

Concepts to Questions: Creating an Electronics Concept Inventory Exam

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Abstract

Concept inventory exams are standardized tests that have been carefully designed to point out the common misconceptions that students have in a specific body of knowledge. We are currently developing an electronics concept inventory (ECI) exam for basic electronic circuits. In this paper, we present an example that is particular to the ECI to illustrate the general process that was used to select the core concepts and then create and revise questions. In addition, we address the current and future state of the ECI, and invite open discussion to improve the content of the ECI.

I. Introduction

Concept inventory exams are standardized tests that have been designed to point out the mastered concepts and common misconceptions that students have in a specific body of knowledge. Such an exam has been used extensively for Newtonian Mechanics and has led to substantial improvements in the physics curriculum in universities across the world¹. Recently, concept inventories have been developed for numerous other subjects such as thermodynamics, electromagnetics, and signals and systems². An added benefit of concept-inventories is that they are accepted as valid data for the ABET Accreditation process by showing proof of student learning and achievement³.

We are currently developing an electronics concept-inventory (ECI) exam for basic electronic circuits. One of the primary challenges in creating a concept inventory is identifying the core concepts of a subject and then the common misconceptions about each of those concepts. In addition, the questions pertaining to each concept must not be based on definitions or rely on computation to get the correct answer. We have gone through a process of selecting the core concepts and then creating and revising questions. The purpose of this paper is threefold: 1) to highlight and provide examples of our process as it relates particularly to the ECI, 2) to inform the community at large of the existence of the ECI and its current state, and 3) to spark debate over the content in the ECI.

A distinction is made between concepts and problem solving performance for the purposes of this exam. A concept is a fundamental idea used to understand electronics. Performance is the ability

to actually solve problems involving electronics. Calculations, procedures, and definitions do not constitute a concept, but all are involved in problem solving performance. Mastery of concepts is therefore a necessary but not sufficient condition for mastery of electronics. As such, we differentiate between this concept exam and a final examination given in a course. Both types of exams are necessary to provide assessment on different aspects of knowledge.

In order to determine which concepts have been mastered, we measure students' performance on questions centered only on basic understanding of the concepts. The question should not require a calculator, and should be able to be answered in a couple of minutes. We evaluate the understanding of the concept on the ECI by asking a question having four possible choices for an answer. One response is correct. The others represent incorrect conclusions arrived at because of common misconceptions such as confusing forward and reverse bias, incorrectly determining what portion of the voltage waveform produced forward bias, etc. By evaluating wrong answers, not only do we see on which concepts students are weak, but we also identify their misconception. Gross trends in mastered concepts and common misconceptions can give indications of learning successes and shortcomings. These indications provide valuable feedback that can be used either to ensure the adequacy of the current curriculum or to make curricular changes.

II. Procedure for Generating Questions

The first step in creating the ECI was to define the scope of the subject material and list the general concepts within this scope. We have informally surveyed 20 schools and found that they have on average 1.5 required semester courses on electronic circuit analysis and design. These courses introduce students to the use of diodes, transistors, and operational amplifiers in electronic circuits. The exam that we are developing is designed to assess student understanding of introductory electronics material that would typically be covered in the first course of a two-course sequence. The particular concepts that we address in the exam are discussed in more detail in Section IV.

The next step was to create and refine questions that cover the individual concepts. To help illustrate this process, we show how a typical circuit analysis problem (Figure 1A) is evolved, using a number of heuristics, into a valid ECI question (Figure 1B). (Note that this example is not an official exam question and therefore we are not compromising the ECI.) The first heuristic is to narrow the scope of the question to cover only a single concept. Although there is a single question shown in Figure 1, a number of different concepts are necessary to solve this problem including: 1) diode biasing, 2) RC time constant, and 3) recognition of circuit topology and function. In order to gain useful information from the results of the exam, it is important that the question focus on a single concept. For this example, we will focus on the effects of the RC time constant on the behavior of the circuit.

The second heuristic employed was to eliminate the need for computation to solve the problem. Computation is avoided by careful wording of the problem statement and presentation of the answers. For this example, the resistor and capacitor values can be removed and the question reworded to "Given that the time constant is large, but not infinite, choose which response most accurately represents the behavior of this circuit." The answers can be supplied in graphical form as shown in Figure 2 so that there is no need for computation.

The third heuristic used was to form the answers such that correct answer identifies proper understanding of the concept, and the incorrect answers accurately represent the students' misconceptions. To apply this heuristic, we attempted to design each incorrect answer to contain a single unique misconception. Figure 2C is the correct answer as specified by the "large, but not infinite" time constant. In Figure 2A, the misconception is to ignore the RC time constant and see only the half-wave rectifier. In Figure 2B the misconception is to confuse a large with a small time constant. In Figure 2D, the misconception is to confuse a large with an infinite time constant. Figure 2E is an example of a poor choice for a possible answer because it contains two concepts. This figure shows a full-wave rectified waveform, which is incorrect, but it also shows a "large, but not infinite" time constant, which is correct. If combined with the other answers, it is ambiguous as to why a student may have chosen answer this answer. The goal of this heuristic is to remove as much of this ambiguity as possible.

The fourth heuristic was to ensure that each problem was not dependent upon a non-standard term or definition. For example, in Figure 1 we assume that "time constant" is a standard term that every student should be required know before taking the ECI and therefore safe to use in the problem statement. The terms "ripple" and "DC power supply", however, may not be used as a standard at every institution and should be removed. Colloquial references to circuit topology should also be avoided. For example, the circuit in Figure 1 could be referred to as a DC power supply, rectifier circuit, or peak detector. If one of these terms is used, then students who have not been exposed to that particular nomenclature would be discriminated against. To ensure that the exam

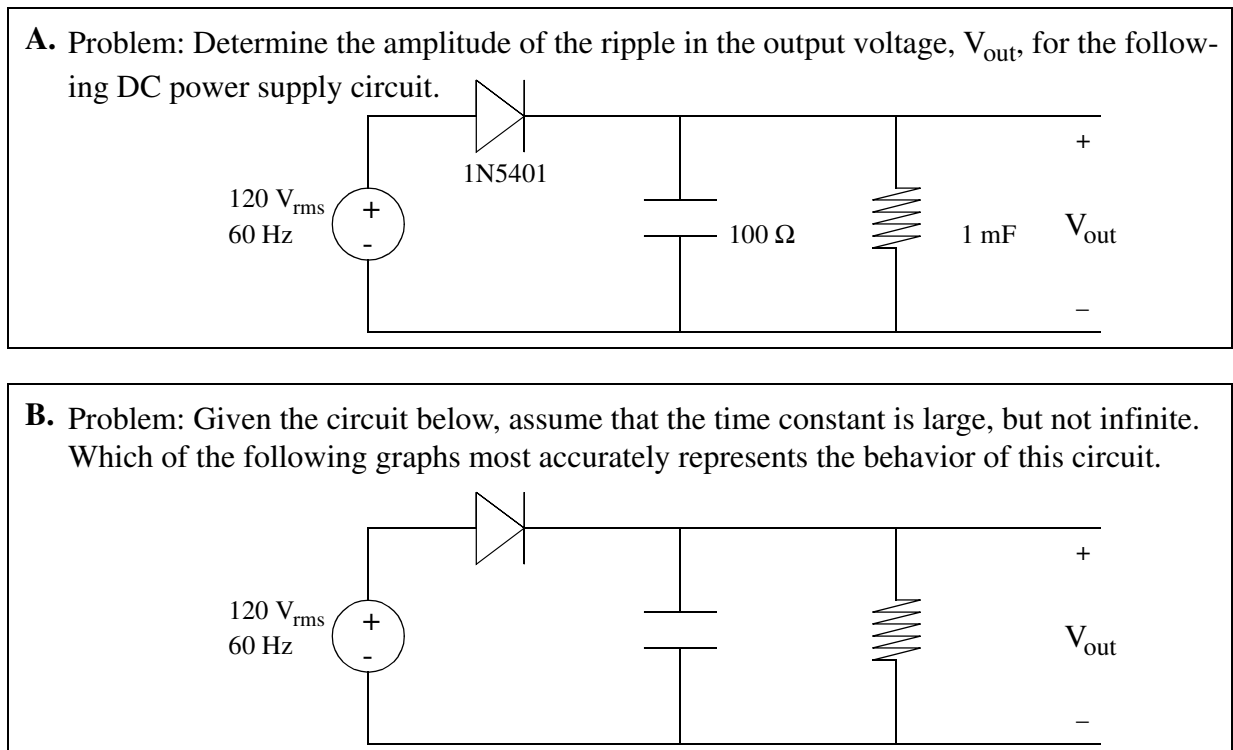


Figure 1: A sample question that illustrates the procedure we used to generate questions for the ECI. **A:** Typical circuit analysis problem for homework or exam in an introductory electronics course. **B:** The ECI question that is evolved from A using the heuristics described in the text. The possible choices for answers are the four graphs, Figure 2A–Figure 2D. Figure 2E would not be use as a possible answer because of an ambiguity.

is free from confusing terminology, we are conducting focus groups with students and soliciting feedback from faculty across the country.

III. Standardization of the Exam

There are two important reasons why the ECI must be accepted as a standard across the country. First, one purpose of a concept inventory is to collect and combine data from as large a sample as possible, which can only happen if the exam is standardized. Second, the ECI data can only be used for ABET accreditation if it is accepted as a national standard³.

In order to give the ECI this significance, we have invited a number of ECE faculty from other universities to participate in its evaluation and generation. The external faculty are asked to critique the present exam and comment on the validity of the present questions. The wording of each question should be analyzed and any ambiguities should be addressed. Confusion in terminology should be identified and removed from the problem. In addition, each external faculty is asked to generate one new question for the exam and to suggest one question that should be removed from the exam.

IV. Current State of the ECI Exam

The exam is currently in its beta testing stage. We have made several revisions to the exam, and have incorporated limited information from external feedback. The exam has been used and preliminary data collected from five courses at Rose-Hulman and two courses from other schools. In addition, we have conducted a focus group with 13 students from Rose-Hulman, who have provided feedback on the wording of the questions. (We will present these preliminary results at the conference.) This summer we will make a final revision of the ECI based on the data that we col-

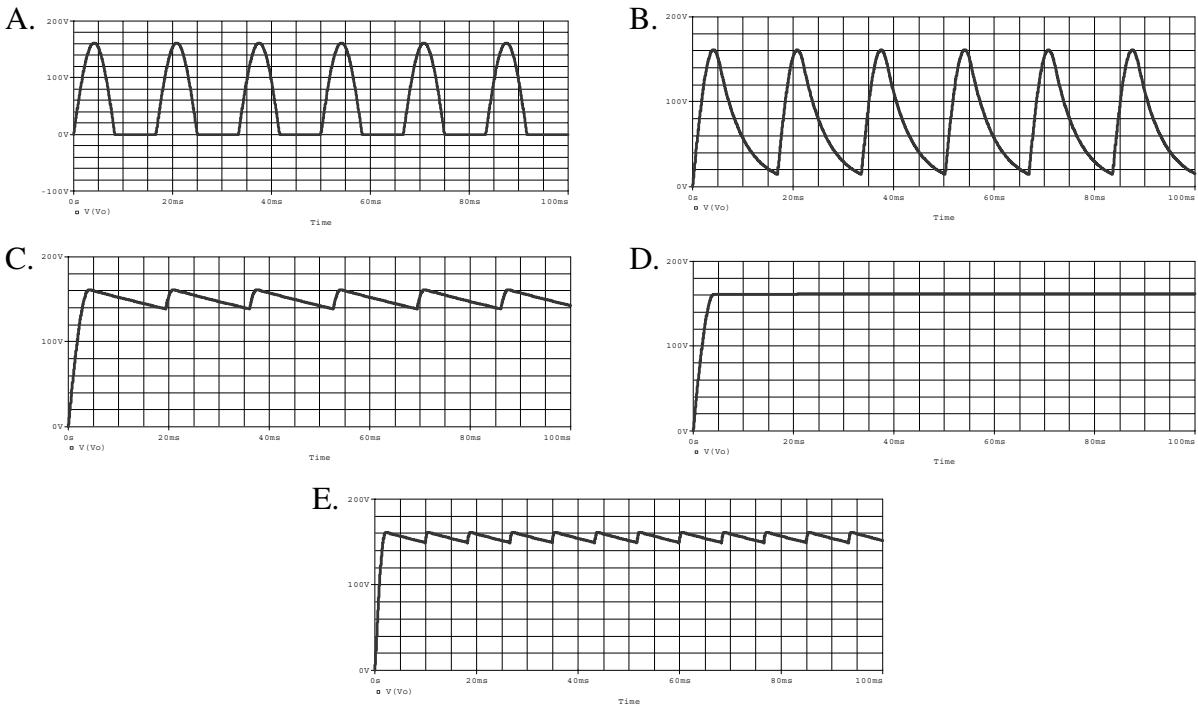


Figure 2: Possible answers that could be used for the sample ECI question in Figure 1B.

lect from beta testing and additional feedback from the faculty external to Rose-Hulman. We expect this version to be released to the public in the Fall of 2004.

The range of topics that are covered on the final version of the exam is still open for debate. Table 1 lists the key subject areas and the number of questions related to each of these subjects that are included in the current beta version of the ECI. As mentioned previously, this exam addresses introductory-level electronics concepts focusing on diodes, single-transistor circuits, and device modeling. To avoid compromising the exam, we are not including a detailed list of concepts in this paper. However, we will be presenting questions from the exam at the conference, and a complete copy of the exam can be requested from any of the authors.

Table 1: Breakdown of Questions for Beta Version of the ECI

Subject	# Questions
Basic Circuit Analysis	7 (23%)
Semiconductor Physics	4 (13%)
Diode Circuit Analysis	4 (13%)
Single Transistor Circuit Analysis	9 (29%)
Device Modeling	7 (23%)

One aspect of this exam for which we have received comments is the inclusion and number of basic circuit analysis questions. These questions are necessary for two reasons. First, they remove some ambiguity from interpretation of the ECI's results by helping to identify the reasons for incorrect answers. These questions were carefully chosen to reflect the background knowledge that is necessary to correctly answer the electronics questions. As such, they can help determine if a student answered incorrectly because they did not understand the electronics concepts or because they did not have the appropriate background knowledge. Second, these background questions help to booster the students' morale by giving them questions that they should be able to answer easily, even when the exam is used as a pretest. Discouragement during test taking can skew the exam results from an accurate representation of what the students know. By boosting their morale slightly, we hope to achieve more accurate results.

V. Summary

We have demonstrated the general process that was used to generate the initial version of the ECI exam. Although the example used to illustrate this process was specific to the ECI, the process itself is general and can be used to generate concept inventory questions for any subject. We are currently working with a number of faculty from other institutions to ensure that the ECI has credibility as a nationally standardized exam and the proper content for it's intended purpose.

VI. Acknowledgments

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VI. References

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VII. Author Information

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