Multiple beam antenna based on a parallel plate waveguide continuous delay lens beamformer

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***Abstract* – A novel quasi-optical beamformer based on a continuous delay lens was designed, manufactured and tested. The wide band and wide scanning capability is demonstrated at Ku band, as well as low return loss at all input ports and low mutual coupling. The agreement between measurements and simulations is outstanding, for both the S parameters and the radiation patterns.**

***Index Terms* — Antennas, quasi-optical beamformers, multiple beam antenna.**

1. Introduction

With the emerging telecommunication systems based on constellations of satellites, there is a need for antennas producing multiple beam coverages over a large angular range (up to ±40°), and operating over a wide band (10-14.5 GHz) or even on dual-frequency band (20-30 GHz). Antennas based on quasi-optical beamformers implemented in parallel plate waveguide technology and terminated by a flare aperture are appropriate for such requirements. There are various options available in the state-of-the-art. The pillbox antenna [1, 2] is an option, but it has the following drawbacks : i) the parallel plate section must be folded twice in order to have the radiating aperture located on the opposite side of the input ports; ii) standard pillbox antenna may introduce phase aberrations for extreme angular range [1]. Constrained lenses, sometimes referred to as bootlace lenses [3], were introduced as a mean to improve scanning performance by adding some extra degrees of freedom to the design. Well-known solutions include the Ruze lens [4] and the Rotman lens [5]. Constrained lenses have the capability to produce multiple focal points, thus providing low phase aberrations over a wider scanning range. In such lenses, the constrained sections introduce however bandwidth limitation.

This paper describes a novel lens beamformer with wide scanning capability and very large bandwidth. Design and measurement results are provided in Ku band.

2. Description of the lens geometry

In a Parallel Plate Waveguide (PPW) beamformer, cylindrical waves launched by the feeds are converted into planar waves at the radiating aperture, as illustrated in Fig.1, and vice-versa.

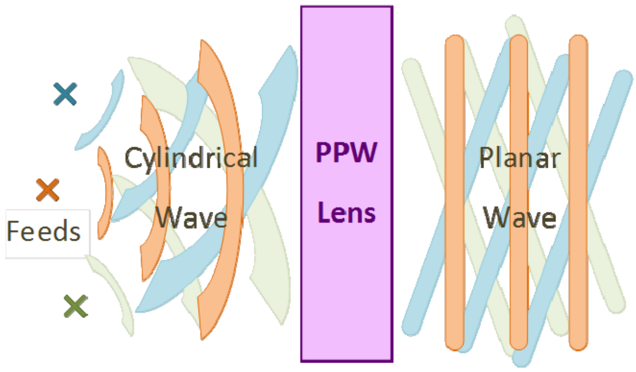

Fig. 1. Principle of operation of the lens.

A 3D view of the proposed lens is represented in Fig. 2. It consists of three main parts: a set of compact sectoral horns (6 horns are shown in Fig. 2), a PPW section with delay lines, and a radiation horn. The delay lines are longer at the center of the lens, and shorter on its sides.

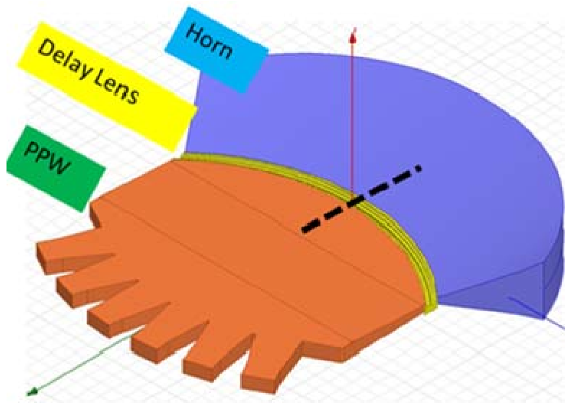

Fig. 2. 3D view of the lens beamformer.

The various sections of the lens (feeds, delay lines) were optimized with a ray tracing tool. The contours of the feed and the delay lines are defined with polynomial curves. They were optimized with an iterative process in order to reduce the phase aberration over the largest scanning range.

3. Design specifications and experimental results

The lens beamformer was designed in the Ku band (10.7-14.5 GHz) so that it produces six beams aligned in the same plane (H-plane) at ±6°, ±18° and ±30°. A low focal over aperture length ratio was enforced to minimize the mass and dimensions of the entire system. The overall dimensions are 290×270mm^2, including a flare of the parallel plate waveguide along a 100mm long section. The fabricated prototype is represented in Fig. 3. It was fabricated using standard milling process. Its mass is 1.5 kg. As the radiating aperture is elongated (290×40mm^2), the beamwidth is wider in the plane orthogonal to the scanning plane.

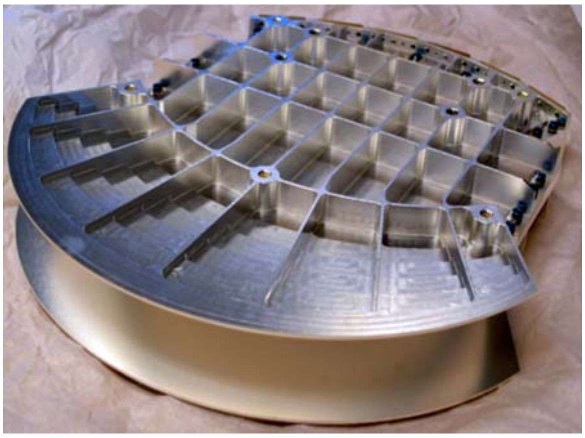

Fig. 3. Fabricated lens beamformer in Ku band producing six beams (Ports are numbered from 1 to 6, starting from the right side)

The complete antenna system was optimized using commercial full wave simulation tools (HFSS, CST), leading to excellent matching levels at each input port (below -21 dB in the band), as shown in Fig. 4. Low mutual coupling amongst ports (< -22 dB) is also achieved. Both tools provide very good prediction of the measurements.

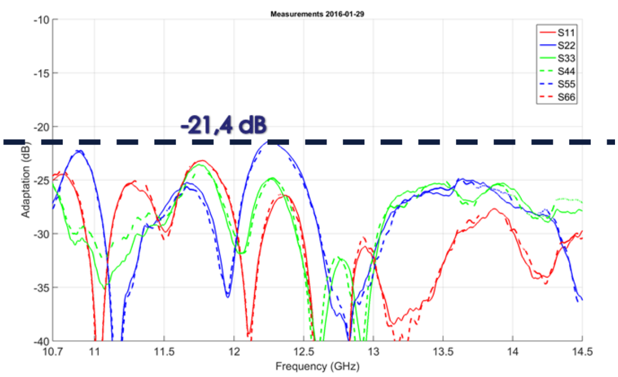

Fig. 4. Measured return loss at each of the six input ports of the antenna

The radiation patterns of the six beams have been measured and lead to excellent performance (Fig. 5). The beams associated to symmetrical ports could be superimposed with a mirrored transformation. The cross polarization level is very low (below -50 dB) along the scanning axis.

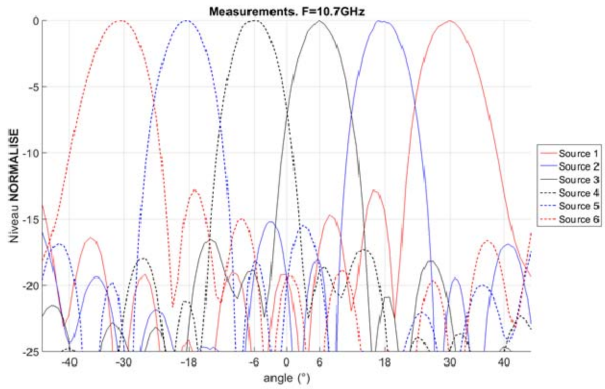

Fig. 5. Normalized Measured radiation patterns of the beams generated by the six ports along the scanning axis.

The gain was measured, and compared to the simulated and measured directivities of the beams. The gain is typically 0.2 dB above the predicted one. As the measured field cuts are in very good agreement with theory, the theoretical directivity is believed accurate. We can thus conclude that the losses within the structure are negligible.

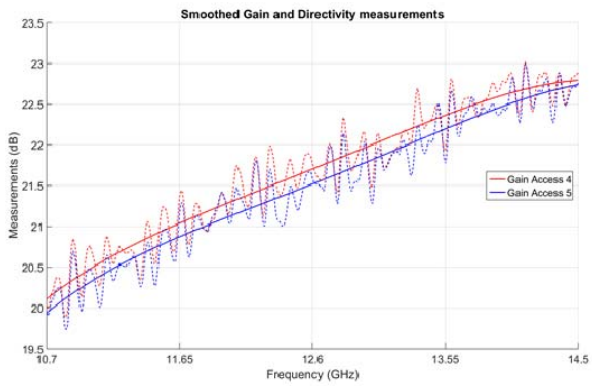

Fig. 5. Measured gain for input ports 4 & 5.

4. Conclusion

A compact antenna with a rectangular radiating aperture producing six beams on a wide angular sector and over a large band (Ku-band) was successfully designed, manufactured and tested.

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