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Quasi-Optical LO Coupling Validation for a Planarly Integrated 2 × 2 Pixel Heterodyne Array at 1.95 THz

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Abstract— **Terahertz heterodyne spectrometer instruments have been traditionally limited to a single pixel or a handful of pixels due to integration and assembly constraints and a limited availability of local oscillator (LO) power. As a solution we propose a novel silicon-micromachined planar and modular packaging strategy, that will allow for a dense integration of a large number of pixels. Moreover, the RF- and LO signals will be quasi-optically coupled via two identical but opposite lens arrays, such that a single LO-source can efficiently pump all HEB-mixers of the 2x2 pixel demonstrator array simultaneously. This work reports on an intermediate step, where we validate the lens array performance and LO power coupling efficiency, by slightly modifying the silicon package into a transmit array configuration. In this way, the LO power coupled into the stack is directly re-radiated on the other side, which is then measured using a liquid helium cooled bolometer.**

I. INTRODUCTION

TERAHERTZ (THZ) spectroscopy instruments are a valuable tool in studying galaxy and star formation, e.g. by the remote sensing of ionized carbon and atomic oxygen found in the interstellar medium. The sensitivity and mapping speed of state-of-the-art instruments are becoming fundamentally limited to their single-pixel detection architectures and a need for an increased pixel count arises [1]. Unfortunately, the current coherent detection architectures are difficult to scale up to large-format (>10^2 pixels) arrays since the receiver front-end for each single pixel is comprised of several metal blocks with strict assembly constraints and tolerances [2]. Secondly, the local oscillator (LO) power budget at these frequencies is typically insufficient to pump multiple mixers, mainly due to the low available LO power and poor power coupling schemes that are generally employed. Those solutions are, for example, lossy waveguide power divider networks, narrowband phase gratings, or quasi-optical coupling using Mylar beam-splitters that disregards 90% of LO power and 10% of RF power. Recently, an efficient quasi-optical THz power distribution scheme has been demonstrated at 550 GHz, in order to coherently excite scanning lens phased arrays in a transmit array configuration [3]. Here, a similar concept is used to couple the LO power from the opposite side of the RF lens array. In this way, the available LO power is more than 6 dB higher than that is available with a Mylar beam-splitter configuration. Furthermore, the lens-antenna feeding structures and mixers are all integrated in a compact silicon micro-machined stack of wafers, drastically decreasing waveguide path lengths as well as decreasing fabrication and assembly difficulties for multiple pixels. As a demonstrator, a 2x2 pixel array is being developed, as is shown in Fig. 1. The silicon package combines the RF and LO signals in a short waveguide network using a quadrature hybrid coupler, that then feeds two balanced hot electron bolometer (HEB) mixers, as shown by the left-bottom inset. In order to validate how much power is coupled into the waveguide network, a slightly modified wafer-stack is used that transmits the LO-signal to the other side, as is visualized in the right-bottom inset. In this contribution, we will validate the coupling efficiency of LO power while simultaneously validating the lens-antenna performance.

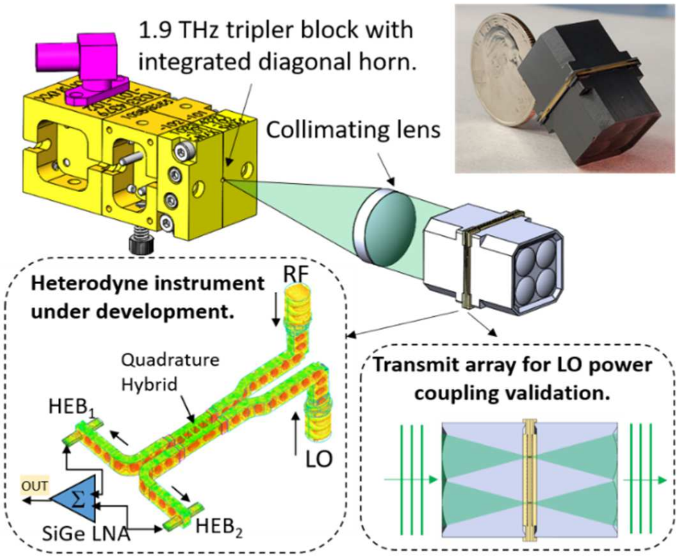

Fig. 1. Schematic showing LO coupling to a 2x2 pixel heterodyne array, integrated in a silicon micromachined package. By slightly modifying the wafer-stack into a transmit array configuration, allows for validating the efficiency of LO coupling and RF antenna performance.

II. SILICON-MICROMACHINED 2X2 TRANSMIT ARRAY

The planarly integrated heterodyne array is designed to operate over a wide bandwidth from 1.4 THz to 2.1 THz, enabled by the use of the wideband multi-mode leaky-wave feeds presented in [4]. The 2x2 lens arrays, with a 5.8mm lens diameter and 6mm periodicity are fabricated using laser ablation technology and have a Parylene-C anti-reflection coating. The lenses couple the radiation into a 6-layer (total thickness of only 2.25 mm) silicon wafer stack that is micro-machined using DRIE technology. The two outer wafers (#1 & #6) will support and align the lens arrays and have a synthesized matching layer as needed for wideband antenna operation [4]. Then, the resonant air cavity (86 μm in height) and circular waveguides (190 μm in diameter) are machined in wafers #2,5. The middle two wafers, #3,4, contain a compact circular-to-rectangular mode transformer, the quadrature hybrid coupler and HEB mixers. Those latter two wafers are omitted to create a transmit array configuration containing only a 520 μm long circular waveguide that redirects the LO-power to the RF lens array. The LO source, shown in Fig. 2(a), is made at JPL and

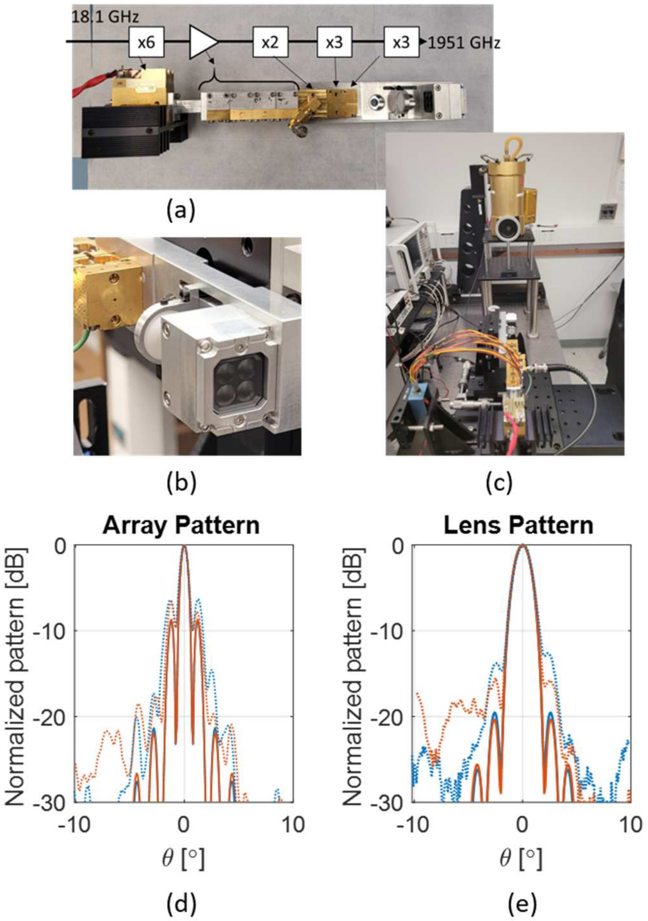

Fig. 2. LO transmit array (a,b), measurement setup (c) and measured array- and lens pattern at 1.95 THz (d,e).

consists of a sextupler, W-band amplifiers, a G-band doubler and two triplers. The last tripler is biasless and has a diagonal horn integrated in the block. The measurements are performed at a fixed frequency of 1.95 THz with a measured LO output power of 40 μW. A 15 mm diameter Teflon lens collimates the LO power, Fig. 2(a,b). The focal distance of the lens, 40 mm, is determined to be the optimal trade-off between spillover of LO power and near-field coupling efficiency to the lens array. The spillover with respect to the LO collimator is simulated to be 0.97 dB. From there, the power that is coupled into the silicon package and re-radiated by the transmit array is 3.2dB lower, as is shown in Fig. 3 by the red line. This includes spillover of the collimated LO power with respect to the four lenses, the field coupling efficiency, and spillover and reflection losses occurring in the transmit array. Since the power is divided over four lenses, the estimated transmission of the collimated LO power by each lens is estimated to be -9.2dB.

III. LO COUPLING VALIDATION

The measurement setup is shown in Fig. 2(c). The transmit array assembly is mounted on a two-axis gimbal stage. A commercially available liquid helium cooled Si bolometer, by IR Labs, is placed at 80 cm distance from the array. A wire-grid is placed right in front of the receiving Winston cone so that only the co-polarized field component is measured. A signal generator provides the 18 GHz signal to the LO-chain, modulated on a 267 Hz square-wave to minimize the Flicker noise contributions of the bolometer. A lock-in amplifier is used to measure the Si bolometer response, cascaded by an ADC that is connected to the measurement computer. A ±10° scan, both in pitch and yaw of the gimbal stage, is performed to measure the full array pattern. The result is shown in Fig. 2(d). The symmetric patterns confirm a proper in-phase excitation of each of the lens elements. However, higher sidelobes and a broader beam indicate that the lens element patterns are less directive than simulated. Then, a 0.5 mm thick, 3D-printed PLA, shield is placed in front of the transmitting lens array in order to measure each lens individually. By first placing the shield in front of the LO source, an absorption higher than 30dB was measured. One of the four measured lens patterns is shown in Fig. 2(e). Overall, the lens pattern is of good quality, but higher sidelobes and an increased spurious radiation at larger angles are measured, possibly due to air gaps that could be present in wafer-stack. By integrating the measured 2D power patterns of each lens and by referring this to the integrated measured 2D field of the collimating LO lens, in absence of the transmit array, a relative power transmission could be derived. This transmission is summarized in Fig. 3 by the dotted blue line for each lens. The measured transmission is 1.3dB to 2.7dB lower than simulated. Although these results are very promising, we are working on an improved transmit array assembly procedure and alignment with the LO collimator to improve in LO coupling efficiency.

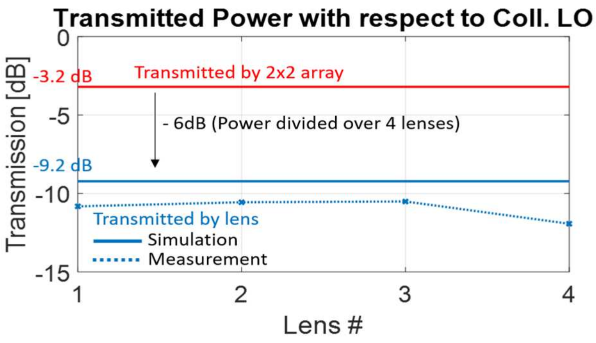

Fig. 3. Simulated and measured transmission for all four lenses.

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