Mm-Wave Beam Steering Antennas using Stacked Parallel Plate Lens Antenna Subarrays

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***Abstract*— A millimeter (mm)-wave beam steering antenna consisting of subarrays of parallel plate lenses is presented for the first time. As compared to a previously reported antenna that utilized subarrays of dielectric slab waveguide lenses, the presented antenna allows to design and control the beamwidth of the radiation pattern in the plane orthogonal to the beam steering plane by stacking the parallel plate lens subarrays. Additionally, full wave simulations of the presented antenna show performance improvements in gain, side lobe level, and field of view in comparison to the previously reported dielectric slab waveguide-based realization.**

I. Introduction

Mm-wave beam steering antennas realized based on lens antenna subarrays (LASs) were shown to operate with better energy efficiency (bits/s/Hz/Watt) in mm-wave wireless networks as compared to traditional phase antenna arrays and lens antennas [1]. Each LAS employs an electrically small lens, M number of feed antennas that can be activated by a single pole M throw $SPMT$ switch, and one phase shifter. An antenna consisting of L LASs approximates an $N = LM$ element traditional phase array while reducing the total number of phase shifters by a factor of M as seen in Fig. 1, and resulting in a lower power consumption hardware with reduced complexity. The inclusion of $SPMT$ switch allows to scan the beam of the subarray which in turn provides an improved scan range as compared to traditional antenna subarrays. In comparison to a traditional lens antenna, a LAS based antenna can perform better beam optimization in poor and rich scattering mm-wave wireless channels to exhibit a higher data rate approaching to that of the traditional phased array. However, this performance requires employment of electrically small lenses with diameters around two wavelengths.

Our research group presented two different hardware realizations of LAS based mm-wave antennas in a way to maintain a large scan range while considering the side lobe level (SLL) trade-off. In [2], we presented a 1D beam-steering 38 GHz antenna by utilizing extended hemi-cylindrical dielectric slab waveguide (DSW) lenses with $N = 20$, $L = 4$, $M = 5$ and a performance of $\pm 37.5°$ scan range (see Fig. 2a). In [3], we presented a 2D beam steering antenna using extended hemispherical dielectric lenses with $N = 119$, $L = 7$, $M = 17$ and a performance of $\pm 36°$ scan range and 9.5 dB SLL.

Certain applications may require 1D beam steering of fan beams, but also require designing of the beamwidth in the plane orthogonal to the beam steering plane. This makes the DSW based 1D beam steering LAS antenna not suitable since the lenses cannot be stacked to narrow the beamwidth. Therefore, in this paper we utilize parallel plate waveguide (PPW) lenses in realization of a 1D beam steering LAS antenna and investigate its performance. Full wave simulations show that the presented antenna can operate with 9 dB SLL and 38-degree scan range while reducing the half power beamwidth (HPBW) in plane orthogonal to the scan direction down to 20 degrees.

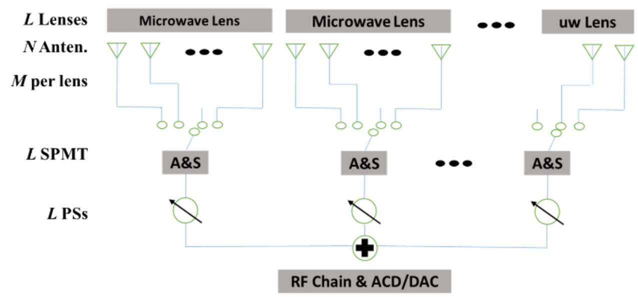
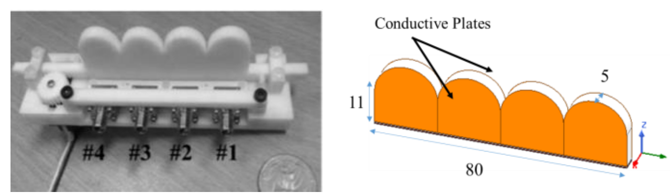


Fig. 1. LAS-based antenna architecture (A&S denote Tx/Rx amplifiers and switches) [2].



(a) (b)

Fig. 2. (a) DSW LAS antenna prototype [2] and (b) parallel plate LAS model (dimensions in *mm*).

II. Parallel Plate Wavegide (PPW) Lens Design

The PPW LAS antenna design is first carried similar to the scenario of [2], where $N = 20$, $M = 5$ and $L = 4$ (see Fig. 2). The dielectric material of the lenses are ABS ($\varepsilon_r = 2.4$, $\tan\delta = 0.006$) to enable implementation with 3D printing. The initial PPW lens dimensions are analytically determined based on the well-known hyper hemispherical lens equations and later optimized to achieve the highest possible realized gain. An extension length of 11 *mm* is found to provide a broadside gain which is of similar value to that of the DSW lens used in [2]. On the other hand, the extension length of the PPW lens is smaller than that of the DSW lens due to the DSW lens being based on a reduced effective dielectric constant value.

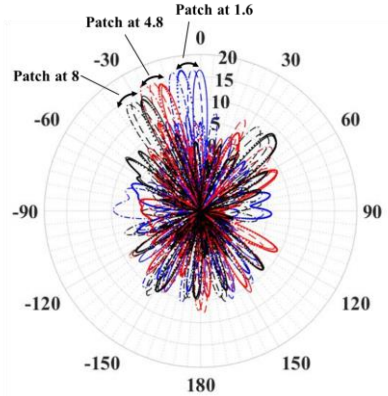


Fig. 3. Simulated H-plane realized gain for the LAS-based antenna employing $L = 4$ PPW lenses at 38 GHz.

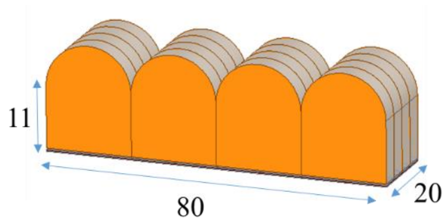


Fig. 4. Stacked PPW LAS antenna.

III. PPW LAS Performance

Since the extension length of the PPW lens is shorter and its dielectric constant is larger (compared to DSW lens), full wave simulations determined that $M = 6$ feed antennas would be more suitable to maximize the beam steering capability. The aperture coupled patch antennas used in [2] are also found to be effective to be employed as the feed antennas of the PPW lens. The locations of the patch antennas are determined to be $\pm 1.6, \pm 4.8$ and ± 8 mm relative to the lens axis for obtaining the best beam steering coverage. Fig. 3 depicts the full-wave simulated H-plane realized gain of the LAS-based antenna employing $L = 4$ PPW lenses at 38 GHz (only half of the beams are shown due to symmetry). Maximum and minimum realized gains are around 17 and 14 dBi, respectively. SLL is better than –9 dB for all beams. Scan range is $\pm 37.5°$.

The SLL performance of the PPW lens-based LAS antenna is better than that of the LAS antenna based on DSW lenses. Another advantage is the ability to stack up the PPW lenses in the E-plane for controlling the HPBW in the plane orthogonal to the beam steering plane. Fig. 4. depicts an example design where an $L = 4 \times 4$ LAS antenna is formed with a stack of 4×1 PPW lenses. Fig. 5. shows full-wave simulated realized gain in *H*-plane. The maximum gain exceeds (22.5 dBi) and SLL is better than -9 dB. Fig. 6 presents the simulated realized gain in *E*-plane when scan direction is set to the broadside, where HPBW is found to be $(20\,°)$ for the stacked PPW LAS antenna. In contrast, the HPBW of the non-stacked (i.e., 4×1) LAS antenna is $(50\,°)$ in the E-plane.

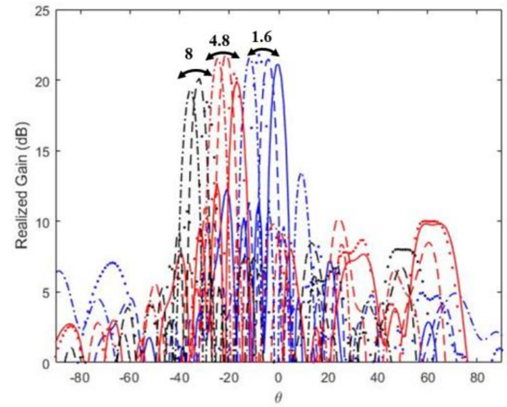


Fig. 5. Simulated H-plane realized gain for the stacked LAS-based antenna employing $L = 4 \times 4$ PPW lenses at 38 GHz.

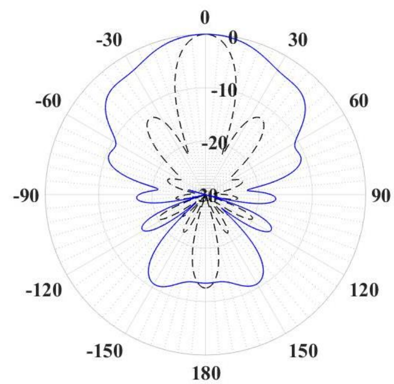


Fig. 6. Simulated E-plane normalized realized gain of stacked and non-stacked LAS-based antennas in the broadside scan direction.

IV. Conclusions

Parallel plate waveguide (PPW) lenses are investigated for utilization in construction of lens antenna subarray (LAS) based mm-wave beam steering antennas. It is shown that PPW lenses can perform similar to the dielectric slab waveguide (DSW) lenses utilized in prior work. However, in contrast to the DSW lenses, the PPW lenses are stackable. Therefore, different LAS based antenna configurations can be realized by utilizing the PPW lenses to control the beam width in the plane orthogonal to the scan direction. Experimental verifications of the designs presented in this paper are underway and their measured performances will be discussed at the time of the conference.

References

[1] M. Karabacak, H. Arslan and G. Mumcu, “Lens Antenna Subarrays in mmWave Hybrid MIMO Systems,” *IEEE Access*, vol. 8, pp. 216634-216644, 2020.

[2] G. Mumcu, M. Kacar and J. Mendoza, “Mm-Wave Beam Steering Antenna with Reduced Hardware Complexity Using Lens Antenna Subarrays,” *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 9, Sep 2018.

[3] K. A. Shila and G. Mumcu, “A Millimeter-Wave 2D Beam Steering Antenna Using Extended Hemispherical Dielectric Lens Antenna Subarrays,” IEEE Access, vol. 10, pp. 103065-103073, 2022