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Testing Patch, Helix and Vertical Dipole GPS Antennas with without Choke Ring Frame

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Abstract: ***The antenna is the connecting part between Global Positioning System (GPS) satellite and receiver, and it works on transferring the satellite signal propagation to the receiver with minimum interruption. This is beside the main role that GPS antenna can play for accurate and precise positioning. High quality GPS antennas have high gain, systematic radiation pattern, Right Hand Circular Polarization (RHCP), and low directivity. Multipath error is a principal error source connected with GPS positioning and it can be mitigated using better antenna design. GPS antennas tend to be provided with choke ring frame for protection from the reflected RHCP electromagnetic waves. In this paper, the performance of three different types of GPS antenna, namely: Microstrip Patch Antenna (MPA), Helix antenna (HA), and Vertical Dipole antenna (VDA), with and without choke ring frame, has been investigated using single frequency GPS receiver. The antennas have been examined under the same GPS environment, including satellites constellation, geometry, and surroundings, with different heights from the ground reflector surface for multipath evaluation. Short base-line kinematic differential code GPS (DGPS) technique has been used for removing and mitigating the main GPS error sources and focusing on multipath effect. Satellite residuals and the quality of the obtained positioning have been considered for evaluating the performance of each antenna. The results have reflected the ability of choke ring frames to improve the performance of the three GPS antennas with different rates in multipath areas, and illustrate the advantages and limitations of each antenna.***

Keywords: Micro-strip, Patch, Helix, Vertical Dipole, GPS, Choke Ring Antenna, Multipath.

I. INTRODUCTION

Antennas are an important part of any GPS receiver design and their importance cannot be stated highly enough. GPS antenna is the connecting element between GPS satellite and receiver, where it works on transferring the satellite signal propagation to the receiver with as less as possible interruption level. GPS antennas should cover most of the sky and see as much satellites as possible from horizon to horizon for high performance. The antenna should have a broad radiation beam, systematic radiation pattern, low directivity and high gain. The antenna must be well-matched in the related frequencies, RHCP and have good visibility to the sky. Ideal performance cannot be obtainable in narrow areas and limited open sky, and the positioning tends to be lost indoors or when covering the antenna. Poor visibility may result in position drift or an extended time to get the first navigation solution, therefore; good sky visibility is an important advantage. GPS signals are extremely weak and present unique demands on the antenna. Based on that, the key factor in GPS systems for high position accuracy and for short acquisition time is the antenna, and the choice and implementation of the antenna type can considerably play a significant role in GPS performance [1].

Passive antennas contain only the radiating element, such as the ceramic patch or the helix structure. In active antennas, Low Noise Amplifier (LNA) is included, which can help to reduce the overall noise figure of the system resulting in a better sensitivity. Furthermore, the losses of the cable after the LNA no longer affect the overall noise figure of the GPS receiver system. Active antenna needs more power than a passive antenna and it is more tolerant to insignificant impedance miss-match or cable length than passive antenna. Active antenna helps also to keep the receiver noise at low level and when provided with filter, it becomes less affected by jamming into the antenna cable than a passive antenna. On the other hand, passive antenna does not add anything to the required power and it has to be connected with a carefully designed micro-strip or strip-line of maximum 10 cm to the GPS receiver for ensure good GPS performance. Jamming signals coupled into the micro-strip or strip-line can negatively affect the performance of passive antenna comparing to active antenna [2].

The most common antenna type for GPS applications is MPA, which consists of a radiating patch on one side of a dielectric substrate and provided with a ground plane on the other side. Patch antennas are flat, generally have a ceramic and metal body and are mounted on a metal base plate. MPA is generally made of conducting material, such as copper and can be made in any possible shape. MPA radiate principally because of the fringing fields between the patch edge and the ground plane. For better performance, a thick dielectric substrate with low dielectric constant is needed, providing better effectiveness, greater bandwidth and better radiation. However, such a structure means larger antenna size, which may not be desirable.

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For compact MPA, higher dielectric constants is used, and as a result, less efficiency and narrower bandwidth tend to be appear. Henceforward, balancing between antenna dimensions, cost, and performance is required [3].

MPA can show a very high gain, especially if they are mounted on top of a large ground plane (70 x 70 mm). Therefore, MPA are ideal for situations where the antenna is mounted on a flat surface, such as the car roof. Ceramic MPA are very common since of the low-costs and the massive variation of obtainable sizes, starting from 10 mm and up to 40 mm. A smaller antenna can show a smaller aperture to collect the signal energy from sky, resulting in a lower overall gain of the antenna. Magnifying the signal after the antenna may not enhance the signal to noise ratio. The antenna position is crucial for an ideal performance of the GPS receiver. MPS plane should be parallel to the geographic horizon for fully view of the sky and ensuring a direct line-of-sight with as many visible satellites as possible [4]. The main benefits of MPA are the light weight and low size, low profile planar structure, low manufacturing cost, supports both, linear and circular polarization, works with dual and triple frequency operations, and robust when mounted on rigid surfaces. On the other hand, MPA suffer from a number of disadvantages as compared to conventional antennas, such as narrow bandwidth, low efficiency, low gain, extraneous radiation from feeds and junctions, low power handling capacity, and surface wave excitation [5].

Another type of GPS antennas is HA. The real geometric volume depends on the dielectric that fills the space between the active elements of the antenna. Using high dielectric constant ceramics helps to provide smaller HA. As in the case of MPA, filling the antenna with a high dielectric constant material can reduce the size of HA. Sizes in the range of 18 mm length and 10 mm diameter are now available in the market. In addition, the antenna gain is affected by the antenna size. HA tends to be used when multiple antenna orientations are expected, providing robust and good navigation performance [6, 7].

For precision applications such as surveying or timing, very high-end antennas are used, which are usually large size, high power consumption and expensive. These designs are highly enhanced to deal with multipath signals reflected from the ground (choke ring antennas, multipath limiting antennas, and VDA. The other advantage of such antennas are the accurate determination of the antenna phase centre, where GPS positioning in the millimetre range, it is important that signals from satellites at all elevations effectively meet at precisely the same point inside the antenna. For this type of application, receivers with multiple antenna inputs are often required [6].

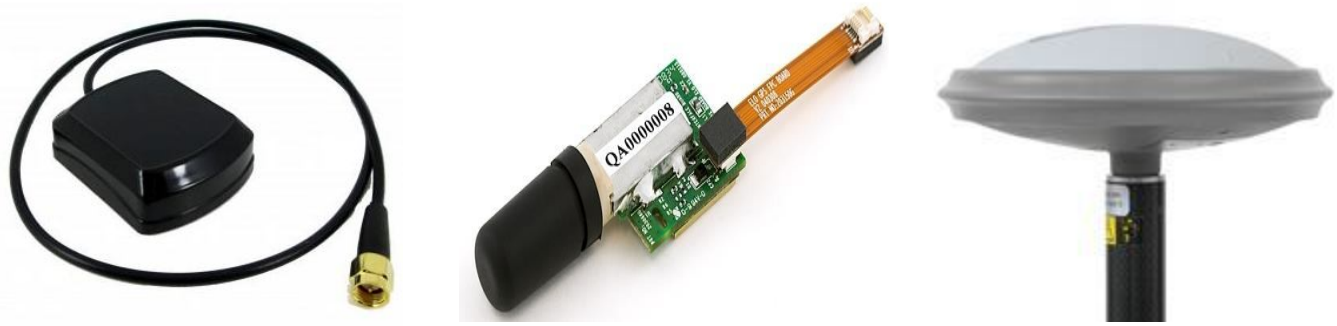


Fig. 1 From the left: MPA, HA, VDA, respectively

Choosing the right GPS antenna depends mainly on the application and positioning quality required. MPA is suitable for rooftop applications. In other applications, such as those of hand held device, the pole like style of the HA is the best. However, comparable antenna gain needs equivalent antenna aperture size, which will lead to a larger size filled by HA in comparison to a patch antenna. This means that HA with a practical size will consequently show a lower sensitivity compared to a reasonably sized MPA. HA might detect more satellites in difficult GPS environments when directly compared with MPA. This can be referred to the fact that HA is able to detect and receive reflected signals through its omni-directional radiation pattern. However, these signals tend to have negative effect on the positioning solution and significant residuals compared to the direct signals. Therefore, the receivers can see more satellites but the navigation solution will be degraded because of distorted range measurements in a multipath environment [6]. The performance of GPS receivers, in general, is affected in urban areas by decreasing the number of satellites, satellites geometry, and multipath effect. The last can reach several meters in high multipath environment using code measurements and several centimetres for L1 carrier phase. Multipath error is a dominant error source connected with GPS positioning. Mitigation of such errors can be achieved by improving signal processing and a better antenna design [7, 8]. GPS antennas tend to be provided with choke ring frame for protection from the reflected RHCP electromagnetic waves. Choke ring can also help to reduce the effects of the electromagnetic fields generated by the surrounding electric sensors, which can considerably affect the antenna directivity [6].

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In this paper, the performance of three types of GPS antennas will be investigated using single frequency GPS receiver with and without choke ring frames, namely: MPA (u-blox), HA (GeoHelix P2) and VDA (Dorne and Margolin C146-10). The antennas will be examined under the same GPS environment, including satellites constellation, geometry and surroundings with different heights from the ground reflector surface for multipath evaluation. Short base-line kinematic DGPS technique will be used for removing and mitigating the GPS error sources and focusing on multipath effect. Satellite residuals and the quality of the obtained positioning will be considered for evaluating the performance of each antenna.

II. TESTS AND RESULTS

Choke ring frames made from strong aluminium papers have been used with MSA, HA and VDA. The designed frame simulates the common designs of choke ring antennas, includes five rings with height of nearly 5 cm, which is equal the quarter of L1 wavelength. The antennas have been tested with and without the choke ring frame to investigate how the antennas deal with multipath in the both cases. See Figure (2).



Fig. 2 From the right: HA, MPA, and VDA, with choke ring frames, respectively

The three antennas have been tested in the same place, at the same height and under the same satellite geometry, where the tests have been carried out in different days at the same time (4 minutes earlier for every day). The antennas have also been tested with different heights from the ground to explore the effect of the signals reflected from the ground on the antennas. GrafNav software has been used to process the collected data using code DGPS and the results have compared with the most probable position achieved via several hours static carrier phase DGPS. Code DGPS positioning technique has been chosen with short baseline for two reasons. the first is to reduce the effect of all errors except multipath effect. The second is that code measurements are significantly affected by multipath compared with phase measurements, thus the effect of using choke ring frame with the individual antennas will be significant [9, 10]. The Root Mean Square Error (RMSE) for each component of the 3D obtained positioning, and the total RMSE have been determined to compare the performance of the three antennas with and without choke ring frame. In addition to that, and for more reliable investigations, more indicators have been determined, namely: the RMSR of the common satellites between the three antennas, the average number of all detected satellites, and the percentage of satellites whom residuals are regarded as outliers.

Identifying outliers is very important, especially when using automation for measuring and determining the observations, where no opportunity for investigating the data manually to check the gross errors. Gross errors for multiple measurements of a single quantity can be detected easily by computing the mean and standard deviation and checking the normal distribution of the observational errors .However, this is not always the case where single measurements fitted together during a least squares computation have to be investigated for outliers. Several methods have been developed for such case, starting from Data Snooping Method (DSM) and extended to Robust Estimation Method (REM) [11, 12]. DSM has been chosen in this paper due to its simplicity and affectivity as it can deal with data including more than one outlier, but in general, the percentage of gross errors to the whole observations should be as small as possible for more reliable results. Firstly, the standard deviation of each observation has been determined from the covariance matrix of residuals. The percentage of each residual to its standard deviation should be bigger than 33.33% to be acceptable with 99.99% confidence level. With 99% confidence level, the critical percentage is nearly 38.5%. This can help to detect outliers with (1-confidence level) probability of rejection the observation when it should be accepted (type 1 error). Table (1) and (2) illustrate: the 3D RMSE, each component RMSE, average number of detected satellites, and the percentage of outlier satellites, for the three antennas with and without choke ring frame, at a height of 2 m, and directly on the ground surface, respectively.

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TABLE 1
ANTENNAS PERFORMANCE (2 M HEIGHT)

Antenna Type	RMSE (m)				Average No. of GNSS Satellites	Outlier Satellite (%)
	X	Y	Z	3D		
VDA + CR	1.21	0.81	1.18	1.87	9	0.5
HA + CR	1.34	0.97	1.58	2.28	10	6
MPA + CR	1.52	1.4	1.79	2.73	12	9.5
VDA	1.68	1.41	1.83	2.85	10	3.5
MPA	2.13	1.61	2.09	3.39	12	10
HA	2.40	1.86	2.80	4.13	14	13

TABLE 2
ANTENNAS PERFORMANCE (ON THE GROUND)

	RMSE (m)				Average No. of GNSS Satellites	Outlier Satellite (%)
	X	Y	Z	3D		
VDA + CR	0.72	0.59	0.87	1.27	9	0.02
HA + CR	1.03	0.89	1.38	1.93	9	0.5
MPA + CR	1.88	1.43	1.79	2.96	12	9.5
VDA	0.93	0.82	1.23	1.74	10	1.5
MPA	1.81	1.63	1.81	3.03	12	9.8
HA	1.38	1.19	1.54	2.38	10	3

III.DISCUSSION

In the first test, where the antennas have been fixed on tripod with 2 m height from the ground, the best performance has been obtained from the choke ring VDA. HA with choke ring came in second, whereas the choke ring MPA came in third. VDA, MPA and HA have been the next, in this order. From Table (1), it is clear that the performance of the antennas has improved with the designed choke ring frame.

This can be referred to the fact that choke ring protects antennas from the electromagnetic wave reflected from the ground. The electromagnetic wave is divided into two field waves. The first surrounds the antenna and creates an electromagnetic field which propagates from the top edge of the groves to the bottom. The second is created by the electromagnetic field of the groves and takes the direction from the bottom to the top cancelling the first one. Choke ring frame prevents the antenna from the electromagnetic fields generating by the surrounding items, which can affect the antenna directivity.

The performance of the choke ring MPA has been relatively the worst compared with the other two choke ring antennas tested. This might be because MPA tends to have high directivity, even if items generating electromagnetic fields do not surround them. This means that the radiation pattern will not be the same in all directions and as a result, satellites signals facing the low gain antenna side may not be received. This can reduce the overall number of satellites and as a result, affecting the positioning quality. Furthermore, HA and VDA antennas have a good RHCP compared to MPA. This helps to receive only the direct GPS signals and neglect the reflected signals that usually have Left Hand Circular Polarization (LHCP).

MPA has high radiation pattern near the zenith, which decreases when moving toward the horizon. This means that just the signal of satellites with high elevation angles can be detected. This can be an advantage for the Patch antenna over the omnidirectional antennas, such as Helix antenna where signals reflected from the ground will not be received in the case of Patch antenna reducing the multipath effect. This is clear from the results when comparing the performance of Patch antenna with the Helix antenna without choke ring frames.

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When comparing the performance of the antennas without the choke ring frames, VDA has given the best results. This could be attributed to its high RHCP that helps the antenna to survive from LHCP multipath signals. This antenna also has an excellent LNA and RF filter for out-of-bound interference rejection. Additionally, the antenna is provided with small ground plate that can help to avoid low angle reflected waves.

MPA has been the second after VDA and before HA. This is because HA is an omnidirectional antenna, which means signals from horizon to horizon at all bearings, and elevations are received equally. This can help to get better positioning in open sky where more satellites can be detected and less multipath effect. However, in urban areas, the multipath increases and signals reflected from ground can be easily received by HA degrading the positioning quality.

The second test has been applied to investigate the effect of the low angle signals, reflected from the ground on the antennas with and without choke ring frame. The antennas have been fixed on the ground directly to make sure no signals arrive from angles under the antenna horizon. From Table (2), it is clear that VDA with the choke ring has been the best and the same antenna without the choke ring came next.

The reason might be that with zero antennas height, there are low possibilities for the multipath signals, reflected from the surrounding buildings to change into RHCP again. Therefore, most of these signals are neglected with this high RHCP antenna. Here, it can be noted that in this test, there is no signal reflected from the ground and the performance of the VDA with choke ring is still better than the individual VDA antenna. Logically, they should be the same, where the choke ring has an effect on the signals reflected from the ground. The reason can be that the choke ring frame has the ability also to prevent the antenna from the electromagnetic field generated by the surrounding items providing better directivity.

The results show also that MPA has been relatively the worst. This is because with zero antenna height, the advantage of not receiving signals from angles under the antenna horizon is disabled. In this test, the three antennas have been tested with multipath coming from higher angles. The high polarization of VDA and HA help to avoid receiving the LHCP signals reflected from buildings. MPA has poorer polarization, which means LHCP signals are received affecting the positioning quality.

IV. CONCLUSION

In this paper, the performance of three types of GPS antenna, namely: MPA, HA, and VDA, with and without choke ring frame, has been studied using single frequency GPS receiver. The antennas have been tested under the same GPS environment with different heights from the ground reflector surface for multipath evaluation. Short base-line kinematic DGPS technique has been used for removing and mitigating the main GPS error sources and focusing on multipath effect. The results have reflected the ability of choke ring frames to improve the performance of the three GPS antennas tested in this paper with different rates in multipath areas. VDA has been the best due to its LNA, high RHCP, and the included ground plate.

MPA has been better than HA at a height from the ground due to the capability of the second to receive the RHCP signals reflected from the ground. However, with choke ring, HA has been better than MPA, where choke ring helps to reduce the effect of the ground reflected signals, and because the majority of the high angle reflected signals are LHCP, which are rejected directly by the RHCP of HA.

On the ground, VDA is still the best, and the choke ring is still able to improve the performance even slightly. MPA with and without choke ring frame has been the worst, where the reflected signals in such case are LHCP, and MPA is not polarized, so any reflected signals can be received. Overall, each type of the three GPS antennas has its advantages and limitations, and can be used in specific application and using choke ring frame with these types helps to improve the performance, providing more precise and accurate positioning.

VDA with and without choke ring frame can be used in applications required high level of precision and accuracy, such as fixing reference survey control monuments using static carrier phase DGPS and Precise Point Positioning (PPP) techniques. HA and MPA without choke is just suitable for low-accuracy GPS applications, such as vehicles navigation and mobile phone usages. HA and MPA with choke ring can be utilized in engineering applications that need a reliable and mid quality level of GPS positioning, such as determining the positioning of soil tests in open and wide areas using just stand-alone low-cost GPS receivers [13]. It is recommended to expand the investigations of this paper to include studying the expected effects of utilizing different types of GPS antennas on the integration of low-cost GPS/INS sensors, which has been studied by the author in [14] and [15].

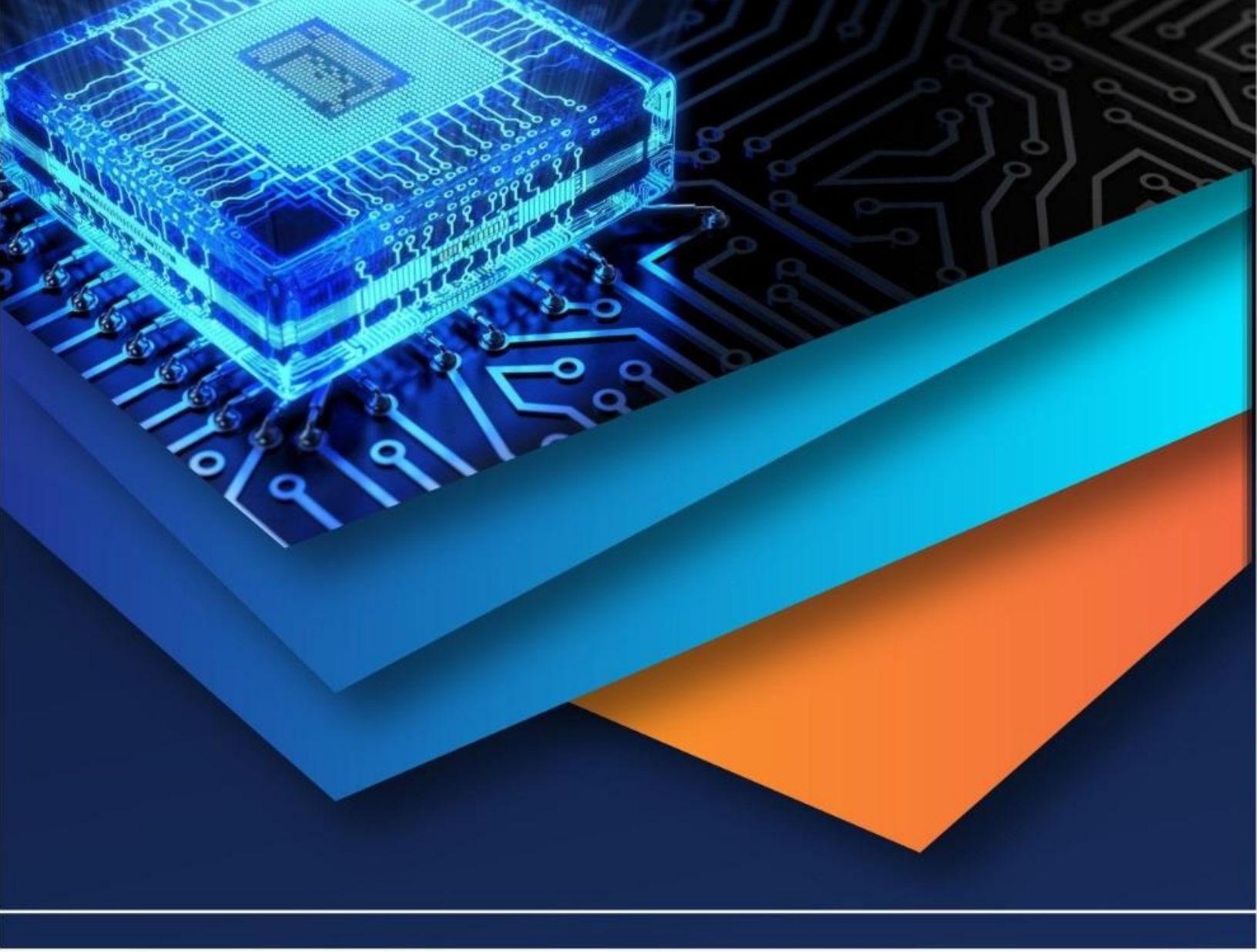
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