3D Bandpass Metafilters for Microwave Applications

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Abstract - Recent research activities on metamaterials (termed also as negative index materials (NIM) or double negative (DNG) media or left handed (LH) materials or backward wave (BW) media), have demonstrated interesting electromagnetic phenomena that are not found in nature and also in its constituent elements - thus have lead to the realisation of promising new kinds of microwave components for the wireless communications and the defense industries. This work aims to develop 3D metamateial bandpass filters by spacing high Q split ring resonators (SRR) periodically where coupling between the resonators is magnetic via the shared flux threading the rings. The design is extremely flexible with several clear advantages over the current designs, such as repairable, easy characterization, variable, tunable and miniature. Here we report the practical realization of 2-, 3-, 4-, 5-, 9-pole SRR bandpass filters. The filter is composed of a series of small (20 mm x 20 mm) glass resin (permittivity ~6.0, height = 1.5 mm, loss tangent = 0.003) substrates, each supporting one patterned SRR resonator. The films were patterned with the mask of a single split ring resonator using conventional photolithography and wet chemical etching process. The analytical evaluation of the filter configuration is done by a full wave electromagnetic simulator- Ansoft HFSS. The focus of the analysis was mainly on investigation of frequency response of different order filters. The filters were measured for transmission and reflection characteristics using HP 8510C vector network anslyser. Measured transmission responses show almost negligible insertion loss (0.05 dB) in 2 pole filter and with the increase in order of the filters, roll off from passband edges to stopband becomes steeper and along with increase in passband insertion loss.

Index Terms— metamaterials, microwave filters, split ring resonators.

I. INTRODUCTION

The microwave bandpass filters with miniaturized size and high selectivity are widely used to enhance the performance of the RF front end of the wireless transceiver. These requirements are stricter recently because of the rapidly expanding cellular communication systems. In the past, the coupling dual-mode ring resonator structures are widely used in filter design. It has advantages of planner structure, easy integration, low cost and so on. However, the presence of spurious harmonic is a fundamental drawback.

A number of improved structures such as half wavelength short circuit stubs, chip capacitors or cascaded rejection band filters have been proposed. These techniques are either less flexibility, increase device area, or introduce significant insertion losses. The metamaterials with negative permittivity and permeability were first proposed by Veselago in the late 1960s [1]. By using a periodic split ring resonator array, a negative effective permeability can be created and bandstop response can be excited. It has been demonstrated that SRRs with only few stages are characteristic of high Q value and significant frequency selectivity [2]. In this paper, SRRs are applied for the development of passband in a functional device by magneto inductively coupling the resonators. The measured frequency response shows the efficiency of this technique.

II. SRRS FILTER DESIGN

The first step is to determine the layout of a split ring resonator in the desired frequency. This has been done according to the standard formulas [3]. The Glass resin substrate with permittivity $\varepsilon_r = 6.0$ and thickness h=1.5mm was used for all simulations. The parameters for split ring resonator structure shown in Fig. 1.

The second step is to simulate the designed circuit by using full wave simulator Ansoft HFSS 3D full wave electromagnetic simulation software. The simulation results is verified by a Agilent 8510C vector network analyzer. At first a 2-pole bandpass filter with central frequency of $f_0 = 1.6$ GHz is developed. The fractional bandwidth is about 9.0%. The size of SRRs can control the location of bandstop response [4]. For a multipole filter as used in this report it can control the center frequency of the pasband.

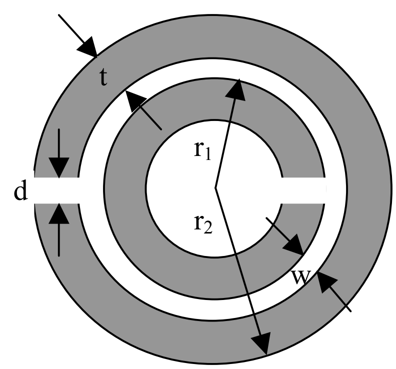

Fig. 1: Split Ring Resonator Size (r_1 = 6.5 mm, r_2 = 8.5 mm, d = 3.0 mm, w = 0.5 mm, t = 1.5 mm)

III. RESULTS AND DISCUSSION

Full wave electromagnetic simulation environment of 5-pole metafilter is shown in Fig. 2. The distance between any two resonators is kept 16 mm and the gap between the input and output loop to the nearest resonators at the both ends is 5.0 mm. In the fig. 3 shows the full wave electromagnetically simulated transmission response of the 5-pole split ring resonator bandpass filter. The filter is design to have 144MHz bandwidth at a center frequency $f_0 = 1.568$ GHz.

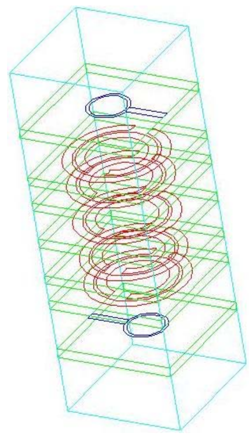

Fig. 2: Full wave simulated environment of 5-pole split ring resonator bandpass filter. Gap between the resonators are 16 mm and the gap between the input and output coupling to the nearest resonators at the both ends is 5.0 mm.

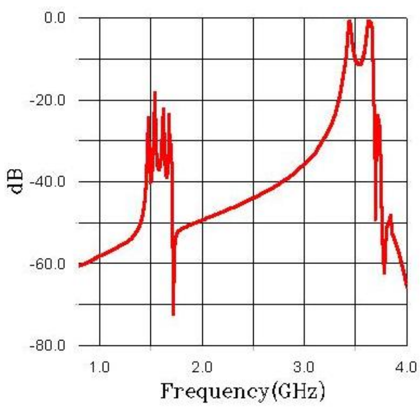

Fig. 3: Full wave simulated transmission response of 5-pole split ring resonator bandpass Filter.

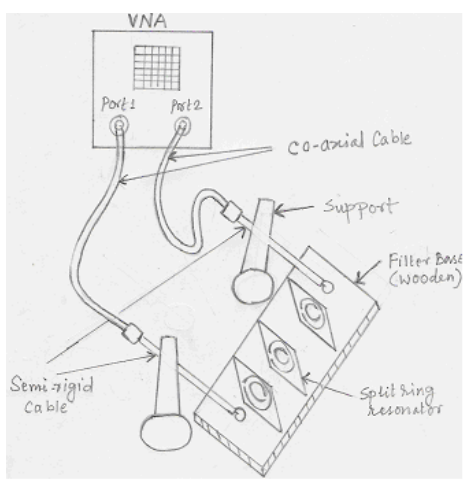

Fig. 4: S-parameters measurement set up for 3D metafilters using split ring resonators.

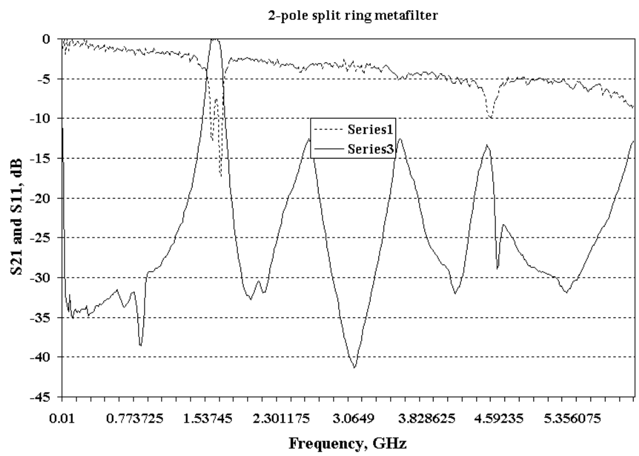

Fig. 5: Measured transmission and reflection responses of 2-pole bandpass metafilter.

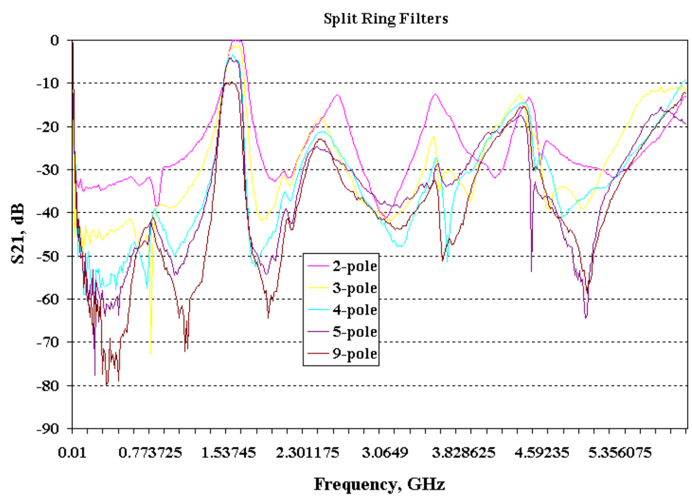

Fig. 6: Measured comparative frequency transmission responses of 2-pole, 3-pole, 4-pole, 5-pole and 9-pole bandpass metafilters.

Table 1

Metafilters configurations	f_0 (MHz)	I L (dB)	Ripple (dB)	3dB BW (MHz)	30-dB BW (MHz)	Denoted by (line with colours)
2-pole	1607	0.05	0.14	146	993	pink
3-pole	1593	1.1	0.29	142	490	yellow
4-pole	1571	3.6	0.68	144	341	green
5-pole	1568	4.25	0.44	144	317	purple
9-pole	1555	9.68	0.35	150	280	brown

2-pole, 3-pole, 4-pole, 5-pole and 9-pole metafilters measured parameters (glass resin substrate height, 1.5 mm, dielectric constant = 6.0)

The split ring resonators were fabricated using copper thin film over a 20 mm x 20 mm square area and 1.5 mm thick glass resin substrate. These filters were patterned using conventional wet chemical photolithography process and each one of them was mounted vertically and parallel to each other by gluing one of its edge to the wooden filter base. Input and output couplings are made using flexible semi rigid coaxial cable. The center conductor of the cable is protruded out by removing the outer jacket to make a small loop of 5 mm diameter at both port ends and the other ends are connected to the vector network analyzer through SMA connectors. Each of these filters is tested in room temperature using an HP8510C vector network analyser with an input power of 0 dBm. Prior to the measurement of the filter, calibration was performed at room temperature. The filters were tuned angling the resonators to the principal axis of the resonators.

The S-parameters measurement set up of these metafilters is shown in Fig. 4. At first a 2 pole SRR metafilter is constructed. The measured frequency response is shown in Fig. 5. The 2-pole filter has a return loss of around 10dB within the passband, insertion loss – 0.05 B and the 3dB fractional bandwidth is 9.0%. After successful development of the 2-pole filter a 3-pole, 4-pole, 5-pole and 9-pole filters were developed. Measured parameters of these filter are tabulated in Table 1. A comparative plot of the measured frequency transmission responses of these filters is shown in Fig. 6. The measurement shows very low insertion loss in case of 2-pole filter and as we increase the order of the filter insertion loss also increases. The rejection level increases with the order of the filter. The limits of miniaturization are determined by the resolution and tolerances of the fabrication process, since a reduction of SRRs diameter requires narrower and closer rings to preserve the quasistatic resonance [4].

IV. CONCLUSION

Using SRRs, a new approach for the development of 3D metafilters in microwave applications has been proposed. In this methodology magneto inductive coupling between the resonators is used to design and fabricate 2-pole, 3-pole, 4-pole, 5-pole and 9-pole metafilters. The measurement shows very low insertion loss in case of 2-pole filter and as we increase the order of the filter insertion loss also increases. The rejection level increases with the order of the filter.

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