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Analysis of Inter-Satellite Optical Wireless Channel for Improved Transmission and Data Rate

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***Abstract*: The inter-satellite optical wireless channel (IS-OWC) systems are becoming popular due to their high performance and features. In this research work, we analyzed the performance of inter-satellite optical wireless channel for increased system capacity and channel length. The satellite link channel was tested at 40 Gbps data rate and a range of 8000 kilometers. The proposed model also supports the increased number of channels, i.e., 64 channels. The results showed the improved performance in terms of quality factor and BER. The achieved quality factor is 15.0432 at the input power of 10 dBm for 64 channels on the network.**

Keywords: ***IS-OWC, duo-binary modulator, Modulation, Q-factor, Input Power, BER.***

I. INTRODUCTION

In optical wireless communication, the integration of DWDM has undeniably transformed the satellite communication systems which will be used in the forthcoming time. The reason of OWC for being popular is because of their uniqueness and outstanding performance [1]. Inter-satellite optical wireless communication achieved the recognition in the small time because of their numerous benefits that increased the performance of such systems. Some of the advantages of using optical wireless communication as compared to RF in the space communication are easy recognition, lightweight circuitry, etc. in several applications [3].Free space optical communication is an essential method which is used for the satellites orbiting around the earth in order to communicate with each other. One of the important application of the WSO/FSO technology is inter-satellite optical wireless communication systems in space [5]. The satellite is the object which orbits around another object in the space. The Inter-Satellite link is called as the communication link which connects two satellites directly. These inter-satellite links are considered as the most important links for communicating between two satellites in the same orbit or in two different orbits [2]. The OWC (Optical Wireless Communication) system is the important part in the architecture of the hybrid wireless communication. In the optical communication, OWC has the medium of unguided visible light, Ultraviolet (UV) and the infrared (IR) light for transmitting the signal. Is-OWC (Inter satellite Optical Wireless Channel) are the models which are used to provide the high bandwidth, low power and are cheaper than the other microwave satellite systems. They are light in weight and have miniature size. FSO (Free Space Optics) has become a more effective technology for the Inter-Satellite Optical Wireless Channels. The operating frequency of these channels is in the visible band, which ranges from 390 to 750 nm or in the solar blind ultraviolet range, which has the range from 200 to 280 nm [2]. The inter-satellite optical wireless communication systems utilize communication between two satellites, which carries the optical signal through the unguided wireless links which may lead to a fusion of the wireless as well as the optical transmission. Is-OWC is also considered as the best way for point to point communication at the higher data rates. As the demand for the video conferencing, as well as the high-definition television, is increasing day by day, hence due to this the demand for the wireless access as well as the high-speed wired systems are also increasing. The IS-OWC systems are different from free space optics and fiber optics in terms of the propagation medium [2]. Optical Wireless Communication channel systems basically consist of a transmitter, propagation channel and the receiver [12]. In a normal Is-OWC network, a transmitter receives the data from the satellite TT and C (Tracking and Communication) system. As the communication is done by the transmitting light, hence the light source is considered as the important part of the optical signal. For the optical communication, the CW laser can be used. This is because the output light emitted by this laser is coherent, high radiated in nature and is monochromatic which is considered as the best source for long distance in the free space. The optical signal from the laser and the electrical signal from the tracking and the communication system is modulated before sending this to space. The optical wireless channel is free from losses which can occur due to weather and the atmospheric attenuation. This channel is considered as the vacuum and hence is free from other losses. The receiving end of this system consists of Photodiodes and the low-pass filter. The amplification in the photodiode occurs when the charged electrons in the high electric field collide with the neural semiconductor atoms [12]. This process is repeated to amplify the limited number of carriers.

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A. Performance Parameters Of Is-Owc System

The following are some parameters that affect the performance of the inter-satellite optical wireless channel.

1) *Wavelength:* Optical systems based on the space selects the wavelength on the basis of the communication between the pointing bias and the receiver sensitivity. This is generally due to the longer wavelengths, and the thermal variations.
2) *Power Level:* The overall system performance can be increased by increasing the power level. Sometimes, there are restrictions in the system components which insist a limit on the input power of the system.
3) *Modulation Format:* There are various modulation formats exists like NRZ (Non-Return to Zero), RZ (Return to Zero), DPSK (Differential Phase shift keying), DQPSK (Differential Quadrature phase shift keying), etc. They are highly effective in making the system efficient and robust.
4) *Data Rate:* The high data rates result in increasing value of the Q-factor and reducing values of the SNR (Signal to Noise Ratio).
5) *Filter Selection:* The filter selection also affects the performance of the Is-OWC systems. In most of the Is-OWC Systems, the low pass filters are generally used having the cut-off frequency as 0.75* Bit rate. The low-pass filter can be Bessel filter, RC filter, Gaussian filter, Cosine Roll-off Filter, etc.

BER and the Q-factor are the main parameters which are used to analyze the overall system performance. BER is defined as the ratio of the total number of the bit errors detected at the receiver side to the total number of bits transmitted. Sometimes, there is noise in the signals, which may lead to incorrect decisions at the receiver side.

The relation between the BER and Q-factor is as shown below: [6]

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \quad BER \approx \frac{1}{\sqrt{2\pi Q}} exp\left(\frac{-Q^2}{2}\right)$$

Here, Q is the Quality Factor. BER must be as small as possible and hence lead to the larger values of the Q-factor.

B. Advantages Of Is-Owc

The inter-satellite optical wireless channels are preferred due to their numerous advantages over the other types of networks. Some of the advantages are listed below:

1) *High Data rates:* These systems provide high data transmission rates and hence the high speed of communication. The data rates are in Gbps (Gigabytes per second).
2) *Narrow Beam Width:* The beam produced by the optical wavelengths are narrow in nature. But for this, the high accurate tracking system is required so that proper alignment of satellites is there.
3) *Lesser Cost:* These systems have the lesser maintenance cost as the lifetime of the system components is more.

II. LITERATURE SURVEY

P. Kaur, A. Gupta, M Chaudhary (2015) demonstrated the comparative analysis of the inter-satellite optical wireless channel for RZ and NRZ modulation formats for the input power of the various levels. In this research, the performance of inter-satellite optical wireless communication system link is presented with the help of DWDM multiplexing technique. The inter-satellite link is modeled at 10 Gbps of the data rate for the 5000 kilometres of communication range. In this research, the modelled system uses 32 channel inter-satellite optical wireless communication systems which are operated at 10 Gbps with the help of various modulation formats. The results indicated that the performance of the NRZ scheme is better as compared to RZ scheme in system efficiency as it achieved the low BER and high-quality factor. The author described that it is preferable to use 20dBm of input power with NRZ modulation scheme in order to get the favourable results [1].

S. Pradhan et al. (2017) described the performance enhancement of an inter-satellite optical wireless communication link with the help of different modulation techniques. In this research, the author simulated and illustrated the inter-satellite optical wireless communication system using various bit rates and different modulation formats such as 16-QAM, DRZ, QSK, and CSRZ. The results of the comparative analysis indicated that at the low bit rate, the proposed model provides minimum BER and maximum quality factor for all the modulation techniques. Also, the MDRZ modulation shows the better performance for 40 Gaps as compared to the DRZ and CSRZ modulations. The performance can be increased with the help of OFDM or MSK techniques than another optimized format [2].

H. Kaur and H. Kaur (2017) reviewed the inter-satellite optical wireless communication system. This research presented the description of the system of inter-satellite optical wireless communication using various different parameters. These parameters

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affect the performance of the system. The results indicated that the performance of the inter-satellite optical wireless communication could be improved with the help of several methods like diversity techniques and advanced modulation format [3].

S. Pradhan et al. (2015) proposed the inter-satellite optical wireless communication system with the help of diversity techniques. In this research, the proposed system is analyzed, simulated and designed for a 6,000km of a link distance with accomplishing the 7.63 Gbps of bit-rate for the 25dBm of input power. The results indicated that the proposed system showed the improvement of the data rate of 1.35 times as compared to the previous research. The system performance parameters are bit error rate, eye-opening, Q-factor, etc. The setup of the purpose system is very practical for the forthcoming and the present generation which has low earth orbit inter-satellite communication applications. The proposed system has also analyzed the effects of the space and polarized diversity techniques for the improvement of performance of the system. This research also analyzed further in order to improve the data rate and link distance [4].

N. Kaur and G. Soni (2015) presented the performance analysis of the inter-satellite optical wireless communication system (IsOWC) with the help of RZ and NRZ modulation. The BER is 10-25 for RZ and 0-41 for NRZ. These two modulations were used for the comparison. The proposed system provides the low cost, low power, lightweight, small size and high bandwidth to the existing microwave satellite systems. In this research, the optical inter-satellite link is modeled with the help of Optisystem. This system is presented between two satellites that are separated by a 1700 km distance and 3 Gbps of the data rate having varying modulation formats. The results of the simulation indicated that optical wireless system which has the ISL link with NRZ is better as compared to the RZ modulation. This is because of the minimum BER in NRZ as compared to RZ [5].

V. Kiran et al. (2017) described the performance analysis of the inter-satellite optical wireless communication. The author described the communication between the two lower earth orbit satellites. In order to analyze the performance of the inter-satellite link, BER and the quality factor are used as a key metric. This research presented the enhancement of the system performance with the help of advanced modulation techniques and several antennas. The author analyzed the optical link performance between the satellites by varying the parameters which affect the performance of the system. The results indicated that the proposed system could support the 10Gbps of data rate and can employ the 4 x 4 transceiver system over the distance of 6000km. In this research, 40 Gbps of higher data rate is accomplished in an inter-satellite optical wireless communication system with the help of QPSK modulation [6].

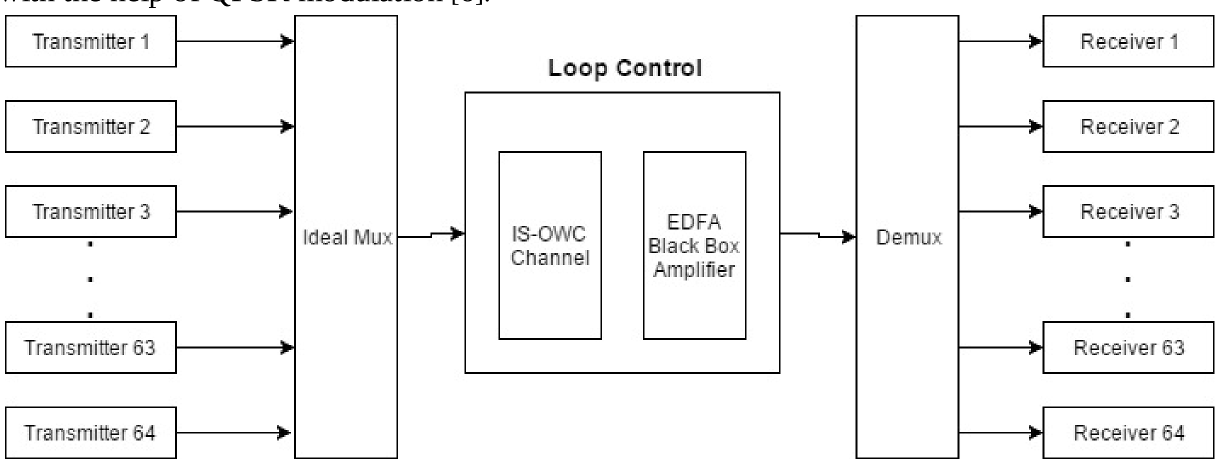

Fig. 1 – Block diagram of Is-OWC system

III. METHODOLOGY

The modulation technique that we have considered is the Duo-Binary Modulation technique. It is the method which seems to be better than the NRZ and RZ modulation techniques because Duobinary modulation turns out to be a much better choice in this case since it is more robust to dispersion and is also reasonably simple to implement. Another reason is the Duo binary modulated optical signal has a narrower bandwidth compared to the NRZ modulated signal. As a result, the effect of fiber dispersion is reduced and ultra-dense WDM systems applications are feasible. In the proposed model, the Duo-Binary Modulation technique is used in the Inter satellite Optical Wireless Channel (IS-WOC). The model provides 64 channel DWDM system for the distance of 8000

Kilometers with the help of inter-satellite optical wireless communication channel. Figure 1 shows the complete structure of the proposed Is-OWC system.

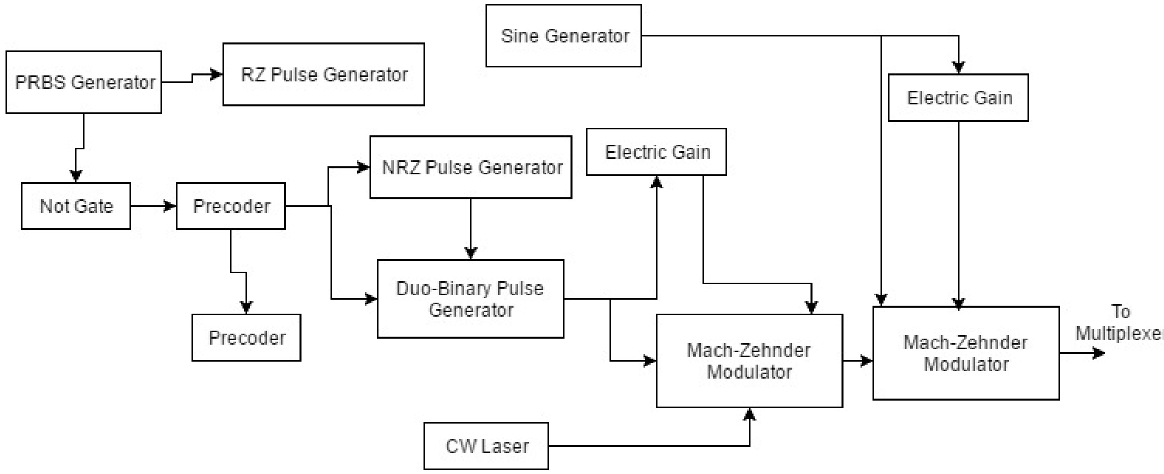

Fig. 2 – Components of DWDM Transmitter

A. The model has the following main parts

1) DMDM transmitter

2) Channel

3) DWDM Receiver

Figure 2 shows the components of the DWDM transmitter. It consists of PRBS generator, CW laser, Duo binary pulse generator, RZ & NRZ pulse generator, Mach-Zehnder Modulator, and other related components.

PRBS stands for Pseudo-Random Bit Sequence Generator. It generates the sequence of random bits and passes all the random generated bits to the RZ Pulse Generator. RZ creates a sequence of pulses that are returned to zero. In our model, the input of the NOT gate is provided by the PRBS generator, and the output is given to the Precoder delay. NRZ creates a sequence of NRZ (Non-Return to Zero) pulses. It is also known as Continuous Wave Laser. Its output is directly given to the MZ modulator.

The Channel consists of the Loop Control, OWC Channel, and the Amplifier. We have used loop control in our circuit as it is used to control a number of loops in the circuit. It is used when we are using the amplifiers in the circuit.

In our case, we are using the EDFA black box Amplifier. EDFA is also known as Erbium Doped Fiber Amplifier. It is used to provide the amplification to the signal when the signal is traveling in the long wavelength of about 1550nm. We have chosen EDFA for our work because of its excellent properties. EDFA can provide in-line amplification which means that we do not need to convert the signal to electrical before its amplification. It has high power transfer efficiency.

DWDM Receiver consists of PIN Photodetector, Filter, 3-R Generator, and the BER Analyser.

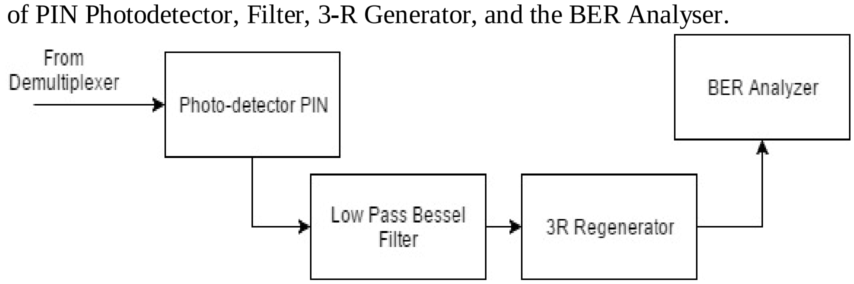

Fig. 3 – DWDM Receiver

The photodetector PIN is used to convert optical signals into the electrical signals. The photodiode is provided with the input from the WDM DeMux, and the output of the PIN Photodiode is transmitted to the low-pass Bessel filter that filters the signals. Then the 3R regenerator simplifies all connections and helps in providing the data that are required in generating the eye diagrams. Further, the BER Analyzer provides the Eye-Diagram, BER plot and various values like BER value, Q-factor value and eye height that helps in checking the quality and efficiency of the model.

IV. SIMULATION SETUP

Figure 4 shows the proposed setup of the system in Optisystem. The Optisystem provides a lot of components and functionalities to simulate the networks of various types.

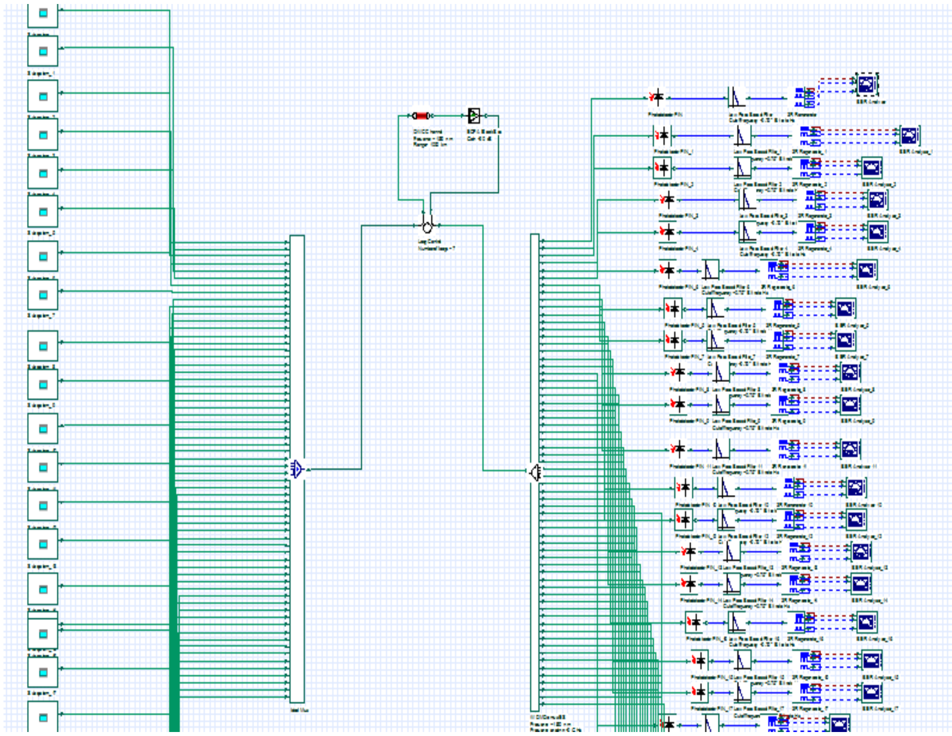

Fig. 4 – Simulation Setup of Proposed work

The parameters are shown in below Table 1 as a comparison with the previous research [1]. The proposed system is tested on the 8000 km with 64 channels. The results are comparatively higher than the results of a previous paper [1].

Table 1: Parameters of Simulation setup

S.NO	Parameters	Previous work	Our Improved Work
1.	Bit Rate	10 Gbps	40 Gbps
2.	Optical Channel Length	5000 Kilometers	8000 Kilometers
3.	Number of channels	32 Channels	64 Channels
4.	Modulation Technique	RZ, NRZ	Duo-Binary

In the previous work, the system was tested for different input power levels [1]. This research also tested the system on input power at 10, 20 and 30 dBm.

V. RESULTS AND DISCUSSIONS

This section presents the results obtained from the simulation of Optisystem. The results are shown in the form of tables and graphs that are easy to interpret and conclude.

Figure 5 shows the resultant eye diagrams at the various input levels that are considered in the research work. The value of Quality factor achieved is same at all the power levels. The difference lies in the value of BER achieved. The achieved quality factor is the 15.0432 that shows high performance of the system. The BER (Bit Error Rate) value is also very small that ensures the good efficiency and performance of the system while having 64 channels and increased the overall capacity of the system.

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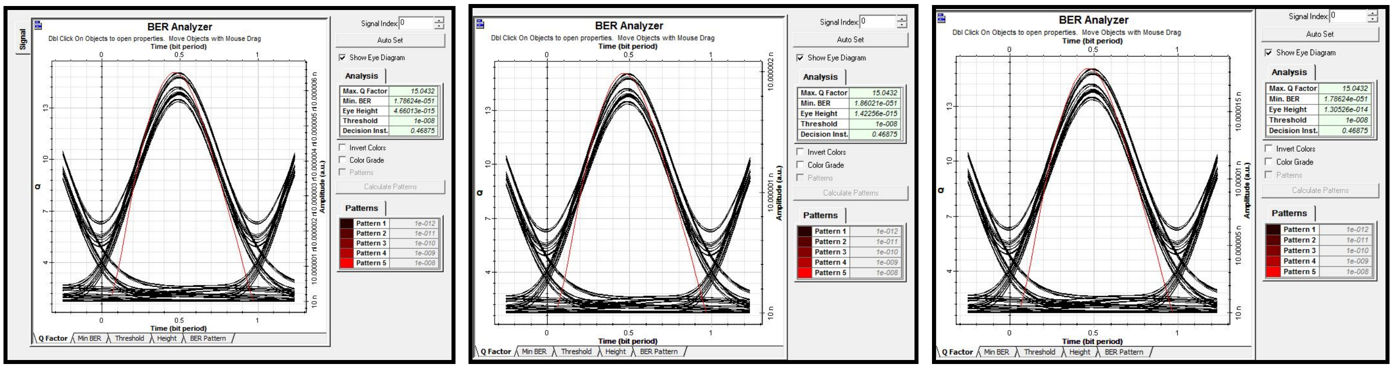

(a) At Input Power 10 dBm (b) At Input Power 20 dBm (c) At Input Power 30 dBm

Fig. 5- EyeDiagrams at various input powers

V. COMPARISON OF RESULTS

The results are compared with the results of previous research [1]. The differences are there in terms of quality factor and achieved BER values. The modeled system encompasses a 64 channels IS-OWC (Inter satellite Optical Wireless Channel) system operating at 40 Gbps using the Duo-Binary modulation format. The system is designed to cover a long distance of 8000 kilometers, and the results have been verified using Optisystem. The comparative analysis of our work with the previous work shows that our scheme performs better than their scheme in terms of system efficiency due to the attainment of a high Q-factor and a low BER.

Table 2: At input power 10 dBm

S.NO	Parameters	Previous work [1]		Proposed System
		NRZ	RZ	
1.	Q- Factor	12.26	12.99	15.0432
2.	BER Value	6.74*10^-39	1.28*10^-38	1.78624*10^-51

Table 3: At input power 20 dBm

S.NO	Parameters	Previous work [1]		Proposed System
		NRZ	RZ	
1.	Q- Factor	13.36	12.98	15.0432
2.	BER Value	4.92*10^-41	7.9* 10^-39	1.86021*10^-51

Table 4: At input power 30 dBm

S.NO	Parameters	Previous work [1]		Proposed System
		NRZ	RZ	
1.	Q- Factor	13.37	13.09	15.0432
2.	BER Value	4.5*10^-41	1.72*10^-39	1.78624e-051

Table 2, 3, and 4 shows the resultant values of quality factor and BER as compared with the previous research [1]. It can be seen that the system achieves the improved performance while having the increased bit rate and a number of users. This also shows the superiority of the modulation technique used, i.e., Duobinary modulation technique.

VI. CONCLUSION

With the growing research trend in the area of Inter-Satellite Optical Wireless Channel, various techniques are being proposed and working on increasing the performance and efficiency of the Is-OWC systems. This research presents an Is-OWC system using Duobinary modulation technique for 64 channels, 8000 Km distance, and 40 Gbps data rate. The proposed system is capable of handling a large number of users without compromising the system performance. The highest quality factor achieved is 15.0432. The system with 10 dBm input power can be considered to provide the best performance and the achieved BER in a system with 10 dBm power is 1.78624*10^-51 that is very less as compared with previous research [1].

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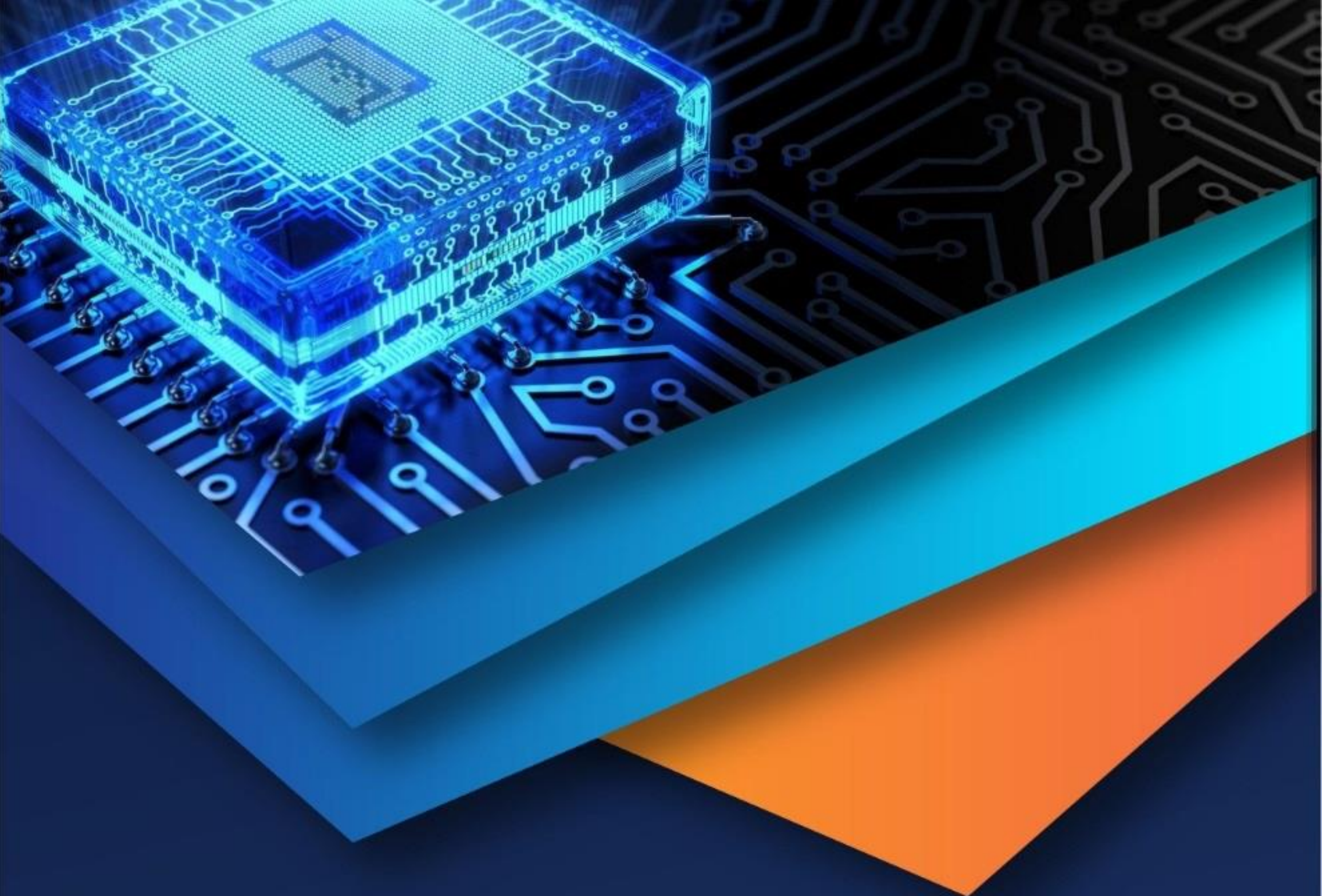

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