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Slit Loaded Stacked Circular Micro strip Antenna for Multiband Applications

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Abstract: In the present endeavor a stacked slit loaded circular microstrip antenna has been presented for wireless systems. The antenna is able to operate in four bands. These bands are fixed at 1.9611GHz, 2.1179GHz, 2.3018GHz and 2.6203GHz. The bands are useful for different wireless applications. The mathematical model presented here is very accurate and gives clear picture of facts happening in the antenna. Antenna parameters like return loss, resonant frequency, gain, directivity have been obtained from simulation and numerically. The simulated results agree well with the numerical data.

Keywords: Stacked, slit, resonant frequency, cavity model, radiation resistance etc.

I. INTRODUCTION

With the advent of different services, the need for multiband antenna is increasing day by day. Due to low profile, light weight, low cost and integration capability with MMICs, the microstrip antennas are becoming popular for wireless communication systems. But low band width and single band of operation has been inherent problem with them. Also, they suffer from low gain and low power handling capacity. Various techniques [1-5] have been evolved by researchers to enhance the bandwidth. In [1], two H-shape stacked microstrip antennas have been analyzed using transmission line model. In this the stacking has been helpful to increase the radiation efficiency to 87% from 23% and bandwidth from 0.42% to 5.5%. An inverted-F antenna has been presented in [2] with the gain of 7.5 dBi and bandwidth of 15.8%. By shorting the edges of the stacked slot loaded rectangular microstrip antennas (RMSA), Broadband operation (impedance bandwidth of 76.25%) is achieved [3]. In [4] the author moved coaxial feed in different positions to obtain circular polarization in rectangular microstrip antenna (RMSA). An E-shaped patch is stacked in [5] on RMSA to improve the impedance bandwidth from 33.8% to 44.9%. There are several other advantages of stacked microstrip antennas like- stacking provides many degrees of freedom like gap between layers feed point, substrate and superstrate parameters. The coaxial feeding technique has been extensively used in stacked patches. The inductive nature of the probe feed limits the bandwidth of the antenna [6]. A dual band operation is achieved in [7] by cutting two identical notches in RMSA. This may be restored by using staked structure.

In the present paper, the stacked circular microstrip antenna is analysed and presented for multi band operation and for wireless application. The structure has three bands of operation which remains unaffected The theoretical and simulated return loss, gain directivity etc. are studied, the details of which are given in the following sections.

II. THEORETICAL CONSIDERATION

In this design the stacked patch has two layers of circular microstrip antennas, placed vertically and center aligned. The

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lower patch with radius a_1 is supported by a substrate of dielectric constant ε_{r1} and the upper one with radius a_2 residing on substrate with dielectric constant ε_{r2}. Two pairs of narrow slits are cut diagonally in the upper patch at 90^0 angle. The width of each slit is 1 mm, the length of slit along horizontal axis is 5 mm and that along vertical axis is 10 mm. The thickness of the lower substrate layer is h_1 and that of the upper is h_2, both 1.6 mm. In the present design both layers are filled with FR4 substrate with relative dielectric constant of 4.4. The center conductor of coaxial probe is electrically connected to the upper circular patch (UCP) through a hole in the lower patch as shown in fig. 1. The 3D view of the structure from full wave electromagnetic simulation software ADS is shown in fig 2. The numerical analysis of antenna is presented in four parts. First part describes design of upper cavity with lower patch as ground plane. Secondly, an analysis is given to incorporate the four slits in the upper patch. In the third part, the lower cavity has been analyzed with superstrate, neglecting effect of upper patch. In the fourth part the combined effect of lower and upper cavity i.e. stacked antenna is investigated. The theoretical and simulated results are found and there is good agreement between them.

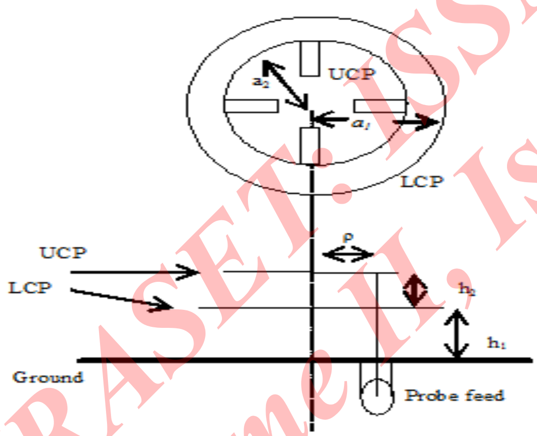

Fig. 1: Structure of proposed antenna

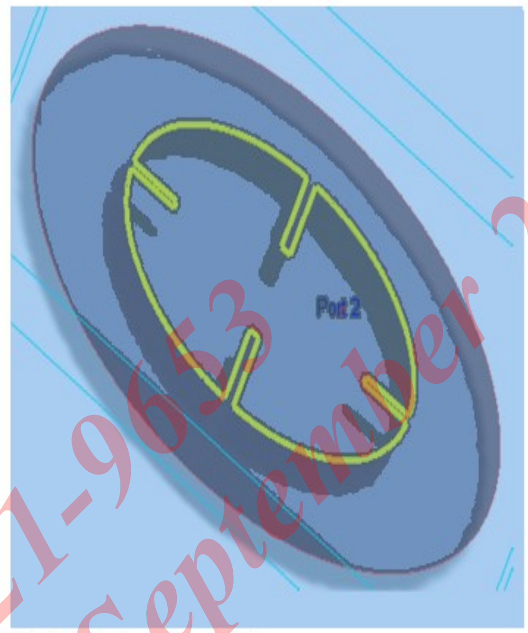

Fig 2: 3D view from ADS

III. ANALYSIS OF UPPER PATCH

The resonant frequency of upper patch is determined by taking substrate height h_2 [8], since lower patch acts as ground plane for upper patch. The size of lower patch is small and acts as finite ground plane. This assumption causes error in the model, since lower patch does not provide sufficient ground.

The input impedance of upper cavity is given as

$$Z_{in2} = \frac{1}{\left\{\left(\frac{1}{R_2}\right) + (j\omega C_2) + \left(\frac{1}{j\omega L_2}\right)\right\}} \quad (1)$$

Where resistance R_2, capacitance C_2 and inductance L_2 are equivalent circuit components for circular microstrip antenna expressed as parallel combination for TM_{np} mode.

The resonance resistance (R_2) is given by [9]

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$$R_2 = \frac{1}{G_T}\frac{J_n^2(k\rho)}{J_n^2(ka_2)} \quad (2)$$

Where ρ is probe position from center, J_n is the first kind of Bessel function of order n with argument $k\rho$ or ka, G_T is total conductance for upper cavity associated with dielectric loss, radiation loss, and conduction loss.

The capacitance associated with upper cavity patch is given by

$$C_2 = \frac{Q_T}{2\pi f_{res2} R_2} \quad (3)$$

and inductance L_2 of upper layer is given as

$$L_2 = \frac{R_2}{2\pi f_{res2} Q_T} \quad (4)$$

Where Q_T is total quality factor [10] of upper cavity, which includes radiation loss, dielectric loss and conductance loss. Then resonant frequency (f_{res2}) of upper cavity circular microstrip antenna is given [11] by

$$f_{res2} = \frac{c\alpha_{mn}}{2\pi a_{eff2}\sqrt{\varepsilon_{reff2}}} \quad (5)$$

Where c is velocity of light in free space, α_{mn} is m[th] zero of first kind Bessel function of order n, a_{eff2} is effective radius of the upper patch and ε_{reff2} is effective permittivity [11] of upper substrate considering fringing effect of upper patch.

IV. ANALYSIS OF SLIT LOADED CIRCULAR MICROSTRIP ANTENNA

The effect of slits may be incorporated in the design by taking the multiple radius of the circular microstrip patch. Due different lengths of the slits, there would be three resonant frequencies [12]

The i[th] resonant frequency may be given as

$$f_{ri} = \frac{1.841c}{P_e\sqrt{\varepsilon_{reff2}}} \quad (6)$$

Where P_e is effective circumference due to slits and is governed by

$$P_e = P_i\left\{1+\frac{2h_2}{\pi a_2\varepsilon_{r2}}\left(\ln\frac{\pi a_2}{2h_2}+1.7726\right)\right\}^{1/2} \quad (7)$$

In the above equation Pi is physical circumference associated to different resonant frequency and is given by

$$P_i = \begin{cases} 2\pi a_2 - 4w \ldots\ldots\ldots\ldots\ldots for-i=1 \\ 2\pi a_2 + 2l_x \ldots\ldots\ldots\ldots\ldots for-i=2 \\ 2\pi a_2 + 2l_y \ldots\ldots\ldots\ldots for-i=3 \\ 2\pi a_2 + 2l_y + 2lx \ldots\ldots for-i=4 \end{cases} \quad (8)$$

For each value of resonant frequencies given in equation (6) the associated physical radius is calculated by dividing equation (8) by 2π.

V. ANALYSIS OF LOWER PATCH

Lower circular patch is analyzed as circular microstrip antenna with superstrate and neglecting the effect of upper patch. One or more dielectric layer above radiating patch disturbs fringing fields thus changing the effective radius of lower patch. Resonant frequency of rectangular microstrip antenna with superstrate has been calculated in [13] taking filling fraction into consideration. In this, an antenna system with one or more superstrate is represented as antenna with one substrate with same radiation characteristics. Moreover, the formulation provided in [11] along with analysis carried

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out in [14] is used to analyze the present problem more accurately.

The effective dielectric constant of equivalent substrate is given as

$$\varepsilon reff = \varepsilon_{r1} p_1 + \varepsilon_{r1}(1-p_1)^2 \times [\varepsilon_{r2}{}^2 p_2 p_3 + \varepsilon_{r2}\{p_2 p_4 + (p_3+p_4)^2\}][\varepsilon_{r2}{}^2 p_2 p_3 p_4 + \varepsilon_{r1}(\varepsilon_{r2} p_3 + p_1) \times (1-p_1-p_4)^2 + \varepsilon_{r2} p_4\{p_2 p_4 + (p_3+p_4)^2\}]^{-1} \quad (9)$$

Where

$$p_1 = 1 - \frac{h_1}{2w_e}\ln(\frac{\pi w_e}{h_1} - 1) - p_4 \quad (10)$$

$$p_2 = 1 - p_1 - p_3 - 2p_4 \quad (11)$$

$$p_3 = \frac{h_1 - g}{2w_e}\ln\left[\frac{\pi w_e}{h_1}\frac{\cos\left(\frac{\pi g}{2h_1}\right)}{\pi(0.5 + \frac{h_2}{h_1}) + \frac{g\pi}{2h_1}} + \sin\left(\frac{g\pi}{2h_1}\right)\right] \quad (12)$$

$$p_4 = \frac{h_1}{2w_e}\ln\left(\frac{\pi}{2} - \frac{h_1}{2w_e}\right) \quad (13)$$

$$g = \frac{2h_1}{\pi}\arctan\left[\frac{\frac{\pi h_2}{h_1}}{\left(\frac{\pi}{2}\right)\left(\frac{w_e}{h_1}\right) - 2}\right] \quad (14)$$

$$w_e = \sqrt{\frac{\varepsilon_r'}{\varepsilon_{reff}}}\left[\left\{w + 0.882h_1 + 0.164h_1\frac{(\varepsilon_r'-1)}{\varepsilon_r'^2}\right\} + h1\frac{(\varepsilon_r'-1)}{\pi\varepsilon_r'}\left\{\ln\left(0.94 + \frac{w}{2h_1}\right) + 1.451\right\}\right] \quad (15)$$

$$\varepsilon_r' = \frac{2\varepsilon_{reff} - 1 + \left(1 + \frac{10h_1}{w_e}\right)^{-0.5}}{1 + \left(1 + \frac{10h_1}{w_e}\right)^{-0.5}} \quad (16)$$

$$w = a(\pi - 2) \quad (17)$$

The parameters w_e and ε_r' are calculated by iteration method [13] with initial value $\varepsilon_r' = \varepsilon_{r1}$ and $\varepsilon_{reff} = \varepsilon_r'$. In the above equation (17) w is width of RMSA equivalent to CMSA with same radiation characteristics [15]. These equations may be calculated by assuming equal fringing field for both structures. When the relative dielectric constant of superstrate is greater than that of substrate, the surface wave may be reduced to a certain extent by choosing appropriate thickness. To accommodate this, a new dielectric constant is defined as

$$\varepsilon_{re} = \frac{\varepsilon_{r1}}{\varepsilon_{reff}} \quad (18)$$

Now effective radius of LCP is calculated as

$$a_{eff1} = a_1\sqrt{(1+q)} \quad (19)$$

In this q is calculated as given in [11] where in equations (9)-(14) the result of above equation (17) is used. Using a_{eff1} as calculated in equation (16), the input impedance of LCP Z_{in1} is calculated. The antenna is assumed to be edge fed in above calculation.

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VI. STAKED CIRCULAR PATCH

There is no variation of electric field in *z* direction so total electric field is sum of the electric fields in LCP and UCP. Moreover, LCP is represented as parallel combination of a resistance (R_1), an inductance (L_1) and a capacitance (C_1). The equivalent circuit of stacked microstrip antenna may be represented as series combination of input impedances of the two antennas i.e. LCP and UCP as shown in fig. 3.

Hence

$$Z_{in} = Z_{in1} + Z_{in2} \quad (20)$$

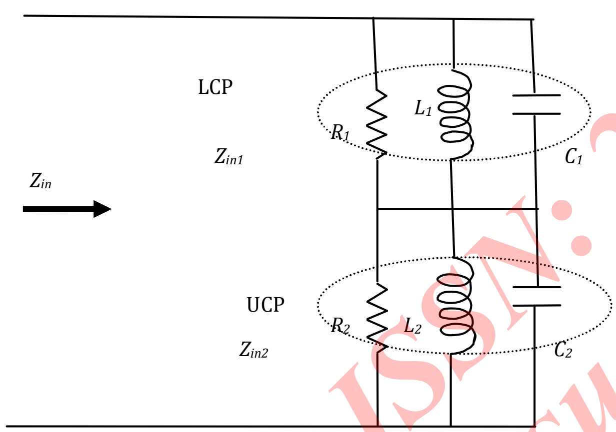

Fig. 3: Equivalent circuit of stacked CMSA

VII. DESIGN PARAMETERS

The stacked circular microstrip antenna is designed to operate on two resonant frequencies - 2.2 GHz and 3.5 GHz without any slit in the upper patch. The motive is to design an antenna that could operate for WiMAX as well as one of PCS, DCS and UTMS bands. For these operating frequencies the antenna design parameters are given in Table I. The radius for UCP is calculated assuming LCP as ground plane.

Table I Stacked CMSA Specification

Parameters	Value
Radius of LCP (a_1)	26mm
Radius of UCP (a_2)	16.25mm
Height of LCP(h_1)	1.6mm
Height of UCP(h_2)	1.6mm
Relative dielectric constant of substrate & superstrate ($\varepsilon_{r1} = \varepsilon_{r2}$)	4.4(FR4)
Width of slit (w)	1 mm
Length of slits (lx, ly)	5mm, 10mm
Loss Tangent ($tan\ \delta$)	0.0012

VIII. RESULTS AND DISCUSSIONS

The proposed antenna was stimulated on Advanced Design System(ADS) Software[16].

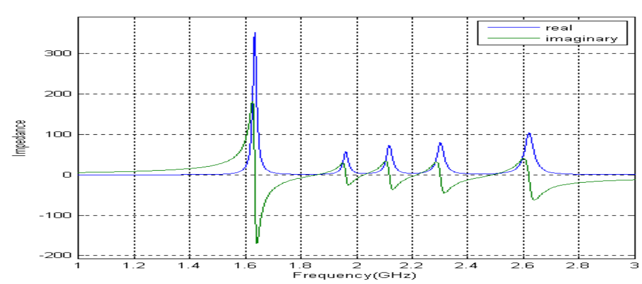

Fig. 4: variation of real and imaginary part of input impedance with frequency from MATLAB for SLSCMSA

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Fig. 4 shows computed real and imaginary part of input impedance from MATLAB for slit loaded stacked circular microstrip antenna (SLSCMSA). The figure shows that there are five resonance frequencies in the stacked antenna at 1.6339GHz, 1.9611GHz, 2.1179GHz, 2.3018GHz and 2.6203GHz. The lowest resonant frequency corresponds to lower CMSA while highest one corresponds to CMSA excluding all the four slits. Fig 5 shows impedance variation with frequency from simulation software. The resonant frequencies from the graph are 1.54GHz, 2.06GHz, 2.4GHz and 2.56GHz. It is noticeable that the two lower resonant frequencies coincide at 1.54GHz. The calculated and simulated resonant frequencies are very close to each other.

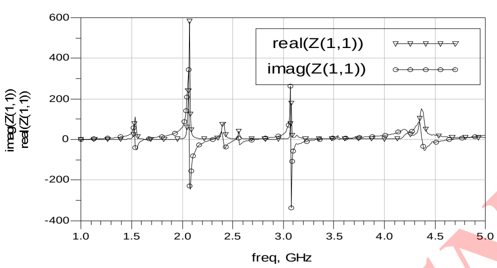

Fig. 5: variation of real and imaginary part of input impedance with frequency from ADS for SLSCMSA

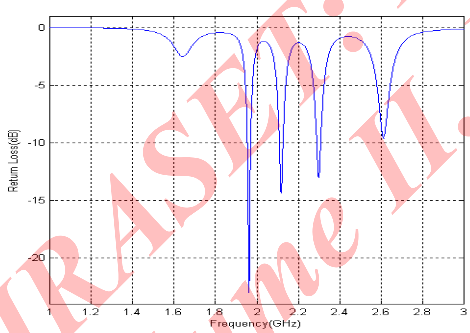

Fig. 6: Return loss variation with frequency from MATLAB for SLSCMSA

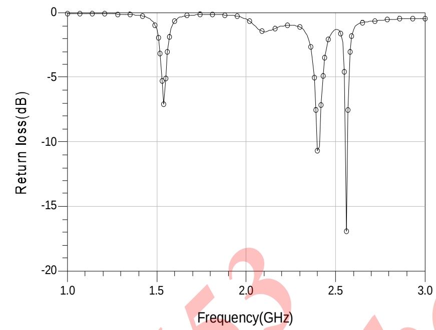

Fig. 7: Return loss variation with frequency from ADS for SLSCMSA

Figures 6 and 7 show computed and simulated return loss variation with frequency.

Table III shows comparison of resonant frequencies from MATLAB and ADS. The results are in close agreement.

Table III: Comparison of resonant frequencies form MATLAB and ADS

	f1	f2	f3	f4	f5
MATLAB	1.6339	1.9611	2.1179	2.3018	2.6203
ADS	1.54	1.54	2.06	2.4	2.56

IX. CONCLUSION

A slit loaded stacked circular microstrip antenna has been analyzed and designed using extended cavity model. Four slits on the upper patch provide multiband opearation to the antenna, which makes antenna suitable for wireless communication like WiMAX, UTMS and PCS bands.

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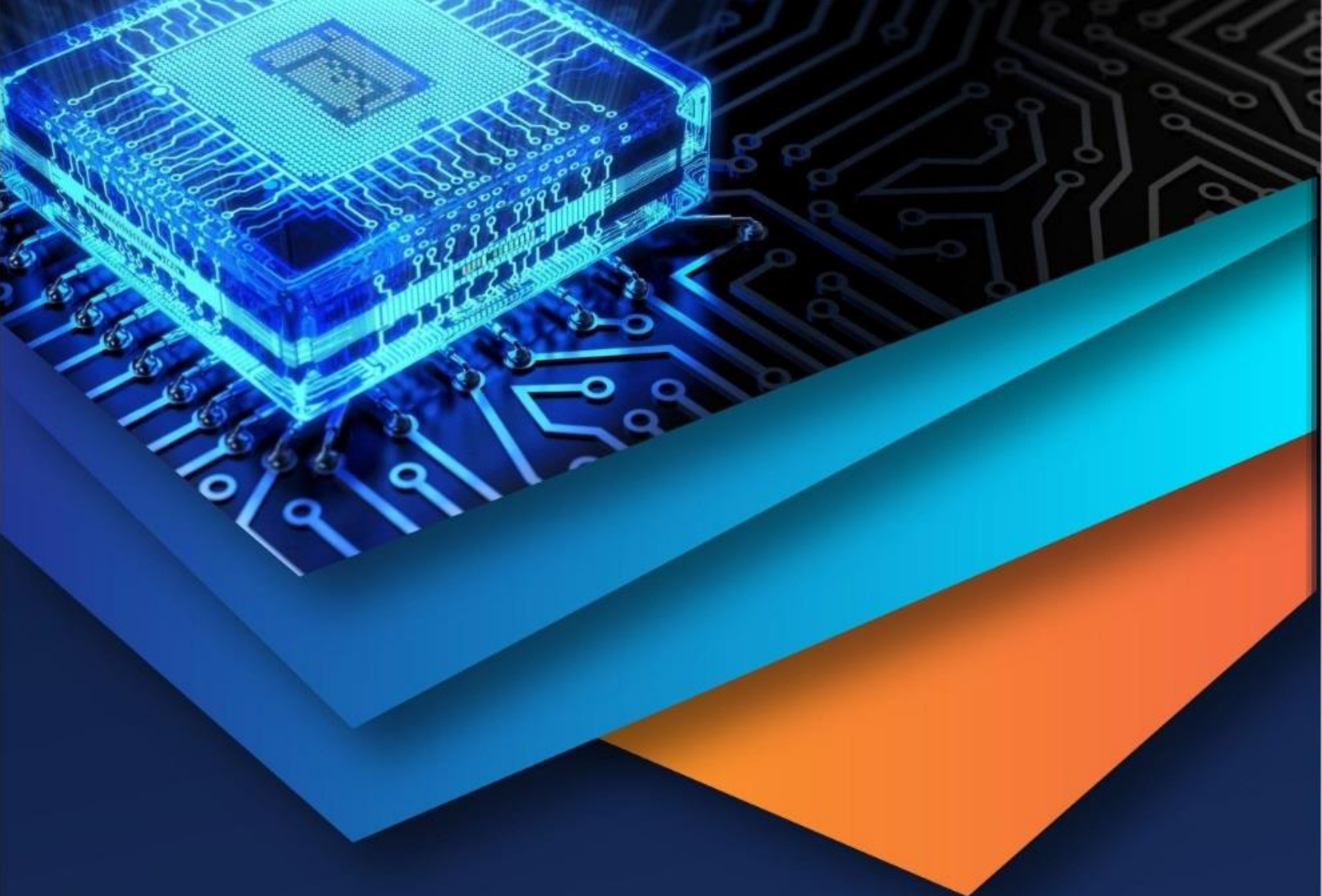

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