Towards 3-D Printed (Sub-)THz Active Device Packaging and Multi-chip Modules

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Abstract—**Additive manufacturing using 3-D printing has created a paradigm shift in the realization of passive microwave, millimeter-wave and (sub-)THz components. The metal-pipe rectangular waveguide (MPRWG) inherently offers superior performance over (co-)planar transmission lines, due to their low loss/high-Q and infinite isolation characteristics [1]. In 2015, the first reported 3-D printed MPRWGs demonstrated measured performances at X-band (8 to 12 GHz) and W-band (75 to 110 GHz) that were comparable to their commercially machined counterparts [2]. Moreover, a 6th-order inductive iris coupled band pass filter exhibited excellent results, with less than 1 dB insertion loss at its center frequency of 107 GHz [2].**

While passive components offer exciting opportunities, there has been little reported on the development of 3-D printed active device packaging and multi-chip modules (MCMs). While low-cost solutions for implementing high performance already exist using an array of different technologies, polymer-based 3-D printing offers unique solutions (for example, in terms of complex geometries needed for conformal packaging). Indeed, while wire-bonding and flip-chip interconnects work well up to ca. 30 GHz and 100 GHz, respectively, these 'electrical' solutions become too lossy at (sub-)THz frequencies. For this reason, in 1998, the concept of a terahertz multi-chip module (T-MCM) that employs electromagnetic coupling at its RF ports was introduced; originally intended for implementation using subtractive multi-layer manufacturing technologies up to 300 GHz [3]. In that concept paper, 140 GHz system on substrate transmitter and receiver architectures were proposed, having integrated 4-element phased array antennas. However, it was not until 2007 that this concept was implemented in practice; a 24 GHz FMCW radar front-end, also having a 4-element antenna array, manufactured using low-cost PCB technology [4].

Since 2015, MPRWGs have been demonstrated using different polymer-based 3-D printer technologies at ever higher frequencies [5] in: G-band (140 to 220 GHz) [6]; WR-2.2 band (325-500 GHz) [7]; WM-380 band (500 to 750 GHz) and WM-250 band (750 to 1100 GHz) [8]. While the reported measured performances have decrease with increasing frequency, due to the increasing significance of printing & plating imperfections (e.g., defects and surface roughness), there are no inherent limitations. As a result, with time, more advanced 3-D printing & plating techniques will become mainstream. For this reason, there is increasing interest, in both academia and industry, to pursue low-cost and high performance 3-D printed active device packaging and multi-chip modules at (sub-)THz frequencies. Indeed, the first reported hybrid integration of 3-D printed MPRWGs (power splitter, power combiner, interconnects and flanges) with high performance active components (packaged laser diodes illuminating silicon implants) was demonstrated with an experimental 500 GHz I-Q vector modulator [7].

An international collaborative research project is currently underway, between Imperial College London and Tohoku University, to realize the original T-MCM concept. Here, 3-D printed MPRWGs are used as the low-cost packaging solution for high performance commercial SiGe chips, operating in D-band (110 to 170 GHz). The preliminary design results will be presented.

Keywords—3-D printing, additive manufacturing, rectangular waveguide, interconnects, packaging, multi-chip modules.

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