iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** IX **Month of publication:** September 2020

DOI: https://doi.org/10.22214/ijraset.2020.31590

Design of On-Chip Spiral Inductors for 2.4 GHZ Low Noise Amplifier

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Abstract: Passive components are indispensable within the design and development of microchips for top frequency applications. Particularly Inductors are used in radio frequency ICs such as Low Noise amplifiers and oscillators. Since the inductors quality factor (Q) value directly play a role in affecting phase noise, the optimization of inductor layout can improve its performance but it is limited by selecting the technology. The project proposed here is to design an On Chip spiral Inductors operated for 2.4 GHZ CMOS Low Noise amplifier with .18µm technology. The designed on chip inductor with predefined structural parameters such as outer dimension, number of turns and pitch which determines the actual inductive performance is simulated with HFSS Software as simulated output.
Keywords: On chip inductors, Inductors for RF frequencies, HFSS design for passive components.

I. INTRODUCTION

A. Inductor for RF

RF inductors are specially designed inductors to be used in radio frequency (RF) and microwave applications. Inductors are basic passive components which serve to oppose changes in current flow. When current is applied from a battery or power source, the inductor temporarily stores it using a magnetic field. When the current flow changes, the magnetic field induces a voltage which opposes the current change. RF inductors are the inductors designed to handle radio frequency signals, which are much higher in frequency than alternating or direct current. Along with capacitors and resistors inductors make up a large majority of the components found in resonant (tunable) circuits essential to radio communication devices.

B. Behavior of Inductor at 2.4 GHZ Frequency

1) Skin effect loss occurs because high-frequency current does not penetrate into the body of a coil's wire, but instead travels along the surface. Because only a small portion of the wire conducts the current, its resistance which may already be elevated due to high frequencies increases.
2) Proximity effect occurs in parallel wire turns within a coil. Eddy currents like those described above pull current to the extreme edge of the wire in relation to the nearest coil turn, causing losses similar to those found in skin effect.
3) Parasitic capacitance resulting from potential differences within the magnetic field, can occur between coil turns. While this does not specifically cause losses, at high frequencies parasitic capacitance can cause the inductor to become undesirably self-resonant.
4) Solutions to Air Core Losses To reduce these conditions, RF inductors are typically designed with coils spaced further apart than low-frequency inductors. They may also feature tubular wire or metal strip to increase surface area.

C. Parameters Of Inductors

Self-resonant frequency (SRF) is the frequency at which an inductor's distributed capacitance resonates with its inductance. At SRF, inductance reaches its minimum value while impedance spikes and then decreases with increasing frequency, causing the inductor to function as a purely resistive component with a *Q* value of zero. At frequencies below SRF, the device operates as an inductor, while above this frequency it behaves more like a capacitor. The equation given here for SRF, where 'L' is the self-inductance and 'C' is the proximity capacitance.

$$SRF = 1/2\pi\sqrt{LC}$$

The inductor works along with its self-inductance and the proximity capacitance of the winding coil turns causes the self-resonance phenomenon. The ideal inductor along with the equal inductance and its phenomenon of self-resonance is further explained by the figure 1.1 follows.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue IX Sep 2020- Available at www.ijraset.com

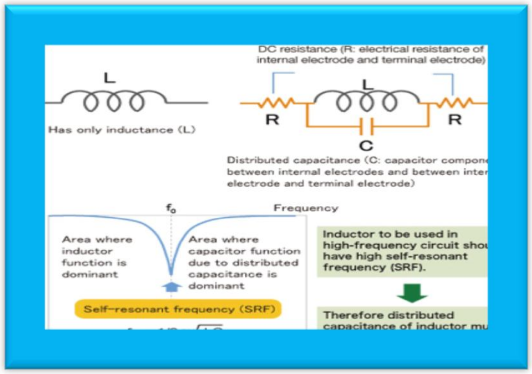

Figure 1.1 self-resonance in inductors

In the context of this discussion, then, inductors intended for high-frequency applications must have relatively high self-resonant frequencies to function as designed.
Quality factor or the Q factor of an inductor is actually the measure of sharpness of LCR circuit. It is the ratio between the resonating frequency and the band width. It is a unit less dimensionless quantity. Larger the value of Q factor the larger will be the sharpness of resonance. You will get a perfect hearing experience if the radio has a LCR circuit with larger value of Q factor, at the operating frequency ω is defined as the ratio of reactance of the coil to its resistance. Thus for an inductor, quality factor is expressed as, Where, L is the effective inductance of the coil in Henrys and R is the effective resistance of the coil in Ohms given the equation follows.

$$Q = (\omega_0 \frac{L}{r}) * \text{Substrate loss factor} * \text{SRF}$$

Also the number of turns and the inner diameter of the core of the inductor defines the figure of quality factor plays a special role in the design of spiral inductor that is given by the figure follows.

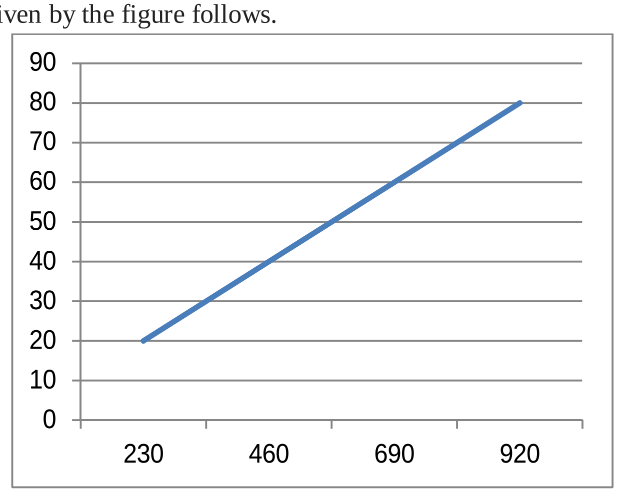

Figure 1.2 Core diameter Vs quality factor

Permittivity and the permeability is that the permittivity measures the obstruction generates by the material in the formation of an electric field Whereas, the permeability measures the ability of the material to allow the magnetic lines of force to pass through it, which is basically the inductance per unit length.
Permittivity of the medium is the product of the dielectric constant and the relative permittivity of the material that which is taken to account

$$|\mathbf{E}| = \frac{q}{4\pi\varepsilon_r\varepsilon_0 R^2} = \frac{q}{4\pi\varepsilon R^2}$$

It is further explained with a table given below.

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Table1.1 Comparison of Permittivity And Permeability

Symbol	ε	μ
Formula	Ratio of displacement field strength to the electric field strength.	Ratio of magnetic field density and magnetic field strength.
SI Unit	Faraday/meter	Henry/meter
Physical Basis	Polarization	Magnetization
Free Space	The permittivity of the free space is 8.85 F/m.	The permeability of the free space is 1.26 H/m.

D. On Chip Inductor

In the case of spiral inductors, where the models can be restricted to specific geometry classes, closed-form analytical models are very well suited for fast and typical designs for the very early stage of the developing process. The distributed vector and scalar fields must be followed in structures which may consist of various inhomogeneous complex shaped three-dimensional regions, like splitting widening, and vertical connections.

E. The CMOS .18μm Technology

The continuous advancement in VLSI technology has replaced discrete components based implementation of wireless receiver using RFICs. The Complementary Metal Oxide Semiconductor (CMOS) technology is undertaken to implement any wireless communication applications system. Also the CMOS technology has low fabrication cost and assures a high level of integration, so it is more attractive solution of 2.4GHz operated inductors.

II. INDUCTOR DESIGN FOR RF IC APPLICATIONS

A. Basic Inductor

In RF applications the net performance of inductor can be varied by adjusting the geometrical parameters, such as area of the coil (A), number of turns (N), length of the coil (*l*), and by varying the material surrounded the inductor to increase the permeability (μ) given by the equation follows.

$$L = N^2 \mu A / l$$

B. Inductors For RF Frequencies

In RFICs, inductors are essential for applications like matching, oscillators, DC-DC converters, filters and so on. To obtain required range of inductance from 1 to 100 *NH*, an approximate two dimensional projection of spirals like a planar rectangular, polygonal or circular spiral is utilized as Shown below.

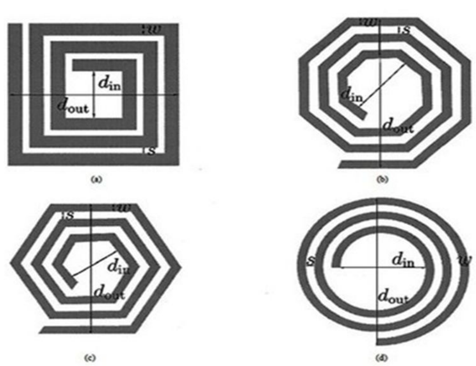

Figure 2.1 Spiral Inductors: a) Square Inductor b) Octagonal Inductor c) Hexagonal Inductor d) Circular Inductor

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C. Proposed System

In this application an optimized model for inductance and resistance analysis of an on-chip inductor at different frequencies is proposed. The model describes the proximity effect and the skin effect typically arising at higher frequencies as well. The three-dimensional finite element simulation is extended with **HFSS** (**High Frequency Structure Simulator)** to implement the developed model. Simulation results demonstrate the physical plausibility of the applied model and numerical methods, as well as the necessity of three-dimensional simulations.

D. Introduction to HFSS

HFSS is a commercial finite element method solver for Electro Magnetic structures like antennas, arrays, RF and microwave components and high speed interconnects. The acronym stands for HIGH FREQUENCY STRUCTURE SIMULATOR. The geometrical dimension of the spiral inductor is predefined with the no of turns, spacing between the spirals, width, and inner and outer diameter is assigned during the design platform to achieve the required output inductor performance.

Table 2.1 Input And Output Parameters

Input dimensions	Output parameters
Number of turns (N)= 3.5	Self -resonant frequency (SRF)≤ 2.4 Ghz
Spacing (S) =1.5 µm	Inductance value against operating frequency (I) =1nH
Width (W) = 15 µm	Quality factor (Q) < 5

E. LNA LAY Out

In any simple LNA circuit, almost 70% of the circuit space is occupied by inductors. The aim of this proposal is to reduce the area occupied by on-chip inductors can be operated at 2.4Ghz freqeuncies in order to produce high Quality factor and to sustain its own inductive parameters to a wider band width.

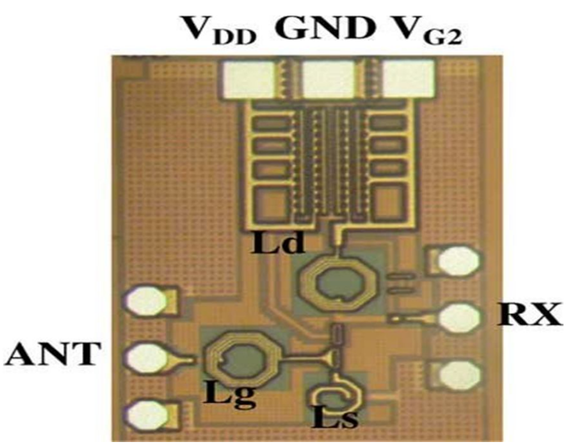

Fig 2.1 LNA Layout

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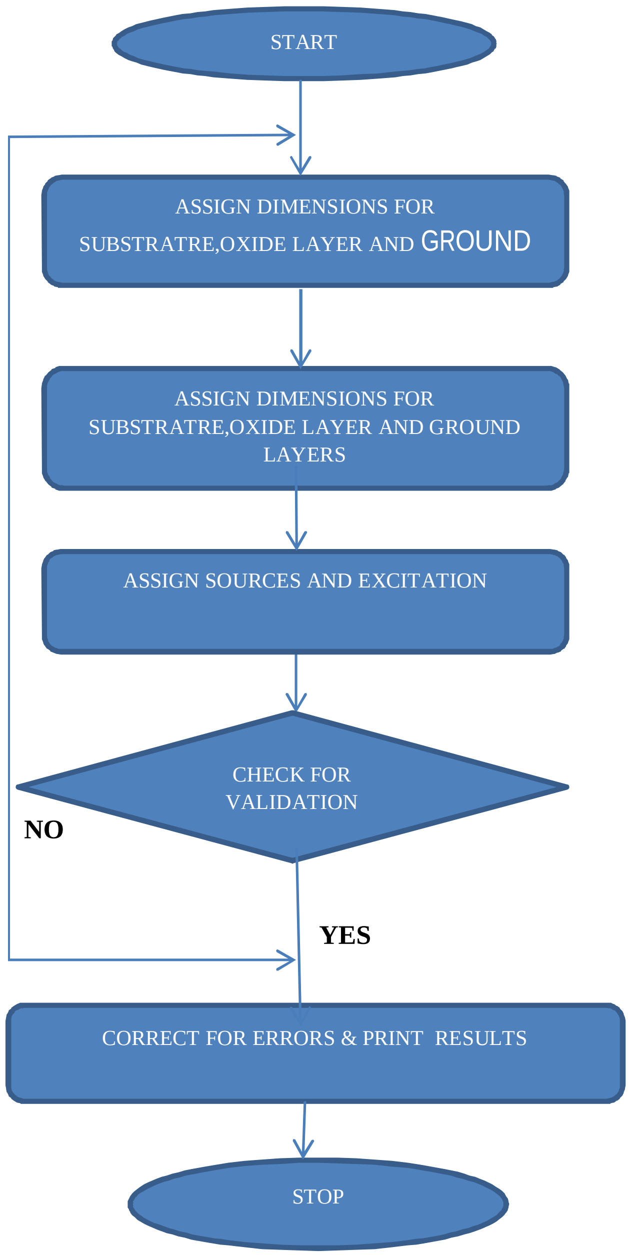
F. HFSS - Layout Block Diagram



III. LNA TOPOLOGIES

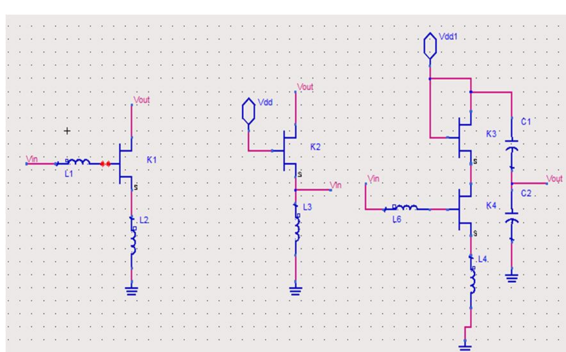


Fig. shows Common-source (CS), Common-gate (CG) and Cascaded topology which are commonly used in LNA design. The use of (CS) topology in LNA circuit will increase the gain and can produce good noise performance. When an inductor is placed on the source of a (CS) stage, then the inductive source will be degenerated. The Cascaded LNA with inductive source degeneration shown in figure3.1(c) has been used extensively and arguably the best topology because it is easier to achieve input matching for higher gain and noise figure compared to using other methods topology. The inhibition of the parasitic capacitances of the input transistor also improves the high-frequency performance of the amplifier.

IV. HFSS LAY OUT FOR ON - CHIP SPIRAL INDUCTOR

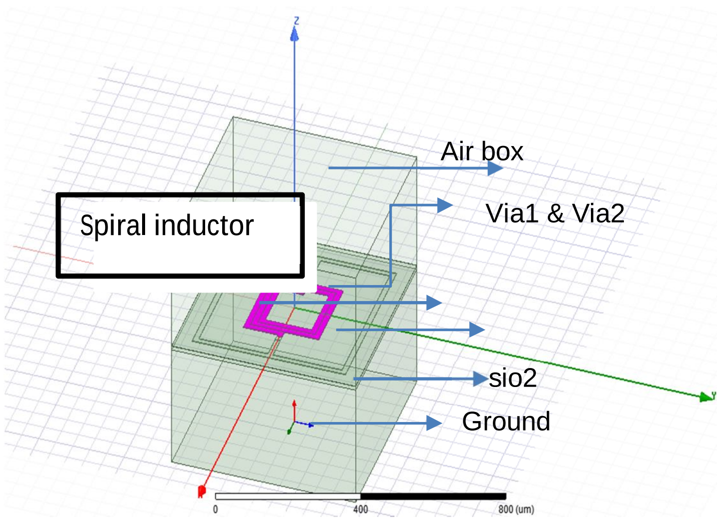


Figure 4.1 ON CHIP SPIRAL INDUCTOR designed in HFSS

V. SIMULATION AND RESULTS

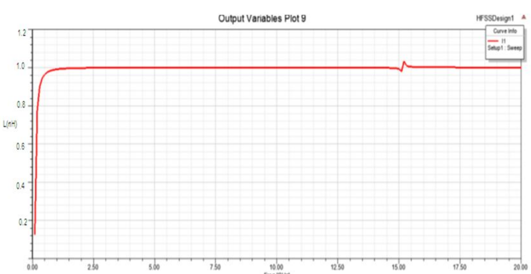


Fig 5.1 frequency Vs inductance value

By simulated result it is found that the inductance value is maintained to be almost a constant throughout the input sweep frequency which is selected(1 to 2.5Ghz) for HFSS simulator.

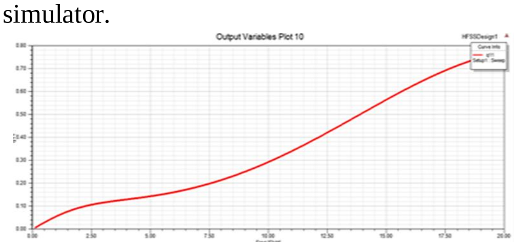


Fig 5.2 Frequency Vs quality factor

Also the quality factor of the on on-chip spiral inductor designed here attains its maximum value where the input sweep frequency is set up to 2.5 GHz.

VI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

The output generated by the HFSS software resulting the graphical solutions for the proposal which is found to be satisfactory. Since the quality factor and the stability of the inductance value is found to be sustained to the required band width with the assurance of making the LNA performances makes better. Also the advantages of the inductor area approximation is also achieved in turn reduces the cost, increases speed of operation of the receiver for the spiral inductors could be contributed.

B. Future Scope

The designed and HFSS simulated on chip spiral inductor of 1nH is planned to be fabricated using FR4 substrate and the same will be analyzed through a vector network analyzer and the results may be verified for the inductance performances for the specified band width.

C. Applications

When the spiral inductors designed here when tied with LNA receiver which is vital part any wireless system will definitely produce a better sensitivity, selectivity and stability in the various communication systems like cellular communication systems, GPS receivers, wireless LANs, both in the narrow band as well us broad band systems Also the on chip spiral inductors finds a vast applications in the area of wireless communication such as RF filters, impedance matching circuits and RF oscillators.

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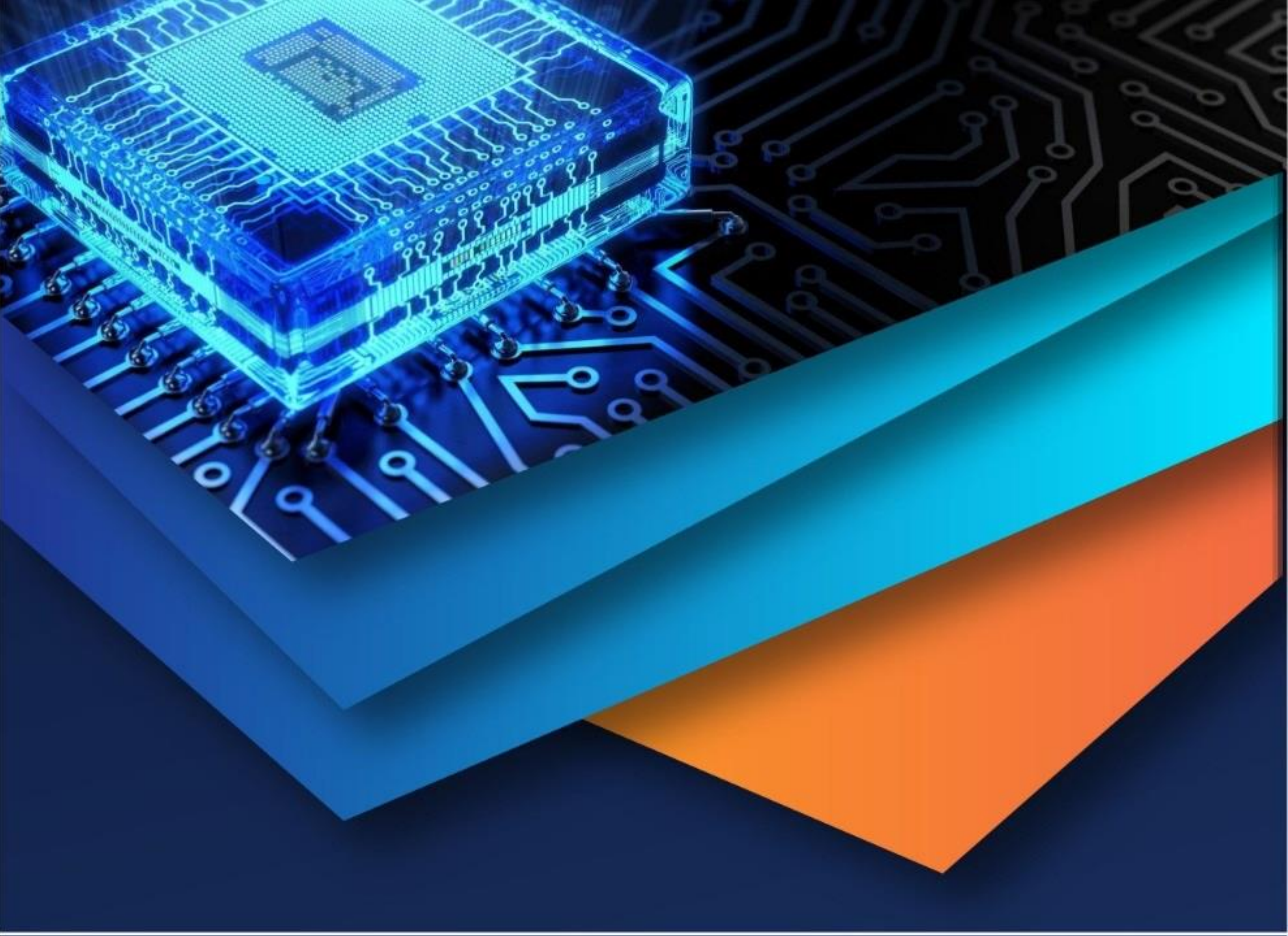

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