Multimode electric ring resonator (ERR) for ultra-wideband (UWB) antenna with multi-notch band

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Abstract. The electric ring resonator (ERR) is widely used for a design of metamaterials. The planar multimode ERR is considered as a promising structure for a design of multiband microwave devices. The ultra-wideband (UWB) planar antenna with multi-notch band is designed as a circular metallic patch fed by a coplanar waveguide (CPW) loaded with the ERR. To achieve the notched characteristics at desirable frequencies, the multimode ERR is incorporated into the CPW feedline of the planar UWB antenna. The notched frequency band is controlled by dimensions of the ERR structure. The antenna demonstrated a VSWR lower than 2.5:1 and consistent monopole-like, omnidirectional radiation patterns over a 4.8:1 bandwidth. A prototype of the antenna with physical dimensions of 50×50×1.52 mm demonstrates multi-notch characteristic at 3.5, 5.8, and 7.5 GHz in the 2.5 - 12 GHz frequency range

1. Introduction
The rapid growth of communication systems employing narrow-band and ultra-wideband (UWB) antennas has increased the demand for compact, low-cost antennas with interference rejection capabilities. Interference between UWB antennas and existing narrowband systems has inspired a growing interest to design the UWB antennas with notch characteristics to avoid the influence of undesired signals on the UWB systems. Various band-notched UWB antennas using different techniques have been designed. The conventional methods use cutting slots of various shapes in the radiating patch, the ground plane, and the feed line. Another approach is based on using planar resonators as parasitic elements (capacitively/inductively coupled; open-ended/short-circuited), placed near the radiating patch, the ground plane and/or the feed line. Alternative ways to design the UWB band-notched antennas include deploying the components used in a design of metamaterials and EBG-structures.

The majority of implementations of negative index media are based on the split-ring resonators (SRR) and the wire media. The SRRs behave similarly to the resonant magnetic dipoles providing μ-negative behavior in a limited frequency range, while the parallel wire medium made as a set of electric dipoles provides ε-negative properties below the plasma frequency. Based on a duality principle, complementary SRRs (CSRRs) were introduced as components of metamaterial with negative permittivity. The CSRR may be considered as an equivalent resonant electric dipole [1]. Both structures contain inductive and capacitance components. If an inductive-capacitive LC resonator with a fundamental mode couples strongly to the uniform electric field, and negligibly to the uniform magnetic field, refers to the electric LC resonator [2]. As an example, the electric-ring resonator (ERR) is shown in Figure 1(a). It consists of the ring, responsible for the inductance, and the capacitive gap. The
The equivalent diagram of the ERR is presented in Figure 1 (b). The resonant frequency is defined as $\omega_0 = \frac{1}{\sqrt{LC}}$ and is determined by the geometry of the ERR. The ERR may be used for a design of the notched UWB antennas.

![ERR diagram](image)

**Figure 1.** ERR (a) and its equivalent diagram (b).

Among numerous versions of the UWB antennas, planar monopole antennas are considered as good candidates for the UWB applications. The planar monopole antenna is designed as a circular (rectangular) metallic patch fed by a microstrip or a coplanar waveguide (CPW) [4, 5]. The triple-frequency notches are provided by loading the feedline of the monopole by three resonators of different geometry. The structures are rather complicated and of large size. To simplify the structure and to achieve the band-notch characteristics, the design is formed by incorporating the ERR with a CPW structure exhibiting a band-stop characteristic [6-8]. To design the UWB multiple-notch antenna, the multimode ERR resonator placed on the backside of the CPW structure was suggested.

2. **Properties of the multi-mode ERR.**

Schematic diagram of the ERR consists of a square ring with the quasi-lumped capacitance inside corresponding to a parallel $LC$-tank (Figure 1). The resonant frequency depends on the inductance $L$ (ring dimensions) and on the capacitance $C$ (the central gap). The surface current distribution for the fundamental mode of the ERR is shown in Figure 2 (a). To analyze the resonant performance, the ERR was placed on the backside of the CPW (Figure 2 (b)). The resonant frequency is controlled by changing the gap dimension or/and by variation of the ring length: the longer ring, the lower is the resonant frequency. The results of simulation of S-parameters of the SRR are presented in Figure 3 (c). The dielectric substrate Rogers RO3003 ($\varepsilon_r = 3$, $\tan(\delta) = 0.0013$) with thickness of 1.52 mm was used for manufacturing the CPW with the SRR.

![Current distribution](image)

**Figure 2.** The surface current distribution in single-mode ERR (a), its position with respect to the CPW (b), and resonant characteristics for three different lengths of the square side (c): L=10 cm (black), L=7 cm (red), L=5 cm (blue).

The modified structure of the dual-mode resonator (dual-ERR) consists of two nested square rings to manipulate the notched effect [see Figure 3(a)]. The behavior of the resonances at the first and second notched frequencies of the dual-ERR has been analyzed during the parametric study of the CPW with dual-ERR [8]. The low-frequency mode ($f = 3.5$ GHz) is provided by the excitation of the central capacitor and the inner ring [see the current distribution in Figure 3(b)]. The current in the outer ring is
conditioned by a mutual inductance between the rings and can be considered as a small perturbation. In general, the resonant frequency of the first mode (5.8 GHz) depends on the dimensions of the inner square ring $L_1$ and the quasi-lumped capacitance $L_c, G_c$. The second mode corresponds to the resonant response of the structure formed by two coupled rings with dimensions $L_1$ and $L_2$. The current distribution corresponding to the odd mode of two coupled rings [see Figure 3(c)] confirms this statement. There is no current flow through the capacitive gap, and the resonant frequency (7.5 GHz) is defined by the geometry of two coupled rings only. The two-mode resonant characteristic is shown in Figure 3 (d).

![Figure 3](image1)

**Figure 3.** The structure of the dual-mode ERR (a); equivalent diagram of the ERR for the first mode and the current distribution (b), equivalent diagram of the ERR for the second mode and the current distribution (c), two-mode resonant characteristic of the ERR.

The triple-mode ERR for a design of the triple-notched band is shown in Figure 4 (a). The resonator contains three coupled rings and the interdigital capacitor. The following dimensions were used: $W_0 = W_1 = 0.5$ mm, $W_2 = W_3 = 0.35$ mm, $L_1 = 6$ mm, $L_2 = 8$ mm, and $L_3 = 10$ mm. The interdigital capacitor integrated into the ERR was used for a realization of the first notch at frequency of 3.5 GHz. The equivalent diagram is shown in Figure 4 (b). The current distributions for the first three modes are presented in Figure 4 (c).

![Figure 4](image2)

**Figure 4.** The structure of the triple-mode ERR (a); the equivalent diagram of the ERR (b), the current distribution for the modes with resonant frequencies: 3.5 GHz, 5.8 GHz, and 7.5 GHz (c).

As in the case of the dual-mode resonator, the low frequency mode is provided by the excitation of the interdigital capacitor and the inner ring. Two other modes arise from the resonances of structures formed by the coupled rings with dimensions $L_1, L_2,$ and $L_3$. Thus, the triple-notched antenna design
starts with the setting of the first mode ($f = 3.5$ GHz) by properly choosing the geometry of the interdigital capacitor and the inner ring ($L_1$); then, the third mode ($f = 7.5$ GHz) is set by choosing the proper dimension of the middle ring ($L_2$); and finally, the second mode ($f = 5.8$ GHz) is set by choosing the proper dimension of the outer ring ($L_3$).

3. Planar UWB antenna with multi-band ERR.

The design of the planar UWB antenna is based on the circular patch fed by the CPW structure. Fig. 5 (a) shows the top side of the monopole antenna fabricated on Rogers RO3003 substrate with thickness of 1.52 mm and dimensions of 50×50 mm. The radius of the circular patch is 12.5 mm, the 50-Ohm CPW feed line is formed by the strip of 4 mm width and two gaps of 0.2 mm width. The full-wave analysis of the antenna has been performed using finite element simulation code [9]. Experimental study was carried out in anechoic chamber with dimensions of 9×5×4 m using E8362C PNA Microwave Network Analyzer. Simulated and measured VSWR and gain of this antenna is shown in Fig. 5 (b). The antenna demonstrated VSWR lower than 2.5:1 over the 4.8:1 bandwidth.

The notch characteristic is provided by the ERR printed on the backside of the CPW (Figure 5 (c) and (d)). Simulation and measurement was carried out for single- and dual-notch antennas. The frequency dependence of VSWR and gain for the dual-notch antenna is shown in Figure 6 (a).

The notch characteristic is provided by the ERR printed on the backside of the CPW (Figure 5 (c) and (d)). Simulation and measurement was carried out for single- and dual-notch antennas. The frequency dependence of VSWR and gain for the dual-notch antenna is shown in Figure 6 (a).

**Figure 5.** The UWB monopole structure fed by the CPW (a); simulated and measured VSWR and simulated gain of the antenna with the single-mode ERR printed on the backside of the CPW (b); the single-mode ERR (c); and the dual-mode ERR (d) printed on the backside of the CPW.

**Figure 6.** Simulated and measured VSWR and gain of the double-notched antenna (a); simulated VSWR and gain of the triple-notched antenna (b).
The triple-notched UWB antenna was designed using the same reference monopole in combination with the triple-mode ERR. The simulated frequency dependence of VSWR and gain of the triple-notched antenna is presented in Figure 6 (b).

4. Conclusion
UWB antennas, as an important part of UWB systems, provides low power dissipation and large impedance bandwidth. UWB antennas with notch characteristics are designed to avoid the influence of undesired signals on the UWB systems. Using the planar multimode resonant structure as a part of the UWB antenna provides the antenna design with the multi-notched response. The multimode ERR was suggested and analyzed for a design of the UWB multi-notched antenna. The antenna is designed as a planar monopole fed by the CPW and the ERR coupled with the feeding structure. The coupling effect provides the notched characteristics at chosen frequencies in the UWB operating band. Using the modified multimode structure of the ERR is followed by a simplification of the UWB antenna design with the multi-notched response.

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6. References
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