Design of a Circular-Slot Multiband (UWB) Antenna with Non-Periodic DGS for WLAN/WiMAX Applications

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Abstract. The paper discusses bandwidth enhancement of a microstrip patch antenna. It explores the application of DGS with parasitic elements to obtain a compact UWB multiband antenna. The antenna is designed on a 14*25 mm² RT-Duroid (5880) substrate. A comparison is made between four antenna designs with the same dielectric substrate. The antenna design with circular slot on the patch, facilitated with the shorting pins, shows bandwidth enhancement. It uses non-periodic Defective Ground Structure (DGS) for improvement in return loss characteristics, bandwidth enhancement and multiband operation. The slot on the patch provides compact size and DGS gives wide bandwidth (80.5%) with five resonant frequencies of 0.92 GHz, 2.36 GHz, 3.46 GHz, 4.78 GHz & 7.9 GHz making it applicable for GSM (890-966 MHz), WLAN/WiMAX (2.4/3.6/4.9), multi-band applications.

Keywords: DGS, Return loss, Bandwidth, GSM, WLAN, WiMAX.

1. Introduction

The diversification of wireless technology thirsts for integrated components composing antennas. Antenna is an important peripheral of wireless technology. Multi-band operation, low profile, simple feeding technique, compact size make microstrip patch antennas popular candidates for modern wireless communication systems. Multi-band working in particular capacitates multi-application antenna. Vigorous research in the field has encouraged the realization of new antenna designs for WLAN/WiMAX applications. IEEE 802.11 workgroup has documented the use of WLAN in five distinct frequency ranges: 2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz and 5.9 GHz bands and IEEE 802.16 assigns frequency bands 2.3 GHz, 2.5 GHz, 3.3 GHz, 3.5 GHz and 5.8 GHz for WiMAX applications. Various antenna designs have been characterized to support different communication systems like WLAN/WiMAX & multi-band operation. Dang et.al in [1] adopted rectangular and trapezoid slots on ground plane for triple-band WLAN/WiMAX applications. W. Hu et.al [3] utilized Symmetrical square slot with L strips for achieving a compact structure suitable for WLAN/WiMAX applications. R. Karimian et.al [4] discussed a novel F shaped slot planar antenna. An inverted U-shaped slot radiator facilitated by defective ground structure was utilized by A. Kunwar [6]. Inverted L-slot with defective ground structure was presented by A. Kunwar et.al [7] for WLAN/WiMAX applications. X Li et.al [8] introduced asymmetric coplanar strip-fed monopole antenna for multi-band operation. P. Liu et.al [9] adopted meandering split ring slot along with modified rectangular slot and symmetrical inverted-L strips. A rectangular ring monopole with a vertical strip, fed by CPW feed line was proposed by A. Z. Manouare et.al [10]. M Palandoken [11] used capacitive and inductive coupling of two open-ended ring resonators for generating dual band. Application of asymmetric loops with
asymmetric feed was exploited by C. M. Peng et al [12]. X. Ren [13] optimized a monopole antenna with hybrid strips for WLAN/ WiMAX applications. S. Verma et al [14] put forth the use of inverted parasitic F-element in inverted L-monopole antenna for dual band applications. H. Wang et al [15] employed a low-height PIFA. Xu-bao Sun et al [17] opted an antenna array of two patches with six rectangular strips on a single substrate and common ground for WLAN applications. H. Zhai et al [18] applied three circular-arc-shaped strips.

All the antenna designs above had the motivation of achieving wide resonance bandwidth with compact antenna size so as to be compatible with WLAN systems. In the present paper a compact UWB-DGS multiband antenna with parasitic elements is explored. The proposed antenna is optimized by studying the other three designs, discussed in antenna design and analysis. Individually all the designs exhibit multiband operation, but the optimized design is proficient to resonate for broad bandwidth of 7.64 GHz (1.84–9.48 GHz) with compact surface area of 350 mm².

2. Antenna Design and Analysis

Fig. 1 depicts the structure of the proposed antenna design. The proposed design has a 14*25 mm² RT-Duroid(5880) substrate with dielectric constant, \( \varepsilon_r = 2.2 \) and 3.175 mm thickness.

![Figure 1. (i) Front, (ii) back & (iii) side view of optimized antenna.](image)

The antenna is fed by Microstrip feedline connected to a square resonator having circular slot. The slot increases the excited patch surface current path, which lowers the resonant frequency and compact antenna size is obtained. In addition, two parasitic resonators adjacent to feed line are taken. Optimized width of feedline \( W_f \), is obtained from the relation [2],

\[
\frac{W_f}{h} = \begin{cases} \frac{8e^{-A}}{e^{+A} - 2}, & \frac{W_f}{h} < 2 \\ \frac{2}{\pi} \left[ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \{ \ln(B - 1) + 0.39 \} - \frac{0.6}{\varepsilon_r} \right], & \frac{W_f}{h} \geq 2 \end{cases}
\]

Where \( A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{\varepsilon_r + 1} \left( \frac{0.11}{\varepsilon_r + 0.23} \right)^2 + 1} \) and \( B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \), \( h \) is the thickness of substrate, \( Z_0 \) is characteristic impedance (50 Ω) of the feedline and \( \varepsilon_r \) is the dielectric constant of the substrate.

Four designs, with same ground plane, were examined for return loss characteristics and final design was optimized considering the UWB nature. The proposed antenna consists of a circular slot on the rectangular patch. The microstrip line has two adjacent rectangular parasitic resonators, with two shorting pins below them. The microstrip feedline is used to feed the shorted patch to obtain wide bandwidth. The Antenna-I doesn’t have circular slot, parasitic resonators and shorting pins. The
Antenna-2 includes only the circular slot. The Antenna-3 doesn’t have the shorting pins. The top view of designs is as shown:

![Comparison of Antenna Designs](image)

**Figure 2.** Comparison of Antenna Designs.

A comparison is made for the return loss variation amongst various antenna designs and optimized design is selected based on bandwidth of antenna. The return loss characteristics of all of the above designs depict multiband resonance in all the designs. The first three antennas resonate in WLAN application region, but bandwidth is small while the fourth design has wide bandwidth. Hence the fourth design is considered as optimized design. The various dimensions of optimized design are given in form of table 1.

**Table 1.** Parameters of UWB Patch Antenna.

| Parameter | Dimension (mm) | Parameter | Dimension (mm) |
|-----------|----------------|-----------|----------------|
| $L$       | 25             | $b$       | 3              |
| $B$       | 14             | $l_1$     | 17.5           |
| $L_i$     | 12             | $l_2$     | 19.5           |
| $B_i$     | 12             | $l_3$     | 3              |
| $L_f$     | 12             | $l_4$     | 2              |
| $W_f$     | 3.68           | $l_5$     | 11             |
| $R$       | 10             | $b_1$     | 12             |
| $h$       | 3.175          | $b_2$     | 3.8            |
| $a$       | 3.5            | $b_3$, $b_4$ | 1              |

![Variation of Return Loss Characteristics for Different Designs](image)

**Figure 3.** Variation of Return Loss Characteristics for Different Designs.

The optimized design shows multiband operation suitable for WLAN/WiMAX applications. The surface current path increases from 12 mm to 31.5 mm as a consequence of circular slot. It modifies the return loss values at lower frequencies and introduction of parasitic resonators gives rise to triple band operation below 4GHz. These characteristics get greatly modified with the addition of shorting pins (radius 0.3 mm and height 3.175 mm) as antenna shows improvement in return loss value of first resonance at 0.9 GHz. The bandwidth modification occurs due to use of parasitic resonators and shorting pins.

The resonances are triggered from various parts of antenna and by varying the dimensions of these parts, the dependence of resonance on them can be calculated. The first resonance is triggered due to the width of rectangular strips ($l_2$ & $l_1$) on ground plane of the antenna. The length of the antenna responsible for first resonance will be:

$$L_{n_1} = 2(l_2 + l_1 + 4b_1) + 3b_4 - 4(2b_3 + R + l_4)$$  \hspace{1cm} (2)
It nearly comes out to be 117 mm and this resonant length will be half the wavelength in the medium [16]. The resonant frequency is obtained using [16],

\[ f_r = \frac{c}{2L_r \sqrt{\varepsilon_{\text{eff}}}} \]  

(3)

Here \( \varepsilon_{\text{eff}} \) is the effective dielectric constant of the substrate of antenna and its value is [5],

\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + 10 \frac{h}{W} \right]^{1/2} \] 

(4)

With \( \varepsilon_r \) = dielectric constant of the substrate, \( h \) = height of the substrate & \( W \) = width of the patch. From the simulated results, the first resonance is found to occur at 0.92 GHz; theoretically the first resonant frequency \( f_{r_1} \) comes out to be nearly 0.93 GHz.

The second resonance is triggered due to the width of vertical rectangular strip \( l_1 \) on ground and \( W_f \) on the patch. The resonant length of antenna is 44.8mm obtained as:

\[ L_{r_2} = 2\left[l_1 + b_3 + b_4\right] + W_f + l_4 \] 

(5)

It gives \( f_{r_2} = 2.42GHz \) which is in good agreement with its simulated value of 2.36 GHz. The width of rectangular strips \( l_1 \) & \( l_2 \) has considerable impact on first and second resonance. To interpret this relation return loss patterns with different values of \( b_3 \) & \( b_4 \) are plotted

2.1. Dependence of first and second resonance on \( b_3 \) and \( b_4 \)

The return loss characteristics of antenna for different values of \( b_3 \) (1 mm to 2.5 mm) varied by 0.5 mm is plotted. The graph clearly shows dependence of \( f_{r_1} \) & \( f_{r_2} \) on \( b_3 \). As \( b_3 \) is increased the effective resonant length of the antenna for first and second resonance increases, which in turn decreases the resonant frequencies. The simulated results are in good agreement with this conclusion.

The antenna is simulated for different values of \( b_4 \) (1 mm to 2.5 mm) in difference of 0.5 mm and corresponding return loss patterns are plotted to make a comparison of the dependence of \( f_{r_1} \) & \( f_{r_2} \) on \( b_4 \). The variation \( b_4 \) has different effect on resonance. For first resonance it decreases the effective resonant length and as a result, resonant frequency increases. But it adds up into resonant length for second resonance and hence antenna resonates at a lower frequency for second resonance.

**Figure 4.** Return loss vs. frequency with variation of \( b_3 \).

**Figure 5.** Return loss vs. frequency with variation of \( b_4 \).
3. Radiation Patterns at Various Resonance Frequencies.
The radiation patterns for the antenna in elevation plane for various resonant frequencies at phi = 0° & 90° are plotted using FEM-based software. At 0.92 GHz, E-plane patterns are similar to dipole radiation pattern. The similar behavior is observed at 2.36 GHz. The radiation patterns at 3.46 GHz tend to become bidirectional in E-plane at phi= 90°. But in E-plane at phi=0° radiation pattern is omnidirectional. Overall E-plane patterns are dipole-shape radiation pattern. The non-periodic DGS is responsible for these omnidirectional radiation patterns.

![Figure 6. Radiation pattern of antenna at various resonance frequencies.](image)

4. Comparison of Proposed Antenna with Reference Antennas.
A comparison of proposed antenna with the references is done in table 2. The bandwidth of proposed antenna is wider than bandwidth of any of the references used. Thus proposed antenna can be treated as modified version of references.

| Reference | Size (mm²) | Frequency range (GHz) | Bandwidth (GHz) |
|-----------|------------|-----------------------|-----------------|
| 6         | 10 * 26    | 2.40-2.52, 3.40-3.60, 5.0-6.0 | 0.12, 0.20, 1.0 |
| 8         | 18 * 37    | 2.35-2.53, 3.34-3.85, 5.05-6.28 | 0.18, 0.51, 1.23 |
| 11        | 60 * 90    | 2.18-2.76, 4.80-6.10 | 0.58, 1.3 |
| 12        | 11 * 33    | 2.3-2.7, 3.3-3.8, 4.9-5.85 | 0.4, 0.5, 0.95 |
| 18        | 18 * 37    | 2.38-2.78, 3.28-3.76, 4.96-5.96 | 0.40, 0.48, 1.00 |
| Proposed  | 14 * 25    | 0.86-1.00, 1.84-9.48 | 0.14, 7.64 |

5. Conclusion.
A novel circular slot antenna with non-periodic DGS is discussed for UWB and multiband operation. The DGS controls resonance characteristics of the antenna and provides wider bandwidth. The effect of the dimensions of the antenna on the resonant frequencies is compared in form of mathematical as well as simulated results. The simulated results are in agreement with the results of design equations.
making it suitable for WLAN/WiMAX multiband applications.

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