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Design and Simulation of Multibeam FSO Communication Channel using VCSEL Laser Diode

Sumaira Rasool[1], Er. Tanika Thakur[2]
[1]*Research Scholar of ECE Dept., SVIET, Banur, I.K. Gujral Punjab Technical University Punjab, India*
[2]*Asst. Prof. of ECE Dept., SVIET, Banur, I.K. Gujral Punjab Technical University Punjab, India*

Abstract: ***Free space optical (FSO) communication is a growing technology to handle high data rate and it has very large information handling capacity. However, the biggest bottleneck in FSO systems is the atmospheric effects that limit their use in long reach applications. Research is consistently being carried out for merging different techniques which aim at reducing these effects, however, they are less efficient during different weather conditions. Thus to make the previous system more efficient, a work is proposed in this paper in which the multi-beam FSO is used instead of single-beam. Moreover, with the increase in distance, the noise gets added in the signal which degrades the system performance. Therefore, in the proposed work different optical filtration techniques are used that will help to enhance the Q factor of the system even at greater link distance. The performance of this proposed approach i.e. VCSEL-MMF-FSO with optical filter, is analyzed by considering different parameters such as BER and Q-factor. Also, the comparison analysis is performed between proposed and previous approach and the obtained results demonstrate the efficiency of proposed work over previous work.***
Keywords: Free Space Optics, VCSEL, Multi-beam FSO, Q-factor, BER.

I. INTRODUCTION

Free Space optical (FSO) interrelate has received great attention from research group of people due to capability of providing increased density routing as well as interconnection and capability to apply difficult 3 dimension interrelate approaches [1] [2]. A number of implementation of optical interconnect requiring group device were reported [3] [4]. But, optical component used in these kind of approaches relay in plane of substrates and not appropriate for monolithic integration. Before, micro machined free-space micro-optical bench technology was introduced [5], [6] that allows both and changeable and fixed optical component to stand at right angles to the substrate. Using this technology, huge number of free-space optical components is monolithically combined on single substrate. VCSEL's are chosen optical source for interconnect due to their capability to form 2 dimensional array, other totally new benefits like low currents, small beam different angle and globular output beam profile. With VLSI chip, it can be potentially combined monolithically.

The applications are chip-to-chip, intra-chip visual linked and board-to-board. Core component of this system is micro-machine micro-Fresnel lens array. Both micro-fresnel lens (MFL) and single three-dimensional MFLs fabrication is reported [5]. Micro-machined 3-dimensional MFL array made at right angle to Si substrate using micro-spring latches and micro-hinges [7]. Moreover, micro-machined 3-dimensional position structure has developed to incorporate VCSEL'S array with MFL array. Combination of vertical-cavity surface emitting lasers and micro-machine element is fascinating as VCSEL has thin beam deviation (small numerical aperture) and patience of passive position relying on pre-aligned micro-machine arrangement is relaxed. Both VCSEL and micro Fresnel lenses can be formed in 2-dimensional and 1-dimensional arrays. This leads to complicated FSO communication scheme be implemented. This method will help in decreasing size, volume and size of FSO communication scheme and additional combine micro-optical scheme.

The electrical signals are converted into optical by transmitter. Light sources like Light Diodes (LDs) or (LEDs) i.e. Light Emitting Diodes or (VCSEL) i.e. Vertical Cavity Surface Emitting Diodes are all contained by transmitter. Laser is applicable in single mode operations, has least width of spectral, and holds most bandwidth, whereas, both LED and VCSEL are applicable for multimode operations and has large and narrow spectral width respectively.

VCSEL can be regarded as an important technology for this modern age as it is a semiconductor micro cavity laser that has found its formation in number of applications. Subsequently analyzing the ancient progress of Vertical Cavity Laser from 30 years, the applications that are considering this optoelectronic development are introduced. For understanding the working of VCSEL, the spectral alignment among laser gain and cavity resonance is taken important. The optical properties of VSCEL are analysed. Properties such as polarization and transverse mode and other parameters that influence the performance of laser are introduced.

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VCSELs are being applied in various optical systems such as optical fibre networks, parallel optical interconnects laser printers, and high density optical disks [8]. Recently, VCSEL array has been proposed as a concept of a compact FSO communications terminal thanks to their high reliability and high-speed modulation (2.5 Gb/s) under high optical power operation [9]. However, the VCSELs for FSO also faces various problems such as devices with maximum power are not accessible this confines the working of FSO links made by VCSEL devices, there are sudden breakdown systems in VCSEL and have restricted wavelength. Thus, number of researches has been carried out in this field as it attracts great attention. Some of the research works related to this field of VCSEL based FSO systems are reviewed in this paper which are discussed in next section:.

II. LITERATURE REVIEW

High power VCSEL as beam source for FSO connections was developed in the paper [10]. VCSEL devices have 16, 4, or 9 at the same time driven spot - related to particular spot VCSEL as well as contain only cone-shaped FFP in high visual output control action on 10, 20 and 40mW. The authors [11] assessed the probability of realizing optical networks utilizing 1.5-µm VCSELs in OOK and 4-PAM arrangement. To enhance power plan of networks, author optimized disappearance ratio of 10.7- and 21.4-Gb/s indicator and develop electrical equalization at receiver. Multi-channel LTE broadcast on RoF scheme realized by low rate and low use 850nm VCSEL and SSMF was planned in framework of wireless system front-haul links [12]. In paper [13], author presented likely RoF scheme that can be deployed in present and future generations of cellular system like LTE or future 5G. System proposed relies on cost-effective and low utilization optical mechanism for example 850 nm Single-Mode VCSELs and SSMF of G.652 type. The author [14] demonstrated and studied 50 Gb/s NRZ broadcast over 15 km of normal SSMF, 60-Gb/s NRZ broadcast above 5 km of SSMF and equal to 64-Gb/s NRZ continuous utilizing a directly change short-cavity long-wavelength single-mode VCSEL produce on 1326 nm. In paper [15], author proposed a model of FSO connected system and consequences of this paper display BER and control of system at dissimilar distances (50 meter to 1000 meter) in high speed information rate of 1.25 Gbps. The paper [16] proposed 2 way lightwave broadcast system and explained a suitable and financial well-known arrangement. In paper [17], author examined its advancement of technology and physics including spectral band from infra to ultraviolet, by using fabrication techniques, materials. Functioning such as, dependability, outcome power, threshold, modulation and polarization were introduced. A FSO based on less power 850nm VCSEL was presented and verified in paper [18] for providing wireless communication (indoor), with 1.05 GHz bandwidth over transmission distance of 3.1m. In paper [19], a hybrid architecture using VCSEL base SMF connection pursue by FSO broadcast, was explored. VCSEL was biased under threshold to produce short optical pulses, which was coded in NRZ format. Long wavelength VCSEL and Single Mode Fibre (SSMF) both dole out effectively for Passive Optical Network (PON) applications. Thus, this approach was considered as a most efficient one.

However, it is analysed that this work is less efficient during rainy weather conditions and also has degraded system performance due to low Q-factor. Therefore, it is required to upgrade the conventional work so that the improved system performance can be achieved for different weather conditions.

III.PRESENT WORK

Various approaches proposed in existing works related to VSCEL based FSO systems are reviewed in the above section. One such technique had been reviewed [19] in which a hybrid architecture using VCSEL based SMF followed by FSO transmission, was introduced. It is considered to be the efficient approach; however, in this work, single beam FSO was used. And the link performance of an FSO communication system with a single-beam transceiver is less efficient during heavy rain. Also, the Q factor decreases with increase in link distance and the BER increases, thus decreasing the system performance. Thus the requirement arises of upgrading the conventional system.

Therefore, in this paper, the conventional system is upgraded to overcome its drawback. In the proposed work, the multi-beam FSO is used instead of single beam FSO (which was used in previous work).

The technique of combining more than one beam in a multi-beam FSO system reduces the effect of turbulent atmosphere, such as scintillation and loss of power in the detector due to heavy rain. The concept of the multi-beam FSO system is the replacement of the single-beam transceiver by multiple-beam transceivers. By this replacement, multiple channels with different attenuation levels in the atmosphere are obtained. A channel with less attenuation will cause less degradation to the transmitted power.

Moreover, with the increase in distance, the noise gets added in the signal which degrades the system performance. The background noise can be controlled by limiting the receiver optical bandwidth. In the conventional work, single optical filtration technique is used to control the amount of background noise. However, it maintains the system quality only up to certain distance and with more increase in distance, the quality get degraded.

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Therefore, in the proposed work different optical filtration techniques are used that will help to enhance the Q factor of the system even at greater link distance. With the help of filters, the unwanted features or components can be removed from the signal. Various illustrious filters are present such as Chebyshev filter, Butterworth filter and Bessel filter. Each of these filters has their own limitations and advantages.

Among these, Bessel filter is regarded as a most efficient filter as it have highest group delay while preserving signals wave shape to be filtered. It is same as Gaussian filter, however, it has more flat phase delay and group delay and better shaping factor. Also, it has been analyzed that its performance in terms of Q-factor is efficient than other filters. Thus, Bessel Optical filter will be used in the proposed work.

Thus, with the help of proposed work, the system with enhanced performance and quality can be achieved.

IV. SIMULINK MODEL

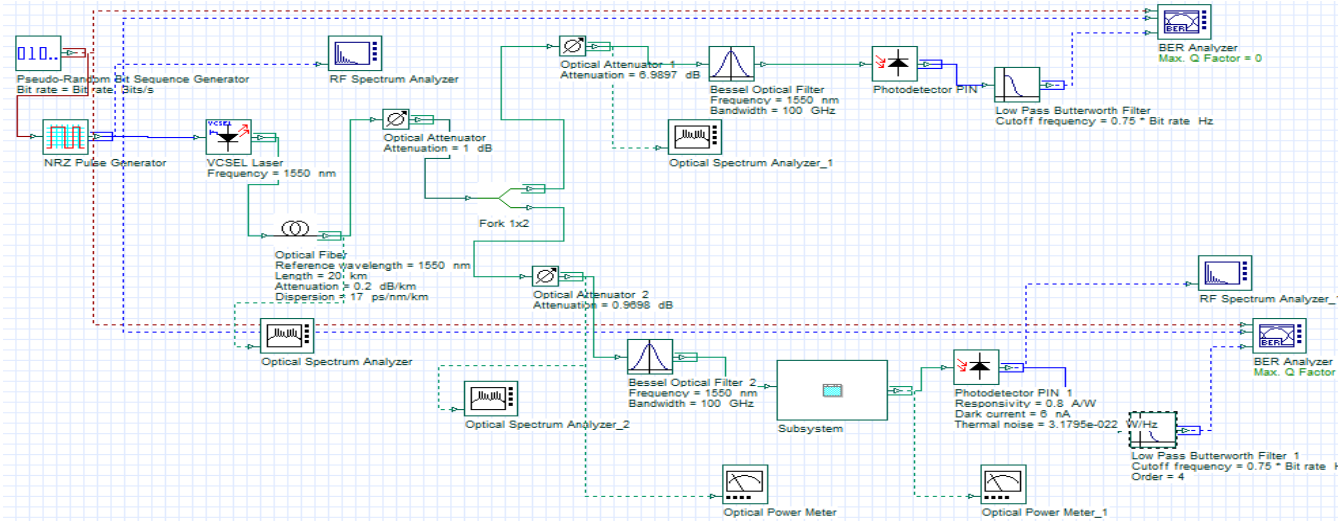

Figure 1: Simulink model of proposed work

The proposed approach i.e. VCSEL based hybrid MMF-FSO link with optical filter, is implemented in Optisystem software and its layout/ simulink model is represented in figure 1. A binary data stream following Pseudo Random Binary Sequence (PRBS) generator is used. The generated current pulses are coded in NRZ format and given as electrical input to VCSEL laser diode which has frequency of 1500 nm. The generated optical pulses are propagated via optical fibre for distance of 20 km. Then, optical attenuator is implemented and then the optical filter is applied in order to reduce the noise from the signal. A 1550 nm InGaAs PIN photodiode based optical receiver is considered in the study. It is modelled as a fourth order low pass filter with cut off frequency at 75% of the data rate. In order to analyse the performance, RF spectrum analyser, BER analyser, optical spectrum analyser and optical power meter are used for visualizing the simulation value. The power meter represents the difference in the output power from the transmitter and the receiver, in order that effect of weather on the transmission can be visualized; whereas, the BER analyser represents the bit errors during transmission.

The performance of this proposed system is evaluated in terms of different parameters i.e. BER and Q-factor. For the simulation, the different transmission data rates are considered i.e. 1.25 Gbps, 2.5 Gbps, 5 Gbps and 10 Gbps. The results obtained in terms of different considered factors are discussed and represented in below section:

V. RESULTS

The proposed approach i.e. VCSEL based hybrid MMF-FSO link with optical filter, is implemented in Optisystem software in order to verify its performance. For the performance evaluation different parameters are considered such as BER and Q-factor. In terms of these parameters, the results are obtained for proposed approach, and the comparative analysis among proposed approach (VCSEL-MMF-FSO) and traditional approach (VCSEL-SMF-FSO) is performed and the obtained results are represented as below:

The proposed and traditional approaches are both compared in terms of Q-factor at different data rates i.e. 1.25 Gbps, 2.5 Gbps, 5 Gbps and 10 Gbps, as shown in graph 2. The obtained graph delineates that the Q-factor value attained in case of proposed approach is higher than traditional approach at all different data rates. Thus, the higher value of Q-factor implies that the system with high quality can be attained.

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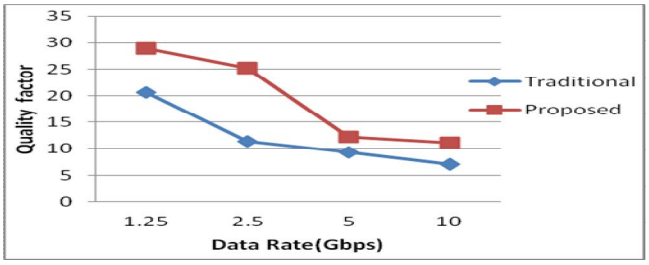

Figure 2: Comparative analysis in terms of Q-factor at different data rates

The Q-factor values attained by both the approach at various data rates are recorded in table 1.

Table.1: Q-factor values attained by different approaches at different data rates

Data rates (Gbps)	Q-factor	
	Traditional approach	Proposed approach
1.25	20.65	28.94
2.5	11.34	25.34
5	9.24	12.25
10	7.01	11.08

From the values recorded in above table, it is comprehensible that there is great difference between Q-factor values of both the approaches, and also, the Q-factor decreases with increase in data rate. The proposed approach has high Q-factor value than traditional approach at every data rate such that, at 1.25 Gbps, 2.5 Gbps, 5 Gbps and 10 Gbps data rate, the Q-factor obtained for proposed approach is 28.94, 25.34, 12.25 and 11.08, respectively, and for traditional approach is 20.65, 11.34, 9.24 and 7.01, respectively. Thus, the higher Q-factor leads to achieve an efficient system with high quality.

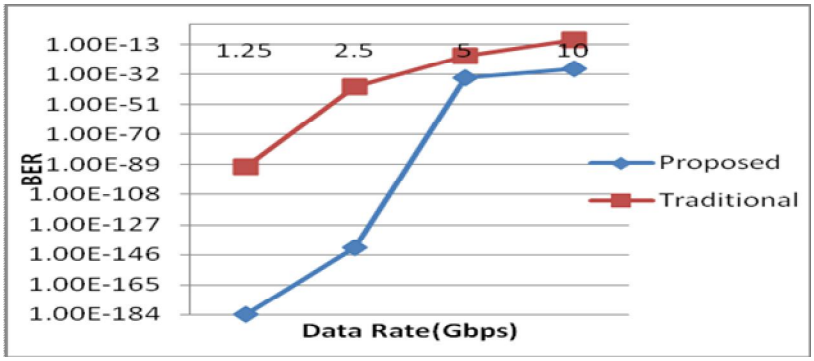

Figure 3: Comparative analysis in terms of BER at different data rates

The comparative analysis among proposed and traditional approach with respect to BER at different data rates is performed and the obtained result is represented graphically in figure 3. The difference between both these lines delineates that the BER of the proposed approach is low than that of traditional approach. And this low BER implies that proposed approach is more efficient than traditional approach that will thus help to achieve an efficient system.

Table 2: BER values attained by different approaches at different data rates

Data rate (Gbps)	BER value	
	Proposed approach	Traditional approach
1.25	1.70E-184	1.00E-90
2.5	5.39E-142	1.50E-40
5	7.91E-35	1.00E-20
10	7.24E-29	1.00E-10

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The BER values attained by proposed and traditional approaches at different data rates are recorded in table 2. From the obtained values, it is concluded that the BER obtained by the proposed approach is low as compared to that obtained by traditional approach at every data rate i.e. 1.25 Gbps, 2.5 Gbps, 5 Gbps, and 10 Gbps. Thus, it demonstrates the efficiency of the proposed approach in terms of BER.

VI. CONCLUSION

VCSEL based multi-beam FSO system with optical filter is introduced in the proposed work, which is the upgraded version of previous approach i.e. VCSEL based SMF-FSO. This new approach is proposed to reduce the effect of turbulent atmosphere on FSO system and to reduce the signal noise and thus enhance the quality and efficiency of the system. In order to analyse the performance of the proposed approach, it is implemented in the Optisystem software and different parameters such as BER and Q-factor are considered for performance evaluation. Also, for the simulation, the different transmission data rates are considered i.e. 1.25 Gbps, 2.5 Gbps, 5 Gbps and 10 Gbps. The results are obtained for all aforementioned data rates with respect to considered parameters. And from the obtained results it has been analysed that with the increase in data rate, the Q-factor gets decrease. Also, the high data rate has high BER than that at low data rate. The comparison analysis among proposed and conventional approach is also performed in terms of BER and Q-factor and the obtained results represents that at different data rates, the Q-factor of proposed work is high and BER is low as compared to Q-factor and BER of conventional work. And high Q-factor and low BER thus helps to achieve an efficient, reliable and qualitative FSO system that can perform efficiently under different weather conditions even at larger distances of link.

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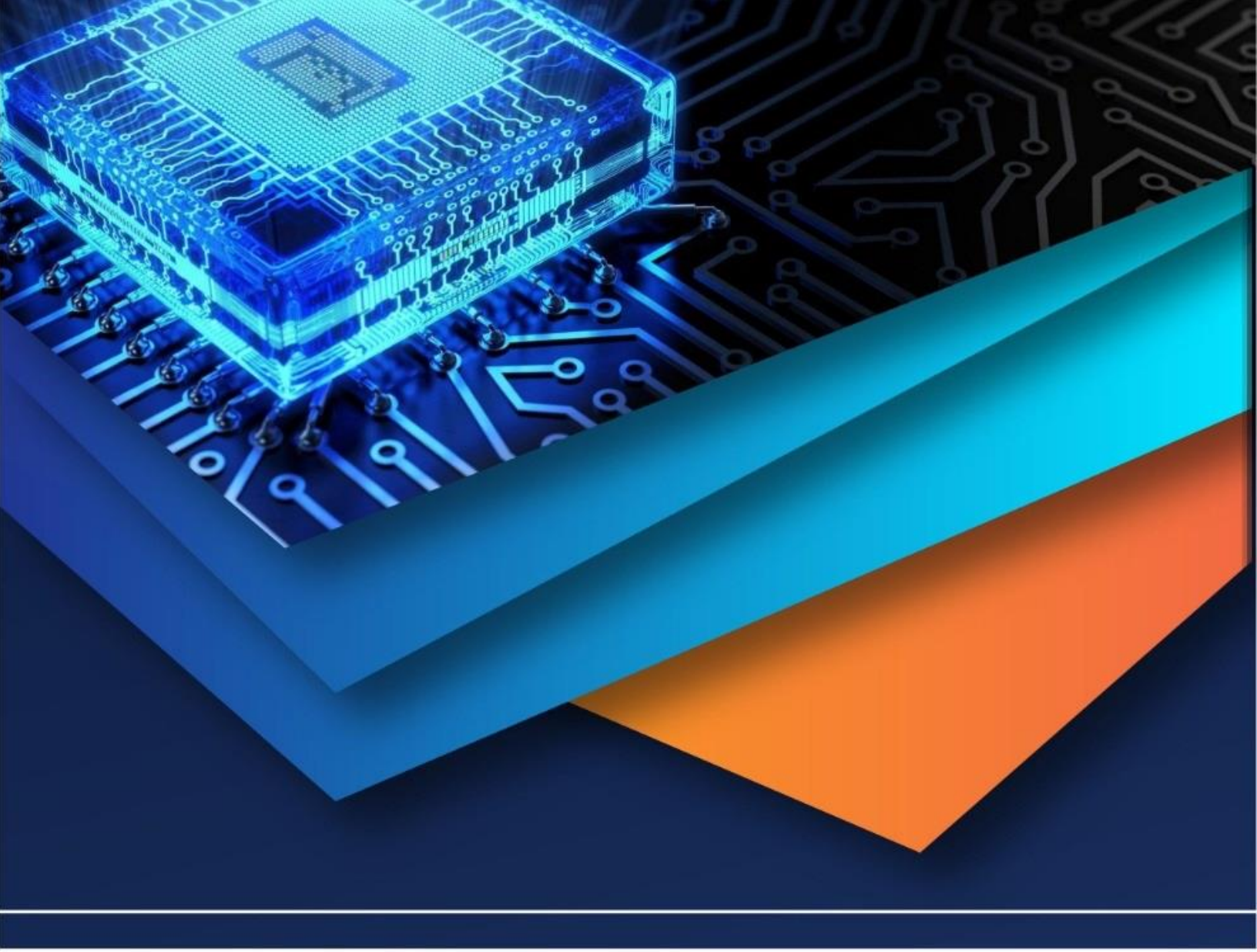

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