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X-Band 3D-Printed Metal-Insert Twist-Component for Bandpass Filter Applications

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Abstract—This work presents the development of an X-band twisted metal-insert bandpass filter as a monolithic 3D-printed structure. The component serves as a compact solution for the incorporation of a fourth-order bandpass filter response while simultaneously rotating the polarization by 90 degrees as a twist-component. The structure is fabricated using low-cost stereolithography 3D-printing and metallized using a simple copper electroplating method. The measured results exhibit an unloaded Q-factor of approximately 2600 and have an insertion loss better than 0.44 dB throughout the passband, ultimately demonstrating a unique use of the metal-insert filter technique and providing a novel presentation on integrated monolithic structures.

Index Terms—3D-printing, bandpass filter, monolithic filter, metal-insert filter, stereolithography, twist component, X-band

I. INTRODUCTION

The exploration of additively manufactured microwave-components has opened the door for many novel concepts to be investigated. One of the most powerful concepts to emerge is the ability to integrate several individual components as a stand-alone monolithic structure. In this manner, the individual components that are traditionally cascaded within an RF feed-chain can be combined and fabricated as a single compact component. This integration inherently reduces the weight, volume, and cost, while simultaneously bypassing the need for component assembly. In addition to these benefits, 3D-printed monolithic designs also allow for the realization of complex structures that may be difficult or impossible to fabricate with traditional milling technologies. For instance, bandpass filter designs that include polarization rotations through the use of twist-like-components have been demonstrated using standard inductive-iris/rectangular-resonator configurations [1], [2], as well as with a dual-mode ellipsoidal cavity configuration [3]. Moreover, [4] and [5] have been able to demonstrate multi-component integration techniques in the form of twist/filter/corner combinations and filter-integrated Butler matrices, respectively.

Traditionally, E-plane fin-line and metal-insert filters have taken the form of three-part construction profiles, where the waveguide housing is split into two separate blocks that

hold the fin-line or metal-insert in place once the filter is fully assembled. Designs for these types of E-plane filter structures have been well defined in the literature by work such as [6]–[9], however, advanced topologies that utilize cross-couplings, folded structures, or aim for component integration can become limited due to their complex multi-part construction profiles and a compounding misalignment of parts can degrade the desired performance considerably. In order to overcome these challenges and advance these types of E-plane structures for future integrated systems, we present a novel twist-component filter design based on the E-plane metal-insert technique, where the proposed structure is designed with a fourth-order Chebyshev filter response and is capable of performing a 90 degree polarization rotation. A prototype of this filter is fabricated as a monolithic structure using low-cost stereolithography (SLA) 3D-printing and is subsequently coated using a simple copper electroplating method. The basic design, fabrication, and measurements are presented throughout the following sections.

II. FILTER DESIGN

For the design of the filter structure, a fourth-order Chebyshev design has been specified with a center frequency of approximately 10.8 GHz and a 20 dB fractional bandwidth (FBW) of 3.7%. The filter is based on fin-line and metal-insert design theory from work such as [6]–[9], where the specified external quality factors and coupling coefficients are $Q_{es} = Q_{el} = 25.19$, $k_{12} = k_{34} = 0.034$, $k_{23} = 0.026$, and follow from the design equations outlined by [10]. Fig. 1 depicts the configuration of the proposed filter with a smooth 90 degree rotating profile. The image exhibits a transparent

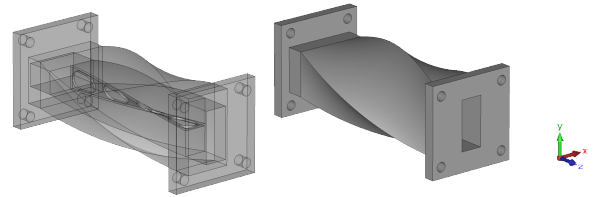


Fig. 1. Configuration of the proposed twist-component filter with WR-90 flanges. The left image depicts a transparent perspective view of the structure, while the right image depicts a solid perspective view of the structure.

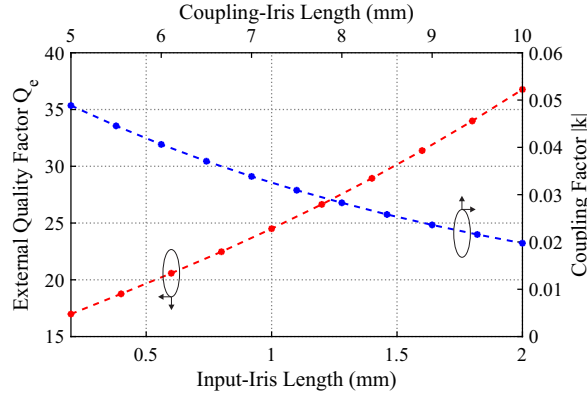


Fig. 2. Preliminary design graph of the metal-insert filter without the 90 degree twisting motion. The external quality factor Q_e (red) and the coupling factor k (blue) values are shown with dependence on the input-iris length and the coupling-iris length, respectively.

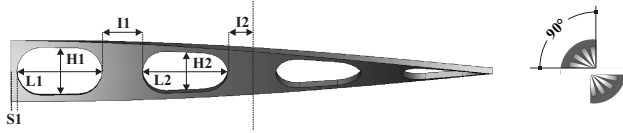


Fig. 3. Metal-insert portion of the twist-component filter. A side view with the corresponding dimensions is depicted in the left image, while an end view is depicted in the right image.

view and a solid view of the design in a WR-90 waveguide housing with the appropriate flanges attached. The metal-insert portion of the filter can be observed throughout the transparent view of the structure and follows the 90 degree twisting motion of the waveguide housing. The initial dimension of the structure can be obtained by creating a generalized metal-insert filter without a 90 degree twisting motion. For a resonator slot with a fixed length of 14.400 mm, height of 8.160 mm, insert thickness of 1.000 mm, and blend radius of 4.000 mm, the external quality factor and coupling coefficient values can be plotted with respect to the input-iris length and the coupling-iris length, respectively. Fig. 2 depicts each of these dependencies as initial design parameters before the 90 degree twisting motion is added. Following from the initial design parameters described above, the dimensions of the metal-insert can be optimized with a 90 degree twisting motion now

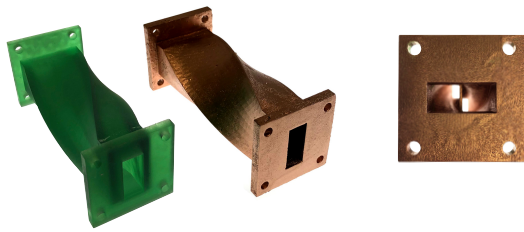


Fig. 4. Prototype construction of the twist-component filter. The left image depicts the prototype in translucent-green photo-polymer resin, while the center and right images depict the prototype and a close-up view of the flange once a base layer of copper aerosol-spray has been applied.

added to the structure while the specified insert thickness and blend radius is held constant. Fig. 3 details the optimized design where the corresponding dimensions are given as $L_1 = 14.247$ mm, $L_2 = 14.296$ mm, $H_1 = H_2 = 8.000$ mm, $I_1 = 6.696$ mm, $I_2 = 3.992$ mm, and $S_1 = 1.026$ mm (all dimensions have been rounded to three decimal places and are symmetric around the center axis of Fig. 3).

III. FABRICATION AND MEASUREMENTS

For the fabrication of the twist-component filter that has been derived in the previous section, stereolithography 3D-printing has been selected for its ability to maintain a low surface roughness, which in turn helps to produce the smooth twisting profile of the component as outlined in Fig. 1. Due to its low-cost and hobbyist-type nature, an Elegoo Mars 2 MSLA printer has been selected for prototyping the component as a monolithic structure with standard photo-polymer resin. In this manner, the typical three-piece construction for metal-insert filters can be avoided while suitably reducing the component footprint. During the printing of this design, the use of support structures inside the filter housing were also avoided in order to keep the interior of the component as smooth as possible. This consideration is made since any remnants of the plastic support structures left within the component can degrade the desired performance. To help maintain a smooth printing process without interior plastic support structures, the slots of the filter's insert section were designed with the blend radius of 4.000 mm and the component was printed at a 65 degree angle with a print-layer thickness of 0.020 mm. Notably, no sidewall slots have been added to the structure for metallization purposes; contrasting a key difference from other monolithic designs ([1], [2]) of this type that are produced with stereolithography 3D-printing.

The metallization of the component is accomplished by copper electroplating and conducted in an acidic electrolytic solution with copper rods running through the structure. An aerosol-based copper spray [11] is used as the precursor for the copper plating to adhere to the plastic 3D-printed component. Fig. 4 depicts a prototype of the twist-component filter in translucent-green photo-polymer resin and a version of the

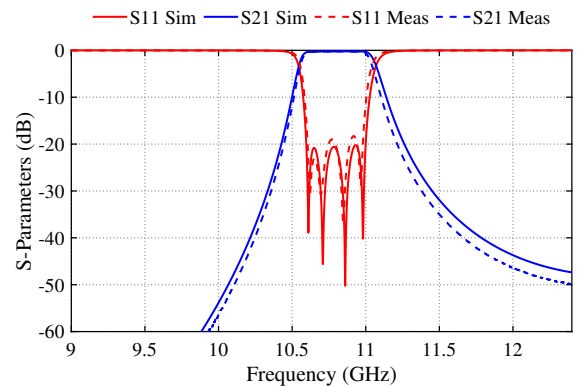


Fig. 5. Simulated versus measured results of the twist-component filter. (Equivalent conductivity of copper is taken as 1.40×10^7 S/m).

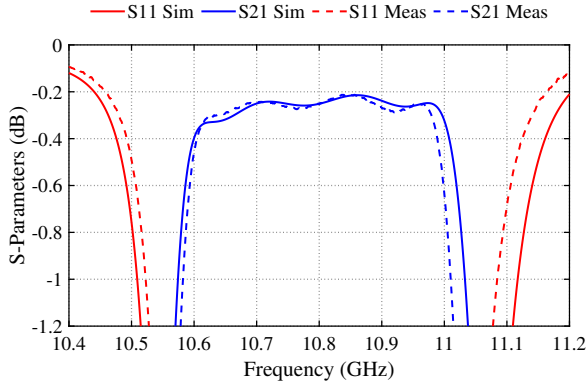


Fig. 6. Close-up view of the simulated versus measured results in order to highlight the passband insertion loss of the twist-component filter. (Equivalent conductivity of copper is taken as 1.40×10^7 S/m).



Fig. 7. Prototype of the twist-component filter connected to the test-bed.

TABLE I. Comparison of monolithic 3D-printed fourth-order band-pass filters with integrated polarization rotation.

Ref.	Tech.	f_0 (GHz)	FBW (%)	RL [‡]	IL [‡]
[1]	SLA	34.0	2.9	>15	0.81*
[2]	SLA	32.0	3.125	>15	0.84*
This work	SLA	10.8	3.7	>18	<0.44

[‡]Measured data, *Reported as an average value.

prototype once a base layer of copper aerosol spray has been applied. A close-up view of the spray-coated flange is also given in Fig. 4; the smooth inner profile and twisted metal-insert portion of the component can be observed throughout. For this design, a uniform scaling factor of 1.0175% was applied in order to compensate for the shrinkage/expansion of the resin curing and the subsequent metallization process. The value of this scaling factor was deduced through trial and error, and as shown in the following results, serves as a sufficient method for obtaining the desired center-frequency response.

Once fabricated and properly metallized, the filter was tested using a Rohde & Schwarz ZVA24 network analyzer. Fig. 5 presents a comparison of the simulated and measured results over 9.0 GHz to 12.4 GHz. This direct comparison demonstrates good measured results; the measured return loss (RL) is better than 18.0 dB throughout the passband and the measured insertion loss (IL) is on the range of 0.22 dB to 0.44 dB. A close-up view of the passband insertion loss is given in Fig. 6 over the range of 10.4 GHz to 11.2 GHz. Fig. 7 depicts the twist-component filter attached to the test-bed during measurement. Analyzing the filter's response, the unloaded

quality factor is found to be approximately $Q_u \approx 2600$. As for the physical properties, the full length of the component is under 109 mm and weights approximately 75 g. In order to help characterize this design further, Table I has been provided for the comparison of this work to other fourth-order bandpass-filter/twist components that have been 3D-printed as integrated monolithic structures. It can be noted that for a similar fractional bandwidth, the measured results obtained from this work surpasses those of other comparable designs that utilize silver as a passivation layer and sidewall slots for metallization.

IV. CONCLUSION

This work presents a new class of 3D-printed twist-component filters which utilizes a metal-insert filter technique within a 90 degree twisted waveguide structure. In general, E-plane metal-insert filter designs take the form of three separated parts, however, through the use of 3D-printing, fabrication of an integrated component which is able to meet the bandpass requirements of a metal-insert filter, while simultaneously rotating the polarization angle by 90 degrees, has been achieved as a monolithic design. A prototype of the twist-component filter has been rendered in photo-polymer resin using a low-cost hobbyist-type stereolithography 3D-printer and metallized by a simple copper electroplating technique. Good measured results have been obtained, therefore allowing the design to be verified and contrasted from other similar work in the literature.

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