IJIREEICE

ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

Impact Factor 8.414 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 14, Issue 5, May 2026

DOI: 10.17148/IJIREEICE.2026.14548

# A Review of Modern Antenna Design Approaches for 5G, 6G, IoT, and Satellite Applications

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**Abstract:** Modern antenna design has advanced with the integration of machine learning, innovative materials, and new fabrication techniques. This paper reviews various antenna design approaches for next-generation systems such as 5G, 6G, IoT, and satellite communication. It covers structures like patch, fractal, flexible, and array antennas, along with machine learning-based optimization methods. The study highlights improvements in performance parameters such as gain, bandwidth, and efficiency, while reducing design complexity. Overall, this review provides insights into current developments and future directions in antenna design.

**Keywords:** Antenna Design, Machine Learning, 5G, 6G, IoT, Satellite Communication, Fractal Antenna.

## I. INTRODUCTION

Antenna design plays a crucial role in modern wireless communication systems, enabling efficient transmission and reception of signals. With the rapid growth of technologies such as 5G, 6G, Internet of Things (IoT), and satellite communication, there is an increasing demand for antennas that are compact, high-performance, and energy-efficient. Traditional antenna design methods often involve complex calculations and time-consuming trial-and-error processes.
To overcome these challenges, recent research focuses on advanced approaches such as machine learning-based design, innovative antenna structures, and modern fabrication techniques. Methods like fractal designs, flexible substrates, and 3D printing have improved antenna performance while reducing size and cost. In addition, machine learning techniques help in optimizing antenna parameters and predicting performance more efficiently.

## II. LITERATURE REVIEW

### 1) Machine Learning Based Patch Antenna Design for 5G (28 GHz)

**Research Objective:**
The main objective of this study is to design and optimize a patch antenna for 5G applications operating at 28 GHz using machine learning techniques. Traditional antenna design methods are time-consuming, so ML is used to improve accuracy and reduce design complexity.

**Methodology / Approach:**
The system uses machine learning models to predict antenna parameters such as gain, bandwidth, and return loss. Simulation data is used to train the model, which then optimizes antenna dimensions automatically.

**Key Concepts:**

- Patch Antenna Design
- Machine Learning Optimization
- Parameter Prediction

**Equations:**
S11 = 20\log$_{10}$

$$Gain = \frac{P_{out}}{P_{in}}$$

$$f = \frac{c}{2L\sqrt{\epsilon_r}}$$

**Working Process**:

1. Generate antenna dataset using simulation
2. Train ML model
3. Predict optimal parameters
4. Validate antenna performance

**Advantages**:

- Reduces design time
- Improves accuracy
- Suitable for 5G applications

**Applications**:

- 5G communication systems
- Wireless networks

**2)High-Gain THz Fractal Loop Antenna for IoT & 6G**

**Research Objective:**

This research focuses on designing a high-gain THz fractal loop antenna for IoT and 6G applications and predicting its efficiency using machine learning models.

**Methodology / Approach:**

A fractal loop antenna structure is designed to achieve high gain and compact size. Machine learning is used to predict antenna efficiency based on design parameters.

**Key Concepts:**

- Fractal Antenna
- THz Frequency
- ML-based Efficiency Prediction

**Equations:**

$$Gain = 10\log_{10}(D \times \eta)$$

$$\eta = \frac{P_{radiated}}{P_{input}}$$

VSWR = 1−|Γ|/1+|Γ|

**Working Process:**

1. Design fractal antenna
2. Extract parameters
3. Train ML model
4. Predict efficiency

**Advantages:**

- High gain
- Compact design
- Suitable for 6G

**Applications:**

- IoT devices
- THz communication

**3) Flexible PDMS-Based Hexagonal Patch Antenna**

**Research Objective:**

The aim is to fabricate a low-cost flexible hexagonal patch antenna using PDMS material and evaluate different machine learning algorithms for performance optimization.

  

**Methodology / Approach:**
A flexible antenna is fabricated using PDMS substrate. Various ML algorithms are applied to compare and predict antenna performance.

**Key Concepts:**

- Flexible Antenna
- PDMS Material
- ML Algorithm Comparison

**Equations:**

$$BW = f_{high} - f_{low}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2}$$

S11=Γ=(ZL+Z0)/(ZL−Z0)

**Working Process:**

1. Fabricate antenna
2. Collect data
3. Apply ML models
4. Compare results

**Advantages:**

- Low cost
- Flexible design
- Lightweight

**Applications:**

- Wearable devices
- Flexible electronics

**4)3D Printed Circularly Polarized 28 GHz Patch Antenna Array**

**Research Objective:**
The main objective of this research is to design and develop a 28 GHz circularly polarized patch antenna array using 3D printing technology for small satellite communication systems. Traditional antenna fabrication methods are complex and costly, so this study focuses on low-cost, lightweight, and efficient antenna structures suitable for space applications.

**Methodology / Approach:**
The antenna array is designed using electromagnetic simulation tools and fabricated using 3D printing techniques. Circular polarization is achieved by modifying the patch geometry and feeding technique. The array configuration improves gain and radiation efficiency.

**Key Concepts:**
**Circular Polarization**
Circular polarization ensures that the antenna can transmit and receive signals regardless of orientation, which is very important in satellite communication.

**Antenna Array**
Multiple patch elements are combined to increase gain and directivity.

**3D Printing Technology**
Used to fabricate lightweight and cost-effective antenna structures.

**Equations:**

$$AR = \frac{E_{max}}{E_{min}}$$

$$Gain = Directivity \times Efficiency$$

$$f = \frac{c}{\lambda}$$

$$BW = f_h - f_l$$

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**Working Process:**

1. Design antenna structure using simulation software
2. Optimize patch dimensions for 28 GHz
3. Fabricate using 3D printing
4. Measure gain, axial ratio, and radiation pattern
5. Validate circular polarization performance

**Advantages:**

- Lightweight and compact design
- Low-cost fabrication using 3D printing
- High gain due to array structure
- Suitable for space and satellite use

**Applications:**

- Small satellite communication
- Space communication systems
- 5G/28 GHz high-frequency systems

**Limitations:**

- Requires precise fabrication accuracy
- Performance depends on printing material quality

**5) Antenna Design Using Machine Learning for Next-Gen IoT Systems**

**Research Objective:**

This research aims to design and analyze antennas for next-generation IoT systems using machine learning techniques. The goal is to reduce manual design complexity and improve antenna performance prediction using data-driven models.

**Methodology / Approach:**

The study uses machine learning algorithms to predict antenna parameters such as gain, return loss, and bandwidth. Training data is collected from simulation results, and the ML model learns the relationship between input parameters and output performance.

**Key Concepts:**

Machine Learning-Based Design
ML models replace traditional trial-and-error antenna design methods.
Data-Driven Optimization
Uses dataset of antenna parameters for prediction and optimization.
IoT Communication Requirements
Focus on low power, compact size, and efficient performance.

**Equations:**

**Equation**

S11 = 20\log$_{10}$

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$Gain = \frac{4\pi A_e}{\lambda^2}$$

$$BW = \frac{f_h - f_l}{f_c}$$

**Working Process:**

1. Generate antenna dataset using simulation
2. Train ML model (ANN / regression)
3. Input design parameters
4. Predict antenna performance
5. Optimize design automatically

**Advantages:**

- Reduces design time significantly
- Improves prediction accuracy
- Suitable for large-scale IoT deployment

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- Eliminates manual tuning

**Applications:**
- IoT communication systems
- Smart devices
- Wireless sensor networks

**Limitations:**
- Requires large training dataset
- Model accuracy depends on data quality
- Initial setup complexity

## III. CONCLUSION

The reviewed studies highlight that antenna design has been greatly enhanced through the use of machine learning, advanced materials, and modern fabrication techniques. These approaches improve key performance parameters such as gain, bandwidth, and efficiency while reducing design complexity and development time. Innovative structures like fractal antennas, flexible designs, and 3D-printed arrays further support compact and cost-effective solutions. Overall, these advancements are essential for developing reliable and high-performance antennas for 5G, 6G, IoT, and satellite communication systems.

Table 1: Comparison Based on System Components

| **Reference** | **Antenna Type** | **Technology Used** | **Fabrication** | **Application** |
|---|---|---|---|---|
| Ref 1 | Patch Antenna (28 GHz) | Machine Learning | Simulation-based | 5G Communication |
| Ref 2 | Fractal Loop Antenna | ML + THz Design | Advanced Design | IoT & 6G |
| Ref 3 | Hexagonal Patch (Flexible) | ML Algorithms | PDMS Fabrication | Wearable Devices |
| Ref 4 | Patch Antenna Array | 3D Printing | Additive Manufacturing | Satellite Communication |
| Ref 5 | General Antenna Design | Machine Learning | Simulation | IoT Systems |

Source: Compiled from [1][2][3][4][5]

Table 2: Comparison Based on Methodology

| **Reference** | **Design Approach** | **Core Technique** | **Processing Method** | **Analysis Type** |
|---|---|---|---|---|
| Ref 1 | ML Optimization | ANN / Regression | Parameter Prediction | Performance Optimization |
| Ref 2 | Fractal Design | ML Prediction | Efficiency Modeling | High-Frequency Analysis |
| Ref 3 | Flexible Design | ML Comparison | Data Evaluation | Algorithm Comparison |
| Ref 4 | Antenna Array | Circular Polarization | EM Simulation | Radiation Analysis |
| Ref 5 | ML-Based Design | ANN / Regression | Data-Driven Model | IoT Optimization |

Source: Compiled from [1][2][3][4][5]

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Table 3: Comparison Based on Input / Dataset

| Reference | Input Type | Dataset Source | Frequency Range | Training Requirement |
|---|---|---|---|---|
| Ref 1 | Simulation Data | Antenna Parameters | 28 GHz | ML Training Required |
| Ref 2 | Design Parameters | Fractal Dataset | THz Range | ML-Based Prediction |
| Ref 3 | Experimental Data | Fabrication Results | GHz Range | Model Comparison |
| Ref 4 | Simulation + Measurement | Antenna Array Data | 28 GHz | No ML Required |
| Ref 5 | Simulation Data | IoT Antenna Dataset | Varies | Large Dataset Needed |

Source: Compiled from [1][2][3][4][5]

Table 4: Comparison Based on Performance

| Reference | Gain | Efficiency | Bandwidth | Complexity |
|---|---|---|---|---|
| Ref 1 | High | Good | Moderate | Medium |
| Ref 2 | Very High | High | Wide | High |
| Ref 3 | Moderate | Good | Moderate | Low |
| Ref 4 | High | High | Moderate | Medium |
| Ref 5 | Optimized | High | Flexible | Medium |

Source: Compiled from [1][2][3][4][5]

Table 5: Comparison Based on Applications

| Reference | 5G/6G | IoT | Satellite | Wearable |
|---|---|---|---|---|
| Ref 1 | Yes | No | No | No |
| Ref 2 | Yes (6G) | Yes | No | No |
| Ref 3 | No | Yes | No | Yes |
| Ref 4 | Yes | No | Yes | No |
| Ref 5 | Yes | Yes | No | No |

Source: Compiled from [1][2][3][4][5]

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Table 6: Comparison Based on Advantages & Limitations

| Reference | Advantages | Limitations | Complexity | Cost |
|---|---|---|---|---|
| Ref 1 | Fast design, accurate | Needs training data | Medium | Medium |
| Ref 2 | High gain, compact | Complex design | High | High |
| Ref 3 | Low cost, flexible | Lower performance | Low | Low |
| Ref 4 | High efficiency, lightweight | Fabrication precision needed | Medium | Medium |
| Ref 5 | Scalable, fast optimization | Data dependent | Medium | Medium |

Source: Compiled from [1][2][3][4][5]

## IV. FUTURE WORK

Future research can focus on improving antenna design by integrating advanced machine learning models such as deep learning for more accurate prediction and optimization. The use of hybrid techniques combining AI with electromagnetic simulation can further enhance performance. Further work may also explore advanced fabrication methods like 3D printing with new materials timprove efficiency and reduce cost. Moreover, integrating antennas with real-time adaptive systems and smart communication platforms can enable dynamic performance tuning. These advancements will support the growing demands of 5G, 6G, satellite, and IoT communication systems.Additionally, the development of flexible, miniaturized, and low-power antennas will be important for next-generation IoT and wearable devices.

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