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interferometer

Buccini Interferometer

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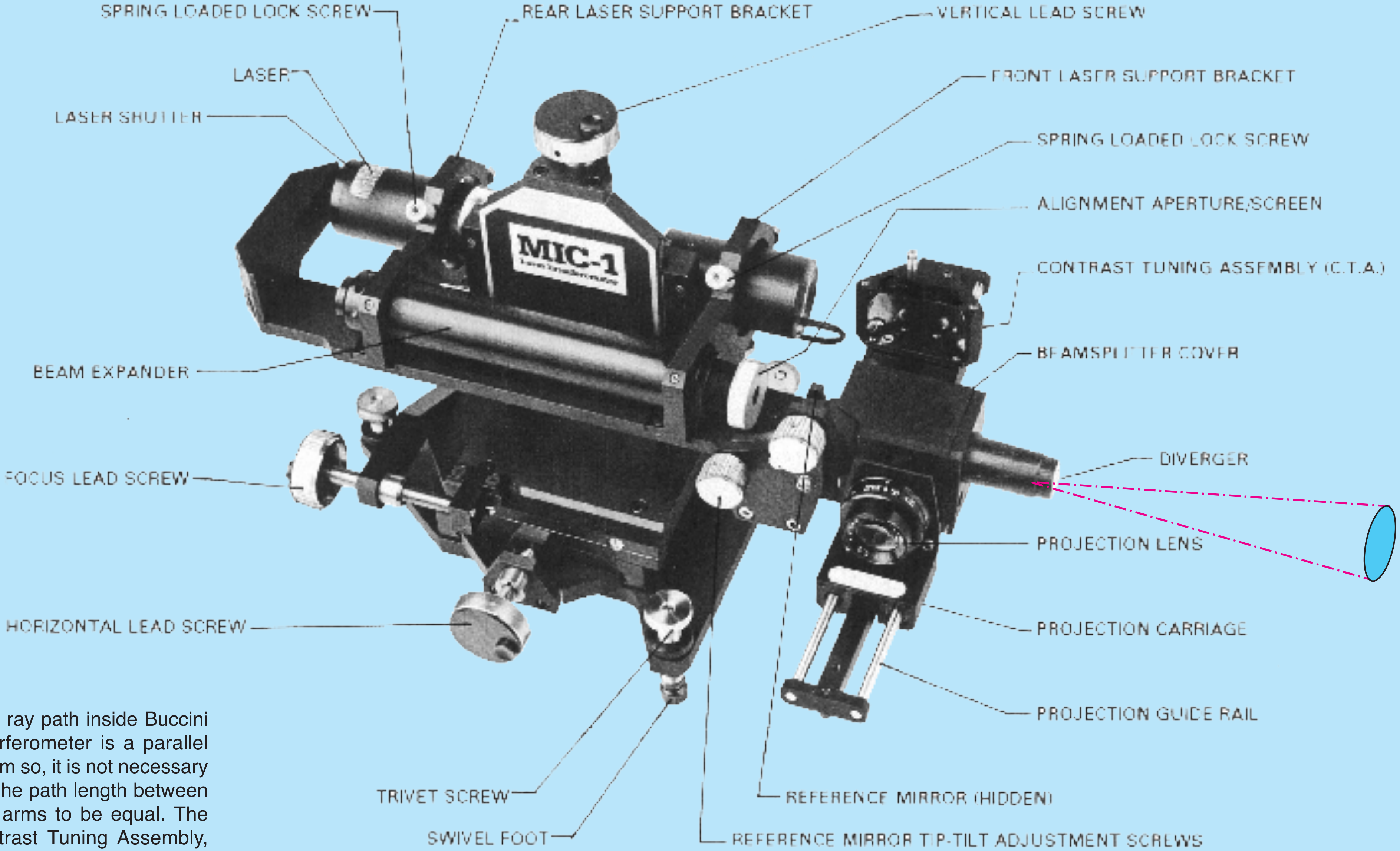
Technical journal of OMiD, Opto-Mechanical Institute of Design

BUCCINI INSTRUMENT COMPANY



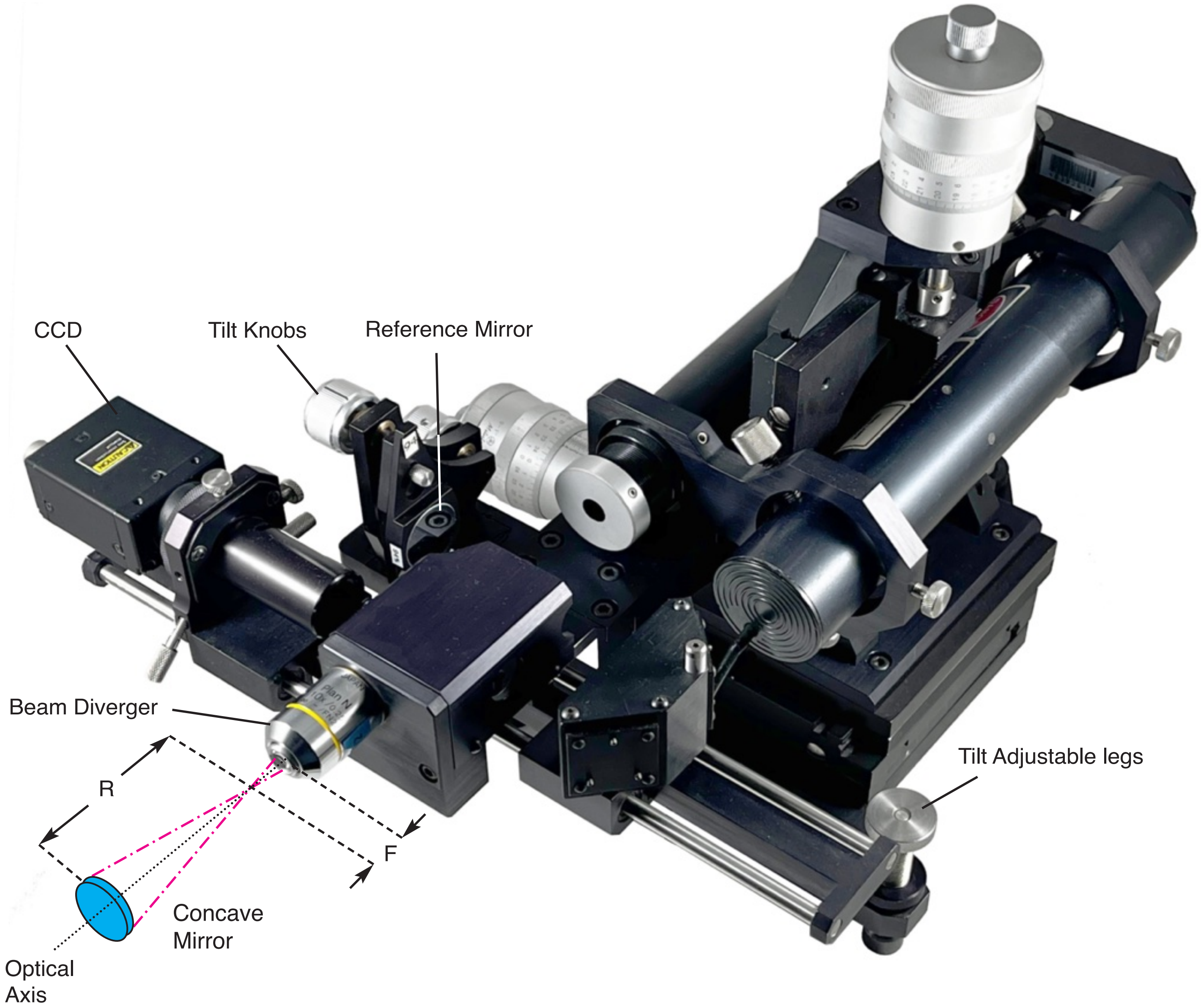
The ray path inside Buccini interferometer is a parallel beam so, it is not necessary for the path length between the arms to be equal. The contrast Tuning Assembly, would normally be utilized for contrast enhancement, not as a delay line.

Buccini Interferometer

Buchini interferometer was designed by Jon Buccini, and meticulously hand crafted to a fine instrument. He built this instrument as if he wanted to build it for himself. John had his own machine shop, and must have hand made its first prototype. Every detail in this instrument is beautifully made, and assembled together to perfection. Only a machinist like myself could tell the detailed attention he must have paid on knurling of the control knobs, the surface finish, and close fit of its modular parts. He probably didn't get rich over this work, but that's not how I value things in the optical industry. I spent a month studying his design, and it was as if I sat with him in person, and he answered all my questions.

We'll test some optical elements, then build a beam reducer (reversed beam expander) to get the surface profile of the polished end of an optical fiber.

Ali Afshari
Editor in Chief
Optomechanix



Buccini interferometer uses folding optics to reduce its original length from 600 mm down to less than 300 mm.

Michaelson Interferometer

It's the simplest form of interferometer named after Michaelson who built it to measure the diameter of a star. I have posted a Youtube video covering his experiment. It uses a beamsplitter to combine two beams coming from a monochromatic light source such as a laser. The basic setup utilizes a spatial filter (Fig.1) to clean up the laser light by focusing it on a 5-10 micron pinhole. This causes the beam to spread out after passing through pinhole according to the f number of the lens (F/D). The beam is then collimated using a larger focal length lens, i.e., F = 150 mm to cover a large portion of the beamsplitter, and the other two mirrors for interference. By the way, the lenses don't have to be achromats because we are dealing with monochromatic light, but if using a singlet, it must have been designed for the wavelength of the laser to have minimum aberrations. Going back to the spatial filter, it works by filtering the unwanted beams coming out of the laser beam by allowing only the center rays to pass through the pinhole. The result is a clean uniform beam suitable for interferometry.

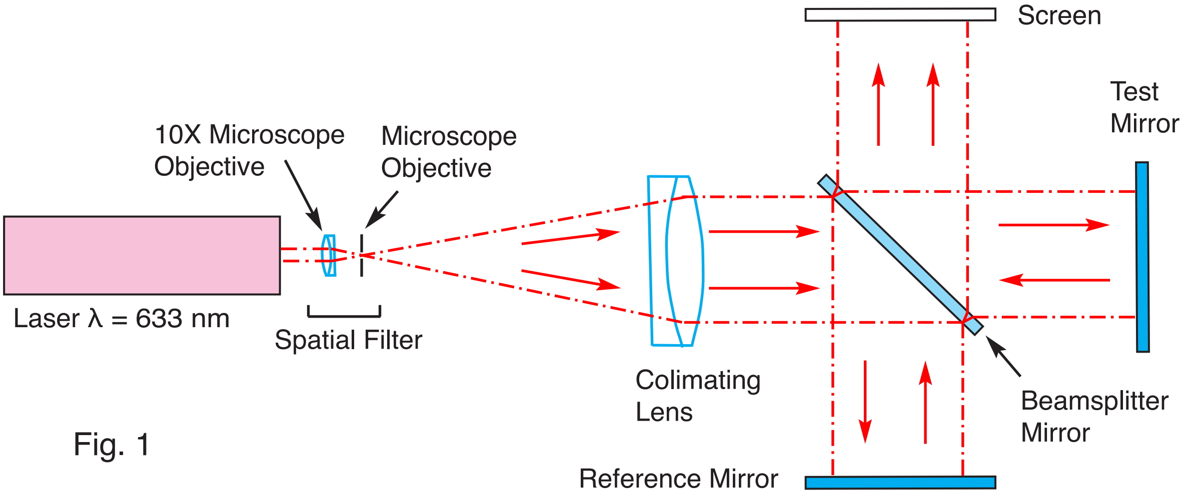


Fig. 1

In its basic arrangement above, Michaelson interferometer could be utilized in testing purposes. The test mirror's surface accuracy is basically checked against the surface flatness of a highly flat reference mirror. Any deviation of the test mirror's interference pattern from perfectly concentric fringes would reveal any errors across the test mirror (above).

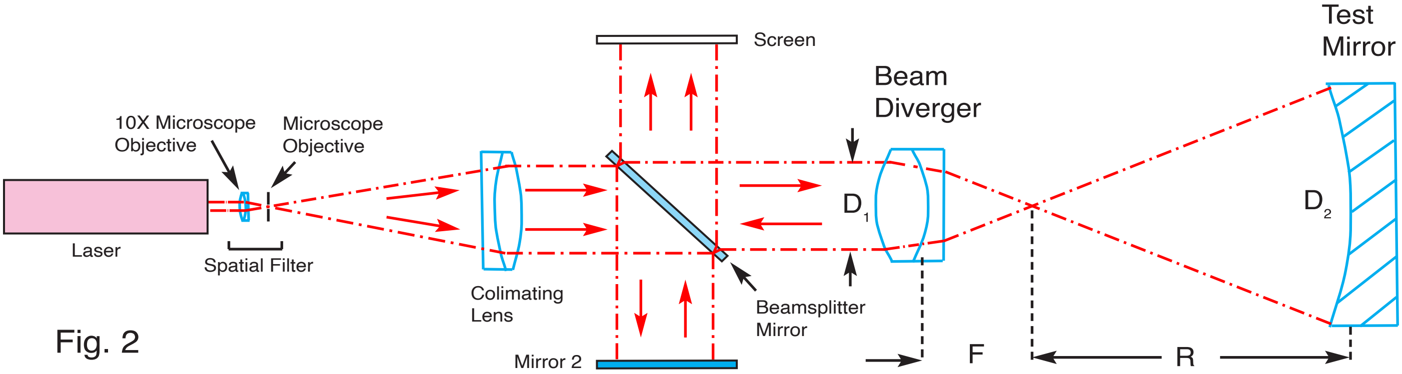
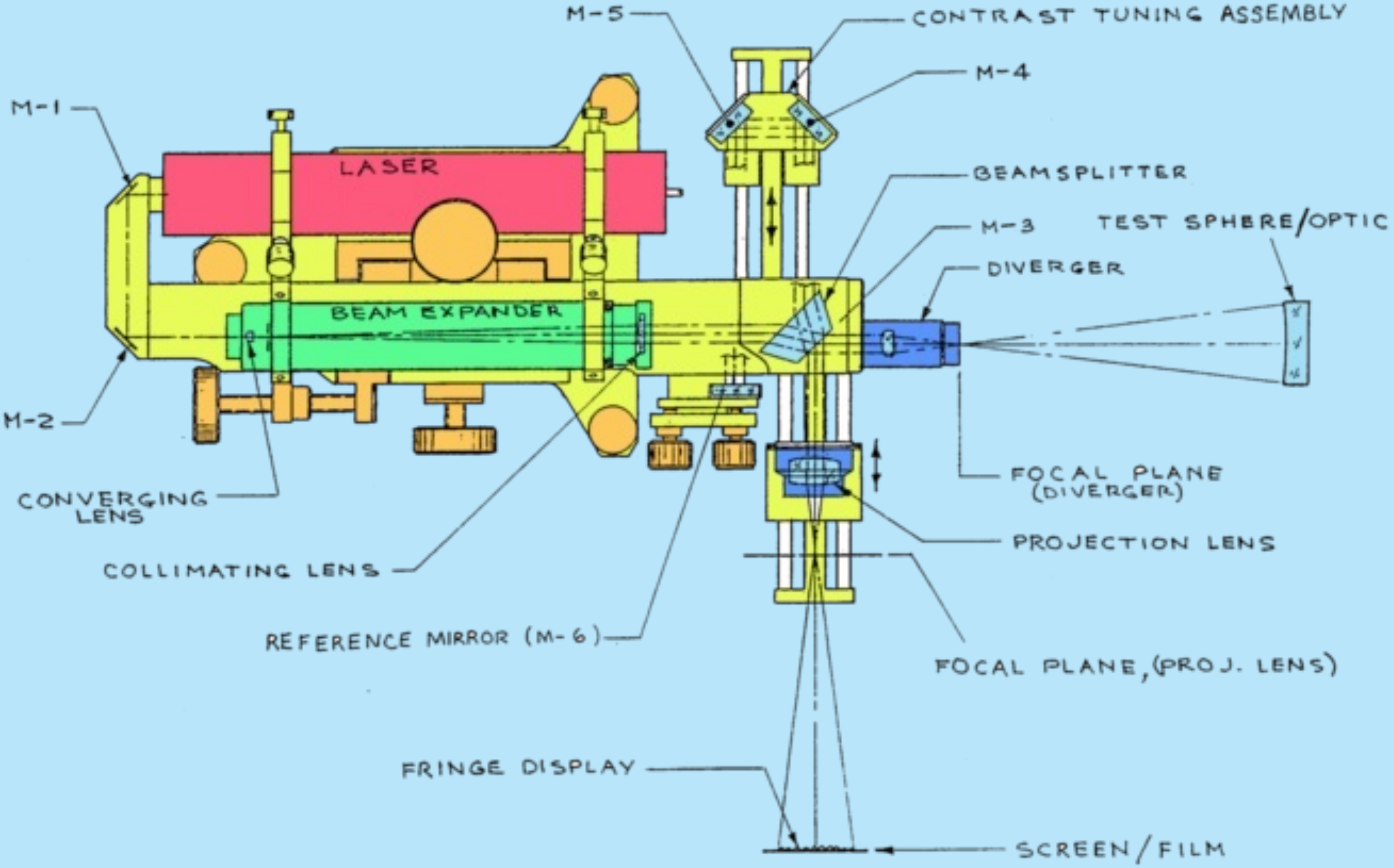


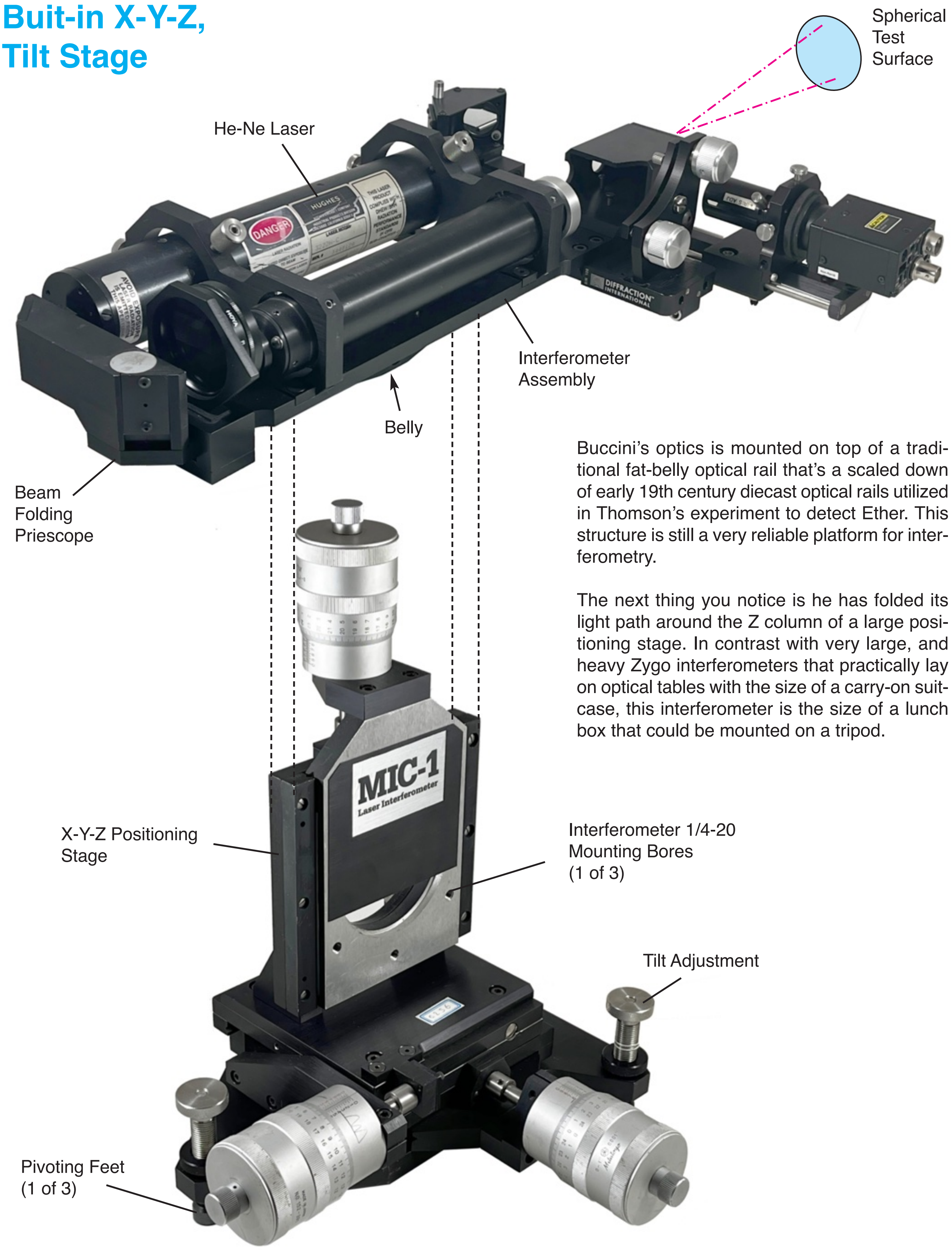
Fig. 2

Testing a Spherical Mirror

Fig. 2 shows the Michaelson interferometer discussed earlier to test the surface accuracy of a spherical mirror. The flat test mirror in Fig.1 is now replaced with a beam diverger to focus the beam at its focal point F. The beam then diverges out to cover the surface of a spherical mirror. Basically to cover the entire surface of the test mirror, the f number of the beam diverger F/D_1 should match the f number of the test mirror 2R/D. In this arrangement, we are comparing the curved surface of the spherical mirror with a perfectly flat (1/10 λ or better) reference mirror. I have seen reference mirrors as good as 1/20 wave. I will show you how the wavefront is curved through the beam diverger to match the curvature of the spherical mirror, and how it gets flat again when it goes back through the diverger.


M-5
CONTRAST TUNING ASSEMBLY
M-4
M-1
LASER
BEAMSPLITTER
M-3
TEST SPHERE/OPTIC
DIVERGER
BEAM EXPANDER
M-2
FOCAL PLANE (DIVERGER)
CONVERGING LENS
PROJECTION LENS
COLLIMATING LENS
REFERENCE MIRROR (M-6)
FOCAL PLANE, (PROJ. LENS)
FRINGE DISPLAY
SCREEN/FILM

Buit-in X-Y-Z, Tilt Stage



Buccini's optics is mounted on top of a traditional fat-belly optical rail that's a scaled down of early 19th century diecast optical rails utilized in Thomson's experiment to detect Ether. This structure is still a very reliable platform for interferometry.

The next thing you notice is he has folded its light path around the Z column of a large positioning stage. In contrast with very large, and heavy Zygo interferometers that practically lay on optical tables with the size of a carry-on suitcase, this interferometer is the size of a lunch box that could be mounted on a tripod.

Buccini's overall compact design: The X-Y-Z / Tilt stage is sandwiched between the laser tube, and beam expander. The X-Y-Z stage is controlled by three 2" diameter Mitutoyo mics, whereas the tilt adjustment screws have pivoting feet. This simple but reliable design has +/-25 mm XYZ positioning, and +/- 10° tilt adjustment range to handle a variety of surface testing challenges.

How to Use Buccini Interefromter

Buccini interferometer uses a microscope objective to send out a beam focused at its focal point (below). To test a telescope mirror, this beam then diverges out like a cone to cover its entire surface. This is why Buccini offered different objectives to match the f-number of the mirror such as f/4, f/8 or f/10. One of the challenges in examining such spherical mirror (such as found in Celestron Schmidt telescopes) is to focus the focal point of the interferometer's microscope objective on the exact focal radius of the mirror. That's where Buccini's X-Y-Z stage becomes useful because both axis must be precisely in line, and that's where the tilt stage is also utilized. As shown below, the wavefront coming back from the test mirror is checked against the perfect surface of a reference flat mirror inside the instrument.

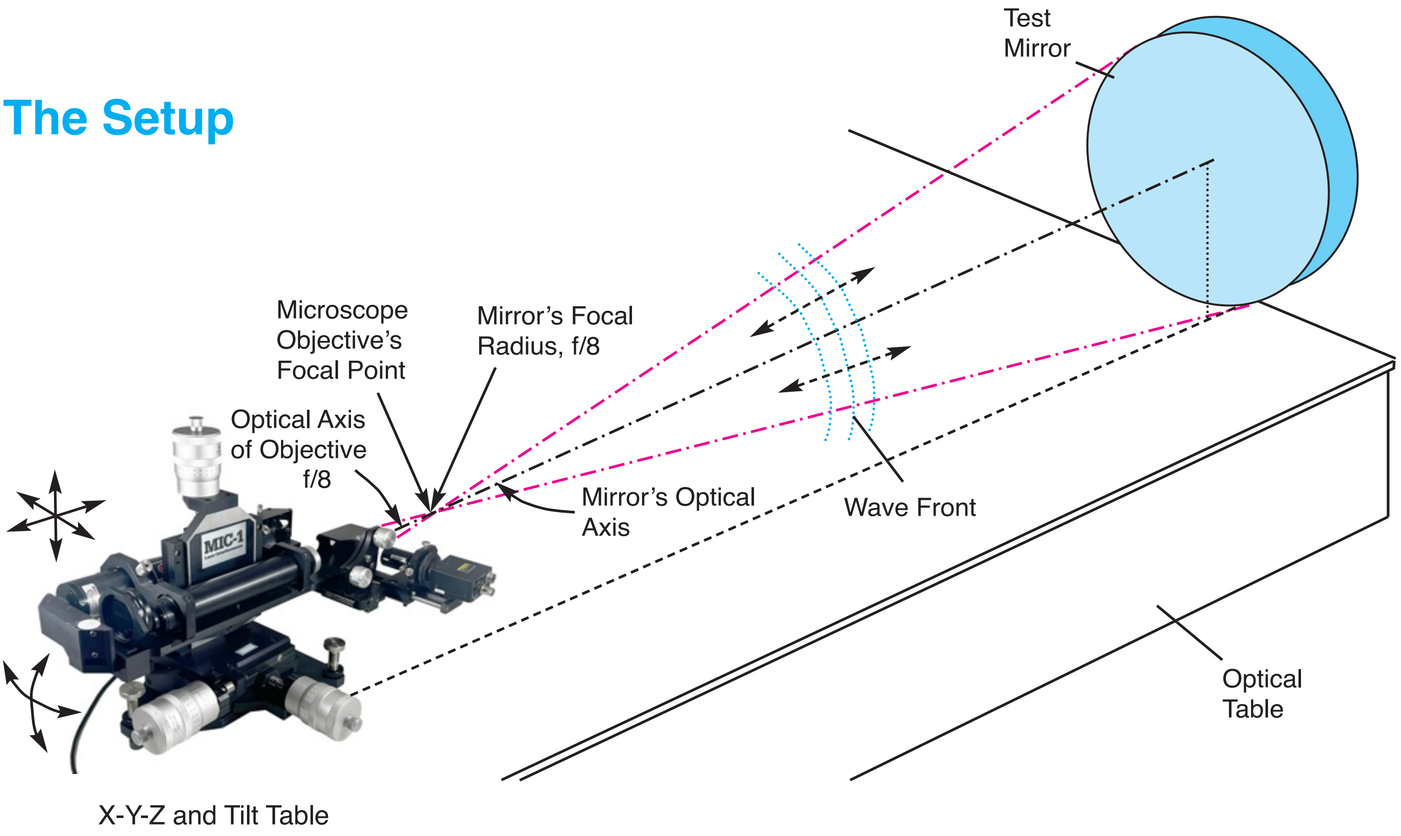
Basically, the wavefront coming back to the instrument is compared with a perfectly shaped reference mirror to produce interference fringes that are then measured by software. The reference mirror is mounted on a piezo driven stage, and is pushed forward in nano steps, causing the interference pattern to scan over the mirror surface. The software algorithm monitors the interference lines passing over the surface to make its measurements. The result is graphically displayed on the screen, showing a 3D profile of the mirror surface.

Buccini interferometer is designed to work properly without needing a vibration isolation table. The internal light path of this instrument (page 5) shows how the beam emerging from the laser is cleaned up by a spatial filter, then expanded to a parallel beam. The dove-looking prism is a smart way of eliminating unwanted reflections ordinarily produced by beamsplitter plates or cubes. The back face of this prism is semi-Aluminum coated to reflect off the beam coming from the test mirror to a viewing screen or CCD camera. The reference mirror is aligned through what looks like a delay line that exists in most interferometers. In this design, it's not.

Because the internal light path of Buccini interferometer is parallel, the delay line does not match the optical path lengths between the test, and reference mirrors. Instead, it acts as a contrast enhancing device to enhance the clarity of fringes. The mirror's focal radius (radius of curvature) is the point where a beam is sent to the mirror, and it's reflected right back to its origin. Buccini offers various beam divergers to match the f number of the test mirror, in this case the spherical mirror of a Schmidt Cassegrain telescope. Through this beam diverger (or microscope objective), the parallel beam inside the interferometer is focused at this point. Then the entire interferometer needs to be physically tilted to be exactly be in line with the beam coming back from the mirror's surface.

Now that we pretty much covered the interferometer hardware, I will cover its inner parts, and the stage the stage is mounted on. More details of the positioning capability of the interferometer is shown below, and on the opposite page.

The Setup



John Buccini (1924-2017) was born in Providence, Rohde Island. A man of great creative talent, John became a national and world recognized mechanical and optical designer, and created a number of state-of-the-art inventions for several industries including manufacturing, the space program, and even advanced nuclear fusion.

Buccini interferometer parts count:	TOTAL: 179
Mechanical Parts	50
Screws, Washers, Springs:	100
Linear Bearings:	4
O-Rings	5
Optical Components:	11
Ball Pivot Joint	1
Piezo Driver + Card + Cable	3
He-Ne Laser + Power Supply	2
Video Camera + Power Supply + Cable:	3

X-Y-Z / Tilt Stage parts Count:	TOTAL: 91
Mechanical Parts:	35
Ball Bearings:	3
Micrometers:	3
Screws, and washers:	44
Linear Bearing Ways:	6

Total Parts Count:	270

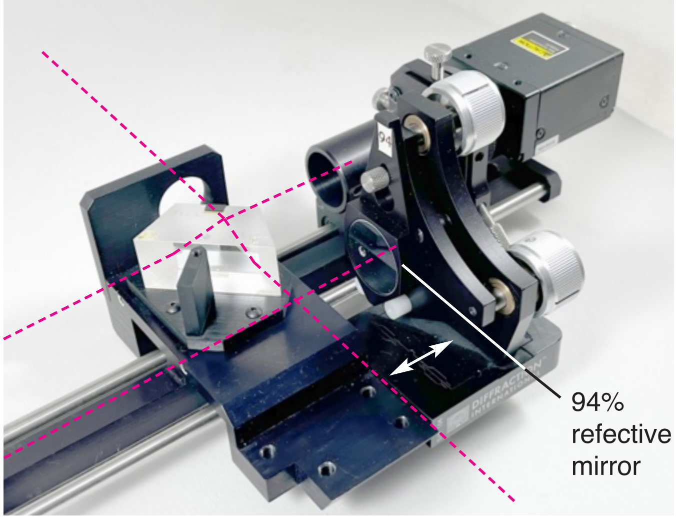
The total number of parts in Buccini are around 270, all of which are custom made. It's one of the best handmade instruments of its kind. It is still a minimalist design. To anyone who wants to copy it, I would say try copying something easier! It's not going to look or function as good if it's not made by those same hands. It's perfection for optomechanics.

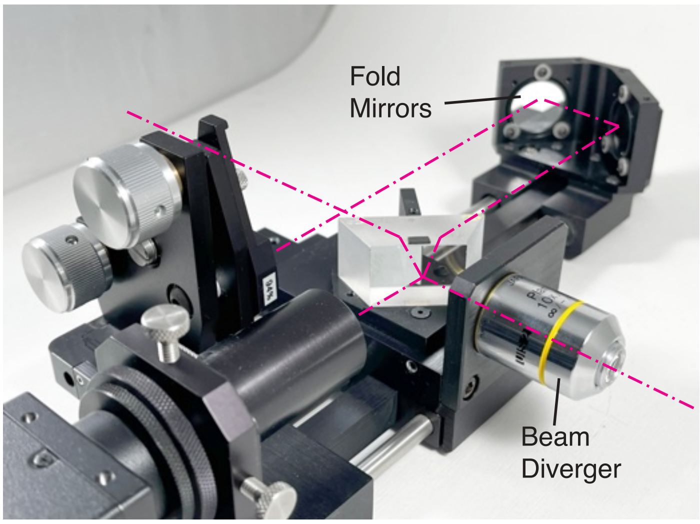
Buccini Interferometer’s Internal Design, and individual parts

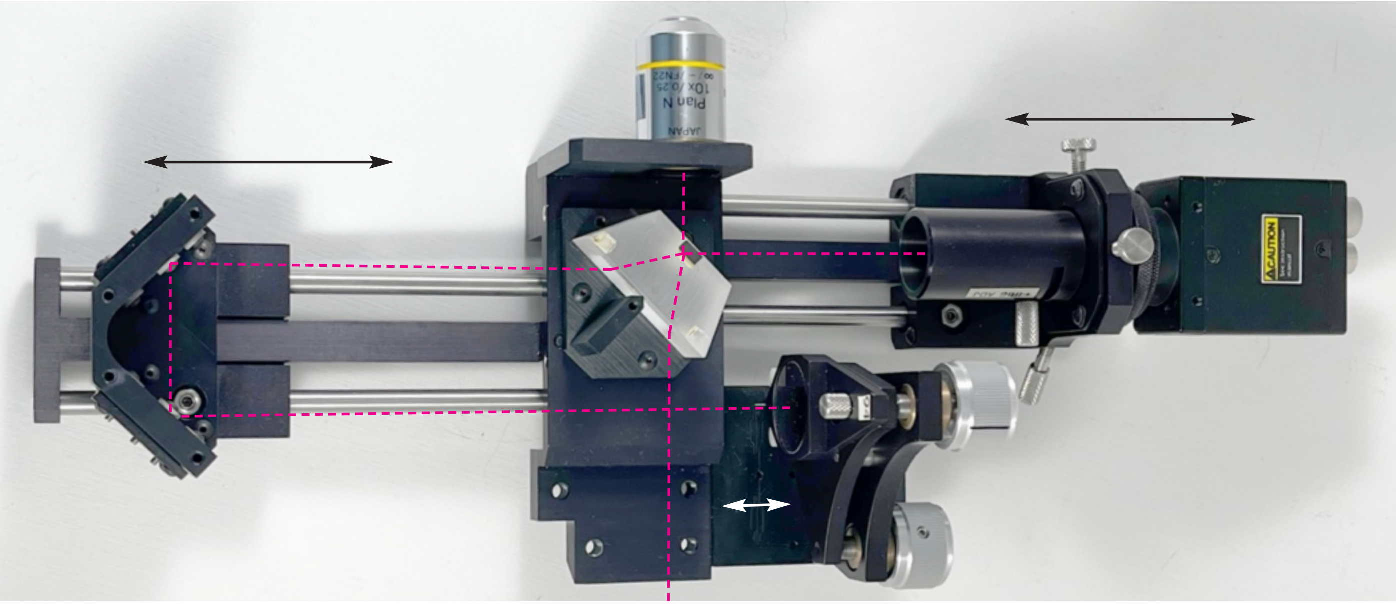
Frontal view of how the interferometer is setup to examine the surface quality of a concave mirror is shown on page 3. The focal length of the beam diverger, or a microscope objective with planar field of view (having less than 1/10 wave spherical aberration) is focused on the focal radius of the mirror. Also, the axis of beam propagation is lined up exactly between the diverger, and the mirror via the finely adjustable tilt legs.

The final adjustment is made by reference mirror tilt knobs. There is a software driven piezo actuator beneath this stage that pushes the fringes across the test mirror to calculate its surface contour, to display it on the computer screen. The software is supplied by Wells Research with user friendly graphic interface.

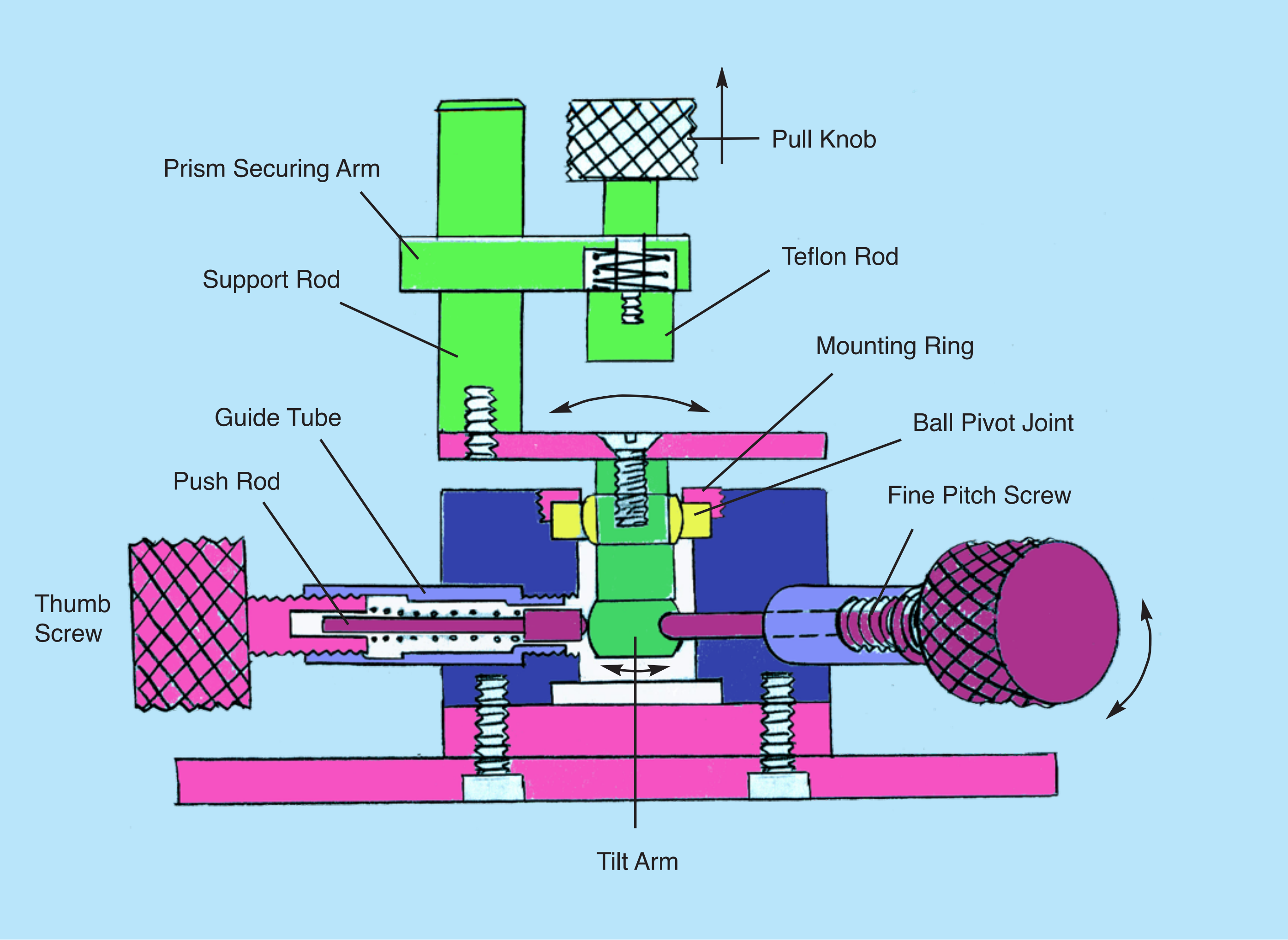
In Buccini, amazing attention has been paid to details. Every component has been made with great care, and I will give it a grade 10/10. One reason must have been because John himself was a machinist, and knew how good quality parts should look like. I don’t even know if he outsourced the parts or he hand made them himself. Many of the parts must have been CNC machined, and knowing the cost of these instruments, I am sure he wouldn’t have ordered more than 10-25 pieces at a time. The design is very optimized, and one can’t imagine to do a better job to improve it. I was particularly impressed with the design of the linear bearing carriers for both the camera, and the delay line. He utilized a combination of linear bearings, and back plungers to provide a smooth travel, and it provides incredible feel to it when using. The friction, and positioning convenience is perfect. The CCD camera, and its zoom-like imaging lens with miniature iris diaphragm is also cleverly designed.



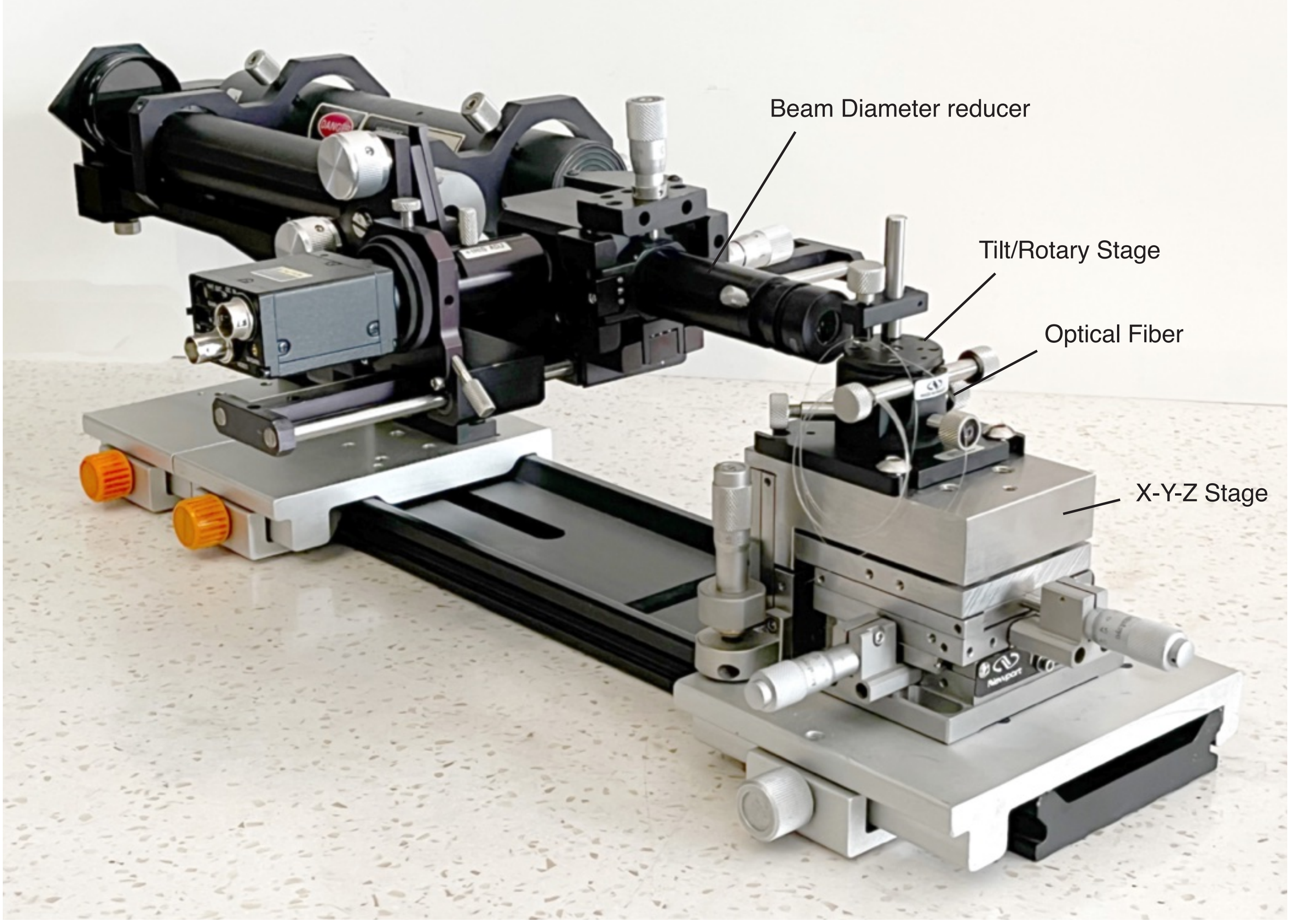




The light path inside the interferometer through the central prism with 50% Aluminum coating: Utilizing this prism eliminates the ghost image inherent in beamsplitter designs. There is obviously a shift of optical axis that is compensated for. The challenge in designing the piezo actuated flexture stage (white arrow, above) in translating the reference mirror, is to maintain its parallelism throughout its travel range.

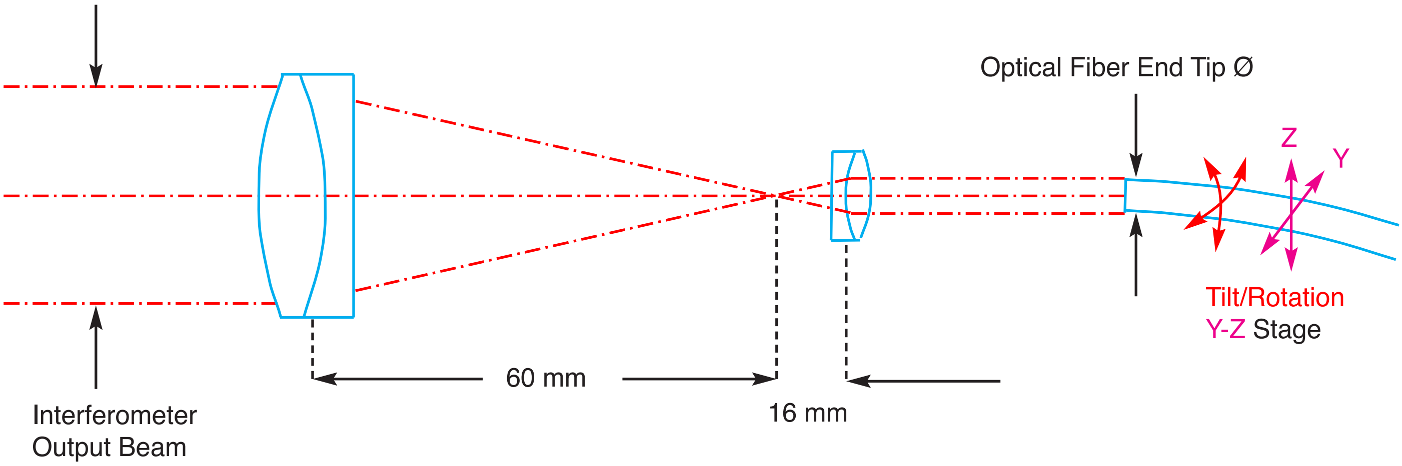

Pull Knob
Prism Securing Arm
Teflon Rod
Support Rod
Mounting Ring
Guide Tube
Ball Pivot Joint
Push Rod
Fine Pitch Screw
Thumb Screw
Tilt Arm

Surface Profiler to Examine the Polished End of a Fiber

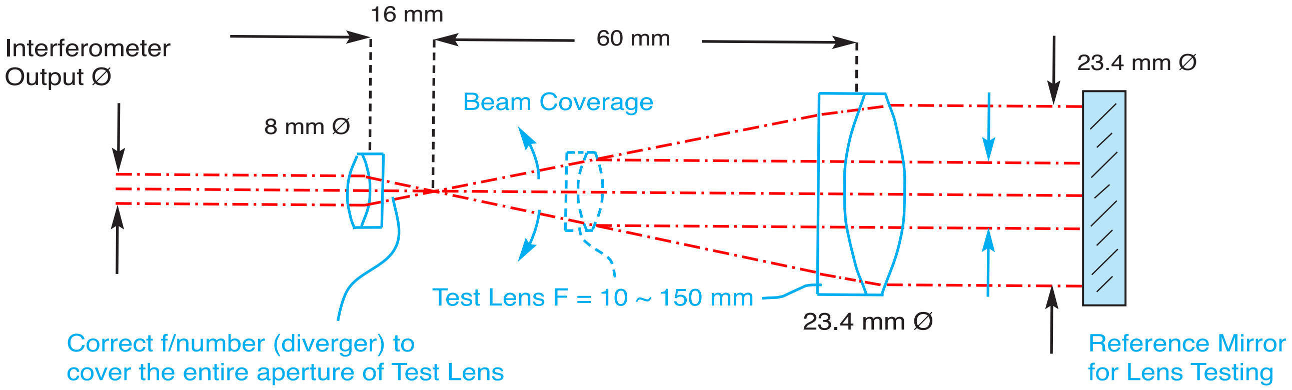


Above, test setup to examine the surface flatness of a polished optical fiber end. The interferometer is equipped with a reversed beam expander to cover a very small area of interest, or a field of view of 1 mm in diameter.

This is an application of the laser interferometer to examine the polished surface quality of an optical fiber. To accomplish this, its beam is reduced in size by a reversed beam expander. To accomplish this, two achromats are utilized with a reducing ratio of focal lengths (below). In this example, the demagnification is 16/60 = 0.62. The wavefront from the interferometer would be projected flat at fiber's tip provided that the achromats are well manufactured to better than 1/10 wave wavefront quality. Plano convex lenses may also be found to perform as well because this is a monochromatic design but high quality achromats are usually easier to find than singlets. A surface profiling software could also be calibrated with a reference flat mirror prior to testing, to compensate for lens aberrations.



How to Build a wavefront Corrected Beam Expander

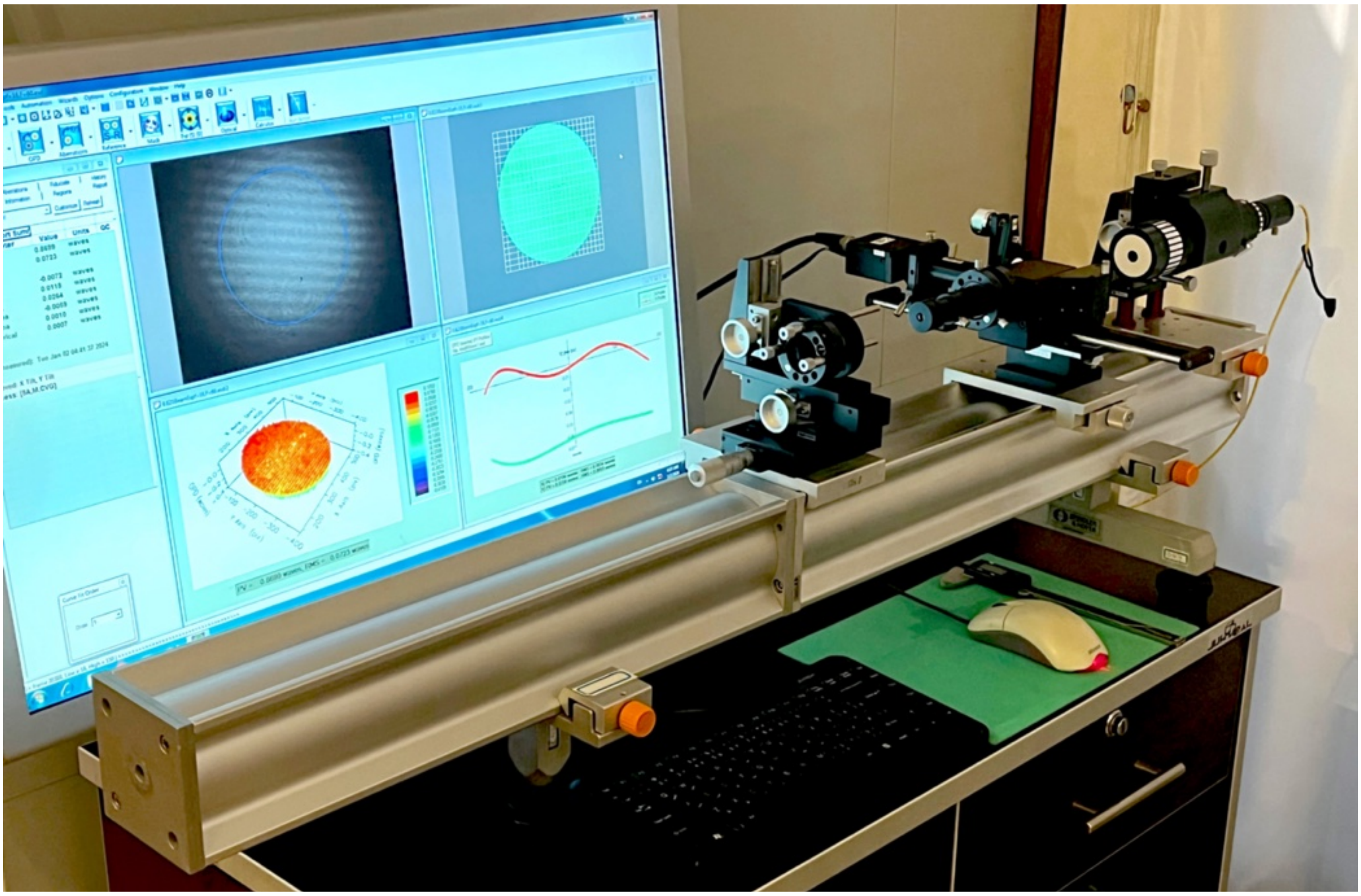


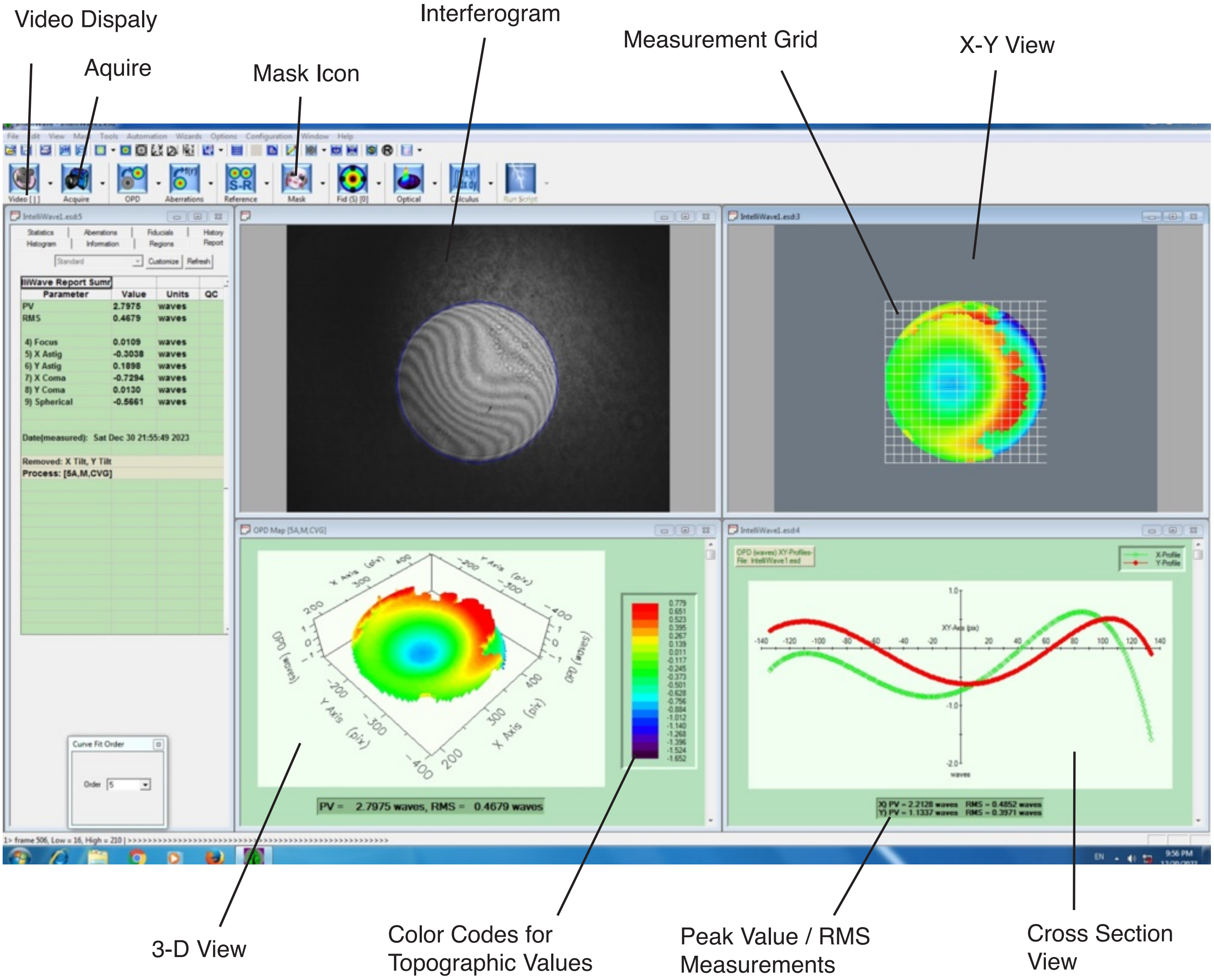
This design is easier to draw but much difficult to implement. One reason is 1/10 wave accuracy lenses are not that easy to find. So, let's say we want to build this beam expander, how would you actually do it then? Well, we'll first need to measure the wavefront flatness of each of these lenses to see how good they are, and then how we could utilize them to build our beam expander. We'll study many Achromats, plano convex PCX, and Biconvex BCX lenses. We'll even look at some quartz lenses. Pay attention to the different lens types, and their wavefront performance. You'll find a mixture of performances, some of them very unpredictable. I always thought of BCX lenses as poor performers but they are not.

How lenses are tested

Let's use the above illustration to show how we are going to test lenses (labeled in blue). The left Achromat would represent the beam diverger, while the larger achromat represents the lens being tested. The reference mirror is first measured to get its profile, and to save it. Since the reference mirror we are using isn't perfect, the software (opposite page) allows subtracting its errors from each lens measurement. So here's our first dilemma: Changing the beam diverger would change our measurement parameters such as the measured profile of the reference mirror.

Some of Optoform's inventory of Achromats, and singlets ranging from f = 10 mm to f = 150 mm. All our 25 mm lens mounts are compatible with Micromax system with M23.4x0.75 thread, and compatible with Spindler & Hoyer/Linos lens cells. This thread compatibility allows direct assembly of optical assemblies such as a beam expander using Micromax tubing. See page 36 for the final assembly.





lliWave Report Sumr			
Parameter	Value	Units	QC
PV	2.7975	waves	
RMS	0.4679	waves	
4) Focus	0.0109	waves	
5) X Astig	-0.3038	waves	
6) Y Astig	0.1898	waves	
7) X Coma	-0.7294	waves	
8) Y Coma	0.0130	waves	
9) Spherical	-0.5661	waves	

Date(measured): Sat Dec 30 21:55:49 2023

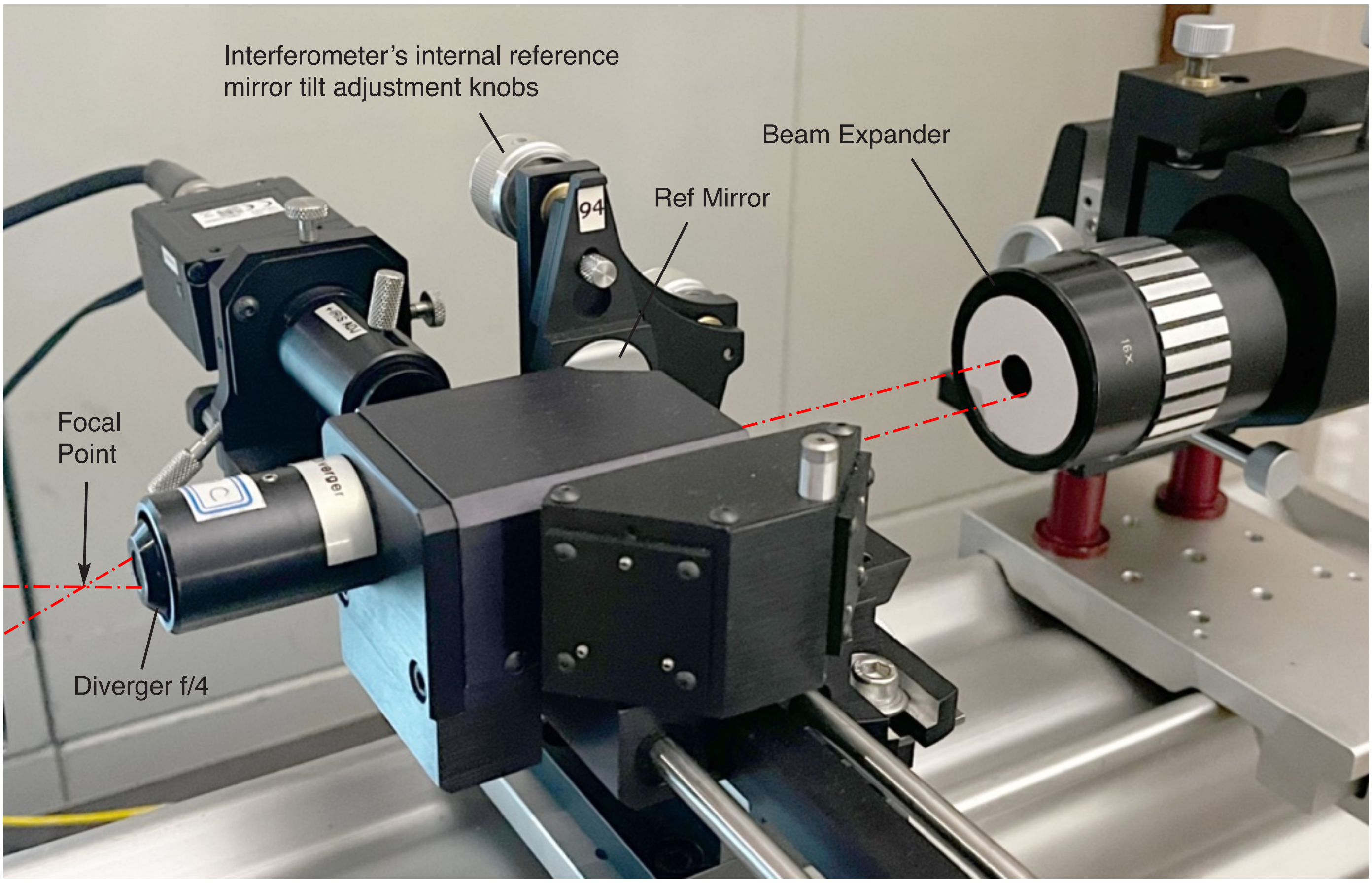
Removed: X Tilt, Y Tilt

Process: [5A,M,CVG]

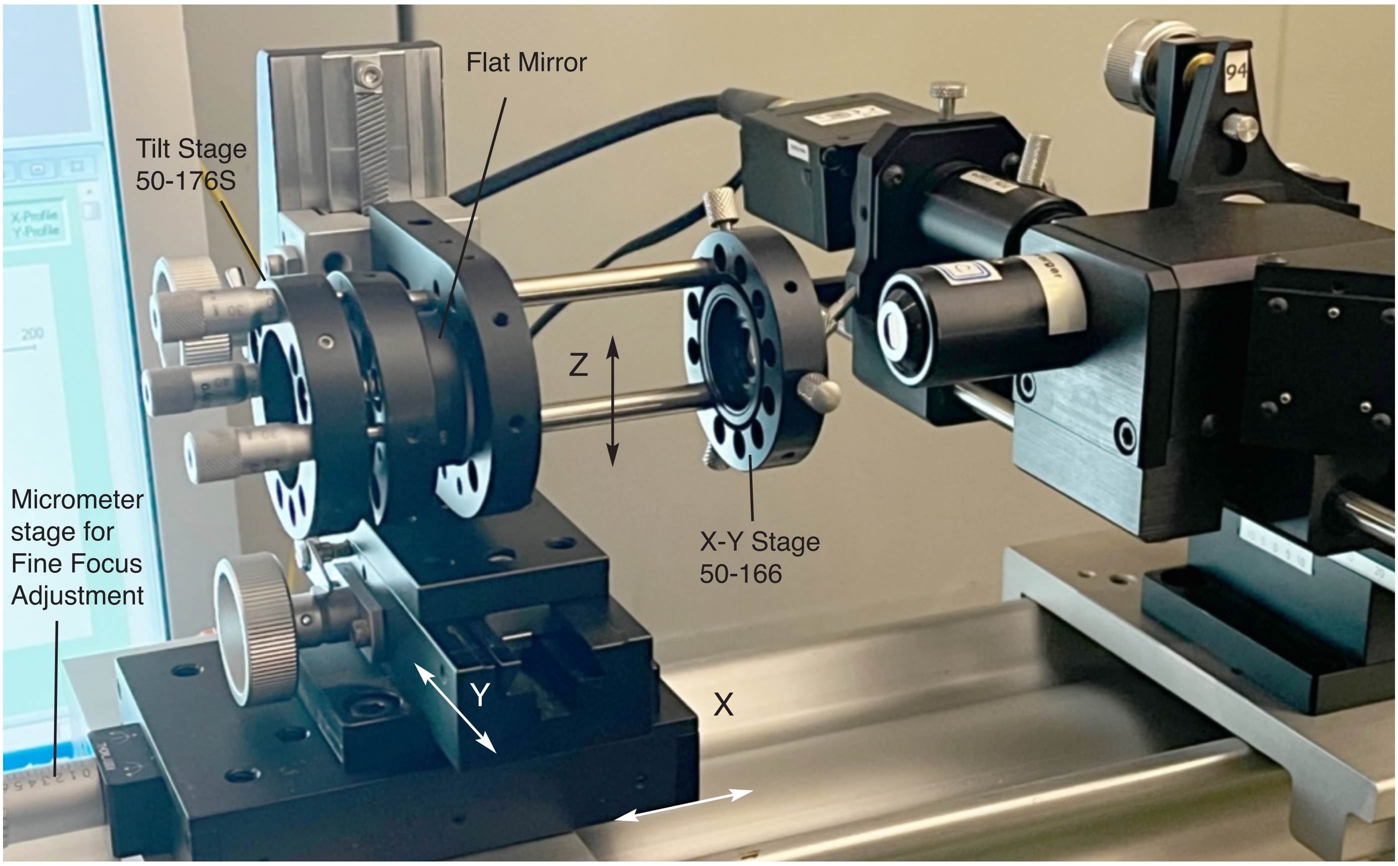
PV = 2.7975 waves, RMS = 0.4679 waves

X) PV = 2.2128 waves RMS = 0.4852 waves
Y) PV = 1.1337 waves RMS = 0.3971 waves

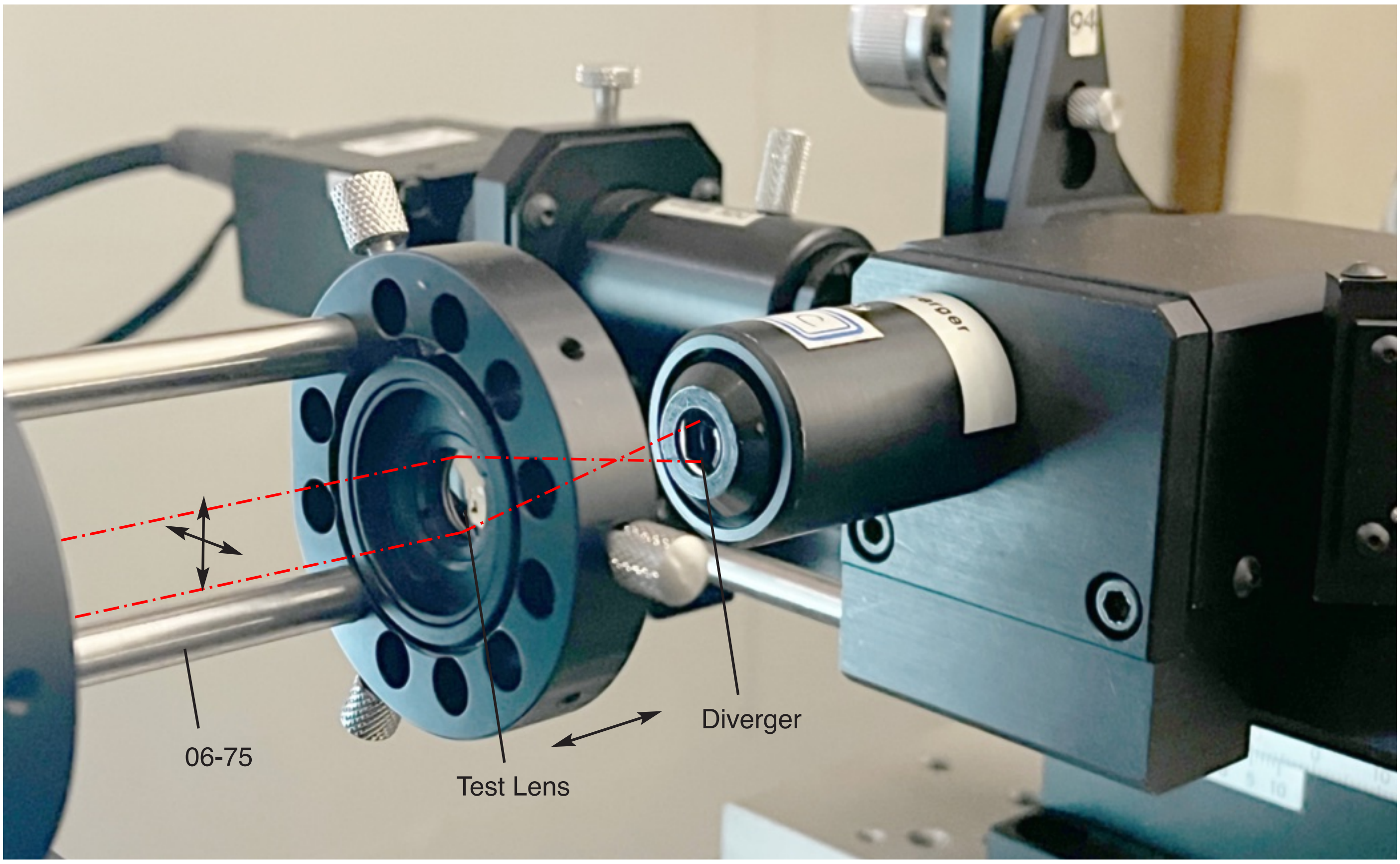
Setting up the interferometer



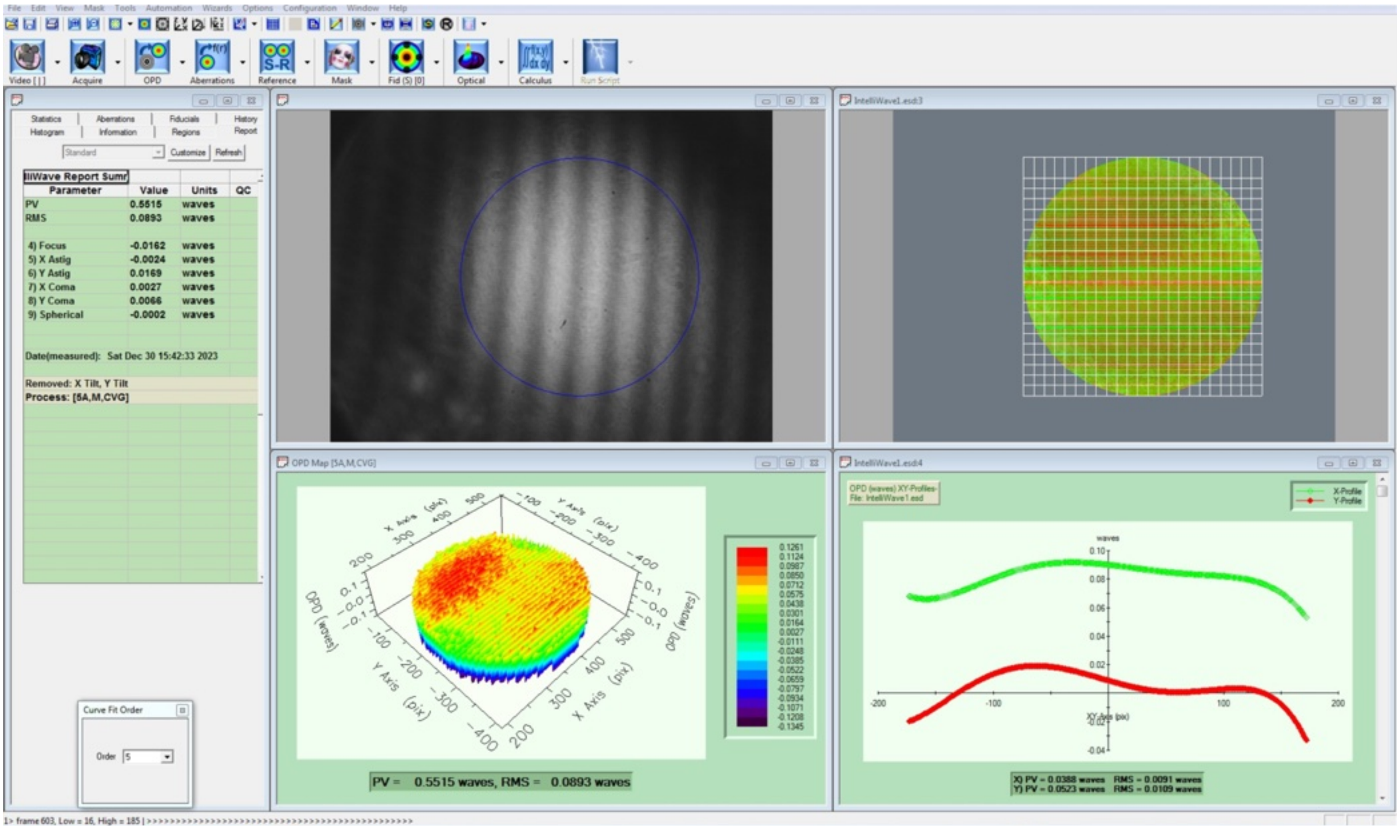
Overview of the setup utilizing the X-95 optical rail, and perfect lab syages.



1) A flat reference mirror better than 1/10 wave is mounted on tilt stage 50-178S to align with interferometer's reference mirror with the diverger, and test lens removed. The reference mirror is centered using the X-Y-Z stage, and locked in place. The fringes are centered on the camera.



2) With the beam diverger installed, each test lens is mounted on X-Y holder 50-166. The lens is perfectly focused to get interference fringes. The fringes are centered via interferometer's internal reference mirror tilt adjustment knobs.



lliWave Report Sumr			
Parameter	Value	Units	QC
PV	0.5515	waves	
RMS	0.0893	waves	
4) Focus	-0.0162	waves	
5) X Astig	-0.0024	waves	
6) Y Astig	0.0169	waves	
7) X Coma	0.0027	waves	
8) Y Coma	0.0066	waves	
9) Spherical	-0.0002	waves	

Date(measured): Sat Dec 30 15:42:33 2023

Removed: X Tilt, Y Tilt
Process: [5A,M,CVG]

```
PV =   0.5515 waves, RMS =   0.0893 waves
```

```
X) PV = 0.0388 waves   RMS = 0.0091 waves
Y) PV = 0.0523 waves   RMS = 0.0109 waves
```

```
1> frame 603, Low = 16, High = 185 |>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
```

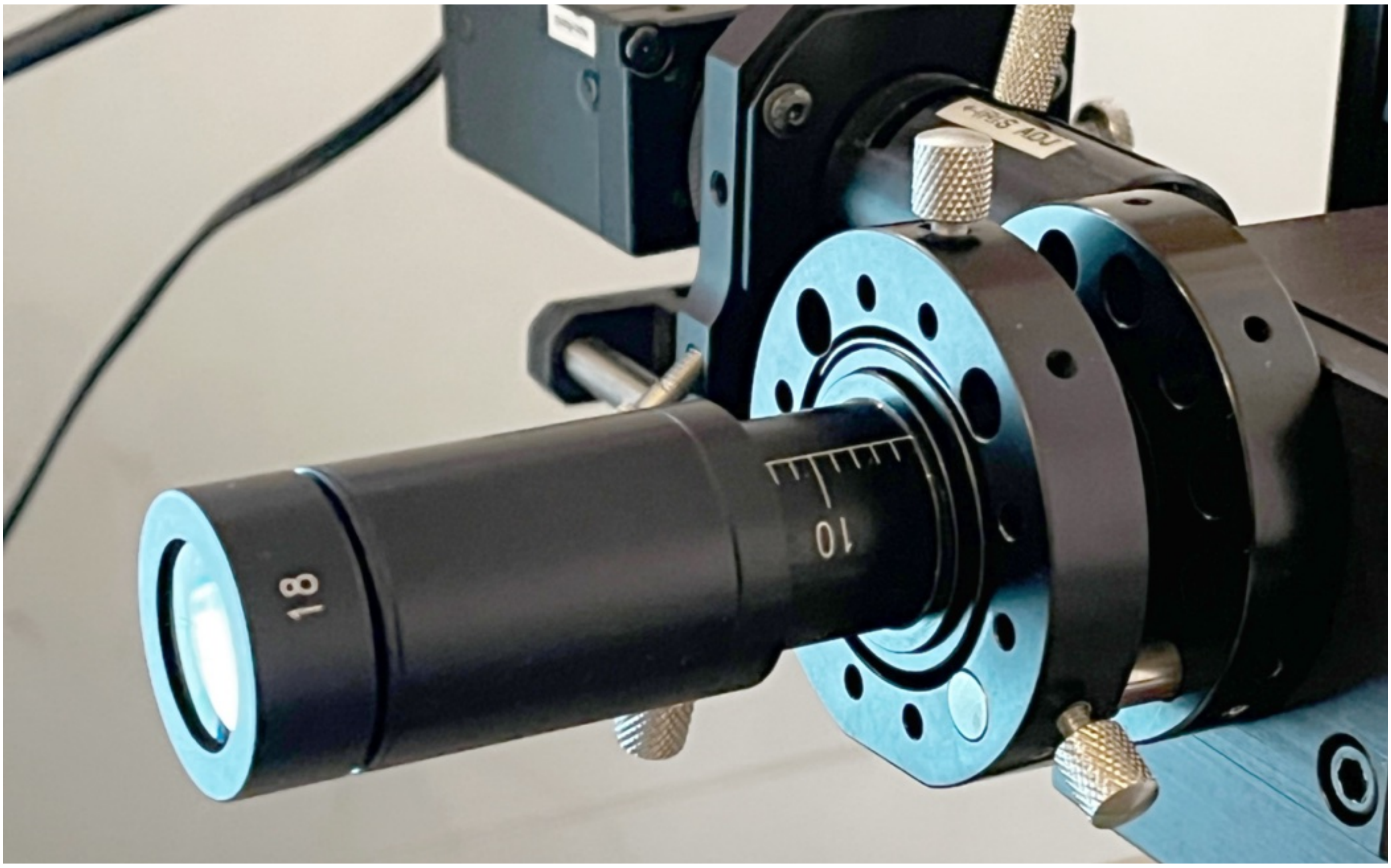
Flat Mirror

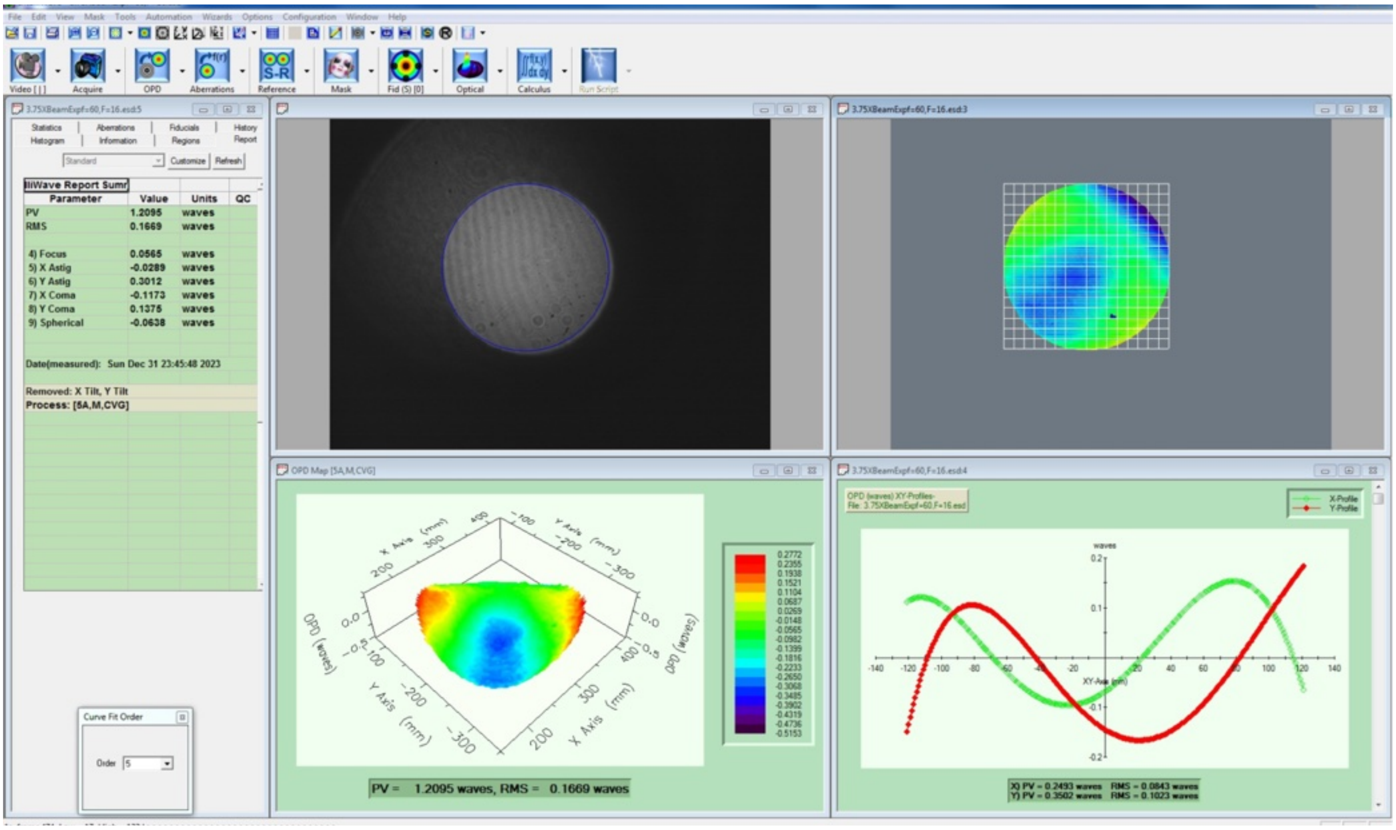
Acquired profile of the flat reference mirror tested against interferometer's internal reference mirror. The claimed flatness was stated 1/10 wave or better, and turned out to be correct.

Picking the Right Lenses to Build a Beam Expander

20-316 25-110 25-128 25-314 20-332

Above, the design can be built with Micromax 25 mounts: Reversing the beam expander optics above would create a beam reducer, and as you can see, a huge improvement on its wavefront flatness (opposite Page). One reason is the circular field of view of the beam expander (defined by F = 60 mm lens) is 21.4 mm whereas the field of view of the beam reducer (defined by F = 16 mm lens) is only 7 mm.





IliWave Report Sumr

Parameter	Value	Units	QC
PV	1.2095	waves	
RMS	0.1669	waves	
4) Focus	0.0565	waves	
5) X Astig	-0.0289	waves	
6) Y Astig	0.3012	waves	
7) X Coma	-0.1173	waves	
8) Y Coma	0.1375	waves	
9) Spherical	-0.0638	waves	

Date(measured): Sun Dec 31 23:45:48 2023

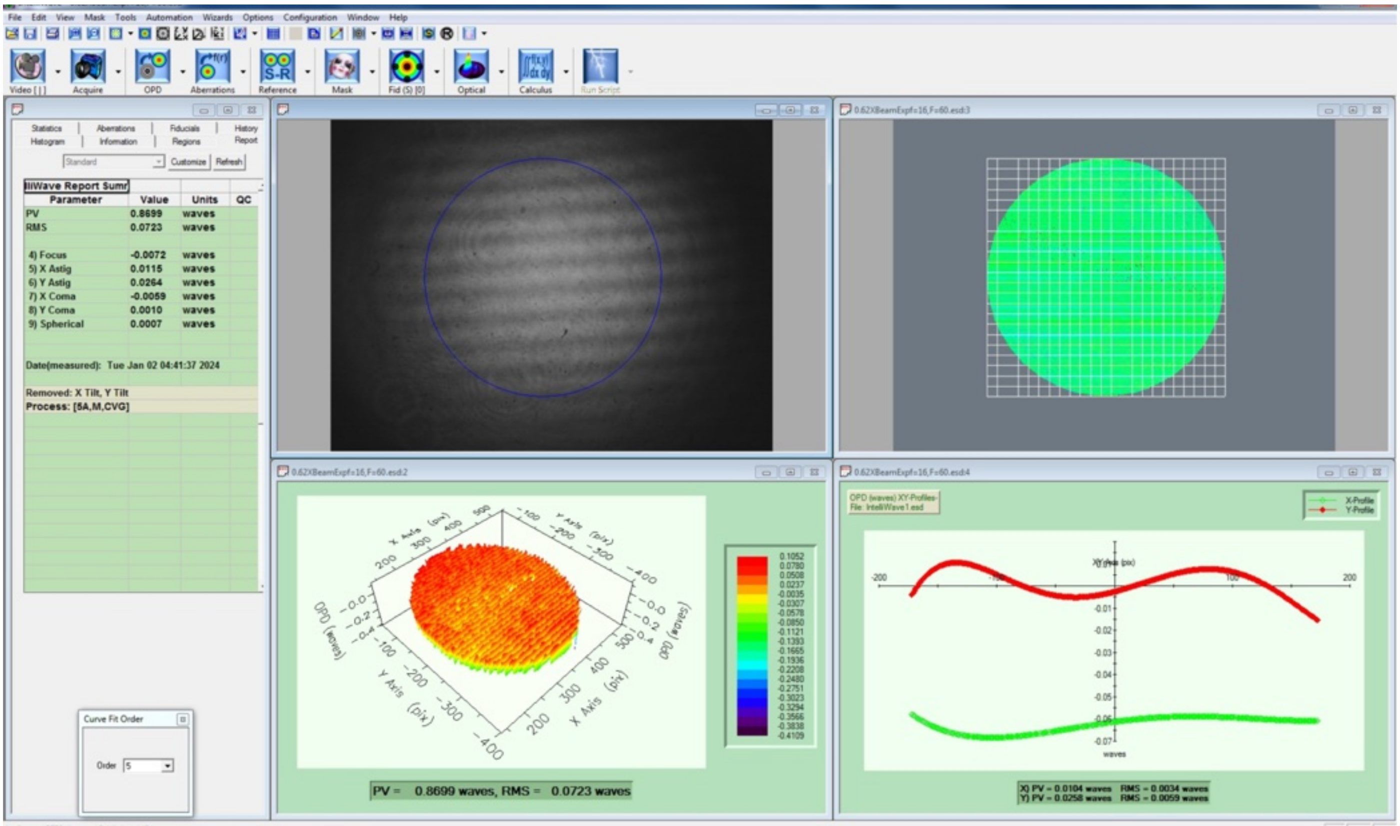
Removed: X Tilt, Y Tilt

Process: [5A,M,CVG]

PV = 1.2095 waves, RMS = 0.1669 waves

X) PV = 0.2493 waves RMS = 0.0843 waves
Y) PV = 0.3502 waves RMS = 0.1023 waves

3.75X Beam Expander F = 16 mm + F = 60 mm



IliWave Report Sumr

Parameter	Value	Units	QC
PV	0.8699	waves	
RMS	0.0723	waves	
4) Focus	-0.0072	waves	
5) X Astig	0.0115	waves	
6) Y Astig	0.0264	waves	
7) X Coma	-0.0059	waves	
8) Y Coma	0.0010	waves	
9) Spherical	0.0007	waves	

Date(measured): Tue Jan 02 04:41:37 2024

Removed: X Tilt, Y Tilt

Process: [5A,M,CVG]

PV = 0.8699 waves, RMS = 0.0723 waves

X) PV = 0.0104 waves RMS = 0.0034 waves
Y) PV = 0.0258 waves RMS = 0.0059 waves

0.62X Beam Reducer F = 60 mm + F = 16 mm

The overall wavefront flatness of this design is 0.35 waves for the beam expander, and 0.05 waves for beam reducer. This is a lucky combination to achieve 1/20 wave performance out of the beam reducer we needed to inspect end of fiber polish. The only reason I could think of is the narrow field of view of the optics. You could get this performance from most of the optics tested here by narrowing their field of view to a small aperture.