Fabrication and testing of a millimeter-wave modulated metasurface antenna

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***Abstract*—**This work presents the design, fabrication, and experimental validation of a circularly polarized metasurface (MTS) antenna operating at 77 GHz within the millimeter-wave band. The antenna features a circular modulated surface impedance profile, generating a pencil beam tilted 20 degrees from broadside. The structure spans a radius of six wavelengths and uses square unit cells with a side length of one-seventh of the free-space wavelength. Fabrication of such dense, high-resolution patterns at millimeter-wave frequencies presents significant challenges, including maintaining resolution, alignment accuracy, and surface uniformity.

The MTS antenna is fabricated on a ceramic-filled polytetrafluoroethylene PTFE laminate with copper foil cladding. The fabrication begins with the application of a protective resist to one side of the substrate, followed by copper growth via wet etching in an ammonium peroxodisulfate (APS) solution. Copper oxide residues are removed using an acetic acid sonic bath. The cleaned surface undergoes hexamethyldisilazane (HMDS) treatment to improve photoresist adhesion. Standard photolithography is then performed using a positive tone resist and ultraviolet light exposure. After development, a low-contact adhesive mask protects non-patterned areas during a second wet etching step, which defines the antenna's copper patch geometry. The photoresist is subsequently stripped, and a laser-drilled via is introduced to enable end-launch connector integration.

The antenna was characterized in an anechoic chamber using a vector network analyzer calibrated at the connector interface. Measurements were restricted to a 2D angular range due to mechanical limitations, with Theta from -45^{o} to 45^{o} and phi from 0^{o} to 360^{o}. Comparison between simulated and measured radiation patterns shows good agreement in co-polarization characteristics and confirms the generation of right-hand circular polarization. However, a slight frequency shift of the main lobe from 77 GHz to 76 GHz was observed. This discrepancy is attributed to increased surface roughness of the copper after wet processing, exceeding one micrometer, which significantly impacts the conductor loss and resonant behavior due to skin depth effects. Fabrication accuracy was estimated to have an average dimensional error of 25 microns, with patch thickness around 5 microns. High side-lobes observed in the radiation pattern are attributed to edge reflections and will be addressed in future designs. A second prototype incorporating corrections for fabrication tolerances is currently under development. This work demonstrates a practical low-profile approach for implementing high-frequency MTS antennas with reasonable agreement between simulations and measurements, despite the constraints imposed by millimeter-wave fabrication techniques.

Keywords—metasurface antenna, microfabrication

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