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RADIATION-REJECTION BAND INSERTED DUAL-BAND ANTENNA USING A SPLIT RING RESONATOR FOR BEYOND 4G APPLICATIONS

In-Yong Park,1 Jung-Nam Lee,2 Kwang-Chun Lee,2 Pyeong-Jung Song,2 and Dongho Kim1
1 Department of Electronic Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul 143–747, Korea; Corresponding author; dongkim@sejong.ac.kr
2 Department of B4G Mobile Communications Research, Electronics and Telecommunications Research Institute, 218 Gajeong-ro, Yuseong-gu, Daejeon 305-700, Korea

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ABSTRACT: We propose a very simple but effective method to switch a single-band antenna into a dual-band antenna by inserting a narrow radiation-prohibited band in the middle of the single pass band. To insert the radiation-rejection band, we intentionally induce strong resonance on a metamaterial-motivated split ring resonator (SRR) by placing it near a signal feeding transmission line of a proximity-coupled microstrip patch antenna, which blocks out flow of electromagnetic waves through the line. To maximize the blockage, we cut the SRR into a quadrangular loop that is exactly interlocked with the two sides of the right-angled microstrip line. Consequently, we show that we can split one pass band into two separated pass bands with an inserted sharp stop band in-between. Good agreements between the prediction and the measurement prove the validity of our approach. © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:961–965, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28240

Key words: radiation-rejection band; guard band; B4G antenna; split ring resonator

1. INTRODUCTION

Recently, mobile communication services have dramatically evolved to the current fourth generation (4G) system that is represented by long-term evolution (LTE) or LTE-advanced technology. Currently, to support an expected explosive increase of data transmission speed and cell capacity in future mobile communication environment, ongoing study continuously extends its research areas beyond 4G (B4G) systems [1].

In accordance with evolution of the mobile communication environment, mobile base station antenna (MBSA) technology has also been developed rapidly. As one prominent approach of useful MBSA techniques, inserting a guard band, which is a sort of suppressed radiation frequency band, has been reported to reduce interference between transmitter and receiver systems [2].

With regard to generation of the guard band, installing an artificial magnetic conductor (AMC) or an electromagnetic (EM) band gap (EBG) material, which is incorporated with an adjacent main radiator, is representative conventional approach [2–4]. Although the mentioned approaches are fairly effective in reducing antenna gain in the guard band, they generally require additional layers or spaces to mount AMCs or EBG structures, which increases complexity and fabrication cost of antennas.

To overcome the problems, we propose a very simple but valuable method to create a radiation-prohibited guard band using a split ring resonator (SRR), which is well-known as one of left-handed metamaterial structures [5, 6]. As was reported in [7, 8], strong energy coupling between a transmission line and a nearby scatterer blocks energy transfer through the line. The strength of the energy blockage is proportional to a total number of scatterers installed near the line, which often becomes an obstructive factor in practical implementation especially under circumstances of requiring strong blockage with only a limited small installation space.

In spite of the well-known drawbacks, in this article, we show that we can introduce a guard band in an existing pass band by placing only one SRR near a bent microstrip line, which provides relatively high radiation-rejection property.

For experimental verification, we apply our idea to a dual-band base station antenna for a B4G mobile communication service, which has a target frequency band covering from 2.5 to 2.695 GHz (Rx: 2.5–2.52 GHz and Tx: 2.675–2.695 GHz). All simulation data are obtained using the commercial simulation tool of CST Microwave Studio [9].

2. ANTENNA DESIGN

Figure 1 shows the exploded view of the proposed antenna. For polarization diversity of 90°, we arrange two signal-feed lines orthogonally with each other, which are shown in Figure 1(a). Each end of the lines is directly connected to a 50-Ω coaxial connector using a direct probe feeding method. EM waves flowing along the feed lines couple to the radiating patch shown in Figure 1(b), which accomplishes proximity coupling from the lines onto the radiating patch [10, 11].

As was aforementioned, one of the target applications of our antenna is a base station antenna required for B4G communications, which usually needs multiple stacks of the proposed antennas to meet the desired performance of mobile cells under various operational environments. Therefore, isolation among antennas should be secured as highly as possible. For that reason, we enclosed our antenna with a metallic cavity as shown in Figure 1(c), which is covered by a top radome. As a result, besides high isolation, we can also increase both realized gain and front-to-back ratio (FBR) up to about 7 and 25 dBi (see Figs. 6 and 7), respectively.

In Figure 1(a), we can find two SRRs placed near each corner of the feed lines, which are installed to introduce a very narrow
stop band into a wide pass band. Figure 2(a) tells us how we can get the very sharp stop band by placing the SRR closed to a normal microstrip line. EM waves propagate into Port 2 along a 50-Ω microstrip line etched on the same substrate used in Figure 1(a). When we put the SRR near the line, the SRR resonates at a specific frequency at which the circumferential length of the SRR becomes about a half of a guided wavelength. At the resonant frequency, the SRR strongly resonates as shown in the inset in Figure 2(a), which conceptually illustrates flowing of induced surface current density. The thicker and the longer arrows mean the stronger current density. From Figure 2(b), it is worth noting that we can change the bandwidth of $S_{11}$ by increasing or decreasing the gap distance ($g_1$) between the microstrip line and the SRR, which can be explained by parasitic inductance and capacitance [12]. In other words, we can control any radiation-rejection bandwidth by changing the distance $g_1$.

**Figure 1** Geometry of the proposed antenna for (a) signal-feed lines, (b) a radiating patch, and (c) a side view of a whole structure with $w_x=70$ mm, $w_y=70$ mm, $w_1=6.3$ mm, $w_2=1$ mm, $w_3=80$ mm, $h_6=37$ mm, $l_6=19$ mm, $l_1=37$ mm, $l_2=29$ mm, $l_3=9.73$ mm, $l_4=9.02$ mm, $g_1=3$ mm, $g_2=1$ mm, $g_3=2.3$ mm, $g_4=1.4$ mm, $h_1=30$ mm, $h_2=1.7$ mm, $h_3=4$ mm, $d_1=1.6$ mm, $d_2=2$ mm, $e_{r1}=e_{r2}=4.3$, and $e_{r3}=3.5$.

**Figure 2** Resonance property of the proposed MTM structure with (a) induced surface current density and (b) $S_{11}$ for some different gap distances ($g_1$). Physical dimension of the SRR is exactly the same with that used in Figure 1(a). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]
The resonance can be explained by strong energy coupling from the line to the SRR, which blocks transfer of almost all energy through the line. Thus, we can introduce a very narrow stop band into a single wide pass band. Consequently, from the remarkably reduced signal transmittance, we can naturally expect that much less power will be radiated through the antenna shown in Figure 1.

There are two important features that should be pointed out: one is that we can place a sharp stop band in an existing pass band with almost no change in overall antenna performance, such as impedance matching bandwidth and antenna gain and so forth. In other words, we can make the antenna operate as a single-band antenna just by eliminating the SRRs without any change in antenna geometry and properties. The other is simplicity in implementation. To maximize energy blockage, we intentionally bend the feed lines at a right angle, which is helpful to increase interlocked lengths between the SRR and the line. Consequently, only one small SRR is sufficient to effectively block waves. Hence, additional layers are totally unnecessary, which are often unavoidable when we use conventional AMC or EBG structures for a similar band separation approach.

Figure 3  Photograph of the proposed antenna: (a) the signal-feed lines, (b) the radiating patch, and (c) the whole structure assembled in a metallic cavity. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 4  Comparison of input reflection coefficients with (a) the SRR (dual-band) and without (b) the SRR (single-band). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]
3. FABRICATION AND EXPERIMENTS

The fabricated components of the proposed antenna are given in Figure 3. Even though the figure is only about the dual-band antenna, every element of the single-band antenna are exactly the same as those shown in Figure 3 except for the SRRs.

Figure 5 Comparison of realized gain with (a) the SRR (dual-band) and without (b) the SRR (single-band). Ports 1 and 2 are used for V- and H-polarization, respectively. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 6 Comparison of radiation patterns measured at 2.54 GHz (in the lower pass band). (a) E-plane and (b) H-plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 7 Comparison of radiation patterns measured at 2.7 GHz (simulation) and 2.76 GHz (experiment; in the higher pass band). (a) E-plane and (b) H-plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]
The measured input reflection coefficients ($S_{11}$) are compared with prediction data obtained by computer simulations, which are given in Figure 4. In Figure 4(a), there is a narrow stop band around 2.6 GHz, which is introduced by resonance of the SRR. It is worth noting that the resonant frequency shown in Figure 2(b) is very close to the frequency at the peak of the stop band, which proves the validity of our idea to divide one pass band into two ones.

Regarding the dual-band data, the peak value of $S_{11}$ in the inserted stop band is not large enough. This is mainly because of high material loss of the substrate used for feed lines. In fabrication, we have used a commercial FR-4 substrate, which has large loss tangent of about 0.13. However, it can be clearly shown that our approach of introducing a sharp stop band is so effective, which explains that we can make the dual-band antenna have good impedance matching and high antenna gain both for vertical and horizontal polarization, which are given in Figure 4. In Figure 4(a), there is a narrow radiation-rejection band around 2.6 GHz, which is introduced by resonance of the SRR. It is worth noting that the resonant frequency shown in the figure, there is a radiation-rejection band around 2.6 GHz, which provides a very high-quality factor. Consequently, we can successfully split a single pass band into two individual pass bands that locates very close from each other.

In terms of spectrum management and quality enhancement of communication services, a narrow stop band inserted between Rx and Tx bands plays a fairly important role of providing a guard band, which potentially relieves burdens of band stop filter circuits used for the blocking of noise signals.

Although additional fine tuning to mitigate unwanted frequency shift is required, our approach has great importance in that it can be directly applicable to commercial base station antennas.

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4. CONCLUSION

We have proposed a dual-band antenna for B4G applications. Instead of applying a conventional complicated multiple resonance scheme, we have used coupled resonance of the SRR, which provides a very high-quality factor. Consequently, we can successfully split a single pass band into two individual pass bands that locates very close from each other.

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ABSTRACT: A MIMO antenna with low ECC is proposed for a 4G mobile terminal. Apart from the resonant mode induced by the ordinary