



M²-200s-FW

Users Guide

For M²-200s Models

Beam

Propagation

Analyzer

For Windows 7[®]

Software Version 4.93 or later

For Sales, Service or Technical Support

Phone: (435) 753-3729

Fax: (435) 753-5231

Service Email
service@us.ophiropt.com

Sales Email
sales@us.ophiropt.com

Ophir-Spiricon, LLC
3050 North 300 West
N. Logan, Utah 84341
© 2009 Ophir-Spiricon Inc.

Manual No. 11382-001
Document No. 11382 Rev H v4.93

Notice

Ultracal™ is a trademark of Ophir-Spiricon, LLC.

Windows®, Windows Vista®, Windows XP®, Windows 7®, Visual Basic®, and Excel® are registered trademarks of Microsoft Corporation.

LabVIEW® is a registered trademark of National Instruments.

Pentium® is registered trademarks of Intel Corporation.

All rights to the product and any accompanying user guide(s) are reserved by Ophir-Spiricon, LLC.

Ophir-Spiricon, LLC reserves the right to make improvements to the product described in this user guide at any time and without prior notice.

While every precaution has been taken in the preparation of this guide, the publisher and author assume no responsibility for errors, omissions, or any loss of data because of said errors or omissions.

Personal computer hardware and component manufacturers, along with operating system providers, constantly revise their products and software upon which this product is dependent. While Ophir-Spiricon, LLC endeavors to maintain maximum compatibility with a wide variety of personal computer configurations, Ophir-Spiricon, LLC makes no guarantee that any one brand or model of personal computer will be compatible with any or all of the features contained in this application, either now or in the future.

Obtain the latest version of this user guide at <http://www.ophiropt.com/laser-measurement-instruments/beam-profilers/services/manuals>.

Table of Contents

Notice.....	2
Table of Contents	3
Table of Figures	5
Table of Equations.....	6
Safety.....	7
M ² -200s Model Numbers	8
General Information.....	9
How to Use This Users Guide.....	11
Chapter 1. Specifications and Connections.....	12
1.1 Specifications.....	12
Chapter 2. M ² -200s Tutorial & M ² Theory.....	16
2.1 Introduction to M ²	16
2.2 Laser Beam Parameters	16
2.3 An M ² -200s Tutorial	19
2.4 M ² -200s Theory of Operation.....	28
2.5 Operation Limitations.....	29
2.6 M ² -200s Electro-Mechanical Operation	30
2.7 Computations	31
2.8 Operating Modes.....	38
Chapter 3. Operating Controls and Displays.....	41
3.1 Operating Modes.....	41
3.2 Load.....	42
3.3 Save As... ..	43
3.4 Export Image.....	44
3.5 Save Config.....	45
3.6 Restore Config... ..	45
3.7 Logging.....	45
3.8 Print... ..	47
3.9 Print Setup.....	48
3.10 Exit	48
3.11 Camera.....	49
3.12 Capture... ..	51
3.13 M ² Setup.....	52
3.14 Advanced M ² Setup	61
3.15 Toolbar Controls.....	64
3.16 Windows	67
Chapter 4. Setup and Operation	73

4.1	Unpacking	73
4.2	Install the M ² Software	74
4.3	Connect the Optical Train.....	74
4.4	Connect the Camera.....	75
4.5	Preliminary System Checkout	75
4.6	Prepare the M ² -200s for Auto Mode	78
4.7	Manual Mode	83
4.8	Operate in Real-time M ² Mode.....	87
4.9	Useful Operations and Functions.....	88
4.10	Using The Four-Cuts Method	92
Chapter 5.	Troubleshooting	96
5.1	Error Messages	96
5.2	Informative Messages.....	98
Chapter 6.	M ² -200s Automation Server.....	100
6.1	Using Automation.....	100
6.2	Properties, Methods, and Events.....	107
6.3	DCOM	120
6.4	If you have a problem	122
Appendix A	Calibration Information	124
Appendix B	Replacement Parts.....	134

Table of Figures

Figure 1. M ² -200s-FW Optical Train Dimensions	15
Figure 2. M ² -200s Component Connections Diagram	15
Figure 3. Beam Propagation with Lens Transform	18
Figure 4. Focused Waist Location vs. Input Beam Waist Location	21
Figure 5. Focused Spot Size vs. Small Beam Waist Location, M ² =1	23
Figure 6. Focused Spot Size vs. Large Beam Waist Location, M ² = 1.	24
Figure 7. Focused Spot Size vs. LargeBeam Waist Location, M ² = 2.	25
Figure 8. Focused Spot Size vs Beam Waist Location vs. λ ,for various input beam widths with M ² = 1	26
Figure 9. Optical Train Diagram	30
Figure 10. Determine Z Lens Distance for the M ² -200s	36
Figure 11. C-Mount Adapter Z _{cam} std values in mm	37
Figure 12. New Auto Stepping Modes	38
Figure 13. The four-cuts Setup	39
Figure 14. C-mount insert and clamp.....	79
Figure 15. Beam Alignment	80
Figure 16. Alignment Tool	81
Figure 17. Manual Mode Optical Rail.....	83
Figure 18. Beam Sampling Diagram.....	89
Figure 19. Beam Energy Too Low.....	90
Figure 20. Beam Energy Too High.....	91
Figure 21. Appropriate Beam Energy	91
Figure 22. The Basic Four-Cuts Layout.....	93
Figure 23. Four-cuts Two Axes.....	94
Figure 24. Four-Cuts Method Dialogue Box	95

Table of Equations

Equation 1 – Beam Propagation	18
Equation 2 – Beam Propagation Ratio.....	18
Equation 3 – The Rayleigh Length.....	18
Equation 4 – Hyperbolic Propagation	28
Equation 5 – M ² and K Factors	32
Equation 6 – BPP Factor.....	32
Equation 7 – Full Divergence Angle	32
Equation 8 – Waist Width	33
Equation 9 – Waist Location when $Z_{\text{laser}} = 0$	33
Equation 10 – Waist Location when $Z_{\text{laser}} > 0$	33
Equation 11 – Rayleigh Range - Artificial.....	34
Equation 12 – Rayleigh Range - Real.....	34
Equation 13 – Astigmatism	34
Equation 14 – Asymmetry	35
Equation 15 – Focal Length at a new λ	35
Equation 16 – Z Lens Distance M ² -200s.....	37
Equation 17 – Focal Length Change vs. Wavelength	125
Equation 18 – Z_{lens} vs Wavelength	125

Safety

Optical Radiation Hazards



Use of this instrument requires the operator to work within the optical path of lasers. Exposure to radiation from these lasers may be sufficient to warrant the use of protective equipment.

Unless the laser's optical path is enclosed, the operator should be protected against accidental exposure. Exposure to personnel other than the operator must also be considered. Hazards include direct beam exposure and reflected radiation.

When working with an unenclosed beam path, it is advisable to do so while the laser is powered down or at reduced power levels. Whenever there is a risk for dangerous exposure, protective eye shields and clothing should be worn.

M²-200s Model Numbers

All standard M²-200s models are sold without a computer, and without external optical accessories. Two basic versions are offered: the Auto Model w/ an optical train and the Manual Model w/o an optical train. If you already own an Ophir-Spiricon SP300 beam analyzer product, you may order an accessory model of the M²-200s. The accessory model allows you to use your SP300 camera in conjunction with the new M²-200s software, thus realizing a considerable cost savings.

Auto Mode System Model Numbers

The Auto Mode Systems includes the M²-200s optical train. Auto mode systems can also operate in Manual mode.

SP90144	M2-200s-FW	Includes a SP300 camera. USB 3.0 interface card available.
SP90145	M2-200s-FW-A	Short optical train accessory model, sold w/o a camera, for customers that already own a SP300 system. Return camera to add M ² license.

Manual Mode System Model Numbers

The Manual Mode System does not include the automated optical train and requires the end user to provide a manually operated optical train. The optical train must include a focusing element, a means to translate the camera behind the focusing element, and a laser beam attenuation system. Accurate results depend upon a well-designed optical system. The user has full responsibility for the system performance.

SP90146	M2-200sM-FW	Includes a SP300 camera. USB 3.0 interface card available.
SP90147	M2-200sM-FW-A	Accessory model, sold w/o a camera, for customers that already own a SP300 system. Return camera to add M ² license.

Note: The M²-200s software is not backward compatible with older systems that used a frame grabber based camera.

USB 3.0 Interface Card Model Numbers

SP90386	PCI-Express USB 3.0 Desktop Card	PCI-Express, USB 3.0 card for installation to desktop PCs. Compatible with all BeamGage USB 3.0 systems.
SP90387	PCI-Express USB 3.0 Laptop Card	PCI-Express, USB 3.0 card for installation to laptop PCs. Compatible with all BeamGage USB 3.0 systems.

General Information

Introduction

The Ophir-Spiricon model M²-200s is a precision instrument designed to measure the propagation characteristics of visible to near-visible laser beams. The M²-200s may be purchased with or without an automated optical translation and attenuation system (optical train). When ordered without the optical train the user is required to provide a manual translation/attenuation apparatus. Without the optical train, the M²-200s software will only run in Manual mode.

If you already own an Ophir-Spiricon model SP300 Laser Beam Analyzer, the M²-200s can be purchased as an optional accessory. There are a number of different configurations regarding the M²-200s; so consult your local Ophir-Spiricon representative, or phone our sales department for assistance.

All of the M²-200s systems will automatically measure propagation characteristics in both the X and Y-axes and display the following parameters:

- X and Y Waist diameters
- X and Y full angle Divergences
- X and Y Waist locations
- X and Y Rayleigh range distances
- M² or K and BPP factors for X and Y axes
- X vs. Y Astigmatism
- X vs. Y Asymmetry

The M²-200s software employs patented calibration procedures (U.S. Patent 5,418,562) and an automatic aperture to achieve the highest possible measurement accuracy.

A fully automatic M²-200s measurement system must include the following equipment:

- A Pentium PC style personal computer running Windows 7 (typically supplied by the user)
- The M²-200s optical train, with wavelength appropriate lens
- Power supply and USB cable
- A SP300 CCD camera w/respective interface card. Additional cameras may be supported in the future.
- One pair of beam alignment Pin-holes

A manual M²-200s measurement system must include the following equipment:

- A Pentium PC style personal computer running Windows 7 (typically supplied by the user)
- A SP300 CCD camera w/respective interface card. Additional cameras may be supported in the future.

A beam-focusing element and laser beam attenuation devices.

An optical rail or some other means of accurately positioning the camera with relationship to the focusing element

Optional accessories:

External laser beam sampler and attenuator (recommended), consult factory.

One pair of beam steering mirrors (recommended).

How to Use This Users Guide

Read this users guide before setting up the M²-200s system. You will become familiar with the M² measurement theory and acquire a basic understanding of how the M²-200s operates. Insights gained through this review will greatly assist you when operating the M²-200s, performing system alignments, and interpreting M² results.

Chapter 1 contains general information and M²-200s instrument specifications.

Chapter 2 presents a tutorial on M² theory and practical insights behind the propagation measurements and the ISO measurement methods, as well as a description of the features in the M²-200s Optical Train and software. We recommend reading this chapter before attempting M² measurements.

Chapter 3 describes the various controls and displays. Become familiar with these and their meaning before attempting to operate the M²-200s.

Chapter 4 provides set up instructions and details Auto and Manual mode operations.

Chapter 5 contains troubleshooting tips and information, and how to respond to error messages.

Chapter 6 presents instructions on how to use the ActiveX-based M²-200s Automation Server.

Appendix A contains calibration information about the M²-200s models.

Appendix B contains a list of replacement parts and optional components.

Chapter 1. Specifications and Connections

1.1 Specifications

Environmental	
Storage Temperature	-30° C to 65° C
Storage Humidity	95% maximum (non-condensing)
Operating Temperature	10° C to 40° C
Operating Humidity	95% maximum (non-condensing)

Power Requirements*	
Line Voltage	95V AC to 250V AC
Line Frequency	47Hz to 63Hz
Maximum Power	4.5 Watts

* For the Optical Train only. The PC computer supplies the power for the system components, such as the CCD camera. An external power supply is provided for Laptop computer use.

Physical	
Weight	15 lbs (without camera)

Standard Optics	
Lenses	Different lenses are needed for different wavelength regions. Three standard lenses are included with the systems with nominal 300mm focal lengths. See below. Additional lenses must be ordered separately. 266-587nm (included) 400-750nm (included) 650-1125nm (included) 1000-1300nm (optional)
Attenuation Range	Nominally from ND 0 to ND 4.8. Actual values vary with wavelength.

Optical Limits	
Wavelength Range	266-1300nm The CCD camera is only operational from 266 to 1300nm. Newer cameras may be incorporated in the future which may extend this operating range
Beam Size	M ² -200s .5mm – 10mm Varies with wavelength, waist size, location, and M ² See Figure 5, Figure 6, Figure 7, Figure 8.

Damage Limits	
Camera ¹	.15 $\mu\text{W}/\text{cm}^2$ CW mode for a 10mm input beam diameter 1.0 $\mu\text{J}/\text{cm}^2$ pulse mode for a 10mm input beam diameter both of the above for an M ² =1 @ 1064nm

General	
Accuracy	$\pm 5\%$ typical, $\pm 12\%$ waist location and Rayleigh length typical (Note: Accuracy can be degraded by a variety of situations, consult text.)
Measurement Cycle Time	2-3 minutes typical, depending on setup conditions and operating mode.
Camera Attachment	Standard C-mount, 90° camera on axis rotation
Translation System	Step motor-driven lead screw
Translation Pitch	4mm/rev optical pitch
Step Angle	1.8° (200 steps/rev)
Sample Range	190 – 600mm, typical

¹ WARNING! CCD cameras can be damaged by power in excess of .1 mW/cm² or energy in excess of 1 $\mu\text{J}/\text{cm}^2$. The M²-200s employs a focusing optic. While it may be that the laser input power or energy density measures well below this damage threshold, it can easily exceed these levels when focused onto the camera sensor. Use caution and err on the side of safety. CCD cameras can be costly to repair or replace.

Camera Specifications	GRAS20*	SP300
Imager	1/1.8" CCD, 1600 x 1200 pixels	1/1.8" CCD, 1928 x 1448 pixels
Format	12 bit A to D	14 bit A to D
Frame Rates	7.5 FPS (at full resolution)	7.5 FPS (at full resolution)
Pixel size	4.4µm x 4.4µm	3.69µm x 3.69µm
Gain	0 to 25dB	0 to 25dB
Dimensions	65x44x35mm	65x44x29mm
Mass	125g	90g
S/N Ratio	59dB at min gain	39dB at min gain
Shutter Control	Programmable from 110µs to 70ms	
Trigger Input	Edge sensitive 3.3/ 5Vdc LVTTTL/TTL (positive or negative, user programmable) Minimum pulse width 10µs External Trigger cable provided	
Trigger Out	3.3Vdc LVTTTL, Programmable	
Voltage Requirement	Powered over Cable	
Power Consumption	<3.5watts	
NOTES:	<i>The camera may have additional features that are not applicable when used with a Model M²-200s. The style and configuration of the camera may change in the future without notice and without regards to the specifications shown here.</i>	

*The GRAS20 has been replaced by the SP300 on new M²-200s systems. However, the GRAS20 is still supported at this time for customers that already own existing systems.

1.1.1 Optical Train Dimensions

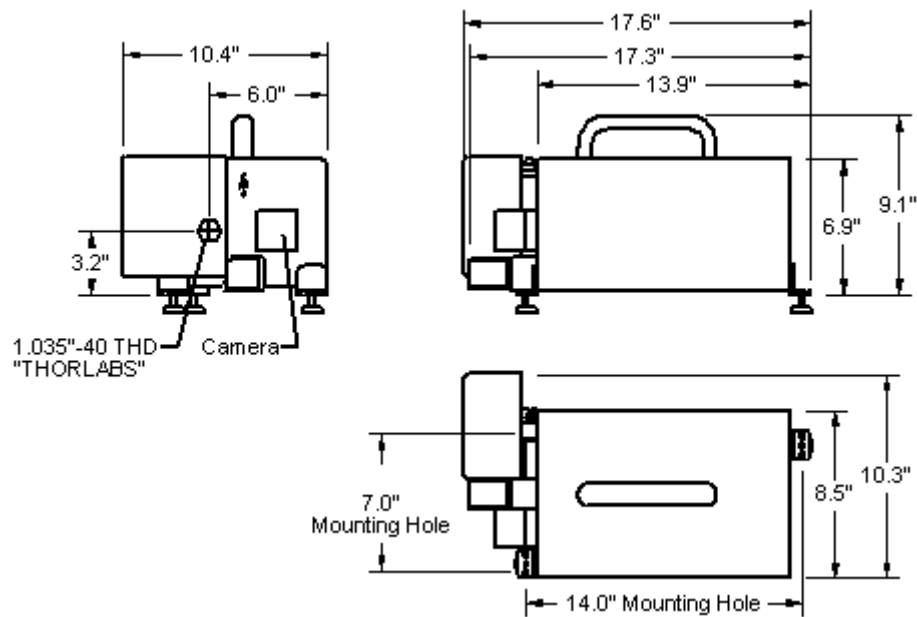


Figure 1. M²-200s-FW Optical Train Dimensions

1.1.2 M²-200s Component Connections Diagram

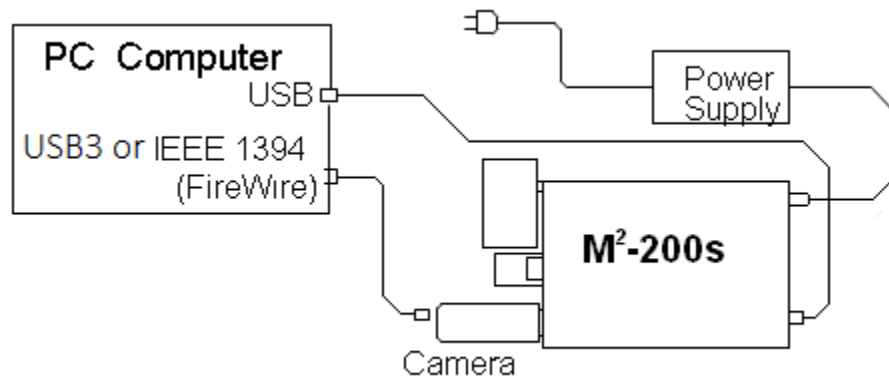


Figure 2. M²-200s Component Connections Diagram

Warning: Take care when connecting components to avoid electrical damage.
Only connect the provided power supply to the STEP IIB Motor Controller or the M²-200s.

Chapter 2. M²-200s Tutorial & M² Theory

2.1 Introduction to M²

The M² model has become an accepted standard used for characterizing the general performance (or “quality”) of a laser beam. This one quantity, in each of the two orthogonal propagation planes, ties together the three interrelated beam parameters of beam Waist Width, Divergence, and Rayleigh Range. This method is based on how a real laser compares to an ideal Gaussian beam. An ideal Gaussian beam (referred to as the fundamental mode or TEM₀₀) will have an M² value of 1. All beams of higher order, beams of mixed modes, will have an M² value greater than 1.

The M² value for a given laser beam is derived from propagation theory and is referred to as the “beam propagation ratios.” One practical consequence of the M² definition is that a beam with an M² value of 1 can be focused to a minimum spot diameter, whereas beams of higher M² values will focus to larger spot diameters in proportion to the M value. That is to say, a beam with an M² value of 2 will have a minimum focus spot M times as large as a Gaussian beam of M² = 1. Thus, knowledge of the M² value can provide meaningful information about lasers, especially if their application involves small focused spot sizes.

By convention, a second, less commonly used notation for beam quality has also been adopted. It is referred to as the “Beam Propagation Factor”, K, where: **K = 1/M²**. Ophir-Spiricon's Beam Propagation Analyzer will report either notation, as selected by the operator.

Recently a third representation called the “Beam Parameter Product”, BPP, has come into use, where: **BPP = M²λ/π**. Version 4.60 or later software can also display this result.

For the remainder of this discussion we will only refer to the M² form.

The International Organization for Standards (ISO) subcommittee on Electro-optical systems has created a standard for test methods relating to the measurement of laser beam parameters. Ophir-Spiricon's M² application employs algorithms that conform to the methods described in the ISO 11146-1, & -3:2005(E) procedures. Copies can be procured from ISO.

ISO 11146-1 describes the method for characterizing Stigmatic and simple Astigmatic beams. The M²-200s is designed to measure these types of lasers.

ISO 11146-2 describes the method for characterizing General Astigmatic beams (twisted beams). The M²-200s is not capable of measuring this class of laser at this time.

ISO 11146-3 describes general measurement methods.

2.2 Laser Beam Parameters

Three beam parameters predict how a radially symmetric laser beam will propagate. These three parameters are:

1. The beam Waist Width (diameter) W₀.

2. Location of the beam waist Z_0 .
3. The far-field divergence angle Θ .

For non-radially symmetric lasers, two sets of these parameters are required to more fully characterize the laser, one set in each of the X and Y axial directions. Since the method for determining the nature of either a single or double set of parameters is essentially the same, only one set will be referenced in the following descriptions.

Note: We have elected to use the term *Beam Width*, instead of *beam diameter* or *radius*, owing to the fact that traditional beam measurement practices (including our own products) compute full beam widths in both the X and Y axial directions. *Beam diameter* and *beam radius* convey the notion that the beam is circular. A laser may in fact be circular, but that is considered to be a special case.

Note: In the past, different conventions and symbols have been utilized by various authors. In the descriptions that follow we use W to represent the full beam width. ISO uses $d_{\sigma x}$ and $d_{\sigma y}$ for the full beam widths and d_{σ} for diameter. Still others use W or w to represent $\frac{1}{2}$ the beam width (or radius).

Upper case Θ is used to describe the full angle divergence while lower case θ is used to indicate the $\frac{1}{2}$ angle divergence.

When a beam is transformed thru a lens the input beam parameters are designated by a 1 while the output parameters are designated by a 2.

All distances are described along the axis of propagation or Z axis and are measured relative to the locus of the transforming lens. Distances z_1 are measured to the left of the lens and z_2 measured to the right.

W_0 and Z_0 represent a beam waist width and its waist location respectively. Z_R is used to represent the Rayleigh distance from the beam waist location Z_0 . In the ISO procedures subscripts x and y are added to represent the axial directions. We have chosen to omit them and describe only one axis.

An "F" is used to indicate the focal length of the lens.

See Figure 3 for a graphical representation of the above conventions.

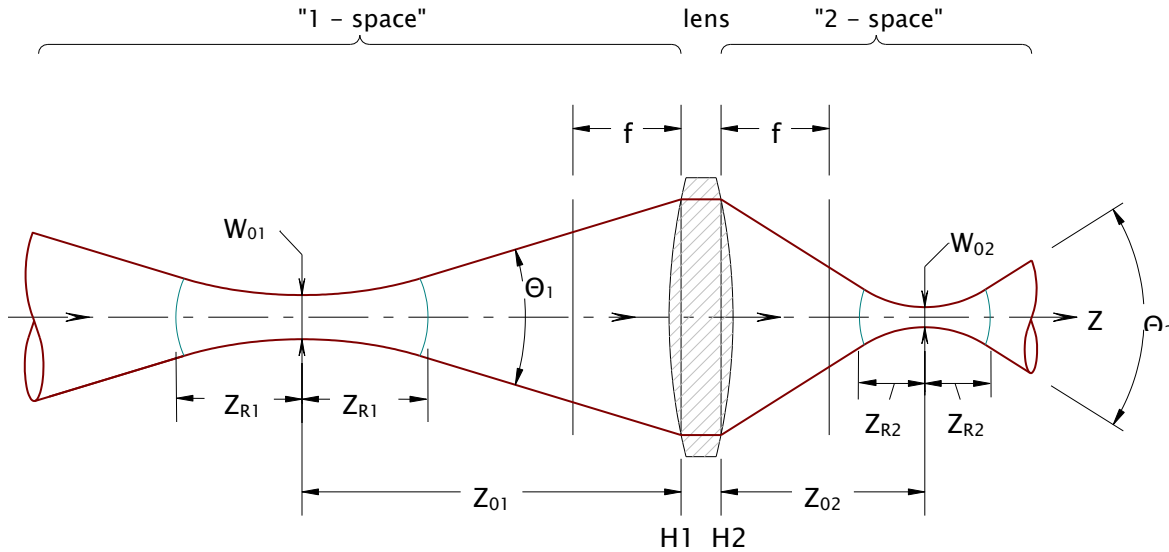


Figure 3. Beam Propagation with Lens Transform

With these three values one can predict the beam width $W(z)$ at any location along the axis of propagation (z), by the application of the beam propagation equation:

Equation 1 – Beam Propagation

$$W(z)^2 = W_0^2 + \Theta^2(z - Z_0)^2$$

The “beam propagation ratio”, M^2 , is defined by the equation:

Equation 2 – Beam Propagation Ratio

$$M^2 = W_0 \Theta \pi n / 4\lambda$$

where: λ = the laser wavelength in vacuum
 n = the index of refraction of the medium (assumed to be ~ 1)

The Rayleigh length defines the near field region on either side of the waist. The full Rayleigh distance is 2 times the following:

Equation 3 – The Rayleigh Length

$$Z_R = W_0 / \Theta$$

The above equations are valid for the beam on either side of the transforming lens as shown in Figure 3.

2.3 An M²-200s Tutorial

From the preceding equations it can be observed that a propagating laser might be directly measured. With numerical analysis, the propagation parameters for W_0 , Θ , and Z_0 are found, and from these the M^2 and Z_R values are calculated. In practice this is usually not a very easy thing to do, and in many cases it is not even possible. For example: The laser waist may be in a non-accessible location, such as inside the laser cavity. Or it may not exist in real space, but behind the laser cavity in virtual space. As laser beams increase in W_0 , they decrease in Θ , making even an accessible waist difficult to locate with great precision. They can also have Rayleigh lengths many meters long. Large beams also quickly become too impractical to measure using readily available detection methods, like CCD cameras.

The solution to many of the above difficulties is accomplished by transforming the beam via a simple focusing optic creating an accessible miniature of the original beam with all of its fundamental properties retained. In this new form the beam can be measured and then mathematically transformed back to reveal its input parameters. To obtain a correct transform of the laser requires some constraints on the design of the transforming system. In particular the transforming lens must be aberration free. In the earlier M²-200 this was accomplished with thin plano-convex lenses having an f-number ≥ 20 . This large f# made the M²-200 package quite long, but was a key reason why it yielded excellent results for a large range of input beams.

The M²-200s is about 1/2 the size of the earlier unit and employs a shorter focal length optic. In order to retain good accuracy the lenses are now Achromats. The Achromat design corrects for spherical aberration, the main culprit responsible for errors with designs that employ lower f# optics. However, even a good Achromat can only maintain its aberration free performance up to point. That point varies with input beam size and decreasing focal length. The manufacturing tolerances of an Achromat are however less accurate ($\pm 1\%$) compared to a typical plano-convex lens ($\pm 1/2\%$). The M²-200s uses a nominal focal length of 300mm. Another benefit of the Achromat design is that its focal length does not vary significantly over its A/R coating range. For the most part, the focal length will shift $< 1\text{mm}$, which is less than the manufacturers fabrication tolerance. See Appendix A for plots of the focal length change vs. wavelength for Achromat and UV lenses supplied with the M²-200s.

Note: For operation at UV wavelengths the lens will still be a simple plano-convex type. At the shorter focal lengths the range of input beam widths is reduced such that even at the 300mm focal length the $f\#\geq 20$ rule is still maintained.

2.3.1 The Transforming Lens

In Figure 3, assume for the moment that the input beam shown to the left of the focusing optic is a fundamental mode Gaussian beam. The beam is shown propagating to the right. The beam's wavefront radius of curvature is becoming shorter as the beam propagates towards its waist until it reaches Z_R , the Rayleigh distance. After the Rayleigh distance, the radius of curvature begins to increase once more until at the waist location, Z_0 , where the radius of curvature is infinite. As the beam passes thru the waist its radius of curvature begins to shorten until it reaches Z_R on the opposite side of the waist. Past Z_R the radius of curvature once again begins to increase towards infinity.

The changing radius of curvature of a propagating laser results in some non-intuitive behavior when applied to a measurement device that transforms with a focusing lens, such as those employed by the M²-200s. The position of the focusing lens relative to the input beam's waist can alter the location of the waist formed after the lens, sometimes dramatically.

Figure 4 shows how the focused waist location moves relative to the input beam waist location for a range of input beam waist widths. The M²-200s has a nominal translation range from 190-600mm. ISO 11146 instructs that at least 10 samples are required to make an accurate M² measurement, with a minimum of 5 taken within the near-field region and 5 taken in the far-field.

Note: *The Near-field is defined as the region $\pm Z_R$ from the waist. For our purposes the Far-field is anywhere beyond $\pm 2Z_R$ from the waist.*

The construction of the M²-200s is designed to yield good access to both the near and far-field regions when the new waist forms in the Z₂ region from 300-400mm from the lens. From Figure 4 this can be observed to favor placing an input beam's waist at least 300mm in front of the M²-200s lens. Observe that for very small beams, the region around Z₀₁ = 300mm in front of the lens yields greater change in the focused waist when there are small changes to input waist location. For very small beams, the laser is better situated when the waist is at least 1000mm before the lens.

Under most circumstances the input beam's waist should avoid being closer than a focal lengths distance from the lens.

For beams whose waist width is ≥ 2 mm the placement will almost always yield a focus near the lens focal length of ~ 300 mm, making placement not critical.

Note: *The following graphs are representative of conditions seen with the M²-200s.*

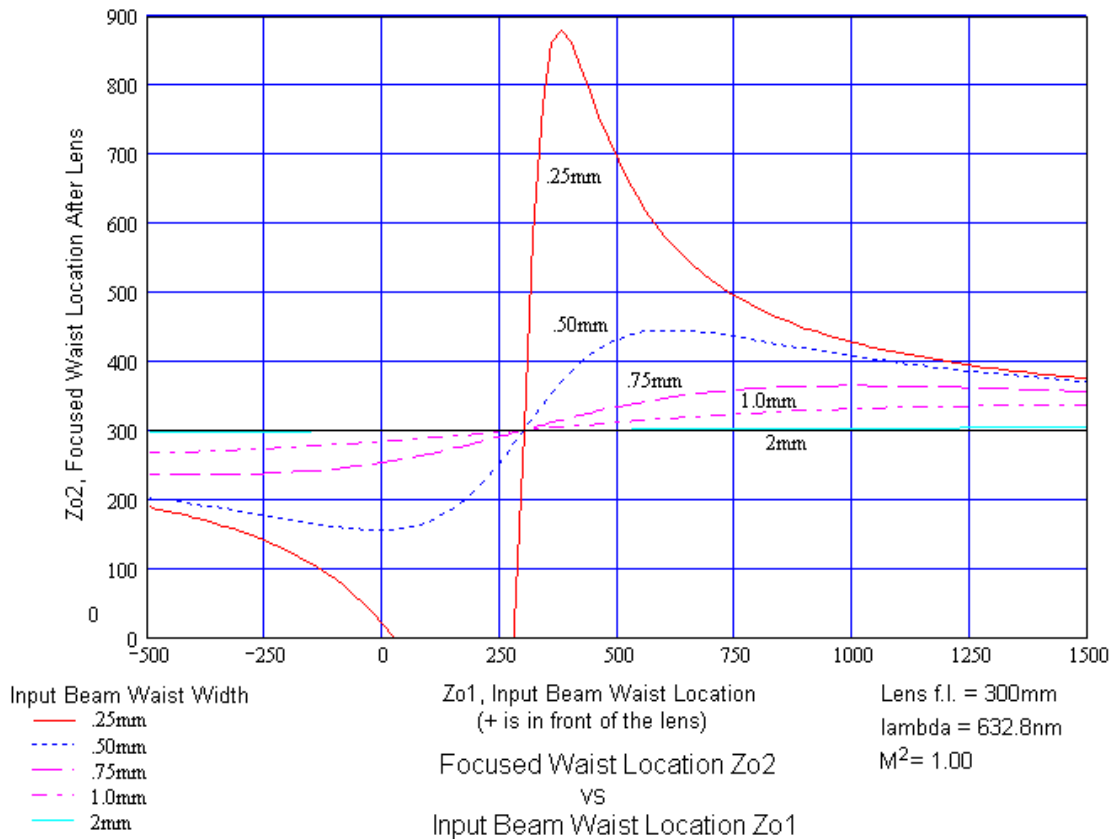


Figure 4. Focused Waist Location vs. Input Beam Waist Location

2.3.2 Beam-Width Measurement Criteria

All laser beam parameter measurements are computed based on beam width measurements. Therefore, making accurate beam width measurements must be an essential feature of any good measurement system. Additionally, the basis chosen for making the beam width measurement must conform to beam propagation theory.

A variety of beam width measurement methods and algorithms have been developed over the years, and development yet continues. The method that conforms to beam propagation theory is referred to as the second moment method. This method defines the beam widths as 4 times the standard deviation (σ), evaluated in the transverse X and Y directions, over the beam intensity profile. While this 4σ definition is the one most desirable, directly making this measurement with great precision can be difficult. The M²-200s software employs special algorithms that allow it to perform very accurate second moment measurements. Some of these methods are covered under U.S. Patent No. 5,418,562. The latest ISO 11146 procedures describes this patented approach.

Under adverse conditions, results using direct second moment measurements may be less than satisfactory. For this reason we have included an alternate Knife-Edge technique. This method will yield somewhat poorer accuracy but can

get you closer to the truth when the second moment algorithm is faced with extraneous noise in the beam wings. The ISO procedure recognizes the problems with making direct second moment beam width measurements and allows for alternate measurement methods.

The legitimacy of the moving knife-edge method lies in its ability to produce a result that is equivalent, or nearly equivalent, to the second moment value. The knife-edge method is described in the ISO procedure, and has been adapted to the M²-200s system using special algorithms developed at Ophir-Spiricon.

Whichever method is employed, one should stay with one approach in order to maintain a good basis for comparison between similar lasers or setup conditions.

2.3.3 Spot Size and Resolution

Any measurement system will have operating limits that are constrained by the methods and materials employed. For the M²-200s, the camera used to measure the beam widths possesses one constraint. The imager's size limits how large a spot can be measured. Generally a spot size should be between $\frac{1}{2}$ to $\frac{2}{3}$ rds the size of the detector in the X and Y directions. To yield high accuracy at the $\frac{2}{3}$ rds fill size, the beam must also be well centered.

To accurately measure small beams is the greater challenge for CCD cameras. From experience, Spiricon has determined that the beam width must be at least 10 pixels wide in both the X and Y directions to yield suitable measurements. Below this limit the beam width can report either under or over-sized results.

The M²-200s software will not prevent you from making measurements below this 10 pixel limit, but the resulting accuracy will be degraded.

The current standard cameras available with the M²-200s employ a 4.4 μ m pixel pitch. This gives them the ability to measure beam widths down to about 44 μ m. As cameras with smaller pixels become available they will be pressed into service. But for the moment, this 44 μ m width limits the operating range of the M²-200s.

The following figures show how the beam width of the focused input laser changes under a range of different conditions. In Figure 5 the focused spot size is plotted against the input waist location for a variety of input beam sizes.

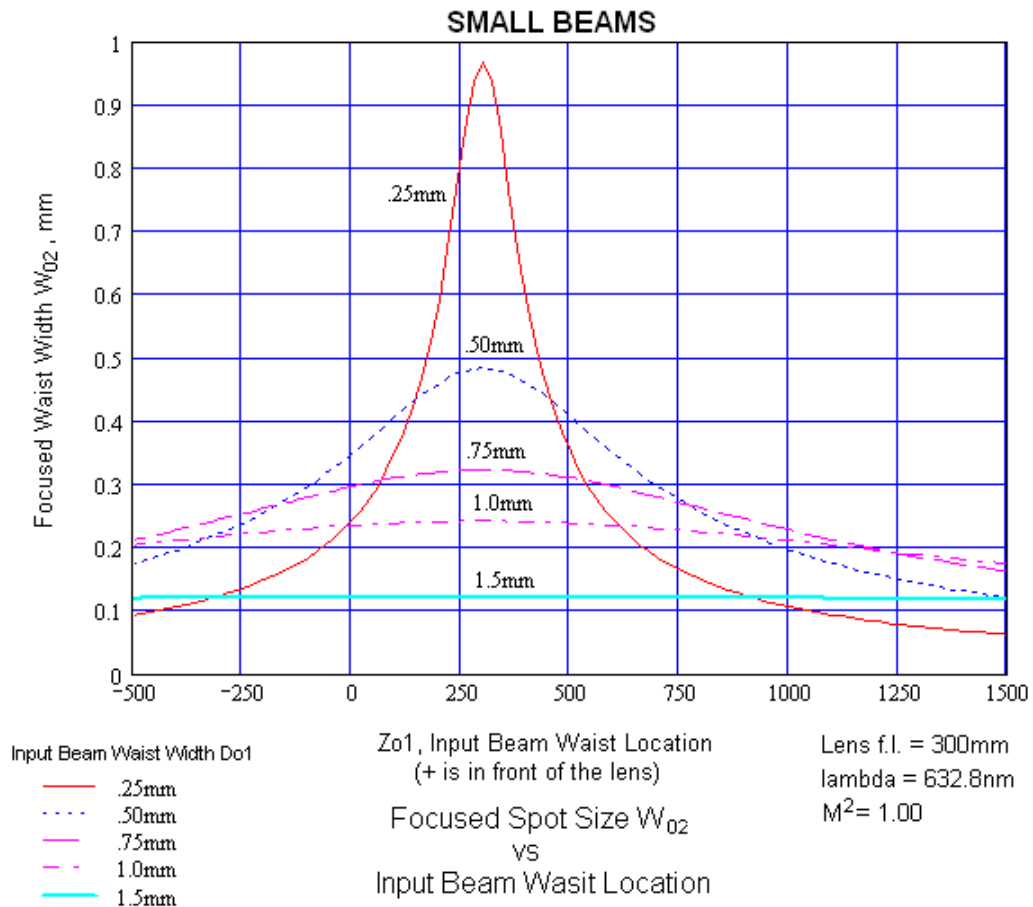


Figure 5. Focused Spot Size vs. Small Beam Waist Location, M²=1

Small beams are shown above and represent only $M^2 = 1$ beams. Recall that the focused spot sizes can only be larger when $M^2 > 1$. None of the focused spot sizes of these examples challenge the resolving limits of the camera.

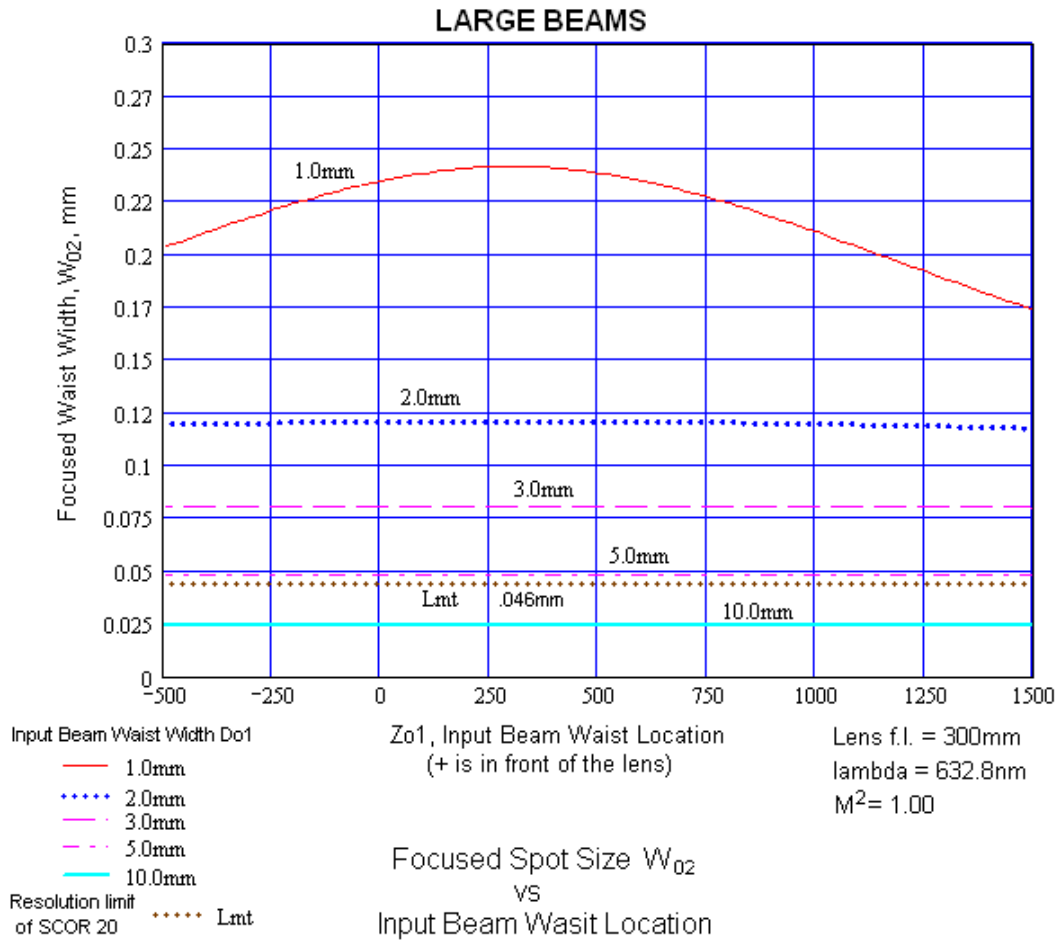


Figure 6. Focused Spot Size vs. Large Beam Waist Location, $M^2 = 1$.

Figure 6 depicts the focused spot sizes for larger input beam sizes also with $M^2 = 1$. Notice that somewhere between 5 and 10mm the focused spot size falls below the 46 μm dotted line which represents the resolution limit of the camera. For these larger beams, the range of operation can now be more significantly impacted by a change in M^2 value.

Figure 7 shows these same beams sizes with an $M^2 = 2$. Observe that now all the input beams focus to a size within the resolution of the camera.

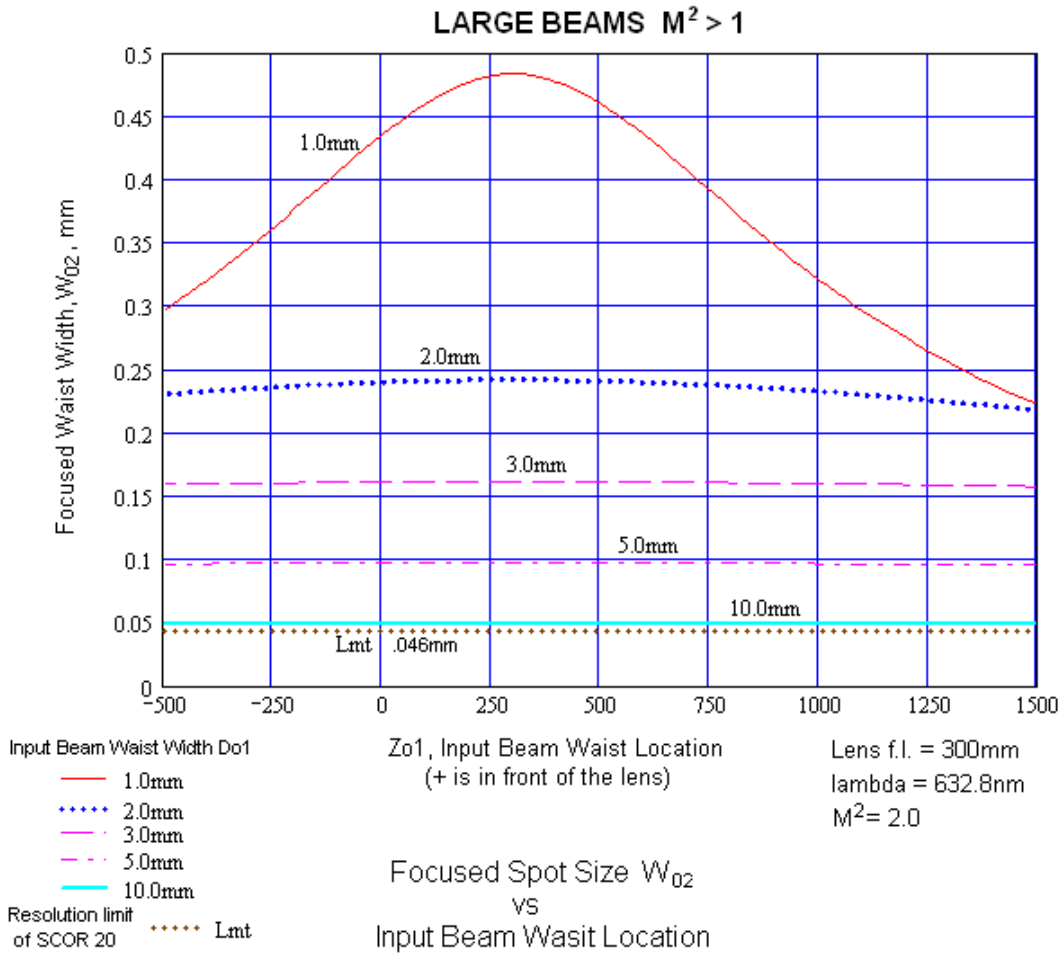


Figure 7. Focused Spot Size vs. LargeBeam Waist Location, $M^2 = 2$.

Note: The M^2 -200s has an at-the-lens absolute maximum input beam size of 10mm. This constraint is a practical limit imposed by the clear apertures of the lens and the ND filters. Beams that are larger than 10mm at the input may encounter edge induced diffraction which may degrade the measurement accuracy of the system.

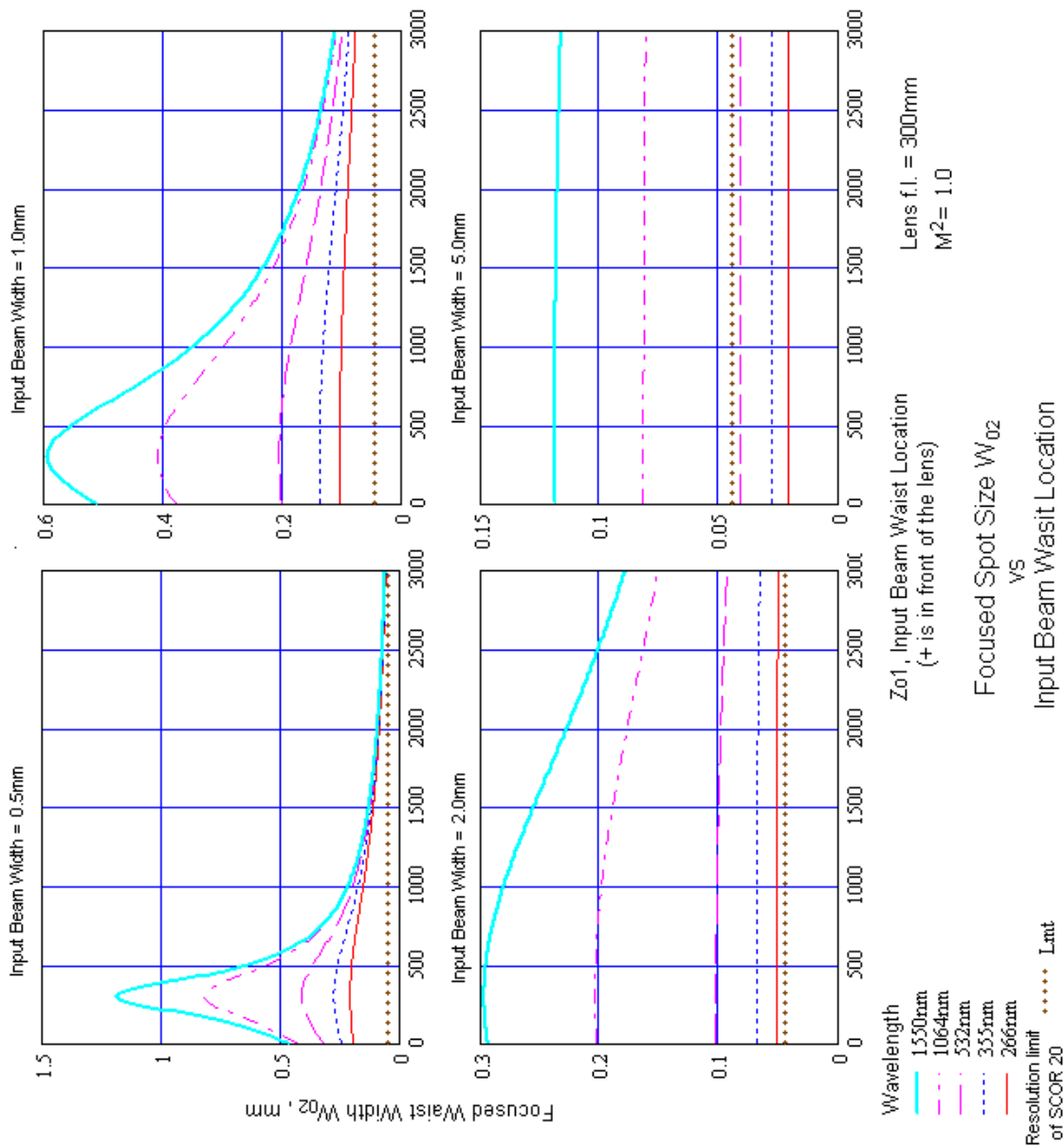


Figure 8. Focused Spot Size vs Beam Waist Location vs. λ , for various input beam widths with $M^2 = 1$

All of the previous figures assumed a fixed beam wavelength of 632.8nm, a HeNe laser. Figure 8 demonstrates the effect of the focused spot size for variations in wavelength. As expected, shorter wavelengths focus smaller than longer wavelengths.

2.3.4 Attenuation, Distortions, and Wavelength

In an ideal world it would be desirable to not insert any optical devices between the laser and the measurement system. At the same time, the ideal system would be capable of operating at any wavelength (or at the very least over a

large range of wavelengths), over a large range of input power, and over a wide range of input beam widths.

To move towards some of these expanded goals, the M²-200s employs a newly designed external beam attenuation system. This new external approach allows the user greater latitude in the setup and better control over the types of problems inherent in a design that attempts to fit a wide range of conditions.

Earlier models of the M²-200 either limited the wavelengths to Visible or YAG at 1064nm, or alternately a Broadband model was offered that attempted to operate from the UV through the YAG wavelengths. However, the Broadband model was a poor compromise for high quality lasers with low M² values. The Broadband model was plagued by two types of problems; ghost beams, and interference fringing. Depending upon usage, these could be a minor annoyance or a serious problem.

The new M²-200s design addresses both of these earlier problems and is sold in only one version that operates well from 266nm through 1064nm, which is the practical operating range of the CCD camera.

Note: *Operation beyond 1064nm may be possible with specialized cameras. In some instances, CCD cameras can be pushed to about 1300nm. Additional testing must be performed to insure good operation at these longer wavelengths.*

This new design employs a combination of both Inconel and bulk absorbing ND filters. Inconel filters are about the worst way to attenuate a laser and avoid interference and ghost beam effects. At the same time, Inconel filters offer the best operation over a wider range of wavelengths with lower impact on ND performance. The new M²-200s employs new and specially designed Inconel filters that reduce the effects of interference fringing.

By placing the filters before the input lens and outside of the optical train, the occurrence of ghost beams are greatly reduced, and more easily mitigated when observed. The external filter system can be detached and placed earlier in the beam path. By repositioning the filter assembly, the ghost beams can be directed to miss the optical axis of the system and not appear on the camera or mixed into the beam caustic.

Since ND filters are still imperfect devices, the new ND design allows the user to easily modify the filters to suit their own special circumstance. Additional filter wheels are available and can be loaded with any standard 1" round filter that the user chooses. The filter wheels can be individually swapped out, or an entirely new filter wheel assembly can be plugged in as a replacement. Thus this new system affords both excellent broadband operation as well as flexible customization paths to cover a wide range of special needs.

For most applications, additional external laser beam attenuation is necessary. For most applications, total input beam power should be reduced before it enters the first ND filter. This is important for two very critical reasons:

The laser may damage the ND filters (\$).

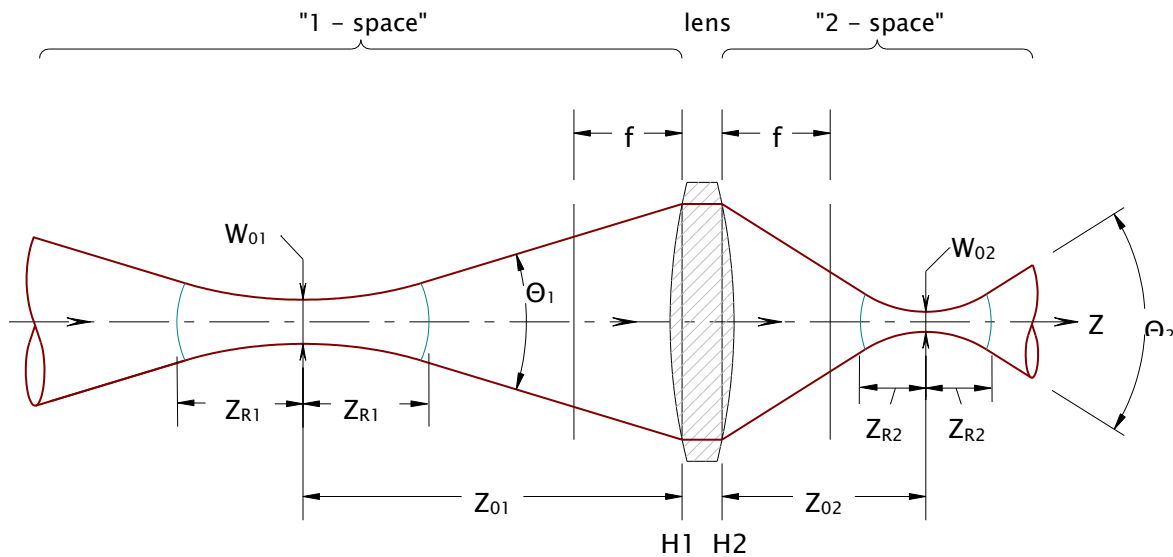
The laser may damage the CCD imager of the camera (\$\$\$\$), which is especially vulnerable when at the focus.

Warning: As a general rule, the input laser power to the M²-200s should never exceed a few tenths of milliwatts of total power.

Since the ND filters may expose the camera to full input power when they are rotating into position, the above warning applies at the filter as much as at the lens.

2.4 M²-200s Theory of Operation

The M²-200s system measures beam parameters by employing a beam focusing and detector translation system that complies with the requirements described in the ISO procedure. This method employs an aberration free lens. (Figure 3 is repeated below for convenience.)



The laser beam is directed through the lens to focus the beam to an “artificial” waist. The propagation of the laser beam through a focus has a direct relationship to how the real unfocused beam propagates in space. The propagation of the beam after a focusing lens is described by the same equation as in Equation 1 above, except that we now use a “2” subscript to denote a lens origin, and the distance z is now measured from the lens.

Equation 4 – Hyperbolic Propagation

$$W_{02}(z)^2 = W_{02}^2 + \Theta_2^2 \cdot (z - Z_{02})^2$$

- where:
- W_{02} = beam width at the artificial waist (the minimum focused spot size)
 - Z_{02} = the artificial waist location (measured from the lens)
 - Θ_2 = the artificial far-field divergence angle

Of interest is the fact that while the three parameters that describe the laser beam before the lens are different from the parameters that describe the beam after the lens, the M² value remains the same. Thus the M² value of the beam will remain constant as

the beam propagates through various optical devices, so long as those devices introduce no aberrations. This relationship allows the M²-200s to analyze the laser beam in the region after the focusing lens and then convert the results of these measurements back to the real beam's propagation parameters.

The method used by the M²-200s to determine the size and location of the “artificial” waist involves taking a series of beam width measurements on both sides of and passing through the artificial waist region. A curve fit will be applied to the measured data based on the hyperbolic propagation equation (Equation 4). The results of this fit yield the artificial waist width (W_{02}), the artificial waist location (Z_{02}), and the artificial divergence angle (Θ_2). The solutions from the fit are then translated back to the real laser beam.

2.5 Operation Limitations

Due to known limitations in the measurement technique employed by the M²-200s, as well as limitations to this ISO case of the propagation theory, usable results can only be obtained from beams originating from stable resonators or unstable resonators without hard-edged apertures. Of the three basic types of aberrations that effect laser beams (mode content, aperture induced diffraction, and optical defects), only mode content is suitable to the current M² measurement methods. The latter two types of defects, depending on severity, may yield varying degrees of anomalous results using the present methods.

The M²-200s computes separate M² results for both the X and Y axes; therefore, the laser under analysis must exhibit either radial symmetry or bi-fold symmetry about these axes. If the laser is radially symmetric, the computed results will be nearly identical for each axis. If the laser is non-radially symmetric, the computed results will describe the separate behavior along each axis. (The M²-200s is equipped with a camera rotation device that conveniently allows camera alignment to the axes of the laser beam.)

Beams that contain simple on-axis astigmatism are covered. However, the M²-200s algorithms do not cover generally astigmatic (or twisted) beams.

If the laser is unstable in mode or wavelength during the measurement period, results will be highly suspect.

2.6 M²-200s Electro-Mechanical Operation

Internal to the M²-200s optical train is a pair of moving mirrors. These mirrors effectively translate a stationary camera along the focused beam's optical path. See Figure 9 below.

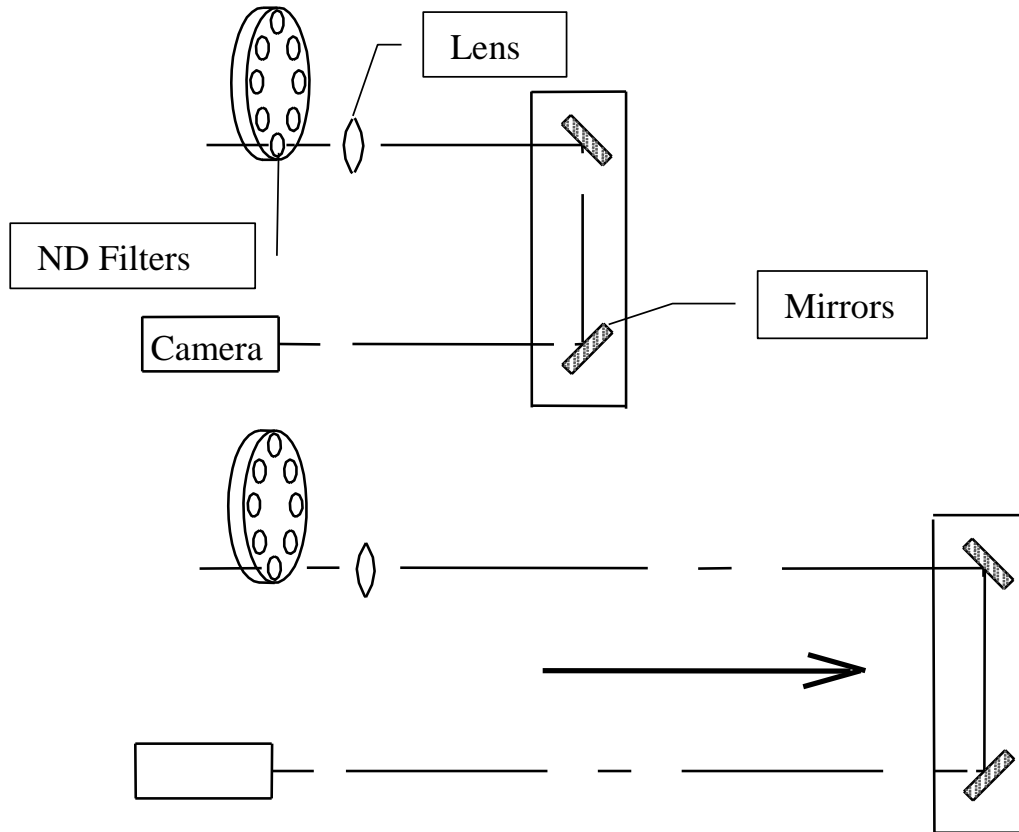


Figure 9. Optical Train Diagram

As the mirrors move, the camera and M²-200s will detect, measure, and display the changing laser beam profile. During the collection process, the M²-200s will automatically adjust for changes in the apparent brightness of the image by commanding the optical train to add or remove ND filters. Whenever the background energy of the camera drifts, the system will automatically perform a camera re-calibration cycle.

After the collection process is completed, the M²-200s calculates and displays the propagation parameters for the input laser beam, the propagation factor, an astigmatism ratio, and an asymmetry ratio. It will also plot graphs of the sampled X and Y beam widths versus distance from the lens and draw the hyperbolic curve fits. The operator can select to display the results for the fitted beam formed by the focusing optic.

If the data plot contains anomalous, or otherwise suspect data points (referred to as "outliers"), the operator can selectively remove these data points from the analysis.

2.7 Computations

This section describes the basic calculations used to compute the M^2 results. No attempt is made to disclose every possible feature of the algorithms employed, but rather to convey the techniques used that will allow the reader to verify conformity to the ISO procedure. All numerical calibration values are also discussed in this section.

The M^2 -200s allows the operators two ways to setup and sample the data points. These options enable a skilled operator to greatly decrease the time it takes to complete M^2 runs. These features will be discussed in more detail at the end of this chapter. The computational methods described here apply equally to all of these options.

2.7.1 Data Collection

During the data acquisition phase, the M^2 -200s will collect a set of data points of the focused laser beam. The number of collected data points depends upon how the operator configures the system. The operator can program the Z_2 axis sample points along the Z axis in a number of different ways. The software will refuse to take data when the beam is either too large or misaligned to be accurately measured. (An override of this feature is provided but using it is discouraged.)

In Auto mode, the software algorithms will attempt to take data at smaller step sizes near the waist, and larger step sizes in the far field. One sample will be taken at the focal length of the lens, so long as that location is accessible. The number of samples collected will affect the time it takes to perform a run.

Note: We suggest a 30-40mm sample step size on the M^2 -200s.

To comply with the ISO² standards recommendation:

"... measurements at least 10 different z positions shall be taken. Approximately half of the measurements shall be distributed within one Rayleigh length on either side of the beam waist, and approximately half of them shall be distributed beyond two Rayleigh lengths from the beam waist."

From experimentation, we have found that at least 5 samples should be collected in the Near-field (within the Rayleigh lengths), and at least three should be collected in each of the two Far-field regions (beyond ± 2 Rayleigh lengths). Another good combination is 6 in the Near-field, and 2 in each Far-field region.

In most cases, the M^2 -200s can be properly aligned with a supplied standard focusing lens. If needed, special longer or shorter focal length lenses can be ordered. Achieving a proper setup that places the waist location within the instrument is important. Obtaining a waist between 300 to 400mm from the lens is near optimum. Chapter 4 will describe this in more detail, and is essential reading.

² Reference ISO 11146-1:2005(E)

2.7.2 Curve Fitting

The collected data samples are then curve fitted to the beam propagation equation (Equation 4, repeated below) using a non-linear least squares fit to the hyperbolic beam propagation equation.

$$W_{02}(z)^2 = W_{02}^2 + \Theta_2^2 \cdot (z - Z_{02})^2$$

The results of the fitting procedure yield values for W_{02} , Θ_2 and Z_{02} in both X and Y axial directions.

2.7.3 M^2 , K, and BPP Factors

The M^2 or K factor is computed from the values obtained from the curve fit as:

Equation 5 – M^2 and K Factors

$$M^2 = \frac{1}{K} = \frac{W_{02} \cdot \Theta_2 \cdot \pi \cdot n}{4 \cdot \lambda}$$

where: λ = the laser wavelength in vacuum
 n = the index of refraction of the medium (~ 1)

The new BPP factor “Beam Parameter Product” is the latest variation that has found favor within certain elements of the laser analysis community. Equation 6 shows how BPP is computed from the M^2 results.

Equation 6 – BPP Factor

$$BPP = \frac{M^2 \cdot \lambda}{\pi}$$

2.7.4 Translation Equations

The real laser beam’s parameters are computed from the following three equations:

- **Full Divergence Angle**

Equation 7 – Full Divergence Angle

$$\Theta_1 = \frac{W_{f2}}{f_\lambda}$$

where: W_{f2} = the beam width at the focal length
 f_λ = the focal length of the lens at the laser wavelength λ

- **Waist Width**

Equation 8 – Waist Width

$$W_{01} = \frac{4 \cdot \lambda \cdot M^2}{\pi \cdot \Theta_1}$$

- **Waist Location**

The Waist Location (Z_{01}) is normally referenced to the front principal plane of the input lens. However, this location is not represented by any accessible physical structure. In some cases the waist location needs to be known relative to the laser face plate. For this reason we have included two (2) different ways to display the input beam waist location.

The first method applies when the Z_{laser} value is set to zero, where the Waist Location results will be computed per ISO, or from the first principal plane, see H1 in Figure 3.

The alternate method applies when the Z_{laser} value is non-zero. In this case, the entered value should represent the beam path distance to the laser face plate. The displayed Waist Location result will now be relative to the laser face plate.

For convenience, all results will be positive when the waist is in front of the lens or in front of the laser and negative when not accessible, either after the lens or behind the laser faceplate. In this computation, no adjustment is made to correct for the small difference between the H1 and H2 principal planes.

Note: The faceplate of the M²-200s is not the front surface of the ND filter holder assembly but is the end plate to which the camera and lens is attached.

- Waist Location relative to the lens principal plane (Laser Location $Z_{laser} = 0$)

Equation 9 – Waist Location when $Z_{laser} = 0$

$$Z_{01} = \frac{f^2 \cdot (Z_{02} - f)}{Z_{R2}^2 + (Z_{02} - f)^2} + f$$

Using the above convention, a positive result means that the waist is located in front of the optical train faceplate; a negative result means that it is behind the faceplate, i.e. not accessible.

- Waist Location relative to the Laser front faceplate (when Laser Location $Z_{laser} =$ the beam path distance between the faceplate and the exit port of the laser):

Equation 10 – Waist Location when $Z_{laser} > 0$

$$Z_{01} = Z_{laser} - \left(\frac{f^2 \cdot (Z_{02} - f)}{Z_{R2}^2 + (Z_{02} - f)^2} + f \right) - Z_{lens}$$

Using the above convention, a positive result means that the waist is located in front of the Laser faceplate, a negative result means that it is behind the faceplate, i.e. not accessible.

2.7.5 Rayleigh Range

The Rayleigh Range is the distance from the waist where a beam of a circular diameter will increase to twice the area at the waist, or where its diameter will increase by the $\sqrt{2}$. This is also the distance where the wave front radius of curvature reaches its minimum value. This later definition is most appropriate considering non-circular beams and in the presence of astigmatism. For an asymmetrical beam the Rayleigh range value is computed for each axial beam orientation. However, practically speaking, the Rayleigh range value is used to describe a region where a laser is generally regarded as being collimated. So the two separate results do convey the region where the beam is likely to be found collimated, especially where they coincide.

The Rayleigh range distance, Z_R , for both the artificial and real laser are computed, respectively, by:

Equation 11 – Rayleigh Range - Artificial

$$Z_{R2} = W_{02} / \Theta_2$$

Equation 12 – Rayleigh Range - Real

$$Z_{R1} = W_{01} / \Theta_1$$

2.7.6 Astigmatism and Asymmetry

The Astigmatism and Asymmetry values (along with the Rayleigh range) are not covered by the ISO procedure, but are provided as ancillary values that may be of use, depending on your laser and individual concerns.

The Astigmatism result is an attempt to provide a figure of merit that indicates the presence and severity of on axis astigmatism. The equation that defines this value is of our own making, and may or may not agree with other conventions in use. The results from this equation relate the following information:

- Results near 0 indicate a lack of significant astigmatism.
- Results from 0 to 1 indicate lasers with increasing degrees of astigmatism, but the two waist locations are each contained within each other's Rayleigh range.
- Results from 1 to 2 indicate lasers with increasing degrees of astigmatism; however, the waist locations no longer fall within each other's Rayleigh range, but the two Rayleigh ranges still have regions of overlap.
- Results greater than 2 indicate a laser with significantly large amounts of astigmatism, such that their Rayleigh ranges no longer have any region of overlap.

Equation 13 – Astigmatism

$$Ast = \frac{|Z_{01X} - Z_{01Y}|}{(Z_{R1X} + Z_{R1Y})/2}$$

The Asymmetry results provide an indication of how circular the laser beam might be. This value compares the two waist widths only, and therefore only has

significance if the laser contains little or no Astigmatism. Asymmetry values will approach 1, indicating that the laser appears circular in the waist region. Values greater than 1 indicate greater amounts of ellipticity, or asymmetric behavior.

Equation 14 – Asymmetry

$$Asy = the_greater_of \left\{ \frac{W_{01X}}{W_{01Y}} \right\} or \left\{ \frac{W_{01Y}}{W_{01X}} \right\}$$

2.7.7 Focal Length Calculation

The Focal Length item in the M² setup dialog box requires the value of the lens focal length. The focal length value (see Appendix A) is the focal length of the lens in use at the current wavelength. The calibration wavelength may vary with lens design.

At different wavelengths a lens will have a different focal length. It is the operator's responsibility to enter the correct lens focal length, at the wavelength of the laser being measured. Curves are provided for the standard and optional lenses supplied with the M²-200s.

Note: For all practical purposes the Visible and NIR Achromat lenses supplied with the M²-200s do not significantly change focal length over their operating wavelength range. However the UV lens does change significantly.

Use Equation 15 to compute the focal length of the lens at a new wavelength based on the design calibration wavelength. (Note: This equation is not valid for Achromat lenses.)

Equation 15 – Focal Length at a new λ

$$f_{\lambda} = \frac{f_{cal}(n_{cal} - 1)}{(n_{\lambda} - 1)}$$

where: f_{cal} = the calibration focal length of the lens
 n_{cal} = the index of refraction of BK-7 or UVFS at the cal λ
 n_{λ} = the index of refraction at the new wavelength

If you choose to use one of your own lenses, then you must enter its focal length based on the known calibration of your lens. Adjust the above equation with your lens' calibration data.

Note: If your lens is not made of BK-7 material, be sure to look up the index of refraction for the material in use. A table of BK-7 and UVFS index of refraction at a number of wavelengths is also supplied in Appendix A.

2.7.8 Path Length Calibration Values

Three path length values are needed to calibrate each M²-200s application to the optical train being used. These three path lengths must be entered into the appropriate M² dialog boxes.

Note: Each M²-200s system is supplied with a write-protected configuration file that already has these values stored in the appropriate places. If your M² unit has been specially calibrated for different wavelengths, then additional configuration files have been supplied for each setup.

The 3 path length values and their definitions are:

- Z_{fixture} = the *minimum* internal beam path length for the M²-200s.
- Z_{lens} = the distance from the lens to the optical train faceplate
- Z_{cam} = the distance from the camera sensor to the optical train face plate

The sum of these three values equals the maximum distance that the camera can be positioned behind the lens.

Note: In Manual mode, none of these Z path length entries have any meaning. They only apply to automatic operations.

▪ Z Fixture

The Z_{fixture} value is determined at the factory and will never change unless the unit is damaged and repairs are performed at the factory. This value is always associated with a particular M²-200s optical train serial number. If you have multiple M²-200s units, make sure that the value entered matches the unit in use. The serial number label affixed to the M²-200s contains the Z_{fixture} path length value that is unique to each M²-200s optical train system.

▪ Z Lens

The Z_{lens} values for the standard supplied lenses are contained in Appendix A. The Z_{lens} distance may change if a variety of different lenses are in use.

Figure 10 shows how this distance is determined for the M²-200s. Most lens makers will supply a *Focal Length* and a *Back Focal Length* value with each lens. Each lens supplied by Ophir-Spiricon will typically be mounted within a lens holder. These lens holders place the back surface of the lens approximately 5.08mm from their male thread end-mounting plane.

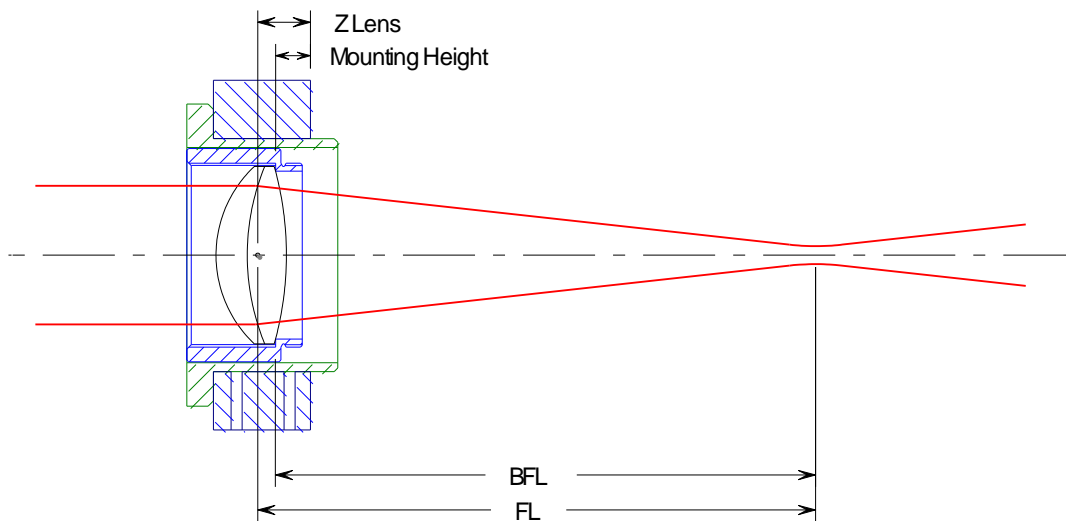


Figure 10. Determine Z Lens Distance for the M²-200s

Thus, to compute Z_{lens} for the M²-200s solve Equation 16:

Equation 16 – Z Lens Distance M²-200s

$$Z_{\text{lens}} = \text{FL} - \text{BLF} + 5.08$$

where: FL = the lens focal length
BFL = the lens back focal length
Mounting Height = 5.08mm

▪ **Z Camera**

The Z_{cam} distance can vary depending upon the physical characteristics of the camera. The M²-200s is supplied with a C-mount adapter that will match most CCD style cameras. The distance from the faceplate to the C-mount adapter-mounting plane is 15.24mm. See Figure 11. The "standard" C-mount lens-mounting plane to CCD imager distance is 17.53mm.

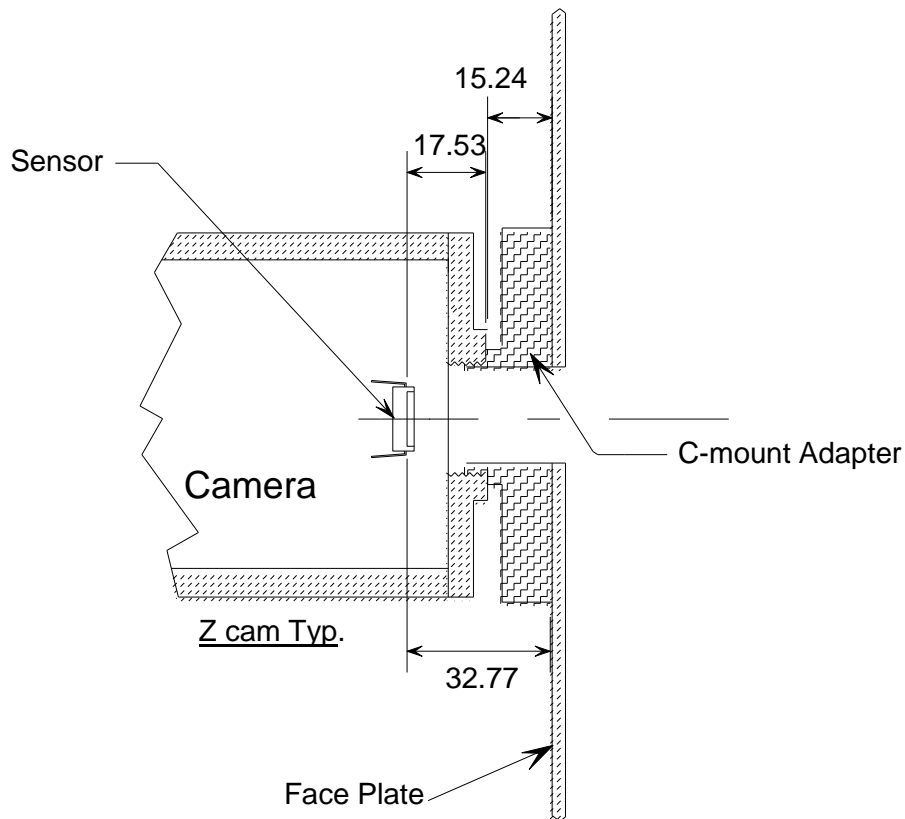


Figure 11. C-Mount Adapter Z_{cam} std values in mm

Thus, for a camera with a standard C-mount configuration, the Z_{cam} distance would be the sum of these two values: 32.77mm.

Note: If the end user provides the camera, we will place the standard 32.77mm value into the supplied default configuration. It will be left up to the end user to correct the Z_{cam} entry based on how their final camera mounting is realized.

2.8 Operating Modes

The software release that accompanied the introduction of the M²-200s has two new operating modes. Both of these modes are a variation on the original Auto mode and are provided to give the user better control over the measurement process. The end result is that the cycle time for making an M² measurement can be significantly shortened.

2.8.1 Manual Step Table

The legacy **Automated Stepping** mode allowed the user to make a minimum number of input settings and obtain a reasonably fast set of M² results. However the cycle time could be quite long even when the user was careful to optimize the starting values, step size, and end point. Often we would see clients making M² runs with 20 to 50 sample points. Much more than the 10 required by ISO. Such runs can take 5 to 15 minutes to complete and the end results are no better than runs that contained 10 to 15 well-chosen samples.

The M² software has a **Manual Step Table** mode (See Figure 12) that allows the user to specify from 5 to 20 preset sample locations along the optical path. In addition, the operator can preset the ND filter values at each data point. This mode includes 2 auto load features that permits you to grab the step points and ND values from a previous M² run, or preload the step values based on the Automated Stepping values. Thus reducing the amount of time spent working out an optimum setup. Recall that only 10 or 11 well-chosen sample points are needed to meet the ISO requirements. Limiting the steps and pre-selecting the ND values can achieve M² runs in less than 2 minutes with the M²-200s.



Figure 12. New Auto Stepping Modes

2.8.2 Four-Cuts Method

The second mode invokes a novel but non-ISO method. This method requires special setup conditions but in return can perform M² runs faster than either of the two previous auto modes. The basis for this approach was introduced by Thomas Johnston in a publication of the journal APPLIED OPTICS / Vol.37, No.21 / 20 July 1998. The title of Johnston's paper is Beam propagation (M²) measurement made as easy as it gets: the four-cuts method. In brief this method teaches that if one makes four well-chosen samples of the caustic it is possible to achieve an accurate set of results in much less time than the standard ISO method. We have tested this method extensively and find that under most conditions the results do indeed correlate well with the ISO method.

We have also modified the method such that it actually takes 6 cuts. But we have retained the nomenclature of four-cuts in order to preserve the linkage to Mr. Johnston and his original thesis.

The expansion to 6 cuts is done to allow for the different X and Y axial results and to incorporate the direct divergence measurement at the lens focal length. Mr. Johnston persuades that the best place for taking the first 3 samples (cuts) is between .5 and 2 Rayleigh lengths from the waist. Experimentation has shown that making these measurements in the far-field region works just as well if not better.

The only instance where the four-cuts method has been observed to fail is when the beam is highly astigmatic. In this case, the X and Y waist locations are far apart and it is difficult to find the 3 starting cut points that satisfy the initial conditions.

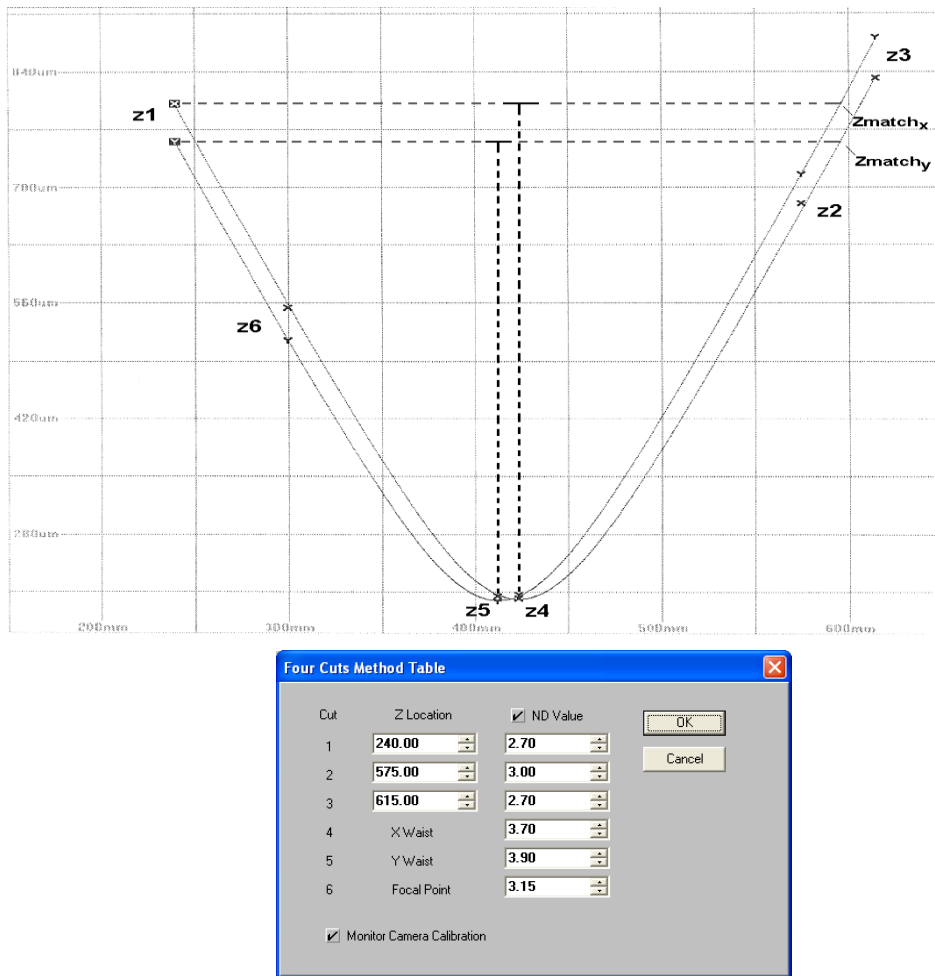


Figure 13. The four-cuts Setup

Figure 13 shows the basic layout of the four-cuts method applied to a plot of beam waists in both the X and Y axes. The operator must preprogram the first three Z cut points such that the beam widths measured at point z1, before the waist, lies between the widths measured at points z2 and z3, beyond the waist. It is also desirable that points z2 and z3 be selected reasonably close together

and lie beyond the Rayleigh range. These conditions must apply to both the X and Y beam width plots, thus the reason why only low astigmatic beams will work well with this method.

The Z locations for the chosen first 3 cuts are then entered into the **Four-Cuts Method Table** dialog box. The first 3 cuts are used to predict the location of the X and Y waist locations, cuts z4 and z5. Measurements are performed at those locations and a final sample is taken at z6, the lens focal length. As in the previous modes, a least squares hyperbolic fit to the data is performed and the final M^2 results computed.

If you preprogram the ND filter settings as well as the Z locations, the cycle times will be even faster.

2.8.3 M^2 Results < 1

It has been suggested that if the M^2 results are computed to be < 1 we should display a 1 as the answer. However the algorithms in the M^2 -200s software make computations and report results as the input settings and the beam samples dictate. This is done to provide useful information to the operator rather than to try and conceal something.

There are two common occurrences when M^2 results are less than 1. The first and most common of these has to do with the operator entering the wrong wavelength value. In this case the results are often well below 1, in the .8-.9 range.

The second most common cause for results <1 is due to nominal accuracy tolerances. These are normal and expected. With a 5% M^2 tolerance results from ~.95 to ~1.05 are very possible. Averaging runs will normally return a mean value to something > than 1, but not always.

Chapter 3. Operating Controls and Displays



3.1 Operating Modes


The M² software has five (5) operating modes plus a non-measurement Alignment mode. Alignment mode assists the operator with the alignment of your laser with the optical train. In this mode, the camera collects data frames and displays them in real-time. To enter alignment mode, click the **LIVE** video tool bar button. See section 4.6.3 or 4.7.2 for step-by-step instructions on how to align the laser with the optical system.

The five operating modes:

- 1) There are 3 **Auto** modes.
 - a) **Automated Stepping** mode, which uses the Ophir-Spiricon M²-200s optical train and automatic algorithms to simplify the setup. This can result in long cycle times when the step size and initial starting conditions are poorly done.
 - b) **Manual Stepping Table** mode, a subset of the auto mode that allows for short cycle times but requires a more precise setup by the operator.
 - c) The **Four-Cuts Method**, even faster cycle times but results are not ISO compliant.
- 2) **Manual** mode. This mode is primarily for users who purchase the Manual version of M²-200s and need to build their own optical system. In manual mode, the user must manually translate the camera behind the lens and apply whatever attenuation is required as the data collection process takes place.
- 3) **Real-time M²** mode supplements both the Auto and Manual modes. This mode can only be activated after the successful completion of one of the first 4 modes. In this mode, the camera is placed at the lens focal length and the M² results will update in real time as you tune the laser. After laser adjustments are complete, perform another analysis using one of the Auto or Manual modes. The Real-time M² mode is not as accurate as the standard Auto or Manual techniques, but does provide a fast response while making small laser adjustments. This mode is not ISO compliant.

Set **Auto** and **Manual** modes within the M² dialog box.

Activate the **Real-time M²** and the **LIVE** video modes from the tool bar. Toggle the  button to start and stop live video operation. Toggle the  button to start and stop the real-time operation.

Note: *The following descriptions will assume operations in **Auto** mode. Instructions that are of special interest to operating in **Manual** mode will begin with a  symbol.*

3.1.1 M² Menu Selections

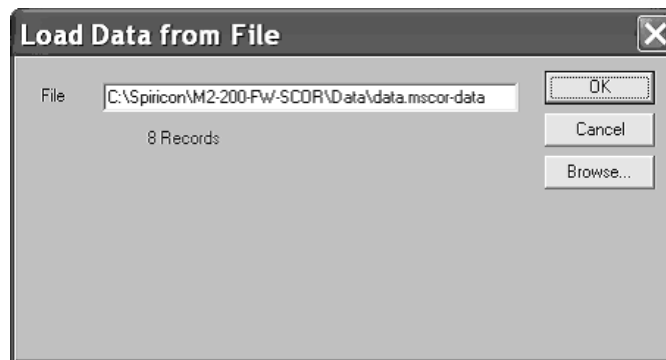
The M²-200s application provides five (5) menus for the control and setup of most M² operations. The following list describes each menu selection item and its related menu entries. This list will also act as a quick reference index to each dialog box section. Items in each dialog box will be found as a sub-topic within each dialog box section. Control features found exclusively on the tool bar are covered in section 3.15.

Note: It is assumed that the reader is already familiar with basic Microsoft Windows techniques and terminology. This user guide will not provide instruction on these topics.

File

3.2 Load...

Load or restore a previously saved data set into the frame buffer and display the M² results. The number of Records indicates the number of frames in the data set. You can scroll through the buffer to view individual frames. Data points may be manually excluded from the M² results (see section 3.15.6).



Whenever a data set is loaded, the current data in the frame buffer will be lost. After loading, the M² results that were displayed at the time when the data file was saved will be reproduced exactly the same (not recalculated).

However, if you make any change to certain settings after the file is loaded, new results will be computed based on the new set of conditions. For example, if you change the wavelength or the lens focal length, or turn on outlier removal, the results will be recalculated upon closing the dialogue box where the change was performed.

Important: It is advisable to save the current configuration (see section 3.5) for future use prior to loading a saved data set. When a saved data set is loaded, some items in the Camera and M² dialog boxes will be changed to the state that they were in when the data set was originally created.

3.2.1 Settings Error Correction

If the restored data contains a settings error among those listed below, make appropriate adjustments and generate corrected results.

- Laser Model
- Serial Number
- Comment Line
- Wavelength
- Laser Location
- Beam Width Method

After the new results are displayed, perform a **Save as...** operation to store or overwrite the old data set.

Important: *If the restored data set was generated using **Results Averaging**, the Plot and M² results will display the correct final values. However, the restored data frames will only contain the last one used in computing the final value. Furthermore, if you modify a setting value, new results will be computed solely on the basis of this last acquired data frame. It is therefore not a good idea to make any setting changes to files created with Results Averaging.*

3.2.2 Loading Data Sets via Windows Explorer

Saved data sets may be loaded via the Windows Drag and Drop convention, or by simply double-clicking the data set file (which will also launch the M²-200s application).

These conventions will work on all data set formats. However, the current camera configuration must match the camera configuration of the data file being loaded.

3.3 Save As...

Once a set of data for M² analysis has accumulated, you can save it to a file for future reference. All of the data frames that were acquired will be saved, including frames that were excluded from the results computations. These data files can be quite large, so make sure the target disk contains sufficient capacity for the number of frames acquired.

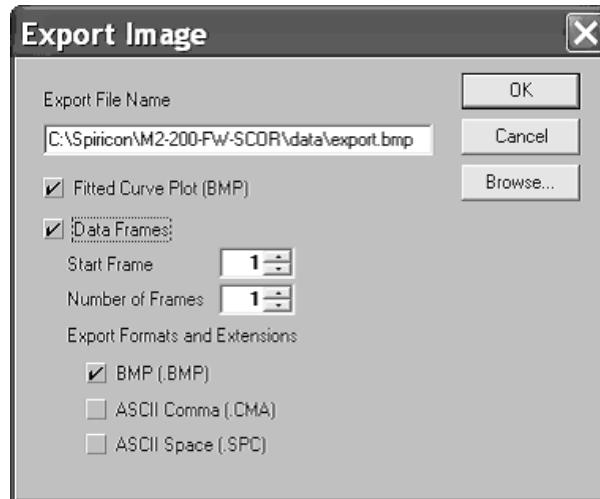
Note: *For data collected with **Results Averaging** active, only the data from the last frame collected in each data point is held in the frame buffer and will be saved. Thus, data sets collected with **Results Averaging** cannot be restored and manipulated as described in section 3.2.*

The M²-200s application generates a native data file format using the following file extension: **.m2-scor-data**

Note: *M²-200s data files are not compatible with LBA-300/400/500/7xxPC/FW data files and vice-versa.*

3.4 Export Image...

Select **Export Image...** to save two-dimensional beam display images and data frames to a file.



Select **Fitted Curve Plot (BMP)** to export the resulting M^2 plot and curve fit. M^2 plot images can only be exported as bitmap (.BMP) graphic files.

Note: *Exported bitmap image files cannot be read back into the M²-200s frame buffer. Utilize the **Save As...** and **Load...** features for retrievable data files.*

Select **Data Frames** to export a single or multiple images or data sets. To save a series, enter the Start Frame and the number of subsequent frames to export. Series can only be saved sequentially from the Start Frame location.

Select up to three of the following export formats:

- A Bitmap (.BMP) graphic file will export an image that appears just as the current beam display appears in the window.
- An ASCII comma delimited (.CMA) file provides input suitable for such common spreadsheet programs as Microsoft Excel.
- An ASCII space delimited (.SPC) file provides data presented in columns at 12 columns per entry, input suitable for such common math programs as Mathcad.

Consult your secondary application's documentation or help system to determine which format to use.

When exporting data frames, each image will be placed into a separate file. A six-digit number will append to the entered file name to differentiate each file in the sequence, incrementing from '000000'. Thus, a given multiple CMA file export creates a series of files that would appear as follows:

```
[filename]000000.cma  
[filename]000001.cma  
...  
[filename]NNNNNN.cma
```

3.5 Save Config...

Select **Save Config...** to preserve the current M² setup configuration to a file. Configuration files are saved with the “.m2-scor-cfg” file extension. Whichever configuration was the last to be saved (or restored) will become the default configuration the next time the M² application launches. The configuration file contains all M² menu selections and setup parameters.

Note: *The configuration file does not preserve (and thus will not restore) data sets. Data set files must be saved and loaded separately. See sections 3.2 and 3.3 above.*

3.6 Restore Config...

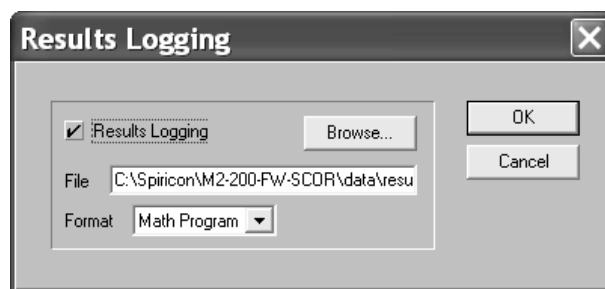
Select **Restore Config...** to load previously saved M² setup configurations files (“.m2-scor-cfg” files). Whichever configuration was the last to be saved (or restored) will become the default configuration the next time the M² application launches. The configuration file contains all M² menu selections and setup parameters.

Note: *The configuration file does not preserve (and thus will not restore) data sets. Data set files must be saved and loaded separately. See sections 3.2 and 3.3 above.*

Important: *Restoring a configuration does not force a read of a [camera type].cam camera type file. Rather, it restores the Camera dialog box settings, just as they were when the Config file was created.*

3.7 Logging...

To record numerical results to a log file, select **Logging....** Results log files are saved with an “.rlg” file extension.



Important: *Logging can only be performed in **Auto** and **Manual** modes. Logging will not function in **Real-time M²** mode.*

Log files may be exported in one of two ASCII comma delimited formats:

- Math Program – Suitable for such applications as Mathcad.
 - i) No column header row
 - ii) Date and Time format: mmddyy and hhmmssdd (no symbols)
- Spreadsheet – Suitable for such applications as Microsoft Excel.

- iii) Text column header
- iv) Date and Time format: mm/dd/yy and hh:mm:ss.dd

Both file types can be viewed in common text editor applications.

A results logging operation will create a single file for each M² run. If statistics are being computed then these results will appear at the end of the file. The data in a logged file without statistics appears as:

```
{frame #1 results}
{frame #2 results}
...
{frame #n results}
{M2 results}
```

With Statistics enabled the file appears as:

```
{frame #1 results}
{frame #2 results}
...
{frame #n results}
{M2 results}
{frame #1 results}
{frame #2 results}
...
{frame #n results}
{M2 results}
{frame #1 results}
{frame #2 results}
...
{frame #n results}
{M2 results}
{statistics}
```

3.7.1 Begin and Terminate Logging Operations

To begin a log file:

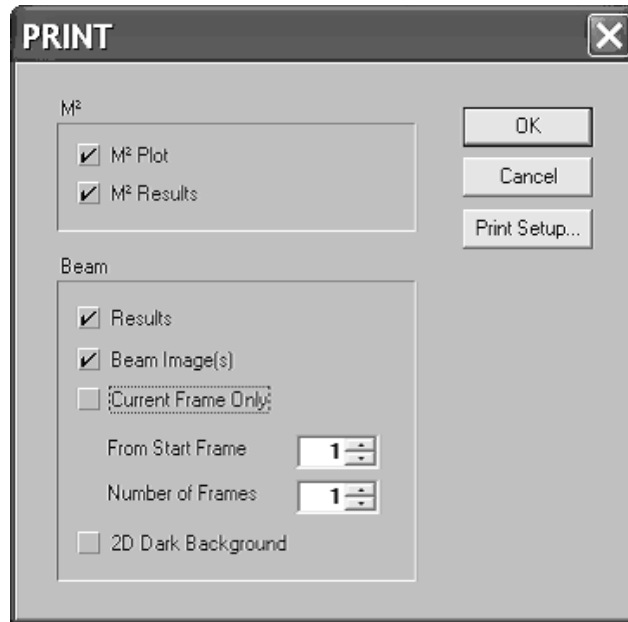
1. Open the **Results Logging** dialog box by selecting the **Logging...** menu item.
2. Select the **Results Logging** check box.
3. Provide a path and filename or browse to an existing folder.
4. Select a log file format.
5. Click **OK**.
6. Click **Start!** on the main menu to begin logging operations.


The log file terminates when the M² data collection process completes. To terminate a log file manually, click **Stop!** on the main menu.

Important: *If a log filename is reused, new logging results will replace the original log data.*

3.8 Print...

Open the Print dialog box to select the M² and Beam information that will be sent to the printer.



Note: Click on the  button located on the tool bar and printing will begin immediately. Output will be based on the last configuration set in the **Print** dialog box.

3.8.1 M² Plot

Check **M² Plot** to print the M² beam width plots and fitted curves.

3.8.2 M² Results

Check the **M² Results** box to print the M² results information. The printed results will consist only of the enabled M² numerical results, including Statistics if enabled. See section 3.13.5.

3.8.3 Beam Results

Check the **Results** box to print the basic numerical results for one or more data frames stored in the frame buffer. The printed results will consist only of the basic computations for the selected frame(s).

3.8.4 Beam Image(s)

Check the **Beam Image(s)** box to print one or more data frames stored in the frame buffer. The printed image will contain everything visible on the screen image, limited only by the resolution and color capabilities of your printer.

Note: If both **Beam Image(s)** and **Results** are checked, a single printed page will contain the image followed by the results.

3.8.5 Current Frame Only

To print only the currently displayed frame and/or its results, check the **Current Frame Only** box.

3.8.6 Multiple Frames

To print multiple frames, deselect **Current Frame Only**, then specify a **Start Frame** and the **Number of Frames** to print.

Note: *Keep the **Current Frame Only** box checked unless multiple frames are absolutely necessary.*

When printing multiple frames, observe that the M² will cycle through the designated frame locations. It will compute the required results for each frame and then print according to the settings above. At the end of this process, the last frame printed and its results will display on the screen.

3.9 Print Setup...

Open the **Page Setup** dialog box to select paper size and source, page orientation and margins. Click the **Printer...** button to select an output device and to access other settings pertaining to your printer.

3.10 Exit

Select **Exit** to close the M² application. This will end the current beam analysis session. Before exiting, consider:

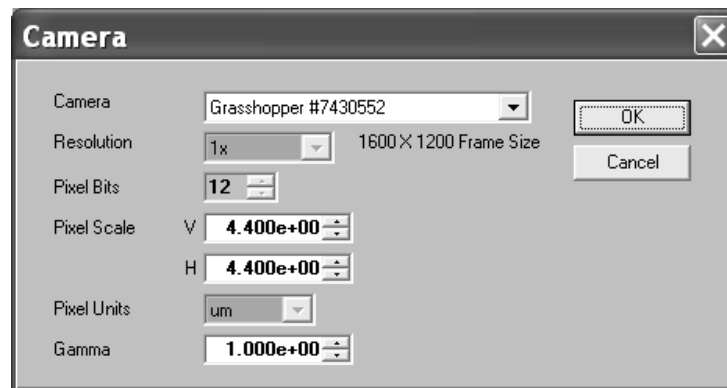
- Saving the current setup to a configuration file.
- Saving any open data sets.

Options

3.11 Camera...

Open the Camera dialog box to make the following selections:

- Select a Camera.
- Modify the Pixel Scale if needed.
- Apply Gamma correction if needed.



Note: *M²-200s supports both the 1394a SCOR20 (Scorpion) and the 1394b GRAS20 (Grasshopper) cameras, which employ the same 2 mega-pixel imager, and the SP300 which employs a 2.8 mega-pixel imager.*

3.11.1 Camera Selection

All cameras currently connected to the computer, regardless of the interface card or port, will appear in the Camera drop-down list. If a camera is plugged in after the **Camera** dialog box is opened, close the Camera dialog box and reopen it to refresh the list.

Only one instance of the M² application can operate on a single PC platform. Cameras in the list may appear in 3 ways:

- Model ser# camera is available for use by this application
- (Model ser#) camera is not available for use because it is in use by another application
- [Model ser#] camera is not available because it is not licensed for this application

Ophir-Spiricon must license each camera used with the M² software. Contact Ophir-Spiricon's Service Department to purchase additional licenses.

To activate an available and licensed camera, perform the following:

- Click on the Camera drop down arrow.
- Select the camera from the list.
- If the desired camera does not appear:

- Verify that the camera is connected to the computer.
- Check that the camera has power. The green LED on the back of the camera should be lit.
- Try resetting the camera. Disconnect the cable, wait 10 seconds, and plug it in again. Close the Camera dialog box and reopen it to refresh the camera list.
- Contact Ophir-Spiricon's Service Department for assistance.

If the desired camera appears in parentheses and cannot be selected:

- The camera is currently active in another application such as LBA-FW running on the same computer. Cameras can only be selected by one application at a time. Either close the other application or select a different camera. To refresh the camera list, close the Camera dialog box and reopen it.
- Contact Ophir-Spiricon's Service Department for assistance.

If the desired camera appears in brackets and cannot be selected:

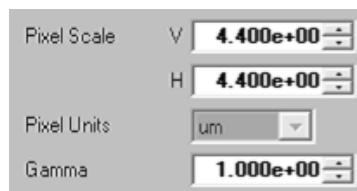
- The camera is not licensed for use with the M²-200s software. Contact Ophir-Spiricon to purchase a license for this camera.

3.11.2 Resolution

The **Resolution** setting indicates the resolution setting found in the selected camera configuration file. This setting is fixed to the camera pixel pitch and is always x1.

3.11.3 Pixel Scale, Pixel Units

Pixel Scale is derived from each camera detector's specifications. It is also user programmable to match the characteristics of a particular optical system.



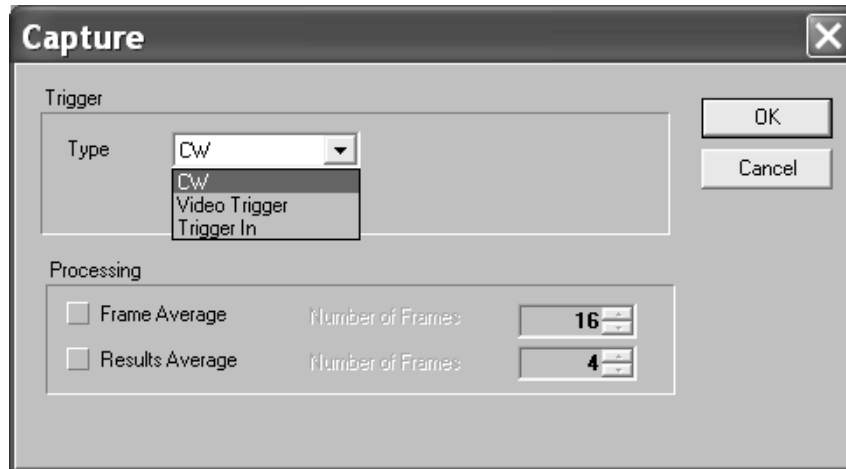
For camera imager-based scale setting, enter a **Pixel Scale** value equal to the minimum line pitch of the camera's detector. For the SP300 camera, this value should only be set to 3.69µm.

3.11.4 Gamma Correction

If the camera in use employs a solid state CCD or MOS style detector, then it responds linearly to monochromatic light. For linearly responding cameras, set the gamma 1.000e+00.

3.12 Capture...

The **Capture** dialog box determines how imaged data is to be acquired, processed and saved into the frame buffer.



3.12.1 Trigger

Adapt image acquisition to either CW or Pulsed lasers via the Trigger panel.

Type

Available Trigger Types:

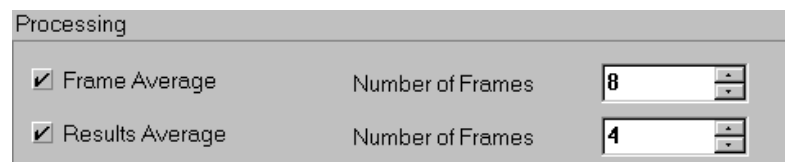
CW: Select this type if the laser under analysis operates in a continuous wave, or pulses at a repetition rate that will appear to the video camera as if continuous.

Video Trigger: Select this type to cause the M²-200s to continuously monitor camera input. When the system detects a laser pulse, the frame is captured.

Trigger In: Select this type to cause the M²-200s to synchronize capture with an external source. Triggers are active low and should only be connected to 3.3 V or 5 V digital logic signals. Higher voltages may damage the camera.

3.12.2 Processing

Choose between two optional processing modes in the **Processing** panel.



These optional settings determine how the final data frame that is stored in the frame buffer will be constructed and how it's computed results will be treated. Usually only one or the other is used at one time. The default setting for both is OFF.

Frame Average

Check **Frame Average** and specify the **Number of Frames** to average into each frame placed in the frame buffer. Frames are always averaged in the order they are received. Frame averaging will improve the signal to noise ratio by approximately the square root of the number of frames averaged.

Note: *If a laser beam has poor pointing stability, then the accuracy of the computed results of averaged frames may not be very reliable. Try using **Results Average** instead.*

Results Average

Check **Results Average** and specify the **Number of Frames** to compute the average of the results of a number of acquired data frames. Frame results are always averaged in the order that they are input. Results averaging will improve the signal to noise ratio by approximately the square root of the number of results averaged.

With results averaging enabled, only the last data frame acquired will actually be placed into the frame buffer. All prior frames are discarded.

3.13 M² Setup...

The **M² Setup** dialog box contains a large number of settings that must match the M²-200s optical train in use.

The screenshot shows the **M² Setup** dialog box with the following settings:

- Laser:**
 - Laser Model: 300mm vis filters
 - Serial Number: 632.8nm HeNe
 - Comment Line: 6/20
 - Wavelength, nm: 632.80
 - Focal Length, mm: 300.16
 - Laser Location, mm: 0.00
- Optical Table Stepping:**
 - Automated Stepping:
 - Z Start, mm: 200.00
 - Z Stop, mm: 598.74
 - Z Step, mm: 40.00
 - Manual Step Table: Edit Step Table...
 - 4 Cuts Method: Edit Four Cuts Table...
- Capture:**
 - M² Mode: Manual
 - Beam Color: Color Continuous
 - Camera Resolution: 1x
- Computations:**
 - Beam Width Method: 4 Sigma
 - Clip %: 9.000e+01, 1.000e+01
 - Multiplier: 1.561e+00
 - Number of RUNs: 25
 - After Lens Results:
 - K Display:
 - Fitted Divergence:
 - Auto Remove Outlier:
 - Disable Camera Imager Boundary Constraint:

Due to this complexity, Ophir-Spiricon supplies one or more special configuration files with each M²-200s system. These configuration files provide a set of baseline settings in the **M² Setup** dialog box.

Note: *These configuration files can be used as a starting point from which you can create your own configurations. These will more closely correspond to actual testing conditions.*

Configuration file names begin with the M²-200s optical train serial number, followed by focal length and wavelength values. The calibration values are only applicable to the specified lens and wavelength.

Configuration filename convention:

~[serial number-focal length-wavelength].cfg

Most systems include one or more standard focal length lenses calibrated at various wavelengths. Therefore, a typical file name would be:

~01234-500-632.cfg

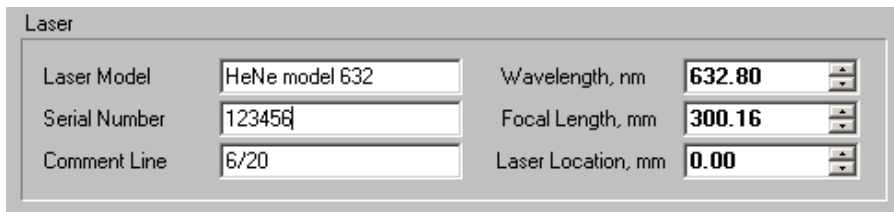
Note: *The ~ (tilde) in front of the file name indicates that the file is write-protected. Retain this file attribute in order to prevent accidental deletion or overwriting.*

At least one configuration file is included for each lens.

† If your system will operate in Manual mode, necessary configuration settings must be manually generated. For your convenience, a ~manual[camera type].cfg template file is included. This file does not contain any meaningful calibration data, but can be used as a starting point for creating a new configuration for your application. DO NOT use an unmodified ~manual[camera type].cfg configuration to perform actual measurements.

3.13.1 Laser Settings

The Laser panel contains both informational data and settings critical to beam propagation analysis.



Laser			
Laser Model	HeNe model 632	Wavelength, nm	632.80
Serial Number	123456	Focal Length, mm	300.16
Comment Line	6/20	Laser Location, mm	0.00

The **Wavelength** and **Focal Length** items must be correctly entered in order to obtain accurate numerical results.

Laser Model, Serial Number, and Comment Line

These three entries provide text labels applicable to the current test situation. The information supplied here will appear concatenated in the title bar of the M² plot window. It will also be saved with every data set file and be restored when the file is loaded. This information will appear on the top of every printed page.

Each line can contain a maximum of 25 alphanumeric characters or symbols.

These entries are optional and do not affect the outcome of the numerical results.

Wavelength

Enter the wavelength (in nanometers) for the laser under analysis.

Note: *The Focal Length value may change whenever the Wavelength value changes. Be sure to verify or update the Focal Length when changing the Wavelength entry.*

Focal Length

In millimeters, enter the Focal Length of the lens used to create the artificial beam waist. This lens (or lenses) is supplied as part of the M²-200s optical train. Calibration information on Ophir-Spiricon supplied lenses can be found in Appendix A. This lens information will also be provided within the special configuration files discussed above.

Refer to section 2.7.7 for a tutorial on how to compute a wavelength corrected for a focal length of a specific lens.

Note: *If the wavelength(s) at which the system will be operated are specified at the time of the order, Ophir-Spiricon will have provided additional configuration files for the specified wavelength(s). The same is true if optional or special lenses are ordered.*

File name convention:

~[serial_number-fl-wavelength].cfg

These configuration files can be used as a starting point from which you can create your own configurations. These will more closely correspond to actual testing conditions.

Laser Location

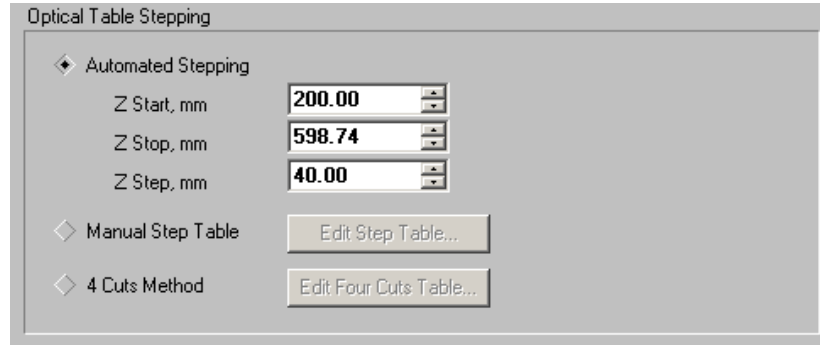
To locate the waist location relative to the M²-200s lens, enter a value of zero. In the M² Results window, a positive beam waist location places the waist in front of the M²-200s faceplate. A negative beam waist location places the waist behind the faceplate. The published waist location and Rayleigh length tolerances are based on this setting being set to zero and the laser waist located about 1 Rayleigh length from the lens.

In millimeters, enter the optical path distance from the laser faceplate to the M²-200s faceplate. This value determines the beam waist location relative to the laser faceplate. In the M² Results window, a positive beam waist location places the waist in front of the laser faceplate. A negative beam waist location places the waist behind the laser faceplate.

† In manual mode, enter a value of zero to locate the waist relative to the lens position. To locate the waist relative to the laser, enter the distance from the lens to the laser faceplate.

3.13.2 Optical Table Stepping

Select which of the three stepping modes to employ. Each choice requires a different set of entries that govern how the system will operate.



Automated Stepping

The range over which the beam samples will be acquired and a basic step distance between sample points must be entered in the Z value edit controls shown below.

The Z Start and Stop limits are bounded by the calibration values Z_{fixture} , Z_{lens} , and Z_{cam} in conjunction with the table's self-calibration cycle that occurs at program launch. All Z-axis dimensions are specified in millimeters.

HINT: You can right- mouse click on any of the numerical settings values to reveal the allowed range limits for any one entry.

Z Start

Enter the Z location that corresponds to the desired camera starting location at the beginning of an M² data collection run. All data runs must start somewhere between the focused beam waist and the lens. Ideally the first sample should be made at least 2 Rayleigh lengths before the focused waist.

Important: To keep the run time as short as possible, select a Z Start value that will produce a beam width that fits within the camera imager. If the start location overfills the camera then a number of wasted sample attempts may be performed before good data is recorded. This will increase measurement cycle time and resetting time between runs.

- † In manual mode, at the beginning of an M² run, you will be prompted to move the camera to the distance equal to the Z Start value. At your discretion, accept and use the suggested value, or enter a custom value.

Z Stop

Enter the Z location that corresponds to the furthest distance where a data sample will be permitted. If possible, this distance should be located in the far-field region 2 Rayleigh lengths from the waist. If, before reaching the Z Stop value, the beam expands to a size larger than the camera imager, data collection will terminate early.

- In manual mode, at the end of an M² run, you will be prompted to move the camera to the distance equal to the Z Stop value. At your discretion, accept and use the suggested value, or enter a custom value.

Z Step

Enter the base translation step size in millimeters. A good starting value is about 40mm, but the final value is best determined after a trial run. Due to the fact that the Automated Stepping mode will attempt to collect more data samples in the waist region, and fewer in the far field, the actual step size will vary from 1/2 to 2 times the entered value.

- In manual mode, during the M² run, you will be prompted to move the camera to a series of locations whose step distance approximately equals the Z-Step value. At your discretion, at each step accept and use the suggested value, or enter a custom value.

Manual Step Table

The Manual Step Table feature allows the operator to optimize the run to meet both ISO requirements and perform runs as quickly as possible. To use the manual step table you must do some additional work and setup each step location. You can also select which filter ND setting will go with each step position. After selecting this mode, click on the **Edit Step Table** bar. This will open the following dialog box:

The dialog box is titled "Z Location Step Table". It features a "Number of Steps" field set to 11. Below this is a table with 20 rows (Step 1 to 20). Each row has two columns: "Z Location" and "ND Value". The "ND Value" column has a checked checkbox next to the label. To the right of the table are buttons for "OK", "Cancel", "Fill from Numbers", and "Fill from Run". At the bottom left, there is a checked checkbox for "Monitor Camera Calibration".

Step	Z Location	ND Value
1	200.00	1.00
2	250.00	1.00
3	300.16	1.00
4	380.00	1.50
5	395.00	1.70
6	410.00	2.00
7	425.00	2.15
8	440.00	2.00
9	455.00	2.00
10	500.00	1.70
11	600.00	1.00
12	600.00	1.00
13	600.00	1.00
14	600.00	1.00
15	600.00	1.00
16	600.00	1.00
17	600.00	1.00
18	600.00	1.00
19	600.00	1.00
20	600.00	1.00

Number of Steps

Enter the number of steps you wish to include in the run. This will cause the same number of **Z Location** edit boxes to enable by turning white.

Fill from Number

Clicking on this bar will cause the **Z Location** edit controls to automatically be preset based on the parameters set in the **Automated Stepping** dialog boxes described in the previous section. This tool is unlikely to yield a really good set of step locations but can be used to create a set of initial starting values that you can manually edit into a more optimum form.

Fill from Run

Clicking on this bar will cause the **Z Location** and the **ND Value** edit controls to automatically be preset based on the results of the currently displayed M² run. While this tool is also unlikely to immediately produce an ideal set of Step and ND filter settings, it can provide a good set of starting values and then be revised and employed iteratively to achieve an optimized setup.

HINT: It is recommended that one of the Z Location values should coincide with the lens focal length setting. This will force the beam divergence to be computed directly rather than from the fitted value.

ND Value check box

Leave this checkbox unchecked until you have filled in the ND values with reasonably accurate estimates. Failure to do so will result in extremely long run times because the set filter values may be far from the correct one needed.

Monitor Camera Calibration check box

This control can be used to override the testing of the camera baseline calibration between steps. If your camera is warmed up and your environment is stable, you can significantly shorten the run time by leaving this box unchecked. When unchecked, the system will perform a baseline Ultracal operation at the start of the run and not recheck it during the run. If you suspect the camera baseline is unstable or your system is subject to fast ambient temperature changes, as during the warm-up period, enable this feature by checking ON this item.

3.13.3 Four-Cuts Method

The Four-cuts method is a non-ISO approach that under many circumstances yields very accurate results in the shortest time possible. After selecting this mode, click on the **Edit Four-Cuts Table** bar. This will open the following dialog box:

Cut	Z Location	ND Value
1	240.00	2.70
2	575.00	3.00
3	615.00	2.70
4	X Waist	3.70
5	Y Waist	3.90
6	Focal Point	3.15

ND Value

Monitor Camera Calibration

OK

Cancel

To use the four-cuts method the operator must enter the first 3 **Cut Z Locations**. The values must be correctly chosen in order to obtain meaningful results. Cuts 4, 5, and 6 are automatically computed.

If you correctly preset the ND values, the run time will be significantly shorter than if the system must find them automatically. See the previous section for more detailed description of the checkbox controls.

3.13.4 Capture

In the **Capture** panel, set the M² operating mode and beam display colors.

Capture

M² Mode: Auto

Beam Color: Color Continuous

Camera Resolution: 1x

M² Mode

If the Ophir-Spiricon M²-200s automated optical train is in use, set this value to Auto. Chapter 4 contains a discussion on how to operate the system in Auto mode.

- † If you are manually translating a camera on an optical rail system, set this value to Manual. Chapter 4 contains a discussion on how to operate the system in manual mode.

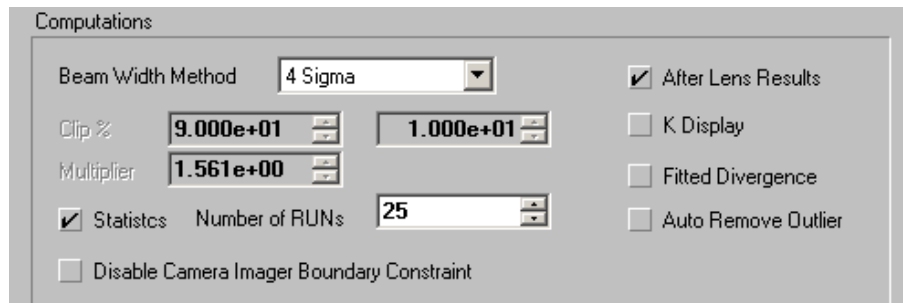
Beam Color

The 2 dimensional beam display can be rendered in Color Continuous (128 colors), Color Bands (16 colors), or Gray Scale (128 shades of gray).

Note: The beam image display will present cursors (in white) that track the image centroid, a rectangular boundary aperture (in white), and an elliptical auto-aperture (in yellow). These features are not controllable by the user.

3.13.5 Computations

In the **Computations** panel, select the computing method used to determine the laser beam's X and Y widths.



As discussed in section 2.3.2, the correct method for computing a beam width is to use the second moment definition, referred to as the $D_{4\sigma}$ (or Dee-4-Sigma) method. For beams with M^2 values approaching 1, the 90/10 Knife Edge method is also very accurate.

Beam Width Method

The **Beam Width Method** selection will determine the technique used to compute the beam width results. The first two methods (4 Sigma and 90/10 Knife Edge) are computed based on industry standard definitions. The remaining Knife Edge choice can be used under rare circumstances where the above two choices may not be optimum.

The **4 Sigma** method directly computes second moment beam widths in the X and Y beam axial directions. Of the two primary methods, 4 Sigma is most sensitive to noise. If the beam's noise content is high, consider activating Frame or Results Averaging (see section 3.12.2) or Statistics (see below) analysis to hone in on more accurate results. Laser mode content does not influence 4 Sigma computations, a significant advantage.

The **90/10 Knife Edge** method employs a fixed 90% and 10% of energy as the moving edge Clip points. The correction **Multiplier** is fixed at 1.561. These settings yield highly accurate second moment equivalent beam widths for beams that are predominantly TEM_{00} in mode content, and for many other mixed mode combinations. There are a few modes for which this method will not prove as accurate, such as Top Hat shaped beams. This method computes beam widths in the X and Y beam axial directions.

If laser mode content is not suitable for measurement using either of the previous methods, use the **Knife Edge** method and enter custom **Clip %** and **Multiplier** factors.

Suggestions:

For a circular Top Hat, enter a Multiplier of 1.455.

For a square Top Hat, enter a Multiplier of 1.444.

Note: *In general, the two Clip level settings should add up to 100%. Avoid clip levels <10%, as this setting begins to approach the camera's noise floor.*

Statistics

To add statistical results to M^2 measurements, check the **Statistics** box and enter the **Number of Runs** from which to compute the statistical information. Statistical results will contain the following items:

- Mean
- Standard Deviation
- Minimum
- Maximum

Statistics will only be computed for the M^2 results items, not for the individual beam samples.

Since statistical results are computed based on a number of M^2 data collection runs, only the last run will reside in the frame buffer. Therefore, at the conclusion of a statistical run, only the last data set will be saved. All prior data will be lost.

After Lens Results

Check this box to see the computed results for the artificial beam waist created after the focusing lens. Normally this information is superfluous; however, if the beam propagation results seem out of place, use this as a sanity check.

K Display

Check this box to set the quality factor in terms of **K**, the Beam-Propagation-Factor, rather than in terms of **M^2** . The BPP factor is always displayed and cannot be disabled.

Fitted Divergence

Check this box to calculate the divergence from the curve fit rather than the actual data point at the focal length. This may be useful in the event the focal length appears anomalous. If the focal length is not accessible, the software will automatically use the fitted divergence and an asterisk (*) will appear next to the divergence results to indicate that the results were from the fit and not from a direct measurement.

Auto Remove Outlier

The M²-200s includes an automatic outlier removal algorithm. Check this box to activate it.

Manual outlier removal or overriding automatic outlier selections is possible via the **Exclude** capability. See section 3.15.6 for a detailed explanation of how to deal with outlier data.

Disable Camera Imager Boundary Constraints

While performing M² runs the beam measurement algorithm will check to see if the beam is either too close to or running beyond the edge of the camera imager area. When this condition is detected, the data collection process will either skip the data point or terminate the run. Check this box to disable this feature. (Not recommended)

3.14 Advanced M² Setup

Caution: *In almost all cases, the user should never alter the settings found in this dialog box. These settings relate to mechanical and optical properties set at the factory. Special factory supplied configurations are provided that contain the settings for these items. See section 3.13 for information about the supplied configuration files.*

To access advanced M² setup items, click the **Advanced...** button in the **M² Setup** dialog box.

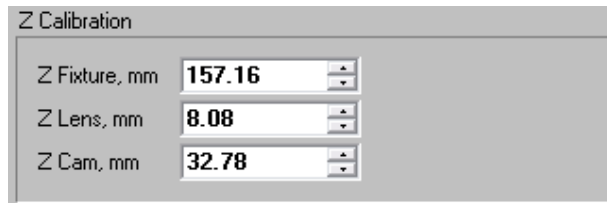
† None of the entries in the Advanced M² Setup apply when operating in Manual mode.

Important: *Making uninformed changes to any settings in the **Advanced M² Setup** dialog box will spoil the accuracy and operating performance of the M²-200s optical train.*

Warning: *DO NOT simply meddle in this area.*

3.14.1 Z Calibration

The sum of the Z Calibration entries defines the maximum possible Z distance from the lens to the camera imager.



Z Calibration	
Z Fixture, mm	157.16
Z Lens, mm	8.08
Z Cam, mm	32.78

All units are in millimeters. See section 2.7.8 for more information.

Z Fixture

This is the Z_{fixture} dimension of the optical train. See the affixed S/N label.

Z Lens

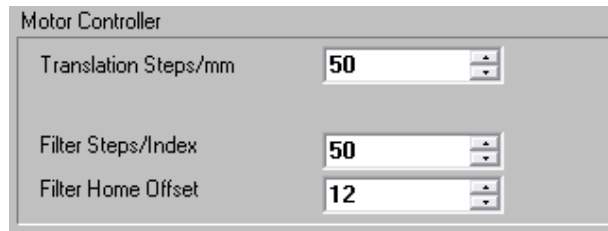
This is the distance from the lens to the M²-200s optical train's faceplate. See Appendix A.

Z Camera

This is the distance from the camera imager to the M²-200s optical train's faceplate.

3.14.2 Motor Controller

These are the stepping motor parameters for the translation mirrors and the ND filter wheel, as well as an offset position for the filter wheel Home position. These values are fixed for each individual M²-200s optical train. See Appendix A to locate the values for the supplied system. The only one of these values that you may ever have cause to modify is the **Filter Home Offset** value.



The image shows a software window titled "Motor Controller" with three input fields. The first field is "Translation Steps/mm" with a value of 50. The second field is "Filter Steps/Index" with a value of 50. The third field is "Filter Home Offset" with a value of 12. Each field has a small up/down arrow icon to its right.

Parameter	Value
Translation Steps/mm	50
Filter Steps/Index	50
Filter Home Offset	12

Translation Steps/mm

Preset to the number of stepper motor steps per millimeter of travel for the mirror translation system.

Filter, Steps/Index

Preset to the number of stepper motor steps between ND filter index positions.

Filter Home Offset

Preset to the number of offset steps required to center the selected ND filter in the laser beam entry port. If you observe the filters not accurately aligning with the entry port you may adjust this value + or – as required.

3.14.3 ND Filter Wheel

This list contains a catalog of the ND filter values as they are currently being used. The **Position** column provides the index location for each filter. Appendix A contains examples of filters vs. their applicable wavelengths. (Refer to the **Calibration Certificate** supplied with your optical train for the correct setup information for your system.) The M² software will compute and apply filters based on the values entered in this list.

Position	Wheel A	Wheel B
0	0.00	4.00
1	0.15	99.00
2	0.30	3.00
3	0.50	99.00
4	0.70	2.00
5	99.00	99.00
6	99.00	1.00
7	100.00	0.00
8	99.00	99.00
9	99.00	99.00

Note: While this list can accommodate up to 10 filters per filter wheel, the current optical tables only support 8 filter positions per wheel.

In a standard system, the ND values specified will be nominal values that will vary depending upon the wavelength in use. The low ND Inconel filters thru ND 1.0 will remain reasonably stable at all wavelengths. The higher ND values in the B wheel will be less stable at longer wavelengths. For this reason, two types of filters are supplied that cover the ND 2, 3, and 4 values. One set of 2-3-4 values are Inconel and operate from 266nm to about 800nm. The second set of 2-3-4 filters are bulk absorbing types and are calibrated at 1064nm, but will operate well from 800nm to 1500nm.

The nominal calibration wavelengths for the Inconel filters are based on a wavelength of 550nm. The user may also calibrate the filters more precisely if they feel the need to achieve better filter control than that found with the standard values.

The user may remove and install their own filters for any specific wavelength and enter the correct ND value into the above table as required. Additional filter wheels can be purchased and configured with the user's own filters, and the values programmed into the above table.

Note: An ND value of 99 indicates a filter position that is to be ignored. An ND value of 100 indicates a filter position that contains a shutter. Only one (1) shutter position should be set to the value 100 at any one time and it must be loaded into Wheel A. An ND value of zero (0) indicates an empty position in the wheel.

3.15 Toolbar Controls

Several convenient toolbar controls allow the user to:

- Set how the beam is displayed.
- Manually position the camera along the Z axis.
- Manually set the ND filters.
- Toggle Live Video mode.
- Toggle Real-time M² mode.
- Manually remove outlier data from the computed results.
- Print the M² results.

A detailed description of each toolbar control follows:

3.15.1 Beam View

Click this button to toggle the beam display between a 2D false color and 3D wire frame. When this button is up, the beam displays as a 2D false color with cursors and profiles. When this button is depressed, the beam displays as a 3D wire frame.

3.15.2 Z Axis Control



This edit box indicates the current Z axial location of the camera from the focusing lens in millimeters. It can also be used to change the Z axis position when in **Live Video** mode, see below.






Place the camera at a new Z axial location by entering a new position in the edit box and then pressing the **Enter** key.

Note: Click the right mouse button and hold inside the data entry field to view a range of acceptable values.

Five shuttle movement buttons are provided to translate the camera along the Z axis:

Click the  or the  button to move the camera one Z Step distance away from or closer to the lens. The Z Step value is programmed in the M² Setup dialog box. See section 3.13.2.

Click the  or the  button to start the camera moving to the minimum or maximum Z limits.

Click the  stop button to terminate the motion of the translation system.

† These motion controls are inactive when in **Manual** mode.

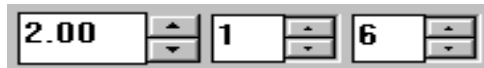
3.15.3 ND Filter Controls

Displays the current setting of the ND filter value and the current A/B wheel setting. It can also be used to change the ND or A/B values when in **Live Video** mode, see below.

The ND filters are arranged in two parallel wheels, labeled A and B. ND filter values are programmable by rotating these wheels setting combinations of these filters. Notice that for some ND values, there might be more than one permutation of the A and B filters. See Appendix A.

Note: Observe that the filter with an ND value of 100 is a shutter. ND values listed as 0.00 are open positions in the wheels.

There are three methods for setting the ND filters. Each control always displays the current setting of the ND filter wheels, but in different ways.



Direct Entry

The number displayed in the leftmost edit control area represents the current ND value obtained by adding together the ND numbers of the A and B wheels. Edit this setting directly by entering the desired ND value, followed by the **Enter** key. If the entered ND value is not available, it is automatically converted to the nearest possible A and B combination.

Incremental ND Adjustment

The leftmost ND value may also be incrementally adjusted in the smallest possible steps by clicking the up and down spin controls. However, this method will only select one permutation for each ND value. If another permutation is desired, use the Individual Wheel Adjustment method.

Individual Wheel Adjustment

Control the position of each ND wheel individually using the edit box/spin control for each wheel.

Note: The values presented in the individual wheel adjustment controls (the two smaller controls on the right side) represent filter positions, not ND filter values.

This method provides access to every possible ND filter combination. Primarily, this method allows the user to select and recalibrate each ND filter value more precisely than those found in the supplied configurations. This may prove useful when using a wavelength that forces the ND filters to deviate significantly from their normal calibration wavelengths.

Note: During the Auto data collection process, the M²-200s will first use the primary default value for each ND setting. If the default value fails to provide optimum attenuation, the application will apply a search algorithm through all the permutations that are near the target attenuation requirements. If this search is

not successful, the data point will be skipped, and an attempt will be made with the next sample.

† These ND controls are inactive while in **Manual** mode.

3.15.4 **Live Video Mode**


Click on the LIVE button to display a camera image in real time. This feature provides real-time laser alignment with the optical system and thus works in both Auto and Manual modes.

Data frames collected in LIVE video mode are not stored in the frame buffer and cannot be saved or loaded. However, basic numerical results computed for LIVE frames are acquired, but without baseline calibration. Thus, the computed beam widths are not accurate. Nevertheless, the Peak Energy level is useful in setting external attenuation such that the dynamic range of the camera is utilized.

Note: *Before an M² data run can be initiated, LIVE mode must be cancelled.*

3.15.5 **Real-time M² Mode**

This mode only becomes available after a successful M² data run has completed. The real-time M² feature provides the ability to make minor tuning adjustments to the laser, while obtaining an estimate of how the M² value is changing. This technique is not highly accurate and should not be used as a substitute for a normal M² data collection run.


Once the above prerequisite is met, click on the  button. The translation system will place the camera at the focal length of the lens, set the ND filter and perform a calibration of the camera. It will then compute, in real-time, the current divergence value and the estimated M² in both the X and Y axial directions. Observe that a separate real-time results list will appear in the numerical results child window. The prior M² results will be retained for comparison purposes.

Note: *If the tuning operation continues for a long period, the camera calibration may drift and cause errors in the real-time results. To overcome this condition, periodically cycle the real-time mode off and on to begin a new calibration and real-time operation.*

3.15.6 **Data Point Exclude**

Manually exclude data points with this button. Use it exclusively or in combination with the automatic exclusion feature. Also use it to override one or more of the automatic outlier selections.

Note: *The M²-200s includes an automatic outlier removal algorithm. Enable or disable this automatic feature in the M² Setup dialog box (see section 3.13.5). We recommend its use, as it will eliminate most (if not all) of the collected anomalous data points.*

To exclude or return a data point, highlight it first, and then click the  button. Each click of the button toggles the exclusion or inclusion of the data point. There are three ways to highlight a data point:

1. Click on the data point with the mouse.
2. Enter the frame number in the Frame edit control on the status bar.
3. Use the up down Frame spin controls to step to the frame required.

Note: *Data points that have been excluded from the computation will be drawn as square dots as opposed to X's and Y's.*

Each time a data point is excluded or added back into the data set, the M^2 results are recalculated. Data sets that are saved will include all the data frames, even the ones for which their data points are excluded from the computed results.

Outlier data points appear for a number of reasons. One of the most common occurs when a pulsed laser is triggered asynchronously to the video camera's scanning rate. Under this condition, strange images may result, unrelated to the actual beam shape. Sometimes these images are good enough to make it into the data plot.

3.15.7 Recalibrate the Optical Table

Clicking on this Table button will cause the optical table to recalibrate and the ND filters to reinitialize.

3.15.8 Print

Click on the **Print** button to send a set of results or beam images to your printer. This method will immediately start a printing operation based on how things are currently configured in the **Print...** dialog box. To change what is printed, use **File, Print....** See section 3.9 for additional printing options.

3.16 Windows

There are three child windows and one status bar that comprise the main screen displays. The three child windows are:

- M² Results window
- M² Plot window
- Beam Display window

3.16.1 M² Results Window

The M² Results window displays all the computed results items. The results title bar displays the frame for which the quantitative results apply. Results are provided in the following order:

	Current	Mean	Units
Quantitative—4 Sigma			
Total	34,209,137		
Peak	1.909e+03		
Min	-1.138e+01		
Width X	9.500e+02		um
Width Y	8.728e+02		um
Z Location	200.00		mm
Statistics			
Samples	5	5	
Laser			
Waist Width X	4.321e+02	4.427e+02	um
Waist Width Y	4.869e+02	4.934e+02	um
Divergence X*	1.907e+00	1.868e+00	mrad
Divergence Y*	1.719e+00	1.703e+00	mrad
Waist Loc X	845.53	841.19	mm
Waist Loc Y	900.21	882.31	mm
M ² X	1.023	1.026	
M ² Y	1.039	1.043	
BPP X	3.989e-03	0.000e+00	mm mrad
BPP Y	4.051e-03	0.000e+00	mm mrad
Rayleigh X	226.58	236.99	mm
Rayleigh Y	283.20	289.80	mm
Astigmatism	0.21	0.15	
Asymmetry	1.13	1.11	
After Lens			
Number in Run	15		
Waist Width X	2.196e+02	2.250e+02	um
Waist Width Y	2.203e+02	2.277e+02	um
Divergence X	3.752e+00	3.676e+00	mrad
Divergence Y	3.800e+00	3.691e+00	mrad

Quantitative - <beam width method>

The quantitative results show the basic beam calculations performed for each frame in the frame buffer. The Z location for each acquired frame of data also appears.

During Live Video mode, these results are not very meaningful, although they do provide an idea of how high or low the peak energy is relative to camera saturation.

Real-time M²

This section only displays when the Real-time mode is active. Four results are displayed: Divergence and estimated M² values in both the X and Y directions.

Laser

This section contains the computed results for the laser under analysis. Both the X and Y axial results will be computed where applicable. These items are:

- Waist Width** **W₀:** The waist width of the laser, in millimeters.
- Divergence** **Θ₀:** The far-field divergence of the laser, in milliradians. If an asterisk (*) appears in the title column it denotes that the divergence results are obtained from the fitted curve rather than from the beam width values at the focal length.

Waist Location	Z₀ : The location of the laser's waist measured from either the laser faceplate or the front of the M ² -200s, in millimeters.
M² or K, BPP	M² : The times-diffraction-limit-factor M ² . K : The beam propagation factor K. BPP : Beam Parameter Product.
Astigmatism	Ast : A computed ratio indicating the degree to which the laser X and Y waist properties exhibit astigmatic behavior.
Asymmetry	Asy : A computed ratio indicating the degree to which the X and Y waist widths form a circle.
Rayleigh	Z_R : The Rayleigh Range of the focused laser, in millimeters.

After Lens

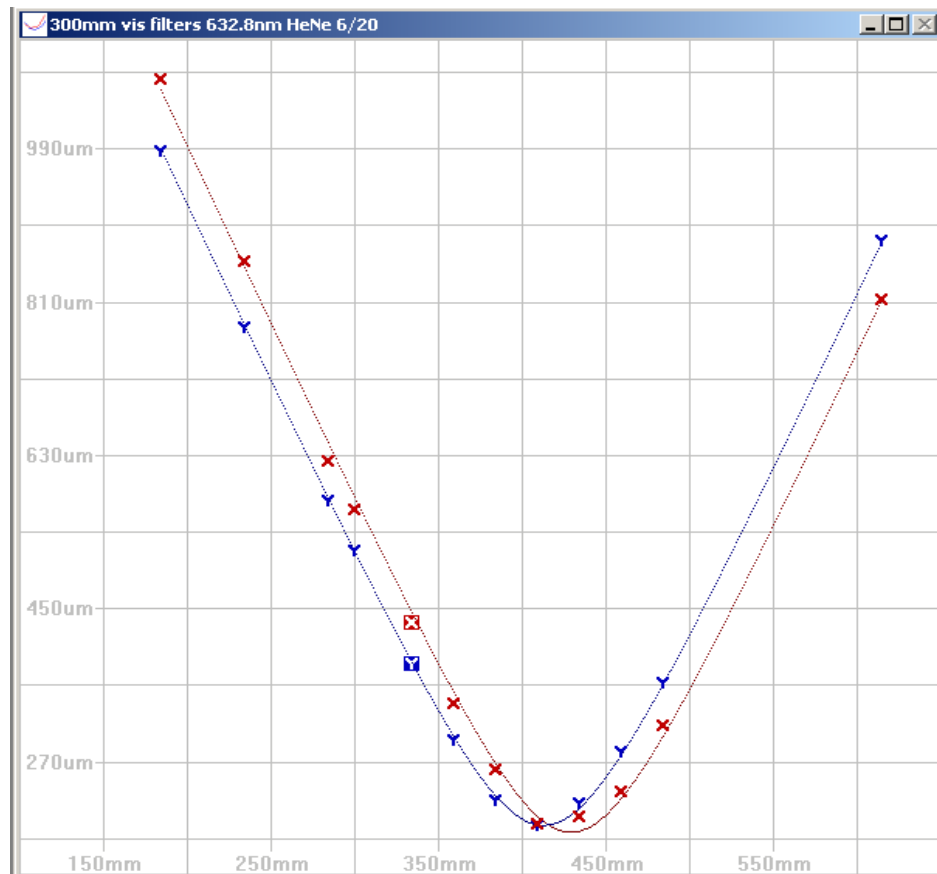
This section only displays when the **After Lens Results** item is checked in the **M² Setup** dialog box. These are the computed results for the laser beam propagating after the lens. Normally this section is suppressed to avoid the risk of accidentally reading one of these result values in place of the result that actually applies to the laser under test.

The after lens properties are referred to as the "artificial results" since they only apply to the focused beam propagating within the optical train. These items are:

Waist Width	W₀ : The artificial waist width, in millimeters.
Divergence	Θ₀ : The artificial far-field divergence, in milliradians.
Waist Location	Z₀ : The artificial waist location measured from the M ² -200s lens, in millimeters.
Astigmatism	Ast : A computed ratio indicating the degree to which the laser X and Y waist properties exhibit astigmatic behavior.
Asymmetry	Asy : A computed ratio indicating the degree to which the X and Y waist widths form a circle.
Rayleigh	Z_R : The Rayleigh Range of the focused laser, in millimeters.

3.16.2 M² Plot Window

The plot window displays the artificial X and Y beam widths plotted against their Z-axis sample locations. The beam widths are plotted in micrometers (μm), the Z values in millimeters (mm). The solid lines are the resulting curve fits of the beam propagation equation. The plotted data auto-scales to fit the window.



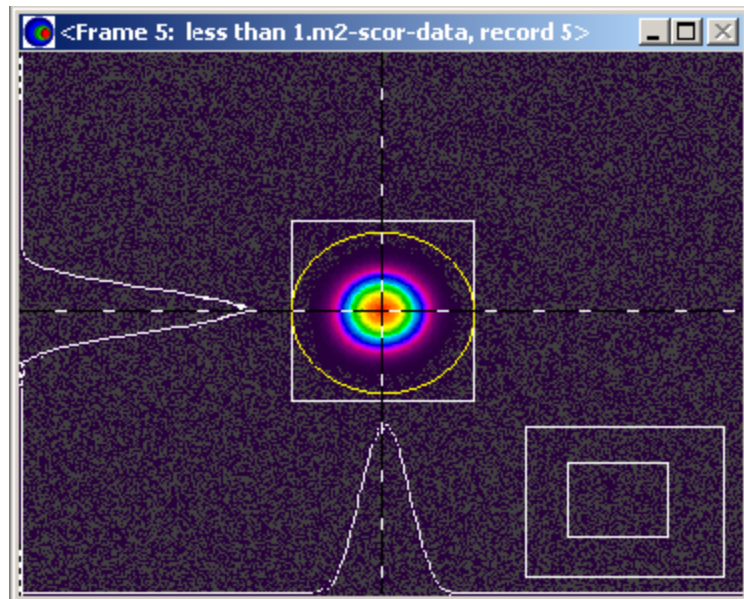
The title bar of this window displays the concatenated **Laser Model**, **Serial Number**, and **Comment Line** information provided in the **M² Setup** dialog box (see section 3.13.1).

After data collection, the leftmost data point will appear highlighted. The highlighted data point corresponds to the same beam image displayed in the **Beam Display** window, and its results appear in the **Quantitative** section of the M² Results window.

To highlight another data point either click on the data point or change the **Frame Value** in the Status bar.

3.16.3 Beam Display Window

The beam display window either displays the current data received from the camera or the selected frame in the frame buffer (shown below).



When displaying a frame, the current frame number appears in the title bar.

When collecting data in either **Auto** or **Real-time M²** mode, the **Beam Display** follows the data collection process. In this way, the operator can monitor what the camera is seeing and assess situations that may be adversely affecting the results.

In **Live Video** mode, use this display to align the laser with the optical train.

After data is collected, review the contents of the frame buffer, frame-by-frame, by setting the frame value in the status bar, or by clicking the data point in the **M² Plot** window.

The **Beam Display** window contains an X and Y cursor through the beam centroid, and displays an X and Y profile along the lines of the cursors. When stopped, drag the cursors with the mouse, or use the X/Y cursor edit controls found on the Status bar.

Double-click and hold, then drag the cursor on the **Beam Display** window to zoom in and pan around in order to view details of the beam. Double-click the left mouse button to zoom in. Double-click the right mouse button to zoom out. Click and hold the left button, then drag to pan toward the area of interest. Zooming and panning operates in either 2D or 3D display modes.

An auto aperture is also visible on many frames. This aperture defines the region of the data where the beam width results are computed.

The above features are always enabled, and appear in beam printouts.

3.16.4 Status Bar Displays and Controls

The **Status Bar** is located along the bottom of the M²-200s main window. The **Status Bar** provides information about the currently displayed beam, and a means to move the cursors and select which frame in the buffer to display.

Cursor Information: X, Y, and I

The X/Y cursor edit boxes display the current X and Y cursor axial locations as seen in the **Beam Display** window.



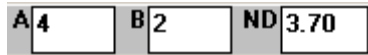
Cursor movement is only allowed when data acquisition has stopped. While data collection is in progress, the cursors automatically follow the beam centroid location.

To move the cursors, enter a new value in the X and Y edit controls, or use the spin controls. Alternately, use the mouse to move them in the **Beam Display** window.

The "I" field indicates the pixel intensity value where the cursors intersect.

A and B Filter Settings

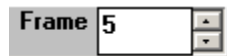
This display indicates the ND setting and **A** and **B** filter wheel positions at the time the data sample was acquired.



Knowing which filters were in use while reviewing a particular data set could prove useful when diagnosing a problem with the ND filter calibration or operation.

Frame Select Control

This control selects the currently displayed frame or frame under acquisition. When collecting new data this control acts only as a display. When stopped, select which frame in the frame buffer to display by editing this value. Spin controls provide an easy frame buffer review, one frame at a time.



Camera Status

This enunciator indicates GREEN when a camera is connected to the application and RED when one is not. This is a warning that your camera may not be plugged in. To connect a camera, go to the Camera menu and select a camera.



Chapter 4. Setup and Operation

This chapter covers the following topics:

- Setting up the M²-200s
 - Installing software
 - Installing computer boards
 - Checking out the equipment
 - Beam conditioning
- Operating the M²-200s
 - Auto Mode
 - System mounting
 - System alignment
 - Manual Mode
 - Setting up and using an Optical Rail
- Using the Real-Time M² Mode
- Interpreting results
- The Four-Cuts Method

4.1 Unpacking

The following components *may* be found in your M²-200s system:

- M²-200s software installation CD
- M²-200s User Guide (this manual)
- CCD camera¹ with M² license
- Model M²-200s optical train²
- Pinhole alignment tool²
- One or more 1" diameter lens assemblies²
- USB interconnect cable
- Power supply for the motor controller²
- Power cord²
- External camera Trigger cable¹

¹ Unless ordered as an accessory to your existing Laser Beam Analyzer.

² Not included with Manual Mode System.

Other optional equipment may include:

- Beam sampling/attenuation equipment
- A pair of beam steering mirrors
- Additional 1" diameter lens assemblies
- USB 3.0 PCI Express card

Additional equipment required for operation:

- A multi-core Pentium (2.00 GHz or better) style or equivalent PC with Windows 7 (32/64) operating system

Inspect all equipment for any damage that may have occurred during shipment. If any damage is found, contact Ophir-Spiricon's Service Department.

4.2 Install the M² Software

Note: If you purchased your M²-200s from Ophir-Spiricon with a computer system and installation, then the software will already be installed and you may skip to section 4.4.

To Install the Spiricon Software Application:

There are two ways to install the software from the Spiricon provided CD. This procedure will work as described on Windows 7 operating systems. All installations must be performed with Administrator privileges.

Note: Spiricon no longer verifies or certifies operation with Windows XP or Vista.

1. If the computer is setup to Auto Play CD's do the following:
 - a. Insert the supplied CD into the CD-ROM drive and wait for the **Spiricon Software Auto Install** screen to appear.
 - b. Click on the **Software Install** button.
 - c. Follow the directions that appear on the screen.
2. If the computer does not have the Auto Play feature enabled:
 - a. Insert the supplied CD into the CD-ROM drive and open **Windows Explorer**.
 - b. Select **My Computer** and right-click on the CD-ROM drive that contains the Spiricon CD. Click on the **Autoplay** option. This will open the **Spiricon Software Auto Install** screen.
 - c. Click on the **Software Install** button.
 - d. Follow the directions that appear on the screen.

Before running the M² application, Windows must be restarted.

4.3 Connect the Optical Train

Note: Perform this step if the optical train accessory is provided.

1. Set the optical train on a flat, stable surface near the PC.
2. Connect the optical train and the power supply as shown in Figure 2.
3. Plug the power supply into a grounded A/C outlet.
4. Connect the USB port on the M²-200s optical train to an available USB port on your PC.
5. When the Optical Train is connected for the first time, a **Found New Hardware** wizard will appear. Follow the wizard directions until the USB Motor driver installation completes.

4.4 Connect the Camera

Without mounting the camera to the optical train, connect the cable from the camera to an available port on the PC.

An interface card has been provided for PCs without an available port.

When the camera is connected for the first time, a **Found New Hardware** wizard will appear. Follow the wizard directions until the driver installation completes.

4.5 Preliminary System Checkout

Start the M² application by double-clicking the M² icon or launch it via the Start button.

If all items are found, then the internal translation table and the ND filter wheels initialize. When these initializations successfully complete, Auto mode operation is allowed.

4.5.1 Load a Configuration

This is a good time to load one of the factory default configuration (~tilde) files supplied with the M² application. At least one such configuration file will be supplied with each system. In some cases, more than one of these files will be present.

To run in Auto mode, perform the following:

1. From the menu select **File, Restore Config...**
2. Open a configuration file that begins with the serial number of your M²-200s Optical Train. See 3.6 for a description of these factory-provided configuration files.

† To run in Manual mode (i.e. without the Spiricon optical train), perform the following:

1. From the menu select **File, Restore Config...**
2. Open the configuration file M2 Manual.cfg.

This M²-200s configuration can now be used as a starting point to create a configuration customized for your testing purposes.

Note: *The settings installed by the Auto mode configuration are much more useful since they relate directly to the actual optical train supplied with your system.*

† *The opposite is true of the Manual configuration settings. Since Spiricon has no knowledge of your actual optical setup, these settings are essentially meaningless, requiring modifications to most every setting.*

4.5.2 Select a Camera

Note: Refer to 3.11 for complete Camera selection and configuration information.

To select a camera:

- Open the **Camera...** dialog box in the **Options** menu.
- Click on the **Camera** type drop down arrow.
- Select a camera serial number from the list.

After selecting the camera, perform a **Save Config...** operation (see section 3.5). Thereafter, when the M² application launches, this new camera setup will be automatically restored. Otherwise the camera selection in the **Camera** dialog box must be manually selected each time the M² application launches.

A **Restore Config...** operation will automatically occur each time the M² application launches. Camera type selections will only occur when a Config file is restored (either automatically at startup or manually), or when a new camera is selected in the Camera dialog box.

Before proceeding, verify that the **Camera** configuration settings in the **Camera** dialog box in the **Options** menu is correct for the camera in use (see section 3.11). Adjust as necessary.

Important: Now is a good time to stop and save a configuration that contains both the optical train and camera settings. Select **File, Save Config...**, enter a file name, and click **Save**. The last saved or loaded configuration will become the default startup configuration. See sections 3.5 and 3.6 for more information.

4.5.3 Check the Camera

Regardless of whether an optical train is attached and functioning, the camera should be tested.

Warning: *The camera imager is windowless and can be easily damaged if it comes in contact with any foreign objects, such as fingers or well-meaning cleaning objects. Only clean the camera imager by gently blowing on it with dry air or nitrogen.*

1. Click **LIVE** on the tool bar. The beam window will change from the invalid data symbol to a real time live video display.
2. Remove the dust cover from the camera allowing light to fall on the sensor. Observe that the beam display lightens and darkens as more and less light falls on the camera's imager.
3. Replace the protective dust cover over the camera lens.

Note: If you purchased the M² optical train, proceed to the next section, otherwise skip to section 4.7.

4.5.4 Check the Optical Train

When the optical train initialized, it cycled the mirror table over its entire range of motion, thus calibrating itself. The total range of motion for the camera in the

Z-axis is determined by the values entered for Z Fixture, Z Lens, and Z Camera, (see section 3.14.1) and by the table calibration just performed.

Note: *Z value factory defaults were set when the matching configuration file loaded (see section 4.5.1 above). If for some reason these values do not match your actual setup, make corrections as needed (see section 3.14.1).*

To determine the optical Z-axis range of motion, perform the following:

1. Click the **LIVE** button on the tool bar to start collecting video frames.
2. Place the mouse cursor inside the Z-axis edit control, then press and hold the right mouse button (see section 3.13.2).
3. Read the input range for the translation table. Record these values.

Test the Z-axis controls described in section 3.15.2. Become familiar with their operation, as it will become necessary to manually move the translation table during the following alignment sections.

Note: *If you found it necessary to modify any of the Z values, perform another **Save Config...** operation to insure that they are correctly restored during subsequent sessions.*

4.5.5 Attenuate the Beam



Avoid eye or skin exposure to direct or scattered radiation!

Warning: *Before allowing laser energy to enter the instrument, it is important to limit the beam intensity. Excessive laser energy may cause damage to the camera or the internal components of the M² optical train.*

Typically, a CCD camera imager can be damaged at energy levels in excess of 1 mJ/cm² or at power levels greater than .15 mW/cm². Adjust these input limits downward based on the likely focused spot size resulting from your M² lens focal length. Beam splitters and/or filters may be used to attenuate the beam, but care must be used to prevent the introduction of distortions.

During an M² measurement operation, the peak energy density that reaches the camera will change, potentially over several orders of magnitude. This is a result of the camera effectively moving from a larger unfocused spot near the lens, into and through the focus at the waist, and then out again to an unfocused spot (see Figure 18 on page 89). The optical train will automatically adjust to accommodate these changes in beam intensity, so long as you, the operator, have prudently selected the initial beam intensity. **Thus, it is your responsibility to attenuate the laser sufficiently to operate within the safe dynamic range of the M²-200s system.**

4.6 Prepare the M²-200s for Auto Mode

The optical train assembly and camera must be mated in order to run in Auto mode. The beam must then be directed into the optical train and aligned along the optical axis of the instrument.

To begin this setup procedure, exit the M²-200s application, shut down Windows and turn off power to the PC, and unplug the camera from its cable.

4.6.1 Mount the Optical Train

For proper operation, the model M²-200s optical train should be mounted on a solid, level surface. Allow enough room at the front of the instrument to direct the laser beam through the input aperture. Position the PC close enough to the optical train so that all of the cables will reach. See Figure 1 and Figure 2 as required.

All mounting should be done using the 3 provided mounting points. Spiricon recommends that the optical train be securely attached to an optical table. Use care not to rack or twist the base when securing the optical train. Do not use the cover as a mounting point.

4.6.2 Install the Camera

Remove the protective dust cover from the camera and thread it onto the C-mount mounting hardware on the optical train.

Important: *If present on your camera, retain the 5mm spacer ring mounted into the camera lens threads. It is easy to detach accidentally when removing the dust cover.*

Warning: *The camera imager is windowless and can be easily damaged if it comes in contact with any foreign objects, such as fingers or well-meaning cleaning objects. Only clean the camera imager by gently blowing on it with dry air or nitrogen.*

M²-200s Camera Mounting

Remove the C-mount threaded insert from the camera mounting clamp. Thread the camera onto the insert's male threads. When properly mounted all of the threads will be drawn up snug. Push the insert back into the clamp until it seats on its mounting flange, orient the camera and then re-tighten the clamp.

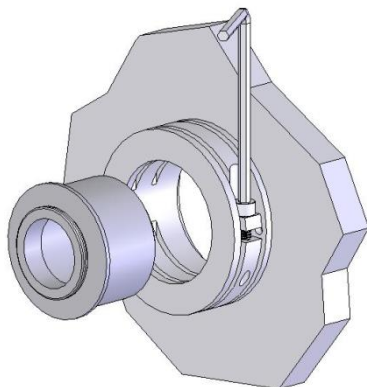


Figure 14. C-mount insert and clamp

Restore power to the PC. Plug the camera into its cable. Restart the M² application. Automatic initialization of the optical train should take place.

If the camera or other configuration parameters need to be changed, then do so now or restore the required configuration. This will not be necessary if the last configuration saved corresponds to the current requirements. Refer to section 4.5.2.

If not already selected, open the **M² Setup** dialog box and set the M² Mode item to **Auto**, then click **OK**.

4.6.3 Beam Alignment and Setup for Auto Mode



Avoid eye or skin exposure to direct or scattered laser radiation!

Warning: The following procedure should only be performed after attenuation of the laser beam, as described in section 4.5.5. Failure to do so may cause damage to the camera.

In order for the M²-200s to operate correctly, the beam must enter the instrument through the center of the lens and align along the instrument's optical axis. The objective is to align the incoming laser such that the beam will remain centered on the camera as the internal mirrors translate along the focusing beam path.

Two steering mirrors should be arranged to direct the beam into the optical train along its optical axis as shown in Figure 15. This axis runs parallel to the instrument's long axis.

Before aiming the laser beam into the instrument, attenuate the beam near the laser source in compliance with section 4.5.5.

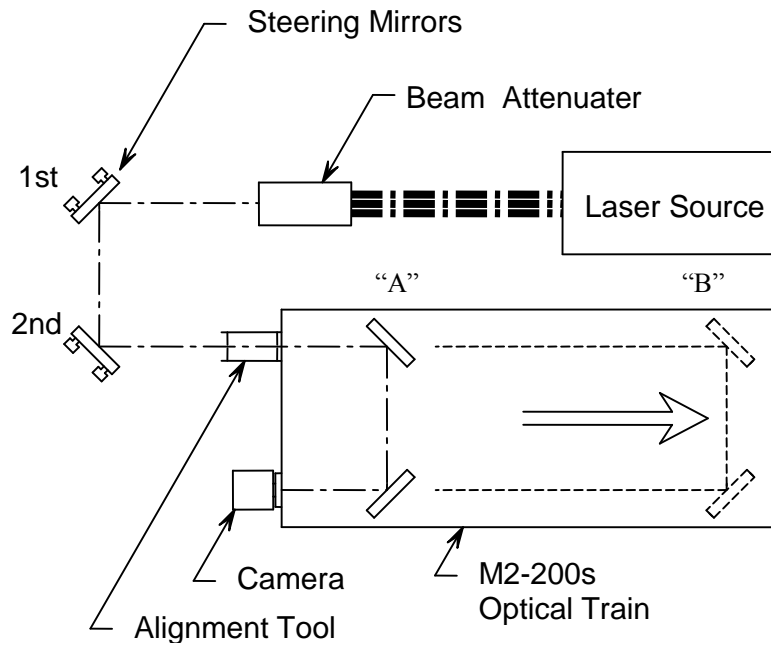


Figure 15. Beam Alignment

After initialization, the mirror path will be near the camera (position "A" in the above figure). Proceed as follows:

- 1) Click on the **LIVE** toolbar button. The live video mode is provided to assist with the alignment process. Live video will appear in the beam display window.
- 2) Set a starting ND value of 2 or 3 in the ND Filter edit control (see section 3.15.3).
- 3) Position the pair of beam steering mirrors; one in the beam axis, and one on the optical axis of the M²-200s.

Note: When possible, the height of the laser beam should be set to the same height as the optical train's optical axis. This will make centering the beam a bit easier, as adjustments to the steering mirrors X and Y tilt adjustments will have similar axial effects. Otherwise, a change in one mirror's X adjustment will require both an X and Y adjustment of the opposite mirror to bring it back to center.

An alignment tool is included to assist in aligning the beam with the instrument. The tool (see Figure 16) consists of two pinholes mounted in an open tube. The pinhole disks are coated with a material that will fluoresce when exposed to infrared at 1064nm and at UV wavelengths.

You can use this tool with both pinholes as shown, or you can remove the outer pinhole and use it singly, depending on your skill level. Most users, after gaining experience with the alignment process, rarely rely on either pinhole to achieve good alignments.

Note: The following description assumes the use of the dual pinhole alignment tool. If you want to try aligning the system without the aid of this device skip down to step 6).

- 4) Begin using this tool by threading it into the end of the input lens.

You must swing the ND filter housing out of the beam path before having access to the lens holder. **If necessary add additional beam attenuation to prevent camera damage.**

Both pinholes are now centered on the optical train's optical axis. When the center of the laser beam is adjusted to pass through both pinholes, it is approximately aligned with the instrument.

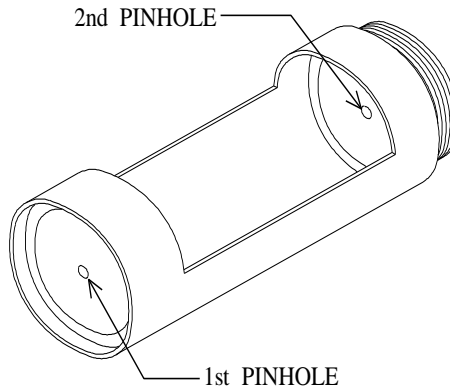


Figure 16. Alignment Tool

With the laser turned on, adjust the mirrors such that the beam falls into the center of the first pinhole in the alignment tool. Observe where the beam falls near the second pinhole. Note the direction the beam must move to center on the second pinhole. Adjust the second mirror to move the beam in this direction. Adjust the first mirror to re-center the beam back onto the first pinhole.

Note: For best results, adjust one axis at a time.

Continue to alternately adjust the mirrors, moving the first mirror to center the beam on the first pinhole, and the second mirror to center the beam on the second pinhole until the beam passes through and is centered on both pinholes.

- 5) At this time, observe the laser beam in the beam display window. Adjust the beam brightness to a visible but unsaturated intensity level by either adding or removing external beam attenuation or adjusting the internal ND filter settings. This may also involve adjusting the camera's electronic shutter (where applicable). Then remove the alignment tool from the input port and swing the ND filters back into position.

Use the ND filter controls on the tool bar to lighten or darken the beam image.

- 6) Now use the translation controls on the tool bar to increase the Z location of the camera. Observe the motion of the beam as the table moves toward position "B." The beam image should be centered in the camera array and not wander significantly during table travel. If the alignment is satisfactory, skip to step 8). Otherwise proceed with the next steps to fine-tune the alignment.
- 7) If the beam does not remain centered as the table translates you will need to make additional small adjustments of the steering mirrors until a stable situation is achieved. This is an iterative process wherein the mirrors are adjusted in opposite X and/or Y directions and the table is translated out and in as necessary. In general, it is best to align one axis at a time to keep the process simple. Once a stable alignment is obtained proceed to the next step.

- 8) With the beam aligned, rotate the camera such that the camera's X and Y-axes align with the X and Y axes of the laser beam. Use the Z location controls on the tool bar to translate the table back and forth and observe the beam's natural X and Y axial orientation. Observe the profile in the beam window and rotate the camera to align the axes. Perform a final attenuation setup. Using the Z location controls, move the translation table until the beam's peak intensity location is found. This is usually near the focal length of the lens, but not always. When the peak energy of the beam falls in the range of 50 to 90% of the camera's total dynamic range, adjust the external attenuation such that the internal ND filters are in a range between ND 2 and 3.

In order to perform the following setup entries, you will need to toggle the Live Video button off in order to enter the **M² Setup...** dialog box.

- 9) Identify a good **Z Start** value. Translate the camera towards the lens until the beam is large enough to fill about two-thirds of the camera's imager or you hit the near limit of the translation range. Note this Z position. Round this figure up to the nearest 5mm multiple and enter this as the **Z Start** value. (You may need to reduce the ND setting as the beam grows in size and dims.)
- 10) Find a good **Z Stop** value. Translate the camera away from the lens until the beam is just large enough to fill the entire imager or you hit the far limit of the translation range. Note the Z position. Round this figure down to the nearest 5mm and enter this as the **Z Stop** value.
- 11) Move the camera back to the **Z Start** position by entering the value derived from step 9 into the Z Location edit control on the toolbar. Set an ND value that displays a beam Peak intensity between 50% and 90% of max (2000-4000 counts).
- 12) Now enter a **Z Step** value that seems reasonable for the range between the **Z Start** and **Z Stop** values. Typically a value of 30, 40, or 50mm will be appropriate. If your beam focuses quickly, consider reducing the step size.
- 13) Enter information about the laser that will be analyzed (see section 3.13.1). This information should be entered for each laser under analysis. It is absolutely necessary to enter the correct **Wavelength** of the laser light and the **Focal Length** of the lens at this wavelength. Refer to section 2.7.7 and Appendix A for additional focal length information.
- 14) In the **Computations** section of this dialog box, select the desired **Beam Width Method** (see section 3.13.5). In this section of the dialog box, additional entries are available. Refer to the remainder of section 3.13.5 for information regarding these settings.
- 15) Most of the prerequisite settings required to begin actually analyzing the laser beam are now set. Save a new configuration file now for this specific set of testing conditions in order to easily retrieve them for later use.
- 16) Click the **LIVE** button to turn off the live video alignment mode.

Note: *Be sure to update the configuration whenever you make a necessary change in the settings above.*

4.6.4 Data Collection in Auto Mode

Click **Start!** to begin collecting frames. The instrument will adjust the internal attenuation, move the translation table, calibrate the camera as needed, collect data frames, and record the beam width data until **Stop!** is clicked, or the run completes. Messages will appear any time that action from the operator is required, such as increasing or reducing external attenuation.

Each collected data point will be plotted. A curve fit to the data will appear as soon as enough data has been acquired to make a reasonable estimation. The numerical results display will update as the collection process continues.

The data collection process will terminate automatically when all the requested data has been successfully recorded.

At the completion of the data collection process, consider saving the data to a file (see section 3.3).

4.7 Manual Mode

† Manual mode requires an optical rail assembly and a focusing element of a known focal length. ISO/DIS 11146-1 must be used as the basis for your rail design. The focusing element must be an aberration-free mirror or a plano-convex lens.

In the following example we have used a lens-based approach. The focusing element should be selected to provide a smallest focused spot width of at least 10 camera pixels across. The rail must be long enough to allow the camera to translate at least 2 Rayleigh lengths beyond the waist region.

When using Manual Mode, the user will be required to change the camera position on the rail, adjust the aim of the beam, adjust the attenuation of the beam, block the beam when prompted and determine whether to accept each data frame. The user must also accurately set the distance from the lens to the sensor inside the camera for each data point.

4.7.1 Optical Rail Setup

Figure 17 depicts the general features of the optical rail arrangement. The rail must be parallel to the incoming laser beam, the lens and camera must be at the same height on the rail, and the camera must be able to slide along the rail. A two-mirror arrangement for aiming the beam along the rail is suggested.

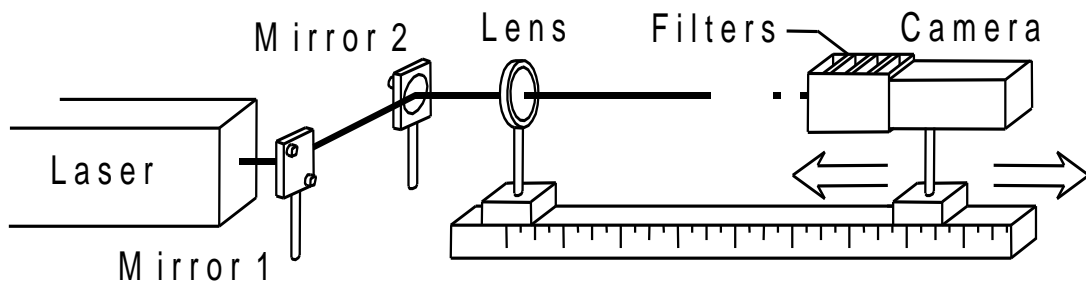


Figure 17. Manual Mode Optical Rail

While not shown in the above figure, it is often advisable to employ additional attenuation between the laser and the first steering mirror. The necessity for this arrangement increases proportionally to the output energy/power of the laser.

Make available a device that can completely block the laser beam from the camera each time the camera performs a calibration or calibration check.

It is also a good idea to place a relatively large ND filter immediately in front of the camera. This filter will be helpful in blocking out ambient background light.

Note: It is recommended that measurements be performed in a low light or a darkened room setting.

4.7.2 Beam Alignment and Setup for Manual Mode



Avoid eye or skin exposure to direct or scattered laser radiation!

Warning: The following procedure should only be performed after attenuation of the laser beam, as described in section 4.5.5. Failure to do so may cause damage to the camera.

Use ND filters near the laser head to attenuate the beam to a safe level. Use the ND filters in front of the camera to adjust the beam brightness to a visible but unsaturated intensity level.

The following steps describe how to set up the rail with the lens and the camera:

If the camera or other configuration parameters need to be changed, then do so now or restore the required configuration. This will not be necessary if the last configuration saved corresponds to the current requirements.

- 1) If not already selected, open the **M² Setup** dialog box and set the M² Mode item to **Manual**, and then click **OK**.
- 2) Click on the **LIVE** tool bar button. The live video mode is provided to assist with the alignment process. Live video will appear in the beam display window.
- 3) The laser must be directed along an axis parallel to the rail, centered on the lens, and centered on the camera. The beam must stay centered on the camera as the camera is translated along the rail.

The X and Y-axes of the camera must also be aligned with the X and Y-axes of the laser beam. Meaningful beam propagation results will not be obtained if the axes are misaligned. To accomplish this alignment, it may be necessary to rotate either the camera or the laser. After making this adjustment, recheck the pointing accuracy by translating the camera along the rail again and assuring that the beam remains centered in the beam window.

When the camera can travel the full length of the rail and the beam profile stays centered in the beam window, alignment is complete.

In order to perform the following setup entries, you will need to toggle the Live Video button off in order to enter the **M² Setup...** dialog box.

- 4) Identify a good **Z Start** value. Move the camera towards the lens until the beam is large enough to fill about two-thirds of the camera's imager. Note the Z position. Round this figure off to the nearest 10mm and enter this as the **Z Start** value.
- 5) Find a good **Z Stop** value. Move the camera away from the lens until the beam is just large enough to fill the entire imager. Note the Z position. Round this figure off to the nearest 10mm and enter this as the **Z Stop** value. Move the camera back to the **Z Start** position.
- 6) Now enter a **Z Step** value that seems reasonable for the range between the **Z Start** and **Z Stop** values. Typically a value of 50mm will be appropriate. If the beam focuses quickly, consider reducing the step size.
- 7) Enter information about the laser that will be analyzed (see section 3.13.1). This information should be entered for each laser under analysis. It is absolutely necessary to enter the

correct **Wavelength** of the laser light and the **Focal Length** of the lens at this wavelength. Refer to section 2.7.7 and Appendix A for additional focal length information.

- 8) In the **Computations** section of this dialog box, select the desired **Beam Width Method** (see section 3.13.5). In this section of the dialog box, additional entries are available. Refer to the remainder of section 3.13.5 for information regarding these settings.
- 9) Most of the prerequisite settings required to actually analyze the laser beam are now set. Save a new configuration file now for this specific set of testing conditions in order to easily retrieve them for later use.

Note: *Be sure to update the configuration whenever you make a necessary change in the above settings.*

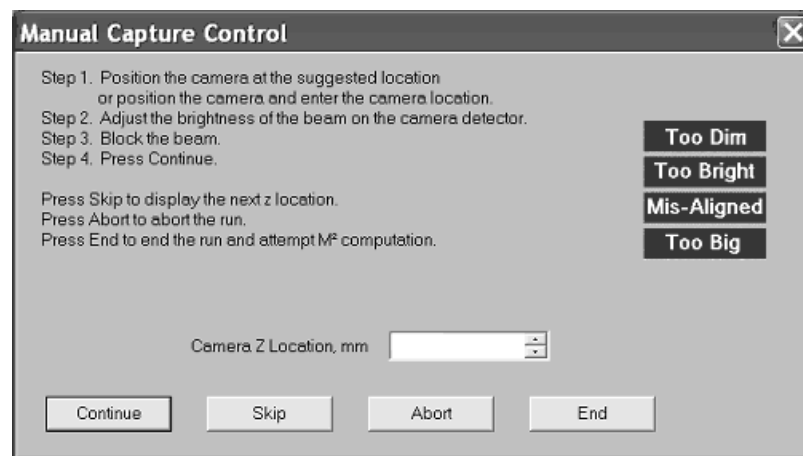
- 10) Click the **LIVE** button to turn off the live video alignment mode.

4.7.3 Data Collection in Manual Mode

Click on **Start!** to begin collecting frames. A live image of the laser profile will appear in the beam window. At this point, a prompt will appear requesting the beam be blocked to allow the execution of a camera baseline calibration. When the calibration process is completed, the following prompt will appear:



Unblock the beam, and then click **OK**. The **Manual Capture Control** dialog box will now appear:



This dialog box will guide you through the acquisition of each frame of data in manual mode. Follow these four steps:

- Step 1** The suggested Z location will appear in the **Camera Z Location** text box. This Z location is based on the **Z Start**, **Z Stop**, and **Z Step** information entered earlier. If an alternate position is desired, place the camera at the desired position and enter the new location

in the **Camera Z Location** text box.

Step 2 Verify that the beam is not too dim or too bright. Adjust the beam attenuation as required.

Step 3 Block the laser beam from reaching the camera in preparation for collecting the next data point.

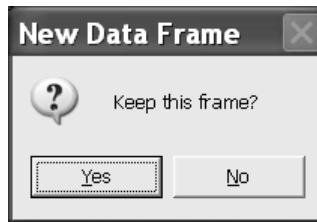
Step 4 Click **Continue** to proceed.

Note: *The red indicators on the right side of the dialog box only appear as a warning when a possible problem is detected. Take appropriate action when indicated.*

The application will perform a camera calibration check. When completed, a prompt will appear:



Unblock the beam, and then click **OK**. A new data frame will be collected and displayed in the beam display window. The following prompt will appear:



Click **Yes** to accept and record this frame or **No** to return to the **Manual Capture Control** dialog box.

On the **Manual Capture Control** dialog box, click **Continue** to attempt to recapture this same data point.

Three other options are available from this dialog box:

Skip Skip recording data at this location and move on to the next programmed Z location. This may be appropriate at points where the beam size is too small to measure accurately, too large to fit sufficiently on the detector (too large in the beam window), or the brightness cannot be adjusted to the range of 50 to 90% of the camera's dynamic range.

Abort Abort the data acquisition process and abandon the beam propagation analysis operation. This completely cancels the measurement process and no attempt to compute M^2 results will

take place.

End End data acquisition and compute the M^2 results using the run's current accumulated data. No additional data points will be collected until a new run is initiated.


The **Manual Capture Control** dialog box will appear at every Z Step along the axis. When the next projected Z Step exceeds the Z Stop value, the M^2 run completes.

Each collected data point appears on a plot. An estimated curve will appear as soon as enough data accumulates, stabilizing as the data accumulation progresses. The numerical results display updates as the collection process continues.

At the completion of the data collection process the collected data may be saved to a file (see section 3.3).

4.8 Operate in Real-time M^2 Mode

The **Real-time M^2** mode is designed for continual, real-time monitoring of a laser beam. It may be used to monitor a laser while the laser cavity is under adjustment, providing feedback to the technician during the tuning process. It may also be used to monitor laser output under normal operating conditions. In this mode, a laser operator may verify laser stability over any time span.

In order to operate in **Real-time M^2** mode, a complete run of either an **Auto** or **Manual** mode data set must be displayed in the **M^2 Plot Window**. This data run can be acquired just prior to operating in **Real-time M^2** mode, or a previously saved data file may be loaded. The  button will only be enabled once a data set is obtained or loaded.

Click the  button to start real-time M^2 monitoring.

If this is done in **Auto** mode, the translation table will position the camera at the focal length of the lens and the camera will be calibrated.

† If this is done in **Manual** mode, a prompt to place the camera at one focal length behind the lens will appear. Make the adjustment and click **OK**. A prompt to block the beam will appear. Block the beam and click **OK**. The system will calibrate the camera. At the conclusion of the calibration, a prompt will appear to unblock the beam. Unblock the beam and click **OK** to begin monitoring.

Observe that a new **Real-time M^2** results item will appear in the **M^2 Results** child window. With the camera at the focal length of the lens, the laser X and Y beam divergence will be continually monitored and a new M^2 (or K factor) is estimated based on the change in beam divergence and the results from the previous M^2 run. While the beam divergence is accurately measured, M^2 (or K) is only estimated and should not be considered reliable. To verify these results, perform another M^2 run.

Note: *Camera background drift will compromise the accuracy of results in real-time M^2 mode. Periodically perform a new camera calibration cycle by turning off*

the real-time M^2 button and then turn it back on. The calibration procedure will be repeated at the beginning of every real-time M^2 session.

In **Real-time M^2** mode, the beam display window becomes a valuable tool during laser cavity tuning and laser monitoring. This beam profile shows much of the energy distribution detail across the laser beam. Changes in the laser mode quality, the optics, and the beam energy can often be first observed here.

To terminate real-time M^2 monitoring, disengage the  button. The application will return to the mode from which **Real-time M^2** monitoring was initiated.

4.9 Useful Operations and Functions

The following information provides illumination on a number of topics that may be of less obvious value to the user.

4.9.1 The Skip Button


During a typical M^2 run (in either Auto or Manual mode) there may be Z locations where a reliable measurement simply may not be possible. Perhaps the beam cannot be made bright enough at that location, or the beam size may not be small enough or large enough. If a measurement cannot be performed at that Z location, then simply skip that location and move on.

4.9.2 Plotted Curve Fit

As soon as data for five or more Z locations (along with their frames) accumulates, a predicted plot fit to the data is attempted and displayed in the plot window. No plot will occur if the data points do not yield a curve fit. This plot is continually updated as new data accumulates.

Note that X-axis and Y-axis results are reported and computed simultaneously. Two data points for each location and two plotted fits to the data will appear in the plot window. This plot shows the beam widths as functions of Z location. Z location is the internal distance from the lens to the camera image plane, so the plot has reference to the focused beam as seen in Figure 18.

4.9.3 Auto Remove Outlier and Manual Exclude

If the **Auto Remove Outlier** feature is enabled in the **M^2 Setup** dialog box, the application will automatically remove data points that appear to be anomalous. Outlier plot points will show up in the plot window as Black X's and Y's. At the end of a run it is also possible to exclude data points that have not been automatically excluded. To do so, highlight these data points using the mouse and click on the  button on the tool bar (see section 3.15.6).

4.9.4 Stepping Through Frames

Conveniently step through accumulated frames in the beam display window by using the Frame edit box at the bottom of the screen. Quickly review a sequence of frames to come to an informed decision about whether a particular point should be excluded or not.

4.9.5 Statistics

Collected statistical information may expand your understanding of the reported beam propagation results. Enable **Statistics** at the beginning of the data collection process. Performing multiple M^2 analyses on a single laser beam may generate valuable statistical results. See section 3.13.5.

4.9.6 Frame Averaging

Use **Frame Averaging** to improve the signal to noise ratio in acquired data frames. See section 3.12.2.

4.9.7 Results Averaging

To improve the signal to noise ratio of acquired frame data when frame averaging is not practical, try using Results Averaging. See section 3.12.2.

In general, use **Frame Averaging** unless the beam exhibits poor pointing stability, in which case employ **Results Averaging**.

4.9.8 Interpreting Results

Three windows in the M^2 -200s application provide feedback to the operator. The beam window displays the energy distribution or profile of the beam. These are cross-sections of the beam at various distances (Z locations) after the lens, (see the "Sample Locations" in Figure 18). The X and Y widths of the beam at each of these locations are plotted in the plot window.

In the **Results** window there are four possible sections providing information about:

- The current beam profile's Quantitative results
- The Laser's current M^2 data analysis results
- The Laser's current real-time M^2 results (when real-time M^2 is on)
- The laser's After Lens results (when the **After Lens Results** checkbox is checked)

The After Lens results contains information about the beam in the after the lens region. This information is only useful if you want to perform some in-depth sanity checks on the M^2 -200s algorithms.

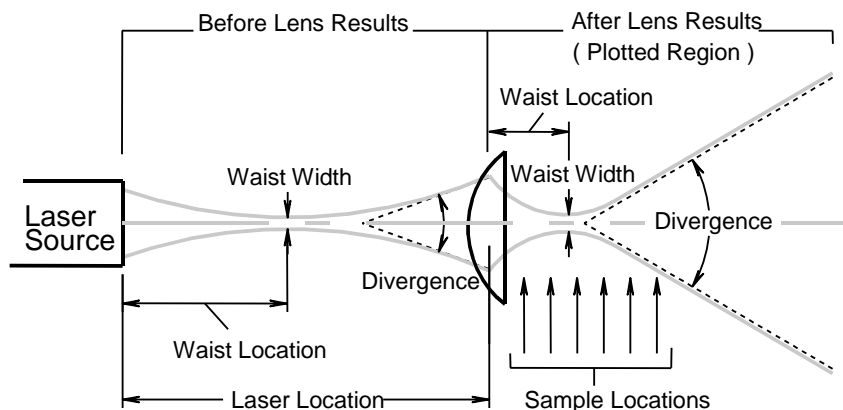


Figure 18. Beam Sampling Diagram

4.9.9 Is the Beam Energy Too High or Too Low?

In **Auto** mode, the M² system will inform the user when the external attenuation requires adjustment so that the internal attenuation will bring the beam's peak energy within the range of 50 to 90% of the camera's dynamic range.

- † In **Manual** mode, the operator is always responsible for adjusting the beam energy.

When the peak energy reported in the **Results** window falls below 50% of the camera's range, the beam profile does not present sufficient contrast from the background. The beam energy is too low (see Figure 19).

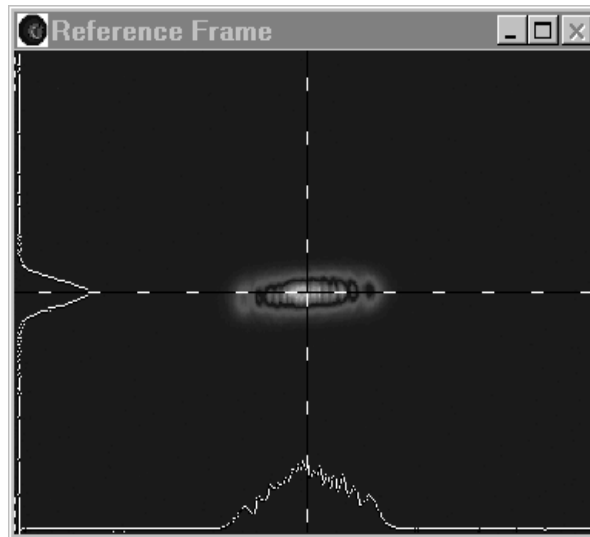


Figure 19. Beam Energy Too Low

To remedy this situation, reduce the attenuation.

If this cannot be done, consider skipping this data point. Use your own judgment as to when the beam intensity is too low to be useful. Between 30 and 50% of peak energy, a reasonably good measurement can still be made, especially in a low noise environment. This situation can often occur during the extreme ends of an M² run, particularly when measuring a low power laser.

When the peak energy reported in the results window is above 90% of the camera's dynamic range, the beam window displays saturated areas (white) where the beam intensity on the camera is too high (see Figure 20).

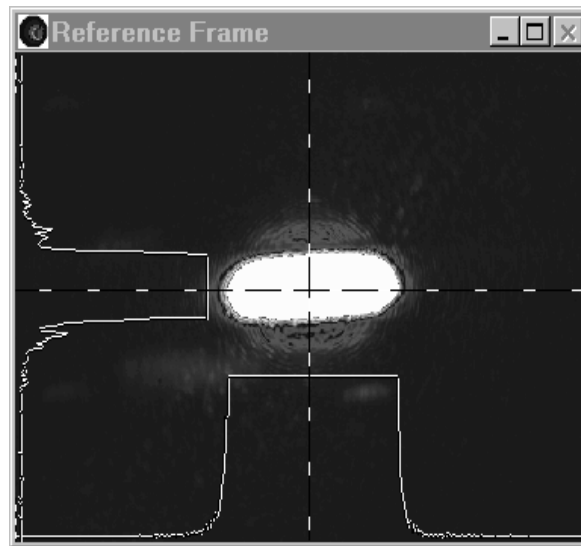


Figure 20. Beam Energy Too High

The beam intensity must be decreased in order to obtain an accurate measurement.

Figure 21 is an example of a beam with correct brightness.

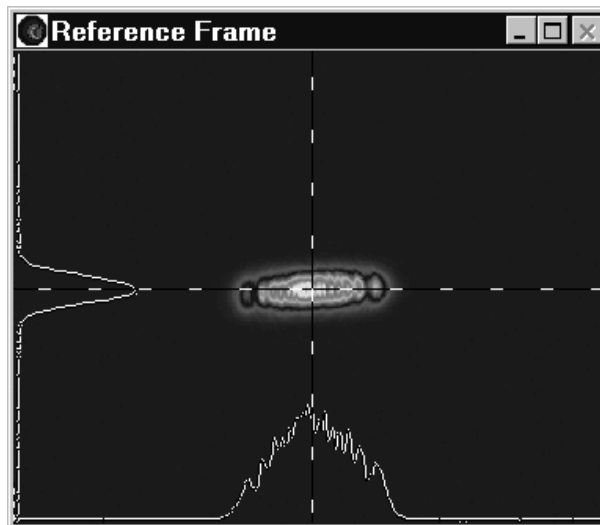


Figure 21. Appropriate Beam Energy

4.9.10 Using Statistics

The M²-200s system provides statistical capabilities in order to satisfy the ISO 11146 reporting requirements for a measurement. Enable **Statistics** in the **Computations** section of the **M² Setup** dialog box. Determine the number of full M² runs to include in the statistics by entering this value in the text box.

Always choose a minimum of at least 3 runs to obtain meaningful statistical results.

Mean, standard deviation, minimum, and maximum will be computed and displayed for all of the parameters in the M^2 results section.

4.9.11 Beam Axial Alignment

Notice in Figure 21 that the obviously asymmetrical beam is only somewhat well aligned with the camera axes.

Axial alignment is important for most all beams, except for those with true circularly symmetric profiles. For the beam shown, the results for the X and Y-axes, beam width, M^2 , waist location, width, etc. will not be the same.

Results calculated in rectangular coordinates by the M^2 -200s application will have the largest range of variation and contain the largest amount of information about the beam, if the camera axes coincide with the natural axes of the laser beam.

Rotate the camera to bring the natural axes of the beam into alignment with the camera axes. When this is completed, the profile in the beam window should inhabit an approximately two-fold symmetry about the X and Y-axes.

For the beam shown in Figure 21, notice that the profile is tilted slightly counter clockwise from the axes of the window. In this case, the camera should be rotated slightly to bring the axes into alignment.

The optional Ophir-Spiricon optical train includes a thumbscrew adjustment on the camera mount, providing free rotation to any angle.

4.9.12 Interpreting Real-time M^2 Results

The **Real-time M^2** capability provides valuable feedback to a technician during the tuning process, pursuant to creating a laser cavity, or making other adjustments to the laser. It also allows a laser operator to monitor whether or not unwanted changes occur during laser operation.

The divergence angles shown in the **Real-time M^2** results window provide useful and accurate measurements of the laser beam's divergence before entering the M^2 -200s optical train or the focusing lens of the user's optical rail. However, the **Real-time M^2** (or K) value is only the best possible estimate based on the change in the divergence of the beam.

The estimated beam quality factor is based on the assumption that the other beam propagation parameters are unchanged—an assumption that may or may not remain valid. To obtain a true final M^2 (or K) value after making changes to a laser, complete a full M^2 run.

4.10 Using The Four-Cuts Method

The Four-cuts method involves taking four essential samples along the length of the beam caustic to get a reasonably accurate M^2 measurement vs. the proscribed ISO method which requires the taking of at least 10 samples. The main purpose of the

method is to speed up the data acquisition process when speed is more important than precision.

The Four-cuts method, as implemented in the Spiricon M² application, will actually involve taking 6 cuts. This is for the purpose of making somewhat better divergence calculations, and for the handling of results in both the X and Y axes.

See section 2.8.2 for a discussion of the origin of the Four-cuts Method.

4.10.1 When to use the Four-Cuts Method

You can employ the Four-cuts method when you have the following prior knowledge of you laser:

- Your beam caustic shows only small or no significant amounts of astigmatism.
- Or, if astigmatism is present, the X and Y divergence values are somewhat similar so as to keep the 3 sample points beyond the Rayleigh range of either axis caustic.

In all cases, you have to have general knowledge of approximately where the focused waists are located and the Rayleigh lengths. This means at some point in the past you've performed a regular style run on this or a similarly known laser.

👤 The Four-cuts method cannot be employed in Manual Mode!

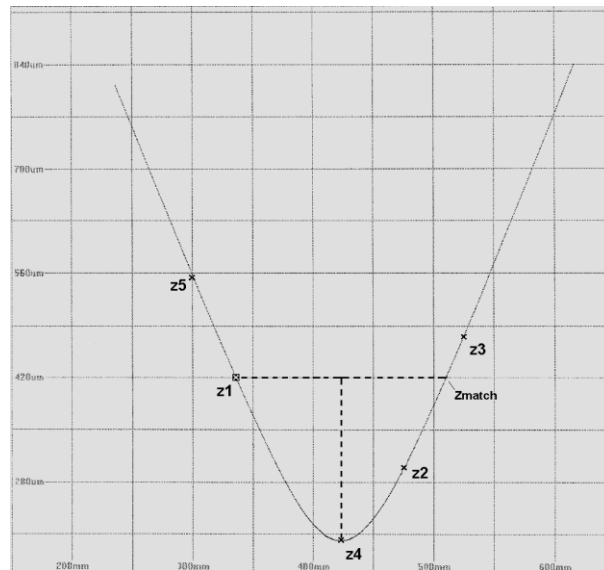


Figure 22. The Basic Four-Cuts Layout

4.10.2 Four-Cuts Basics

The first cut, z1, must be made along the beam path to the left of (before) the beam waist. The second and third cuts, z2 and z3, must be made to the right of (after) the beam waist. See Figure 22.

The z locations must be selected on the basis that the beam widths at z1-z2-z3 meet the criteria that $W_{z3} < W_{z1} > W_{z2}$ and that all three locations are outside the Rayleigh range $\pm Z_{R2}$ from the waist location z4.

The waist location z4 is computed by projecting the z1 beam width onto a linear interpolation of a line connecting the z2 and z3 beam widths, and then bisecting that line. This is shown as a dashed line in Figure 22.

These 4 data points are sufficient to fit the hyperbolic beam propagation equation, also shown in Figure 22.

A fifth sample, z5, can be taken at the lens focal length, and used to compute the input beam divergence as in the ISO method.

4.10.3 Four-Cuts on Two Axes

The M² application always treats lasers as if they have two orthogonal axes. Because of this, the Four-cuts method is expanded further and will compute results separately in the X and Y axial directions. Figure 23 shows how the two axis samples are taken. In this example, the beam has very little astigmatism and the divergence on each axis is very similar. Even so you should observe that the z1-z2-z3 cuts are placed beyond the Rayleigh regions furthest extent applying the Z_{RY} boundary on the left but the Z_{RX} boundary on the right.

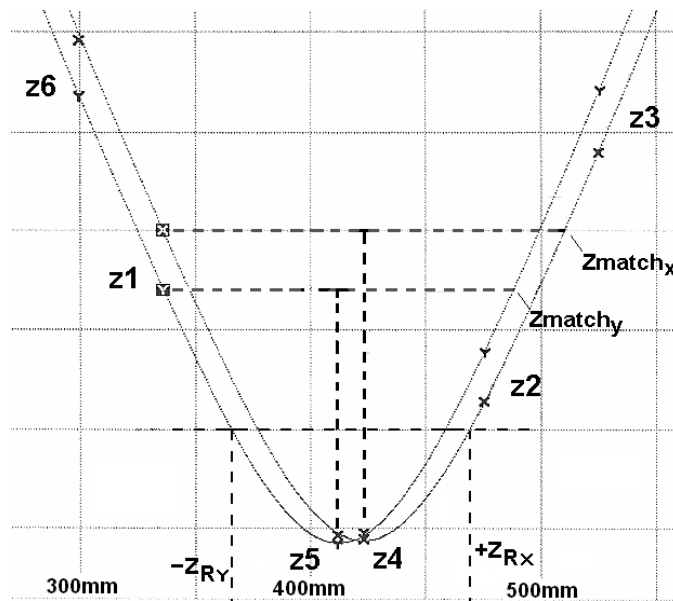


Figure 23. Four-cuts Two Axes

The z4 and z5 samples are the computed X and Y waist locations, respectively, and the new z6 location is made at the lens focal length. Figure 24 shows how this final layout is applied to the settings shown in the dialogue box. The Cut numbers correspond to the z#'s.

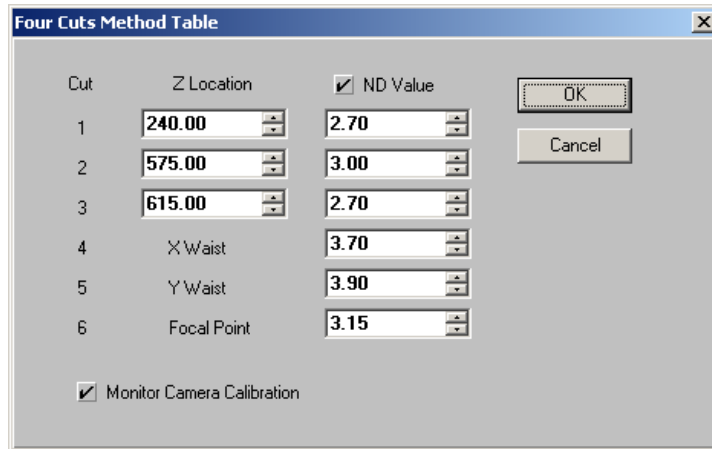


Figure 24. Four-Cuts Method Dialogue Box

It should be noted that the closer z2 and z3 can be placed without crossing the Zmatch planes, the better the calculation of the waist locations z4-z5. This occurs due to the curvature of the calculated fit between these two points. When they are placed in a region of greater curvature (such as occurs inside the Rayleigh lengths), the linear interpolation becomes less precise with respect to the real curve.

4.10.4 The Four-Cuts Setup

To really optimize the Four-cuts method requires that you also preset the ND filter values. The best way to do this is to examine the settings from an earlier run. The results of any good run can be used, either an **Auto Stepping** run or from a **Manual Step Table** setup loaded from a Manual Step table run. The results from a previous Four-cuts run are also a good place to start. Even if the Z locations are somewhat different, you should be able to derive a good estimate of a where to set the **ND value** for each Z location.

Don't forget to check the **ND Value** checkbox to make the entries go active. Otherwise the ND search algorithms will take over and the runs will end up slower rather than faster.

Unless your camera is still warming up you should avoid checking the **Monitor Camera Calibration** box, as it will only slow things down.

Chapter 5. Troubleshooting

This chapter is intended to assist the operator in identifying and correcting particular types of installation and measurement problems. While it is impossible to anticipate every problem that might arise, we have attempted to identify some of the most common and serious. Sources of difficulty can range from fatal hardware failures to a disconnected cable. In some instances, the message is merely informative and does not indicate anything actually wrong.

The first sections in this chapter will review the most serious situations. Usually these problems must be corrected in order to operate the M²-200s. Note that one error message may have several possible causes.

The later section involves messages that are more informative in nature.

In the event corrective measures suggested here prove unsuccessful, or an undocumented error message appears, please contact Ophir-Spiricon's Service Department for assistance.

5.1 Error Messages

This section presents a list of common error messages, their causes and possible remedies.

5.1.1 Motor Controller not found. M²-200 set to Manual mode.

This message indicates that the M² application could not find a motor controller. If the above message is observed check for one of the following problems:

- The motor controller is not receiving power.
- The motor controller's USB cable is not plugged in.
- You may have a defective USB port on your PC.
- The motor controller is defective.

This error message will also appear if **Cancel** is clicked during the Translation Table initialization phase. See section 5.2.4.

5.1.2 Table Move Failed. Move Error.

If the motor controller card does not receive confirmation from the optical train that a move has taken place, then this message will occur. This could indicate:

- a problem with the motor controller card
- a problem with the cable from the motor controller card to the optical train
- a problem with the power supply to the motor controller card
- a problem with the optical train.

To restore correct system operation, check all cables then exit and restart the M² application.

5.1.3 Translation Table Motor Not Responding

This message can occur in Auto mode after 3 minutes of trying to initialize the translation table. Likely causes are:

- loose or disconnected cables
- a disconnected or unplugged motor controller power supply

5.1.4 The Z Calibration value is too small for this table. You MUST correct the Z Fixture value to obtain accurate measurements.

If the operator has entered an unrealistic value into the Z Fixture edit control in the Advanced dialog box (found in the M² Setup dialog box), the M² application will detect the error and display this message. Correct the Z Fixture value. The correct Z Fixture value is provided with each optical train. See Appendix A.

5.1.5 Minimum pixel value is less than 1. Ultracal may not be as accurate as normal.

This error message can appear when the M² application is performing a camera baseline black level calibration. This calibration is essential for making accurate beam width measurements. This error can occur when the black level on a digital camera is set too low.

Accept this condition, with the understanding that your beam propagation results may not be as accurate as they should be, or abort operations and attempt to adjust the video offset on the digital camera such that the **Minimum** observed in the results window is always greater than approximately 2% of the camera range. Enter LIVE video mode with the laser beam blocked from the camera to make this adjustment.

5.1.6 Please block the beam.

This message may appear when the M² application performs a camera baseline black level calibration and the application detects that energy is still present on the camera's imager.

If this message appears while operating in manual mode, simply block the laser beam so that it does not reach the camera and retry the calibration.

If this message appears while operating in auto mode, it could indicate that the ND filter system has been temporarily shifted out of alignment. It could also indicate the presence of a light leak onto the camera imager. Check for these conditions and then restart the data collection process.

5.1.7 The beam is slightly misaligned or The beam is severely misaligned.

One of these messages may appear when the incoming beam has not been properly aligned along the axis of the optical train. Resolving this problem usually

requires realignment of the beam along the axis of the instrument. See section 4.6.3.

LIVE video mode automatically accompanies this message. This will permit immediate re-alignment of the laser beam by adjusting one of the external beam steering mirrors. After the beam is centered, click **Retry** to continue.

Note: *This technique is provided as a quick fix to a slight misalignment problem and should not be relied upon as a means for avoiding a proper initial beam alignment.*

If alignment of the beam using the external steering mirrors will not solve the problem, then internal components on the optical train may have shifted out of adjustment. This may be particularly pertinent if the unit has been recently shipped or has received a severe blow. In this case, the unit should be returned to Ophir-Spiricon for re-alignment and calibration. Contact Ophir-Spiricon's Service Department to make necessary arrangements.

5.1.8 The beam is too dim.

This error message will only appear in Auto mode and indicates that the instrument has removed all internal attenuation and the peak beam energy is still below 50% of the camera's dynamic range.

To correct this problem, reduce the external beam attenuation and click **Retry** to continue making measurements. If the external attenuation cannot be reduced any further, then skip this point (click **Skip**) or abort the run (click **Abort**). Click **End** to cease data collection and perform the computations using the accumulated data.

5.1.9 The beam is too bright.

This error message will only appear in Auto mode and indicates that the instrument has maximized internal attenuation and the peak beam energy is still too high (greater than 90% of the camera's dynamic range).

To correct this problem, add external attenuation and click **Retry** to continue taking measurements. Skip this point (click **Skip**) or abort the run (click **Abort**).

5.1.10 Logging Error Messages

This class of error message can result if logging is enabled but the entered file name or directory path has a problem. It may be that the directory did not exist or the filename contained illegal characters.

Note: *When a results logging error occurs, logging will be automatically disabled (i.e. the Results Logging check box will be unchecked).*

5.2 Informative Messages

Some messages displayed on the screen are merely informative statements that may not indicate an error. These messages inform the operator about certain conditions or request the confirmation of certain action. Some examples:

5.2.1 You pressed Stop! on the Menu bar.

While running in Auto mode the operator may stop the run at any time by clicking **Stop!** on the menu bar. The program will query as to how to proceed, providing several choices:

Click on **Continue** if the **Stop!** was inadvertent. This will cause the run to resume from where it left off.

Click **Abort** to cancel and terminate the run.

Click **End** to stop the run and perform the M^2 computations using the accumulated data. If **Stop!** is clicked before enough data points accumulate, then **End** will not be provided as an option.

5.2.2 Cannot compute M^2 results from data in the run.

Under certain conditions, acquired data will not yield a result consistent with a valid M^2 analysis. Such a situation might be encountered with a mode-hopping laser. This condition could also result from an unstable camera or light leaks from secondary sources.

Try to determine and correct the cause of the problem and attempt another measurement cycle.

5.2.3 File's camera does not match configuration camera. Do you want to change the configuration camera?

If an attempt to load a data file contains a camera configuration different than the current settings, this warning provides the opportunity to either cancel the loading operation or accept the changes.

Most of these configuration settings are associated with the camera. They include resolution, bits per pixel, energy calibration and pixel scale.

5.2.4 Initialization Messages.

When launching the M^2 application, a few initialization messages appear. These involve the initialization of the translation table and the ND filter wheels. The posted messages appear in the following order:

Initializing Translation Table.

Initializing Filter Wheel

During Translation Table initialization click **Cancel** to terminate the process early and force the system into Manual operating mode.

Note: *If you force this condition and then want to re-enable Auto mode, close and restart the M^2 application.*

Chapter 6. M²-200s Automation Server

The M²-200s Automation Server provides external control of the M²-200s from within such applications as Microsoft Excel, Visual Basic, and LabVIEW. The Automation Server provides access to frame data, beam display images, plot display images, and allows retrieval of all results and statistics values. The server runs under Windows operating systems.

Using the M²-200s Automation Server, you can:

- Start & Stop M² Auto Mode: Runs, Live Video, and Real-time
- Start & Stop M² Manual Mode: Live Video and Real-time
- Restore an M²-200s configuration from file
- Read new data frames and basic frame time and size information
- Read a bitmap image of the beam display
- Read a bitmap image of the plot display
- Read computed M²-200s and frame results
- Read M²-200s statistics results
- Change the translation table location in live mode
- Change the filter settings in live mode
- Save M²-200s data to a file
- Modify M²-200s setup dialog settings when stopped
- Select Auto or Manual Mode when stopped
- Perform Ultracal when stopped

Using the M²-200s Automation server, you cannot:

- Detect or handle M²-200s errors or error messages
- Modify an M²-200s configuration (except for the M² Setup dialog settings)
- Read random data frames (frames are sent in order during the run)
- Edit manual mode outliers
- Adjust the M²-200s cursor controls

6.1 Using Automation

Many modern development languages such as Visual Basic, Visual C++, and Borland C++ Builder support COM (Component Object Model). Many applications such as Microsoft Word, Microsoft Excel, and National Instruments LabVIEW also support COM objects.

There are two common types of COM object housings: "in-process" (such as ActiveX control housings) and "out-of-process," such as Automation executables. The COM interface for the M²-200s is provided through an out-of-process automation executable or as an "Automation Server".

Presented below are brief instructions on how to use the M² Automation Server in Microsoft Excel, Visual Basic, and LabVIEW.

6.1.1 Microsoft Excel

Microsoft Excel includes Visual Basic for Applications (VBA), an integrated programming platform that allows user-developed applications to function within spreadsheets.

Note: Refer to the example of this spreadsheet and macro located under the M²-200s installation directory: `\ActiveX Examples\Excel`. You may need to lower Excel's Macro security level to Medium in order to work with the example.

Follow these steps to access the M²-200s automation server in Microsoft Excel:

1. Create a new workbook in Excel.
2. On the **Tools** menu, select **Macro**, and then select **Visual Basic Editor**. A new VBA window will open.
3. Reference the M²-200s server:
On the **Tools** menu (in the VBA editor), select **References...** and scroll down to the "M2X Library" reference. Activate the checkbox.

Note: For this example, we will access the M²-200s Automation server within a form.

4. Create a new form:
On the Insert menu, select **UserForm**. A form will display in a new window.
5. Add four buttons to the form:
Click on the button control in the toolbox and then on the form.
In the properties window for each button, change the **Caption** fields to "Open", "StartLive", "Stop", and "Terminate".
6. Declare a variable to hold an M²-200s server object:
On the **View** menu, select **Code**. A new window will appear with an outline of the **UserForm_Click()** subroutine.
At the top of the code window, above the UserForm_Click function, enter:

```
Dim WithEvents M2XObject As M2X.M2ActiveX
```

7. Initialize the M2ActiveX object and launch the M² Application:
There are two list boxes at the top of the code window. In the left list box, select **UserForm**. In the right list box, select **Initialize**. A new subroutine called UserForm_Initialize() appears. Within this subroutine enter:

```
Set M2XObject = New M2X.M2ActiveX
```


This statement creates a new M²-200s Automation server object and assigns it to the M2XObject variable.

On the next line, enter:

```
M2XObject.Open  
M2XObject.Open
```

These statements launch the M²-200s application at runtime, if it is not already running. If the application is already running, this command will connect the server to the M²-200s application and mark it as "in use."

Note: "Open" must be issued once to launch the M²-200s application and issued again to connect to it. If "open" is issued twice while already connected, there is no effect. In this example, we will launch the application from the "Initialize" subroutine and connect when the user clicks the "Open" button.

- To finish up the initialization, set two server properties to tell the automation server to wait for the signal before sending a new frame:

Just below the "Open" call, enter two lines:

```
M2XObject.HoldNewFrame = true
M2XObject.NewFrame = false
```

The first of these two lines tells the automation server to wait for the signal before sending the next frame.

The second line provides the signal used to tell the server that we are ready for the next frame so go ahead and overwrite the current results and frame data properties.

Note: Each time the automation server receives a new frame and sees that we are ready for it, the automation server updates the properties, sets the "NewFrame" property to "true" and calls the OnNewFrame event.

- To respond to the "OnNewFrame" event:

Select the **M2XObject** in the left list box and edit the generated "M2XObject_OnNewFrame()" subroutine.

Within the subroutine, read the result values and write them to the Excel spreadsheet. For example:

```
Dim r As Long
For r = 0 To 5
    CellLocation = Format(r + 3, "B#")
    Range(CellLocation).Value = _
        M2XObject.QuantitativeResults(r)
Next r
```

The flag value sent with the event indicates the frame number received. It will enumerate each frame when running in auto mode. In Live and M² Real-time modes, the flag value = 0 for all frames.

- After reading the new frame data, set the NewFrame property to "false" to request the next frame from the automation server:

As the final line in the M2XObject_OnNewFrame() subroutine, enter:

```
M2XObject.NewFrame = False
```

- Click the **Run** button to execute the code.

Note: When the example application is started, the application will launch the M²-200s but you will need to initiate the connection between the M² server and M²-200s itself by pressing the Open button. Afterwards, press StartLive and the other buttons to call those routines.

When M²-200s is running in live mode it can only send you quantitative frame results. Read/write these new results while still inside the OnNewFrame event.

6.1.2 Visual Basic (Visual Studio)

In this section, Visual Basic refers to the Visual Basic part of the Microsoft Visual Studio 6.0 with Service Pack 6 installed. Follow these steps to use the M²-200s Automation server in Microsoft Visual Basic:

Note: Refer to the example of this spreadsheet and macro located under the M²-200s installation directory: `\ActiveX Examples\Visual Basic`

1. Start a new Visual Basic Project
2. Reference the M²-200s server:
On the **Project** menu select **References...** and scroll down to the "M2X Library" reference. Activate the checkbox.
3. Declare a variable to hold an M²-200s automation server object:
On the **View** menu, select **Code**. A new code window appears.
At the top, enter:

```
Dim WithEvents M2XObject As M2X.M2ActiveX
```

4. Initialize the M2ActiveX object and launch the M² Application:
There are two list boxes at the top of the code window. In the left list box, select **Form**. In the right list box, select **Initialize**. An outline of the `Form_Initialize()` subroutine is placed in the code window. Within this subroutine enter

```
Set M2XObject = New M2X.M2ActiveX
```


This statement creates a new M²-200s Automation server object and assigns it to the `M2XObject` variable.
On the next line, enter:

```
M2XObject.Open `this launches the application if not open  
M2XObject.Open `this connects the server to the application
```


This statement launches the M²-200s application, at runtime, if it is not already running. If the application is already running, this command will connect the server to the M²-200s application and mark it as "in use".

Note: "Open" must be issued once to launch the M²-200s application and issued again to connect to it. If "open" is issued twice while already connected, there is no effect. In this example, we will launch the application from the "Initialize" subroutine and connect when the user clicks the "Open" button.

5. Add four buttons to the form:
Click on the button control in the toolbox and then on the form.
In the properties window for each button, change the **Caption** field to "Open", "StartLive", "Stop", and "Terminate".
6. To finish up the initialization, set two server properties to tell the automation server to wait for the signal before sending a new frame:
Just below the "Open" call, enter two lines:

```
M2XObject.HoldNewFrame = true  
M2XObject.NewFrame = false
```

The first of these two lines tells the automation server to wait for the signal before sending the next frame.

The second line provides the signal used to tell the server that we are ready for the next frame so go ahead and overwrite the current results and frame data properties.

Note: Each time the automation server receives a new frame and sees that we are ready for it, the automation server will update the properties, set the "NewFrame" property to "true" then call the OnNewFrame event.

7. To respond to the "OnNewFrame" event:
8. Select M2XObject in the left list box and edit the generated "M2XObject_OnNewFrame()" subroutine.

Within the subroutine, read the results values and place them in a text box. For example:

```
Dim r As Long
For r = 0 To 5
    CellLocation = Format(r + 3, "B#")
    Range(CellLocation).Value = _
        M2XObject.QuantitativeResults(r)
Next r
```

The flag value sent with the event indicates the frame number received. It will enumerate each frame when running in auto mode. In Live and M² Real-time modes the flag value = 0 for all frames.

9. Click the Run button to execute the code.

Note: When the example application is started, the application will launch the M²-200s but you will need to initiate the connection between the M² server and M²-200s itself by pressing the **Open** button. Afterwards, press **StartLive** and the other buttons to call those routines.

When M²-200s is running in live mode it can only send quantitative frame results. Read/write these new results while still inside the OnNewFrame event.

6.1.3 LabVIEW

In this section we will create a LabVIEW Virtual Instrument to control the M²-200s. This example was written in LabVIEW 8.0. The methods described here will also work with LabVIEW 7.1. Earlier versions of LabVIEW that do not support the "Register for events node" will not be able to use these techniques. Refer to the LBA-PC LabVIEW examples to see how to use ActiveX event queues instead.

1. Open LabVIEW and create a "Blank VI."
2. On the block diagram place a stacked sequence structure with three frames:
On the Functions window select **Programming > Structures > Stacked Sequence** and stretch a box across the **Block Diagram** window.
Right click on the **Stacked Sequence** frame and select **Add Frame After**, repeat this action again. Press the left **Stacked Sequence** arrow key to bring up the first frame (frame 0).
3. Open a reference to the M² automation server:
On the functions palette, select **Connectivity > ActiveX > Automation Open** and place the automation open function on the block diagram.
Right click on the top left terminal (the **Automation Refnum** input) and select **Create Constant**. LabVIEW will auto generate an Automation Refnum constant on this input terminal.

On the generated Refnum, right-click and choose **Select ActiveX Class > Browse....** This will cause LabVIEW to scan your system for registered COM components.

When LabVIEW is done scanning, a dialog will open. Click on the drop down box arrow, scroll down to "M2X Library Version 1.0" and select it.

In the **Objects** group select M2ActiveX (M2X.M2ActiveX) and click **OK**.

4. Create controls to hold the quantitative results:

On the front panel, right-click and select **Modern > Numeric > Numeric Indicator**. Place the control on the front panel.

Copy the new control five times and give the six controls the following names: "Total", "Peak", "Min", "Width X", "Width Y", and "Z Location", respectively.

5. Create buttons:

On the Front Panel, right-click and select **Modern > Boolean > OK**.

Click on the form to place the new **OK** button.

Copy this button three times and give the buttons the following names: "Open", "StartLive", "Stop", and "Terminate".

6. Establish a picture control to display the beam image:

Right-click on the front panel and select **Modern > Graph > Controls > Picture** and place the new picture control on the front panel. Name it "M² Beam Display" and activate the vertical and horizontal scroll bars.

Note: *Eleven controls should now be present. The four button controls will simply send commands to the automation server. The seven other controls will display the quantitative results and the beam image while running.*

7. We will update these controls inside a callback VI that we must create to handle the new frame event. To do this we must first create a cluster of references to these controls and pass them into the callback VI. This allows the callback VI to obtain the automation server properties as well as the front panel controls we want it to update.

Right-click on each of the seven controls (the six numeric controls and the picture control) and select **Create > Reference**.

After creating the seven references, right-click on the block diagram and select **Programming > Cluster & Variant > Bundle**. Place and resize the bundle function to fit the seven control references, and the single reference to the M²-200s Automation Server. Wire the references to the bundle function.

8. Create a callback VI to handle the new frame event:

On the block diagram, right-click and select **Connectivity > ActiveX > Register Event Callback**. Place the node on the block diagram.

Wire the **Automation Refnum** output of the **Automation Open** node to "Event" input of the new callback registration node. Yes, this one you must take on faith!

Now from the "Event" drop down arrow, select "OnNewFrame". Wire the output of the bundle function to the "user parameter" input of the callback registration node. You are now ready to create that promised callback VI.

On the "VI Ref" input of the callback registration node, right-click and select **Create Callback VI**. Now admit it, that is the fastest VI you have ever made!

Save the new VI in the same directory as the top-level VI using a unique name.

We will use "NewFrame Callback.vi". Open the block diagram of the new VI.

9. In the new VI, unbundle the "user parameter" to access each of the references:

Right-click and select **Programming > Cluster & Variant > Unbundle**. Place the node and right click again and select **Connectivity > ActiveX > Property Node** and place the property node on the block diagram.

Now wire the output of the "user parameter" to the input of the "Unbundle" node. Then wire the M2X.M2ActiveX reference to the refnum input of the Property Node.

Resize the property node to access two properties. Using the Hand tool, click on the arrows on the node and select "QuantitativeResults" in the top property and "BeamBitmap" in the bottom property. These two properties are variants that to which we must assign a type in order to access their data.

Right-click on the block diagram and select **Programming > Cluster & Variant > Variant to Data**. Place two of these nodes on the block diagram. Wire the **Quantitative Results** output to the variant input one of the nodes you just placed and the Beam Bitmap output to the other.

The array type of the Quantitative Results is "1D array of double". The array type of the Beam Bitmap is "1D array of I32". Create two array constants of these types and wire them to their respective "Variant to Data" nodes.

For the Quantitative results, the output 1D-array will need to be indexed for each of the six results items. See section 6.2.1 below to learn the order in which these are items are provided.

Now place a Property Node for each of the seven controls you will be updating. Wire the references from the user parameter to the reference inputs of the Property Nodes. The Quantitative Results values you indexed out of the variant array of doubles should be wired to the "Value" property on each of the property nodes in their respective orders.

For the Bitmap Array of I32, you have one additional VI that must be used to get the bitmap data into a format that the picture control will understand. Right-click on the block diagram and choose **Select a VI...** Browse to the LabVIEW Examples folder under the M²-200s installation folder.

Locate the VI called "M2Bitmap.vi" and place it on your block diagram. Wire the output of the "Variant to Data" node to the input of this VI and the output of this VI to the input of the Picture Control. While there, view the example "NewFrame Callback.vi" to see if all your connections match the example. When completed, save this VI. You are now outfitted to handle the new frame event triggered by the automation server.

10. Setup the four buttons to send commands to the automation server:

Go back to the top-level VI where we placed the register for events node. Switch to the second sequence frame and place an event structure in a while loop. Add events for each of the four buttons.

In the event handler blocks for each event, call an "Invoke Node" on the Open, StartLive, Stop, and Terminate methods of the automation server.

In the last sequence frame, close the automation server with the "Automation Close" node found on the ActiveX functions palette. View the example VI to see one way this is done. Run the VI continuously. Remember to press the **Open** button before trying to issue any of the other commands.

Note: *This example only provides a sampling of the features controllable on the M²-200s. The remainder of this chapter provides all the important details.*

6.2 Properties, Methods, and Events

6.2.1 Properties

Not all properties may be set during video capture modes. The M²-200s must be stopped before setting parameters that affect settings in the **M² Setup** dialog. If an attempt is made to change an **M² Setup** dialog value during video capture, a COM exception will be thrown. When exceptions are thrown, read the `OperationError` property to see additional information about the error. All properties may be read at any time.

AppInfo

`AppInfo` is a read-only, two-dimensional array of integer packed as a Variant. The leftmost dimension is 0 to 31 and the rightmost is 0 to 2. This array contains information about Ophir-Spiricon applications that are running and available for connection via an automation server. When running more than one Ophir-Spiricon application in a single machine, inspect which of these applications is connected to an automation server and which is available for connection by examining first row of elements in this array. An Ophir-Spiricon application will only allow one server at a time to connect to it.

The `AppInfo` property is a two dimensional array of 32-bit values. Each row of the `AppInfo` array provides three 32-bit elements. The third element is unused. For the first and second elements, bits 1-31 of each element corresponds to array elements 1-31, respectively. Thus, if the `App Available Bits` appears as `[01100...0]` and the `In Use Bits` appears as `[01000...0]`, we know that there are two applications running (two bits are set to 1). The first application is in use by another automation server (its in-use bit is set to 1). The second application is available, but is not being used by another server (its in-use bit is set to 0). As such, we could use the `OpenIndex` method on the second application and gain a connection to it. The layout of the `AppInfo` array is as follows:

32 – App Available Bits	32 – App In Use Bits	Unused
First Application Type	Model of Product	Serial Number of Product
Second Application Type	"	"
Third Application Type	"	"
...

Application type contains values for the different types of M²-200s applications. `AppInfo` only sees and lists M² applications. Model and Serial Number will contain the Frame Grabber model and serial number.

Not all array rows will contain application information. Some rows may be all zero. If the application type is zero, then that row of the array does not contain application information. Each launched application will find the first empty row and place its information in that row. Once placed, it will remain in that row position for its process duration.

Running

Running is a read-only Boolean property and will remain true while the M²-200s collects frames of data.

OperationError

This is a read/write byte string property that logs error messages. Read this property after an error occurs to learn the reason for the failure. Write an empty string to the property to clear its value.

NewFrame & HoldNewFrame

The new frame read/write property is set to "true" each time the M²-200s sends the automation server a new frame of data. The HoldNewFrame read/write property tells the M²-200s not to send new frames of data until it is given the signal to do so. HoldNewFrame is "true" by default.

If HoldNewFrame is set to "false", M²-200s will update the M²-200s server and overwrite the current frame data and results values at will. This may not be desirable if each set of results must be obtained before they are overwritten. To signal M² to send a new frame of data, simply set the NewFrame property value to "false".

FrameData, FrameWidth, & Height

These read-only properties provide M²-200s data frames and info about the data. FrameData is a two dimensional array, double packaged as a Variant. The leftmost dimension is the number of rows and has the range 0 to FrameHeight - 1. The rightmost dimension is the number of columns and has the range 0 to FrameWidth - 1. The FrameData is in the same order as displayed in the M²-200s Beam Display Window, top to bottom and left to right.

The M²-200s automation server does not allow the user to view previously collected frames of data. Automation server users must store the data as it is sent and implement their own frame array indexing mechanisms.

FrameYear, FrameMonth, FrameDay

These read-only properties provide the date on which the frame was collected. To assure these values correspond to the current frame, read them before setting NewFrame to "false". All frame time stamps are based on the system clock.

FrameHour, FrameMinute, FrameSecond

These read-only properties provide the 24 Hour time on which the frame was collected. To assure these values correspond to the current frame, read them before setting NewFrame to "false". All frame time stamps are based on the system clock.

FrameMilliseconds

This read-only property provides the number of milliseconds after the time the frame was collected. To assure this value corresponds to the current frame, read it before setting New Frame to "false". All frame time stamps are based on the system clock.

PixelHScale, PixelVScale

These read-only properties are the horizontal and vertical pixel scales of the camera. The scale units are specified in the **Camera** dialog box.

BeamBitmap, PlotBitmap

These read-only properties are one-dimensional arrays of integers packaged as a Variant. This information can be used to create a Windows bitmap or a LabVIEW picture.

BeamBitmap and PlotBitmap are exact copies of the M²-200s Beam display and Plot display, respectively. If any display options are currently displayed on these windows, they will likewise be displayed on the Beam and Plot bitmap images. The data is packed in the arrays as follows:

BitmapInfoHeader Windows BITMAPINFOHEADER structure

Palette 256 element array of Windows PALETTEENTRY

Bits Two-dimensional array of byte. The size of this array is specified in the BitmapInfoHeader.biSizeImage.

In LabVIEW, convert these properties using the "Variant To Data" function and then pass the resulting array to the M2Bitmap.vi. The output from this VI is a LabVIEW picture. See the **\ActiveX Examples** folder under the folder where the M²-200s is installed.

In Visual Basic, pass these properties to the BitmapPicture function. The output from this function is a StdPicture that can be used anywhere a picture is allowed. See the Visual Basic example in the **\ActiveX Examples** folder under the folder where M²-200s is installed.

FrameNumber

Each M² run will produce an ordered collection of results and a data frame to match those results. These data samples are enumerated from 1 to a user specified number of samples. Frame number is a read-only property that will report the current sample enumeration. There is no enumeration for Live Video and Real-time modes; in these modes FrameNumber will always be zero. To assure this value corresponds to the current frame, read it before setting NewFrame to "false".

LaserModel

This read/write byte string property may be set to record information about the laser in use. Strings over 31 characters in length will be truncated.

SerialNumber

This read/write byte string property may be set to record information about the laser in use. Strings over 31 characters in length will be truncated.

CommentLine

This read/write byte string property may be set to record information about the laser in use. Strings over 31 characters in length will be truncated.

Note: For the following Properties, refer to Chapter 3 for a complete description of the possible values.

Wavelength

This read/write property is the wavelength of the laser under test.

FocalLength

This read/write property is the focal length of the lens at the laser wavelength under test.

AutomatedTableStepping

AutomatedTableStepping is a read/write property used to enable the Automated Stepping method for deciding where to collect frames during a run.

ManualStepTable

ManualStepTable is a read/write property used to enable the Manual Step Table method which specifies where to collect frames during a run.

FourCutsMethod

FourCutsMethod is a read/write property used to enable the Four-Cuts Method.

ZStart

ZStart is a read/write property used to enter the camera starting location.

ZStop

ZStop is a read/write property used to enter the farthest distance at which a sample may be taken.

ZStep

ZStep is a read/write property used to enter the step size between samples.

LaserLocation

LaserLocation is a read/write property used to set the optical path distance from the laser faceplate to the M²-200s faceplate.

M2Mode

M2Mode is a read/write property, which allows the user to switch between Auto and Manual modes.

BeamWidthMethod

BeamWidthMethod is a read/write short property, which allows the user to select between 4 Sigma, 90/10 Knife Edge and Knife Edge beam width measurement methods. The following values correspond to the listed method:

- 0** 4 Sigma
- 1** 90/10 Knife Edge
- 2** Knife Edge

StatisticsOn

StatisticsOn is a read/write Boolean value used to enable or disable the computation of statistical runs. Set this value to "true" to enable statistics.

NumberOfRuns

NumberOfRuns is a read/write property used to specify the number of samples in a statistical M² run.

AfterLensOn

AfterLensOn is a read/write property with enables After Lens Results when set to "true".

KDisplayOn

KDisplayOn is a read/write property value that causes the beam quality factor to display in terms of K as opposed to M², when set to "true".

FittedDivergenceOn

FittedDivergenceOn is a read/write property, which, if "true", causes the divergence to be calculated from a fitted curve of the data as opposed to the actual data.

AutoRemoveOutlierOn

AutoRemoveOutlierOn is a read/write property use to enable/disable the automatic outlier removal feature. Set to "true" to enable.

ZLocation

ZLocation is a read/write property used to set the current location of the Camera. This property may be used as you would the Z-Position Edit box on the M² applications toolbar. You may not change the ZLocation while running in auto mode.

NDFilter

NDFilter is a read/write property used to set the current ND filter value. The M²-200s allows users to specify a filter value on the toolbar. Once the user enters a value, the application will automatically adjust the wheel to the closest possible ND setting.

This control works in a similar fashion. When this property is set, the M²-200s may adjust the value depending on the available filters. After you set a filter, wait until the M²-200s triggers the OnFilterMoveDone event, and then read the property to find out the exact ND value that was used.

M2Results

M2Results is a read-only, one-dimensional array of results values packed as a variant. This property is made up of the Quantitative, Laser, Lens and Real-time Results values in a single array property. Values are reported as 0 until valid results are computed. Array layout:

Index	Result Description
0	Quantitative Aperture Total in raw pixel counts
1	Quantitative Beam Peak value in raw pixel counts
2	Quantitative Beam Min value in raw pixel counts
3	4 Sigma X Width -units as per camera dialog pixel units setting
4	4 Sigma Y Width -units as per camera dialog pixel units setting
5	Z Location of the acquired data frame in millimeters
6	Artificial (Lens) X Waist Width -units as selected in the camera dialog
7	Artificial (Lens) Y Waist Width -units as selected in the camera dialog
8	Artificial (Lens) X Divergence Angle in micro radians
9	Artificial (Lens) Y Divergence Angle in micro radians
10	Artificial (Lens) X Waist Location measured from the lens in millimeters
11	Artificial (Lens) Y Waist Location measured from the lens in millimeters
12	Artificial (Lens) X Rayleigh Range in millimeters
13	Artificial (Lens) Y Rayleigh Range in millimeters
14	X M ² or K result
15	Y M ² or K result
16	X BPP result
17	Y BPP result
18	Artificial Astigmatism
19	Artificial Asymmetry

Index	Result Description
20	Laser X Waist Width -units as selected in the camera dialog
21	Laser Y Waist Width -units as selected in the camera dialog
22	Laser X Divergence Angle in micro radians
23	Laser Y Divergence Angle in micro radians
24	Laser X Waist Location in millimeters
25	Laser Y Waist Location in millimeters
26	Laser X Rayleigh Range in millimeters
27	Laser Y Rayleigh Range in millimeters
28	X M ² or K result
29	Y M ² or K result
30	X BPP results
31	Y BPP results
32	Laser Astigmatism
33	Laser Asymmetry
34	Real-time X Divergence Angle in micro radians
35	Real-time Y Divergence Angle in micro radians
36	Real-time X M ² or K value depending on the KDisplay setting
37	Real-time Y M ² or K value depending on the KDisplay setting

QuantitativeResults

QuantitativeResults is a read-only, one-dimensional array of results values packed as a variant. This property is made up of the Quantitative results values in a single array property. Values are reported as 0 until valid results are computed. Array layout:

Index	Result Description
0	Quantitative Aperture Total in raw pixel counts
1	Quantitative Beam Peak value in raw pixel counts
2	Quantitative Beam Min value in raw pixel counts
3	4 Sigma X Width -units as per camera dialog pixel units setting
4	4 Sigma Y Width -units as per camera dialog pixel units setting
5	Z Location of the acquired data frame in millimeters

LaserResults

LaserResults is a read-only, one-dimensional array of results values packed as a variant. This property is made up of the Laser results values in a single array property. Values are reported as 0 until valid results are computed. Array layout:

Index	Result Description
0	Laser X Waist Width -units as selected in the camera dialog
1	Laser Y Waist Width -units as selected in the camera dialog

Index	Result Description
2	Laser X Divergence Angle in micro radians
3	Laser Y Divergence Angle in micro radians
4	Laser X Waist Location in millimeters
5	Laser Y Waist Location in millimeters
6	Laser X Rayleigh Range in millimeters
7	Laser Y Rayleigh Range in millimeters
8	X M ² or K result as per KDisplay setting
9	Y M ² or K result as per KDisplay setting
10	X BPP result
11	Y BPP result
12	Laser Astigmatism
13	Laser Asymmetry

LensResults

LensResults is a read-only, one-dimensional array of results values packed as a variant. This property is made up of the Lens results values in a single array property. Values are reported as 0 until valid results are computed. Array layout:

Index	Result Description
0	Artificial (Lens) X Waist Width -units as selected in the camera dialog
1	Artificial (Lens) Y Waist Width -units as selected in the camera dialog
2	Artificial (Lens) X Divergence Angle in micro radians
3	Artificial (Lens) Y Divergence Angle in micro radians
4	Artificial (Lens) X Waist Location measured form the lens in millimeters
5	Artificial (Lens) Y Waist Location measured from the lens in millimeters
6	Artificial (Lens) X Rayleigh Range in millimeters
7	Artificial (Lens) Y Rayleigh Range in millimeters
8	X M ² or K result
9	Y M ² or K result
10	X BPP result
11	Y BPP result
12	Artificial Astigmatism
13	Artificial Asymmetry

StatisticsResults

StatisticsResults is a read-only, 2-Dimensional array of results values packed as a variant. This property is made up of the M² Statistics results values in a single array property. Values are reported as 0 until valid results are computed. Array layout:

Index / Result	Mean	Dev	Min	Max
0 / Number of Runs	#	*	*	*
1 / Artificial (Lens) X Waist Width	"	"	"	"
2 / Artificial (Lens) Y Waist Width	"	"	"	"
3 / Artificial (Lens) X Divergence Angle	"	"	"	"
4 / Artificial (Lens) Y Divergence Angle	"	"	"	"
5 / Artificial (Lens) X Waist Location	"	"	"	"
6 / Artificial (Lens) Y Waist Location	"	"	"	"
7 / Artificial (Lens) X Rayleigh	"	"	"	"
8 / Artificial (Lens) Y Rayleigh	"	"	"	"
9/ X M ² or K result	"	"	"	"
10/ Y M ² or K result	"	"	"	"
11/ X BPP result	"	"	"	"
12/ Y BPP result	"	"	"	"
13/ Artificial Astigmatism	"	"	"	"
14/ Artificial Asymmetry	"	"	"	"
15 / Laser X Waist Width	"	"	"	"
16 / Laser Y Waist Width	"	"	"	"
18 / Laser X Divergence Angle	"	"	"	"
19 / Laser Y Divergence Angle	"	"	"	"
20 / Laser X Waist Location	"	"	"	"
21 / Laser Y Waist Location	"	"	"	"
22 / Laser X Rayleigh	"	"	"	"
23 / Laser Y Rayleigh	"	"	"	"
24 / X M ² or K results	"	"	"	"
25 / Y M ² or K results	"	"	"	"
26/ X BPP results	"	"	"	"
28/ Y BPP results	"	"	"	"
29 / Laser Astigmatism	"	"	"	"
30 / Laser Asymmetry	"	"	"	"

* place keepers

" statistical results value

RealTimeResults

RealTimeResults is a read-only, one-dimensional array of results values packed as a variant. This property is made up of the Real-time results values in a single array property. Values are reported as 0 until valid results are computed. Array layout:

Index	Result Description
0	Real-time X Divergence Angle in micro radians
1	Real-time Y Divergence Angle in micro radians
2	Real-time X M ² or K value depending on the KDisplay setting
3	Real-time Y M ² or K value depending on the KDisplay setting

6.2.2 Methods

Open

It is important to understand that the M2X server runs in a process that is completely separate from the M²-200s application. If the M2X server is running, it does not necessarily have control of the M²-200s. There may be more than one M²-200s running, yet the server can only control one of these applications at a time.

You must connect the M2X server to an M²-200s before any of the properties, methods or events will work. The easiest way to do this is with the Open method. This method will open the first instance of an available application it can find. This means it will open the lowest indexed entry in the AppInfo array that is currently available. For most setups there is only one M²-200s running and this method will quickly give you the connection you want. The Open method will return an integer value to communicate the success of the operation. The return values of this method:

Return Value	Meaning:
-3	The M2X server is already connected to M ² -200s
-2	M ² -200s was not running so one was launched
-1	No M ² -200s available, all are in use by other servers
0	Successfully connected to an M ² -200s
1	Failed to connect for some unknown reason

Call the Close method when finished to make the application available for connection.

OpenIndex

OpenIndex allows the application to specify to which M² application to connect. This method would be used after examining the AppInfo array and discover the need to pick from many running M² application. The return values of this method:

Return Value	Meaning:
-3	The M2X server is already connected to M ² -200s
-2	M ² -200s was not running so one was launched
-1	The specified M ² is in use by some other server.
0	Successfully connected to an M ² -200s
1	Failed to connect for some unknown reason

Call the Close method when finished to make the application available for connection.

Close

When the Open method is called, the AppInfo array is updated and the newly connected M²-200s is marked as in-use. The close method removes the in-use bit to make the M² application available again. If you do not call Close after Open, you will not be able to connect to the M²-200s until you kill and restart the M²-200s. The return values of this method:

Return Value	Meaning:
-2	Failed to access the available applications info
-1	There is no M ² -200s connected to close
0	Successfully closed the application
1	Failed to close the connection for some unknown reason

TerminateM2

Video capture must not be active when executing this method. If the application is capturing video, first call the stop method, and then call this method.

Return Value	Meaning:
-1	There is no M ² -200s connected to terminate
0	Terminated successfully
1	Failed to terminate for some unknown reason

LoadConfig

The M²-200s application must be in the stopped state in order to call this method. Call this method with a byte string giving the fully qualified name of the configuration to load.

Return Value	Meaning:
-1	There is no M ² -200s connected
0	Configuration loaded successfully
1	Failed - you cannot load a configuration while running
2	Failed - the specified path was too large for M ² -200s buffers

SaveData

Call this method with a fully qualified path to cause M²-200s to save the current data to a file. This method works like the **File > Save As...** menu command on the M²-200s. Stop the video capture in order to enable data saves.

Return Value	Meaning:
-1	There is no M ² -200s connected
0	Data saved successfully
1	Failed - you cannot save data while running
2	Failed - the specified path was too large for M ² -200s buffers

StartM2Run

Call this method to begin an M² run with the current configuration. The M²-200s must be in the stopped state to issue this command.

Return Value	Meaning:
-1	There is no M ² -200s connected
0	Command issued successfully
1	Command not allowed at this time

StartReal

Call this method, only after a valid M² run has been completed, to begin Real-time M² mode. The M²-200s must be in the stopped state to issue this command.

Return Value	Meaning:
-1	There is no M ² -200s connected
0	Command issued successfully
1	Command not allowed at this time

StartLive

Call this method to start live video capture mode. The M²-200s must be in the stopped state to issue this command.

Return Value	Meaning:
-1	There is no M ² -200s connected
0	Command issued successfully
1	Command not allowed at this time

Ultracal

Call this method to begin an Ultracal cycle. The M²-200s must be in the stopped state to issue this command.

Return Value	Meaning:
-1	There is no M ² -200s connected
0	Command issued successfully
1	Command not allowed at this time

Stop

Call this method from the M2-Run, Live Video or Real-time video capture states to stop the operation and return M²-200s to the stopped state.

Return Value	Meaning:
-1	There is no M ² -200s connected
0	Command issued successfully
1	Command not allowed at this time

6.2.3 Events

OnNewFrame

This event will trigger each time the M²-200s has valid data to send to the server. In Live Video mode, this event is called each time a new frame of data is captured. In Real-time mode, this event is called after real time results are finished computing for each new frame of data. In M2-Run mode this event is triggered only after a valid frame of data is found and a new set of X & Y points are added to the M² Plot.

Flag Value	Meaning:
#	The Frame number that applies to the new property/results values

OnEndM2Run

This event is called when the M²-200s has finished attempting/finished an M2-Run.

Flag Value	Meaning:
0	Unused

OnTableMoveDone

When the ZLocation property is set to a given value, wait for this event to trigger before proceeding. After this event triggers, re-read the ZLocation property to learn the actual location at which the translation table stopped.

Flag Value	Meaning:
0	Unused

OnFilterMoveDone

When the NDFilter property is set to a given value, wait for this event to trigger before proceeding. After this event triggers, re-read the NDFilter property to learn the actual ND setting that was acquired.

Flag Value	Meaning:
0	Unused

OnUltracalDone

When the Ultracal method is called, this event will fire when the Ultracal process is finished.

Flag Value	Meaning:
0	Unused

OnLoadConfigDone

When the LoadConfig method is called, wait for this event to trigger before reading the current setup parameters. This will assure that the property values read are the new values you intended.

Flag Value	Meaning:
0	Unused

6.3 DCOM

ActiveX is based on Component Object Model (COM) technology. Distributed COM (DCOM) extends COM to support communication among objects on different computers—on a local area network (LAN), a wide area network (WAN), or even the Internet.

The M²-200s automation server supports DCOM. The M²-200s automation server always runs on the M²-200s computer and can easily be configured for local or remote access. Whether local or remote, the Properties, methods, and events are the same as described above.

Local access is always the default. When M²-200s is installed, the M²-200s automation server is automatically registered for local access.

6.3.1 Enable Remote Access to the M²-200s Server Computer

To enable remote access to the M²-200s computer, follow these steps for Windows XP.

Note: Spiricon no longer verifies or certifies operation with Windows XP but these steps will provide a starting point.

1. Start DCOMCNFG: From the Start menu select **Run...**, enter 'dcomcnfg' and click **OK**.
2. Enable DCOM: Click the plus (+) symbol next to **Component Services** then the plus symbol next to **Computers**. Right click on **My Computer** and select **Properties**. On the **Default Properties** tab select the **Enable Distributed COM on this computer** check box. Click **OK**.
3. Configure the M²-200s Automation server: Click the plus (+) symbol next to **My Computer** then the plus symbol next to **DCOM Config**. Scroll down to the M2ActiveX entry. Right-click on M2ActiveX and select **Properties**. On the **Identity** tab, select the **Interactive user** radio button. Click **OK**.
4. Configure access from the remote (client) computer: There are two ways to allow access from the client computer—
 - a. Default Security: Changing the default security will affect all DCOM applications. From the **My Computer > Properties** window, click on the **Default COM Security** tab. Edit the **Access Permissions** and **Launch Permissions** to allow access from the remote computer.
 - b. Application Security: From the **M2ActiveX > Properties** window, click on the **Security** tab. Enable and edit the custom access and launch permissions to allow access from the remote computer.

6.3.2 Enable Remote Access from the Client (Application) Computer

To enable remote access from the application computer, follow these steps for Windows XP.

Note: Spiricon no longer verifies or certifies operation with Windows XP but these steps will provide a starting point.

1. Copy the M²-200s ActiveX server: Place a copy of the files **M2X.exe** and **M2X.tlb** on your application computer. These files can be found in the **M2-200\ActiveX** directory of the installation CD or the ActiveX subdirectory under the M²-200s installation directory on the M²-200s computer.
2. Register the M²-200s ActiveX server: From the directory where you copied the files, run **M2X.exe**. The M²-200s ActiveX server automatically registers itself then stops.

3. Start DCOMCNFG: From the **Start** menu select **Run...**, enter 'dcomcnfg' and click **OK**.
4. Enable DCOM: Click the plus (+) symbol next to **Component Services** then the plus symbol next to **Computers**. Right-click on **My Computer** and select **Properties**. On the **Default Properties** tab select the **Enable Distributed COM on this computer** check box. Click **OK**.

6.3.3 Automatic Remote Access

Automatic remote access means that when an M²-200s ActiveX server object is created on the application computer, DCOM automatically creates the object on the M²-200s computer. DCOM then manages communication as if the object were on the application computer.

To enable automatic remote access, specify the location of the M²-200s computer from the application computer:

Windows XP

1. Start DCOMCNFG: From the **Start** menu select **Run...**, enter 'dcomcnfg' and click **OK**.
2. Configure the client computer for automatic remote access: Click the plus (+) symbol next to **Component Services**, then the plus symbol next to **My Computer**, then the plus symbol next to **DCOM Config**. Scroll down until to the M2ActiveX entry. Right-click on **M2ActiveX** and select **Properties**. Click on the **Location** tab. Deselect the **Run application on this computer** check box.
3. Select the **Run application on the following computer:** check box. Enter the name of the M2-200s computer or click **Browse...** to browse the available network. Click **OK**.

6.3.4 Programmatic Remote Access

In Visual Basic, use the CreateObject function to create an object and specify the remote computer. See the Visual Basic documentation for more information.

In LabVIEW, the Automation Open VI contains a Machine Name input terminal where the remote computer can be specified. See the LabVIEW documentation for more information.

6.4 If you have a problem

- Start simple. Don't try to do everything in the first attempt. Start with a test application that simply creates an M²-200s ActiveX server object. On the M²-200s computer, a small window will briefly appear then disappear when the M²-200s ActiveX server object is created.
- Verify all the DCOM settings on both computers. Make sure to check both the default settings and the settings specific to the M²-200s ActiveX server.
- Reboot both computers after configuring DCOM on each computer.
- Minimize network problems. Remove all network protocols from both computers except one and try again.

Note: *The Default Protocols tab in DCOMCNFG appears to be only guidelines. Network protocols can still cause DCOM problems even if they are removed from the Default Protocols list. You must remove the protocol from your network connection.*

- Use Microsoft resources. Search Microsoft articles and knowledge base for an error code or error message. The Microsoft Developer Network web site, msdn.microsoft.com, contains a wealth of information for developers.
- Use National Instruments resources. The NI Developer Zone contains articles, examples, and a knowledgebase about using ActiveX with LabVIEW.
- Search news groups. There are many news groups devoted to COM/DCOM, OLE, ActiveX, etc. Use your favorite search engine to locate these news groups. Chances are someone has encountered the same problem in the past.
- We will be happy to help in any way we can, especially if the M²-200s ActiveX server or a supplied example is misbehaving or not operating as described in this user guide. However, since DCOM introduces so many variables that are beyond our control—especially related to protocols, connections, security, timeouts, etc.—we may be of limited help with your particular implementation. After all, the list of techniques and resources above is where we go when you call...

Appendix A Calibration Information

A.1 General

Each Optical Train system will ship with a calibration certificate that contains all of the calibration parameters related to the specific model in question. This also applies to units returned for periodic re-calibration.

Note: Information regarding the lenses may be omitted from the calibration certificate if the original lenses are not returned with the unit.

Each new optical train system will ship with a CD-ROM that contains:

- the latest M²-200s-FW software release
- copies of configuration files that have the calibration information preconfigured specific to the model and serial number of the optical train

A.2 Calibration of the M²-200s models

Each M²-200s-FW unit will have spatial calibration values as follows:

- A Z_{fixture} value that represents the **minimum** optical path length of the optical train measured from the front faceplate with the mirrors at their closest limit.
- A Z_{camera} value that represents the distance of the mounted camera's imager plane to the front faceplate.
- One or more Z_{lens} values that represent the distance of the lens principal plane to the front faceplate. One for each lens supplied.
- The focal length for each supplied lens.

In addition to the above spatial values, also supplied are one or more tables indicating the nominal ND values of the supplied filters at specified wavelengths.

The M²-200s model ships with three (3) standard lenses each coated for a different wavelength range. An optional fourth lens is also available. The UV coated lens is a plano-convex style and its focal length can vary significantly with changes in wavelength. The three (3) other lenses are Achromat designs and their focal lengths will not change significantly with variation in wavelength. The following figures are plots of the focal length shift for each of these four (4) lenses.

A.3 Plano Convex Lens Calibration Adjustments

The following table can be used to record entries for the supplied plano-convex lenses when used at different wavelengths. You will need to do the math and calculate the new focal length, see Equation 17. In most cases, the principle plane will not move significantly but you can compute the new Z_{lens} value with Equation 18.

Warning: Do not apply these equations to Achromat lenses.

Equation 17 – Focal Length Change vs. Wavelength

$$f_{\lambda} = \frac{f_{cal}(n_{cal} - 1)}{(n_{\lambda} - 1)}$$

Equation 18 – Z_{lens} vs Wavelength

$$Z_{lens\lambda} = (EFL_{cal} - BFL_{cal}) \frac{n_{cal}}{n_{\lambda}} + MountingHeight$$

Where: f_{cal} = the measured focal length of the lens at the calibration wavelength

f_{λ} = the calculated focal length of the lens at the desired wavelength

n_{cal} = the index of refraction of the lens material at the calibration wavelength (see table A.4)

n_{λ} = the index of refraction of the lens material at the desired wavelength (see table in A.4)

$Z_{lens\lambda}$ = the Z_{lens} value entry in the M² software

Mounting Height = 5.08mm for the M²-200s

Calibration Information:

Lens Part number	Cal EFL (mm)	Cal BFL (mm)	Cal f_{λ} (nm)		New f_{λ} (nm)	New EFL (mm)	New Z_{lens} (mm)	Notes

A.4 Lens Data

UV lens Assembly p/n 11402-002

Lens p/n 10571-015

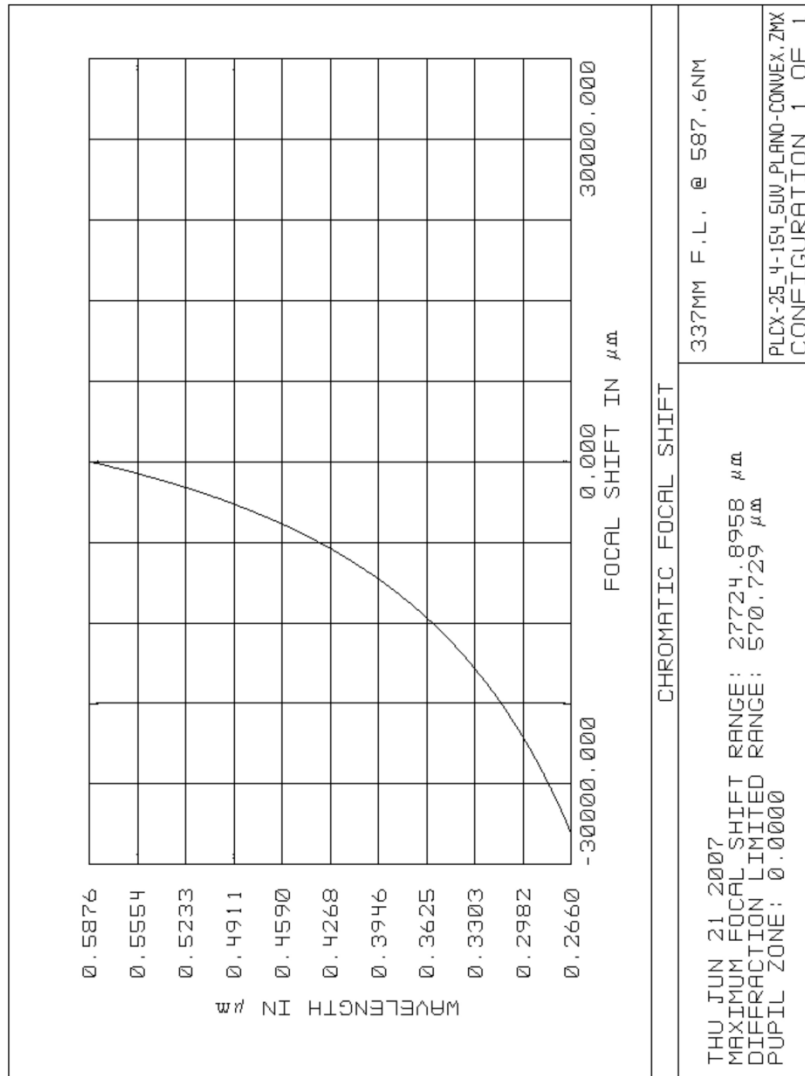


Figure A 1. Focal Length Shift for the Plano-convex UV lens

VIS lens Assembly p/n 11402-003

Lens p/n 11398-001

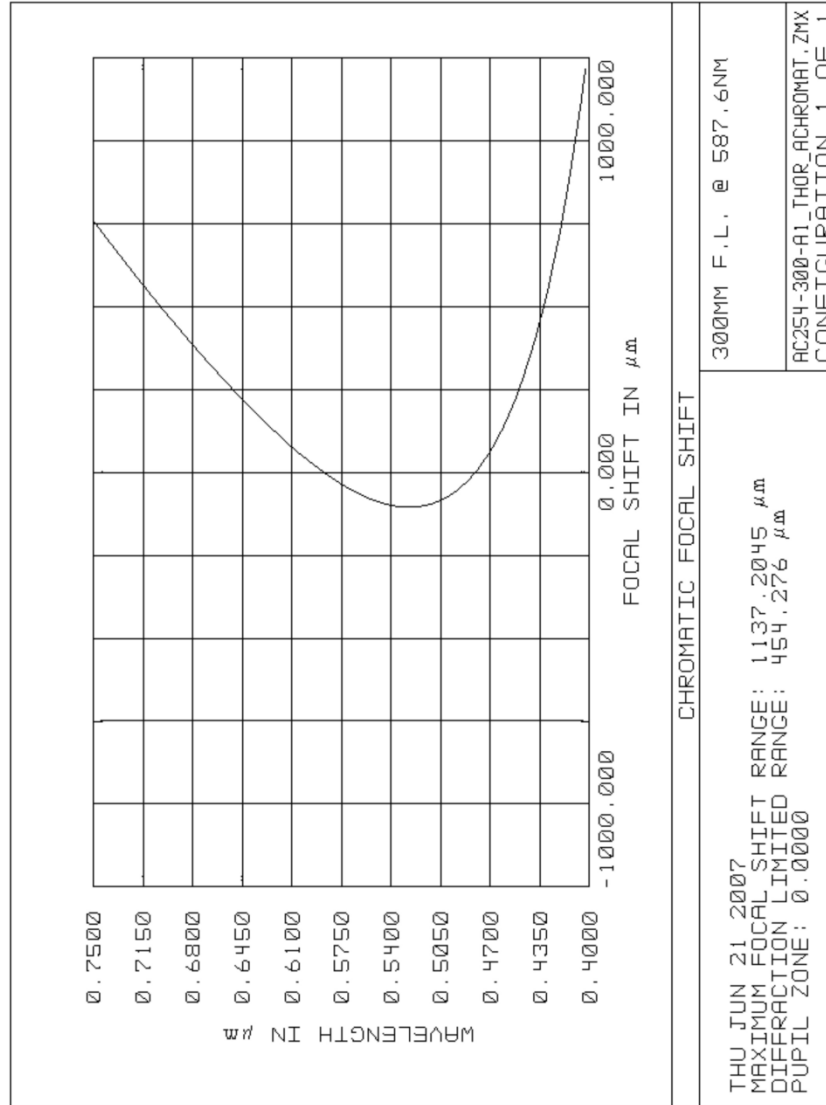


Figure A 2. Focal Length Shift for the Visible Achromat lens

NIR lens Assembly p/n 11402-004

Lens p/n 11398-002

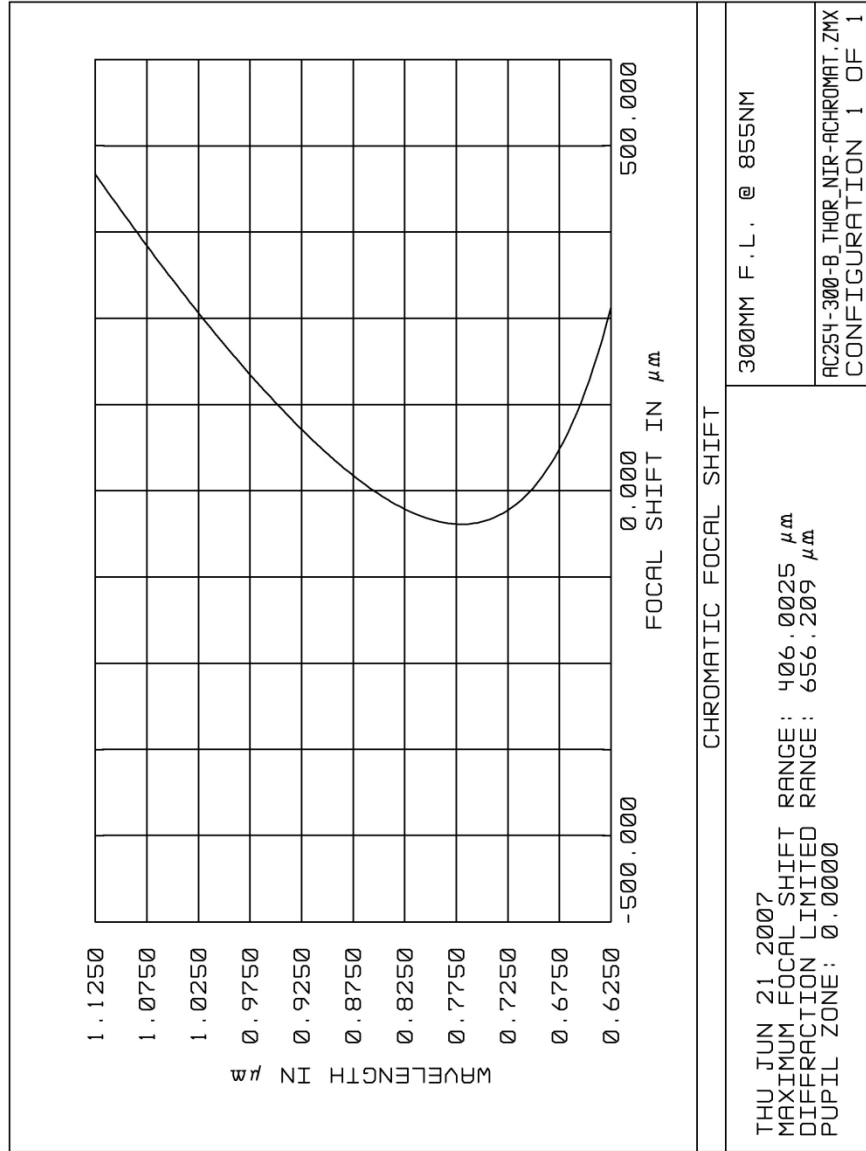


Figure A 3. Focal Length Shift for the NIR Achromat lens

Optional Telecom lens Assembly p/n 11402-001
 Lens p/n 11398-003

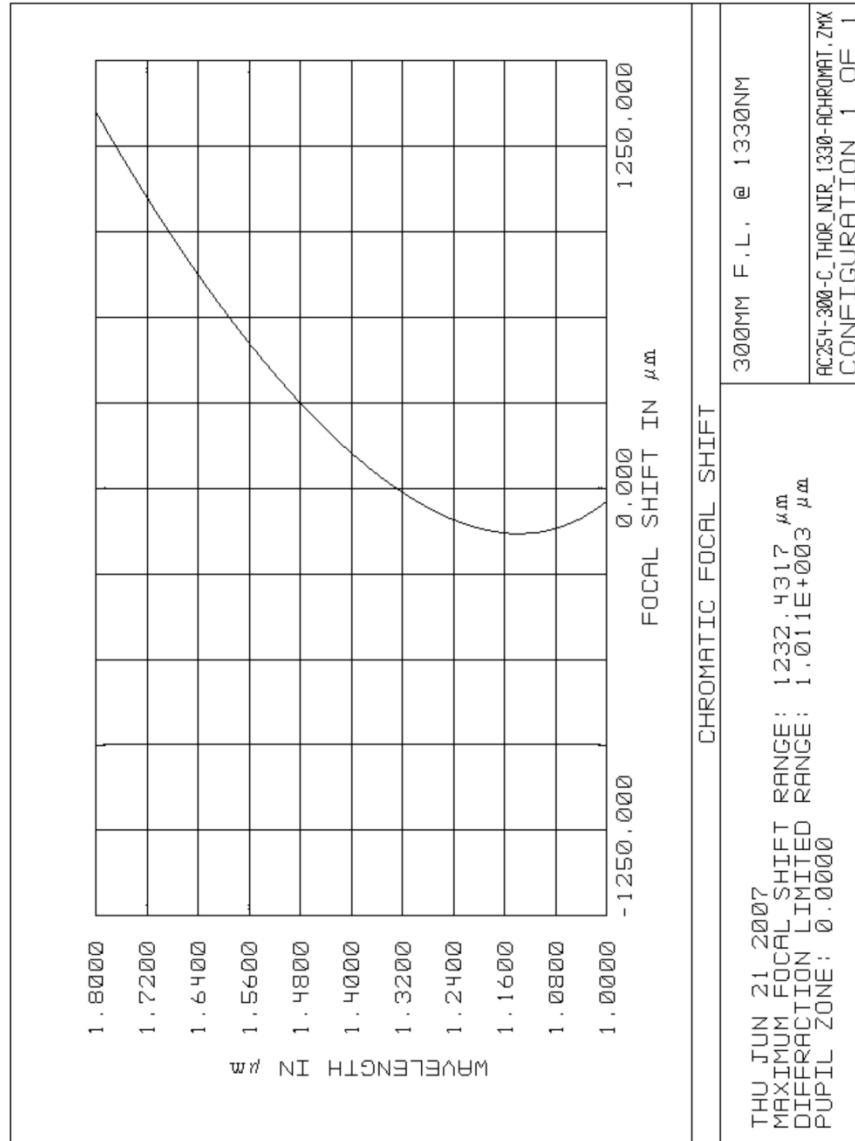


Figure A 4. Focal Length Shift for the Optional Telecom Achromat lens

A.5 Filter Table Setup Examples

The following are examples of filter wheel setups that might be encountered. Do not confuse these examples with your actual unit as these can vary significantly from time to time and model to model.

100 = Shutter, should be only one and in Wheel A

99 = Not Used Positions (empty positions will be filled with a shutter but marked 99)

BB = Broadband systems.

Note: Actual ND values and locations may vary.

ND Filter Setup for Visible bulk absorbing style ND filters

Calibration Wavelength: **632.8nm**

Index Position	Wheel A	Wheel B
0	0	0
1	.2	1
2	.3	2
3	.4	3
4	.6	4
5	.7	99
6	.8	99
7	100	99

Units are in N.D. numbers.
Wheel A is the driven wheel (i.e. furthest from the camera).

ND Filter Setup for Visible bulk absorbing style filters calibrated @1064nm

Calibration Wavelength: **1064nm**

Index Position	Wheel A	Wheel B
0	0	0
1	.36	1.08
2	.55	1.50
3	.41	2.10
4	.65	2.90
5	.76	99
6	.87	99
7	100	99

Units are in N.D. numbers.
Wheel A is the driven wheel (i.e. furthest from the camera).

ND Filter Setup for NIR bulk absorbing style filters.

Calibration Wavelength: **1064nm**

Index Position	Wheel A	Wheel B
0	0	0
1	.2	1.0
2	.4	2.0
3	.6	3.0
4	.8	4.0
5	99	99
6	99	99
7	100	99

Units are in N.D. numbers.
Wheel A is the driven wheel (i.e. furthest from the camera).

ND Filter Setup for old style BB Inconel filters.

Calibration Wavelength: **UV-NIR**

Index Position	Wheel A	Wheel B
0	0	0
1	99	.1
2	99	.2
3	99	.4
4	1.5	.6
5	1.3	.8
6	1.0	1.5
7	100	99

Units are in N.D. numbers.
Wheel A is the driven wheel (i.e. furthest from the camera).

ND Filter Setup for Hybrid systems that use both Inconel and bulk absorbing style filters.

Calibration Wavelength: **266-800nm**

Index Position	Wheel A	Wheel B
0	0	4.0*
1	.2	99
2	.4	3.0*
3	.6	99
4	.8	2.0*
5	99	99
6	99	1.0*
7	100	0

Units are in N.D. numbers.
 Wheel A is the driven wheel.
 *Inconel style filters

ND Filter Setup for Hybrid systems that use both Inconel and bulk absorbing style filters.

Calibration Wavelength: **800-1300**

Index Position	Wheel A	Wheel B
0	0	99
1	.2	4.0*
2	.4	99
3	.6	3.0*
4	.8	99
5	99	2.0*
6	99	1.0
7	100	0

Units are in N.D. numbers.
 Wheel A is the driven wheel
 *Bulk style filters calibrated @ 1064nm

A.6 Refractive Index of Common Lens Materials*

Wavelength (nm)	BK 7	UV Fused Silica
180.0	-	1.58529
190.0	-	1.56572
200.0	-	1.55051
213.9	-	1.53431
230.2	-	1.52008
248.3	-	1.50840
265.2	-	1.50003
280.3	-	1.49404
296.7	-	1.48873
330.3	-	1.48054
351.1	1.53894	1.47671
404.7	1.53024	1.46962
435.8	1.52669	1.46669
441.6	1.52611	1.46622
457.9	1.52462	1.46498
476.5	1.52310	1.46372
486.1	1.52238	1.46313
488.0	1.52224	1.46301
496.5	1.52165	1.46252
514.5	1.52049	1.46156
532.0	1.51947	1.46071
546.1	1.51872	1.46008
587.6	1.51680	1.45846
589.3	1.51673	1.45840
632.8	1.51509	1.45702
643.8	1.51472	1.45670
656.3	1.51432	1.45637
694.3	1.51322	1.45542
706.5	-	1.45515
786.0	1.51106	1.45356
820.5	1.51037	1.45298
830.0	1.51021	1.45282
852.1	1.50981	1.45247
904.0	1.50894	1.45170
1014.0	1.50731	1.45024
1060.0	1.50669	-
1064.0	-	1.44963
1100.0	-	1.44920
1200.0	-	1.44805
1300.0	1.50371	1.44692
1400.0	-	1.44578
1500.0	1.50130	1.44462
1550.0	1.50068	1.44402
1660.0	-	1.44267
1700.0	-	1.44217
1800.0	-	1.44087
1900.0	-	1.43951
1970.1	1.49500	-
2000.0	-	1.43809
2100.0	-	1.43659
2325.4	1.48929	-

* This table does not apply to Achromat lenses, just plano-convex

Appendix B Replacement Parts

B.1 Common replacement parts and optional components

Part Number	Description
11404-020	Inconel ND 0.2 filter
11404-040	Inconel ND 0.4 filter
11404-060	Inconel ND 0.6 filter
11404-080	Inconel ND 0.8 filter
11404-100	Inconel ND 1.0 filter
11404-200	Inconel ND 2.0 filter
11404-300	Inconel ND 3.0 filter
11404-400	Inconel ND 4.0 filter
10855-200	Bulk Abs. ND 2.0 filter, 1064nm
10855-300	Bulk Abs. ND 3.0 filter, 1064nm
10855-400	Bulk Abs. ND 4.0 filter, 1064nm
Slug-1"	Shutter Disk, Black, 1" dia
11377-001	Mirror, 2" dia, UV enhanced alum.
11408+100	Do-it-yourself, A-Filter Wheel Kit, w/o ND Filters
11408+101	Do-it-yourself, B-Filter Wheel Kit, w/o ND Filters
11379+001	Assy, Pinhole aligner, complete
VISIR1	Pinhole disk, w/1064nm phosphor
FW10024-D5+	Power Supply, 24Vdc, 4Amp
11402-001	Lens Assy, Telcom, 300mm fl
11402-002	Lens Assy, UV, 300mm fl
11402-003	Lens Assy, VIS, 300mm fl
11402-004	Lens Assy, NIR, 300mm fl
11368-001	C-mount camera adapter tube
11396+006	6 ft. Extension Cable, ND Filter Assy
11397+001	Ribbon Cable, ND Filter Assy