# Expanding Packaging Technologies into Antenna Technology

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Since the mid-1990s, complementary metal oxide semiconductor has been the technology driver for the wireless revolution. It is in fact now the dominant technology for the fifth generation (5G) New Radio (NR).

AiP technology integrates an antenna (or antennas) with a radio chip (or chips) in a package [1, 2]. It balances performance, size, and cost well. Hence, it has been the antenna and packaging technology for millimetre-wave (mmWave) 5G NR.

AiP technology has fundamentally changed the ecosystem of radios and radars for wireless applications: (1) It has enhanced the operation of the multi-scale multi-physics co-design platform. (2) It has promoted the development of new materials and processes for advanced packaging. Currently, flip-chip AiP dominates in mmWave 5G market. However, fan-out AiP with much thinner die to die integration is promising for more compact mmWave 5G NR integration. (3) It has advanced the measurement of antennas and packages to an unprecedented level. New testing strategies and equipment have been specifically developed for fast functional verification of AiP in production lines. (4) It has enriched the techniques to suppress electromagnetic interference. The conformal shield and compartment shield using laser trench, paste filling, and metal coating are effective to suppress electromagnetic interference in AiP. (5) It has found many other applications, including Internet of Things devices at 2.4 GHz, virtual reality, augmented reality, and gesture radars at 60 GHz, automotive radars at 79 GHz, imagers at 94 GHz, sensors at 122, 145, and 160 GHz, as well as 300-GHz wireless links. The advantages of AiP technology will continue to generate new applications, for example, the use of AiP technology in mmWave 5G based industrial Internet has huge potential.

Recently there have been many reports of AiP element designs and research using different fabrication processes. But in order to cover the whole 5G NR band from 24.25 to 40 GHz, a broadband and miniaturized AiP design is necessary to reduce the set of arrays and achieve better performance. Such design has been reported by Lin et al. in 2020 [3] (Fig. 1), which used Yagi elements instead of dipole-type radiators to reduce the total size and successfully achieved excellent endfire radiation capability. Glass packaging technology was utilized because it can support low-cost and scalable structures with better surface roughness and coefficient of thermal expansion match to silicon dies.

Additive manufacturing techniques, such as inkjet printing and 3D printing, have become especially popular for AiP because they are customized, low-cost, user-friendly and cause less waste of materials [4]. Inkjet printing technology enables the deposition of a wide variety of materials such as dielectrics, conductors, and semi-conductors onto rigid or flexible substrates. Inkjet-printed interconnects feature a more rugged, planar, and conformal structure, which offers an improved RF performance even in challenging configurations [5]. Fully inkjet printed sloped "ramp" interconnects (Fig. 2) on 3D printed substrates can form smoother transitions from a molded IC die to an external plane of its encapsulation with lower loss up to 95GHz [6, 7]. 3D printing technologies like FDM and SLA printing demonstrate significant advantages in creating selective customized vertical structures for more compact and complex multilayer integration. The combination of inkjet printing and 3D printing makes it possible to implement innovative 3D packaging design [8]. It is also possible to integrate reconfigurable "origami-inspired" structures into RF designs (Fig. 3) to enable more tunability for more application scenarios [9, 10].

In summary, AiP technology impacts on both antenna and packaging industries tremendously. The traditional antenna industry has begun to lose some business, while the packaging companies has expanded their business into the antenna domain for the first time [11].

## Figures

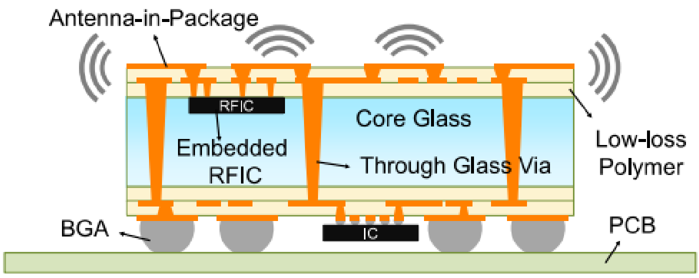


Fig. 1 Three-dimensional SiP module with AiP designs for 5G applications [3].

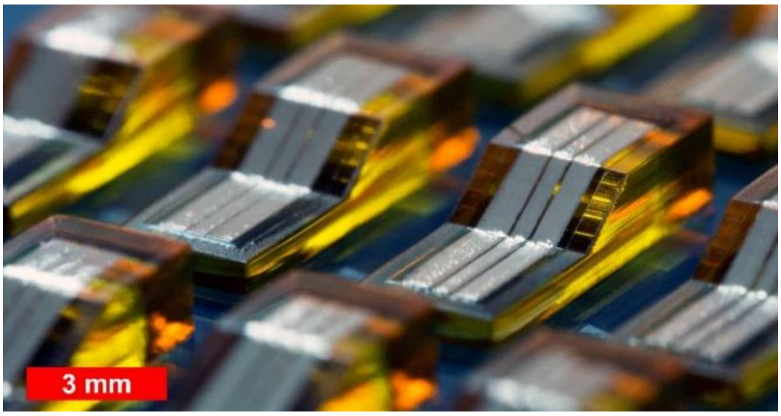


Fig. 2 3D-printed ramp structures with inkjet-printed CPW interconnects, highlighting the 35° slope ramps [7].

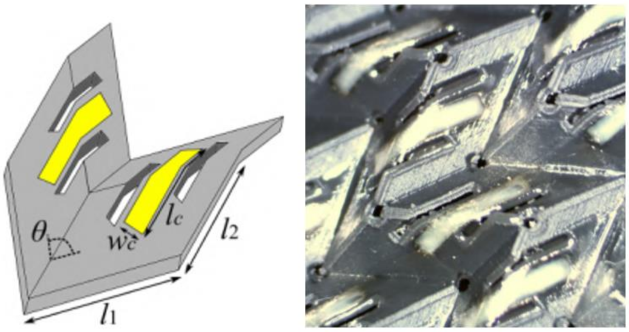


Fig. 3 3D-printed and inkjet printed origami-inspired reconfigurable frequency selective surface element [10].

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## References

[1] Zhang, Y.P, and Duixian Liu. "Antenna-on-Chip and Antenna-in-Package Solutions to Highly Integrated Millimeter-Wave Devices for Wireless Communications." IEEE Transactions on Antennas and Propagation, vol. 57, no. 10, IEEE, 2009, pp. 2830–41, doi:10.1109/TAP.2009.2029295.

[2] Tsai, Mike, et al. “Advanced Antenna Integration of 3D System in Package Solutions for IoT and 5G Application.” 2019 22nd European Microelectronics and Packaging Conference & Exhibition (EMPC), IMAPS-Europe, 2019, pp. 1–6, doi:10.23919/EMPC44848.2019.8951765.

[3] T. -H. Lin et al., "Broadband and Miniaturized Antenna-in-Package (AiP) Design for 5G Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 19, no. 11, pp. 1963-1967, Nov. 2020, doi: 10.1109/LAWP.2020.3018064.

[4] R.Bahr, B.Tehrani, M.M.Tentzeris and K.Byers, "A Novel Integration of Stereolithography and Inkjet Printing for Multichip Modules with High Frequency Packaging Applications", Proc. of the 2018 IEEE ECTC Conference, San Diego, CA, May 2018, pp.2498-2504.

[5] X. He, B. K. Tehrani, R. Bahr, W. Su and M. M. Tentzeris, "Additively Manufactured mm-Wave Multichip Modules With Fully Printed “Smart” Encapsulation Structures," in IEEE Transactions on Microwave Theory and Techniques, vol. 68, no. 7, pp. 2716-2724, July 2020, doi: 10.1109/TMTT.2019.2956934.

[6] Tehrani, Bijan K, et al. “Inkjet and 3D Printing Technology for Fundamental Millimeter-Wave Wireless Packaging.” Journal of Microelectronics and Electronic Packaging, vol. 15, no. 3, 2018, pp. 101–06, doi:10.4071/imaps.660476.

[7] B. K. Tehrani, R. A. Bahr, W. Su, B. S. Cook and M. M. Tentzeris, "E-band characterization of 3D-printed dielectrics for fully-printed millimeter-wave wireless system packaging," 2017 IEEE MTT-S International Microwave Symposium (IMS), 2017, pp. 1756-1759, doi: 10.1109/MWSYM.2017.8058985.

[8] T.-H.Lin, R.Bahr, M.M.Tentzeris, P.M.Raj, V.Sundaram and R.Tummala, "Novel 3D-/Inkjet-Printed Flexible On-Package Antennas, Packaging Structures, and Modules for Broadband 5G Applications", Proc. of the 2018 IEEE ECTC Conference, San Diego, CA, May 2018, pp.214-220.

[9] Kimionis, John, et al. “3D-Printed Origami Packaging With Inkjet-Printed Antennas for RF Harvesting Sensors.” IEEE Transactions on Microwave Theory and Techniques, vol. 63, no. 12, IEEE, 2015, pp. 4521–32, doi:10.1109/TMTT.2015.2494580.

[10] Y. Cui, S. A. Nauroze and M. M. Tentzeris, "Novel 3D-Printed Reconfigurable Origami Frequency Selective Surfaces With Flexible Inkjet-Printed Conductor Traces," 2019 IEEE

MTT-S International Microwave Symposium (IMS), 2019, pp. 1367-1370, doi: 10.1109/MWSYM.2019.8700994.

[11] C. Zwenger, and V. Chaudhry, “Antenna in package (AiP) technology for 5G growth”, Chip Scale Review, vol. 24, no. 2, 2020.