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CRLH and SRR Based Microwave Filter Design Useful for Communication Applications

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Abstract**—**CRLH (composite right/left-handed) based and SRR (split-ring resonator) based filters have been designed at microwave frequency which can provide better performance compared to conventional edge-coupled band-pass filter designed around the same frequency, 2.45 GHz. Both CRLH and SRR are unit cells used in metamaterial design. The primary aim of designing filters with such structures is to realize size reduction and also to realize novel filter performance. The CRLH based filter has been designed in microstrip transmission line, while the SRR based filter is designed with SRR loading in waveguide. The CRLH based filter designed at 2.45 GHz provides an insertion loss of 1.6 dB with harmonic suppression up to 10 GHz with 67 % size reduction when compared with a conventional edge-coupled band-pass filter designed around the same frequency. One dimensional (1-D) SRR matrix loaded in a waveguide shows the possibility of realizing a stop-band with sharp skirts in the pass-band while a stop-band in the pass-band of normal rectangular waveguide with tailoring of the dimensions of SRR unit cells. Such filters are expected to be very useful for communication systems at microwave frequency.

Keywords**—**BPF, CRLH, Harmonic, Metamaterial, SRR, Waveguide.

I. Introduction

METAMATERIAL research during last two decades has seen an exponential growth in this emerging topic of electromagnetic material both as an exotic material and with many engineering applications. Inspired by its transmission line realization with CRLH and magnetic inclusion structure SRR microwave passive components, antennas, filter etc. have been developed during last one decade or so with improved performance and size miniaturization. SRR was reported by [1] and CRLH transmission structure was reported by [2]. Many researchers have used these structures to develop microwave passive components [3], antennas [4] and also filters [5], [6]. In the present work we have reported two types of filter design taking inspiration from metamaterial development; one using CRLH transmission line and the other using SRR loaded waveguide at microwave frequency.

II. CRLH Transmission Line Based Filter Design

The conventional and CRLH band pass filters (BPF) are designed, simulated and optimized in this section. Method of Moments (MoM) based Numerical tool Advance Design System (ADS) from Keysight Technologies is used for optimization of these filters. The specification of the filter is shown in Table I. These filters are designed and fabricated on 20mil Rogers RT/Duroid 5880 substrate having dielectric constant 2.2 and loss tangent 0.0009. The filters are fed with 50Ω microstrip line.

Three CRLH resonators are used in the design of microwave band-pass filter in which 1st and 3rd resonators are of the asymmetric type (vide Fig. 1 (a)) while the 2nd one is symmetric CRLH (vide Fig. 1 (b)). At first the resonators were optimized separately at the design frequency of 2.45 GHz in the circuit simulator of ADS using standard formulae [7] for calculating the initial values of the inductance and capacitance of the inter-digital capacitor and stub inductor given below.

$$C_R = \varepsilon_{eff} \frac{W_{stub} \cdot l_{stub}}{h}$$

$$L_R = \frac{Z_c \tan(\beta_{eff} l_{IDC})}{N\omega}$$

$$L_L = \frac{Z_c}{\omega} \tan(\beta_{eff} l_{stub})$$

$$C_L = (\varepsilon_r - 1) l_{IDC} [(N-3)A_1 + A_2] pF$$

where;

$$A_1 = 4.409 \tanh\left\{0.55\left(\frac{h}{W_{IDC}}\right)^{0.45}\right\} 10^{-6}\ pF/\mu m$$

$$A_2 = 9.92 \tanh\left\{0.52\left(\frac{h}{W_{IDC}}\right)^{0.5}\right\} 10^{-6}\ pF/\mu m \qquad (1)$$

The optimized schematic was next converted to layout in ADS and finally this layout was again optimized using MoM solver in ADS. The optimized final dimensions for CRLH BPF are shown in Table II.

Similarly, a conventional three pole edge-coupled microstrip line based BPF has been designed and its final optimized dimensions are shown in Table III. Both the filters are fabricated using standard etching techniques. The fabricated CRLH transmission line based BPF is shown in Fig. 2 (a). The size comparison of CRLH and conventional edge coupled microstrip line based BPF is shown in Fig. 2 (b), where it can be observed that the CRLH filter is 67 % smaller

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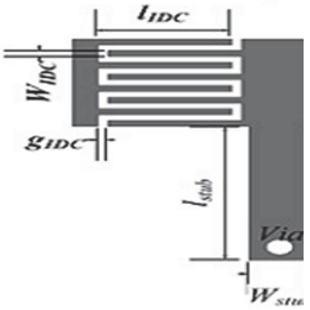
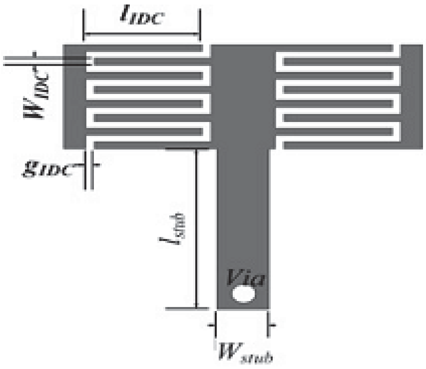
than the conventional one. The simulated and measured performance characteristics for both the filters are shown in Figs. 2 (c), (d) and the summery of result is in Table IV.



(a)



(b)

Fig. 1 (a) Asymmetric CRLH resonator section (b) Symmetric CRLH resonator section

TABLE I
SPECIFICATIONS OF BPF

Parameter	Specification
Centre frequency	2.45GHz
Bandwidth	100 MHZ
Order	3
Insertion Loss	< 1dB
Passband Ripple	< 0.1 dB
Return Loss	< 10dB

III. SRR Loaded Waveguide Filter

A schematic diagram showing rectangular waveguide loaded with SRR matrices in 1-D structure is given in Fig. 3 (a), together with an SRR unit cell in Fig. 3 (b).

SRRs are basically μ-negative magnetic inclusion structures used in metamaterial design. Such loading of waveguide with negative permeability structures would allow us to introduce selective absorption in the pass-band of normal waveguide propagation and selective transmission in the stop-band. Referring to Fig. 4 (a), it may be observed that we have been able to introduce a stop-band in the normal pass-band of a rectangular waveguide having cut-off frequency 2.5 GHz. The stop-band of the metamaterial inclusion loaded waveguide can be placed at 2.56 GHz, 2.95 GHz and 4.84 GHz with respective bandwidths 0.04 GHz, 0.04 GHz and 0.02 GHz, which has been realized with SRR outer radius 5.6 mm, 5 mm and 3.4 mm, respectively. Similarly, in the stop-band of a rectangular waveguide a pass-band may be introduced by loading the waveguide with SRR metamaterial inclusion as shown in Fig. 4 (b). The pass-band has been introduced at 9.38 GHz, 2.95 GHz and 1.95 GHz with respective bandwidths 0.25 GHz, 0.78 GHz and 2.16 GHz using SRR radius of 2.1mm, 5 mm and 7 mm respectively for the rectangular waveguide having cut-off frequency 10 GHz.

TABLE II
DIMENSIONS OF CRLH BPF AT 2.45GHZ

Dimension	Resonator 1 and 3 (mm)	Resonator 2 (mm)
W_{IDC}	0.466	0.2
l_{IDC}	5.6	3
g_{IDC}	0.18	0.36
W_{stub}	1	0.95
l_{stub}	8.8	12.67
No of fingers	2	2

TABLE III
DIMENSIONS OF CONVENTIONAL BPF AT 2.45GHZ

Dimension	Resonator 1 and 4 (mm)	Resonator 2 and 3 (mm)
Width	1	1.47
Separation	0.2	0.92
Length	22.42	21.93

TABLE IV
FILTER PERFORMANCE COMPARISON

Property	CRLH BPF	Edge coupled BPF
Insertion Loss	1.6dB	2.3dB
Return Loss	15dB	18dB
Harmonics	Suppressed up to 10GHz	2nd ,3rd etc
Size	4.3cm x 3cm	6.5cm x 6cm

Detailed analysis of SRR-array as a combination of mutually coupled resonators gives the μ_{reff} of the composite magnetic inclusion structure as:

$$\mu_{reff} = 1 - \frac{4.24r^3/l^3}{1 + \frac{j2\rho}{\omega\mu_0 Ct} - \frac{4d}{\omega^2\pi^2R^2\mu_0\varepsilon t}} \tag{2}$$

When this is compared with the original expression of μ_{reff} by [1], it is seen that the resonant frequency of the composite SRR array remains the same as the single SRR and depends on the geometrical parameters of the SRR structure. However, the fill-factor in this case: $F=4.24r^3/l^3$ (where r is the radius of individual SRR and l is the mean circumferential length) is modified due to the array structure; this affects the bandwidth of the system. The bandwidth and location of the pass-band and stop-band caused by the loading of the SRR array in waveguide is thus controllable by changing the geometrical dimensions of the SRR elements.

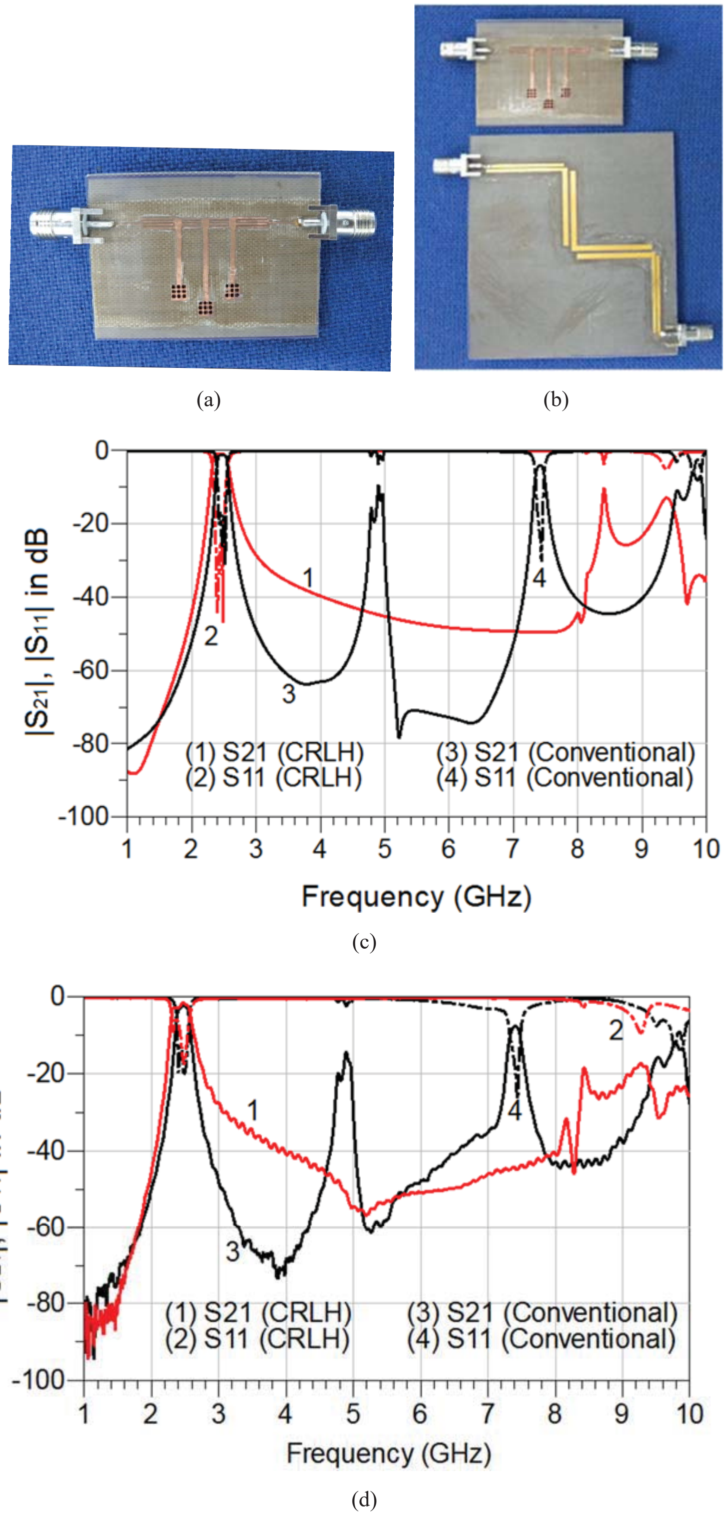
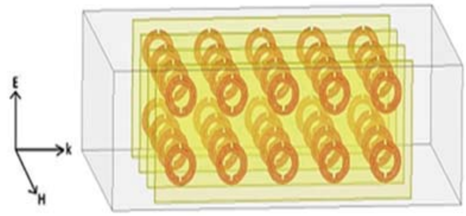


Fig. 2 (a) Fabricated CRLH BPF at 2.45GHz (b). Comparison of fabricated CRLH and conventional BPF at 2.45GHz, (c) Simulated Performance Characteristics of BPF, (d) Measured Performance Characteristics of BPF

IV. Conclusion

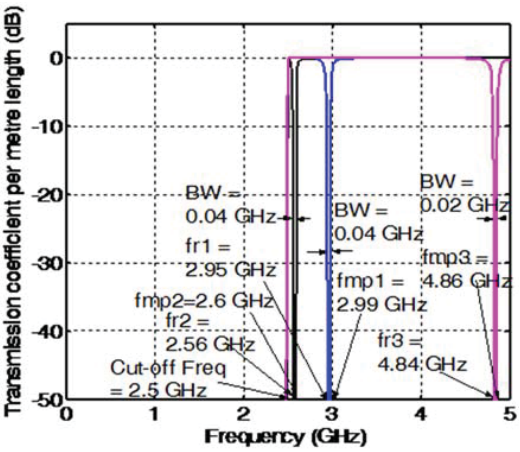
CRLH transmission line based filter and 1-D SRR matrix loaded waveguide filter has been designed and investigated. The CRLH type filter has 67 % smaller dimensions and better performance in regard to its lower insertion loss and improved harmonic suppression when compared with conventional edge coupled microstrip band-pass filter designed at 2.45 GHz. The SRR loaded waveguide filter can provide sharp stop-band in the propagation band of normal waveguide and can thus be used as notch-type band-reject filter at microwave frequency useful for communication applications.



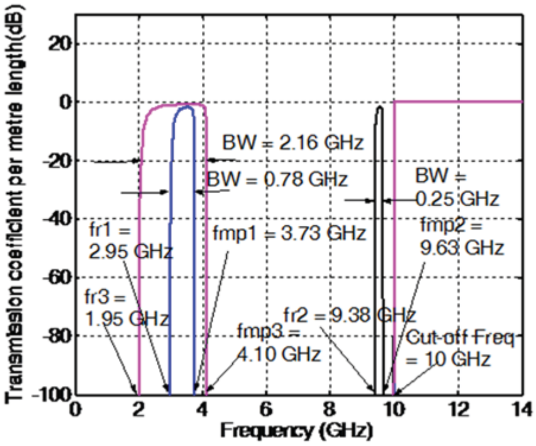
(a)

(b)

Fig. 3 (a) SRR loaded Rectangular Waveguide, (b) SRR unit cell



(a)



(b)

Fig. 4 (a) Transmission coefficient vs frequency showing LHM stop-band, (b) Transmission coefficient vs frequency showing LHM pass-band

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