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Lau, Buon Kiong

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Design of Low-Cost Sub-THz Antennas for Distributed Deployment in 6G

Buon Kiong Lau

Department of Electrical and Information Technology

Lund University

Lund, Sweden

buon_kiong.lau@eit.lth.se

Abstract—Although 6G is not only about higher data rates, its envisioned peak data rate of 1 terabits per second requires larger frequency bandwidth than what 5G millimeter wave bands offer. Therefore, new frequency bands have been allocated in the sub-THz range for 6G applications. This paper reviews the concept of distributed deployment to provide coverage in sub-THz bands, focusing on the design and implementation of low-cost antennas-in-package that enable the use case.

Index Terms—6G, sub-THz coverage, distributed antennas, antenna-in-package.

I. INTRODUCTION

As mobile communications continue to evolve, the focus is no longer on ever increasing data rate, but utilizing advanced network functionalities to leverage advanced services and applications such as global coverage, wide-area mass-market mixed reality, and autonomous mobility [1].

Nevertheless, providing higher and higher data rates will continue to be important for future networks, as more information is often needed to enable more advanced services, such as mixed reality. To this end, 6G will go beyond the 5G millimeter-wave frequencies to utilize new frequency resources in the sub-THz range (*i.e.*, 90-300 GHz). In particular, ITU Radio Sector (ITU-R) has allocated many frequency bands in the D-band (*i.e.*, 110-170 GHz) for mobile and fixed wireless services [1].

One vision of effectively deploying mobile services in sub-THz bands is presented by the Horizon Europe project "A Dual-frequency Distributed MIMO Approach for Future 6G Applications (6GTandem)", which foresees the tight collaboration of subsystems in two different frequency ranges to provide 6G services with high performance [2]. In this vision, a sub-THz subsystem works in tandem with a sub-10 GHz subsystem to provide high reliability and wide coverage on the one hand (*i.e.*, the domain of the sub-10 GHz subsystem), but also the possibility to achieve ultrahigh data rate for offloading and special use cases on the other hand (*i.e.*, the domain of the sub-THz subsystem).

For the sub-THz subsystem, the coverage is provided by distributing the radiofrequency (RF) signal from a central unit

(CU) to radio units (RUs) along multiple radiostripes, with each RU covering only a small area, as depicted in Fig. 1. For sub-THz application, each radiostripe consists of a polymer microwave fiber (PMF) cable, serving as a relatively low-loss waveguide. To provide some degree of resilience from signal blockage common at such high frequencies, the coverage areas of the RUs are overlapped. Apart from providing overlapping coverage with over-the-air spot-beam transmission, the regularly spaced RUs also serve the function of boosting the signal received from the previous PMF cable before it is forwarded to the next PMF cable section. In the case that more amplification is needed, booster units (BUs) can also be added between the RUs.

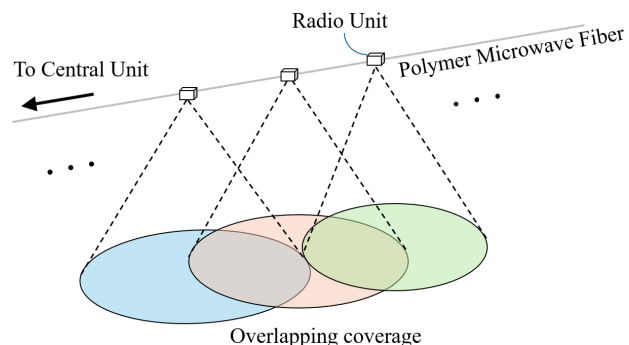


Fig. 1. Overlapping coverage of sub-THz RUs along a PMF.

II. D-BAND ANTENNA-IN-PACKAGE CONCEPTS

Given that the coverage area per RU involves only a moderate range, the required antenna gain is likewise moderate, which can be met by high-gain single-element antennas or small arrays. For example, in an indoor office environment, the RUs are placed along PMF cables that are mounted on the ceiling, which implies a typical range of only a few meters. This relaxed gain requirement translates to relatively small and low-complexity antenna structures. Therefore, it is both feasible and attractive to apply antenna-in-package technologies [3] to integrate the antennas or arrays with the chip in a package. Moreover, this divide-and-conquer approach using moderate-gain antennas also enables large enough 3 dB beamwidth for the spot beam coverage.

In 6GTandem, the embedded wafer level ball grid array (eWLB) packaging technology is used to integrate multiple RF chips in the RU due to its fan-out area being adaptable to needs [4], including the possibility to integrate antennas directly onto the package. Moreover, it is suitable for mass production and hence presents a low-cost solution, which is particularly attractive given that many RUs would be required to provide coverage of a sub-THz subsystem.

There are several ways to design an antenna on an eWLB package, as illustrated in Fig. 2 and described in the following subsections.

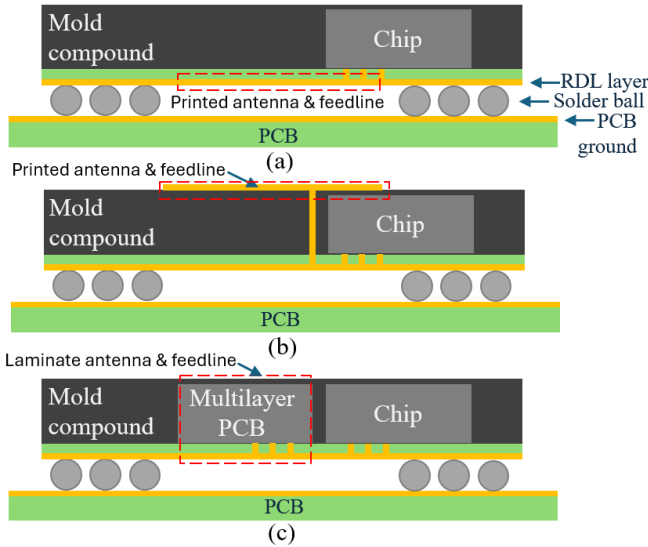


Fig. 2. Three options for antenna integration on eWLB package: (a) direct integration on bottom redistribution layer (RDL), (b) integration on top RDL using vertical transition, and (c) integration of antenna in embedded multilayer PCB

A. Direct Integration on Bottom Redistribution Layer

The most convenient way to integrate an antenna in an eWLB package is to print it on a redistribution layer (RDL) at the bottom of the package in the fan-out area, as shown in Fig. 2(a) [4]. The ground provided by the PCB can then be opportunistic used as a reflector. Recently, this concept was adopted by 6GTandem to design a wideband circularly polarized patch antenna on the D-band [5], fed by a coplanar waveguide (CPW). Circular polarization was chosen due to the expected random orientation of the user device as well as the interest to avoid the complexity of a dual-polarized (dual-channel) configuration.

However, this initial design was based on a relatively small package and a small reflector. In real applications, the package size is larger and even more so the PCB size, which present a significant challenge to achieving stable performance across a wide frequency band. This is because there is significant surface wave propagation from such a patch antenna, which makes it sensitive to the package and ground sizes. Moreover, the presence of solder balls, chip(s) and other asymmetrical

structures makes it difficult for the antenna to achieve a wide axial-ratio bandwidth.

B. Integration on Top Redistribution Layer

Due to the limitations of the direct integration approach, another option is to employ a vertical transition to route the signal to the top of the package and use an upper RDL to design the radiator, as shown in Fig. 2(b) [4]. In this method, the bottom RDL can be used as the local ground plane, enabling the antenna performance to be "shielded" from structures below the package. However, this approach still suffers from surface wave propagation as well as the influence of the package, including the package size and the presence of chip(s).

C. Integration of Antenna in Embedded Multilayer PCB

As a further step to improve design flexibility, a multilayer PCB can be embedded into the mold compound of the package, as depicted in Fig. 2(c). For this option, a low-cost high density interconnect (HDI) multilayer PCB technology can be used to produce the antenna, such as a coplanar parasitic patch antenna that offers high gain and wideband operation in D-band [6]. In general, HDI multilayer structure introduces a high degree of design flexibility, including the possible use of cavity-based structures to effectively isolate the antenna performance from the package.

III. CONCLUSIONS

Thanks to the abundance of frequency resource in the sub-THz range, achieving unprecedented data rates is technically possible. However, to meet practical requirements such as low complexity, mass production and loss cost, this paper presents the 6GTandem approach of distributed deployment using radio units with antennas-in-package as an attractive sub-THz system solution. Future work includes experimental work to validate the design concepts presented herein.

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