TFCalc/WDM Software

Introduction. TFCalc/WDM is a software tool for finding narrow bandpass filter designs. The software is capable of examining designs very rapidly, displaying the performance of promising designs as they are found. The designs can be printed, saved as TFCalc files, or saved in a compact format for future reference.

Model. The software assumes a simple model for the bandpass filter:
- The filter consists of layers of two dielectric materials denoted by H and L.
- The layers form a symmetric structure; i.e., the first layer is the same as the last layer, the second is the same as the second-to-the-last, etc.
- The incident and exit mediums are the same[1].
- The incident angle is always zero – normal incidence.
- The thickness of all layers is an integral number of quarter waves.
- The reference wavelength for optical thickness is the filter's central wavelength.

Filter Structure. The filter structure is organized in terms of cavities and mirrors. The cavity layers (also called spacers) consist of an even number of QWOTs[2]. The simplest cavities are 2L and 2H, which are termed first-order cavities. Second-order cavities are 4L and 4H. Every cavity layer is between mirrors, which consist of alternating layers of L and H. For example, HLHLHL is a 6-layer mirror whose structure can be written as (HL)^3. Putting cavities and mirrors together, we obtain a filter structure, such as (HL)^3 2H (LH)^3.

TFCalc/WDM works by generating and evaluating all possible designs within a range given by the user. Although the number of possible designs is quite large, the software can evaluate thousands of designs per second. The user can specify:
- The number of cavities, up to 21.
- The range of cavity orders; e.g., orders from 1 to 5.
- The range of mirror layers; e.g. 10 to 30 layers.
- Whether L layers are allowed next to the incident/exit mediums.
- Whether cavities must be only L layers, only H layers, or whether they may be either L or H.

Alternate Notation. When viewing many similar filter designs, the conventional notation, such as (HL)^3 2H (LH)^3 becomes burdensome. Instead, we use a more compact form in which the mirror layers are given as <N>, where N is the number of alternating layers. Using this notation, (HL)^3 2H (LH)^3 becomes <6> 2H <6>. In this notation, the exact mirror structure depends on the context. For example, <2> 2H <2> means HL 2H LH, but <2> 2L <2> means LH 2L HL.

Starting TFCalc/WDM. To start the software, just double-click on the TFCalc/WDM icon on the Windows desktop. The next page shows the initial appearance of the software.

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[1] It is quite easy to convert a design to work for dissimilar incident and exit mediums.
[2] QWOT means Quarter-Wave Optical Thickness
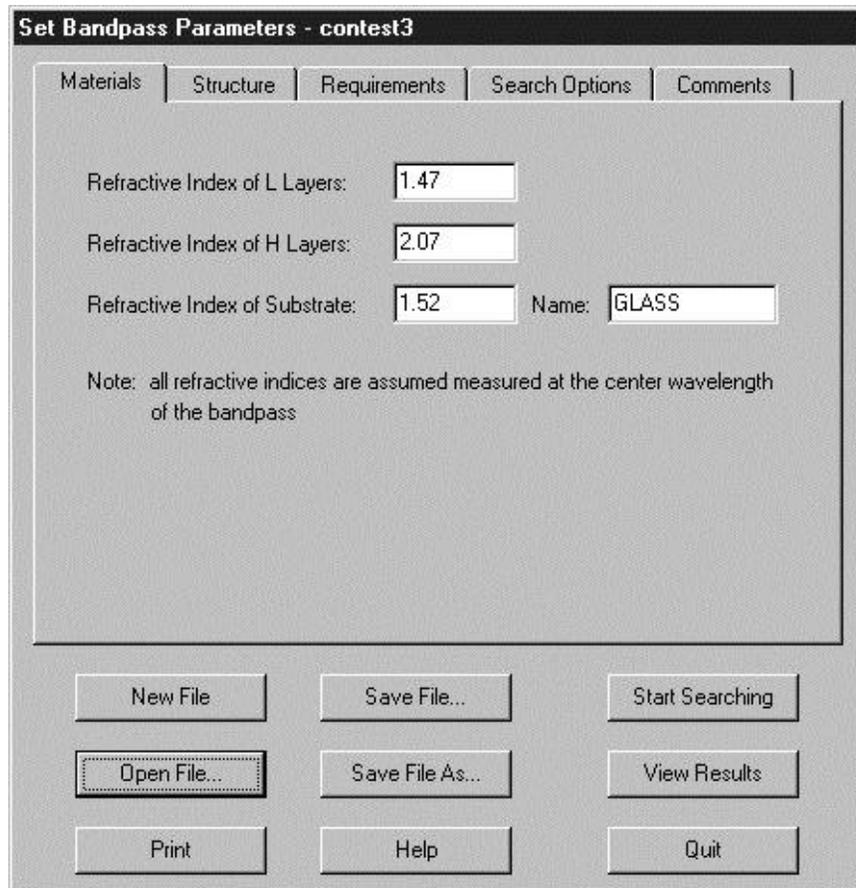
Input Panels. The top portion of the screen shows the various types of inputs accepted by the program: Materials, Structure, Requirements, Search Options, and Comments. When the user clicks on one of these names, the input panel changes.

Command Buttons. The lower portion of the screen shows the commands that are available to the user. Here is a short description of the commands:

- Use **New File** to start a new bandpass design file. If you previously saved a bandpass design file called DEFAULT, then that file will be read.
- Use **Open File** to open an existing bandpass design file. If the file contains designs, the View button can be used to view those designs.
- Use the **Save File** command to save the current bandpass design file.
- Use the **Save File As** command to save the current work in a new file.
- Use **Print** to print all the design parameters.
- Use **Help** to display instructions.
- Use the **Start Searching** command to start the search process.
- Use the **View Results** command to view designs previously found.

Materials Panel. This panel, shown above, allows the user to enter data about the H and L materials, and about the substrate, which is used for both the incident and exit mediums. The name of the substrate is important when a design is saved as a TFCalc file.
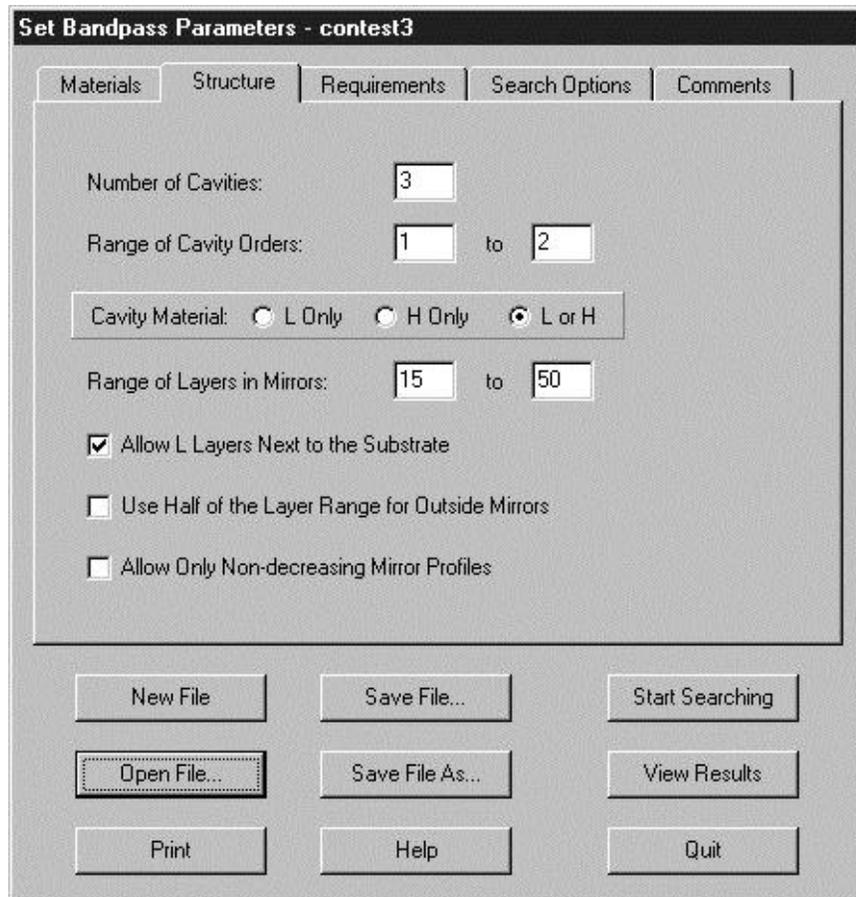
Structure Panel. This panel controls the structure of the bandpass filters. The program will generate all designs based on these inputs. An extremely large number of designs can be generated!

The **Use Half the Layer Range for Outside Mirrors** checkbox can speed the search process. In almost all good WDM designs, the number of layers in the outside mirrors (the first and last mirrors) tends to be about half the number of layers in the inside mirrors. This means that much of the search is wasted on analyzing unsuitable designs. When this checkbox is checked, you should narrow the **Range of Layers in Mirrors**. So instead of using a 15 to 50 range, narrow the range to 30 to 50 layers, which will tell the software to use from 15 to 25 layers in the outside mirrors.

Another way of speeding up the search process is to use the **Allow Only Non-decreasing Mirror Profiles** checkbox. In most good WDM designs, the number of layers in each mirror is non-decreasing as we look at mirrors from the outside to the center of the design. When this checkbox is checked, only designs with a non-decreasing mirror profile are searched. Using this feature can speedup the search for a 15-cavity design by a factor of about 1000.

Set Bandpass Parameters - contest3

| Materials | Structure | Requirements | Search Options | Comments |

Center Wavelength (nm): `1550.0`

Minimum T in Passband (%): `90.0`

Allowable Passband Width (nm): `0.22` to `0.25`

Max. Bandwidth at 50% T (nm): `0.3`

Isolation Level (% T): `1.0`

Max. Bandwidth at the Isolation Level (nm): `0.6`

New File	Save File...	Start Searching
Open File...	Save File As...	View Results
Print	Help	Quit

Requirements Panel. This panel determines which designs will be shown to the user; if a generated design fails to meet one of these requirements, it is ignored. The requirements consist of three levels of transmission (passband, 50%, and isolation) and the bandwidth at those three levels. The passband level (**Minimum T in Passband**) is the lowest transmission allowed in the passband. So that not all designs are rejected, we recommend that this level be fairly low. The **Allowable Bandpass Width** is the range of widths that are acceptable; designs with a bandwidth outside of this range will be rejected. Allowing a fairly wide range of widths is recommended.
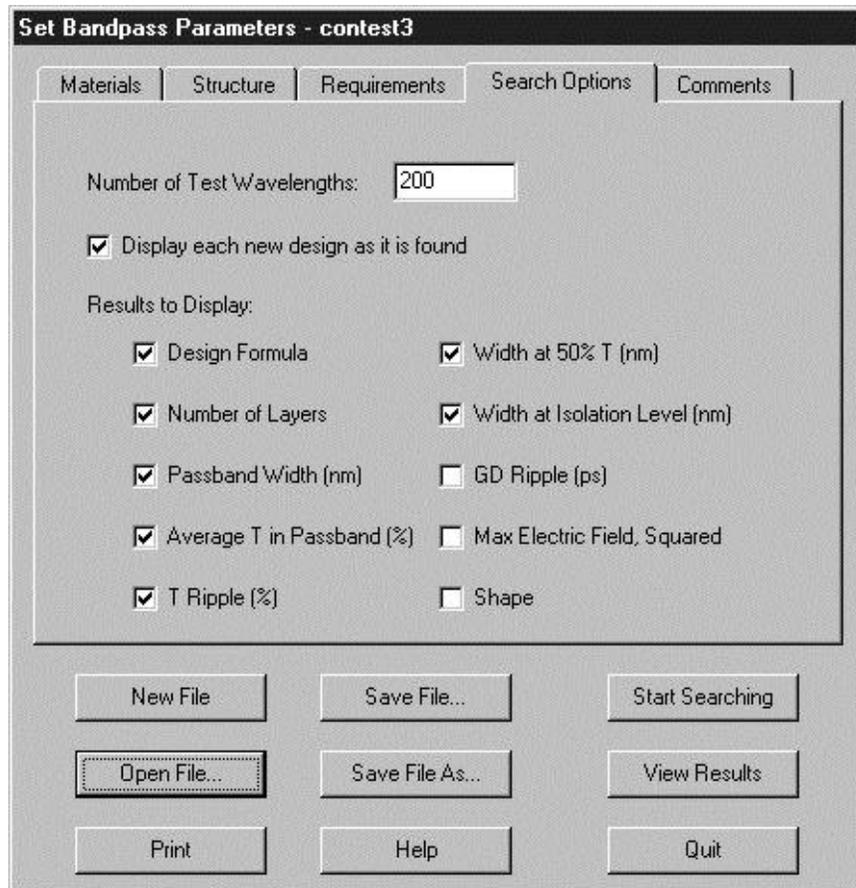
Search Options Panel. The first item in this panel controls how many wavelengths are used to analyze the design. The number must be between 100 and 1000. The analysis is faster if a small number is used. However, the bandwidths are determined more accurately if a large number is used. The next item controls whether new designs are displayed as they are found. Finally, the user has a choice of what to display during the search:

- The design formula, in the alternative notation described on the first page.
- The number of layers in the design.
- The width of the passband.
- The average transmittance on the passband.
- The ripple in the passband. It is defined as $100 - x$, where x is the minimum transmittance in the range from the central wavelength to the last local maximum in the passband.
- The width at 50% transmittance.
- The width at the isolation level.
- The GD (group delay) ripple in the passband. This is normalized so that the minimum GD is zero in the passband. When this item is selected, GD is plotted also.
- The maximum electric field squared.
- The design's shape factor. In this program, it is defined as the isolation bandwidth divided by the width of the passband.
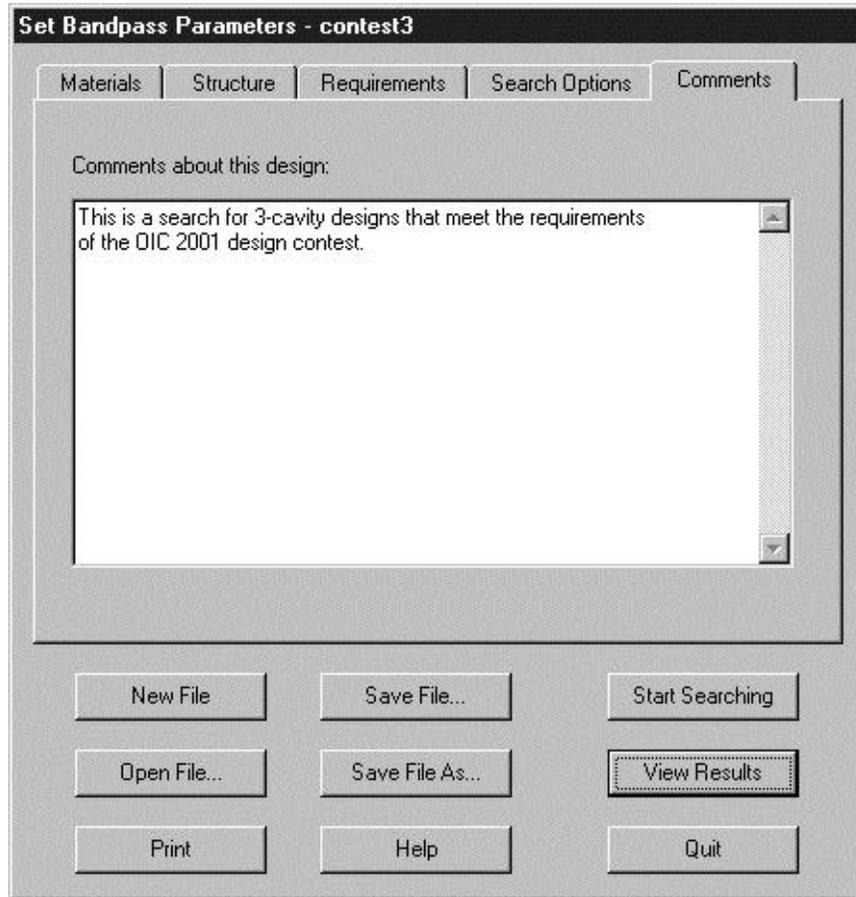
Comments Panel. This panel allows the user to save some comments about the design.

Search Results. This screen, shown on the next page, is displayed during the search process. There is also a progress indicator, which shows how many designs have been searched. The **Stop Searching** button stops the search process. The table displays designs that meet the search requirements. It can be sorted by clicking on a column title; the first click sorts in ascending order; a second click sorts in descending order.

The plot, which displays the performance of the highlighted design, has three parts:
• The top third shows the passband transmittance on a linear scale.
• The middle third shows transmittance down to 10% on a linear scale.
• The bottom third shows transmittance from 10% down to 0.01% on a logarithmic scale.

When you have selected **GD Ripple** in the **Search Options** panel, then the group delay ripple will be displayed on the plot also. It is plotted as a blue curve on a linear scale going from 0 to 30 ps (picoseconds).

After the search is complete, you can change which quantities are displayed in the table by clicking the **Done** button, changing options in the **Search Options** panel, and then pressing the **View Results** button.

Phase I Search Results - contest3

Total Number of Designs: 10,368

Designs Found: 5   Elapsed time: 3.2 seconds.   Designs Selected: 0

No.	Layers	Width	Ave T	Rip T	50Wide	IsoWid	Rip GD	Max E	Shape	Design Formula
001	129	0.232	95.81	8.38	0.275	0.492	17.20	1905	2.119	<21> 2L <42> 2H <42> 2L <21>
002	123	0.227	98.94	0.92	0.291	0.569	9.58	1032	2.513	<20> 4L <40> 4H <40> 4L <20>
003	125	0.239	96.65	6.56	0.287	0.519	15.14	1032	2.169	<20> 4H <41> 2H <41> 4H <20>
004	127	0.244	95.20	9.73	0.288	0.510	17.50	1032	2.088	<21> 4H <41> 2H <41> 4H <21>
005	127	0.222	98.73	1.56	0.281	0.540	10.90	1032	2.430	<21> 2H <41> 4H <41> 2H <21>

Design 001

90.0%

50.0%

1.0%

Save Selected Designs as TFCalc Files...

Save List of Selected Designs in Text File...

Print List of Selected Designs

Print Plots of Selected Designs

Delete Selected Designs

Select All

Select None

Select Some...

Stop Searching

Done

One or more designs can be selected by clicking in the checkboxes on the left side of the table; all designs can be selected by clicking the **Select All** button. Use the **Select Some** button to select designs based on some numerical criteria, such as Ripple < 0.5 and Width > 1.0. Selected designs can be printed, saved as a text file, saved as a TFCalc file, or deleted. Click the **Done** button to return to the previous screen.

An example of the **Select Some** dialog is shown below. This dialog is useful when many designs are found. It allows the designer to select designs based on numerical criteria. In the text box next to each property, the designer may enter a number such as > 100 or < 0.5. For example, to select all the designs having fewer than 200 layers, type < 200 in the text box next to "Layers". If a text box is blank, it means that the property is not used for selecting designs. In general, most of the text boxes will be blank.

Select Designs

Designs will be selected based on the following criteria:

Number of Layers:	< 200
Passband Width:	
Average T in Passband:	
Passband Ripple:	
Width at 50% T:	
Width at Isolation Level:	
GD Ripple (ps):	< 10
Max. E-Field, Squared:	
Shape:	

OK   Cancel