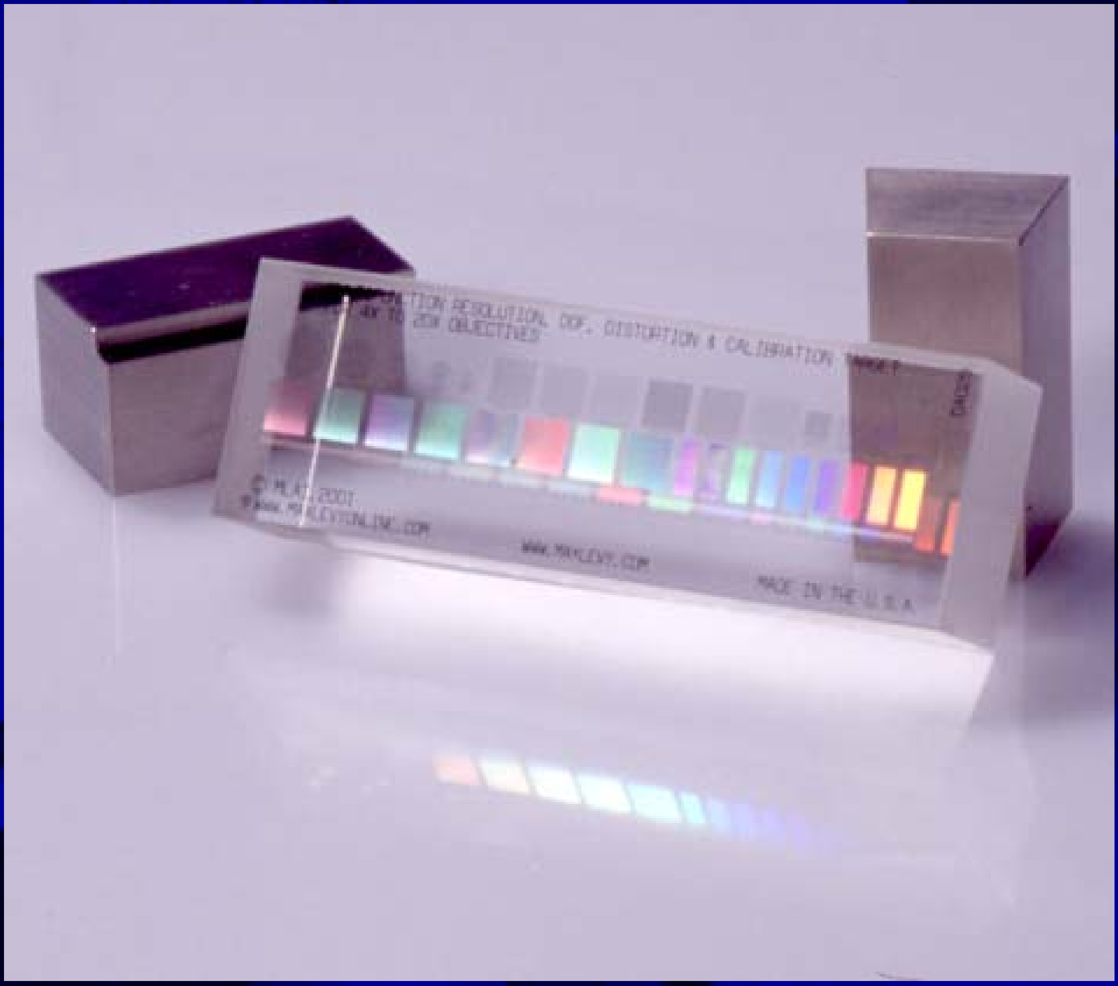
A GUIDE TO THE

MULTIFUNCTION TARGET



MAX LEVY AUTOGRAPH

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Table of Contents

1.0 Introduction

The multifunction target is a versatile target specifically designed to measure the performance characteristics of various optical systems. The target can be used as a human visual measurement and calibration tool or as a calibration tool for Machine Vision Cameras and their associated Image Capture and Measurement Software. The target is manufactured to the highest level of precision to ensure meaningful test results.

The target contains several patterns which in combination, perform the function of several other individual targets, including standard resolution targets, distortion targets, DOF targets, and linear calibration measurement scales.

Two versions of the target are offered. One version is intended for low to mid range magnification optics and optical systems such as magnifiers, eye loupes, low power stereoptic microscopes, machine vision systems and their associated image capture software, video microscopy systems, high definition line scan cameras, macro lenses, telecentric lenses and other specialized optical systems. The other target is designed for mid to high power magnification systems of all types.

To ensure durability under a broad range of conditions, the target is patterned in double layer, reflective evaporative-deposited chrome. Dual layers are utilized to ensure a high optical density. This allows the target to be used in top-lit, through-the-lens, and bottom-lit configurations. The target is patterned on quartz glass optimized for flatness, parallelism, squareness, and scratch:dig. To accommodate various magnifications and fields of view, each feature on the target is reproduced in multiple scale configurations. These include variations in frequency, overall pattern size, spacing, and line width. This makes the target a very versatile tool for covering a wide range of optical configurations and camera interfaces.

The high accuracy of the target allows the user to accurately quantify MTF, field of view, depth of field, and distortion under a variety of set-up conditions. Advanced applications include the testing and calibration of various machine vision camera and image capture software systems. This includes linear, circular and retangular feature sizes, positional accuracy for non-contact metrology systems and verification of subpixelization routines.

The Multifunction Target kit includes a brief user card to acquaint the user with some of the basic applications of the target. This includes the method for using edge blocks to determine Depth of Field measurements. The purpose of this manual is to completely examine the uses of the target. For each application, the manual lists the entire procedure and gives complete specifications for all features necessary to use the target as an objective certification device.

1.1 Summary of Features

Concentric Circles					
DA029 4X-20X objective target			DA030 20X-100X objective target		
OD (mm)	Incr. by dia. (mm)	Line width (microns)	OD (mm)	Incr. by dia. (mm)	Line width (microns)
5.0	0.25	20	3.0	0.25	10
4.0	0.25	15	2.0	0.1	7.5
3.0	0.25	10	1.5	0.1	5
2.0	0.1	7.5	1.5	0.1	2.5
1.0	0.1	5	1.0	0.05	5
			1.0	0.05	2.5

Grids					
DA029 4X-20X objective target			DA030 20X-100X objective target		
Width (mm)	Incr. by dia. (mm)	Line width (microns)	Width (mm)	Incr. by dia. (mm)	Line width (microns)
4.5	0.25	20	3.0	0.25	10
4.5	0.25	15	3.0	0.25	7.5
4.5	0.25	10	3.0	0.25	5
4.5	0.10	15	3.0	0.10	10
4.5	0.10	10	3.0	0.10	7.5
4.5	0.10	5	3.0	0.10	5
2.55	0.075	10	2.55	0.075	10
2.55	0.075	5	2.55	0.075	5
2.55	0.050	5	2.55	0.050	5
2.55	0.050	2.5	2.55	0.050	2.5

Ronchi rulings			
DA029 4X-20X objective target		DA030 20X-100X objective target	
Range (LP/mm)	Increment Steps (LP/mm)	Range (LP/mm)	Increment Steps (LP/mm)
60-380	20	240-600	10

Linear microscale					
DA029 4X-20X objective target			DA030 20X-100X objective target		
Length (mm)	Divisions/mm	Microns/division	Length (mm)	Divisions/mm	Microns/division
0-68.2	20	50	0-68.2	20	50

Edge blocks (DOF)					
DA029 4X-20X objective target			DA030 20X-100X objective target		
5/1	10/1	End Support	20/1	40/1	70/1

2.0 Hardware

2.1 The Multifunction Target comes as part of a kit. The following configurations are available:

DA029: Multifunction Target Kit for 4X-20X Objectives

Kit includes:

- 4X-20X Multifunction Target
- 5/1 ratio edge block
- 10/1 ratio edge block
- End support
- User information card
- CD-ROM containing user manual and spreadsheets
- Carrying case with molded foam insert

DA030: Multifunction Target Kit for 20X-100X Objectives

Kit includes:

- 20X-100X Multifunction Target
- 20/1 ratio edge block
- 40/1 ratio edge block
- 70/1 ratio edge block
- User information card
- CD-ROM containing user manual and spreadsheets
- Carrying case with molded foam insert

DA031: Multifunction Target Kit for 4X-20X objectives and 20X-100X objectives

Kit includes:

- 4X-20X Multifunction Target
- 20X-100X Multifunction Target
- 5/1, 10/1, 20/1, 40/1, 70/1 ratio edge blocks
- End support
- User information card
- CD-ROM containing manual and spreadsheets
- Carrying case with molded foam insert to hold both targets

2.2 General Handling and Care

2.2.1 Handling

The target consists of an optical glass substrate patterned with reflective chrome. It should be treated in the same manner as other precision optical or glass components. The target should be kept away from acids and etchants at all times.

It is recommended that the user wear protective latex gloves at all times when handling the target. This is to prevent oils from the user's skin from coming in contact with the glass surface or the pattern. Oils can adhere to the target, obscuring the fine features on the pattern. Over time, acids or oils canl degrade the quality of the pattern and/or glass. If the target becomes dirty due to oil or grease, follow the cleaning procedure in section 2.2.2.

Similar care should be taken when handling the edge blocks. Precautions should be taken not to drop or chip the metal edge blocks, as this can alter the precise angles that the block is held to, which are critical for depth of field measurements. If the protective finish becomes dirty, follow the cleaning procedure listed in section 2.2.2.

When not in use, the target should always be stored in its carrying case or in a safe, dust-free location. To remove the target or the edge blocks from the carrying case, push down on the foam insert and lift the target out the case by holding the top and bottom edges.

2.2.2 Cleaning

Materials:

- Lint-free textile cloth or other non-abrasive lint-free cloth
- Lens tissue
- Lens Cleaner or Isopropanol (reagent grade)
- Gloves or finger cots
- Air gun (optional)

Procedure:

Begin by blowing loose material off of the target. An air gun and clean, dry, oil free compressed air source may be used. Note: avoid shop air lines that are not filtered, as these lines frequently contain particulate, oil and water that can damage the target or deposit films on the optical surface.

Dampen lint-free cloth in Lens Cleaner or Isopropanol. Gently wipe the surface of the target with the damp cloth. Drag the wipe across the surface just fast enough so that the liquid evaporates right behind the cotton. When finished, there should be no streaks left on the target. If streaks remain, use a new lint-free cloth and repeat the wiping procedure.

Inspection:

The final step in the cleaning procedure is to examine the cleaned target. This should be done in both reflected and transmitted light, preferably against a black background. Any visible residue can be cleaned by repeating the cleaning procedure. If the residue cannot be removed, it is possible that target pattern has been damaged.

2.2.3 Operating Environment

The target has been designed for use at room temperature and normal humidity. The glass used to make the target has a low coefficient of thermal expansion, so changes in temperature will not significantly affect its size. The target should be kept from extreme conditions of temperature and heat.

2.3 Concentric Circles

Concentric circles are a series of circles sharing the same center point but having different diameters. The sets of concentric circles on the target are bisected by a crosshair to aid in determining the exact center of the circle pattern. Concentric circles are defined by the following parameters. All diameter and spacing dimensions are center-to-center line dimensions regardless of the line width.

- Outer Diameter (OD) : Centerline diameter of the largest circle in the series
- Incremental Spacing: Centerline distance between concentric circles, defined in terms of the difference in diameter between adjacent circles.
- Line width: Distance between the outer edge and the inner edge of a specific circle, as measured tangent to the circle.

Applications:

Concentric circles are used primarily for quantifying Field of View and in detecting certain types of lens defects, such as spherical aberration and astigmatism. For systems where the image plane is circular such as microscopes and video microscopy cameras, concentric circles can be used to quickly determine the extent of the Field of View. Concentric circles are also well suited to identifying spherical aberration and astigmatism. For a complete description of the procedure to test these characteristics, see sections 3.1 and 3.4.

When using the concentric circles on the target for qualifying image capture software, the mean "as seen" measured diameter of the concentric circle is the capture value of the OD of the circle plus the capture value of the ID of the circle divided by two. This "as seen" value is then compared to the published value for that target feature. This manual capture and calculation is necessary for edge detection systems that do not do these these two captures and calculate the center automatically.

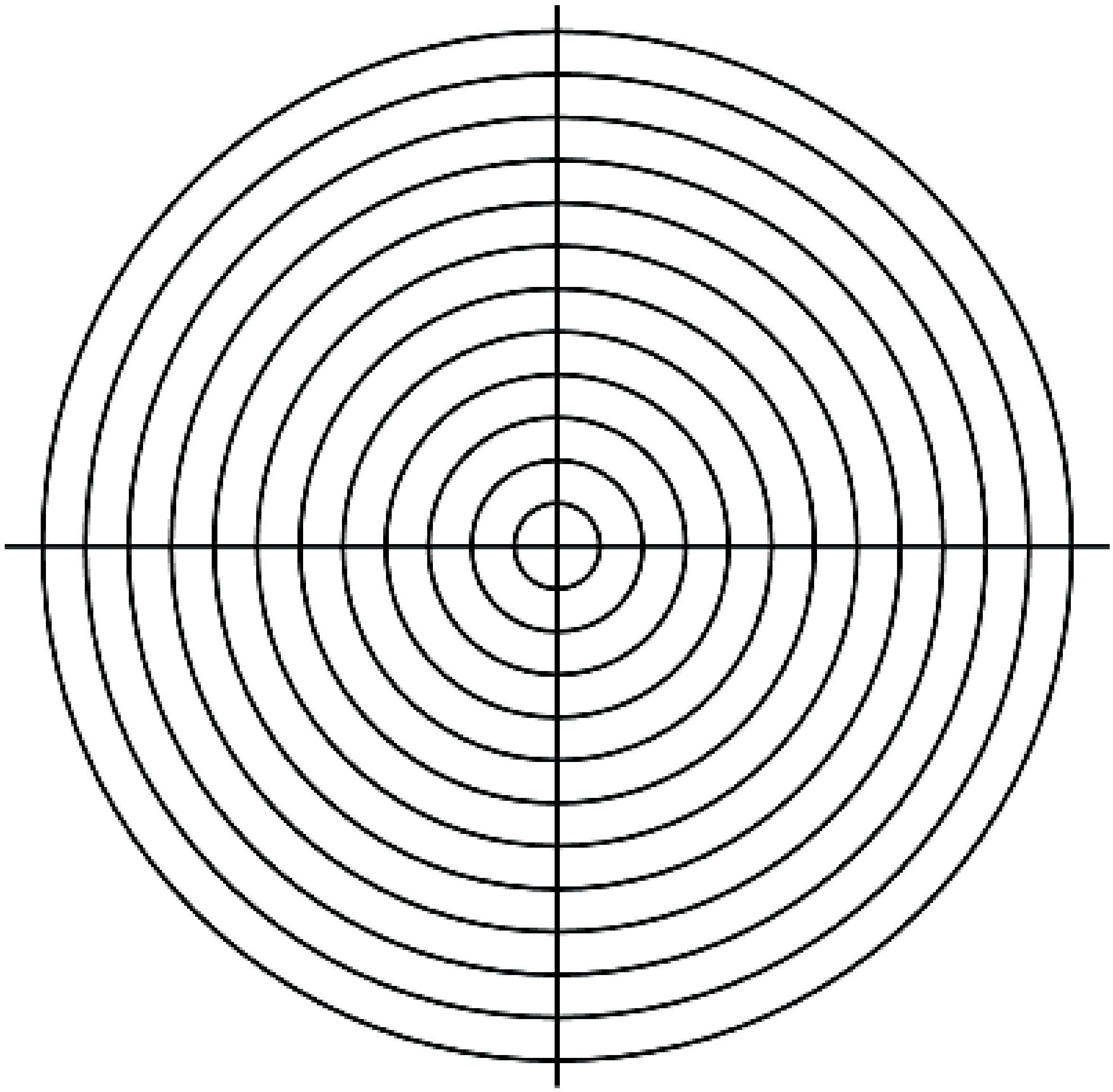
Features:

For the 4X-20X Multifunction Target

- 5.0mm OD, 0.25mm increments, 20 micron line width
- 4.0mm OD, 0.25mm increments, 15 micron line width
- 3.0mm OD, 0.25mm increments, 10 micron line width
- 2.0mm OD, 0.1mm increments, 7. 5 micron line width
- 1.0mm OD, 0.1mm increments, 5.0 micron line width

For the 20X-100X Multifunction Target

- 3.0mm OD, 0.25mm increments, 10 micron line width
- 2.0mm OD, 0.1mm increments, 7.5 micron line width
- 1.5mm OD, 0.1mm increments, 5 micron line width
- 1.5mm OD, 0.1mm increments, 2.5 micron line width
- 1.0mm OD, 0.05mm increments, 5 micron line width
- 1.0mm OD, 0.05mm increments, 2.5 micron line width



2.4 **Square Grids**: The grids on the target are composed of intersecting straight lines spaced at regular intervals orthogonal to each other. Grid patterns, spacing and line widths are selected to cover a range of magnifications and fields of view. Square grids are defined by the following parameters. All linear dimensions are center-to-center line dimensions regardless of the line width.

- Overall Size: Center line to centerline distance between the lines forming the outside box of the square grid pattern is used to define the "Overall Size". The Overall Size plus the line width defines the distance between the far outer edges of the grid pattern.
- Incremental Spacing : Distance between the centerline to centerline of adjacent lines on the grid.
- Line width: The width of any line on the grid.

Applications:

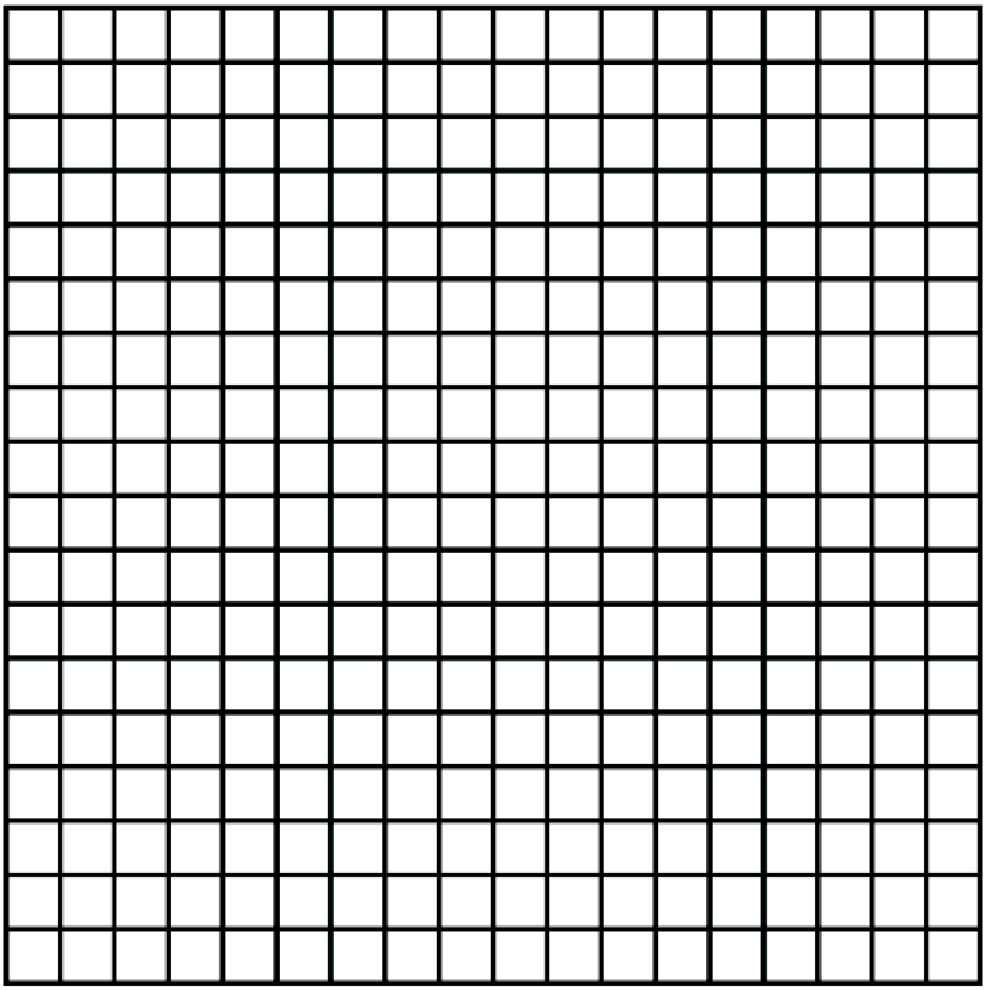
Square grids are useful as an analysis tool for detecting types of distortion, especially pincushioning and barreling. For machine vision systems, grids can be used to test the accuracy of subpixelization routines by comparing experimental results to the known specifications of the grid. For a complete description of the procedure to test these characteristics, see section 3.4.

When using the grids on the target for qualifying image capture software, the mean measured dimensions between two grid lines is the distance between the centers of the two lines. By taking the distance from the outer edge of the first line to the inner edge of the second line and adding to it the distance from the inner edge of the first line to the outer of edge of the second line and dividing by 2, the "as seen" distance between the centers of the two lines is obtained. This "as seen" value is then compared to the published value for that target feature. This manual capture and calculate is necessary for edge detection systems that can not do these line captures and calculate the two line centers automatically.

Features:

For the 4X-20X Multifunction Target
- 4.5mm square grid, 0.25mm increments, 20 micron line width
- 4.5mm square grid, 0.25mm increments, 15 micron line width
- 4.5mm square grid, 0.25mm increments, 10 micron line width
- 4.5mm square grid, 0.10mm increments, 15 micron line width
- 4.5mm square grid, 0.10mm increments, 10 micron line width
- 4.5mm square grid, 0.10mm increments, 5 micron line width
- 2.55mm square grid, 0.075mm increments, 10 micron line width
- 2.55mm square grid, 0.075mm increments, 5 micron line width
- 2.55mm square grid, 0.050mm increments, 5 micron line width
- 2.55mm square grid, 0.050mm increments, 2.5 micron line width

For the 20X-100X Multifunction Target
- 3.0mm square grid, 0.25mm increments, 10 micron line width
- 3.0mm square grid, 0.25mm increments, 7.5 micron line width
- 3.0mm square grid, 0.25mm increments, 5 micron line width
- 3.0mm square grid, 0.10mm increments, 10 micron line width
- 3.0mm square grid, 0.10mm increments, 7.5 micron line width
- 3.0mm square grid, 0.10mm increments, 5 micron line width
- 2.55mm square grid, 0.075mm increments, 10 micron line width
- 2.55mm square grid, 0.075mm increments, 5 micron line width
- 2.55mm square grid, 0.050mm increments, 5 micron line width
- 2.55mm square grid, 0.050mm increments, 2.5 micron line width



2.5 Ronchi Rulings

Ronchi Rulings are patterns of evenly spaced alternating clear and opaque lines. The lines and spaces have equal widths and are most commonly defined in terms of frequency either in line pairs per mm (lp/mm), or line pairs per inch (lpi). All frequencies of ronchi rulings on these targets are in terms of lp/mm.

Applications:

The Ronchi Rulings included on the Multifunction Targe tare used primarily for determining the MTF (Modulation Transfer Function)/ maximum possible resolution and the maximum resolution for best acuity. By viewing progressively higher frequency ronchi rulings, the user can determine the point at which the system can no longer resolve detail. The rulings can also be used to measure fine line widths and spaces.

Ronchi rulings are also used in this application to determine the Depth of Field when used in conjunction with the included Edge Blocks. By examining a tilted ronchi ruling under the objective, the “in-focus” distance can be determined and this result can be translated into a depth measurement using a direct formula. For a complete description of the procedure, see sections 3.2 and 3.3.

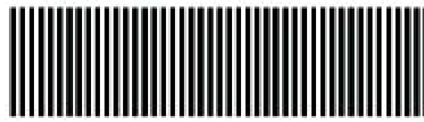
Features:

For the 4X-20X Multifunction Target:

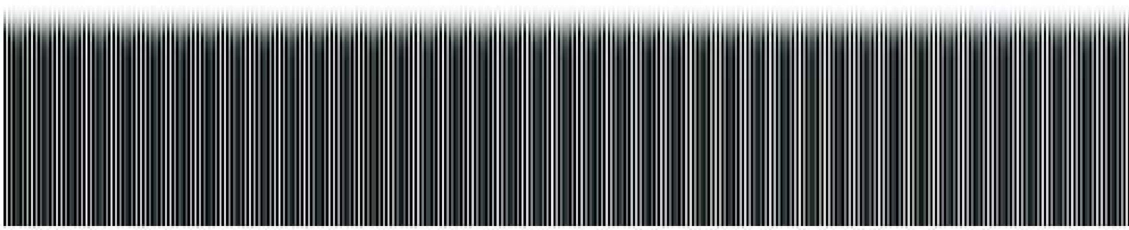
17 Ronchi rulings range from 60 LP/mm to 380 LP/mm, in 20 LP/mm increments.

For the 20X-100X Multifunction Target:

Total of 34 Ronchi rulings:
4 Ronchi rulings range from 240 LP/mm to 300 LP/mm, in 20 LP/mm increments.
30 Ronchi rulings range from 310 LP/mm to 600 LP/mm in 10 LP/mm increments.



60LP/mm



60LP/mm

2.6 Linear Microscale

The “Microscale” included on the Multifunction Target is a high precision linear scale. The scale is graduated with a repeative line pattern with varying length lines, numbered every mm, to aid in making linear measurements.

Applications:

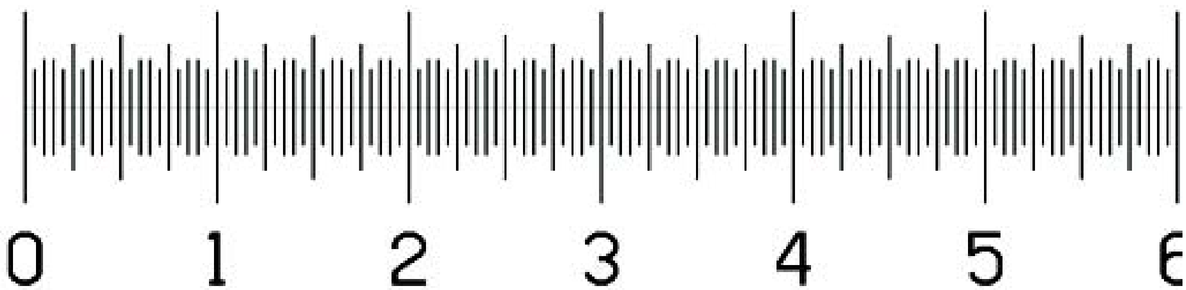
The Microscale is used to check field of view for magnifiers, microscopes, and machine vision systems. It can also be used to assist in depth of field calculations in the absence of a digital stage to measure the “in focus” distance.

Additionally, the linear Microscale can be used as a reference standard for calibrating digital motion stages as well as non-contact metrology systems.

Features:

For both the 4X-20X Multifunction Target and 20X-100X Multifunction Target:

0-68.2mm long
20 divisions/mm
50 microns/division
10 micron line width
Number markings every mm.


0
1
2
3
4
5

2.7 Edge blocks

A different set of edge blocks are provided with each of the two versions of the multifunction target. The purpose of the edge block is to raise one edge of the target to a known height so that the target is at a specific angle. The edge blocks included with each version of the target are specifically suited to the magnification range of the typical lens systems that will be placed under test.

Low magnification systems typically have a both a larger field of view and a greater depth of field than high magnification systems. An additional consideration is that high magnification systems have a shorter working distance, which limits the angle to which the target can be raised. The Target Rulings, Circle and Grid Arrays and the Edge Blocks have been designed to work within these functional parameters of the various lens systems.

Applications:

The edge blocks are used in conjunction with the Ronchi Rulings and/or the Linear Microscale to provide a Depth of Field measurement for the optical system. By measuring the “in-focus” length along the surface of the target, the depth of field can be quickly calculated with the use of a conversion factor. The Ronchi Rulings work best for MTF evaluation at at various frequencies and required depths of field. The edge blocks can also be useful to evaluate the ability of machine vision cameras and their capture software to handle X - Y measurement tasks of objects with vertical topography.

To provide the fastest conversion from the observed “in-focus” distance to the actual depth-of-field, the edge blocks hold the target at known angles. To convert from a linear distance to the Depth of Field, the user simply divides the linear distance by the ratio printed on the edge block being used.

On the low-frequency version of the Multifunction Target, an end support is included to prevent the target from moving while it is held by the edge blocks.

For a complete description of the procedure to determine Depth of Field, please see section 3.2.

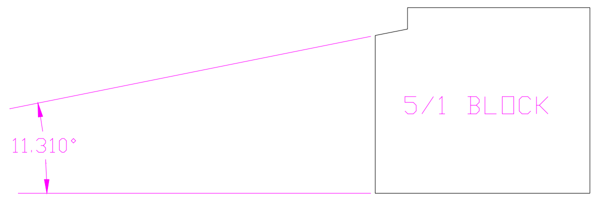
Features:

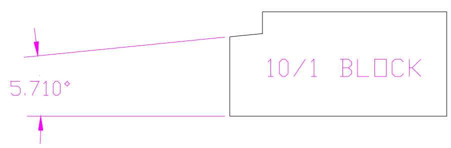
For the 4X-20X Multifunction Target:

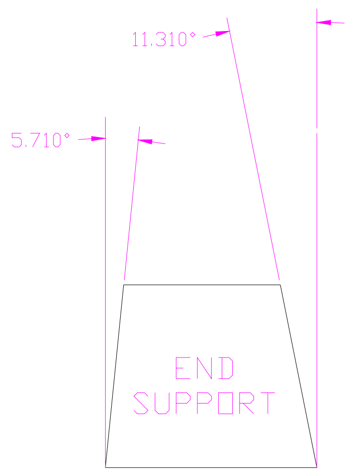
- A 5/1 ratio edge block, which holds the target at 11.31º
- A 10/1 edge block, which holds the target at 5.71º
- An end support cut to match the opposite end of the target while it is held in place by the edge block

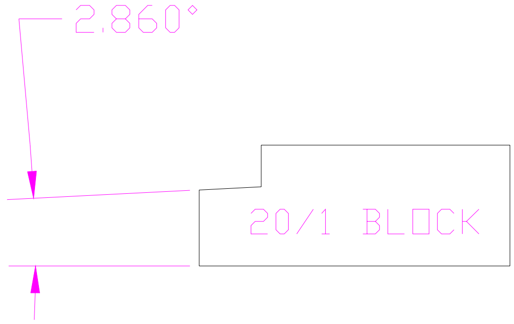
For the 20X-100X Multifunction Target:

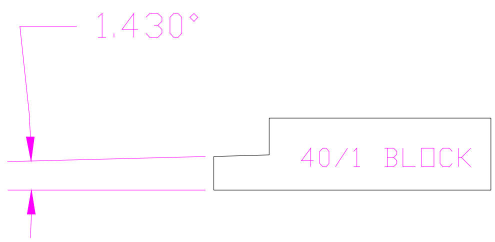
- A 20/1 ratio edge block, which holds the target at 2.86º
- A 40/1 ratio edge block, which holds the target at 1.43º
- A 70/1 ratio edge block, which holds the target at 0.82º

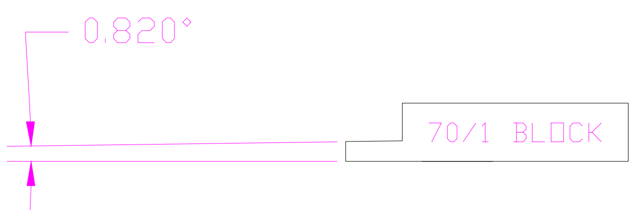

5/1 BLOCK
11.310°


10/1 BLOCK
5.710°


11.310°
5.710°
END
SUPPORT


2.860°
20/1 BLOCK


1.430°
40/1 BLOCK


0.820°
70/1 BLOCK

3.0 Applications

The Multifunction Target is a versatile optical reference which can be used to measure several critical criteria on a range of optical systems. The major functions of the target include:

- **Field of View**
- **Depth of Field**
- **Resolution**
- **Distortion**
- **Linear Calibration**
- **Modulation Transfer Function**
- **Machine Vision Camera and Image Capture Software Qualification**

3.1 Field of View

Field of View is a measure of the extent of the subject that is observable/captured by the optical system. Depending on the design of the optical system, the image plane can be defined as a circle, square, rectangle or other shape. The Multifunction Target can be used to measure and quantify this parameter.

Procedure:

Method 1: Using the Circles and Grids:

Position the optic over the smallest circle or grid that will still fill the field of view. If there is a cross hair in the optic, align the crosshair with the center of the circle or the centerline of the grid and count the number of circles or grid lines visible. Since the spacing between the circles are known you can interpolate between the circles or grid lines for a close estimation of the Field of View. Using the circles you can also tell how well the crosshair is centered in the optic.

Method 2: Using the Linear Microscale:

Position the Microscale so that it is aligned horizontally across the image plane, with the left edge of the Microscale in line with the left edge of the field of view. Without moving the stage, observe the opposite edge of the field and record its value. Repeat this measurement three times and average the results. Repeat this procedure again, this time with the target rotated 90º from its previous position to check the other axis.

1. Center the Microscale in the field of view, with the scale oriented horizontally
2. Line up the edge of the Microscale (0mm) with the left edge of the field of view
3. Without moving the stage, observe the right edge of the image field and record the last observable ruling line on the Microscale.
4. Remove and replace the target. Repeat steps 1 through 3 three times then average the results.
5. Repeat the procedure again to test the vertical axis.

Method 3: Using a digital stage in conjunction with Ronchi rulings:
(system must have crosshair reticle to use this method)

An alternative method to measuring the field of view with the Microscale is to use a digital stage and a Ronchi Ruling that is within the resolving capability of the optical system. The line to line spacing on the Linear Scale is 50 microns. With interpolation, the far edge of the field of view can be estimated to within 25 microns. The lowest resolution Ronchi Ruling on the Multifunction Target is 60LP/mm: or, a line and space width of 8,3333 microns. A stage with a read out resolution of better than 10 microns, in conjunction with any of the precision Ronchi Rulings, has the ability to provide a more accurate estimate of the field of view.

1. Position the target so that it is parallel to the X axis of the stage, with the Ronchi ruling lines oriented vertically
2. Using a low frequency ruling on the target, line up the right edge of the field of view with the last line on the Ronchi ruling
3. Zero the readout on the digital scale or note its current position, then move the X-Y stage so that the crosshair is now over the line that was previously at the edge of the field of view
4. Multiply the resulting value by 2 to get the total field of view

NOTE: For stereo microscopes, field of view should be measured separately for each set of optics.

3.2 **Depth of Field**

Depth of Field is the range of distances in the object space which will resolve the image over a given range “s”. The Multifunction Target can be used to test theoretical calculations of DOF by experimentally determining this value over a wide range of resolutions. The true DOF of an optical system is a useful measurement when observing three-dimensional objects or for creating flatness and wedge tolerances for linear stages that are used with the subject optical system.

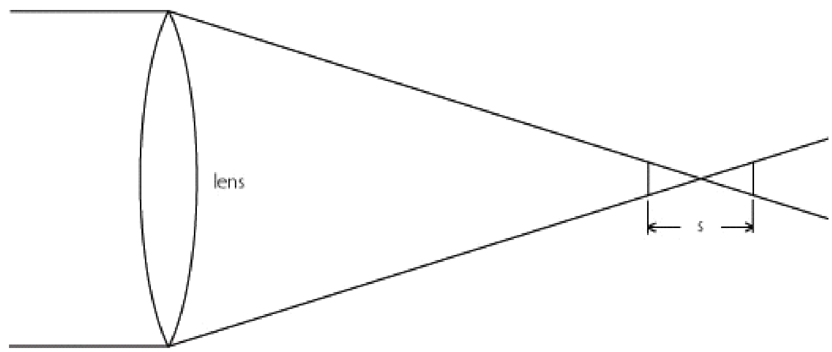


Figure 3.2.1
Depth of Field

The edge blocks included with the Multifunction Target are designed specifically for use in performing depth of field measurements. They allow the user to assess depth based on a range of flat targets with a series of Line Pair/mm Ronchi Ruling resolutions. These rulings are representative of the required resolution and depth of field requirements for the actual items to be viewed using the optical system under test . When the target is propped up on one of the edge blocks, a linear “in focus” distance can be measured in the image plane. This distance can then be translated into a vertical “depth” by dividing it by the ratio number of the edge block being used. This relationship can be seen in Figure 3.2.3

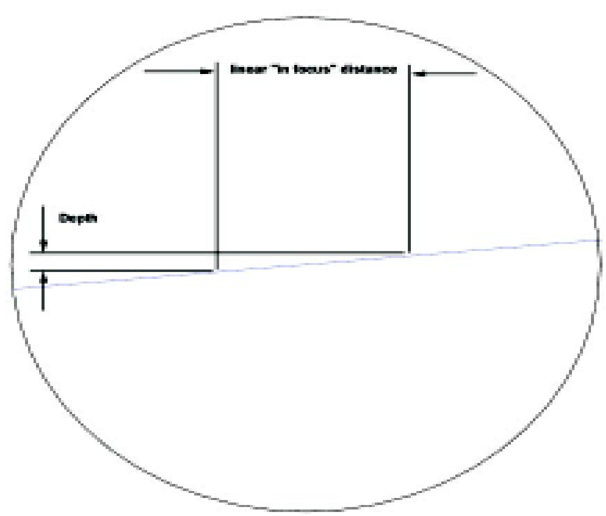


Figure 3.2.2
Relationship between distance measured in
image plane and depth of field

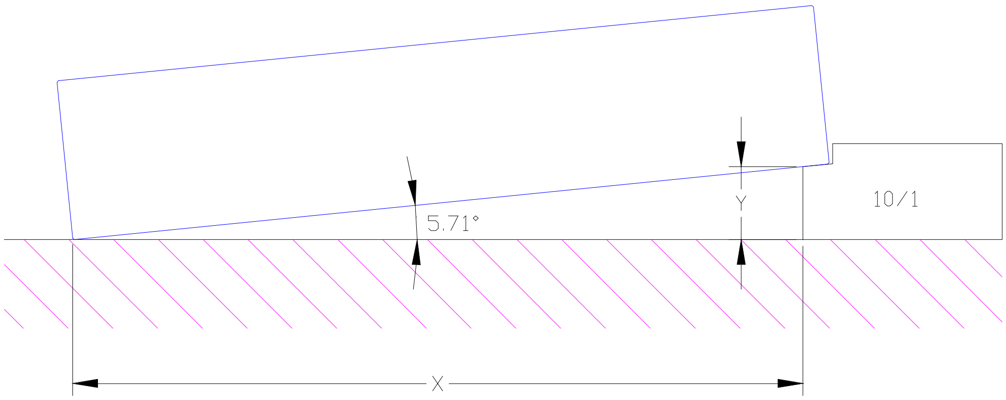


Figure 3.2.3
Explanation of relationship between edge blocks and depth of field

$$\tan 5.71° = \frac{Y}{X}$$

$$Y = \frac{X}{10}$$

$$Y = 0.09998X$$

$$\therefore \text{Depth} = \frac{\text{"in focus" distance}}{\text{block ratio}}$$

Procedure:

The first step is to place the Multifunction Flat and scan across, from left to right the Ronchi Ruling target sets to determine the range of resolutions that are within the range of resolution by the optical system under test. If a moveable stage is being used it is also advisable to scan across the Linear Scale on the Multifunction target and determine if the stage is flat and perpendicular to the optical axis of the system.

Once an acceptable resolution range has been determined this range of Rulings should be used to evaluate the Depth of Field capabilities of the system.

This Depth of Field calculation requires the included edge blocks. High magnification optical systems require a smaller edge block (higher ratio) than low magnification systems. Determine which edge block is correct by starting with the highest ratio in the kit. If the Depth of Field is too large for the small edge block, move to a lower ratio edge block.

Determine the Far Field:

1. Position the target so that the right edge of the target is resting on the edge block. Be sure to push the target all the way against the retaining wall of the edge block.NOTE: When using the 5:1 or 10:1 ratio edge block, be sure to place the end support on the opposite edge of the target. The end support keeps the target immobile during testing.

2. Move the objective over the pre-selected Ronchi Ruling that gives the maximum resolution for best acuity (See resolution). Move the center of the objective to the far right edge of the Ronchi ruling.

3. Adjust the objective for the best focus in the center of the objective.

4. Move the objective towards the left of the target by moving the microscope or the stage until acuity is lost on the Ronchi ruling. The point at which acuity is lost is subjective and will vary from user to user. Record the position using a digital stage or by using the Microscale below the ronchi rulings.

5. Divide this “in focus” distance by the ratio of the edge block. For example, divide the reading by 20 when using the 20:1 edge block. This distance is the Far Field.

Determine the Near Field:

1. Position the target so that the right edge of the target is resting on the edge block. Be sure to push the target all the way against the retaining wall of the edge block.

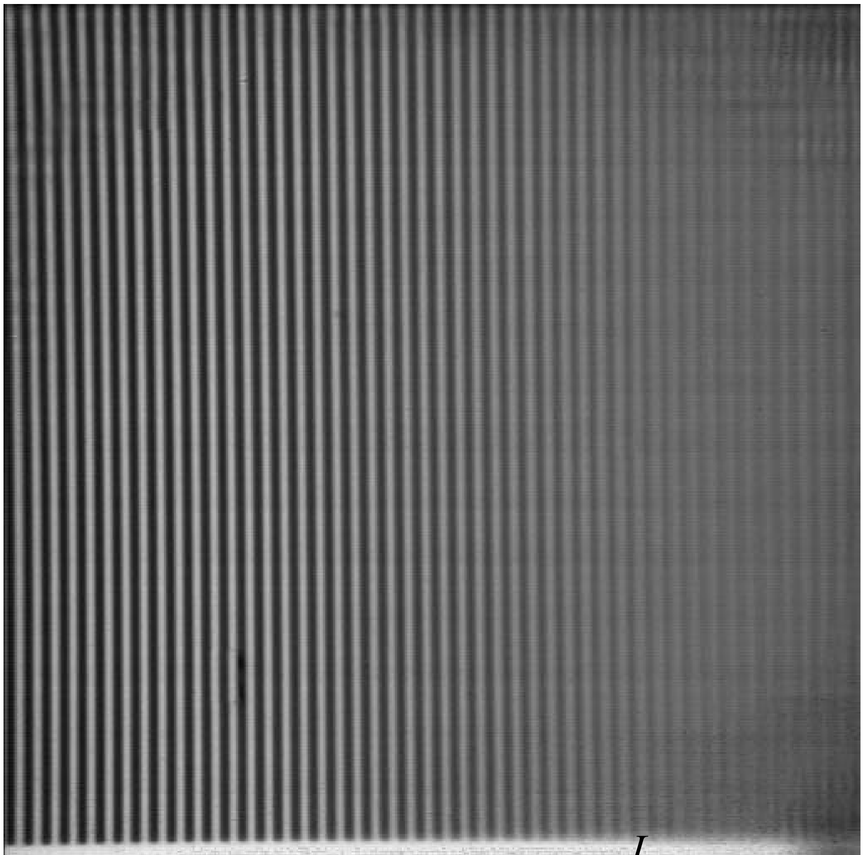
2. Move the objective over the Ronchi ruling that gives the maximum resolution for best acuity. Move the center of the objective to the far left edge of the Ronchi ruling.

3. Adjust the objective for the best focus in the center of the objective.

4. Move the objective towards the right of the target by moving the microscope or the stage until acuity is lost on the Ronchi ruling. Record the position using a digital stage or by using the Microscale below the ronchi rulings.

5. Divide this “in focus” distance by the ratio of the edge block. For example, divide the reading by 20 when using the 20:1 edge block. This distance is the Near Field.

The total depth of field is then found by adding the values for the near and far field together.



$$farfield = \frac{L_F}{B}$$

$$nearfield = \frac{L_N}{B}$$

L = linear “in focus” distance
B = block ratio (e.g. - 5 for 5/1 block, 20 for 20/1, etc)

Depth of Field = nearfield + farfield

A note on lighting: For depth of field measurements, it is usually necessary to use bottom lighting. Top lighting, or through-the-lens lighting, usually will reflect off the chrome rulings on the angled target and away from the lens, making it difficult to take measurements. An alternate to bottom lighting is to use an edge light that will reflect the light off the target and up into the lens system.

3.3 Resolution

Resolution is the measurement of an optical system's ability to convey detail. Measurements are normally made using a standard test pattern, such as a Ronchi ruling or resolution target. MTF is a measure of resolution. (See paragraph 3.6)

There are two useful measurements associated with resolution. The first is the maximum measurable resolution. This is the point at which two adjacent lines cannot be distinguished from one another. With the Ronchi Rulings, when the line pairs blend together the result is a continuous tone gray level. The other important measurement regarding resolving capability is the maximum resolution for best acuity, which describes the point at which there is still a clean black/white transition between lines. Ronchi rulings are used primarily for determining the maximum possible resolution and the maximum resolution for best acuity. By viewing progressively higher frequency ronchi rulings, the user can determine the point at which the system can no longer resolve detail. Units are usually in line pairs per millimeter (LP/mm).

It is also common for a system to have different resolving capabilities in different orientations. To account for this, multiple resolution tests should be carried out at 90° to one another. The Multifunction target also provideds Grid and Circle Patterns to aid in evaluating resolution over the entire field of view of the optical system.

Procedure:

Maximum LP/mm measured resolution: Move up the variable frequency portion of the target until the segment is reached where you have minimum acceptable resolvable acuity. This will vary slightly from user to user and with various lighting set ups.

Maximum resolution for best acuity: Starting at the point of max. measurable resolution (above), back down the scale until a ruling is reached where there is a clean black/white transition between the lines at the desired illumination level.

3.4 Distortion/Abberations

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

Pincushioning – Distortion in which the magnification increases towards the edge of the field. Information, except for positional location, is not lost in this type of distortion, just moved to a different point in the image.

Barreling – Distortion in which the magnification decreases towards the edge of the field. Information, except for positional location, is not lost in this type of distortion, just moved to a different point in the image.

Spherical aberration – A lens defect in which image forming rays passing through the outer zones of the lens focus at a distance from the principal plane different from that of the rays passing through the center of the lens. This causes rays to cut the axis at points in front of or behind the point focus. If the center of the equally spaced circles is centered on the optical axis, any spherical aberration would show up as a combination of line width blur and possibly some deviation in the regular spacing between consecutive circles. The visual effects are more severe with chromatic lens systems that are not color corrected than they are for lenses used in mono-chromatic systems.

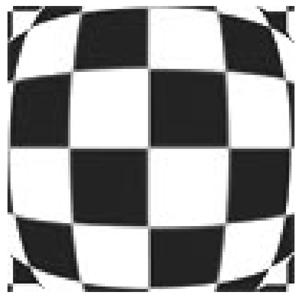
Astigmatism – a result of a cylindrical wavefront aberration, which increases as the square of the distance off axis and the square of the aperture. The focus consists of two concentrations of rays known as focal lines, with a blurred circular region representing the best approximation to a point focus. By positioning the concentric circles at various points within the field of view, astigmatism will show up as an elongation or stretching of the circles into elliptical shapes. This will be most noticeable with the smallest of the concentric circles.

Procedure:

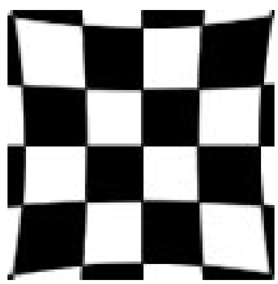
Determination of allowable distortion is largely a subjective measure. Quantification of distortion or lens aberration is difficult without performing a paraxial ray trace on the optical system. The preferred method for viewing distortion is using an inline crosshair reticle in the eyepiece. If the Multifunction Target is being viewed with a machine vision system, it is possible to superimpose a straight line over the image to use as a comarison to any distorted lines that are present. Comparing the straight line of a cross hair or other reference to the edges of the observed features on the target clearly shows distortion in the system. With Zoom and Variable *"f"* Nunber Optics these tests should be repeated under all the conditions of possible use. Most optical systems are designed so that the performance is highest in the center of the field of view. Typically, distortion increases further towards the edges of the image plane. To compare the outer edges of the image plane to a straight line, it is necessary to use an adjustable crosshair.

The primary feature used to detect distortion is the array of line grids. On most high quality optical systems, it is not typical for any significant pincushioning or barreling to be evident without the use of a straight line.

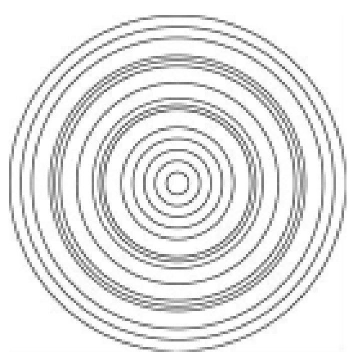
Concentric circles will detect spherical aberrations and astigmatism. These forms of distortion are difficult to quantify.The Multifunction Target will show mderate to severe deviations and permit the quantification from correct function.



Barrel distortion



Pincushion distortion



Spherical aberration

3.5 Linear Calibration

The Multifunction Target can be used to calibrate non-contact metrology devices and other optical measuring instruments. The target provides an accurate reference standard to calibrate instruments for distances within the image plane and up to the length of the Microscale. The Multifunction Target is manufactured to very high accuracy and precision and is NIST Traceable. For a complete description of the manufacturing tolerances associated with the manufacture of the Multifunction Target see APPENDIX A and the accompaning spread sheets on this CD.

Procedure:

To calibrate a non-contact metrology device, position the objective over a line grid. De pending on the nature of the system, measurements will be taken in different ways. Any number of points can be taken on the grid and compared to the actual dimensions listed in Appendix A. For Microscopes with a built in Linear Scale the Multifunction Target Linear Scale is an ideal way to check the accuracy of this scale in the actual optical system.

For calibration of digital motion stages, use the linear Microscale as a reference standard. This scale has a manufacturing tolerance, including measurement uncertanity of +/- 1 micron for the full scale length from the "0" to 68.2mm point. It is advised to take several readings at the same point and then average the results in order to eliminate operator error.

Calibration along the vertical optical axis: On some optical systems, such as high precision microscopes, there is a scale on the focal adjustment knob that allows the user to measure distances along the optical axis. By making a slight adjustment to the procedure used for depth of field calculations, it is possible to calibrate the true distance being moved along the optical axis. This is done by setting the target up on an edge block as before, then moving a predetermined distance across the ronchi rulings and refocusing at that point. The width of each ronchi ruling pattern is very precise, and can be used as a reference for the known distance being moved.

1. Begin by choosing the edge block appropriate for your objective.
    - Low-power objectives --> steeper angle --> lower ratio
    - High-power objectives --> shallower angle --> higher ratio
2. Place the right edge of the target on the edge block
3. Using a low frequency ronchi ruling on the target, focus on an edge and note the position, using either a digital stage or the linear microscale located directly under the ronchi rulings
4. Move the stage across the entire ronchi ruling to the opposite edge and refocus
5. Divide the distance moved across the image plane by the ratio of the edge block being used. This value is the actual distance moved along the optical axis. Compare this value against the theoretical distance moved as specified by the scale on the focal adjustment knob

3.6 Modulation Transfer Function (MTF)

Modulation is a measurement of an optical system's ability to delineate image detail. As details in the image get progressively finer, the contrast between adjacent features drops. Several sets of line patterns of different spacings are imaged by the system under test and the finest set in which the line structure can be discerned is considered to be the limit of resolution of the system, which is expressed as a certain number of line pairs per millimeter (LP/mm). These line patterns are called Ronchi Rulings, which were discussed in more detail in sections 2.5, 2.7, 3.2 and 3.3. When the contrast between features drops below the smallest amount the system can detect, the features can no longer be resolved.

It should also be noted that the limiting resolution does not fully describe the performance of the system.

Modulation is defined as follows for a square-wave pattern:

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

Where L_{max} = The maximum luminance in the image plane and
L_{min} = The minimum luminance in the image plane

$$\text{MTF}(v) = \frac{M_i}{M_o}$$

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

In the case of the bottom illuminated Ronchi Rulings, M_o will always be equal to 1 due to the sharp contrast between the alternating opaque, dark and light bars.

A plot of MTF compared to spatial frequency "v" is a useful measure of the resolving performance of an optical system at various levels of spatial frequency. A plot of MTF aids the user in extrapolating the performance of the lens system under varying spatial frequencies. When viewing three dimensional objects MTF must be evaluated along with the combined effects of depth of field and distortion parameters discussed and evaluated in the preceeding sections.

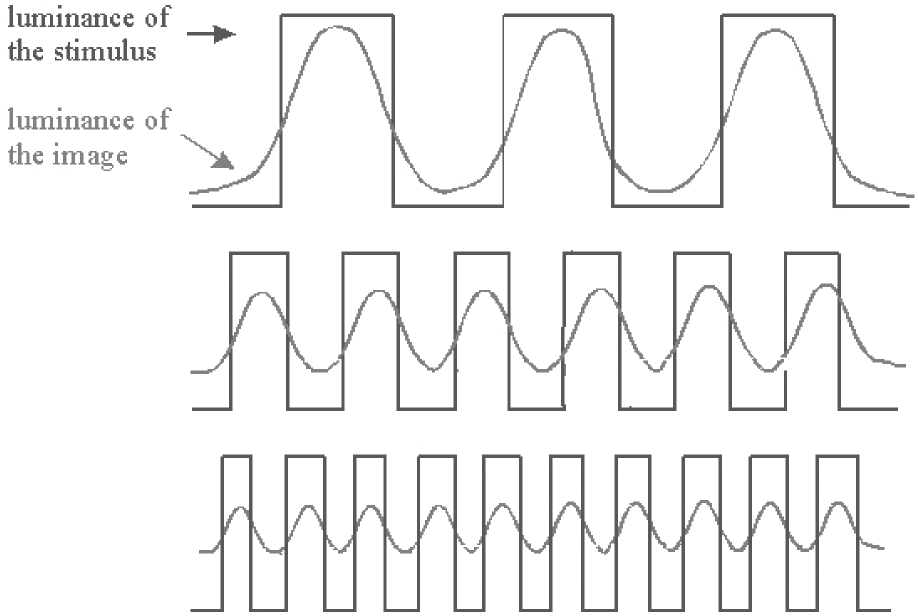


Figure 3.6
Modulation at different spatial frequencies

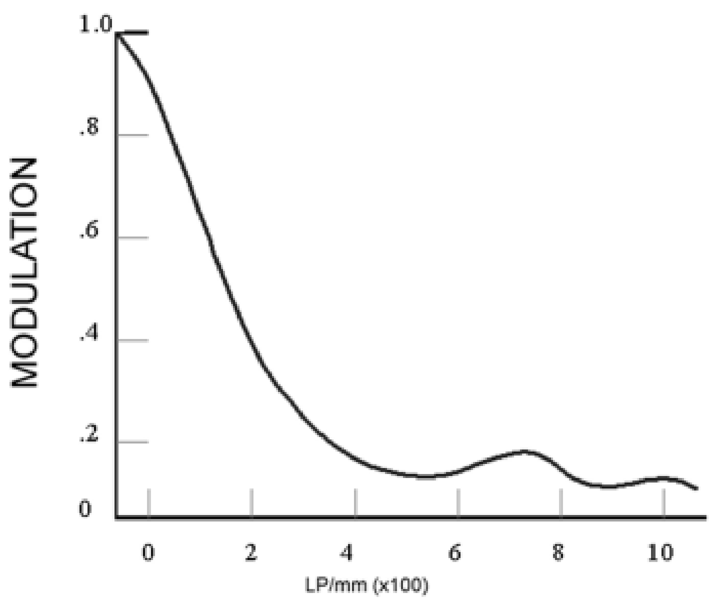


Figure 3.7
A sample Modulation Transfer Function

3.7 Working with Image Capture Software

The Multifunction Target has various features that can aid in the qualification and calibration of image capture software that is used in conjunction with machine vision cameras.

Applications:

Concentric circles on the target can be used to qualify features such as holes, pads, and donuts.

When using the concentric circles on the target for qualifying image capture software, the mean "as seen" measured diameter of the concentric circle is the capture value of the OD of the circle plus the capture value of the ID of the circle divided by two. This "as seen" value is then compared to the published value for that target feature. This manual capture and calculation is necessary for edge detection systems that do not do these these two captures and calculate the center automatically.

With CCD camera systems, blooming becomes an important issue when measuring holes and pads. With these cameras, both normal and reverse video measurements should be made and compared to the actual target dimensional values.

Square Grids on the target can be used to qualify rectangular features in the image plane. The square grids are also useful in detecting distortion in the image plane that creates erroneous readings.

When using the grids on the target for qualifying image capture software, the mean measured dimensions between two grid lines is the distance between the centers of the two lines. By taking the distance from the outer edge of the first line to the inner edge of the second line and adding to it the distance from the inner edge of the first line to the outer of edge of the second line and dividing by 2, the "as seen" distance between the centers of the two lines is obtained. This "as seen" value is then compared to the published value for that target feature. This manual capture and calculate is necessary for edge detection systems that can not do these line captures and calculate the two line centers automatically.

Line Widths and Spaces can be evaluated by using the Ronchi Rulings on the target. Here again, it is important to use the reverse video feature to accurately determine the effect of blooming on the measurements being made by the imaging system. The edge blocks can also be useful to evaluate the ability of machine vision cameras and their capture software to handle X - Y measurement tasks of objects with vertical topography.

4.0 Appendix

A. Specifications

Substrate material: Schott Crown glass (S1-523-586)
Flatness: No more than 1 wave per 2mm of length and 10 waves overall
Squareness: 3 minutes of arc
Perpendicularity: 3 minutes of arc
Parallelism: 1 minute of arc
Scratch:Dig 10-2 over pattern area
CTE: 5.5 x 10^{-7} mm / ºC

Substrate dimensions:
DA029: 4X-20X target

1”(25.4mm) x 3”(76.2mm) x 0.2559”(6.5mm)

DA030: 20X-100X target

1”(25.4mm) x 3”(76.2mm) x 0.2559”(6.5mm)

Pattern material: Double-layer deposited evaporated chrome
Optical density of 3.0 or greater

Edge block angles:

5/1 ratio: 11.31º
10/1 ratio: 5.71º
20/1 ratio: 2.86º
40/1 ratio: 1.43º
70/1 ratio: 0.82º
End support: 11.31º on one side and 5.71º on the opposite side

Pattern Accuracy:

1. The Multifunction is replicated from a photomask generated on the Ultra-High precision ALTA3500-25 Laser Writer with an address size of 0.08333 microns. The amount of snapping to the address grid is not measureable. A CD (Critical Dimension) of 0.8333 microns specified for generation of this mask and the CD tolerance was +/-0.050 microns absolute. The actual certified NIST traceable measured value was 0.8240 microns, a deviation of 0.009 microns.

2. To illustrate the accuracy of the Multifunction Target please see the enclosed Excel Spread Sheets for the DA029 4X-20X and the DA030 20X-100X RONCHI RULING ACCURACY ANALYSIS. If we consider the 240LP/mm Ronch Ruling on the 20X-100X Target as an example, the address snap “CUMULATIVE ERROR DECISION POINT” (Column E) in microns is 0.08333/2 = 0.04167 microns. (This is the point where the calculated point we want to be in order to create a perfect line width of 2.08333 microns (Column C), is exactly half way between two points on the address increment (Column D) snap grid. All of the rulings are begun on a grid snap point; however, due to the line width not being a precise equal snap increment, small errors in line width and position occur.

The calculated line or space width, in microns, of the ruling is 1000/(240 X 2) = 2.0833333.....microns. When we divide the line width by the address size (Column F) we get the even number of address increments plus the carry over. The phototool generator will snap the drawing tool to the closest address point on the address snap grid. It does however, continue to calculate the cumulative desired position; and, when the error becomes equal to or greater than 1/2 the address size, snaps to the next grid point. The "PERIODIC ADDRESS SNAP ERROR" (Column L) is always the address size in microns. In the case of the ALTA3500 Phototool Generator this address size is fixed at 0.08333 microns.

As example, with the 240LP/mm ruling the .001 odd grid period (Cloumn F) means that the system draws the lines and spaces at exactly 25 address widths and the line width error is .001 X .08333 = .0000833 microns. What happens is that the system calculates the point where the line start or end is for each line and space and then, when the calculation indicates, snaps forward one address. In this case it would be .04167/.0000833 = 500 lines and spaces, or 250 periods. (Column M) Since the Ronchi Ruling CL-CL (Center Line to Center Line) width is 1,495.833 microns there would be 359 Line Pairs plus one end line total in the 240LP/mm Ronchi Ruling this would indicate that there would be one snap of .08333 microns along the ruling at around the 250th period.

The "CALCULATED ADDRESS SNAP ERROR" (Column K), is derived by taking the "EDGE-EDGE TOTAL WIDTH OF RULING" in microns, (Column H), and dividing by the address increment (Column D) to determine the overall error of the last tool flash relative to Edge-Edge Width. Since, in the case of the 240LP/mm Ruling the residual is about .715, we would multiply (1-.715) X .08333 = .024 microns as the calculated error. The 1-.715 is used because the system will snap forward to the next even address increment and this distance is .285 X .08333 = .024 microns. (Column K).

The "MAXIMUM REPLICATION TOLERANCE" (Column O) is derived by taking the ratio of +/-1 micron maximum error allowed for the overall 68.2mm length of the Linear Scale on the Multifiunction Target to the length of the ruling or feature size of the target being evaluated. In the case of the 240LP/mm ruling the ratio is the "CENTER LINE - CENTERLINE TOTAL WIDTH OF THE RULING" in microns,(Column G) divided by 68,000 times the 1 micron allowable error. This equals 1495.833 X1/68000 = .022 microns.

The "OVERALL SNAP PLUS REPLICATION ERROR" in microns (Column P) is shown as the sum of "CALCULATED ADDRESS SNAP ERROR", (Column K) plus the "MAXIMUM REPLICATION TOLERANCE" (Column O). One could argue that these are not additive and that the lesser error derived by using the square root of the sum of the squares method should be used. However, in reviewing the data derived from the sum method the error, in all cases, appears to be less than the address snap increment of .08333 microns. There is also the CD or "Critical Dimention Tolerance" of +/-.05 microns for this Phototool Generator that was measured to be an actual error of .009 microns. In theory this error could be additive. If we did consider this third variable the sum of the squares statistical method would be indicated.

From a practical standpoint, a Maximum Stated Error Tolerance for a Ruling Set, Grid or Circle Target of +/-0.1 microns Line-Line or Feature to Feature Point; and, an overall Maximum Stated Error Tolerance for the total Feature Outline or specific Ruling Frequency Outline of +/-0.25 microns is considered a reasonable overall Maximum Replication Error that can be encountered on any specific Multifunction Target