Session _____

Use of Microsoft Excel to Create Graphs for Classroom and Quizzes

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Abstract

Graphs of voltage, current, and power waveforms, as well as transfer functions are extremely useful in the classroom for illustrating theoretical points, yet their preparation is laborious when done by hand. Preparing them using traditional programming languages requires some level of mastery of those languages and debugging such programs is an error-prone process, to put it mildly. These difficulties often lead to the continual re-use of identical plots, sometimes undermining the learning process. Such obstacles also discourage the preparation of original quiz or test questions, making it more tempting for students to substitute memory work for real learning. In this paper, we explore the preparation of customized plots using Microsoft Excel, a widely available spreadsheet program. The author has used this method extensively in teaching electrical engineering to students in the humanities and in other engineering disciplines.

1. Introduction

Textbooks on many technical subjects, electrical engineering included, make frequent use of graphs to convey ideas more effectively. Preparing these by hand for use in the classroom or in quizzes, tests, and exams can be laborious as to be discouraging. Yet recycling old ones puts a temptation in the path of harried students: rather than buckling down and learning the subject, they can merely memorize old examples and so avoid the entire point of education. If it were only easier to modify such plots, teachers would feel much more inclined to produce new ones.

Using the Excel spreadsheet program does make it easy to create parametric plots and permits their quick modification. There is practically no inherent limit on the complexity of the plots: they can range from simple lines, parabolas, and sinusoids to complex forms such as multi-frequency waveforms, decaying exponentials, and damped oscillations. The author has used this method in the classroom to teach the interpretation of sine waves on an oscilloscope, the meaning of filter time constants, and the interpretation of pulse characteristics, as well as in preparation of professional-looking test questions. By incorporating the plots produced by this method into documents produced with a word processor or a graphics program, there is no reason to avoid producing them and no reason not to generate highly readable final products.

2. What is a spreadsheet?

The smallest unit of computation in a spreadsheet is a cell. The entire spreadsheet consists of an array of these cells arranged into rows and columns. That each cell can contain a variety of kinds of data is what gives spreadsheets such power.

The data can be numbers, alphanumeric text, or equations. The spreadsheet program makes it convenient to copy equations with slight changes and this, in turn, makes it feasible to create graphs. The basic idea is to compute each coordinate of a graph and then plot the entire set of coordinates.

Say we want to generate a plot of the equation $v(t) = 3 + 5\sin[2p(60\ \text{Hz})t + 35°]$. We must first decide the range of values of time t over which we wish to plot this function. Say we wish to plot it from an initial time $t_0 = -1\ \text{ms}$ to a final time $t_f = 3\ \text{ms}$. Excel cannot compute the function at all values of time t so we must first decide how many intermediate values of time t to use. Say we want $N = 300$ of them. First let Excel generate the index numbers from 1 to 300 and place them in a column of cells. We can do this by starting the sequence and then letting Excel finish it.

Put 1 in a cell, put 2 in the cell below it, then drag the pointer across the two cells, selecting them. This is shown in Figure 1. Now place the cursor on the small black square in the lower right-hand corner of the cell with the 2 in it. Drag this marker down through the cells in the same column

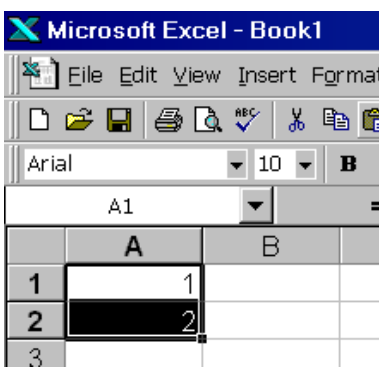


Figure 1: Starting a list of integers

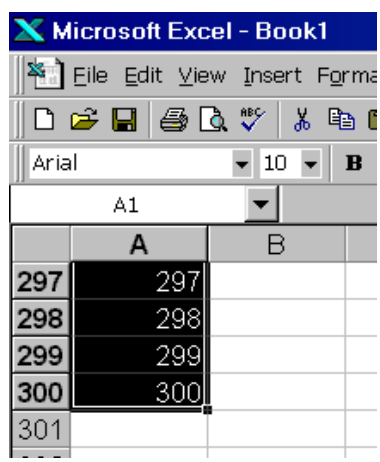


Figure 2: Finishing the list of integers

until you have 300 numbers. At each instant as you drag the marker down, Excel will show you how many numbers you have created so far. Figure 2 shows the last few integers generated in this way.

The next step is to write an equation which will convert this series of integers into a series of

times in the desired domain. The step-size Δt is the total time span divided by the number of steps, $300 - 1 = 299$ in the case:

$$\Delta t = \frac{t_f - t_0}{N-1} = \frac{\left(3\ \text{ms}\right) - \left(-1\ \text{ms}\right)}{300-1} = \frac{4\ \text{ms}}{299} = 13.4\ ms$$

A particular time t_k is then just the initial time t_0 plus the number of steps times the size of the step. In mathematical notation, this is $t_k = t_0 + k \cdot \Delta t = \left(-1\ \text{ms}\right) + k \cdot \left(13.4\ ms\right)$ where k can range from 0 to $N-1$. In Excel, we put the cursor into the first cell where we want such an equation to appear, namely column B, row 1. The equation takes on this form:

```
=-1e-3+A1*13.4e-6
```

The equation starts with an equal sign (`=`) which tells Excel that an equation follows. The symbol `A1` refers to column A, row 1. You could type it manually but Excel will fill it in automatically if you simply point to the corresponding cell when you get to that part of the equation and select it by pressing the left mouse button. The expression `-1e-3` means -1×10^{-3}. Multiplication is specified by use of the symbol `*`.

Except for the particular step number, contained in cell `A1`, we really want the same equation to appear in all 300 rows of column B. If we select cell `B1`, then drag the cross at its lower right corner down 300 rows, Excel will copy the equation, making the appropriate cell reference for each row. For example, in row 150 will appear the equation:

```
=-0.001+A150*0.0000134
```

Note that Excel has chosen to display the exponential numbers in a fixed decimal format here.

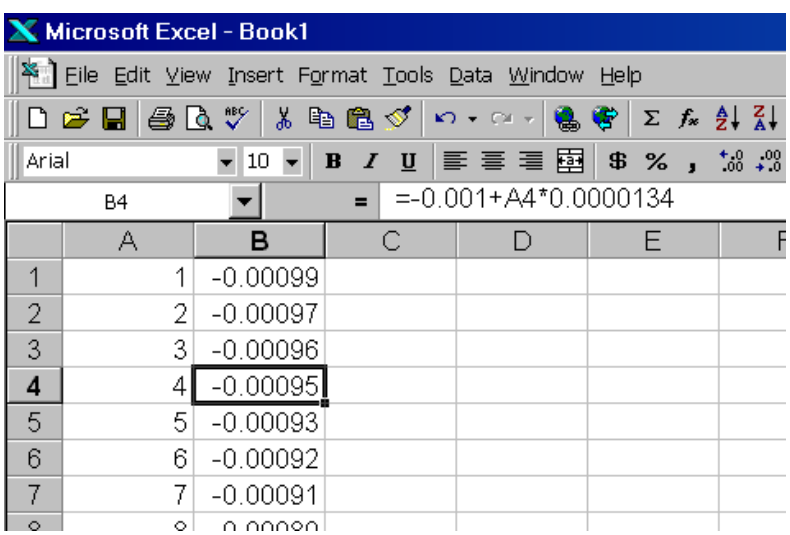


Figure 3: An equation is replicated to generate various times *t*.

Although Excel places equations in each cell, it displays the results of the equations, not the equations themselves, as seen in Figure 3.

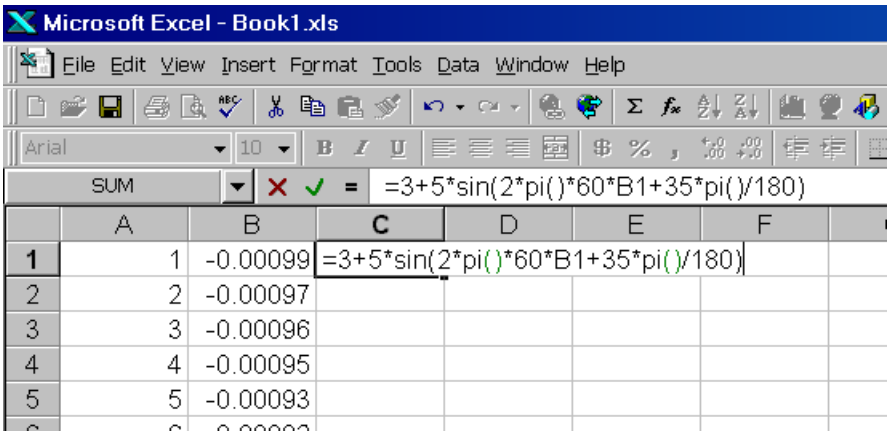


Figure 4: Entering a sinusoidal equation into Excel

We now can enter the equation whose plot we want. Figure 4 shows the equation in a form suitable for Excel. Note that the constant p is provided by the Excel function pi(). The parentheses are necessary so that Excel understands that we want the built-in constant p. We also have to convert the angle $35°$ to radians. Excel cannot find the sine of an angle unless the angle is specified in radians. Finally, the time of evaluation of the function is given by the contents of cell B1.

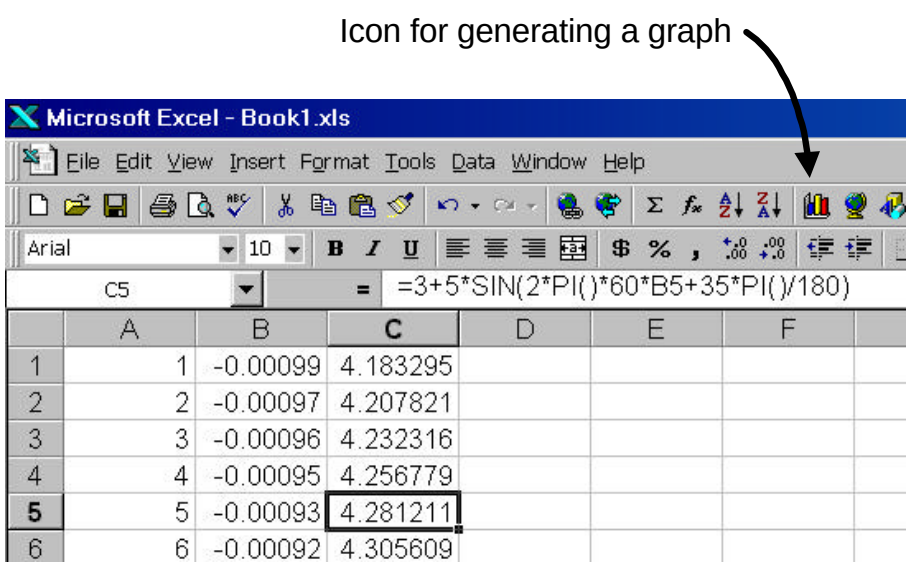


Figure 5: Replication of the equation to all rows. Note how the time in row 5 is found in cell B5. Excel figures this out for itself.

Once we have entered the equation once, we can copy it to the remaining 299 cells. This is done just as it was when we wanted to copy the expression for computing the time. Select the cell whose equation you want copy, then select the lower right corner of that cell and drag it down

through the additional 299 rows. Excel will replace the time by the one adjacent to the equation. For example, in row 5, the time will be that provided in cell `B5`, as shown in Figure 5.

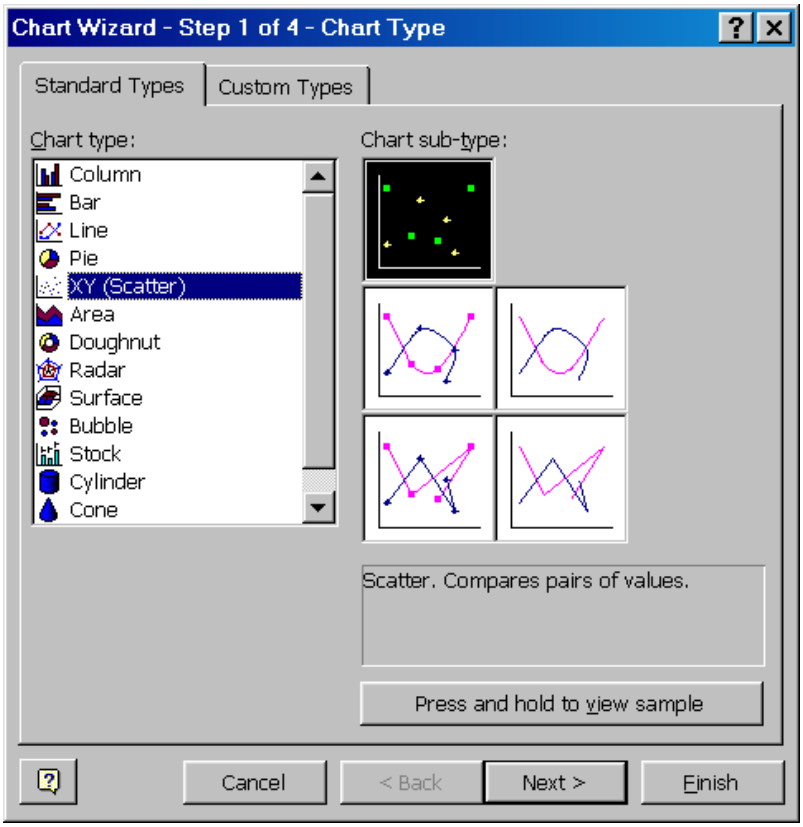


Figure 6: The first of four dialog boxes for describing a chart based on the data we've computed so far.

Now we're ready to plot the data. Put the cursor in any convenient location, say cell `D1` and select the icon for producing a plot. This icon is marked in Figure 5.

Excel now leads you through a series of dialog boxes, a so-called chart wizard. The first of these boxes is shown in Figure 6 and lets you pick the type of chart. The XY (Scatter) type lets you plot two-coordinate points such as those our spreadsheet now contains. Of these XY charts, pick the first one.

The next box (see Figure 7) lets you specify whether data can be found in rows or columns. Our data appear in columns.

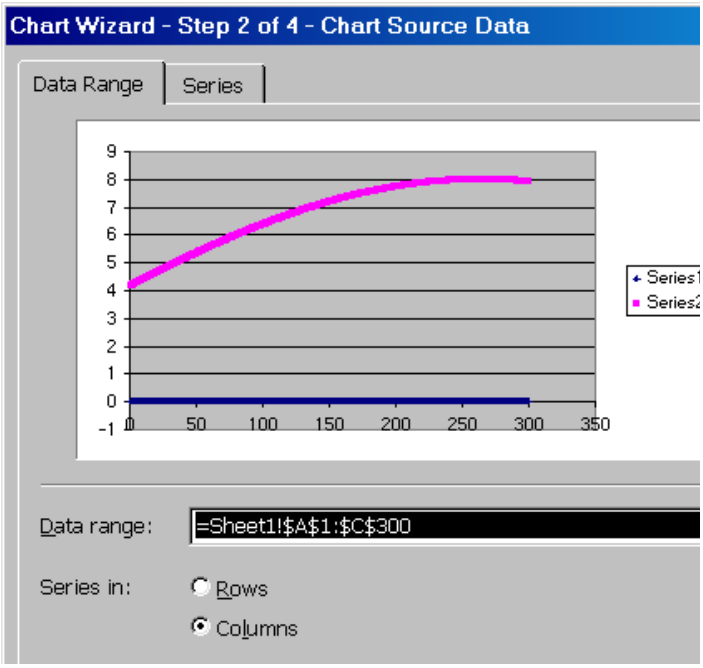


Figure 7: The second of the Chart Wizard dialog boxes, letting you specify the source of the data to be plotted.

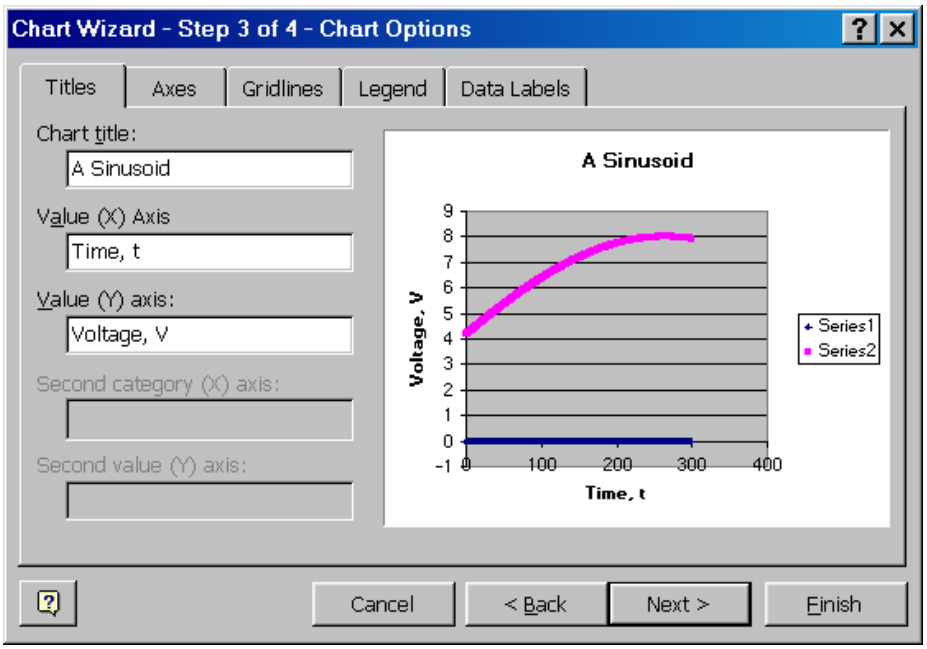


Figure 8: Entering a heading for the chart, along with labels for the horizontal and vertical axes.

The third Chart Wizard dialog box (Figure 8) allows you to specify a chart title and labels for the horizontal and vertical axes.

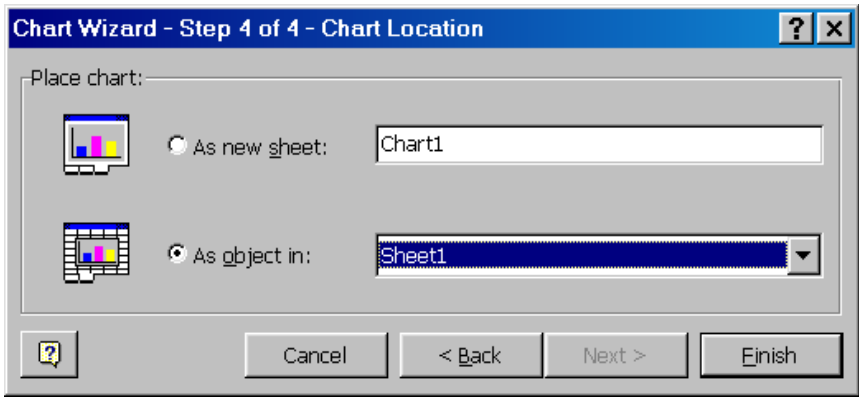


Figure 9: The final Chart Wizard dialog box lets you place the finished chart in the original spreadsheet or in a new spreadsheet.

The fourth and final dialog box (Figure 9) lets you decide whether the resultant chart should appear in the original spreadsheet or be placed in a new spreadsheet. We'll take the first choice and then select "Finish".

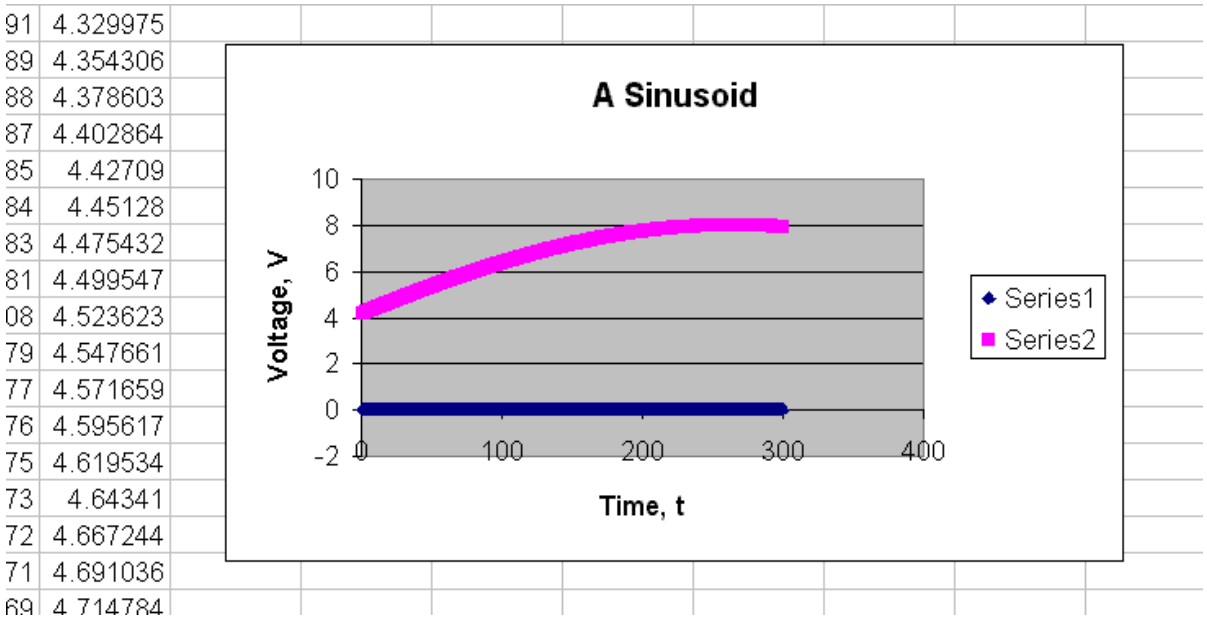


Figure 10: The finished chart. It is not yet very attractive so we'll work next on improving it.

Figure 10 shows the finished chart. It is not yet very appealing looking so we will look next at how to put it into a more pleasing form.

What is wrong with it? The first thing we note is that in addition to the sinusoid, there are points plotted along the time axis, too. We don't need these latter points. The thickness of the sinusoid is too big. There is no need for the legend at the right which labels the two series. It would be nicer to see two or three periods of the sinusoid.

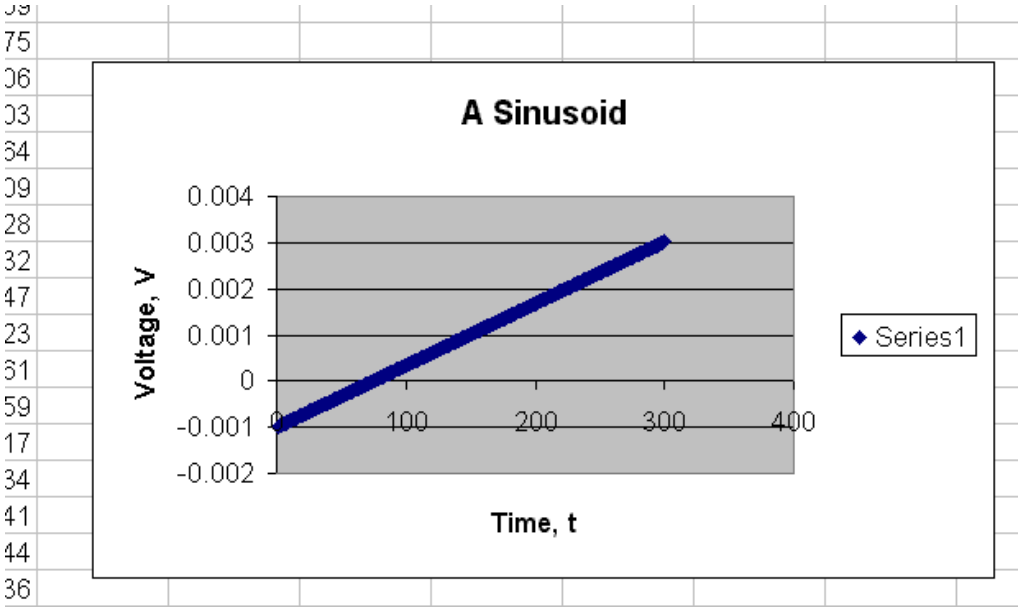


Figure 11: The unneeded plot along the time axis has now been removed. Note how the chart was automatically rescaled.

3. Improving the Plot

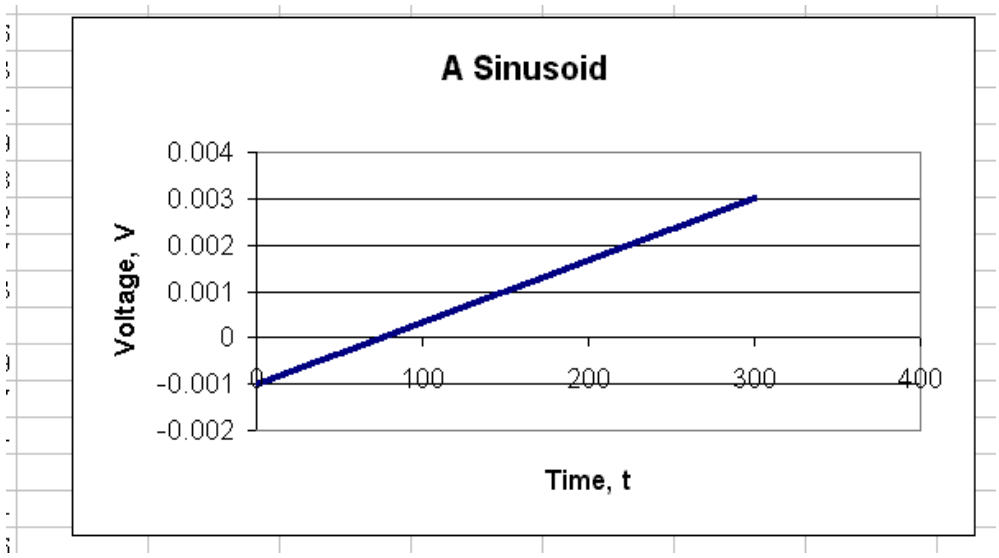


Figure 12: The chart is improved by removing the excessively large markers for the points, removing the legend, and joining successive points with a thick line.

First let's get rid of the plot along the time axis. Put the cursor over that plot, push the right mouse button, and select **Source Data**. Now select the **Series** tab, select **Series2** in the **Series** window, select the **Remove** button, and select **OK**. The result of these steps is shown in Figure 11.

Next, let's get rid of the legend. Select it with the cursor and press the **Delete** key on the keyboard.

To reduce the thickness of the graph, point at it with the cursor, push the right mouse button, and select **Format Data Series**. Under **Marker**, select **None**. This gets rid of the large diamond shapes currently used in the plot. Under **Line**, select **Automatic** to connect all data points with a straight line and select a heavier **Weight** to make the line more easily seen against the background. While we're at it, let's get rid of the gray background. To do this, put the cursor over an empty area of the gray background and push the right mouse button, then select **Format Plot Area**. Under **Area**, select **None**. Figure 12 shows these improvements.

4. Generalizing the chart

We still have not extended the chart to several periods of the oscillation of the sine wave and we will turn to that next. In fact, this is a good time to alter the spread sheet so that we can vary amplitude, frequency, amplitude offset, and phase delay without too much trouble. Let's clear some space at the top of the spreadsheet for specifying these parameters and then we'll look into how to incorporate them into the equations. Highlight the cells from `A1` to `C9` by dragging the cursor across them. Placing the cursor within the highlighted area, push the right mouse button and select **Insert**. You will be asked how you want to perform the insertion: select **Shift Cells Down**. Figure 13 shows the results of these operations.

We now enter the names of the parameters into column A and their associated values in column B. Just type these items into the appropriate cells as shown in Figure 14. The start time and the end time will allow us to control how much of the sinusoid we plot. The number of points can be altered to permit a finer spacing between successive points on the plot. For rapidly changing plots, a higher number will give better detail at the cost of more storage and more computation time. We have chosen 600 for this illustration, considerably higher than the 300 points used up to now. Note that the items in column A are wider than the space available as shown in Figure 14. You can widen the column by dragging the right-hand bar in the column label (A, say) as far right as you like.

We only have to write one equation using the new parameters for we can then rely on Excel to replicate it as many times as necessary. The equation currently in cell C10 is:

```
=3+5*SIN(2*PI()*60*B10+35*PI()/180)
```

Modify this to read:

```
=$B$3+$B$1*SIN(2*PI()*$B$2*B10+$B$4*PI()/180)
```

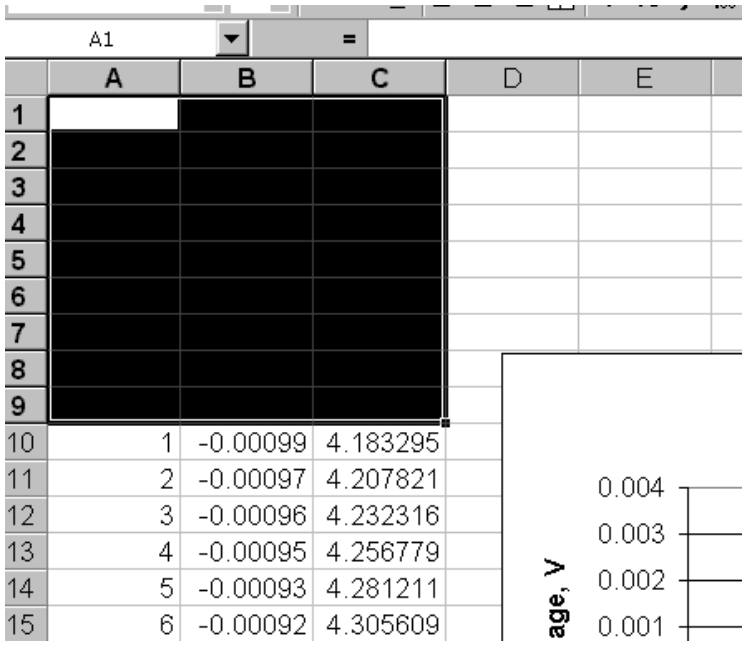


Figure 13: Make some room at the top of the spreadsheet for specifying parameters of the graph.

Some explanation is required here. In standard mathematical notation, this could be written $V_{DC} + V_P \sin\left(2pft + j\right)$ where j is expressed in degrees and converted to radians. We have replaced the numbers in the first expression with cell references in the second. For example, the amplitude of 5 specified in the first expression is replaced by `$B$1` in the second. This refers to cell `B1`, where the amplitude will be placed henceforth. What do the "$" signs do? They specify that when you copy cells, the cell reference should not be updated by Excel. Notice that the only cell reference without these "$" signs is `B10`. We do want Excel to modify this cell reference every time the equation is copied to a new line for this is whether the variable time *t* comes from. (You can avoid the need to type in the "$" signs and the address by selecting the desired cell and pressing the **F4** button on the keyboard.)

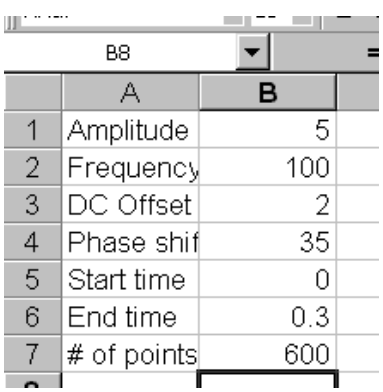


Figure 14: Basic parameters for a generalized sinusoid.

Up to now we have had this expression in cell `B10`:

```
=-0.001+A10*0.0000134
```

We should modify this, too, to read:

```
=$B$5+A10*($B$6-$B$5)/($B$7-1)
```

which represents $t_n = t_0 + n\dfrac{t_f - t_0}{N-1}$. Copy cells `A10` through `B10` into the row 11 by highlighting them and dragging them down using the cross in the lower right corner. Next, put the

number 2 in cell `A11`. (If we don't first put a different index number in cell A11, we will end up copying the index number 1 600 times, instead of incrementing it by 1 for each new row.) To copy these equations 600 times, select cells `A10` through `C11` and drag them down through 600 rows, ending up in row 609. As a check, the last row should contain the values

```
600   0.300501   3.572244
```

Now we want to update the plot. Point at the graph, push the right mouse button, select the **Series** tab, change the **X Values** from `=Sheet1!$A$10:$A$309` to `=Sheet1!$b$10:$b$609` and change the **Y Values** from `=Sheet1!$B$10:$B$309` to `=Sheet1!$c$10:$c$609.` Figure 15 shows the resultant graph.

It is hard to read because the choice of the end time was too high. If we change this to 0.03, the plot of Figure 16 will result.

All that is wrong with Figure 16 is that the graph has been calculated only for 0 to 0.3 but the plot

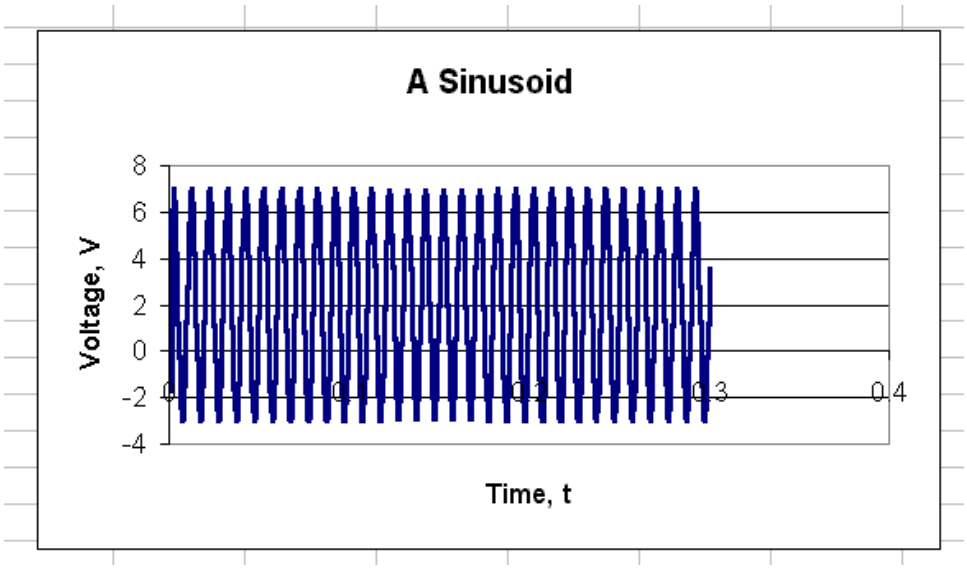


Figure 15: Sinusoid with too many periods for easy viewing.

is wide enough to go all the way to 0.04. We can narrow this by placing the cursor over the horizontal axis and pressing the right mouse button, selecting **Format Axis**. Select the **Scale** tab and change the **Maximum** from 0.03 to 0.04. Then select **OK**. The result of this action is shown in Figure 17.

Because the plot has been generalized by the introduction of parameters, it is easy to generate

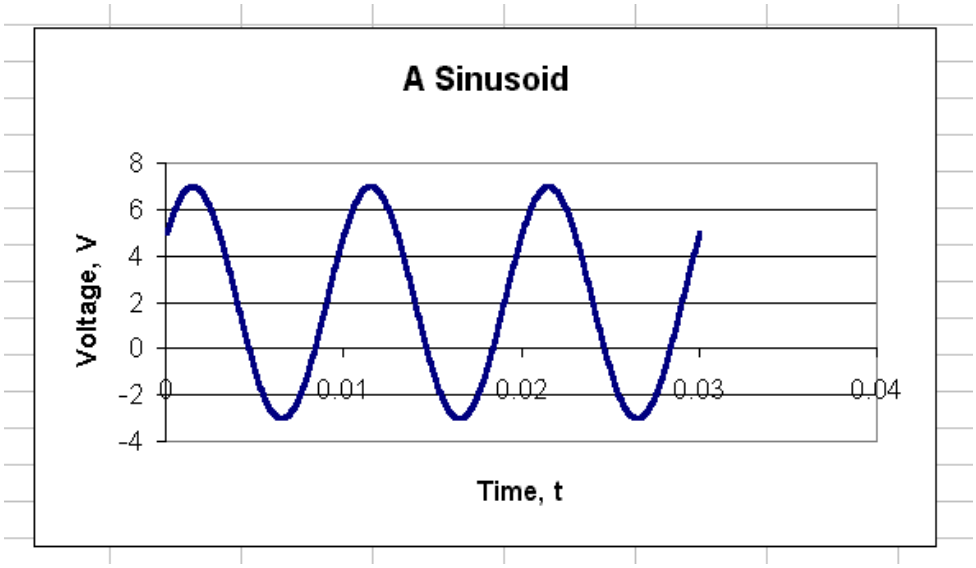


Figure 16: Changing the end time to 0.03 alters the plot easily so it contains a reasonable number of oscillations.

variations just by changing the parameters and, if necessary, altering the horizontal and vertical scales of the plots.

In a classroom setting, it can be helpful to have vertical grid markings, too. These are easily added by putting the cursor over an empty section of the plot, pressing the right mouse button, selecting **Chart Options**, selecting the **Gridlines** tab, and selecting **Major gridlines** in the **Value (X) axis** section.

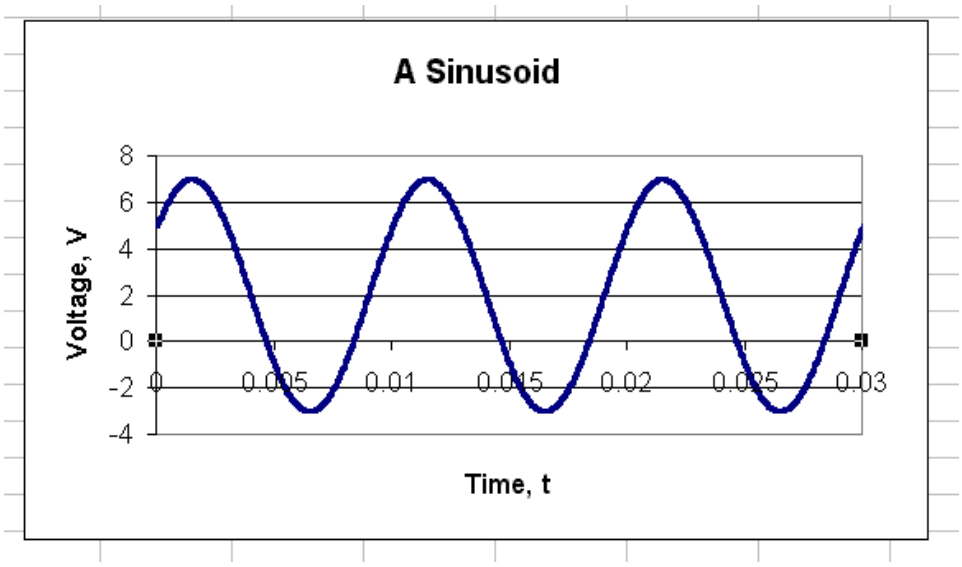
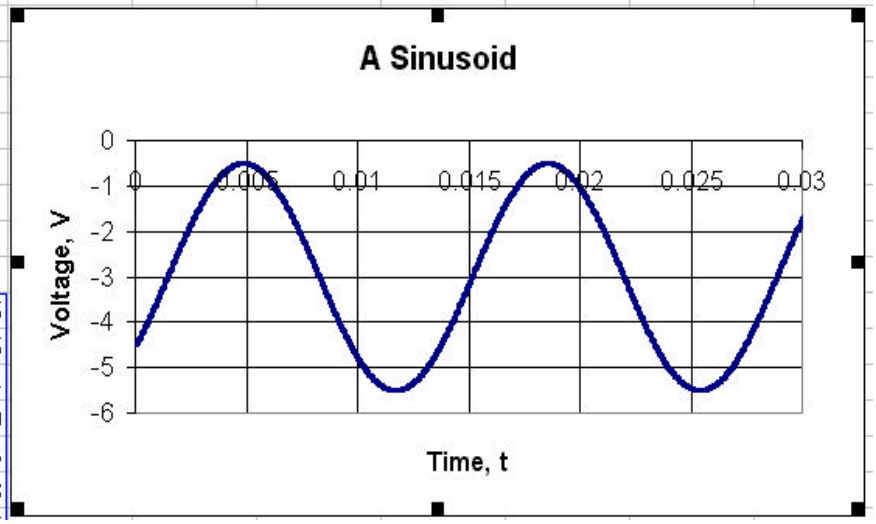


Figure 17: The width of the plot frame has been changed so that the calculated points just fit within it.

Two representative examples of plots taken with different parameter selections and with gridlines present are shown in Figure 18.

Amplitude	2.5	
Frequency	73	
DC Offset	-3	
Phase shift	-38	
Start time	0	
End time	0.03	
# of points	600	
1	5.01E-05	-4.4935
2	0.0001	-4.44705
3	0.00015	-4.39984
4	0.0002	-4.35189
5	0.00025	-4.30323
6	0.000301	-4.25388



Amplitude	7	
Frequency	155	
DC Offset	8	
Phase shift	133	
Start time	0	
End time	0.03	
# of points	600	
1	5.01E-05	12.88062
2	0.0001	12.63016
3	0.00015	12.36869
4	0.0002	12.09682
5	0.00025	11.81521
6	0.000301	11.52452

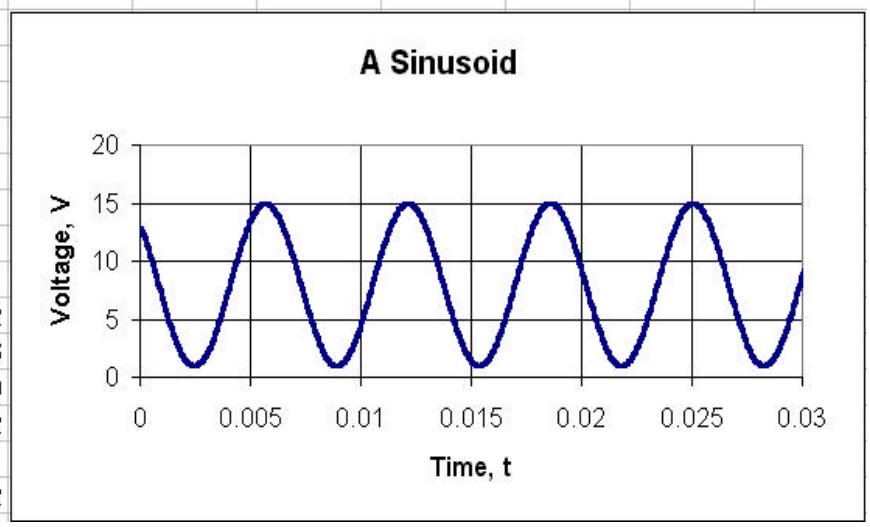


Figure 18: Two representative examples of sine waves generated automatically by simply altering the parameters used to define them:

5. Conclusion

This completes an introduction to the general method of producing plots for classroom use and for use on tests and quizzes.

The main principles to be grasped here are:

a. Use index numbers and appropriate formulas to generate the x-ordinates (abscissae) of the plots.

b. Use formulas to calculate the y-ordinates of the plots. Parameters should be referred to using “absolute” cell references in lieu of “relative” cell coordinates (*e.g.*, `$B$10` will always point to the same cell when copied whereas `B10` will be modified to point to the same *relative* cell when copied.)

c. Include more calculated points to achieve a higher density of points and so be able to track rapid oscillations or changes more accurately.

d. Plot the calculated points using the versatile plotting features of Excel.

It is possible to use this approach to generate quite complex plots very quickly. Two final examples of more complex plots than those presented to this point are shown in 14 and 14. Permitting the modification of the plots to be done through modification of parameters makes the generation of new plots very painless indeed. As a side-benefit, it makes it quite easy to generate families of related plots, something which often reveals subtle points in a topic.

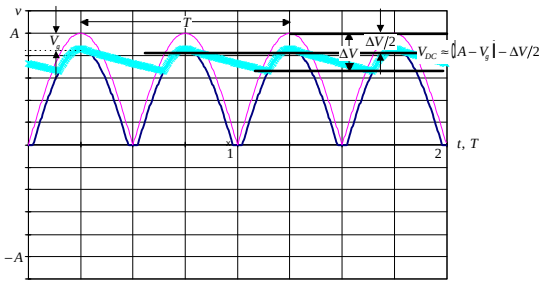


Figure 19: A plot generated to illustrate full-wave rectification.

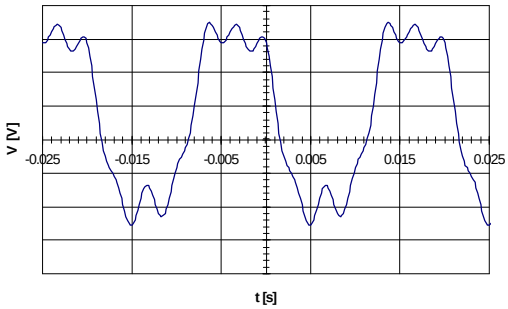


Figure 20: A graph showing the results of combining several waveforms of different amplitude, frequency, and phase.

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