

Novel SiP/SoP RF Modules and Smart Packaging Enabled by Additive Manufacturing

[Tong-Hong Lin, Tony He, Bijan Tehrani & Manos M . Tentzeris (Georgia Tech)]

I. INTRODUCTION

Additive manufacturing is emerging as a promising alternative to traditional manufacturing methods for use in RF applications. With new areas such as 5G and IoT applications, the need for inexpensive, rapidly deployable and high performance RF systems necessitates the need for additive manufacturing to be incorporated into the fabrication process. Various RF components can be fabricated utilizing additive manufacturing techniques and are summarized in this article which includes cutting edge SiP, SoP and smart module encapsulation.

II. ADDITIVE MANUFACTURING CAPABILITIES

A. Inkjet Printed Interconnects for SiP

The development of 3D RF SiP modules requires the ability to pattern unique nonplanar interconnects between in-package passive and active components. While traditional laminate-based fabrication techniques rely on subtractive micromachining and plating processes to fabricate vertical via structures, additive manufacturing techniques enable the rapid fabrication of arbitrarily shaped RF interconnects within any printed substrate, superstrate, or other intra-package structure. Additionally, first-level interconnects to active bare-die MMIC devices can be achieved through the additive printing of 3D ramped interconnects directly to die pads, providing a wide-band, low-loss alternative to traditional wire and ribbon bond SiP solutions. Inkjet and 3D printing fabrication techniques are the key components of this hybrid additive manufacturing-based packaging method. Stereolithography (SLA) 3D printing is a prime tooling technology to fabricate the complex 3D assemblies in conjunction with the RF circuit topologies present within 3D SiP architectures. These 3D-printed structures are

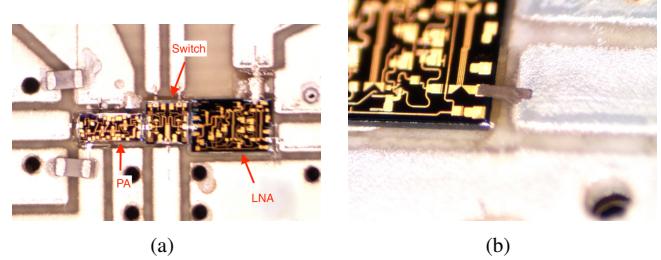


Fig. 2. Non-encapsulated mm-wave front end MCM fabricated using inkjet printing. (a) Fully printed front-end module MCM. (b) A close up view of one of the inkjet printed RF interconnects on the output of the LNA.

then passivated and metallized using an inkjet printing process through the selective patterning of both dielectric and conductive inks, respectively, interconnecting the RF devices within the module in an efficient fashion. These methods have the potential to reduce tooling costs and leadtime associate with RF SiP manufacturing, as well as provide another dimension of design and integration for next-generation RF applications.

B. Inkjet and 3D Printed SoP Modules

Additive manufacturing technologies offer great structural flexibility and new possibilities while integrating different components into one system-on-package (SoP) module as shown in Fig. 1. The core substrate for the packaging can be 3D printed with various 3D structures. As shown in Fig. 1, the cavities can be 3D printed with different sizes and heights for the embedding of various dies. The micro-channels for microfluidics are printed for heat dissipation or biomedical applications. Through packaging vias and ramp non-orthogonal interconnects can be used to connect components at different layers. The broadband corrugated horn antenna or other antenna-in-package (AiP) designs can be directly printed on the top of dies to minimize the interconnect distances and loss, especially at the mm-wave frequency range. The gradient lenses can be printed directly on top of the antenna to further enhance the performances of AiP designs. By combining inkjet printing and 3D printing technologies, more complex 3D structural SoP designs with better performances and more functionalities can be realized paving the way to the new 5G and IoT applications.

C. Additively Manufactured mmWave Multichip Modules (MCM)

Additive manufacturing can dramatically speed up the implementation of 5G networks. It allows for print-on-demand

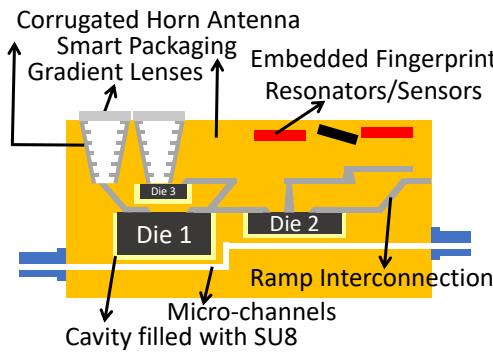


Fig. 1. Additively manufactured 3D system-on-package module.

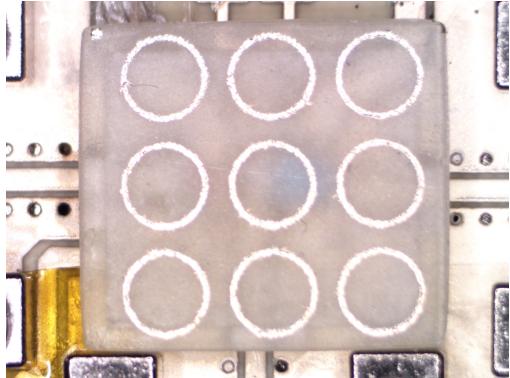


Fig. 3. 24 GHz FSS inkjet printed on top of the 3D printed encapsulation.

capabilities and enabling the realization of a multitude of customized parts that can be assembled quickly and cheaply, reducing the development of a concept to final product from weeks to just hours. Utilizing additive manufacturing, it is possible to create fully printed mmWave RF MCMs for 5G applications.

To create the fully functioning front-end modules, multiple chips operating in the frequency range of 24-40 GHz are placed into cavities and connected together using inkjet printing as shown in Fig. 2. The inkjet printed interconnects offers superior RF performance due to their planar structure, reducing the need for lossy wirebonds. Not only does it improve mechanical stability and RF performance, the additive manufacturing process is modular and can be easily retooled in seconds for different system architectures and applications making it a versatile and flexible tool.

The combination of 3D printing and inkjet printing can also be utilized for encapsulation purposes. The modular capability of additive manufacturing enables "smart" encapsulation structures, which gives encapsulation, usable features other than for just environmental protection. The encapsulation shown in Fig. 3 also features a Frequency Selective Surface which filters EMI emissions which can disrupt nearby circuits or prevent unwanted data signals to be leaked to unauthorized recipients.

III. CONCLUSION

Various state-of-the-art RF systems and components which are fabricated utilizing additive manufacturing are detailed in this article. These include advanced interconnects, encapsulation and system level integration which reach into mm-wave frequencies. These prototype lays the foundations for more advanced and complex systems which can be cheaply manufactured and offers competitive performance to traditional manufacturing techniques.