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A Novel Dual-Bandpass Microwave Filter Using Espilon-Near-Zero Metamaterials

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***Abstract* – A dual-band filter design using the epsilon-near-zero (ENZ) metamaterials (MTMs) is considered. A novel dual-mode resonator on combination of a substrate integrated waveguide (SIW) capacitively loaded cavity and a complimentary split-ring resonator (CSRR) etched on the SIW top cover is proposed. At the both resonant frequencies such a resonator behaves as an ENZ MTM. The resonator has a small size and suits well for the design of compact dual-bandpass filters with a low loss. Design of a dual-band filter for WLAN application is presented.**

I. INTRODUCTION

A split-ring resonator (SRR) and its dual counterpart known as a complimentary split-ring resonator (CSRR) have for years been the most popular canonical "metaparticles" employed to design electromagnetic metamaterials (MTMs). Though the SRRs were originally designed to provide a mu-negative MTM response, using the SRRs and CSRRs modifications, changing the resonator orientation with respect to the incident electromagnetic field or changing the resonator connection with the host structure allows obtaining different MTM responses including those of the epsilon-negative MTMs and the epsilon-near-zero (ENZ) MTMs.

The SRRs and CSSRs have been recently used to design single-band as well as dual-band microwave filters in planar [1]-[3] and substrate integrated waveguide (SIW) [4]-[7] technologies. The CSRRs can be easily adopted on a metal cover of the SIW structure to provide a stopband above the waveguide cut-off frequency. Using the highpass behaviour of the SIW and the bandstop characteristic of the CSRRs, a bandpass filter can be designed [4]. The stopband switches to a passband when the CSRRs are resonant below the SIW cut-off frequency [5]. A dual-bandpass filter response can be obtained using a pair of CSRRs with different resonant frequencies lower than the SIW cut-off frequency [6], [7].

This paper presents a dual-bandpass filter design based on a novel dual-mode resonator that is a combination of a CSRR and a SIW cavity loaded with a mushroom-like structure. The capacitively loaded cavity operates at the lower resonant frequency while the higher resonance of the dual-mode resonator is provided by the CSRR. Extraction of the effective permittivity and permeability reveled that the dual-mode resonator behaves as an ENZ MTM at the both resonant frequencies. As compared with the dual-mode resonator using a pair of different-in-size CSRRs etched on the metal cover of SIW [6], [7], the proposed resonator structure has a smaller footprint. Experimental verification confirmed a high potential of the proposed resonator for the design of compact and low-loss dual-band filters. A dual-band filter for WLAN application at 2.45 GHz and 5.5 GHz was designed using the developed resonator.

II. DUAL-MODE EPSILON-NEAR-ZERO RESONATOR

A dual-mode SIW-based resonator can be designed as a combination of a miniaturized capacitively loaded cavity [8] and a CSRR etched on the cavity top cover as shown in Fig. 1-a. The SIW cavity is loaded by a mushroom-like structure consisting of a conductive post with a capacitive plate at one end. The capacitive load results in a remarkable reduction of the cavity size while still maintaining a relatively high unloaded Q-factor. The capacitively loaded cavity provides the lower resonance of the dual-mode resonator (f_{01}) whereas the higher resonance (f_{02}) is due to the presence of the CSRR. An equivalent diagram of the proposed dual-mode resonator is illustrated in Fig. 1-b (the input and output inductive couplings are not shown).

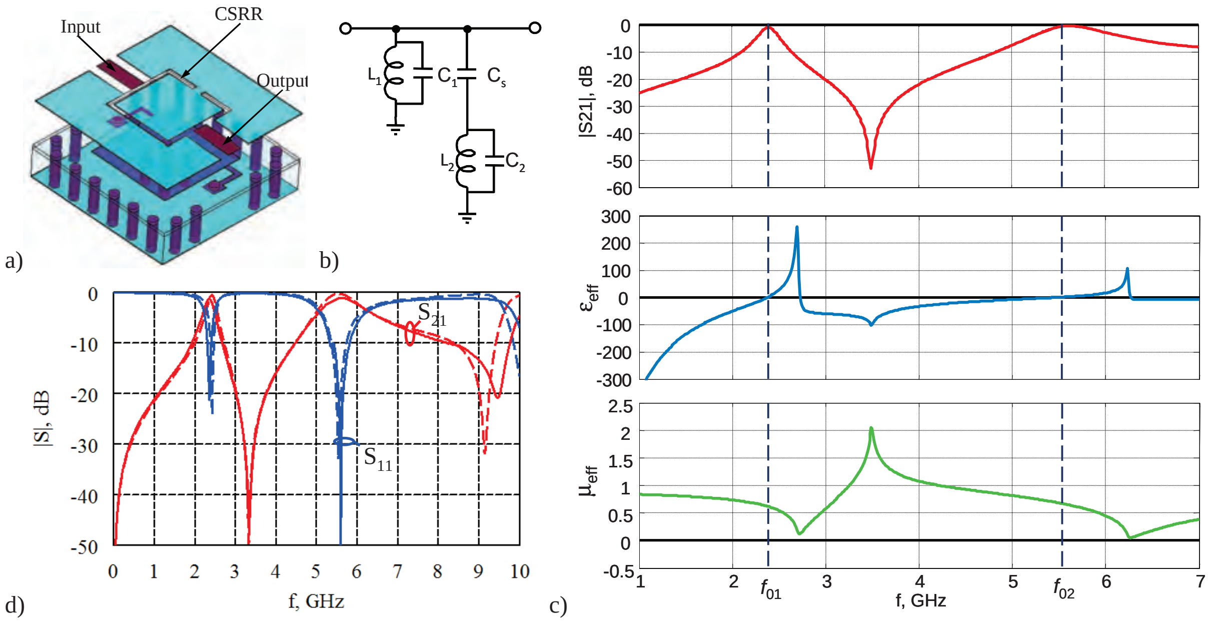

Fig. 1. Dual-mode resonator on a combination of a capacitively loaded SIW cavity and a CSRR: (a) structure; (b) equivalent diagram; (c) simulated transmission coefficient and extracted effective parameters; (d) measured (solid lines) and simulated (dashed lines) frequency response.

The entire size of the dual-mode resonator depends mainly on the dimensions of the capacitively loaded cavity which can be as small as one eighth of the guided wavelength ($\lambda_g/8$) at the resonance frequency [8]. The dual-mode resonator with $f_{01} = 2.4$ GHz and $f_{02} = 5.5$ GHz implemented on 1.7 mm thick Rogers RO4003 ($\varepsilon_r = 3.55$, tan $\delta = 0.0027$) PCB occupies the area of 10 mm × 10 mm corresponding to $\lambda_g/8$ at the lower resonant frequency. It is worth noting that the proposed resonator has a smaller footprint compared with the dual-mode resonator based on a SIW loaded with a pair of CSRRs [6], [7].

The frequency dependence of the transmission coefficient of the dual-band resonator simulated by using Ansoft HFSS 3D electromagnetic field solver is plotted in Fig. 1-c in line with the extracted effective permittivity and permeability. The extraction was performed using Mathlab software following [9] and [10]. At the both resonant frequencies the proposed resonator behaves as an ENZ MTM. Measured frequency response of the resonator is presented in Fig. 1-d in comparison with the simulated characteristics. The measurements was performed using Rohde & Schwarz ZVL vector network analyzer and Anritsu 3680K universal test fixture.

III. Dual-Band Filter Design

A two-pole dual-bandpass filter for WLAN application at 2.3–2.5 GHz and 5.1–5.8 GHz was designed using the developed dual-mode resonators (Fig. 2-a). In the filter structure the resonators are coupled in different ways. A coupling between the capacitively loaded cavities is provided by an iris arranged in their mutual sidewall. However, it influences the coupling between the corresponding CSRRs as well. In order to adjust the coupling between the CSRRs independently, they are connected by a slotline providing a tapered coupling whose value depends on a connection point position. In contrast to different CSRR-based filters where the necessary coupling value is achieved by adjusting the distance between the coupled CSRRs, the use of the tapered slotline coupling allows placing CSRRs equidistantly. An equivalent diagram in shown in Fig. 2-b. The two-pole filter uses the input and output inductive couplings similar to those of the single dual-mode resonator (not shown in Fig. 2-b).

Simulated and measured filter characteristics are presented in Fig. 2-b. The measured insertion loss in the two passbands is 2.5 dB and 1.4 dB, correspondingly. The measured return loss is better than 12 dB. The filter occupies the area of 20 mm × 10 mm.

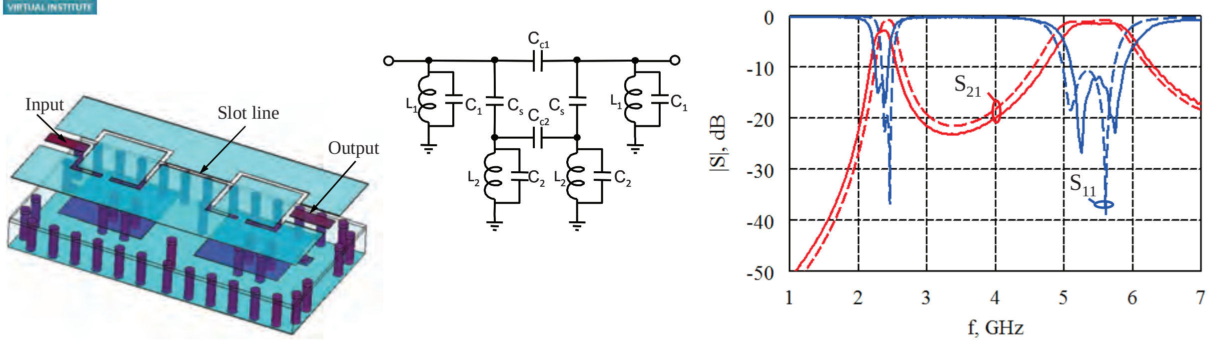

Fig. 2. Two-pole dual-band filter based on proposed dual-mode resonators: (a) structure; (b) equivalent diagram; (c) measured (solid lines) and simulated (dashed lines) characteristics.

IV. Conclusion

A novel approach to design of dual-bandpass microwave filters using the ENZ MTMs has been presented. A compact dual-mode resonator that is a combination of a CSRR and a SIW capacitively loaded cavity has been proposed and investigated by numerical simulation and experimentally. Extraction of the effective permittivity and permeability from the numerically simulated characteristics has shown that the resonator provides an ENZ MTM response at the both resonant frequencies. The developed resonator suits well for a design of dual-band filters with the small size and low insertion loss. Design, simulated and measured characteristics of the two-pole bandpass filter for WLAN application in two frequency bands have been presented.

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