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Tolerance Analysis of THz-range Integrated Lens Antennas

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1. Introduction

The advanced performance of submillimeter detectors is often based on symmetry of their RF structure. The relevant examples are array-antenna mixers and detectors integrated with a dielectric lens. Numerical models of such structures are generally based on its perfect symmetry and accuracy of parameters of the detectors. However, this cannot be always achieved at submillimeter wavelength. The accuracy of mechanical (optical) parts and their alignment are limited usually for few micrometers. The misalignment of the lithography process is typically up to one micron. The required accuracy of size for a detector element, e.g. for a SIS junction or a TES detector, is often below 50 nm. This list does not include yet some random defects of the structure and slight changes in properties of sputtered films and materials, which are difficult to detect. Since we are developing quasioptical sensors for various frequencies starting from 200 GHz for TES detectors [1] up to 950 GHz for ALMA project [2], many precise components are used, and the tolerance analysis is of great interest for understanding possible restriction on design/performance of our devices. A typical integrated lens antenna consists of immersion dielectric lens with a chip-detector or a mixer integrated with a planar antenna mounted on the flat back of the lens as in [3]. The use of a lens antenna allows for employing a large chip (about 1 mm) with complex circuitry even at THz frequencies that is not possible with waveguide design. However, very often beam quality, especially symmetry and sidelobes level are not as good as for a corrugated horn antenna, which is a usual beam launcher of a waveguide system. Since now the reasons of distortion of the beam of lens-antennas are not fully understood, this paper makes an attempt to classify the possible sources of the distortion (except the dielectric lens accuracy).

2. Description of model and method

Here we consider SIS mixers and TES detectors coupled into double-dipole and double-slot antennas, which are under development [1], [2] (presented in Fig. 1). The SIS mixer from Fig. 1(a) has been tested up to 1 THz demonstrating record-low noise-temperature (below 250 K at 935 GHz) [4]. The extended hemispherical lens is often the design-of-choice due to its manufacturing simplicity. There are at least two known low-aberration focusing positions for an extended hemispherical lens: aplanatic focus (Lext=R/nd~0.29R for silicon) and elliptical focus (Lext=0.39R for silicon). The extended spherical lens in elliptical regime of focusing creates a flat wavefront that gives diffraction-limited beam of high directivity that is defined by the lens diameter D. This beam can be adjusted for a direct coupling to the main dish of a telescope. The extended spherical lens in aplanatic regime of focusing converts spherical wave into another spherical wave with beam divergence of about 25 degree (for silicon at -10 dB taper). The beam-width does not depend essentially on both the lens diameter and frequency. However, additional optical elements should be used, if narrower beam is needed. Note that intervening optics is not necessary for the case of elliptical focus, so requirement of high Gaussicity (Gaussian-coupling efficiency) can be relaxed for many practical cases. In Fig. 2 (a) the calculated beam pattern is presented in comparison with its Gaussian fit [3] for the case of elliptical focusing. Since the Gaussian fit of the lens-antenna beam is

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good down to the edge of the sub-reflector at -10 dB, the beam of the telescope will be essentially the same as the sub-reflector were illuminated with a corrugated horn antenna.

The usual difficulty in simulation of an integrated lens antenna using finite-element simulators (as e.g. HFSS) is the lack of RAM memory. That is why we apply technique of the Kirhoff-Hugens' diffraction integral. We assume the far-field beam condition at the lens surface and sinusoidal current distribution along the two antenna elements. The result shown in Fig. 2 is found in a good agreement with [3], [5]. Below we apply our method for calculating the antenna beam in case of broken symmetry of the system.

3. Results and discussion

As shown in Fig. 2 (a) 10-μm off axis misalignment for 5.8 mm-diameter extended spherical lens in elliptical regime of focusing at 865 GHz produces 0.5-degree beam tilt. This can be compensated by mechanical adjustment (rotation) of the mixer-block (or additional flat mirror). The along-axis feed displacement can be present due to variations in either substrate or glue layer thickness. We found that up to 20-μm displacement along the optical axis is negligible (see Fig. 2 (b)). Axial symmetry of beam of a double-slot (double-dipole) antenna can be achieved only if excitation signals of both slots (dipoles) are equal in amplitude and phase. In practice the asymmetry in excitation can be a result of different length of transmission lines between antennas and the detector(s) that can be caused by the mask misalignment during the photolithography process (see Fig. 1 (c, d, e, f)). The resulting beam pattern is shown on Fig. 2 (c). Difference in junction size of twin-SIS mixer can affect similarly to the layer misalignment, causing both amplitude and phase errors (see Fig. 1 (c, d, e, f) and Fig. 2 (d)). Few-micron variation in thickness of anti-reflection coating brings negligible effect to beam pattern shape and its symmetry. One can see that each one of the misalignment factors described above cannot cause severe degradation of the beam. However, if we consider all these small factors statistically independent and estimate their joint action, the distortion became quite pronounced that presented in Fig. 2 (e, f).

4. Conclusions.

The most probable factors of distortion of the beam of integrated lens antenna are considered. The numerical analysis demonstrated that a double-dipole antenna with a back reflector is a more tolerable system then a double-slot (see Fig. 1 (g,h)). If one compares two focusing regimes of an extended hemispherical lens (Fig. 2 (e,f)), it is possible to conclude that the elliptical regime is less sensitive to all types of misalignment. It seems that the advantage of better Gaussicity of aplanatic position can be easier compromised due to unavoidable little asymmetry of the lens-antenna system. This result is not yet combined with possible disturbance due to limited accuracy of alignment with intervening optics, which is required for the aplanatic regime.

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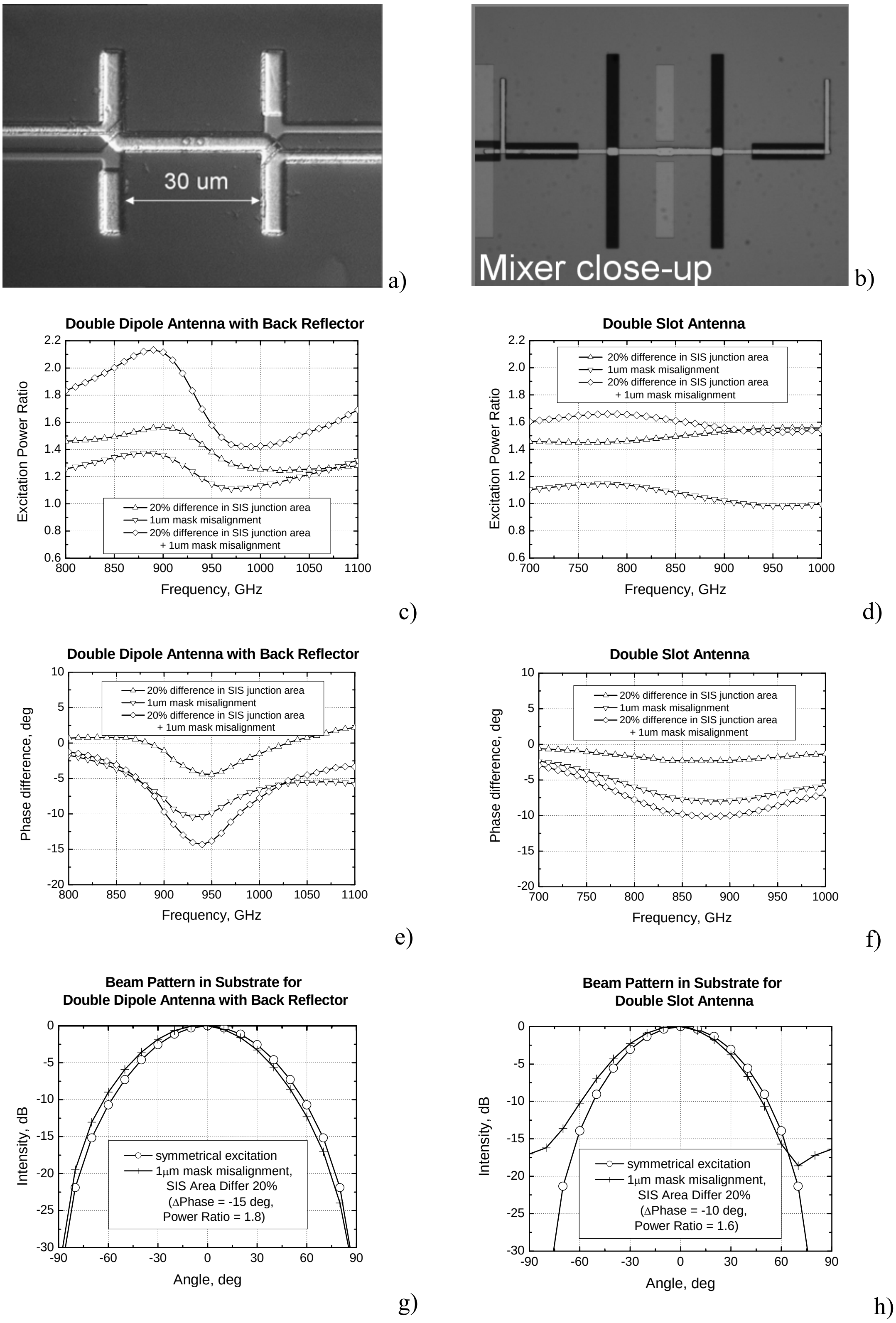
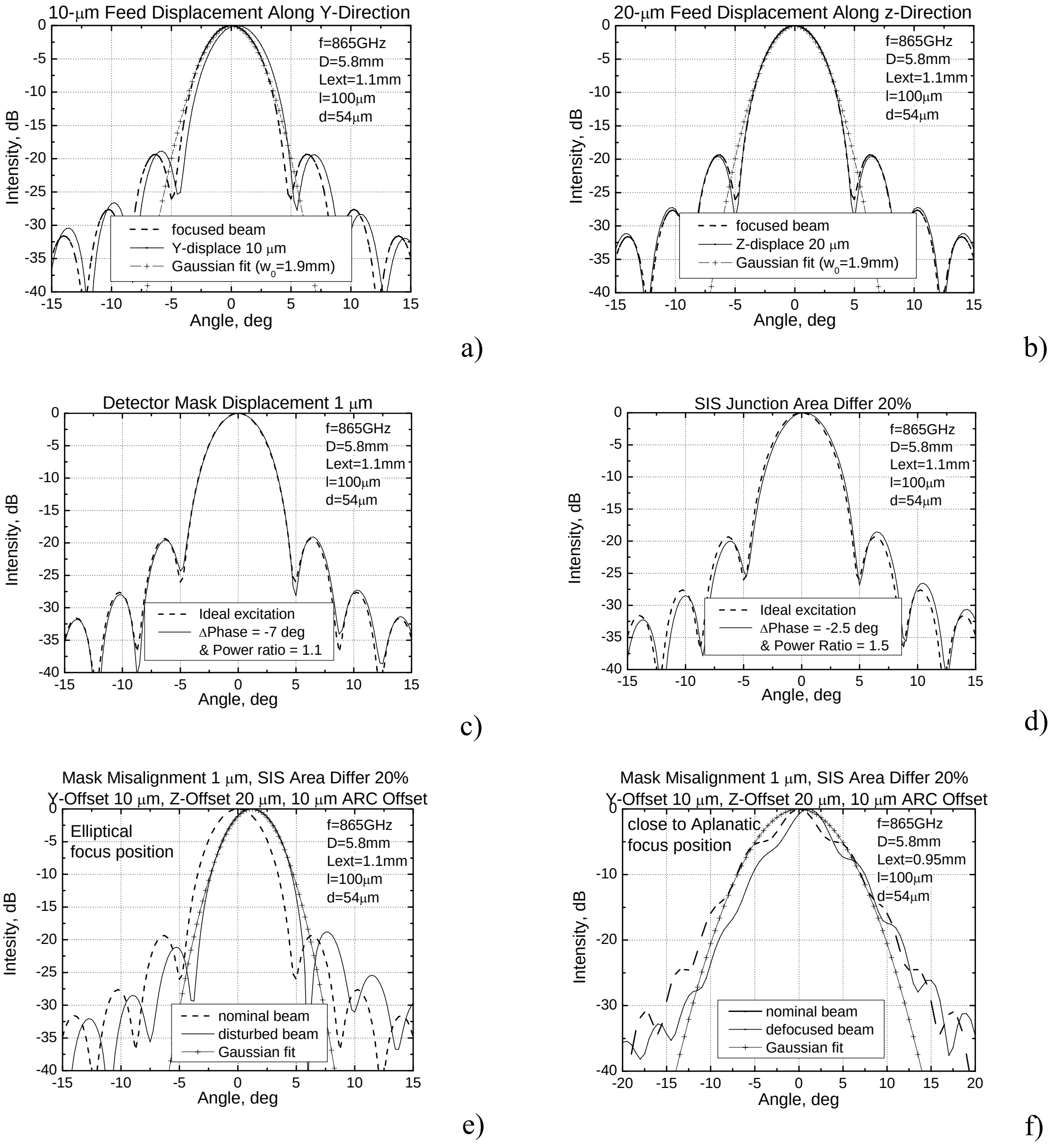


Figure 1: Planar feeds characteristics. a) – twin-SIS mixer coupled into double-dipole antenna; b) – twin-SIS mixer coupled into double-slot antenna; c), d) – excitation power ratio for different types of photolithography misalignment; e), f) – phase error of excitation; h), i) – beam pattern inside the silicon lens.



a) b) c) d) e) f)

Figure 2: Double-slot lens antenna far-field beam patterns for different types of asymmetry.

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