Ultra-Wideband (UWB) Planar Antenna with Single-, Dual-, and Triple-Band Notched Characteristic Based on Electric Ring Resonator

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Abstract—The ultra-wideband (UWB) planar antenna is designed as a circular metallic patch fed by a coplanar waveguide (CPW). This antenna provides the impedance bandwidth of the wideband response from 2.5 GHz to 12 GHz. To achieve the notched characteristics at desirable frequencies, the electric ring resonator (ERR) incorporated into the CPW feed line is proposed to use in the planar configuration of the UWB antenna. The notch frequency band is controlled by dimensions of the ERR structure. The single notched band can be obtained by placing a single ERR beneath the CPW structure. For implementation of the multi-notch band, a modified multi-mode structure of the ERR is examined. Reconfigurability of the first notched band is provided by using a digital variable capacitor (DVC) instead of ERR’s quasi-lumped capacitance. The results of simulations and measurements are in a good agreement.

Index Terms—Band notch, dual-band notched, triple-band notched, electric ring resonator (ERR), dual-mode ERR (dual-ERR), tri-mode ERR (tri-ERR), multi-mode ERR, monopole, reconfigurability, ultra-wideband (UWB) antenna

I. INTRODUCTION

UWB systems are of great interest due to their possibility to provide high-data-rate wireless transmission, wireless connectivity; longer-range applications, low-data-rate applications and using for radar and imaging systems. UWB antennas, as important part of UWB systems providing low power dissipation and large impedance bandwidth, have attracted great attention of researchers. Among numerous versions of UWB antennas, planar monopole antennas are considered as good candidates for UWB applications.

In reality, many other narrowband services occupy frequencies in the UWB range, for example, WiMAX for some European and Asian countries (3.3-3.6 GHz) and WLAN for IEEE 802.11a in the USA (5.15-5.35 GHz and 5.725-5.825 GHz) etc. 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 design techniques have been reported recently [1-16].

The conventional methods focus on cutting slots of various shapes in the radiating patch [1-6], the ground plane [5], and the feed line [7]. Another methods are based on using planar resonators as parasitic elements (capacitively/inductively coupled; open-ended/short-circuited), placed near the radiating patch [3, 6, 8, 10-13], the ground plane [4, 9-11] and/or the feed line [2, 9, 14]. To achieve multi-band notched characteristics, combinations of different design techniques are used [3, 6, 9-11]. Although these methods of design provide desired performances, there are drawbacks for practical applications such as complicated structures and large dimensions, strong coupling between band notched structures etc.

Alternative ways to design UWB band-notched antennas include deploying the components widely used in a design of metamaterials and EBG-structures [15, 16].

To achieve reconfigurability of a band-notched response, usage of PIN-diodes and varactor diodes incorporated into slots/stubs of UWB antenna is commonly used [17].

In this work, the UWB antenna is based on the planar monopole configuration designed as a circular metallic patch fed by a coplanar waveguide (CPW) [18]. The impedance bandwidth of the wideband response is observed in the frequency range 2.5-12 GHz. To achieve the band-notch characteristics, the design was performed by incorporating the electric ring resonator (ERR) with a CPW structure exhibiting a band-stop characteristic. The frequency of notch is controlled by the ERR geometry. To design a single notched band, it is necessary to add a single ERR beneath the CPW structure. To obtain double or triple notched bands, a cascaded structure of the ERRs with different resonant frequencies can be used [19, 20]. Alternative way to realize multi-notched bands is using...
modified multi-mode structure of the ERR providing a notch response in a narrow frequency range at the chosen frequency. Reconfigurability of the first notched band is obtained by using a digital variable capacitor (DVC) instead of ERR’s quasi-lumped capacitance.

II. REFERENCE UWB MONOPOLE ANTENNA

The design of the reference antenna is based on the circular patch fed by the CPW structure. Fig. 1 (a) shows the top side of the monopole antenna fabricated on Rogers RO3003 substrate with ε_r=3, tan δ=0.0013, 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. Simulated and measured VSWR and simulated peak gain of this reference antenna are shown in Fig. 1 (b). The radiation patterns of the antenna at three chosen frequencies 3.5, 5.8, and 7.5 GHz are presented in Fig. 2 (a), (b), and (c), correspondingly.

III. ELECTRIC RING RESONATOR (ERR)

The resonator coupled with a transmission line provides a narrow stopband at the resonant frequency depending on the dimensions of the resonant structure. The ERR used in a design of metamaterial structure [21, 22] is suggested as a component of the UWB antenna with the notched characteristic. Schematic diagram of the ERR consists of a square ring with the quasi-lumped capacitance inside. The equivalent diagram of the ERR corresponds to a parallel LC-tank [21]. The resonant frequency depends on the inductance L (ring dimensions) and on the capacitance C (the central gap width G_c and length L_c).

The modified structure of the dual-mode resonator (dual-ERR) consists of two nested square rings to manipulate the notched effect (Fig. 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 [20]. The low-frequency mode is provided by the excitation of the central capacitor and the inner ring (see the current distribution in Fig. 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_3. The current distribution corresponding to odd mode of two coupled rings (Fig. 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.

IV. UWB BAND-NOTCHED ANTENNA DESIGN AND MEASUREMENTS

Bottom side of the UWB antenna with single notched band (5.8 GHz) provided by the single-mode resonator is shown in Fig. 4 (a). The characteristics of antenna are presented in Fig. 4 (b). The ERR of the UWB antenna is characterized by the following dimensions W_c = W_1 = W_c = 0.3 mm, L_c = 2 mm, G_c = 0.5 mm, L_1 = 7 mm.

The full-wave analysis has been performed using finite element simulation code [23]. Experimental study was carried out in anechoic chamber with dimensions of 9×5×4 m using E8362C PNA Microwave Network Analyzer. The peak gain parameter and VSWR (Fig. 4 (b)) are in agreement with the expected results. For tuning the notched frequency from 5.8 GHz to 3.5 GHz or 7.5 GHz, it is enough to change the
dimension of the resonator $L_1$ from 7 mm to 10 mm or 5.3 mm correspondingly [19].

Bottom side of the double notched UWB antenna (5.8 GHz and 7.5 GHz) with the dual-ERR is shown in Fig. 5 (a). The dual-ERR of the UWB antenna is characterized by the following dimensions: $W_0 = W_1 = W_2 = W_C = 0.5 \text{ mm}, L_C = 3 \text{ mm}, G_C = 0.2 \text{ mm}, L_1 = 6 \text{ mm}, L_2 = 8.7 \text{ mm}$. The characteristics of the antenna are presented in Fig. 5 (b). The simulated and measured results are in a good agreement.

V. UWB TRIPLE-NOTCHED ANTENNA

The tri-mode ERR (tri-ERR) for a design of the triple notched band is shown in Fig. 6 (a). The tri-ERR of the UWB antenna contains three coupled rings and the interdigital capacitor. The following dimensions were used: $W_0 = W_1 = 0.5 \text{ mm}, W_2 = W_3 = 0.35 \text{ mm}, L_1 = 6 \text{ mm}, L_2 = 8 \text{ mm}, L_3 = 10 \text{ mm}$. The interdigital capacitor integrated into the tri-ERR was used for a realization of the first notch at frequency of 3.5 GHz. The current distributions for the first three modes are presented in Fig. 6 (b), (c), and (d). 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 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 by proper choosing the geometry of the capacitance and the inner ring ($L_1$); then, the third mode is setting by choosing the proper dimension of the middle ring ($L_2$); and finally, the second mode is setting by choosing the proper dimension of the outer ring ($L_3$).

The simulated response of the triple notched UWB antenna (3.5 GHz, 5.8 GHz, and 7.5 GHz) containing the tri-ERR described above is presented in Fig. 7.

In Table I, the characteristics of the previously reported tri-band notched UWB antennas are compared with this work. For the simulation and the experimental verification, we used the substrate of 50×50 mm. The ground plane size of this antenna affects the lower cut-off frequency, so by using the 35×35 mm substrate, the simulations show practically the same results suitable for UWB (lower cut-off frequency of 3.1 GHz). Though the notched antenna in [13] contains only one resonator providing three notches (similar case), increasing number of notches is limited by a worse performance of the antenna. The authors of [13] argue that “...the more the number of resonators used the more complicated the UWB system is.” Moreover, for higher frequency, the degradation of responses is observed (Fig. 2 (b) in [13]).

VI. RECONFIGURABLE UWB BAND-NOTCHED ANTENNA

For a design of the reconfigurable notched response, we propose to use a digital variable capacitor (DVC) instead of ERR’s quasi-lumped capacitance. As it follows from the current distribution (Fig. 6), only the resonant frequency of the first mode is influenced by the capacitance value. The higher modes are insensible to the capacitor inclusion. The reconfigurability of the tri-ERR with inserted DVC 32CK301 by Cavendish Kinetics Inc. [24] is demonstrated in Fig. 8 (loss

**Table I**

<table>
<thead>
<tr>
<th>f1/f2/f3 [GHz]</th>
<th>Number of notching elements</th>
<th>Antenna dimensions [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work</td>
<td>3.5/5.8/7.5</td>
<td>50×50</td>
</tr>
<tr>
<td>[5]</td>
<td>3.5/5.5/8.2</td>
<td>32×35</td>
</tr>
<tr>
<td>[6]</td>
<td>3.5/5.5/7.5</td>
<td>28×30</td>
</tr>
<tr>
<td>[7]</td>
<td>3.6/5.6/8.3</td>
<td>27×30.5</td>
</tr>
<tr>
<td>[8]</td>
<td>3.5/5.2/5.8</td>
<td>18×25</td>
</tr>
<tr>
<td>[9]</td>
<td>3.5/5.3/5.8</td>
<td>30×39.3</td>
</tr>
<tr>
<td>[10]</td>
<td>3.5/5.8/6</td>
<td>30×35</td>
</tr>
<tr>
<td>[16]</td>
<td>3.6/5.5/8.2</td>
<td>35×35</td>
</tr>
</tbody>
</table>
factor of the DVC has not been taken into account). Evidently the first resonant frequency of the tri-ERR and the corresponding notch frequency are tuned from 2.8 up to 4.2 GHz by changing the capacitance from 0.4 pF up to 1 pF with the step of 0.01-0.02 pF.

By analogy with the proposed reconfigurable triple notched UWB antenna, frequency tuning of the first notched frequencies in single and double notched UWB antennas can be provided.

VII. CONCLUSION

The planar UWB antenna with the electric ring resonator has been described exhibiting the band-notched characteristics. The antenna is designed as a planar monopole fed by the CPW and the electric ring resonator coupled with the feeding structure. The coupling effect provides the notched characteristics at chosen frequencies in the UWB operating band. The use of a modified multi-mode structure of the ERR is followed by a simplification of a UWB antenna design with the multi-notched response. Finally, using the digital variable capacitor (DVC) instead of ERR’s capacitance provides the reconfigurable notched antenna response.

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