EE200 Users Guide

For TI-89 Calculators

This version of the EE200 Users Guide applies to version 1.0 of the EE200 software.

September 7, 2000

author's note to EE200 users –

Writing software for the use of a large group of people – college students, in this case – can be a lesson in humility. The user interface which seems so manifestly obvious and intuitive to its programmer is, not infrequently, a puzzle to many potential users. EE200 version 1.0 may turn out to be no better than most software in this respect. Nevertheless I'm convinced that, for those freshman and sophomore engineering students who are willing to try out EE200 by running the four examples in this short manual, the program will prove to be useful.

Naturally I believe the program is useful because I wrote it, but there is more to it than that. The program was developed while I myself was taking the first circuit analysis course sequence at Oregon State University. I wrote it, initially for my own use, because I found myself making more errors than I wanted to on homework and exams, and taking so long to work out solutions that I didn't have time to go back and check my work. It frustrated me that even when I could write down the correct equations, I still missed getting the right answer because of arithmetic or algebra mistakes.

I have earned a living as a computer programmer for thirty years, so I am used to relying on computers to make up for my own weaknesses in memory, arithmetic, and higher math. The TI-89 and TI-92 Plus "calculators" – actually pocket-sized computers more powerful than the PCs of a few years ago – provide plenty of resources for the EE200 program to help me avoid errors, speed up my work, and give me the time to check my answers.

EE200 has already proved valuable to me in sophomore-level circuits courses. I hope that it will be as helpful to others undertaking similar coursework. I would especially like to hear users' comments. I invite you to send your questions needing immediate answers to me at help@unit-smart.com, and any other suggestions or complaints to author@unit-smart.com. I look forward to hearing from you.

Dave Conklin
August 26, 2000

Table of Contents

Acknowledgments

Users familiar with the da Vinci Technologies EE•Pro product will recognize some user interface similarities between EE200 and EE•Pro, despite their functional differences. The similarities arise from the author's participation in the development of EE•Pro while employed by da Vinci Technologies, and are the subject of a cross-license agreement between the author and his former employer. I wish to thank my friends at da Vinci for their encouragement and cooperation.

The example problems used in this manual are taken from midterm and final exams given in Prof. Tom Plant's ENGR 201 course at Oregon State University during the fall and winter terms of the 1999-2000 school year. Prof. Plant has graciously given his permission for the use of these problems here.

A number of students at Oregon State University and Linn-Benton Community College have used beta versions of the EE200 software. I am endebted to them for their help and suggestions, and for their patience with buggy early versions. I especially wish to thank OSU students Matt Johnson and Chad Webb for their contributions, and John Sweet on the faculty at LBCC for allowing me to sit in on his summer ENGR 201 and ENGR 202 courses while EE200 was in beta test.

Dave Conklin

INSTALLING EE200 IN YOUR TI-89 CALCULATOR

EE200 is distributed in *two different forms*:
- as a **secured** application distributed electronically by Texas Instruments' webstore, and
- as a **shareware** file available from Unit-Smart Software and its resellers.

EE200 may be loaded into any TI-89 which has version 2.04 or later of TI's Advanced Mathematics Software (AMS). If you have an earlier version of the AMS in your TI-89, you may obtain AMS 2.04 or any later versions from Texas Instruments' website[1]. Note that while it is possible to load EE200 into a calculator with AMS 2.03, EE200 *does not appear on the APPS/1:FlashApps menu unless the AMS version is 2.04 or higher.*

If you have purchased the **secured** form of the software from Texas Instruments' webstore, please follow the instructions provided on their webpages for installing EE200 into your calculator, or follow the instructions given below for downloading EE200 from a PC. Note that the TI webstore sends two files: a *certificate* file and the EE200 file itself. Both files must be downloaded into your calculator from the PC, and the certificate file must be downloaded *first*, before the EE200 file is downloaded. Note that obtaining and entering **a registration number is not necessary for the secured form** of EE200.

The EE200 **shareware file** may be installed for limited demo use *or* for extended use. Installing for **extended use requires a registration number**. The registration number is an 8-digit, hexadecimal number keyed to the serial number of the calculator and the version of the EE200 file.

You don't need a registration number to load the shareware file and try out the software. However, unless you enter a registration number, after a limited number of uses EE200 will be automatically erased from the calculator's Flash memory. If you don't have the registration number when you first load EE200, **don't worry** – each time the program calculates a solution, it tells you how many "free solutions" remain in the limited demo period and gives you another opportunity to enter the registration number.

There are **2 ways to load** the EE200 shareware file into your TI-89 calculator:
- **copy** EE200 from one TI-89 to another using the calculator's **VAR-LINK** command, *or*
- **download** from a PC or Mac using **TI-GRAPH LINK™** software.

To copy EE200 from one TI-89 to another, all you need is the little black unit-to-unit link cable that came with your calculator. Here are the steps:

1. Connect the two calculators with the link cable by plugging one end of the cable into each calculator's I/O port. The I/O port is located at the center of the bottom edge of the calculator.
2. Make sure the two calculators are both at their HOME screens. If necessary, press HOME.
3. On the receiving calculator, press 2nd/VAR-LINK/F3:Link and select 2:Receive.
4. On the sending calculator, press 2nd/VAR-LINK/2nd/F7:FlashApp. Move the cursor to EE200. Then press F3:Link and select 1:Send to TI-89.

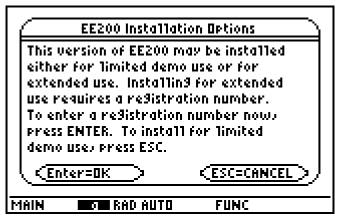
To download EE200 from a PC or Mac, you will need a TI-GRAPH LINK cable and software. The software is available for free from TI's website, but the cable is an extra-cost accessory not included with the calculator itself. The cable comes in two different TI products:
- TI-GRAPH LINK Full Package, which works for both PCs and Macs, and
- TI-GRAPH LINK for Windows, for Windows 95, 98, NT, and, presumably, later versions. This one costs less than the Full Package.

Here are the steps for downloading:

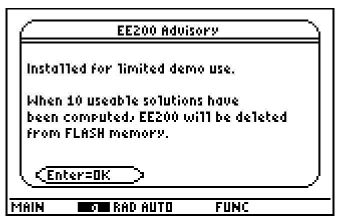
[1] Go to web address www.ti.com/calc/docs/ and click on "Free Downloads".

1. Connect the TI-GRAPH LINK cable to a serial port of your computer and to the I/O port of the calculator. The I/O port is located at the center of the bottom edge of the calculator.
2. Make sure the calculator is at its HOME screen. If necessary, press HOME.
3. Start the TI-GRAPH LINK program on the computer. Click on LINK/Send Flash Software/Applications and Certificates. Select the appropriate disk drive and directory, and select or enter “EE200.89k” as the file name. Click on ADD; this will enter the EE200.89k file name in the “Files selected:” list. Now click on OK.

When the EE200 shareware file is first loaded, a dialog box is displayed on the TI-89:

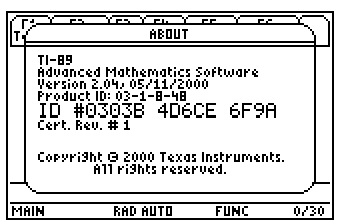


If you have not yet obtained a registration number, press ESC. An advisory message is displayed:



This dialog box notifies you that, after a limited number of solutions have been calculated, EE200 will *automatically* erase itself from the calculator’s Flash memory. After each solution is calculated, EE200 will remind you of the remaining number of solutions available for use; it will also give you another chance to enter a registration number.

To obtain a registration number, send e-mail to help@unit-smart.com. In your e-mail, tell us the serial number of your calculator and the version of your EE200 software. Each of these is found by pressing F1:Tools/A:About. When you do this from the calculator’s HOME screen, you get the calculator’s software serial number:



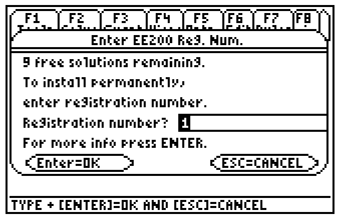
The calculator’s software serial number is the 16 digit hexadecimal “ID #” in the middle of the screen, and it is different from calculator to calculator. Note that the serial number on the back of the calculator is not the same. When EE200 is running and you press F1:Tools/A:About, you see a screen like:

The top line identifies the version of the EE200 software.

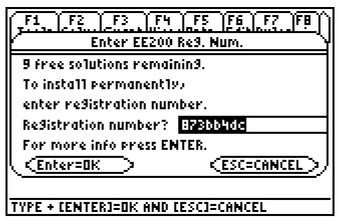
If you have already purchased your copy of EE200, then please also include in your e-mail to us the product serial number. Your EE200 product serial number is of the form "EE200-89-XXXXX". It is written or stamped on the outside of the package, and also on the cover or first page of the manual. Telling us your product serial number is how we know that your copy of EE200 has already been paid for.

If your copy of EE200 has not yet been paid for, then our e-mail reply will let you know how to remit payment.

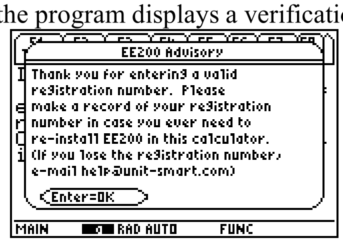
When you have your registration number, watch for an opportunity to enter it when you see a dialog box like this:



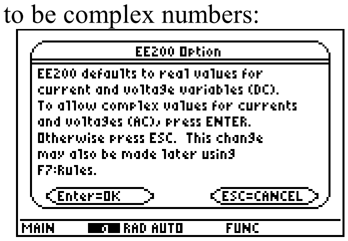
Key in your 8-digit hexadecimal registration number; then, press ENTER. Pressing ENTER the first time just highlights the entry:



Pressing ENTER again exits the dialog box. After verifying that the registration number is valid for your calculator and the version of EE200, the program displays a verification message:



EE200 installation concludes by asking you to select between requiring electric current and voltage values to be real numbers, or allowing them to be complex numbers:



If you are beginning your first circuit analysis course, you will probably start by solving problems in which the currents and voltages are not time-varying, i.e., DC circuits. In that case, press ESC to constrain voltage and current values to real numbers. Otherwise, press ENTER here to allow currents and voltages to take on complex values, which is appropriate for phasor domain analysis of AC circuits.

WHAT EE200 IS GOOD FOR…

EE200 is a calculator application program which **helps students avoid math and units errors** on homework problems and tests in electrical engineering courses. EE200 runs on TI-92 Plus and TI-89 calculators manufactured by Texas Instruments. This Users Guide is written for use with TI-89 calculators.

When using EE200 to solve a problem, the student enters the equations, *including measurement units*, and the known values. EE200 alerts the user to any "adding-apples-and-oranges" errors, i.e. equations in which the units are unbalanced. It then solves the equations simultaneously for the unknowns. Because EE200 verifies that units balance, the user is told immediately if he is multiplying when he should be dividing or vice versa. For example, the user who mistakenly enters the equation for Ohm's Law as V × I = R, instead of correctly entering V = I × R, would be alerted of an error by EE200 immediately because the *units of* V × I = R *are unbalanced*.

Entering the measurement units is quick and easy because EE200 follows common electrical engineering notation conventions. For example, variables which begin with the letter V are assumed to be voltages; variables which begin with I are assumed to be currents.

EE200 helps to **avoid errors by checking its own answers** to make certain they make sense given their units. For example, suppose Ohm's Law V = I × R is entered, along with known values V = 6 volts and I = -2 amps. EE200 calculates the answer as R = - 3 ohms. However, since negative values don't make sense for resistance, EE200 alerts the user that there may be an error in the data as entered by displaying the message: *"No useable solution found"*.

When there are **several possible correct answers**, EE200 lets the user know. For example, suppose that P = 100 watts and R = 4 ohms. Solving the equation $P = I^2 \times R$ for I produces two equally reasonable answers: the current I may be either +5 amps or –5 amps. EE200 alerts the user that there are 2 useable solutions and allows the choice of either one.

EE200 allows the user to **enter known values in any common units** and **always displays units with its calculated answers**. Moreover, the user **may readily switch between units of different scale**. For example, suppose that, for the equation $P = I^2 \times R$, the known value for power is 10 milliwatts instead of 100 watts and R remains 4 ohms. EE200 calculates the current to be 0.05 amps. The user may tell EE200 to use milliamps for I instead of amps. EE200 then converts its answer to milliamps and displays I = 50 mA.

EE200 is easy to use. The student only has to remember one simple rule:

Enter what you know. Then press F2:Solve.

EE200 does the rest.

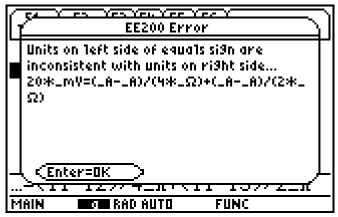
EE200 is also very flexible. It allows the student to modify the notation rules, if necessary, to match the particular conventions used by the professor. In addition, the user may *override the notation rule* for any particular variable by selecting its units explicitly the first time it is used.

After entering equations and data and calculating answers, the user may **save his work in a descriptively-named folder**. This provides a way for a student taking an exam, once he has completed all the problems on the exam the first time, to return to each problem and check over the work without having to enter the equations and data again.

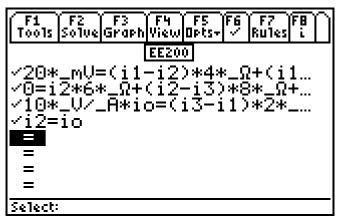
Individual equations or sets of **equations may be imported into EE200 from EE•Pro.** EE200 includes a function, 9:GetEqns on its F1:Tools menu, which can be used to extract sets of equations from the da Vinci Technologies EE•Pro software and "paste" the equations into EE200's equation screen.

WHAT EE200 WILL AND WON'T DO FOR YOU

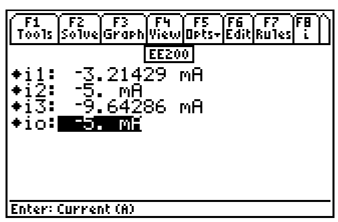
Even with EE200, **the user can't solve a problem without having a working knowledge of the relationships of the variables,** knowledge sufficient to formulate appropriate equations. Using notation conventions appropriate for the problem allows the calculator to alert the student if he inadvertantly enters an equation in which the units don't balance. For example, the calculator displays an error message if the user confuses node voltage and mesh current equations, dividing by the resistances in a mesh analysis equation instead of multiplying:



The **student doesn't have to do the algebra to isolate the unknowns** For example, a mesh current circuit analysis problem with 3 meshes and one current-controlled voltage source is described by 4 equations in 4 unknowns:

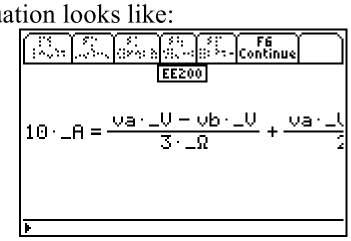


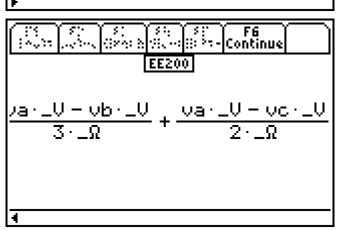
EE200 takes it from there: simultaneously solving the 4 equations *and* displaying the results labeled with their units:



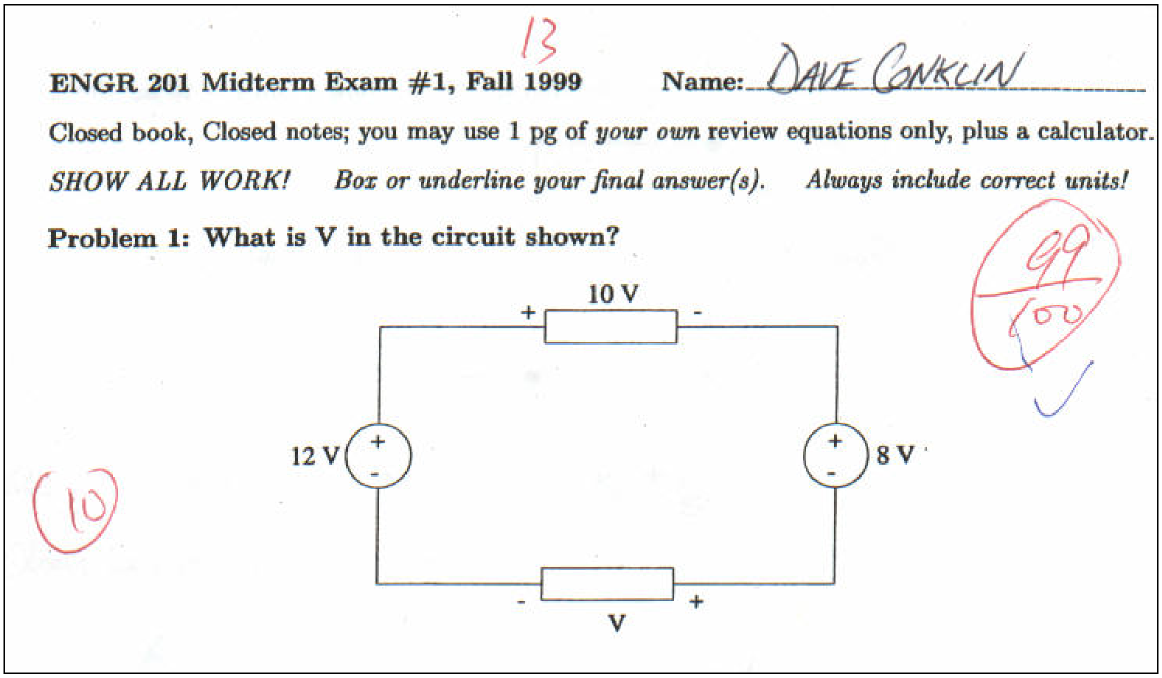
EE200 also **handles unit conversions** ***automatically***. Appropriate unit conversions are made as long as the equation is valid in SI units. When the calculator solves the problem, it first converts all the values to their equivalent values in SI base units. Answers are subsequently converted back to, and labeled with, the user's choice of units. Thus, in the previous example, calculations were done with numbers in amps, but the results are displayed in milliamps.

Complicated equations may be viewed in *"textbook"* form with all the units visible by pressing F4:View. In textbook form, a node voltage equation looks like:





GETTING STARTED – AN EASY PROBLEM FROM A REAL MIDTERM


ENGR 201 Midterm Exam #1, Fall 1999 Name: Dave Conklin

Closed book, Closed notes; you may use 1 pg of *your own* review equations only, plus a calculator.

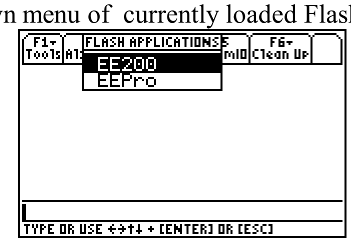
SHOW ALL WORK! Box or underline your final answer(s). Always include correct units!

Problem 1: What is V in the circuit shown?

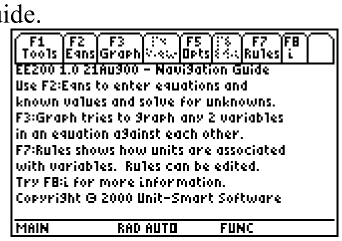
Kirchoff's voltage law (KVL) is used to solve this problem, which Prof. Plant put in as a confidence builder for students taking the first midterm in his ENGR 201 class at Oregon State. KVL says that the sum of the voltage rises around a loop must equal the sum of the voltage drops. Consider a clockwise path around the loop. Then, the 12V source is a voltage **rise**; the 10V load, the unknown load V, and the 8V source are all voltage **drops**. To use EE200 to solve this problem, follow these steps:

1. Press the ON key in the lower left corner of the TI-89 keyboard.

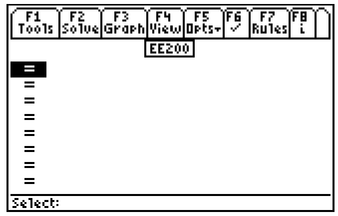
2. Press the APPS key (3rd row center); then, place the cursor on 1:FlashApps; press ENTER (bottom right corner). This will display a pull-down menu of currently loaded Flash Apps:



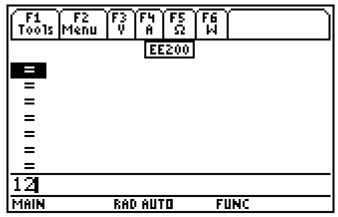
Use the up or down cursors to highlight EE200; then, press ENTER. EE200's *Navigation Guide* is displayed. If EE200 has been run previously in this folder, it will resume where it left off. In that case, press ESC to get to the Navigation Guide.



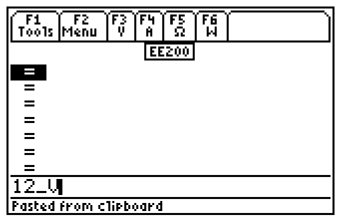
3. Familiarize yourself with the short notes in the Navigation Guide. If you wish, press 2nd/F8:***i*** to see additional notes on the program. When you are ready to move ahead, press F2:Eqns.



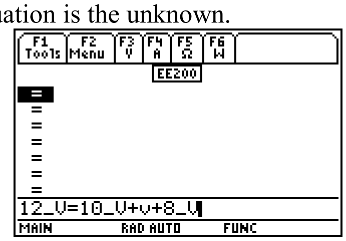
4. *Now key in the KVL equation*. Set the voltage rise equal to the sum of the voltage drops. *Begin* by entering "12" for the 12 volt source:



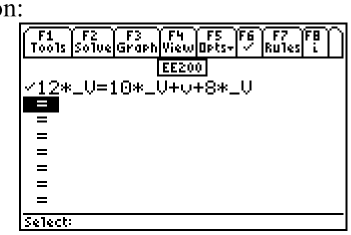
To indicate **units**, press F3:V.



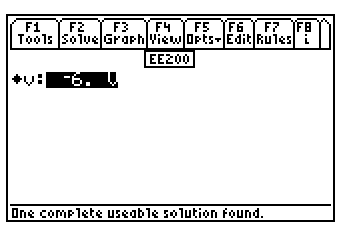
Key in the remainder of the equation. Remember to enter the units again for the 10 volt load and the 8 volt source. The *lower case 'v'* in the equation is the unknown.



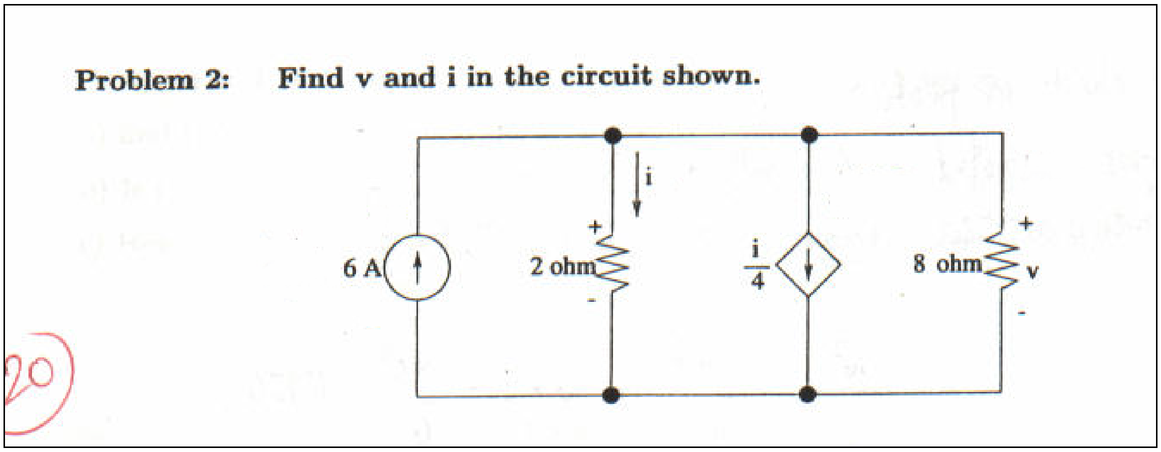
Press ENTER to terminate the equation:



5. Press F2:Solve to display the *Solver screen*; then, press F2:Solve *again* to calculate a value for the unknown variable **v**:



2ND EXAMPLE – APPLYING KIRCHOFF'S CURRENT LAW AND OHM'S LAW

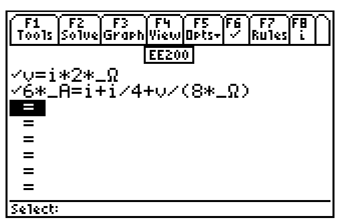


This problem, like the others, is taken from an actual midterm given in an ENGR 201 class at Oregon State University. The key to its solution is to observe that the voltage drop across the 8 ohm resistor, which is the unknown voltage **v,** is the same as that across the 2 ohm resistor. Hence the two unknowns **i** and **v** are related by Ohm's law. Once **v** is known, **i** may be readily calculated. The unknown **v** may be calculated by applying Kirchoff's current law at the upper node. Two equations are required :

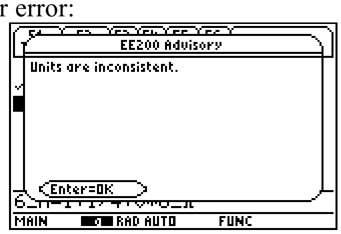
$v = i \times 2\Omega$	Ohm's law
$6A = i + i/4 + v/8\Omega$	Kirchoff's current law (KCL)

The KCL equation sets the current into the upper node equal to the sum of the currents out of the node. The **i/4** term reflects the fact that that the current-controlled current source provides a current equal to one fourth of the unknown current **i**; the constant of proportionality has units of amps per amps, so the units may be omitted. On the other hand, the ***units are necessary*** in the **v/8Ω** term in order for the units to balance in the equation as a whole.

In EE200, use F1:Tools/8:NewProb to clear the equations and variables from the previous problem. Enter the two required equations. Note that the first equation only takes 6 keystrokes to enter, even though there are 8 characters in the display form: after pressing the digit 2 key, you need only press the F5:Ω softkey. EE200 inserts the multiply sign and the underscore before sending the equation to the calculator's parser. Similarly, the second equation may be entered in 13 keystrokes, even though the displayed form has 19 characters.

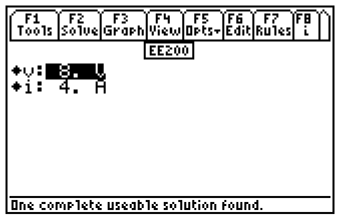


If you had mistakenly entered the third term on the right side of the KCL equation as $v \times 8\Omega$ instead of $v / 8\Omega$, EE200 would alert you to your error:

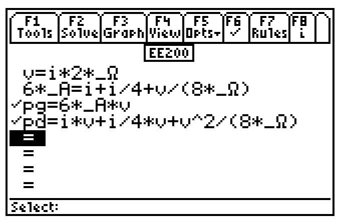


In that case, pressing ENTER leads to a more detailed explanation of the error:

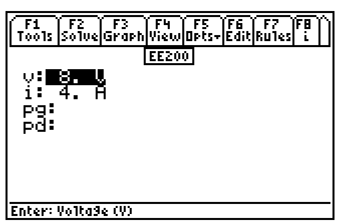
When the equations have been entered correctly, press F2:Solve to access the Solver screen. Then, to calculate the solution, press F2:Solve *again* :



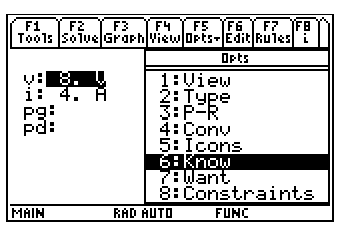
To do a **power check** on this solution, press ESC to return to the equations screen. Enter equations for the power generated (**pg**) and the power dissipated (**pd**). Move the cursor to the original two equations. Use 2nd/F6:√ to *deselect* them.

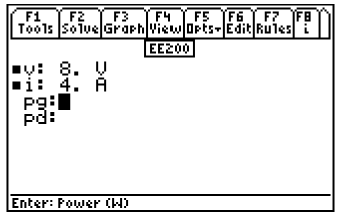


Since the current is flowing out of the positive terminal, the power generated comes from the 6A current source. Since, for the dependent current source, the current is flowing out of the negative terminal, power is dissipated in the dependent current source as well as in the two resistors. Press F2:Solve to bring up the Solver screen again:

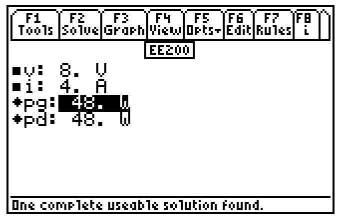


For the power check, use the calculated values of **v** and **i** as inputs. Move the cursor to each in turn and use F5:Opts/6:Know to set their values as *knowns*:





Note the *small squares* next to the variables **v** and **i**. These icons indicate that the displayed values will be taken as inputs in the calculation of the remaining, unknown variables. Press F2:Solve to calculate **pg** and **pd**.

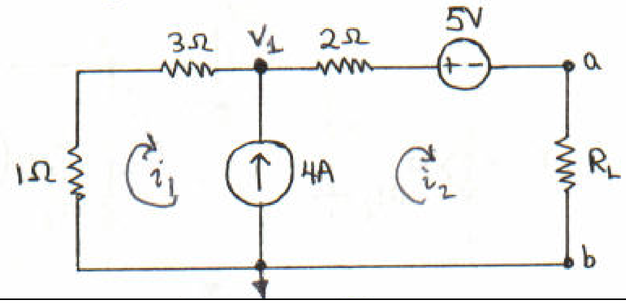


The power generated, **pg**, and the power dissipated, **pd**, are both equal to 48 watts, so the circuit solution passes the power check. The *diamonds* next to **pg** and **pd** indicate that their values have been found by solving the equations with the known data.

3rd EXAMPLE – MAXIMUM POWER TRANSFER AND MESH ANALYSIS

ENGR 201 Winter 2000 Final Exam **Page 3/6**

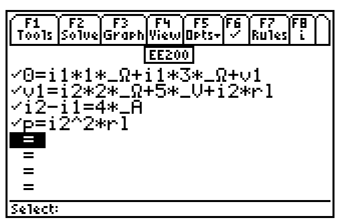
4. (20 points) In the circuit below, (a) find R_L for maximum power transfer and (b) find the maximum power transferred to the load.



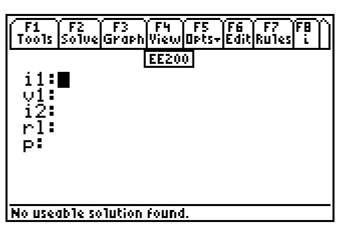
To do this problem, mesh analysis is used to solve for the power transferred as a function of the load, R_L. Then R_L is set equal to R_{Th}, the Thevenin equivalent resistance of the circuit. Four equations are required to solve the problem: two mesh equations, an equation which relates the value of the current source to the mesh currents, and an equation for the power transferred, **p**:

$0 = i_1 \times 1\Omega + i_1 \times 3\Omega + v_1$	mesh 1
$v_1 = i_2 \times 2\Omega + 5V + i_2 \times r_L$	mesh 2
$i_2 - i_1 = 4A$	relate current source to mesh currents
$p = i_2^2 \times r_L$	power transferred

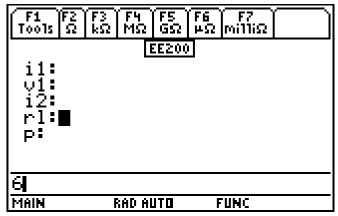
Note that TI89/92 calculators do not distinguish between upper and lower case letters in variable names. Use F1:Tools/8:NewProb to clear out any existing equations and variables as before. Then enter the four equations:



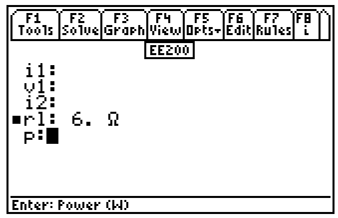
Press F2:Solve to access the Solver screen. If you now press F2:Solve *again*, the calculator is *unable to find a solution* because there are five unknowns but only four equations. This is indicated in the status line at the bottom of the screen:



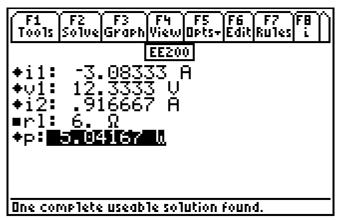
The Thevenin equivalent resistance of the circuit, looking in across a and b, may be found by inspection through deactivating the sources (replace the voltage source with a short circuit and the current source with an open circuit). The result is simply the sum of the 3 resistors in series: 6Ω. Move the cursor down to **rl** and enter *6Ω*:



Note that, as soon as you begin entering the value of **rl**, the softkey labels for F2...F7 show ohms, kiloohms, megaohms, etc. Press F2:Ω to complete the entry:

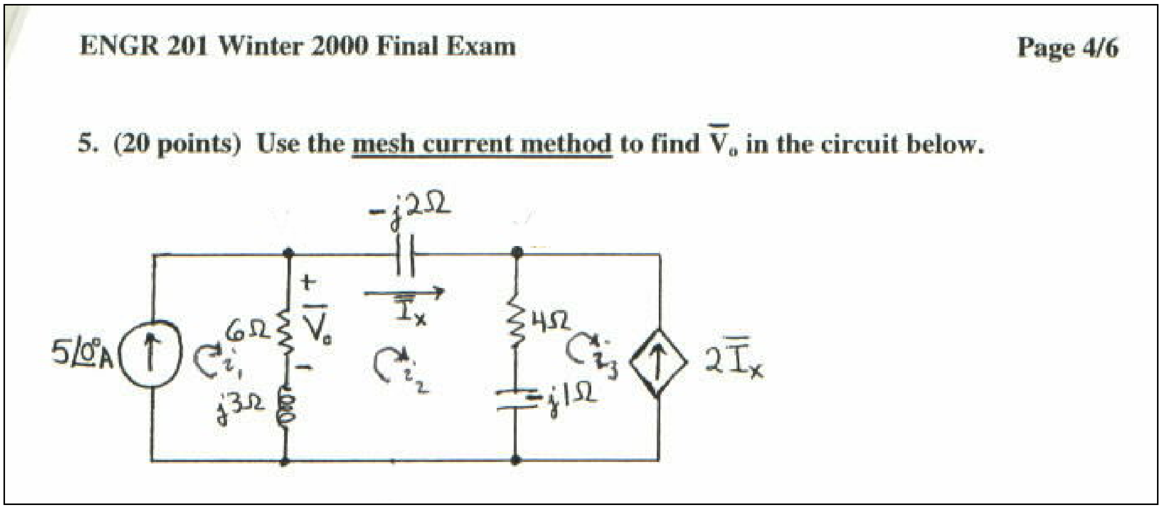


Now, press F2:Solve. The completed solution screen now displays:



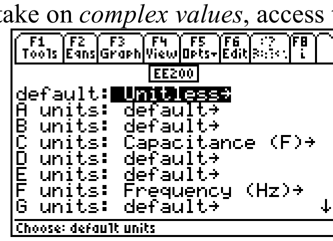
The *maximum power transferred* is 5.04 watts and occurs when the load resistance is 6 ohms. **To save your work** so that you can check it later, use F1:Tools/2:Save As. When prompted for a folder name, enter a short descriptive name such as "ex3" for "example 3". *To return to this problem later,* use the F1:Tools/1:Open function.

4^{TH} EXAMPLE – MESH ANALYSIS IN THE PHASOR DOMAIN

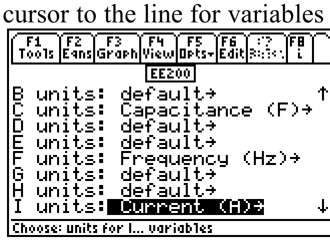

ENGR 201 Winter 2000 Final Exam Page 4/6

5. (20 points) Use the <u>mesh current method</u> to find $\overline{V}_o$ in the circuit below.

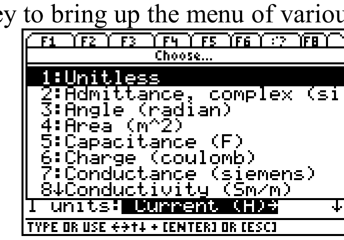
For this final exam problem, mesh analysis is to be used to calculate $\mathbf{V_0}$, the voltage across the 6Ω resistor. There are three mesh currents: $\mathbf{I_1}$, $\mathbf{I_2}$, and $\mathbf{I_3}$. Calculations are to be done in the phasor domain, so all variables can take on *complex values*. In previous examples, current variables, beginning with 'i', and voltage variables, beginning with 'v', have been constrained to be *real numbers only*. *To alter the rules* for 'i' and 'v' variables to allow them to take on *complex values*, access the Rules screen. Press 2nd/F7:Rules.



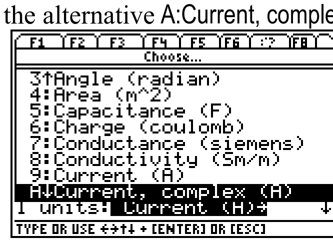
Now use the down-arrow to move the cursor to the line for variables beginning with **'i'**:



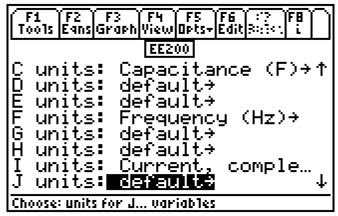
Press 2nd/F6:Edit or the right-arrow key to bring up the menu of various **unit categories**:



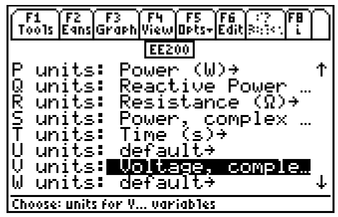
Now use the down-arrow to highlight the alternative A:Current, complex (A).



Press the ENTER key *to associate complex current values with variables that start with "i"* :



Note that the line for variables beginning with 'i' now includes the word "complex". Next, *assign complex voltage units* to the rule for variables beginning with 'v' in the same way that you assigned complex current units to 'i' variables:



Now use F1:Tools/8:New Prob to get ready to solve this problem.

There are three meshes in the circuit. $\mathbf{I_1}$ can be read directly from the schematic as *$5\angle 0°$ amps*, so it isn't necessary to key in an equation for the left hand mesh. The Kirchoff's Voltage Law equation for the center mesh is:

$$0 = (I_2 - I_1)\times(6+j3)\Omega + I_2\times(-j2\Omega) + (I_2 - I_3)\times(4-j1)\Omega$$

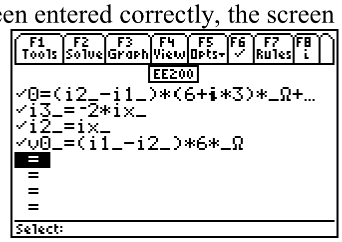
The mesh currents $\mathbf{I_2}$ and $\mathbf{I_3}$ in the center and right hand meshes are related to each other thru the variable $\mathbf{I_x}$ and the dependent current source in the right hand mesh:

$$I_3 = -2I_x$$
$$I_2 = I_x$$

One more equation is needed to relate the variable of interest $\mathbf{V_0}$ to the mesh currents:

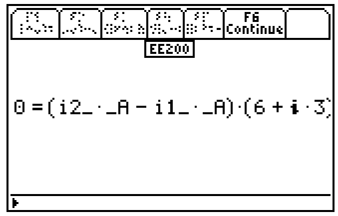
$$V_0 = (I_1 - I_2)\times 6\Omega$$

Key in the four equations. Note that although electrical engineering notation for the *square root of minus one* is a *script j*, the TI-92 calculator follows the more common math notation of *script i* for the square root of minus one. *Script i* can be found on the TI-89 keyboard as the yellow-shifted function on the CATALOG key. Be careful not to mix up the regular letter 'i' with the script i. Users unfamiliar with TI calculators should also note that the *unary minus sign* in the middle term of the right hand side of the first equation *is on a different key* ("(-)", bottom row, lower right corner, between the decimal point key and the ENTER key) than the regular binary minus ("-", two keys up from the ENTER key, above the "+" key). Unary minus also appears on the right side of the second equation. Mixing up unary and binary minus signs causes "syntax" errors. When the 4 equations have been entered correctly, the screen displays :

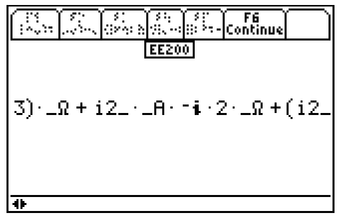


Note that EE200 now adds an underscore to the end of variables which begin with 'i' or 'v' in conformance with the TI calculator's convention for variables which can take on complex values.

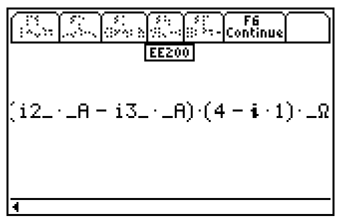
The first equation doesn't fit on the screen in the regular display mode, but it can be reviewed by placing the cursor on it and pressing F4:View. The View command shows the equation in textbook format with all its units visible. When any part of the equation is out of sight off the edge of the display, an indicator shows up on the status line at the bottom of the screen to cue the user that he may press the cursor key(s) to view the hidden part.



In this case, the right-arrow key will move the window to the right about one character at a time. The *yellow-shifted* right-arrow key moves the window one screen-width *or* to the right edge of the item being displayed:

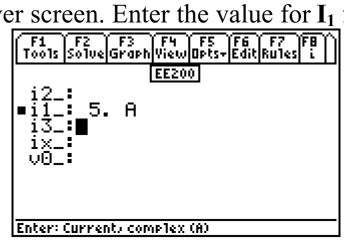


The *diamond-shifted* right-arrow key moves the window immediately to the right edge of the item being displayed.

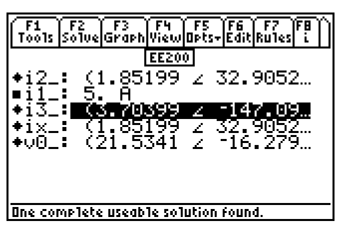


To return from the View display to the regular display, press 2nd/F6:Continue or any other key.

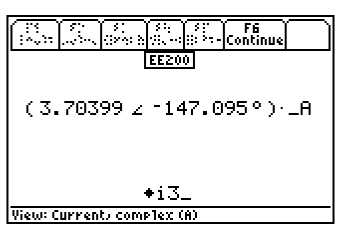
Now press F2:Solve to access the Solver screen. Enter the value for $\mathbf{I_1}$ from the circuit diagram:



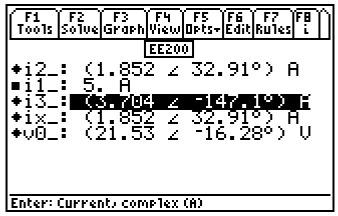
Press F2:Solve *again* to calculate the solution shown below:



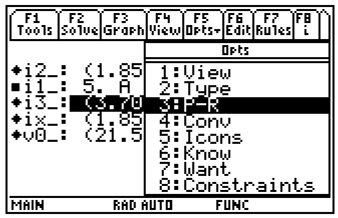
As with the equations, values which don't fit entirely on the screen may be viewed using F4:View or the right arrow key:



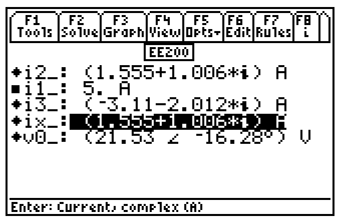
Alternatively, you might choose to reduce the number of significant digits displayed from 6 to 4 using the MODE key (4th row, 2nd column). Then all the values and their units will fit in the display:



Variables with complex current or voltage units default to *polar form*, but it's easy to convert them to *rectangular* form if desired. To convert, use F5:Opts/3:P-R.



Here all the currents have been converted to rectangular form, while the voltage has been left in polar form:



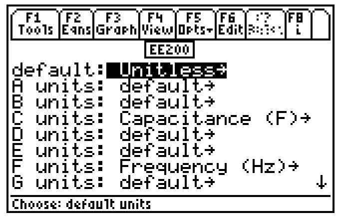
A particular variable converted from polar to rectangular form will continue to be displayed in rectangular form until you use F5:Opts/3:P-R again to convert back to polar form.

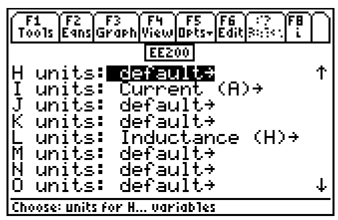
HOW DOES EE200 WORK?

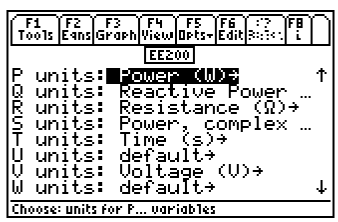
Notation Rules

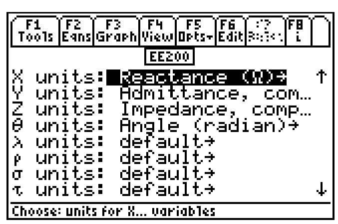
EE200 uses of *a set of notation rules to infer the units associated with a variable* **from the first letter** of the variable's name. This method follows common classroom notation: variables beginning with the same letter usually have the same units. For example, in an electrical engineering class, variables such as v_1 and v_2 stand for voltages; i_a and i_b for currents; and so on.

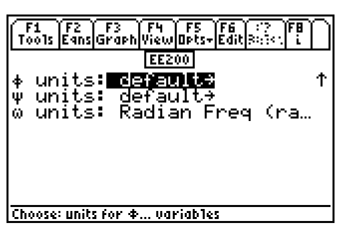
The *rules for individual letters* may be examined and, if desired, *changed* in the Rules screen. In the fourth example above, the rules for the letters 'i' and 'v' were changed to specify that new variables beginning with those letters should be allowed to take on complex values. The Rules screen may be accessed by pressing 2nd/F7:Rules. The default rules are shown here. The rules for variables beginning with 'i' and 'v' may have been altered to allow complex values when EE200 was installed.





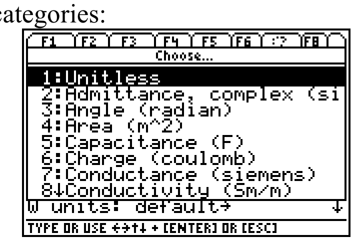


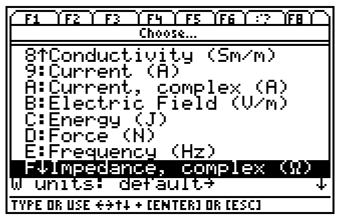


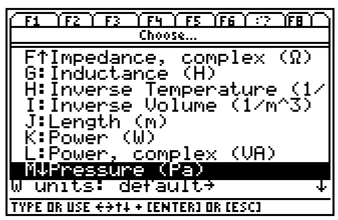


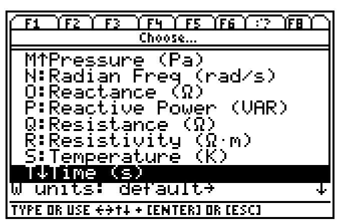
Note that in addition to the rules for the 26 letters of the *Roman* alphabet, there are rules for 8 letters of the *Greek* alphabet. Remember, too, that the TI calculator operating system is *case-insensitive* with respect to the Roman alphabet; e.g., 'A' and 'a' are treated as though they were identical. However, upper and lower case *Greek* letters *are* distinguished.

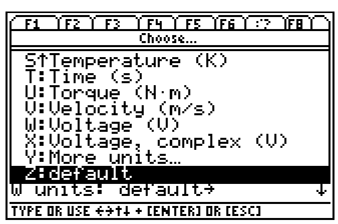
Each of the 26 Roman letters and 8 Greek letters can be individually associated with a unit category, "voltage", "current", "impedance", etc.; or, with dimensionless variables, "unitless"; or, with the current default unit category. The *current default unit category is displayed in the first line of the Rules screen*; it starts out as "unitless", but can be changed to any other unit category. Pressing 2nd/F6:Edit or the right-arrow key brings up a menu of unit categories:



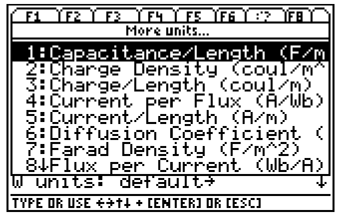


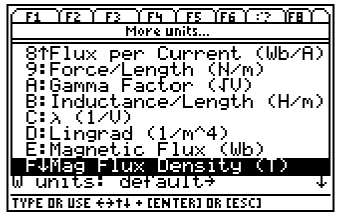


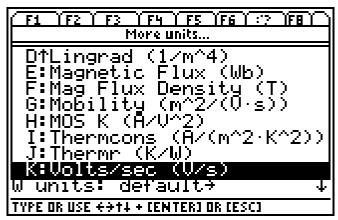




There are *three special items in this menu*: 1:Unitless at the top of the menu; Z:default at the bottom of the menu; and Y:More units..., which is the next to last item on the menu. Selecting Y:More units... accesses still another menu:



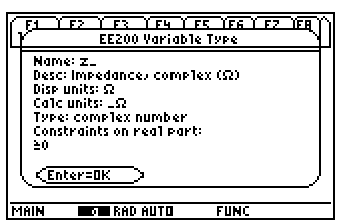




There are *52 unit categories* in all which are available in EE200 for assignment to notation rules. See **Appendix B** for the *complete list of unit categories* (e.g., Voltage) and their *associated choices of scale factors* (e.g., V, mV, μV, etc.). The 52 unit categories are placed in two menus due to the TI calculator's limit of 35 items in a menu.

The Attributes of a Variable

EE200 remembers a number of attributes about each variable used in an equation. The attributes are determined in the beginning by the units associated with the variable, but some of the attributes may subsequently be changed by the user. Attributes of a variable may be viewed by highlighting the variable in the Solver screen and pressing F5:Opts/2:Type. For example, variables beginning with **z** default to impedance:



Natural Language Syntax for Units

With some exceptions, the TI calculator's operating system treats unit variables as syntactically equivalent to normal variables with regard to precedence. This has results which are different from what one might expect. For example, to calculate the average speed of a car, you divide the distance traveled by the elapsed time. If the elapsed time is 40 minutes and the distance is 30 miles, we would write:

speed = 30 miles/40 minutes = 45 mph

TI calculator notation uses "*_mi*" for miles and "*_min*" for minutes, so the natural way to express the equation for speed is:

speed = 30_mi/40_min

However, that leads to the *wrong result* because the *TI parser interprets*

speed = 30_mi/40_min

as

speed = ((30 × miles) / 40) × minutes

= (30/40) × miles × minutes

The units "_min" are interpreted to be in the numerator rather than in the denominator. EE200, however, scans the user's equations and binds units to their associated variables or numbers before sending the equation to the TI parser. The syntax rule in EE200 is that *a variable name beginning with an underscore binds directly to the variable name, number, or parenthetical expression that precedes it*. While this rule is awkward to express, it is easy to use because it **implements the way we use units in ordinarylanguage and notation**. When you enter an equation with units into EE200, you simply write the units with their associated quantities or variables the way you would if you were writing the equation on a piece of paper or a blackboard. EE200 does the rest.

EE200 Sets Up the Problem for the Calculator's Math Engine

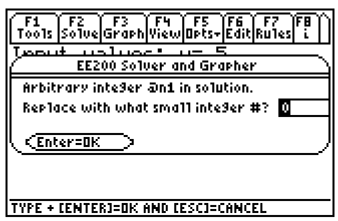
Although EE200 always displays numbers scaled in the units chosen by the user, it **stores values scaled in SI base units**. These are the units of the International System of Units, adopted by the 11th General Conference on Weights and Measures in 1960. They are the *lingua franca* of measurements for science throughout the world. We know them in the United States as *metric units*. When the user presses F2:Solve in the Solver screen, EE200 constructs a TI Basic SOLVE command and passes it to the calculator's math engine for evaluation. EE200 strips units from the equations before passing them to the math engine. EE200 then automatically rescales the answers provided by the math engine back into the user's chosen units.

EXAMINING THE RAW SOLUTION

EE200 constructs a TI Basic SOLVE command and passes it to the calculator's math engine. A user who wants to see exactly how the problem was formulated and exactly what answer was given by the math engine may do so on the calculator's home screen by recalling the contents of the variable USPROBLM to the author line. This will place the SOLVE command, in string form, on the author line. By first deleting the quote marks at the beginning and end of the string and then pressing ENTER, you may execute the SOLVE command. The answer will be displayed in the history area of the HOME screen. EE200 stores the answer it receives in the variables USANSWER (string form) and USANSMAT (matrix form). EE200's characterization of the answer, e.g. "One complete useable solution found", is stored in the variable USANSTYP. The values of the knowns in the equations are stored in the variable USINPUT.

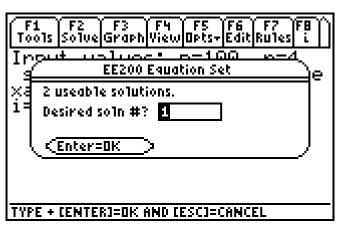
ARBITRARY INTEGERS IN THE SOLUTION

Sometimes the solution returned by the math engine will include arbitrary integers, represented as "@n1", "@n2", etc. This may happen, for example, when the solution includes an inverse trig function: "SOLVE(Y=TAN(X), X)" gives "X=TAN^{-1}(Y) + @N1*π". When EE200 receives an answer back from the math engine which contains an arbitrary integer, it prompts the user to specify a particular value to substitute for the arbitrary integer:



MULTIPLE SOLUTIONS

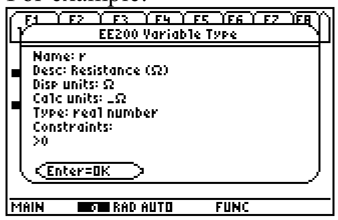
Sometimes, as in the example given in the first section of solving the equation $P = I^2 \times R$ for I, there is *more than one **valid** solution* to a problem. In such cases, EE200 puts up a dialog box to inform the user of the number of useable solutions and to ask the user which solution he wishes to view:



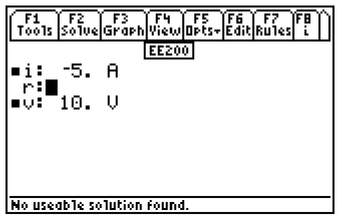
By solving the problem more than once and specifying different solution numbers, you can examine all the available valid solutions.

USEABLE *VS.* UNUSABLE SOLUTIONS

Not every mathematically valid answer makes good ***physical*** *sense.* For example, solving Ohm's Law V = I × R for R when V = 10 volts and I = -5 amps gives R = **-2** ohms. This is mathematically correct but physical nonsense. EE200 tries to weed out such nonsensical answers by applying constraints according to the units associated with the variable. For example:

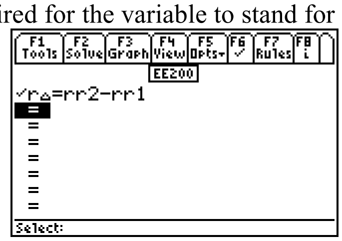


The constraint ">0" is applied after the math engine returns its answer. If the answer doesn't meet the constraint, *EE200 discards the answer and reports* **"No useable solution found"**. See the status line at the bottom of the screen:

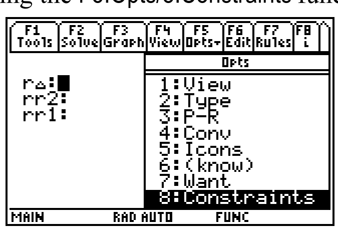


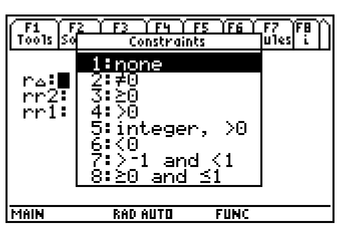
CONSTRAINTS ON VARIABLES

Negative values don't make sense for a variable whose value represents a measurement of certain kinds: resistance, area, etc. On the other hand, it is possible for a variable having those same units (ohms, acres) to represent the difference of two such measurements. In that case, negative values may be meaningful after all. The default constraints on variables in EE200 are set up with the assumption that the variable stands for a measurement. If it is desired for the variable to stand for a difference of two measurements,



then *the constraint can be changed* using the F5:Opts/8:Constraints function:



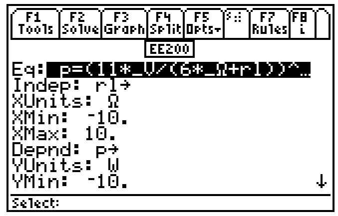


GRAPHING

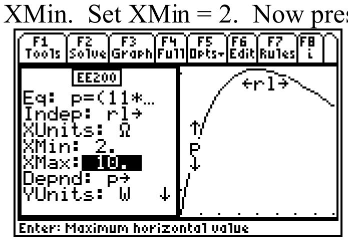
EE200 includes the capability to *graph relationships between variables* in the entered equations. For example, in the maximum power transfer problem given above, the power **p** may expressed as a function of the load resistance $\mathbf{r_L}$ as

$$p = (11V/(6\Omega+R_L))^2 \times R_L$$

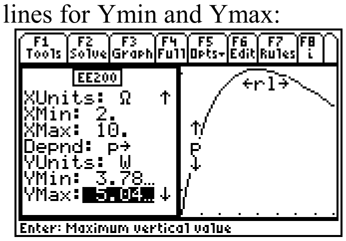
Enter this equation, then press F3:Graph.



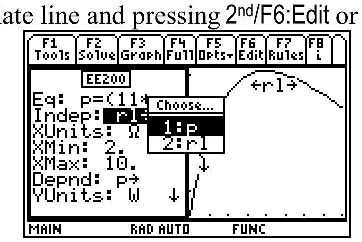
We know from that same example that power will be at its maximum when r_L is 6Ω. Use the down-arrow key to move the cursor to the line for XMin. Set XMin = 2. Now press F3:Graph again:

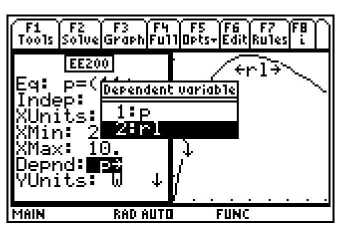


Use the down arrow key to get to the lines for Ymin and Ymax:

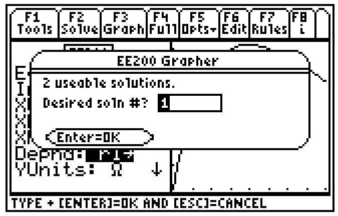


The values for YMin and YMax indicate that the power varies over the range of 3.78W to 5.04W as the load resistance varies from 2Ω to 10Ω. Now the independent and dependent variables may be interchanged by moving the cursor to the appropriate line and pressing 2nd/F6:Edit or the right-arrow key:

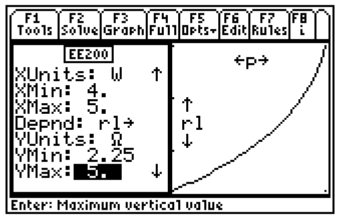




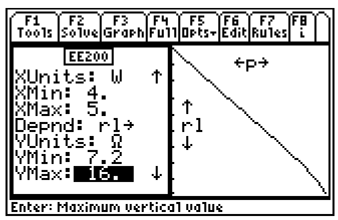
Set XMin to 4 and XMax to 5. The independent variable **p** will vary from 4W to 5W. Press F3:Graph again:



The grapher alerts us that there are *two solutions* for the load resistance in terms of the power. Choose the *1st solution*. When the graph is completed, look at Ymin and Ymax:



The first solution shows that values of the load resistance from 2.25Ω to 5Ω produce power transfer in the 4W to 5W range, with increasing power corresponding to increasing load resistance in this region. Now press F3:Graph again. This time, choose solution #2:



In the 2nd solution, values of load resistance from 7.2Ω to 16Ω produce power transfer in the range of 4W to 5W, with increasing power corresponding to decreasing load resistance.

SAVING YOUR WORK – TACTICS FOR TAKING TESTS

EE200 makes it easier to *check your work* in any time remaining in an exam period after you have worked all the problems on the test. *After working each problem the first time*, use the F1:Tools/2:Save As command to save the equations and data for that problem in a new folder whose name identifies it with the problem just solved. Then use F1:Tools/8:New Prob to start the next problem.

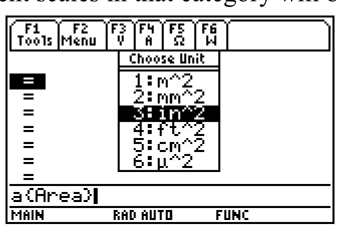
After you have worked all the problems the first time and entered your answers on the exam paper, you can go back and *check over your work problem by problem*. Use the F1:Tools/1:Open command to *open the saved folder for each problem* in turn. Then, *without having to re-enter* any equations or data, you can examine the equations you used to get your original answer. For certain kinds of problems, you may be able to enter additional equations to test whether the answer originally obtained is internally consistent. For example, when working electrical circuit problems, you can calculate the sum of the power absorbed or generated by each circuit element based on the originally-calculated currents and voltages. This checks that the total power absorbed is equal to the total power generated.

GETTING EXACTLY THE UNIT YOU WANT

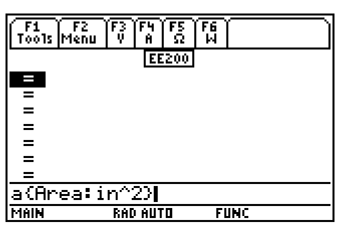
Redefining Softkeys

While you are entering equations, the F2-F7 softkeys are redefined to make it easier to enter units, either the unit category associated with a variable or the units associated with a constant. F2 is *always* labeled F2:Menu. Softkeys F3-F7 are labeled with specific units. When you press one of these redefined softkeys, what happens *generally* is that unit information is "pasted" into the equation on the author line. What happens *exactly* depends on what was entered just prior to pressing a particular softkey. Specifically, if you have just entered a variable name, then a unit category in braces (e.g. "{Voltage}") will be placed after the variable name. The unit category entered in this way overrides the default unit category for the variable name. At any time other than immediately following a variable name, pressing the softkey will paste in the string for the unit itself (e.g. "_V").

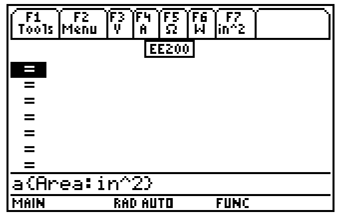
The F2:Menu key is *especially versatile*. It may be used to enter a unit or unit category which is not on any of the F3-F7 softkeys. In addition, if you press the F2:Menu key immediately after entering a unit or unit category, a menu of the units of different scales in that category will be displayed. For example:



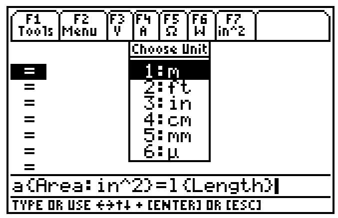
The unit selected from the menu is appended to the unit category to indicate the units in which the variable's value should be displayed:

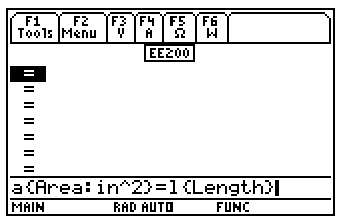


In addition, the unit selected may then be associated with one of the **F3-F7 softkeys** for future use. Simply press the desired softkey *immediately after* entering the unit. In the screen below, the 2nd/F7 key was pressed after *in*^{2} were selected:



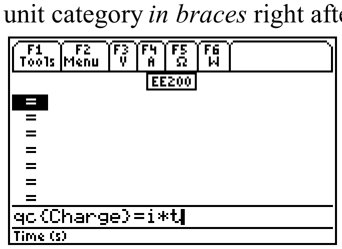
The *unit associated with a softkey* may be *cleared* by pressing ESC at the unit menu and *then* pressing the softkey:





Overriding the Notation Rules for a Specific Variable

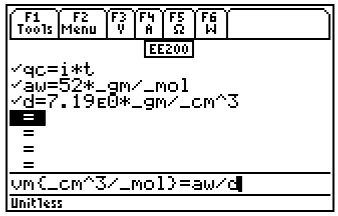
Sometimes it is desirable to *disregard the notation convention for* ***one*** *specific variable*. For example, the built-in rule for variables beginning with the letter 'q' is that they represent reactive power with units of VARs. For some problems, it might be more natural for a particular variable beginning with the letter 'q', say the variable "qc", to represent electric charge, say the charge on a capacitor, with units of coulombs. You *could* go to the trouble of changing the rule for the letter 'q' from reactive power to electric charge. However, *another way* is to specify the units for the specific variable the first time the variable is used, by including the name of the appropriate unit category *in braces* right after the variable name:



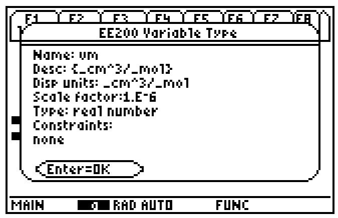
You can enter the braces and unit category name directly if you are confident of the spelling. An *alternative* is to use any of the softkeys F2-F7. F2:Menu brings up the list of all the unit categories.

What To Do If the Unit You Want Isn't Built -in

The previous section described a shortcut for assigning to a variable a unit category different from the one specified by the rule for the first letter of the variable's name. A variation on this method can be used to specify units which aren't included among the built-in unit categories. Assume that, for an electroplating problem, you need a variable, **vm,** in units of molar volume, i.e., volume in cubic centimeters per mole of the metal being plated. Molar volume isn't one of the built-in unit categories in EE200. However, the *exact unit expression for the desired units* may be used between the braces in place of a unit category name:



In this example, the variables "aw" and "d" have been previously defined as atomic weight (g/mol) and density (g/cm^3), respectively. Note that for variables defined with explicit unit expressions, the F5:Opts/2:Type dialog box looks a little different than for other variables:



The name of the unit category is unknown; therefore, the *"Desc"* shows *instead* the explicit unit expression that the user entered for the variable. The *"scale factor"* is the ratio of the display unit expression to the corresponding SI base unit expression, i.e., the ratio of the value of the variable as stored to the value of the variable as displayed.

HOW TO IMPORT EQUATIONS FROM EE•PRO

EE•Pro is an application software product from da Vinci Technologies Group, Inc. It includes an extensive collection of equation sets pertaining to different electrical engineering problems. To import one or more equations from EE•Pro into EE200, *first* execute EE•Pro and access the desired equation set. *Select* the desired equation(s). Selected equations are displayed in EE•Pro as they are in EE200: with a √ icon in the first column. *Now* execute EE200, go to the equation screen, and use the F1:Tools/9:GetEqns function **to import the equations** from EE•Pro. The GetEqns function first copies the equations from EE•Pro to the clipboard, adding unit category information in braces after each variable; it then pastes the clipboard into the EE200 equation screen. Once the equations are in the EE200 equation screen, they may be edited as desired.

HOW TO GET TECHNICAL SUPPORT FOR EE200

Technical support for EE200 is available *via e-mail* from Unit-Smart Software. Please send your inquiries to help@unit-smart.com. In addition, don't overlook the series of helpful information screens available on the calculator itself. Press the 2nd/F8:***i***nformation key on EE200's top-level toolbar.

HOW TO SEND SUGGESTIONS AND CRITICISMS TO THE DEVELOPER

Your suggestions for changes or additions to EE200 and for potential future products from Unit-Smart Software are welcome and solicited. Please *e-mail* them to Dave Conklin at author@unit-smart.com.

APPENDIX A - SPECIFICATIONS

In a single folder, EE200 can accommodate up to 20 equations and 39 variables at any one time. Solving more than a handful of equations at a time may take a long time. The solving process may always be interrupted by pressing the ON key.

When EE200 is first loaded into the calculator, it takes up about 134Kbytes of Flash memory and about 13Kbytes of RAM.

In each folder in which it runs, EE200 creates a variable named **USDATA1** to save the user's current set of equations, variables, and notation rules. The USDATA1 variable in each of EE200's folders takes up about 2K bytes of RAM. Its exact length depends on the number and lengths of the equations and variables entered by the user in that folder.

EE200 has 52 categories of built-in units. Its unit categories are listed below in Appendix B.

APPENDIX B – BUILT-IN UNIT CATEGORIES

EE200 has 52 built-in unit categories. Because the TI calculator limits the number of alternatives in dropdown menus to 35, EE200's unit categories are organized into two menus. The first menu contains the most commonly used units. The first item on the first menu is 1:Unitless, followed by 32 common unit categories arranged alphabetically. It ends with an alternative, Y:More units... which accesses a second menu. The second menu has an additional 20 unit categories arranged alphabetically. The two unit category menus are listed below. The equals sign in each line marks the unit scale factor corresponding to SI base units, which are used for calculations and stored values.

First Unit Category Menu

	F2	F3	F4	F5	F6	F7
1:Unitless						
2:Admittance, complex	=siemens	ksiemens	Msiemens	mmho	µmho	
3: Angle	=rad	deg	grad			
4: Area	$=m^2$	mm^2	in^2	ft^2	cm^2	μ^2
5:Capacitance	µF	NF	pF	fF	=F	mF
6:Charge	=coul	mcoul	µcoul	ncoul	pcoul	fcoul
7:Conductance	=siemens	ksiemens	Msiemens	mmho	µmho	
8:Conductivity	Sm/cm	=Sm/m	kSm/cm	kSm/mm	Sm/in	
9:Current	=A	mA	µA	nanoA	pA	fA
A:Current, complex	=A	mA	µA	nanoA	pA	fA
B:Electric Field	V/cm	kV/cm	=V/m	kV/in	kV/mil	
C:Energy	=J	kJ	eV	cal	erg	Btu
D:Force	=N	kN	lbf	kip	dyne	
E:Frequency	=Hz	kHz	MHz	GHz		
F:Impedance, complex	=Ω	kΩ	MΩ	GΩ	µΩ	milliΩ
G:Inductance	mH	µH	nH	pH	fH	=henry
H:Inverse Temperature	=1/K	1/°C	1/°F	1/°R		
I:Inverse Volume	$=1/m^3$	$1/cm^3$				
J:Length	=m	ft	in	cm	mm	µ
K:Power	=W	milliW	kW	MW	GW	hp
L:Power, complex	=VA	milliVA	kVA	MVA	GVA	
M:Pressure	=Pa	MPa	GPa	psi	atm	torr
N:Radian Freq	=rad/s	krad/s	Mrad/s	deg/s	Hz	rpm
O:Reactance	=Ω	kΩ	MΩ	GΩ	µΩ	milliΩ
P:Reactive Power	=VAR	milliVAR	kVAR	MVAR	GVAR	
Q:Resistance	=Ω	kΩ	MΩ	GΩ	µΩ	milliΩ
R:Resistivity	Ω•cm	=Ω•m	Ω•in	Ω•cm	$\Omega \cdot mm^2/m$	
S:Temperature	=K	°C	°F	°R		
T:Time	=s	ms	µs	ns	min	hr
U:Torque	=N•m	ft•lbf				
V:Velocity	=m/s	cm/s	ft/s	in/s	kph	mph
W:Voltage	=V	mV	µV	kV	MV	GV
X:Voltage, complex	=V	mV	µV	kV	MV	GV
Y:More Units						

Second Unit Category Menu

	F2	F3	F4	F5	F6	F7
1:Capacitance/length	pF/km	pF/mi	µF/km	µF/m	=F/m	
2:Charge Density	$=C/m^2$	C/cm^2	$\mu C/m^2$			
3:Charge/Length	=C/m	mC/m	µC/m	pC/cm		
4:Current/Flux	=A/Wb	mA/Wb				
5:Current/Length	mA/cm	A/cm	=A/m	ma/m		
6:Diffusion Coefficient	$=m^2/s$	cm^2/s	in^2/s	m^2/hr	cm^2/hr	in^2/hr
7:Farad Density	pf/cm^2	$\mu F/cm^2$	$=F/m^2$			
8:Flux/Current	=Wb/A	mWb/A				
9:Force/Length	=N/m	kN/m	lbf/ft	kip/ft	lbf/in	N/cm
A:Gamma Factor	$=\sqrt{V}$					
B:Inductance/Length	µH/km	µH/mi	mH/km	mH/mi	H/km	=H/m
C:λ	=1/V	1/mV				
D:Lingrad	$=1/m^4$	$1/cm^4$				
E:Magnetic Flux	=Wb					
F:Mag Flux Density	=T	mT	Gs			
G:Mobility	$=m^2/(V\bullet s)$	$cm^2/(V\bullet s)$				
H:MOS K	$=A/V^2$	mA/V^2	kA/V^2			
I:Thermcons	$=A/(m^2K^2)$	$A/(cm^2K^2)$	$mA/(cm^2K^2)$			
J:Thermr	=K/W	°C/W	°F/W	°R/W		
K:Volts/sec	=V/s	mV/s	V/µs	V/ns		

INDEX