

# Multibeam antenna design based on transmit-arrays with low $F/D$ operation

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**Abstract**— Cost-effective multibeam millimeter wave antenna solutions are required to enable the deployment of 5G NR. The complex trade-off between system complexity and RF requirements (such as high gain, number of beams, beam scanning capability,) needs to be carefully optimized. Transmit-arrays (TAs) can provide a low-cost solution for multibeam operation by having a feeding array placed at a given focal distance. However, the maximum number of feeds and cross-over levels are constrained by the focal distance to aperture diameter ratio ( $F/D$ ). On the one hand, reducing the  $F/D$  allows designing more compact feeding array elements, on the other hand, it limits the maximum angle coverage due to scanning aberrations. In this work, we show that a TA optimized for operating simultaneously with low  $F/D$  and wide-angle coverage can improve the performance of this classical configuration. We design a Ka-band multibeam antenna with a TA fed by a  $19 \times 5$  array of standard WR38 waveguide operating with  $F/D=0.34$ . It provides 25 dBi of gain with scan losses below 3 dB when scanning in a zenith plane up to  $-55$  degrees, covering 80 degrees ( $-55$  to 25 degrees) with cross-over levels around 3 dB.

**Index Terms**— Ka-band, Multibeam antenna, Transmit-arrays, Multifocal design

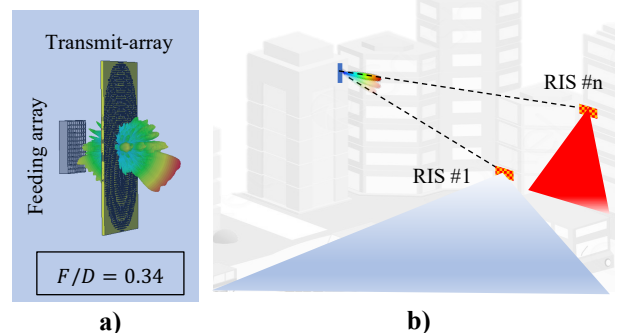
## I. INTRODUCTION

Multibeam antennas are a fundamental component for the deployment of next-generation millimeter wave (mmW) communication systems, fomented by the development of massive MIMO [1]. Different implementations can be used, such as: reconfigurable intelligent surfaces (RIS) [2], phase arrays [3], or quasi-optical multi-beam antennas [4]. In Figure 1, we represent a use case where the multibeam antenna is placed as the base station for a set of RIS deployed along a city landscape.

Spatially fed array antenna [5] is a cost-effective configuration which avoids the complexity of having a feeding network controlling each sub-wavelength element that forms the aperture – as it happens for RIS or phased arrays. One key design parameter is  $F/D$ , which defines the necessary directivity of the feeding elements, limiting the minimum physical space occupied by each element, as well as the density of the feeding array. The authors present in [6] a

new iterative design approach – the multifocal transmit-array – for operating with extremely low  $F/D$  and wide-angle beam scanning. In this work, we further explore this concept for the design of a low-cost multibeam antenna. In previous works we have been working on low profile solutions for wide-angle coverage using mechanical scanning. Herein, the focus is on the design of an antenna with multiple simultaneous beams, which shares some figure of merits (angle coverage, scan loss, gain), but also has specific performance parameters, such as the number of beams or cross-over levels.

We design a Ka-band multifocal TA operating with  $F/D = 0.34$  fed by a  $19 \times 5$  feed array of standard open-ended waveguide elements (WR28), Figure 1. A wide-angle coverage is achieved with 96 beams, with 25 dBi gain, scan loss below 3dB and side lobe level below 10 dB, as show in the Section III. We then prove that the concept of multifocal TA can be a cost-effective way of enhancing the performance of multibeam antennas in terms of angular coverage and cross-over levels.

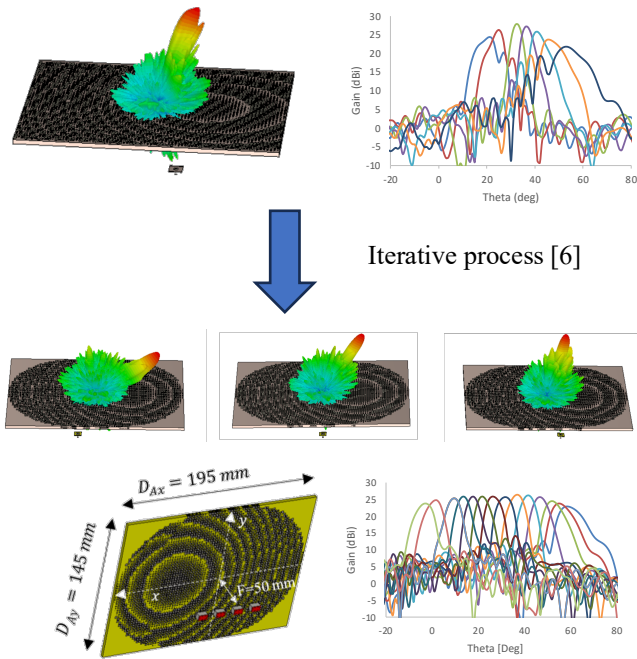


**Figure 1:** (a) Multibeam antenna composed of a  $19 \times 5$  feeding array of WR28 standard waveguide and a multifocal transmit array optimized for wide-angle coverage with low  $F/D$  [6]; (b) Use case for 5G and beyond systems where the multibeam antenna act as a basestation for multiple RIS panels.

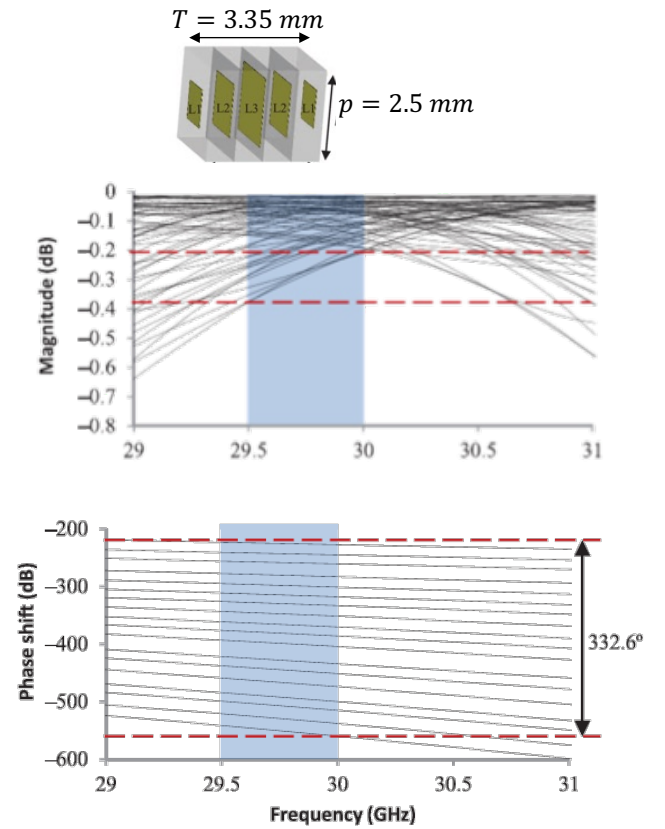
## II. ANTENNA DESIGN

In [6] we have presented a new design procedure for optimizing iteratively the phase correction of the TA that minimizes the beam aberration for multiple feed positions, schematically represented in Figure 2. In Figure 2 we depicted the improvement that can be achieved when starting from a conventional offset collimation phase correction. The final design is shown in the inset of Figure 2, resulting from the iterative method described in [6] that sets the position and corresponding outgoing angles of 11 focal points. The multifocal transmit-array optimized phase correction is implemented using the collection of patch-based unit cells (details can be found in [7]) shown in Figure 3.

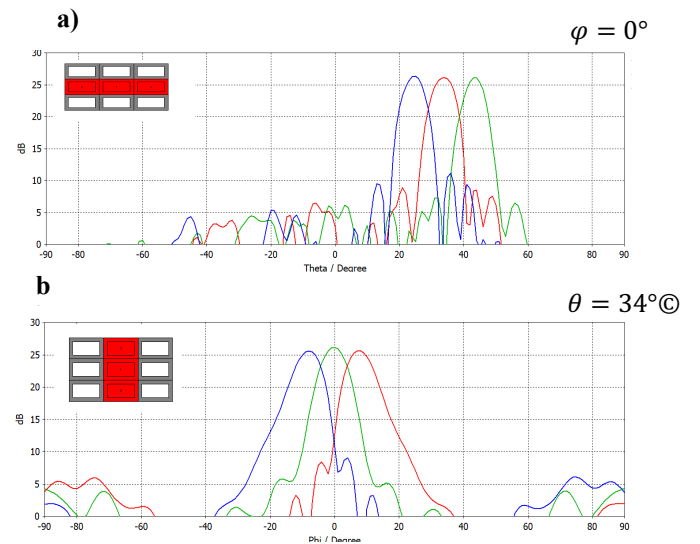
Operating with low F/D enables the use of low gain feeding elements leading to reduced angular separation between beams. We use a standard open waveguide (WR28) that ensures a proper illumination taper of the aperture (12 dB). In Figure 4, we report the results of a 3x3 feeding array producing well defined collimated beams with good cross-over levels. In the next section we present the performance of an extended feeding array composed by 19x5 elements.



**Figure 2:** Overview of the scanning performance improvement achieving by the multifocal TA iterative design approach [6] using  $F/D = 0.34$ .



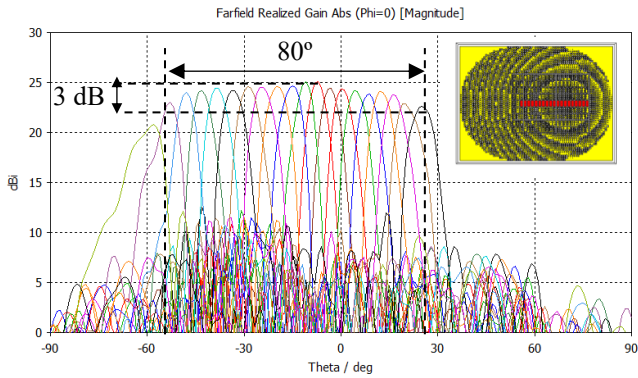
**Figure 3:** Unit cell used for implementing the TA multifocal phase correction [7].



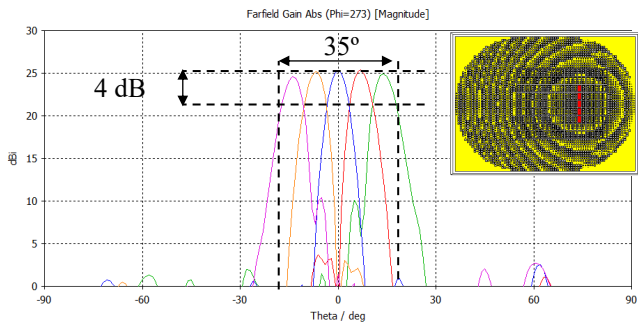
**Figure 4:** a) Multibeam configuration of the TA illuminated by a 3x3 matrix of WR28 waveguides. b) radiation pattern (gain) for  $\varphi = 0^\circ$  considering the 3 feeding elements in the central line. c) radiation pattern (gain) for  $\theta = 34^\circ$  considering the vertical central line of the feeding matrix.

### III. MULTIBEAM ANTENNA PERFORMANCE

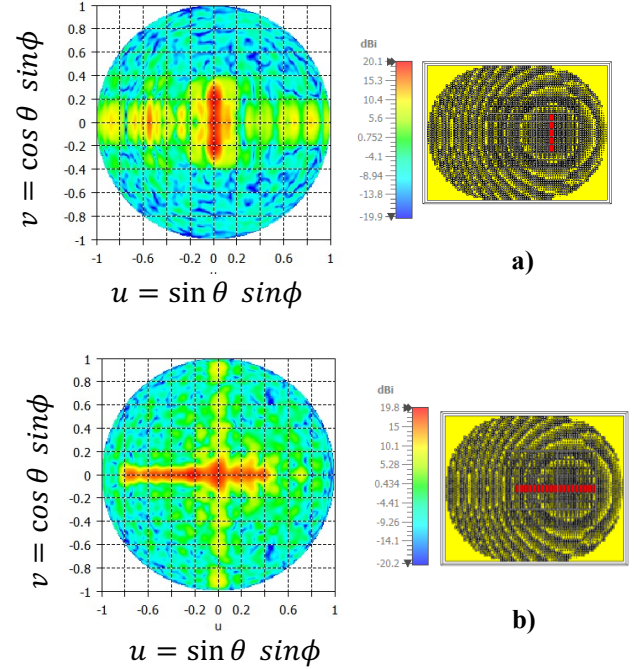
We consider now a feeding array composed by 19x5 array elements. In Figure 5 we analyze the angle coverage of the multibeam antenna when the ports of the central line of the feeding array are sequentially excited. In the  $\phi = 0$  plane the antenna has an angular coverage between  $-55^\circ$  to  $25^\circ$ , a maximum gain of 25 dBi, a scan loss below 3 dB and cross-over levels of 3dB. In Figure 6, we plot the radiation patterns in the plane  $\phi = 273$  for the five elements of the corresponding scanning row (number 13, as show in the inset of Figure 6). In this plane it is possible to have an angular coverage of 35 degrees with low side lobe level (SLL). The cross over level is lower than the previous case (around 4dB) due to the spacing between elements being higher in this direction. In Figure 7, simultaneous excitation is used to show the overall coverage are of the antenna in the orthographic projection coordinates. A nearly continuous coverage from  $-0.75 < u < 0.41$  and  $-0.23 < v < 0.23$  with 96 well defined beams is achieved.



**Figure 5:** Beam radiation patterns of the multibeam antenna using 20 elements of the central line (19 beams have less than 3dB scan loss and cross-over levels).



**Figure 6:** Beam radiation patterns of the multibeam antenna using 5 vertical elements of the line 13 of the feeding array.



**Figure 7:** Radiation patterns of the multibeam antenna using orthographic project coordinates for combined ports excitation with equal amplitude and phase: a) using 19 elements of the central line; b) using 5 elements of the 13<sup>th</sup> row.

### IV. CONCLUSIONS

A multibeam antenna was design based on the concept of multifocal transmit-arrays. The phase correction was optimized for providing a beam tilt of 55 degrees (zenith) with  $F/D = 0.34$ , which enables the use of a standard Ka-band waveguide (WR28) to populate a feeding array with 95 (19x5) elements. It is shown that the antenna can provide wide-angle coverage, with good cross-over levels, high gain and low side lobe levels. We then demonstrate that the multifocal concept, first introduce in [6] in the context of mechanical scanning, can also be an interesting solution for the design of low-cost multibeam antennas.

### ACKNOWLEDGMENT

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