Chapter 21
Polar Plots

In addition to X-Y plots, Mathcad worksheets can contain polar plots. Using polar coordinates, you can quickly and easily display angle-dependent data.

The following sections describe how to create, use, and format polar plots:

Creating a polar plot

Basic steps in creating a polar plot. QuickPlots versus plots where you explicitly specify the range on the angular axis.

Graphing more than one expression

Procedures for creating polar plots with multiple traces.

Formatting the axes

Procedures for modifying the radial and angular axes.

Formatting individual curves

Procedures for modifying curves or traces in a polar plot.

Setting default formats

Procedures for using default format settings for polar plots.

Labeling your polar plot

Procedures for working with titles, legends, and other labels.

Modifying your polar plot's perspective

Procedures for changing the size of the plot, zooming in on a portion of the plot, and finding coordinates in it.

Gallery of polar plots

A set of sample polar plots illustrating the options for creating polar plots.

Creating a polar plot

Mathcad's *polar plot operator* lets you plot functions that do not lend themselves well to Cartesian (*x*-*y*) coordinates. A typical polar plot shows the value of a radial expression *r* versus an angular expression θ. For example, you could use a polar plot to graph circular antenna patterns or electric field intensities around an object.

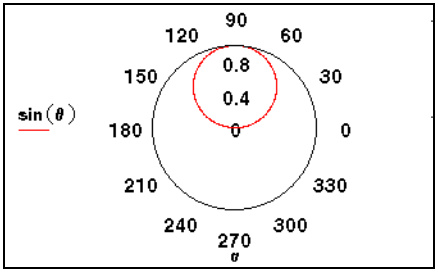
Mathcad draws polar plots by mapping *r* and θ onto *x* and *y* using the standard transformations $x = r\cos(\theta)$ and $y = r\sin(\theta)$. *r* and θ can assume positive or negative values.

You insert the polar plot operator into a blank space in your worksheet by choosing any one of three equivalent methods: by choosing **Graph⇒Polar Plot** from the **Insert** menu, by typing [**Ctrl**]**7**, or by clicking the Polar Plot button in the Graph Palette. Like the X-Y plot operator described in Chapter 20, "Graphs," the polar plot has placeholders on its axes for you to fill in that specify expressions to be computed and displayed, and it automatically chooses a default range for the angular axis variable if you do not specify one. In the case where you do not specify the angular axis variable, Mathcad creates a polar *QuickPlot*.

Polar QuickPlot

You can quickly and easily create a polar plot from a single Mathcad expression. To do so:

- Enter the expression or function of a single variable you want to plot. Make sure the editing lines remain in the expression.
- Choose **Graph⇒Polar Plot** from the **Insert** menu.
- Press [**Enter**] or click away from the graph.



Mathcad automatically produces a polar plot over a default range of the dependent variable on the angular axis: 0 to 360 degrees (0 to 2π radians). You can graph multiple expressions on the radial axis, generating several traces on the polar plot, by entering them as described in "Graphing more than one expression" on page 500.

Notice that you can create a QuickPlot in one of two ways. You can either:

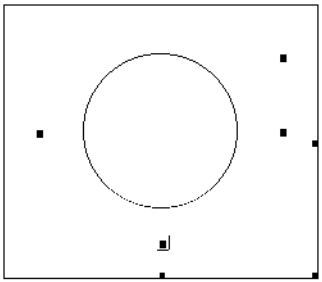
- First type an expression and then choose **Graph⇒Polar Plot** from the **Insert** menu, in which case your expression appears automatically in the radial axis placeholder; or

- First choose **Graph⇒Polar Plot** from the **Insert** menu and then enter an expression in the radial axis placeholder.

Explicitly specifying the range on the angular axis

When you want to specify the angular axis argument or the range variable used, use the following steps to create a polar plot:

- Click where you want the polar plot to appear.
- Choose **Graph⇒Polar Plot** from the Insert menu. Mathcad shows a circle with four placeholders as shown below:



- Above the plot region, define an angle θ and a function of the angle, $r(\theta)$.
- The bottom placeholder holds the angle variable to plot against. Enter a range variable or any expression involving a range variable in this placeholder.
- The left placeholder holds a radial expression to plot.
- The two placeholders to the right hold the upper and lower radial limits. Mathcad fills in these placeholders by default. If you want, you can modify these limits. See the section "Formatting the axes" on page 502.

Just as with an equation or other plot types, Mathcad will not process the polar plot until you click outside the plot.

You can specify many of the characteristics of the polar plot including the size, the number of grid lines, and the upper and lower radial axis limits. The procedures for specifying these characteristics are described later in this chapter.

Here are the typical steps in plotting a function like the one shown in Figure 21-1:

- Define a range and an increment for θ. If you don't, Mathcad generates a polar plot over a default range of 0 to 360 degrees.
- Define $r(\theta)$, a function of θ.
- Show $r(\theta)$ in a polar plot.

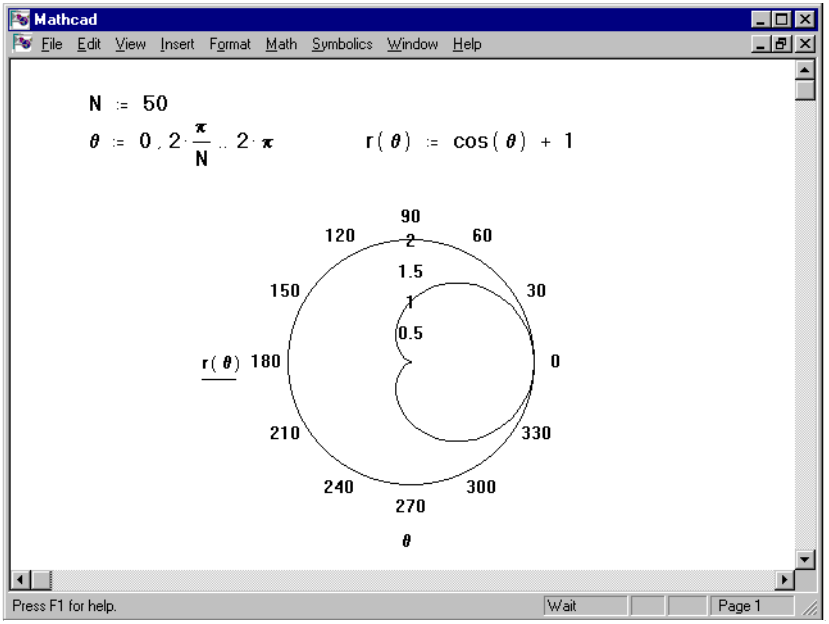


Figure 21-1: Polar plot of a function of θ.

Graphing more than one expression

Just as you can graph several expressions on a single Cartesian (X-Y) plot, you can graph several expressions on the same polar plot. Each expression generates a *trace*. A polar plot can show several *r* expressions against the same θ expression, or it can match up several *r* expressions with corresponding θ expressions.

To graph several *r* expressions versus one θ expression, enter the first *r* expression followed by a comma. You'll see a placeholder immediately below this first expression. Enter the second expression here, followed by another comma to get another empty placeholder. All the expressions should use the same range variable, as shown in Figure 21-2. Figure 21-2 also shows how to define an angular range in degrees.

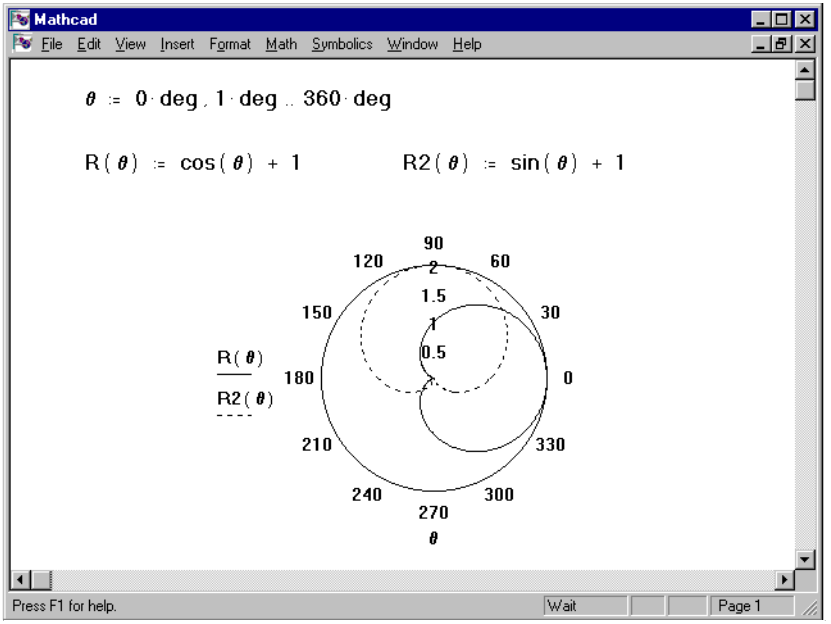


Figure 21-2: Polar plot with multiple expressions.

To graph several independent curves on the same polar plot, enter two or more expressions separated by commas in the angular axis placeholder and the same number of expressions in the radial axis placeholder. For example, to plot $r(\theta)$ against θ and $s(\phi)$ against ϕ you could type "$r(\theta)$, $s(\phi)$" in one placeholder and "θ, ϕ" in the other. Mathcad matches the expressions in pairs—$r(\theta)$ with θ and $s(\phi)$ with ϕ. It then draws a trace for each pair. Each matching pair of expressions should use the same range variable. The range variable for one pair need not match the range variables for the other pairs.

As with *x-y* plots, you can plot one vector of values against another, using a range variable to index the two vectors. This is illustrated in Figure 21-3.

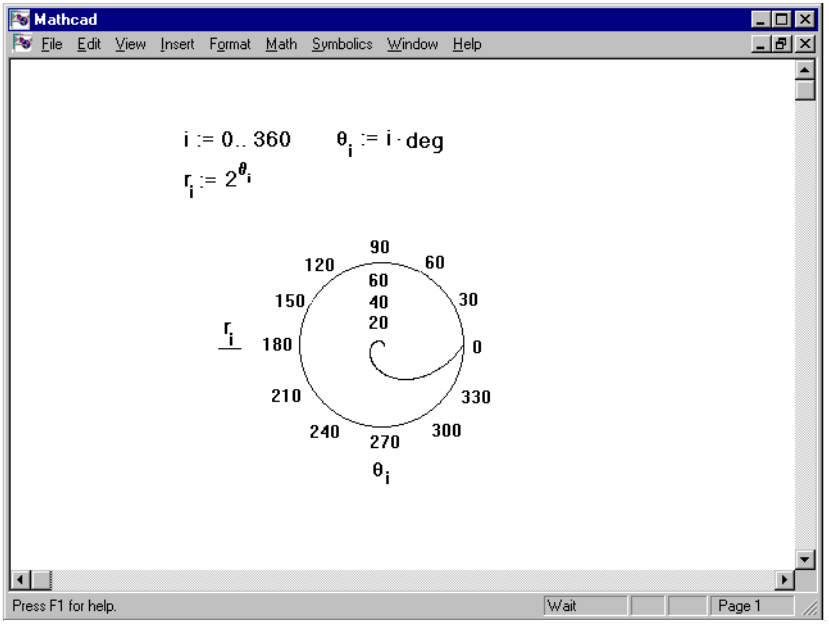


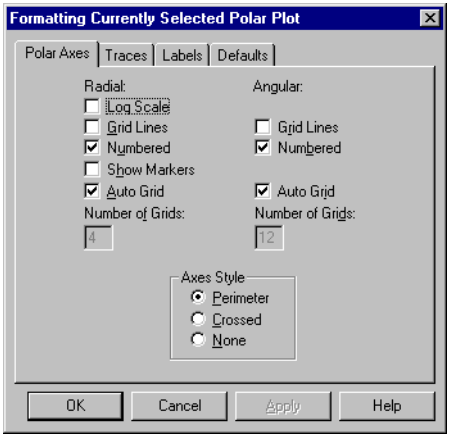
Figure 21-3: Plotting one vector against another.

Formatting the axes

You can reformat your polar plot's axes, using the Polar Axes page of the dialog box for formatting polar plots.

To change a polar plot's format:

- Click in the polar plot to select it.
- Double-click in the polar plot. Alternatively, choose **Graph⇒Polar Plot** from the **Format** menu. You'll see the dialog box for formatting polar plots, shown below.
- If necessary, click the Polar Axes tab.
- There is a complete group of settings for each axis. Change the appropriate settings.
- Click “OK” to accept your changes and close the dialog box. Mathcad redraws the polar plot with the new settings in effect. Alternatively, click “Apply” to see the plot redrawn without closing the dialog box.



Axis settings

Each axis has the following settings associated with it:

Log Scale

When this box is checked, the radial axis is logarithmic. Axis limits must be positive. This setting is available only for the radial axis. Figure 21-10 on page 517 illustrates a polar plot with a logarithmic axis.

Grid Lines

When this box is checked, the tick marks on the selected axis are replaced by grid lines. If the axis is logarithmic, then logarithmically spaced grid lines are added if space permits. Radial grid lines are circles of fixed radius; angular grid lines radiate out from the origin at a fixed angle. Figure 21-8 on page 516 compares a plot with tick marks to the same plot with grid lines.

Numbered

When this box is checked, the selected grid lines are numbered. Figure 21-8 on page 516 illustrates numbers being used with grid lines.

Show Markers

When this box is checked, you can add reference lines to your polar plot. See “Adding radial reference lines” on page 505.

Auto Grid

When this box is checked, Mathcad automatically selects the number of grid markings (tick marks or grid lines). When the box is unchecked, you choose the number of grid markings (from 2 to 99) by typing a number in the No. of Grids text box. You can specify the number of grid markings only when Log Scale is unchecked. Figure 21-9 on page 516 illustrates the effect of Auto Grid.

In addition to these check boxes, the dialog boxes contain the following:

No. of Grids

When available, this text box indicates the number of tick marks or grid lines on the associated axis. You can enter a number between 2 and 99, inclusive. This box

is only available when Auto Grid and Log Scale are unchecked. Figure 21-9 on page 516 shows the effects of defining the number of grid lines on both the radial and the angular axes.

Axes Style

These buttons let you choose between crossed axes, no axes at all, and a plot enclosed by a circle (perimeter). Figure 21-11 on page 517 illustrates the difference between perimeter and crossed axes.

See the section “Setting default formats” below to learn how to:

- Quickly restore a polar plot to its default format settings.
- Use a particular plot as a model for all future polar plots.

Setting limits for axes

Mathcad sets the upper and lower radial axis limits by default. For a linear scale, the upper limit is the maximum radial value of whatever is plotted. The lower limit is zero. For a logarithmic scale, the upper limit is set to the next higher integer power of ten above the maximum of the data. The lower limit on a logarithmic scale is set to the next integer power of ten below the minimum of the data.

You may want to use axis limits other than those set by Mathcad. You can override Mathcad's limits by entering limits directly on the graph. To do so:

- Click in the polar plot to select it. Mathcad shows two additional numbers on the upper right of the polar plot. These numbers are enclosed within corner symbols, as illustrated by the selected plot in Figure 21-4, below.
- Mathcad treats a negative radial limit as a positive value. To set the maximum value of the radial axis, click on the number in the top placeholder and type in a new number. While there's rarely a reason to change the minimum value, you can do this by clicking on the lower number and typing a new number.
- Click outside the plot, Mathcad immediately redraws it using the axis limits you specify. Figure 21-4 shows the effect of manually setting limits on a polar plot.

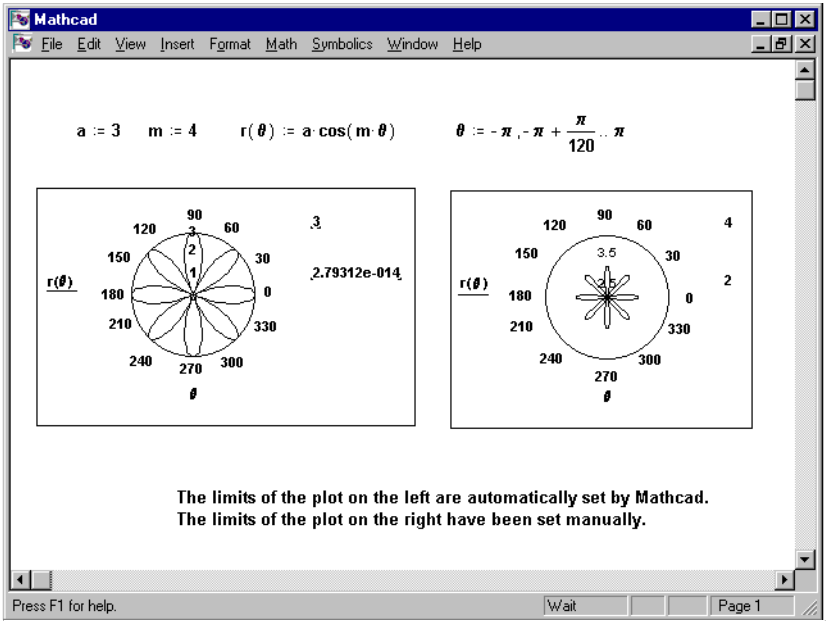


Figure 21-4: Manually setting axis limits.

Adding radial reference lines

Mathcad places linearly or logarithmically spaced radial grid lines on a polar plot. The spaces between grid lines are relatively round numbers that span the range of values on the angular axis. There may, however, be occasions when you need to place a radial line somewhere other than where Mathcad would normally place a grid line.

To add a radial reference line to the polar plot:

- Click in the polar plot to select it.
- Choose **Graph⇒Polar Plot** from the **Format** menu or double-click on the plot to display the dialog box for formatting polar plots. If necessary, click on the Polar Axes page.
- Click the Show Markers check box in the radial axis column to add a check. Click "OK". Mathcad shows two additional placeholders on the upper-left side of the plot.
- Click on one of the placeholders and type in the value at which you want the radial reference line drawn. Repeat this process with the other placeholder to add two radial reference lines.

When you click outside the graph, Mathcad draws a dashed circle at each number that you specified. The number that you typed appears on this dashed circle. To move the dashed circle, click on the appropriate number and change it. To delete the circle, delete this number or click on the Show Markers check box to remove the check. Figure 21-5 illustrates the use of radial reference lines.

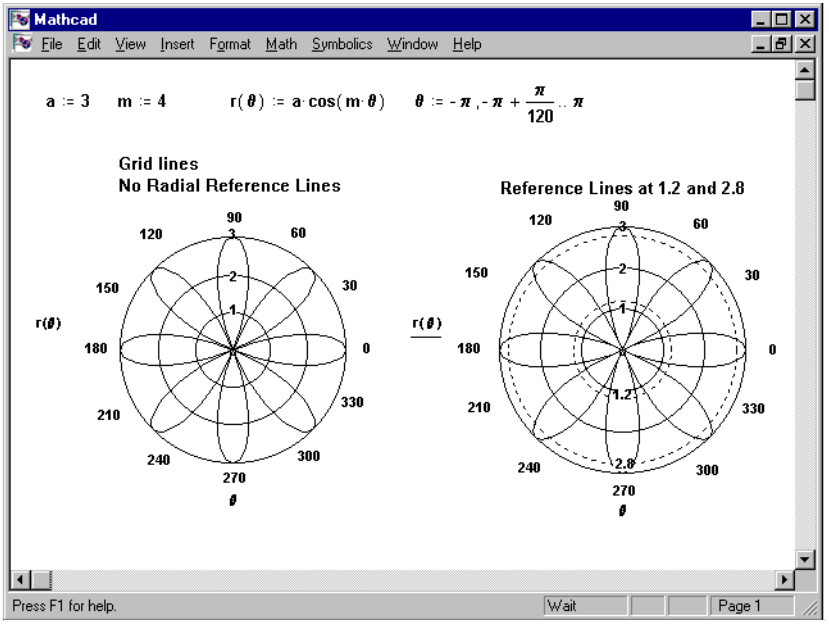


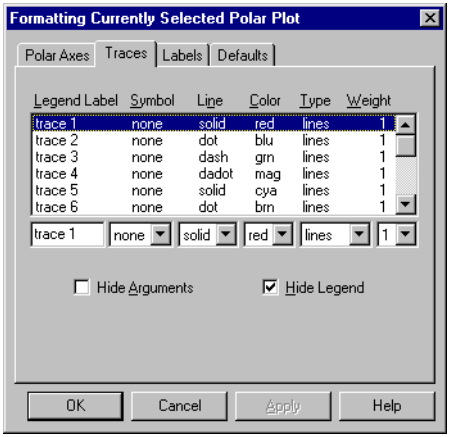
Figure 21-5: Adding radial reference lines to a polar plot.

Formatting individual curves

You can reformat the traces on your polar plot, using the Traces page of the dialog box for formatting polar plots.

To reformat a plot's traces:

- Click in the polar plot to select it.
- Double-click in the polar plot. Alternatively, choose **Graph⇒Polar Plot** from the **Format** menu. Mathcad displays the dialog box for formatting polar plots.
- If necessary, click the Traces tab.
- Click on the appropriate line in the scrolling list box to select a trace. To change the name of the trace, type the new name in the text box under the "Legend Label" column. To assign a symbol or marker, line type, color, trace type, and line weight to this trace, click on the arrow beside each text box to see a drop-down list of options, and then click on the option you want. See the next section, "Trace settings," for complete explanations of these fields.
- Click "OK" to accept your changes and close the dialog box. Mathcad redraws the plot with the new settings in effect. Alternatively, click "Apply" to preview your changes without closing the dialog box.



Trace settings

A graph can have up to sixteen individual traces. Each trace is described by a line in the scrolling list. Mathcad uses these lines as needed, assigning one for each trace in your plot. Each line has six fields:

Legend Label

This is the name of the trace as it would appear in the legend beneath the plot. See the section "Displaying or hiding arguments and legends" on page 511 for more information about legends.

Symbol

This controls whether each point on the curve is marked with a symbol. If y you choose, you can mark each point with either an "×," a "+," a hollow box, or a hollow diamond. If you have a lot of points packed closely together, you should probably select "none." Figure 21-12 on page 518 shows an example in which each data point is marked by with an "×."

Line

This controls whether the line is solid, dotted, or dashed or whether it consists of alternating dashes and dots. This feature provides a useful way to distinguish unmarked curves in black and white printouts.

Color

This controls whether the selected trace is red, blue, green, magenta, cyan (a light blue), brown, black, or white. Mathcad ignores this on monochrome displays.

Type

This controls the type of trace that will be displayed. Mathcad can generate the following types of plots: curves, bar graphs, stepped curves, error bars, stem graphs, and points. (You must have at least two traces to use error bars.) Figure 21-13 on page 518 illustrates the same polar plot, displayed with a variety of trace types.

Weight

This controls the weight or thickness of the trace. Select from 1 to 9 (thinnest to

thickest). Select “p” for the lightest (single-pixel) trace. Although this may look like weight 1 on your screen, a high resolution printer will print it as a very fine line. This field also controls the size of the symbols marking data points, if you have selected a symbol other than “none”. If you have selected trace type points, this field sets the weight of the dot plotted at each data point.

See “Setting default formats” below to learn how to:

- Quickly restore a polar plot to its default format settings.
- Use a particular plot as a model for all future polar plots.

In addition to the scrolling list and its associated text box and lists, the Trace page has two check boxes: Hide Arguments and Hide Legend. These are explained fully in the “Displaying or hiding arguments and legends” on page 511.

Setting default formats

Mathcad uses default settings to format the axes and traces of new polar plots as you create them. You can change these defaults in two ways:

- By saving as defaults the settings of your current plot.
- By using the Setting Default Formats for Polar Plots dialog box to set defaults, if you don't want to use an existing plot.

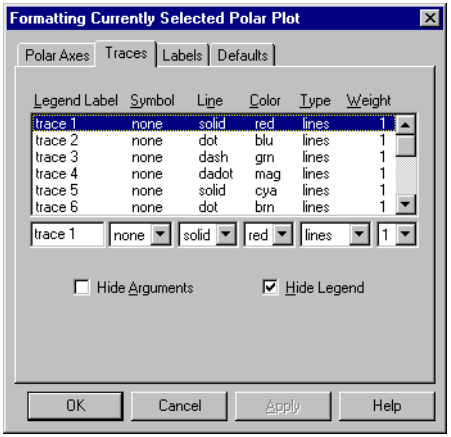
Changing defaults only affects new polar plots; previously existing plots are unaffected.

Copying defaults from an existing plot

One way to create a new set of defaults is to use the format settings of an existing polar plot. The advantage of this method is that you can use “Apply” to see how the format settings look while you define them.

To use the format of a particular polar plot as the default polar plot settings:

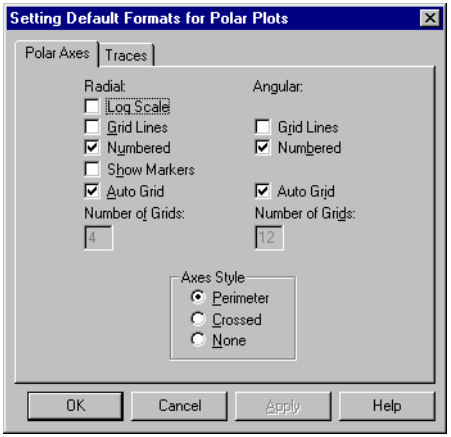
- Select the graph by clicking on it.
- Click the Defaults tab on the dialog box for formatting polar plots. The Defaults page appears, as shown below.
- If the Use for Defaults check box isn't checked, click on it to add one. When you close the dialog box, Mathcad saves these settings as your default settings.



Setting defaults without using a polar plot

You don't have to use an existing polar plot to create or revise default formats. Instead, you can use the dialog box for polar plot defaults. To set defaults this way:

- Make sure that you don't have any plots selected.
- Choose **Graph⇒Polar Plot** from the **Format** menu. You'll see the dialog box for polar plot defaults. The following figure shows an example of this dialog box with the Polar Axes page displayed.
- Change the appropriate settings on the Polar Axes and Traces pages.
- Click “OK” to accept your changes and close the dialog box.



Using default graph settings

If you don't want the format changes made to your polar plot since creating the last set of default settings, you can restore the plot to its current default settings. To do so:

- Click the Defaults tab on the dialog box for polar plots.
- Click “Change to Defaults”.
- Click “OK” to close the dialog box.

Mathcad redraws the plot, using the most recent set of default format settings. Mathcad does not use any defaults you might have set using the Use for Defaults check box at any time after the creation of this plot.

Labeling your polar plot

Mathcad provides several ways to help you to identify what it is you've plotted. You can display:

- A *title* centered above or below the polar plot.
- A *legend* identifying each trace.
- The arguments you used to create the plot.

Figure 21-6 shows the relative locations of each of these labels on a perimeter graph and on a crossed axes graph.

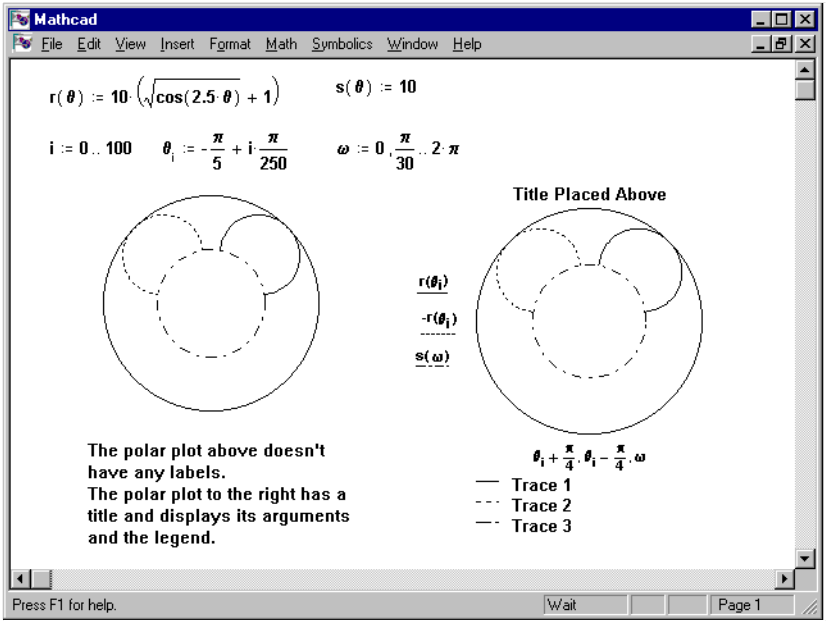


Figure 21-6: Graphs with different labels.

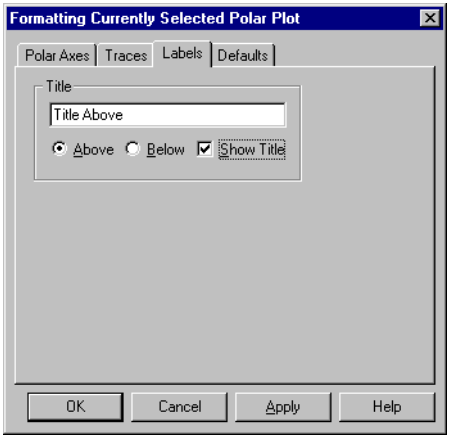
You can use these labels all together or in any combination. By default, Mathcad hides the title, displays arguments, and hides the legend.

Working with titles

To add a title to a polar plot, follow these steps:

- Click in the polar plot to select it.
- Choose **Graph⇒Polar Plot** from the **Format** menu or double-click on the selected plot. Mathcad displays the dialog box for formatting polar plots. If necessary, click on the Labels tab to see the Labels page, as shown below.
- Type a title for your polar plot into the Title text box.
- Click on either the Above or Below button, depending upon where you want to put the title.
- Make sure that the Show Title check box is checked. If it isn't, Mathcad still remembers the title but won't display it.
- Click “OK” to accept your changes. Mathcad redraws the polar plot with the title in place. Alternatively, click “Apply” to preview your title without closing the dialog box.

To change the title's text or position, edit the information in the Title group as appropriate. To delete the title, highlight it in the text box and press **[Del]**.



Displaying or hiding arguments and legends

Mathcad provides both arguments and legends for identifying specific traces on a polar plot:

- Arguments are the expressions that you typed into the placeholders to create the polar plot. By default, Mathcad displays arguments.

- Legends are labels that appear underneath the polar plot. They contain a name and an example of the line and symbols used to draw the trace. By default, Mathcad hides legends.

To display or hide arguments and legends:

- Click in the polar plot to select it.
- Choose **Graph⇒Polar Plot** from the **Format** menu or double-click on the graph. Mathcad displays the dialog box for formatting polar plots. If necessary, click on the Traces tab.
- To suppress the display of the arguments, click on the Hide Arguments check box to add a check.
- To show the legend, click on the Hide Legend check box to remove the check.

Modifying your polar plot's perspective

Mathcad provides options for manipulating the presentation of your polar plot:

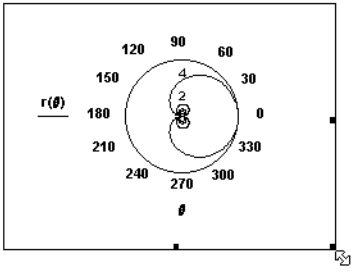
- You can make the plot larger or smaller.
- You can zoom in on a portion of the plot.
- You can get the coordinates for any point that was plotted to construct the plot.
- You can get the coordinates for any location within the plot.

The rest of this section shows how to use these features.

Resizing a polar plot

Resizing a polar plot is very much like resizing a window:

- Click in the polar plot to select it.
- Move the mouse pointer to one of the three handles along the edge of the polar plot. The pointer will change to a double-headed arrow.

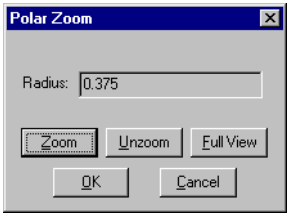


- Press and hold down the mouse button and move the mouse in the direction in which you want the polar plot's dimensions to change.
- Once the polar plot is the right size, let go of the mouse button.
- Click outside the polar plot to deselect it.

Zooming in on a polar plot

Mathcad allows you to select a region of a polar plot and magnify it. To zoom in on a portion of a plot, follow these steps:

- Click in the polar plot to select it.
- Choose **Graph⇒Zoom** from the **Format** menu, or click on the Zoom button in the Graph Palette. The Polar Zoom dialog box appears.



- If necessary, reposition the Polar Zoom dialog box so that you can see the entire region of the graph you want to zoom.
- Click in the polar plot region and drag the mouse while holding down the mouse button. A dashed selection circle is centered in the plot.
- When the selection circle just encloses the region you want to magnify, let go of the mouse button.
- The radius of the selected region is shown in the Radius box of the Polar Plot Zoom dialog box. Click the “Zoom” button to redraw the plot. The axis limits are temporarily set to the coordinates specified in the Polar Plot Zoom dialog box.

Before you make these axis limits permanent, you can select another region to zoom by enclosing another selection circle around the new region. Click “Unzoom” to start the zooming process over. If you're working with a plot that has already been zoomed, you may want to view the original plot as it looked before any zooming took place. To do so, click on “Full View”.

Figure 21-7 shows the effects of zooming in on a portion of a polar plot.

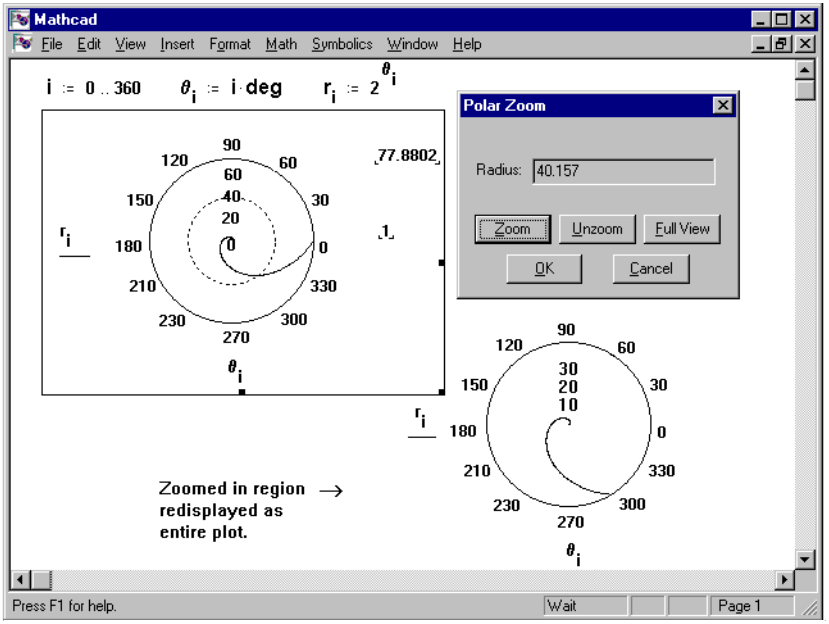
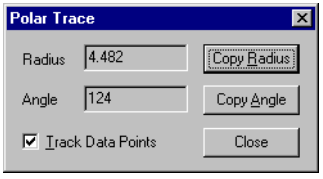


Figure 21-7: A zoomed-in region of a polar plot.

Getting a readout of polar plot coordinates

To see a readout of polar plot coordinates of the specific points that make up a trace, follow these steps:

- Click in the polar plot to select it.
- Choose **Graph⇒Trace** from the **Format** menu to show the Polar Trace dialog box.



- If necessary, reposition the Polar Trace dialog box so that you can see the entire region of the graph.
- Drag the mouse along the trace whose coordinates you want to see. A dotted crosshair jumps from one point to the next as you move the pointer along the trace.
- Use the left and right arrows to move to the previous and next data points. Use the up and down arrows to move to other traces.
- As the pointer reaches each point on the trace, Mathcad displays the coordinates of the pointer location in the Radius and Angle boxes.

- When you release the mouse button, the radius and angle settings of the last point selected are shown in the Radius and Angle boxes. The crosshair remains until you click outside the polar plot.
- Double-click on the control box in the upper-left-hand corner to close the Polar Trace dialog box. The crosshair will remain on your plot until you click anywhere outside it.

To copy a coordinate to the clipboard:

- Click “Copy Radius” or “Copy Angle”.
- You can then paste that value into either a math or text region of your Mathcad worksheet, into a spreadsheet, or into any other application that allows pasting from the clipboard.

To see a readout of coordinates for any location in a polar plot:

- Follow the above procedures to call up the Polar Trace dialog box.
- Click on Track Data Points to uncheck it.
- In the polar plot region, click and drag the mouse pointer over the points whose coordinates you want to see. A dotted crosshair follows the pointer as you drag it over the plot. Mathcad displays the coordinates of the pointer in the Radius and Angle boxes. The radius and angle values change continuously to reflect the current pointer position.
- When you release the mouse button, the Radius and Angle boxes show the r and θ values of the last pixel selected.

Gallery of polar plots

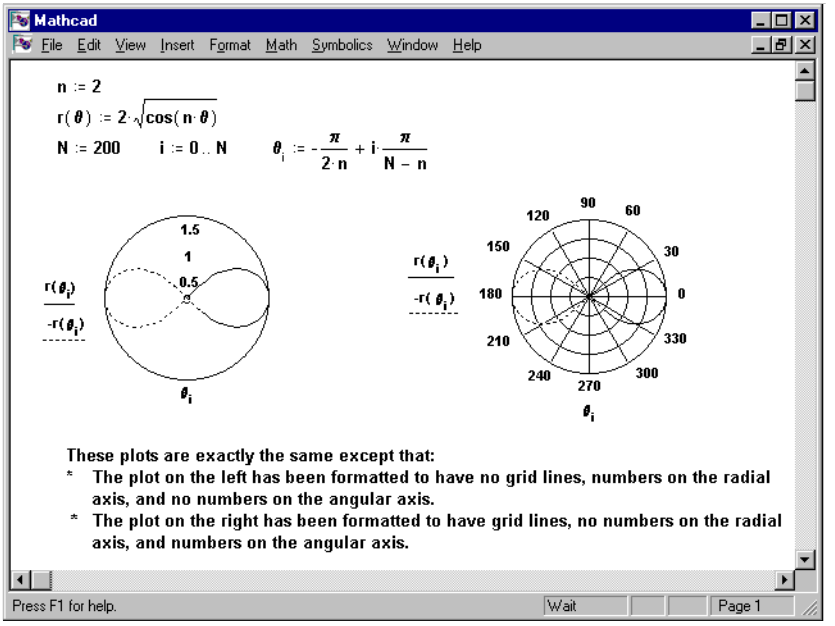


Figure 21-8: Different axis formats on the same polar plot.

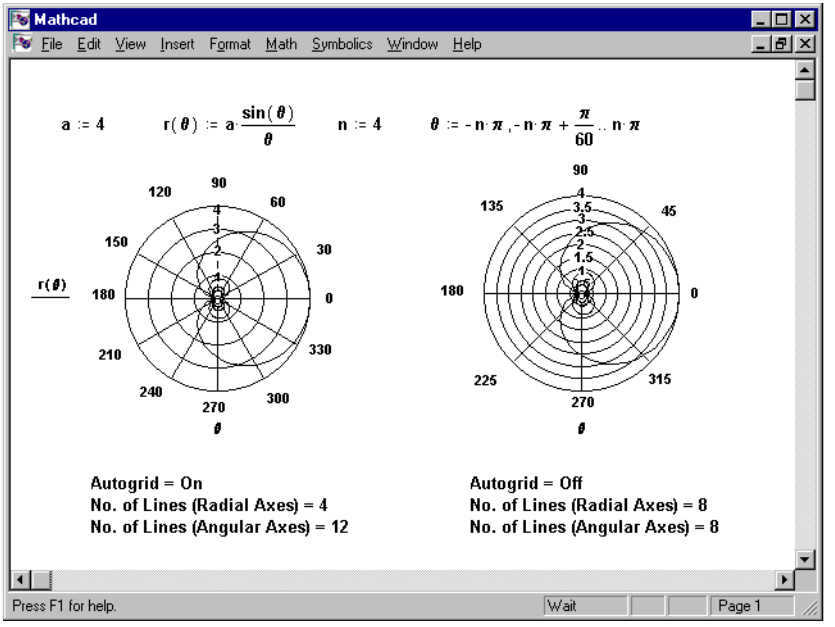


Figure 21-9: Using Auto Grid on the same polar plot.

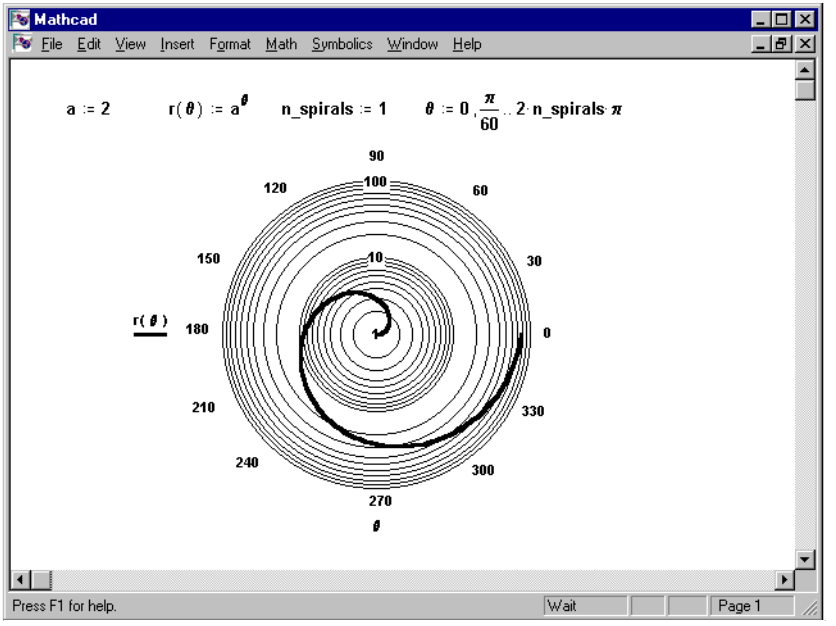


Figure 21-10: Polar plot with a logarithmic axis.

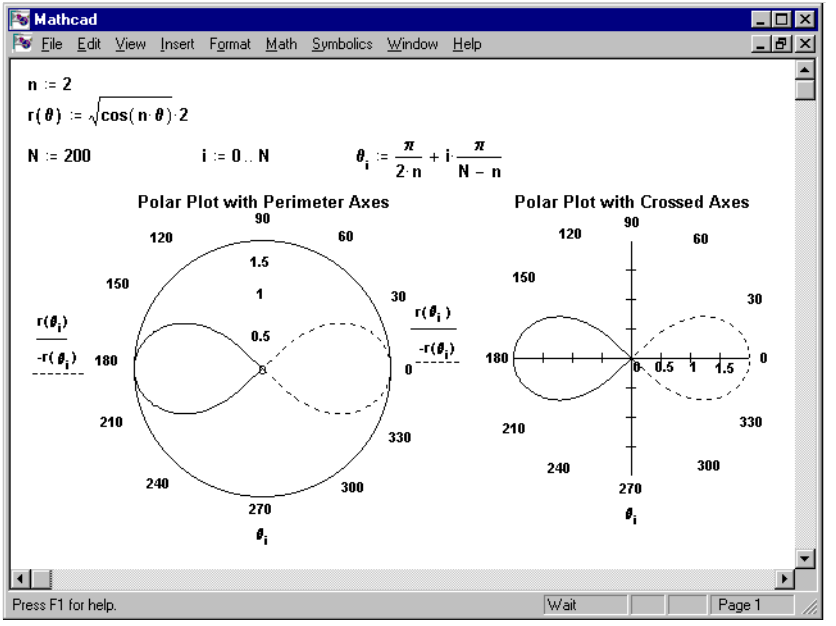


Figure 21-11: Using perimeter and crossed axes styles on the same polar plot.

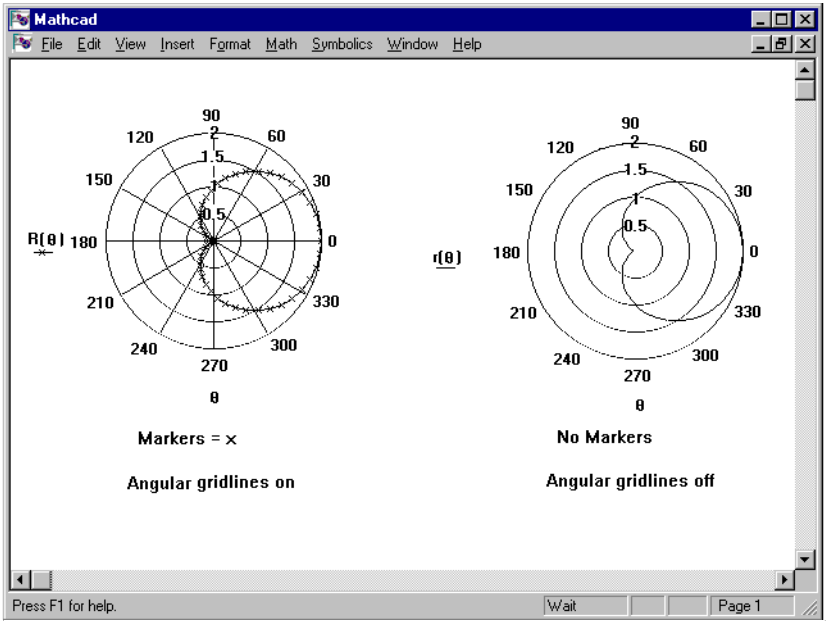


Figure 21-12: Using symbols and lines on the same polar chart.

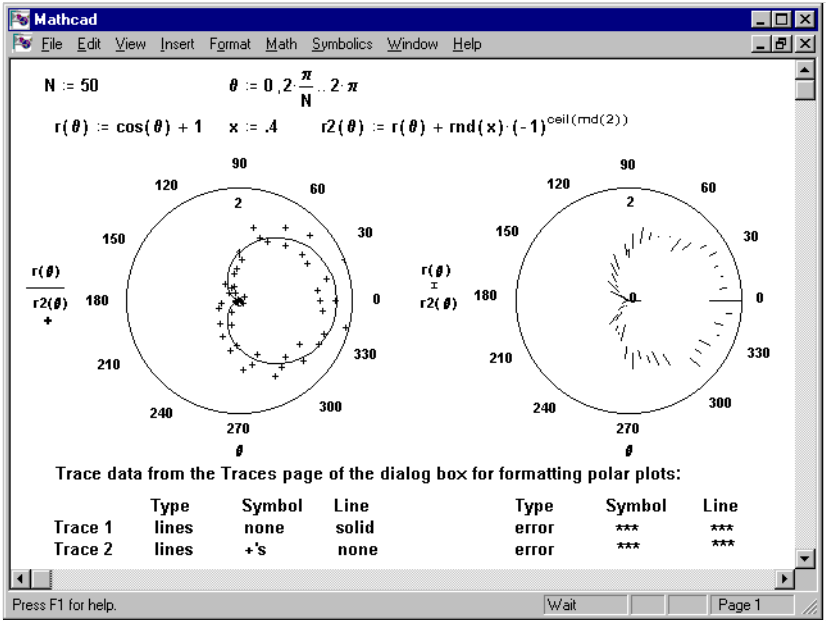


Figure 21-13: Presenting the same plot formatted as lines and symbols and then as error bars.