Multifunction Target
For .08X-4X Vision Systems

Usage and Applications Guide

Max Levy Autograph, Inc.

Table Of Contents

1 Introduction

The DA066, DA068 & DA069 Multifunction Target Sets are versatile dual target assemblies designed to measure the optical characteristics of imaging systems that employ wide field of view optics and low to medium-magnification. With their specially designed patterns these targets address the vision resolution capabilities, measurement accuracy, traceability and illumination issues inherent in optical systems used in camera and non-contact metrology systems.

These high contrast target sets have been designed and manufactured to provide the highest possible accuracy when used to perform various system performance tests. Specifically, the target features are designed to test the following lens, camera and integrated vision system characteristics:

- Resolution
- Field of View
- Depth of Field
- Magnification
- Modulation Transfer Function
- Telecentricity (for Telecentric Lenses)
- Flat Field Distortion
- Object measurement functions for circular objects (positive and negative, including blooming)
- Object measurement functions for rectangular objects (positive and negative, including blooming)
- Calibration for linear stages
- Software sub-pixelization accuracy
- The effect of various illumination modes on system performance

These targets have been manufactured from ultra high precision tooling in order to guarantee accurate measurements. In addition, all dimensions listed on the target have been verified at our facility using our NIST traceable inspection/calibration systems. A complete traceability statement for the target is listed in the Appendix of this manual.

2 Hardware

2.1 Parts List and Application

DA066

This Target Set has two low reflection chrome patterns on clear glass substrates that are suitable for use with systems with Top, Off Axis Oblique, and Bottom Illumination.

The following hardware is included as part of the DA066 Multifunction Target Kit:

- Calibration Target 1 (Variable Ronchi Rulings)
- Calibration Target 2 (Flat field and Object Calibration Standards)
- Target Support Base
- Opaque White Background Cards (Used to provide greater contrast.)
- Custom Carrying Case
- Usage and application guide on CD
- Quick Reference Card

DA068

This Target Set has two low reflection chrome patterns on white semi-diffuse translucent Opal Glass. These Targets are designed for systems with Top and Off Axis Oblique Illumination. They are required where the Target Images and background must be co-planar and present very high contrast and minimum retro-reflections to the system under test.

The following hardware is included as part of the DA068 Multifunction Target Kit:

- Calibration Target 1 on White, Semi-Diffuse Translucent Opal Glass
- Calibration Target 2 on White, Semi-Diffuse Translucent Opal Glass
- Target Support Base
- Custom Carrying Case
- Usage and Application Guide on CD
- Quick Reference Card

DA069

This Four Target Set has both the DA066 and DA068 Targets and is used where the system has both Top, Off Axis Oblique and Bottom Illumination and requires the higher contrast and reduced retro-reflections when the Illumination is directed at the Target rather than through the substrate.

The following hardware is included as part of the DA069 Multifunction Target Kit:

- Calibration Target 1 on Clear Glass
- Calibration Target 2 on Clear Glass
- Calibration Target 1 on White, Semi-Diffuse Translucent Opal Glass
- Calibration Target 2 on White, Semi-Diffuse Translucent Opal Glass
- Target Support Base
- Opaque White Background Cards
- Custom Carrying Case
- Usage and Application Guide on CD
- Quick Reference Card

2.2 General Handling and Care

2.2.1 Handling

The targets are made from an optical glass substrate patterned with an opaque, low reflection chromium coating. This part should be generally handled in the same manner as other precision optical parts.

The pattern consists of a dual layer of thin, low reflection chromium metal. The metal is durable and will withstand hundreds of cleanings without degradation as long as it is cleaned and handled properly. Avoid using any abrasive objects in the pattern area. Take special care not to scratch the pattern with any sharp object. Scratches in the pattern area cannot be repaired.

Always take special care not to drop the glass target. Dropping the glass target can break the target or may cause a crack which will affect the accuracy of the target.

If possible, use gloves or finger cots to handle the target. This will prevent oils from the user's skin from coming in contact with the target. These oils are difficult to clean properly.

2.2.2 Cleaning

Materials:

- Lint-free textile cloth or synthetic cloth
- Acetone, Isopropanol, or non-abrasive glass cleaner
- Gloves
- Air gun (optional)

Procedure:

Begin by blowing any loose particles off of the target with a clean air gun. Dampen a lint free cloth with the cleaning solvent. Gently wipe across the surface of target with a slow wipe, cleaning as wide a path as possible.

To clean dried water spots, it is sometimes necessary to use your breath to create a fog on the glass. Immediately wipe the fog with solvent to remove the water spots.

Wipe the target gently several times until the glass and pattern are clean. It may be necessary to use a new wipe to finish the cleaning.

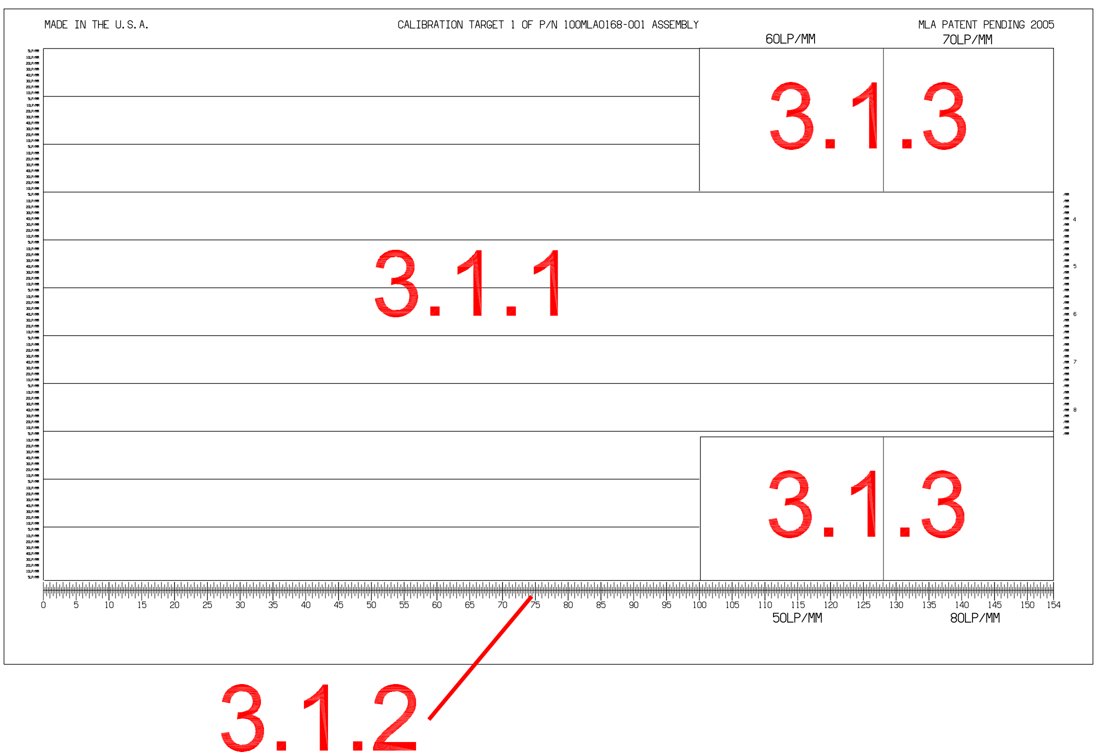
2.2.3 Operating Environment

The target is certified for operation at 20°C. Temperature extremes will alter the size of the glass very slightly.

3 Usage

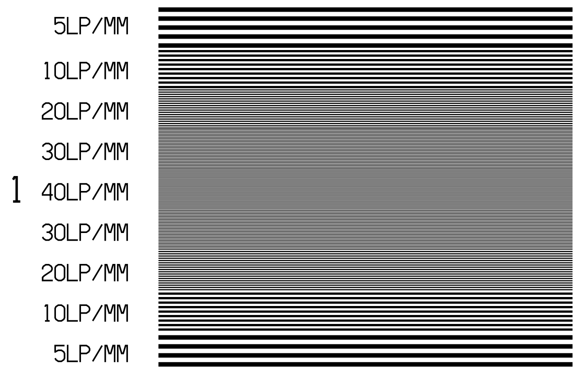
These Multifunction Targets were designed to test a wide variety of system characteristics. The targets are divided into groups of functional features. Each of the functional groups are discussed below. Further explanations of the optical concepts are available in the Applications Guide in Section 4.

3.1 Target 1 – Ronchi Rulings and Scale



Overview of Target 1
Numbers correspond to section numbers in this Manual

3.1.1 Variable Frequency Ronchi Rulings



Variable Frequency Ronchi Ruling Pattern

Applications

The 11-set Variable Frequency Ronchi Ruling pattern is designed to allow the user to simultaneously view an array of Ronchi Rulings at several spatial frequencies within the current Field of View. This allows the user to quickly determine the maximum resolution of the system by finding the point at which the system loses contrast between adjacent lines.

When mounted to the Support Base and viewed at an angle, the effective depth of field for the lens can be evaluated over the range of spatial frequencies.

The pattern can also be used to generate an MTF analysis quickly. The 11 sets of patterns span an overall ruling width of 81.2mm. This allows a large lens with a field of view of up to 162mm to be tested by dividing the image into four quadrants. Contrast measurements can be taken at each frequency. These measurements will then be used as data points in constructing an MTF curve.

Additionally, the Ronchi Rulings can be used in image sensor analysis. Certain system configurations can create distortion along the boundary of low and high luminance features. The distortion varies with spatial frequency. A simple analysis of luminance along a line perpendicular to the pattern will characterize this error.

Features: 11 Groups of Variable Ronchi Rulings, each containing 5,10,20,30,40, 30, 20, 10, 5 LP/mm. The adjacent ruling sets share the interior 5LP/mm and 40LP/mm rulings. Each discrete frequency occupies 0.9mm in the vertical axis, excluding the first 5LP/mm which is 1.0mm as required to provide the starting opaque "edge of ruling" delimiter.

3.1.2 Linear Scale

154 mm Long Linear Scale with .250mm Divisions

The linear Scale included on the Multifunction Target is a high accuracy scale traceable to the N.I.S.T. A traceability statement is included with the target in the Certificate of Accuracy package.

Applications for the Linear Scale

The linear scale can be used to determine

- Field of View
- Accuracy of non-contact metrology software
- Accuracy of linear stages

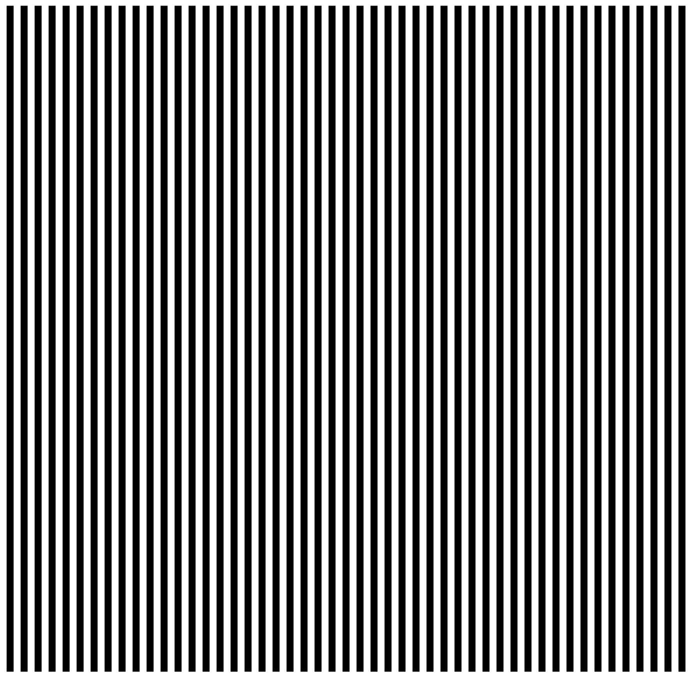
Features

The Linear Scale has an overall length of 154mm, with divisions every .250mm.

The Line Width for all lines on the scale is .080mm.

The Scale has a line-to-line accuracy of 0.0003 mm and an overall accuracy of +.004 / -.001mm.

3.1.3 Fixed Frequency Ronchi Rulings



Fixed Frequency Ronchi Pattern

Ronchi Rulings are patterns of evenly spaced alternating clear and opaque lines. The clear and opaque lines have equal width. These rulings are defined in terms of frequency, expressed in Line Pairs per Millimeter (lp/mm).

The line width for a particular frequency is given by the equation

$$W_L = \frac{1}{2 \cdot f}$$

Applications for Ronchi Rulings

- Resolution – The high frequency of the Ronchi Ruling is ideally suited to testing the maximum resolution of a system. Image analysis can be performed on the Ruling to determine the maximum spatial frequency at which the system can operate.
  By viewing progressively higher frequency Ronchi Targets, the user can determine the frequency at which the system can no longer resolve the pattern. The highest frequency at which the system can resolve detail is an accurate measurement of the system's maximum resolution.
- MTF (Modulation Transfer Function) – Modulation is a measurement of an optical system's ability to resolve detail. As the features in an image get finer, the contrast between adjacent features decreases. The Modulation Transfer Function characterizes the resolving ability of an optical system at several spatial frequencies. This better characterizes the performance of an optical system than the maximum resolution. Further details on MTF analysis can be found in section 4.5.
- Depth of Focus – When used with the Target Support Base, the Ronchi Rulings can be used to experimentally determine the Depth of Field for a system. By looking at a tilted target, the in focus distance can be found and translated into a focal plane depth. More information is available in the Section 4.3.
- Calibration of Line Width Measurements – Because the opaque lines and clear spaces are equal in width, the apparent line width of each can be measured and compared to determine the measurement accuracy of the system. Phenomena such as blooming or anti-aliasing routines inherent in the vision system can distort the ratio between the line widths. If the line widths cannot be accurately measured after calibrating the system, then the resolution is likely beyond the Nyquist frequency of the system. For details on the Nyquist frequency, see 4.1.

Features

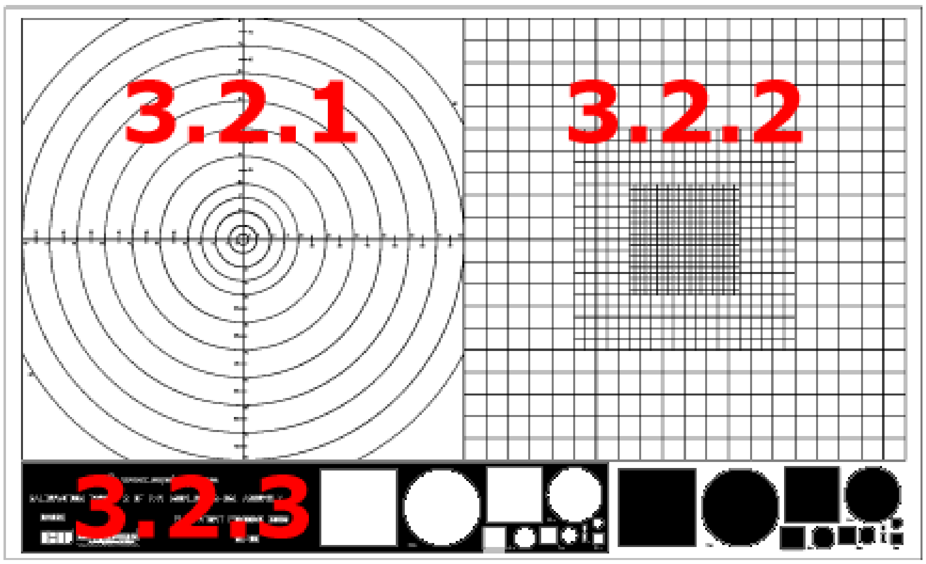
Target 1 of the kit includes the following fixed frequency Ronchi patterns:

- 50 lp/mm
- 60 lp/mm
- 70 lp/mm
- 80 lp/mm

The spatial frequency of the ruling is listed on the glass substrate outside of the pattern area.

Note: The lines of the Fixed Frequency Ronchi Rulings are oriented vertically on the target, parallel to the short edge of the substrate.

3.2 Target 2 –Field of View, Image Distortion, Image Capture Accuracy/Calibration, Illumination Analysis (Blooming) Target



Overview of Target 2
Numbers correspond to section numbers in this Manual.

3.2.1 Concentric Circles

Concentric circles share the same center point but have different diameters. The sets of concentric circles on this target are bisected by a crosshair to aid in determining the center of the circle pattern. Concentric circles are defined by the following measurements. All distances given are relative to the center of a line's width.

- Diameter – Defined as the distance along a straight line from one point along the curve of any specific circle, through the center, to another point on the circle. Radius is measured from the center of the circle to the middle of the line width.
- Incremental Spacing – Difference between the diameters of two concentric circles
- Line Width – Difference between the Outer Diameter and the Inner Diameter of a discrete circle

Applications

The Concentric Circle Pattern can be used for the following tests. Detailed information is available in the Applications Guide in Section 4.

- Field of View (FOV) - By examining circles of a known diameter, the Field of View can quickly be found in both axes.
- Distortion – An optical system will introduce some amount of distortion to the resulting image. With the known diameters of the circles, measurement systems can be fine-tuned to eliminate as much of the distortion as possible. The measurements listed below are N.I.S.T. Traceable through the Certificate of Accuracy included with the target.

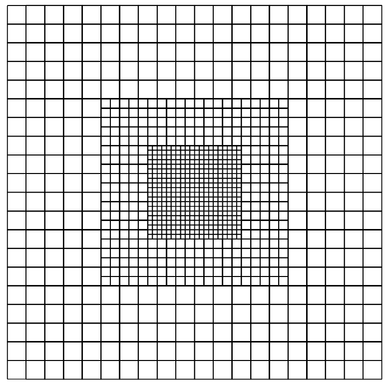
Features

Circles have the following Diameters: 2,5,10,15,20,30,40,50,60,70,80 mm.
Partial Circles are also provided at 90mm diameter in the four corners.

Axes are marked with ticks at the following distances from the center:
2,5,10,15,20,25,30,35,40,45,50,55,60,65,70,75,80 mm.

Line width is .100 mm for all circles and lines

3.2.2 Square Grids



The grids on this target consist of intersecting straight lines spaced at regular intervals. Three grid patterns are superimposed on the target so that the pattern can be used to calibrate optical systems with varying FOV.

Square grids are defined by the following parameters:

- Overall size – The edge length of a square grid as measured from the centerline of one line to the center line of another line
- Incremental Spacing – The center-to-center distance between adjacent lines in the grid
- Line Width

Applications

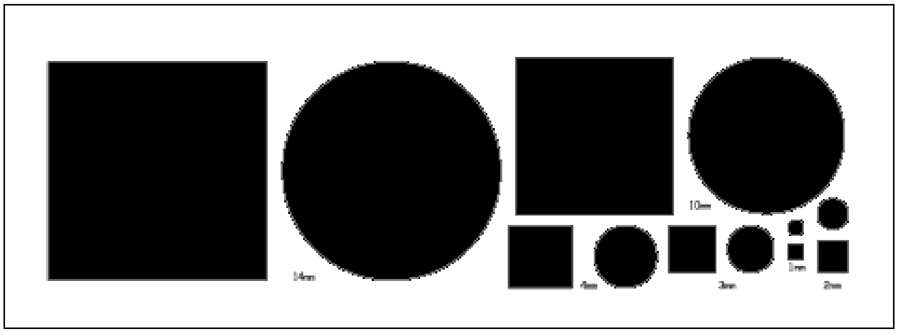
Square grids are useful for measuring several optical characteristics. These are listed below. More detailed test procedures are available in the Applications Guide in Section 4.

- Flat field and Depth of Field distortion
- Barrel and pincushion distortion
- Calibration for non-contact metrology systems
- Analysis of sub-pixel interpolation accuracy

Features

- 20mm Square Grid, 1mm Incremental spacing, .100mm Line Width
- 40mm Square Grid, 2mm Incremental spacing, .100mm Line Width
- 80mm Square Grid, 4mm Incremental spacing, .100mm Line Width

3.2.3 Calibration Features



Two sets of identical calibration features are included with the Multifunction Target: One has Opaque Circles and Squares on a Clear Background and one has Clear Circles and Squares on an Opaque Background. These features allow the user to calibrate a non-contact metrology system and then test the system for accuracy. In determining the size of features with a vision system, phenomena such as blooming can alter the perceived size of a feature. The positive and negative versions of the target allow the user to test system accuracy in both polarities using a traceable standard.

Applications

The Circle and Square Calibration Features are designed to be used for the following tests:

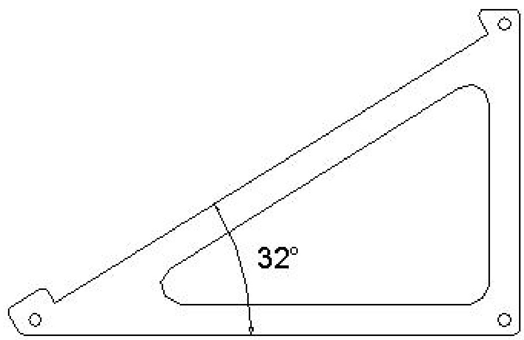
- Calibration of non-contact metrology systems
- Determination of system anomalies such as blooming and edge detection errors that result from:
    - Illumination modes (top, oblique, or bottom-lighting and illumination intensity)
    - Camera optics
    - Image analysis software

Features

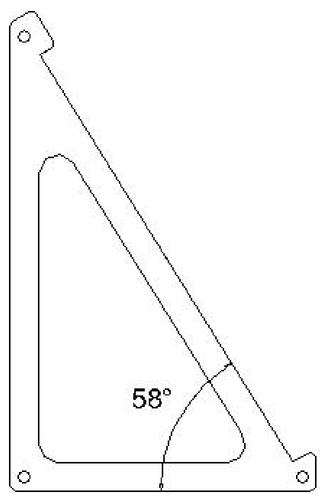
The following features are printed on the Target in both Positive and Negative Versions:

- Circles: 1,2,3,4,10, and 14mm Diameter Circles
- Squares: 1,2,3,4,10, and 14mm Length Squares

3.3 Target Support Base



Included Support Base – 32° Configuration



Included Support Base - 58° Configuration

The target support base adds a great deal of functionality to the Multifunction Targets. With the two fixed angles, the base can be used in conjunction with the target to experimentally determine the Depth of Field, MTF verses Depth of Field, Distortion verses Depth of Field and Telecentricity. These applications are discussed further in the Applications Guide in Section 4.

4 Applications Guide

The Multifunction Target is a versatile test tool for imaging systems. The major functions of the target are discussed in the following sections in this manual. The applications guide assumes some familiarity with basic optical concepts and concentrates on the applications of this target to the following tests.

4.1 Resolution

Resolution is the ability of an optical system to differentiate between two features that are close together. Measurements of resolution are usually made using a resolution target or Ronchi Rulings. The Multifunction Target allows the user to test the three dimensional resolution of the system over the entire Field of View and Depth of Field.

There are two essential measurements associated with Resolution:

Maximum Resolution – This is the highest spatial frequency at which two lines can be distinguished from each other. The contrast between the lines is greatly diminished at this point. However, the imaging system is still able to extract enough contrast from the resulting image that adjacent features can be identified. It is important to note that the maximum resolution of a sensor is sometimes different for horizontal and vertical orientations, as well as diagonal orientations. For this reason, the resolution should be tested with the target features at varying angles to the image sensor. When a system is tested, using the Resolution Target mounted at an angle on the Target Base, the Maximum Resolution will decrease from the center of the focal plane as the image is viewed forward and aft of this ideal plane. From a practical point of view, this decrease in resolution with increasing depth of field controls the maximum system resolution for a particular three dimensional object of interest. The resolution as measured on the Angled Target that matches the height of the object of interest provides this parameter. If a system has a flat field resolution of 20LP/mm but needs to resolve and/or measure an object accurately that has significant height, a Telecentric Lens System may be indicated as a standard lens system may not hold the required resolution or size accuracy. The Multifunction Target allows this analysis to be made by actual test.

Nyquist Frequency – This frequency, sometimes called the Critical Frequency, is defined by the Nyquist-Shannon Sampling Theorem. This spatial resolution describes the point at which aliasing can be avoided. This is essential in preventing the formation of artifacts such as moiré patterns. In theory, the Nyquist frequency is essentially half the sampling frequency.

$$f_N = \frac{f_{sensor}}{2}$$

For digital imaging systems, there are several additional factors such that the theoretical determination of the Nyquist Frequency is impractical. It is useful in this case to use the variable Ronchi Rulings included on the Multifunction Target to experimentally determine the Nyquist Frequency.

Procedure:

The resolution of a system can be determined using the Variable Frequency Ronchi Rulings included on Target 1. The resolution across the entire image field can be determined using the Fixed Frequency Ronchi Rulings on the same target.

1. Position the target in the Field of View of the camera
2. Properly focus the system and adjust the lighting to give the best contrast. If the lines in the Ronchi Ruling are not visible, the spatial frequency is beyond that of the Lens and Camera combination. Use a smaller field of view with higher magnification Lens or a higher pixel count Camera or both. A lower frequency ruling below the 5LP/mm minimum included on the Multifunction Target can also be used to perform resolution testing of very low resolution systems.
3. Capture the image and import the image into an image analysis program.
4. Plot the intensity profile along a straight line perpendicular to the direction of the pattern lines.

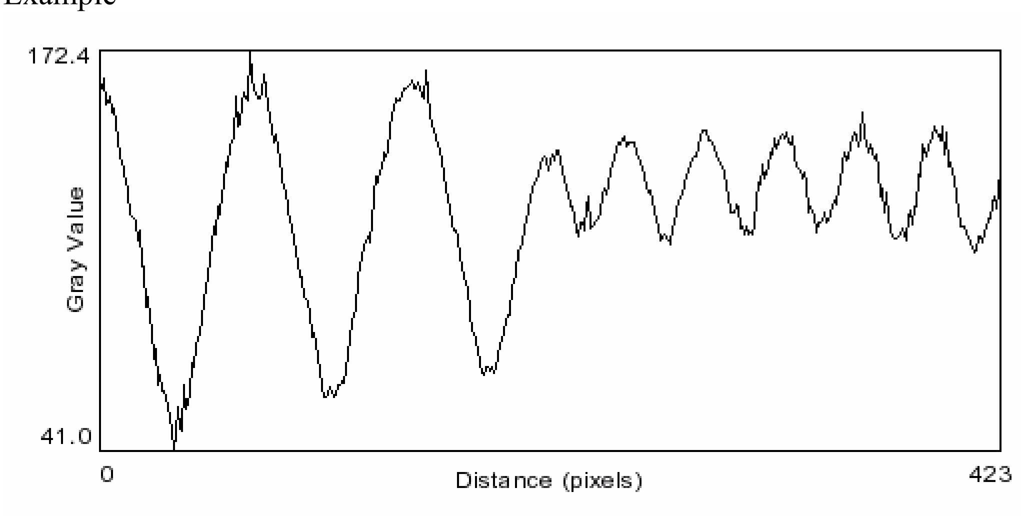
Analysis

In the plot of intensity profile, the major factor affecting resolution is the contrast. In simple terms the contrast is expressed in the following ratio:

$$C(f) = \frac{I_H - I_L}{I_H + I_L}$$

Where
C = Contrast
I_H = Maximum intensity of the pattern at some spatial frequency f
I_L = Minimum intensity of the pattern at spatial frequency f

Example



In the above intensity profile plot, the spatial frequency doubles near the midpoint of the plot. The decreased contrast is evidence that the system is approaching its resolution limit.

4.2 Field of View

Field of view is a measure of the extent of the subject that is observable within the projected image plane. The Multifunction Target can be used to objectively quantify the Field of View.

Procedure:

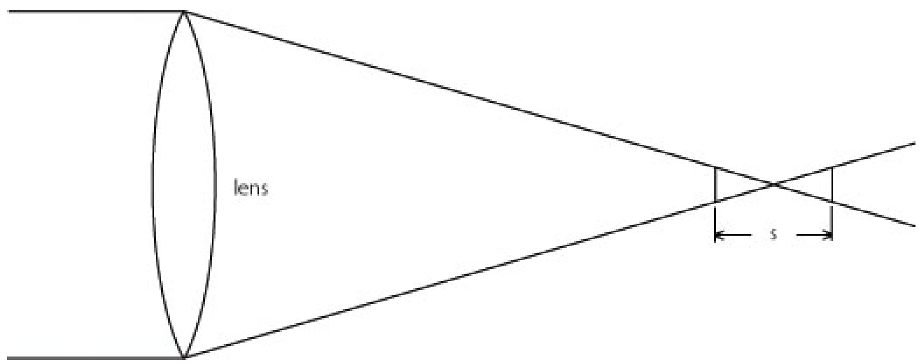
1. Position the Linear Scale within the Field of View so that it is horizontally aligned to the image plane.
2. Line up the left edge of the Linear Scale (0 mm) with the left edge of the image field.
3. Without moving the stage, observe the right edge of the image field and record the last observable ruling on the scale.
4. Repeat steps 1-3 several times and then average the results.
5. Position the Linear Scale so that it is aligned to the vertical axis of the image area.
6. Repeat the measurement in the vertical axis and record the results.

Analysis

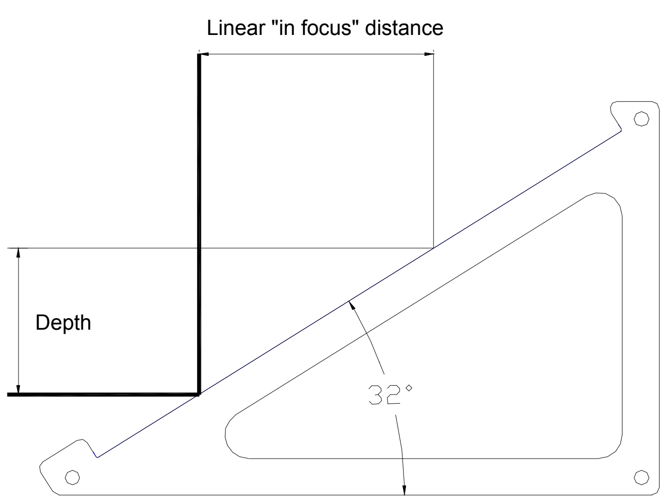
The Field of View is determined experimentally. Each division on the Linear Scale is equal to 0.250mm.

4.3 Depth of Field

Depth of Field is the distance, s, over which an image has an acceptably sharp focus. The Multifunction Target can be used to experimentally determine the DOF and to test the manufacturer's specifications on various lenses. The DOF of a system is a useful parameter when the system is used for observing, resolving and measuring three dimensional objects.



The Target Support Base is integral to the Depth of Field measurement. The base supports the target at a well known angle such that the corresponding "in focus" distance can be converted to a useful depth of field about the ideal focal plane. The relationship is illustrated below.

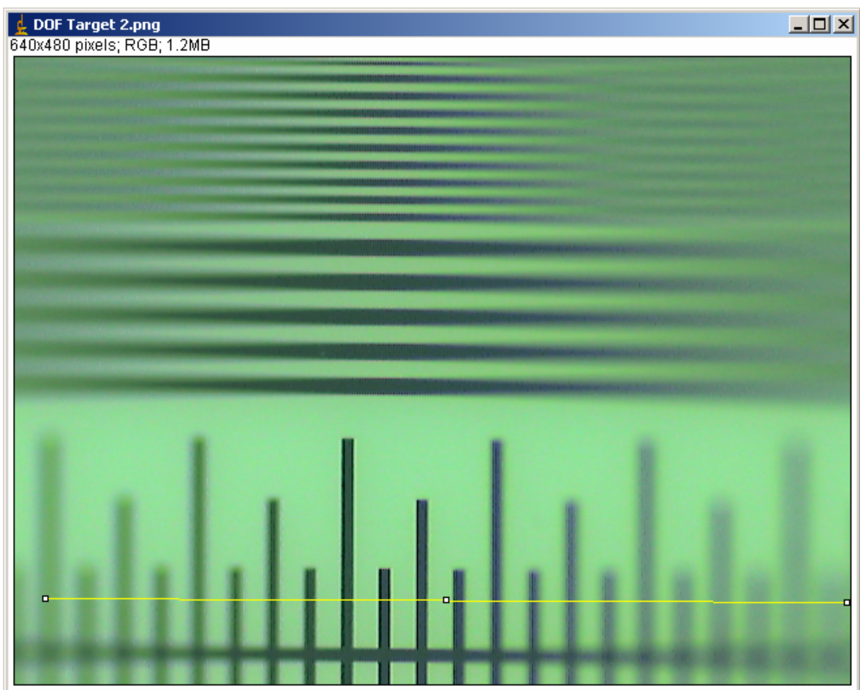


Procedure

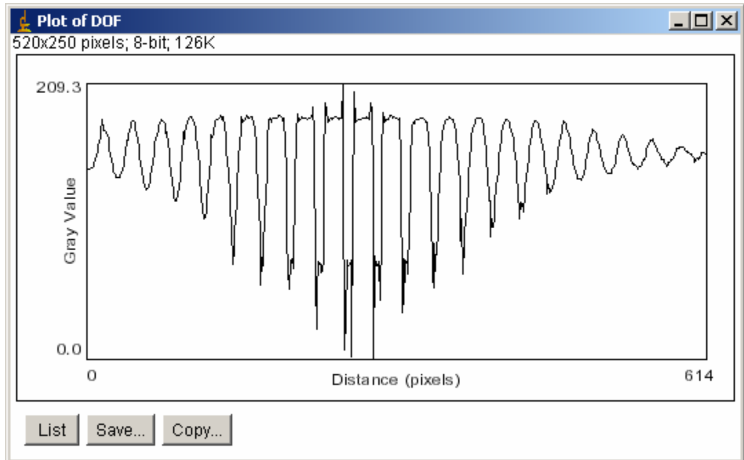
The Depth of Field Measurement requires the Target Base to be used. The base can be used in either the 32° or 58° setup. **Note:** When observing the in-focus distance of the target, it is important to account for the cosine error introduced by the angle of the target to the camera. This projection must be considered for accurate results.

To determine the Far Field and Near Field:

1. Position the target on the base within the camera's field of view. Move the target so that the Linear Scale is aligned to the horizontal axis of the image area.
2. Focus the system so that the center of the image field is focused properly.
3. Perform a plot analysis along a straight line parallel to the scale (see below)
4. Determine the points on the analysis at which the contrast drops below the useful limit. These points are the Near Field and Far Field. These points can also be determined by direct observation of the operator; however the measurement is somewhat subjective.



Actual image of the Linear Scale captured
through a Telecentric lens



Intensity analysis of the above image

5. Subtract the smaller quantity from the larger to get the "in focus" distance.
6. Perform the analysis below to convert the "in focus" distance to a DOF measurement.

Analysis

If a linear stage is being used the following quantities should be determined in order to computer the DOF:

$$L_I = |L_F - L_N|$$

where L_I = In Focus Distance
L_F = Far Field Distance
L_N = Near Field Distance

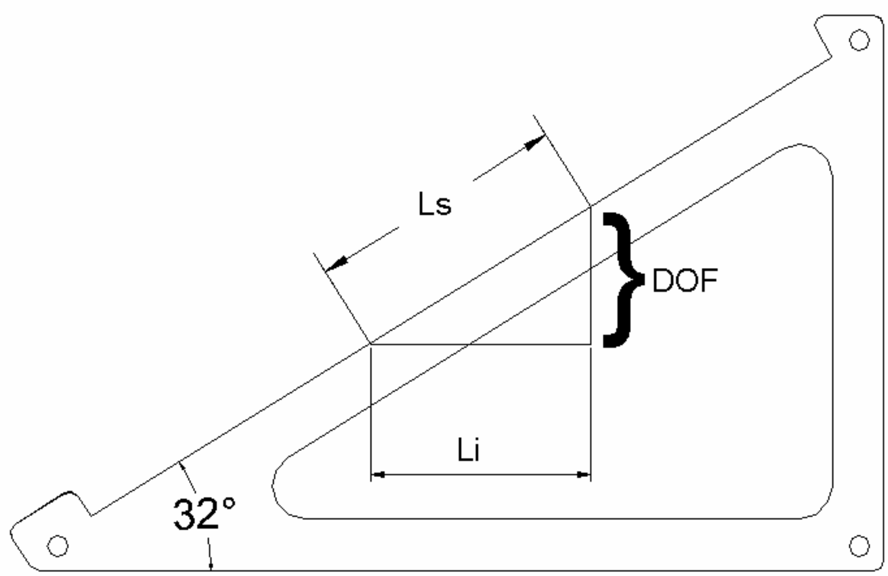
The In Focus distance must then be corrected for the projection resulting from the angle of the target base (cosine error). Depending on the orientation of the base, the angle θ is either 32° or 58°.

To find DOF use the formula:

$$DOF = L_I \tan\theta$$

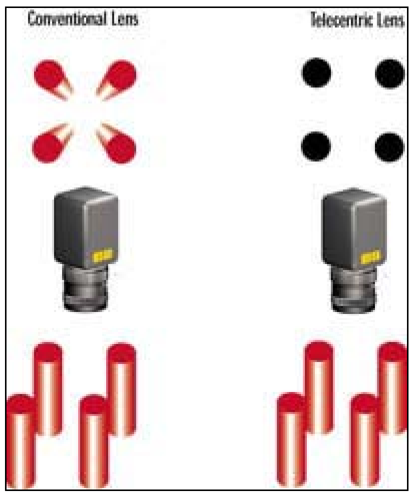
If readings are taken directly from the scale, then L_s equals the length of the scale that is in focus and:

$$DOF = L_S \sin\theta$$



4.4 Telecentricity

Telecentric lenses are ideally suited to metrology applications. By collecting light rays onto a lens that is larger than the field of view (FOV), Telecentric lenses maintain equal magnification throughout the depth of field. This greatly reduces the effects of geometric and dimensional variance with an object's distance from the lens. Telecentricity is a test that can be performed to measure the effectiveness of a Telecentric lens. There is no widely accepted standard to quantify Telecentricity. However, the Multifunction Target allows the user to test the basic functionality of the Telecentric optics



Telecentric Effect
Image courtesy Edmund Optics Worldwide

Procedure

The target base must be used to check Telecentricity. The line grid section of Target 2 is ideal for this application.

1. Position Target 2 in the Target Base holder and align the target to the FOV of the camera.
2. Focus the system so that the center of the FOV is in best focus.
3. Observe the lines perpendicular to the slope of the target.

Analysis

The effectiveness of Telecentric optics can be evaluated by checking the parallelism of the lines running perpendicular to the slope of the target. Parallel lines indicate that the magnification remains constant throughout the Depth of Field. Divergent lines indicate that the magnification has changed with distance from the lens.

4.5 Modulation Transfer Function (MTF)

Modulation is a measurement of an optical system's ability to delineate image detail. As features in the image get progressively finer, the contrast between adjacent features drops. Several different sets of Ronchi Rulings with different spatial frequencies are imaged by the system under test and the finest set in which the line structure can be discerned is considered to be the resolution limit of the system, expressed in terms of spatial frequency. The spatial frequency is typically expressed in terms of Line Pairs per MM, or LP/MM.

It should be noted that the maximum resolution does not fully characterize the performance of a system. It is important to account for the resolving ability at several different spatial frequencies. The Modulation Transfer Function is a tool used to quantify this response curve.

Modulation is defined as follows for a square-wave pattern at a certain spatial frequency:

$$\text{Modulation} = \frac{L_{MAX} - L_{MIN}}{L_{MAX} + L_{MIN}}$$

Where L_{MAX} = The maximum luminance in the image field
L_{MIN} = The minimum luminance in the image field

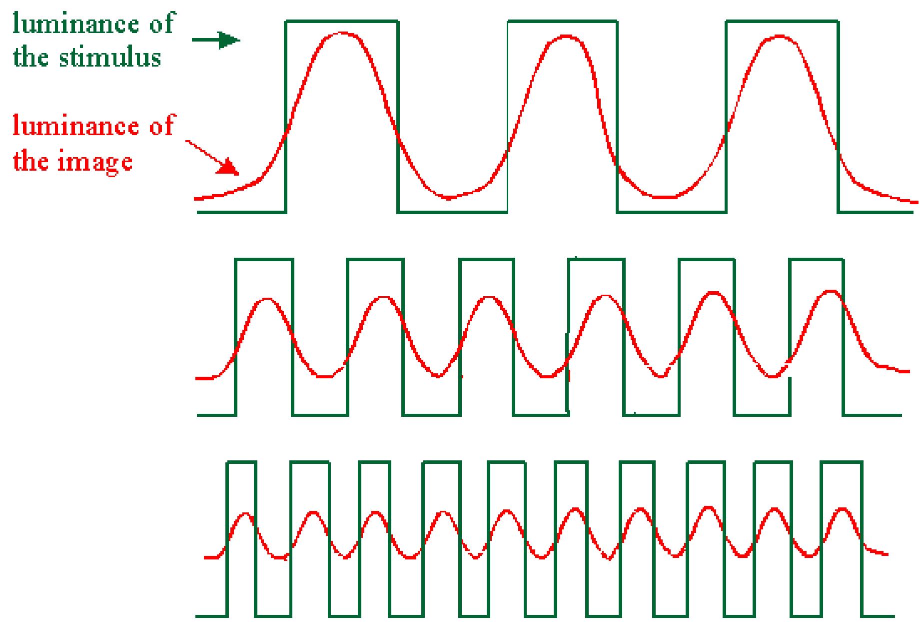
The Modulation Transfer Function is derived by measuring the modulation at several spatial frequencies.

$$MTF(v) = \frac{M_i}{M_0}$$

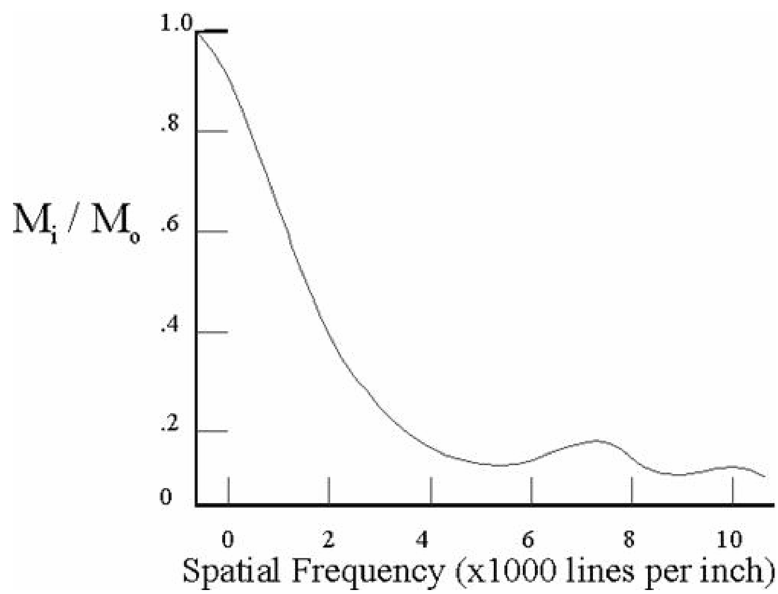
Where M_i= The modulation of the image at spatial frequency v
M_0=The modulation of the object being viewed

In the case of Ronchi Rulings, M_0 will always be equal to 1 due to the high contrast between neighboring dark and light bars.

An MTF plot is a useful measure of the resolving performance of an optical system at various spatial frequencies. A plot of MTF also aids the operator in determining the resolution and magnification required to acquire useful data from an imager. With three dimensional objects, the Multifunction Target, when mounted on the tilted Base, can be used to evaluate MTF over the Depth of Field range required for the height of the object that the system is intended to view.



Modulation at different spatial frequencies



An example plot of MTF

Procedure

The Multifunction Target was designed to ease the process of producing an MTF plot. Target 1 contains a specially constructed pattern of Variable Ronchi Rulings designed to make the process as easy as possible.

1. Begin by placing Target 1 perpendicular to the Imagining Optics and in full view of the Imaging System. Align the Target so that the variable frequency

ronchi rulings cover the entire field of view of the Imaging System. Focus the optical system and adjust the light source for the best visual acuity.

2. Make sure that the Image Display has the native resolution required to display the field of view of the Imaging System at the maximum expected Imaging System Resolution. For large lens systems it is most likely that the resolution of the display will be below that of the Imaging System and that the Analysis Software will not permit a full field of view display. For instance, a typical LCD flat panel 19" Display at 1280 X 1024 resolution would only be able to display a resolution of about 6LP/mm for a 80mm 3 displayed at about a 9" screen diameter. With the display set to view one set of the 5-40-5LP/mm rulings the resolution capability would be over 60LP/mm with this same display.
3. Use analysis software to plot the MTF curve. The frequency of the Ronchi Rulings follows the specifications below.
4. Place the Target on the tilted frame and repeat the Imaging System Resolution Test to determine the resolution capabilities over the entire depth of field of the system.

Examples using native camera resolution

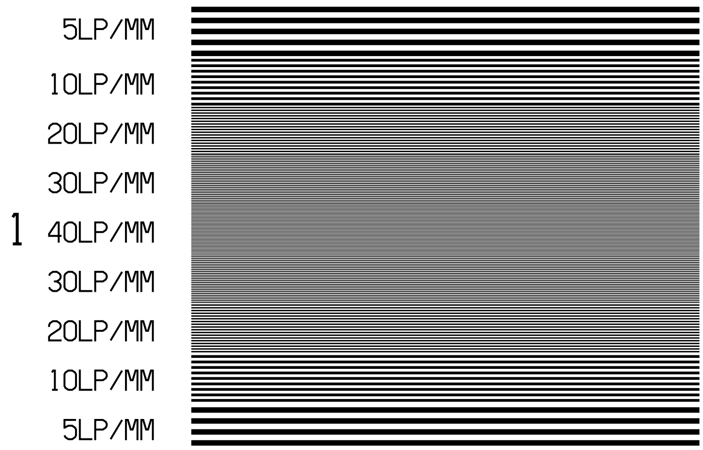
Example 1: The Jai-Pulnix TM-4100GE camera uses a 2048 x 2048 pixel detector. Using an 80 mm diameter lens system each pixel has a coverage area of (80mm / 2048 pixels), or .039mm. The finest frequency of lines that this setup can see clearly would be the case where one pixel captures a .039mm dark line and the pixel next to it saw a .039mm clear line. That frequency would be 1/.078mm, or 12.82 Lp/mm. Resolving ability is lost at frequencies greater then 12.82 Lp/mm.

Example 2: The Lumenera Lw11050 camera uses a 4008 x 2672 pixel detector. Using an 80 mm diameter lens system each pixel has a coverage area of (80mm / 4008 pixels), or .01996 mm. The finest frequency of lines that this setup can see clearly would be the case where one pixel captures a .01996 mm dark line and the pixel next to it saw a .01996mm clear line. That frequency would be 1/.03992 mm, or 25.05 Lp/mm. Resolving ability is lost at frequencies greater then 25.05 Lp/mm.

Also see the discussion of Nyquist Frequency in section 4.1.

Features

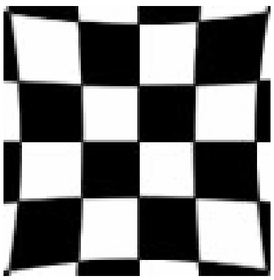
11 Groups of Variable Ronchi Rulings, each containing 5,10,20,30,40, 30, 20, 10, 5LP/mm. The adjacent ruling sets share the interior 5LP/mm and 40LP/mm rulings.
The 11 sets of patterns span an overall ruling width of 81.2mm.
Each discrete frequency occupies 0.9mm in the vertical axis, excluding the first 5LP/mm which is 1.0mm as required to provide the starting opaque "edge of ruling" delimiter.



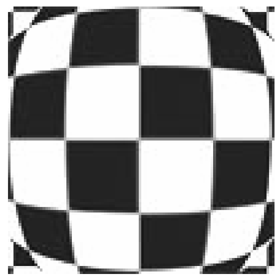
Variable Frequency Ronchi Ruling pattern group

4.6 Distortion

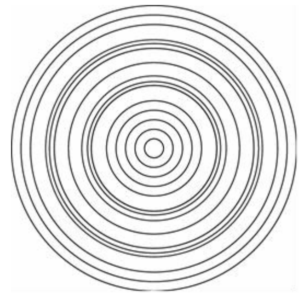
Distortion is an alteration in the shape and/or proportion of an image. The Multifunction Target is useful for detecting the presence of four major types of distortion:



Pincushioning



Barreling



Spherical Aberration

Major Types of Distortion

Pincushioning – Distortion in which the magnification of the lens increases toward the edge of the Field of View. Information is not lost in this type of distortion; it is moved to a different point in the image.

Barreling – Distortion in which the magnification decreases towards the edge of the field. The image information is not lost in this type of distortion; it is moved to a different point in the image.

Spherical Aberration – Distortion is caused by a lens defect in which image forming rays passing through the outer zones of the lens focus at a distance from the principle plane different from the rays passing through the center of the lens. This causes rays to cross the axis at points in front of or behind the point of focus. Those rays form a halo around the focal point.

Astigmatism – Distortion is a result of a cylindrical wavefront aberration, which increases as a square of the distance off axis and the square of the aperture. The focus consists of two concentrations of rays known as focal lines, with a blurred circular region representing the best approximation to a point focus. The result of this type of distortion is that circles appear elongated into elliptical shapes.

Procedure

Determination of distortion is largely a subjective measure. Quantification of distortion or lens aberration is difficult without performing a paraxial ray trace on the optical system.

Pincushioning and Barreling distortion can both be tested using the line grids on Target 2. These types of distortion will result in the lines bending across the Field of View. Straight lines can be superimposed over the imaged lines using software to show the effects of the distortion. It is important to note that most optical systems are designed so that the performance is highest in the center of the FOV. Distortion increases near the edges of the image. The target can be used in this case to determine how much of the image area is usable in metrology applications.

Spherical aberration and astigmatism can be test using the Concentric Circles pattern on Target 2. These types of distortion are harder to detect than flat field distortion. Image analysis software can be used to measure the diameters and centricity of the various circles on the target. Using this method, the operator is able to detect severe deviations from the correct function of the optical system. If these distortions are present, then there is likely an error in the configuration of the imaging system.

All of the above tests, when conducted flat and then using the tilted frame, will provide the Imagining System user with a good understanding of how these parameters effect image capture and dimensional analysis over the full depth of field of the Imagining System.

4.7 Linear Calibration

The Multifunction Target is well suited to calibrating non-contact metrology devices. The target provides an accurate, traceable standard to calibrate instruments for distances within the image plane and up to the length of the linear scale.

Procedure

For Calibration within the FOV

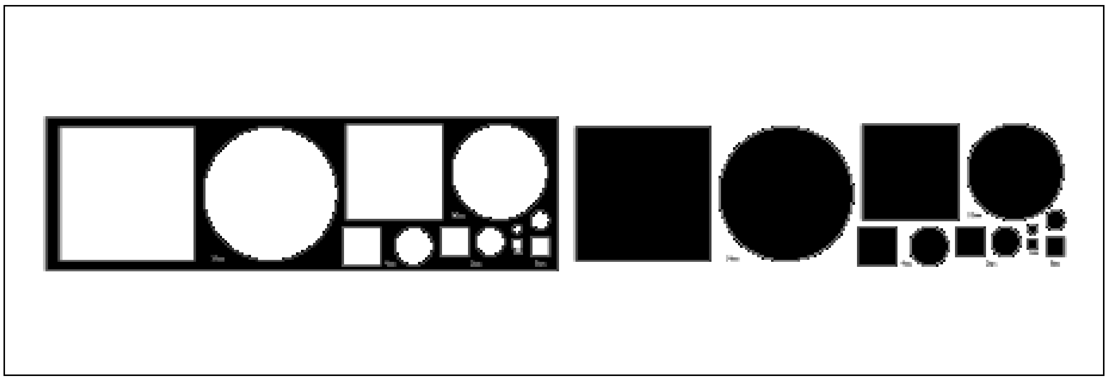
Several features on the target can be used to calibrate metrology systems. For direct measurement within the field of view, the Line Grid on Target 2 is most useful. Position the line grid target within the Field of View. Most software packages allow for the calibration of the image field using a flat field target. The line spacing on this target is specified in the Appendix.

For Calibration of Digital Stages

1. Place Target 1 on the digital stage and focus on the Linear Scale.
2. Measure the centroid of a bar within the field of view to find its location
3. Move the stage a specified amount. The movement should be an increment of a millimeter.
4. Perform a measurement on the new feature that it is the same location as the previous feature. The offset between the two features is the error inherent in the digital stage.

4.8 Blooming

Blooming is a condition affecting mainly CCD image sensors in which the charge from one pixel spills over into adjacent pixels, causing distortion at the pixel level. The resulting features appear larger than they are due to this growth. This can cause significant error in metrology applications. The Multifunction Target includes a series of features designed to detect the presence of blooming as well as calibrate the system for non-contact metrology. Often, the problem can be lessened through proper lighting and filters. The Multifunction Target is a useful tool in this process.



Calibration Features on Target 2

Procedure

1. Place the target in front of the camera objective and focus on a positive feature (chrome on a clear glass field)
2. Perform a measurement of the diameter or edge length of the selected feature using image capture software designed for metrology use; or, visually with the optical crosshair, stage and digital encoder readout. On Imaging Systems with software generated crosshairs and measurement scales, where the feature falls within the field of view of the system, the target feature can also be used to check the accuracy of these system features.
3. Move the system to focus on the same feature in the Negative field.
4. Measure the negative feature with the same measurement function
5. Compare the measurements of the positive and negative versions of the feature.
6. Adjust the illumination or gain to yield the same data for both the positive and negative versions of the target.
7. Adjust the calibration parameters offered by the image capture software to match the known dimensions of the Target Feature.

Analysis

A significant variation in size between the positive and negative features is an indication of blooming. Light features tend to grow as a result of blooming. Depending on the type of lighting used, either the positive or negative region will have high luminance features. Look for the high luminance features to grow outward. Often, the problem can be corrected through proper lighting or anti-blooming software. In either case, these features are ideal to test for the condition.

5 Appendix

1. List of features and dimensions
2. Certificate of Accuracy

5.1 List of Features

Target 1: 300MLA0139-001

- 11 Groups of Variable Ronchi Rulings, each containing 5,10,20,30,40, 30, 20, 10, 5LP/mm. The adjacent ruling sets share the interior 5LP/mm and 40LP/mm rulings.
    - Overall ruling width of the pattern is 81.2mm
    - Each discrete frequency occupies 0.9mm in the vertical axis, except for the first 5LP/mm ruling band. This initial band is 1.0mm wide and serves as the starting opaque "edge of ruling" delimiter.
- Fixed Frequency Ronchi Rulings
    - 50 lp/mm
    - 60 lp/mm
    - 70 lp/mm
    - 80 lp/mm
- Linear Scale, 154mm in length
    - Line width .080mm
    - Overall accuracy +.004 / -.001mm

Target 2: 300MLA0139-002

- Concentric Circles
    - Diameters 2,5,10,15,20,30,40,50,60,70,80 and partial 90 mm
    - Tick marks along axes at 2,5,10,15,20,25,30,35,40,45,50,55,60,65,70,75,80 mm
    - Line width is .100mm for all circles and lines
- Square Grid
    - 20mm Square Grid, 1mm Increments
    - 40mm Square Grid, 2mm Increments
    - 80mm Square Grid, 4mm Increments
    - All lines have width .100mm
- Calibration Features
    - Positive and Negative Circles with the following diameters: 1,2,3,4,10, and 14mm
    - Positive and Negative Squares with the following side lengths: 1,2,3,4,10, and 14mm

5.2 Sample Certificate of Accuracy

MAX LEVY AUTOGRAPH, INC.

Specialists in Ultra-Precision Technical Artwork, Replication Tooling and Opto-Mechanical Components

220 WEST ROBERTS AVENUE PHILADELPHIA, PENNSYLVANIA 19144-4298

Telephone: 215-842-3675 *Fax: 215-842-3637* *www.maxlevy.com*

CERTIFICATE OF ACCURACY

Multifunction Target
PN: DA066
SN: SAMPLE

This is to certify that the DA066 Multifunction Target on Soda Lime Glass substrate, P/N DA066, S/N SAMPLE has been inspected for conformance to Drawing Number 100MLA0168-001.

This part has been replicated from a Master Phototools "MTF-TARGET" and "MTF-TARGET2" under controlled environmental conditions to ensure dimensional accuracy. The replication was performed at 68ºF ± .5ºF. The total replication error has been experimentally determined to be less than .001 mm.

The pattern was measured with an HP-5501B laser interferometer system according to ITP-1001 as part of the final inspection. All measurements are traceable to NIST Test Number 821/262115-99. The procedures used are in compliance with MIL-STD-45662A. The results of the final inspection are listed below. These measurements represent the As Found condition of the part. No adjustments were made to the part.

	Nominal	Measured
Scale Length:	154mm	
Line Width, 80lp/mm	.00625mm	

This measurement have an uncertainty of .0009mm at α=2.

Inspected by:____________________

Date:________________

Manufacturers of Reticles, Encoders, Large Scale Precision Replication Tooling, Circuitry, Photo-Etched Metal, Ceramic & Glass Parts, Microscales, Film & Glass Grids, Diffraction and Phase Gratings, Special & Ronchi Rulings