Inkjet Printed Lange Coupler for Antenna Systems

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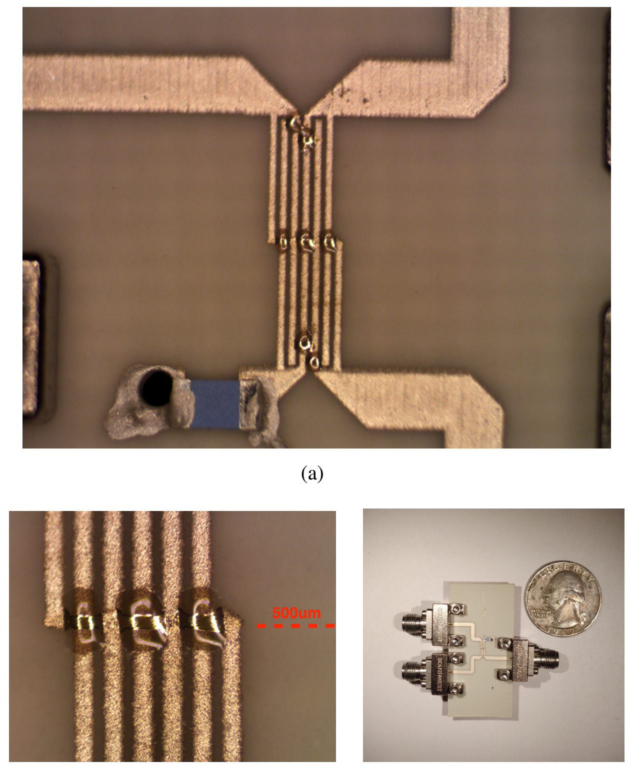
***Abstract*—This paper introduces a novel application for inkjet printing for the use in lange coupler designs and in antenna integration. Lange couplers is a subclass of quadrature couplers where the coupled and through ports have a wideband input match, 3 dB split and 90 degree phase shift relative to branchline couplers. However, traditional lange couplers need crossover paths which requires the need for multilayer structures with vias or bondwires, which adds manufacturing complexity. With inkjet printing, the manufacturing complexity is drastically decreased by utilizing single process fabrication using only one machine, the inkjet printer. This work demonstrates, for the first time, a fully inkjet printed lange coupler structure and the easy of integrating this process into designing and fabricating antenna systems.**

I. Introduction

With the growing demand for low cost, enhanced customizability, and ease of fabrication methods, inkjet printing has become more and more encouraging alternative to traditional subtractive fabrication methods. Due to these factors, it is beneficial for more and more components to be able to be inkjet printed. Already, inkjet printed passive components [1] and antennas [2] have already been fabricated, however components with 3D elements are still difficult to be realized using inkjet printing. Traditionally, inkjet printing is only 2 dimensional, meaning that a structure like a lange coupler would typically difficult to design, since there requires a crossover path requiring either vias or bondwires. It is possible, however to inkjet print small ramp structures in lieu of bondwires, creating a crossover path. This eliminates the need for laying down an entire dielectric layer, which can introduce dielectric loading and more loss, and saves on material costs. The ability to fully inkjet print the lange coupler introduces more flexibility for the RF/antenna designer, as it adds more customizability to RF systems, and the speed at which RF/antenna systems can be fabricated, since inkjet printing can be easily applied to a roll-to-roll process.

In this paper, a simulation and measured results of the inkjet printed lange coupler is presented, and additionally a system level integration of this coupler is discussed. Lange couplers are quadrature couplers which offers equal power splitting and 90 degree phase shift and at a relatively larger bandwidth compared to branchline quadrature couplers. Thus it is possible to create a wideband antenna system using two linear polarized antennas to generate a circular polarized antenna. Depending on the application, it might be difficult to create a planar circular polarization antenna, but easy to create a linear polarized antenna, thus creating the need for the lange coupler, which can force two linear polarized antennas to become a circular polarized one due to its quadrature nature.



(a)

(b)

(c)

Fig. 1. Fully inkjet printed lange coupler on RO4003C with resistive isolation termination.(a) full view, (b) crossover connections (c) Size comparison

II. Coupler Design and Fabrication

A fully fabricated 6 finger lange coupler designed at 8GHz is shown in Fig. 1. Traditional lange couplers utilize $\lambda/4$ finger lengths and a crossover connection between alternating fingers as shown in Fig. 1b, where the inkjet printed dielectric ramps and conductive traces were used as the crossover. Between the coupled and through ports exists a 90 degree phase shift and equal power split and to realize tighter coupling, spacing

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between fingers can be decreased. To get greater coupling bandwidth, it is better to design an overcoupled coupler, where the coupled and through ports overlap each other. The coupler was designed and layed out in Keysight ADS and EM simulation was performed on CST Microwave Studio. Simulation showed that a finger length of 4.9mm long and finger widths of 0.12mm wide and the spacing between each as 0.09mm, allowed for a 1dB coupling bandwidth of 5-12.5 GHz. The lange coupler was printed on 0.51mm thick Rogers 4003C substrate with one copper side etched off. Conductive traces were fabricated using Suntronic EMD5730 silver nanoparticle (SNP) ink, and dielectric ramps were fabricated using SU8. Both materials were deposited using the Dimatix DMP 2800 printer. The isolation port was terminated with a 50Ω high frequency FC series RF resistor from Vishay. On a cleaned 4003C substrate the silver traces including transmission line and lange coupler fingers were inkjet printed using 5 layers of SNP at 30um drop spacing. Following a 150°C cure of 15 mins, 4 layers of SU8 were inkjet printed to obtain the crossover ramps and UV cured at 300mJ/cm^2 and hardbaked at 160°C for 5 mins. The final SNP layers were printed on top of the SU8 as the bridging connections. the Vishay 50Ω resistor was placed on the isolated port using silver epoxy. For measurements Southwest end launch connectors were attached to the input, coupled and through ports.

III. Measurement Results

Fig 2 shows the plotted S-parameters of the measured and simulation results of the coupler. From Fig 2, the measurement has good input matching along its bandwidth, and equal power split of 1dB imbalance between both ports from 5.4 to 11.4 GHz, with near identical split between 5.8GHz to 9.7GHz. Fig. 3 also shows the phase difference between the two ports, showing that there is 90 degree phase shift along the same frequency range. A bit more loss was observed in the measurement due to the conductive losses of the SNP. To mitigate this loss, more layers of SNP can be printed to

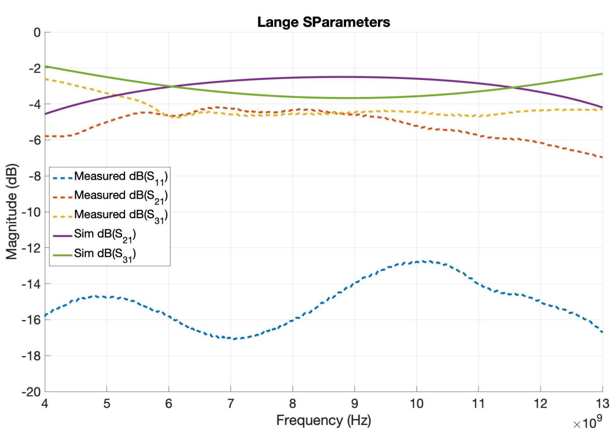

Fig. 2. Lange coupler S-parameters demonstrating a close agreement with the measured and simulation results with around 1db difference between the measured and simulation.

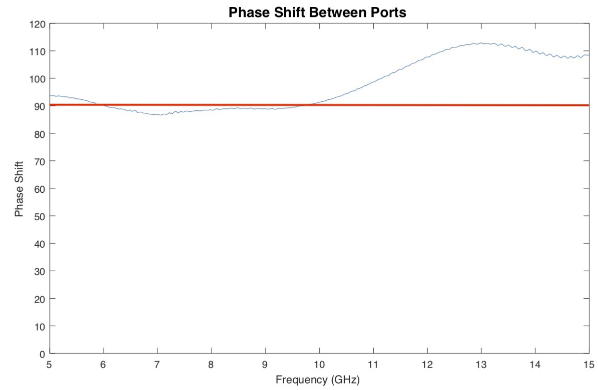

Fig. 3. Phase shift between the through and coupled ports shows a close proximity to 90 degrees around its designed frequency of 8GHz.

increase the conductivity and increasing the finger width and decreasing the finger spacing can increase the coupling.

Nevertheless, performance of the lange coupler is acceptable and can be utilized into system level applications. A proposed application is described in [3], to induce wideband applications for planar linear polarized antennas. This can be further extended in to array structures to create large wideband circular polarized arrays for communication or radars for 5G applications.The fully inkjet printed fashion of these systems grants ease of fabrication, customizability and low cost manufacturing for RF and antenna systems.

IV. Conclusion

This work presents the first time a lange coupler has been fabricated using inkjet printing adding another component in the RF and antenna designer's repertoire of components that can be inkjet printed with high performance and low cost fashion. The process flow for this inkjet printing technique to create 3D structures using a traditional 2D method can enable unique RF designs and versatility in integration with other components. The fabrication method can be extended to higher frequencies for 5G applications at 28GHz just by simply shortening the length of the fingers. At even higher frequencies, the fingers get very short, and more advanced inkjet printers which can realize 1um features such as the SIJ printer are needed to print the ramps. Future work regarding integration with antenna elements to create low cost 5G systems can now be possible using only one single inkjet printing process.

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