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Ring Slot Antenna for WiMAX Application

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A B S T R A C T :

WiMAX (Worldwide Interoperability for Microwave Access) technology provides high-speed broadband wireless access over long distances, making it ideal for fixed wireless services, last-mile connectivity, and rural internet access. To support these applications, antennas with compact size, high performance, and ease of integration are essential. In this project, a Defected Ground Structure (DGS)-based ring slot microstrip antenna is designed and analyzed to operate at 3.5 GHz, a key frequency band in WiMAX communications. The antenna is developed on an FR4 substrate with a dielectric constant (εr) of 4.4, loss tangent (tan δ) of 0.02, and a thickness of 1.6 mm. The overall physical dimensions of the antenna are 52 mm × 43 mm × 1.6 mm, and its electrical volume corresponds to approximately $0.607\lambda_o \times 0.501\lambda_o \times 0.0186\lambda_o$ at 3.5 GHz. The design employs a ring slot radiator combined with a DGS for enhanced impedance matching and size reduction. Simulated using Ansys HFSS, the antenna achieves a return loss (S11) of −22.68 dB at the resonant frequency of 3.5 GHz, with a VSWR of 1.16 and a directional radiation pattern, making it suitable for point-to-point WiMAX communication. The compact structure, strong reflection coefficient, and stable radiation characteristics confirm the antenna's suitability for integration into modern wireless systems, especially for WiMAX-based applications.

Keywords: WiMAX, Microstrip Antenna, Ring Slot Antenna, Defected Ground Structure (DGS), FR4 Substrate, Return Loss (S11), VSWR, Impedance Matching, Directional Radiation Pattern.

1.Introduction

The increasing global need for reliable, high-speed wireless connectivity has led to the development of advanced broadband communication technologies, among which WiMAX (Worldwide Interoperability for Microwave Access) stands out as a prominent solution. WiMAX supports both fixed and mobile wireless access and is capable of delivering data rates up to 70 Mbps with coverage extending several kilometers. It is particularly effective in providing last-mile internet access, especially in remote and underserved regions where the deployment of wired infrastructure is challenging. One of the key operational frequency bands in WiMAX systems is 3.5 GHz, which offers a balance between range and data throughput, making it ideal for fixed broadband wireless applications. To fully exploit the capabilities of WiMAX, the design and implementation of high-performance antennas become a critical requirement. Antennas used in these systems must exhibit characteristics such as compact size, good impedance matching, high gain, stable radiation patterns, and low fabrication cost. Microstrip patch antennas, due to their planar structure, ease of fabrication, and compatibility with printed circuit board (PCB) technology, are widely utilized in such applications. However, conventional microstrip designs often suffer from narrow bandwidth, lower radiation efficiency, and limited gain. To overcome these drawbacks, Defected Ground Structure (DGS) techniques have been employed. DGS introduces intentional discontinuities in the ground plane, which effectively alters the current distribution, suppresses unwanted surface waves, and improves radiation efficiency and impedance bandwidth. Integrating DGS with a ring slot radiating element not only improves return loss and compactness but also allows for better control over the antenna's resonant behavior.

In this work, a DGS-based ring slot microstrip antenna is proposed, designed to resonate at 3.5 GHz, specifically targeting WiMAX applications. The antenna is fabricated on a cost-effective FR4 substrate with a dielectric constant (εr) of 4.4, loss tangent (tan δ) of 0.02, and a thickness of 1.6 mm. The overall antenna dimensions are 42 mm × 42 mm × 1.6 mm, corresponding to an electrical size of $0.607\lambda_o \times 0.501\lambda_o \times 0.0186\lambda_o$, making it compact enough for integration into modern wireless devices. The antenna is simulated using Ansys HFSS, a high-frequency electromagnetic simulation software. The simulated results show a return loss (S11) of −22.68 dB at 3.5 GHz, indicating excellent impedance matching. The Voltage Standing Wave Ratio (VSWR) is observed to be 1.16, confirming low reflection, and the radiation pattern exhibits directionality, making it suitable for targeted communication links. Additionally, the design ensures stable performance in the intended frequency band, contributing to efficient spectrum utilization. By addressing the limitations of conventional designs and enhancing performance using modern techniques, the proposed antenna stands as a viable solution for WiMAX communication systems, particularly in scenarios requiring compactness, cost-efficiency, and reliable signal integrity.

1.1. HFSS

Ansys HFSS 13.0 is a powerful 3D full-wave electromagnetic field simulation software based on the Finite Element Method (FEM). It is extensively utilized for the design and optimization of high-frequency and high-speed components such as antennas, RF/microwave circuits, and waveguides. HFSS enables the accurate calculation of S-parameters, return loss, voltage standing wave ratio (VSWR), current distribution, radiation efficiency, and far-field patterns. Version 13.0 of HFSS includes enhanced meshing algorithms, adaptive refinement techniques, and advanced solver options to provide high precision in complex simulations. The software supports parametric and optimization studies, allowing designers to investigate the influence of various geometric and material parameters on antenna performance.

In this work, HFSS 13.0 is employed to simulate the proposed DGS-based ring slot microstrip antenna operating at 3.5 GHz. It enables the evaluation of critical performance metrics including return loss (S11), impedance bandwidth, gain, and radiation characteristics. The tool's ability to visualize field distributions and simulate real-world conditions ensures the antenna design meets the required specifications for WiMAX-based wireless communication systems.

2. Design of Proposed antenna

The proposed antenna is designed to operate at a resonant frequency of 3.5 GHz, targeting applications in WiMAX communication systems. The structure is based on a ring slot microstrip antenna integrated with a Defected Ground Structure (DGS) to enhance performance in terms of bandwidth and impedance matching while maintaining compact dimensions. The antenna is fabricated on an FR4 epoxy substrate, which has a dielectric constant (εr) of 4.4, a loss tangent (tan δ) of 0.02, and a substrate thickness of 1.6 mm. The overall dimensions of the antenna are 52 mm × 43 mm × 1.6 mm, corresponding to an electrical size of approximately $0.58\lambda_0 \times 0.58\lambda_0 \times 0.022\lambda_0$ at 3.5 GHz, making it suitable for integration in compact wireless devices. The Figure 1 will illustrate our antenna design.

The design comprises a centrally placed ring slot etched on the radiating patch and a rectangular defect introduced in the ground plane to form the DGS. The ring slot structure acts as the primary radiator, while the DGS enhances the current path and suppresses surface waves, leading to improved impedance characteristics and radiation efficiency. A 50-ohm microstrip feed line is used to excite the antenna, ensuring proper matching with standard RF ports.

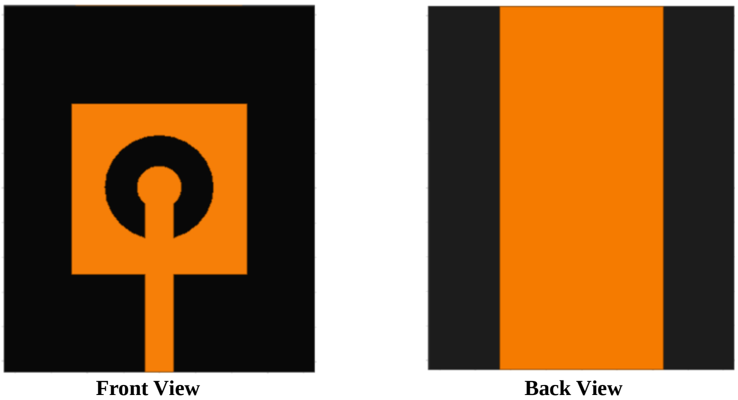

Figure 1 – Layout of the Proposed antenna

2.1. Antenna parameters

The geometry of the proposed DGS-based ring slot microstrip antenna is defined by a set of critical design parameters that govern its performance in the WiMAX frequency band. These parameters include the overall dimensions of the substrate, patch, feed line, ring slot, and ground structure. Each parameter is carefully chosen and optimized to ensure proper resonance at 3.5 GHz, efficient impedance matching, and compact physical size. The detailed description of the parameters used in the antenna design is as follows:

- **L** and **W** represent the length and width of the substrate, determining the overall size and boundary limits of the antenna.
- **Pl** and **Pw** denote the length and width of the radiating patch, which directly influence the resonant frequency and radiation characteristics.
- **FL** and **FW** are the length and width of the feed line, responsible for delivering the RF signal to the patch with minimal reflection.
- **R1** and **R2** represent the inner and outer radii of the ring slot, forming the core radiating structure and affecting the impedance and bandwidth.
- **GW** refers to the width of the defected ground slot, which is introduced to alter the current distribution on the ground plane and improve return loss.

Parameters	L	W	P_l	P_w	F_L	F_W	R1	R2	G_W
Value in (mm)	52.72	43.04	24.58	24.33	13.41	3.98	7.54	3.10	23.08

Table 1 : Parameter of the proposed antenna

2.2. Formulas are used for proposed antenna

In the design of the ring slot microstrip antenna loaded with Defected Ground Structure (DGS) for WiMAX applications, various formulas were used to analyze and optimize key parameters such as resonant frequency, bandwidth, impedance, and return loss. Below are the important formulas used in the project:

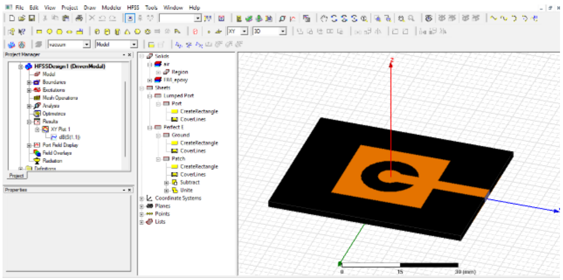

Figure 2 – Design of Ring Slot Antenna

2.2.1. Formulas are used for proposed antenna

The funda mental antenna parameters, such as the resonant frequency and size of the proposed antenna, are initially calculated using the basic microstrip patch antenna design equations (Equations (1) to (6)). Following this, calculations for the ring slot are per formed (Equations (7) to (12)). To achieve better impedance matching, further optimization is carried out after these initial calculations. The antenna is composed of a ring slot antenna, a microstrip feed line of width FW for 50Ω impedance matching on the front side and defected ground structure on the back side.[1]

$$f_r = \frac{c}{2L\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{2}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-1/2} \tag{3}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{5}$$

where f_r is the resonant frequency, c the speed of light in a vacuum (3×108m/s), ε_{eff} the effective dielectric constant of the substrate, h the height of the substrate, W width of the patch, ε_{eff} the effective dielectric constant, ε_r the relative permittivity (dielectric constant) of the substrate, ΔL the extension in patch length, Leff the effective length of the patch, and L the length of the patch.[1]

2.2.2. Equation used for Design of the Ring Slot antenna

$$\lambda_{eff} = \frac{c}{f_r\sqrt{\varepsilon_{eff}}} \tag{6}$$

$$r_{mean} = \frac{r_i+r_0}{2} \tag{7}$$

$$2\pi r_{mean} = \frac{\lambda_{eff}}{2} \tag{8}$$

$$r_o = r_{mean} + \frac{w_s}{2} \tag{9}$$

$$r_i = r_{mean} - \frac{w_s}{2} \tag{10}$$

$$w_s = r_o - r_i \tag{11}$$

where λ_{eff} is the effective wavelength, r_{mean} the mean radius of the ring, r_i the inner radius of the ring, r_o the outer radius of the ring, and w_s the slot width.[1]

3. Performance Analysis for proposed antenna

To assess the performance of the proposed DGS-based ring slot microstrip antenna designed for WiMAX applications, full-wave electromagnetic simulations were performed using Ansys HFSS (High-Frequency Structure Simulator). The analysis focused on key parameters such as the return loss (S-parameter), voltage standing wave ratio (VSWR), and far-field radiation patterns at the operating frequency of 3.5 GHz. The return loss (S11) indicates the amount of power reflected back from the antenna due to impedance mismatch. From the simulation in HFSS, the antenna shows a clear resonant frequency at 3.5Ghz GHz, with a minimum return loss of −22.68 dB. This reflects excellent impedance matching between the antenna and the feed line, ensuring minimal reflection and maximum power transmission. The −3 dB bandwidth obtained is suitable for narrowband WiMAX communication, confirming the antenna's capability to operate efficiently in the desired frequency range. The Figure 3 will indicate the VSWR plot

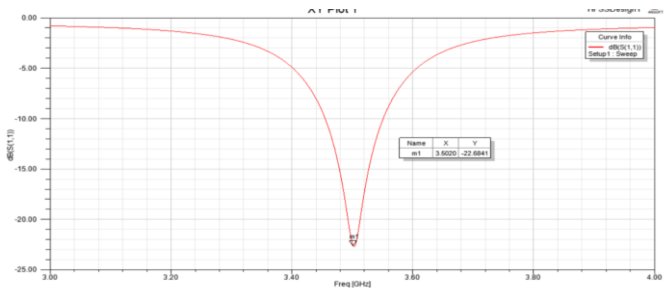

Figure 3 - S – Parameter $|S_{11}|$ [Return loss] plot

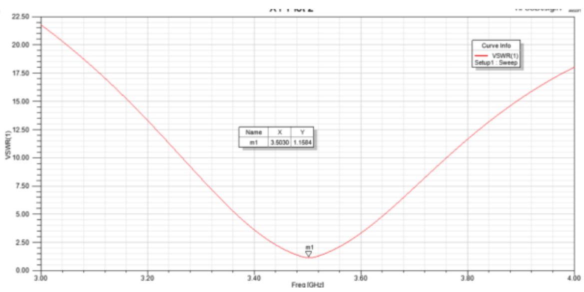

Figure 4– VSWR Plot

The simulated VSWR value at 3.5 GHz is approximately 1.16, which is well below the acceptable threshold of 2.0. This indicates that the antenna exhibits low reflection and good impedance matching at the resonant frequency, contributing to efficient energy transfer from the source to the antenna. A VSWR value close to 1 implies near-ideal matching, which is particularly crucial for communication systems like WiMAX that demand high reliability and minimal signal loss. The antenna's 3D far-field radiation pattern simulated in HFSS illustrates a directional radiation behavior, with strong forward radiation and suppressed back radiation. The E-plane and H-plane 2D radiation plots also confirm consistent and stable beam formation.

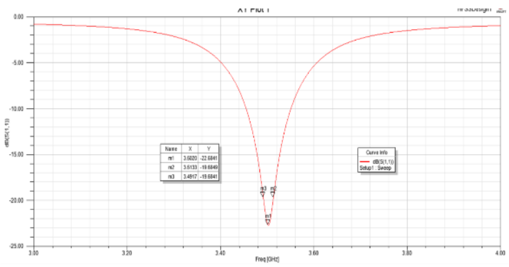

Figure 5 – Bandwidth Plot

The bandwidth of the antenna is measured at the −3 dB return loss threshold, which spans **from 3.49 GHz to 3.51 GHz**, resulting in a total bandwidth of **20MHz**. This bandwidth is sufficient to support WiMAX communication standards, which typically require wide and stable operating frequency bands for reliable broadband access. Such a directional pattern is beneficial for point-to-point WiMAX applications, where focused radiation leads to higher gain and better link quality. The gain at 3.5 GHz, while moderate, is adequate for short- to medium-range wireless transmission scenarios.

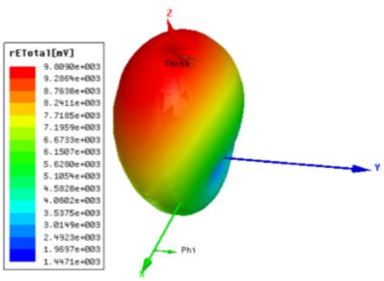

Figure 6 – Gain Plot

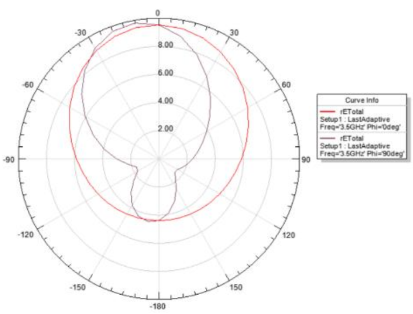

Figure 7 – Radiation Pattern

Conclusion

In this project, a compact DGS-based ring slot microstrip antenna was designed and analyzed for WiMAX applications operating at 3.5 GHz. The antenna was developed on an FR4 substrate with a dielectric constant of 4.4 and a loss tangent of 0.02, offering a cost-effective and practical solution for fixed wireless access systems. Using Ansys HFSS, the antenna’s performance was thoroughly evaluated. The simulation results demonstrated a resonant return loss (S11) of −22.68 dB, confirming strong impedance matching. The corresponding VSWR of 1.16 indicates minimal reflection and efficient power transmission at the target frequency. Additionally, the directional radiation pattern makes the antenna suitable for point-to-point communication scenarios in WiMAX networks. The antenna achieves good performance within a compact footprint, making it suitable for integration into wireless devices where space, cost, and efficiency are critical factors. The use of DGS effectively improves bandwidth control and impedance characteristics without significantly increasing the design complexity. Overall, the proposed antenna is well-suited for narrowband WiMAX communication systems and provides a balance between simplicity, performance, and cost-effectiveness.

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