Revisiting Risley Prism Transmit-array antennas using a novel co-design phase correction approach

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***Abstract*—Mechanical beam steering using two independent axial rotating metasurfaces (Risley Prism configuration) have been shown to be a cost-effective solution for millimeter wave (mmW) antennas. By adapting to mmW this canonical beam steering concept of optics using metasurfaces (instead of wedge prisms) allows achieving a greater design flexibility. Many works have explored different ways of encoding the required phase correction. All of them implicitly implement three operations: i) beam collimation (i.e., plane wave conversion); ii) 1D beam tilting along a given axis; iii) a second 1D beam tilting for a different direction according to the prescribed beam pointing direction. Conventionally, steps i) and ii) are solved by the first operating metasurface, which sets the phase delay profile of the second metasurface. Recently, the authors have shown an alternative approach where the beam collimation is performed by the combined effect of the two metasurfaces. Using 3D-printed perforated slabs we have previously demonstrated that this generalized approach is effective for the reduction of the side lobe level of the conventional case. In this communication, we will present alternative implementations of this concept to demonstrate the wider reach of our findings.**

I. Introduction

Mobile communications based on millimeter waves are becoming a reality, driving the future of terrestrial and satellite networks. There is an ongoing research effort for the developed affordable electronic beam steering technologies for these antennas. The intrinsic complexity of reconfiguring the phase delays of thousands of elements that compose the antenna aperture drives the research of alternative solutions based on mechanical beam steering [1]. In particular, adapting the Risley prism concept from optics to the microwave domain, taking full advantage of the benefits of Transmit-array (TA) technology (see Figure 1) is a topic attracting a lot of attention from researchers [2]-[4] . Recently, the authors shown that the high side lobe levels of this solution emerge from the macro-cell periodicity of the second transmit-array [5]. A more general framework was developed that can produce the same overall phase compensation effect but using, in each lens, different phase compensation profiles that do not imply having this macro-cell periodicity. This concept has been experimentally shown using perforated dielectric slabs as TAs. In this work, we provide additional numerical examples showing that the reported performance enhancement is a quite general result that should be accounted for future designs using this configuration.

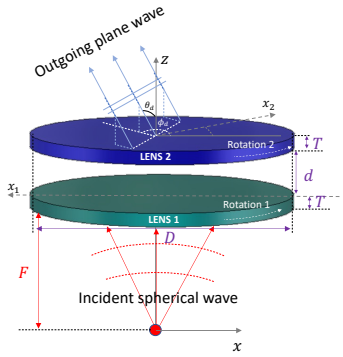


Figure 1. Schematics of Risley Prism configuration

II. Generalized Framework

The working principle of the Risley Prism results from the combined effect of the two TAs. In a conventional solution

$$\begin{cases} \phi_{TA_1}(x_1, y_1) = k_0\sqrt{x_1^2 + y_1^2 + F^2} - k_0 \sin\alpha_0\, x_1 \\ \phi_{TA_2}(x_2, y_2) = -k_0 \sin\alpha_0\, x_2 \end{cases} \quad (1)$$

However, is possible to further generalized (1) by adding and subtracting in each surface an arbitrary function, $\Psi(r, z)$, that is invariant under an axial rotation without changing the outgoing phase, as follows.

$$\begin{cases} \phi_{TA_1}^{New}(x_1, y_1) = \phi_{TA_1}(x_1, y_1) + \Psi(r, z) \\ \phi_{TA_2}^{New}(x_2, y_2) = \phi_{TA_2}(x_2, y_2) - \Psi(r, z) \end{cases} \quad (2)$$

where $r = \sqrt{x_1^2 + y_1^2} = \sqrt{x_2^2 + y_2^2}$. The Ψ function can be arbitrary and provides interesting degrees of freedom for further investigations. In [5] we used the function

$$\Psi(x,y) = -k_0\sqrt{x^2 + y^2 + F_2^2} \tag{3}$$

where F_2 defines the position of a virtual focus that was chosen arbitrarily. In this work another Ansatz could be followed. In this work we considered

$$\Psi(r,z) = -\frac{k_0}{2}\sqrt{x_1^2 + y_1^2 + F^2} \tag{4}$$

Which implies that both surfaces have the same phase correction. In Figure 2 we present a visualization of the corresponding TA profiles for each of the approaches described herein.

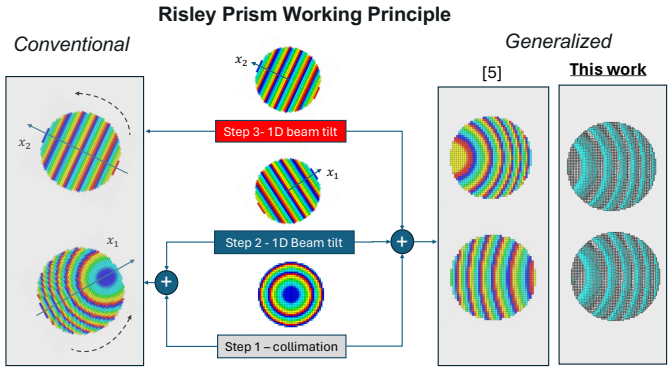


Figure 2. Different implementation of Risley Prism Concept

III. Numerical Evaluation

In [5] the advantage of the developed generalized framework has been numerically and experimentally demonstrated using perforated dielectric slabs. However, a more sceptic reader could ask the question if this is an advantage observed only for this type of implementation. To clarify this point, we use the formulation of equivalent dielectric unit cells developed in [6] to devise ideal unit cells with perfect free-space matching (each unit cell is a dielectric block with equal permittivity and permeability). In Figure 3 is clear that even for this idealize case SLL reduction occurs, proving that this is indeed a general result.

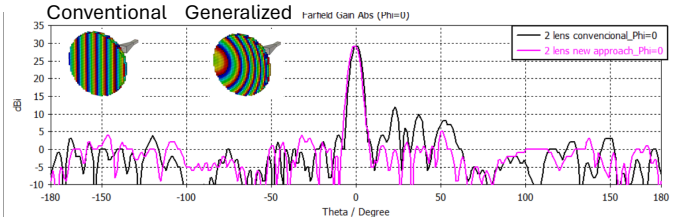


Figure 3 Comparison of conventional and generalized implementation of Risley Prism concept (Eq. 3) using idealized unit cells for 30 GHz with $\alpha_0 = 25°$, $D = 140\ mm$, $F = 100$ mm and $F_2 = 150\ mm$.

The second numerical example provide herein compares the two implementations of the generalized concept show in the inset of Fig. 2, using the same type of perforated dielectric unit cells. Similar performances are obtained, confirming that this general framework provides a greater flexibility for the design of the Risley Prism TA antenna.

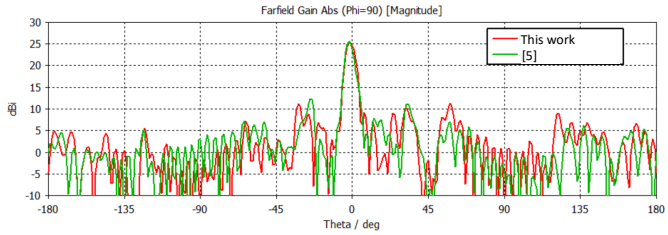


Figure 2. Comparison of two implementations of the generalized Risley Prism approach.

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IV. Conclusions

A novel design approach for impementing the classical concept of Risley prism using TAs is presented. The motivation is to reduce the gratting lobes that limits the SLL performance of this cost-effective mechanical scanning approach. This work highligths that under a generalized framework this problem can be easily circuvented with multiple alternative designs, paving the way for further optimizations.

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