ECE 304: Using EXCEL

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ECE 304: Using EXCEL

Preliminaries

It is assumed that you know a little about spreadsheets. Here we will construct a spreadsheet that calculates gain and phase margin as an illustration of the most useful of EXCEL's features, including some advanced features.

Construction of Spreadsheet

1. Open EXCEL. In Cell B1 enter "Gain and Phase Margin for Three-pole System". Click on an empty cell. Click on Cell B1. On the toolbar select FORMAT/CELLS. Select the FONT tab. Select ARIAL/BOLD/14.

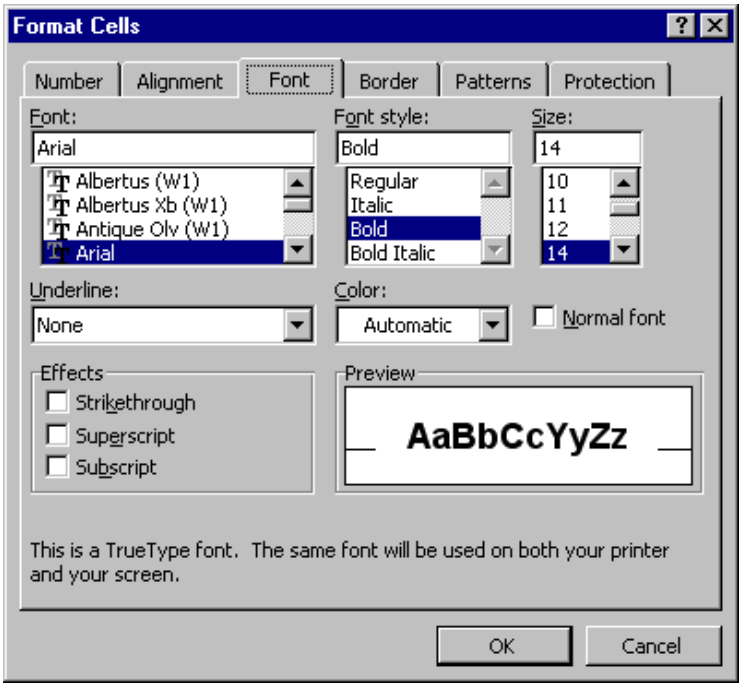

FIGURE 1:
FORMAT CELLS menu with selected font settings.

2. Right click on the tab at the lower right that says SHEET 1. Select the option RENAME, and change the name of the sheet to INPUT DATA.

Using WordArt in EXCEL

3. On the toolbar select VIEW/TOOLBARS/WORDART. Click on the colored letter A at the end of the toolbar to get the menu of Figure 2. Choose the entry in row 2 column 3. In the EDIT WORDART TEXT menu of Figure 3, insert "Input Data" and choose the font as shown in Figure 3 Right click on the pasted Word Art insert and select FORMAT WORDART. Make the selections in Figure 4. Drag the WordArt to Cell E3. The result is shown in Figure 5.
4. In Cell C4 enter the text "Open loop gain"
5. In Cell C5 enter the text "First pole frequency"
6. In Cell C6 enter the text "Second pole"
7. In Cell C7 enter the text "Third pole"
8. Highlight cells C4-C7 by dragging the mouse over them, and select the "right alignment" button on the toolbar. The right alignment icon is .

9. Highlight the cells C4-C7 and choose blue lettering (blue letter A) from the toolbar next to the paint bucket. Highlighting the same Cells, select bold type (B). The result is shown in Figure 6.

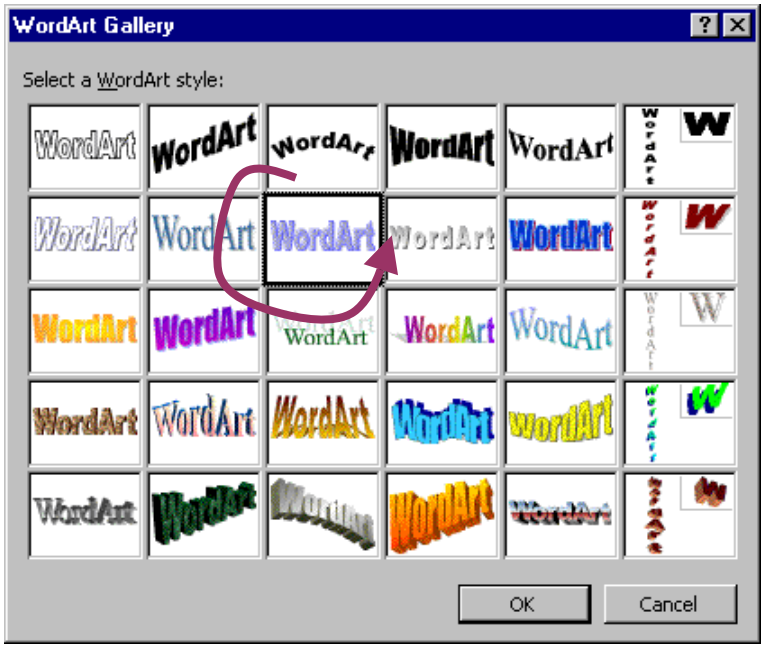

FIGURE 2:
WORD ART menu with selection circled

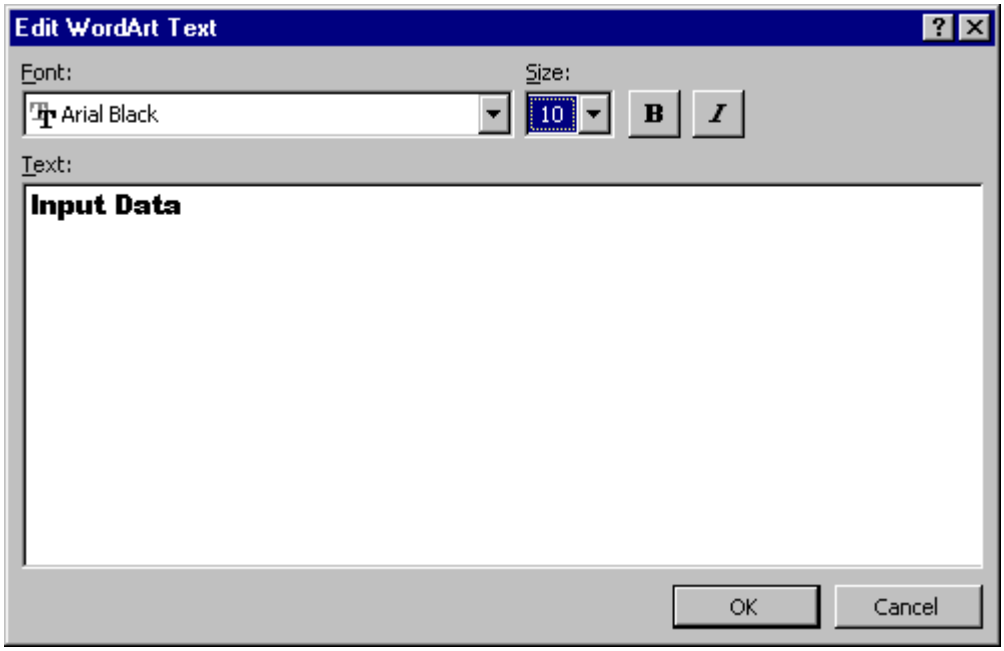

FIGURE 3:
EDIT WORDART TEXT menu

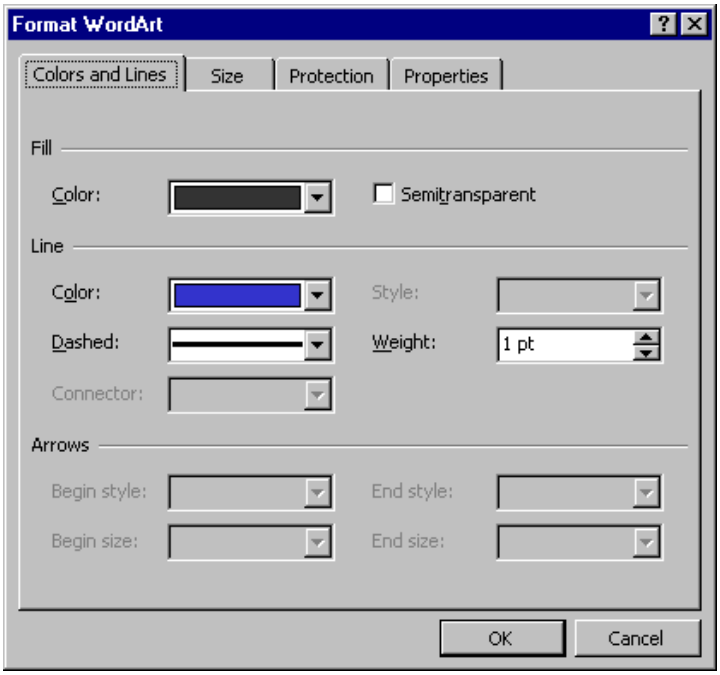

FIGURE 4:
FORMAT WORDART menu with black FILL COLOR selected and the SEMITRANSPARENT box unchecked

	A	B	C	D	E	F	G	H
1		**Gain and Phase Margin for Three-pole System**						
2								
3					Input Data			

FIGURE 5:
The spreadsheet after adding WordArt

	Gain and Phase Margin for Three-pole System						
				Input Data			
	Open-loop gain						
	First pole frequency						
	Second pole						
	Third pole						

FIGURE 6:
The spreadsheet after adding the row labels

Setting Fonts

10. In Column D4-D7 enter Ao=, fP1=, fP2=, fP3=.
11. Highlight the "o" in Ao and select FORMAT CELLS/FONT and check the SUBSCRIPT box. Likewise for the other entries. Select D4-D7 and click on the right-alignment button.

	Gain and Phase Margin for Three-pole System						
				Input Data			
	Open-loop gain		A_o=				
	First pole frequency		f_{P1}=				
	Second pole		f_{P2}=				
	Third pole		f_{P3}=				

FIGURE 7:
Spreadsheet after putting variables in D4-D7

12. In D8 enter the text "Feedback b". Place the mouse between the labels D and E at the top of the columns and drag the mouse to the right to make the D-column wide enough to contain the text "Feedback b". Click on D8 and highlight "b" in the text window. Select FORMAT/CELLS and scroll down the FONT window to select SYMBOL, as shown in Figure 8.
13. In Cell D9 enter b^-1 and change the b to β
14. In Cell E9 enter the gain with feedback in dB, namely =20*log10(1/Feedback_b). Don't worry about the #NAME? warning entry – it will go away when we name the variable in Cell E8 as "Feedback_b" in step 15 below.

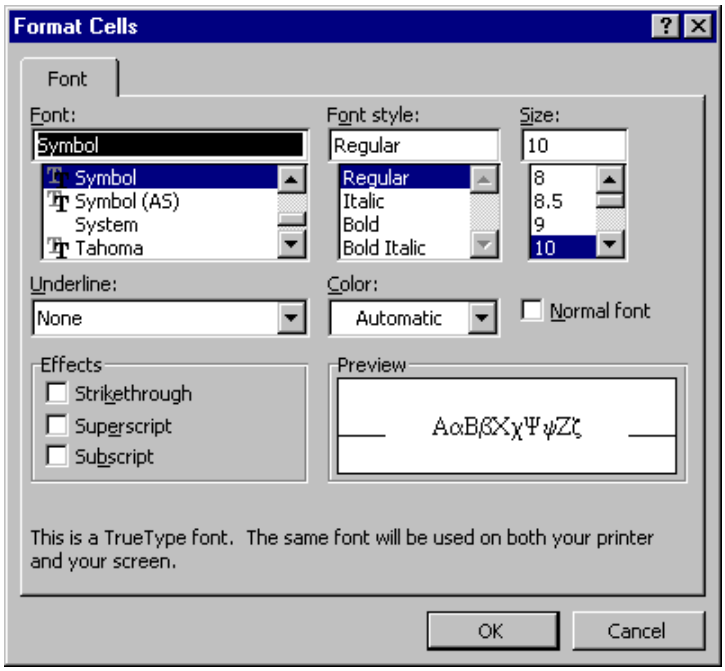

FIGURE 8:
Selecting the Symbol font for β

Naming Variable Cells

15. We now name the variable cells E4-E9. Select both D4-D9 and E4-E9. On the toolbar select INSERT/NAME/CREATE as shown in Figure 9. The result is that cells E4-E9 are now named after the entries in Cells D4-D9. To check, click on any of the cells E4-E9 and look in the name box just above the Column A label. As you click down the column E4-E9 you will see the names Ao, fP1_, fp2_, fp3_, Feedback_b, and b__1. EXCEL puts an underscore after fP1_ to distinguish this variable from the name of the cell FP1. Also, an underscore is placed in Feedback_b because EXCEL cannot use variables with spaces in their names. Likewise, it interprets the power sign ^ as an underscore.

16. Enter values in the input cells E4-E8. The values chosen in Figure 10 correspond to an example in S&S pp. 727-729.
17. Color the input cells green to show they accept user input, and color the cell E9 blue to show it is a calculated value. This coloring avoids mistakes when the spreadsheet is used. For example, you don't want to erase your formula for 1/β by accidentally entering data in the cell E9. See Figure 10

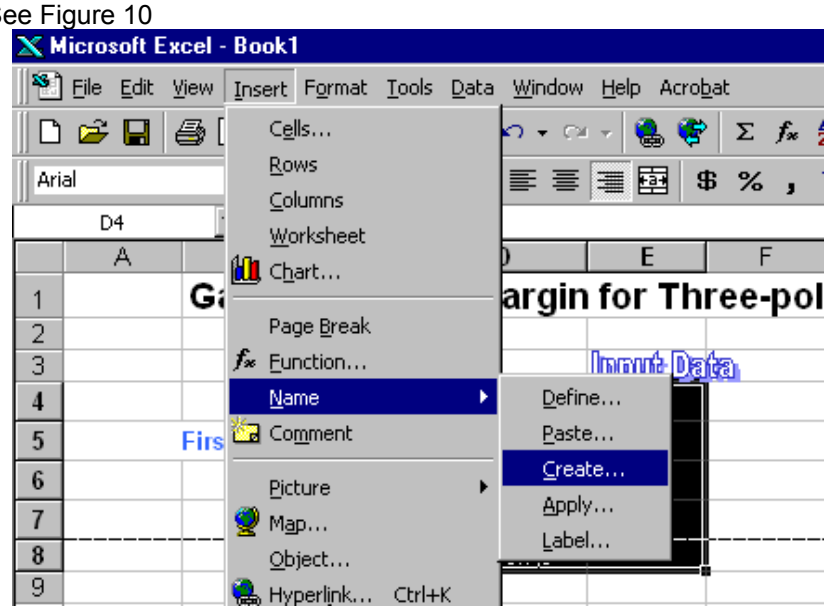

FIGURE 9:
Naming the variables in cells E4-E8

	Gain and Phase Margin for Three-pole System		
			Input Data
	Open-loop gain	A_o=	1.00E+05
	First pole frequency	f_{P1}=	1.00E+05
	Second pole	f_{P2}=	1.00E+06
	Third pole	f_{P3}=	1.00E+07
		Feedback β =	5.62E-05
		β^-1=	85.00527

FIGURE 10:
Spreadsheet after coloring Input Cells green and Output Cells blue

18. Rename Sheet 2 as "Calculate"
19. Click on the CALCULATE tab to get the new sheet.
20. Label cells E13-H13 as Frequency, Magnitude, dB, and Phase

Filling in a Series

21. Under column FREQUENCY we want a log type scale. As an example, in the Cell D13 enter 1. Move the mouse to the lower right corner until it changes to a black plus sign. Hold down the right mouse button and drag down the column as far as you want to go. Release the right mouse button and a drop-down menu appears. Select the option "series". See Figure 11. Follow the selections shown in Figure 11. Highlight the column label E and select FORMAT/ CELLS. Choose the NUMBER tab and select SCIENTIFIC. The result is shown in Figure 12.

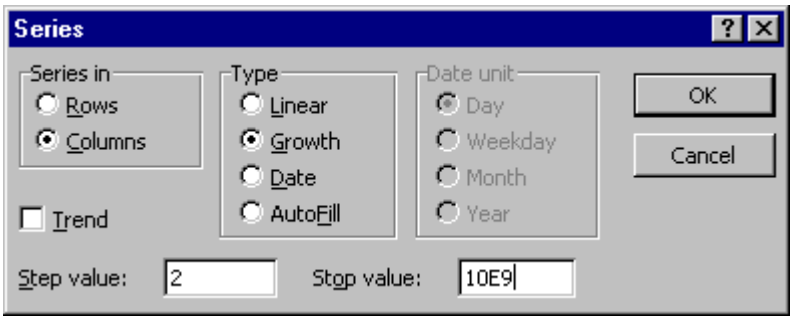

FIGURE 11:
The SERIES menu showing selection of the GROWTH option with each step incremented by a factor given by the STEP VALUE of 2. The fill is to stop at a frequency of 10GHz,

	E	F	G	H
12	Frequency	Magnitude	dB	Phase
13	1.00E+00	100000	100	-0.000636
14	2.00E+00	100000	100	-0.001272
15	4.00E+00	100000	100	-0.002544
16	8.00E+00	100000	100	-0.005088
17	1.60E+01	100000	100	-0.010176
18	3.20E+01	99999.99	100	-0.020351
19	6.40E+01	99999.98	100	-0.040703
20	1.28E+02	99999.92	99.99999	-0.081406
21	2.56E+02	99999.67	99.99997	-0.162811
22	5.12E+02	99998.68	99.99989	-0.325621
23	1.02E+03	99994.7	99.99954	-0.651226
24	2.05E+03	99978.82	99.99816	-1.302329

FIGURE 12:
The first few cells of the Calculate Worksheet with the frequencies entered as powers of 2.

Naming Variable Arrays

22. We already have named individual cells. Now we name arrays of cells. Highlight the entire four columns labeled Frequency, Magnitude, dB, and Phase along with their titles. Use INSERT/NAME/CREATE to create named arrays with these names.

Entering Formulas using Built-in Functions

23. In the magnitude column we want to enter the magnitude of the three-pole gain. The complex gain is $A(f) = \frac{A_O}{(1 + jf / f_{P1})(1 + jf / f_{P2})(1 + jf / f_{P3})}$. The magnitude of this gain is

$$|A(f)| = \frac{A_O}{|(1 + jf / f_{P1})||(1 + jf / f_{P2})||(1 + jf / f_{P3})|} = \frac{A_O}{\sqrt{(1 + (f / f_{P1})^2)(1 + (f / f_{P2})^2)(1 + (f / f_{P3})^2)}}$$

The phase of the gain is

$$\arg(A(f)) = -\tan^{-1}(f / f_{P1}) - \tan^{-1}(f / f_{P2}) - \tan^{-1}(f / f_{P3})$$

24. In Cell F13 enter
=Ao/SQRT((1+(Frequency/fP1_)^2)*(1+(Frequency/fP2_)^2)*(1+(Frequency/fP3_)^2))
25. In Cell G13 enter =20*LOG10(Magnitude)
26. In Cell H13 enter
=(–ATAN(Frequency/fP1_)–ATAN(Frequency/fP2_)–ATAN(Frequency/fP3_))*180/pi

The factor 180/pi converts radians to degrees. For the formula to work, we have to define pi. In Cell B12 enter pi=, and in Cell B13 enter 3.1415926. Then use INSERT/NAME/CREATE to identify pi as a variable.

27. The functions SQRT, ATAN, LOG10 etc. are built into EXCEL. You can find them by highlighting an empty cell and using the toolbar INPUT/FUNCTION to obtain the menu of Figure 13.

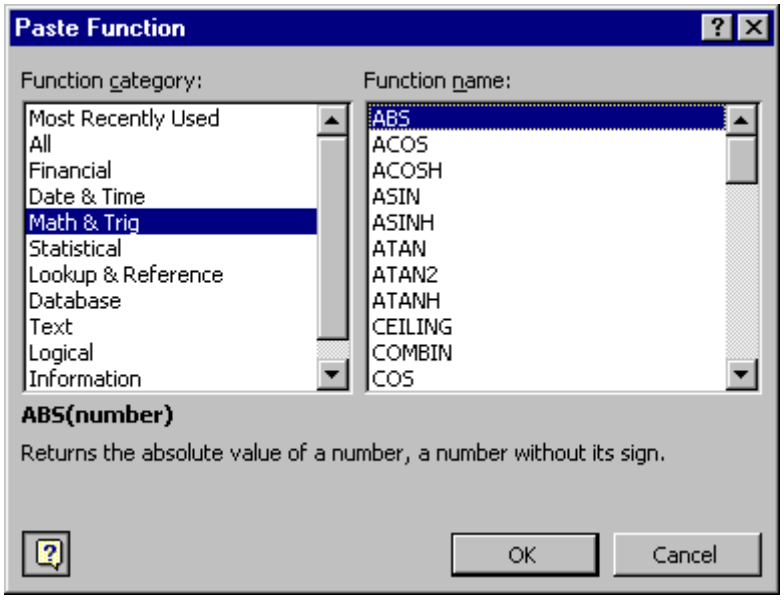

FIGURE 13:

The PASTE FUNCTION menu showing the built-in functions available in EXCEL

28. Highlight Cells F13, G13, and H13. Move the mouse to the lower right corner of Cell H13 until it changes to a small black plus sign, hold down the left mouse button, and drag down to Cell H46 to fill in the formulas throughout the arrays. Because we have used named variables, the entered formulas are easy to read, being algebraic expressions. This ease of reading makes tracking down entry errors easy, and also makes it easy to read the spreadsheet if you return to it later, after you have forgotten how it works.

Using Charts in EXCEL

29. Next we construct a dB-Bode plot (Microsoft calls it a Chart). Highlight the Frequency column, including its title. Hold down the Ctrl key and move the mouse to the dB column. Then sweep the entire dB column including its title. Then release the Ctrl key and the Mouse button, leaving both the Frequency and dB columns highlighted. See Figure 14.

	A	B	C	D	E	F	G	H	I
9									
10									
11									
12		pi=	3.141593		Frequency	Magnitude	dB	Phase	
13					1.00E+00	100000	100	-0.000636	
14					2.00E+00	100000	100	-0.001272	
15					4.00E+00	100000	100	-0.002544	
16					8.00E+00	100000	100	-0.005088	
17					1.60E+01	100000	100	-0.010176	
18					3.20E+01	99999.99	100	-0.020351	
19					6.40E+01	99999.98	100	-0.040703	
20					1.28E+02	99999.92	99.99999	-0.081406	
21					2.56E+02	99999.67	99.99997	-0.162811	
22					5.12E+02	99998.68	99.99989	-0.325621	

FIGURE 14:

Section of Chart input data with both frequency and dB columns highlighted. Insertion of variable pi is discussed later.

30. Move the mouse to the Chart Wizard on the Toolbar. The icon is shown below.

Click on the icon to obtain the menu shown in Figure 15.

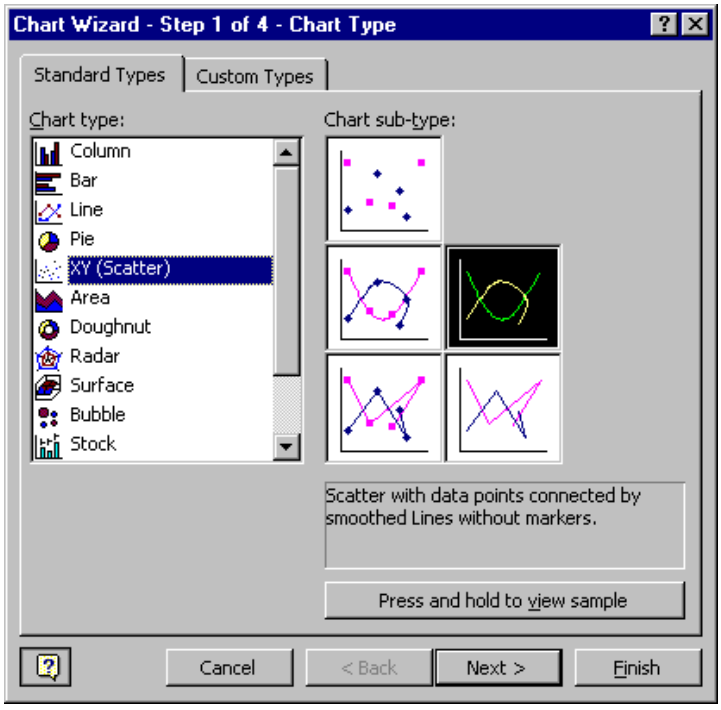

FIGURE 15:

The CHART WIZARD menu with XY plot selected and a subspecies of XY plot selected that fits a curved line to the data points but doesn't show the data points.

Hit the FINISH button to obtain the plot shown in Figure 16.

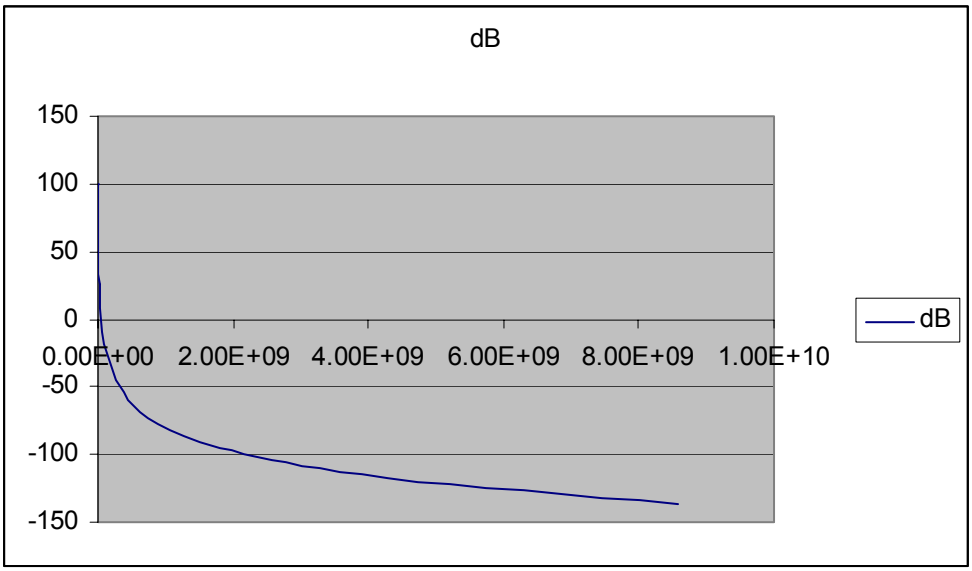

FIGURE 16:

Initial form of chart from the chart wizard

Place the mouse inside the chart area and right click. Chose FORMAT PLOT AREA to obtain the menu in Figure 17. Select the white background color, OK.

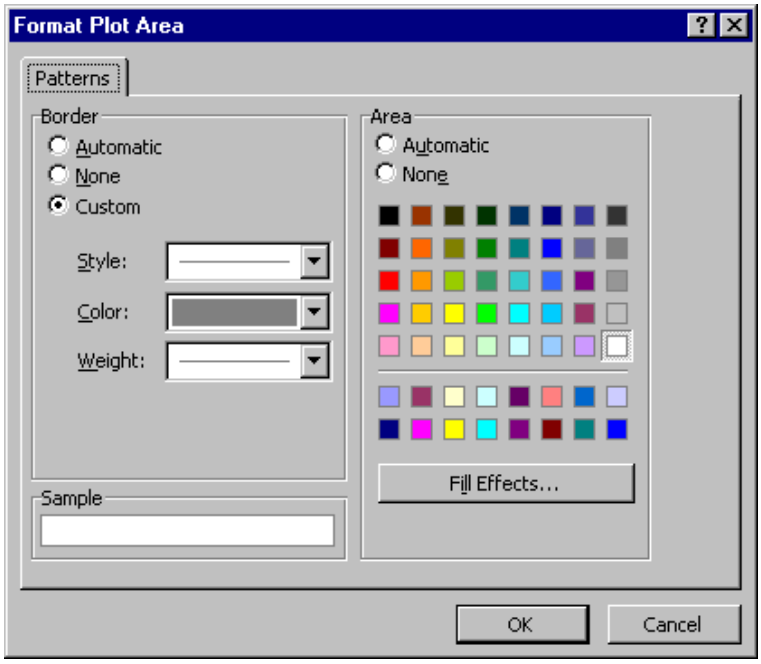

FIGURE 17:

The FORMAT PLOT AREA menu with the white background square in the AREA array of colors selected.

Return to the plot and right click on the plotted curve. Select FORMAT DATA SERIES to get the menu of Figure 18. Select the color and weight of the curve, OK.

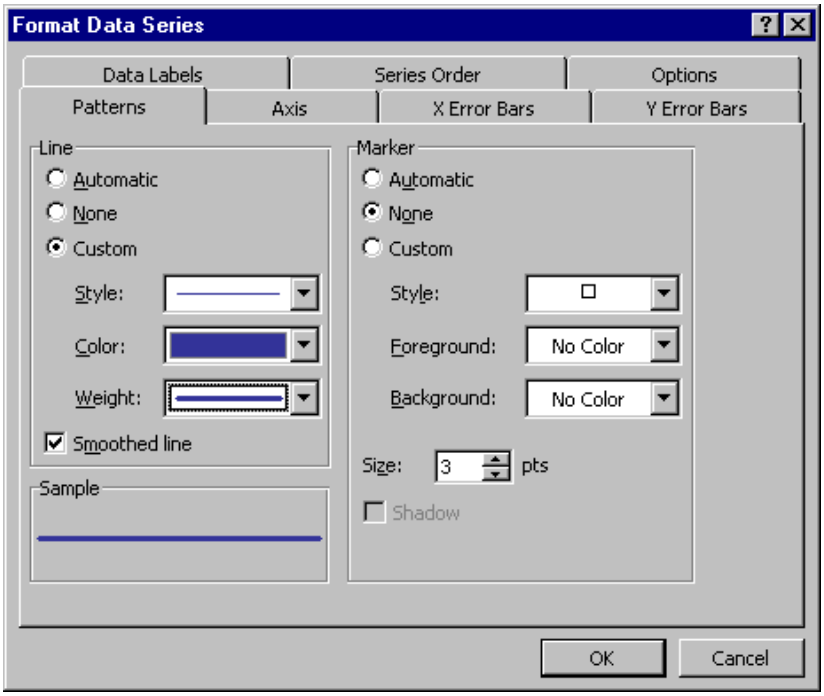

FIGURE 18:

The FORMAT DATA SERIES menu with color indigo blue selected and the heaviest weight available.

Place the mouse in the left margin of the plot and right click. Select FORMAT AXIS to get the menu of Figure 19. Change the CROSSES AT box to set the X-axis position.

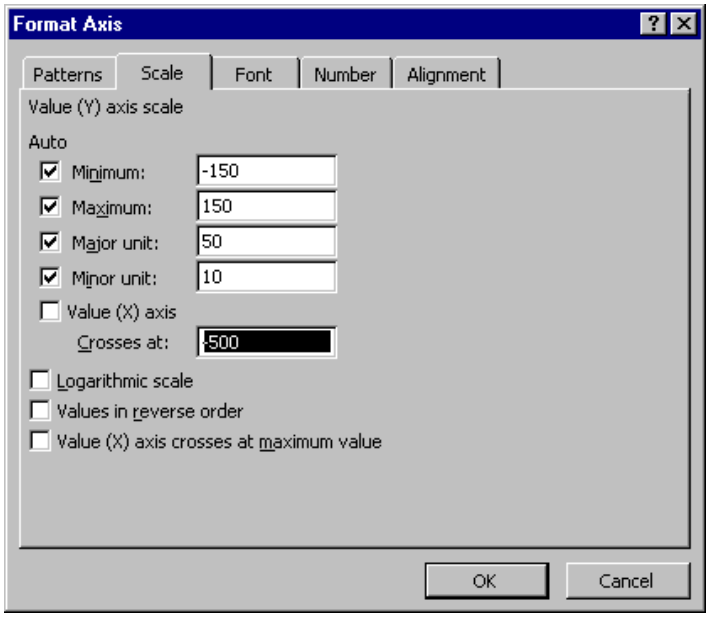

FIGURE 19:

The FORMAT AXIS menu with the CROSSES AT box set to –500 as the position where the X-axis crosses the Y-axis.

Put the mouse in the lower margin and right click to obtain the same menu for the X-axis. Select LOGARITHMIC SCALE. Select the NUMBER tab and reduce the number of decimal places to zero.

Put the mouse inside the plot area and right click CHART OPTIONS to obtain the menu of Figure 20. Select the GRIDLINES tab and set MAJOR and MINOR gridlines for the x-axis.

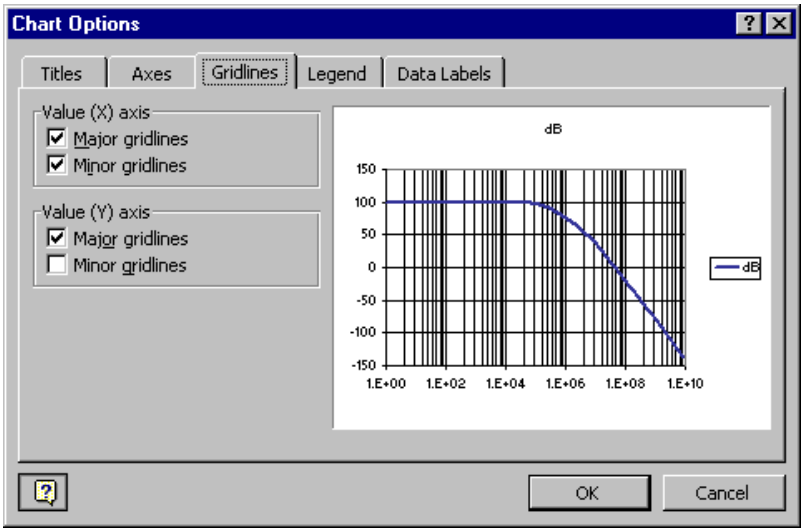

FIGURE 20:

The CHART OPTIONS menu with the GRIDLINES tab selected. MAJOR and MINOR gridlines have been chosen for the X-axis.

The scale on the x-axis goes up by factors of 100 instead of 10. Place the mouse on the right edge of the plot halfway up and move it until it becomes a double-headed arrow. Then hold down

the left mouse button and drag the right edge of the plot until the scale adjusts to show factor of ten increases in scale. The plot now looks like Figure 21.

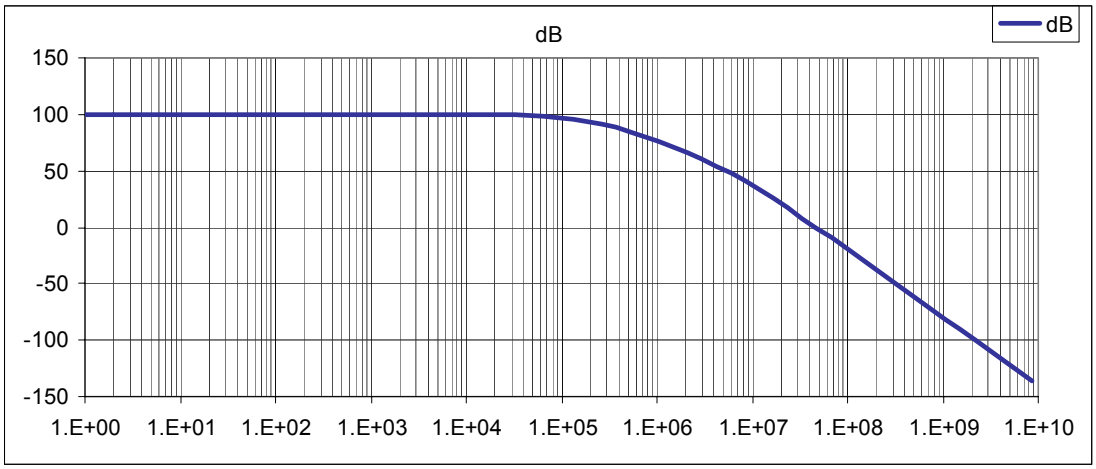

FIGURE 21:

The Bode dB plot from EXCEL.

Place the mouse inside the plot on the vertical gridlines. Right-click. Select FORMAT GRIDLINES to obtain the menu of Figure 22. Select a gray grid color.

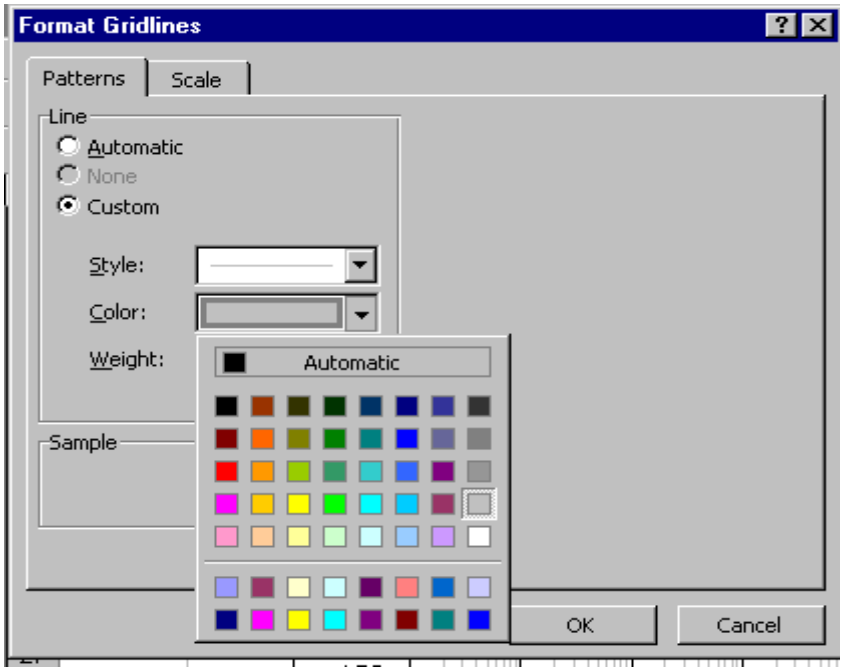

FIGURE 22:

The FORMAT GRIDLINES menu with a gridline color of gray selected.

Now, left-click on the edge of the plot to highlight it, right-click and select CUT. Left-click on the INPUT DATA worksheet tab, place the mouse in Cell C14, right-click and select PASTE. The plot now appears on the INPUT DATA sheet.

In the same way, we create a phase plot. The final result is shown in Figure 23.

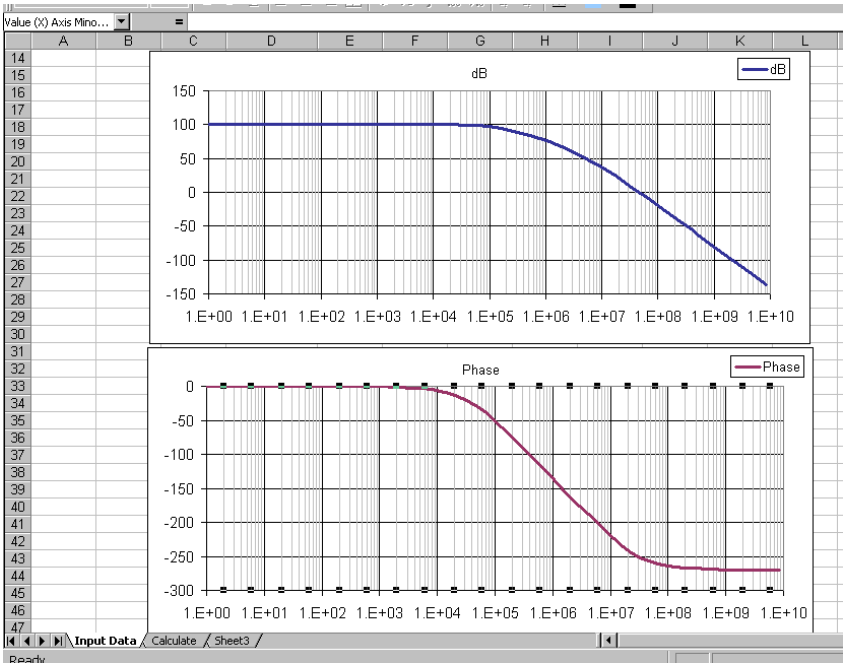

FIGURE 23:

The Bode phase and Magnitude plots on the INPUT DATA worksheet

Using Goal Seek

In studying amplifier stability, it is important to know the frequency f_1 (called the unity loop-gain frequency) where the loop gain $\beta|A(f_1)|=1$. Also, we want the frequency where the phase is $-180°$ (called the sign-flip frequency, f_{180}). To find f_1, we could go to the part of the table where the unity gain frequency is straddled, as shown in Figure 24.

Frequency	Magnitude	dB	Phase
2.62E+05	3.45E+04	90.74756	-85.3105
5.24E+05	1.66E+04	84.3868	-109.87

FIGURE 24:

Segment of table straddling the unity gain frequency f_1 where $|A(f_1)| = 1/\beta = 85$ dB. From this table, 2.62×10^5 Hz < f_1 < 5.24×10^5 Hz

By entering a finer grid of frequencies at this point in the table, we could find f_1 accurately. However, these frequencies can be found much more easily in EXCEL using a built-in nonlinear root solver called GOAL SEEK. GOAL SEEK will change the value of a specified parameter until a specified function of that parameter takes on a specified value. In this case, we will vary the parameter f_1 until the gain equals $1/\beta$. To do this we first set up a "target cell" that contains the function. I chose the function to be $|A(f)|-1/\beta$, with both in dB.

31. In Cell I4, enter =20*LOG10(Ao/SQRT((1+(f1_/fP1_)^2)*(1+(f1_/fP2_)^2)*(1+(f1_/fP3_)^2)))-b__1. In Cell J4 enter f1=. Then with Cell J4 and K4 highlighted, use INSERT/NAME/CREATE to name K4 as f1_. Now, highlight cell I4 and use the toolbar TOOLS/GOAL SEEK. The resulting menu is shown in Figure 25. Fill in the menu as shown in the figure.

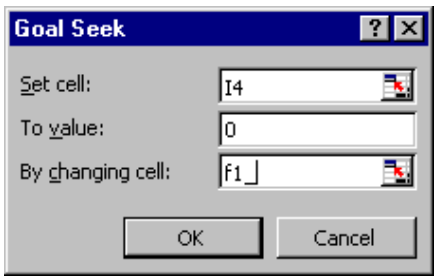

FIGURE 25:

The GOAL SEEK menu with target cell I4, target value of 0 and parameter cell f1_.

When OK is hit, the cell f1_ is adjusted until the target cell hits the target value.

32. Likewise, set up a target cell with target value zero for the sign-flip frequency f_{180}

33. We can plot the results on the graphs for easy visualization by adding some data. In Cell M14 add "f180 on dB plot". In Cell M15 enter =f180_. Likewise in Cell M16. In Cell N15 enter = and then go to the CALCULATE worksheet and click on G13. In Cell N16 enter = and go to the CALCULATE worksheet and click on G46. In this way we insure that the plot of f_{180} will run from the maximum gain value to the minimum gain value, regardless of the gain value A_O we use in our examples.

34. Now place the mouse inside the dB plot area and right click. Select SOURCE DATA. On the menu choose the SERIES tab. At the bottom of the SERIES box, click on the ADD button. In the NAME box type in f180. Put the cursor in the XVALUES box. Clear out anything in the box. With the cursor still in the box, move the mouse to select Cells M15 and M16. Move the cursor to the YVALUES box. Clear it out. With the cursor still in the box move the mouse to select Cells N15 and N16. Click OK on the menu. You now have the f180 curve plotted. In the same way you can add the f1 curve and so forth. The result is shown in Figure 26.

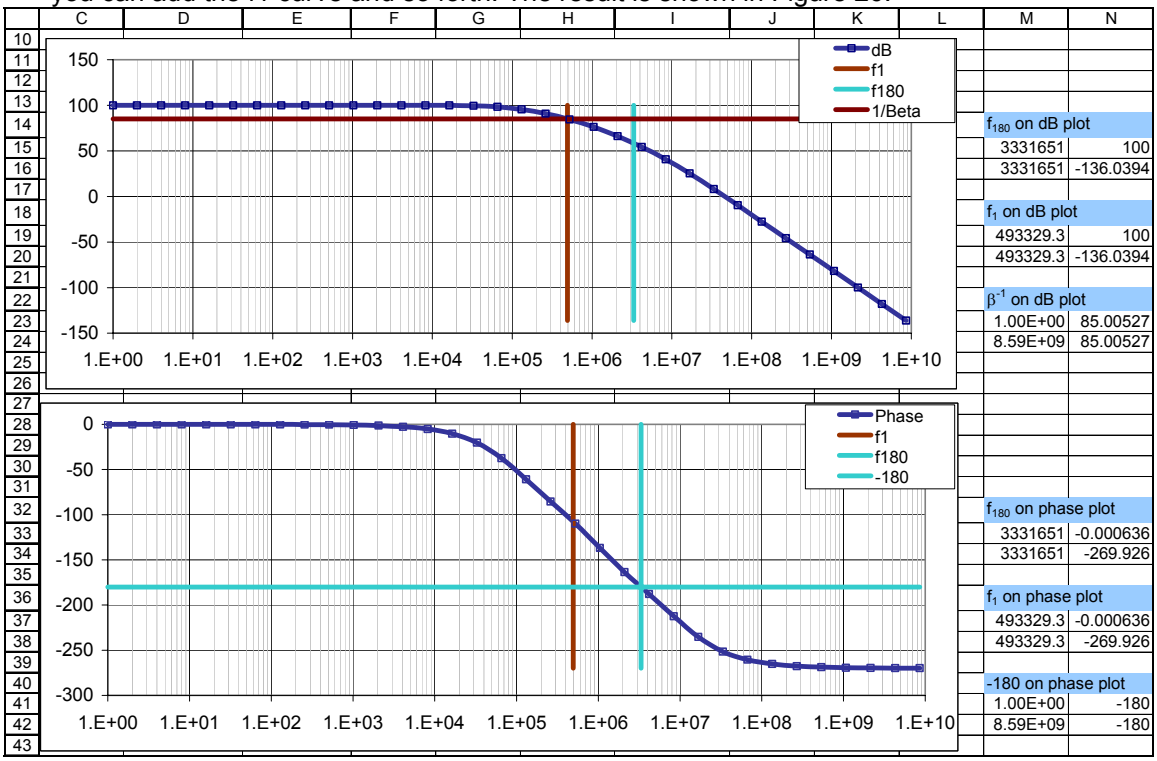

FIGURE 26:

The plots with various added curves.

According to their definitions, the f_{180} line should intersect the $-180°$ line on the phase plot (the two aqua lines) and the f_1 line should intersect the $1/\beta$-line on the dB plot (the brown lines).

35. The Bode plots in Figure 26 have been changed to show the data points. To reformat the Bode curves, right click on the curves and select FORMAT DATA SERIES to obtain the menu of Figure 27. Make the MARKER selections indicated in the figure.

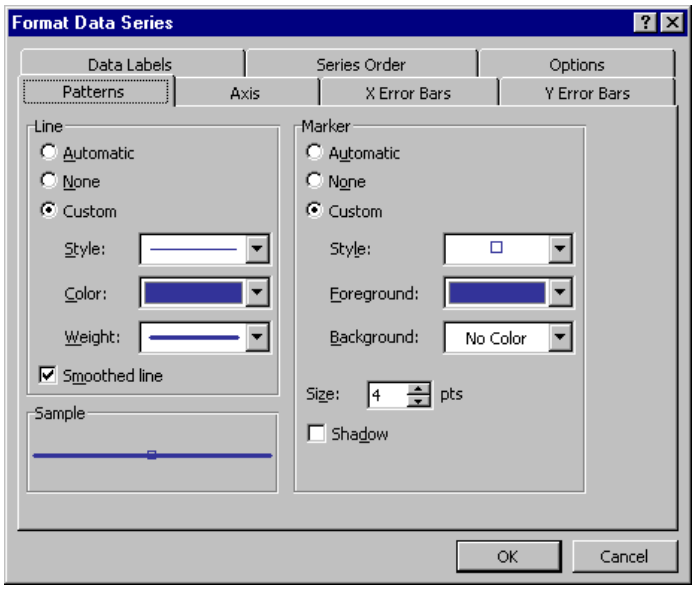

FIGURE 27:
Adjusting the Bode plots to show the data points

Using the Macro Recorder

It is a nuisance to go through the GOAL SEEK menu sequence every time you want to find the frequencies f_1 and f_{180}. This sequence can be automated. First, we record the sequence. Then we implement a Command Button that initiates the sequence.

36. On the INPUT DATA worksheet, click on an empty cell.
37. On the TOOLBAR select TOOLS/MACRO/RECORD NEW MACRO. You will obtain the menu in Figure 28. Fill out the menu and click OK.

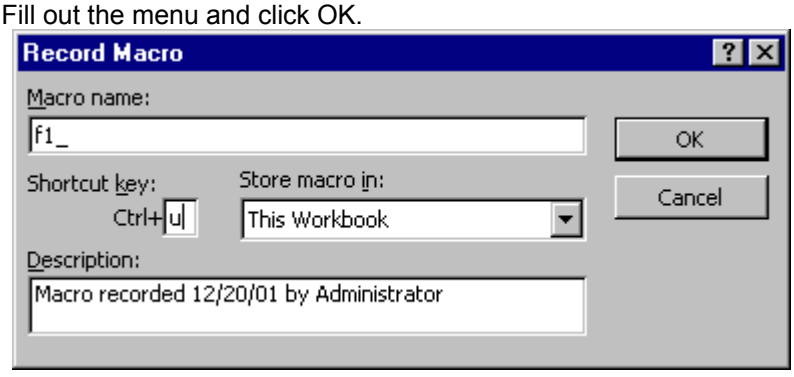

FIGURE 28:
The RECORD MACRO menu with the macro name set to f1_ and the shortcut key set to Ctrl+u (u for unity gain frequency)

38. Select Cell K4 and set f1_ = 1. Select Cell I4. Go to the toolbar and select TOOLS/GOAL SEEK. Fill in the GOAL SEEK menu. Go through the sequence we have already done manually. When you are finished finding f_1, go to the toolbar and select TOOLS/MACRO/STOP RECORDING.
39. At this point you can check your macro. Go to the toolbar, TOOLS/MACRO/MACROS/EDIT. You should see the following listing (it is a Visual Basic program)

```
Sub f1_()
'
' f1_ Macro
' Macro recorded 12/20/01 by Administrator
'
' Keyboard Shortcut: Ctrl+u
'
    Range("K4").Select
    ActiveCell.FormulaR1C1 = "1"
    Range("I4").Select
    Range("I4").GoalSeek Goal:=0, ChangingCell:=Range("K4")
End Sub
```

This code should be modified as follows, so it will work even if you move the cells around on the spreadsheet:

```
Sub f1_()
'
' f1_ Macro
' Macro recorded 12/20/01 by Administrator
'
' Keyboard Shortcut: Ctrl+u
'
    Range("f1_").Select
    ActiveCell.FormulaR1C1 = "1"
    Range("Target_f1").Select
    Range("Target_f1").GoalSeek Goal:=0, ChangingCell:=Range("f1_")
End Sub
```

For this modified code to work, you have to use INSERT/NAME/CREATE to define the target cell I4 as Target_f1.

At this point, to run the GOAL SEEK operation, all you need to do is press Ctrl+u and away it goes.

40. Do the same for f_{180}. The modified code is shown below.

```
Sub f180_()
'
' f180_ Macro
' Macro recorded 12/20/01 by Administrator
'
' Keyboard Shortcut: Ctrl+p
'
    Range("f180_").Select
    ActiveCell.FormulaR1C1 = "1"
    Range("Target_f180").Select
    Range("Target_f180").GoalSeek Goal:=0, ChangingCell:=Range("f180_")
End Sub
```

Using Command Buttons

Although the determination of f_1 and f_{180} now is automated using Ctrl+u and Ctrl+p, you might want to use the mouse and simply click a button that executes the macros. To do this, go to the toolbar and select VIEW/TOOLBARS/CONTROL TOOLBOX, as shown in Figure 29.

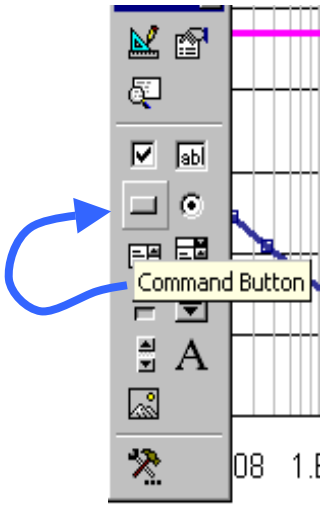

FIGURE 29:
The TOOLBOX menu with the COMMAND BUTTON selected

41. Click on the COMMAND BUTTON and then use the right mouse button to outline Cell M4. When you release the mouse button, a command button will fill the cell.
42. Do the same for Cell M5
43. Right click on the first command button. Select PROPERTIES. Make the changes indicated in Figure 30

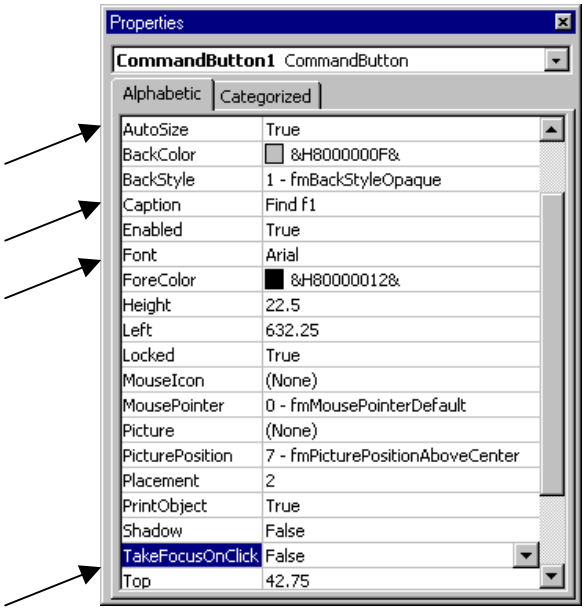

FIGURE 30:
The command button properties. CAPTION has been changed to “Find f1” and TAKES FOCUS ON CLICK has been changed to FALSE. In addition, AUTOSIZE has been set to true, and FONT to Arial, FONT STYLE to Bold, FONT SIZE to 8.

44. Do the same with the second button, using the caption “Find f180”.

45. Right click on the first command button and select VIEW CODE. Add the macro names to the code window, as shown in Figure 31

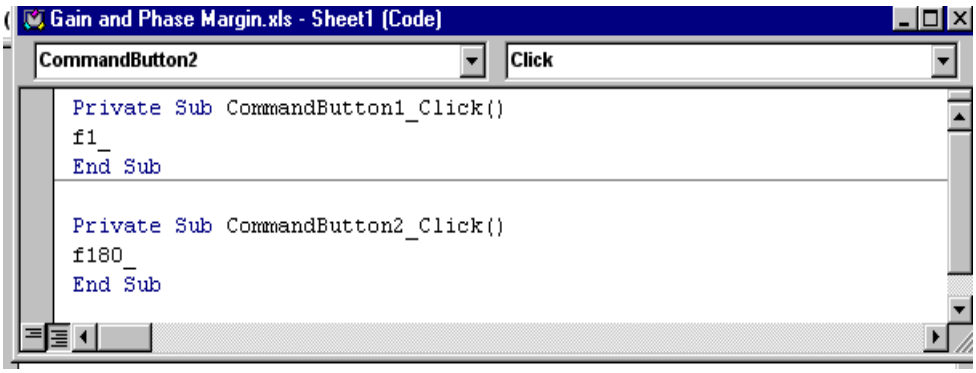

FIGURE 31:
The code for the two command buttons

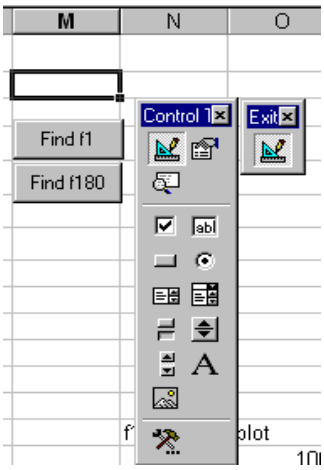

FIGURE 32:
The two command buttons and the TOOLBOX menu. The EXIT button is beside the TOOLBOX menu. Sometimes this box does not appear. The similar button on the TOOLBOX menu can be used instead.

46. Click the pencil-and-triangle icon on the EXIT button to leave the DESIGN MODE for the COMMAND BUTTONS. This action activates the command buttons.
47. Now clicking on the buttons has the same effect as using the keyboard shortcuts.

Gain and Phase Margins

Later in the course we will find that for a stable feedback amplifier we want the unity loop gain frequency $f_1 \le$ sign-flip frequency f_{180}. (That is, for stability, the loop gain should drop below unity before the feedback signal flips sign.) As a measure of the stability, the gain margin is defined as how many dB the gain at f_{180} is <u>below</u> the gain at f_1, that is,

$$\text{Gain margin} = 20*\log_{10}(|A(f_1)|/|A(f_{180})|) = 20*\log_{10}(|1/\beta|/|A(f_{180})|)$$

A similar measure of stability is the phase margin, which is how many degrees the phase at f_1, denoted by $\phi(f_1)$, falls short of $-180°$. That is, the phase margin is

$$\text{Phase margin} = \phi(f_1) - (-180°)$$

These two margins are easily added to the spreadsheet.

48. In Cell I8 enter =(-ATAN(f1_/fP1_)-ATAN(f1_/fP2_)-ATAN(f1_/fP3_))*180/pi+180

49. In Cell I9 enter
=20*LOG10(SQRT(((1+(f180_/fP1_)^2)*(1+(f180_/fP2_)^2)*(1+(f180_/fP3_)^2))/((1+(f1_/fP1_)^2)*(1+(f1_/fP2_)^2)*(1+(f1_/fP3_)^2))))

50. Add labels. The final result is shown in Figure 33.

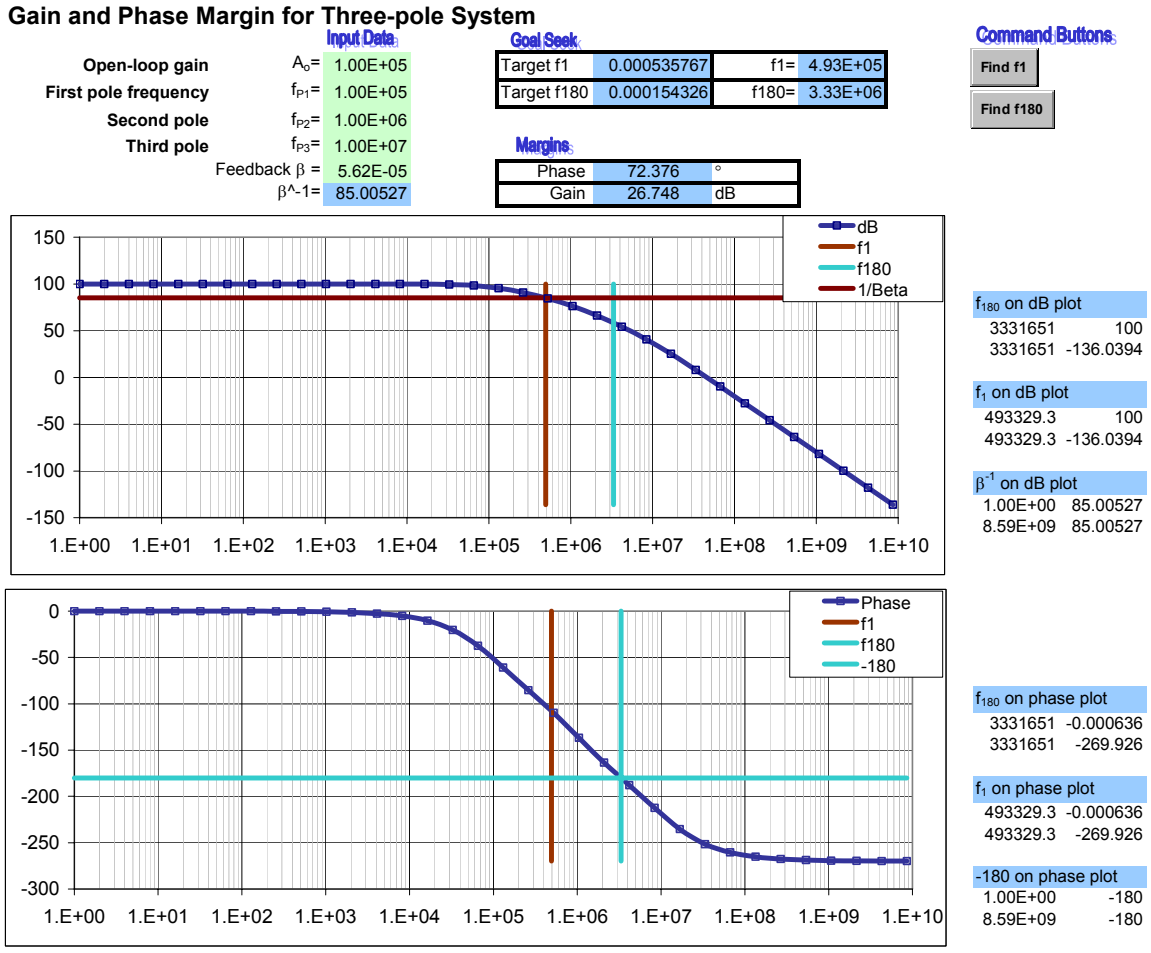

FIGURE 33:
Worksheet Input Data of final spreadsheet. The entry =CHAR(126) produces the ° symbol.