Continuous Parallel Plate Waveguide Lenses for Future Low-Cost and High-Performances Multiple Beam Antennas

Abstract:

Nowadays, there is a strong demand for high-performance yet low-cost multiple beam antennas for future satellite communication systems (GEO, LEO constellations). Over the past few years, the use of quasi-optical beamformers in combination with a continuous line source appears as a very promising solution since they provide a wide band of operation and avoid undesired effects such as propagation cut-off and grating lobes. Their simpler mechanical aspect is also quite attractive.

A new concept of continuous parallel plate waveguide (PPW) beamformer came out of a recent research activity between ESA/ESTEC, Thales Alenia Space and IETR in the frame of the Technology Research Program (TRP) of ESA. The design approach is based on a constrained lens design but removing the aperture discretization and the complex transmission lines used to create the wave front transformation. In this respect, the proposed solution resembles the pillbox antenna, while providing significantly improved performance. The proposed solution transforms the cylindrical wave launched by one of the feed horns and propagating inside the PPW section into a nearly plane wave radiating in free space by the radiating horn (vice-versa), using a PPW lens made of a transversal ridge and cavity. The proposed concept can be manufactured using only metallic parts, providing a solution compatible with high-power applications. The simplicity of the mechanical design is also expected to enable low-cost antennas without compromising performance. A proof-of-concept has been developed and tested by TAS in the frame of the aforementioned TRP activity. A large scanning range ([-30° 30°]) has been demonstrated over the entire Ku-band dedicated to satellite communications and the measurements of the corresponding prototype, proved to be in very good agreement with simulation results. However, this design was based on a time consuming full-wave implementation; this approach cannot be applied to propose design and optimization processes in order to cope with different scenarios with specific requirements (scanning range, number of beams, frequency band). This work aims to develop the main theoretical aspects to study the concept. Evolutions of the solutions to improve the scanning capabilities or the performance in compactness have to be studied.

An efficient analytical tool based on geometrical optics (GO) is first developed. A fast and accurate prediction of the radiation performance is provided. The procedure proposed relies on geometrical optics (GO) to characterize the wave front propagation into the PPW section but also in the transversal cavity, working as a delay lens. The results computed with the GO tool are compared successfully to full-wave results obtained with Ansoft HFSS.

The numerical tool developed has been combined with optimization procedures, based on the minimization of the phase aberrations along the radiating aperture and also based on a direct pattern optimization to account for both phase and amplitude errors in the aperture. Additional degrees of freedom, making use of polynomial profiles, have been introduced to shape the PPW lens. Phase aberrations similar to those obtained with simplified constrained lens designs (Rotman or Bifocal lens), where true focal points exist, are demonstrated. In line with this

aspect, a stability of the radiation pattern performances (HPBW, SLL, scan loss) with the scanning angle is shown.

A breadboard operating over the Ka-band uplink ([27.5-31] GHz) has been proposed in order to validate the expected scanning capabilities. A full metal solution has been manufactured using a classical milling process. An excellent agreement is demonstrated between the FEM simulation and the measurement. The scanning properties are validated including a stability of the performances over the frequency band. We demonstrate again the capability to propose a low-cost approach. High radiation efficiencies are also demonstrated, which is particularly suitable for space applications.

The performance in compactness has been then studied in order to fulfill stringent integration requirements, or propose a stack of beamformers to produce a planar array. The transversal cavity, working as a delay lens, is the main limitation for the reduction of the beamformer height. A second prototype, working over the same fraction of the Ka-band ([27.5-31] GHz) and targeting the same RF performances is proposed. In this case, multiple PPW delay lenses are optimized in order to reduce the antenna size. With the final FEM model, the reduction of the longitudinal and transversal dimensions is significant while proposing similar simulated RF results. This prototype should be manufactured soon at IETR and tested in an anechoic chamber.