PocketProfessional®

EE•*Pro*™

User's Guide

SPARCOM CORPORATION

Edition 2: April 1994 Software Reorder No. 10211-1A

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In memory of

Amy Lynne Otto

Notice

Customer Support

Customer satisfaction is important to Sparcom Corporation. Technical support is available Monday through Friday, 9 a.m. to 5 p.m. Pacific Coast Time. The support phone number is (503) 757-8416. Your questions are also welcome by facsimile (503) 753-7821 or by e-mail (Internet: support@sparcom.com).

Credits

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Chapter 1

Getting Started

PocketProfessional® software is the first of its kind, developed to provide speed, efficiency and portability to students and professionals in technical fields. When you slide a PocketProfessional plug-in card into your HP 48GX or HP 48SX, your calculator is instantly transformed into an electronic "textbook," ready to efficiently solve your technical problems.

PocketProfessional EE•*Pro*™ is state-of-the-art electrical engineering software for the HP 48GX and HP 48SX calculators. Sparcom Corporation thanks all the current owners of our PocketProfessional software for their many helpful suggestions and comments.

This chapter covers:

NOTE	Please retain the software license agreement printed on the envelope your EE•*Pro* card came in. It contains important information regarding your rights.

Key Features of EE•*Pro*

- *Highest speed and performance of any HP 48 software sold today*
- *Easy-to-use, menu-based interface*
- *Context-sensitive help text for every screen*
- *Advanced electrical engineering analysis routines, equations, and reference tables*
- *Integrated access to the HP 48 stack for calculations*
- *Comprehensive documentation for quick reference*
- *Learn one* Pro *product and you can use them all!*

How to Use This Manual

This manual is designed as a learning and reference tool to be used with your PocketProfessional EE•*Pro* software. This section explains the layout of the manual.

Manual Organization

The manual is divided into four parts: Analysis, Equations, Reference, and Programming & Advanced Use. These sections mirror the divisions within EE•*Pro*, with the addition of an advanced section for experienced users.

Part 1: Analysis includes analysis routines to perform calculations, such as AC circuit analysis, two-port networks, and computer engineering. Easy-to-use, intuitive analysis screens are available for each routine.

Part 2: Equations includes an equation library of over five hundred solvable equations organized in related groups. Full descriptions of each variable, a variety of user-selectable units, and appropriate diagrams are included.

Part 3: Reference includes reference tables based on information in standard reference books, such as Laplace transform tables, semiconductor properties, and donor and acceptor levels in silicon.

Part 4: Programming & Advanced Use includes detailed syntax for each programmable command included in EE•*Pro* and other tips for experienced users.

What to Read Next...

To get the most information from this manual, read the following sections:

1. Read all of this chapter, "Getting Started." You will learn how to install EE•*Pro*, and you will be introduced to the menus and screens of EE•*Pro*, which provide easy-to-use access to all the features.

2. Read the Navigation Guides for Analysis, Equations and Reference (Chapters 2, 16, and 33). You will learn how to use each major section of EE•*Pro* through step-by-step instructions and context-sensitive help.

3. Use the table of contents and index to locate further topics of interest.

4. Refer to Appendix D, "Questions and Answers," to answer the most commonly asked questions about EE•*Pro*.

Manual Conventions

There are a few simple conventions used throughout this manual:

- The heading of each chapter and its modules displays a "map" of the path taken to get to that particular section. For example, the Impedance Calculations analysis section is in the chapter on AC Circuits, in the Analysis section. The heading shows this path. Keep in mind that there may be several sections within the AC Circuits chapter. The heading only shows the current one.

Impedance Calculations

Analysis
AC Circuits
Impedance Calculations
Equations
Reference

- Keys on the HP 48 keyboard are shown in a boxed typeface, such as [ENTER].

- Boxed typeface is also used to indicate the green and purple key labels (HP 48GX) or the blue and orange key labels (HP 48SX) located above the keys. For instance, on the HP 48 GX, the I/O command is a green label located above the [1] key, and is accessed by pressing the green shift key then the [1] key. In this manual, these keystrokes are represented in the following manner: [→][I/O].

Similarly, with the HP 48SX, the I/O command is an orange label located above the [PRG] key, and is accessed by pressing the orange shift key then the [PRG] key. In this manual, these keystrokes are represented in the following manner: [←][I/O].

- Keys which should be pressed at the same time are indicated with a hyphen between them: [ON]-[I/O]. **Do not press the minus key.**

- Menu keys are located at the bottom of the HP 48 screen and correspond directly to the top row of keys on the HP 48 keyboard. They are shown in inverse typeface, such as HOME.

- Programmable commands are shown in uppercase letters, such as SIN. Uppercase is also used to show field names, like RESULT, which are displayed on the HP 48 screen.

- Steps to be followed in a particular order are numbered: 1, 2, 3, etc.

- HP 48 variables/directories are listed in single quotes, such as 'SPARCOM'.

- Equation variables are shown in boldface to separate them from the text, as in: "The source current and impedance are **Is** and **Zs**, respectively."

- All examples assume that pressing [α][α] locks the Alpha entry mode. If you have set the HP 48 system flag -60, press [α] instead of [α][α] to lock Alpha entry mode.

- In each example, there is a box listing the mode settings for that example. To change the modes, press the [CST] key at any EE•*Pro* screen. Most examples are in the following modes:

MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press [CST])	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Differences between HP 48GX and HP 48SX

This manual was written using the HP 48GX as the standard, with notations made for the HP 48SX where necessary. The following keys are different between the HP 48GX and HP 48SX, but they perform the same function:

HP 48GX	HP 48SX	Description
[→] [LIBRARY]	[←] [LIBRARY]	Displays all libraries.
[ON]-[I/O]	[ON]-[MTH]	Performs a screen dump.
[→] [CMD]	[→] [VISIT]	Displays an item if it is too wide for the screen.

Memory Requirements

A minimum of 5 Kbytes of free memory is needed for using EE•*Pro*, although complicated operations may require more memory. If EE•*Pro* seems to be functioning incorrectly, low memory may be the cause. For more information about free memory, see your HP 48 User's Guide. If you are using EE•*Pro* in Card Slot 2 of an HP 48GX and you receive the error message, "Insufficient Memory," you should reinstall EE•*Pro* in Card Slot 1, which requires less memory overhead. See "Installing and Removing a Card" below for more information about how to switch EE•*Pro* from Card Slot 2 to Card Slot 1.

Environmental Limits

The reliability of a PocketProfessional plug-in card depends upon the following temperature and humidity limits:

- **Operating Temperature:** 0 to 45° C (32 to 113° F).
- **Storage Temperature:** –20 to 60° C (–4 to 140° F).
- **Operating and Storage Humidity:** 90% relative humidity at 40° C (104° F) maximum.

Installing and Removing a Card

The HP 48GX and HP 48SX have two ports for installing PocketProfessional plug-in cards. A card can be installed in either port. Due to the manner in which the HP 48GX manages memory, EE•*Pro* will perform better in Card Slot 1 of an HP 48GX. EE•*Pro* will perform equally well in either card slot on the HP 48SX.

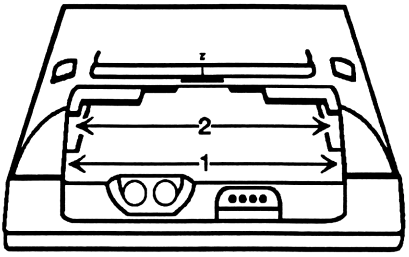
WARNING	Turn off the HP 48 *before* installing or removing a card! Otherwise, user memory may be erased.

Installing a Card

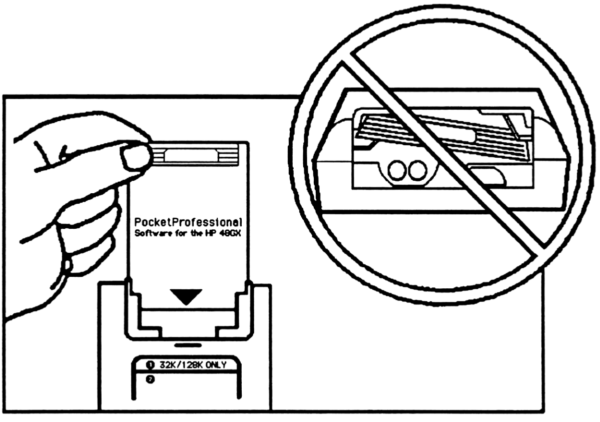
To install a card, follow these steps:

1. Press [↱] [OFF] to turn the HP 48 off. Do not turn it back on until you have completed the installation procedure.

2. Remove the port cover. Press against the grip lines and push forward. Lift the cover to expose the two plug-in ports, as shown to the right:



3. Select either empty port for the card, and position the card just outside the slot. (HP 48GX users will find that placing the card in Port 1 gives optimal performance.) Point the triangular arrow on the card toward the HP 48 port opening, as shown below:



4. Slide the card firmly into the slot. After you first feel resistance, push the card further (about 5-6 mm or about 1/4 inch), until it is fully seated.

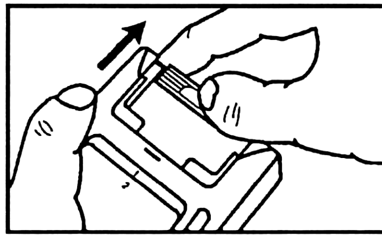
5. Replace the port cover. Press [ON] to turn the HP 48 on.

Removing a Card

To remove a card, follow these steps:

1. Press [→] [OFF] to turn the HP 48 off. Do not turn it back on until you have removed the card.

2. Remove the port cover. Press against the grip lines and push forward. Lift the cover to expose the two plug-in ports, as shown in "Installing a Card."



3. Press against the card's grip and slide the card out of the port, as shown.

4. Replace the port cover. Press [ON] to turn the HP 48 on.

Starting EE•*Pro*

To start EE•*Pro*, follow these steps:

1. Install the card as described above and press [ON] to turn the HP 48 on.

2. HP 48GX: Press [→] [LIBRARY] to display the available libraries.
   HP 48SX: Press [←] [LIBRARY] to display the available libraries.

3. Press [EE] to display the EE•*Pro* library menu.

4. Press [EE] to start EE•*Pro*, or press [ABOUT] to display product information and the current version of EE•*Pro*. The other menu keys in the EE•*Pro* library menu are covered in Chapter 43, "Programmable Commands."

NOTE

At any point, you can exit EE•*Pro* and return to the HP 48 stacks by pressing [ON]. You can return to EE•*Pro* at exactly the same point you left it, by pressing [→] [LIBRARY] (GX) or [←] [LIBRARY] (SX) [EE] [EE], or by typing [α] [α] EE [ENTER].

Using the Home Screen

The home screen appears when you start EE•*Pro* for the first time. It can also be reached by pressing [⮡] [HOME] from any EE•*Pro* screen.

The home screen lists the three major sections of EE•*Pro*: Analysis, Equations, and Reference. To select a section, move the highlight bar up or down ([▲] or [▼]) to the desired section and press [ENTER] or [►].

> **NOTE**
>
> To move back to a previous screen at any time, press [◄] or [UP]. To return to the home screen at any time, press [⮡] [HOME] or [HOME].

ABOUT Displays product information and current version of EE•*Pro*.

VIEW Displays the highlighted item on the screen by itself, in the large font (text view). This is useful if the item scrolls off the right side of the screen with an ellipsis ("...") displayed.

FIND Searches for the specified character or string. To perform a search, enter a letter or string of letters of the desired word or sequence and press [ENTER]. **FIND** only searches the current screen for a match.

OPTS Displays the options menu. See "Options Menu," page 9.

PATH Displays screens chosen to reach the current screen. After pressing this key, you will see the path listing in the title bar of the screen. Press **→STK** to place this path list on the stack. This can then be used to create a quick link to that specific screen. See chapter 44 "Programmable Screens" for more details.

QUIT Quits EE•*Pro* and returns to the HP 48 stack.

At screens other than the home screen, two new menu keys may appear:

HOME Goes to the home screen.

UP Goes to the previous screen.

Navigating through EE•*Pro*

The HP 48 arrow keys are your navigation tools for accessing every part of EE•*Pro*. The right arrow [►] takes you to the next screen. The left arrow [◄] takes you to the previous screen. When you have gone as far as you can go in one path, for instance:

Analysis [►]

AC Circuits [►]

Impedance Calculations [►]

To return to the previous screens, press:

[◄] Impedance Calculations

[◄] AC Circuits

[◄] Analysis

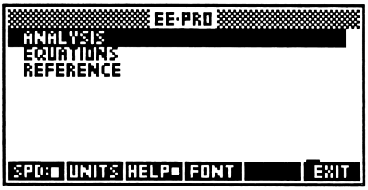
or press [⮫] [HOME] to return to the home screen.

The up arrow [▲] and down arrow [▼] allow you to move the highlight bar from one line to another, selecting a new topic or a new field.

Options Menu

The options menu helps you customize settings for EE•*Pro* and is available throughout the software. These settings apply to EE•*Pro* only, not to the HP 48 stack.

To access the options menu, press **OPTS** or [⮪] [CST]. This will display the following menu keys:



SPD:■ Changes the scrolling speed of the highlight bar. The bar inside the key (**SPD:■**), shows the current level of speed: a tall bar indicates fast scrolling speed, while a short bar indicates slow scrolling speed. To change the speed, press the **SPD:■** button to step through the choices.

UNITS Toggles units on or off. When the block inside the key appears (**UNIT▪**), units are turned on.

HELP Toggles display of help text on the bottom of the screen. When the block inside the key appears (**HELP▪**), help is turned on.

FONT Toggles font size between large and small. The default setting is the small font, which displays information in condensed, uppercase letters only. The large font displays information in a larger, case-sensitive font.

EXIT Leaves the options menu. Returns to the regular menu.

For more options, press [NXT] to display the following additional menu keys (you can also display these menu keys by pressing [→][CST]):

→STK Copies one or all of the items shown to the HP 48 stack. Pressing this key prompts you for **ONE** or **ALL**. If you decide not to copy the item to the stack, press [ON] to cancel.

VIEW Displays the highlighted item in a text view. This is useful if the item scrolls off the right side of the screen with "..." (an ellipsis) displayed.

If the highlighted item is an equation, pressing [→] or [←] **VIEW** displays the equation in graphics view.

FIND Searches for a specified character or string. To perform a search, enter a letter or string of letters of the desired word or sequence and press [ENTER]. **FIND** only searches the current screen for a match. See detailed explanation below, "Using the Find Option."

PRINT Prints one or all of the items shown to an HP 48 printer.

PATH Displays screens chosen to reach the current screen. After pressing this key, you will see the path listing in the title bar of the screen. Press **→STK** to place this path list on the stack. This can then be used to create a quick link to that specific screen. See chapter 44 "Programmable Screens" for more details.

EXIT Leaves the options menu. Returns to the regular menu.

Press [←][PREV] or [NXT] to go to the previous "page" of menu keys.

Using the Find Option

To initiate a search, press **FIND** to display the following screen:

The HP 48 is now ready to search for the information entered at the command line. The calculator is automatically locked in alpha entry mode, which activates the capital letters printed in white to the lower right of selected keys.

To perform a search, enter a letter or string of letters of the desired word or sequence and press [ENTER]. The find function is not case-sensitive. **FIND** then searches the current screen for a match. To abort the search, press [ON] (Cancel). To repeat the search, press the **FIND** key again and the last search string will be displayed. Press the [ENTER] key to renew the search.

The menu keys on the Find screen are the standard HP 48 editing keys and are described below. To use these keys, turn the Alpha lock off by pressing [α]. To turn Alpha lock back on, press [α][α].

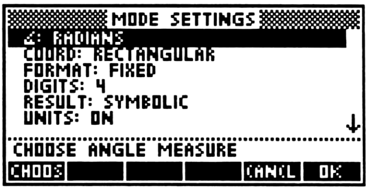
←SKIP Moves the cursor to the beginning of the current word.
SKIP→ Moves the cursor to the beginning of the next word.
←DEL Deletes the characters from the beginning of the word to the cursor.
DEL→ Deletes the characters from the cursor to the end of the word.
INS▪ Switches the entry mode between *Insert* mode (← cursor) and *Replace* mode (▮ cursor). A ▪ in the menu key indicates Insert mode is active.
↑STK Allows you to copy an item from the HP 48 stack:

1. Press [α] to cancel the alpha-entry mode, then press ↑STK to go to the HP 48 stack.
2. Use the arrow keys to select the stack level with the desired item.
3. Press ECHO then [ENTER] to copy the item into the 'Find' string.

Custom Settings Screen

The custom settings screen is displayed by pressing [CST]. This screen sets the default settings for the HP 48 and EE•*Pro*. Once you leave the EE•*Pro* program, these settings will still remain in effect. The custom settings screen is available throughout EE•*Pro*.

To change any of these settings, move the highlight bar to the desired item and press CHOOS or [+/-]. Then press OK to implement the changes, or to exit the screen without changing the settings, press CANCL or [ON].



∡: (*Angle measure*) Press CHOOS or [ENTER] to select degrees, radians, or grads. Determines how angular functions interpret angular inputs and what angle measure is used to display angular outputs.

Coord: (*Coordinate system*) Press CHOOS or [ENTER] to select rectangular, polar or spherical. Determines whether complex numbers are displayed as (x,y) or (r,∡θ).

Format: (*Number format*) Press CHOOS or [ENTER] to select Standard, Fixed, Scientific or Engineering.

Digits: (*# of decimal places displayed*) Type in the desired number of decimal places. (This field disappears when Standard number format has been selected.)

Result: (*Result mode*) Press CHOOS or ENTER to select symbolic or numeric. Determines whether some functions return symbolic or numeric results.

Units: (*Units*) Press CHOOS or ENTER to select on or off. Determines whether units are on or off for Equations and Reference. In the Analysis sections units are disregarded completely, so the units setting makes no difference.

Help: (*Help text*) Press CHOOS or ENTER to select on or off. Determines whether context-sensitive help text is displayed on the screen.

Font: (*Font size*) Press CHOOS or ENTER to select on or off. Determines whether items are displayed in large or small font.

Part 1

Analysis

Chapter 2

Analysis: Navigation Guide

Analysis
Equations
Reference

This chapter is designed as a navigation guide to introduce you to the Analysis section, show you the keys available at each screen, and describe the types of input fields you will encounter. At the end of the chapter is a detailed Analysis example.

Introduction

EE•*Pro* is divided into three major sections: Analysis, Equations, and Reference. This chapter addresses the Analysis section, which includes analysis routines covering AC circuits, polyphase circuits, ladder networks, filter design, gain and frequency, Fourier transforms, two-port networks, transformer performance, transmission lines, computer engineering, algebraic functions, error functions, and capital budgeting.

The Analysis routines are indispensable tools for performing quick calculations. You can design filters, evaluate performance of two-port networks, calculate transmission line properties, design transformers or minimize logic neworks, draw the classic Bode plot, and determine capital budget constraints—all with context-sensitive help.

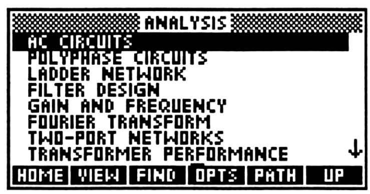
Finding Analysis

The Analysis section is found at the home screen of EE•*Pro*.

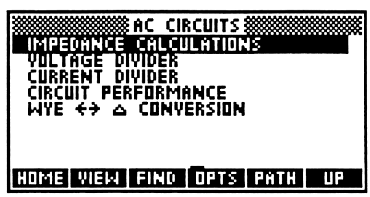
1. Start EE•*Pro*:
   - HP 48GX: Press [→] [LIBRARY] [EE] [EE].
   - HP 48SX: Press [←] [LIBRARY] [EE] [EE].
   - Press [→] [HOME] to show the home screen.

   EE•*Pro* is structured with a hierarchy of screens for choosing a specific topic or item. This is the home screen. To return here at any time, press [→] [HOME] or [→] [◄].

2. Select Analysis by moving the highlight bar to Analysis and pressing [ENTER] or [►]. The screen now displays Analysis as its title and a list of Analysis sections from which to choose.



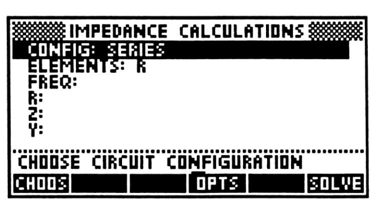
3. Choose an Analysis section by moving the highlight bar to the desired item and pressing [ENTER] or [►]. This will display a list of topics for the selected section. For the purposes of this navigation guide, select AC Circuits, then Impedance Calculations.



Pressing [UP] (if available) or [◄] returns you to the previous screen.
Pressing [HOME] (if available) or [→] [HOME] returns you to the home screen.

Analysis Screens

An Analysis screen displays a list of fields for entering and displaying data. The screen to the right is the Impedance Calculations screen. To get to this screen, select Analysis, then AC Circuits, then Impedance Calculations (as described above). The main part of the screen contains input fields for data entry and

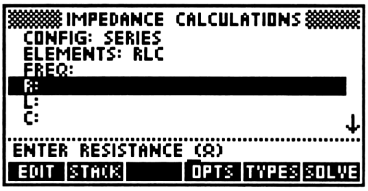


result fields for displaying calculated results. The help text at the bottom of the screen describes the action required for the highlighted field or the type of result to be displayed. In screens with numerous fields, you may want to turn the help text off to view more of the fields at one time. See "Options Menu," page 9 for more information.

Analysis modules which contain more than two or three result fields will display those results in a separate output screen. To view the output screen, input values for the necessary fields and press SOLVE.

Using Analysis Routines

The instructions below are general instructions for using Analysis routines. For a detailed example using Impedance Calculations, see page 20. In addition, each section in each Analysis chapter contains at least one example.



1. Choose parameters (if available). In the screen for Impedance Calculations to the right, the **Config** and **Elements** fields are *choose* fields and contain a list of items for selection. Press CHOOS to access this list, or press [+/-] to step through the choices.

> **NOTE**
>
> Some choose fields affect the appearance of the remaining fields. For instance, choosing RLC in the **Elements** field here displays all the remaining input fields: **Freq**, **R**, **L**, and **C**. However, if R is chosen in the **Elements** field, only the relevant fields **Freq** and **R** appear.

2. Enter values into the *edit* fields. In this screen, the **Freq**, **R**, **L**, and **C** are edit fields. The values are to be entered as real numbers, but they will be interpreted as being in the units specified in the help text at the bottom of the screen. In this screen, the resistance entered in field **R** will be assumed to be a quantity of ohms.

> **NOTE**
>
> If an edit field requires a delimiter, it will automatically be inserted. Typical delimiters are: { } for a list, [ ] for an array, ' ' for a symbolic expression, and # for a binary number.

3. Press SOLVE to calculate the result of the analysis.
4. The result appears in the *result* field(s) – in this case, **Impedance** and **Admittance**.
   Some Analysis modules have too many result fields to display on the input screen. In that case, a separate output screen is displayed with all the result fields.
5. When finished press [◄] to return to the AC Circuits screen or press [↱] [HOME] to return to the home screen.

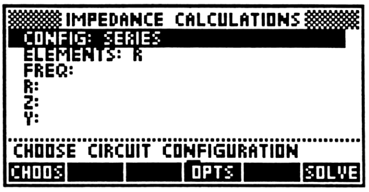
Analysis Menu Keys

The menu keys in Analysis screens change depending on the type of field that is highlighted. Analysis screens use three basic types of fields: choose fields, edit fields and result fields. These fields and their associated menu keys are outlined below. The OPTS and SOLVE menu keys are always present, regardless of the field type.

Input Screens

Input screens contain fields for entering data and, in some cases, for displaying the results of the calculations. The screen below is the Impedance Calculations input screen.

Choose Fields: These fields only accept values from a pre-defined list that is accessed by pressing CHOOS. In this example, both **Config** and **Elements** are choose fields.

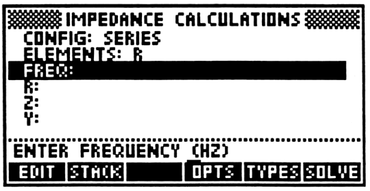


CHOOS Displays the possible choices for a choose field. In the list of choices, highlight the desired item and press [ENTER] or OK, or press CANCL to abort the selection.

OPTS Displays the options menu. For more information, see "Options Menu," page 9.

SOLVE Performs a calculation using the inputs that have been entered. The result is displayed in the result field(s).

Edit Fields: These fields accept values entered from the keyboard. In this example, **Freq**, **R**, **L**, and **C** are edit fields.



EDIT Edits the highlighted item. The menu keys then change to the standard HP 48 editing keys. Press [ENTER] to save edit changes or [ON] to cancel editing.

STACK Copies the highlighted item to

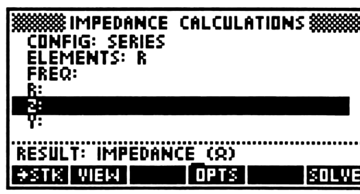
the HP 48 stack and temporarily goes to the HP 48 stack environment. While at the stack, you can use all the normal built-in functions of your HP 48 to manipulate or change the copied item. When you have finished editing the item, press **OK** to leave the stack and insert the edited item into the current edit field, or press **CANCL** to leave the stack without changing the value of the current edit field.

OPTS Displays the options menu. For more information, see "Options Menu," page 9.

TYPES Displays the allowed object types, such as real number, list, array, algebraic, etc. Move the highlight bar to the desired input type and press **OK** or ENTER to start a new item of that type, with the appropriate delimiters, on the command line. Or press **CANCL** to return to the Analysis screen.

SOLVE Performs a calculation using the entered values. The result is displayed in the result field(s).

Result Field: These fields display the result of a calculation. In the Impedance Calculations screen, both **Z** and **Y** are result fields.



→STK Copies one or all of the items shown to the HP 48 stack. For more information, see "Options Menu," page 9.

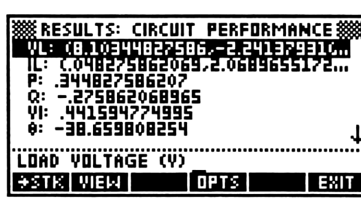
VIEW Displays the highlighted item in a text view. For more information, see "Options Menu," page 9.

OPTS Displays the options menu. For more information, see "Options Menu," page 9.

SOLVE Performs a calculation using the entered values. The result is displayed in the result field(s).

Output Screens

Output screens contain *only* result fields, so the menu keys are the same as those above, with the addition of an **EXIT** key. The screen below is the output screen from the Circuit Performance example in the AC Circuits chapter, see page 24.



→STK Copies one or all of the items shown to the HP 48 stack. For more information, see "Options Menu" page 9.

VIEW Displays the highlighted item in a text view. For more information, see "Options Menu," page 9.

OPTS Displays the options menu. For more information, see "Options Menu," page 9.

EXIT Returns to the input screen.

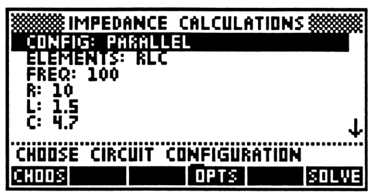
> **NOTE**
>
> Pressing [→] [HOME] will not work at an output screen. To return to the home screen, first press **EXIT** to return to the input screen, *then* press [→] [HOME] or [→] [◄].

Example: Parallel RLC Circuit

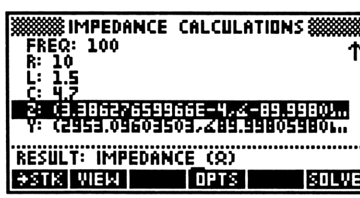
MODES (Press [CST])				
	∡:	Degrees	**Result:**	Symbolic
	Coord:	Polar	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Compute the impedance of a parallel RLC circuit with a 10 ohm resistor, a 1.5 Henry inductor and a 4.7 farad capacitor at a frequency of 100 hertz.

1. Go to the Impedance Calculations screen:
   a. Press [→] [HOME] to go to the home screen.
   b. Choose Analysis.
   c. Choose AC Circuits.
   d. Choose Impedance Calculations.



2. Move the highlight bar to the **Config** field and press **CHOOS** to display the two choices for this field. Move the highlight bar down to Parallel and press **OK** or [ENTER]. The circuit configuration is now set and the highlight bar will automatically move down to the next field.
3. At the **Elements** field press **CHOOS** and select RLC.
4. Enter 100 for **Freq**, 10 for **R**, 1.5 for **L**, and 4.7 for **C**. If you make a mistake while entering these values, move the highlight bar back up to the field with the incorrect value and type in the correct value.



5. Press **SOLVE** to calculate the impedance **Z** and admittance **Y**. Because the result for the impedance is too wide for the screen, move the highlight bar to the **Z** field and press **VIEW** to display the full value in text view, if desired.
6. When finished press [◄] to return to the AC Circuits screen or press [→] [HOME] to return to the home screen.

Chapter 3

AC Circuits

Analysis
AC Circuits
Equations
Reference

This chapter covers the basic properties of simple AC circuits:

- ❑ Impedance Calculations
- ❑ Voltage Divider
- ❑ Current Divider
- ❑ Circuit Performance
- ❑ Wye ↔ Δ Conversion

Impedance Calculations

Analysis
AC Circuits
Impedance Calculations
Equations
Reference

The Impedance Calculations section computes the conductance of a resistor, the impedance and admittance of an isolated inductor or a capacitor, and the impedance and admittance of a series or parallel combination of a resistor, inductor and/or capacitor.

Field Descriptions

Config: (*Circuit Configuration*) Press CHOOS to select Series or Parallel.
Elements: (*Element Combination*) Press CHOOS to select R, L, C, RL, RC, LC, or RLC. Determines which of the remaining fields are visible: **Freq**, **R**, **L** and/or **C**.
Freq: (*Frequency in Hz*) Enter a real number, global name, or algebraic.
R: (*Resistance in Ω - only appears if* R, RL, RC *or* RLC *is chosen in* **Elements** *field*) Enter a real number, global name, or algebraic.
L: (*Inductance in H - only appears if* L, RL, LC *or* RLC *is chosen in* **Elements** *field*) Enter a real number, global name, or algebraic.
C: (*Capacitance in F - only appears if* C, LC, RC *or* RLC *is chosen in* **Elements** *field*) Enter a real number, global name, or algebraic.
Z: (*Impedance in Ω*) Returns a real or complex number, global name, or algebraic.

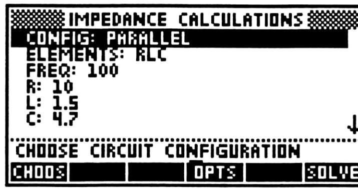
Y: (*Admittance in S*) Returns a real or complex number, global name, or algebraic.

Example

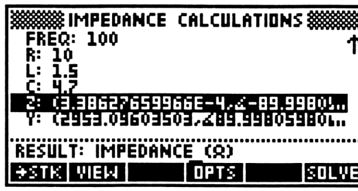
MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Polar	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Compute the impedance of a parallel RLC circuit consisting of a 10 ohm resistor, a 1.5 Henry inductor and a 4.7 farad capacitor at a frequency of 100 hertz.

1. Choose Parallel for **Config** and RLC for **Elements**.
2. Enter 100 for **Freq**.
3. Enter 10 for **R**, 1.5 for **L**, and 4.7 for **C**.
4. Press SOLVE to calculate **Z** and **Y**.



Input Screen



Output Screen

Voltage Divider

Analysis
 AC Circuits
  Voltage Divider
Equations
Reference

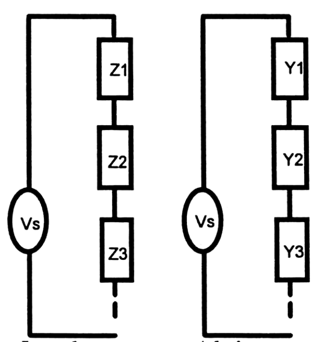
This section computes the voltage drop across a load connected to an ideal voltage or current source. The load chain consists of impedances in series or admittances in series. The module computes the voltage across each impedance/admittance and the current through the load.

Field Descriptions

Load Type: (*Type of Load*) Press CHOOS to select Impedance (Z) or Admittance (Y). Determines whether the third field is Z (impedance chain) or Y (admittance chain).

Vs: (*Source Voltage in V*) Enter a real or complex number, global name, or algebraic.

Z: (*Impedances*) Enter a list of real or complex numbers, global names, or algebraics.



Impedances ***Admittances***

Y: (*Admittances*) Enter a list of real or complex numbers, global names, or algebraics.

IL: (*Output Current in A*) Returns a real or complex number, global name or algebraic.

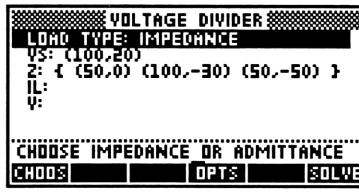
V: (*Element Voltages in V*) Returns a list of real or complex numbers, global names, or algebraics.

Example

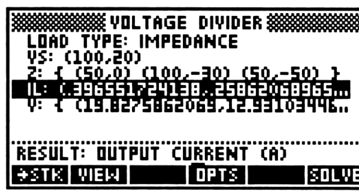
MODES				
(Press [CST])	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

An ideal voltage source with a (100,20) AC voltage is connected to three impedances (50,0), (100,-30) and (50,-50) connected in series. Compute the load current and the voltage drop across each impedance.

1. Choose Impedances for **Load Type**.
2. Enter (100,20) for **Vs**.
3. Enter {(50,0) (100,-30) (50,-50)} for **Z**.
4. Press SOLVE to calculate **IL** and **V**.



Input Screen



Output Screen

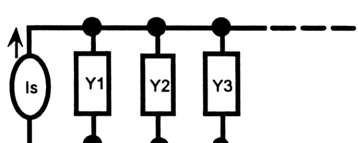
Current Divider

Analysis
AC Circuits
Current Divider
Equations
Reference

This section computes the individual branch currents in a load defined as a set of impedances or admittances connected in parallel. The section also computes the voltage across the load.

Field Descriptions

Load Type: (*Type of Load*) Press CHOOS to select Impedance (Z) or Admittance (Y). This sets the third field to be Z (Impedances) or Y (Admittances).

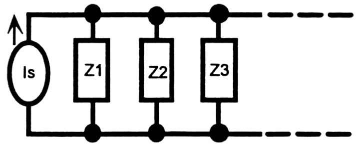


Admittances

Is: (*Source Current in A*) Enter a real or complex number, global name, or algebraic.

Z: (*Impedances*) Enter a list of real or complex numbers, global names or algebraics.

Y: (*Admittances*) Enter a list of real or complex numbers, global names or algebraics.



Impedances

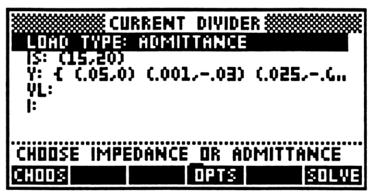
VL: (*Load Voltage in V*) Returns a real or complex number, global name or algebraic.

I: (*Currents in A*) Returns a list of real or complex numbers, global names or algebraics.

Example

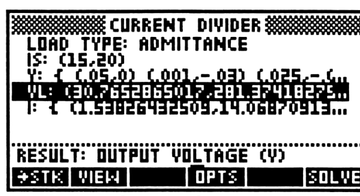
MODES (Press [CST])	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

An AC current source of (15, 20) amps has a load consisting of three admittances: (0.05, 0), (0.001, -0.03) and (0.025, -0.015) mhos, connected in parallel. Compute the current in each element and the voltage drop across the load.



Input Screen

1. Choose Admittance for **Load Type**.
2. Enter (15,20) for **Is**.
3. Enter {(.05,0) (.001,-.03) (.025,-.015)} for **Y**.
4. Press SOLVE to calculate **VL** and **I**.



Output Screen

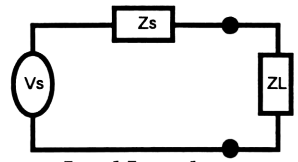
Circuit Performance

Analysis
  AC Circuits
    Circuit Performance
Equations
Reference

This section computes the circuit performance of a simple load connected to a voltage or a current source. Performance parameters computed include load voltage and current, complex power delivered, power factor, maximum power available to the load, and the load impedance required to deliver maximum power.

Field Descriptions - Input Screen

Load Type: (*Type of Load*) Press CHOOS to select load impedance (Z) or admittance (Y). Determines whether remaining fields are **Vs**, **Zs**, and **ZL** or **Is**, **Ys**, and **YL**, respectively.

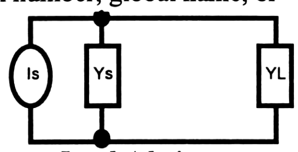


Load Impedance

Vs: (*RMS Source Voltage in V*) Enter a real or complex number, global name, or algebraic.

Zs: (*Source Impedance in Ω*) Enter a real or complex number, global name, or algebraic.

ZL: (*Load Impedance in Ω*) Enter a real or complex number, global name, or algebraic.



Load Admittance

Is: (*RMS Source Current in A*) Enter a real or complex number, global name, or algebraic.

Ys: (*Source Admittance in S*) Enter a real or complex number, global name, or algebraic.

YL: (*Load Admittance in S*) Enter a real or complex number, global name, or algebraic.

Field Descriptions - Output Screen

VL: (*Load Voltage in V*) Returns a real or complex number, global name, or algebraic.

IL: (*Load Current in A*) Returns a real or complex number, global name, or algebraic.

P: (*Real Power in W*) Returns a complex number, global name, or algebraic.

Q: (*Reactive Power in W*) Returns a complex number, global name, or algebraic.

VI: (*Apparent Power in W*) Returns a complex number, global name, or algebraic.

θ: (*PF Angle in ∡*) Returns a real number, global name or algebraic.

PF: (*Load Power Factor*) Returns a real number, global name, or algebraic.

Pmax: (*Maximum Power Available in W*) Returns a real number, global name, or algebraic.

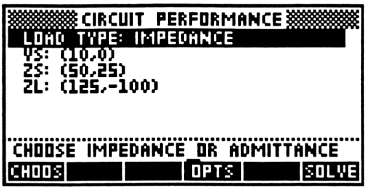
YLopt: (*Load Admittance for Maximum Power in S - if* Admittance *was chosen for* **Load Type** *at input screen*) Returns a real or complex number, global name, or algebraic.

ZLopt: (*Load Impedance for Maximum Power in Ω - if* Impedance *was chosen for* **Load Type** *at input screen*) Returns a real or complex number, global name, or algebraic.

Example

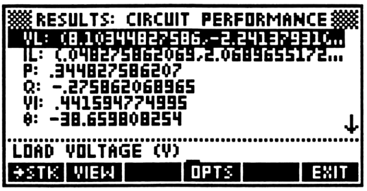
MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Calculate the circuit performance parameters for a (125,-100) ohm load connected to an AC voltage source with a voltage of (10, 0) and a source impedance of (50, 25) ohms.



Input Screen

1. Choose Impedance for **Load Type**.
2. Enter (10, 0) for **Vs**, (50, 25) for **Zs**, and (125, -100) for **ZL**.
3. Press SOLVE to calculate the results, which will be displayed in the output screen.

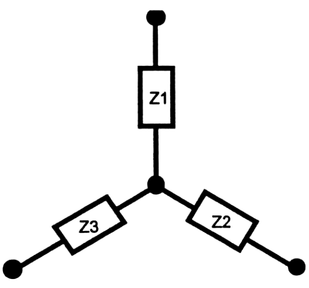


Output Screen

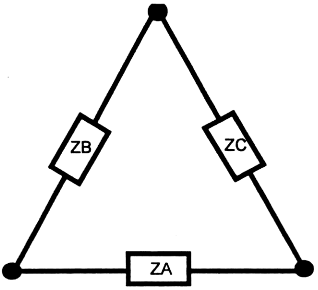
Wye ↔ Δ Conversion

Analysis
AC Circuits
Wye ↔ Δ Conversion
Equations
Reference

This section converts the three impedances Z1, Z2 and Z3 connected in a Y configuration to its equivalent Δ values of ZA, ZB and ZC or vice versa, as shown in the diagrams below. This section uses the clockwise notation.



Wye Configuration



Δ Configuration

Field Descriptions

Input Type: (*Circuit Configuration*) Press CHOOS to select Δ→Y or Y→Δ. Determines whether next 3 fields (input fields) accept Δ Impedances or Z Impedances.

ZA: (*Δ Impedance in Ω*) Real or complex number, global name, or algebraic.

ZB: (*Δ Impedance in Ω*) Real or complex number, global name, or algebraic.

ZC: (*Δ Impedance in Ω*) Real or complex number, global name, or algebraic.

Z1: (*Y Impedance in Ω*) Real or complex number, global name, or algebraic.

Z2: (*Y Impedance in Ω*) Real or complex number, global name, or algebraic.

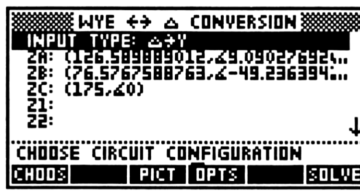
Z3: (*Y Impedance in Ω*) Real or complex number, global name, or algebraic.

Example

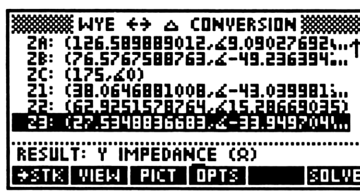
MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Polar	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Convert a **Δ** network with impedances (125,20), (50,-58) and (175,0) to its equivalent **Y** values.

1. Choose Δ→Y for **Input Type**.
2. Enter (125,20) for **ZA**, (50,-58) for **ZB**, and (175,0) for **ZC**.
3. Press SOLVE to calculate **Z1**, **Z2** and **Z3**.



Input Screen



Output Screen

Chapter 4

Polyphase Circuits

Analysis
Polyphase Circuits
Equations
Reference

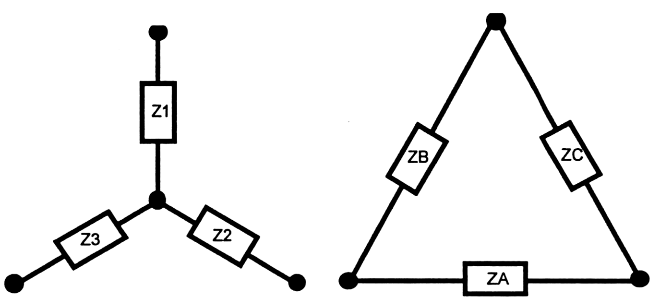
This chapter covers the basic principles of polyphase (3 phase) circuits:

- ❑ Wye ↔ Δ Conversion
- ❑ Balanced Wye Load
- ❑ Balanced Δ Load

Wye ↔ Δ Conversion

Analysis
Polyphase Circuits
Wye ↔ Δ Conversion
Equations
Reference

This section converts the three impedances Z1, Z2 and Z3 connected to form a Wye connection to their equivalent Δ values of ZA, ZB and ZC or vice versa, as shown in the diagram below. Clockwise notation is used for the conversion.



Wye Configuration　　*Δ Configuration*

Field Descriptions

Input Type: (*Circuit Configuration*) Press CHOOS to select Δ→Y or Y→Δ. Determines whether next 3 fields (input fields) accept Δ Impedances or Wye Impedances.

ZA: (*Δ Impedance*) Real or complex number, global name, or algebraic.

ZB: (*Δ Impedance*) Real or complex number, global name, or algebraic.

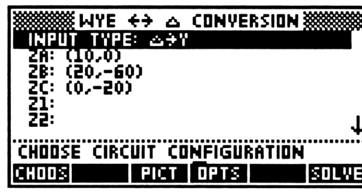
ZC: (*Δ Impedance*) Real or complex number, global name, or algebraic.
Z1: (*Y Impedance*) Real or complex number, global name, or algebraic.
Z2: (*Y Impedance*) Real or complex number, global name, or algebraic.
Z3: (*Y Impedance*) Real or complex number, global name, or algebraic.

Example 1

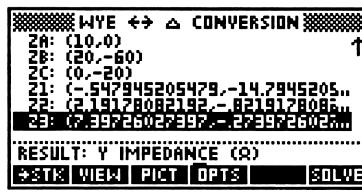
MODES (Press CST)				
	∡:	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Convert a Δ network with impedances (10,0), (20,-60) and (0,-20) to its equivalent Wye values.

1. Choose Δ→Y for **Input Type**.
2. Enter (10,0) for **ZA**, (20,-60) for **ZB**, and (0,-20) for **ZC**.
3. Press SOLVE to calculate **Z1**, **Z2** and **Z3**.



Input Screen



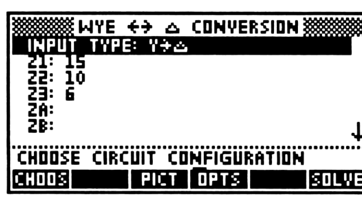
Output Screen

Example 2

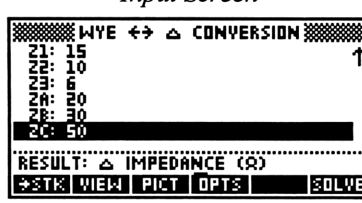
MODES (Press CST)				
	∡:	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Convert a Wye network with impedances 15, 10 and 6 to its equivalent Δ values.

1. Choose Y→Δ for **Input Type**.
2. Enter 15 for **Z1**, 10 for **Z2**, and 6 for **Z3**.
3. Press SOLVE to calculate **ZA**, **ZB** and **ZC**.



Input Screen

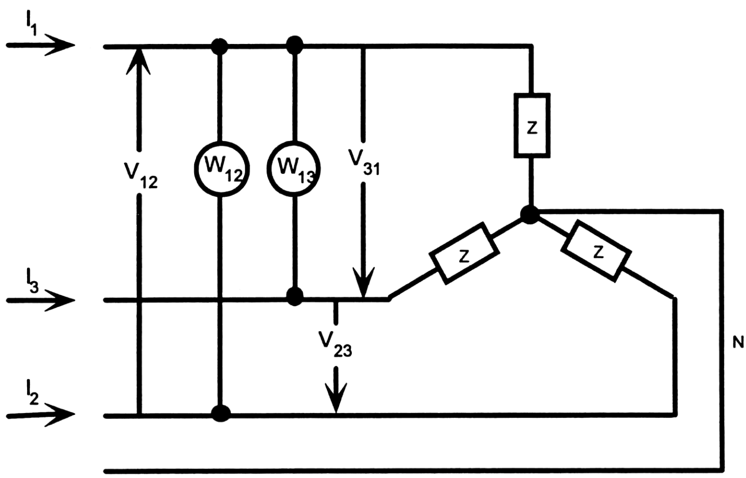


Output Screen

Balanced Wye Load

Analysis Polyphase Circuits ***Balanced Wye Load*** Equations Reference

In this section, three identical impedances **Z** are connected in the Wye configuration. The voltge **V12** represents the line voltage from line 1 to line 2 which is the reference voltage applied to this Wye network. The voltages across lines 2 and 3, and 3 and 1 have the same magnitude as **V12**, but are out of phase by -120° and 120° respectively. This section calculates the currents **I1, I2,** and **I3** in each leg of the Wye network, line to neutral voltage in each phase **V1N, V2N,** and **V3N,** power dissipated in each phase **P**, wattmeter readings **W12** and **W13** connected as shown in the figure below.



Field Descriptions - Input Screen

V12: (*Reference Voltage in V across lines 1 and 2*) Enter a real or complex number, global name, or algebraic.

Z: (*Phase Impedance in Ω*) Enter a real or complex number, global name, or algebraic.

Field Descriptions - Output Screen

V23: (*Voltage in V across lines 2 and 3*) Returns a real or complex number, global name or algebraic.

V31: (*Voltage in V across lines 3 and 1*) Returns a real or complex number, global name or algebraic.

V1N: (*Voltage in V across 1N*) Returns a real or complex number, global name or algebraic.

V2N: (*Voltage in V across 2N*) Returns a real or complex number, global name or algebraic.

V3N: (*Voltage in V across 3N*) Returns a real or complex number, global name or algebraic.

I1: (*Line Current 1 in A*) Returns a real or complex number, global name or algebraic.

I2: (*Line Current 2 in A*) Returns a real or complex number, global name or algebraic.

I3: (*Line Current 3 in A*) Returns a real or complex number, global name or algebraic.

P: (*Phase Power in W*) Returns a real number, global name or algebraic.

W12: (*Wattmeter reading in W across lines 1 and 2*) Returns a real number.

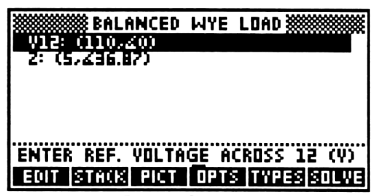
W13: (*Wattmeter reading in W across lines 1 and 3*) Returns a real number.

Example

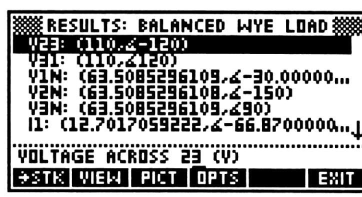
MODES				
(Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Polar	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

A Wye network consists of three impedances of (5,∡36.87) ohms each and is supplied by a reference voltage of (110,0) volts. Compute the line currents and the power dissipated in each leg of the network.

1. Enter (110,0) for **V12**.
2. Enter the value (5,∡36.87) for **Z**.
3. Press SOLVE to calculate the results, which will be displayed in the output screen.



Input Screen



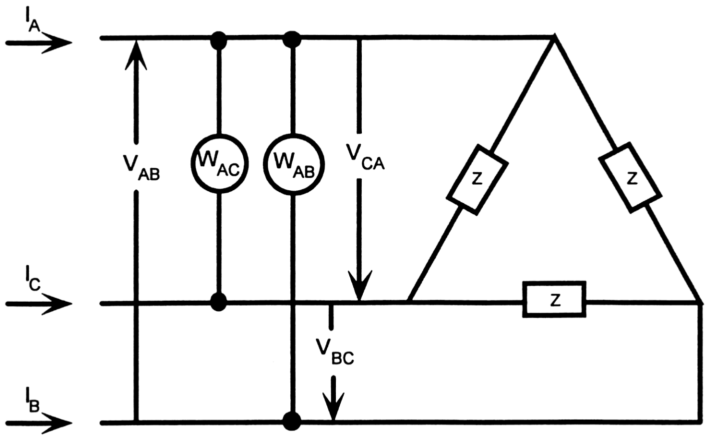
Output Screen

Balanced Δ Load

Analysis
  Polyphase Circuits
    Balanced Δ Load
Equations
Reference

In this section, three identical impedances **Z** are connected in a Δ configuration. The voltge **VAB** represents the line voltage from line A to line B which is the reference voltage applied to this Δ network. The voltages across lines B and

C, and C and A have the same magnitude as **VAB**, but are out of phase by -120° and 120° respectively. This section calculates the currents **IA, IB**, and **IC** in each leg of the Δ network, power dissipated in each phase **P**, and the readings in a two-wattmeter system of power measurement **WAB** and **WAC**.



Field Descriptions - Input Screen

VAB: (*Reference Voltage in V across lines 1 and 2*) Enter a real or complex number, global name, or algebraic.

Z: (*Phase Impedance in Ω*) Enter a real or complex number, global name, or algebraic.

Field Descriptions - Output Screen

VBC: (*Voltage in V across lines B and C*) Returns a real or complex number, global name or algebraic.

VCA: (*Voltage in V across lines C and A*) Returns a real or complex number, global name or algebraic.

IA: (*Line Current A in A*) Returns a real or complex number, global name or algebraic.

IB: (*Line Current B in A*) Returns a real or complex number, global name or algebraic.

IC: (*Line Current C in A*) Returns a real or complex number, global name or algebraic.

P: (*Phase Power in W*) Returns a real number, global name or algebraic.

WAB: (*Wattmeter reading in W across lines A and B*) Returns a real number.

WAC: (*Wattmeter reading in W across lines A and C*) Returns a real number.

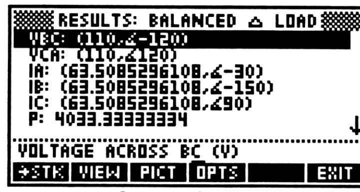
Example

MODES				
(Press CST)	**∡:** Degrees		**Result:**	Symbolic
	Coord:	Polar	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

A Δ network consists of three impedances of 3 ohms each and is supplied by a reference voltage of (110, 0) volts. Compute the line currents and the power dissipated in each leg of the network.

2. Enter (110, 0) for **VAB**.
1. Enter 3 for **Z**.
3. Press SOLVE to calculate the final results as shown in the output screen.

Input Screen



Output Screen

Chapter 5

Ladder Network

Analysis
Ladder Network
Equations
Reference

This chapter covers ladder network analysis: a circuit reduction method by which branches of the circuit are treated as rungs (series connection) or sides (parallel or shunt connection) of a ladder.

Using Ladder Network

> **NOTE**
>
> In a ladder network, the order in which you enter the elements is significant.

In the examples that follow, the left end of the ladder is the input end and the right end of the ladder is the output end, where the load is connected. The elements of the ladder (from 1 to N) are entered from right to left, as you go from output to input. The input impedance Zin is calculated as if you were "looking in" to the left end of the ladder.

Field Descriptions - Input Screen

Frequency: (*Frequency*) Enter a real number, global name, or algebraic.
Load: (*Initial Load*) Enter a real or complex number, global name, or algebraic.

1: (*Element 1 - closest to the load*)

...

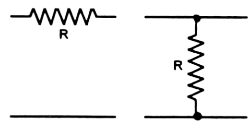
N: (*Element N - furthest from the load*)

Field Descriptions - Element Screen

Press **ADD** from the input screen to add one of the sixteen different element types.

Resistor

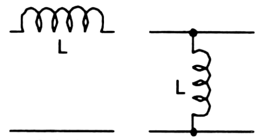
Can be added as a rung or side. Choose Series or Parallel for **Config** and enter a value for **R**.



Series R Parallel R

Inductor

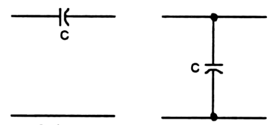
(ideal inductor) Can be added as a rung or side. Choose Series or Parallel for **Config** and enter a value for **L**.



Series L Parallel L

Capacitor

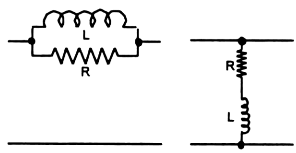
(ideal capacitor) Can be added as a rung or side. Choose Series or Parallel for **Config** and enter a value for **C**.



Series C Parallel C

RL

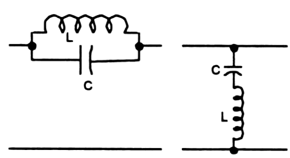
RL series circuit can be added as a rung. RL parallel circuit can be added as a side. Choose Series or Parallel for **Config** and enter a value for **R** and **L**.



Series RL Parallel RL

LC

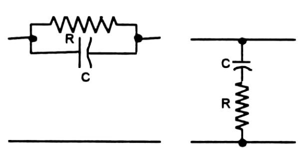
LC series circuit can be added as a rung. LC parallel circuit can be added as a side Choose Series or Parallel for **Config** and enter a value for **L** and **C**.



Series LC Parallel LC

RC

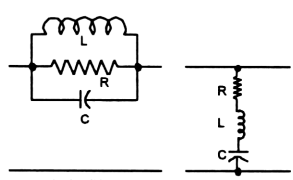
RC series circuit can be added as a rung. RC parallel circuit can be added as a side. Choose Series or Parallel for **Config** and enter a value for **R** and **C**.



Series RC Parallel RC

RLC

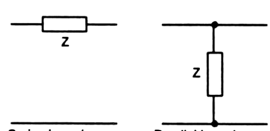
RLC series circuit can be added as a rung. RLC parallel circuit can be added as a side. Choose Series or Parallel for **Config** and enter a value for **R**, **L**, and **C**.



Series RLC Parallel RLC

General Impedance

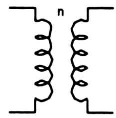
Can be added as a rung or a side. Choose Series or Parallel for **Config** and enter a value for **Z**.



Series Impedance Parallel Impedance

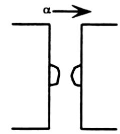
Transformer

(ideal transformer) Can be added only in cascade connection. Specify turns ratio, by entering a value for **N**.



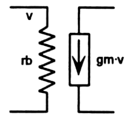
Gyrator

(synthetic inductance filer) Can be added only in cascade connection. Specify gyrator parameter by entering a value for α.



Voltage-Controlled I

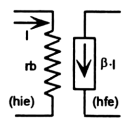
Can be added only in cascade connection. Specify base resistance and transconductance by entering values for **rb** and **gm**.



VCIS

Current-Controlled I

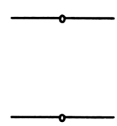
Can be added only in cascade connection. Specify base resistance and common base current gain by entering values for **rb** and β.



ICIS

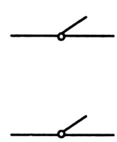
Transmission Line

Can be added only in cascade connection. Specify characteristic impedance and electrical length by entering values for **Z0** and **θ0**.



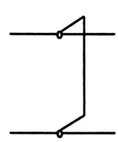
Open Circuited Stub

Can be added only in cascade connection. Specify characteristic impedance and electrical length by entering values for **Z0** and **θ0**.

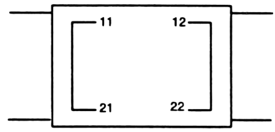


Short Circuited Stub

Can be added only in cascade connection. Specify characteristic impedance and electrical length by entering values for **Z0** and **θ0**.



Two-Port Network



Can be added only in cascade connection. Choose z, y, g, h, a, or b for Input Parameters, and enter values for **..11**, **..12**, **..21**, and **..22**.

Field Descriptions - Output Screen

Zin: (*Input Impedance*) Returns a real or complex number, global name or algebraic.

I2/V1: (*Forward Transfer Admittance*) Returns a real or complex number, global name or algebraic.

I2/I1: (*Current Transfer Ratio*) Returns a real or complex number, global name or algebraic.

Pout/Pin: (*Real Power Gain*) Returns a real or complex number, global name or algebraic.

V2/V1: (*Forward Voltage Transfer Ratio*) Returns a real or complex number, global name or algebraic.

V2/I1: (*Forward Transfer Impedance*) Returns a real or complex number, global name or algebraic.

To use Ladder Network:

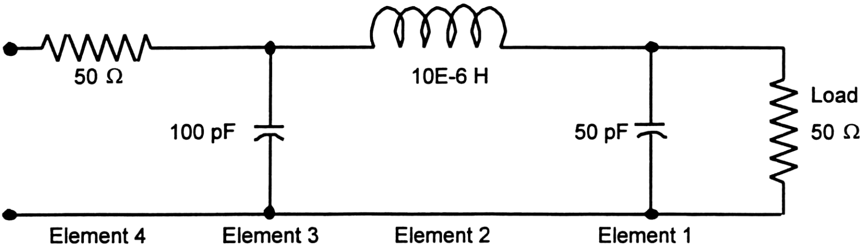
These are general instructions for entering the elements and computing the parameters of a ladder network.

1. Enter **Frequency** and **Load**.
2. Build the ladder by adding elements to it. Press ADD to insert an element on the line below the highlight bar.
3. Choose an element type and press ENTER or OK.
4. Enter the appropriate values.
5. Press OK to return to the Ladder Network screen.
6. Repeat steps 2-5 as needed to add more elements.
7. If you decide to delete an element, move the highlight bar to that element and press DEL.
8. Press SOLVE to compute the overall ladder network parameters.

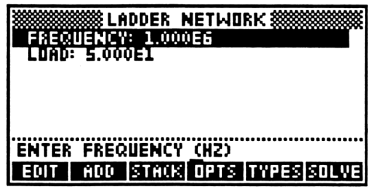
Example 1

MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Scientific	**Help:**	On
	Digits:	3	**Font:**	Small

What is the input impedance of the circuit shown below at 1 MHz and 10 MHz?

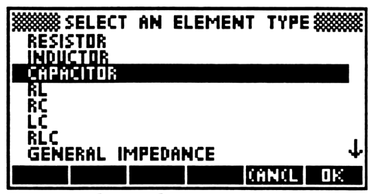


1. Enter 1E6 for **Frequency**.
2. Enter 50 for **Load**.
3. Press ADD to enter the first element.



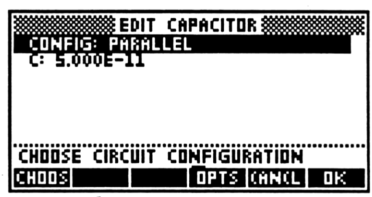
Input Screen

4. In the Select Element screen, move the highlight bar to **Capacitor** and press ENTER or OK to enter the Edit Capacitor screen.



Select Element Screen

5. In the Edit Capacitor screen, choose Parallel for **Config**.
6. Enter 50E-12 for **C**.
7. Press OK to return to the Ladder Network screen.
8. Move the highlight bar to **1: Capacitor** and press ADD to enter the second element.

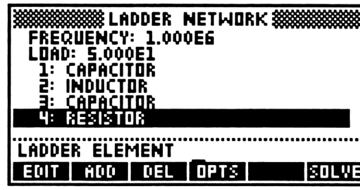


Edit Capacitor Screen

> **NOTE**
>
> The ADD key adds a new element on the line *below* the highlight bar, so make sure the highlight bar is on the last element entered (in this case, **1: Capacitor**) before adding the second element.

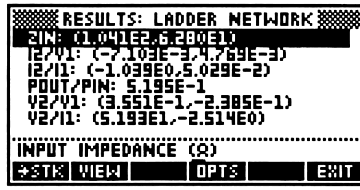
9. Move the highlight bar to **Inductor** and press ENTER or OK to enter the Edit Inductor screen.
10. Choose Series for **Config**
11. Enter 10E-6 for **L**.

12. Press **OK** to return to the original screen.
13. Enter the remaining two elements in the same manner as the first two: a 100pF (100E-12) capacitor in parallel and a 50 ohm resistor in series.



Input Screen (completed)

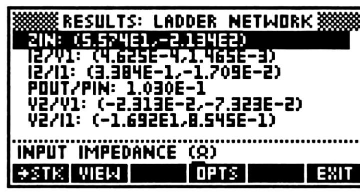
13. Press **SOLVE** to calculate the results, which will be displayed in the output screen.



Output Screen (1 MHz)

To find the ladder network parameters at a second frequency of 10 MHz:

1. Press ◄ to return to the input screen.
2. In the **Frequency** field, type 10E6.
3. Press **SOLVE** to calculated the results, which will be displayed in the output screen.

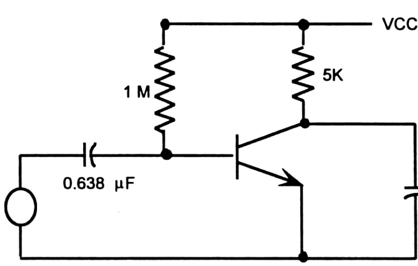


Output Screen (10 MHz)

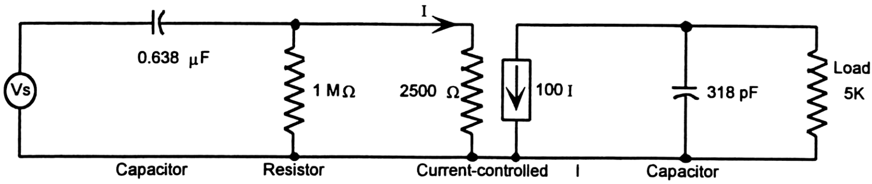
Example 2

MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Scientific	**Help:**	On
	Digits:	3	**Font:**	Small

A transistor amplifier is shown in the figure below. The transistor is characterized by a base resistance of 2500 ohms, a current gain of 100 and is operating at a frequency of 10,000 Hertz.

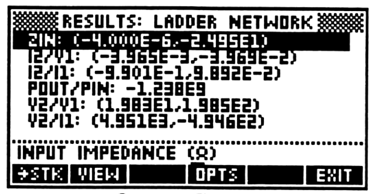


This schematic can be reduced to the ladder network that appears on the next page.



1. Enter the frequency and load values:
   Frequency: 10,000 Hz
   Load: 5000 ohms
2. Enter the ladder elements in the following order:
   1: Capacitor: Parallel, 318E-12
   2: Current-Controlled I: Enter 2500 for **RB** and 100 for **β**
   3: Resistor: Parallel, 1E6
   4: Capacitor: Series, 0.638E-6
3. Press SOLVE to compute the results, which will be displayed in the output screen.

Input Screen



Output Screen

Chapter 6

Filter Design

Analysis
 Filter Design
Equations
Reference

This chapter covers the basic design principles for three commonly-used filters:

- ❑ Chebyshev Filter
- ❑ Butterworth Filter
- ❑ Active Filter

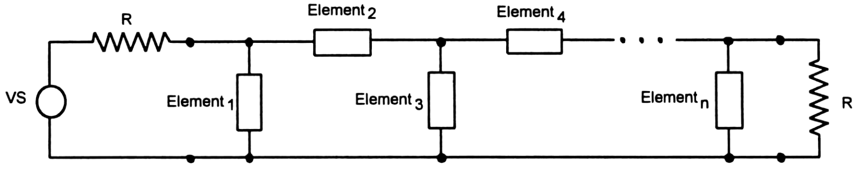
Chebyshev Filter

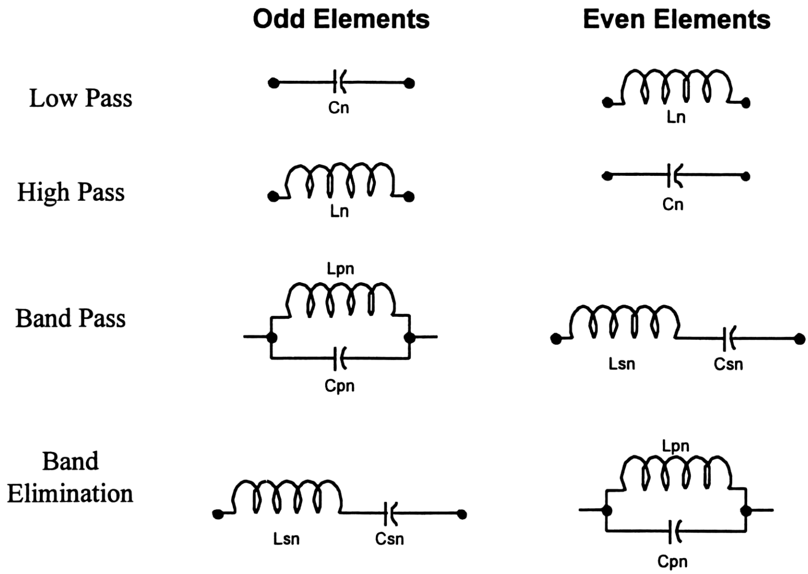
Analysis
 Filter Design
  Chebyshev Filter
Equations
Reference

This section computes component values for Chebyshev filters between equal terminations. Inputs are termination resistance, pass band characteristics, attenuation at some out-of-band frequency, and allowable passband ripple. The Chebyshev circuit elements are assumed to be ideal, and are illustrated below.

NOTE

The order of the Chebyshev filter module is reported only in odd numbers. If the result is computed to be an even number, it will be incremented to the next higher odd number.





Field Descriptions - Input Screen

Char: (*Bandpass Characteristic*) Press CHOOS to select Low Pass, High Pass, Band Pass, or Band Elimination.

R: (*Termination Resistance in Ohms*) Enter a real number, global name or algebraic.

f0: (*Cutoff Frequency in Hz - for Low Pass and High Pass*) Enter a real number.

(*Center Frequency in Hz - for Band Pass and Band Elimination*) Enter a real number.

f1: (*Attenuation Frequency in Hz*) Enter a real number.

ΔdB: (*Attenuation in dB*) Enter a real number.

Bandwidth: (*Bandwidth in Hz - only appears for Band Pass or Band Elimination*) Enter a real number.

Ripple: (*Pass Band Ripple in dB*) Enter a real number.

Field Descriptions - Output Screen

Element1: (*First element in parallel*) Returns a real number.

Element2: (*Second element in series*) Returns a real number.

Element3: (*Third element in parallel*) Returns a real number.

Element4: (*Fourth element in series*) Returns a real number.

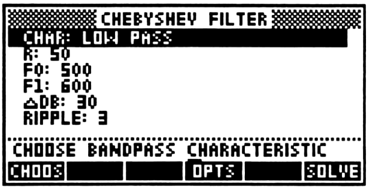
ElementN: (*nth element in series because N is always odd*) Returns a real number.

Example

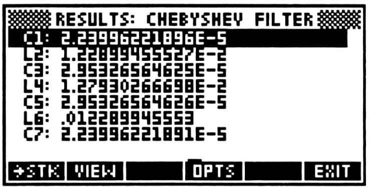
MODES				
(Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Design a low-pass Chebyshev filter with a cutoff at 500 Hz, a termination resistance of 50 ohm, 3 dB pass band ripple, and a 30 dB attenuation at 600 Hz.

1. Enter 50 for **R**, 500 for **f0**, and 600 for **f1**.
2. Enter 30 for **ΔdB** and 3 for **Ripple**.
3. Press SOLVE to calculate the results, which will be displayed in the output screen.



Input Screen

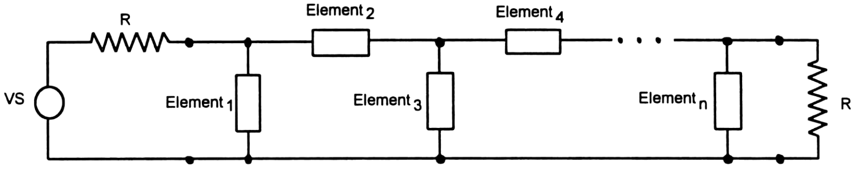


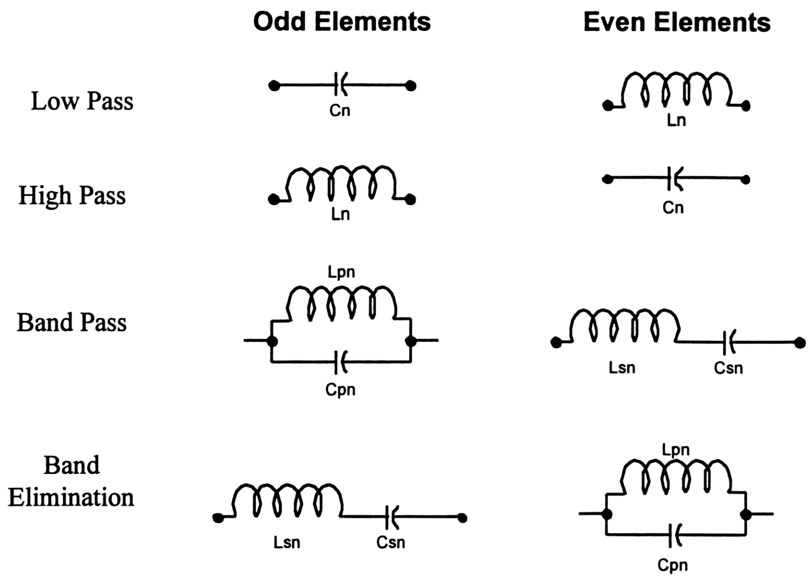
Output Screen

Butterworth Filter

Analysis
Filter Design
Butterworth Filter
Equations
Reference

This section computes the component values for Butterworth filters between equal terminations. Inputs are termination resistance, pass band characteristics, and attenuation at some out-of-band frequency. The basic form of the filter is shown in the figures below:





Field Descriptions - Input Screen

Char: (*Bandpass Characteristic*) Press CHOOS to select Low Pass, High Pass, Band Pass, or Band Elimination.

R: (*Termination Resistance in Ohms*) Enter a real number.

f0: (*Cutoff Frequency in Hz - for Low Pass and High Pass*) Enter a real number.

(*Center Frequency in Hz - for Band Pass and Band Elimination*) Enter a real number.

f1: (*Attenuation Frequency in Hz*) Enter a real number.

ΔdB: (*Attenuation in DB*) Enter a real number.

Bandwidth: (*Bandwidth in Hz - for Band Pass or Band Elimination*) Enter a real number.

Field Descriptions - Output Screen

Element1: (*First element in parallel*) Returns a real number.

Element2: (*Second element in series*) Returns a real number.

Element3: (*Third element in parallel*) Returns a real number.

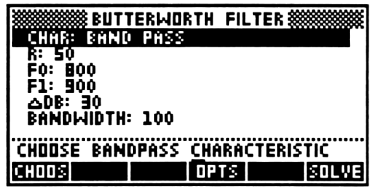
Element4: (*Fourth element in series*) Returns a real number.

ElementN: (*nth element in series (if n is odd) or parallel (if n is even)*) Returns a real number.

Example

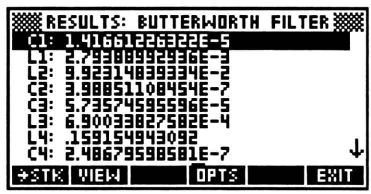
MODES (Press CST)				
	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

Design a 100 Hz wide Butterworth band pass filter centered at 800 Hz with a 30 dB attenuation at 900 Hz. The termination resistance is 50 ohms. The source resistance is also 50 ohms.



Input Screen

1. Choose Band Pass for **Char**.
2. Enter 50 for **R** and 800 for **f0**, and 900 for **f1**.
3. Enter 30 for **ΔdB** and 100 for **Bandwidth**.
4. Press SOLVE to calculate the results, which will be displayed in the output screen.



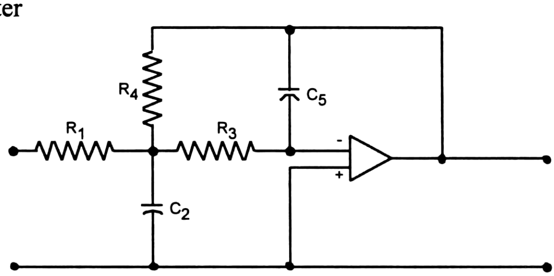
Output Screen

Active Filter

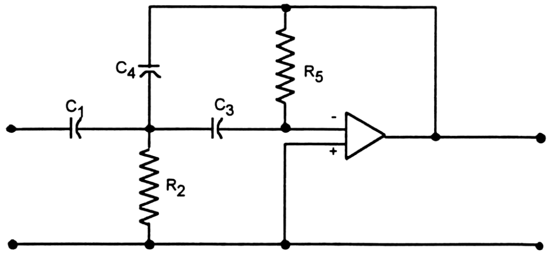
Analysis
Filter Design
Active Filter
Equations
Reference

This section computes element values for the standard active filter circuits shown below. In each case, five different elements are calculated.

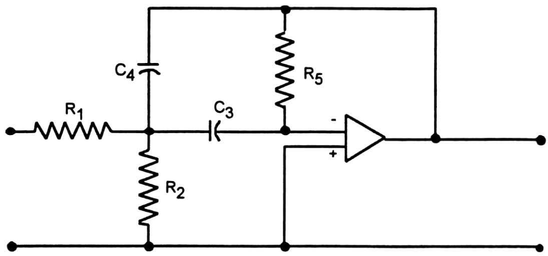
Low Pass Filter



High Pass Filter



Band Pass Filter



Field Descriptions - Input Screen

Type: (*Filter Type*) Press CHOOS to select Low Pass, High Pass, or Band Pass.

f0: (*Band Cutoff in Hz*) Enter a real number, global name, or algebraic.

A: (*Midband Gain in dB*) Enter a real number, global name, or algebraic.

Q: (*Quality Factor:* $Q = \frac{1}{\alpha} = \frac{1}{2\zeta}$ *where* α *is peaking factor and* ζ *is damping factor*) Enter a real number, global name, or algebraic.

C: (*Capacitor in F*) Enter a real number, global name, or algebraic.

Field Descriptions - Output Screen

Element1: (*First element*) Returns a real number.

Element2: (*Second element*) Returns a real number.

Element3: (*Third element*) Returns a real number.

Element4: (*Fourth element*) Returns a real number.

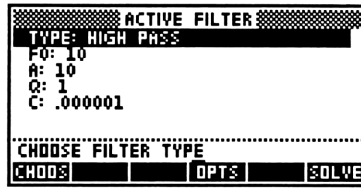
Element5: (*Fifth element*) Returns a real number.

Example

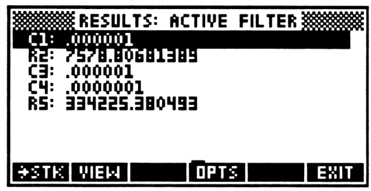
MODES	∡:	Degrees	Result:	Symbolic
(Press CST)	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

Design a High Pass active filter with a cutoff at 10 Hz, a midband gain of 10, a quality factor of 1 and a capacitor of 1 μF.

1. Choose High Pass for **Type**.
2. Enter 10 for **f0** and 10 for **A**.
3. Enter 1 for **Q** and 1E-6 for **C**.
4. Press SOLVE to calculate the results, which will be displayed in the output screen.



Input Screen



Output Screen

Chapter 7

Gain and Frequency

Analysis   ***Gain and Frequency*** Equations Reference

This chapter covers the basic principles of circuit analysis involving a transfer function model and plots the resulting equations using the classic graphical representation referred to as Bode plots for gain or phase:

- ❑ Transfer Function
- ❑ Bode Plots

Transfer Function

Analysis
  Gain and Frequency
    Transfer Function
Equations
Reference

A transfer function is defined as the ratio of an output to its input signal and is generally modified by the network between the two. In the classic sense, the transfer function is dependent upon the output and input definitions and is represented by a ratio of two polynomials of s. The roots of the numerator and denominator polynomials are referred to as *zeros* and *poles*, respectively. Transfer functions can be defined by the poles and zeros or by the coefficients of the numerator and denominator polynomials. The results computed include symbolic expressions for the transfer function and its partial fraction expansion.

Field Descriptions

Inputs: (*Type of Input*) Press CHOOS to select Roots or Coefficients. Determines whether the third and fourth fields are **Zeros** and **Poles** or **Numer** and **Denom**.

Constant: (*Constant Multiplier*) Enter a real number. Default is 1.

Zeros: (*Numerator Roots - if Roots chosen for input type*) Enter an array or list of real or complex numbers. The number of zeros must be less than the number of poles.

Poles: (*Denominator Roots - if Roots chosen for input type*) Enter an array or list of real or complex numbers. The number of poles must be greater than the number of zeros.

Numer: (*Numerator Coefficients - if Coefficients chosen for input type*) Enter an array or list of real or complex numbers. The number of numerator coefficients must be less than the number of denominator coefficients.

Denom: (*Denominator Coefficients - if Coefficients chosen for input type*) Enter an array or list of real or complex numbers. The number of denominator coefficients must be greater than the number of numerator coefficients.

H(s): (*Transfer Function*) Returns a symbolic expression of the form

$$\frac{K\cdot(1-s/z_1)(1-s/z_2)\ldots}{(1-s/p_1)(1-s/p_2)\ldots}$$

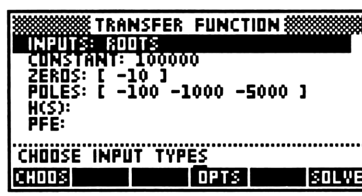
PFE: (*Partial Fraction Expansion*) Returns a symbolic expression of the form

$$\frac{K_1}{1-s/p_1}+\frac{K_2}{1-s/p_2}+\ldots$$

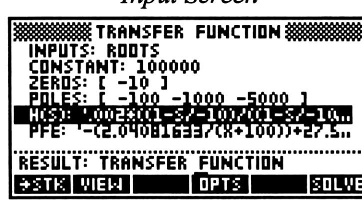
Example

MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Find the transfer function and its partial fraction expansion for a circuit with a zero located at -10 r/s and three poles located at -100 r/s, -1000 r/s and -5000 r/s. Assume that the multiplier constant is 100000.



Input Screen



Output Screen

1. Choose Roots for **Inputs**.
2. Enter 100000 for **Constant**, [-10] for **Zeros**, and [-100 -1000 -5000] for **Poles**.
3. Press SOLVE to calculate **H(s)** and **PFE**.
4. To use this transfer function in the next example, "Bode Gain and Phase Plot," move the highlight bar to the **H(s)** field and press →STK. This will place the transfer function on the first level of the stack so that you can use it in the next example. At the message screen "Copy to Stack...", press ONE.

5. Now you are ready to go on to the next example. Press [◄] to return to the Gain and Frequency screen and choose Bode Plots. The next example is on page 51.

Analysis
  Gain and Frequency
    Bode Plots
Equations
Reference

Bode Plots

The behavior of the transfer function, as the frequency of a sinusoidal source varies, is of great interest to engineers. A very effective way to grasp the relationship between transfer function and frequency is to plot the magnitude and argument of the transfer function on two separate graphs. These plots are often called Bode gain and phase plots. A gain plot shows the magnitude of the transfer function expressed in decibels (dB) as 20*LOG(Magnitude of Transfer Function) as a function of the logarithm of the radian frequency on the horizontal scale. The phase plot shows the argument of the transfer function expressed as the phase angle (i.e., ARG(Transfer Function)) plotted as a function of the logarithm of the radian frequency on the horizontal scale.

Field Descriptions

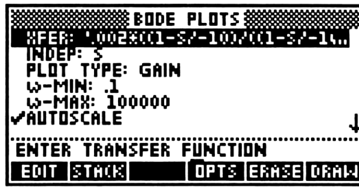
Xfer: (*Transfer Function*) Enter a symbolic expression.
Indep: (*Independent Variable*) Enter a global name. Default is 's'.
Plot Type: (*Bode Gain or Bode Phase*) Press CHOOS to select Gain or Phase. Determines whether the y axis range fields appear as **A-Min** and **A-Max** (for Gain) or **θ-Min** and **θ-Max** (for Phase).
ω-Min: (*Minimum Frequency in r/s - X axis*) Enter a real number.
ω-Max: (*Maximum Frequency in r/s - X axis*) Enter a real number.
Autoscale: (*Scales the plot - hides A-min and A-max fields*) Press ✓CHK to select.
A-Min: (*Minimum amplitude in dB (Y axis) - if Gain is chosen for* **Plot Type**) Enter a real number.
A-Max: (*Maximum amplitude in dB (Y axis) - if Gain is chosen for* **Plot Type**) Enter a real number.
θ-Min: (*Minimum amplitude in dB (Y axis) - if Phase is chosen for* **Plot Type**) Enter a real number, which will be interpreted as degrees or radians, depending on the current setting in the Custom Settings screen.
θ-Max: (*Maximum amplitude in dB (Y axis) - if Phase is chosen for* **Plot Type**) Enter a real number, which will be interpreted as degrees or radians, depending on the current setting in the Custom Settings screen.
Label Plot: (*Labels X and Y axes*) Press ✓CHK to label the plot.

Example

MODES (Press CST)				
	∡:	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

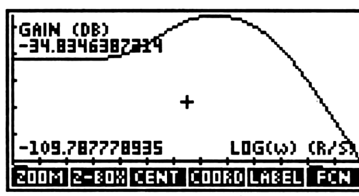
Plot the gain and phase plots for the transfer function example on page 49.

Plot the Bode gain plot



Input Screen

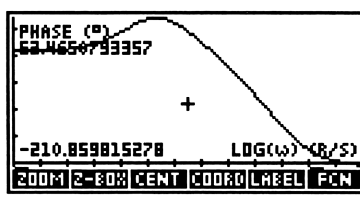
1. Complete the entire example for the transfer function on page 49.
2. In the Bode Plots screen, move the highlight bar to the **Xfer** field and press STACK. The **H(s)** field result from the transfer function example will be on the first level of the stack. Press OK to copy it into the Bode Plots screen in the **Xfer** field.
3. Choose **s** for **Indep**. (The default is **s** and should rarely be changed, because the Transfer Functions screen always generates transfer functions as functions of lowercase **s**.)
4. Choose Gain for **Plot Type**.
5. Enter 0.1 for **ω-Min** as the start of the radian frequency plot.
6. Enter 100000 for **ω-Max** as the endpoint of the radian frequency plot.
7. Put a checkmark in the **Autoscale** field. Press ✓CHK if necessary.
8. Put a checkmark in the **Label Plot** field. Press ✓CHK if necessary.
9. Press ERASE to clear previous plots.
10. Press DRAW to plot the function.



Output Screen - Bode gain plot

Plot the Bode phase plot

1. Press ON to return to the input screen.
2. Choose Phase for **Plot Type**.
3. Press ERASE to erase previous plot.
4. Press DRAW to plot the function.



Output Screen - Bode phase plot

> **NOTE**
>
> This example is shown in degrees. If your HP 48 is set to radians, it will scale the vertical axis in radians.

Chapter 8

Fourier Transforms

Analysis
    Fourier Transforms
Equations
Reference

This chapter covers discrete "Fast" Fourier transforms:

- ❑ FFT
- ❑ Inverse FFT

FFT

Analysis
    Fourier Transforms
        FFT
Equations
Reference

A physical process can be monitored in two significantly different ways. First, the process can be monitored in time domain in analog or digital form. Second, the data can be collected in the frequency domain in analog or digital form. In a variety of measurement and digital storage devices, data is gathered at regular, discrete time intervals. This data can be converted to its equivalent set in the frequency domain by the use of the so-called FFT algorithm. This algorithm maps a data array of N items to the corresponding array in the frequency domain using the following equation.

$$H_k = \sum_{n=0}^{N-1} h_n \cdot e^{-2\pi j \cdot k \cdot n/N}$$

where $\mathbf{h_n}$ is the nth element in the time domain and $\mathbf{H_k}$ is the kth element in the frequency domain. The FFT algorithm treats the data block provided as though it is one of a periodic sequence. If the underlying data is not periodic, the resulting FFT-created wave is subject to substantial harmonic distortion. This section does not pad the input array with 0's when the number of data points is not a power of 2.

Field Descriptions

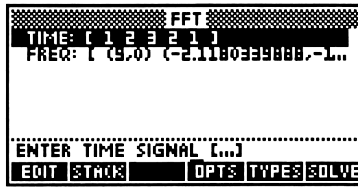
Time: (*Time Signal*) Enter an array or list of real or complex numbers.
Freq: (*Frequency Spectrum*) Returns spectral coefficients.

Example

MODES (Press CST)	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

Find spectral coefficients for the periodic time signal [1 2 3 2 1].

1. Enter [1 2 3 2 1] for **Time**.
2. Press SOLVE to calculate **Freq**.



Output Screen

Analysis
 Fourier Transforms
  Inverse FFT
Equations
Reference

Inverse FFT

This section focuses on transforming data from the frequency domain to the time domain. The inverse transform algorithm uses the relationship displayed here, where $\mathbf{H_k}$ is the kth element in the frequency domain and $\mathbf{h_n}$ is the nth element in the time domain.

$$h_n = \frac{1}{N}\sum_{k=0}^{N-1} H_k \cdot e^{2\pi j \cdot k \cdot n/N}$$

Field Descriptions

Freq: (*Frequency Spectrum*) Enter an array or list of real or complex numbers.

Time: (*Time Signal*) Returns time signal.

Example

MODES (Press CST)	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

Given [1 2 3 4] as coefficients, find the original time signal.

1. Enter [1 2 3 4] for **Freq**.
2. Press SOLVE to calculate **Time**.

Output Screen

Chapter 9

Two-Port Networks

Analysis
Two-Port Networks
Equations
Reference

This chapter covers the basic principles of two-port network analysis:

- ❏ Parameter Conversion
- ❏ Circuit Performance
- ❏ Interconnected Two-Ports

Parameter Conversion

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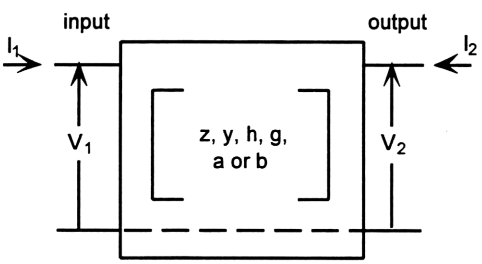
Many electrical or electronic circuits are modelled as two-port networks with four variables, namely input voltage $\mathbf{V_1}$, input current $\mathbf{I_1}$, output voltage $\mathbf{V_2}$, and output current $\mathbf{I_2}$. In broad terms, a two-port network is a black-box approach to solving simple to sophisticated problems of electical and electronic circuits. The figure below shows a schematic representation of a two-port network where all four variables are identified.



For instance, a two-port characterized by **z** parameters is defined by the following pair of equations:

$$V_1 = I_1 \cdot Z_{11} + I_2 \cdot Z_{12}$$
$$V_2 = I_1 \cdot Z_{21} + I_2 \cdot Z_{22}$$

The four components of **z** parameters are defined as follows:

$Z_{11} = V_1/I_1$ with $I_2 = 0$ $Z_{21} = V_2/I_1$ with $I_2 = 0$
$Z_{12} = V_1/I_2$ with $I_1 = 0$ $Z_{22} = V_2/I_2$ with $I_1 = 0$

The table below lists the choices for the independent variables for two-port circuits, followed by the dependent variables and parameters associated with each set of independent variables. This section allows you to convert two-port parameters from one type to another.

Independent Variables	Dependent Variables	Two-Port Parameter Type
I_1, I_2	V_1, V_2	z
V_1, V_2	I_1, I_2	y
I_1, V_2	V_1, I_2	h
I_2, V_1	I_1, V_2	g
V_2, I_2	V_1, I_1	b
V_1, I_1	V_2, I_2	a

Field Descriptions - Input Screen

Input Type: Press CHOOS to select **z**, **y**, **h**, **g**, **a**, or **b**.
..11: Enter a real or complex number, global name, or algebraic.
..12: Enter a real or complex number, global name, or algebraic.
..21: Enter a real or complex number, global name, or algebraic.
..22: Enter a real or complex number, global name, or algebraic.
Output Type: Press CHOOS to select **z**, **y**, **h**, **g**, **a**, or **b**.

Note: The help text (e.g., "Enter P1 Impedance V1/I1 (I2=0)") shows whether the ratio is an impedance, admittance or dimensionless ratio; which port is being described; and whether it is the current or the voltage that is open.

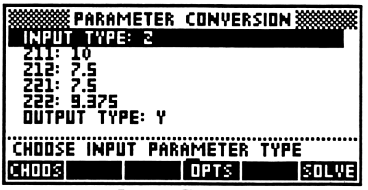
Field Descriptions - Output Screen

..11: Returns a real or complex number, global name, or algebraic.
..12: Returns a real or complex number, global name, or algebraic.
..21: Returns a real or complex number, global name, or algebraic.
..22: Returns a real or complex number, global name, or algebraic.

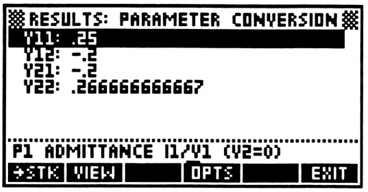
Example

MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Convert a resistive two-port network with $z_{11} = 10$, $z_{12} = 7.5$, $z_{21} = 7.5$, $z_{22} = 9.375$ into its equivalent y values.



Input Screen



Output Screen

1. Choose z for **Input Type**.
2. Enter 10 for **z11**, 7.5 for **z12**, 7.5 for **z21**, and 9.375 for **z22**.
3. Choose y for **Output Type**.
4. Press SOLVE to calculate the results which will be displayed in the output screen.

Circuit Performance

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Two-Port Networks
Circuit Performance
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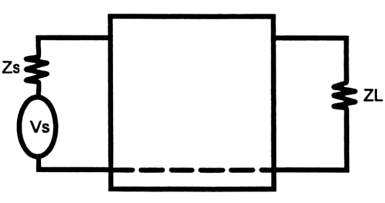
This section computes the circuit performance of a two-port network. For example, given a voltage source of a finite impedance with a finite load, this section will computes the input and output impedances, current and voltage gain, voltage gain to source, current gain to source, power gain, power available at the load, maximum power available at the load, and load impedance for maximum power deliverable to the load.

Field Descriptions - Input Screen

Parameter Type: Press CHOOS to select **z**, **y**, **h**, **g**, **a**, or **b**.
..11: Enter a real or complex number, global name, or algebraic.
..12: Enter a real or complex number, global name, or algebraic.
..21: Enter a real or complex number, global name, or algebraic.
..22: Enter a real or complex number, global name, or algebraic.

Note: The help text (e.g., "Enter P1 Impedance V1/I1 (I2=0)") shows whether the ratio is an impedance, admittance or dimensionless ratio; which port is being described; and whether it is the current or the voltage that is open.

Vs: (*Source Voltage in V*) Enter a real or complex number, global name, or algebraic.



Zs: (*Source Impedance in Ω*) Enter a real or complex number, global name, or algebraic.

ZL: (*Load Impedance in Ω*) Enter a real or complex number, global name, or algebraic.

Field Descriptions - Output Screen

Zin: (*Input Impedance*) Returns a real or complex number, global name, or algebraic.

Iout: (*Output Current*) Returns a real or complex number, global name, or algebraic.

Vout: (*Thevenin Voltage*) Returns a real or complex number, global name, or algebraic.

Zout: (*Thevenin Impedance*) Returns a real or complex number, global name, or algebraic.

I2/I1: (*Current Gain*) Returns a real or complex number, global name, or algebraic.

V2/V1: (*Voltage Gain*) Returns a real or complex number, global name, or algebraic.

V2/Vs: (*Absolute Voltage Gain*) Returns a real or complex number, global name, or algebraic.

GP: (*Power Gain*) Returns a real or complex number, global name, or algebraic.

Pav: (*Average Power*) Returns a real or complex number, global name, or algebraic.

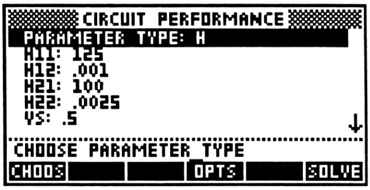
Pmax: (*Maximum Power at ZLopt*) Returns a real or complex number, global name, or algebraic.

ZLopt: (*Optimum Load Impedance*) Returns a real or complex number, global name, or algebraic.

Example

MODES (Press [CST])	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

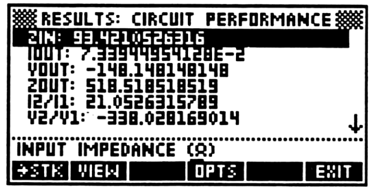
Find the circuit performance for a transistor amplifier given the following conditions: h_{11} = 125, h_{12} = .001, h_{21} = 100, h_{22} = .0025, source voltage Vs = 0.50, source impedance Zs = 50, and load impedance Zl = 1500.



Input Screen

1. Choose **h** for **Parameter**.

2. Enter 125 for **h11**, .001 for **h12**, 100 for **h21**, and .0025 for **h22**.
3. Enter 0.5 for **Vs**, 50 for **Zs** and 1500 for **ZL**.
4. Press SOLVE to calculate the results, which will be displayed in the output screen.



Output Screen

Interconnected Two-Ports

Analysis
  Two-Port Networks
    Interconnected Two-Ports
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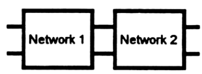
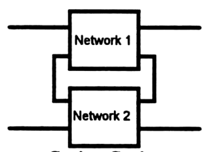
Two-port networks constitute basic building blocks of linear electrical/electronic systems. In the design of large, complex systems, it is easier to synthesize the system by first designing subsections. Usually, a large and complex system can be built using simpler two-port building blocks. The two-port subsections can be interconnected in five ways:

- **Cascade:** The output of network 1 is connected directly to the input of network 2.



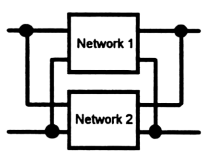
Cascade

- **Series-Series:** The inputs and outputs of the two networks are both connected in series.



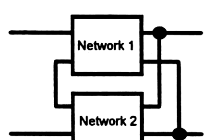
Series-Series

- **Parallel-Parallel:** The inputs and outputs of the two networks are both connected in parallel.



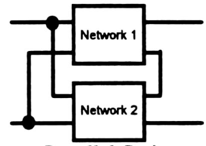
Parallel-Parallel

- **Series-Parallel:** The inputs of the two networks are connected in series, while the outputs are connected in parallel.



Series-Parallel

- **Parallel-Series:** The inputs of the two networks are connected in parallel, while the outputs are connected in series.



Parallel-Series

> **NOTE**
>
> When using this section, the user needs to pay particular attention to the two-ports being interconnected in non-cascaded modes. Natural laws can be violated when the two-port network contains dependent voltage or current sources and the so-called Brune's test has to be satisfied. EE•*Pro* does *not* check for Brune's test.

This section accepts parameters for either network as **z**, **y**, **h**, **g**, **a**, or **b** and yields the output in any form based on the choice made.

Field Descriptions - Input Screen

Connection: (*Type of Connection*) Press CHOOS to select Cascade, Series Series, Parallel Parallel, Series Parallel, or Parallel Series.
First Input Type: Press CHOOS to select **z**, **y**, **h**, **g**, **a**, or **b**.
..111: Enter a real or complex number, global name, or algebraic.
..112: Enter a real or complex number, global name, or algebraic.
..121: Enter a real or complex number, global name, or algebraic.
..122: Enter a real or complex number, global name, or algebraic.
Second Input Type: Press CHOOS to select **z**, **y**, **h**, **g**, **a**, or **b**.
..211: Enter a real or complex number, global name, or algebraic.
..212: Enter a real or complex number, global name, or algebraic.
..221: Enter a real or complex number, global name, or algebraic.
..222: Enter a real or complex number, global name, or algebraic.
Output Type: Press CHOOS to select **z**, **y**, **h**, **g**, **a**, or **b**.

Note: The help text (e.g., "Enter P1 Impedance V1/I1 (I2=0)") shows whether the ratio is an impedance, admittance or dimensionless ratio; which port is being described; and whether it is the current or the voltage that is open.

Field Descriptions - Output Screen

..11: Returns a real or complex number, global name, or algebraic.
..12: Returns a real or complex number, global name, or algebraic.
..21: Returns a real or complex number, global name, or algebraic.

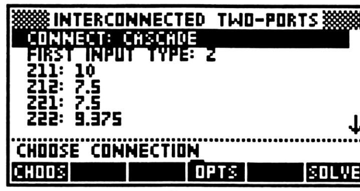
..22: Returns a real or complex number, global name, or algebraic.

Example

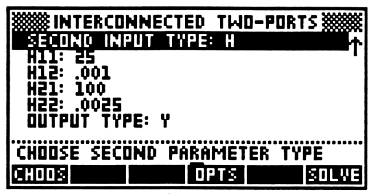
MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

The 2 two-port networks in the two previous examples ("Parameter Conversion," page 55, and "Circuit Performance," page 57) were described in terms of their **z** and **h** parameters. If the two-ports are connected in a cascade configuration, compute the y parameters for the resulting equivalent two-port.

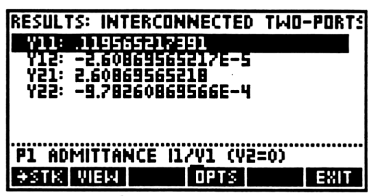
1. Choose Cascade for **Connection**.
2. Choose **z** for **First Input Type**.
3. Enter 10 for **z11**, 7.5 for **z12**, 7.5 for **z21**, and 9.375 for **z22**.
4. Choose **h** for **Second Input Type**.
5. Enter 25 for **h11**, .001 for **h12**, 100 for **h21**, and .0025 for **h22**.
6. Choose y for **Output Type**.
7. Press SOLVE to calculate the results, which will be displayed in the output screen..



Input Screen - Z



Input Screen - H



Output Screen

Chapter 10

Transformer Performance

Analysis
Transformer Performance
Equations
Reference

This chapter covers important power transformer principles: The open and short circuit tests, and chain parameters, which form the basis of a two-port network approach to evaluating transformer performance:

- ❑ Open Circuit Test
- ❑ Short Circuit Test
- ❑ Chain Parameters

Open Circuit Test

Analysis
Transformer Performance
Open Circuit Test
Equations
Reference

The open circuit test described in this section is performed at rated values of primary or secondary windings. It is assumed that the voltage is applied to the primary windings. The primary voltage, current, and power determine the core parameters of the transformer.

Field Descriptions - Input Screen

V1: (*Primary RMS Voltage in V*) Enter a real number, global name, or algebraic.

V2: (*Secondary RMS Voltage in V*) Enter a real number, global name, or algebraic.

I1: (*Primary RMS Current in A*) Enter a real number, global name, or algebraic.

P1: (*Primary Real Power in W*) Enter a real number, global name, or algebraic.

Field Descriptions - Output Screen

n: (Primary to secondary *turns ratio*) Returns a real number, global name, or algebraic.

Q1: (*Reactive* power *in W*) Returns a real number, global name, or algebraic.

Gc: (Primary *core conductance in S*) Returns a real number, global name, or algebraic.

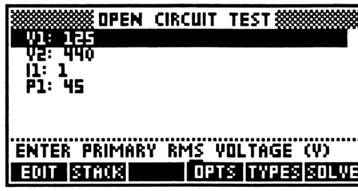
Bc: (Primary *core susceptance in S*) Returns a real number, global name, or algebraic.

Example

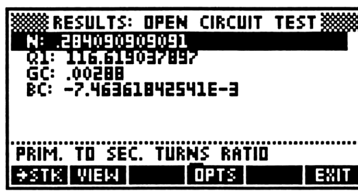
MODES (Press CST)				
	∡: Degrees		**Result:** Symbolic	
	Coord: Rectangular		**Units:** On or Off	
	Format: Standard		**Help:** On	
	Digits: N/A		**Font:** Small	

Perform an open circuit test on the primary side of a transformer using the following data: The input to primary is 125 volts, with an open circuit current of 1 ampere and a power input of 45 watts. The secondary open circuit voltage is 440 volts. Find the circuit parameters of the transformer.

1. Enter the values 125 for **V1** and 440 for **V2**.
2. Enter 1 for **I1** and 45 for **P1**.
3. Press SOLVE to calculate the results, which will be displayed in the output screen.



Input Screen



Output Screen

Short Circuit Test

Analysis
  Transformer Performance
    Short Circuit Test
Equations
Reference

Short circuit tests are often used to determine winding impedances of a transformer and are conducted at rated values. The test consists of placing a short circuit on the secondary windings and measuring primary and secondary currents, and power supplied to the transformer. The calculated circuit parameters (i.e., resistance and reactance of primary and secondary coils) are based on the assumption that the heat dissipation in the primary and secondary windings are equal.

Field Descriptions - Input Screen

V1: (*Primary RMS Voltage in V*) Enter a real number, global name, or algebraic.

I2: (*Secondary RMS Current in A*) Enter a real number, global name, or algebraic.

P1: (*Primary Real Power in W*) Enter a real number, global name, or algebraic.

kVA: (*kVA rating in kVA*) Enter a real number, global name, or algebraic.

V1R: (*Primary Voltage Rating in V*) Enter a real number, global name, or algebraic.

Field Descriptions - Output Screen

n: (*Primary to secondary* turns *ratio*) Returns a real number, global name, or algebraic.

Q1: (*Primary Reactive Power in W*) Returns a real number, global name, or algebraic.

R1: (*Primary Resistance in Ω*) Returns a real number, global name, or algebraic.

R2: (*Secondary Resistance in Ω*) Returns a real number, global name, or algebraic.

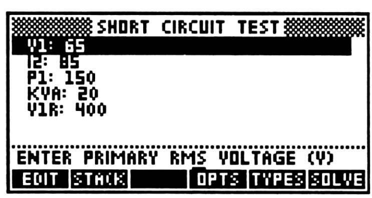
X1: (*Primary Reactance in Ω*) Returns a real number, global name, or algebraic.

X2: (*Secondary Reactance in Ω*) Returns a real number, global name, or algebraic.

Example

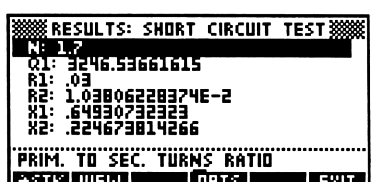
MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

A transformer rated at 20 kVA and 400 volts is subjected to a short circuit test. The measured current in the secondary is 85 amperes. A primary voltage of 65 volts and a power of 150 watts are applied to obtain this current in the secondary. Find the transformer parameter.



Input Screen

1. Enter the values 65 for **V1**, 85 for **I2**, and 150 for **P1**.
2. Enter 20 for **kVA** and 400 for **V1R**.
3. Press SOLVE to calculate the results, which will be displayed in the output screen.



Output Screen

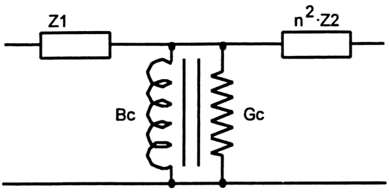
Chain Parameters

Analysis
Transformer Performance
Chain Parameters
Equations
Reference

Chain parameters (or the so-called ABCD parameters) are convenient problem-solving tools used in solving transmission and distribution problems. The parameters are expressed essentially as two-port type parameters by the use of the following pair of linear equations:

$Vin = A \cdot Vout - B \cdot Iout$

$Iin = C \cdot Vout - D \cdot Iout$



where Vin and Iin are input voltage and current, and Vout and Iout are output voltage and current. (All quantities in the diagram refer to the primary winding.) This approach is useful as cascaded tranformers follow two-port rules.

Field Descriptions - Input Screen

Z1: (*Primary impedance in Ω*) Enter a real or complex number, global name, or algebraic.

Z2: (*Secondary impedance in Ω*) Enter a real or complex number, global name, or algebraic.

n: (*Primary to secondary turns ratio*) Returns a real number, global name, or algebraic.

Gc: (*Primary core conductance in S*) Enter a real number, global name, or algebraic.

Bc: (*Primary core susceptance in S*) Enter a real number, global name, or algebraic.

Field Descriptions - Output Screen

A: (*A Parameter*) Returns a real or complex number, global name, or algebraic.

B: (*B Parameter*) Returns a real or complex number, global name, or algebraic.

C: (*C Parameter*) Returns a real or complex number, global name, or algebraic.

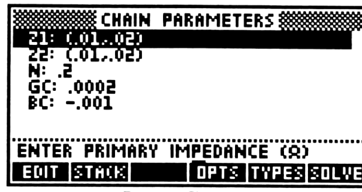
D: (*D Parameter*) Returns a real or complex number, global name, or algebraic.

Example

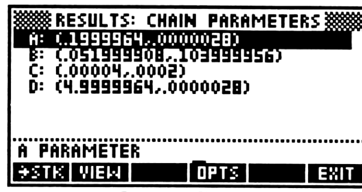
MODES (Press CST)				
	∡:	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

A transformer has an input impedance of (0.01, 0.02) and a core admittance of (0.0002, -0.001). Find the ABCD parameter if the turns ratio is 0.2.

1. Enter (0.01, 0.02) for **Z1** and (0.01, 0.02) for **Z2**.
2. Enter 0.2 for **N**, 0.0002 for **Gc**, and -0.001 for **Bc**.
3. Press solve to calculate the results, which will be displayed in the output screen.



Input Screen



Output Screen

Chapter 11

Transmission Lines

Analysis
Transmission Lines
Equations
Reference

This chapter covers the basic principles of transmission line analysis:

- ❑ Line Characteristics
- ❑ Line Parameters
- ❑ Fault Location Estimate
- ❑ Stub Impedance Matching

Line Characteristics

Analysis
Transmission Lines
Line Characteristics
Equations
Reference

This section computes the basic characteristics of a transmission line from the given parameters.

Field Descriptions - Input Screen

L: (*Series Inductance in H/Unit Length*) Enter a real number, global name or algebraic.

R: (*Series Resistance in Ω/Unit Length*) Enter a real number, global name or algebraic.

G: (*Shunt Conductance in S/Unit Length*) Enter a real number, global name or algebraic.

C: (*Shunt Capacitance in F/Unit Length*) Enter a real number, global name or algebraic.

ZL: (*Load Impedance in Ω*) Enter a real or complex number, global name or algebraic.

d: (*Distance to Load - unit length*) Enter a real number, global name or algebraic.

f: (*Frequency in Hz*) Enter a real number, global name or algebraic.

Field Descriptions - Output Screen

Z0: (*Characteristic Impedance in Ω*) Returns a real or complex number, global name, or algebraic.

Y0: (*Characteristic Admittance in S*) Returns a real or complex number, global name, or algebraic.

α: (*Neper Constant in 1/unit length*) Returns a real number, global name, or algebraic.

β: (*Phase Constant in ∡/unit length*) Returns a real number, global name, or algebraic.

λ: (*Wavelength in unit lengths*) Returns a real number, global name, or algebraic.

vp: (*Phase Velocity in unit length/s*) Returns a real number, global name, or algebraic.

Zoc: (*Open Circuit Impedance in Ω*) Returns a real or complex number, global name, or algebraic.

Zsc: (*Short Circuit Impedance in Ω*) Returns a real or complex number, global name, or algebraic.

ρ: (*Reflection Coefficient*) Returns a real or complex number, global name, or algebraic.

SWR: (*Standing Wave Ratio*) Returns a real number, global name, or algebraic.

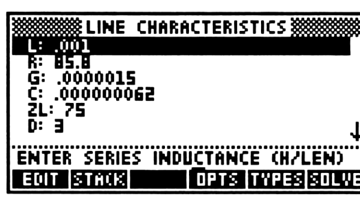
Example

MODES (Press CST)	**∡:**	Radian	**Result:**	Symbolic
	Coord:	Polar	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

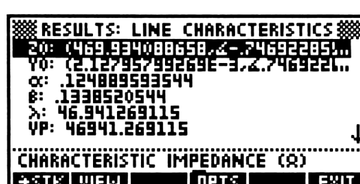
A transmission line has a series inductance of 1 mH/mile, a line resistance of 85.8 ohm/mile, a conductance of 1.5 x 10^{-6} mhos/mile, and a shunt capacitance of 62 x 10^{-9} F/mile. With a load impedance of 75 ohms at 3 miles from the load, compute the line characteristics at a frequency of 1000 Hz.

Note: For this example, the unit length is the mile, so all values will be entered with respect to miles.

1. Enter the values 0.001, 85.8, and 1.5E-6 for **L**, **R**, and **G**, respectively.
2. Enter the values 62E-9, 75, and 3 for **C**, **ZL**, and **d**, respectively.



Input Screen



Output Screen

3. Enter 1000 for **f**.
4. Press SOLVE to calculate the results and display them as shown to the right.

Line Parameters

Analysis
Transmission Lines
Line Parameters
Equations
Reference

This section computes the parameters of a transmission line from measured data describing the line.

> **NOTE** The algorithm used in this section solves for **γ** in the following equation, where $\gamma = 2 + j\beta$:
>
> $$\mathrm{TANH}(\gamma \cdot d) = \sqrt{Z_{sc}/Z_{oc}}$$
>
> In general **γ**, **Zsc**, and **Zoc** have complex values. In solving for **γ**, there is a principal value and a set of equivalent values because of the cyclical nature of the equation. Recognizing the fact that physical parameters such as **R**, **L**, **G**, **C**, and **vp** are all real and positive numbers, extreme caution should be exercised when entering input data. In particular, **d** should be less than one wavelength.

Field Descriptions - Input Screen

Zoc: (*Open Circuit Impedance in Ω*) Enter a real number.
Zsc: (*Short Circuit Impedance in Ω*) Enter a real number.
d: (*Distance to Load Location*) Enter a real number.
f: (*Frequency in Hertz*) Enter a real number.

Field Descriptions - Output Screen

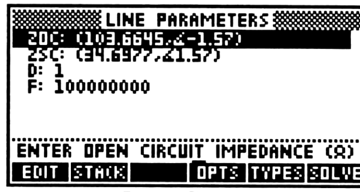
R: (*Series Resistance in Ω/unit length*) Returns a real number.
L: (*Series Inductance in H/unit length*) Returns a real number.
G: (*Shunt Conductance in S/unit length*) Returns a real number.
C: (*Shunt Capacitance in F/unit length*) Returns a real number.
Z0: (*Characteristic Impedance in Ω*) Returns a real number.
Y0: (*Characteristic Admittance in Ω*) Returns a real number.
α: (*Neper Constant in 1/unit length*) Returns a real number.
β: (*Phase Constant in ∡/unit length*) Returns a real number.
vp: (*Phase Velocity in unit length/s*) Returns a real number.

Example

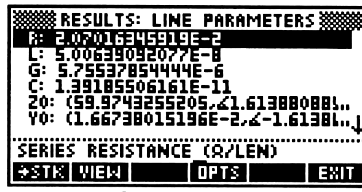
MODES (Press CST)	**∡:**	Radian	**Result:**	Symbolic
	Coord:	Polar	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

A transmission line is measured to have an open circuit impedance of (103.6645,∡-1.57) and a short circuit of (34.6977,∡1.57) at a distance 1 unit length from the load location. All measurements are carried out at 100 MHz. Compute all the parameters.

1. Enter (103.6645, ∡-1.57) for **Zoc**.
2. Enter (34.6977, ∡1.57) for **Zsc**.
3. Enter 1 and 100E6 for **d** and **f**, respectively.
4. Press SOLVE to calculate the results and display them as shown to the right.



Input Screen



Output Screen

Fault Location Estimate

Analysis
Transmission Lines
Fault Location Estimate
Equations
Reference

This section makes a best estimate of the closest possible location of a fault in a lossless transmission line.

Field Descriptions

Xin: (*Input Reactance in Ω*) Enter a real number, global name, or algebraic.

R0: (*Characteristic Resistance in Ω*) Enter a real number, global name, or algebraic.

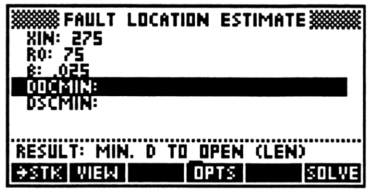
β: (*Phase Constant - ∡/unit length*) Enter a real number, global name, or algebraic.

docmin: (*Minimum distance to an open circuit fault in unit lengths*) Returns a real number, global name, or algebraic.

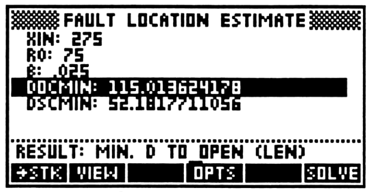
dscmin: (*Minimum distance to short circuit fault in unit lengths*) Returns a real number, global name, or algebraic.

Example

MODES				
(Press CST)	∡:	Radians	Result:	Symbolic
	Coord:	Polar	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small



Input Screen



Output Screen

A transmission line measures a capacitive reactive impedance of 275 ohms. The characteristic line impedance is 75 ohms, with a phase constant of 0.025 r/length. Estimate the fault location.

1. Enter the values 275, 75, and 0.025 for **Xin**, **R0**, and **β**, respectively.
2. Press SOLVE to calculate the results as shown in the screen to the right.

Stub Impedance Matching

Analysis
  Transmission Lines
    Stub Impedance Matching
Equations
Reference

This section calculates the parameters of a single-stub impedance-matching device.
From the input data, the location and electrical length of an open- and short-circuit stub is computed. Because the solution is circular in nature, there are two possible stub-locations d1 and d2.

Field Descriptions - Input Screen

ZL: (*Load Impedance in Ω*) Enter a real or complex number, global name, or algebraic.

R0: (*Characteristic Resistance in Ω*) Enter a real, global name, or algebraic.

Field Descriptions - Output Screen

β*d1: (*Electrical length from a stub at location d1 to the load in ∡*) Returns a real, global name, or algebraic.

β*d1-sc: (*Electrical length of a short-circuited shunt stub at distance d1 from load in ∡*) Returns a real, global name, or algebraic.

β*d1-oc: (*Electrical length of an open-circuited shunt stub at distance d1 from load in ∡*) Returns a real, global name, or algebraic.

β*d2: (*Electrical length from a stub at location d2 to the load in ∡*) Returns a real, global name, or algebraic.

β*d2-sc: (*Electrical length of a short-circuited shunt stub at distance d2 from load in ∡*) Returns a real, global name, or algebraic.

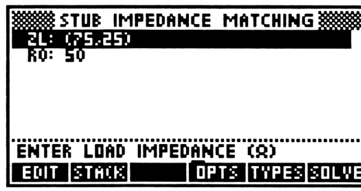
β*d2-oc: (*Electrical length of an open-circuited shunt stub at distance d2 from load in ∡*) Returns a real, global name, or algebraic.

Example

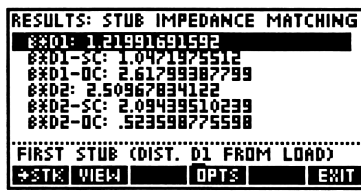
MODES	**∡:**	Radians	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

A transmission line has a terminating impedance of (75,25) ohms and a characteristic impedance of 50 ohms. Eliminate standing waves in the transmission line using a short or open shunt stub. Determine the electrical length of the stub and its distance from the load.

1. Enter (75,25) for **ZL** and 50 for **R0**.
2. Press SOLVE to calculate the results, which will be displayed in the output screen.



Input Screen



Output Screen

Chapter 12

Computer Engineering

Analysis
Computer Engineering
Equations
Reference

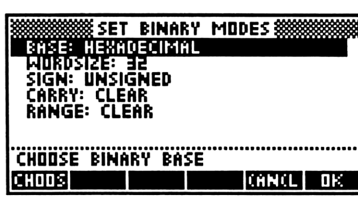
This chapter covers functions of interest in the design of logic systems commonly used by students and professionals in computer engineering. The modules include binary arithmetic, bit operations, comparisons and a form of logic minimization using the Quine-McCluskey algorithm:

- ❑ Binary Modes Screen
- ❑ Binary Arithmetic
- ❑ Register Operations
- ❑ Bit Operations
- ❑ Binary Conversions
- ❑ Binary Comparisons
- ❑ Karnaugh Map

Binary Modes Screen

The binary modes screen, available in all Computer Engineering screens except Karnaugh Map, is displayed by pressing MODE. The first three settings will remain in effect until the user resets them again from the binary modes screen. The Carry and Range flags may be set or cleared by various functions in the Computer Engineering module. The binary modes screen simply gives the user a way to set or clear them by hand.

To change any of these settings, move the highlight bar to the desired item and press CHOOS or [+/-]. Then press OK to implement the changes, or to exit the screen without changing the settings, press CANCL or [ON].



Base: (*Binary Base*) Press CHOOS to select Binary, Octal, Decimal or Hexadecimal.

Wordsize: (*Size of Binary Number*) Enter a number from 0 to 64 to set word size.
Sign: (*Sign Convention*) Press **CHOOS** to select Unsigned, One's Complement, or Two's Complement.
Carry: (*Carry Flag - User Flag 4*) Press **CHOOS** to select Set or Clear.
Range: (*Range Flag - User Flag 5*) Press **CHOOS** to select Set or Clear.

Range and Carry Flags

Whenever a binary addition results in a carry beyond the most significant bit, the carry flag will be set. If an addition does not result in a carry, the flag will be cleared. This is true for all complement modes.

Whenever binary arithmetic results cannot be represented in the current word size and complement mode, the range flag will be set.

Binary Arithmetic

Analysis
  Computer Engineering
    Binary Arithmetic
Equations
Reference

This section allows you to add, subtract, multiply, and divide binary numbers, as well as negate or find the absolute value of a binary number.

Field Descriptions

Binary: (*Input Field*) Enter a binary integer.
Binary: (*Input Field*) Enter a binary integer.
Operator: (*Binary Operation*) Press **CHOOS** to select:

- ADD16C — Add two binary or real numbers. Affects range and carry flags.
- SUB16C — Subtract one binary or real number from another. Affects range and carry flags.
- MULT16C — Multiply two binary or real numbers. Affects range and carry flags.
- DIV16C — Divide two binary or real numbers and return quotient. Affects carry flag only.
- RMD16C — Divide two binary or real numbers and return remainder. Does not affect range or carry flags.
- NEG16C — Negate a binary or real number. Affects range flag only.
- ABS16C — Find the absolute value of a binary or real number. Affects range flag only.

Result: (*Binary Function Value*) Returns a binary integer or real number.
Flags: (*State of Carry and Range Flags*) Returns Carry if carry flag is set. Returns Range if range flag is set.

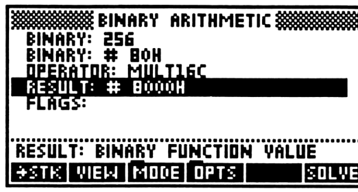
Example

MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Binary Modes Press MODE	**Base:**	Hexadecimal	**Carry:**	Clear
	Wordsize:	32	**Range:**	Clear
	Sign:	Unsigned		

Multiply a real number 256 and a binary number #128d.

1. In the first **Binary** field, press TYPES to select Real Number.
2. Enter 256 in the first **Binary** field.
3. Enter 128d (128 α ← D) in the second **Binary** field.
4. Choose MULT16C for **Operator**.
5. Press SOLVE to calculate **Result**.



Output Screen

Register Operations

Analysis
Computer Engineering
Register Operations
Equations
Reference

This section allows you to perform operations on any bit of a binary integer. Such operations include shifting bits to the left or right, rotating bits to the left or right, and shifting or rotating through the carry flag.

Field Descriptions

Binary: (*Input Field*) Enter a binary integer.

N: (*Number of places for shifting or rotating - appears only when SRN16C, RLN16C, RLN16C, RRN16C, RLCN16C, or RRCN16C are selected*) Enter a real number.

Operator: (*Binary Operation*) Press CHOOS to select:

Note: All register operations set the carry flag if a 1 is rotated or shifted off the end, otherwise they clear the carry flag.

SL16C Shifts the input to the left by one bit and shifts a 0 into the rightmost position.

SR16C Shifts the input to the right by one bit and shifts a 0 into the leftmost position.

RL16C	Rotates the input to the left by one bit. The leftmost bit wraps around to the rightmost position.
RR16C	Rotates the input to the right by one bit. The rightmost bit wraps around to the leftmost position.
RLC16C	Rotates bits left by one bit through carry. Loads the leftmost bit into the carry and moves the carry bit into the rightmost position.
RRC16C	Rotates bits right by one bit through carry. Loads the rightmost bit into the carry and moves the carry bit into the leftmost position.
ASR16C	Arithmetic shift right: For One's Complement and Two's Complement, shifts bits to the right, but keeps the leftmost bit (the sign bit) the same. For Unsigned mode, which has no sign bit, a 0 is shifted into the leftmost position.
SLN16C	Shifts left by N bits.
SRN16C	Shifts right by N bits.
RLN16C	Rotate left by N bits.
RRN16C	Rotate right by N bits.
RLCN16C	Rotate left by N bits through the carry.
RRCN16C	Rotate right by N bits through the carry.

Result: (*Binary Function Value*) Returns a binary integer.

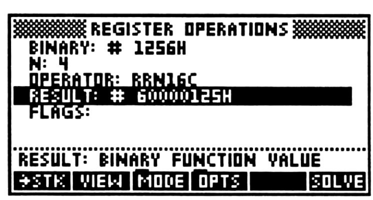
Example

MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Binary Modes Press MODE	**Base:**	Hexadecimal	**Carry:**	Clear
	Wordsize:	32	**Range:**	Clear
	Sign:	Unsigned		

Rotate the binary number 1256 to the right by 4 bits.

1. Enter 1256 in the **Binary** field.
2. Choose RRN16C for **Operator**.
3. Enter 4 for **N**.
4. Press SOLVE to calculate **Result**.



Output Screen

Bit Operations

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This section allows you to perform bit-specific operations. You can set a bit, clear a bit, test a bit or find the total number of bits set.

Field Descriptions

Binary: (*Input Field*) Enter a binary integer.

Bit #: (*Bit Position - not active if ΣB is selected*) Enter a binary integer or real number.

Operator: (*Binary Operation*) Press CHOOS to select

Note: All bit operations affect the carry flag only.

SB Sets the bit in the specified position.
CB Clears the bit in the specified position.
B? Tests the bit in the specified position.
ΣB Returns the number of bits set.

Result: (*Binary Function Value*) Returns a binary integer.

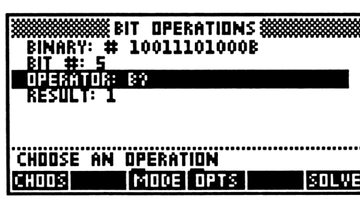
Example

MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Binary Modes Press MODE	**Base:**	Binary	**Carry:**	Clear
	Wordsize:	32	**Range:**	Clear
	Sign:	Unsigned		

Test the fifth bit of the binary number #1256d in its binary form.

4. Enter 1256d (1256 α ← D) for **Binary**.
5. Enter 5 for **Bit #**.
6. Choose B? for **Operator**.
7. Press SOLVE to calculate **Result**. A "1" means the bit is set.



Output Screen

Binary Conversions

This section allows you convert real numbers to binary numbers and vice versa. It also allows you to convert real numbers to IEEE format and vice versa.

Field Descriptions

Binary: (*Input Field for B→R16C and IEEE→*) Enter a binary integer.
Real: (*Input Field for R→B16C and →IEEE*) Enter a real number.
Function: (*Binary Function*) Press CHOOS to select:

R→B16C	Converts a real number to a binary number (decimal, binary, hexadecimal or octal). Affects the range flag only.
B→R16C	Converts a binary number (decimal, binary, hexadecimal or octal) to a real number.
→IEEE	Converts a real number to the IEEE 32 bit format. The word size is automatically set to 32 bits. Affects the range flag only.
IEEE→	Converts a IEEE number to a real number. The word size is automatically set to 32 bits. Affects the carry and range flags.

Result: (*Binary Function Value*) Returns a binary integer.

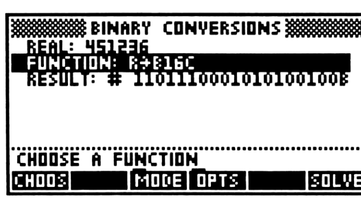
Example

MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Binary Modes Press MODE	**Base:**	Binary	**Carry:**	Clear
	Wordsize:	32	**Range:**	Clear
	Sign:	Unsigned		

Convert the real number 451236 to a binary number.

1. Enter 451236 for **Real**.
2. Choose R→B16C for **Function**.
3. Press SOLVE to calculate **Result**.



Output Screen

Binary Comparisons

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This section allows you to compare two binary numbers to determine if they are the same value, unequal, greater than, less than, etc.

Field Descriptions

Binary: (*Input Field*) Enter a binary integer or real number.
Binary: (*Input Field*) Enter a binary integer or real number.
Operator: (*Binary Operation*) Press CHOOS to select:

Note: All binary comparison commands affect the carry flag only.

==16C Compares two binary or real numbers. The result field shows a 1 if they are equal, otherwise 0.

≠16C Compares two binary or real numbers. The result field shows a 1if they are NOT equal, otherwise 0.

<16C Compares two binary or real numbers. If the number in the first field is less than the number in the second field, then the result field displays a 1, otherwise 0.

>16C Compares two binary or real numbers. If the number in the first field is greater than the number in the second field, then the result field displays a 1, otherwise 0.

≤16C Compares two binary or real numbers. If the number in the first field is less than or equal to the number in the second field, then the result field displays a 1, otherwise 0.

≥16C Compares two binary or real numbers. If the number in the first field is greater than or equal to the number in the second field, then the result field displays a 1, otherwise 0.

Result: (*Binary Function Value*) Returns 1 (True) or 0 (False).

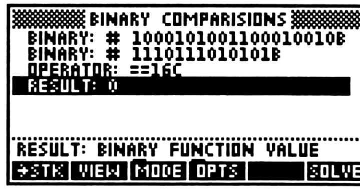
Example

MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Binary Modes Press MODE	**Base:**	Binary	**Carry:**	Clear
	Wordsize:	32	**Range:**	Clear
	Sign:	Unsigned		

Compare two binary numbers #45312h and #16725o and determine if they are equal.

1. Enter 45312h (45312 [α] [⬅] H) in the first **Binary** field.
2. Enter 16725o [α] [⬅] O) in the second **Binary** field.
3. Choose ==16C for **Operator**.
4. Press SOLVE to calculate **Result**.
5. The result is 0, meaning false, so the two numbers are not equal.



Output Screen

Karnaugh Map

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In this section, the user is provided with a powerful tool to design efficient combinatorial logic networks. The program provides a convenient symbolic representation of the minimization method in a "sum of products form." The variable naming convention is restricted to 1 character per variable and is case-sensitive. The algorithm used in developing the logic uses the defined form of minimization developed by W.V. Quine and E.J. McCluskey. The resulting output is an algebraic expression for the prime implicants. In this representation, a logic variable (e.g., A) represents its true value, while A' is used to represent its negation.

> **NOTE** The sum of products form displayed here may not be the most optimum solution.

Field Descriptions

Minterms: (*List if Minterms*) Enter a list of real or binary numbers. Real and binary numbers can be combined in the same list.

Don't Care: (*List of Don't Care Terms*) Enter a list of real or binary numbers. Real and binary numbers can be combined in the same list.

Variables: (*List of Variables*) Enter a string or global name, with no spaces between variables.

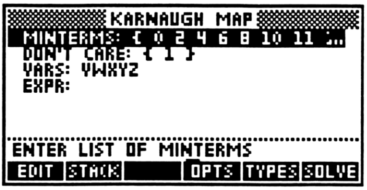
Expr: (*Prime Implicant Expression*) Returns an algebraic expression.

Example

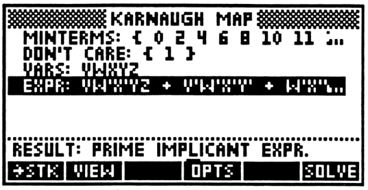
MODES	∡:	Degrees	Result:	Symbolic
(Press CST)	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

Minimize a five input function with minterms at 0, 2, 4, 6, 8, 10, 11, 12, 13, 14, 16, 19, 29, 30. The input variables are V, W, X, Y and Z. Find the prime implicant expression.

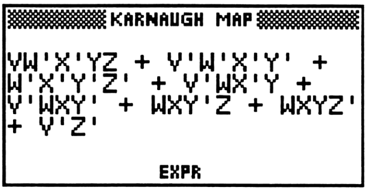
1. Enter {0, 2, 4, 6, 8, 10, 11, 12, 13, 14, 16, 19, 29, 30} for **Minterms**.
2. Enter {1} for **Don't Care**.
3. Enter VWXYZ for **Vars**.
4. Press SOLVE to calculate **Expr**.
5. Move the highlight bar to the **Expr** field and view the entire result by pressing VIEW.



Input Screen



Output Screen



Chapter 13

Algebraic Functions

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This chapter covers commonly-used algebraic functions:

- ❑ Partial Fraction Expansion
- ❑ Piecewise Functions
- ❑ Polynomial Coefficients
- ❑ Polynomial Equation
- ❑ Polynomial Roots
- ❑ Symbolic Simplification
- ❑ Taylor Polynomial

Partial Fraction Expansion

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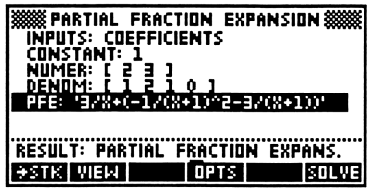
The partial fraction expansion function separates a rational function of the form $f(x)/g(x)$ by splitting it into a sum of fractions with simpler denominators.

Field Descriptions

Inputs: (*Form of numerator and denominator*) Press CHOOS to select Coefficients or Roots. Determines whether inputs for **Numer** and **Denom** are interpreted as coefficients or roots.
Constant: (*Constant*) Enter a real number. (Default is 1.)
Numer: (*Numerator coefficients or roots*) Enter an array or list of real or complex numbers.
Denom: (*Denominator coefficients or roots*) Enter an array or list of real or complex numbers.
PFE: (*Partial fraction expansion*) Returns an algebraic expression.

Example: Coefficients Format

MODES				
(Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

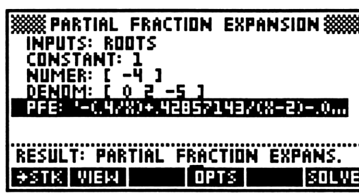


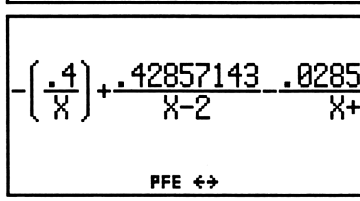
What is the partial fraction expansion of the rational function $\dfrac{2x+3}{x^3+2x^2+x}$?

1. Choose Coefficients for **Inputs**.
2. Enter 1 for **Constant**.
3. Enter [2 3] for **Numer** and [1 2 1 0] for **Denom**.
4. Press SOLVE to calculate **PFE**.

Example: Roots Format

MODES				
(Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small





What is the partial fraction expansion of the rational function $\dfrac{x+4}{x(x-2)(x+5)}$?

1. Choose Roots for **Inputs**.
2. Enter 1 for **Constant**.
3. Enter [-4] for **Numer** and [0 2 -5] for **Denom**.
4. Press SOLVE to calculate **PFE**.
5. To display **PFE** in graphics view, press ◄┘ or ┕► VIEW.
6. Press ◄ and ► to scroll the equation.

Piecewise Functions

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Piecewise functions take on different functional forms (expressions) over different regions of the independent variable:

$$f(x)=\begin{cases}\text{expression}_1 & \text{region}_1\\ \text{expression}_2 & \text{region}_2\end{cases}$$

The HP 48 can manipulate and plot piecewise functions if they are entered in the IFTE (If-Then-Else) format:

$$f(x) = \text{IFTE}(\text{region}_1, \text{expression}_1, \text{expression}_2)$$

This section enables you to easily enter a piecewise function as one or more *terms*, where each term is specified by two fields: one for the expression (EXPR) and the other for the corresponding region (REGION). Then the appropriate IFTE representation of the piecewise function is generated.

Entry Rules

- Use == in place of =. The HP 48 uses the = operator only for assigning variables, while the == command is used to check for equality. Therefore, the region X=0 should be entered as 'X==0'. The most common operators used in regions are found in the TEST menu: ==, ≠, <, >, ≤ and ≥.

- To make a section of a piecewise function undefined, enter Undefined as the expression for the term, along with the corresponding region. An Undefined term will automatically be appended to complete all one-term piecewise functions. (**Note:** Undefined is simply a global name that presumably does not exist in user memory and will therefore remain unevaluated when plotting.)

- Always specify terms in the function in order of increasing regions. For example, specify the term for the region X<-3 before the term for the region X<3. This is because the HP 48 will not properly evaluate expressions like '-3<X<3', so this region must be entered as 'X<3'. However, this would incorrectly imply that the corresponding expression should be used for all values of X<3, so you must have first entered a term for the region X≤-3.

- For regions like X = 2,3 the entry must be split into two separate terms because the HP 48 will not recognize an expression like 'X==2,3'. Therefore, enter the same expression twice, for two different regions: 'X==2' and 'X==3'.

Field Descriptions

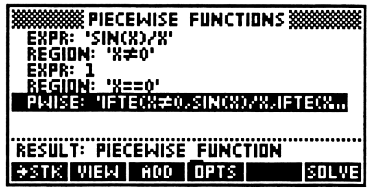
Expr: (*Expression*) Enter a real number, complex number, global name, algebraic or unit.
Region: (*Region of validity*) Enter a real number, global name or algebraic.
Pwise: (*Piecewise function*) Returns an algebraic expression.

Example 1

MODES				
(Press CST)	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

Define the piecewise function

$$f(x)=\begin{cases}\sin(x)/x & x\neq 0\\ 1 & x=0\end{cases}$$



This will require two terms.

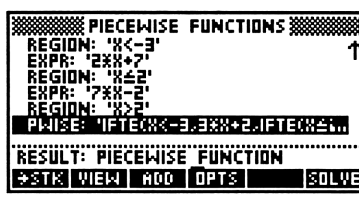
1. Enter SIN(X)/X for **Expr**.
2. Enter X≠0 for **Region** (key sequence: α X PRG TEST ≠ 0 ENTER).
3. Press ADD to create new **Expr** and **Region** fields for the second term.
4. Enter 1 for the second **Expr** field and X==0 for the **Region** field.
5. Press SOLVE to calculate **Pwise**.

Example 2

MODES				
(Press CST)	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

Define the piecewise function: $f(x)=\begin{cases}3x+2 & x<-3\\ 2x+7 & -3\leq x\leq 2\\ 7x-2 & x>2\end{cases}$

This will require three terms.



1. Enter 3*X+2 for **Expr** and X<-3 for **Region**.
2. Press ADD to create new **Expr** and **Region** fields.
3. Enter 2*X+7 for the second **Expr** field and X≤2 for **Region**.
4. Press ADD.
5. Enter 7*X-2 for the third **Expr** field and X>2 for **Region**.
6. Press SOLVE to calculate **Pwise**.

Polynomial Coefficients

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This section takes the roots (real or complex) of a polynomial and returns the coefficients (real or complex) of the polynomial.

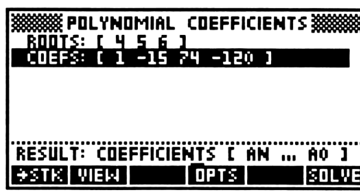
Field Descriptions

Roots: (*Polynomial roots*) Enter an array or list of real or complex numbers.
Coefs: (*Polynomial coefficients*) Returns a real or complex array.

Example

MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

What are the coefficients of the polynomial that has the roots 4, 5, and 6? (What equation results when (x-4), (x-5), and (x-6) are multiplied?)



1. Enter [4 5 6] for **Roots**.
2. Press SOLVE to calculate **Coefs**. The result is [1 -15 74 -120], which means the polynomial is $x^3 - 15x^2 + 74x - 120$.

> **NOTE**
> Round-off error limits the accuracy of coefficients returned by the polynomial coefficients function, so the coefficients are automatically rounded to 8 digit accuracy.

Polynomial Equation

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This section takes the coefficients (real or complex) of a polynomial and returns the polynomial as an algebraic expression. The coefficients must be entered in descending order, as in: [AN … A2 A1 A0], which represents the equation $A_n \cdot x^n + \ldots + A_2 \cdot x^2 + A_1 \cdot x + A_0$.

Field Descriptions

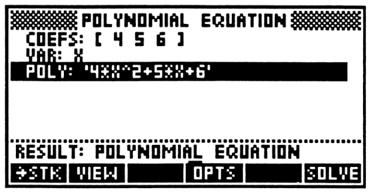
Coefs: (*Polynomial coefficients*) Enter an array or list of real or complex numbers.
Var: (*Variable*) Enter global name.
Poly: (*Polynomial equation*) Returns an algebraic expression.

Example

MODES (Press CST)				
	∡:	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

The coefficients (in descending order) of an equation are 4, 5, and 6.

1. Enter [4 5 6] for **Coefs**.
2. Press SOLVE to calculate **Poly**.



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Polynomial Roots

This section takes the coefficients (real or complex) of a polynomial and returns the roots of that polynomial.

Field Descriptions

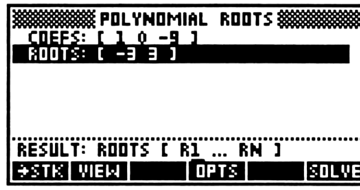
Coefs: (*Polynomial coefficients*) Enter an array or list of real or complex numbers.
Roots: (*Polynomial roots*) Returns a real or complex array.

Example

MODES (Press CST)				
	∡:	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

What are the roots of the polynomial $x^2 - 9 = 0$?

1. Enter [1 0 -9] for **Coefs**.
2. Press SOLVE, to calculate **Roots**. The result is [-3 3], which means the polynomial has the two roots 3 and -3.



NOTE	Round-off error limits the accuracy of roots returned by the polynomial roots function, so the roots are automatically rounded to 8 digit accuracy. To improve the accuracy of a particular root, use the built-in HP 48 solver to solve the original polynomial equation for 'X', using the value of the desired root returned by the polynomial roots function as a guess. The polynomial roots function is based on a routine developed by Wayne Scott, using the Bairstow algorithm for finding quadratic factors.

Symbolic Simplification

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This section returns the simplified form of an expression.

Field Descriptions

Expr: (*Expression*) Enter a real number, complex number, global name or algebraic.

Simpl: (*Simplified expression*) Returns a real number, complex number, global name, or algebraic.

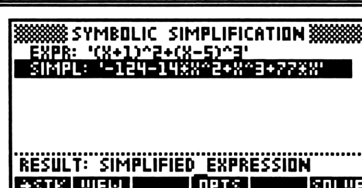
Example

MODES				
(Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Simplify the expression $(x+1)^2 + (x-5)^3$.

1. Enter (X+1)^2+(X-5)^3 for **Expr**.
2. Press SOLVE, to calculate **Simpl**.

   The result is $x^3 - 14x^2 + 77x - 124$.



Taylor Polynomial

This section computes the Taylor Polynomial of a function to the specified order about a given point.

Field Descriptions

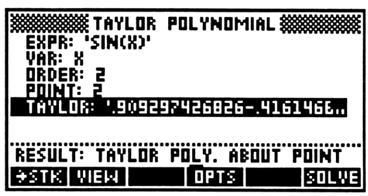
Expr: (*Expression*) Enter a global name or algebraic.
Var: (*Variable*) Enter a global name.
Order: (*Order of Taylor polynomial*) Enter a real number.
Point: (*Expansion point*) Enter a real or complex number, or global name.
Taylor: (*Taylor polynomial*) Returns an algebraic expression.

Example

MODES (Press CST)	**∡:**	Radians	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

What is the 2nd-order Taylor polynomial of 'SIN(X)' about the point X=2?

1. Enter SIN(X) for **Expr** and X for **Var**.
2. Enter 2 for **Order** and 2 for **Point**.
3. Press SOLVE to calculate **Taylor**.



Chapter 14

Error Functions

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This chapter covers the error function and the complementary error function:

- ❑ Error Functions

Using Error Functions

This section computes the numerical values for the error function and complementary error function of one real argument. The definitions of the error function and complementary error function are:

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \qquad erfc(x) \equiv 1 - erf(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2} dt$$

Field Descriptions

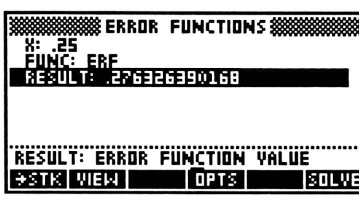
X: (*Value*) Enter a real number, global name, or algebraic.
Func: (*Error function type*) Press CHOOS to select ERF or ERFC.
Result: (*Error function value*) Returns a real number or algebraic.

Example

MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

What is the value of ERF(.25)?

1. Enter .25 for **X**.
2. Choose ERF in **Func**.
3. Press SOLVE to calculate **Result**.



Chapter 15

Capital Budgeting

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Capital Budgeting
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This chapter covers the four basic measures of capital budgeting:

- ❑ Payback Period
- ❑ Net Present Value
- ❑ Internal Rate of Return
- ❑ Profitability Index

Using Capital Budgeting

This section allow you to analyze the capital expenditure of a project and compare projects against one another. Four measures of capital budgeting are included in this section: Payback period (Payback), Net Present Value (NPV), Internal Rate of Return (IRR), and Profitability Index (PI). This module provides the capability of entering, storing and editing capital expenditures for nine different projects. The following definitions are important:

CF_t: Cash Flow at time t.

Payback: The number of time periods (usually years) it takes a firm to recover its original investment.

NPV: The present values of all future cash flows, discounted at the selected rate, minus the cost of the investment.

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+k)^t} - CF_{t=0}$$

IRR: The discount rate that equates the present value of expected cash flows to the initial cost of the project.

$$\sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t} - CF_{t=0} = 0$$

PI: The present value of the future cash flows, discounted at the selected rate, over the initial cash outlay.

$$PI = \frac{\sum_{t=1}^{n} \frac{CF_t}{(1+k)^t}}{CF_{t=0}}$$

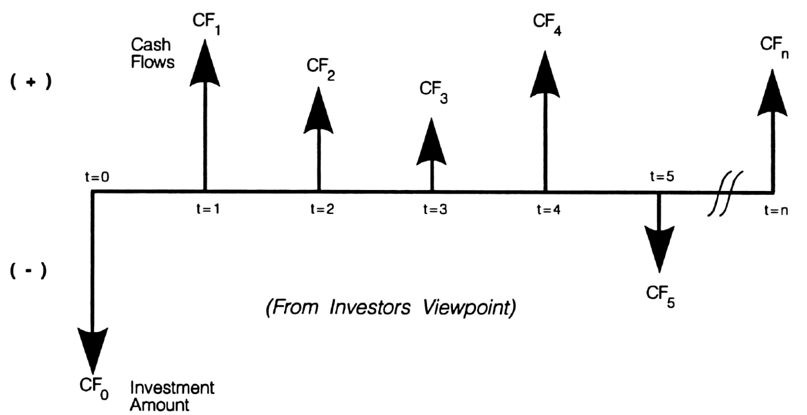
Field Descriptions - Input Screen

Project: (*Project*) Press CHOOS to select one one of nine unique projects or edit the current project by pressing CASH.
k: (*Discount Rate per Period in %*) Enter a real number.
Payback: (*Payback Period*) Returns a real number.
NPV: (*Net Present Value*) Returns a real number.
IRR: (*Internal Rate of Return*) Returns a real number (%).
PI: (*Profitability Index*) Returns a real number.

Field Descriptions - Project Edit Screen

Name: (*Project Name*) Enter name of the project.
t0: (*Investment at t=0*) Enter a real number. Must be a negative number.
t1: (*Cash flow at t=1*) Enter a real number. Can be positive or negative.
....
tn: (*Cash flow at t=n*) Enter a real number. Can be positve or negative.

Cash Flow Diagram



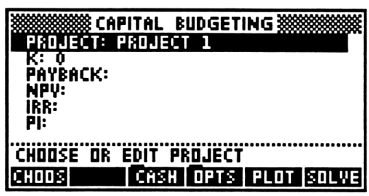
Example

MODES				
(Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

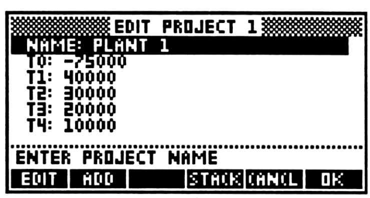
The following projects have been proposed by your company. What is the payback period, Net Present Value, Internal Rate of Return, and Profitability Index of each project? Which is the more viable project?

Name of Project:	**Plant 1**		**Plant 2**	
Investment Outlay:	**$75,000** *(at t=0)*		**$75,000** *(at t=0)*	
Cost of Capital:	**12%**		**12%**	
	Year	Net Cash Flow ($)	Year	Net Cash Flow ($)
	0	-75,000	0	-75,000
	1	40,000	1	10,000
	2	30,000	2	20,000
	3	20,000	3	30,000
	4	10,000	4	40,000

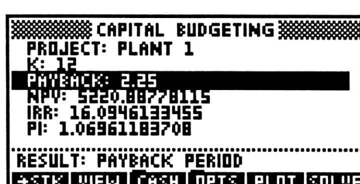
1. With the highlight bar on the **Project** field, press CHOOS to select a project to edit. Select a project that has not been used (this example uses projects 1 and 2). Press OK to return to the Capital Budgeting screen.
2. Press CASH to enter the Project Edit screen and edit the cash flows.
3. Enter Plant 1 for **Name**.
4. Press ADD 5 times to add 5 time points and enter the cash flows at each time point from the table above. When finished, your screen should look like the Project Edit screen to the right. Be sure to enter 75,000 as a negative number. Press OK to save your changes and return to the Capital Budgeting screen.
5. Enter 12 for **K**.
6. Press SOLVE to calculate **Payback**, **NPV**, **IRR**, and **PI**.



Input Screen

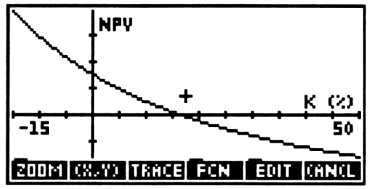


Project Edit Screen



Output Screen

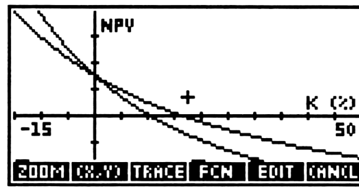
7. Press PLOT to show the curvilinear relationship between the Net Present Value and the Discount Rate. You will see a message screen asking if you wish to clear the previous plot. Press ■ YES.



Plot Screen

The curve indicates that where K=0, the Net Present Value is simply cash inflows minus cash outflows. The IRR % is shown at the point where NPV=0. Using the built-in graphing capabilities of the HP 48, you can trace the graph to find the values for these two points. The HP 48GX will give you the exact coordinates of any point, the HP 48SX will only give you a close approximation. Press CANCL to return to the Capital Budgeting screen.

8. Repeat steps 1 through 7 for the second project. Name the project Plant 2 and input the values in the table on page 92. When you plot the second project, press NO when you are prompted to clear the previous plot. This will overlay the second project on the first for a quick comparison of the two projects. The most viable project in terms of discounted cash flows, in this example, is the one with the highest curve: Plant 1.



Plot Screen II

Bibiography

Campsey, B.J., and Eugene F. Brigham, *Introduction to Financial Management*, Dryden Press, 1985, pp. 392-400.

Van Horne, James C., *Financial Management and Policy*, Eighth Edition, Prentice Hall, 1989, pp. 126-132.

Part 2

Equations

Chapter 16

Equations: Navigation Guide

Analysis
Equations
Reference

This chapter is designed as a navigation guide to introduce you to the Equations section, show you the keys available at each screen, and describe the types of input fields and symbols you will encounter. At the end of the chapter is a detailed Equations example.

Introduction

EE•*Pro* is divided into three major sections: Analysis, Equations, and Reference. This chapter addresses the Equations section, which includes equations covering resistive circuits, capacitance and electric fields, inductance and magnetism, electron motion, RLC circuits, AC circuits, motors and generators, OpAmp circuits, transformers, linear circuits, and solid state devices.

The Equations section enables you to select a specific equation or a set of equations, solve for specific variables, and plot the equations with the EE•*Pro* plotting functions. The three equation-related features of selecting, solving, and plotting, each have their own screen. The Equations screen displays a group of related equations, which can be selected for solving or plotting. The Solver screen allows you to enter and convert values, then solve for unknowns. The Plotter screen allows you to plot the selected equation. A diagram is often available to illustrate the variable relationships in the selected equation set and can be accessed from any of these three screens. In some cases, extra diagrams in the manual help illustrate the nature of the problems being solved.

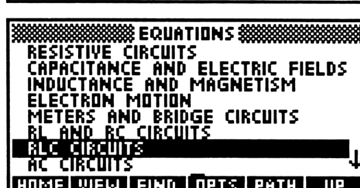
Finding Equations

The Equations section is found at the home screen of EE•*Pro*.

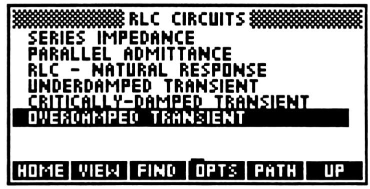
1. Start EE•*Pro*:
   - HP 48GX: Press [→] [LIBRARY] [EE] [EE].
   - HP 48SX: Press [←] [LIBRARY] [EE] [EE].
   - Press [→] [HOME] to show the home screen.

   EE•*Pro* is structured with a hierarchy of screens for choosing a specific topic or item. This is the home screen. To return here at any time, press [→] [HOME] or [→] [◄].

2. Select Equations by moving the highlight bar to Equations and pressing [ENTER] or [►]. The screen now displays Equations as its title and a list of Equations sections from which to choose.



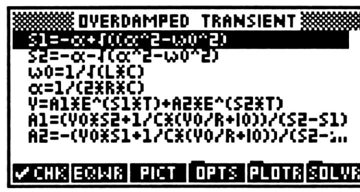
3. Choose an Equations section by moving the highlight bar to the desired item and pressing [ENTER] or [►]. This will display a list of topics for the selected section. For the purposes of this navigation guide, select RLC Circuits then Overdamped Transient.



Pressing **UP** (if available) or [◄] returns you to the previous screen.
Pressing **HOME** (if available) or [↱] [HOME] returns you to the home screen.

Equations Screens

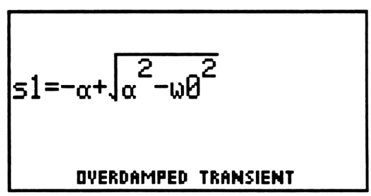
An Equations screen displays a list of related equations which can be displayed in a graphics view or selected for solving. The screen to the right is the Overdamped Transients screen.



The Equations screen is accessible from the Plotter screen or the Solver screen by pressing **EQNS**.

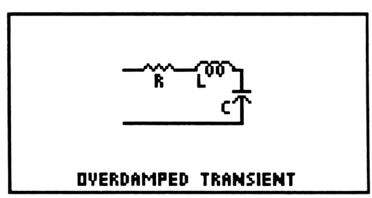
Viewing Equations

To display an equation in a graphics view using the HP 48 EquationWriter , move the highlight bar to the desired equation and press **EQWR**. Press any key to return to the Equations screen.

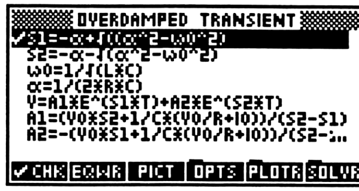


Displaying a Picture

To display a diagram for the current equation set, press **PICT**. If available, this menu key will also appear in the Plotter screen and the Solver screen. (**Note:** Variable names in pictures are always uppercase, regardless of which case they appear when encountered in the equations themselves.) Press any key to return to the previous screen.



Selecting Equations

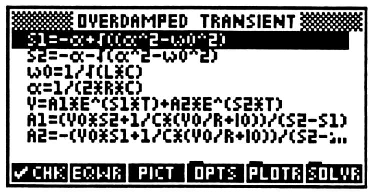


When solving a problem, one or more of the equations from the Equations screen can be selected for use at the Solver screen. Generally, you will want to solve all of the equations together, but sometimes it may be the case that you can quickly select a single equation or a subset of the entire equation set to speed up the solving computations. (Solving one or two equations is usually faster than solving many equations.)

To select an equation, move the highlight bar to the desired equation and press ✓CHK or +/-. Once selected, an equation can be unselected in the same fashion.

Equations Menu Keys

These are descriptions of the menu keys available at Equations screens:



- **✓CHK** Checks or unchecks the highlighted equation. Only checked equations will be solved, but if none of the equations are checked, all of them will be solved.
- **EQWR** Displays the highlighted equation in a graphics view.
- **PICT** Displays a picture for the equation set.
- **OPTS** Displays the options menu. For more information, see "Options Menu," page 9.
- **PLOTR** Goes to the Plotter screen. For more information, see "Plotter Screens," page 106.
- **SOLVR** Goes to the Solver screen. Solves only the checked equations (unless none are checked, in which case all are solved). For more information, see "Solver Screens" below.

Solver Screens

A Solver screen allows you to enter values for each variable in the selected equation(s). Variables can also be edited, copied to the stack, or converted to different units. After all the known variables have been entered, you can press SOLVE to compute the values of the unknown variables.

NOTE	The Solver cannot handle complex numbers. To solve a problem which requires complex inputs, use the appropriate Analysis routine.

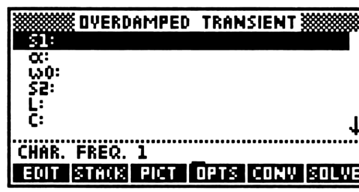
The Solver screen is accessible from the Equations screen or the Plotter screen by pressing SOLVR.

Solving an Equation

Below are general instructions for using Solver screens. For a detailed example using Overdamped Transient, see page 110.

1. *Optional:* Select equation(s) to solve. (If no equations are selected, the Solver will solve all the equations in the set.)
   a. Go to the Equations screen by pressing NXT EQNS.
   b. Move the highlight bar to the desired equation(s) and press ✓CHK. (**Note:** The following screens assume that none of the equations have been selected, and therefore all will be solved.)

2. Go to the Solver screen by pressing SOLVR from the Equations screen or the Plotter screen. The screen to the right is the Solver screen for Overdamped Transient.



3. Enter the known values.
   a. Move the highlight bar to the desired variable.
   b. Type in the appropriate value for the variable and press ENTER or a unit menu key to complete the entry.

   If you make a mistake or want to change the value of a variable:
   a. Move the highlight bar to the variable and press EDIT to place it on the command line.
   b. Edit the value.
   c. After you have finished editing the value, press ENTER to change the value or ON to abort the change.

   Alternatively, to *replace* the existing value of a variable:
   a. Move the highlight bar to the variable.
   b. Type in the new value.
   c. Press ENTER or a unit menu key to complete the entry.

   Any time you edit or change a value, that variable will be marked as "known" with a solid circle (●). See "Solver Icons," page 103.

4. Press SOLVE to solve for the remaining variables. Shaded circles (●) will appear next to variables for which exact solutions have been found. See "Solver Icons," page 103.
5. *Optional:* Press [◄] to return to the RLC Circuits screen or press [→] [HOME] to return to the home screen.

Using the HP 48 Stack

There are two stack-related commands:

→STK Copies one or all of the variables currently on the screen to the HP 48 stack for later use, without leaving the Solver screen.

1. To access this command, press OPTS [NXT] or [→] [CST] then →STK.
2. You will be asked if you want to copy one or all items to the stack.
3. Choose ONE or ALL, or press [ON] to abort the copy.

STACK Copies the value of the highlighted variable to the HP 48 stack for immediate use and temporarily goes to the HP 48 stack environment. For more information, see "Solver Menu Keys," page 105.

Resetting Variables

To reset the values of variables, press [DEL] or [NXT] RESET and select ONE or ALL. This will clear the values of the selected variables at the Solver screen and will also purge the selected variables from user memory, where they are created by the solver each time you enter a value or press SOLVE.

Converting a Value

Once a variable value has been entered, it can easily be converted to different units. To do this, highlight the desired variable and press CONV. The available units for the highlighted variable will be displayed as menu keys (press [NXT] for more menu keys, if appropriate). When you have finished coverting a value, either move the highlight bar to another variable value to convert it, or press EXIT to leave the convert menu and return to the standard menu.

Units On/Units Off

You can choose to display variable values with units (units on) or without units (units off). With units on, variable values will be displayed in the units you specify when you enter the value or when you convert the value to a different unit. If you simply enter a number and press [ENTER], the default unit will be the SI unit for the variable. The default SI unit is typically displayed as the first menu key when entering a value.

With units off, variable values will be displayed as SI values without units. The units you specified will be remembered if you later turn units on again, but all values will temporarily be converted and displayed in the default SI units. SI units are used to ensure that the values sent to the solver are consistent with each other.

To access the units setting:

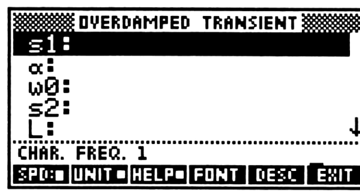
1. Press [OPTS] or [←][CST] and then [UNITS] to turn units on or off. When the block inside the key appears ([UNIT■]), units are turned on. Press [EXIT] to leave the Options menu and return to the standard Solver menu keys.

OR

2. Press [←][UNITS] or [→][UNITS] to turn units on or off. When units appear next to the values, units are turned on.

Font Size

The small font shows variables only in uppercase, which makes it difficult to distinguish between an **a** and an **A**. However, it does allow more data to be displayed on the screen, making it easier to see your results.



To change the font size:

1. Press [OPTS] [FONT] to switch to the larger font, which is case-sensitive. Also, pressing [HELP■] to turn help text off provides more room on the screen so that more of the variables can be displayed at once.
2. Press [EXIT] to leave the options menu and return to the standard menu.

Solver Icons

There are several different symbols or icons used to identify different kinds of variables. To see a list of these icons, press [NXT] [ICONS] to display the Solver Icons screen. See Chapter 33, "Advanced Use of the Solver."

✓ Wanted Variables

A check mark (✓) indicates that a variable is wanted. It is not necessary to mark the desired variable(s) as wanted in order to calculate their values, because the solver will calculate the values of *all* unknown variables (those with no icons) if none are marked as wanted. The reason you may want to mark one or more variables as wanted is if you want the solver to *stop* after it has found the values of those wanted variables and not continue to calculate the values of all remaining unknown variables. If you are solving multiple equations with many variables and you only want the value of a specific variable, it is a good idea to mark that variable as wanted by selecting it with the highlight bar and pressing WANT. To remove a wanted icon from a variable, move the highlight bar to the variable and press WANT again.

The solver may still calculate the values of other unknown variables in addition to those specifically marked as wanted, most likely because it is impossible to calculate the value of the wanted variable(s) without first calculating the values of other variables.

● Known Variables

A solid circle (●) indicates that a variable is known. The values of known variables are never changed by the solver, because those variables are considered user-defined. Every time you enter a value for a variable, the variable is automatically marked as known. To remove the known icon from a variable, move the highlight bar to the variable and press KNOW or +/-, and the solid circle will disappear, which means the variable is unknown.

> **NOTE**
>
> Every time you want to solve equations, you must pick some variables to be known and enter values for them, so the solver can use the known variables to calculate values for any unknown variables.

✺ Solution Found

A shaded circle (✺) indicates that an exact solution was found for a variable by the Solver.

No Solution Found

When the solver cannot find a solution, one of three messages will be displayed:

∿ **No Solution** (Extremum)

This message is displayed when the solver finds a point where the value of the equation approximates a local minimum or maximum, or when the solver had to stop searching because it encountered the largest (MAXR) or smallest (–MAXR) possible number.

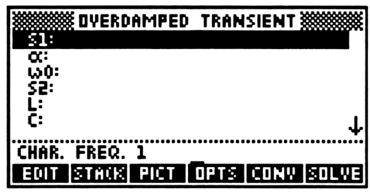
※ **No Solution** (Bad Guess)
This message is displayed when one or more of the initial guesses are outside the domain of the equation, or when complex numbers are encountered by the Solver.

▭ **No Solution** (Constant).
This message is displayed when the equation has the same value at every point sampled.

For more information, see Chapter 33, "Advanced Use of the Solver."

Solver Menu Keys

These are descriptions of the menu keys available at Solver screens:



EDIT Edits the highlighted variable. Press [ENTER] to save edit changes or [ON] to cancel editing.

STACK Copies the highlighted variable to the HP 48 stack and temporarily goes to the HP 48 stack environment. While at the stack, you can use all the normal built-in functions of your HP 48 to manipulate or change the copied value. When you have finished editing the value, press OK to leave the stack and insert the edited value into the current variable, or press CANCL to leave the stack without changing the value of the current variable.

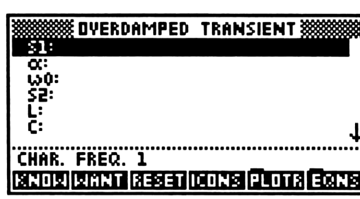
PICT Displays a picture, if available.

OPTS Displays the options menu. For more information, see "Options Menu," page 9.

CONV Displays the convert menu for the highlighted variable. For more information, see "Converting a Value," page 102.

SOLVE Solves the equation(s) using the known values. For more information, see "Solving an Equation," page 101.

Press [NXT] for the following menu keys:



KNOW Marks or unmarks the highlighted variable as known. See "Known Variables," page 104.

WANT Marks or unmarks the highlighted variable as wanted. See "Wanted Variables," page 103.

RESET Resets one or all of the variables. See "Resetting Variables," page 102.

ICONS Displays the Solver Icons screen. See Chapter 33, "Advanced Use of the Solver."

PLOTR Goes to the Plotter screen. See "Plotter Screens," page 106.
EQNS Goes to the Equations screen. See "Equations Screens," page 99.

Plotter Screens

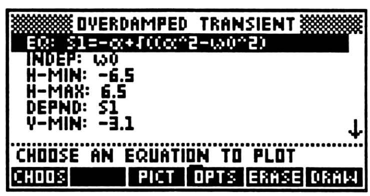
A Plotter screen enables you to plot any of the equations from the Equations screen. A variety of plot parameters can be specified. The HP 48 graphics environment is used to display the plots.

Below are general instructions for using Plotter screens. For a detailed example using Overdamped Transient, see page 110.

Plotting an Equation

1. Go to the Plotter screen by pressing PLOTR from the Equations screen or Solver screen.

2. Select an equation to plot.
   a. Move the highlight bar to the **EQ** field, which displays the equation to be plotted.
   b. To choose another equation, press CHOOS and select the desired equation from the list that appears.



   Selecting an equation automatically sets default values for the independent and dependent variables and units.

3. Set the values of any extra variables. (Only the independent and dependent variables will vary as the equation is plotted, so all other variables must have constant values.)
   a. Press NXT SOLVR to go to the Solver screen.
   b. Move the highlight bar to each of the remaining variables in turn and type in values for them.
   c. Press NXT PLOTR to return to the Plotter screen.

4. Selecting the independent variable.
   a. Move the highlight bar to the **INDEP** field.
   b. Press CHOOS or +/- to select the independent variable.
   c. If units are turned on, choose the desired units for the independent variable in the **H-UNITS** field by moving the highlight bar to that field

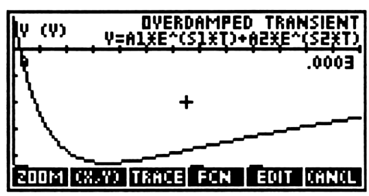
and pressing CHOOS. Once you have selected the desired units, press OK to return to the Plotter screen.

5. Set the horizontal range.
   a. Move the highlight bar to the **H-MIN** and **H-MAX** fields and enter values for the range of the horizontal axis in the plot.

6. Select the dependent variable.
   a. Move the highlight bar to the **DEPND** field.
   b. Press CHOOS or [+/-] to select the dependent variable.
   c. If units are turned on, choose the desired units for the dependent variable in the **V-UNITS** field by scrolling down to that field and pressing CHOOS. Once you have selected the desired units, press OK to return to the Plotter screen.

7. Set the vertical range *OR* autoscale.
   - To set the vertical range: Move the highlight bar to the **V-MIN** and **V-MAX** fields and enter values for the range of the vertical axis in the plot.
   - To autoscale the plot: Move the highlight bar to the **Autoscale** field and press ✓CHK.

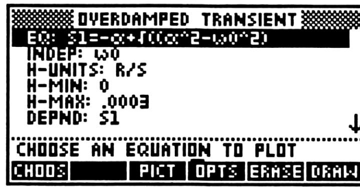
8. Draw the plot.
   a. *Optional:* Press ERASE to erase any previous plots. As with the built-in plotting routines of the HP 48, you can overlay multiple plots by pressing DRAW more than once with different parameters without pressing ERASE between plots.



   b. Press DRAW to plot the equation. (The plot shown above is from the example on page 110.)
   c. Press [ON] to return to the Plotter screen.
9. *Optional:* Press [◄] to return to the RLC Circuits screen or press [↱] [HOME] to return to the home screen.

Plotter Field Descriptions

These are descriptions of each of the fields which appear in a Plotter screen.



EQ:(*Equation to plot*) Press CHOOS to select an equation the current Equations screen.

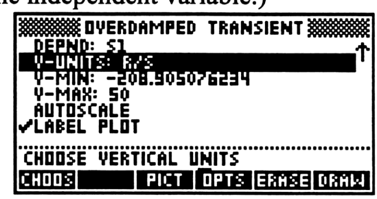
INDEP: (*Independent variable*) This variable varies across the horizontal axis of the plot. Changing the independent variable automatically resets the independent variable units to the default SI unit. Press CHOOS to select from the variables in current equation.

H-UNITS: (*Horizontal axis units*) This field contains the independent variable units. To select the units for the horizontal axis, press CHOOS. This field is only present if units are on. To turn units on or off, press [⬅] UNITS.

H-MIN: (*Horizontal axis minimum*) This is the minimum value of the independent variable, which is plotted along the horizontal axis.

H-MAX: (*Horizontal axis maximum*) This is the maximum value of the independent variable.

DEPND: (*Dependent variable*) This variable varies along the vertical axis of the plot. Changing the dependent variable automatically resets the dependent variable units to the default SI unit. Press CHOOS to select from the variables in current equation. (The dependent variable should be different from the independent variable.)



V-UNITS: (*Vertical axis units*) This field contains the dependent variable units. To select the units for the vertical axis, press CHOOS. This field is only present if units are on. To turn units on or off, press [⬅] UNITS.

V-MIN: (*Vertical axis minimum*) This is the minimum value of the dependent variable, which is plotted along the vertical axis. This field is disregarded if autoscale is on.

V-MAX: (*Vertical axis maximum*) This is the maximum value of the dependent variable. This field is disregarded if autoscale is on.

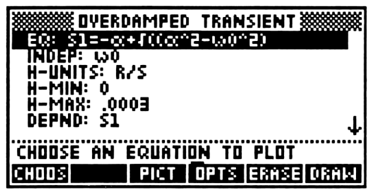
Autoscale: (*Autoscale vertical axis*) Press ✓CHK to autoscale the plot. If autoscale is checked (✓), the values for **V-MIN** and **V-MAX** are disregarded.

Label Plot: (*Label plot*) Press ✓CHK to control whether plot is labeled (checked) or not labeled (unchecked).

Plotter Menu Keys

The menu keys in Plotter screens change depending on the type of field that is highlighted. Plotter screens use three basic types of fields: **Edit** fields, **Choose** fields and **Check** fields. These fields and their associated menu keys are outlined below. The OPTS, ERASE and DRAW menu keys are always present regardless of the field type.

Choose Fields: These fields only accept values from a pre-defined list that is accessed by pressing CHOOS. **EQ**, **INDEP**, **H-UNITS**, **DEPND**, and **V-UNITS** are **Choose** fields.



CHOOS Displays the possible choices for a choose field. Highlight the desired value and press ENTER or OK, or press CANCL to abort the selection.

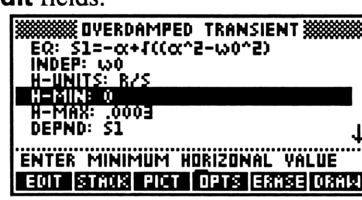
PICT Displays a picture.

OPTS Displays the options menu. For more information, see "Options Menu," page 9.

ERASE Erases any previous plots.

DRAW Plots the current equation. As with the built-in plotting routines of the HP 48, you can overlay multiple plots by pressing DRAW more than once with different parameters without pressing ERASE between plots.

Edit Fields: These fields accept values entered from the keyboard. **H-MIN**, **H-MAX**, **V-MIN** and **V-MAX** are **Edit** fields.



EDIT Edits the highlighted item. The menu keys then change to the standard HP 48 editing keys. Press ENTER to save edit changes or ON to cancel editing.

STACK Copies the highlighted item to the HP 48 stack and temporarily goes to the HP 48 stack environment. While at the stack, you can use all the normal built-in functions of your HP 48 to manipulate or change the copied item. When you have finished editing the item, press OK to leave the stack and insert the edited item into the current **Edit** field, or press CANCL to leave the stack without changing the value of the current **Edit** field.

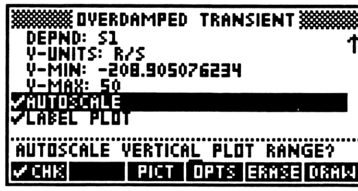
PICT Displays a picture (if available).

OPTS Displays the options menu. For more information, see "Options Menu," page 9.

ERASE Erases any previous plots.

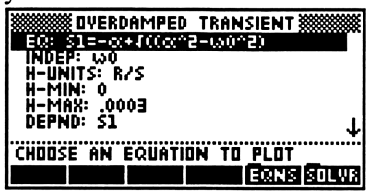
DRAW Plots the current equation.

Check Fields: These fields are toggle fields. A ✓ in front of the field turns that specific control on. **Autoscale** and **Label Plot** are **Check** fields.



✓CHK Toggles a check mark.
PICT Displays a picture (if available).
OPTS Displays the options menu.
ERASE Erases any previous plots.
DRAW Plots the current equation.

In all fields, press [NXT] for these two menu keys:



EQNS Goes to the Equations screen. See "Equations Screens."
SOLVR Goes to the Solver screen. See "Solver Screens," page 100.

Example: Overdamped Parallel RLC Circuit

MODES (Press [CST])	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

An overdamped parallel RLC circuit is characterized by a 100 ohm resistor, a 40 mH inductor and a 0.25 μF capacitor. The inital inductor current is 2 A, and the capacitor has an initial charge of 50 V. Find the voltage transient response across the parallel circuit. Plot the voltage across the capacitor during the first 300 μs.

Solve Multiple Equations

1. Enter the Overdamped Transient screen:
   a. Press [→] [HOME] to go to the home screen.
   b. Choose Equations.
   c. Choose RLC Circuits.
   d. Choose Overdamped Transient.
2. At the Equations screen, make sure no equations are checked and press

Equations Screen

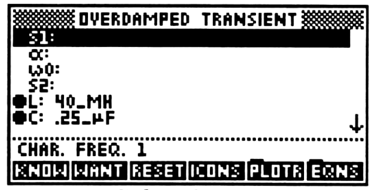
SOLVR to go to the Solver screen.

3. Reset all the variable values by pressing DEL, then ALL.

4. Enter the following values in the appropriate fields. Select the units by pressing the indicated menu key:

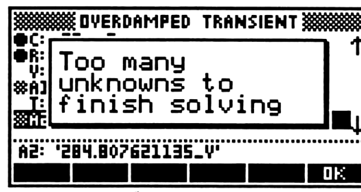
L: 40 (MH)
C: 0.25 (μF)
R: 100 (Ω)
V0: 50 (V)
I0: 2 (A)

A solid circle will appear beside the entered variables, marking them as known. If necessary, press ← UNITS to turn units on.



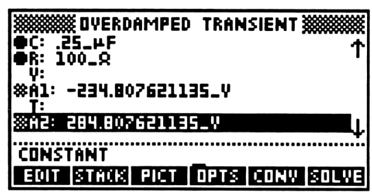
Solver Screen

5. Press SOLVE. The solver will solve for the unknown variables, one by one. With the information entered, it will not be able to find values for **v** or **t**, so you will get the message shown to the right. Press OK to continue.



Solver Message

The found variables are those for which values were calculated and are marked by shaded circles. You have just computed the values of the variables **A1**, **s1**, **A2**, and **s2** in the equation $v = A1 \cdot e^{s1 \cdot t} + A2 \cdot e^{s2 \cdot t}$ which determines the capacitor voltage as a function of time.

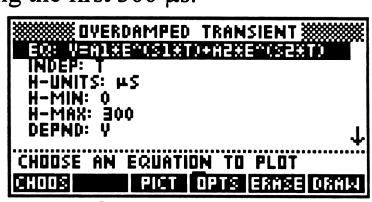


Solver: Answers

Plot one Equation

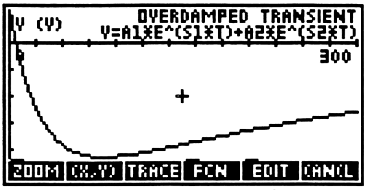
To plot the voltage across the capacitor during the first 300 μs:

1. Press NXT PLOTR to go to the Plotter screen.
2. In the **EQ** field, press ENTER and choose the equation pictured to the right.
3. Choose **t** for **INDEP**.
4. Choose **μs** for **H-UNITS**.
5. Enter 0 for **H-MIN** and .0003 for **H-MAX**.
6. Choose **v** for **DEPND**.



Plotter Entry Screen

7. Scroll down to the **Autoscale** field and press ✓CHK to turn autoscale on.
8. Scroll down to the **Label Plot** field and press ✓CHK to turn label the plot.
9. Press ERASE to erase any previous plots.
10. Press DRAW to draw the plot.
11. *Optional:* Press [◄] to return to the RLC Circuits screen or press [→] [HOME] to return to the home screen.



Plot of Capacitor Voltage

Chapter 17

Resistive Circuits

This chapter covers the equations relevant for dealing with simple resistive circuits.

- ❑ Resistance and Conductance
- ❑ Ohm's Law and Power
- ❑ Temperature Effects
- ❑ Maximum Power Theorem
- ❑ V and I Source Equivalence

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

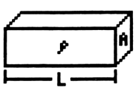
Variable	Description	Unit
α	Temperature coefficient	1/K
A	Area	m^2
G	Conductance	S
I	Current	A
Il	Load current	A
Is	Current source	A
len	Length	m
P	Power	W
Pmax	Maximum power in load	W
ρ	Resistivity	Ω*m
R	Resistance	Ω
R1	Resistance, T1	Ω
R2	Resistance, T2	Ω
Rl	Load resistance	Ω
Rlm	Match load resistance	Ω
Rs	Source resistance	Ω
σ	Conductivity	S/m
T1	Temperature 1	K

T2	Temperature 2	K
V	Voltage	V
Vl	Load voltage	V
Vs	Source voltage	V

Resistance and Conductance

Analysis
Equations
  Resistive Circuits
    Resistance & Condunctance
Reference

The four equations in this section represent the basic relationships between resistance and conductance. The first equation describes the resistance **R** of a bar with a length **len** and a uniform cross-sectional area **A** with a resistivity **ρ**. The second equation defines the conductance **G** of the same bar in terms of conductivity **σ** and **len** and **A.** The third equation shows the reciprocity between conductance **G** and resistance **R**, while the fourth equation shows the corresponding reciprocity between resistivity **ρ** and conductivity **σ**.



$$R=\frac{\rho\cdot len}{A} \qquad G=\frac{\sigma\cdot A}{len} \qquad G=\frac{1}{R} \qquad \sigma=\frac{1}{\rho}$$

Ohm's Law and Power

Analysis
Equations
  Resistive Circuits
    Ohm's Law and Power
Reference

These equations represent the fundamental relationships between voltage, current and power. The first equation expresses the relationship between current **I** and voltage **V** in terms of the resistance **R,** the classic Ohm's law. The next four equations connect power dissipation **P**, voltage **V**, current **I,** resistance **R** and conductance **G**. The final equation represents the reciprocity between resistance **R** and conductance **G**.

$$V=I\cdot R \qquad P=V\cdot I \qquad P=I^2\cdot R$$

$$P=\frac{V^2}{R} \qquad P=V^2\cdot G \qquad R=\frac{1}{G}$$

Temperature Effect

Analysis
Equations
Resistive Circuits
Temperature Effect
Reference

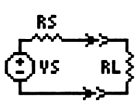
This equation shows the effect of temperature on resistance. Resistance changes from **R1** to **R2** when the temperature **T1** to a temperature **T2** is modulated by the temperature coefficient resistance **α.**

$$R2=R1\cdot(1+\alpha\cdot(T2-T1))$$

Maximum Power Transfer

Analysis
Equations
Resistive Circuits
Maximum Power Transfer
Reference

These five equations are organized to compute load voltage **Vl**, load current **Il**, power dissipation in the load **P**, maximum power available in the load **Pmax**, and load impedance **Rlm** needed for maximum power deliverable to the load. The first equation computes the load voltage **Vl** of a circuit with a simple voltage source **Vs**, source resistance **Rs**, and a load resistance **Rl**. The second equation defines the load current **Il** in terms of **Vs, Rs** and **Rl.** The power dissipation in the load resistance is defined by the third equation linking **P** with **Il** and **Vl.** The fourth equation refers to maximum power available to the load from the voltage source **Vs** with its internal resistance **Rs**. The last equation represents load resistance value needed for a maximum power to be transferred from the source.

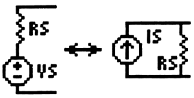


$$Vl=\frac{Vs\cdot Rl}{Rs+Rl} \qquad Il=\frac{Vs}{Rs+Rl} \qquad P=Il\cdot Vl$$

$$Pmax=\frac{Vs^2}{4\cdot Rs} \qquad Rlm=Rs$$

V and I Source Equivalence

The two equations in this section represent the equivalence between a voltage source and a current source. A voltage source **Vs** with an internal series resistance of **Rs** is equivalent in all its functionality to a current source **Is** with a resistance **Rs** connected across it.



$$Is=\frac{Vs}{Rs} \qquad Vs=Is\cdot Rs$$

Bibliography

Edminister, Joseph A., *Electric Circuits, 2nd Edition, Schaum's Outline Series in Engineering*, McGraw-Hill Book Company, New York, N.Y. 1983.

Nilsson, James W., *Electric Circuits, 2nd Edition,* Addison-Wesley Publishing Company, Reading, MA 1987.

Chapter 18

Capacitance and Electric Fields

Analysis
Equations
Capacitance & Electric Fields
Reference

This chapter covers the equations describing a variety of configurations where capacitive properties are calculated.

- ❑ Point Charge
- ❑ Long Charged Line
- ❑ Charged Disk
- ❑ Parallel Plates
- ❑ Parallel Wires
- ❑ Coaxial Cable
- ❑ Sphere

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
a	Radius	m
A	Area	m^2
b	Outer radius	m
C	Capacitance	F
c	Capacitance per unit length	F/m
d	Separation	m
E	Electric field	V/m
εr	Relative permittivity	unitless
Er	Radial electric field	V/m
Ez	Electric field along z axis	V/m
F	Force on plate	N
Q	Charge	C
r	Radial distance	m
ρl	Line charge	C/m

ρs	Charge density	C/m^2
V	Potential	V
Vz	Potential along z axis	V
W	Energy stored	J
z	z axis distance from disk	m

Point Charge

Analysis
Equations
Capacitance & Electric Fields
Point Charge
Reference

The two equations in this module represent the radial electric field **Er** and the potential **V** at a location **r** away from a point change **Q**. It is evident that the electric field is inversely proportional to the square of the distance **r**, while the potential is inversely proportional to **r**. The equations have been generalized to include **εr**, the relative permittivity of the medium.

$$Er=\frac{Q}{4\cdot\pi\cdot\varepsilon 0\cdot\varepsilon r\cdot r^2} \qquad V=\frac{Q}{4\cdot\pi\cdot\varepsilon 0\cdot\varepsilon r\cdot r}$$

Long Charged Line

Analysis
Equations
Capacitance & Electric Fields
Long Charged Line
Reference

An infinite line charge with a strength of **ρl** Coulombs per unit length exerts a radial electric field a distance **r** away from the line. The electric field **Er** is radial and can be easily seen to decay inversely as **r**.

$$Er=\frac{\rho l}{2\cdot\pi\cdot\varepsilon 0\cdot\varepsilon r\cdot r}$$

Charged Disk

Analysis
Equations
Capacitance & Electric Fields
Charged Disk
Reference

There are two equations listed here describing the electric field and potential along the vertical axis through the center of a uniformly charged disk. The first equation defines the electric field along the z-axis of the disk with a radius **a** and charge density of **ρs**, a distance **z** from the plane of the disk. The second equation yields the electrostatic potential **Vz** at an arbitrary point along the z-axis.

$$Ez=\frac{\rho s}{2\cdot\varepsilon 0\cdot\varepsilon r}\cdot\left(1-\frac{ABS(z)}{\sqrt{a^2+z^2}}\right) \qquad Vz=\frac{\rho s}{2\cdot\varepsilon 0\cdot\varepsilon r}\cdot\left(\sqrt{a^2+z^2}-ABS(z)\right)$$

Parallel Plates

Analysis
Equations
Capacitance & Electric Fields
Parallel Plates
Reference

The five equations listed in this section describe the electrical and mechanical properties of a parallel plate capacitor. It is assumed that plate separation **d** is small compared to the lateral dimensions so that fringing field effects can be ignored. The first equation yields the electric field **E** at the plate for a potential difference **V** between the plates. The second equation computes the capacitance **C** of the system given the relative permittivity **εr** and area **A**. The third equation shows the charge on each parallel plate. The last two equations show the mechanical force **F** on the plates and energy stored **W** in the capacitor.

$$E=\frac{V}{d} \qquad C=\frac{\varepsilon 0\cdot\varepsilon r\cdot A}{d} \qquad Q=C\cdot V$$

$$F=\frac{\frac{-1}{2}\cdot V^2\cdot C}{d} \qquad W=\frac{1}{2}\cdot V^2\cdot C$$

Parallel Wires

Analysis
Equations
Capacitance & Electric Fields
Parallel Wires
Reference

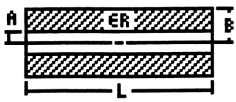
The equation listed here represents the calculation of capacitance per unit length **c** of a pair of transmission lines of radius **a** and center to center spacing **d** in a dielectric medium with a relative permittivity of **εr**.

$$C=\frac{\pi\cdot\varepsilon 0\cdot\varepsilon r}{\text{ACOSH}\left(\frac{d}{2\cdot a}\right)}$$

Coaxial Cable

Analysis
Equations
  Capacitance & Electric Fields
    Coaxial Cable
Reference

These three equations describe properties of a coaxial cable. The first two equations show the voltage between the outer and inner conductors caryying a charge of **ρl** per unit length, relative permittivity **εr**, and conductor diameters **a** and **b**. The last equation computes the radial electric field **Er** between the conductors while the last equation calculates the capacitance per unit length.



$$V=\frac{\rho l}{2\cdot\pi\cdot\varepsilon 0\cdot\varepsilon r}\cdot\text{LN}\left(\frac{b}{a}\right) \qquad Er=\frac{V}{r\cdot\text{LN}\left(\frac{b}{a}\right)} \qquad C=\frac{2\cdot\pi\cdot\varepsilon 0\cdot\varepsilon r}{\text{LN}\left(\frac{b}{a}\right)}$$

Sphere

Analysis
Equations
  Capacitance & Electric Fields
    Sphere
Reference

The three equations in this module compute the potential between two concentric spheres of radius **a** and **b**, with a charge **Q**, and separated by a medium with a relative permittivity of **εr**. The second equation computes the electric field outside a sphere at a distance **r** from the center of the sphere. The last equation computes the capacitance between the spheres.

$$V=\frac{Q}{4\cdot\pi\cdot\varepsilon 0\cdot\varepsilon r}\cdot\left(\frac{1}{a}-\frac{1}{b}\right) \qquad Er=\frac{Q}{4\cdot\pi\cdot\varepsilon 0\cdot\varepsilon r\cdot r^2} \qquad C=\frac{4\cdot\pi\cdot\varepsilon 0\cdot\varepsilon r\cdot a\cdot b}{b-a}$$

Chapter 19

Inductance and Magnetism

Analysis
Equations
Inductance and Magnetism
Reference

This chapter covers the equations describing inductance and magnetic properties of typical electrical configurations.

- ❑ Long Line
- ❑ Long Strip
- ❑ Parallel Wires
- ❑ Loop
- ❑ Coaxial Cable
- ❑ Skin Effect

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
a	Loop radius or side	m
b	Side b of loop	m
B	Magnetic field	T
Bx	Magnetic field, x axis	T
By	Magnetic field, y axis	T
δ	Skin depth	m
d	Strip width	m
D	Center-center wire spacing	m
f	Frequency	Hz
F	Force between wires	N/m
I	Current	A
I1	Current in line 1	A
I2	Current in line 2	A
Is	Current in strip	A/m
L	Inductance per unit length	H/m
L12	Mutual inductance	H
Ls	Loop self-inductance	H
μr	Relative permeability	unitless

r	Radial distance	m
r0	Loop wire radius	m
ρ	Resistivity	Ω*m
η	Angle	r
Reff	Effective resistance	Ω
T12	Torque	N*m
x	x axis distance	m
y	y axis distance	m
z	Distance to loop z axis	m

Long Line

Analysis
Equations
  Inductance and Magnetism
    Long Line
Reference

The magnetic field **B** due to a current **I** from an infinite wire in an infinitely long line is computed here at a distance **r** from the line.

$$B=\frac{\mu 0\cdot I}{2\cdot \pi \cdot r}$$

Long Strip

Analysis
Equations
  Inductance and Magnetism
    Long Strip
Reference

A thin conducting ribbon strip of width **d** is infinitely long and carrying a current **Is** amperes per meter. The **x** and **y** component of the mangetic field **Bx** and **By** are dependent upon the location described by (x, y) coordinates.

$$Bx=\frac{-\mu 0\cdot Is}{2\cdot \pi}\cdot\left(ATAN\left(\frac{\left(x+\frac{d}{2}\right)}{y}\right)-ATAN\left(\frac{\left(x-\frac{d}{2}\right)}{y}\right)\right)$$

$$By=\frac{\mu 0\cdot Is}{4\cdot \pi}\cdot LN\left(\frac{\left(y^2+\left(x+\frac{d}{2}\right)^2\right)}{y^2+\left(x-\frac{d}{2}\right)^2}\right)$$

Parallel Wires

Analysis
Equations
Inductance and Magnetism
Parallel Wires
Reference

Two thin infinite wires carrying currents **I1** and **I2** separated by a distance **D** exert a force of **F** newtons/m between them and generate a tangential magnetic field **B** at the center of one wire due to the field from the other wire. The third equation shows the expression for the tangential magnetic field **B** between the two parallel wires. The distance **x** is measured from the line carrying current **I1**, while the distance of the same point from the second line carrying a current **I2**. The last equation in this set computes the inductance from the two wires of diameter **a** with a spacing of **D**, carrying equal and opposite currents.

$$B=\frac{\mu 0\cdot I}{2\cdot \pi \cdot D} \qquad F=\frac{\mu 0\cdot I1\cdot I2}{2\cdot \pi \cdot D} \qquad Bx=\frac{\mu 0\cdot I}{2\cdot \pi}\cdot\left(\frac{1}{x}+\frac{1}{D-x}\right)$$

$$L=\frac{\mu 0}{4\cdot \pi}+\frac{\mu 0}{\pi}\cdot \mathrm{ACOSH}\left(\frac{D}{2\cdot a}\right)$$

Loop

Analysis
Equations
Inductance and Magnetism
Loop
Reference

The first two equations consider a thin wire bent into a circular loop and carrying a current **I**. The loop radius is **a** and is in the xy plane. The equation for the magnetic field **B** is computed along the z-axis through the center of the loop. The second equation shows the self-inductance of the loop. The last two equations represent the inductance **L12** and torque **T12** of a rectangular loop of sides **a** and **b**, and carrying a current **I2** in the vicinity of a wire carrying a current of **I1** and located at distance **D** as shown in the diagram to the left here.

$$B=\frac{\mu 0\cdot I\cdot a^2}{2\cdot\sqrt{a^2+z^2}^{3}} \qquad Ls=\mu 0\cdot a\cdot\left(\mathrm{LN}\left(\frac{8\cdot a}{r0}\right)-2\right)$$

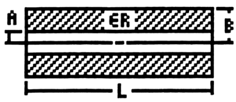
$$L12=\frac{-\mu 0\cdot a\cdot \mathrm{COS}(\theta)}{2\cdot \pi}\cdot \mathrm{LN}\left(\frac{(b+d)}{d}\right)$$

$$T12=\frac{\mu0\cdot a\cdot SIN(\theta)}{2\cdot\pi}\cdot I1\cdot I2\cdot LN\left(\frac{(b+d)}{d}\right)$$

Coaxial Cable

Analysis
Equations
Inductance and Magnetism
Coaxial Cable
Reference

A coaxial transmission line with an outer radius of inner conductor of **a** and inner radius of the outer conductor of **b** is characterized by the inductance **L**.



$$L=\frac{\mu0}{8\cdot\pi}+\frac{\mu0}{2\cdot\pi}\cdot LN\left(\frac{b}{a}\right)$$

Skin Effect

Analysis
Equations
Inductance and Magnetism
Skin Effect
Reference

These two equations represent the effect of high frequency on the resistance of a conductor. The first equation connects the skin depth **δ** with the frequency **f** and the resistivity **ρ**. The skin depth represents the RF signal penetration from the surface of a conductor. The second equation shows the relationship between the effective resistance and **f** and **ρ**. The effective resistance **Reff** is specified in terms of ohms/length/width or often specified as ohms/square.

$$\delta=\frac{1}{\sqrt{\frac{\pi\cdot f\cdot\mu0\cdot\mu r}{\rho}}} \qquad Reff=\sqrt{\pi\cdot f\cdot\mu0\cdot\mu r\cdot\rho}$$

Bibliography

Plonsey, Robert and Robert E. Collin, *Principles and Applications of Electromagnetic Fields*, McGraw-Hill Book Company, Inc. 1961.

Chapter 20

Electron Motion

Analysis Equations *Electron Motion* Reference

This chapter covers equations describing the properties of electrons as they are subjected to electric and magnetic fields.

- ❑ Electron Beam Deflection
- ❑ Thermionic Emission
- ❑ Photoemission

Variables

The table below lists all the variables used in this chapter.

Variable	Description	Unit
A0	Richardson's constant	$A/(m^2*K^2)$
B	Magnetic field	T
d	Deflection tube diameter	m
f	Frequency	Hz
f0	Critical frequency	Hz
I	Thermionic current	A
L	Deflecting plate length	m
Ls	Beam length to destination	m
ϕ	Work function voltage	V
r	Radius of circular path	m
S	Surface area	m^2
T	Temperature	K
u	Velocity	m/s
u0	Electron velocity	m/s
v	Vertical velocity	m/s
Va	Accelerating voltage	V
Vd	Deflecting voltage	V
y	Vertical deflection	m
yd	Beam deflection on screen	m
z	Distance along beam axis	m

Electron Beam Deflection

Analysis
Equations
  Electron Motion
    Electron Beam Deflection
Reference

A beam of electrons subject to accelerating voltage **Va** achieves a velocity **v** as described by the first equation. The second equation computes the radius of curvature **r** when an electron beam with an electron velocity **u0** is passing through a magnetic field **B**. The last two equations show the y-deflection **yd** at distance **Ls** from the center of deflection plates separated by a distance **d** and subject to a deflecting voltage **Vd**.

$$v=\sqrt{2\cdot\left(\frac{q}{me}\right)\cdot Va} \qquad r=\frac{me\cdot u0}{q\cdot B} \qquad yd=\frac{L\cdot Ls}{2\cdot d\cdot Va}\cdot Vd \qquad y=\frac{q\cdot Vd}{2\cdot me\cdot d\cdot u^2}\cdot z^2$$

Thermionic Emission

Analysis
Equations
  Electron Motion
    Thermionic Emission
Reference

When a material is heated to a high temperature **T** the free electrons gain enough thermal energy, forcing a finite fraction to escape the work function barrier **ϕ** and contribute to the external current **I**. The current also depends directly on the surface area **S** and the so-called Richardson's constant **A0**.

$$I=A0\cdot S\cdot T^2\cdot e^{\frac{-q\cdot \phi}{k\cdot T}}$$

Photoemission

Analysis
Equations
  Electron Motion
    Photoemission
Reference

These two equations represent the behavior of electrons when excited by photon energy. A light beam with a frequency **f** generates an RMS velocity **v** for electrons that have to overcome a work function **ϕ**. The second equation shows the threshold frequency for the light beam to extract electrons from the surface of a solid.

$$h \cdot f = q \cdot \phi + \frac{1}{2} \cdot me \cdot v^2 \qquad f0 = \frac{q \cdot \phi}{h}$$

Bibliography

Ryder, John D., *Electronic Fundamentals and Applications*, 5th Edition, Prentice-Hall, Inc., Englewood Cliffs, NJ 1976.

Smith, Ralph J., *Electronics Circuits and Devices*, Second Edition, John Wiley and Sons, New York, NY 1980.

Chapter 21

Meters and Bridge Circuits

This chapter covers the equations describing commonly-used meters, bridges, and attenuator circuits.

- ❑ Amp, Volt, and Ohmmeter
- ❑ Wheatstone Bridge
- ❑ Wien Bridge
- ❑ Maxwell Bridge
- ❑ Owen Bridge
- ❑ Symmetrical Resistive Attenuator
- ❑ Unsymmetrical Resistive Attenuator

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

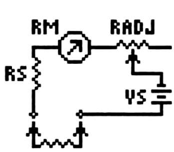
Variable	Description	Unit
C2	Capacitance, arm 2	F
C4	Capacitance, arm 4	F
Cs	Series capacitor	F
Cx	Unknown capacitor	F
DB	Attenuator loss	unitless
f	Frequency	Hz
Ig	Galvanometer current	A
Imax	Maximum current	A
Isen	Current sensitivity	A
Lx	Unknown inductance	H
Q	Quality factor	unitless
R1	Resistance, arm 1	Ω
R2	Resistance, arm 2	Ω
R3	Resistance, arm 3	Ω

R4	Resistance, arm 4	Ω
Ra	Resistance, leg a	Ω
Radj	Adjustable resistor	Ω
Rb	Resistance, leg b	Ω
Rc	Resistance, leg c	Ω
Rg	Galvanometer resistance	Ω
Rj	Resistance in L pad	Ω
Rk	Resistance in L pad	Ω
Rl	Resistance from left	Ω
Rm	Meter resistance	Ω
Ro	Terminating resistance	Ω
Rr	Resistance from right	Ω
Rs	Series resistance	Ω
Rse	Series resistance	Ω
Rsh	Shunt resistance	A
Rx	Unknown resistance	Ω
Vm	Voltage across meter	V
Vmax	Maximum voltage	V
Vs	Source voltage	V
Vsen	Voltage sensitivity	V
ω	Radian frequency	r/s

Amp, Volt, and Ohmmeter

Analysis
Equations
Meters and Bridge Circuits
Amp, Volt, and Ohmmeter
Reference

The three equations in this section highlight the use of resistors in extending the range of ammeters, voltmeters and ohmmeters. The first equation illustrates the use of a shunt resistor **Rsh** to increase the range of an ammeter with a current sensitivity **Isen** and a maximum range **Imax.** The second equation shows the use of a series resistance **Rse** to extend the range of a voltmeter. The third equation extends the range of a series ohmmeter with an internal resistance **Rm** and internal voltage **Vs,** with an adjustable resistor **Radj.** In a practical setup, **Radj** is usually set at its midpoint to compensate for variations in the component values, resulting in a systematic error in the measured result. The third equation is also applicable to a measurement system wherein an unknown resistance is placed in parallel to a shunt ohmmeter. In such a configuration, the meter deflection is designed to show full deflection for an infinite unknown impedance and zero deflection for a short circuit.

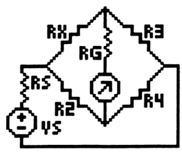


$$Rsh=\frac{Rm\cdot Isen}{Imax-Isen} \qquad Rse=\frac{(Vmax-Vsen)}{Isen} \qquad Isen=\frac{Vs}{Rs+Rm+\frac{Radj}{2}}$$

Wheatstone Bridge

Analysis
Equations
  Meters and Bridge Circuits
    Wheatstone Bridge
Reference

These three equations represent the classic relationship in a Wheatstone bridge network with four resistor elements **Rx, R2, R3** and **R4.** When the bridge is balanced, there is no current in the galvanometer circuit. The first equation defines the requirement for a balanced bridge. The second and third equations compute the voltage **Vm** across the bridge and the galvanometer current **Ig.** The special function GALV calculates the voltage across the bridge, and is a complex function of **Vs, Rx, R2, R3, R4, Rg** and **Rs.**

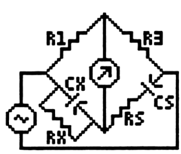


$$\frac{Rx}{R2}=\frac{R3}{R4} \qquad Vm=GALV(Rx,R2,R3,R4,Rg,Rs,Vs) \qquad Ig=\frac{Vm}{Rg}$$

Wien Bridge

Analysis
Equations
  Meters and Bridge Circuits
    Wien Bridge
Reference

A Wien bridge circuit is designed to measure an unknown capacitance **Cx.** The first two equations focus on two methods of measuring **Cx** in terms of the branch resistances **R1** and **R3,** series resistance **Rs,** and parallel resistance **Rx.** The bridge can also be used to measure frequency **f** with the third equation after setting **Cx=Cs, Rx=Rs,** and **R3=2*R1.**

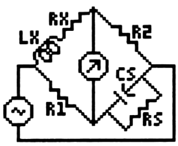


$$\frac{Cx}{Cs}=\frac{R3}{R1}-\frac{Rs}{Rx} \qquad Cs\cdot Cx=\frac{1}{\omega^2\cdot Rs\cdot Rx} \qquad f=\frac{1}{\frac{2}{\pi}\cdot Cs\cdot Rs} \qquad \omega=2\cdot\pi\cdot f$$

Maxwell Bridge

Analysis
Equations
Meters and Bridge Circuits
Maxwell Bridge
Reference

A Maxwell bridge is designed to measure the inductance **Lx** and its series resistance **Rx** in a bridge circuit. The input stimulus to the bridge circuit is typically an AC source with variable frequency and an AC meter detecting a null. The first two equations measure the unknown inductance **Lx** and its resistance **Rx** is by varying the capacitance **Cs** and its parallel resistance **Rs.** The third and fourth equations measure the quality factor **Q** by using either measured **Lx** and **Rx** or known **Cs** and **Rs.** The final equation links the radian frequency **ω** to the frequency **f.**



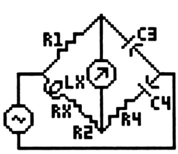
$$Lx = R2 \cdot R3 \cdot Cs \qquad Rx = \frac{R2 \cdot R3}{Rs} \qquad Q = \omega \cdot \left(\frac{Lx}{Rx}\right)$$

$$Q = \omega \cdot Cs \cdot Rs \qquad \omega = 2 \cdot \pi \cdot f$$

Owen Bridge

Analysis
Equations
Meters and Bridge Circuits
Owen Bridge
Reference

The Owen bridge circuit is an alternative AC bridge circuit used to measure an inductance and its series resistance. The input stimulus to the bridge circuit is typically an AC source with variable frequency and an AC meter detecting a null. The inductance **Lx** is measured in terms of the capacitor **C3,** and the branch resistance **R1** and **R4**. The series resistance **Rx** is measured by a ratio of the capacitors **C3** and **C4** tempered by **R2**, the variable resistance in the **Lx** arm of the bridge.

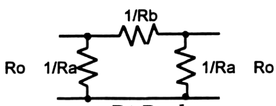


$$Lx = C3 \cdot R1 \cdot R4 \qquad Rx = \frac{C3 \cdot R1}{C4} - R2$$

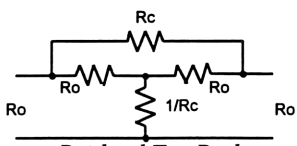
Symmetrical Resistive Attenuator

Analysis
Equations
  Meters and Bridge Circuits
    Sym. Resistive Attenuator
Reference

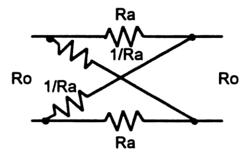
Balanced resistive networks are commonly used as attenuators in transmission line circuits. These three equations form the basis of design of an attenuator in a Tee pad, a Pi pad, a bridged Tee pad or a balanced pad configuration. These design equations compute the resistance values in the circuit given an attenuation loss **DB**, which is defined in decibels. The first equation defines the value of **Ra** for a Tee pad, Pi pad, a bridged Tee pad or a balanced pad configuration. The resistance **Rb** is defined by the second equation for a Tee pad or a Pi pad. The third equation defines **Rc** for a bridged Tee pad or a balanced pad configuration.



Pi Pad



Bridged Tee Pad



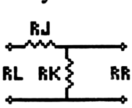
Balanced Pad

$$Ra=\frac{Ro\cdot\left(10^{\frac{DB}{20}}-1\right)}{10^{\frac{DB}{20}}+1}\qquad Rb=\frac{Ro\cdot 2\cdot 10^{\frac{DB}{20}}}{10^{\frac{DB}{10}}-1}\qquad Rc=Ro\cdot\left(10^{\frac{DB}{20}}-1\right)$$

Unsymmetrical Resistive Attenuator

Analysis
Equations
  Meters and Bridge Circuits
    Unsym. Res. Attenuator
Reference

Unsymmetrical resistive attenuator design equations are given in this section. These equations compute the resistance values for a minimum loss L pad of an unsymmetrical network with an impedance **Rl** to the left of the L-network and an impedance **Rr** to the right of the network. The first two equations calculate **Rj** and **Rk**, the resistor values of the L network. The third equation determines the minimum loss of signal strength **DB**.



$$Rj=Rl-\frac{Rk\cdot Rr}{Rk+Rr}\qquad Rk=\sqrt{\frac{Rl\cdot Rr^{2}}{Rl-Rr}}\qquad DB=20\cdot LOG\left(\sqrt{\frac{(Rl-Rr)}{Rr}}+\sqrt{\frac{Rl}{Rr}}\right)$$

Bibliography

Robert L. Boylestad, *Introductory Circuit Analysis, 3rd Edition,* Charles E. Merrill Publishing Company, A Bell and Howell Company, Columbus, OH 43216, 1977.

Joseph A. Edminister, *Electric Circuits, 2nd Edition, Schaum's Outline Series in Engineering*, McGraw-Hill Book Company, New York, N.Y. 1983.

Edward C. Jordan, Editor in Chief, *Reference Data for Engineers: Radio, Electronics, Computer and Communications, Seventh Edition,* Howard and Sams & Co, Inc., A Subsidiary of Macmillan, Inc., Indianapolis IN 46268, 1985.

Chapter 22

RL and RC Circuits

This chapter covers equations for on RL and RC Circuits.

- ❑ RL Natural Response
- ❑ RC Natural Response
- ❑ RL Step Response
- ❑ RC Step Response
- ❑ RL Series to Parallel
- ❑ RC Series to Parallel

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
C	Capacitor	F
Cs	Series capacitance	F
Cp	Parallel capacitance	F
f	Frequency	Hz
iC	Capacitor current	A
iL	Inductor current	A
I0	Initial inductor current	A
L	Inductance	H
Lp	Parallel inductance	H
Ls	Series inductance	H
Qp	Q, parallel circuit	unitless
Qs	Q, series circuit	unitless
R	Resistance	Ω
Rp	Parallel resistance	Ω
Rs	Series resistance	Ω
τ	Time constant	s

t	Time	s
vC	Capacitor voltage	V
vL	Inductor voltage	V
V0	Initial capacitor voltage	V
Vs	Voltage stimulus	V
ω	Radian frequency	r/s
W	Energy dissipated	J

RL Natural Response

Analysis
Equations
  RL and RC Circuits
    RL Natural Response
Reference

These four equations define all the key properties for the natural response of an RL circuit with no energy sources. The first equation shows the characteristic time constant **τ** in terms of the resistance **R** and the inductance **L**. The second equation computes the decay of the voltage **vL** across the inductor with an inital current **I0**. The third equation displays the decay of the inductor current **iL**. The final equation shows the energy dissipation properties of the circuit.

$$\tau=\frac{L}{R}$$

$$vL=I0\cdot R\cdot e^{\frac{-t}{\tau}}$$

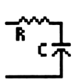
$$iL=I0\cdot e^{\frac{-t}{\tau}}$$

$$W=\frac{1}{2}\cdot L\cdot I0^{2}\cdot\left(1-e^{\frac{-2\cdot t}{\tau}}\right)$$

RC Natural Response

Analysis
Equations
  RL and RC Circuits
    RC Natural Response
Reference

These four equations define all the natural response characteristics of an RC circuit with no energy sources. The first equation specifies the characteristic time constant **τ** in terms of the resistance **R** and the capacitance **C**. The second equation computes the decay of the voltage **vC** across the capacitor with an initial voltage of **V0**. The third equation shows the decay of the capacitor current **iC**. The final equation computes the energy dissipation properties.



$$\tau = R \cdot C \qquad vC = V0 \cdot e^{\frac{-t}{\tau}} \qquad iC = \frac{V0}{R} \cdot e^{\frac{-t}{\tau}}$$

$$W = \frac{1}{2} \cdot C \cdot V0^2 \cdot \left(1 - e^{\frac{-2 \cdot t}{\tau}}\right)$$

RL Step Response

Analysis
Equations
  RL and RC Circuits
    RL Step Response
Reference

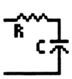
These three equations describe the response of an inductive circuit to a voltage step stimulus. The first equation calculates the time constant **τ** in terms of the inductance **L** and the resistance **R**. The last two equations compute the inductor voltage **vL** and current **iL** in terms of the step stimulus **Vs**, initial condition **I0**, time **t**, and time constant **τ**.

$$\tau = \frac{L}{R} \qquad vL = (Vs - I0 \cdot R) \cdot e^{\frac{-t}{\tau}} \qquad iL = \frac{Vs}{R} + \left(I0 - \frac{Vs}{R}\right) \cdot e^{\frac{-t}{\tau}}$$

RC Step Response

Analysis
Equations
  RL and RC Circuits
    RC Step Response
Reference

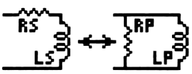
These three equations show the step response properties of an RC circuit. The first equation defines the characteristic time constant **τ** in terms of the resistance **R** and the capacitance **C**. The last two equations compute the capacitor voltage **vC** and current **iC** in terms of the step stimulus voltage **Vs**, initial capacitor voltage **V0**, time **t** and time constant **τ**.



$$\tau = R \cdot C \qquad vC = Vs + (V0 - Vs) \cdot e^{\frac{-t}{\tau}} \qquad iC = \frac{(Vs - V0)}{R} \cdot e^{\frac{-t}{\tau}}$$

RL Series to Parallel

The ten equations in this section show the equivalence between a series RL circuit with values **Rs** and **Ls** and its parallel equivalent circuit with values **Rp**, **Lp**. The first equation defines the relationship between the radian frequency **ω** and the frequency **f.** The second equation specifies the quality factor **Qs** for the series circuit values **Rs** and **Ls**. The next two equations define the values of **Rp** and **Lp** in terms of **Rs, Ls** and the radian frequency **ω.** The fifth and sixth equations compute **Rp** and **Lp** in terms of **Rs**, **Ls** and **Qs**. The remaining five equations show the inverse relationships, where the series equivalent values **Rs** and **Ls** are expressed in terms of the parallel RL circuit values **Rp, Lp, ω** and the quality factor for the parallel RL circuit **Qp**.



$$\omega=2\cdot\pi\cdot f$$

$$Qs=\frac{\omega\cdot Ls}{Rs}$$

$$Rp=\frac{\left(Rs^2+\omega^2\cdot Ls^2\right)}{Rs}$$

$$Lp=\frac{\left(Rs^2+\omega^2\cdot Ls^2\right)}{\omega^2\cdot Ls}$$

$$Rp=Rs\cdot\left(1+Qs^2\right)$$

$$Lp=Ls\cdot\left(1+\frac{1}{Qs^2}\right)$$

$$Qp=\frac{Rp}{\omega\cdot Lp}$$

$$Rs=\frac{\omega^2\cdot Lp^2\cdot Rp}{Rp^2+\omega^2\cdot Lp^2}$$

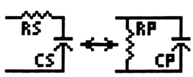
$$Ls=\frac{Rp^2\cdot Lp}{Rp^2+\omega^2\cdot Lp^2}$$

$$Rs=\frac{Rp}{1+Qp^2}$$

$$Ls=\frac{Qp^2\cdot Lp}{1+Qp^2}$$

RC Series to Parallel

The ten equations in this section show the equivalence between a series RC circuit with values **Rs** and **Cs** and its parallel equivalent circuit with values **Rp**, and **Cp**. The first equation defines the radian frequency **ω** in terms of **f**. The second equation computes the quality factor **Qs** in terms of **ω** and the series resistance **Rs** and capacitance **Cs**. The next two equations compute the parallel equivalent values as a function of **Rs** and **ω**. The fifth equation computes **Rp** as a function of **Rs**, **Cs** and **Qs**. The remaining five equations show the inverse set of relationships where the series equivalent values **Rs** and **Cs** are expressed in terms of the parallel RC circuit values **Rp, Cp, ω** and the quality factor for the parallel RC circuit **Qp**.



$$\omega = 2 \cdot \pi \cdot f$$

$$Qs = \frac{1}{\omega \cdot Rs \cdot Cs}$$

$$Rp = Rs \cdot \left(1 + \frac{1}{\omega^2 \cdot Rs^2 \cdot Cs^2}\right)$$

$$Cp = \frac{Cs}{1 + \omega^2 \cdot Cs^2 \cdot Rs^2}$$

$$Rp = Rs \cdot \left(1 + Qs^2\right)$$

$$Qp = \omega \cdot Rp \cdot Cp$$

$$Rs = \frac{Rp}{1 + \omega^2 \cdot Rp^2 \cdot Cp^2}$$

$$Cs = \frac{\left(1 + \omega^2 \cdot Rp^2 \cdot Cp^2\right)}{\omega^2 \cdot Rp^2 \cdot Cp}$$

$$Rs = \frac{Rp}{1 + Qp^2}$$

$$Cs = \frac{Cp \cdot \left(1 + Qp^2\right)}{Qp^2}$$

Bibliography

Nilsson, James W., *Electric Circuits, 2nd Edition,* Addison-Wesley Publishing Company, Reading, MA 1987.

Chapter 23

RLC Circuits

Analysis
Equations
RLC Circuits
Reference

This chapter covers all the essential equations for computing impedance and admittance, natural response, and transient behavior of RLC circuits.

- ❑ Series Impedance
- ❑ Parallel Admittance
- ❑ RLC Natural Response
- ❑ Underdamped Transient
- ❑ Critically-Damped Transient
- ❑ Overdamped Transient

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
α	Neper's frequency	r/s
A1	Constant	V
A2	Constant	V
B	Susceptance	S
B1	Constant	V
B2	Constant	V
BC	Capacitive susceptance	S
BL	Inductive susceptance	S
C	Capacitance	F
D1	Constant	V/s
D2	Constant	V
f	Frequency	Hz
G	Conductance	S
I0	Initial inductor current	A
L	Inductance	H
θ	Phase angle	r

R	Resistance	Ω
s1	Characteristic frequency 1	r/s
s2	Characteristic frequency 2	r/s
s1i	Characteristic frequency 1 (imag.)	unitless
s1r	Characteristic frequency 1 (real)	unitless
s2i	Characteristic frequency 2 (imag.)	unitless
s2r	Characteristic frequency 2 (real)	unitless
t	Time	s
v	Capacitor voltage	V
V0	Initial capacitor voltage	V
ω	Radian frequency	r/s
ωd	Damped resonant frequency	r/s
ω0	Classical resonant frequency	r/s
X	Reactance	Ω
XC	Capacitive reactance	Ω
XL	Inductive reactance	Ω
Ym	Admittance magnitude	S
Zm	Impedance magnitude	Ω

Series Impedance

Analysis
Equations
  RLC Circuits
    Series Impedance
Reference

These six equations compute the series impedance of an RLC circuit. The first two equations focus on calculating the magnitude and phase angle of the impedance in terms of resistance the **R** and reactance **X**. The third equation computes the reactance **X** as the sum of the inductive and capacitive parts **XL** and **XC**, respectively. In the fourth and fifth equations, **XL** is computed in terms of the radian frequency **ω** and inductance **L**, while **XC** is computed in terms of **ω** and **C**. In the last equation, **ω** is defined in terms of the frequency **f**.

$$\mathrm{ABS}(Zm)^2 = R^2 + X^2 \qquad \theta = \mathrm{ATAN}\left(\frac{X}{R}\right) \qquad X = XL + XC$$

$$XL = \omega \cdot L \qquad XC = \frac{-1}{\omega \cdot C} \qquad \omega = 2 \cdot \pi \cdot f$$

Parallel Admittance

Analysis
Equations
  RLC Circuits
    Parallel Admittance
Reference

These seven equations compute the admittance of an RLC parallel circuit. The first two equations calculate the magnitude of the admittance **Ym** and its phase angle **θ** in terms of the conductance **G** and susceptance **B**. The third equation calculates the conductance **G** in terms of the resistance **B**. The next three equations compute the susceptance **B** as a sum of its inductive and capacitive components **BL** and **BC**, respectively. The final equation links the radian frequency **ω** and frequency **f**.

$$\mathrm{ABS}(Ym)^2=G^2+B^2 \qquad \theta=\mathrm{ATAN}\left(\frac{G}{B}\right) \qquad G=\frac{1}{R}$$

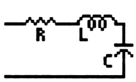
$$B=BL+BC \qquad BL=\frac{-1}{\omega\cdot L} \qquad BC=\omega\cdot C$$

$$\omega=2\cdot\pi\cdot f$$

RLC Natural Response

Analysis
Equations
  RLC Circuits
    RLC Natural Response
Reference

These six equations compute the generalized complex frequencies for an RLC circuit. In general there are two complex conjugate frequencies **s1** and **s2** with real and imaginary parts **s1r**, **s1i**, **s2r**, and **s2i**, respectively. They are computed in terms of the classical resonant frequency **ω0**, and Neper's frequency **α**, which are defined by the final two equations.



$$s1r=\mathrm{RE}\left(-\alpha+\sqrt{\alpha^2-\omega0^2}\right) \qquad s1i=\mathrm{IM}\left(-\alpha+\sqrt{\alpha^2-\omega0^2}\right)$$

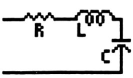
$$s2r=\mathrm{RE}\left(-\alpha-\sqrt{\alpha^2-\omega0^2}\right) \qquad s2i=\mathrm{IM}\left(-\alpha-\sqrt{\alpha^2-\omega0^2}\right) \qquad \omega0=\sqrt{\frac{1}{L\cdot C}}$$

$$\alpha=\frac{1}{2\cdot R\cdot C}$$

Underdamped Transient

Analysis
Equations
  RLC Circuits
    Underdamped Transient
Reference

The six equations in this section represent the transient response of an underdamped RLC circuit. *The condition for an underdamped system is that* **ω0** > **α**. The first equation shows the classical radian frequency **ω0**, which is determined by the inductance and capacitance **L** and **C**. The Neper's frequency **α** is calculated in the second equation. The damped resonant frequency **ωd** is computed from **ω0** and **α** in the third equation. The fourth equation shows the voltage across the capacitor **v**, while the last two equations show the relationship of the constants **B1** and **B2** to the initial capacitor voltage **V0**, initial inductor current



I0, the capacitor **C** and resistor **R**, and frequencies **ωd** and **α**. The voltage across the capacitor shows an osillatory behavior with respect to the characteristic frequency **ωd**.

$$\omega 0=\sqrt{\frac{1}{L\cdot C}} \qquad \alpha=\frac{1}{2\cdot R\cdot C} \qquad \omega d=\sqrt{\omega 0^2-\alpha^2}$$

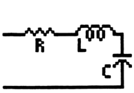
$$v=B1\cdot e^{-\alpha\cdot t}\cdot \mathrm{COS}(\omega d\cdot t)+B2\cdot e^{-\alpha\cdot t}\cdot \mathrm{SIN}(\omega d\cdot t) \qquad B1=V0$$

$$B2=\frac{-\alpha}{\omega d}\cdot V0-\frac{1}{\omega d\cdot C}\cdot\left(\frac{V0}{R}+I0\right)$$

Critically-Damped Transient

Analysis
Equations
  RLC Circuits
    Critically-Damped Transient
Reference

The five equations in this section represent the RLC transient response of a critically-damped circuit. *The condition for an critically-damped system is that* **ω0** = **α**. The first two equations define the Neper's frequency **α** and the classical resonant frequency **ω0**. The third equation represents the transient response to a step function stimulus of the voltage across the capacitor **v**, as expressed in terms of the constants **D1** and **D2**, Neper's frequency, and time **t**.



The last two equations compute the constants **D1** and **D2** in terms of the capacitor voltage **V0** and the initial inductor current **I0**.

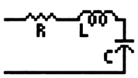
$$\alpha=\frac{-1}{2\cdot R\cdot C} \qquad \omega0=\sqrt{\frac{1}{L\cdot C}} \qquad v=D1\cdot t\cdot e^{\alpha\cdot t}+D2\cdot e^{\alpha\cdot t}$$

$$D1=-\alpha\cdot(V0+2\cdot I0\cdot R) \qquad D2=V0$$

Overdamped Transient

Analysis
Equations
RLC Circuits
Overdamped Transient
Reference

The seven equations in this section show the transient performance of an overdamped RLC circuit.. *The condition for an overdamped system is that* **α** > **ω0**. The first two equations define the characteristic frequencies **s1** and **s2** in terms of the Neper's frequency **α** and the classical resonant frequency **ω0**, which are calculated in the third and fourth equations. The fifth equation represents the transient response to a step function stimulus of the voltage across the capacitor **v**. This response is determined by the constants **A1** and **A2**, the characteristic frequencies **s1** and **s2**, and the time **t**. The last two equations compute the constants **A1** and **A2** from the initial capacitor voltage **V0**, the initial inductor current **I0**, and the characteristic frequencies **s1** and **s2**.



$$s1=-\alpha+\sqrt{\alpha^2-\omega0^2} \qquad s2=-\alpha-\sqrt{\alpha^2-\omega0^2} \qquad \omega0=\frac{1}{\sqrt{L\cdot C}}$$

$$\alpha=\frac{1}{2\cdot R\cdot C} \qquad v=A1\cdot e^{s1\cdot t}+A2\cdot e^{s2\cdot t} \qquad A1=\frac{\left[V0\cdot s2+\frac{1}{C}\cdot\left(\frac{V0}{R}+I0\right)\right]}{s2-s1}$$

$$A2=\frac{-\left[V0\cdot s1+\frac{1}{C}\cdot\left(\frac{V0}{R}+I0\right)\right]}{s2-s1}$$

Bibliography

Nilsson, James W., *Electric Circuits, 2nd Edition, Chapter 8*, Addison-Wesley Publishing Company, Reading, MA 1987.

Chapter 24

AC Circuits

Analysis
Equations
AC Circuits
Reference

This chapter covers equations describing the properties of AC circuits.

- ❑ RL Series Impedance
- ❑ RC Series Impedance
- ❑ Impedance ↔ Admittance
- ❑ Two Impedances in Series
- ❑ Two Impedances in Parallel

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
B	Susceptance	S
C	Capacitance	F
f	Frequency	Hz
G	Conductance	S
I	Instantaneous current	A
Im	Current amplitude	A
L	Inductance	H
θ	Impedance phase angle	r
θ1	Phase angle 1	r
θ2	Phase angle 2	r
θy	Admittance phase angle	r
θz	Impedance phase angle	r
R	Resistance	Ω
R1	Resistance 1	Ω
R2	Resistance 2	Ω
t	Time	s
V	Total voltage	V
VC	Voltage across capacitor	V

VL	Voltage across inductor	V
Vm	Maximum voltage	V
VR	Voltage across resistor	V
ω	Radian frequency	r/s
X	Reactance	Ω
X1	Reactance 1	Ω
X2	Reactance 2	Ω
Ym	Admittance magnitude	S
Z1m	Impedance 1 magnitude	Ω
Z2m	Impedance 2 magnitude	Ω
Zm	Impedance magnitude	Ω

RL Series Impedance

Analysis
Equations
AC Circuits
RL Series Impedance
Reference

The eight equations in this section describe the relationships of an RL series circuit. The first equation shows a sinusoidal current **I** defined in terms of an amplitude **Im**, radian frequency **ω**, and time **t**. The second equation defines the magnitude of the impedance **Zm** in terms of the resistance **R**, and the inductance **L** and **ω**. The third and fourth equations show the voltage drops **VR** and **VL** across the resistor and inductor, respectively. The fifth equation shows the instantaneous voltage across the RL circuit, the next two equations

show the amplitude **VM** and phase **θ** of the voltage across the circuit. The final equation shows the relation between **ω** and frequency **f**.

$$I=Im\cdot SIN(\omega\cdot t) \qquad ABS(Zm)^2=R^2+\omega^2\cdot L^2$$

$$VR=Zm\cdot Im\cdot SIN(\omega\cdot t)\cdot COS(\theta) \qquad VL=Zm\cdot Im\cdot COS(\omega\cdot t)\cdot SIN(\theta)$$

$$V=VR+VL \qquad Vm=Im\cdot Zm \qquad \theta=ATAN\left(\frac{\omega\cdot L}{R}\right)$$

$$\omega=2\cdot\pi\cdot f$$

RC Series Impedance

Analysis
Equations
AC Circuits
RC Series Impedance
Reference

The eight equations in this section describe the relationships of an RC series circuit. The first equation shows a sinusoidal current **I** defined in terms of an amplitude **Im**, radian frequency **ω**, and time **t**. The second equation defines the magnitude **Zm** of the AC impedance of the circuit in terms of the resistance **R**, capacitance **C**, and radian frequency **ω**. The third and fourth equations express the voltage **VR** across the resistor and the voltage **VC** across the capacitor. The sum of **VR** and **VC** represents the total voltage **V** across the RC series circuit. The next two equations show the amplitude **Vm** and phase **θ** of the voltage across the circuit. The final equation connects **ω** with the frequency **f**.

$$I = Im \cdot SIN(\omega \cdot t)$$

$$ABS(Zm)^2 = R^2 + \frac{1}{(\omega \cdot C)^2}$$

$$VR = Zm \cdot Im \cdot SIN(\omega \cdot t) \cdot COS(\theta)$$

$$VC = Zm \cdot Im \cdot COS(\omega \cdot t) \cdot SIN(\theta)$$

$$V = VR + VC$$

$$Vm = Im \cdot Zm$$

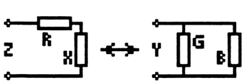
$$\theta = ATAN\left(\frac{-1}{\omega \cdot C \cdot R}\right)$$

$$\omega = 2 \cdot \pi \cdot f$$

Impedance ↔ Admittance

Analysis
Equations
AC Circuits
Impedance ↔ Admittance
Reference

These ten equations describe the relationship between impedance and admittance. The first four equations focus on the impedance: its magnitude **Zm**, its real and imaginary parts **R** and **X**, and its phase angle **θz**. The fifth and sixth equations link the phase and magnitude of the impedance and admittance. The last five equations focus on the admittance: its magnitude **Ym**, its real and imaginary parts **G** and **B**, and its phase angle **θy**.



$$ABS(Zm)^2=R^2+X^2 \qquad \theta z=ATAN\left(\frac{X}{R}\right) \qquad R=Zm\cdot COS(\theta z)$$

$$X=Zm\cdot SIN(\theta z) \qquad \theta y=-\theta z \qquad Ym=\frac{1}{Zm}$$

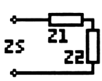
$$G=Ym\cdot COS(\theta y) \qquad B=Ym\cdot SIN(\theta y) \qquad ABS(Ym)^2=G^2+B^2$$

$$\theta y=ATAN\left(\frac{B}{G}\right)$$

Two Impedances in Series

Analysis
Equations
  AC Circuits
    Two Impedances in Series
Reference

These eight equations characterize the manner of combining two impedances **Z1** and **Z2** in series with real and imaginary parts **R1** and **X1**, **R2** and **X2**, respectively. The impedances **Z1** and **Z2** can be expressed in terms of their magnitudes **Z1m** and **Z2m**, and phase angles **θ1** and **θ2** as shown by the last four equations. The resulting impedance has a magnitude **Zm** and a phase angle **θ**, as shown by the first two equations. **R** and **X** represent the real and imaginary parts of the resulting impedance, and are defined by the third and fourth equations.



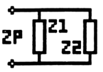
$$ABS(Zm)^2=R^2+X^2 \qquad \theta=ATAN\left(\frac{X}{R}\right) \qquad R=R1+R2$$

$$X=X1+X2 \qquad ABS(Z1m)^2=R1^2+X1^2$$

$$ABS(Z2m)^2=R2^2+X2^2 \qquad \theta 1=ATAN\left(\frac{X1}{R1}\right) \qquad \theta 2=ATAN\left(\frac{X2}{R2}\right)$$

Two Impedances in Parallel

These eight equations describe the properties of combining two impedances **Z1** and **Z2** in parallel. **Z1** is expressed in terms of real and imaginary parts **R1** and **X1**, or of magnitude **Z1m** and phase **θ1**. Similarly, **Z2** can be defined by real and imaginary parts **R2** and **X2** or magnitude and phase **Z2m** and **θ2**. **Zm** and **θ** are computed from known values of **R1**, **X1**, **R2** and **X2**.



$$\mathrm{ABS}(Zm)^2 = \frac{\left((R1 \cdot R2 - X1 \cdot X2)^2 + (R1 \cdot X2 + R2 \cdot X1)^2\right)}{(R1+R2)^2 + (X1+X2)^2}$$

$$\theta = \mathrm{ATAN}\left(\frac{(X1 \cdot R2 + R1 \cdot X2)}{R1 \cdot R2 - X1 \cdot X2}\right) - \mathrm{ATAN}\left(\frac{(X1+X2)}{R1+R2}\right)$$

$$R = Zm \cdot \mathrm{COS}(\theta) \qquad X = Zm \cdot \mathrm{SIN}(\theta) \qquad \mathrm{ABS}(Z1m)^2 = R1^2 + X1^2$$

$$\mathrm{ABS}(Z2m)^2 = R2^2 + X2^2 \qquad \theta1 = \mathrm{ATAN}\left(\frac{X1}{R1}\right) \qquad \theta2 = \mathrm{ATAN}\left(\frac{X2}{R2}\right)$$

Chapter 25

Polyphase Circuits

Analysis
Equations
Polyphase Circuits
Reference

This chapter covers equations describing polyphase circuits.

- ❑ Balanced Δ Network
- ❑ Balanced Wye Network
- ❑ Power Measurements

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
IL	Line current	A
Ip	Phase current	A
P	Power per phase	W
PT	Total power	W
θ	Impedance angle	r
VL	Line voltage	V
Vp	Phase voltage	V
W1	Wattmeter 1	W
W2	Wattmeter 2	W

Balanced Δ Network

Analysis
Equations
Polyphase Circuits
Balanced Δ Network
Reference

These five equations cover the essential relationships for a balanced Δ network. The first equation defines the line voltage **VL** in terms of the phase voltage **Vp**. The second equation defines the line current **IL** in terms of the phase current **Ip**. The third equation shows the power in each phase in terms of **Vp**, **Ip** and the phase delay **θ** between voltage and current. The last two equations represent the total power **PT** delivered to the system in terms of line voltage and current or the phase voltage and current.

$$VL=Vp \qquad IL=\sqrt{3}\cdot Ip \qquad P=Vp\cdot Ip\cdot COS(\theta)$$

$$PT=3\cdot Vp\cdot Ip\cdot COS(\theta) \qquad PT=\sqrt{3}\cdot VL\cdot IL\cdot COS(\theta)$$

Balanced Wye Network

Analysis
Equations
  Polyphase Circuits
    Balanced Wye Network
Reference

These five equations cover the essential relationships for a balanced star network. The first equation defines the line voltage **VL** in terms of the phase voltage **Vp**. The second equation defines the line current **IL** in terms of the phase current **Ip**. The third equation shows the power in each phase in terms of **Vp**, **Ip** and phase delay **θ**. The last two equations represent total power **PT** delivered to the system in terms of line voltage and current or phase voltage and current.

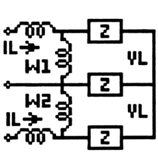
$$VL=\sqrt{3}\cdot Vp \qquad IL=Ip \qquad P=Vp\cdot Ip\cdot COS(\theta)$$

$$PT=3\cdot Vp\cdot Ip\cdot COS(\theta) \qquad PT=\sqrt{3}\cdot VL\cdot IL\cdot COS(\theta)$$

Power Measurements

Analysis
Equations
  Polyphase Circuits
    Power Measurements
Reference

These three equations for a two-wattmeter connection are used to measure the total



power of a balanced network. The wattmeter readings **W1** and **W2** are expressed in terms of the line current **IL**, line voltage **VL**, and phase delay **θ** between voltage and current. The final equation represents the total power delivered to the three-phase load.

$$W1=VL\cdot IL\cdot COS\left(\theta+\frac{\pi}{6}\right) \qquad W2=VL\cdot IL\cdot COS\left(\theta-\frac{\pi}{6}\right) \qquad PT=\sqrt{3}\cdot VL\cdot IL\cdot COS(\theta)$$

Chapter 26

Electrical Resonance

This chapter covers equations describing the electrical properties of resonance in circuits made of ideal circuit elements.

- ❑ Parallel Resonance I
- ❑ Parallel Resonance II
- ❑ Resonance in Lossy Inductor
- ❑ Series Resonance

Variables

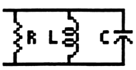
The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
α	Damping coefficient	r/s
β	Bandwidth	r/s
C	Capacitance	F
Im	Current	A
L	Inductance	H
η	Phase angle	r
Q	Quality factor	unitless
R	Resistance	Ω
Rg	Generator resistance	Ω
Vm	Maximum voltage	V
ω	Radian frequency	r/s
$\omega 0$	Resonant frequency	r/s
$\omega 1$	Lower cutoff frequency	r/s
$\omega 2$	Upper cutoff frequency	r/s
ωd	Damped resonant frequency	r/s
ωm	Frequency for max amplitude	r/s
Yres	Admittance at resonance	S
Z	Impedance	Ω
Zres	Impedance at resonance	Ω

Parallel Resonance I

Analysis
Equations
  Electrical Resonance
    Parallel Resonance I
Reference

These nine equations describe the properties of a parallel resonant circuit. The first equation expresses **Vm**, the voltage across the circuit, in terms of **Im**, the magnitude of the current supplied and the equivalent impedance of the parallel circuit consisting of an inductor **L**, a capacitor **C** and a resistor **R** at the radian frequency **ω**. The second equation shows the phase angle relationship between **Vm** and **Im**. The third equation connects the resonant frequency **ω0** and reactive parameters **L** and **C**. The equations for **ω1** and **ω2** represent the upper and lower cutoff frequencies beyond resonance, where the impedance is half the impedance at resonance. The bandwidth **β** is expressed in terms of **ω1** and **ω2**. The last three equations calculate the quality factor **Q** in terms of **R**, **C**, **L** and **ω0**.



$$Vm=\frac{Im}{\sqrt{\frac{1}{R^2}+\left(\omega\cdot C-\frac{1}{\omega\cdot L}\right)^2}}\qquad TAN(\theta)=\left(\omega\cdot C-\frac{1}{\omega\cdot L}\right)\cdot R\qquad \omega0=\frac{1}{\sqrt{L\cdot C}}$$

$$\omega1=\frac{-1}{2\cdot R\cdot C}+\sqrt{\frac{1}{(2\cdot R\cdot C)^2}+\frac{1}{L\cdot C}}\qquad \omega2=\frac{1}{2\cdot R\cdot C}+\sqrt{\frac{1}{(2\cdot R\cdot C)^2}+\frac{1}{L\cdot C}}\qquad \beta=\omega2-\omega1$$

$$Q=\frac{\omega0}{\beta}\qquad Q=R\cdot\sqrt{\frac{C}{L}}\qquad Q=\omega0\cdot R\cdot C$$

Parallel Resonance II

Analysis
Equations
  Electrical Resonance
    Parallel Resonance II
Reference

These seven equations represent an alternative method of expressing the properties of a resonant circuit in terms of the quality factor **Q**. The first equation links **Q** with the resonant frequency **ω0** and the bandwidth **β**. The equations for **ω1** and **ω2** show the connection between the upper and lower cutoff frequencies and **ωo** and **Q**. The fourth equation computes **α**, the damping coefficient, while the damped resonant frequency **ωd** is expressed in terms of **α** and **ω0** or **ω0** and **Q**. The last equation is an alternative form of equating **α** with **Q** and **ω0**.

$$Q=\frac{\omega 0}{\beta} \qquad \omega 1=\omega 0\cdot\left(\frac{-1}{2\cdot Q}+\sqrt{\frac{1}{(2\cdot Q)^2}+1}\right) \qquad \omega 2=\omega 0\cdot\left(\frac{1}{2\cdot Q}+\sqrt{\frac{1}{(2\cdot Q)^2}+1}\right)$$

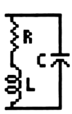
$$\alpha=\frac{1}{2\cdot R\cdot C} \qquad \omega d=\sqrt{\omega 0^2-\alpha^2} \qquad \omega d=\omega 0\cdot\sqrt{1-\frac{1}{4\cdot Q^2}}$$

$$\alpha=\frac{\omega 0}{2\cdot Q}$$

Resonance in Lossy Inductor

Analysis
Equations
Electrical Resonance
Resonance in Lossy Inductor
Reference

These four equations characterize the properties of a lossy inductor in parallel with an ideal capacitor sourced from a current source with an impedance of **Rg**. **ω0** represents the radian frequency when the admittance of the parallel circuit is purely conductive. **Yres** and **Zres** represent the impedance and admittance of the circuit at resonance. **ωm** represents the frequency wherein the amplitude of the voltage across the resonant circuit is at maximum.



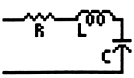
$$\omega 0=\sqrt{\frac{1}{L\cdot C}-\left(\frac{R}{L}\right)^2} \qquad Yres=\frac{(L+Rg\cdot R\cdot C)}{L\cdot Rg} \qquad Zres=\frac{1}{Yres}$$

$$\omega m=\sqrt{\sqrt{\left(\frac{1}{L\cdot C}\right)^2\cdot\left(1+\frac{2\cdot R}{Rg}\right)+\left(\frac{R}{L}\right)^2\cdot\left(\frac{2}{L\cdot C}\right)}-\left(\frac{R}{L}\right)^2}$$

Series Resonance

Analysis
Equations
Electrical Resonance
Series Resonance
Reference

These nine equations characterize the properties of a series resonant circuit. The first equation connects the resonant frequency **ω0** and the reactive parameters **L** and **C**. The second and third equations compute the magnitude **Z** and phase **θ** of the impedance. The equations for **ω1** and **ω2** represent the upper and lower cutoff frequencies beyond resonance, where the impedance is half the impedance at resonance. The expression for **β** represents the bandwidth for the resonant circuit. The last two equations determine the quality factor **Q** in terms of **R**, **C**, **L**, and **ω0**.



$$\omega 0=\frac{1}{\sqrt{L\cdot C}} \qquad Z=\sqrt{R^2+\left(\omega\cdot L-\frac{1}{\omega\cdot C}\right)^2} \qquad \theta=\mathrm{ATAN}\left(\frac{\left(\omega\cdot L-\frac{1}{\omega\cdot C}\right)}{R}\right)$$

$$\omega 1=\frac{-R}{2\cdot L}+\sqrt{\left(\frac{R}{2\cdot L}\right)^2+\frac{1}{L\cdot C}} \qquad \omega 2=\frac{R}{2\cdot L}+\sqrt{\left(\frac{R}{2\cdot L}\right)^2+\frac{1}{L\cdot C}} \qquad \beta=\omega 2-\omega 1$$

$$\beta=\frac{R}{L} \qquad Q=\frac{\omega 0\cdot L}{R} \qquad Q=\frac{1}{R}\cdot\sqrt{\frac{L}{C}}$$

Chapter 27

OpAmp Circuits

Analysis
Equations
OpAmp Circuits
Reference

Seven commonly-used OpAmp circuits are presented in this chapter. An OpAmp is a direct-coupled high-gain amplifier that can be designed with the use of feedback to control its overall performance characteristics. The two inputs are labelled + and -. The manner in which input signals are connected to these terminals defines the inverting or non-inverting properties of the circuit.

- ❑ Basic Inverter
- ❑ Non-Inverting Amplifier
- ❑ Current Amplifier
- ❑ Transconductance Amplifier
- ❑ Level Detector (Inverting)
- ❑ Level Detector (Non-Inverting)
- ❑ Differentiator
- ❑ Differential Amplifier

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

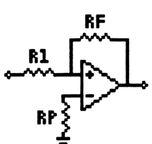
Variable	Description	Unit
Acc	CM current gain	unitless
Aco	CM gain from real OpAmp	unitless
Ad	Differential mode gain	unitless
Agc	Transconductance	S
Aic	Current gain	unitless
Av	Voltage gain	unitless
C1	Input capacitor	F
Cf	Feedback capacitor	F
CMRR	CM rejection ratio	unitless
Cp	Bypass capacitor	F
fcp	3dB bandwidth, circuit	Hz

fd	Characteristic frequency	Hz
f0	Passband, geometric center	Hz
fop	3dB bandwidth, OpAmp	Hz
If	Maximum current through Rf	A
R1	Input resistor	Ω
R2	Current stabilizor	Ω
R3	Feedback resistor	Ω
R4	Resistor	Ω
Rf	Feedback resistor	Ω
Rin	Input resistance	Ω
Rl	Load resistance	Ω
Ro	Output resistance, OpAmp	Ω
Rout	Output resistance	Ω
Rp	Bias current resistor	Ω
Rs	Voltage divide resistor	Ω
tr	10-90% rise time	s
ΔVH	Hysteresis	V
VL	Detection threshold, low	V
Vomax	Maximum circuit output	V
VR	Reference voltage	V
Vrate	Maximum voltage rate	V/s
VU	Detection threshold, high	V
Vz1	Zener breakdown 1	V
Vz2	Zener breakdown 2	V

Basic Inverter

Analysis
Equations
OpAmp Circuits
Basic Inverter
Reference

These four equations define the characteristics of a basic inverter. The first equation links the voltage gain **Av** to the feedback resistance **Rf** and input resistance **R1**. The optimum value of **Rp** is defined by the second equation to minimize output-voltage offset due to input bias current. The first pole frequency **fcp** (i.e., 3dB bandwidth) is defined by the third equation. Small signal rise time **tr** (10 to 90%) is defined by the fourth equation.



$$Av=\frac{-Rf}{R1}$$

$$Rp=\frac{R1\cdot Rf}{R1+Rf}$$

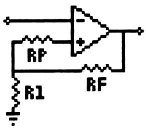
$$fcp=fop\cdot Av\cdot\left(\frac{R1}{Rf}\right)$$

$$tr=\frac{.35\cdot Rf}{fop\cdot Av\cdot R1}$$

Non-Inverting Amplifier

Analysis
Equations
OpAmp Circuits
Non-Inverting Amplifier
Reference

These four equations define the properties of a non-inverting amplifier. The first equation expresses the voltage gain **Av** in terms of the feedback resistor **Rf** and resistor **R1**. The second equation gives the value of **Rp** needed in the input circuit to minimize offset current effects. The third equation defines the 3dB bandwidth of the circuit in terms of the first pole **fop** of the OpAmp and **Av**, **R1**, and **Rf**. The final equation expresses the small-signal rise time **tr**.



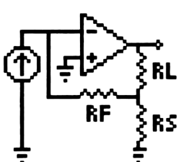
$$Av=1+\frac{Rf}{R1} \qquad Rp=\frac{R1\cdot Rf}{R1+Rf} \qquad fcp=\frac{fop\cdot Av\cdot R1}{R1+Rf}$$

$$tr=\frac{.35\cdot(R1+Rf)}{fop\cdot Av\cdot R1}$$

Current Amplifier

Analysis
Equations
OpAmp Circuits
Current Amplifier
Reference

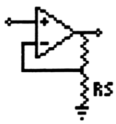
Properties of a current amplifier are covered in this section. The first equation shows the relationship between the current gain **Aic** with feedback resistance **Rf**, load resistance **Rl**, output resistance of OpAmp **Ro**, voltage divide resistor **Rs**, and voltage gain **Av**. The remaining equations define the input resistance **Rin** and output resistance **Rout** of the system.



$$Aic=\frac{(Rs+Rf)\cdot Av}{Rl+Ro+Rs\cdot(1+Av)} \qquad Rin=\frac{Rf}{1+Av} \qquad Rout=Rs\cdot(1+Av)$$

Transconductance Amplifier

Analysis
Equations
OpAmp Circuits
Transconductance Amplifier
Reference



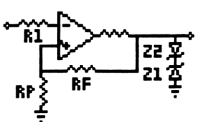
The two equations in this section specify a closed loop transconductance **Agc** and output resistance **Rout** in terms of the resistance **Rs** and voltage gain **Av**.

$$Agc=\frac{1}{Rs} \qquad Rout=Rs\cdot(1+Av)$$

Level Detector (Inverting)

Analysis
Equations
OpAmp Circuits
Level Detector (Inverting)
Reference

The first equation in this section computes the value of the resistor **R1** attached to an OpAmp inverting input. The second equation calculates the hysteresis (or memory) **ΔVH** of the level detector circuit. The third and fourth equations define the upper and lower trip voltages **VU** and **VL** for an ideal inverting level detector, assuming a reference voltage **VR** and breakdown voltages **Vz1** and **Vz2**, in terms of **Rp** and **Rf**.



$$R1=\frac{Rp\cdot Rf}{Rp+Rf} \qquad \Delta VH=\frac{(Vz1+Vz2)\cdot Rp}{Rp+Rf} \qquad VU=\frac{(VR\cdot Rf+Rp\cdot Vz1)}{Rf+Rp}$$

$$VL=\frac{(VR\cdot Rf-Rp\cdot Vz2)}{Rf+Rp}$$

Level Detector (Non-Inverting)

Analysis
Equations
OpAmp Circuits
Level Detector (Non-Invert.)
Reference

The first equation in this section computes the value of the resistor **R1** attached to an OpAmp non-inverting input. The second equation calculates the hysteresis (or memory) **ΔVH** of the level detector circuit. The third and fourth equations define the upper and lower trip voltages **VU** and **VL** for an ideal inverting level detector, assuming a reference voltage **VR** and breakdown voltages **Vz1** and **Vz2**, in terms of **Rp** and **Rf**.

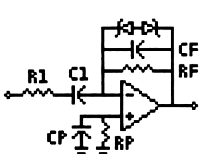
$$R1=\frac{Rp\cdot Rf}{Rp+Rf} \qquad \Delta VH=\frac{(Vz1+Vz2)\cdot Rp}{Rp+Rf}$$

$$VU=\frac{(VR\cdot(Rf+Rp)+Rp\cdot Vz1)}{Rf} \qquad VL=\frac{(VR\cdot(Rp+Rf)-Rp\cdot Vz2)}{Rf}$$

Differentiator

Analysis
Equations
OpAmp Circuits
Differentiator
Reference

These design equations represent all the components needed for a differentiator. The first equation defines the feedback resistor **Rf** in terms of the maximum output voltage **Vomax** and current **If**. Typically, **If** is of the order of 0.1 - 0.5 mA. The second equation computes the value for the resistor **Rp** used to cancel the effects of OpAmp input bias current. **C1** is the input capacitor required for the differentiator, and **R1** is the resistor utilized for stability. The characteristic frequency of the differentiator **fd** is expressed by the fifth equation. The last two equations compute the bypass capacitor **Cp** and the feedback capacitor **Cf**.



$$Rf=\frac{Vomax}{If} \qquad Rp=Rf \qquad C1=\frac{Vomax}{Rf\cdot Vrate}$$

$$R1=\frac{1}{2\cdot\pi\cdot fd\cdot C1} \qquad fd=\frac{1}{2\cdot\pi\cdot Rf\cdot C1} \qquad Cp=\frac{10}{2\cdot\pi\cdot f0\cdot Rp}$$

$$Cf=\frac{1}{4\cdot\pi\cdot f0\cdot Rf}$$

Differential Amplifier

Analysis
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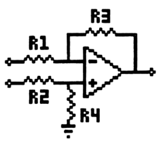
OpAmp Circuits
Differential Amplifier
Reference

These four equations show the primary relationships involved in the design of a differential amplifier. The first equation computes the differential gain **Ad** in terms of the input and feeback resistors **R1** and **R3**. The second equation shows the common-mode gain **Aco** in terms of **R3**, **R1**, and the common-mode rejection ratio **CMMR**. The third equation expands the definition of **Ad** from the first equation to accomodate a practical OpAmp with a finite voltage gain **Av**. The final equation shows the common-mode gain due to resistor mismatching.



$$Ad=\frac{R3}{R1}\qquad Aco=\frac{R3^2}{R3\cdot(R1+R3)\cdot CMRR}\qquad Ad=\frac{Av\cdot R3}{\sqrt{R1^2\cdot Av^2+R3^2}}$$

$$Acc=\frac{(R4\cdot R1-R2\cdot R3)}{R1\cdot(R2+R4)}$$

Bibliography

Coughlin, Robert F. and Frederick F. Driscoll, *Operational Amplifiers & Linear Integrated Circuits*, Prentice Hall, Englewood Cliffs, NJ 07632, 1991.

Johnson, David E. and V. Jayakumar, *Operational Amplifer Circuits - Design and Application*, Prentice-Hall Inc. Englewood Cliffs, NJ 07632, 1982.

Stout, David F. (Milton Kaufman, Editor) *Handbook of Operational Amplifier Circuit Design*, McGraw-Hill Book Company, New York NY, 1976.

Chapter 28

Solid State Devices

Analysis
Equations
Solid State Devices
Reference

This chapter covers equations describing a variety of solid state devices.

- ❑ Semiconductor Basics
- ❑ PN Junctions
- ❑ PN Junction Currents
- ❑ Transistor Currents
- ❑ Eber-Moll Equations
- ❑ Ideal Currents - pnp
- ❑ Switching Transients
- ❑ MOS Transistor I
- ❑ MOS Transistor II
- ❑ MOS Inverter (Resistive)
- ❑ MOS Inverter (Saturated)
- ❑ MOS Inverter (Depletion)
- ❑ CMOS Transistor Pair
- ❑ Junction FET

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
α	CB current gain	unitless
a	Linearly graded junction parameter	$1/m^4$
A	Area	m^2
A1	EB junction area	m^2
A2	CB junction area	m^2
αf	Forward α	unitless
Aj	Junction area	m^2
αr	Reverse α	unitless

β	CE current gain	unitless
b	Channel width	m
βf	Forward β	unitless
βr	Reverse β	unitless
Cj	Junction capacitance	F
CL	Load capacitance	F
Cox	Oxide capacitance per unit area	F/m^2
D	Diffusion coefficient	m^2/s
DB	Base diffusion coefficient	m^2/s
DC	Collector diffusion coefficient	m^2/s
DE	Emitter diffusion coefficient	m^2/s
Dn	n diffusion coefficient	m^2/s
Dp	p diffusion coefficient	m^2/s
εox	Oxide permittivity	unitless
εs	Permittivity	unitless
Ec	Conduction band	J
EF	Fermi level	J
Ei	Intrinsic Fermi level	J
Ev	Valence band	J
fmax	Maximum frequency	Hz
γ	Body coefficient	$V^{.5}$
gd	Drain conductance	S
gm	Transconductance	S
gmL	Transconductance, load device	S
Go	Conductance	S
I	Junction current	A
I0	Saturation current	A
IB	Base current	A
IC	Collector current	A
ICB0	CB leakage, E open	A
ICE0	CE leakage, B open	A
ICsat	Collector I at saturation edge	A
ID	Drain current	A
IDλ	Channel modulation drain current	A
ID0	Drain current	A
IDsat	Drain saturation current	A
IE	Emitter current	A
If	Forward current	A
Ir	Reverse current	A
Ir0	E-M reverse current component	A
IRG	G-R current	A
IRG0	Zero bias G-R current	A
λ	Modulation parameter	1/V
Is	Saturation current	A
kD	MOS constant, driver	A/V^2

kL	MOS constant, load	A/V^2
kn	MOS constant	A/V^2
kn1	MOS process constant	A/V^2
kN	MOS constant, n channel	A/V^2
kP	MOS constant, p channel	A/V^2
KR	Ratio	unitless
L	MOS transistor length	m
LC	Diffusion length, collector	m
LD	Drive transistor length	m
LE	Diffusion length, emitter	m
LL	Load transistor length	m
Ln	Diffusion length, n	m
lN	n-channel length	m
Lp	Diffusion length, p	m
lP	p-channel length	m
μn	n mobility	$m^2/(V*s)$
μp	p mobility	$m^2/(V*s)$
mn	n effective mass	unitless
mp	p effective mass	unitless
N	Doping concentration	$1/m^3$
Na	Acceptor density	$1/m^3$
nC	n density, collector	$1/m^3$
Nd	Donor density	$1/m^3$
nE	n density, emitter	$1/m^3$
ni	Intrinsic density	$1/m^3$
N0	Surface concentration	$1/m^3$
npo	n density, p type	$1/m^3$
p	p density	$1/m^3$
pB	p density, base	$1/m^3$
ϕF	Fermi potential	V
ϕGC	Work function potential	V
pno	p density, n type	$1/m^3$
Q	Total surface impurities	unitless
Qb	Bulk charge at bias	C/m^2
Qb0	Bulk charge at 0 bias	C/m^2
Qox	Oxide charge density	C/m^2
Qsat	Base Q, transition edge	C
ρn	n resistivity	Ω*m
ρp	p resistivity	Ω*m
Rl	Load resistance	Ω
τB	lifetime in base	s
τD	Time constant	s
τL	Time constant	s
τo	Lifetime	s
τp	Minority carrier lifetime	s

τt	Base transit time	s
t	Time	s
T	Temperature	K
tch	Charging time	s
tdis	Discharge time	s
tox	Gate oxide thickness	m
tr	Collector current rise time	s
ts	Charge storage time	s
tsd1	Storage delay, turn off	s
tsd2	Storage delay, turn off	s
Ttr	Transit time	s
V1	Input voltage	V
Va	Applied voltage	V
Vbi	Built-in voltage	V
VBE	BE bias voltage	V
VCB	CB bias voltage	V
VCC	Collector supply voltage	V
VCEsat	CE saturation voltage	V
VDD	Drain supply voltage	V
VDS	Drain voltage	V
VDsat	Drain saturation voltage	V
VEB	EB bias voltage	V
VG	Gate voltage	V
VGS	Gate to source voltage	V
VIH	Input high	V
Vin	Input voltage	V
VIL	Input low voltage	V
VL	Load voltage	V
VM	Midpoint voltage	V
VOH	Output high	V
VOL	Output low	V
Vo	Output voltage	V
Vp	Pinchoff voltage	V
VSB	Substrate bias	V
VT	Threshold voltage	V
VT0	Threshold voltage at 0 bias	V
VTD	Depletion transistor threshold	V
VTL	Load transistor threshold	V
VTL0	Load transistor threshold	V
VTN	n channel threshold	V
VTP	p channel threshold	V
W	MOS transistor width	m
WB	Base width	m
WD	Drive transistor width	m
WL	Load transistor width	m

WN	n-channel width	m
WP	p-channel width	m
x	Depth from surface	m
xd	Depletion layer width	m
xn	Depletion width, n side	m
xp	Depletion width, p side	m
Z	JFET width	m

Semiconductor Basics

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Reference

Nine equations form the foundation of this module. The first two equations define the resistivities **ρn** and **ρp** of n- and p-type semiconductor material in terms of the electron and hole mobilities **μn** and **μp** and doping densities **Nd** and **Na.** The third and fourth equations connect the electron and hole diffusion coefficients **Dn** and **Dp,** using the so-called Einstein's relationship in terms of **μn** and **μp** and temperature **T.** The next two equations compute the Fermi level **EF** relative to the intrinsic Fermi Level **Ei** in terms of temperature **T, Na** or **Nd,** and the intrinsic carrier density **ni.** The intrinsic Fermi level **Ei** is calculated by the seventh equation in terms of the conduction and valence band levels **Ec** and **Ev,** temperature **T** and the effective masses **mp** and **mn** of holes and electrons. The eighth equation illustrates the diffusion of impurities in a semiconductor subject to an infinite source with a surface concentration **N0** at a depth **x** below the surface after a time **t,** given the diffusion coefficient **D.** The diffusion equation in this case follows the complementary error function distribution. The final equation details the diffusion from a finite impurity source **Q** over a surface area **A** with the classic Gaussian distribution.

$$\rho n=\frac{1}{q\cdot \mu n\cdot Nd} \qquad \rho p=\frac{1}{q\cdot \mu p\cdot Na} \qquad \frac{Dn}{\mu n}=\frac{k\cdot T}{q}$$

$$\frac{Dp}{\mu p}=\frac{k\cdot T}{q} \qquad Ei-EF=k\cdot T\cdot LN\left(\frac{Na}{ni}\right) \qquad EF-Ei=k\cdot T\cdot LN\left(\frac{Nd}{ni}\right)$$

$$Ei=\frac{(Ec+Ev)}{2}+\frac{3}{4}\cdot(k\cdot T)\cdot LN\left(\frac{mp}{mn}\right) \qquad N=N0\cdot ERFC\left(\frac{x}{2\cdot\sqrt{D\cdot t}}\right)$$

$$N=\frac{Q}{A\cdot\sqrt{\pi\cdot D\cdot t}}\cdot e^{\frac{-x^2}{4\cdot D\cdot t}}$$

PN Junctions

Analysis
Equations
  Solid State Devices
    PN Junctions
Reference

These seven equations cover the properties of PN junctions. The first equation shows the calculation for the built-in voltage **Vbi** for a step junction in terms of temperature **T**, the doping densities **Nd** and **Na,** and the intrinsic density **ni**. The next three equations focus on the depletion layers **xn** and **xp** in the p and the n regions of the PN junction in terms of the dielectric constant **εs**, doping densities **Nd** and **Na**, built-in voltage **Vbi** and the applied voltage **Va.** The variable **xd** represents the total depletion region width for a given applied voltage. The fifth equation shows the capacitance **Cj** of a PN junction in terms of **εs**, junction area **Aj** and **xd**. The last two equations calculate **Vbi** and **xd** for a linearly-graded junction with a gradient parameter **a.**

$$Vbi=\frac{k\cdot T}{q}\cdot LN\left(\frac{Nd\cdot Na}{ni^{2}}\right)$$

$$xn=\sqrt{\frac{\frac{2\cdot \varepsilon s\cdot \varepsilon 0\cdot ABS(Vbi-Va)}{q}\cdot Na}{Nd\cdot (Na+Nd)}}$$

$$xp=\frac{Nd}{Na}\cdot xn$$

$$xd=xn+xp$$

$$Cj=\frac{\varepsilon s\cdot \varepsilon 0\cdot Aj}{xd}$$

$$Vbi=\frac{2\cdot k\cdot T}{q}\cdot LN\left(\frac{a\cdot xd}{2\cdot ni}\right)$$

$$xd=\left(\frac{12\cdot \varepsilon s\cdot \varepsilon 0}{q\cdot a}\cdot ABS(Vbi-Va)\right)^{\frac{1}{3}}$$

PN Junction Currents

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Reference

Eight equations characterize many of the relationships that play a key role in computing currents in PN junctions. The first two equations show the current in two alternate forms. First, the junction current **I** in terms of the junction area **Aj**, diffusion coefficients **Dn** and **Dp,** diffusion lengths **Ln** and **Lp**, equilibrium densities of minority carriers **npo** and **pno**, applied bias **Va**, and temperature **T**. The second equation is a simplified form of the first equation in which **I0** is defined as the multiplier of the exponential term. The third equation calculates this saturation current **I0**. The so-called Generation-Recombination current **IRG0** at 0 bias is calculated by the fourth equation in terms of junction area **Aj**, average recombination time **τo**, intrinsic density **ni**, depletion width

xd. On applying a voltage **Va**, this generation recombination current **IRG** increases exponentially, as shown by the fifth equation. The next equation computes **Go**, the small signal conductance, in terms of temperature **T** and currents **I** and **I0**. The last two equations synthesize the charge storage time **ts** when the diode current is switched externally from **If** to **Ir**. It is seen from these two equations that **ts** depends strongly upon the minority carrier lifetime **τp**.

$$I=q\cdot Aj\cdot\left(\frac{Dn}{Ln}\cdot npo+\frac{Dp}{Lp}\cdot pno\right)\cdot\left(e^{\frac{q\cdot Va}{k\cdot T}}-1\right) \qquad I=I0\cdot\left(e^{\frac{q\cdot Va}{k\cdot T}}-1\right)$$

$$I0=q\cdot Aj\cdot\left(\frac{Dn}{Ln}\cdot npo+\frac{Dp}{Lp}\cdot pno\right) \qquad IRG0=\frac{-q\cdot Aj\cdot ni\cdot xd}{2\cdot\tau o}$$

$$IRG=\frac{q\cdot Aj\cdot ni\cdot xd}{2\cdot\tau o}\cdot\left(e^{\frac{q\cdot Va}{2\cdot k\cdot T}}-1\right) \qquad Go=\frac{q}{k\cdot T}\cdot(I+I0)$$

$$ts=\tau p\cdot LN\left(1+\frac{If}{Ir}\right) \qquad ERF\left(\sqrt{\frac{ts}{\tau p}}\right)=\frac{1}{1+\frac{Ir}{If}}$$

Transistor Currents

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Reference

The seven equations in this section show top-level relationships between the emitter, base and collector currents **IE, IB** and **IC**, respectively. The first equation defines the common base current gain **α** as the ratio of **IC** to **IE**. The second equation defines the common emitter current gain **β** in terms of **α.** The third equation represents Kirchoff's current law for the transistor. The next three equations represent alternate forms of the collector current in terms of **α, IE, IB, β** and the leakage currents **ICE**, and **ICB0**. The final equation links **ICE0** and **ICB0** in terms of **β**.

$$\alpha=\frac{IC}{IE} \qquad \beta=\frac{\alpha}{1-\alpha} \qquad IE=IB+IC$$

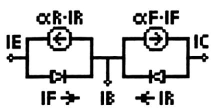
$$IC=\alpha\cdot IE+ICB0 \qquad IC=\frac{\alpha}{1-\alpha}\cdot IB+\frac{ICB0}{1-\alpha} \qquad IC=\beta\cdot IB+ICE0$$

$$ICE0=ICB0\cdot(\beta+1)$$

Ebers-Moll Equations

Analysis
Equations
  Solid State Devices
    Ebers-Moll Equations
Reference

These ten equations show a collection of relevant relationships developed by J. J. Ebers and J. L. Moll in the mid-1950s recognizing the basic reciprocal behavior of a bipolar transistor. The first three equations connect the emitter, collector and base currents **IE, IC** and **IB** in terms of forward and reverse current gain **αf** and **αr** and forward and reverse currents **If** and **Ir.** The corresponding common emitter current gains in the forward and reverse directions are given by **βf** and **βr**, in terms of **αf** and **αr.** The reciprocity relationships between



αf and **αr**, **If** and **Ir**, and the saturation current **Is** are defined by the next two equations. The last three equations help define **ICE0** and **ICB0** in terms of **αf**, **αr**, and **Ir0.**

$$IE=If-\alpha r\cdot Ir \qquad IC=\alpha f\cdot If-Ir \qquad IB=(1-\alpha f)\cdot If+(1-\alpha r)\cdot Ir$$

$$\beta f=\frac{\alpha f}{1-\alpha f} \qquad \beta r=\frac{\alpha r}{1-\alpha r} \qquad \alpha f\cdot If=Is$$

$$\alpha r\cdot Ir=Is \qquad ICB0=(1-\alpha r\cdot\alpha f)\cdot Ir0 \qquad ICE0=ICB0\cdot(\beta f+1)$$

$$ICE0=\frac{Ir0\cdot(1-\alpha f\cdot\alpha r)}{1-\alpha f}$$

Ideal Currents - pnp

Analysis
Equations
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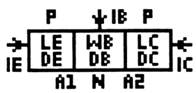
    Ideal Currents - pnp
Reference

The four equations in this set form the basis of transistor action resulting in emitter, base and collector currents in a pnp transistor. The first three equations show the emitter, collector and base currents **IE**, **IC**, and **IB** in terms of emitter base area **A1**, diffusion coefficients **DE, DB**, and **DC,** the minority carrier densities



nE, pB, and **nC,** emitter and collector diffusion lengths **LE** and **LC,** base width **WB,** emitter-base and collector base voltages **VBE** and **VBC,** base collection junction **A2** and temperature **T.** The last equation shows the relationship between **α, DB, pB, WB, DE, nE** and **LE**. The corresponding equations for an npn transistor can be derived from this equation set by proper use of sign conventions.

$$IE=q\cdot A1\cdot\left(\frac{DE\cdot nE}{LE}+\frac{DB\cdot pB}{WB}\right)\cdot\left(e^{\frac{q\cdot VEB}{k\cdot T}}-1\right)-\frac{q\cdot A2\cdot DB}{WB}\cdot pB\cdot\left(e^{\frac{q\cdot VCB}{k\cdot T}}-1\right)$$

$$IC=\frac{q\cdot A1\cdot DB\cdot pB}{WB}\cdot\left(e^{\frac{q\cdot VEB}{k\cdot T}}-1\right)-q\cdot A2\cdot\left(\frac{DC\cdot nC}{LC}+\frac{DB\cdot pB}{WB}\right)\cdot\left(e^{\frac{q\cdot VCB}{k\cdot T}}-1\right)$$

$$IB=\frac{q\cdot A1\cdot DE}{LE}\cdot nE\cdot\left(e^{\frac{q\cdot VBE}{k\cdot T}}-1\right)+\frac{q\cdot A2\cdot DC}{LC}\cdot nC\cdot\left(e^{\frac{q\cdot VCB}{k\cdot T}}-1\right)$$

$$\alpha=\frac{\frac{DB\cdot pB}{WB}}{\frac{DB\cdot pB}{WB}+\frac{DE\cdot nE}{LE}}$$

Switching Transients

Analysis
Equations
Solid State Devices
Switching Transients
Reference

These six equations show the key relationships in determining switching response times of bipolar transistors. The first equation shows the base charge at the edge of saturation **Qsat** in terms of collector saturation current **ICsat** and base transit time **τt**. The collector saturation is determined (approximately) by the second equation in terms of supply voltage **VCC** and load resistance **RLD**. The third equation calculates the turn-on transient time tr in terms of base recombination time **τB**, **ICsat**, base current **IB** and base transit time **τt**. The next equation computes the storage delay **tsd1** when the bipolar transistor is switched from the saturation region to cutoff by switching base current from **IB** to 0. The penultimate equation shows the storage delay **tsd2** when the base current is switched from **IB** to **-IB**. The final equation computes the saturation voltage **VCEsat**, the voltage drop between the collector and the emitter under full saturation, in terms of the collector and base currents **IC** and **IB** and the forward and reverse **α**'s **αf** and **αr**.

$$Qsat=ICsat\cdot\tau t \qquad ICsat=\frac{VCC}{Rl} \qquad tr=\tau B\cdot LN\left(\frac{1}{1-\frac{ICsat\cdot\tau t}{IB\cdot\tau B}}\right)$$

$$tsd1=\tau B\cdot LN\left(\frac{IB\cdot\tau B}{ICsat\cdot\tau t}\right) \qquad tsd2=\tau B\cdot LN\left(\frac{2\cdot IB\cdot\tau B}{ICsat\cdot\tau t\cdot\left(1+\frac{IB\cdot\tau B}{ICsat\cdot\tau t}\right)}\right)$$

$$VCEsat=\frac{k\cdot T}{q}\cdot LN\left(1+\frac{\frac{IC}{IB}\cdot(1-\alpha r)}{\alpha r\cdot\left(1-\frac{\frac{IC}{IB}\cdot(1-\alpha f)}{\alpha f}\right)}\right)$$

MOS Transistor I

Analysis
Equations
Solid State Devices
MOS Transistor I
Reference

The seven equations in this section form the basic equations of charge, capacitance and threshold voltage for a MOS transistor. The first equation shows the Fermi potential **ϕF** defined in terms of temperature **T**, the intrinsic carrier density **ni**, and the hole density **p**. The second equation shows the depletion layer **xd** at the surface of a p-type semiconductor in terms of the relative dielectric constant **εs**, Fermi potential **ϕF**, and doping density **Na**. The third equation computes the charge density **Qb0** accumulated at the surface of the semiconductor due to band bending. The fourth equation shows how surface charge density **Qb** is influenced by the substrate bias **VSB**. A thin oxide layer with a thickness **tox** on the surface of the semiconductor results in a capacitance **Cox** per unit area. The sixth equation defines the body coefficient **γ** in terms of **Cox**, **Na**, and **εs**. The final equation computes the threshold voltage for a MOS system with a work function potential of **ϕGC** and residual oxide charge density **Qox**.

$$\emptyset F=\frac{k\cdot T}{q}\cdot LN\left(\frac{ni}{p}\right) \qquad xd=\sqrt{\frac{2\cdot\epsilon s\cdot\epsilon 0\cdot(2\cdot\emptyset F)}{q\cdot Na}}$$

$$Qb0=-\sqrt{2\cdot q\cdot Na\cdot\epsilon s\cdot\epsilon 0\cdot ABS(2\cdot\emptyset F)}$$

$$Qb=-\sqrt{2\cdot q\cdot Na\cdot\epsilon s\cdot\epsilon 0\cdot ABS(-2\cdot\emptyset F+VSB)} \qquad Cox=\frac{\epsilon ox\cdot\epsilon 0}{tox}$$

$$\gamma=\frac{1}{Cox}\cdot\sqrt{2\cdot q\cdot Na\cdot \varepsilon s\cdot \varepsilon 0}\qquad VT0=\phi GC-2\cdot\phi F-\frac{Qb0}{Cox}-\frac{Qox}{Cox}$$

MOS Transistor II

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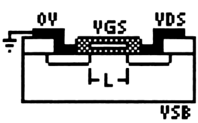
Reference

These eleven equations describe the performance characteristics of a MOS transistor. The first two equations give two alternate forms for the process constant **kn1** in terms of electron mobility **μn**, oxide capacitance per unit area **Cox**, relative oxide permittivity **εox**, and oxide thickness **tox**. The third equation links the process constant **kn1** to the device constant **kn**, device length **L**, and width **W**. The fourth equation defines the drain current **IDλ** when saturated in terms of **kn**, gate voltage **VGS**, threshold voltage **VT**, conductance parameter **λ**, and drain voltage **VDS**. The fifth equation computes **ID** under linear or saturated conditions in terms of **kn**, **VGS**, **VT**, and **VDS**. The expression for the threshold voltage **VT** is defined in terms of zero substrate bias threshold voltage **VTO**, body coefficient **γ**, substrate bias **VSB**, and Fermi potential **ϕF**. The last four equations calculate performance parameters such as transconductance **gm**, transit time through the channel **Ttr**, maximum frequency of operation **fmax**, and drain conductance **gd**.



$$kn1=\mu n\cdot Cox\qquad kn1=\frac{\mu n\cdot \varepsilon ox\cdot \varepsilon 0}{tox}\qquad kn=\frac{kn1\cdot W}{L}$$

$$ID=\frac{kn}{2}\cdot(VGS-VT)^{2}\cdot(1+\lambda\cdot VDS)$$

$$ID=IFTE\left(VGS-VT\le VDS,\frac{kn}{2}\cdot\left(2\cdot(VGS-VT)\cdot VDS-VDS^{2}\right),\frac{kn}{2}\cdot(VGS-VT)^{2}\right)$$

$$VT=VT0+\gamma\cdot\left(\sqrt{ABS(-2\cdot\phi F+VSB)}-\sqrt{2\cdot\phi F}\right)\qquad gm=kn\cdot(VGS-VT)$$

$$Ttr=\frac{\frac{4}{3}\cdot L^{2}}{\mu n\cdot(VGS-VT)}\qquad fmax=\frac{gm}{2\cdot\pi\cdot Cox\cdot W\cdot L}\qquad gd=kn\cdot(VGS-VT)$$

MOS Inverter (Resistive)

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Equations
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    MOS Inverter (Resistive)
Reference

These five equations represent the design equations for a MOS inverter with a resistive load. The first equation specifies the device constant **kD** for the driver transistor in terms of its gate capacitance **Cox**, mobility **μn**, width **WD**, and channel length **LD**. The second equation specifies the output voltage when input to the driver is below the threshold voltage. The third equation determines **VOL**, the output low voltage when the input is driven high. This equation is a quadratic in **VOL**, and the solution is meaningful for positive values of **VOL**. The next equation computs **VIH** in the linear region of the drain current equation. The final equation computes the midpoint voltage **VM** for which the driver transistor is in saturation.

$$kD=\frac{\mu n\cdot Cox\cdot WD}{LD} \qquad VOH=VDD$$

$$VOL^2-2\cdot\left(\frac{1}{kD\cdot R1}+VDD-VT\right)\cdot VOL+\frac{2\cdot VDD}{kD\cdot R1}=0$$

$$\frac{kD}{2}\cdot\left(2\cdot(VIH-VT)\cdot Vo-Vo^2\right)=\frac{(VDD-Vo)}{R1}$$

$$\frac{kD}{2}\cdot(VM-VT)^2=\frac{(VDD-VM)}{R1}$$

MOS Inverter (Saturated)

Analysis
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    MOS Inverter (Saturated)
Reference

A MOS inverter with a saturated enhancement transistor load is the focus of this section. The first two equations define the device constants for the load transistor (**kL**, **WL**, **LL**) and the driver transistor (**kD**, **WD**, **LD**) in terms of the process parameters, namely mobility **μn** and gate capacitance per unit area **Cox**. The third equation defines the geometry ratio **KR** of the load and drive transistors. Output high **VOH** is calculated in terms of **VDD**, **VTO** and **γ**. The next equation defines the input voltage **Vin** in terms of **KR**, **VDD**, threshold of the load and drive transistors **VTL** and **VTD**. The sixth equation defines the threshold voltage of the load transistor. The equation that follows computes the input high **VIH** in terms of **VDD**, **VTL**, **KR** and **VTO**. The output voltage **Vo** is computed in terms of **VDD**, **VTL**, **VTO** and **KR**. The last five equations show the performance parameters of the inverter circuit. The equation for **gmL** defines the transconductance of the load circuit while the equation for **τL** defines the characteristic time to charge the load capacitance **CL**. The charging time **tch** is the time required for the output rise to move from **Vo** to **V1**. The final two equations focus on the characteristic time **τD** and discharge time **tdis** for the circuit.

$$kL=\frac{\mu n\cdot Cox\cdot WL}{LL} \qquad kD=\frac{\mu n\cdot Cox\cdot WD}{LD} \qquad KR=\frac{kD}{kL}$$

$$VOH=VDD-\left(VT0+\gamma\cdot\left(\sqrt{VOH+2\cdot\varnothing F}-\sqrt{2\cdot\varnothing F}\right)\right)$$

$$KR\cdot\left(2\cdot(Vin-VTD)\cdot Vo-Vo^2\right)=(VDD-Vo-VTL)^2$$

$$VTL=VT0+\gamma\cdot\left(\sqrt{Vo+2\cdot\varnothing F}-\sqrt{2\cdot\varnothing F}\right) \qquad VIH=\frac{2\cdot(VDD-VTL)}{\sqrt{3\cdot KR}+1}+VT0$$

$$Vo=\frac{\left(VDD-VTL+VT0+VT0\cdot\sqrt{KR}\right)}{1+\sqrt{KR}} \qquad gmL=kL\cdot(VDD-VTL)$$

$$\tau L=\frac{CL}{gmL} \qquad tch=\tau L\cdot\left(\frac{V1}{Vo}-1\right) \qquad \tau D=\frac{CL}{kD\cdot(V1-VT0)}$$

$$tdis=\tau D\cdot\left(\frac{2\cdot VTD}{V1-VTD}+LN\left(\frac{2\cdot(V1-VTD)}{Vo}-1\right)\right)$$

MOS Inverter (Depletion)

Analysis
Equations
Solid State Devices
MOS Inverter (Depletion)
Reference

These six equations are the design equations for a MOS inverter with a depletion load. The first two equations compute device constants **kL** and **kD** for the load and the driver transistors in terms of their geometries **WD**, **WL**, **LD**, and **LL**. At the output low and output high, **VOL** and **VOH**, the driver is in the linear region while the load device is saturated. The fourth equation computes the threshold voltage **VTL** for the load transistor in terms of its zero bias threshold **VTL0**, Fermi potential **ϕF**, and body coefficient **γ**. The fifth equation shows the charging time for the capacitive load. The last equation computes current in the depletion load device **I0**.

$$kL=\frac{\mu n\cdot Cox\cdot WL}{LL} \qquad kD=\frac{\mu n\cdot Cox\cdot WD}{LD}$$

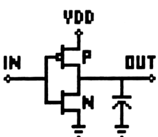
$$\frac{kD}{2}\cdot\left(2\cdot(VOH-VT0)\cdot VOL-VOL^{2}\right)=\frac{kL}{2}\cdot VTL^{2}$$

$$VTL=VTL0+\gamma\cdot\left(\sqrt{Vo+2\cdot\phi F}-\sqrt{2\cdot\phi F}\right) \qquad tch=\frac{CL\cdot VL}{I0} \qquad I0=kL\cdot VTL^{2}$$

CMOS Transistor Pair

Analysis
Equations
  Solid State Devices
    CMOS Transistor Pair
Reference

These five equations describe the properties of a CMOS inverter. The first two equations



compute device parameters for n and p channel devices. The next two equations compute input voltages **VIH** and **VIL**. The last equation compute **Vin** when the n-channel driver is in saturation and the p-channel device is in the linear region.

$$kP=\frac{\mu n\cdot Cox\cdot WP}{lP} \qquad kN=\frac{\mu p\cdot Cox\cdot WN}{lN}$$

$$VIH=2\cdot Vo+VTN+\frac{\frac{kP}{kN}\cdot(VDD-ABS(VTP))}{1+\frac{kP}{kN}}$$

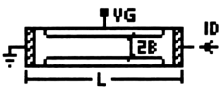
$$VIL=\frac{\left(2\cdot Vo-VDD-VTP+\frac{kN}{kP}\cdot VTN\right)}{1+\frac{kN}{kP}}$$

$$\frac{kN}{2}\cdot(Vin-VTN)^{2}=\frac{kP}{2}\cdot(VDD-Vin-ABS(VTP))^{2}$$

Junction FET

Analysis
Equations
  Solid State Devices
    Junction FET
Reference

These five equations describe the characteristics of a symmetrical junction field effect transistor. The first equation stipulates the drain current **ID** in terms of the electron mobility **μn**, doping density **Nd**, channel width **b**, channel length **L**, channel depth **Z**, supply voltage **VDD**, pinch-off voltage **Vp**, gate voltage **VG**, and built-in voltage **Vbi**. The channel height **b** is related to the dielectronic constant **εs**, **Nd**, **Vbi**, and drain saturation voltage **VDsat**. The last two equations show the relationship for drain voltage and drain current upon saturation.



$$ID=\frac{2\cdot q\cdot Z\cdot \mu n\cdot Nd\cdot b}{L}\cdot\left(VDD-\frac{2}{3}\cdot(Vbi-Vp)\cdot\left(\left(\frac{(VDD+Vbi-VG)}{Vbi-Vp}\right)^{1.5}-\left(\frac{(Vbi-VG)}{Vbi-Vp}\right)^{1.5}\right)\right)$$

$$IDsat=\frac{2\cdot q\cdot Z\cdot \mu n\cdot Nd\cdot b}{L}\cdot\left(VDsat-\frac{2}{3}\cdot(Vbi-Vp)\cdot\left(\left(\frac{(VDD+Vbi-VG)}{Vbi-Vp}\right)^{1.5}-\left(\frac{(Vbi-VG)}{Vbi-Vp}\right)^{1.5}\right)\right)$$

$$b=\sqrt{\frac{2\cdot \varepsilon 0\cdot \varepsilon s}{q\cdot Nd}\cdot(Vbi+VDsat-VG)}$$

$$VDsat=VG-Vp$$

$$IDsat=ID0\cdot\left(1-\frac{VG}{Vp}\right)^{2}$$

Chapter 29

Linear Amplifiers

Analysis
Equations
Linear Amplifiers
Reference

In this chapter, linear circuit models (sometimes called small signal models) are used to make first level computations for amplifiers using bipolar or junction transistors. Device configurations include Darlington connections, emitter-coupled pair, differential amplifer and a source-coupled pair.

- ❑ BJT (Common Base)
- ❑ BJT (Common Emitter)
- ❑ BJT (Common Collector)
- ❑ FET (Common Gate)
- ❑ FET (Common Source)
- ❑ FET (Common Drain)
- ❑ Darlington (CC-CC)
- ❑ Darlington (CC-CE)
- ❑ Emitter-Coupled Amplifier
- ❑ Differential Amplifier
- ❑ Source-Coupled JFET Pair

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
α0	Current gain, CE	unitless
Ac	Common mode gain	unitless
Ad	Differential mode gain	unitless
Ai	Current gain, CB	unitless
Aov	Overall voltage gain	unitless
Av	Voltage gain, CC/CD	unitless
β0	Current gain, CB	unitless
CMMR	Common mode reject ratio	unitless
gm	Transconductance	S

μ	Amplification factor	unitless
rb	Base resistance	Ω
rc	Collector resistance	Ω
rd	Drain resistance	Ω
re	Emitter resistance	Ω
RBA	External base resistance	Ω
RCA	External collector resistance	Ω
RDA	External drain resistance	Ω
REA	External emitter resistance	Ω
RG	External gate resistance	Ω
Ric	Common mode input resistance	Ω
Rid	Differential input resistance	Ω
Rin	Input resistance	Ω
Rl	Load resistance	Ω
Ro	Output resistance	Ω
Rs	Source resistance	Ω

BJT (Common Base)

Analysis
Equations
Linear Amplifiers
BJT (Common Base)
Reference

These six equations represent properties of a transistor amplifier connected in the common base configuration at mid frequencies. The first equation connects common base current gain **α0** with common emitter current gain **β0**. The second equation computes the input impedance **Rin** at the input terminals of the amplifier. **Ro** represents the output resistance and **Ai** the current gain. The final two equations cover the voltage gain **Av** and overall voltage gain **Aov** for the amplifier system. **Aov** includes the effect of source impedance **Rs**.

$$\beta 0=\frac{\alpha 0}{1-\alpha 0} \qquad Rin=re+\frac{rb}{\beta 0} \qquad Ro=rc$$

$$Ai=\alpha 0 \qquad Av=\frac{\alpha 0\cdot Rl}{re+\frac{rb}{\beta 0}} \qquad Aov=\frac{\alpha 0\cdot rc\cdot\left(\frac{Rin}{Rin+Rs}\right)}{re+\frac{rb}{\beta 0}}$$

BJT (Common Emitter)

Analysis
Equations
  Linear Amplifiers
    BJT (Common Emitter)
Reference

These six equations represent properties of a transistor amplifier connected in the common emitter configuration at mid frequencies. The first equation connects common base current gain **α0** with common emitter current gain **β0**. The second equation computes the input **Rin**, in terms of base resistance **rb**, emitter resistance **re**, and **β0**. The output resistance **Ro** is defined by the third equation in terms of collector resistance, **rc**. The next equation defines current gain **Ai**. The final two equations cover the voltage gain **Av** and overall voltage gain **Aov** for the amplifier system. **Aov** includes the effect of source impedance **Rs**.

$$\beta 0=\frac{\alpha 0}{1-\alpha 0} \qquad Rin=rb+\beta 0\cdot re \qquad Ro=rc$$

$$Ai=-\beta 0 \qquad Av=\frac{-\beta 0\cdot Rl}{\beta 0\cdot re+rb} \qquad Aov=\frac{-\beta 0\cdot Rl}{Rs+Rin}$$

BJT (Common Collector)

Analysis
Equations
  Linear Amplifiers
    BJT (Common Collector)
Reference

These six equations are the properties of a transistor amplifier connected in the common collector configuration at the mid frequencies. The first equation connects common base current gain **α0** with common emitter current gain **β0**. The second equation computes the input impedance **Rin** in terms of base resistance **rb**, emitter resistance **re**, **β0**, and load resistance **Rl**. **Ro** represents the output resistance. The current gain **Ai** is shown in the next equation in terms of **rc**, **α0**, **re**, and **Rl**. The final two equations cover the voltage gain **Av** and overall voltage gain **Aov** for the amplifier system. **Aov** includes the effect of source impedance **Rs**.

$$\beta 0=\frac{\alpha 0}{1-\alpha 0} \qquad Rin=rb+\beta 0\cdot re+(\beta 0+1)\cdot Rl \qquad Ro=re+\frac{(Rs+rb)}{\beta 0}$$

$$Ai=\frac{rc}{rc\cdot(1-\alpha 0)+Rl+re} \quad Av=\frac{\alpha 0\cdot Rl}{re+Rl} \quad Aov=\frac{(\beta 0+1)\cdot Rl}{Rs+Rin+(\beta 0+1)\cdot Rl}$$

FET (Common Gate)

Analysis
Equations
  Linear Amplifiers
    FET (Common Gate)
Reference

The four equations in this section focus on an FET amplifier in the common gate configuration. The first equation defines the amplification factor **μ** in terms of transconductance **gm** and drain resistance **rd**. The second equation computes input resistance **Rin** as a function of load resistance **RL**, **rd** and **μ**. Voltage gain **Av** is defined in the third equation. The final equation computes the output resistance **Ro** in terms of **rd**, **μ**, and external gate resistance **RG**.

$$\mu=gm\cdot rd \quad Rin=\frac{(Rl+rd)}{\mu+1} \quad Av=\frac{(\mu+1)\cdot Rl}{rd+Rl}$$

$$Ro=rd+(\mu+1)\cdot RG$$

FET (Common Source)

Analysis
Equations
  Linear Amplifiers
    FET (Common Source)
Reference

These four equations represent the key properties of an FET amplifier in the mid frequency range. The first equation defines the amplification factor **μ** in terms of transconductance **gm** and drain resistance **rd**. The second equation computes input resistance **Rin** as a function of load resistance **RL**, **rd** and **μ**. Voltage gain **Av** is defined in the third equation. The final equation computes the output resistance.

$$\mu=gm\cdot rd \quad Rin=\frac{(Rl+rd)}{\mu+1} \quad Av=-gm\cdot\left(\frac{rd\cdot Rl}{rd+Rl}\right)$$

$$Ro=rd$$

FET (Common Drain)

Analysis
Equations
Linear Amplifiers
FET (Common Drain)
Reference

The four equations in this section focus on an FET amplifier connected in the common drain configuration. The first equation defines the amplification factor **μ** in terms of transconductance **gm** and drain resistance **rd**. The second equation computes input resistance **Rin** as a function of load resistance **RL**, **rd** and **μ**. Voltage gain **Av** is defined in the third equation. The final equation computes the output resistance, **Ro**.

$$\mu = gm \cdot rd \qquad Rin = \frac{(Rl + rd)}{\mu + 1} \qquad Av = \frac{\mu \cdot Rl}{(\mu + 1) \cdot Rl + rd}$$

$$Ro = \frac{rd}{\mu + 1}$$

Darlington (CC-CC)

Analysis
Equations
Linear Amplifiers
Darlington (CC-CC)
Reference

The Darlington configuration connected as a common collector-common collector is a frequently-used configuration for achieving large current gains. The first two equations yield the input and output resistances **Rin** and **Ro**, computed in terms of emitter resistance **re**, load resistance **RL**, current gain **β0**, base resistance **rb**, and source resistance **Rs**. The final equation computes overall current gain **Ai** for the transistor pair.

$$Rin = \beta0 \cdot (re + \beta0 \cdot (re + Rl)) \qquad Ro = re + \frac{(\beta0 \cdot (re + rb) + Rs)}{\beta0^2}$$

$$Ai = \frac{\beta0^2 \cdot RBA}{RBA + \beta0 \cdot (Rl + re)}$$

Darlington (CC-CE)

Analysis
Equations
Linear Amplifiers
Darlington (CC-CE)
Reference

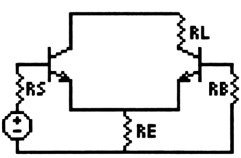
The Darlington configuration connected as a common collector-common emitter configuration is covered in this section. The first two equations define the input resistance **Rin** and output resistance **Ro**, in terms of base resistance **rb**, emitter resistance **re**, collector resistance **rc**, and current gain **β0**. The final equation calculates voltage gain **Av**.

$$Rin=rb+\beta0\cdot re \qquad Ro=\frac{rc}{\beta0} \qquad Av=\frac{\frac{-Rl}{re}\cdot re}{re+\frac{Rs}{\beta0^2}}$$

Emitter-Coupled Amplifier

Analysis
Equations
Linear Amplifiers
Emitter-Coupled Amplifier
Reference

Two classes of emitter-coupled amplifiers are covered in this section. The first equation shows the general relationship between **β0** and **α0**, the current gains under common base and common emitter configurations. The next three equations show the input resistance **Rin**, output resistance **Ro**, and voltage gain **Av** for a common collector-common base method of connection. The last three equations correspond to cascade configuration of the transistors, which is a combination of common emitter-common base configuration resulting in a current gain **Ai** with corresponding input resistance **Rin** and output resistance **Ro**.



$$\beta0=\frac{\alpha0}{1-\alpha0} \qquad Rin=\beta0\cdot(re+\beta0\cdot(Rl+re))$$

$$Ro=re+\frac{(\beta0\cdot(re+rb)+Rs)}{\beta0^2} \qquad Av=\frac{Rl}{re}\cdot\left(\frac{\beta0\cdot re}{2\cdot\beta0\cdot re+Rl}\right) \qquad Ai=-\alpha0\cdot\beta0$$

$$Rin=\beta0\cdot re+rb \qquad Ro=rc$$

Differential Amplifier

Analysis
Equations
  Linear Amplifiers
    Differential Amplifier
Reference

These four equations cover a differential amplifier. The gain **Ad** in the differential mode of operation is given by the first equation. The second equation shows the gain **Ac** for a common mode input. The last two equations show input resistance for differential and common mode inputs **Rid** and **Ric**.

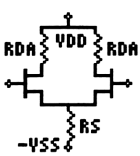
$$Ad=\frac{-1}{2}\cdot gm\cdot RCA \qquad Ac=\frac{-\alpha 0\cdot RCA}{2\cdot REA+re} \qquad Rid=2\cdot(rb+\beta 0\cdot re)$$

$$Ric=\beta 0\cdot REA$$

Source-Coupled JFET Pair

Analysis
Equations
  Linear Amplifiers
    Source-Coupled JFET Pair
Reference

The first two equations cover differential and common mode gain for a source-coupled JFET pair. The third equation shows the amplification factor, while the last equation shows the common mode rejection ratio.



$$Ad=\frac{\frac{-1}{2}\cdot gm\cdot(rd\cdot RDA)}{rd+RDA} \qquad Ac=\frac{-\mu\cdot RDA}{(\mu+1)\cdot 2\cdot Rs+rd+RDA}$$

$$\mu=gm\cdot rd \qquad CMMR=gm\cdot Rs$$

Bibliography

Mohammed S. Ghausi, *Electronic Devices and Circuits: Discrete and Integrated*, Holt, Rinehart and Winston, New York NY 1985.

Chapter 30

Class A, B, and C Amplifiers

Analysis
Equations
Class A, B, and C Amplifiers
Reference

This chapter covers equations describing the performance of Class A, B, and C power amplifiers.

- ❑ Class A Amplifier
- ❑ Power Transistor
- ❑ Push-Pull Principle
- ❑ Class B Amplifier
- ❑ Class C Amplifier

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

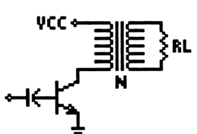
Variable	Description	Unit
gm	Transconductance	S
hFE	CE current gain	unitless
hOE	CE output conductance	S
I	Current	A
IB	Base current	A
IC	Collector current	A
ΔIC	Current swing from operating pt.	A
ICBO	Collector current EB open	A
ICQ	Current at operating point	A
Idc	DC current	A
Imax	Maximum current	A
K	Constant	unitless
m	Constant	1/K
η	Efficiency	unitless
n	Turns ratio	unitless
N1	# turns in primary	unitless

N2	# turns in secondary	unitless
Pd	Power dissipated	W
Pdc	DC power input to amp	W
Po	Power output	W
PP	Compliance	V
Q	Quality factor	unitless
θJA	Thermal resistance	W/K
R	Equivalent resistance	Ω
R0	Internal circuit loss	Ω
R2	Load resistance	Ω
RB	External base resistance	Ω
Rc	Coupled load resistance	Ω
Re	External emitter resistance	Ω
Rl	Load resistance	Ω
S	Instability factor	unitless
TA	Ambient temperature	K
TJ	Junction temperature	K
ΔTj	Change in temperature	K
V0	Voltage across tank circuit	V
V1	Voltage across tuned circuit	V
VBE	Base emitter voltage	V
VCC	Collector supply voltage	V
ΔVCE	Voltage swing from operating pt.	V
VCEmax	Maximum transistor rating	V
VCEmin	Minimum transistor rating	V
Vm	Maximum amplitude	V
VPP	Peak-peak volts, secondary	V
XC	Tuned circuit parameter	Ω
XC1	π equivalent circuit parameter	Ω
XC2	π equivalent circuit parameter	Ω
XL	π series reactance	Ω

Class A Amplifier

Analysis
Equations
Class A, B, and C Amplifiers
Class A Amplifier
Reference

The eight equations in this section form the basis for analyzing a Class A amplifier with an ideal transformer coupled resistive load. The first equation specifies the equivalent load resistance **R** from the load resistance **Rl** in the secondary of the transformer with a turns ratio **n**. The second equation defines the AC current swing **ΔIC** in terms of the voltage swing **ΔVCE** and **R**. The next equation computes the maximum collector current **Imax**



in terms of **ICQ** and **ΔIC**. The DC power available **Pdc** is shown in the fourth equation. The compliance **PP** is defined as the full voltage swing across the emitter and collector. **VPP** represents the peak to peak voltage in the secondary. The final two equations compute the output power **Po** and the conversion efficiency **η**.

$$R=n^2\cdot Rl \qquad \Delta IC=\frac{\Delta VCE}{R} \qquad Imax=ICQ+\Delta IC$$

$$Pdc=VCC\cdot ICQ \qquad PP=VCEmax-VCEmin \qquad VPP=n\cdot PP$$

$$Po=\frac{\Delta IC^2\cdot R}{8} \qquad \eta=\frac{Po}{Pdc}$$

Power Transistor

Analysis
Equations
Class A, B, and C Amplifiers
Power Transistor
Reference

Power amplifiers generate heat needing rapid transfer to the amibient. The six equations in this section focus on these thermal problems, the instability factor and the currents. The first equation defines the junction temperature **TJ** as linearly related to the power dissipation **Pd** and thermal resistance **θJA**. The next two equations focus on the collector current **IC** and base current **IB** in terms of the current gain **hFE**, leakage current **ICBO**, external emitter resistance **Re** and external base resistance **RB**. The fourth equation expresses **IC** in terms of **hFE**, **Re**, **RB**, **ICBO**, and **VBE**. The instability factor **S** is given by the fifth equation, while the final equation computes **IC** in terms of **hFE**, **ICBO**, a parameter **m**, **S**, and the change in junction temperature **ΔTj**.

$$TJ=TA+\theta JA\cdot Pd \qquad IC=hFE\cdot IB+(1+hFE)\cdot ICBO$$

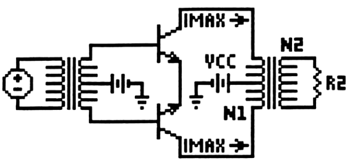
$$IB=\frac{-(IC\cdot Re-VBE)}{Re+RB} \qquad IC=\frac{-hFE\cdot VBE}{hFE\cdot Re+RB}+\frac{hFE\cdot(Re+RB)}{hFE\cdot Re+RB}\cdot ICBO$$

$$S=\frac{\left(1+\frac{RB}{Re}\right)\cdot hFE}{hFE+\frac{RB}{Re}} \qquad IC=-hFE\cdot IB+S\cdot ICBO\cdot(1+m\cdot\Delta Tj)$$

Push-Pull Principle

Analysis
Equations
 Class A, B, and C Amplifiers
  Push-Pull Principle
Reference

These three equations introduce the push-pull principle, commonly used in power amplifier design. Two transistors have their collector outputs connected to the center-tapped primary winding of a transformer. The secondary winding is connected to a load **R2**. The first equation computes an equivalent resistance **R** based on the maximum current supplied to the load **Imax**. The power output is computed by the second equation in terms of **VCC** and **R**. The final equation computes the power in terms of load resistance **R2** and transformer windings **N1** and **N2**.



$$R=\frac{VCC}{Imax} \qquad Po=\frac{VCC^2}{2\cdot R} \qquad Po=\frac{\left(\frac{N2}{2\cdot N1}\right)^2\cdot VCC^2}{2\cdot R2}$$

Class B Amplifier

Analysis
Equations
 Class A, B, and C Amplifiers
  Class B Amplifier
Reference

Power transistors that are connected in a push-pull mode and biased to cutoff, operate under the Class B condition where alternate half-cycles of input are of forward polarity for each transistor. The nine equations in this section define the characteristic properties of this class of amplifiers. The first equation represents the power output at any signal level in terms of the constant **K**, supply voltage **VCC**, and an equivalent resistance **R**. The second equation defines the DC current **Idc** as the average value of a sinusoidal half-wave adjusted by **K**. The next two equations focus on the DC power **Pdc** in terms of **VCC**, **K**, **R**, and **Imax**. The efficiency of power conversion **η** is given by the next equations. The eighth equation covers the voltage across a tuned RLC circuit in terms of the transconductance **gm**, load resistance **RL**, and output conductance **hOE**. The final equation calculates the average collector current for a half-sine wave.

$$Po=\frac{K^2\cdot VCC^2}{2\cdot R}$$ $$Idc=\frac{2\cdot K\cdot Imax}{\pi}$$ $$Pdc=\frac{2\cdot K\cdot Imax\cdot VCC}{\pi}$$

$$Pdc=\frac{2\cdot K\cdot VCC^2}{\pi\cdot R}$$ $$\eta=\frac{Po}{Pdc}$$ $$\eta=\frac{\pi\cdot K}{4}$$

$$Pd=\frac{2\cdot VCC^2}{\pi\cdot R}\cdot\left(K-\frac{K^2\cdot\pi}{4}\right)$$ $$V1=\frac{gm\cdot R1\cdot Vm}{2\cdot\sqrt{2}}\cdot\left(\frac{1}{1+\frac{hOE\cdot R1}{2}}\right)$$

$$IC=\frac{gm\cdot Vm}{\pi}\cdot\left(\frac{1}{1+\frac{hOE\cdot R1}{2}}\right)$$

Class C Amplifier

These six equations outline the properties of a Class C amplifier. The first equation defines the efficiency of conversion **η** in terms of the current **I**, the coupled-in load **Rc**, and equivalent internal circuit loss resistance **R0**. The tuned circuit parameters have a capacitive reactance of **XC**, which is given in terms of the load voltage **V0**, quality factor **Q**, and power **Po**. **XL** is expressed in terms of **XC** and **Q**, load resistance **RL**, and resistance **R2**. The equations for **XC1** and **XC2** represent load harmonic suppression values in the output circuit.

$$\eta=\frac{I^2\cdot Rc}{I^2\cdot(Rc+R0)}$$ $$XC=\frac{V0^2}{Q\cdot Po}$$ $$XL=\frac{XC\cdot Q^2}{Q^2+1}$$

$$XC1=\frac{-R1}{Q}$$ $$XL=\frac{1}{Q}\cdot\left(R1+\sqrt{R1\cdot R2}\right)$$ $$XC2=\frac{-R2}{Q}$$

Chapter 31

Transformers

Analysis
Equations
Transformers
Reference

This chapter covers equations for simplified design parameters of transformers.

- ❑ Ideal Transformer
- ❑ Linear Equivalent Circuit

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
I1	Primary current	A
I2	Secondary current	A
N1	# primary turns	unitless
N2	# secondary turns	unitless
R1	Primary resistance	Ω
R2	Secondary resistance	Ω
Rin	Equiv. primary resistance	Ω
Rl	Resistive part of load	Ω
V1	Primary voltage	V
V2	Secondary voltage	V
X1	Primary reactance	Ω
X2	Secondary reactance	Ω
Xin	Equivalent primary reactance	Ω
Xl	Reactive part of load	Ω
Zin	Primary impedance	Ω
ZL	Secondary load	Ω

Ideal Transformer

Analysis
Equations
  Transformers
    Ideal Transformer
Reference

Four equations describe the properties of an ideal transformer. The first equation links the primary and secondary voltages **V1** and **V2** in terms of the primary and secondary turns **N1** and **N2**. The second equation shows the corresponding relationship between the primary and secondary currents **I1** and **I2**. The third equation shows the condition equating primary and secondary power. The final equation shows the impact of a load impedance **ZL** experienced at the primary winding terminal on the primary impedance **Zin**.

$$\frac{V1}{V2}=\frac{N1}{N2} \qquad I1\cdot N1=I2\cdot N2 \qquad V1\cdot I1=V2\cdot I2$$

$$Zin=\left(\frac{N1}{N2}\right)^2\cdot ZL$$

Linear Equivalent Circuit

Analysis
Equations
  Transformers
    Linear Equivalent Circuit
Reference

The first two equations define the primary voltage and current **V1** and **I1** in terms of **V2** and **I2**. The last two equations expand the equivalent resistance and reactance at the primary terminals in terms of the primary winding resistance **R1**, secondary winding resistance **R2**, load resistance **Rl**, and load reactance **Xl**.

$$V1=\frac{N1}{N2}\cdot V2 \qquad I1=\frac{I2\cdot N2}{N1} \qquad Rin=R1+\left(\frac{N1}{N2}\right)^2\cdot(R2+Rl)$$

$$Xin=X1+\left(\frac{N1}{N2}\right)^2\cdot(X2+Xl)$$

Chapter 32

Motors and Generators

Thirteen sections covering various aspects of AC and DC motors and generators are included in this module:

- ❑ Energy Conversion
- ❑ DC Generator
- ❑ Separately-Excited DC Generator
- ❑ DC Shunt Generator
- ❑ DC Series Generator
- ❑ Separately-Excited DC Motor
- ❑ DC Shunt Motor
- ❑ DC Series Motor
- ❑ Permanent Magnet Motor
- ❑ Induction Motor I
- ❑ Induction Motor II
- ❑ Single-Phase Induction Motor
- ❑ Synchronous Machines

Variables

The table below lists all the variables used in this chapter, along with a brief description and appropriate units.

Variable	Description	Unit
A	Area	m^2
ap	# parallel paths	unitless
B	Magnetic induction	T
Ea	Average emf induced in armature	V
Ef	Field voltage	V
Ema	Phase voltage	V
Es	Induced voltage	V
Eta	Average emf induced per turn	V

F	Magnetic pressure	Pa
H	Magnetic field intensity	A/m
Ia	Armature current	A
If	Field current	A
IL	Load current	A
Ir	Rotor current per phase	A
Isb	Backward stator current	A
Isf	Forward stator current	A
K	Machine constant	unitless
Kf	Field coefficient	A/Wb
KM	Induction motor constant	unitless
L	Length of each turn	m
η	Phase delay	r
N	Total # armature coils	unitless
Ns	# stator coils	unitless
ρ	Resistivity	Ω/m
ϕ	Flux	Wb
p	# poles	unitless
P	Power	W
Pa	Mechanical power	W
Pma	Power in rotor per phase	W
Pme	Mechanical power	W
Pr	Rotor power per phase	W
R1	Rotor resistance per phase	Ω
Ra	Armature resistance	Ω
Rd	Adjustable resistance	Ω
Re	Ext. shunt resistance	Ω
Rel	Magnetic reluctance	A/Wb
Rf	Field coil resistance	Ω
Rl	Load resistance	Ω
Rr	Equivalent rotor resistance	Ω
Rs	Series field resistance	Ω
Rst	Stator resistance	Ω
s	Slip	unitless
sf	Slip for forward flux	unitless
sm	Maximum slip	unitless
T	Internal torque	N*m
Tb	Backward torque	N*m
Tf	Forward torque	N*m
Tgmax	Breakdown torque	N*m
TL	Load torque	N*m
Tloss	Torque loss	N*m
Tmax	Pullout torque	N*m
Tmmax	Maximum positive torque	N*m
Ts	Shaft torque	N*m

Va	Applied voltage	V
Vf	Field voltage	V
Vfs	Field voltage	V
Vt	Terminal voltage	V
ωm	Mechical radian frequency	r/s
ωme	Electrical radian frequency	r/s
ωr	Electrical rotor speed	r/s
ωs	Electrical stator speed	r/s
Wf	Magnetic energy	J
XL	Inductive reactance	Ω

Energy Conversion

Analysis
Equations
  Motors and Generators
    Energy Conversion
Reference

The four equations in this section display the fundamental relationship amongst electrical, magnetic and mechanical aspects of a system. For example, the first two equations show two ways of computing energy density **Wf** stored in a magnetic field. The first equation uses the field intensity **H** and flux density **B** in a magnetic region with length **L** and area **A**. The second equation uses the magnetic reluctance **Rel** and flux **ϕ** to compute **Wf**. The third equation defines the mechanical force **F** due to the flux density **B**, while the last equation shows the rms value of the emf **Es** induced by **Ns** turns moving with an angular velocity **ωs** sweeping a magnetic flux of **ϕ**.

$$Wf=\frac{1}{2}\cdot H\cdot B\cdot L\cdot A \qquad Wf=\frac{1}{2}\cdot Rel\cdot \phi^2 \qquad F=\frac{B^2}{2\cdot \mu 0}$$

$$Es=\frac{Ns\cdot \omega s\cdot \phi}{\sqrt{2}}$$

DC Generator

Analysis
Equations
  Motors and Generators
    DC Generator
Reference

The eleven equations in this section describe the properties of a DC generator. The first equation describes the relation between electrical radian frequency **ωme**, the mechanical angular frequency **ωm**, and the number of poles in the generator **p**. The next equation expresses the emf generated per turn **Eta** with the relative motion of the coil with respect to the magnetic field. The next pair of equations illustrate two ways to express induced armature emf **Ea** as a function of number of armature coils **N**, the number of parallel paths **ap**, number of poles **p**, the mechanical radian frequency **ωm**, a machine constant **K**, and flux **ϕ**. The machine constant **K**, expressed by the fifth equation, is seen to be dependent purely on the characteristics of the machine. The next equation shows the conversion of mechanical energy available as torque **T** and mechanical angular velocity **ωm** to its electrical counterpart – namely, the emf and current in the armature **Ea**, and **Ia** and the voltage and current in the field windings **Ef** and **If**. The next equation for torque connects **T** with **K**, **ϕ**, and the current **Ia**. The armature resistance is given by the equation for **Ra** in terms of **N**, **ap**, coil length **L**, area **A** and its resistivity **ρ**. **Vf** represents the voltage across the field winding carrying a current **If** and a resistance **Rf**. The terminal voltage **Vt** represents the induced voltage minus the IR drop in the armature. The final equation represents the shaft torque **Ts** needed to generate the induced emf, assuming a given value for equivalent loss of torque **Tloss**.

$$wme=\frac{p}{2}\cdot wm \qquad Eta=\frac{p}{\pi}\cdot wm\cdot \phi \qquad Ea=\frac{N}{ap}\cdot\left(\frac{p}{\pi}\right)\cdot wm\cdot \phi$$

$$Ea=K\cdot wm\cdot \phi \qquad K=\frac{N\cdot p}{ap\cdot \pi} \qquad T\cdot wm=Ea\cdot Ia+Ef\cdot If$$

$$T=K\cdot \phi\cdot Ia \qquad Ra=\frac{\frac{\rho\cdot N}{2}}{ap}\cdot\left(\frac{L}{A}\right) \qquad Vf=Rf\cdot If$$

$$Vt=K\cdot wm\cdot \phi-Ra\cdot Ia \qquad Ts=K\cdot \phi\cdot Ia+Tloss$$

Separately-Excited DC Generator

Analysis
Equations
  Motors and Generators
    Sep.-Excited DC Generator
Reference

The five equations in this section describe the properties of a separately excited DC generator. The first equation computes the field current **If** in terms of field voltage **Vfs**, external shunt resistance **Re**, and field coil resistance **Rf**. The second equation evaluates armature induced voltage **Ea** as a function of machine constant **K**, mechanical radian frequency **ωm**, and flux **ϕ**. The third and fourth equations are alternate forms of expressing terminal voltage **Vt** in terms of load current **IL**, load resistance **RL**, armature resistance **Ra**. The final equation shows the armature current **IL** in terms of **K**, **ϕ**, **ωm**, **Ra** and **RL**.

$$I_f=\frac{V_{fs}}{R_e+R_f} \qquad E_a=K\cdot\omega m\cdot\phi \qquad V_t=I_L\cdot R_l$$

$$V_t=E_a-R_a\cdot I_L \qquad I_L=\frac{K\cdot\phi\cdot\omega m}{R_a+R_l}$$

DC Shunt Generator

Analysis
Equations
Motors and Generators
DC Shunt Generator
Reference

The first equation in this section expresses induced armature voltage **Ea** in terms of machine constant **K**, mechanial angular frequency **ωm**, and flux **ϕ**. The second equation defines terminal voltage **Vt** in terms of field current **If**, external resistance **Re**, and field coil resistance **Rf**. The third equation computes **Vt** in terms of load current **IL** and load resistance **Rl**. The fourth equation expresses **Vt** as induced emf **Ea** minus armature IR drop. The armature current **Ia** is the sum of the load current **IL** and field current **If**. The final equation is an alternate form of expression for **Ea**.

$$E_a=K\cdot\omega m\cdot\phi \qquad V_t=(R_e+R_f)\cdot I_f \qquad V_t=I_L\cdot R_l$$

$$V_t=E_a-R_a\cdot I_a \qquad I_a=I_L+I_f \qquad E_a=R_a\cdot I_a+(R_e+R_f)\cdot I_f$$

DC Series Generator

Analysis
Equations
Motors and Generators
DC Series Generator
Reference

The two equations in this section describe the properties of a series DC generator. The first equation specifies the field current and the armature current to be the same. The second equation computes the terminal voltage **Vt** in terms of induced emf **Ea**, load current **IL**, armature resistance **Ra**, and series field windings **Rs**.

$$I_a=I_f \qquad V_t=E_a-(R_a+R_s)\cdot I_L$$

Separately-Excited DC Motor

Analysis
Equations
Motors and Generators
Sep.-Excited DC Motor
Reference

These eight equations form the foundation of the workings of a separately excited motor. The first equation calculates the field voltage **Vf** in terms of the field current **If** and field coil resistance **Rf**. The second equation shows the computation of terminal voltage **Vt** in terms of machine constant **K**, magnetic flux **ϕ**, mechanical radian frequency **ωm**, armature current **Ia**, and armature resistance **Ra**. The third equation calculates the load torque **TL** in terms of **K**, **ϕ**, **Ia** and **Tloss**. The fourth equation calculates **Ea**, the back emf induced in the rotor. The next equation links torque **T** with **K**, **ϕ**, and **Ia**. The reciprocal power relationship between **ωm** and **ϕ** is shown in the next equation. The seventh equation shows the relationship between **T**, **Tloss** and **TL**. The last equation shows power providing a torque **T**, with an angular velocity **ωm**.

$$Vf=Rf\cdot If \qquad Vt=K\cdot\phi\cdot \omega m+Ra\cdot Ia \qquad TL=K\cdot\phi\cdot Ia-Tloss$$

$$Ea=K\cdot\omega m\cdot\phi \qquad T=K\cdot Ia\cdot\phi \qquad \omega m=\frac{Vt}{K\cdot\phi}-\frac{Ra\cdot T}{(K\cdot\phi)^2}$$

$$T=Tloss+TL \qquad P=T\cdot\omega m$$

DC Shunt Motor

Analysis
Equations
Motors and Generators
DC Shunt Motor
Reference

These seven equations describe the principal characteristics of a DC shunt motor. The first equation expresses the terminal voltage **Vt** in terms of the field current **If** and field resistance **Rf** along with the external field resistance **Re**. The second equation defines the terminal voltage **Vt** in terms of the back emf (expressed in terms of the machine constant **K**, flux swept **ϕ**, and angular velocity **ωm**) and the IR drop in the armature circuit. The third equation refers to the torque available at the load **TL** due to the current **Ia** in the armature minus the loss of torque due to friction and other reasons. The fourth equation gives the definitive relationship between the back emf **Ea**, **K**, **ϕ** and **ωm**. The next equation shows the reciprocal quadratic relationship between **ωm**, **Vt**, **K**, **ϕ**,

Ra, **Rd** and **T**. The last two equations compute torque **T** in terms of **Tloss**, load torque **TL**, flux **ϕ**, **Ia**, and **K**.

$$Vt=(Re+Rf)\cdot If \qquad Vt=K\cdot\emptyset\cdot wm+Ra\cdot Ia \qquad TL=K\cdot\emptyset\cdot Ia-Tloss$$

$$Ea=K\cdot wm\cdot\emptyset \qquad wm=\frac{Vt}{K\cdot\emptyset}-\frac{(Ra+Rd)\cdot T}{(K\cdot\emptyset)^2} \qquad T=Tloss+TL$$

$$T=K\cdot\emptyset\cdot Ia$$

DC Series Motor

Analysis
Equations
Motors and Generators
DC Series Motor
Reference

These eight equations describe the performance characteristics of a series DC motor. The first equation links the terminal voltage to back emf (**Ea** defined by the third equation) and the the IR drop through the armature due to armature resistance **Ra**, adjustable resistance **Rd**, and series resistance **Rs**. The second equation connects load torque **TL** with machine constant **K**, flux **ϕ**, load current **IL**, and the torque loss **Tloss**. The third equation defines the equation for the back emf in the armature **Ea** in terms of **K**, **ϕ**, and mechanical frequency **ωm**. The fourth equation shows torque generated at the rotor due the magnetic flux **ϕ** and current **IL**. The next relationship shows the reciprocal quadratic nature of the link between **ωm**, **Vt**, **K**, **ϕ**, **Ra**, **Rs**, **Rd**, and torque **T**. The next equation shows that the generated torque **T** is the sum of load torque **TL** and lost **Tloss**. The last two equations show the connection between **K**, **ϕ**, a field constant **Kf**, load current **IL**, and torque **T**.

$$Vt=K\cdot\emptyset\cdot wm+(Ra+Rs+Rd)\cdot IL \qquad TL=K\cdot\emptyset\cdot IL-Tloss \qquad Ea=K\cdot wm\cdot\emptyset$$

$$T=K\cdot\emptyset\cdot IL \qquad wm=\frac{Vt}{K\cdot\emptyset}-\frac{(Ra+Rs+Rd)\cdot T}{(K\cdot\emptyset)^2} \qquad T=Tloss+TL$$

$$K\cdot\emptyset=Kf\cdot IL \qquad T=Kf\cdot IL^2$$

Permanent Magnet Motor

Analysis
Equations
Motors and Generators
Permanent Magnet Motor
Reference

These five equations characterize the permanent magnet motor. The first equation shows the back emf **Ea** in terms of machine constant **K**, flux **ϕ**, and radian velocity **ωm**. The second equation shows the connection between generated torque **T**, **K**, **ϕ** and armature current **Ia**. The terminal voltage **Vt** is the sum of back emf **Ea** and the **IR** drop in the armature. The fourth equation shows conservation of various torques **T**, **TL** and **Tloss**. The final equation shows the quadratic relationship of **ωm** in terms of **K**, **Vt**, **ϕ**, **T** and **Ra**.

$$Ea=K\cdot\phi\cdot\omega m \qquad T=K\cdot\phi\cdot Ia \qquad Vt=Ea+Ra\cdot Ia$$

$$T=Tloss+TL \qquad \omega m=\frac{Vt}{K\cdot\phi}-\frac{Ra\cdot T}{(K\cdot\phi)^2}$$

Induction Motor I

Analysis
Equations
Motors and Generators
Induction Motor I
Reference

These eleven equations define the relationships amongst key variables in evaluating the performance of an induction motor. The first equation indicates the relationship between the radian frequency induced in the rotor **ω r**, the angular speed of the rotating magnetic field of the stator **ωs**, the number of poles **p**, and the mechanical angular speed **ωm**. The next three equations describe the slip **s** in three ways in terms of **ωr** and **ωs**, **ωm**, **p**, the induced rotor power per phase **Pr**, and the power transferred to the rotor per phase **Pma**. **Pma** is defined in terms of the rotor current **Ir** and the rotor phase voltage **Ema**. The next two equations account for the mechanical power **Pme** in terms of **p**, **ωm**, **ωs**, **Pma**, and torque **T**. The torque equation can be expressed in terms of **p**, **Pma**, and **ωs**, as shown by the next equation. The last three equations show an equivalent circuit representation of induction motor action and link power with rotor resistance **Rr**, rotor current **Ir**, slip **s**, and a machine constant **KM**.

$$\omega r=\omega s-\frac{p}{2}\cdot\omega m \qquad s=1-\frac{p}{2}\cdot\left(\frac{\omega m}{\omega s}\right) \qquad \frac{Pr}{Pma}=s$$

$$\omega r=s\cdot\omega s \qquad Pma=3\cdot Ir\cdot Ema \qquad Pme=3\cdot\left(\frac{p}{2}\right)\cdot\left(\frac{\omega m}{\omega s}\right)\cdot Pma$$

$$Pme=T\cdot\omega m \qquad T=3\cdot\left(\frac{p}{2}\right)\cdot\left(\frac{Pma}{\omega s}\right) \qquad Pma=Rr\cdot Ir^2+\frac{(1-s)}{s}\cdot Rr\cdot Ir^2$$

$$Pa=\frac{(1-s)}{s}\cdot Rr\cdot Ir^2 \qquad Rr=\frac{R1}{KM^2}$$

Induction Motor II

These seven equations describe equivalent circuit analysis of an induction motor. The first equation shows power **Pma** in the rotor per phase, as defined in terms of the rotor current **Ir**, rotor resistance **Rr**, and slip **s**. The second equation shows the expression for torque **T** in terms of poles **p**, **Pma** and radian frequency of the induced voltage in the stator. The third equation is an alternate representation of torque in terms of terminal voltage **Va**, stator resistance **Rst**, **Rr**, inductive reactance **XL**, and **ωs**. The equation for **Tmmax** represents the maximum positive torque available at the rotor, given the parameters of the induction motor **Rst**, **Rr**, **XL**, **Va**, **p**, and **ωs**. The torque equation shows a relationship between torque **T** and slip **s**; **sm** represents the condition when dT/ds=0. The sixth equation defines the so-called breakdown torque **Tgmax** of the motor. The final equation connects **Rr** with machine constant **KM**.

$$Pma=\frac{Rr}{s}\cdot Ir^2 \qquad T=\frac{3}{2}\cdot\left(\frac{p\cdot Pma}{\omega s}\right) \qquad T=\frac{3}{2}\cdot\left(\frac{p}{\omega s}\right)\cdot\left(\frac{Rr}{s}\right)\cdot\left(\frac{Va^2}{\left(Rst+\frac{Rr}{s}\right)^2+XL^2}\right)$$

$$Tmmax=\frac{3}{4}\cdot\left(\frac{p}{\omega s}\right)\cdot\left(\frac{Va^2}{\sqrt{Rst^2+XL^2}+Rst}\right) \qquad sm=\frac{Rr}{\sqrt{Rs^2+XL^2}}$$

$$Tgmax=-\left(\frac{3}{4}\right)\cdot\left(\frac{p}{\omega s}\right)\cdot\left(\frac{Va^2}{\sqrt{Rs^2+XL^2}-Rst}\right) \qquad Rr=\frac{R1}{KM^2}$$

Single-Phase Induction Motor

Analysis
Equations
Motors and Generators
Single-Phase Induct. Motor
Reference

These three equations describe the properties of a single-phase induction motor. The first equation defines the slip frequency **sf** with respect to the forward rotating flux, the radian frequency of induced current in the rotor, and the angular mechanical speed of the rotor **ωm**. The final two equations represent the forward and backward torques **Tf** and **Tb** for the system.

$$sf=1-\frac{p}{2}\cdot\left(\frac{\omega m}{\omega s}\right) \quad Tf=\frac{p}{2}\cdot\left(\frac{1}{\omega s}\right)\cdot\left(\frac{Isf^2\cdot Rr}{2\cdot sf}\right) \quad Tb=-\left(\frac{p}{2}\right)\cdot\left(\frac{1}{\omega s}\right)\cdot\left[\frac{Isb^2\cdot Rr}{2\cdot(2-sf)}\right]$$

Synchronous Machines

Analysis
Equations
Motors and Generators
Synchronous Machines
Reference

These five equations focus on the basic properties of a synchronous machine. The first equation links the radian mechanical and electrical speeds **ωm** and **ωs** with the number of poles **p**. The second equation shows maximum torque **Tmax** in terms of current **If**, terminal voltage **Va**, **p**, and **ωs**. **Pma** represents the power produced in the load with a phase delay of **θ**. The last two equations show torque relationships with mechanical power **Pme**, **ωm**, **Pma**, and **ωs**.

$$\omega m=\frac{2}{p}\cdot\omega s \quad Tmax=3\cdot\left(\frac{p}{2}\right)\cdot\left(\frac{If\cdot Va}{\omega s}\right) \quad Pma=Va\cdot Ia\cdot COS(\theta)$$

$$T=\frac{Pme}{\omega m} \quad T=3\cdot\left(\frac{p}{2}\right)\cdot\left(\frac{Pma}{\omega s}\right)$$

Bibliography

Slemon, G.R. and A. Straughen, *Electric Machines*, Addison Wesley, Reading, MA, 1980.

Part 3

Reference

Chapter 33

Reference: Navigation Guide

Analysis
Equations
Reference

This chapter is designed as a navigation guide to introduce you to the Reference tables, and show you the keys available at each screen. At the end of the chapter is a detailed Reference example.

Introduction

EE•*Pro* is divided into three major sections: Analysis, Equations, and Reference. This chapter addresses the Reference section, which includes Reference tables covering resistor colors, standard (or preferred) component values, semiconductor properties, Boolean expressions, Boolean algebra properties, transforms, constants, SI prefixes, and the Greek alphabet.

The Reference tables contain indispensable information for solving problems. You can find physical constants, look up properties of semiconductors, and access Fourier, Laplace, and z-transforms – all with context-sensitive help. Some Reference tables, such as Resistor Color Chart and Standard Component Values, are more sophisticated and can perform calculations. Many Reference tables include a picture for more information.

Unlike Analysis screens (which tend to be similar) and Equations screens (which tend to be identical), each Reference screen may differ significantly, depending on the type of Reference information being presented.

Finding Reference

The Reference section is found at the home screen of EE•*Pro*.

1. Start EE•*Pro*:
   - HP 48GX: Press [→] [LIBRARY] [EE] [EE].
   - HP 48SX: Press [←] [LIBRARY] [EE] [EE].
   - Press [→] [HOME] to show the home screen.

   EE•*Pro* is structured with a hierarchy of screens for choosing a specific topic. This is the home screen. To return here at any time, press [→] [HOME] or [→] [◄].

2. Select Reference by moving the highlight bar to Reference and pressing [ENTER] or [►]. The screen now displays Reference as its title and a list of Reference tables from which to choose.

3. Select a Reference table by moving the highlight bar to the desired item and pressing [ENTER] or [►]. This will display the selected Reference table. For the purposes of this navigation guide, select Reference, then Constants.

Pressing [UP] (if available) or [◄] returns you to the previous screen. Pressing [HOME] (if available) or [→] [HOME] returns you to the home screen.

Reference Screens

A basic Reference screen displays a Reference table. Most of the Reference tables contain information organized in the same manner as a printed reference book. The information may consist of data, equations, text, or a combination of these types. The screen pictured here is the Constants reference table.

All the screens in this chapter assume units are on. (Press [OPTS], then [UNITS] to toggle units on or off.)

Using Reference Tables

The instructions below are general instructions for using the basic Reference tables. For a detailed example using the Constants, see page 206. In addition, each section in each Reference chapter contains at least one example.

1. Choose parameters (if available). Some Reference tables have **Choose** fields which control the specific data to be displayed, while other Reference tables consist of only one table of data.

2. Locate the specific item of interest. If necessary, use the search feature to scan through the data to find the item. Because the search feature will only scan the labels and data displayed on the main part of the screen, it may be necessary to press DESC or [VAR] to toggle the positions of the help text and the data. That way, the search feature can be used to search the information normally displayed in the help text area at the bottom of the screen.

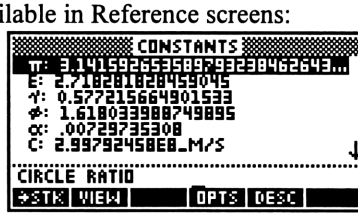
3. *Optional*: Press →STK to copy the desired item(s) to the stack for use in further calculations.

4. When finished, press [◄] to return to the Reference screen or press [↱] [HOME] to return to the home screen.

Some Reference tables, such as Resistor Color Chart or Standard Component Values, are more sophisticated and can perform calculations, much like Analysis routines. For these types of Reference tables, the basic steps are identical to those used in Analysis routines, as described on page 17.

Reference Menu Keys

These are descriptions of the menu keys available in Reference screens:



→STK Copies one or all of the items to the HP 48 stack.

VIEW Displays the highlighted item in text view.

PICT Displays a picture (if available). This menu key will not appear for Reference tables which do not have a picture.

OPTS Displays the option menu. For more information, see "Options Menu" page 9.

DESC▪ Toggles positions of data and help text (if appropriate). This menu key will not appear for Reference tables which do not have switchable help text.

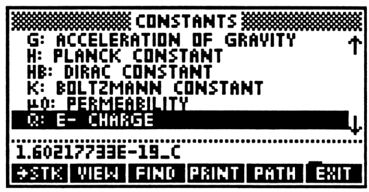
SOLVE Performs a calculation using the entered values. This menu key will not appear for Reference tables which do not have a custom solving routine.

Example: Electron Charge

MODES (Press CST)	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Find the constant for electron charge.

1. Press **DESC** or VAR to toggle the position of the constant values and the help text (the constant names), so that the names of the constants are listed in the main display area with the constants themselves. This places the names of the constants where they can be accessed by the search feature, which does not search through items displayed in the help text at the bottom of the screen.
2. Press **OPTS** NXT **FIND** to activate the search feature.



3. Type the name or part of the name of the item and press ENTER. For example, type CHARGE to find the electronic charge on an electron. The search feature is not case-sensitive, so typing in all caps is acceptable. The e- charge is the constant q and its value is 1.60217733E-19_C.
4. Press **EXIT** to leave the options menu.

NOTE

When you exit a Reference table, the position of the data and the help text will revert to the default setting. Pressing **DESC** only toggles the positions while you are at a particular screen.

5. When finished press ◄ to return to the Reference screen or press ↱ HOME to return to the home screen.

Chapter 34

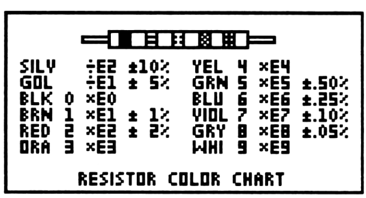
Resistor Color Chart

Analysis
Equations
Reference
Resistor Color Chart

This chapter covers the resistor color chart reference table, which is a sophisticated routine to allow you to specify the color bands of a resistor and compute the value and tolerance. Using the Resistor Color Chart screen is similar to using most Analysis screens.

Field Descriptions

Num. of Bands: (*Number of Bands*) Press CHOOS to select 3, 4, or 5.
Band 1: (*see table below*) Press CHOOS to select color.
Band 2: (*see table below*) Press CHOOS to select color.
Band 3: (*see table below*) Press CHOOS to select color.
Band 4: (*see table below*) Press CHOOS to select color.
Band 5: (*see table below*) Press CHOOS to select color.
Value: (*Resistor Value*) Returns a unit object.
Tolerance: (*Resistor Tolerance*) Returns a percent.



Band positions represent:

	3-Band	4-Band	5-Band
Band 1	digit	digit	digit
Band 2	digit	digit	digit
Band 3	mulitplier	multiplier	digit
Band 4	N/A	tolerance	multiplier
Band 5	N/A	N/A	tolerance

Colors represent:

	DIGIT	MULTIPLIER	TOLERANCE
SILVER	-	÷E2	10%
GOLD	-	÷E1	5%
BLACK	0	xE0	-
BROWN	1	xE1	1%
RED	2	xE2	2%
ORANGE	3	xE3	-
YELLOW	4	xE4	-
GREEN	5	xE5	0.5%
BLUE	6	xE6	0.25%
VIOLET	7	xE7	0.1%
GREY	8	xE8	0.05%
WHITE	9	xE9	-

Using the Resistor Color Chart

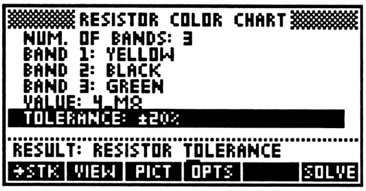
1. With the highlight bar on **Num. of Bands**, press CHOOS to select 3, 4 or 5. This will determine the number of **Band** fields that appear.
2. In each **Band** field, press CHOOS to select the desired color of the band.
3. Press SOLVE to find the value of the resistor and its tolerance.

Example

MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press CST)	**Coord:**	Rectangular	**Units:**	On
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Find the value and tolerance of a resistor with band colors yellow, black, and green.

1. Choose 3 for **Num. of Bands**.
2. Choose Yellow for **Band 1**, Black for **Band 2**, and Green for **Band 3**.
4. Press SOLVE to calculate **Value** and **Tolerance**.



NOTE

In the small font, it is not possible to distinguish between the prefix for milli (m) and Mega (M), so be sure to switch to the large font if there is any chance of ambiguity in the value. Press OPTS FONT to toggle the font size.

Chapter 35

Standard Component Values

Analysis
Standard Component Values
Equations
Reference

This chapter covers the standard component values reference table, which is a sophisticated routine to allow you to compute the closest standard value (also known as the "preferred" value) of a resistor, capacitor, or inductor. Using the Standard Component Values screen will be similar to using most Analysis screens.

Field Descriptions

Value: (*Desired Value or Design Spec.*) Enter a real number.
Tolerance: (*Tolerance of Component*) Press CHOOS to select a tolerace ±20% down to ±.0.05%.
Component: (*Type of Component*) Press CHOOS to select Resistor, Inductor, or Capacitor.
Value: (*Closest Standard Value to the Desired Value*) Returns a unit object.
Bands: (*Resistor Color Bands - if the Component is a Resistor*) Returns the color bands in a resistor.

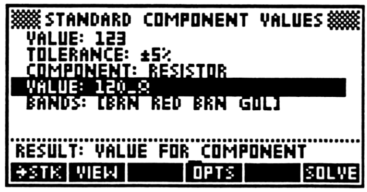
Using Standard Component Values

1. In the **Value** field, enter the desired value of the component.
2. In the **Tolerance** field, press CHOOS or ENTER to choose the tolerance of the component.
3. In the **Component** field, press CHOOS or ENTER to choose the type of component.
4. Press SOLVE to find the closest standard value for the component and (if a resistor) the color bands.

Example

MODES				
(Press [CST])	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Find the closest standard value for a 123 Ω resistor at 5% tolerance.



1. Enter 123 for **Value**.
2. Choose 5% for **Tolerance**.
3. Choose Resistor for **Component**.
3. Press SOLVE to calculate **Value** and **Bands**.

Chapter 36

Semiconductor Properties

Analysis Equations Reference *Semiconductor Properties*

This chapter covers the semiconductor properties reference table. A number of different sections include a wide variety of commonly-used semiconductor data. All data can be viewed, printed, or copied to the stack for use in further calculations.

Field Descriptions

Below is a list of fields found in each section. Due to limited space in this manual, the list has been abbreviated. The complete list of properties can be found in EE•*Pro* itself. All properties listed are at 300 K unless otherwise specifically stated.

Module	Fields
Semiconductors	**Semiconductor:** Press CHOOS or +/- to select Si or GaAs. **Atoms:** *(Atoms)* Displays real number. **At Wt:** *(Atomic Weight)* Displays real number. **Br Fld:** *(Breakdown Field)* Displays real number. ...
III-V, II-VI Compounds	**Compound:** Press CHOOS or +/- to select compound. **EG:** *(Band Gap)* Displays real number. **µn:** *(n - Mobility)* Displays real number. **µp:** *(p - Mobility)* Displays real number. ...

Module	Fields
Si Donor Levels	**Li:** Displays real number. **Sb:** Displays real number. **P:** Displays real number. ...
Si Acceptor Levels	**Mg(CD):** Displays real number. **Mg(CB):** Displays real number. **Cs:** Displays real number. ...
Si02/Si3N4 Colors	**Color:** Press CHOOS or [+/-] to select color. **Si02:** *(Film Thickness)* Displays real number. **Si3N4:** *(Film Thickness)* Displays real number. **Order:** *(Order)* Displays real number.

Using Semiconductor Properties

1. If the first field is a choose field (Semiconductors, III-V & II-VI Compounds, and Si02/Si3N4 Colors), press CHOOS or [+/-] to select the desired item. The properties of that item will then be displayed in the remaining fields.
2. Scroll down to select the desired property.
3. Once you have selected a property, you can
   - Press VIEW to display it in a text view.
   - Press →STK to copy one or all to the HP 48 stack.
   - Press OPTS [NXT] PRINT to send one or all to a printer.
4. *Optional*: When finished, press [◄] to go to the previous screen or [↱] [HOME] to go to the home screen.

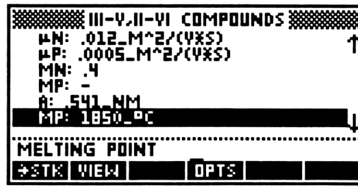
Example

MODES	**∡:**	Degrees	**Result:**	Symbolic
(Press [CST])	**Coord:**	Rectangular	**Units:**	On
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Find the density of zinc sulfide.

1. From the Semiconductor Properties menu, scroll down to III-V, II-VI Compounds and press [►].
2. If there are no units, press UNITS to display them.
3. In the **Compound** field press CHOOS to select ZnS.

4. Find the melting point by
   - Scrolling down to the ρ field or
   - Press OPTS NXT FIND. Type ρ (↱ R) and press ENTER. (If necessary, first press ON to clear the previous search.)



5. Once you have found the density, you can
   - Press VIEW to display the property in a text view.
   - Press →STK to copy one or all to the HP 48 stack.
   - Press OPTS NXT PRINT to send one or all to a printer.
5. When you are finished, press ◄ to return to the Semiconductor Properties screen.

Chapter 37

Boolean Expressions

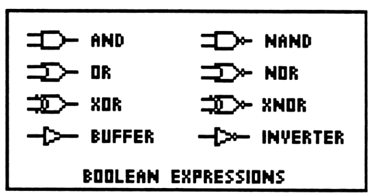
Analysis
Equations
Reference
Boolean Expressions

This chapter covers the Boolean expressions reference table, which includes 16 commonly-used Boolean expressions and also a diagram of the most commonly-used logic components.

Using Boolean Expressions

This section lists the rules for two-valued Boolean algebra, where "AND" is represented by "·", "OR" is represented by "+", and "NOT" is represented by "'".

1. Scroll through the Boolean Expressions screen with [▲] and [▼] or search with FIND to select an expression.
2. When you have found the desired item:
   - Press VIEW to display it in a text view.
   - Press →STK to copy one or all to the HP 48 stack.
   - Press OPTS [NXT] PRINT to print one or all to a printer.
3. You can view a picture of the logic components by pressing PICT at any time.



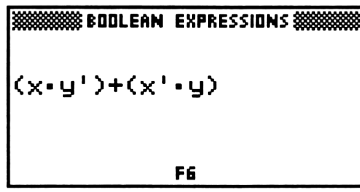
4. *Optional*: When finished, press [◄] to go to the previous screen or [↱] [HOME] to go to the home screen.

Example

MODES				
(Press [CST])	∡:	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Find the Exclusive expression.

1. Press DESC to toggle the help text and the expressions.
2. Press OPTS [NXT] FIND to search for the property.
3. Type EXCL and press [ENTER] to start the search. The highlight bar will move to the first match, which is the answer. Press EXIT to exit the options menu.
4. Press VIEW to display the property in a text view, as shown.



5. When you have finished viewing the property, press any key to return to the previous screen.
6. *Optional*: Press DESC to toggle the help text and the expressions back to their original positions.

Bibliography

Mano, M. Morris, *Digital Logic and Computer Design*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1979, pp 34-54.

Chapter 38

Boolean Algebra Properties

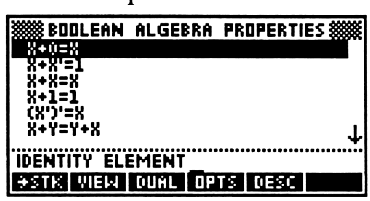
Analysis
Equations
Reference
Boolean Algebra Properties

This chapter covers the Boolean algebra properties reference table, which includes 10 commonly-used Boolean algebra properties and their duals.

Using Boolean Algebra Properties

This section lists the rules for two-valued Boolean algebra, where “AND” is represented by “·”, “OR” is represented by “+”, and “NOT” is represented by “'”.

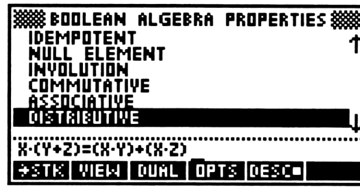
1. Scroll through the Boolean Algebra Properties screen with [▲] and [▼] or search with FIND to select an expression.
2. When you have found the desired item:
   - Press VIEW to display it in a text view.
   - Press →STK to copy one or all to the HP 48 stack.
   - Press OPTS [NXT] PRINT to print one or all to a printer.
3. You can view the duals of the Boolean Algebra Properties by pressing DUAL at any time.
4. *Optional*: When finished, press [◄] to go to the previous screen or [↱] [HOME] to go to the home screen.



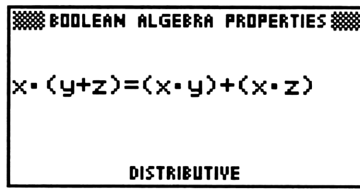
Example

MODES (Press CST)	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small

Find the expression of the Distributive Property.



1. Press DESC to toggle the help text and the expressions.
2. Press OPTS NXT FIND to search for the property.
3. Type DIST and press ENTER to start the search. (If necessary, first press ON to delete the previous search string.) The highlight bar will move to the first match, which is the answer. Press EXIT to exit the options menu.
4. Press VIEW to display the property in a text view, as shown.
5. When you have finished viewing the property, press any key to return to the previous screen.
6. *Optional*: press DESC to toggle the help text and the expressions back to their original positions.



Bibliography

Mano, M. Morris, *Digital Logic and Computer Design*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1979, pp 34-54.

Chapter 39

Transforms

Analysis
Equations
Reference
Transforms

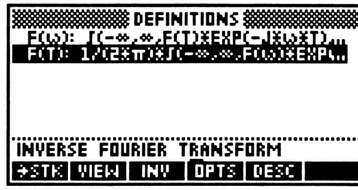
This chapter covers the Transforms reference table, which includesdefinitions, properties, and transform pairs for continuous-time Fourier transforms, bilateral Laplace transforms, and bilateral z-transforms. All formulas can be viewed in the EquationWriter, printed, or copied to the stack for future use. However, these sections do not include any Analysis-type routines.

Using Transforms

1. Select Fourier Transforms, Laplace Transforms, or z-Transforms and press [ENTER] or [►].
2. Select Definitions, Properties or Transform Pairs and press [ENTER] or [►]. By default, the forward transforms are displayed.
3. Select the desired equation and:
   - Press INV to display the inverse transforms, which will switch the positions of the time and frequency functions.
   - Press DESC to toggle the help text and the transform (not available in Transform Pairs).
   - Press VIEW to display the transform in a text view.
   - Press [⬅] or [➡] VIEW to display the transform in a graphics view. If the graphics form is wider than the screen, press [◄] and [►] to scroll. When you have finished viewing the transform, press any key to return to the previous screen.
   - Press →STK to copy one or all to the HP 48 stack.
   - Press OPTS [NXT] PRINT to send one or all to a printer.
4. When you have finished with Transforms, press [◄] to go to the previous screen, [➡][HOME] to go to the home screen, or [ON] to quit EE•*Pro*.

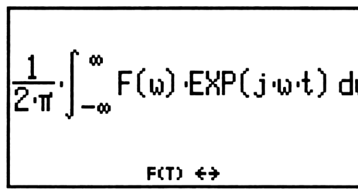
Example 1

MODES (Press [CST])	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small



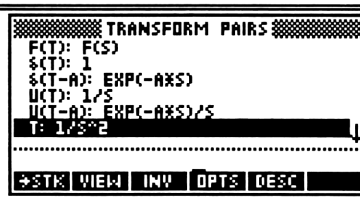
What is the definition of the Inverse Fourier transform?

1. In the initial Transforms screen, move the highlight bar to Fourier Transforms and press [ENTER] or [►].
2. Move the highlight bar to Definitions and press [ENTER] or [►].
3. Move the highlight bar to the second definition and press [⬅] **VIEW** to view it in a graphics view.
4. Press [◄] and [►] to scroll. When you have finished viewing the transform, press any key to return to the previous screen.



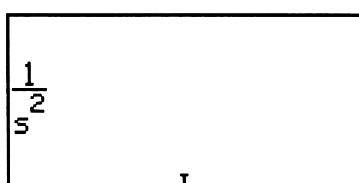
Example 2

MODES (Press [CST])	∡:	Degrees	Result:	Symbolic
	Coord:	Rectangular	Units:	On or Off
	Format:	Standard	Help:	On
	Digits:	N/A	Font:	Small



Look up the Laplace transform of the time function f(t)=t.

1. In the initial Transforms screen, move the highlight bar to Laplace Transforms and press [ENTER] or [►].
2. Move the highlight bar to Transform Pairs and press [ENTER] or [►].
3. Scroll down to t: 1/s^2 and press [⬅] **VIEW** to view it in a graphics view.
4. When you have finished viewing the transform, press any key to return to the previous screen.



Chapter 40

Constants

Analysis
Equations
Reference
Constants

This chapter covers the Constants reference table, which includes 43 commonly-used universal constants, descriptions, and units. Many of these constants are embedded in equations in the Equations sections of EE*Pro, and their values are automatically inserted during Solver computations. All constants can be viewed, printed, or copied to the stack for future use.

Using Constants

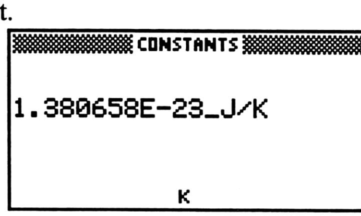
1. Scroll through the Constants screen with [▲] and [▼] or search with FIND to select a constant.
2. When you have found the desired item:
   - Press VIEW to display it in a text view.
   - Press →STK to copy one or all to the HP 48 stack.
   - Press OPTS [NXT] PRINT to send one or all to a printer.
3. *Optional*: When finished, press [◄] to go to the previous screen or [↱] [HOME] to go to the home screen.

Example

MODES (Press [CST])	**∡:**	Degrees	**Result:**	Symbolic
	Coord:	Rectangular	**Units:**	On or Off
	Format:	Standard	**Help:**	On
	Digits:	N/A	**Font:**	Small

Look up the value of the Boltzmann constant.

1. Press DESC or [VAR] to toggle the position of the constant values and the help text, so that the names of the constants are listed in the main display area. (If necessary, first press [ON] to clear the previous search string.)



2. Press OPTS [NXT] FIND to activate the search feature.

3. Type BOLTZ and press ENTER to start the search. The highlight bar will move to the first match, which is the answer. To turn units on or off, press NXT UNITS.
4. Press NXT VIEW to display the constant in text view as shown here.
5. When you have finished, press any key to return to the previous screen.
6. *Optional*: Press EXIT to exit the options menu.
7. *Optional*: Press DESC or VAR to toggle the help text back to its original position at the bottom of the screen.

Constants Reference Table

Const.	Description	Const.	Description
π	circle ratio	μq	mass μ / mass e-
e	Napier constant	c1	1st radiation constant
γ	Euler constant	c2	2nd radiation constant
ø	golden ratio	b	Wien displacement
α	fine structure	λc	e- Compton wavelength
c	speed of light	λn	n Compton wavelength
∈0	permittivity	λp	p+ Compton wavelength
F	Faraday constant	NA	Avogadro constant
G	Newton constant	ø0	magnetic flux quantum
g	acceleration of gravity	R	molar gas constant
h	Planck constant	a0	Bohr radius
hb	Dirac constant	R∞	Rydberg constant
k	Boltzmann constant	σ	Stefan-Boltzmann constant
μ0	permeability	μB	Bohr magneton
q	e- charge	μe	e- magnetic moment
em	e- charge / mass	μN	nuclear magneton
me	e- rest mass	μp	p+ magnetic moment
mn	n rest mass	μμ	μ magnetic moment
mp	p+ rest mass	SP	standard pressure
mμ	μ rest mass	ST	standard temperature
pe	mass p+ / mass e-	Vm	molar volume at STP
re	classical e- radius		

Bibliography

Based on Cohen and Taylor, "The 1986 Adjustment of the Fundamental Physical Constants," *Rev. Mod. Phys.*, Vol. 59, No. 4, October 1987, 1139-1145.

Chapter 41

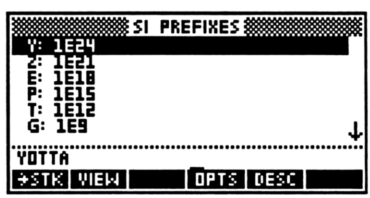
SI Prefixes

Analysis
Equations
Reference
SI Prefixes

This chapter covers the SI Prefixes reference table, which includes all currently-accepted prefixes for Le Systeme International d'Unites. All of these prefixes are recognized by the HP 48GX, and all but the most recent four of them (Y, Z, y, and z) are recognized by the HP 48SX.

Using SI Prefixes

1. Scroll through the SI Prefixes screen with [▲] and [▼] or search with **FIND**.
2. When you have found the desired item:
   - Press **VIEW** to display it in a text view.
   - Press **→STK** to copy one or all to the HP 48 stack.
   - Press **OPTS** [NXT] **PRINT** to print one or all to a printer.
3. *Optional*: When finished, press [◄] to go to the previous screen or [↱] [HOME] to go to the home screen.



Chapter 42

Greek Alphabet

Analysis Equations Reference *Greek Alphabet*

This chapter covers the Greek Alphabet reference table, which includes a picture displaying all uppercase and lowercase letters in the Greek alphabet. Many of these characters are built-in to the HP 48 fonts, but not all.

Press any key to return to the previous screen. (This is simply a display. These characters can not be copied to the stack.)

(Note that the uppercase and lowercase Greek letters alternate positions from one line to the next.)

Part 4

Programming & Advanced Use

Chapter 43

Programmable Commands

This chapter covers programming with EE•*Pro* and includes a summary of the programmable commands. Each of these commands can be executed directly from the HP 48 stack or included in user programs. For more information about programming, see the HP 48 manual.

This chapter covers:

- Using Programmable Commands
- Object Syntax
- EE Library Commands
- AC Circuits
- Polyphase Circuits
- Filter Design
- Gain and Frequency
- Fourier Transforms
- Two-Port Networks
- Transformer Performance
- Transmission Lines
- Binary Arithmetic
- Register Operations
- Bit Operations
- Binary Conversions
- Binary Comparisons
- Binary Modes
- Miscellaneous Binary Operations
- Karnaugh Map
- Algebraic Functions
- Error Functions
- Capital Budgeting
- Reference

Using Programmable Commands

Programmable commands can be used from the stack or incorporated into a user program. The tables in this chapter are organized to provide you with the inputs and outputs of each command, as well as the types of arguments accepted. The object syntax table lists the abbreviations used for the different argument types. For more information about writing programs see your HP 48 User's Guide.

Using Programmable Commands From the Stack

1. Type the input argument(s). For example, type the input array for the →FFT command [1 2 3 2 1].
2. Enter the command by either typing it or using the EE•*Pro* library menu:
   - [α] [α] →FFT [ENTER] or
   - Press [→] [LIBRARY] (HP 48GX) or [←] [LIBRARY] (HP 48SX) then **EE** **CMDS** **FFT** **→FFT**.

Object Syntax

These are the various objects listed as inputs or outputs in this chapter.

Object Syntax	Description	Examples
x y a b c d	Real number	1.523 5.55 10
m n	Positive integer (real number)	1 2 3
(x,y)	Complex number or rectangular point	(0,1) (1,2) (1.5,-3.3)
z	Real or complex number	1.523 (0,1)
x_unit	Real number with units	10_m/s 20.587_ft
{list}	List of objects	{ 2 2 3 } { (0,1) (1,2) }
[array]	Real or complex array	[1 2 3] [(0,1) (1,2)]
'name'	Global or local name	'X' 'Y' 'Z'
'symb'	Algebraic expression or name	'SIN(X)' 'LN(Z)' 'X'
#bin	Binary integer	10110
'expr_x'	Real number, algebraic or global name	2.7 'SIN(X)' 'X'
'expr_z'	Real or complex number, algebraic or global name	2.7 (10, 52) 'SIN(X)' 'X'
T/F	1 (True) or 0 (False)	1 0

EE Library Commands

These are the commands in the EE•*Pro* library menu.

Command/Description	Input(s)	Output
EE Runs EE•*Pro*	-	-
ABOUTEE Displays the EE•*Pro* 'About' screen	-	-
CMDSEE Displays the EE•*Pro* commands in the menu keys	-	-
GOEE Goes to the specified screen in EE•*Pro*, see chapter 32	{list}	specified screen

AC Circuits

These commands are found in the CMDS AC menu. For more information, see Chapter 3, "AC Circuits."

Command/Description	Input(s)	Output(s)
VZDIV Voltage Divider (Z)	**Vs**: 'expr_z' **Z**: $\{Z_1 .. Z_n\}$	**IL**: 'expr_z' **V**: $\{V_1 .. V_n\}$
VYDIV Voltage Divider (Y)	**Vs**: 'expr_z' **Y**: $\{Y_1 .. Y_n\}$	**IL**: 'expr_z' **V**: $\{V_1 .. V_n\}$
CZDIV Current Divider (Z)	**Is**: 'expr_z' **Z**: $\{Z_1 .. Z_n\}$	**VL**: 'expr_z' **I**: $\{I_1 .. I_n\}$
CYDIV Current Divider (Y)	**Is**: 'expr_z' **Y**: $\{Y_1 .. Y_n\}$	**VL**: 'expr_z' **I**: $\{I_1 .. I_n\}$
ZCPERF Circuit Performance (Z)	**Vs**: 'expr_z' **Zs**: 'expr_z' **ZL**: 'expr_z'	**VL**: 'expr_z' **IL**: 'expr_z' **P**: 'expr_x' **Q**: 'expr_x' **VI**: 'expr_z' **θ**: 'expr_x' **PF**: 'expr_x' **Pmax**: 'expr_x' **ZLopt**: 'expr_z'

YPERF Circuit Performance (Y)	**Vs**: 'expr_z' **Ys**: 'expr_z' **YL**: 'expr_z'	**VL**: 'expr_z' **IL**: 'expr_z' **P**: 'expr_x' **Q**: 'expr_x' **VI**: 'expr_z' **θ**: 'expr_x' **PF**: 'expr_x' **Pmax**: 'expr_x' **YLopt**: 'expr_z'
Y↔Δ Wye to Delta Conversion	**Z1**: 'expr_z' **Z2**: 'expr_z' **Z3**: 'expr_z'	**ZA**: 'expr_z' **ZB**: 'expr_z' **ZC**: 'expr_z'
Δ↔Y Delta to Wye Conversion	**ZA**: 'expr_z' **ZB**: 'expr_z' **ZC**: 'expr_z'	**Z1**: 'expr_z' **Z2**: 'expr_z' **Z3**: 'expr_z'

Polyphase Circuits

These commands are found in the CMDS PHASE menu. For more information, see Chapter 4, "Polyphase Circuits."

Command/Description	Input(s)	Output(s)
Y↔Δ Wye to Delta Conversion	**Z1**: 'expr_z' **Z2**: 'expr_z' **Z3**: 'expr_z'	**ZA**: 'expr_z' **ZB**: 'expr_z' **ZC**: 'expr_z'
Δ↔Y Delta to Wye Conversion	**ZA**: 'expr_z' **ZB**: 'expr_z' **ZC**: 'expr_z'	**Z1**: 'expr_z' **Z2**: 'expr_z' **Z3**: 'expr_z'
ΔLOAD Balanced Delta Load	**VAB**: 'expr_z' **Z**: 'expr_z'	**VBC**: 'expr_z' **VCA**: 'expr_z' **VAN**: 'expr_z' **VBN**: 'expr_z' **VCN**: 'expr_z' **IA**: 'expr_z' **IB**: 'expr_z' **IC**: 'expr_z' **P**: 'expr_x' **WAB**: 'expr_x' **WAC**: 'expr_x'

YLOAD Balanced Wye Load	**V12:** 'expr_z' **Z:** 'expr_z'	**V23:** 'expr_z' **V31:** 'expr_z' **V1N:** 'expr_z' **V2N:** 'expr_z' **V3N:** 'expr_z' **I1:** 'expr_z' **I2:** 'expr_z' **I3:** 'expr_z' **P:** 'expr_x' **W12:** 'expr_x' **W13:** 'expr_x'

Filter Design

These commands are found in the CMDS FILTR menu. For more information, see Chapter 6, "Filter Design."

Command/Description	Input(s)	Output(s)
CHLP Low Pass Chebyshev Filter	**R:** x **f0:** x **f1:** x **ΔdB:** x **Ripple:** x	**C1:** x **L2:** x ... **# of arguments:** x
CHHP High Pass Chebyshev Filter	**R:** x **f0:** x **f1:** x **ΔdB:** x **Ripple:** x	**L1:** x **C2:** x ... **# of arguments:** x
CHBP Band Pass Chebyshev Filter	**R:** x **f0:** x **f1:** x **ΔdB:** x **Bandwidth:** x **Ripple:** x	**C1:** x **L1:** x **L2:** x **C2:** x ... **# of arguments:** x
CHBE Band Elimination Chebyshev Filter	**R:** x **f0:** x **f1:** x **ΔdB:** x **Bandwidth:** x **Ripple:** x	**L1:** x **C1:** x **C2:** x **L2:** x ... **# of arguments:** x
BWLP Low Pass Butterworth Filter	**R:** x **f0:** x **f1:** x **ΔdB:** x	**C1:** x **L2:** x ... **# of arguments:** x

BWHP High Pass Butterworth Filter	**R:** x **f0:** x **f1:** x **ΔdB:** x	**L1:** x **C2:** x ... **# of arguments:** x
BWBP Band Pass Butterworth Filter	**R:** x **f0:** x **f1:** x **ΔdB:** x **Bandwidth:** x	**C1:** x **L1:** x **L2:** x **C2:** x ... **# of arguments:** x
BWBE Band Elimination Butterworth Filter	**R:** x **f0:** x **f1:** x **ΔdB:** x **Bandwidth:** x	**L1:** x **C1:** x **C2:** x **L2:** x ... **# of arguments:** x
ACLP Low Pass Active Filter	**f0:** 'expr_x' **A:** 'expr_x' **Q:** 'expr_x' **C:** 'expr_x'	**R1:** 'expr_x' **C2:** 'expr_x' **R3:** 'expr_x' **R4:** 'expr_x' **C5:** 'expr_x'
ACHP High Pass Active Filter	**f0:** 'expr_x' **A:** 'expr_x' **Q:** 'expr_x' **C:** 'expr_x'	**C1:** 'expr_x' **R2:** 'expr_x' **C3:** 'expr_x' **C4:** 'expr_x' **R5:** 'expr_x'
ACBP Band Pass Active Filter	**f0:** 'expr_x' **A:** 'expr_x' **Q:** 'expr_x' **C:** 'expr_x'	**R1:** 'expr_x' **R2:** 'expr_x' **C3:** 'expr_x' **C4:** 'expr_x' **R5:** 'expr_x'

Gain and Frequency

These commands are found in the CMDS GAIN menu. For more information, see Chapter 7, "Gain and Frequency."

Command/Description	Input(s)	Output(s)
XFERPZ Transfer Function, Roots	**Constant:** c **Zeros:** [A_M .. A_0] **Poles:** [A_N .. A_0]	**H(s):** 'symb'
XFERND Transfer Function, Coefficients	**Constant:** c **Num:** [R_1 .. R_M] **Denom:** [R_1 .. R_N]	**H(s):** 'symb'

PFER Partial Fraction Expansion, Roots	**Constant:** c **Zeros:** [R_1 .. R_M] **Poles:** [R_1 .. R_N]	**PFE:** 'symb'
PFEC Partial Fraction Expansion, Coefficients	**Constant:** c **Num:** [A_M .. A_0] **Denom:** [A_N .. A_0]	**PFE:** 'symb'

Fourier Transforms

These commands are found in the CMDS FFT menu. For more information, see Chapter 8, "Fourier Transforms."

Command/Description	Input(s)	Output(s)
→FFT Fast Fourier Transform	**Time:** [array]	**Freq:** [array]
FFT→ Inverse Fast Fourier Transform	**Freq:** [array]	**Time:** [array]

Two-Port Networks

These commands are found in the CMDS 2PORT menu. For more information, see Chapter 9, "Two-Port Networks."
Note: 'name' can be the global name 'z', 'y', 'h', 'g', 'a', or 'b'.

Command/Description	Input(s)	Output(s)
PCON Parameter Conversion	**Input Type:** 'name' **..11:** 'expr_z' **..12:** 'expr_z' **..21:** 'expr_z' **..22:** 'expr_z' **Output Type:** 'name'	**..11:** 'expr_z' **..12:** 'expr_z' **..21:** 'expr_z' **..22:** 'expr_z'
PCPERF Circuit Performance	**Parameter Type:** 'name' **..11:** 'expr_z' **..12:** 'expr_z' **..21:** 'expr_z' **..22:** 'expr_z' **Vs:** 'expr_z' **Zs:** 'expr_z' **ZL:** 'expr_z'	**Zin:** 'expr_z' **Iout:** 'expr_z' **Vout:** 'expr_z' **Zout:** 'expr_z' **I2/I1:** 'expr_z' **V2/V1:** 'expr_z' **V2/Vs:** 'expr_z' **GP:** 'expr_z' **Pav:** 'expr_z' **Pmax:** 'expr_z' **Zlopt:** 'expr_z'

I2PCAS Inter-connected Two-Ports in Cascade configuration	**1st Input Type:** 'name' **..11:** 'expr_z' **..12:** 'expr_z' **..21:** 'expr_z' **..22:** 'expr_z' **2nd Input Type:** 'name **..11:** 'expr_z' **..12:** 'expr_z' **..21:** 'expr_z' **..22:** 'expr_z' **Output Type:** 'name'	**..11:** 'expr_z' **..12:** 'expr_z' **..21:** 'expr_z' **..22:** 'expr_z'
I2PSS Inter-connected Two-Ports in Series-Series configuration	**same as I2PCAS**	**same as I2PCAS**
I2PPP Inter-connected Two-Ports in Parallel-Parallel configuration	**same as I2PCAS**	**same as I2PCAS**
I2PSP Inter-connected Two-Ports in Series-Parallel configuration	**same as I2PCAS**	**same as I2PCAS**
I2PPS Inter-connected Two-Ports in Parallel-Series configuration	**same as I2PCAS**	**same as I2PCAS**

Transformer Performance

These commands are found in the **CMDS** [NXT] **XFMR** menu. For more information, see Chapter 10, "Transformer Performance."

Command/Description	Input(s)	Output(s)
OCTST Open Circuit Test	**V1:** 'expr_x' **V2:** 'expr_x' **I1:** 'expr_x' **P1:** 'expr_x'	**n:** 'expr_x' **Q1:** 'expr_x' **Gc:** 'expr_x' **Bc:** 'expr_x'
SCTST Closed Circuit Test	**V1:** 'expr_x' **I1:** 'expr_x' **P1:** 'expr_x' **kVA:** 'expr_x' **V1R:** 'expr_x'	**n:** 'expr_x' **Q1:** 'expr_x' **R1:** 'expr_x' **R2:** 'expr_x' **X1:** 'expr_x' **X2:** 'expr_x'
CHAIN Chain Parameters	**Z1:** 'expr_z' **Z2:** 'expr_z' **n:** 'expr_x' **Gc:** 'expr_x' **Bc:** 'expr_x'	**A:** 'expr_z' **B:** 'expr_z' **C:** 'expr_z' **D:** 'expr_z'

Transmission Lines

These commands are found in the CMDS NXT XMS menu. For more information, see Chapter 11, "Transmission Lines."

Command/Description	Input(s)	Output(s)
XLCHR Line Characteristics	**L:** 'expr_x' **R:** 'expr_x' **G:** 'expr_x' **C:** 'expr_x' **ZL:** 'expr_z' **d:** 'expr_x' **f:** 'expr_x'	**Z0:** 'expr_z' **Y0:** 'expr_z' **α:** 'expr_x' **β:** 'expr_x' **λ:** 'expr_x' **vp:** 'expr_x' **Zoc:** 'expr_z' **Zsc:** 'expr_z' **ρ:** 'expr_z' **SWR:** 'expr_x'
XLPAR Line Parameters	**Zoc:** 'expr_z' **Zsc:** 'expr_z' **d:** 'expr_x' **f:** 'expr_x'	**R:** 'expr_x' **L:** 'expr_x' **G:** 'expr_x' **C:** 'expr_x' **Z0:** 'expr_z' **Y0:** 'expr_z' **α:** 'expr_x' **β:** 'expr_x' **vp:** 'expr_x'
XLFAULT Fault Location Estimate	**Xin:** 'expr_x' **R0:** 'expr_x' **ß:** 'expr_x'	**docmin:** 'expr_x' **dscmin:** 'expr_x'
XLZ Lossless Line Impedance	**ZL:** 'expr_z' **R0:** 'expr_x'	**ß*d1:** 'expr_x' **ß*d1-sc:** 'expr_x' **ß*d1-oc:** 'expr_x' **ß*d2:** 'expr_x' **ß*d2-sc:** 'expr_x' **ß*d2-oc:** 'expr_x'

Binary Arithmetic

These commands are found in the CMDS NXT COMP ARTH menu. For more information, see Chapter 12, "Computer Engineering."

Command/Description	Input(s)	Output(s)
ADD16C Binary Addition	**Binary:** #bin x **Binary:** #bin x	**Sum:** #bin x

SUB16C Binary Subraction	**Binary:** #bin x **Binary:** #bin x	**Difference:** #bin x
MULT16C Binary Multiplication	**Binary:** #bin x **Binary:** #bin x	**Product:** #bin x
DIV16C Binary Division	**Dividend:** #bin x **Divisor:** #bin x	**Quotient:** #bin
RMD16C Remainder	**Dividend:** #bin x **Divisor:** #bin x	**Remainder:** #bin
NEG16C Binary Negation	**Binary:** #bin	**Result:** #bin
ABS16C Absolute Value	**Binary:** #bin	**Result:** #bin

Register Operations

These commands are found in the CMDS NXT COMP REG menu. For more information, see Chapter 12, "Computer Engineering."

Command/Description	Input(s)	Output(s)
SL16C Shift Left	**Binary:** #bin	**Result:** #bin
SR16C Shift Right	**Binary:** #bin	**Result:** #bin
RL16C Rotate Left	**Binary:** #bin	**Result:** #bin
RR16C Rotate Right	**Binary:** #bin	**Result:** #bin
RLC16C Rotate Left Through Carry	**Binary:** #bin	**Result:** #bin
RRC16C Rotate Right Through Carry	**Binary:** #bin	**Result:** #bin
SLN16C Shift Left n Bits	**Binary:** #bin **n:** #bin x	**Result:** #bin
SRN16C Shift Right n Bits	**Binary:** #bin **n:** #bin x	**Result:** #bin
RLN16C Rotate Left n Bits	**Binary:** #bin **n:** #bin x	**Result:** #bin
RRN16C Rotate Right n Bits	**Binary:** #bin **n:** #bin x	**Result:** #bin
RLCN16C Rotate Left Through Carry n Bits	**Binary:** #bin **n:** #bin x	**Result:** #bin
RRCN16C Rotate Right Through Carry n Bits	**Binary:** #bin **n:** #bin x	**Result:** #bin
ASR16C Arithmatic Shift Right	**Binary:** #bin	**Result:** #bin

Bit Operations

These commands are found in the CMDS NXT COMP BIT menu. For more information, see Chapter 12, "Computer Engineering."

Command/Description	Input(s)	Output(s)
SB Set Bit	**Binary:** #bin **Bit #:** #bin x	**Result:** #bin
CB Clear Bit	**Binary:** #bin **Bit #:** #bin x	**Result:** #bin
B? Check Bit	**Binary:** #bin **Bit #:** #bin x	**Result:** #bin
ΣB Sum of Bits	**Binary:** #bin	**Result:** #bin

Binary Conversions

These commands are found in the CMDS NXT COMP CNVT menu. For more information, see Chapter 12, "Computer Engineering."

Command/Description	Input(s)	Output(s)
R→B16C Real to Binary Conversion	**Real:** x	**Result:** #bin
B→R16C Binary to Real Conversion	**Binary:** #bin	**Result:** x
→IEEE Real to IEEE 32-bit Format Conversion	**Real:** x	**Result:** #bin
IEEE→ IEEE 32-bit Format to Real Conversion	**Binary:** #bin	**Result:** x

Binary Comparisons

These commands are found in the CMDS NXT COMP CMPR menu. For more information, see Chapter 12, "Computer Engineering."

Command/Description	Input(s)	Output(s)
==16C Binary Equals	**Binary:** #bin x **Binary:** #bin x	**Result:** T/F
≠16C Binary Not Equals	**Binary:** #bin x **Binary:** #bin x	**Result:** T/F
<16C Binary Less Than	**Binary:** #bin x **Binary:** #bin x	**Result:** T/F

>16C Binary Greater Than	**Binary:** #bin x **Binary:** #bin x	**Result:** T/F
≤16C Binary Less Than or Equal	**Binary:** #bin x **Binary:** #bin x	**Result:** T/F
≥16C Binary Greater Than or Equal	**Binary:** #bin x **Binary:** #bin x	**Result:** T/F

Binary Modes

These commands are found in the CMDS NXT COMP MODES menu. For more information, see Chapter 12, "Computer Engineering."

Command/Description	Input(s)	Output(s)
SETC Set Carry Flag	-	**Set User Flag 4**
CLRC Clear Carry Flag	-	**Clear User Flag 4**
CRRY? Check Carry Flag	-	**Test Flag 4:** T/F
SETR Set Range Flag	-	**Set User Flag 5**
CLRR Clear Range Flag	-	**Clear User Flag 5**
RNG? Check Range Flag	-	**Test User Flag 5:** T/F
UNSGN Set Unsigned Mode	-	Put 48 in unsigned mode
ONES Set One's Complement Mode	-	Put 48 in one's complements mode
TWOS Set Two's Complement Mode	-	Put 48 in two's complements mode
CMP? Complement Mode	-	**Complement mode:** 0,1,2

Miscellaneous Binary Operations

These commands are found in the CMDS NXT COMP NXT MISC menu. These operations cannot be found in any EE•*Pro* screen. They are provided as programmable commands in order to complete the set of commands that are provided by the HP 16C "Computer Scientist Calculator"

Command/Description	Input(s)	Output(s)
DBLx Double-word Multiply	**Binary:** #bin **Binary:** #bin	**Product, 1st ½:** #bin **Product, 2nd ½:** #bin

DBL÷ Double-word Divide	**Dividend, 1st ½:** #bin **Dividend,2nd ½:** #bin **Divisor:** #bin	**Quotient:** #bin
DBLR Double-word Divide Remainder	**Dividend, 1st ½:** #bin **Dividend,2nd ½:** #bin **Divisor:** #bin	**Remainder:** #bin
LJ16C Left Justify	**Binary:** #bin	**Binary:** #bin **n:** #bin (number of bits shifted)
MSKL Left-justified Mask with n Bits	**n:** #bin x	**Binary:** #bin
MSKR Right-justified Mask with n Bits	**n:** #bin x	**Binary:** #bin
FLOAT	**Binary:** #bin$_1$ **Binary:** #bin$_2$	**REAL:** #bin$_1$*2^(#bin$_1$)
FIXED	**Real:** x	**32-bit Mantissa:** #bin **Exponent of 2:** #bin

Karnaugh Map

These commands are found in the CMDS NXT COMP NXT menu. For more information, see Chapter 12, "Computer Engineering."

Command/Description	Input(s)	Output(s)
KMAP Karnaugh Map	**Minterms:** {#$_1$ .. #$_N$} **Don't Care:** {#$_1$ .. #$_M$} **Vars:** 'A..Z'	**Prime Implicants:** 'string'

Algebraic Functions

These commands are found in the CMDS NXT ALGB menu. For more information, see Chapter 13, "Algebraic Functions."

Command/Description	Input(s)	Output(s)
PFEC Partial Fraction Expansion, Coefficients	**Constant:** c **Num:** [A_M .. A_0] **Denom:** [A_N .. A_0]	**PFE:** 'symb'
PFER Partial Fraction Expansion, Roots	**Coefficient:** c **Num:** [R_1 .. R_M] **Denom:** [R_1 .. R_N]	**PFE:** 'symb'
POLYC Polynomial Coefficients	**Roots:** [R_1 .. R_N]	**Coefs:** [A_N .. A_0]

POLYE Polynomial Equation	**Coefs:** $[A_N .. A_0]$ **Var:** 'name'	**Poly:** 'symb'
POLYR Polynomial Roots	**Coefs:** $[A_N .. A_0]$	**Roots:** $[R_1 .. R_N]$
SIMPL Symbolic Simplification	**Expr:** 'expr_z'	**Simpl:** 'symb'
TYLRA Taylor Polynomial	**Expr:** 'symb' **Var:** 'name' **Order:** x **Point:** 'expr_z'	**Taylor:** 'symb'

Error Functions

These commands are found in the CMDS NXT ERROR menu. For more information, see Chapter 14, "Error Function."

Command/Description	Input(s)	Output(s)
ERF Error Function	**X:** x	**Result:** x
ERFC Inverse Error Function	**X:** x	**Result:** x

Capital Budgeting

These commands are found in the CMDS NXT BUDG menu. For more information, see Chapter 15, "Capital Budgeting."

Command/Description	Input(s)	Output(s)
PAYB Payback Period	**Cash:** $[T_0 .. T_n]$	**Payback:** x
NPV Net Present Value	**Cash:** $[T_0 .. T_n]$ **Discount rate:** x	**NPV:** x
IRR Internal rate of return	**Cash:** $[T_0 .. T_n]$	**IRR:** x
PIDX Profitability Index	**Cash:** $[T_0 .. T_n]$ **Discount rate:** x	**PI:** x

Reference

These commands are found in the CMDS NXT NXT REF menu. For more information, see Chapter 35 "Standard Component Values" and Chapter 40, "Constants".

Command/Description	Input(s)	Output(s)
RVAL Standard Resistor Value	**Value:** x **Tolerance:** y	**Std Value:** x_unit **Color Bands:** "string"
LVAL Standard Inductor Value	**Value:** x **Tolerance:** y	**Std Value:** x_unit
CVAL Standard Capacitor Value	**Value:** x **Tolerance:** y	**Std Value:** x_unit
CONS Constant Function	**Constant:** 'name'	**Value:** x or x_unit

CONS: Constants

This command provides programmable access to the values of the constants in the Constants reference table. The value of the constant will be returned with units if user flag 61 is clear or without units if user flag 61 is set. (For more information, see Appendix C, "User Flags.") CONS can be used in an algebraic expression, such as 'CONS(h)', or in a user program, such as « 'h' CONS ». CONS is also affected by system flags -2 and -3, which control symbolic constants and numeric results—if either flag -2 or -3 is set, 'h' CONS will return a numeric value, but if both are clear, 'h' CONS will return 'CONS(h)', which will only evaluate to a numeric value after [→NUM]. To replace a built-in constant with a different value, you can place an override constant in a variable named "$" followed by the constant name, such as '$h'.

Example: *Create an equation with a constant.* The mass-energy relation is $E = mc^2$. To write this as an HP 48 equation which accesses the speed of light constant included in EE•*Pro*, use the equation:

'E = m * CONS(c) ^ 2'

This equation will call the command CONS to access the value of the speed of light constant **c**. The value of **c** will be returned as 299792458_m/s if flag 61 is clear (units on), or as 299792458 if flag 61 is set (units off).

Example: *Override a built-in constant.* To solve gravitational problems on the moon (instead of the Earth), the acceleration of gravity **g**, must be overridden. To override the built-in value of 9.80665 m/s (the gravitational acceleration at the surface of the Earth), store the value 1.55 m/s into the variable '$g'. The value of **g** will now be returned by CONS as 1.55 m/s. To return to the original value, purge the variable '$g' from user memory.

Chapter 44

Programmable Screens

EE•*Pro* is designed to allow you to jump directly to any Analysis, Equation, or Reference screen from the HP 48 stack with the GOEE command. This chapter describes how to use these "programmable screens."

This chapter covers:

- ❑ Using Programmable Screens
- ❑ Analysis Screens
- ❑ Equations Screens
- ❑ Reference Screens

Using Programmable Screens

The GOEE command, located in the library menu of EE•*Pro*, allows you to jump directly to a particular screen in EE•*Pro*.

Example: HP 48 Stack

Browse Constants from the HP 48 stack.

1. From the HP 48 stack, type [←] [{ }] 3 [SPC] 7 [ENTER] to put the list { 3 7 } on the stack.
2. Press [→] [LIBRARY] (on the HP 48GX) or [←] [LIBRARY] (on the HP 48SX), then press [EE] [GOEE] and the Constants screen will appear.

Example: User Program

Create a user program that goes directly to the Constants reference table from the HP 48 stack.

1. Type [←] [« »] [←] [{ }] 3 [SPC] 7 [►] [SPC] [←] [LIBRARY] [EE] [GOEE] [ENTER] to put the program « { 3 7 } GOEE » on the stack.
2. Type ['] [α] [α] GOCONS [ENTER] to put the name 'GOCONS' on the stack. Press [STO] to store the program into GOCONS.

3. To execute GOCONS from the HP 48 stack, press VAR GOCO and the Constants screen will appear.
The program could also be stored in your custom menu for quick access. For more information, see your HP 48 User's Guide.

Analysis Screens

This is a summary of the EE•*Pro* Analysis screens and their corresponding path lists for use with the GOEE command.

Menu Item	Path
Home	{ }
Analysis	{ 1 }
AC Circuits	{ 1 1 }
Impedance Calculations	{ 1 1 1 }
Voltage Divider	{ 1 1 2 }
Current Divider	{ 1 1 3 }
Circuit Performance	{ 1 1 4 }
Wye ↔ Δ Conversion	{ 1 1 5 }
Polyphase Circuits	{ 1 2 }
Wye ↔ Δ Conversion	{ 1 2 1 }
Balanced Wye Load	{ 1 2 2 }
Balanced Δ Load	{ 1 2 3 }
Ladder Network	{ 1 3 }
Filter Design	{ 1 4 }
Chebyshev Filter	{ 1 4 1 }
Butterworth Filter	{ 1 4 2 }
Active Filter	{ 1 4 3 }
Gain and Frequency	{ 1 5 }
Transfer Function	{ 1 5 1 }
Bode Plots	{ 1 5 2 }
Fourier Transforms	{ 1 6 }
FFT	{ 1 6 1 }
Inverse FFT	{ 1 6 2 }
Two-Port Networks	{ 1 7 }
Parameter Conversion	{ 1 7 1 }
Circuit Performance	{ 1 7 2 }
Interconnected Two-Ports	{ 1 7 3 }
Transformer Performance	{ 1 8 }
Open Circuit Test	{ 1 8 1 }
Short Circuit Test	{ 1 8 2 }

Chain Parameters	{ 1 8 3 }
Transmission Lines	{ 1 9 }
Line Characteristics	{ 1 9 1 }
Line Parameter Calculations	{ 1 9 2 }
Fault Location Estimate	{ 1 9 3 }
Lossless Line Impedance	{ 1 9 4 }
Computer Engineering	{ 1 10 }
Binary Arithmetic	{ 1 10 1 }
Register Operations	{ 1 10 2 }
Bit Operations	{ 1 10 3 }
Binary Conversions	{ 1 10 4 }
Binary Comparisons	{ 1 10 5 }
Karnaugh Map	{ 1 10 6 }
Algebraic Functions	{ 1 11 }
Partial Fraction Expansion	{ 1 11 1 }
Piecewise Functions	{ 1 11 2 }
Polynomial Coefficients	{ 1 11 3 }
Polynomial Equation	{ 1 11 4 }
Polynomial Roots	{ 1 11 5 }
Symbolic Simplification	{ 1 11 6 }
Taylor Polynomial	{ 1 11 7 }
Error Functions	{ 1 12 }
Capital Budgeting	{ 1 13 }

Equations Screens

This is a summary of the EE•*Pro* Equations screens and their corresponding path lists for use with the GOEE command.

Menu Item	Path
Home	{ }
Equations	{ 2 }
Resistive Circuits	{ 2 1 }
Resistance and Conductance	{ 2 1 1 }
Ohm's Law and Power	{ 2 1 2 }
Temperature Effect	{ 2 1 3 }
Maximum Power Transfer	{ 2 1 4 }
V and I Source Equivalence	{ 2 1 5 }
Capacitance and Electric Fields	{ 2 2 }
Point Charge	{ 2 2 1 }

Long Charged Line	{ 2 2 2 }
Charged Disk	{ 2 2 3 }
Parallel Plates	{ 2 2 4 }
Parallel Wires	{ 2 2 5 }
Coaxial Cable	{ 2 2 6 }
Sphere	{ 2 2 7 }
Inductance and Magnetism	{ 2 3 }
Long Line	{ 2 3 1 }
Long Strip	{ 2 3 2 }
Parallel Wires	{ 2 3 3 }
Loop	{ 2 3 4 }
Coaxial Cable	{ 2 3 5 }
Skin Effect	{ 2 3 6 }
Electron Motion	{ 2 4 }
Electron Beam Deflection	{ 2 4 1 }
Thermionic Emission	{ 2 4 2 }
Photoemission	{ 2 4 3 }
Meters and Bridge Circuits	{ 2 5 }
Amp, Volt, and Ohmmeter	{ 2 5 1 }
Wheatstone Bridge	{ 2 5 2 }
Wien Bridge	{ 2 5 3 }
Maxwell Bridge	{ 2 5 4 }
Owen Bridge	{ 2 5 5 }
Sym. Resistive Attenuator	{ 2 5 6 }
Unsym. Resistive Attenuator	{ 2 5 7 }
RL and RC Circuits	{ 2 6 }
RL Natural Response	{ 2 6 1 }
RC Natural Response	{ 2 6 2 }
RL Step Response	{ 2 6 3 }
RC Step Response	{ 2 6 4 }
RL Series to Parallel	{ 2 6 5 }
RC Series to Parallel	{ 2 6 6 }
RLC Circuits	{ 2 7 }
Series Impedance	{ 2 7 1 }
Parallel Admittance	{ 2 7 2 }
RLC Natural Response	{ 2 7 3 }
Underdamped Transient	{ 2 7 4 }
Critically-Damped Transient	{ 2 7 5 }
Overdamped Transient	{ 2 7 6 }
AC Circuits	{ 2 8 }
RL Series Impedance	{ 2 8 1 }
RC Series Impedance	{ 2 8 2 }
Impedance ↔ Admittance	{ 2 8 3 }
Two Impedances in Series	{ 2 8 4 }
Two Impedances in Parallel	{ 2 8 5 }

Class A, B, and C Amplifiers	{ 2 14 }
Class A Amplifier	{ 2 14 1 }
Power Transistor	{ 2 14 2 }
Push-Pull Principle	{ 2 14 3 }
Class B Amplifier	{ 2 14 4 }
Class C Amplifier	{ 2 14 5 }
Transformers	{ 2 15 }
Ideal Transformer	{ 2 15 1 }
Linear Equivalent Circuit	{ 2 15 2 }
Motors and Generators	{ 2 16 }
Energy Conversion	{ 2 16 1 }
DC Generator	{ 2 16 2 }
Separately-Excited DC Genr.	{ 2 16 3 }
DC Shunt Generator	{ 2 16 4 }
DC Series Generator	{ 2 16 5 }
Separately-Excited DC Motor	{ 2 16 6 }
DC Shunt Motor	{ 2 16 7 }
DC Series Motor	{ 2 16 8 }
Permanent Magnet Motor	{ 2 16 9 }
Induction Motor I	{ 2 16 10 }
Induction Motor II	{ 2 16 11 }
Single-Phase Induction Motor	{ 2 16 12 }
Synchronous Machines	{ 2 16 13 }

Reference Screens

This is a summary of the EE•*Pro* Reference screens and their corresponding path lists for use with the GOEE command.

Menu Item	Path
Home	{ }
Reference	{ 3 }
Resistor Color Chart	{ 3 1 }
Standard Component Values	{ 3 2 }
Semiconductor Properties	{ 3 3 }
Semiconductors	{ 3 3 1 }
III-V, II-VI Compounds	{ 3 3 2 }
Si Donor Levels	{ 3 3 3 }
Si Acceptor Levels	{ 3 3 4 }
SiO2/Si3N4 Colors	{ 3 3 5 }
Boolean Expressions	{ 3 4 }
Boolean Algebra Properties	{ 3 5 }
Transforms	{ 3 6 }
Fourier Transforms	{ 3 6 1 }
Definitions	{ 3 6 1 1 }
Properties	{ 3 6 1 2 }
Transform Pairs	{ 3 6 1 3 }
Laplace Transforms	{ 3 6 2 }
Definitions	{ 3 6 2 1 }
Properties	{ 3 6 2 2 }
Transform Pairs	{ 3 6 2 3 }
z-Transforms	{ 3 6 3 }
Definitions	{ 3 6 3 1 }
Properties	{ 3 6 3 2 }
Transform Pairs	{ 3 6 3 3 }
Contants	{ 3 7 }
SI Prefixes	{ 3 8 }
Greek Alphabet	{ 3 9 }

Chapter 45

Tips for Using the Solver

This chapter covers tips for using the solver in the Equations section.

- Creating a Working Directory
- How are Multiple Equations Solved?
- Using Guesses to Improve Solving
- Solver Icons

Creating a Working Directory

Every time the solver solves an equation, it stores the variable values into your HP 48 user memory, in the directory you were at when you ran EE•*Pro*. If you would prefer to organize the equation variables into a specific subdirectory in your HP 48 user memory, follow these steps:

1. Quit EE•*Pro* to the HP 48 stack.
2. Press [→] [HOME] to go to the HOME directory of your HP 48.
3. Press [VAR] to display the variables in the HOME directory.
4. Decide on a name for the work subdirectory (e.g., WORK).
5. Type ['] [α] [α] WORK [ENTER] to put the name on the stack.
6. Type [α] [α] CRDIR [ENTER] to create the subdirectory 'WORK' in your HOME directory. It should appear in the variable menu as WORK.

You have now created the subdirectory { HOME WORK }. In order to store all equation variables created by EE•*Pro* in { HOME WORK }, each time you run the software, first follow these steps:

1. Press [→] [HOME] to go to the HOME directory of your HP 48.
2. Press [VAR] to display the variables in the HOME directory.
3. Press WORK to switch to the { HOME WORK } subdirectory.
4. Start EE•*Pro*, as described in Chapter 1, "Getting Started."

For more information on directories, see the HP 48 manual.

How are Multiple Equations Solved?

The solver in the Equations section of EE•*Pro* is a *systematic* solver, not a *simultaneous* one. For example, the solver can solve this set of equations, provided it is given a known value of either x or y:

$$x + y + z = 5$$
$$x + y = 3$$

However, the solver cannot solve this set of equations, when neither x or y is known in advance:

$$x + y = 2$$
$$x - y = 0$$

The solver iterates through a set of equations, searching for an equation with only one unknown variable. When an equation satisfying this requirement is found, the solver uses the built-in HP 48 root-finder to solve for the unknown variable. After the value is found, that variable is marked as found, and the solver continues to search. The solver does not terminate its search until one of three conditions occurs:

- All equations are solved, and all unknown variables are found.
- All variables marked as wanted are found.
- No more equations can be solved, because all remaining unsolved equations have more than one unknown variable.

All variables for which values are found in a solving operation are marked with a shaded circle at the solver screen.

Using Guesses to Improve Solving

Pressing SOLVE calls the built-in HP 48 root-finder to solve each equation. The root-finder requires an initial value on which to base its search for the solution. If no value exists, the solver uses a default guess of 1, but you can provide a guess to override that value. The root-finder then generates pairs of intermediate values and interpolates between them to find the solution. The time required to find the solution (the root) depends on how close the initial guess is to the actual solution.

You can shorten the solution time by providing a guess close to the expected solution. Go to the Solver screen and move the highlight bar to the variable in question, and enter a guess. The variable will automatically be marked as known, so move the highlight bar back to the variable and press KNOW or [+/-] to unmark the variable as known, so it will be calculated by the solver. Then press SOLVE and the solver will use the current value as the initial guess for the variable.

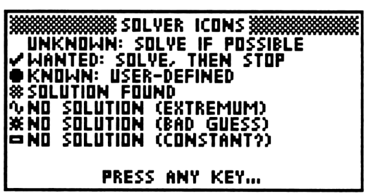
There is another advantage to using a guess, which is that you can help the solver find a specific solution to an equation which may have multiple valid solutions or roots.

Example: Imagine solving the equation $x^2 = 9$. Possible solutions include 3 and -3. Both of these solutions are right, but which one do you want? If you enter a guess of -1 for *x*, the solver will find the -3 solution, but if you enter a guess of 1 for *x* (which is the default guess), the solver will find the 3 solution. Depending on which solution you want, you may have to enter a guess for *x*.

Solver Icons

At the Solver screen, the status of variables is indicated by icons which appear to the left of the variable name. You control the presence of some of the icons, and the solver controls the presence of the other icons.

To display the icon screen from the Solver screen, press ICONS.



Press any key to return to the previous screen.

User-Controlled Icons

You control the presence of unknown (blank icon), known, and wanted icons by pressing KNOW or WANT.

UNKNOWN: *Solve if possible.* The solver will calculate the values of all unknown variables, unless it first stops because all wanted variables have been found. As a result of a calculation, the solver may change the status of unknown variables to solution found or no solution. However, if there are not enough known variables to solve for the unknown variable, the status will remain unchanged as unknown.

● **KNOWN:** *User-defined.* The values of the known variables are used to calculate the values of the unknown and wanted variables. The solver will not change the status of known variables.

✓ **WANTED:** *Solve, then stop.* The solver will calculate the values of all wanted variables and then stop. While solving for the wanted variables, the solver may also have to calculate the values of some unknown variables in order to find solutions to the wanted variables. As a result of a calculation, the solver may change the status of wanted variables to solution found or no solution. However, if there are not enough known variables to solve for the wanted variable, the status will remain unchanged as wanted.

Solver-Controlled Icons

The solver places icons for solution found and no solution. Each time you change a value or press SOLVE to start a new calculation, the solution found and no solution icons are all removed and the variables reset to unknown.

✹ **SOLUTION FOUND:** *Solution found.* A solution found icon indicates a solution has been found for the variable. Solutions may be indicated either as *zeros* or *sign reversals*, both of which are accurate solutions.

∿ **NO SOLUTION:** *Extremum.* An extremum icon indicates a solution has not been found for the variable. This occurs when the solver finds a point where the value of the variable being solved approximates a local minimum or maximum, or when the largest (MAXR) or smallest (–MAXR) number is encountered.

⋇ **NO SOLUTION:** *Bad guess.* A bad guess icon indicates a solution has not been found for the variable. This occurs when the initial guess for the variable is outside the domain of the equation. An example of this is a negative value inside a square root, which will cause a bad guess error, because the solver does not support complex numbers.

▭ **NO SOLUTION:** *Constant?* A constant icon indicates a solution has not been found for the variable. This occurs when the value of the variable is the same at every point sampled across the domain of the equation.

For more information, see Chapter 16, "Equations Navigation Guide."

Chapter 46

Tips for Using the Plotter

This chapter covers advanced use of the plotter in the Equations section.

- ❑ How are Equations Plotted?

How are Equations Plotted?

To plot an equation, it must be in the form $y = f(x)$, where **x** represents the independent variable and **y** the dependent variable. The plotter must be able to isolate the dependent variable on the left side of the equation before plotting. For this reason, there are equations in which certain variables should not be selected as the dependent variable, because they cannot be isolated.

Example: *How can the first equation in the RLC Circuits-Overdamped Transient module be plotted?* The equation is:

$$s1=-\alpha+\sqrt{\alpha^2-\omega o^2}$$

In this equation, any variable can be selected as the independent variable, but only **s1** or **ωo** should be selected as the dependent variable, because **α** appears more than once in the equation and cannot be isolated easily.

This table shows the possible combinations of the independent and dependent variables for the equation above and shows exactly what form the equation takes for plotting in each case.

Dependent	Independent	Isolated Equation
s1	α	$s1 = f(\alpha) = -\alpha + \sqrt{\alpha^2 + \omega 0^2}$
s1	ωo	$s1 = f(\omega 0) = -\alpha + \sqrt{\alpha^2 + \omega 0^2}$
ωo	s1	$\omega o = f(s1) = s1 \cdot \sqrt{\alpha^2 - SQ(s1 + \alpha)}$

ωo	**α**	$\omega o = f(\alpha) = s1 \cdot \sqrt{\alpha^2 - SQ(s1 + \alpha)}$
α	**ωo**	Cannot isolate **α** easily
α	**s1**	Cannot isolate **α** easily

*When isolating **s1** or **ωo**, the plotter also automatically selects the principal value (or branch) of the solution, if there are multiple solutions. Observe that the first three equations also have a negative solution to the square root, but the principal solution is the positive one, so that is what is used for plotting.*

After plotting an equation, to examine the form of the actual equation which was plotted, quit EE•*Pro* and look at the variable 'EQ' in the user memory of your HP 48. (**Note:** 'EQ' is not created until the plot is drawn.)

Appendixes and Index

Appendix A

Service and Warranty

Technical Support

You can get answers to your questions about EE•*Pro* from Sparcom Corporation. If you cannot find the information in this manual or in the HP 48S/SX or HP 48G/GX User's Guide, contact us in one of the following ways:

- **E-Mail**
  From Internet: support@sparcom.com
  From Compuserve: >Internet:support@sparcom.com
  From FidoNet: To:support@sparcom.com

- **Standard Mail**
  Sparcom Corporation
  Attn: Technical Support Department
  P.O. Box 927
  Corvallis, OR 97339, USA

- **Telephone**
  (503) 757–8416
  Monday to Friday, 9 a.m. to 12 p.m., Pacific Time

- **Facsimile**
  (503) 753–7821

Shipping Instructions

If your card requires service:

1. Call Sparcom Corporation for a Return Merchandise Authorization (RMA) number.

2. Ship the card back to Sparcom Corporation in the following manner:

   - Include your return address, phone number and a description of the problem.
   - INCLUDE YOUR **RMA** NUMBER WITH THE MERCHANDISE. The RMA number must be written on the outside of the package, or the package will be returned to you unopened.
   - If the card is still under warranty, include the proof of purchase date.
   - Include a check, purchase order, or credit card number and expiration date (VISA or MasterCard) to cover the estimated charge.
   - Should the card require further service, Sparcom Corporation will notify you of the additional repairs and charges.
   - Ship your card, postage prepaid, in protective packaging adequate to prevent damage. Ship the package to:

     Sparcom Corporation
     RMA # __________
     897 NW Grant Avenue
     Corvallis, OR 97330, USA

   - It is highly recommended that you insure the shipment.

   Cards are usually serviced and reshipped within five working days.

Service Charge for Out-of-Warranty Cards

Charges for out-of-warranty repairs are individually determined based on time and material. These charges are subject to your local sales or value-added tax, wherever applicable.

Limited 90-Day Warranty

What Is Covered

The card is warranted by Sparcom Corporation against defects in materials and workmanship for ninety days from the date of original purchase. If you sell your card or give it as a gift, the warranty is automatically transferred to the new owner and remains in effect for the original ninety-day period. During the warranty period, we will repair or, at our option, replace at no charge a card that proves to be defective, provided you return the card, shipping prepaid, to Sparcom Corporation. (Replacement may be made with a newer card of equal or better functionality.)

This warranty gives you specific legal rights, and you may also have other rights that vary from state to state, province to province, or country to country.

What Is Not Covered

This warranty does not apply if the card has been damaged by accident or misuse or as the result of service or modification by other than an authorized Sparcom Corporation service center.

No other express warranty is given. The repair or replacement of the card is your exclusive remedy. ANY OTHER IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS IS LIMITED TO THE NINETY-DAY DURATION OF THIS WRITTEN WARRANTY. Some states, provinces, or countries do not allow limitations on how long an implied warranty lasts, so the above limitation may not apply to you. IN NO EVENT SHALL SPARCOM CORPORATION BE LIABLE FOR CONSEQUENTIAL DAMAGES. Some state, provinces, or countries do not allow the exclusion or limitation of incidental or consequential damages, so the above limitation or exclusion may not apply to you.

Cards are sold on the basis of specifications applicable at the time of manufacture. Sparcom Corporation shall have no obligation to modify or update cards, once sold.

Appendix B

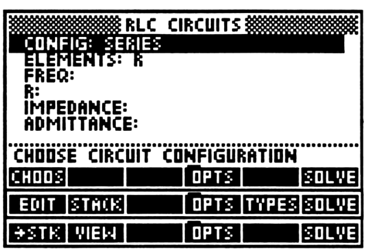
Key and Screen Summary

This appendix covers:

- ❑ Screen Summary
- ❑ Key Summary

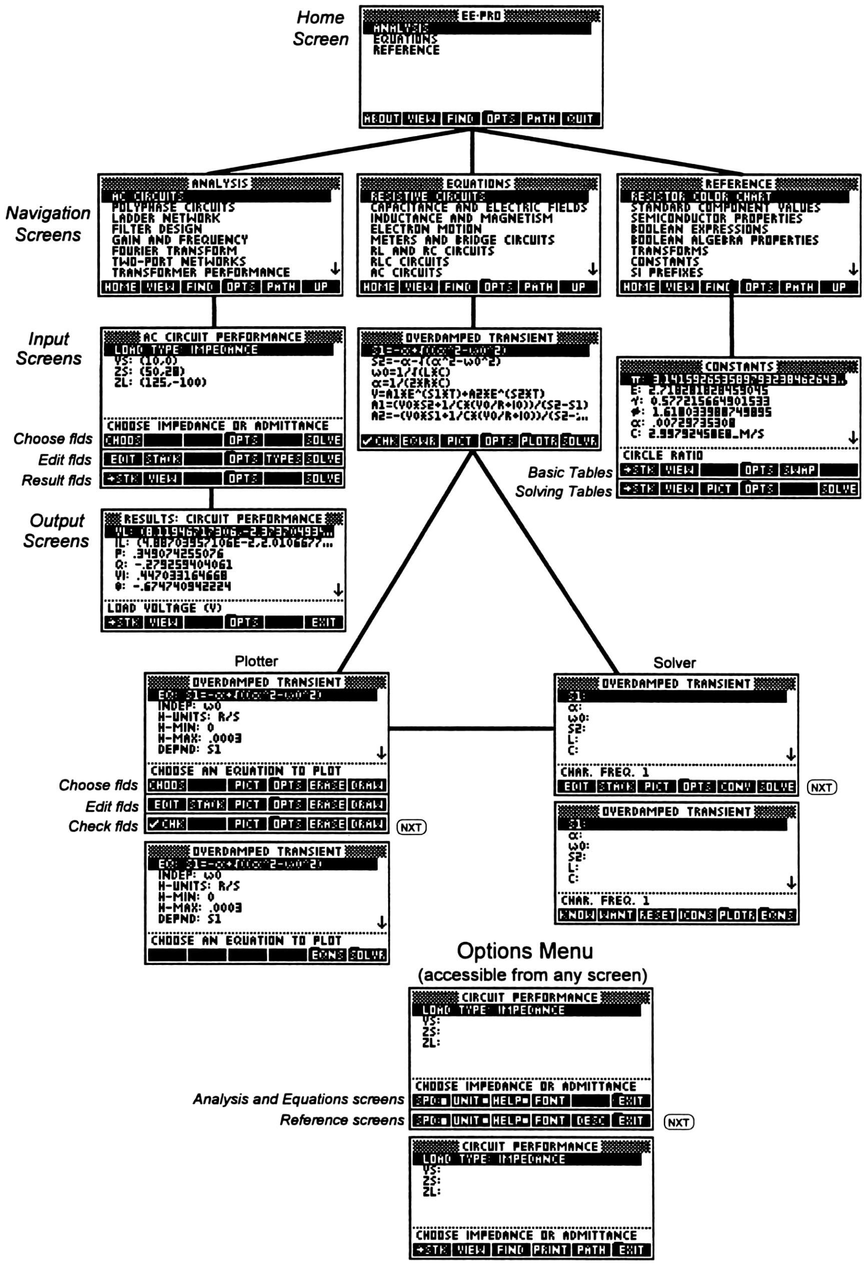
This appendix provides a summary of the structure of EE•*Pro*, the different types of screens, and the keys available at each screen.

The screen summary on the following page provides a "map" of EE•*Pro* and how it is organized. Screens with multiple menu rows, such as the Analysis screen shown here, indicate that the menu keys change depending on which field is highlighted. In the case of the options menu, the menu keys change depending on which section you were in when you entered the options menu.



Following the screen summary is a listing of the keyboard commands that are available throughout the program and at each type of screen.

Screen Summary



Key Summary

EE•*Pro*

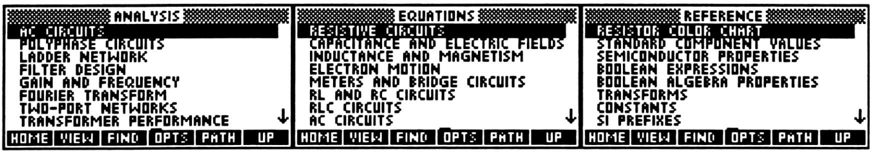
The following key commands are available throughout EE•*Pro*.

[▲] or [▼]	Moves the highlight bar up or down one item.
[◄shift][▲] or [◄shift][▼]	Moves the highlight bar to top or bottom of screen.
[►shift][▲] or [►shift][▼]	Moves the highlight bar to top or bottom of list.
[◄] or [◄shift][UP]	Goes to the previous screen.
[►shift][◄] or [►shift][HOME]	Goes to the home screen.
[ENTER] or [►]	Enters the highlighted section (in a navigation screen).
[NXT] or [◄shift][PREV]	Goes to the next or previous menu row (if appropriate).
[CST]	Goes to the custom settings screen.
[◄shift][CST] or [►shift][CST]	Goes to the first or second page of the options menu.
[►shift][CMD]	HP 48GX: Displays the highlighted item in a text view.
[►shift][VISIT]	HP 48SX: Displays the highlighted item in a text view.
[ON]	Quits EE•*Pro* to the HP 48 stack.

Home Screen

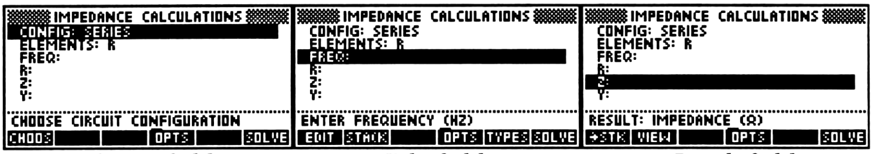
ABOUT	Displays product information and current version.
VIEW	Displays the highlighted item in text view (larger font, one item per screen). [◄shift] or [►shift] VIEW displays the highlighted item in graphics view (if highlighted item is an equation, etc.).
FIND	Searches for the specified character or string.
OPTS	Displays the options menu, see page 266.
PATH	Displays screens chosen to reach the current screen.
QUIT	Quits EE•*Pro* to the HP 48 stack.

Navigation Screens



HOME Goes to the home screen.
VIEW Displays the highlighted item in text view (larger font, one item per screen). Press [⬅] or [➦] **VIEW** to display the highlighted item in graphics view (if highlighted item is an equation, etc.).
FIND Searches for the specified character or string.
OPTS Displays the options menu, see page 266.
PATH Displays screens chosen to reach the current screen.
UP Goes to the previous screen.

Analysis Input Screens



Choose fields *Edit fields* *Result fields*

CHOOS Displays possible choices for a choose field (*Choose fields only*).
EDIT Edits the highlighted item (*Edit fields only*).
STACK Copies the highlighted item to the HP 48 stack and temporarily goes to the HP 48 stack environment (*Edit fields only*).
TYPES Displays the allowed object types for an edit field (*Edit fields only*).
→STK Copies one or all of the items shown to the HP 48 stack (*Result fields only*).
VIEW Displays the highlighted item in text view (larger font, one item per screen). Press [⬅] or [➦] **VIEW** to display the highlighted item in graphics view (if highlighted item is an equation, etc.).
OPTS Displays the options menu, see page 266.
SOLVE Performs a calculation using the displayed values.

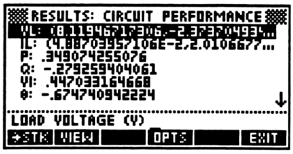
[ENTER] or [►] Enters the highlighted section (in a navigation screen).

Edits the highlighted item (for an edit field).

Displays the possible choices (for a choose field).

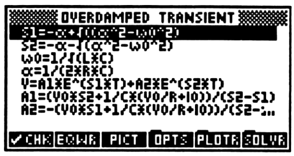
Copies item(s) shown to the stack (for a result field).

Analysis Output Screens



→STK Copies one or all of the items shown to the HP 48 stack.
VIEW Displays the highlighted item in text view.
OPTS Displays the options menu, see page 266.
EXIT Returns to the input screen.

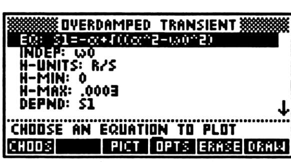
Equations Screens



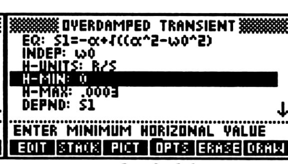
✓CHK Checks or unchecks the highlighted item for solving or plotting.
EQWR Displays the highlighted item in graphics view.
PICT Displays a picture for the equation set (if available).
OPTS Displays the options menu, see page 266.
PLOTR Goes to the Plotter screen.
SOLVR Goes to the Solver screen.

ENTER or ▶	Enters the highlighted section (in a navigation screen).
	Checks or unchecks the highlighted equation.
+/-	Checks or unchecks the highlighted equation.

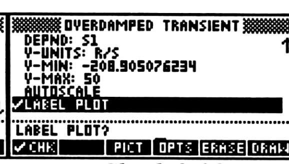
Plotter Screens



Choose fields

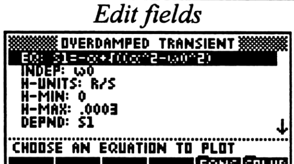


Edit fields



Check fields

NXT

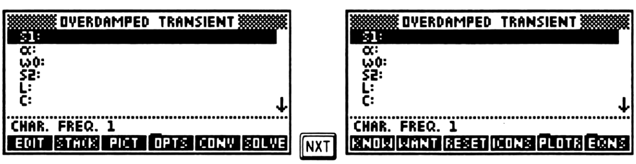


all fields

CHOOS Displays possible choices for a choose field (*Choose fields only*).
EDIT Edits the highlighted item (*Edit fields only*).
STACK Copies the highlighted item to the HP 48 stack and temporarily goes to the HP 48 stack environment.
✓CHK Checks or unchecks the highlighted item. This selects or unselects an item for solving or plotting (*Check fields only*).
PICT Displays a picture for the equation set (if available).
OPTS Displays the options menu, see page 266.
ERASE Erases any previous plots.
DRAW Plots the current equation.
EQNS Goes to the Equations screen.
SOLVR Goes to the Solver screen.

[ENTER] or [►]	Edits the highlighted item (for an edit field).
	Displays the possible choices (for a choose field).
	Checks or unchecks highlighted item (for check field).
[+/-]	Toggles through possible choices (for a choose field).
[◄][UNITS] or [►][UNITS]	Toggles units on or off.

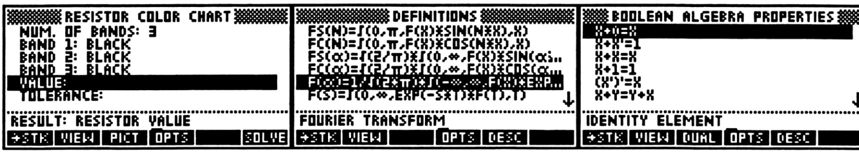
Solver Screens



EDIT Edits the highlighted item.
STACK Copies the highlighted item to the HP 48 stack and temporarily goes to the HP 48 stack environment.
PICT Displays a picture for the equation set (if available).
OPTS Displays the options menu, see page 266.
CONV Displays the possible units for converting the highlighted variable. The appropriate units appear in the menu keys. Press [NXT] and/or **EXIT** to return to the Solver.
SOLVE Erases any previous plots.
KNOW Marks or unmarks the highlighted variable as known.
WANT Marks or unmarks the highlighted variable as wanted.
RESET Resets one or all of the variables.
ICONS Displays the icons used to indicate variable status.
PLOTR Goes to the Plotter screen.
EQNS Goes to the Equations screen.

[ENTER] or [►]	Edits the highlighted variable.
[+/-]	Marks or unmarks highlighted variable as known.
[VAR]	Toggles positions of variable values and descriptions.
[DEL]	Resets one or all of the variables.
[⬅] [UNITS] or [➡] [UNITS]	Toggles units on or off.

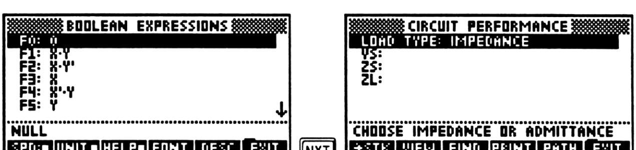
Reference Screens



→STK	Copies one or all of the items shown to the HP 48 stack.
VIEW	Displays the highlighted item in text view. Press [⬅] or [➡] VIEW for graphics view (if highlighted item is an equation, etc.).
PICT	Displays a picture for the reference table (if appropriate).
DUAL	Displays the duals of the property or expression (if appropriate).
OPTS	Displays the options menu, see page 266.
DESC▪	Toggles position of data and help text (if appropriate).
SOLVE	Activates the custom solving routine (if appropriate).

[ENTER] or [►]	Enters highlighted section (in a navigation screen).
	Edits the highlighted item (for an edit field).
	Copies item(s) shown to the stack (for a result field).
[VAR]	Toggles position of data and help text (if appropriate).
[⬅] [UNITS] or [➡] [UNITS]	Toggles units on or off.

Options Menu



SPD:▪	Changes the scrolling speed of the highlight bar.
UNIT▪	Toggles units on or off.
HELP▪	Toggles display of help text at the bottom of the screen.
FONT	Toggles font size between large and small.

DESC▪ Toggles position of data and help text (*if appropriate*).
→STK Copies one or all of the items shown to the HP 48 stack.
VIEW Displays the highlighted item in text view. Press ⬅ or ➡ VIEW for graphics view (if highlighted item is equation).
FIND Searches for the specified character or string.
PRINT Prints one or all of the items shown to an HP 48 printer.
PATH Displays screens chosen to reach the current screen.
EXIT Leaves the options menu.

Appendix C

User Flags

This appendix covers:

- ❑ Flag 4: Carry Flag
- ❑ Flag 5: Range Flag
- ❑ Flags 13 & 14: Binary Sign Mode
- ❑ Flag 57: Font Size
- ❑ Flag 58: Help Text
- ❑ Flag 61: Units
- ❑ User Flag Summary

Flag 4: Carry Flag

The carry flag, used by the binary commands in the Computer Engineering section of EE•*Pro*, is controlled by the setting of user flag 4:

- **Flag 4 Clear:** *Places a 0 in the Carry bit.*
- **Flag 4 Set:** *Places a 1 in the Carry bit.*

To change the carry flag while using EE•*Pro*, go to Analysis, Computer Engineering, then to one of the listed sections (e.g., Register Operations). Press MODE, then choose Clear or Set for the **Carry** field.

To set or clear the carry flag from the HP 48 stack, type 4 [α][α] SF or 4 [α][α] CF.

Flag 5: Range Flag

The range flag, used by the binary commands in the Computer Engineering section of EE•*Pro*, is controlled by the setting of user flag 5:

- **Flag 5 Clear:** *Places a 0 in the Range bit.*

- **Flag 5 Set:** *Places a 1 in the Range bit.*

To change the range flag while using EE•*Pro*, go to Analysis, Computer Engineering, then to one of the listed sections (e.g. Register Operations). Press MODE, then choose Clear or Set for the **Range** field.

To change the range flag from the HP 48 stack, type 5 [α][α] SF or 5 [α][α] CF.

Flags 13 and 14: Binary Sign Mode

The binary sign mode is controlled by the setting of user flags 13 and 14 in combination:

Mode	Flag 13	Flag 14
Unsigned	Clear	Clear
One's Complement	Set	Clear
Two's Complement	Set	Set

To change the binary mode while using EE•*Pro*, go to Analysis, Computer Engineering, then to one of the listed sections (e.g. Register Operations). Press MODE, then choose Unsigned, One's Complement, or Two's Complement for the **Sign** field.

To set or clear flag 13 (or 14) from the HP 48 stack, type 13 [α][α] SF or 13 [α][α] CF.

Flag 57: Font Size

The display font size is controlled by the setting of user flag 57:

- **Flag 57 Clear:** *Small display font.* The small font contains 3x5 uppercase letters and fits eight vertical lines of text on the screen (without help text).

- **Flag 57 Set:** *Large display font.* The large font contains 5x7 uppercase and lowercase letters and fits six vertical lines of text on the screen (without help text).

To change the font size while using EE•*Pro*, press OPTS, then FONT.

To change the font size from the HP 48 stack, type 57 [α] [α] SF or 57 [α] [α] CF.

Flag 58: Help Text

The presence of context-sensitive help text along the bottom of the screen is controlled by the setting of user flag 58.

- **Flag 58 Clear:** *Help text on.* Help text is displayed at the bottom of the HP 48 screen, directly above the menu keys. Help text is always displayed in the small font, regardless of the setting of flag 57.

- **Flag 58 Set:** *Help text off.* When help text is off, one or two more lines available on the screen for displaying information.

To toggle help text while using EE•*Pro*, press OPTS, then HELP. When the block inside the key appears (HELP■), the help text is turned on.

To toggle help text from the HP 48 stack, type 58 [α] [α] SF or 58 [α] [α] CF.

Flag 61: Units

The presence of units is controlled by the setting of user flag 61.

- **Flag 61 Clear:** *Units on.* Equations can be solved and plotted with or without units, and Reference tables can be displayed with or without units.

- **Flag 61 Set:** *Units off.*

To toggle units while using EE•*Pro*, press OPTS, then UNITS. When the block inside the key appears (UNIT■), units are turned on.

To toggle units from the HP 48 stack, type 61 [α] [α] SF or 61 [α] [α] CF.

User Flag Summary

Flag	Affects	Clear	Set
4	Carry Flag	Value of Carry bit is 0	Value of Carry bit is 1
5	Range Flag	Result within the range	Result outside the range
13 & 14	Binary Mode	Unsigned: 13 - Clear, 14 - Clear One's Complement: 13 - Set, 14 - Clear Two's Complement: 13 - Set, 14 - Set	
57	Font Size	Small font (default)	Large font
58	Help Text	Help text on (default)	Help text off
61	Units	Units on	Units off (default)

Appendix D

Questions and Answers

This appendix lists the most common questions about EE•*Pro*. Scan this list before you call customer support—you might save yourself a phone call!

This appendix covers:

- ❑ General Questions
- ❑ Analysis Questions
- ❑ Equations Questions
- ❑ Reference Questions

General Questions

These are the most commonly asked questions about general features of EE•*Pro*. For more information, see Chapter 1, "Getting Started."

Q I can't get out of a screen. When I quit by pressing [ON] and go back into EE•*Pro* I'm right back where I was when I exited. How do I get back to the home screen?

> **A** Pressing [ENTER] usually goes into a section, but you may have a difficult time finding your way back out. The easiest way to remember how to navigate the screens is to learn that [▲], [▼], [◄], and [►] are the only four keys you need to use to navigate through EE•*Pro*. [▲] and [▼] move the highlight bar up and down. [►] usually enters a section, and [◄] usually returns back out of a section to the previous screen. Repeatedly pressing [◄] will eventually get you to the home screen. Or press [↱][HOME] or [↱][◄] to go directly to the home screen.

Q I tried pressing [◄] and [↱][◄] to go up a section but the HP 48 just beeps. How do I get out of this screen?

> **A** Some screens allow you to make selections, such as a choose screen, or change settings, such as the Custom Settings screen. The only way to

exit these screens is by pressing OK, which accepts the current selection or settings, or by pressing CANCL or [ON], which exits the screen without making any changes. After you have exited the screen, you should be able to go up a section by pressing [◄] or [↱][◄].

Q Why is there a 'SPARCOM' directory in my HP 48 user memory? (It appears as SPARC when you press [VAR] to display the variable menu.)

A Special parameter variables are stored in the 'SPARCOM' directory by EE•*Pro*. One of those variables is 'EEPAR', which contains information about which screen you were at when you quit EE•*Pro*, so that screen will re-appear the next time you run the software.

Variables created during equation solving and plotting are not necessarily stored in the 'SPARCOM' directory, but in whatever directory you were at when you ran the software. This is so that you can create working subdirectories to organize your sets of variables if you commonly solve different sets of equations.

Q What do three dots (...) mean at the end of an item on the screen?

A The three dots (an ellipsis) indicate the item is too wide to fit on the screen. To display the item in a text view, move the highlight bar to it and press VIEW or [↱][CMD] (HP 48GX) or [↱][VISIT] (HP 48SX). To display the item in a graphics view, move the highlight bar to it and press [↱] VIEW.

Q I solved a problem a long time ago, and I want to find those values again for a problem I'm working on now, but I can't find them. Where are they?

A Values entered in Analysis screens are usually forgotten by EE•*Pro* when you leave the Analysis screen, because they are not stored in user memory. (An exception to this is the Capital Budgeting section, which *does* store project files in user memory.) However, values entered in Equations screens *are* stored in variables in user memory. Those variables will remain in whatever directory you were at when you solved the problem, unless you have cleared your HP 48 memory or reset the variables since you originally solved the problem.

Q I'm trying to find something which I know is in EE•*Pro* somewhere, but the find operation keeps telling me, "String Not Found."

A The find feature only searches information in the current screen. It cannot find an item if it is not displayed on the current screen. If you need to find out where a feature is located in EE•*Pro*, use the table of contents or index of this manual.

Q I can't find an item in a menu. I think I'm in the right spot but I can't find the correct menu key label. Where can it be?

A Some menus have more than one page. Try pressing [NXT]. If the menu *does* have more than six items, the next menu page will be displayed.

Analysis Questions

These are the most commonly asked questions about the Analysis section of EE•*Pro*. For more information, see Chapter 2, "Analysis: Navigation Guide" and your HP 48 User's Guide.

Q My screen doesn't look exactly the same as the example in the manual. What could be wrong?

A The mode settings on your HP 48 may be set incorrectly. Each example displays a box with all relevant mode settings. Press [CST] to display the Custom Settings screen and verify that they match those used in the example.

Q The result isn't the value I expected. What could be wrong?

A Your HP 48 may be in an incorrect mode. For example, you may be expecting an answer in degrees but your HP 48 may be set to radians. Press [CST] to display the Custom Settings screen, correct any mode settings, and re-solve the problem.

Q When I press SOLVE, the result is an expression, not a number. Why?

A If you enter a variable name or an algebraic expression as your input, some of your results may be symbolic. If you want to further evaluate or manipulate a symbolic result, move the highlight bar to the field containing the result and press →STK to copy it to the stack. Press [ON] to go to the stack where you can further evaluate the result.

Q When I press SOLVE, I get the message, "Undefined Name." Why?

A Your HP 48 may be in numeric results mode instead of symbolic results mode. Press [CST] to display the Custom Settings screen, change the result mode to Symbolic, and re-solve.

Q How can I avoid getting an "Infinite Result" error in my calculations in EE•*Pro*?

A You can set flag -22 (Infinite Result Exception) to return the value 9.99999999999E499 (MAXR) instead:

1. Go to the stack. If you are in EE•*Pro*, press [ON] to get to the stack.
2. Type in -22 [α][α] SF and press [ENTER]. The flag is now set.
3. To return to EE•*Pro*, press [→][LIBRARY] (on the HP 48GX) or [←][LIBRARY] (on the HP 48SX), then [EE] [EE].

Q Units mode is turned on in the Custom Settings screen ([CST]). Why can't I enter units?

A Analysis screens *do not* allow unit objects. Only Equations and Reference screens have unit management.

Equations Questions

These are the most commonly asked questions about the Equations section of EE•*Pro*. For more information, see Chapter 16, "Equations: Navigation Guide" and your HP 48 User's Guide.

Q I turned units off and all my values changed. What happened?

A When units are on, values can be entered and saved in any unit. When units are off, values can be entered in any unit, but the values will automatically be displayed on the screen in the default SI units. This is necessary so that when you press [SOLVE] to solve an equation, all the values will be consistent with each other and your answer will be correct. If you don't want to be restricted to SI units, turn units back on.

Q I entered values for some variables and pressed [SOLVE], but I get the message, "Too many unknowns to finish solving." Why?

A Sometimes the solver doesn't have enough information (i.e., enough known variables) to solve for all the remaining, unknown variables. If you don't yet have an answer to your problem, then you will have to enter more known values and re-solve.

Q There are already values stored in some of my variables. How do I clear those values?

A The values remain from previous solving operations. It is okay to ignore the values, because as long as they aren't marked as known, they will be overwritten by new solutions. If you want to reset the variables, press RESET or DEL to clear one or all of the variables.

Q I entered values for some variables and pressed SOLVE, but I get the message, "Bad Guess(es)". Why?

A There are several possibilities, but in all cases, the solver has encountered trouble while trying to solve for a particular variable. The problem variable is marked with an icon indicating a bad guess error occurred while solving for that variable.

Q The solution to my problem is clearly wrong! (An angle might be negative or unreasonably large.) Why?

A This is most likely to happen when angles are involved in the equation(s) you are solving. What has happened is that the HP 48 has found a non-principal solution to your equation.

Example: Imagine solving the equation $\sin(x) = 0.5$. Solutions include: 30°, 390°, -330°, 750°, etc., but the *principal* solution is 30°.

If a non-principal solution is found, it may then be used to solve other equations, leading to strange results.

Example (cont.): Now imagine solving the equation $x + y = 90°$. If x is 30°, then y should be 60°. But if a non-principal solution for x was found, such as 750°, then the value of y will be -660°, which although technically correct, is also not a principal solution.

The way to fix this problem is to put in an initial guess for angle variables.

Example (cont.): Before solving for x, enter the value 45° for x and then press KNOW or +/- to unmark x as known. Now, when you press SOLVE to solve for x, the guess of 45° will be used, and it is close enough to the principal solution of 30° that the solver is very likely to find the principal solution.

Q I tried plotting an equation and got the message, "Variable Not Defined in Solver Screen." Why?

A When plotting, all variables other than the independent and dependent variables *must* have values. The other variables will be held constant during plotting, but if they are undefined, this error will occur. Go to the Solver screen and enter values for the other variables in the equation you are plotting, return to the Plotter screen, and re-plot.

Q I tried plotting an equation and got the message, "Unable to Isolate." Why?

A The variable you have selected as the dependent variable occurs more than once in the equation, which means it can't be isolated. This means that you can't plot the equation with that variable as the dependent variable. (Note: In a few cases, it will actually be possible to isolate the variable, but not by a simple isolation, so the HP 48 will be unable to do so.)

Reference Questions

These are the most commonly asked questions about the Reference section of EE•*Pro*. For more information, see Chapter 33, "Reference: Navigation Guide" and your HP 48 User's Guide.

Q Why is the menu key DESC available in some screen and not in others?

A Some screens have information in the help text that may be useful to view in the main display area of the screen, instead of only line by line. DESC will be available in these screens. When turned on, the help text information will be swapped with the data normally shown in the main display area. However, if the help text is sparse or non-existent, then DESC will not be available.

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