Identification of Key Variables in Improving the Performance of Electronic Circuits

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Due to the increasing demand for more efficient and reliable electronic devices, it is crucial to understand which factors most significantly influence the performance of these circuits. This study focuses on the identification and prioritization of key variables for improving the performance of electronic circuits, using the Regnier's Abacus method. A review of the literature was carried out to identify relevant variables, followed by an assessment by a panel of experts in electronic engineering. The Regnier's Abacus method allowed the study to show, among other findings, that the quality of the components, the operating parameters (voltage, current, and frequency), and the ambient temperature are the most critical variables. These results provide valuable guidance for engineers and designers, promoting electronic circuit optimization and innovation in the field.

Keywords: electronic circuits, circuit performance, Regnier's abacus, component quality, circuit design.

1. Introduction

Improving electronic circuit performance (ECP) is a fundamental field of research in modern engineering and technology. Electronic circuits are essential components of a large number of devices and systems, from simple household appliances to complex industrial and communications equipment (Wilamowski & Irwin, 2018). The performance of these circuits not only determines the efficiency and functionality of the devices, but also affects their reliability, durability, and energy efficiency (Skjong et al., 2016). Due to continued advancement in component miniaturization and increasing demand for faster and more efficient electronic devices, the need to optimize ECP is more critical than ever (Băjenescu, 2021).

Despite significant advances in electronic circuit technology, identifying and prioritizing the variables that most impact their performance remains a complex challenge (O'Brien et al., 2020). The lack of a clear consensus on which factors are most critical can lead to suboptimal designs and inefficient use of resources. Furthermore, the variability in the applications and contexts of the use of electronic circuits adds an additional layer of complexity to this problem, regarding which are the most relevant variables that must be considered in the design and optimization of electronic circuits to guarantee optimal performance.

Some studies have approached the improvement of ECP from different perspectives. For example, previous research has analyzed the influence of component quality, thermal management, and operating parameters such as voltage and current (Rahman et al., 2024). Other studies have explored the importance of factors such as circuit topology and component configuration (Tietze et al.,2015). However, these studies often focus on specific variables without offering a comprehensive view that allows variables to be prioritized based on their relative impact on circuit performance. The Regnier's Abacus method has been used in other areas of engineering for priority assessment (Betancourt & Scarpetta, 2017), but its specific application in the context of electronic circuits is still limited and requires further exploration.

In this context, this study focuses on the identification of key variables that influence the improvement of the ECP. Using the Regnier's Abacus method, a structured and systematic approach, these variables are evaluated and prioritized with the aim of providing clear guidance for electronic designers and engineers. This approach allows not only to identify which variables are most important but also to understand how they interact with each other to optimize circuit performance.

The identification and prioritization of key variables in improving the performance of electronic circuits has significant implications for both theory and practice. From a theoretical perspective, this study will contribute to a deeper understanding of the factors that determine circuit performance, providing a solid foundation for future research. From a practical perspective, the results of this study will offer designers and engineers clear guidance on where to focus their efforts to maximize circuit efficiency and reliability. This is particularly relevant in a context where the demand for more efficient and durable electronic devices is constantly increasing.

2. Methodology

This study is classified as descriptive research with an exploratory approach, the objective of which is to identify and analyze the key variables to improve the ECP using the Regnier's Abacus method. The exploratory nature of the research allows the study to address a complex and understudied problem (Swedberg, 2020), providing findings that can guide future research and practices in electronic engineering. A mixed research design was adopted, combining qualitative and quantitative elements to achieve a comprehensive understanding of the key variables in the ECP (Halcomb & Hickman, 2015).

Qualitative phase

A systematic literature review was carried out to identify the key variables in the improvement of ECP. This process involved a search in academic databases such as IEEE Xplore, ScienceDirect, and Google Scholar, as well as consulting specialized books, scientific journals, and other relevant resources. Predefined inclusion and exclusion criteria were established, such as thematic relevance, methodological quality, and timeliness of the publications, which allowed the most relevant and high-quality studies to be filtered. This process allowed relevant studies to be collected and analyzed, identifying and categorizing the key variables that influence the ECP. From this information, a preliminary list of variables was prepared for subsequent assessment and prioritization using the Regnier's Abacus method (Benjumea-Arias et al., 2016).

Quantitative phase

In the quantitative phase, the Regnier's Abacus method was applied with a panel of experts in electronic engineering. This method, known for its effectiveness in prioritizing complex variables, involved the collaboration of a group of experts carefully selected due to their experience and knowledge in the area (Riemens, et al., 2021). The experts evaluated and prioritized the variables identified during the qualitative phase through structured discussion rounds and individual assessments. Each round allowed the experts to reflect on the variables, discuss their views, and adjust their assessments based on the discussions and new information provided by their colleagues.

Each variable was valued numerically according to its importance for the improvement of the ECP, using the predefined scale shown in Table 1. The use of this predefined scale facilitated the quantification and comparison of the experts' opinions. Subsequently, numerical ratings were collected and statistically analyzed to calculate an overall importance score for each variable. This analysis process included the application of descriptive and, if necessary, inferential statistical methods to ensure the validity and reliability of the results obtained. The methodical and systematic approach of this quantitative phase allowed key variables to be prioritized in an objective and well-founded manner.

Table 1. Regnier's Abacus Scale

Dark Green	5	Very Important
Light Green	4	Important
Yellow	3	Doubt
Fuchsia	2	Little Important
Red	1	Not Important
White	0	No Response

Source: Authors

Procedure

To carry out this research, a meticulous procedure divided into several phases was followed:

Literature review: A review was carried out to identify the key variables in the improvement of the ECP. Relevant studies were collected and analyzed according to predefined inclusion and exclusion criteria.

Preparation of the preliminary list: Based on the literature review, the key variables were identified and categorized, preparing a preliminary list for subsequent assessment using the Regnier's Abacus method.

Assessment and prioritization: A panel of seven experts in electronic engineering was convened and selected using criteria of experience and knowledge in the field. The experts assigned numerical scores to each variable according to their relative importance for the improvement of the ECP.

Data analysis: The scores assigned by the experts were analyzed with the Regnier's Abacus method to calculate a global importance score for each variable.

This study seeks to impulse knowledge in the context of the ECP, offering practical and applicable tools to improve the design and results of these circuits in various engineering contexts.

3. Results

La revisión de la bibliografía identificó 18 variables, las cuales se categorizaron conformando siete grupos: variables técnicas, variables de fabricación, variables de ambiente, variables de prueba y validación, variables de mantenimiento, variables de costo y variables de innovación. A continuación, se presentan dichas variables en la Tabla 2.

Table 2. Key variables identified for the application of Regnier's Abacus.

Technical Variables
1.Type of Electronic Components
2. Quality of Components
3. Circuit Design
4. Electrical Parameters
Manufacturing Variables
5. Assembly Techniques
6. Weld Quality
7. Printed Circuit Board (PCB) Materials
Environmental Variables
8. Operating Conditions
9. Electromagnetic Interference (EMI)
10. Vibrations and Mechanical Shocks
Test and Validation Variables
11. Test Methods
12. Test Equipment

Maintenance Variables
13. Ease of Repair
14. Diagnostic Techniques
Cost Variables
15. Component Cost
16. Production Cost
Innovation Variables
17. New Technologies
18. Upgrade and Scalability

Source: Authors

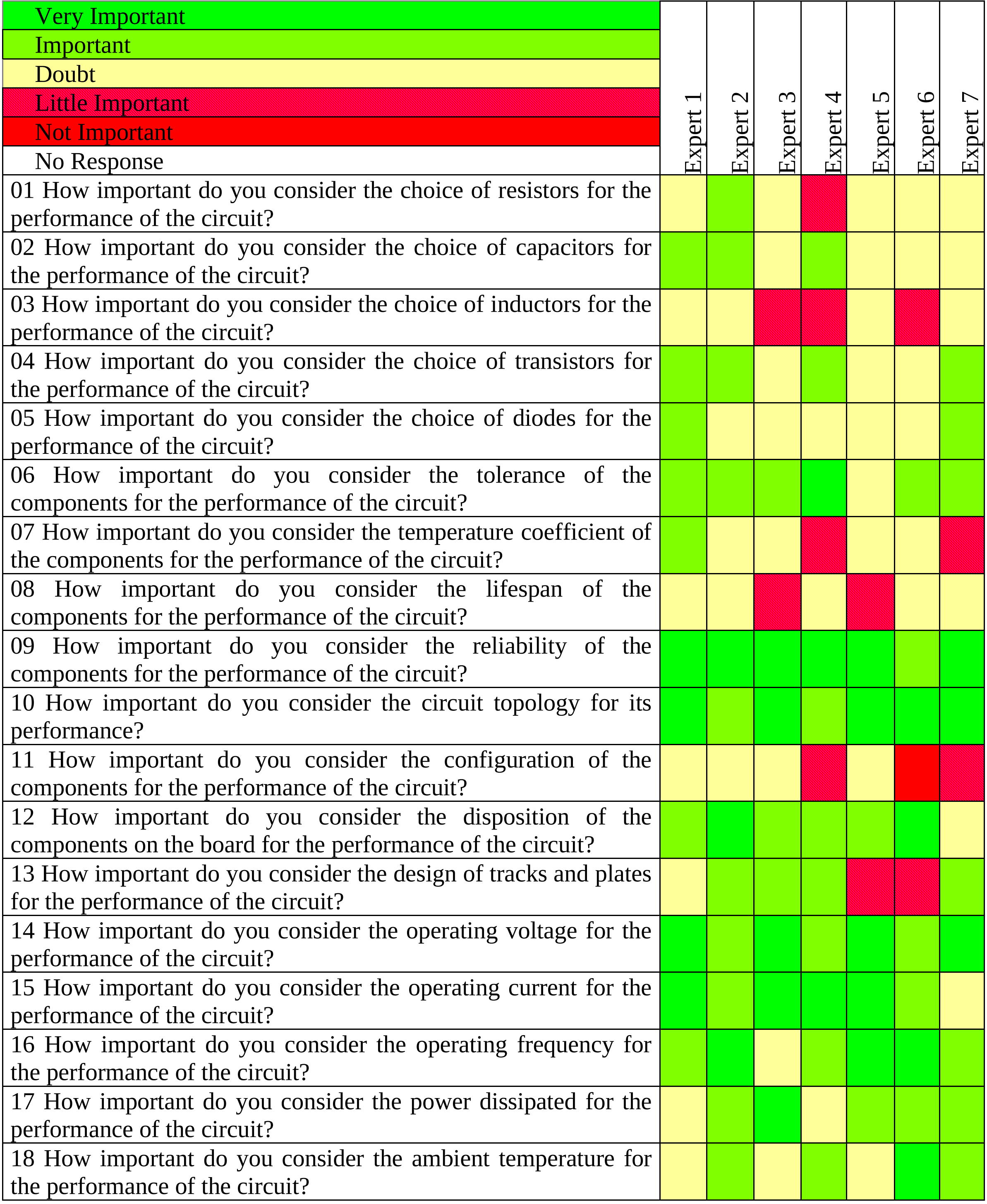
Based on the selected variables, a questionnaire was designed to assess the importance of various factors in improving the performance of electronic circuits. The analysis was carried out by a panel of seven experts in electronics and circuit design, who evaluated 18 identified variables. This panel was made up of professionals with extensive experience in different areas of electronics, including circuit design, PCB (Printed Circuit Board) manufacturing, and component quality. The selected experts have an average of more than 12 years of experience in the field and have worked on research and development projects in both industry and academia.

The result obtained is presented in Table 3, where each expert's detailed response can be seen. In this table, the questions are arranged in the rows, while the answers of each expert are in the corresponding columns. Each expert assigned a score to the 18 questions using the Regnier's Abacus scale. This scale categorizes the perceived importance of each item as follows: Very Important (5), Important (4), Doubt (3), Little Important (2), and Not Important (1).

By looking at the table, it is possible to analyze how the perception of importance varies among experts for each specific question. This variability provides a comprehensive view of the differences and similarities in the experts' judgments, allowing areas of consensus and disagreement to be identified. Likewise, the use of the Regnier's Abacus scale facilitates a clear and precise quantification of the evaluations, thus contributing to a more objective and structured assessment of the topics analyzed.

Furthermore, the analysis of these scores can offer valuable information for decision-making, as it highlights which aspects are considered priorities by experts and which might require further reflection or reconsideration. Table 3 not only shows the individual results of each expert but also allows a critical comparison and synthesis of their opinions, which provides information for the interpretation of the data.

Table 3. Expert responses presented in the form of a color table



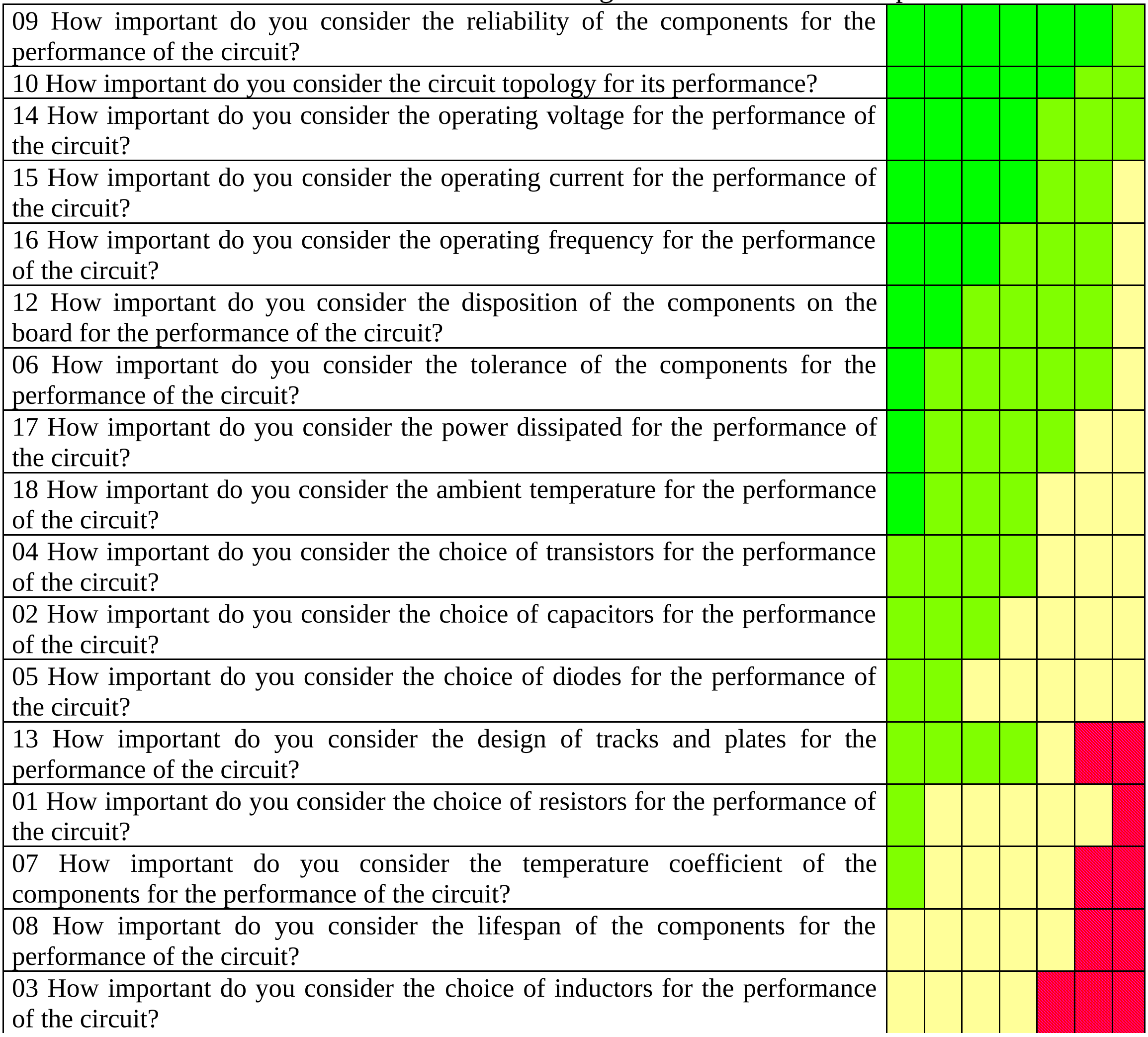
🟩 Very Important 🟢 Important 🟨 Doubt ▨ Little Important 🟥 Not Important ⬜ No Response	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
01 How important do you consider the choice of resistors for the performance of the circuit?	🟨	🟢	🟨	▨	🟨	🟨	🟨
02 How important do you consider the choice of capacitors for the performance of the circuit?	🟢	🟢	🟨	🟢	🟨	🟨	🟨
03 How important do you consider the choice of inductors for the performance of the circuit?	🟨	🟨	▨	▨	🟨	▨	🟨
04 How important do you consider the choice of transistors for the performance of the circuit?	🟢	🟢	🟨	🟢	🟨	🟨	🟢
05 How important do you consider the choice of diodes for the performance of the circuit?	🟢	🟨	🟨	🟨	🟨	🟨	🟢
06 How important do you consider the tolerance of the components for the performance of the circuit?	🟢	🟢	🟢	🟩	🟨	🟢	🟢
07 How important do you consider the temperature coefficient of the components for the performance of the circuit?	🟢	🟨	🟨	▨	🟨	🟨	▨
08 How important do you consider the lifespan of the components for the performance of the circuit?	🟨	🟨	▨	🟨	▨	🟨	🟨
09 How important do you consider the reliability of the components for the performance of the circuit?	🟩	🟩	🟩	🟩	🟩	🟢	🟩
10 How important do you consider the circuit topology for its performance?	🟩	🟢	🟩	🟢	🟩	🟩	🟩
11 How important do you consider the configuration of the components for the performance of the circuit?	🟨	🟨	🟨	▨	🟨	🟥	▨
12 How important do you consider the disposition of the components on the board for the performance of the circuit?	🟢	🟩	🟢	🟢	🟢	🟩	🟨
13 How important do you consider the design of tracks and plates for the performance of the circuit?	🟨	🟢	🟢	🟢	▨	▨	🟢
14 How important do you consider the operating voltage for the performance of the circuit?	🟩	🟢	🟩	🟢	🟩	🟢	🟩
15 How important do you consider the operating current for the performance of the circuit?	🟩	🟢	🟩	🟩	🟩	🟢	🟨
16 How important do you consider the operating frequency for the performance of the circuit?	🟢	🟩	🟨	🟢	🟩	🟩	🟢
17 How important do you consider the power dissipated for the performance of the circuit?	🟨	🟢	🟩	🟨	🟢	🟢	🟢
18 How important do you consider the ambient temperature for the performance of the circuit?	🟨	🟢	🟨	🟢	🟨	🟩	🟢

Source: Authors

To clearly identify areas of agreement and disagreement among the experts, the statements were organized progressively from left to right. This ordering begins with the statements that showed the highest degree of consensus and moves towards those that showed the greatest discrepancies. Statements that reflect opposing positions were placed in the center, indicating a balance between consensus and disagreement, or a predominance of divided opinions. This approach allows an intuitive visualization of the variability of opinions, facilitating the identification of topics on which experts broadly agree and those that are more controversial. Table 4 illustrates this arrangement using a color palette derived from the study, where each shade represents the corresponding level of agreement or disagreement.

The progressive organization of the statements and their visual representation in Table 4 provide a deeper and more detailed understanding of the experts' opinions, facilitating a comprehensive and nuanced evaluation of the key variables in improving the performance of electronic circuits.

Table 4. Statements ordered according to consensus and discrepancies



09 How important do you consider the reliability of the components for the performance of the circuit?	🟩	🟩	🟩	🟩	🟩	🟩	🟢
10 How important do you consider the circuit topology for its performance?	🟩	🟩	🟩	🟩	🟩	🟢	🟢
14 How important do you consider the operating voltage for the performance of the circuit?	🟩	🟩	🟩	🟩	🟢	🟢	🟢
15 How important do you consider the operating current for the performance of the circuit?	🟩	🟩	🟩	🟩	🟢	🟢	🟨
16 How important do you consider the operating frequency for the performance of the circuit?	🟩	🟩	🟩	🟢	🟢	🟢	🟨
12 How important do you consider the disposition of the components on the board for the performance of the circuit?	🟩	🟩	🟢	🟢	🟢	🟢	🟨
06 How important do you consider the tolerance of the components for the performance of the circuit?	🟩	🟢	🟢	🟢	🟢	🟢	🟨
17 How important do you consider the power dissipated for the performance of the circuit?	🟩	🟢	🟢	🟢	🟢	🟨	🟨
18 How important do you consider the ambient temperature for the performance of the circuit?	🟩	🟢	🟢	🟢	🟨	🟨	🟨
04 How important do you consider the choice of transistors for the performance of the circuit?	🟢	🟢	🟢	🟢	🟨	🟨	🟨
02 How important do you consider the choice of capacitors for the performance of the circuit?	🟢	🟢	🟢	🟨	🟨	🟨	🟨
05 How important do you consider the choice of diodes for the performance of the circuit?	🟢	🟢	🟨	🟨	🟨	🟨	🟨
13 How important do you consider the design of tracks and plates for the performance of the circuit?	🟢	🟢	🟢	🟢	🟨	🟥	🟥
01 How important do you consider the choice of resistors for the performance of the circuit?	🟢	🟨	🟨	🟨	🟨	🟨	🟥
07 How important do you consider the temperature coefficient of the components for the performance of the circuit?	🟢	🟨	🟨	🟨	🟨	🟥	🟥
08 How important do you consider the lifespan of the components for the performance of the circuit?	🟨	🟨	🟨	🟨	🟨	🟥	🟥
03 How important do you consider the choice of inductors for the performance of the circuit?	🟨	🟨	🟨	🟨	🟥	🟥	🟥

11 How important do you consider the configuration of the components for the performance of the circuit?	🟨	🟨	🟨	🟨	🟥	🟥	🟥

Source: Authors

The results obtained reflect a clear and coherent perspective on the priorities of the experts in the field of electronic circuits. The high appreciation of component quality and circuit design underscores the critical importance these elements have in the performance and reliability of electronic systems. First of all, the reliability of the components, which occupies the first place in the table, is a fundamental aspect, because high-quality components not only guarantee better performance but also reduce the probability of failures, which is essential for applications where precision and durability are crucial. This emphasis on reliability reflects a deep understanding that any weakness in individual components can compromise the entire system.

Placing component reliability first is consistent with the need to ensure that each component functions correctly over the expected life of the circuit. According to Yang et al. (2010), reliability affects not only the immediate performance of the device but also its longevity and the reduction of long-term costs for maintenance and replacement. This high rating may suggest that experts are particularly concerned about minimizing the risk of failure, especially in applications where safety and precision are paramount, such as in medical devices or aerospace systems.

Regarding the importance attributed to the circuit topology, the need for a well-thought-out and efficient design stands out. In this sense, according to Chakraborty et al. (2009), a suitable topology not only optimizes performance but also improves energy efficiency and can simplify circuit implementation and maintenance. Likewise, considering circuit topology so highly indicates that experts value a holistic approach to design, where circuit architecture is as important as individual components.

The interaction between component quality and circuit topology deserves additional consideration. Superior circuit design can compensate for certain component limitations, and vice versa. For example, an innovative topology can allow the use of more economical components without sacrificing performance. This synergy is key in electronic systems engineering, where global optimization surpasses the improvement of individual elements.

Among the electrical parameters, operating voltage, operating current, and operating frequency were ranked in the following positions, reflecting their essential role in the stability and functionality of the circuit. Operating voltage is crucial for the proper functioning of electronic components. Inappropriate voltage can cause circuit malfunction, affect stability, and potentially damage components. For its part, the operating current is essential in determining the amount of energy that flows through a circuit, so an inappropriate current can result in overheating, damage to components, and loss of efficiency. While the operating frequency directly affects the dynamic behavior and response of electronic circuits, especially those that handle communication and data processing signals.

According to Zhang et al. (2021), a constant and adequate voltage ensures circuit stability by ensuring that all components operate within their optimal ranges. This is crucial to maintain system integrity and avoid fluctuations that can cause intermittent failures or long-term damage. Abas et al. (2020) note that proper voltage prevents damage to sensitive components that could occur with inadequate voltages, such as overvoltages that can burn out circuits or undervoltages that can result in inefficient performance. Similarly, Esho et al. (2024) state that a correct operating voltage contributes to the energy efficiency of the circuit, reducing unnecessary losses. Well-managed voltage minimizes heat losses and other types of energy dissipation, which is crucial for sustainability and reduced operating costs.

Regarding the operating current, Mohapatra and Dey (2024) state that proper control of the current prevents overheating of the components. Current management is essential to prevent excess heat, which can degrade materials and shorten the lifespan of electronic components. Additionally, overcurrent can trigger catastrophic failures, so keeping current within safe limits is vital to system reliability. Zhu et al. (2020) add that operating current ensures that components operate within their specified parameters, which is crucial to maintaining circuit accuracy and efficiency. A circuit that operates with the proper current maximizes its performance and functionality, ensuring that each component contributes to the overall task of the system without being subjected to undue stress.

Regarding the operating frequency, Shang et al. (2021) indicate that it influences the response and dynamic performance of the circuit. A proper operating frequency allows circuits to handle signals accurately, which is especially important in high-speed applications and communications. The circuit's ability to respond quickly to changes in incoming signals results in better overall system performance. Jiang (2024) also notes that proper frequency ensures that signals are transmitted and processed correctly without distortion. Correct operating frequency is essential to avoid loss of information and maintain signal integrity, which is critical in communication and data processing systems where accuracy is paramount.

Among the operating conditions evaluated, ambient temperature stood out as an important variable for the ECP, obtaining a score that places it in first place among the operating conditions. This importance lies in several critical factors that affect both the reliability and efficiency of the circuits. For example: Ambient temperature has a significant impact on the reliability of electronic components according to He et al. (2021), components are designed to operate within a specific temperature range. If the ambient temperature exceeds this range, materials can suffer thermal stress, which reduces their lifespan and can lead to premature failure. Likewise, Shukla et al. (2017) point out that the ambient temperature affects the overall thermal performance of the circuit.

On the other hand, variables such as the lifespan of the components, the inductors, and the configuration of the components in the circuit design obtained lower scores, indicating that, although relevant, they are considered of lower priority compared to the other variables evaluated. Component life is a variable that affects long-term performance but has no immediate impact on the initial performance of the circuit. Likewise, inductors are crucial components in certain specific applications, such as filters and power converters. However, its use is not as widespread as that of other components such as resistors and capacitors. Additionally, component configurations can be adjusted and optimized during the design process without requiring significant changes to individual components or circuit operating specifications.

The results obtained reflect a clear hierarchy of priorities that should guide the design and optimization of electronic circuits. The highest priority variables are those that directly affect the stability, efficiency, and immediate performance of the circuit. These must be managed with special care and precision to ensure the success of the design. At the same time, it is important not to neglect lower-priority variables, since their impact, although less immediate, can be significant in certain contexts and specific applications. The balanced management of all the evaluated variables will contribute to the creation of robust, efficient, and long-lasting electronic circuits.

4. Conclusions

The results of the Regnier's Abacus method provide a clear view of the priorities in improving the performance of electronic circuits. The high valuation of component reliability and circuit topology suggests that these aspects should be the main focus in the design and selection of components to ensure the stability, efficiency, and immediate performance of the circuit. However, lower-priority variables must also be managed appropriately to ensure the long-term longevity and adaptability of the system. Furthermore, attention to electrical parameters and operating conditions is crucial to optimize circuit performance and stability.

The results obtained provide valuable guidance for engineers and designers in making informed and strategic decisions. By correctly understanding and prioritizing these variables, more robust, efficient, and sustainable electronic circuits can be developed, thus promoting continuous improvement and innovation in the field of electronics. The findings of this study may also guide future research and practices in the field of electronics.

Despite valuable findings, this study has some limitations. Reliance on a literature review, although exhaustive, may not have captured all recent perspectives and advances in the field. The focus on a predefined set of 18 variables may have excluded important others, and the Regnier's Abacus method, although useful, is subjective and does not always capture the interdependence between variables. Furthermore, the findings are based on a specific context and their generalization to other contexts should be done with caution. Recognizing these limitations is essential to critically interpret the results and guide future research.

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