On the Crosstalks between a Pair of Transmission Lines in the Presence of a 3D Printed Electrifi Trace

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***Abstract*—The technology of additive manufacturing results in 3D printing of conductive traces in radio frequency circuits. This creates a plethora of possibilities in realizing flexible and wearable electronics. While the prototypes of microstrip transmission lines and antennas have been recently reported, there is now a need of Electromagnetic Compatibility based study of such 3D printed conductive traces. This paper presents a comparative study on the near end and far end unintentional crosstalk components between a pair of microstrip transmission lines made of Copper in the presence of a 3D printed conductive trace made of a commercially available conductive filament, *Electrifi*. Any physical contact with the 3D printed trace has been purposefully averted to discard the high contact resistance between the trace and such contacts.**

Keywords*—additive manufacturing, crosstalk, electrifi, EMC analysis, transmission lines.

I. INTRODUCTION

Additive manufacturing (AM) technology has been gaining popularity among researchers [1] - [3] in realizing radio frequency (RF) circuits for applications such as Internet of Things (IoT), health monitoring, sports monitoring, and consumer electronics. Researchers have recently demonstrated that it is now possible to develop printed microstrip transmission lines (TLs) [1] – [2] and simple microstrip antennas [3] by incorporating the economic fused filament fabrication (FFF) method of AM technology. Specifically, a commercially available conductive filament [4], *Electrifi*, was used in designing such RF circuits. Now, it is imperative to perform an electromagnetic compatibility (EMC) analysis on such a material to better understand its suitability for use in the proximity of other RF circuitry. One of the major aspects of EMC analysis is to find out the crosstalk or noise coupling components of the printed transmission lines. To the best of the authors' knowledge, this paper presents for the first time an EMC analysis of a 3D printed *Electrifi* based trace in the proximity of a pair of copper-based microstrip TLs. Specifically, the pair of copper-based microstrip TLs was initially prototyped ("setup a") and validated by comparing the measured near-end and far-end crosstalk elements with a full wave simulation model. Next, the *Electrifi* based trace was placed in between the copper-based TL ("setup b") and the measurement was again taken. Finally, an equivalent full-wave simulation model was designed and presented for comparison. It must be noted here that to prevent any error in the study due to reported high resistive contact between the *Electrifi* based trace and connectors [1], the authors purposefully avoided usual study cases which might involve a physical contact between the 3D printed *Electrifi* trace and connector(s).

II. METHODOLOGY AND FABRICATION OF PROTOTYPE

Two test setups were considered to test the interaction of the 3D printed Electrifi 50 Ω trace, when placed between two standard 50 Ω microstrip TLs, as shown in Fig. 1. Both the setups (a) and (b) were prototyped on Rogers TMM4 [5] (ε_r = 4.5 and tan δ = 0.0020) with a thickness of 1.52 mm with 35μm copper cladding on the bottom (i.e., grounded substrate). The Electrifi trace in setup (b) was fabricated using a Creality CR-10 printer by FFF process. The 3-D printing settings mentioned in [2] were followed. The manufactured prototypes are shown in Fig. 2. The fabricated prototypes were also full-wave modeled in HFSS [5].

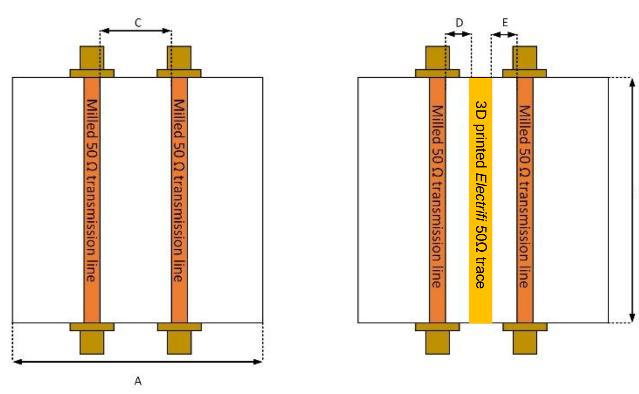

Fig. 1. Diagram of the two test setups on a 1.57 mm thick Rogers TMM4 substrate (bottom plane → grounded), involving (a) only a pair of 50 Ω microstrip TLs, and (b) with a presence of the 3D printed *Electrifi* 50 Ω trace in-between. Dimensions: A = B = 50 mm, C = 8 mm and D = E = 2.6mm.

III. SIMULATION AND MEASUREMENT VALIDATION RESULTS

All the measurements were performed using a Keysight

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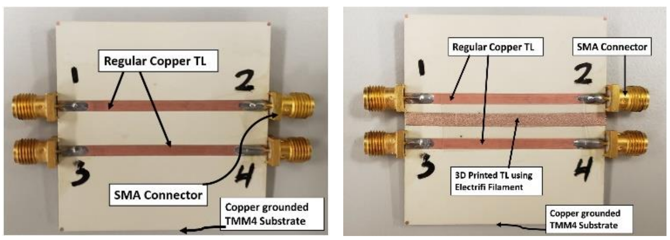
E5071C 100 KHz – 8.5 GHz ENA series network analyzer. The network analyzer was set from 1GHz to 5GHz with 1601 points before calibration. The prototypes of setups (a) and (b) are shown in Figs. 2 (a) and (b), respectively. The ports not being measured were terminated each time with a 50 Ω load. Followed by a two-port (SOLT) calibration in the network analyzer, the magnitudes of the near-end coupling components (S_{31} and S_{42}) and the far-end coupling components (S_{32} and S_{41}) were measured for both setups. Fig. 3 demonstrates the near end coupling components (S_{31} and S_{42}) for both setups. It was observed that in the presence of *Electrifi* trace between the two regular copper TLs, the near end coupling voltage changes significantly at the resonant frequencies. Fig. 4 shows the far end coupling voltages (S_{31} and S_{42}) for both the cases. A significant change in the far end coupling components was also observed with the addition of 3D printed trace between the two regular copper TLs. Overall, a fair agreement between measurements and full-wave simulation can be observed.



(a) (b)

Fig. 2. Prototype of the two test setups on a 1.57 mm thick Rogers TMM4 substrate (bottom plane → grounded), involving (a) only a pair of 50 Ω microstrip TLs, and (b) with a presence of the 3D printed Electrifi 50 Ω trace in-between.

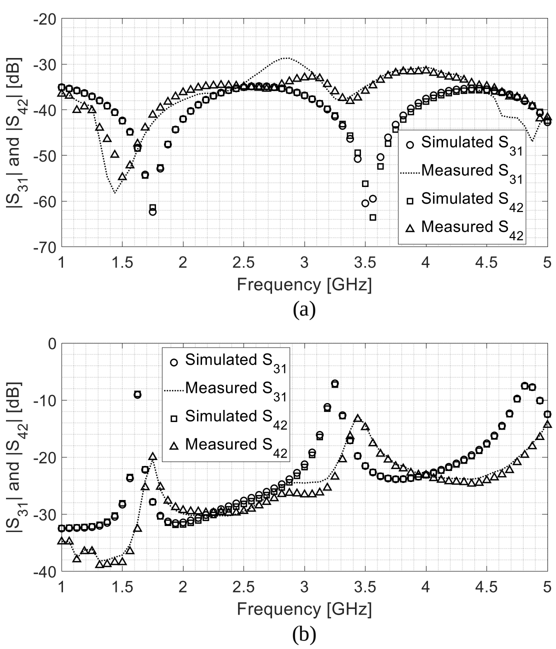


Fig. 3. Near End Coupling components (a) without 3D printed trace and (b) with 3D printed trace.

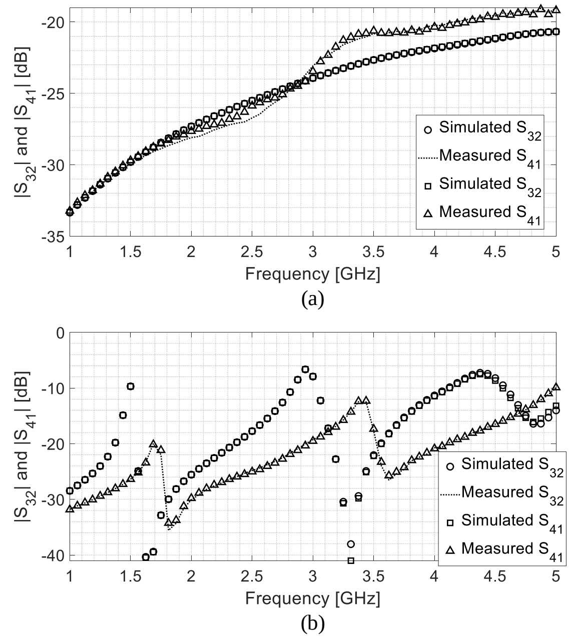


Fig. 4. Far End Coupling components (a) without 3D printed line (case 1) and (b) with 3D printed line (case 2).

IV. Conclusion

An analysis of the unintentional noise crosstalk between two regular copper TLs in the presence of a conductive *Electrifi* filament-based 3D printed trace is presented here. Two prototypes were tested: “without 3D printed trace” and “with 3D printed trace”. The full wave simulated model and measured near and far end noise coupling scattering parameters for both the cases were presented for validation. An overall agreement between simulations and measurements were observed.

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