An Inkjet-printed Flexible Broadband Multilayer SIW Coupler for Antenna Array Systems

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***Abstract*—In this paper, a novel inkjet-printed flexible broadband multilayer coupler on a polyimide film (Kapton) in substrate integrated waveguide (SIW) technology is implemented for the first time. A flexible broadband microstrip-to-SIW interconnect is inkjet-printed and its flexibility is tested. An inkjet-printed multilayer coupler is also demonstrated based on the flexible SIW interconnect.**

I. Introduction

It is critical to implement low-cost compact wireless electronics because they are key components for realizing integrated sensors and communication systems involving complex antenna systems, such as multi beam antennas (MBA). MBA can be implemented by utilizing antenna arrays fed by a multiple beam forming networks like Butler matrix which consists of couplers [1]. The coupler is typically an electrically large structure in terms of wavelength (λ_0) which results in a relatively large form factor of the implemented MBA. The implementation of flexible compact multilayer structures is especially challenging because of the limited flexibility due to substrate thickness and the misalignment/fabrication uncertainties of the multilayer fabrication process [2].

Above all, flexible interconnects is one of the most critical components in order to implement flexible multilayer systems requiring the utilization of flexible substrates to achieve high flexibility as well as adequate fabrication/metallization methods which are compatible with the chosen substrate. Via metallization and alignment techniques are also important to implement truly flexible RF modules and antenna systems. The cost efficiency of the whole system should be considered while satisfying the system requirements.

In this paper, a novel approach which utilizes inkjet printing technology to fabricate scalable flexible multilayer 2D/3D electronics in SIW technology, that can be suitable for various antenna array applications for communication, RFID and sensing, is proposed. The cost effective nanoparticle-based inkjet printing fabrication method is used to take advantage of the full range of flexible substrates which eliminates the need for costly time-consuming and environmentally-unfriendly clean room processes. A laser cutter is used to drill viaholes that can be utilized as alignment marks for the each layer. The proposed compact multilayer coupler is a critical component for implementing compact multiple beam antennas.

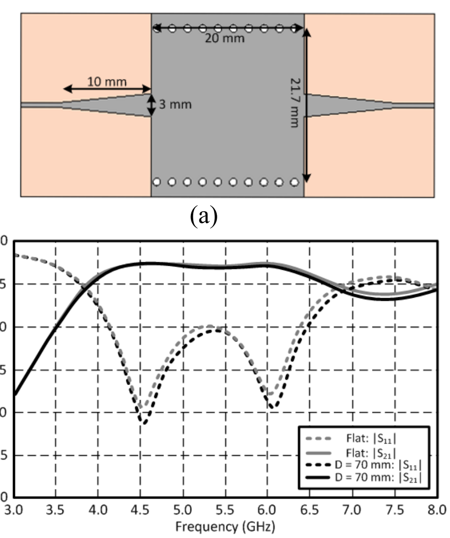


Fig. 1. (a) Geometry of the SIW interconnect and (b) its measured S-parameters (S_{11} & S_{21})

II. Flexible Inkjet-printed Multilayer Coupler

A. Flexible SIW Interconnect

First of all, a SIW interconnect has been printed on a thin polyimide film as shown in Fig. 1(a). The SIW was designed to have the cutoff frequency of 4 GHz (fundamental mode (f_0) of the SIW) resulted in the center frequency of 5.4 GHz. The diameter of the vias was 1.0 mm and their pitch was 2 mm. The ratio of the length to the width of the transition was set to 3 and optimized to enalbe the effective matching of the fields of the microstrip line (quasi-TEM mode) and the SIW (TE_{10} mode) [3].

The 3D full wave electromagnetic solver, Ansys HFSS, was used to design and simulate the SIW structures including the microstrip-to-SIW transitions. The substrate thickness is 0.254 mm. It has dielectric permittivity (ε_r) of 3.0 and the loss tangent (tan δ) of 0.03. The measured insertion loss (IL) of the printed microstip-to-SIW transition is about 0.8 dB while

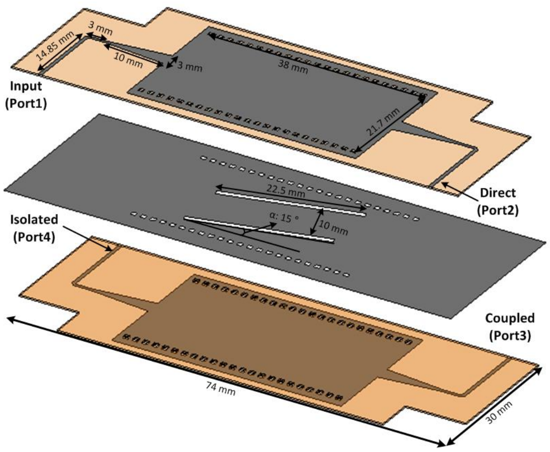


Fig. 2. Geometry of multilayer broadband coupler.

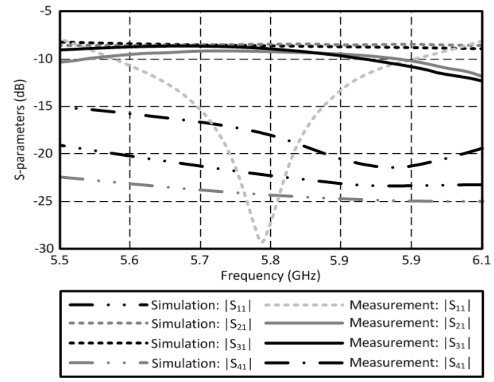
typically reported transitions has about the IL of 0.2 ~ 0.3 dB when built on low-loss substrates with loss tangent (tan δ) of 0.001. Measured S-parameters (S_{11} & S_{21}) agree with simulation result as shown in Fig. 1(b). The flexibility of the designed SIW interconnect was tested by wrapping it around a cylinder with a diameter (D) of 70 mm. The magnitudes of the S-parameters are stable although the SIW interconnect is bent along a cylinder (D = 70 mm) (Fig. 1(b)).

B. Inkjet-printed Multilayer Coupler

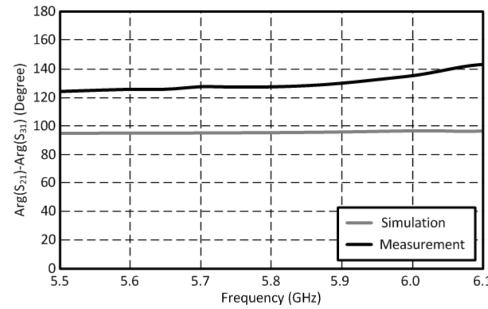
The geometry of the double-layered SIW coupler consists of two SIWs – one on top of the other coupled through two slanted slots (Fig. 2). The dimensions of the 1 mm thick slanted slots, such as the length, the angle and the distance, are optimized to realize maximum coupling at the desired operation frequency of 5.8 GHz [1]. The overall coupler size is 30 mm × 74 mm with a total thickness of 0.5 mm since two 0.254 mm thick kapton layers are stacked. The volume of the proposed coupler ($0.74\lambda_0 \times 0.42\lambda_0 \times 0.01\lambda_0$) in multilayer SIW configuration was successfully miniaturized by about 58 times in terms of volume at the operation frequency compared to a reported coupler ($2\lambda_0 \times 1\lambda_0 \times 0.09\lambda_0$) [4]. The two individual SIWs have been printed separately on the two overlying polyimide layers that share a ground plane which has the slanted slot for coupling. The coupler has been designed for the operation frequency at 5.8 GHz with a 90 degree phase difference between the direct port (Port2) and the coupled (Port3) [4]. The measured insertion loss (IL) of the fabricated multilayer coupler is 9.3 dB (Fig. 3(a)) and the phase difference is 127 degrees at 5.8 GHz (Fig. 3(b)), while the simulated IL and phase difference are 8.5 dB and 96.7 degrees, respectively. The fabricated coupler has a relatively broad bandwidth of 10.3 %. Additional losses have come from the conductors because the measured thickness of the printed nanoparticle layer is about 2.4 µm while the skin depth of the printed silver at 5.8 GHz is about 2.7 µm.

III. SUMMARY

A flexible SIW interconnect and a compact multilayer broadband coupler utilizing the inkjet printing technology have been demonstrated for the first time. The inkjet-printed SIW interconnect and coupler successfully demonstrated the feasibility of flexible 2D/3D SIW systems utilizing additive manufacturing technologies. The multilayer coupler is a first step toward fully inkjet-printed antennas and electronic systems for wearable, sensing, RFID and communication systems. A printed compact flexible multilayer Butler matrix for MBA or multiple beam forming networks can be built based on the study presented in this paper and will be presented at the conference.



(a)



(b)

Fig. 3. Geometry of multilayer broadband coupler.

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REFERENCES

[1] A. A. M. Ali, N. J. G. Fonseca, F. Coccetti and H. Aubert, "Design and Implementation of Two-Layer Compact Wideband Butler Matrices in SIW Technology for Ku-Band Applications," *IEEE Antennas Propag. Mag.*, vol.59, no.2, pp.503-512, Jan. 2010.

[2] A. Nathan, A. Ahnood, M. T. Cole, S. Lee, Y. Suzuki, P. Hiralal, F. Bonaccorso, T. Hasan, L. Garcia-Gancedo, A. Dyadyusha, S. Haque, P. Andrew, S. Hofmann, J. Moultrie, C. Daping, A. J. Flewitt, A. C. Ferrari, M. J. Kelly, J. Robertson, G. Amaratunga and W. I. Milne, " Flexible Electronics: The Next Ubiquitous Platform," *Proc. IEEE*, vol.100, pp.1486-1517, May 2012.

[3] D. Deslandes and K. Wu, "Integrated Microstrip and Rectangular Waveguide in Planar Form," *IEEE Microw. Wireless Compon. Lett.*, vol.11, no.3, pp.68-70, Feb. 2001.

[4] J. -X. Chen, W. Hong, Z. -C. Haom H. Li and K. Wu, "Development of a Low Cost Microwave Mixer using a Broad-band Substrate Integrated Waveguide (SIW) Coupler," *IEEE Microw. Wireless Compon. Lett.*, vol.16, no.2, pp.84-86, Feb. 2006.