ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

2017 ASEE Mid Atlantic Section
Spring Conference: Morgan State University, Baltimore, Maryland Apr 7 Paper ID #20816

Assessing ABET Outcome E in a Junior Level Circuit Analysis Course Using a TPN Design Problem.

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Assessing ABET Outcome E in a Junior Level Circuit Analysis Course Using a Two Port Network Design Problem.

By

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Abstract

A major challenge in the education of engineers is to get student to develop critical thinking skills. ABET[1] outcome E states that students should be able to "*identify, formulate, and solve engineering problems*". Although a major amount of time in class is usually devoted to the process of solving engineering problems, not as much is allotted to the identification of a problem or the formulation of a unique solution to that problem. Students routinely can assess an engineering problem and identify a procedure, similar to one shown in class, to find a solution but they may struggle formulating their own strategy to yield a solution. Thus, the opportunity to develop critically thinking skills is lost.

This paper outlines the procedure followed to collect and demonstrate ABET outcome E in a junior level Electrical Circuits course. The paper describes a multi-step design of a two-port network used to achieve a bi-directional match of an arbitrary complex load to an arbitrary complex source. Additionally, it provides the details of the problem, the assessment method implemented to demonstrate Outcome E, and the results obtained.

Background

At Penn State Hazleton, students in the Bachelor of General Engineering Program[2],[3] (BSGE) are required to complete two electrical circuit analysis courses. The relevant educational objectives of this series of two courses are:

- Learn the fundamental skills in the analysis of electrical circuits by integrating a background in physics and mathematics with the conventions of electrical engineering.
- Apply the definition of driving point impedance to find the terminal impedance of a circuit and design an equivalent circuit.
- Apply the definitions of Two Port Networks to find the TPN model of a circuit.
- Use driving point impedances and Thevenin equivalent circuits to analyze/design circuit interfaces for voltage, current, and power transfer.

In the first course (PSU EE 210) they learn the fundamentals of circuit analysis. One concept they learn is Thevenin's Theorem, where any linear circuit can be modeled as a one-port device consisting of an AC voltage source, V_t, in series with an impedance Z_S. A complex load, Z_L, can then be connected to the Thevenin equivalent source, as shown in Figure 1, to achieve maximum power transfer to the load. This occurs when the load impedance is chosen to be the complex conjugate of the source impedance: $Z_L = Z_S^*$. In the case of pure resistance, the load resistance simply equals the source resistance for max power.

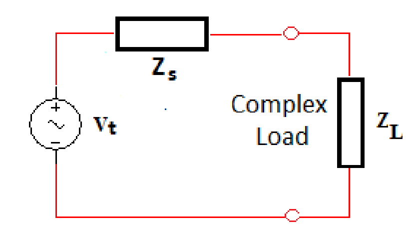
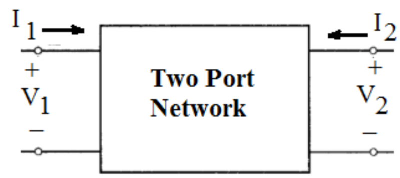


Figure 1

In the second circuit analysis course (PSU EE 314), the students are introduced to the concept of a two-port network (TPN). As shown in Figure 2, the TPN has an input port on the left, port 1, and an output port on the right, port 2. The TPN's Z parameters, Z_{11}, Z_{12}, Z_{21}, Z_{22}, are defined in such a way as to relate the voltages on either side to the currents. Additionally, the network system equations in matrix form are also shown in Figure 2.



$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \end{pmatrix}$$

Figure 2

Once the Z-parameters of any TPN are known, it is useful to analyze the performance of the TPN with a complex Thevenin source connected to port 1 and a complex load connected to port 2, as shown in Figure 3. The impedance the load sees looking into port 2, Z_{th}, is found by setting the source voltage, V_t, to 0V and applying 1V on port 2. Using the network equations in Figure 2, I_2 can easily be calculated and Z_{th}, becomes the reciprocal of I_2, and found to be:

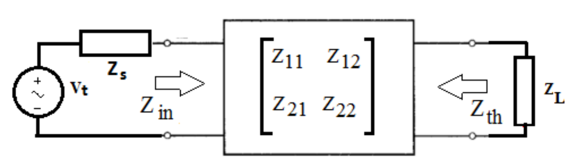


Figure 3

$$Z_{th} = Z_{22} - \frac{Z_{12}Z_{21}}{Z_{11} + Z_S} \quad \text{(Eq. 1)}$$

The impedance the source sees, Z_{in}, looking into port 1 when port 2 is terminated by a load impedance Z_L, is found by applying 1V to port 1 and calculating I_1. Z_{in} is the reciprocal of I_1 and found to be:

$$Z_{in} = Z_{11} - \frac{Z_{12}Z_{21}}{Z_{22} + Z_L} \quad \text{(Eq. 2)}$$

Design Problem

Matching a load to a source for max power, as shown in Figure 1, is relatively simple if you can arbitrarily select the load impedance to be the complex conjugate of the source impedance. In many practical situations however, the source and load impedances are fixed. In this situation, it is required to design a two-port matching network.

The students are given this assignment in two parts. During the first part, they are instructed to describe the approach they will take to design the matching network if values for Z_S and Z_L are given. Further, they are instructed to set $Z_{11}=Z_S^* + 1$ to make the formulation simpler, and also to assume a bilateral "tee" structure for the actual matching network, which makes Z_{12} equal to Z_{21}. This reduces the four unknown Z parameters to just two: Z_{21} and Z_{22}. The following questions must be answered for Part 1, before they receive the instructions for Part 2.

1) See if you can construct two independent complex equations in terms of Z_{21} and Z_{22} that can be solved simultaneously to yield the solution for the Z matrix. You can assume the complex load impedance, Z_L, is known.
Do not attempt to solve these equations until the instructor has verified that your approach is appropriate. If you are unable to write the actual equations, at least discuss the concepts needed for matching this system from both directions.

2) Show how the calculated values of the bilateral Z matrix can be used to construct the impedance "Tee" network and actual resulting bilateral "Tee" impedances Z_A, Z_B, and Z_C.

3) With the values Z_A, Z_B, and Z_C determined, discuss how you can test your design and verify it meets the design specifications.

Referring to Figure 3, if the students can formulate their own approach to this design, they will understand that the impedance the load sees looking into port 2, Z_{TH}, must equal the conjugate of the load impedance, Z_L. Setting this equal to (Eq. 1) yields:

$$Z_{th} = Z_{22} - \frac{Z_{12}Z_{21}}{Z_{11}+Z_S} = Z_{22} - \frac{Z_{21}^{\ 2}}{(Z_S^{\ *}+1)+Z_S} = Z_L^{\ *} \quad \text{(Eq. 3)}$$

In a similar way, the input impedance seen looking into port 1, Z_{in}, must equal the conjugate of Z_S and setting this equal to (Eq. 2) yields:

$$Z_{in} = Z_{11} - \frac{Z_{12}Z_{21}}{Z_{22}+Z_L} = (Z_S^{\ *}+1) - \frac{Z_{21}^{\ 2}}{Z_{22}+Z_L} = Z_S^{\ *} \quad \text{(Eq. 4)}$$

(Eq. 3) can be solved for Z_{21}^2 and substituted into (Eq. 4) to yield Z_{22}. Once Z_{22} is found, Z_{21} can be found by substitution.

The actual bi-lateral "Tee" impedances, shown in Figure 4, are calculated as:

$Z_A = Z_{11} - Z_{21}$
$Z_B = Z_{22} - Z_{21}$
$Z_C = Z_{21}$

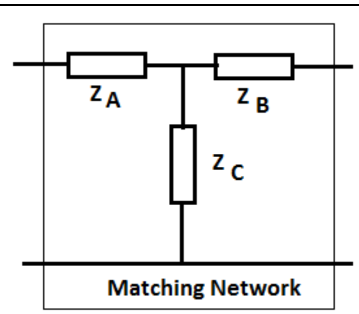


Figure 4

To test the solution, students need to simply insert the bi-lateral “Tee” values into the TPN box of Figure 3, and using series and parallel impedance formulas, verify that:

$$[(Z_B + Z_L) \parallel Z_C] + Z_A = Z_S^*, \quad \text{and} \quad [(Z_A + Z_S) \parallel Z_C] + Z_B = Z_L^*.$$

By verifying these conditions, the design is proven correct.

Assessment Procedure

The General Engineering Program Outcomes, a through k, are directly mapped from the ABET criteria also named as such. A program wide rubric for each outcome was created, and targeted courses for each were identified to demonstrate each outcome[4]. For each rubric, several performance indicators were developed. In the case of program outcome E, “*students shall identify, formulate, and solve engineering problems*“, the three performance indicators that were defined are

- (5.1) Identify and define engineering problems completely & accurately.
- (5.2) Select appropriate methods and tools for the solution of engineering problems.
- (5.3) Implement engineering solutions and verify that they meet requirements.

EE 314 was one course chosen to demonstrate successful student performance for Outcome E. Specifically, the design assignment detailed in this paper was measured against performance indicator PI (5.3).

The rubric lists the student proficiency levels for PI (5.3) as:

> <u>Unsatisfactory:</u> Student cannot implement any solutions to a given engineering problem. Cannot verify whether a solution meets the given requirements of the problem.
>
> <u>Developing:</u> Student can partially implement a solution to a given engineering problem. Can partially verify whether a solution meets the given requirements of the problem.
>
> <u>Satisfactory:</u> Student can implement a basic solution to a given engineering problem. Can verify whether a solution meets the given requirements of the problem at a basic level.
>
> <u>Exemplary:</u> Student can fully implement an advanced solution to a given engineering problem. Can fully verify whether a solution meets the given requirements of the problem at an advanced level.

It is important to realize that the Program Outcomes and corresponding performance indicators are general in nature and not course specific. This requires that each instructor using the rubric to reflect seriously on the choice of appropriate course evidence and the attained proficiency levels associated with that evidence.

As previously mentioned, the TPN design assignment outlined here was split into two parts. The first part required the student to formulate their own design approach by using concepts previously learned and apply them in an innovative way. Once that part was completed, it was collected, assessed, and graded. The various solutions were reviewed with the students and they were then directed to complete part 2. Each student was assigned different numerical values and asked to complete the TPN matching network design and verify that their results were accurate.

In order to access the student performance level using the TPN design problem, the following *course specific* performance indicator was developed:

- EE 314 course specific Performance Indicator (5.3):
  Student will be able to formulate a solution to design a two port bilateral matching network that will match a complex load to a complex source impedance. Student will be able to test the solution to verify it meets the design specification.

To access the performance level of each student, the following *course specific* rubric was developed:

<u>Unsatisfactory:</u> Student cannot solve for equivalent Thevenin source impedance. Does not understand the concept of impedance matching for maximum power transfer and therefore cannot develop a formula.

<u>Developing:</u> Student can solve for the equivalent Thevenin source impedance. Can relate the concept of forward matching: Zin =Zs* and/or reverse matching: Zthev=ZL* Can formulate an approach that yields at least one of the two required non-linear equations.

<u>Satisfactory:</u> Student can solve for the equivalent Thevenin source impedance. Can relate the concept of forward matching: Zin =Zs* and reverse matching: Zthev=ZL*. Can formulate an approach that yields both of the non-linear simultaneous equations . Can find solutions if given minimal direction.

<u>Exemplary:</u> Student can solve for the equivalent Thevenin source impedance. Can relate the concept of forward matching: Zin =Zs* and reverse matching: Zthev=ZL*. Can formulate an approach that yields both of the non-linear simultaneous equations and can independently find solutions. Is able to test solutions by verifying that the resulting forward input impedance of the T network terminated with ZL equals Zs*, and the reverse Thevenin impedance the T network and Zs equals ZL*.

Results and Conclusions

The TPN matching network assignment was administered to eight students for the first time during the fall of 2016 semester. Results of the assessment are shown below in Figure 5. The number of students attaining each performance level is divided into three parts: part 1, part 2, and overall. Successful student performance translates into a performance level of satisfactory or exemplary.

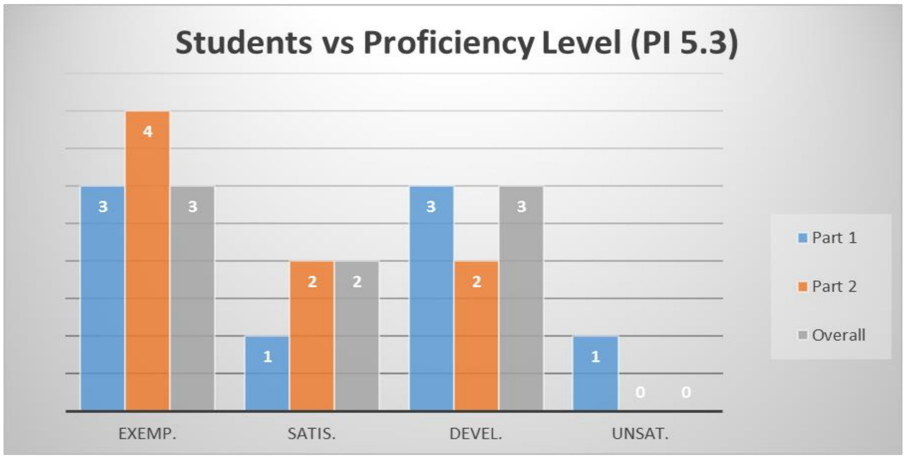


Figure 5

The data indicates that students' success attaining this performance indicator, was higher in part 2 (75%) than in part 1 (50%). This is as expected result, since part 1 required more critical thinking skills, than part 2. Overall, the students performed 63% percent. This level of success leaves much room for quality improvement, but at least there is confidence that the assessment procedure outlined in this work is a good tool for measuring and demonstrating ABET outcome E.

[1] www.abet.org

[2] Dudeck, K., Grebski, W. (2013). Energy Education and Training: A Case Study. In Anwar, S. (Eds.), (Vol. On line, March 2013). Taylor and Francis. http://www.tandfonline.com/doi/abs/10.1081/E-EEE-120048423.

[3] Dudeck, K., Grebski, W. (2011) "New General Engineering Program with Alternative Energy and Power Generation Track at Penn State". *American Society for Engineering Education, (ASEE) Annual Conference ASEE New England Regional Conference Proceedings*.

[4] Dudeck, K., Ranalli, J. (2015). "ABET Accreditation Model for a Multi-Option General Engineering Program at Multiple Locations." ASEE Mid-Atlantic Regional Conference Proceedings. (pp. 7). American Society of Engineering Education.