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Mathematical Modeling of Changes During Time of Metrological Characteristics of Intelligent Measurement Systems

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Abstract: ***The article discusses the methods of improving the metrological reliability of analog blocks of measuring channels and information-measuring systems (IMS) in general, indicators of their metrological reliability. Algorithms for improving the metrological reliability of IMS are proposed according to the criteria of a given value of a metrological resource, the probability of maintaining metrological health at the design stage.***
Keywords: ***Measuring Instruments (MI), Information-measuring systems (IMS), metrological characteristics (MCH), metrological reliability (MR), Mathematical modeling***

I. INTRODUCTION

One of the most important characteristics of the quality of measuring instruments (MI) is metrological reliability.

The complication of measuring equipment, increased accuracy requirements, the use of qualitatively new elements, on the one hand, and the ever-increasing role of MI in the production process, on the other, set the task of developing scientifically based methods for assessing the metrological reliability of designed SIs among the most important tasks of theoretical and practical metrology [1].

Currently, among the various groups of MIs that are the most intensively used in many industries as information-measuring tools, information-measuring systems (IMS) of materials and products with wide functional capabilities and allowing for the implementation of quite complex measurement algorithms are widely used.

Means of IMS have significant differences in functionality and hardware implementation, they have an identical structure, which differs only in the specific performance of individual devices. The main functional units included in the IMS are: measuring channel (amplifier, ADC), computational part (microprocessor, RAM, ROM), auxiliary part (power supply, input / output devices) [2].

II. MAIN PART

The metrological properties of IMS are determined to the greatest extent by the characteristics of the measuring channel.

The greatest influence on the metrological characteristics of MI and, in particular, IMS is exerted by analog blocks that perform the conversion and rationing of primary measurement information (for example, amplifiers, dividers, analog-pulse converters, etc.), that is, analog blocks that make up the measuring channel materials.

Thus, the actual task is to assess and improve the metrological resource of analog units of the measuring channel, and ultimately increase the metrological resource of IMS as a whole. The generalized block diagram of IMS is shown in Fig. 1.

PMT-primary measuring transducers;
SMT-secondary measuring transducer;
IPD- information processing device;
ADC analog digital converter.

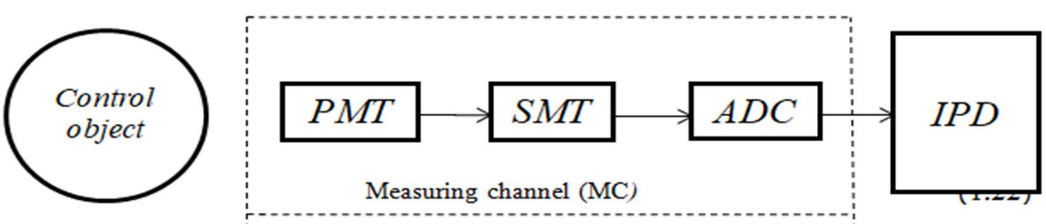

Fig. 1. A generalized block diagram of IMS

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To solve the problem of increasing metrological reliability, the following a priori knowledge is assumed to be known: mathematical model of functioning of the IMS tool, characterizing the dependence of the output parameter y values of the input parameter x, parameters of the element base and external disturbing influences:

$$y = F(x, \xi, \varphi) \tag{1}$$

where y is the output signal; x - input signal; $\{\varphi_1, — \varphi_n\}$ - vector of parameters of the component elements of the block; $\varphi=\{\varphi_1,\varphi_2,\ldots, \varphi_n\}$ is the vector of external influences (temperature, humidity, vibration, etc.). A mathematical model of the metrological characteristic S of the investigated IMS, obtained from (1):

$$S = F_2(*E, \varphi) \quad . \tag{2}$$

Metrological serviceability of the device in time is estimated by the inequality: [3]

$$|S(t)| \leq |S_{rel}| \tag{3}$$

Indicators of the metrological reliability of the investigated IMS is the probability of metrological good work at times t_{Jt}

J=1,…….,K

$$P(t) = \frac{1}{\sqrt{2\pi * \sigma_s(t_j)}} * \int_{-S_{rel}}^{S_{rel}} exp\{-\frac{[S(t) - m_s(t_j)]}{2\sigma^2 s(t_j)}\} dS \tag{4}$$

metrological resource t_P, determined by the time of intersection of realizations of a random process of changing their tolerance margin.

The main functional units included in the IMS include the measuring channel (MC) as was counted above, the metrological properties of IMS are determined to the greatest extent by the metrological properties of the MC. By increasing the values of the indicators of the MR measuring channel, it is possible to increase the metrological reliability of the IMS resource as a whole at the design stage [1].

Among the most important characteristics that determine quality
measuring instruments (MI), metrological reliability (MR) occupies a special place.

The main factors determining the MR of the IMS are:

-quality of the circuit solution of the studied MI;

-quality of the element base for a given structure of IMS;

-Acceptable level of accuracy of IMS, set tolerances on the normalized MCH.

The task of increasing MR may be solved as by varying
these factors, and taking into account the most significant of them [3].

Other indicators used primarily for direct prediction of MR are the probability of maintaining the metrological health of $P_h(0)$ at an arbitrary time of operation, which is calculated by the equation:

$$P_H(t_k) \int_{-S_{rel}}^{S_{rel}} \frac{1}{\sqrt{2\pi * \sigma_s(t_j)}} * exp\{-\frac{[S(t) - m_s(t_j)]}{2\sigma^2 s(t_j)}\} dS$$

As known, the metrological properties and metrological reliability of IMS are determined to the greatest extent by the metrological properties of the measuring channel MC, which belongs to the main functional units included in IMS [4,5].

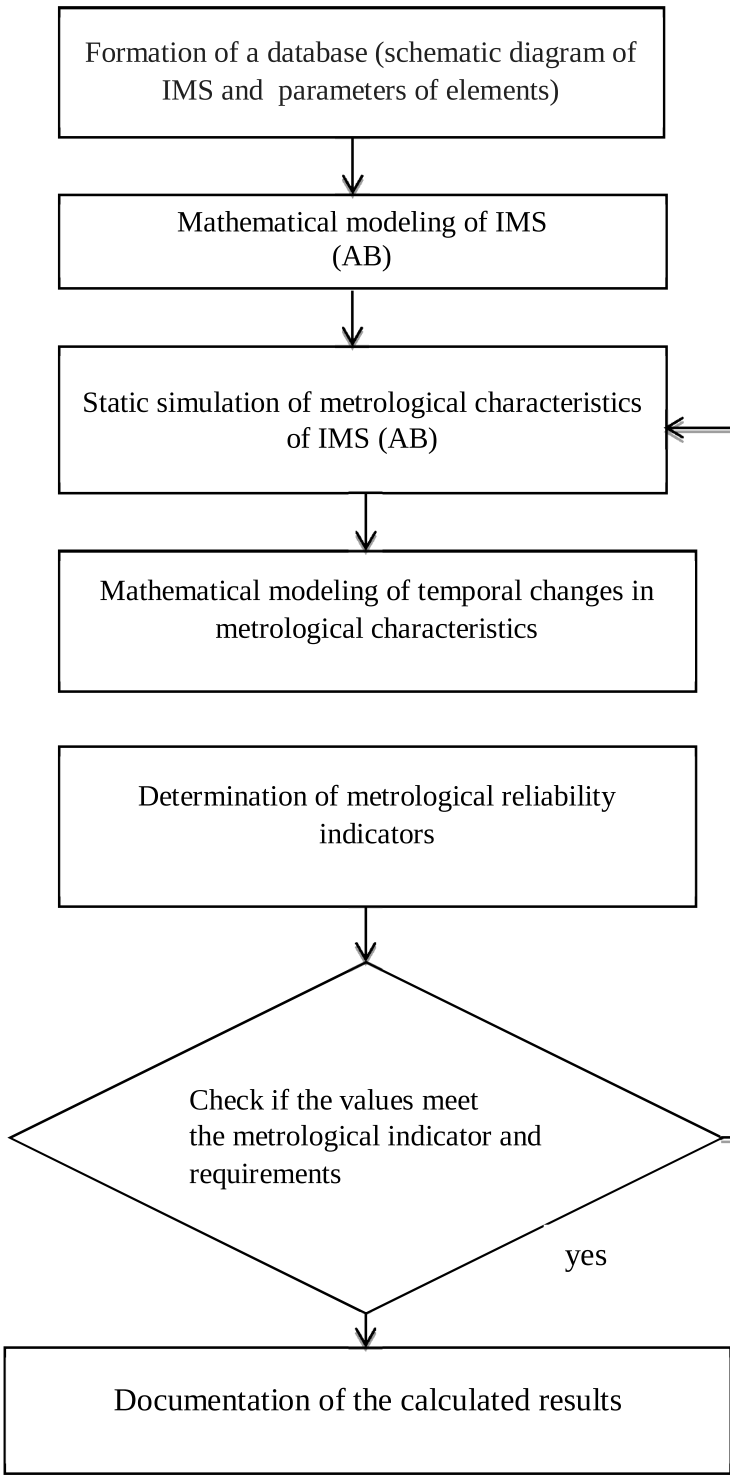

Fig.2. The block is a scheme of a general algorithm for improving the metrological reliability of the MI.

By increasing the metrological resource values of the analog block (AB) of the measuring channel, it is possible to increase the metrological resource and the MR of the measuring channel and the IMS in general.

The change in time of the metrological characteristics of the AB is shown in Fig.3.

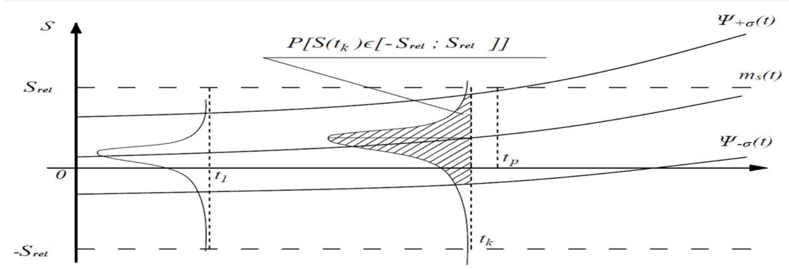

Fig.3 - Change in time of metrological characteristics. The structure of the MC includes an analog block (AB).

In the general case, the prediction of the state of the metrological characteristics of IIS blocks can be carried out on the basis of [2]:

1) The study of a priori information about blocks of MC, which is a set of data characterizing the behavior of the metrological characteristics of blocks of MC in the field of control (on the observation interval).
2) Constructing approximation functions expressing the dependence of the metrological characteristic of S on time t.
3) Extrapolation of the dependence of S (t) on the control area

The method of determining the indicators of MR electronic MIs is based on the analytical-probabilistic approach based on the mathematical modeling of non-stationary random processes of change in time of the metrological characteristics of measuring tools. The most crucial step in the use of this method is the mathematical modeling of the MI under study. Such models are built on the basis of the structural and conceptual schemes of MI with the use of graphical theory, modern methods for calculating electronic circuits, and the theoretical foundations of electrical engineering.

The task is to develop a method for improving metrological reliability by the criterion of the probability of metrological reliability by selecting the denominations of the elements ensuring

$$P_{rel}(t) = P\{0 \leq \delta(t) \leq \delta_{err}\} = \max when, \delta(t,\varphi) = var, y(t,\varphi) \in A \quad (5)$$

where $P_{rel}(t)$ is the probability of metrological reliability; δ_{err} is the value of the permissible error; t - time; P- is the vector of external disturbing influences; $y(t,\varphi)$- is the set of output characteristics of IMS; A - area of health.

Obviously, the solution to problem (5) is preceded by the task of finding the maximum value of the probability of metrological health for each of the AB that make up the measuring channel:

$$max\{P_{rel_i}(t)\} when, S(t,\varphi) = var, \varphi \in \Phi, y_i(t,\varphi) \in A_i \quad (6)$$

where $\boldsymbol{y_i}$ - is the output signal of the *i-th* AB component constituting MC, $\boldsymbol{A_i}$ - is the area of operability of the corresponding block.

To solve this problem, an algorithm for increasing metrological reliability by the criterion of the maximum probability of metrological health has been developed, shown in Fig. 1.

The main stages of the implementation of the considered algorithm are as follows:

a) The parameters of the elements that make up the AB under study are introduced.
b) A procedure of mathematical modeling MCH is carried out, a model of temporal change of a mathematical characteristic is constructed, which makes it possible to estimate the probability $\boldsymbol{P_{rel}}$, and a control point is selected in which the optimization process is considered. The value of the moment of time $\boldsymbol{t_k}$ is selected from the condition that the value of the margin in accuracy at this time point corresponds to the expression:

$$\Delta = \delta_{err} - \delta(t_k) = (0{,}1 \ldots\ldots\ldots 0{,}3) * \delta_{err} \quad (7)$$

c) In case of inconsistency value of the $P_{rel}(0)$, the selection of the elements to be replaced is performed, which allows solving the optimization problem, and the degree of influence of the parameter of each element on the value of the metrological characteristic is estimated, as shown in paragraph 2. by the value of the normalized partial derivative of the form $C_z(y)$:
d) A trial search and selection of the search direction is carried out, and MCH mathematical modeling is performed again and the required parameter MR P_{rel} is determined, and the selected elements of the analog block are modified in accordance with the chosen parametric optimization method.
e) If $\boldsymbol{P_{rel}(t)} < \boldsymbol{P'_{rel}(t)}$, then a working search is carried out for the parameters of the elements in the selected direction and a new value is calculated for the probability index of maintaining metrological health, the value of which is compared to the previous one in the working search procedure.

f) Parameter optimization and calculation of the probability values for the preservation of its metrological operability of the investigated IC until the maximum value of the probability-and-metrological operability is reached. The flowchart of the algorithm is shown in Fig. 4.

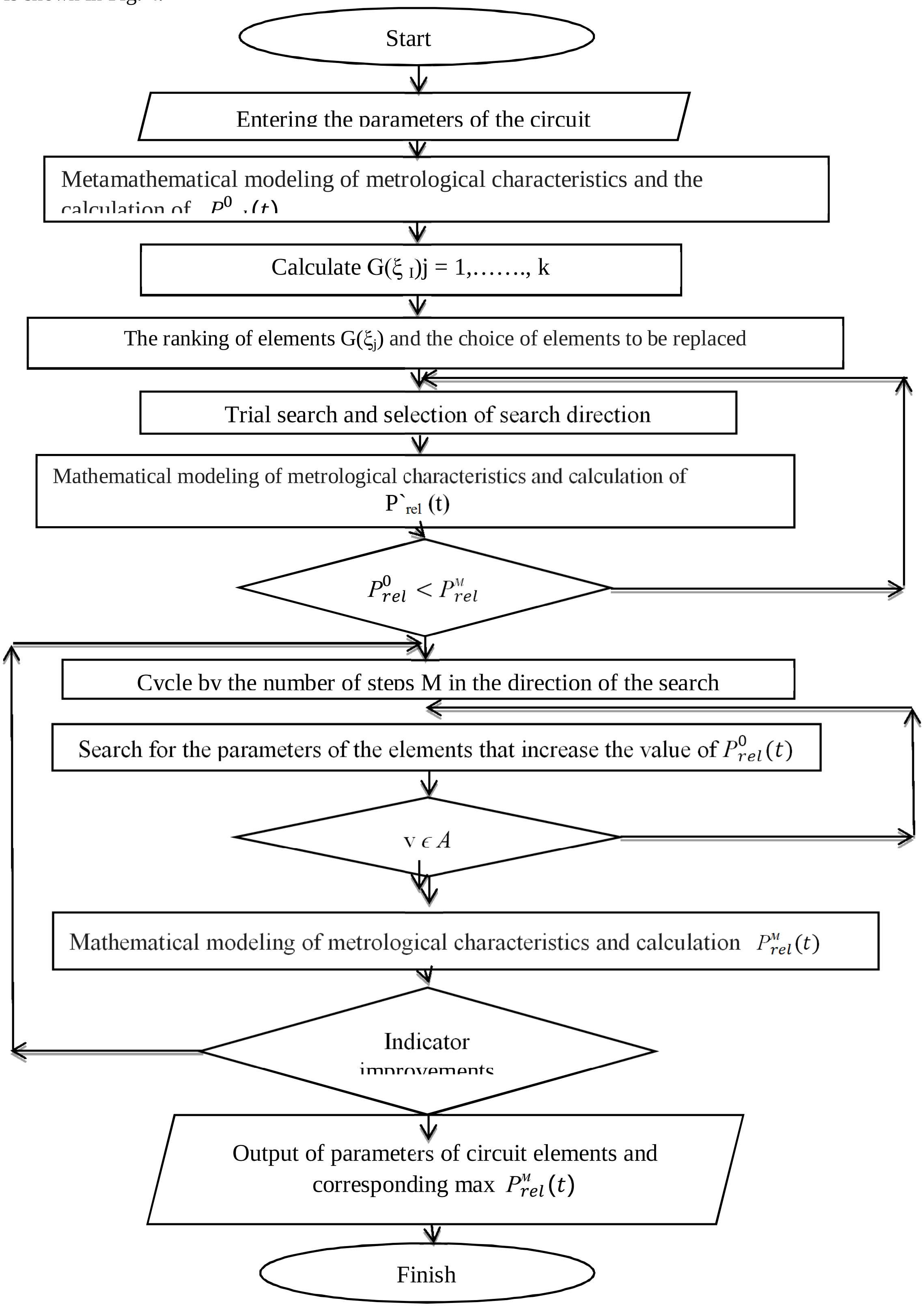

Fig.4: Block diagram of the algorithm for finding the maximum value of the probability of preserving metrological health

To improve the metrological reliability of the measuring channel of the IMS in general, by the criterion of the probability of metrological health to expression (7), it is necessary to evaluate the named criterion for all ABs included in the measuring channel of the IMS. The magnitude of the probability of maintaining the metrological health of the whole MC is calculated by the equation:

$$P_{rel}^{t} = \min\{p_{rel}\}$$

III. CONCLUSIONS

1.An algorithm has been developed for searching for the maximum of the AB metrological resources that make up IMS. The algorithm allows using the mathematical model of AB and the database of elements to determine the maximum possible value of the metrological resource of the investigated AB.

2. An algorithm has been developed to improve the metrological reliability of IMS by the criterion of the required value of a metrological resource, based on mathematical modeling of the metrological characteristics of the block under study. The algorithm is to search for the optimal values of the parameters of the element base of AB, providing the desired value of the selected indicator MCH

3. An algorithm has been developed to increase the MCH of the IMS according to the criterion of the probability of preserving metrological health, which consists in finding the optimal values of the parameters of the element base of AB IMS providing the maximum value of the probability index of preserving metrological health at an arbitrary time of the upcoming operation of the IMS.

IV. ACKNOWKEDGMENT

An algorithm has been developed for increasing the MR IMS by the criterion of the probability of saving metric corrections, which consists in finding the optimal values of the parameters of the element base of AB IMS.

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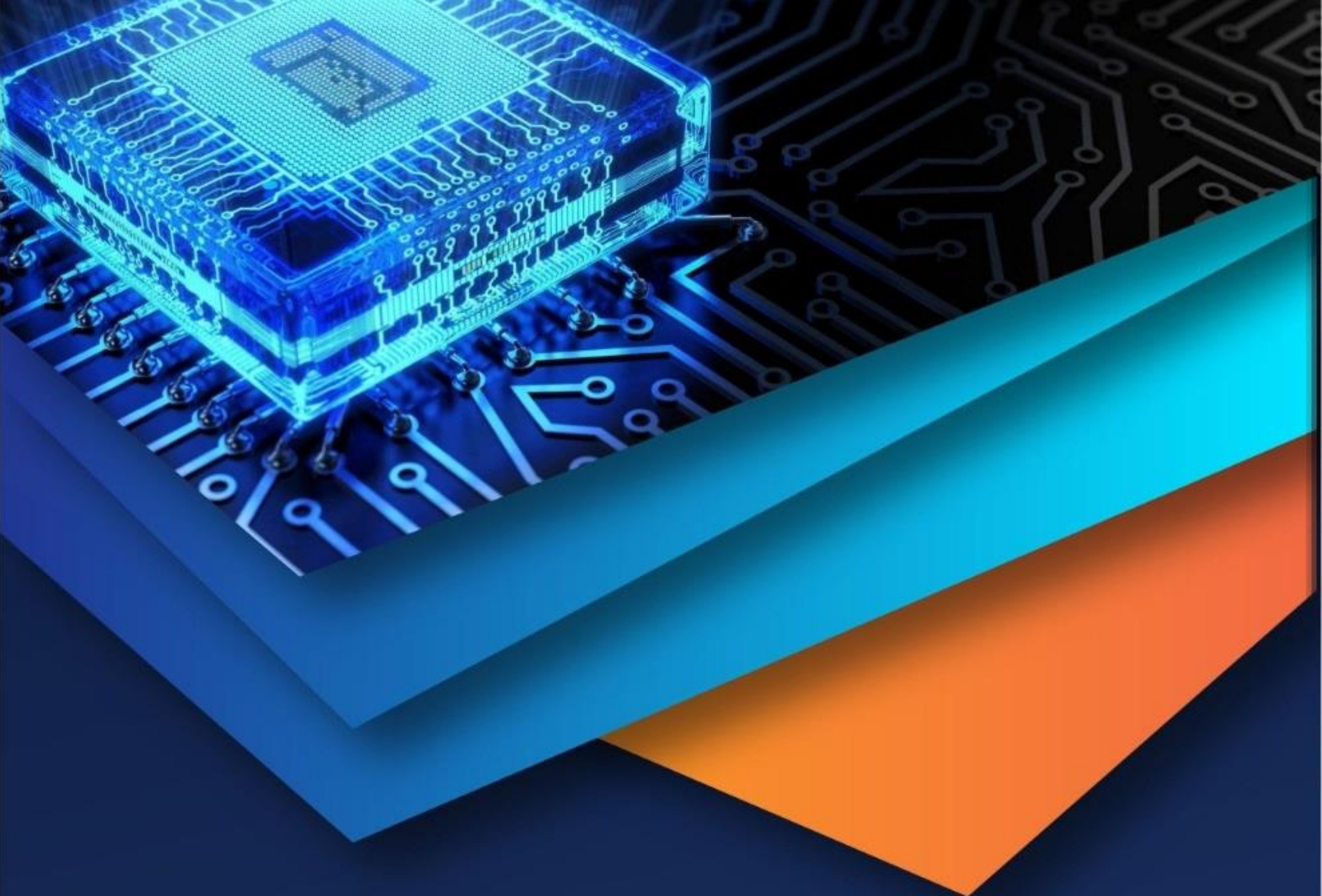

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