High-Angular-Resolution Sub-THz Imaging System with Antenna-in-Package Technologies

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***Abstract*— The high-angular-resolution imaging capability of future automotive and security sensing systems is in favor of compact, fully-integrated and reconfigurable antenna arrays. The adoption of sub-terahertz (sub-THz) frequencies in such systems relieves the hardware requirements for the physical size and fractional bandwidth. This project proposes a sub-THz 4D imaging system that decouples the designs of active circuits (transceivers) and large passive antenna array (reflectarray), which naturally circumvents those challenges of circuit complexities, electronic density and computation power, in traditional phased/MIMO arrays. A sub-THz transceiver system and a sub-THz reflectarray are designed under commercial CMOS process. Towards better practicality, antenna-in-package (AiP) technology is implemented in antenna designs for both the transceiver and the reflectarray. The two systems have been jointly assembled for complete imaging operations, and the basic system functionalities have been verified by measurement.**

***Index Terms*—Reconfigurable reflectarray (RRA), phase quantization, angular resolution, terahertz (THz), CMOS, radar imaging, antenna in package (AiP)**

I. INTRODUCTION

AUTOMOTIVE and security screening systems [1] have increasing demands for the object-recognition capability of high-angular-resolution 4D imaging, which favors electrical 2D beam steering. Due to the Fourier-like transformation between an antenna aperture area and its directivity, a sharp beam response (i.e. high directivity), thus high angular resolution, requires a large aperture area (measured by the number of wavelengths). Moreover, to achieve 4D imaging, >10 GHz absolute bandwidth (BW) is required for centimeter to millimeter-level ranging resolution. Therefore, sub-THz imaging system is a preferred electronic solution compared to its microwave counterpart. As for optical solutions, it is noteworthy that, LiDARs [2], while providing excellent resolution, cannot operate reliably under degraded visual (e.g. cloudy, rainy etc.) conditions [3] or strong light interference [4]. In comparison, wave transmission even with cloudy, dusty and humid conditions has low loss within a few sub-THz transmission windows [5], [6].

Recent research in sub-THz phased/MIMO arrays [7]–[9] has made significant progress but also are facing increasing electronic density problems, because each element needs an individual active feeding circuit and must be well fitted into a small $\lambda/2\times\lambda/2$ (λ: wavelength) area to avoid large grating lobes. Techniques based on virtual arrays can relieve such “half-wavelength dilemma”, but still become highly challenging when scaling up to a very large 2D aperture and operating at sub-THz frequencies. This project proposes a high-angular-resolution sub-THz 4D imaging system based on a reflectarray topology (Fig. 1), which decouples the design of active transceiver circuits with the large-scale but passive antenna array. The passive reflectarray only has sub-THz switches and digital circuits implemented for phase tuning, so that the “half-wavelength dilemma” is naturally circumvented. Towards better practicality, antenna-in-package (AiP) technology is implemented in antenna designs for both the transceiver and the reflectarray, which significantly improves the radiation efficiency, thus system link budget.

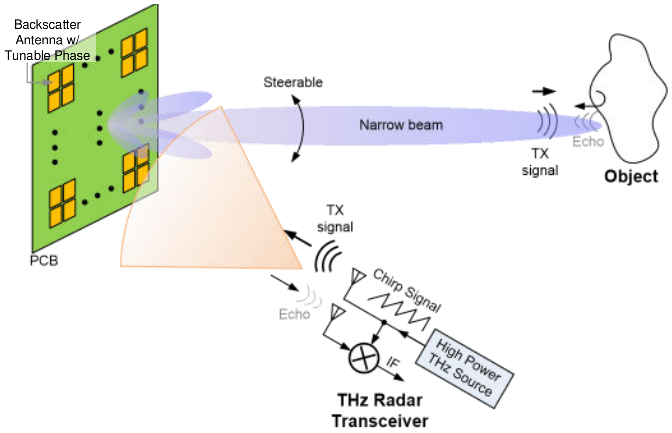

Fig. 1: Reflectarray topology: decoupling the active circuits with the large-scale passive antenna array.

This project is also funded by Intel Corporation through a Semiconductor Research Corporation Member Specific Research Grant to MIT. The project team members include Xibi Chen and Prof. Ruonan Han from MIT, and Dr. Georgios C. Dogiamis from Intel Corporation.

II. PROJECT RESULTS

Fig. 2a shows the system configuration. Both the transceiver (TRX) and the reflectarray antennas are realized by AiP technology, so that the antenna efficiency can be much higher than on-chip antennas. The whole reflectarray consists of multiple package units, where each package unit has multiple AiP elements. Those AiP elements are further divided into several sub-arrays, where each sub-array is controlled by an individual CMOS chiplet. Only digital memories, control circuits, and RF switches are implemented in every chiplet. To further enlarge the array aperture with the same number of antennas, the antenna periodicity on the package is chosen to be slightly larger than $\lambda/2$. Compare to a full-silicon solution with the same aperture area, the silicon area being used is reduced by an order. To further mitigate the grating lobes due to the

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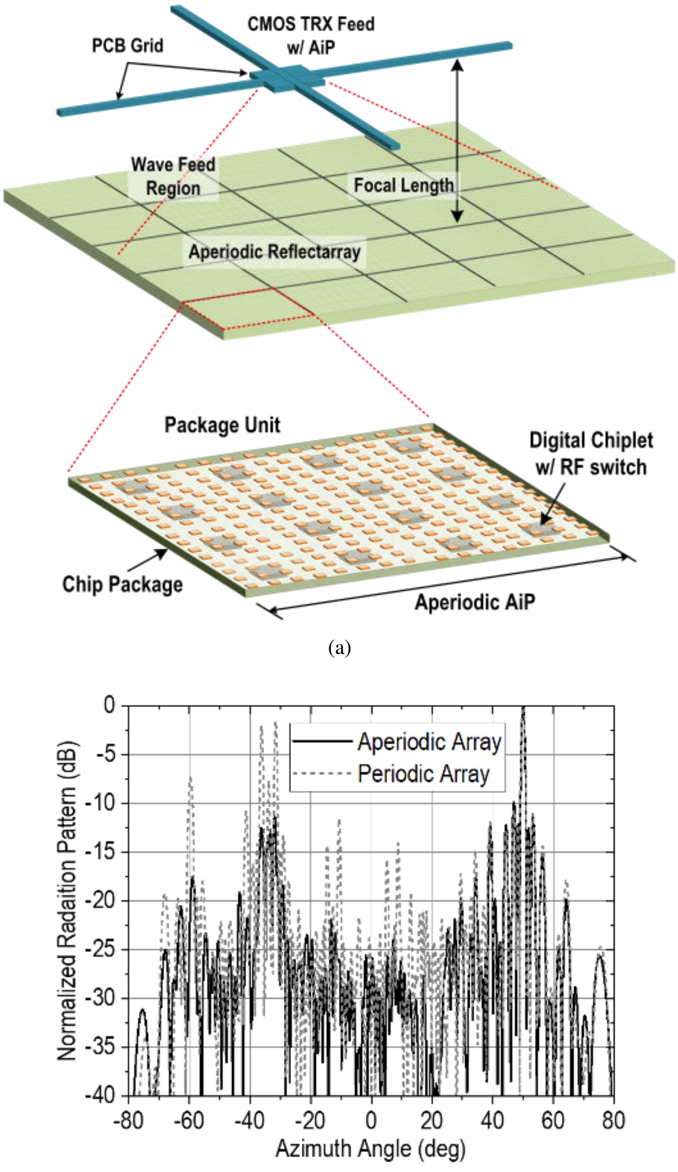

Fig. 2: System configuration: (a) TRX feed and aperiodic reflectarray with AiP implementations, (b) simulated radiation pattern for aperiodic reflectarray.

$> \lambda/2$ periodicity, an aperiodic array design is implemented in both each package unit and the whole reflectarray (Fig. 2a). The original grating lobes are significantly suppressed down by the aperiodic array design, as shown in Fig. 2b. The transceiver (TRX) and reflectarray systems are designed through a commercial CMOS process with packaging (AiP). The basic functions of both the TRX and the reflectarray have been verified by measurement. Fig. 3 shows the simulated angular resolution of the system for a round-trip radar detection (i.e. point spread function, PSF), which is even comparable with typical LiDARs [2]. Detailed results and demonstrations will be reported in future publications.

III. Fellowship Impact and Career Plan

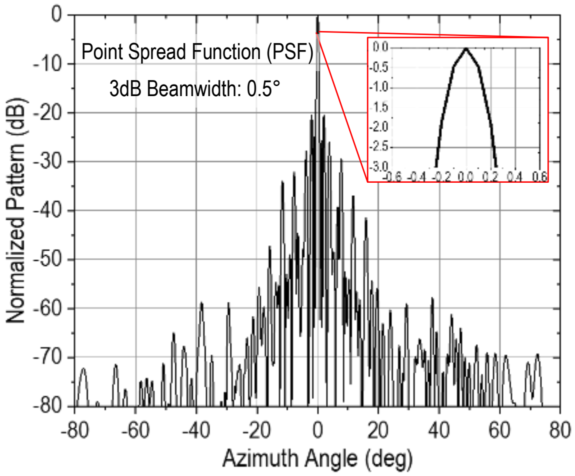

Fig. 3: Simulated angular resolution of the complete system for a round-trip radar detection: point-spread-function (PSF).

It has been a great honor to me for winning the 2024 IEEE Microwave Theory & Technique Society (MTT-S) Graduate Fellowship, as well as the 2024 IEEE MTT-S Tom Brazil Graduate Fellowship. This award has been a great support and recognition of my current research. Moreover, being selected by the award further encourages me to keep conducting research on next-generation high-frequency/high-speed electronic systems. I would like to thank the MTT-S Education Committee for announcing me the award. I would also like to thank my supervisor, Prof. Ruonan Han, for his supports and guidance in my research projects.

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