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Modeling and Analysis of Open-End Microstrip line Discontinuity on Multilayer Semiconductor Substrate for Microwave Integrated Circuits

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Abstract: In this paper, the modelling and analysis of open-end microstrip line discontinuity on multilayer semiconductor substrate is presented. The equivalent lumped circuit model is used to compute the frequency dependent reflection coefficient from the open-end microstrip line discontinuity. The lumped circuit elements, capacitance, inductance and resistance, are computed using closed-form expressions in term of the width of microstrip line discontinuity and thickness of the dielectric substrate. To compute the characteristic impedance of microstrip line on multilayer dielectric substrate, static Spectral Domain Analysis (SDA) method and Single Layer Reduction (SLR) techniques are used.
Keywords: Static Spectral Domain Analysis method, Single Layer Reduction technique, Multilayer Microstrip line, Open-End Discontinuity.

I. INTRODUCTION

Microstrip line are extensively used in the design of microwave components such as couplers, filters, interconnects and matching components in hybrid and monolithic integrated circuits. Different types of discontinuities such as open-end, gap and step discontinuity are essential part in the design of planar microwave components. In the complex circuits, the microstrip line and discontinuities are integral part in designing process. Various types of transmission line discontinuities, open-end, short-end, step and bend have been analyzed using equivalent circuits model at low frequency. Full wave methods have been used for frequency dependent analysis. Full wave methods are difficult to implement and time consuming. For fast microwave circuit design the equivalent circuit model of discontinuities are widely used [1-7]. Most of the circuit model are frequency independent. The frequency dependent parameters of microwave components can be further improved by incorporating the frequency in the lumped circuit model. The circuit model for open-end discontinuity has been modified and results are compared with full-wave spectral domain analysis [5].

In the hybrid and semiconductor based integrated circuits, the microwave circuits are designed on multilayer substrates. Therefore, it is essential to analyze and characterize the microstrip line discontinuities on multilayer substrate. This paper presents analysis of open-end microstrip line discontinuity on multilayer dielectric substrate. For this, the static spectral domain analysis method along with single layer reduction technique are used to obtain the characteristic parameter i.e., characteristic impedance and effective relative permittivity of the microstrip line. The equivalent circuit model has been used to compute the frequency dependent magnitude and phase of the reflection coefficient of open-end microstrip line discontinuity. The static spectral domain analysis method for multilayer microstrip line is discussed in section-II. The circuit model for open-end discontinuity and computed numerical results are discussed in section-III and Section-IV respectively.

II. ANALYSIS OF MULTILAYER MICROSTRIP LINE

For the computation of characteristic impedance of multilayer microstrip line several full wave methods, spectral domain Approach (SDA) and Mode Matching Method are discussed [8]. At low frequency, quasi static methods, conformal mapping, variational method are used for computation of characteristic impedance and effective relative permittivity. In this paper, Galerkin’s techniques based static spectral domain analysis method is used for calculating the capacitance of multilayer microstrip line. The characteristic impedance of multilayer microstrip line is computed from the line capacitance. The Green’s function in Fourier domain for multilayer microstrip line structure is obtained using transverse transmission line (TTL) technique [8-11].

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The cross section of a shielded multilayer microstrip line is shown in Fig.1. The structural parameters of microstrip line are width of strip (W), dielectric substrate of thickness H_1, H_2 and H_3. The permittivity of dielectric substrate is ε_1, ε_2, and ε_3. The formulation to compute line capacitance is discussed in [8-11]. The per unit length capacitance is computed from following relation.

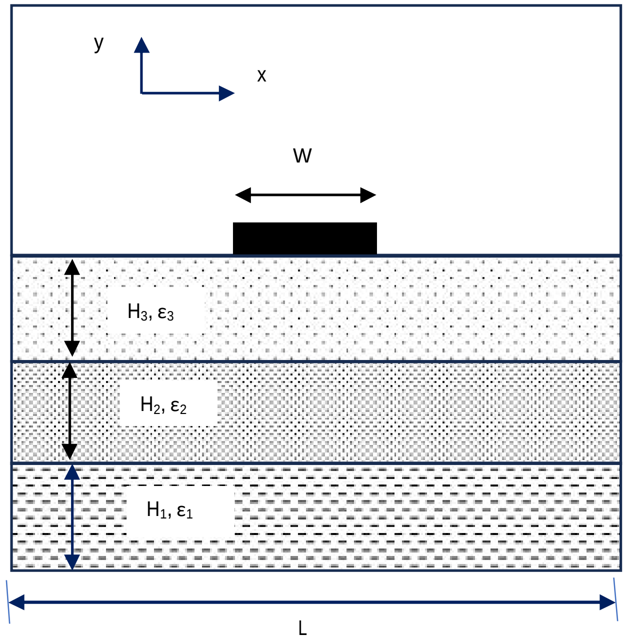

Fig.1 Multilayer Microstrip Line

$$\frac{1}{C} = \frac{L}{2\varepsilon_o Q^2}\sum_{n=1}^{\infty} \tilde{\rho}_s^2 (\beta_n, y)\tilde{G}(\beta_n, y) \qquad (1)$$

where $\tilde{G}(\beta_n, y)$ is Fourier transform of Green's function, $\tilde{\rho_s}$ is Fourier transform of charge distribution present on the conductor strip, Q is total charge present on strip. The characteristic impedance is computed from following relation.

$$Z_o = \frac{1}{c\sqrt{C_d C_{air}}} \qquad (2)$$

III. OPEN-END MICROSTRIP LINE DISCONTINUITY

The equivalent circuit model for open-end microstrip line discontinuity is shown in Fig.2. This circuit model consists of parallel combination of a Capacitor (C_1) and a series LC_2R resonating circuit. The closed form expression for capacitance, inductance and resistance are calculated in terms of physical parameters of microstrip line, i.e., width of strip conductor and thickness of dielectric substrate [5]. The characteristic impedance of multilayer microstrip line is computed from the static spectral domain analysis method [8-10] discussed in section-II.

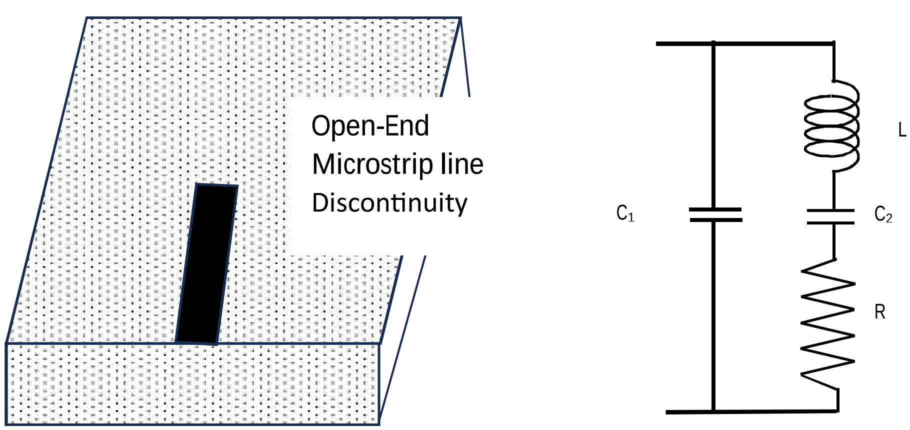

Fig.2 Oen-End Microstrip line Discontinuity and Equivalent Circuit Model

$$C_1 = \left(\frac{1}{Z_o}\right)\left[1.125 tanh\left(\frac{1.358W}{h}\right) - 0.315\right] \text{ pF} \quad (3a)$$

$$C_2 = \left(\frac{1}{Z_o}\right)\left[6.832 tanh\left(\frac{0.0109W}{h}\right) + 0.91\right] \text{ pF} \quad (3b)$$

$$L = (Z_o)\left[0.008285 tanh\left(\frac{0.5665W}{h}\right) + 0.0103\right] \text{ nH} \quad (3c)$$

$$R = (Z_o)\left[1.024 tanh\left(\frac{2.025W}{h}\right)\right] \; ohm \quad (3d)$$

The reflection coefficient of open-end discontinuity is computed from following relation-

$$\Gamma = \frac{Y_o - Y_{in}}{Y_o + Y_{in}} \quad (4)$$

Where Y_{in} is input admittance of the equivalent circuit and Y_o is characteristic admittance of the microstrip line. The input admittance of the circuit is computed by following expression [5]-

$$Y_{in} = j\omega C_1 + \left[\frac{1}{R + i\omega L + \frac{1}{j\omega C_2}}\right] \quad (5)$$

IV. NUMERICAL RESULT AND DISCUSSION

The characteristic impedance for microstrip line for different strip width W=0.15mm to W=0.4mm are computed using spectral domain analysis method. The results for characteristic impedance are given in Table-I. Open-end microstrip line discontinuity is taken on two-layer dielectric substrates. We have taken first layer of silicon (Si) dielectric substrate ε_{r1} = 11.9 with thickness H_1 = 0.4mm. On silicon substrate, a thin silicon dioxide dielectric substrate layer ε_{r2} = 3.9 and thickness H_2 = 3μm has been taken. The normalized capacitance, inductance and resistance are computed for different strip width ranging from 0.15mm to 0.4mm and dielectric substrate thickness H_1 = 400μm and H_2 = 3μm. Fig. 3(a) shows the variation of normalized capacitance (C_1/ε_o) and (C_2/ε_o) with width of microstrip line.

Table-I

↓ Z \ W →	W=0.15mm	W=0.2mm	W=0.25mm	W=0.3mm	W=0.35mm	W=0.4mm
Zo (ohm)	69.57	62.46	57.03	52.68	49.05	45.97

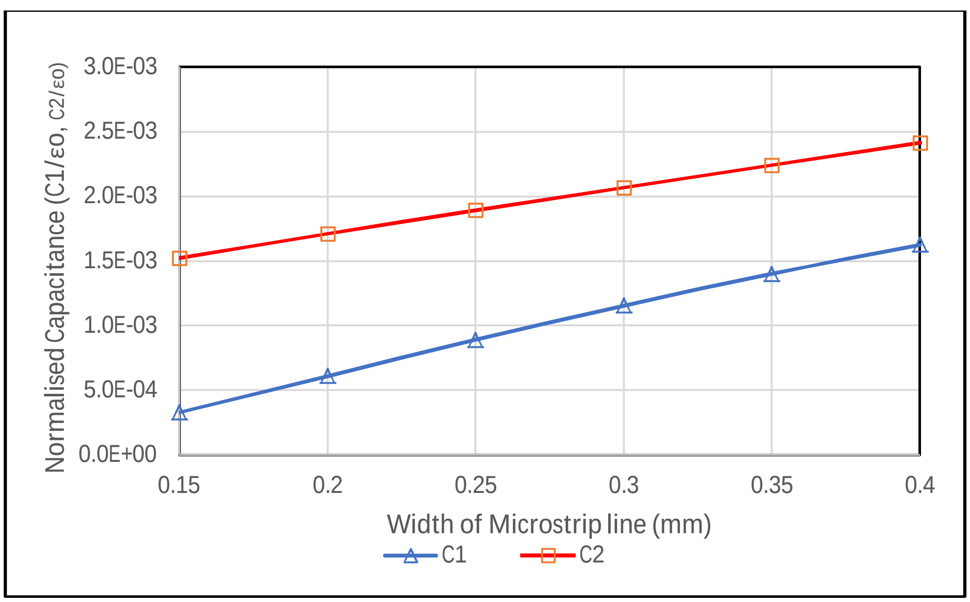

Fig. 3(a) Normalized Capacitance C_1 and C_2

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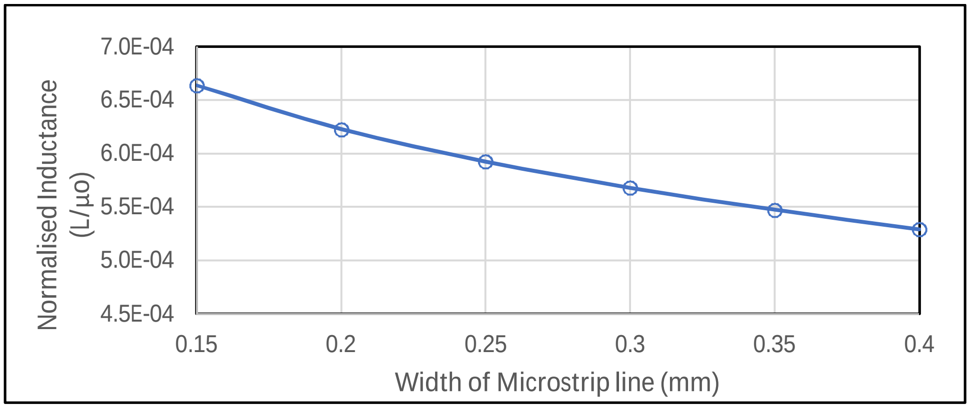

Fig. 3(b) Normalized Inductance

The shunt capacitance increases as the width of microstrip line increases. The minimum and maximum value of normalized C_1 is 3.28×10^{-4} and 1.63×10^{-3} for W=0.15mm and W=0.4mm respectively. Similarly, this value for normalized C_2 is 1.52×10^{-3} and 2.41×10^{-3}. The normalized inductance and resistance of equivalent circuit are plotted in Fig. 3(b) and Fig. 3(c) respectively. The inductance decrease as the width of strip increases but resistance increase as width of strip increases. This shows the that wider strip has more loss.

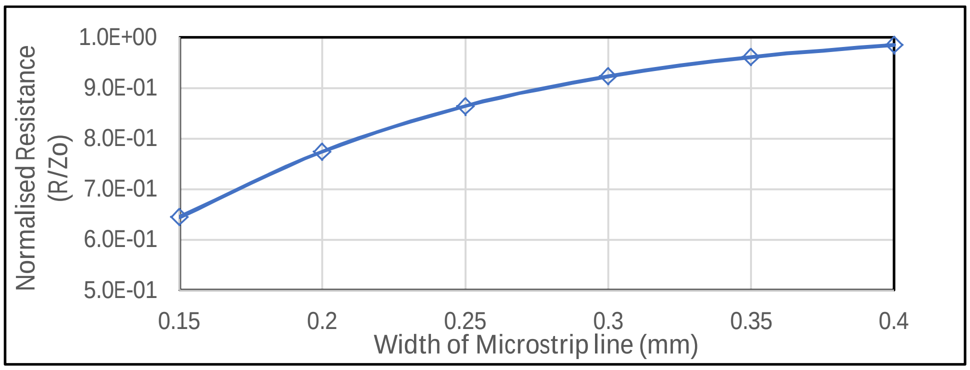

Fig. 3(c) Normalized Resistance

Fig. 4(a) and Fig. 4(b) shows the variation of normalized conductance and normalized susceptance with frequency. As the operating frequency increases, more field is radiated from the edges of the open-end discontinuity. The frequency dependent circuit model also demonstrates this. As the frequency increases the power loss, radiation loss and surface wave loss increases. Furthermore, the magnitude and the phase angle of reflection coefficient are plotted in Fig. 5(a) and Fig. 5(b) respectively with four microstrip line width, W=0.2mm, 0.25mm, 0.3mm and 0.350m. As the frequency increases, the reflection coefficient decreases.

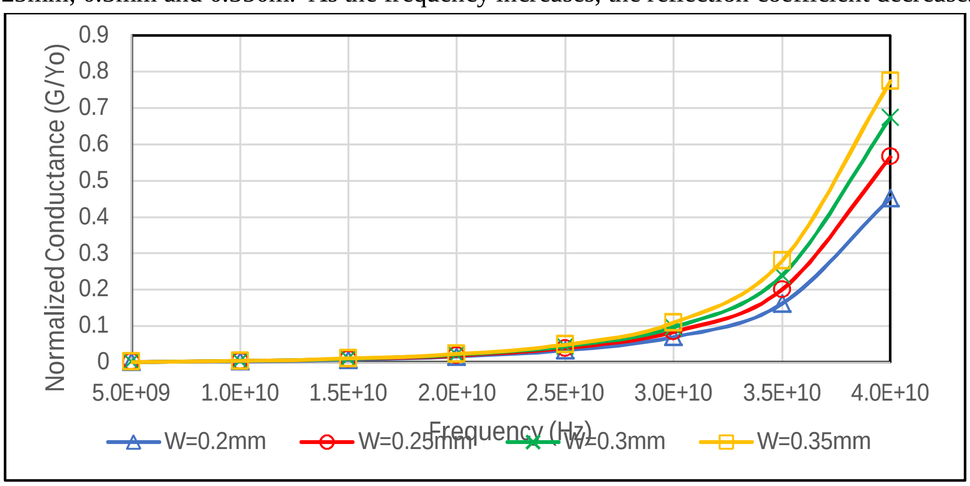

Fig. 4(a) Normalized Conductance

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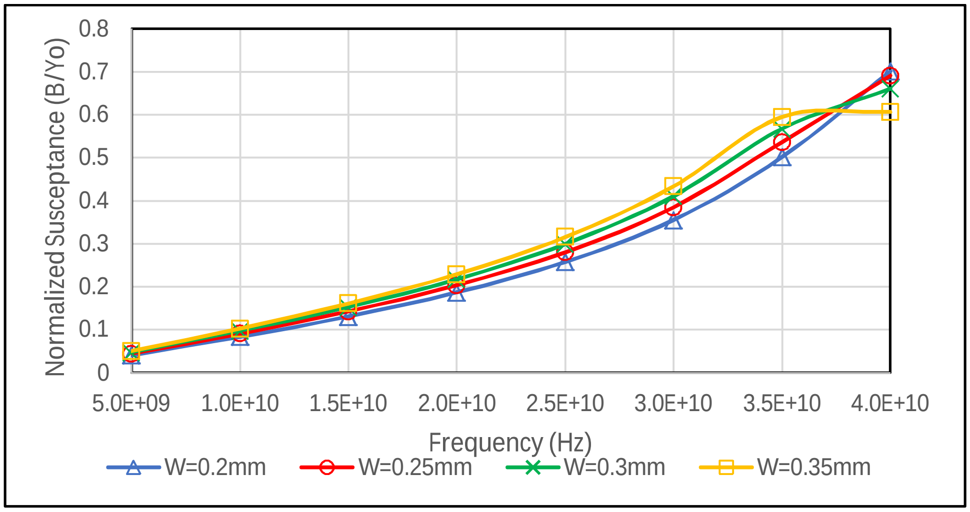

Fig. 4(b) Normalized Susceptance

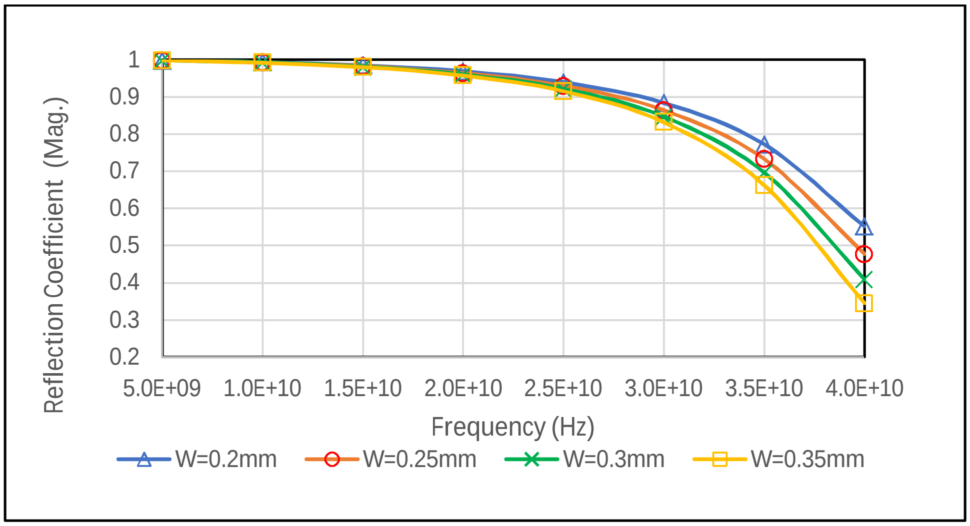

Fig. 5(a) Reflection Coefficient (Mag.)

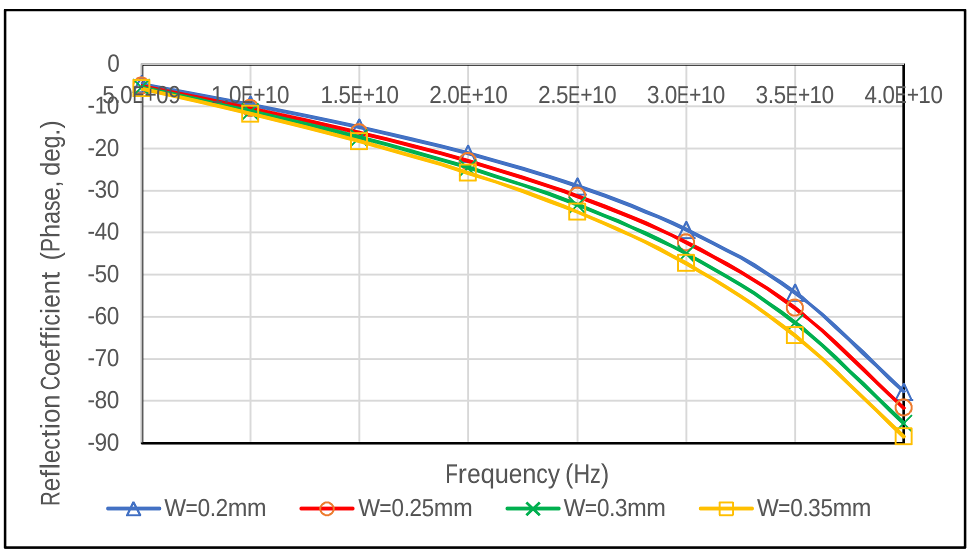

Fig. 5(b) Reflection Coefficient (Phase, deg.)

V. CONCLUSION

In this paper, lumped circuit model of open-end microstrip line discontinuity on multilayer semiconductor substrate has been present. The lumped circuit model can be used to analyze and compute the reflection coefficient for microwave component and circuit design.

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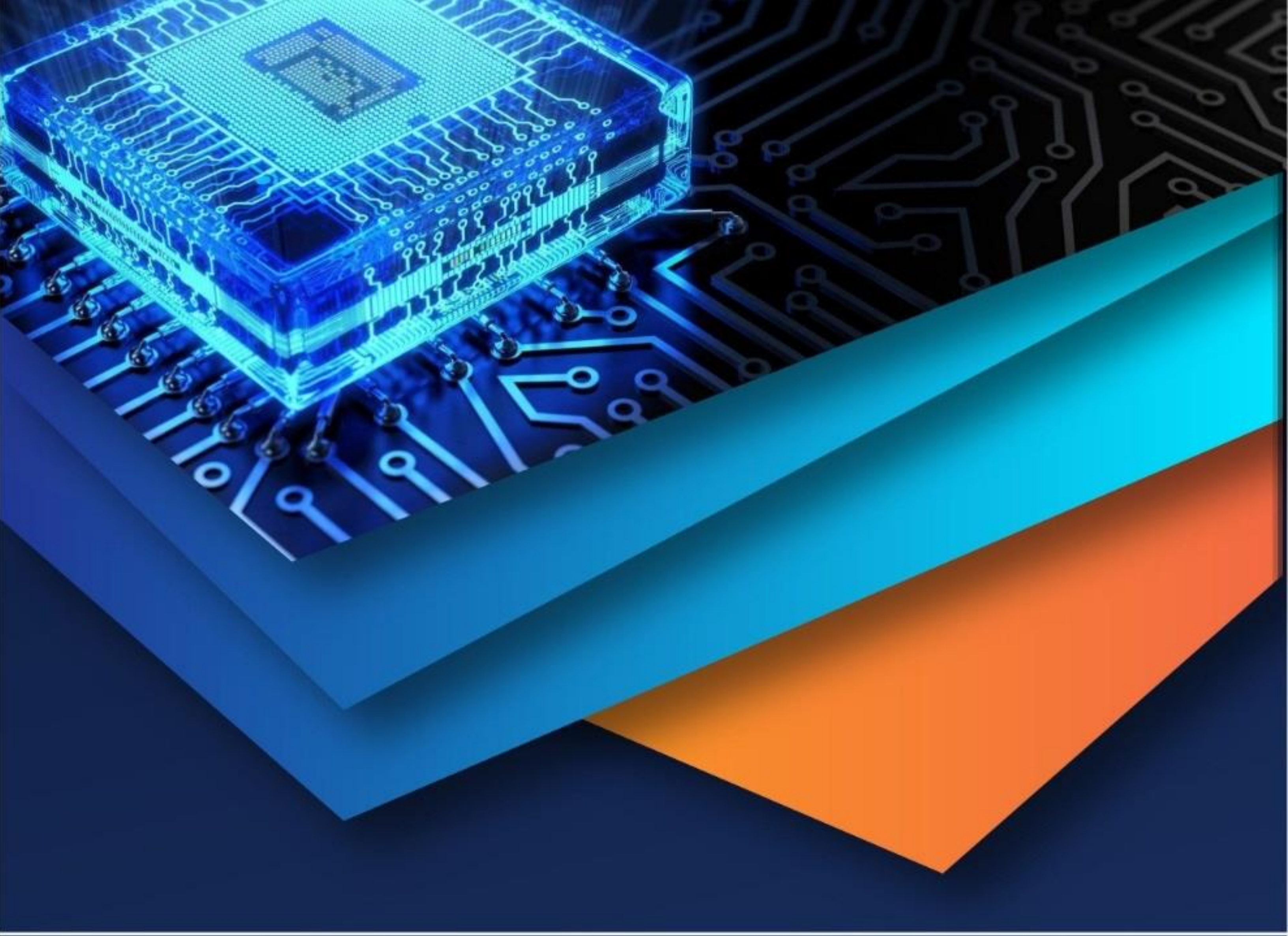

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