3-D PRINTED BAND-PASS COMBLINE FILTER

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ABSTRACT

This paper describes a fourth-order 3-D printed combline filter with a Chebyshev response, operating at central frequency 3 GHz and having a 3% fractional bandwidth. The filter is designed using the coupling matrix theory, fabricated, and experimental results are presented. Comparison between simulations and measurements shows good agreement.

Key words

Coupled resonators; 3-D printed filters; combline filters

INTRODUCTION

Recently 3-D printing or additive manufacturing has become of interest in the fabrication of microwave filters and other passive components (e.g. [1-4]). This is because very complex structures can be easily made in the lightweight materials. It is possible for a 3-D printing process to manufacture the whole circuit as a unique single piece; examples can be seen in [1, 2]. Many types of 3-D printing processes are available, and the most popular are fused deposition modelling (FDM), stereolithography apparatus (SLA) and selective laser sintering (SLS). Among them, SLA offers the best surface integrity as well as the highest resolution [3], and hence is popular in the production of microwave filters.

Here we propose a combline filter made using SLA-based 3-D printing. The filter has a centre frequency of 3 GHz and is designed based on four coupled square coaxial resonators. To the best of authors' knowledge, this is the first ever demonstrated 3-D printed combline filter and also the first 3-D printed filter to be reported for such a low frequency of operation. Conventionally such low frequency filters have been designed in microstrip or solid metal coaxial waveguide technology, and are largely useful in modern communication systems because of their small size [5]. In microstrip, the final design cannot be tuned easily to adjust the frequency response. This is easier with coaxial waveguide and 3-D printing, by adding tuning screws. In addition, the coaxial resonators present a higher unloaded quality factor because of the low loss compared with a microstrip. When high Q, narrow band, low insertion loss filters are required, microstrip cannot always provide the Q required. Often combline or coaxial filters are used when rectangular waveguide would be too cumbersome.

Different types of materials can be used in 3-D printing, including metal, polymers and ceramics. In this case we are using polymer 3-D printing with plating of copper. Alternatives are all metal printing, but this method to date has a higher surface roughness (~6 μm, [4]) and is much heavier.

One advantage of using 3-D printing in this case is the very light weight, which makes it suitable for satellite applications. In addition, very complex shapes can be made; with this filter the resonator lengths are different as are the gaps. Holes for connectors are explicitly included. This is straightforward for the 3-D printing technology and the complexity could be much greater. In addition because of the flexibility of the manufacturing, high current points can be fully connected which is sometimes difficult if the filter is made in individual parts. In this case, the base of the quarter wavelength resonator is fully connected and has no gap between it and the base. The 3-D printing used here is very accurate and therefore no tuning screws are required.

DESIGN

The filter design follows the coupling theory, as described in [6]. With a Chebyshev response, it was designed to operate at a central frequency of 3 GHz, with 3% of fractional bandwidth (FBW), and 20 dB of return loss in the passband. These specifications result in the following values of coupling coefficient and external quality factor: $M_{12} = M_{34} = 0.0273$, $M_{23} = 0.021$; and $Q_{e1} = Q_{e2} = 31.0467$. Fig. 1 illustrates the final filter design, showing the inside of the filter, where the four coupled rectangular resonators can be seen. In addition, the input coupling is formed from extension of the centre conductor of the SMA connector [7]. The resonators are about one quarter wavelength long and the spacing between them, $d_{12} = d_{34}$ and d_{23} with $L_{R2} = L_{R3}$ (by symmetry), is set by the couplings M_{12}, M_{34}, M_{23} respectively. The spacing between the input connector and the first resonator, or the output connector and the fourth resonator ($d_{CR1} = d_{CR4}$), as well as the resonators lengths ($L_{R1} = L_{R4}$), is mainly set by the external Q values. The distances between the resonators are estimated by looking at couplings between only two resonators (for coupling coefficients). The distance from the input feed and the first (and last) resonator is obtained by looking at a single resonator which is weakly coupled to two input feed lines in order to get the required Q_e [6]. These initial values are then optimised in CST [8] to get the final required frequency response. Comparison between the initial and the optimized dimensions are shown in Table 1. In Fig. 2, the frequency response obtained by the coupling matrix calculation is shown with the CST simulated filter results for comparison. There is a good agreement; both of the responses show four accurately positioned reflection zeros.

EXPERIMENTAL RESULTS

The filter structure is a 3-D printed polymer subsequently coated with 25 µm copper. It is fabricated using a stereolithographic printing technique (SLA) at Swissto12 [9], whose fabrication process can be found with more details in [10]. A photo of the filter is shown in Fig. 3, and its experimental results are shown in Fig. 4. The weight of the filter without connectors and screws for the lid is 57 g which is only 13% of the weight of an equivalent copper filter (423 g).

The results show an excellent agreement between simulated and measured frequency responses. There has been no tuning of the filter. The expanded view of S_{21} parameter shown in Fig. 4(a) exhibits a maximum insertion loss of about 0.23 dB for the simulation, and about 0.31 dB for the experimental results. This corresponds to resonator Q values of 2873 and 2131, respectively. The degradation of Q is due to the additional insertion loss of the connectors and the non-perfect copper. It can also be seen in the frequency responses presented in Fig. 4(a) and Fig. 4(b), that there is a small frequency shift. It is about 12 MHz and can be accounted for by the differences between the designed filter dimensions and the fabricated filter ones. Comparison between the dimensions can be found in Table 1.

CONCLUSION

This paper has demonstrated the first 3-D printed filter in the low GHz frequency range. The 3% bandwidth filter centered at 3 GHz shows an excellent S-parameter response with no tuning. The filter is made using specialised stereolithographic printing resulting in a very high dimensional accuracy structure. The advantages of making the filter by 3-D printing are clear, with the lightweight being particularly striking. However, the advantages of producing a complex structure quickly and with continuous metallization in high current areas are also of importance. Such filters can be relevant not only for prototyping but also in satellite applications where weight is important. Clearly integration of more complex structures in such applications is of great interest.

Figure 1: The filter design showing the inner part, where the four resonators can be seen together with the inner conductor of the SMA connectors. The distance between the internal wall and inner conductor is $d_{CB1} = d_{CB2} = 6.35$, and the box dimensions in the design are $L_B = 81.86$, $W_B = 37.5$, $H_B = 20$ and $t_B = 5$. Unit: millimetre.

Figure 2: Simulated results of the filter, in comparison with the ideal responses plotted from the coupling matrix.

Figure 3: Photograph of the fourth-order 3-D printed combline bandpass filter together with the pair of SMA connectors.

Figure 4: Measurement (solid lines) and simulation (dashed lines) results of the 3-D printed combline filter.

(a) Magnitude responses of S_{21}. The inserts show the responses over a wide frequency range (from 1 to 5 GHz) as well as over the passband. Conductivity of copper is used in the simulations.

(b) Magnitude responses of S_{11}.

Table 1: Comparison between the internal dimensions of the designed filter (before and after CST optimization) and the manufactured filter.

REFERENCES

1. C. Guo, X. Shang, J. Li, F. Zhang, M. J. Lancaster, and J. Xu, A lightweight 3-D printed X-band bandpass filter based on spherical dual-mode resonators, IEEE Microw Wirel Compon Lett 26 (2016), 568–570.

2. B. Zhang and H. Zirath, 3D printed iris bandpass filters for millimetre-wave applications, Electron Lett 51 (2015), 1791–1793.

3. M. D'Auria, W.J. Otter, J. Hazell, et al, 3-D printed metal-pipe rectangular waveguides, IEEE Trans Compon Packag Manuf Technol 5 (2015), 1339–1349.

4. B. Zhang and H. Zirath, Metallic 3-D printed rectangular waveguides for millimetre-wave applications, IEEE Trans Compon Packag Manuf Technol 6 (2016), 796-804.

5. R. J. Cameron, C. M. Kudsia, and R. R. Mansour, Microwave filters for communication systems – fundamentals, design, and applications, John Wiley & Sons. Inc, New Jersey, USA, 2007.

6. J. S. Hong and M. J. Lancaster, Microstrip filters for RF/Microwave Applications, Wiley, New York, USA, 2001.

7. RS Components Ltd: Panel mount SMA connector, http://uk.rs-online.com/web/p/products/4683249/?sra=p&r=t, accessed July 2016.

8. Computer Simulation Technology (CST), Microwave Studio, 2016. Available at http:www.cst.com

9. Swissto12, Switzerland. Available at http://www.Swissto12.com

10. A. Macor, E. Rijk, S. Alberti, T. Goodman, and J.-P. Ansermet, Three-dimensional stereolithography for millimeter wave and terahertz applications, Rev. Sci. Instrum. 83 (2012), 046103.

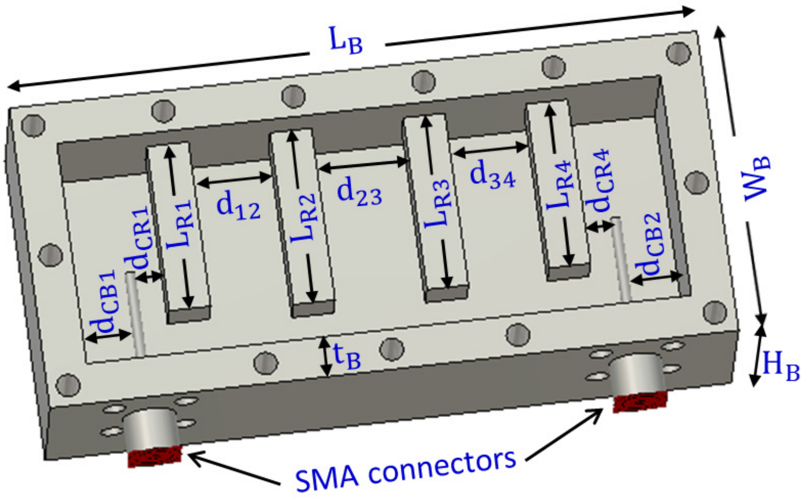


Figure 1

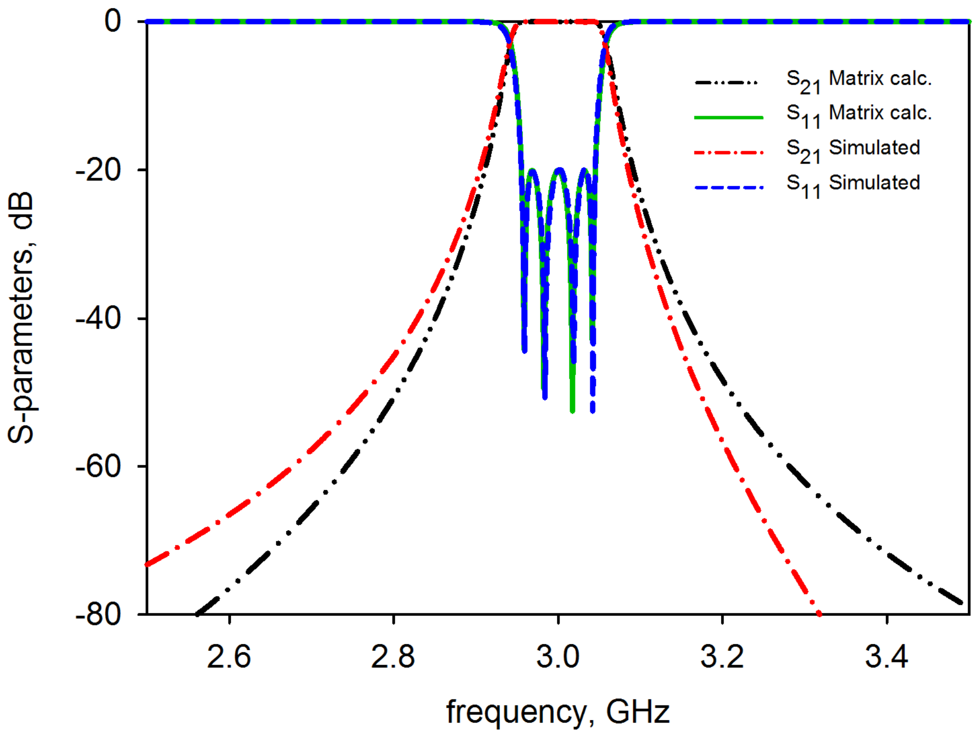


Figure 2

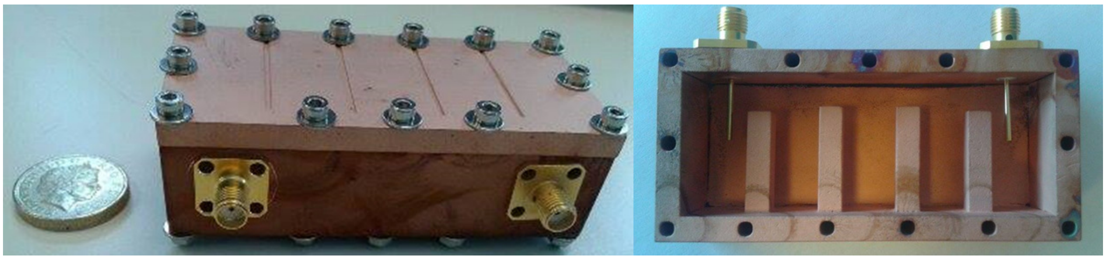
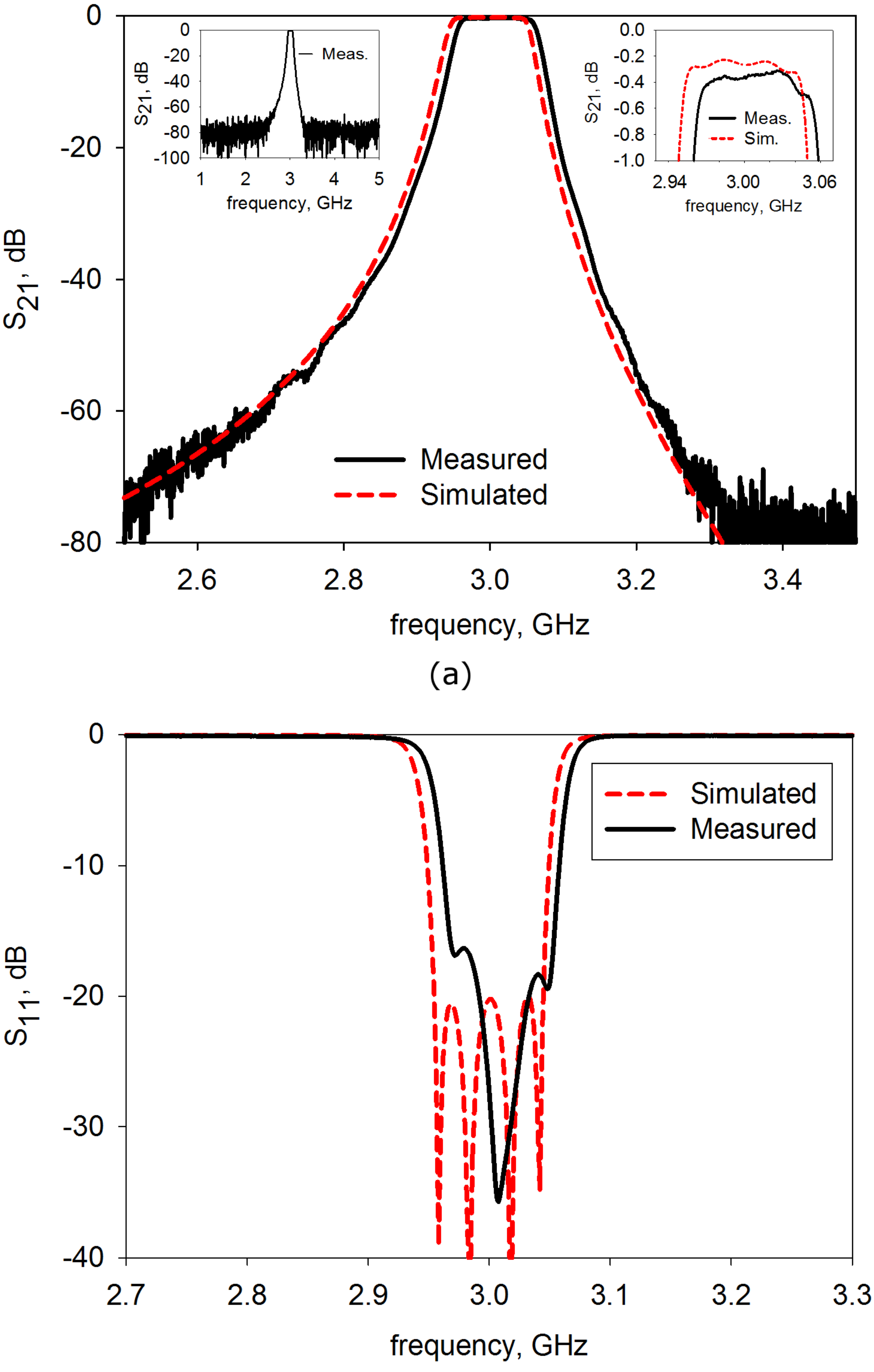


Figure 3


0
-20
-40
-60
-80
S_{21}, dB
2.6
2.8
3.0
3.2
3.4
frequency, GHz
0
-20
-40
-60
-80
-100
S_{21}, dB
1
2
3
4
5
frequency, GHz
Meas.
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
S_{21}, dB
2.94
3.00
3.06
frequency, GHz
Meas.
Sim.
Measured
Simulated
0
-10
-20
-30
-40
S_{11}, dB
2.7
2.8
2.9
3.0
3.1
3.2
3.3
frequency, GHz
Simulated
Measured

(a)

(b)

Figure 4

Table 1:

Filter Dimensions	Designed (mm)		Measured (mm)
	Before optimization	After optimization	
$L_{R1} = L_{R4}$	19.57	20.58	20.64
$L_{R2} = L_{R3}$	20.62	21.54	21.44
$d_{12} = d_{34}$	11.09	9.67	9.72
d_{23}	11.46	10.9	11
$d_{CR1} = d_{CR4}$	4.09	3.15	3