**Introduction of emerging materials and manufacturing technologies for low-loss circuits realization**

In this Chapter the application of emerging materials and manufacturing technologies for the realization of low loss microwave circuits in strip transmission line technique is considered and discussed. Application of various additive manufacturing technologies and dedicated materials are the subject of this study including 3D printing technologies such as Fused Deposition Modeling (FDM) and Poly Jet Printing (PJP) as well as wide variety of conductive and dielectric materials.

*Initially adopted for rapid prototyping, to test the design before the final product development, additive manufacturing (AM) technologies have rapidly evolved toward the complete (one-pass) manufacturing of end-use components \cite{pieee\_sorrentino}. This is due to significant development of the manufacturing equipment as well as material engineering. Recently also RF engineers have started to leverage AM technologies including 3D printing to develop the next generation of microwave and millimeter-wave devices aimed at several applications operating from a hundreds of megahertz to hundreds of gigahertz, among which are millimeter-wave wireless and satelite communication systems and components such as waveguides, sensors, antennas, filters, power dividers, etc.. In such areas, AM offers several advantages such as superior design and geometrical flexibility of the circuits due to three-dimensional nature of the technology as in contrary to 2.5D for conventional techniques, near-net shape manufacturing, reduced tooling and fixtures, and almost no process waste. Moreover, another enabling advantage of AM processes is that it allows for the realization of multifunction parts, which is the implementation of several functionalities (electrical, thermal, or structural) in a single object. Finally, compared to conventional machining techniques, AM can be applied to produce custom microwave devices at reduced lead time and costs.*

~~An increased interest in utilization of different additive manufacturing technologies for realization of microwave circuit and systems is observed in recent years as the technology have rapidly evolved toward the complete (one-pass) manufacturing of end-use components. providing novel non-conductive and conductive materials. Moreover, 3D printing allows for greater freedom of circuits geometry due to three-dimensional nature of the technology as in contrary to 2.5D for conventional techniques. Additionally, additive manufacturing allows for fast prototyping and evaluation of the microwave devices, as well as lowering the overall time and cost of production. Therefore, the novel manufacturing technologies have found their application for realization of circuits such as waveguides, sensors’ application, antennas, filters, power dividers, etc.~~

The Author has experimentally investigated various additive manufacturing technologies and dedicated materials in terms of low-loss stripline microwave circuits realization as well as developed novel circuits taking advantage of the recent developments in technology and mateirals. T*he results of the conducted research have been a subject of one paper being prepared for a Transactions journal submission and three conference papers presented at \textit{International Conference on Electrical, Electronisc and System Engineering ICEESE`17} and \textit{Electronic Components and Technology Conference ECTC`18}, all under the auspice of the Institute of Electrical and Electronics Engineers IEEE, which constitute the Chapter.*

*The applicability of additive manufacturing with conductive Polylactic Acid (PLA) based filament for the realization of low-loss suspended microstrip microwave circuits is investigated. Filament is used to 3D print case which serve three major functions: provides mechanical enclosure and support for the circuit, provides appropriate elevation of the thin laminate with circuit mosaic over the ground plane and can potentially serve as the ground plane. The influence of the bulk conductivity of the utilized filament on total losses within the structure has been studied. Moreover, an exemplary transmission line hosted in Fused Deposition Modelling (FDM) 3D printed case has been manufactured and measured. Graphene-enhanced PLA material having volume conductivity of $\approx$ 166 S/m has been used yielding total loss of $\approx$ 0.14 dB/cm/GHz while reference case with copper foil ground plane yields total loss of $\approx$ 0.04 dB/cm/GHz.*

*Following, the realization of microwave circuits in suspended microstrip structure with a 3D printed conductive enclosure is presented for the first time. An example of a low-pass filter with a cut-off frequency of 2.5 GHz was designed, manufactured and measured. A Fused Deposition Modeling (FDM) type 3D printing and a conductive copper-based filament recently developed by Multi 3D were employed to realize an enclosure serving both mechanical and electrical purposes. The influence of the ground plane conductivity on the total loss within the circuit was studied, and requirements for the conductive material properties were established. Moreover, the impact of the print parameters as well as the connection between microstrip line and SMA connectors were investigated. The obtained measurements proved that the proposed approach is of potential use for circuits and systems operating within low GHz frequency range.*

*Moreover, an application of additive manufacturing technologies for realization of multilayer microwave circuits in microstrip transmission line technique is presented for the first time. An example of a second-order cascaded loops directional filter allowing to separate 2100 MHz LTE band was designed in suspended microstrip technique with three metal layers, manufactured using a combination of PolyJet 3D printing with UV cured VeroWhitePlus polymer material and magnetron sputtering of copper, and assembled out of two parts using a “lego-like” process. The obtained results for the manufactured circuit confirmed that the proposed approach is of potential use for circuits and systems operating within the microwave frequency range.*

*Finally, a novel approach for the realization of high-performance coupled-line directional couplers in suspended stripline technique is proposed taking advantage of recent development in 3D printing technology. A third degree of freedom is introduced to a 2.5D structure allowing to combine the advantages of strip-transmission-line techniques, for which the circuit can still be considered as a quasi-planar structure, with the 3D printing flexibility of air layer thickness variation limited only by technological constraints. It is shown, that the proposed approach is well suitable for the realization of low-loss circuits, where tight coupling and superior performance are required, as well as compactness. Moreover, it is shown that compensating elements, often required to improve couplers` performance, can easily be realized as a combination of a circuit mosaic and ground plane integrated 3D structures allowing for better circuit volume utilization. An example of a 3-dB coupled-line directional coupler operating within the ISM 5.8 GHz band is designed, manufactured and measured for experimental verification. The obtained results confirm the applicability of the proposed approach.*