

Microstrip antenna system for communication capabilities applications

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ABSTRACT

In this comparative study, seven different microstrip antenna shapes, including rectangular, elliptical, triangular, inset fed, H-notch, and E-notch, were observed and analyzed, focusing on their suitability for global positioning system (GPS) application in microsatellites. To enable meaningful comparison, the study utilized the optimal resonant frequency in GPS applications, which is 1.57542 GHz. All the antenna designs have been generated using MATLAB's Antenna Toolbox and are 100% efficient under ideal conditions with zero polarization loss, which is assumed in the link budget analysis. The results show that each antenna shape has been found to offer distinct advantages and limitations. Along with this, the circular and elliptical patch antenna presented a well-balanced performance, which is suitable for GPS applications. However, the elliptical shape falls behind the circular shape, which was determined to be the most optimal choice for GPS application, providing excellent isotropic antenna gain, return loss, voltage standing wave ratio (VSWR), and strong link budget analysis results.

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1. INTRODUCTION

In today's world of emerging technology, satellite systems serve an essential purpose in humans' daily lives. It serves a pivotal role in relaying communication, broadcasting, navigation, weather forecasting, and various other services that uphold modern society, including the most prominent application, which is global positioning system "(GPS)," which stands for global positioning system [1]. In addition, microsatellites have gained prominence in the satellite industry, where these compact-size satellites have been utilized in GPS applications to augment capabilities for a particular specification [2], [3]. Although GPS does not entirely base microsatellites in its system. Microsatellites play a role in research and development, such as improving signal reception in specific regions or testing other GPS-related emerging technologies [4].

However, given its small size and compactness, it poses challenges when it comes to integration and the performance characteristic for the desired function [5], [6]. The application of microsatellites consists of a microstrip in which the type of antenna shape is among the critical components in a microsatellite's GPS. On the other hand, the performance of microstrip antennas is related to the shape and design, which manufacturers favor for being dynamic [4], [7]. With this, the selection of the antenna shape impacts the

satellite's overall effectiveness as well as the coverage and precision of data to be transmitted [8]. Having microstrip antennas holds significant importance, and there is a need to obtain and explore in-depth information for the optimal antenna shape that considers factors such as polarization, signal strength, and the most suitable for a specific application that considers the enhancement of GPS capabilities. Therefore, this study will involve the analysis of the variation of shapes of the patch antennas like the rectangular, circular-shape, elliptical-shape, triangular, inset fed, E-notch, and H-notch. Along with this, the structure of the microstrip antennas, radiation pattern, and the resulting beamwidth will be demonstrated to be able to provide insights into the distinction of each of the shapes.

Microsatellites global positioning system: the efficiency and performance of the GPS on microsatellites largely depend on the shape or design characteristics of the antennas [9]. Accurate phase of the antenna between the satellites and the receiver is essential to avoid offset values and phase center variation, which are the main issues in the precise positioning of the GPS. Nonetheless, in a miniaturized GPS receiver, the antenna that is being applied is a microstrip antenna that weighs a few grams of mass or fewer [10]. As microstrip antennas compromise different shape variations, one of the examples is a coplanar microstrip antenna demonstrated promising results in the intelligent transportation system and GPS [11]. Another is a coplanar-slotted microstrip patch transmitter for dedicated short-range communications (DSRC) or dedicated short-range communication applications [12]. A hexagon microstrip antenna is effective in vehicle-to-vehicle communication because of its omnidirectional radiation pattern [13]. With the following applications provided, communication systems are widely present up to date to match the evolving lifestyle of humans, particularly on various navigation systems such as the GPS [14].

On the other hand, the GPS is composed of satellites, the command or receiver stations, and GPS receivers, which are all the components needed to do the transmission. Although the antennas do most of the emission and reception of data, they are primarily applied in non-wired systems for communication. The capabilities of the transmitter have not been limited to strengthening signal interception but also enable precise positioning, navigation, and other space-based applications [15], [16]. Therefore, microstrip antennas play an essential role as a propagation medium. In contrast, the study will consider a range of variations of microstrip antenna shapes and systematically compare their radiation pattern and other characteristics to identify the optimal configuration of microstrip antenna for microsatellite-based GPS applications.

GPS enables ease of navigation among millions of users across the globe. However, despite its fast-paced development, position determination through GPS and the accuracy of the positions it gives are based on the transmitted signals' nature, satellite geometry, signal blockage, and atmospheric conditions, among many other factors [17], [18]. With this, it is essential to determine the most suitable shape of the transmitter to be used effectively in the antenna transmission of information. Given the various shapes and dimensions available on microstrip antennas, the most suitable antenna will be measured based on different parameters using ideal antenna testing and link budget analysis. Using MATLAB, these simulations will bring out the necessary information to determine the most suitable antenna without incurring the cost of live experimentation.

Users are often misled by incorrectly drawn maps, missing roads and buildings, and mislabeled buildings in GPS. Despite this problem, GPS continues to attract multiple users because of its ease of access, as it tells you about the direction for every turn you need to take to reach your destination. Furthermore, GPS is used by millions of users due to its worldwide availability and low cost. Providing a more accurate signal through the continuous improvement brought about by determining the most suitable shape of microstrip antenna will solve this problem and contribute to the development of this technology to its full potential.

Basic operation, design, and variations of microstrip antenna: a microstrip antenna has a metal plate, which is described as a very thin strip of radiating metal located on one side of a thin substrate, while the substrate plane is also metal located on the other side. Meanwhile, the thickness of the substrate is typically about 0.01 to 0.05 wavelengths in the free space and is mainly used to provide suitable spacing and mechanical support between the patch and the ground. The substrate material can be separated by having a dielectric constant between 1.0 and 2.0 (e.g., air, honeycomb dielectric), 2.0-4.0 (e.g., fiberglass), and 4-10 (e.g., ceramic, quartz).

The metallic conductor in a microstrip antenna is usually in the form of a rectangle, circle, triangular, or ellipse. Aside from these shapes, microstrip antennas have also taken the form of letters. Four main parameters should be considered in the design process of a microstrip antenna—operating frequency, patch width, effective dielectric constant, and patch length [10], [19]-[22]. However, generalized expressions are complex to obtain as they are on a case-to-case basis depending on the selected shape of the microstrip antenna.

Link budget analysis: link budget analysis serves as a method to quantify the communication performance and concerns itself with various essential channel and transceiver parameters like transmit power, channel bandwidth, required signal-to-noise ratio (SNR), and temperature, among many other

parameters [23], [24]. It is used during the early stages of the design process to assess whether these design parameters are obtained as well as whether the specifications mandated by regulatory bodies are achieved. The received power can be determined by using the transmission power, transmission antenna gain, and the receiver gain. Link budget analysis puts link margin on the focus. The link margin is described as the minimum received level of signal minus the actual power received [25]. A link is possible when the power minus all the losses surpasses the minimum received signal level of the receiver. This means the link margin of the system should be above zero and maximized for a system to work well. It should be noted that its equation does not consider the cable losses and voltage standing wave ratio (VSWR) mismatches in the system. It should also be noted that the power also depends on the receiver antenna gain and its directivity [26].

Previous studies: several studies have explored various shapes in designing microstrip antennas. Most of the time, comparative studies only compare the performance between two different shapes or substrates, but some papers conduct a comparative study on four shapes at a time. In a 2018 study, Meena and Kannan analyzed the most appropriate substrate and tested it on four different shapes—H-shape, E-shape, S-shape, and U-shape—to be used based on the gain, directivity, bandwidth, and return loss [27]. The study revealed better performance in RT/Duroid5880 in terms of bandwidth and better gain in FR-4 for any shape.

Bhoot *et al.* [28], a comparative performance analysis was made on four different shapes—E-shape, T-shape, H-shape, and F-shape. Four parameters were used to assess the effectiveness of the patch antenna: gain, return loss, directivity, and polarization. In this study, it was concluded that the E-shaped antenna is more suitable for practical applications, especially where wide bandwidth is required, as it returned the values of 7.22 dB, -15.62 dB, 7.06 dB, and 3.44 for the gain, return loss, directivity, and polarization, respectively. Microstrip antennas have also been used for GPS applications. Lin and Huang designed a compact antenna consisting of two parts—a fundamental mode truncated square patch antenna and a higher-order mode annular ring patch antenna—operating at 1575 MHz with 8 MHz bandwidth and has high performance for both GPS and digital communication system (DCS) applications [29]. Bilotti and Vegni also presented two designs of microstrip receiving antennas for GPS, which use multiple feeds to increase polarization purity and radiation pattern symmetry [30]. The first antenna consists of a truncated corner squared patch fed through a bifilar transmission line, while the second antenna consists of a reduced surface wave circular patch antenna with four feeds. Both designs have performances fitting in high-precision GPS receiver antennas. On the other hand, Al-Rizzo *et al.* [31] investigated the usage of folded and drooped ground planes using solid and annular microstrip antennas to enhance low-angle GPS coverage. Compared to their conventional counterparts, the folded antennas provide a marginally improved 3-dB beam width and excellent phase center stability without degradation of the bore-sight gain. This addresses the problem of a decrease in gain on low-elevation angles.

2. METHODS

The primary system of the project is a microstrip antenna designed for GPS capabilities in microsatellites. The physical construction of the transmitter is constructed through a microstrip element, a substrate of dielectric material, a feedline, and a metal ground plane. These microstrip antennas are produced in various dimensions and patterns. The area of the antennas are as follows: rectangular—1.09, circular—0.99, elliptical—3.7, triangle—0.77, inset fed—0.73, E-notch ~ 0.69, and H-notch ~ 0.43. All in terms of centimeters squared. The space satellite unit is a microsatellite orbiting in LEO or low Earth orbit. The GPS capabilities of the system are in the form of the frequency it uses, which is in the L-band frequency spectrum with a frequency of 1.57542 GHz, a bandwidth of 24 MHz, and a bit rate of 1.023 Mbps.

2.1. Theoretical considerations

In satellite space systems fitted for GPS communications, factors such as the operating frequency, bandwidth, altitude, and bit rate contribute to the downlink performance of signal transmission. The operating frequency required for GPS capabilities is 1575.42 MHz, which lies in the L-band frequency spectrum that encompasses frequencies from 1518 to 1657 MHz [32]. Moreover, the bandwidth occupied by this frequency is at 24 MHz. The study assumes that the microsatellite is in low Earth orbit and thus is at an altitude of 700 to 3000 kilometers. However, the paper will assume the highest altitude of 3000 kilometers for the methodology. Lastly, the primary pseudo random noise (PRN) code length for GPS transmission capabilities is at 1023 bits PRN transmitted at a rate of 1.023 Mbps.

2.2. Methodological flowchart

As Figure 1 presents, the methodology is composed of three major stages: antenna design, ideal antenna testing, and link budget analysis. The antenna design stage deals with the construction of the various microstrip antenna shapes in MATLAB's Antenna Toolbox using the design function with a specified

operating frequency of 1.57542 GHz [33]. The ideal antenna testing stage involves determining the critical antenna characteristics such as antenna gain, efficiency, impedance, return loss, VSWR, beamwidth, and the 3D radiation pattern for each antenna [34].

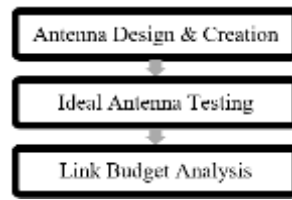


Figure 1. Methodology flowchart

The last stage revolves around the use of the link budget analysis. The link budget analysis is a method of analyzing the gains, losses, and other pertinent parameters in a communications link. In the context of this paper, link budget analysis was performed using the MATLAB app to analyze the performance of the different microstrip antennas in space satellite communications [35]. A downlink procedure was performed in the analysis as the antennas transmit information to a ground station receiver. It is worth noting that not all required parameters present in the link budget analysis can be fitted for the antenna shapes. Thus, these values are kept at default to ensure uniformity for all antenna patterns.

3. DATA AND RESULTS

The researchers tested and simulated seven (7) patch microstrip antenna shapes in MATLAB: rectangular, circular, elliptical, triangular, Inset Fed, E-notch, and H-notch. These antenna shapes will be compared with several different parameters to analyze and conclude the strengths and weaknesses of each antenna. Rectangular antenna the rectangular antenna is relatively small, having a length of 0.0913 m, a width of 0.1189 m, and a height of 0.00189 m. Additionally, the antenna also uses a dielectric substrate. The radiation pattern of the rectangular antenna is seen in Figure 2. The antenna has a frequency of 1.57542 GHz with maximum and minimum values of 10.1 dBi and -34.7 dBi, respectively. Notably, the radiation pattern shows a relatively circular shape from the z to -z-axis. Figure 3 illustrates the beamwidth of the rectangular antenna, which spans 57 degrees, ranging from 117 degrees to 60 degrees.

Circular antenna the compact size of the circular antenna is evident, featuring a radius of 0.0561 meters and a height of 0.0038 meters, along with a dielectric substrate. For Figure 4, the radiation pattern of the circular antenna has a maximum value of 9.69 dBi and a minimum value of -19.6 dBi while having a frequency of 1.57542 GHz. Similar to Figure 2, the radiation pattern exhibits a predominantly circular shape when observed from the z to -z-axis. Figure 5 depicts the beamwidth of the circular antenna, which covers 54 degrees, extending from 117 degrees to 63 degrees.

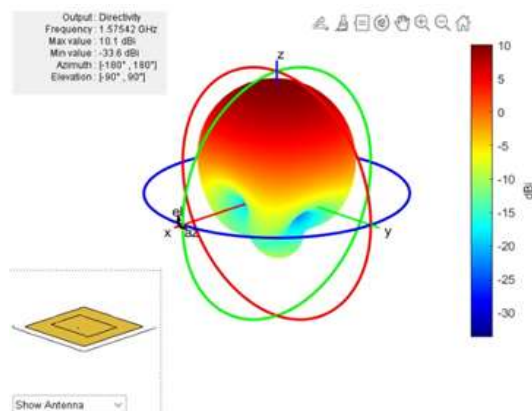


Figure 2. Radiation pattern of rectangular antenna

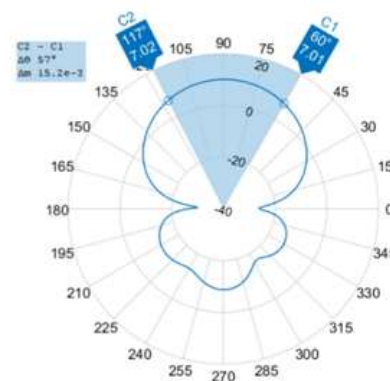


Figure 3. The beamwidth of rectangular antenna

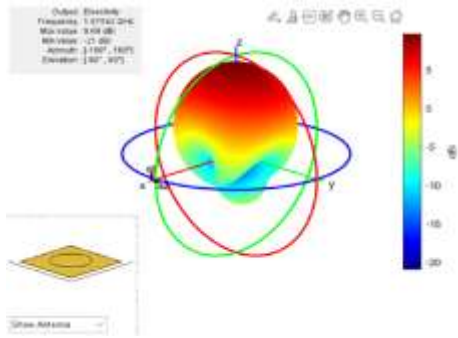


Figure 4. Radiation pattern of circular antenna

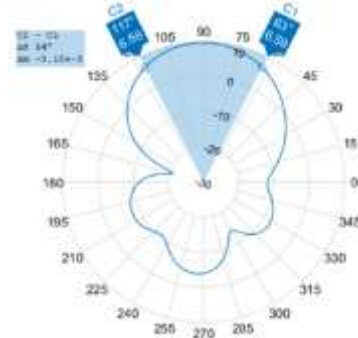


Figure 5. The beamwidth of circular antenna

Elliptical antenna similar to the rectangular and circular antenna, the elliptical antenna has a dielectric substrate. Its dimensions comprise a significant axis length of 0.1099 m and a minor axis length of 0.1080 m. In Figure 6, the radiation pattern of the elliptical antenna reaches a peak of 9.4 dBi and a lowest point of -15.1 dBi, all at a frequency of 1.57542 GHz. Additionally, the radiation pattern exhibits a circular shape and gradually decreases in size going down the z-axis. Figure 7 portrays the beamwidth of the elliptical antenna, spanning 59 degrees, from 117 degrees to 63 degrees.

Triangular antenna The triangular antenna shows consistent measurements on all sides, spanning 0.1332 meters, with a height of 0.0076 meters, and incorporates a dielectric substrate. The radiation pattern of the triangular antenna as shown in Figure 8 takes on a somewhat distorted circular appearance, mainly exhibiting more distortions along the z-axis. Furthermore, it operates at a frequency of 1.57542 GHz, with minimum and maximum values of 8.83 dBi and -18.5 dBi, respectively. In Figure 9, the beamwidth characteristics of the triangular antenna can be observed. The beamwidth of this antenna is relatively wide, measuring 69 degrees in total. This wide beamwidth extends from 124 degrees on one side to 55 degrees on the other, showcasing the ability of the antenna to cover a broad angular range in its radiation pattern.

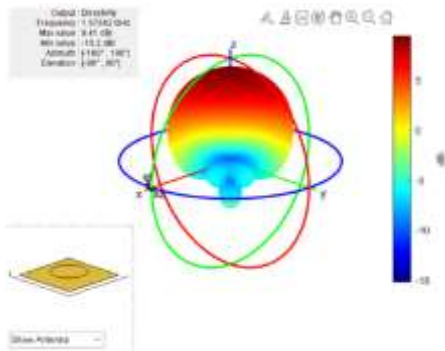


Figure 6. Radiation pattern of elliptical antenna

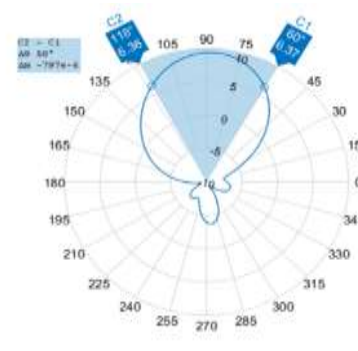


Figure 7. The beamwidth of elliptical antenna

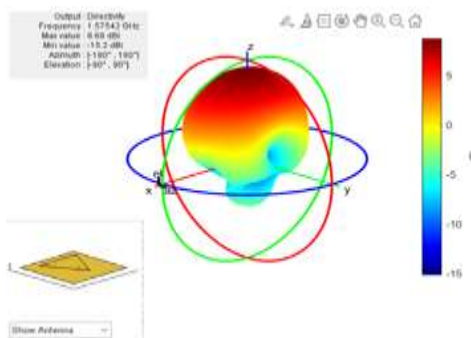


Figure 8. Radiation pattern of triangular antenna

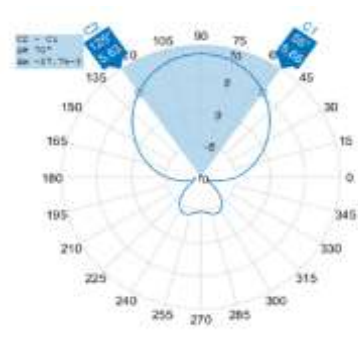


Figure 9. The beamwidth of triangular antenna

Inset Fed antenna the software generated the inset fed antenna for a resonant frequency of 1575.42 MHz with a length of 0.0856 m, a width of 0.0856 mm, and a height of 0.0048 m. Additionally, the strip line width, notch length, notch width, ground plane length, and ground plane width were recorded to be 0.0054 m, 0.0127 m, 0.095 m, 0.1903 m, and 0.1903 m, respectively. The radiation pattern of the inset fed antenna is shown in Figure 10. The maximum antenna gain with an isotropic antenna as reference is 9.59 dBi, with a minimum value of -32.8 dBi. Evident from the radiation pattern is that the radiation is spherical, and the high gain is centered around the positive z-axis. This gain decreases as the z-axis is lowered. The antenna beamwidth of the inset fed shape is shown in Figure 11. The beamwidth of the antenna is 58 degrees, which is from 61 to 119 degrees.

E-Notch antenna the E-notch antenna has a resonant frequency of 1575.42 MHz with a length of 0.0809 m, a width of 0.0847 mm, and a height of 0.0136 m. The center arm notch length and width are 0.0119 m, and 0.0136 m, respectively. Furthermore, the ground plane length, ground plane width, and feed diameter are 0.1059 m, 0.1271 m, and 0.055 m, respectively. The radiation pattern of the E-notch antenna is shown in Figure 12. The maximum antenna gain with an isotropic antenna as reference is 6.05 dBi, with a minimum value of -8.17 dBi. The radiation pattern is that the radiation is spherical at the positive z-axis and takes an uneven pattern at the negative z-axis. The power gain decreases from the positive z-axis to the negative z-axis. Yet, the lowest gain is at the center of the pattern, which is not visible in the figure. The antenna beamwidth of the E-notch shape is shown in Figure 13. The beamwidth of the antenna is 61 degrees, which is from 51 to 122 degrees.

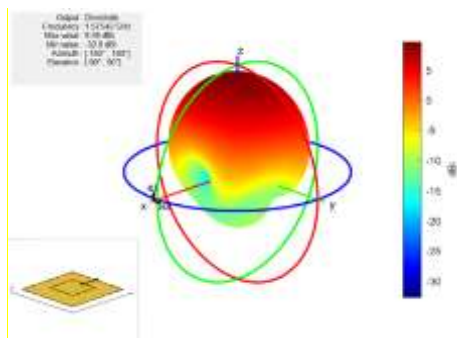


Figure 10. Radiation pattern of inset fed antenna

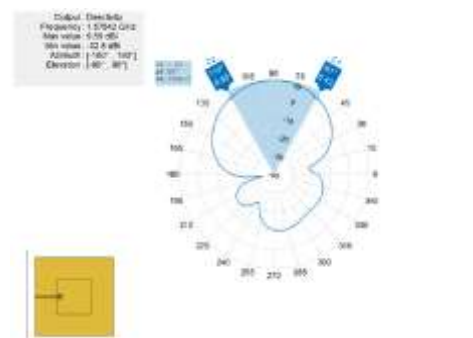


Figure 11. Beamwidth of Inset fed antenna

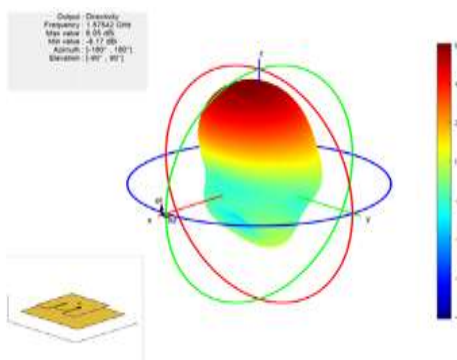


Figure 12. Radiation pattern of e-notch antenna

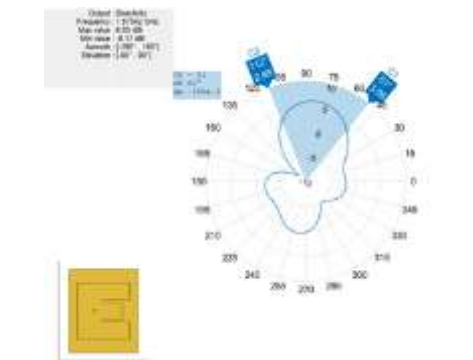


Figure 13. Beamwidth of e-notch antenna

H-notch antenna the radiation pattern of the H-notch antenna is shown in Figure 14. The maximum antenna gain with an isotropic antenna as reference is 7.17 dBi, with a minimum value of -11.6 dBi. It is evident from the radiation pattern that it is spherical on both the positive z-axis and the negative z-axis. However, the spherical shape in the positive z-axis is larger. Additionally, both sides have a high dBi at the far positive z value and the negative z value. Lastly, the gain steeply reaches its minimum as it transitions from its maximum at farther z-axis values to zero. The antenna beamwidth of the H-notch shape is shown in Figure 15. The beamwidth of the antenna is 66 degrees, which is from 56 to 122 degrees.

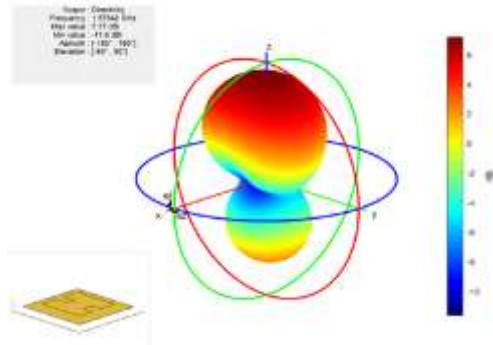


Figure 14. Radiation pattern of H-notch antenna

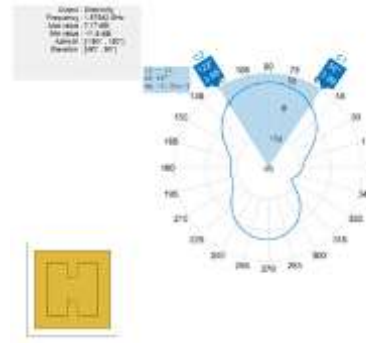


Figure 15. Beamwidth of H-notch antenna

3.1. Antenna design performance link budget data

The generated designs for the seven antenna shapes were tested on the following parameters: impedance, efficiency, return loss, and VSWR. Then, the antenna shapes were tested upon a link budget analysis from the satellite to the ground station using the link budget analyzer of the antenna toolbox. Table 1 shows a summary of all the values collected from the ideal antenna testing. It shows the impedance, max dBi or antenna gain, return loss, and the voltage standing wave ratio. These parameters describe the performance of the antennas in the ideal antenna test. On the other hand, Table 2 summarizes the results of the satellite communications link budget analysis for all the declared antennas. The results are the distance, elevation, transmitter equivalent isotropic radiated power, polarization loss, free space propagation loss, received isotropic power, carrier-to-noise ratio, received Eb/No, and the link margin.

Table 1. More antenna design performance output

	Impedance	Max dBi	Return loss	VSWR
Rectangular	56.4479+ 0.6133i	10.1	24.3154	1.1296
Circular	8.9859 – 4.4445i	9.69	3.1302	5.6097
Elliptical	22.8564+ 40.0088i	9.40	4.7065	3.7809
Triangular	8.9990-8.4109i	8.83	3.0964	5.7185
Inset Fed	40.0805 – 7.2627i	9.59	17.3269	1.3149
E-Notch	10.6180 + 20.6931i	6.05	3.1660	5.5476
H-Notch	3.4557 – 1.3561i	7.17	1.2016	14.4797

Table 2. Link budget analysis of seven patch microstrip antennas

Parameter	Antenna Shape						
	Rectangular	Circular	Elliptical	Triangular	Inset Fed	E-Notch	H-Notch
Distance (km)	3000	3000	3000	3000	3000	3000	3000
Elevation (deg)	90	90	90	90	90	90	90
Tx EIRP (dBW)	-5.2154	15.7598	13.6935	14.7606	1.2631	11.8840	17.3884
FSPL (dB)	165.9381	165.9381	165.9381	165.9381	165.9381	165.9381	165.9381
Received Isotropic Power (dBW)	-174.1448	-153.1696	-155.2359	-154.1688	-167.6750	-157.0541	-151.5497
C/No (dB)	77.4543	98.4295	96.3632	97.4303	83.9242	94.5451	100.0495
C/N (dB-Hz)	3.6522	24.6274	22.5611	23.6282	10.1221	20.7430	26.2474
Received Eb/No (dB)	17.3556	38.3308	36.2645	37.3316	23.8254	34.4463	39.9507
Margin (dB)	8.6537	26.3308	24.2645	25.3316	11.8254	22.4463	27.9507

4. ANALYSIS OF DATA

Across all seven (7) antennas in use, the resonant frequency of 1.57542 GHz served as a common reference point for comparison. This uniform frequency was adopted to facilitate meaningful comparisons and evaluations of their respective parameters. In all the antennas’ construction, the authors made use of the MATLAB function “design” to design the antenna dimensions automatically based on the resonant frequency given. Thus, the resulting antenna efficiency for all shapes is at 100% in these ideal conditions. Moreover, in the link budget analysis, all antennas were initiated and assumed to be in perfect polarization with the ground station and thus have zero polarization loss.

In the link budget analysis, the elevation pertains to the angle between the ground station and the space satellite antenna [36]. The Tx EIRP or the equivalent isotropic radiated power defines the total radiated power coming from the transmitter antenna multiplied by its directivity, as seen by the beamwidth figures.

The free space propagation loss or FPSL is equal for all shapes, given that all antennas are 100% efficient with zero polarization loss given the previous assumption. The received isotropic power defines the received power in dBW that is absorbed by the ground station receiver. The C/No and C/N describe the carrier-to-noise ratio and carrier-to-noise power density, which is similar to SNR. Lastly, the margin or link margin describes the amount of allowable signal loss before the information becomes unusable.

In Tables 1 and 2, the rectangular antenna excels in its provision of the highest antenna gain recorded, as well as the highest return loss and lowest VSWR. The ideal value for voltage standing wave ratio is at 1, meaning that the impedances are matched and thus can mitigate the existence of reflected waves. The closer the VSWR is to 1, the more desirable it is. The opposite is said for the return loss, where it is better to receive a higher return loss as it results in less insertion loss. However, the rectangular antenna falls short in the link budget analysis, where other antenna shapes provide a significantly higher value for all parameters.

The circular and elliptical patch antennas produce results that are within close vicinity of one another. Both excel highly in the link budget analysis, with the circular attaining the second highest value of all link budget parameters, and in the ideal antenna test, where both provide satisfactory results. The triangular patch antenna comes in between the circular and elliptical antenna results for the link budget analysis; however, it does not perform as well in its antenna gain, return loss, and VSWR values compared to the other antennas. It has one of the lowest return losses and highest VSWR values.

The inset fed microstrip antenna has the best return loss and VSWR and has the third-highest antenna gain in the group. However, its performance in the link budget analysis is one of the least proficient. It is the second least proficient antenna in the analysis next to the rectangular microstrip. The E-notch microstrip has the lowest amount of antenna gain and has one of the least desirable return losses and VSWR. Moreover, in the link budget analysis, the E-notch provides more inferior values, being the third to the last in link margin, EIRP, carrier-to-noise ratio, and received isotropic power. Lastly, the H-notch has the best performance in the link budget analysis, attaining the highest values for all results. Despite this, it has significant drawbacks in its antenna gain, return loss, and VSWR.

Out of all the tested microstrip antenna shapes, the shape that is most suitable for GPS communications in microsattellites is the circular microstrip antenna due to its balanced performance. At first glance, the H-notch antenna would be the most promising as it produced the highest values of measure for received isotropic power, carrier-to-noise ratio, margin, and EIRP, and with a relatively proficient gain. However, its return loss and VSWR are largely undesirable compared to other patch antenna shapes, which have a higher return loss and lower VSWR. The rectangular patch antenna may also be a promising selection, given that it has the highest gain, lowest VSWR, and highest return loss. However, its performance in the link budget analysis has proven ineffective compared to other more promising microstrip antenna shapes. The circular patch antenna properties are a combination of both the H-notch and rectangular antenna results. It has the second-highest antenna gain, received isotropic power, carrier-to-noise ratio, margin, and EIRP. Although its return loss is low and its VSWR is relatively large, it is not to the point of great undesirability and ineffectiveness compared to the other antennas. Another promising patch shape would be the elliptical microstrip antenna. It is very similar to the circular patch antenna with desirable antenna gain, received isotropic power, carrier-to-noise ratio, margin, and EIRP, but it excels more in its return loss and VSWR value. Despite these proficient values, the circular microstrip antenna performs much better in the link budget analysis portion, which proves its effectiveness as a space system satellite.

5. CONCLUSION

GPS drives the navigation of millions of users across the globe. For such reason, the improvement of its design is necessary for continuous development. The current study explored all seven (7) of the available microstrip antenna shapes (e.g., rectangular, circular, elliptical, triangular, inset fed, H-notch, and E-notch) from the antenna toolbox of MATLAB and sought the most suitable antenna for GPS applications. The antenna shapes were first designed based on a 1575.42 MHz resonant frequency and then tested upon its efficiency, impedance, return loss, VSWR, beamwidth, and radiation pattern. After this, the antennas are tested based on their link budget from the satellite to the ground station. Out of all microstrip antennas tested, the circular shape was determined to be the optimal choice for the application mentioned above. The circular antenna received a max isotropic antenna gain of 9.68 dBi, an impedance of $8.9859 - 4.445i$ ohms, a return loss of 3.1302, and a VSWR of 5.6097. In terms of the downlink link budget analysis, the antenna received a Tx EIRP of 15.7598 dBW, a C/No of 98.4295 dB, a C/N of 24.6274 dB-Hz, a received Eb/No of 38.3308 dB, and a margin of 26.3308 dB. Even though the H-notch antenna performed the strongest in terms of max dBi gain, CNR, margin, and EIRP, this is underscored by its low return loss and higher VSWR. A similar scenario caused the rectangular antenna to be outscored by the circular antenna. The rectangular antenna

achieved the highest gain, lowest VSWR, and highest return loss yet performed poorly in the link budget analysis. Overall, all seven shapes produced results that allowed each antenna to serve a unique purpose. A specific shape may serve favorably if certain parameters are given higher priority. In terms of overall performance with the right balance between the ideal antenna test and satellite-to-ground station link budget analysis, the circular antenna is the favorable shape for GPS applications. Further recommendations to future researchers of this study are to expand on the specifications of GPS communications. Exploring other frequencies and bandwidths by which GPS communications are used would further shed light on the flexibility of microstrip antennas. Reconfiguring the space system paradigm would provide more insight into the effectiveness and efficiency of patch antennas in space. Considering a geostationary orbit satellite or a constellation of CubeSats and microsattellites are some recommendations that could be followed. Further researching and utilizing MATLAB's link budget analysis to its fullest extent by filling out all the required parameters for the antenna could significantly assist in gathering more information on the antenna's performance. Lastly, experimenting on the different kinds of atmospheric losses, such as rain attenuation, and providing polarization mismatching would be recommended to insert cases of unideal scenarios.




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