ImageMaster®

Worldwide Leader in MTF Testing

ImageMaster®

R&D Line
Universal Line
Production Line

Page

TRIOPTICS
TRIOPTICS GMBH · OPTISCHE INSTRUMENTE

ImageMaster®
The most comprehensive line of MTF Equipment

Designed for complete characterization of optical systems

The **ImageMaster®** Series has been designed to measure the MTF (Modulation Transfer Function) describing the optical performance of lenses and optical systems.

ImageMaster® is able to measure a wide range of optical parameters related to almost all typical optical components and lens systems. Virtually any existing lens systems ranging from high performance imaging lenses over to high resolution endoscope to military sighting devices, ophtalmic lenses, singlets and doublets or molded plastic lenses can be accurately characterized.

In addition to the MTF, as the generally accepted method to determine the imaging quality of a lens, ImageMaster® Series is able to measure a wide range of other optical parameters:

- Effective Focal Length (EFL)
- Flange Focal Length (FFL)
- Back Focal Length (BFL)
- Distortion
- Field Curvature
- Chromatic aberrations
- Astigmatism
- Relative Transmission
- Vignetting
- Field of View
- Chief Ray Angle
- Depth of focus, etc.
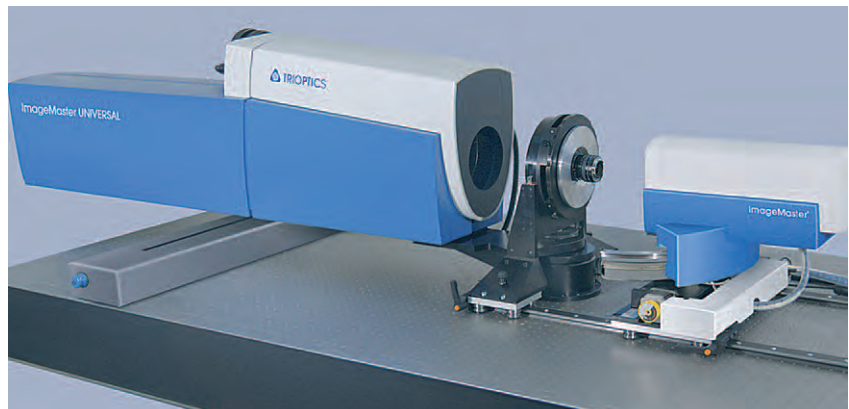
MTF-Testing of lenses in visual range
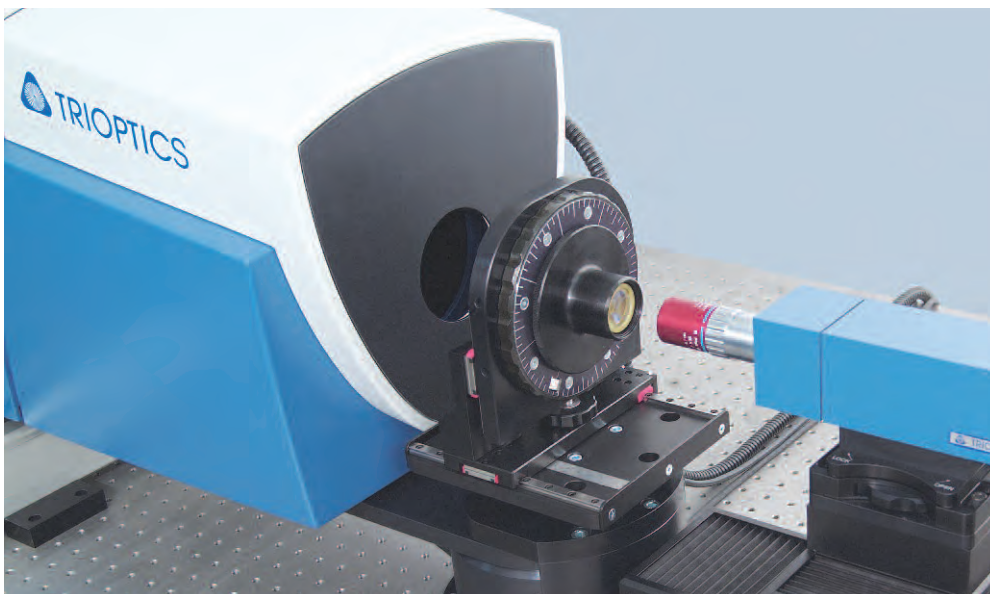
MTF-Testing of lenses in NIR spectral range

Widespread Applications

TRIOPTICS offers the widest and most advanced product series for MTF measurement world wide. No matter how small or large, any lens from tiny micro lenses to large telescope objectives can be accurately measured.

The multitude of models offered by the ImageMaster® series allows for MTF measurements over the whole spectral range from UV (<200 nm) over visual spectral range up to far infrared (14 μm). ImageMaster® series covers a large variety of applications:

- Digital camera lenses
- Mobile phone lenses
- Copier and enlarger lenses
- Camera modules for visual applications
- Intraocular, contact and further ophthalmic lenses
- Binocular and telescopes
- Military sighting devices
- Image intensifiers
- Endoscopes and further medical optics
- Machine vision lenses
- Optics for space applications
- Wafer level lenses
- Automotive cameras

Testing of CMOS-Camera Modules

Testing wafer level lenses with ImageMaster®

Testing wafer level lenses with ImageMaster® PRO Wafer
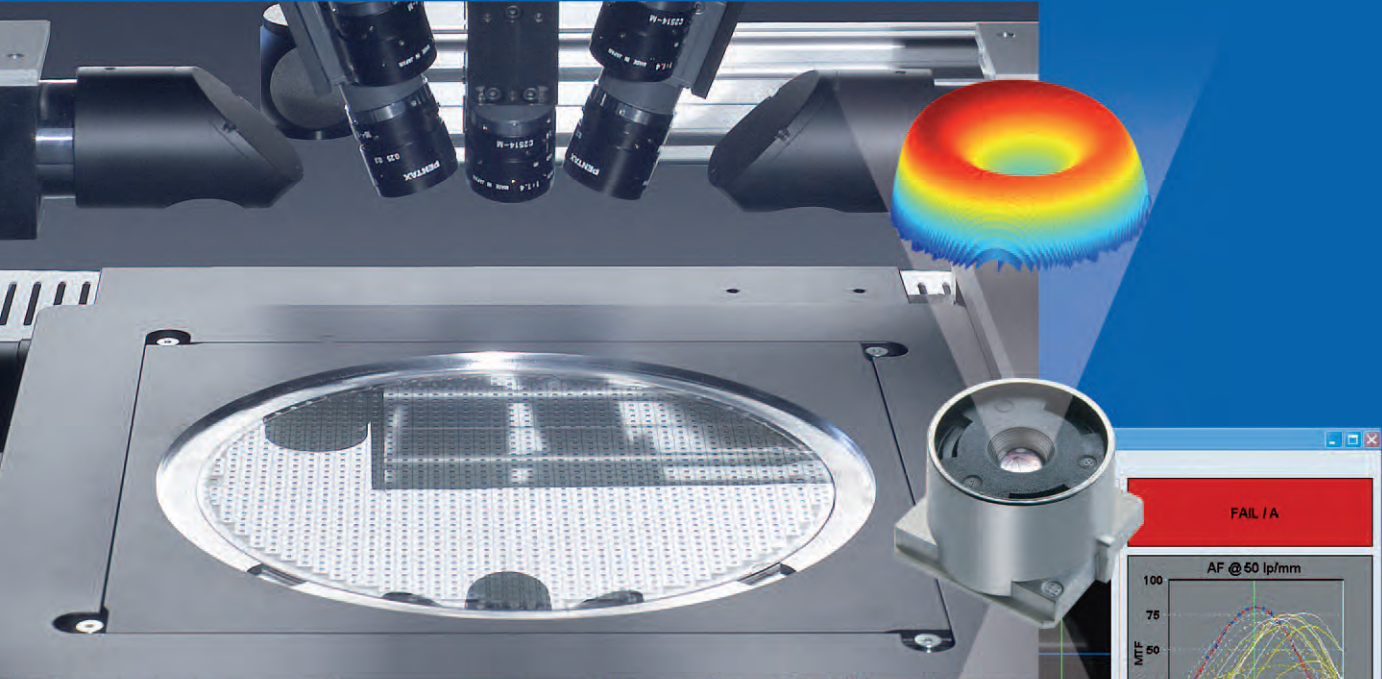
® PRO Wafer

ImageMaster® PRO Ultra-fast for production testing of mobile phone lenses

Measurement of CCD-Objective lenses

The most comprehensive line of MTF-Equipment

Like all TRIOPTICS instrumentation **Image-Master®** Series is not just a custom laboratory set up but a fully designed, standard turnkey automated instrument which can be used in production environment as well.

ImageMaster® PRO - Ultra-fast for production testing of mobile phone lenses

Different applications and requirements within the testing of the image quality of optical systems require a wide range of different test equipment. TRIOPTICS offers not only customized solutions but three specific product lines:
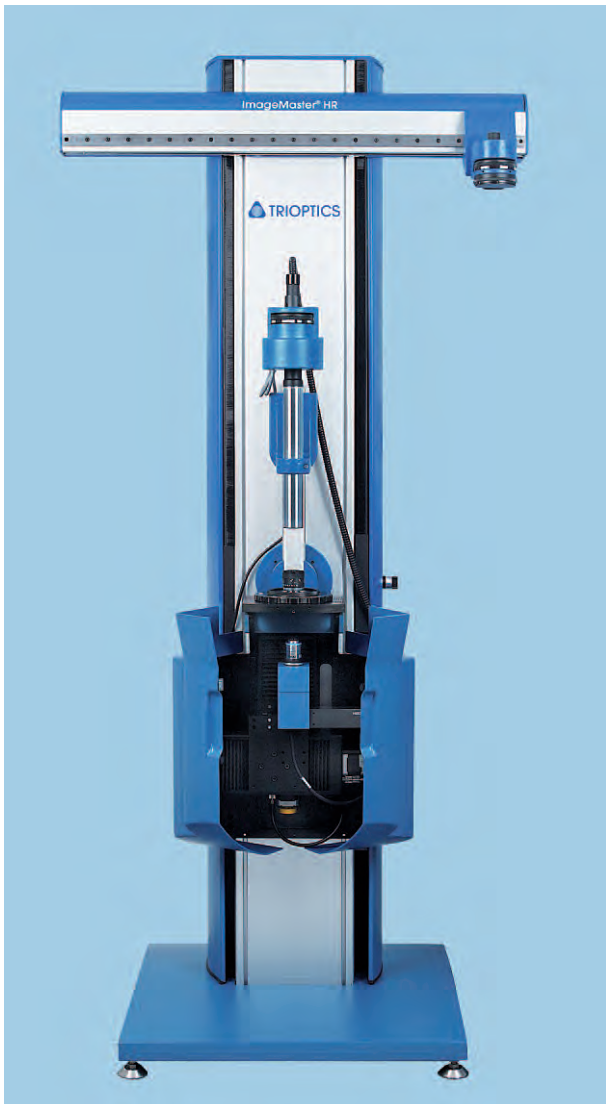
ImageMaster® HR-Ultra-accurate for lab and research

Our MTF-Equipment includes the perfect suited product version for any kind of application. This is the result of the unprecedented cooperation with our customers; the multitude of ImageMaster® product versions illustrates the level of understanding of customer needs.

ImageMaster® Universal - ready for any application

ImageMaster® R&D Line

The **ImageMaster® R&D Line** provides an outstanding level of accuracy and flexibility. The equipment is modular and upgradeable to allow for custom configuration as test requirements change. The instrument can be configured for testing optical systems with:

- object at infinity
- object and image at finite conjugates

The equipment range includes the following product versions:

ImageMaster® Compact is a cost-effective, horizontal table-top instrument capable of measuring MTF and other optical parameters. Its modular design permits testing of a wide range of lenses and other optical assemblies. The motorized pivot arm with the measurement head and the sample rotate to quickly generate reliable on-axis and off-axis measurements. The instrument can be configured for testing optical systems with:

- object at infinity
- object and image at finite conjugates

ImageMaster® HR is the top instrument of our R&D series. It has been developed to fulfil customer requirements for increased accuracy and flexibility in the measurement of optical parameters.

ImageMaster® HR is an ultra-accurate MTF Test Station dedicated to the laboratory and research work. It is a modular, upgradeable instrument in a vertical set up, capable to measure the MTF and a wide range of other optical parameters. This instrument is used in almost all R&D departments of leading companies in the field of digital camera and mobile phone visual applications.

ImageMaster® HR is the preferred instrument in R&D labs worldwide

ImageMaster® Universal Line

The **ImageMaster® Universal Line** is supporting our leadership in MTF-Testing. Innovative design, high quality and long life components are combined with advanced software in or-

most unlimited: lenses with focal length from 1 mm to 2000 mm can be easily measured with highest achievable accuracy.

Whatever type of lens, with object at infinity or at finite conjugates (from some millimeters to 3 meters), the ImageMaster® Universal Series can be easily configured for manual or auto-

ImageMaster® Universal - is the most flexible product line for MTF testing

der to provide the highest level of performance. This line of equipment offers both exceptional levels of flexibility and practically unlimited measurement capabilities.

Multi-Wavelength Capabilities: the use of high quality mirror optics and specific detectors enables measurement over the entire spectral range from UV (<200 nm) to far IR (14 μm).

According to customer needs the ImageMaster® Universal Line can be configured to measure optical systems with a clear aperture from a few millimeters up to 450 mm. The range of measurable focal lengths is also al-

mated test sequences. An ultra-precision automated afocal unit allows for the fast and accurate measurement of telescopes and other afocal systems.

ImageMaster® Production Line

The **ImageMaster® PRO Line** is designed for accurate, ultra-fast MTF testing of mobile phone and digital camera lenses from high-volume production.

Moving imaging applications into high volume markets such as mobile phones and

PDAs, has posed a new challenge to the quality control and characterisation of imaging optics. The basic requirements for high volume MTF testing including ultra-fast measurement time, multiple field measurement points, fast and accurate autofocus and extremely stable software have already been fulfilled successfully by the first generation of ImageMaster® PRO instruments.

TRIOPTICS has been involved in the first R&D projects related to visual applications in the field of mobile communications. We are proud that the very first mobile phone lenses ever manufactured, have been measured and qualified by using the ImageMaster® PRO 1 originally developed by TRIOPTICS. In the following years the ImageMaster® PRO series became the uncontested international standard for MTF testing of mobile phone lenses.

The latest MTF production tester, ImageMaster® PRO 5 is incorporating high quality components as ultra-precision stages, stable electronics and frame grabbers, high resolution CCD-camera, all controlled by dedicated software designed for production line environment. The long life components and the error proof design allow maintenance free operation 24 hours a day.

ImageMaster® PRO 5 provides fast and reliable measurement results (in less than 2 sec.) directly traceable to international standards. This is the only MTF production tester using master lenses certified by international standard organisations for accurate calibration and direct traceability.

Other outstanding features of ImageMaster® PRO 5 include the integrated optical alignment tool for quick alignment, reduced 4 buttons keyboard (Start, Stop, Measure, Custom) for PC independent operation, factory adjusted exchange reticles with kinematic mount, fast, tool free adjusting facilities.

The masterpiece of ImageMaster® PRO 4 is the ultra-stable, production proof software providing three security levels, automatic Pass/Fail, automatic correction for sample dis-

ImageMaster® PRO Wafer

tortion, individual setting of spatial frequencies for each camera, set up files, storage of lens and batch data, data analysis using Excel, intuitive graphical display of the sample properties, image plane tilt, etc.

The latest addition to the Production Line is the ImageMaster® PRO 5 Wafer, a sophisticated MTF production tester for wafer level lenses.

Principle of Measurement

MTF-Modulation Transfer Function

The Modulation Transfer Function (MTF) is an important aid to objective evaluation of the image-forming capability of optical systems. Not only that the MTF provides a means of expressing the imaging quality of optical systems objectively and quantitatively, but it can be calculated from the lens design data. In this way it allows optical and systems designers to predict reliably the performance of the optical systems. The manufacturers can compare the image quality of the manufactured lenses with the design expectations.

The Modulation Transfer Function (MTF), describing the resolution and performance of an optical system is the ratio of relative image contrast divided by relative object contrast MTF = Relative Image Contrast/Relative Object Contrast. When an object (illuminated target or reticle) is observed with an optical system, the resulting image will be somewhat degraded due to inevitable aberrations and diffraction phenomena. In addition, a real lens will not fully conform with the design data. Manufacturing errors, assembly

inal patterns. In general an illuminated target can be defined by its spatial frequency (number of bright and dark areas per millimeter) and the contrast (the apparent difference in brightness between bright and dark areas of the image).

By convention, the modulation transfer function is normalized to unity at zero spatial frequency. For low spatial frequencies, the modulation transfer function is close to 1 (or 100%) and generally falls as the spatial frequency increases until it reaches zero. The contrast values are lower for higher spatial frequencies as shown above. As spatial frequency increases,
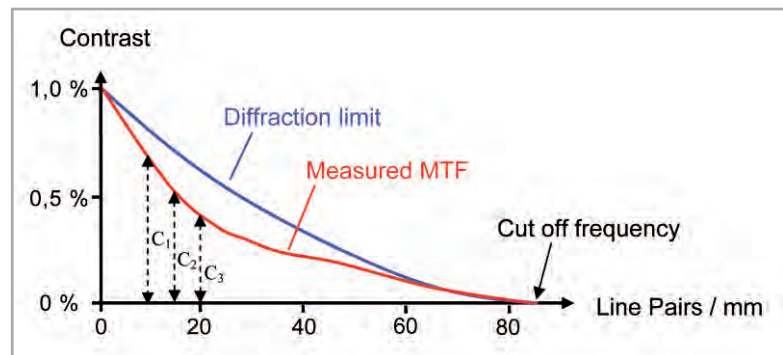
Fig. 2 MTF = Contrast vs. spatial frequency. This figure shows the MTF of a diffraction limited optics and a measured MTF referring to Fig. 1

the MTF curve falls until it reaches zero. This is the limit of resolution for a given optical system or the so called cut off frequency (see figure below). When the contrast value reaches zero, the image becomes a uniform shade of grey.

The grids shown in Figure 1 are actually no longer used in order to measure the MTF. Modern MTF-Testers like the ImageMaster® use a single illuminated slit on opaque background as the object. From a mathematical point of view a single slit can be regarded as the sum over all spatial frequencies (Fourier synthesis). All frequencies contribute with the same amplitude (=1) to this slit not taking the finite slit width into ac-

Fig. 1 A perfect grid pattern is imaged through the sample into the image plane

and alignment errors in the optics will deteriorate the overall imaging performance of the system. As a result, in the image, bright highlights will not appear as bright as they do in the object, and dark or shadowed areas will not be as black as those observed in the orig-

count for this description. This single slit will be imaged into the image plane of the sample. Due to diffraction and aberrations there will be no perfect slit image in this plane, instead the slit image is broadened. It represents the so called Line Spread Function (LSF). On the

Fig. 3: The image of a perfect slit is called "Line Spread Function"

basis of Fourier analysis the contribution of each spatial frequency to the LSF can be calculated. Actually the amplitude of each spatial frequency is equal to the contrast at this frequency. The Fourier analysis of the Lines Spread Function corresponds to the MTF of the sample. Taking a single image of the LSF unveils the complete MTF.

Alternatively it is also possible to use a cross (i.e. two perpendicular slits) for the target. This enables the ImageMaster® to measure the MTF in two image directions simultaneously provided a CCD camera is used for the image analyzer. And finally a pinhole target can be used as the object, too. The image of a pinhole target is called Point Spread Function. This function contains the complete MTF information in all image directions. The basic terms and mathematical relations used for MTF are described in the ISO 9334 standard.

The modulation transfer function varies not only related to the spatial frequency but also with the position in the field of view. The MTF measurement along the axis of symmetry of the optical system is known as on-axis measurement.

To completely characterize the imaging performance of an optical system, the MTF must be measured at different positions within the field of view. The MTF measurement within the

Fig. 4: Typical setup for off-axis MTF measurements. The tangential (T) and sagittal (S) measurement sections are indicated.

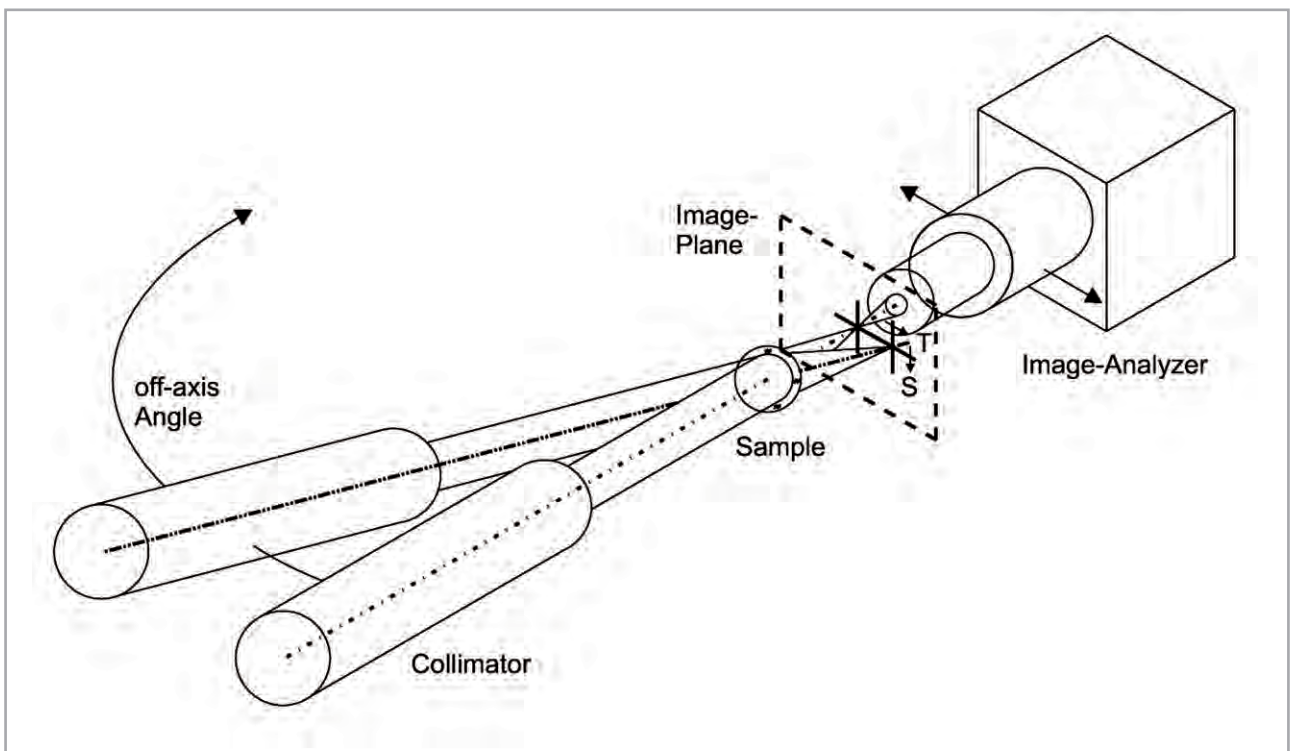field of view is known as off-axis measurement. In order to achieve an off-axis measurement, the target is moved in the field of view at the desired object position and the image analyzer to the corresponding image position.

The MTF measurement can be accomplished at a single wavelength or in a spectral range covering a finite band of wavelengths. The resulting measurement data are known as monochromatic or polychromatic MTF values, respectively.

Usually the MTF is used in its one-dimensional form, calculated for one azimuthal section through the image plane. The azimuth (section plane) of the object pattern is called sagittal azimuth when the prolongation of the slit or object passes through the reference axis. When the prolongation of the slit pattern is perpendicular to the reference axis, the azimuth is called tangential azimuth.

In this so-called finite-finite imaging condition the illuminated slit or crosshair target is directly moved in the object plane of the sample. In the more common infinite-finite imaging condition, the illuminated slit or crosshair is part of a collimator projecting the target to infinity. The collimator is then oriented at different off-axis angles for characterizing the MTF at the corresponding image fields. Figure 4 shows the typical setup for this imaging condition.

EFL

The Effective Focal Length (EFL) or equivalent focal length is the distance from the focal points of the lens to the respective principal planes. The EFL determines the magnification of a lens and hence the image size. Because the principal planes are usually inside the lens at unknown locations, the direct measurement of the EFL is difficult.

However, the EFL can be measured quickly and with sufficient accuracy using the method of measuring the magnification of a double bar target. Certified master lenses from NPL (National Physical Laboratory of UK) and PTB (National German Standard Institute) are available at TRIOPTICS and are used for the calibration of the measurement setup. The measurement data are thus directly traceable to international standards.

EFL and Distortion

Distortion is the percentage of change in magnification between the center of the field of view and off-axis positions in the field of view. In order to determine the distortion a different method of measuring the EFL is used:

- A MTF measurement on axis (at a selected frequency) is carried out. The paraxial focal plane is determined using the MTF measurement at a frequency of interest. To achieve a high accuracy monochromatic light and MTF curve fitting are used while the aperture of the lens is reduced by a diaphragm.
- An angular field range and a number of measurement points is selected. The object generator will automatically move to the selected field positions.
- At each position in field the image height is measured. A table with value pairs image height h vs. field angles α is provided.
- The EFL is calculated with the formula $h/(\tan \alpha)$ and drawn into a curve vs field angle. A polynomial fitting of the EFL close to $\alpha=0$ allows the accurate and independent calculation of the paraxial focal length.
- The distortion is calculated as the ratio between paraxial and field focal length.

This procedure requires a comparatively large number of measurement points with accurately known object angles and field positions. For this reason ImageMaster® instruments with dedicated distortion measurement option feature a high precision angular encoder for the object generator (accuracy 5 arcsec) and a high precision linear encoder for the image field stage (accuracy 0.2 µm).

This way, the EFL is calculated as an absolute quantity, not depending on calibration parameters.

Depth of focus

The depth of focus, is the extent of the region in front of and behind the image plane in which the image will appear to be sharp.

The depth of focus can be determined using a "through focus scan" of the MTF and setting appropriate tolerances for the drop in MTF. The depth of focus between the set tolerances will be measured and displayed.

A more complex measurement can be done simulating the range of object distances covered by the lens and measuring the MTF at the corresponding image distances.

Field Curvature

Field curvature is an optical aberration in which the focus position changes from the center to the edge of the field of view. The curvature of the image field is a lens aberration that causes a flat object surface to be imaged onto a curved surface rather than a plane. Field curvature varies with the square of field angle or the square of image height.

In the presence of the astigmatism, there are two separate astigmatic focal surfaces in orthogonal directions.
To determine the field curvature a set of through focus measurements at different positions in the field are taken.
The MTF maxima and the corresponding positions in field are determined. The values are collected by a software routine and displayed in graphical and tabular form.

Vignetting

Vignetting in an optical system is the gradual reduction of the image brightness with increased off-axis angle. This phenomenon results from the apparent limitation of the clear aperture depending on the field angle. Vignetting is defined as the ratio of the central transmission and the transmission at the edge of the field of view.

The ImageMaster®-Software measures continuously the light intensity of the test pattern in order to avoid saturation. In this way the necessary data is available for determining the vignetting.

Chief Ray Angle (CRA)

A chief ray is the ray from an off-axis object point which passes through the center of the aperture stop of an optical system. The chief ray enters the optical system along a line directed towards the midpoint of the entrance pupil, and leaves the system along a line passing through the center of the exit pupil. To measure the angle between the optical axis and the chief ray on the image side the following method is used: The lens under test is illuminated by the collimator at different angles corresponding to the object sided chief ray angles. The detector head is moved to the image field position at which the lens focuses the image. Now the detector head is moved towards the lens in small steps while the software registers the lateral movement of the focused spot. From these lateral movements the CRA is calculated.
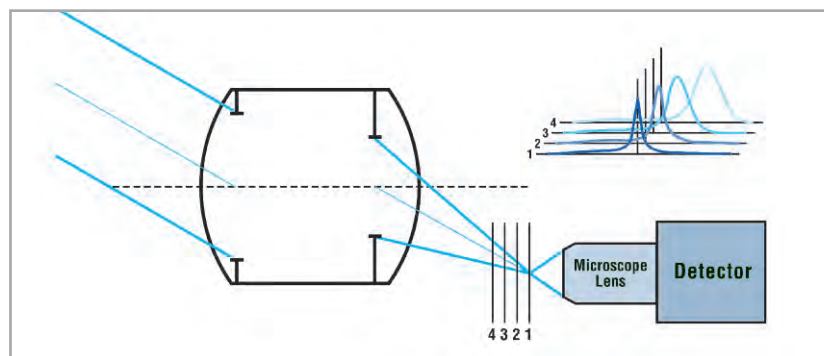

Fig. 5. Measurement procedure of the Chief Ray Angle

F-number

The F-Number of a lens is defined by the ratio between the EFL and the diameter of the entrance pupil. The ImageMaster® series instruments use the ISO-517 method to accom-
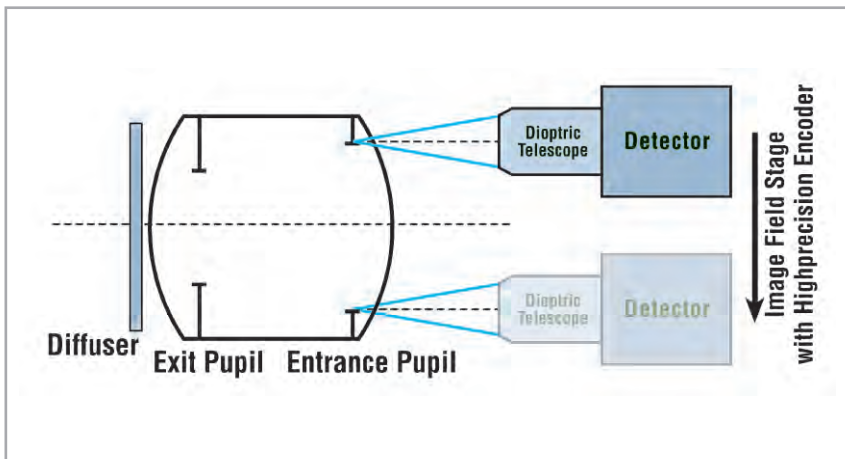

Fig. 6. Measurement procedure of F-number

plish the measurement: First the EFL is measured according to the procedure described before. Then the sample is turned around with the entrance pupil facing towards the detector head. The diameter of the entrance pupil is measured by first focussing on the left, then on the right edge of the pupil. The travelling distance of the image field stage represents the diameter of the entrance pupil. By choosing the proper head lens of the detector head even pupils positioned far inside of the system under test can be measured.

Chromatic Aberrations

Due to the dispersion of refractive optical systems the image position and also magnification of an optical system depends on the wavelength of the light. The dependence of the axial image position on the wavelength is called Chromatic Focal Shift. The dependence of the magnification on the wavelength is called Lateral Chromatic Abberation. Both aberrations can be measured with the ImageMaster®.

The collimator of the ImageMaster® is equipped with different narrow bandwidth color filters. Together with the highly corrected relay optics this enables the system to focus in axial direction to the different image positions for different colors. The image position measurement can be done with submicron accuracy. Measuring the lateral image position for different object angles enables the system to measure the lateral chromatic aberration.
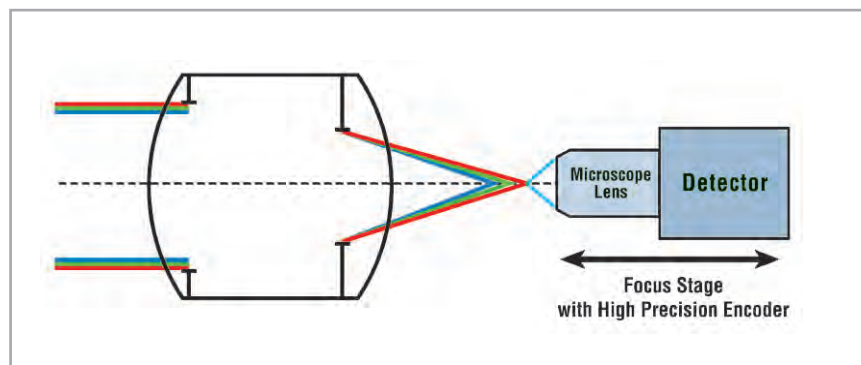

Fig. 7. Principle of Measurement of axial chromatic aberrations

Advanced Features of the ImageMaster® Series

Measuring Head

Relay Optics of negligible Residual Aberrations

The long term cooperation of TRIOPTICS with world known companies like Zeiss and Leica resulted in specially selected, high performance microscope objectives manufactured by these companies and used in TRIOPTICS instruments as relay optics. ImageMaster® Series incorporates only relay optics with negligible residual aberrations and with large numerical aperture. The selection of the relay optics is continuously improved and adapted to the specific instrument layout.

Selection and Characterisation of the CCD-Camera

The CCD cameras used in TRIOPTICS MTF equipment are measured and selected in order to determine the MTF of the camera itself. Selection criteria are the own camera MTF, Progressive Scan CCD, optimal resolution, low noise and high dynamic range.

Perfectly aligned Image Analyzer

An important error source in MTF measurement is related to the design and alignment of the image analyser. To avoid any conceivable misalignment or focus error.

TRIOPTICS developed a proprietary procedure to perfectly locate the CCD sensor in the focal plane of the tube lens. In a second step the centering of the relay and the tube lens is optimized so that the residual errors of the relay optics are negligible. This highly accurate alignment of the optical head is an essential and distinctive feature of the ImageMaster® series, ensuring excellent accuracy and repeatability.

Optical Bench and Stages

The geometry of the optical bench system and the quality of making (straightness, flatness, long term stability, etc.) are essential for a high level of accuracy in MTF measurement. The ImageMaster® series includes only guide ways, linear and rotary stages made of high stiffness, corrosion resistant materials and feature exceptional straightness and running tolerances.

The stepper motor stages have typically a positioning accuracy of 0.2 µm and superior straightness tolerances due to high precision guides with roller cross bearings. The swinging arm relies on an ultra precision bearing and Heidenhain encoders with an angular resolution of 0.36 arcsec.

The sample holder is given special attention in design and manufacturing. The stiffness and stability is essential for a repeatable location of the lens under test. The rotation of the sample in order to achieve an azimuth change is ensured by precision bearings and precise alignment so that no focus change occurs during the rotation.

Collimators

TRIOPTICS is offering the largest range of collimators, autocollimators and accessories worldwide. A careful selection of the best collimators and an accurate focus alignment deliver nearly aberration free collimators with perfect collimation. A certificate of calibration of collimation can be supplied with the collimator.

Depending on the spectral range required for the MTF-measurement, the ImageMaster® series is equipped with refractive or mirror collimators. The TRIOPTICS refractive collimators are mounted in a hard chrome plated tube in order to ensure long term mechanical and thermal stability. The mirror collimators feature highest surface qualities, typically $\lambda/10$ to $\lambda/15$, are made of Zerodur and mounted in a rugged, but lightweight aluminium structure.

ImageMaster® R&D Line

ImageMaster® Compact

Compact and motorized MTF Test Station for use in prototype and small serial production

ImageMaster® Compact

The ImageMaster® Compact is a cost-effective, horizontal table-top instrument capable of measuring MTF and other optical parameters. Its modular design permits testing of a wide range of lenses and other optical assemblies. The motorized pivot arm with the measurement head and the sample rotate to quickly generate reliable on-axis and off-axis measurements. The instrument can be configured for testing optical systems with:

- object at infinity
- object and image at finite conjugates

ImageMaster® Compact also comes with the latest simple-to-use and accurate software.

Measurement Parameter

- MTF at single point
- Plot of MTF vs. field
- Plot of MTF vs. focus
- MTF surface plot (MTF vs. field and focus)
- EFL
- BFL, FFL
- Astigmatism
- Others on request

Modular Design

The ImageMaster® Compact offers a variety of options and a modular design, making a change between different setups very simple, optimal for R&D applications.
Changing between the infinite and the optional finite conjugate system can be reconfigured very fast. The collimator can simply be exchanged with a back-lit source, mounted on a precise motorized stage. Furthermore, a selection of collimators with different effective focal lengths guarantees the best solution for the customer's application. The manual filter and reticle changer, motorized optional, allow a variety of wavelength and images to be used for analysis.

Specification for Standard Instrument

The standard instrument comes as an infinite conjugate system and has following specification:

Setup:	Horizontal, collimator is fixed
Conjugate system:	Infinite
Object angle:	± 130°
Collimator:	EFL: 300mm, CA: 50mm with 6xRC/FC
Spectral range:	450…750nm; halogen
Image height:	± 20mm
Microscope:	Zeiss 50x NA0.7
EFL/MTF range:	1mm to 100mm
FFL range:	1mm to 50mm
MTF repeatability:	± 1%
MTF accuracy:	± 3%
Max. frequency:	500 lp/mm
EFL accuracy:	From 0.5…3mm: ± 5µm From 3…100mm: 0.2%
Distortion accuracy:	< 1% without encoder
Distortion repeatability:	< 0.5% without encoder

ImageMaster® HR

Fully or semi automated, ultra-accurate, multi functional MTF-Test Station

ImageMaster® HR is a fully equipped though compact R&D quality MTF test station for medium and small sized sample lenses. Its design is kept modular and upgradeable allowing for almost unlimited optical test applications today or in future. The instrument is used in the R&D laboratory as well as in the quality control or in production.

Space saving vertical setup of the ImageMaster® HR

The unique vertical setup of ImageMaster® HR is-space saving in the measurement room and ensures the most convenient and accurate positioning of the sample lens mounts. For the majority of lenses this vertical measurement with the gravitational force along the optical axis is advantageous. This way the lens can be kept in the sample holder in a precise and stable position supported by its own weight.

For the object generator a high quality refractive collimator is mounted above the sample table on a motorized pivoting arm equipped with a backlash free transmission gear. The collimator projects the MTF test target to the entrance pupil of the sample.

Optimal design prevents vignetting

To prevent vignetting the location of the entrance pupil can be precisely adjusted to the collimator's center of rotation depending on the sample height. This unique feature is ensured by the precise height adjustment of the complete sample holder assembly into the appropriate position.

Largest off-axis angles for ultra-wide field angles

A precision swinging arm for the object generator equipped with a backlash free rotation gear allows for ultra-wide field angles of ±120°. The standard high accuracy of the angular positioning provided by the stepper motor can be further increased by a high precision angular encoder. TRIOPTICS is using only high quality Heidenhain encoders providing excellent absolute accuracy and resolution of 0.36 arcsec. For accurate distortion measurements of lenses with short focal length the use of the angular encoder is a prerequisite.

Motorized finite conjugates stage for long conjugate distances

An additional linear stage with a target generator consisting of a reticle changer and illumination unit is optionally available for the finite-finite imaging configuration. For operator convenience the distance setting of the conjugate distances is motorized. The distance setting for a certain sample can be saved to a file and used for future measurements.

The finite conjugates assembly features both long conjugate distances (up to 1.3 m) and very large object height (standard +/-500 mm, as special version up to ±1 m).

High quality image analyzer

The centerpiece of ImageMaster® HR is the high-quality image analyzer including relay optics of negligible residual aberrations, selected and tested CCD camera and perfectly aligned optical head assemblies.

The high-quality image analyzer with an exchangeable high-NA microscope relay lens is

located beneath the sample table. It is mounted on precision motorized linear stages for focus and image field positioning. For the ultra-precise distortion and EFL measurement the object generator arm and the image field stage can be optionally equipped with precision encoders assuring the accurate position feedback needed in these measurements.

Precision Sample holder

The measurement accuracy of a MTF-Test Station is significantly influenced by the quality and stability of the sample holder. The sample holder integrated in ImageMaster® HR includes an ultra accurate rotary bearing, precision reference surfaces square and parallel to the optical axis, rotation facilities over 360° and fine adjustment in X, Y direction. The rotation of the sample holder is alternatively available in manual or software controlled motorized version.

State of the art software

The most comprehensive software on the market extends the measurement capabilities and allows for the complete characterization of optical systems:

- MTF on-axis and off-axis
- Though Focus characteristics
- EFL
- FFL (relative)
- Distortion
- Astigmatism
- Field curvature
- Chromatic aberrations
- Chief ray angle
- F/#
- Field of View
- Relative illumination etc.

The state of the art software features advanced capabilities for the detailed analysis of all aspects in imaging quality evaluation.

The high resolution (0.01 MTF) and accuracy (0.02 MTF) of ImageMaster® HR is individually

verified and certified for each instrument using PTB certified samples. The measurement results are thus directly traceable to national and international standards.

ImageMaster® HR including table for PC and controls

Features and Measurement Configurations

- Vertical set up
- Automated angle setting for off axis measurements with collimator on pivoting arm and motorized by a stepper motor
- Autofocus function using stepper motor stage
- Automated field position stage using a stepper motor stage
- Measurement in the CCD spectral range
- Optional finite-finite imaging stage available
- Optional encoder set for precision distortion and EFL measurements available
- Exchangeable high-NA relay lenses
- Broad range of collimator focal lengths from 25 mm up to 500 mm available to adapt to the sample EFL.

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- Motorized filter changer for quick measurement wavelength selection and chromatic aberration measurements.
- Software includes a script language for user defined measurement procedures
- Classical and reverse imaging configuration possible

Classical Configuration

In this test configuration the collimator on the pivoting arm projects the test target towards the entrance pupil of the sample. The sample

ImageMaster® HR- Detail

is imaging the target to its focal plane. This image of the test target is magnified by the microscope relay lens and projected onto a CCD sensor. The instrument can be configured for testing optical systems with:

- object at infinity
  using the collimator on the pivoting arm
- object and image at finite conjugates
  using the finite object stage with illuminated target reticle

Reverse Imaging Configuration

In this configuration the illuminated target reticle is placed in the image plane of the sample lens. The parallel beam emerging from the sample's entrance pupil is collected by a precision telescope and focussed onto the CCD.

For certain sample types and test conditions this is a very economic solution for saving the expensive relay lens. Furthermore, the target reticle can be designed and precisely manufactured with test patterns at fixed image field positions to be tested, thus saving the field stage, too. Both is possible without sacrificing the measurement accuracy. This makes this configuration the preferred solution for production testing where the somewhat limited flexibility is acceptable. TRIOPTICS was the first company to introduce this MTF measurement method to high volume MTF production test equipment (refer to ImageMaster® PRO series).

Two possible configurations are possible:

- image at infinity
  using the telescope on the pivoting arm and the test object in the focal plane
- object and image at finite conjugates
  using the test object at the shorter conjugate and a linear stage with CCD camera at the longer conjugate

Software MTF-Lab

TRIOPTICS has developed a new forward-looking software package.

One main feature is the support of UV or IR detectors employing the scanning aperture method. Several useful functions are integrated which help the user in scanning and perceiving the correct image position of the sample under test. Changing the measurement mode is easy and time-saving. All important measurements for the imaging properties have been revised and are quickly accessible.

Software LAB provides powerful features to support the user in optimizing the measurement process:

- Striking new and easy to handle graphical user interface makes the most important functions only one mouse-click away
- Customizable arrangement of graph windows
- Script tools to create automated user defined measurements including high-level programming functions such as stage controlling, data manipulation, loops and variables

- Data export to a variety of file formats
- Logging of successive measurements
- Making up certificates using the hypertext language protocol (HTML)

All these features make the ImageMaster® MTF Lab software the preferred choice for R&D and laboratory work. The software is designed to work under Microsoft Windows operating system.
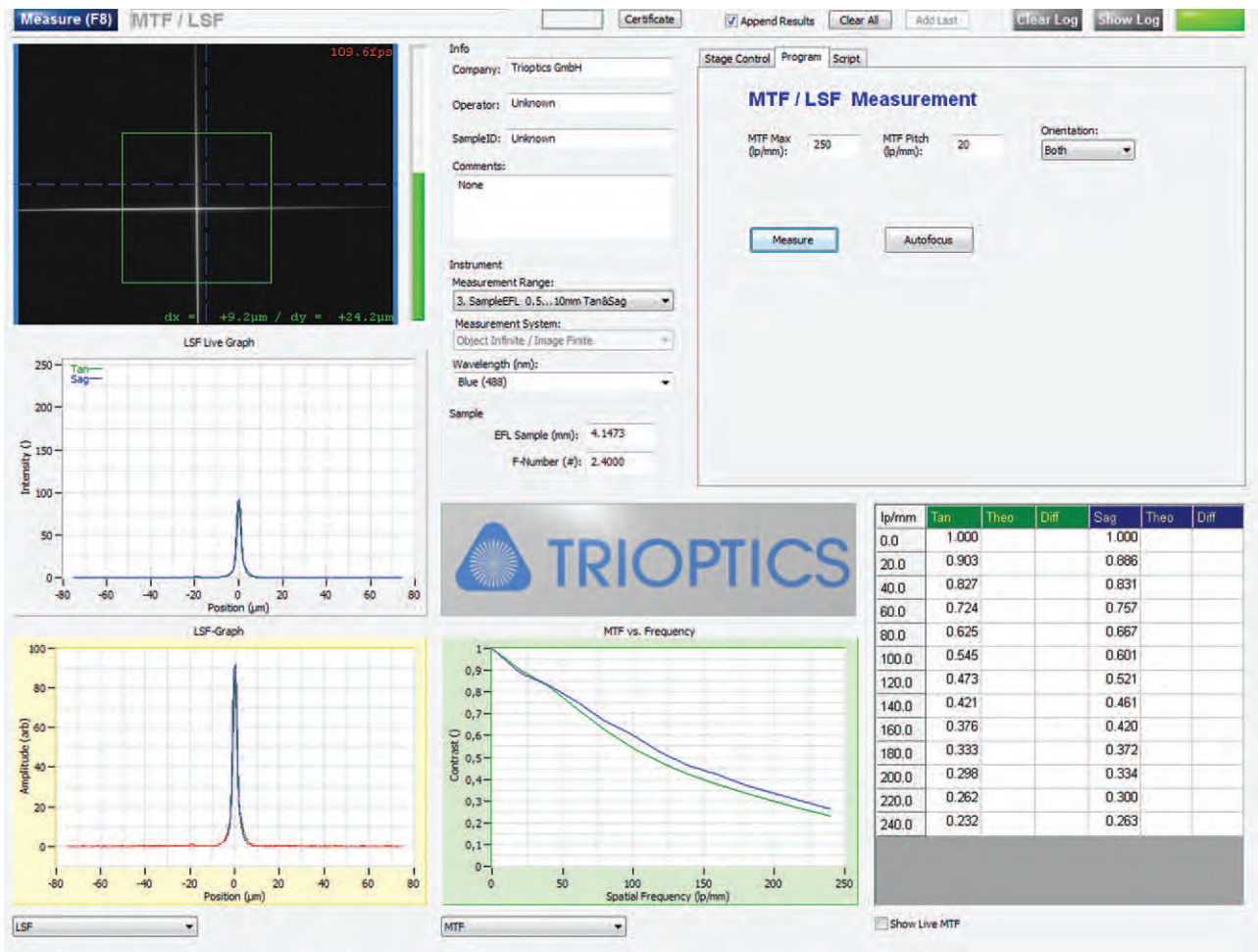
Simultaneous MTF measurement in the sagittal and tangential planes with a crosshair target

ImageMaster® HR IR

The only Vertical and Camera Based MTF Test Station Covering the Complete Spectral Range from VIS to IR

ImageMaster® HR IR, based on the well proven ImageMaster® HR, has been developed to fulfill customer requirements for highest accuracy and flexibility. It is designed for the measurement of MTF and other optical parameters of today's high-end IR optics in R&D and production.

The fully computer-controlled instrument comes with a high-quality mirror collimator, broadband IR light source and IR focal plane array image sensor.

It can be configured for testing optical systems with:

• Object at infinity
• On-axis and off-axis (up to ± 90°)
• Clear aperture up to 60 mm
• VIS spectral range optional
• Sample EFL range 10-100 mm

The ImageMaster® HR IR Professional Software

The ImageMaster® Software provides unique features to optimize the measurement process:

• Measurements of MTF, FFL and a range of other parameters using special target patterns and dedicated software routines

  • Conventional MTF measurement using a single slit or a crosshair as a target

  • Optionally automated selection and positioning of the suitable reticle (target) and filter for the current ap plication

  • Configuration files with optimized process parameters and pass word protected access for operator and supervisor

  • Script tools for custom programming and analysis

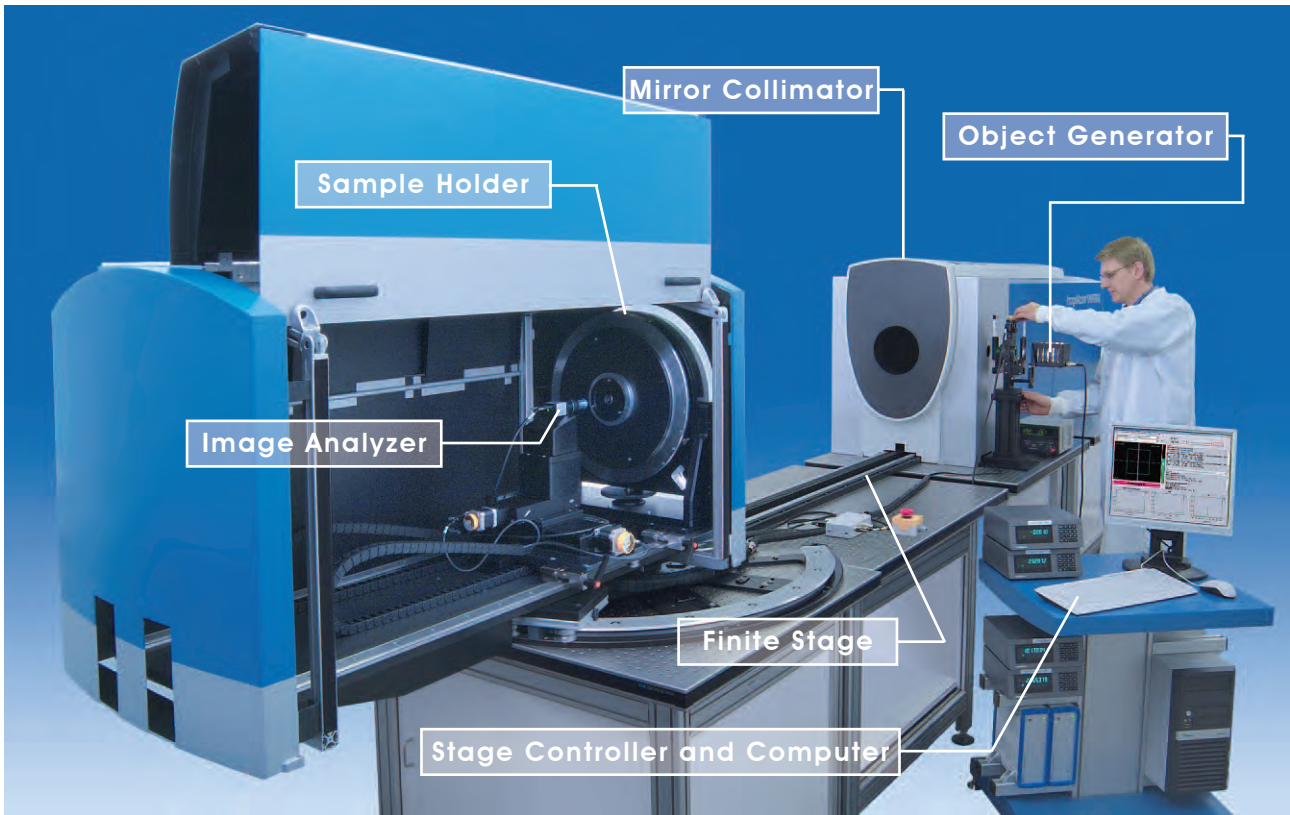

ImageMaster® HR IR is the preferred instrument in R&D labs worldwide
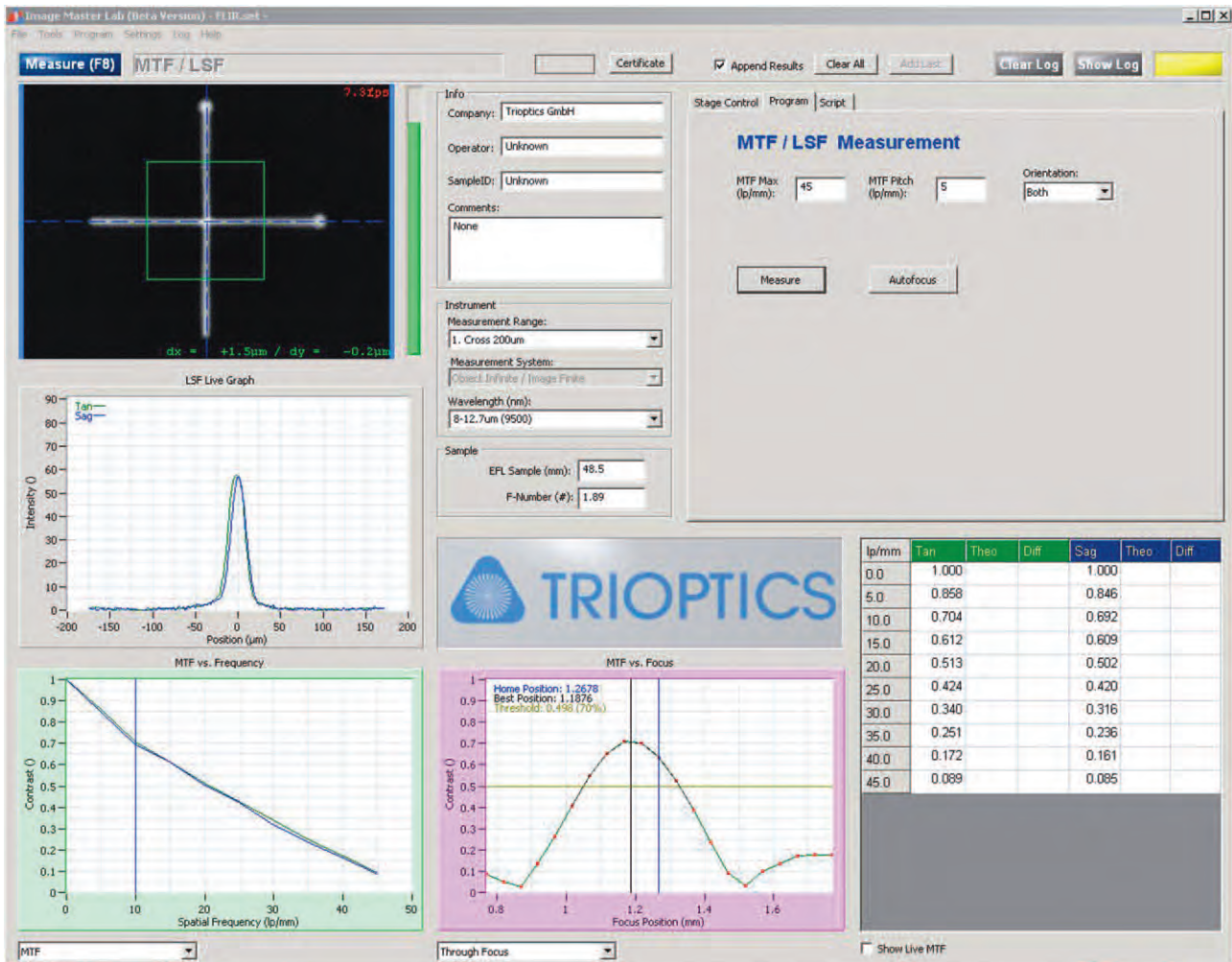
ImageMaster® HR IR is the preferred instrument in R&D labs worldwide

Specifications ImageMaster® HR IR

Configuration	Infinity conjugate
Spectral range	LWIR (8-12 µm)
Optical parameters	MTF on-axis, off-axis (angle up to +/- 90°) Effective Focal Length (EFL) relative Flange Focal Length (FFL) Distortion Astigmatism Chromatic aberrations and more
Sample EFL range	10 – 100 mm
Clear aperture	60 mm
MTF accuracy	+/- 0.03 MTF
MTF repeatability	+/- 0.02 MTF
Spatial frequency range	0-50 lp/mm
Azimuth range	360°

ImageMaster® Universal - is the most flexible product line for MTF testing

ImageMaster® Universal Line

ImageMaster® Universal

The **ImageMaster® Universal Series** has been specificly developed to cover a wide spectral range. It is designed to measure the complete set of optical parameters over the extended wavelength range.

Virtually any existing lens system ranging from high performance photographic imaging lenses to high resolution telescopes can be accurately measured in: IR, Visible, UV. To fulfil these demands the system provides a flexible and modular structure which allows the user to adapt and expand it to different test requirements. As an example the whole system can be reconfigured from an infinity conjugate to a finite conjugates setup, or from measurements in the visible spectrum to the infrared spectrum in the twinkle of an eye.

ImageMaster® Universal consists of several main opto-mechanical assemblies. In particular these are the Object Generator, the Mirror Collimator, the Sample Holder, the Swinging Arm assembly and the Image Analyzer. Optionally the system can be equipped with a Finite Stage which makes the measurement at finite conjugates feasible. Also available as an option: the automated ultra-precision Afocal Unit.

For the operation of the system a powerful software package has been developed which processes all measurement data and controls all motorized stages and position feedback encoders.

The Object Generator comprises a halogen light source for generating spectra in the extended visible regime. It can be easily exchanged for an infrared light source. A kinematic mount facilitates the exchange of several light sources without the need for a realignment of the source.

The output spectrum can be optionally narrowed with high performance optical filters. The illuminated target can be a single or double slit as well as crosshairs or USAF 1951 and

Set of filters and collimators for short focal distances

other resolution targets. The exchange of the targets is very simple with a novel slider technique or it can be motorized for automation. Optionally the object generator can be mounted onto the finite stage for positioning the target at **finite conjugates.**

Set of alignment tools

Reflecting Collimator Assembly

The target is imaged to infinity by a precisely aligned mirror collimator of remarkable surface quality. This guarantees diffraction-limited performance to highest precision. TRIOPTICS is the only company in the market that exclusively uses high quality diffraction limited collimators completely covered with stable, vibration damping, dust free and internally black matte-coated housings, eliminating the wavefront distortion due to air turbulences and ambient light influences.
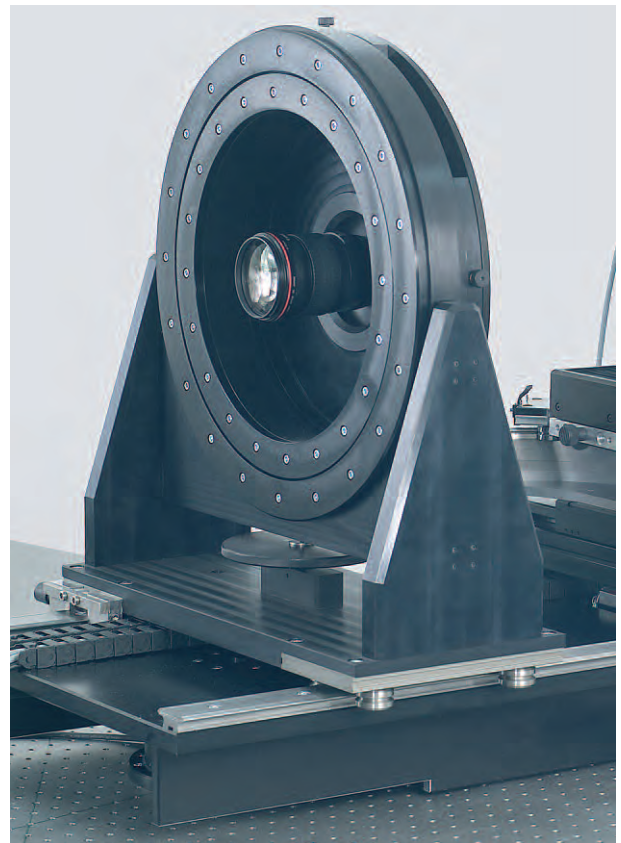
Heavy duty rotary precision holder

Heavy Duty Precision Sample Holder

A high performance MTF-Test station requires a precision rotary sample holder featuring negligible radial and axial run out, extreme stability and reference surfaces machined with highest accuracy. TRIOPTICS has invested a lot of efforts in the design and manufacturing a sample holder fulfilling these requirements.

The heart of the holder is an ultra accurate, heavy duty rotary bearing. The precision, steel ground reference surfaces, square and parallel to the optical axis, allow for an accurate positioning of the sample. Rotation facilities over 360° can be motorized and software controlled. Fine adjustment in X, Y direction permits the accurate centering of the sample to the optical axis. Height adjustment of the sample holder and a linear stage for translation of the sample holder further increase the flexibility of the system.

By default the sample under test is clamped to the Sample Holder by a self-centering chuck. As a matter of fact this can be replaced by a custom made bearing surface manufactured for the specific sample mount.

Precision Swinging Arm Assembly
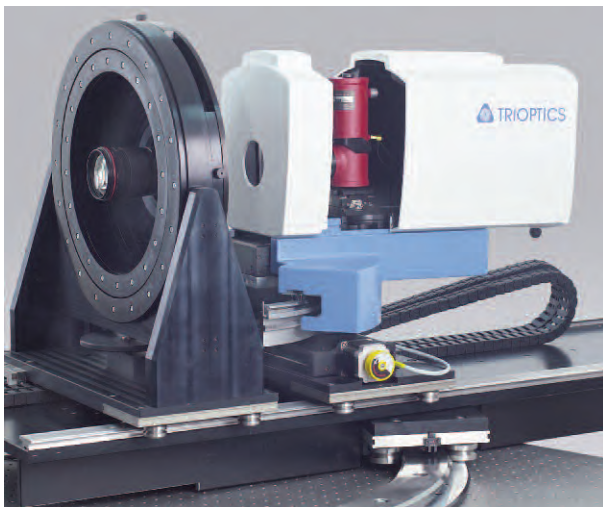
Motorized swinging arm with IR-image analyzer

The main parts of the swinging arm include:

- Stepper motor precision swinging arm with rotation facilities for very large field angles (up to ±140 degrees rotation).
- High precision gear and arc rail with angular scale for backlash free rotation of the swinging arm.
- Precision Angular Encoder with resolution 0.18 arcsec
- Linear optical rail for IR Image Analyzer Unit and sample holder

## Automated Ultra-Precision Afocal Unit

It includes:

- Semicircular guide ways, made of high stiffness, corrosion resistant materials and featuring exceptional straightness and running tolerances
- Precision drive with stepper motor and controller
- PC-controlled rotation of the optical head to the required angle, range +/-30°
- Guide ways for translation of the afocal unit along the optical axis in order to accurately position the image analyser in the centre of the exit pupil of the sample (telescope)
- Decollimators for the spectral ranges specified
- Software module for afocal systems

Image Analyzer

The Image analyzer can be equipped either with a CCD camera for measurements in the visible spectrum as well as with InSb- or- MCT-detectors to cover the infrared spectrum from SWIR to LWIR, Pbs-detector for SWIR and photomultiplyer for UV. The imaging device for the visible range is equipped with a high performance apochromatic relay lens. This lens focuses to the image plane of the lens under test and magnifies the target image onto the detector chip.

As the present technical development does not permit using CCD-like cameras in the UV or SWIR to LWIR region, TRIOPTICS made much effort in developing "scanning aperture" methods with point-like sensor chips for the these regions.

A high-precision air slit or pinhole of a few microns width is scanned in the image plane of the sample and the intensity profile of the line spread function (LSF) is recorded by the UV- or IR- detector. The intensity profile can be either scanned in tangential or in sagittal direction. The captured data is transferred to a computer which performs the data analysis. State of the art signal acquisition equipment with opti-

Optional Modules ImageMaster® Universal
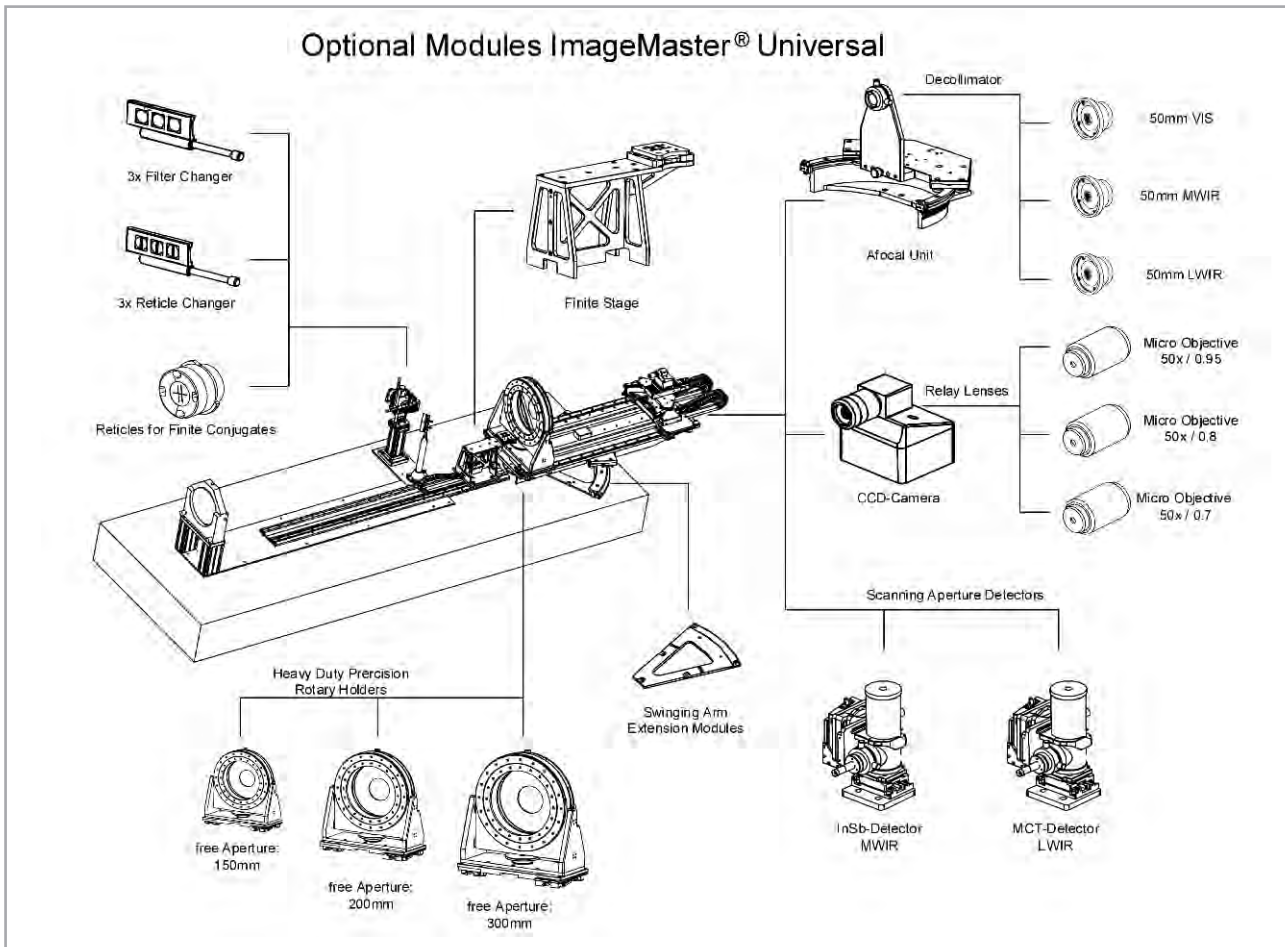
Optional Modules for the ImageMaster® Universal

cal light choppers, low-noise preamplifiers and digital lock-in amplifiers is used to obtain the optimum signal-to-noise ratio and MTF results of highest precision.
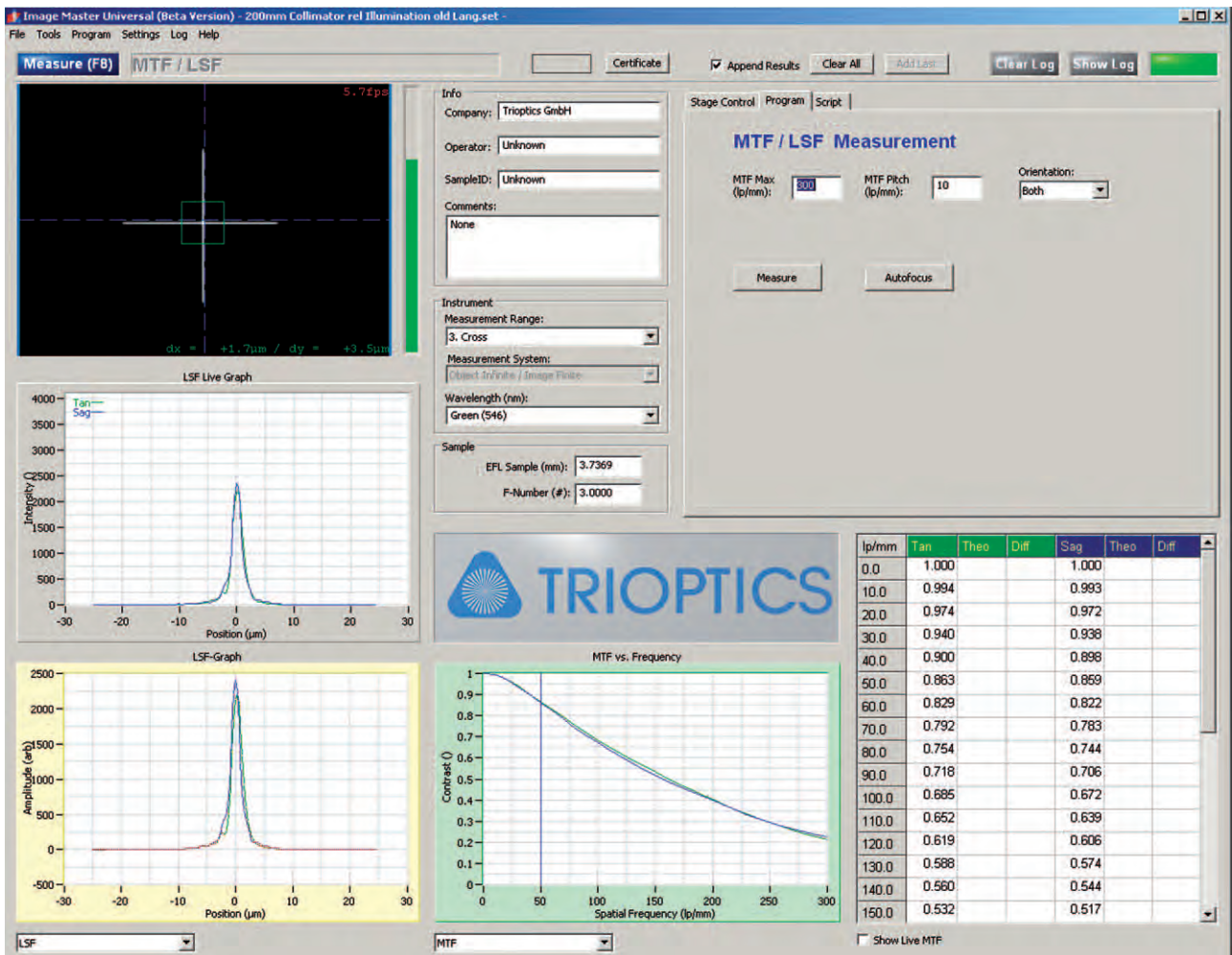
Software MTF-Lab

TRIOPTICS has developed a new forward-looking software package.

One main feature is the support of UV or IR detectors employing the scanning aperture method. Several useful functions are integrated which help the user in scanning and perceiving the correct image position of the sample under test. Changing the measurement mode is easy and time-saving. All important measurements for the imaging properties have been revised and are quickly accessible.

Software LAB provides powerful features to support the user in optimizing the measurement process:

• Striking new and easy to handle graphical user interface makes the most important functions only one mouse-click away
• Customizable arrangement of graph windows
• Script tools to create automated user defined measurements including high-level programming functions such as stage controlling, data manipulation, loops and variables
• Data export to a variety of file formats
• Logging of successive measurements
• Making up certificates using the hypertext language protocol (HTML)

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New graphical user interface makes the common measurement functions easy accessible

All these features make the Software MTF LAB software package the preferred choice for R&D and laboratory work. The software is designed to work under Microsoft Windows operating system.

Script editor for custom programming of test sequences

Specifications ImageMaster® Universal

Measurement of MTF in the following configurations:

- Infinity conjugate
- Finite conjugates
- Afocal systems
- MTF on-axis, MTF off-axis, off-axis angle up to +/-140°

Spectral range:

- VIS (Visible range)
- NIR (Near infrared)
- SWIR (1-3 μm)
- IR (Infrared) 3-5 μm and 8-12 μm
- UV (Ultraviolet)

Further optical parameters:

- EFL (Effective Focal Length)
- FFL (Flange Focal Length)

- PTF (Phase Transfer Function)
- Distortion
- Astigmatism
- Field curvature
- Chromatic aberrations
- Relative transmission
- Chief ray angle

System Specifications:

- Accuracy MTF: +/-0.02 MTF (directly traceable to international standards)
- Repeatability MTF: +/-0.01 MTF
- Azimuth measurements over 360°
- Spatial frequency range: 0-1000 lp/mm, 0-60 c/deg
- Lens focal length range: 1.0-2000 mm
- Max. clear aperture: up to 450 mm
- Measuring process: manual or fully automated

ImageMaster® Universal

TRIOPTICS

ImageMaster® Production Line

High Speed Production MTF-Tester

Leadership in testing mobile phone and digital camera lenses

Since the first developments on miniature mobile phone lenses in the year 2000 TRIOPTICS is in close cooperation with the leading manufacturers in this business. Due to the long-term experience and the high quality standards, TRIOPTICS has become the world wide market leader for MTF production testers.

ImageMaster® PRO, the latest development for MTF-production testing, is the leading instrument for testing mobile phone and digital camera lenses. It is recognized as the industry standard providing highest accuracy and reliability. The calibration of the instrument is directly traceable to international standards.

Ultra-fast measurement of high volume quantities

The ImageMaster® PRO line family of instruments has been developed for the fast inspection of the imaging quality (in terms of MTF) of objective lenses in high volume production lines, especially for the mobile phone lens market, but also for digital compact camera lenses. Hence, these instruments are optimized for smaller samples with shorter effective focal lengths.

The ImageMaster® PRO 5 measures the sample EFL and the on- and off-axis MTF within less than 2 seconds per lens including the

lens positioning and autofocus procedure. Of course, for each image field position both the tangential and the sagittal MTF is measured.

Quality, long life and reliability

Typically, ImageMaster® PRO 5 equipment is used in the quality assurance where 100% testing is required. The oversized build and high quality components guarantee highest MTBF (mean time between failures) even at 24hours / 7days operation. The measurement is based on state of the art image analysis and MTF evaluation according to the ISO 9334/5 standard giving objective and repeatable results. Besides numerous mechanical features for fully

ImageMaster® PRO 5 - Self-contained, movable ergonomic cabinet

automatic measurements also the software has been adapted to the requirements in high volume production lines. The simple but effective user interface and program layout makes it an indispensable tool for the final inspection of objective lenses.

TRIOPTICS
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Measurement principle

The measurement principle is based on the reverse projection method which TRIOPTICS has successfully introduced into the market of MTF production testers and used since then. The test target is an illuminated reticle which carries crosshair type test patterns of a few microns line width and sub-micron lithographic accuracy. It typically has the size of the sensor in the sample lens application. The test patterns are at defined field locations according to the customer's specification.

The target reticle is moved by a precision autofocus stage to the focal plane of the sample lens, so that the test pattern is projected to infinity. For each field angle there is a dedicated CCD telescope which images a magnified image of the test pattern to the CCD sensor. Typically 5 or 13 image field locations are analyzed thus an according number of camera images is simultaneously grabbed and transferred to the PC.

This setup significantly reduces the total measurement time compared to traditional MTF testers thanks to the common test target and dedicated CCD telescopes for all measured image field positions. Today, ImageMaster®

ImageMaster® PRO 5 - Ultra-fast for production testing

PRO 5 instruments are installed and in operation for objective lens resolutions ranging from CIF and VGA up to 8 megapixels and spatial frequencies up to 300 lp/mm. The instrument allows the measurement of high distortion wide-angle objective lenses with a field of view (FOV) >165°.
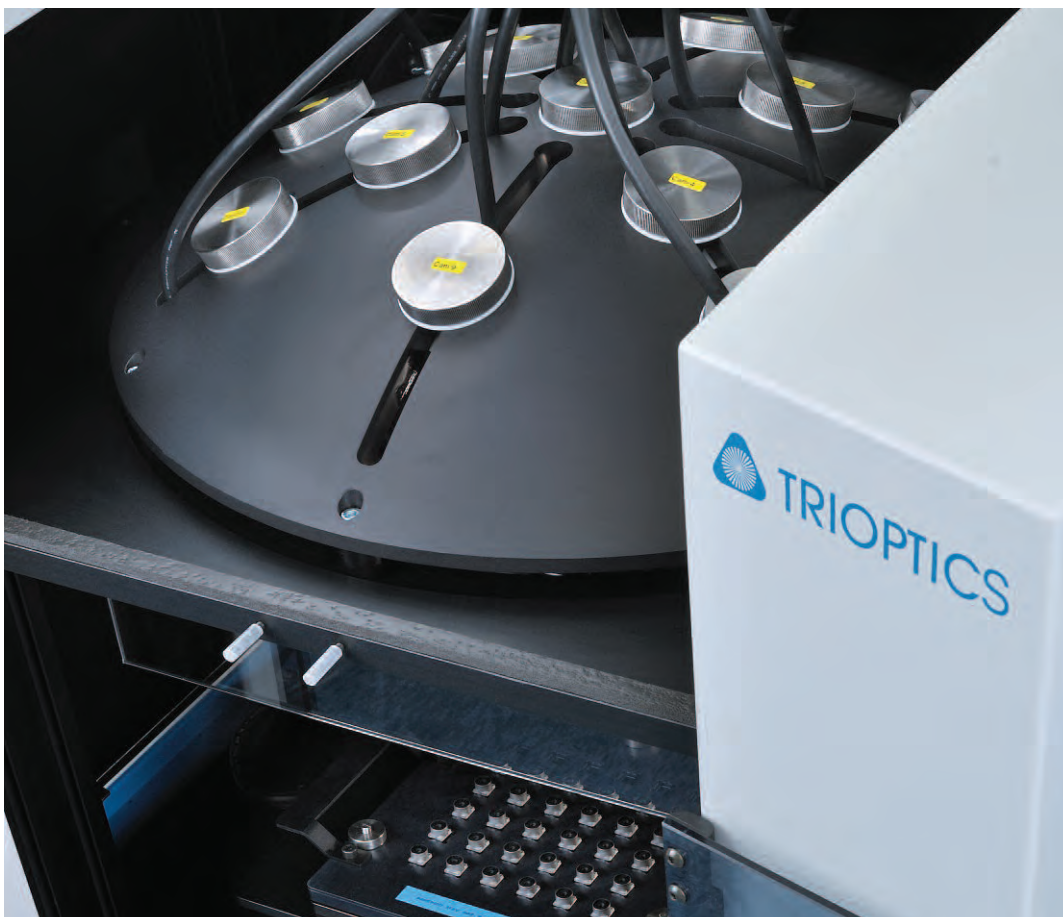
ImageMaster® PRO 5

ImageMaster® PRO Series are the leading instruments for testing image quality of mobile phone and digital camera lenses and are recognized as the industry standard providing highest accuracy and reliability. The calibration of the instruments is directly traceable to international standards. The PRO 5 Series is the most successful production MTF-testers from TRIOPTICS for singulated lenses and wafer level samples (WL-lenses). In WL-lens applications the PRO 5 series reach a measurement time of less than one second per sample. The continuous development on the software represents a significant improvement of the test cycle time.

Advantages of the new ImageMaster® PRO 5 Series at a glance:

- Reduced cycle time compared with ImageMaster® PRO 4 systems
- Improvement of the signal noise ratio
- Higher accuracy of the alignment tools
- High precision sample holders for 5 MP, 8 MP and 12 MP lenses
- New tray technology for diced WL-lenses with short EFL
- Advanced and stable software with additional functions

ImageMaster® PRO 5 - Ingenious design for easy alignment
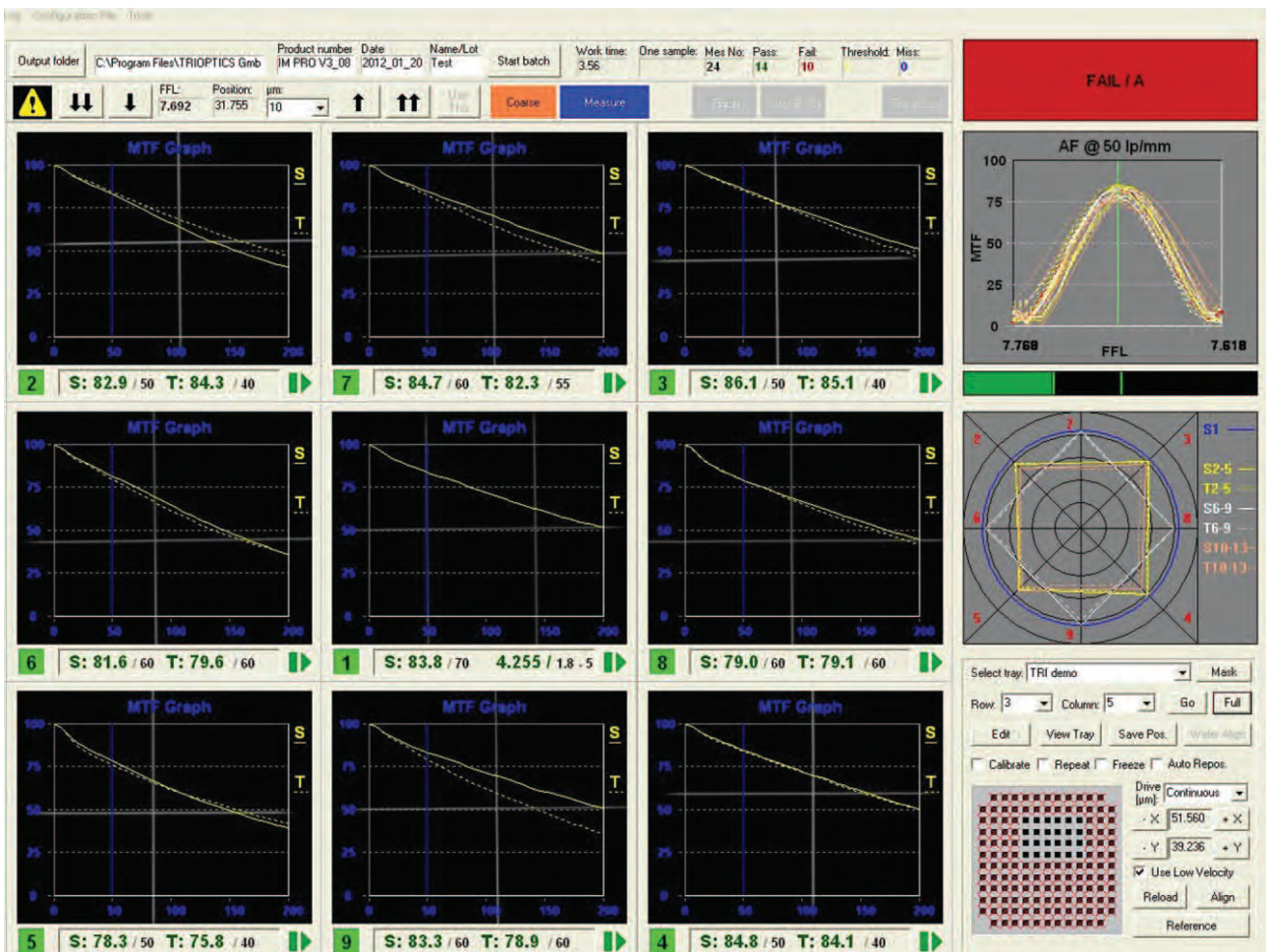
Software ImageMaster® PRO 5

The software for the MTF tester is specially designed for the use in a production line environment. ImageMaster PRO provides a stable platform and overwhelming number of features.

The ImageMaster® PRO 5 software uses proven algorithms for calculation of the MTF, automatic correction for spatial frequencies in off- axis positions taking into account of the sample distortion, noise reduction and provides reliable and ultra-accurate measurement results. Further features include:

- Automatic pass or fail results based on a multitude of freely selectable criteria

- Software enabling real- time images of all cameras.
- Individual setting of spatial frequencies for each camera
- Settings to enable focussing curve for on-axis and/or off-axis cameras
- Three security levels, set up files and critical functions are password protected
- Storage of lens and batch data, data analysis over Excel
- Graphical intuitive representation of the measurement data in order to detect lenses out of specification at an early stage
- Polar diagram for displaying MTF symmetry in image field

In order to meet increasing requirements of high volume lens testing, TRIOPTICS added a

ImageMaster® PRO 5 Software-User Interface
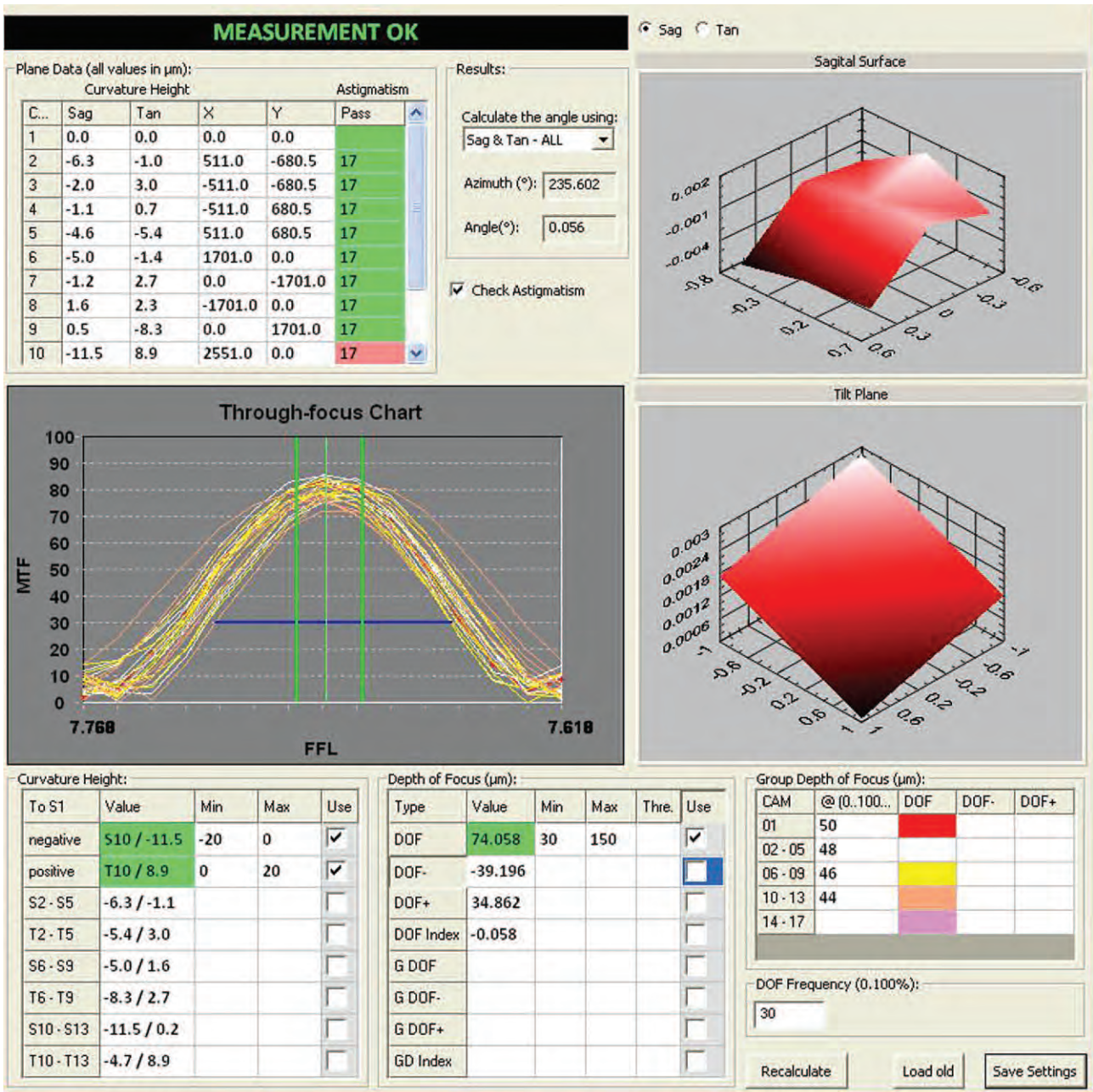
ImagePlane-Display of the measurement results

new software module called ImagePlane. The ImagePlane-Software module provides additional information about the optical and geometrical parameters of the sample:

- Tilt of the image plane
- Field Curvature
- Depth of focus
- Astigmatism

The additional characterisation of the sample provides valuable data to be used in the optimization of the production process.

ImageMaster® PRO 5 Ultra

Description

ImageMaster® PRO 5 Ultra Series the improved instruments for testing image quality of mobile phone and digital camera lenses. New algorithms provide the industry in production the fastest measurement time, highest accuracy and reliability. All TRIOPTICS MTF- testers are traceable to international standards. The PRO 5 Ultra Series is the next big improved production MTF-tester for singulated samples and wafer level lenses (WL-lenses). In applications for insulated objective samples the Ultra series reach a measurement time of less than two seconds per sample. The continuous development on hard- and software represents a significant improvement of the test cycle time and accuracy.

Advantages of the new ImageMaster® PRO 5 Ultra Series at a glance:

- Reduced measurement time of lower than 2 seconds
- Vibration isolated measurement chamber
- Stable feet construction and improved mechanics

ImageMaster® PRO 5 Ultra

An additional alignment tool which determines the wafer position allows for easy and accurate loading of the instrument while an ultra-precision distance sensor measures accurately the bending of the wafer.

All the advantages and features of Image-Master Pro 5 can be found in the wafer testing instrument. In addition wafer specific functions have been added:
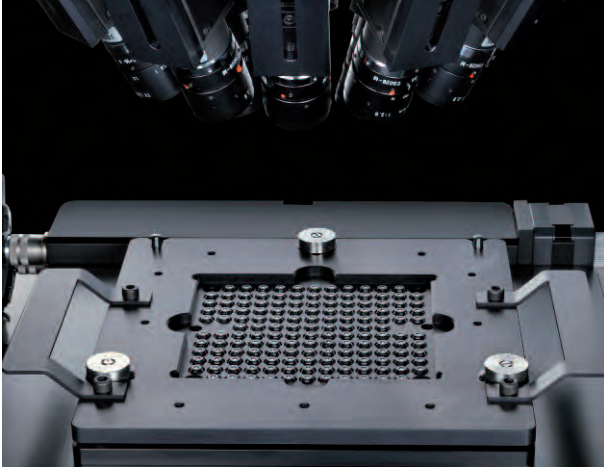
Measurement chamber with 17 telescopes and a tray with 148 samples

- Ultra-accurate FFL measurement
- MTF-measurement in fixed image field planes
- Wafer bow measurement
- Faster measurement time (less 1 sec. per lens)
- Quick, software controlled wafer alignment
- Data processing for next production steps
- Clean room compatibility
- Operation status light indicator
- Easy loading due to kinematic mount and wafer rotation adjustment tool
- An assortment of pass and fail criteria allows for using the most suitable criterion for each type of lens

- Higher accuracy of high precision stages and new motor controller
- High precision sample holders for 5MP, 8MP, 12MP lenses and higher
- Advanced and robust software with additional fast measurement functions

ImageMaster® PRO 5 Wafer

Description

The **Image Master® PRO Wafer** has been designed to meet the requirements of the quality assurance within the production of the new generation of objective lenses i.e. for mobile phone / digital cameras or automotive sensors that are fabricated in large quantities on wafers. Wafers of any size up to a diameter of 8'' and thousands of miniature lenses or objectives can be tested and qualified in one fully automatic test run at high speed.
The brand new instrument is fully automated and prepared for measurement of lenses on circular wafers or single lenses that are arranged in a tray.

ImageMaster® PRO 5 Wafer

Wafer loading and alignment tools

Due to an easy to use wafer loading and alignment tool high precision alignment of
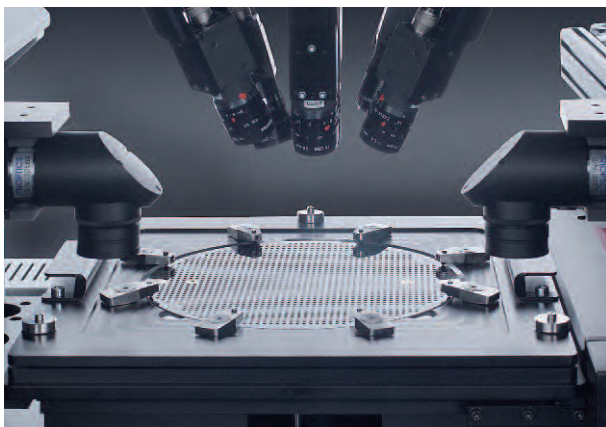

ImageMaster® PRO Wafer

each new wafer before measurement is not needed. After inserting a wafer into the wafer holder the instrument determines the rotation as well as the lateral offset of the lens pattern with respect to the corresponding tray file by comparing alignment marks on the wafer. Thus, the position of each lens on the wafer can be determined and used during the series measurements.

ImageMaster® PRO 5 Wafer measurement chamber

Since wafers usually show bending caused by gravity (single wafers) or internal stress from the joining process (wafer stacks) a tracking mechanism ensures that the MTF is always measured in the same plane relatively to the wafer surface for every single lens.

Software ImageMaster® PRO 5 Wafer

The ImageMaster® PRO 5 Wafer-Software, except for accurate MTF-measurement, needs to fulfil further specific requirements of wafer lens testing:

- Recognition of wafer marks and control of wafer alignment
- Generation of a testing pattern depending on the wafer specification
- Integration of an optical sensor for bow mesurement
- Mapping of the wafer in order to determine the FFL and the dimensions of the spacers
- Bow compensation algorithms
- Generation of appropriate masks for wafer testing
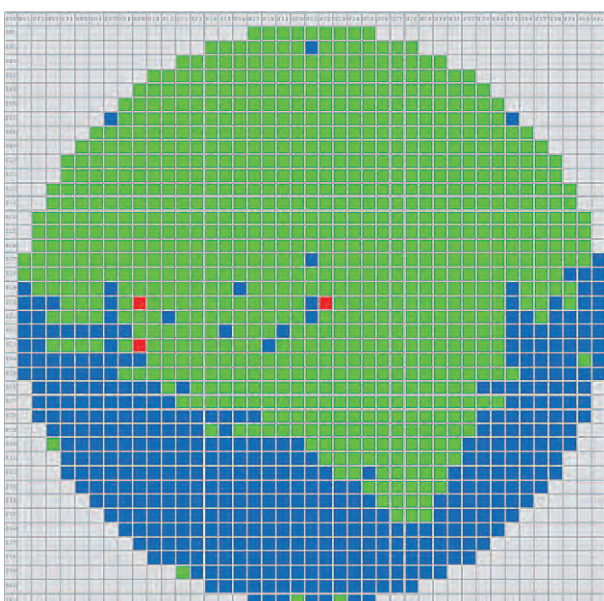
Wafer-Tray Pattern Generation

For each type of lens wafer a unique wafer-tray representation file has to be generated once, which is then used by the software to find the optimum measurement conditions for each single lens on wafers of the same kind.

The Wafer-Tray pattern generation module is extremely flexible and allows for easy creation of files from wafer design data or machine data. A multitude of tools for pattern process-

ing is available and enables masking, fiducial generation, export to next manufacturing steps, etc.

Wafer-Tray Generator input mask
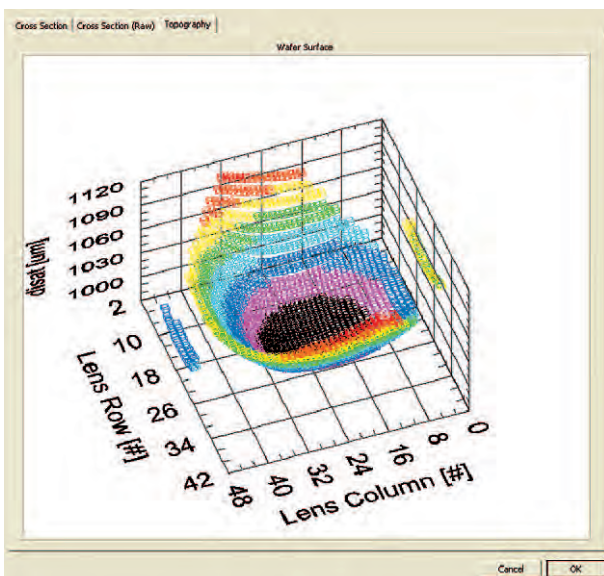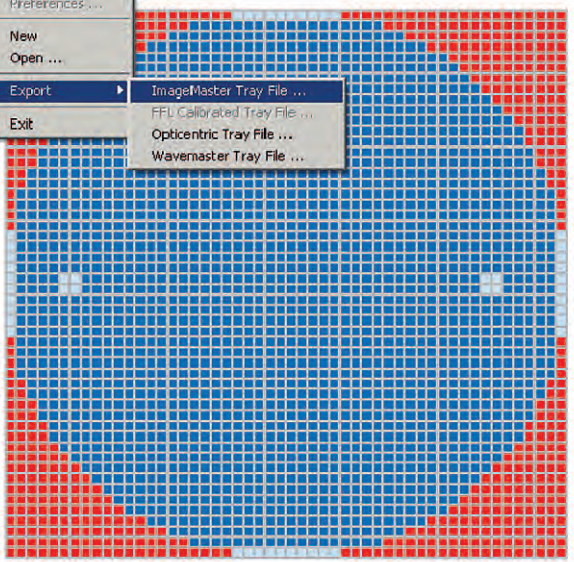
ImageMaster® PRO Wafer-3-D Wafer Topography

ImageMaster® PRO 5 Wafer - View after measurement

Wafer-Tray Generator export windows

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ImageMaster® Compact PRO

The **ImageMaster® Compact PRO** is a production MTF tester for qualifying mobile phone and other miniature lenses measuring objective lenses with an effective focal length between 1 and 12 mm. The instrument is optimized for throughput, compactness and durability. With the typical measurement time of 4 sec per lens more than 10.000 lenses are tested within a 24h shift.

Like every ImageMaster® production tester the Compact PRO fulfills the testing requirements for the latest generation of mobile phone lenses. The on-axis MTF is checked with an accuracy of 2% MTF traceable to international standards, and of course further impor-

tant parameters like EFL and FFL are measured, too. For the test target illumination TRIOPTICS has chosen an innovative white light LED design with a long life time and constant parameters.

The **ImageMaster® Compact PRO** is designed for future developments like the upcoming generation of five mega pixel objective lenses.

It is a space saving table top device and is easily integrated into the production environment.

The **ImageMaster® Compact PRO** is available as a single seat tester or with an automatic multi-sample tray system for high volume testing.

ImageMaster® Compact PRO

Technical Data of ImageMaster® Compact PRO with Autotray

Accuracy MTF on-axis	2 % MTF (traceable)
Accuracy MTF off-axis	4 % MTF
Measurement time/sample	4 sec.
Resolution	0,01"
Measurement time all Through Focus Curves /sample	8 sec.
Measurement parameters	MTF on-axis, MTF off-axis, trough focus curves, effective focal length, flange focal length, depth of focus, tilt of image plane, azimuth of image plane, field curvature, astigmatism, relative optical distortion
Light source	white LED (halogen optional)
Filter	VIS (NIR Optional)
Stage accuracy (x,y,z)	2 µm
System alignment	Autocollimator optional (one for every customer)
Type of instrument	Table top device with PC and monitor / table optional
Sample holder: travel	Tray 140mm x 140mm
Dimensions (width × height × depth)	650 mm × 682 mm × 610 mm
Weight	90 kg

Technical Data ImageMaster® PRO 5 Series

	ImageMaster® PRO 5 Ultra	ImageMaster® PRO 5	ImageMaster® PRO 5 Wafer	ImageMaster® Compact PRO
Optical set up	Infinity-finite conjugates	Infinity-finite conjugates	Infinity-finite conjugates	Infinity-finite conjugates
Spatial frequency	0 … 300 lp /mm	0 … 300 lp /mm	0 … 300 lp /mm	0 … 200 lp /mm
Accuracy MTF on-axis	1.5 % MTF	2 % MTF	2 % MTF	3 % MTF
Accuracy MTF off-axis	2,5 % MTF	3 % MTF	3 % MTF	4 % MTF
Accuracy EFL (Effective Focal Length)	5 µm	5 µm	5 µm	5 µm
Accuracy FFL (Flange Focal Length)	6 µm	8 µm	4 µm	10 µm
Minimum measurement time	1,0 sec / sample	1,2 sec / sample	1,0 sec / sample	4,0 sec / sample
Average measurement time	2,0 sec / sample	2,5 sec / sample	2,5 sec / sample	5,0 sec / sample
Dimensions (height x width x depth)	1365 mm x 1350 mm x 675 mm	1350 mm x 1330 mm x 660 mm	1350 mm x 1330 mm x 660 mm	682 mm x 650 mm x 610 mm
Weight	210 kg	180 kg	190 kg	90 kg
Sample holder	Tray with multiple sample seats (3 quality classes)	Tray with multiple sample seats (3 quality classes)	Wafer tray	Tray with multiple sample seats (3 quality classes)
Clean room class FS 209 / ISO14644-1	100 / ISO 5	100 / ISO 5	100 / ISO 5	no cert.

TRIOPTICS