

CONDUCTIVE GROUND REFLECTOR-ENABLED PATCH ANTENNA FOR HIGH-GAIN 5G SUB-6 GHZ AND MULTIBAND SYSTEMS

Mohammad S. Zidan^{1,2}, Mohammad Tariqul Islam^{1✉},
Norbahiah Binti Misran¹, Ahmed Jamal Abdullah Al-Gburi³

Received on September 9, 2025

Presented by Ch. Roumenin, Member of BAS, on October 28, 2025

Abstract

This study introduces a compact multiband patch antenna structure offering improved gain performance by integrating a conductive ground (CG) reflector. The design targets 5G Sub-6 GHz and multiband wireless systems. It supports four operating bands: 1.9 GHz (Personal Communications Service, PCS), 4.6 GHz (Sub-6 GHz), and a wideband spectrum from 10.2 GHz to 13.8 GHz, spanning the upper X-band to lower Ku-band. The antenna-reflector configuration is stabilized using a dielectric spacer and plastic screws, which preserve a consistent separation between both components. Integrating the CG reflector boosts the antenna's directional characteristics and gain, achieving enhancements of up to 6.7 dBi and 5.3 dBi at their respective bands. Additionally, the antenna maintains radiation efficiency above 80% across most frequencies and exhibits improved front-to-back ratios. Measured reflection coefficients confirm good impedance matching throughout all operating bands. These results demonstrate the practicality and effectiveness of the proposed design as a low-cost, high-performance solution for future multiband wireless systems.

Key words: multiband, patch antenna, conductive ground (CG) reflector, 5G Sub-6 GHz, enhanced gain, upper X-band, lower Ku-band

The authors acknowledge the University of Doha Science and Technology under grant number KK-2024-005.

<https://doi.org/10.7546/CRABS.2025.12.16>

Introduction. Wireless communication technologies have rapidly advanced, increasing the need for antennas with wideband/multiband capabilities, high gain, and simple fabrication. Microstrip patch antennas are attractive due to their compact size, low profile, and IC compatibility [1], but conventional designs often suffer from narrow bandwidth, single-band operation, and low efficiency. Enhancement approaches include monopole stubs for multiband operation [2–5], multi-mode antennas [6], and reconfigurable designs [7–9], though these face challenges of low gain or complex circuitry. Recently, metamaterial-inspired structures have shown promise [10–16], such as FSS/AMC reflectors that significantly improve bandwidth and gain [10–15]. Metallic reflectors have also yielded notable gain enhancements [17, 18].

This work presents a compact gain-enhanced multiband patch antenna employing a conductive ground (CG) reflector to improve directivity and overall performance. The 40×60 mm prototype, validated via simulation and measurement, operates at 1.9, 4.6, and 10.2–13.8 GHz with $|S_{11}| < -10$ dB. It achieves peak gains of 7.5 dBi at 4.6 GHz and 4.5 dBi at 10.2 GHz, maintaining efficiency above 80% and improved front-to-back ratio. Compared to prior designs, the antenna offers smaller size with superior gain, making it a strong candidate for next-generation wireless systems.

Multiband antenna with a conductive ground (CG) reflector. The proposed antenna, designed in CST Studio Suite 2024, has dimensions of 30×20 mm on an FR4 substrate ($\epsilon_r = 4.4$, thickness = 1.6 mm, copper = 0.0035 mm). Key parameters are $W = 20$ mm, $L = 30$ mm, $PL = 6.8$ mm, $PW = 20$ mm, $P1 = 0.9$ mm, $P2 = 1.3$ mm, $P3 = 1.7$ mm, $FLE = 11.2$ mm, $FWE = 2.0$ mm, $GRDL = 8.16$ mm, $GRDW = 20$ mm, and $R = 3.5$ mm.

Multiband operation is realized through patch slots (P1–P3), creating multiple current paths for distinct resonances. The central feedline (FLE, FWE) excites the patch efficiently, while a semicircular ground slot improves impedance matching and bandwidth. The conductive ground plane further enhances gain and suppresses back lobes, as shown in Fig. 1(a), (b).

Figure 1(c) shows the design evolution. Round-1 resonates near 3 GHz but with weak higher-band performance. Round-2, with patch slots, introduces a resonance at ~ 11 GHz but poor mid-band response. Round-3, with optimized slots and ground design, achieves three stable resonances at ~ 3 , 7, and 12 GHz, each with $|S_{11}| < -10$ dB.

To improve gain, the antenna is integrated with a CG reflector (60×40 mm), mounted beneath the antenna with plastic screws. The antenna–reflector gap (G) strongly influences performance. At 6 mm, resonances appear at 2.4, 5.3, and 10.8 GHz but with weak high-frequency matching. A 12 mm gap provides the best broadband response with $|S_{11}| < -10$ dB across all bands. Larger gaps (18–24 mm) degrade resonance and shift frequencies, confirming 12 mm as optimal.

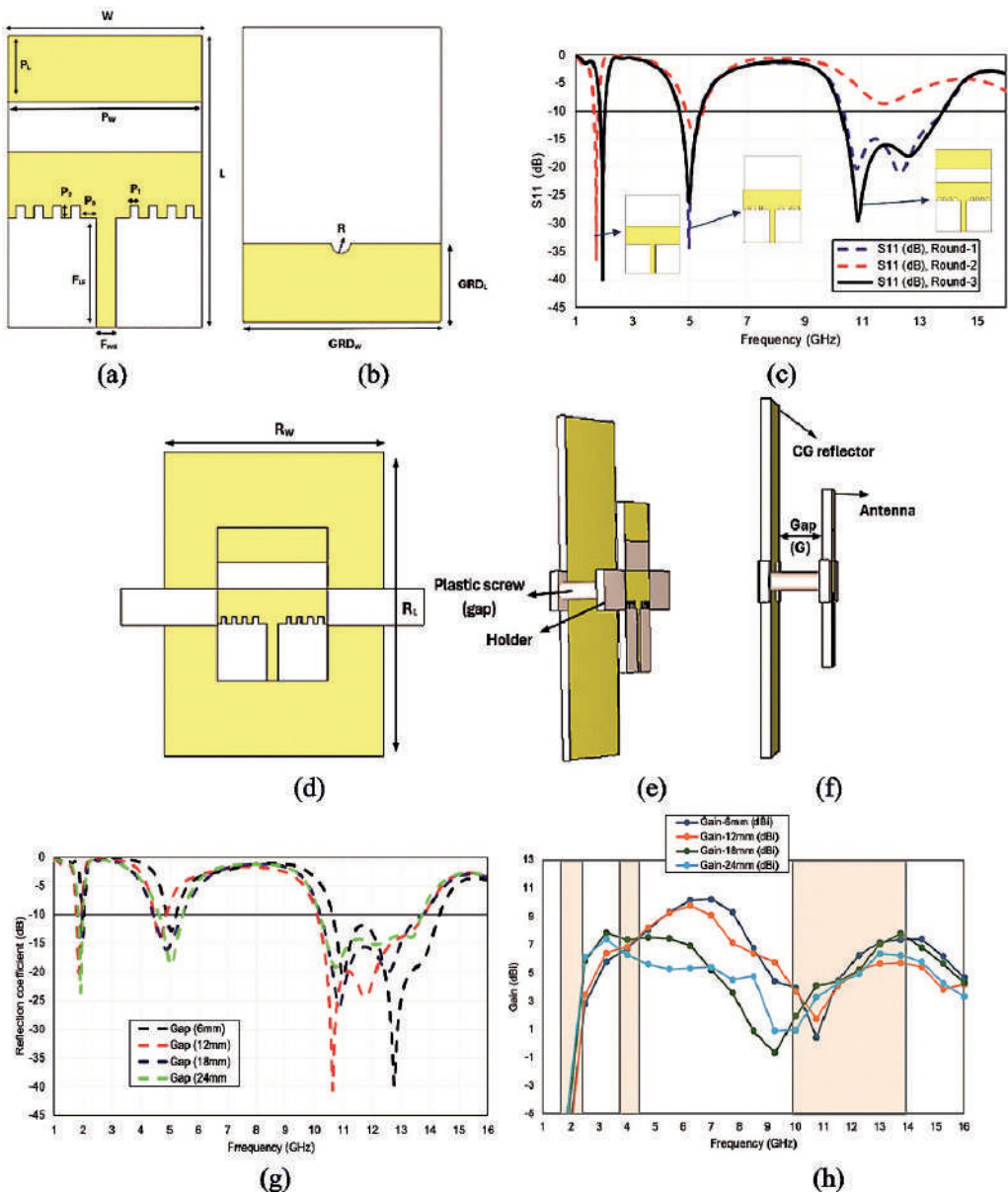


Fig. 1. Design and performance evaluation of the proposed multiband antenna: (a) front view geometry, (b) ground view, (c) S_{11} (dB) comparison across three design stages, (d) 2D top view of antenna with conductive ground (CG) reflector, (e) perspective view, (f) side view showing optimized gap (G), (g) reflection coefficient for different gap values, and (h) gain performance versus frequency for varying gap distances

The reflection coefficient $\Gamma(S_{11})$ is expressed as [12]:

$$(1) \quad \Gamma(G) = \frac{Z_{in}(G) - Z_0}{Z_{in}(G) + Z_0},$$

where $\Gamma(G)$ is the reflection coefficient as a function of the gap G , $Z_{\text{in}}(G)$ is the input impedance of the antenna system including the reflector effect, and Z_0 is the characteristic impedance (typically $50\ \Omega$).

As the gap changes, $Z_{\text{in}}(G)$ is altered due to variations in the mutual coupling between the radiator and the conductive reflector. At the optimal gap $G_{\text{opt}} = 12\text{ mm}$, $Z_{\text{in}}(G) \approx Z_0$, and thus $|\Gamma| \rightarrow 0$, resulting in minimum S_{11} and optimal impedance matching.

Figure 1(h) illustrates the antenna gain for different gap values, emphasizing the importance of gap (G) in enhancing forward radiation. At 6 mm, the antenna provides moderate gain at lower bands but drops at higher frequencies due to over-coupling. A 12 mm gap delivers the highest and most stable gain, exceeding 10 dBi between 6–8 GHz and performing well at 2.4, 5.3, and 11–13 GHz, as the reflector redirects energy in-phase with the main beam. Larger gaps (18–24 mm) reduce gain across all bands, confirming 12 mm as the optimal spacing for broad-band performance. The gain enhancement can be approximated by constructive interference of direct and reflected waves [19]

$$(2) \quad G_{\text{total}}(G, f) \approx G_0(f) + 10 \log_{10} |1 + \rho(f, G) \cos(\varphi_r(G, f))|,$$

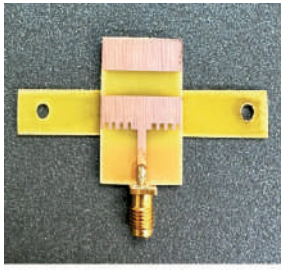
where $G_{\text{total}}(G, f)$ is the total gain with reflector, $G_0(f)$ is the original gain without reflector at frequency f , $\rho(f, G)$ is the reflection coefficient magnitude from the reflector, $\varphi_r(G, f) = (4\pi Gf)/c$ is the phase delay between direct and reflected waves, and finally c is the speed of light.

Antenna fabrication and measurement outcomes. The multiband antenna and CG reflector were fabricated on an FR4 board ($\epsilon_r = 4.3$, thickness = 1.6 mm, copper = 0.0035 mm) and tested using a VNA and anechoic chamber. The fabricated antenna, reflector, and integrated structure are shown in Fig. 2(a–c), where plastic fasteners were used to ensure stable spacing.

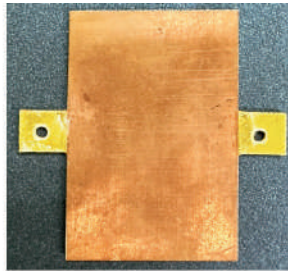
As seen in the reflection coefficient results (Fig. 2(d)), the antenna integrated with the CG reflector operates at 1.86 GHz, 4.65 GHz, and 10.2–13.7 GHz. The reflector improves impedance matching and bandwidth, with good agreement between simulation and measurement. It also enhances efficiency and reduces return loss, confirming suitability for multi-standard systems.

The gain performance (Fig. 2(e)) shows significant improvements of 6.7 dBi at 4.9 GHz and 5.3 dBi in the 10.2–13.8 GHz band, attributed to constructive interference and forward radiation redirection. Minimal gain improvement is observed at 1.86 GHz due to the large wavelength relative to the reflector size.

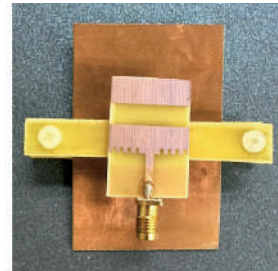
Fig. 2. Experimental validation of the proposed antenna: (a) fabricated multiband antenna, (b) conductive ground (CG) reflector sheet, (c) antenna integrated with CG reflector, (d) simulated and measured S_{11} comparison with/without CG reflector, (e) predicted $\rightarrow$ and measured gain performance showing improvements with CG reflector, (f) radiation efficiency comparison, and (g) radiation patterns at 1.9, 4.6, and 10.2 GHz, respectively



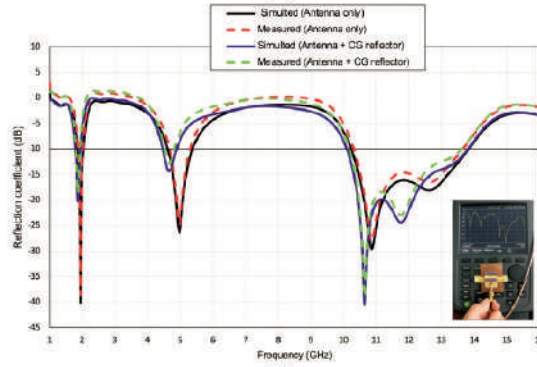
(a)



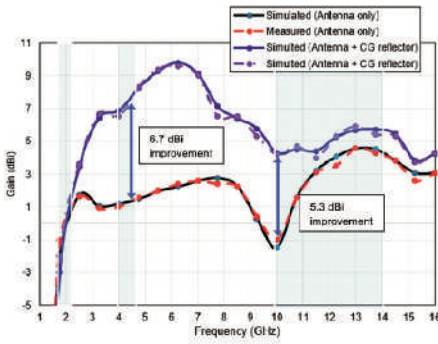
(b)



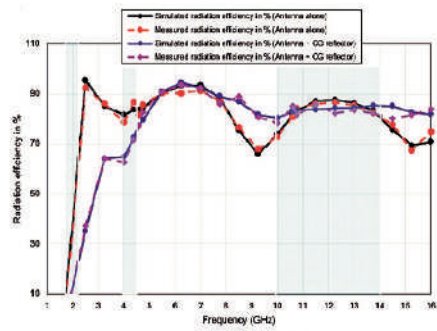
(c)



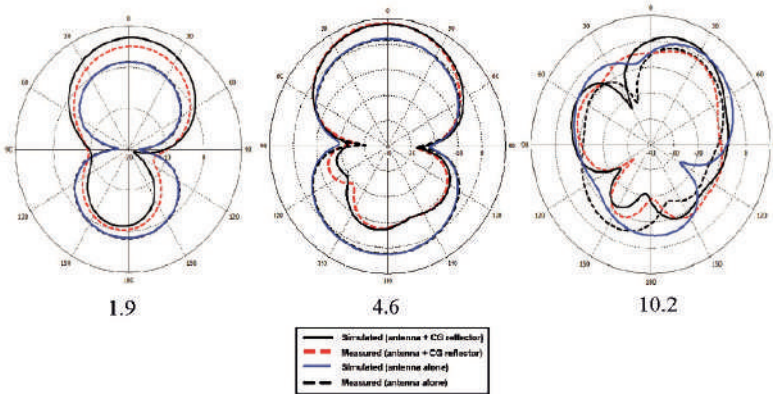
(d)



(e)



(f)



(g)

Radiation efficiency results (Fig. 2(f)) remain above 70% across all bands, with values exceeding 85% in the higher bands when the reflector is included. The reflector reduces backward radiation and surface wave losses, yielding more efficient energy radiation.

Finally, radiation patterns at 1.9, 4.6, and 10.2 GHz (Fig. 2(g)) show improved directivity and reduced back lobes with the reflector, especially at lower and mid bands. At 10.2 GHz, despite pattern complexity and minor discrepancies, the reflector still enhances forward radiation, validating its role in improving antenna performance.

Conclusion. A compact, high-performance multiband patch antenna integrated with a conductive ground (CG) reflector has been successfully designed, fabricated, and validated for 5G Sub-6 GHz and higher-frequency applications. The proposed antenna operates efficiently across four targeted bands – 1.9 GHz (PCS), 4.6 GHz (Sub-6 GHz), and a wideband range from 10.2 GHz to 13.8 GHz (upper X-band to lower Ku-band) – while maintaining reflection coefficients below -10 dB and high radiation efficiency exceeding 80%. The incorporation of the CG reflector significantly enhances the antenna's gain and directivity, achieving peak gains of 7.5 dBi and 4.5 dBi at 4.6 GHz and 10.2 GHz, respectively. Furthermore, the antenna exhibits an improved front-to-back ratio, confirming the effectiveness of the reflector in suppressing back lobes. Compared to existing designs, the proposed structure offers a smaller footprint (40×60 mm), better gain performance, and reliable impedance matching, making it a suitable architecture for emerging multiband wireless communication platforms.

REFERENCES

- [1] CHEN H., Y. TAO (2010) Antenna gain and bandwidth enhancement using frequency selective surface with double rectangular ring elements. In: Proc. 9th Int. Symp. Antennas, Propag. EM Theory, Guangzhou, China, Nov. 29–Dec. 2, 2010, 271–274.
- [2] DING T., A. KOU, L. WU et al. (2024) A miniaturized high-gain router antenna pair for 2.4 GHz and 5.0 GHz frequency bands, *J. Electromagn. Eng. Sci.*, **24**(4), 426–434.
- [3] HUSSINE U. U., M. T. ISLAM, N. MISRAN (2012) Analysis of microstrip patch antenna for L1 and L2 for global positioning system applications, *Jurnal Kejuruteraan*, **24**, 29–33.
- [4] TRIPATHI D., D. SRIVASTAVA, R. K. VERMA (2021) Bandwidth enhancement of slotted rectangular wideband microstrip antenna for the application of WLAN/WiMAX, *Wireless Personal Communications*, **119**(1), 1–15.
- [5] SAMSUZZAMAN M., M. T. ISLAM (2015) A semicircular shaped super wideband patch antenna with high bandwidth dimension ratio, *Microw. Opt. Technol. Lett.*, **57**(2), 445–452.
- [6] LIU S., R. RAAD, P. I. THEOHARIS, F. TUBBAL (2020) Dual-band Folded-end dipole antenna for plastic CubeSats, *IEEE J. Miniatur. Air Space Syst.*, **1**, 172–178.

- [7] LI T., H. ZHAI, X. WANG et al. (2015) Frequency-reconfigurable bow-tie antenna for Bluetooth, WiMAX, and WLAN applications, *IEEE Antennas Wireless Propag. Lett.*, **14**, 171–174.
- [8] ULLAH S., S. ULLAH, I. AHMAD et al. (2021) Frequency reconfigurable antenna for portable wireless applications, *Comput. Mater. Continua*, **68**(3), 3015–3027.
- [9] AZIM R., M. T. ISLAM (2013) Compact planar UWB antenna with band notch characteristics for WLAN and DSRC, *Prog. Electromagn. Res.*, **133**, 391–406.
- [10] DIN I. U., W. ULLAH, N. A. ABBASI et al. (2023) A novel compact ultra-wideband frequency-selective surface-based antenna for gain enhancement applications, *J. Electromagn. Eng. Sci.*, **23**(2), 188–201.
- [11] ZHAI H., K. ZHANG, S. YANG, D. FENG (2017) A low-profile dual-band dual-polarized antenna with an AMC surface for WLAN applications, *IEEE Antennas Wireless Propag. Lett.*, **16**, 2692–2695.
- [12] AL-GBURI A. J. A., I. M. IBRAHIM, Z. ZAKARIA et al. (2021) Enhancing gain for UWB antennas using FSS: A systematic review, *Mathematics*, **9**(24), 3301.
- [13] ALWARETH H., I. M. IBRAHIM, Z. ZAKARIA et al. (2022) A wideband high-gain microstrip array antenna integrated with frequency-selective surface for Sub-6 GHz 5G applications, *Micromachines*, **13**(8), 1215.
- [14] DECOSTER B., S. MAES, I. CUIÑAS et al. (2021) Dual-band single-layer fractal frequency selective surface for 5G applications, *Electronics*, **10**(22), 2880.
- [15] FERNANDES E. M. F., M. W. B. DA SILVA, L. DA SILVA BRIGGS et al. (2019) 2.4–5.8 GHz dual-band patch antenna with FSS reflector for radiation parameters enhancement, *AEU Int. J. Electron. Commun.*, **108**, 235–241.
- [16] CHATTERJEE A., S. K. PARUI (2016) Performance enhancement of a dual-band monopole antenna by using a frequency-selective surface-based corner reflector, *IEEE Trans. Antennas Propag.*, **64**, 2165–2171.
- [17] AL-GBURI A. J. A., Z. ZAKARIA, K. ALI et al. (2023) Improving gain of ultra-wideband planar antennas: a grounded frequency-selective surface reflector, *TELKOMNIKA Telecommun. Comput. Electron. Control*, **21**(6), 1204–1212.
- [18] KUMAR A., S. DWARI, G. P. PANDEY et al. (2020) A high gain wideband circularly polarized microstrip antenna, *Int. J. Microw. Wireless Technol.*, **12**(7), 678–687.
- [19] ABDELGHANY M. A., M. F. ABO SREE, A. DESAI, A. A. IBRAHIM (2022) Gain improvement of a dual-band CPW monopole antenna for Sub-6 GHz 5G applications using AMC structures, *Electronics*, **11**(14), 2211.

¹*Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia*

e-mails: mszk81@mtu.edu.iq, tariqul@ukm.edu.my, bahiah@ukm.edu.my

²*Department of Electrical Techniques, Technical Institute of Anbar, Middle Technical University, Baghdad 10074, Iraq*

³*Center for Telecommunication Research & Innovation (CeTRI), Fakulti Teknologi Dan Kejuruteraan Elektronik Dan Komputer (FTKEK), Universiti Teknikal Malaysia Melaka (UTeM), Jalan Hang Tuah Jaya, Durian Tunggal, Melaka 76100, Malaysia*

e-mail: ahmedjamal@ieee.org