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An Overview on Global Navigation Satellite System

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Abstract— **Global Navigation Satellite System is a standard name given to any satellite navigation system that provides geo-spatial positioning with global coverage. This paper gives an overview on GNSS i.e. different satellite navigation systems developed by various nations around the world. Various navigation systems such as NAVSTAR GPS, GLONASS, GALILEO, BEIDOU, and IRNSS have been discussed in this paper. This also gives a description on various navigation receivers, different effects on GNSSS signals and applications. Advanced GNSS concepts such as differential GNSS, Real time kinematic positioning and integrated inertial navigation systems also discussed.**
Keywords— **Global Navigation Satellite System, Timation, differential GNSS, Real time kinematic, inertial navigation system, amplitude scintillation, phase scintillation, tropospheric delay, multipath.**

I. INTRODUCTION TO GNSS

Navigation is a branch of science which deals with getting of a person or a vehicle from one place to another place. In order to have accurate knowledge of our position or transmit time to a desired location, some navigational aids are required. Navigational aids may be in the form of a clock to determine velocity over a known distance or odometer to keep the track of distance travelled. Most of the navigational aids transmit electronic signals. Signals from these navigational aids enable the user to compute their position. The receiver performs various navigational computations for the user to navigate to a desired location. These navigational aids are characterized into space based and ground based. The accuracy of ground based navigational aids is proportional to their operating frequency. Early space based systems referred to as Transmit provided a two-dimensional high accuracy positioning service. These attributes are suitable for ship navigation but not aircraft and high dynamic users. A number of navigational techniques and developments took place in order to calculate accurate PVT information (position, velocity and time).

In the late 1900's with the advent of radio signals, the signals were sent to ships so that the ships can regularly adjust their chronometers according to the signals. LORAN (Long Range Navigation) technique was introduced in 1940's with the help of which the ships can triangulate their position using the radio signals which are sent to them from LORAN station located at shore-based locations. In the early 1960's the US government organizations were very much interested in developing the satellite system having the following attributes like global coverage, continuous weather operation, ability to serve high dynamic operations, and high accuracy for three dimensional position. In 1967 Timation was developed by NRL (Naval Research Laboratory) which demonstrated that highly accurate atomic clocks could be operated in space to achieve precise time transfer. Around same time US air force developed SYSTEM 612B which provided three dimensional positioning. In 1973,a system was developed combining early Navy and air force programs called NAVSTAR GPS (NAVigation System using Timing and Ranging).

NAVSTAR=USN TIMATION + USAF 621B.

Satellite orbits were based on Timation. Signal structure and frequencies were based on System 621B and satellites would use atomic clocks. The system became fully operational in 1995. This system provides accurate, continuous worldwide, three dimensional position and velocity information to users with having appropriate receiver equipment. In the late 1970's the navigational technique called GNSS (Global Navigational Satellite System) was started with the launch of Sputnik. Global Navigational Satellite Systems (GNSS) refers to extraction of different satellite navigational systems using one receiver. So a GNSS receiver allows the extraction of signals of any navigational satellite system like GPS, GLONASS, and GALILEO etc.

II. VARIOUS GNSS SYSTEMS

Satellite Navigational system is a system of satellites that transmits timing signals along line-of sight by radio which allows receivers to determine location (longitude, latitude and altitude) in order to provide geo-spatial positioning with global coverage. A satellite navigational system with global coverage can be termed as GNSS (Global Navigational Satellite System). GNSS is used to describe collection of satellite positioning system that are now operating or planned.

As GNSS is referred to as the collection of different systems, some of them are GPS, GLONASS, GALILEO, COMPASS, IRNSS, and QZSS.

A. GPS

GPS (Global Positioning System) was introduced by United States Department of Defence which uses a constellation of 24 or 32 satellites provides global coverage. It provides location and time information in all weather conditions anywhere on earth when there is unobstructed line-of sight. A world-wide ground network that uploads navigation and other data to satellites. The satellites broadcasts ranging codes and navigation data on two frequencies using a technique called CDMA. There are only two frequencies in use by this system called L1(1,575.42 MHz) and L2(1,227 MHz).Each satellite generates a short code referred to as code/acquisition or C/A code and a long code referred to as P code(precision code).

B. Glonass

GLONASS stands for Global Navigational Satellite Systems which is a Russian based satellite navigation System which is owned and maintained by Russian Space Forces. Compared to GLONASS has increased satellite signal observations and spatial distribution of visible satellites.

C. Compass

It is a regional navigation system of China called Beidou of China, they are planning to make this system into a global navigation system by 2020.This Compass system of China utilizes 30 medium earth orbit satellites and five geostationary satellites.

D. Galileo

Galileo is Europe's own global navigational satellite system introduced as an alternative to GPS, called the Galileo positioning system. Galileo is expected to be compatible with the modernized GPS. The first experimental satellite GIOVE-A was launched on 28 December 2005.The second experimental satellite GIOVE-B was launched in 2008.GIOVE-A is the first Galileo In-orbit validation element which was named in tribute to Galileo Galilee. The main objective of this system is to seek interoperability between the existing systems. The receivers will be able to combine the signals from GPS and Galileo to greatly increase the accuracy.

E. IRNSS

Indian Regional Navigational Satellite System (IRNSS) is a regional based satellite navigation system of India which is developed by Indian Space Research Organization (ISRO) and controlled by government of India. It is a navigational system of satellites to enable civilian and military establishments with navigation in and around India. The government of India approved this project in May 2006 which is a constellation of 7 navigational satellites which are placed in the geostationary orbit (GEO).The first satellite IRNSS-1A was launched on July 1st, 2013. IRNSS satellite system operates in L5 band (1176.45 MHz) and S band (2492.028 MHz) and IRNSS civilian signal will be modulated by a 1-Mhz BPSK signal.

F. QZSS

The Quasi-Zenith Satellite System is an enhancement for GPS covering Japan and proposed as three satellite regional time transfer system. The first satellite was launched in September 2010.

III. GNSS RECEIVERS

GNSS Receiver is an electronic device that receives signals from satellite constellation and digitally processes the signals in order to provide position, velocity and time. GNSS receivers are may be of hardware or software. In case of Hardware receivers, it consists of a chip (ASIC) that is built in order to perform receiver operation. Coming to Software receivers, it is designed and implemented as software running on CPU. It allows flexibility compared to hardware receivers as the features of the receiver can be modified just through software. GNSS Receivers are of various types like civilian (used in phones, vehicles) or scientific (used for research purposes).

A. Scientific Receiver

There are various blocks in this receiver such as GNSS Antenna, Front-End, Baseband Processing, and Application Processing. The first segment of this receiver is GNSS antenna. This antenna is Right Hand Circularly Polarized (RHCP) which receives signals in L-band. The reception of the signals depends on two factors VSWR and polarization. VSWR is the measure of the amount of signal absorbed. Polarization refers to the orientation of the electric field from radio frequency transmission. Coming

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to RF front end, it receives RF inputs from the antenna and performs down-conversion. So in this down-conversion process Intermediate frequency is created by mixing the carrier signal with another signal generated by local oscillator. After the down-conversion process the analog IF is converted to digital IF sample streams.

Next block in the GNSS receiver is baseband processing, which is categorized into parts that is Acquisition and Tracking. The purpose of acquisition is to identify the number of satellites visible to the user. The acquisition part mostly identifies two properties of the signal that is frequency and code phase. Coming to the tracking part the main purpose is to correct the values of frequency and code-phase in order to keep the track these signal properties change over time. Delay Lock Loop (DLL), Phase Lock Loop (PLL) and Frequency Lock Loop (FLL) are the three tracking loops in this receiver which usually correct the signal properties (code phase and frequency). Next segment of this receiver is the Application Processing in which it extracts the navigation message from each of the channel of baseband processing block. Finally the information provided by this receiver is Position, velocity and time.

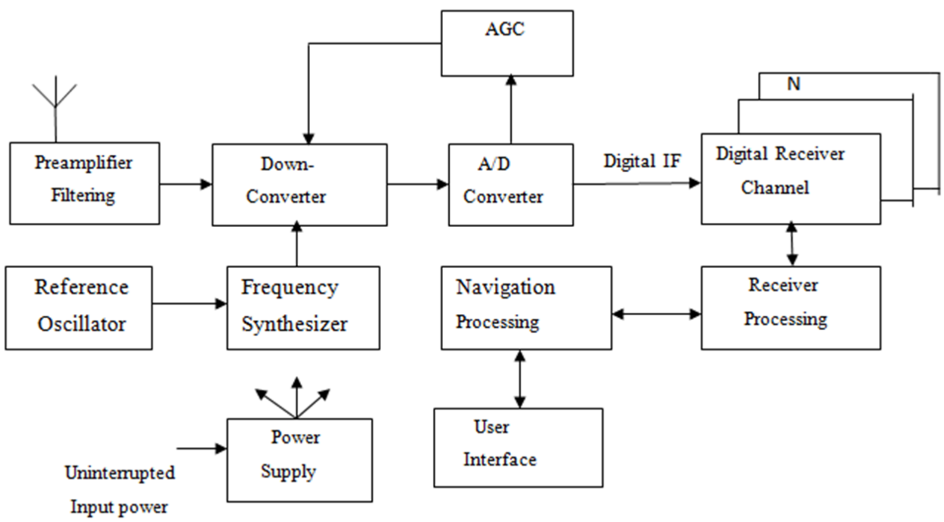

Fig.1.GNSS Receiver Block Diagram

B. Civilian Receivers

The first civilian application of these receivers was on large ships as their prices have fallen receivers are now incorporated in cars as well as phones. They became common in small vessels as well. In case of cars these systems may interact with the CD-ROM player of car in order to obtain map information and present it on a dash-board video display.

Fig.2. Civilian Receiver

Most of the civilian and military users utilize these receivers for map making. Navigators use these receivers in order to calculate precise velocity and orientation measurements

IV. ADVANCED CONCEPTS IN GNSS

A. Differential GNSS

Differential GNSS is an improvement to the primary system in which the position of fixed GNSS receiver known as **base station** is determined to a high degree of accuracy. It provides accuracy of the order of 1 km for the users which are in the range of few tens of km from the base station. The advantage of this method is its slow variation with time and user position due to errors such as tropospheric and ionospheric delays, residual satellite clocks etc. the base station calculates ranges to different GNSS satellites using the known locations of base station and the satellites, the satellites location is obtained by the ephemerides and satellite time. Thus the base station compares the ranges and the difference between the ranges results in satellite ephemeris and clock errors. But mostly these errors are due to atmospheric delays. These errors are transmitted by the base station to other receivers known as rovers, which use them in order to calculate their respective positions. This technique requires a data link between base station and rovers for the transmission of corrections and also at least four GNSS satellites must be in view at base station and the receivers. The accuracy of calculated position of rovers depends on the accuracy of base station's position. The rover stations when spread over a too large area give rise to an improvement in accuracy, integrity and availability of signals and such systems are called **Satellite Based Augmentation Systems (SBAS).** At present there are different augmentation systems of which some fully operational and some are in developing stage., European Geostationary Navigation Overlay Service (EGNOS) by Europe, Multi-Functional Satellite Augmentation System (MSAS) by Japan, Wide Area Augmentation System (WAAS) by United States are fully operational and GPS Aided Geo Augmented Navigation or GPS and Geo Augmented Navigation system (GAGAN) by India, System for Differential Corrections and Monitoring (SDCM) by Russia, Satellite Navigation Augmentation System (SNAS) by China are under implementation.

B. Real Time Kinematic

It is a differential GNSS based navigation technique which is mainly used in surveying applications because of its high accuracy. It considers the phase of the carrier signal rather than information content present in it. Coming to the architecture of RTK, it consists of a base station, one or more rovers and a real time communication channel. Here the basic concept is to reduce the errors for base station and rover pair. The range between the base station and rovers is obtained by calculating the number of cycles in the carrier and multiplying this number with the carrier wavelength. The total number of cycles is determined by a process called ambiguity resolution. The position of rover is calculated using certain algorithms which are incorporated with differential corrections and ambiguity resolution. The corrections provided in this technique are more accurate which give accuracy up to centimetre range. RTK usage can be extended by a virtual reference station which is based on several permanent base stations spaced widely. The position data from all these stations is sent to a central a processing station which calculates and transmits the corrections needed to the user terminal. A network of RTK base stations called Continuously Operating Reference Station (CORS) broadcasts the required corrections over an internet connection. There are some limitations in RTK which include the need of communication channel in real time, variation in convergence time which ranges from few seconds to minutes depending on the type of algorithm used and the distance between base station and the rover. Another limitation is that the rover should track the GNSS signals continuously which may not be possible in urban areas. Hence this explains about Real Time Kinematic positioning.

C. Integrated Gnss And Inertial Navigation Systems:

GNSS provides an excellent navigation when there is a line of sight path between satellites and the antenna. In the presence of any obstacles in the path between the antenna and the satellite, the performance of the system would be degraded. But GNSS provides long time stability. On the other hand, the inertial navigation system provides rotation and acceleration information to compute the position over a period of time. INS can also be able to calculate the attitude of the vehicle and it does not depend on any external sources for computation of the solution. INS can be used for short duration of time as the error increases with square of the time due to double integration over the period, if any. Hence, by combining the strengths of both GNSS and Inertial Navigation System, an integrated system has been developed to get a powerful navigation solution.

V. EFFECTS ON GNSS

A. Multipath

Multipath is the phenomenon in which the satellites signals reach the receiving antenna not only through a direct line of sight path but also from multiple indirect paths, because of different electromagnetic effects as signal diffraction or reflection. There are two types of multipath namely, specular multipath with arises from discrete and coherent reflections from smooth surfaces and diffuse multipath that arising from sources of diffraction. Multipath propagation causes position degradation and also dominates the total error budget in precise applications. At the receiving antenna, a compound signal is received due to the superposition of multipath component signals and the line of sight signals. This causes a constructive or destructive interference phenomenon depending on the relative phase between them which results in deformed correlation output, between received output and local pseudo random sequence generated by the receiver. The correlation output is of much significance because it serves as an input for next iteration of the code and carrier phase loops and also for C/N0estimating algorithms. Thus multipath effects three GNSS observables i.e. code phase, carrier phase and signal C/N0 indirectly. C/N0 is the only observable in which the multipath effects are directly visible without any further processing of data. In contrast, the effects on code phase and carrier phase can be studied by much analysis of the data. Thus C/N0 has given much importance in multipath studies rather than code and carrier phase. Hence this explains the multipath phenomenon.

B. Tropospheric Effects

Troposphere is the lowermost layer of the atmosphere extending up to 60 km from the earth's surface and it is one of the factors that cause delay in signal measurement while travelling from satellite to the receiver. Tropospheric effects are independent of the frequencies of the signals and hence carrier and code measurements are affected by same amount of delay. The amount of delay depends on different factors such as temperature, humidity, pressure and also the location of transmitting and receiving antennas and each of these factors has different effects on the signal. There are two types of effects on the GNSS signals in the troposphere.

Hydrostatic component delay: It is a predictable delay that varies with temperature and pressure. It is mainly caused by the dry gases present in the troposphere such as oxygen, nitrogen, argon etc. the error caused by this is 2.3m in the zenith direction and 10^0 for lower elevations.

Wet component delay: it is an unpredictable delay which varies randomly and faster when compared to hydrostatic component delay. It is caused by the water vapour and clouds and hence much more dependent on weather conditions. Thus the modelling becomes difficult.

Tropospheric models are basically classified in to two groups i.e. geodetic oriented and navigation oriented. The first group is more accurate and requires meteorological data and the second group is less accurate and does not require any meteorological data.

C. Ionospheric Effects

Ionosphere is the uppermost layer of the atmosphere that extends at an altitude of above 60km from the earth's surface. By its name, it is clear that ionosphere consists of a partially ionizing medium as a result of X-rays and UV rays from sun's radiation. The propagation speed of GNSS signals depend on the electron density which is present over there. The electron density varies with two processes i.e. during day time, neutral atoms are ionised due to sun's radiation which increases the electron density and during night time those get recombined to form neutral atoms resulting in low electron density. The GNSS signal when passed through ionosphere undergoes two types of effects i.e. amplitude scintillation and phase scintillation. Amplitude scintillation is the phenomenon in which the signal amplitude fluctuates as a result of diffraction of the signal wave front when passed through ionospheric irregularities and is quantified by a statistical parameter called S4 (scintillation index). During strong scintillations, the receiver may lose signal tracking and in worst case complete solution may also be lost. Phase scintillation refers to the fluctuations in the phase of the carrier when the signal is passed through small scale ionospheric irregularities which may lead to loss of loss of the signal in the receiver.in order to correct the ionospheric errors, different models have been invented.

VI. APPLICATIONS OF GNSS

There are numerous applications of GNSS, of which some are explained as follows:

A. Surveying

Surveying is the technique of determining the distance between the points on the earth's surface and angles between them. GNSS based surveying reduces the amount of equipment and labour needed. GNSS surveying equipment became small and easier to use when compared to another techniques. Based on the receiver position, this technique is of two type i.e. static survey for fixed receiver and dynamic receiver for moving receiver. Thus GNSS plays an important role in surveying.

B. Agriculture

GNSS applications in agriculture have made farming easier and more efficient. This method is used for supporting soil sampling, field mapping, tractor guidance etc. They can automatically guide the farm machinery along the earth's surface and the machinery can be operated at higher speeds at any time of the day there by saving fuel and time in order to increase the efficiency.

C. Defence

The defence sector makes wide range of uses with GNSS that includes search and rescue, navigation, unmanned vehicles, reconnaissance and map creation. In navigation, pilots are provided with GNSS receivers to navigate unknown terrains and also to conduct night time operations. Any plane would be equipped with GNSS receiver so that it can be located whenever it is crashed somewhere.in military, GNSS is used to create maps of the enemy territory and to mark reconnaissance points. Thus GNSS plays a significant role in defence.

D. Transportation

Different modes of transportation seek the need of GNSSS technology such as rail transport, aviation, under water surveying, marine transportation and surface transportation. In rail transport, GNSS is used in conjunction with other technologies in order to locate rail cars, maintenance equipment. Thus by knowing the precise location of the rail equipment, the probability of occurrence of accidents can be reduced, safety and customer service can be increased. In marine transportation, GNSS is used to determine the accurate position of ships when they are in open sea or in some congested ports. In aviation, GNSS is used for aircraft navigation from departure to landing and mainly for collision avoidance. In surface transportation, vehicles are being equipped with navigation displays for enhancing the efficiency and driver safety. Thus, almost every mode of transportation finds its use from GNSS technology.

E. Consumer

A wide of products have been introduced in the market incorporating GNSS technology such as portable navigation devices for drivers in order to show directions. Present day mobile communication systems are integrated with GNSS technology so that the users can reach their destination using best path. An outdoor recreational activity known as Geocaching, in which the participants use GNSS receiver to hide and seek the containers anywhere in the world.

F. Photogrammetry

Photogrammetry refers to the recording of images of an area on the earth's surface from an elevated position such as aircrafts. Now a days this system is generally referred to as **remote** sensing since the images are taken from aircrafts or satellites. The camera is integrated with GNSS and INS to automate the process in order to transfer the location accuracy of the air craft, which is determined by the receiver, to the image. The aerial photographs are used in online map systems such as Google maps where the users can be able to locate even their houses and cars. GNSS technology has also been incorporated with LIDAR (Light Detection and Ranging) in order to find range to the distant targets.

G. Marine Applications

Early explorers faced many challenges to navigate in the sea and it has become very easy for the voyagers to locate them anywhere in the sea with reference to the ground with the help of GNSS technology. Thus the marine navigation also became very easy with the aid of GNSS technology. GNSS also being used in many marine applications such as under water cable installation, rescue and recovery, dredging of ports.

H. Timing applications

GNSS satellite clocks which are accurate up to Nano seconds are synchronized with seismic monitoring equipment used to determine the epic centre of the earth quake by triangulation method based on exact time of the earth quake as determined by the monitor.

I. GNSS Sonobuoys

It is an interesting application of GNSS in which the GNSS equipped sonobuoys are dropped under water over an area of interest and are left to float automatically. The sonobuoys detect approaching ships and other hazards in water by transmitting sound waves through water which are get reflected. The echo is transmitted to the survey ship along the GNSS positioning data over a radio link. Thus the survey ship collects the information from all the sonobuoys and analyses the sonar data in order to determine the position of ship in any area of interest.

VII. CONCLUSION

This paper has given a brief overview on GNSS and different navigation systems which are fully operational and also which are under implementation. Some of the countries are also in the developing phase of their own regional navigation systems such as IRNSS etc. This paper can provide as a basic to those who involved in research regarding GNSS and also to study various effects on GNSS.

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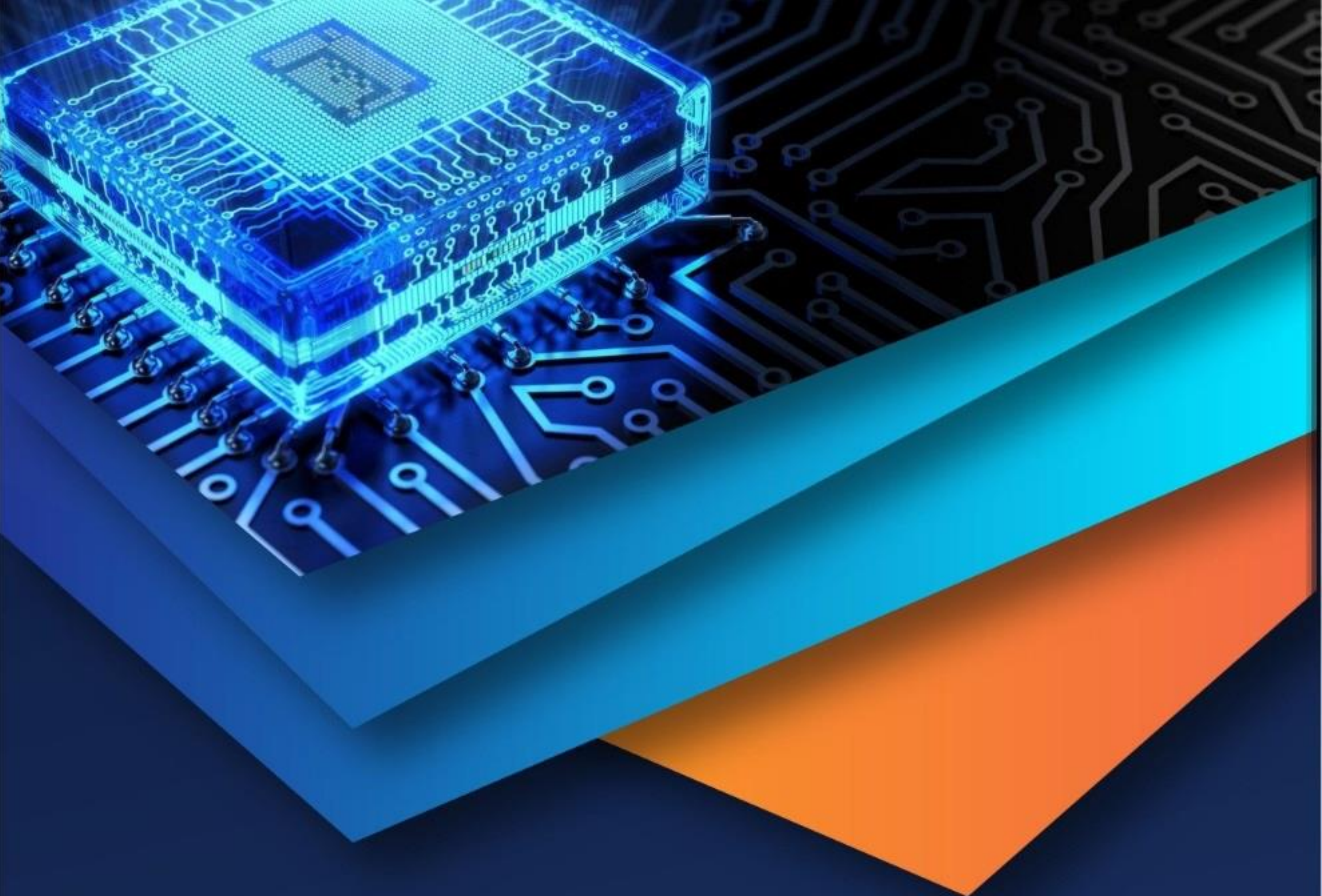

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