PRINTED, PLANAR MICROWAVE CONNECTOR WITH MULTIPLE SIGNAL LINES

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***Abstract*—Microwave connectors with a planar geometry have been demonstrated using additive manufacturing techniques. This planar form factor is expected to enable connectors to be integrated directly with other components onto a printed circuit board. The connectors were developed with multiple signal lines that will increase the density of signal connections to PCBs, eliminating the physical constraints of single-signal COTS microwave connectors. This work developed electromagnetic models (using Ansys HFSS) of these planar connectors to predict performance and optimize connector design. Materials and printing processes were developed to fabricate the connectors based on high-temperature PEEK thermoplastics. The multiple signal connectors were designed to operate over the 1-6GHz band and are built upon the single signal printed planar geometry connector introduced in a previous paper [1].**

Keywords-; Microwave connector; Printed electronics; Additive Manufacturing; Multiple signal connector; Broadband;

I. INTRODUCTION

Additive manufacturing (AM) is shaping the design and realization of microwave electronic systems today. The benefits of AM such as rapid prototyping, short lead times, and utilization of printable materials can potentially compliment (or replace) conventional production of electronic systems. Although AM has been exploited to print circuit elements (e.g., passive devices, chip interconnects, etc.) the development of printed connectors has not been adequately explored. The motivation of this research aims to achieve printed connectors that can support multiple signals that can find application in fully-printed electronic systems.

In traditional electronic systems, connectors provide a separable interface between elements of an electronic system without compromising the performance of the system. In the microwave regime, Commercial Off-the-Shelf (COTS) connectors such as SMA connectors have been the common method of interfacing with conventional Printed Circuit Boards (PCBs). The interest in using AM technology to print electronic systems must address the need to integrate a process for connector fabrication, thus eliminating the reliance on bulky and unusable COTS connectors [2-3].

Components such as antennas, phase shifters, transmission lines etc. have already been achieved with AM technology [4-8]. In a previous study by our team, a printed, planar microwave connector was fabricated using an AM process. [1]. There has also been a report on using AM to print an SMA connector [9]. In both of these previous publications, the connector consisted of a single microwave signal.

In this work, two versions of multiple signal line connectors have been fabricated and tested. One version consists of a combination of one RF and one DC line, and another version has two RF and one DC lines. These examples of planar geometry connectors demonstrate that printed connectors with multiple lines and different signal formats can be realized in a single connector. This approach could lead to fully-printed electronic systems with a higher density of I/O's to a fully printed PCB. The ability to tailor the connector design to the printed system can optimize the layout of the system when compared to use of COTS connectors.

II. MULTIPLE SIGNAL CONNECTOR DESIGN DIMENSIONS

Multiple signal/line connectors were initially fabricated on commercial double-sided copper laminate (ISOLA I-TERA MT40) to demonstrate the planar form factor. This design was then translated into an all-printed version based on a 3D-printed Polyetheretherketone (PEEK) thermoplastic substrate and Dupont CB028 conductive paste. The RF signal lines of the connector are based on a Grounded CoPlanar Waveguide (GCPW) transmission line [10]. The connector, shown in Figure 1, consists of two GCPWs stacked on top of each other.

A. Electromechanical design dimensions

The RF signal line and a DC line are printed on the same PEEK substrate as shown in Figure 1. Figure 2 shows a connector with two RF signal lines and a DC line. The dimensions of the GCPW were chosen using a transmission line calculator [9] to achieve a 50Ω characteristic impedance. Two PEEK substrates with matched GCPW lines (green) and a DC line (blue) are placed on top of each other so that the signal lines and ground planes are in contact in the overlap region as shown in Figure 1 and Figure 2.

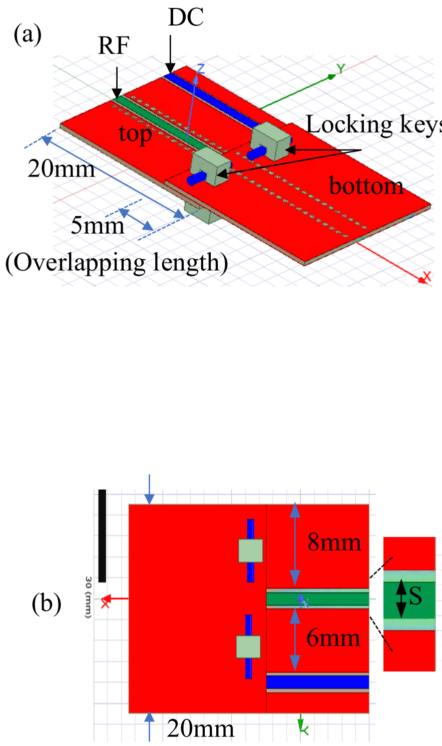

Figure 1. The (a) isometric view and (b) top view of PEEK based multi signal (two-line) planar printed microwave connector.

Optimization of the connector was done using the Ansys HFSS simulator to achieve the proper dimensions of the GCPW transmission lines. When the two GCPW-based substrates are interlocked to form the connector, the system port impedance changed. HFSS was used to determine the overlapping length to maintain a 50Ω characteristic impedance . The DC line was equal to the signal line width to ease fabrication. The PEEK GCPWs dimensions are in Table 1.

Table 1. The design dimensions of the PEEK GCPW used in multiple signal connectors

Gap	S	H
0.4mm	1.2mm	0.5mm

PEEK was chosen as a substrate because of its ability to withstand subsequent thermal treatment (for conductive ink sintering) and its excellent RF electrical properties. The extruded PEEK printed and characterized using a WR90 waveguide technique, yielding a Dk = 3+/-.05 and a loss tangent = 0.0028. These electrical properties were used in the Ansys HFSS simulator to determine the dimensions of a matched GCPW shown in Table 1 (H is the thickness of the PEEK substrate).

B. Mechanical design

As described in a previous publication [1], the mechanical design uses slots for aligning the two GCPWs substrates so that the signal lines and ground planes are aligned. PEEK-printed locking keys are inserted into the slots and the metal pressure rods are inserted to apply pressure to insure electrical contact between the metallic features on both substrates. The substrates that are placed with an overlapping length of 5mm. Figure 2 shows the HFSS model of the connector with two RF signals and a DC line showing the dimensions for the electromechanical design of the connector.

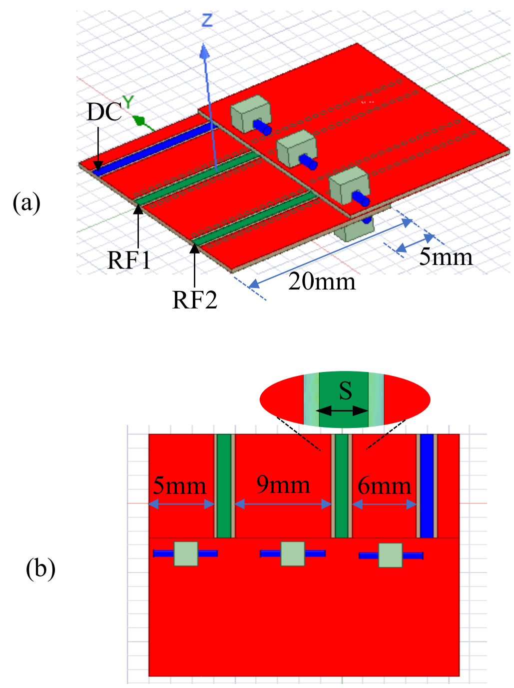

Figure 2. The (a) isometric view and (b) top view of PEEK based multiple signal (three-line) printed microwave connector (2RF + DC).

The same mechanical design of using a slot and a locking key [9] was used to align the two GCPW based substrates and provide intimate contact between the electrical elements of the connector. The slots in the locking mechanism are 2.5mm by 3.3mm. The overlapping region of 5mm, must accommodate the slots where the locking keys are placed. The locking key is made of PEEK posts and the pressure rods are metallic. The 9 mm spacing between RF lines was made large to accommodate the COTS connectors that were used to characterize the connector. In future embodiments it will be possible to significantly reduce this spacing, thus allowing a higher density of RF lines within a connector.

III. METHODS AND PROTOTYPES

The double-sided copper laminate (ISOLA I–TERA MT40) was initially used to fabricate these planar connectors. They were fabricated using standard subtractive methods using LPKF Protomat and LPKF Protolaser systems. All-printed PEEK versions were subsequently fabricated.

A. Two-line (RF+DC) printed microwave connector

The two-line connector fabricated from Isola MT-40 material is shown in Figure 3. All of the connectors shown in the figures used commercial microwave connectors for the purpose of characterizing the performance with a network analyzer. The printed version of the connector (PEEK substrate) is shown in Figure 4.

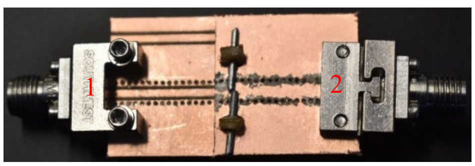

Figure 3. Fully assembled two-line (RF+DC) connector on MT40.

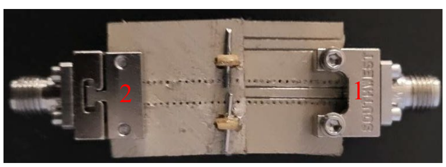

Figure 4. Fully assembled two-line (RF + DC) PEEK printed connector.

The PEEK connector shown in Figure 4 was created in the Hyrel 3D printer using additive and subtractive methods. Firstly, the PEEK substrate was extruded using a Hyrel 3D printer. Conductive paste (Dupont CB028) was coated on the substrate using a draw down method. The sample was heat cured in oven at 90ºF for 3 hours. A milling tool on the Hyrel system was used to remove a portion of the conductive ink to create the GCPW gaps and DC line. The top ground planes are connected to the backside using ground vias. The details of the fabrication process can be found in Reference 11. The two GCPWs on substrates achieved are then assembled to have the multiple signal printed PEEK connector in Figure 4.

B. Three-line (2RF+DC) printed microwave connector

The three-line connector also was firstly demonstrated in double sided copper laminate (ISOLA MT40) as shown in Figure 5. This was fabricated using the LPKF ProtoMart and ProtoLaser (PMPL) system for the patterning. The two structures for that make up a connector were assembled, and the prototype is shown in Figure 5 with COTs connectors attached for testing purposes.

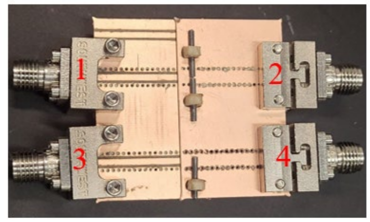

Figure 5. The three-line (2RF+DC), planar microwave connector based on ISOLA MT40 material.

After the proof-of-concept connector was demonstrated in double-sided copper laminate (Figure 5), the design was translated into a printed PEEK version (Figure 6). The printed PEEK version was fabricated using the Hyrel Hydra 3D printer as described previously. The connector in Figure 6 is a fully-assembled printed PEEK version where the locking keys have been placed in the overlapping region where the two GCPW based substrates on contact with each other.

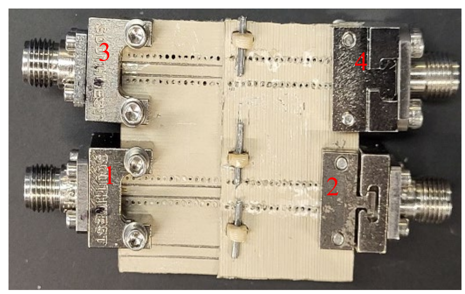

Figure 6. PEEK-based, three-line (2RF+DC) printed microwave connector.

SIMULATION AND MEASUREMENTS RESULTS

Simulations of the multiple signal connectors were done using the Ansys HFSS tool. The simulator predicted S-parameters performance and are shown in subsequent figures. The design goal was for a port impedance of 50Ω. to eliminate mismatch losses when the connector integrates with other microwave/RF components. The measurements were done on a Keysight Network Analyzer. Figure 7 shows the simulated and measured values of S21 and S11 for the, two-line and 3-line connectors. The SMA connectors used to make these measurements prototypes were for characterization purpose. The measured results show reasonable performance (S11< -10 dB) and reasonable agreement with the simulated performance.

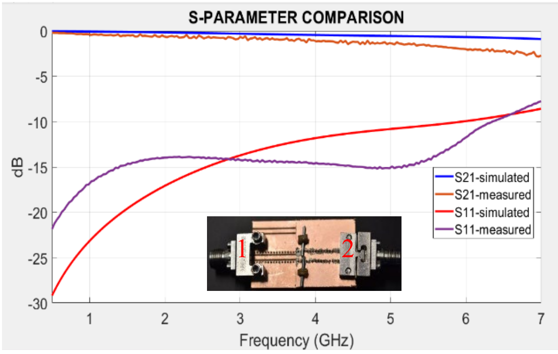

Figure 7. Characterization of ISOLA MT40 printed two-line microwave connector according to S-parameters.

The measured results for the printed PEEK version of the two-line connector, shown in Figure 8, also show good agreement with simulated performance. The DC line was only tested for continuity and no further DC characterization was performed.

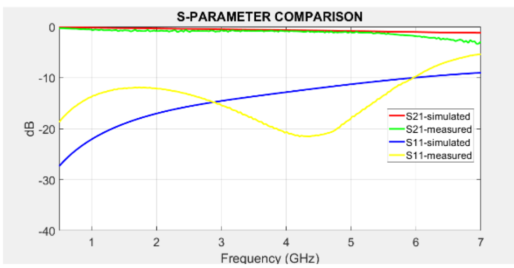

Figure 8. The S-parameters measurements of the printed PEEK two-line microwave connector.

The measured and simulated S-parameters are shown in Figures 9 and 10 for the 3-line printed PEEK connector. The results show low reflection loss (S11< -10 dB) for most of the 1-6GHz band. Figure 11 shows crosstalk measurements between the two RF lines, showing very low crosstalk (< -50 dB) across the band.

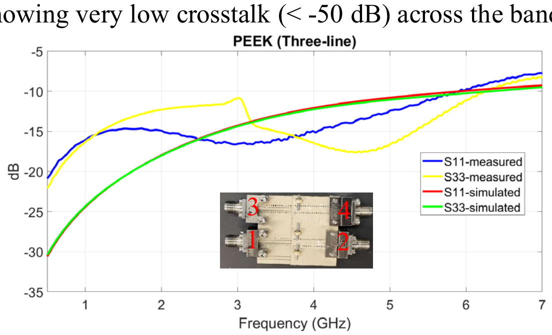

Figure 9. The reflection coefficient (S11) of the three-line PEEK printed microwave connector.

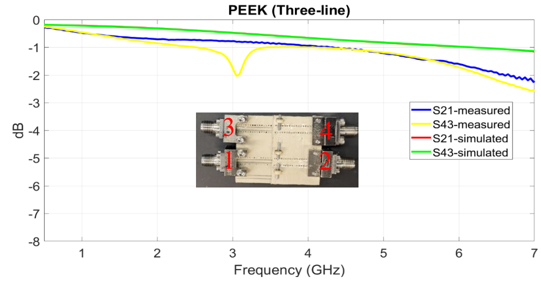

Figure 10. The insertion loss (S21) of the three-line PEEK printed microwave connector.

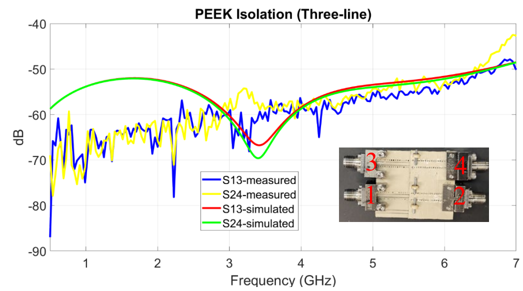

Figure 11. The port isolation (S13 and S24) of the three-line PEEK printed microwave connector.

IV. DISCUSSIONS AND CONCLUSION

Printed, planar multiple-signal microwave connectors were demonstrated operating over the 1-6 GHz band. HFSS was used to generate predictive models of these connectors and mechanical designs were developed to accommodate the planar geometry. The measured insertion loss of the connectors were < 2dB across the band for both two line and three-line connectors, in agreement with the simulated results. Inter-line isolation was demonstrated to be less than -50dB across the band. These results demonstrate that printed connectors with good performance can be integrated into an all-printed electronic system. Moreover, these results suggest that AM can be used to tailor the connector design to fit the need for a specific system and can also be used to increase the density of I/O's in a printed electronic system.

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