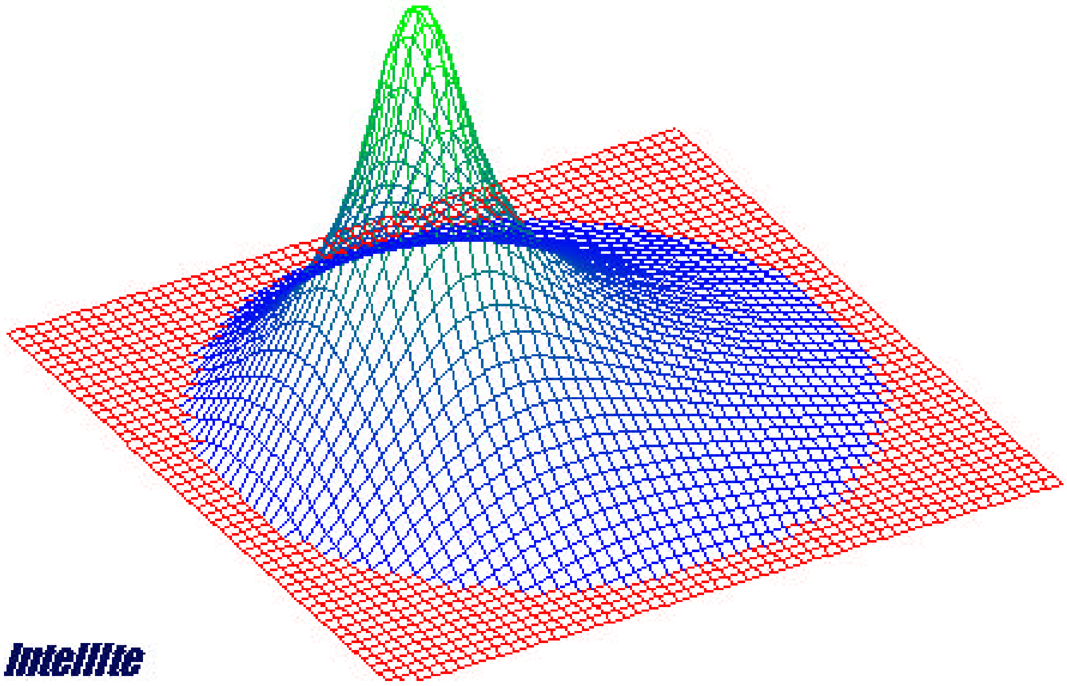
Deformable Mirror Modeling Software

Version 1.0

Intellite



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Introduction

Intellite's deformable mirror modeling software was designed to aid in the design of our patented micromachined deformable mirror technology, but it can be used to model virtually any continuous membrane deformable mirror. The modeling software begins by determining influence functions for a given mirror architecture. Influence functions are derived by actuating each actuator individually and storing the membrane response. The response of the mirror to voltage allows us to estimate the mechanical resonance frequency. The influence functions can be summed to determine the mirror surface shape for any configuration of voltages. The mirror surface can then be decomposed into its Zernike terms or into its own modes using single-value decomposition (SVD). Finally, Fourier transforming its electric field distribution allows us to calculate the far-field intensity profile of a beam after reflection from a deformable mirror surface.

Deformable Mirrors

The first step in using the modeling software is to choose a deformable mirror (DM) architecture. Second, specify the material parameters via the graphic user interface (GUI). This section will introduce the different deformable mirror architectures and how to enter the different mirror parameters.

The deformable mirror modeling software can model several different electrostatically actuated deformable mirror architectures, but generally these can be divided into two-layer and three-layer deformable mirrors (For now, the software is limited to only electrostatic force, but other forces can easily be added later). Figure 1 shows a cross-sectional view of four different types of two-layer and three-layer deformable mirrors. Figure 2 outlines nomenclature for two and three level mirrors.

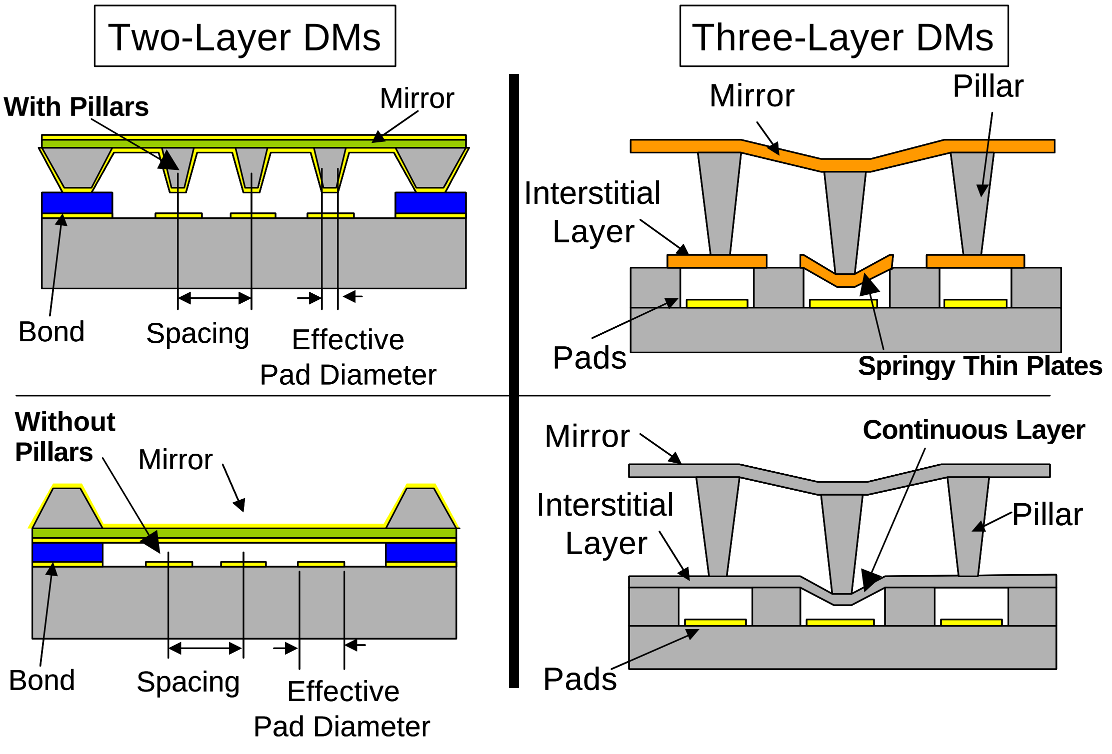


Figure 1 - Cross-sectional illustrations of two-layer and three-layer deformable mirror architectures.

Two-Layer Deformable Mirrors

Two-layer deformable mirrors, named for the mirror layer and the electrostatic pad layer, are characterized by the inability to provide any active restoring force. The most common two-layer deformable mirror is a simple membrane deformable mirror, like those developed by Perkin-Elmer[1] in the 1970's and by NASA's Jet Propulsion Laboratory[2] in the 1990's. Another type of two-layer deformable mirror is one in which pillars are attached to the reverse side of the mirror, like that developed at Stanford in the 1990's.[3] The attachment of the pillars facilitates fabrication while helping prevent snap-down damage and creates small stiff regions of the membrane. These stiff sections are modeled in the finite element analysis (FEA) code.

Three-Layer Deformable Mirrors

The three-layer deformable mirror provides a mechanical restoring force via the deflection of an interstitial layer that is added between the mirror and the electrostatic pads, and thus provides a more localized deflection. The three-layer deformable mirror architecture can be thought of as an array of mechanical springs attached to a continuous surface. When the springs are stiff compared to the continuous surface, like a piece of plastic wrap stretched over an array of bedsprings, a force downward on a single spring causes a distortion in the continuous surface, but the surrounding springs provide enough restoring force to localize the deflection. When the springs are weak compared to the continuous surface, like a plate of steel on an array of bedsprings, a force on the continuous surface above a single spring will cause a deflection of the plate that is no different than if the springs were not there.

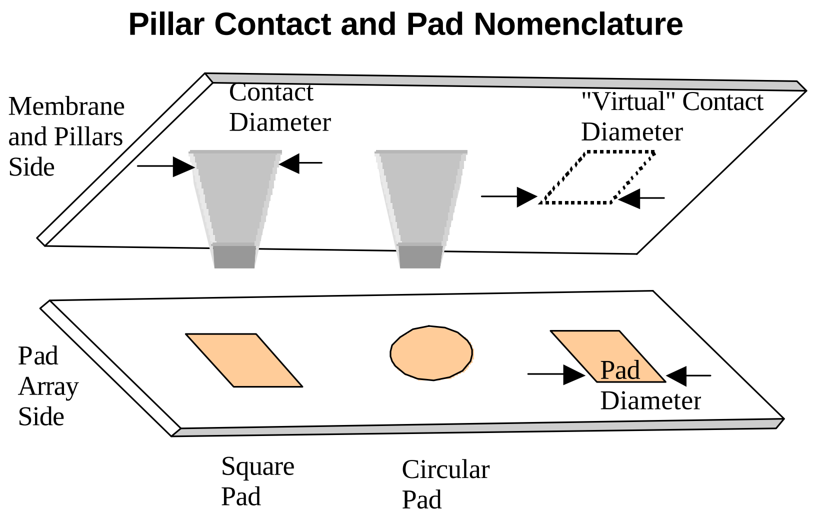


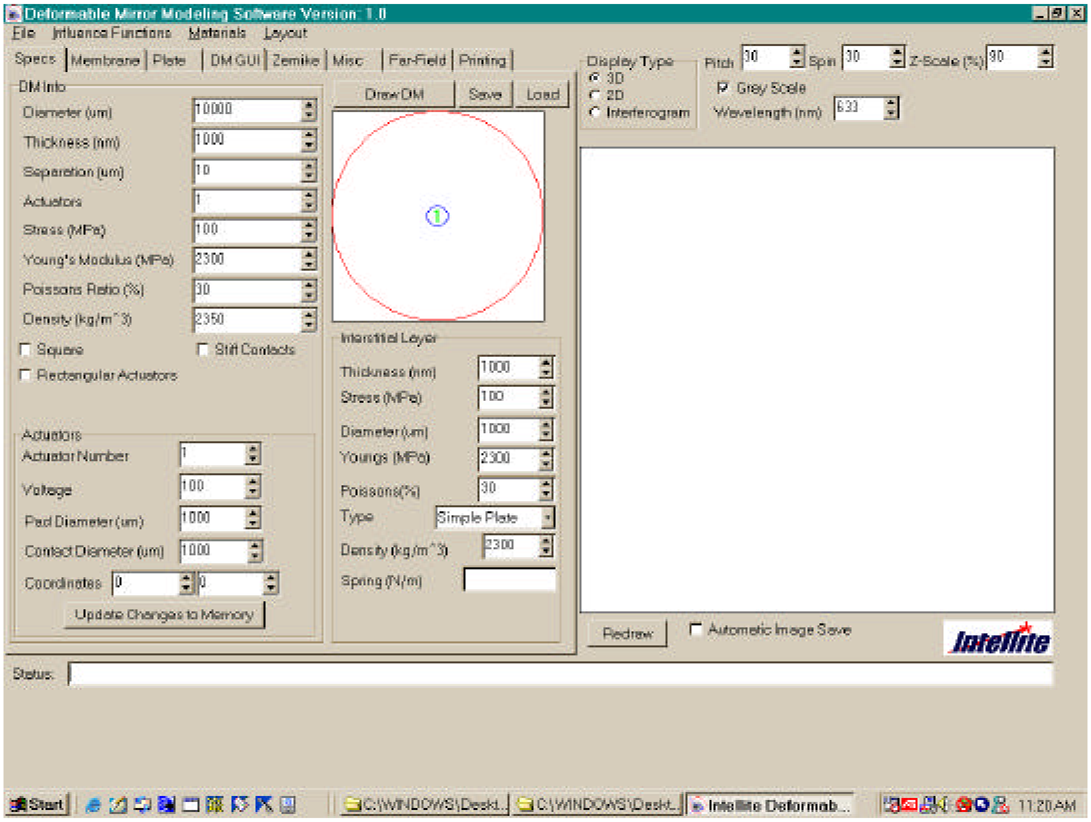
Figure 2 - Deformable Mirror Nomenclature

Getting Started

DMModel™ allows a micromachined deformable mirror customer to model their mirror and understand how the membrane-based mirror will distort and perform under varying electrostatic loads. The modeler can adjust the size, actuator placement, voltages, membrane material and thickness, and stress parameters.

Many advanced features are built into the program such as fitting the distorted membrane to Zernike coefficients and predicting how accurately the user's mirror will correct for their particular aberrations or distortions.

There are a great variety of display options that allow the user to visualize their membrane while activated, including a simulated interferogram option that should match the image from a laboratory based Michelson (or other) interferometer exactly. While the operational details of the code are long and involved, this section is meant to get an unfamiliar user to the point where simple models can be constructed. The user can then "experiment" with the options in later sections of this manual to discover the extensive capabilities of this modeling software.



DM Info
Diameter (um) 10000
Thickness (nm) 1000
Separation (um) 10
Actuators 1
Stress (MPa) 100
Young's Modulus (MPa) 2300
Poissons Ratio (%) 30
Density (kg/m^3) 2350
☐ Square
☐ Stiff Contacts
☐ Rectangular Actuators

Actuators
Actuator Number 1
Voltage 100
Pad Diameter (um) 1000
Contact Diameter (um) 1000
Coordinates 0 0

Interstitial Layer
Thickness (nm) 1000
Stress (MPa) 100
Diameter (um) 1000
Youngs (MPa) 2300
Poissons(%) 30
Type Simple Plate
Density (kg/m^3) 2300
Spring (N/m)

Display Type
● 3D
○ 2D
○ Interferogram
Pitch 30
Spin 30
Z-Scale (%) 90
☑ Grey Scale
Wavelength (nm) 633
☐ Automatic Image Save
Status:

Figure 3 - Main GUI Overview Screen

Once brought up, the DMModel™ code will display this initial screen, as shown in Figure 3. Notice the tabs along the top menu which allow a user to set up the particular physical geometry of their mirror, conduct user-selected analyses, and investigate a wide variety of model variations.

The “Specs” tab will initially show a default mirror design with one central actuator and 100v placed on the actuator pad. “Specs” allows the user to establish the physical description of the mirror that can be modified later as desired to do variational analyses.

In a general sense, the tabs can be selected in order to run through the mirror modeling effort.

First “Specs” is selected and adjusted to the user’s design.

Then “Membrane” is chosen to perform the modeling using the Finite Element Analysis (FEA) or other algorithms.

“Plate” is an alternative to “Membrane” that allows the user the capability to model the surface as a plate. Plates are generally thicker than membranes and have different bending dynamics.

“DM GUI” means Deformable Mirror-Graphical User Interface, this screen allows the user to quickly set up the voltages on the electrostatic pads using a select-then-mouse-click technique.

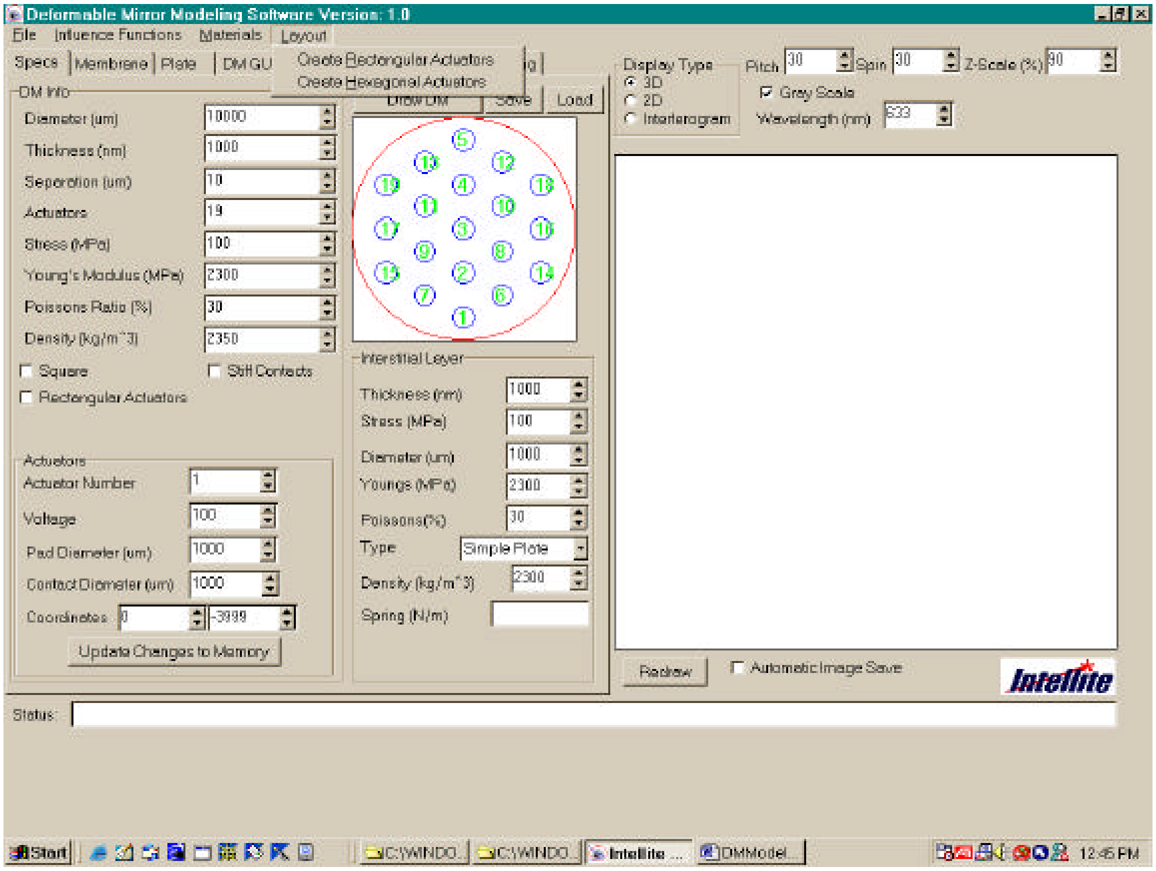
“Zernike” permits the user to do a Zernike analysis of the distorted mirror surface, after the Finite Element Analyses are run. Zernike polynomials are a standard set of orthogonal functions used commonly in optical analyses to separate or break down the aberrations into easily visualized and understood distortions. Focus (spherical) and coma are two examples of Zernike functions.

“Far-field” allows the user to propagate the beam reflected off of the distorted mirror into the far field, as to a focal point or to an infinite distance.

“Printing” permits printing of the important case descriptions and results.

The user can also select options that are positioned above the tabs. These include “File” which permits saving and reloading of prior cases; “Influence Functions” which allow the user to load previously calculated influence functions, greatly saving analysis time when cases are brought back; “Materials” which permits loading of a standard set of material properties into the “Specs” page based on selecting the material from a file listing; and “Layout” which eases the user’s design and layout of the actuator pads.

“Layout” is the usually the first user selection on the “Specs” page since it greatly facilitates laying out the pad array. The pad coordinates are automatically located based on standard hexagonal or rectangular geometries and uniform pad sizing and spacing.



DM Info
Diameter (um) 10000
Thickness (nm) 1000
Separation (um) 10
Actuators 19
Stress (MPa) 100
Young's Modulus (MPa) 2300
Poissons Ratio (%) 30
Density (kg/m^3) 2350
☐ Square
☐ Stiff Contacts
☐ Rectangular Actuators

Actuators
Actuator Number 1
Voltage 100
Pad Diameter (um) 1000
Contact Diameter (um) 1000
Coordinates 0 -3999

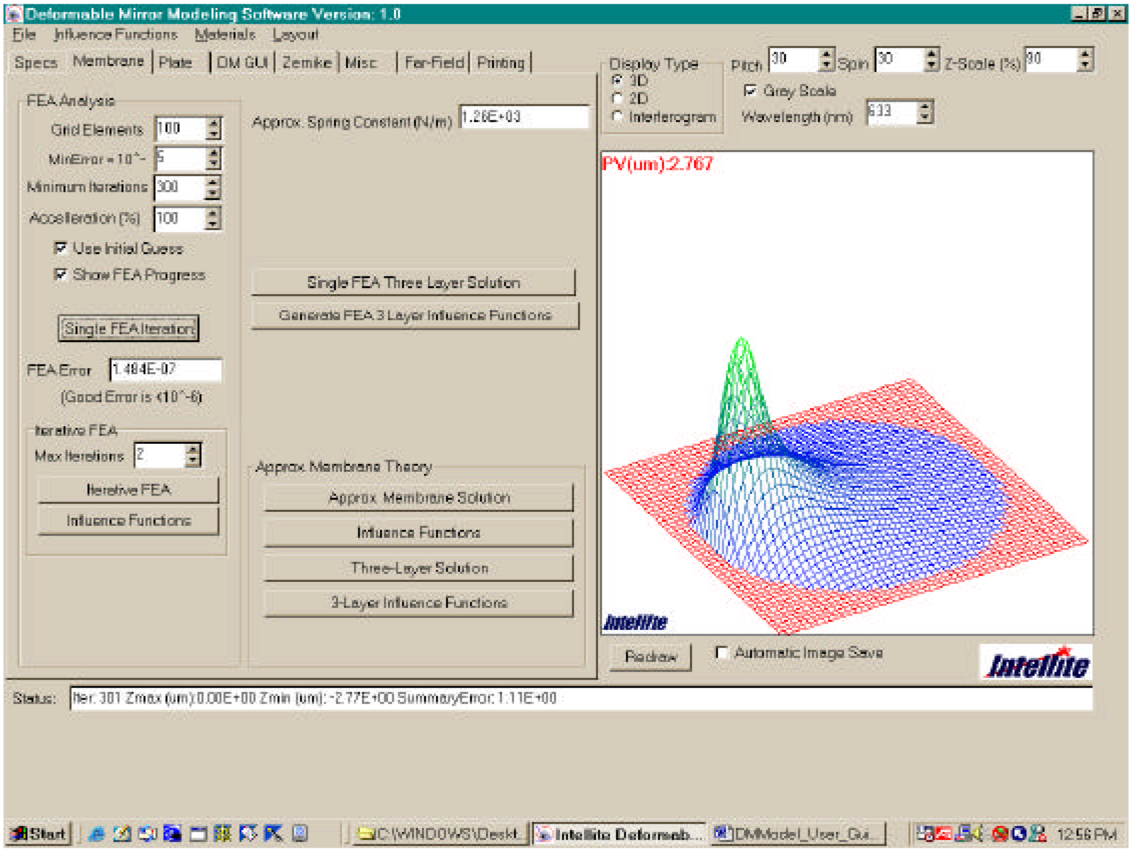
Interstitial Layer
Thickness (nm) 1000
Stress (MPa) 100
Diameter (um) 1000
Youngs (MPa) 2300
Poissons(%) 30
Type Simple Plate
Density (kg/m^3) 2300
Spring (N/m)

Display Type
● 3D
○ 2D
○ Interferogram
Pitch 30
Spin 30
Z-Scale (%) 90
☑ Grey Scale
Wavelength (nm) 633
☐ Automatic Image Save
Status:

Figure 4 - Specifications Tab Screen

The screen shot in Figure 4 shows the layout of the pads after “Create Hexagonal Actuators” was selected and three rings of pads were designed and automatically laid out. The pads are numbered and they are scaled to, and plotted onto, the mirror surface. The default shape is circular, but square membranes and rectangular actuators are possible with the check boxes on this page. Understand that manual changes to the pad locations can be made with the software on this screen, including the Pad Diameter (pads are on the backplane) and the Contact Diameter (the other electrostatic areas located on the back of the mirror surface.) Similarly, manual changes to pad voltages are possible. Select “Stiff Contacts” when pillars are attached to the membrane surface.

With the mirror design established, the next step is to call for a Finite Element Analysis (FEA). The user should select the “Membrane” tab, and select one of the FEA buttons. The single FEA will give a quick approximation to the distortion as seen below, but the “Iterative FEA” button will result in more accurate models.



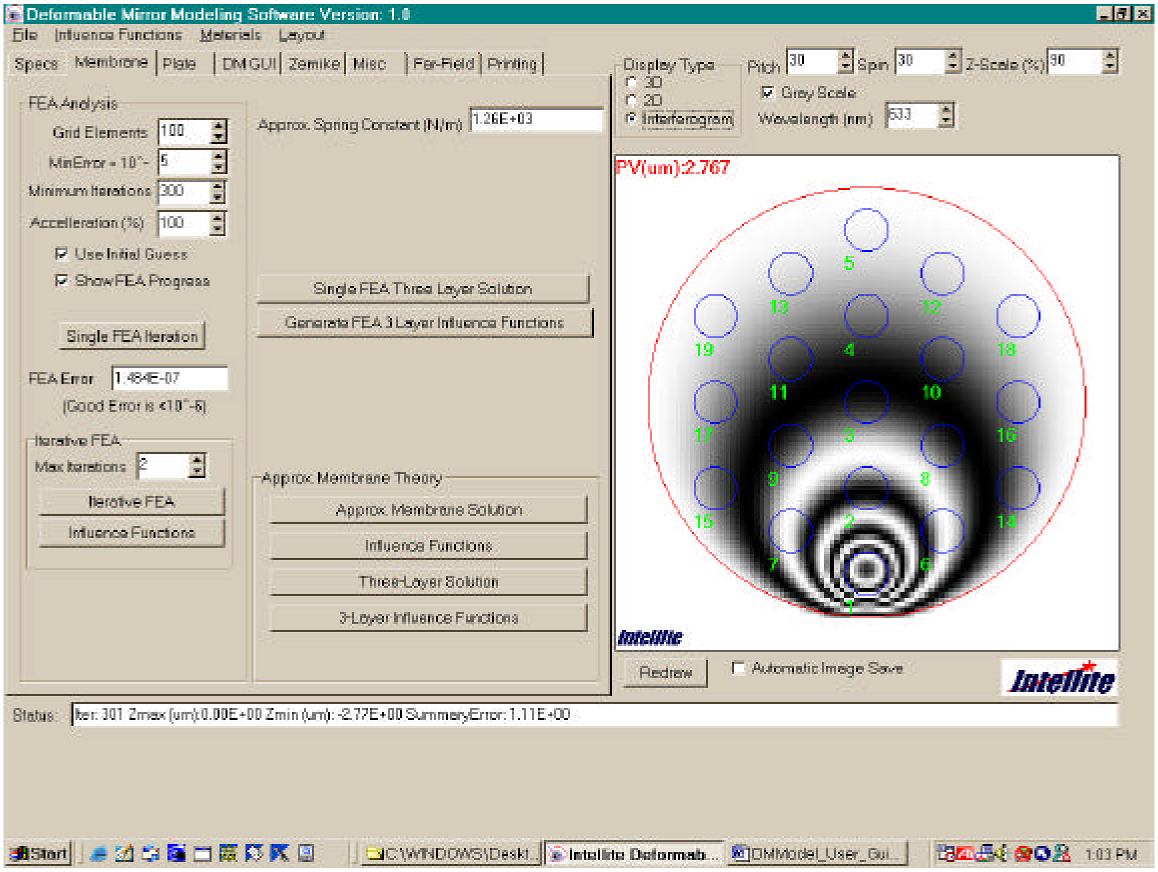
Grid Elements 100
MinError = 10^- 5
Minimum Iterations 300
Accelleration (%) 100
☑ Use Initial Guess
☑ Show FEA Progress
FEA Error 1.484E-07
Max Iterations 2
Approx. Spring Constant (N/m) 1.26E+03
Display Type ● 3D ○ 2D ○ Interferogram
Pitch 30 Spin 30 Z-Scale (%) 80
☑ Grey Scale
Wavelength (nm) 633
PV(um):2.767
☐ Automatic Image Save
Status: Iter: 301 Zmax (um):0.00E+00 Zmin (um): -2.77E+00 SummaryError: 1.11E+00

Figure 5 - Membrane Tab Screen Shot

In Figure 5, the user may select the "Single FEA Iteration" button and the code will iterate to develop the final estimated membrane displacement. (Note that the plot is exaggerated and inverted to facilitate visualization of the movement…the actual displacement is a depression toward the actuator pad set.) The resultant plot shows the effect on the mirror surface when actuator #1 has been set to 100v, which was done by default in the code initialization.

With this screen up, the user has the flexibility to adjust the viewing angles by using the “pitch” and “spin” control boxes and the “z-scale” height to adjust the reality of the plot for better presentation. “Redraw” must be selected to get a new plot.

One useful option is to change the Display Type to Interferogram, which brings up the following screen in Figure 6. This plot can be directly compared to the output of a Zygo or other interferometer, or the processed output from a wavefront analyzer.



Grid Elements 100

MinError = 10^- 5

Minimum Iterations 300

Accelleration (%) 100

☑ Use Initial Guess

☑ Show FEA Progress

FEA Error 1.484E-07

Max Iterations 2

Approx. Spring Constant (N/m) 1.26E+03

● Interferogram

Pitch 30 Spin 30 Z-Scale (%) 90

☑ Grey Scale

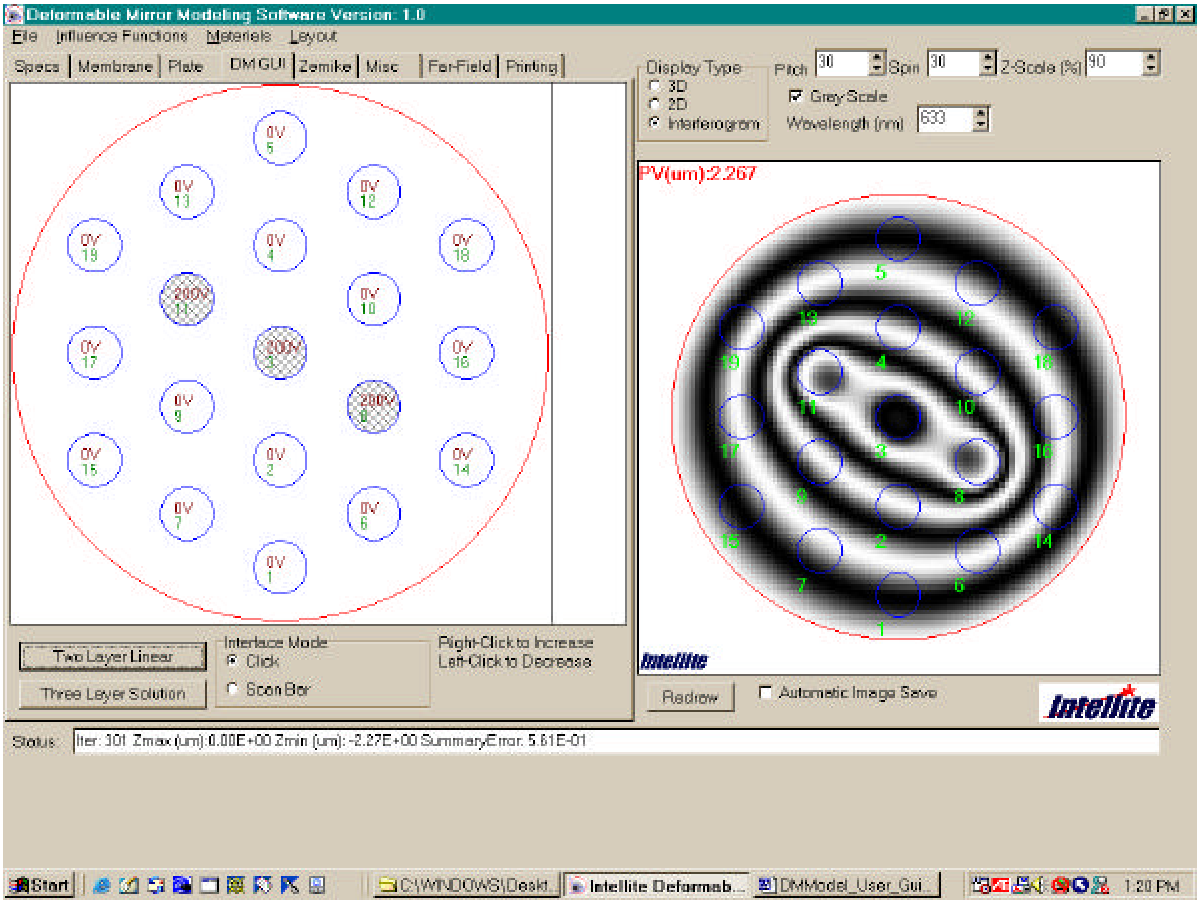
Wavelength (nm) 633

☐ Automatic Image Save

Status: Iter: 301 Zmax (um):0.00E+00 Zmin (um): -2.77E+00 SummeryError: 1.11E+00

Figure 6 - Alternate Plot using Interferogram

The user can now opt to energize a different or larger number of actuators by selecting the "DM GUI" tab which brings up the following screen in Figure 7. On this screen, three of the center actuators have been set to 200 volts using the mouse to select the pad of interest, then the left-mouse-click to step the voltages up to 200v in 10v increments. The user can reduce the voltages similarly using a right-mouse-click. Note that the default-set voltage on actuator #1 was reduced to zero volts.



Display Type ○ 3D ○ 2D ● Interferogram

Pitch 30 Spin 30 Z-Scale (%) 90

☑ Grey Scale

Wavelength (nm) 633

PV(um):2.267

Interface Mode ● Click ○ Scan Bar

☐ Automatic Image Save

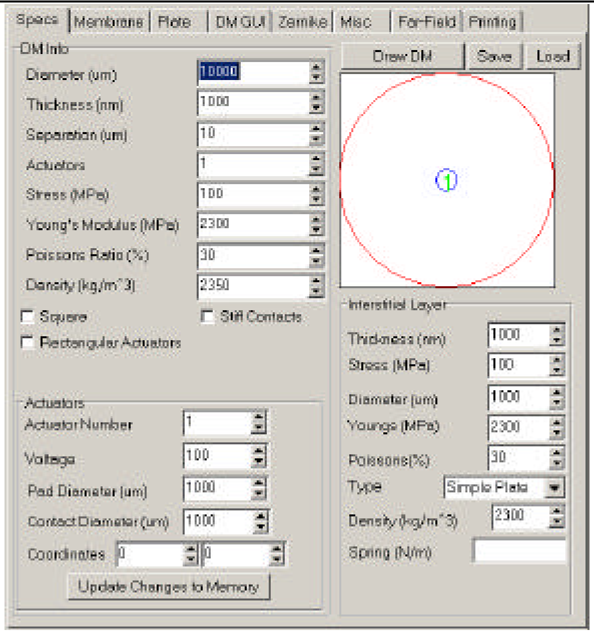
Status: Iter: 301 Zmax (um):0.00E+00 Zmin (um): -2.27E+00 SummaryError: 5.61E-01

Figure 7 - DM GUI Tab Screen Shot

To create this screen, the new voltage settings were made on the "DM GUI" tab screen, then the user returned to the "Membrane" tab screen and selected the "Iterative FEA" button, which caused the code to recalculate the membrane distortions. Returning to the "DM GUI" screen resulted in the image you see above.

This first section of the guide should get the casual user started in the design of their own micromachined deformable mirrors. The following sections delve more deeply into the mechanics of the code and expose more of the features and capabilities.

Setting-Up a Deformable Mirror



DM Info

Diameter (um)	10000
Thickness (nm)	1000
Separation (um)	10
Actuators	1
Stress (MPa)	100
Young's Modulus (MPa)	2300
Poissons Ratio (%)	30
Density (kg/m^3)	2350

☐ Square ☐ Stiff Contacts
☐ Rectangular Actuators

Actuators

Actuator Number	1
Voltage	100
Pad Diameter (um)	1000
Contact Diameter (um)	1000
Coordinates	0 0

Interstitial Layer

Thickness (nm)	1000
Stress (MPa)	100
Diameter (um)	1000
Youngs (MPa)	2300
Poissons(%)	30
Type	Simple Plate
Density (kg/m^3)	2300
Spring (N/m)	

Figure 8 - Specifications Tab

Figure 8 shows the first tab sheet that allows the entry of the deformable mirror mechanical parameters. The first group box, entitled "DM Info", allows users to enter all the pertinent parameters of the mirror surface. The "Square" check box allows the user to select a square or circular mirror aperture. The "Stiff Contacts" check box allows the user to select a stiff-contact of the actuator to the mirror, usually implying a pillar design, like that shown in the upper-left of Figure 1, or a non-stiff contact, like that shown in the lower left of Figure 1. The "Rectangular Actuators" check box allows the user to select whether the actuators are rectangular or circular in cross section.

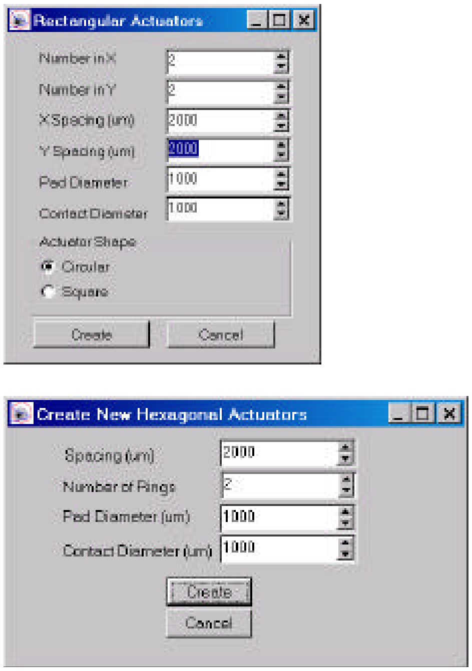
The "Actuators" group box shows the position, size, and voltage applied to each of the actuators. The pad diameter is the effective size of the electrostatic pad for each actuator. The contact diameter is the size of the physical contact of the actuator to the mirror. For a standard membrane deformable mirror, shown in the upper left of Figure 1, these parameters are the same. For the pillared two-layer deformable mirror, the pad diameter is the size of the pillar tip nearest the electrostatic pad and the contact diameter is the size of the top of the pillar contacting the mirror surface. Clicking the "Update Changes to Memory" button must follow any changes to actuator parameters.

The upper left box shows a schematic view of the deformable mirror aperture and the position and size of all the actuators. The blue lines outline the contact diameter on the mirror. The red line shows the mirror aperture. The actuator numbers are shown in green. A larger view of this is shown in the DM GUI (Deformable Mirror Graphic User Interface) tab.

The "Interstitial Layer" group box allows the user to adjust the mechanical parameters of the interstitial layer. The interstitial layer, which provides a restoring force to the mirror, can be modeled as several different mechanical types including a simply supported plate, a plate with clamped edges, a membrane, an analytical approximation of a membrane, or a user-specified spring constant. Use of an interstitial layer is inherent in the Three-Layer DM design only.

Quick Actuator Setup

It is possible to enter all the parameters of each actuator in the "Actuators" group box, but it is easier to use the "Layout" main menu option. Under the "Layout" menu, there are two options: "Create Rectangular Actuators" or "Create Hexagonal Actuators". Upon selecting the "Create Rectangular Actuators" menu option, a dialog box will appear like that shown in upper half of Figure 9, to allow the user to setup a rectangular array of actuators. The user can adjust the number of actuators in each dimension, the X and Y spacing of the actuators, the pad diameter, the contact diameter, and the shape of the actuators (either square or circular). Upon selecting the "Create Hexagonal Actuators" menu option, a dialog box will appear like that shown in the lower half of Figure 9, to allow the user to setup a hexagonal array of actuators. The user can adjust the number of rings of hexagonal actuators, the spacing of the actuators, the pad diameter, and the contact diameter.



Number in X: 2
Number in Y: 2
X Spacing (um): 2000
Y Spacing (um): 2000
Pad Diameter: 1000
Contact Diameter: 1000
Actuator Shape
● Circular
○ Square

Spacing (um): 2000
Number of Rings: 2
Pad Diameter (um): 1000
Contact Diameter (um): 1000

Figure 9 - Dialog box for setting up the rectangular array of actuators (above) and the hexagonal array of actuators (below).

Loading or Saving Material Characteristics

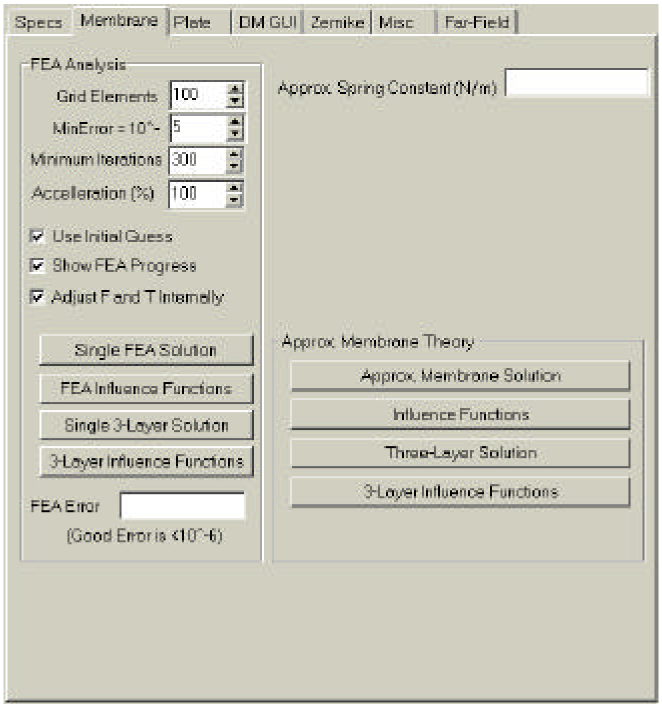
Material parameters can be loaded or saved from the mirror or the interstitial layer using the "Materials" menu. Using this option allows the user to load or save the stress, Young's modulus, Poisson's ratio, and density.

Modeling Mirror Performance

The mirror surface can be modeled as a membrane, a simply supported plate, a clamped-edge plate, or an analytical approximation to a membrane. The "Membrane" tab allows the user to model the mirror surface as a membrane. The "Plate" tab allows the user to model the mirror surface as a plate. In each of these types of model, the user can model a single surface based on the applied voltages, all the influence functions of the actuators in a two-layer architecture, a single surface of a three-layer architecture, or all the influence functions of the three-layer architecture.

Membranes

The ideal mechanical model for a membrane assumes that the bending stresses are negligible and the dominant forces are those internal to the membrane. The surface of a membrane, Z(x,y), under tension, T(x,y), and with an applied force load, F(x,y), can be determined mathematically by solving the differential equation, $\nabla^2 Z(x,y) = \frac{F(x,y)}{T(x,y)}$.[1] For a circular membrane loaded at the center, an analytical solution to the membrane shape is known, but there is not an analytical solution for an off-center force loading the membrane. Therefore, the modeling software uses finite element analysis (FEA) to solve the membrane differential equation and find the surface for a given force.



Grid Elements 100
MinError = 10^- 5
Minimum Iterations 300
Accelleration (%) 100
☑ Use Initial Guess
☑ Show FEA Progress
☑ Adjust F and T Internally
FEA Error
(Good Error is <10^-6)
Approx. Spring Constant (N/m)

Figure 10 - Membrane Tab

Figure 10 shows the Membrane tab. The “Approx. Membrane Theory” group box contains buttons to generate a mirror surface or influence functions based on an approximation of the membrane theory finite element solutions.

The “FEA Analysis” group box contains the options available for the user to control the finite element analysis used to determine the mirror surface based on the applied voltages. The “Grid Elements” option allows the user to control the size of the grid of samples used to generate the mirror surface. This size is used for every type of mirror surface. There are two different controls on the automatic termination of the finite element analysis. The iterative routine terminates when the maximum error limit is reached. If the program gets below the maximum error and the minimum number of iterations is not reached, the program continues until the minimum number of iterations is reached. Thus the minimum number of iterations is more important than the maximum error. In certain cases the FEA algorithm goes unstable. The program will terminate at 5000 iterations. To increase the odds of termination, the “Acceleration” factor should be reduced.

There are several different check boxes in the “FEA Analysis” group box that allows the user to control different aspects of the FEA performance. The user can often increase the speed of the convergence of the FEA routine by using the approximate analytical solution as a starting point. The user can choose to see the FEA progress every 50 iterations to show the progress. The user can also choose to regenerate the force (F) and tension (T) distributions using the current position of the mirror surface because the force changes due to the reduced gap between the electrodes and the tension increases due to the stretching of the mirror material.

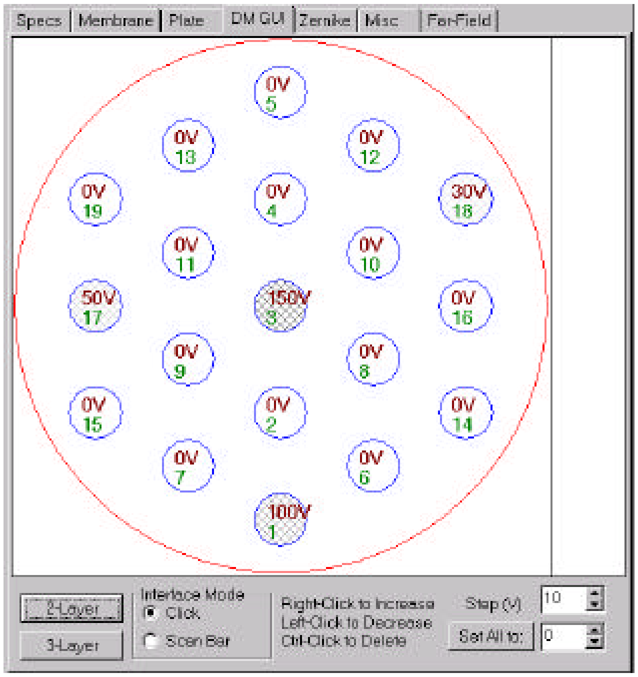
Plates

In either the two or three-layer architectures, the mirror surface can be modeled as a plate or a membrane. The ideal mechanical model for a plate assumes only a bending restoring force, but no internal stress. Membranes are infinitely thin plates that do not have sufficient thickness to develop internal stresses. This approximation is reasonably valid only if the plate is bending less than its thickness and that the plate is under negligible internal stress. Various plate solutions are published in Timoshenko’s Theory of Plates and Shells and in Roark’s Formulas for Stress and Strain. The modeling software uses these solutions and does not incorporate any effects of internal stresses.

Generating Influence Functions

The mirror influence functions are modeled by poking the mirror with the highest voltage on any of the actuators.

Deformable Mirror Graphic User Interface (DM GUI)



Interface Mode
● Click
○ Scan Bar
Step (V) 10
Set All to: 0

Figure 11 - The DM GUI Tab.

In a perfectly linear system, the mirror response to any set of forces can be represented as a linear superposition of these influence functions. Unfortunately, non-linearity causes this not to be rigorously accurate, but for most analysis this approximation is sufficient.

The DM GUI tab as shown in Figure 11allows the user to quickly sum the influence functions to show the mirror response.

The voltage on each of the actuators can be adjusted either by right and left clicking on the actuators in the image or with a pop-up window with a sliding bar based on the selection in the “Interface Mode” group-box. If the “Click” radio button is selected, clicks allow the user to increase the voltage by the value in the “Step (V)” edit box on the bottom of the screen. Right-clicks are for increasing the voltage and left-clicks are for decreasing the voltage. If the “Scan Bar” radio button is selected, a scroll bar appears when the user clicks on an actuator and the voltage can be set on the bar. An actuator can be deleted by holding down the “ctrl” button on the keyboard and clicking the actuator.

Once the voltages are setup, the user can calculate the response of the two-layer mirror by summing the influence functions by pressing the “2-Layer” button. The “3-Layer” button allows the user to sum the three-layer influence functions based on the applied voltages.

Analysis and Characterization

The software has the ability to apply several different types of analysis to a mirror surface, including various surface plotting routines, Zernike decomposition, resonance frequency determination, singular value decomposition, and far-field intensity distribution calculation.

Surface Plotting

The mirror surface can be represented as a three-dimensional rendering (Figure 12), a two-dimensional false-color rendering, or an optical interference pattern (Figure 6) as if the mirror was part of a Michelson interferometer. This gives "contour" plots where each ring is one-half wave displacement from the next. Sometimes due to resolution limitations, the plots are aliased and do not appear normal. This is to be expected. Any of these three options can be selected by using the "Display Type" group box above the surface plot. When using the "3D" plot, the "Pitch", "Spin", and "Z-Scale" boxes to the right of the "Display Type" group box can be used to adjust the view. When using the "2D" plot or the "Interferogram" plot, a gray-scale view can be chosen with the "Gray-Scale" check box. The wavelength of the interferogram can be adjusted above the display as well. The scale can be determined via the peak-to-valley measurement shown in the upper left corner of the image in microns.

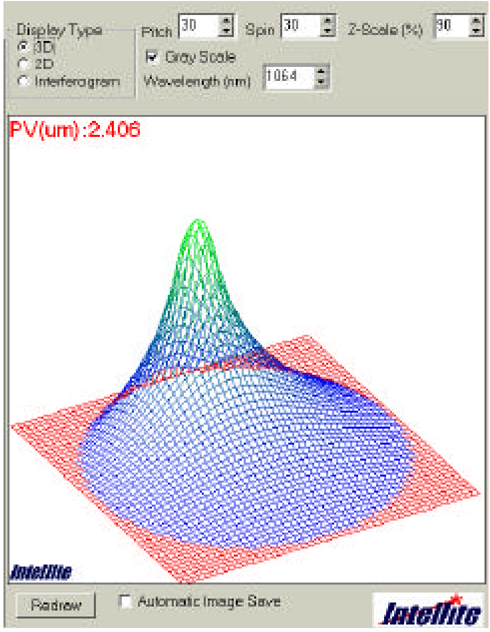

Display Type
● 3D
○ 2D
○ Interferogram
Pitch 30
Spin 30
Z-Scale (%) 90
☑ Gray Scale
Wavelength (nm) 1064
PV(um):2.406
☐ Automatic Image Save

Figure 12 - Surface plotting area

Zernike Decomposition

The "Zernike" tab, shown in Figure 13, allows the user to perform a Zernike decomposition of the mirror surface or search through applied voltages to maximize a single Zernike term. The Zernike terms are numbered sequentially starting with the piston term at 0. The user can adjust the number of Zernikes that are used for the decomposition and the percent of the mirror radius that is used for the fitting since often the edges of the mirrors are typically not under control. One pictorial Example is shown in Figure 14

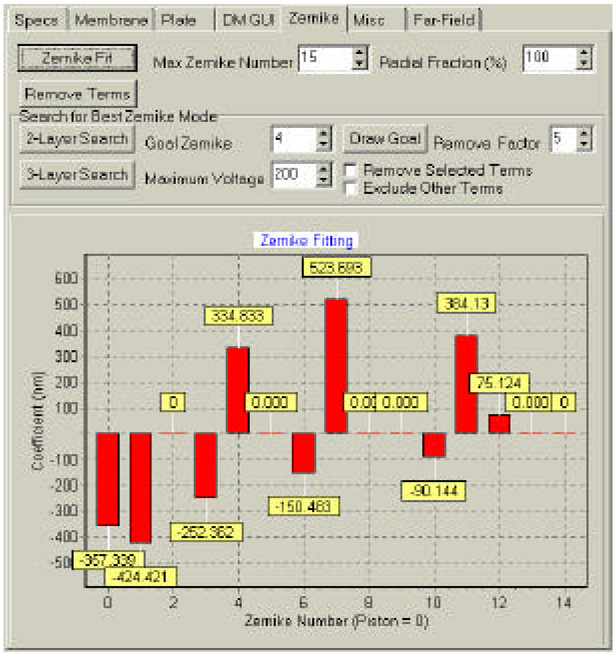

Max Zernike Number 15
Radial Fraction (%) 100
Search for Best Zernike Mode
Goal Zernike 4
Remove Factor 5
Maximum Voltage 200
☐ Remove Selected Terms
☐ Exclude Other Terms

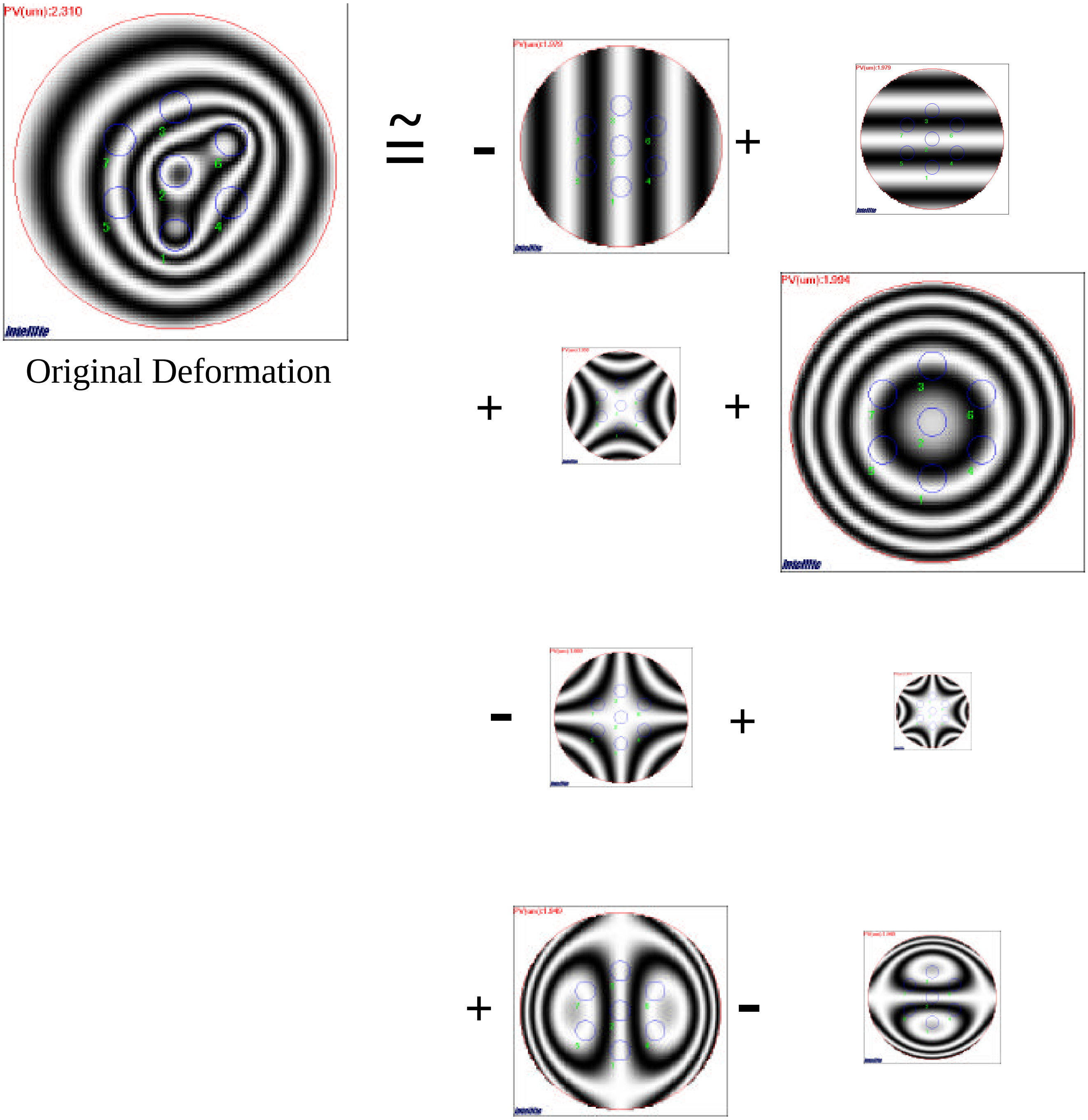
Figure 13 - Zernike Tab

Selecting the "Remove Terms" button allows the user to fit to any set of Zernike terms and subtract them from the modeled mirror surface. Upon clicking the button, a dialog box appears with a list of the Zernike terms along with their names and a column for selecting the Zernike term to remove.

In addition to fitting a mirror surface to the Zernike terms, the software can search through the actuator voltages to maximize a Zernike term specified by the "Goal Zernike Number". The "Draw Goal" button allows the user to draw the goal Zernike term to verify if the correct term is being searched for. The "Remove Selected Terms" check box is used to remove the selected Zernike terms from the fit during the search. The "Remove Selected Terms" check box allows the user to optimize the goal term while minimizing the other terms to try to achieve a pure Zernike term. This search can become unstable, so the user can increase the chance for stability by decreasing the “Remove Factor”.

Zernike Decomposition Pictorially

Figure 14 - Zernike Decompositon Pictorially

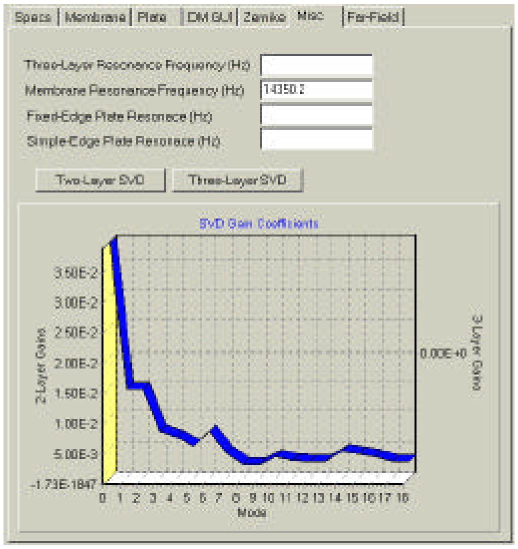


Resonance Frequency Determination

The program approximates the resonance frequency of the structure by evaluating the spring constant and the mass and calculating the √k/m. These results are presented in the “Misc” tab, shown in Figure 15.

Singular Value Decomposition (SVD)

Once the influence functions are determined, the orthogonal modes of the mirror can be determined using singular value decomposition. These results are presented in the “Misc” tab, shown in Figure 15. During the SVD routine, each of the mirror modes is shown in the screen and can be captured in a series of bitmap images to disk using the “Automatic Image Save” check box at the bottom of the images screen. The gain coefficients of the different modes are plotted in a graph. SVD is similar to Zernikes and allows the designer to decompose his surface into separable, orthogonal surfaces.

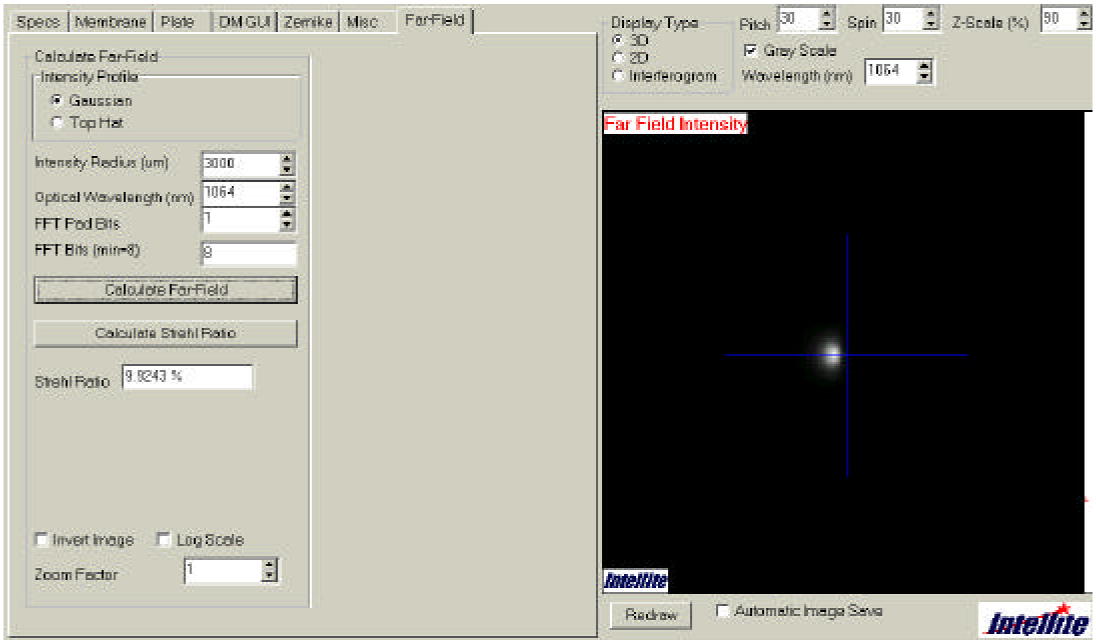


Three-Layer Resonance Frequency (Hz)
Membrane Resonance Frequency (Hz) 14350.2
Fixed-Edge Plate Resonace (Hz)
Simple-Edge Plate Resonace (Hz)

Figure 15 - Miscellaneous Tab

Far-Field Intensity Profile

The “Far-Field” tab allows the user to model the far-field intensity pattern (reference Figure 16) after illuminating the mirror surface with a beam of light with a flat wavefront and propagating the beam to the far-field. The user can adjust the shape, size, and wavelength of the intensity profile incident on the mirror. To obtain more detailed far-field patterns, the user can increase the number of padding bits on the near field pattern with the “FFT Pad Bits” edit box. The program displays the total number of bits used for the far-field calculation in the “FFT Bits” box. The program can also use the far-field pattern calculations to calculate the Strehl ratio by comparing the maximum intensity of the unaberrated far-field distribution with the maximum intensity of the aberrated far-field distribution.



Calculate Far-Field
Intensity Profile
● Gaussian
○ Top Hat
Intensity Radius (um) 3000
Optical Wavelength (nm) 1064
FFT Pad Bits 1
FFT Bits (min=8) 9
Strehl Ratio 9.9243 %
☐ Invert Image ☐ Log Scale
Zoom Factor 1

Display Type
● 3D
○ 2D
○ Interferogram
Pitch 30 Spin 30 Z-Scale (%) 90
☑ Grey Scale
Wavelength (nm) 1064
☐ Automatic Image Save

Figure 16 - Far-field tab and an image of the far-field intensity distribution.

Main Menu Options

The main menu can be used for various options. The "File" menu options allow the user to save the image on the right of the screen as a bitmap, export the mirror surface to a text file, save and load deformable mirror parameters, print an image of the form, or exit the program. The "Influence Functions" menu allows the user to save and load the two-layer and three-layer influence functions. The "Materials" menu allows the user to load and save the materials of the interstitial layer or mirror layer. The "Layout" menu allows the user to automatically generate a regular rectangular or hexagonal array of actuators.

Known Software Limitations

There are several features of the code that are currently under further development. The modeling of the three-layer architecture is quite complex, so sometimes the three-layer models do not perform exactly as expected. Specifically, when the interstitial layer is very stiff, the model shows the mirror surface actually pushing up above the static mirror surface position. This is usually only a 5 to 10% error, but it is under investigation.

We are also currently implementing a multi-threading approach to allow the user to stop the sometimes-lengthy calculations.

References

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[1] R. P. Grosso and M. Yellin. "The membrane mirror as an adaptive optical element", J. Opt. Soc. Am., **67**, 399-406, (1977).

[2] L.M. Miller, M.L. Argonin, R.K. Bartman, W.J. Kaiser, T.W. Kenny, R.L. Norton, E.C. Vote. "Fabrication and characterization of a micromachined deformable mirror for adaptive optics applications", SPIE Vol. 1945, 421-430 (1993).

[3] J. D. Mansell and R. L. Byer. "Silicon Micromachined Deformable Mirror", US Patent 6,108,121.