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DESIGN AND SIMULATION OF A CIRCULAR PATCH MICROSTRIP ANTENNA FOR WIMAX 3.5 GHZ APPLICATIONS

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Abstract

A circular patch microstrip antenna for WiMAX applications has been successfully designed and simulated using CST Studio Suite software. The antenna is designed on a lossy FR-4 substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm. The substrate dimensions are 41 mm × 35 mm × 1.6 mm. The circular-shaped patch is modified with double-slot features on the feedline to enhance impedance matching performance. Simulation results indicate that the antenna resonates at 3.5 GHz, achieving a return loss of –19 dB, meeting the minimum standard for wireless communication applications. The VSWR at the resonant frequency is 1.24, and the antenna bandwidth (at –10 dB return loss) reaches 300 MHz, covering the 3.35–3.65 GHz frequency range. The realized gain is 2.33 dBi with a total efficiency of 42.3%. The antenna exhibits a directional radiation pattern with omnidirectional characteristics. These results indicate that the proposed circular patch microstrip antenna is suitable for WiMAX applications, fulfilling essential performance metrics including return loss, bandwidth, and gain, making it suitable for WiMAX-based wireless applications.

Keywords:

Microstrip Antenna, Circular Patch, WiMAX, Return Loss, VSWR

1. INTRODUCTION

The global digital transformation has accelerated innovations in wireless communication technologies, including broadband systems such as WiMAX. WiMAX (Worldwide Interoperability for Microwave Access) is designed to deliver broadband services with wide coverage, high speed, and more cost-efficient implementation compared to wired networks. WiMAX operates over several frequency bands, with 3.5 GHz being a commonly used band worldwide, including in Indonesia [1].

Antenna performance is a crucial component in WiMAX systems. Microstrip patch antennas are widely favored due to their flat profile, lightweight nature, ease of fabrication, and compatibility with modern device surfaces [2]. Among the various patch geometries, the circular patch is notable for its symmetric radiation pattern and support for circular polarization, which helps reduce multipath interference [3].

Several studies have designed microstrip antennas for WiMAX at 3.5 GHz, but challenges remain in impedance matching, bandwidth enhancement, and gain and efficiency optimization, especially when using cost-effective substrates like lossy FR-4 [4]. Structural modifications to the feedline and patch are necessary to achieve optimal performance. Recent studies have demonstrated that circularly polarized microstrip patch antennas designed for WiMAX at 3.5 GHz can achieve wide impedance bandwidth and improved axial ratio, making them suitable for stable broadband communication [5]. In addition, modifications such as the introduction of slots or impedance surfaces have been shown to enhance gain and radiation efficiency without significantly increasing the antenna size [6].

This study aims to design and simulate a circular patch microstrip antenna with slot modifications on the feedline using a lossy FR-4 substrate, operating at 3.5 GHz. Performance evaluation is based on return loss, VSWR, bandwidth, gain, efficiency, and radiation pattern. The results are expected to offer an efficient alternative antenna design for WiMAX and other mid-frequency wireless communication systems [7]

2. METHOD

This engineering research is conducted through simulation using CST Studio Suite. The process begins with a literature review to understand microstrip antenna principles, circular patch characteristics, and performance standards for 3.5 GHz WiMAX antennas.

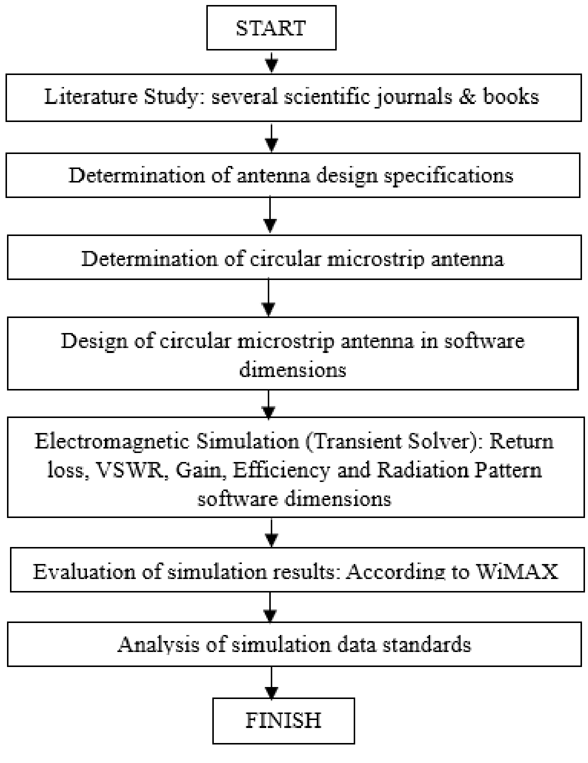

Fig.1. Flowchart of Research

A circular patch geometry with double-slot modifications on the feedline is then designed to enhance impedance matching.

The antenna is designed with an FR-4 lossy substrate (εr = 4.4), thickness of 1.6 mm, and overall dimensions of 41 mm × 35 mm × 1.6 mm. The 3D model is built in CST Studio Suite, focusing on key parameters such as patch size, feedline, and ground plane.

After the modeling process is complete, electromagnetic simulation based on the time domain is conducted using the Transient Solver on CST Studio Suite. This simulation allows for the analysis of antenna characteristics against electromagnetic waves at certain frequency ranges, such as return loss (S11), VSWR, gain, efficiency, and radiation patterns. With this method, the performance of the antenna for WiMAX applications at a frequency of 3.5 GHz can be analyzed comprehensively.

The results of the simulation are then evaluated based on the minimum performance standards of WiMAX antennas, particularly in terms of return loss which must be less than 10 dB, a VSWR value close to 1, as well as gain and efficiency that support wireless signal transmission. The evaluation method used has been widely adopted in previous antenna design studies, where return loss, bandwidth, and efficiency are considered as key benchmarks for WiMAX applications [8]. The steps in this research can be illustrated with a flowchart in Fig.1.

2.1 CALCULATION OF PATCH RADIUS

The radius of the patch for a 3.5 GHz frequency and dielectric constant εr = 4.4 was calculated using the basic formula from Balanis [9]:

$$F=\frac{8.791\times10^{9}}{f_r\sqrt{\varepsilon_r}},\ a=\frac{F}{\sqrt{1+\frac{2h}{\pi F\varepsilon_r}\left(\ln\left(\frac{\pi F}{2h}\right)+1.7726\right)}} \quad (1)$$

$$F=\frac{8.791\times10^{9}}{f_r\sqrt{\varepsilon_r}}=\frac{8.791\times10^{9}}{3.5\times10^{9}\sqrt{4.4}}\approx 2.728\text{mm} \quad (2)$$

$$a=\frac{F}{\sqrt{1+\frac{2h}{\pi F\varepsilon_r}\left(\ln\left(\frac{\pi F}{2h}\right)+1.7726\right)}}=12.1\text{mm} \quad (3)$$

The parameter F is an intermediate value obtained from the resonance frequency (f_r) and the relative permittivity (ε_r) of the substrate. It is used in the calculation of the patch radius (a) for the circular microstrip antenna. Since F does not represent a physical dimension of the antenna, it is not included in the table of physical design parameters. On the other hand, a denotes the actual patch radius and is listed as a key physical dimension.

Additionally, a comprehensive review study highlights that patch radius and related geometrical parameters are critical determinants of resonant frequency and bandwidth in microstrip antenna design. Auxiliary parameters such as *F* serve primarily as computational intermediates rather than physical dimensions, reinforcing why only the actual radius *a* is included in design specifications [10].

From the calculation results, an initial patch radius of approximately ±12.1 mm was obtained. This value was then used in the antenna design in CST Studio. The simulation was carried out using the Transient Solver in CST with a frequency range of 2–5 GHz to analyze antenna performance parameters including Return Loss (S11), VSWR, Gain, Radiation Efficiency, and Radiation Pattern.

2.2 DESIGN ANTENNA

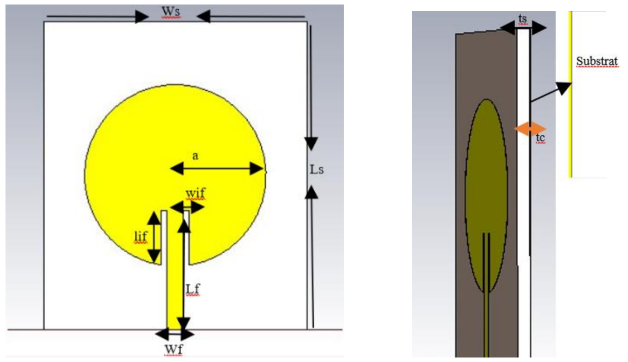

Fig.2. (a) Front view and (b) side view of the circular patch microstrip antenna design with dimension annotations

Table.1. Antenna Design Dimension Specifications

Parameter	Value (mm)	Description
a	12,092	Patch radius
Wf	2.2	Feedline width
Lf	10.4	Feedline length
wif	0.75	Slot width
lif	7.4	Slot length
Ws	35	Substrate width
Ls	41	Substrate length
ts	1.6	Substrate thickness
tc	0.035	Substrate copper

3. RESULTS AND DISCUSSION

The microstrip antenna design in the form of a circular patch with a dual slot modification on the feedline has been simulated using CST Studio Suite for WiMAX applications at a frequency of 3.5 GHz. Evaluation was conducted on the parameters S11, VSWR, bandwidth, gain, radiation efficiency, and radiation pattern.

In Fig.3, the return loss (S11) value obtained from the simulation shows optimal performance at the resonance frequency of 3.5 GHz with a value of 19 dB. This figure is much lower than the minimum standard of 10 dB required for wireless communication, indicating very good impedance matching.

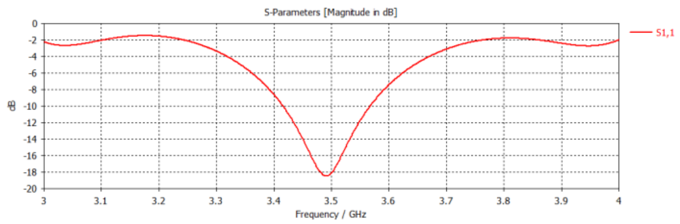

Fig.3. Return Loss Simulation Result of Circular Patch Microstrip Antenna

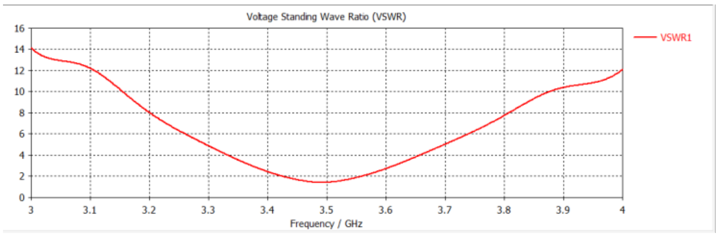

Fig.4. VSWR Simulation Result of Circular Patch Microstrip Antenna

Furthermore, in Fig.4, the recorded VSWR value at that frequency is 1.24, approaching the ideal value (VSWR = 1), which indicates a low power reflection level and high transmission efficiency. This result supports the effectiveness of the dual slot design on the feedline in improving impedance matching.

To verify this simulation result, the theoretical relationship between return loss and VSWR can be calculated using the formulas:

$$|\Gamma| = 10^{S_{11}/20} \quad (4)$$

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (5)$$

By inserting the S11 value of –19 dB:

$$|\Gamma| = 10^{-19/20} \approx 0.112 \quad (6)$$

$$VSWR = \frac{1+0.112}{1-0.112} \approx 1.25 \quad (7)$$

This value is very close to the CST simulation result of 1.24, thus indicating that the numerical results obtained are consistent with the theoretical calculations. This result also confirms the effectiveness of the dual slot design on the feedline in significantly reducing the reflection coefficient and improving impedance matching.

3.1 BANDWIDTH

The bandwidth of the antenna is calculated from the frequency range where the return loss value remains below –10 dB. Based on the simulation results, the antenna operates within the frequency range of 3.35 GHz to 3.65 GHz, providing a bandwidth of 300 MHz. This bandwidth is very sufficient for WiMAX application needs, which require wide transmission channels to support high-speed data services.

This increase in bandwidth is achieved through the modification of the slot on the feedline, which results in changes in current distribution and reduces the reflection value around the operating frequency.

3.2 GAIN, EFFICIENCY AND DIRECTIVITY

Far-field simulation results demonstrate a directivity of 6.08 dBi, but the total gain is recorded at –3.75 dB, with a radiation efficiency of 3.63 dB. This relatively low gain value is caused by the use of lossy FR 4 substrate, which has significant dielectric losses (loss tangent = 0.02), affecting the efficiency of power conversion from electrical current to electromagnetic radiation. However, the high directivity value indicates that the antenna is capable of focusing radiation in a specific direction. Fig.5 shows the 3D radiation pattern indicating that the maximum radiation direction is along the Z-axis, supporting point-to-multipoint communication applications. The sufficiently high directivity value indicates that the antenna can still focus radiation in a specific direction, which is beneficial for wireless communication applications with directional transmission needs or point-to-multipoint.

3.3 RADIATION PATTERN

The 3D radiation pattern shown in Fig.5 and fig.6 illustrates the omnidirectional radiation distribution in the horizontal plane. This characteristic is very suitable for WiMAX applications that demand uniform signal coverage in various directions, especially in urban areas with high multipath potential. The radiation pattern consistently peaks at an elevation angle of 90°, indicating optimal performance in the horizontal plane.

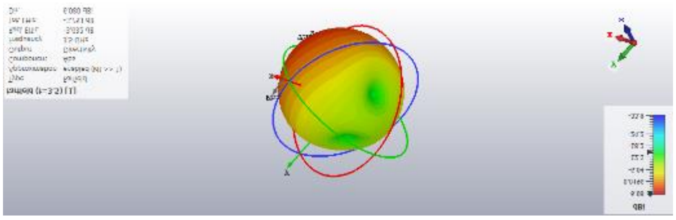

Fig.5. Radiation Pattern of the Antenna at 3.5 GHz with a Directivity Value of 6.08 dBi

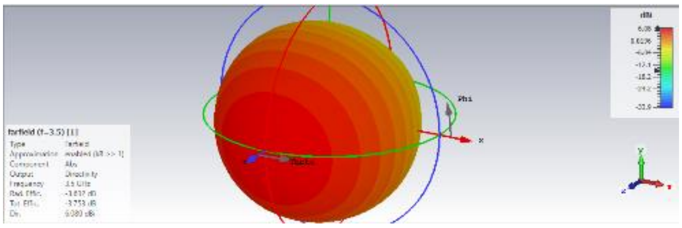

Fig.6. Visualization of the Contour of the Radiation Pattern of the Antenna Surface

3.4 SURFACE CURRENT DISTRIBUTION

The Fig.7 shows the surface current distribution on the circular patch antenna at a working frequency of 3.5 GHz.

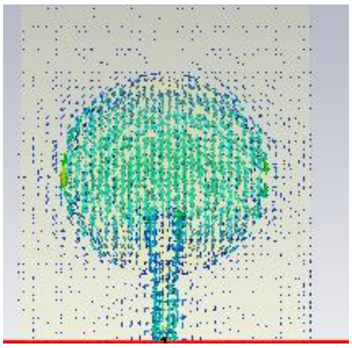

Fig.7. Surface Current Distribution Result

The current is concentrated in the dual slot area on the feedline and spreads evenly across the upper patch surface. This indicates that the slot modification plays an important role in forming additional resonance paths, as well as improving impedance matching and expanding bandwidth. This current distribution also corresponds to the fundamental mode (TM_{11}) characteristics of the circular antenna, where the field is symmetrically distributed from the center to the edge of the patch.

3.5 COMPARISON WITH PREVIOUS STUDIES

To evaluate the performance of the designed circular patch microstrip antenna, a comparative analysis was conducted against several previous studies with similar working frequencies, specifically at 3.5 GHz for WiMAX applications. The parameters compared include return loss, bandwidth, gain, and the type of substrate used.

Table.2. Comparison of Simulation Results with Previous Studies

Study	GHz	dB	MHz	dBi	Substrat
This Study	3.5	-19	300	-3.75	FR-4
Aulia et al. [4]	3.5	-14.5	220	1.2	FR-4
Zhang et al. [11]	3.5	-18.2	250	2.0	Rogers 5880
Wijaya et al. [12]	3.5	-16	180	0.8	FR-4

The designed antenna in this study achieved a return loss of –19 dB, which is better than the results from Aulia et al. [4] (–14.5 dB) and Wijaya et al. [12] (–16 dB). A lower return loss indicates better impedance matching. In terms of bandwidth, this design covers 300 MHz, wider than other studies which generally range from 180–250 MHz. This shows that the double-slot feedline modification positively impacts bandwidth expansion. However, it should be noted that the antenna gain is still relatively low at –3.75 dB due to the use of a lossy FR-4 substrate. Other studies using premium substrates such as Rogers 5880 showed higher gains, such as Zhang et al. [11] who reported a gain of 2.0 dBi. Overall, this antenna design shows advantages in return loss and bandwidth, although there is still room for improvement in gain and radiation efficiency, especially by selecting better dielectric materials.

In addition, recent studies provide further insights into antenna performance at the 3.5 GHz frequency. The experiment by Gupta and Mishra [10] designed an antenna for WiMAX applications with patch dimension optimization, achieving a return loss of approximately –17 dB and a bandwidth of 270 MHz using an FR-4 substrate. These results are comparable to this study, although the obtained bandwidth is slightly narrower. Meanwhile, Chen et al. [8] proposed a multi-parametric optimization approach to improve the performance of microstrip patch antennas, which successfully extended the bandwidth up to 320 MHz and increased radiation efficiency by more than 50%. Compared with this study, which achieved a 300 MHz bandwidth, the proposed design remains competitive and demonstrates potential for further development, particularly in terms of radiation efficiency.

4. CONCLUSION

This study successfully designed and simulated a circular patch microstrip antenna with a double-slot feedline modification using lossy FR-4 substrate for WiMAX applications at 3.5 GHz. Based on simulation results, the antenna demonstrated good performance with a return loss of –19 dB, VSWR of 1.24, bandwidth of 300 MHz, and directivity of 6.08 dBi. Although the recorded gain is relatively low at –3.75 dB due to dielectric losses in the substrate, the antenna still shows strong potential for wireless communication applications. The double-slot modification proved effective in improving impedance matching and expanding bandwidth. Therefore, this antenna design is feasible for WiMAX implementation and can be further developed using substrates with better dielectric properties to enhance efficiency and gain.

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