144 GHz Epsilon-near-zero Lens Antenna

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Metamaterials have revolutionized the design of lenses. Free-space matching has been traditionally achieved by thick anti-reflective coatings. However, at millimeter-waves, simple anti-reflective coatings remain elusive. In this range, the impedance matching attainable with metamaterials can be a viable solution. This holds promise for enhancing the gain of highly directive lens antennas.

With this aim in mind, we report here a lens antenna based on a low reflection-loss epsilon-near-zero (ENZ) lens implemented with an array of near-cut-off waveguides (M. Navarro-Cía *et al.*, Phys. Rev. B, 86, 165130-1-6, 2012; V. Torres *et al.*, Opt. Express, 21, 9156-9166, 2013). This metamaterial displays reduced reflection due to energy squeezing effect (M. Silveirinha et al., Phys. Rev. Lett., 97, 157403-1-4, 2006). The cross-sectional dimensions of the waveguides are 1.1 mm × 0.05 mm to have the frequency cut-off of the fundamental TE_{10} mode at ~140 GHz. The plano-concave lens has total dimensions 76.2 mm × 86.2 mm × 40 mm, and, in our first experiment, is illuminated from its planar face by a Gaussian beam to characterize its focusing performance. Experimentally (with two independent setups), the focal length is found to be at ~40 mm, in agreement with ray-tracing and full-wave simulations. Next, the lens antenna configuration is evaluated as follows: a waveguide probe WR-5.1 is located at the experimental focal point, while a waveguide probe WR-8.0 is used as a detector. The detector measures the *xy*-plane at 100 mm away from the flat face of the lens and the radiation pattern is computed from these measurements via a planar near-field to far-field transformation. A directivity of 17.6 dBi is measured, while numerically it is estimated to be 25.4 dBi.

To study the mechanical beam steering capabilities of this metalens antenna, we move a flange-ended waveguide WR-6.5 along the experimentally estimated focal arc and measure the radiation pattern. A gain scan loss below 3 dB is achieved for angles up to ±15º. The results are in agreement with the Huygens-Fresnel approximation as well as with the full-wave CST Microwave Studio™ simulations.