Dipole fed by the RGW. To avoid the appearing of high grading lobes, the proposed antenna is designed to have a spacing of less than λ_0 in both the x- and the y-direction, where λ_0 is the free-space wavelength at 30 GHz. In this work, the aperture coupling technique is employed to excite the radiating elements [7]. The energy coming from the proposed RGW is coupled to the radiating element through the "I-shaped" slot. The "I-shaped" is employed to maximize the energy coupled into the radiating elements over the limited spacing. The radiating elements of the proposed array antenna are realized by the four metallic pins and the cavity walls surrounding them. The electric dipole of the proposed configuration is realized by the top surface of four metallic pins. Two pairs of the electric dipole are realized along the x-direction. As for the equivalent magnetic dipole, it is accomplished by the gaps between the metallic pins as well as the gap between the cavity wall along the y-direction. The realization of the ME-dipole concept is similar to the techniques discussed in [7] and [9].

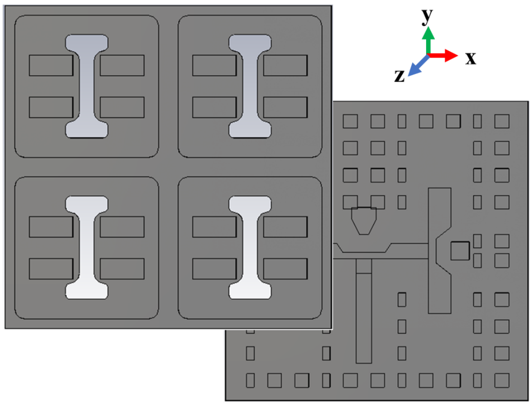

Fig. 2: The proposed 2×2 ME-Dipole fed by RGW.

IV. SIMULATION RESULTS

The simulation and optimization of the proposed 2×2 ME-dipole have been carried out by employing Computer Simulation Technology (CST) software. Fig 3 shows simulated results of the reflection coefficient S_{11} and the directivity D_0 of the proposed ME-Dipole. As can be seen from the results, the proposed antenna has a -10 dB fractional bandwidth of 22% covering the $24-30$ GHz frequency band. The proposed antenna has also provided a stable directivity performance

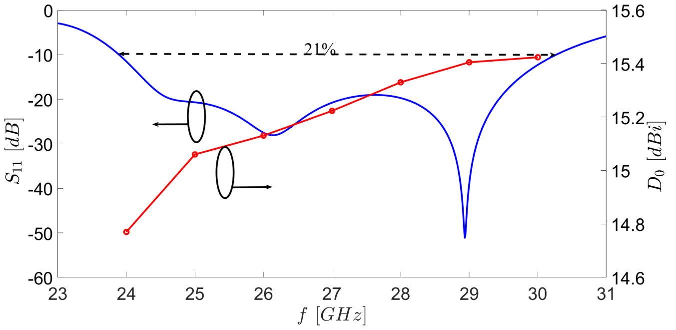

Fig. 3: Simulated reflection coefficient S_{11} and directivity D_0. f denotes the frequency.

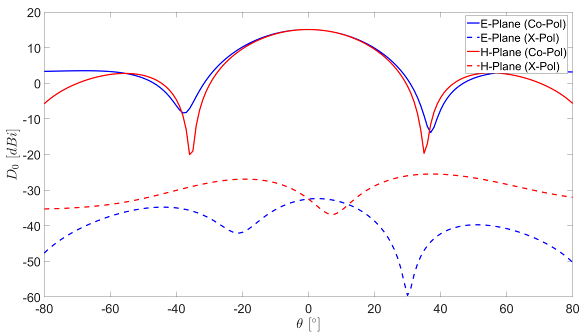

Fig. 4: Comparison of the simulated radiation pattern for both the E- and H-planes at 25 GHz. The Co-Pol represent co-polar radiation pattern and X-Pol represent cross-polar radiation pattern.

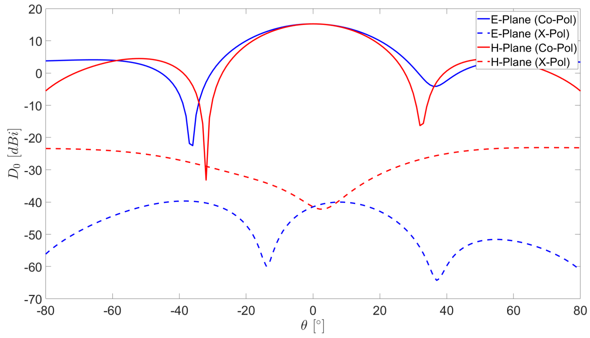

Fig. 5: Comparison of the simulated radiation pattern for both the E- and H-planes at 27 GHz. The Co-Pol represent co-polar radiation pattern and X-Pol represent cross-polar radiation pattern.

which is around 15 ± 0.3 dBi over the whole operating bandwidth. Fig 4 shows the simulated radiation pattern of the proposed antenna at 25 GHz for both the E- and the H-plane. Radiation patterns at 27 GHz and 29 GHz are shown in Fig 5 and Fig 6, respectively. As can be seen, the E-plane and the H-plane radiation patterns are almost identical at these frequencies. In addition, the relative cross-polarization level for both the E- and the H-planes are below -30 dBi at these frequencies. Compared to the works presented in [13] and [14], our proposed antenna solution shows a promising performance for wideband single-layer RGW-feed array antenna for 5G fixed beam applications.

V. CONCLUSION

The numerical design of a 2×2 wideband magneto-electric (ME) dipole antenna fed by a single-layer corporate-feed network based on the ridge gap waveguide technology is presented in this paper. The ME-dipole antenna is realized using four metallic pins surrounded by a metallic cavity. The antenna is excited employing the aperture-coupled technique. The proposed antenna has been designed to operate at the frequency band covering $24 - 30$ GHz, which is one of the potential mmWave bands for 5G wireless systems. The

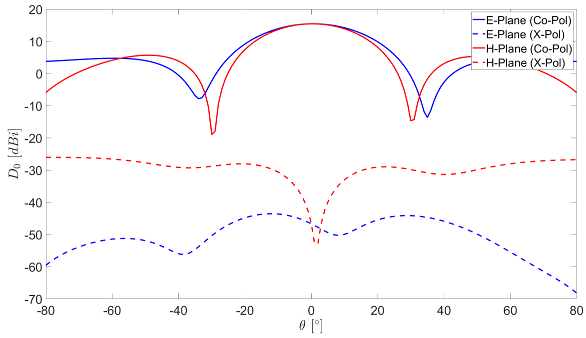

Fig. 6: Comparison of the simulated radiation pattern for both the E- and H-planes at 29 GHz. The Co-Pol represent co-polar radiation pattern and X-Pol represent cross-polar radiation pattern.

maximum computed directivity is of around 15.4 dBi over the operating frequency. The proposed design is a promising solution in designing a wideband single-layer corporate-feed network array antenna. Our future work will focused in developing a larger array antenna based on the proposed solution.

ACKNOWLEDGMENT

This project has received funding from the European Union Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No. 766231 WAVECOMBE H2020-MSCA-ITN-2017.

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