

Development of Miniatured Planar Antenna for IoT Devices

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Abstract

The goal of this project is to create a miniature planar antenna that is intended for the use of Internet of things devices. The objective is to develop a high-performing, small antenna that can function effectively in important IoT frequency ranges. The methodology entails defining specific performance objectives after a thorough literature review to identify current challenges and requirements. CST software is used to create and simulate initial antenna designs, and iterative optimization is used to improve efficiency and signal performance. Copper and FR-4 materials are used to fabricate prototypes. The finished design would strictly validate to make sure it satisfies the requirements, and it eventually offers a workable and effective way to satisfy the growing demands of IoT technology. The advancement of sophisticated antenna solutions, which are essential to the expansion and efficacy of Internet of Things applications, is aided by this project.

1. Introduction

In the age of smart technologies, IoT devices have become integral to daily life, connecting everything from home automation to industrial systems. These devices rely heavily on efficient and compact antennas for wireless communication. To meet the growing demand for miniaturized and high-performance antennas, this project focuses on developing a planar antenna optimized for IoT applications. This antenna is designed to operate efficiently within a targeted frequency range, ensuring robust connectivity while maintaining a compact form factor. By addressing issues like impedance matching, gain, and radiation efficiency, this project aims to enhance the reliability of IoT devices while minimizing design complexity and costs.

1.1 Substrate Selection

The planar antenna uses the FR-4 substrate due to its affordability, availability, and adequate electrical properties for IoT applications[1]. The substrate provides mechanical support and contributes to impedance matching, making it essential for achieving desired performance metrics like gain and bandwidth.

1.2 Simulation Software

The antenna design is simulated using CST Studio Suite 2019[1]. This software provides tools to model and optimize the antenna's physical structure and electromagnetic properties. The key parameters analyzed include the reflection coefficient (S11), gain, radiation pattern, and VSWR, ensuring the design meets operational requirements.

1.3 Antenna Design Parameters

The miniature planar antenna is designed to operate within a specified frequency range, particularly focusing on the 5.14 GHz band. It is optimized for IoT devices requiring dual-band performance, compact size, and efficient radiation characteristics. Critical dimensions are defined during simulation to achieve these goals.

1.4 Performance Evaluation

The performance of the fabricated antenna is tested using a Vector Network Analyzer (VNA). Key parameters such as S11, VSWR, gain, and radiation patterns are measured and compared with simulation results. This evaluation ensures that the antenna performs reliably under real-world conditions.

2. Methodology

2.1 Project Flowchart

It begins by determining the type of antenna (planar) and selecting a suitable substrate (FR-4). The desired frequency range (0-5 GHz) is then decided upon. If the initial design is unsatisfactory, modifications are made iteratively. The antenna is designed using CST Studio Suite 2019, where key parameters such as the reflection coefficient (S11), VSWR, radiation pattern, gain, and efficiency are evaluated. Once the simulation results meet the required specifications, the antenna is fabricated. The fabricated antenna is tested using a Vector Network Analyzer (VNA), and the results are compared with the simulation data. Any discrepancies are resolved through further refinements. This **Fig.1** process ensures an optimized antenna design that meets the desired performance criteria.

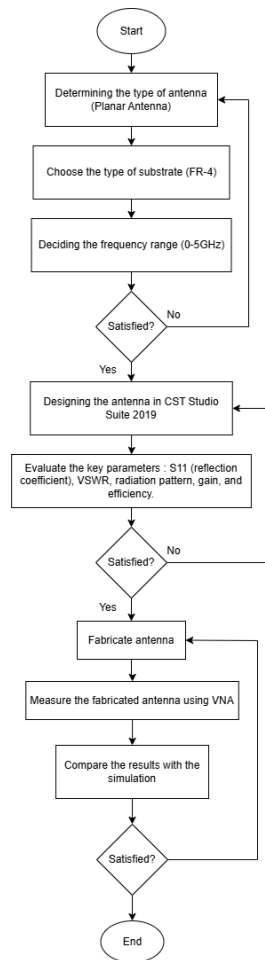


Fig. 1: Project Flowchart

3. Result and Discussion

This chapter discusses the findings derived from both simulations and laboratory experiments. The simulations, performed using CST software, are analysed to assess key parameters, including the reflection coefficient,

bandwidth, Voltage Standing Wave Ratio (VSWR), radiation patterns, gain, directivity, efficiency, and surface current distribution.

3.1 Planar Antenna with FR-4 at 0-10 GHz

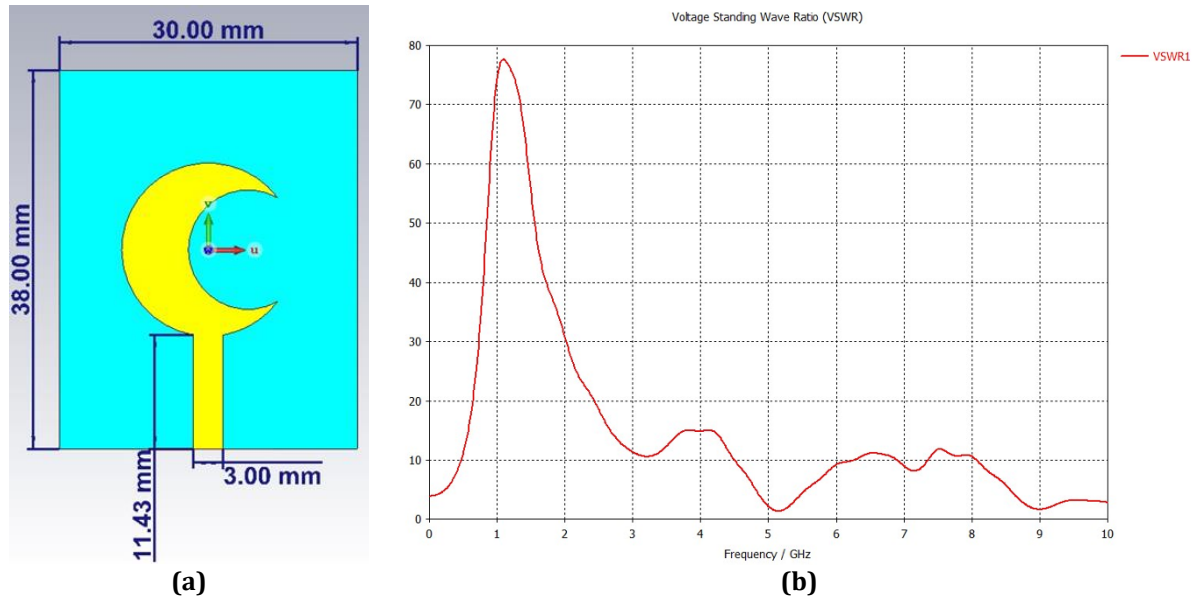
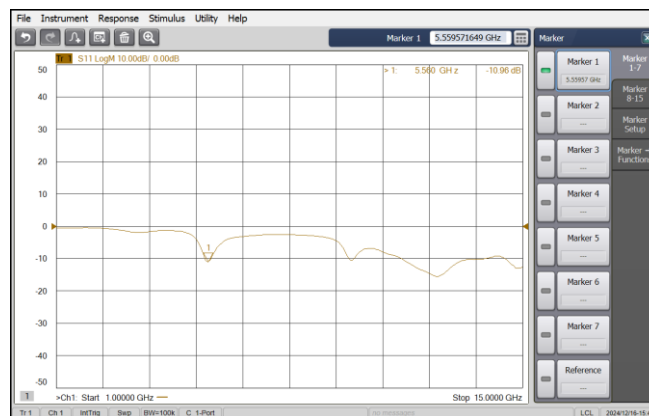


Fig. 2: (a) Planar Antenna (b) Simulated reflection coefficient and bandwidth of the planar antenna

Fig.2 (a) depicts the antenna's physical layout, a rectangular patch with a crescent-shaped slot cut out of it. The dimensions of the patch (38mm x 30mm) and the feed line (11.43mm long and 3mm wide) are indicated. **Fig.2 (b)** presents the simulated Voltage Standing Wave Ratio (VSWR) of the antenna across a frequency range. The VSWR values are generally lower at higher frequencies, suggesting better impedance matching and potentially usable bandwidth in those regions.

3.2 Comparison Between Simulation and Real Time Measurement



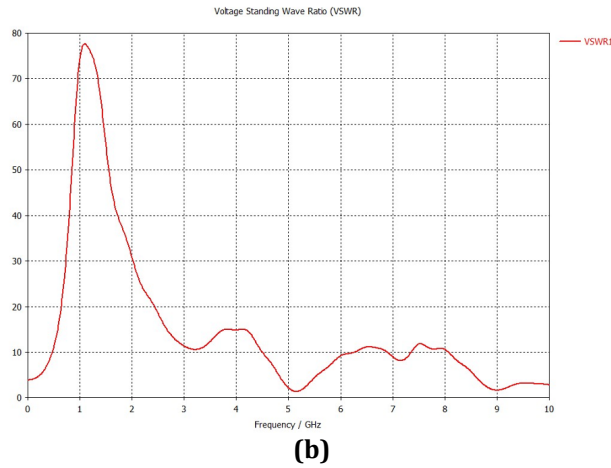
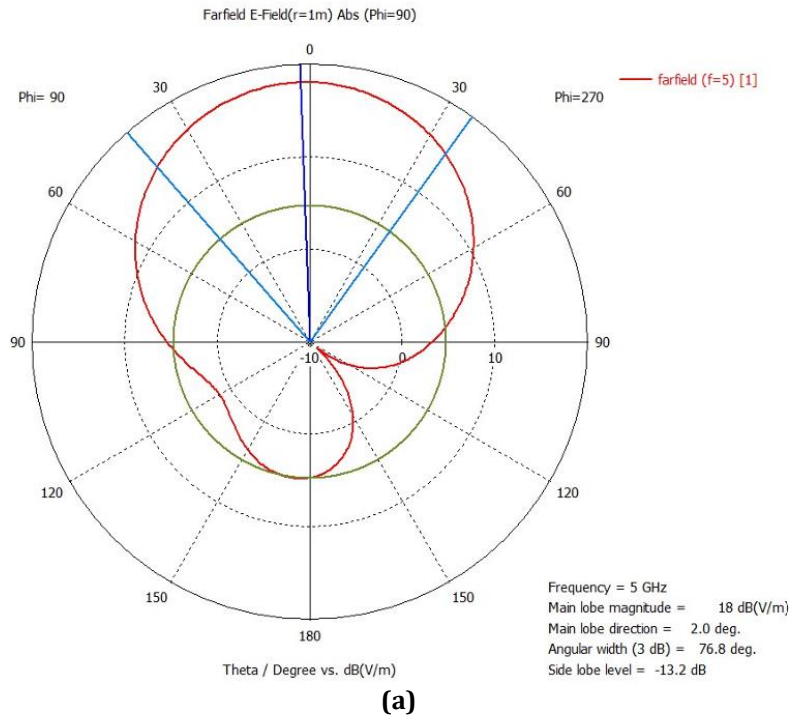
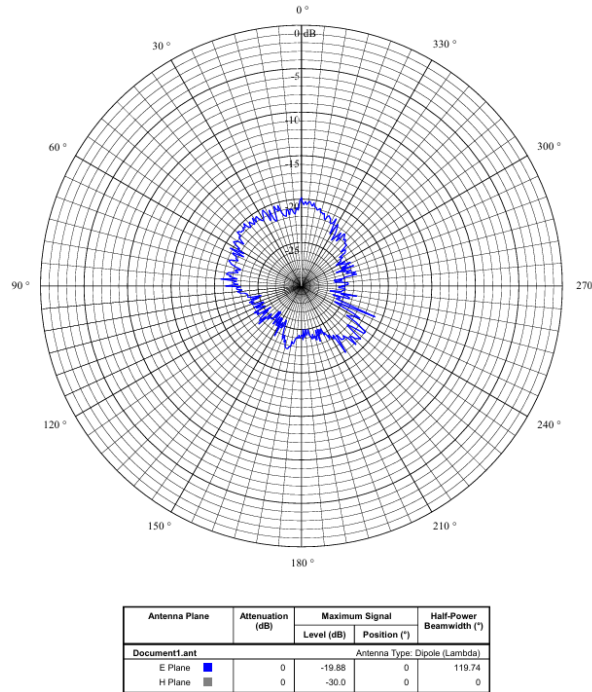


Fig. 3: (a) Real time simulation (b) Software simulation

Fig.3 (a) shows the results from a real-time measurement, likely using a network analyzer. The graph displays the S11 parameter (reflection coefficient) in dB, which indicates how much power is reflected from the antenna. A lower S11 value signifies better matching and less reflection. The graph shows a dip around 5GHz frequency, suggesting the antenna's operating frequency. **Fig.3 (b)** presents the simulated Voltage Standing Wave Ratio (VSWR) of the same antenna. The VSWR graph also shows a peak around a similar frequency as the dip in the S11 graph, confirming the antenna's resonant frequency. While the exact values and shapes of the graphs differ slightly, due to factors like measurement inaccuracies and simulation approximations, both figures generally agree on the antenna's operating frequency range.

3.3 Radiation Pattern

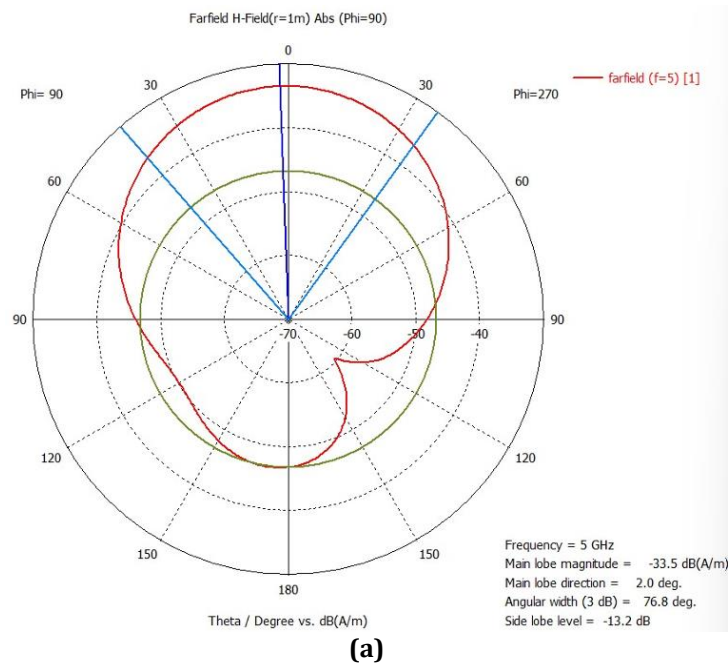




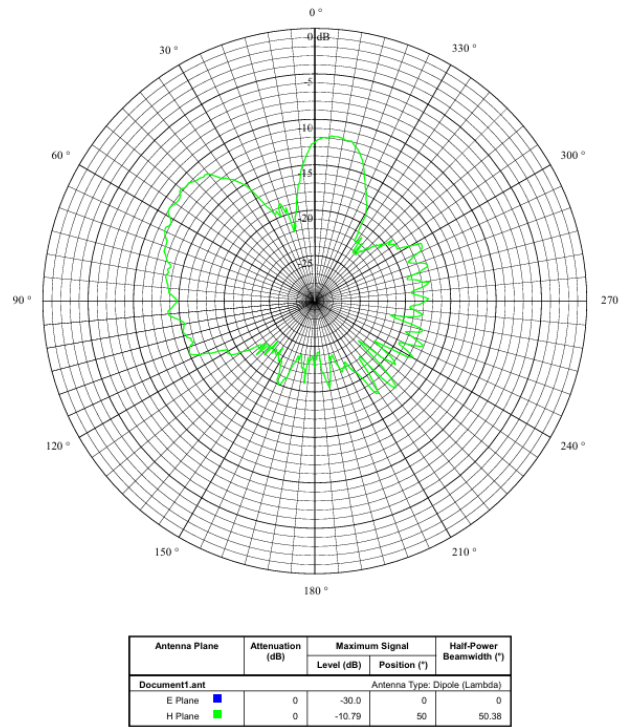
(b)

Fig. 4: (a) 5 GHz E-Plane result from simulation (b) 5 GHz E-plane result from antenna

Fig.4 compares the simulated and measured E-plane radiation patterns of a planar antenna operating at 5 GHz. The simulated pattern Fig.4 (a) shows a smooth and idealized distribution with a main lobe direction of 2 degrees, an angular width of 76.8 degrees, and a side lobe level of -13.2 dB. In contrast, the measured pattern Fig.4 (b) reveals a main lobe at 0 degrees with broader beamwidth and irregularities caused by noise, ambient reflections, and fabrication tolerances. These differences highlight the gap between theoretical models and real-world performance, emphasizing the need for practical validation in antenna design.



(a)



(b)
Fig. 5: (a) 5 GHz H-Plane result from simulation (b) 5GHz H-Plane result from antenna

Fig. 5 (a) presents a polar plot of the antenna's far-field radiation pattern at 5 GHz. The red line represents the magnitude of the radiation, showing a main lobe (direction of strongest radiation) and smaller side lobes. Key parameters are provided: the maximum field magnitude (-33.5 dB(A/m)), the main lobe direction (2.0 degrees), the angular width of the main lobe (3 dB beamwidth, 26.8 degrees), and the side lobe level (-13.2 dB). **Fig.5 (b)** appears to show a similar radiation pattern, possibly in a different plane (likely the E-plane, while **Fig.5 (a)** might be the H-plane), but presented in a different format, possibly from a different simulation or measurement software. It also includes a table summarizing key antenna characteristics, including maximum signal levels and beamwidth. Both figures together provide a comprehensive view of the antenna's directional radiation properties.

3.4 Gain

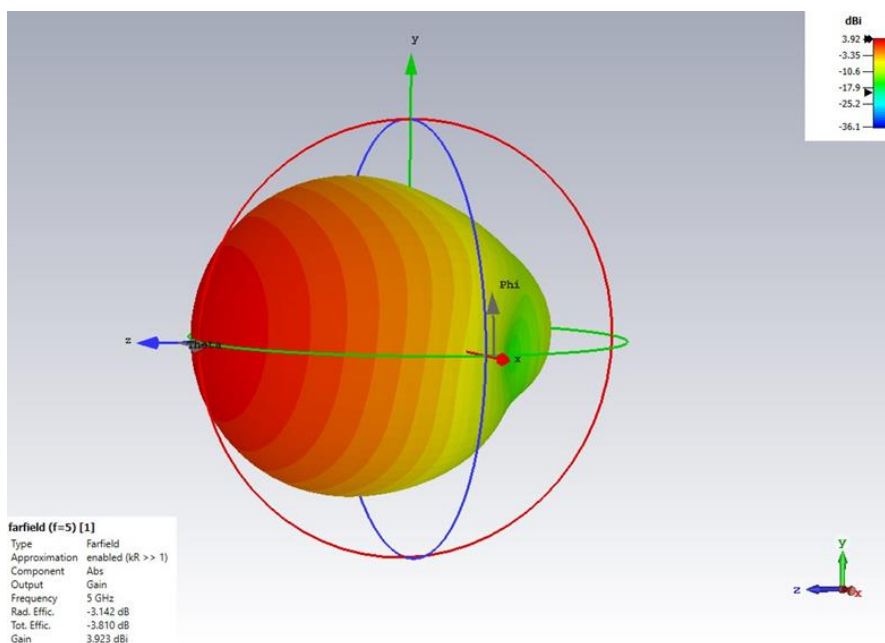


Fig. 6: Gain from the simulation of planar antenna

The simulation in **Fig.6** shows the far-field gain pattern of a planar antenna operating at 5 GHz as shown in Figure 4.9. The antenna exhibits a nearly omnidirectional radiation pattern, with the maximum gain of 3.923 dBi concentrated in a specific direction, indicating its ability to radiate efficiently in that direction. The radiation efficiency is -3.142 dB, reflecting some power loss due to material and conductor losses, while the total efficiency is -3.810 dB, which accounts for all losses, including mismatch losses. The colour gradient represents the gain distribution, with red areas indicating higher gain and blue areas lower gain, highlighting the main lobe and weaker radiation directions. This result demonstrates the antenna's suitability for applications requiring moderate gain and efficient performance at 5 GHz.

3.5 Surface Current Distribution

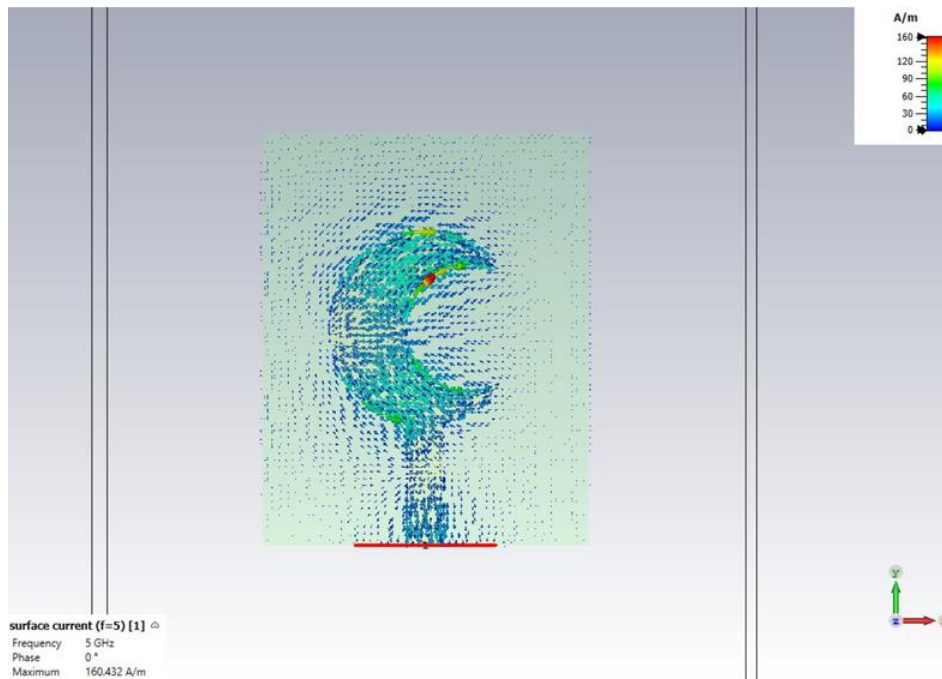


Fig. 7: Surface current of the planar antenna

The surface current on this **Fig.7** planar antenna is most intense at the feed point, where energy is injected, and flows outward across the conductive patch as shown in **Fig.7**, the current density diminishes as it spreads from the feed, indicating energy radiating as electromagnetic waves. A distinct flow pattern emerges, likely dictated by the antenna's specific shape, with potential current concentration along its edges due to material discontinuities. This current distribution, visualized at a resonant frequency of 5 GHz, likely forms a standing wave pattern, characteristic of resonance.

4. Comparison with Past Researchers

Table 1: Comparison to past antenna researchers

Antenna Reference	Frequency (GHz)	Reflection Coefficient (dB)	Gain (dBi)	Dimension (mm)
[2]	1.8 and 2.1	-10	3.3	30 x 60
[3]	3.5	-31	6.2	25.6 x 18.04
[4]	24	-10	20	23.4 x 16.4
[5]	29	-21.5	6.56	13 x 13 x 0.787
This Project	5.14	-16.57	3.93	38 x 30

Table 1 shows the comparison of the proposed antenna with existing research in terms of frequency, reflection coefficient, gain, and dimensions. The proposed antenna operates at 5.14 GHz with a reflection coefficient of -16.57 dB, indicating good impedance matching. It achieves a gain of 3.93 dBi and has dimensions of 38 x 30 mm. Compared to the other antennas listed, the proposed antenna offers a good balance between gain and size. Some antennas operate at lower frequencies or have higher gains but are significantly larger. The proposed antenna, operating at 5.14 GHz, finds relevance in modern wireless communication systems, and its compact size makes it suitable for integration into various devices.

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References

- [1] Abdelaal, M. A., & Ghouz, H. H. M. (2014b). NEW COMPACT CIRCULAR RING MICROSTRIP PATCH ANTENNAS. Progress in Electromagnetics Research C. Pier C, 46, 135–143. <https://doi.org/10.2528/pierc13121602>
- [2] Bhardwaj, S., Malik, P. K., Islam, T., Gehlot, A., Das, S., & Asha, S. (2023). A Printed Monopole Antenna for Next Generation Internet of Things: Narrow Band Internet of Things (NB-IoT). Progress in Electromagnetics Research C. Pier C, 138, 117–129. <https://doi.org/10.2528/pierc23090202>
- [3] Fayza, B. (2021). Design of Miniature Planar Antennas for 5G Systems. Advances in Wireless Communications and Networks, 7(1), 1. <https://doi.org/10.11648/j.awcn.20210701.11>
- [4] Advanced radio frequency antennas for modern communication and medical systems. (n.d.). Google Books. https://books.google.com.my/books?hl=en&lr=&id=M7ItEAAAQBAJ&oi=fnd&pg=PA49&dq=planar+antenna+for+iot+devices&ots=_rCda9rfgi&sig=bN6LldFFAIWso2REf3v8VrbLO4E&redir_esc=y#v=onepage&q=planar%20antenna%20for%20iot%20devices&f=false
- [5] Planar MIMO antennas for IoT and CR applications. (2017, December 1). IEEE Conference Publication Xplore. <https://ieeexplore.ieee.org/abstract/document/8325738>