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Experimental and Numerical study for Multi-Phases flow Measurement by Microwave Cavity

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Abstract: Monitoring of two phase flow or multiphase flow in the industrial and service networks of pipelines is a significant problem. In order to manage this pipelines networks efficiently, an accurate on-line sensors and non-intrusive require to monitor the phase flow in the pipelines. This research presents the studying of a non-intrusive electromagnetic wave sensor (EM sensor) operating at radio and microwave frequencies for on-line monitoring and measuring two phase flow fractions of (water/oil), expressed in volume percentage in pipeline. The resonator inside cavity, used the shift in resonant frequency to detect and measure the components of two phase flow in a pipeline networks. The result show the possibility to developed non-intrusive sensor, based on EM waves capabilities to monitor the volume frication percentage of mufti-phases flow, and numerical results using HFSS code show a good agree with experimental results.
Keywords: Multi-Phase flow, EM wave Sensor, Resonance Frequency, and Phase Fraction, Stratified Flow, HFSS.

I. INTRODUCTION

The monitoring and measuring the mixture fractions of multi-phase flow of (oil, gas, and water) are necessary requirements, to enhance the quality of production, and improve the process for both operation and transportation in the pipeline network of industry productions, chiefly in the oil industries.

The literature survey shows many researchers working on different methods and using different techniques such as Z.Y. Wang et al. (2010) [2], Domenico Strazza et al. (2011) [3], Ajmal Shah et al. (2013) [4], Chao Tan et al. (2013) [5], Marco Joseda Silva and Uwe Hampel (2013) [6], Yu.P. Filippov et al. (2014) [7], El Abd (2014) [8], Zhao An et al. (2014) [9], Chao Tan et al. (2014) [10]. These researchers used techniques including Gamma Ray Attenuation, Electrical Impedance, Coriolis Mass Flow and Nuclear Magnetic Resonance to measuring multiphase fraction. Recently the other researchers, Almuradi et al., 2015 [11], and Al-Kizwini et al., 2013 [12] have used EM techniques to analyze different mixtures and phase fractions at rest inside a microwave cavity. The two phase flow (oil / water) mixture signified problems in oil wells and oil production industries. For example, the rates of fluid mixture flow from oil well was measured by using separators to separation of flow ingredients oil, gas water mixture, and the measuring the phase of outputs fluids by using principle of conventional single-phase techniques, the useful of using this techniques for controlling oil well , it takes many hours to determine the flow rates for each so if we have more than 10 wells to be monitored in the oil fields. The use of multiphase flow meters (MPFMs), it is the alternative of using the separators . Generally in the oil and gas industries, it is recognized that MPFMs could lead more advantages in the reservoir management, well testing, layout of production facilities and monitoring [1]. This paper contributes to the science of measurement and concerned with the use of EM wave (Radio frequencies (RF) and Microwave Frequencies) technique and data processing to quantify flow of two-phase of (oil/water) mixtures.

A. Multiphase Flow Meters

One of the challenged in the network pipelines, especially in the petroleum industry was how to meter oil–water–gas mixtures. Since 1980 many considerable research has been conducted into the development of a multiphase flow meter suitable for use in an industrial environment. In spite of the large number of solutions that have been proposed in recent years, no commercially available for mufti-phase flow meter meets all requirements such as nonintrusive, suitable for use over the full mixture component fraction rang, although some are getting close [1] and [13]. The use of multi-phase flow meter offers many operational advantages in the oil industries, as will offering economic benefits. Barson et. al compared the cost of using a multi-phase flow meter with using a conventional separator with test lines, for the subsea metering of a satellite well. They showed the cost of a multi-phase flow meter to be at least 47% less than that of the conventional solution[14].

Many technical methods are commercially available for measuring the Phase fractions of multiphase flows; however, this measuring procedure is always combined with a degree of difficulty due to the natural complexity of multiphase flows. In this paper it is considered the EM wave technique as a case study for a successful and practical method of two-phase flow monitoring.

B. Resonant Cavity Sensor

A smart EM sensor based on resonant cavity which is an electrically closed structure. Electromagnetic waves injected into a cavity reflect back and forth inside it, until the energy is dissipated. If the wavelength of the waves matches the geometry of the box a well-defined manner, then the reflected waves will back and forth in phase with one another generating a high level energy of standing wave [15].

The resonant frequency of the two types modes of cavities can be calculated using the equation [16]:

$$f_{r,nml} = \frac{1}{2\sqrt{\mu_r \varepsilon_r}}\left[\left(\frac{x_{nm}}{\pi a}\right)^2 + \left(\frac{l}{d}\right)^2\right]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: μ_r = relative permeability, ε_r = relative permittivity, a = radius of the cavity, b = depth (height) of the cavity, l = 0, 1, 2, 3, 4…..

$x_{nm} = p'_{nm}$ (zeros of the first derivative of the m^th-order Bessel function of the first kind) for TE_{nml} mode, $x_{nm} = p_{nm}$ (zeros of the m^th-order Bessel function of the first kind) for TM_{nml} mode.

C. Experimental Study

The rage setup of the microwave cavity system is shown in Fig.1. The main part of experimental setup is an aluminum cylindrical cavity. The cavity (EM sensor) had with an internal diameter of 89mm, and a height of 98mm. The cavity contains two excitation ports (P_1 and P_2) (Ø = 31.4mm) each containing a copper loop antennas. The loop diameter is 25mm and diameter of the wire is 1.5 mm. They are positioned inside the cavity. The upper aperture (Ø = 15mm) is the entrance of the dynamic testing sample tubes. The experimental setup is simplified in the block diagram in figure 2. A non-intrusive EM wave sensors operating at RF and microwave frequencies was constructed for online monitoring and measuring multiphase flow (oil, and water) fractions, expressed in volume percent in pipeline. The aim of an EM wave sensor for multiphase measurement is to find the relative permittivity of the mixture and then to use the knowledge of the relative permittivity of the components to solve for the phase area fractions. The interaction of electric field with mater under test is particularly strong in polar materials such as water which have a relative permittivity about 81 at the room temperature (23 ^{o}C). While oil is non-polar, so the relative permittivity is about 2.2 at the room temperature [17]. The sensor system set up shown in Figure (1), uses the HP 68720 ET vector network analyzer with a frequency range of 0.5 GHz to 10 GHz. The loop antenna (transmitting and receiving antenna). The cavity dimensions was chosen to avoid the multi-resonates of the water in high frequencies, and to identified the spectrum analyzer. The prototype was initially tested by raising the water volume percentages of (water/oil) mixture from 0 to100%. The same procedures were applied to the oil volume percentages which were varied from 0 to 100% in the mixture. The simple stratified flow was represented, and the electromagnetic spectrum would be captured, so it shows the shift of resonant peaks. These were found to shift in a repeatable and predictable manner. The block diagram of the EM sensor system which used in the experiments illustrated in Figure (2).

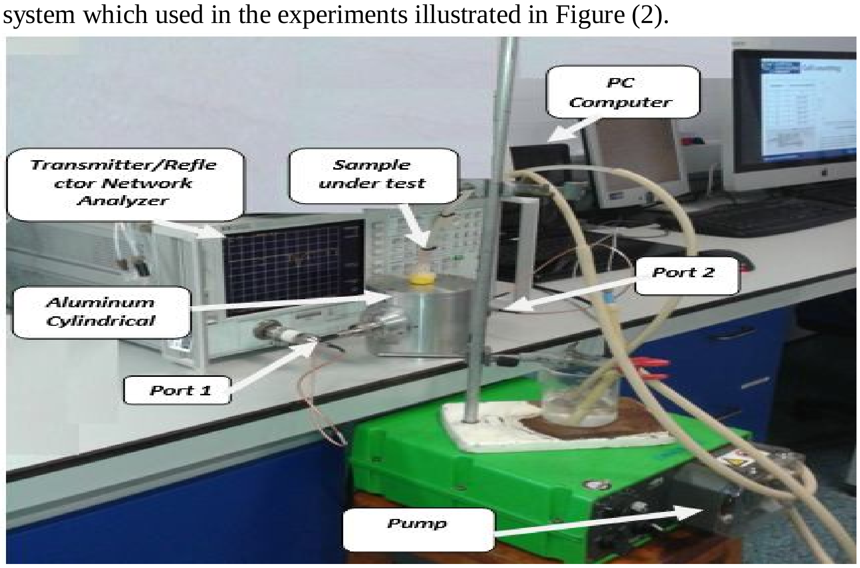

Figure (1) Smart microwave sensor system set up.

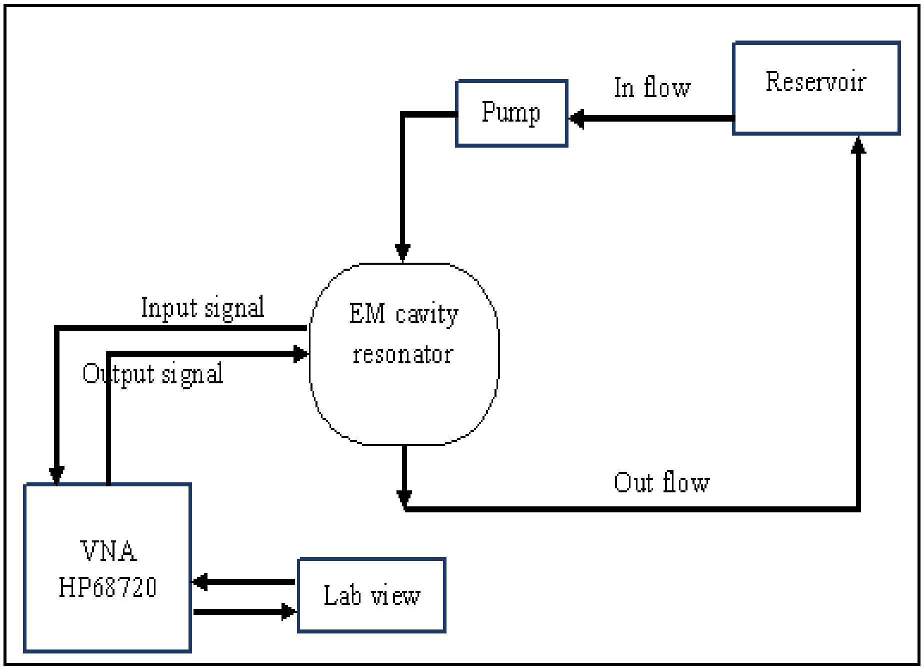

Figure (2) Sensor system block diagram.

A sample of the frequency spectrum is shown in figure (3); the resonant frequencies where the modes can presented as the sharp peaks . The sharper of resonant peak is indicate to higher quality factor attained. The spectrum, shows many resonances in which can be analyzed to determine further parameters of the water/oil mixture. The modes and resonances appears in the spectrum, it is require complex analysis and take along time. So to minimize the time and efforts, it was sufficient to recognize the essential resonance to measuring most of the flow mixture features including the friction percentages of water/oil/gas in the pipe.

Figures (4) and (5) represent the spectrum captured during the experimental results that carried out over a full range of the mixture (water/ oil) 2-phase flow, in the cavity represent 2-phase stratified flow.

It can be seen from figures that the changes of mixture volume ratios cause a shift in the resonant peaks of TE_{111} mode. The frequency shifts are varying with fraction of volume percentages of water from 0 -100% in the sample tube, is about 47.2 MHz, and the maximum power amplitude is less than 45 µW. One of the attractive factors that can be seen is the power amplitude which is less than 48 µW, it was used lees microwatts for analysis process and that indicating to the economics of this sensor.

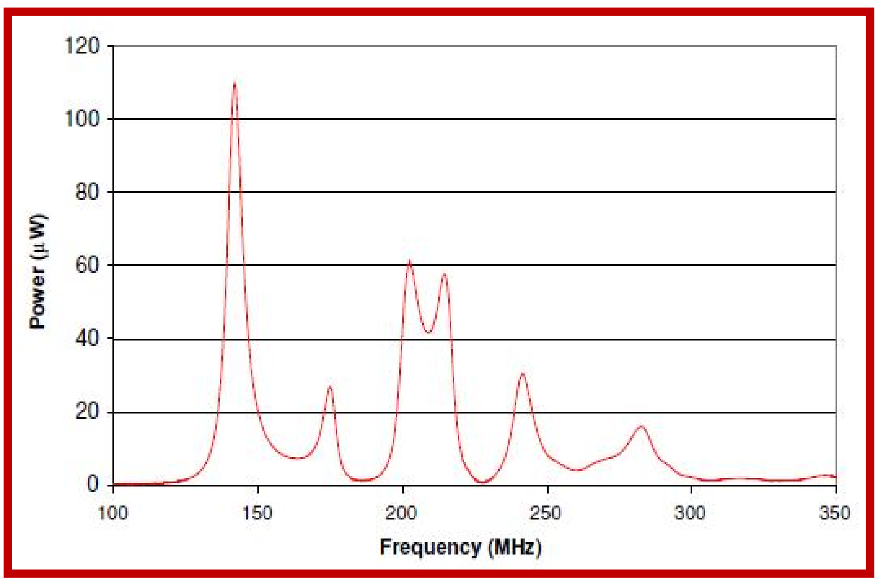

Figure (3) The total frequency range for 2-phase flow mixture of 100% water

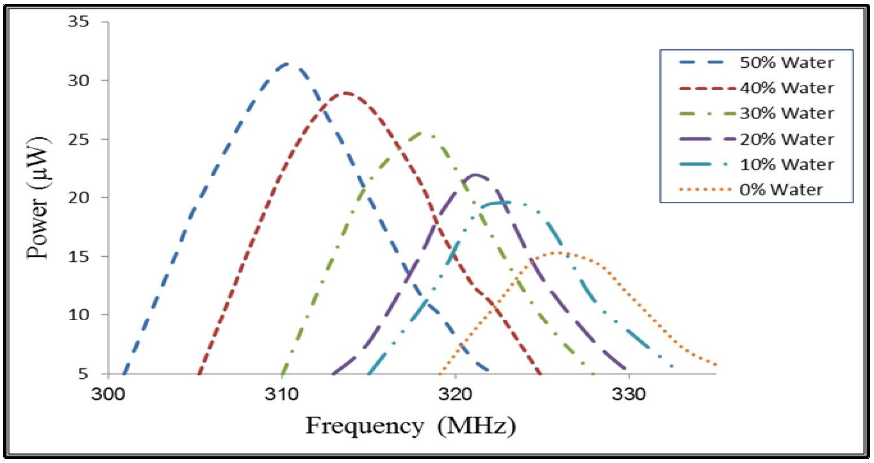

Figure (4) The two phase (water/oil) mixture with volume percentages fraction of (0 - 50% water) captured experimentally.

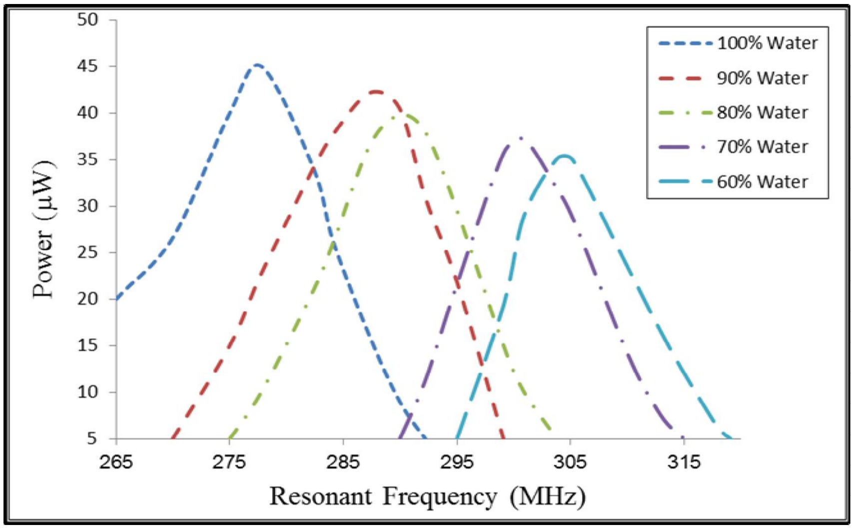

Figure (5) The two phase (water/oil) mixture with volume percentages fraction of (60 - 100% water) captured experimentally.

D. Simulation Study

The simulation study done by using HFSS (Version 11.1) software code, it is familiar with calculating the electromagnetic behavior of a flow mixture. The post-processing of software cod give the analyzing behavior of 2-phase mixture flow in detail. An soft HFSS code, it can measure the Eigenmodes, or resonances, of a structure. HFSS is based on the finite element method two compute the resonances for the model based on the geometry, materials, and boundaries. The HFSS simulation code usually used to capture the electromagnetic field inside a structure. Although its implementation is largely transparent, a general understanding of the method is useful in making the most effective use of HFSS. A conclusion can be made from the definition of HFSS package that this package has been designed for compute the electromagnetic behavior of a mixture components, so that the package must be reconstructed for our purposes of finding the shift in resonant frequencies due to change of component fraction and regime of multiphase flow. For the stratified flow regimes the design of the cavity simulation can be achieved by imagine the shape of flow within the pipe, so we are suggest to design two parallel layers within the inner pipe of the cavity representing two phases in stratified flow regime on the assumption that no mixing between the phases as shown in figure (6). Changing fraction ratios can be achieved by changing the area of the two parallel layers (sectors), then assigning material properties for these two sectors to achieve representative permittivity of the required phases (oil, water, and gas). After that the design completed and the simulation can be started.

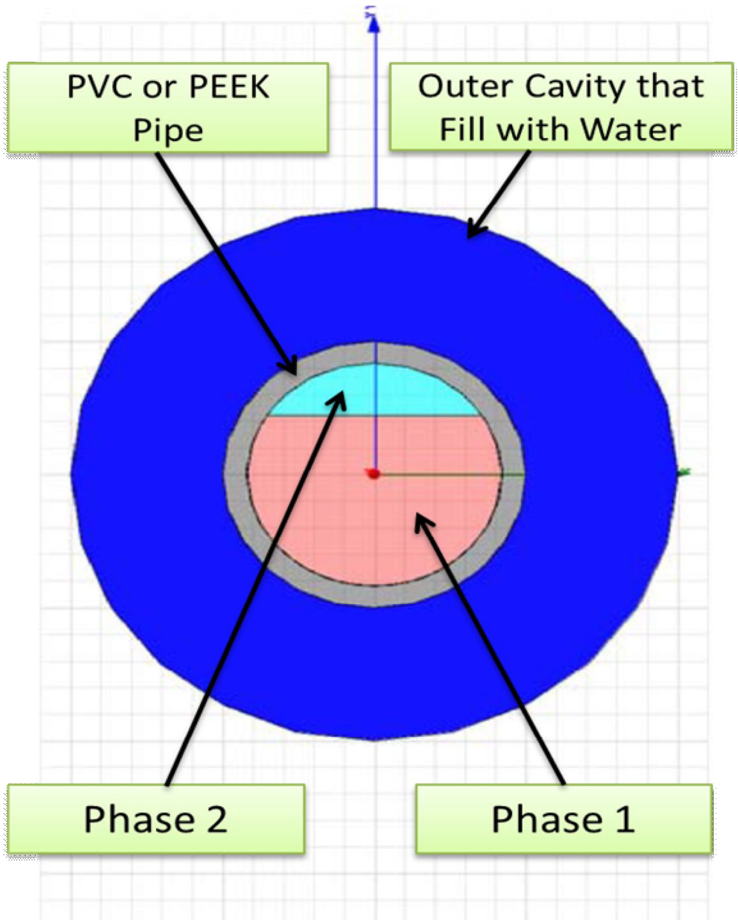

Figure (6) Cavity cross section shows stratified regime design in HFSS.

The validation of the HFSS simulation results, with the experimental results to verify the HFSS results for one cases, then it can use the HFSS simulation to study the sensor behavior for other cases. The validation done by verify the HFSS simulator when compare the simulation result with the experimental result of the 2-phase stratified flow case.

Figure (7) compare the simulated and experimental resonant response with respect to the water hold-up level of two phase mixture of (water/oil) that represent simple stratified regime within the pipe. The experimental results were in a good agreement with theoretical predictions by HFSS, with some error due to the uncertainty of volume fraction and the noise signal. It is shown in figure that the maximum error of 4.8% occurs at 20% water hold-up level.

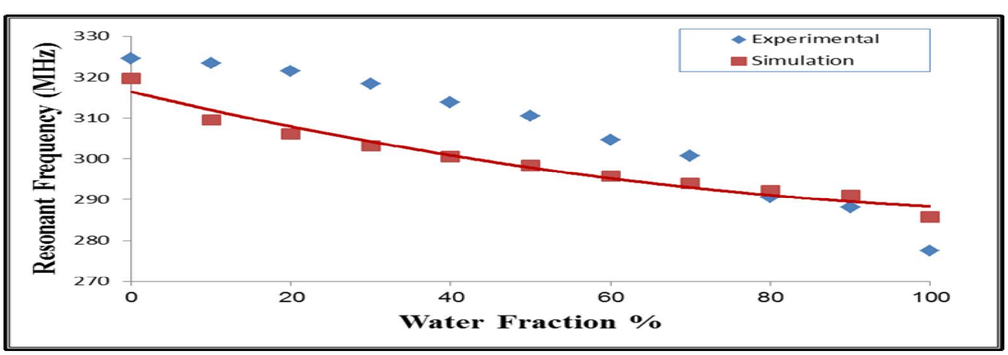

Figure (7) The validation of numerical result by compare with experimental result for stratified regime of (water/oil mixture) .

II. CONCLUSION

The experimental and numerical study investigated on this paper aimed to show the possibility to use EM cavity to design smart non-intrusive sensor, based on the principle of resonate of electromagnetic waves in designed aluminum cavity to achieve real time online system to monitor the percentage of volume friction of 2- phases flow. The resonant frequencies shifts that occur within the resonator, it's found that the experimental results are in good correlation with numerical model simulated by HFSS code. Also the sensor amplitude expressed in microwatts, indicating how the sensor economic is because used low wave wattage . the results shows that the mentioned EM cavity system will form the basis for the low cost-effective real-time monitoring system that would be able to capture the components of multiphase flow with reasonable accuracy.

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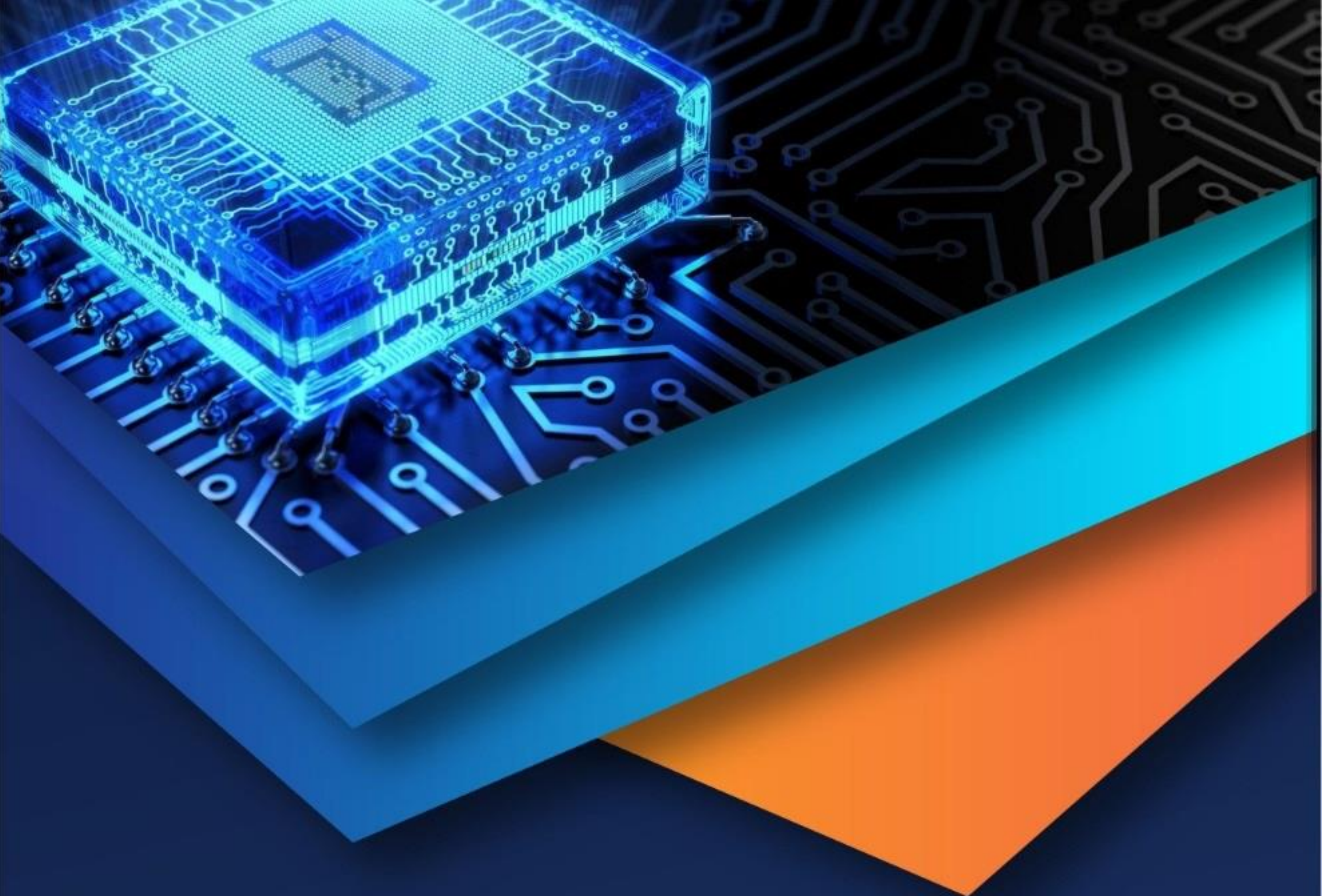

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