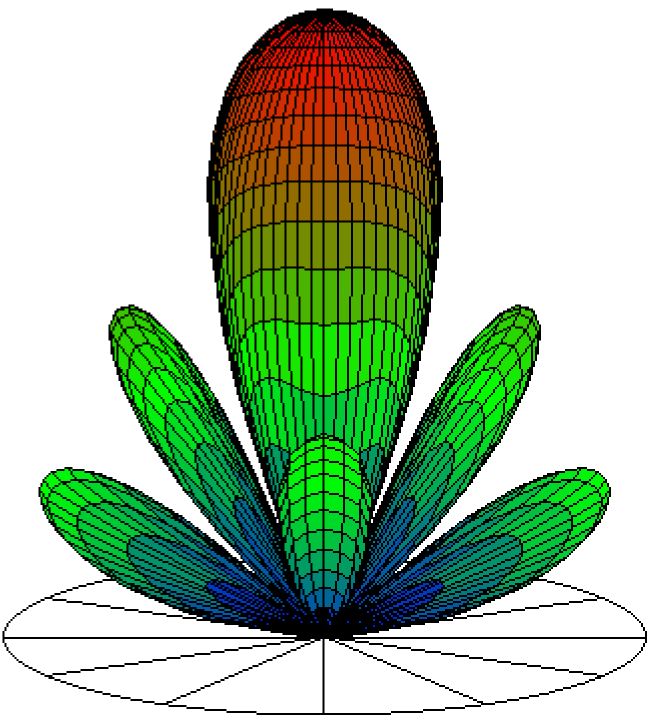
PCAAD 7.0

Personal
Computer
Aided
Antenna
Design



Version 7.0

Antenna Design Associates, Inc.
Leverett, MA 01054
USA

On the cover: A 3-D pattern plot of a 3 x 4 rectangular array of horizontal dipoles $\lambda/4$ above a ground plane, with 0.4λ spacing.

David M. Pozar
Antenna Design Associates, Inc.
55 Teawaddle Hill Road
Leverett, MA 01054
USA

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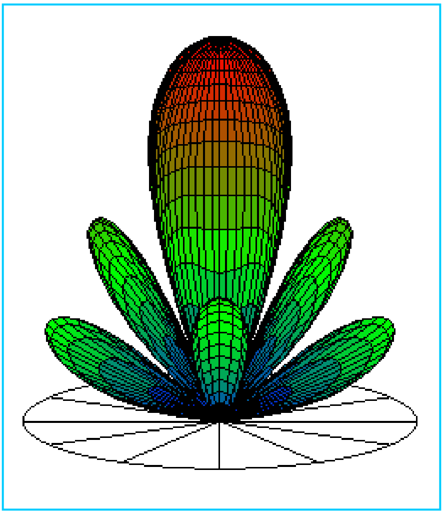


PCAAD 7.0 (Personal Computer Aided Antenna Design, version 7) is a Windows-compatible software package that contains over 55 separate routines for the analysis and design of wire antennas, array antennas, aperture antennas, microstrip antennas, transmission lines and waveguides, and additional utilities. These routines are integrated into a menu-driven, user-friendly software package that allows you to quickly evaluate the characteristics of a large variety of antennas. Some of the key features of PCAAD 7.0 include the following:

- An improved user-friendly Windows interface
- Very simple and intuitive operation
- Fast results for first-cut designs
- Graphic illustrations of each antenna geometry
- Polar, rectangular, and 3-D pattern plots
- Smith chart, VSWR, and return loss plots for input impedance
- Data file output for patterns and impedance matrices
- On-line help and a hard-copy manual
- Validation examples for each analysis routine

A. What's New in PCAAD 7.0

PCAAD 7.0 for Windows features a complete rewrite of the software with up-to-date user interface elements, new analysis routines, and improved features. Some of the most significant improvements in this version of PCAAD include:

- analysis of symmetric and offset parabolic reflector antennas
- analysis of spherical reflector antennas
- viewing of amplitude and phase distributions for reflectors
- modeling of horizontal and vertical dipoles over a ground plane
- full-wave analysis of multilayer stripline
- full-wave analysis of multilayer microstrip line
- full-wave analysis of surface waves on a multilayer substrate
- analysis of coupled striplines and coupled microstrip lines
- calculation of antenna beam efficiency
- polar and rectangular pattern plots with up to five patterns

- Smith chart plots with up to five plots
- 3-D pattern plots have an optional cross-section view
- optional setting of a default data file directory path
- tutorials on transmission lines, the Smith chart, and small antennas
- improved user interface
- faster graphics

PCAAD 7.0 is intended for use by systems and design engineers, researchers, and students who need quick solutions to canonical antenna design or analysis problems. The routines implemented in PCAAD 7.0 are based on proven antenna theory and analysis as described in numerous textbooks, handbooks, and other literature [1]-[8].

B. Disclaimer

This software package has been written and tested with care. Nevertheless, this software and its associated user's manual are provided as is, without warranty of any kind. Neither the author nor Antenna Design Associates, Inc., make any warranties, expressed or implied, that the software or the manual are free of error, or will meet specific requirements of any particular application. The software should not be relied upon for the generation of data where such data, if incorrect or inapplicable, could result in loss of property or personal injury. Any use of the software or the manual in such a manner is at the user's own risk. The author and Antenna Design Associates, Inc., disclaim all liability for direct, incidental, or consequential damages resulting from any use of the software or manual.

II. Getting Started With PCAAD 7.0

A. System Requirements

PCAAD 7.0 will operate on computers running Windows XP, Windows Vista, Windows 7, or Windows 8. The software is distributed on a CD-ROM, and installation requires a CD-ROM drive. PCAAD 7.0 occupies less than 5 MB of disk space.

Since PCAAD 7.0 runs under Microsoft Windows operating systems, the user should be familiar with basic Windows usage, such as how to run programs from Windows; how to create and rearrange program shortcuts on the desktop; how to create, copy, and delete files and directories; how to use Windows menus, text boxes, and control buttons; and how to open, close, move, and resize windows.

B. Installing PCAAD 7.0

Installing PCAAD 7.0 on your system is easy. Insert the distribution CD into your CD drive, and execute the **`Setup.exe`** file that is located on the CD. Installation may require **Administrator** access, depending on your operating system and your **User** settings. The setup program will decompress and install all necessary files, and create the necessary directories. A PCAAD 7.0 entry will be created on your **Start Menu**, and a PCAAD 7.0 icon should be installed on your desktop.

To uninstall PCAAD 7.0, use the **Uninstall** facility from the Windows **Control Panel**. This will properly remove the PCAAD 7.0 systems files from your computer and entries from the registry. Any data files that you created when using PCAAD 7.0 can be deleted separately, from your user directory, if desired.

C. Folders Used By PCAAD 7.0

The PCAAD 7.0 installer program will create two new folders. A folder called **PCAAD 7.0**, in the **Program Files** folder (or the **Programx86 Files** folder), is used for the system operating files for PCAAD 7.0. A separate folder will be created for your PCAAD user data files. This folder typically has a path name such as `C:\USERS\username\AppData\Roaming\PCAAD7`, but this may be different for different operating systems. Note that you can save your user data files in other directories, but preferably not in the **PCAAD 7.0 Program Files** directory (which is reserved for system files). You can easily view the locations of the various directories being used by PCAAD 7.0 from **About PCAAD**, via the PCAAD **Help** menu. You can set a default file directory using the **Default Directory Path** option from the **Plot** menu.

The setup procedure also installs PDF files for the introductory short course on basic antenna theory, and tutorials on transmission lines, the Smith chart, and electrically small antenna design. The antenna short course is arranged by Chapters 0 through 7, where Chapter 0 lists the contents and syllabus for the course. Chapters

1 through 7 provide a basic introduction to antenna theory and design, and include examples, review questions, and problems. The short course concludes with the Antenna IQ test. Answers to the test and all problems are given in the `Answers.pdf` file. There is also a short Glossary on commonly used terms related to antenna technology. All of these files may be accessed from the PCAAD 7.0 **Help** menu, or directly from the PCAAD user data file directory. The Acrobat PDF reader is required to view the short course and tutorial files.

D. The PCAAD7.INI file

PCAAD 7.0 uses an initialization file, called `PCAAD7.INI`, located in your PCAAD 7.0 user directory, to set various options and directory locations that are required for proper operation of PCAAD. Generally, you will not have to modify this file, and, like most `.INI` files, improper entries can cause errors when running PCAAD. Here we describe the entries in the `PCAAD7.INI` file, with their default values:

`[PCAAD7]`	
`Bitmaps=1`	PCAAD bitmap option (0-off; 1-on)
`SavePhaseData=0`	phase data save option (0-don't save; 1-save phase data)
`PatternPlotType=1`	default pattern plot type (1-polar; 2-rectangular, 3 -3D)
`ImpedancePlotType=0`	default impedance plot type (0-Smith chart; 1-`VSWR/RL)`
`PatternAzimuthAngle=0.0`	azimuth angle for pattern plots
`PatternStepSize=0.5`	step size for pattern plots
`3DAzimuthStep=5.0`	azimuth step size for 3-D plots
`3DElevationStep=2.0`	elevation step size for 3-D plots
`UpperHemisphereOnly=0`	3-D plot type (0-both hemispheres; 1-upper only)
`PlanarPlotData#1Color=255`	color for data set #1 (pattern plots)
`PlanarPlotData#2Color=16711680`	color for data set #2 (pattern plots)
`PlanarPlotData#3Color=32768`	color for data set #3 (pattern plots)
`PlanarPlotData#4Color=16744700`	color for data set #4 (pattern plots)
`PlanarPlotData#5Color=4194304`	color for data set #5 (pattern plots)
`AngleCursor=65535`	color for angle cursor
`PlotBackgroundColor=12632256`	color for plot background
`RL/VSWRPlotData#1Color=255`	color for data set #1 (RL/VSWR)
`RL/VSWRPlotData#2Color=16711680`	color for data set #1 (RL/VSWR)
`RectangularPatternPlotLabel=Pattern (dB)`	vertical label on rectangular
`PatternPlaneType=1`	type of pattern cut
`SmithPlotData#1Color=255`	color for data set #1 (Smith plot)
`SmithPlotData#2Color=16711680`	color for data set #2 (Smith plot)
`SmithPlotData#3Color=32768`	color for data set #3 (Smith plot)
`SmithPlotData#4Color=16744700`	color for data set #4 (Smith plot)

`SmithPlotData#5Color=4194304`	color for data set #5 (Smith plot)
`FileDir=C:\Users\user\..`	default path for data files

The above values are typical entries that are set upon installation, but most of these values will change according to the plotting and color options that are set and saved when using the **Plot Default Types** and **Plot Default Colors** options from the **Plot** menu. It is recommended that the user not directly modify the `PCAAD7.INI` file, except perhaps to set the vertical axis label for the rectangular pattern plot routine.

III. Using PCAAD 7.0 – General Instructions

A. Organization of PCAAD 7.0

The main window is displayed when PCAAD 7.0 starts, and forms the background for all modules and routines. The menu bar at the top of the window categorizes the antenna modules into several groups, along with plotting routines and other utilities. The individual menus and routines are listed and summarized below:

Plot

Polar Pattern Plot	-plot antenna patterns in polar form
Rectangular Pattern Plot	-plot antenna patterns in rectangular form
3-D Pattern Plot	-plot antenna patterns in 3-D form
Smith Chart Plot	-plot and tune impedance on a Smith chart
VSWR/Return Loss Plot	-plot VSWR or Return Loss
Plot Default Types . . .	-set default types of pattern and impedance plots
Plot Default Colors . . .	-set color preferences for plots
Default Directory Path	-set the default directory path for data files
Exit	-exit PCAAD 7.0

Edit

Copy Window	-copy current Window to Windows clipboard
Copy Graph	-copy current plot to Windows clipboard
Copy Text	-copy selected text to Windows clipboard
Paste Text	-paste text from Windows clipboard
Edit File	-invoke system text editor (Notepad)
Print Window	-print current PCAAD window and its contents

Wire

Dipole Antenna	-analyze wire dipole antenna
Dipole RCS	-compute radar cross section of wire dipole
Dipole (H) Over Ground Plane	-analyze horizontal dipole over ground plane
Dipole (V) Over Ground Plane	-analyze vertical dipole over ground plane
V-dipole Antenna	-analyze V-dipole wire antenna
Loop Antenna	-analyze wire loop antenna
Yagi Antenna	-analyze wire dipole Yagi array
Dipole Array	-analyze finite planar dipole array
LPDA Design	-design log periodic dipole array
LPDA Analysis	-analyze log periodic dipole array
General Wire Antenna	-analyze arbitrary wire antenna geometry

Arrays

Uniform Linear Array	-patterns and directivity of a uniform linear array
Linear Subarray	-patterns of a linear array of subarrays
Uniform Rectangular Array	-patterns and directivity of a rectangular array
Uniform Circular Array	-patterns and directivity of a circular planar array
Arbitrary Planar Array	-patterns and directivity of an arbitrary planar array
Infinite Printed Dipole Array	-active impedance of infinite printed dipole array
Linear Array Pattern Synthesis	-Woodward-Lawson array synthesis
Grating Lobe Diagram	-grating lobe diagram for a planar array
Effect of Random Array Errors	-effect of random array excitation errors

Apertures

Line Source	-patterns of an arbitrary line source
Rectangular Aperture	-patterns of a rectangular aperture antenna
Circular Aperture	-patterns of a circular aperture antenna
E-plane Sectoral Horn	-analyze an E-plane sectoral horn
H-plane Sectoral Horn	-analyze an H-plane sectoral horn
Pyramidal Horn	-analyze a pyramidal horn
Diagonal Horn	-analyze a diagonal horn antenna
Corrugated Pyramidal Horn	-analyze a corrugated pyramidal horn
Conical Horn	-analyze a conical horn
Corrugated Conical Horn	-analyze a corrugated conical horn
Parabolic Reflector (approximate)	-approximate analysis of prime-focus reflector
Symmetric Parabolic Reflector Analysis	-analyze a symmetric parabolic reflector
Offset Parabolic Reflector Analysis	-analyze an offset parabolic reflector
Spherical Reflector Analysis	-analyze a spherical reflector
Beam Efficiency	-beam efficiency of an aperture antenna

Microstrip

Rectangular Probe-fed (Carver)	-probe-fed patch analysis (Carver's model)
Rectangular Probe-fed (cavity)	-probe-fed patch analysis (cavity model)
Rectangular Line-fed (t-line)	-line-fed patch analysis (t-line model)
Rectangular Proximity-fed (t-line)	-proximity-fed patch analysis (t-line model)
Rectangular Aperture-fed (cavity)	-aperture coupled patch analysis (cavity model)
Circular Probe-fed (cavity)	-probe-fed patch analysis (cavity model)

Transmission Lines

Coaxial Line	-analyze a coaxial line
Rectangular Waveguide	-analyze a rectangular waveguide
Rectangular Waveguide Data	-standard rectangular waveguide data
Circular Waveguide	-analyze a circular waveguide
Microstrip Line (quasi-static)	-quasi-static analysis and design of microstrip line
Stripline (quasi-static)	-quasi-static analysis and design of stripline
Multilayer Microstrip (full-wave)	-full-wave analysis of multilayer microstrip line
Multilayer Stripline (full-wave)	-full-wave analysis of multilayer stripline
Coupled Microstrip Lines (full-wave)	-full-wave analysis of coupled microstrip lines
Coupled Striplines (full-wave)	-full-wave analysis of coupled striplines
Single Layer Surface Wave Modes	-surface wave modes of a dielectric layer
Multilayer Surface Wave Mode	-surface wave mode of multilayer dielectric

Miscellaneous

Link Loss	-Friis formula for radio links
Polarization Mismatch	-polarization mismatch between two antennas
Atmospheric Attenuation	-propagation loss due to atmosphere or rain
Axial Ratio vs. Errors	-axial ratio vs. amplitude and phase errors
Antenna Temperature	-antenna sky noise temperature
Calculator	-useful antenna and microwave calculations

Help

Help Table of Contents	-contents of Help
Help Index	-index for Help
Context Help (F1)	-context help for current routine (also F1 key)
Short Course and Tutorials	-antenna short course and related tutorials
About PCAAD	-information about PCAAD 7.0 and directories

After selecting a particular antenna or transmission line topic from the main PCAAD menu, a window will open for that routine. The windows for all routines have the same format: a small graphic image of the antenna or transmission line geometry is shown at the top left of the window, with data entry at the top right, and output data listed below. Most routines have a **Compute** button that is used to initiate computations after all data has been entered. Results are displayed after the computation is finished, and most routines then show a **Results** tree that allow the option of plotting data, saving data in a file, or showing related output data. Input data values are retained until the window is closed, making it easy to change one parameter and run a new solution. Most routines have error checking of input data, but the software is not completely foolproof.

B. Entering Data and Running the Routines

Numerical values are entered in PCAAD 7.0 using text boxes. When a routine starts, a flashing cursor bar will appear in the text box for the first data entry item. Type in a numerical value, and press **Enter** on the keyboard to move to the next entry. You can also use the **Tab** key, or the mouse, to move to the next data entry. Error checking is performed for most data entries, generally after the **Compute** button is pressed. If a value is found to be in error, a small error message box is displayed. Click the **OK** button on this box, and focus will return to the data item that was found to be in error. After you have computed a solution, you can change one or more problem parameters by simply entering new values for those items, without having to re-enter all other parameters.

C. Pattern Calculation and Plotting

Many routines involve the calculation of far-field radiation patterns. These may be plotted as planar pattern cuts on a polar or rectangular plot, or as a 3-D volumetric plot. The type of plot desired for a particular routine is specified by clicking the **Pattern Type** select button. Elevation plane patterns can be plotted at a specified azimuthal angle for E-theta / E-phi or Co-pol / X-pol patterns (using Ludwig's third definition), or E-plane / H-plane patterns can be selected. Plotting parameters, such as azimuth angle and step sizes, are also specified with this window. Default values can be set with the **Plot Default Types** option from the **Plot** menu. Pattern plots can be invoked directly from a PCAAD antenna analysis routine (from the **Results** tree), or patterns can be plotted from data files through the **Plot** menu. Up to five separate patterns can be plotted on the polar or rectangular plots, but only one pattern can be plotted as a 3-D plot. Plots may be printed (click the **Print Plot** button in the plotting window), or copied to the Windows clipboard for use in other applications (click the **Copy to Clipboard** button on the plotting window, or use the **Copy Graph** option from the **Edit** menu).

D. Saving Pattern Data

Routines that provide far-field radiation patterns also allow the option of saving pattern data (planar or 3-D patterns) to a file with the **Save Patterns** entry on the

Results tree. PCAAD 7.0 now allows saving of far-field phase data, in addition to the pattern amplitude (for planar patterns). Phase data can be useful when using PCAAD results with other programs, such as characterizing a feed for reflector antenna analysis. Planar pattern data is saved as an ASCII text file, with one row for each angle. The format is: pattern angle in degrees, pattern amplitude in dB, and pattern phase in degrees. These values are delimited with one or more spaces. The PCAAD polar and rectangular pattern plotting routines can read these files, with or without the phase column. You can control whether the phase information is saved by using the check box on the **Default Plot Types** menu. For 3-D volumetric patterns the following data file format is used: the first line has three values: the elevation angle step size (degrees), the azimuth angle step size (degrees), and the maximum elevation angle range (90º for upper hemisphere only, or 180º for both hemispheres). This is followed by N = 1 + 360 / (azimuth step size) lines, one for each azimuth angle. Each line contains 1 + 90/(elevation angle step size) pattern values, normalized from 0 to 1.

E. Impedance Calculation and Plotting

Several routines, such as the wire antenna and microstrip antenna routines, perform calculations of input impedance over a swept frequency range. The parameters of this sweep are specified as the center frequency, the frequency step size, and the number of frequency points. You can enter specific values for these parameters in the appropriate boxes, or allow PCAAD to provide estimates by clicking the **Compute** button. Note that the center frequency parameter refers to the middle of the frequency sweep range, which may be different from the operating frequency of the antenna. Impedance versus frequency can be plotted on a Smith Chart plot or on a VSWR/Return Loss plot; the default type of impedance plot can be set from the **Plot Default Types** option from the **Plot** menu. The Smith chart window also contains a powerful impedance matching utility.

F. Help

PCAAD 7.0 contains a comprehensive help file in standard Windows format, with convenient cross-references and search options. The help file is context-sensitive, meaning that you can simply press the **F1** key while using any analysis routine to get help on that particular routine. Pressing the **F1** key while on the main window will bring up the help contents for PCAAD 7.0. Help can also be accessed by clicking **Help - Context Help** from the main menu bar. The **Help Table of Contents** and **Help Index** are also available from the **Help** menu.

You can also access the antenna short course and tutorials from the **Help** menu. The short course is grouped by chapters into individual PDF files, along with a Glossary, and a quiz on antennas. Select **Short Course and Tutorials** from the **Help** menu, and the desired file from the directory listing. The file should open with the Acrobat Reader. You need to have the Acrobat Reader installed on your computer.

IV. Using PCAAD 7.0 – Instructions and Examples

This chapter will describe in detail the operation of each antenna, transmission line, and utility routine in PCAAD 7.0 in terms of the input and output data, and a brief discussion of the theory of the solution. Validation examples are also included for the analysis routines.

A. The Plot Menu

The first five of the entries on the **Plot** menu allow you to plot data from files using PCAAD's plotting routines. Antenna patterns can be plotted in planar polar or rectangular form, or in 3-D volumetric form. Impedance data can be plotted on a Smith chart, or on a VSWR / Return Loss plot. The **Default Plot Types** option is used to control the default plot type when patterns or impedances are plotted directly from PCAAD's antenna routines. **Default Plot Colors** is used to set the preferred colors used in the pattern and impedance plots. **Exit** is used to exit the program.

A.1. Polar Pattern Plot

This routine is used to plot up to five planar antenna patterns in polar form. It can be invoked directly from most of the PCAAD antenna routines to plot patterns, or used independently from the **Plot** menu to plot patterns from data files. The routine also computes the main beam pointing angle, the 3 dB beamwidth of the main beam, and provides a movable angle cursor to read pattern values at any angle. The **Plot Options** window allows control of various plot parameters such as the number of divisions, scales, plotting ranges, offsets, line styles, and colors. The resulting plot can be printed on your printer, or exported to another application using the Windows clipboard and the **Copy to Clipboard** button, or the **Copy Graph** option from the **Edit** menu.

To read pattern data from a data file, click the **Read Data File** button, and use the file dialog box to specify a filename. The data file should be in ASCII form, with each line consisting of an angle (in degrees) and the pattern (in dB) at that angle (a phase entry is optional, and not used for plotting). The data must be sequential, in order of increasing angle. The pattern files written by PCAAD 7.0 are in this format, and can be read by either the polar or the rectangular plotting routine. Up to five separate patterns can be plotted simultaneously, either from data files or PCAAD antenna routines. Each data set may be offset by a fixed amount (through the **Plot Options** window), allowing patterns to be plotted in terms of absolute gain, or to facilitate comparison of patterns normalized to different values. The default file extension for planar pattern data files is `.DAT`.

Pattern parameters for a selected pattern are shown at the top left of the polar plotting window. Select the desired pattern by using the pull-down box. The displayed parameters include the name of the file (or the name of the data set, as set in the **Plot Options** window**),** the main beam pointing angle, the 3 dB beamwidth, the pattern value at the moveable angle cursor, and the offset of the data (as set in the **Plot Options** window). If the pattern does not have a well-defined main beam, or has more than one main beam (e.g., grating lobes), the beam position and beamwidth may not be meaningful, and may not be shown. The angle cursor is drawn as a dashed radial line, and can be moved by clicking or dragging with the mouse. Notice that the mouse cursor changes from an arrow to a cross-hair when moved inside the polar plotting region. Clicking the mouse inside the polar plot will snap the angle cursor to that angular position on the graph. Alternatively, the angle cursor can be moved by clicking the mouse on the angle cursor (note that the mouse cursor changes to a directional icon when over the angle cursor), and dragging to the desired position. The pattern value display is updated instantly. This feature is useful for reading sidelobe or cross-pol levels. In addition, moving the mouse over the pattern will provide an immediate display of the angle and pattern value at the mouse cursor point (the mouse cursor must be near a data point of the pattern for this to occur).

Each pattern can be identified with a movable text label. The text is set from **Plot Options**, and the labels can be turned on or off using the check box for **Show Pattern Labels**. Use the mouse to drag the label to the desired position on the plot.

A.2. Rectangular Pattern Plot

This routine is used to plot up to five planar antenna radiation patterns in rectangular form. It can be invoked directly from most of the PCAAD antenna routines to plot patterns, or used independently from the **Plot** menu to plot patterns from a data file. The routine also computes the main beam pointing angle, the 3 dB beamwidth of the main beam, and provides a movable angle cursor to read pattern values at any angle. The **Plot Options** window allows control of various plot parameters such as the number of divisions, scales, plotting ranges, offsets, line styles, and colors. The resulting plot can be printed on your printer, or exported to another application using the Windows clipboard and the **Copy to Clipboard** button, or the **Copy Graph** option from the **Edit** menu.

To read pattern data from a data file, click the **Read Data File** button, and use the file dialog box to specify a filename. The data file should be in ASCII form, with each line consisting of an angle (in degrees) and the pattern (in dB) at that angle (a phase entry is optional, and not used for plotting). The data must be sequential, in order of increasing angle. The pattern files written by PCAAD 7.0 are in this format, and can be read by either the polar or the rectangular plotting routine. Up to five separate patterns can be plotted simultaneously, either from data files or PCAAD antenna routines. Each data set may be offset by a fixed amount (through the **Plot Options** window), allowing patterns to be plotted in terms of absolute gain, or to facilitate comparison of patterns normalized to different values. The default file extension for planar pattern data files is `.DAT`.

Pattern parameters for a selected pattern are shown at the top left of the polar plotting window. Select the desired pattern by using the pull-down box. The displayed parameters include the name of the file (or the name of the data set, as set in the **Plot Options** window), the main beam pointing angle, the 3 dB beamwidth, the pattern value at the moveable angle cursor, and the offset of the data (as set in the **Plot Options** window). If the pattern does not have a well-defined main beam, or has more than one main beam (e.g., grating lobes), the beam position and beamwidth may not be meaningful, and may not be shown. The angle cursor is drawn as a dashed vertical line, and can be moved by either clicking or dragging with the mouse. When using the mouse, notice that the mouse cursor changes from an arrow to a cross-hair when moved inside the rectangular plotting region. Clicking the mouse inside the rectangular plot will snap the angle cursor to that angular position on the graph. Alternatively, the angle cursor can be moved by clicking the mouse on the angle cursor (note that the mouse cursor changes to a directional icon when over the angle cursor), and dragging to the desired position. The pattern value display is updated instantly. This feature is useful for reading sidelobe or cross-pol levels. In addition, moving the mouse over the pattern will provide an immediate display of the angle and pattern value at the mouse cursor point (the mouse cursor must be near a data point of the pattern for this to occur).

Each pattern can be identified with a movable text label. The label is set from **Plot Options**, and the labels can be turned on or off using the check box for **Show Pattern Labels**. Use the mouse to drag the label to the desired position on the plot. The vertical axis is normally labeled as *Pattern (dB)*, but this label can be changed by modifying the `PCAAD7.INI` file - this can be useful when plotting directivity or gain.

A.3. 3-D Pattern Plot

This routine plots an antenna radiation pattern in a 3-D volumetric form. It can be invoked directly from most of the PCAAD antenna routines to plot patterns, or used independently from the **PLOT** menu to plot patterns from a data file. Data files of this type can be generated from most of the PCAAD routines, and are given the default file extension `.3DP`, to distinguish them from planar pattern data files. The 3-D pattern plot can be printed on your printer, or exported to another application using the Windows clipboard and the **Copy to Clipboard** button, or the **Copy Graph** option from the **Edit** menu.

For 3-D volumetric patterns, the following data file format is used. The first line has three values: the elevation angle step size (degrees), the azimuth angle step size (degrees), and the maximum elevation angle range (90º for upper hemisphere only, or 180º for both hemispheres). This is followed by N = 1 + 360 / (azimuth step size) lines, one for each azimuth angle. Each of these lines contains 1 + 90/(elevation angle step size) pattern values, normalized from 0 to 1. (The data is generated by normalizing the pattern to 0 dB, limiting the lowest pattern value to -30 dB, then scaling to the range of 0 to 1 for plotting.)

The routine has three slider controls to allow adjustment of the plot size, the elevation view angle, and the azimuth view angle. The plot is redrawn after each adjustment of these controls. A color bar near the bottom of the window shows the scale, with red corresponding to 0 dB, and blue to -30 dB. There are checkbox options for showing the gridlines on the plot, for displaying the coordinate axes, and for showing the reference scale. There is also an option to display a cross-sectional view of the 3-D plot over a 90º sector.

A.4. Smith Chart Plot

The Smith Chart plotting routine is a very versatile tool, capable of plotting up to five sets of impedance data, and incorporating an easy-to-use impedance matching capability. It can be invoked directly from routines that calculate impedance, such as the wire antenna and microstrip element routines, or it can be used independently from the **Plot** menu to plot impedance data from ASCII data files. The Smith chart plot can be printed on your printer, or exported to another application using the Windows clipboard and the **Copy to Clipboard** button, or the **Copy Graph** option from the **Edit** menu.

When used with data files, the file should be in ASCII form with one line for each data point. The real part, the imaginary part, and an optional data point label (up to five characters long) should be delimited with commas or spaces. The data point labels are commonly used as frequency markers, but other parameters can be used as well (such as scan angle). The impedance data is assumed to be in absolute (ohms, not normalized) form. Click the **Read Data File** button to select a data file. Up to five data sets can be displayed, except when the impedance matching solution is used. The impedance matching response must always be the last data set, so further data is prevented from being read when the impedance matching response is on.

From the Smith chart window, you can use the mouse to click on any data point, and read the exact value of its impedance in the data box at the top left of the window. This display also gives the corresponding normalized impedance, and the reflection coefficient for that impedance. The chart also shows a constant VSWR circle (dashed circle), which may be adjusted by either dragging with the mouse cursor, or by entering a new value in the **SWR** data entry box at the left side of the chart. Similarly, the chart also shows a dashed radial line indicating wavelengths toward the load (WTL), and wavelengths toward the generator (WTG). This line may be set by dragging with the mouse, or by entering a value of WTL or WTG in the appropriate data box. In addition, the VSWR and WTL/WTG cursors may be set to a particular data point by double clicking on that point. Smith chart options such as interpolation, characteristic impedance, a rotated 1+jx circle, colors, and other display options can be set by clicking the **Plot Options** button. Colors can be set from the **Default Plot Colors** window available under **Plot** on the main menu bar - this window also allows saving of your color selections as defaults. Each impedance data set can be identified with a movable text label. The label is initially set as the filename for that data set (if the data was read from a file), or the name of the calling routine (if the data was obtained from another PCAAD routine). You can also set the labels from the **Plot Options** window, and the labels can be turned on or off using the check box for **Show Data Point and Set Labels** (enter blanks for the data set label if you want data point labels but not a data set label). Use the mouse to drag the label to the desired position on the Smith chart.

PCAAD also features a general purpose impedance matching routine coupled to the Smith chart. With one or more (but less than five) data sets displayed, first select a data set and a matching frequency by clicking on the desired data point (if you do not select a data point, the program will use the midpoint of the first data set). Then turn on the impedance matching feature by clicking the **On** button in the **Impedance Matching** frame. The response of the matched impedance data will be displayed. You may change the matching frequency using the scroll box (the impedance data set must have frequency labels for each data point). You may choose the type of matching circuit from the list box – a quarter-wave transformer, LC networks, open- and short-circuit shunt stubs, and open- and short-circuit series stubs are available (see [9] for a discussion of impedance matching techniques). Except for the quarter-wave transformer, each of these circuits yields two different matching solutions, which can be selected with the buttons marked **Solution #1** and **Solution #2**. Each matching solution has two parameters (transformer impedance and length; series and shunt component values; or stub length and position). These values are listed for the selected matching network and solution. (For the stub tuners, the characteristic impedance of the transmission line and stub are assumed to be the same as the characteristic impedance of the Smith chart.) Only a single impedance data set can be matched at one time; to change the data set to be matched, turn off the impedance matching feature, select a data point on the new data set, and turn impedance matching back on. Once the matching parameters have been selected, the routine calculates the input impedance seen looking into the matching network at each frequency, and plots this as a new impedance locus on the chart. The user can study the effect of changing matching circuits, the match frequency, and different matching solutions very easily with this routine. The effect of changes in component values can be studied simply be entering new values in the component value boxes. Note that, for data sets having a wide frequency range between data points, it is possible that the plotted impedance loci for the original or matched data sets may run off the edge of the chart – this is because the accuracy of interpolation may not be sufficient. If this is a problem, interpolation may be turned off in the **Plot Options** window. When the impedance matching feature is in use, no further data sets may be read.

A.5. VSWR / Return Loss Plot

This routine plots up to two sets of impedance data as either VSWR or return loss (in dB) versus frequency. It can be invoked directly from PCAAD routines that calculate impedance, such as the wire antenna and microstrip element routines, or it can be used independently from the **Plot** menu to plot impedance data from a file. The resulting plot can be printed on your printer, or exported to another application using the Windows clipboard and the **Copy to Clipboard** button, or the **Copy Graph** option from the **Edit** menu.

Select either a **VSWR** or **Return Loss** plot by clicking the appropriate option button to the left of the plot. Plot options, such as interpolation and color of plotted data, characteristic impedance, and the range and number of divisions for the vertical and frequency scales, can be set by clicking the **Plot Options** button.

When used with a data file, the file should be in ASCII form with one line for each data point. The real part, the imaginary part, and the frequency (up to five characters) should be delimited with commas or spaces. The impedance data is assumed to be in absolute (ohms, not normalized) form. This is the same format used by the Smith chart routine, and the format that PCAAD uses when saving impedance data to a file.

A.6. Default Plot Types

The default type of antenna pattern plots (polar, rectangular or 3-D), and impedance plots (Smith chart or VSWR/Return Loss) are selected with this window. You can select planar pattern cuts in polar or rectangular form, or a three dimensional volumetric pattern plot. Your selections on this window can be saved as default values by clicking the **Save Defaults** button.

For planar patterns, you have the choice of viewing either E-theta / E-phi, Co-pol / X-pol (Ludwig's third definition) or E-plane / H-plane patterns, at a particular azimuth angle. (E-plane / H-plane patterns are not available in some PCAAD routines.) The elevation angle step size can also be specified. You can also control whether or not phase data is saved with the planar pattern data to a file by using the check box.

For 3-D volumetric patterns, the elevation and azimuth step sizes can be specified - these values should generally be between 2º to 10º for best results. Volumetric patterns may be plotted over either the upper hemisphere, or both upper and lower hemispheres, depending on the type of antenna. You can choose to display only the upper hemisphere of a 3-D pattern plot by using the check box. Note that many antennas in PCAAD (microstrip antennas, horn antennas, and antennas over a ground plane) have volumetric patterns that extend only over the upper hemisphere.

A.7. Default Plot Colors

This window is used to set the default colors used in the pattern (polar and rectangular) and impedance (Smith chart and VSWR/Return Loss) plotting routines. Line colors for data sets can be set, as well as the cursor color and background color. Color selections can be saved as defaults for later use.

A.8 Default Directory Path

Windows usually defines a preferred directory for user applications. For example, Windows 7 may use `C:\Users\`*`user`*`\AppData\Roaming\PCAAD7` as the directory path for your data files. The **Default Directory Path** menu option allows you to choose alternate directories where PCAAD data files are stored. The window displays the current default directory that PCAAD is using for data files, and the Windows user directory path for the PCAAD application. You can change the default directory to the Windows User directory, or to another directory of your choosing. You may also save your choice of default directory to the `PCAAD.INI` file. Directories can also be chosen when using a **File Dialog** to read or save a particular data file in PCAAD.

A.9. Exit

Click this option to exit PCAAD, or close the main PCAAD window.

B. The Edit Menu

Being a Windows application, PCAAD 7.0 allows use of the standard Windows methods of cutting, copying, and pasting data and graphics from PCAAD routines to or from the Windows clipboard. PCAAD has some useful additional commands available from the **Edit** menu to facilitate copying, editing, and printing, as described below.

B.1. Copy Window

Copy Window allows you to copy the currently active window to the Windows clipboard. This image may then be pasted into another Windows application, such as PowerPoint or Word. This action is similar to pressing **Alt-PrintScreen**, which also copies the active window to the clipboard. Note that the entire screen image can be copied to the clipboard by pressing **PrintScreen** (these are standard Windows commands).

B.2. Copy Graph

Copy Graph allows you to copy the current graph or plot to the Windows clipboard. The graph or plot may then be pasted into another Windows application, such as PowerPoint or Word. Note that this command only copies the graph or plot, not the complete window.

B.3. Copy Text

To copy a value from a data box to the Windows clipboard, first select the data using the mouse. Then click **Copy Text** from the **Edit** menu. This function can also be accomplished by pressing **Ctrl-C** after selecting the desired data, or by right-clicking the mouse and selecting **Copy**.

B.4. Paste Text

To copy a value from the Windows clipboard to a data box in PCAAD, click on the desired data box, then click **Paste Text** from the **Edit** menu. This function can also be accomplished by pressing **Ctrl-V**, or by right-clicking the mouse and selecting **Paste**.

B.5. Edit File

Click the **Edit File** option from the **Edit** menu to invoke the Windows system text editor (typically **Notepad**). This allows you to easily view or edit data files when using PCAAD 7.0.

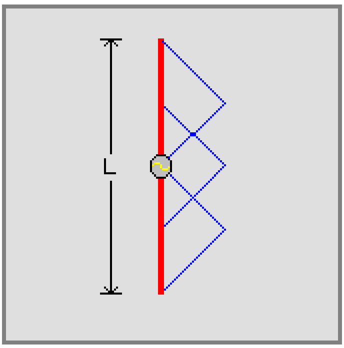
B.6. Print Window

This option is used to print the current active analysis or plotting routine window. This feature is useful for obtaining a hard copy of the complete set of input and output data associated with a PCAAD 7.0 routine. Input data, output data, and graphics are printed.

C. The Wire Antennas Menu

These nine routines involve the analysis and design of various wire antennas. Wire dipoles, loops, Yagi-Uda arrays, planar dipole arrays, log periodic dipole arrays, and more general wire antenna geometries are modeled using a standard thin-wire Galerkin moment method solution with piecewise sinusoidal modes, as described in references [2], [10].

C.1. Dipole Antenna



This routine computes the input impedance, broadside gain, and radiation pattern of a dipole antenna. The feed point can be placed at the center of any expansion mode. The solution uses the piecewise sinusoidal expansion (PWS) Galerkin method, with the exact exponential integral expressions used for the impedance matrix elements, as detailed in references [10], [11]. This method has proven to be an accurate and efficient technique for solving thin wire antenna and scattering problems.

Begin by entering the dipole length, the dipole radius, the number of PWS expansion modes, and the position of the feed generator. The generator feed point must be located at the center of a PWS expansion mode. If the dipole is center-fed, the number of expansion modes should be odd, and the mode number of the generator should be the middle mode (this mode number is automatically selected as the default mode number for the generator). Pattern plots can be made in the E- and H-planes of the dipole, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button. The resonant frequency of the dipole, the frequency step size, and the default number (7) of frequency points are displayed to the right of the **Compute** button. These values can be estimated by the routine by clicking the **Compute** button, or you can enter your own values for center frequency, frequency step size, and the number of frequency points.

Upon clicking the **Compute** button, the routine will calculate the moment method solution for the dipole, and list the input impedance versus frequency in the list box. The scroll bar can be used to scroll through the data. The gain of the dipole at its beam maximum is computed at the center frequency of the frequency sweep. At this point, from the **Results** tree, you can plot the impedance characteristics versus frequency on a Smith chart plot or a VSWR/Return Loss plot, and can save the impedance data in a data file. The specified patterns are calculated at the center frequency, and may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files. The geometry of the dipole may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors.

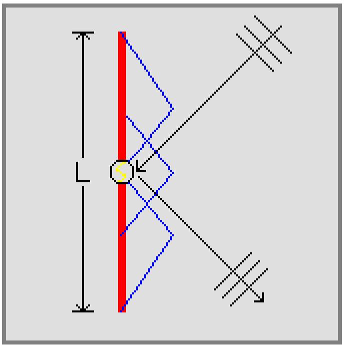
Validation

Consider a half-wave dipole with a radius of 0.001λ. Calculated input impedance results from PCAAD 7.0 are compared with those from [1] and [10], versus N, the number of expansion modes:

N	Reference [1]	PCAAD 7.0
1	73.1 + j 42.3 Ω	73.1 + j 42.2 Ω
3	81.2 + j 41.3 Ω	81.2 + j 41.3 Ω
5	82.8 + j 42.0 Ω	82.8 + j 42.0 Ω
7	83.6 + j 42.7 Ω	83.6 + j 42.7 Ω

The gain of a half-wave dipole is 2.15 dB; PCAAD 7.0 gives 2.2 dB.

C.2. Dipole Radar Cross-Section



This routine is very similar to the dipole antenna routine, except that it computes the bistatic radar cross section (RCS) for a loaded wire dipole. The solution uses the piecewise sinusoidal expansion (PWS) Galerkin method, with the exact exponential integral expressions used for the impedance matrix elements, as detailed in references [10], [11]. This method has proven to be an accurate and efficient technique for solving thin wire antenna and scattering problems.

Begin by entering the dipole length, the dipole radius, and the incidence and scattering angles. These angles are measured from the axis of the dipole, and have default values of 90º (broadside). Next enter the number of PWS expansion modes, and the mode number of the lumped-element load impedance. The default number of expansion modes is 3, and the default position of the lumped load is at the terminals of the middle expansion mode. Then enter the real and imaginary parts of the load impedance; the default values are zero. The resonant frequency of the dipole, the frequency step size, and the default number (7) of frequency points are displayed to the right of the **Compute** button. These values can be estimated by the routine by clicking the **Compute** button, or you can enter your own values for center frequency, frequency step size, and the number of frequency points. The geometry of the dipole may be viewed in three dimensions by clicking the **Show Geometry** button.

Upon clicking the **Compute** button, the routine will calculate the moment method solution for the dipole, compute the RCS of the dipole over the specified frequency sweep, and list the results in dB per square meter, and in dB per square wavelength, in a list box. The scroll bar can be used to scroll through the data. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors. The RCS data (in dBsm) can be written to a data file by clicking **Save Data**.

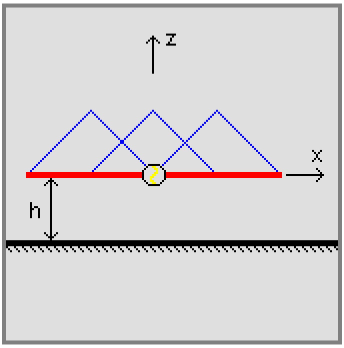
Validation

Consider a dipole 6.0 cm long with a radius of 0.002 cm. At 3 GHz, using three PWS expansion modes, the RCS was computed at broadside and compared with results from [10] for two values of load impedance:

Z_L	Reference [10]	PCAAD 7.0
0 Ω	-22.0 dBsm	-21.9 dBsm
70 Ω	-26.5 dBsm	-26.7 dBsm

Results were also compared with RCS data from [3]. The angle dependence of the routine was checked by verifying that the RCS of a short dipole dropped off by 6 dB when both the incidence and scattering angles were changed to 45°.

C.3. Horizontal Dipole Over Ground Plane



This routine computes the input impedance, broadside gain, and radiation pattern of a horizontal dipole antenna over an infinite perfectly conducting ground plane. The feed point can be placed at the center of any expansion mode. The solution uses the piecewise sinusoidal expansion (PWS) Galerkin method, with the exact exponential integral expressions used for the impedance matrix elements, as detailed in references [10], [11]. This method has proven to be an accurate and efficient technique for solving thin wire antenna and scattering problems.

Begin by entering the dipole length, the dipole radius, the height above the ground plane, the number of PWS expansion modes, and the position of the feed generator. The dipole must be above the ground plane. The generator feed point must be located at the center of a PWS expansion mode. If the dipole is center-fed, the number of expansion modes should be odd, and the mode number of the generator should be the middle mode (this mode number is automatically selected as the default mode number for the generator). Pattern plots can be made in the E- and H-planes of the dipole, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button. The resonant frequency of the dipole, the frequency step size, and the default number (7) of frequency points are displayed to the right of the **Compute** button. These values can be estimated by the routine by clicking the **Compute** button, or you can enter your own values for center frequency, frequency step size, and the number of frequency points.

Upon clicking the **Compute** button, the routine will calculate the moment method solution for the dipole, and list the input impedance versus frequency in the list box. The scroll bar can be used to scroll through the data. The gain of the dipole at its beam maximum is computed at the center frequency of the frequency sweep. At this point, from the **Results** tree, you can plot the impedance characteristics versus frequency on a Smith Chart plot or a VSWR/Return Loss plot, and can save the impedance data in a data file. The specified patterns are calculated at the center frequency, and may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files. The geometry of the dipole may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors.

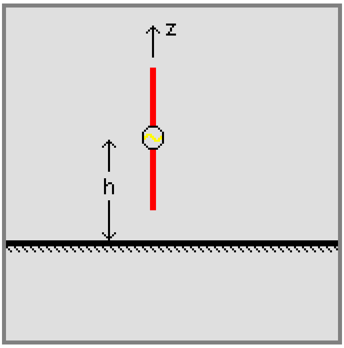
Validation

Consider a horizontal center-fed dipole with length λ/2 and radius 0.001λ, with three expansion modes. PCAAD gives the following results for input impedance and directivity, for three values of ground plane spacing:

d / λ	Input Impedance	Directivity
0.10	24.9 + j 66.9 Ω	8.8 dB
0.25	99.7 + j 73.1 Ω	7.5 dB
0.55	66.4 + j 30.5 Ω	9.0 dB

These values are in close agreement with the results from the finite dipole array routine, after applying image theory to remove the ground plane, and replacing the horizontal dipole with an array of two parallel dipoles having excitations of unit amplitude and a 180º phase shift. Three dB is added to the directivity of the array to account for the ground plane.

C.4. Vertical Dipole Over Ground Plane



This routine computes the input impedance, broadside gain, and radiation pattern of a vertical dipole antenna over an infinite perfectly conducting ground plane. The feed point can be placed at the center of any expansion mode. The solution uses the piecewise sinusoidal expansion (PWS) Galerkin method, with the exact exponential integral expressions used for the impedance matrix elements, as detailed in references [10], [11]. This method has proven to be an accurate and efficient technique for solving thin wire antenna and scattering problems.

Begin by entering the dipole length, the dipole radius, the height (of the center of the dipole) above the ground plane, the number of PWS expansion modes, and the position of the feed generator. The entire dipole must be above the ground plane. The generator feed point must be located at the center of a PWS expansion mode. If the dipole is center-fed, the number of expansion modes should be odd, and the mode number of the generator should be the middle mode (this mode number is automatically selected as the default mode number for the generator). Pattern plots can be made in the E- and H-planes of the dipole, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button. The resonant frequency of the dipole, the frequency step size, and the default number (7) of frequency points are displayed to the right of the **Compute** button. These values can be estimated by the routine by clicking the **Compute** button, or you can enter your own values for center frequency, frequency step size, and the number of frequency points.

Upon clicking the **Compute** button, the routine will calculate the moment method solution for the dipole, and list the input impedance versus frequency in the list box. The scroll bar can be used to scroll through the data. The gain of the dipole at its beam maximum is computed at the center frequency of the frequency sweep. At this point, from the **Results** tree, you can plot the impedance characteristics versus frequency on a Smith chart plot or a VSWR/Return Loss plot, and can save the impedance data in a data file. The specified patterns are calculated at the center frequency, and may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files. The geometry of the dipole may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors.

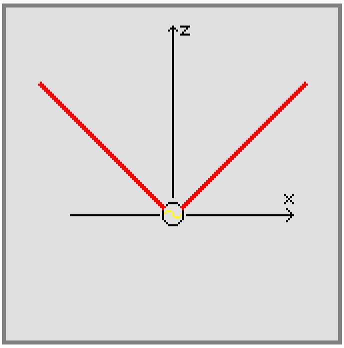
Validation

Consider a vertical center-fed dipole with length λ/2 and radius 0.001λ, with three expansion modes. PCAAD gives the following results for input impedance and directivity, for three values of ground plane spacing:

d/λ	Input Impedance	Directivity
0.25001	118.2 + j 62.1 Ω	6.8 dB
0.45	76.8 + j 37.4 Ω	8.4 dB
0.55	78.0 + j 43.3 Ω	8.4 dB

These values are in agreement with the results from the finite dipole array routine, after applying image theory to remove the ground plane, replacing the vertical dipole with an array of two collinear dipoles having the same excitation. Three dB is added to the directivity of the array to account for the ground plane.

C.5. V-Dipole Antenna



This routine computes the input impedance, gain, and radiation pattern of a V-dipole antenna. The internal angle of the V-dipole is variable (an angle of 180º corresponds to a straight dipole). The feed point is at the apex of the wire arms. The solution uses the piecewise sinusoidal expansion (PWS) Galerkin method, with the exact exponential integral expressions used for the impedance matrix elements, as detailed in references [10], [11]. This method has proven to be an accurate and efficient technique for solving thin wire antenna and scattering problems.

Begin by entering the dipole arm length, the dipole radius, the number of PWS expansion modes, and the internal angle of the dipole (between 2º and 180º). Because of symmetry, the number of PWS expansion modes must be odd. Pattern plots can be made in the E- and H-planes of the dipole, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button. The resonant frequency of the V-dipole, the frequency step size, and the default number (7) of frequency points are displayed to the right of the **Compute** button. These values can be estimated by the routine by clicking the **Compute** button, or you can enter your own values for center frequency, frequency step size, and the number of frequency points.

Upon clicking the **Compute** button, the routine will calculate the moment method solution for the V-dipole, and list the input impedance versus frequency in the list box. The scroll bar can be used to scroll through the data. The gain of the dipole at its beam maximum is computed at the center frequency of the frequency sweep. At this point, from the **Results** tree, you can plot the impedance characteristics versus frequency on a Smith chart plot or a VSWR/Return Loss plot, and can save the impedance data in a data file. The specified patterns are calculated at the center frequency, and may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files. The geometry of the V-dipole antenna may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors.

Validation #1

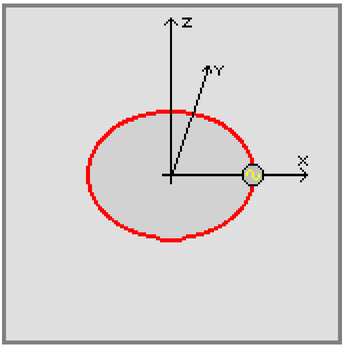
Consider a V-dipole antenna with arm lengths of 0.25λ, radius of 0.001λ, and variable angle. Calculated input impedance results from PCAAD are compared with data from [10], using one PWS expansion mode:

Angle	Reference [10]	PCAAD 7.0
90°	40.9 + j 9.0 Ω	40.1 + j 8.9 Ω
150°	69.3 + j 39. Ω	69.1 + j 38.9 Ω
180°	73.1 + j 42. Ω	73.1 + j 42.2 Ω

Validation #2

Consider a V-dipole with arm lengths of 1.5λ, and radius 0.001λ. From [2], the internal angle that results in maximum directivity is 82.5°. The resulting directivity from [2] is approximately 7.5 dB. Using 11 expansion modes, PCAAD gives a value of 7.8 dB.

C.6. Loop Antenna



This routine computes the input impedance, gain, and radiation pattern of a wire loop antenna. The solution uses the piecewise sinusoidal expansion (PWS) Galerkin method, with the exact exponential integral expressions used for the impedance matrix elements, as detailed in references [10], [11]. This method has proven to be an accurate and efficient technique for solving thin wire antenna and scattering problems.

Begin by entering the radius of the loop, the wire radius, and the number of PWS expansion modes. Pattern plots can be made in the E- and H-planes of the loop, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Note that electrically small loops have an E-phi polarization, but larger loops may have E-theta polarization (the Co- and X-pol fields are assumed to be E-phi and E-theta for this routine). Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button. The resonant frequency of the loop, the frequency step size, and the default number (7) of frequency points are displayed to the right of the **Compute** button. These values can be estimated by the routine by clicking the **Compute** button, or you can enter your own values for center frequency, frequency step size, and the number of frequency points.

Upon clicking the **Compute** button, the routine will calculate the moment method solution for the loop antenna, and list the input impedance versus frequency in the list box. The scroll bar can be used to scroll through the data. The gain of the loop at its beam maximum is computed at the center frequency of the frequency sweep (note that electrically small loops have a pattern null on axis, while larger loops have a beam maximum on the axis of the loop). At this point, from the **Results** tree, you can plot the impedance characteristics versus frequency on a Smith chart plot or a VSWR/Return Loss plot, and can save the impedance data in a data file. The specified patterns are calculated at the center frequency, and may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files. The geometry of the loop may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors.

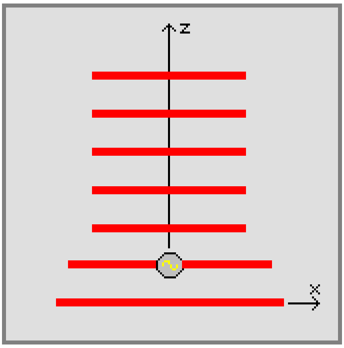
Validation

Consider a wire loop antenna with a wire radius of 0.001λ. The calculated input impedance from [10] is compared with results from PCAAD 7.0 for various loop radii and expansion modes. Note that using four expansion modes corresponds to a square loop, while eight modes corresponds to an octagonal loop, etc.

Loop Radius	PWS Modes	Zin Reference [10]	Zin PCAAD 7.0
0.0707 λ	4	44.8 + j 1589. Ω	44.8 + j 1589. Ω
0.1592 λ	4	92.4 – j 300.9 Ω	92.4 –j 300.9 Ω
0.1592 λ	8	109.7 – j 149.3 Ω	109.7 – j 149.3 Ω
0.1592 λ	16	116.0 – j 109.1 Ω	116.0 – j 109.1 Ω
0.1592 λ	64	117.5 – j 95. Ω	117.5 – j 95.4 Ω

The directivity of a loop having a circumference of 1 λ (radius = 0.1592 λ) is about 3.4 dB [2]. PCAAD 7.0 gives a value of 3.3 – 3.5 dB, depending on the number of expansion modes used.

C.7. Yagi Antenna



This routine analyzes a Yagi-Uda dipole array using a moment method solution that includes all mutual coupling terms. Dipole currents are expanded using piecewise sinusoidal (PWS) modes, as described in references [10], [11]. The routine computes input impedance, gain, front-to-back ratio, and patterns for the array. The array is assumed to have one dipole reflector element, one driven dipole element, and an arbitrary number of dipole director elements. The length and spacing for each element is variable, but the radius is assumed to be the same for all elements.

Begin by entering the frequency, the dipole radius, the number of PWS modes on each dipole, and the number of director elements. Next, specify the lengths and spacings of the elements using the scroll bar and boxes. The name of each element is listed in the box to the right of the scroll bar, followed by boxes for its length and spacing from the previous element. Thus, the spacing of the first element (the reflector) is not used, and is set to zero. Use the scroll bar to scroll through the elements to set or change lengths and spacings. Pattern plots can be made in the E- and H-planes of the array, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button.

When all data is entered, click the **Compute** button to calculate the moment method solution for the Yagi antenna. The input impedance, gain, and front-to-back ratio will be listed. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files. The geometry of the Yagi may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors.

Validation
Consider a Yagi array with the following specifications:

Reflector length	47.9 cm
Fed element length	45.3 cm
Director length (1)	45.1 cm
Spacing between reflector and feed	25.0 cm
Spacing between feed and director	25.0 cm
Dipole radius	0.25 cm
Frequency	0.30 GHz

This geometry is analyzed in [3], although the number of expansion modes is not stated. Running PCAAD 7.0 with 9 PWS modes per element (27 modes total) gives the following results:

Quantity	Reference [3]	PCAAD 7.0
Input impedance	22 + j 15 Ω	22 + j 14 Ω
Gain	9.4 dB	9.5 dB
Front-to-back ratio	5.6 dB	5.7 dB

The principal plane patterns of the Yagi array are shown below.

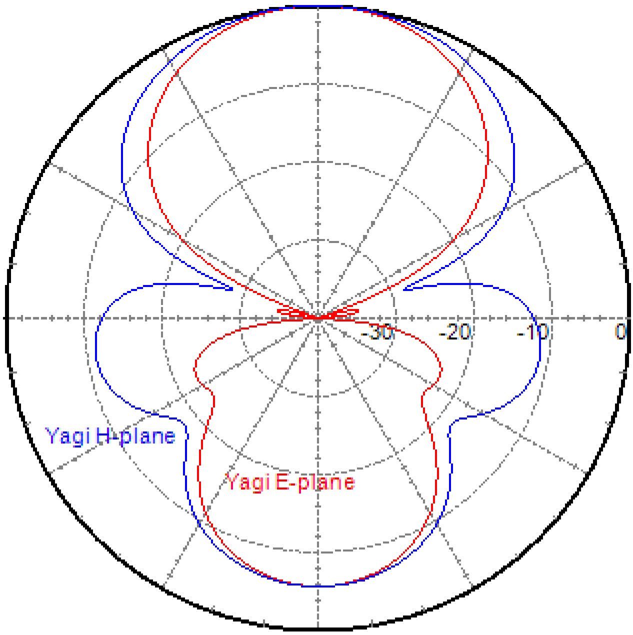
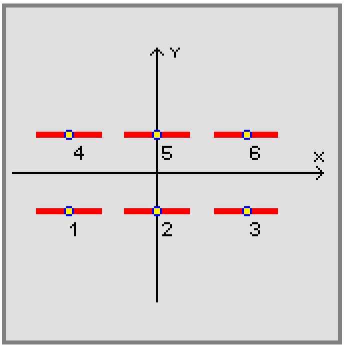


Figure 1. E-plane and H-plane patterns of the Yagi array example.

C.8. Dipole Array



This routine analyzes a finite planar wire dipole array using a moment method solution that includes all mutual coupling terms. Dipole currents are expanded using piecewise sinusoidal (PWS) modes, as described in references [10], [11]. The routine computes input impedance at each dipole, the array gain, and patterns for the array. The number and spacing of dipoles in each plane of the array is variable, but all dipoles are assumed to have the same length and radius. Each dipole is center-fed with an arbitrary voltage generator, with a series generator impedance. As shown in the graphic, the dipoles are all parallel to the x-axis, and are numbered by rows along the x-axis.

Begin by entering the frequency, the number of dipoles in the x and y-directions, and the spacings (center-to-center) of the dipoles in the x and y-directions. Also enter the dipole length, the dipole radius, the number of PWS modes on each dipole, and the series generator resistance. The generator resistance is the same for all dipoles. Next, specify the generator voltage at each dipole using the scroll bar and boxes. The dipole index (numbered along the x axis, by rows, starting at the bottom) is listed in the box to the right of the scroll bar, followed by boxes for the generator voltage magnitude and phase (in degrees). Use the scroll bar to scroll through the elements to set or change generator voltages. Pattern plots can be made in the E- and H-planes of the array, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button.

When all data is entered, click the **Compute** button to calculate the moment method solution. The input impedance for each dipole will be listed in the box below the **Compute** button; use the scroll bar to scroll through the data. The input impedance is that seen looking into the dipole terminals, in contrast to the impedance seen from the generator (which would include the generator series resistance). The routine computes the gain of the array at the main beam position, assuming the main beam occurs in the plane where the patterns have been specified. The gain is computed in terms of the input power to the dipoles, and does not include power dissipated in the generator impedance. The logic here is that a realistic source will consist of a voltage generator and a series generator impedance, and the power dissipated in the source impedance should not be considered as a loss in the antenna itself.

The specified patterns may be plotted by clicking the appropriate option in the

Results tree, or saved to data files. The geometry of the dipole array may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors. The modes are counted from left to right for each element, and along the E-plane rows of the array.

Validation

Consider a 12-element linear H-plane dipole array. The dipole length is 5 cm, the radius is 0.001 cm, the spacing between the elements is 5 cm, and the frequency is 3 GHz. The generator impedance is 0 Ω, and the voltage sources are phased to scan the beam to -45° in the H-plane. Five PWS modes are used on each dipole. This geometry is the same as that treated in reference [2]. Input impedance magnitudes from [2] are compared below with data computed from PCAAD 7.0:

Dipole	Generator Voltage	Zin PCAAD 7.0	|Zin| PCAAD 7.0	|Zin| Ref [2]
1	1.0/0°	107.1 + j 9.6 Ω	107.5 Ω	107.1 Ω
2	1.0/127°	97.8 + j 42.0 Ω	106.4 Ω	105.9 Ω
3	1.0/254°	91.0 + j 46.0 Ω	102.0 Ω	101.5 Ω
4	1.0/381°	87.8 + j 45.3 Ω	98.8 Ω	98.2 Ω
5	1.0/508°	86.4 + j 43.9 Ω	96.9 Ω	96.3 Ω
6	1.0/635°	85.9 + j 42.5 Ω	95.8 Ω	95.2 Ω
7	1.0/762°	86.1 + j 41.0 Ω	95.3 Ω	94.7 Ω
8	1.0/889°	87.5 + j 39.3 Ω	95.9 Ω	95.4 Ω
9	1.0/1016°	90.7 + j 38.9 Ω	98.7 Ω	98.2 Ω
10	1.0/1143°	95.0 + j 42.6 Ω	104.2 Ω	103.7 Ω
11	1.0/1270°	92.8 + j 55.2 Ω	108.0 Ω	107.3 Ω
12	1.0/1397°	57.4 + j 47.8 Ω	74.7 Ω	74.0 Ω

The H-plane pattern for this case is shown in Figure 2 below, and is in good agreement with the pattern in [2] (the pattern in [2] is scanned to 45°, while the PCAAD results are for an array scanned to -45°; the difference can be attributed to a difference in numbering the dipoles).

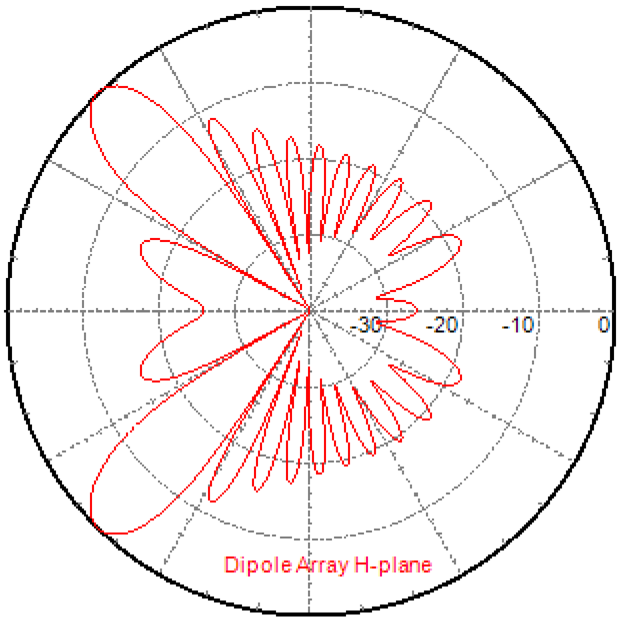
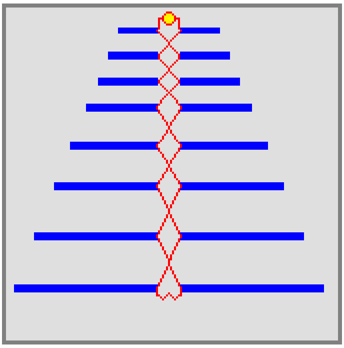


Figure 2. H-plane pattern of the dipole array example.

C.9. Log Periodic Dipole Array Design



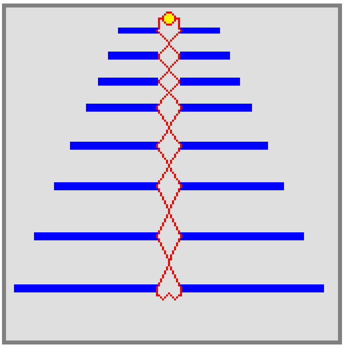
This routine gives an approximate design for a log-periodic dipole array, for a specified bandwidth and gain, based on the formulas given in reference [1], with corrections from reference [7]. The routine computes the necessary number of dipoles in the array, and the spacings, lengths, and radii for each element.

First enter the lower and upper frequencies of the desired operating band. Then enter the desired gain (between 7 and 11 dB), and the radius of the largest dipole. The routine prints out the log-periodic array scale factors, σ and τ, followed by a list of the spacing, length, and radius for each element in the array. The scroll bar in the list box can be used to scroll through the elements. Spacings are measured from the largest dipole; the last spacing is not used.

Validation
Consider an LPDA design with a lower frequency of 54 MHz, an upper frequency of 216 MHz, a directivity of 7.5 dB, and a largest dipole radius of 1 cm. This case is given in [1], with the following results:

Quantity	Reference [1]	PCAAD 7.0
σ	0.147	0.147
τ	0.822	0.822
First dipole length	264.8 cm	264.8 cm
Spacing to second dipole	77.8 cm	77.8 cm
Third dipole radius	0.64 cm	0.64 cm
Last dipole length	55.2 cm	55.2 cm

C.10. Log Periodic Dipole Array Analysis



This routine performs a complete analysis of a log-periodic dipole array using a moment method solution that includes all mutual coupling terms. Dipole currents are expanded using piecewise sinusoidal (PWS) modes, as described in references [10], [11]. The array is fed with a transmission line having alternating terminals, and analyzed using port admittance matrices as described in reference [2]. The routine computes the input impedance at the feed port, the array directivity and gain, and the patterns for the array. As shown in the graphic, the dipoles are all parallel to the x-axis, with the main beam in the z direction. The feed is assumed to be at the terminals of the smallest dipole, and a matched load is assumed to be located at the terminals of the largest dipole. The dimensions and spacings can be manually entered for each dipole, or you can enter the σ and τ parameters for the array and let the routine calculate all necessary dimensions.

Begin by entering the frequency, the feed line characteristic impedance, the number of dipoles in the array, and the number of expansion modes to be used on each dipole (this value may need to be increased for frequencies at the high end of the operating range). At this point you can click the **Get Data** button to enter the σ and τ parameters of the LPDA array, along with the length and radius of the first (longest) dipole in the array. The routine will then compute all necessary dimensions and spacings for the array, and automatically enter these values (upon clicking the **OK** button) into the scroll boxes. Alternatively, you can manually enter the length, spacing, and radius for each dipole in the array. The dipoles are numbered starting from the largest element; the last spacing value is not used. Pattern plots can be made in the E- and H-planes of the array, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button.

When all data is entered, click the **Compute** button to calculate the moment method solution. The input impedance, directivity, and gain (accounting for power lost in the termination resistor), and the front-to-back ratio are listed, along with the magnitude and phase of the terminal currents at each dipole (these values include the 180º phase reversal introduced by the feed line). This data can be used to observe how the "active region" moves along the array as frequency changes. From the **Results** tree, you can plot the patterns of the LPDA by clicking the appropriate option in the **Results** tree, or save the patterns to data files. The geometry of the LPDA may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors.

Validation

Consider a log periodic dipole array having 18 elements and $\sigma = 0.169$, $\tau = 0.917$, with the largest dipole having a length of 75 cm and radius of 0.3 cm. The characteristic impedance is 83 Ω. The table below compares the calculated input impedance and gain with values from [2]. Five expansion modes per dipole were used in the PCAAD solution.

Frequency (MHz)	Reference [2]		PCAAD 7.0	
	Zin (Ω)	Gain (dB)	Zin (Ω)	Gain (dB)
200	69 – j 7	8.8	71 – j 6	9.0
300	72 – j 4	9.4	72 – j 3	9.5
450	76 – j 6	9.5	75 – j 8	9.6
600	78 – j 11	9.4	80 – j 12	9.3

The figure below show the principal plane patterns for the array at 300 MHz.

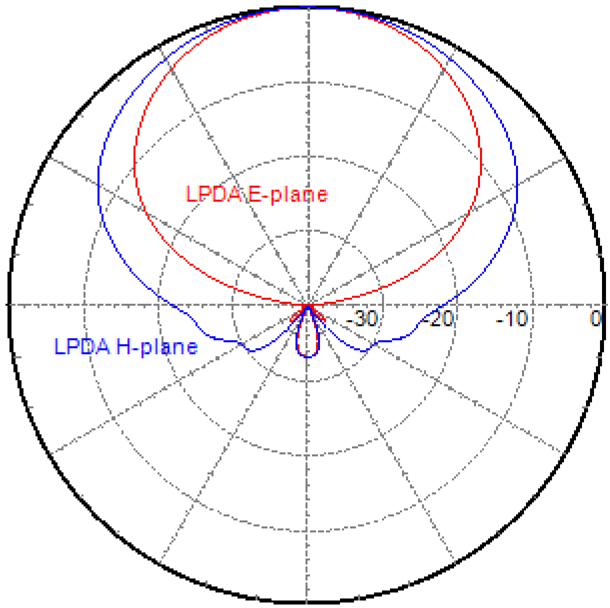
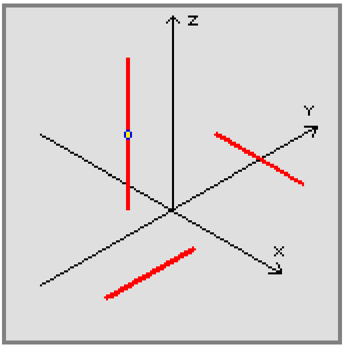


Figure 3. E-plane and H-plane patterns of the LPDA array example.

C.11. General Wire Antenna



This routine analyzes a general wire antenna geometry using a moment method solution that includes all mutual coupling terms. An arbitrary number of bent wire segments can be specified, with arbitrary positions, and voltage generators and lumped loads can be specified at the terminals of any expansion mode. The main limitation is that junctions between more than two wires are not allowed. All wires must also have the same radius. Wire currents are expanded using piecewise sinusoidal (PWS) modes, as described in references [10], [11]. The wire geometry is specified by defining a set of x, y, z coordinates to define the terminals of each PWS expansion mode on the wire structure. The geometry is specified in an ASCII data file (extension `.ANT`), with the following format:

`FREQ, A`	frequency (GHz), wire radius (cm)
`NP`	number of points on the wire structure
`X, Y, Z`	coordinates (in cm) of each point on the wire geometry (one row for each point)
`NM`	number of PWS expansion modes
`I1, I2, I3`	indices of the three coordinates that define each PWS mode
`NPORTS`	number of generator and/or load ports
`PMODE, VGR, VGI, ZLR, ZLI`	mode number of port, real and imaginary generator voltage, real and imaginary load impedance (one line for each port)

This data file can be created using a standard text editor; (see the `DIPOLE.ANT`, `ARRAY.ANT`, and `YAGI.ANT` files in the PCAAD user directory for examples of how the geometry files can be written). PWS expansion modes are laid out along the wires starting from the first endpoint at point I1, to the terminals at point I2, and to the second endpoint at point I3. Note that each arm of a PWS expansion mode must be less than a quarter-wavelength long at the operating frequency. The routine computes the currents on the wires, the input impedance at each port, the directivity and gain of the antenna, the radiation efficiency, and the radiation patterns for the antenna.

The routine begins with a dialog box to enter a filename for the wire antenna geometry. The routine then lists some of the parameters of the wire geometry (number of points, number of expansion modes, and the number of feed ports) in three text boxes - these can only be changed by changing the geometry data file. The routine also reads the operating frequency from the data file, but you may enter a different operating frequency, if desired. Because the polarization of an arbitrary wire antenna is not known, E-plane / H-plane patterns and Co-pol / X-pol patterns are not available for this routine, but E-theta and E-phi patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button.

Click the **Compute** button to begin computation of the moment method solution. When this calculation is complete, the gain, directivity, radiation efficiency, port impedances, and mode currents will be listed. At this point, from the **Results** tree, you can plot the specified patterns by clicking the appropriate option in the **Results** tree, or save the patterns to data files. The geometry of the wire antenna may be viewed in three dimensions by clicking the **Show Geometry** item in the **Results** tree. The perspective view may be rotated in elevation and azimuth using the scroll bars at the sides of the graph, and can be adjusted in size by using the zoom scroll bar. After each computation, data is automatically written to a log file called `WIRE.LOG`, located in your PCAAD user directory. This data includes the frequency, wire radius, coordinates of all points on the wire structure, the definition of the PWS expansion modes, the moment method impedance matrix, and the voltage and current vectors.

As in the case of the planar dipole array, this routine computes the input impedance at each port as seen looking into the wire terminals, and does not directly include the series load impedance, if present. Similarly, the power dissipated in the antenna does not include power lost in the series generator impedances. If a port has a load impedance without a generator, however, the power lost in that load is included in the antenna loss. The logic here is that a realistic source will consist of a voltage generator and a series generator impedance, and the power dissipated in the source impedance should not be considered as a loss in the antenna itself. Lumped loads apart from the generators will, however, contribute to antenna loss. Thus an antenna with matched generators, but without separate lumped loads, will have an efficiency of 100%. An antenna having resistive lumped loads (e.g., a loaded dipole) will have an efficiency less than 100%.

Validation
The Yagi-Uda array example described in Section C.7. is used as a validation example for this routine, but with one expansion mode per element. The data file for this antenna is shown below (this file, `YAGI.ANT`, is supplied with PCAAD 7.0):

```
0.3,.25
9
-23.95,0,0
0,0,0
23.95,0,0
```

```
-22.65,0,25.
0.,0.,25.
22.65,0,25.
-22.55,0.,50.
0.,0.,50.
22.55,0.,50.
3
1,2,3
4,5,6
7,8,9
1
2,1.,0.,0.,0.
```

PCAAD 7.0 produced the following results:

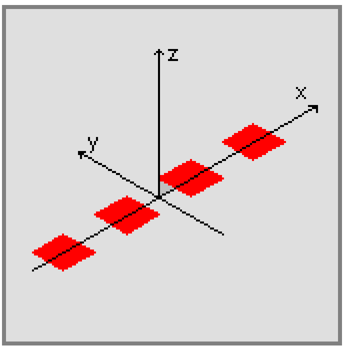
Input impedance	18.6 - j 3.0 Ω
Gain	9.5 dB
Front-to-back ratio	6.6 dB

These results agree with those obtained from the Yagi array example in Section C.7 with one expansion mode per element.

D. The Array Antennas Menu

This set of routines can be used to plot patterns for linear, rectangular planar, and circular planar arrays, to compute the input impedance of an infinite array of printed dipoles, and to plot a grating lobe diagram for planar arrays. Arrays of subarrays or elements with arbitrary patterns, and planar arrays with elements having arbitrary positions, can also be treated, and pattern synthesis can be performed for linear arrays using the Woodward-Lawson method. The array pattern routines are very flexible, allowing you to specify amplitude and phase variations, amplitude and phase errors, and the type of radiating element.

D.1. Uniform Linear Array



This routine is used to plot patterns and compute directivity of a linear array antenna having uniform spacing. You can specify array size, amplitude taper, phase distribution, and element type. Co-pol and cross-pol patterns can be calculated in an arbitrary elevation plane, and can be plotted either separately or together on a polar or rectangular pattern plot, or saved to data files. The routine can also be used to compute the directivity of the array. As indicated in the picture at the top left of the form, the array is assumed to lie along the *x*-axis; if a ground plane is present (depending on the element type), it is positioned below the array parallel to the *x-y* plane. The pattern is computed using the array factor of the array multiplied by the element factor. Mutual coupling effects are not included in this routine. Directivity is computed by numerical integration of the pattern, which can be time consuming for large arrays. The maximum size of the array is limited to 200 elements. This routine uses three additional windows to select the array amplitude distribution, the array phase distribution, and the array element type. These windows are accessed by clicking the small **Select** button to the right of the appropriate text box for amplitude, phase, and element type.

Pattern plots can be made in the E- and H-planes of the array, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Note that E-plane / H-plane patterns are not available when the array elements are vertical monopoles. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button.

The **Array Amplitude Distribution** window allows you to choose from four commonly-used amplitude distributions, or to read amplitude data from a data file:

- **Uniform** — uniform amplitude distribution
- **Chebyshev** — Chebyshev amplitude taper for a specified sidelobe level
- **Taylor** — Taylor amplitude taper for a specified sidelobe level and n-bar parameter
- **Cosine on a pedestal** — cosine on a pedestal distribution of the form $C + (1 - C)\cos(\pi x / L)$
- **Data File** — amplitude data is read from a specified data file

Select one of the five amplitude distribution options by clicking the appropriate button. For the Chebyshev distribution the desired sidelobe level must also be entered as a positive value in dB. The Chebyshev coefficients are computed using the highly accurate and efficient algorithm discussed in reference [18]. The Taylor distribution option requires sidelobe level as well as the n-bar parameter to be entered; the n-bar parameter must be in the range from 2 to 6. The Taylor coefficients are computed using the algorithm of reference [19], which is much more accurate and efficient for large arrays than the null-matching or aperture sampling techniques. The cosine-on-a-pedestal distribution requires entry of the pedestal height, C, in negative dB. Data read from an ASCII data file should be in absolute (not dB) voltage or current form (not power), with one line for each element in the array. If the size of the array is larger than the number of elements in the specified data file, the unspecified element amplitudes will be set to zero. The elements are counted by rows along the x-dimension, from left to right. You also have the option of adding gaussian distributed zero-mean random errors to any amplitude distribution. This is done by specifying the rms value (or standard deviation) of the errors in dB; specifying a value of zero rms error implies no amplitude error. Entering a new value for the rms error will cause the amplitude excitation to be re-computed, and updated in the list box. The excitation amplitudes for the array elements are shown in the list box in the amplitude distribution window, in absolute form (voltage or current amplitudes), and in dB. The scroll bar can be used to scroll through the list of excitations. You also have the option of saving the amplitude distribution to a data file, by clicking the **Save Data** button.

The **Array Phase Distribution** window allows you to choose the phase variation across the array from one of three options, or to read phase data from a data file.

- **Broadside Beam** — phase set to zero on each element
- **Specify Scan Angle** — progressive phase shift to steer beam to a specified scan angle
- **Specify Phase Shift** — progressive phase shift applied
- **Data File** — phase data is read from a specified data file

The **Specify Scan Angle** and **Specify Phase Shift** options require entry of the main beam scan angle, or the interelement phase shift, respectively. Specifying the scan angle for a linear array requires only the elevation angle, while the scan angle for a planar array requires both the elevation angle and the azimuth angle. Once a phase distribution has been selected, the routine will calculate the new set of excitation phases for the array elements, and display them in the list box. The scroll bar can be used to scroll through the list of excitation phases. These quantities will change when the frequency or element spacing is changed from the linear array window. Gaussian distributed zero-mean errors can also be added to the phase distribution by entering a non-zero value for the rms error (standard deviation). Entering a non-zero value causes the phase excitation to be modified, and updated in the list box. The phase excitation data can also be saved in an ASCII data file by clicking the **Save Data** button.

The **Array Element Selection** window allows you to select from one of six different element types, and to select the polarization of the element when possible:

- **Isotropic** — ideal isotropic point source elements
- **Wire Dipole** — thin wire dipole with or without a ground plane
- **Rectangular Waveguide** — rectangular waveguide aperture in a ground plane
- **Circular Waveguide** — circular waveguide aperture in a ground plane
- **Rectangular Microstrip Patch** — rectangular microstrip patch elements
- **Circular Microstrip Patch** — circular microstrip patch elements

Select the array element type by clicking the appropriate button. All but the isotropic element option requires entry of the element dimensions and polarization. The waveguide elements and the microstrip patch elements may be polarized in either the x direction (the plane of the array), or in the y direction (orthogonal to the plane of the array). The wire dipole may be polarized in the x, y, or z (vertical) direction, and may include a ground plane spaced a specified distance below the element. Specify no ground plane by setting the ground plane spacing to zero. The rectangular waveguide is assumed to have a TE_{10} mode distribution, while the circular waveguide is assumed to have a TE_{11} mode distribution. The patch elements are assumed to be operating in the dominant resonant mode.

Validation #1

We first consider the directivity of a single element computed from PCAAD and compared with data from the literature, for each of the possible element types:

Element type	Literature	PCAAD 7.0
Isotropic	0.00 dB [1]	0.00 dB
Dipole (L = λ/2)	2.15 dB [1]	2.2 dB
Dipole, horizontal (L = λ/20, λ/4 above GP)	7.17 dB [1]	7.2 dB
Dipole, vertical (L = λ/20, λ/4 above GP)	6.63 dB [1]	6.6 dB
Rectangular aperture (L = W = 10λ)	30.1 dB [1]	30.0 dB
Circular aperture (radius = 5λ)	29.2 dB [1]	29.1 dB
Rectangular patch (L = 0.328λ, W = 0.219λ)	7.0 dB [8]	7.1 dB
Circular patch (radius = 0.185λ)	7.1 dB [8]	7.1 dB

Validation #2
Consider a five element array of isotropic elements, with 0.4λ spacing, uniform amplitude, and phased to scan at 60°. Reference [1] gives the directivity as 7.0 dB; PCAAD 7.0 gives 7.1 dB.

Validation #3
Consider a 10 element broadside array of isotropic elements with a spacing of λ/2 and a 26 dB Chebyshev amplitude distribution. Element excitations from [1] are compared with results from PCAAD:

Element #	Reference [1]	PCAAD 7.0
1	0.357	0.361
2	0.485	0.489
3	0.706	0.711
4	0.890	0.895
5	1.000	1.000

The excitations for elements 6 through 10 are symmetric with these. The differences in the third decimal place in the above results can be attributed to round off error in the calculations in [1], as carrying through those calculations with five digit accuracy gives exact agreement with the results from PCAAD. The directivity from PCAAD is 9.5 dB, while in [1] an approximate result of 9.6 dB is given.

Validation #4

Consider a 10 element broadside array of isotropic elements with a spacing of 0.5λ and a 25 dB Taylor amplitude weighting with n-bar = 2. Element excitations from [19] are compared with results from PCAAD below. Excitations for elements 6 through 10 are symmetric with these.

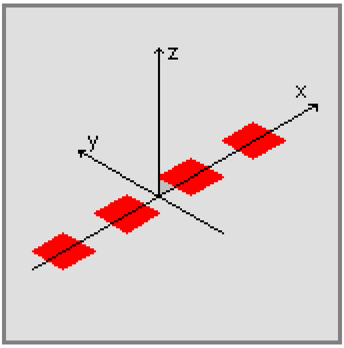
Element #	Reference [19]	PCAAD 7.0
1	0.417	0.417
2	0.528	0.528
3	0.709	0.709
4	0.889	0.889
5	1.000	1.000

Validation #5

Consider a 20 element broadside array of isotropic elements with a spacing of λ/2. If the elements are uniformly excited the directivity of this array is $D_0 = N = 20 =$ 13 dB. If phase or amplitude errors are added to the excitations, the directivity will be reduced according to the formula, $D = D_0 / (1 + \sigma^2)$, where σ is the rms error. Running PCAAD for a rms phase error of 30°, or a rms amplitude error of 3 dB, and averaging over ten trials gives the following results:

Case	σ (rms error)	D (formula)	D PCAAD 7.0
no errors	0	13.0 dB	13.0 dB
phase errors	30°	11.9 dB	11.7 dB
amplitude errors	3 dB	12.3 dB	12.4 dB

D.2. Linear Subarray



This routine is used to plot patterns of a linear array antenna composed of elements having an arbitrary element pattern defined by a data file. This is useful for analyzing arrays of subarrays, or arrays of elements that are not available through the element menu of the linear array routine. For example, this routine can be used to find patterns of an array of elements having a measured element pattern, an array of horn antennas, or an array of subarrays. You can specify array size (number of elements or subarrays), the amplitude taper, and the phase distribution. The element spacing is measured between the centers of adjacent elements (or subarrays). The element pattern is specified only in the plane of the array, and assumed to be constant in the plane orthogonal to the array. For this reason the directivity may not be meaningful, and is not calculated. Without loss of generality, the polarization of the elements or subarrays is assumed to be along the *x*-axis. Pattern plots can be made in the E- and H-planes of the array, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button. As indicated in the picture at the top left of the form, the array is assumed to lie along the *x*-axis; if a ground plane is present (depending on the element type), it is positioned below the array parallel to the *x-y* plane. The pattern is computed using the array factor of the array multiplied by the subarray pattern. Mutual coupling effects are not included in this routine. The maximum size of the array is limited to 200 elements.

This routine uses two additional windows to select the array amplitude distribution, and the array phase distribution. The available amplitude and phase options are the same as those for the linear array module described in Section D.1., and are accessed by clicking the small **Select** button to the right of the appropriate text box for amplitude and phase. The selected amplitude and phase distributions can each be modified with gaussian distributed random errors, and can be saved as data files. The element pattern file is selected with a file dialog box. The element pattern data is assumed to be in the format of (angle in degrees, pattern in dB), with an angle range from -90º to 90°. The step size of the element data file is arbitrary – numerical interpolation is used when necessary. Pattern files generated by other PCAAD routines follow this format, allowing other PCAAD routines to be used to generate element patterns for direct use in this routine. For example, a horn antenna module can be used to generate a pattern file, which can then be used in this routine to find the pattern of an array of horns.

Validation
Consider an H-plane broadside array of 8 half-wave dipoles in free-space having a spacing of 0.6λ, and a uniform amplitude distribution. The pattern can be calculated using the linear array analysis routine, which gives a 3 dB beamwidth of 10.6°.

This same array can also be considered as a 4 element array, where each element now consists of a two-element H-plane subarray of two dipoles with a spacing of 0.6λ. The subarray pattern can be calculated using the linear array routine, and saved as a data file. This data file can then be used in the linear subarray routine, with N = 4 subarrays, and a spacing of 1.2λ between subarrays. The computed pattern and beamwidth agrees with the pattern obtained from the linear array routine. The pattern is shown below.

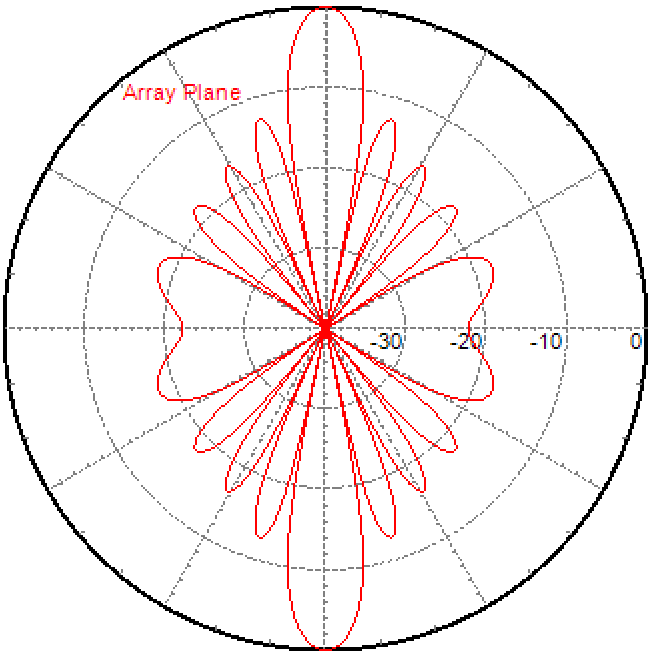
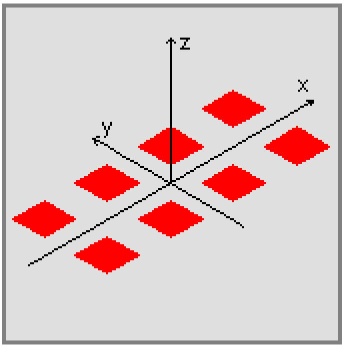


Figure 4. Pattern of an array consisting of four two-element H-plane dipole subarrays.

D.3. Uniform Rectangular Array



This routine is used to plot patterns and compute the directivity of a rectangular planar array antenna having uniform spacing. You can specify array size, amplitude taper, phase distribution, and element type. The number of elements and the element spacing (center-to-center) in each plane can be specified separately. Pattern plots can be made in the E- and H-planes of the array, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Note that E-plane / H-plane patterns are not available when the array elements are vertical monopoles. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button. The directivity of the array can also be calculated. As indicated in the picture at the top left of the form, the array is assumed to lie in the *x-y* plane; if a ground plane is present (depending on the element type), it is positioned below the array parallel to the *x-y* plane. The pattern is computed using the array factor of the array multiplied by the element factor. Mutual coupling effects are not included in this routine. Directivity is computed by numerical integration of the pattern, which can be very time consuming for large arrays. The maximum size of the array is limited to 200 elements in each dimension.

As indicated in the picture at the top left of the form, the array is assumed to lie in the *x-y* plane; if a ground plane is present (depending on the element type), it is positioned below the array parallel to the *x-y* plane. The angle of the grid can be adjusted to treat arrays having either a rectangular or a triangular grid. The grid angle is 90° for a rectangular grid; for an equilateral triangular grid the grid angle is 60°, and the relation between the element spacings in the *x* and *y* directions is

$$d_y = d_x \sin\alpha = \frac{\sqrt{3}}{2} d_x .$$

Like the linear array routine, this routine uses three additional windows to select the **Array Amplitude Distribution**, the **Array Phase Distribution**, and the **Array Element Selection**. These three windows are described in Section D.1.

Validation #1

Consider a 2×2 broadside array of isotropic elements, with λ/2 spacings and uniform amplitude excitation. An exact expression for the directivity of broadside planar arrays of isotropic sources is given in [5]. This expression gives a directivity of 7.08 dB for this array; PCAAD gives 7.1 dB.

This routine was also validated by checking several special cases of single elements and linear arrays with the linear array routine. Planar array patterns were also checked for the correct scan angles and sidelobes.

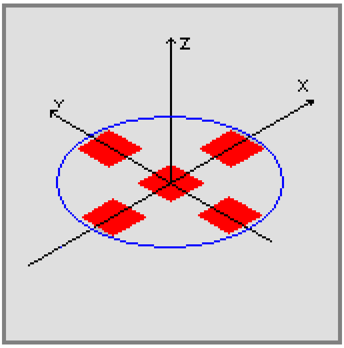
Validation #2

Consider a 4×4 planar array of x-polarized rectangular microstrip patches, with a triangular grid of 60°, a spacing in the x-direction of 0.5774λ, and a spacing in the y-direction of 0.5λ. The patch length and width are 0.3λ. PCAAD 7.0 gives the following results:

Quantity	PCAAD 7.0
3 dB beamwidth in ϕ=0° plane	21.7°
3 dB beamwidth in ϕ=45° plane	22.7°
3 dB beamwidth in ϕ=90° plane	25.1°
Directivity	18.0 dB

These results should be similar to those obtained with an array using a rectangular grid and filling the same aperture area. For example, a patch array with a rectangular grid having 8 elements in the x-direction with a spacing of 0.289λ (= 4 × 0.5774λ / 8), and 4 elements in the y-direction with a spacing of 0.5λ, yields a directivity of 18.1 dB.

D.4. Uniform Circular Array



This routine is used to plot patterns and compute the directivity of a circular planar array. You can specify the radius of the array, element spacing (center-to-center), a radial amplitude taper, and the element type. The grid spacing of the elements is rectangular, and the routine calculates the number of elements that will approximately fit within a circular area of the specified radius. The amplitude taper is applied linearly (in dB) in the radial direction, assuming 0 dB at the center of the array, and an edge taper as specified. The element type is selected by clicking the small **Select** button to the right of the text box for element type. Pattern plots can be made in the E- and H-planes of the array, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Note that E-plane / H-plane patterns are not available when the array elements are vertical monopoles. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type s**elect button. The directivity of the array can also be calculated. As indicated in the picture at the top left of the form, the array is assumed to lie in the *x-y* plane; if a ground plane is present (depending on the element type), it is positioned below the array parallel to the *x-y* plane. The pattern is computed using the array factor of the array multiplied by the element factor. Mutual coupling effects are not included in this routine. Directivity is computed by numerical integration of the pattern, which can be very time consuming for large arrays. There is no limit to the maximum size of the array, but the directivity calculation will be unacceptably time consuming for more than about 100 elements.

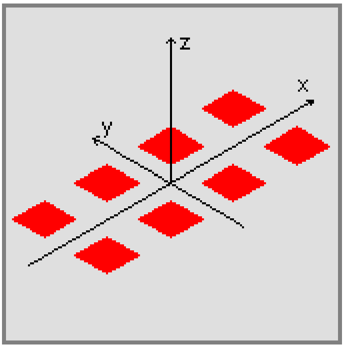
Validation #1

First consider a circular planar array with an outer radius of 1λ and an element spacing of 0.6λ, with isotropic elements. This results in a uniform rectangular grid of 3×3 elements, for which the circular array routine gives a directivity of 11.6 dB, and a half-power beamwidth of 30.6°. The rectangular planar array routine can be used for the same geometry, and gives identical results.

Validation #2

Next consider a circular planar array with an outer radius of 5λ and an element spacing of 0.5λ, with rectangular microstrip patches of size 0.3λ × 0.3λ. This results in an array of 317 elements. For a uniform amplitude distribution, PCAAD 7.0 gives a directivity of 30.1 dB for this array. Using the formula $D = 4\pi^2 R^2 / \lambda^2$ gives a value of 29.9 dB.

D.5. Arbitrary Planar Array



This routine is used to plot patterns and compute directivity of a planar array of elements having arbitrary locations in the *x-y* plane, and arbitrary excitations. This can be useful for treating arrays that do not conform to the linear or planar apertures of the other array routines in PCAAD. A data file is used to specify element coordinates, excitation amplitude, and excitation phase. You can specify the element type from the same selection of elements available in the other array routines. Pattern plots can be made in the E- and H-planes of the array, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. Note that E-plane / H-plane patterns are not available when the array elements are vertical monopoles. Patterns can be plotted in polar, rectangular, or volumetric (3-D) form, and patterns can be saved as data files. Select the pattern type and parameters with the **Pattern Type** select button. The directivity of the array can also be calculated. As indicated in the picture at the top left of the form, the array is assumed to lie in the *x-y* plane; if a ground plane is present (depending on the element type), it is positioned below the array parallel to the *x-y* plane. The pattern is computed using the array factor of the array multiplied by the element factor. Mutual coupling effects are not included in this routine. Directivity is computed by numerical integration of the pattern, which can be very time consuming for large arrays. The maximum size of the array is limited to 200 elements in each dimension.

The element data file is selected with a file dialog box. The data file should have the format of (*x*-coord in cm, *y*-coord in cm, amplitude, phase in degrees), with one line for each element. The amplitude data is in absolute voltage or current form (not in dB). The routine uses an additional window to select the array element type, accessed by clicking the **Select** button to the right of the text box.

Validation

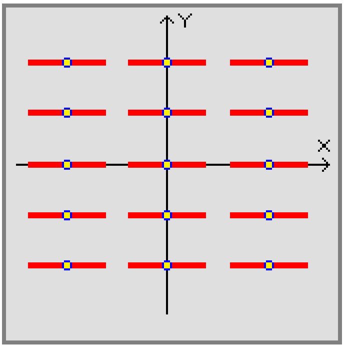
The 4×4 patch array with a triangular grid that was treated in ***Validation #2*** of Section D.3 was used here as well. The data file listing the element coordinates and excitations for this array is listed below (this file, `ARRAY4X4.DAT`, is supplied with PCAAD 7.0):

```
0.      0.0  1.0   0.0
0.5774  0.0  1.0   0.0
1.154   0.0  1.0   0.0
1.732   0.0  1.0   0.0
0.2887  0.5  1.0   0.0
0.8661  0.5  1.0   0.0
```

```
1.444   0.5  1.0   0.0
2.0209  0.5  1.0   0.0
0.      1.0  1.0   0.0
0.5774  1.0  1.0   0.0
1.154   1.0  1.0   0.0
1.732   1.0  1.0   0.0
0.2887  1.5  1.0   0.0
0.8661  1.5  1.0   0.0
1.444   1.5  1.0   0.0
2.0209  1.5  1.0   0.0
```

Results from this routine are in agreement with those obtained in Section D.3.

D.6. Infinite Printed Dipole Array



This routine computes the input impedance of an infinite array of dipole antennas printed on a grounded dielectric substrate using the full-wave solution described in reference [12]. It uses the exact Green's function for the dielectric substrate, and includes all mutual coupling effects. It can be used to treat dipoles in free-space above a ground plane by using a substrate dielectric constant of 1.0 The number of piecewise sinusoidal expansion modes on each dipole can also be chosen; this should be an odd number since the dipoles are assumed to be center-fed. One to three modes is usually sufficient for accurate results.

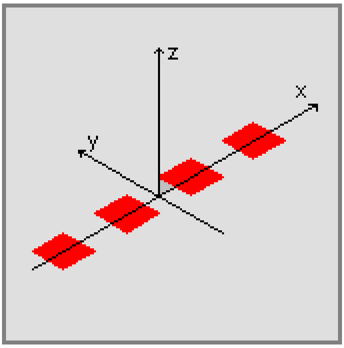
The required array parameters include the element spacings in the E and H planes, the dipole length and width, and the substrate thickness and dielectric constant. Input impedance data will be calculated for a fixed azimuth scan angle, and for elevation angles from zero to 90°. You must enter both the azimuth angle and the elevation step size. Since this is a full-wave calculation, it can be time consuming on slow computers, so it is helpful to not specify too small of a step size, to avoid unreasonably long run times. The input impedance at each elevation angle is listed in the list box as it is computed. Scroll through the list using the scroll bar. You also have the option, from the **Results** tree, of plotting the impedance data on a Smith chart plot or a VSWR/Return Loss plot, or saving the data to a file.

Validation

Consider an infinite array with an E- and H-plane spacing of 5 cm, a dipole length of 3.9 cm, a dipole width of 0.02 cm, a substrate with a thickness of 1.9 cm and a dielectric constant of 2.55, and a frequency of 3 GHz. This example corresponds to the first case considered in [12]. For $\phi = 0$, with three expansion modes per dipole, we obtain the following results:

Theta	Zin - Reference [12]	Zin - PCAAD 7.0
0°	74.8 + j 2.7 Ω	74.8 + j 2.8 Ω
30°	73.3 + j 37.3 Ω	73.4 + j 37.3 Ω
60°	40.7 + j 1.9 Ω	40.7 + j 2.0 Ω
90°	0.10 + j 55.7 Ω	0.10 + j 55.7 Ω

D.7 Linear Array Pattern Synthesis



This routine is used to synthesize the pattern of a uniform linear array using the Woodward-Lawson method [1], [2]. You can specify array size, element spacing, and frequency. The pattern values to be synthesized are specified at discrete pattern angles according to the Woodward-Lawson algorithm. The amplitude and phase excitation for each element are computed. Planar patterns may be plotted for the array plane, or a volumetric (3-D) pattern may be plotted. The array elements are assumed to be isotropic sources. The pattern is computed using the array factor of the array; mutual coupling effects are not included. A property of the Woodward-Lawson synthesis method is that it will provide a pattern that exactly matches the desired pattern at the sample angles. The maximum size of the array is limited to 200 elements.

Begin by entering the operating frequency, the number of elements in the array, and the element spacing. The routine will calculate discrete angles where the pattern will be sampled, and list these in the scroll box. The desired pattern value (in dB) can then be filled in the text box for each angle. Use the scroll bar to scroll through the set of samples. Select the pattern type and parameters with the **Pattern Type** select button. The routine will then compute the required amplitude and phase necessary to reproduce the desired pattern at the sample values, list these values in a scroll box, and compute the resulting synthesized pattern. From the **Results** tree you can plot the patterns of the array by clicking the appropriate option, or save the patterns to data files. The calculated pattern is not normalized (other PCAAD routines normalize the maximum pattern value to 0 dB), in order to compare the synthesized pattern with the specified pattern values. For this reason, it may be necessary to adjust the maximum value of the pattern plot to view the entire pattern. When plotting the pattern of sample points, it may be helpful to set the **Line Style** to **Data Points Only**, via the **Plot Options** routine.

Validation

Consider the synthesis of a sector pattern with an 11 element array having 0.5λ spacing. The sector pattern is defined as 0 dB between the angles of -45° and 45°, and -60 dB elsewhere. The following pattern values are entered at the sample points in the routine:

```
±65.4°        -60 dB
±46.7°        -60 dB
±33.1°          0 dB
±21.3°          0 dB
```

```
±10.5°          0 dB
  0.0°          0 dB
```

The resulting synthesized pattern is plotted below. Note that the pattern values match those listed above.

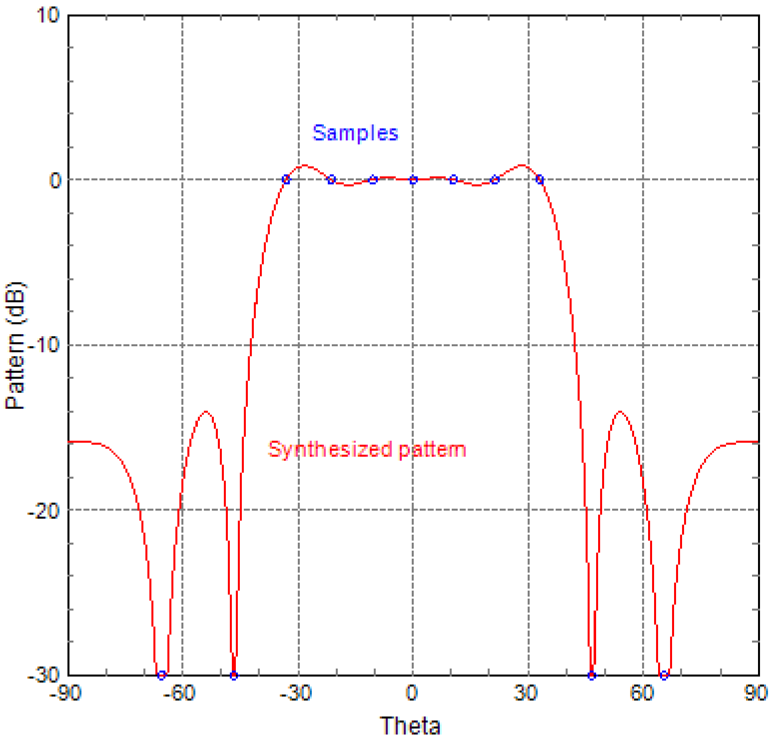
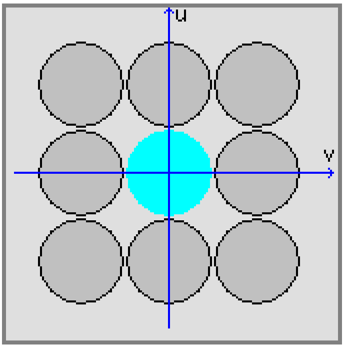


Figure 5. Synthesized sector pattern for an 11 element array. The specified pattern samples are shown as blue circles.

D.8. Grating Lobe Diagram



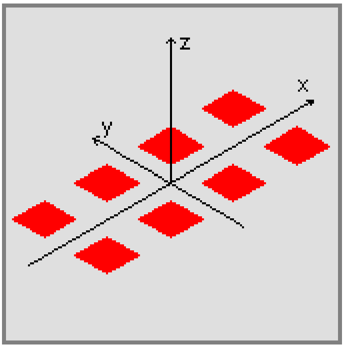
This routine plots a grating lobe diagram for a periodic planar array antenna, including the optional plotting of surface wave circles. A grating lobe diagram can be very helpful for determining the presence and location of grating lobes, and the movement of grating lobes with scan angle. In conjunction with surface wave circles, the grating lobe diagram can be used to predict the location of scan blindness angles in printed array antennas, as discussed in reference [12], or other arrays having a structure that supports guided waves. This routine provides a zoom control to adjust the size of $u-v$ space that is plotted, and a convenient readout in $u-v$ and $\theta-\phi$ coordinates of the mouse cursor when it is positioned in the visible space region of the grating lobe diagram.

Begin by entering the array operating frequency, and the element spacings (center-to-center) in the horizontal and vertical directions. Next, enter the array grid angle. A grid angle of 90º corresponds to a rectangular array, while a grid angle of 60º corresponds to an array with a hexagonal grid. (For a hexagonal grid, the maximum element spacings with no grating lobes in visible space are 0.5774λ (horizontal), 0.5λ (vertical)). If you want to plot surface wave circles, enter a non-zero value for the normalized surface wave propagation constant; this can be computed using the **Surface Waves** routine under the **Transmission Lines** menu. Click the **Plot Circles** button to draw the grating lobe circles; the plot will automatically be updated if new data is entered, or if the zoom scroll bar is used. By default, the routine plots a segment of the $u = \sin\theta\cos\phi$, $v = \sin\theta\sin\phi$ plane from $-3 < u < 3$ and $-3 < v < 3$. The zoom scroll bar near the top of the window can be used to adjust this range. The visible space region of the grating lobe diagram occurs for $u^2 + v^2 < 1$, and is colored in light gray on the plot. The grating lobe circles are drawn in blue, and the surface wave circles are drawn as red circles. Moving the mouse cursor through the visible space region of the diagram will cause the readout box near the middle of the window to give a display of the cursor position in *u*-*v* space, as well as the corresponding $\theta-\phi$ scan angle. In this way, you can easily determine the scan angle at which a grating lobe enters visible space, or the angle at which a scan blindness will occur. More accuracy can be obtained by zooming in on the visible space region by using the zoom scroll bar.

Validation

Consider an example from [12], for an array of printed dipoles with E- and H-plane spacings of $\lambda/2$, on a dielectric substrate with $\varepsilon_r = 12.8$ and a thickness of 0.06λ. The array grid is rectangular. The PCAAD 7.0 **Surface Waves** routine gives a normalized surface wave propagation constant of 1.285816. Plotting the grating lobe diagram shows that no grating lobes will be present in visible space. Using the cursor to move to the intersection of a surface wave circle and the E-plane scan plane ($v = 0$) indicates a scan blindness will occur at 45°, in close agreement with the result of 46° from the full-wave solution in [12].

D.9. Effect of Random Array Errors



The effect of random amplitude and phase errors on the pattern of an array is to raise the sidelobe level and decrease the gain. This routine computes the average sidelobe level and average loss in gain for an array having random amplitude and phase errors. The routine also includes the effect of failed elements in an array, and the quantization phase error and quantization lobe level due to phase shifter quantization. This routine is based on results from [25].

Begin by entering the rms amplitude error, in +dB, followed by the rms phase error, in degrees. Each of these errors is assumed to have a normal distribution with zero mean. The phase error may be positive or negative. If desired, also enter the percentage of elements in the array considered to have failed (this value should be less than 100%). Click the **Compute** button to calculate the resulting average sidelobe level, and loss in gain, due to the entered errors and failed elements.

Note that the average sidelobe level is given relative to isotropic. The array directivity must be known to convert this value to a sidelobe level relative to the main beam of the array. For example, if the average sidelobe level due to errors is 5 dBi, and the error-free directivity of the array is 23 dB, then the sidelobe level relative to the main beam would be 5 – 23 = -18 dB. Note that this is a residual sidelobe level caused by errors, in contrast to the design sidelobe level that is determined by the amplitude taper. The resulting sidelobe level will be the larger of these two levels. Thus, for the example above, if the array were designed for -13 dB sidelobes, the average error sidelobe level of -18 dB would probably not be noticeable. If, however, the array were designed for -25 dB sidelobes, the actual sidelobe level in the presence of errors would be in the range of -18 dB.

A separate frame is provide for phase shifter quantization effects. Use the list box to enter the number of bits for the phase shifters. Once a value is selected, the peak phase error (+/- degrees) will be displayed, along with the rms phase error (+/- degrees). The rms phase error value is also transferred to the phase error box in the excitation errors frame, for convenience. The level of the quantization lobe is also displayed – note that this value is given relative to the main beam of the array. The quantization lobe is due to the periodic phase error that is introduced when digital phase shifters are used in an array. This lobe is often higher than nearby sidelobes, especially when a small number of phase shifter bits are used. See [25]_for techniques to reduce the effects of quantization lobes. Setting the phase shifter bits to **Off** turns off the phase shifter calculation functions.

Validation

The average sidelobe level due to amplitude and phase errors, relative to isotropic, is given by,

$$\overline{SLL_i} = \sigma_\Delta^2 + \sigma_\phi^2 ,$$

where $\sigma_\Delta = 10^{\sigma_\Delta(dB)/20} - 1$ is the rms amplitude error, and σ_ϕ is the rms phase error (in radians). Direct calculations shows that a 10° rms phase error leads to an average isotropic sidelobe level of -15.2 dB, and a 1.5 dB rms amplitude error leads to an average isotropic sidelobe level of -14.5 dB. PCAAD gives -15.2 dB, and -14.5 dB, respectively, for these two cases. If 50% of the array elements have failed, the gain is seen to be reduced by 3 dB, as expected.

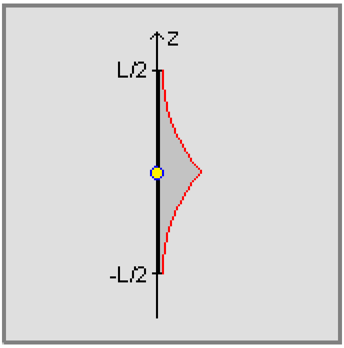
E. The Aperture Antennas Menu

These routines are used for the analysis of various aperture antennas. Patterns and directivity can be calculated for line sources, rectangular and circular apertures, E and H-plane sectoral horns, pyramidal horns, corrugated pyramidal horns, conical horns, and corrugated conical horns. New in PCAAD 7.0 are fast and accurate analysis routines for parabolic reflectors, offset parabolic reflectors, and spherical reflectors, based on the Jacobi-Bessell expansion technique described in reference [29]. These routines calculate patterns, directivity, and aperture efficiencies, and allow feed displacements for limited beam scanning. Prime focus parabolic reflectors can also treated using an idealized feed pattern of the $\cos^n\theta$ form, providing aperture efficiency and directivity [1]. Also new is a routine to calculate the beam efficiency of a variety of aperture antennas.

Waveguide horns are analyzed by the usual assumption of a waveguide field distribution in the aperture plane multiplied by a quadratic phase factor. For sectoral and pyramidal horns this results in closed-form expressions for patterns and directivity in terms of Fresnel integrals [1], [2]. No such results are available for the conical or corrugated conical horns, so these cases are treated using a fairly efficient numerical integration technique.

The phase center is calculated for sectoral, pyramidal, corrugated pyramidal, diagonal, conical, and corrugated conical horn antennas using the derivative method with numerical integration, described in reference [28]. The phase center of an antenna is defined as the apparent center (along the axis of the main beam) of the circular far-zone phase fronts. For an ideal point source, the phase center is located at the point source. For small apertures with uniform phase, the phase center is located at the center of the aperture. For antennas with non-uniform phase, however, the phase center may be behind or in front of the aperture, and is generally different for different azimuthal planes. In many cases a unique phase center cannot be defined. The phase center location calculated in PCAAD may not be accurate for horns with very wide angles or very large phase errors

E.1. Line Source



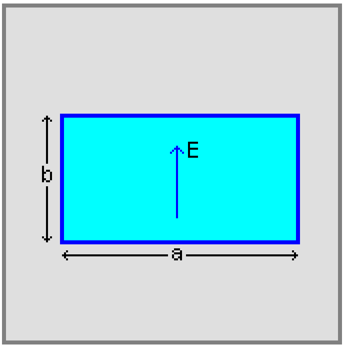
This routine calculates the pattern and directivity for a traveling wave electric line source antenna on the z-axis. Examples of such antennas include long wire antennas, dielectric rod antennas, electrically long slot antennas, and leaky wave antennas. The phase constant and attenuation constant can be specified, and the antenna can be fed at either the end or at the center of the line. A $\sin\theta$ element pattern factor can also be included, if desired. Patterns are computed using the closed-form expressions found in reference [1]. Directivity is also calculated using closed-form expressions.

Begin by entering the frequency, line source length, and phase and attenuation constants. Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to calculate the patterns and directivity. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation

Consider a traveling wave end-fed wire antenna with a length of 5λ. The phase constant will be close to 360°/λ, and the attenuation may be neglected. Since this is a wire antenna, a $\sin\theta$ factor should be used. Reference [1] gives a beam maximum angle of 22.0° from the axis of the wire, in agreement with the pattern calculated by PCAAD. The free-space directivity from [1] is 10.7 dB, also in agreement with PCAAD.

E.2. Rectangular Aperture



This routine computes the patterns and directivity of a rectangular aperture antenna having a uniform phase distribution and either uniform or cosine tapered amplitude distributions in the E- and H-planes. The patterns are computed using closed-form expressions from references [1], [2]. For accuracy for small apertures, the directivity is calculated by numerical integration when the aperture is smaller than 10λ on a side. For electrically large apertures the usual directivity approximation of $4\pi A/\lambda^2$ (with the appropriate aperture efficiency) is used. The aperture is assumed to be located in an infinite ground plane, polarized in the y-direction, and the radiation is assumed to be one-sided. This analysis assumes an equivalent magnetic current only, and so does not include a $(1+\cos\theta)$ obliquity factor, in contrast to the horn antenna analyses.

Begin by entering the frequency, and the E-plane and H-plane aperture dimensions. Then select the amplitude taper using the pull-down menu. You may choose to have either a uniform or a cosine taper in either of the two dimensions of the aperture (a TE_{10} waveguide mode corresponds to uniform in y, cosine in x). Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to compute the patterns and directivity. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

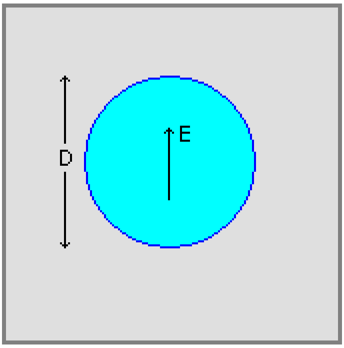
Validation #1

An open-ended X-band waveguide has an E-plane aperture dimension of 1.016 cm, and an H-plane aperture dimension of 2.286 cm. At 10 GHz, the linear array routine of PCAAD, with one waveguide element in the array, gives a directivity of 6.3 dB. The rectangular aperture routine, with a uniform amplitude taper in the E-plane and a cosine taper in the H-plane, gives a directivity of 6.3 dB.

Validation #2

A rectangular array of 24 x 24 microstrip patches, with lengths and widths of 0.3λ, element spacings of 0.5λ, and uniform amplitude and phase distributions, yields a directivity of 32.6 dB (using the PCAAD planar array routine). The rectangular aperture routine, for an aperture of 12λ x 12λ with uniform amplitude tapers in both directions, gives a directivity of 32.6 dB.

E.3. Circular Aperture

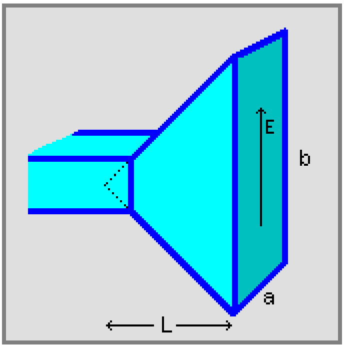


This routine computes the patterns and directivity of a circular aperture antenna having a uniform phase distribution and either uniform or a parabolic tapered amplitude distributions in the radial plane. The patterns are computed using closed-form expressions from references [1], [2]. For accuracy for small apertures, the directivity is calculated by numerical integration when the aperture is smaller than 10λ in diameter. For electrically large apertures the usual directivity approximation of $4\pi A/\lambda^2$ (with the appropriate aperture efficiency) is used. The aperture is assumed to be located in an infinite ground plane, polarized in the y-direction, and the radiation is assumed to be one-sided. This analysis assumes an equivalent magnetic current only, and so does not include a $(1+\cos\theta)$ obliquity factor, in contrast to the horn antenna analyses.

Begin by entering the frequency, and the aperture diameter. Then select the amplitude taper using the pull-down menu. You may choose to have either a uniform or a parabolic taper in the radial direction (the parabolic taper has a maximum at the center of the aperture, and is zero at the edge). Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to calculate the patterns and directivity. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation
A circular planar array of diameter 10λ, with microstrip patches having lengths and widths of 0.3λ, element spacings of 0.5λ, and uniform amplitude and phase distributions, yields a directivity of 30.1 dB (using the PCAAD circular planar array routine). The circular aperture routine, for an aperture of 10λ diameter and a uniform amplitude taper, gives a directivity of 30.0 dB.

E.4. E-plane Sectoral Horn



This routine computes the patterns and directivity of an E-plane sectoral horn antenna, using closed-form expressions from reference [1]. The directivity expression has been corrected according to reference [17]. The phase center, for both principal planes, is also computed. The phase center is measured back from the aperture, toward the apex of the horn.

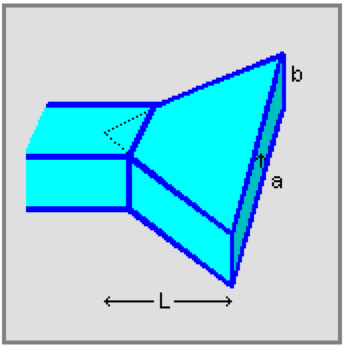
Begin by entering the frequency, the E-plane aperture dimension, the H-plane aperture dimension, and the axial length of the horn. This length is the distance from the imaginary apex of the horn to the mouth of the horn (not the slant length). Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to calculate the patterns and related antenna parameters. The routine prints out the maximum phase error at the edge of the aperture (relative to the center of the aperture), the optimum E-plane aperture dimension, the directivity of the horn, and the E- and H-plane phase centers. The optimum aperture dimension is the dimension that will result in maximum directivity for a horn of the same length. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation

Consider an E-plane sectoral horn at 3 GHz with an E-plane aperture dimension of 27.5 cm, an H-plane aperture dimension of 5 cm, and an axial length of 60 cm. Results for this example can be found in [1], and are compared with results from PCAAD below:

Quantity	Reference [1]	PCAAD 7.0
Max. phase error	56.7°	56.7°
Directivity	11.1 dB	11.1 dB
H-plane pattern at 60°	-5 dB (approx)	-4.1 dB

E.5. H-plane Sectoral Horn



This routine computes the patterns and directivity of an H-plane sectoral horn antenna, using closed-form expressions from reference [1]. The phase center, for both principal planes, is also computed. The phase center is measured back from the aperture, toward the apex of the horn.

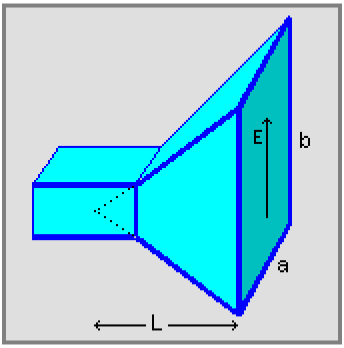
Begin by entering the frequency, the E-plane aperture dimension, the H-plane aperture dimension, and the axial length of the horn. This length is the distance from the imaginary apex of the horn to the mouth of the horn (not the slant length). Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to calculate the patterns and related antenna parameters. The routine prints out the maximum phase error at the edge of the aperture (relative to the center of the aperture), the optimum E-plane aperture dimension, the directivity of the horn, and the E- and H-plane phase centers. The optimum aperture dimension is the dimension that will result in maximum directivity for a horn of the same length. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation

Consider an H-plane sectoral horn at 3 GHz with an E-plane aperture dimension of 2.5 cm, an H-plane aperture dimension of 55 cm, and an axial length of 60 cm. Results for this example can be found in [1], and are compared with results from PCAAD below:

Quantity	Reference [2]	PCAAD 7.0
Max. phase error	226.9°	226.9°
Directivity	8.76 dB	8.8 dB
E-plane pattern at 60°	-3.5 dB (approx)	-3.2 dB
H-plane pattern at 30°	-15 dB (approx)	-15.7 dB

E.6. Pyramidal Horn



This routine computes the patterns and directivity of a pyramidal horn antenna, using closed-form expressions from reference [1]. For horns with small apertures, accuracy is improved by computing the directivity by numerical integration of the pattern. The phase center, for both principal planes, is also computed.

Begin by entering the frequency, the E and H-plane aperture dimensions, and the axial lengths of the horn in the E and H planes. The axial lengths are the distances from the imaginary apex of the horn in the E and H planes to the mouth of the horn (not the slant lengths). Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to compute the patterns and related antenna parameters. The routine prints out the maximum phase errors at the edges of the aperture (relative to the center of the aperture), the optimum aperture dimensions, the directivity of the horn, and the E- and H-plane phase centers. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation #1
Consider a pyramidal horn at 3 GHz with an E-plane aperture dimension of 27.5 cm, an H-plane aperture dimension of 55 cm, and an axial length of 60 cm. Results for this example can be found in [1], and are compared with results from PCAAD below:

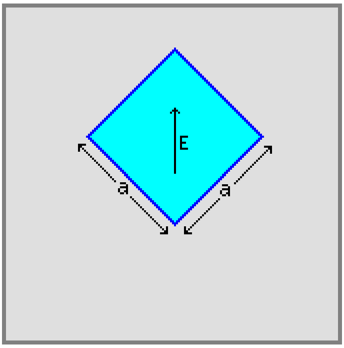
Quantity	Reference [1]	PCAAD 7.0
Max. phase error (E-plane)	56.7°	56.7°
Max. phase error (H-plane)	226.9°	226.9°
Directivity	18.8 dB	18.8 dB

Validation #2
Consider a pyramidal horn at 3.333 GHz with an E-plane aperture dimension 24 cm, an H-plane aperture dimension of 32.41 cm, an E-plane axial length of 40.41 cm, and an H-plane axial length of 44.59 cm. Reference [17] gives a directivity of 18.6 dB for this example; PCAAD gives 18.5 dB.

Validation #3

A standard gain horn has an E-plane aperture dimension of 8.3 cm, an H-plane aperture dimension of 10.2 cm, an E-plane axial length of 22.7 cm, and an H-plane axial length of 24.1 cm. At 24 GHz, the measured gain is 24.7 dB; PCAAD gives a directivity of 24.7 dB. Comparisons with measurements of other standard gain horns typically are in agreement to within about 0.1 dB.

E.7. Diagonal Horn

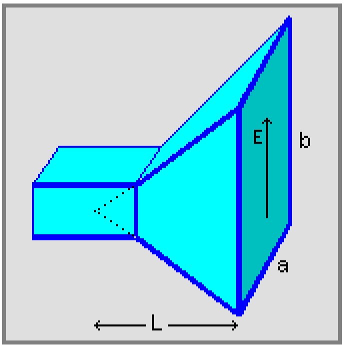


The diagonal horn antenna has a square aperture with the exciting electric field oriented along a diagonal axis. The main beam of the diagonal horn has circular symmetry, and the principal plane patterns have low sidelobes, with no cross-polarization. Further discussion of the diagonal horn antenna can be found in [27].

Begin by entering the frequency, the (square) aperture dimension, and the axial length of the horn. Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to compute the patterns and related antenna parameters. The routine prints out the maximum phase error at the edges of the aperture (relative to the center of the aperture), the directivity of the horn, and the E- and H-plane phase centers (which are always identical). The phase center is measured back from the aperture, toward the apex of the horn. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation
A square diagonal horn with a width of 12.7 cm, and a very long length, is described in [27]. At 16.5 GHz the 3 dB beamwidth is given as 8.5° in both principal planes and the diagonal planes. PCAAD gives a 3 dB beamwidth of 8.3°. Reference [27] lists the aperture efficiency of the diagonal horn as 81% which, given the aperture area, yields a directivity of 27.0 dB. PCAAD gives 27.0 dB. The patterns show relatively high cross-polarization lobes of -15 dB in the diagonal planes.

E.8. Corrugated Pyramidal Horn



This routine computes the patterns and directivity of a corrugated pyramidal horn antenna, using closed-form expressions from reference [1]. For horns with small apertures, accuracy is improved by computing the directivity by numerical integration of the pattern. The phase center, for both principal planes, is also computed.

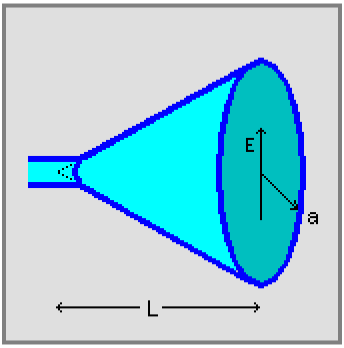
Begin by entering the frequency, the E and H-plane aperture dimensions, and the axial lengths of the horn in the E and H planes. The axial lengths are the distances from the imaginary apex of the horn in the E and H planes to the mouth of the horn (not the slant lengths). Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to compute the patterns and related antenna parameters. The routine prints out the maximum phase errors at the edges of the aperture (relative to the center of the aperture), the optimum aperture dimensions, the directivity of the horn, and the E- and H-plane phase centers. The phase center is measured back from the aperture, toward the apex of the horn. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation

A corrugated pyramidal horn has E- and H-plane aperture dimensions of 24.2 cm, and E- and H-plane axial lengths of 57.6 cm. Reference [21] provides measured 3 dB beamwidths versus frequency, along with independent calculations. This data is compared with results from PCAAD below:

Frequency (GHz)	Measured Beamwidth [21]	Calculated Beamwidth [21]	PCAAD Beamwidth
4.5	18°	19.3°	19.2°
6.0	15°	14.9°	14.8°
7.2	13°	12.8°	12.7°

E.9. Conical Horn



This routine computes the patterns and directivity of a conical (TE_{11} mode) horn antenna. The principle plane patterns are computed using an efficient numerical integration algorithm that includes the quadratic phase error term. The phase center, for both principal planes, is also computed.

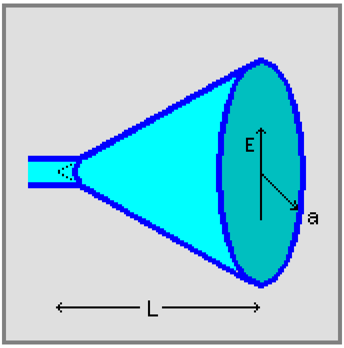
Begin by entering the frequency, the aperture radius, and the axial length of the horn. This length is the distance from the imaginary apex of the horn to the mouth of the horn (not the slant length). Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to compute the patterns and related antenna parameters. The routine prints out the maximum phase error at the edge of the aperture (relative to the center of the aperture), the directivity of the horn, and the E- and H-plane phase centers. The phase center is measured back from the aperture, toward the apex of the horn. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation

Consider a conical horn at 5 GHz with an aperture radius of 12 cm and an axial length of 48.6 cm. Results from reference [4] are compared with PCAAD:

Quantity	Reference [4]	PCAAD 7.0
Max. phase error	86.4°	88.9°
Directivity	20.4 dB	20.3 dB
E-plane pattern at 20°	-13.4 dB	-12.9 dB
H-plane pattern at 20°	-15.0 dB	-14.8 dB

E.10. Corrugated Conical Horn



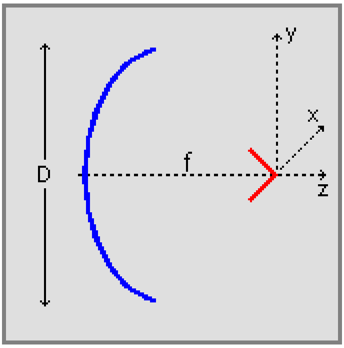
This routine computes the patterns and directivity of a corrugated conical (HE_{11} mode) horn antenna. The principle plane patterns are computed using an efficient numerical integration algorithm that includes the quadratic phase error term. The phase center, for both principal planes, is also computed.

Begin by entering the frequency, the aperture radius, and the axial length of the horn. This length is the distance from the imaginary apex of the horn to the mouth of the horn (not the slant length). Select the pattern type and parameters with the **Pattern Type** select button. Click the **Compute** button to compute the patterns and related antenna parameters. The routine prints out the maximum phase error at the edge of the aperture (relative to the center of the aperture), the directivity of the horn, and the E- and H-plane phase centers (which are always identical). The phase center is measured back from the aperture, toward the apex of the horn. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

Validation
Consider a corrugated conical horn at 5 GHz with an aperture radius of 12 cm and an axial length of 48.6 cm. Results from reference [4] are compared with PCAAD:

Quantity	Reference [4]	PCAAD 7.0
Max. phase error	86.4°	88.9°
Directivity	19.9 dB	19.4 dB
E-plane pattern at 17.5°	-10 dB	-9.9 dB
H-plane pattern at 17.5°	-10 dB	-10.3 dB

E.11. Parabolic Reflector (Approximate Model)



This routine analyzes the performance of a prime-focus parabolic reflector antenna, under the assumption that the feed antenna has a rotationally symmetric power pattern that can be approximated as $\cos^n \theta$. In this case, simple (but exact) expressions can be obtained for the spillover and taper efficiencies, as discussed in reference [1]. The effect of surface roughness can also be included.

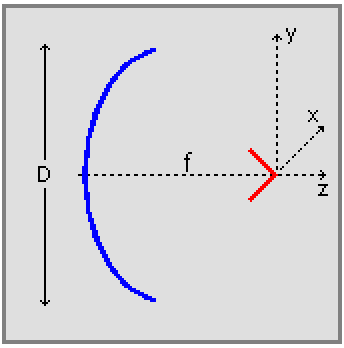
Begin by entering the frequency, the f/D ratio, the dish diameter, and the rms surface roughness. The surface roughness dimension has a default value of zero. Next, specify the feed pattern in one of three forms: enter either the 3 dB beamwidth, the 10 dB beamwidth, or the actual value of $n = 2$, 4, 6, or 8 for a power pattern of the form $\cos^n \theta$. If you specify a beamwidth, the routine will calculate the closest value of n that approximates this beamwidth, and will display the value of n that it will use. The routine computes the spillover, taper, roughness, and total aperture efficiencies, then computes the directivity of the antenna. The 3 dB beamwidth is calculated from the directivity.

Validation

A parabolic reflector has a diameter of 1000 cm, an f/D ratio of 0.5, a feed pattern with $n = 2$, and no surface roughness. The operating frequency is 3 GHz. This example is considered in [1], and compared with PCAAD below:

Quantity	Reference [1]	PCAAD 7.0
Spillover efficiency	0.784	0.784
Taper efficiency	0.957	0.957
Aperture efficiency	0.750	0.751
Directivity	48.7 dB	48.7 dB

E.12. Symmetric Parabolic Reflector Analysis



This routine computes the patterns of a symmetric parabolic reflector antenna using the Jacobi-Bessel series method described in [29]. This method is rigorous, but does not require integration of the aperture for each pattern angle, and therefore is extremely fast computationally. It provides accurate patterns at wide angles, for a variety of feeds, including displaced feeds. In addition to computing co- and cross-pol patterns, this routine can also provide plots of the aperture amplitude distribution, the aperture phase distribution, the reflector geometry, the antenna gain, and the losses associated with spillover, amplitude taper, polarization loss, surface roughness, and feed blockage. The user can choose from a set of built-in feed antennas, including an ideal $\cos^q \theta$ pattern, a dipole, a pyramidal horn, or circular horns. The feed pattern may also be specified using data files for the E- and H-plane patterns.

Begin by entering the frequency, the f / D ratio, the dish diameter, and the surface roughness for the reflector (the surface roughness dimension has a default value of zero). Next, select the feed antenna from one of the five choices using the pull-down list, or select **Feed From Data Files** to use external feed pattern data. Depending on the choice of feed, additional parameters will be specified for the feed dipole or horn dimensions. For the ideal $\cos^q \theta$ (field) feed, specify either the exponent, q>0, or specify the -10 dB angle of the feed (the half-angle, in degrees). When specifying the feed pattern from data files, the feed pattern data must be in the format of (angle in degrees, pattern amplitude in dB), with delimiters of either commas, spaces, or tabs, with an angle range that extends at least from -90º to 90º. Optionally, feed pattern phase can be included as (angle in degrees, pattern amplitude in dB, pattern phase in degrees). The step size of the feed pattern data file is arbitrary - numerical interpolation is used when necessary. Pattern files generated by other PCAAD routines follow this format, allowing other PCAAD routines to be used to generate feed patterns for direct use in this routine. For example, the array antenna module can be used to generate E- and H-plane feed pattern files, which can then be used in this routine to find the secondary patterns of the reflector.

Next, specify the displacement of the feed from the focal point of the reflector. The feed may be displaced laterally (the x or y directions), or axially (the z direction). The displacement is limited to less than 2λ in the lateral directions to avoid long computation times (and because large displacements are generally not used in practice due to large drops in gain). A lateral displacement will result in a shift of the main beam in the opposite direction, while a axial displacement will result in de-focusing of the main beam. Note that the coordinate reference point for the feed is at the center of the dipole, or at the center of the aperture for horns. This point may not coincide with the true phase center of the feed antenna. Aperture blockage by the feed can also be specified, if desired. Feed blockage is computed by eliminating a central disk of the aperture excitation during numerical integration. The feed polarization can be chosen to be either vertical (y direction), or horizontal (x direction).

Select the pattern type and parameters with the **Pattern Type** select button. Pattern plots can be made in the E- and H-planes of the reflector, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. 3-D volumetric patterns are not available because the beamwidth of most reflectors is too narrow to be plotted in volumetric form. Since most reflector antennas have narrow beamwidths, the elevation step size should be small, typically between 0.01º and 0.1º. Also specify the maximum angular range of the elevation pattern plot. Because of the narrow beamwidth of most reflector antennas, the maximum angular range of the pattern calculation usually does not need to exceed a few degrees. Unlike other methods of reflector antenna analysis, the Jacobi-Bessel method does not use appreciably more computer time as the pattern step size, or pattern angle range, is increased.

After clicking the **Compute** button, the patterns will be calculated and various results will be presented. On the right side of the window a loss budget for the reflector will be given, starting with the maximum directivity that is available from the aperture area of the reflector. Below this is listed the spillover loss, the amplitude taper loss, the phase error loss, the surface roughness loss, and the feed blockage loss. The net result is the **Estimated Gain** of the reflector. Note that several of these figures are only estimates when feed displacements are non-zero because of the complicated interaction between phase, amplitude, main beam position, and the resulting gain, and the fact that these losses are computed independently of each other. The gain figure listed on the left side of the window, however, is based on the rigorously computed far-field pattern, and should be accurate. Note that both gain figures are for the gain at the main beam position; when an axial offset is present, the main beam often has a "dip" so that the maximum gain does not occur at the center of the main beam. The beam deformation factor, subtended half-angle of the dish, and the aperture efficiency (based on the maximum directivity of the aperture and the computed gain), is also listed on the left side of the window.

Other results are available as listed in the **Results** tree. Plot the patterns of the reflector, or save the patterns to a data file, by clicking the appropriate item in the **Results** tree. Click **Co-pol Amplitude**, **X-pol Amplitude**, or **Co-pol Phase** to plot the corresponding data for the aperture distribution of the reflector. The geometry of the reflector antenna may be viewed by clicking **Show Geometry**. Information on the solution (including the number of term used in the Jacobi-Bessel method, the CPU time, and similar data) can be viewed under **Solution**

Notes. Solution time is fastest for the $\cos^q \theta$ and dipole feeds, and slower for horn feeds, particularly for the circular horn feeds since these require numerical integration to calculate their patterns.

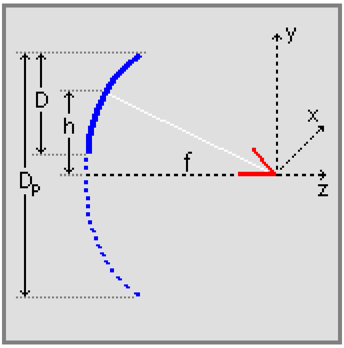
Validation

Consider a parabolic reflector with a diameter of 274.3 cm, $f/D = 0.4$, a circular waveguide feed with a radius of 1.27 cm, operating at 7.9 GHz. The circular waveguide feed can be modeled as a conical horn with a very long length. The following results for beam position and gain are obtained when the feed is on axis ($\delta_x = 0$), or with a lateral displacement ($\delta_x = 4\lambda$).

δ_x / λ	Beam Position	Gain
0.0	0.0	45.8 dB
4.0	6.6º	41.9 dB

Reference [7] gives a gain drop of about 4.0 dB for the displaced feed case.

E.13. Offset Parabolic Reflector Analysis



This routine computes the patterns of an offset parabolic reflector antenna using the Jacobi-Bessel series method described in [29]. This method is rigorous, but does not require integration of the aperture for each pattern angle, and therefore is extremely fast computationally. It provides accurate patterns at wide angles, for a variety of feeds, including displaced feeds. In addition to computing co- and cross-pol patterns, this routine can also provide plots of the aperture amplitude distribution, the aperture phase distribution, the reflector geometry, the antenna gain, and the loss associated with surface roughness. The user can choose from a set of built-in feed antennas, including an ideal $\cos^q \theta$ pattern, a dipole, a pyramidal horn, or circular horns. The feed pattern may also be specified using data files for the E- and H-plane patterns. The analysis of the offset reflector uses the same routine as for the symmetric reflector (where h = 0), but the symmetric reflector case allows fairly accurate independent calculations of spillover, taper, and phase losses.

Begin by entering the frequency, the *f / Dp* ratio (where *Dp* is the diameter of the parent paraboloid), the actual dish diameter, the surface roughness for the reflector (the surface roughness dimension has a default value of zero), and the height, h, of the center of the projected aperture above the axis of the reflector. Next, select the feed antenna from one of the five choices using the pull-down list, or select **Feed From Data Files** to use external feed pattern data. Depending on the choice of feed, additional parameters will be specified for the feed dipole or horn dimensions. For the ideal $\cos^q \theta$ (field) feed, specify either the exponent, q>0, or specify the -10 dB angle of the feed (the half-angle, in degrees). When specifying the feed pattern from data files, the feed pattern data must be in the format of (angle in degrees, pattern amplitude in dB), with delimiters of either commas, spaces, or tabs, with an angle range that extends at least from -90º to 90º. Optionally, feed pattern phase can be included as (angle in degrees, pattern amplitude in dB, pattern phase in degrees). The step size of the feed pattern data file is arbitrary - numerical interpolation is used when necessary. Pattern files generated by other PCAAD routines follow this format, allowing other PCAAD routines to be used to generate feed patterns for direct use in this routine. For example, the array antenna module can be used to generate E- and H-plane feed pattern files, which can then be used in this routine to find the secondary patterns of the reflector.

Next, specify the displacement of the feed from the focal point of the reflector. The feed may be displaced laterally (in the x or y directions), or axially (the z direction). The displacement is limited to less than 2λ in the lateral directions to avoid long computation times (and because large displacements are generally not used in practice due to large drops in gain). A lateral displacement will result in a shift of the main beam in the opposite direction, while a axial displacement will result in de-focusing of the main beam. Note that the coordinate reference point for the feed is at the center of the dipole, or at the center of the aperture for the horns. This point may not coincide with the actual phase center of the feed antenna. The feed polarization can be chosen to be either vertical (y direction), or horizontal (x direction). The feed is assumed to be pointed at an angle toward the center of the dish.

Select the pattern type and parameters with the **Pattern Type** select button. Pattern plots can be made in the E- and H-planes of the reflector, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. 3-D volumetric patterns are not available because the beamwidth of most reflectors is too narrow to be plotted in volumetric form. Since most reflector antennas have narrow beamwidths, the elevation step size should be small, typically between 0.01° and 0.1°. Also specify the maximum angular range of the elevation pattern plot. Because of the narrow beamwidth of most reflector antennas, the maximum angular range of the pattern calculation usually does not need to exceed a few degrees. Unlike other methods of reflector antenna analysis, the Jacobi-Bessel method does not use appreciably more computer time as the pattern step size, or pattern angle range, is increased.

After clicking the **Compute** button, the patterns will be calculated and various results will be presented. On the right side of the window the maximum directivity that is available from the aperture of the reflector will be printed, along with losses due to spillover, amplitude taper, and surface roughness. On the left side of the window is printed the subtended angle from the horizontal axis to the center of the dish, the beam deformation factor, the aperture efficiency (based on the maximum directivity of the aperture), and the calculated gain (based on the rigorously computed far-field pattern).

Other results are available as listed in the **Results** tree. Plot the patterns of the reflector, or save the patterns to a data file, by clicking the appropriate item in the **Results** tree. Click **Co-pol Amplitude**, **X-pol Amplitude**, or **Co-pol Phase** to plot the corresponding data for the aperture distribution of the reflector. The geometry of the reflector antenna may be viewed by clicking **Show Geometry**. Additional information on the solution (including the number of term used in the Jacobi-Bessel method, the CPU time, and some useful geometrical parameters of the offset reflector) can be viewed under **Solution Notes**. Solution time is fastest for the $\cos^q \theta$ and dipole feeds, and slower for the horn feeds, particularly for the circular horn feeds since these require numerical integration to calculate their patterns.

Validation

An offset parabolic reflector has a diameter of 100λ, $f\,/\,D_p$ = 70λ, and a $\cos^q\theta$ feed pattern with q = 13.09. The following results are obtained, and compared with data from the reflector analysis software PRAC. The pattern is shown below.

Quantity	PCAAD 7.0	PRAC
Gain	49.01 dB	49.01 dB
Aperture efficiency	80.7 %	80.7 %
HPBW	0.65º	0.64º
First sidelobe	-24.3 dB	-24.3 dB
Peak X-pol level	-28 dB	-28 dB

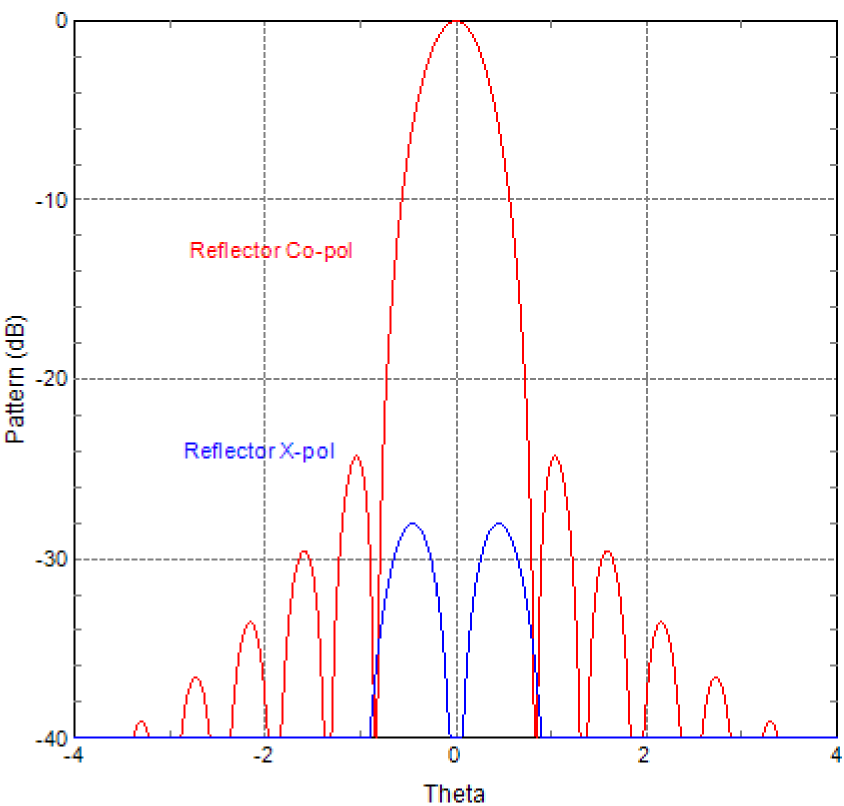
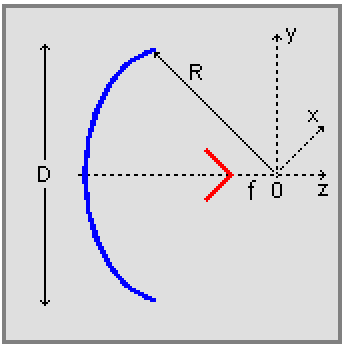


Figure 6. Co-pol and X-pol patterns of the offset reflector antenna.

E.14. Spherical Reflector Analysis



This routine computes the patterns of a spherical reflector antenna using the Jacobi-Bessel series method described in [29]. This method is rigorous, but does not require integration of the aperture for each pattern angle, and therefore is extremely fast computationally. It provides accurate patterns for a variety of feeds. In addition to computing co- and cross-pol patterns, this routine can also provide plots of the aperture amplitude distribution, the aperture phase distribution, the reflector geometry, the antenna gain, and the losses associated with spillover, amplitude taper, phase errors, and surface roughness. The user can choose from a set of built-in feed antennas, including an ideal $\cos^q \theta$ pattern, a dipole, a pyramidal horn, or circular horns. The feed pattern may also be specified using data files for the E- and H-plane patterns. Due to problems with numerical convergence, it is best to avoid reflectors that are close to hemispherical - thus the program restricts reflector diameter to be less than 80% of the spherical diameter.

Begin by entering the frequency, the radius of the spherical reflector surface, the dish diameter, and the surface roughness for the reflector (the surface roughness dimension has a default value of zero). Next, select the feed antenna from one of the five choices using the pull-down list, or select **Feed From Data Files** to use external feed pattern data. Depending on the choice of feed, additional parameters will be specified for the feed dipole or horn dimensions. For the ideal $\cos^q \theta$ (field) feed, specify either the exponent, q>0, or specify the -10 dB angle of the feed (the half-angle, in degrees). When specifying the feed pattern from data files, the feed pattern data must be in the format of (angle in degrees, pattern amplitude in dB), with delimiters of either commas, spaces, or tabs, with an angle range that extends at least from -90º to 90º. Optionally, feed pattern phase can be included as (angle in degrees, pattern amplitude in dB, pattern phase in degrees). The step size of the feed pattern data file is arbitrary - numerical interpolation is used when necessary. Pattern files generated by other PCAAD routines follow this format, allowing other PCAAD routines to be used to generate feed patterns for direct use in this routine. For example, the array antenna module can be used to generate E- and H-plane feed pattern files, which can then be used in this routine to find the secondary patterns of the reflector.

Next, specify the axial displacement of the feed from the center of the reflector. Typically a spherical reflector uses a feed located approximately halfway between the reflector surface and the center of the sphere (the entry in this case would be a positive value). Note that the coordinate reference point for the feed is at the center of the dipole, or at the center of the aperture for the horns. This point may not coincide with the phase center of the feed antenna. The feed polarization can be chosen to be either vertical (y direction), or horizontal (x direction).

Select the pattern type and parameters with the **Pattern Type** select button. Pattern plots can be made in the E- and H-planes of the reflector, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. 3-D volumetric patterns are not available because the beamwidth of most reflectors is too narrow to be plotted in volumetric form. Since most reflector antennas have narrow beamwidths, the elevation step size should be small, typically between 0.01º and 0.1º. Also specify the maximum angular range of the elevation pattern plot. Because of the narrow beamwidth of most reflector antennas, the maximum angular range of the pattern calculation usually does not need to exceed a few degrees. Unlike other methods of reflector antenna analysis, the Jacobi-Bessel method does not use appreciably more computer time as the pattern step size, or pattern angle range, is increased. Note that because most spherical reflectors are under illuminated, the pattern at wide angles will likely be inaccurate - it is therefore suggested to limit the pattern computation range to a few beamwidths.

After clicking the **Compute** button, the patterns will be calculated and various results will be presented. On the right side of the window a loss budget for the reflector will be given, starting with the maximum directivity that is available from the aperture area of the reflector. Below this is listed the spillover loss, the amplitude taper loss, the phase error loss, and the surface roughness loss. The net result is the Estimated Gain of the reflector. On the right side of the window is listed the subtended half angle of the reflector, the aperture efficiency (based on the maximum directivity of the aperture and the computed gain), and the computed gain (as found from the computed far-field pattern).

Other results are available as listed in the **Results** tree. Plot the patterns of the reflector, or save the patterns to a data file, by clicking the appropriate item in the **Results** tree. Click **Co-pol Amplitude**, **X-pol Amplitude**, or **Co-pol Phase** to plot the corresponding data for the aperture distribution of the reflector. The geometry of the reflector antenna may be viewed by clicking **Show Geometry**. Information on the solution (including the number of term used in the Jacobi-Bessel method, the CPU time, and similar data) can be viewed under **Solution Notes**. Solution time is fastest for the $\cos^q \theta$ and dipole feeds, and slower for the horn feeds, particularly for the circular horn feeds since these require numerical integration to calculate their patterns.

Validation

A spherical reflector has a radius of 97λ, and a diameter of 48λ. The feed is located 48.87λ from the center of the sphere, and has a $\cos^q \theta$ feed pattern, with q = 17.09. PCAAD produces the following results. The pattern is in good agreement with that given in reference [29].

Maximum directivity	43.57 dB
Spillover loss	-0.06 dB
Amplitude taper loss	-1.31 dB
Phase taper loss	-0.02 dB
Directivity - Losses	42.2 dB
Calculated gain	42.3 dB

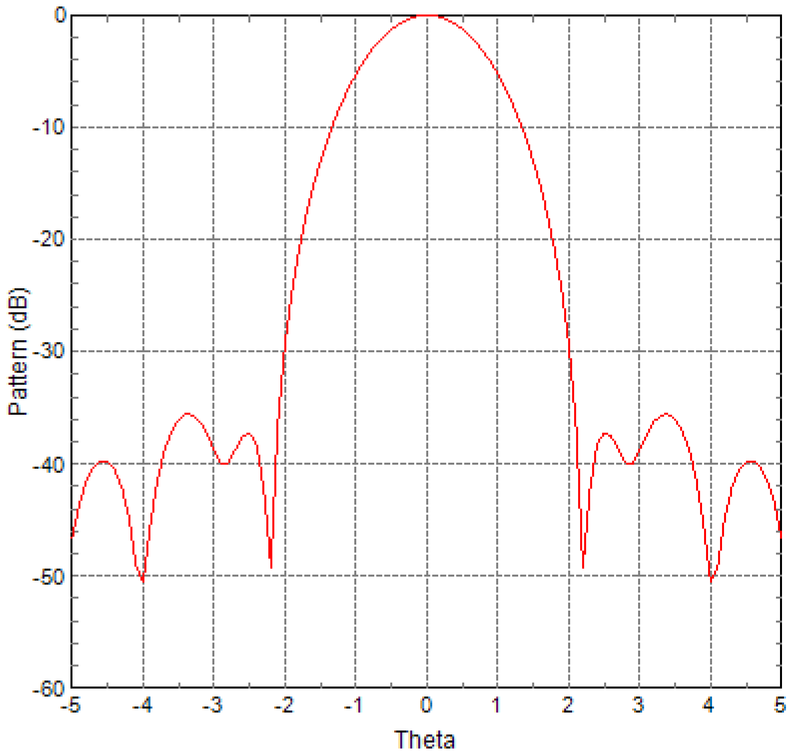
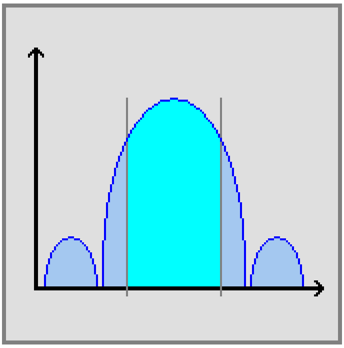


Figure 7. Pattern of the spherical reflector

E.15. Beam Efficiency



This routine calculates the beam efficiency of an aperture antenna. Beam efficiency is defined as the ratio of the radiated power over a fixed angular range to the total radiated power. The angular range is often chosen as the -3 dB points or -10 dB points, but may be arbitrary. This quantity gives a measure of how much power is radiated in the main beam relative to the total power, and is useful in a number of applications where the power received off the main beam is important to system performance.

Enter the frequency of operation, the maximum angle for the beam efficiency calculation, and the desired step size. Next, select the antenna type from one of the five choices using the pull-down list, or select **Feed From Data Files** to use external feed pattern data. Depending on the choice of feed, additional parameters will be specified for the feed dipole or horn dimensions. For the ideal $\cos^q \theta$ (field) feed pattern, specify the exponent of the field pattern, q>0. When specifying the feed pattern from data files, the feed pattern data must be in the format of (angle in degrees, pattern amplitude in dB), with delimiters of either commas, spaces, or tabs, with an angle range that extends at least from -90º to 90º. Optionally, feed pattern phase can be included as (angle in degrees, pattern amplitude in dB, pattern phase in degrees). The step size of the feed pattern data file is arbitrary - numerical interpolation is used when necessary. Pattern files generated by other PCAAD routines follow this format, allowing other PCAAD routines to be used to generate feed patterns for direct use in this routine. For example, the array antenna module can be used to generate E- and H-plane feed pattern files, which can then be used in this routine to find the secondary patterns of the reflector.

Click **Compute** to compute the beam efficiency over the selected range of angles. The beam efficiency data will be listed versus angle in the list box. The beam efficiency may be plotted by clicking **Plot Beam Efficiency** option in the **Results** tree, or saved to a data file by clicking **Save Data**.

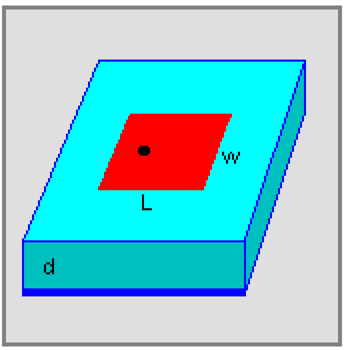
Validation

Consider a pencil beam antenna with a power pattern given by $F(\theta,\phi) = \cos^3\theta$, for $0 \le \theta \le \pi/2$. For this case, q = 1.5. Direct integration gives the beam efficiency as $\eta_b = 1 - \cos^4\theta_0$. At $\theta_0 = 30°$ this gives an efficiency of 43.8%; at $\theta_0 = 60°$, the efficiency is 93.8%. These values agree with the data from the beam efficiency routine of PCAAD 7.0.

F. The Microstrip Antennas Menu

This set of routines implement approximate solutions for rectangular and circular microstrip antennas. Two different solutions are available for probe-fed rectangular patches, as well as solutions for a microstrip line fed rectangular patch, a proximity coupled rectangular patch, an aperture coupled rectangular patch, and a probe-fed circular patch. In general, these solutions work well for microstrip antennas on thin substrates, but fail for substrates thicker than about 0.02λ. Subject to this limitation, these routines can be used to get a reasonably good estimate of the resonant frequency and input impedance for these antennas, but be aware that these routines will not be as accurate as full-wave solutions. Use of the integrated Smith chart routine gives quick results for tuning and matching microstrip antenna designs. The routines also compute patterns and directivity.

F.1. Rectangular Probe-Fed Patch (Carver model)

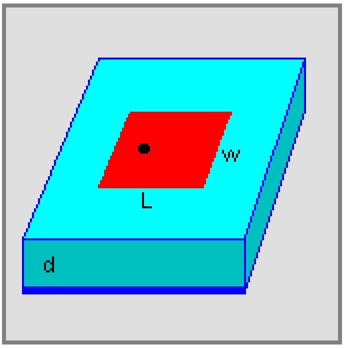


This routine analyzes a rectangular probe-fed microstrip antenna using Carver's transmission line model discussed in references [5] and [13]. It treats the patch as a transmission line with equivalent end admittances to account for radiation, and length extensions are used to account for fringing fields at the radiating edges. The radiation patterns are found from the equivalent magnetic currents for the dominant TM_{10} mode at the edges of the patch, including the sidewall contributions. The sidewall currents do not contribute to the principal plane patterns, but do have an effect on cross-pol fields and directivity, which is calculated by integrating the far-field patterns. This solution generally gives good results for microstrip antennas on thin substrates with low dielectric constants.

Enter the patch length (in the resonant direction), the patch width, the dielectric constant, the substrate thickness, the dielectric loss tangent, and the distance of the probe from the radiating edge of the patch. Select the pattern type and parameters with the **Pattern Type** select button. Pattern plots can be made in the E- and H-planes of the patch, or E-theta / E-phi or Co-pol / X-pol patterns can be made at an arbitrary azimuth angle. The routine will then compute the approximate resonant frequency, the input resistance, the approximate bandwidth, the radiation efficiency, and the directivity. The specified patterns may be plotted by clicking the appropriate option in the **Results** tree, or saved to data files.

See the following section for validation examples.

F.2. Rectangular Probe-Fed Patch (cavity model)



This routine analyzes a rectangular probe-fed microstrip antenna using a cavity model similar to that discussed in reference [7]. The patch is treated as a lossy cavity to account for radiation, and length extensions are used to account for fringing fields at the radiating edges. A parallel RLC equivalent circuit is then used to compute the input impedance versus frequency. The radiation patterns are found from the equivalent magnetic currents for the dominant TM_{10} mode at the edges of the patch. The directivity is calculated by integrating the far-field patterns. This solution generally gives good results for microstrip antennas on thin substrates with low dielectric constants.

Enter the patch length (in the resonant direction), the patch width, the dielectric constant, the substrate thickness, the dielectric loss tangent, and the distance of the probe from the radiating edge of the patch (the probe is assumed to be centered along the width dimension). The routine will then estimate the resonant frequency of the antenna, and suggest a frequency step size. These values are displayed, along with the default number of frequency points, in three boxes to the right of the **Compute** button**.** Click the **Compute** button to accept these values for the frequency sweep, or enter new values for the sweep center frequency, the frequency step size, or the number of frequency points. Select the pattern type and parameters with the **Pattern Type** select button. The routine will compute the input impedance of the antenna over the frequency sweep and display the results in the list box. If necessary, use the scroll bar at the right of the box to scroll through the list of impedances. The routine also computes the approximate bandwidth, the radiation efficiency, and the directivity of the antenna. From the **Results** tree you can plot patterns or the impedance locus vs. frequency, and save patterns or impedance to data files.

Validation #1
Consider a rectangular probe-fed patch with a length of 4.92 cm, a width of 3.28 cm, a substrate with a dielectric constant of 2.32 and a thickness of 0.159 cm, and a feed probe positioned 1.0 cm from the edge of the patch. This example is given in reference [8], with the following results compared with Carver’s model and the cavity model from PCAAD:

Quantity	Reference [8]	Carver Model	Cavity Model
Resonant frequency	2.00 GHz	1.94 GHz	1.97 GHz
Resonant resistance	n/a	336 Ω	192 Ω
Bandwidth	0.7 %	1.2 %	1.7 %
E-plane beamwidth	102º	103º	101º
H-plane beamwidth	85º	86º	86º
Directivity	7.0 dB	7.0 dB	7.0 dB

Validation #2

Consider a probe-fed rectangular patch with a length of 1.8 cm, a width of 2.505 cm, a substrate with a dielectric constant of 2.2 and a thickness of 0.159 cm. The probe is positioned 0.5 cm from the edge of the patch. Results from the cavity model of PCAAD are plotted on the Smith chart below, and compared with measured data. Agreement is very good, particularly near resonance.

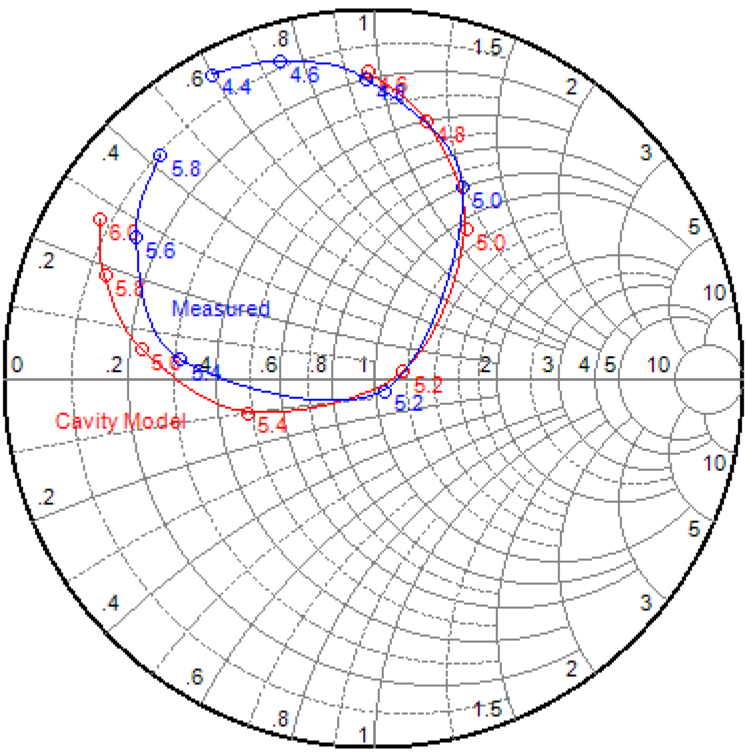
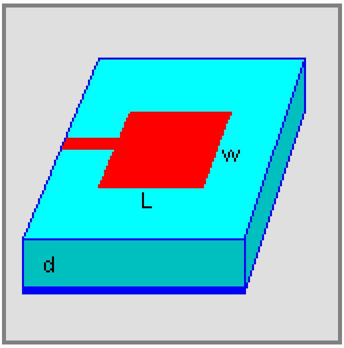


Figure 8. Smith chart plot of calculated (red) and measured (blue) data for a probe-fed rectangular microstrip antenna.

F.3. Rectangular Line-Fed Patch (t-line model)



This routine analyzes a rectangular microstrip line-fed microstrip antenna using the transmission line model discussed in reference [8]. The patch is treated as a transmission line with equivalent end admittances to account for radiation, and length extensions are used to account for fringing fields at the radiating edges. The transmission line circuit is used to compute input impedance versus frequency. The radiation patterns are found from the equivalent magnetic currents for the dominant TM_{10} mode at the edges of the patch. The directivity is calculated by integrating the far-field patterns. This solution has been validated for a large number of practical designs, and generally gives good results for microstrip antennas on thin substrates with low dielectric constants.

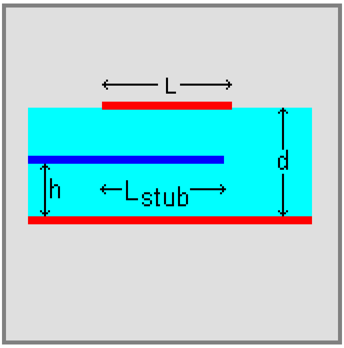
Enter the patch length (in the resonant direction), the patch width, the dielectric constant, the substrate thickness, the dielectric loss tangent, and the width of the microstrip feed line. The routine will compute and display the required feed line width for a 50 Ω line; enter a new value if your line width is different. The routine will then estimate the resonant frequency of the antenna, and suggest a frequency step size. These values are displayed, along with the default number of frequency points, in three boxes to the right of the **Compute** button**.** Click the **Compute** button to accept these values for the frequency sweep, or enter new values for the sweep center frequency, the frequency step size, or the number of frequency points. Select the pattern type and parameters with the **Pattern Type** select button. The routine will then compute the input impedance of the antenna over this frequency sweep, and display the results in the list box. If necessary, use the scroll bar at the right of the box to scroll through the list of impedances. The routine also computes the approximate bandwidth, the radiation efficiency, and the directivity of the antenna. From the **Results** tree you can plot patterns or the impedance locus vs. frequency, and save patterns or impedance to data files.

Validation

Consider a rectangular microstrip line-fed microstrip antenna with a patch length of 3.315 cm, a patch width of 3.317 cm, a dielectric constant of 2.2, a substrate thickness of 0.079 cm, a loss tangent of 0.001, and a feed line width of 0.47 cm. Measured results from [8] are compared with PCAAD:

Quantity	Measured [8]	PCAAD 7.0
Resonant frequency	3.00 GHz	3.01 GHz
Resonant resistance	278 Ω	241 Ω
Bandwidth	1.1 %	1.1 %

F.4. Rectangular Proximity-Coupled Patch (t-line model)



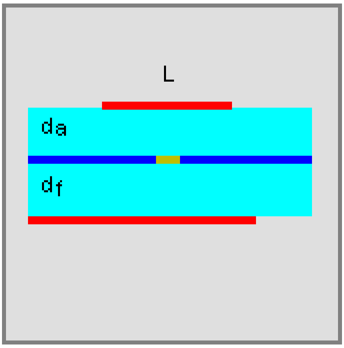
This routine analyzes a rectangular proximity-coupled microstrip antenna using a transmission line model discussed in references [8], [20]. The patch is treated as a transmission line with equivalent end admittances to account for radiation, and length extensions are used to account for fringing fields at the radiating edges. The reciprocity method is used to compute the coupling term between the feed line and the edge of the patch, and the transmission line circuit is used to compute input impedance versus frequency. The radiation patterns are found from the equivalent magnetic currents for the dominant TM_{10} mode at the edges of the patch. The directivity is calculated by integrating the far-field patterns. This solution is not highly accurate, but generally gives reasonable results for microstrip antennas on thin substrates with low dielectric constants.

Enter the patch length (in the resonant direction), the patch width, the total substrate thickness (d), the dielectric constant, and the height (h) of the feed line above the ground plane (this must be less than the substrate thickness). Next enter the width of the microstrip feed line, and the loss tangent of the substrate material. Finally, enter the stub length, as measured from the edge of the patch to the end of the stub. The routine will then estimate the resonant frequency of the antenna, and suggest a frequency step size. These values are displayed, along with the default number of frequency points, in three boxes to the right of the **Compute** button**.** Click the **Compute** button to accept these values for the frequency sweep, or enter new values for the sweep center frequency, the frequency step size, or the number of frequency points. Select the pattern type and parameters with the **Pattern Type** select button. The routine will then compute the input impedance of the antenna over this frequency sweep, and display the results in the list box. If necessary, use the scroll bar at the right of the box to scroll through the list of impedances. The routine also computes the approximate bandwidth, the radiation efficiency, and the directivity of the antenna. From the **Results** tree you can plot patterns or the impedance locus vs. frequency, and save patterns or impedance to data files.

Validation

Consider a proximity-coupled patch with a length of 2.5 cm, a width of 4.0 cm, and a substrate with a dielectric constant of 2.2 and a thickness of 0.316 cm. The feed height is 0.158 cm, and the feed line width is 0.5 cm. The length of the stub is 1.25 cm. At 3.6 GHz, PCAAD gives an input impedance of 34 - j 3 Ω, while measured data from [5] gives an impedance of about 40 + j 3 Ω.

F.5. Rectangular Aperture Coupled Patch (cavity model)



This routine analyzes a rectangular aperture coupled microstrip antenna [14], using a cavity model solution for the patch combined with the reciprocity method [15] for treating the slot feed and microstrip line. The patch is modeled as a lossy cavity with magnetic sidewalls, and the Q is found by integrating the radiated fields of the patch. Length extensions are used to account for fringing fields at the radiating edges of the patch, and closed-form approximations for short slots are used for the slot self-conductance and susceptance. The radiation patterns are found from the equivalent magnetic currents for the dominant TM_{10} mode at the edges of the patch. The directivity is calculated by integrating the far-field patterns. It is assumed that the coupling slot is centered under the patch, the feed line is centered across the slot, and that the feed line is terminated with an open-circuited stub.

First enter the parameters for the patch side of the antenna geometry: the substrate thickness, dielectric constant, patch length (resonant dimension), patch width, slot length (long dimension), and slot width (short dimension). Then enter the parameters for the feed side of the antenna: the substrate thickness, dielectric constant, feed line width, and tuning stub length (measured from the center of the slot to the end of the stub). The routine will then estimate the resonant frequency of the antenna, and suggest a frequency step size. These values are displayed, along with the default number of frequency points, in three boxes to the right of the **Compute** button**.** Click the **Compute** button to accept these values for the frequency sweep, or enter new values for the sweep center frequency, the frequency step size, or the number of frequency points. Select the pattern type and parameters with the **Pattern Type** select button. The routine will then compute the input impedance of the antenna over this frequency sweep, and display the results in the list box. If necessary, use the scroll bar at the right of the box to scroll through the list of impedances. The routine also computes the approximate bandwidth, the radiation efficiency, the front-to-back ratio, and the directivity of the antenna. From the **Results** tree you can plot patterns or the impedance locus vs. frequency, and save patterns or impedance to data files.

Validation

Consider a rectangular aperture coupled microstrip antenna with the following parameters:

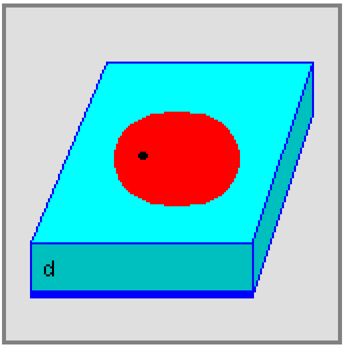
Antenna substrate dielectric constant:	2.54
Antenna substrate thickness:	0.16 cm
Patch length:	4.0 cm
Patch width:	3.0 cm

Feed substrate dielectric constant:	2.54
Feed substrate thickness:	0.16 cm
Slot length:	1.12 cm
Slot width:	0.155 cm
Feed line width:	0.442 cm
Stub length:	2.0 cm

Calculated data using the model of [15] are compared with PCAAD at f = 2.217 GHz:

Quantity	Reference [15]	PCAAD 7.0
Input impedance	65 - j 17 Ω	64 - j 0.8 Ω
Gain (efficiency × directivity)	6.2 dB	6.1 dB
Front-to-back ratio	23 dB	25 dB

F.6. Circular Probe-Fed Patch (cavity model)



This routine analyzes a circular probe-fed microstrip antenna using a cavity model similar to that discussed in reference [8]. The patch is treated as a lossy cavity to account for radiation, and length extensions are used to account for fringing fields at the patch edge. A parallel RLC equivalent circuit is then used to compute the input impedance versus frequency. The radiation patterns are found from the equivalent magnetic currents for the dominant TM_{11} mode. The directivity is calculated by integrating the far-field patterns. This solution generally gives good results for microstrip antennas on thin substrates with low dielectric constants.

Enter the patch radius, the radial distance to the feed probe, the substrate thickness, the dielectric constant, and the dielectric loss tangent. The routine will then estimate the resonant frequency of the antenna, and suggest a frequency step size. These values are displayed, along with the default number of frequency points, in three boxes to the right of the **Compute** button**.** Click the **Compute** button to accept these values for the frequency sweep, or enter new values for the sweep center frequency, the frequency step size, or the number of frequency points. Select the pattern type and parameters with the **Pattern Type** select button. The routine will then compute the input impedance of the antenna over this frequency sweep, and display the results in the list box. If necessary, use the scroll bar at the right of the box to scroll through the list of impedances. The routine also computes the approximate bandwidth, the radiation efficiency, and the directivity of the antenna. From the **Results** tree you can plot patterns or the impedance locus vs. frequency, and save patterns or impedance to data files.

Validation #1

Consider a circular probe-fed patch with a radius of 6.7 cm, on a substrate with a dielectric constant of 2.62 and a thickness of 0.16 cm, and a probe positioned 5.03 cm from the center of the patch. This example is given in [7] using a different cavity model, and compared with the following results from PCAAD:

Quantity	Reference [7]	PCAAD 7.0
Resonant frequency	793 MHz	796 MHz
Resonant resistance	180 Ω	219 Ω

Validation #2

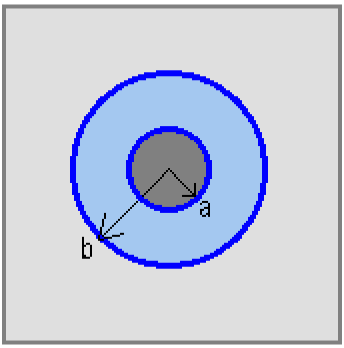
Consider a circular probe-fed patch with a radius of 2.78 cm on a substrate with a dielectric constant of 2.32 and a thickness of 0.16 cm, and a feed probe at the edge of the patch. Reference [8] gives the following data, compared with PCAAD:

Quantity	Reference [8]	PCAAD 7.0
Resonant frequency	2.00 GHz	1.996 GHz
Directivity	7.1 dB	7.1 dB
Bandwidth	1.1 %	1.3 %
E-plane 3 dB beamwidth	100°	103°
H-plane 3 dB beamwidth	80°	81°

G. The Transmission Lines and Waveguides Menu

This set of routines provides solutions for the analysis and design of several types of transmission lines and waveguides that are commonly used in microwave and antenna systems. Included are analysis of coaxial line, rectangular and circular waveguides, and analysis and design of microstrip line and stripline (based on quasistatic formulas). New in PCAAD 7.0 are several full-wave analysis routines for planar transmission lines. These include multilayer microstrip line, multilayer stripline, coupled microstrip lines, coupled striplines, and surface waves on single and multilayer dielectric sheets. Also included is a routine that lists data for standard rectangular waveguide.

G.1. Coaxial Line



This routine computes the characteristic impedance and attenuation due to dielectric loss and conductor loss for a coaxial line. It also computes the cut-off frequency of the TE_{11} waveguide mode of the coaxial line. The formulas used in this routine are standard results, as found in reference [9].

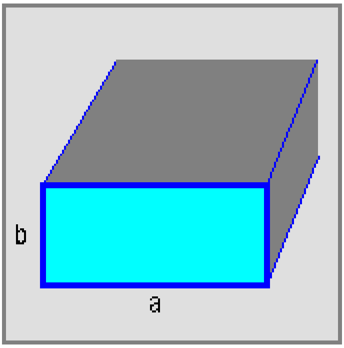
Begin by entering the inner conductor radius, the outer conductor radius, and the dielectric constant. Click the **Compute Zo** button, and the routine will compute and print the characteristic impedance of the coaxial line and the approximate cut-off frequency of the TE_{11} waveguide mode. You can compute attenuation for the coaxial line by entering the frequency, the loss tangent of the dielectric filling material, and the conductivity of the coax conductors. The conductivity may be entered as a value in Siemens/meter, or a specific conductor material can be selected from the drop-down menu at the right of the conductivity box. Click the **Compute Attenuation** button, and the attenuation due to dielectric loss, conductor loss, and the total attenuation will be printed in dB/cm.

Validation

Consider a copper coaxial line with an inner conductor radius of 0.5 mm, an outer conductor radius of 1.5 mm, a dielectric constant of 2.5, and a loss tangent of 0.01, operating at 10 GHz. The formulas in [9] give the following results compared with PCAAD:

Quantity	Reference [9]	PCAAD 7.0
Characteristic impedance	41.7 Ω	41.7 Ω
TE_{11} mode cutoff frequency	30.2 GHz	30.2 GHz
Conductor attenuation	0.0115 dB/cm	0.012 dB/cm
Dielectric attenuation	0.145 dB/cm	0.144 dB/cm

G.2. Rectangular Waveguide



This routine computes the cut-off frequencies and propagation constants for the five lowest order modes of a rectangular waveguide, and the attenuation due to dielectric and conductor losses for the TE_{10} mode. Begin by entering the E-plane (narrow wall) and H-plane (broad wall) inside dimensions of the guide, the dielectric constant of the material filling the guide, and the operating frequency. Click the **Compute** button, and the routine will compute and print the cutoff frequencies of the (1,0), (2,0), (0,1), (1,1), and (0,2) modes; if the mode is propagating at the specified frequency, the propagation constant will also be printed; otherwise it is listed as cut-off. The formulas used in this routine are standard results, as found in reference [9].

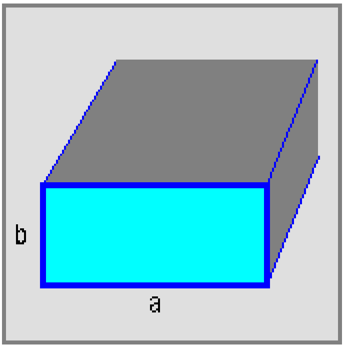
You can compute attenuation for the dominant TE_{10} mode, if it is propagating, by entering the loss tangent of the dielectric filling material and the conductivity of the waveguide walls. The conductivity may be entered as a value in Siemens/meter, or a specific conductor material can be selected from the drop-down menu at the right of the conductivity box. Click the **Compute Attenuation** button, and the attenuation due to dielectric loss, conductor loss, and the total attenuation will be printed in dB/cm.

Validation

Consider a copper K-band waveguide of dimensions 1.07 cm × 0.43 cm, operating at 15 GHz. The guide is filled with Teflon (dielectric constant of 2.08, loss tangent of 0.0004). This problem is treated in Example 3.1 of [9], and the results are compared with those from PCAAD below:

Quantity	Reference [9]	PCAAD 7.0
(1,0) mode cutoff frequency	9.72 GHz	9.720 GHz
(2,0) mode cutoff frequency	19.44 GHz	19.440 GHz
(0,1) mode cutoff frequency	24.19 GHz	24.188 GHz
(1,1) mode cutoff frequency	26.07 GHz	26.068 GHz
TE_{10} propagation constant	345.1 rad/m	345.08 rad/m
Conductor attenuation	0.00434 dB/cm	0.00433 dB/cm
Dielectric attenuation	0.0103 dB/cm	0.01034 dB/cm

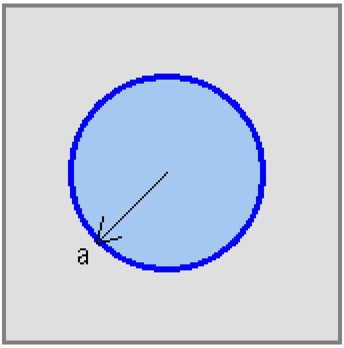
G.3. Rectangular Waveguide Data



This routine lists data for standard rectangular waveguide, including the WR-number, the standard band letter designation, the recommended operating frequency range, the cut-off frequency for the TE_{10} mode, and the inner dimensions of the guide. The scroll bar at the right side of the list box can be used to scroll the entries up or down. The source data for this routine is stored in the ASCII file `RecWGData.dat` (in the PCAAD user directory), which you may edit to add or change the data displayed by PCAAD 7.0. The data for each waveguide is entered on a separate line, with spaces or tabs as delimiters between the data elements.

The routine also allows you to send dimensions for a particular waveguide to the rectangular waveguide analysis routine (Section G.2), for convenient calculation of propagation constants, higher-order mode cutoff frequencies, or attenuation. Select a waveguide by clicking on the appropriate line in the list box (the line will be highlighted), then click the **Send to Rec. WG** button. The window for the **Standard Rectangular Waveguide Data** routine will close, and the **Rectangular Waveguide Analysis** window will open, with the dimensions for the selected guide automatically entered in the appropriate data boxes.

G.4. Circular Waveguide



This routine computes the cut-off frequencies and propagation constants for the five lowest order modes of a circular waveguide, and the attenuation due to dielectric and conductor losses for the dominant TE_{11} mode. Begin by entering the inside radius of the guide, the dielectric constant of the material filling the guide, and the operating frequency. Click the **Compute** button, and the routine will compute and print the cutoff frequencies of the TE_{11}, TM_{01}, TE_{21}, TE_{01}, and TM_{11} modes; if the mode is propagating at the specified frequency, the propagation constant will also be printed; otherwise it is listed as cut-off. The formulas used in this routine are standard results, as found in reference [9].

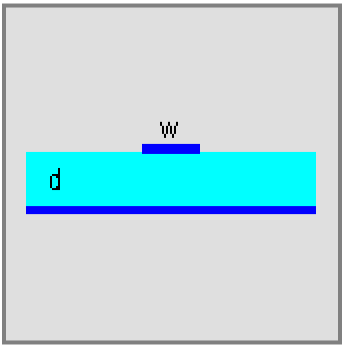
You can compute attenuation for the dominant TE_{11} mode, if it is propagating, by entering the loss tangent of the dielectric filling material and the conductivity of the waveguide walls. The conductivity may be entered as a value in Siemens/meter, or a specific conductor material can be selected from the drop-down menu at the right of the conductivity box. Click the **Compute Attenuation** button, and the attenuation due to dielectric loss, conductor loss, and the total attenuation will be printed in dB/cm.

Validation

Consider a circular waveguide with an inner radius of 0.5 cm, filled with Teflon (dielectric constant of 2.08, loss tangent of 0.0004). The waveguide is gold plated, and is operating at 14 GHz. This problem is presented as Example 3.2 in [9], with results compared to PCAAD below:

Quantity	Reference [9]	PCAAD 7.0
(1,1) mode cutoff frequency	12.19 GHz	12.190 GHz
(0,1) mode cutoff frequency	15.92 GHz	15.924 GHz
TE_{11} propagation constant	208.0 rad/m	207.984 rad/m
Conductor attenuation	0.00583 dB/cm	0.0058 dB/cm
Dielectric attenuation	0.0149 dB/cm	0.0149 dB/cm

G.5. Microstrip Line (quasi-static)



This routine is used to find the characteristic impedance of a microstrip transmission line, given the substrate parameters and line width, or to find the line width, given the substrate parameters and the characteristic impedance. Attenuation due to conductor and dielectric loss can also be calculated, if desired. These solutions employ closed-form quasi-static formulas that generally give good results for most practical design problems, as discussed in reference [9].

First choose either the **Compute Zo** option, or the **Compute width** option, by clicking the appropriate radio button at the left side of the window. This will change the input statements for the relevant data entry. When computing characteristic impedance, you will enter the dielectric constant, the substrate thickness, and the line width. Click the **Compute Zo** button to compute and print the characteristic impedance and the effective dielectric constant for the line. When calculating line width for microstrip design, you will enter the characteristic impedance, the dielectric constant, and the substrate thickness. Click the **Compute width** button to compute and print the required line width, and the effective dielectric constant for the line.

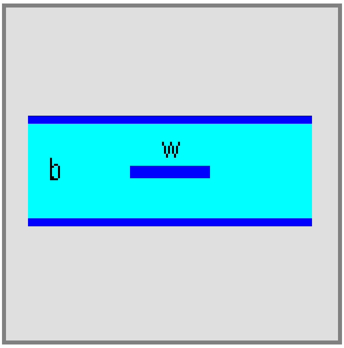
You may compute the attenuation for the line for either the line analysis or the line design case. Enter the frequency, the loss tangent of the dielectric filling material, and the conductivity of the microstrip conductors. The conductivity may be entered as a value in Siemens/meter, or a specific conductor material can be selected from the drop-down menu at the right of the conductivity box. Click the **Compute Attenuation** button, and the attenuation due to dielectric loss, conductor loss, and the total attenuation will be printed in dB/cm. Note that, unlike most other PCAAD routines, this routine uses dimensions in millimeters.

Validation

Consider the design of a 50 Ω microstrip line on a substrate with a dielectric constant of 2.08 and a thickness of 1.59 mm, at a frequency of 5 GHz. The conductors are copper and the dielectric loss tangent is 0.0004. This example corresponds to Example 6.2 in [9], and results are compared with PCAAD below:

Quantity	Reference [9]	PCAAD 7.0
Line width	5.08 mm	5.08 mm
Effective permittivity	1.80	1.806
Conductor attenuation	0.00629 dB/cm	0.0049 dB/cm
Dielectric attenuation	0.00208 dB/cm	0.0021 dB/cm

G.6. Stripline (quasi-static)



This routine is used to find the characteristic impedance of a stripline transmission line, given the substrate parameters and line width, or to find the line width, given the substrate parameters and the characteristic impedance. Attenuation due to conductor and dielectric loss can also be calculated, if desired. These solutions employ closed-form quasi-static formulas that generally give good results for most practical design problems, as discussed in reference [9].

First choose either the **Compute Zo** option or the **Compute width** option, by clicking the appropriate radio button at the left side of the window. This will change the input statements for the relevant data entry. When computing characteristic impedance, you will enter the dielectric constant, the ground plane spacing, the line width, and the strip thickness. Click the **Compute Zo** button to compute and print the characteristic impedance and the cut-off frequency of the parallel-plate waveguide mode. When calculating line width for stripline design, you will enter the characteristic impedance, the dielectric constant, the ground plane spacing, and the strip thickness. Click the **Compute width** button to compute and print the required line width, and the cut-off frequency of the parallel-plate waveguide mode.

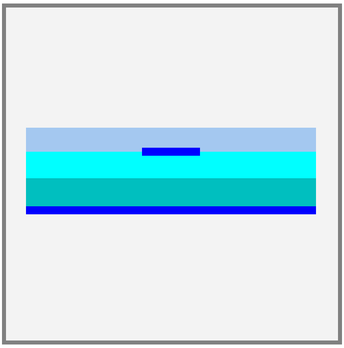
You may compute the attenuation for the line for either the line analysis or the line design case. Enter the frequency, the loss tangent of the dielectric filling material, and the conductivity of the stripline conductors. The conductivity may be entered as a value in Siemens/meter, or a specific conductor material can be selected from the drop-down menu at the right of the conductivity box. Click the **Compute Attenuation** button, and the attenuation due to dielectric loss, conductor loss, and the total attenuation will be printed in dB/cm. Note that, unlike most other PCAAD routines, this routine uses dimensions in millimeters.

Validation

Consider the design of a 50 Ω stripline at 10 GHz on a substrate with a dielectric constant of 2.2 and a ground plane spacing of 3.2 mm. The thickness of the strip is 0.01 mm, the conductors are copper, and the dielectric loss tangent is 0.001. This example corresponds to Example 3.5 in [9], and results are compared with PCAAD below:

Quantity	Reference [9]	PCAAD 7.0
Line width	2.66 mm	2.62 mm
Conductor attenuation	0.0106 dB/cm	0.0105 dB/cm
Dielectric attenuation	0.0135 dB/cm	0.0135 dB/cm

G.7. Multilayer Microstrip Line (full-wave)



This routine implements a full-wave moment method solution for the analysis of a multilayered microstrip line geometry. Up to four dielectric layers below the strip conductor, and four dielectric layers above the strip conductor, can be treated. The effective dielectric constant, the characteristic impedance, and the attenuation constant are computed. This is a rigorous spectral domain solution using the exact Green's function for a multi-layer dielectric medium, with the spectral perturbation technique for calculating the attenuation constant [22].

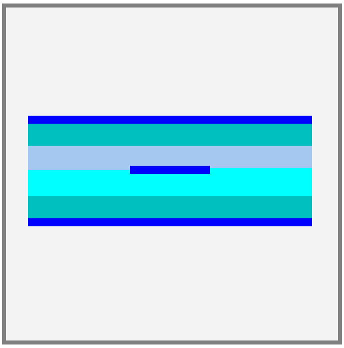
Begin by entering the number of dielectric layers above the strip conductor. Then enter the thickness, dielectric constant, and loss tangent for each layer, using the scroll bar to move between layers. Note that there must be at least one layer above the strip, and that the topmost layer is always of infinite thickness. Next enter the number of layers below the strip, and the corresponding parameters for each layer. The routine plots a small graphic showing the actual number of layers in the multilayer geometry. Then enter the frequency, line width, and the conductivity of the line. The conductivity may be entered as a value in Siemens/meter, or a specific conductor material can be selected from the drop-down menu at the right of the conductivity box. Click the **Compute** button, and the effective dielectric constant, the characteristic impedance, and the total attenuation (in dB/cm) will be displayed. The attenuation includes dielectric loss and loss due to finite conductivity of the strip; loss in the ground plane is not included. Note that, unlike most other PCAAD routines, this routine uses dimensions in millimeters.

Validation

Consider covered microstrip line, with one dielectric layer between the ground plane and the strip, and one dielectric layer above the strip (with air above that). Let $\varepsilon_{r1} = \varepsilon_{r2} = 2.53$, and $d_1 = d_2 = 1.0$ mm, with a loss tangent $\tan\delta = 0.001$, and copper conductors, operating at 1 GHz. Results from PCAAD are compared below with data from another commercial software package for various line widths:

W	Other Software		PCAAD 7.0	
	Z_0	ε_e	Z_0	ε_e
1.0 mm	78	2.39	79	2.41
2.0 mm	56	2.38	56	2.38
4.0 mm	36	2.38	37	2.38

G.8. Multilayer Stripline (full-wave)



This routine implements a full-wave moment method solution for the analysis of a multilayered stripline geometry. Up to four dielectric layers below the strip conductor, and four dielectric layers above the strip conductor, can be treated. The stripline geometry assumes ground planes at the bottom and top of the structure. The effective dielectric constant, the characteristic impedance, and the attenuation constant are computed. This is a rigorous spectral domain solution using the exact Green's function for a multi-layer dielectric medium, with the spectral perturbation technique for calculating the attenuation constant [22].

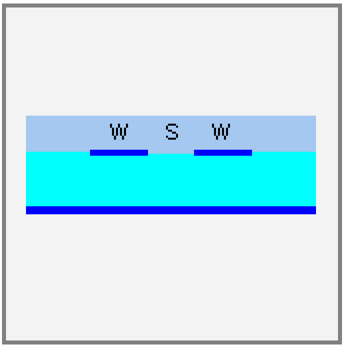
Begin by entering the number of dielectric layers above the strip. Then enter the thickness, dielectric constant, and loss tangent for each layer, using the scroll bar to move between layers. Next enter the number of layers below the strip, and the corresponding parameters for each layer. The routine plots a small graphic showing the actual number of layers in the multilayer geometry. Then enter the frequency, line width, and the conductivity of the line. The conductivity may be entered as a value in Siemens/meter, or a specific conductor material can be selected from the drop-down menu at the right of the conductivity box. Click the **Compute** button, and the effective dielectric constant, the characteristic impedance, and the total attenuation (in dB/cm) will be displayed. The attenuation includes dielectric loss and loss due to finite conductivity of the strip; loss in the ground plane is not included. Note that, unlike most other PCAAD routines, this routine uses dimensions in millimeters.

Validation

Consider a stripline with two different dielectric layers, $\varepsilon_{r1} = 10.2$, $d_1 = 0.635$ mm, $\varepsilon_{r2} = 2.2$, $d_2 = 1.57$ mm, and operation at 3 GHz. Results are compared below with data from another commercial software package:

W	Other CAD Software		PCAAD 7.0	
	Z_0	ε_e	Z_0	ε_e
0.5 mm	49.8	7.047	51.2	7.069
1.0 mm	35.0	7.386	36.0	7.372
2.0 mm	22.2	7.776	23.3	7.749

G.9. Coupled Microstrip Lines (full-wave)



This routine implements a full-wave moment method solution for the analysis of coupled microstrip lines, including a dielectric cover layer. This is a rigorous spectral domain solution using the exact Green's function for the dielectric medium. The effective dielectric constant and characteristic impedance are calculated for even and odd propagation modes. (Although it is straightforward to compute attenuation for coupled lines, the attenuation constants for even and odd modes are generally not useful in practice. This is because most applications of coupled lines involve a superposition of even and odd modes, and superposition does not apply to power loss.)

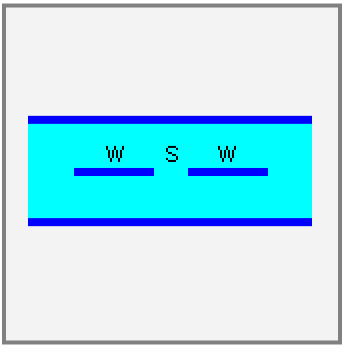
Begin by entering the dielectric constant and thickness for the substrate layer below the strip, then the dielectric constant and thickness for the cover layer (enter values of 0 and 1, respectively, if there is no cover layer). Next enter the width of the lines and the (edge-to-edge) separation between the lines, followed by the frequency. Click the **Compute** button, and the effective dielectric constant and the characteristic impedance will be displayed for the even and odd modes of the coupled lines. Note that, unlike most other PCAAD routines, this routine uses dimensions in millimeters.

Validation

Consider coupled microstrip lines on a substrate with $\varepsilon_r = 10.2$, $d = 1.0$ mm, a line width of $W = 1.0$ mm, and operation at 3 GHz. The even and odd mode impedances and effective dielectric constants from PCAAD are compared with results from another commercial code, for various line separations:

S	Other CAD Software				PCAAD 7.0			
	Z_{0e}	ε_{ee}	Z_{0o}	ε_{eo}	Z_{0e}	ε_{ee}	Z_{0o}	ε_{eo}
0.1 mm	67.0	7.50	29.3	5.91	67.0	7.51	29.3	5.91
1.0 mm	55.0	7.66	41.4	6.17	55.1	7.65	41.6	6.16

G.10. Coupled Striplines (full-wave)



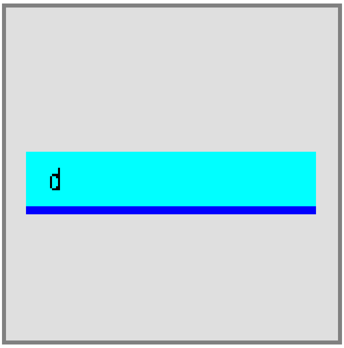
This routine implements a full-wave moment method solution for the analysis of coupled striplines, with separate dielectric layers above and below the strip conductors. This is a rigorous spectral domain solution using the exact Green's function for the dielectric medium. The effective dielectric constant and characteristic impedance are calculated for even and odd propagation modes. (Although it is straightforward to compute attenuation for coupled lines, the attenuation constants for even and odd modes are generally not useful in practice. This is because most applications of coupled lines involve a superposition of even and odd modes, and superposition does not apply to power loss.)

Begin by entering the dielectric constant and thickness for the dielectric layer below the strip, then the dielectric constant and thickness for the dielectric layer above the strip. Next enter the width of the lines and the (edge-to-edge) separation between the lines, followed by the frequency. Click the **Compute** button, and the effective dielectric constant and the characteristic impedance will be displayed for the even and odd modes of the coupled lines. Note that, unlike most other PCAAD routines, this routine uses dimensions in millimeters.

Validation
Consider coupled striplines with a dielectric constant of 10.2, a total dielectric thickness of 2.0 mm, and a strip width of 1.0 mm, operating at 3 GHz. The even and odd mode impedances from PCAAD are compared with results from another commercial code, for various line separations:

S	Other Software		PCAAD 7.0	
	Z_{0e}	Z_{0o}	Z_{0e}	Z_{0o}
0.1 mm	40.75	20.9	40.8	21.1
0.5 mm	35.7	26.0	35.9	26.0
5.0 mm	30.8	30.8	31.0	31.0

G.11. Single Layer Surface Wave Modes (full-wave)



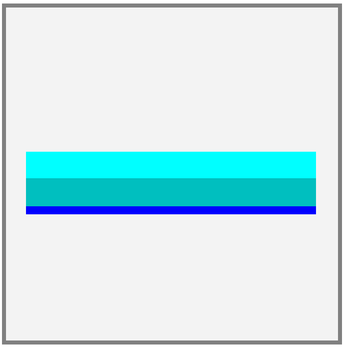
This routine computes TM and TE surface wave propagation constants for a grounded dielectric substrate. It first determines the number of propagating surface wave modes on the slab, then uses a Newton-Rhapson iteration technique to find the propagation constants. It is based on standard results, as found in reference [9].

Enter the frequency, the substrate dielectric constant, and the substrate thickness. Click the **Compute** button to print out the normalized (to k_0) propagation constant for each propagating surface wave mode. The routine also computes and prints an approximate value for the radiation efficiency of a printed antenna on this substrate. This efficiency is based on power lost to surface waves, and is meaningful because it has been shown that this type of radiation efficiency is fairly independent of the type or size of the actual radiating element, depending primarily on the substrate dielectric constant and thickness, as discussed in reference [16]. Note that, unlike most other PCAAD routines, this routine uses dimensions in millimeters.

Validation

Consider the surface wave for a substrate with a dielectric constant of 2.55 and a thickness of 1.9 mm, operating at 30 GHz. This case occurs in [12], where the normalized propagation constant is given as $\beta / k_0 = 1.283$; PCAAD gives a value of 1.28249.

G.12. Multilayer Surface Wave Mode (full-wave)



This routine computes the TM_0 (lowest order) surface wave propagation constant for a multilayer dielectric geometry with a ground plane. This is a rigorous spectral domain solution using the exact Green's function for a multi-layer dielectric medium [22].

Begin by entering the number of dielectric layers above the ground plane. Note that there must be at least two layers, and that the top layer is of infinite extent. Next enter the thickness and dielectric constant for each layer, using the scroll bar to move between layers. The routine plots a small graphic showing the actual number of layers in the multilayer geometry. Then enter the frequency, and click the **Compute** button to compute the propagation constant of the surface wave mode. The propagation constant is also printed out in normalized (to k_0) form. Note that, unlike most other PCAAD routines, this routine uses dimensions in millimeters.

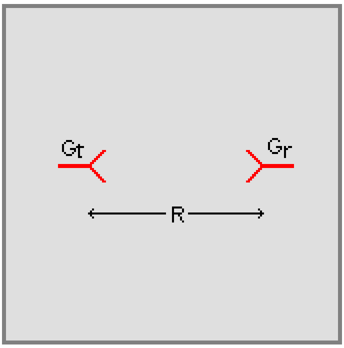
Validation

Consider the same case as in Section G.11, but constructed with two dielectric layers having the same dielectric constant and the same total thickness. Thus, let $\varepsilon_{r1} = \varepsilon_{r2} = 2.55$, and $d_1 = d_2 = 0.95$ mm, with a frequency of 30 GHz. The multilayer surface wave routine gives a value of $\beta / k_0 = 1.28249$, in agreement with the single layer case.

H. The Miscellaneous Menu

This set of routines provide several solutions and data for a variety of topics related to antennas and applications. Included are routines for calculating communication link loss, the polarization mismatch between two antennas, the degradation in axial ratio caused by amplitude and phase errors, graphs for atmospheric attenuation and antenna temperature, and a calculator for useful microwave and antenna functions.

H.1. Communication Link Loss



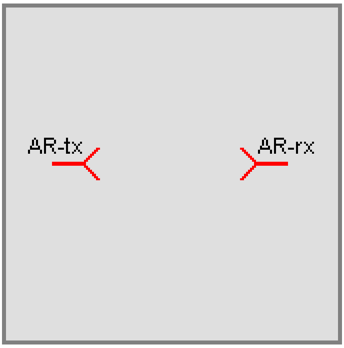
This routine computes the link loss for a radio communications link using the Friis formula [1], [2], [9].

Enter the gains of the transmit and receive antennas, the range between transmitter and receiver, the frequency, the polarization mismatch (enter 0 dB for no mismatch), and the atmospheric attenuation. The routine calculates the link loss assuming impedance matched antennas.

Validation

Example 14.4 of [9] describes the link loss of a DBS satellite, with a transmit antenna gain of 34.0 dB, a receive antenna gain of 33.5 dB, a range of 39,000 km, and an operating frequency of 12.45 GHz. PCAAD gives a link loss of 138.7 dB, in agreement with the result of [9].

H.2. Polarization Mismatch



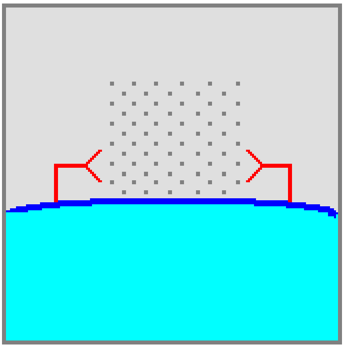
This routine calculates the maximum and minimum polarization mismatch between two arbitrarily polarized antennas using the formulation presented in [23].

Enter the axial ratio of each antenna, and specify the polarization sense (right hand or left hand). For an ideal linearly polarized antenna, enter a large value, such as 100 dB, for its axial ratio. The routine then computes the maximum and minimum losses due to polarization mismatch. Note that these values, being defined as losses, appear as positive dB. The actual loss in practice will depend on the relative orientation of the polarization ellipses of the two antennas, but will always be between the minimum and maximum values given by this routine.

Validation #1
Consider the mismatch between an ideal circularly polarized antenna and an ideal linearly polarized antenna. By entering 0 dB for the axial ratio of the circularly polarized antenna, and 100 dB for the axial ratio of the linearly polarized antenna, PCAAD gives a minimum and maximum mismatch loss of 3.01 dB, as expected.

Validation #2
Consider a RHCP antenna with an axial ratio of 8 dB, and a RHCP antenna with an axial ratio of 4 dB. PCAAD gives the minimum and maximum mismatch losses as 0.15 dB and 1.85 dB. These values are in agreement with an example in [23].

H.3. Atmospheric Attenuation

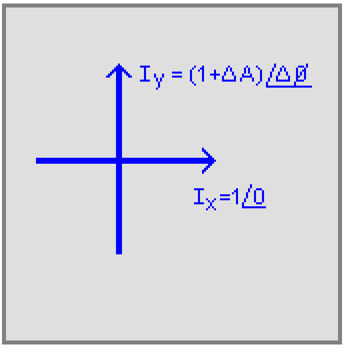


This routine presents a graph of atmospheric attenuation versus frequency, along with attenuation due to rain, as given in [7]. The atmospheric attenuation is at sea level, while the rain attenuation is given for three different rain rates.

Validation

At a frequency of 60 GHz, the attenuation rate of the atmosphere is 15 dB/km. At 40 GHz, the attenuation due to rain at a rate of 1 mm/hr is 0.33 dB/km; rain at the rate of 16 mm/hr increases to 4.9 dB/km.

H.4. Axial Ratio versus Errors



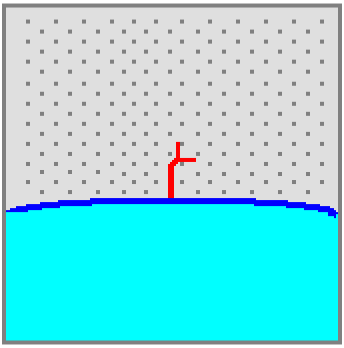
Many circularly polarized antennas are constructed using two orthogonal linearly polarized antennas fed with equal amplitude excitations that are 90º out of phase. As presented in [24], this routine gives the resulting axial ratio due to errors in the actual amplitudes and phases.

Enter the amplitude error (in dB), and the phase error (in degrees). The resulting axial ratio is calculated. Changing the sign of the amplitude error, or the phase error, does not change the resulting axial ratio. A graph illustrating constant axial ratio contours versus amplitude and phase errors is also shown - this can be useful for estimating the amplitude and phase accuracies required for a given axial ratio.

Validation

For two orthogonal linearly polarized antennas having excitations with zero phase error and 3 dB amplitude error, PCAAD gives an axial ratio of 3 dB, in agreement with the graph, and with the results in [24]. For the case of zero amplitude error and a phase error of 30°, PCAAD gives an axial ratio of 4.8 dB, in agreement with the graph, and with the results in [24].

H.5. Antenna Temperature

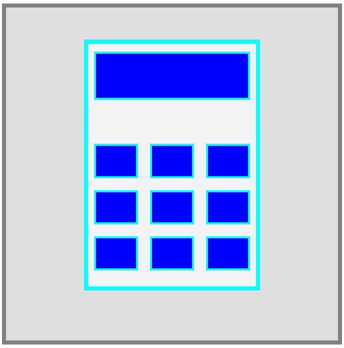


This routine presents a graph of the background noise temperature for an ideal (lossless) antenna versus frequency and elevation angle (elevation angle is measured from the horizon, so $\theta = 90°$ is overhead). The antenna is assumed to have a narrow pencil beam, with no sidelobes pointed toward the earth. Results are given for various elevation angles. The minimum and maximum noise temperatures are also shown. This data is taken from [26].

Validation

At a frequency of 2 GHz, a narrow beam antenna pointed directly overhead will see an apparent noise temperature of about 9 K. An antenna with a more omnidirectional pattern will see a noise temperature as high as 100 K.

H.6. Calculator



This routine provides a calculator function for three different types of conversions: conversion of dimensions (between meters, centimeters, millimeters, inches, and mils), conversion of return loss and VSWR (between return loss, reflection coefficient magnitude, VSWR, and mismatch loss), and conversion of dB and ratios (between ratios in dB, nepers, power ratios, and voltage ratios). Each of these functions operate in the same way. Simply enter the known value in the appropriate text box, press **Enter**, and the converted values will appear in the remaining boxes. Note that all dimensions must be greater than zero; return loss, reflection coefficient magnitude, mismatch loss, voltage ratio, and power ratio must be non-negative; and VSWR must be unity or larger.

Validation
Consider an antenna having an input VSWR of 2.0. Entering this value in the VSWR box of the calculator routine and pressing **Enter** shows that the input reflection coefficient magnitude is 0.3333, the input return loss is 9.54 dB, and the mismatch loss is 0.512 dB.

I. The Help Menu

PCAAD has a comprehensive Help file system, based an HTML compiled help system. The Help file is named `PCAAD7.CHM`, and is located in the application directory.

H.1. Help Table of Contents

This menu option shows the Table of Contents of the Help file, with all routines listed according to type. The Help index can also be accessed.

H.2. Help Index

This menu option leads directly to the index of the Help file.

H.3. Context Help (F1)

Context Help provides assistance for the routine that is currently being used. You can also access context help by pressing the F1 key.

H.4. Short Course and Tutorials

The short course on antennas can be accessed from this menu option, along with tutorials on transmission lines, the Smith chart, and the design of electrically small antennas. This material is given in PDF format, and requires a PDF reader.

H.5. About PCAAD

This menu option shows the main and sub versions of PCAAD. Also shown are the directory path for the PCAAD application directory, the location of the bitmap files used by PCAAD, the current default directory for user data files, the Windows application directory for user data files, the path for the `PCAAD7.INI` file, the path for the Short Course and Tutorial files, and the path for the PCAAD Help file.

V. References

[1] C. A. Balanis, **Antenna Theory: Analysis and Design**, 3rd edition, John Wiley & Sons, New York, NY, 2012.

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