iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** VII **Month of publication:** July 2019

DOI: http://doi.org/10.22214/ijraset.2019.7180

Measurement and Analysis of the Consistency of Rain Induced Impairment on Line-of-Sight Links in Middle Belt, Jos-Nigeria

Igbekele O. J.[1], Ogherohwo E. P.[2], Zhimwang J.T.[3]
[1, 2, 3]*Department of Physics, University of Jos, Nigeria.*

Abstract: This paper presents the measurement and analysis of the consistency of rain induced impairment on Line-of-sight links in middle belt region of Nigeria. The experiment was carried out at the Globacom switch house, Jos Plateau state (9.9565° N, 8.8583° E; 1258 meters). Rain rate data were obtained for the period of eight months (April, May, June, July, August, September, October and November 2017). The Davis Vantage Vue weather station was used to measured and recorded one-minute rain-rates. Microsoft Excel application package was used to analyze the obtained rain rate data through which the frequency and exceeded frequency percentage of time was calculated. Results obtained shows that the rain induced impairment within the study area are cause mostly by widespread (>5-25mm/hr) and shower (>25-120mm/hr). Higher rainfall intensities were obtained between 0.01 and 0.001% exceeded percentage of time where maximum rain induced impairment can best be estimated.
Keyword: Line-of-sight link, rain rate, rain induced impairment

I. INTRODUCTION

Rain is the major variable in the design of microwave satellite link budgets. Rainfall intensity along earth path is in-homogeneous in space, time and the raindrops have a non-spherical shape, thereby causing attenuation on the horizontally polarized wave to be greater than the attenuation of the vertically polarized waves (Mukesh et al., 2014). Above a certain threshold of frequency, signal losses due to rain induced impairment becomes one of the most important limits of the performance of line-of-sight (LOS) links. Generally, at frequencies below 7 GHz, excess attenuation due to rainfall and atmospheric gaseous is very small and can be neglected in radio system design. When designing LOS link operating at frequency above 10 GHz, the occurrence of rain along the transmission path is considered as a main impairment factor for microwave system degradation (Ibrahim et al., 2017)

Rain can cause uncontrolled variations in signal amplitude, phase, polarization and angle of arrival, which result in a reduction in the quality of transmission and an increase in the bit error rate of digital transmissions. Therefore, this work focuses on measuring and analyzing the rain rate data obtained within the middle belt region of Nigeria with the aim of estimating the type of rainfall (either Stratiform or Convection) that causes more signals impairments on LOS links.

Previous researchers based their data on temperate regions and developed most of the already existing models used by designers. Rain in these regions is mostly of stratified structure, which is generally light with relatively large rain cells diameter. However, in the middle belt regions of Nigeria, in particular Jos, rain is from convective rain cells, with relatively small diameters, often resulting in heavy down pour that causes various impairment on LOS hence the need for this work.

Rainfall is broadly classified into two types:

1) Stratiform (drizzle and widespread) and
2) Convective (shower and thunderstorm)

The drizzle is a type of rain which consists entirely of small rain drops usually of diameter less than 1 mm and commonly falls in damp weather from shallow layer clouds. It is characterized by very low rainfall rates with typical values not greater than 5 mm/h. The widespread rain is associated with stratiform clouds. It is developed by sublimation through coalescence process. It consists largely of medium rain drops of diameter ranging from 1 to 2.5 mm. Widespread rainy events usually have intensity between about 9 – 25 mm/h and the intensity may be practically constant or change only gradually during precipitation. The duration of widespread rain event may be several hours. This type of rain may sometimes extend to the Zero Degree Isotherm (ZDI) height since the ice phase is involved (Ajewole, 2011).

The shower type of rain on the other hand originates from cumuliform clouds. This type of rain is characterized majorly by high intensity values, ranging from about 50 mm/h to about 120 mm/h and raindrops with diameter greater than 2 mm. The fall duration of showery precipitation is about 10 – 15 minutes. It is formed below the Zero Degree Isotherm (ZDI) height through the process of accretion. Its formation is due largely to the rate of accretion, the thickness of clouds, and the strength of the up draughts (Ajewole, 2011). The thunderstorm rain is usually generated within the cumulonimbus cloud systems (Hassen, 2006). It consists of one or more active cells containing strong vertical air currents. These are usually the centre of raindrop and lightning activities. Each rain cell goes through a life cycle of growth, maturity and decaying stages when lightning occurs. During thunderstorm activity, the precipitation particles grow in size until they grow large to become drops of diameter greater than about 3 mm and are no longer supported by the upward currents. At this stage, they fall to the ground with values of rain rate between about 50 mm/h and 240 mm/h in tropical locations (Adimula, 1995). At maturity, as columns of cooled air sink to the ground with strong down drifts and horizontal wind, electrical charges accumulate on cloud particles and lightning occurs. The lightning heats the air producing huge intense shock waves and rumbling observed as thunder. The shower and thunderstorm rain types usually occur over very limited horizontal extent typically of 1 – 2 km and are therefore localized. They have the most effect on terrestrial and Earth-space communications especially in tropical locations (Ajewole, 2011). In stratiform rain, with point R≤10mm/hr, the rain height is constant and equal to isotherm height above mean sea level whose values is given by ITU-RP.839-4 (ITU-R, 2013). Similarly, in convective rainstorms, when R>10mm/hr, the effective rain height depends on the rain rate because strong storms push rain higher into the atmosphere, lengthening the slant path. He attenuation time series is depicted as (Sujan and Dong-You, 2017)

$$A_{p\%} = \gamma L_s; \quad R_{p\%} \leq 10mm/hr \tag{1}$$

$$L_s = \frac{H_R - H_S}{sin\theta} \tag{2}$$

Where $A_{p\%}$ and $R_{p\%}$ are the attenuation and rain rate exceeded for p% of time, $\boldsymbol{\gamma}$ is the specific attenuation due to rainfall, L_s is slant path length up to rain height, H_R is rain height above mean sea level, H_s is station height, and θ is elevation angle of the top of rain height.

In convective rainstorms, when p% >10mm/hr, a modified value of effective path length is used for determination of slant-path attenuation as

$$A_{p\%} = \gamma \frac{1 - exp[-\propto b\text{In}(R_{p\%}/10]L_s cos\theta}{\alpha b\text{In}\left(\frac{R_{p\%}}{10}\right)cos\theta} \tag{3}$$

Wherw b = 1/22. Furthermore, the empirical expression for effective rain height H_R is given as

$$H_R = \begin{cases} H_0; & R \leq 10\,\text{mm/hr} \\ H_0 + \log\left(\frac{R}{10}\right); & R > 10\,\text{mm/hr.} \end{cases} \tag{4}$$

$$\%\text{ contribution of stratiform} = 100 \times \frac{widespread + shower}{Total\ (Y)} \tag{5}$$

$$\%\text{ contribution of convective} = 100 \times \frac{shower + thunder}{Total\ (Y)} \tag{6}$$

II. MATERIALS AND METHODS

The equipment were setup at the experimental site located at a Nigeria's Telecoms Operator Switch Center (9.9565° N, 8.8583° E; 1258 meters) Jos Plateau state middle belt region of Nigeria. Data were obtained for the period of eight months (April, May, June, July, August, September, October and November 2017). The equipment used includes the following: Davis weather station, USB data logger, computer system, Compass, Radio frequency power meter, Coaxial cable port connector and connecting cable (coaxial cable). The Davis Vantage Vue weather station is an equipped with an integrated sensor suite (ISS) and weather link data logger, and was used to measure and record one-minute rain-rates. Its electronic weather link console serves as the user interface, data display and analogue to digital converter, and has capacity to log 2560 measurements. The rain gauge instrument is a self-emptying tipping spoon, with gauge resolution of 0.2 mm per tip. It is able to measure rainfall intensity from a minimum of 0.8 mm/h up to a value of 460 mm/h, with an accuracy of 0.2 mm/h. The precipitation data, with date and time is captured on the micro-chip of the wireless electronic data logger, which, when calibrated, logs on data every minute. The microchip has storage capacity of about 2563 pages, each page stands for one record, after which (i.e. after 42hours) the memory overwrites and recorded data is lost if not copied to an external memory device. Technically, the data logger is connected to a Personal computer to harvest the data on a daily basis to prevent data loss. However the data obtained were used in determining the rain induced impairment on LOS link.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VII, July 2019- Available at www.ijraset.com

III. RESULTS

Table 1: computation of the exceeded frequency percentage of time from April to November 2017 using rainfall rate

Rain rate (mm/hr)	Exceeded Frequency Percentage of time (%)							
	April 2017	May 2017	June 2017	July 2017	August 2017	September 2017	October 2017	November 2017
1	7.236	8.879	8.259	13.266	11.940	9.034	6.151	2.231
2	5.516	6.709	6.321	10.743	9.612	7.041	5.047	1.574
4	3.030	4.433	4.145	7.193	6.205	4.305	3.606	0.856
6	1.574	2.437	2.194	3.707	2.983	2.280	2.287	0.518
8	1.009	1.642	1.486	2.441	1.796	1.585	1.801	0.356
10	0.750	1.292	1.185	1.951	1.339	1.152	1.550	0.273
15	0.574	1.090	1.009	1.698	1.129	0.986	1.326	0.212
20	0.293	0.754	0.736	1.290	0.875	0.803	1.052	0.100
25	0.187	0.577	0.583	1.084	0.721	0.638	0.878	0.050
30	0.127	0.465	0.490	0.898	0.598	0.546	0.723	0.046
35	0.078	0.358	0.400	0.728	0.501	0.467	0.593	0.037
40	0.053	0.270	0.331	0.600	0.416	0.395	0.501	0.023
45	0.037	0.235	0.270	0.510	0.347	0.317	0.421	0.023
50	0.020	0.194	0.210	0.416	0.280	0.273	0.365	0.018
60	0.020	0.154	0.162	0.327	0.224	0.224	0.284	0.018
70	0.011	0.085	0.115	0.203	0.136	0.157	0.224	0.013
80	0.006	0.058	0.067	0.107	0.103	0.092	0.125	0.009
90	-	0.026	0.037	0.060	0.071	0.081	0.085	-
100	-	0.017	0.025	0.031	0.053	0.064	0.056	-
120	-	0.015	0.016	0.026	0.035	0.043	0.031	-
140	-	0.002	0.006	0.017	0.015	0.020	0.013	-
160	-	-	-	0.002	0.013	0.018	0.008	-
180	-	-	-	-	0.006	-	-	-
200	-	-	-	-	0.002	-	-	-

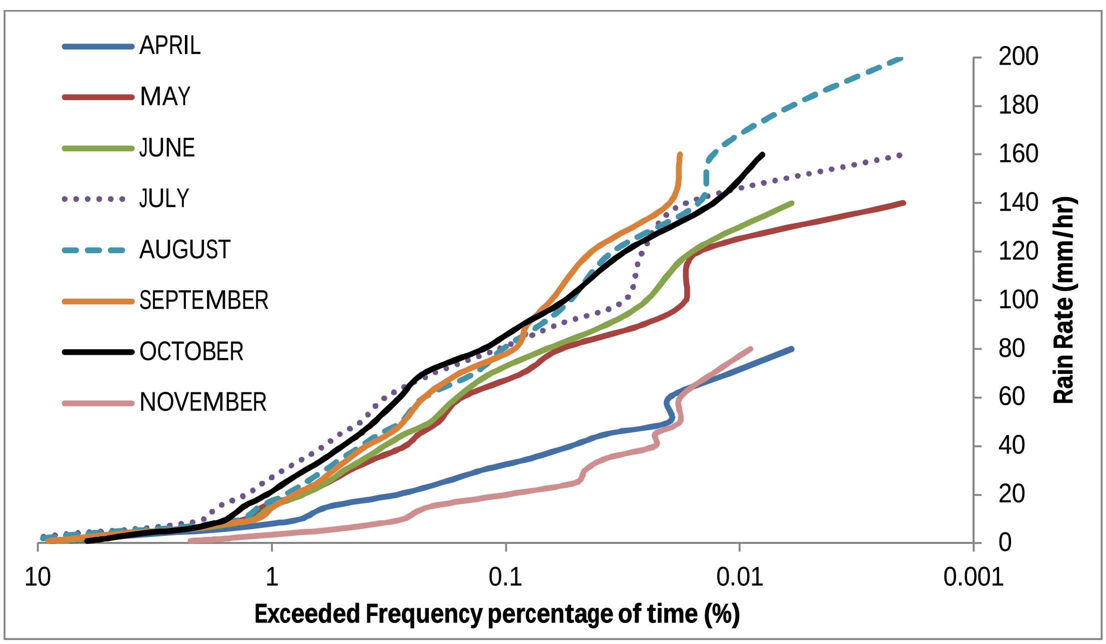

Figure 1: Relationship between rainfall rate and various exceeded frequency percentage of time

Table 2: Monthly categorization of rain in 2017

R-Amt (mm)	April	May	June	July	August	September	October	November	Total
< 0.2 (<1mm/h)	397	550	482	702	611	476	247	140	3605
>=0.2 (>=1mm/h)	1420	1435	1270	3906	3705	2919	889	454	15998
Total (X)	1817	1985	1752	4608	4316	3395	1136	594	19603
Drizzle (1-5 mm/h)	2119	2528	2310	4405	4167	2961	1628	622	20740
Widespread (>5-25 mm/h)	235	329	260	414	287	230	312	80	2147
Shower (>25-120 mm/h)	46	143	136	263	168	139	198	12	1105
Thunderstorm (>120mm/h)	9	72	99	156	103	101	129	8	677
Total (Y)	2409	3072	2805	5238	4725	3431	2267	722	24669
% Contribution of Stratiform	11.665	15.365	14.118	8.367	9.629	10.754	22.496	12.742	13.183
% Contribution of Convective	2.283	6.998	8.377	7.999	5.735	9.530	14.424	2.770	7.223

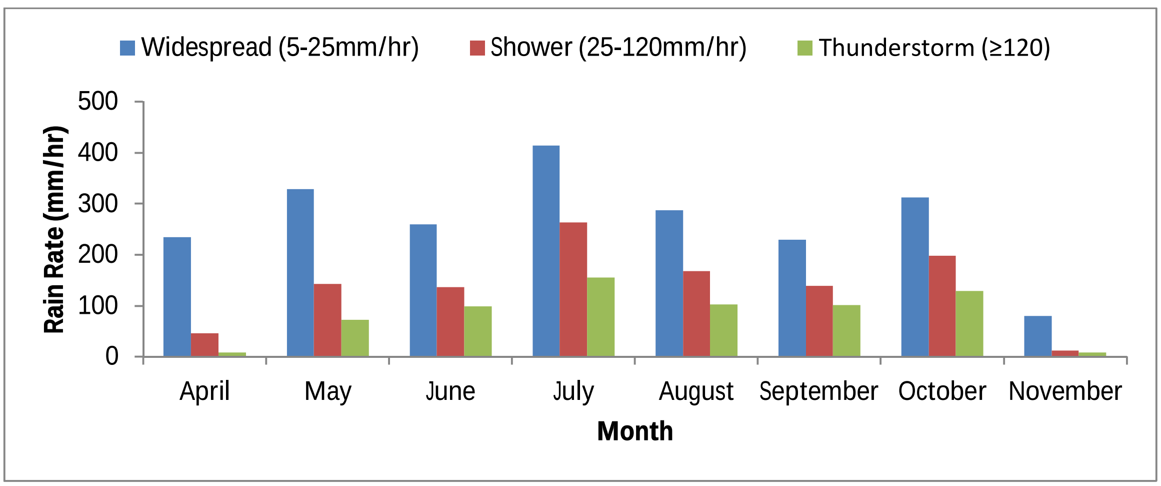

Figure 2: Amount of various categories of rain from April to November 2017

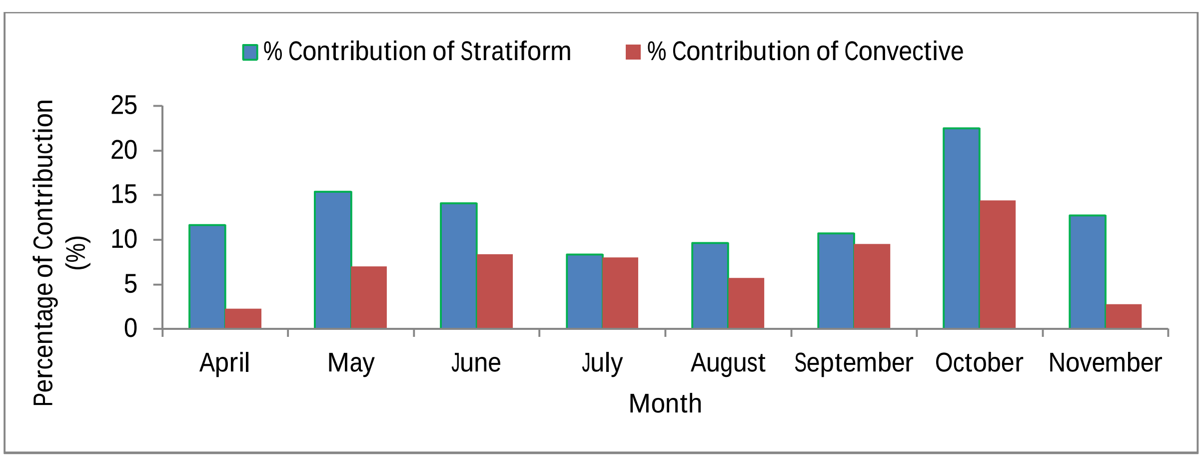

Figure 3: % contribution of stratiform and convective rainfall in 2017

IV. DISCUSSIONS

Table 1 presents the computation of the exceeded frequency percentage of time from April to November 2017 using rainfall rate. The month of August recorded the highest rainfall rate of 200mm/hr with exceeded frequency percentage of time of 0.002% follow by the months of July, September and October with rainfall rate 160mm/hr each with exceeded frequency percentage of time of 0.002%, 0.018% and 0.008% respectively. Figure 1 presents the Relationship between rainfall rate and various exceeded frequency percentage of time for the month of April, may, June, July, August, September, October and November 2017. From the results it can clearly be seen that higher rainfall intensities were obtained between 0.01 and 0.001% exceeded percentage of time. This further revealed that maximum rain induced impairment can best be estimated at 0.01% and 0.001%.

Table 2 presents the monthly categorization of rainfall in 2017. Figure 2 presents the quantity of various categories of rain from April to November 2017 while Figure 3 presents the percentage contribution of stratiform and convective rainfall in 2017. The result shows that the month of July has the highest rainfall intensity of both the widespread, shower, and thunderstorm. Among the categories of rainfall consider in this study, stratiform has the highest percentage of contribution which shows that the rain induced impairment within the study area are cause mostly by widespread (>5-25mm/hr) and shower (>25-120mm/hr). These results are in agreement with that of Zhimwang et al., (2018) which stated that higher rainfall rate (above 100 mm/hr) account for about 0.01 and 0.001% exceeded frequency percentage of time and it is during such times that maximum propagation losses due to rainfall is significant.

V. CONCLUSSION

Measurement and analysis of the consistency of rain induced impairment on Line-of-sight links was carried out. The measured rain rate data obtained for the months of April, May, June, July, August, September, October and November 2017 within the study area were classified into Stratiform and Convective rainfall. Results obtained shows that the rain induced impairment within the study area are cause mostly by widespread (>5-25mm/hr) and shower (>25-120mm/hr). Also, exceeded frequency percentage of time was calculated for each month under study which revealed that higher rainfall intensities were obtained between 0.01 and 0.001% exceeded percentage of time which revealed that maximum rain induced impairment can best be estimated at 0.01% and 0.001%.

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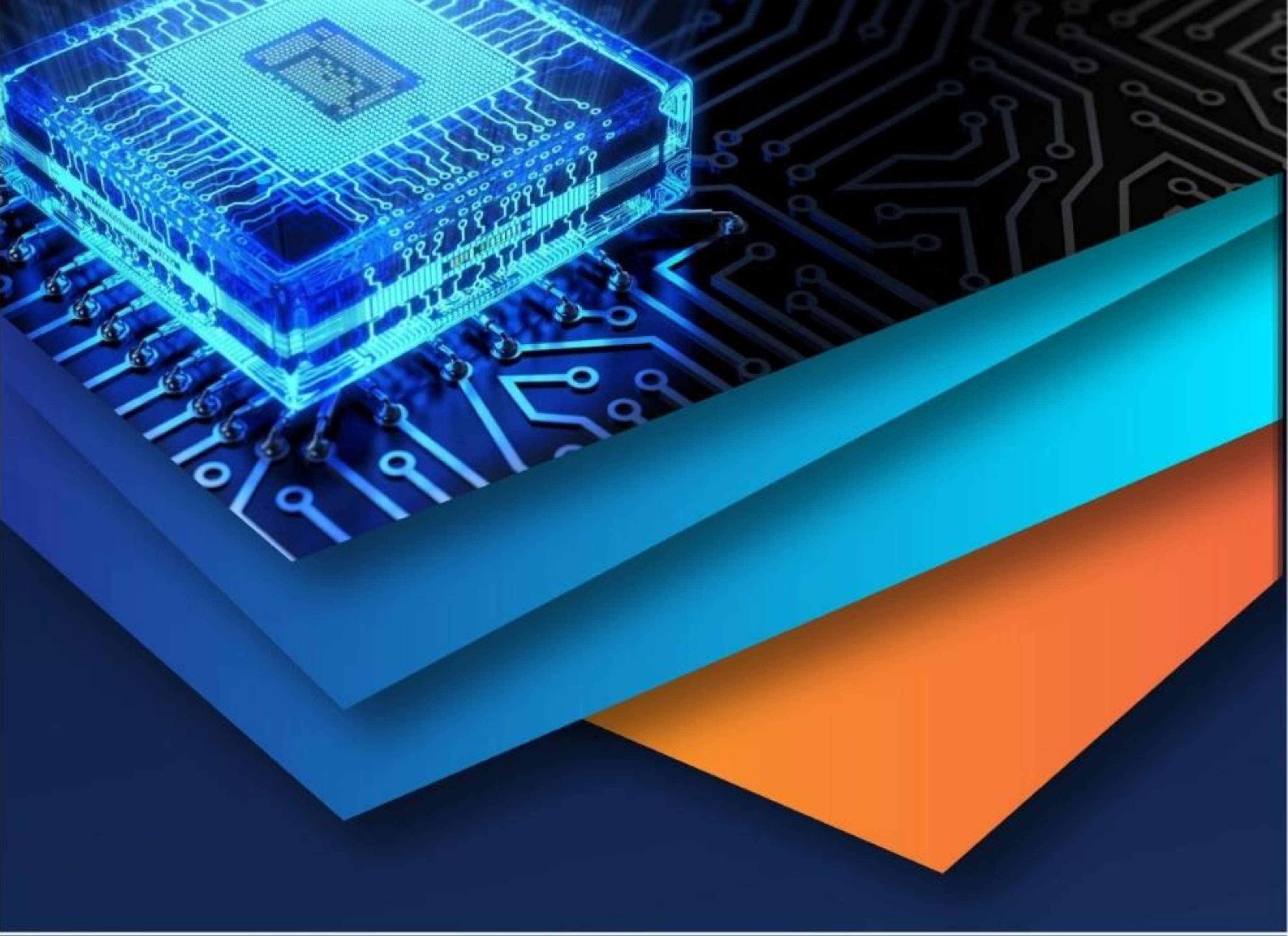

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