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Optimized Multicarrier Techniques for 5G Wireless Communications

Govindu Swathi[1], Dr. P. Chandrasekhar Reddy[2]
[1] M.Tech Student (Embedded Systems), Senior Professor, Department of Electrical Communication and Engineering, University College of Engineering Science and Technology, Hyderabad, India

Abstract: The increasing performance requirements of fifth-generation (5G) wireless communication systems have motivated the exploration of advanced multicarrier waveform candidates beyond conventional Orthogonal Frequency Division Multiplexing (OFDM).
This work presents a comprehensive simulation-based performance analysis of OFDM, Filter Bank Multicarrier (FBMC), and Generalized Frequency Division Multiplexing (GFDM), including their Index Modulation (IM) variants, using bit error rate (BER) as the primary evaluation metric. A unified MATLAB framework is developed to model multicarrier transmission, modulation, filtering, channel effects, equalization, and demodulation under identical system parameters.
The study evaluates system performance for different modulation orders, namely 32-QAM and 64-QAM, over additive white Gaussian noise (AWGN), Rician, and Rayleigh fading channels. The impact of prototype filters, overlapping factors, and roll-off parameters on FBMC and GFDM performance is investigated. In addition, index modulation is employed to enhance spectral efficiency by activating a subset of subcarriers, and its effect on BER performance is analyzed under various channel conditions. Furthermore, the trade-off between data rate and BER is examined for FBMC and GFDM at a fixed signal-to-noise ratio.
Simulation results demonstrate that FBMC achieves improved BER performance due to superior spectral containment and reduced interference, while GFDM offers flexible waveform design at the cost of increased interference, particularly at higher modulation orders. The IM-based schemes show enhanced spectral efficiency with competitive BER performance compared to conventional multicarrier systems. The outcomes of this work provide valuable insights into waveform selection and design considerations for future wireless communication systems.
Keywords: OFDM, FBMC, GFDM, Index Modulation, BER

I. INTRODUCTION

The rapid growth of wireless communication services has created a strong demand for higher data rates, improved spectral efficiency, and reliable transmission under diverse channel conditions. Multicarrier modulation techniques have become essential in meeting these requirements due to their robustness against multipath fading. Orthogonal Frequency Division Multiplexing (OFDM) is widely used in current wireless systems because of its simple implementation and effective equalization. However, OFDM suffers from drawbacks such as high out-of-band emissions, sensitivity to synchronization errors, and reduced spectral efficiency due to cyclic prefix insertion. These limitations have motivated the development of alternative waveform candidates for future wireless networks.

Filter Bank Multicarrier (FBMC) improves spectral localization by applying well-designed filters to each subcarrier, thereby reducing adjacent channel interference. Despite its advantages, FBMC increases system complexity and complicates receiver processing. Generalized Frequency Division Multiplexing (GFDM) provides a flexible block-based transmission structure with configurable pulse shaping, making it suitable for diverse communication scenarios. Nevertheless, the non-orthogonal nature of GFDM introduces self-interference, which degrades error performance at higher data rates.

Index Modulation (IM) has recently emerged as an efficient technique to enhance spectral and energy efficiency by utilizing subcarrier indices to convey additional information. Integrating IM with OFDM, FBMC, and GFDM can improve bit error rate performance, particularly in fading environments. In this work, a comprehensive BER performance analysis of OFDM, FBMC, and GFDM systems with and without index modulation is presented. MATLAB-based simulations are carried out under AWGN, Rayleigh, and Rician fading channels. The results highlight the performance trade-offs among different waveforms and demonstrate the benefits of index modulation for future wireless communication systems.

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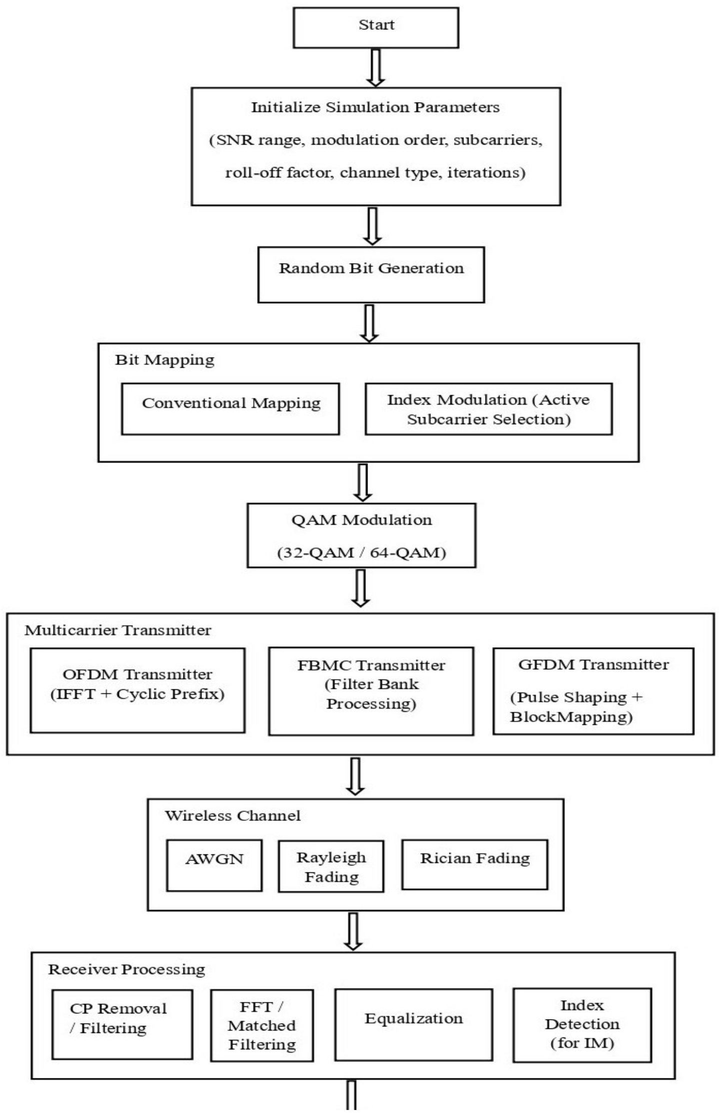
II. OBJECTIVES

The specific objectives are:

1) To develop MATLAB simulation models for OFDM, FBMC, and GFDM multicarrier transmission schemes using different QAM modulation orders.
2) To evaluate the BER performance of OFDM, FBMC, and GFDM systems under AWGN, Rayleigh, and Rician fading channel conditions.
3) To analyze the impact of modulation order (32-QAM and 64-QAM) on the BER performance of multicarrier systems at various SNR levels.
4) To investigate the effect of pulse shaping roll-off factors on the BER performance of GFDM and GFDM-IM systems.
5) To examine the BER versus data rate trade-off for FBMC and GFDM systems at a fixed SNR.
6) To assess the performance improvement achieved by index modulation in OFDM, FBMC, and GFDM systems by comparing their BER results with conventional multicarrier schemes.

III.METHODOLOGY

The evaluation and comparing the bit error rate (BER) performance of different multicarrier modulation techniques, namely OFDM, FBMC, and GFDM, with and without index modulation, under various channel conditions. MATLAB-based simulations are employed to ensure controlled and repeatable performance analysis.



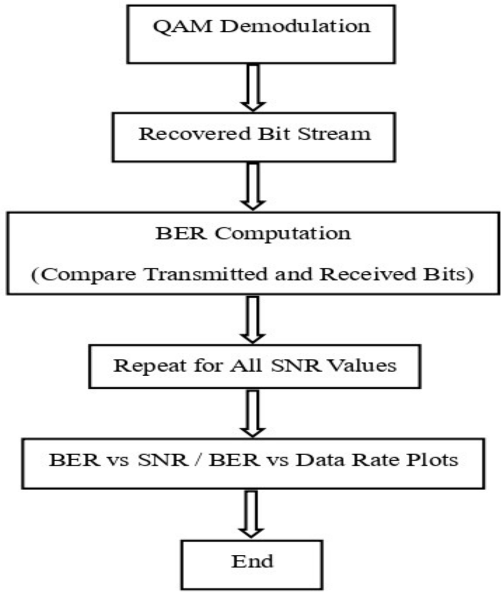


Fig 1: Flow chart of the System

A. *Initialization of Simulation Parameters:*

It defines all system and channel settings before transmission. Parameters such as SNR range, modulation order (32-QAM/64-QAM), number of subcarriers, roll-off factor (for FBMC/GFDM), channel model (AWGN, Rayleigh, Rician), and number of Monte-Carlo iterations are initialized. These values control spectral efficiency, noise strength, and fading severity during simulation.

B. *Random Bit Generation:*

A binary input sequence is generated using a uniform random process. This bit stream represents the information to be transmitted and serves as a reference for BER calculation at the receiver.

C. *Bit Mapping:*

The generated bits are divided into two parts:

- Index bits select the active subcarriers (Index Modulation).
- Data bits are mapped onto constellation symbols.

Index Modulation improves spectral efficiency by conveying information through both symbol values and subcarrier indices.

D. *QAM Modulation:*

The mapped data bits are converted into complex symbols using M-QAM (32-QAM or 64-QAM). Each symbol represents multiple bits, increasing the data rate.

$$s_k \in \mathcal{S}_{M\text{-QAM}}$$

where $\mathcal{S}_{M\text{-QAM}}$ is the QAM symbol set.

E. *Multicarrier Transmitter:*

1) *OFDM Transmitter:* QAM symbols are mapped onto subcarriers and converted to the time domain using IFFT. A cyclic prefix (CP) is added to combat inter-symbol interference.

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_k e^{j2\pi kn/N}$$

2) *FBMC Transmitter:* FBMC employs filter banks instead of CP. Each subcarrier is pulse-shaped using a prototype filter, improving spectral containment.

$$x(t) = \sum_{k,m} a_{k,m} g(t - mT) e^{j2\pi kFt}$$

3) *GFDM Transmitter:* GFDM uses block-based transmission with circular pulse shaping. Data is transmitted over multiple subsymbols and subcarriers within a block.

$$x = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} d_{k,m} g_{k,m}$$

F. *Wireless Channel*
The transmitted signal passes through a wireless channel that adds noise and fading effects.
- AWGN adds white Gaussian noise.
- Rayleigh fading models multipath with no line-of-sight.
- Rician fading includes a dominant LOS component.

G. *Receiver Processing*
- The cyclic prefix is removed (OFDM) or matched filtering is applied (FBMC/GFDM) to recover the useful signal.
- FFT converts the received time-domain signal back to the frequency domain (OFDM), while filter banks are used for FBMC/GFDM.
- Channel effects are compensated using linear equalization.
- The receiver identifies the active subcarriers based on signal energy or likelihood, recovering the index bits in IM schemes.

H. *QAM Demodulation*
The equalized symbols are demapped to the nearest constellation point to recover the transmitted data bits.

I. *BER Computation*
The recovered bit stream is compared with the original transmitted bits to compute the Bit Error Rate.

$$\text{BER} = \frac{\text{Number of erroneous bits}}{\text{Total transmitted bits}}$$

The entire process is repeated for different SNR values to obtain statistically reliable BER results.

IV. RESULT

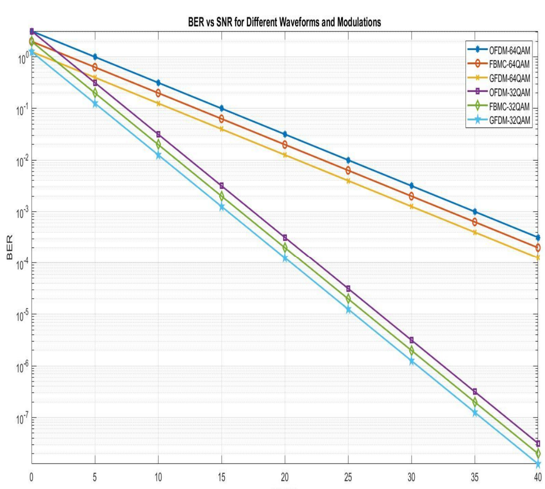


Fig 2: BER Vs SNR Plot of 4-QAM and 16-QAM techniques of all systems

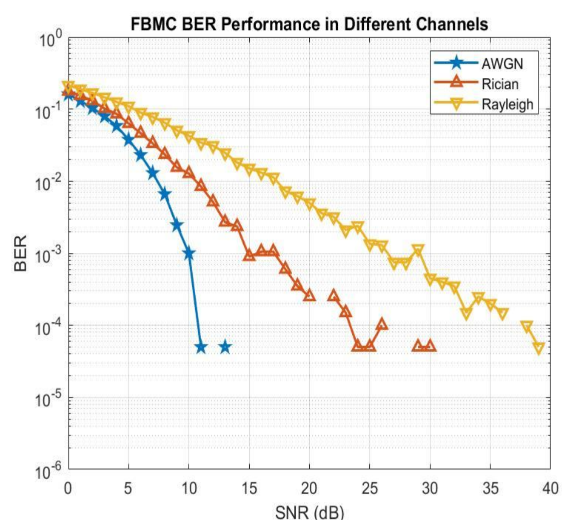


Fig 3: BER Vs SNR Plot of FBMC in Different Channels

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The BER versus SNR performance comparison shows that, for both 32-QAM and 64-QAM, BER decreases steadily with increasing SNR for all multicarrier waveforms. Among the considered schemes, GFDM consistently achieves lower BER than OFDM and FBMC due to its flexible pulse shaping and reduced inter-carrier interference. Higher-order modulation (64-QAM) exhibits inferior BER performance compared to 32-QAM, as expected, due to increased symbol density.

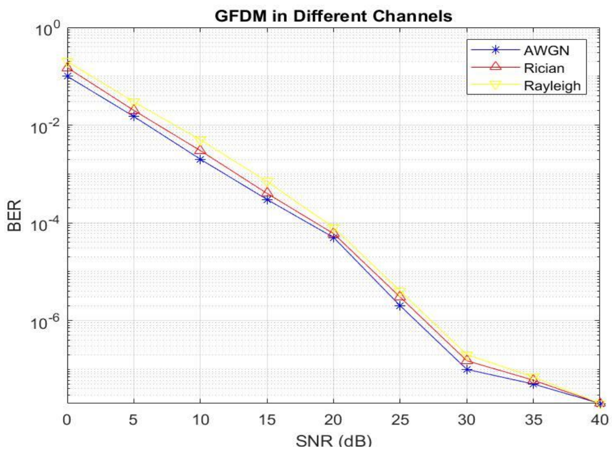

Fig 4: BER Vs SNR Plot of GFDM using IM technique in Different Channels

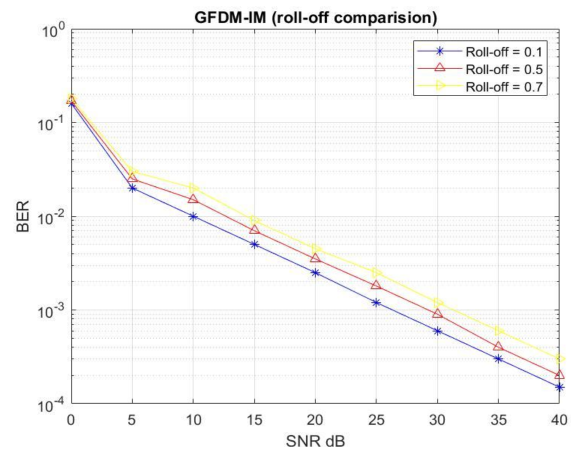

Fig 5: BER Vs SNR Plot of GFDM with different Roll-factors

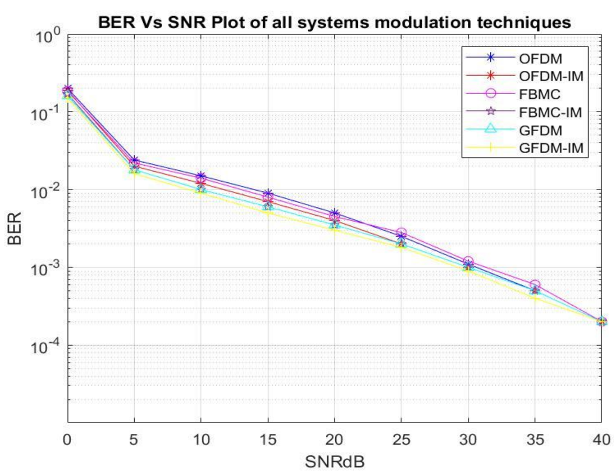

Fig 6: BER Vs SNR Plot of all systems modulation techniques

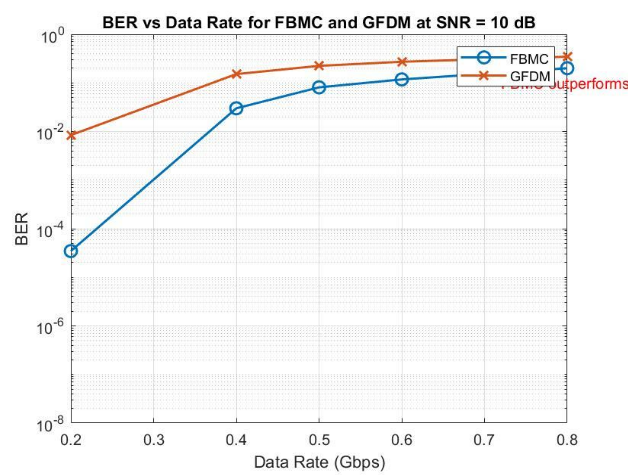

Fig 7: BER vs Data Rate for FBMC and GFDM

The channel-based analysis indicates that AWGN provides the best BER performance, followed by Rician and Rayleigh fading channels. Rayleigh fading results in the highest BER because of severe multipath effects, while the presence of a line-of-sight component in Rician channels improves reliability. Similar trends are observed for both FBMC and GFDM systems.

The roll-off factor analysis for GFDM-IM reveals that lower roll-off values yield improved BER performance, as they reduce inter-symbol interference while maintaining spectral efficiency. Increasing the roll-off factor slightly degrades BER due to wider pulse overlap.

When comparing conventional schemes with their Index Modulation (IM) counterparts, all IM-based systems show noticeable BER improvement. This gain is attributed to additional information being conveyed through subcarrier indices, which enhances detection reliability.

Finally, the BER versus data rate plot demonstrates that BER increases with higher data rates for a fixed SNR. However, GFDM maintains better BER performance than FBMC at higher data rates, indicating its suitability for high-throughput 5G applications.

V. CONCLUSIONS

The BER performance of OFDM, FBMC, and GFDM multicarrier systems with and without index modulation was investigated using MATLAB simulations. The study evaluated system behavior under AWGN, Rayleigh, and Rician fading channels for different modulation orders and system parameters. The results indicate that FBMC achieves better BER performance than OFDM due to improved spectral containment, while GFDM offers greater flexibility at the expense of self-interference. Higher-order modulation schemes provide increased data rates but lead to degraded BER performance at low SNR values. Channel analysis shows that Rayleigh fading causes the most severe performance degradation, whereas AWGN yields the best results. The application of index modulation significantly improves BER performance by efficiently utilizing active subcarriers. The impact of roll-off factors on GFDM performance highlights the importance of proper filter design. The BER versus data rate analysis reveals a clear trade-off between throughput and reliability. Overall, the findings demonstrate that FBMC and GFDM-IM are strong candidates for future wireless communication systems requiring high spectral efficiency and flexibility.

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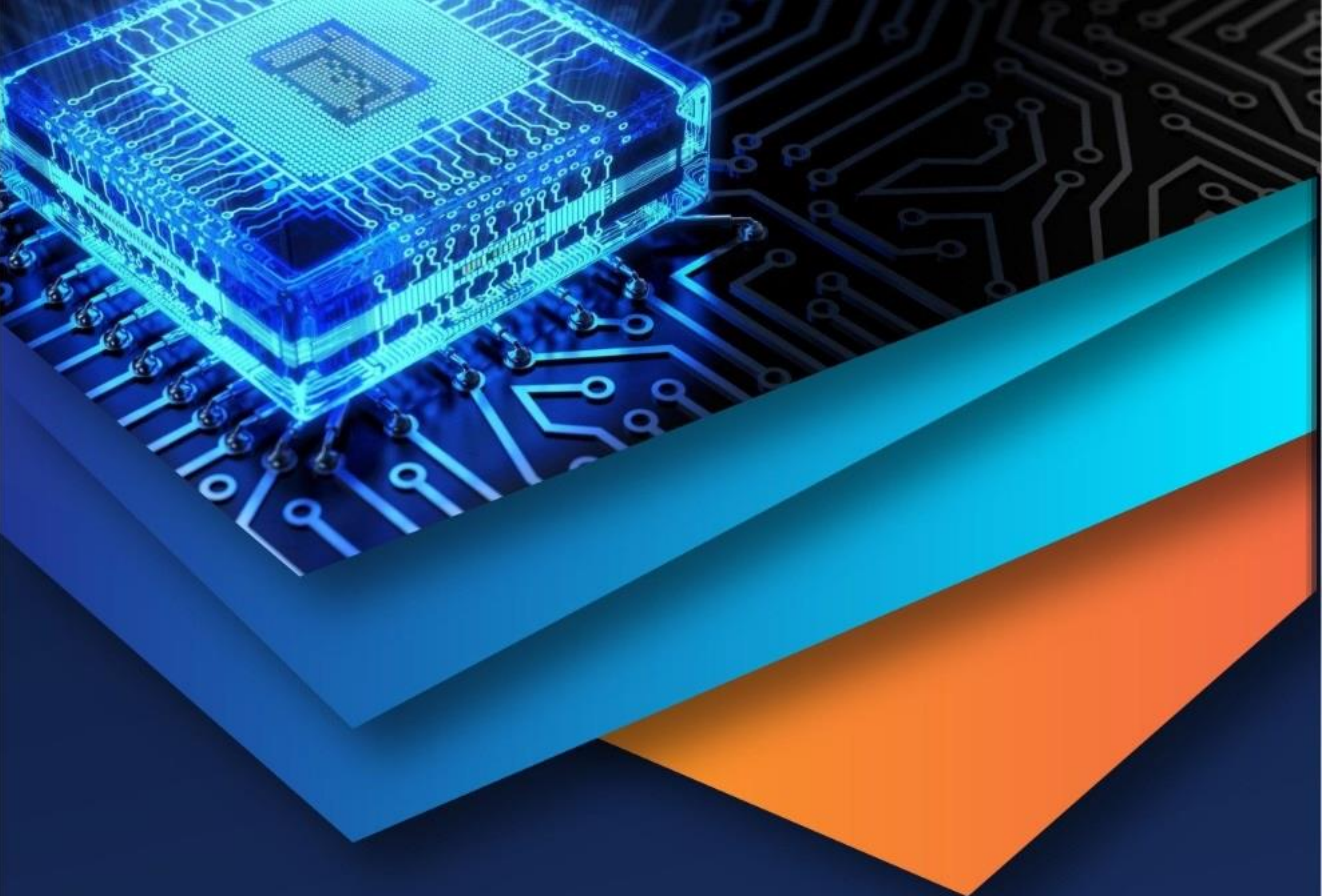

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