Optimize Structured LCD Backlight Components – Accurately and Quickly
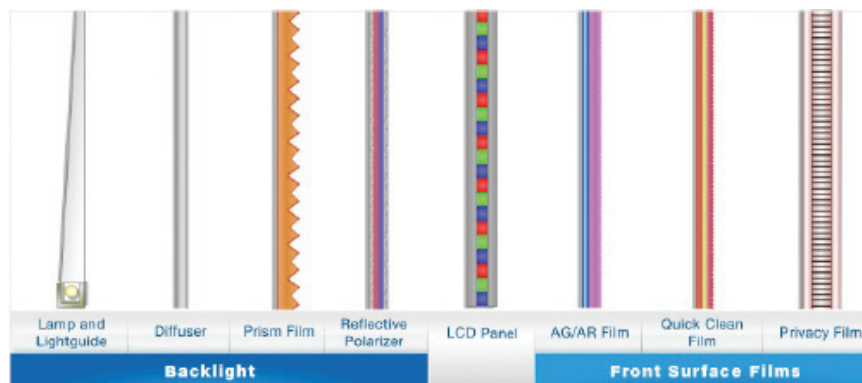
With TracePro® Opto-Mechanical Design Software's Textured RepTile™ Optimization Utility

TracePro's Textured RepTile Optimization Utility helps users optimize structured Liquid Crystal Display (LCD) back-light components including Brightness Enhancement Films (BEFs), Turning Films, and extraction features in light-guides. With a TracePro model of the LCD, the utility generates and optimizes a Textured RepTile surface property for uniformity or flux. While useful for optimizing structured backlight components, this tool can also be used to opti-mize any Textured RepTile in TracePro. The utility requires the most recent release of TracePro Expert 4.1.

The setup files and instructions for installation of the Textured Reptile Optimization Utility may be downloaded: http://www.lambdares.com/technical_support/tracepro/early_access/.

Liquid Crystal Displays (LCDs)

There are many types of LCDs differing in performance characteristics – brightness, color, viewing angle and contrast. Optical, electrical and mechanical engineers have an extensive toolbox of component and film alternatives when designing the LCD panel, its front surface films, and its backlight.

Courtesy of 3M Corporation

Predictive modeling of LCDs and LCD components with TracePro opto-mechanical design software enables adherence to performance, consistency and cost, without the cost and time associated with iterative hardware prototyping - including the very high costs of batch processing thin films, polymers, and semiconductor materials.

Predictive Modeling of LCDs

TracePro

TracePro is a comprehensive, versatile software tool for modeling the propagation of light in opto-mechanical systems. Models are created by importing design files from a lens design program or a CAD program or by directly creating the solid geometry in TracePro. Optical and mechanical properties are applied to materials and surfaces. Source rays propagate

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through the model with portions of the flux of each ray allocated for absorption, specular reflection and transmission, phosphorescence, and scattering.
From the model, analyze:

- Light distributions in illumination systems
- Lumens exiting, absorbing, and incident at the component and system levels
- Stray light, scattered light, and aperture diffraction
- Throughput, loss, or system transmittance
- Flux or power absorbed by surfaces and bulk media
- Polarization effects
- Birefringence effects
- CIE plots and Candela distributions
- Optical efficiency, luminance and radiance metrics
- Fluorescence effects of phosphors in white light LEDs

## Modeling LCD Components
LCD Panels
An LCD panel consists of a liquid crystal sandwiched between two polarizers. By varying the voltage applied to the liquid crystal in combination with the polarizers, varying shades of grey pixels are created. With the addition of a color filter, each red, green and blue subpixel is individually controlled, allowing varying amounts of red, green, and blue.

In addition to the spectral throughput characteristics of filters, TracePro has the ability to accurately model the polarization extinction ratio, the absorbance, and the temperature dependence for the breadth of polarizers used in LCDs including iodine and organic dye stained polyvinyl alcohol (PVA), chemically altered PVA and wire grid.
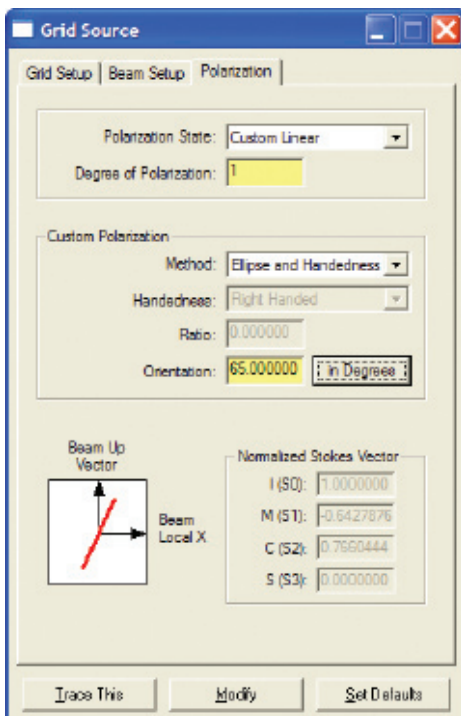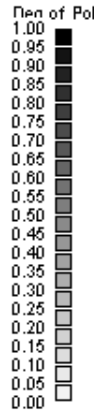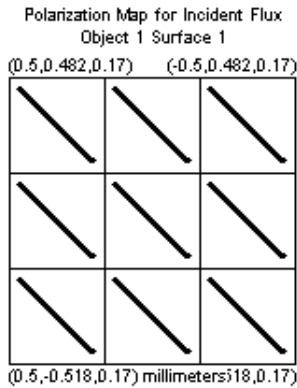

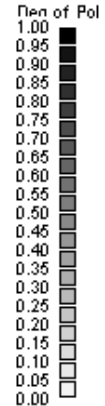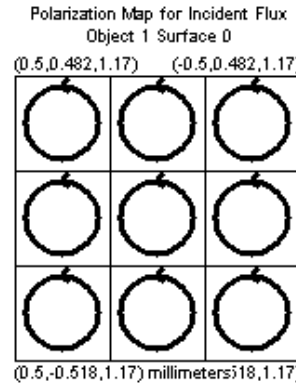Illumination source specifying polarization state
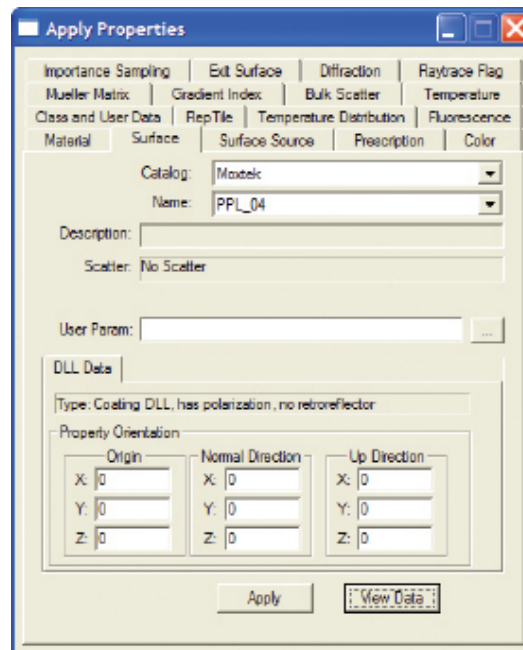
Moxtek wire grid polarizer database

TracePro's Polarization Maps map the polarization ellipse for the incident flux on to any selected surface in the model.


Polarization map: linear at 45 degrees

Polarization map: circular polarization

Front Surface Films

Front surface films may be applied to an LCD panel to enhance its performance - anti-glare coatings that scatter light and anti-reflective films that reduce reflections improve the readability under brightly lit conditions – and privacy films that control the direction of light make images visible only from direct viewing angles.

TracePro has the ability to accurately model films by either specifying the thin film stack layer prescription or specifying the reflection, transmission, absorption for each wavelength, incident angle, polarization, and temperature.
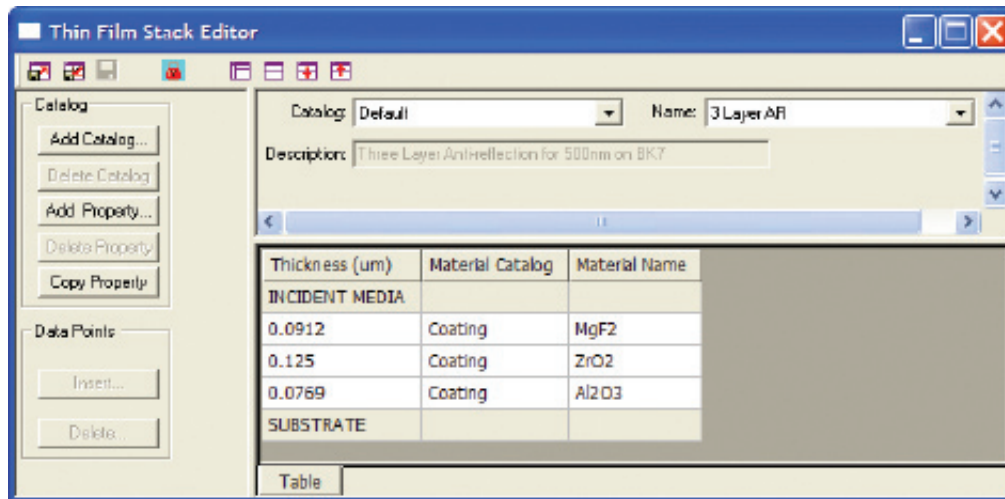
Thin Film Stack Editor: 3 layer anti-reflection coating

Backlights
Sources
Illumination sources are selected based on the balance of color, power consumption, size, and cost. They include ambient sunlight, cold cathode fluorescent lamps (CCFLs), arc lamps, and Light Emitting Diodes (LEDs). With TracePro, the user can define sources or rays that launch into the model for ray trace, choose from a database of commercially available sources, or with the Surface Source Property Utility, read the spectrum and angular radiation pattern directly from the source manufacturer's datasheet.

Enhancement Films
Enhancement films optimize the angular direction and polarization of the uniform light exiting the lightguide and the diffuser to maximize the display's brightness. Lamp cavity reflectors maximize the light entering the lightguide. Reflectors increase the recycled light reflected from the rear of the backlight. Prism films that include Brightness Enhancement Films (BEFs) and Turning Films optimize the angle of light exiting the display such that most of it is directed toward the viewer. Reflective polarizers optimize the polarization state to minimize the amount of light lost by the LCD panel's absorbing polarizers.
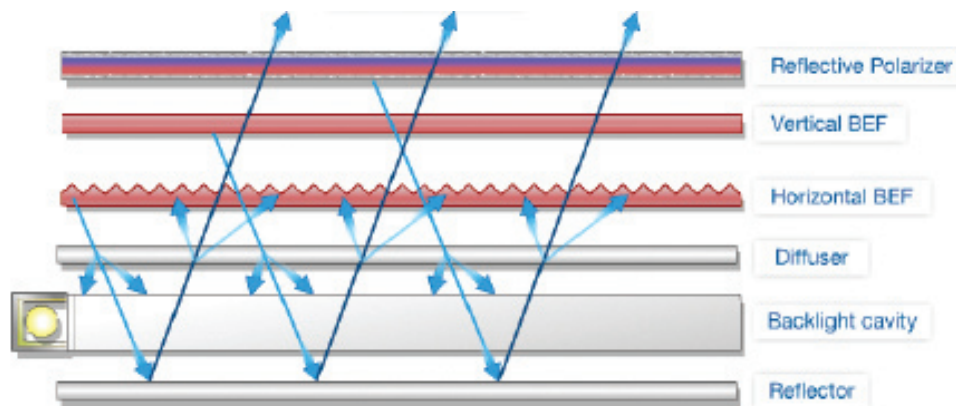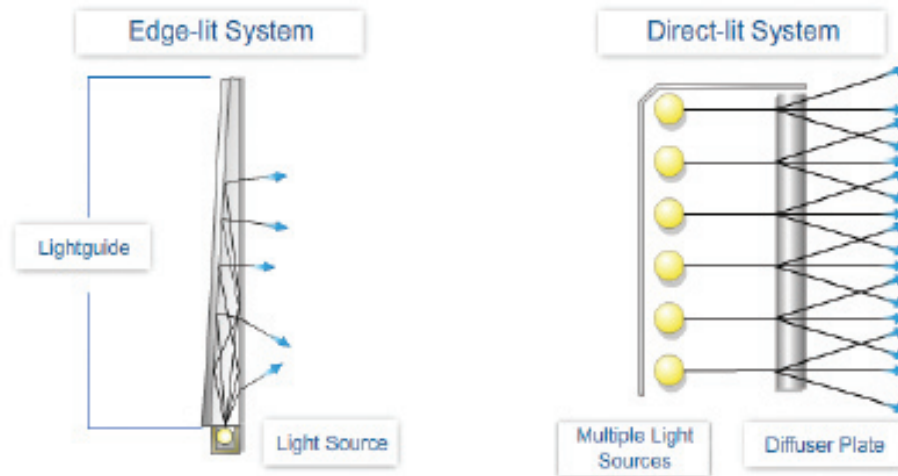

Courtesy of 3M Corporation

Diffusers, reflectors, and reflective polarizers may be modeled in TracePro with the same methods as described for Front Surface Films and absorbing polarizers above. Referencing below, prism films with textured geometric structures may be quickly modeled and raytraced with TracePro's Textured RepTile feature.

Lightguides and Diffuser Plates
Uniform illumination is achieved with a lightguide or a diffuser plate in edge lit or direct lit LCD systems. TracePro has the capability of modeling lightguides and diffuser plates and analyzing uniformity at any plane in the LCD model.

Courtesy of 3M Corporation

A wedge lightguide uses Total Internal Reflection (TIR) failure to uniformly illuminate a display. Hybrid lightguides may include extraction features to improve uniformity and/or linear prisms to reduce the angular spread of the extracted light. Referencing below, extraction points and prism films with textured geometric structures may be quickly modeled and raytraced with TracePro's Textured RepTile feature.
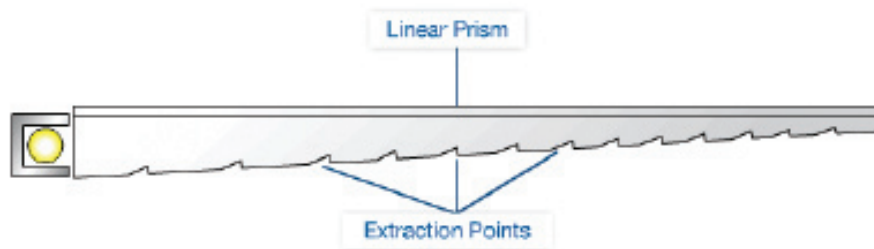

Courtesy of 3M Corporation

Modeling Structured LCD Backlight Components

Textured RepTile

The RepTile feature within TracePro allows users to place repetitive structure on planar surfaces with different geometric patterns and without the need to develop each geometric element individually. It is possible to create constant or parameterized geometry within the repetitive tiles within the defined surface property boundary. The enhanced Textured RepTile feature allows users to create random arrays of RepTiles, multiple RepTiles per cell, and/or more complex parameterization for the placement and shape of structured features.
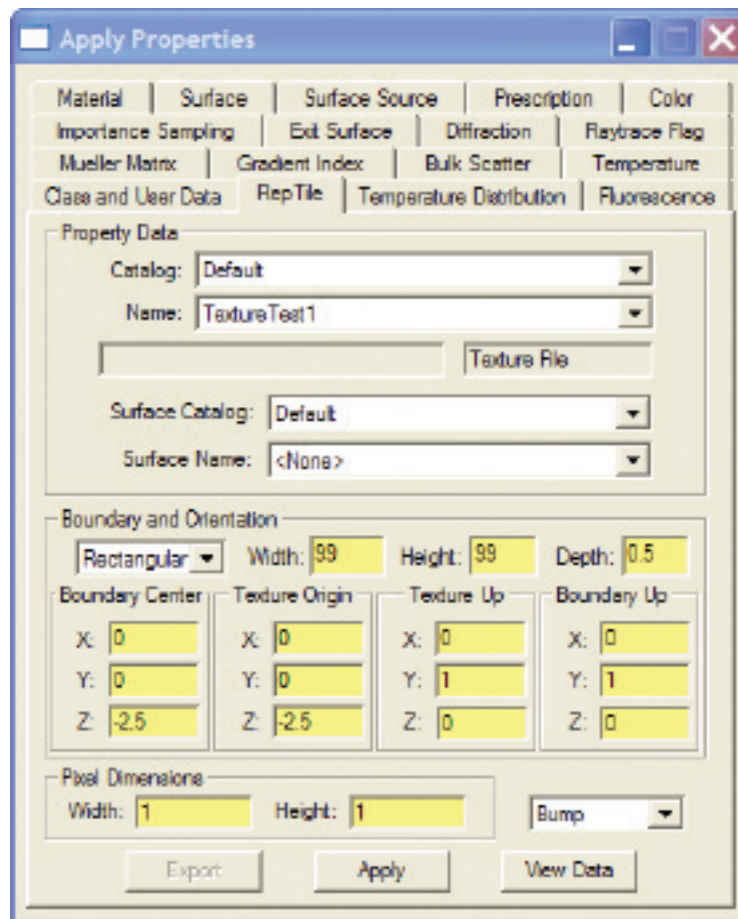

Specify boundary, orientation and texture of RepTile surface property

TracePro Textured RepTile Optimization Utility

TracePro's Textured RepTile Optimization Utility generates and optimizes a Textured RepTile surface property for uniformity or flux. The utility requires the most recent release of TracePro Expert 4.1. The setup files and instructions for installation may be downloaded: http://www.lambdares.com/technical_support/tracepro/early_access/.

Architecture
The user interface includes three panels – "Texture Generator", "Optimization Control Panel", and "Target Map". Optimization is based on an algorithm that assumes the irradiance is directly proportional to the density of the texture. Values in the irradiance map are used to predict the subsequent texture density value with a linear relation at each simulation.
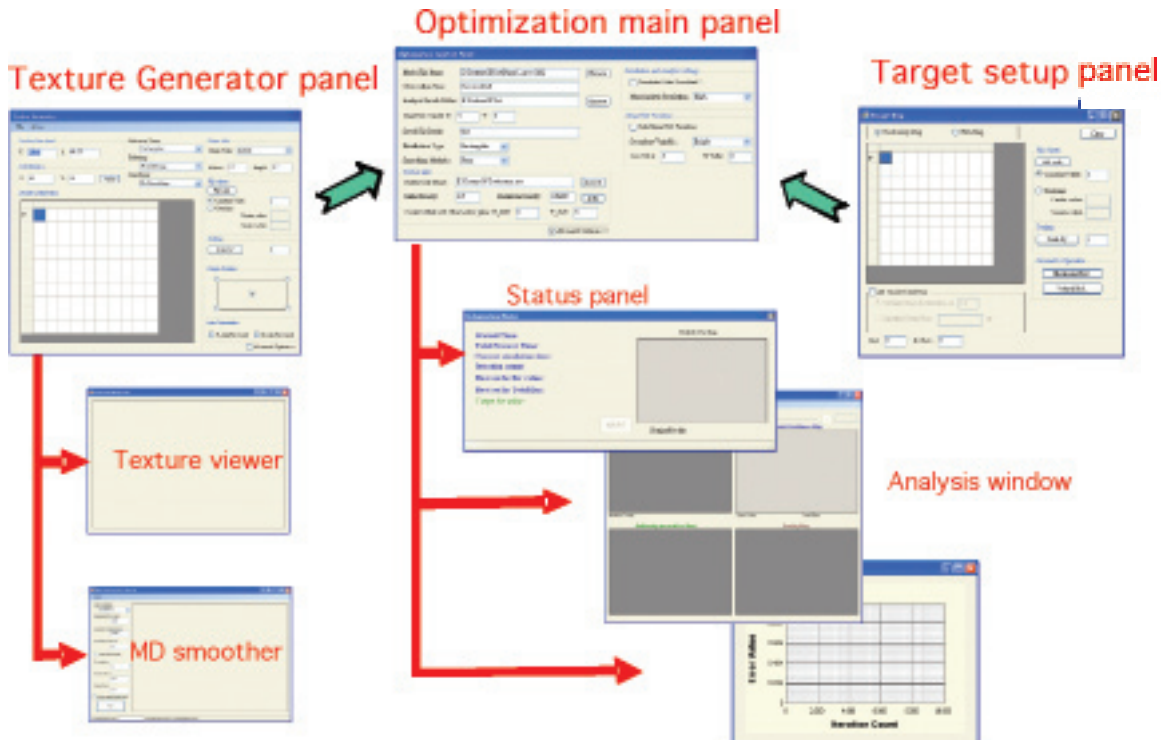
Architecture of Textured RepTile Optimization Utility

Target Map
In the "Target Map", the user specifies the uniformity or flux optimization targets. When optimizing for uniformity, specify "Uniformity Map" and input values in "Grid View"; these values will be normalized as the targets for optimization. Similarly, when optimizing for flux, specify "Flux Map" and input values; these values are the amount of flux obtained in the irradiance map and will be the targets for optimization. The number of rows and columns is specified in the lower left corner of the panel in "Col:" and "Row:".
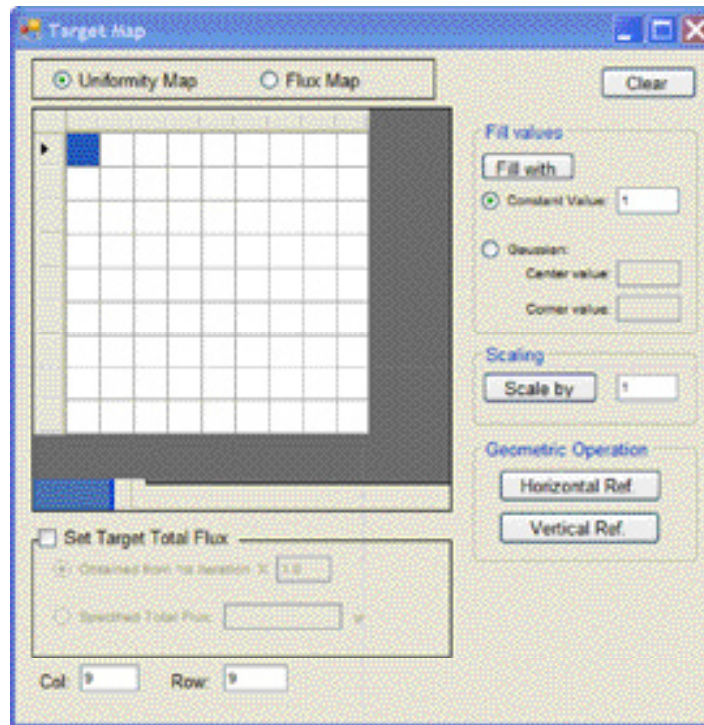
"Grid View" of Target Map with uniformity optimization targets

When using the "Uniformity Map", there is an option to "Set Target Total Flux". When selected, the flux for each cell will be automatically calculated based on the input value of total target flux. Total target flux may be specified as a scaled factor of the total flux obtained from the 1st iteration of the optimization routine by selecting "Obtained from 1st iteration X" and by entering the scale factor in the adjacent data field. Total target flux may also be defined by selecting "Specified Total Flux" and entering the value in Watts.

Additional features for editing the "Target Map" include:
- Shift + mouse click to select a rectangular range of cells
- Ctrl-V to paste copied data from clipboard
- In "Fill values", specify a "Constant Value" for all cells
- In "Fill values", specify a uniform "Gaussian" distribution by specifying "Center Value" and "Corner Value"
- In "Geometric Operation", mirror selected cell values either horizontally or vertically, by selecting "Horizontal Ref." or "Vertical Ref."
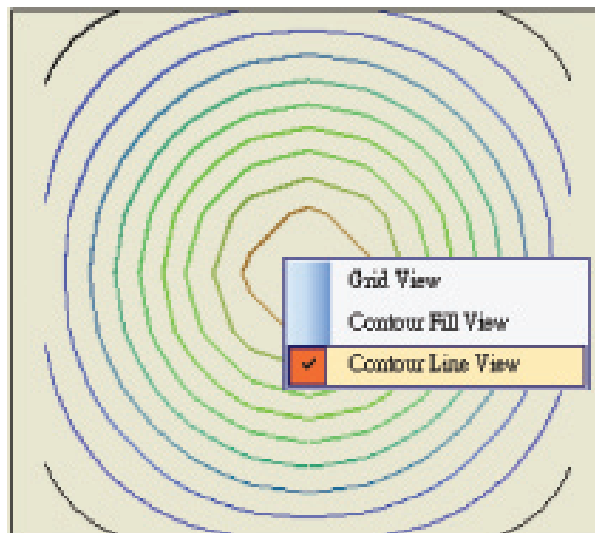
Options in addition to "Grid View" for viewing the map include "Contour Fill View" and "Contour Line View". These options are accessible with left mouse click on map window.
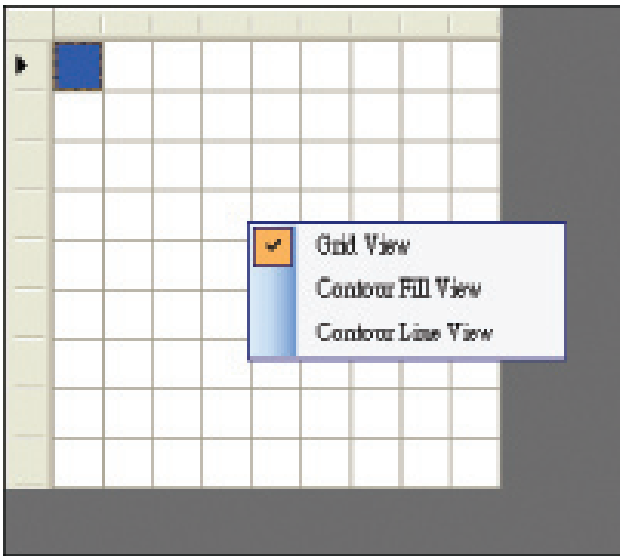
Grid View
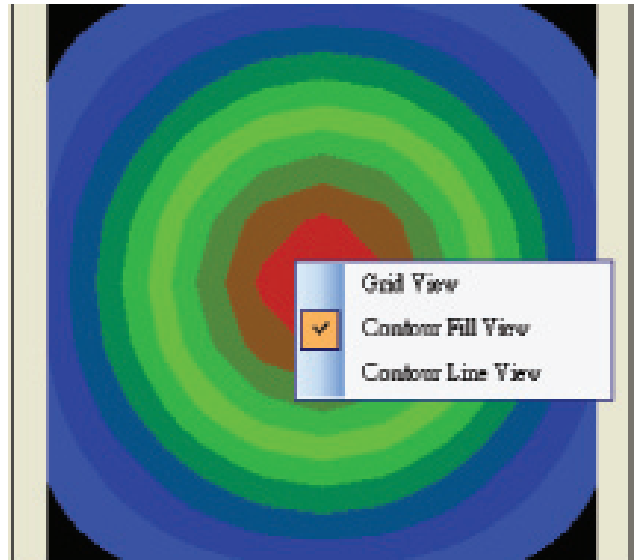
Contour Fill View

Contour Line View

Texture Generator

In the "Texture Generator", the user specifies and then generates a TracePro Textured RepTile file that is the starting point optimization.

Texture Generator Panel
The user generates the texture file by first specifying Textured RepTile characteristics. The size of the map used to generate the texture is defined in millimeters in the upper left corner of the panel, "Texture Size". The number of rows and columns within the map are defined just below in "Cell Number". After defining, click "Apply". Reference below to see the corresponding texture defining values in the Optimization Utility and TracePro.
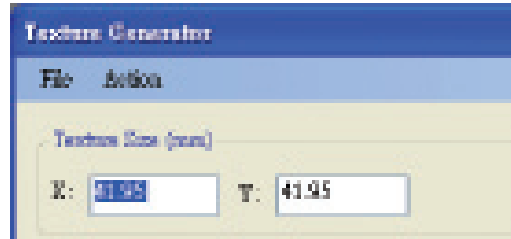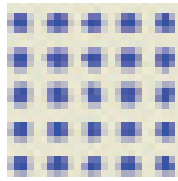

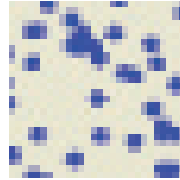Defining texture in Optimization Utility's "Texture Generator"
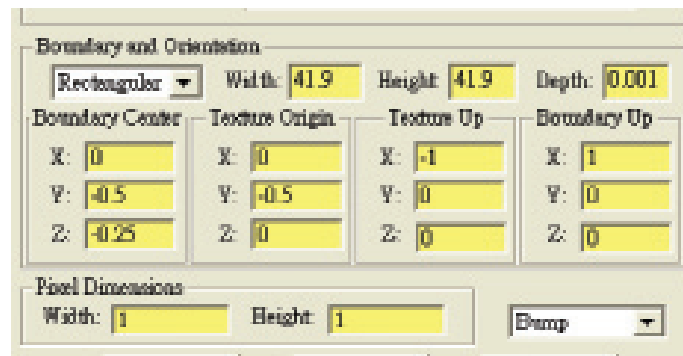
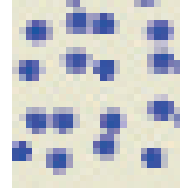Defining texture in TracePro's Textured RepTile surface property

Patterning Shape
The pattern is selected from the drop down list in "Patterning Shape". Options include rectangular, hexagonal, random, staggered grid, and fixed position.
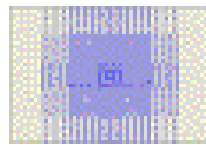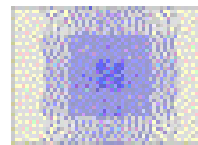

Rectangular   Hexagonal   Random

A "StaggerGrid" patterned shape is a rectangular grid pattern with a sine function applied in both X and Y directions. The frequencies and amplitudes of the sine function are determined by internal coefficients and are not user editable.


Rectangular   StaggerGrid

A "FixedPosition" patterned shape allows the user to vary the shape's dimensions. Specify the dimension to vary from the "Variable" drop down list – "Radius", "Height" or set the height and radius equal with "Radius=Height". Specify in "Unit Size", the dimensions of each shape. Note that the height dimension of a "Thin Cone" shape is fixed at 0.001mm and thus, the height dimension may not be varied.
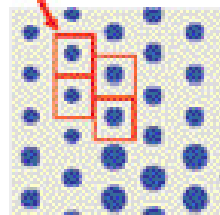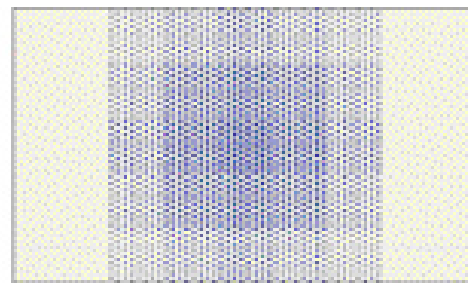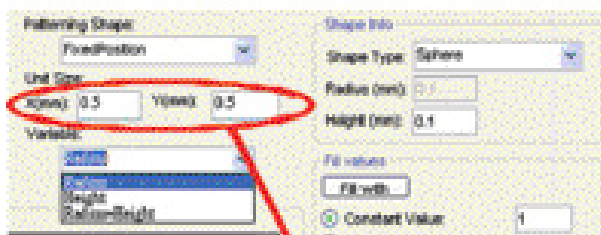
FixedPosition patterned shape generator

Dithering
Dithering is enabled or disabled from the drop down list in "Dithering". Options include "limited" or "random". With dithering disabled, dot locations will remain fixed after applying patterned shape settings. With limited dithering, dot locations will change but within the boundary condition of its density value. With random dithering, dot locations will change but only within the boundary condition that the number of dots remains constant. Fundamentally, this is termed "Molecular Dynamic Smoothing" and is equivalent to the smoothing operation performed in "MD Smooth" of the "Texture Generator" tool bar.

Smoothing
Smoothing is enabled or disabled and smoothing algorithms are selected from the drop down list in "Smoothing". The "HomogeneousXY" algorithm changes the cell size for each dot based on its neighboring densities. This algorithm is suitable only when density values change homogeneously in each X and Y directions. Refer to "MD Smooth" of the "Texture Generator" tool bar for an additional smoothing alternative.

Shape
The shape of the texture structure is defined in "Shape Info". Select "Sphere" or "Thin Cone" from the drop down menu in "Shape Type". Specify the dimensions in millimeters in "Radius" and "Height". Note that a "Thin Cone" shape is used to model ink printing on illuminated key pads and signage. Referencing below, the cone geometry in TracePro has several parameters. For simplicity, these parameters are fixed when specifying "Thin Cone" to reflect those representative of ink printing. The height is fixed as 0.001mm; the cone angle is fixed at 0.01 degree; the chamfer height is 0.0001mm; and the chamfer angle is fixed at 89.9 degree.
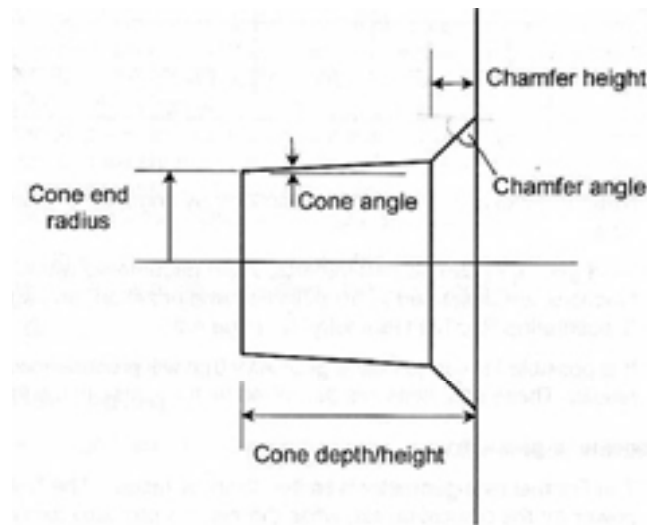
"Thin Cone" geometry representative of ink printing

Positioning
The positioning of the texture is controlled in "Origin Position" and "Axis Orientation". "Origin Position" determines the coordinates of the origin and boundaries as specified in TracePro's RepTile surface property. For example, if the texture size is 10mm x 10mm and the center of the box in "Origin Position" is selected, the coordinates of the top-left and bottom-right boundary will be (-5, 5) and (5,-5) respectively. Similarly, if top-left corner of the box in "Origin Position" is selected, the coordinates of top-left and bottom-right boundary will be (0,0) and (10,-10) respectively. The default "Axis Orientation" occurs when neither "Y Axis Reversed" nor "Y Axis Reversed" are selected and corresponds to a positive rightward X direction and positive upward Y direction. Selecting "Y Axis Reversed" and/or "Y Axis Reversed" reversed the orientations. The purpose of

this option is to overcome accommodate assumption made as to which side of the surface the texture resides in the real 3-D world.

Top Menu Bar

File, viewing, and smoothing functions are accessible from the top menu bar are. It is possible to load and save Density Map files. Density map files may be created in third party software programs and imported as *.den files. It is also possible to "Export" and "View" the Textured RepTile file by selecting "Export TextureFIle" and "View TextureMap".
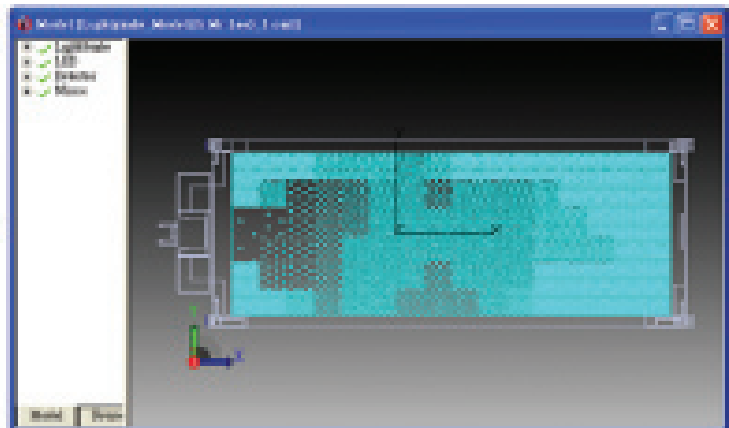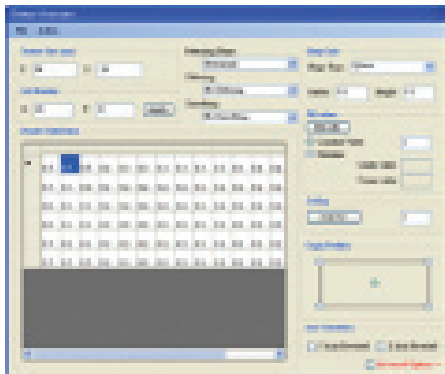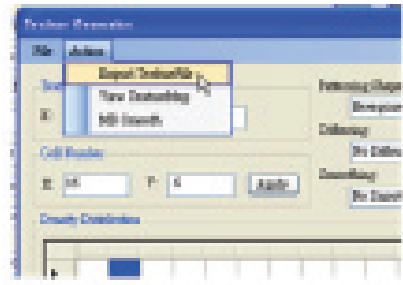
Export generated texture
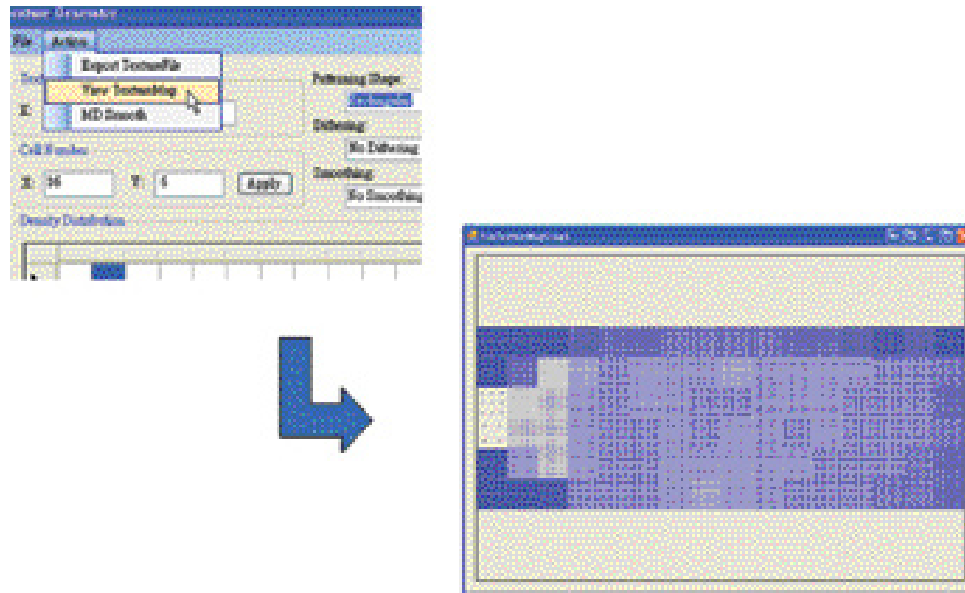
View generated texture

It is possible to smooth the active Textured RepTile by selecting "MD Smooth" from the "Action" drop down menu. This algorithm generates a smoother pattern without the homogeneous density limitations that apply to the "HomogenousXY" smooth option in the "Smoothing" drop down list found in the "Texture Generator" panel. It applies molecular dynamic theory. For more information regarding this smoothing method, refer to Random-dot pattern design of a light guide in an edge-lit backlight: integration of optical design and dot generation scheme by the molecular-dynamics method; Jee-Gong Chang and Cheng-Tai Lee of National Center for High-Performance Computing, No. 28, Nan-Ke 3rd Road, Hsin-Shi, Tainan, Taiwan; Vol. 24, No. 3/March 2007/J. Opt. Soc. Am. A.

To implement smoothing based on the molecular dynamics algorithm, select "Random" from both "Patterning Shape" and "Dithering" drop down lists. Select "MD Smooth" from "Action" in the Top Menu Bar of the Texture Generator panel. Ignore the paramenters in the "Molecular Dynamics Smooth" form and select "Start". The user may view the progress of the optimization in the "Molecular Dynamics Smooth" window.

Optimization Control Panel

In the "Optimization Control Panel", the user specifies information about the TracePro model in that the generated Texture RepTile property will reside. The path to the TracePro model is specified in "Model File Name". Each step and final results of the optimization are saved to a folder specified in "Analysis Results Folder". The user may specify a file prefix to be added to each saved data file in "Saved File Prefix".

In "Texture info", specify the path to the TracePro *.txt texture file in the user's database. Specify the density starting point and maximum density for the optimization in "Initial Density" and "Maximum Density". Click "Auto" to automatically calculate "Maximum Density" based on "Input the minimum spacing for texture" specified by the user in the pop-up dialog box.

The observation plane in the TracePro model on which the irradiance analysis will be done is specified in "Observation Plane". Specify the horizontal and vertical offset of the texture from the Observation Plane in "Central offset with Observation plane".
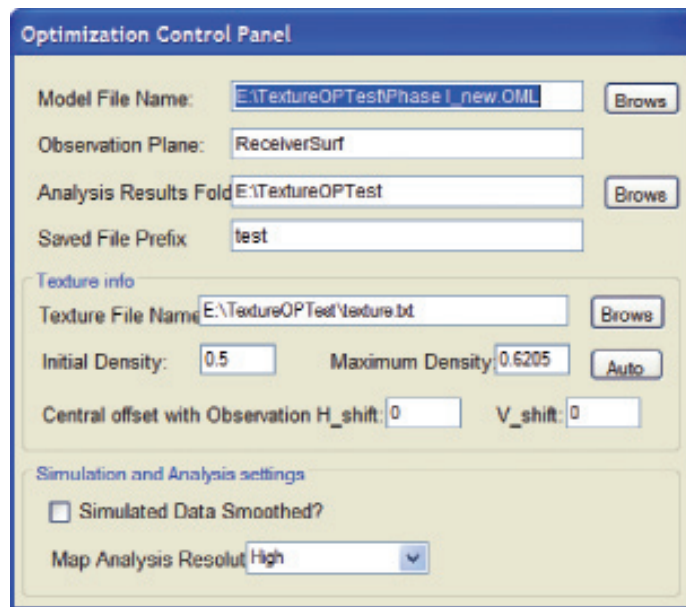

Optimization Control Panel
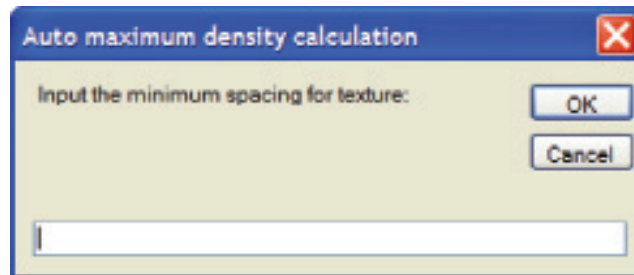
Auto calculate maximum density dialog box

Enable and disable the smoothing option and specify the resolution of TracePro's Irradiance setup with "Simulation and Analysis settings".

Texture Optimization Tool Bar
Optimization is initiated and paused with the red arrow and grey square buttons in the main Texture Optimization tool bar.
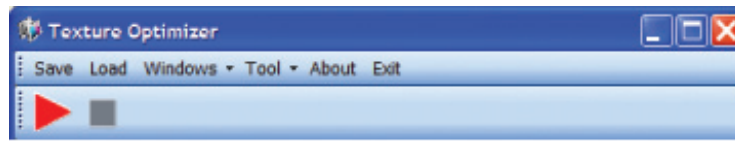

Texture Optimizer Tool Bar

Select "Save" to save the current panel settings to *.cfg configuration file. Select "Load" to load the saved configuration file. Select "Tool" to launch or abort TracePro, to bring TracePro to the front, or to make the Texture Optimizer form transparent.

Select "Windows" to open and close the three panels and view the trend and status of the optimization process. The user can monitor the optimization progress with three tools accessible from "Windows" in the main tool bar. With "Analysis – Last Iteration", the latest flux data, irradiance map, uniformity and texture density map are displayed. The user can opt for automatic or manual update and can view historical data from previous iterations via the slider.

In "Analysis – Last Iteration" window, the latest flux data, irradiance map, uniformity and texture density map are displayed. The user can opt for automatic or manual update and can view historical data from previous iterations via the slider. Select Grid View, Contour Fill View or Contour Line View by right mouse clicking on any of the sub-windows.

On completion of the optimization process, in the menu bar of the "Analysis – Last Iteration", it is possible to load the historical log of all iteration results, _History.Log, from the results folder specified in "Optimization Control Panel". In the "Optimization Status" window, compare the results of the best optimization iteration with the target values. The window displays the irradiance map of the optimum iteration.
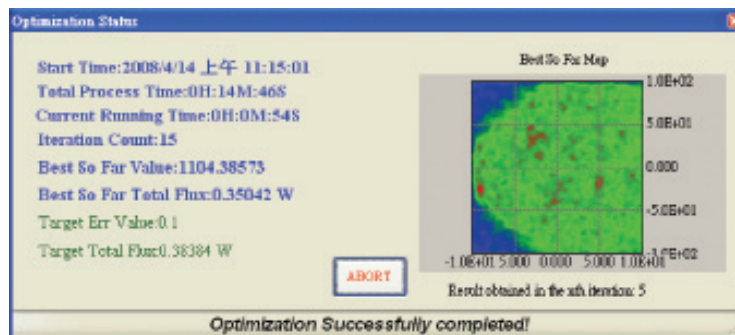
Optimization Status window displaying results of iteration most closely teaching criteria specified in "Target Map" panel

In the "Trend Chart" window, view the Error Value trend over iteration count. Right mouse click on area outside chart to change the scale of the chart or copy the data to the clipboard. Additional options include:

> • Left mouse click on chart and move mouse to translate chart
> • Double mouse click to auto-zoom the chart
> • Right mouse click and move mouse to define the zoom range
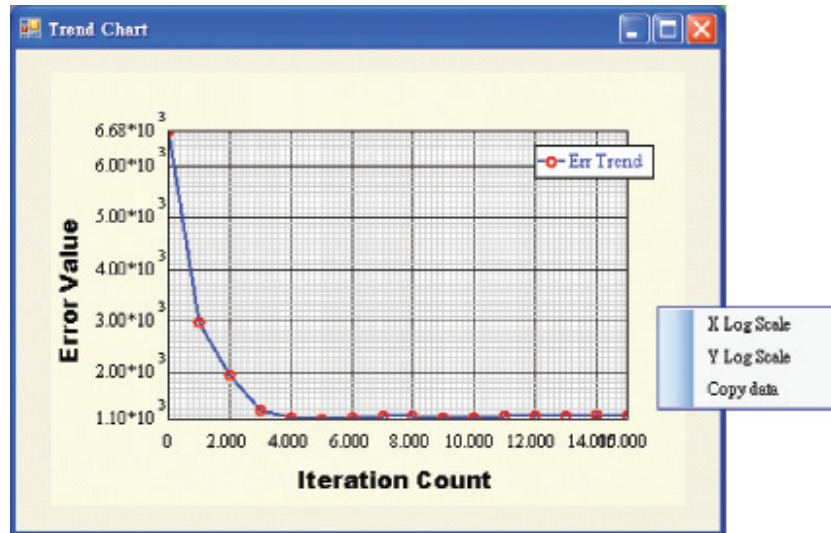
Saved Optimization Data
TracePro and Optimization Utility results data is saved to the folder specified in the "Optimization Control Panel". Saved data includes:
> • TracePro irradiance map, *.bmp
> • TracePro texture file for each iteration, _texture.txt
> • Optimization Utility density map for each iteration, * .den
> • Optimization Utility matrix values for each iteration from the "Analysis – Last Iteration"
>   window including flux data, irradiance map, uniformity and texture density map, *.map
> • Optimization Utility results of best iteration, _BestSoFar.*
> • Optimization Utility historical log that can be loaded from the menu bar of "Analysis – Last Iteration"
>   window, _History.Log

## Optimizing Structured LCD Backlight Components

TracePro's Textured RepTile Optimization Utility helps users optimize structured LCD backlight components including Brightness Enhancement Films (BEFs), Turning Films, and extraction features in light guides.

LCD Backlight Light Guide

A step-by-step example using the Textured RepTile Optimization Utility to optimize the uniformity of LED illumination of an LCD Backlight Light Guide is given below. The TracePro model (Ex1.oml), the textured RepTile file (Ex1Texture.txt) and the Optimization Utility configuration file (Ex1Settings.cfg) may be downloaded from the TracePro Technical Notes page of www.lambdares.com/software_products/tracepro/tracepro/technical_notes/.
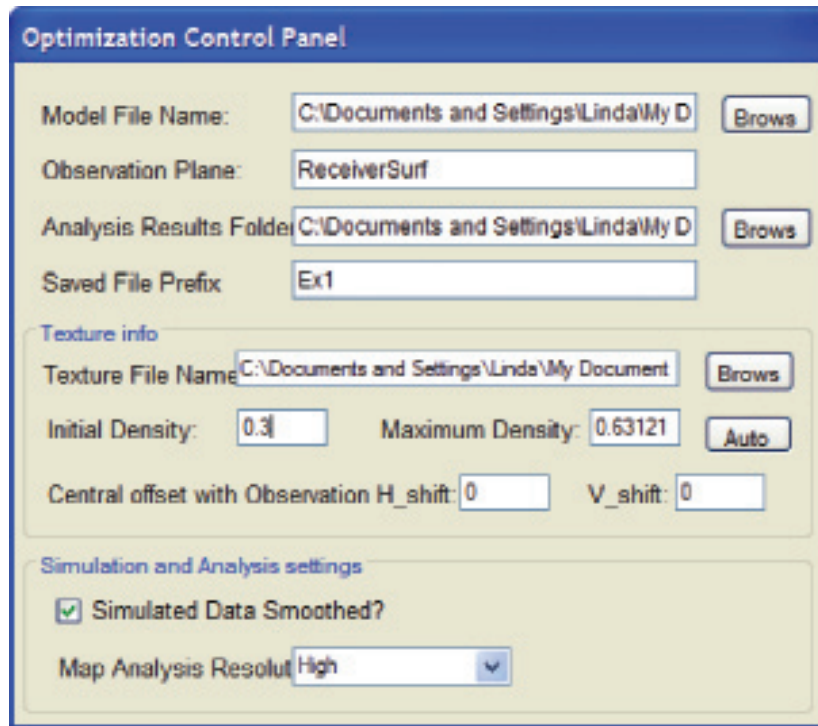
Setup

Select "Load" to load the downloaded configuration file, Ex1Settings.cfg. Select "Tool" to launch TracePro and then open the downloaded TracePro model, Ex1.oml.
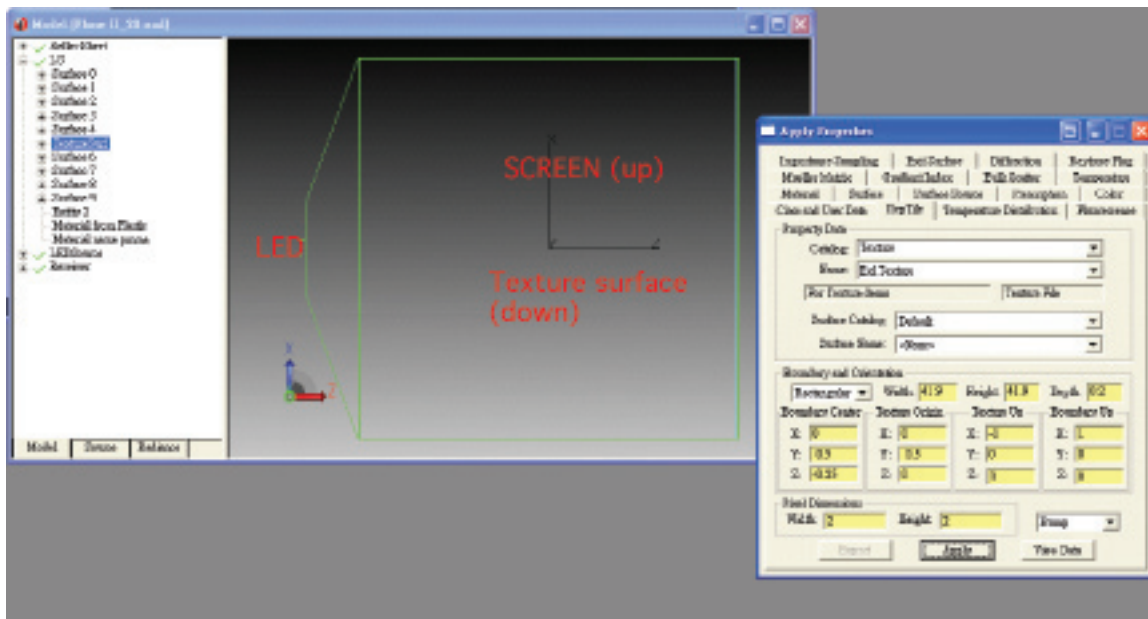
TracePro model Ex1.oml with RepTile Surface Property Data

Optimization Control Panel
In the "Optimization Control Panel", specify the file path to the TracePro model, the TracePro texture file and the folder to where the analysis results will be saved. The file prefix for the saved analysis files in this example is "Ex1".

Optimization Control Panel: LCD Backlight Light Guide Example

In "Texture info", the density starting point and maximum density for the optimization are specified as 0.3 and 0.63121 respectively. The observation plane in the TracePro model on which the irradiance analysis will be performed is specified with zero horizontal and vertical shifts from the Observation Plane.

In "Simulation and Analysis settings", simulated data smoothing is enabled and map resolution is set to high.

Target Map
In the "Target Map", normalized uniformity optimization target values are defined in the previously loaded configuration file, Ex1Settings.cfg.
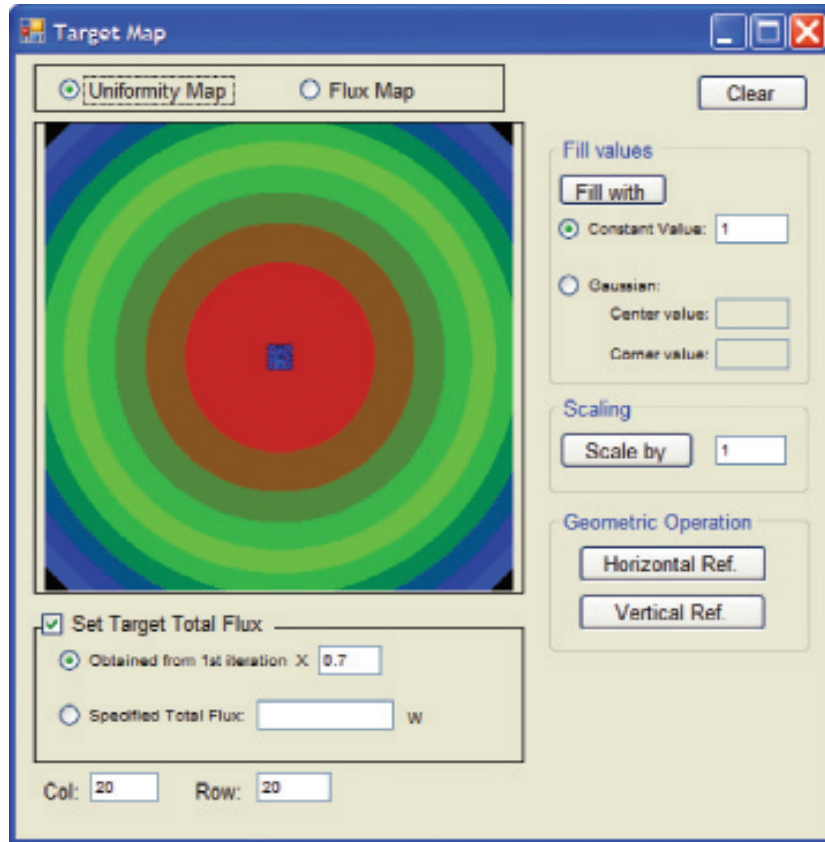

Contour Fill View of Target Map Panel: LCD Backlight Light Guide Example

The option to "Set Target Total Flux" is enabled so that the flux for each cell will be automatically calculated based on the input value of total target flux. The input target value of total flux is defined as 70% of that obtained from the 1st iteration of the optimization routine.

Texture Generator
In "Texture Generator", the Textured RepTile surface property characteristics are defined.
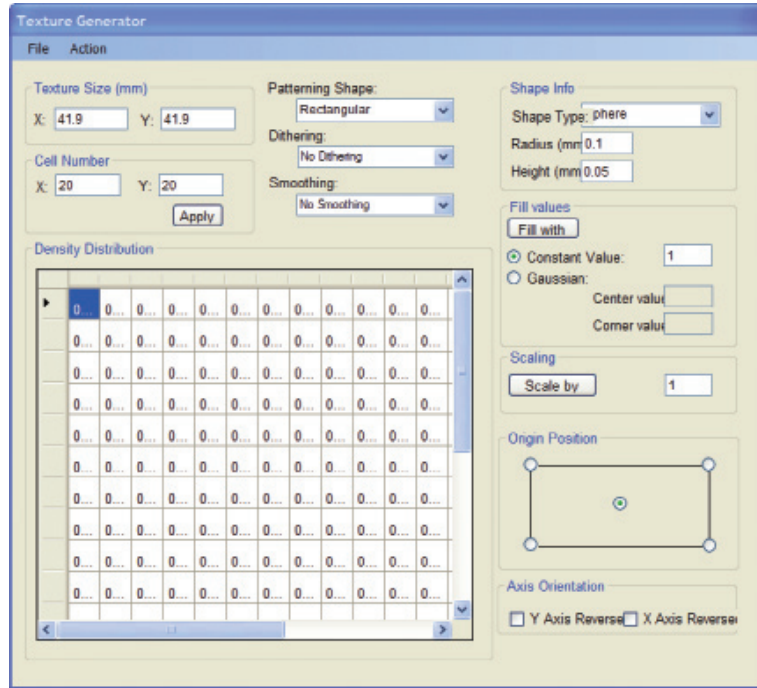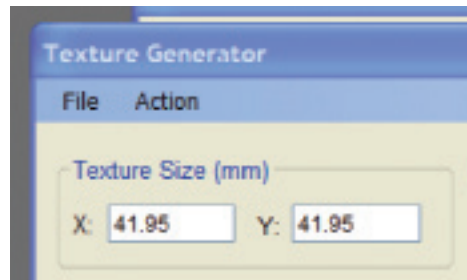

Texture Generator Panel

The size of the map used to generate the texture is defined as 41.9 x 41.9mm. These are the boundary dimensions of the TracePro textured RepTile surface property. The number of rows and columns within the map are defined as 20 x 20 – consistent with the definition in the "Target Map" panel.

The Patterning Shape is "Rectangular". Dithering and Smoothing are disabled. The Shape Type is "Sphere" with a radius of 0.1mm and height of 0.05mm. Texture origin position is set in the center which is the reference for coordinates of dots. Neither Y nor X axis reverses is activated.

Reference below to see the corresponding texture defining values in the Optimization Utility and TracePro.
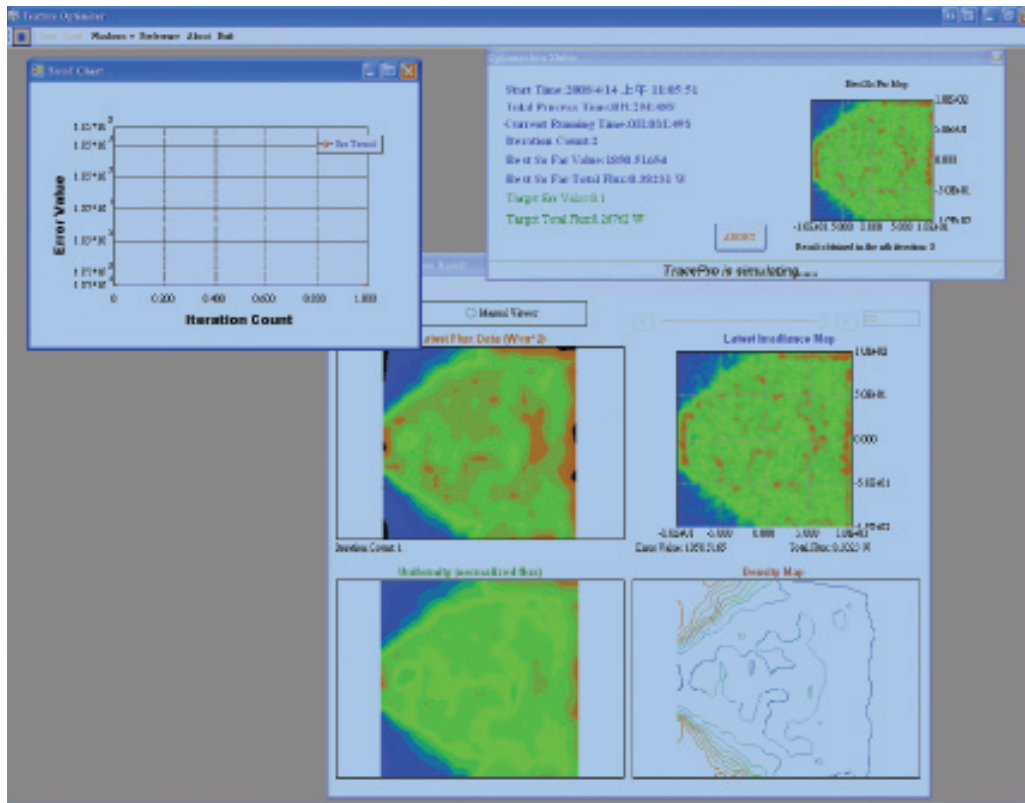

Defining texture in Optimization Utility's "Texture Generator"
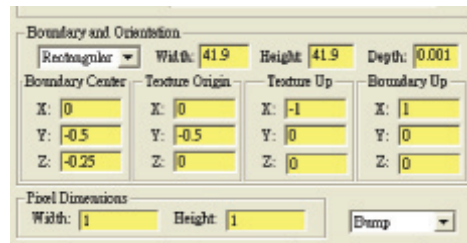
Defining texture in TracePro's Textured RepTile surface property

Optimization and Results
In the main Texture Optimization Tool Bar, select "Windows" and open "Analysis – Last Iteration", "Optimization Status" and "Optimization Trend". Then, initiate the optimization by selecting the Red Arrow.

Analysis – Last Iteration", "Optimization Status" and "Optimization Trend" windows display optimization progress and results

In the "Analysis – Last Iteration" window, view the flux data, irradiance map, uniformity and texture density map of the last optimization iteration. In this example, the window is updating automatically. In the "Optimization Status" window, compare the results of the best optimization iteration with the target values. The window displays the irradiance map of the optimum iteration.

In the "Trend Chart" window, view the Error Value trend over iteration count. In this example, the lowest error value is achieved at the fifth optimization iteration.

The optimized results for this example are below:
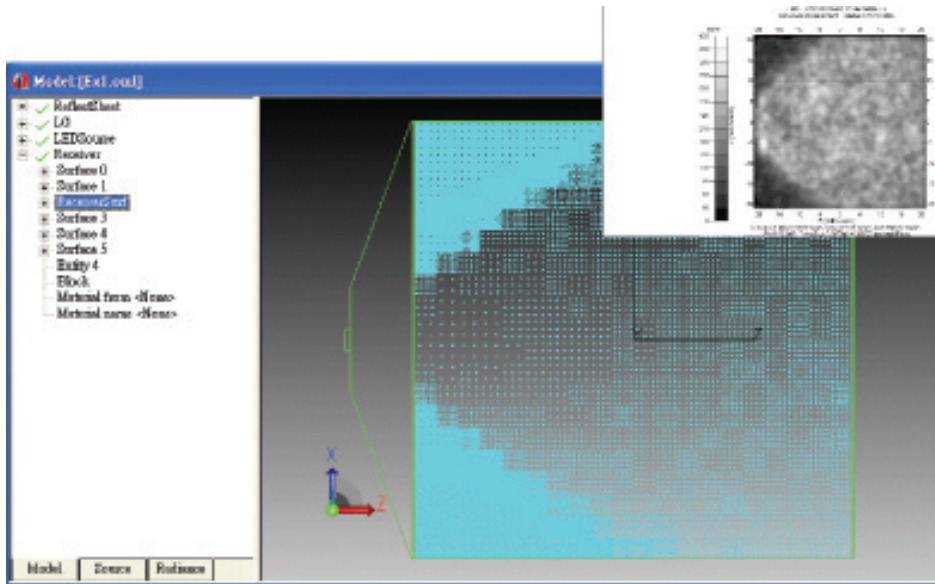
Optimization results for LCD Backlight Light Guide example

This example did not yield a uniform irradiance map at the observation plane because the source was Lambertian and the optimization target included a target total flux criteria. Removing or lowering the total flux criteria in the "Target Map" panel will yield a more uniform irradiance map, but with lower flux.

Summary

TracePro's Textured RepTile Optimization Utility generates and optimizes a Textured RepTile surface for uniformity or flux. While useful for optimizing structured backlight components, this tool can also be used to optimize any Textured RepTile surface property in TracePro. In line with TracePro's simple, intuitive interface and short learning curve, the Utility allows users to quickly reach design criteria by generating textured RepTile texture starting points, testing alternatives, and automating optimization iterations. For more information, please contact Lambda Research's Application Engineers at sales@lambdares.com.