Novel Wide Stopband Filter using CSRR and Open Stubs

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Abstract:
A novel wide stopband filter has been proposed. It consists of complementary split ring resonator (CSRR) loaded transmission line with two open-ended stubs at both sides of the CSRR.. CSRR provides a shunt type of resonance at two different resonant frequencies and it has a sharp passband to stopband transition and a narrow stopband. A capacitor on the other hand has a wide stopband but slow passband to stopband transition. By proper choice of the capacitor placed in shunt with CSRR, the passband between the two resonant peaks can be converted to a stopband, thus resulting in a large stopband. This can be used in conjunction with any kind of microstrip filter to eliminate undesired passbands or for harmonic suppression.

Key Words: Stopband filters, Complementary split ring resonator (CSRR), Capacitive stubs

I INTRODUCTION:

In the operation of electronic systems and circuits, the basic function of a filter is to selectively pass, by frequency, desired signals and to suppress undesired signals. The amount of loss and phase shift encountered by a signal passing through the filter is a function of the filter design. Similarly, the amount of rejection of an undesired signal is a function of the filter design. Microwave filters have a variety of applications in virtually any kind of microwave communication systems, Radars or test and measurement systems. Some of the most commonly used filters include the End coupled filter, parallel coupled filter, Interdigital filter and the combline filters [1]-[2]. These filters suffer from a major drawback. The presence of spurious passband close to the fundamental frequency band poses a grave problem to filter designers.

The use of subwavelength resonators (namely, split-ring resonators (SRRs) [3]-[4], Complementary split-ring resonators (CSRRs) [5], and related structures have been recently established as a cure for the suppression of harmonics in bandpass filters. These can be applied to a wide variety of filter types, responses, and technologies including planar and waveguide technologies. They not only suppress the harmonics, but also the rejection levels and bandwidth are controllable. CSRR provides a shunt type of resonance at two different resonant frequencies and it has a sharp passband to stopband transition and a narrow stopband. A capacitor on the other hand has a wide stopband but slow passband to stopband transition. By proper choice of the capacitor placed in shunt with CSRR, the passband between the two resonant peaks can be converted to a stopband, thus resulting in a large stopband. This can be used in conjunction with any kind of microstrip filter to eliminate undesired passbands.

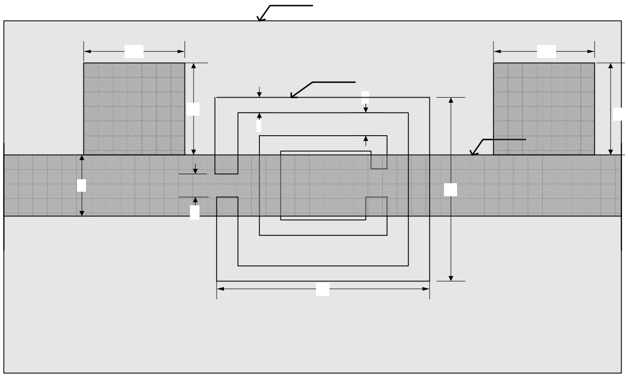

Fig. 1(a)

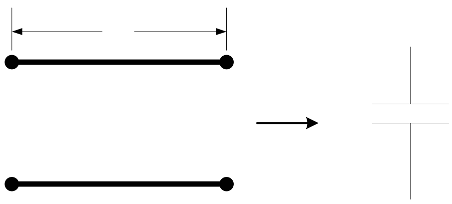

Fig. 1(b)

Figure 1 (a) General configuration of Stub-CSRR filter (b) λ/8 transmission line approximated to a capacitor

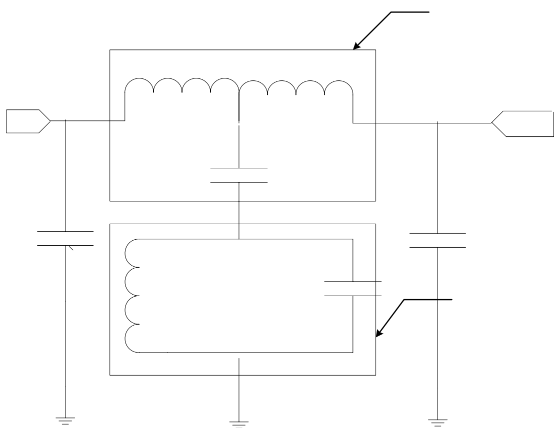

Fig. 2(a)

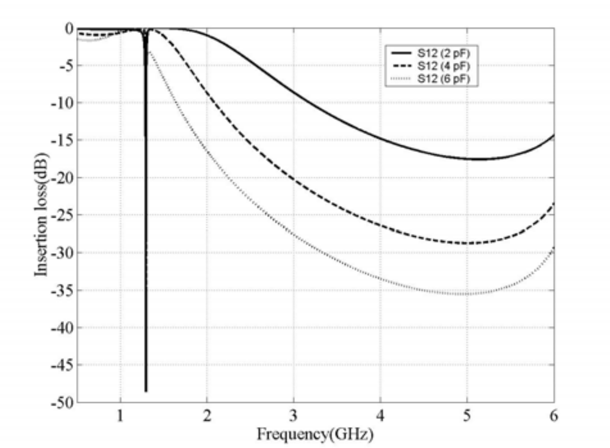

Fig. 2(b)

Figure 2 (a) Equivalent model of stub-CSRR filter and (b) Equivalent model frequency response of stub-CSRR filter using different stub capacitances

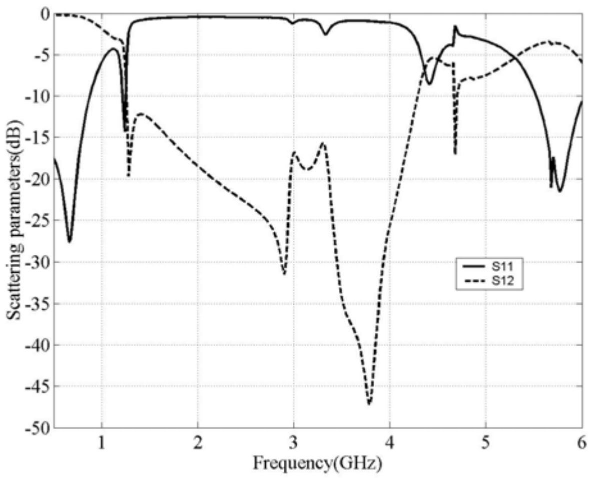

Fig. 3

Figure 3 EM simulated result for a stub-CSRR filter

Fig. 4 (a)

Fig. 4 (b)

Figure 4 Photograph of the fabricated Stub-CSRR filter (a) Top View (b) Bottom View

III. STUB-CSRR FILTER

The general configuration for the stub-CSRR filter is provided in Figure 1 (a). It consists of two open ended stubs added to the CSRR loaded transmission line on both the sides of the CSRR. It has been observed that the square CSRR provides a shunt type of resonance at two different resonant frequencies. It has a sharp passband to stopband transition and a narrow stopband. A capacitor on the other hand has a wide stopband but slow passband to stopband transition. By proper choice of the capacitor placed in shunt with CSRR, the passband between the two resonant peaks can be converted to a stopband, thus resulting in a large stopband. This can be used in conjunction with any kind of microstrip filter to eliminate undesired passbands.

The two main components of the filter are the stub and the CSRR. The CSRR resonant frequency is chosen to be passband to stopband transition frequency. The open-ended stub can be modeled as a shunt capacitor for a particular band of frequencies. The equivalent circuit for an open-ended stub is shown in Figure 1(b). The input impedance of transmission line seen looking towards the load is given by,

$$Z_{in} = Z_0 \frac{Z_l + jZ_0 Tan\beta l}{Z_0 + jZ_l Tan\beta l}$$

Z_0 is the characteristic Impedance, Z_l is the load, l is the length of the transmission line and β is the phase constant given by,

$$\beta = 2\pi / \lambda$$

We have l= $\lambda / 8$ and hence *tan βl =1*. Because of the open ended stub, $Z_L = \infty$. Therefore previous equation reduces to,

$$Z_{in} = \frac{Z_0}{j}$$

We have modeled the open-ended stub with a capacitor. Therefore,

$$\frac{1}{j\omega C} = \frac{Z_0}{j}$$
$$Z_0 \omega C = 1$$

This approximation holds good only for a particular band of frequencies. As frequency changes, so do the properties of the stub. The stopband to passband transition frequency of the filter is dependent on the stub. Once the stub starts losing its capacitive properties, there is a transition from stopband to passband. The stub-CSR filter can then be modeled as shown in Figure 2(a). The inductance and capacitance values for the equivalent circuit model of a transmission line can be obtained using the following relations.

$$Z_0 = \sqrt{\frac{L}{C}}$$

$$C_0 = \sqrt{\frac{\varepsilon_e}{LC}}$$

L and C are the inductance and capacitance per unit length of the equivalent circuit shown in Figure 2(a), Z_0 is the characteristic Impedance and C_0 is the velocity of light (3 x 10^8 m/sec). We have modeled a transmission line of 50 Ω characteristic impedance and a CSRR, which resonates at 1.3 GHz using the lumped element model as in Figure 2(a). Using the above equations, we obtain L_1=6 nH, L_2 = 2.818 nH, C_1 = 1.9 pF and C_2= 0.652 pF. The simulation results for the equivalent circuit model of Figure 2(a) are shown in Figure 2(b). In order to observe the effect of the stub capacitance on the filter response, we have plotted the Insertion loss (S_{21}) at various frequencies for different stub capacitances. The simulations have been carried out using Ansoft Designer SV 9.0. As the capacitance increases, the stopband start frequency decreases and the rejection level (which is directly proportional to the insertion loss) increases. The decrease in the stopband start frequency and the increase in the rejection level can both be attributed to the decrease in the impedance of the shunt stub because of higher capacitance.

This filter is realized on FR4 epoxy substrate with substrate thickness of 1.6 mm and copper thickness of 0.035 mm. We use a transmission line of width, w = 3 mm to have a characteristic impedance of 50 Ω. The filter has been designed to have a passband to stopband transition at 1.3 GHz. The dimensions of the CSRR have been chosen as, $a_1 = a_2$ = 13 mm and g = t = c = 0.5 mm. A CSRR with the above dimensions has a resonant frequency at 1.3 GHz. The stub is designed to have a length $L_1 = L_2$ = 11.5 mm ($\lambda/8$ at 1.3 GHz). The width of the stub determined in this case are $w_1 = w_2$ = 8 mm. During the microstrip realization of the stub-CSRR filter, a fair amount of fine-tuning is required to obtain good results. The EM simulated results of the filter are shown in Figure 3. The simulations were carried out using FEM based software. The filter thus obtained has a sharp cut-off, large rejection bandwidth and good stopband attenuation. The filter size is also very small when compared with other stopband filters (2-by-2 cm^2). It has a cutoff frequency at 1.7 GHz and a rejection bandwidth of 4 GHz. It has a maximum stopband attenuation of around 40 dB. Fabrication was performed using LPKF Protomat C-60 milling machine. Measurements have been done using the Agilent 8753ES Network Analyzer. The fabricated filter and its frequency response are shown in Figure 4 and 5 respectively. The measured response shows a stopband extending from 1.239 GHz to 5.18 GHz and a passband insertion loss of 0.7362 dB. The slight discrepancies between simulation and measurement results can be attributed to the small values of g, t and c, which are close to the resolution limit of the fabrication process (0.1 mm). The Stub-CSRR filter has various advantages when compared with other bandstop and lowpass filters. It has a sharp passband to stopband transition. It is also compact and easy to fabricate. It is particularly suitable for use in L (1-2 GHz) and S (2-4 GHz) band applications. Several such filters can be cascaded together to provide a larger rejection bandwidth. They can also be used in conjunction with other microstrip filters to remove the undesired bands.

Fig. 5 (a)

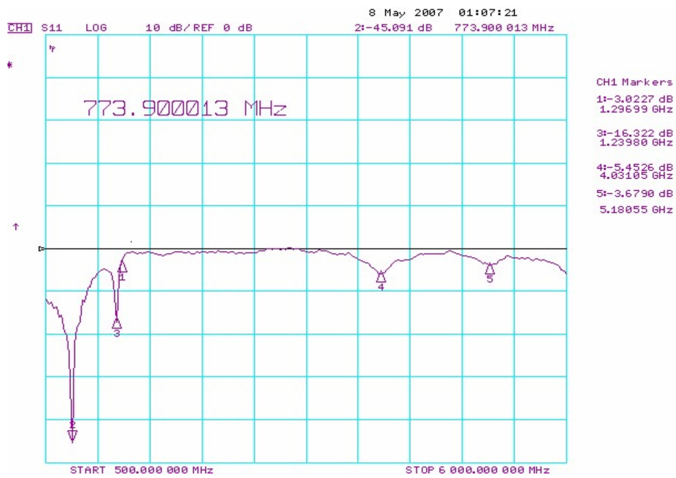

Fig. 5 (b)

Figure 5 (a) Insertion loss vs. Frequency of the fabricated Stub-CSRR filter (b) Return loss vs. Frequency of the fabricated Stub-CSRR filter

CONCLUSION

A novel stopband filter with a large rejection bandwidth has been designed using CSRRs and open stubs. This filter has a sharp cut-off, large rejection bandwidth and good stopband attenuation. The filter size is also very small when compared with other stopband filters (2-by-2 cm^2). It has a cutoff frequency at 1.7 GHz and a rejection bandwidth of 4 GHz. It has a maximum stopband attenuation of around 40 dB. The fabricated filter and its measured frequency response show a stopband extending from 1.239 GHz to 5.18 GHz and a passband insertion loss of 0.7362 dB. The slight discrepancies between simulation and measurement results can be attributed to the small values of g, t and c, which are close to the resolution limit of the fabrication process (0.1 mm). The Stub-CSRR filter has various advantages when compared with other bandstop and lowpass filters. It has a sharp passband to stopband transition. It is also compact and easy to fabricate. This particular filter is suitable for use in L (1-2 GHz) and S (2-4 GHz) band applications. We can also design other CSRR-stub filter for various applications using the design methodology which has been clearly mentioned in the paper. Several such filters can be connected in series to provide a larger rejection bandwidth. This CSRR-stub filter can be used in conjunction with any other type of filters to get rid of spurious bands or for harmonic suppression and it is the subject of our further research.

ACKNOWLEDGMENT

Authors are grateful to the Science and Engineering Research Council, Department of Science Technology, Government of India for supporting this study.

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BIO DATA

Dr. Rakhesh Singh Kshetrimayum received the B. Tech. degree in Electrical Engineering from the Indian Institute of Technology, Bombay, the Ph.D. degree from the Nanyang Technological University, Singapore. He did his postdoctoral research from the Microwave Lab, Indian Institute of Science, Bangalore and Electromagnetic Communication Lab, Pennsylvania State University, University Park. Since 2005 he is a faculty member at the department of Electronics and Communication Engineering, Indian Institute of Technology, Guwahati and presently he is an Assistant Professor. His research interests include RF, Microwaves, Antennas, Numerical Electromagnetics and Neural Networks.

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