

DESIGN AND SIMULATION OF OPTIMUM ANTENNA FOR IOT
BASED GEOSATELLITE SYSTEM

THESIS REPORT

*Submitted in partial fulfillment of the requirements for the award of the
Degree of Master of Technology in Electronics and Communication
Engineering with specialization in Communication Systems by the
A P J Abdul Kalam Technological University*

by

DIVYA S

Reg.No TKM21ECCS03



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ENGINEERING

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CERTIFICATE

Certified that this Project report titled "**DESIGN AND SIMULATION OF OPTIMUM ANTENNA FOR IOT BASED GEOSATELLITE SYSTEM**" is a bonafide record of the work done by **DIVYA S** (Reg.No.TKM21ECCS03) under my supervision, in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Electronics and Communication Engineering with specialization in Communication Systems by the A P J Abdul Kalam Technological University.

Guide and Coordinator

Dr. NISHANTH N

Professor

Dept. of ECE, TKMCE

Co-Guide

Dr. MANOJ B S

Professor

Dept. of Avionics, IIST

HoD

Prof. Shabeer S

Head, Dept. of ECE

TKMCE

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DIVYA S

TKM21ECCS03

ABSTRACT

Small-sized antennas are preferred for geostationary satellites for a number of reasons. The cost of manufacturing and launching smaller antennas is generally lower than that of larger ones. It is particularly important for commercial satellite operators who wish to minimize costs and maximize profits. It is more difficult and more expensive to launch large antennas into space due to their weight. It is easier to launch small antennas into orbit because they are lighter. The GEO satellites are located at an altitude of approximately 36,000 kilometers and have a limited amount of space. With smaller antennas on a satellite, more equipment can be installed. Beam coverage: Small antennas provide a narrow beam coverage with a high gain. In order to operate in a fixed position relative to the Earth and to cover a large area on the ground, geostationary satellites require highly directional antennas. In general, small-sized antennas are preferred for geostationary satellites due to their cost-effectiveness, lightweight, ability to take up less space, and narrow beam coverage with high gain.

In view of the fact that antennas designed for Geo-satellites were large and bulky, we are currently developing antennas that are smaller in order to be used in agricultural fields and other remote locations. In this case, the antenna will have direct access to the Geo-satellite without using the terrestrial network, since the use of the terrestrial network would cause a bottleneck in the communication between the antenna and the satellite. For the purpose of avoiding the bottleneck connection, a direct connection will be estimated based on a link budget. Based on the link budget, the antenna was designed and simulated.

In this work, we are aiming to simulate a small size, base heavy antenna for Geo-satellite which can work in the power range from 20-35dB. And has a gain more than 2 dB. So, that the antenna can communicate without the use of terrestrial networks.

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Chapter 1

Introduction

There are several reasons why small antennas play a significant role in geostationary satellites (GEOs). Efficient use of limited space: GEO satellites operate at an altitude of approximately 36,000 km and have limited space. Small antennas take up less space, allowing more equipment to be installed on the satellite. This includes additional transponders, sensors, or other instruments. Cost-effective: Smaller antennas are generally cheaper to manufacture and launch than larger ones. This is especially relevant for commercial satellite operators who want to minimize costs and maximize profits. Reduced launch costs: Smaller antennas are lighter and can be easily launched into orbit, reducing launch costs. Narrow beam coverage with high gain: Those antennas can provide narrow beam coverage with high gain. GEO satellites operate in a fixed position relative to Earth and cover a large area on the ground. Therefore, highly directional antennas are required to provide focused and efficient communication and data transmission services. Increased reliability: Smaller antennas are more reliable as they have fewer mechanical parts and are less prone to damage from vibration, mechanical stress, or thermal expansion. In summary, small-sized antennas are essential in GEO satellites due to their efficient use of limited space, cost-effectiveness, reduced launch costs, narrow beam coverage with high gain, and increased reliability.

Our ultimate goal is design an antennas for Geo-satellites that are smaller in order to be used in agricultural fields and other remote locations. In this case, the antenna will have direct access to the Geo-satellite without using the terrestrial network, since the use of the terrestrial network would cause a bottleneck in the communication between the antenna and the satellite. For the purpose of avoiding the bottleneck

connection, a direct connection will be estimated based on a link budget. Based on the link budget, the antenna was designed and simulated. In this work, in order to gain direct access to the satellite, we developed and simulated three models. The first model design was a helical antenna in axial mode and the gain achieved from the model was 13.4 dB. The second model designed was an inverted-conical and inverted- pyramidal antennas which was a base heavy model as we are trying to provide a base heavy model so the antenna doesn't topple over the gain derived from the model with the material used. Due to their strong directivity, which enables them to focus the signal in a particular direction, and their capacity to function at high frequencies, inverted-conical and inverted-pyramidal antennas are both often employed in microwave and radio-frequency communication systems. They are also employed in satellite communication, radar systems, and other applications that call for directional antennas.

Chapter 2

Literature Review

This section, presents an overview of some works related to the proposed approach.

Yan Zhu *et.al.*, and [1] the proposed that this study, Internet-of-Remote Things (IoRT) networks with integrated unmanned aerial vehicle (UAV) access and geostationary orbit (GEO) satellite back-haul show significant promise for providing Internet-of-Things (IoT) users and devices with acceptable access services. The performance analysis of network performance and access scalability is essential to IoRT network optimization. The stochastic network calculus-based min-plus convolution and the leftover service were developed in order to handle the challenges given by the complex network structure (i.e., two-level queuing network together with converged traffic). To address the analytical challenges provided by the continuous-time arrival process and heterogeneous two-level link capabilities, the closed form formulations of the network backlog and delay restrictions based on the martingale theory were developed. In order to pursue higher throughput while guaranteeing delay performance, it was decided to create a mixed-integer optimization problem of the access scale that includes a non-differentiable variable produced from a transcendental equation. A three-directional iterative (TDI) method was developed to identify the most effective solution to the optimization problem due to its tractability. Results from simulations confirm the value of the proposed method and the tightness of our performance limits in compared to the standard bound. Due to the study's tight performance constraints compared to the traditional bound and the optimality of the suggested approach, we were able to design the optimal network access numbers of UAVs and users for IoRT networks.

Zhang *et.al.*, [2] the proposed model for calculating the coverage probability and the maximum achievable rate of the multiple UAV-assisted downlink communications, a mathematical framework is developed employing stochastic geometry and an explicit consideration of the spatial distribution of the ground IoT devices. The evaluation of 3-D UAV-assisted networks takes the heights and speed of the UAVs into account, in contrast to the stochastic geometry analysis on 2-D terrestrial networks. Traceable analytical formulations for both performance measurements give insightful design guidelines for UAV-assisted networks. The efficiency of the created framework is validated using extensive numerical results, which also show how network characteristics like UAV speed, channel number, and altitude affect system performance. The parameters that will optimise both the average attainable rate and the coverage probability. The performance of the network is altered in the system-level simulations that are currently being done for network scenarios with several moving UAVs. The method's benefit is that it analyses only devices that have successfully established a full transmission to the UAV, characterising the features of UAV-assisted networks. In real wireless network systems, channel access delay is independent of any protocol characteristics during connection establishment and may be brought on by channel detection, handover, precoding, decoding, or satellite communication link delay. Therefore, if the association time exceeds the channel access delay, there will be a disruption between a conventional device and a UAV.

C.Su *et.al.*, [3] proposed model for an innovative multiperiod wireless charging system made possible by UAVs is provided for Energy-Constrained Devices (ECDs). The Markov aspect of the charging process is taken into account in the provided scenario since the current state and action may have an influence on the upcoming period state. Following the realistic situation, the energy needs of UAVs and wireless power chargers (WPCs) are also taken into consideration. To solve the challenge of multiperiod wireless charging, the multistage dynamic bipartite matching with one-sided preference is created to model the interaction between the ECDs and UAVs. This research significantly departs from the prior matching approach by focusing on multiple-stage dynamic matching rather than one-shot matching. The dynamic matching is carried out in order to maximise each ECD's charge amount using the Bellman equation-based evaluation function, which considers both the present reward and the future reward.

To achieve a higher charge amount, the proactive four-step charging technique was developed. The first stage involves setting up every local MDP for ECDs, which is crucial for predicting the payout in the future. In the second step, the random serial dictatorship (RSD) matching approach is recommended as a further course of action in line with the current circumstances. The combined MDP is generated in the third stage based on the results of the previous two steps. The Bellman equation-based estimated reward is developed to select the optimal branch. It is possible to evaluate the effectiveness of the postulated mechanism using numerical simulations. The simulation results demonstrate the effectiveness of the recommended technique. The implementation strategy and parameter effect of the recommended algorithm are also discussed, which provides more illuminating insights. The finding of this study is that performing the wireless charging process for energy-constrained IoT devices with unmanned aerial vehicles (UAVs) is not practical, especially in hostile environments. A lot of people are interested in UAVs because of its versatility, affordability, and wide variety of potential applications. UAVs are employed as mobile stations or mobile relays to support wireless communications. The charge quantities are decreased since the UAVs must take longer time to fly while spending less time hovering over the ECDs.

Wei Pei *et.al.*, [4] proposed model, which the GCV has the following characteristics: When using the C band or Ku band instead of the L band for GNSS, the ionosphere's impact can be reduced. The master clock of ground composite clocks, which is more precise than the onboard atomic clock for GNSS, serves as the time source in GCV. Using the GCV, time may be transferred from one time laboratory to several users as opposed to the paired transfer made available by TWSTFT. Differential observation reduces the influence of orbit accuracies and the imprecision of the propagation delay model. The service objectives of the GCV are the static users who want a high-precision time standard. A Very Small Aperture Terminal (VSAT) may be used to observe GEO communication satellites, enhance the S/N ratio, and improve the range accuracy and anti-multipath capabilities when compared to the traditional common-view approach. The study's findings receiver delays weren't totally eliminated. The RMS of the residual error was better than 1.4 ns. the mean, maximum, lowest, and RMS values of the GCV with residual error. The benefits of

this approach include the following: (1) some areas can be continuously covered by the GEO communication satellite's signal; (2) users can use small-aperture parabolic antenna systems with only receiving capability to observe the GEO satellite signals to improve the S/N ratio, ranging accuracy, and anti-multipath ability; and (3) signals are transmitted using the C band or Ku band for satellite communications., which can lessen the ionosphere's impact. The GEO satellite's exact orbit, station locations, and atmospheric delay should all be known in advance.

The data prediction model proposed by S.Wu *et.al.*, [5] The heterogeneous architecture may make use of both the GEO-layer and LEO-layer, resulting in seamless coverage and enhanced capacity. Several IoRT gateways are positioned to collect data produced by nearby IoRT devices and send it through satellite links to the terrestrial data centre. An ideal age-oriented access control problem is created in order to lower the system's long-term average peak AoI (PAoI). We use a model-free Markov Decision Process to solve this non-convex sequential decision-making problem in order to handle the time-varying channels and erratic data arrivals (MDP). Dueling-Double-Deep-Q Learning (D3QN) is a centralised policy that may be taught offline and applied online to gain consensus. The D3QN-based approach significantly outperforms cutting-edge techniques in simulation results for the AoI performance. The suggested method provides shared access to the satellite network and intelligent decision-making over access in response to traffic demands. Research has the benefit of being helpful to both geosynchronous and Leo satellites since neither the RSS-ACS approach nor the MT-ACS strategy can ensure queue stability. The LEO layer network benefits when more LEO resources are made available since the transmission and queueing delays may be less than the propagation delays experienced by GEO signals.

Z. Li *et.al.*, [6] this is the first study to examine resource allocation for UAV networks in the context of space-air-ground heterogeneous communication systems, taking into consideration the actual deployment of drones with the aim of minimising cross-tier interference. A two-stage combined hovering altitude and power control solution is looked at for our proposed model. The concave-convex procedure (CCP) and Lagrange dual decomposition techniques are used to approximate the relaxed convex problem. A low-complexity greedy proportionable power-constrained technique is also recommended for resource allocation in UAV networks. We execute a large

number of simulations to evaluate the effectiveness of our two-stage joint resource allocation (TSJ-RA) approach. The results of the simulation show that our resource allocation technique increases the UAV network's overall throughput while accounting for the inevitable cross-tier interference. This study uses mix-integer non-linear non-convex programming to jointly optimise sub-channel selection, uplink transmission power control, and the placement of UAV relays in maximising system energy efficiency. Calculations show that the suggested method outperforms other reference method by at least 21.9 percent in terms of system energy efficiency. The research's three-tier, heterogeneous space-air-ground network, which consists of UAVs with a range of communication payloads and base stations, is useful because it increases the capacity of the Internet of Things networks, which are becoming more and more successful, while also enabling seamless coverage.

Tong *et.al.*, [7] proposed a paper with three nominal grids-NGP grid, NNGP grid, and frame-imaging grid were presented and derived in accordance with the principles of the satellite imaging modes. In the experimental results it was found. The comprehension of the created nominal grid dataset and the following products based on the grid is hampered by the normalised geostationary projection (NGP) model's absence of the matching imaging mode and physical interpretation in the available literature. It was suggested to use a non-standard normalised geostationary projection (NNGP), which is perfectly consistent with the circumstances of the American GOES-R and Chinese Fengyun-4A satellites (FY-4A). new nominal projection model for frame imaging that is compatible with China's Gaofen-4's imaging mode. Finally, in-depth experiments were created to compare analyse the three nominal grids and show the differences in detail. New nominal projection model for frame imaging that is compatible with China's Gaofen-4's imaging mode. In addition, the conversion between various datasets originating from various nominal grid data were demonstrated as well as a full comparison of the three nominal grids through extensive tests. The algorithms play a critical role in reliably delivering meteorological data with comparable quality to that from GOES-R and offer the technological foundation for high-precision picture navigation and registration. The NGP grid is more consistent with the frame-imaging grid and the three nominal grids were similar in the central region of the whole disc, close to the subsatellite point. This paper is crucial for the near-real-

time creation, dissemination, and application of gridded data from remote sensing satellites in geostationary orbit as well as the conversion between various gridded data types. The advantage of this paper is that, in-depth comparisons were done between the CGMS standard's NGP grid and the NNGP grid in this article (used by GOES-R and FY-4A). The GOES-R and FY-4A nominal grids are determined by the ABI optical-mechanical structure, but the CGMS standard maintains the previous scanning method of spin stabilisation geostationary satellites.

JiXiang *et.al.*, [8] This research, discusses the steerable spot beam reflector antenna installed on the satellite's east and west sides. By rotating the reflector just about its vertex (known as "Vertex Rotation"), the steerable spot beam may be easily moved to give variable coverage. This method has several benefits, including outstanding electrical performances, a simple mechanical design, lightweight, and low cost. Both the measurement findings and the antenna design processes are discussed. This antenna is ideal for geostationary satellite payloads since it exhibits scan loss, sidelobe level (SLL), cross-polarization level (XP), and pointing accuracy measurements of 0.6dB, -25.9dB, -26.2dB, and $0.04^\circ/\text{axis}$, respectively, within the steering range of 8.0° . The reflector is rotated about its vertex the steerable spot beam can be easily a steerable spot beam antenna can be directed in one of two ways: "Gimballed Antenna Assembly" or "Gimballed Reflector" generally speaking, a steerable spot beam antenna is better suited to be mounted on the satellite's Earth-facing deck The only drawback of a "Gimballed Reflector" is scan loss caused by the feed's displacement from the reflector's focal point. The feed chain and antenna support structure remain. The antenna beam is steerable and may provide flexible coverage to any place on the whole visible Earth surface thanks to "Vertex Rotation," which has more advantages than "Focus Rotation" (such as high electrical performance, a simple mechanical design, light weight, and low cost).

Chapter 3

Proposed Model

Traditionally, the antennas designed for Geo-satellites were large and bulky, we are currently developing antennas that are smaller in order to be used in agricultural fields and other remote locations. In this case, the antenna will have direct access to the Geo-satellite without using the terrestrial network, since the use of the terrestrial network would cause a bottleneck in the communication between the antenna and the satellite. The first model design was a helical antenna in axial mode. The second model designed was an inverted-conical and inverted- pyramidal antennas which was a base heavy model as we are trying to provide a base heavy model so the antenna doesn't topple over the gain derived from the model with the material used. Due to their strong directivity, which enables them to focus the signal in a particular direction, and their capacity to function at high frequencies, inverted-conical and inverted-pyramidal antennas are both often employed in microwave and radio-frequency communication systems. They are also employed in satellite communication, radar systems, and other applications that call for directional antennas.

3.1 Software used for simulation

The software used for simulation is HFSS(High Frequency Simulation Software) which is a 3D electromagnetic (EM) simulation program called Ansys HFSS is used to design and simulate high-frequency electronic devices such antennas, antenna arrays, RF or microwave components, high-speed interconnects, filters, connectors, IC packages, and printed circuit boards. Ansys HFSS software is used by engineers all

around the world to create the high-frequency, high-speed circuits used in satellites, ADAS, communications systems, and internet-of-things (IoT) devices.

3.2 Helical Antenna Model

The helical antenna was designed by opening the software and clicking on view ACT Extensions and then to launch wizard then to HFSS Antenna Toolkit and then to Helix and to Axial mode. The antenna will be created according to our preference as the number of turns is 18 the thickness is 0.8 cm and the Height of the antenna is 20cm

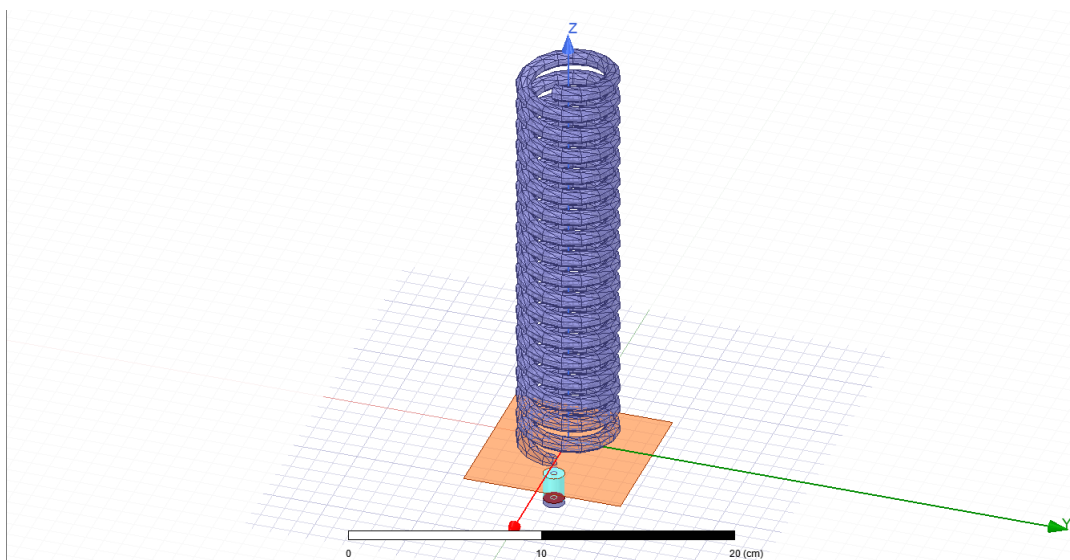


Figure 3.1: Proposed Helical Antenna

3.3 Inverted-conical antenna model

In the design of the inverted conical design we were designing an antenna with heavy base so that the antenna doesn't topple over so the designing was done as the largest ring in antenna has a diameter of 12.8 cm and the the size of the rings decreases as it goes higher and the size difference of the rings is 1 cm, the size of the last ring is 2.8cm . The number of rings in the antenna is 11 and the distance between the rings is 3 cm.

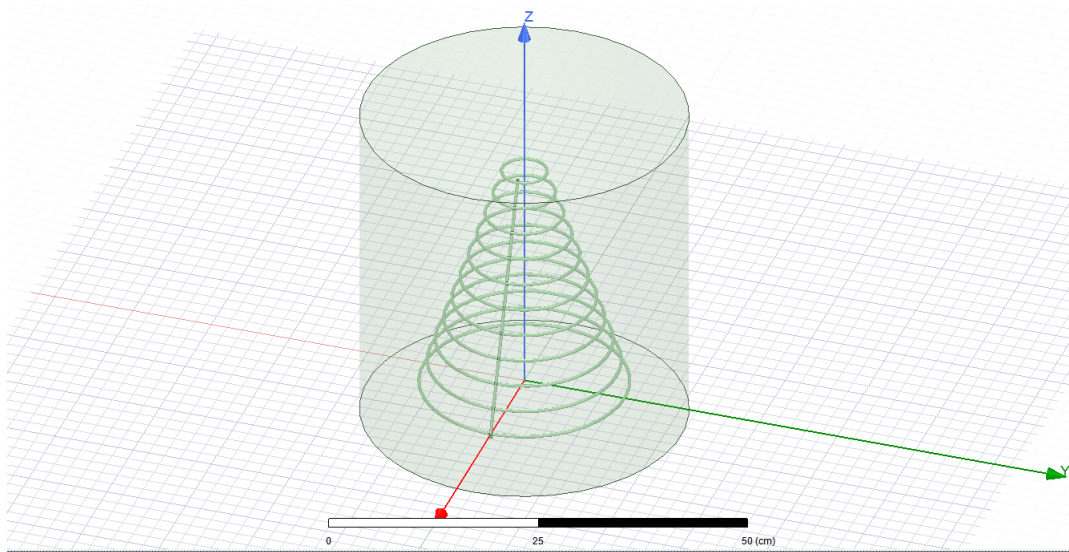


Figure 3.2: Proposed Inverted-conical Antenna

3.4 Inverted-pyramidal antenna model

In the design of the inverted-pyramidal design we were designing an antenna with heavy base so that the antenna doesn't topple over so the designing was done as the largest square in antenna has a length of 6 cm and the the size of the square decreases as it goes higher and the size difference of the squares is 0.4 cm, the size of the last square is 1.2cm . The number of rings in the antenna is 13 and the distance between the rings is 0.6 cm.

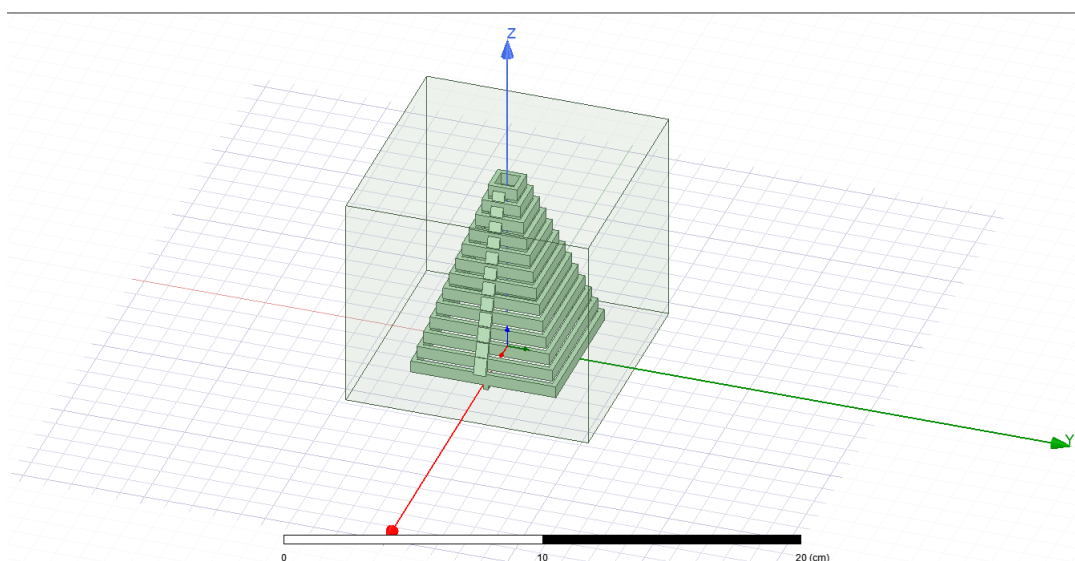


Figure 3.3: Proposed Inverted-pyramidal Antenna

Chapter 4

Result and Discussions

The results of the an antenna's gain is a crucial performance metric that reflects its capacity to concentrate electromagnetic radiation in a certain direction. The radiation strength in the direction of the antenna's greatest radiation is compared to that of an isotropic radiator, which radiates equally in all directions, to determine the gain, which is commonly given in decibels (dB). In order to obtain the necessary performance characteristics, such as gain, an antenna must first be designed, which entails specifying the physical dimensions and specifications of the antenna. The performance of the antenna is often optimised throughout the design phase utilising simulation software.

4.1 Helical Antenna Gain

The radiation efficiency of the helical antenna depends on the electrical characteristics of the helix and the feed structure. In general, higher radiation efficiencies are achieved with larger diameter helices and tighter pitch angles. The gain of a helical antenna can be further increased by stacking multiple helices in series or parallel to form an array. This can increase the directivity and gain of the antenna, but also increases the complexity of the design and the feed structure. Overall, helical antennas are commonly used in applications such as satellite communication, radio astronomy, and direction finding, due to their high gain and directional properties. Helical antenna has a gain was 13.4dB.

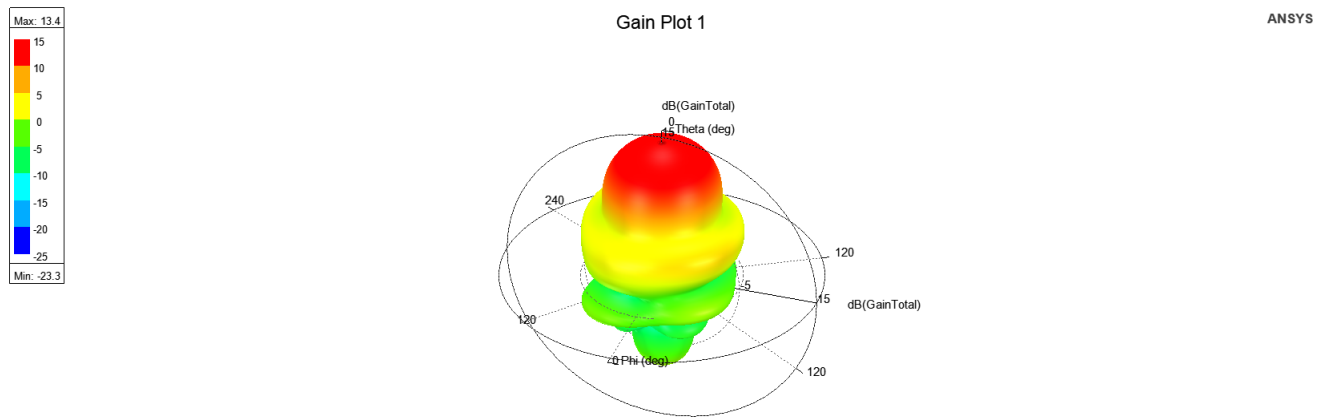


Figure 4.1: Proposed Helical Antenna

4.2 Inverted-Conical Gain

The gain of an inverted-conical antenna can be maximized by selecting appropriate values for the half-angle, length, and diameter of the cone, and by optimizing the radiation efficiency of the antenna. In general, inverted-conical antennas are used in applications that require high gain and directivity, such as satellite communication, radar, and terrestrial communication systems. The gain of antenna was increased as 1.2dB in silver than copper and copper-alloy and gold gain in 5.3 dB. In the frequency range of 920-927 MHz and power of 1 watt or 30 dB.

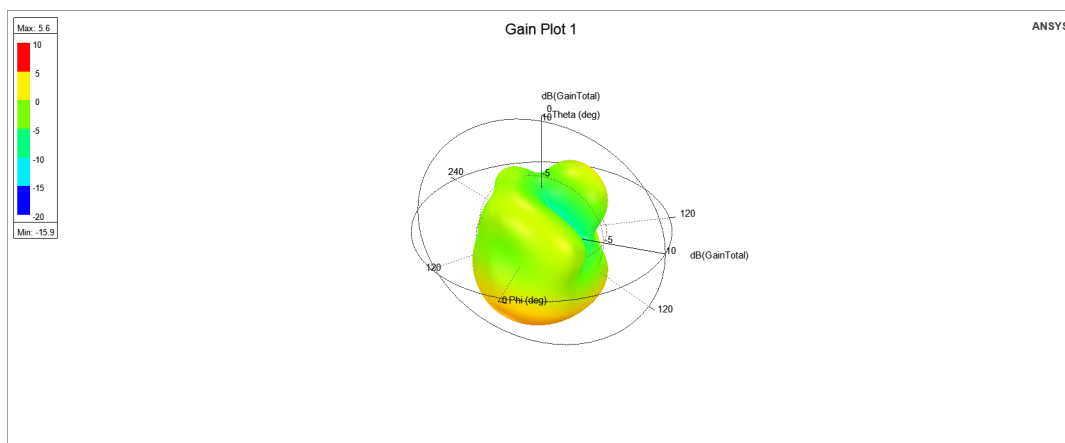


Figure 4.2: Inverted-Conical Copper gain

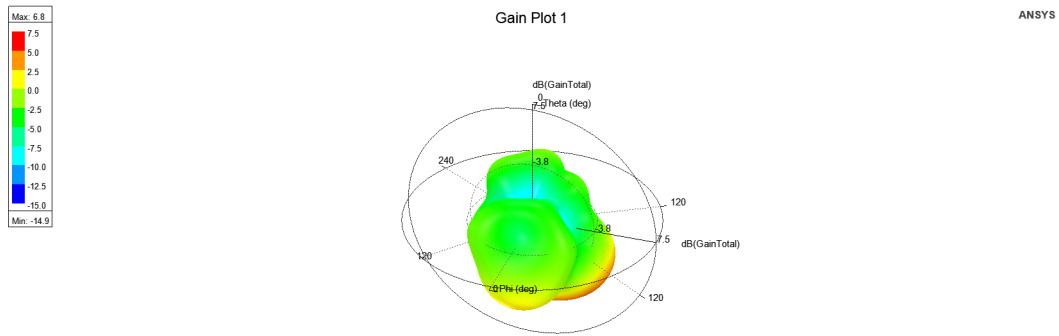


Figure 4.3: Inverted-Conical Silver gain

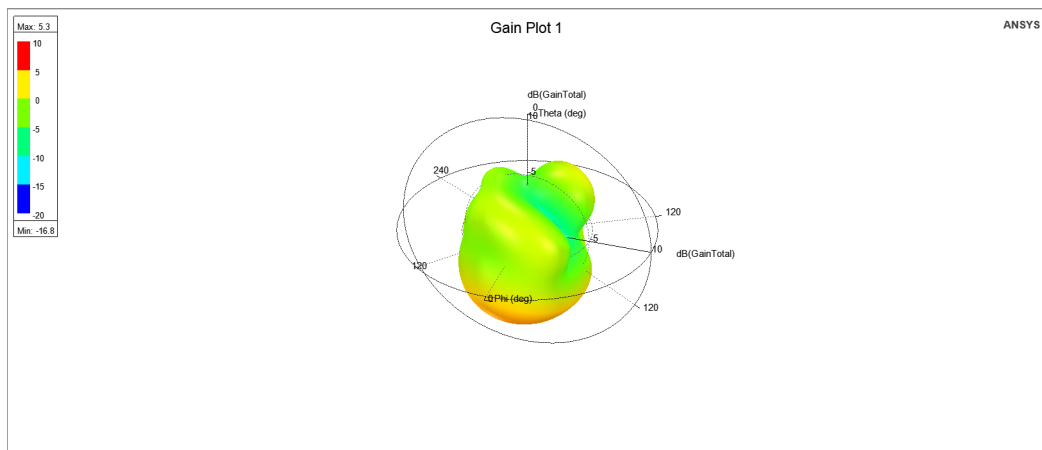


Figure 4.4: Inverted-Conical Gold gain

4.3 Inverted-pyramidal Gain

The gain of an inverted-pyramidal antenna can be further optimized by selecting an appropriate apex angle for the pyramid. In general, smaller apex angles result in higher gain antennas, but also increase the complexity and difficulty of the design. Inverted-pyramidal antennas are used in applications that require high gain and directivity, such as satellite communication, radar, and terrestrial communication systems. The design of an inverted-pyramidal antenna involves optimizing the physical dimensions of the pyramid and the radiation efficiency of the antenna to achieve the desired performance characteristics. The gain of the inverted-pyramidal was found 7.2dB and silver is 7.2 dB. As there was not increases in gain there can be optimization can be done as the antenna has not reached its optimum value which will help us to communicate with the Geo satellite. The optimization of an inverted-conical antenna involves

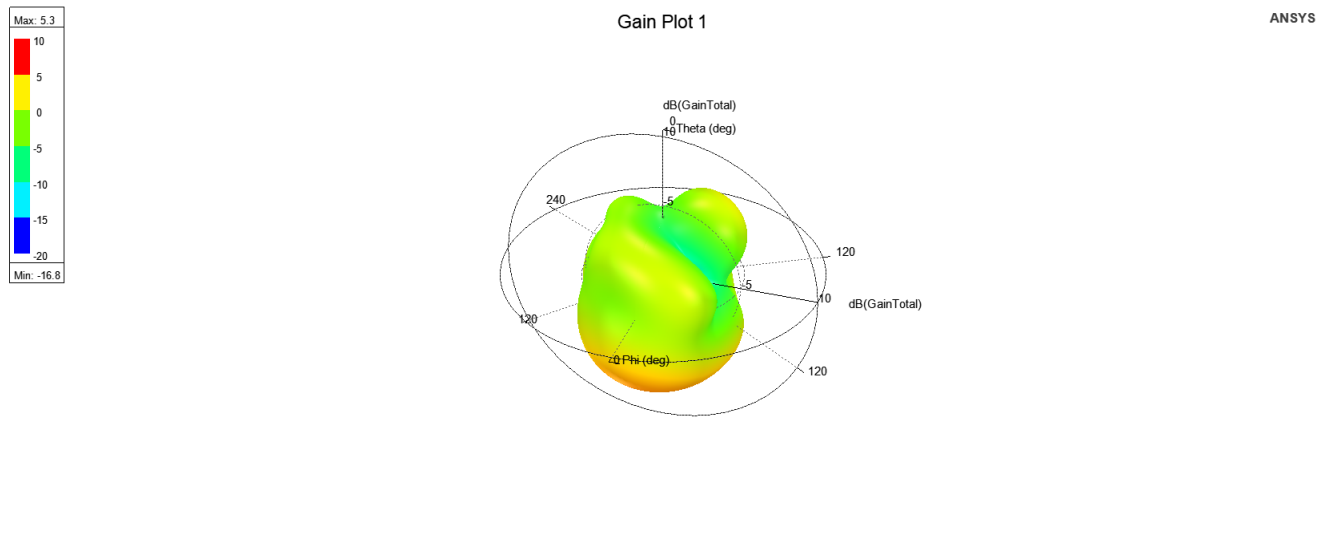


Figure 4.5: Inverted-Conical copper-alloy gain

adjusting the physical dimensions of the antenna, the feed type and location, the material and fabrication techniques, and the radiation efficiency to achieve the desired performance characteristics. This requires a combination of theoretical analysis and experimental testing to determine the optimal design parameters for the antenna.

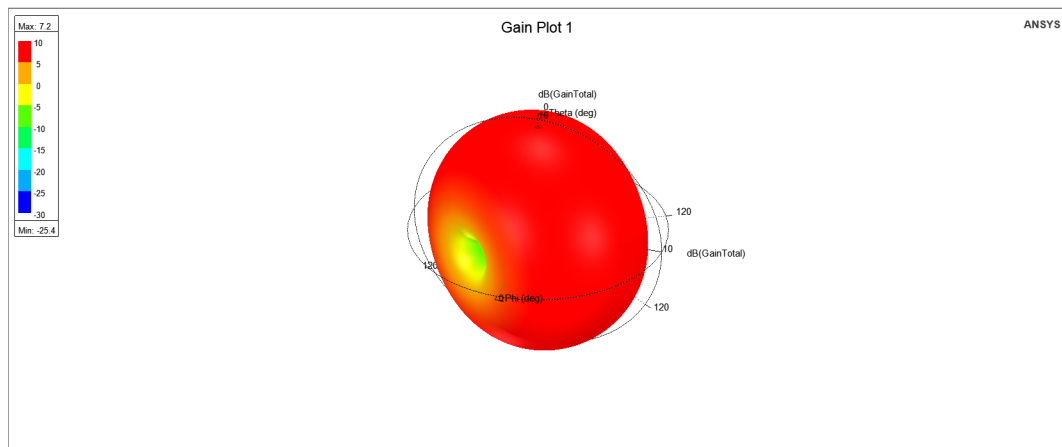


Figure 4.6: Inverted-pyramidal copper Gain

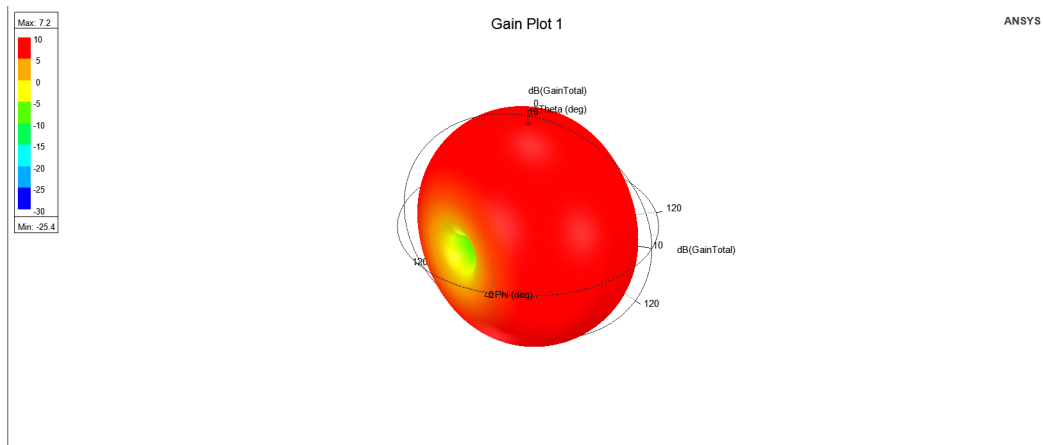


Figure 4.7: Inverted-pyramidal Silver Gain

Chapter 5

Future Scope

Small size antennas in Geo-satellite communication have a bright future. Small, effective antennas that can provide high-quality communication services have been made possible by the development of novel materials, manufacturing processes, and enhanced signal processing technologies. Our model has provided with the possibility of small sized antenna that can communicate with the Geo-satellite using a LoRaWAN network.

We concluded that by assigning different materials to the antenna that the gain of the antenna can be increased. And the optimization of the inverted pyramidal can be achieved which will help in compacting the size of the antenna.

Chapter 6

Conclusion

In view of the fact that antennas designed for Geo-satellites were large and bulky, we are currently developing antennas that are smaller in order to be used in agricultural fields and other remote locations. In this case, the antenna will have direct access to the Geo-satellite without using the terrestrial network, since the use of the terrestrial network would cause a bottleneck in the communication between the antenna and the satellite. For the purpose of avoiding the bottleneck connection, a direct connection will be estimated based on a link budget. Based on the link budget, the antenna was designed and simulated.

In this work, in order to gain direct access to the satellite, we developed and simulated three models. The first model design was a helical antenna in axial mode and the gain achieved from the model was 13.4 dB. The second model designed was an inverted-conical antenna which was a base heavy model as we are trying to provide a base heavy model so the antenna doesn't topple over the gain derived from the model with the material used was copper(Cu) was 5.6dB, Silver(Ag) was 6.8 dB, Gold(Au) was 5.3 dB and copper-alloy was 5.3dB. As we can see from the model the material affected the gain very little and the difference between the gain was 1.2 dB. The third model designed was an inverted pyramidal antenna. The gain achieved from the model with the material used was copper(Cu) was 7.2dB and silver(Ag) was 7.2 dB.

We came to the conclusion that the inverted-pyramidal antenna's gain could be optimised, and that the inverted-conical antenna's gain was 5.6dB when developed and simulated.

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