Abstract—Two different types of innovative all-silicon integrated THz harmonic source and receiver components potentially enabling new THz active imaging modalities are introduced. The first consists of a multiplier-chain based power source and a harmonic heterodyne 2x2 receiver array, both operating simultaneously at multiple harmonics in the 160-1000 GHz band and therefore enabling the multi-color imaging principle with a single TX/RX chip-set. The other is a programmable single-chip 4x4 source module operating at 519-536 GHz that addresses the global illumination concept with the spatially-extended source components. All are implemented in a SiGe HBT technology and integrated with silicon optics.

Despite the recent progress in device technologies, room-temperature receivers still lack the sensitivity required for passive imaging. Therefore, they need some artificial power sources illuminating the scene to achieve a higher contrast or a signal-to-noise ratio for better detection capabilities. However, the contemporary active imaging systems based on focused illumination with a single coherent source lack some interesting features. Coherent CW sources, in particular, create specular reflections and are inherently narrowband. In order to improve the image detection statistics or to reveal the material dispersion characteristics, combining spectroscopic information with classical imaging can be applied. Forming an image at different frequencies may help to isolate samples surrounded by confusion materials. Multi-color imaging can reduce the influence of standing waves, the complex object geometry and its scattering on the image recognition quality and the material characterization uncertainty. Furthermore, the application of global illumination scenarios [1, 2] with multiple spatially-extended source components could serve the same purposes by providing a spatial, angular, phase, and polarization diversity. The key idea underlying this approach is the capability of creation of multiple physically distinct coherent images accumulated within a receiving array that result from a number of independent illumination patterns. The feasibility and the widespread use of these recently introduced imaging modalities will strongly depend upon the existence of low-cost, configurable, and handheld source and receiver components.

In view of the aforesaid, two different groups of innovative all-silicon integrated THz harmonic source and receiver components are presented in this paper. The first is intended to address the idea of multi-color imaging, whereas the other supports the concept of spatially-extended illumination.

I. MULTIPLIER-CHAIN BASED TX AND RX MODULES

The proposed THz system is realized in the form of two independent highly-integrated and low-cost transmitter and receiver modules, as shown in Fig. 1 [3, 4]. Each module comprises a single die with a silicon lens-integrated wideband on-chip antenna system and is simply wire-bonded onto a regular PCB that is equipped with an additional copper heat sink. The chipset is implemented in a 250nm SiGe HBT BiCMOS technology with ft/fmax of 280/435 GHz. To overcome the limitations of power generation in silicon, 4 parallel multiplier chains on a single TX chip are spatially combined by a 2x2 on-chip antenna array illuminating a silicon lens through the chip backside. Each transmitter path consists of a harmonic generator that is driven by a separate x9 multiplier chain fed from an external tunable reference signal centered around 18.2 GHz. The harmonic generator circuit is capable of providing multiple harmonics of the fundamental frequency centered around 164 GHz (9 x 18.2 GHz) present at its inputs with the power levels permitting a high SNR operation of the complete imaging system up to 1 THz. The receiver chip is arranged as a 2x2 array of wideband harmonic single-balanced mixers fed from a common x9 multiplier chain; similar to that from the transmitter chip. Each of the mixers is driven differentially from a broadband silicon lens-integrated on-chip ring antenna.

The simultaneous operation at multiple harmonics is capable of a considerable acquisition time reduction for applications requiring both the spectral information and the high spectral resolution provided by the multiplier-chain architecture at the same time.
one synthesizer is offset by $\Delta f$ from the other which, in turn, after a $x9$ multiplication defines a fundamental IF frequency of the complete imaging system. This way, all harmonics of 164 GHz radiated from the transmitter are assigned to the corresponding integer numbers of the mentioned fundamental IF frequency at the receiver outputs. The IF output spectrum is acquired by a spectrum analyzer and an ADC card and then further post-processed in MATLAB to result in a set of images at frequencies from 160 GHz up to 1000 GHz. For a 1 Hz resolution bandwidth, the complete system achieves an SNR of up to 115 dB. An exemplary multi-color image of various leaves taken with this imaging setup is shown in Fig. 3.

Fig. 3 Multi-color image of various leaves and a piece of dried apple taken with the imaging setup from Fig. 2. Normalized intensity in dB-scale is shown.

II. 4X4 SOURCE ARRAY MODULE OF 3-PUSH OSCILLATORS

A high-power single-chip reconfigurable source module operating at 519-536 GHz was implemented in a SiGe HBT technology with $f_t/f_{max}$ of 300/500 GHz (see Fig. 4) [5, 6]. The module comprises a 4x4 array of 3-push Colpitts oscillators operating incoherently that are equipped with the appropriate on-chip differential ring antennas illuminating a common silicon lens through the chip backside. The overall chip/lens combination is wire-bonded onto a low-cost FR-4 PCB and enclosed in a metal housing altogether with an additional readout electronics allowing its operation through a regular USB port. Each of the source pixels can be powered down at runtime through a programmable logic implemented in the CMOS portion of the technology. This way, an arbitrary radiation pattern configuration with an angular diversity of illumination can be loaded to adjust the lighting conditions of an object plane. The module delivers a total radiated power of up to 1 mW with 62.5 $\mu$W per pixel on average, thus, potentially providing sufficiently high radiation intensity over a large object plane to support real-time imaging with the focal-plane arrays of detectors. An exemplary measured radiation pattern for the array chip mounted on a 15-mm diameter silicon lens with all pixels activated is shown in Fig. 4. All 16 beams cover a field of view of around $\pm15^\circ$. The radiation patterns were taken in the antenna far-field zone with the array module positioned in the pivotal point of a 2-axis computer controlled rotational joint.

Fig. 4 Single-chip 4x4 array of 3-push oscillator based power sources: system-level architecture (top), hardware integration (left), azimuthal view of the measured normalized radiation patterns (dB-scale) of the complete module on a 15-mm diameter lens with all 16 pixels activated (right).

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