

A Comparative Analysis of Simulation Software for a Circuit Analysis Course

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Abstract

Numerous textbooks in circuit analysis use simulation software to offer an alternative method of understanding the class material. These software packages enable a student to develop various problems, understand what the solutions are, and to assist in visualizing the resulting outputs.

The textbook in one of the third year ECET (Electrical and Computer Engineering Technology) courses at New Jersey Institute of Technology use Matlab as one of the simulation tools. The examples using Matlab are in areas such as solving simultaneous loop equations, plotting output voltages for a simple RC circuit, Laplace transforms, inverse Laplace transforms, impulse responses and Bode plots.

Over the last year, the author has incorporated Mathcad into this course, and used that application to create the simulation examples that were originally in Matlab. The actual application that the students used was a free version of Mathcad, called Mathcad Explorer.

There were several advantages for the student in using Mathcad, and this paper will discuss the advantages and disadvantages of each package in creating and modifying these types of examples. There were other areas in the text that needed examples from one of these simulation applications and some of the additional examples will be discussed. Also, student experiences using Mathcad will be reviewed.

Introduction

A variety of software tools have been used to enhance the learning process for technical courses. These mathematical computational tools allow the students to both compute and visualize solutions to many difficult problems. Two of the more commonly used mathematical computational tools are Matlab® (The Mathworks, Inc.) and Mathcad® (Mathsoft, Inc.). Both applications are used extensively in both research and teaching.

In the ECET (Electrical and Computer Engineering Technology) program at New Jersey Institute of Technology, there is a course entitled "Circuit Analysis - Transform Methods". Topics such as graphical differentiation and integration, Laplace Transforms, Bode plots and Fourier analysis are covered in this course. In addition, topics such as complex numbers and time analysis of circuits are reviewed. The current edition of the textbook for this course¹, which is utilized by EET programs in numerous colleges, contains examples using both Matlab and Electronics Workbench.

There were two problems with the Matlab examples in the textbook. The first problem was that only a few concepts in the text were illustrated with Matlab examples. Additional concepts could be illustrated, and it was important that the students be given these examples. The second problem was that students did not use Matlab prior to this course. This is because all the students are transfer students from community colleges, since the ECET program at NJIT is an upper division engineering technology program.

In reviewing the need for additional examples, the author was concerned that there would be too much time spent by the students learning Matlab. However, Mathcad (either version 7.0, 8.0 or the new 2000 version) could be used as an alternative software application for most of the Matlab examples, as well as illustrating areas not covered by Matlab examples in the text.

Mathcad had several benefits for the students. First, NJIT has a license for Mathcad, and it was available on the campus computers. This was also true for Matlab. The second benefit was that Mathcad offers a more realistic looking equation than Matlab, especially when dealing with integrals and derivatives.

A third benefit was based on the author's six year experience as a computer training consultant. The author felt that in comparing applications, Mathcad would have a much smaller learning curve. In fact, students were able to learn the basics of this application within a week, using a brief training manual that was developed by the author. The Mathcad manual provided a brief introduction to basic concepts, and if students were interested in learning more about the application, two additional texts^{2,3} were suggested.

A fourth benefit in using Mathcad was that multiple examples could be opened, without closing the original example. NJIT provides carts with computers and projectors which can be incorporated into the lecture. The ability of switching to multiple examples by going to the Windows part of the menu bar provided a quicker means to the author of demonstrating these examples to the students.

There was one final benefit with using Mathcad instead of Matlab. Students were able to download a free limited version, called Mathcad 8 Explorer, by going to the home page of Mathcad, <http://www.mathcad.com/>. Mathcad Explorer is a free read-only version of Mathcad, with the major limitation that students could not save their work. However, students could still create and solve problems using this software, as well as open and modify worksheets that were created by the author. The student version of Matlab 5.3, which is available directly from the manufacture, costs \$99.

General comparison

The relative complexity and results using both Matlab and Mathcad can be illustrated by reviewing sample problems from Matlab texts^{4,5} and from the course textbook. These examples were created using Mathcad 7.0 Professional, which is actually two versions older than the

current version Mathcad 2000, and the most recent student version of Matlab, which is version 5.3. This student version of Matlab has the same functionality as the standard version.

The first topic that was discussed in the course was complex numbers. Many topics in this course require the students to have a complete understanding of complex numbers. This understanding includes conversion of polar to rectangular forms, rectangular to polar forms, and adding, multiplying and dividing complex numbers. Figure 1 shows a Mathcad worksheet that was provided to the students by the author, to help practice some of their skills in complex number. Fig. 2 shows a related Matlab command window.

$$\begin{aligned} A &:= 5 + 5j \\ B &:= 2 - 3j \\ C &:= 6 + j \\ D &:= -2 + 5j \\ \frac{A}{D} &= 0.517 - 1.207i \\ \frac{B \cdot C}{D} &= -3.793 - 1.483i \\ \frac{A + C \cdot D}{B} &= -9.462 + 2.308i \end{aligned}$$

Figure 1 Example of complex number Mathcad worksheet

```

>> A = 5+5j;
>> B = 2-3j;
>> C = 6+j;
>> D = -2+5j;
>> A/D
ans =
    0.5172 - 1.2069i
>> (B*C)/D
ans =
   -3.7931 - 1.4828i
>> (A+C*D)/B
ans =
   -9.4615 + 2.3077i

```

Figure 2 Example of complex number Matlab command window

In both applications, the variables A, B, C and D first need to be defined. Note that in the Mathcad application (Figure 1) expressions, such as $\frac{A + CD}{B}$ are entered as if you were to write

them on paper, while the Matlab expressions (Figure 2) appear to be similar to a programming language context. One very important difference between the two applications is that a student can easily go back to the top of the Mathcad worksheet, click and drag over the original

expression for a variable, such as A in Fig.1, and enter a new expression. After entering the new value for the variable, and clicking outside that expression, Mathcad will automatically recalculate expressions that utilize that variable. The author provided the students with the worksheets that are shown in this paper, and the students could modify quickly these worksheets to create new problems. As soon as they modified the worksheet, Mathcad would recalculate the new expressions. Matlab does not allow you to go back and redo the original value. Students must redefine the variable again by typing a new formula at the bottom of the window, such as $A=2-3j$, and then retype the expression to obtain a new value. For examples such as Figure 1 and Figure 2, Mathcad would be much quicker to create several new examples based on the original worksheet.

Another demonstration of how Mathcad displays more realistic looking expressions can be seen in Figures 3 and 4. These figures illustrate how both Mathcad and Matlab can be used to change a rectangular form to a polar form.

Rectangular to Polar Conversion

$A := 5 + 5j$

To convert from rectangular to polar, you need to derive magnitude and phase

$$\text{magA} := \sqrt{\text{Re}(A)^2 + \text{Im}(A)^2} \quad \text{phaseA} := \text{atan}\left(\frac{\text{Im}(A)}{\text{Re}(A)}\right)$$

$\text{magA} = 7.071 \quad \text{phaseA} = 45^\circ \text{deg}$

If you want to use standard Mathcad operators for magnitude and phase, the results would be the same.

$$|A| = 7.071 \quad \text{arg}(A) = 45^\circ \text{deg}$$

Figure 3 Rectangular to Polar conversion using Mathcad

```

>> % Rectangular to Polar Conversion
>> A= 5+5j;
>> mag = sqrt(real(A)^2+imag(A)^2);
>> mag

mag =

    7.0711

>> phase = (atan(imag(A)/real(A)))*180/pi;
>> phase

phase =

    45

>> %There are standard Matlab expressions for magnitude and phase
>> abs(A)

ans =

    7.0711

>> angle(A)

ans =

    0.7854

```

Figure 4 Rectangular to Polar conversion using Matlab

There are several significant differences between Figures 3 and 4. The first difference is that the expressions for square root and square using Mathcad are more realistic than the expressions used for Matlab. A second difference between the two applications is that if the variable A (Figure 3) were changed in Mathcad, the answers would be automatically recalculated. A third difference is that in finding the standard Mathcad expressions for magnitude and phase, a standard windows help dialog box was used, and features such as index and find are available. In addition, a toolbar in Mathcad was used to find the expression. In Matlab, the help dialog box is not a traditional windows format, and there are no toolbars or menu bars to help find the appropriate command.

The students in this class were experienced with several Window based applications, such as Word, PowerPoint and Excel. Computer applications that follow the standard Windows format, using a traditional help window dialog box and menu bars or toolbars for the various commands, are much easier for students to learn.

There are two other significant advantages for students using Mathcad that are demonstrated in this simple example. The first advantage is that you can easily type anywhere in the worksheet, format the text with available fonts and styles, and move the text around the worksheet. This enables the student to create a well-designed assignment that can be either printed from Mathcad or incorporated into another application, such as Word.

The other advantage for Mathcad is in its use with applications such as Word or Excel. Students must incorporate these Mathcad examples in a report, by copying and pasting the results within Word. If a change needs to be made in the Mathcad example, then simply double clicking within the pasted object will open up the Mathcad application, since this application supports

OLE automation. The students can modify the pasted object without having to open Mathcad. This is not possible with Matlab.

There are other advantages in using Mathcad over Matlab for the various examples in the text. One of these advantages occurs when a plot is needed. Figure 5 shows the results when an exponential equation, such as the output voltage of a RC circuit, is plotted using Mathcad. Figure 6 shows the same results using Matlab.

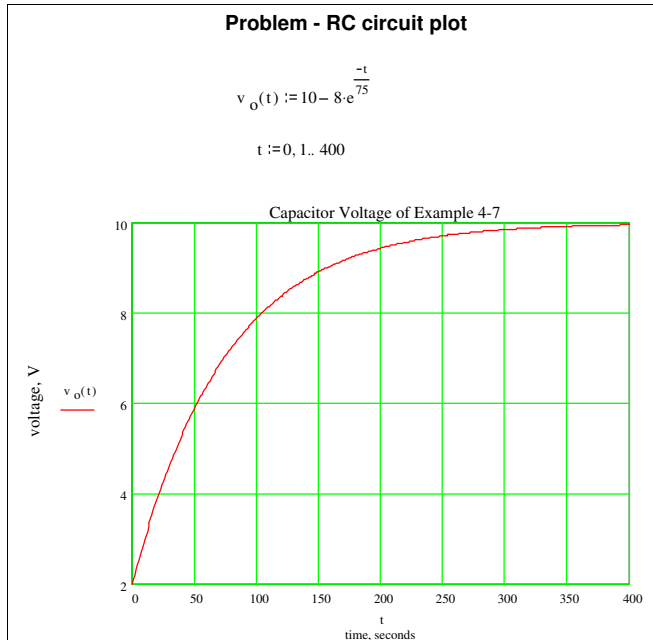


Figure 5 Graph of output voltage equation using Mathcad

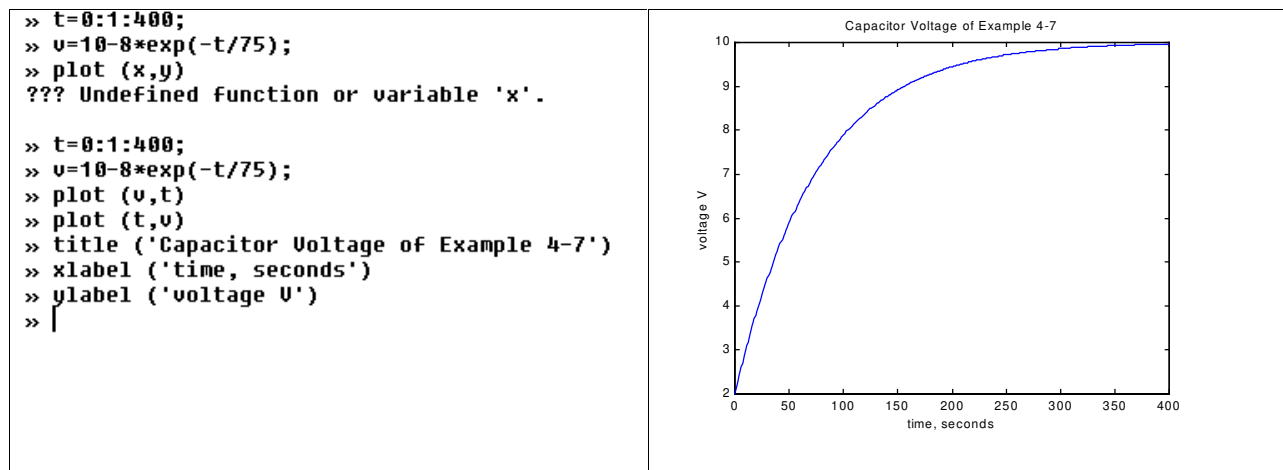


Figure 6 Graph of output voltage equation using Matlab

The best way to graph a function, in both applications, is to define the limits of the variable, t , before the graph is created. In Figures 5 and 6, the limits of t are from 0 to 400, in increments of 1. However, both applications have the ability to graph a function even though you have not defined the dependent variable.

Once the function is defined, such as $v_0(t)$, typing that function in Mathcad followed by the @ sign (Shift-2) causes a graph of that function to appear. In Matlab, you need to type the word Plot, followed by various commands. Therefore, in creating a graph, both applications are equivalent. Once a graph is created, doubling clicking in the appropriate area of the graph in Mathcad (either the graph area or the axes) will produce a dialog box, which can be used to modify the graph. The most recent version of Matlab, version 5.3, has also incorporated this feature.

There are two advantages to the students using Mathcad for this example. One of the advantages is in the way mistakes can be corrected. A mistake was purposely made in Figure 6, while programming in Matlab. Once a mistake is made, the student cannot go back and correct it. The student must continue typing in the code, and possibly have additional errors. In Mathcad, the an error is indicated by the expression turning red. The student can drag the mouse over the expression and correct it.

The other advantage to the student when comparing Figures 5 and 6 is that in Mathcad the calculations and the graph are on one worksheet. If the student wants to copy and paste to a Word document, or a PowerPoint application, the entire worksheet can be embedded in the application. In Matlab, the code and the graph are separate. Figure 6 is a result of the author placing the two separate sections in a table, rather than embedded as one object.

Based on these observations, additional examples were either modified for Mathcad or created for Mathcad.

Laplace Transform

Mathcad can perform symbolic mathematics, such as the Laplace Transform of a time function or the inverse transform. A worksheet was set up so the students could easily change the original time function or transform (see Figure 7), and observe the resulting calculations.

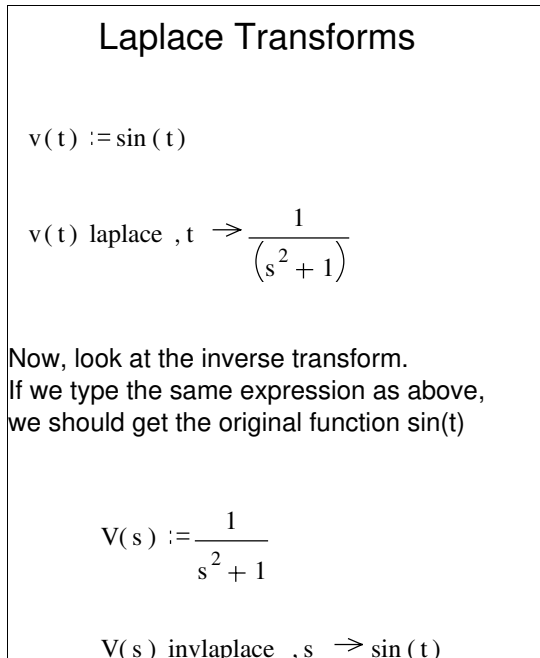


Figure 7 Laplace transforms using Mathcad

Students could graph the results of the inverse transform (see Figure 8), and then by changing the transform in the worksheets of both Figures 7& 8, and observe a new time solution and graph, which would be automatically recalculated. This was an original Matlab example.

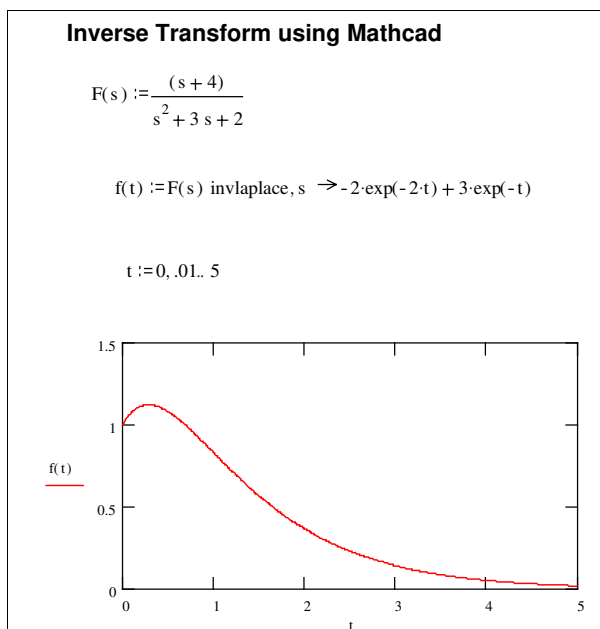


Figure 8 Graphing results of inverse transforms using Mathcad

Fourier Analysis

The concept of creating a waveform from a harmonically related summation of sinusoids was demonstrated in Mathcad with the worksheet in Fig. 9. There were no Matlab examples illustrating this chapter. This Mathcad workbook was designed to demonstrate to students how adding harmonics of a sine wave could produce other waveforms. The summation item in the Calculus Palette of Mathcad was used to create the Fourier series representation, and a generalized function $g(i,t)$ was created so that the Fourier series representation can be easily changed, and a new graph would be automatically created. Three functions (Odd, Even, and All) were created to account for odd, even or all harmonics being present in the Fourier series. By changing the variable n , the resulting change in the graph will show the effects of adding additional harmonics. This was very effective in helping the students understand how many harmonics are necessary to adequately reproduce a square wave. A similar worksheet could be created for another waveform.

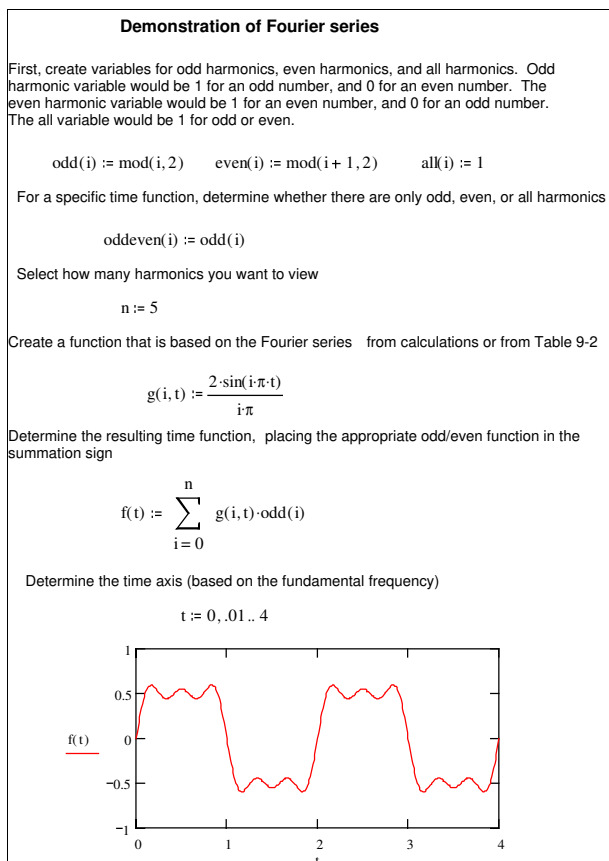


Figure 9 Mathcad worksheet demonstrating the sum of harmonically related sinusoidal functions

Student Experiences

A survey of twenty-six students in two sections during the spring 1999 semester was taken at the end of the semester. Using a ranking of 1 to 5, where 1 indicated a lack of knowledge of the program and 5 indicated an expert in the program, the student average in in Mathcad knowledge changed from 1.27 to 2.62. This analysis was not based on measuring the students' actual use of the software packages, but rather measured their perception of how well they understood these packages. Many students were able to modify the worksheets that were provided to them within one week after reading the author's manual

When asked what specific part of the course the simulation software helped, the majority of students wrote that Mathcad helped in better understanding complex numbers and integration. In addition, from the results in the two sections final exam, compared to previous semester's finals, the students appeared to better understand the concepts of Fourier analysis.

Conclusion

While both Mathcad and Matlab are excellent mathematical computation tools that can be used in research, Mathcad offered several advantages in using this type of computer application for educational purposes. The ease of use, the ability to incorporate the results in Word documents, and the ability to modify variables and automatically recalculate results made this application helpful to junior level engineering technology students.

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