Characterization of Multiple Reflections within an Extended Hemispherical Lens Used in THz Time Domain Spectroscopy

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Extended hemispherical lenses integrated with planar antennas are widely used for imaging or diagnostics in THz and mmW applications such as time-domain spectroscopy (TDS). The desired beam structure in such applications is a collimated one, which closely resembles a Gaussian beam. In fact, this is achieved fairly well for the first-order transmission, which comprises the fields radiated from the antenna into the lens, which are then transmitted from the lens through the air. However, a significant portion of the fields is reflected back into the lens, which may then undergo additional internal reflections before being transmitted through the lens-air boundary. Although such secondary reflections can be time-gated in TDS systems, for continuous-wave (CW) THz spectroscopy system, the optical properties of such secondary reflections could potentially be detrimental. In fact, the second order signal is not collimated outside the lens, and thus does not properly follow the focusing optics designed for the main signal. Thus, accurate assessment the analysis of the internal reflections within an extended hemispherical lens is critical.

In this paper, we present a ray-tracing-based study to characterize the multiple internal reflections in extended hemispherical lenses. The optical properties of the second-order beams, such as far-field patterns, Gaussicity and waist radius, are considered for a double-slot antenna integrated on a high-resistivity Silicon (HRSi) lens ($E_r = 11.7$). We consider the effects of the multiple reflections from the lens-air boundary as well as the cylindrical extension used to optimize the antenna placement at the focal plane. The first- and second order transmitted fields are calculated everywhere inside and outside the lens by employing the induced surface current densities in the Stratton-Chu vector formulation of the Huygens' principle. The effects of the position of the off-axis parabolic reflectors (which are typically used in spectroscopy systems to focus the signal on the sample under test) on the optical behavior of the second-order fields are analyzed for various scenarios. The results show that the internal reflections of the extended hemispherical lens can have a significant impact on overall performance of CW systems, especially for high dielectric constant lens materials such as HRSi.