How to Measure Wedge

In Brief

This application note teaches how to measure an optical wedge or a group of optical wedges by transmission or reflection.

This includes the interferometer setup procedure for the wedge test, setting the correct values in ÄPRE's REVEAL software to properly report wedge, and how wedge data is reported

Purpose

Optical Wedge Application (OWA) is an add-on analysis tool for measurement of optical wedges in either transmission or reflection. OWA can measure a single part or many parts simultaneously (e.g. on a pallet), as seen in Figures 2 and 3.

The Optical Wedge Application (OWA) is part of the Optical Shop Testing package and can only be accessed if purchased. OWA is not part of ÄPRE's Basic Interferometry package.

Introduction

OWA presents wedge data in two ways: Graphical displays of the measured wedge data along with wedge slope direction, and tabulated representations of calculated wedge data

Tabulated wedge data includes:

- **Wedge Magnitude:** Wedge between front and back surface of the optic, i.e., net deviation of the optic from parallelism.
- **Wedge Angle:** Wedge direction, counterclockwise from the horizontal axis.
- **X Wedge**: Deviation from parallelism in the X direction.
- **Y Wedge:** Deviation from parallelism in the Y direction.
- **Tilt X**: Measured wavefront tilt in the X direction.
- **Tilt Y**: Measured wavefront tilt in the Y direction.
- **Tilt Magnitude**: Magnitude of wavefront tilt, vector sum of X and Y directions.
- **Tilt Angle**: The angle of maximum tilt of the tilt magnitude.
- **Points**: Number of points in the measurement area (island area).

Tools Needed

- Interferometer
- Transmission or Fizeau Flat (TF)
- Wedge(s) to be tested
- Reference Flat (RF)
- Specific Mount for Wedge (e.g. three jaw chuck)
- Appropriate Mount for RF

Measurement Setup (In Transmission)

1. Place a Transmission Flat (TF) on the interferometer and perform fine and rough alignment as described in the standard test part alignment procedure. Place an adjacent Reference Flat (RF) a few inches in front the TF.
2. Position your wedge for testing in an appropriate mount. Center the wedge(s) between the TF and RF, as shown below, so that the beam of light goes through the central axis of all three components – TF, wedge(s), and RF.
3. It is advisable to reduce the distance between all components to minimize environmental errors during testing.

Figure 1: Wedge Setup with basic components, from left to right respectively - mounted Reference Flat (RF), Wedge, and Transmission Flat (TF)

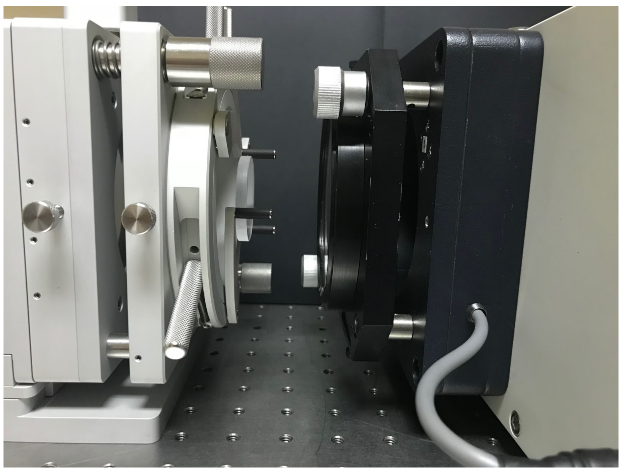

Figure 2a: Setup with single wedge

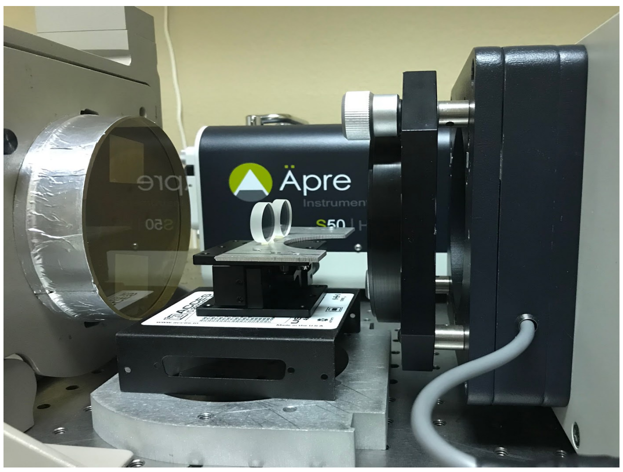

Figure 2b: Setup with two wedges

Measurement Setup (In Transmission)

Aligning The TF, Wedge, and RF

1. Bring up the Live Video in both the alignment and measurement camera windows, and adjust the knobs on the TF and RF mounts to align the two reflected beams of light (from the TF and RF) as done in standard measurements of a flat. For ease, the alignment of the TF can be done prior to placing the RF in front the interferometer field of view. The RF can then be put into place and aligned and the wedge(s) then placed between the two aligned parts.

2. Reduce the amount of fringes that are visible on the Measurement Camera Live Video screen by adjusting the knobs of the RF mount, adjusting close to the null state is preferred but not necessary
3. Slightly tilt the measured part such that no reflection off front or back is picked up by the measurement camera
4. Focus the measurement camera: In the Measurement Camera Live Video screen, zoom in on the image by placing the cursor in the live video image, click and rotate the mouse wheel. Place a straight edge sheet of paper in front the wedge(s), and use the stage control to focus the image on the edge of the paper, creating a sharp, finely focused image.

The OWA Application

1. Click "Single Measurement" to record the fringes once the fringes become stable and minimal (nulled). Or, use the averaged measurement to reduce environmental errors in the wedge data.
2. Open the OWA using menu *Analysis→ Optical Wedge*; then, using the screen toolbar, select the optical wedge screen to bring the wedge analysis data to view. Figures 3 and 4 illustrate the Optical Wedge Analysis window when a single wedge and multiple wedges are measured, respectively.
3. Reveal automatically identifies different areas of the RF and wedge, assigning a number to each region detected. This allows the software to perform calculations using the differences in the data from the RF regions relative to the wedge area.
    a. The **important** step in analysis is to ensure that reference and wedge areas are clearly separated. This can be done either by properly selecting threshold values in Auto Frame Masking or by applying masks interactively to frames (see Frames screen) or to optical wedge data (this screen).
    b. It may be advisable to apply the Data Erosion Filter to the data until edge effects are minimized. (The Data Erosion Filter can be found via clicking the wrench icon below the wedge phase map followed by the mask icon, then dragging the filter into the upper box of Data Filters. Refer to the REVEAL manual for more masking information.)

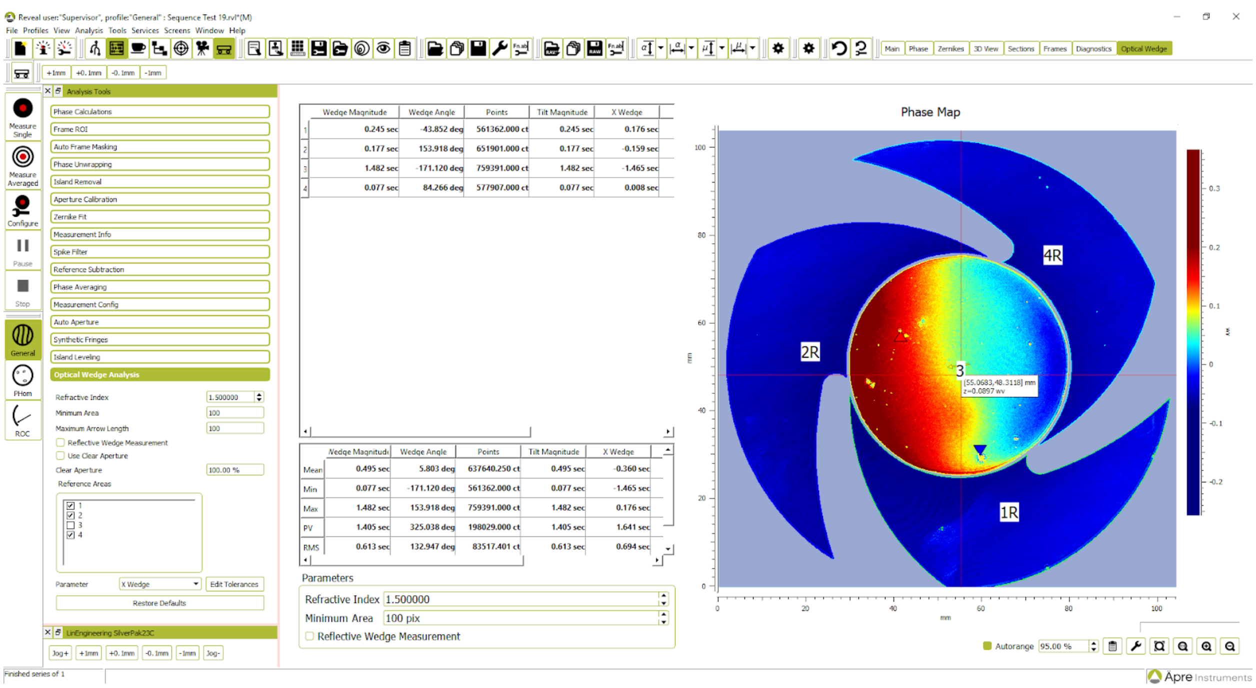

Figure 3: View of optical wedge analysis window in REVEAL for single wedge

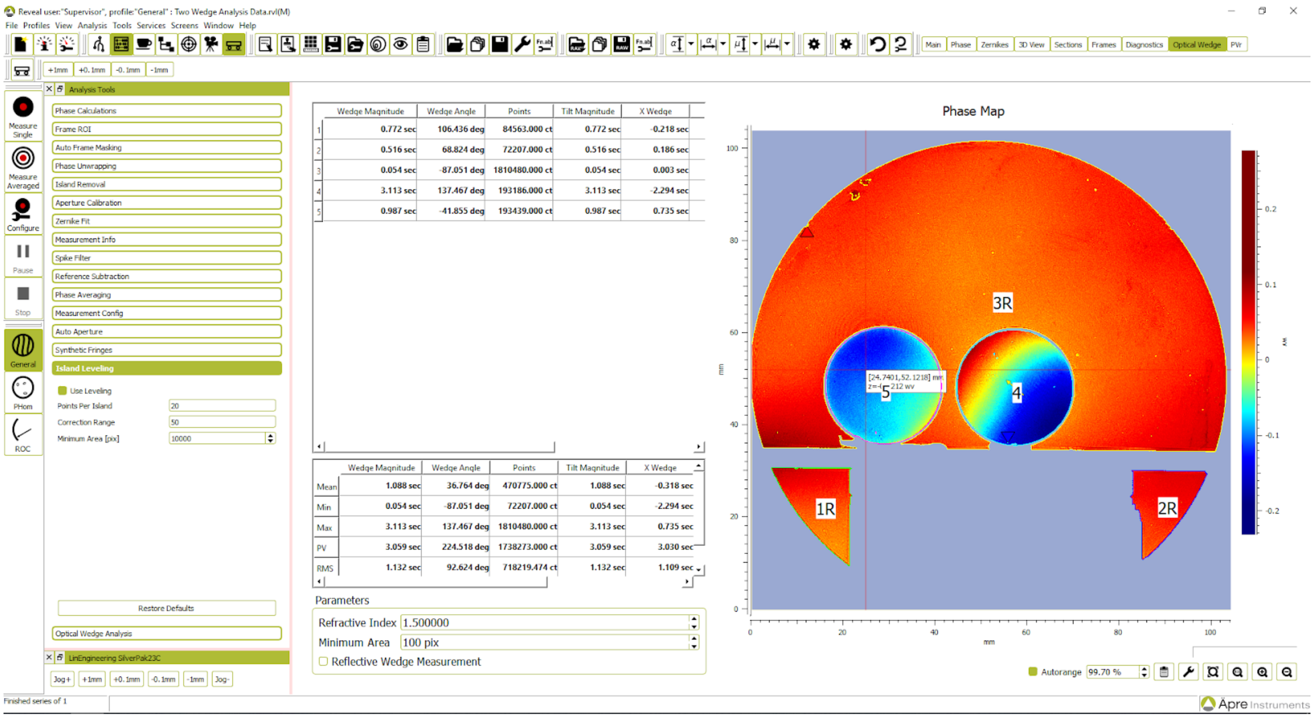

Figure 4: View of optical wedge analysis window in REVEAL for two wedges

4. Specify which numbered regions represent the RF area:

   a. Under the Analysis Tools shown on the left-hand side of REVEAL, select the *Optical Wedge Analysis* submenu.

   b. Beside "Reference areas," check the boxes next to the numbers that differentiate various locations on the RF. Now, REVEAL can perform a calculation with these marked areas as a reference to the unchecked wedge data. Figure 3 demonstrates this process with boxes 1, 2 and 4 selected on the left and the corresponding regions 1R, 2R, and 4R automatically labeled on the Phase Map.

5. Additionally, to ensure the calculations have the correct input data, it is vital to complete the following:

   a. Provide the correct Refractive Index of the Wedge: Type the wedge refractive index in the "Refractive Index" box displayed at the bottom left side of the optical wedge data analysis window. In Figure 6, this parameter is set at 1.500000.

   b. Calibrate the pixel size for the wedge measurements: Click the icon on the universal toolbar. Choose an area on the displayed image of known distance (i.e. the diameter of the wedge or RF). Draw a line across this known distance. Type the known length, of the line drawn, in the "Line Length" box. This scales all numbers used in the wedge calculations. Finally, click "Set Diameter" to save the corrections. Figure 5 shows an example of this calibration step performed with a test flat.

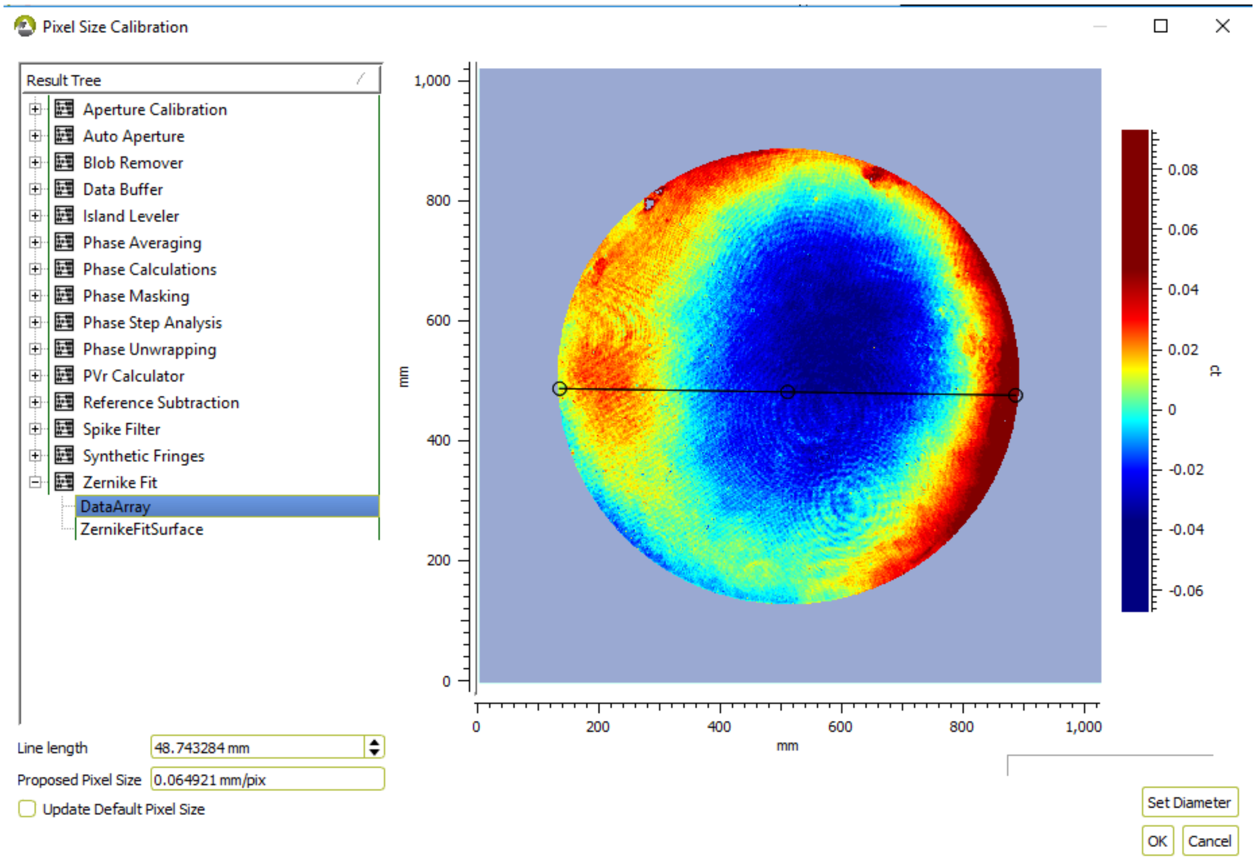

Figure 5: Pixel Calibration tool used to scale the pixel count to units of distance (mm); Test Flat measured has known diameter of 48.74 mm

Identifying the Numerical Wedge Data

Reveal can calculate wedge values for multiple parts simultaneously, that is why wedge analysis results are presented in tabulated form. Each row in the table refers to a single island of data with row index corresponding to the island index shown in the main plot. Figure 6 illustrates how REVEAL tabulates the optical wedge data, with each output based off the numbered islands. Figure 7 shows an exemplary table of statistics associated with the wedge data.

	Wedge Magnitude	Wedge Angle	Points	Tilt Magnitude	X Wedge	Y Wedge
1	**100.823 sec**	**120.762 deg**	**28353.000 ct**	**102.839 sec**	**-51.569 sec**	**86.637 sec**
2	**116.680 sec**	**96.014 deg**	**2321.000 ct**	**119.014 sec**	**-12.224 sec**	**116.038 sec**
3	0.000 sec	0.000 deg	**307.000 ct**	0.000 sec	0.000 sec	0.000 sec
4	**74.121 sec**	**129.018 deg**	**12127.000 ct**	**75.603 sec**	**-46.664 sec**	**57.588 sec**

Figure 6: Table of optical wedge data from OWA providing information regarding Wedge Magnitude, Wedge Angle, Points, Tilt Magnitude, X wedge, Y wedge, X tilt, and Y tilt (Phase Map for this data can be found in the Appendix}

	Wedge Magnitude	Wedge Angle	Points	Tilt Magnitude	X Wedge	Y Wedge	X Tilt
Mean	**8.888 sec**	**-26.529 deg**	**50293.000 ct**	**8.888 sec**	**7.952 sec**	**-3.970 sec**	**7.952 sec**
Min	**8.888 sec**	**-26.529 deg**	**50293.000 ct**	**8.888 sec**	**7.952 sec**	**-3.970 sec**	**7.952 sec**
Max	**8.888 sec**	**-26.529 deg**	**50293.000 ct**	**8.888 sec**	**7.952 sec**	**-3.970 sec**	**7.952 sec**
PV	0.000 sec	0.000 deg	0.000 ct	0.000 sec	0.000 sec	0.000 sec	0.000 sec

Parameters

Refractive Index 1.500000

Minimum Area 100 pix

☐ Reflective Wedge Measurement

Figure 7: Statistical table of optical wedge data from OWA providing information regarding Wedge Magnitude, Wedge Angle, Points, Tilt Magnitude, X wedge, Y wedge, X tilt, and Y tilt

Printing the Wedge Data

To print a report of the data, go to the *Main* window, select *Report*, select *Optical Wedge* from the "Report Type" drop-down menu, and print.

Results

Optical Wedge Analysis Data

Table 1: Definitions of results produced by wedge analysis

Parameter	Description
Wedge Magnitude	Absolute value of wedge formed between front and back surface of the element. Angle is displayed using currently selected vertical angle units.
Wedge Angle	Direction of the wedge, measured counter-clockwise, from the horizontal axis. Wedge direction is measured from lower to higher phase values. It is displayed in currently selected lateral angular units.
Tilt Magnitude	Magnitude of the measured wavefront tilt, vector sum of X and Y tilt. Angle is displayed using currently selected vertical angle units. This value refers to measured wavefront tilt, it is twice the value of wedge beam deviation.
X Wedge	X component of the wedge formed between front and back surface of the element. Angle is displayed using currently selected vertical angle units.
Y Wedge	Y component of the wedge formed between front and back surface of the element. Angle is displayed using currently selected vertical angle units.
X Tilt	X component of the measured wavefront tilt. Angle is displayed using currently selected vertical angle units. This value refers to measured wavefront tilt, it is twice the value of wedge beam deviation.
Y Tilt	Y component of the measured wavefront tilt. Angle is displayed using currently selected vertical angle units. This value refers to measured wavefront tilt, it is twice the value of wedge beam deviation.
Points	Number of points per island

Statistical Results

Table 2: Definitions of statistics of the wedge analysis data

Parameter	Description
Min	Minimum parameter value for corresponding result table column.
Max	Maximum parameter value for corresponding result table column.
Mean	Average value of the column of data (i.e. Average Wedge Magnitude, Tilt X, Tilt Y, Tilt Angle, Points, etc.)
PV	Difference between maximum and minimum parameter value for corresponding result table column.
RMS	Root-mean-square of the parameters for corresponding result table column.

Input Parameters

Within the Analysis Tools (found on the left-hand side of REVEAL), the Optical Analysis Tool tab has a set of parameters for manipulation according to wedge measurement type and specificity. These tools aid REVEAL in accurately determining the wedge results desired by the user. These parameters, shown in Figure 8, are described below.

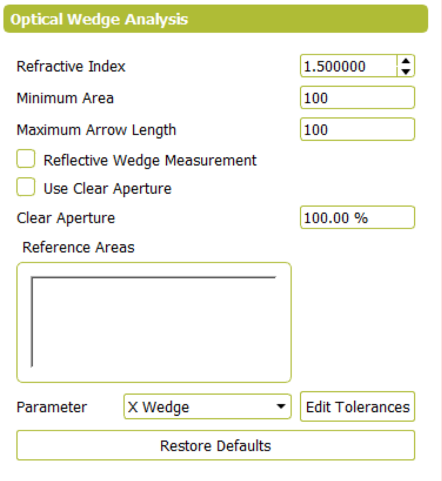

Figure 8: Optical Wedge Analysis tab in Reveal

Refractive Index (*n*): The refractive index of the test optic - in this case, the wedge. The specific *n* for the wedge must be adjusted accordingly if measurements are taken of a wedge in transmission. When measuring or analyzing a wedge in reflection, check off the box adjacent to "Reflective Wedge Measurement" in the Optical Wedge Analysis Tool tab; this will grey-out the *n* parameter, as it is not needed in software calculations for wedges in reflection.

Minimum Area: The limit on how small the phase map areas under analysis can be, defined by the pixel count. Reveal reports the amount of pixels measured in each numbered area of the phase map. This pixel count per area is found in the "Points" column of the data table (as seen Figure 6). In order to remove smaller areas of noise from analysis, one can (1) locate numbered regions of the phase map pertaining to noise, (2) find the number of points measured in this region via the data table, and (3) increase the "Minimum Area" value until this region is removed.

Maximum Arrow Length: The limit on how large the phase map arrows in pixels - representing the optical wedge magnitudes within each numbered area - will be displayed. Reveal uses vector to help the user better visualize the orientation of the wedge magnitude in each of the areas enumerated on the phase map. The user has the option to adjust the lengths of these arrows with the "Maximum Arrow Length" parameter.

Reflective Wedge Measurement: This option differentiates between a wedge in transmission and a wedge in reflection. If the test optic is to be tested under reflection, check off this parameter so that Reveal will omit the effect of refractive index in calculating wedge results.

Use Clear Aperture: This option allows the user to focus in on the region of interest or of most importance to the overall functionality of the test optic. Each island of data will be reduced in size to value specified in percent of the original size. Reveal automatically differentiates circular, elliptical and rectangular shapes and applies appropriate algorithm.

Reference Areas: Regions throughout the recorded data that represent the reference area (RF). It is vital to correctly identify parts of the phase map that pertain to the RF. This allows the software to form RF-to-Wedge planes needed for calculating the resulting wedge data.

Parameter: Tool used to select **X Wedge, Y Wedge, Wedge Magnitude, Wedge Angle, Points, X Tilt, Y Tilt, or Tilt Magnitude** and adjust tolerance parameters. Refer to the REVEAL Manual for more information on the usefulness of the Tolerance tool.

Result Calculations

In performing all calculations, the software requires an input value for the *refractive index* of the wedge under testing as well as identification of which regions of the measured data belong to the wedge and which belong to the reference flat. Identifying the test optic and RF areas allows the software to create a differential plane between the wedge (T) and the reference surface (R).

T-R Difference Plane

It is important to take a good measurement with a uniform phase map across the RF areas so that the differential plane is indeed planar. The correct use of REVEAL's analysis tools - like the Auto-Aperture Filter, Island Leveling tool, Spike Filter, and Universal Phase Calculator Correction - establishes this essential uniform phase map. The difference between the uniform RF data and wedge data provide the parameters for the following OWA results:

- X Tilt: Wavefront tilt in the X direction
- Y Tilt: Wavefront tilt in the Y direction
- Tilt Magnitude: Wavefront tilt [vector sum of X and Y tilt]
- Points: Number of points per island of data

Wedge Deviation

Refractive Index Greater than 1:

- X wedge = X Tilt/ [2*(*refractive index*-1)]
- Y wedge = Y Tilt/ [2*(*refractive index*-1)]
- Wedge Magnitude = Tilt Magnitude/ [2*(*refractive index*-1)]
- Wedge Angle: overall wedge deviation, counter-clockwise, from the horizontal axis

Refractive Index Less than 1:

- X wedge = X Tilt/ 2
- Y wedge = Y Tilt/ 2
- Wedge Magnitude = Tilt Magnitude/ 2
- Wedge Angle: overall wedge deviation, counter-clockwise, from the horizontal axis

Appendix

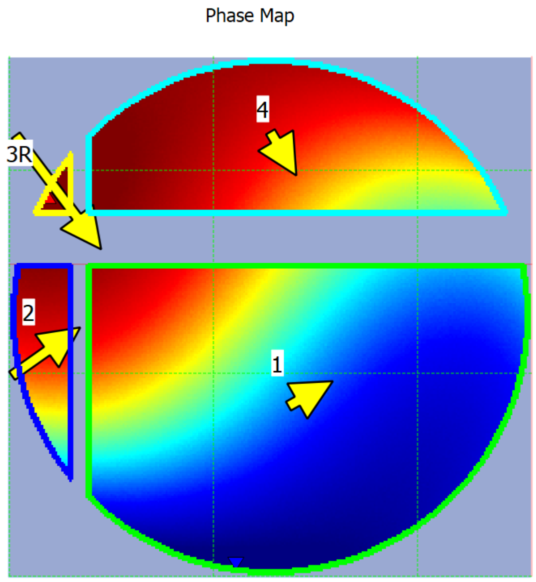

Figure (i): Phase Map associated with tabulated data displayed in Figure 6.

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