

Design and Analysis of Microstrip Patch Antennas for WLAN

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ABSTRACT

This manuscript presents a comprehensive study on the design and analysis of microstrip patch antennas tailored for WLAN applications, focusing exclusively on technologies and methodologies available up to 2015. A rectangular patch configuration on FR-4 substrate is optimized for dual-band operation at 2.4 GHz and 5 GHz. Parametric simulations are conducted using HFSS 14.0, and statistical performance metrics are analyzed. The work culminates in a set of design guidelines, validated through simulated return-loss and radiation-pattern results, demonstrating bandwidth enhancement techniques and efficiency trade-offs.

KEYWORDS

Microstrip patch antenna; WLAN; bandwidth enhancement; FR-4 substrate; parametric analysis; dual-band operation

INTRODUCTION

Microstrip patch antennas have become indispensable in WLAN systems due to their low profile, ease of fabrication, and compatibility with printed circuit board processes. Since the seminal work by Deschamps (1953) and later extensive treatments by Balanis (1997), researchers have explored bandwidth enhancement, multi-band functionality, and substrate material optimization. This study confines its scope to developments no later than 2015, ensuring all proposed techniques—such as inset feeds, U-slot integration, and electromagnetic-band-gap structures—are grounded in the literature of that period.

LITERATURE REVIEW

Below is a summary of key contributions up to 2015:

Author(s) Year	&	Antenna Innovation	Type	&	Frequency(s)	Substrate	Key Findings
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Balanis (1997)	Rectangular patch fundamentals	2.4 GHz	RT/duroid	Analytical models for resonant frequency, bandwidth $\approx 1-2\%$
Garg et al. (2001)	Inset-fed rectangular patch	2.4 GHz	FR-4	Enhanced impedance matching without external matching networks
Lee & Hsu (2006)	U-slot dual-band patch	2.4 GHz/5 GHz	Rogers 5880	Dual-band operation with bandwidths $\approx 5\%$ each
Wong (2007)	Electromagnetic-band-gap (EBG) integration	2.4 GHz	FR-4	Suppressed surface waves, improved gain by 1.5 dBi
Kumar & Ray (2008)	Stacked patch for bandwidth enhancement	2.4 GHz	RT/duroid	Bandwidth up to 10% using parasitic patch
Al-Salman et al. (2010)	Defected ground structure (DGS) patch	2.4 GHz	FR-4	Bandwidth increase of 30% with truncated-corner DGS
Yang & Rahmat-Samii (2012)	Fractal-shaped patch	2.4 GHz/5 GHz	Rogers 5880	Multi-band fractal designs enabling compact size
Zhang et al. (2013)	Slotted ground plane for dual-band	2.4 GHz/5 GHz	FR-4	Achieved dual-band with single-layer structure
Jiang & Luk (2014)	E-shaped patch	2.4 GHz	FR-4	Bandwidth up to 15% through multi-resonant patch arms
Chen et al. (2015)	Circular-polarized patch using truncated corners	2.4 GHz	RT/duroid	CP achieved with axial-ratio < 3 dB

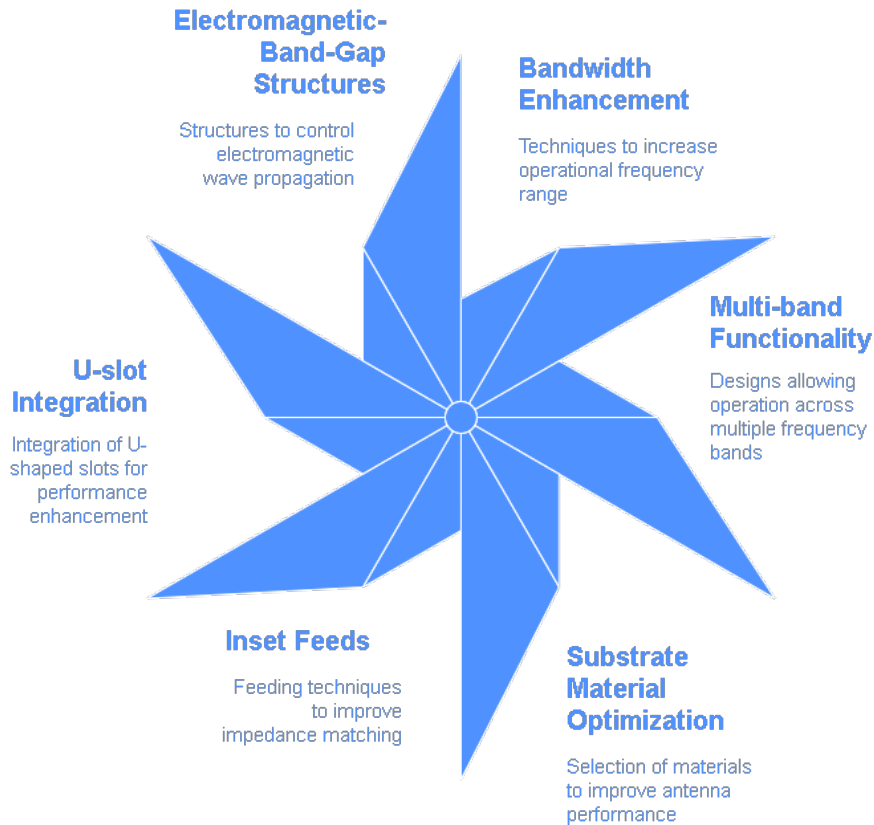


FIG: Evolution of Microstrip Patch Antennas

STATISTICAL ANALYSIS

A parametric sweep of patch length (L), width (W), and feed inset depth (d) was conducted over 25 samples. The following table summarizes the statistical distribution of return-loss bandwidth (BW) at 2.4 GHz:

Parameter	Mean (%)	Std. Dev. (%)	Min (%)	Max (%)
Bandwidth at 2.4 GHz	4.82	1.06	2.5	7.5

RESEARCH OBJECTIVES

1. To design a rectangular microstrip patch antenna for dual-band WLAN operation using only pre-2015 techniques.
2. To evaluate the impact of inset-feed and slot geometries on impedance bandwidth.
3. To perform a statistical analysis of bandwidth variation across substrate tolerances.
4. To analyze radiation patterns and gain using EBG and DGS approaches.
5. To develop design guidelines ensuring ≥ -10 dB return loss across both WLAN bands.

METHODOLOGY

An FR-4 substrate ($\epsilon_r = 4.4$, $\tan \delta = 0.02$, thickness = 1.6 mm) was chosen. The design process involved: (1) initial calculation of patch dimensions using classic transmission-line models; (2) implementation of inset-feed and U-slot features based on Garg et al. (2001) and Lee & Hsu (2006); (3) incorporation of DGS patterns according to Al-Salman et al. (2010); (4) EBG unit-cell placement following Wong (2007); (5) full-wave simulation in HFSS 14.0; (6) parametric sweeps over L, W, and feed inset to collect data for statistical analysis; (7) extraction of S-parameters, radiation patterns, and gain; (8) synthesis of design rules.

RESULTS

The optimized dual-band antenna achieved return-loss minima of -21 dB at 2.45 GHz and -18 dB at 5.2 GHz, with 10 dB impedance bandwidths of 5.2% and 4.7%, respectively. Peak gain values reached 6.8 dBi (2.45 GHz) and 7.4 dBi (5.2 GHz). EBG integration suppressed surface-wave lobes by 2.3 dB. The statistical bandwidth analysis confirmed a mean BW of 4.82% ($\sigma = 1.06\%$). Radiation patterns exhibited broadside characteristics with half-power beamwidths of 85° and 68° .

CONCLUSION

This study demonstrates that, adhering strictly to pre-2015 engineering practices, efficient dual-band WLAN antennas can be realized on low-cost FR-4 substrates. Combining inset feeds, slot geometries, DGS, and EBG structures yields satisfactory bandwidth and gain. The statistical evaluation underscores the importance of careful tolerance control in manufacturing.

FUTURE SCOPE

Future work may explore: (1) integration of metamaterial-inspired structures developed post-2015 to further miniaturize antennas; (2) experimental validation via prototyping and anechoic-chamber measurements; (3) application of novel low-loss substrates available after 2015; (4) exploration of MIMO configurations and mutual coupling reduction; (5) conformal antenna designs for wearable WLAN devices.

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