# Dual Polarized THz Imaging FPA in 22nm CMOS

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***Abstract*—In this contribution a THz imaging camera, supported in a 22nm CMOS technology, is presented that is suitable for passive, incoherent, THz imaging applications over a large bandwidth from 200 GHz to 600 GHz. The camera architecture is composed by a focal plane array (FPA) of connected dipoles supporting a leaky wave radiating in the presence of a dielectric lens. The dipoles are tapered into a checkerboard type configuration. This configuration not only reduces the mutual coupling between adjacent pixels, but simultaneously allows for doubling the amount of pixels on the same chip without loss in efficiency, thanks to their orthogonal polarization. The two effects result in an FPA that offers near diffraction limited resolution while still operating efficiently with an average efficiency of 45% over the full bandwidth. A prototype with $3 \times 3$ horizontally polarized and $2 \times 2$ vertically polarized pixels is planned for fabrication.**

## I. Introduction

The development of passive THz imaging cameras can be considered challenging for multiple reasons. Firstly, the integration of coherent circuitry such as amplifiers, oscillators and mixers, obstruct the fabrication of large FPAs due to their size and power consumption [1], making incoherent (direct) detection architectures preferred for THz imaging. Secondly, in a direct detection scenario, sufficient temperature sensitivity can only be achieved when a large portion of the available spectral bandwidth the THz regime is efficiently exploited [2]. Large state-of-the-art uncooled THz cameras still rely on active illumination [3], [4] over narrow band. Thirdly, the temperature sensitivity and angular resolution are always in trade-off, since an increase in angular resolution requires a decrease in pixel periodicity (i.e. sampling of the array) [2]. Tightly sampled arrays suffer from high mutual coupling between adjacent pixels and less directive antenna feeds that illuminate a dielectric lens poorly. Guided by these challenges, this contribution presents the simulated performance of a wideband, dual-polarized, connected FPA, supported in a 22nm CMOS stratification, that allows for passive imaging applications with near diffraction-limited resolution and high efficiency over broad-band .

## II. Results

Designing tightly sampled, efficient, wideband and CMOS compatible FPAs is considered challenging. Efficient wideband solutions such as double-slot based antennas [4]–[6] are relatively large, decreasing the angular resolution. Instead, for tightly sampled arrays, a connected array of dipoles or slots [7] is a viable solution. Thanks to its leaky-wave nature when combined with a dense dielectric lens [8], the effective area of a pixel can be larger than the physical area that is dedicated to the pixel, maximizing the directivity and thus system efficiency. A connected array of dipoles is optimized in the top metal layer in Global Foundries 22nm CMOS technology. The low-resistive bulk-silicon of the chip is thinned down to 200 $\mu$m to reduce ohmic dissipation, and is glued to an elliptical silicon lens with diameter $D = 1$ cm, which defines the complete imaging system.

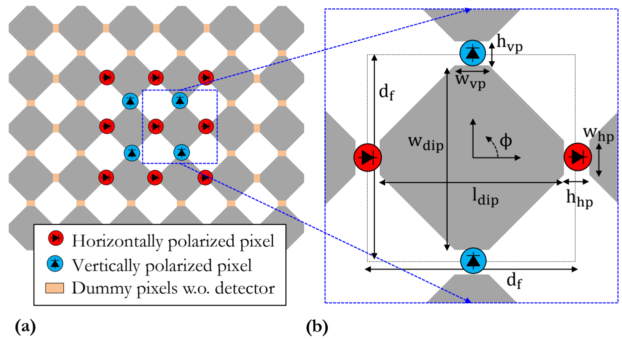


Fig. 1. Layout of the array containing $3 \times 3$ horizontally polarized elements and $2 \times 2$ vertically polarized elements. The pixel periodicity $d_f = 130\mu m$, dipole dimensions $l_{dip}, w_{dip} = 115\mu m$ and feeding gap dimensions $h_{hp}, h_{vp} = 15\mu m$ and $w_{hp}, w_{vp} = 20\mu m$.

The connected array of dipoles is optimized in transmission, radiating into infinite silicon, by using CST Microwave Studio. The dipoles of the array are tapered with a $45°$ angle. Tapering the dipoles reduces the mutual coupling between the pixel elements. Furthermore the array becomes geometrically identical in both the horizontal and vertical polarization directions. Such antenna architecture allows for doubling the amount of pixels, by exploiting both polarizations on the same chip area. Since the two polarizations are highly decoupled, the angular resolution is doubled without increasing in mutual coupling between the pixels. In Fig. 1, a small array exploiting this concept is proposed that contains $3 \times 3$ horizontally polarized elements and in addition a $2 \times 2$ array of vertically polarized elements on the same chip area. Effectively this results in a hexagonal grid.

In Fig. 2(a) the system efficiency of the dual-polarized connected array is shown, neglecting any ohmic dissipation. A second x-axis translates the frequency to the sampling periodicity of the horizontally polarized pixels. The connected array is tightly sampled with a $1F_{\#}\lambda_c$ periodicity at the center frequency, where $F_{\#} = F/D$ is the focal number of the optics. A comparison is made with the system efficiency that can be achieved with ideal uniform aperture feeds [2]. The

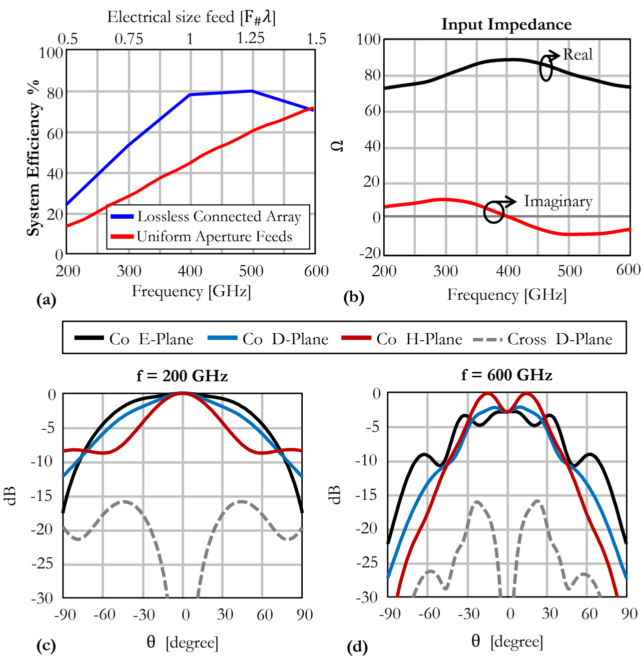


Fig. 2. In (a) the system efficiency is shown, neglecting any losses, and compared to the system efficiency of ideal uniform aperture feeds. (b) shows the input impedance of the antenna. In (c) and (d) the normalized radiation pattern inside infinite silicon are shown at 200 GHz and 600 GHz respectively.

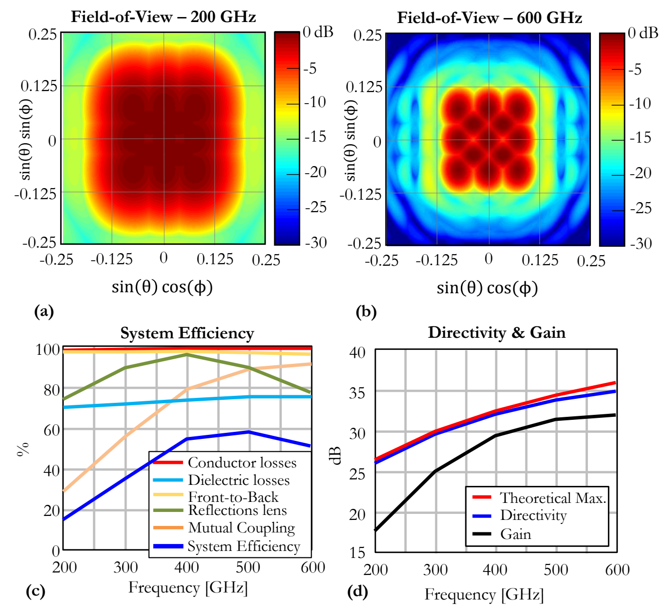


Fig. 3. The Field-of-View of the array at 200 GHz (a) and 600 GHz (b). In (c) the system efficiency is decomposed in all of its contributions. In (d) the directivity and gain are shown.

comparison illustrates the enormous improvement in efficiency when utilizing a connected array in tightly sampled FPA configurations. The current distribution of one pixel in a connected array flows in adjacent pixels, making the individual pixels more directive and therefore achieving a more efficient illumination of a dielectric lens. In addition, the vertically polarized pixels effectively reduce the sampling periodicity in the diagonal plane, reaching near-diffraction limited resolution.[1]

The input impedance is shown in Fig. 2(b). The radiation patterns inside the silicon associated with the centered, horizontally polarized, element are shown in Fig. 2(c) and (d) at 200 GHz and 600 GHz respectively. The 2D radiation patterns after the elliptical lens are calculated for the full array by using an in-house physical optics (PO) tool. The Field-of-View of the imager is shown in Fig. 3(a) and (b) for 200 GHz and 600 GHz respectively and the individual patterns symmetric over the full frequency band. The beam roll-off is defined at the point where the individual beam patterns of adjacent pixels overlap and determines the angular resolution of the system. The beam roll-off at the main planes of the array is approximately -3dB at the center frequency 400 GHz, whereas at the diagonal planes the roll-off is around -1.5dB, reaching near-diffraction limited resolution [2].

The efficiency of the complete system is shown in Fig. 3(c). The main contributions to the system efficiency are the dielectric losses in the low-resistive silicon and mutual coupling between the pixels, inherent to tightly sampled arrays. The radiometer has an average system efficiency of 45% over the full bandwidth. The ohmic loss could be reduced further by further thinning down the CMOS wafers.

In order to reach a 1 K temperature sensitivity at real-time refresh rates, the required detector Noise Equivalent Power is in the order of $\mathrm{pW}/\sqrt{\mathrm{Hz}}$ [2], which is already available in the literature [9], illustrating the great potentials for uncooled passive THz imaging.

[1]For incoherent imaging, diffraction limited resolution is achieved for a sampling periodicity of $0.5F_{\#}\lambda_c$ [2].

## ACKNOWLEDGEMENT

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