

DESIGN Version 2.61

INDEX Version 2.51

FILM★STAR

for Microsoft Windows

Advanced Optical Thin Film Technology from



**FTG Software
Associates**

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User Guide

Getting Started

Installation

FilmStar requires a PC running Microsoft Windows 2000 or newer. 512 MB or more is recommended. To install from CD-ROM, run `..\install\setup32.exe` from Start... Run. An installation password and Administrator privileges are required. Setup will not overwrite previous data files.

Complete installation as well as update files can be found at

<http://ftgsoftware.com/updates.htm>

Please visit this page often to keep your software up-to-date. If you have problems or questions about running the software your solution may be already be at our Technical Issues page

<http://ftgsoftware.com/issues.htm>

Reported installation difficulties are discussed on

http://ftgsoftware.com/issues_installation.htm

A Security ID Module must be attached to the parallel or USB port.

When installing with USB Security ID Module for the first time, DO NOT plug in the module until installation is completed! Windows will automatically locate the new device.

FilmStar provides an extensive set of Help screens. Press <F1> from any menu item or dialog box for context-sensitive help. The help system is identical to this manual's Reference section.

Historical Note

FilmStar 32-bit for Windows (1998) is derived from three previous FTG Software programs: FilmStar for HP-9000 (1981), FilmCalc for DOS (1987), FilmStar 16-bit for Windows (1991).

The organization of the program is adapted from the **DAFT/DAN** (Differential Aadjustment of Film Thickness / Differential Aadjustment of Index) FORTRAN program developed by Dr. Arthur Francis Turner and Bob MacIntyre at Bausch and Lomb in Rochester in the 1960's. This evolved into the now defunct Genesee Films program which was available on Cybernet and later on the IBM-PC.

Layer #1 is next to the substrate.

$QWOT = 0.25$ and $QWOT = 1.0$ are both supported.

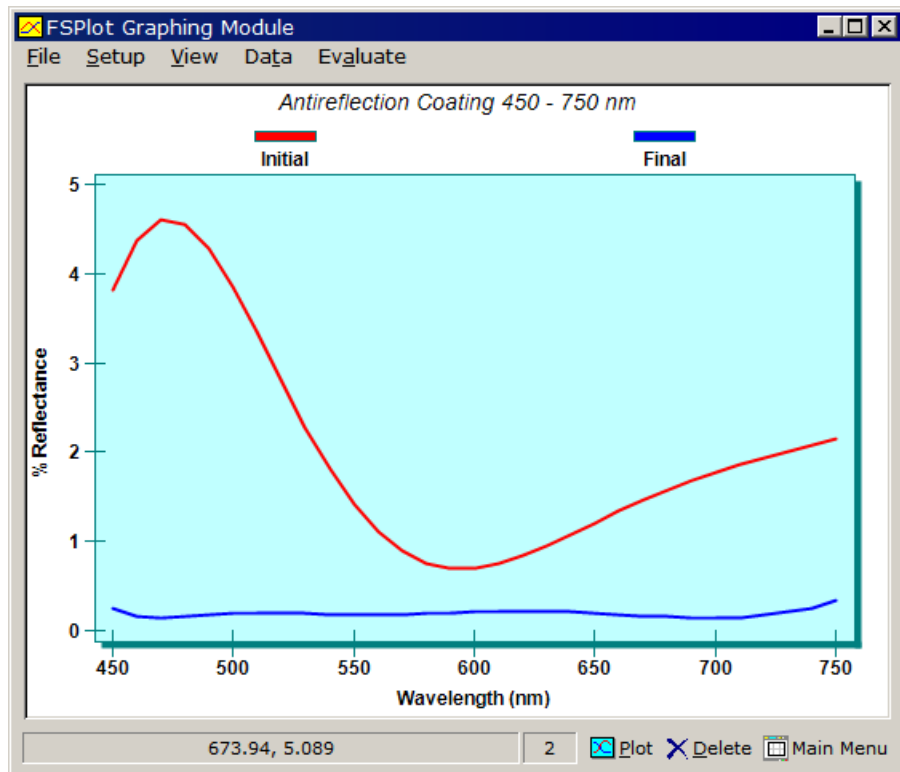
The thin film design $.1H .1L .5H .25L$ is expressed in optical thickness units where $.25$ corresponds to one QWOT (quarter wave optical thickness) at Design Wavelength 550 nm. Each layer includes a numeric value and a one-letter index symbol indicating the material index of refraction. The words *Design (from substrate)* remind us that layer 1 is always next to the substrate in DESIGN. Users adapting designs from elsewhere should be aware that layer 1 often refers to the layer next to the entrance medium (air).

The relationship between index symbols and values is given in the table underneath the design. **AIR** (1.0) indicates entrance medium and **SUB** (1.52) indicates substrate. The three materials **L** (1.46), **H** (2.3) and **M** (2.1) also have constant indices. The entry to the right of *Symbols* reminds us that these refer to optical film thicknesses with $.25$ corresponding to one QWOT.

We can improve the antireflection design through optimization (refinement) by clicking **Optimize...Optimize <Ctrl+O>**. The vertical green lines on the screen indicate the location of optimization targets and the X's show current values. Click **OK** to accept default values of 10 iterations and damping = $.671$. At the end of 10 iterations click **Cancel** to return to the Main Menu.

Click **Calculate** to compute the new spectrum. Click **Axes** to draw new axes and replot the spectrum. Click the color button to change the color. Access the Review Design screen to see how optimization has changed layer thicknesses.

Click **Tools...FSPlot Module <F4>** to access the FSPlot Graphing Module. Click **Plot** to redraw the curve. Return to the Main Menu by clicking in the window or pressing **<Esc>** (as shown below, you can return to FSPlot to add more spectra) or close the FSPlot Module with **<Alt+F4>**.

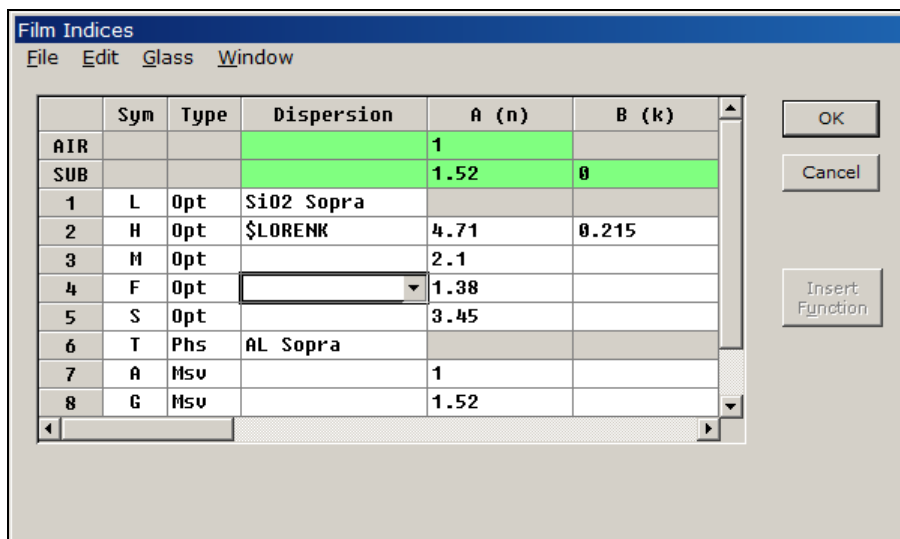


Congratulations, you're now a thin film designer.

Film Indices (page 31)

Hint: clear the current design before setting up completely new index symbols.

How did we set up the calculation? In general, DESIGN has no "beginning, middle and end". You can do (almost) anything in any order with the exception that *index symbols must be defined in the Index Editor before being used in a design.* While failure to heed this dictum will not crash the program, it will generate the *Design and/or Film Indices error* message. This might happen when you load a design from disk which includes an index symbol not currently defined in the Film Indices editor.



In reviewing how the BBAR problem was set up, we start with the Film Indices editor. Click **Setup...Film Indices <Ctrl+I>** to obtain the dialog box illustrated above. Several FilmStar screens, particularly those with data entry grids, can be resized by dragging edges or by choices in **Window**.

In the grid, use **<Tab>** or arrow keys to move from cell to cell. The grid has the focus when you can see the cell highlight. (**<Ctrl+Tab>** moves the focus from the grid. Or press **<Tab>** in the last editable grid cell.) To edit the contents of a cell, first press **<F2>** or **<Insert>**. To clear a cell press **<Delete>**. Most grids require that you fill each row before proceeding to the next.

DESIGN can automatically convert thickness types.

The **Type** column specifies film thickness type for each index symbol. Select **Opt** for optical thickness, **Phs** for physical thickness and **Msv** for massive thickness in millimeters. The green rows at the top remind you they apply to entrance (AIR) and exit (SUB) media.

To use a dispersive index file or function select from the **Dispersion** list. This list is recreated whenever the Film Indices dialog box is accessed.

For practice, change the index of H from 2.3 to 2.4. Remember to click **OK** instead of **Cancel** in order to keep the change. Return to the Main Menu and recalculate the spectrum. Then select file TIO2 and see the effect.

For further practice, adjust entries in order to reproduce the Review Design screens shown below. If we use a lookup table for H instead of $n=2.3$, the name of the file (*i.e.* TIO2A appears under **Dispersion** and any numeric values in A-G are ignored. Dispersive tables (n,k vs. wavelength) are created and edited in FilmStar INDEX (not included with the Trial Version).

Indx Symb	File \$Funct	A(n)	B(k)	C	D	E	F	G
L		1.46	0	0	0	0	0	0
H	TIO2A	0	0	0	0	0	0	0

If we use a dispersive index function, the name of the function preceded by '\$' appears under **Dispersion** (i.e. \$LORENK) and the function's coefficients are given in columns **A-G**. We want to use dispersive functions rather than index tables when determining refractive indices from measured data.

Indx Symb	File \$Funct	A(n)	B(k)	C	D	E	F	G
L		1.46	0	0	0	0	0	0
H	\$LORENK	4.4398	.45667	336.87	.52305	0	0	0

Groups Design Editor (page 44)

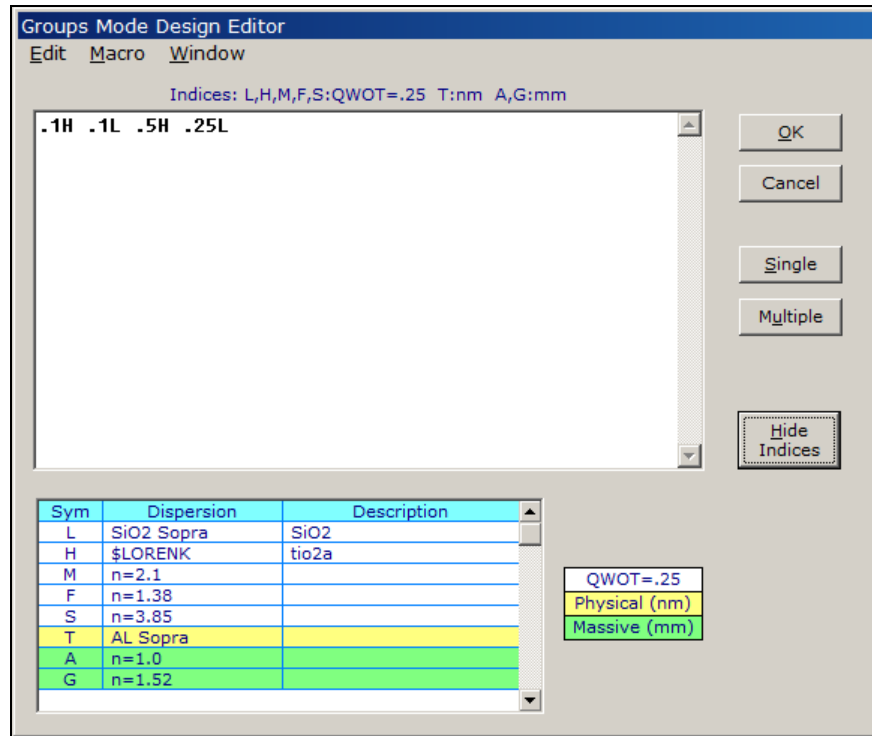
Before proceeding, please reload FILM Archive "bbar". There may be several prompts asking if you wish to update disk files before proceeding. Click **No** in each case.

From the Main Menu click **Design...Groups Editor <Ctrl+D>** to access the Groups design editor. In this editor layers can be enclosed within parentheses to generate designs such as

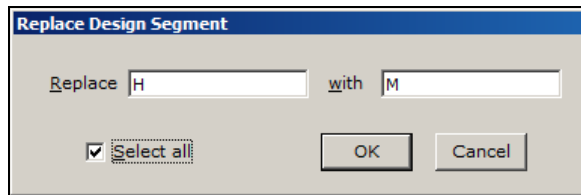
.125L (.25H .25L)10 .288H (.325L .325H)10 .163L

DESIGN automatically converts .25H .25H to .5H

The editor works equally well for individual layers. Allowed index symbols (already defined in Film Indices) are displayed on top of the text edit box and by clicking **Show Indices** (as below). Click **Multiple** to display layers on different lines and **Single** to display all layers on one line. The edit box is a normal Windows text box and supports the usual text editing commands.



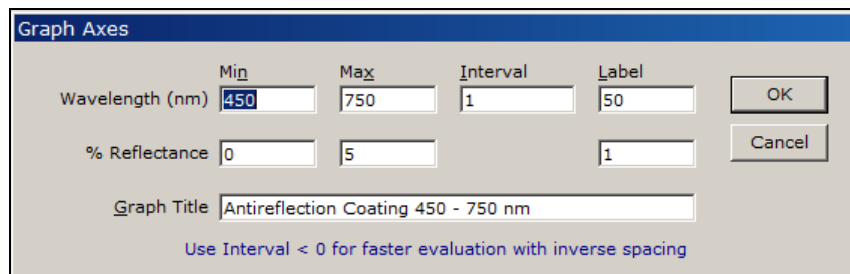
Next, click **Edit...Replace <Ctrl+E>** to activate the Replace Design Segment dialog box. Enter the values shown below and click **OK**.



Upon returning to the design editor click **OK <Enter>** to accept changes or **Cancel <Escape>** to ignore them. If you frequently lose changes by pressing **<Escape>** instead of **<Enter>**, access **File...Configuration... Preferences** and check the box labeled **<Cancel> warning in data editors**. This generates a confirmation dialog box upon pressing **<Escape>**.

Graph Axes (page 33)

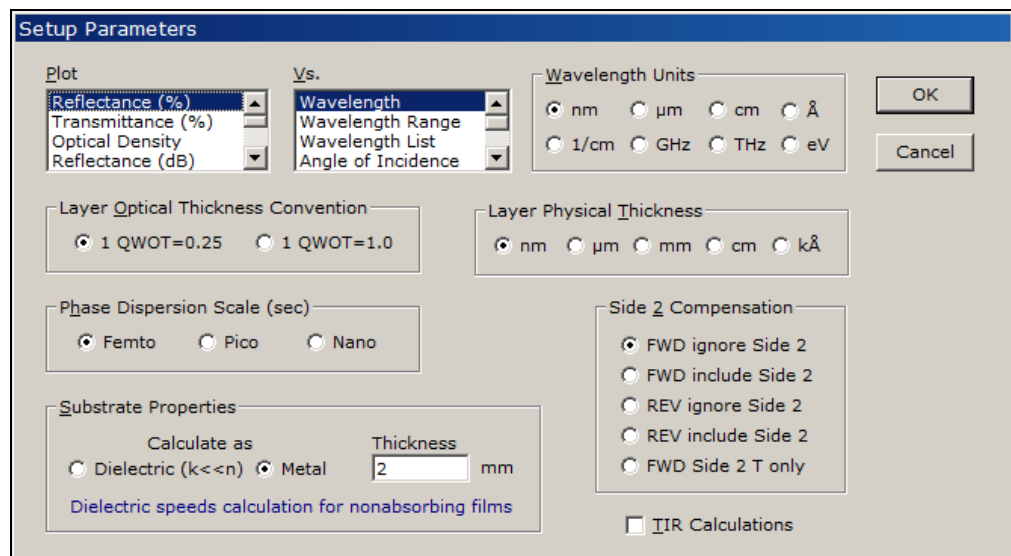
Before proceeding, please reload FILM Archive "bbar".



Click **Setup...Graph Axes <Ctrl+G>** for the Graph Axes editor. Edit fields as shown and click **OK**. Graph axes are automatically redrawn.

Return to the Main Menu, recalculate the spectrum and copy it to the clipboard with **<Ctrl+C>**. Click **Tools...Workbook <F3>**. If there is no worksheet visible, click **File...New**. Paste the spectrum with **Edit...Paste <Ctrl+V>**. The difference between the first two wavelengths is 2.0 nm. Press **<Ctrl+Down>** to reach the end of the table and observe that the difference is 6.0 nm.

Setup Parameters (page 38)



Axis choices are stored with Graph Axes.

Since there's no vertical axis scale choice in the Graph Axes editor, how do we change from Reflectance to Transmittance? This and numerous other choices are implemented through the Setup Parameters editor **Setup...Parameters <Ctrl+P>** illustrated above. Axes selectors at the top left (**Plot** and **vs.**) scroll to reveal further choices.

After changing the **Layer Optical Thickness Convention** from 0.25 to 1.0 verify that the design has changed accordingly and that the spectrum is the same. Try changing **Wavelength Units** from nanometers to microns. Change **Side 2 Compensation** to "FWD include Side 2" and recalculate.

Be sure that "Metal" is selected under **Substrate Properties** if the substrate is actually a metal or semiconductor. Colored filter glass substrates may be accurately treated as "Dielectric".

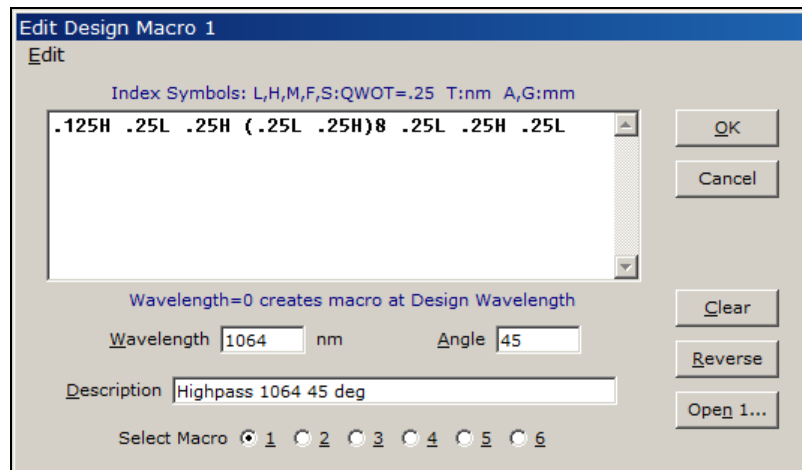
HIGHPASS - Example 2

We'll now move to a different example illustrating further features. Open FILM Archive "highpass" (**File...Open <Ctrl+F12>**).

Design Macros (page 43)

Access the Groups design editor and copy the entire design to the clipboard using **Edit...Copy All <Ctrl+A>**. (A design fragment is copied by highlighting it and clicking **Edit...Copy**.) Next, click **Edit...Macro <Ctrl+M>** to activate the Design Macro dialog box. This lets you enter up to six designs or fragments which can be adjusted for center wavelength and angle. It is especially useful for multiple stacks centered at different wavelengths.

Rather than type a design we click **Paste** to transfer from the clipboard. Enter the Wavelength, Angle and Description shown below and click **OK**.



This specifies an angle-matched and wavelength-centered design and returns to the Groups design editor. Now press **<Shift+F1>**. The following design will have been pasted into the editor:

```
.2942H .6401L .5885H (.6401L .5885H)8 .6401L .5885H .6401L
```

Note that the description is now included in the **Macro** menu. Your results will be different if the original film indices were changed. Click **Multiple** and note that the group in parentheses is displayed on a separate line.

Optimization Targets (page 57)

Before proceeding, please reload FILM Archive "highpass". Prompts may ask you to update disk files before proceeding. Click **No** in each case.

Click **Calculate** to evaluate the spectrum. This is a poor highpass design because there is too much reflection from 580 to 800 nm. DESIGN needs to minimize the reflectance. This is specified through the Optimization Targets editor

Optimize...Targets <Ctrl+T> displayed on the next page.

The easiest way to delete all entries is to click the grid's upper left corner and press Delete.

There are 15 reflectance (**Type** = "% Refl") targets over the **Wavelength** range 580 to 800 nm. Each target is set to **Target** = 0, **Tolerance** = 1, **Angle** = 0 and **Polarization** = "R" (random). Tolerance is an inverse weighting factor - the smaller the number the greater the relative importance of the target. If we are more concerned about performance in the middle of the wavelength range, we could 'loosen' the tolerances at 580 and 800 nm by assigning values **Tol** = 2.

	Type	Wave (nm)	Target	Tol	Angle	Pol
1	% Refl	450.000	0.000	2.000	0.00	R
2	% Refl	471.390	0.000	1.000	0.00	R
3	% Refl	493.797	0.000	1.000	0.00	R
4	% Refl	517.269	0.000	1.000	0.00	R
5	% Refl	541.857	0.000	1.000	0.00	R
6	% Refl	567.614	0.000	1.000	0.00	R
7	% Refl	594.595	0.000	1.000	0.00	R
8	% Refl	622.858	0.000	1.000	0.00	R
9	% Refl	652.465	0.000	1.000	0.00	R
10	% Refl	683.479	0.000	1.000	0.00	R

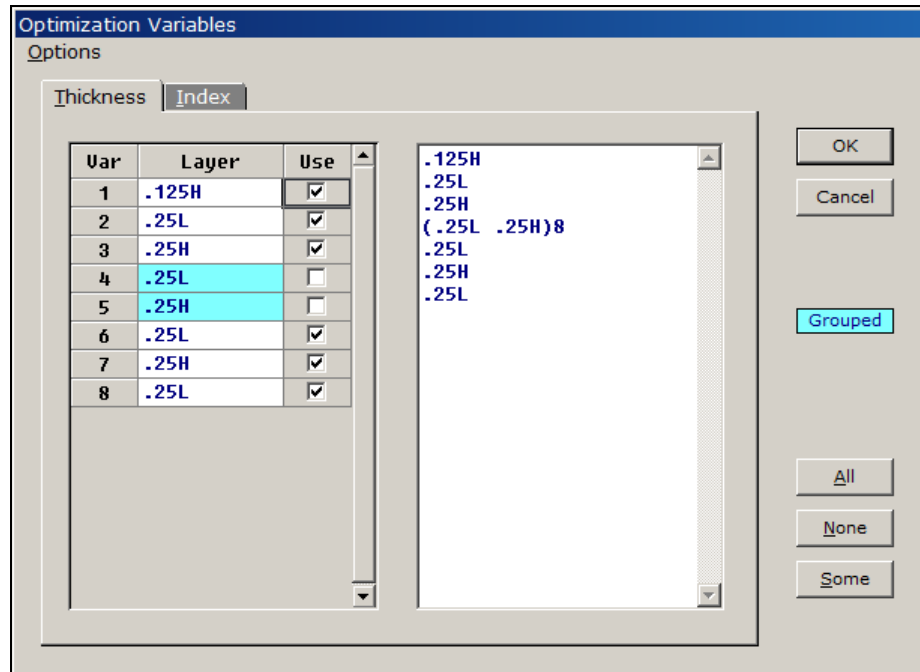
The editor allows you to change multiple values by copying cells to the clipboard and pasting in multiple rows. For example, change the value of the first **Angle** value to 15. Click **Edit...Copy** to copy the value to the clipboard. Now highlight several rows in the Angle column and click **Edit...Paste**.

Click **Setup...Generate <Ctrl+G>** to access the Target Generator (page 62). This dialog provides a very convenient way to input targets over a wavelength range. Targets are spaced inversely in wavelength in order to provide more of them at shorter wavelengths where there are more 'wiggles'. The Target Generator can be used repeatedly to build up a complex list of targets. Adjust values as shown above and click **OK**.

Optimization Variables (page 59)

Before proceeding, please reload FILM Archive "highpass".

Once targets are specified we must indicate what layers (and/or indices) should be varied in the search for a solution. Click **Optimize...Variables <Ctrl+B>** to access the Optimization Variables editor.



The program assigns variables as follows: If the design does not include parentheses the thickness variable is the layer number (from the substrate). If there are parentheses the variable is the layer number ignoring parentheses:

Design	.125H	.25L	.25H	(.25L	.25H)8	.25L	.25H	.25L
Variable	1	2	3	4	5	6	7	8

Note that grouped variables 4 and 5 remain fixed during the optimization. This is a typical technique for simplifying optimization problems. Finally, return to the Main Menu and optimize the design for 10 iterations. Click the **Calculate** button or **Evaluate... Recalculate <F9>** to evaluate and plot the new design.

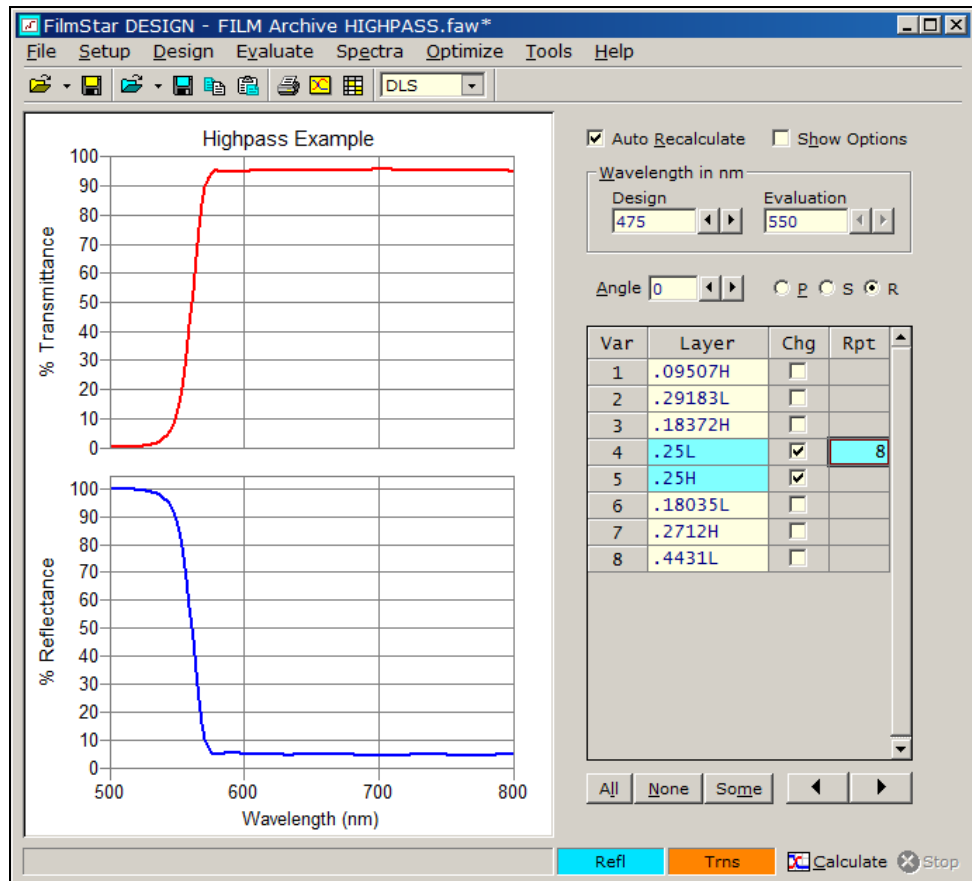
Interactor (page 49)

From the Main Menu click **Setup...Parameters <Ctrl+P>** and change *Side 2 Compensation* to *FWD include Side 2*. This takes into account the reflectance of the second surface in the calculation, thereby lowering the transmittance when recalculated. Click **Evaluate...Interactor <Ctrl+Q>** to activate the Interactor.

The Interactor is an alternate FilmStar environment which make it easy to study design changes. Here layer thicknesses can be adjusted individually or in groups. quantities are adjusted by clicking up and down arrow keys. Holding arrow keys down and then releasing makes it possible to implement large changes without annoying intermediate updates.

At this point it might be a good idea to click **File...Save All**. This stores the current FILM Archive in temporary file *work.faw*. Later, click **File...Open All** to reload the saved design. These commands can prevent a lot of aggravation!

Now, play with the arrow keys to see what happens. Holding down **<Ctrl>** speeds changes while holding down **<Shift>** slows changes. Experiment with the layer repeat factor; this is the only entry that can be directly typed into. Remember, you can also use the programs regular design editors; the Interactor list will be automatically updated. *When no layers are checked*, a single layer can be changed if it is highlighted in the grid (Layer column). You can also use the **< >** keys and **+ -** on the numerical keypad to change values. *When no layers are checked*, angle and wavelengths can also be changed via the keyboard if the corresponding text box has the focus.



Click *Show Options* to enable a properties dialog below the layers grid. A scrollbar enables you to access the dialog without enlarging the DESIGN window. Interactor Mode *Design* supports up to 3 plots in the same graph while *Compare* lets you import a measured spectrum for reverse engineering.

The Interactor has some limitations: it does not support plots vs. physical thickness and does not display optimization targets. Certain program features, such as FilmStar BASIC and tolerancing, are disabled in Interact mode.

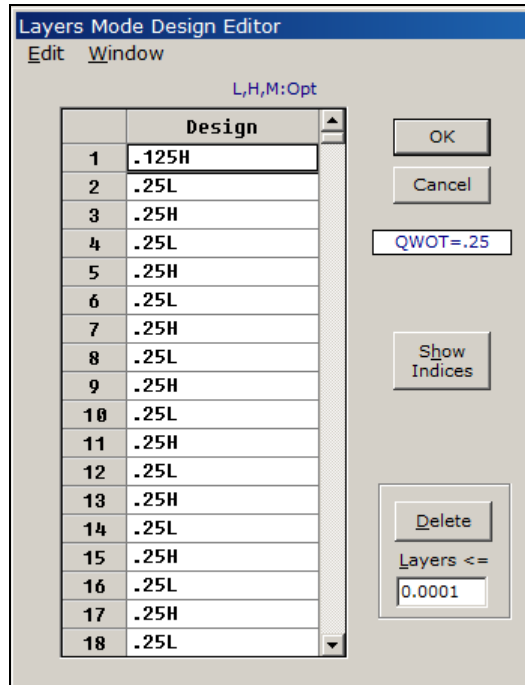
Layers Design Editor (page 46)

Before proceeding, please reload FILM Archive "highpass".

From the Main Menu click **Design...Layers Editor <Ctrl+L>** to access the Layers design editor. Since the current design includes parentheses a confirmation request is issued. Why remove parentheses? Possibly you need physical thicknesses for monitoring, or you want to convert an optimized design to individual layers for tolerancing with Excel. It's probably a good idea to store the design

before converting it to separate layers because there's no automatic way to put back parentheses.

We eventually arrive at the editor shown below. You can delete a block of layers by selecting them and pressing ****. You can insert *a single layer* by typing its formula into the **Insert** text box and clicking **Insert <Alt+I>**.



FilmStar Workbook

Tolerancing offers an excellent example for the FilmStar Workbook. By tolerancing, we mean estimating coating yields using simulated manufacturing errors. There are several options in FilmStar. The built-in tolerancing generator computes absolute or relative (percent) normally distributed thickness variations and recalculates the spectrum for a specified number of iterations. The tolerancing generator can be accessed from the Main Menu, CIE Color Module, and the FilmStar Workbook.

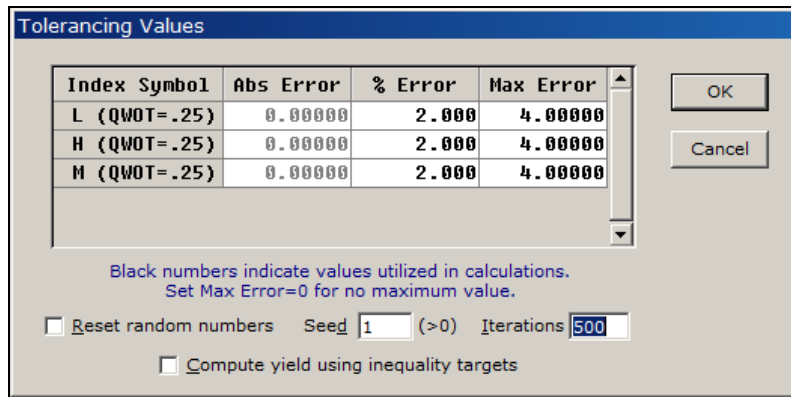
Before proceeding, back up file ..\winfilm\designs\bbar-o.faw in order to protect against unwanted alterations!

Check that FILM Archive Mode is enabled in the File menu and open FILM Archive "bbar-o". Exit the Interactor <Ctrl+Q> if you haven't done so.

Tolerancing in Main Menu (page 49)

Click **Evaluate...Tolerancing...Values <Ctrl+N>** to bring up the tolerancing generator, enter the following values, and click **Run <Shift+Ctrl+F9>**.

Here we specify 4% standard deviation with a maximum relative error of 8%. While the resulting overlaid curves are interesting they are difficult to interpret. (You might want to exit and change the graph axes scale to 0-2% Reflectance and try again.)



Tolerancing in FilmStar Workbook (page 95)

What coating engineers really need to do is predict percent yield for particular specifications. For example, what is the yield if the average reflectance must be less than 0.5% and the maximum less than 1.0% in the range 450-750 nm? Such specifications are easily expressed in the FilmStar Workbook.

Activate the Workbook with **Tools...Workbook <F3>**. Close any open worksheets with **File...Close** and open ..\winfilm\workbook\qcbbar.xls.

	A	B	C	D	E
1	DataType 1				
2					
3	Wave (nm)	% Refl	% Trns		
4	450.000	0.24683	99.75317		
5	460.000	0.14477	99.85522	Average	0.186
6	470.000	0.13266	99.86734	Maximum	0.325
7	480.000	0.15347	99.84653		
8	490.000	0.17722	99.82278	Passed	TRUE
9	500.000	0.19176	99.80824		
10	510.000	0.19523	99.80477		

From the Workbook click **Evaluate...Tolerancing... Values <Ctrl+N>** and enter 100 iterations. Now click **Evaluate...Tolerancing... Run <Shift+Ctrl+F9>**. Note that the spectrum is pasted into the spreadsheet during each iteration. The percent yield is given by the number of iterations for which cell E8 is TRUE.

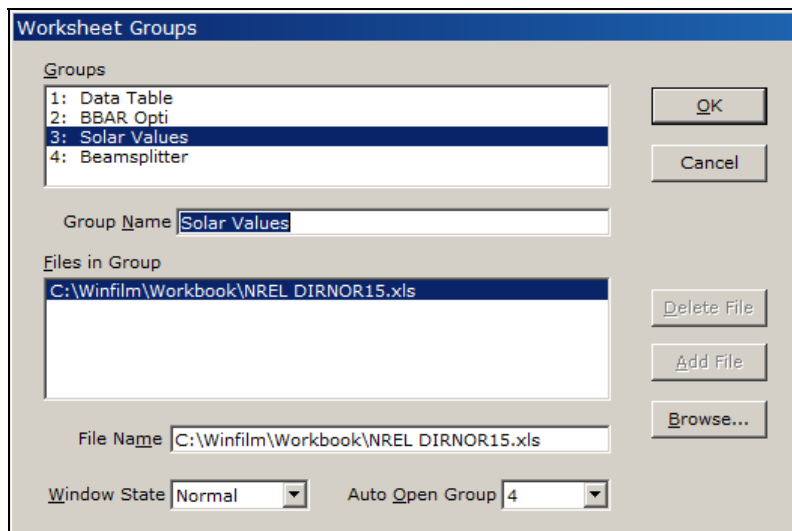
Basic spreadsheet knowledge is required to develop Workbook modules. Tutorials can be found in bookstores. Formulas are similar to those in MS Excel; click <Ctrl+F1> for help.

How does this work? Cell E8 has been assigned special defined name *Passed*. (The yellow background is automatically applied to cells with special defined names.) The formula for cell F1 is given by

$$=AND(\$E\$5<=0.5, \$E\$6<=1)$$

which returns TRUE or FALSE depending on whether specifications are met.

Not that worksheet model(s) can be assigned to a single hot-key or opened automatically through **File...Open Worksheet Group...Edit Groups**. This is very useful when working repeatedly with the same worksheet(s). Worksheets can also be opened through FilmStar BASIC.

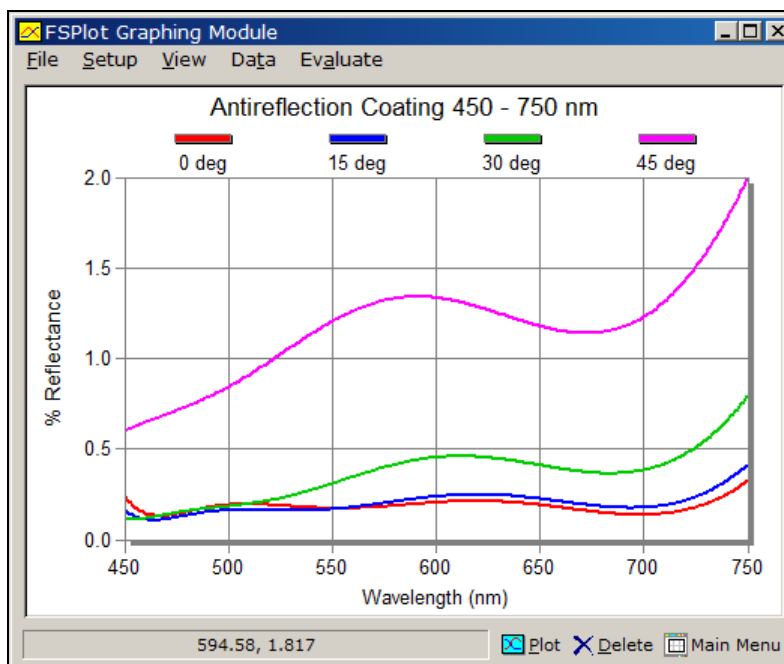


FSPlot Module

Before proceeding, close the Workbook and reload FILM Archive "bbar-o"; click Evaluate...Recalculate <F9> to obtain a spectrum on the screen.

In addition to the main screen graphics, FilmStar provides a second graphics module with numerous capabilities. From the Main Menu, click **Tools...FSPlot Module <F4>** to bring up the FSPlot Module (page 100).

Click **Plot <Alt+P>** in the bottom command bar to add the graph; then return to the main screen (click on it or click **Main Menu** on the command bar) and calculate again at 15 deg. Repeat for 30 and 45 degrees. Ultimately the graph will appear similar to the one shown below.



Duplicate the above appearance exactly by experimenting with the different settings in **Setup...Graph Details <Ctrl+H>**. Adjustments are implemented

without shutting the dialog. Closing that dialog, adjust font size in Setup Font and legend text and position in **Setup...Legends <Ctrl+E>**.

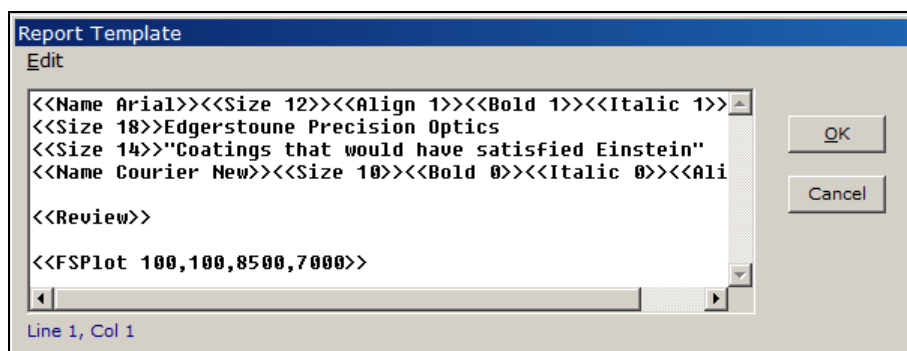
Report Generator

Before proceeding, please close the FSPlot Module and reload FILM Archive "bbar-o" and click Evaluate...Recalculate <F9>.

Power users can generate reports in MS Word.

FilmStar supports printed output combining graphics and text. From the Main Menu, click **File...Report Generator <F7>** to bring up the Report Generator (page 105). Examine the print preview window and click **Setup** to view margin and other settings. The margins should be 0.75" and line spacing 100%.

Print the report. If it doesn't look right it's possible that font *Courier New* is not installed. From the Report Generator dialog click **Template** and change the font name (<<Name *Courier New*>>) to an available fixed pitch font.



Actually, it's only necessary to include font information in the Template if multiple fonts are required. For a simple template such as

```
<<Review>>  
<<FSPlot>>
```

the font information stored in the Report Setup dialog may be sufficient.

If you've altered the template, please reload FILM Archive "bbar-o" before proceeding.

Going one step further, the Report Generator can include calculated results. Returning to the Main Menu, click **Tools...Workbook <F3>** and check that qcbbar.xls is displayed. If not, load it manually. We include the contents of cells *E5* and *E6* in our report by adding the listed lines to the end of the template. (Note that ← is a line continuation character. That is, the first two lines below are really one long line.)

```
<<Align 1>><<Name Arial>><<Size 16>><<Bold 1>>  
←Average = <<WbText E5>>%, Maximum = <<WbText E6>>%
```

FilmStar BASIC

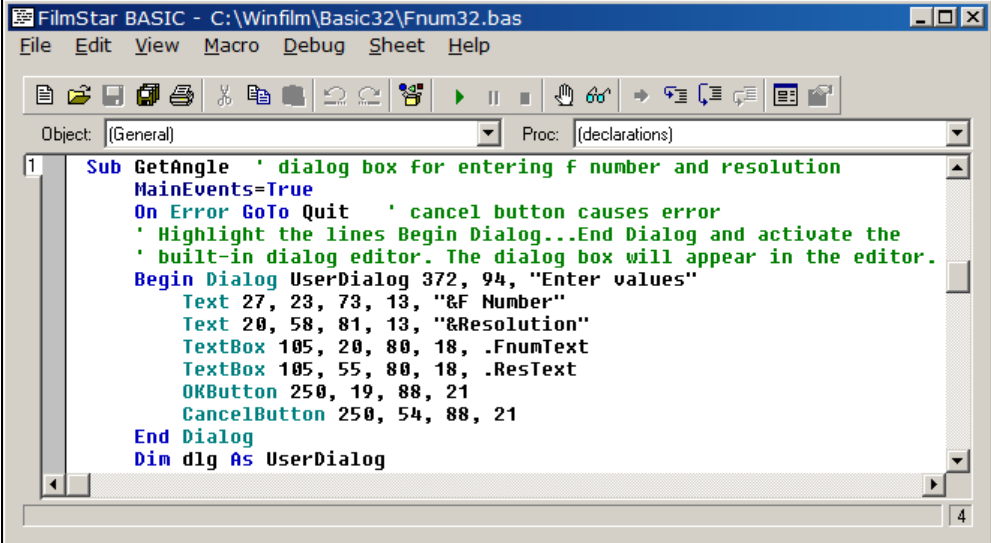
Before proceeding load FILM Archive "fnum". Click Evaluate...Recalculate to display the spectrum.

FilmStar BASIC (page 73) provides a powerful and flexible environment for automating calculations and simplifying repetitive operations.

Calculations in BASIC

Up to nine BASIC programs can be opened.

From the Main Menu click **Tools... BASIC Editor <F6>** followed by **File...Open <Ctrl+F12>**. Open file ".\Winfilm\Basic32\Fnum32.bas". Click **Macro...Run <F5>** or click the icon with the green start icon. If everything is working as it should, an *Enter values* dialog appears; just click OK to proceed.



```
FilmStar BASIC - C:\Winfilm\Basic32\Fnum32.bas
File Edit View Macro Debug Sheet Help
[Icons]
Object: (General) Proc: (declarations)
1 Sub GetAngle ' dialog box for entering f number and resolution
  MainEvents=True
  On Error GoTo Quit ' cancel button causes error
  ' Highlight the lines Begin Dialog...End Dialog and activate the
  ' built-in dialog editor. The dialog box will appear in the editor.
  Begin Dialog UserDialog 372, 94, "Enter values"
    Text 27, 23, 73, 13, "&F Number"
    Text 20, 58, 81, 13, "&Resolution"
    TextBox 105, 20, 80, 18, .FnumText
    TextBox 105, 55, 80, 18, .ResText
    OKButton 250, 19, 88, 21
    CancelButton 250, 54, 88, 21
  End Dialog
  Dim dlg As UserDialog
```

After the calculation is completed you will see that the original square filter has acquired a triangular shape. (If the BASIC editor has obscured the plot, click **Redraw**.) Simulating the effect of a wide cone angle, fnum.bas has repeatedly calculated and averaged the spectrum over a range of angles.

Calculations can be run without viewing the BASIC editor. One way to do this is to assign a macro key. Click **Tools...Macro Commands <Ctrl+Z>** and enter the following (changing the drive letter if required):

Description: FNUM Run

Command: BasRun c:\winfilm\Basic32\Fnum32.bas;busy 0;

Finally, making sure that the BASIC editor is closed (not just deactivated), click the **Tools...** selection corresponding to label **FNUM Run**. Alternatively, click corresponding macro button (1-6) in the Main Menu toolbar. (Enable macro buttons in **File... Toolbars**.) Note that the description is used for button tooltip text.

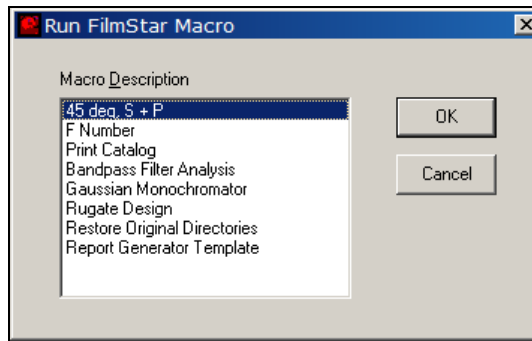
Simplifying Program Operation

Click **Tools...Macro Commands <Ctrl+Z>** and enter the following (changing the drive letter if required):

Description: Macro List

Command: BasRun c:\winfilm\basic\mselect.bas;busy 0;

This brings up the screen shown below. Click Report Generator Template to run program "template.bas"; select AR Coating Specifications. This macro not only opens the correct Workbook sheet but also computes the Report Generator template. In this way, engineers with moderate programming skills can implement new levels of computing power for coating and QC technicians.



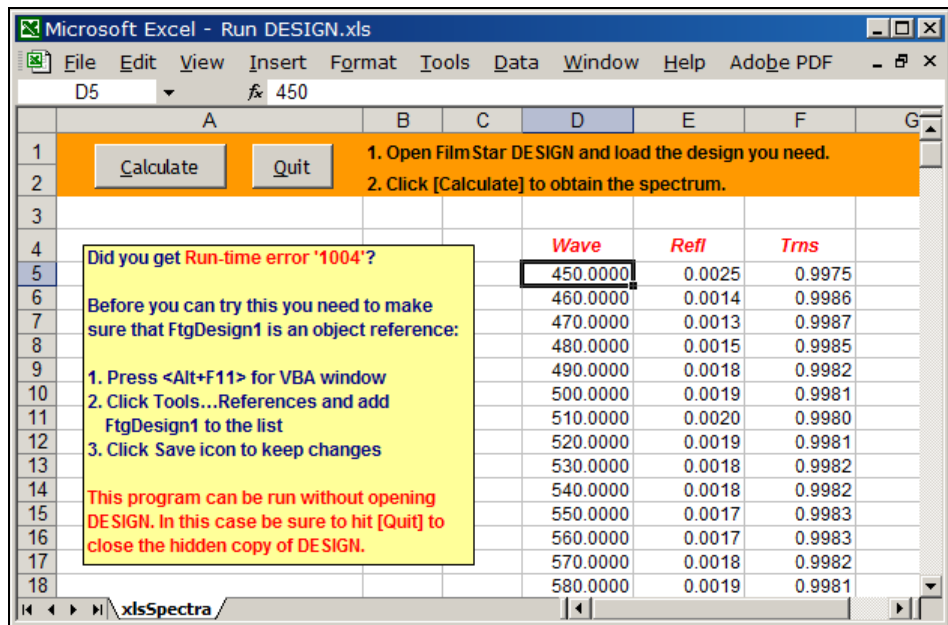
Using DESIGN spectra in Excel

Before proceeding load FILM Archive "bbar-o". Click Evaluate...Recalculate to display and verify the spectrum. Then close down FilmStar DESIGN.

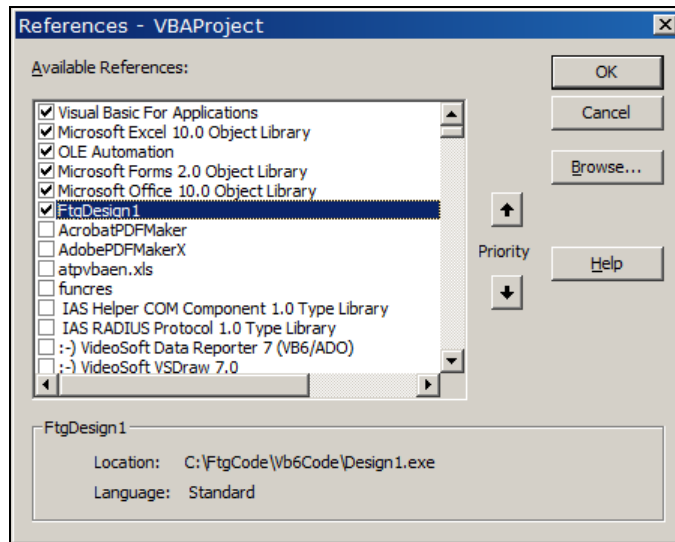
FilmStar is highly compatible with other Windows applications, including MS Office. You can, for example, utilize FilmStar spectra in Excel, or use Word instead of the built-in Report Generator to print documents.

Suppose you want to use Excel instead of the built-in Workbook to analyze thin film spectra. You could do this by copying and pasting but might find it tedious if the calculations are frequently required. In addition, the calculations might need to be performed by personnel who are not familiar with FilmStar.

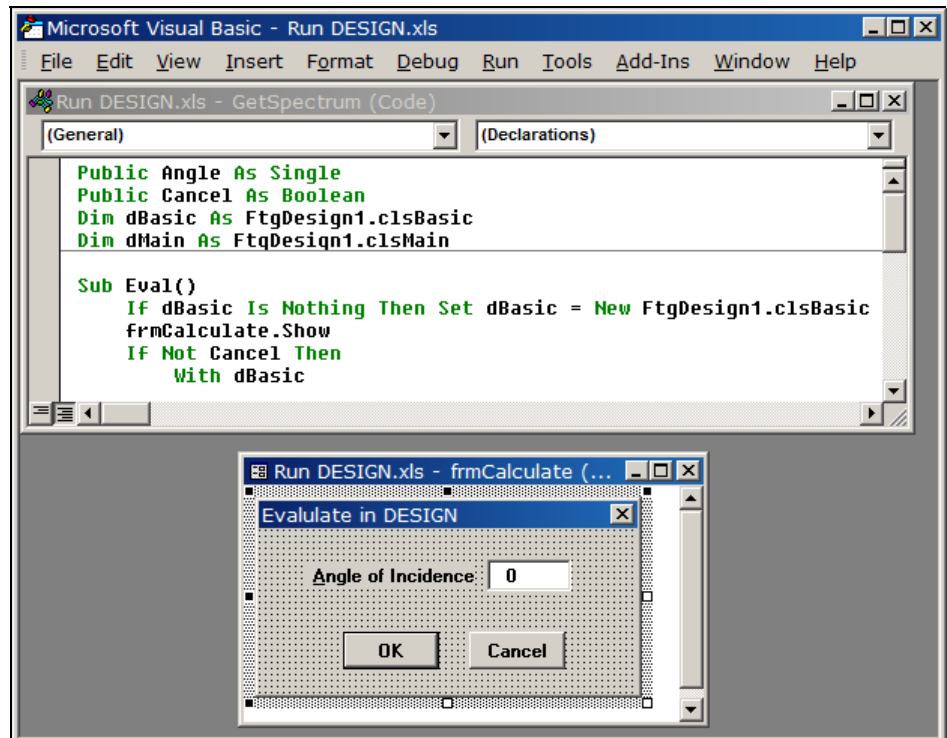
Start Excel and load C:\Winfilm\Excel 97\Run Design.xls to obtain the screen shown below. Click Calculate to obtain a spectrum calculated in DESIGN.



How does Excel know about DESIGN? From Excel click **Tools...Macro...Visual Basic Editor**. Then click **Tools...References**. A reference to **FtgDesign1** should be checked. If not, scroll down the list and check it. Next click **View...Object Browser**, select **FtgDesign1** followed by **clsBasic**. You will see that FilmStar BASIC functions are now exposed to Excel.



Finally, examine the code module and form shown below to better understand how objects in DESIGN are utilized in Excel.



INDEX Tutorial

Index from Measured Data

Optical coating engineers need to understand the dispersive properties of high index films such as TiO₂ in the visible and near UV regions. Faced with this need while employed in industry, we developed a practical technique for determining indices from measured data.

A thick oxide layer is deposited on a transparent substrate such as fused silica - typically 15 to 20 monitor quarter waves. When the part is removed and measured in a spectrophotometer there must be a number of transmission peaks and valleys in the near UV to red regions.

By counting the number of quarter waves on the monitor, the user will also be able to calculate the monitor to substrate tooling factor in program MONITOR.

We take advantage of the facts that the oxides are only slightly absorbing and nearly nondispersive in the red region. In the 'old' days a slide rule was used to find the integral ratio at half wave peaks or quarter wave valleys. Now program INDEX does the same thing.

Physical thickness is calculated according to the number of quarter waves and index determined in the red according to %T max - %T min. The index at shorter wavelengths is then calculated according to the deviation of peaks from their non-dispersive positions. Finally absorption k is calculated.

Here's the step-by-step procedure:

1. Deposit a thick film on a transparent substrate.
2. Measure its transmission at normal incidence in a spectrophotometer and store the data on disk.
3. If you are not using FilmStar MEASURE you will need to translate the file into a DESIGN compatible ".csv" spectral data file. See *File Open and Save* under "Spectra Menu" on page 52.
4. Click **Solve...Open Spectrum <Ctrl+F11>** to open the spectral file. Your hard disk should include the sample file ".\winfilm\spectra\tio2.csv" used here. If it doesn't, generate a file in DESIGN using dispersive index table TIO2A. Here the layer thickness is 1000 nm. Remember to use calculation mode **FWD include Side 2**.

Before proceeding, you should also check that **Solve...Spectrum Type** is set to **Continuous**.

5. Click **Setup...Graph Axes <Ctrl+G>** and adjust entries as shown below.

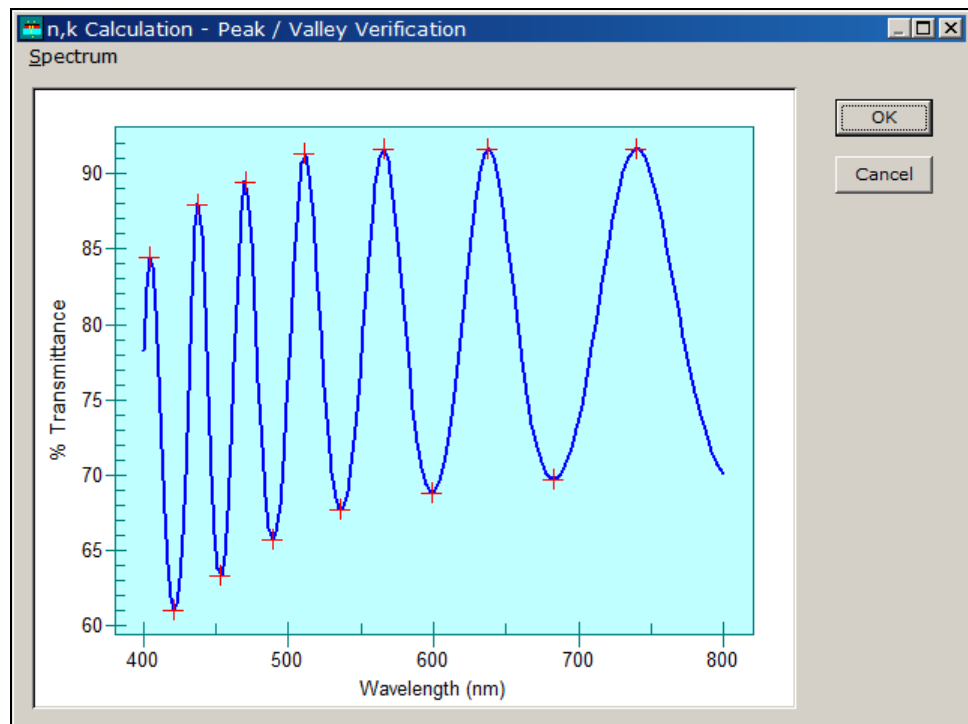
Graph Axes

Wavelength (nm)	Min 400	Max 800	k-Scale <input type="radio"/> Linear <input checked="" type="radio"/> Log $\times 10^{0}$	<input type="button" value="OK"/> <input type="button" value="Cancel"/>
Real Index n	2.2	2.5		
Imaginary Index k	-5	-2		

Description

This screen is important because k is fitted differently according to the **k Scale** entry. In oxides where k varies rapidly with wavelength near its absorption edge, select **Log**.

- Click **Solve...Calculate n,k <F9>** and specify **Algorithm 2**. The following screen eventually appears:



The entire data file is used in the calculation. If actual data shows spurious noise peaks, it is likely that the wavelength interval in the data file is too small. Data can be acquired again or Excel can be used to remove points. Click **OK** to proceed or **Cancel** if the data appears incorrect.

- The next screen includes various calculation parameters.

Click **OK** to calculate physical thickness. The idea is to minimize the estimated **Error** in the calculation. Here INDEX found that 10 quarter waves gave minimum error. (Test this manually by returning to the previous screen with Recalculate. Enter **1** in **Use...peaks** followed by **8** in **Fixed # quarter waves**. The error increases by several orders of magnitude.)

Click OK to create a new Index Table.

Verification is extremely important in index calculations! Please do not ignore the next step.

8. Store the new Index Table on disk with a new file name and use it in DESIGN with the calculated film thickness. Overlay your actual measured data. There should be excellent agreement.

Index Functions

The index determination procedures discussed above will meet the requirements of many users. But it is possible to proceed further by fitting a dispersive index function to the data. Following the initial fit in INDEX, functions can be further optimized in DESIGN.

Edit the Index Table generated in the previous section so that only wavelengths illustrated below are displayed. By eliminating 'bad' points we help the curve fitting process.

Index Table - TIO2A.itw
File Edit Window

	Wave (nm)	n	k
1	370.000	2.62000	3.7000E-03
2	390.000	2.43000	2.7000E-03
3	430.000	2.42000	1.3000E-03
4	470.000	2.35000	8.0000E-04
5	510.000	2.30000	2.0000E-04
6	550.000	2.27000	1.0000E-04
7	590.000	2.25000	1.0000E-04
8	670.000	2.22000	1.0000E-04
9	2000.000	2.22000	1.0000E-04
10			

OK
Cancel

Click **Function...Fit Index <Ctrl+F>** and enter the following in the Dispersive Index Functions dialog box.

LORENK A=5, B=1, C=300, D=1, k-Tolerance=10

Click OK to accept these values and return to the Main Menu. To see the effect,, click **Plot <Alt+P>** followed by **Functions...Plot <Ctrl+T>**. The fit is far from optimum. Return to **Function...Fit Index**, click **Fit** and let the refinement proceed for 30 iterations. You should finally obtain the following values:

Dispersive Index Functions
Edit Glass Adjust

Type

- CAUCHYM
- F-B
- LOREN
- LORENK**
- N
- NK
- SELL
- SELLG
- T-L

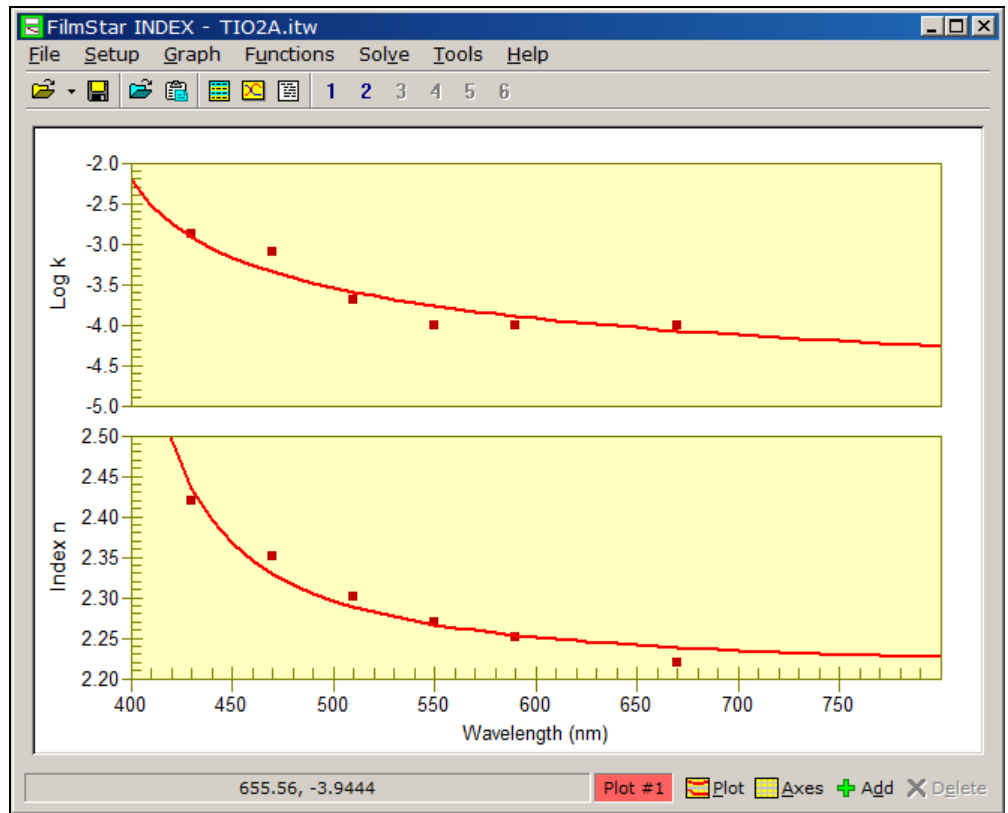
	Coefficient
A	4.58038E+00
B	2.89613E-01
C	3.81028E+02
D	3.99160E-01

Iteration
Merit
Ratio
Damping
k-Tolerance
Fit Restore
 Show Iterations

Wavelength Range... Angle
 Restrict fit to range P S
Plot Function Auto Replot

OK
Cancel

Once again, return to the Main Menu with **OK** and plot the function with **Functions...Plot <Ctrl+T>**. Your results should be similar to those shown below.



Suggestion: Compare the function with TiO₂A n,k values in DESIGN.

DESIGN Reference

File Menu

Five component files are utilized in specifying a thin film design:

1. Graph Axes (.axw) (page 33)
2. Film Indices (.inw) (page 31)
3. Design (.dew) (page 42)
4. Optimization Targets (.trw) (page 57)
5. Optimization Variables (.vaw) (page 59)

These files constitute a FILM File which can be loaded with a single file name. **Since a FILM File is only a collection of file names, the constituent files must be stored separately.** A FILM File does not have to be updated unless the names of the component files have changed. That is, if you update Graph Axes file "bbar" you do not have to update FILM File "bbar".

As a recommended alternative, a FILM Archive File (.faw) is a single file containing all the data stored as a FILM. This mode is enabled and disabled by clicking **File...FILM Archive Mode**. When enabled it is still possible to load or store separate component files via the keyboard or via macro commands such as **AxesOpen**. MONITOR and CRYSTAL support both file structures via **File...Open...Design** or **File...Open Archive Design** selections.

FILM Archive Mode (recommended) offers maximum security against inadvertent design changes. FILM components can also be loaded and saved in FILM Archive mode.

Click **File...Archive n,k Data** to include dispersion data in a FILM Archive. In this mode film indices cannot be edited. This mode is useful for permanent storage and/or sending designs to FTG Software, as it eliminates the need to include dispersive files.

It is possible (see "n,k Archive Mode" on page 32) to convert archived n,k data into dispersion files, thereby enabling editing upon exiting n,k Archive Mode.

Two other DESIGN files are accessed from other menus:

1. Spectral data
2. Wavelength List

Dispersive index tables are used by DESIGN but created and edited in separate program INDEX.

Open <Ctrl+F12>

The FILM File automatically loads component files. These files can also be loaded individually. DESIGN keeps track of data that has changed and prompts users to update old files before loading new ones. In FILM Archive Mode only one file is loaded.

Save As <F12>

When Archive Mode is disabled this leads to the Save Files dialog box which provides Save and Save As functions for the five components in a thin film design. In FILM Mode check **Auto FILM** to automatically store all component files with the same file name (and description) as the FILM file.

Disable **Overwrite warning** in **File...Configuration...Preferences** if overwrite confirmation messages are annoying.

Save All

Quickly saves the five files constituting a FILM as "work" files in appropriate default directories. These files are automatically loaded at start-up and automatically saved when exiting DESIGN. This function is included for users who experience unrecoverable program or Windows failures and for users who exit Windows by shutting off the computer (not recommended).

Copy Graphics

Copies the current screen graphic to the clipboard for pasting into other applications.

Print Graphics

Print the screen graphic to the current Windows default printer. Best results are obtained with a white background.

Report Generator <F7> (page 105)

Access the FilmStar Report Generator. This lets you combine text and graphics in multi-page documents

Quick Print Report <Ctrl+F7>

Print a report without accessing the FilmStar Report Generator. Use this when the report has been set up and tested.

Exit <Alt+F4>

Upon exiting configuration file "..\winfilm\config\design1.ini" is updated. Configuration includes **File...Configuration** settings, Graph Details (line thickness, etc.) and position and size of the program window.

Current design, film indices and similar data is automatically saved in files "work.*" (same as selecting **Save All**). This ensures the program will be in the same state upon restarting.

Configuration - Capacity

File...Configuration...Capacity

Users can configure DESIGN for optimum memory utilization (and improved speed in loading forms containing grids) by entering values not exceeding anticipated maxima.

Capacity changes are not implemented until programs are exited and restarted.

Film Indices (page 31)

Specifying up to 52 correspondings to index symbols A...Z and a...z in the Film Indices editor. If 26 or less are specified, index symbols are converted to upper case when entered. Specifying more than 52 materials places DESIGN in *Extended Materials* mode where letters are replaced by film material numbers within square brackets. That is, .25H might become .25[55].

Coefficients

Dispersive index functions (Sellmeier, etc.) are used to fit n,k values to measured spectra. Some of the more complex index functions require more than the default (7) number of coefficients.

Groups

Maximum number of individual layers or groups of layers. Maximum capacity has not been determined.

Layers in group

Maximum number of layers within a group.

Targets

Maximum number of optimization targets. The maximum number of targets has not been determined.

Variables

Maximum number of optimization variables. The maximum number of variables has not been determined. Note that each index variable adds 1-7 actual variables to the calculation. Enter a value that is a multiple of five.

n,k Wavelengths

Maximum number of wavelengths allowed in a dispersion table (n,k vs. wavelength) created in program INDEX.

Wavelength List

Maximum number of entries which can be edited in the Wavelength List editor. This is not the same as the number which can actually be utilized in an optical thin film calculation.

Wave/Angle List

Maximum number of entries which can be edited in the Wave/Angle List editor.

Configuration - Directories

File...Configuration...Directories

User Name

The user name appears in the Review Design screen. It also is used in FILM Archive file properties (NTFS only) when *Enable file properties* is checked. File properties can be used for 'who designed this?' and/or to add comments to FILM Archive files. The same capability is found in FilmStar INDEX. *Check Work File ID* if sharing designs on a network drive. This tags your 'work file' with your user name.

Directories

Files are stored in four default directories. While files can be loaded from any directory, they can only be stored in the default directories. (Exception: spectral data files can be stored anywhere.)

Data

Film indices (.inw), Graph Axes (.axw), Wavelength List (.wls), Optimization Targets (.trw), Optimization Variables (.vaw), and FILM Files (.flw)

Designs

Thin film Designs (.dew) and FILM Archives (.faw).

n,k Tables

Dispersion tables created in program INDEX (.itw).

Spectra

Spectral data files (*.csv) in 'comma-separated values' format. These files can be loaded in Excel. Since .csv is not a FilmStar-specific extension, users are advised to utilize unique directories for spectral data: *i.e.* "c:\excel\mydata". European users may have problems with CSV format.

Database Configuration

FilmStar BASIC programs can be assigned to *DB Retrieve* and *DB Save* menu commands in the File and Spectra menus. An example is the FileMaker Pro database solution included with FilmStar. The examples show how database technology and ActiveX provide means to sort and select designs and spectra. Users are not restricted to FileMaker Pro. MS Access programmers can develop similar functionality.

Enter file names of BASIC programs to be assigned to menu commands. Click **Edit...Select <F3>** to browse and select files.

Configuration - Preferences

File...Configuration...Preferences

Changes in the following are recorded in "..\winfilm\config\design1.ini" upon exiting DESIGN.

Use Windows message box

Message boxes display **OK Cancel**, **Yes No** and similar messages. There is a choice of Windows default message boxes (centered in screen) or FTG Software message boxes (normally centered in active window). Windows message boxes support Windows sound effects and local languages. You may find FTG message boxes easier to read.

Cancel warning in data entry dialogs

Issues a warning message if you modify a data entry in a dialog box and then click **Cancel** to close the box.

Overwrite warning on file open and save

Issues warning (recommended) when opening or saving a file (*Save*) when relevant changes have been made.

Automatic edit after file open

Access appropriate data editor immediately after loading new file from disk (emulates FilmCalc).

Automatic review design

Display the Review Design screen immediately after loading a new design from disk.

Use FILM Archive (FILM) description for graph title

Normally the Graph Axes title is printed at the top of the main spectral plot. Check this box if you prefer to utilize the file description from the design Save As dialog box.

Display and save file descriptions

Check to save and list file descriptions (50 characters maximum). This facility is a carry-over from 16-bit Windows (8 character file names). The option adds **File...List** and **Spectra...List** commands.

Augment File Open/Save in FILM Archive Mode

Adds File Menu commands for opening and saving FILM components (Graph Axes, Film Indices, etc.) while in FILM Archive Mode. The same capability is provided by "Keyboard Commands" (see page 111) if Augment is unchecked.

The following advanced settings, not included in menu selections, require that users modify "..\winfilm\config\design1.ini" in Notepad or any text editor. Do not type comments (starting with ;) on the same line as a setting.

CIE User-Illuminants

Users can add any number of illuminant files as follows. For further information see "CIE Color Module" on page 98.

```
[CIE Color]
Illum1=Xenon Lamp;arclamps\xenon.csv
Illum2=Fluorescent Cool;fcool.csv
Illum3=Fluorescent Warm;fwarm.csv
```

The first description appearing in the pull-down illuminant list is *Xenon Lamp* and the corresponding file name is *xenon.csv*. Files should be stored the FilmStar program directory (usually c:\winfilm), but an optional subdirectory (arclamps) can be added.

Negative k (gain)

DESIGN and INDEX will accept negative values of k (corresponding to gain) if the following line is inserted:

```
[Configuration]
AllowNegAbs=-1 ;enable k<0 (gain)
```

Negative n (left-handed materials)

DESIGN and INDEX will accept negative values of n (corresponding to left-handed materials) if the following line is inserted:

```
[Configuration]
AllowNegInx=-1 ;enable n<0 (left-handed)
```

This is of theoretical interest and seems to work for thin layers only. Anyone using this capability should familiarize himself with previous work on left-handed materials and verify results against the literature.

Configuration - Miscellaneous

File...Configuration...Misc

Graph Axes Labels

This provides means to replace default English graph axes labels with international equivalents. Labels apply to the FSPlot Module as well as the main screen. Check *English characters only* if using Japanese and similar fonts which do not display "Å" and "µ" symbols (replaced by "A" and "u").

Print Graphics Plot Size

Sets plot sizes for the Print Graphics command in the File menu.

DDE Timeout

DDE (dynamic data exchange) is a (now obsolete) way for Windows programs to communicate. If the connection is not made in the specified time, an error message is generated.

Show DDE Import/Export commands

DDE (dynamic data exchange) can be used to exchange data with Excel and other programs. Check to add DDE commands to menus.

Configuration - Security

File...Configuration...Security

ID Module

An FTG Software Security ID Module must be attached to the parallel (printer) or USB port. The printer can be attached to the parallel module. HASP modules are embedded with company name. The previous black Activator module is no longer supported. Contact FTG Software to arrange module exchange.

Encrypting designs

An encrypted design cannot be viewed or edited. This allows thin film vendors to supply proprietary designs and index tables to customers while maintaining trade secrets.

Do not use this facility casually. Be sure to back up designs and index tables before encrypting!

Users who require this feature should visit the Technical Issues page and click *Encrypting designs* under *DESIGN*.

FilmCalc Compatibility

Convert.exe (included on FilmStar CD-ROM) converts historic FilmCalc (DOS) data files to FilmStar format. The program is run from the Windows Program Manager via

File...Run "..\winfilm\convert.exe"

Note that there are two gray text boxes. The smaller box shows progress during conversion while the larger box shows accumulated errors. If you want to print the errors, highlight the text, copy it to the Windows clipboard with **<Ctrl+C>** and paste it into Windows Notepad.

Convert

FilmCalc files are opened, converted and saved in FilmStar format. Original files are not erased.

With one exception, all files should convert without any user-attention. But there are difficulties associated with ***n,k Tables*** (dispersive index files). In FilmStar all parameters are stored in ".itw" files (*n,k Tables* directory). In FilmCalc the following extensions are used: ".itb" (*Index Table* in *n,k Tables* directory), ".axi" (*Graph Axes* in *Data* directory), ".itf" (*File Functions* in *Data* directory) and ".nkt" (*n,k Fit Parameters* in *Data* directory).

After converting the *Index Table*, CONVERT looks for ".axi", ".itf" and ".nkt" files with the same file name. If the original FilmCalc table is "tio2a.itb", CONVERT will attempt to open "tio2a.axi", "tio2a.itf" and "tio2a.nkt".

Since FilmStar INDEX always displays graphs of *n* and *k* vs. wavelength, *Graph Axes* information (optional in FilmCalc) is required. If no ".axi" file is found, CONVERT examines the *Index Table* and assign values.

File Types

Check some or all types to be converted.

Duplicate File Names

It is likely that some FilmCalc files ("bbar", "highpass", etc.) have the same names as FilmStar files already on your disk. You can decide whether to overwrite or skip these files.

File...Directories <Ctrl+D>

Enter directories for both programs. CONVERT can be repeatedly run with different directory assignments. CONVERT will not create directories; if you wish to copy to an empty directory, create it first with Windows File Manager or another utility.

File...Exit <Alt+F4>

Program setup is stored in "..\winfilm\config\design1.ini".

Setup Menu

Film Indices

Setup...Film Indices <Ctrl+I>

The Film Indices editor lists the materials used in a thin film design. It is possible to list more materials than those actually used. Layer thicknesses are later specified in the Groups or Layers design editors.

Materials must be defined before being used in a thin film design.

AIR indicates entrance medium (normally air) and **SUB** indicates exit medium (normally the substrate).

Enter Index Values

1. Define a symbol by entering a one letter index symbol 'A' to 'Z' in the **Symbol** column. If more than 26 materials have been allocated (see "" on page 26) then 'a' to 'z' are also used; otherwise all entries are capitalized. If more than 52 materials are used materials are indicated by numbers.
2. Specify film thickness convention:
 - a. **Optical thickness**...Set **Type** to **Opt** (type O). Specify quarter wave optical thickness QWOT =.25 or 1 in Setup Parameters. Optical thickness makes no sense for metals. If the substrate is a metal, select 'Metal' under Substrate Properties in the Setup Parameters dialog (page 38).
 - b. **Physical thickness**...Set **Type** to **Phs** (type P) for layers described by physical thickness. Specify physical thickness units in Setup Parameters. It is possible to automatically convert optical to physical thickness; this updates the **Type** column automatically.
 - c. **Massive thickness** (see "Massive Layers" on page 37)...Set **Type** to **Msv** (type M) for massive (thick) layers described by physical thickness in mm. This allows evaluation and optimization for films on both substrate surfaces or with multiple substrates and air gaps. In most cases the user will assign $n=1.0$ to both AIR (entrance medium) and SUB (exit medium).
3. Specify film indices:
 - a. **Constant**...Leave the **Dispersion** column blank and enter constant values for n and k . Columns C-G are disabled (grayed out).

- b. **Table...** Under **Dispersion** select the name of a dispersive Index Table previously stored in program INDEX. Longer file names may appear truncated, but when pulled down the list becomes wide enough for the longest name. Hovering the pointer over a truncated file name displays the full name as tooltip text. In addition columns may be made wider by dragging at the top. The **Refresh** check box forces the reloading of index tables. Check this if you have altered dispersive index data in INDEX while running DESIGN. Columns A-G are disabled. A dispersive Index Table with an entry at only one wavelength is treated as a constant.
- c. **Function...** Under **Dispersion** select the name of an Index Function (see “Index Functions - Built-in” on page 34 and “Index Functions - User Defined” on page 34) starting with \$ rather than a file name. Columns A-G (further columns displayed if more than 7 coefficients are specified) are the relevant coefficients. Index optimization variables are specified in the Optimization Variables dialog (page 59). Note that unused columns are disabled. **Edit...Copy Function** copies function coefficients to the clipboard for pasting into program INDEX. Check **Edit...Scientific Notation** to enter all function values in scientific notation.
- d. **Function Fit from File...** Under **Dispersion** select the name of a dispersive Index Table previously created and saved in program INDEX. If available, the index function fit for that table is inserted by clicking the **Insert Function** button. In the event of error message *Index fit undefined* (missing User Index function) close Film Indices and open the offending Index Table file in FilmStar INDEX. (No need to shut down DESIGN.) Navigate to the User Index Function dialog and click **Save Collection** to save the function. Returning to DESIGN and open the saved function with **Open Collection** in the User Index Function dialog. Finally, open the DESIGN Film Indices dialog and try the **Insert Function** button again. The new function is saved with the FILM Archive file.
- e. **Description...** The **Description** (16 characters maximum) is utilized in Review Design as well as FilmStar BASIC. Entering a description for all film materials enables **Edit...Sort by Description** and makes it possible to select materials by description in the Layers Editor. By including string "QWOT" (not case sensitive) in the description a corresponding optical film layer is calculated as a quarter wave at *any evaluation wavelength*. If the index of this material is equal to the square root of a massive layer onto which it is deposited, the film layer becomes *unobtainium* - a perfect antireflector at zero degrees.

n,k Archive Mode

Thin film designs normally refer to separate n,k files (.itw). This can lead to difficulties if materials are altered. *n,k Archive Mode* avoids such problems by storing n,k values in the design itself. This is convenient when transferring designs to other users since n,k files are not required.

The normal procedure is to open a FILM Archive and then enable n,k Archive Mode. Names under **Dispersion** remain the same but now refer to internal lists of n,k values instead of files. Select a row containing a dispersion name and click **View n,k Data**. Note that values cannot be edited.

The Index Table viewer includes two functions in the File menu: copy and save. Saving is intended for users who don't have original materials files and need to recreate them. Since a saved table may not have all the attributes of

the original index file, particularly dispersive index functions, users are not permitted to overwrite a file with the same name.

Graph Axes

Setup...Graph Axes <Ctrl+G>

Horizontal (wavelength, angle, thickness) and vertical (%R, %T, etc.) axes types must be specified before editing this dialog box. (See "Setup Parameters" on page 38). Report Generator templates are stored with Graph Axes.

Interval

When plotting vs. wavelength, use Interval < 0 for faster calculation with inverse wavelength spacing.

For example, let Min=400, Max=1200 and Interval=-10. During evaluation the wavelength interval changes from 10 at 400 nm to 30 at 1200 nm.

Interval < 0 is not permitted when plotting vs. angle or when the horizontal scale is expressed in wavenumbers.

List Name

When using a wavelength list, Interval is replaced with the name of a Wavelength List file (".wls") stored in the Data directory.

Label

Axis label and grid spacing.

Graph Title

In addition to the graph title, labels may be placed on the graph by pressing <Shift+Click> when the cursor is in the plot area (crosshair shape). Far more sophisticated labels are available in the FSPlot Module.

Specify evaluation wavelengths in Wavelength List

When the horizontal axis is physical thickness, check this option to assign different evaluation wavelengths for each layer according to values in the Wavelength List editor. While this is somewhat useful for optical monitor simulations, FilmStar MONITOR offers far more capability.

Graph Details

Setup...Graph Details <Ctrl+H>

Options relating to graph appearance are provided in this dialog. Most options include tooltip help messages. A similar dialog is included in the FSPlot Module.

Ignore FSPlot Status requires explanation. If a FILM or FILM Archive file is opened while the FSPlot window is visible, it is assumed that the user wishes to retain current graph axes settings. Since the FSPlot Module requires that multiple plots have identical wavelength values, *Ignore FSPlot Status* = False facilitates comparing spectra from different designs.

To change line colors with the keyboard, press <Alt+R>, use left and right arrow keys to select and press <Enter>. <Shift+Enter> changes colors without replotting the spectrum. Colors can also be selected with a single keystroke:

blacK, Red, Yellow, Blue, Green, Magenta, Cyan, White

Index Functions - Built-in

Setup...Index Functions...Built-in

This dialog selects built-in index functions to be shown under *Dispersion* in the Film Indices editor. Functions which are never used can be suppressed in order to simplify choices. In the same way, Index Tables which are never used can be kept in a backup directory.

Opening a FILM or FILM Archive referencing a deselected index function automatically adds that function to the list. A warning is displayed if the number of coefficients exceeds the maximum specified in **File...Configuration...Capacity**.

The specialized GaAlAs function is given below.

GAALAS $Ga(1-x)Al(x)As$ where $x=A$
M. Afromowitz, SS Comm 15, 59 (1974)
Additional absorption:
 $\alpha = 3e-18*B + 7e-18*C + D$
(α in cm^{-1} , B n-type doping,
C p-type doping, D extra term)
Temperature variation:
 $n = n*(1 + 7e-5*E)$
(E: deviation from room temperature)

Index Functions - User Defined

Setup...Index Functions...User Defined

Supplementing built-in index functions, advanced users may define their own functions as formulas, in FilmStar BASIC (page 73), in the FilmStar Workbook (page 94), or in other Windows applications such as Excel.

User Defined functions are stored in FILM Archive files *.faw or Film Indices files *.itw. The procedure for transferring functions from DESIGN to INDEX is to store a collection of functions (*.itf) which can then be opened in INDEX. Click **File...Save Collection** in DESIGN followed by **File...Open Collection** in INDEX.

User Defined functions are stored in FILM Archive files *.faw (as well as Film Indices files *.inw). They are also stored temporarily in design1.ini for utilization in program INDEX. If INDEX is open at the same time as DESIGN, the best procedure is to click **File...Save Collection** to store a collection of functions (*.itf) which can then be opened in INDEX.

The formula evaluator and built-in FilmStar Workbook have calculation speed advantages and should be used when possible. Formulas should be developed in INDEX where they can be verified by plotting.

Click tab **Workbook/DDE** to define index functions in the Workbook or in external programs such as Excel. Click **Formula** to define functions as formulas. The latter is much easier if one line formulas can be written for n and k. Click tab **BASIC** to define index functions in a FilmStar BASIC program.

Be sure that the correct tab for each function is selected before proceeding to the next function with Select Function.

Function

Each function has a name (seven characters maximum) which will be automatically inserted in the dispersion list in the Film Indices editor

(preceded by '\$'). You must also enter the number of variables (coefficients utilized) as well as whether or not the function is absorbing.

Coefficients

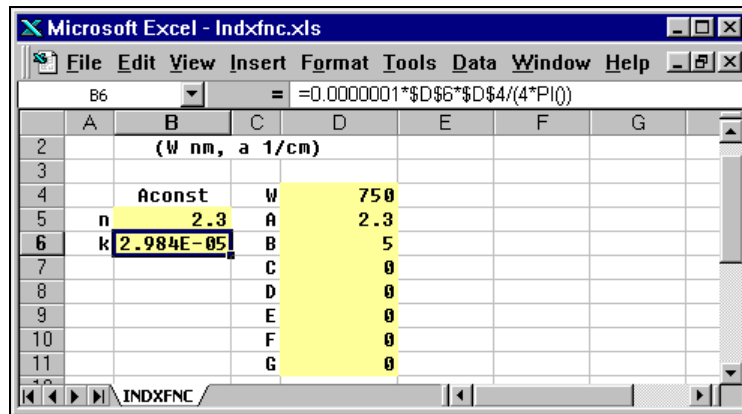
These are exported to the external application as eight lines of text. The first line is wavelength in nanometers and the remaining lines correspond to coefficients A-G.

Indices

These are imported by DESIGN as two lines of text. The first line is n and the second is k.

Execute

In some cases it is necessary to execute a command in the external application. In Excel this corresponds to executing a VBA macro.



Consider an example using Microsoft Excel worksheet "indxnc.xls". User-function **Aconst** returns n,k for a given absorption coefficient a (alpha) in 1/cm: $k=1.e-7*a*W/(4*PI)$ for wavelength W in nanometers

D4:D11	AconstCoeff
B5:B6	AconstIndex
B5	=\$D\$5
B6	=0.0000001*\$D\$6*\$D\$4/(4*PI())

In DESIGN (and INDEX) the function is specified as follows:

Name	Aconst	# Coefficients	2	Absorption	TRUE
Coefficients	Topic	Excel indxnc.xls	Item	AconstCoeff	
Indices	Topic	Excel indxnc.xls	Item	AconstIndex	

In this case it is not necessary to execute any commands by running a macro in Excel. But if it were necessary the following format would be used:

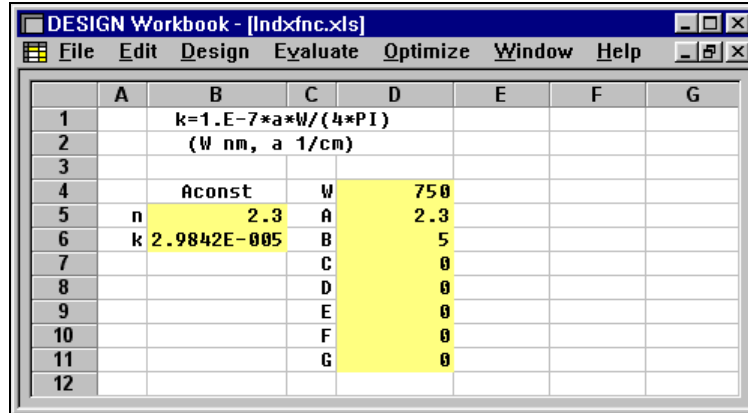
Topic	Excel System
Command	[RUN("AconstCalc")]

where AconstCalc is the name of the required macro. The user can verify that this works by implementing a test macro that merely beeps:

```
Sub AconstCalc()
    Beep
End Sub
```

Note that Excel must remain open during the calculation. A built-in worksheet is treated the same way, but without 'Excel|' in Topic entries; here macros are not available however:

Name	Aconws	# Coefficients	2	Absorption	TRUE
Coefficients	Topic	indxfunc.xls		Item	Coefficients
Indices	Topic	indxfunc.xls		Item	AconstIndex
Execute	Topic			Command	



Cells \$D\$4:\$D\$11 are named 'Coefficients' and cells \$B\$5:\$B\$6 are named 'AconstIndex' in the Workbook's **Edit...Define Name** dialog box.

In **Formula** mode we have the following which is considerably simpler.

Formula

Type a formula for n and a separate formula for k. In addition to coefficients A-G (typical), allowed variables are WN for wavelength in nanometers and WM for wavelength in microns.

Formula syntax can be tested in the DESIGN or INDEX Main Menu Help...Calculator <Ctrl+X> dialog.

As an example **Aconfnc** computes n,k for a given absorption coefficient b (alpha) in 1/cm. $k=1.e^{-4*a*W}/(4*PI)$ for wavelength W in microns. Then

$$n=a$$

$$k=.0001*b*wm/(4*3.14159)$$

Mixed materials formulas can utilize up to three dispersive tables. For example, consider index function SI-SIO2 which is a mixture of Si and SiO2. Under Table 1 select SI and under Table 2 select SIO2. Then type

$$n=A*N1 + (1-A)*N2$$

$$k=A*K1 + (1-A)*K2$$

Here the one coefficient A is the mixing ratio. Results can be tested in program INDEX.

Click **Leibold SYRUSpro Mode** in the Special menu to enter formulas to be included in SYRUSpro Monitor Reports. The actual XML file is later created in MONITOR in FTG-supplied program *SproMonitorReport.bas*. Formulas cannot be entered manually. Click **Insert SYRUSpro...** to enter a required material name such as SiO2 and then check *n,k Table* or select separate functions for n and k. *Table* always refers to the index table in the current file. We suggest that you contact us for a run-through via <http://ftg.glance.net>.

SYRUSpro users who have not heard about Monitor Reports should contact their Leybold representatives for a system software upgrade.

BASIC

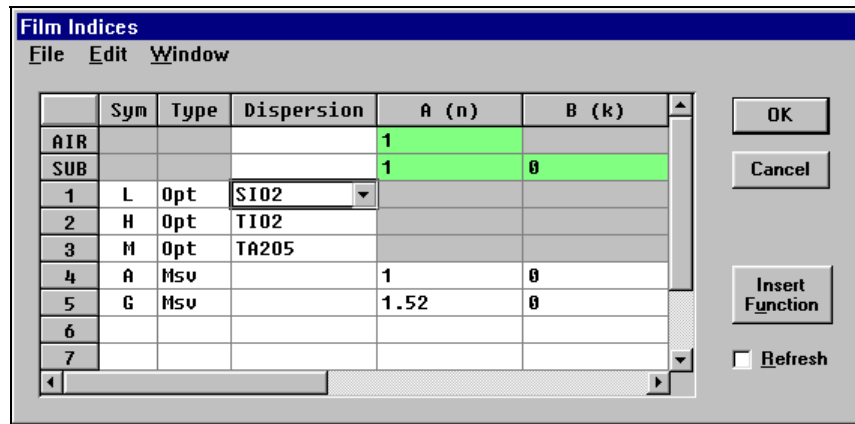
Specify the name of a FilmStar BASIC program which computes indices. Data is automatically transferred to your BASIC program via built-in clipboard functions. Copy the example below, changing Section 2 (User-code) as required. Note that BASIC functions cannot be utilized when accessed by BASIC macros.

```
' ACONST.BAS for FilmStar DESIGN
' This program shows how to define
' index functions in FilmStar BASIC.
DefInt I-N
DefSng A-H, 0-Z
Dim Aconst(1 To 7)
Sub Main
' 1. Get comma-delimited coefficients from clipboard
s$ = Clipboard$( )
Parse s$, wave
For i = 1 To 7      ' 7 maximum
    Parse s$, Aconst(i)
Next i
' 2. User-code to calculate indices
xi = Aconst(1)
xk = .0000001 * Aconst(2) * wave / (4 * 3.14159)
' 3. Copy indices to clipboard
Clipboard Cstr(xi) & "," & Cstr(xk)
End Sub
Sub Parse (s$, x)
i = InStr(s$, ",") ' comma delimited
x = Val(Mid$(s$, 1, i - 1))
s$ = Mid$(s$, i + 1)
End Sub
```

Massive Layers

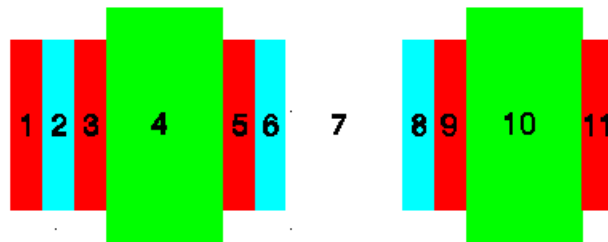
DESIGN allows virtually any number of massive (thick) layers to be included in a thin film design. In order to specify an index symbols as massive, set **Type** to **Msv** in the Film Indices editor (page 31).

Massive thickness is expressed in millimeters and **FWD Ignore Side 2** calculation mode is required. While designs containing groups are supported, massive layers cannot be placed within parentheses.



As shown in the above screen image, n=1 for AIR and SUB is usually entered in the Film Indices editor. By defining "A" as a massive layer with n=1.0, we can insert an air gap.

As quite complex film-substrate structures can be designed, users must be very careful with layer numbering when transferring designs into manufacturing processes. The design illustrated below has three massive layers: two glass (4, 10) and one air (7). If layers are numbered from 'left' to 'right', light is incident from the right.



Reversing the design (see "Design Menu" on page 42) can be very helpful when splitting complex constructions containing massive layers into single surface components.

Users are sometimes surprised when a design containing a nonabsorbing massive glass layer such as

$$(.25H .25L)10 .25H 2G .25H (.25L .25H)10$$

does not produce expected blocking. If the transmittance with the coating on only one side is 0.02%, they are surprised that the calculated transmittance with both sides coated is 0.01% - not 0.004% as usually observed experimentally.

The discrepancy is understood upon including absorption in the massive layer... say $k=10^{-6}$ or even less. While this has little effect on the transmittance of an uncoated substrate, it damps multiple reflections between surfaces and profoundly affects the transmittance of a substrate coated on both sides.

Setup Parameters

Setup...Parameters <Ctrl+P>

Plot

The following quantities may be calculated and plotted: Reflectance, Transmittance, Optical density, Absorptance, Phase, Electric Field, Ellipsometric

Psi/Delta, Group Delay, Group Delay Dispersion, Third Order Dispersion, Chromatic Dispersion, Refractive Index.

Click **User Defined** to specify user-defined functions User 1-6. Variables are RFP (refl P pol), TRP (trns P pol), RFS (refl S pol), TRS (trns S pol), RPP (refl phase P pol), TPP (trns phase P pol), RPS (refl phase S pol), TPS (trns phase S pol). Reflectance and transmittance are in percent; phase is in degrees. The same functions can be accessed in the Optimization Targets dialog. Functions appear in the *Plot* pull-down list. Note that user-defined functions are saved with Optimization Targets.

Several horizontal axis options are available. Select Wavelength Range or Angle Range to specify an evaluation range different from the graph axes range. This is intended for calculations where the evaluation range (say 380-780 nm) does not make for pleasing graph axes (350-800 x50 nm).

Select Wavelength List to compute spectra at wavelengths specified in a list (*.wls) stored in the data files directory. This is useful for tolerancing involving discrete wavelengths. When computing tolerancing Select Wave/Angle List to compute spectra at wavelengths, angles and polarizations specified in a similar list (*.wal) . The file name of these lists are used instead of Interval in the Graph Axes editor. Wave/Angle List is automatically selected for ellipsometric calculations.

Select Thickness for monitor or sensitivity plots where the horizontal axis represents physical thickness. Thickness axes are not allowed in a design containing parentheses. (Use the Layers design editor to 'explode' groups into separate layers.) Axes settings are stored with Graph Axes.

Wavelength Units

Internal calculations are performed in nanometers but displayed in nanometers, microns, Angstroms or inverse cm. This choice does not, therefore, affect spectral data files. Units can be switched at any time.

Layer Optical Thickness Convention

Quarter Wave Optical Thickness (QWOT) at a given Design Wavelength can be specified in two ways:

1. QWOT=.25 (quarter wave stack: .25H .25L .25H etc.)
2. QWOT= 1 (quarter wave stack: 1H 1L 1H etc.)

Layer Physical Thickness

Physical thickness (Nanometers, Microns, etc.) is used for layers when **Phs** is included in the corresponding **Type** column in the Film Indices dialog (page 31). Otherwise optical thickness is utilized.

***Thickness and wavelength units can be changed at any time.
Unit-dependent quantities will update automatically.***

Substrate Properties

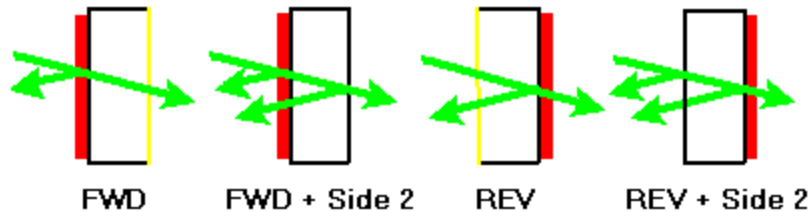
Calculate as...For maximum calculation speed when film layers are non-absorbing, select Dielectric when the absorbing substrate is a filter glass ($k \ll n$). Otherwise select Metal.

Metal gives correct answers for dielectric substrates, but **Dielectric** gives *wrong answers* for metallic substrates. In most cases erroneous results will be very far off; misinterpretation is therefore unlikely.

Thickness...Useful for filter glass substrates. May be ignored for nonabsorbing substrates. Entering 0 for metal substrates produces erroneous transmittance values!

Side 2 Compensation

Modes 1-4...Include or ignore reflection from the second surface. Ignoring reflection is equivalent to a perfect antireflection coating on Side 2. In most transmission measurements, the second surface is not AR coated and Side 2 compensation must be included for accurate results. In reflection measurements, Side 2 effects are often eliminated by grinding the uncoated surface.



Mode 5...This special mode is intended for inverse synthesis. The uncoated surface is included in transmission but ignored in reflection. This corresponds to the practice of grinding the second surface in order to obtain more accurate reflection measurements.

FWD (forward) denotes light incident on the filmed surface (Side 1) and **REV**(reverse) denotes light incident on the uncoated (Side 2) surface.

FWD and **REV** always give the same transmittance but reflectance is only the same when there is no absorption. DESIGN adds surface reflections incoherently. While this is applicable to filters and other light-controlling devices, it is incorrect for etalons and similar devices where surface reflections must be added coherently. An etalon can be treated as a thin film assembly with AIR and SUB indices equal to 1.

If not using FILM Archive Mode, Setup Parameters are stored in related disk files as follows:

Plot Type/Axes	Graph Axes
Wavelength Units	Graph Axes
Thickness Convention/Units	Design
Dielectric/Metallic Substrate	Film Indices
Substrate Thickness	Design
Side 2 Compensation	Design

TIR Calculations (Total Internal Reflection)

When the index of the incident medium exceeds 1.0, internal angles beyond the critical angle will cause a mathematical error. Preventing this error, checking this box automatically replaces $k=0$ by $k=10^{-8}$ in nonabsorbing films and substrates.

Enable TIR mode ONLY when performing TIR calculations.

Tooling Factors

Setup...Tooling Factors

When fabricating a design it is reasonable to suppose that all layers of each material type are too thick or too thin by the same factor. To test this idea users can compute a tooling correction factor for each material by inverse synthesis optimization. Targets (Target Type = *Equality*) are the actual spectrum and variables are thickness ratios for each material.

If any correction factor is unequal to 1.0, a warning message is displayed in design editors and the Review Design screen. Loading a new design from disk restores 1.0.

Under **Compute** use the space bar or mouse to insert (remove) the check mark and activate (deactivate) the material in the tooling factor calculation. Check marks are stored with Film Indices.

In order to use this method, do the following: 1. Load the design which will be your 'starting' design for synthesis, 2. Load a spectrum in the **Spectra** menu, 3. Convert it to targets in **Optimize...Targets...Generate**. Then return to the Tooling Factor dialog box and click **Compute**.

Tooling correction is not intended for modifying designs. It is intended for adjusting optical or crystal monitor parameters.

Wavelength List

Setup...Wavelength (Wave/Angle) List...Edit

The Wavelength List editor creates and edits custom lists of wavelengths for evaluation. This is useful for filters which operate in distinct wavelength regions; 'don't care' regions can be skipped. It is also useful when detail is required in one region (*i.e.* bandpass) but not required elsewhere.

The Wavelength List editor is also used for specifying evaluation wavelengths when plotting vs. physical thickness with multi-wave mode enabled (see "Graph Axes" on page 33).

The maximum size of the list is specified in **Configuration...Capacity**. This is *not the same as the size of the list that can be utilized...only the size that can be edited in DESIGN*. A list with 2001 points can be used in a thin film evaluation but cannot be edited if the capacity is set at 101 (default).

One or more wavelengths can be deleted by highlighting and pressing ****. The entire list is highlighted by clicking the column title ('Wave...').

The file can also be created in Excel or a text editor. File format is shown below. Wavelength entries are always in nanometers. *Click label 'List Name' to view the list of available files.*

```
Description
# of entries
Wavelength #1
Wavelength #2
etc...
```

An actual Wavelength List file resembles the following:

```
"Top secret laser wavelengths"
3
450.2
490.1
552.8
```

The Wave/Angle List file appears as follows:

```
"Test for ellipsometer"
6
500,45,"R"
500,60,"R"
```

500,75,"R"
700,45,"S"
700,60,"P"
700,75,"R"

In Excel, use **Save As**, select "CSV" format and add extension ".wls". The wavelength list must be stored on disk before it can be used in a thin film calculation. The list's file name is entered in the Graph Axes editor. The file extension for wave/angle lists is ".wal".

Generate

Repeatedly adds new wavelengths.

When Multi-wave mode is utilized for plotting vs. thickness, highlight multiple rows before typing to input the same wavelength for adjacent layers.

Edit...Paste

Pastes an Excel column into the editor.

Design Menu

Review Design <Ctrl+R>

Display current design and indices. Useful for observing progress during optimization. Click **Edit...Copy All** to place the entire text into the Windows clipboard or **Edit...Copy** to copy highlighted text. The review can be edited and printed.

There are three format options for the review. **Option 1** (original) shows index file/function names and coefficients A-G as displayed in the Film Indices editor. **Option 2** show material descriptions as entered in the Film Indices editor (to the right of column G). **Option 3** displays individual layers with material descriptions. Note that this option also converts layers within parentheses to separate layers.

Wavelength <Ctrl+W>

Change current design wavelength, angle and polarization without calculating a new spectrum.

Optical to Physical

Convert layers from optical to physical thickness units in nm or μm as specified in Setup Parameters. This conversion is automatic when optimizing index and thickness simultaneously.

Physical thicknesses should be utilized when studying spectral shifts caused by index shifts. Designs described by optical thickness will give the impression that spectral features are not dependent on indices.

Physical to Optical

Convert layers from physical to optical thickness units in integral or quarter waves as specified in Setup Parameters. Makes no sense for metals.

Reverse Design

Reverse layer numbering in Groups or Layers notation:

SUB (.25H .25L)2 .125H AIR

becomes

SUB .125H (.25L .25H)2 AIR

Reverse Design is useful when computing reverse reflectance in designs containing massive layers and/or in storing design segments.

Adjust Design

Design...Conversions...Adjust Design <Ctrl+J>

This dialog box enables users to modify designs by (repeatedly) performing arithmetic operations on some or all layers. **Since designs are permanently changed, users should save initial designs on disk.** Designs containing groups (parentheses) are supported and layer numbering follows the optimization variables convention.

Design Macros

from Groups Editor: Macro...Edit <Ctrl+M>

A design macro is a wavelength and/or angle-matched design segment which is pasted into the Groups Mode editor at the cursor position. Up to six macros can be defined. A macro is inserted with <Shift+F1>...<Shift+F6>. This facility is especially useful for assembling complex filters. The concept is best explained by example:

	Design	Wavelength
A.	(.25H .25L)10 .25H	1064
B.	(.125H .25L .125H)10	0

For normal incidence and design wavelength = 550nm (L=1.46 and H=2.3), Macro A is inserted as

(.48364H .48364L)10 .48364H

while Macro B remains unaltered.

If Angle = 45 deg Macro A will be inserted as

(.50825H .5528L)10 .50825H

and is centered at 1064nm when evaluated at 45 deg. Macro B is inserted as

(.13136H .28575L .13136H)10

and is centered at the design wavelength (550nm) when evaluated at 45 deg. Note that design macros are stored with the thin film design and that existing designs can be opened as macros.

Design

Enter a design fragment in the large text box. Parentheses are permitted. Only index symbols previously entered in Film Indices can be typed.

Wavelength

Enter 0 to insert the Macro at the current Design Wavelength. A wavelength greater than zero adjusts layers for the Macro wavelength.

Angle

Angle-matching increases thicknesses so that quarter waves occur at designated wavelengths.

Description

The first 24 characters of the description field are displayed in the Groups Mode design editor Macro menu.

Reverse

Reverse the displayed design. This only works if the displayed design is, by itself, correctly entered. Parentheses must be matched and index symbols defined in the Film Indices editor, etc.

Open 1...6

Open an existing design to use as a fragment in the new composite design. If the design contains index symbols undefined in Film Indices a warning is issued but the design is still displayed.

Groups Design Editor

Design...Groups Editor <Ctrl+D>

In this full-screen design editor ()N can be used to repeat a group of layers: *i.e.* (.25H .25L)3 is equivalent to .25H .25L .25H .25L .25H .25L but is evaluated much faster by the Tschebysheff algorithm. A Group is any construction within parentheses or any individual layer not within parentheses.

Layers are written as QD where D is a symbol A...Z (previously defined in Film Indices) designating a film material and Q is the numerical optical or physical thickness of the layer. **Layer #1 is next to the substrate (exit medium).**

Thicknesses are specified in three ways:

1. **Optical Thickness...** .25H (or 1.0H) is 1 QWOT (quarter wave optical thickness) at the design wavelength. Enter **Opt** under **Type** in the Film Indices editor.
2. **Physical Thickness...** .234 .7H (or .2347H) is physical thickness in nanometers (or microns). Enter **Phs** under **Type** in the Film Indices editor. Design wavelength does not apply.
3. **Massive Thickness...** .2G is physical thickness in millimeters. Enter **Msv** under **Type** in the Film Indices dialog. Massive layers are treated according to P. Baumeister, et al, *Optica Acta* 19, 853 (1972). Designs can contain any number of massive layers.

Normal Windows text editing commands work in the design editor. A design is deleted by highlighting it and pressing . Copy a design segment to the clipboard by highlighting and pressing <Ctrl+C>. Paste from the clipboard with <Ctrl+V>. This technique is very useful for inserting a design segment elsewhere in the design. To quickly clear the editor use <Shift+Ctrl+End> to highlight the entire design. Designs may also be altered via **Edit...Replace**.

QWOT and physical thickness units can be changed in Setup Parameters <Ctrl+P>. Layers are input from the SUBSTRATE as follows:

.25L .25H .25L .25H .25L .125H

and may be grouped within parentheses:

.25L (.125H .25L .125H)10 .5L (.25H .25L)3 .5H

Parentheses cannot be nested. Groups can be converted to layers (parentheses removed) by accessing the Layers Editor. Retain the original design by saving to disk <Ctrl+Shift+D> before converting. Groups to Layers conversion fails if the total exceeds maximum layer capacity.

Click **Single** to display the design as one long string and **Multiple** to place each group on a separate line.

DESIGN automatically combines adjacent layers with the same index symbol. **Take care when deleting layers while optimizing:** variables may no longer be

consistent with your intentions! As it is possible to lose a design (by deleting a currently used index symbol from Film Indices, for example) we suggest that you periodically save your latest design.

When using massive layers, it is usual to enter n=1 for AIR and SUB. Layers are input from left to right and light is incident from the right. When saving designs for later use in MONITOR or CRYSTAL, the total design must be split into layers deposited on each substrate surface. Use **Reverse Design** to store layers in the correct order. For example, the following design

AIR .165H (.33L .33H)2 2G (.25H .25L)2 .125H AIR

must be split into two designs

Design 1: SUB (.33H .33L)2 .165H AIR

Design 2: SUB (.25H .25L)2 .125H AIR

Multiple massive layers are allowed, but massive layers may not be placed within parentheses. Assuming that G represents a massive layer:

OK: AIR (.25L .25H)2 2G .25H 2G .25H .25L AIR

NO GOOD: AIR (.25L .25H 2G)2 (.25H .25L)3 AIR

Access the Layers editor to 'explode' Groups into separate layers.

When more than 52 materials are used in a design (Extended Materials Mode), indices are indicated by bracketed numbers. In this case a design might look like

.25[1] .25[2] .25[1] .25[2] .25[1] .125[2]

Edit...Reverse Segment <Ctrl+S>

When combining separate designs it often becomes necessary to reverse part of the design. While this duplicates what can be accomplished in the Design Macro dialog, users might prefer to use the capability herein.

Edit...Inhomogeneous <Ctrl+I>

Layers may be subdivided into sublayers with different indices.

Edit...Combine Layers

Adjacent layers of the same material are usually combined into a single layer. Click to turn this off. Separating a thick layer into adjacent layers might be useful in optical monitoring.

Macro...Edit <Ctrl+M>

Create designs or design fragments which are angle-matched and centered at specified wavelengths.

Herpin Equivalent Layers

Design...Conversions...Herpin Equivalent <Ctrl+H>

This dialog box enables users to replace intermediate indices with three layer Herpin equivalents. **Since designs will be changed, users should save initial designs on disk.** Designs with layer groups (parentheses) are supported and layer numbering for such designs follows the optimization variables convention. The calculation method is based on M. C. Ohmer "Design of three-layer equivalent films", *J Opt Soc Am* 68, 137-139 (1978).

Herpin equivalent layers are defined at one particular wavelength, angle and polarization. The program compares final reflectance with the value calculated with the original design (before replacement). If values differ by more than the **Accuracy** value (1e-9 to 1e-1, default 1e-7), the solution is rejected as spurious.

The value should be increased (try 1e-3) when film materials are absorbing. Herpin replacement assumes $k=0$. If $k>0$ the final calculated reflectance differs from the original value. This adjustment makes it possible to use slightly absorbing dielectric film materials ($k \ll n$) in Herpin calculations; it is NOT intended for metals.

Increasing minimum layer thickness results in different solutions. As in design editors, **Index Symbols** used in the replacement must previously be defined in the Film Indices editor.

Inhomogeneous Layers

from Groups Editor: Edit...Inhomogeneous <Ctrl+I>

This dialog box allows users to replace single film layers by multiple layer groups with graded indices. Each multiple layer group consists of one to five initial layers of specified thickness followed by a final layer of variable thickness. The method is best explained by example:

Suppose we have a filter containing the layer **100H** (physical thickness 100 nanometers). Assume that the index of this film is 2.4 for the first 10 nm, 2.35 for the next 5 nm and 2.3 thereafter. Assume that the following values are already entered in the Film Indices editor:

A*	2.4
B*	2.35
H*	2.3

Input the following in any row in the Inhomogeneous Layer editor:

Sym	Layer 1	Layer 2
H	10A	5B

Click the left (gray) cell for the row. This highlights the row and enables **OK** - returning the user to the Groups design editor where it is seen that **100H** has been replaced by

10A 5B 85H

Other examples:

35H	->	10A 5B 20H
15H	->	10A 5B
12H	->	10A 2B
5.5H	->	5.5A

Upon returning to the design editor, the user can still abort the conversion with **Cancel**.

Obviously it takes careful experiments and inverse synthesis calculations to determine the physical thickness and index of sublayers. If the user can establish this relationship for single layers, it should be possible to more accurately predict the performance of complex designs. Inhomogeneous Layer setup is automatically saved in "design1.ini" upon exiting DESIGN.

Layers Design Editor

Design...Layers Editor <Ctrl+L>

The Layers Mode design editor is best suited to constructions which have no repeated groups of layers. The editor 'explodes' designs containing layer groups

(parentheses) into individual layers. **If you wish to retain group construction, save the design before accessing this editor.**

Layers are written as QD where D is a symbol A...Z (previously defined in Film Indices) designating a film material and Q is the numerical optical or physical thickness of the layer. **Layer #1 is next to the substrate (exit medium).**

Thicknesses are specified in three ways:

1. **Optical Thickness... .25H** (or **1.0H**) is 1 QWOT (quarter wave optical thickness) at the design wavelength. Select **Opt** under **Type** in the Film Indices editor.
2. **Physical Thickness...234.7H** (or **.2347H**) is physical thickness in nanometers (or microns). Select **Phs** under **Type** in the Film Indices editor. Design wavelength does not apply.
3. **Massive Thickness...2G** is physical thickness in millimeters. Select **Msv** under **Type** in the Index Editor. Massive layers are treated according to P. Baumeister, et al, *Optica Acta* 19, 853 (1972). Designs can contain any number of massive layers.

QWOT and physical thickness units can be changed in Setup Parameters.

One or more highlighted layers can be cleared with the **** key. To highlight the entire design click the column heading ('Design'). (You can still recover the original design with **Cancel**). Upon exiting the editor adjacent layers with the same index symbol are automatically combined into single layers. *Take care when deleting layers during optimization; variables may no longer be consistent.*

Edit...Ignore Layer <Ctrl+L>

It may be advantageous to evaluate a design with layers ignored. This might be useful when analyzing coatings manufactured in stages. While this can be done by deleting layers, it is often more convenient to temporarily mark them as ignored. Select a layer or range of layers and press **<Ctrl+L>** to ignore and unignore. When layers are ignored, some menu commands are disabled. Settings are temporary and not stored with the film design.

Edit...Combine Layers

Adjacent layers of the same material are usually combined into a single layer. Click to turn this off. This setting is stored with the thin film design.

View...Index Columns

Click to display material dispersion and description columns. This facility is intended for designs with many materials, as might be typical when simulating inhomogeneous layers. The dialog must be made wider in order to view the new columns. If the Film Indices dialog includes a description for all film materials, the Layers Editor Description column becomes a pull-down list.

Layer Error Analyzer

Design...Error Analyzer

The Layer Error Analyzer provides advanced users with means to calculate optical or physical thickness differences between a theoretical reference design and a reverse-engineered best-fit design. The dialog is enabled for designs without parentheses; up to four film materials are supported.

Click **Reference Design** to clear the grid and insert the reference design. Since values are retained, you can optionally close the dialog. After reverse-engineering that design, click **Best-Fit Design** to insert and display deviations.

Click **Calculate...Copy Corrected Design** to copy the corrected design to the clipboard and optionally to replace the design in memory with the corrected design. **Be sure to re-store the corrected design with a new file name.** The corrected design is then utilized in optical or crystal monitoring. If reverse-engineering determines that a layer is actually too thin, the corrected design replaces that layer with a thicker layer, etc.

What about correcting a *new design*? Are the deviations random, or do they follow a pattern? If there is a pattern, are deviations a function of layer thickness (as in errors caused by nucleation effects) or are deviations a function of total thickness (as in changing tooling factors)? Select **Correction Factor** or **% Deviation** in the *Calculate* menu, Finally, select a film material and click the **Layer Thickness** or **Total Thickness** button. If a pattern is apparent, click **Linear Fit** or **Quadratic Fit** to determine and plot a deviation or correction function.

The final step in the process is clicking **Calculate...Create BASIC Code <Ctrl+B>** to generate a BASIC correction function (as shown below) for DESIGN (printing a list of monitor thicknesses), CRYSTAL or MONITOR.

```
Function CF_H(Byval qLay As Single) As Single
    'qLay is Layer Thickness (QWOT=.25)
    'TiO2 chamber 3 correction
    CF_H = 0.947 + 9.355E-4 * qLay - 3.445E-6 * qLay^2
End Function
```

Recorder

The Design Recorder tracks design changes. Users can thereby roll-back to previous revisions.

Click **Design...Recorder Options** to enable the Recorder. Check *Snapshot* for manual recording and/or *Movie* for automatic recording during optimization and after design or indices changes. Movie mode provides two choices: *Record/Pause* and *Continuous* recording. The Recorder is not available when both *Snapshot* and *Movie* modes are unchecked. The Recorder is also not available in second and subsequent instances of DESIGN.

Only Snapshot mode is available in the Interactor.

The Recorder activates upon clicking the DESIGN **Snap <Alt+N>** button or the **Record <Alt+R>** button. In *Continuous* recording, the Recorder automatically activates and the **Record <Alt+R>** button merely displays the Recorder window which is possibly hidden under the main screen. *Note that the Recorder must be closed before options can be changed.*

Closing the Recorder does not delete entries. Click **File...Clear All Rows <Ctrl+E>** or **File...Clear to End <Ctrl+D>** to remove entries. Multiple rows can be deleted with **<Delete>**. Click the *Merit* header to sort by merit (best designs at top) and the *Date & Time* header to sort by date & time (most recent at top). Click anywhere in a row (or highlight and press **<Enter>**) to open the design. The Recorder can be minimized to reduce desktop clutter.

Advanced users: If the FilmStar Workbook is visible, the *Objective* value replaces the usual optimization merit function. The **Snap <Alt+N>** button may be used, but a Workbook macro is required. At a minimum the macro need only contain the *Calculate* command.

Replace Design Segment

from Groups Editor: Edit...Replace <Ctrl+E>

This dialog enables users to quickly modify designs by replacing design strings (100 characters maximum) such as .25 or .25H or (.125L .25H .125L) throughout some or all of a thin film design. If only a partial replacement is required, first select the portion in the design editor. To replace a string throughout the design, check **Select all** in the dialog box. After making changes, users may still recover their original design by clicking **Cancel**.

Set Zero Layers

Design...Set Zero Layers

This function will not be required by most users. It prevents overflow errors which occur when thick absorbing designs are evaluated at short wavelengths: for example a 10 μm IR reflector evaluated at 0.1 μm .

In such cases eliminating layers (by setting to zero thickness) close to the substrate has no discernible effect on the reflectance spectrum (transmittance will be zero in such cases) and eliminates the overflow error. This is easily verified by manually deleting layers and evaluating resulting spectra. When enabled, a warning *Zero Layers Enabled* appears to the right of the DESIGN toolbar.

Use this function only to prevent the Overflow error message!

Setting zero layers is temporary.

Evaluate Menu

Recalculate <F9>

Calculate a new spectrum without the Calculate dialog box.

Merit Function <Shift+F9>

Calculate and display the current Merit Function. This is defined as the sum of the squares of deviations

$$\text{SUM}(((\text{Targets-Value})/\text{To1})^2)$$

where targets are specified in the Optimization Targets editor.

Interactor

Evaluate...Interactor <Ctrl+Q>

The DESIGN Interactor provides a highly intuitive environment for quickly visualizing changes as design parameters are varied. Click <Ctrl+Q> again to return to the traditional DESIGN screen.

Checking **Show Options** displays an *Options* dialog at the bottom of the Interactor window. The Interactor has scroll bars displayed when screen height is insufficient. Depending on mode, 1-3 plots (either separate or overlapped) are shown. Restrictions: graphs with thickness axes are not supported, optimization targets are not displayed, and tolerancing is not available.

There are three modes: *Design*, *Compare* and *Difference*. Design mode supports multiple axes, while Compare and Difference modes let you open or paste a measured spectrum (blue line/symbols) to compare with the calculated one (red line). These modes also make it possible to view optimization targets.

Under *Colors*, select *Show RGB* to visualize reflected and transmitted colors (D65 illumination) and *CIE Window* to calculate CIE coordinates. Click the CIE plot (or **Setup...CIE Parameters**) to adjust CIE mode, graph range and other quantities. Move the cursor over the CIE plot to read coordinates. Another color option is dominant wavelength, enabled when RGB displayed & *Mode* = Design & *Type* = Single Plot. The RGB Comparator makes it easy to compare colors corresponding to calculated and imported spectra. RGB Boost provides means for visualizing the slight reflected color of AR coatings.

For the most part, quantities are changed by up/down arrows. Depressing the **Ctrl** key speeds changes and depressing the **Shift** key slows them. Depressing an arrow (mouse down) gives continuous changes, but recalculation does not take place until the arrow is released (mouse up). This lets you quickly evaluate the effects of large changes. Users with fast computers can also select *Movie* option which replots continuously as the mouse button is depressed. Users with slow computers might prefer to turn *Auto Recalculate* off. Advanced users should note (under *Automation*) that the Interactor can trigger BASIC macros.

< > keys and numeric keypad keys - + also trigger design changes. *When no layer is checked*, a single layer will be varied if the row is specified in the grid Layer column. This enables users to quickly modify layers with the keyboard. In addition, *when no layer is checked*, angle and wavelengths can be changed from the keyboard if the corresponding text cells have the focus. Note that thickness changes can be relative (%) or absolute.

Zooming is supported. Shift-click the graph or click **Setup...Zoom <Ctrl+Z>** to enter zoom mode; a full-screen cursor appears. Click and hold the mouse button down to draw a bounding rectangle around the region of interest. Exit zoom mode by pressing **<Esc>**. Zoom mode is also exited when axes are changed, etc.

The design grid lets you select which layers are changed as up/down arrow keys are depressed. Highlight multiple layer cells (hold shift key down) to restrict *All*, *None*, and *Some* button actions to the selected rows. (This makes it much easier, for example, to select half the layers.) Layers displayed with a green background are massive, and cyan indicates layers grouped within parentheses (similar to the Optimization Variables dialog). Group repeat factor is adjusted by typing in a new value or using up/down arrows within each cell.

Selecting absorptance vs. wavelength triggers an additional Absorptance option under Graph when there are no parentheses or massive layers in the design. This option makes it possible to plot absorptance in selected layers. Selecting *Triple plot* gives absorptance in the selected layer, total absorptance, and % absorptance in the selected layer. This facility helps users working in solar energy and other active devices.

Transmittance vs. wavelength offers three formats: linear %T (default), diabatic t (0-1) and diabatic %T. *Diabatic* refers to Schott's definition: $1 - \log(\log(1/t))$ and not to the usual thermodynamics definition. While the diabatic axis is fixed, clicking **Setup...Zoom Mode <Ctrl+Z>** expands the vertical range to include %T>97.5. The *Trns Format* option is only available in single plot types; when multiple plots are specified, the transmittance scale reverts to linear. Diabatic scales are also available in the FSPlot Module.

Wavelength range is manually adjusted in the Graph Axes dialog; ordinate values are scaled manually or automatically. Should the Interactor not update properly due to unanticipated changes, exit and reactivate via **<Ctrl+Q>**.

Film indices are varied via **Setup...Adjust Indices <Ctrl+A>**. This displays an Interactor version of the Film Indices editor. Move the grid highlight to an appropriate cell and vary the selected coefficient via the up/down arrow control.

Here again, the **Ctrl** key speeds changes and the **Shift** key slows them. You can also type new coefficient values.

One possible application is reverse-engineering films which may be expressed as a linear combination of two index tables, say good and bad TiO₂. In that case, User Function TiO₂Mix might be defined as

$$n = A*N1 + (1-A)*N2, \quad k = A*K1 + (1-A)*K2$$

where Table 1 is *TiO₂ Good* and Table 2 is *TiO₂ Bad*. The advantage here is that only one variable is required. Note that physical thickness should be utilized in reverse-engineering tasks involving index changes.

Another application is controlling optical properties with films that purposely vary according to deposition conditions. Users will want to convince themselves that intermediate index values are accurately expressed as a combination of index tables. Advanced users can define indices in the FilmStar Workbook.

One of the most powerful features is the ability to run a BASIC macro each time the spectrum is updated. Interactor macros are enabled under *Automation* in the Interactor Options box. Workbook calculations are supported and performed before running any macro. Workbook-related BASIC commands are largely disabled in the Interactor. Exceptions are WbCopy, WbGetNum, WbGetText, WbRecalc.

BASIC macros can also be edited and run from the Tools Menu when *Tools Menu = Long* is specified under *Automation*. Note that a Tools Menu macro cannot trigger an Interactor macro. Optimization is also possible when *Optimize Menu = Long* is specified in the *Optimization* section.

Tolerancing

Evaluate...Tolerancing...Values <Ctrl+N>

Tolerancing is the estimation of manufacturing yields by assuming random errors in layer thicknesses. Tolerancing is supported in the Main Menu, the CIE Color Module and the FilmStar Workbook. When activated from the Main Menu, there are two modes:

1. Plot mode - spectra are continuously replotted and the user estimates the effects of thickness errors through inspection.
2. Yield mode - % yield is computed using inequality optimization targets as pass/fail criteria. This mode requires that inequality targets are specified in the *Optimize* menu and the *Compute yield...* check box is selected.

In the other cases DESIGN also uses a pass/fail condition to provide a numerical estimate of the yield. When accessed from the CIE Color Module, a scatter plot is obtained on the CIE color scale. Here an acceptance polygon is defined as the pass/fail condition. When accessed from the Workbook, the pass/fail condition is the logical TRUE or FALSE value of named cell 'Passed'.

Enter a non-zero value for **Absolute** or **% Relative** thickness error for each material included in the calculation. This is treated as the standard deviation of the error. In order to prevent errors which are too large, enter an absolute or relative (according to which column is non-zero) **Maximum** value. If this value is zero then errors are not limited.

Spectra Menu

Data Table (page 54) <F8>

Examine the calculated spectrum. Disabled if there is no data to view. This function can also be implemented in the Workbook.

Convert Table <Ctrl+F8>

Convert the current data table to a new table with the horizontal axis wavelength spacing displayed in the Graph Axes editor. This is useful when comparing measured spectra with calculated results, calculating color coordinates, and using the FSPlot graphing module. Linear interpolation is used. If the spectrum being converted is outside the range of Graph Axes values, an error message is issued, but the spectrum is converted anyway.

Clear Data <Ctrl+E>

DESIGN automatically replots the current spectrum after changing graph axes, etc. This can be annoying at times. Replot is eliminated by clearing the current spectrum from memory.

Copy Data, Paste Data

Exchange spectral data with other applications via the clipboard. Most importantly, data can be easily transferred to and from a range of cells in Excel. When examined with a text editor, data appears as shown below (depending on tab settings):

400	2.676706E-02	.9732329
450	3.414683E-02	.9658532
500	9.240174E-02	.9075983
550	.7369852	.2630148
600	.999822	1.779826E-04

The first column is wavelength (nanometers) followed by reflectance (0-1) and transmittance (0-1). Columns are TAB (ASCII 9) delimited and lines are CRLF (ASCII 13 + ASCII 10) delimited:

```
400TAB2.676706E-02TAB.9732329CRLF
```

More generally, data columns are arranged as follows according to plot scale:

1. **R,T,OD:** Wave(nm) Refl (0-1) Trns (0-1)
2. **R Phase:** Wave(nm) R-Phase (rad) Refl (0-1)
3. **T Phase:** Wave(nm) T-Phase (rad) Trns (0-1)

Phase is **absolute** when the angle of incidence is zero or when P or S polarization is specified. Phase **difference** is displayed when the angle > 0 and Random polarization is specified. Phase is expressed in radians. (See **Format Options** below.) When plotting vs. physical thickness, the first column is thickness in nanometers from the substrate. Layer boundaries are shown as duplicate thickness values: then last value in layer j and the first value in layer j+1.

Two-column data (wavelength and reflectance OR transmittance) can also be pasted. Data is pasted as reflectance or transmittance depending on graph axes setting.

DDE (Dynamic Data Exchange)

Data can also be exchanged (**DDE...Import** and **DDE...Export**) by dynamic data exchange. This is especially appropriate for Excel models such as CIE which utilize fixed data ranges, say 380-780 X 5 nm. Be sure that the DDE Topic and Item are correct. In Excel the Topic might be *excel|sheet1* while the Item is the named region *spectrum*. Note that the named Excel region must have three columns and sufficient rows.

File Open and Save

Spectra can be opened and saved disk as FilmStar/Excel .csv, JCAMP .dx and Excel .xls files. In addition, Galactic GRAMS .spc files can be opened. When examined with a text editor, a FilmStar .csv file resembles the following:

```
"FilmStar .csv format example"  
31  
450,2.468316E-03, .9975317  
460,1.44774E-03, .9985523  
470,1.326643E-03, .9986734  
etc.
```

The first line is an optional description (50 characters maximum); the line is included even if the description is blank. The second line is the number of spectral points. The third and subsequent lines are wavelength (nm), reflectance (0-1) and transmittance (0-1). If *For Excel* is checked the following is obtained:

```
450,2.468731E-03,0.9975313  
460,1.447442E-03,0.9985526  
470,1.325849E-03,0.9986742  
etc.
```

In Europe, users might set their computer's number settings (Control Panel Regional Settings) as follows: decimal symbol ",", digit grouping symbol (thousands separator) ".", list separator ";". In this case the Excel file looks like the following:

```
450;2,468316E-03;0,9975317  
460;1,44774E-03;0,9985523  
470;1,326643E-03;0,9986734  
etc.
```

JCAMP and FilmStar .csv formats do not change when European number notation is used. Two-column data (wavelength and reflectance OR transmittance) can also be opened. Data is loaded as reflectance or transmittance depending on graph axes setting.

Excel .xls format eliminates problems associated with .csv. While spectra can be opened in any version of Excel, FilmStar can only open FilmStar-created .xls spectra. Excel is not required.

W (nm)	%R
450	0.2528
460	0.146188
470	0.13243
480	0.15352

Users with more complex requirements, for example exporting multiple spectra to a single Excel file, can utilize a FilmStar BASIC macro. In that case, however, Excel must be installed.

Quick Save

If there are too many points (~>1000 wavelengths) data transfer via the clipboard may not work. Quick Save stores the current spectrum as "work.csv" in the spectra directory. This file can then be opened in Excel and copied to the appropriate worksheet. *Be sure to close "work.csv" in Excel before returning to DESIGN and repeating the procedure.*

Data Table

Spectra...Data Table <F8>

The format of the Data Table depends on plot scale. Select phase if phase information is required. Phase is ABSOLUTE when the angle of incidence is zero or when P or S polarization is specified. Phase DIFFERENCE is displayed when angle > 0 and Random polarization is specified. Phase is expressed in degrees in a 360 region starting at the graph minimum.

The table calculates minimum, average and maximum values over any selected range. Click the column title to select an entire column.

Select **Print** to print data on the Windows default printer. **Printer** provides font and margin options. For more elaborate formatting, return to the main menu and select **Spectra...Copy Data <Ctrl+C>** to copy the spectrum to the clipboard. The spectrum can then be pasted into Excel or a word processor.

Data Table functions can be duplicated and extended in the FilmStar Workbook.

Format Options

Spectra...Format Options

As described above, spectra are normally copied and pasted (DDE transfer) with wavelength in nm (despite the Graph Axes setting). Check **Current units** to copy and paste spectra with the Wavelength Units specified in **Setup...Parameters**. Normally reflectance and transmittance values are 0-1 and phase shift is in radians. Check **R & T in %; Phase** in deg to change this to percent and degrees.

There are two modes for loading and saving spectra. All files are saved in ASCII format and can be read with a text editor. **CSV** (comma-separated values) is DESIGN's default mode. **JCAMP** is a 'standard' which offers compatibility with spectroscopy software from other vendors. **JCAMP + Perkin-Elmer compatible** provides better compatibility when saving P-E JCAMP files. Use this mode to generate Spectrum 2000 'soft instrument' files for MEASURE. Information about JCAMP is provided in Robert S. McDonald and Paul A. Wilks Jr., *Appl. Spectroscopy* **42**, 151 (1988).

JCAMP stores reflectance or transmittance values, not both. The following method lets you load both into DESIGN: 1. Load reflectance data, 2. Load transmittance or O.D. data with the *same number of data points*. JCAMP cannot be used for non-spectroscopic spectra such as phase shift. Options are stored with Graph Axes.

Some programs deviate from published JCAMP standards or provide incomplete support. Programs frequently fail to support unequally-spaced wavelength data. Users who discover an incompatible JCAMP variation should contact FTG Software.

Optimize Menu

Optimization refines the current thin film design in order to achieve spectral targets. Five algorithms are available: Damped Least Squares (DLS), modified Levenberg-Marquardt least squares, Simplex, a suite of gradient methods called the Numerical Optimization Library (NOL), and genetic evolution.

Optimize <Ctrl+O>

Starts the refinement process. This requires a valid design as well as optimization targets and variables.

1. **Damped Least Squares (DLS)**...Computes derivatives at each target, and is usually the fastest method. A reasonable starting design is required. It is recommended for inverse synthesis. The maximum number of targets times variables is 8192, but DLS method will probably fail with 'Cannot invert singular matrix' before that number is reached. The number of targets should be greater or equal to the number of variables.

An initial damping factor is suggested. This can be decreased if the design changes very little or increased if there is too much change. Optimization proceeds for a given number of iterations.

2. **Levenberg-Marquardt**...While slower for problems which are also amenable to DLS solutions, this method is similar to DLS but more robust...allowing more targets and variables. A reasonable starting design is required. The number of targets must be greater or equal to the number of variables.

Optimization proceeds until no improvement is possible according to the Tolerance specified in the Parameters dialog. Further improvement is possible by restarting with decreased Tolerance and/or Epsilon values.

3. **Simplex**...A large number of iterations may be required. If the design has reached a minimum, try restarting. (The simplex has become too small to crawl out of the minimum. Restarting creates a new simplex.) Restart by selecting **Cancel** at the '# Iterations?' prompt to leave the optimization loop. Select **Optimize <Ctrl+O>** to start again. This method is useful for improving designs obtained with other methods and for cases where the number of targets is less than the number of variables.
4. **NOL Gradient Method**...This method computes an array of the gradient of the objective (merit) function with respect to thickness variables. Far larger numbers of targets and variables are possible and constraints are allowed via the FilmStar Workbook (page 94).

Optimization proceeds until additional iterations provide no further improvement. Further improvement might result from restarting with different parameters.

5. **Genetic Evolution**...Evolution has been determined to be a useful technique for the design of optical coatings. While the method is very slow, it can lead to solutions for problems which cannot otherwise be solved.
6. **Flip-Flop**...This method has been developed and popularized by W. H. Southwell. Layers with high index are alternatively replaced by layers with low index. If the merit function is lower (improved) the layer is kept, if it is higher the original layer is put back. In our modification of the flip-flop method, multiple flip layers may be specified. By adding a zero thickness layer, the algorithm can also remove layers.

7. **Global Search**... This 'brute force' method loops through ranges of values and retains the design with the lowest merit function. Use the Groups Mode or Layers Mode design editor to specify the structure of the design. The design might consist of all zero thickness layers: *OH OL OH OL*, etc. Global Search is supported in the FilmStar Workbook (page 94), but constraints are ignored (constraints require the NOL Gradient Method.)

Users are warned if a calculation is expected to take longer than about five minutes. Designs containing up to 50 possible optimization variables can be utilized. When entering values, note that **Edit...Clone Row** sets subsequent rows to the Min, Max, and Step entries in the current row.

In all cases, in-process optimization can be aborted by clicking **Cancel <Esc>**. The best design will be retained, even if the iteration currently displayed on the screen is not as good as previous ones. As keyboard input is only tested at the start of each iteration, there could be a significant delay for large numbers of targets and variables.

During DLS refinement you may get the *Cannot invert singular matrix* error if a selected variable has no effect on one or more optimization targets. Following optimization, press **<Alt+C>** to calculate the new spectrum or press **<Ctrl+R>** to review the new thin film design.

Index/Thickness Limits, Link Variables

Refer to "Optimization Variables" on page 59.

Use All Layers

Optimize...Use All Layers <Ctrl+U>

Click to quickly assign all layers as optimization thickness variables. This is the same as checking **Use** in the Optimization Variables dialog, and is useful after deleting thin layers. Alternatively, check **Auto All Layers** to automatically adjust variables as layers are added or removed.

Synthesis

Optimize...Synthesis <Ctrl+Y>

Needle synthesis (A. Tikhonravov), is supported. When adding needles, DESIGN seeks a place within the stack where the merit function is most improved. If the merit function cannot be lowered, the process is repeated with thinner layers. The design may then be refined by DLS, L-M, or NOL methods. *Note that layer materials utilized in needle synthesis are always defined in physical thickness.*

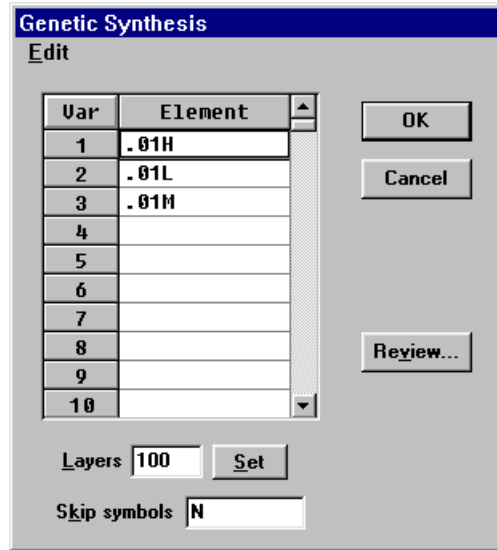
In the needle method, the starting design is typically a thick layer of one of the materials in the film stack. Multiple thick layers are appropriate when there are massive or skipped layers in the design.

Check **Auto-adjust** to update variables automatically and **Auto-synthesize** to continuously insert needles and refine. Massive layers are always skipped during needle insertion. Other layers to be skipped (*i.e.* metallic or active layers) may be specified. Needle synthesis is also possible with an objective (merit function) defined in the FilmStar Workbook *when no constraints are included*. Uncheck **Auto Refine** in the Refinement menu to continuously insert needles without refining layers.

A completely different dialog appears when genetic or flip-flop synthesis is selected as optimization method. Here 'variables' are layer elements. Consider the synthesis elements shown below. Upon clicking Optimize in the Main Menu, the program attempts to generate a 100 layer coating by selecting layers from the

following three elements: .01H, .01L, 01M. In genetic synthesis, layers are selected by evolution; in flip-flop layers are replaced one at a time as a lower merit function is sought.

A zero layer, say 0L, can be added to remove layers. Ultimately the design consists of adjacent layers of the same type which can be combined in the Layers Mode editor. Note that the editor does not combine adjacent layers of the same type when the optimization algorithm program is set to genetic or flip-flop synthesis.



If the current design has a number of layers equal to the *Layers* setting, the design becomes the initial design in genetic or flip-flop synthesis. Otherwise synthesis will start with what is effectively a thick layer of the first element in the table. If that layer is zero (say 0L), there is no starting design. Clicking the **Set** button in the dialog automatically sets the number of synthesis layers to the number of layers in the current design (removing parentheses). This makes it easy to enter a starting design without having to determine the number of layers.

Massive layers in a starting design are ignored, as are layers with index symbols listed in the *Skip symbols* box. This could be useful in synthesizing designs containing fixed metallic or active layers. Synthesis is supported in the Workbook under the condition that constraints are not utilized.

Optimization Targets

Optimize...Targets <Ctrl+T>

1. % Reflectance
2. % Transmittance
3. Optical Density
4. Reflectance dB
5. Transmittance dB
6. Phase in Reflection
7. Phase in Transmission
8. % Reverse Reflectance...useful for designs with massive layers.
Architectural glass is one potential application

9. Ellipsometric Psi (= $\text{Atn}(\text{Sqr}(\text{rfp}/\text{rfs}))$)
Psi and Delta targets for the same wavelength and angle are entered on two consecutive lines.
10. Ellipsometric Delta (= $\text{rpp}-\text{rps}+180^\circ$)
- 11-19. Group Delay and similar functions in reflectance and transmittance

Phase and ellipsometric targets are not permitted in designs containing massive layers.

- 20-25. Click the **User Defined** button to specify user-defined functions User 1-6. Variables are RFP (refl P pol), TRP (trns P pol), RFS (refl S pol), TRS (trns S pol), RPP (refl phase P pol), TPP (trns phase P pol), RPS (refl phase S pol), TPS (trns phase S pol). Reflectance and transmittance are in percent; phase is in degrees. The same functions can be accessed in the Setup Parameters dialog. User-defined functions appear under *Type*. Note that user-defined functions are saved with Optimization Targets.

Wavelength

Use current wavelength units. Out-of-order entries will be sorted. More than one target can be entered at any wavelength. To delete a target, delete the associated wavelength with ****.

Target

Desired value in units specified in *Type*. When Target Type = *Inequality*, minimum and maximum values are entered. When Target Type = *Average*, $(\text{Min} + \text{Max})/2$ is used.

Since phase is expressed in a 360 degree region starting at the graph minimum, it is important to select phase Graph Axes when optimizing phase shift.

Tolerance

Inverse weighting (0.1-100). Smaller values tighten the tolerance and increase the importance of the target. When designing an AR from 450-750 nm one might set Tol=2 at 450 and 750 and Tol=1 elsewhere. A global tolerance value is specified when Target Type = *Inequality* or *Average*.

Angle

Angle of incidence (0-90°) in the entrance medium. Independent of evaluation angle.

Polarization

P S R Random (average) denotes $.5*(P+S)$ for %R and %T targets, (P-S) difference for phase targets when Angle>0.

Generate <Alt+G>

Automatic Targets Generator for entering targets spanning a range of wavelengths or angles. Repeat to add more targets.

User Defined <Alt+U>

Define new targets as functions of R/T, phase.

Formula syntax can be tested in the Main Menu Help... Calculator dialog.

Convert Spectrum <Alt+C>

Convert a spectrum to targets for inverse synthesis (reverse-engineering). This option is visible when Target Type is Equality and horizontal axis is

wavelength (or wavenumber). Repeat to utilize multiple spectra. Note that the button is disabled when there is no spectrum in memory.

An extremely important optimization rule is summarized in the ***Eleventh Commandment***:

Thou shalt have more targets than wiggles

A band of targets may be required when designing a multilayer AR coating for one wavelength or when reducing the E-field by minimizing absorptance at one wavelength.

Users can duplicate cell values down all or part of a column with **Edit...Spawn <Ctrl+W>**. A method which works with multiple columns is to copy cells to the clipboard and highlight a region before pasting. To clear all targets, click the upper left box to highlight all cells and press the Delete button. Alternatively click **File...Clear Grid <Shift+Del>**.

Optimization Variables

Optimize...Variables <Ctrl+B>

Design changes can cause a numbering mismatch. Return to Optimization Variables to reassign. Check/uncheck to add/delete a variable.

Designs without parentheses

Optimization layer variables correspond to actual layer numbers starting at the substrate.

Designs with parentheses

Optimization layer variables are numbered as follows:

```
SUB .25H (.25L .25H)10 (.25H .25L)10 .25H .25L AIR
      1      2      3          4      5          6      7
```

If Layer #1 has the same index as the substrate, it must NOT BE SELECTED as an optimization variable. Its thickness is indeterminate; requesting a solution will cause a mathematical error.

Index variables

Indices defined by functions in the Film Indices editor can be utilized as optimization variables in DLS refinement. The actual number of added variables is the total number of coefficients for the specified materials. That is, if there are 20 layer variables, adding 2 index variables each containing 3 coefficients raises the total to 26.

Symbols

Automatically generate optimization variables corresponding to some or all index symbols. Enter one or more index symbols such as "LH" in the text box (or check the **All** box) and click **Use**.

Thickness and Index Limits

Thickness and index limits are assigned after completing the optimization variables dialog.

Be sure to re-edit limits dialogs after deleting or otherwise changing optimization variables.

Link Variables

Link variables are assigned after completing the optimization variables dialog. A linked variable preserves optical or physical thickness ratio. Links are often utilized to preserve quarter wave stacks.

```
SUB .25H (.25L .25H)10 (.25H .25L)10 .25H .25L AIR
      1      2      3      4      5      6      7
```

As an example, suppose we specify variables 1, 4, 7 as optimization variables. The following is then entered into the link variables dialog:

Var	Use	Link to Variables
1	x	2,3
4	x	5,6

After optimization we would get a design resembling the following:

```
SUB .215H (.215L .215H)10 (.324H .324L)10 .324H .227L AIR
```

Be sure to re-edit the link dialog after deleting or otherwise changing optimization variables.

DLS Parameters

Optimize...Parameters

Damping restricts changes in layer thickness as optimization proceeds. With no damping the design can 'blow-up'. With too much damping too many iterations are required. If no better solution is forthcoming, DESIGN nudges layer thicknesses to climb out of a local minimum. Click **Nudge Parameters** to adjust the amount of nudging or to disable. When disabled, DESIGN performs as in previous versions and will continue optimizing for the requested number of iterations.

Compound damping is recommended. Damping factors are internally adjusted according to the sensitivity of individual variables. Optimum damping parameters must be determined experimentally.

Levenberg-Marquardt Parameters

Optimize...Parameters

This method, a modification of the Levenberg-Marquardt procedure, is adapted from the public-domain Argonne National Laboratory Minpack library. The contribution of the U.S. Department of Energy is gratefully acknowledged.

Initial Step Factor is used in determining the initial step bound. Try decreasing this number if initial iterations are too far from the starting design. A value of 100 is recommended.

Unlike DLS, this algorithm runs until successive iterations are within conditions set in the **Tolerance** field. If this number is too large, optimization will not have converged fully. If the number is too small, the program could be spending too much time attempting further insignificant improvements in the merit function. **Epsilon** determines a suitable step length for the forward-difference approximation used in calculating derivatives. If the value is too small the accuracy of derivatives may be affected. Check **Terminate** to automatically halt the algorithm after 200*(Variables +1) iterations.

Example: Using the Boudot Challenge problem, we obtain very good and rapid results with Initial Step Factor=100, Tolerance=0.0001 and Epsilon=0.0001.

NOL Gradient Method Parameters

Optimize...Parameters

NOL Gradient Methods provide optimization routines for a range of problems. An objective function is maximized or minimized while meeting optional constraints.

When NOL is accessed from the Main Menu the objective function is computed from the familiar merit function described in the Optimization Targets editor. Here there are no constraints.

When NOL is accessed from the CIE Color Module the objective function is the photopic response (or average) in transmission or reflection; the two constraints are the required color coordinates. When NOL is accessed from the Workbook, the objective function is the value computed in named cell *Objective*. Optional constraints are contained in an N row by two column region named *Constraint*.

Thickness Limits restrict all variables to the specified range. Enter a large value, say 1.E+15, for **Maximum** if there are no upper limits. As an alternative to general thickness limits (the same for all layers), it is possible to include constraints on individual variables in the Workbook.

Relative and **Minimum Delta Q** are utilized in computing gradients by finite difference steps. A step is equal to relative Delta Q times the current thickness. If that value is too small, the minimum Delta Q is substituted.

There are several choices of **Optimizer** and **1-D Search** algorithms. Experience indicates that the BFGS optimizer works best in most cases. **Scaling** is somewhat problematic and does not seem to help unconstrained problems; it does appear to help when constraints are utilized. The **Merit Exponent** entry appears only when the dialog box is called from the Main Menu. This entry relates the NOL objective function to the merit function calculated from targets. It appears that increasing the value is useful when a solution is nearly reached.

In order to speed up operations when using NOL from the Main Menu, it is suggested that the screen be updated only once every 20 or 50 iterations. Note that the **Update graph** text box is displayed only when Optimization Parameters are accessed from the Main Menu.

Example from Main Menu: Using the Boudot Challenge problem, we obtain good results with Thickness Limits Min = 0.01, Relative Delta Q = 0.001, Minimum Delta Q = 0.00001, Optimizer = BFGS, 1-D Search = GS + Interp, Scaling = OFF, and Merit Exponent = 0.5. Convergence is fairly slow.

Simplex Parameters

Optimize...Parameters

Simplex (Nelder and Mead) is a non-derivative method which systematically varies every layer in the search for a global minimum. Try the simplex method after DLS in order to see if you can locate a better solution.

The size of the Initial Step is important and is best determined by observing the screen during simplex initialization (before the Iterations prompt). If there is no apparent movement, increase the step size; if the movement is wild, decrease the step size.

Genetic Parameters

Optimize...Parameters

Refine current design and **Digital synthesis** offer considerably different functions. The first case provides familiar continuous refinement according to optimization variables and *required* thickness limits. In digital synthesis designs are built up from elements defined in the Synthesis dialog. If the elements are restricted to quarter waves, the final design consists of quarter wave multiples. Use the Layers Mode editor to delete zero layers and combine adjacent layers of the same type.

The genetic algorithm (Genetic Server) has numerous choices which are explained in a separate help file accessed by clicking the **Help** button.

Target Generator/Converter

from Targets Editor...Generate <Alt+G> or Convert <Alt+C>

Use the optimization Target Generator to automatically fill in target entries. Inverse wavelength spacing correctly puts more targets at shorter wavelengths (where the density of 'wiggles' is higher). The generator *supplements* existing targets and may be used repeatedly to create multiple band filters.

The maximum number of targets which may be generated (2 minimum) is indicated. Select **Cancel** to exit without adding new targets. Click **OK** to generate new targets and return to the Target Editor. If the new targets are incorrect, immediately click **Cancel** to restore original values.

When the horizontal axis is wavelength and Target Type is Equality, clicking **Convert Spectrum** instead of **Generate** in Optimization Targets converts spectral data to targets within the specified wavelength range. Measured data can be loaded from disk or pasted from the Windows clipboard in the Spectra menu. This facility is intended for inverse synthesis (reverse-engineering).

Tools Menu

This menu provides access to the following programmable modules: FilmStar Workbook (page 94), FSPlot Graphing Module (page 100) and FilmStar BASIC (page 73). Complying with the usual Windows location for print commands, the Report Generator (page 105) is accessed from the File Menu.

Macro Commands

Tools...Macro Commands <Ctrl+Z>

A FilmStar macro is a series of commands that can be executed by FilmStar itself or by other Windows applications by dynamic data exchange (DDE). While DDE is older technology largely supplanted by FilmStar-supported ActiveX, it provides the means to communicate with DDE-compliant 16-bit applications. The following section provides a complete command list.

The Macro Commands dialog lists up to six macro descriptions and corresponding commands. The most important macro commands are *BasOpen* (open a BASIC program for editing) and *BasRun* (run a program). Commands in the **Edit Menu** simplify data entry by locating BASIC (.bas) files. Macro descriptions are then used in both the Tools Menu and in the Macro Buttons toolbar where they appear as tooltip text. Commands can be saved. Short BASIC programs can be run with *BasExec*.

Should six commands be insufficient, multiple macros can be assigned to a Macro Button. Click here for further information.

Macro Reference (DDE)

Programming skills in Excel or other Windows languages may be required to implement some topics discussed below. Please contact FTG Software Associates for assistance.

Dynamic data exchange (DDE) provides means for importing and exporting data and commands across Windows applications. While superseded by 32-bit object-oriented methods (supported by FilmStar), DDE links 16 and 32-bit programs as well as 32-bit programs which do not support objects. Several DESIGN dialog boxes include **Import** and/or **Export** commands as well as **DDE Options**. These are accessed from an **Edit** sub menu.

Import/Export

In Windows jargon these are actually Link Request and Link Poke events. DESIGN uses manual links because topics attached to dialog box forms are unloaded from memory when the form is unloaded. (In an automatic link data is exchanged whenever the linked data changes.)

Options

Each option includes a Topic and an Item. These are automatically stored on disk on quitting DESIGN. Topics for Microsoft Windows applications are as follows:

Application	DDE application name
Microsoft Excel	Excel
Microsoft Word for Windows	WinWord

An example is provided in Excel model "indices.xls" supplied with FilmStar. Here the Topic includes the name "excel" followed by "|" (vertical bar) and the path and file name of the Excel model. The Item **editor** is the name of the defined range \$A\$2:\$J\$14 which is linked to DESIGN's Film Indices editor grid.

Topic	excel e:\excel\films\indices.xls
Item	editor

Consult appropriate reference manuals for DDE application names for other Windows programs.

Macro Commands

As illustrated in the calculation of user-defined index functions, DDE provides means for executing DESIGN commands in other Windows programs. Conversely, DESIGN accepts commands from other applications. The commands and their formats are listed below.

FilmStar BASIC (page 73) duplicates macro commands and has the advantage of displaying syntax in an object browser. In addition there are numerous BASIC commands and functions which do not have macro equivalents.

The same commands are used with Main Menu's command macro facility or with macros set up in the FilmStar Workbook. Capitalization is unimportant except where a command contains labels. Multiple commands may be placed in the same line. Each command terminates with a semicolon. In the list below Italics indicate comments and are not part of the command.

AbsorbLayer...Specify layer for absorption vs. wavelength or angle.

```
AbsorbLayer 3;   Absorptance in Layer 3
AbsorbLayer 0;   Total absorptance
```

Angle...Set angle and polarization (P,S,R)

```
Angle 30 P;
```

ArchiveMode...Set FILM Archive Mode on/off

```
ArchiveMode 0;   Off
ArchiveMode 1;   On
```

ArchiveNK...Add dispersive index tables to FILM Archive

```
ArchiveNK 0;     Off
ArchiveNK 1;     On
```

AxesCopy...Copy graph axes settings to clipboard. Excel-compatible format similar to Edit...Copy command in graph axes editor, but the Interval field is not used.

```
AxesCopy;
```

AxesCopyDelta...As above, but includes evaluation interval (delta).

```
AxesCopyDelta;
```

AxesDraw...Draw new graph axes

```
AxesDraw;
```

AxesOpen...Open graph axes. AxesPath or DefaultPath changes the directory; the directory can also be included in the command. If you add an (optional) extension it must be correct. Similar commands: **IndexOpen (.inw)**, **DesignOpen (.dew)**, **OptiTargOpen (.trw)**, **OptiVarOpen (.vaw)**, **FilmOpen (.flw)**, **ArchiveOpen (.faw)**.

```
AxesOpen bbar;
AxesOpen c:\winfilm\axes\bbar;
AxesOpen c:\winfilm\axes\bbar.axw;
```

AxesPaste...Paste graph axes from clipboard. Excel-compatible format identical with Edit...Copy command in graph axes editor

```
AxesPaste;
```

AxesPath...Change the default path for retrieving graph axes from disk. Similar commands: **IndexPath**, **DesignPath**, **OptiTargPath**, **OptiVarPath**. Also see **DefaultPath**.

```
AxesPath c:\winfilm\data;
```

AxesSubTitle...Specify FSPlot subtitle.

```
AxesSubTitle This is FSPlot subtitle (small font);
```

AxesTitle...Specify title in main graph and FSPlot.

```
AxesTitle This is main graph and FSPlot title;
```

BasChain...Immediately run FilmStar BASIC program from within another BASIC program.

```
BasChain d:\winfilm\basic\fnun.bas;
```

BasExec...Run a FilmStar BASIC program expressed as a string. *For brevity, optionally omit 'Sub Main' and 'End Sub' when Sub Main is the only module.* The pipe character "|" separates lines.

```
BasExec Dim a!|a=5|MsgBox Cstr(a),48,"It works!";
```

Since FilmStar automatically adds 'Sub Main' and 'End Sub', the above sample code actually has five lines, not three. BasExec is best utilized for short code segments and is not intended to replace BasRun; it is especially useful in Workbook macros.

BasOpen...Open FilmStar BASIC program and display the code in the BASIC editor. Do not execute this command from BASIC!

```
BasOpen d:\winfilm\basic\fnm.bas;
```

BasRun...Immediately run FilmStar BASIC program without displaying the editor. Do not execute this command from BASIC!

```
BasRun d:\winfilm\basic\fnm.bas;
```

BasWindow...Set BASIC window state: 0 normal, 1 minimized, 2 maximized. This is useful if you want to get the window out of the way while running BASIC programs.

```
BasWindow 0;
```

Busy...Set mousepointer to hourglass (1) or default (0).

```
Busy 0;
```

Calculate...Evaluate the current thin film design

```
Calculate;  
Calculate 5; 5 nm monochromator simulation
```

Calculate is an Excel VBA keyword. If Excel is a reference, use Macro "Calculate;" rather than the BASIC Calculate command.

CalcPlot...Evaluate the thin film design and display the plot. This command must be preceded by PLOTSTART and followed by PLOTDONE.

```
CalcPlot;  
CalcPlot 5; 5 nm monochromator simulation
```

CalcRand...Evaluate the thin film design with the random errors specified in **Evaluate...Tolerancing...Values**. The original design is retained in memory. The design must be in Layers Mode (no parentheses).

```
CalcRand;  
CalcRand 5; 5 nm monochromator simulation
```

CalcRandSeed...Set random number seed; 0 uses current time.

```
CalcRandSeed 1;
```

CaptionCopy...Copy the main DESIGN caption (title bar) to the clipboard. This is required for Visual Basic's AppActivate method.

```
CaptionCopy;
```

CieWindow...Set CIE Color Module window state: 0 normal, 1 minimized, 2 maximized. Minimizing the Window prevents users from clicking menus while running BASIC programs.

CieWindow 0;

DataConvert...Convert (interpolate) current spectrum to range defined in Graph Axes (or Range). New range must be within original range.

DataConvert;

DataConvertRange...Convert (interpolate) current spectrum to specified range (min max interval). Useful for reducing number of data points.

DataConvertRange 380 780 5;
DataConvertRange 400 800 -2;

DataCopy...Copy spectrum to the clipboard

DataCopy;

DataDesc...Description for spectral data. Do not use ';' in the description!

DataDesc Say hello to Chuck!;

DataExport...Export spectrum via DDE

DataExport;

DataExportItem...Change DDE export item. In Excel this corresponds to the named range

DataExportItem spectrum;

DataExportTopic...Change DDE export topic. In Excel 5.0 this corresponds to 'excel' & pipe character (vertical line) & workbook name

DataExportTopic excel|book1; or
DataExportTopic excel|analyze.xls;

DataImport...Import spectral data via DDE

DataImport;

DataImportItem...Change DDE import item. In Excel this corresponds to the named range

DataImportItem result;

DataImportTopic...Change DDE import topic. In Excel 5.0 this corresponds to 'excel' & pipe character (vertical line) & workbook name

DataImportTopic excel|book1; or
DataImportTopic excel|analyze.xls;

DataOpen...Open spectral data file from disk. Use in conjunction with SpecTargets. Adding an extension specifies data format. If a path is not included the default path is used. See **DataPath** and **TypeDataFile**.

DataOpen test1;
DataOpen c:\winfilm\spectra\test1;
DataOpen c:\winfilm\spectra\test1.csv;
DataOpen c:\winfilm\spectra\test1.dx;

DataPaste...Paste spectral data from clipboard

DataPaste;

DataPath...Change path for spectral data. Only required if changing from 'Spectra' path specified in **File...Configuration...Directories**. See **DefaultPath**.

```
DataPath c:\excel\spectra;
```

DataSave...Save spectrum to disk. Adding an extension specifies data type. If a path is not included the default path is used. See **DataPath** and **TypeDataFile**.

```
DataSave test1;  
DataSave c:\winfilm\spectra\test1;  
DataSave c:\winfilm\spectra\test1.dx;  
DataSave c:\winfilm\spectra\test1.csv;
```

DataSmooth...Smooth *equally spaced* data with moving average or Savitzky-Golay filter. Moving average is better at reducing noise; S-G is better at preserving structure and peak heights. An *odd number* of points is required; S-G polynomial orders can be 2, 4, 6. Use this capability to smooth noisy spectral data for n,k determination.

```
DataSmooth 1 11 0;   moving average, 31 points  
DataSmooth 2 11 2;   S-G, 11 points, smoothing  
                    polynomial order 2  
DataSmooth 2 13 4;   S-G, 13 points, smoothing  
                    polynomial order 4
```

DefaultPath...Change paths listed in **File...Configuration...Directories** corresponding to **Parameters**, **Designs**, **n,k Tables**, and **Spectra**. All four paths, separated by spaces, are entered in one command and any directories changed by **AxesPath**, *etc.* are changed back to defaults.

```
DefaultPath c:\winfilm\data c:\winfilm\designs  
c:\winfilm\data c:\winfilm\spectra;
```

To leave one or more paths unchanged, substitute the word **same** for file name as follows

```
DefaultPath same c:\winfilm\designs same same;
```

DesignAdd...Add quantity (0.01) to all (H) layers with given index

```
DesignAdd H 0.01;
```

DesignConvert...Convert design from optical to physical thickness or *vice versa*; optional second character specifies units.

```
DesignConvert 1;      Opti to phys (current units)  
DesignConvert 1 N;    Opti to phys in nm  
                    N nm, M μm, L mm, E cm, K kÅ  
DesignConvert 2;      Phys to opti (current units)  
DesignConvert 2 1;    Phys to opti QWOT = .25  
DesignConvert 2 4;    Phys to opti QWOT = 1
```

DesignMult...Multiply all (H) layers with given index by (1.1)

```
DesignMult H 1.1;
```

DesignPaste...Paste design from clipboard

```
DesignPaste;
```

DesignText...Specify design as text

```
DesignText .25H (.25L .25H)10;
```

DesignWave...Set design wavelength in nanometers

```
DesignWave 550;
```

EvalWave...Set evaluation wavelength in nanometers; use when plotting vs. angle or physical thickness.

```
EvalWave 550;
```

GramsOpen...Import Galactic's GRAMS .spc spectrum file.

```
GramsOpen;
```

GroupsCopy...Copy design to clipboard as single string

```
GroupsCopy;
```

*When executed from the FilmStar Workbook the action is different. The design is pasted in a column starting at named cell **Design** without regard to parentheses. This column is the same as in Thickness Variables Numbering Scheme in Optimization Variables. This makes it easy to set up thickness constraints for layers in parentheses.*

IndexCopy...Copy Film Indices editor contents to clipboard

```
IndexCopy;
```

IndexPaste...Paste indices from clipboard. Format as in "indices.xls". Non-zero numeric argument forces program to refresh dispersive index file data each time command is executed.

```
IndexPaste 0;
```

LayersCopy...Convert groups to layers and copy the design to clipboard as column. When executed from the FilmStar Workbook the design is pasted in column format starting at named cell **Design**.

```
LayersCopy;
```

LineColor...Change line color as follows: black, Red, Yellow, Blue, Green, Magenta, Cyan, White

```
LineColor R;
```

MainWindow...Set Main Menu window state: 0 normal, 1 minimized, 2 maximized. This is useful if you want to get the window out of the way while running BASIC programs.

```
MainWindow 0;
```

Merit...Compute optimization merit function and copy result to clipboard

```
Merit;
```

Optimize...Optimize the design according to the currently set method, targets and variables. This can be used with Simplex or Flip-Flop if the number of iterations is added. Click **Optimize...Parameters** to adjust termination criteria.

```
Optimize;
```

```
Optimize 1000; (Simplex or Flip-Flop)
```

Following the optimization, the design can be retrieved with DDE macro command **LayersCopy** or **GroupsCopy**. Use DDE command **Merit** to obtain the new merit function.

OptiTool...Optimize the design according to the currently set method, targets and tooling variables checked in **Setup...Tooling Factors**. This cannot be used with simplex. Click **Optimize...Parameters** to adjust termination criteria.

```
OptiTool;
```

Following the optimization, tooling factors are copied to the Windows clipboard on separate lines. A typical result might look like

```
1.190345  
1.059823
```

OptiVars...Assign some optimization variables.

```
OptiVars 1,4,5;
```

OptiVarsAll...Assign all layers to optimization variables.

```
OptiVarsAll;
```

PhaseSmooth...Automatically remove vertical jumps in phase shift (radians) data by adding or subtracting 2 PI.

```
PhaseSmooth;
```

PlotDone...Must be issued after the last CALC PLOT command

```
PlotDone;
```

PlotStart...Must be issued before the first CALC PLOT command if multiple graphs are plotted on the Main Menu screen.

```
PlotStart;
```

PlotSelect...Allows plotting R/T/A on the same axes in the Main Menu graph and in FSPlot. PlotType > 0 is equivalent to unchecking **New axes after changing Graph Axes** in **File...Configuration...Preferences**. But here the Select Plot dialog box is suppressed and selection is as below.

```
PlotSelect 0;   As in Setup Parameters  
PlotSelect 1;   Plot reflectance  
PlotSelect 2;   Plot transmittance  
PlotSelect 3;   Plot absorptance (1-R-T)
```

Typical use in FilmStar BASIC is:

```
k = Macro("Calculate;")  
PlotClose      ' erase current FSPlot graphs  
PlotActivate   ' activate FSPlot window  
PlotLegendOn 1 ' turn on plot legends  
k = Macro("PlotType 1;") ' select reflectance  
PlotLegend(1) = "Reflectance"  
PlotNext       ' plot graph 1  
k = Macro("PlotType 2;") ' select transmittance  
PlotLegend(2) = "Transmittance"  
PlotNext       ' plot graph 2  
k=Macro("ReportShow;")  ' get Report Generator
```

PlotWindow...Set FSPlot window state: 0 normal, 1 minimized, 2 maximized. This is useful if you want to get the window out of the way while running BASIC programs.

```
PlotWindow 0;
```

Replot...Replot current spectrum. Use with AxesDraw when drawing a new graph.

```
AxesDraw;Replot;
```

ReportPrint (PrintReport)...Print the current report without displaying it. Same as File...Quick Print Report. Use ReportShow to display the Report Generator dialog before printing.

```
ReportPrint;
```

ReportSave (SaveReport)...Save report as a binary printer file (*.prt), Adobe Acrobat (*.pdf), or rich text format (*.rtf) . The report is not displayed. Include path and extension.

```
ReportSave c:\winfilm\reports\test1.prt;
```

ReportShow (ShowReport)...Preview report and optionally print it.

```
ReportShow;
```

ReverseDesign...Reverses design

```
ReverseDesign;
```

SpecTargets...Convert current spectrum to optimization targets. If New=0 then new targets supplement those already in the target list. If New<>0 then a new list is created. The other quantities are the same as those the optimization targets editor.

```
SpecTargets New Type$ Tol Angle Pol$;  
SpecTargets 1 R 1 45 R;
```

StatusLabel...Display message in status label at screen lower left. Do not include ';' in the label.

```
StatusLabel Visit Princeton soon;  
StatusLabel; Clears label
```

StopCalc...Try this command if you have a problem running DESIGN from other programs. A typical symptom is DDE timeout. StopCalc prevents DESIGN from responding to Windows messages until the current task is completed. The Stop command is the Main Menu is disabled when StopCalc is set to zero.

```
StopCalc 0; Turn off DoEvents  
StopCalc -1; Turn on DoEvents (default)
```

TargetsCopy...Copy optimization targets to clipboard.

```
TargetsCopy;
```

TargetsPaste...Paste optimization targets from clipboard.

```
TargetsPaste;
```

TargetsShow...Display optimization targets.

```
TargetsShow;
```

Tooling... Assign values shown in Tooling Factors dialog. Useful for evaluating and optimizing designs averaging over angle and thickness distribution, as in curved reflectors.

```
Tooling 1.05 1.06 1.10;  
Tooling;   Sets all values to 1.0
```

TypeContour... Mode for contour data.

```
TypeContour 0;   Data in matrix  
TypeContour 1;   Data in triplets
```

TypeDataCopy... Copy and paste (DDE import/export) spectral data using R/T = 0-100% instead of 0-1. See **Spectra...Format Options (page 54) Format Options**.

```
TypeDataCopy 0;   R/T 0-1  
TypeDataCopy 1;   R/T 0-100%
```

TypeDataFile... Open and save spectral data using .csv or JCAMP format. This can also be selected manually in **Spectra...Format Options**. JCAMP is a 'standard' spectroscopy file format and provides a link to Spectrum 2000 and other software packages

```
TypeDataFile 0;   .csv ASCII format  
TypeDataFile 1;   JCAMP format  
TypeDataFile 11;  JCAMP, P-E compatible  
TypeDataFile 100; .csv for Excel
```

TypeSide2... Specify Side 2 Compensation (page 40). User values 1-5 corresponding to list in Setup Parameters.

```
TypeSide2 2;   FWD include Side 2
```

TypeWaveCopy... Copy and paste (DDE import/export) spectral data using current wavelength units rather than nanometers. This can also be selected manually in **Spectra...Format Options**.

```
TypeWaveCopy 0;   Wavelength in nanometers  
TypeWaveCopy 1;   Wavelength in user-specified units
```

WbActivate... Activate FilmStar Workbook module. This is identical to pressing **[F3]** from the Main Menu.

```
WbActivate;
```

WbSetName... (Re)assign Workbook defined name. Especially useful for moving DataMarker in complex models requiring multiple spectral ranges. Reassigning DataMarker resets data looping.

```
WbSetName DataMarker $A$100;  
WbSetName DataMarker Test2.vts!$A$100;
```

WbWindow... Set Workbook window state: 0 normal, 1 minimized, 2 maximized. This is useful if you want to get the window out of the way while running BASIC programs.

```
WbWindow 0;
```

Each command is followed by a semicolon (;). Commands may be grouped or sent in separate EXECUTE commands. *Do not use semicolons in text strings!* Spaces separate parameters in some commands.

The following MS Excel VBA macro updates DESIGN ("design1.exe") with the design in the clipboard, sets angle to 30, polarization to random, design wavelength to 525 nm, calculates the spectrum and copies the spectrum to the clipboard. *The command string in DDEExecute must be surrounded by square brackets.* The DDEExecute command is one macro statement on one line.

```
Sub Evaluate(iter As Integer)
    ch = DDEInitiate("DESIGN1","Main")
    DDEExecute ch, "[StatusLabel Iteration"
    & Format$(iter,"0")& ";DesignPaste;Angle 30 R;
    DesignWave 525;Calculate;DataCopy;]"
    DDETerminate ch
End Sub
```

Macro command 'Fred' is useful for making sure that things work!

```
Sub Main
    Ch = DDEInitiate("DESIGN1","Main")
    DDEExecute Ch, "[Fred;]"
    DDETerminate Ch
End Sub
```

Normal error-checking methods may be suppressed when running DESIGN with DDE commands. For example, DataSave overwrites files with the same name.

Macro Commands <Shift + F1>...<Shift + F6>

The above DDE commands may also be internally sent to DESIGN. Macros are defined in the Macro Commands dialog in the Tools Menu and are stored with the DESIGN Configuration. The following example calculates S and P spectra with a single keystroke.

Description: 45 deg, S + P

Command: axesdraw;plotstart;angle 45 p;linecolor r;
calplot;angle 45 s;linecolor b;calplot;plotdone;

Users with suggestions for additional macro functions should contact FTG Software.

Status Bar Commands

Button Bar

Axes <Alt+A>

Redraw graph axes and automatically replot the current spectrum.

Color <Alt+R>

There are two color palettes: light and dark. Select in **Setup...Graph Details <Ctrl+H>**. The spectrum is replotted in the selected color. To suppress replotting hold down the shift key while selecting a color.

To change colors with the keyboard, press <Alt+R>, use left and right arrow keys to select and press <Enter>. Press <Shift+Alt+R> to change colors

without replotting the current spectrum. Colors can also be selected with a single keystroke:

blac**K**, **R**ed, **Y**ellow, **B**lue, **G**reen, **M**agenta, **C**yan, **W**hite

Stop <Escape>

Stop or pause calculation or optimization and return to the Main Menu.

Calculate

Calculate <Alt+C>

Design wavelength

Wavelength where an optical thickness of .25 (or 1 as specified in Setup Parameters) corresponds to an optical quarter wave. The calculated spectrum is independent of design wavelength when all layers are in physical thickness.

Evaluation wavelength

Enabled when the horizontal axis is angle or physical thickness; otherwise disabled.

Plot type

Select Monitor to show the behavior of the thin film assembly as layers are deposited; select Sensitivity to show the behavior of the entire stack when varying each layer from zero to its final thickness.

FilmStar BASIC

FilmStar BASIC is a development environment for customizing FilmStar. Using Sax Basic, FilmStar BASIC adds the special commands and keywords discussed in this section. Two macro commands are supported: BasOpen and BasRun.

The FilmStar BASIC language is nearly 100% compatible with Microsoft VBA (Visual Basic for Applications). The IDE (Integrated Development Environment) (**Tools...BASIC Editor <F6>**) provides means to edit and test BASIC programs.

BASIC Code Generators

Users will find *Create BASIC Code* commands in three places: Report Generator (File menu), FSPlot Module (File menu and Setup...Annotations menu). This enables advanced users to define reports and graphs in BASIC programs. In this way consistency is maintained even if users purposefully or accidentally modify report and graph settings.

The trick to developing Reports or Annotations containing computed values is to create the BASIC code and then replace constants with functions. As an example, the following Annotation code (vertical line at 1640 nm)

```
"\vline 1640.00,5,|b 1640.00 nm,16711680;0" & vbCrLf
```

would be replaced by

```
"\vline " & format$(wc, "0.00") & ",5,|b " & _  
Format$(wc, "0.00") & " nm,16711680;0" & vbCrLf
```

where wc is the center wavelength computed by BASIC *Sub BandCtr*, as in BASIC program BandWidthPlot.bas.

FilmStar DESIGN Extensions

Summary documentation for FilmStar extensions is provided in the BASIC editor (IDE). Click the Browse Object icon.

Variables can be transferred to and from DESIGN to FilmStar BASIC for various calculations. In addition a number of functions and subroutines are available. Capitalization is not important in the following:

Property AbsorbLayer%...Specify layer for absorption vs. wavelength or angle.

```
AbsorbLayer = 3
```

Property Angle!...Assign/get angle of incidence in degrees

```
x! = Angle  
Angle = 34
```

Note that the following does NOT work:

```
For angle = 0 To 30 ' doesn't work  
  CalcPlot  
Next angle
```

Instead, you should use

```
For a = 0 To 30 Step 5  
  angle = a ' sets angle in DESIGN  
  CalcPlot  
Next a
```

Property ArchiveMode As Boolean...Assign/get FILM Archive mode

```
ArchiveMode = True  
k = ArchiveMode
```

Property ArchiveNK As Boolean...Assign/get FILM Archive n,k table mode.

```
ArchiveNK = True ' store index tables with Archive  
k = ArchiveNK
```

Sub AxesAutoScale(Optional xAxis As Boolean, Optional yAxis as Boolean = True)...Auto scale horizontal and/or vertical axes. Especially useful when importing data.

```
AxesAutoScale ' autoscale y axis  
AxesAutoScale True ' autoscale x & y axes  
AxesAutoScale True, False ' autoscale x axis
```

Sub AxesCopy(Optional kInt As Boolean)...Copy axes settings to clipboard, include calculation interval (delta) if kInt is True. Use to determine format for AxesPaste.

```
AxesCopy ' copy without calculation interval  
AxesCopy True ' include interval (delta)
```

Sub AxesDraw...Draw new graph axes.

```
AxesDraw
```

Sub AxesPaste(Optional s\$)...Paste graph axes from clipboard or from optional TAB & CRLF delimited string (see AxesCopy).

```
AxesPaste
```

```
AxesPaste s$ ' use axes string s$ instead of clipboard
```

Property AxesYtype\$...Returns vertical axis setting: R, T, O, etc.

```
S$ = AxesYtype
```

Sub BandCtr(wMin!, wMax!, wCtr!, kErr As Boolean, Optional kType%)... Compute bandpass mean center wavelength $wCtr$ in range $wMin$ to $wMax$; set $kType=1$ for average center wavelength; returns $kErr=True$ if error.

```
BandCtr 400, 800, wCtr, kErr
```

Sub BandMax(wMin!, wMax!, bMax!, kErr As Boolean)...Compute maximum bandpass value $bmax$ in range $wMin$ to $wMax$; returns $kErr=True$ if error.

```
BandMax 400, 800, bMax, kErr
```

Sub BandWidth(Level!, wMin!, wMax!, bw!, kErr As Boolean)...Compute bandwidth bw at a given % Level within range $wMin$ to $wMax$; returns $kErr=True$ if error.

```
BandWidth 50, 400, 800, bw, kErr ' 50% bandwidth
```

```
BandWidth 10, 400, 800, bw, kErr ' 10% bandwidth
```

Sub BasActivate...Return focus to BASIC's IDE (integrated development environment).

```
BasActivate
```

Sub BasChain(file\$)...Immediately run BASIC program from current program.

```
BasChain "c:\winfilm\basic32\eval1.bas"
```

Property BasText\$(0)...**BasText\$(15)**...Set text variables for use in the Report Generator with action commands *BASTEXT* and *BASBLOCK*. Text can be a fragment or a block of paragraphs.

```
BasText(0) = "Welcome to FilmStar Programming"
```

Sub Busy(k As Boolean)...Turn hourglass cursor on/off

```
Busy False ' turn off hourglass cursor
```

Sub CalcPlot(Optional hWidth!, Optional kType%)...Calculate and plot spectrum. For multiple plots, precede by CalcPlotStart and follow with CalcPlotDone. See Sub Calculate.

```
CalcPlot
```

```
CalcPlot 5 ' simulate 5 nm monochromator bandwidth
```

Sub CalcPlotDone...Conclude series of multiple plots on same graph (main screen).

```
CalcPlotDone
```

Sub CalcPlotStart...Begin series of multiple plots on same graph (main screen).

```
CalcPlotStart
```

Sub CalcRand(Optional hWidth!, Optional kType%)...Evaluate design with the random errors specified in Evaluate...Tolerancing...Values. The design must be in Layers Mode (no parentheses). The original design is retained in memory unless kType = 1.

```
CalcRand
CalcRand 5 ' simulate 5 nm monochromator bandwidth
CalcRand 0, 1 ' keep randomized design
```

Why keep the randomized design? This feature was added for testing the reliability of inverse-synthesis. Assign Design0\$ = Design before CalcRand and then Design = Design0\$ to later restore the original design.

Sub CalcRandSeed(Optional seed#)...Set random number seed; 0 uses current time. Set seed<>0 before RndNorm to repeat random numbers.

```
CalcRandSeed 1.23
```

Sub Calculate(Optional hWidth!, Optional kType%)...Calculate without plotting spectrum; this can be noticeably faster than CalcPlot. Halfwidth hWidth (nm) simulates monochromator response. kType reserved for future use.

```
Calculate
Calculate 5 ' simulate 5 nm monochromator bandwidth
```

Calculate is an MS Excel VBA keyword. If Excel is an object reference in your BASIC program, use Macro "Calculate;" instead of Calculate.

Sub CieActivate(Optional kHide%, Optional Title\$)...Activate CIE dialog; kHide = 1 hide color bars, +2 hide bottom, +4 hide menus, +8 compact graph

```
CieActivate(15, "Reflected Color")
```

Sub CieClose...Close CIE dialog box

```
CieClose
```

Property CieParams\$...Get string showing CIE parameters. The same string is displayed in the CIE Graph Axes title.

```
s$ = CieParams ' returns "1931 x,y (2°) Illuminant A"
```

Sub CieOptimize()...Performs CIE optimization using current CIE target settings; CieClose closes dialog afterwards.

```
CieOptimize
CieClose
```

Sub CieWindow(kState%)...Set CIE window state: 0 normal, 1 min, 2 max

```
CieWindow 2
```

Property CieYield!...Compute CIE color yield using current CIE parameters and tolerance settings; CieClose closes dialog afterwards.

```
CieOptimize
s! = CieYield
CieClose
```

Sub ConfigOpen...Reload configuration from design1.ini.

```
ConfigOpen
```

Sub DataClear...Erase current spectrum.

```
DataClear
```

Sub DataConvert(Optional wmin!, Optional wmax!, Optional wint!)...

Convert spectrum range to current axes or range settings; optionally specify min, max and interval. If wmin=0 then use current settings

```
DataConvert ' use current graph axes or range settings
DataConvert 400,600,2 ' convert data to 400-600x2 array
```

Sub DataConvertList(List\$)...Convert (interpolate) current spectrum to specified Wavelength List file.

```
DataConvertList "LBL Window" ' default directory
DataConvertList "c:\winfilm\wave\LBL Window.wls"
```

Sub DataCopy...Copy spectrum to clipboard in Excel format.

```
DataCopy
```

Sub DataExport(Optional topic\$, Optional item\$)...Export data via DDE; optionally specify new topic and/or item.

```
DataExport
```

Sub DataImport(Optional topic\$, Optional item\$)...Import data via DDE; optionally specify new topic and/or item.

```
DataImport
```

Sub DataPaste...Paste spectrum from clipboard or from optional string. Excel-compatible (TAB and CRLF limited) format as in DataCopy.

```
DataPaste
DataPaste s$ ' use data string s$ instead of clipboard
```

Sub DataPoints%...Returns number of points (wavelengths) in the current spectrum.

```
n = DataPoints
```

Sub DataSmooth(kType%, nPoints, Optional kPoly)...Smooth *equally spaced* data: kType=1 moving average, 2 Savitzky-Golay filter; kPoints is *odd number*; kPoly is S-G polynomial order 2,4,6. Moving average is better at reducing noise; S-G is better at preserving structure and peak heights. Use this capability to smooth noisy spectral data for n,k determination.

```
DataSmooth 1 11 ' moving average, 11 points
DataSmooth 2 11 2 ' S-G, 11 points, smoothing
                  ' polynomial order 2
DataSmooth 2 13 4 ' S-G, 13 points, smoothing
                  ' polynomial order 4
```

Sub DefaultPath(Optional pParam\$, Optional pDesign\$, Optional pIndex\$, Optional pSpectra\$)...Change some or all default paths listed in configuration dialog; restore current directories to default.

```
DefaultPath , , "c:\dwdm\test004" ' change spectra path
```

Property Design\$...Assign/get film design as continuous string. See **Layers**.

```
s$ = Design
Design = ".25H .25L .25H"
Clipboard$ Design ' copy design to clipboard
```

Sub DesignAdjust(kType, Symb\$, AdjVal)...Adjust (kType=1 add, 2 multiply) layers with index symbol Symb\$; Symb\$="" adjusts all layers

DesignAdjust 1, "H", .02

Sub DesignConvert(k, Optional unit As Variant)...k=1 optical to physical, 2 physical to optical; physical unit N nm, M μm, L mm, E cm, K kÅ; optical unit 1, 4;

```
DesignConvert 1, M ' optical to physical (μm)
DesignConvert 1 ' optical to physical (current units)
```

Sub DesignPaste...Paste design from clipboard.

```
DesignPaste
```

Property DesignPhysUnit\$...Returns design physical thickness unit: N nm, M μm, L mm, E cm, K kÅ

```
u$ = DesignPhysUnit
```

Property DesignQwotUnit%...Returns design QWOT unit: 1 (QWOT=.25) or 4 (QWOT=1)

```
k = DesignQwotUnit
```

Sub DesignReverse...Reverse the thin film design.

```
DesignReverse
```

Function DesignReverseStr\$(Byval qf\$)...Reverse a design segment.

```
qrev$ = DesignReverseStr(".25H .25L")
```

Property DesignWave!...Specify/get design wavelength in current wavelength units.

```
DesignWave = 1550
w = DesignWave
```

Sub DispBox(text\$, icon%, title\$)...Display a message box without buttons. This is useful for status messages when no response is required. Use the following icon numbers: 16-Stop, 32-Question, 48-Attention, 64-Information. Use the BASIC MsgBox instruction when a user response is required.

```
DispBox "Waiting for stabilization", 48, "Heater"
Wait 10 ' wait 10 seconds
DispBox "", 0, "" ' remove the box
```

Sub Display(text\$, title\$, wd%, ht%, FontName\$, FontSize!, FontBold%)... Display a multiline text box in a dialog box with width wd% (twips) and height ht%.

```
Display "FTG Software Associates", "Princeton, New
Jersey", 5000, 3000, "Arial", 18, 1
```

Sub EdgeCalc(Level!, wMin!, wMax!, wEdge!, yEdge!, kErr As Boolean)...Compute cuton/cutoff wavelength wEdge and R/T value yEdge at a given % Level within range wMin to wMax; returns kErr=True if error.

```
EdgeCalc 50, 400, 800, wEdge, yEdge, kErr ' 50% cut
```

Property EvalWave!...Specify/get evaluation wavelength in current wavelength units.

```
EvalWave = 854
a = EvalWave
```

Property FileDescription\$(k%)...Assign/get file description: k=1 Spectral Data, 2 Axes, 3 Indices, 4 Design, 5 Targets, 6 Variables, 7 FILM, 8 FILM Archive.

```
S$ = FileDescription(8)
FileDescription(8)= "100% yield DWDM design"
```

Property FileName\$(k%)...Assign/get file name: k=1 Spectral Data, 2 Axes, 3 Indices, 4 Design, 5 Targets, 6 Variables, 7 FILM, 8 FILM Archive

```
s$ = FileName(8) ' FILM Archive file name
FileName(1) = "Mirror"
```

Function FileOpen(file\$, Optional k%) As Boolean...Open file; optional path; use extension or k to specify type: k=1 Spectral Data (.csv, .dx), 2 Axes (.axw), 3 Indices (.inw), 4 Design (.dew), 5 Targets (.trw), 6 Variables (.vaw), 7 FILM (.flw), 8 FILM Archive (.faw). Returns True if successful. All of the following will work:

```
FileOpen "c:\winfilm\data\spec1.csv"
FileOpen "c:\winfilm\data\spec1", 1
FileOpen "spec1.csv", 1 ' default path used
FileOpen "spec1", 1      "      "      "      "

If Not FileOpen("spec1.csv") Then
    MsgBox "Bad file name",vbCritical,"Open"
    Exit Sub
End If
```

Property FilePath\$(k%)...Assign/get current file path: k=1 to 8 as above

```
s$ = FilePath(1)
FilePath(1) = "c:\dwdm\spectra"
```

Function FilePropsGet(FileName\$, Title\$, Subject\$, Author\$, LastAuthor\$, Keywords\$, Comment\$, ReadOnly as Boolean) as Boolean...Returns NTFS properties for any file. Include file name with path and extension.

Sub FilePropsList(Files\$)...Returns array of spectra or FILM Archive files displayed in the File Properties List dialog. Users can then use FileOpen to open and analyze similar spectra or designs.

```
Sub Main
    Dim k&, files$()
    On Error GoTo NoList ' important
    FilePropsList files$()
    For k = 1 To UBound(files$)
        Debug.Print files$(k)
    Next k
NoList:
    Exit Sub
End Sub
```

Function FilePropsSet(Title\$, Comment\$, Optional FileName\$, Optional User\$, Optional Subject\$, Optional Keywords\$) As Boolean...Adds NTFS file properties to FILM Archive files (*.faw). The following values are utilized when optional fields are blank or missing:

FileName: Current FILM Archive file name
 User: User Name in File...Configuration dialog
 Subject: "FilmStar DESIGN FILM Archive"
 Keywords: "FTG FilmStar FILM Archive design (.faw)"
 FilePropsSet "BBAR", "450-750 nm"

Function FileSave(File\$, Optional k%) As Boolean...Save file; optional path; use extension or k to specify type: k=1 Spectral Data (.csv, .dx), 2 Axes (.axw), 3 Indices (.inw), 4 Design (.dew), 5 Targets (.trw), 6 Variables (.vaw), 7 FILM (.flw), 8 FILM Archive (.faw). All of the following will work:

```

FileSave "c:\winfilm\data\spec1.csv"
FileSave "c:\winfilm\data\spec1", 1
FileSave "spec1.csv", 1 ' default path used
FileSave "spec1", 1      '      "      "      "

If Not FileSave("c:\winfilm\data\spec1.csv") Then
  MsgBox "Could not save", vbCritical, "Save"
Exit Sub
End If
  
```

Function fMsgBox%(text\$, icon%, title\$)...Similar to BASIC's MsgBox function but will be modal within FilmStar DESIGN. This prevents covering the dialog box by clicking on the DESIGN window.

```
k = fMsgBox("Do you want to proceed?", 36, "BASIC")
```

Property Footer\$...Assign/get report footer.

```

Footer = "Text at bottom of report"
s$ = Footer
  
```

Sub GetCie(x!, y!, yy!, Optional yp!, Optional Mode\$) ...Evaluate design and calculate CIE color coordinate triplet (x, y, Y), (u, v, L) or (a*, b*, L*) depending on CIE settings (stored with film design). Optional yp returns photopic response (same as yy if CIE x, y specified) independent of CIE settings. Optional Mode = R or T overrides current program setting.

```
GetCie x, y, yy, yp, "R"
```

Sub GetCieData(x!, y!, yy!, Optional yp!, Optional Mode\$)...Same as **Sub GetCie**, except that the spectrum currently in memory is used. The spectrum must contain 380-780 x 1 nm or 380-780 x 5 nm data

```
GetCieData x, y, yy
```

Sub GetCieTri(X!, Y!, Z!, Optional Mode\$) ...Evaluate design and calculate CIE tristimulus values. Optional Mode = R or T overrides current program setting.

```
GetCieTri X, Y, Z
```

Sub GetCieTriData(X!, Y!, Z!, Optional Mode\$)...Same as **Sub GetCieTri**, except that the spectrum currently in memory is used. The spectrum must contain 380-780 x 1 nm or 380-780 x 5 nm data

```
GetCieTriData X, Y, Z
```

Sub GetIndex(sym As Variant, wave!, xn!, xk!)...Calculate film indices for material defined by index symbol *sym* (use AIR and SUB for entrance and exit media) at wavelength *wave*. *sym* can also be the row number in the Film Indices editor: AIR=1, SUB=2, first film=3, etc.

```

GetIndex "AIR", 1064, xn, xk
GetIndex 4, 632.8, xn, xk
GetIndex "H", 550, xn, xk

```

Sub GetIndexList(symb\$(), ntyp\$(), file\$(), desc\$())...Get index list as in the Film Indices dialog. Note that symb\$(1) returns "AIR" and symb\$(2) returns "SUB". See Sub SetIndexList.

```

Sub Main
  Dim i%, symb$(), ntyp$(), file$(), desc$()
  GetIndexList symb$(), ntyp$(), file$(), desc$()
  n = UBound(symb$)
  For i = 1 To UBound(symb$)
    Debug.Print symb$(i)&" "& ntyp$(i)&" "& file$(i)
  Next i
End Sub

```

Sub GetLayers(nLayers%, thick!(), type\$(), desc\$(), Optional kType%)...Get thin film design in layers mode as numeric thickness, materials type and materials description arrays. If kType=1 file names used instead of description. Useful for calculations, reports and export to other programs.

```

Dim i%, n%, q!(), qt$(), qd$()
Sub Main
  GetLayers n, q(), qt(), qd()
  For i = 1 To n
    s$ = format$(q(i),"0.0000") & " " & qd(i)
    Debug.Print s$
  Next i
End Sub

```

Sub GetRTData(ByVal wave#, ByVal ang#, Rs#, Rp#, Ts#, Tp#, Optional ByVal PC As Boolean)...Returns a row of R/T data for export to Excel or other software. Set PC = True if R/T data is needed in percent. A row of data with values -999 indicates a calculation error. The calculation utilizes the current Side 2 Compensation setting.

```

Dim Rs#, Rp#, Ts#, Tp#
GetRTData 500, 30, Rs, Rp, Ts, Tp

```

Sub GetTableData(ByVal wave#, ByVal ang#, Rs#, Rp#, Ts#, Tp#, Ars#, Arp#, Ats#, Atp#, Optional ByVal PC As Boolean, Optional ByVal Deg As Boolean = True, Optional ByVal DegMin# = -180)...Returns a row of R/T and phase data for export to lens design software, particularly Zemax. Set PC = True if R/T data is needed in percent. See examples TableDataTest.bas and Zemax.bas. A row of data with values -999 indicates a calculation error. *The calculation assumes Side 2 Compensation = FWD Ign Sd2.*

```

GetTableData 500, 30, Rs, Rp, Ts, T, Ars, Arp, Ats, Atp

```

Sub GetWaveRange(wMin!, wMax!)...Returns current min and max calculation wavelengths in nm. Supported for *Wavelength*, *Wavelength Range*, and *Wavelength List* plot axes. 0, 0 indicates error.

```

GetWaveRange w1!, w2!

```

Property Header\$...Assign/get report header

```
Header = "Text at top of report"  
s$ = Header
```

Function IndexCoeff!(row%, col%)...Get index coefficient as displayed in the Film Indices editor.

```
Dim xi!(3 To 5, 1 To 7)  
For i = 3 To 5  
  For j = 1 To 7  
    xi(i, j) = IndexCoeff(i, j)  
  Next j  
Next i
```

Sub IndexCopy...Copy film indices dialog values to clipboard.

```
IndexCopy
```

Function IndexPaste(Optional s\$) As Boolean...Paste film indices from clipboard or from optional TAB & CRLF delimited string. Returns True if successful.

```
IndexPaste  
IndexPaste s$ ' use string s$ instead of clipboard  
If Not IndexPaste() Then Exit Sub
```

Function IniString\$(section\$, key\$)...Get user-defined initialization variable from design1.ini.

```
s$ = IniString$("Chuck Vogel", "LastFileName")
```

returns "WW098909" if the following is in design1.ini:

```
[Chuck Vogel]  
LastFileName=WW098909
```

Property Interactor as Boolean...Assign or get Interactor status.

```
If Interactor Then DoThis ' get Interactor status  
Interactor = True ' activate Interactor
```

Property Layers\$...Get thin film design as separate lines of text. Automatically converts groups to layers (removes parentheses). See **Design**.

```
s$ = Layers  
Clipboard$ Layers ' copy layers to clipboard
```

Sub LimitsThkCopy...Copy optimization Thickness Limits to clipboard.

```
LimitsThkCopy
```

Sub LimitsThkPaste(Optional s\$)...Paste optimization Thickness Limits from clipboard or from optional TAB & CRLF delimited string

```
LimitsThkPaste  
LimitsThkPaste s$ ' use string s$ instead of clipboard
```

Sub LineColor(color\$)...Color\$=K black, B blue, G green, C cyan, R red, M magenta, Y yellow, W white (applies to main graph)

```
LineColor "R" ' red
```

Function Macro(text\$) As Boolean...Run macro commands from BASIC.

```
k = Macro("ReverseDesign;Calculate;")
```

k returns False (0) if there was an error executing the macro. This function is no longer required as BASIC functions now duplicate macro commands.

Sub MainActivate...Return focus to DESIGN's Main Menu.

```
MainActivate
```

Property MainEvents As Boolean...By default, running a program from the BASIC editor (IDE) enables FilmStar keyboard and mouse events. By default, running a program via macro command *basrun* disables FilmStar keyboard and mouse events. This behavior may be changed in a BASIC program by setting *MainEvents* true or false.

```
MainEvents = True   ' respond to keyboard/mouse
                   ' default in IDE
MainEvents = False  ' do not respond to keyboard/mouse
                   ' default when run without IDE
```

Most importantly, setting *MainEvents = True* in a BASIC program run from *basrun* adds an **Abort BASIC** menu command.

Sub MainWindow(kState%)...Set main window state: 0 normal, 1 min, 2 max.

```
MainWindow 0
```

Property Merit!...Compute and get current merit function defined by Optimization Targets editor.

```
x! = Merit
```

MonoLight(Width!, kErr As Boolean, Optional kType%)...Simulate response to monochromatic (Gaussian) light with 50% bandwidth = *hWidth* (nm); *kType* reserved for future use. (See *Calculate* and *CalcPlot*.)

```
MonoLight 5, kErr

Sub Main
  Dim kErr As Boolean
  Calculate
  MonoLight 5, kErr
  If Not kErr Then Replot
End Sub
```

Property MsgBoxTimer!...Set time interval for automatically clicking Enter in the *fMsgBox* or *sMsgBox* message box if the user does nothing. For this to work you must make sure that *Use Windows message box* is unchecked in **File...Configuration...Preferences**. Since the timer is disabled when the message box is closed, the *MsgBoxTimer* statement is required before each box containing a timer. The maximum value is 65 seconds.

```
Beep
MsgBoxTimer=15 '15 seconds timeout
sMsgBox "Get a cup of coffee!", 48, "Working Hard"
```

Property NumLayers%...Returns the number of layers in the current design. If the design contains parentheses the number of groups is returned.

```
n% = NumLayers
```

Sub OptiClear()...Clear all optimization targets and variables.

```
OptiClear
```

Sub Optimize(Optional Mode%, Optional Iter&)...Mode=0 optimization using current method, targets and variables; Mode=1 use tooling variables (Setup Tooling Factors); add Iter for Simplex and Flip-Flop methods. *Note: NOL optimization does not work when running from the BASIC IDE.*

```
Optimize 'normal optimization
Optimize 0, 1000 '1000 iterations (Simplex enabled)
Optimize 1 'tooling factor determination
```

Following the optimization, tooling factors are copied to the Windows clipboard on separate lines. A typical result might look like

```
1.190345
1.059823
```

Sub OptiVars(Optional Varlist\$, Optional Skip\$, Optional Massive as Boolean)...Assign optimization variables; VarList comma delimited, i.e. OptiVars "2,3"; VarList="" assigns all layers as variables and offers options to skip layers with index symbols in Skip\$ or to include massive layers.

```
OptiVars "2,3,4" ' assign variables 2,3,4
OptiVars          ' assign all layers as variables
OptiVars "", "M" ' assign all, skip "M"
OptiVars "", "", True ' assign all, including massive
```

Function PadString\$(text\$, length%, align%)...This function pads a string with spaces to return a string of given length. Spaces are added to the left (align=0) or right (align=2) or the string is centered (align=1). This function is useful for generating reports.

```
BasText$(0) = PadString$(format$(x!, "0.000"), 8, 0)
```

Property PgmCaption\$...Get main caption (title bar). This is required for Visual Basic's AppActivate method.

```
s$ = PgmCaption
```

Property PgmExe\$...Get the name of the FilmStar .EXE file. This can be useful when you want to use the same BASIC programs for DESIGN and MEASURE.

```
s$ = PgmExe ' returns "Design1"
```

Property PgmPath\$...Get the name of the FilmStar program path. This is useful for opening Workbook files with WbOpen.

```
s$ = PgmPath ' returns "C:\Winfilm"
```

Sub PhaseSmooth...Automatically remove vertical jumps in phase shift (radians) data by adding or subtracting 2 PI.

```
PhaseSmooth
```

Sub PlotActivate(Optional hide As Boolean)...Activate the FSPlot Module.

```
PlotActivate
PlotActivate True ' activate hidden FSPlot Module
```

Sub PlotAnnotate(kShow As Boolean)...Turn FSPlot annotations on/off; must precede PlotActivate

```
PlotAnnotate False
```

Property PlotAnnotation\$...Assign/get FSPlot Annotation string.
Annotations can be customized with BASIC's *Replace* function:

```
s$ = PlotAnnotation
PlotAnnotation = Replace(s$, "SerNum", "45678", 1, -1)
ReportPrint
PlotAnnotation = s$ 'put back original
```

Sub PlotClear...Clears all FSPlot graphs without closing the module.

```
PlotClear
```

Sub PlotClose...Close FSPlot (clears all graphs).

```
PlotClose
```

Plot Configuration Subroutines...FSPlot configuration includes a number of subroutines which need not be documented because the BASIC code is automatically generated via **File...Create BASIC Code** in the FSPlot Module.

```
PlotConfig, PlotSize, PlotTitleFont, PlotTitleSize, PlotLegendSize
PlotAxesFont, PlotAxesLabelSize, PlotAxesNumberSize, PlotFontFixed
PlotFontFixedSize, PlotAxesConfig, PlotEdgeSpace, PlotAxesSpace
PlotColors, PlotBitmapMode, PlotTableColors
```

Sub PlotCopy(Optional kType%, Optional Zoom%)...Copy FSPlot image to clipboard; kType=0 metafile (default), 1 bitmap, 2 jpeg; zoom in % (default 100)

```
PlotCopy 1, 125 ' copy as bitmap 125%
PlotCopy      ' copy as metafile
```

Sub PlotDataCopy()...Copy FSPlot data to clipboard; same as **Edit...Copy Data** in plot module. Useful for transferring results back to the main program when using the Formulater for normalizing spectrophotometer data. The main application is normalizing spectrophotometer data. **IMPORTANT:** *Before normalization, spectrophotometer data may be < 0 or > 100%. If the range is insufficient, FSPlot data may be clipped. Specify a range -20 to 120% to prevent clipping errors.*

```
Calculate          ' create a spectrum
PlotActivate True  ' hide the FSPlot dialog
PlotNext           ' store data in FSPlot memory
PlotRun "C=2*B; del B" ' run formula
PlotDataCopy       ' copy FSPlot memory to clipboard
PlotClose          ' close hidden FSPlot
DataPaste          ' paste data into memory
```

Sub PlotDataOpen(Optional file\$)...Open FSPlot data. Specify a complete file name (path & ext) or leave blank to activate a file open dialog.

```
PlotDataOpen "c:\winfilm\spectra\filter.csv"
PlotDataOpen      ' file dialog
```

Sub PlotDataPaste()...Paste tab-separated (Excel format) FSPlot data.

```
PlotDataPaste
```

Sub PlotDataSave(Optional file\$)...Save FSPlot data in Excel-compatible CSV format. Specify a complete file name (path & ext) or leave blank to activate a file save dialog.

```
PlotDataSave "c:\winfilm\spectra\filter.csv"  
PlotDataSave      ' file dialog
```

Sub PlotDelete...Delete last FSPlot spectrum.

```
PlotDelete
```

PlotLegend\$(1)...PlotLegend\$(12)...Set the text for FSPlot legends 1-12.

```
PlotLegend(1) = "Angle = 0°"
```

Sub PlotLegendOn(k As Boolean)...Turn plot legends on or off.

```
PlotLegendOn False  ' no plot legends  
PlotLegendOn True   ' use legends
```

Property PlotLegendSize%...Set FSPlot legend relative font size (50-150, 100 default)

```
PlotLegendSize = 110
```

Sub PlotNext...Add another graph to FSPlot window. Same as clicking the Plot button.

```
PlotNext
```

Sub PlotNoSave(k As Boolean)...Set k=True to prevent FSPlot settings from being re-stored in design1.ini. Useful for temporary changes.

```
PlotNoSave True  ' FSPlot settings not saved  
PlotNoSave False ' FSPlot settings saved (default)
```

Property PlotNumber%...Returns the current number of plots in the FSPlot Module. This is useful for assigning plot legend strings.

```
n = PlotNumber  
PlotLegend(n) = "Plot number " & Cstr(n)
```

Sub PlotOpen(file\$)...Open a binary FSPlot test image (.bin extension). This is intended mainly as a debugging tool.

```
PlotOpen "c:\Winfilm\Spectra\plot.bin"
```

Sub PlotReload...Reload FSPlot settings from design1.ini.

```
PlotReload
```

Sub PlotRun(Optional formula\$)...Run Plot Formula to modify FSPlot graphs. The formula should be thoroughly tested in the FSPlot Formulator (page 104) before being used in FilmStar BASIC code. If *formula\$* is blank or missing the Plot Formula currently in memory is utilized.

```
PlotRun      ' Run formula currently in memory  
PlotRun "B=if(A>=425 & A<=515, 100*B, B)"
```

Sub PlotSave(file\$)...Save FSPlot graphs to disk as a windows metafile or bitmap. *Include the full path and optionally add .wmf, .bmp, .png or .bin (test file) extension.* If no extension, file type depends on selection in FSPlot Setup. Use this routine to generate reports with multiple FSPlot graphs.

```
PlotSave "d:\winfilm\save1"
```

When creating complex documents with a series of graphs to be plotted later in the Report Generator use the following idea:

```

PlotSize 8000, 6500, 75 ' set graph size
For i = 1 To 10
    ' code to calculate designs and draw graph
    PlotSave "d:\winfilm\psave" & format(i,"00")
Next i

```

Sub PlotSize(width%, height%, csize%)...Assign FSPlot window size in twips (1440 twips = 1") in order to fix the graph size. This is useful when storing a series of graphs on disk. csize (50-300) is relative character size.

```

PlotSize 8500, 6500, 75

```

Property PlotSubTitle\$...Specify FSPlot secondary title.

```

PlotSubTitle = "Visit Princeton today!"

```

Property PlotTableGrid\$...String specifying table contents in grid format where columns are TAB delimited, rows are CRLF delimited. In the following sample code (generated in FSPlot via **File...Create BASIC Setup**) values such as "550 nm" need to be replaced by functions.

```

PlotTableGrid="Center "& vbTab & "550 nm" & vbCrLf & _
    "Maximum " & vbTab & "98.23 %" & vbCrLf & _
    "50% Bandwidth " & vbTab & "4.25 nm"

```

Property PlotTitle\$...Specify FSPlot main title

```

PlotTitle = "Fred is great!"

```

Sub PlotWindow(kState%)...FSPlot window: 0 normal, 1 min, 2 max

```

PlotWindow 0

```

Property Pol\$...Assign/get polarization; values are P, S or R (random). Capitalization is not important.

```

Pol = "S"

```

Many more DESIGN variables can be set with BASIC's SendKeys command. For example, the following sequence sets design wavelength to 1064 nm:

```

MainActivate ' set focus to Main Menu window
SendKeys "%dw1064{ENTER}", 1

```

Sub Replot...Replot current spectrum.

```

Replot

```

Sub ReportPrint...Print the current report without displaying it

```

ReportPrint

```

Sub ReportSave(file\$)...Save report (not displayed) as binary printer file; include path and extension.

```

ReportSave "c:\winfilm\reports\dwdm.bin"

```

Sub ReportShow...Preview report and optionally print it.

```

ReportShow

```

Property Review\$(k%)...Get Review Design screen. Format k = 1 to 3

```

s$ = Review(1)

```

Property RndNorm!...Generate pseudo-Gaussian random number. Use CalcRandSeed to repeat random number sequence.

```
v! = RndNorm
```

Sub SetCieAxes(xmin!, xmax!, xLbl!, yMin!, yMax!, yLbl!, Optional Toler\$, Optional xTarg!, Optional yTarg!)...Specify CIE axes range; optional tolerance box; optional target circle

```
SetCieAxes .2, .5, .05, .1, .6, .1
```

Sub SetCieMode(mode%, observer%, delta%)...*Mode 1: 1931 x,y; Mode 2: 1960 UV; Mode 3: 1976 L*U*V; Mode 4: 1976 L*a*b*; Observer 1: 2°; Observer 2: 10°; Delta (calculation interval in nm): 1 or 5.*

```
SetCieMode 2, 1, 5
```

Sub SetIlluminant(type%, degrees!)...Assign illuminant (and blackbody temperature in degrees Kelvin) for CIE color calculations. *Type* corresponds to the CIE Setup Parameters Illuminant list as follows: *Type 1* Black Body; *Type 2-11* Illuminants A, C, D50, D55, D65, D75, E (uniform), F2, F7, F11; *Types > 11* User .

```
SetIlluminant 1, 5500 ' 5500 deg blackbody  
SetIlluminant 6 ' Illuminant D65
```

Sub SetIndexCoeff(row%, col%, value!)...Assign index coefficient as in the Film Indices dialog

```
SetIndexCoeff 4, 1, 1.95
```

Sub SetIndexFile(row%, name\$)...Assign dispersive file name as in the Film Indices dialog

```
SetIndexCoeff 4, "TI02 Patinal 300C"
```

Sub SetIndexList(symb\$(), ntyp\$(), file\$(), desc\$())...Assign dispersive index list as in the Film Indices dialog. See Sub GetIndexList. Note that symb\$(1), symb\$(2), ntyp\$(1), ntyp\$(2) are not used.

Sub SetLayers(thick!(), type\$())...Assign layer thicknesses and material types. This can also be done with Design = s\$

```
Redim q!(1 to 2), qt$(1 to 2)  
q(1) = .25: qt(1) = "H"  
q(2) = .25: qt(2) = "L"  
SetLayers q(), qt()
```

Sub SetLayersIgnore(s\$)...Assign layer numbers to be ignored during calculations. Blank removes all ignores. This facility helps users plan strategies for broadband optical monitors.

```
SetLayersIgnore "1-3,8,10-12" ' ignore 1,2,3,8,10,11,12  
SetLayersIgnore ' remove all ignores
```

Sub sMsgBox(text\$, icon%, title\$)...Similar to BASIC's MsgBox instruction but will be modal within FilmStar DESIGN. This prevents covering the dialog box by clicking on the DESIGN window.

```
sMsgBox "Get a cup of coffee!", 48, "Working Hard"
```

Function SpecTargets(kNew As Boolean, Type\$, Tol, Angle, Pol\$)... Convert spectrum to opti targets; kNew=0 supplements existing targets. Type\$ = "R", "T", "V" (reverse reflectance), Pol\$ = "P", "S", "R".

```

If SpecTargets(True,"R", 1, 45, "R") Then
    DoSomething
End If

```

Property Spectrum_X As Variant...Assign/get spectral X values (wavelength or angle depending on Setup Parameters)

Property Spectrum_Y As Variant...Assign/get spectral Y values (reflectance, transmittance, etc.)

```

' Transferring spectra from DESIGN
Option Base 1
DefInt I-N
DefSng A-H, 0-Z
Sub Main
    ReDim xd(1), yd(1, 1) ' MUST BE 'SINGLE'
    xd = Spectrum_X ' Get X values
    yd = Spectrum_Y ' Get Y values
    For i = 1 To UBound(xd) ' Rows
        Debug.Print xd(i)
        For j = 1 To UBound(yd, 2) ' Columns
            Debug.Print yd(i, j)
        Next j
    Next i
End Sub

' Transferring spectra to DESIGN
Option Base 1
DefInt I-N
DefSng A-H, 0-Z
Sub Main
    ReDim xd(17), yd(17, 2) ' MUST BE 'SINGLE'
    For i = 1 To Ubound(xd)
        xd(i) = 400 + 25*(i - 1)
        yd(i, 1) = .3 + .02*(i - 1)
        yd(i, 2) = .5 - .01*(i - 1)
    Next i
    Spectrum_X = xd ' Set X values
    Spectrum_Y = yd ' Set Y values
End Sub

```

Sub StatusLabel(s\$)...Display label in status window.

```
StatusLabel = "Visit Princeton soon"
```

Property StopCalc As Boolean...Default True; set False to prevent DESIGN from responding to Windows messages.

```
StopCalc = False
```

Property SubThick!...Assign/get current substrate thickness, as defined in Setup Parameters, in mm.

```

s! = SubThick
SubThick = 2.5

```

Property SubType\$...Assign substrate calculation type “D” (dielectric) or “M” (metal), as defined in Setup Parameters. *This applies to the case where only the substrate is absorbing.* Selecting “D” speeds up calculations for filter glass substrates coated with dielectrics.

```
SubType = "D"
```

Property SynElements\$...Assign/get synthesis layer elements utilized in genetic and flip-flop synthesis. The string is equivalent to the entries in the synthesis dialog. The format of SynLayers is as follows:

```
SynElements = ".05H" & vbCrLf & ".05L" & vbCrLf
```

As shown here, one use (with SynLayers) is to split layers into thinner layers for further synthesis.

```
Sub Main
  Dim d$, s$
  d$ = Design
  d$ = Replace(d$,".05H", ".025H .025H")
  d$ = Replace(d$,".05L", ".025L .025L")
  Design = d$
  s$ = SynElements
  s$ = ".025H" & vbCrLf & ".025L" & vbCrLf & s$
  SynElements = s$
  SynLayers = NumLayers
  Busy False
End Sub
```

Property SynLayers...Assign number of layers to use in genetic and flip-flop synthesis.

```
SynLayers = NumLayers
```

Sub TargetsCopy...Copy optimization targets to clipboard.

```
TargetsCopy
```

Sub TargetsPaste(Optional s\$)...Paste optimization targets from clipboard or from optional TAB & CRLF delimited string.

```
TargetsPaste
TargetsPaste s$ ' use string s$ instead of clipboard
```

Sub TargetsSelect(wMin!, Optional wMax!, Optional Types\$)...Select targets in range wMin to wMax (optional) with optional type Types\$ (R reflectance, T transmittance, V reverse reflectance). wMin and wMax are in current wavelength units.

```
TargetsSelect 500           ' all targets at 500 nm
TargetsSelect 500, 650     ' all targets 500-650
TargetsSelect 500,, "RV"   ' R & V targets 500 nm
TargetsSelect 500, 650, "RV" ' R & V targets 500-600
```

This subroutine makes it possible to isolate particular targets, as in wavelength by wavelength n,k determination. Use FileOpen or TargetsPaste to restore targets to the original table for further selecting.

Sub TargetsShow...Display optimization targets.

```
TargetsShow
```

Property Template\$...Assign/get Report Generator template. This should be done before showing or printing the report.

```
s$ = "<<Name Arial>><<Size 24>>" & Chr$(13) & Chr$(10)
Template = s$ & "FilmStar for Windows"
k = Macro("ShowReport;")
```

Use BASIC's file capabilities to load templates from disk:

```
Open "c:\fstemp\catalog.txt" For Output As #1
Print #1, Template
Close #1

Open "c:\fstemp\catalog.txt" For Input As #1
Template = Input$(Lof(1),1) ' do not add '$' here
Close #1
k = Macro("PrintReport;")
```

Property Tooling\$...Assign values shown in Tooling Factors dialog. Useful for evaluating and optimizing designs averaging over angle and thickness distribution, as in curved reflectors.

```
Tooling = "1.05 1.06 1.10"
Tooling = "" ' sets all values to 1.0
```

Property TypeContour%...Assign mode for contour data: 0 matrix, 1 triplets

```
TypeContour = 1
```

Property TypeDataCopy%...Assign spectra copy/paste format: 0 0-1, phase radians; 1 0-100%, phase degrees

```
TypeDataCopy = 0
```

Property TypeDataFile%...Assign spectra file format: 0 .csv, 1 .dx, 11 .dx for P-E, 100 .csv for Excel

```
TypeDataFile = 1
```

Property TypeSide2%...Assign Side 2 (uncoated substrate surface) compensation: 1 Forward, 2 Forward + Side 2, 3 Reverse, 4 Reverse + Side 2, 5 Forward + Side 2 in transmittance

```
TypeSide2 = 1
```

Property TypeWaveCopy%...Assign Spectra copy/paste wavelength format: 0 nm, 1 current units

```
TypeWaveCopy = 1
```

Property UserName\$...Get/assign User Name (set in File...Configuration... Directories)

```
S$ = UserName$
UserName$ = "Bill Clinton"
```

Property UUID\$...Returns UUID (Universal Unique Identifier) for use in XML files.

```
Debug.Print UUID$ gives (at one moment in time)
3C02DD00-699D-4203-A5CD-C64345FC0FF7
```

Sub WaitTillReady()...Wait in a loop until the Main Menu gets the focus. This prevents a BASIC program from proceeding when other DESIGN windows

are activated. The following code changes the color scale to 1976 CIE L*U*V*, closes the CIE Color Module and returns to the Main Menu.

```
MainActivate
SendKeys "^c^p{HOME}{DOWN}{DOWN}%o%{F4}", 1
WaitTillReady
```

Property WaveUnit\$...Get current wavelength unit: *N* nm, *M* μm, *E* cm, *A* Ångstroms, *C* 1/cm, *G* GHz, *T* Thz

```
S$ = WaveUnit$
```

Sub WbActivate...Activate the FilmStar Workbook. This is similar to pressing [F3] from the Main Menu except that the Auto Open Group is disabled.

```
WbActivate
```

Sub WbClear(cells\$)...Clear cells with address or named region cell\$. If more than one worksheet is open, use a unique named region or specify the worksheet to ensure the correct cell is cleared.

```
WbClear "B14:D28" or
WbClear "Sheet7!Average" ' specifies worksheet
```

Sub WbCopy(cells\$)...Copy contents to clipboard.

```
WbCopy "B14:D28" or
WbCopy "mtable.xls!Average"
```

Sub WbCloseAll...Close all open worksheets. This occurs instantly without prompting to resave changed sheets.

```
WbCloseAll
```

Sub WbExecute(Optional cmd\$)...Run Workbook macro command. If optional cmd\$ is blank or missing then use macro defined in Workbook.

```
WbActivate ' make sure that Workbook has focus
              ' (not required for hidden Workbook)
WbExecute "Angle 45 P;Calculate;Angle 45 S;Calculate;"
WbExecute ' run the macro defined in Workbook
```

Sub WbExit...Close the Workbook.

```
WbExit
```

Function WbGetNum(cell\$)...Get number from a spreadsheet cell. If you use cell references instead of a named region and if more than one sheet is open, be sure to include the name of the sheet as shown below. Be sure that any cell name you specify actually exists!

```
v! = WbGetNum("Average") ' look in all open sheets
v! = WbGetNum("mtable.xls!Average")
v! = WbGetNum("mtable.xls!g23")
```

Function WbGetText(cell\$)...Get text from a spreadsheet cell. (See WbGetNum for remarks about cell names.)

```
s$ = WbGetText("PassOrFail")
```

Function WbOpen%(file\$)...Open worksheet. Include path and extension. More than one worksheet can be opened. Returns -1 (true) if successful. *Note that this was Sub WbOpen prior to Version 1.8.*

```
k = WbOpen(PgmPath & "\\workbook\mtable.xls")
```

Function WbOpenHidden%(file\$)...Open hidden worksheet. Include path and extension. Only one worksheet can be opened. Returns -1 (true) if successful. Hidden worksheets enable users to do looping calculations without annoying flicker and about 250% faster.

```
k = WbOpenHidden(PgmPath & "\\workbook\mtable.xls")
```

Sub WbOptimize...Optimize in the Workbook. *The Workbook Macro cannot contain BasRun, BasExec or BasChain commands when triggered from this subroutine.* The following displays the Workbook

```
WbOpen "c:\Winfilm\Workbook\OptiTest.vts"  
WbOptimize
```

While the following hides the Workbook

```
WbOpenHidden "c:\Winfilm\Workbook\OptiTest.vts"  
WbOptimize
```

Sub WbPaste(cell\$)...Paste contents of clipboard.

```
WbPaste "C1"
```

Data can be transferred from one worksheet to another as follows:

```
WbCopy "mtable.xls!b4:b6"  
WbPaste "sheet7!a1"
```

Sub WbRecalc...Recalculate all open worksheets.

```
WbRecalc
```

Sub WbResetLoop...Resets Worksheet Data Loop. Useful for hidden worksheet calculations using multiple data columns.

```
WbResetLoop
```

Sub WbSetFormula(cell\$, text\$)...Set formula in a spreadsheet cell. Cell location or defined name can be used. Note that the equal sign is not included in the expression for the formula.

```
WbSetFormula "Average", "AVERAGE $C$3:$C$45"  
WbSetFormula "$C$5", "AVERAGE Reflectance"
```

Sub WbSetName(name\$, range\$)...(Re)assign Workbook defined name. Especially useful for moving DataMarker in complex models requiring multiple spectral ranges. Reassigning DataMarker resets data looping. Note that there is a DDE macro version of this command.

```
WbSetName "DataMarker", "$A$100"  
WbSetName "DataMarker", "Test2.vts!$A$100"
```

Sub WbSetNum(cell\$, value!)...Set numerical value in a spreadsheet cell. Cell location or defined name can be used.

```
WbSetNum "StdDeviation", 1.45  
WbSetNum "$C$5", 1.45
```

Sub WbSetText(cell\$, text\$)...Set text in a spreadsheet cell. Cell location or defined name can be used.

```
WbSetText "Name", "Edgerstoune Optics"  
WbSetText "$C$5", "Edgerstoune Optics"
```

Sub WbWindow(kState)...Set Workbook window state: 0 normal, 1 min, 2 max

WbWindow 0

Sub WriteIniString\$(section\$, key\$, text\$)...Store user-define initialization variables in design1.ini.

WriteIniString "Chuck Vogel", "LastFileName", "WW098909"

inserts/modifies the following entry in design1.ini:

[Chuck Vogel]

LastFileName=WW098909

FilmStar Workbook

The Workbook is an Excel-compatible programmable spreadsheet (Microsoft Excel not required) for calculations and optimization. This offers great flexibility in setting up optimization problems. The Workbook also supports user-defined dispersive index functions, but these are rarely required.

The Workbook contains worksheets and menu commands. Each worksheet has its own file. For convenience, several worksheets can be loaded in a group. A group could contain the main calculation worksheet, an index function worksheet, and an illuminant worksheet. Most Excel 5.0 spreadsheet formulas are supported and the Workbook is integrated with FilmStar BASIC (page 73) and the Report Generator (page 105).

File Menu

Most commands will be familiar to spreadsheet users. Worksheet files can be loaded and saved in native .vts or Excel 5.0/95-compatible .xls format. Worksheet files can be saved in groups and loaded with hot-keys <Shift+F1>...<Shift+F4>.

Microsoft Excel files saved in 5.0/95 format can be opened in the FilmStar Workbook. Features from newer Excel versions, such as multiple sheets, are not supported.

Open Worksheet Groups...Edit Groups <Ctrl+G>

This leads to the Edit Worksheet Groups dialog box.

Group Name...Assign a name to appear in the Open Worksheet Groups menu alongside the hot-keys <Shift+F1>...<Shift+F4>.

Files in Group...Click on a file name to place it in the **File Name** editor or remove the file from the group by pressing **Delete File**.

File Name...Typing in this text box activates the **Add File** button.

Printer Setup

Headers and footers can contain text and special formatting codes as follows:

&L	Left-aligns the characters that follow
&C	Centers the characters that follow
&R	Right-aligns the characters that follow
&D	Prints the current date
&T	Prints the current time
&F	Prints the worksheet name
&P	Prints the page number

The following font codes must be placed before the preceding ones.

&B Bold
&I Italic
&"fontname" Use the specified font
&nn Use the specified font size (2 digit number)

Evaluate Menu

Execute Macro <F8>

Execute DESIGN commands contained in a worksheet cell or group of cells with defined name *Macro*. Functions are identical with those listed under "Macro Reference (DDE)" on page 63. The same macros are automatically executed during optimization or tolerancing. Note that similar macros are available in the Main Menu and can be run from "" on page 73.

Reset Data Loop <Ctrl+F8>

If looping is enabled (see *Data Type* below) multiple calculations are placed in adjacent worksheet columns. Users can then develop functions of several spectra. This command resets column position to the first column.

Recalculate <F9>

Only the active window is recalculated. Recalculation is automatic during optimization and tolerancing.

Auto Recalculate

Recalculation of all open windows is automatic if this entry is checked. During optimization and tolerancing, however, windows are automatically recalculated and this entry can be left unchecked. This could provide some speed improvement since intermediate calculations are suppressed.

Optimize Menu

Workbook optimization is independent of any optimization targets defined in the Main Menu. See the following section Defined Names for further information. Optimization variables, however, are the same.

Formulas

Many Excel-compatible formulas are supported in the FilmStar Workbook. An A-Z Function Reference is provided in help file *wbfs_az.hlp*. This file may be accessed from the FilmStar Workbook by clicking **Help...Function Reference <Ctrl+F1>**. Note that Workbook models developed for fixed wavelength or angle ranges will be far simpler than models which allow any range.

Defined Names

A worksheet communicates with DESIGN's calculation and optimization routines through eight special reserved defined names:

Constraint, DataMarker, DataType, Design, Macro, Objective, Passed, Yield

These are assigned to a worksheet file with **Edit...Defined Names**.

Special reserved names must be in a single worksheet.

When a worksheet is utilized for index functions, user-defined cell names are referenced in **Setup...Index Functions**. Index functions are normally defined in a separate worksheet, not the worksheet containing *DataMarker*.

Constraint

The NOL gradient optimizer used by the FilmStar Workbook supports multiple linear and nonlinear constraints. *Constraint* has N rows and two columns where N is the number of constraints. The first column includes constraint formulas and the second includes constraint types. Constraint types are as follows:

- 2 Linear equality constraint
- 1 Nonlinear equality constraint
- 1 Nonlinear inequality constraint
- 2 Linear inequality constraint

In the illustrative BBAR example we design an AR coating with three thickness constraints given in {G5:H7}.

1. Total thickness < 225 nm {G5=F17-225, H5=2}
2. Layer 1 = Layer 2 {G6=F12-F13, H6=-2}
3. Layer 3 = Layer 4. {G7=F12-F13, H6=-2}

DataMarker

	A	B	C	D	E	F	G	H
1	DataType	0	Macro	LAYERSCOPY;	CALCULATE;			
2								
3								
4	DataMarker				Objective		Constraint	
5	450.00	0.017	0.983	Average=	0.53008		-0.000	2
6	460.00	0.010	0.990	Max=	2.45529		0.000	-2
7	470.00	0.006	0.994				0.000	-2
8	480.00	0.003	0.997		Passed			
9	490.00	0.001	0.999		FALSE			
10	500.00	0.001	0.999					
11	510.00	0.001	0.999		Design			
12	520.00	0.001	0.999		18.4H	18.40		
13	530.00	0.001	0.999		18.4L	18.40		
14	540.00	0.002	0.998		94.06H	94.06		
15	550.00	0.002	0.998		94.06L	94.06		
16	560.00	0.002	0.998					
17	570.00	0.002	0.998	Total Thickness=	224.92			

Workbook containing worksheet BBAR.XLS. Named regions shown in yellow.

During evaluation and optimization the Workbook calculates required spectra in DESIGN. The spectrum is subsequently transferred to the active worksheet below the *DataMarker* cell as shown in the BBAR example. Data transfer is automatic whenever the Workbook is activated by pressing <F3> or by clicking on it.

If *DataMarker* is not defined, users can paste spectral data manually by copying the data to the clipboard in DESIGN (**Spectra...Copy Data <Ctrl+C>**) and pasting it in the Workbook with **Edit...Paste <Ctrl+V>**.

DataType

This integer contains the following bit values: *Format* Bit 0
(+1) Formatting enabled
Loop Bit 1 (+2) Looping enabled
Phase Bit 2 (+4) Phase values included when bit 0 = 0
One Column Bit 3 (+8) Paste one data column (mode dependent)
No Paste Bit 4 (+16) Suppress data auto-pasting
No Constraint Bit 5 (+32) Disable constraints
PhaseSmooth Bit 6 (+64) Smooth phase column (radians)

	A	B	C	D	E
1	DataType 1				
2					
3	Wave (nm)	% Refl	% Trns		
4	450.000	0.24687	99.75313		
5	460.000	0.14474	99.85526	Average	0.19
6	470.000	0.13258	99.86742	Maximum	0.33
7	480.000	0.15336	99.84664		
8	490.000	0.17710	99.82290	Passed	TRUE
9	500.000	0.19164	99.80836		

Automatic column labels in formatted worksheet.

Formatting adds labels and displays percent values for R and T. The *DataMarker* cell now contains the label 'Wave (nm)'.

Looping makes it possible to utilize multiple spectra in the Workbook. Each time the Workbook is activated the new spectrum is pasted to the right of the previous one. To start again, click **Evaluate...Reset Data Loop <Ctrl+F8>** before deactivating the Workbook and returning to the Main Menu.

Looping is automatically enabled when macros are run. If the macro includes multiple calculations, spectra are automatically pasted into adjacent columns without having to set *DataType* bit 1. It is not necessary to include a zero *DataType* cell in a worksheet. If it is missing, it is the same as 0.

Two calculated columns plus the wavelength column are normally pasted into the worksheet at *DataMarker* each time it is activated. Additional calculated columns corresponding to reflected and transmitted phase shift (radians) are available by setting *DataType* bit 2 (+4). This only works when formatting is disabled (bit 0 = 0). If bit 4 (+16) is set, spectral data is not automatically pasted into the Workbook when it is activated. Set *DataType* bit 5 (+32) to (temporarily) disable any constraints.

Design

It is sometimes useful to include layer thicknesses in Workbook calculations. Layers mode designs are automatically pasted into a worksheet by executing macro command *LAYERSCOPY* from a worksheet which includes defined name *Design*. In the 'bbar.xls' example *Design* is defined as cell {E12}; it could also be defined as {E12:E15}.

Macro

A worksheet can 'send' commands to DESIGN. Commands are listed under "Macro Reference (DDE)" on page 63. Commands can be grouped in one cell

{D1="LAYERSCOPY;CALCULATE;" } or in a single column (easier to read). Each command is terminated with a semicolon. Macro commands must be assigned defined name *Macro*.

Macros are automatically executed each time the optimizer or tolerancing module calls DESIGN's calculation routines. Click **Evaluate...Execute Macro <F8>** to run command macros manually. When macros containing multiple *CALCULATE* or *CALCPLOT* commands are run, spectra are automatically pasted into adjacent columns.

While there is no macro language in the Workbook itself, it can be accessed from FilmStar BASIC.

Objective

The objective (merit function) is a mathematical expression for the performance of the coating. It may be the only expression (unconstrained problem) or it may be combined with constraint conditions. In the illustrated sample worksheet 'bbar.xls', we minimize average reflectance {E5} subject to constraints expressed in {G5:H7}.

When there are NO constraints, optimization may be terminated early by pressing <Esc>. With constraints, early termination might result in loss of the best design.

Passed

A logical function evaluating to *TRUE* if the spectrum passes some specification and *FALSE* if it fails. In 'bbar.xls' *Passed* {E9} is defined as

$$=AND(E5<0.005, E6<0.01) .$$

The coating passes if the average is less than 0.5% and maximum less than 1.0%. This allows users to set up tolerancing problems in the Workbook.

Yield

Used in conjunction with *Passed*. Provides a tally in % of the number of passes divided by the number of iterations.

CIE Color Module

The CIE Color Module provides facilities for evaluating and optimizing color coatings where there is a single color specification. More complex cases (*i.e.* color requirements in reflection *and* transmission or color requirements over an angle range) can be set up in the Workbook. The module is activated from the Main Menu by clicking **Evaluate...CIE Color <Ctrl+F9>**. To exit the module, click on the Main Menu or press <Esc>. Close the module with <Alt+F4>.

There is no need to set Graph Axes for the CIE range 380-780 nm when using the Color Module. It is not necessary to calculate a spectrum before accessing the module.

Colors displayed in the module's status area are approximate and should never be used as a basis for color specifications.

Module parameters, including color optimization targets, are stored with the thin film design.

Setup Menu

Parameters <Ctrl+P>

Modes...Four calculation modes are current supported: CIE 1931, CIE 1964, CIE 1976 L*U*V*, and CIE 1976 L*a*b*.

If you change modes you can get the 'Overflow' error because displayed graph axes are out-of-range for the new calculation. Fix this by adjusting graph axes.

Observer...2° and 10° observers may be selected.

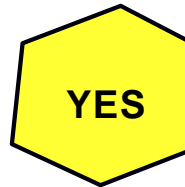
Illuminant...Black body and illuminants A/C/D50/D55/D65/D75/E plus fluorescent F2/F7/F11 are included. Users can define any number of additional illuminants as ASCII files stored in the DESIGN program directory (usually \winfilm). Each file includes a single column of numbers giving the relative intensity from 380 to 780 x 5 nm (or 1 nm). Illuminant descriptions and corresponding file names are entered in design1.ini as described in "Configuration - Preferences" on page 28.

User-illuminant files are defined from 380 to 780 x5 nm or x1 nm intervals. There must be 81 or 401 entries.

Calculation Interval...An interval of 5 nm is sufficient for most color calculations. When 1 nm spacing is specified, the module generates 1 nm tables from 5 nm CIE data. The finer interval will only be required if there are exceptionally sharp spectral features in the filter. If there are sharp spectral features in the source, users can construct 1 nm user-illuminant files. (1 nm illuminant files can be utilized in 5 nm calculations.)

Tolerance Box...Acceptability polygon for tolerancing. Color coordinates pass the specification if they are in the box. Enter coordinates in clockwise order for each point describing a convex polygon. Coordinates are comma and line separated as shown. A convex polygon is shown at the left; the concave polygon (one or more sides with internal angle > 180 degrees) will not work.

.27 , .27	↑
.29 , .33	
.33 , .33	
.31 , .27	↓



Use Current Spectrum

Check this command to utilize the spectrum currently in memory rather than the calculated spectrum. This also adds **Spectrum Open** and **Spectrum Paste** commands under **Evaluate**, making it unnecessary to return to the Main Menu for these commands. The current spectrum must encompass the range 380-780 nm x 1 or 5 nm interval (*i.e.* 350-800 nm x 1 nm).

Evaluate Menu

Calculate <F9>

Click if the module fails to recalculate automatically. If you don't see coordinates drawn as a circle, try **Draw New Axes <Ctrl+A>** followed by <F9>. If **Setup...Use Current Spectrum** is checked, the calculation uses the current spectrum; that is, no new thin film calculation takes place.

Tolerancing...Values <Ctrl+N>

This brings up the same Tolerancing dialog as in the Main Menu and Worksheet. If no tolerance box is defined in CIE Setup Parameters, a scatter plot is still obtained, but yield will not be computed.

Optimize Menu

Optimize <Ctrl+O>

During optimization progress is shown on screen. As with all constrained problems, it is recommended that you allow optimization to proceed to its conclusion. Termination by pressing <Esc> could result in the loss of the best design.

Targets <Ctrl+T>

Color optimization targets are independent of the optimization targets defined in the Main Menu.

The NOL gradient optimizer attempts to maximize or minimize photopic response Y (or L* for L*U*V*, L*a*b*) in reflection or transmission while simultaneously meeting CIE color coordinate constraints. Fixed Y, L* values (0-100) are also permitted. Color constraints may be disabled in order to design coatings only meeting photopic response requirements.

If **Minimize (Maximize) Average** is checked, the unweighted average over wavelength range 400-720 is utilized.

FSPlot Graphing Module

The FSPlot Graphing Module creates publication-quality graphs for proposals, reports and publications. It has its own memory and can store spectra independent of the main program. FSPlot graphs may be combined with text in the Report Generator (page 105).

After calculating a spectrum (vs. wavelength or angle) in the Main Menu, click **Tools...FSPlot Module <F4>** to activate the graphing module. Click **Plot** and the graph is replotted. Each spectrum must have exactly the same horizontal axis values. This can be a problem when importing data from disk files. Use **Convert Table** in the Spectra Menu (page 52) to equalize horizontal axis spacing.

File Menu

Save As <F12>

Save the graph as a Windows metafile (.wmf) or bitmap (.bmp, .png). This can then be imported by word processors or graphics programs. Use PNG (Portable Network Graphics) for web graphics; bitmap (.bmp) files are large and should not be posted to web sites or sent as e-mail attachments.

Copy <Ctrl+C>

Copy to the clipboard. The image can be pasted into word processors or graphics packages. The image will be a metafile (vector) or bitmap according to *Graphics Mode* setting.

Bitmap Size

This enlarges the bitmap (PNG recommended) to match printer resolution.

Create BASIC Setup

Creates FilmStar BASIC code describing the current FSPlot configuration. The code is copied to the clipboard for pasting into the BASIC editor.

Reload Setup

Reloads the FSPlot configuration stored in design1.ini. This is useful if you have temporarily changed colors and wish to return to a standard format.

Disable Save

Normally the current FSPlot configuration is stored in design1.ini upon exiting FilmStar DESIGN. Check this box to disable that function. Save can also be disabled by setting *PlotNoSave=True* in FilmStar BASIC.

Setup Menu

Once a format (including the size of the FSPlot window) is decided upon, it is saved upon leaving DESIGN. Try a dark background for 2x2" slides. For monochrome printing, enabling Grays may be preferable to Patterns. The lack of thick patterned lines is a Windows limitation.

Plot %T + OD

This mode is supported when Optical Density is selected in Setup Parameters. Here the left hand axis is $T = 0-100\%$ while the right hand axis is optical density according to Graph Axes settings. When switching this mode it may be necessary to close and reopen the FSPlot Module. This label for this option varies according to program conditions.

Transmittance Format

When the vertical axis is transmittance, there are options for two Schott diatomic scales 0-1 and 0-100% in addition to the 0-100% linear scale. This format makes it easy to visualize both passband and blocking regions.

Legends

Legends and a subtitle are added to the graph in the Graph Legends editor. Note that subtitle font size is fixed relative to title font size.

Table

A table annotation can be added to the graph. This is used to display summary calculated results in a convenient format. As such, it is normally used in conjunction with FilmStar BASIC.

Graph Details <Ctrl+H>

This dialog provides a vast number of customization options, including the possibility of web and PowerPoint graphics. One interesting possibility is to utilize RGB values for line colors. An updated graphics engine was implemented in DESIGN 2.60.0000. This may effect line thicknesses in graphs created by earlier versions.

View Menu

This menu enables users to turn off Annotations (page 102) and Legends.

Group Legends

If left and right y-axes are specified (*Plot %T + OD etc.*) it makes sense to use the same colors in each set of two data plots (6 Legends maximum). *Be sure*

to enter *every other legend* (odd rows) in the Graph Legends dialog box. Legends are not grouped if there is only one plot set.

Zoom Mode <Ctrl+Z>

Check this setting makes it possible to zoom into an area of interest via a mouse-controlled bounding box.

Data Menu

File and clipboard operations make it possible to load and save data associated with multiple plots. Data is saved in Excel-compatible .csv format (no header).

Formulator (page 104) <Ctrl+F>

Create and edit a Plot Formula for arithmetic operations on displayed data sets. The Plot Formula is stored with Graph Axes or FILM Archive.

Run Formula <Ctrl+R>

Apply an existing Plot Formula to the displayed data. Doing this twice in a row can have unwanted consequences. If that happens and only one data set is being used, click **Delete #1** and **Plot** to recover the original graph.

Annotations

Annotations (stored with Graph Axes) may be added to FSPlot graphs. This is especially useful for quality control. Note that Annotations are not currently supported for plots where the horizontal axis is thickness.

graph x, y, type, text, color... Draw lines and place text anywhere. When drawing a series of lines *text* is blank and at two or more *graph* statements are required. The first *graph* statement uses the following *type* values:

Thin solid = 38; Dash = 39; Dot = 40
Dash dot = 41; Dash dot dot = 42
Medium solid = 43; Thick solid = 44

Subsequent *GRAPH* statements in a line series use the following *type* value:

Continue line = 45

Other values of *type* add text with numerous optional symbols. Some of these types are indicated below. Other values may be determined by examining the annotation after using the Annotator.

0 none; 1 plus; 2 cross; 4 solid dot; 6 solid square;
37 pointer

Color values are correspond to RGB values 0 to 16777215. This is different from older versions which allowed 16 colors. Older versions are automatically converted, as indicated by header line *VERS2*.

In the example below, *a-d* define the first series of lines, and *e-h* define the second line series. Note that the left-hand axis is used for coordinates *x, y*.

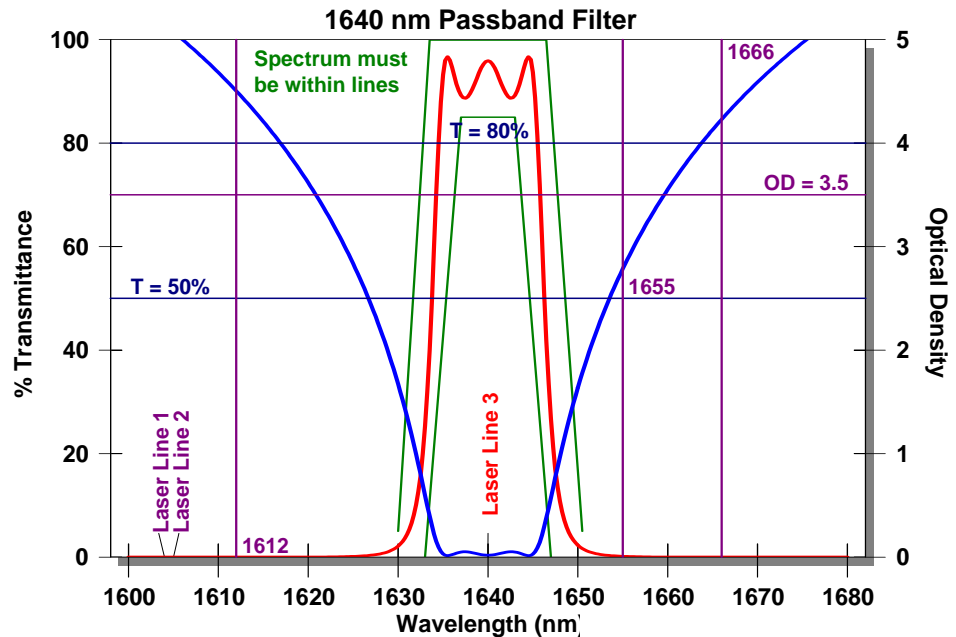
hline y, type, text, color... Draw a horizontal annotated line. Line *type* is as follows:

Thin solid = 0; Dash = 1; Dot = 2
Dash dot = 3; Dash dot dot = 4
Medium solid = 5; Thick solid = 6

In the example below, *k* illustrates the use of *hline*. Colors are as listed above under *graph*.

vline x, type, text, color...Draw a vertical annotated line. Line *type* is as listed above for *hline*. Illustrated in the example below in lines *l,m*.

xaxis x, text, color...Label special positions on the horizontal axis. As illustrated below in *n,o* closely spaced laser lines can be marked without overlapping text. A similar **yaxis** statement is also available.



Note that letters *a*...*s* just identify statements and are not actually included in the annotation editor. Do not remove the header line *VERS2* or *VERS3*.

VERS2

- a. graph 1630, 5, 43,, 32768;0
- b. graph 1633.5, 99.9, 45,, 32768;1
- c. graph 1646.5, 99.9, 45,, 32768;2
- d. graph 1650.5, 5, 45,, 32768;3
- e. graph 1633, 0, 43,, 32768;4
- f. graph 1637, 85, 45,, 32768;5
- g. graph 1643, 85, 45,, 32768;6
- h. graph 1647, 0, 45,, 32768;7
- i. graph 1614, 94, 0, Spectrum must, 32768;8
- j. graph 1614, 89, 0, be within lines, 32768;9
- k. hline 70, 5, |rOD = 3.5, 8388736;0
- l. hline 80, 5, |cT = 80%, 8388608;1
- m. hline 50, 5, |T = 50%, 8388608;2
- n. vline 1612, 5, |b 1612, 8388736;0
- o. vline 1655, 5, |c 1655, 8388736;1
- p. vline 1666, 5, |t 1666, 8388736;2
- q. xaxis 1604, Laser Line 1, 8388736;0
- r. xaxis 1605, Laser Line 2, 8388736;1
- s. xaxis 1640, \\\Laser Line 3, 255;2

Hline labels are justified with codes |L (left outside), |l (left inside), |c (center), |r (right inside) and |R (right outside) where "|" is the pipe symbol (shift backslash). *Vline* labels are justified with codes |B (bottom outside), |b (bottom inside), |c (center), |t (top inside) and |T (top outside).

As illustrated in *s*, backslashes ("\") in *text* fields are converted to spaces. In addition reverse quotation marks ("`) are converted to commas.

The system automatically adds a semicolon and index number to each annotation. This identifies the annotation to the Annotator.

Annotator

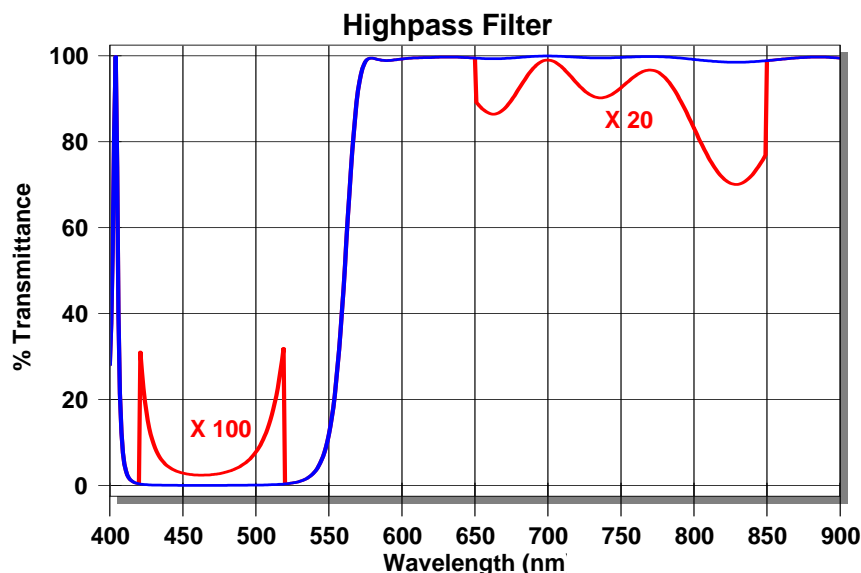
As an alternative or supplement to manual entry, annotations can be added and edited interactively. You can also use the Annotator to edit annotations previously entered manually.

Click on the FSPlot graph region with the left mouse button to bring up the Annotator dialog box. Note that mouse x,y coordinates are automatically transferred. The annotation is actually added when **Add** is clicked. Once the annotation is drawn, return to the graph region and locate it with the mouse. Observe that the cursor changes to a hand shape. Now click again and note that the **Add** button has been changed to a **Replace** button. In addition a **Delete** button becomes visible.

To draw line segments select **Type New Line Segment** and click **Add**, followed by one or more *Continue Line Segments*, clicking **Add** for each new segment. To add temporary annotations (not stored with Graph Axes), clear the **Permanent** check box. In the annotation editor temporary annotations include a tilde ("~") before the annotation line.

Formulator

The FSPlot Formulator modifies data displayed in graphs. Typical applications might include manipulating data values to show detail, averaging curves, plotting difference between curves, etc.



After plotting all required curves, click **Edit...Formulator (Ctrl+F)** in the FSPlot Module. Enter an appropriate formula and click **Apply**. Examine the data in the grid as well as the FSPlot graph; if incorrect click **Revert** to restore the original data array. Finally, click **Close** to exit. In the illustrated example the following formula is used:

```
C=B;  
B=if(A>420 & A<520, 100*B, if(A>650 &  
A<850, 100-(100-B)*20, B))
```

Multiple formulas are separated by semicolons (;). Letters refer to columns A-M (A is wavelength, B is first data set, etc.). The following operators are supported

```
+ Addition  
- Subtraction  
^ Exponentiation  
* Multiplication  
/ Division  
& Logical And  
| Logical Or
```

The following functions are also supported:

```
if(X,Y,Z) If X is true Y is returned, otherwise Z is returned  
abs(Y) Absolute value
```

Special operator *del* deletes unwanted data columns

```
del C Remove column C
```

For example

```
D=.5*(B+C);del B;del B
```

yields columns A and B where B is the average of the two original columns A and B. Note that *del* is always used at the end of a formula.

Report Generator

Using ComponentOne's VsPrint7.ocx module the Report Generator combines text and graphics in multi-page documents. The Report Generator interacts with the FSPlot Graphing Module (page 100), FilmStar BASIC (page 73), and FilmStar Workbook (page 94) to provide great flexibility and many options. It is possible, for example, to publish an entire catalog of filter designs with a single keystroke.

While the Report Generator is not a word processor, it provides many word processor printing features including print preview. Reports may be saved in three formats: binary (.prt) for reprinting in FilmStar, Adobe Acrobat (.pdf), and rich text (.rtf). Rich text may be opened in MS Word and resaved in .doc format.

Report Setup

The options in this dialog box are the default format options for the report. Options can be changed throughout the document by using formatting field codes in the Template.

Header/Footer

Headers and footers are composed of three sections separated by pipe characters ("|"). The first section is left-justified, the second is centered, the third is right-justified. A page number field is embedded by including the

code "%d" in the text; use code "%d/n" to add total number of pages (*i.e.* Page 3/7). In the following example the second section is blank:

```
FilmStar Report Generator | | Page %d/n
```

In the next example only the second section is used:

```
| FilmStar Report Generator Page %d/n |
```

Headers and footers use default report fonts which can be changed by clicking **Fonts**. In the header or footer fonts are printed italic if the default font is not italic, and vice-versa.

Margins & Line Spacing

Margins are in inches or mm. Line spacing is expressed as percent of font size. Margins should be the same throughout any document.

Metric Paper

When metric paper is selected, margins and some other length settings will be in mm instead of inches.

Color Printer

This toggles whether the print preview shows colors. Memory is saved by displaying monochrome graphics. It does not affect the actual printout.

Auto Preview

This toggles whether print preview is updated automatically whenever conditions are changed. When disabled a **Preview** button appears in the Report Generator main menu.

Show Graphics

This toggles whether graphics are displayed in the preview. When turned off graphics are shown as rectangles. This option saves memory and increases redraw speed. It does not affect the actual printout.

Report Template

The report template includes text and codes. Codes are surrounded by double left and right arrow keys. In the following definitions commands are capitalized and parameters are shown in lower case. When actually typing commands, however, capitalization is unimportant.

Templates are stored with Graph Axes. To keep new templates re-save the Graph Axes file with a different name. Templates can also be assigned in BASIC (see "FilmStar DESIGN Extensions" on page 74).

Action Commands

Action commands insert text and graphics.

<<BASBLOCK value>>...Value 0 to 15. Insert text block paragraph(s) created in FilmStar BASIC by assigning BasText\$(0)...BasText\$(15). See Indent-First, IndentLeft, and IndentRight. This is useful for paragraphs containing calculated text. Otherwise consider using FileText.

```
<<BasBlock 5>> ' insert block text BasText$(5)
```

<<BASEXEC code>>...Run a FilmStar BASIC program expressed as a string. *For brevity, optionally omit 'Sub Main' and 'End Sub' when Sub Main is the only module.* The pipe character "|" (not shown here) separates lines.

```
<<BasExec BasText(0)=CStr(Now)>><<BasText 0>>
```

Since FilmStar adds 'Sub Main' and 'End Sub' as needed, the above sample code to insert date and time actually has three lines, not one. BasExec is best utilized for short code segments.

<<BASRUN name>>...Run a FilmStar BASIC macro. This provides means to include calculated values in reports, for example total layer thickness.

```
<<BasRun c:\Winfilm\Basic32\TotThick.bas>>
```

While the macro could alternatively be assigned to a macro key, including the macro name in the template may sometimes be preferred. The complete path must be given, and *a template containing a BASIC macro cannot be triggered by another BASIC macro.*

<<BASTEXT value>>...Value 0 to 15. Insert string created in FilmStar BASIC by assigning BasText\$(0)...BasText\$(15).

```
<<BasText 5>>      ' insert BasText$(5)
```

<<DRAWLINE>>...Insert a horizontal line between the current margins adjusted by IndentLeft and IndentRight.

```
<<DrawLine>>
```

<<FILETEXT name>>...Insert a text file as a paragraph(s). This is useful for proposals and quotations. See IndentFirst, IndentLeft, and IndentRight.

```
<<FileText d:\winfilm\pro1.txt>>
```

<<FSPLOTT zoom, fontsize, width, height>>...Zoom and font size in %, width and height in twips. Insert a graph from the FSPlot Module. The graph is inserted at the screen size times zoom in %. Font size can be adjusted by optionally adding relative values in %. The FSPlot window size is adjusted by optionally adding width and height in twips (1 inch = 1440 twips, 1 mm = 56.7 twips). This ensures that graphs are printed at repeatable sizes even if users have altered FSPlot window dimensions.

```
<<FSPlot>>          'zoom=100%, font size=100%
<<FSPlot 75>>        'zoom=75%,  font size=100%
<<FSPlot 75,120>>    'zoom=75%,  font size = 120%
<<FSPlot 105,110,7500,6000>> ' zoom=105%, font size=110%
                        ' ht=7500, wd=6500
```

There are two modes: 1. The FSPlot module is closed when a report is generated and, 2. FSPlot is open (visible). In the first case, each graph automatically plots the latest spectrum. FSPlot operation remains hidden.

If the FSPlot module is open when a report is generated, the displayed graph is placed into the report. In this case FSPlot is not refreshed automatically with the latest spectrum. To automatically include multiple graphs on a plot, use BASIC function PlotActivate to display the module and PlotNext to add new graphs. To plot reflectance and transmittance on the same graph use macro function PlotSelect. Generate a report with k = Macro("ShowReport;"), and use PlotClose to close FSPlot, erasing all graphs.

After font or window size is adjusted, close and open the Report Generator in order to see the changes. To include multiple FSPlot graphs in a report, use BASIC function PlotSave to store each graph as a picture. Then use template function Picture (see below) to print graphs.

<<GRAPH zoom>>...Insert the bitmap graph shown in DESIGN's Main Menu. The graph is inserted at the screen size times zoom in %. An FSPlot graph can also be inserted as a bitmap by checking **File...Bitmap Mode**.

```
<<Graph 70>>      ' zoom=70%
<<Graph>>          ' zoom=100%
```

<<PICTURE name, zoom>>...Insert a picture file with .bmp (bitmap) or .wmf (metafile) extension. Pictures are centered between current margins. Zoom is optional and is 100% if not specified. Use Picture in conjunction with FilmStar BASIC's PlotSave to print documents containing several FSPlot graphs. Picture is convenient for printing company letterheads and logos.

```
<<Picture d:\winfilm\ftglogo.wmf, 75>> 'zoom=75%
<<Picture d:\winfilm\ftglogo.wmf>>      'zoom=100%
```

<<REVIEW format>>...Insert the Review Design screen. An optional format number (1-3) corresponds to the numbering in the Review Design screen.

```
<<Review>>        ' format 1 (original)
<<Review 2>>      ' format 2
```

<<TABLE>>...Insert current spectrum as a data table.

```
<<Table>>
```

<<WBTEXT cell>>...Insert string as formatted in Workbook cell. If only one worksheet is open or if the defined name is unique you can eliminate the worksheet name in the cell name. To get required formatting for numerical values, use the Workbook's TEXT function.

```
<<WbText Rmin>>
<<WbText sheet2!Rmax>>
<<WbText mtable.xls!Average>>
<<WbText mtable.xls!b14>>
```

Format Commands

The simple formatting in the Report Setup dialog box will be sufficient for many applications. Additional formatting is possible with the following template commands.

<<ALIGN type>>...Align text between margins.

```
<<Align 0>>      ' align left
<<Align 1>>      ' align center
<<Align 2>>      ' align right
<<Align 9>>      ' justify
```

Left alignment allows you to format words within a line. In center and right alignment the entire line will have the same formatting.

<<BOLD boolean>>...Font bold or normal.

```
<<Bold 0>>       ' following text is normal
<<Bold 1>>       ' following text is bold
```

<<BORDER value>>...Page border, values 0 to 7: 0 none, 1 bottom, 2 top, 3 top & bottom, 4 box, 5 columns, 6 columns & top & bottom, 7 all. If Border is not specified, a top border is drawn if there is a header and the bottom is drawn if there is a footer.

```
<<Border 4>>     ' draw box around each page
```

<<COLOR value>>...Color 0 to 15: 0 black, 1 blue, 2 green, 3 cyan, 4 red, 5 magenta, 6 yellow, 7 light gray, 8 dark gray, 9 blue, 10 green, 11 cyan, 12 red, 13 magenta, 14 yellow, 15 white. 1-6 are dark versions of 9-14.

<<Color 9>> ' text is blue

<<COLUMNS value>>...Print in multiple columns.

<<Columns 2>> ' print in 2 columns

<<COLUMNSPACING value>>...Space between columns. (twips, default 180)

<<ColumnSpacing 240>> ' column spacing is 240 twips

<<DEFFONTS>>...Returns **Name**, **Size**, **Bold**, **Italic** and **Spacing** to default values.

<<DefFonts>>

<<DEFNAME font>>...Sets new default font name. **DefSize**, **DefBold**, **DefItalic** and **DefSpacing** are similar.

<<DefName Lucida Sans Typewriter>>

<<FOOTTEXT text>>...Overwrite the default footer. *See HdrText below.*

<<FootText |This is the footer - Page 1|>> ' footer text

<<HDRBOLD boolean>>...Header and footer font bold or normal.

<<HdrBold 1>> ' header/footer text is bold

<<HDRCOLOR value>>...Header/footer color. See Color.

<<HdrColor 12>> ' header/footer text is red

<<HDRITALIC boolean>>...Header/footer font bold or normal.

<<HdrItalic 1>> ' header/footer text is italic

<<HDRNAME value>>...Header/footer font name

<<HdrName Arial>>

<<HDRSIZE points>>...Header/footer font size.

<<HdrSize 10>> ' header/footer size is 10 points

<<HDRTEXT text>>...Overwrite the default header.

<<HdrText |This is the header - Page 1|>> ' header text

This is useful for creating multipage documents from single page reports with BASIC as shown in the following code snippet:

```
Sub PrintPage (nPage as Integer)
    t$ = Template$ 'get the template
    p$ = Cstr(nPage) 'page number
    t$ = t$ & "<<HdrText |Catalog - Pg " & p$ & "|>>"
    Template = t$ 'reassign template
    PrintReport
End Sub
```

<<INDENTFIRST length>>...Additional left indent for the first line of a paragraph in inches or mm (metric paper).

<<IndentFirst .3>> ' first indent=.3"

<<INDENTLEFT length>>...Left indent in inches or mm (metric paper).

<<IndentLeft .75>> ' left indent=.75"

<<INDENTRIGHT length>>...Right indent in inches or mm (metric paper).

<<IndentRight .75>> ' right indent=.75"

<<INDENTTAB length>>...Tab spacing in inches or mm (metric paper).

<<IndentTab .5>> ' tab spacing is =.5"

<<ITALIC boolean>>...Font italic or normal.

<<Italic 0>> ' following text is normal

<<Italic 1>> ' following text is italic

<<LINECOLOR value>>...Line color used for borders. See **Color**.

<<LineColor 12>> ' borders in red

<<LINEWIDTH points>>...Line width in points used for borders. The default is zero. This may be acceptable for 300 dpi printers but will be probably be too thin for higher resolution printers.

<<LineWidth 1.5>> ' line width 1.5 points

<<MARGINS metric, left, right, top, bottom>>...Set English/metric units and margins. Any non-zero value for the first field sets metric paper. If utilized, Margins should be the first command in a template.

<<Margins 0, .75, .75, .5, .5>> ' English units

This command is useful for templates created and stored through BASIC. Users can then be sure that margins are correct even if the Graph Axes file was overwritten.

<<NAME font>>...Font name. This must correspond to your printer. See also Size, Bold and Italic.

<<Name Lucida Sans Typewriter>>

<<NEWCOLUMN>>...Insert column break.

<<NewColumn>> ' insert column break

<<NEWPAGE>>...Insert page break. Page breaks are automatically inserted if a graph is too big for the page.

<<NewPage>> ' insert page break

<<Page>> ' alternative

<<SIZE points>>...Text font size in points (1" = 72 points)

<<Size 10>>

<<SPACEAFTER points>>...Extra space in points (1" = 72 points) to be added after paragraphs.

<<SpaceAfter 8>> ' 8 point space after paragraphs

<<SPACING percent>>...Line spacing as a percent of the current font size. The default can be set in the Report Setup dialog box.

<<Spacing 120>>

<<UP lines>>...Move up the page. This is helpful when formatting commands have added unwanted white space between lines.

<<Up>> ' move up one line
<<Up 2>> ' move up 2 lines

General Information

Clipboard Functions

The Windows clipboard is supported throughout FilmStar. The terms *Copy* and *Paste* refer to the clipboard and *Import* and *Export* refer to DDE. Experimenting with the clipboard is easier if you activate the Windows' clipboard viewer. Windows shortcuts <Ctrl+C>, <Ctrl+V> and <Ctrl+X> are used throughout, but the data they refer to can be very different. When pasting data, be sure that its source is correct. You would not want, for example, to paste a thin film design into spectral data.

File Manager

FilmStar file commands will be familiar from other Windows applications, but there are some differences because of the number of file types utilized.

Delete

Only a highlighted file can be deleted. The current file cannot be deleted.

List Files

To create a master list of all files, use the **Copy** command and paste the text into Notepad with <Ctrl+V>. Repeat for other file types. Lists can be printed.

Show Film

Only available when opening a FILM File. Shows the individual file names (Graph Axes, Film Indices, Design, Targets, Variables) comprising the highlighted FILM File name.

Keyboard Commands

Keyboard commands are generally identical with those in other Windows applications. But the custom grid control and our use of **Cancel** warrant some explanation.

Cancel

Upon selecting **Cancel** <Escape> changes in the dialog box are lost. If you are constantly losing data in this manner you should set a cancel confirmation flag in **File...Configuration...Preferences**.

Grid Control

The Farpoint grid control makes it possible to edit large data sets within a dialog box.

Mouse...Click on the required cell. A single cell is selected when highlighted by a box. Note that the box is sometimes a pull-down list. Multiple cells are highlighted in black by holding down the mouse button.

Keyboard...Use <Arrows>, <Home>, <End>, <Ctrl+Home> and <Ctrl+End> to move the focus and scroll the grid. Hold down the shift key to select multiple

cells. **<PgUp>** and **<PgDn>** also work. **<Tab>** navigates to the next available cell. Most grids will not let you enter data more than one row below the last row containing data.

Press **** or **<BkSp>** to clear an entry or a selected region. Note that rows can be deleted, inserted and sorted by wavelength. To edit a cell without replacing it (*i.e.* overwrite mode), press **<F2>** or **<Insert>**.

The program attempts to prevent erroneous data. In most cases the offending data cell is highlighted in yellow. Additional checks are performed upon clicking the OK button.

Shortcut Keys

There are a number of shortcut keys. Dialog boxes may contain their own shortcuts (not shown here). Note that File Save **<Shift+Ctrl+k>** and Save As **<Shift+Alt+k>** sequences are not displayed in menus. File shortcuts are not really needed when Windows file dialogs rather than FTG file dialogs are utilized. Clipboard shortcuts **<Ctrl+C>** (copy), **<Ctrl+V>** (paste), and **<Ctrl+X>** (cut) are used throughout.

<F2>	DB Save design
<Shift+Ctrl+F2>	DB Retrieve design
<F3>	FilmStar Workbook
<F4>	FSPlot Module
<F6>	FilmStar BASIC
<F7>	Report Generator
<Ctrl+F7>	Quick print report without preview
<F8>	View data table
<Ctrl+F8>	Convert spectral data range
<Shift+Ctrl+F8>	Export spectral data via DDE
<F9>	Calculate spectrum (no dialog)
<Ctrl+F9>	CIE color module
<Shift+F9>	Calculate merit function
<Shift+Ctrl+F9>	Run tolerancing
<F11>	Spectrum Save As
<Ctrl+F11>	Spectrum Open
<Shift+F11>	Spectrum Save
<Shift+Ctrl+F11>	DB Retrieve spectrum
<F12>	FILM (Archive) Save As
<Ctrl+F12>	FILM (Archive) Open
<Shift+F1...F6>	Execute macro command #1 to #6
<Alt+A>	Draw new graph axes
<Alt+C>	Calculate spectrum (with dialog)
<Alt+R>	Change plot line color
<Ctrl+A>	Auto-scale current spectrum
<Ctrl+B>	Optimization Variables dialog
<Ctrl+D>	Groups design editor
<Ctrl+E>	Erase current spectrum from memory
<Ctrl+G>	Graph Axes dialog

<Ctrl+H>	Graph Details dialog
<Ctrl+I>	Film Indices dialog
<Ctrl+J>	Adjust design (arithmetic operations)
<Ctrl+L>	Layers design editor
<Ctrl+M>	Optimization parameters
<Ctrl+N>	Tolerancing setup dialog
<Ctrl+O>	Optimize
<Ctrl+P>	Setup Parameters
<Ctrl+R>	Review design
<Ctrl+T>	Optimization Targets dialog
<Ctrl+U>	Use all layers as optimization variables
<Ctrl+X>	Calculator (test user formula syntax)
<Ctrl+Y>	Synthesis dialog
<Ctrl+Z>	Macro command dialog
<Alt+Ctrl+k>	Open
<Alt+Shift+k>	Save As
k = B	Optimization Variables
k = D	Design
k = G	Graph Axes
k = I	Film Indices (disabled in n,k Archive mode)
k = T	Optimization Targets

Graphics Labels

Labels may be placed on the screen by pressing **<Shift+Click>** (left mouse button) when the cursor is in the plot area (crosshair shape). Left, center and right justification may be selected as well as an italic font.

The label will have the same color as the last spectrum. To change the color (before placing the label), select a color from the color button. Simultaneously, hold down the shift key to suppress replotting the last spectrum.

INDEX Reference

INDEX File Menu

Index Tables, Graph Axes, Function Parameters and n,k Calculation parameters are all stored in the same file (*.itw).

Import

Import Sopra *.nk or Woollam *.mat files. The Sopra database is available in a self-installing version on the FTG web site and FilmStar CD-ROM.

Two additional sources of n,k data are <http://www.RefractiveIndex.INFO> and <http://www.luxpop.com/RefractiveIndexList.html>. Data may be imported with FilmStar BASIC macros RefractiveIndexInfo.bas and LuxpopNK.bas.

Users who have n,k files in other ASCII formats should contact us about supplying an appropriate FilmStar BASIC macro or adding the capability directly to the Import command.

Copy and Paste

A three column (wavelength, n, k) tab separated (Excel compatible) format is utilized. Wavelength is in nanometers and $k > 0$.

INDEX Setup Menu

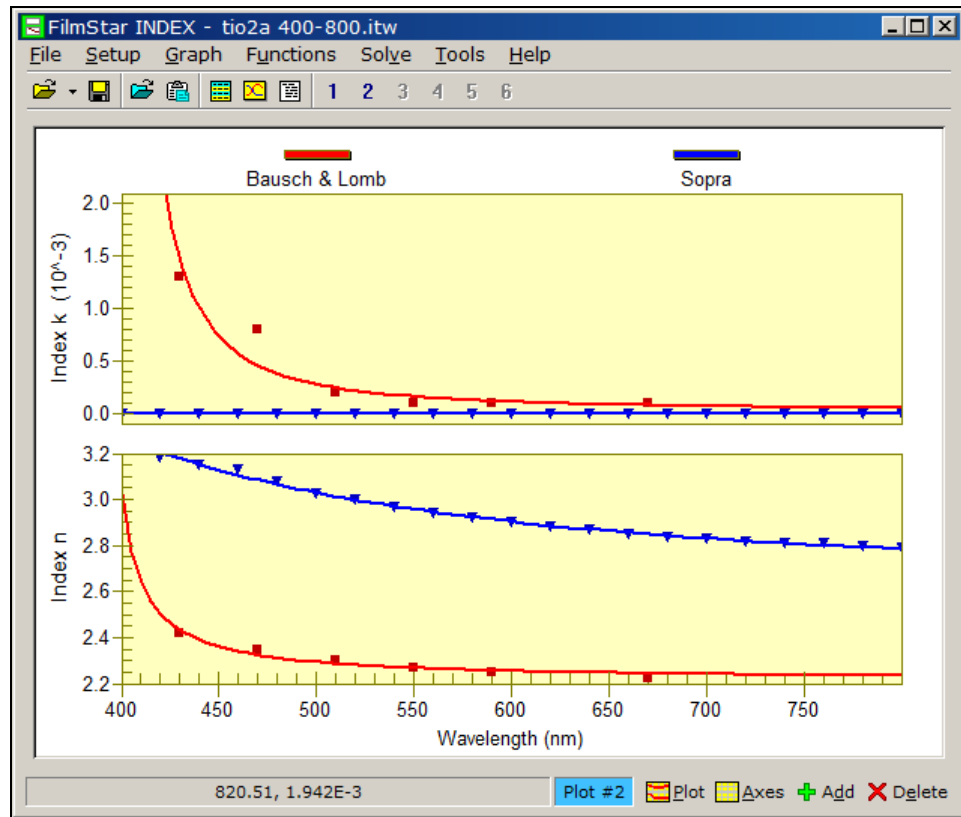
Graph Axes

Setup...Graph Axes <Ctrl+G>

INDEX allows users to plot index data to verify file integrity. Index functions can also be plotted. Graph Axes parameters are automatically stored with the dispersive Index Table.

Select **k-Scale...Log** when working with materials exhibiting orders-of-magnitude absorption variations over the specified wavelength range. This changes the display format in the k column in Index Table from fixed to scientific notation. Alternatively a multiplier can be applied to the linear scale.

As shown below, n,k comparisons can be very useful. Here, B&L TiO₂ data (from the 70's) is markedly different from Sopra data. Up to 4 multiple graphs can be superimposed by clicking **Add** in the bottom command bar.



Index Parameters

Setup...Parameters <Ctrl+P>

Table type

Choose *Index* for n,k vs. wavelength and *Filter glass* for filter mode. Filter mode is intended for absorbing glasses and other materials where $k \ll n$. *Alpha* choices are used with Wavelength in eV and are intended for semiconductor properties.

Filter specifications

These apply when *Filter glass* is selected: index table k values in internal transmittance t (as in the Schott catalog) or % T (as measured in a spectrophotometer at normal incidence). Enter substrate thickness in millimeters. When using % T data it is assumed that both surfaces are uncoated.

k-Tolerance > 0 prevents $t > 1$ or % $T >$ theoretical maximum errors caused by round-off or experimental error. It may be necessary to increase the default value (1.E-8) when utilizing measured spectra. (INDEX assigns $k=0$ when $-kTol < k < 0$.)

Index Table

Setup...Index Table <Ctrl+I>

Users can copy the contents of one cell to many cells. For example, to enter $n=1.52$ in all rows type '1.52' in the first row and copy that entry to the clipboard with **Edit...Copy Cell**. Then highlight the required number of rows and click **Edit...Paste Cell** to duplicate that entry.

Rows can be wavelength sorted at any time by clicking **Edit...Sort**. Upon clicking **OK**, duplicate wavelength entries are flagged. Include more values in regions where n or k vary rapidly with wavelength. Negative entries are not allowed. Each table must have at least three entries.

To prevent out-of-range errors in DESIGN, be sure that INDEX wavelengths encompass the anticipated Graph Axes range in DESIGN.

In Filter mode, the program will not accept internal transmittance values greater than 1 or measured %T entries exceeding the theoretical maximum for two uncoated surfaces. In Index mode the k column uses fixed floating point notation (0.00000) when k -Scale is linear and scientific notation when k -Scale is logarithmic. Select scale type in **Setup...Graph Axes**.

INDEX Functions Menu

Indices can be described by constants n and k , look-up tables and dispersive functions. Functions are specified in DESIGN by assigning a dispersive 'file name' which is the function name (seven characters maximum) preceded by '\$'.

Fit Index <Ctrl+F>

Select a function type and edit coefficients. It is also possible to determine the best least-squares fit to current index values. Select **Type "-----"** if functions are not utilized for the material.

Plot <Ctrl+T>

Plot the current dispersion function vs. wavelength. In some cases there will be a mathematical error because the function is not valid over the entire plot range. In that case click **Wavelength Range** to edit the evaluation range.

Create Table

Create or add entries to a dispersive index table using the current Index Function. This can be activated repeatedly with different functions. In some cases a single dispersion function can be used directly in DESIGN. In other cases, the function will not describe the index over a sufficiently wide wavelength range and look-up tables are required.

Note also that user-defined functions transfer data via DDE. As this can be a slow process, calculations may proceed much faster if the functions (once the coefficients have been determined) are ultimately converted to tables. Users who determine that certain functions are useful should contact FTG Software about coding the function as a built-in.

User Defined

Please refer to "" on page 34 in the DESIGN Reference section.

Dispersive Index Functions

Functions...Fit Index

In DESIGN dispersive indices can be described by Sellmeier and similar functions by entering the function name preceded by \$ under **File/\$Fn** in the Film Indices (page 31) editor. Each function contains up to seven coefficients (or more if specified in **File...Configuration...Capacity**) which may be deduced from experimental spectral data via 'inverse synthesis'.

To fit these functions in DESIGN, the starting approximation must be reasonably close. INDEX provides an optimization procedure for deducing

coefficients from the current Index Table. There are two function categories: built-in and user-defined (see "" on page 34). User-defined functions are automatically included in the scrolling **Type** list. Click **Edit...Paste Function** to insert a function name and values copied in the **DESIGN** Film Indices dialog or in the **INDEX** Functions dialog. Click **Edit...Copy Function** to copy a function; this is normally used to transfer settings from one Index Table to another.

User Defined functions are stored in Index Table files *.itw. The procedure for transferring functions from INDEX to DESIGN is to store a collection of functions (*.itf) which can then be opened in DESIGN. Click **File...Save Collection** in INDEX followed by **File...Open Collection** in DESIGN.

Click **Fit** to solve for coefficients which provide the best least-squares fit to current index data. Select a small number of iterations, say 5 or 10 and observe the improvement **Ratio** in the merit function. Try starting with a higher damping number (*i.e.* 100 or 1000) if values change too rapidly.

Compare calculated results with the Index Table by selecting **Functions...Plot <Ctrl+T>** in the main menu. It is essential to match the spectral shape. In some cases it will be necessary to perform piece wise fits over large spectral ranges.

The calculation of k is different when a logarithmic k scale is used; in this case the program solves for log k instead of k. The log k scale is suggested for oxides and other materials with sharp absorption edges. Scale type is selected in **Graph Axes <Ctrl+G>**.

Relative k-convergence can be decreased by increasing (relative) k-Tolerance. That is, if k changes too fast relative to n, increasing k-Tolerance slows changes in k. Users who are not happy with results can click **Restore** to recover original coefficients or **Cancel** to leave the editor.

Sometimes removing a few wavelength points from the Index Table results in dramatic improvements. For example, if the index of a material to be fit with function LOREN is essentially constant from 750 to 2000 nm, leave out this range and fit the function from 380 to 750 nm. Use **Functions...Create Table** to generate a table spaced according to the Graph Axes editor. Later insert points from 750 to 2000 manually.

Sample values which will serve as starting points:

BK7	BUCH	A=1.5184, B=-.044736, C=-.00032737
TA205	LOREN	A=2.7342, B=1.3767, C=212.02
TIO2	LOREN	A=4.3603, B=.5034, C=354.23
TIO2A	LORENK	A=4.4398, B=.45667, C=336.87, D=.52305

Please contact FTG Software if you have difficulties finding a fit to n,k data. If you supply a table of index values we may be able to locate a suitable function.

INDEX Solve Menu

INDEX includes several algorithms for generating a dispersive Index Table from measured spectral data:

1. Algorithm #1 requires accurate reflectance and transmittance spectra for a film of known thickness on a nonabsorbing substrate. It calculates n,k values at each point in the spectrum.
2. Algorithms #2/3 are valid for nonabsorbing or slightly absorbing films on nonabsorbing substrates; it only requires normal incidence transmission

or reflection measurements. The film must be thick enough to produce a good number of peaks and valleys in the wavelength range of interest. **The film must also be nondispersive on the long wavelength side.** This algorithm is especially useful for TiO₂, ZnS and similar nearly transparent dispersive materials.

- Algorithm #4/5/6 are used for determining n,k for colored/transparent glasses and similar **substrates**.

Determining indices is not a simple task and requires judgment. Users must verify that any dispersive table produced by INDEX gives expected results in DESIGN.

Open Spectrum <Ctrl+F11>

Load spectrum previously stored on disk in DESIGN or MEASURE.

Paste Spectrum <Ctrl+V>

Paste spectrum previously copied to the Windows clipboard in DESIGN or MEASURE.

Spectrum Type...Peaks

Users without computer-compatible spectrophotometers can use Algorithm 2 (discussed below, T known, $k \ll n$) by creating a set of wavelength and transmission values corresponding to measured peaks and valleys. Sample data created in Excel is shown below. Wavelengths must be in increasing order; transmittance values are between 0 and 1 and a blank middle column of zeroes (corresponding to reflectance) must be included.

	A	B	C	D	E	F	G
2	17						
3	383.6	0	0.810				
4	390.0	0	0.591				
5	404.6	0	0.846				
6	421.0	0	0.610				
7	437.7	0	0.881				
8	453.0	0	0.633				
9	470.1	0	0.895				
10	489.3	0	0.657				
11	511.0	0	0.913				
12	536.3	0	0.677				
13	565.6	0	0.916				
14	598.9	0	0.688				
15	637.7	0	0.916				
16	683.1	0	0.697				
17	740.0	0	0.917				
18	807.3	0	0.697				
19	888.0	0	0.917				

Using Excel there are two ways to transfer spectral data to INDEX: 1. Data may be stored on disk as a .csv file. The first line is a description and the second line is the number of spectral points. 2. Data may be copied and pasted. Ignoring the first two rows, A3:C19 is copied to the clipboard.

Calculate n,k <F9>

Enabled when a spectrum is loaded.

n & k Algorithm 1 (R, T and t known)

This algorithm requires accurate reflectance and transmittance spectra for a film deposited on a nonabsorbing substrate. The physical thickness of the film must be known. The algorithm determines n,k at each wavelength point, using values at the previous wavelength as a new starting guess.

One way to test this algorithm is to create spectral files in DESIGN and to see whether INDEX can recover the n,k table used in the calculation (Gedankenspektrum method). But calculated data may be too accurate and provide a false sense of security. Users can simulate measured data by adding random error to calculated spectra in Excel (or in FilmStar BASIC) and noting whether INDEX still converges to the starting n,k table. Of course, experimental accuracy is not the only problem; inhomogeneity can also cause spurious solutions.

The user must choose film thickness wisely. Films that are too thick or too thin will not lead to solutions.

Side 2 Compensation

Select **None** if the second surface has an antireflection coating. Select **Transmission only** if the second surface was ground or coated for the reflection measurement but untreated for the transmission measurement. Select **Transmission and reflection** if both measurements were performed with an untreated uncoated surface.

Start at high wavelength

The calculation should be started in the spectral region where Starting Values are likely to be most accurate.

n & k Algorithm 2 (T known, Film $k \ll n$)

This algorithm is useful for high index oxides and other films which are slightly absorbing over the wavelength range of interest and nondispersive as well as nonabsorbing at long wavelengths. Only normal incidence transmission values are required. The substrate must be transparent and the film thick enough to produce a number of spectral peaks/valleys (where n,k will be calculated) in the wavelength region of interest. The calculation assumes that films are homogeneous and that the substrate is uncoated on the reverse side. This corresponds to calculation mode **FWD include Side 2** in DESIGN.

The **Peak/Valley Verification** screen shows the wavelengths at which n,k will be calculated. INDEX determines extrema by scanning sets of points and looking for a best fit. Spurious results are possible when there are too many (noise peaks) or too few data points. (Suggested settings for MEASURE: discrete scan mode and inverse wavelength spacing. For example: 400 to 800 by -2 nm.)

The algorithm computes quarter wave film thickness by fitting peaks in the non-dispersive (long wavelength) portion of the spectrum. Users may specify the number of peaks (default 3) used in the calculation as well as a starting number of quarter waves (default 3). This starting value must be less than the actual number of quarter waves at the maximum wavelength. n is determined from $T_{\max} - T_{\min}$ at the maximum peak wavelength in the spectral data set. Values of n at shorter wavelengths are computed at max/min positions and k is computed with a least-squares routine. These n,k values can be used in fitting LORENK and similar dispersive index functions in INDEX and in DESIGN.

The accuracy of the quarter wave determination depends on the film being non-dispersive on the long wavelength side. Beware of spurious solutions! Index tables must be verified in DESIGN.

If the calculated spectrum does not match the measured spectrum it is likely that the number of quarter waves (and film thickness) is incorrect. Manually enter a fixed value for the number of quarter waves by first entering '1' for "peaks for film thickness calculation". Try a new value that differs by a multiple of 2 from the value calculated by INDEX. (When film index is greater than substrate index a transmission peak corresponds to an even number of quarter waves, while a minimum corresponds to an odd number. When film index is less than substrate index a transmission peak corresponds to an odd number of quarter waves, while a transmission minimum corresponds to an even number.)

n & k Algorithm 3 (R known, Film $k \ll n$)

This algorithm is similar to Algorithm 2 (see above) and is intended for opaque reflective substrates such as silicon. There is the same condition that films must be nonabsorbing and nondispersive at the long wavelength side. *Films on metals can be examined, but results will probably not be inaccurate.*

Beware of spurious solutions! Index tables must be verified in DESIGN. Use Gedankenspektrum methods to determine the regimes where accurate results are possible.

It is assumed that there is no reflection from the uncoated side. This corresponds to DESIGN calculation mode **FWD ignore Side 2**. If the substrate is not opaque, the uncoated surface must be ground to eliminate reflections.

n & k Algorithm 4 (Substrate $k \ll n$)

This algorithm computes n,k for colored glasses and other slightly absorbing materials where $k \ll n$. Reflectance and transmittance values are required in the same data file. Use Excel to combine two separate MEASURE data files which have the same wavelengths.

Reflection measurements must be taken at (or near) normal incidence with the substrate second surface ground to eliminate reflections from that surface. Transmission measurements at normal incidence are made with an uncoated substrate. This corresponds to calculation mode **FWD Side 2 T only** in DESIGN. Use this mode to create test files.

If the sample is too thick to provide accurate transmittance values, use a thinner sample. If you only have transmission measurements or catalog internal transmittance values, and know n, use Filter Mode in the main index editor to convert t or %T values to k.

n & k Algorithms 5,6 (Substrate $k=0$)

If it is known that the substrate is nonabsorbing ($k=0$) throughout the entire wavelength range, n values may be computed from reflectance (Algorithm 5) or transmittance (Algorithm 6) values at normal incidence. In the case of reflectance, the substrate must be ground to eliminate second surface effects.

FilmStar BASIC (INDEX)

FilmStar BASIC is a development environment for customizing FilmStar. Using Sax Basic, FilmStar BASIC adds the special commands and keywords discussed in this section. Two macro commands are supported: BasOpen and BasRun.

The FilmStar BASIC language is nearly 100% compatible with Microsoft VBA (Visual Basic for Applications). The IDE (Integrated Development Environment) (**Tools...BASIC Editor <F6>**) provides means to edit and test BASIC programs.

INDEX Extensions

Summary documentation for all extensions is provided in the BASIC IDE. Click the Browse Object icon (6'th from left).

Capitalization is not important in the following:

Sub AutoAxes...Compute axes range and replot; use when importing data

AutoAxes

Sub BasActivate...Return focus to BASIC's IDE (integrated development environment).

BasActivate

Sub Display(text\$, title\$, wd%, ht%, FontName\$, FontSize!, FontBold%)... Display a multiline text box in a dialog box with width wd% (twips) and height ht%.

```
Display "FTG Software Associates", "Princeton, New  
Jersey", 5000, 3000, "Arial", 18, 1
```

Function FileOpen(file\$) as Boolean...Open index table file. Same as IndexOpen (see below), except can return success.

```
Ok = FileOpen("Ti02")
```

Function FilePropsGet(FileName\$, Title\$, Subject\$, Author\$, LastAuthor\$, Keywords\$, Comment\$, ReadOnly as Boolean) as Boolean...Returns NTFS properties for any file. Include complete file name with path and extension.

Sub FilePropsList(Files\$)...Returns array of n,k files (*.itw) displayed in the File Properties List dialog.

```
Sub Main  
  Dim k&, files$(  
  On Error GoTo NoList ' important  
  FilePropsList files$(  
  For k = 1 To UBound(files$)  
    Debug.Print files$(k)  
  Next k  
NoList:  
  Exit Sub  
End Sub
```

Function FilePropsSet(Title\$, Comment\$, Optional FileName\$, Optional User\$, Optional Subject\$, Optional Keywords\$) As Boolean...Adds NTFS file properties to INDEX n,k files (*.itw). The following values are utilized when optional fields are blank or missing:

```
FileName: Current n,k Table file name  
User: User Name in File...Configuration dialog  
Subject: FilmStar INDEX n,k Table  
Keywords: FTG FilmStar n,k Index Table Dispersion (.itw)
```

FilePropsSet "TiO2-E", "Eddy 36 chamber"

Function FileSave(file\$) as Boolean...Save index table file. Same options as IndexOpen (see below).

```
Ok = FileSave("TiO2")
```

Function fMsgBox%(text\$, icon%, title\$)...Similar to BASIC's MsgBox function but will be modal within FilmStar INDEX. This prevents covering the dialog box by clicking on the INDEX window.

```
k = fMsgBox("Do you want to proceed?", 36, "BASIC")
```

Sub FunctionClear()... Clears current function name and coefficients. Useful when importing index data.

```
FunctionClear
```

Property FunctionCode\$... Returns index function code created in SYRUSpro mode.

```
S$ = FunctionCode$
```

Property FunctionCoeff as Variant... Sets/returns Index Function coefficients.

```
ReDim coeff(2) as Single  
coeff(1) = 3.25  
coeff(2) = .1234  
FunctionCoeff = coeff
```

Sub FunctionPlot()...Plot the current function; see TablePlot

```
FunctionPlot
```

Property FunctionRange as Variant... Sets/returns index function range in nm as in the Wavelength Range dialog.

```
Dim range(2) as Single  
range(1) = 400  
range(2) = 800  
FunctionRange = range
```

Sub FunctionToTable(Optional wmin!, Optional wmax!, Optional wdel!)... Generates table from the current Index Function using current wavelength range settings; optionally specify min, max and interval.

```
FunctionToTable ' create table with current settings  
FunctionToTable 400,600,2 ' create table 400-600 x2
```

Sub IndexConvert(Optional wmin!, Optional wmax!, Optional wdel!)... Converts index table to current function range settings; optionally specify min, max and interval.

```
IndexConvert ' use current or range settings  
IndexConvert 400,600,2 ' convert data to 400-600 x2
```

Sub IndexCopy...Copy index table to clipboard (Excel format)

```
IndexCopy
```

Property IndexDescription\$...Get file description

```
s$ = IndexDescription$
```

Property IndexList\$...Get index table as text list

```
s$ = IndexList$
```

Property IndexName\$...Get/assign name to index table file

```
s$ = IndexName$  
IndexName$ = "TiO2 Chamber 3"
```

Sub IndexOpen(file\$)...Open index table file

```
IndexOpen "c:\winfilm\data\TiO2.itw"  
IndexOpen "c:\winfilm\data\TiO2"  
IndexOpen "TiO2.itw" ' default path  
IndexOpen "TiO2" ' " "
```

Sub IndexPaste...Paste index table from clipboard (Excel format)

```
IndexCopy
```

Property IndexPath\$...Get/assign path for index table files

```
s$ = IndexPath$  
IndexPath$ = "c:\winfilm\import"
```

Function IniString\$(section\$, key\$)...Get user-defined initialization variable from design1.ini.

```
s$ = IniString$("Chuck Vogel", "LastFileName")
```

returns "WW098909" if the following is in design1.ini:

```
[Chuck Vogel]  
LastFileName=WW098909
```

Sub MainActivate...Return focus to INDEX's Main Menu

```
MainActivate
```

Property MainEvents As Boolean...By default, running a program from the BASIC editor (IDE) enables FilmStar keyboard and mouse events. By default, running a program via macro command *basrun* disables FilmStar keyboard and mouse events. This behavior may be changed in a BASIC program by setting *MainEvents* true or false.

```
MainEvents = True ' respond to keyboard/mouse  
                ' default in IDE  
MainEvents = False ' do not respond to keyboard/mouse  
                ' default when run without IDE
```

Most importantly, setting *MainEvents = True* in a BASIC program run from *basrun* adds an **Abort BASIC** menu command.

Property Merit!...Computes and returns least squares merit function for current Index Table and dispersive Index Function

```
v! = Merit
```

Property nIndex%...Returns number of wavelengths in current index table

```
K = nIndex
```

Property nkTable as Variant...Assign/get index table

```
' Transferring n,k table from INDEX
Option Base 1
DefInt I-N
DefSng A-H, 0-Z
Sub Main
  Dim i, j
  ReDim xIndx(1, 1) ' MUST BE 'SINGLE'
  xIndx = nkTable ' Get table
  For i = 1 To nIndex ' # of data points
    For j = 1 to 3
      Debug.Print xIndx(i, j)
    Next j
  Next i
End Sub

' Transferring n,k table to INDEX
Option Base 1
DefInt I-N
DefSng A-H, 0-Z
Sub Main
  Dim i
  ReDim xIndx(10, 3) ' MUST BE 'SINGLE'
  For i = 1 to 10 ' make up some data
    xIndx(i, 1) = 400 + 20 * i
    xIndx(i, 2) = 1.52 -.002 * (i-1)
    xIndx(i, 3) = 0
  Next i
  nkTable = xIndx ' transfer to INDEX variables
  AutoAxes ' plot index values
End Sub
```

Property PgmCaption\$...Get main caption (title bar).

```
s$ = PgmCaption
```

Property PgmPath\$...Get the name of the FilmStar program path. This is useful for saving imported index tables.

```
s$ = PgmPath ' returns "C:\Winfilm"
```

Sub PlotAdd()...Add new plot (maximum 4)

```
PlotAdd
```

Sub PlotDelete()...Delete current plot

```
PlotDelete
```

Sub PlotDeleteAll()...Delete all plots, clearing the graph completely

```
PlotDeleteAll
```

Sub sMsgBox(text\$, icon%, title\$)...Similar to BASIC's MsgBox instruction but will be modal within FilmStar INDEX. This prevents covering the dialog box by clicking on the INDEX window.

```
sMsgBox "Get a cup of coffee!", 48, "Working Hard"
```

Sub TablePlot()...Plot the current n,k table; see FunctionPlot

```
TablePlot
```

Sub WriteIniString\$(section\$, key\$, text\$)...Store user-define initialization variables in design1.ini

```
WriteIniString "Chuck Vogel", "LastName", "WW098909"
```

inserts/modifies the following entry in design1.ini:

```
[Chuck Vogel]
```

```
LastName=WW098909
```

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