EUREKA+
Electric circuits SUccessful Resolution with Kaleidoscopic Aid PLUS
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Abstract—The purpose of this paper is to introduce a new online software application known as EUREKA+. EUREKA+ is a continuing work of an existing online software application: EUREKA and also contributes with new contributions. EUREKA+ is a software application that generates an unlimited number of aleatory circuits, questions and multiple choice answers. The subjects evaluated by it are organized in different Topics and each one is divided in Concepts that, in turn, are split into degrees of difficulty. EUREKA+ introduces a new category of exercises, exercises with a specific function. Another goal is to generate multiple choice options with intelligence.

Index Terms—EUREKA+, online software application, e-learning

I. INTRODUCTION

The main objective of EUREKA+ is to be used as an educational tool to assist the students when they have not only basic circuit analysis courses but also more advanced courses. Due to this, this software application is really helpful for them. Initially, some contributions were set to include in EUREKA+. However, it was essential to have a feedback from the students in relation to the performance of EUREKA, so a questionnaire was made. With it, some improvements can be applied in EUREKA that before this questionnaire were not considered.

A. EUREKA

EUREKA is a software application that generates aleatory circuits, questions about them and multiple choice answers. Besides, it is an online application that everyone can use, without any cost, and its interface is all in English, see [1].

EUREKA was developed, in order to be used as an educational tool. The majority of the users that may utilize this platform are students studying circuits analysis concepts. This tool is a way to help students to better understand the characteristics of the circuits and circuit analysis methodologies: from the simplest to more advanced ones. This is possible because EUREKA has the subjects organized in Topics, in consonance with the subjects normally addressed in Circuit Theory. However, these subjects are broad, so the Topics are divided into Concepts. When a student is learning new matters, the first exercises should not be too complicated, otherwise he would feel unmotivated. As the knowledge increases, the student needs to be put at proof, in other words, he needs to do challenging exercises, in order to gain confidence. These were the reasons why the problems on EUREKA were divided into two degrees of difficulty: regular and challenging.

EUREKA allows the user to learn and practice certain circuit behaviour. Besides this, in the initial Topic, it is given help to assist the student in case of doubt. It is essential to have it in the initial Topic, because at this stage the student does not have any notions about circuits. Moreover, EUREKA generates questions in consonance with the chosen Topic/Concepts. In order to get the right answer, the circuit needs to be simulated, using NGSPICE. The other multiple choice alternatives are formed by multiplying the right answer by a constant, that, can change the sign and / or can create a big or small discrepancy in relation to the correct value of the answer.

B. Questionnaire

The main purpose of the questionnaire was to know if there were another possibilities of improving EUREKA, according to the desires and tastes of the students. The developer of EUREKA can think that the organization or the colors of the site suits better the interest of the students, but it can be the contrary. To clarify this situation two samples were chosen: one from Biomedical Engineering and the other from Electrical and Computer Engineering.

In order to develop the questionnaire, it was necessary to do a small research on how to create a good one, see [2] to [5]. Consequently, the inquiry creation followed a few rules:

• it had a small abstract to introduce the questionnaire purpose;
• it was used the third person instead of the second person to avoid a threatening tone;
• it began with general questions and gradually evolved to more specific questions;
• all the questions followed a precise order (initially it was asked about the software application aspect and also about its performance and then about the quality and characteristics of the problems).
The results of the questionnaire concerning the multiple choice questions (such as "Classify the problems for regular mode with respect to its degree of difficulty.") did not bring any suggestion of improvement to EUREKA+, because the answers of the majority of those surveyed were always inconclusive. In other words, the answers showed that they like EUREKA: its structure, difficulty level, exercises and appearance. However, in the questions with open response, there are a lot of suggestions. Some of them were taken into account, others did not. The latter happens, due to the fact that some ideas were not explicit and others were not included in the scope of this thesis: "make a smart phone application for EUREKA" and "history of the circuits that each student made". Also, suggestions such as a "detailed resolution of each circuit in EUREKA" is not admissible, because the purpose of Help option is, through an exercise, to make the student remember the concepts in study and not to prevent the student from thinking. The ideas considered were:

- Some problems had information in excess;
- Have Help option in all topics;
- The colors used in the circuit sometimes causes difficulty in reading.

II. EUREKA+

The main contributions are to improve some of the Topics that already exist in EUREKA, add problems that point out the real application of the circuits, introduce intelligence on the multiple choice options and include help for all Topics.

The first statement implies that there are some aspects that need to be changed, in order to increase even more the level of complexity of EUREKA. For example, sometimes, the value of the dependent concepts are not of the same order of magnitude as the respective quantities. This can not happen, because they would have either to few or to much impact on the circuit, affecting its behaviour.

The second one means that new circuits will be added, introducing the notions of active and passive filters, rectifiers and limiters using diodes and bipolar junction transistors (BJT) amplifiers. Circuits representing passive filters exist in EUREKA, however, pointing out their behaviours and functionalities, is new. The same happens with rectifiers and limiters. However, for BJT amplifiers and active filters, it will be necessary to build the circuits from scratch and formulate new questions. For circuits with distinct functions, the components that belong to the circuit can not have random values. For instance, to control the natural frequency, quality factor and the gain in filters, it is essential to define the values of the components, in order to have the quantities mentioned before within a certain range. These circuits will be gathered in a new Topic, where the object of study is the function of the circuits.

As for the intelligence in the multiple choices, it is achieved by using common students’ mistakes. The main goal is to prevent the student from eliminating, before calculations, a certain option, increasing the level of difficulty of the exercise. So, for each Topic / Concepts the typical errors were analysed and picked, in order to be used as the wrong answers on each problem.

The Help option, for all the topics, will follow the same reasoning as the Help from Topic one in EUREKA. It will provide a step-by-step solution to a representative problem, from both difficulty modes, that will guide the student to the final answer. So, it was picked from each mode, regular and challenging, a circuit that was not trivial, and then through some explanations and formulas, necessary to guide the student to the final answer, was developed the solution.

III. IMPROVEMENTS AND NEW CONTRIBUTIONS

A. Improvements

In this section, some of the principal modifications made to the existing Topics of EUREKA will be described.

On Topic 2 of EUREKA, Circuit Simplification Methods, the subjects object of study are: association of resistors and sources, and current and voltage dividers. At times, there were circuits, where no simplification could not be made. So, the topologies had to be rethought. Also, the structure of the Concepts was modified. Concepts A, instead of having association of resistors and sources, now have only association of resistors. Concepts C introduces the association of sources. With this new implementation, the students can consolidate more clearly the subjects.

On Topic 3 of EUREKA, Systematic Methods of Circuit Analysis, the concept of Scaling Method was unknown. Now, in EUREKA+, it exists. This method was included, because, sometimes, it is easier to do calculations, using the linear property:

\[ f(x\alpha) = \alpha f(x), \]

instead of applying other methods.

On Topic 5 of EUREKA, Step Response of Circuits w/a Capacitor or an Inductor, where the subject of study is the transient analysis of first order circuits, the main questions are the voltage across the capacitor, the current through an inductor and the power on the inductor or capacitor. So, new questions were added, concerning the current and the voltage across a resistor, the current through the capacitor and the voltage across the inductor. With this approach, there was an increase of the diversity of the questions.

On Topic 7 of EUREKA, Circuits with Diodes, instead of having only one diode, now it has exercises with two diodes. New topologies and questions were set to implement more efficiently the modification. New algorithms were implemented to simulate the several combinations of states: two diodes ON, one diode ON and other OFF, or both OFF. Also, for the internal resistances and threshold voltages of the diode were picked values that represent ideal diodes and others that represent real diodes.

On Topic 8 of EUREKA, Circuits with Operational Amplifiers, the addressed subjects are saturated and not saturated circuits with only one OPAMP. Now there is a new Concepts, Concepts C, that generates exercises with two operational amplifiers. Also, it was introduced a new element, which is the comparator, and the diversity of the topologies increased.
Considering an ideal OPAMP, the current at the plus and minus terminals is zero. However, in reality, this does not happen, their values are in the order of few μA. Sometimes, the current across the components is small, the same order of magnitude as the current in the terminal plus and minus of the OPAMP. To prevent this case, the components were sized depending on the configurations on Concepts A/B.

B. New contributions

A new Topic was created in EUREKA+ containing a subject already addressed in EUREKA: Nodal and Loop analysis.

As EUREKA has transient analysis of the first order circuits, EUREKA+ added the second order. The topologies were defined (the circuit has to have one inductor and one capacitor) and the questions chosen were the same as used in the first order, except the questions concerning the resistor. The calculations used to reach the final answer were obtained by hand, in other words, for each circuit was set the expressions for the natural frequency, \( \omega_n \), damping factor, \( \xi \), and for the initial conditions. After knowing \( \xi \), it is possible to know the equation that represents the behaviour of the circuit. Knowing all these the rest of the values needed to compute the final answer are easily obtained.

Zener diode is a diode used in the more advanced circuit analysis, because it can operate with negative voltages, in other words, when the voltage across the diode is less than the voltage for him to conduct in the reverse bias (breakdown voltage). The structure used for the zener diode is similar to the one used for the junction diode. However, a new algorithm, different from the one for junction diodes was developed, because zener diode has three different operating regions, contrary to the diode regions which are only two. The same considerations used in junction diodes are applied here in relation to the internal resistances and to the threshold and breakdown voltages.

Topic 12 of EUREKA+ corresponds to circuits with Bipolar Junction Transistors (BJT) and it has three Concepts. The first and the second correspond to operating point analysis. The last one contains incremental circuits. In this Topic, since the operating region of the transistor depends on the values of the components of the circuit, a sizing had to be made in order to ensure that the region is the desired on. The possible operating regions are: forward active, cut off and saturation. Each of the regions has specific conditions, Table I. These conditions concern PNP transistors, but they are applicable to NPN transistors. It is only necessary to consider, instead of \( V_{BE} \) and \( V_{CE} \), \( V_{BE} \) and \( V_{CE} \). The questions for the first two Concepts are the current or voltage at the base, emitter and collector; the voltage or the lost power between the collector and the emitter and there is also the possibility of asking the value of a certain component of the circuit.

There are three distinct topologies in these Concepts, as illustrated on Figures 1a, 1b, and 1c. These figures contain the maximum number of components that these topologies can have. For instance, Figure 1a can have only one independent source and two resistors or Figure 1b can have at minimum two/three independent sources and three/two resistors, respectively. Furthermore, BJT topologies have not only voltage sources, but also current sources, Figure 1a and consider both PNP and NPN transistors.

The last Concepts uses the sizing to ensure that all the circuits are in the forward active region, and knowing the values of \( I_C \) and \( \beta \), the constants: output impedance, \( r_o \), transconductance, \( g_m \) and \( r_\pi \) are calculated, Table II. \( V_T \) is the thermal voltage, typically \( V_T = 25mV \), and \( VA \) is the Early voltage, \( VA \in [50,150]V \).

The questions for this Concepts concern the output resistance, the input resistance and the gain and consider that the output can be either on the emitter or on the collector.

The last Topic that was implemented (Topic 13), gathers five Concepts that focus on the applicabilities of the circuits: Concepts A considers limiter and rectifier circuits; Concepts B contains circuits that perform arithmetic operations like sum, difference, derivative and integration; Concepts C has passive filters; Concepts D has active filters and Concepts E has amplifiers, using BJT.

### IV. INTELLIGENCE IN MULTIPLE CHOICE ANSWERS

The multiple choice intelligence consists on picking a set of typical errors of the students and then using them as the wrong answers for each problem. This intelligence varies according to the Topic / Concepts that the students pick, because the typical errors are dependent on the subject in study.

Considering the first Topic, Concepts A, the basic law is: Ohm’s Law. Therefore, the questions are:

- The current through a certain component;
- The voltage between to different nodes;
- The power in a certain component.

Then, some beginners errors are: get confused with Ohm’s law formula or with the order of magnitude of the components, changing current direction or voltage polarity and switch values of two components of the same type.

Here, circuits generated have only two nodes and two branches. So, they have, exclusively, two components: one independent source and a resistor. With this topology, the chosen errors for each question were:

**Voltage between two different nodes**

<table>
<thead>
<tr>
<th>Necessary conditions</th>
<th>Formulas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward active</strong> ( V_{BE} = 0.7V ) ( V_{CE} &gt; 0.2V ) ( I_C = \beta I_B )</td>
<td>( r_o = \frac{V_A}{I_C} ) ( g_m = \frac{V_C}{I_C} ) ( r_\pi = \frac{\beta}{g_m} )</td>
</tr>
<tr>
<td><strong>Saturation</strong> ( V_{BE} = 0.7V ) ( V_{CE} = 0.2V ) ( I_C &lt; \beta I_B )</td>
<td></td>
</tr>
<tr>
<td><strong>Cut off</strong> ( V_{BE} &lt; 0V ) ( V_{CE} &gt; 0V ) ( I_C = I_B = I_E = 0 )</td>
<td></td>
</tr>
</tbody>
</table>

TABLE I: Necessary conditions for each operating region.

TABLE II: \( r_o/g_m/r_\pi \) expressions.
MSC DISSERTATION, EXTENDED ABSTRACT, OCTOBER 2014

\[ X = -X, \quad (2) \]
\[ X = \pm I/R, \quad (3) \]
\[ X = \pm R/I. \quad (4) \]

Current through a certain component

\[ X = -I, \quad (5) \]
\[ X = \pm V \times R, \quad (6) \]
\[ X = \pm R/V. \quad (7) \]

Power in a certain component

\[ X = \pm R \times I, \quad (8) \]
\[ X = \pm V \times R. \quad (9) \]

The last one is the magnitude order mistake and it is applicable in all questions, due to the fact that in each circuit, the components values have different prefixes and, for example, the user can think that \( \mu \) is \( 10^{-3} \) instead of \( 10^{-6} \). Therefore, this value is calculated:

\[ X = \text{TrueValue} \times 10^{\text{interval}}, \quad (10) \]

\text{interval}=[-6,-3,3,6]. This interval illustrate some of the typical mistakes.

Note: \( X \) stands for the error associated with a certain quantity and \( \text{TrueValue} \) corresponds to the correct answer.

Since these circuits are linear and have only two elements, to achieve the wrong answers the circuit did not need to be simulated again. Each option is obtained by multiplying or dividing by a factor. For instance, in equation (3), the multiple choice option is obtained by dividing the correct answer by the resistor squared. According to the question, one of the options described above is picked up. However, as a result of the randomness, sometimes, it is possible to generate a multiple choice that is equal to the correct answer or even two equal multiple choice options. To prevent that, an additional error was applied. The approach used was to change the order of magnitude or the order of magnitude combined with a different signal.

V. THE NAVIGATION OF EUREKA+

EUREKA+ follows mostly the same navigation structure of EUREKA.

EUREKA has four buttons: Help, that enables the student to have some guidance in a certain Topic and degree of difficulty; Submit, that is used when the student thinks that he knows the final solution; Home, that is used to come back to the home page and finally New, when he wants a new exercise from the same Topic, Concepts and Degree of difficulty that he picked. When a student wants to change the degree of difficulty, for example, from regular to challenging, he has to go to the homepage and select, again, the Topic and the Concepts and lastly the degree of difficulty. So, instead of having only a NEW button, the student has now two buttons.
Eureka+

Electric circuits successfully Resolution with Kaleidoscopic Aid

Pick a topic from the list!

- Credits •

Eureka+ is under construction. Don’t let the bugs bite you!
Last update: 2014-10-10

What do you feel like practicing today? Start solving circuits like a pro!

1. Resistive Circuits with Constant Sources
2. Efficient Circuit Analysis Methods
3. Analysis Methods for Linear Circuits
4. Systematic Methods of Circuit Analysis
5. Circuits with Capacitors & Inductors
6. Transient Analysis of First-Order Circuits
7. Transient Analysis of Second-Order Circuits
8. AC Steady-State Circuit Analysis
9. Circuits with Junction Diodes
10. Circuits with Zener Diodes
11. Circuits with Operational Amplifiers
12. Circuits with Bipolar Junction Transistors
13. What are circuits for?

Mode: Regular Challenging

Fig. 2: EUREKA+ homepage

One of them that only generates exercises from the regular mode and the other that only generates circuits from the challenging mode. Figure 4b represents EUREKA navigation structure while Figure 4a represents the navigation structure of EUREKA+. Moreover, the last Topic on EUREKA+ does not have the possibility of choosing the respective mode. So that option was eliminated, as shown on Figures 3a and 3b. Also, the colors used in the online software application were changed to blue, to resemble more closely the colors of Instituto Superior Técnico and to provide more sharpness to the problems as it was one of the concerns of the students, Figure 2.

VI. FUTURE WORK

Although the work EUREKA+ is finished, it is possible to envisage several aspects to consider in a possible future work. At this time several aspects may be pointed out concerning the inclusion of new Topics and a more advanced version of existing ones.

Sometimes, the fact of seeing the graphics of the temporal evolutions of the signals of the circuits, it is a good idea to increase the knowledge and comprehension of the student. So, if EUREKA+ provides this tool would help even more students to consolidate better the subjects of study.

Since filtering circuits are included, relatively to the filters Topic, if a student could have the possibility of introducing an audio file in EUREKA+ to understand what the filter, object of analysis, does, it would be a source of motivation for him and a funnier way of learning while listening input and output signals to the differences between them.

Besides the new contributions and the improvements already described on this thesis, there are more subjects that can be added. For instance, EUREKA+ introduced transistors, however, only of the Bipolar Junction Transistor type. MOSFET or JFET transistors are also important and subject of study in many electronics courses. So they could be considered in a future work.
Two-port network analysis can also constitute a new Topic, because it is an useful tool in terms of simplification of circuit analysis. This is also a subject of interest in the first courses of electronics and even very useful in more advanced courses.

Relatively to the zener diodes Topic, this Topic could have exercises with not only one junction diode and one zener diode, but with two zener diodes, or instead of having an ideal diode whose threshold voltage is zero, it could be added exercises where that diode has an internal resistance and a threshold voltage different than zero.

Furthermore, full-wave rectifiers and precision rectifiers could be added. With this exercises, the students would join the Concepts learned on operational amplifier and on junction and zener diodes and their knowledge would be put at proof.

Also, ideal transformer could be included.

A new contribution could be a data base system, that could keep the information of each student. For that, the student would have to sign up. With a data base system, it could be generated graphics that would represent the evolution of the knowledge of the student, making him more confident or call him attention.

VII. CONCLUSIONS

EUREKA+ provides a student a free online software application for circuit analysis techniques practising. This application has the ability to provide an endless number of randomly generated circuits on thirteen main topics of circuit analysis. The first Topic concerns basic circuit analysis concepts. The second, third and fourth Topics introduces new methodologies of analysing a certain circuit. The fifth Topic introduces the first concepts studied about inductors and capacitors. The sixth and seventh Topics considers transient analysis of the first and second order circuits, respectively. In the eighth Topic it is the first time that students contact with AC analysis. The ninth and tenth have circuits with junction and zener diodes. Eleventh Topic introduces a new component: operational amplifier and the notion of saturated and not saturated amplifier. Twelfth Topic contains for the first time bipolar junction transistors. The last one gathers all the circuits that represents a specific function: rectifiers and limiters, arithmetic operations, active and passive filters and amplifiers. EUREKA+ is an useful tool that can follow a student in several courses, ranging from basic circuit analysis to introductory electronics, helping him/her to consolidate more efficiently the subjects that are object of study. It is possible to consider that EUREKA+ provides an alternative to the existent online software applications in the resolution of problems concerning circuit analysis and can be found at [http://eurekaaplus.tecnico.ulisboa.pt/](http://eurekaaplus.tecnico.ulisboa.pt/)

EUREKA+ provides multiple choice answers and a student has to choose between three or two different possibilities, depending on the subject being considered and the type of question being asked. In the case of three choices, the two wrong answers are not established randomly, but with intelligence, meaning that they are based on typical mistakes performed by students on each subject.

The application respects each student own pace and method while studying and practising circuit analysis because he/she is free to navigate to each Topic and Concept and to decide either to practice on basic or more advanced circuit analysis concepts or circuit topology and complexity. In order to help the first steps of a student on each Topic and Concept, help is provided with an example of a solved problem. Having this Help Option assures that the user can be reminded of the Concepts and the rationale used in the different Topics.

Although EUREKA+ has its basis on EUREKA, it improves and gathers more Topics/Concepts than are considered in EUREKA. EUREKA+ improves Topics/Concepts of EUREKA at several levels, namely circuit topology and constitution, organization of the Topics/Concepts. All inconsistencies that were found while testing EUREKA were also corrected.

REFERENCES