

# AI-optimized rectangular-slotted microstrip antenna on Rogers RT5880 for 5.8 GHz sub-6 GHz wireless applications

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**Abstract.** A small rectangular microstrip antenna operated around 5.8 GHz was designed and numerically investigated for sub-6 GHz wireless communications. To facilitate a clear design procedure, this work is divided into three steps. In the first step is a basic patch antenna, in the second step is a rectangular-slotted patch antenna, which enhances both effective current path length and impedance bandwidth and finally in the third Step is a slotted patch antenna, which has been optimized using a genetic algorithm. The optimization was performed by simulation in CST Microwave Studio to find the combinations of the slot width and slot length, slot position, patch dimensions, and partial ground length that yield highest fitness function value. This fitness function combines performance criteria such as resonant frequency error, reflection coefficient, impedance bandwidth, and radiation performance. The optimized antenna has small size of  $15 \times 30 \times 1.6 \text{ mm}^3$  and resonates at 5.795 GHz with low return loss, large operating bandwidth, and increased back radiation gain. The results show enhancements compared to a basic patch antenna of size  $20 \times 40 \times 1.6 \text{ mm}^3$ .

**Keywords:** Microstrip patch antenna; rectangular slot; genetic algorithm optimization; sub-6 GHz antenna; Rogers RT5880.

## 1 Introduction

The rapid expansion of 5G services is driving the need for compact low profile high-efficiency antennas that support broadband operation across large bandwidths [1]. In the sub-6 GHz band, conventional solutions often resort to microstrip antennas due to their simple configuration, low-cost fabrication, planar low-profile features, and integration capability with printed circuit boards [2]. Despite having several advantages, conventional rectangular patch antennas suffer from a drawback of having narrow impedance bandwidth and of limited tuning capabilities. In recent times, various approaches have been investigated to enhance the impedance bandwidth of standard rectangular patch antennas.

Many of these approaches incorporate various geometric modifications, such as cut-out slots, defected ground structures, parasitic elements and modified feeds [3, 4], etc. One of the easiest and effective approach of such modifications is to cut a rectangular slot in the radiating patch. This geometry is simple to implement and acts by directly modifying the current path.

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For achieving efficient antenna design, methods inspired by artificial intelligence are increasingly used to reduce the tedious manual trial-and-error process [2, 5]. In cases where there are strong coupling effects between several geometric parameters, global search-based methods like genetic algorithms can efficiently search for designs that simultaneously optimize multiple objectives such as resonance frequency, reflection coefficient, impedance bandwidth and gain, when several geometric parameters are strongly coupled. This paper presents an antenna design through three stages of optimization, starting from a basic patch antenna, followed by a rectangular-slotted patch, and ending with an AI-optimized slotted patch [2, 5, 6].

Unlike most of the conventional slotted antennas reported in the literature, the major originality of this work is related to the three stages' design methodology, to a rational physical interpretation of the three stages of design, and to the optimization of the three stages using Artificial Intelligence (AI) techniques. A major feature of the proposed work is related to the adopted objective function, which is a combined electromagnetic based function, aiming to simultaneously obtain optimal values for multiple electromagnetic objectives, such as resonance frequency, reflection coefficient at resonance frequency, bandwidth, and maximum of directivity.

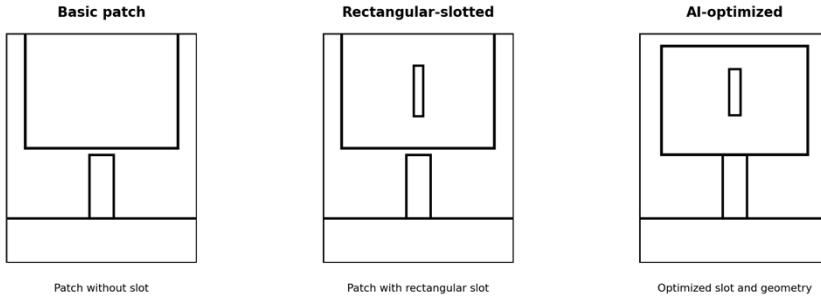
The scientific contribution of this work is not limited to the use of a genetic algorithm, which is already well established in antenna design. The originality lies in the combined design strategy adopted here. First, the antenna is developed through a physically interpretable three-stage progression, from a basic inset-fed patch to a rectangular-slotted patch and then to an optimized slotted configuration, allowing the electromagnetic role of each geometric modification to be clearly identified. Second, the optimization is driven by a compact multi-criterion fitness function that jointly accounts for resonance-frequency accuracy, impedance matching, bandwidth, and radiation performance rather than optimizing a single metric in isolation. Third, the proposed study focuses on a compact 5.8 GHz rectangular-slotted geometry on Rogers RT5880 with partial ground tuning, which provides a practical and reproducible framework for sub-6 GHz antenna design. Therefore, the contribution of this paper is methodological and electromagnetic at the same time: it combines progressive physical design understanding with AI-assisted global optimization in a unified workflow.

## **2 Antenna configuration and progressive design patch**

The designed antenna is implemented on Rogers RT5880 substrate, which has relative permittivity of 2.2, loss tangent of 0.0009 and thickness of 1.588 mm [7]. The antenna is placed on one side with microstrip feed and a rectangular patch as the active element, and a partial ground plane on the opposite side. Designs in antenna implementations generally follow a step by step approach or a sudden jump, instead of being progressive for clear electromagnetic effects observation. In this paper, a progressive approach is followed for the antenna design.

### **2.1 Stage 1: basic rectangular patch antenna with inset**

For the first configuration a standard rectangular patch is used as the starting point. This patch is fed from an edge via a 50-ohm microstrip line and represents a simple reference structure for subsequent variations. Using CST MWS full wave simulations, it can be seen that the structure resonates at a frequency of 5.885 GHz with a reflection coefficient of -14.95 dB, indicating good coupling to the feed but a still somewhat insufficient tuning above the 5.8 GHz target frequency.



**Fig. 1.** Geometry of the proposed antenna: basic patch, rectangular-slotted patch, and AI-optimized slotted patch.

### 2.2 Stage 2: rectangular-slotted patch antenna

To further adjust the frequency and input impedance in a second stage of tuning, a simple rectangular slot is cut in the patch. The increased effective current path length due to the slot, together with the additional free parameter, do not result in a significant increase in complexity. After the slot was inserted, the frequency shifted toward the targeted frequency band and the input impedance was matched to approximately -23.86 dB at 5.785 GHz. This shows that slot loading can effectively perturb the surface currents.

### 2.3 Stage 3: AI-optimized slotted antenna

The third stage keeps the same overall configuration but is optimized in terms of slot length, slot width, slot position, patch size and partial ground size. This optimization is performed using a combination of a genetic algorithm and a three-dimensional full-wave simulator CST Microwave Studio. The final optimized structure configures the best performance achieved from the three configurations, with resonant frequency at around 5.80 GHz, reflection coefficient less than -26 dB, wider -10 dB bandwidth and higher gain compared to the previous two configurations.

## 3 Initial dimension estimation and design equations

**Initial Dimensions of the Basic Patch** The initial dimensions of the basic patch can be determined using the classical transmission-line model [8]. For a target resonant frequency  $f_r$ , the patch width  $W$  is first estimated from

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

The effective dielectric constant is then approximated by

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \sqrt{\frac{1}{1 + 12h/W}} \tag{2}$$

The effective resonant length becomes

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{eff}}} \tag{3}$$

and the physical length is written as

$$L = L_{eff} - 2\Delta L \tag{4}$$

where  $\Delta L$  accounts for fringing fields.

The above equations provide a physically meaningful starting point for initial dimension configuration. In addition to the resonant frequency response, other factors including feed, partial ground plane, and slot perturbation contribute to the antenna performance. Thus, the tabulated dimensions in Table 1 serve as a pre-optimization before further fine-tuning using a full-wave solver.

**Table 1.** Initial antenna dimensions before optimization.

Parameter	Symbol	Value
Substrate width / length	$W_{sub} / L_{sub}$	35 mm / 30 mm
Patch width / length	$W_p / L_p$	20.4 mm / 16.652 mm
Ground width / length	$W_g / L_g$	35 mm / 30 mm
Feed width / length	$W_f / L_f$	3.8 mm / 10 mm
Slot length	$L_s$	8.0 mm
Slot width	$W_s$	1.5 mm
Slot position	$X_s / Y_s$	0 mm / 0 mm

## 4 GA-based optimization framework

Since several design parameters are highly interdependent, it is not efficient to do an exhaustive search. A genetic algorithm was used to perform an efficient search over the design space [9]. Using this, for each design geometry, simulations were performed in CST Microwave Studio to extract the resonance frequency, minimum S11, impedance bandwidth and gain, and these used in the objective function. The fitness function used in this work can be written as

$$F(x) = 0.40 \left| \frac{fr(x) - 5.8}{5.8} \right| + \frac{0.30}{|S_{11, min}(x)|} + \frac{0.20}{BW(x)} + \frac{0.10}{G(x)} \quad (5)$$

Our preference criteria emphasise correct tuning to 5.8 GHz, good impedance bandwidth, and sufficient gain whilst still rewarding increased bandwidth.

**Table 2.** Optimization variables and search ranges.

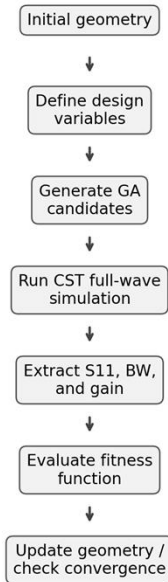
Variable	Symbol	Search range / note
Patch length	$L_p$	Optimized around the baseline value reported in Table 1
Patch width	$W_p$	Optimized around the baseline value reported in Table 1
Slot length / width	$L_s / W_s$	Adjusted to improve matching and bandwidth
Slot position	$X_s / Y_s$	Shifted around the patch center for resonance control
Partial ground length	$L_g$	Co-optimized with patch and slot parameters

I used a variety of parameters for optimisation but tried to keep them at a level that allowed for decent optimisation performance within a reasonable timeframe. These parameters provide a good trade-off between converging to a local optimum, and exploring the parameter space thoroughly.

The genetic algorithm hyperparameters used in this study are summarized in Table 3. A population size of 20 individuals and 30 generations were selected as a compromise between optimization quality and computational cost. Tournament selection was adopted to preserve competitive solutions, while a crossover rate of 0.80 and mutation rate of 0.10 were used to balance exploitation and exploration of the search space.

**Table 3.** Genetic Algorithm parameters.

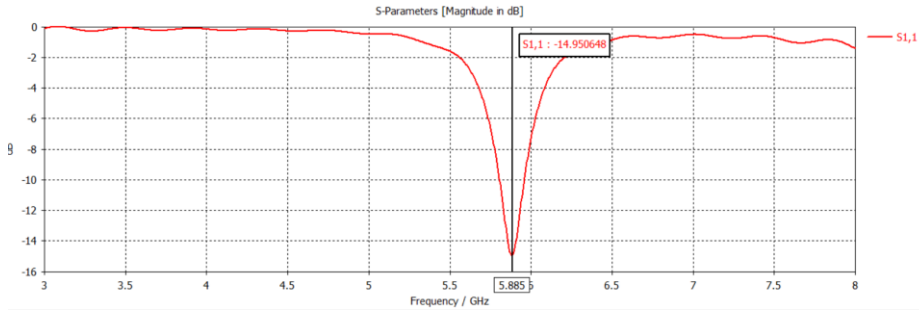
Parameter	Value
Population size	20
Number of generations	30
Crossover rate	0.80
Mutation rate	0.10
Selection method	Tournament selection
Stopping criterion	Maximum number of generations



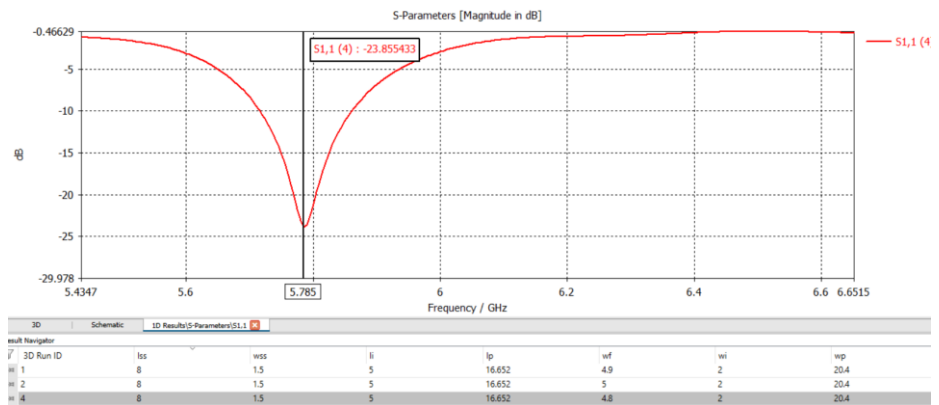
**Fig. 2.** Workflow of the GA-assisted optimization process used in this study.

## 5 Results and discussion

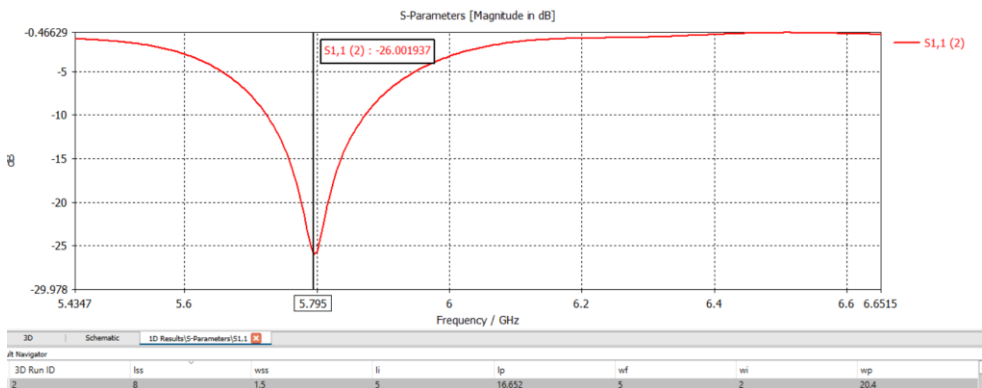
The CST results are presented in the same order as the designs shown previously. Starting with the basic patch and moving through the slotted design (with geometric perturbations) to the optimized design (with the best compromise of the selected metrics) allows for an understanding of how each design step improves performance consistent with similar studies reported in the literature [10, 11, 12]. For S11, the results from CST simulations show a continuous improvement in terms of resonant frequency and passive matching for the three designs. The basic reference patch resonates closest to 5.885 GHz with the minimum magnitude of the reflection coefficient equal to -14.95 dB. The rectangular slot embedded patch resonates at the target frequency of 5.8 GHz. The GA-refined configuration optimizes the performance to obtain the best possible trade-off between bandwidth and active gain while achieving improved passive matching.



**Fig. 3.** CST response of the basic patch antenna. The reference structure resonates around 5.885 GHz with a minimum reflection coefficient close to -14.95 dB.



**Fig. 4.** S11 response of the rectangular-slotted antenna after geometric refinement, showing resonance near 5.785 GHz with a minimum S11 of about -23.86 dB.



**Fig. 5.** Final optimized S11 response obtained after GA-based parameter tuning, showing resonance at 5.795 GHz with a minimum reflection coefficient of about -26.00 dB.

The S11 responses of the basic, rectangular-slotted and final GA-optimized antennas are depicted in Figs. 3, 4 and 5, respectively. It can be observed that the optimized design attains

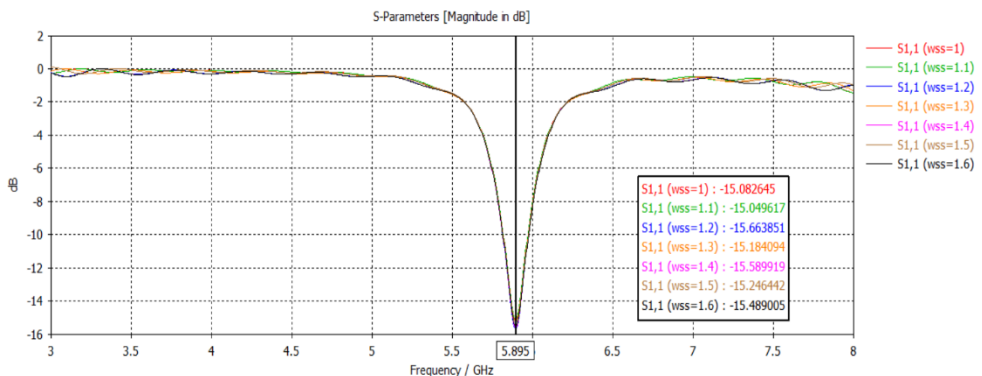
the deepest matching and adjusts the resonant frequency to the closest value to 5.8 GHz using the selected set of geometric parameters.

Similar trends are observed for bandwidth and gain. The -10 dB impedance bandwidth for the basic patch, the increased bandwidth after the slot is inserted, and the largest bandwidth for the optimized patch follow a corresponding increasing trend for the corresponding antennas' far-field results. The final optimized antenna achieves a stable and homogeneous beamwidth distribution with a directivity of 7.70 dBi at 5.8 GHz, making it suitable for sub-6 GHz wireless links. From a practical perspective, the slot effectively increases the current path length on the patch surface and redistributes the surface currents. In the optimization phase, the coupling between the feed line, patch, slot, and partial ground plane has been fine-tuned.

Since the present study is simulation-based, an additional robustness assessment was carried out through a manufacturing-tolerance analysis in CST Microwave Studio. In particular, the slot width was perturbed around its nominal value of 1.5 mm by considering a machining deviation of  $\pm 0.1$  mm, while the other parameters were kept unchanged. The corresponding changes in the resonance frequency and reflection coefficient were monitored to evaluate the practical sensitivity of the optimized geometry. The results show that the optimized antenna preserves its operating behavior around 5.8 GHz, although a moderate frequency shift and matching variation are observed as expected. This confirms that the proposed design is reasonably robust with respect to small fabrication errors and improves the practical credibility of the simulation-based optimization framework.

### 5.1 Manufacturing tolerance and sensitivity analysis

Since the study is based on full-wave numerical simulations, a manufacturing-tolerance analysis is conducted in CST Microwave Studio to investigate the sensitivity of the antenna performance with respect to the slot-width *wss*. The slot-width is varied from 1.0 mm to 1.6 mm in step of 0.1 mm, while other dimensions are kept unchanged. Corresponding S11 responses are plotted versus frequency to study the possible shifts in the resonance frequency and variations in the impedance matching bandwidth.



**Fig. 6.** Simulated reflection coefficient |S11| of the proposed antenna for different slot-width *wss* from 1.0 mm to 1.6 mm with 0.1 mm increments.

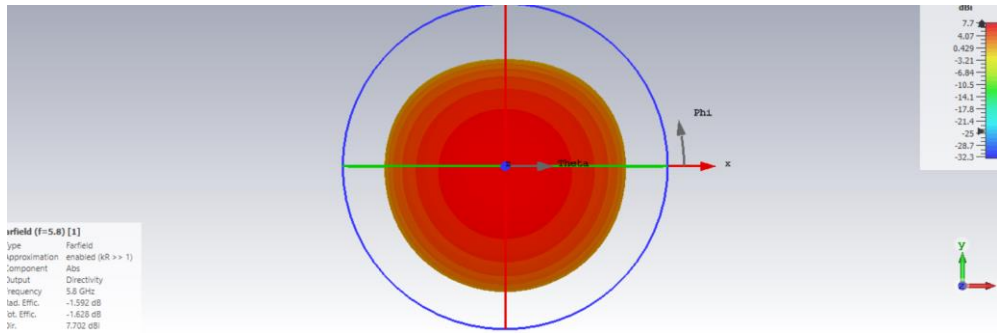
There is very little change with respect to variation in slot-width; the resonant frequency is virtually constant at around 5.895 GHz. In Figure 6, the simulated S11 for different slot-widths shows almost overlapped coupling-sets in the investigated slot-widths range. As it can be seen, the resonant frequency does not experience a noticeable shift along the frequency

band and remains almost constant at 5.895 GHz. Conversely, the minimum reflection coefficient changes just slightly for all the geometries tested. A comprehensive analysis of the sensitivity of the matching circuit performance for the proposed antenna configuration to variations in the slot-width has been conducted.

**Table 4.** Sensitivity of the antenna matching performance to slot-width variation.

Slot width, wss (mm)	Minimum S11 (dB)	Observation
1.0	-15.082645	Stable
1.1	-15.049617	Stable
1.2	-15.663851	Slightly improved matching
1.3	-15.184094	Stable
1.4	-15.589919	Stable
1.5	-15.246442	Nominal configuration
1.6	-15.489005	Stable

The minimum reflection coefficient remains virtually constant and lies within a narrow band of values varying from approximately -15.05 dB to -15.66 dB. This result reveals that moderate deviations in the slot-width are unlikely to cause significant degradation in the performance of the antenna. The design is therefore considered reasonably robust.



**Fig. 7.** Far-field directivity pattern of the final optimized antenna at 5.8 GHz, showing a peak directivity of about 7.70 dBi.

**Table 5.** Simulated performance comparison of the three antenna stages.

Antenna	fr (GHz)	S11 (dB)	Gain
Basic patch	5.885	-14.95	7.61 dBi
Rectangular-slotted patch	5.785	-23.86	7.68 dBi
AI-optimized slotted patch	5.795	-26	7.72 dBi

## 6 Positioning with recent literature

To situate the proposed design within current literature, analogous antennas operating at sub-6 GHz or 5.8 GHz have been developed employing slotted configurations, miniaturization techniques and AI-empowered methodologies. This paper, however, differs from previous works where the mere employment of a genetic algorithm grants superiority. The work introduces novelty by combining geometry perturbation, a multi-objective optimization strategy and incrementally constructing a three-stage design methodology while sustaining inherent electromagnetic effects throughout the design progression.

To better position the proposed design with respect to recent literature, Table 4 provides a quantitative comparison including operating frequency, bandwidth, gain, fractional bandwidth, reported efficiency when available. For some published studies, these values not reported and so marked as N/R.

**Table 6.** Quantitative comparison of the proposed antenna with selected recent sub-6 GHz and 5.8 GHz antennas from the literature.

Ref.	Antenna type	Substrate	fr	Bandwidth / Gain	Bandwidth (%)	Efficiency	Size (mm <sup>2</sup> )
[3]	Slotted plus-shaped patch with DGS	RT5880	3.12 GHz	2.56 GHz / 2.44 dBi	82.1	N/R	N/R
[4]	E-shaped microstrip antenna	FR-4	5.80 GHz	Narrowband / -	N/R	N/R	N/R
[5]	Dual-band patch with parasitic strip	FR-4	3.45 / 5.90 GHz	160 / 220 MHz; 3.83 / 0.576 dBi	4.6 / 3.7	N/R	N/R
[6]	Dual-band compact 2.45/5.8 GHz patch	Low-cost substrate	2.45 / 5.80 GHz	140 / 510 MHz	5.7 / 8.8	N/R	N/R
[7]	Miniaturized EBG 5.8 GHz antenna	High-frequency laminate	5.80 GHz	Focused band / high efficiency	N/R	Reported as high	N/R
This work	AI-optimized rectangular-slotted patch	RT5880	5.80 GHz	0.71 GHz / 7.72 dBi	12.2 (sim.)	N/R	1050

## 7 Conclusion

This paper presented a three-stage design methodology for a 5.8 GHz microstrip antenna implemented on Rogers RT5880. Starting from a basic inset-fed patch, the design was progressively improved by introducing a rectangular slot and then optimizing the geometry using a genetic algorithm coupled with CST Microwave Studio. The final optimized configuration achieved improved impedance matching, enhanced bandwidth, and higher gain while maintaining a compact and physically simple structure. These results show that the proposed progressive design strategy combined with AI-assisted optimization is an effective approach for sub-6 GHz antenna development. Future work will include fabrication, experimental validation, and extended tolerance analysis to further assess the practical robustness of the proposed antenna. In the future, we will make the fabricated-prototype and measure the radiation patterns. Furthermore, the same method can be applied to design multiband or MIMO type sub-6 GHz antennas.

**Authors contribution:** Amal Nejjari contributed to antenna design, CST simulations, genetic-algorithm-based optimization, data analysis, and manuscript drafting. Anouar Es-Saleh contributed to methodology, scientific supervision, and manuscript revision. Sara Said contributed to literature review, results interpretation, and manuscript editing. Ahmed Faize contributed to conceptual guidance, validation of the scientific approach, and final review of the manuscript.

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## References

1. T. S. Rappaport, Y. Xing, O. Kanhere, S. Ju, A. Madanayake, S. Mandal, B. Alkhateeb, and G. C. Trichopoulos, Wireless communications and applications above 100 GHz: Opportunities and challenges for 6G and beyond. *IEEE Access* **7**, 78729–78757 (2019).
2. N. Chhaule, C. K. Ramiah, A. O. Ojo, and T. S. Ustun, A comprehensive review on conventional and machine learning-assisted design of 5G microstrip patch antenna. *Electronics* **13**, 3819 (2024). <https://doi.org/10.3390/electronics13193819>
3. L. C. Paul, S. C. Das, T. Rani, S. M. Muyeen, S. A. Shezan, and M. F. Ishraque, A slotted plus-shaped antenna with a DGS for 5G Sub-6 GHz/WiMAX applications. *Heliyon* **8**, e12040 (2022). <https://doi.org/10.1016/j.heliyon.2022.e12040>
4. S. K. Noor, M. Jusoh, T. Sabapathy, A. H. Rambe, H. Vettikalladi, A. M. Albishi, and M. Himdi, A patch antenna with enhanced gain and bandwidth for Sub-6 GHz and Sub-7 GHz 5G wireless applications. *Electronics* **12**, 2555 (2023). <https://doi.org/10.3390/electronics12122555>
5. S. Chen, G.-H. Sun, and K. Wang, Inverse design of microstrip antennas based on deep learning. *Electronics* **14**, 2510 (2025). <https://doi.org/10.3390/electronics14132510>
6. H. Ahmed, A. M. Ameen, A. Magdy, A. Nasser, and M. Abo-Zahhad, A Sub-6GHz two-port crescent MIMO array antenna for 5G applications. *Electronics* **14**, 411 (2025). <https://doi.org/10.3390/electronics14030411>
7. Rogers Corporation, *RT/duroid 5870/5880 data sheet*.
8. C. A. Balanis, *Antenna theory: analysis and design*, 4th edn. (Wiley, Hoboken, 2016).
9. J. M. Johnson and V. Rahmat-Samii, Genetic algorithms in engineering electromagnetics. *IEEE Antennas Propag. Mag.* **39**, 7–21 (1997). <https://doi.org/10.1109/74.632992>
10. Y. Albaihani, R. Akram, A. M. Almohaimeed, Z. M. Almohaimeed, L. O. Buhari, and M. Shaban, Miniaturized EBG antenna for efficient 5.8 GHz RF energy harvesting in self-powered IoT and medical sensors. *Sensors* **25**, 4777 (2025). <https://doi.org/10.3390/s25154777>
11. O. Assogba, A. Breard, and Y. Duroc, A new low-cost compact antenna for the 2.45 and 5.8 GHz ISM bands. *Appl. Sci.* **15**, 1912 (2025). <https://doi.org/10.3390/app15041912>
12. M. T. Guneser, C. Seker, M. I. Guler, N. L. Fitriyani, and M. Syafrudin, Efficient 5.8 GHz microstrip antennas for intelligent transportation systems: Design, fabrication, and performance analysis. *Mathematics* **12**, 1202 (2024). <https://doi.org/10.3390/math12081202>