National Aeronautics and Space Administration

Planar Multi-Pixel Heterodyne Array Architecture Suitable for Large Arrays

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Program: FY22 R&TD Strategic Initiative **Strategic Focus Area: Long-Wavelength Detectors**

Objective:

The main objective of this long-wavelength initiative is to develop a novel submillimeter-wave heterodyne detection architecture, suitable to realize large-format arrays that contain hundreds of pixels integrated in a highly compact and efficient instrument package. The proposed multi-pixel architecture overcomes the integration difficulties and poor local oscillator (LO) power distribution that traditionally restricted heterodyne instruments to only a handful of pixels. Two key objectives, that allow to extend the pixel counts of such instruments substantially compared to the state-of-the-art, are (1) a quasi-optical distribution of LO power, without making use of lossy beam splitters or corporate waveguide networks, and (2) an innovative planar integration architecture. In particular, we are developing a modular multi-pixel 1.9 THz heterodyne array where the LO and RF signals are coupled from two opposite faces. The LO signal is quasi-optically distributed and divided equally amongst the multiple receivers. Such coupling scheme is highly efficient and broadband. The RF and LO signals are coupled into a planar, silicon micromachined, wafer stack that contains the receivers. Silicon microfabrication allows for the fabrication of smaller features, higher accuracy, and better surface roughness compared to metal machining, leading to a more compact architecture, improved sensitivity and larger pixel-count.

Background:

The sensitivity and achievable mapping speed for imaging spectrometers significantly improve with the increase in the number of pixels. Unfortunately, current state-of-the-art submillimeter wave heterodyne receivers have been restricted to just a handful of pixels for mainly two reasons. First, severe integration difficulties need to be overcome. Current instruments rely on the fabrication and assembly of several metal blocks containing the receiver front-end. This technology is constrained by the tolerances and accuracies achieved in the fabrication and assembly processes. Secondly, a scarcity of LO power prohibits to pump a large number of mixers. The current method of combining LO and RF signal into the mixer, by using a thin Mylar film beam-splitter, is very inefficient. This method discards at least 90% of the LO power and can only be used for single-pixel configurations, as the required LO power to feed multiple HEB mixers is too high. Another solution is a waveguide based LO distribution schemes that divides the available LO power using Y-junction power dividers. At frequencies beyond a couple of hundred gigahertz, the waveguide losses are substantial, leading to a very inefficient LO coupling scheme, limiting the pixel count in an array. Both bottlenecks are addressed in this initiative.

Approach and Results:

The basic layout of the proposed front-end multi-pixel architecture is shown in Fig. 1. It is composed of a planar HEB mixer array fabricated on thin silicon membrane and integrated on silicon micromachined packaging and two arrays of lenses couple the RF and LO signals from the front and back respectively. For demonstration purposes, we decided to design and fabricate a 2x2 hot electron bolometer (HEB) based receiver array. The way forward towards large-format arrays is shown, indicating a modular architecture of 19-pixel subarrays with their IF routing scheme.

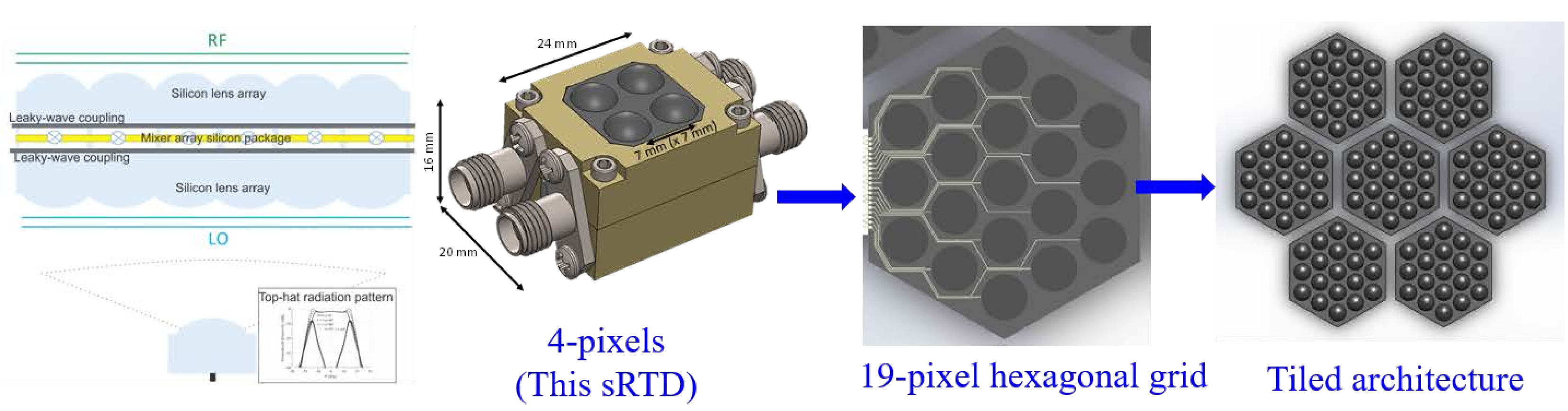

Figure 1. Schematic of the basic architecture of the multi-pixel planar terahertz heterodyne receiver array and the way forward to large-format arrays.

Figure 2 shows the finalized design of the silicon micromachined package containing the receiver front-end. Alignment springs ensure an alignment accuracy of 1 µm. The RF and LO are combined in the package using a quadrature hybrid coupler and fed to two balanced HEB mixers. The synthesized matching layer is part of a novel designed lens antenna feed for efficient and wideband operation.

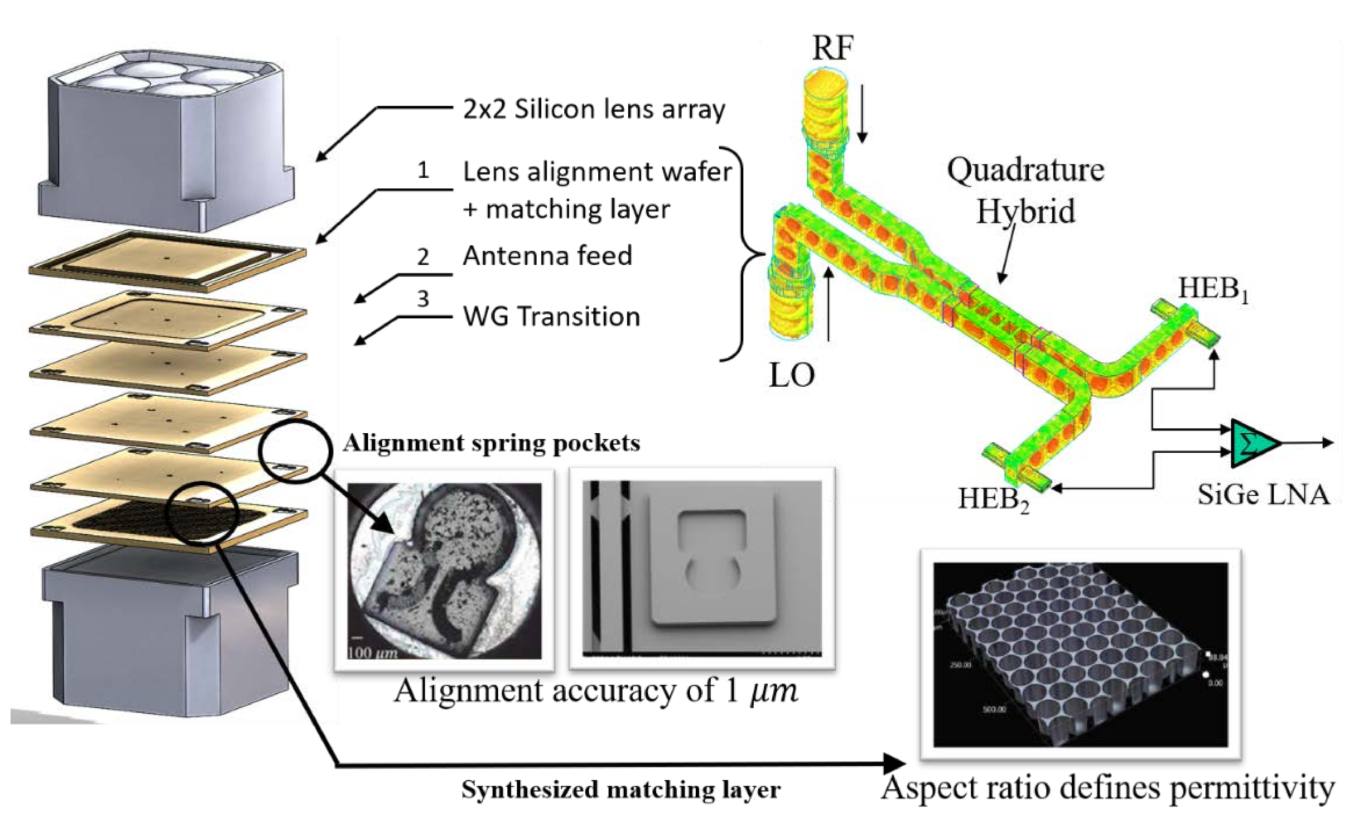

Figure 2. Planar integration of receiver front-end, fabricated using silicon micromachining technology. The wafer stack contains the lens antenna feeds, hybrid coupler and balanced HEB mixers.

Antenna and Quasi-Optical Design: A novel multi-mode resonant leaky-wave (LW) antenna has been designed for the RF- and LO signal coupling. An aperture efficiency higher than 80% is achieved from 1.4 THz to 2 THz. This efficient and wideband performance is thanks to the novel matching layer from Figure 2, also indicated in Figure 3. Additionally, the matching layer eliminates the need of the fragile feeding membrane, easing fabrication significantly. A compact waveguide transition is designed that converts the TE11 circular waveguide mode to a TE10 rectangular mode. Similarly, an identical, but mirrored, array of lens antennas will couple the LO signal to the HEBs in the same wafer stack and combined with a quadrature hybrid coupler. The design maximizes the entire LO-to-HEB link budget, simulated to be -13 dB. The wafers are currently being fabricated at JPL's microdevices laboratory. The silicon lenses are fabricated externally with laser ablation.

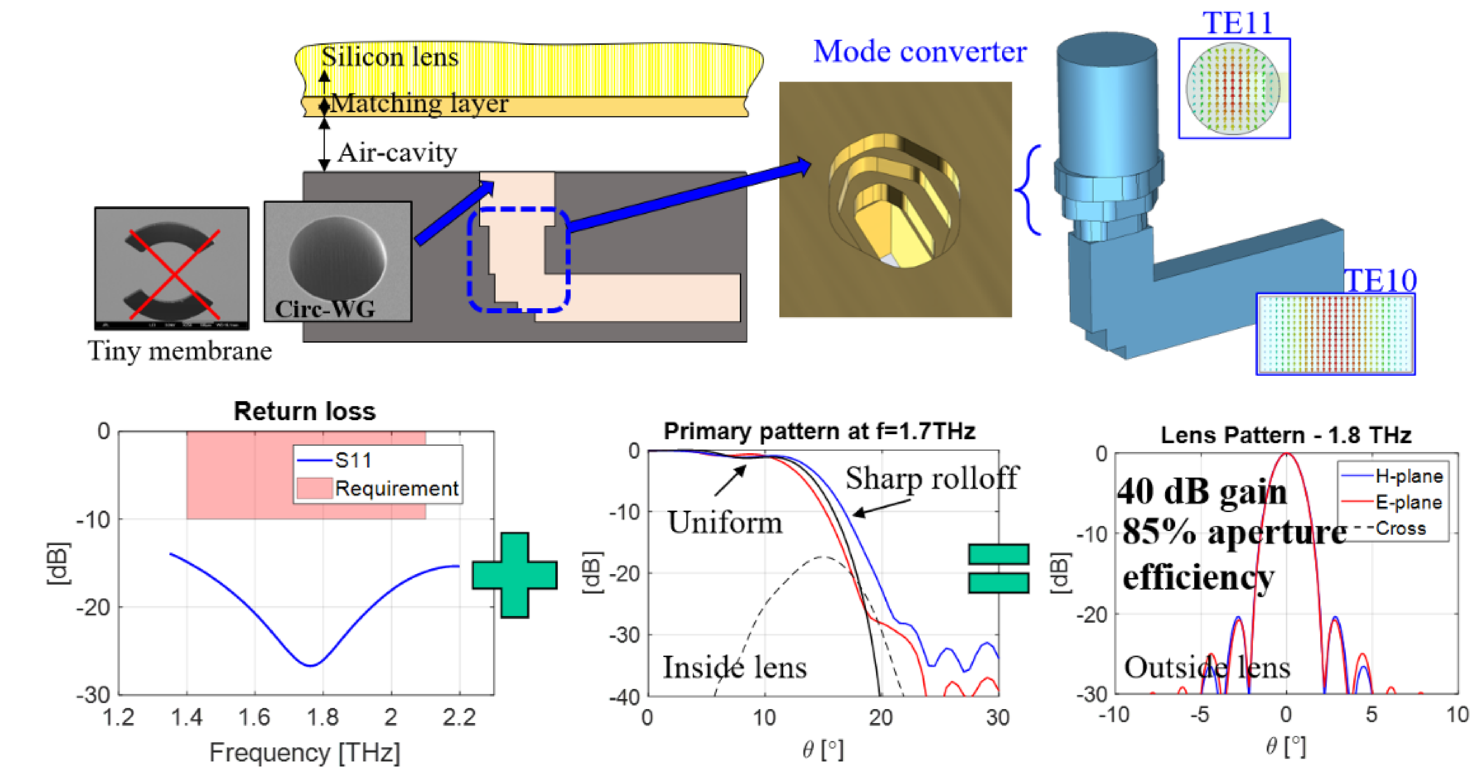

Figure 3. RF- and LO-coupling scheme, based on a novel multi-mode leaky-wave antenna feed and a compact mode converter.

LO, SiGe Based IF LNA and Mixers: The LO source to feed the 4-pixel array, containing a total of 8 HEBs, has been fully assembled and characterized, Figure 4. A high output power, >40 µW, has been measured at 1.9 THz, which gives a comfortable margin to pump all HEB mixers (>2 µW arrives at each HEB). Low-power cryogenic (4K) low-noise amplifiers (LNAs) have been designed, optimized for large format arrays. We aim to have less than 2mW of DC power consumption with a goal of 1 mW DC power consumption per pixel. The LNA has been submitted for fabrication. The packaging of the LNA for testing at 4K temperature in a 40 Ohm connectorized environment is completed, Figure 4. The HEB mixers will be fabricated at MDL using NbN superconducting films. The mask layout is complete and the fabrication process has started.

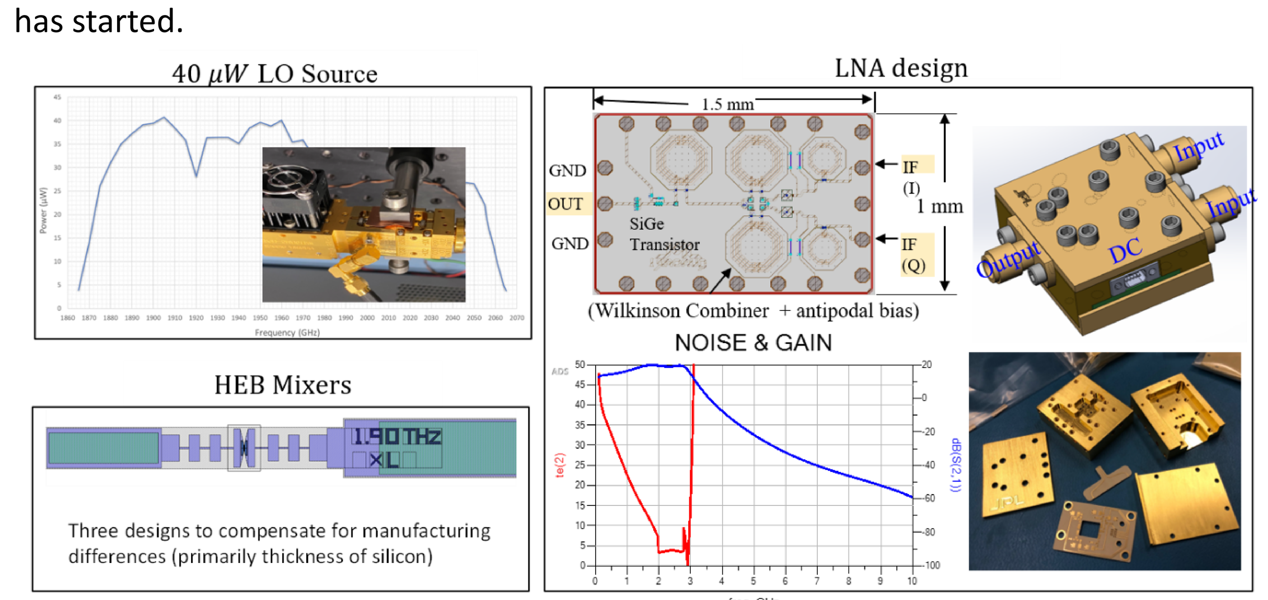

Figure 4. Devices for the multi-pixel heterodyne array.

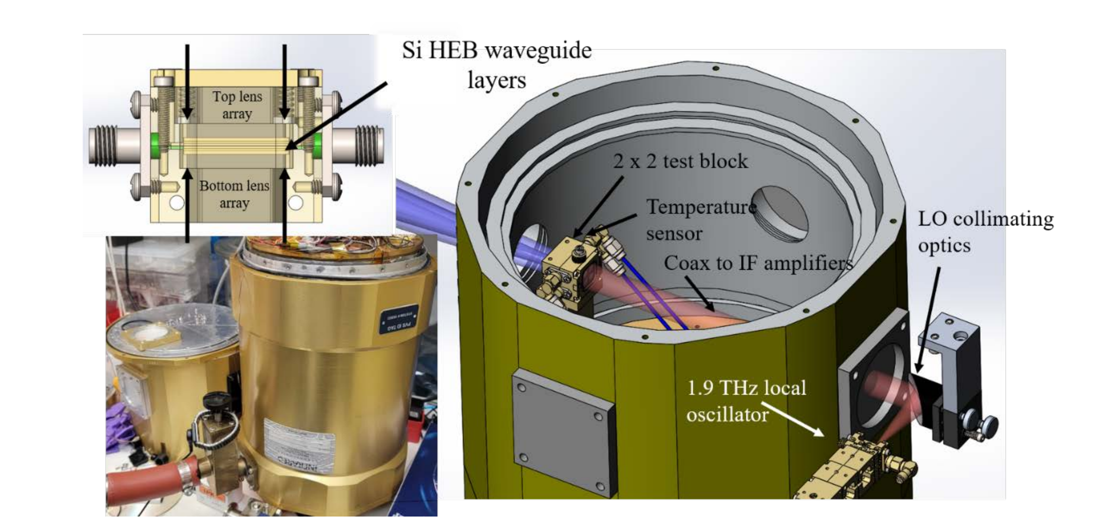

Figure 5. Packaging for the multi-pixel heterodyne receiver and measurement setup in a cryostat.

Measurement setup and packaging: The cryogenic cooler has been installed in the lab, see Figure 5. Testing will include the mixer/system sensitivity (hot/cold load Y-factor), beam patterns (glow bar with X-Y stage), cross-talk characterization, and LO/RF coupling efficiency evaluation. The device packaging, shown in top left, includes springs allowing for thermal expansion.

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Significant Benefit to JPL and NASA:

A clear need has been identified to develop large-format arrays for future planetary and astrophysics missions. Such a new class of instruments would facilitate more and better science, thanks to a potentially orders of magnitude improvement in sensitivity and/or mapping speed. This work paves the way how large-format multi-pixel heterodyne instruments can be built and deployed by proposing new technology solutions. We have shown that a planar multi-pixel array design is possible and the proposed modular design approach will enable instruments with many more pixels. Planar packaging, facilitated by silicon micro-machining technology, offers the required alignment tolerances, accuracies and surface roughness that simply cannot be achieved with metal-machined packaging. Moreover, an efficient quasi-optical distribution of the scarcely available LO power results in highly compact and power efficient systems. The deployment of multi-pixel heterodyne arrays for future planetary or astrophysics missions could be identified as a long-term goal. However, the emphasis under this long-wavelength initiative is also to mature existing technologies to a stage where they can help bridge gaps in technological needs for instruments that can be proposed for future flight missions on somewhat short time-scale.

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