

HP Solve Equation Library Application Card

The card contains a library of 315 equations, the periodic table of the elements, a constants library, a multiple equation solver, a finance application, and engineering utilities.

by Eric L. Vogel

HISTORICALLY, EVERY HP programmable calculator has had programs available in some form. There are application books with printed programs and keystroke sequences for machines like the HP 55, 25, 33E, 11C, and 32S, application pacs with programs on magnetic cards for the HP 65 and 67, and pacs with programs in plug-in modules for the HP 41 and 71. These books and pacs focus on computation-intensive (as opposed to data-intensive) problems in specific science or engineering disciplines. Program size and capability are limited primarily by available memory and the single-line calculator display.

The HP Solve Equation Library application card provides this capability for the HP 48SX scientific expandable calculator, but without the limitations of previous pacs. The focus on computation-intensive solutions is preserved, but for a wider range of disciplines than in individual pacs in

the past. An additional focus on data-intensive applications has been added in the form of on-line, electronic reference information (two thirds of the card contains data). The 128K-byte memory capacity of the card makes these two emphases possible, and the large display allows improved user interfaces for the interactive applications.

The card contains six major applications:

- Equation Library (Fig. 1). This is the primary application for which the card was named: a collection of 315 equations organized in a catalog of 15 different subjects, each containing a catalog of equation titles. For each title, the user can examine the equations and catalogs of names, descriptions, and SI or English units for its variables. A key contribution is pictures that describe the physical situations represented by the equations. Our goal was that the subject, title, and reference information would help a user select an equation to use with the HP Solve

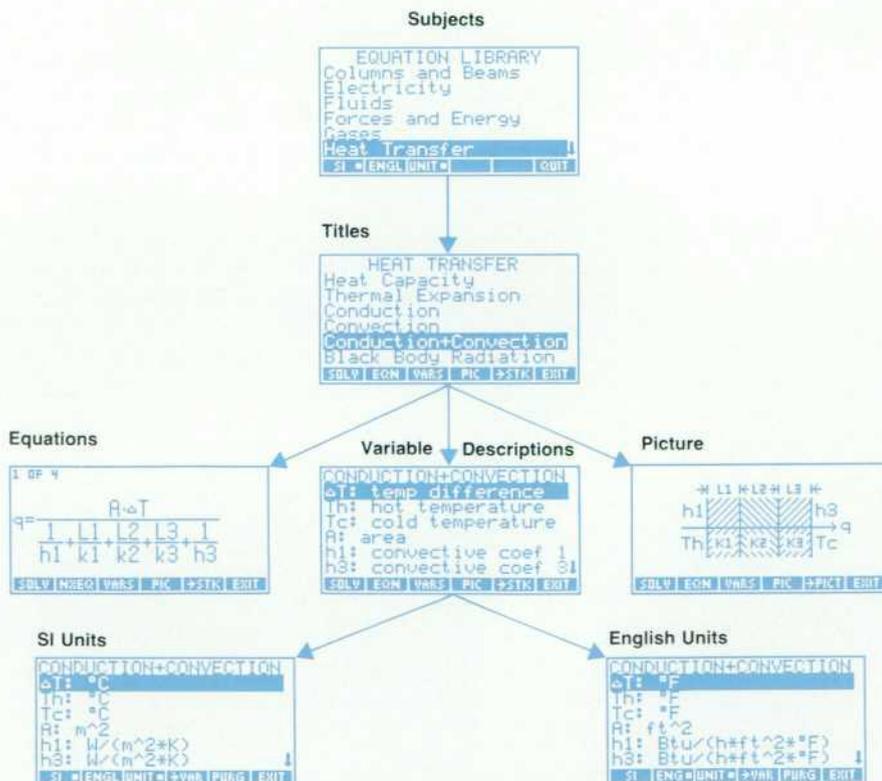


Fig. 1. Equation Library user interface.

application or the card's Multiple Equation Solver (discussed below).

- Periodic Table (Fig. 2). This application contains all the chemical data (such as atomic weight and density) that appears on a standard periodic table of the elements. The primary user interface is the universally recognized grid of elements. The user can move a highlight block to see any element and its most-used properties on the grid. There is also a catalog of 23 properties available for each of the 106 elements. Properties can be plotted versus atomic number to reinforce the relationship between property and atomic structure. A molecular weight calculator allows typing chemical formulas and quickly calculating their molecular weights.
- Constants Library. This is a collection of 39 commonly-used physical constants. These appear in catalogs of symbols, descriptive names, values, and SI or English units.
- Multiple Equation Solver. This is a collection of commands that make it possible to use the Multiple Equation Solver to interact with the user's own equations as a group, rather than just the groups of equations from the Equation Library.
- Finance. This application duplicates the basic calculations performed by HP financial calculators: time value of money (the relationship between the number of payments, interest rate, present value, payment, and future value) and amortization.
- Engineering Utilities. These are engineering functions that support the computational needs of some of the equations in the Equation Library.

These applications come in two forms: interactive for

working with the application and its data, and noninteractive for programmatic calculations and access to the on-line data.

Equation Library Evolution

The Equation Library concept stemmed from three observations. First, students need a wide variety of solutions because of the number of classes they take. Because application pacs are limited to specific areas, students often need several pacs to cover the different disciplines they study simultaneously. Second, most of the engineering applications for the HP 41 and its predecessors are programs that simply solve an equation for a specific variable. More sophisticated programs of this type allow interchangeable solutions in which most or all of the unknown variables can be calculated as long as they can be isolated algebraically in the equation. Some programs use iterative techniques to find a solution when an algebraic isolation is not possible. Later application pacs attempt to allow the user to select different units for the different variables.

Third, the HP Solve application in the HP 48SX takes an equation and makes it into a small, self-contained application. It solves for any variable given the others, allows units to be specified for each variable, handles unit conversions automatically, and provides a consistent, straightforward user interface for interacting with all the variables.

From these three observations, we realized that we could create a collection of small applications in most of the science and engineering disciplines of previous application pacs by combining a collection of equations with HP Solve. The HP Solve user interface allows each application to work the same way, and the ability to solve for any variable and automate unit conversions makes these applications more versatile than in previous application pacs.

Interacting with Groups of Equations

As the equation selection proceeded, we found that related equations were usually needed as a group, rather than independently (Fig. 3). While there are certainly instances where only one of the equations is needed, more often the entire set is used to find the value for a particular variable. To provide simplified access to related equations, we group them together under a single title, such as Linear Motion or Ohm's Law and Power, rather than forcing the user to return to the Equation Library to select each equation individually.

When we examined how a user typically interacts with a group of equations, we realized that the solution proce-

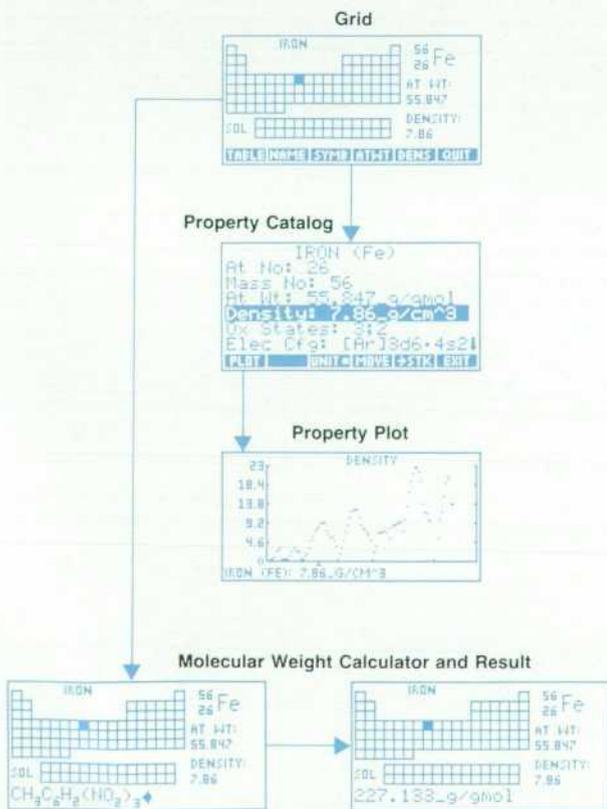


Fig. 2. Periodic Table user interface.

$x = x_0 + v_0 t + \frac{1}{2} a t^2$	$V = I R$
$x = x_0 + v_0 t - \frac{1}{2} a t^2$	$P = V I$
$x = x_0 + \frac{1}{2} (v_0 + v) t$	$P = I^2 R$
$v = v_0 + a t$	$P = \frac{V^2}{R}$

(a) Linear Motion (b) Ohm's Law and Power

Fig. 3. Examples of common equation sets.

ture is straightforward, but gets tedious as the number of equations and variables gets large. Here is the manual process for finding all the variables for a set of equations given that some of them are known:

- Use the known variables to select an equation containing only one unknown.
- Solve for the unknown.
- Add the variable just calculated to the set of known variables.
- Use the combined set of known and calculated variables to select another equation containing only one unknown.
- Solve for the unknown.
- Repeat this process until either all the unknowns have been found or as many unknowns as possible have been found from the given set of knowns.

To make using the equations more straightforward, we have automated this manual select-and-solve process by developing an extension to HP Solve called the Multiple Equation Solver (MES). The MES selects the appropriate equation to solve based on whether it has one remaining unknown, and then solves for that unknown using the same numerical root finder used by the HP Solve application. It tracks the variables that have been solved for, and uses different equations to calculate other unknowns as soon as there is enough information available.

The barrier to proper functioning of the MES was identifying whether a variable is known or unknown. The existence of the variable alone is not sufficient—after a solution has been determined, all the variables exist. The key under-

lying principle is that the state of a variable (known or unknown) is independent of the value of the variable. The MES uses this state information to select the equations to be solved and the order in which to solve them.

Displaying Variable States

The MES user interface is similar to that of HP Solve. A menu of variable names is displayed in the menu key area at the bottom of the display. The appearance of the menu keys is used to distinguish the MES state information. An extra key, ALL, appears at the end of the menu.

Initially all the menu keys are white with black letters (like HP Solve), indicating that all of the variables are unknown (Fig. 4a). Typing a value and pressing a menu key stores the value in that variable and changes the key to black with white letters, indicating that the variable is known (Fig. 4b).

Pressing the ALL key solves for all remaining variables, or as many as can be found from the given set of knowns.

Messages appear during the solution identifying which variable is being solved for and its resulting value. After the solution has completed, each variable retains its initial state. Correspondingly, each menu key retains its initial appearance. Black keys (knowns) remain black, and white keys (unknowns) remain white. This simplifies solving a problem using the same knowns and unknowns but with different values.

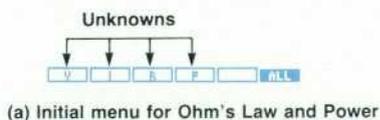
Indicating Variable Relationships

After a solution, some of the menu keys will have a small block in them to indicate the roles their variables played in the solution (Fig. 4c). A block in a black key (known) indicates that the variable was used to find an unknown in a particular equation. A block in a white key (unknown) indicates a value was calculated for that variable during the solution. This represents a unique state for a variable—it is an unknown, yet it has a calculated value. The next time this variable is solved for, this calculated value will be used as its initial guess.

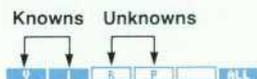
Pressing the shift key followed by a menu key solves for that specific variable, regardless of whether it is black or white (known or unknown). After a variable is solved for, its menu key is shown in white with a block to indicate an unknown that was solved for with a calculated value (Fig. 4d). Other menu keys may have blocks in them based on the roles their variables played in the solution.

Solution Summary

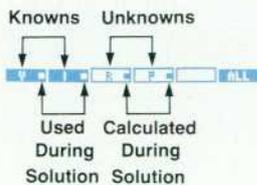
A summary of the solution procedure is available by pressing the shift key followed by the ALL key (Fig. 5). This summary shows a catalog of each unknown that was found,



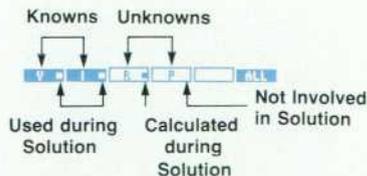
(a) Initial menu for Ohm's Law and Power



(b) After entering values for V and I



(c) After solving for all unknowns

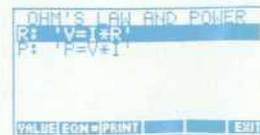


(d) After solving for R only

Fig. 4. Multiple Equation Solver menu key appearance.



(a) Values Calculated during Solution



(b) Equations Used during Solution

Fig. 5. Solution summary.

its calculated value, and the equation that was solved to find it, in the order that the unknowns were determined by the solution procedure.

Acknowledgments

I would like to thank the rest of the development team and the people who made exceptional contributions to the product: Jim Donnelly and Megha Shyam for making it all

happen, Dennis York for the initial vision, Lynn Winter for a catalog engine that was an enduring foundation, Chris Bunsen for critical design advice and testing for the Multiple Equation Solver, Diana Byrne for spearheading the software testing effort, Hank Schroeder for an owner's manual in a remarkably short time, and Ray Depew, whose thoroughness testing the Periodic Table was critical to both the card and the HP 48SX.

Hardware Design of the HP 48SX Scientific Expandable Calculator

Leveraging an earlier design resulted in prototypes with 90% production tooled parts only nine months after the start of the project. The HP 48SX includes an 8-line-by-22-character super-twisted nematic liquid crystal display, two expansion ports for ROM or battery-backed RAM cards, and two I/O ports: RS-232 and infrared.

by Mark A. Smith, Lester S. Moore, Preston D. Brown, James P. Dickie, David L. Smith, Thomas B. Lindberg, and M. Jack Muranami

THE NEEDS OF HP HANDHELD CALCULATOR customers—engineering, math, and science students and business and scientific professionals—have radically changed over the years, as the personal computer has become the standard tool of technical students and professionals. However, the need for convenient, handheld computation has not disappeared, but simply evolved.

Surveys of our high-end technical calculator customers reveal that nearly all own or have access to a personal computer, that they use their calculator daily, that professionals make up about half of the customers for high-end technical calculators, and that they need a powerful handheld calculator with graphics and I/O capabilities. The HP 48SX scientific expandable calculator (see Fig. 1 on page 6) is designed to meet their needs for more advanced computation, graphics, customizability, expandability, and the ability to link to their personal computers.

The 64-row-by-131-column STN LCD (super-twisted nematic liquid crystal display) provides the means for presenting the power of HP 48SX graphics, matrix manipulations, and equation entry. Two plug-in card slots provide RAM expansion (in 32K-byte or 128K-byte increments) and customization (plug-in application ROMs such as HP's Equation Library ROM card described in the article on page 22). A serial I/O port provides a means to link to an IBM PC-compatible or Apple Macintosh computer, and an IR (infrared) port allows sharing of solutions between

HP 48SX calculators and provides a link to the HP 82440B infrared printer.

Previous Series Leveraged

One of the primary project objectives for the HP 48SX was extensive leverage from the design and manufacturing

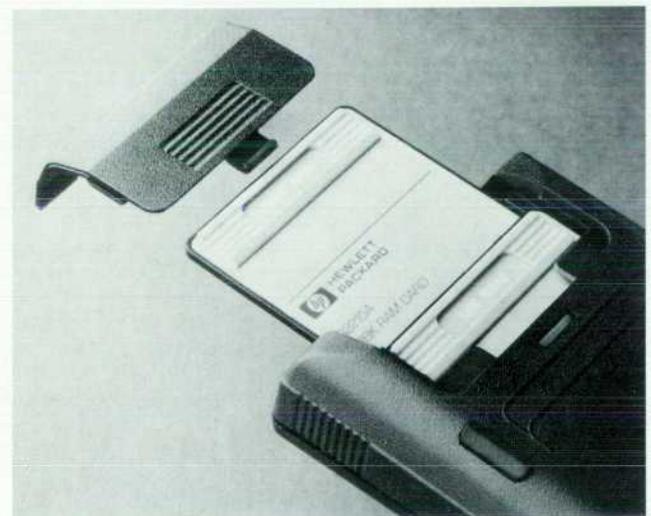


Fig. 1. Two expansion ports accept ROM or battery-backed RAM cards.