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Design Optimization of Compact Patch Antenna and Novel Microstrip Integrated Array

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Abstract: An E-shape patch antenna and integrated array antenna are designed for a frequency range around 2.45GHz ISM band. A well known Particle Swarm Optimization (PSO) algorithm is used for optimizing the antenna. The concept of PSO is briefly introduced in this paper and the design parameters are optimized. Such antennas are used for wireless applications. The arrays are intended to serve as sub arrays that are low cost and very compact. This work focuses on identifying the increasing popularity of swarm intelligence specifically among the electromagnetic community. It achieves 65% aperture efficiency and 7.5 dBi gain for a single patch antenna and 17.6dBi gain for array antenna. It can be achieved by numerical algorithms for electromagnetic solutions like Finite Element Method (FEM) and the Method of Moments (MOM) by using electromagnetic simulation software. For validation purpose CAD FEKO 6.1 suite is used. The bandwidth and gain achieved in the array antenna is 15% greater than the single patch antenna.

Index Terms: Antenna design, particle swarm optimization, Antenna Array, Circular Polarization, wireless communication

I. INTRODUCTION

The continuous technological development of WLAN technology (Wireless Local Area Network) leads to several constraints in terms of size, bandwidth, gain, polarization and many other antenna performance parameters. Since WLAN antennas are deployed in a wide range of topological situations, a major design constraint is the space occupied by the antenna. This constraint can be translated into the requirement of high aperture efficiency.

Single elements can also be used in WLAN, but in some outdoor medium range applications it must be required to obtain a higher directivity, and possibly even some degree of flexibility. A possible solution is to design the antenna as an array switching between several sub arrays. In order to meet the challenges and requirements presented by these sophisticated wireless systems, there is a need to develop a dedicated antenna design and these antennas are in urgent demand for this type of application. Utilization of optimization schemes to solve electromagnetic problems, specifically antenna designs, has been reported with very encouraging results. The basic idea of this approach is to specify the design requirements for the problem and let the optimizer generate an optimal solution which meets the goals and requirements.

A microstrip patch excited by microstrip transmission line feed so that the microstrip line is connected directly to the edge of the microstrip patch. The edge impedance should be matched with the impedance of the feed line for maximum power transfer. A method of impedance matching between the feed line and radiating patch is achieved by introducing a single or multi-section quarter-wavelength transformers. This feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure, so that they can be easily fabricated. The conducting strip is smaller in width than the patch size which leads to increasing in undesired radiation.

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Optimization is the mathematical process of adjusting a set of relevant input parameters to characterize a device. It is an experiment with the objective to find the minimum or maximum desired output quantities. The input typically consists of parameters such as the cost function, objective function or a fitness function and the output parameter is the cost or fitness function. The optimization schemes can be classified into local and global optimization techniques. Local optimization techniques include quasi-Newton methods, conjugate gradient methods, etc, while the global optimization techniques include simulated annealing, ant colony optimization (ACO), genetic algorithms (GAs), and particle swarm optimization (PSO).

In many situations single element can be used in WLAN. In order to obtain high directivity and even some degree of flexibility there is a need of switching to antenna arrays.

The two main issues such as bandwidth and space occupied can be readily solved by optimization. For good antenna operation a higher Bandwidth is desirable which is actually only a fraction i.e. only a few percent. As in present age of communication the data to be sent is increasing and hence there is an increasing demand for Bandwidth so increasing the bandwidth of antennas becomes important technically as well as commercially. Bandwidth is proportional to the height 'h' (Substrate thickness).
This introduces Surface Waves which diminish effective power available for radiation. Stacking and coupled patches can also be used for bandwidth but they increase the complexity. The better way is to choose E shaped or slotted patch.

II. SINGLE ELEMENT ANTENNA ARRAY

A. Antenna Design

The configuration of the E-Shape Microstrip patch antenna is shown in Fig. 1. A probe of 0.5mm diameter, which is an extension of the inner conductor of a coaxial feed line, feeds the patch. The gap between the patch and the ground plane may be filled either fully or partly with air material for mechanical stability. The parameters that characterize the antenna are the patch length and width (L_p,W_p), the height of the patch be H_p and the location of the coaxial probe is X_f from the center. There are 7 Optimization parameters that defines the problem space are listed in the table 1.

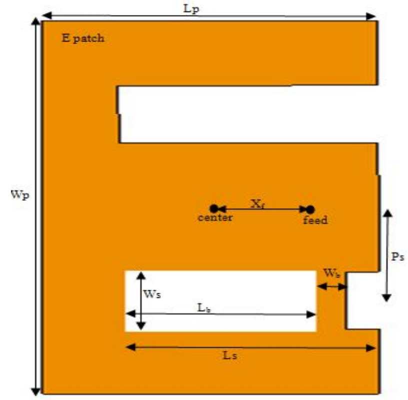

Fig 1: Configuration of a CP E-shaped patch antenna

CP microstrip antennas have been widely used in different wireless applications as they provide additional polarization flexibility by reducing mismatch losses. It has been shown that CP wave transmission significantly alleviates multipath fading from indoor environments, and it even reduces root-mean square (RMS) delay spread compared to linearly polarized (LP) antennas which are intended for line-of-sight (LOS) applications.
Recently, an E-shaped patch antenna was investigated for its Circular Polarization (CP) characteristics through the parametric studies. Parametric studies involving complex parameters make it further more difficult to quantitatively estimate the effect of each design parameter on the antenna performance. The antenna is validated with Feko Solver and observed for the performance. The parameters such as Reflection Coefficient, Axial Ratio, S-Parameter are obtained, which is shown in the figure.
The bar introduces asymmetric orthogonal currents with a quadrature phase thus generating circular polarization. A multilayer substrate is used for ease of manufacturing the prototype. Fig.1 shows the configuration of the antenna to be optimized. A bar of width, W_b is introduced and added to one of the slots of the E-shaped patch antenna and the location of the bar is also taken as one of the design parameters.

B. PSO Implementation for Patch Antenna

1) *Methodology*: In this section, the formulation and implementation of the PSO algorithm is described. The main steps are to be noted that the developer and designers can come to a design solution through the power of PSO. This will also include both the preliminary steps before coding as well as the steps that are needed for the optimizer to come to an optimized solution. These steps are defined and are listed below:
a) *Defining the Optimization Problem:* This seems to be obvious to the reader, to determine the best design solution that meets the given specifications. But minimizing the number of variables can be quite a challenge in many applications. The criteria should be met with a minimum number of variables. This step helps to choose a proper design which has enough flexibility in order to meet design criteria but has a low number of optimization parameters and to reduce the optimization dimensionality.

b) *Defining the Solution Space:* After the design and its variables have been specified, the next step is the identification of the boundaries for each optimization parameter. For that, a compromise has been made between an extensive range and a limited range for each variable. An extensive range have a poor convergence rate while a limited range reduces design flexibility. Therefore, a proper range must be chosen by the designer. Choose an upper range $x_{max,n}$ and a lower range $x_{min,n}$ where n =1 . . . N for all the N optimization parameters such that it balances these two opposing requirements.

c) *Defining a Fitness Function:* This step is one of the most important steps for any optimization process because a poor formulation of the fitness function will seriously impair the ability for the optimizer to recognize superior designs. The fitness function links the physical system and the optimizer, and it is defined in an integer value.

d) *Initialize Particle Locations and Velocities:* This step begins with the execution of the PSO algorithm. For this, each particle is randomly initialized throughout the solution space with a uniform distribution. The velocity is also initialized and randomly generated with a uniform distribution from ($-v_{max}$,v_{max}). If the particle has no previous history at this stage, each particle's position becomes the pBest for each particle.

These are the basic steps in performing PSO algorithm. It should also be noted that a particle has the ability to fly outside the solution space, and therefore a boundary condition is tested and it is typically associated with the fitness function evaluation. The particle swarm algorithm (PSO) lends to easy parallelization of the code in order to reduce computation time drastically. The parallel algorithm manifests in the use of one computer node for each particle fitness evaluation, which is typically the most computationally intensive component in PSO.

C. Simulation and Measurement

A CP E-shaped patch antenna using the PSO-MOM and PSO–FEM scheme to maximize the performance in terms of axial ratio (AR) and S_{11} bandwidth with the potential to implement active microelectromechanical system (MEMS) switches and make the antenna both frequency and polarization reconfigurable. Table 1 shows the list of the fixed parameters, optimization parameters, swarm size, number of iterations, and the different boundaries and constraints used in this CP E-shaped patch antenna implementation.

Table 1. Summary of the CP E-Shaped Patch Antenna Optimization (All Length Dimensions in Millimeters)

Fixed parameters	L_g =100mm W_g=120mm W_b=5mm t=1.57mm substrate = duroid
Optimisation parameters	L_p, W_p, L_s, W_s, P_s, X_f, L_b (7 dimensional problem)
Swarm size	16
Maximum iterations	200
Boundaries	L_p(30,96), W_p(30,96), L_s(0,96), W_s(7.5,48), P_s(0,48), X_f(-48,48), L_b(0,96)

The resonant frequencies obtained through simulation are 0.9GHz, 1.8GHz and 2.2GHz. Fig 3 shows the Circularly Polarized radiation pattern which will provide the radiation in all 360 degrees. The far field radiation patterns for different frequencies are taken and it is plotted accordingly. For theta=2.2GHz and phi=90 degrees gives the better radiation at nulls. It exhibits three different resonant frequencies both at 0.9GHz, 1.8GHz and 2.2GHz. It is measured in dB scale. At the frequency of 2.2GHz the desired AR value is close to -3dB. Typical AR value ranges from 1 to infinity. The value of Reflection Coefficient is close to -10dB. In order to weigh both the AR and reflection magnitude equally, a factor of 4 for Γ is used.

The bandwidth parameter is activated once both AR and reflection magnitude satisfy the criteria given in the fitness function. The weight of the bandwidth parameter is chosen such that the bandwidth is given a higher priority than the other parameters when the

AR and reflection magnitude satisfy the given specified criteria of design. The PSO–FEM design shows a good convergence to an optimized design under 300 iterations. Table 1 enlists the optimized dimensions of the CP E-shaped patch antenna using PSO–FEM program. Fig. 3 shows the axial ratio data for the optimized CP prototyped E-shaped patch antenna design. A -10dB S_{11} bandwidth of 210 MHz is obtained through measurements.

Only some slight differences in the results can be attributed to alignment issues for the multilayer design. Fig.4 shows the simulated pattern for the E-plane of the antenna at 0.9GHz, 1.8GHz and 2.2GHz. The radiation patterns show excellent agreement for the co polarized and cross polarized fields. Higher cross polarization can be observed due to the asymmetric nature of the antenna. Fig. 5 shows the S-parameter response at bore sight. Typically, for circular polarization, acceptable AR values are less than -3 dB.

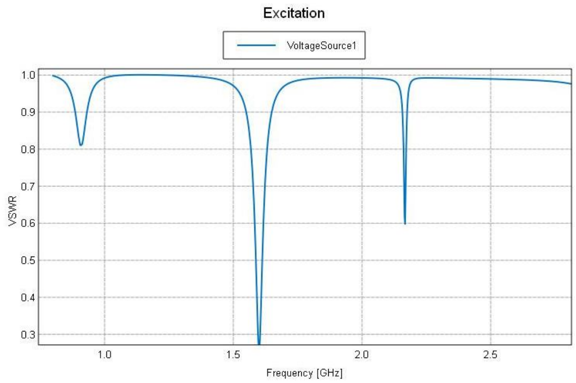

Fig 2. VSWR measurement graph

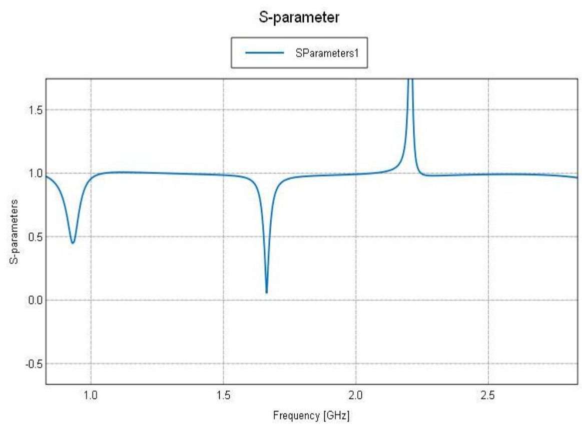

Fig 3. scattering parameter

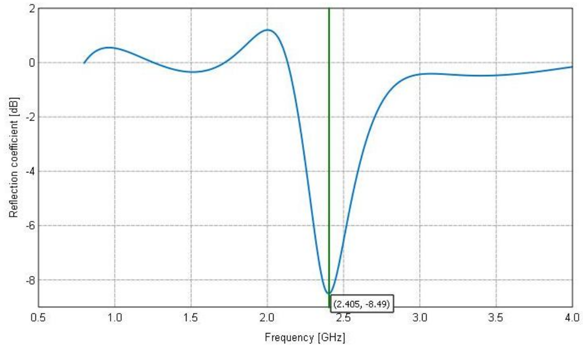

Fig 4. Reflection coefficient

Fig 3 shows the simulated S-parameter value in dB. Slight discrepancies in simulation and measurement of AR can be attributed to diffraction from the antenna chamber positioning.

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III. INTEGRATED ANTENNA ARRAY

A. Antenna Design

A compact integrated E-shaped patch array is designed and its performance is estimated. It achieves 65% aperture efficiency. The idea is to make E shaped patch element as a splitter in a series fed topology. It can also be used as a radiator and a kind of T-junction like splitter, ending up with a two-dimensional array, and also to try to achieve the design requirements with an aperture efficiency as high as possible. All elements are E-shaped patches to achieve the wide bandwidth. It achieves 17.6 dBi gain. Its bandwidth for a 10 dB return loss is 15%. It will be shown that even our initial structure achieves a much wider bandwidth. The initial requirement for the bandwidth was set at 15%. Element A is a feed-split element. It contains the primary feed, takes care of some of the radiation, and further distributes the rest of the power to the other elements. Elements B and C are identical and they are only radiating. These three patches are connected in series by 4 mm wide microstrip lines. The entire structure is symmetrical with respect to the horizontal axis. The elements B and C are mirrored with respect to A in order to minimize the length of the transmission lines connecting them with element A, while keeping the correct phase. The main excitation is a 50 Ohm coaxial feed connected to patch A. A single-layered structure with FR4 is by far not able to deliver a 15% bandwidth. The minimal height of the first array in order to achieve a 15% bandwidth was determined by the PSO-MoM optimization framework to be 8 mm. The medium between substrate and ground plane is air. The four rectangular patches are connected to the center feeding element by a bending microstrip line. This can lead to impedance mismatching and unwanted radiation at the bending. In the proposed array, this bending is completely avoided. Only straight microstrip lines are used. In order to maximize the available area for element B and C, these straight microstrip lines are located at the edges of the feeding/split element A. The array was thus prototyped on a 192 mm × 224 mm ground plane

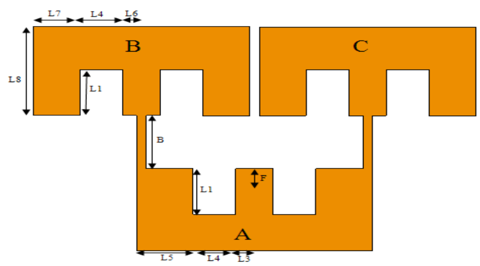

Fig 5: Configuration of a CP E-shaped integrated array antenna

B. Simulation and Measurement

The fabricated prototype is shown in Fig.2. The S11 parameter is plotted in Fig. The relative bandwidths calculated with Feko Solver is15.0% respectively. The measured gain 10dBi difference with the single patch antenna. The radiation patterns in E-plane and H-plane at 2.45 GHz, calculated.

The graphs are normalized with respect to the maximum value of the co-polar component. The cross-polar component is more than -20 dB lower than the co-polar component in the main beam direction for both E-plane and H-plane. The main beam in the E-plane has a shift to the right of about 5 degrees. The broadside gain and directivity at 2.45 GHz simulated in Feko solver are 11.9 dBi and 12 dBi, respectively. The radiation efficiency is 98%. The maximal aperture efficiencies achieved by measurements are 55% and 51%, respectively. Table 2 shows the parameter optimization range and optimal parameter value.

Parameter name	Parameter Optimization Range(mm)	Optimal Parameter Value(mm)
F	(5,25)	5
B	(20,32)	32
L1	(4,30)	28
L2	(30,60)	50
L3	(6,12)	8
L4	(8,20)	18
L5	(10,24)	24
L6	(6,12)	16
L7	(10,44)	24
L8	(20,70)	54

Table 2. Summary of the integrated array Antenna Optimization (All Length Dimensions in Millimeters)

The maximal aperture efficiency of the three element array proposed in the previous section is 55%, which is in the typical range for a wideband microstrip array. The aperture efficiency of this type of array can be improved in several ways. In cases that a lower bandwidth is tolerable, a first technique is to decrease the thickness of the air layer. The main purpose is to reduce the necessary size of the ground plane, since the ground plane dimensions have to be chosen taking into account this thickness, as mentioned before. Decreasing the specified bandwidth to 10%, it was found that the air layer thickness can be reduced to a value of 5.5 mm.

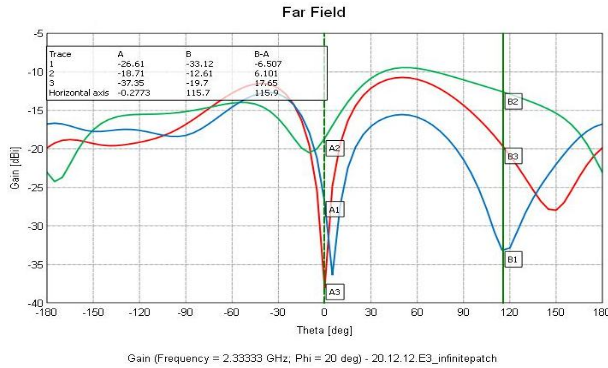

Fig 6. The simulated results for Gain

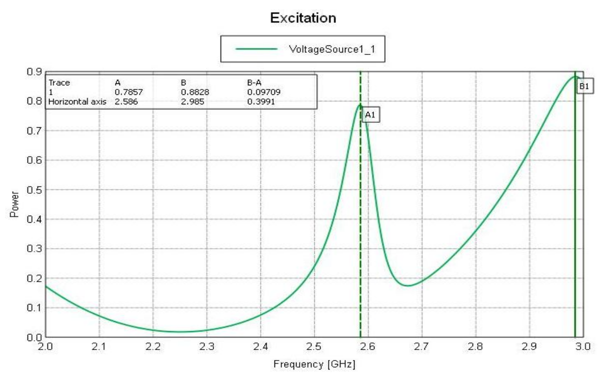

Fig 7. The simulated results for power

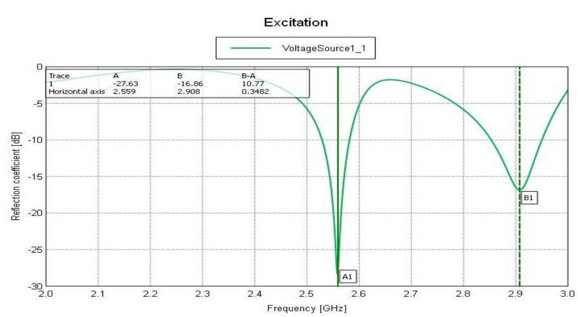

Fig 8. The simulated results for Reflection Coefficient

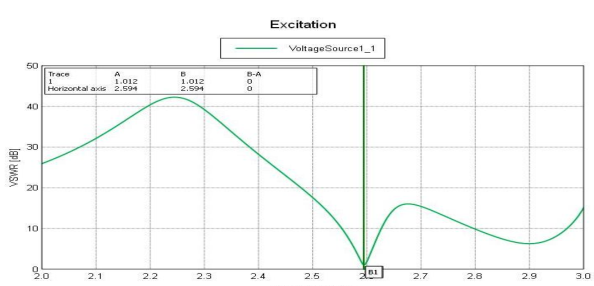

Fig 9. The simulated results for VSWR

The simulated results of the integrated array antenna shows that the gain achieved is 17.6dBi, which is around 40% greater than single E shape patch antenna. The bandwidth obtained is 15% more than single patch antenna. Thus, the integrated array antenna design achieves more gain and bandwidth and gives less radiated power in the order of 0.9mv as required for wireless application.

IV. CONCLUSION AND FUTURE WORK

Wireless telecommunications is a rapidly evolving industry, and the abrupt changes to the antenna system are often necessary to accommodate the system needs and PSO in particular has a widespread recognition for these strengths. Some background on general optimization technique was developed, and the basics for PSO and its implementation were discussed.

Using PSO, E patch antenna used in wireless communications were developed and optimized. Further the multiband handset antenna, the hybrid PSO–MoM program was able to achieve through an antenna array design that efficiently utilized a small space and gives excellent dual-band performance. Overall, optimization plays a paramount role in the present and future designs of antennas to meet the ever demanding needs of wireless communication systems. Further several optimization techniques can also be used for the design. And an analysis based on the concept of array antenna need to be simulated. The simulations show that when the transversal distance between the top microstrip layer and the edge of the finite ground plane is about 3 times the array thickness, a good tradeoff between gain and bandwidth is obtained.

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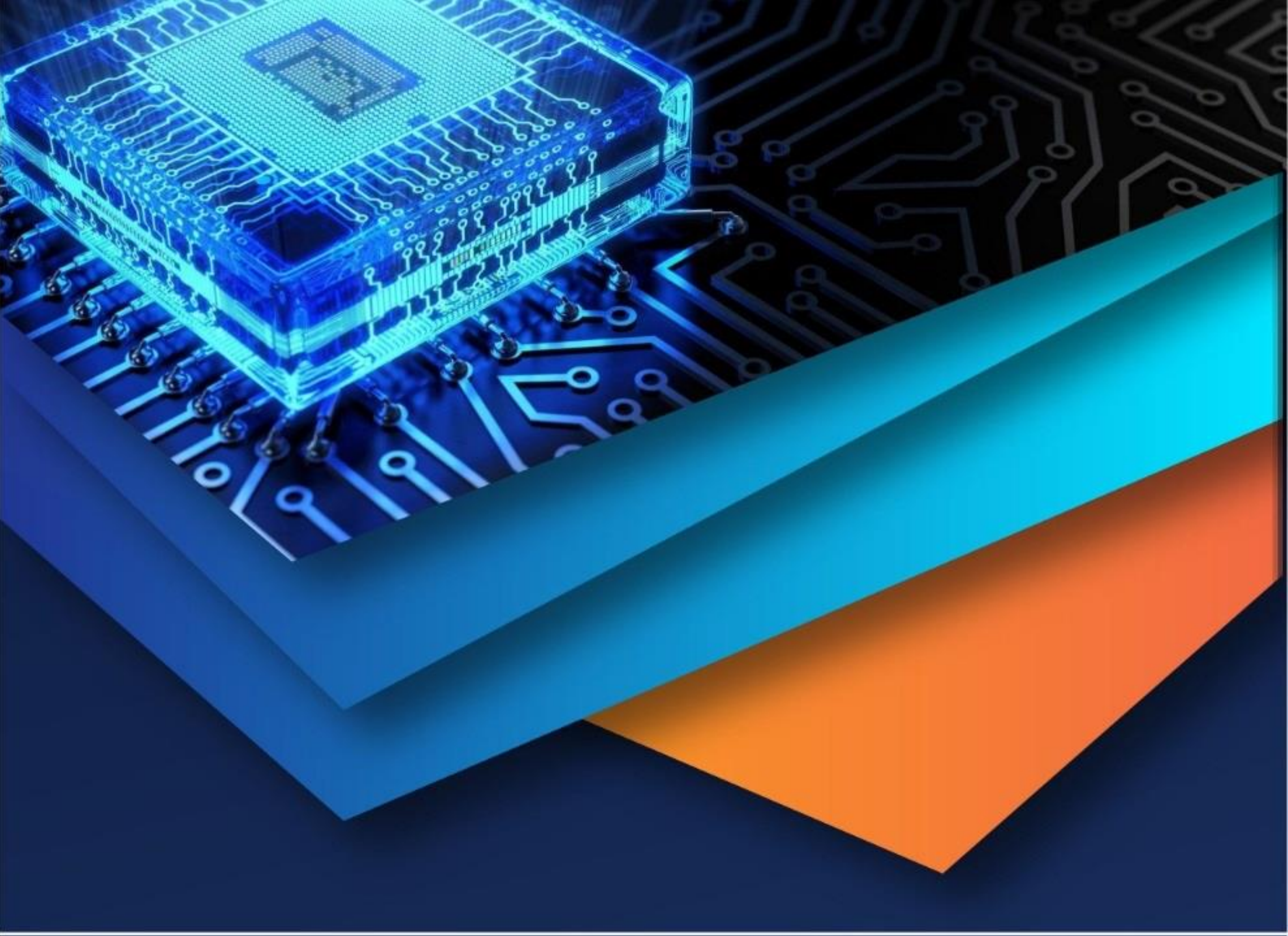

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