URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Substrate Integrated Waveguide (SIW)

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Guided-wave structures are no doubt the most fundamental building elements of high-frequency antennas, circuits and systems. They are usually composed of metallic and dielectric topologies or mixed forms of both, which are made in the form of planar and non-planar geometries, depending on design approaches, processing technologies and application requirements. Earlier than year 2000, the development of high-performance RF wireless, microwave, and millimeter-wave (mmW) techniques over MHz-through-THz frequencies had often experienced difficult and expensive integration issues between planar integrated circuits and non-planar waveguide components. Usually, the non-planar structures are bulky and costly and they are not mechanically, thermally and electrically compatible with low-cost planar counterparts. This unfortunate mismatch or incompatibility created at that time a huge challenge for transceiver front-end integration and packaging.

Since year 2000, substrate integrated waveguide (SIW) [1-4] has emerged as a powerful set of guided-wave techniques providing alternative solutions to existing planar and non-planar structures such as microstrip lines and metallic waveguides. Now, the SIW technology has already become an indispensable research and development scheme in the fields of microwave and mmW engineering. This technology has provided an attractive choice in support of cost-effective integrated transceiver front-end design and development thanks to intensive R&D activities over the last 20 years or so worldwide, which can be evidenced by about 15,000 paper publications and countless patents to date on this topic.

The invention of SIW sets the stage for exploiting the inherent integration nature and common design space of planar and non-planar structures through single or multilayer substrate in which the non-planar part is structurally synthesized in planar form. In other words, the SIW solution is nothing but a non-planar-to-planar transformation, which can be theoretically applied to any non-planar structures including coaxial lines and dielectric waveguides among many others even though the earliest versions of SIW were merely related to the presentation of metallic rectangular waveguide and non-radiative dielectric waveguide cases. As such, nearly any specific processing (fabrication) technique can be used for developing such dissimilar geometries within the same platform. This planarization of non-planar structures, which has been realized by the use of arrays or fences of metalized via or air hole or other features created on substrate for mimicking metallic walls or creating dielectric contrasts. This approach fundamentally preserves the essential features of original non-planar structures in terms of electromagnetic property and modal integrity. Thanks to a rapid evolution of processing facilities and enabling techniques, currently deployed processing techniques allow for very efficient and high-precision fabrication of those metalized via holes or air holes within any substrate of interest. Note that such precision synthesis techniques were not readily available before year 2000.

Figure 1 describes typical non-TEM mode-based SIW structures [5], which are synthesized within substrate for creating the similar electromagnetic wave-guiding conditions of original waveguide counterparts. Of course, there are also TEM mode-based non-planar structures (not shown in the figure) such as coaxial lines, which can directly be synthesizable in a similar way. Interestingly, the rapid emergence and mega-popularity of substrate integration technology for the development of antennas, circuits and systems can be well understood from both historical advancement and future prospective of transmission line or waveguide technology development roadmap, which was also made to extrapolate future trends with reference to the evolution of guided-wave structures, as briefly explained in [6].

The current and future expansion of SIW activities is essentially motivated by the following interests and aspects: (1) substrate integrated metallic and dielectric waveguides for CMOS and 3D ICs development, allowing for an unprecedented exploration of high-performance microsystems; (2) the use of advanced smart materials in creating reconfigurable and innovative SIW techniques; (3) 3D multi-layered SIW solutions through emerging processing techniques such as 3D printing; (4) large-scale integration and exploitation of dissimilar SIW structures for front-end system developments; (5) design convergence and structure integration of SIW-based antenna-circuit; and (6) search for nonlinear SIW structures for exploring non-TEM mode active circuits and systems. Some of those activities were predicted and discussed in [4, 7-8].

Although there are so many papers published and patents released already in the literature on the topics, it seems that research interest and development enthusiasm in this connection are not expected to cease any sooner and in fact can be found in an unbelievably upbeat mood for

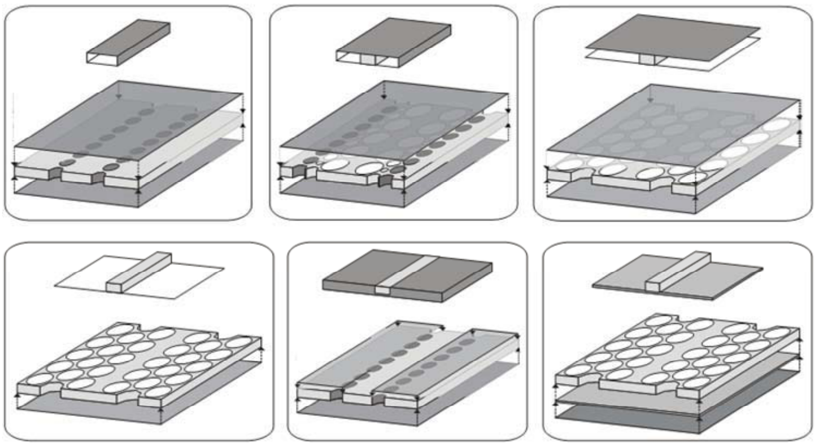

Figure 1. Typical topologies of non-TEM mode-based substrate integration structures.

continuous expansion and evolution with reference to both fundamental research and practical development. This is fundamentally driven by the unprecedentedly growing requirements for low-cost and highly reliable microwave, mmW and THz products and deployments for emerging 5G wireless communications and applications, internet of space (IoS), autonomous driving and flying, next-generation IoT, intelligent manufacturing (Industry 4.0), virtual (augmented) reality and hardware intelligence converged by electromagnetic identification, sensing, positioning, and imaging recognition among many others.

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