Design of Wideband Dielectric Resonator Antenna for D-Band Applications

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***Abstract* – In this paper, a wideband dielectric resonator antenna (DRA) is proposed for the D-band antenna-in-package (AiP) solution. A low-cost AiP solution based on the high density interconnect (HDI) printed circuit board (PCB) process is proposed for the first time for D-band applications. The radio-frequency (RF) chip is embedded in the multi-layer PCBs and packaged with flip-chip bonding. The RF signal is transferred from the chip to the top of the package by a vertical transition for antenna excitation. As an example, the DRA (0.5 mm Alumina cube) is designed with a single-ended microstrip-fed on the package top. The measured impedance matching bandwidth is 115-162 GHz with a peak gain of 5.5 dBi at 154 GHz.**

***Keywords* — Antenna-in-package (AiP), D-band, dielectric resonator antenna (DRA), sub-Terahertz.**

I. INTRODUCTION

Wireless communication is moving towards “Beyond 5G” and 6G due to the emerging applications, e.g. virtual/augmented reality (VAR), industrial automation, autonomous vehicles, Internet of Things (IoT) and wireless backhaul. With high demands on data rates, typically in the 100 Gbps level. The D-band is quite compelling for such high data rate due to the low attenuation by atmospheric absorption and large available bandwidth. However, interconnecting between the antenna substrate and RF chip at such frequencies becomes a challenge [1].

A promising solution is to integrate an off-chip antenna within the chip package, namely antenna-in-package. Various AiP solutions have been proposed in the literature [2]-[6]. In order to realize the scalable package at a low cost, an HDI PCB is employed for package implementation. In this paper, an AiP architecture is first introduced with DRA featuring wide bandwidth and low cost. The design procedure of DRA is also detailed with experimental results.

II. HDI PCB BASED AIP

The configuration of the proposed AiP solution is shown in Fig. 1. As can be seen, the RF chip is attached in the cavity of the packaging substrate by using a thermal adhesive. Additionally, the open-cavity package has thermal vias connecting the metal die pad and the back metallization, which enhance heat dissipation of the RF chip. The antenna superstrate including the redistribution layer (RDL) is flip-chip bonded on the top of RF chip and packaging substrate. Hence, a PCB fan-out technique. In this way, the RF chip is embedded in the multi-layer PCB and scalable sealed package is formed. As a result, the superstrate is used to design the antenna in a flexible manner, enabling a wideband, low cost and low complexity solution for the antenna. Since DRAs have been successfully demonstrated for mmW applications [7], [8] a microstrip fed DRA is chosen.

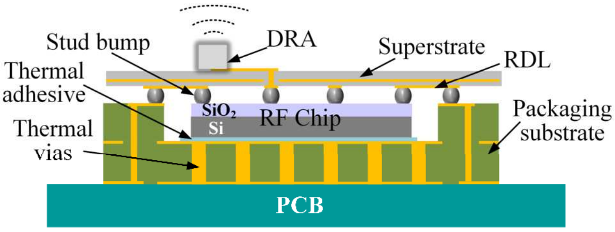

Fig. 1. Configuration of proposed antenna-in-package.

III. DESIGN OF DRA ON THE PACKAGE

A. Configuration

To verify the antenna for the proposed D-band package, a stand-alone single-ended microstrip-fed DRA is designed, as shown in Fig. 2. The antenna substrate Megtron R5680(N) with a thickness of 60 µm, a dielectric constant of 3.14 and a loss tangent of 0.003 at 50 GHz is used. The 50 Ω microstrip line with a shorted via, acting as a shorted strip or patch antenna, is used to feed the DRA cube (99.8% Alumina with a dimension of 0.5 mm). The adhesive used to attach the DRA to the superstrate is Polytec TC 430 with a dielectric constant of 3.2 and loss tangent of 0.023 [9]. A probe and the corresponding pads are also considered in the simulations.

B. Simulations and Experiments

Fig. 3 shows the PCB prototype and DRA, as well as the simulated reflection coefficient of the stand-alone DRA. As can be seen, the simulated impedance bandwidth ranges from 109 GHz to 164 GHz with a radiation efficiency better than 90% and total efficiency larger than 85%. The simulated and measured reflection coefficients of DRA with the probe are also compared in Fig. 3, where the measured impedance bandwidth of 115-162 GHz with slight mismatches at 121.8 GHz and 133.8 GHz. Fig.4 shows the achieved gains of DRA with the probe. The simulated gains of DRA with and without (w/o) a probe are both 4.6-6.3 dBi over 110-160

GHz. While the measured peak gain of 5.5 dBi is found around 154 GHz and the approximate 3-dB gain bandwidth is 128-161 GHz. It should be noted that the transition of probe and microstrip is included which might decrease the achieved gain. More accurate results are anticipated with further calibration, i.e. multi-line TRL calibration.

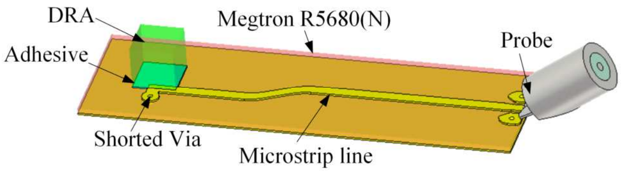

Fig. 2. Configuration of proposed DRA.

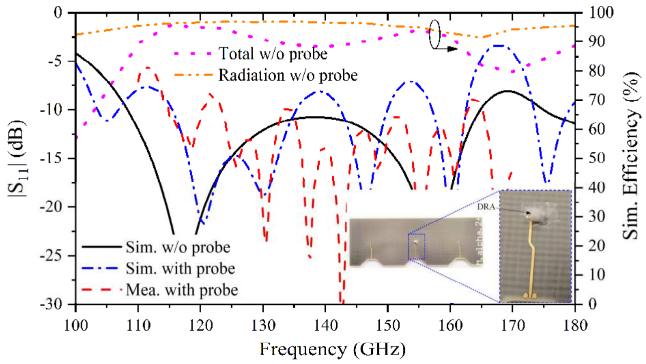

Fig. 3. Photo of prototype, simulated and measured reflection coefficients and simulated efficiency of DRA.

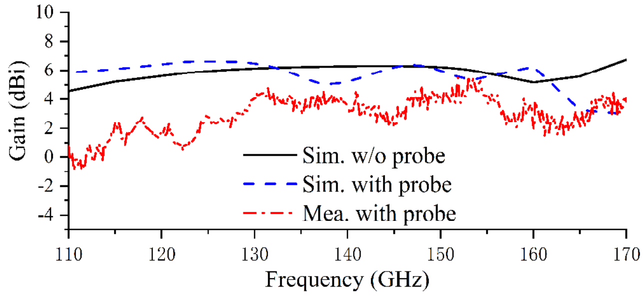

Fig. 4. Simulated and measured gains of DRA.

Fig. 5 shows the simulated and measured radiation patterns in the E- and H-planes at 110 GHz, 135 GHz and 160 GHz where the gain is normalized at θ = 0°. It is found that the measured curve tendencies agree with the simulations. The ripples are probably caused by the surrounding setup. The cross-polarized levels are less than -6.5 dB at the boresight which could be improved by using a differential feed.

IV. CONCLUSION

A wideband microstrip-fed DRA has been proposed for PCB-based AiP solution. The proposed package solution features low-cost and scalability. The DRA attached on the PCB has been designed on the package and experimentally verified compared with simulations. The results have shown that the DRA concept is a good candidate for D-band applications with the proposed AiP solution.

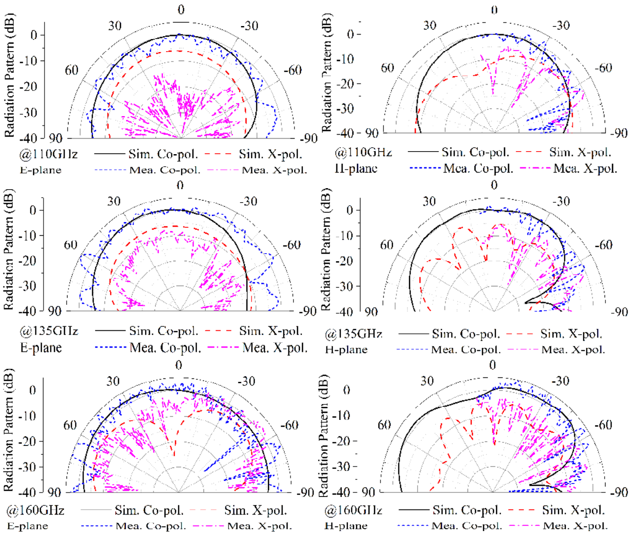

Fig. 5. Simulated and measured normalized radiation patterns in the E- and H-planes at 110 GHz, 135 GHz and 160 GHz.

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REFERENCES

[1] J. Schäfer, H. Gulan, D. Müller and T. Zwick, "On-chip millimeter wave surface wave launcher for off-chip leaky wave antennas," *Proc. 48th Eur. Microw. Conf. (EuMC)*, pp. 1113–1116, Sep. 2018.

[2] S. Beer, C. Rusch, H. Gulan, B. Göttel, M.G. Girma, J. Hasch, et al., "An integrated 122-GHz antenna array with wire bond compensation for SMT radar sensors," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 12, pp. 5976–5983, Dec. 2013.

[3] F. Ahmed, M. Furqan and A. Stelzer, "120-GHz and 240-GHz broadband bow-tie antennas in eWLB package for high resolution radar applications," *Proc. 48th Eur. Microw. Conf. (EuMC)*, pp. 1109–1112, Sep. 2018.

[4] S. Shahramian, M. Holyoak, A. Singh, B. J. Farahani and Y. Baeyens, "A fully integrated scalable W-band phased-array module with integrated antennas self-alignment and self-test," *Proc. IEEE Int. Solid - State Circuits Conf.*, pp. 74–76, Feb. 2018.

[5] A. Bhutani, B. Gottel, A. Lipp and T. Zwick, "Packaging solution based on low-temperature cofired ceramic technology for frequencies beyond 100 GHz," *IEEE Trans. Compon. Packag. Manuf. Technol.*, vol. 9, no. 5, pp. 945–954, May 2019.

[6] A. O. Watanabe et al., "Glass-based IC-embedded antenna-integrated packages for 28-GHz high-speed data communications," *Proc. IEEE 70th Electron. Compon. Technol. Conf. (ECTC)*, pp. 89–94, Jun. 2020.

[7] J. Kowalewski, J. Eisenbeis, A. Jauch, J. Mayer, M. Kretschmann and T. Zwick, "A mmW broadband dual-polarized dielectric resonator antenna based on hybrid modes," *IEEE Antennas Wireless Propag. Lett.*, vol. 19, no. 7, pp. 1068–1072, Jul. 2020.

[8] A. Visweswaran et al., "An integrated 132–147GHz power source with +27dBm EIRP," *Proc. IEEE Radio Freq. Integr. Circuits Symp. (RFIC)*, pp. 219–222, Jun. 2020.

[9] B. Goettel, W. Winkler, A. Bhutani, F. Boes, M. Pauli and T. Zwick, "Packaging solution for a millimeter-wave system-on-chip radar," *IEEE Trans. Compon. Packag. Manuf. Technol.*, vol. 8, no. 1, pp. 73–81, Jan. 2018.