

Appendix B

Excel Figures Help and Hints

Overview:

This appendix is intended to help students use Excel more effectively to generate good graphs for transfer into laboratory reports. It is not intended to be a tutorial on Excel, and does not address graphs used for more general purposes. The problem for the laboratory report writer is that the defaults in Excel seem intended to support the development of viewgraphs for “slide shows.” Those defaults often do not work well for reports. Chapter 5 contains information on what we would like graphs to look like when they appear in a report. This chapter addresses how to get them to look like that. Appendix E contains some additional information about transporting such graphics into a report as it shows examples of such graphics done poorly.

Excel has evolved considerably in the past and has to be expected to continue. Consequently, this appendix will try to explain things in general terms rather than with reference to particular items, menu selections, and such. This edition of the Manual has been prepared using Excel 2016. It is possible that some features and capabilities will be eliminated, or made difficult to find or use in the future. It is hoped that the reader will be able to find tools that can accomplish these same things.

Use of Excel for generating graphs has several advantages. The graph artwork when pasted into a Word document appears as line graphics rather than a pixelated graphics image, so that as sizes and shape is changed in the graphic the resolution will remain appropriate and sharp. Furthermore, the graphic in the Word document can remain linked to the original Excel file, so that later changes made in Excel are automatically reflected in the Word document. It is also possible to port Excel graphics into PowerPoint where additional graphics features such as annotations can be added, while still retaining the sharpness of line graphics, prior to pasting into Word.

Simple Graphs:

The simplest case for graphs seen in reports is one dependent variable plotted versus an independent variable, where neither has a particularly wide dynamic range. That allows linear (rather than logarithmic) scales to be used for both area. With only one dependent variable, there is no need for a “legend.” The place to start is with data already existing in the Excel spreadsheet. Here in Table B-1 we use the same capacitor example data shown in Chapter 5, as it might have originally been typed in:

Table B-1 Data Table for Graph Example

Capacitor Voltage and Current

Time (s)	Voltage (V)	Current (mA)
0	0	0.1
0.1	1.97	0.061
0.2	3.16	0.037
0.3	3.88	0.022
0.4	4.32	0.013
0.5	4.59	0.008
0.7	4.85	0.003
0.9	4.94	0.001

Since we want a simple graph of one dependent variable, we start with Voltage. By doing an “Insert Chart” operation, with the columns for Time and Voltage highlighted, and “X-Y Scatter selected, we get the graph shown in Figure B-1 below:

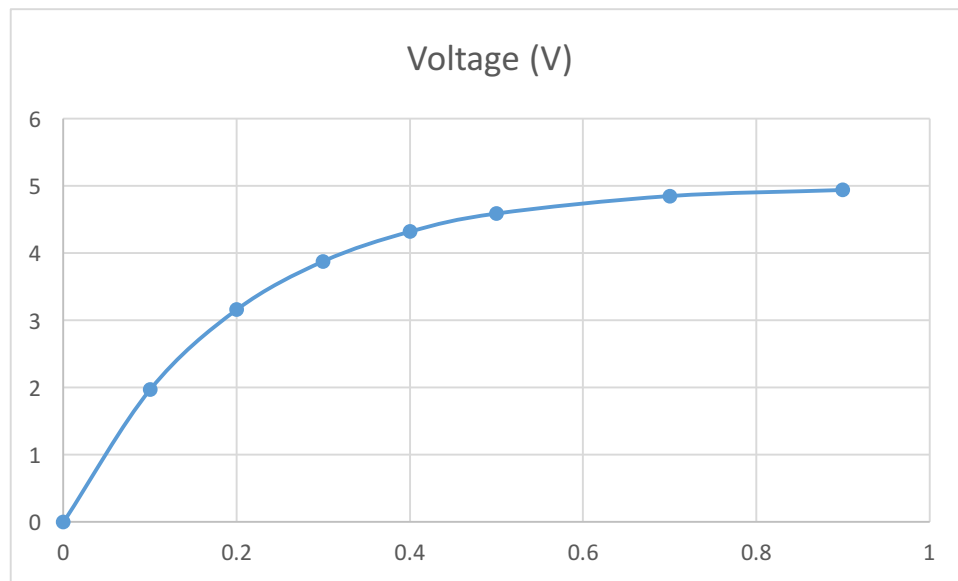


Figure B-1 Initial Voltage versus Time Graph

This isn't a terrible graph, but there are numerous problems. Grey or light blue rather than black is used, reducing contrast. The label for the second column was turned into a label for the graph, placed over the figure instead of under it. There are no axis labels or units. There is an undesired box around the figure. These things can all be fixed, but it takes some doing. We take it step by step:

1. First, delete the title by clicking on it and hit “delete”.
2. Add axis labels by finding “Add Chart Element” (upper left of the Chart Design Toolbar in Excel 2016) and add both Primary Horizontal and Primary Vertical Axis Titles.
3. Replace “Axis Title” on the graph with appropriate labels, “Time (seconds)” for the horizontal axis and “Voltage (V)” for the vertical axis.
4. Remove the outer box. Double click somewhere on the background outside the graph proper (pop-up label “chart area,” not “plot area”). This brings up a tool sub-window for formatting the chart area. Under the “paint bucket” symbol and “Border” item, choose “No Line”. The figure will no longer be boxed.
5. To turn grey features to black, you need to click on each of those features in turn and change the color to black. Clicking on the horizontal axis, for example, for “Axis Options” under the paint bucket, one can choose the line color to make it black rather than grey. Under “Text Options” the numerical labels for the axis can be made black. The same can be done for the vertical axis. The graph points (or trend line) can be clicked on and the colors changed from blue to black for both the line and the points.

With these modifications, we get the graph shown in Figure B-2 below. Further modifications could be made to move the labels and stretch the plot area to utilize more of the space on the page, but the graph as shown should be satisfactory for most purposes. (Note that in this appendix a “Paste special” was used, and “Microsoft Office graphic” was selected, so that the graph was uncoupled from the original Excel file in which it originated. That is the form of past you will usually want to utilize.)

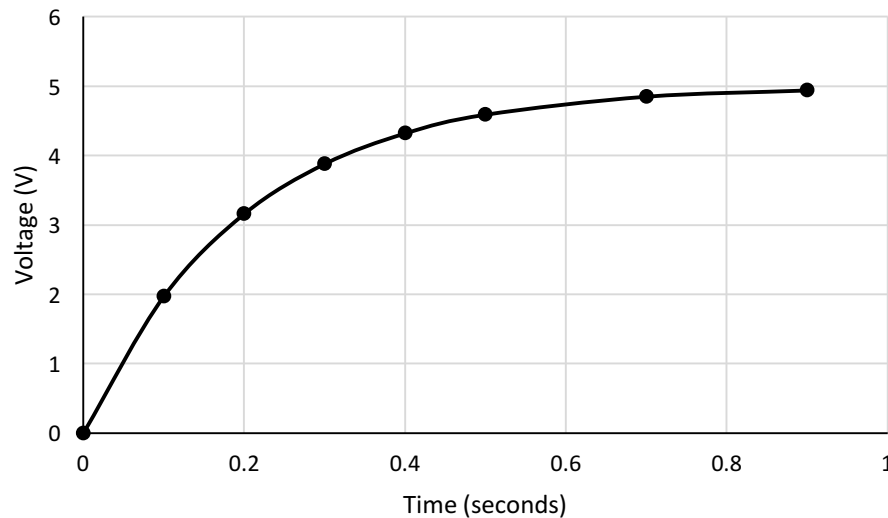


Figure B-2 Voltage versus Time Graph as Modified

It is possible that your version of Excel has defaults that present a grey background to the chart or have some other undesirable visual features. You will need to track down the chart options that let you fix those problems.

Adding a trendline:

The graph as shown in Figure B-2 above includes a smoothed line connecting the points. One could also choose straight lines. But often what is desired is a “fit” of a mathematical expression to the data. This is especially true in a characterization exercise. Excel has some (limited) support for doing that. What we want is a “trend line”. We can add one (after removing the connecting line). There are several choices for trendline options. What we need is a “rising exponential”. Unfortunately, that option is not available. If we were to choose “Polynomial” of order 2, and require that the trendline cross the axis where the actual data does, we get the figure B-3 below.

The trendline options include placing the fit equation and the goodness of Fit (R^2) directly on the graph. If you need this information, you need to do that, at least long enough to copy the information into your document elsewhere. I don’t like to see this on the graph itself, preferring that the goodness of fit issues be addressed explicitly in the text if it is important enough to discuss. There are faculty members and report formats that do allow this information to remain on the graph.

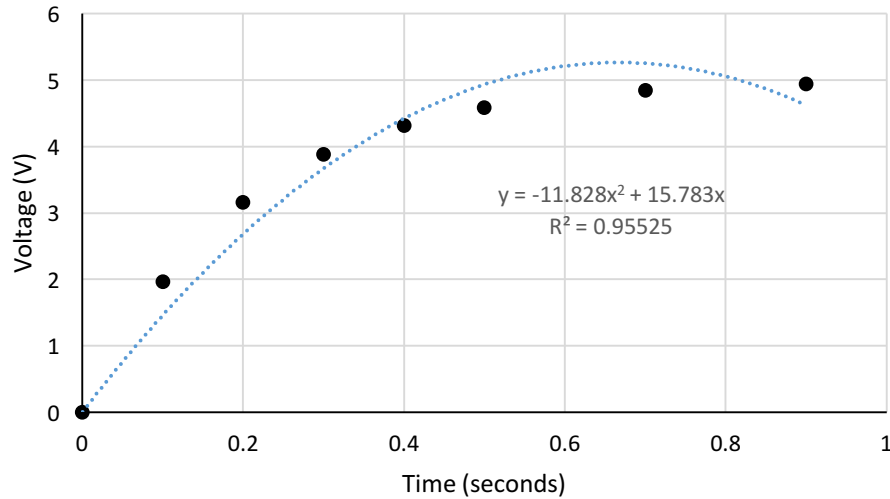


Figure B-3 Voltage versus Time Graph with Quadratic Polynomial Trendline

The R^2 value indicates goodness of fit, with a value of 1.00 being ideal. The value here of about .95 is not particularly good. That isn't so surprising, since we know that the curve ought to be a rising exponential instead of polynomial. You can get a better fit by increasing the number of polynomial terms, but that still won't really be what you want, a fit to a rising exponential. MATLAB can do that job for you. To do it in Excel, you have to find a function of the original data that would fit one of the available trendline types. In this case that isn't difficult. The value of 5V-Voltage is a falling exponential, and that's an option we have. See Figure B-4. (We have not taken the time to pretty it up, since all we want is the fit information.) Applying that information to the original chart, we get $y=5-5e^{-4.964t}$. (We substitute t for x since it represents time.) We have a goodness of fit for that equation of $R^2 = .9998$. That's much better than the polynomial fit. Note that we did need to set the initial value to match exactly 5.0 Volts, just as we would set a match for the original chart to be 0.0 for time = 0. From the goodness of fit equation exponent we find a "time constant" of $1/4.964$ seconds, so $RC=.2015$. If we know that R has the value of $1.01K\Omega$, we can now calculate $C=199 \mu F$.

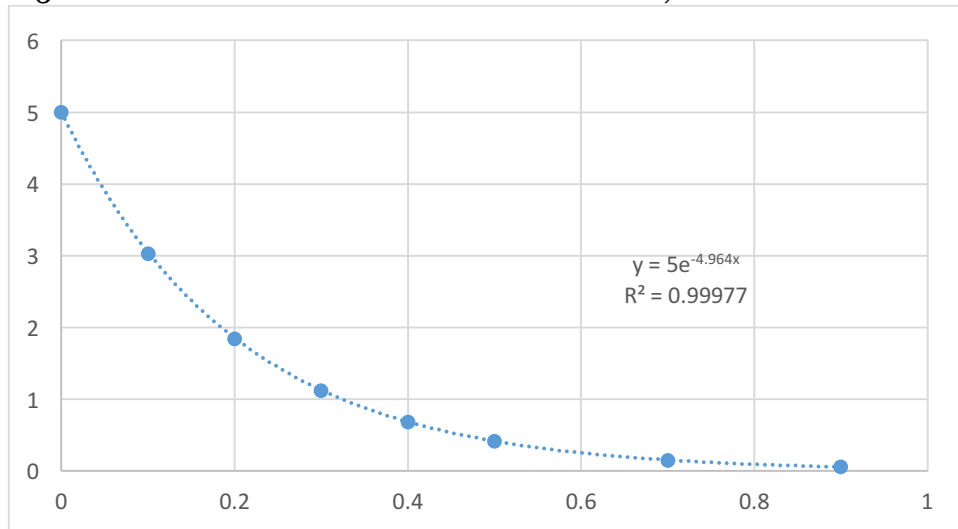


Figure B-4 Chart used to find the goodness of fit for the rising exponential.

The trend line can now be placed on a chart with the original data by adding it as a second set of data. The table in Excel used to do that is shown below, Table B-2. Each trendline value is calculated using the formula, “=5-5*exp(-4.964*E2)” (where E2 was the cell containing the corresponding time for t=0), filled down. The “trendline” data is plotted with a connected, smoothed line but no data, and the Voltage data is plotted with points but no line. It looks very much like the graph shown in Figure B-2, since the fit was so good. (It is probably not worth including this graph in a report if the fit equation and goodness of fit are cited, since the graph doesn’t add much information.)

Table B-2 Table of data with trendline calculations

Time	Voltage (V)	trendline
0	0	0
0.1	1.97	1.956409
0.2	3.16	3.147311
0.3	3.88	3.872235
0.4	4.32	4.313509
0.5	4.59	4.582120
0.7	4.85	4.845160
0.9	4.94	4.942626

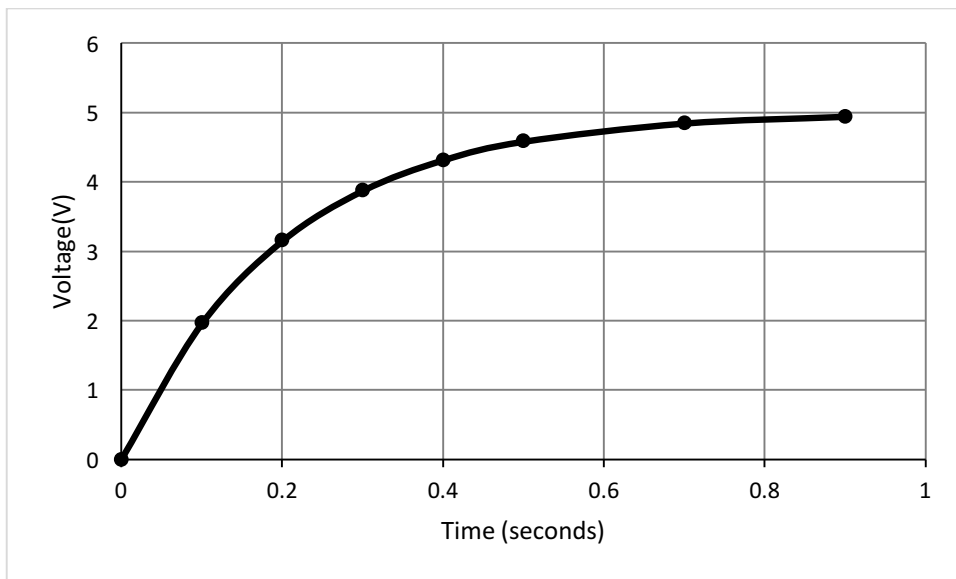


Figure B-5 Graph with trendline added as a second data set

Multiple Sets of Data:

Often it is necessary to plot more than one set of data against the independent variable. There are two cases. In the simplest case, both (or more than two) sets of data have similar units and range, and can this be plotted against the same vertical axis. For example, In EE283 students need to plot the impedances of a resistor, capacitor, and inductor against frequency. (Technically, it’s the magnitude of impedance that is plotted.) Since the unit for impedance is Ohms in all three cases, and the results have a reasonably similar range, only one vertical axis is needed. That is a relatively easy case. It is necessary to go beyond what is described above to choose a data point symbol and

line format that is different from that of the first data set, and a “legend” but be added to distinguish the different sets of data.

A more complex case is when we want two sets of data plotted together that have very different values and/or units. Plotting both the Voltage and Current from Table B-1, we want to get a graph like that shown as Figure B-6.

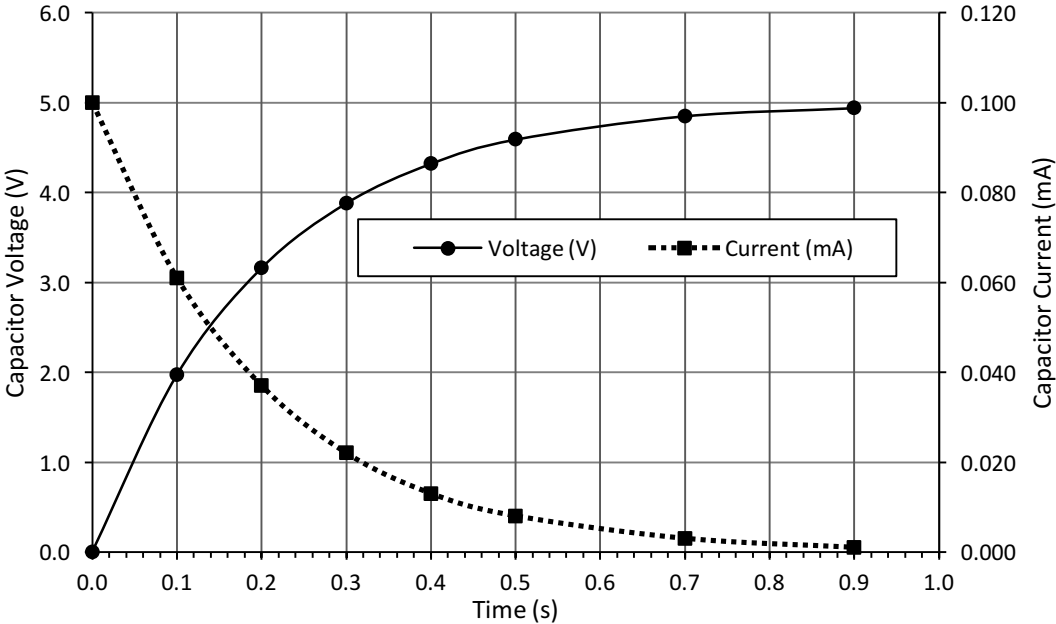


Figure B-6 Graph with two very different quantities plotted.

Plotting two very different quantities together like this requires the use of a secondary vertical axis, shown here on the right. The chart design toolbar “Add Chart Element” pull down menu can be used to add a secondary vertical axis. An axis title can be added to go with it. The line styles and marker shapes need to be distinct. The “legend” identifying which markers and line is which needs to be placed somewhere out of the way, but not wasting space.

However, the trickiest issue is to make the grid lines come out usefully consistent. While in theory one could use two distinct different styles of horizontal gridlines, that would be very confusing. So, in order to use the same grid lines, the scaling of the two vertical axes and the spacing of their major units need to be made consistent so that grid lines can be used for either plotted value set. Here, the first set of data, Voltage, uses a scale of 1 to 6 with even numbers of Volts as the major units. To match that, Current uses 0 to .12 with .2 as the major units, both giving 6 major grid lines in addition to the horizontal axis.

So, what if there are three very different sets of data that need to be plotted together? One could add yet another vertical axis for each (perhaps requiring later editing after copying the graphic out of Excel). Additional axes are typically placed to the left or right of the leftmost or rightmost axis, respectively. Getting the one set of

horizontal grid lines to be consistently useful becomes still trickier. A second option is to adapt the units to the scale that already is in use. In the example above, current could have been plotted in units of .02mA, so that “5” would indicate 5 (.02) mA = 1mA. This option is most attractive if the ratio is a power of 10. A caution might be placed in the text to point out this kind of scaling for a figure. Of course, one might use different charts, but then the value of being able to see different variables changing together is lost.

Large Dynamic Range (and logarithmic plotting):

There are two circumstances where a logarithmic plot is needed. Sometimes the trend of the data ought to fall in an exponential or logarithmic pattern, and that relationship is best seen in the figure using a semi-log graph, where one or the other axis is logarithmic causing the data to appear as a straight line. The other case is where one or more of the axis variables has a very large dynamic range covering orders of magnitude.

Examples of the first case include the current vs. Voltage relationship for a diode, and the response curve of a Negative Temperature Coefficient (NTC) temperature sensor. An example of plotted diode data is shown in Table B-3 and Figure B-7 below.

Table B-3 Diode Data

Diode Response

Voltage(V)	Current(A)
0	0
0.2	0
0.4	0
0.5	0.0005
0.55	0.0031
0.6	0.022
0.65	0.147
0.7	1.02
0.73	3.1

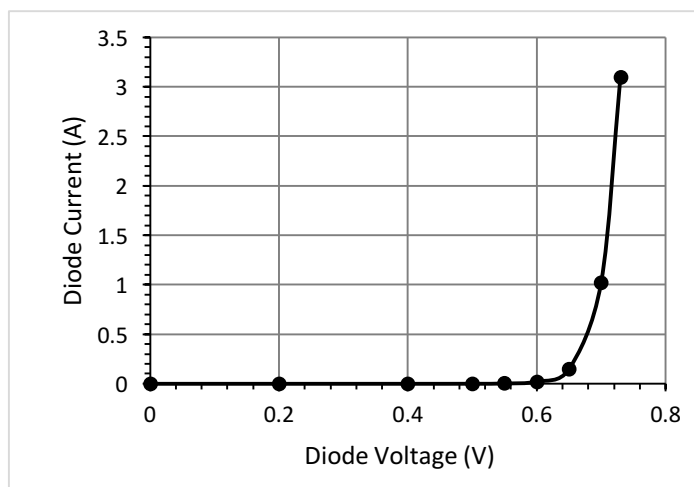


Figure B-7 Diode Current vs Voltage on linear graph

The problem with this graph is that the reader cannot really discern what is happening in the .5V to .6V region. The points lie so close to the axis that the subtle differences are not discernable. The data for current span 5 orders of magnitude as measured. The zero values for .2V and .4V no doubt reflect the fact that there were nonzero currents that were just not measurable; the actual dynamic range would be even larger with better equipment.

This is a good case where use of a logarithmic scale for current would be helpful. There are two choices. One is to add a spreadsheet column for the logarithm of current, then plot that on a linear scale. If that is done, the Axis label needs to be “Log₁₀ of

Current (A)” or something similar. It is much preferable to simply change the axis to a logarithmic scale.

However, in either case there is a potential problem. What is the logarithm of 0? Yes, before a meaningful log plot can be made, you must get rid of the zeros. That means that the Voltage scale will now no longer include values of 0 to .4. Figure B-8 shows a plot with Current on a log scale. It is now very obvious that the relationship is exponential. The trendline (used instead of a smoothed curve) shows that the curve fits an exponential relationship: $I=3 \times 10^{-12} \text{ A } e^{38.16 \text{ V}}$ with $R^2=.99993$. Note that minor grid lines are shown. This is particularly helpful on graphs where a logarithmic scale is used, because it is more difficult to estimate values between grid lines when the scale is not linear.

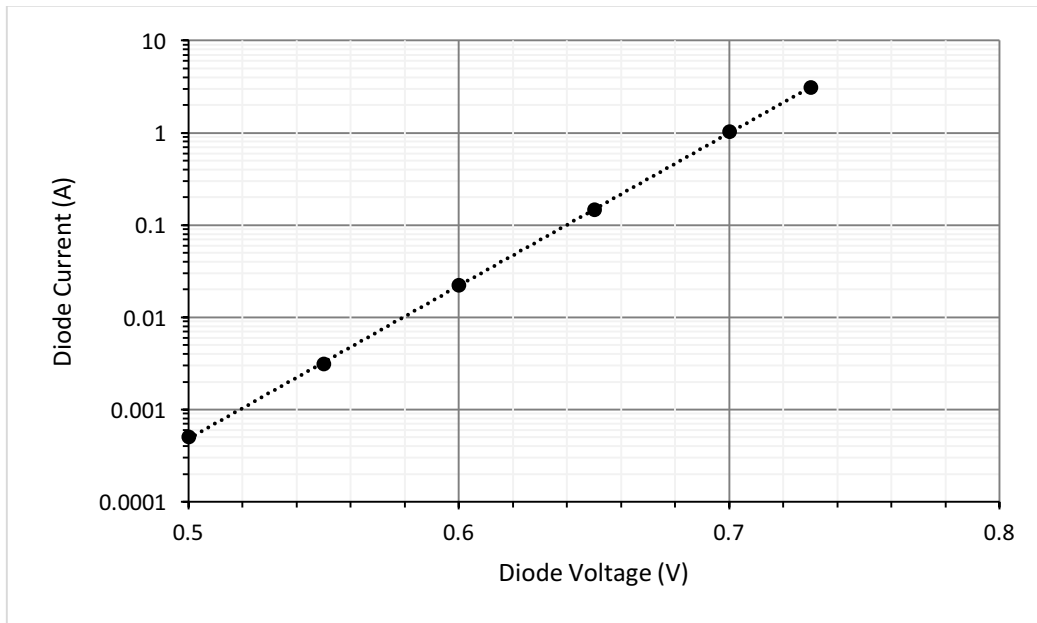


Figure B-8 Diode Current vs Voltage on a semilog graph

Notice a couple of issues that come up in doing this graph. One of them is that Excel will want to put the horizontal axis at 1 Ampere (or 0 on a linear vertical axis). The setting for where the horizontal axis crosses is a Vertical axis setting. (It can be hard to find.) Tick marks have been added to both axes. These are especially important if you do not use minor grid lines, or if the minor grid lines are very light, as here. (Indeed, the minor grid lines should probably have been made darker.)

There will be circumstances where a large dynamic range is coupled to the need to show more than one variable, one linear and the other of which is logarithmic. An amplifier frequency response curve is an example. Figure B-9 shows such a case.

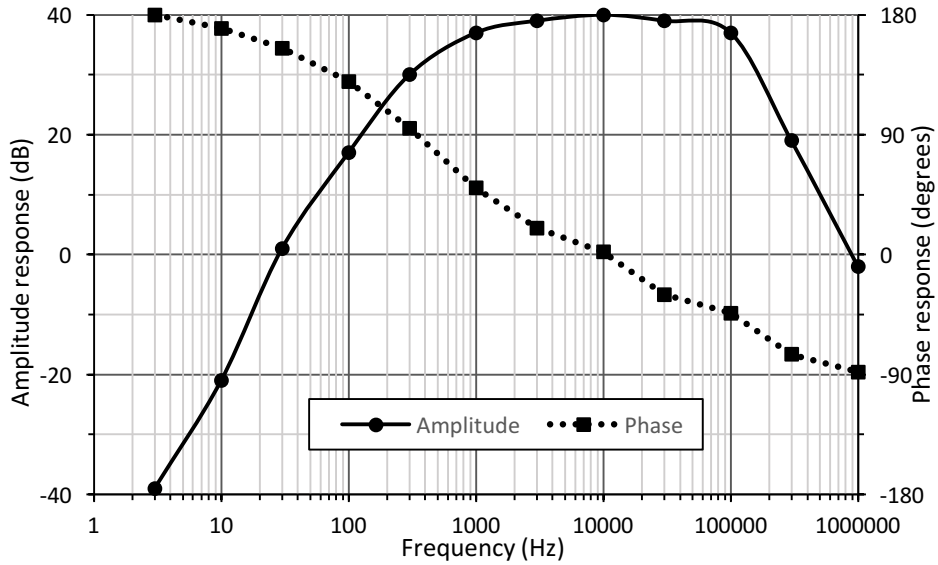


Figure B-9 A graph of amplifier frequency response, a “Bode Plot”

The six orders of magnitude variation in frequency demands a logarithmic plot for the horizontal axis. If Amplitude Response was given in Volts per Volt, the dynamic range would be .01 (at the bottom) and 100 (at the top). The discipline (EE) provides a solution: The Voltage scale can be converted to decibels. Each “Bel” is an order of magnitude of power. Since a factor of 10 increase in Voltage gives a factor of 100 increase in power, we would convert a factor of 10 for Voltage to be 2 Bels (a factor of 100 for power, assuming a constant resistive load) or 20 decibels, abbreviated dB. That allows us to use a linear scale for both Amplitude and Phase response. If we had to do amplitude using a log scale, we’d get figure B-10 below. Note that the horizontal minor gridlines do not match up with the phase scale (but the major gridlines do).

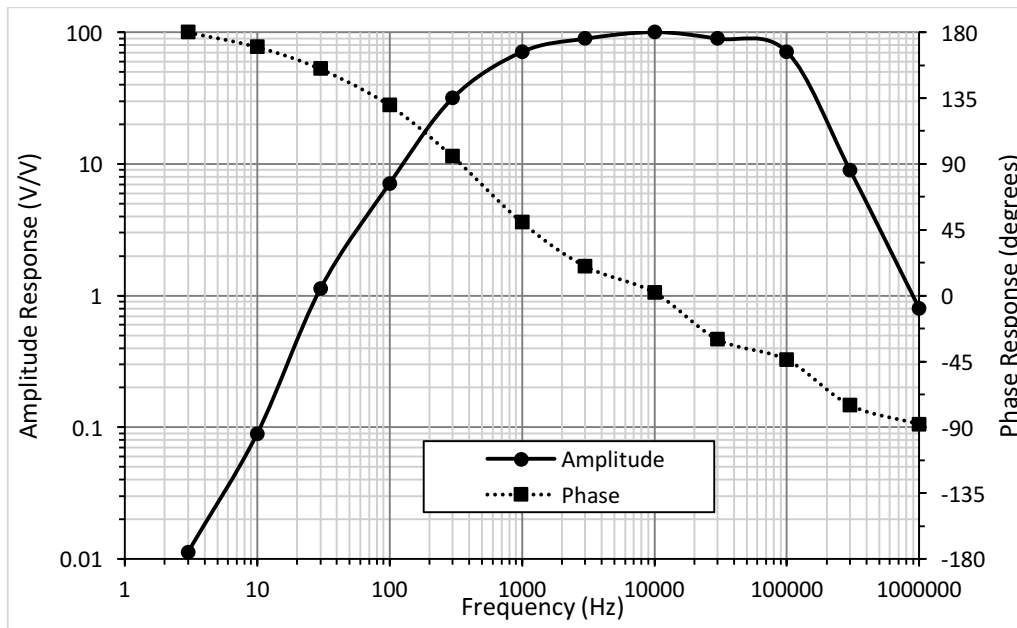


Figure B-10 Amplifier response with magnitude in V/V