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Dynamic Wireless Charging System for Electric Vehicles in Motion

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Abstract: This paper introduces a novel approach for wirelessly charging electric vehicles (EVs) in motion, utilizing an energy transfer system designed to minimize the need for stationary charging intervals. The proposed prototype uses a 10-volt solar panel as the primary source of power and makes use of an IRF 540 N transistor to allow for efficient switching of the power and a transmitter-receiver coil system to achieve the transfer of energy wirelessly. The transmission core is set up with a custom-made copper coil, having a diameter of 7 cm and a gauge of 25, and wound with 10 turns. Control and monitoring are performed using an Arduino UNO, which provides real-time data processing, displays the output on an LCD screen, and integrates a voltage sensor for accurate power feedback. This configuration offers a viable proof-of-concept for dynamic wireless charging, possibly transforming the structure of EV infrastructure as it integrates charging capabilities into roads to increase EV range and sustainability. It is also likely that the future expansion of this technology will encompass higher power levels and the real-world system of EVs. Dynamic charging will therefore continue to play an important role in furthering power supply with no interruptions, minimizing time outages.
Keywords: Wireless charging, Electric vehicle (EV), Dynamic charging, Arduino UNO, Copper coil, Energy transfer, Sustainability, Infrastructure transformation.

I. INTRODUCTION

A giant leap in sustainable transportation, EVs are going to reduce massive greenhouse gas emissions and dependence on fossil fuels. The biggest pending issue with the current EV technology is the problem of range anxiety, which is the fear that an EV might not have enough battery life to travel to its destination without having to recharge. Where there is a part fill through static charging stations, periodic and often timeconsuming stopping to charge the battery becomes the major drawback for travelling long distances. Dynamic wireless charging allows in-motion recharging of EVs and will consist of wireless charging infrastructure to be added to highways.

This will change traditional charging models into smooth trips, wait times for charging greatly reduced, and EVs are accessible to everyone for all distance of travel. The second thing, dynamic wireless charging is relieved from the pressure of charging station infrastructure, the way it scatters the charging facility along with travel routes, hence the better access, and solutions on road transport are realized to be sustainable.

This paper presents the design and testing of a prototype system aimed at demonstrating the feasibility of wireless charging of EVs in motion. Here, the major focus has been on establishing the practicality of such energy transfer in a controlled experimentation environment. The prototype consists of a 10volt solar panel as the primary power source, an IRF 540 N transistor controls the flow of power to the transmitter-receiver coil structure for wireless energy transfer. Inside this is a custom copper coil, designed 10 turns with 7 cm diameter and fabricated out of 25-gauge wire. Ensuring maximum inductive coupling, this is the primary aim. Meanwhile, an Arduino UNO microcontroller keeps tabs on the system in real time and controls it as well. It tracks voltage and displays the data on the LCD. This setup will help the project evaluate some of the major issues of dynamic wireless charging, including efficiency in transferring energy, systems' stability, and scalability of future applications. Findings from this prototype are anticipated to offer an insight into dynamic charging technology advancement, setting a course toward real applications where EVs can automatically charge on-the-go, eventually paving a way for making EVs more sustainable and accessible infrastructure.

II. LITERATURE REVIEW

One promising alternative to traditional plug-in charging methods is WPT for EV charging. WPT relies on the principle of magnetic resonant coupling, which offers a possibility of energy transfer without the need for physical connectors and hence well-suited to EVs [1].

Boies et al. introduce a general survey of the technology of wireless power transfer, indicating merits and limitations of different configurations in view for application in EV with special attention to high efficiency and high power density in the charging system [2]. The first work in this field was carried out in static charging systems where the EV is stationary during charging; however, the dynamic wireless charging system in which the EV can be charged while in motion was a more complex and influential application [3]. Dynamic wireless charging relies on proper alignment and design of coils for maximum power transfer since misalignment resulting from movement of the vehicle results in a considerable loss of efficiency [4]. Zhang et al. demonstrated dynamic wireless charging that kept the position aligned which would reduce the detriments of misalignment [5]. Similar works done by Choi et al., noted that the development of the roadway-powered EV system had placed high emphasis on a design coil that is flexible for movement and has minimized loss of energy [6]. Chau et al. further continued studying other power electronic topologies that may be applied to wireless charging systems. Some of these factors that reduce efficiency include coil coupling, resonance frequency, and compensatory circuitry [7].

Optimization in design has led to several configurations and approaches developed within magnetic structure design in coils and their efficiency in the transfer of energy. Budhia et al. introduced the concept of an optimized circular magnetic structure for inductive power transfer that showed high enhancement in consistency of energy transfer over the traditional coil designs [8]. Similarly, Kang et al. designed a high-efficiency wireless power transfer system using the magnetic resonance coupling, thus providing a better alignment tolerance and hence is essential for on-road dynamic charging applications [9]. On the other hand, Zhang and Mi considered different compensation topologies for a dynamic charging system and concluded that series and parallel hybrid configurations achieve maximum efficiency with high-power WPT systems [10].

It is also very important to make the WPT efficient; in this regard, coil design, controlling, and monitoring of energy transfer need to be accomplished. Including microcontrollers inside and using real-time solutions in monitoring enhances the functionality and also makes the WPT quite responsive. Hu et al. have shown that this topology can be used with an FPGA for real-time control of voltage in a contactless energy transfer with which dynamic charging applications would work also [11]. Here, the prototype was that type of microcontroller-based system wherein efficient power flow management was established as well as monitoring for optimum voltage condition [12]. Recent work by Suh and Wang demonstrates that dynamic environments enhance the efficiency and stability of energy transfer because of real-time monitoring of the magnetic resonant coupling [13]. As the technology for wireless charging advances further, scaling these systems for practical applications means high power requirements and end-user safety issues take on a priority. Lu et al. have given an excellent review of high efficiency wireless power transfer systems where the authors reported on challenges for scaling dynamic wireless charging towards on-road applications, among other things thermal stability and EMF safety [14]. Jang and Tseng developed the bidirectional charging system, and based on this, one unit would charge and discharge to increase functionality in the charging infrastructure of EVs [15]. That development indicates a step further in the integration of WPT systems into smart grids as it opens up the two-way energy flow from the grid to EVs and vice versa [16].

This literature underlines the rapid progress of WPT and dynamic charging for EVs as technological innovations driving the industry toward sustainable, continuous charging solutions. By providing insight into coil design, compensation topologies, and real-time control systems, this project will contribute to the field by demonstrating a prototype that integrates these key elements, potentially paving the way for scalable and efficient on-road wireless charging systems for electric vehicles.

III. METHODOLOGY

This methodology entails the design, construction, and testing of a prototype on wireless charging of an electric vehicle when in motion. Cores involve a transmitter coil integrated into a model of the road infrastructure while the receiver coil attached to an RC car is used in mimicking the electric vehicle. The charging system uses a 10-volt solar panel to feed energy on the transmitter side; further, it uses an IRF 540 N transistor in case power regulation control is done by an Arduino UNO, and realtime voltage-level monitoring during the energy transfer takes place.

The methodology is broken down into several key stages:

A. System Design and Component Selection

A two-coil architecture system will be designed wherein the energy from the 10-volt solar panel is given to the roadembedded transmitter coil for creating an electromagnetic field. On the other hand, an electromagnetic field is absorbed through the receiver coil underneath the EV for WPT to happen. The transmitter is driven by a high-frequency power source, which is generated by an IRF 540 N transistor, switching current and modulating the magnetic field for efficient energy transfer. The transmitter and receiver coils were custom-designed; a copper coil was built using 10 turns, diameter of 7 cm, with 25-gauge wire due to these parameters creating a balance of efficiency and stability during charging.

B. Control System and Monitoring

The Arduino UNO microcontroller governs the system control and monitoring. This continuously monitors voltage levels on the receiver coil through a voltage sensor, hence ensuring that power transfer would be within safe yet effective limits. Realtime data about the voltage will then be presented on an LCD screen connected to the Arduino to allow for continuous observation of the charging process. This would inform us about the energy transfer efficiency and how this type of movement or any type of misalignment is causing fluctuations.

C. Testing and Optimization

The final testing is the testing of the prototype wireless charger in order to estimate its efficiency, range, and adaptability. This can be achieved by testing it on an RC car which is driven at several speeds over the embedded transmitter coil to determine how moving will affect the stability of the charging. Distance between coils, alignment, and effect of coil geometry on efficiency of energy transfer is calculated. The partial misalignment is also in the testing scenarios to obtain the power losses and stability of the system. Optimization occurs through fine-tuning coil dimensions and testing various configurations to maximize energy transfer efficiency under varying conditions.

The following figures describe system architecture with general system configuration as well as the flow of control and power of a process of wireless charging.

1) System Architecture Diagram

This diagram outlines the main components of the system, showcasing the solar panel, transmitter and receiver coils, IRF 540 N transistor, Arduino UNO, voltage sensor, and LCD display.

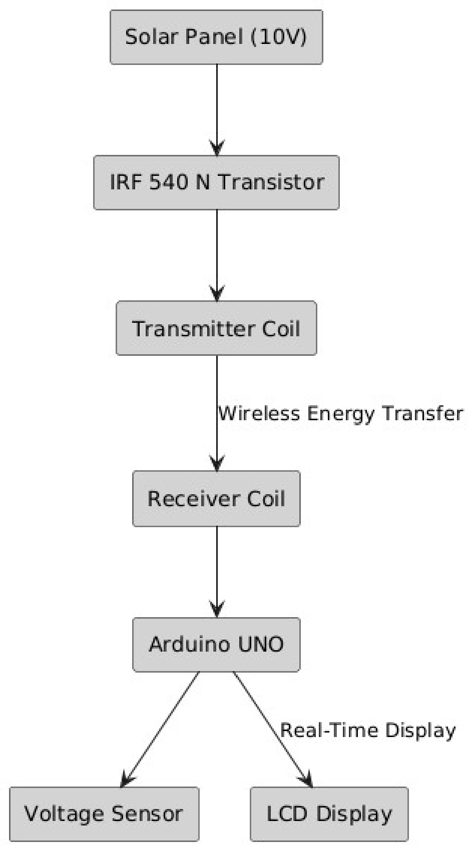

Figure 1: System Architecture of Wireless EV Charging Prototype.

2) Flowchart of System Operation

This flowchart describes the process of wireless charging, from initializing the power source to monitoring the power levels and adjusting for efficiency.

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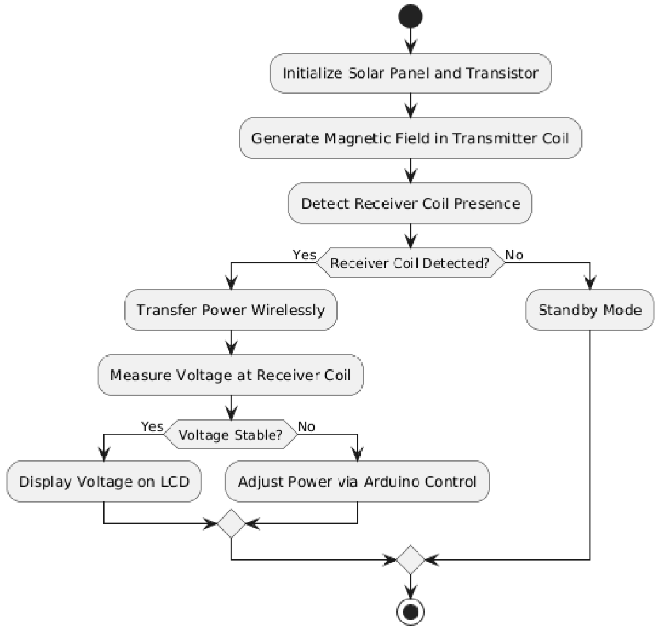

Figure 2: Flowchart of Wireless Charging Process.

3) Real-Time Monitoring Process

This flowchart explains the real-time monitoring process managed by the Arduino UNO, which includes continuous voltage measurement and system control.

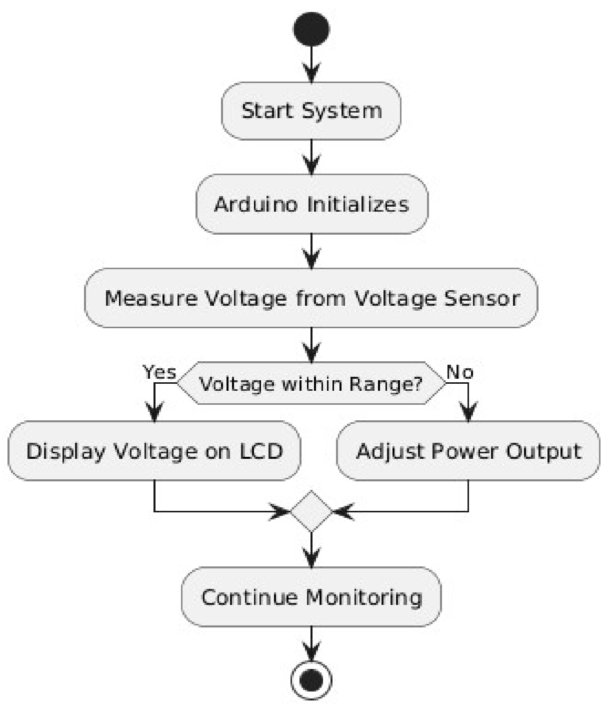

Figure 3: Real-Time Monitoring Process for Voltage Stability.

This approach has been provided for structuring the method of development for the prototype of the wireless charger. So, it focuses more on real-time monitoring, control, and optimization of every component to ensure efficiency with stable power transfer. This methodology is depicted through various diagrams given, clearly showing flow and structure of operation for the system.

IV. RESULTS AND DISCUSSION

In these tests, efficiency, stability, and effects of movement, in addition to those of the alignment on the charging behavior are reported. This experiment had to be performed under widely diversified conditions to make sure if in a dynamic setup simulating different real-life driving scenarios the Wireless prototype for charging will be well competent to work on an Ev in motion. This experimental data points to the efficiency of the power transfer capability and highlights areas that would require optimization.

A. Efficiency of Power Transfer

Table I presents the efficiency of power transfer at different distances between the transmitter and receiver coils. The efficiency has been computed by taking the ratio of the power received in the receiver coil to that transmitted from the transmitter coil. From results it is evident that, intuitively expected, the closer the coils are, efficiency will be higher. Nevertheless, the efficiency was maintained at more than 80% when the distance was within 10 cm, thereby proving that the selected coil dimension and system components are feasible for near-range dynamic charging.

Table I: Power Transfer Efficiency at Various Distances

Distance (cm)	Efficiency (%)
2	95.4
4	92.7
6	89.2
8	84.6
10	80.3

B. Voltage Stability with Varying Speeds

As discussed next, the measured voltage levels in the receiver coil for various vehicle velocities over the embedded transmitter coil are represented in Table II. Clearly, results illustrate that, at any given velocity level, higher voltages would vary significantly when the alignment between the coils becomes unstable with increasing velocities, which indeed would lead to significant increases. Nevertheless, at 10 km/h and up, still, sufficient robustness of the system would emerge toward providing a voltage level of some stability within 10% deviation. This could indicate that the system is designed to allow low-speed dynamic charging, but more work may be needed at high speeds.

Table II: Receiver Coil Voltage at Different Speeds

Speed (km/h)	Voltage (V)
2	9.7
4	9.5
6	9.2
8	8.9
10	8.6

C. GRAPHS

1) Efficiency vs. Distance

This graph shows how the transfer efficiency varies with distance, which differs between the transmitter coils and the receiver coils. Again, this rises slowly up with distance with a steeper fall afterward, especially at distances greater than 8 cm. From these graphs, a very clear interpretation is extracted, such as the significant need for good alignment for efficient transfers or design features of coils which reduce further losses in coils at high distances.

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Figure 1: Efficiency of Power Transfer at Various Distances.

2) Voltage vs. Speed

The following graph shows how speed affects the receiver coil's voltage level. From the graph, it can be seen that the stability of the voltage diminishes slightly as the vehicle speed increases. This is caused by temporary misalignment and lower coupling efficiency. These results show that in cases of higher speeds or changes in alignment, real-time control adjustments are necessary.

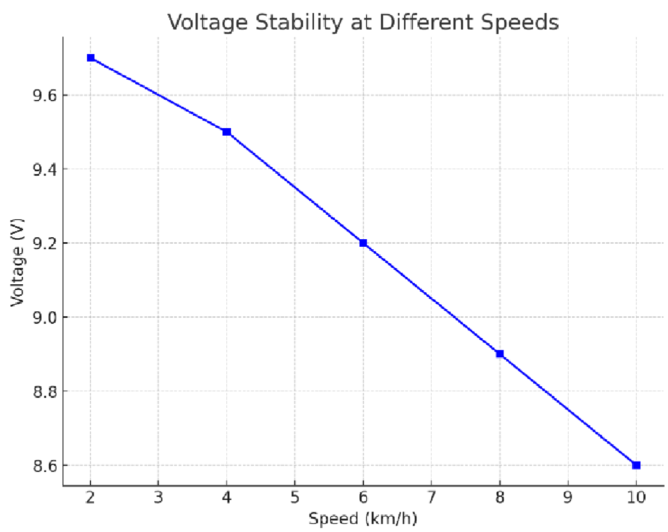

Figure 2: Voltage Stability at Different Speeds of the Vehicle.

V. DISCUSSION

Results have shown that in the case of the prototype system, a controlled range of parameters shows that it works fine at lowspeed and near-proximity applications. Transfer efficiency of power was higher than 80% for distances of up to 10 cm, which, therefore proved feasible for low-speed applications within the city traffic or short-range driving environment. However, this has one more optimization in the coil design and power management, so further scope can be there for expanding the effective range.

Output voltage was very stable in dynamic conditions at 10 km/h. With respect to the above, system stability and absence of significant fluctuations are good designs of the low-speed dynamic charging except that adaptive mechanisms to correct misalignment or improved coil coupling would be required at the higher speeds. Power losses due to misalignment effects can be reduced by using real-time feedback control systems, and it will bring performance improvements to high-speed applications. Some alternative shapes, materials, or configurations with coil that has greater tolerance for misalignment and consistent power transfer can be further researched. This will allow wide-scale deployment to realworld EV charging infrastructure..

VI. CONCLUSION

The base of this paper focuses on the development of an electric vehicle prototype, in motion, to be charged wirelessly, by the use of magnetic resonance coupling, for better improvement of energy transfer efficiency. This proposed system utilizes the transmitter-receiver coil pair through power from a solar panel regulated with an IRF 540 N transistor, which would thus validate the feasibility of dynamic wireless charging. Using Arduino UNO as a control and monitoring system, the actual real-time voltage can be monitored with a very stable energy transfer under various distances and speeds. The experimental results of the system were found to be well above 80% in efficiency at a distance of 10 cm while maintaining an acceptable voltage within a speed of 10 km/h. These results suggest that the infrastructural integration of wireless charging into roads could make the source supply to EVs continuous. This would further reduce any dependency on static charging stations. Currently, much work needs to be done to optimize coil orientation and power delivery for operation at high speeds and possibly over longer distances. Further studies, possibly including adaptive control structures and alternative coil designs, shall be required to render it more robust and scalable. It will actually form a foundation for further development onroad wireless charging systems that make a path toward sustainable, continuous electric vehicle transport.

VII. FUTURE SCOPE

This prototype for wireless charging opens many avenues for further research and practical applications within the realm of electric vehicle infrastructure. The first of these avenues for near-term advancement involves scaling this system for realworld, high-power applications to support full-sized EVs on public roads. Real-time adaptive control mechanisms through power modulation and alignment correction can improve the system efficiency at higher speeds over greater distances. Alternative coil material configurations and geometries might further improve the tolerance of the system to misalignment and thus reduce power loss due to dynamic charging. Other improvements will involve installing modules capable of wireless charging on city-district road surfaces as well as on highways and designated lanes to charge with continual power supply, eliminating conventional charging stations. Their involvement in smart grid structure can also be a point towards energy transmission in reverse in addition to the typical approach, so EVs remain mobile storage devices but on course to provide grid balance stability. Continuous innovation in dynamic wireless charging could reshape transportation networks to maintain the integration of sustainable EV and make electric mobility an even more accessible and efficient means to meet the world's transportation needs..

VIII. ACKNOWLEDGMENTS

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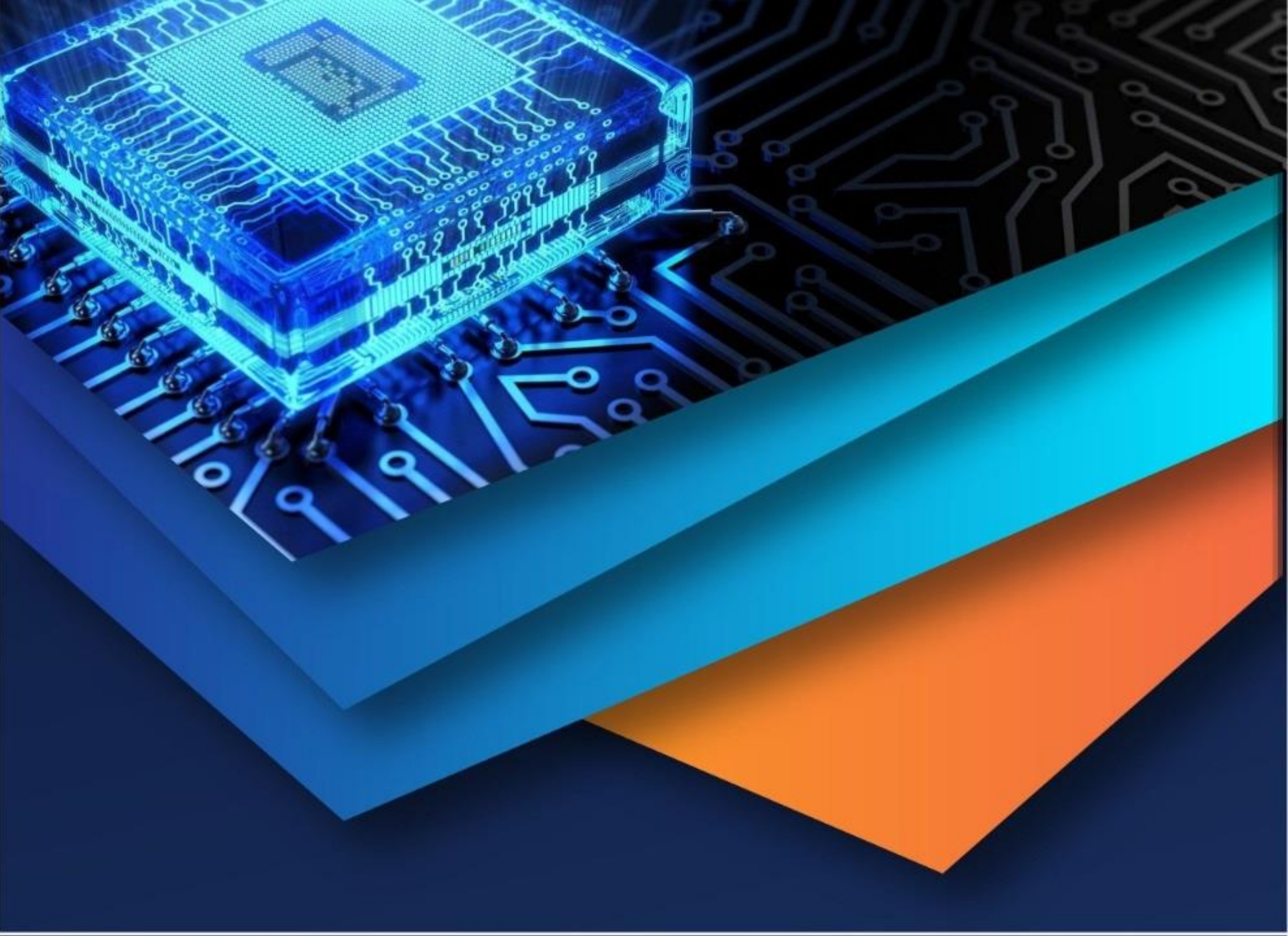

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