Miniaturized Microstrip Bandpass Filter Using Coupled Metamaterial Resonators

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***Abstract*-A compact microstrip band pass filter using metamaterial resonators is proposed and implemented, aiming at high level of miniaturization, low cost and ease of fabrication. Some considerations in order to improve and control the coupling coefficients between resonators are exposed. The magnetic and electric character of the coupling coefficient is analyzed in detail. The proposed filter has narrow bandwidth, low insertion loss and compact dimensions. It is observed that the measured results are good agreement with the simulated results.**

***Index Terms*-Coupling coefficient, metamaterial, microstrip filters, split-ring resonators.**

I. INTRODUCTION

Metamaterials are artificial structures that can be designed to exhibit specific electromagnetic properties that transcend those of natural media (‘meta’ means ‘beyond’ in greek). Recently, metamaterials commonly referred to as left-handed medium (LHM) have gained lot of popularity. The concept of Left Hand Metamaterials (LHMs) was theorized by Veselago in 1967 [1]. The electric field, magnetic field and wave vector of electromagnetic wave propagation in left-handed (LH) materials obey left-hand rule, instead of the right-hand rule for usual materials. In such a medium, the permittivity and permeability are negative simultaneously and exhibits many unusual physical properties different from the conventional right-handed (RH) material, such as negative refraction index, backward Cerenkov radiation, reversed Doppler shift, etc. Unfortunately, such a medium does not exist in nature, which has restricted further investigations of LHM for a long time. Recently, left-handed structure has been realized using wires and split-ring resonators (SRRs) experimentally [2-5].

Split-ring resonators (SRRs), originally proposed by Pendry *et al.* [2], have attracted great interest among microwave engineers due to their potential applications to the synthesis of artificial materials (metamaterials). It has also been demonstrated that many other resonator topologies, derived from the basic SRR proposed by Pendry *et al.*, are appropriate to achieve effective (continuous) media with negative permeability [6]. Hence, these resonators considered as quasi-lumped elements and are, therefore, also very interesting for the miniaturization of planar microwave devices such as filters and diplexers, or to improve their performance. In 2004, an extended concept of composite right/left-handed transmission line was developed and demonstrated the practical application of LH structure [7-13]. Since then, left-handed materials become an attractive topic and an extensive study has been conducted in the new physical characteristics, experiments, and potential applications [14-18].

Bandpass filters are often employed in microwave and millimeter wave communication systems to remove and suppress spurious signals from an undesired frequency/channel. With the rapid development of microwave and millimeter wave communication systems, it greatly stimulates the demand on high performance bandpass filters with compact dimensions, low insertion loss, high attenuation in stopband and low cost. However, most of conventional bandpass filters are unsuitable for miniaturized realization demand of modern communication and electronic systems. In this letter, we developed a novel compact narrow-band bandpass filter using metamaterials. The aim is to apply the filter synthesis proposed by Hong and Lancaster [19], based on the coupling coefficient approach to the design based on metamaterial resonators. The performance of the device investigated analytically and experimentally. The simulation is done using moments method software tool [20].The novel bandpass filter has shown its low insert loss, compactness, etc. and can be easily integrated with microwave or millimeter wave planar circuits.

II. MAGNETIC AND ELECTRIC COUPLING BETWEEN RESONATORS

SRRs can be applied to the design of compact narrow bandpass filters and diplexers, in microstrip and CPW technology, by combining metamaterial particles with other planar elements such as shunt stubs or series gaps [21]. Although final dimensions of the structures can be made significantly small, the approach neglects interaction between adjacent resonators, and it is not based on a design methodology where electrical parameters can be inferred from device specifications. A very important step in the design of cross-coupled band pass filters is the determination of the type of coupling between the resonators involved in the filter.

The nature of the coupling is directly related to the sign of the corresponding coefficients of the coupling matrix that is obtained from filter specifications [22]. Filter constituents square open loop resonators coupled in the configuration shown in Fig. 1(a) (electric coupling) and Fig. 1(b) (magnetic coupling). When the resonators are arranged in different way as shown in Fig. 1(c) or Fig. 1(d), the coupling is mixed. Depending on the particular orientation or distance between resonators, the electric and magnetic couplings tend to add or to cancel each other, and the determination of the sign of the coupling coefficient is not an obvious task. In these cases, the usual way to determine the sign of the coupling coefficient is based on the comparison of the phases of the insertion loss when the resonators are excited in a symmetrical way [19].

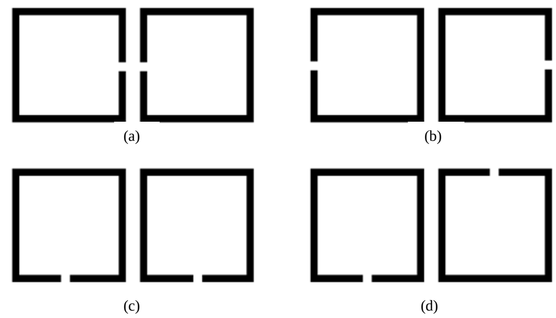

Fig.1. Coupled resonators with: (a) electric coupling, (b) magnetic coupling, and (c) and (d) mixed coupling.

The coupling coefficient is a numerical estimation of the energy exchange between resonators. This energy is produced by the electromagnetic fields present in the vicinity of the particles. In microstrip technology, these fields are strongly affected by the presence of the ground plane.

III. FILTER DESIGN AND IMPLEMENTATION

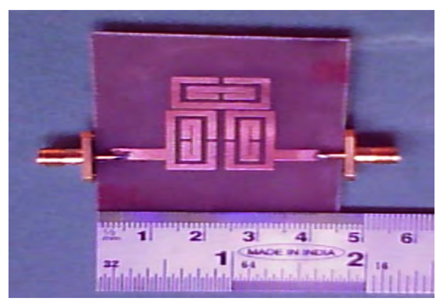

Fig.2. Photographed layout of the bandpass filter using coupled metamaterial resonators

By means of metamaterial particles, it is possible to achieve substantial miniaturization in filters based on coupled resonators. A microstrip trisection coupled filter with different resonator shapes, such as open-loop resonators and triangular patch resonators can produce asymmetric frequency responses with an attenuation pole of finite frequency on either side of the pass band. The proposed design of bandpass filter with trisection metamaterial resonators is shown in figure 2.

The midband frequency is taken as 1.8 GHz, the dielectric permittivity is 4.4 with thickness 1.6 mm. The loss tangent considered is 0.02. Having obtained the required design parameters for the bandpass filter, the physical dimensions of the microstrip trisection filter determined using full-wave EM simulations to extract the desired coupling coefficients and external quality factors. Figure 3 (a) shows the layout of the designed filters with the dimensions. The size is evidently compact. The proposed filter physically implemented on top of a FR/4 'Glass/Epoxy' substrate using conventional fabrication process. The corresponding frequency response curve shown in figure 3 (b) and 3 (c).

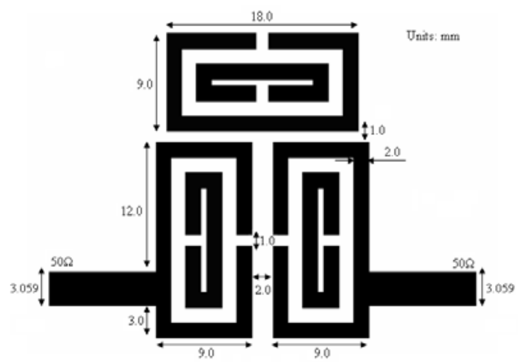

Fig.3 (a). Layout of the proposed filter

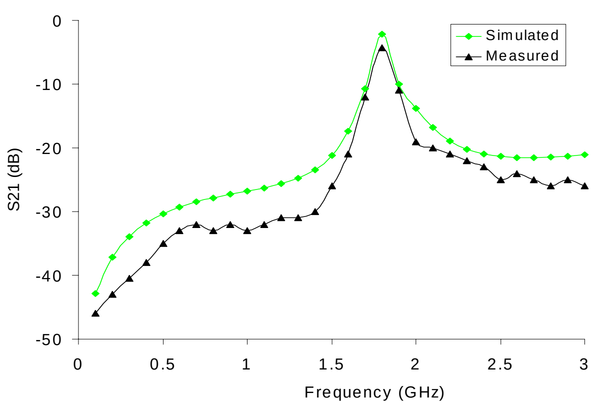

Fig.3 (b). Transmission coefficient plot

The analytical and measured results are in good agreement. As can be seen, an attenuation pole of finite frequency on the upper side of the pass band leads to a higher selectivity on this side of the passband. The midband insertion loss is about 2dB, appropriate for metamaterial devices, is mainly due to the conductor loss of copper microstrip. The fractional bandwidth is calculated to be 4.41% at 1.8 GHz. The coupling parameters are $M_{1,2} = M_{2,3} = 0.04753$ and $M_{1,3} = 0.02907$. The input and output quality factor is 15.7203.

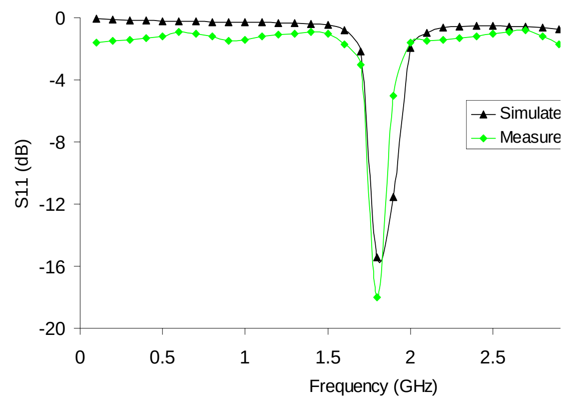

Fig.3 (c). Reflection coefficient plot

IV. CONCLUSION

The coupling method can also be applied to the synthesis of any kind of filters. It has been shown that the use of sub-wavelength resonators in the coupling coefficient method provides significant reduction in the active area of planar microwave filters. The effective permittivity and effective permeability can be extracted from the S-parameters with NRW (Nicholson-Ross-Weir) approach and found out to be negative. The dimensions of the fabricated devices are small, while reasonable performance has been obtained. Measured in-band losses are not negligible, but they can be improved by using high-temperature superconductors (HTSs).

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