Design of a Reflectarray Antenna at 300 GHz Based on Cells with Three Coplanar Dipoles

Rafael Florencio, Rafael R. Boix

Jose A. Encinar

***Abstract*—Simulated results are presented for a reflectarray antenna designed to produce a collimated beam at 300 GHz within a 13% bandwidth. The reflectarray cells are made of three parallel dipoles printed on one side of a 110-µm Quartz wafer coated with a conductive ground plane on the back side, where the phase is adjusted by varying the length of the dipoles. A practically linear phase variation is achieved in a range greater than 360° and frequencies from 280 GHz to 320 GHz. A reflectarray antenna was designed taking into account the angle of incidence and the polarization of the incident field. The simulated radiation patterns show a fixed collimated beam with variations in gain lower than 2.6 dB within a 13% bandwidth.**

I. Introduction

Printed reflectarrays can be used to produce a collimated beam in sub-millimeter wave and THz ranges. The phasing can be implemented by varying-sized metallic patches, realized by selectively wet etching a thin copper conductive layer deposited on an optical quality quartz wafer, as described in [1]. The manufacturing tolerances achieved in [1] for the printed elements (±2µm) is sufficient for applications up to a few THz's. However, a reflectarray made of a single layer of varying sized-patches is constrained by a narrow frequency band. It was proved that the use of multi–resonant elements made of parallel dipoles provides an improved bandwidth of the reflectarray element [2]. A preliminary design of a reflectarray at 300 GHz was presented in [2], but in that reference the approximate design was carried out by using the data for normal incidence at 300 GHz obtained by CST Microwave Studio®. This approach, which neglects the effect of the angle of incidence, was based on the fact that the proposed reflectarray element exhibit a low sensitivity to the angle of incidence for angles up to 30°. However a more accurate design will require to account for the real angle of incidence at each reflectarray element. An efficient technique based on Spectral-Domain Method of Moments (SD-MoM) has been implemented for the analysis of reflectarray antennas made of a single layer of metallizations composed of cells with three parallel dipoles [3].

The analysis technique proposed in [3] has been used in the present work to carry out a more accurate design of a reflectarray antenna using the reflectarray elements defined in [2], by accounting for the angle of incidence in each reflectarray element and assuming local periodicity. Thanks to the efficiency of the analysis technique, the design is completed within reasonable CPU times in a conventional laptop. The analysis technique also accounts for the ohmic losses in the dielectric layer, conductive dipoles and ground plane, which are not negligible at 300 GHz.

II. Characterization of Reflectarray Element

The reflectarray element is made of three parallel dipoles printed on the same side of a quartz ($\varepsilon_r = 3.78$, $\tan\delta = 0.002$) wafer 110µm thick, which is coated with a conductive layer on the back side to form the ground plane. The three dipoles are oriented in the direction of the *y*-axis and are symmetrically placed in a periodic cell of 0.5mmx0.5mm, see Fig. 1. The center of lateral dipoles are separated 167µm from the center of central dipole, which is placed along the *y*-axis. The dipole widths is 50-µm and the ratio between the length of lateral and central dipoles is chosen as 0.65. Fig. 2. shows the amplitude (dB) and phase (deg.) of the reflection coefficient at three frequencies (280, 300 and 320 GHz) under two angles of incidence (φ=0°, θ=0° and θ=30°). The curves show very linear phase behavior at frequencies ranging from 280GHz to 320GHz, which means a 13% element bandwidth. When varying the angle of incidence from 0° to 30°, there are variations in phase up to 30° at 300 GHz, 18° at 280 GHz and 57° at 320 GHz. These phase variations, neglected in the approximate design in [2], can produce some distortions in the radiation pattern, particularly at 320 GHz where the phase error is larger. The ohmic losses in the quartz layer and in the printed dipoles made of copper can increase up to 1 dB for large dipoles. These losses are quite larger than those presented in [2] because of the copper losses, not included in [2] and computed here (0.57dB), while the losses in the quartz are 0.27dB.

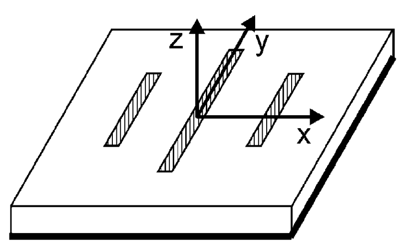


Figure 1. Reflectarray element made of 3 parallel dipoles.

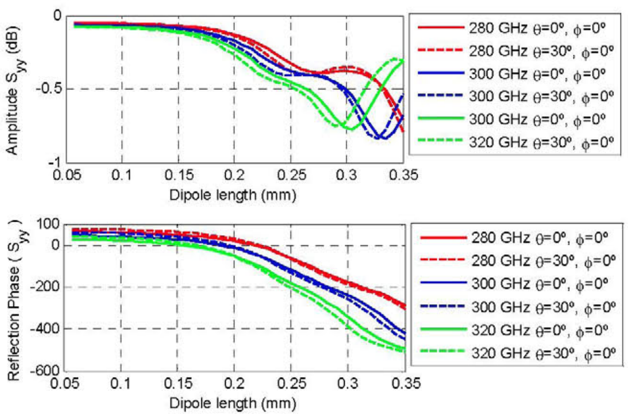
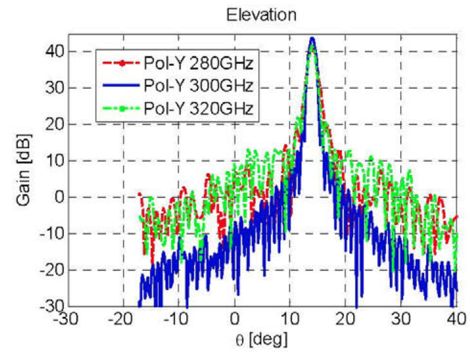
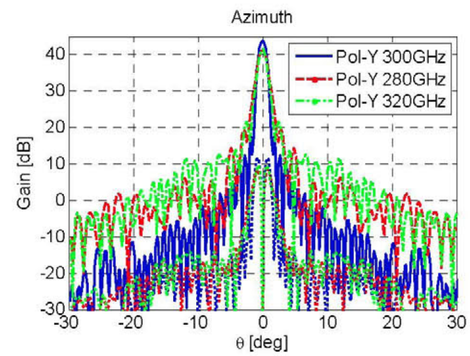


Figure 2. Amplitude and phase of the reflection coefficient for different frequencies and angles of incidence.



(a)



(b)

Figure 3. Co- and cross-polarization radiation patterns at 3 frequencies in elevation (a) and azimuth (b) planes.

III. Antenna Design

A quasi-circular reflectarray made up of 11704 elements arranged in a 124x120 grid with an ideal feed situated at coordinates $X_F = -21\text{mm}$, $Y_F = 0\text{mm}$ $Z_F = 80\text{mm}$ respect to the reflectarray center, is designed to generate a pencil-beam in the direction θ_b=14° φ_b=0°. The feed-horn is modeled by a conventional $\cos^q(\theta)$ function with q=20, which provides and edge illumination level of -12dB.

The reflectarray is designed by adjusting the dipole lengths oriented in ***y***-direction to match the phase-shift distribution at 300 GHz required to produce a collimated beam at 14° from broadside. For each element, the dipole lengths are adjusted by using a zero finding routine that iteratively calls the analysis routine [3], as described in [4]. The design is completed in 4 hours and 23 minutes on a laptop with Intel Core i5-2540M at 2.60GHz and 8GB of RAM. As a result, the dimensions of all the dipoles are obtained and the lay-out for the photo-etching is defined.

I. Simulation Results

The reflectarray antenna is analyzed by the SD-MoM technique assuming local periodicity and accounting for the angle of incidence and polarization of the incident field. The analysis technique also accounts for the ohmic losses in both quartz layer, copper dipoles and ground plane. Fig. 3 shows the simulated radiation patterns in elevation (XZ) and azimuth planes for co- and cross-polar components at three frequencies. The simulated radiation patterns are very similar to those obtained by the ideal phase distribution (not shown in the figure), but with a reduction in gain of 0.5 dB produced by the ohmic losses. The cross-polarization level is better than 30 dB below the co-polar maximum, see Fig. 3(b), because the reflectarray element based on parallel dipoles produces very low cross-polarization. The radiation patterns at 280 and 320 GHz show that there is a reduction in gain less than 2.61dB in the whole frequency band (13 % bandwidth).

IV. Conclusions

The results presented here show that the proposed configuration can be used for fixed collimated-beam antennas with improved bandwidth for sub-millimeter wave and THz applications.

Acknowledgement

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References

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