File SFCODES3.DOC contains the following bookmarks. Select the topic you are trying to find from the list and double click the highlighted text.

AlgebraicOperationSymbols
ArithmeticOperations
AxisLabels
Beta
ConvertF
CreatingNewPlotFiles
CurveLabels
ExampleQuikplotFile
ExampleTablplotFile
FScale
HardCopyOfGraphicsScreens
InputFileKeywords
IntegratingCurvesOrData
Kilpat
LineWidths
List35
MarkerSize
MK_SFINI
PlottingCodePreferenceFiles
PlottingProgramMenus
PlotTitleAndAxes
PolynomialFitting
Quikplot
QuikplotAxisLabels
QuikplotDataFormat
SampleInputFiles
SegField
SF8
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Tablplot
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XIV. Plotting Programs Quikplot and Tablplot

This section describes the general purpose plotting programs Quikplot, and Tablplot. These programs read data from a text file that you can prepare with an editor or with another program. Quikplot produces X-Y plots of independent data sets read from a text file. Tablplot reads a table of related parameters and plots any number of columns versus any other column. All the data sets appear on the same graph in various colors and line-styles. The two programs share a number of features, including:

- User-defined heading lines including justification
- Optional scaling of the data upon start up
- Control over both X and Y scales
- Curve labels
- Log or linear scales
- Polynomial fits for interpolation
- Plots of the fit residuals
- Integration of the data or the fitted curve
- Comment lines in the input file
- Control of the marker size and connecting lines
- Option to include every Nth line of a table (Tablplot)
- Algebraic, trigonometric, or log operations on data sets or columns
- Creation of new data columns by algebraic combination of existing data columns
- Creation of new Tablplot input files containing the currently selected arrays
- Several type of hardcopy graphics output

A. Starting a plotting code

Start Quikplot by double-clicking on a file with the QKP extension or start Tablplot by double-clicking on a file with the TBL extension You can also use a command line to start the code:

Quikplot *filename time*
Tablplot *filename time*

where *filename* is the name of a data file. Both command-line parameters are optional and they can be in either order if both appear on the line. If the command line contains no filename you can browse for a file after the program starts. The *time* parameter specifies the number of seconds to display the plot before stopping automatically. For interactive operation do not include a *time* on the command line. Using the *time* parameter permits a batch files to run unattended.

If launched from the Start menu, Quikplot and Tablplot switch to the directory where the code last ran, and display the File select dialog window. If it still exists, the last file opened will appear in the “Filename:” field. To open the last file automatically

(bypassing the Select file dialog), set AlwaysBrowse = No in the [Quikplot] or [Tablplot] section of SF.INI.

1. Opening files

Menu item File, Open brings up the standard Windows file selector dialog. The dialog allows the user to enter a new file name or path or browse for the file. Quikplot opens the selected file and displays the data.

Quikplot displays on the status bar current values of SF.INI variables MaxDataSets and MaxPoints, and Tablplot displays variables MaxColumns and MaxLines. The status bar also shows progress as the it reads an input file. If the file contains more data than the current SF.INI settings, the status bar will indicate that the code is skipping some data, which may be helpful when reading large files.

2. Editing files

Menu item File, Edit brings up the standard Windows file selector dialog with the name of the present data file pre-selected in the Filename field. Select Open to open that file or choose another plot file. The code opens the selected file in a text editor window. If you edit the current file, then when you quit the editor the code automatically rereads the file and displays the data, thus incorporating any changes you made in the editor. If you edit a different file, the code will ask if you want to switch to that file when you close the editor.

3. Stopping the program

Menu item File, **E**xit stops the program. You also can type a single letter “E” to stop the program.

B. Input data files

Table XIV-1 lists the keywords for Quikplot and Table XIV-2 lists keywords for Tablplot. See Sample input files for examples of a Quikplot file and a Tablplot file. Keywords can be in upper, lower, or mixed case. Some keywords specify the *value* of a parameter separated from the keyword by a space or comma. These keywords include either “value” of “v” in the tables. Other keywords must appear as a single word on a line. The order of the keywords in the data file is unimportant with one exception. In Tablplot files, the Titles table must appear before the Data and EndData section. The code stops reading any further data in the file if it finds an EndFile line. Comments can appear on any line after a semicolon (;) or exclamation mark (!).

1. Quikplot data format

In Quikplot, the data table contains pairs of X,Y data points to be plotted, or a single stream of Y data plotted versus a counter. Lines between the Data and EndData must contain only numbers, comments (after a semicolon or exclamation point), the Multiply keyword, or the Hide keyword. Enter the data in coordinate pairs X,Y separated by blanks or commas. Note that Quikplot interprets a comma at the very end of a line as an

extra number (equal to zero). For a single stream of Y data, use keywords SData and EndData.

The maximum number of data sets and maximum length of the data sets are both user configurable using settings in file SF.INI. Variable MaxDataSets determines the maximum number of data sets, and MaxPoints sets the maximum number of X-Y data points in each set. These settings are limited only by available memory. The default settings are MaxPoints = 10000 and MaxDataSets = 10. The array allocation is independent of the actual requirements of a particular data file.

Separate Data and EndData keywords delimit each data set. Quikplot plots all the data on the same graph using various colors and markers to distinguish the sets.

a. Curve labels

A label of up to 16 characters may appear on each Data line. The code plots these labels along side data for each set when displaying 10 or fewer data sets.

b. Mathematical operations

Use the Multiply keyword to scale X or Y data by a constant factor. This keyword must be between the Data and EndData keywords. It is not a valid keyword anywhere else in the input file. For example, to reduce all the X data for a data set by a factor of 10, insert the following line in the file:

```
Multiply X by 0.1
```

You can modify the X and the Y data by inserting a Multiply command for each axis. To modify the data in all sets, use separate Multiply commands between each pair of Data and EndData keywords. More than one Multiply command for either axis may appear in a data set, but only the last one has any effect.

Table XIV-1. Quikplot input-file keywords.

Keyword	Description
; !	These characters indicate a comment.
Title	Line following is the plot title of up to 120 characters.
Subtitle	Line following is a subtitle of up to 120 characters.
Left	Left justify the title and subtitle (the default).
Center	Center the title and subtitle.
Right	Right justify the title and subtitle.
LeftFooter	Line following is printed in small font at lower left.
RightFooter	Line following is printed in small font at lower right.
XLabel	Line following is the X-axis label of up to 120 characters.
YLabel	Line following is the Y-axis label of up to 120 characters.
Data	Lines following contain the data points.
SData	Lines following contain a single stream of Y data.
Multiply, value	Multiply X or Y data by a constant factor.
Hide	If between Data and EndData, do not plot this data at startup.
EndData	End of the data-point input.
NoMarkers	Do not plot a marker at each data point location.
NoConnect	Do not connect data points with a line.
NoTimeDate	Do not include file time and date in the plot heading.
NoFileID	Do not include the file name in the plot heading.
NoSort	Data will not be sorted before plotting.
MarkerSize, value	Size of plotted data points.
XScale, value	Minimum and maximum X scale values.
YScale, value	Minimum and maximum Y scale values.
EndFile	End of the input file.

Table XIV-2. Tablplot input-file keywords.

Keyword	Description
; !	These characters indicate a comment.
Title	Line following is the plot title of up to 120 characters.
Subtitle	Line following is a subtitle of up to 120 characters.
Left	Left justify the title and subtitle (the default).
Center	Center the title and subtitle.
Right	Right justify the title and subtitle.
LeftFooter	Line following is printed in small font at lower left.
RightFooter	Line following is printed in small font at lower right.
Titles	Lines following contain column titles (32 characters).
EndTitles	End of the column titles.
AxisLabels	Lines following contain the axis labels (120 characters).
CurveLabels	Lines following contain the curve labels (12 characters).
EndLabels	End of the axis labels or curve labels.
Skip, value	Number of lines skipped between data lines read.
NoSort	Data will not be sorted before plotting.
SortByColumn	Sort the data table by the specified column and then skip sorting by abscissa.
LabelByColumn, value	Label plotted points by the values from the selected column.
FirstPointLabeled, value	First data point labeled when LabelByColumn is active.
LabelSignificantDigits, v	Number of significant digits for point labels (2 to 8).
SkipBetweenLables, v	Number of points to skip between labeled points.
LabelOrientation, value	Sets fixed orientation angle (–90 to 90 degrees) for all point labels.
Data	Lines following contain the data table.
EndData	End of the data table.
NoMarkers	Do not plot a marker at each data point location.
NoConnect	Do not connect data points with a line.
NoTimeDate	Do not include file time and date in the plot heading.
NoFileID	Do not include the file name in the plot heading.
MarkerSize, value	Size of markers plotted at each data point location.
YLabel	Line following is the ordinate label.
XScale, value	Minimum and maximum X scale values.
YScale, value	Minimum and maximum Y scale values.
LockScale	Locks the ordinate scale while selecting columns.
Abscissa, value	Data column to plot on the abscissa.
Ordinate, value(s)	Data columns to plot on the ordinate.
EndFile	End of the input file.

2. Tablplot data format

Tablplot plots columns of data. The maximum number of columns and maximum length of the data table are both user configurable using settings in file SF.INI. Variable MaxColumns sets the maximum number of columns and variable MaxLines sets the maximum number of lines in the table. The default settings are MaxLines = 10000 and MaxColumns = 16. The upper limit for MaxColumns is 999. The array allocation is independent of the actual requirements of a particular data file.

A line can have up to 8000 characters. Lines between the Data and EndData keywords must contain only numbers or comments (after a semicolon or exclamation point). Separate entries by blanks or commas. Tablplot assumes that two successive commas

implies a value of zero between the commas. It interprets a comma at the end of a line as an extra number (equal to zero).

If you omit the Abscissa and Ordinate keywords, then Tablplot uses column 1 for the abscissa and the plots the next 10 columns on the ordinate. You can select other plots later using the Select data menu item.

a. Column titles

Lines between keywords Titles and EndTitles identify each column of data that appears later between keywords Data and EndData. There is one title to a line and the maximum length of a title is 32 characters. These titles appear in pull-down menus in some dialog windows.

b. Axis labels

Lines between keywords AxisLabels and EndLabels contain axis labels for the data columns, one label to a line. The maximum length of an axis label is 120 characters. The code labels the abscissa using entries from the list of AxisLabels. The code also labels the ordinate using AxisLabels if the ordinate includes only one column. For multiple columns, Tablplot uses the YLabel entry. You can change the ordinate label after the program is running using the Display, Y Label menu item.

c. Curve labels

Lines between keywords CurveLabels and EndLabels contain curve labels for the data columns, one label to a line. The maximum length of a curve label is 16 characters. The code plots these labels along side data for each ordinate column when displaying 10 or fewer columns.

d. Option to skip lines

By default, Tablplot reads every line of data up to the maximum number of lines. If a Skip directive appears before the Data keyword, then the code skips the specified number of lines after every line read. This option is useful if the table length exceeds the current setting in SF.INI for the maximum number of lines that the program can read. For example, if the program can read only 10,000 lines, but your data table has 40,000 lines, tell the code to read every fourth line with “Skip 3”.

e. Mathematical operations

Each line in the Titles table can include up to 10 mathematical operations from Table XIV-3. The code will perform these operations on the column data when the program starts. The commands should appear in the order you want them executed. In the following table, nn.n refers to a number found on the title line after one of the math operation symbols. Each math operator starts with the colon character.

Table XIV-3. Mathematical operations upon starting Tablplot.

Operation	Symbol	Function
Add	:+ nn.n	Add nn.n to all numbers in a column.
Subtract	:– nn.n	Subtract all numbers in a column from nn.n.
Multiply	:* nn.n	Multiply all numbers in a column by nn.n.
Divide	:/ nn.n	Divide nn.n by all numbers in a column.
Exponentiation	:** nn.n	Raise all numbers in a column to the power nn.n.
Exponential	:EXP	Raise e to the power of each number in the column.
Exponential	:10EXP	Raise 10 to the power of each number in the column.
Natural log	:LOG	Take the natural log of all numbers in a column.
Common log	:LOG10	Take the log base 10 of all numbers in a column.
Sine	:SIN	Take the sine of all numbers in a column.
Cosine	:COS	Take the cosine of all numbers in a column.
Tangent	:TAN	Take the tangent of all numbers in a column.
Inverse sine	:ASIN	Take the arcsine of all numbers in a column.
Inverse cosine	:ACOS	Take the arccosine of all numbers in a column.
Inverse tangent	:ATAN	Take the arctangent of all numbers in a column.

Suppose one of your data columns contains the kinetic energy in units of MeV, but you wish to plot the data in keV. The following line names the column “Kinetic energy (keV)” and scales all values by a factor of 1000:

```
Kinetic energy (keV)          :* 1000
```

To illustrate the use of multiple operations on a line, suppose that a data column contains the angle θ in degrees, but you wish to plot a quantity ζ, which is called “Zeta” on the title line for this column. If the relation between these two angles is $\zeta = \sqrt{1+2\sin\theta}$, then here is a title line that converts θ to ζ:

```
Zeta          :*0.01745329    :SIN    :*2          :+1.0        :**0.5
```

The first operation changes the angle from degrees to radians. (All the trigonometric functions use radians.) The last operation is equivalent to taking the square root. To do more complicated conversions, use the Write command to make new files containing intermediate results. To combine data from one column with another column, use menu item Edit, Combine Columns and select from the algebraic combinations available in the dialog box.

C. Main display window

Table XIV-4 lists the Quikplot menu items and Table XIV-5 lists Tablplot menu items. Underlined letters on menu items indicate the standard Windows Alt-key method to choose the command. A few of the letters indicated in **Bold** font also are available as single-character commands that serve as shortcuts. For example, pressing the “E” key exits the program and so does pressing Alt-F, X. Note that pressing Alt-C brings up the HardCopy pull-down menu, but pressing only “C” actually starts the hardcopy. These character commands are not case sensitive. The number keys 1 through 9 switch to the numbered zoom level, if available.

Table XIV-4. Quikplot menu items.

Menu item	Function
File, Open File	Read a new solution file.
File, Edit File	Edit a Quikplot data file or other text file.
File, File Statistics	Report current SF.INI settings and number of data sets and points read.
File, Save Data	Save the present data to a tab-delimited text file.
File, Exit	End the program.
Edit, X Data	Start a dialog window to manipulate arithmetically the X data.
Edit, Y Data	Start a dialog window to manipulate arithmetically the Y data.
Data, All	Display all the data sets.
Data, Select	Select the data sets for display from the list of labels.
HardCopy, Start	Make a hardcopy of the present display.
HardCopy, Options	Select options for the active hardcopy driver.
HardCopy, Driver	Show the list of hardcopy drivers. The active driver is checked (✓).
Fit, None	Forget any stored fitted coefficients.
Fit, Linear	Fit selected data to straight line.
Fit, Quadratic	Fit selected data to a curve quadratic in X.
Fit, Cubic	Fit selected data to a curve cubic in X.
Fit, Fourth Power	Fit selected data to a fourth order polynomial in X.
Fit, Fifth Power	Fit selected data to a fifth order polynomial in X.
Fit, Square Root	Fit selected data to constant plus √X term.
Fit, Select Data	Select data to be included in the fitted curve.
Fit, Y Value vs X	Start a dialog window to interpolate values on the fitted curve.
Fit, Residuals	Display the residuals of the fit.
Display, Line Widths	Start a dialog window to select line widths of display items.
Display, Marker Size	Start a dialog window to select the marker size and type.
Display, Swap XY	Interchange X and Y data.
Display, Redraw Plot	Redraw the plot (e.g., after changing window size by a large amount).
Display, Reset Defaults	Reset all display parameters to SF.INI settings or default values.
Display, X Log Scale	Make X axis a logarithmic scale. Setting is checked (✓) when active.
Display, X Linear Scale	Make X axis a linear scale. Setting is checked (✓) when active.
Display, Y Log Scale	Make Y axis a logarithmic scale. Setting is checked (✓) when active.
Display, Y Linear Scale	Make Y axis a linear scale. Setting is checked (✓) when active.
View, Show Title	Display the plot title if checked (✓).
View, Connect Points	Connect points with a line if checked (✓).
View, Curve Labels	Display the curve labels if checked (✓).
View, Markers	Display markers at each data point location if checked (✓).
View, Show Fit	Display the fitted curve if checked (✓).
View, Show All	Display all data including data sets not included in fit if checked (✓).
Zoom, Forward	Go forward one zoom level.
Zoom, Backward	Go back one zoom level.
Zoom, Original	Go back to the original display (zoom level 1).
Zoom, Manual Entry	Start a dialog window to enter plot limits for a zoom level.
Integrate	Start a dialog window to integrate data sets or the fitted curve.
Help, About Quikplot	Brief code description, release date, version number, copyright notice.

Table XIV-5. Tablplot menu items.

Menu item	Function
File, Open File	Read a new solution file.
File, Edit File	Edit a Quikplot data file or other text file.
File, File Statistics	Report current SF.INI settings and number lines of data table read.
File, Save Data	Save the present data to a tab-delimited text file.
File, Write QKP File	Save the present data to a Quikplot input file.
File, Write TBL File	Save the present data to a new Tablplot input file.
File, Exit	End the program.
Edit, Edit Column	Start a dialog window to manipulate arithmetically a data column.
Edit, Combine Columns	Start a dialog window to combine algebraically two data columns.
Data, X = First Available	Abscissa is the first data column that is not constant in all rows.
Data, Y = All Other Columns	Selects all columns except the current abscissa for the ordinate arrays.
Data, Select X and Y	Select the abscissa and multiple ordinate arrays from the list of columns.
Data, Sort by Column	Select the column by which the entire table is sorted.
HardCopy, Start	Make a hardcopy of the present display.
HardCopy, Options	Select options for the active hardcopy driver.
HardCopy, Driver	Show the list of hardcopy drivers. The active driver is checked (✓).
Fit, None	Forget any stored fitted coefficients.
Fit, Linear	Fit selected data to straight line.
Fit, Quadratic	Fit selected data to a curve quadratic in X.
Fit, Cubic	Fit selected data to a curve cubic in X.
Fit, Fourth Power	Fit selected data to a fourth order polynomial in X.
Fit, Fifth Power	Fit selected data to a fifth order polynomial in X.
Fit, Square Root	Fit selected data to constant plus √X term.
Fit, Select Data	Select data column to fit.
Fit, Y Value vs X	Start a dialog window to interpolate values on the fitted curve.
Fit, Residuals	Display the residuals of the fit.
Display, Line Widths	Start a dialog window to select line widths of display items.
Display, Y Label	Define the ordinate label.
Display, Marker Size	Start a dialog window to set the marker size and type.
Display, Point Labels	Start a dialog window to label data points by a selected column's data.
Display, Redraw Plot	Redraw the plot (e.g., after changing window size by a large amount).
Display, Reset Defaults	Reset all display parameters to SF.INI settings or default values.
Display, X Log Scale	Make X axis a logarithmic scale. Setting is checked (✓) when active.
Display, X Linear Scale	Make X axis a linear scale. Setting is checked (✓) when active.
Display, Y Log Scale	Make Y axis a logarithmic scale. Setting is checked (✓) when active.
Display, Y Linear Scale	Make Y axis a linear scale. Setting is checked (✓) when active.
Display, Lock Scale	Prevent ordinate scale changes while selecting columns, if checked (✓).
View, Show Title	Display the plot title if checked (✓).
View, Connect Points	Connect points with a line if checked (✓).
View, Curve Labels	Display the curve labels if checked (✓).
View, Markers	Display markers at each data point location if checked (✓).
View, Point Labels	Display selected column value near each data point if checked (✓).
View, Show Fit	Display the fitted curve if checked (✓).
View, Show All	Display all selected columns when displaying fit if checked (✓).
Zoom, Forward	Go forward one zoom level.
Zoom, Backward	Go back one zoom level.
Zoom, Original	Go back to the original display (zoom level 1).
Zoom, Manual Entry	Start a dialog window to enter plot limits for a zoom level.
Integrate	Start a dialog window to integrate a data column or the fitted curve.

Help, About Tablplot	Brief code description, release date, version number, copyright notice.

1. Display features

Several menu items control the presentation of the data on the screen.

a. Abscissa and ordinate axes

In Quikplot, input-file keywords XLabel and YLabel define labels for the horizontal (X) and vertical (Y) axes. Axis labels can be up to 120 characters long. The code reduces the font size, if necessary so the text all fits on the screen. The keyword appears alone on one line followed by the line of text.

Tablplot does not use the XLabel entry. The code labels the ordinate using the supplied AxisLabels if the ordinate includes only one column. For multiple columns, Tablplot uses the YLabel entry. You can change YLabel after the program is running using menu item Display, Y Label. The dialog box has a check box that forces use of the YLabel text even when displaying one column of data.

SF.INI variable AxisLineWidth sets the initial line width in pixels of the boundary axes. The default setting is 1 pixel. If the axis line width is 2 pixels or more, then all the text is bold. After the program is running, select menu item Display, Line Widths to change the line width.

b. X and Y scales, zoom levels

You can preset the X and Y scales in the input file using the XScale and YScale lines. Each line includes the minimum and maximum scale values and the can include the optional keyword LOG to select a logarithmic scale. The program ignores equal scale limits. If you omit either XScale or YScale, the code sets a linear scale according to the range of data encountered in the file.

Once the program has started, there are two methods for changing the scale. One method uses the mouse to define two corners of a rectangle in the current display area. Click and hold down the left mouse button to anchor one corner of the rectangle. Move the mouse to frame the desired area. When you release the left mouse button, the display zooms in on the area within the rectangle. The code assigns the expanded area to the next numbered zoom level (overwriting any selection already occupying that level). If you are already at zoom level 9, the new display replaces the level 9 settings.

The other method uses a dialog box to enter the scale values. Select menu item Zoom, **M**anual Entry (or press the “M” key) to brings up the dialog window. Enter minimum and maximum X and Y coordinates for the new display area, and assign these settings to one of the *zoom levels* already in use, or to the next level available. You can define up to nine zoom levels.

The status bar displays the current zoom level and the highest zoom level defined so far. Step backwards or forward though zoom levels with the menu items Zoom, Forward (or the “F” key) and Zoom, Backward (or the “B” key). Menu item Zoom, Original (or the “O” key) returns to zoom level 1. You can also type one of the digits 1 through 9 to go directly to a particular level. When you end the program, a preference file contains data

describing all the current screens that you have set up. Upon restarting the same input file, the code starts with the last screen you had displayed.

c. Plot title and coordinate axes

Menu item View, Plot Title toggles the title at the top of the graphic screen on and off. A one- or two-line plot heading appears above the graph is the menu item is checked (✓). The heading lines can be up to 120 characters long. The code reduces the font size, if necessary so the text fits on the screen.

Use the Title and Subtitle keywords in the input file to enter two lines for the plot heading. Each keyword appears alone on one line followed on the next line by the title or subtitle. (Tablplot also recognizes the old method where both lines follow the Headings keyword.) You can specify the justification of the heading lines with the keywords Left, Center, or Right. Only the last of these lines to appear in the input file has any effect. The default is to left justify the heading lines.

The plot heading includes the name of the data file and the file's time and date information. This line appears in a small font, right justified, just above data rectangle. Use the NoFileID or NoTimeDate keywords in the data file to omit the indicated information.

Use input file keywords LeftFooter and RightFooter to enter text strings to appear along the bottom edge of the plot. Each keyword appears alone on one line followed on the next line by the footer text.

d. Marker size and type

Menu item View, Markers toggles the markers at each data point location on and off. The markers appear on the plot if this menu item is checked (✓). Menu item Display, Marker Size starts a dialog window in which you can set the marker size and type. The allowed range of sizes is from 0.1% to 10% of the screen width. Markers smaller than 0.1% of the screen width are difficult to see. If you specify a smaller size, the code uses 0.1%. The dialog box displays two choices for the marker type, either circles for all curves or a different marker for each curve.

You can preset the marker size and type in the input file. The absolute value of the MarkerSize entry specifies the size as a percentage of the screen width and the sign selects either circles for all curves (positive value) or different makers for each curve (negative value). If the MarkerSize is absent (or if its magnitude exceeds 10), then the code will select a marker size based on the number of data points in the file.

If keyword NoMarkers appears in the input file, then the markers will not be displayed when the code first starts. After the program starts, you can turn the markers on using menu item View, Markers.

e. Curve labels

Menu item View, Curve **L**abels toggles on and off the curve labels. Tablplot labels curves with the information in the table of CurveLabels (if any) in the input file. In Quikplot, the labels come from the Data lines. For plots containing more than 3 or 4

curves, adding the labels may take a little extra time as the code searches for unambiguous locations near the respective curves.

Neither Tablplot nor Quikplot attempts to label the curves when displaying more than 10 curves.

f. Line widths

Select menu item Display, Line Widths (or the "W" key) to specify lines widths in pixels of data curves and the X and Y axes. SF.INI configuration variables CurveLineWidth and AxisLineWidth control the initial line widths used for Quikplot and Tablplot displays. The default line width is 1 pixel. If the axis line width is greater than 1 pixel, then the screen text will use a **bold** font. The plotting code's preference file stores the most recent line-width settings, which the code will use the next time it starts (overriding the SF.INI settings).

The line-width settings affect both the screen display and the line thickness for hardcopy output. The HardCopy, Options menu includes a setting for line thickness in tenths of a point. The default setting of 0.5 points corresponds to approximately 1 pixel on the display screen. When you start a hardcopy, the code first checks the current setting for the hardcopy line thickness. Each time the line width of the display screen changes in accordance with current settings, the code finds the hardcopy line thickness by multiplying the line width times the initial hardcopy line thickness. For example, if the data curves are 2 pixels wide, and the initial hardcopy line thickness is the default 5 tenths of a point, then the curve thickness on the hardcopy will be 1 point (10 tenths).

2. Arithmetic operations in Quikplot and Tablplot

In Quikplot, you can edit the X- or Y-coordinate data for any or all data sets by performing simple arithmetic operations. Menu items Edit, X Data and Edit, Y Data bring up a dialog box in which you can perform one of the actions in Table XIV-6 on selected data sets. These operations permanently change the data until you either read the file again or use the appropriate command to change it back.

In Tablplot, you can edit an individual data column. Menu item Edit, Edit Column brings up a dialog box in which you select the column from a pull-down list, and choose one of the actions in Table XIV-6. You can assign the edited data either to the same column number or to another column number. The last column number available is one larger than the current number of columns. Assigning the result to this last column number preserves all the other data columns. Assigning the data to a column number that already contains data overwrites the original data. You can restore the data by re-reading the file (e.g., by using menu item File, Open). The dialog includes three text fields in which you can enter the column title, axis label, and curve label. Check or un-check as appropriate the box labeled "Include in current plot." If you assign the new data to the column number that is the current abscissa, this box is checked automatically and cannot be un-checked.

Table XIV-6. Arithmetic operations.

Action
Add a constant value to selected data.
Subtract selected data from a constant.
Multiply selected data by a constant.
Divide selected data into a constant.

3. Interchanging the X and Y axes in Quikplot

Quikplot menu item Display, **S**wap XY interchanges the X and Y data. The program retains scale limits, but it cancels any fitted curve. To switch back to the original orientation, select the menu item again. This function is not available in Tablplot.

4. Sorting and point labeling in Tablplot

The default behavior in Tablplot is to sort the data to be plotted by the abscissa. There are times when you may not wish to sort the data or you wish to sort the data by some other data column. Menu item Data, Sort by Column brings up a dialog box in which you can choose how to sort the data table. The two choices are to resume sorting the data by the selected abscissa or to sort by a selected data column. When you sort by a selected column, the code performs the sort immediately, then turns off subsequent sorting by the abscissa. If you select the option to sort by the abscissa, Tablplot performs the sort by the current abscissa immediately, then turns on subsequent sorting by the abscissa.

To perform no sorting, insert the keyword NoSort in the Tablplot input file. Once the data table has been sorted, it cannot be undone without restarting the program.

One reason to sort the data by a column other than the abscissa is to view a trajectory of points in the X-Y plane as a function of some other variable. For example, one may plot the rf reflection coefficient in the complex plane, but sort the points according to the rf frequency. Menu item Display, Point Labels brings up a dialog box for selecting which column to use when labeling the data points. You can select which point to start with, how many points to skip between labeled points, and the number of significant digits in the labels. There are two choices for the label orientation. If the selection is Automatic, then Tablplot chooses the orientation angle of each label based upon the proximity of nearby points. The other choice is to provide a single angle between –90 and +90 degrees to use for all the labels. When the dialog box first appears the box “Activate point labeling” is checked. Uncheck the box to turn off point labeling. Menu item View, Point Labels toggles point labeling on and off.

Several optional input file keywords affect the sorting and point labeling features. Keyword NoSort turns off sorting by the abscissa before plotting. SortByColumn sorts the data table by the column number that appears on the same line and also turns off sorting by the abscissa. Keyword LabelByColumn activates the point labeling feature using the column number that appears on the same line. Keywords FirstPointLabeled, SkipBetweenLables, LabelSignificantDigits, and LabelOrientation set initial values for these items that appear in the Display, Point Labels dialog box.

5. Constructing a new data column in Tablplot

Menu item Edit, Combine Columns brings up a dialog box in which you can create a new data column from an algebraic combination shown in Table XIV-7. The dialog has two pull-down lists from which you select columns A and B.

You also can assign the new data to any column number. The last column number available is one larger than the current number of columns. Assigning the result to this last column number preserves all the other data columns. Assigning the data to a column number that already contains data overwrites the original data. You can restore the data by re-reading the file (e.g., by using menu item File, Open). The dialog includes three text fields in which you can enter the column title, axis label, and curve label.

Check or un-check as appropriate the box labeled "Include in current plot." If you assign the new data to the column number that is the current abscissa, this box is checked automatically and cannot be un-checked.

Table XIV-7. Tablplot algebraic operations.

Operation	Description
A+B	Add the two data columns together.
A–B	Subtract column B data from column A data.
A*B	Multiply the two data columns together.
A/B	Divide column A data by column B data.

6. Selecting data to display

Menu item Data, Select in Quikplot or Data, Select X and Y in Tablplot brings up a dialog box to select which data to display. In Quikplot, you choose from the list of labels that appeared on the Data lines. For Data lines without labels, the code uses the form "Set nn," where nn is location of the Data/EndData section in the input file. Quikplot menu item Data, All immediately selects all data sets without the need of the dialog box.

In Tablplot, the dialog box allows you to chose one column for the abscissa and any number of columns for the ordinate arrays from the list of column titles. Tablplot menu item Data, X = First Available sets the abscissa to the first column of data that does not have a constant value in all rows. Menu item Data, Y = All Other Columns selects all columns except the current abscissa for the ordinate arrays.

Where multiple selections are allowed, the dialog box has buttons to select or clear all entries. You also can use standard Windows techniques to select items. Hold down the Ctrl key to toggle individual entries. Drag the mouse or hold down the Shift key to select a range of items.

a. Locking the Y-axis scale in Tablplot

Menu item Display, Lock Scale determines whether the program re-scales the Y axis as you select or deselect columns for the ordinate. If checked (✓), the scale will not change. The default setting is off. You also can insert keyword LockScale in the input file to set this switch.

7. Fitted curves

The Fit menu item selects a fitted curve to display with the data. Table XIV-8 shows the available curves. The default setting in Quikplot fits the curve to data set 1. For multiple data sets in Quikplot, click on Fit, Select Data to bring up a dialog box to choose one or more data sets to include in the fit. Click the button Select All Data to include all the data, or use standard Windows techniques to select items. Hold down the Ctrl key to toggle individual entries. Drag the mouse or hold down the Shift key to select a range of items.

In Tablplot, the independent variable is always the current abscissa, and the dependent variable is any one of the data columns. By default the code uses the first selected column for the fit. The selected columns are those highlighted in the Data, Select X and Y dialog box.

Table XIV-8. Fit menu items for selecting a fitted curve.

Menu item	Description
Fit, None	Forget any stored fitted coefficients.
Fit, Linear	Fit selected data to straight line.
Fit, Quadratic	Fit selected data to a curve quadratic in X.
Fit, Cubic	Fit selected data to a curve cubic in X.
Fit, Fourth Power	Fit selected data to a fourth order polynomial in X.
Fit, Fifth Power	Fit selected data to a fifth order polynomial in X.
Fit, Square Root	Fit selected data to constant plus √X term.

The program writes the fitted equation in the log file. The root-mean-square (RMS) deviation of the data from the fit appears after the equation.

a. Interpolating a value from the fitted curve

Menu item Fit, Y **V**alue vs X opens a dialog box for computing the Y value of the current fitted curve for a given X value. Continue typing X values to interpolate more points.

b. Plotting the residuals of the fit

Menu item Fit, Residuals plots the residuals of the fit. Residuals are differences between the fit and the data. The scale is percentage of has average absolute value of the Y data.

c. Integrating the fitted curve or the data

The **I**ntegrate menu item opens a dialog box for integrating either the fitted curve or a data set or data column between selected limits. The code integrates data using the trapezoidal rule. The default limits of integration are the current X plotting limits. Edit these entries as necessary and click the Get Value button to compute the integral. Results appear in a scrollable window and also in the log file.

D. Output from the plotting codes

Quikplot and Tablplot write log files listing the results of the some calculations performed while running the code. The codes also write graphics files using one of the available hardcopy drivers, and a *preference file* containing saved screen settings to be used the next time the program starts. The codes can produce tab-delimited text files for

supplying the data to other applications. Program Tablplot can also create new Tablplot and Quikplot files that contain the currently selected data columns.

1. Log file

Quikplot and Tablplot write log files Quikplot.Log and Tablplot.Log. The log file lists the results of the some calculations performed while running the code, such as the coefficients of fitted curves, interpolated values on fitted curves, integrals of the data or a fitted curve.

If SF.INI variable CreateNewLog = Yes, then the code creates new a log file on startup. This file is in the directory that is current when the code starts. If CreateNewLog = No, then the code appends to any existing log file in the startup directory.

2. Hardcopy of graphics screens

The HardCopy, Driver menu lists several software drivers for producing hardcopy graphics files or printing directly to a printer using the Windows Print Manager. Select HardCopy, Start (or the "C" key) to create the hardcopy output. The plotting code re-plots the present screen using the active driver. You can set a preference for the hardcopy driver in file SF.INI. A check mark (✓) appears next to the currently selected driver. The software drivers have configurable options that you can edit from the HardCopy, Options menu.

The HardCopy, Options menu also includes the full path and name of the graphics output file (if any). You can choose a different name, if desired, but we recommend that you retain the suggested filename extension. In the case of BMP/PCX/PNG bit-image driver, the filename extension will correspond to one of these three graphic types. If you select a different graphic type in the Options menu, and if you do not alter the default filename in any way, then the code will generate the a new default filename with the proper extension. However, the new name will not immediately appear in the File field. If you close the Options dialog box and reopen it, the new filename will appear. If you modify the filename, be sure that the extension corresponds to the correct graphic type. The code does not check the extension if you override the default filename.

If the active driver is the BMP/PCX/PNG bit-image driver, then the code sets the default image size to match the current screen size. If you resize the window, the image size also changes. If you want a different size image, you can override the settings HardCopy, Options menu and start a hardcopy before resizing the image.

Each hardcopy driver's Options menu includes a setting for the line thickness in tenths of a point. Both this setting and the screen line widths that you select for the curves and axes affect the hardcopy line thickness as discussed in section C.1.f. For a discussion of the graphics export formats, refer to the WSFplot chapter.

3. Quikplot and Tablplot preference files

Quikplot and Tablplot each write a *preference file* containing saved screen settings to be used the next time the program starts. The name and location of the file depends upon the SF.INI variable SaveSettingsTo. The choices are:

SaveSettingsTo = Local Directory
SaveSettingsTo = Individual File
SaveSettingsTo = *filename*
SaveSettingsTo = *directory*

where *filename* is the name of an actual file (including path) to be created and *directory* is the name of an existing directory. If variable SaveSettingsTo = Local Directory (the default), then the code creates file QplotPRF.TXT or TplotPRF.TXT in the current directory. If variable SaveSettingsTo = Individual File , then the code writes an output file named after the input file with characters PRF appended and with extension TXT. For any setting other than "Local Directory" or "Individual File," the code checks first to see if the entry is a valid directory name. If so, it reads or creates a preference file named after the program name in that directory. If the entry is not a directory, but is an existing file (or the file can be created), then that file is the preference file. Otherwise, the code assumes SaveSettingsTo = Local Directory.

The preference file is useful when you need to look at the same X-Y plotting area after making changes in the input data. The preference file includes the following information:

1. window size and location, and locations of previously opened dialogs,
2. currently active hardcopy graphics driver,
3. currently active graphic elements (title, connecting lines, curve labels),
4. line widths of curves, and axes,
5. problem filename and first title line,
6. linear or log settings for each axis,
7. boundaries for all zoom levels, and
8. current zoom level.

If SF.INI variable UseSavedSettings = Yes, then Quikplot or Tablplot will attempt to use information stored in the preference file. The codes always uses items 1 through 4, but they use items 6 though 8 only if the present filename and title match the information in item 5. If you start a plotting code and would rather not use previously saved screen settings, select menu item Display, Reset **D**efaults (or press the "D" key). You also can simply delete the preference file before starting the program to accomplish the same thing. Deleting the preference file also restores the original window sizes and locations.

4. Tab-delimited text files

Menu item File, Save Data creates a file of tab-separated data readable by other applications (e.g., Microsoft Graph). The default extension is TXT. These files contain no plotting-program keywords. When you create a TXT file from Quikplot, the X and Y axis labels appear on the first line of each data set. Using Tablplot, the axis labels and curve labels appear on lines 1 and 2 separated by tabs. The data following the axis labels, also are separated by tabs rather than spaces.

5. New Quikplot and Tablplot files

In Tablplot, menu item File, Write TBL File command generates a new input file containing a subset of the original data. Menu item File, Write QKP File generates a Quikplot input file using the currently selected data. Tablplot names the new data file by appending a sequence number to the original filename. These options do not exist in Quikplot.

One use of menu item File, Write TBL File is write a file containing new columns of data that you constructed from the original data using algebraic operations or combinations of data columns. Another use is to discard unwanted columns from the table.

E. Sample input files

The Examples\Plotting subdirectory includes sample input files for the plotting codes. Your installation will include additional subdirectories under Examples for Poisson Superfish problems. To view the plots they produce, run these sample files.

1. Example data file for Quikplot

Here is a sample Quikplot data file.

```
; File: QDEMO.QKP
; Data on Electro-Craft motor controller reading versus voltage.

Center
Title
Voltage versus Electro-Craft motor controller reading

LeftFooter
Use this area for other information regarding the data.

RightFooter
Right footer area.

Xscale 0 5000
Yscale 0 12

Xlabel      ! Line following labels the X axis
Reading

Ylabel      ! Line following labels the Y axis
Voltage (volts)

Data      Set 1
; 58 .4                          ! Unused entries. Remove the semicolon to include in the plot.
; 137 .6
224 .8
315 1
408 1.2
502 1.4
597 1.6
692 1.8
```

```
784 2.
929 2.3
977 2.4
EndData

Data Set 2
1001 2.45
1075 2.6
1123 2.7
1268 3
1487 3.45
1756 4
2000 4.5
2981 6.5
3005 6.55
3964 8.5
3999 8.57
4703 10.
EndData
EndFile
```

2. Example data file for Tablplot

Following is a sample Tablplot data file that includes data from a design program from radio-frequency quadrupole (RFQ) linacs.

```
; File TDEMO.TBL  Sample input file for Tablplot

Center
Title
Sample Tablplot file for RFQ design parameters, Scale shows: Aperture a (mm);
SubTitle
Radius r0 (mm); Energy W (MeV); Modulation m; Synchronous Phase phi

LeftFooter
Use this area for other information regarding the data.

RightFooter
Right footer area.
NoTimeDate

xscale 0 2.2
yscale 0 3.5
LockScale

Abscissa  13
Ordinate  8 9 11 3 7 6
```

```
Titles
Cell number
Vane voltage
Energy
Beta
Ezero
SQRT(10A)    :*10  :**.5
sin(Phase)   :*-0.017453293 :sin   ; sin assumes angles in radians
Aperture     :*  10
Modulation
B
R0           :*10
Cell length
Position     :*   0.01
Endtitles

CurveLabels
N
V
W
beta
E0
SQRT(10A)
-sin(phi)
a
m
B
r0
L
Z
EndLabels

AxisLabels
Cell Number
Vane Voltage (kV)
Energy (MeV)
Beta
Ezero (MV/m)
SQRT(10A)
sin(phi)
Aperture (mm)
Modulation
B
R0 (mm)
Cell Length (cm)
Position (m)
EndLabels

; Design code output
;nc  v    ws   beta ez   capa  phi    a    m     b    r0   cl    tl
data
0       .071    .0350   .0086   .000    .0000   -90.0   .261    1.000   5.423   .261    .303    .00
5       .071    .0350   .0086   .014    .0006   -89.8   .261    1.002   5.423   .261    .303    1.51
10      .071    .0350   .0086   .084    .0036   -88.5   .260    1.014   5.423   .261    .303    3.03
15      .071    .0351   .0087   .153    .0065   -87.3   .258    1.026   5.423   .261    .303    4.55
20      .071    .0353   .0087   .222    .0095   -86.1   .257    1.037   5.423   .261    .304    6.07
25      .071    .0356   .0087   .291    .0125   -84.9   .255    1.049   5.423   .261    .305    7.59
```

30	.071	.0360	.0088	.360	.0156	-83.6	.254	1.061	5.423	.261	.307	9.12
35	.071	.0366	.0088	.417	.0182	-82.4	.253	1.070	5.423	.261	.309	10.66
40	.071	.0374	.0089	.475	.0210	-81.2	.252	1.079	5.423	.261	.312	12.21
45	.071	.0384	.0091	.537	.0241	-79.9	.251	1.089	5.423	.261	.316	13.78
50	.071	.0398	.0092	.603	.0275	-78.6	.250	1.099	5.423	.261	.322	15.38
55	.071	.0416	.0094	.668	.0311	-77.3	.249	1.108	5.423	.261	.329	17.01
60	.071	.0437	.0097	.708	.0339	-76.0	.248	1.112	5.423	.261	.337	18.68
65	.071	.0463	.0099	.752	.0370	-74.6	.248	1.116	5.423	.261	.346	20.39
70	.071	.0493	.0103	.798	.0405	-73.2	.247	1.121	5.423	.261	.357	22.15
75	.071	.0529	.0106	.847	.0445	-71.7	.247	1.126	5.423	.261	.370	23.98
80	.071	.0572	.0110	.883	.0483	-70.2	.246	1.128	5.423	.261	.385	25.87
85	.071	.0622	.0115	.913	.0521	-68.6	.246	1.130	5.423	.261	.401	27.85
90	.071	.0680	.0120	.942	.0561	-66.9	.246	1.132	5.423	.261	.419	29.91
95	.071	.0746	.0126	.968	.0605	-65.2	.246	1.134	5.423	.261	.439	32.06
100	.071	.0827	.0133	1.046	.0688	-62.5	.245	1.144	5.423	.261	.463	34.33
105	.071	.0928	.0141	1.139	.0793	-59.4	.243	1.156	5.423	.261	.490	36.72
110	.071	.1058	.0150	1.258	.0936	-56.0	.241	1.174	5.423	.261	.523	39.27
115	.071	.1229	.0162	1.422	.1140	-52.3	.238	1.201	5.423	.261	.563	42.00
120	.071	.1459	.0176	1.641	.1435	-48.3	.234	1.240	5.423	.261	.613	44.96
125	.071	.1779	.0195	1.944	.1877	-44.0	.227	1.303	5.423	.261	.676	48.21
130	.071	.2244	.0219	2.385	.2585	-39.3	.217	1.412	5.423	.261	.759	51.83
135	.071	.2950	.0251	2.950	.3667	-35.0	.200	1.600	5.417	.261	.866	55.94
140	.071	.3818	.0285	2.749	.3887	-34.8	.199	1.616	5.357	.263	.986	60.62
145	.071	.4733	.0318	2.585	.4069	-34.6	.198	1.634	5.289	.265	1.100	65.90
150	.071	.5689	.0348	2.453	.4232	-34.4	.197	1.654	5.215	.266	1.208	71.72
155	.071	.6683	.0377	2.344	.4384	-34.2	.197	1.676	5.134	.269	1.310	78.07
160	.071	.7713	.0405	2.255	.4530	-33.9	.196	1.699	5.047	.271	1.409	84.92
165	.071	.8779	.0432	2.180	.4672	-33.7	.196	1.724	4.953	.273	1.504	92.25
170	.071	.9881	.0459	2.116	.4811	-33.4	.196	1.751	4.853	.276	1.597	100.0
175	.071	1.101	.0484	2.062	.4950	-33.1	.195	1.779	4.748	.279	1.687	108.3
180	.071	1.219	.0509	2.015	.5087	-32.7	.195	1.809	4.637	.283	1.775	117.0
185	.071	1.340	.0534	1.973	.5223	-32.4	.195	1.841	4.520	.286	1.862	126.1
190	.071	1.464	.0558	1.936	.5358	-32.1	.195	1.874	4.398	.290	1.947	135.7
195	.071	1.593	.0582	1.904	.5492	-31.7	.195	1.908	4.271	.294	2.031	145.7
200	.071	1.725	.0606	1.874	.5625	-31.3	.195	1.944	4.138	.299	2.114	156.1
205	.071	1.860	.0629	1.847	.5757	-30.9	.196	1.981	4.000	.304	2.196	166.9
210	.071	1.999	.0652	1.821	.5886	-30.5	.196	2.019	3.856	.310	2.276	178.1
215	.071	2.142	.0675	1.798	.6014	-30.1	.197	2.059	3.708	.316	2.357	189.7
220	.071	2.289	.0697	1.776	.6140	-29.6	.198	2.100	3.554	.323	2.436	201.7
225	.071	2.439	.0720	1.755	.6263	-29.2	.199	2.143	3.396	.330	2.515	214.2
227	.071	2.500	.0729	1.747	.6312	-29.0	.200	2.160	3.331	.333	2.546	220.0

EndData
EndFile

XV. Utility Programs

A. List35: lists the contents of the binary solution file

Post processor programs such as SFO, Force, and WSFplot read information in the binary solution file and display the results in a variety of useful formats. List35 permits the user to examine the contents of the solution-file arrays. List35 writes the text file TAPE35.TXT. The binary solution file contains several data arrays and the problem variables. Automesh writes a complete description of the mesh geometry. Fish, CFish, Poisson, and Pandira the Superfish or Poisson solution, consisting of either the rf magnetic field (for Superfish problems), vector potential (for Poisson and Pandira magnet problems), or the scalar potential (for Poisson and Pandira electrostatic problems) at each mesh point. Because of symmetry, rf magnetic field or the vector potential can have only one nonzero component. The codes store a single number at each mesh point: H_z for Superfish problems in Cartesian coordinates, H_ϕ for Superfish problems in cylindrical coordinates, A_z for Poisson and Pandira problems in Cartesian coordinates, and rA_ϕ for Poisson and Pandira problems in cylindrical coordinates.

To start List35, double-click on the solution file with the T35 extension, or right-click on the T35 file and select Create List. You can also use a command line to start the code:

List35 *full* *T35file*

Both command-line parameters are optional and they can be in either order if both appear on the line. The *full* parameter is just the character string “full” and instructs the program to include data for mesh points that are not part of the problem geometry. The filename *T35file* is the name of a binary solution file. It is usually not necessary to enter the name of the binary solution file because the code will find the name of the solution file to open in file TAPE35.INF. You can always omit the *T35file* when starting List35 immediately after running any other Poisson Superfish code. The configuration file SF.INI included these original settings:

```
[Global]
TAPE35Extension = T35        ; Change only if the extension conflicts with another program
UseTAPE35Extension = Yes
AutoOpenTAPE35 = LastUsed
```

The first two settings control the name of the binary solution file and the third setting declares a preference for opening the last used solution file (rather than the one last generated by Automesh, if they are different). For these SF.INI settings and Automesh input file PROB1, the name of the binary solution file is PROB1.T35. List35 writes a text file named after the Automesh input file, but with extension TXT.

If you want to start List35 on a different solution file, the *T35file* command-line entry must include the filename extension .T35. For example, to list solution arrays in a file generated from Automesh input file OLD1, use the following command:

List35 OLD1.T35

The program lists data from each record that it finds. The first table is the list of problem variables that appears in the OUTxxx files written by the other codes. The next table

contains information in Table XV-1 about the region materials and source terms that Automesh writes in the TAPE36 file.

Table XV-1. Column headings for the region material table.

Heading	Definition
Reg.	Region number.
Mat.	Material code.
Density	Current density.

For Superfish problems the List35 output text file includes the segment data needed in SFO for power and frequency shift calculations. This information is stored in two solution-file arrays. The first array contains the indices of all the boundary points. The second array stores pointers to the starting and ending points for each segment in the boundary-point array. List35 makes two tables from this data. Both tables include the K and L coordinates associated with each mesh-point index.

The next file entry lists mesh-point data described in Table XV-2. The values of K and L do not actually appear in the binary solution file. List35 provides them for convenience. For a full list of the array, points not used in the problem solution will have X and Y values equal to the special “indefinite” number –1.0D+99.

Table XV-2. Column headings for the mesh-point data table.

Heading	Definition
IR	Location in the array (often called IROW in the codes).
K	Logical coordinate along the abscissa.
L	Logical coordinate along the ordinate.
X	Physical coordinate along the abscissa.
Y	Physical coordinate along the ordinate.
AVECTOR	RF field (Superfish); vector or scalar potential (Poisson, Pandira).
UP	Region number of the point’s upper triangle (array IREGUP).
DN	Region number of the point’s lower triangle (array IREGDN).
KS	Array KSCAT.
KF	Array KFILT.
NG	Array NGO.

For Poisson and Pandira problems, the binary solution file includes additional data after the mesh-point data. Arrays JNDEX and JUP supply information to Poisson and Pandira about the material in triangles around each point. Complex Superfish problems (for program CFish) may include an another array that contains the imaginary part of the magnetic field on multiple drive points. The table containing the solution array repeats the logical and physical coordinates from the mesh table.

1. LAST35, indicates the last program to update the binary solution file

LAST35 is an integer that indicates which program wrote to the binary solution file. Table XV-3 lists the possible values. Program List35 reports the name of the program as it writes the information to the output text file.

Table XV-3. LAST35 code numbers.

LAST35	Program
1	Automesh
2	Fish
3	CFish
4	SFO
5	Poisson
6	Pandira

B. SFOtable: make Tablplot file from families of SFO files

SFOtable reads families of SFO output files and makes a Tablplot input file for displaying cavity parameters. The tuning programs (CCLfish, CDTfish, DTLfish, ELLfish, MDTfish, RFQfish, and SCCfish) create the SFO output files. SFOtable scales parameters for fixed E_0, E_0T, peak electric field, or peak power density. E_0 is the average axial electric field and T is the transit time factor. For cylindrically symmetric Superfish runs (created by all tuning codes except RFQfish), the table of up to 20 columns has entries from the following list:

- Beta
- Beam energy
- Up to 10 tuning-code setup parameters
- E_0
- E_0T
- Peak electric field
- Peak power density
- Transit time factor
- Shunt impedance
- ZT^2
- Cavity Q
- Power
- Average magnetic field at coupling slot location
- Peak magnetic field

The default scaling is for fixed E_0. SFOtable omits the data column that corresponds to the scaling parameter. If a large number (8 to 10) tuning-code setup parameters are included, then some of the columns at the end of the list will be omitted.

For Superfish runs created by RFQfish, the keyword CartesianCoordinates must appear on a single line in the SFOtable control file. Then the table has entries from the following list:

- Power
- Peak electric field
- Peak power density
- Peak magnetic field
- Cavity Q
- Up to 10 tuning-code setup parameters

1. Starting program SFOtable

To start SFOtable, double-click on a file with the SFT extension, or right-click on the SFT file and select Open. To open the file in Notepad, right click on the SFT file and choose Edit. You can also use a command line to start the code:

SFOtable *controlfile*

where *controlfile* is the name of the control file. It sets the normalization and contains filename information for the families of SFO data files. If the command line contains no filename the program will prompt for it. Enter a complete file specification to override the default filename of SFOTBL.CTL.

2. Files used in SFOtable

Complete file specifications consist of the filename of up to eight characters and an extension of up to three characters separated by a dot (.). SFOtable reads a control file and writes a Tablplot output file. It also reads groups of SFO output files whose names appear in the control file. Program SFO writes an output file named after the Automesh input file, but with extension SFO. This file includes a summary of cavity parameters. Keywords FILEname_prefix and SEQuence_number in the SFOtable control file select the names of these files to include in the Tablplot file.

The SFOtable output file is an input file for programs Tablplot. The default name of the file is SFODATA.TBL. Use the OUTPUT filename keyword to specify another name. The file always has extension TBL.

3. The SFOtable control file

The SFOtable control file defines parameters for a Tablplot file, which will contain data from up to 50 SFO files. The default name is SFOTBL.CTL, but it can have any name or extension. The program first looks for the exact filename you entered. If it cannot find that file, it looks for the file you entered with no extension. If that file does not exist, it looks for the file you entered with extension CTL.

SFOtable recognizes the keywords listed in Table XV-4. Keywords can be in upper, lower, or mixed case. The list below shows the shortest possible abbreviation in capital letters. Some keywords have synonyms that might be more convenient. You may include comment lines in the control file after a semicolon (;) or exclamation mark (!). The program ignores everything after a comment indicator. It also ignores blank lines. Comments or blank lines may appear anywhere in the file.

Table XV-4. SFOtable control-file keywords.

Keyword	Synonym	Description
;!		These characters indicate a comment.
OUTPUT_filename		Name of the Tablplot file to create.
CartesianCoordinates		Do not search for E0, T, ZTT, etc.
FILEname_prefix		Can include a drive letter and path (default is CELL).
SEQuence_numbers		Two one-to-four-digit integers.
E0	EZERO	Normalize data to E_0 on this line.
E0T	EZEROT	Normalize data to E_0T on this line.
EPeak	EMax	Normalize data to E_{Max} on this line.
POWER_Density	PD, P.D.	Normalize data to peak power density on this line.
INCLude		Add a data column for a tuning-code setup parameter.
EndFile		End of the control file.

a. OUTPUT file, name of the Tablplot file

The SFOtable output file is an input file for programs Tablplot. The default name is SFODATA.TBL. Use the OUTPUT_filename keyword to specify another name, but do not include the extension. The file always has extension TBL.

b. Filenames for SFO files

Two control-file keywords, FILEname_prefix and SEQuence_numbers, specify names of the SFO data files to read. FILEname_prefix is a character string to which SFOtable appends consecutive sequence numbers starting and ending with numbers on the SEQuence_number line. The prefix can include a drive letter and path. Valid sequence numbers used by the tuning programs are from 1 to 9999.

SFOtable adds the extension SFO to make each complete filename. The control file can include up to 200 starting and ending sequence numbers. Redefining the filename prefix between SEQuence_number keywords is optional. For example, suppose these lines appear in the control file:

```
FILEname_prefix      A
SEQuence_numbers     101 to 105
SEQuence_numbers     111 to 115
FILEname_prefix      B
SEQuence_numbers     101 to 105
```

This list defines 15 filenames. The word “to” in the SEQuence_number lines is optional. The first five files are A101.SFO, A102.SFO, A103.SFO, A104.SFO, and A105.SFO. The next five are A111.SFO to A115.SFO, and the last five are B101.SFO to B105.SFO.

c. Field normalization options in SFOtable

SFOtable scales parameters read from the SFO files for fixed E_0, E_0T, peak electric field, or peak power density. If one of the normalization keywords E0, E0T, EPeak or POWER_Density appears in the control file, then SFOtable normalizes the data read from all the SFO files to the value specified. If more than one normalization keyword appears in the file, the last one takes precedence.

Normalizing data to either E_0 or E_0T

E_0 is the average axial electric field in MV/m and T is the transit time factor. You can scale the Tablplot file for either a fixed E_0 or for a fixed E_0T. For example, to calculate parameters corresponding to E_0 = 4.4 MV/m include the following line in the control file:

E0 = 4.4

To calculate parameters corresponding to E_0T = 1.5 MV/m include use the line:

E0T = 1.5

Normalizing data to the peak electric field

EPeak is the peak surface electric field in the cavity in MV/m. For example, to calculate parameters corresponding to EPeak = 20 MV/m include the following line in the control file:

EPeak = 20

Normalizing data to the peak power density

POWER_Density refers to the peak power density in W/cm^{2}on all cell surfaces. For example, to calculate parameters corresponding to 20 W/cm^2 include the following line in the control file:

POWER_Density = 20

d. Including tuning-code setup parameters in the Tablplot file

The tuning programs (CCLfish, CDTfish, DTLfish, ELLfish, MDTfish, RFQfish, and SCCfish) write the geometrical setup parameters near the beginning of the SFO output files. These parameters come from current values specified by the control-file keywords. For RFQfish, they include the first 8 columns of the Data/EndData section of the RFQfish control file. Also, for RFQfish, keyword CartesianCoordinates must appear on a single line in the SFOtable control file.

SFOtable can include up to ten of these parameters as columns in the Tablplot file. To include a tuning-code setup parameter in the plot file, use the following command in the SFOtable *controlfile*:

INCLude *keyword* *label*

where *keyword* is a tuning-code *controlfile* parameter and *label* is an optional string to use as a curve label instead of the *controlfile* keyword. For example, Most of the tuning codes (the exception is RFQfish) use the *keyword* GAP_Length for the length of the drift-tube gap. Here is a line that will add the gap length as a column in the Tablplot file and label the curve with the single letter “g.”

INCLude GAP_Length g

You can select one of the tuning-code setup parameter as the abscissa for the initial Tablplot display by appending the word Abscissa to the Include line for that parameter. For example,

INCLude *keyword* *label* Abscissa

or

INCLude *keyword* Abscissa

e. EndFile, the last line in the file

EndFile is the last line in the control file read by SFOtable. You can add more information to the file without using comment line indicators.

4. SFOtable sample control file and output file

Here is a sample SFOtable control file. It reads 8 SFO files created during a DTLfish session. The program normalizes the data for a constant E_0T product of 1.7 MV/m. It includes columns in the Tablplot file for the face angle, but not for other title-line parameters (which presumably did not vary for the 8 problems included here).

```
; SFOtable control file
OUTPUT_file             RGDTL
FILEname_prefix         RGDTL
SEQuence_numbers        1 to 11
E0*T = 1.73333
INCLude                 Length        L
INCLude                 G_Over_Beta_Lambda          g/bl
EndFile
```

Following is the Tablplot file created by this control file. Numbers in the data columns usually have up to eight significant digits. For this example, they have been shortened to fit all the data on the screen.

```
; File: RGDTL.TBL  06/28/96  11:53:08

Headings
OUTPUT cavity parameters for E0*T =  1.7333 MV/m



SOlid
NoTimeDate

ABscissa 1
ORdinate  6  7  8  9 10 11 12 13
```

Titles
Beta
Beam energy
Length
G_Over_Beta_Lambda
E0
Peak electric field
Peak power density
Transit time
Shunt impedance
ZTT
Cavity Q
Power
Peak magnetic field
ENDTitles

AXis_labels
Beta
Beam energy (MeV)
Length
G_Over_Beta_Lambda
E0 (MV/m)
Emax (MV/m)
Peak power density (W/cm^2)
T*100
Shunt impedance (Mohm/m)
ZTT (Mohm/m)
Cavity Q (10^3)
Power (10^2 W)
Hmax (kAmp/m)
EndLabels

CUrve_labels
Beta
W
L
g/bl
E0
Emax
P.D.
T*100
Z
ZTT
Q/10^3
P/10^2
Hmax
EndLabels

Data

;Beta	W	L	g/bl	E0	Emax	P.D	T*100	Z	ZTT	Q/10^3	P/10^2	Hmax
0.065188	2.002	4.598352	0.167535	2.127722	14.90330	9.222296	81.46413	68.685	45.582	40.1135	15.15444	5.7879
0.072853	2.503	5.139065	0.176513	2.080542	14.03131	9.019511	83.31145	71.442	49.586	41.6799	15.56878	5.7239
0.079775	3.003	5.627322	0.184101	2.050426	13.42662	8.966164	84.53511	73.353	52.420	42.8788	16.12648	5.7069
0.086133	3.504	6.075783	0.190706	2.030964	12.94893	8.972148	85.34519	74.963	54.602	43.8314	16.71589	5.7088
0.092043	4.004	6.492702	0.196636	2.017231	12.57035	9.019982	85.92619	76.232	56.284	44.6078	17.32895	5.7240
0.097588	4.505	6.883813	0.202021	2.007997	12.24758	9.092083	86.32135	77.322	57.615	45.2541	17.94831	5.7469
0.102826	5.005	7.253294	0.206998	2.001300	11.97609	9.182624	86.61021	78.227	58.680	45.7997	18.56840	5.7754
0.107802	5.506	7.604299	0.211646	1.996662	11.73807	9.283127	86.81140	78.997	59.534	46.2666	19.18790	5.8069
0.112550	6.007	7.939280	0.215943	1.995194	11.53349	9.406850	86.87524	79.682	60.138	46.6720	19.83178	5.8455
0.117100	6.507	8.260188	0.220052	1.993674	11.34461	9.523390	86.94147	80.282	60.683	47.0245	20.44809	5.8816
0.121472	7.008	8.568605	0.224006	1.991455	11.15815	9.622331	87.03837	80.886	61.277	47.3322	21.00615	5.9121

EndData
EndFile

C. SegField: make plot files of fields on boundary segments

For rf cavity problems, SegField reads an SFO output file and makes a Tablplot input files for displaying E, H, power density, and radiation pressure along boundary segments. You can supply this to a thermal and mechanical analysis code and then use the mesh modification option in Automesh to read the displaced boundary-point coordinates. The code scales parameters for a specified field normalization. When using the mesh modification option include the line NodesOnly in the SegField input file so the code extracts data only for the mesh-point nodes. (If this line does not appear, the Tablplot file includes points at the midpoint of each triangle leg along the boundary.)

To start SegField, double-click on an input file with the SGF extension or right-click on the SGF file and select Open. To open the file in Notepad, right click on the SGF file and choose Edit. You can also use a command line to start the code:

SegField *controlfile*

where *controlfile* is the name of the control file. It sets the normalization and contains the names of the input and output files. If the command line contains no filename the program will prompt for it. Use the Windows tools described above or enter a complete file specification to override the default filename of SEGFLD.

This code was written for cylindrically symmetric rf cavity problems. The results obtained with other types of Superfish or Poisson problems may be unpredictable.

SegField recognizes the keywords listed in Table XV-5. Keywords can be in upper, lower, or mixed case. The list below shows the shortest possible abbreviation in capital letters. Some keywords have synonyms that might be more convenient. You may include comment lines in the control file after a semicolon (;) or exclamation mark (!). The program ignores everything after a comment indicator. It also ignores blank lines. Comments or blank lines may appear anywhere in the file.

Table XV-5. SegField control-file keywords.

Keyword	Synonym	Description
;!		These characters indicate a comment.
OUTPUT_file		Name of the output Tablplot file.
INPUT_filename		Name of the input file written by the code SFO.
SEGment_numbers		First and last segment numbers of a contiguous boundary path.
E0	EZERO	Normalize data to E_0 on this line.
E0T	EZEROT	Normalize data to E_0T on this line.
EPeak	EMax	Normalize data to E_{Max} on this line.
POWER_Density	PD, P.D.	Normalize data to peak power density on this line.
NodesOnly		Extract data only on mesh-point nodes.
EndFile		End of the control file.

Enter complete file specifications to override the default filenames for the input and output files. Look in the SFO output file summary near the end of the file for valid segment numbers. SegField writes an output file for program Tablplot. The file contains columns of data listed in Table XV-6. The distance S along the boundary is the default

abscissa. For the power density calculation, the code uses the surface resistance for individual segments. The column of electromagnetic radiation pressure on the surface is of interest to designers of superconducting cavities for estimating the Lorentz-force detuning of the cavity. The radiation pressure is given by the equation:

$$P = \frac{1}{4}\left(\mu_0 H^2 - \varepsilon_0 E^2\right),$$

where H and E are the peak values o f the magnetic and electric fields during an rf cycle.. The batch file RUNSCAN.BAT in the FishScan subdirectory runs SegField after solving the on-axis coupled cavity problem.

Table XV-6. Columns in the SegField output file.

Column label	Description
Z	Longitudinal coordinate in cm.
R	Radial coordinate in cm.
S	Distance along the boundary in cm.
E	Electric field in MV/m.
H	Magnetic field in kA/m.
P.D.	Power density in W/cm^2.
P	Radiation pressure in Pa or kPa.

D. Beta: lists particle β as a function of kinetic energy

Program Beta calculates particle velocity β relative to the speed of light for a given kinetic energy W in MeV. The tabulated results also include the relativistic factor γ. Beta also can display W and γ computed from β, or W and β computed from γ. Given a particle rest mass energy and any one of the three quantities W, β, and γ, the code solves the following equations for the other two quantities:

$$\gamma = 1 + \frac{W}{mc^2} \text{ and } \beta = \sqrt{1 - \frac{1}{\gamma^2}}.$$

Start Beta from the Windows Start menu under Programs, Poisson Superfish, Utility Programs. Click on "Energy to particle velocity." In the dialog window, choose a particle or enter a mass in the "Other" section. Particle masses are entered and displayed as either rest mass energies in MeV or as masses in amu. Select the type of calculation to perform and enter a single value (W, β, or γ) or a range of values for a table. You can highlight and copy data (use Ctrl-C) from the scrolling output box and paste it into other applications. The dialog window controls the maximum number of significant digits to display in the results, which are always the second and third columns in the table. The code determines the number of significant digits needed for the first column.

For individual particles, the mass values displayed are the 2002 values recommended by the National Institute of Standards and Technology. Values include (in parentheses) uncertainties in the last two digits.

If you frequently use the program for a particular particle or energy range, use the SF.INI settings to define the initial display preferences.

E. Kilpat: calculate the Kilpatrick field for a given frequency

Program Kilpat calculates the Kilpatrick field limit in MV/m for a given frequency in MHz. For more information on the "Kilpatrick limit", see the paper "A Criterion for Vacuum Sparking Designed to Include Both R. F. and D. C." by W. D. Kilpatrick, Review of Scientific Instruments 28, page 824 (1957). Kilpatrick observed experimentally that the field level in resonant cavities at which breakdown would occur was related to the resonant frequency. T. J. Boyd of Los Alamos expressed Kilpatrick's result in a convenient formula, which is now widely used. The formula relates frequency F in MHz to the Kilpatrick limit E_k in MV/m:

$$F = 1.643 E_k^2 \exp\left(\frac{-8.5}{E_k}\right).$$

Though the Kilpatrick field is no longer considered a limit on the maximum achievable field level, it is still commonly used in reference to the design field level for accelerating cavities. Cleaner surfaces and better vacuum systems are now available compared to ~40 years ago. Field levels well over $2E_k$ have been achieved in some applications. Design field levels for modern accelerating cavities are typically in the range from $1.0E_k$ to $2.0E_k$. Program SFO reports the ratio of a cavity's maximum field to the Kilpatrick field in the output summary.

Start Kilpat from the Windows Start menu under Programs, Poisson Superfish, Utility Programs. Click on "Kilpatrick field factor." In the dialog window, enter a single frequency or a range of frequencies for a table. You can highlight and copy data (use Ctrl-C) from the scrolling output box and paste it into other applications.

Starting Kilpat from the Start menu does not supply any information on the command line. You can also use a command line or a batch file to start the code:

Kilpat [F_1, F_2, ΔF]

where the optional parameters are frequencies in MHz. F_1 is the starting frequency for a table (or a single value if no more parameters appear), F_2 is the ending frequency for the table, and ΔE is the frequency increment.

F. ConvertF: convert frequencies between different conditions

After building an rf cavity, one usually tunes it in the laboratory at low rf power before operating the cavity under vacuum at the design temperature. Program ConvertF provides a convenient method for computing the "target frequency" to use when the measurements are performed in air at a temperature different from the operating temperature. Gases other air (e.g., nitrogen, argon, or helium) also may fill the cavity.

Start ConvertF from the Windows Start menu under Programs, Poisson Superfish, Utility Programs. Click on "Frequency converter." The program displays a dialog box containing a number of input fields and the results of the conversion for the current settings. The most recent results will appear in file XFREQ.TXT after exiting the program. If this file exists upon starting ConvertF, the code uses its current settings. You can select a cavity material from a list of a few materials (copper, aluminum, niobium, and iron). For a copper plated cavity, select the bulk material of the cavity and the cavity temperature. For example, copper-plated aluminum will expand as aluminum. The dialog box includes a selection for the conversion direction, which allows entry of either the measured frequency under ambient conditions or the cavity frequency under vacuum at a given temperature. The program will convert either frequency to the other condition.

The ambient conditions include not only the gas temperature (which may differ from the cavity material temperature), but also the barometric pressure and relative humidity. Temperatures can be entered in either Fahrenheit, Celsius, or Kelvin degrees. Barometric pressure can be entered in either inches or millimeters of mercury. The code will compute the dielectric constant of the humid air and include its effect in the frequency conversion. The user should be aware these important assumptions:

- The entire cavity is made of the same bulk material,
- The cavity temperature is isothermal,
- The shape of the cavity does not distort when under vacuum,
- Effects of rf probes, drive irises, or drive loops are the same under both conditions,
- Coupling to other cavity modes is not considered.

Table XV-7 lists the thermal expansion data used in ConvertF. The data are from the chapter titled "Thermal Expansion, Metallic Elements and Alloys" by Y. S. Touloukian, R. K. Kirby, R. E. Taylor, and P. D. Desai in Thermophysical Properties of Matter, Volume 12, published by IFI Plenum, June, 1975. Within each applicable temperature range let T_{Ref} be the lower temperature of the range. The following polynomial expression gives the percentage change in length at temperature T_{Cav} of the cavity.

$$\frac{\Delta L}{L} = C_0 + C_1\left(T_{Cav} - T_{Ref}\right) + C_2\left(T_{Cav} - T_{Ref}\right)^2 + C_3\left(T_{Cav} - T_{Ref}\right)^3 .$$

We adjusted coefficient C_0 for the lower temperature ranges slightly (<1%) to force exact agreement of $\Delta L/L$ at the temperature boundary with the next highest range. Without this

adjustment the algorithm used in the code would show spurious results when the operating temperature and cavity temperature were near the temperature boundary, but in different ranges. The frequency of a resonant cavity scales as the reciprocal of its linear dimensions. Thus we may write

$$f = C_P \times \frac{1}{L},$$

where C_P is a constant of proportionality. If we apply a differential operator to this equation, we have

$$df = C_P \times d\left(L^{-1}\right) = -C_P L^{-2} dL.$$

Dividing by the original equation gives

$$\frac{df}{f} = -\frac{dL}{L}.$$

Writing this equation in terms of small, but macroscopic, changes in frequency and length we have

$$\frac{\Delta f}{f} = -\frac{\Delta L}{L}.$$

Table XV-7. Thermal expansion data.

Metal	Temperature range	C_0	C_1	C_2	C_3
Aluminum	5 K to 300 K	–0.420	-1.415×10^{-4}	8.077×10^{-6}	-8.656×10^{-9}
Aluminum	300 K to 900 K	0.018	2.364×10^{-3}	4.164×10^{-7}	8.270×10^{-10}
Copper	0 K to 100 K	–0.324	-9.019×10^{-5}	2.942×10^{-6}	2.132×10^{-8}
Copper	100 K to 293 K	–0.281	1.073×10^{-3}	2.904×10^{-6}	-4.548×10^{-9}
Copper	293 K to 1300 K	0.0	1.685×10^{-3}	2.702×10^{-7}	1.149×10^{-10}
Iron	5 K to 300 K	–0.206	-5.905×10^{-5}	3.650×10^{-6}	-3.389×10^{-9}
Iron	300 K to 1185 K	0.007	1.210×10^{-3}	6.504×10^{-7}	-3.140×10^{-10}
Niobium	0 K to 100 K	–0.147	-5.542×10^{-5}	1.723×10^{-6}	9.001×10^{-9}
Niobium	100 K to 293 K	–0.125	5.164×10^{-4}	9.858×10^{-7}	-1.525×10^{-9}
Niobium	293 K to 2300 K	0.0	7.265×10^{-4}	1.026×10^{-7}	-1.032×10^{-11}

ConvertF stores a table of the vapor pressure of water as a function of temperature from 32 F to 138.2 F (0 C to 59 C). These data are from the Handbook of Chemistry and Physics published by the Chemical Rubber Company (CRC). Also in the CRC handbook, one finds the dielectric constant at rf frequencies for common gases. To compute the dielectric constant of gases, ConvertF uses a formula proposed in one of the books from the MIT Radiation Laboratory Series ("Techniques of Microwave Measurements," edited by Carol G. Montgomery, McGraw-Hill, 1947). The formula for relative dielectric constant of air quoted in Montgomery is:

$$\left(\varepsilon_r - 1\right)\times 10^6 = 210\frac{P_{air}}{T} + 180\left(1+\frac{5580}{T}\right)\frac{P_{water}}{T},$$

where T is the absolute temperature, and P_{air} and P_{water} are the partial pressures of air and water vapor, respectively. The first term corresponds to dry air at a given temperature. The coefficient 210 (rounded to two significant figures) comes from scaling the dielectric constant of dry air at standard temperature and pressure (20 C and 760 mm Hg). We have modified the formula by replacing P_{air} with P_{gas} to allow for the gases listed in Table XV-8. ConvertF uses the temperature T_{gas} entered in the dialog box.

Table XV-8. Dielectric constants of gases.

Gas	$(\varepsilon_r - 1) \times 10^6$	Coefficient of P_{gas}/T_{gas}
Air	536.6	207
Nitrogen	548.0	211
Argon	517.7	200
Helium	65.4	25

We now outline the sequence of calculations performed by ConvertF. Consider the sample output file XFREQ.TXT shown in Figure XV-1. For this example, we have measured the frequency of a copper cavity in air at 71.5 degrees F to be 804.953 MHz. We want to know what its frequency will be under vacuum at 90 degrees F. The atmospheric conditions at the time of the measurement were 23.3 inches Hg barometric pressure and 22% relative humidity (these values are typical at Los Alamos, NM). ConvertF first looks up the saturated vapor pressure of water at 71.5 F and then multiplies by 0.22 to obtain a water vapor pressure of 4.35 mm Hg. Converting the barometric pressure to the same units we obtain 591.82 mm Hg. Thus, the partial pressure of dry air is (591.82 – 4.35) mm Hg = 587.47 mm Hg. Substitution of T = 295.12 K and the partial pressures into the equation for the dielectric constant yields

$$\left(\varepsilon_r - 1\right)\times 10^6 = 207\frac{587.47}{295.12} + 180\left(1+\frac{5580}{295.12}\right)\frac{4.35}{295.12} = 464.8$$

or $\varepsilon_r = 1.0004648$.

The frequency of an rf mode is proportional to the speed of light in the medium. In vacuum,

$$f_{Vacuum} = \frac{c}{\lambda} = \frac{1}{\sqrt{\varepsilon_0\mu_0}\lambda}.$$

In a gas with dielectric constant $\varepsilon=\varepsilon_r\varepsilon_0$,

$$f_{Gas} = \frac{1}{\sqrt{\varepsilon\mu_0}\lambda} = \frac{f_{Vacuum}}{\sqrt{\varepsilon_r}}.$$

Therefore, removal of the air from the cavity will raise the cavity frequency by the square root of ε_r. The vacuum frequency is 805.140 MHz, which we then use in the equation for the thermal expansion effect. Raising the temperature of the cavity from 71.5 F to 90 F will lower the frequency. To compute the amount, convert the two temperatures to Kelvin degrees (295.12 K and 305.34 K) and apply the thermal expansion formula for the highest temperature range given for copper. The net percentage length change between the two temperatures is:

$$\left(\frac{\Delta L}{L_0}\right) = \left(\frac{\Delta L}{L_0}\right)_{90} - \left(\frac{\Delta L}{L_0}\right)_{71.5} = 0.020395\% - 0.0035809\% = 0.01736\% .$$

Then, apply the relation between relative frequency change and relative length change to get the frequency shift:

$$\Delta f = -\frac{\Delta L}{L_0} f_0 = -0.0001736 \times 805.140 \text{ MHz} = -0.1397 \text{ MHz} .$$

And finally, add this frequency change to the frequency f_0 to get the vacuum frequency at a temperature of 90 F:

$$f_{90} = 805.140 \text{ MHz} - 0.1397 \text{ MHz} = 805.0003 \text{ MHz} .$$

The code always applies the temperature correction to an evacuated cavity. Thus, when converting vacuum frequency to ambient frequency the temperature calculation occurs first, resulting in an intermediate frequency. The dielectric effect of the gas then modifies this intermediate frequency.

Cavity Material =	copper
Ambient-condition gas =	air
Ambient frequency =	804.95300 MHz
Ambient temperature =	71.50000 F
Ambient cavity temperature =	68.00000 F
Operating temperature =	70.00000 F
Gas temperature =	80.00000 F
Barometric pressure =	23.30000 inches Hg
Relative humidity =	22.00000 %
Saturated vapor pressure =	19.76161 mm Hg
Partial pressure of gas	587.47245 mm Hg
Partial pressure of water =	4.34755 mm Hg
Dielectric constant =	1.0004648
Vacuum frequency =	805.00030 MHz
F(ambient) – F(vacuum) =	–0.04730 MHz

Figure XV-1. Sample XFREQ.TXT output from ConvertF.

G. FScale: Scale dimensions in tuning-code control files

Program FScale provides a convenient method for generating a new tuning-program control file, but for a different rf frequency than contained in the original file. For example, suppose you used CCLfish to design several cells at a resonant frequency of 500 MHz and you now wish to design a similar linac at 600 MHz. You can instruct program FScale to read the original control file and generate a new file with all linear dimensions scaled by the factor 5/6. The code works with control files for any of the tuning programs CCLfish, CDTfish, DTLfish, ELLfish, MDTfish, RFQfish, and SCCfish. All that is required is addition of the keyword line NEWFREQuency in the original control file. FScale will create the next file in the sequence of filenames with three-digit numerical extensions 000, 001, etc.

To start FScale, double-click on a tuning program control file (with extension CCL, CDT, DTL, ELL, MDT, RFQ, or SCC), or right-click on the control file and select “Scale Frequency.” You can also use a command line to start the code:

FScale *controlfile*

where *controlfile* is the name of the control file.

Notice that certain assumptions have been made regarding the use of program FScale. The most important assumption is that all of the problems in the control file correspond to the same resonant frequency. Although this condition quite common in the use of the tuning codes, it is not necessary. If a control file contains more than one occurrence of either keyword FREQuency or NEWFREQuency, only the last one has any effect.

The FScale code scales all linear dimensions by the same factor. Often, when designing ion linacs at different frequencies, the designer cannot afford to scale the bore radius by the same factor as other linear dimensions because of the risk of losing beam. The accelerator designer can edit the new control file to set the bore radius to the desired value. In this case, however, it will usually be necessary to modify other cavity dimensions for high power efficiency. The scaled control file provides a good starting point for a design study at the new frequency.

H. SF8: Coupling slot effects

SF8 computes the coupling between two cavities given information about the coupling slot dimensions and properties of the two cavities. The program also computes the frequency shift in each cavity caused by the slot. SF8 is intended to aid in the construction of coupled-cavity linac structures. The tuning programs CCLfish and CDTfish design the accelerating cavities of such structures. Usually, the coupling cavities are designed "manually" using the stand-along programs Automesh, Fish and SFO.

The calculation in SF8 is an adaptation of J. Gao's paper "Analytical formulas for the resonant frequency changes due to opening apertures on cavity walls," Nuclear Instruments and Methods in Physics Research **A311**, pp. 437-443 (1992). The paper describes a Slater perturbation method, which results in analytical formulas that closely approximate measurements of the computed quantities.

This code involves a number of approximations that need to be evaluated carefully for each application. The intention of the code is to provide a systematic method for computing the effects of the coupling slot. We recommend comparing the results with measurements performed on actual cavity models before proceeding with the construction of a large number of cavities. Some adjustments of the predicted frequency shifts and coupling may be necessary for your application.

1. Starting program SF8

To start SF8, double-click on a file with the IN8 extension, or right-click on the IN8 file and select Open. To open the IN8 file in Notepad, right click on the file and choose Edit. You can also use a command line to start the code:

SF8 *controlfile*

where *controlfile* is the name of the control file, which defines cavity properties and coupling slot properties.

2. Files used in SF8

Complete file specifications consist of the filename of up to eight characters and an extension of up to three characters separated by a dot (.). SF8 reads the control file and, if specified in the control file, two Superfish solution files. The code writes the results of the calculation to file OUTSF8.TXT.

3. The SF8 control file

The SF8 control file defines properties of two rf cavities and the coupling slot that connects them. The default name of the file is IN8.CTL, but it can have any name or extension. The program first looks for the exact filename you entered. If it cannot find that file, it looks for the file you entered with no extension. If that file does not exist, it looks for the file you entered with extension CTL.

SF8 recognizes the keywords listed in Table XV-9. Keywords can be in upper, lower, or mixed case. The list below shows the shortest possible abbreviation in capital letters. You may include comment lines in the control file after a semicolon (;) or exclamation mark

(!). The program ignores everything after a comment indicator. It also ignores blank lines. Comments or blank lines may appear anywhere in the file.

Table XV-9. SF8 control-file keywords.

Keywords	Description
; !	These characters indicate a comment.
Cavity	Selects either cavity 1 or cavity2. Subsequent keywords define properties of the selected cavity. The affected keywords are FILEname, Xc, Yc, Rc, CAVITYFraction, E, H, and U.
FILEname	Name of the Superfish solution file.
Xc, Yc, Rc	Center of curvature coordinates and corner radius in the same units used in the Automesh input file. These three separate keywords are required when a Superfish solution file has been entered.
E, H, U	Electric and magnetic fields at the slot (E in MV/m, H in A/m) and the cavity stored energy in Joules. These three separate keywords are required when a Superfish solution file has not been entered.
CAVITYFraction	Fraction of the full cavity modeled in the Superfish solution (or to which the stored energy U refers).
FREQuency	Resonant frequency of the rf structure in MHz. This entry is optional unless no solution files are included. By default, the code uses either the average frequency from both solution files or the frequency of the only solution file. If FREQD has a nonzero value in the solution file, then SF8 uses it for the cavity frequency. Otherwise the code uses the value of FREQ. Tuning codes set FREQD equal to the FREQuency supplied in the control file.
SLOTdata	Start of a table of entries for the slot geometry. The entries are the length, width and thickness of the slot and two angles, one for each cavity, that locates the edge of the coupling slot with respect to coordinates Xc, Yc. The angles are used only when a Superfish solution file has been entered for the cavity.
ENDSlotdata	End of slot geometry data.
LENGTHoutput	Three parameters that specify a range of slot lengths in cm. Parameters are the starting length, ending length and an increment. If this line does not appear in the control file, SF8 will generate data for each entry in the SLOTdata table.
EndFile	End of the control file.

a. Cavity keywords

The Cavity keyword selects one of the two rf cavities. Cavity 1 is an accelerating cavity and cavity 2 is a (usually) smaller coupling cavity. The right-hand side of Figure XV-2 shows a typical CCL half cavity designed by the CCLfish program. The origin of the Superfish mesh is the lower left of this figure. From a computer-aided design (CAD) program, we determine the angle θ at which lie the points P_1 and P_2 shown in the figure. The cavity fields E and H correspond to these points. Other keywords (FILEname, Xc, Yc, Rc, CAVITYFraction, E, H, and U.) that follow the Cavity selection then refer to the selected cavity number. The only valid entries are “Cavity 1” or “Cavity 2” with the default setting equal to 1 if any other value appears on the keyword line.

There are two methods for supplying the cavity data. For each cavity, you can supply either the complete set of keywords FILEname Xc, Yc, and Rc, or the complete set of keywords E, H and U. In the first case, the program will use the cavity stored energy U found in the Superfish solution file and it will interpolate the fields E and H from the solution at coordinates $X = X_c + R_c \cos\theta$ and $Y = Y_c + R_c \sin\theta$. The coordinates X_c, Y_c

of the corner arc center of curvature and its radius R_c may be found by inspecting the Automesh input file (with extension REG) produced by CCLfish for the cavity. For the second method, the code uses the fields and stored energy supplied in the control file. The CAVITYFraction keyword, which has a default value of 1.0, is optional in either set of cavity data. For example, if you used the CCLfish code to design an accelerating cavity and you supply the solution file, set CAVITYFraction = 0.5 because the CCLfish code models only half of the full cavity. Note that the CAVITYFraction setting also applies to the interpretation of U for the second method where the cavity fields and stored energy appear in the control file. If U corresponds to the full-cavity stored energy, set CAVITYFraction = 1.

The keyword FILEname specifies name of the Superfish solution file for a cavity. The name must include the extension (usually T35) and it may also include a drive letter and path. When you supply the FILEname for a cavity, then you also must supply the data that determines where to interpolate the fields E and H for the cavity.

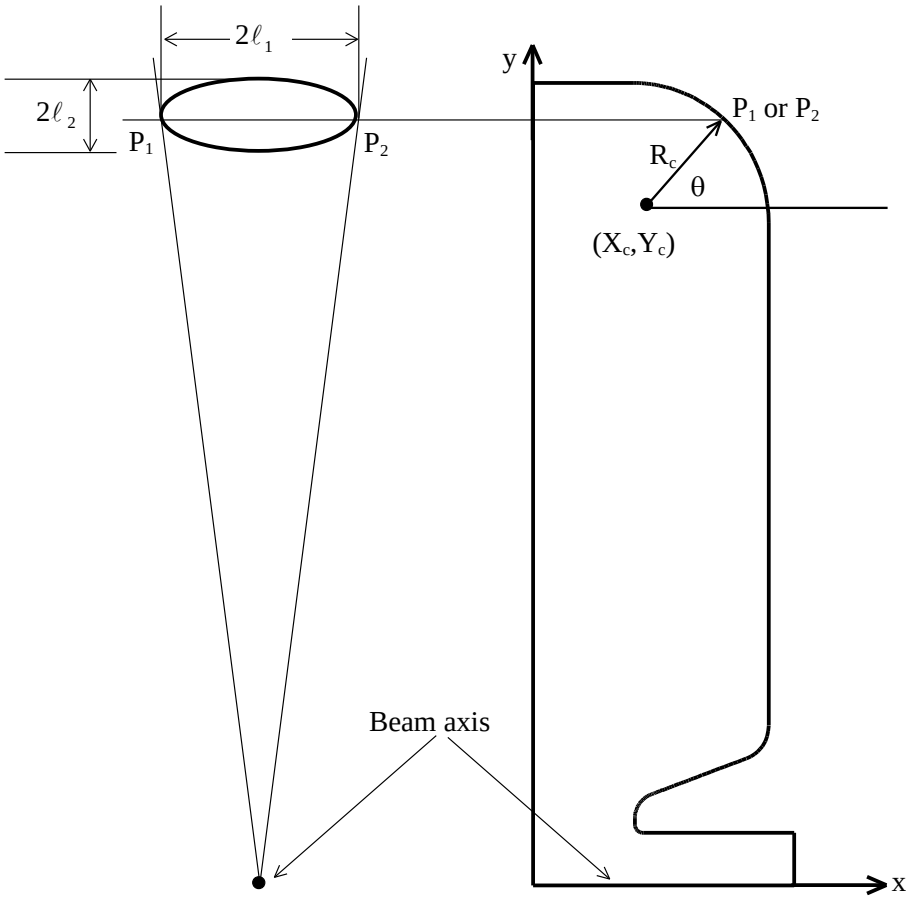

Figure XV-2. Coupling slot location in a CCL cavity.
The left-side view looking along the beam axis of the cavity shows how we define the length and width of the aperture. Although it is shown here as an ellipse, the aperture is actually a more complicated shape.

b. FREQuency keyword

The resonant frequency of the coupled-cavity structure determines the free-space wavelength λ used in the equations for the attenuation factors discussed in section 4 below. A FREQuency entry is optional unless no solution files are included in the control file. By default, SF8 will use the average frequency from both solution files or the frequency of the only solution file supplied. If the FREQuency keyword appears, the value in MHz overrides any frequencies found in the solution files.

The Superfish frequencies of the two rf cavities will usually be several MHz higher than the frequency of the coupled structure. The coupling slot lowers the frequency of each cavity. SF8 should be given the fields and stored energies of the unperturbed cavities before the coupling slot has been cut in the cavity walls. For example, consider a 700-MHz accelerating structure that operates in the π/2 structure mode. For beam-dynamics design studies, which require transit-time factor data at the design frequency, the Superfish code provides the necessary data for 700-MHz accelerating cavities. Before building the cavities, the designer raises the frequency of the accelerating cavities by reducing the cavity diameter. This step anticipates the frequency effect of the coupling slot and ultimately will have essentially no effect on the cavity fields in the region of the beam axis after the coupling slot has been cut. Suppose that for the coupling chosen for the design that the coupling slot lowers the accelerating cavity frequency by 10 MHz and the coupling cavity frequency by 40 MHz. (These numbers, though typical, depend upon the detailed shapes of the cavities and will in general vary throughout the linac.) For this example, SF8 should work with an accelerating cavity whose unperturbed frequency is 710 MHz, a coupling cavity whose unperturbed frequency is 740 MHz, and a FREQuency setting of 700 MHz.

```
Cavity    1
H = 5115.446
E = 0.505139
U = 8.25326e-2

Cavity    2
Filename=61mm.t35
CavityFraction = 0.5
Xc = 2.11328
Yc = 7.7724
Rc = 0.9525

LengthOutput      9        10       0.01

SlotData
9     3.24        0       30
EndSlotData
EndFile
```

Figure XV-3. Sample SF8 control file.
This example uses a Superfish solution file for cavity 2, but not for cavity 1. Instead, the fields and stored energies are provided for cavity 1. Output file OUTSF8.TXT will include a table of entries for slot lengths 9 cm to 10 cm in steps of 0.01 cm.

4. Mathematical formulas in SF8

We follow Gao's approach with some additional assumptions and definitions necessary for the geometry of a typical side-coupled accelerating structure. The Gao paper treats elliptical shaped apertures between cavities if the same type. Equations 39 through and 44 of the paper express the results of interest, which are the mode frequencies of the coupled system. We reproduce the two equations (43 and 44) for the $\pi/2$ mode:

$$\omega^2 = \omega_{\pi/2}^2\left(1-\frac{2N\pi\left(1-e_0^2\right)\ell_1^3\varepsilon_0 E_1 E_2\cos\left(\beta_0 D\right)}{12\,E\left(e_0\right)U}e^{-\alpha_1 d}\right),$$

and

$$\omega^2 = \omega_{\pi/2}^2\left(1+\frac{2N\pi\, e_0^2\ell_1^3\mu_0 H_1 H_2\cos\left(\beta_0 D\right)}{12\left(K\left(e_0\right)-E\left(e_0\right)\right)U}e^{-\alpha_2 d}\right).$$

The first equation corresponds to an electrically coupled system and the second to a magnetically coupled system. In these equations, N is the number of coupling apertures per cavity, E_1 and E_2 are the electric fields near the aperture in cavities 1 and 2, H_1 and H_2 are the magnetic fields near the aperture in cavities 1 and 2, $K(e_0)$ and $E(e_0)$ are complete elliptic integrals of the first and second kind, ε_0 is the permittivity of free space, μ_0 is the permeability of free space, and e_0 is eccentricity parameter given by the relation

$$e_0 = \left(1-\ell_2^2/\ell_1^2\right)^{1/2},$$

where $2\ell_1$ and $2\ell_2$ are lengths of the major and minor axes of the elliptical aperture. There can be some ambiguity in the slot dimensions to use. Figure XV-2 shows the definition that we have used at Los Alamos for the accelerating cavity. We recommend using the values of ℓ_1 and ℓ_2 determined for cavity 1 (the accelerating cavity) for both cavities even though a picture similar to Figure XV-2 drawn for the coupling cavity might result in slightly different lengths.

The fields are those in the cavity before being perturbed by the aperture. The electric fields are perpendicular to the place of the aperture and the magnetic fields are in the place of the aperture. The cosine terms define a dispersion relation for the modes. The quantity D is the space periodicity of the structure and β_0 is the fundamental wave number. In the exponential terms, d is the thickness of the aperture and the attenuation factors α_1 and α_2 are expressed as follows:

$$\alpha_1 = \frac{2\pi}{\lambda}\left[\left(\frac{\lambda}{\lambda_{c1}}\right)^2-1\right]^{1/2},$$

and

$$\alpha_2 = \frac{2\pi}{\lambda}\left[\left(\frac{\lambda}{\lambda_{c2}}\right)^2-1\right]^{1/2},$$

where λ is the wavelength in free space, λ_{c1} is the cutoff wavelength of a TM_{01} mode transmitted through the aperture (for the electric coupling case) and λ_{c2} is the cutoff wavelength of the TE_{11} mode transmitted through the aperture (for the magnetic coupling case). The SF8 code uses the wavelength that corresponds to the value supplied on the FREQuency line of the control file.

We now identify the collection of terms multiplying the cosines as the electric and magnetic coupling factors k_e and k_m. In a biperiodic structure such as a side-coupled linac, the two cavities have a different shape and hence different stored energies. For this case, we replace the U with the quantity $(U_1U_2)^{1/2}$. In addition, we assume that N = 2. Thus, the net coupling is the sum of two terms, a magnetic-field term and an electric-field term:

$$k = k_m + k_e,$$

where
$$k_m = \frac{\pi}{3}\mu_0 e_0^2 \ell_1^3 \frac{H_1 H_2}{K(e_0) - E(e_0)} \frac{1}{\sqrt{U_1 U_2}} e^{-\alpha_2 d}$$

and
$$k_e = -\frac{\pi}{3}\varepsilon_0 e_0^2 \ell_1^3 \frac{E_1 E_2}{E(e_0)} \frac{1}{\sqrt{U_1 U_2}} e^{-\alpha_1 d}.$$

Though the coupling slot in a side-coupled structure is not exactly elliptical in shape, it is nearly so. The user is free to choose any definition of the length $2\ell_1$, width $2\ell_2$, and thickness d for the coupling slot. We have used the following definitions with some success. For the length, we measure the straight-line distance between the points on the edges of the slot that are tangent to lines drawn from the cavity center. These locations are the points at which we instruct the code to interpolate the electric and magnetic fields to use in the coupling equations. The length of this line will generally not be the maximum length of the coupling slot, but we have found reasonable agreement between the formula and measurements using this definition. The slot width is the size of the opening at the midpoint of the above line. The thickness d is measured at the two tangent points. When initially machined, the coupling slot has a “knife edge” and thus has zero thickness. We later machine the edges of the slot to enlarge it slightly, which results in a nonzero thickness.

To compute the attenuation factors α_1 and α_2 we used Superfish to find the cutoff wavelengths for several elliptical waveguides having aspect ratios ℓ_2/ℓ_1 ranging from 0.25 to 1.00. The Superfish runs all corresponded to a major axis length $2\ell_1$ = 9 cm. The results for other slot lengths can then be found by scaling the 9-cm values to the desired length. If ℓ_1 is in cm, the following expressions give the cutoff wavelengths in cm in the applicable ranges of ℓ_2/ℓ_1

$$\lambda_{c1} = \frac{2\ell_1}{9\text{cm}}\left[-6.69801\left(\frac{\ell_2}{\ell_1}\right)^2 + 18.4251\frac{\ell_2}{\ell_1} - 0.0515169\right],$$

$$\lambda_{c2} = \frac{2\ell_1}{9\text{cm}}\left[0.381635\left(\frac{\ell_2}{\ell_1}\right)^2 + 0.0256036\frac{\ell_2}{\ell_1} + 14.9831\right].$$

I. MK_SFINI: Create or update file SF.INI.

Program MK_SFINI creates a new copy of the SF.INI file. The installation program runs this code to update or create file SF.INI. The installer leaves a copy of MK_SFINI in the installation directory. To start MK_SFINI use the following command line:

MK_SFINI [*directory*]

where *directory* is the optional destination directory. The destination directory must already exist before running MK_SFINI. If no directory appears the MK_SFINI creates the file in the current directory. To create file SF.INI in the C:\LANL directory enter the following command:

MK_SFINI C:\LANL

The content of the resulting file depends upon whether a copy of SF.INI already exists in the specified directory. If SF.INI does not already exist in the destination directory, the new file will contain the default settings for a new installation. If SF.INI does exist, then MK_SFINI will retain settings from the present copy and only add missing entries from the default installation set. The code also retains additional comment lines added by the user. Comment lines start with a semicolon (;) or exclamation mark (!).

Program MK_SFINI ignores any keywords and comments that appear after an invalid section heading. A section heading is the name of a program in square brackets (e.g., [Automesh]).