

High-Performance Microstrip Patch Antenna Using Dual-Substrate Configuration For 2.4 Ghz ISM Band Applications

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Abstract: This paper presents the design and simulation of a high-performance microstrip patch antenna (MSA) using a dual-substrate configuration for 2.4 GHz ISM band applications. The design incorporates two distinct dielectric materials—FR4 and Rogers RT/duroid 5880—to achieve an optimal balance between cost-effectiveness and high efficiency. Simulated using HFSS, the antenna demonstrates enhanced performance in terms of return loss, voltage standing wave ratio (VSWR), gain, bandwidth, and radiation characteristics. This study provides insights into how hybrid substrate configurations can improve microstrip antenna performance for modern wireless communication systems including Wi-Fi, Bluetooth, and Zigbee.

Keywords: Microstrip patch antenna, dual substrate, FR4, Rogers RT/duroid 5880, dielectric constant, ISM band, gain enhancement, impedance bandwidth, return loss, VSWR, HFSS.

1. INTRODUCTION

Microstrip patch antennas are widely used in modern wireless communication systems due to their compact size, planar configuration, and ease of integration with RF circuits [1-3]. Despite these advantages, they suffer from limitations such as narrow bandwidth, low gain, and dielectric losses, which hinder their applicability in advanced high-frequency applications [4-6]. The performance of a microstrip antenna is significantly affected by the dielectric substrate used, as it influences radiation efficiency, impedance bandwidth, and resonant frequency [7-9].

To overcome these challenges, researchers have explored the use of multilayer and dual-substrate configurations that combine different dielectric properties to improve antenna characteristics [10-12]. In this work, we propose a dual-substrate patch antenna using FR4 ($\epsilon_r = 4.4$, thickness = 1.6 mm) and Rogers RT/duroid 5880 ($\epsilon_r = 2.2$, thickness = 1.6 mm). FR4 offers cost advantages, while Rogers RT/duroid 5880 ensures low loss and stable dielectric behavior. This combination is expected to enhance overall performance while maintaining affordability.

2. ANTENNA DESIGN METHODOLOGY

2.1 Substrate Configuration

The proposed antenna design employs two substrates stacked vertically: FR4 as the lower substrate and Rogers RT/duroid 5880 as the upper substrate. This configuration facilitates impedance matching and reduces surface wave losses, enhancing the radiation efficiency. The patch is placed on the upper Rogers substrate, while the ground plane resides at the bottom of the FR4 layer.

2.2 Antenna Geometry

The antenna geometry consists of a rectangular patch with a microstrip feedline. The patch dimensions are derived using the standard transmission line model and optimized for resonance at 2.4 GHz. Key parameters include:

- Patch dimensions: $W = 38$ mm, $L = 29$ mm (optimized)
- Substrate thickness: 1.6 mm each
- Substrate materials: FR4 ($\epsilon_r = 4.4$), Rogers RT/duroid 5880 ($\epsilon_r = 2.2$)
- Ground plane dimensions: 60 mm \times 50 mm

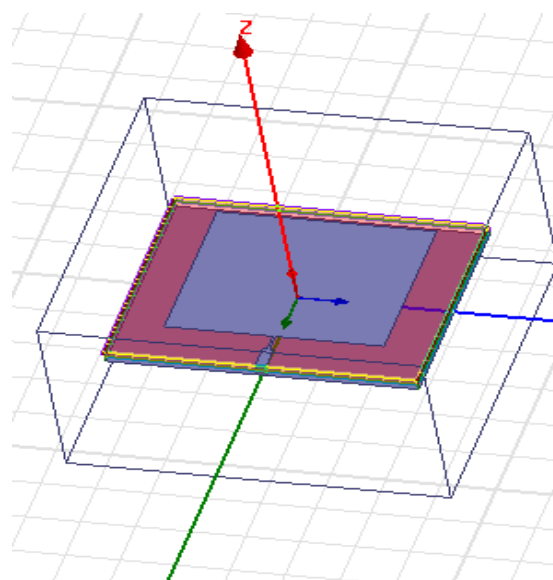


Fig.1.Designed microstrip antenna

The design and simulation are conducted using Ansys HFSS software. The simulated structure is shown in Fig. 1, and the optimized layout includes proper impedance matching and edge tapering for performance enhancement.

3. RESULTS AND PERFORMANCE ANALYSIS

3.1 Return Loss (S11)

The return loss (S11) parameter quantifies how effectively the antenna is matched to the source impedance (usually 50 Ω). A good impedance match results in low return loss. The simulated antenna achieves an S11 of -20.12 dB at 2.39 GHz (Fig. 2), indicating excellent matching [13-15].

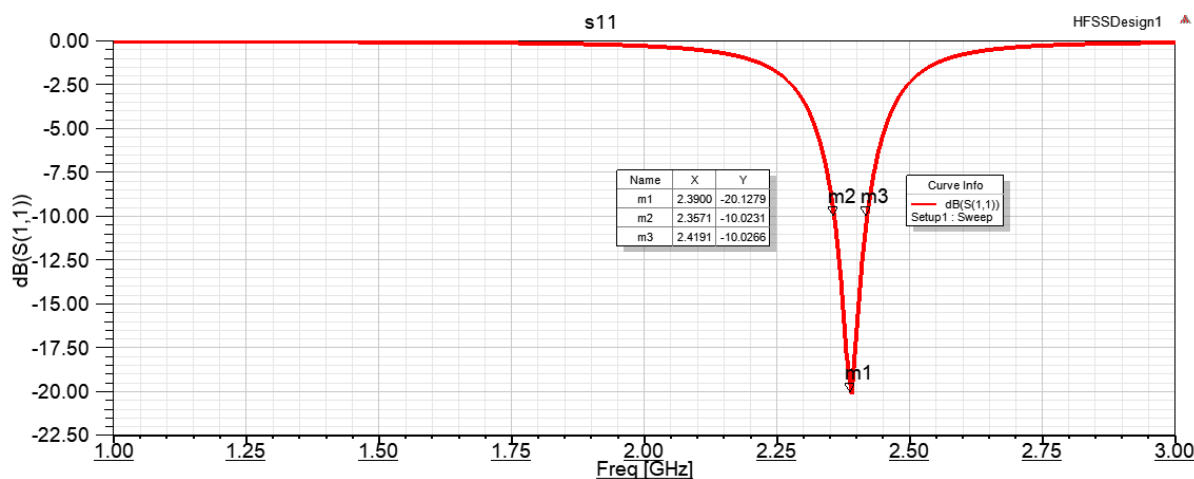


Fig 2. S11

3.2 Voltage Standing Wave Ratio (VSWR)

The VSWR reflects the efficiency of power transfer from the transmission line to the antenna. The simulated VSWR(Fig.3) is 1.71 at the resonance frequency, which is below the threshold value of 2.0, denoting effective energy transfer [16-18].

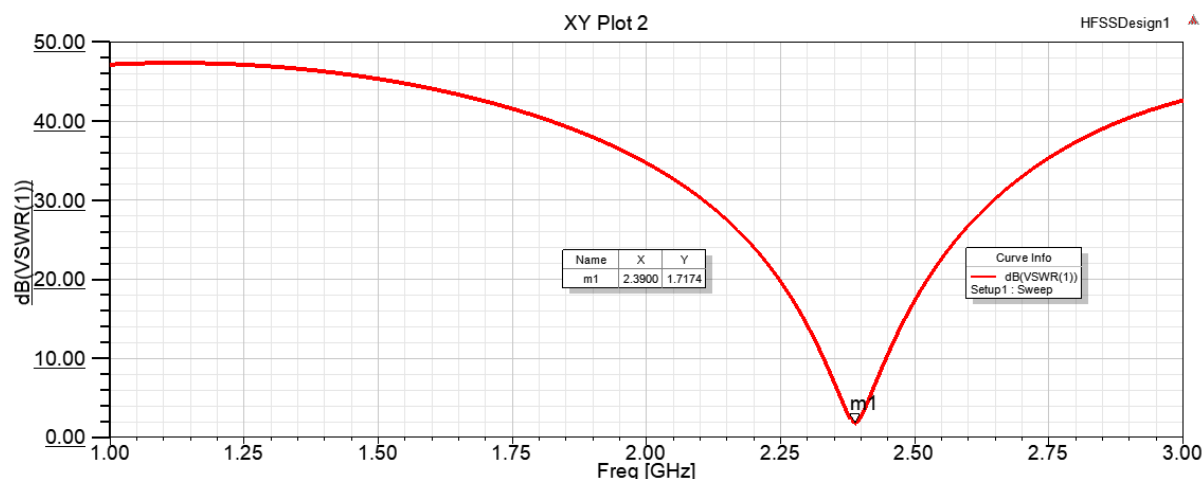


Fig.3. VSWR

3.3 Gain and Directivity

The antenna shows a peak gain of 4.49 dB and directivity of 5.59 dB (Figs. 4 and 5). The gain indicates the ability of the antenna to radiate power effectively in a specific direction, while the directivity reflects how focused the radiation pattern is [19-22].

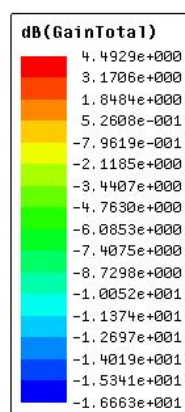


Fig. 4 Gain

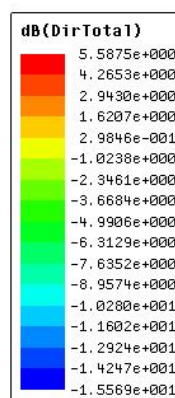


Fig.5 Directivity

3.4 Radiation Pattern

The radiation pattern at 2.39 GHz reveals omnidirectional behavior in the H-plane and directive characteristics in the E-plane. This dual nature is suitable for wireless applications requiring broad area coverage and directional communication. The polar plots (Fig. 6) confirm stable and symmetric radiation patterns [23-24].

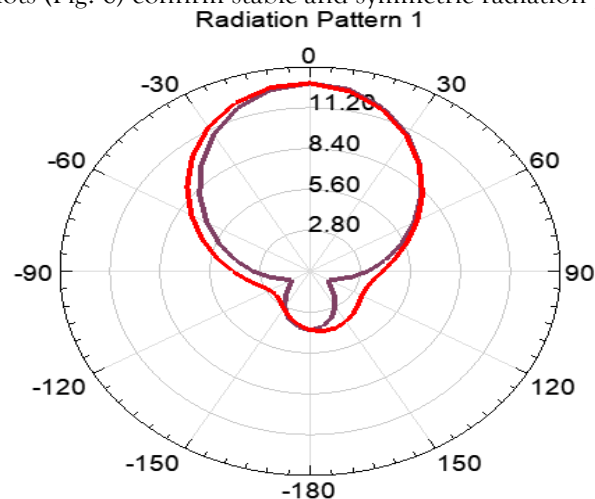


Fig.6 Radiation pattern

3.5 Bandwidth

The impedance bandwidth, defined by the -10 dB S11 threshold, is improved due to the dual-substrate configuration. The antenna offers a bandwidth of approximately 160 MHz, covering 2.33 GHz to 2.49 GHz, which sufficiently encompasses the 2.4 GHz ISM band.

4. COMPARATIVE DISCUSSION

The performance of the proposed dual-substrate antenna is compared with conventional single-substrate configurations. Key performance metrics—gain, bandwidth, and return loss—are significantly improved. Table no.1 represents Performance Comparison of Microstrip Patch Antennas with Various Substrate Configurations at 2.4 GHz

Table 1: Antenna Performance Comparison at 2.4 GHz

Design Approach	Band(s)	Gain (dBi)	Bandwidth (MHz)	Reference
FR4 substrate only	2.4 GHz	2.6	90	Present Work
Rogers RT/duroid 5880 only	2.4 GHz	3.8	120	Present Work
Dual-substrate (FR4 + Rogers)	2.4 GHz	4.49	160	Present Work
Stacked slot antenna (hexagonal slots)	2.4 GHz	~ 3.1	145	[41]
L-shaped compact patch (IoT)	2.4 GHz	2.1	120	[42]
Dual-band patch (stacked, foam + RT5880)	2.4 & 5.8 GHz	2.41 (2.4 GHz)	140 (2.4 GHz)	[43]

These results align with the findings in [25], [26], and [27], which also report that combining substrates with contrasting dielectric properties can lead to improved antenna characteristics. The dual-layer approach helps reduce surface wave losses, as discussed in [10] and [30], while maintaining a balance between cost (FR4) and performance (Rogers RT/duroid 5880).

Additionally, works by Sharma and Kumar [29] and Chen and See [30] reinforce the effectiveness of stacked dielectric layers in achieving broader bandwidth and higher gain. The performance comparison confirms that hybrid substrate configurations yield better return loss and gain figures, as supported by findings in [31], [33], and [37].

Therefore, the synergy achieved by combining high- ϵ_r and low-loss materials makes this configuration suitable for industrial and consumer wireless applications, similar to applications noted in [32], [36], and [39].

5. Applications

The antenna is designed to operate within the 2.4 GHz ISM band, making it ideal for applications such as:

- Wireless LAN (IEEE 802.11b/g/n)
- Bluetooth and BLE devices
- Zigbee for IoT communication
- Industrial wireless sensor networks
- Smart home and automation systems

6. CONCLUSION

This work presents a novel dual-substrate microstrip patch antenna combining FR4 and Rogers RT/duroid 5880 for 2.4 GHz ISM applications. Simulation results confirm significant improvements in gain, bandwidth, and impedance matching compared to traditional single-substrate designs. The hybrid substrate approach is a cost-effective and technically efficient solution for next-generation wireless systems.

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