NewView™ Surface Profiler Presentation

Prepared for

University of Pennsylvania

Prepared by

Daniel Russano

Jennifer Chen

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Outline

- Lecture
  - Basic Theory of NewView Operation
  - MetroPro Surface Texture Parameters
  - Analysis Data Flow
  - Noise, Its Effects, Its Sources, and Countermeasures
- Laboratory
  - MetroPro Operation
  - MetroPro Plots, Displays, and Results
  - Fundamentals of Data Filtering
  - How to Customize MetroPro Applications
  - Surface Segmentation Fundamentals
  - MetroPro Process Statistics Recording
  - MetroPro Metrology Report Generation

Basic Theory of NewView Operation

- **Hardware introduction**
- Wave theory and interferometry
- Microscopy basics
- Scanning white light interferometry
- Practical Concerns

Terms and Definitions

- **Accuracy**
  The degree to which the measurement (value of the quantity as determined from an instrument) represents the ***true value*** of the quantity which is being measured.

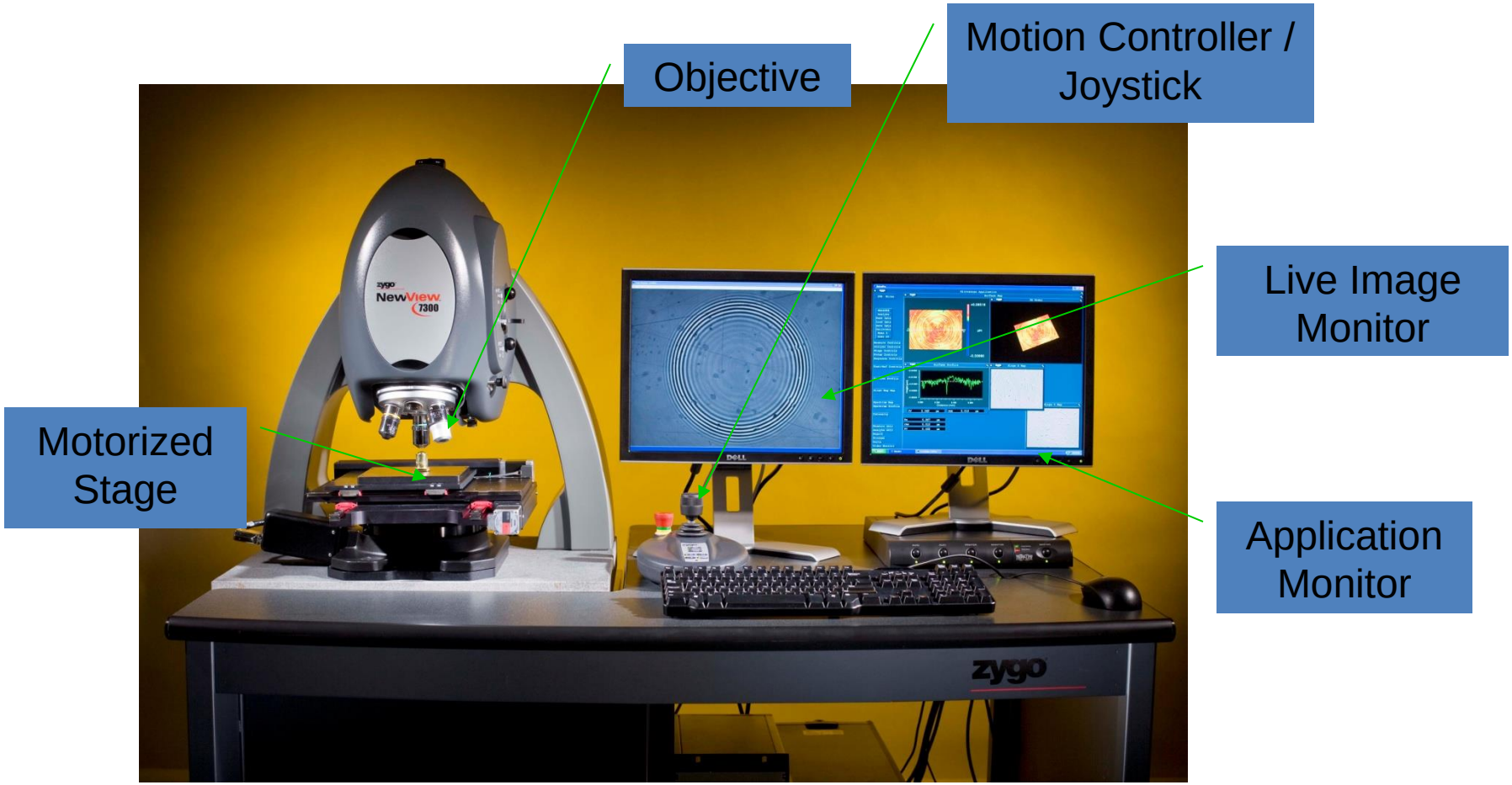
- **Precision (repeatability)**
  Represents the variance of measurement, including all random and cyclic error; statistical quantity which is ***not*** related to the ***true value*** of the quantity being measured.

- **Resolution**
  As applied to interferometers, resolution might refer to the number of bits used to digitize interferogram intensities or final phase values, or spatial sampling of the detector array for optical resolution.

References:

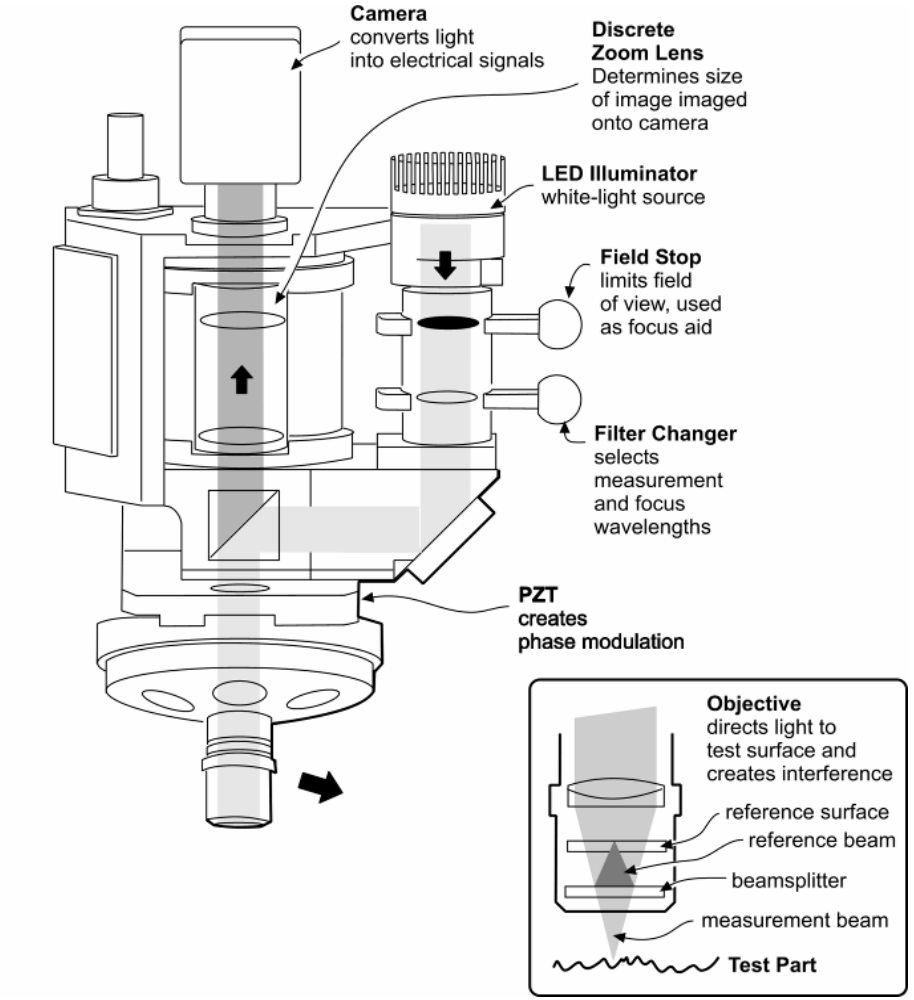
- "Interferometer accuracy and precision", Lars Selberg (SPIE Vol. 1400 Optical Fabrication and Testing), 1990
- "Clash of cultures: uncertainty vs accuracy", Chris Evans (OSA Conference Paper, Optical Fabrication and Testing, 2010)

NewView 7300 System Overview



NewView Optical Setup

- "Scanning White Light Interferometer"
- Microscope + interferometer combined in a single instrument
- Three-dimensional surface structure analysis



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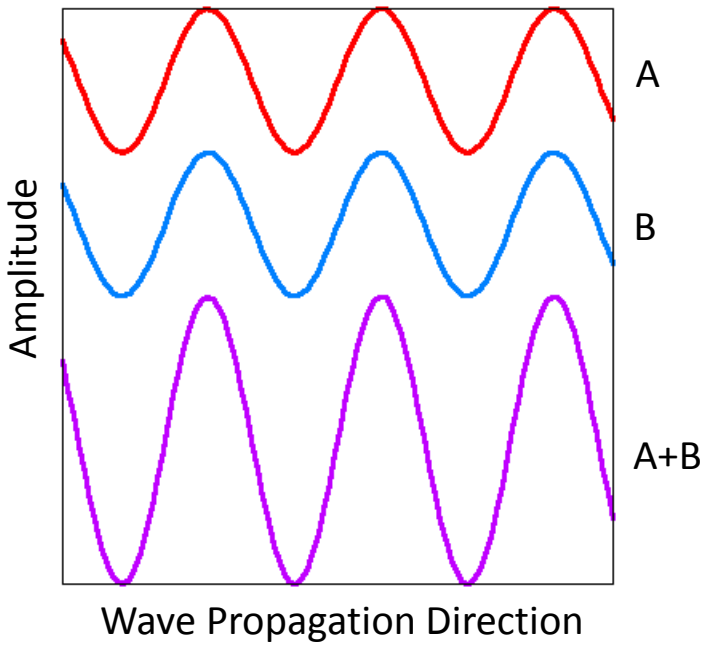
Wave Nature of Light

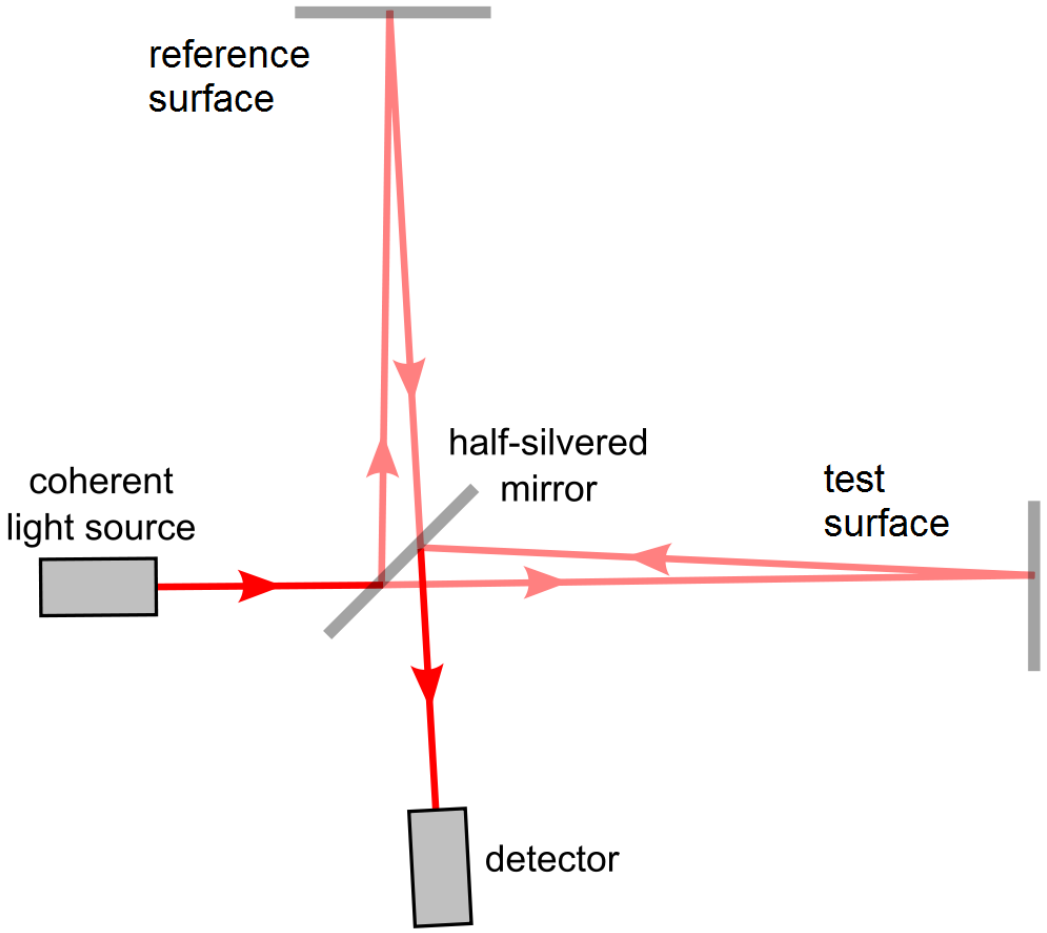
- Light is a wave, thus light can interfere (under the correct conditions).
- No detector can directly measure the oscillations of light, we measure time averaged intensity, $I \propto \langle E^2 \rangle$.
- By varying the relative phase of two beams of light, interference will produce bright or dark spots at a detector!



A Basic Interferometer

The difference in distance between the two legs of the interferometer (the optical path difference, OPD) will determine whether the detector sees a bright or dark spot.

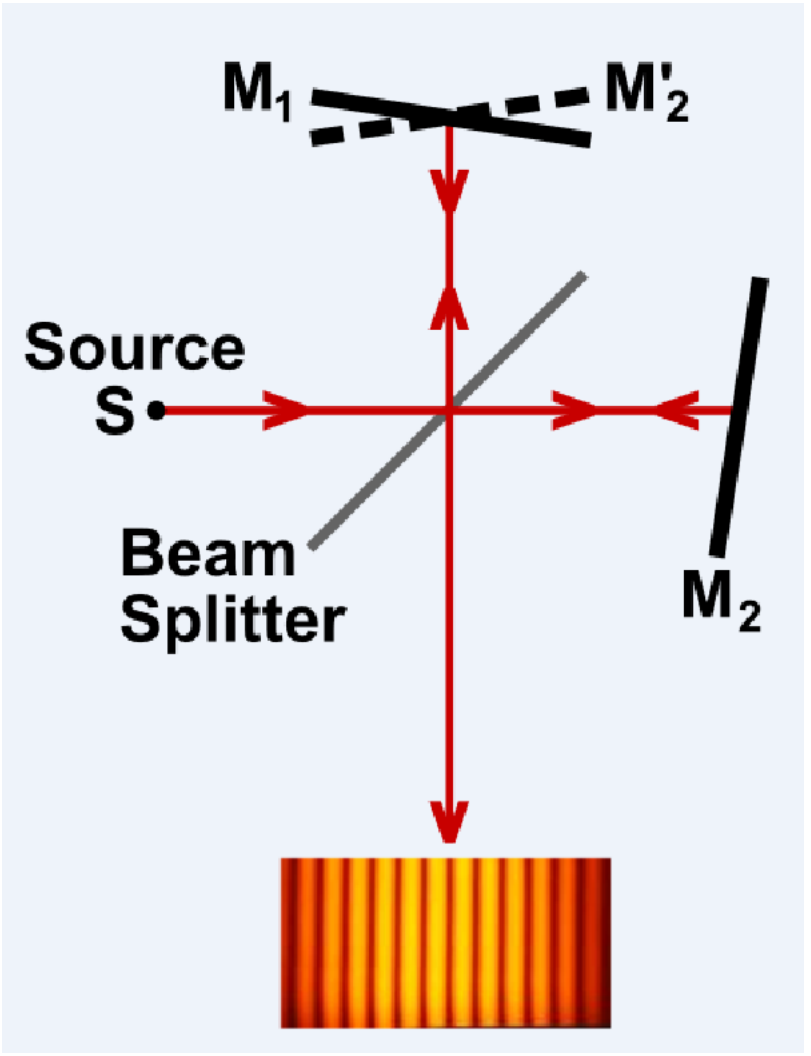
Moving one surface relative to the other will cause the spot to vary in intensity like a sinusoid.



Interference over an extended surface

If the light beam has a size (as all real beams do), variations in the OPD between different parts of the surface will result in an **interference pattern** at the detector, which will describe the **cavity** between the test and reference surface.

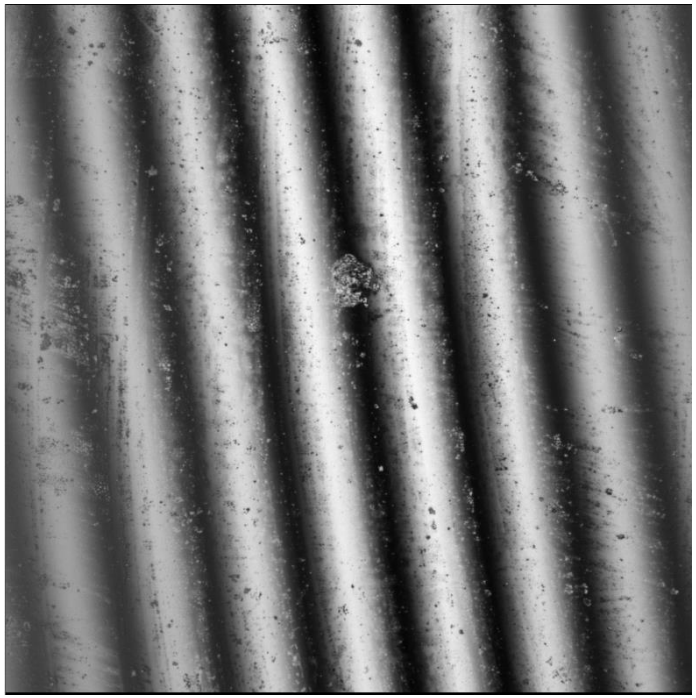
This pattern is simply interference as described before happening at every point on the surface.

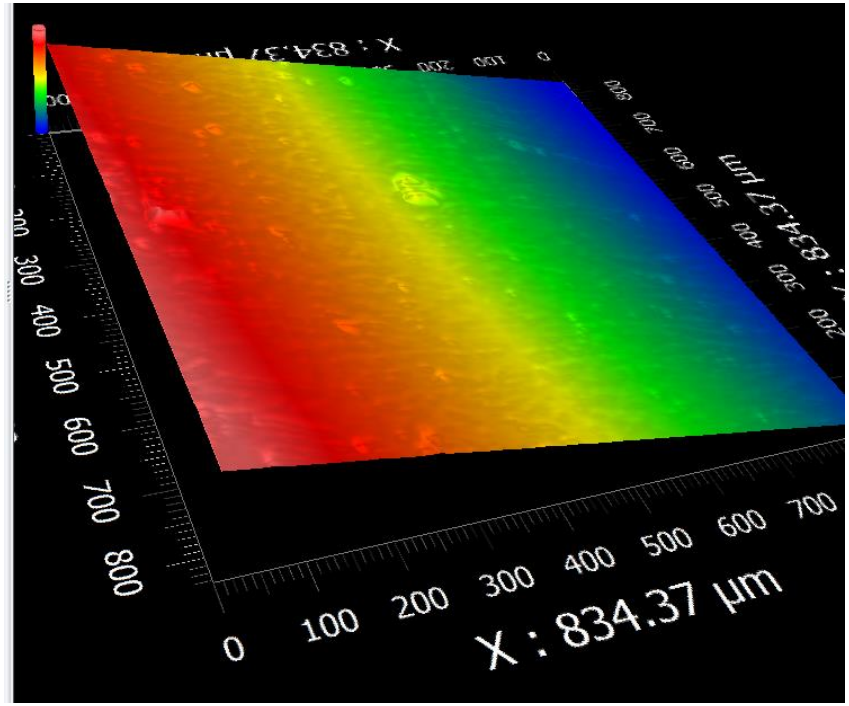


Fringes as contours: intuitive height visualization

The intensity of the resulting light at any point is a function of the optical path difference. Thus, for points where the optical path difference is the same, the intensity will be the same.

Continuous fringes are surfaces of constant height on the test part.





Basic Theory of NewView Operation

- Hardware introduction
- Wave theory and interferometry
- **Microscopy basics**
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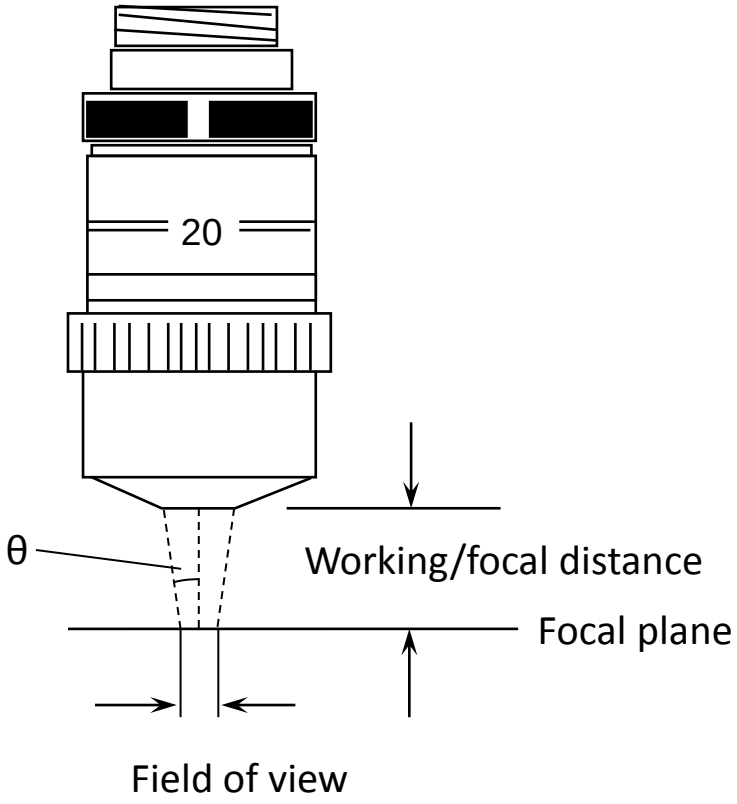
- Practical Concerns

Microscopes

- The purpose of a microscope is to examine small objects!
- The magnification (or power), field of view, resolution, working distance, and numerical aperture are all related and dependent upon the objective you choose to use.
- Picking the proper objective for your sample is very important!

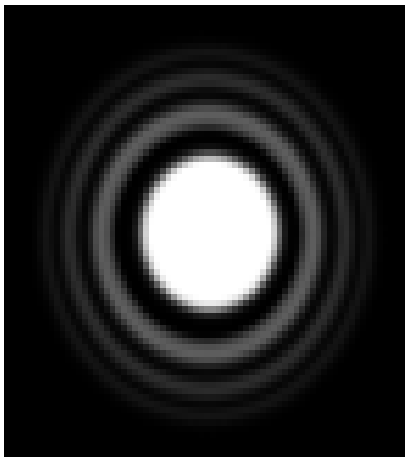
$$NA = \sin\theta$$

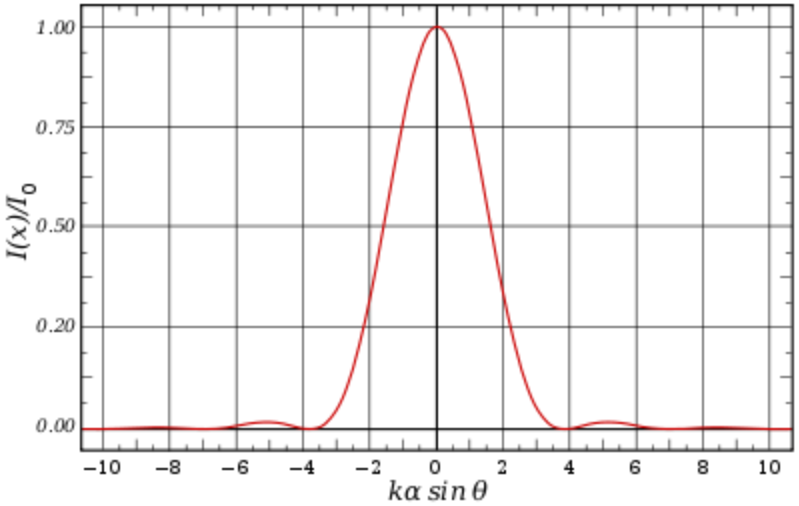


Optical Resolution: The Airy Disk

Diffraction of light through a circular aperture (like a lens) limits the resolution of any optical system.

The best focus of a point source of light from a lens system will form an Airy disk due to this diffraction, rather than the idealized point source.



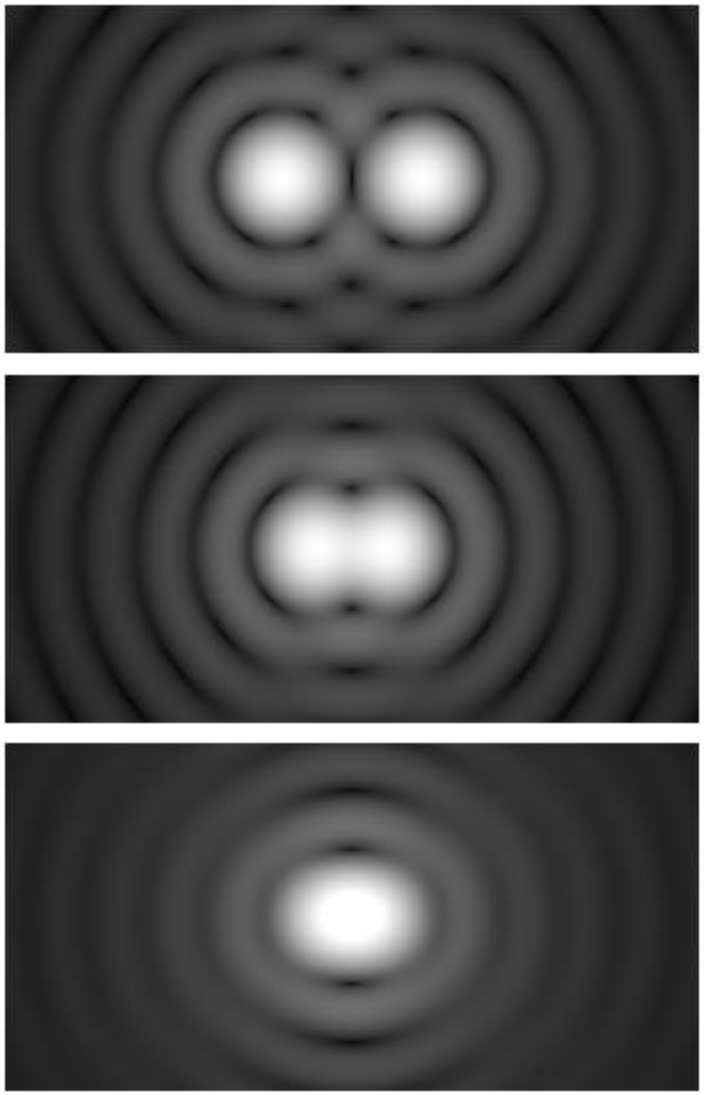


Optical Resolution

- Optical resolution is usually defined as the ability to distinguish two objects which are close together, which is difficult due to the overlap of the Airy disks.

- Common criteria for the resolution R:
  - The Rayleigh Criterion: R = 0.61λ/NA
  - The Sparrow Criterion: R = 0.5λ/NA (used by Zygo)

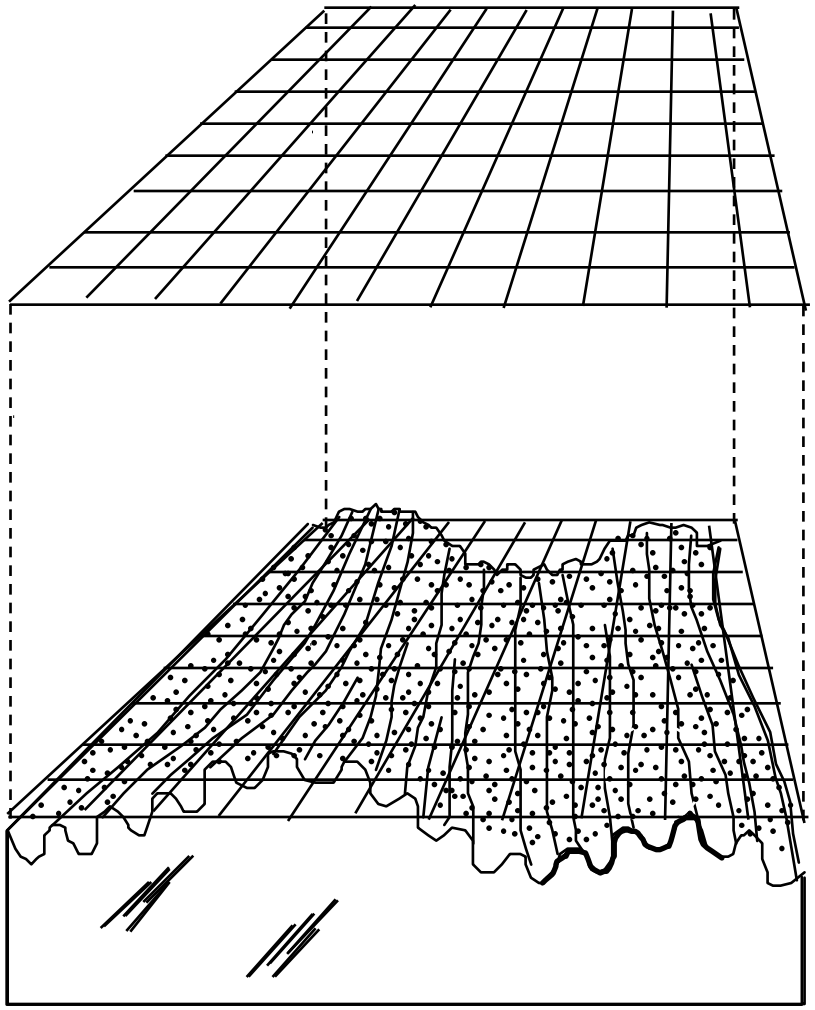
- Note: This resolution is in the lateral (parallel to the focal plane) direction – it is not related to the vertical resolution of the NewView's measurements.



Spatial Sampling

The detector in the NewView system is a CCD camera with a finite number of pixels. Thus, the optical resolution is also limited by the spatial sampling of the system, i.e. the field of view divided by the number of pixels.

Objective selection tip: Select an objective with sufficient optical resolution and spatial sampling to image the smallest feature size you are interested in.

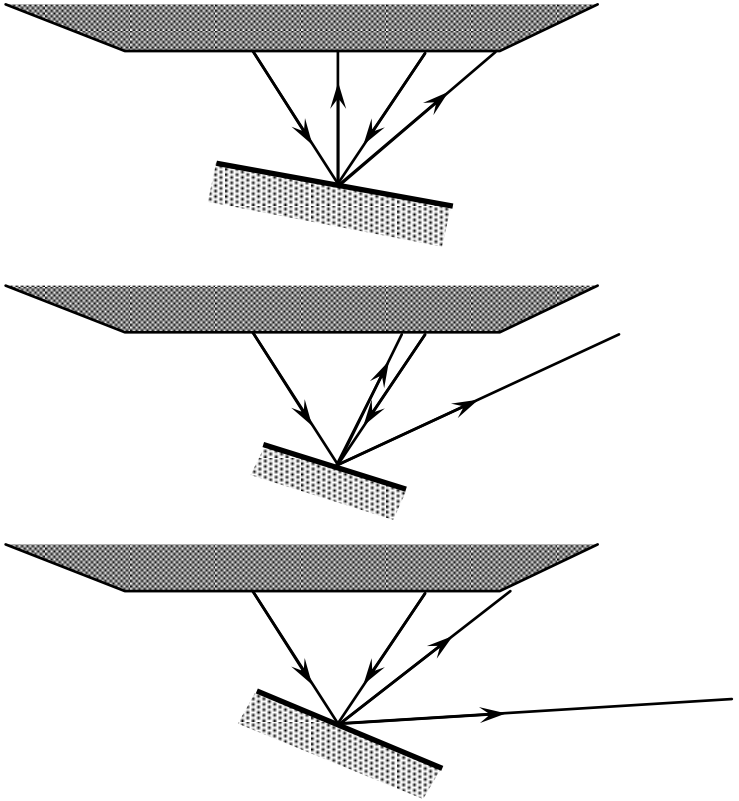


Importance of Numerical Aperture

The numerical aperture of a lens system is a descriptor of the size of the cone which light is collected from.

A high NA lens will collect a larger cone angle, which allows for collection of light on **steeper slopes**.

Objective selection tip: If you are having difficulty capturing data on a part with steep valleys or high slope, try a higher NA objective.



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Coherence length vs. bandwidth

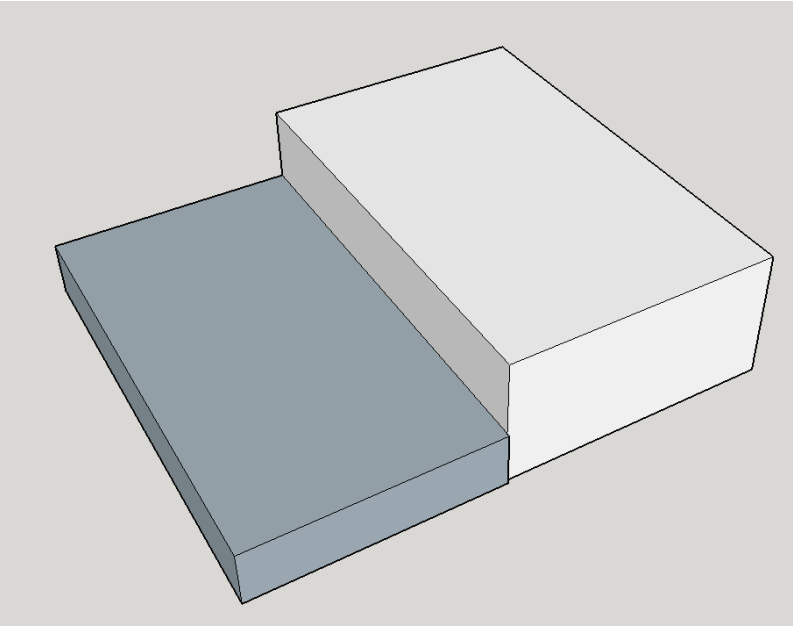
- Coherence (between two waves) refers to the ability of the waves to interfere with each other in an observable way; a property which naturally diminishes as a beam propagates.
- ‘Coherence length’ is the length over which a beam remains coherent – the distance over which interference may occur.
- The coherence length of a beam is inversely related to the bandwidth, or the spread of different frequencies, of the light.
- Coherence length of white light sources (lightbulbs) is typically 1-5 microns, while stabilized lasers can have coherence lengths of hundreds of meters.

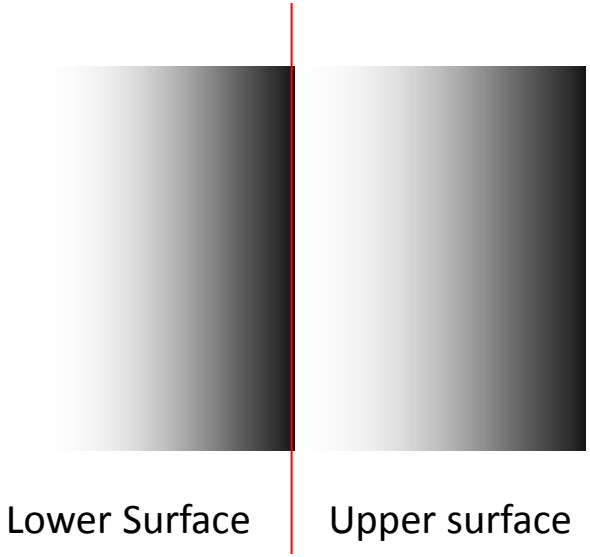
Operational tip: If you are measuring a very rough surface, the use of a narrowband ‘rough’ filter can make it easier to find fringes and make measurements, by increasing the coherence length.

Why White Light?

• Laser interferometers have long been the standard. But what happens when we have a rough surface?

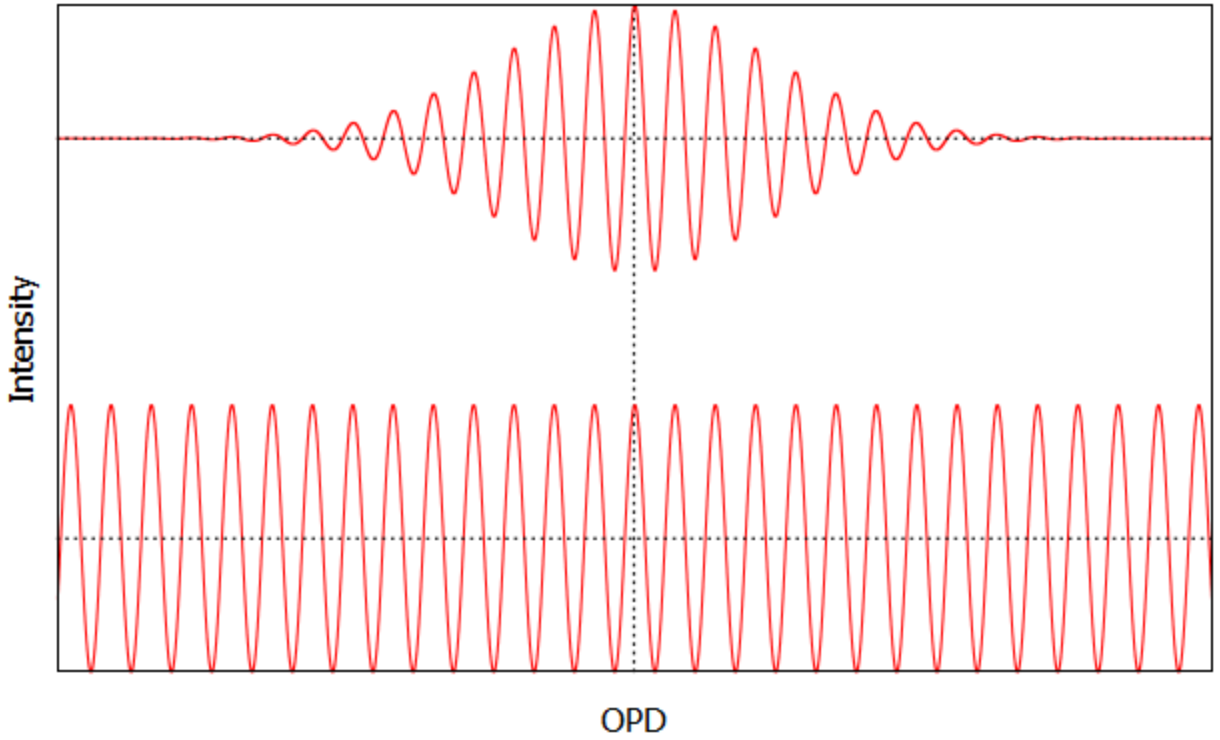
•There is ambiguity in the fringes when the sample height changes by more than λ/4 between pixels, due to the (essentially infinite) coherence length of a laser: we have no way to tell how many fringes are “jumped” at this discontinuity.





Why White Light?

- The short coherence length of white light compared to laser light reduces the intensity of the interference rapidly as the OPD increases from zero. **Outside the coherence length the light loses the ability to interfere in an observable way. Thus, the maximum of intensity occurs at the zero OPD point.**



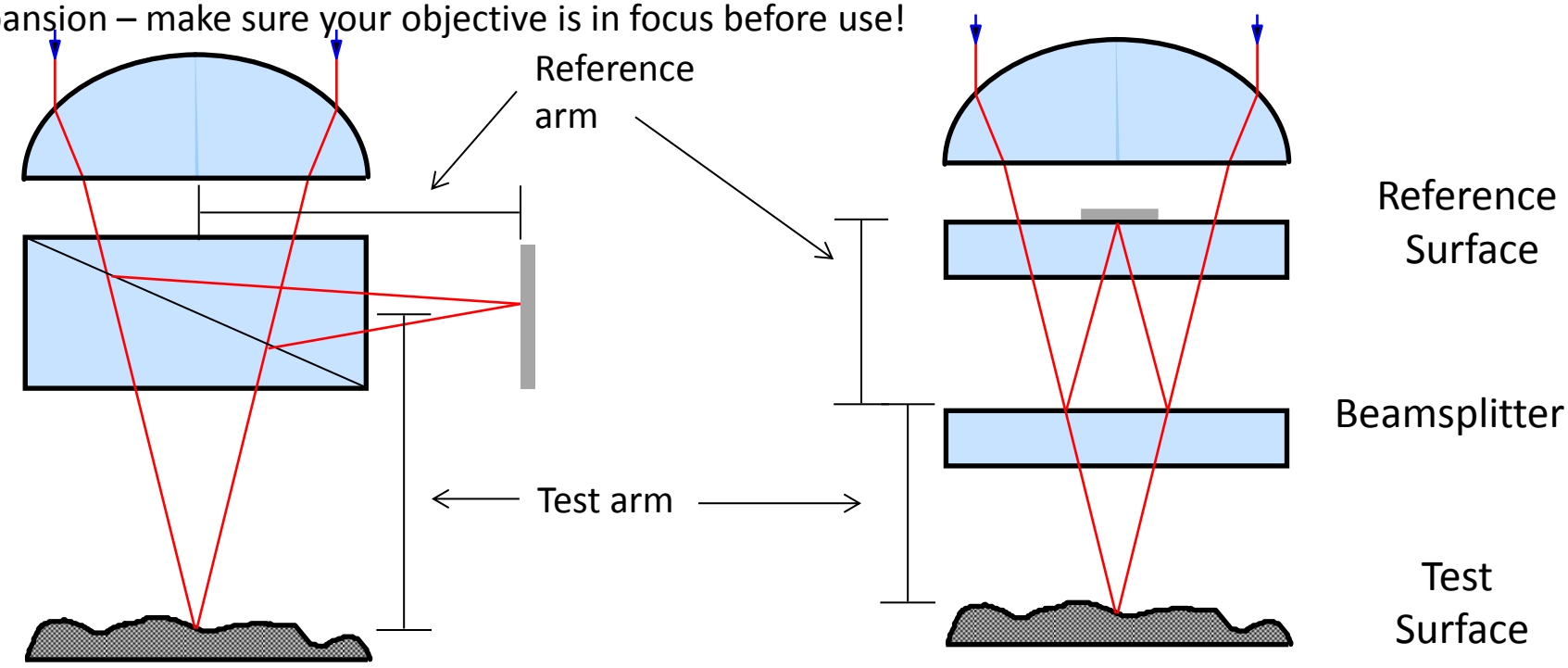
White light **interferogram**

Laser light **interferogram**

Combining interferometry and microscopy

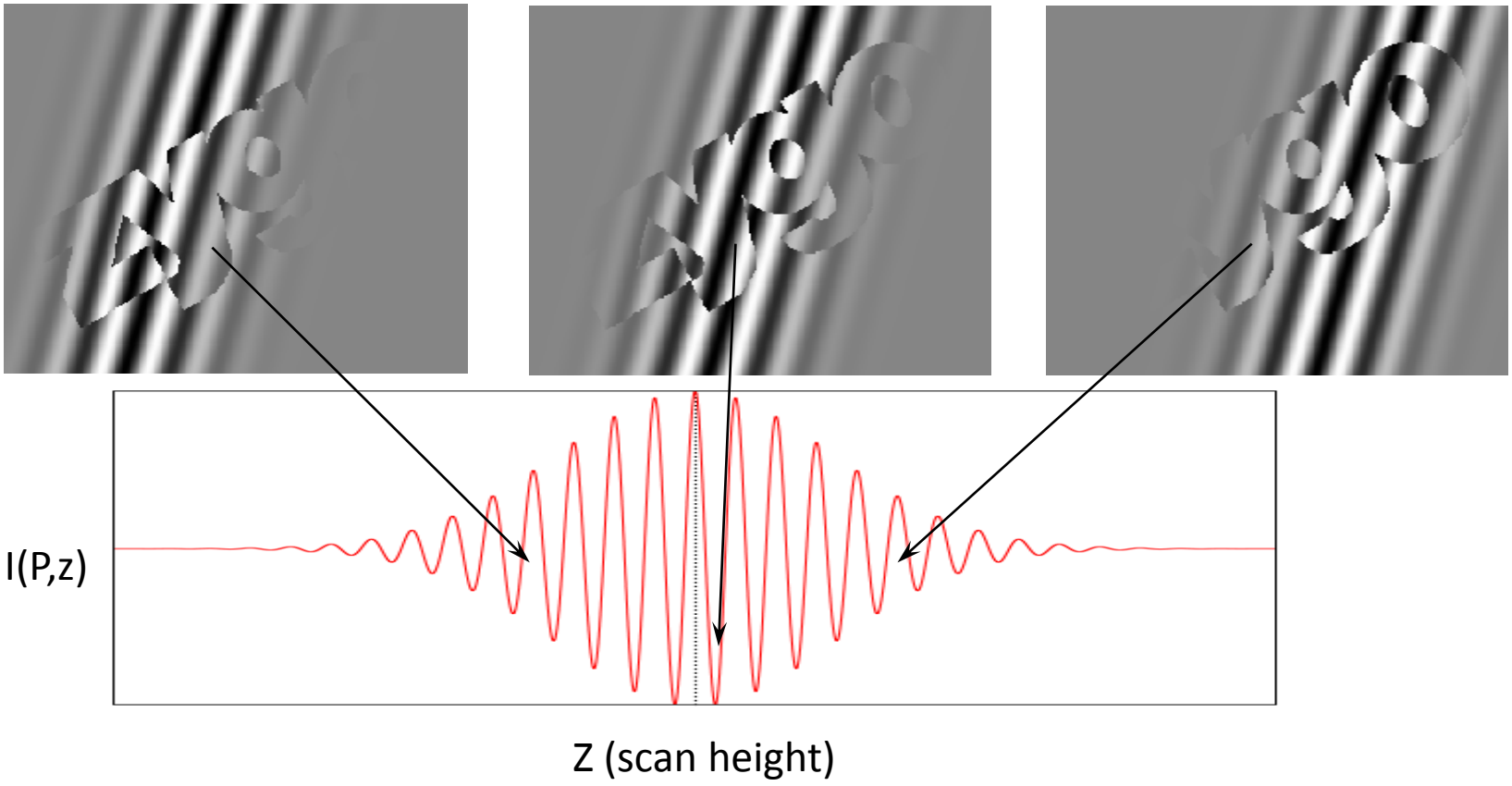
- The interferometric microscope objective comes in two flavors: Michelson (left) and Mirau (right).
  - Michelson objectives have longer working distances and wider fields of view, while Mirau objectives are used when higher magnification and NA are needed.
- The objectives are calibrated* so that the point of zero OPD is the same as the focal distance, i.e. the distance from the beamsplitter to the reference surface is the same as the focal length.

***Warning:** The 50x and 100x objectives are equipped with a focusing knob to account for thermal expansion – make sure your objective is in focus before use!



Scanning White Light Interferometry

By measuring the intensity of the fringes over the entire range of the interferogram, we can determine the point of zero OPD. The measurement is accomplished by scanning the objective in the z-axis.

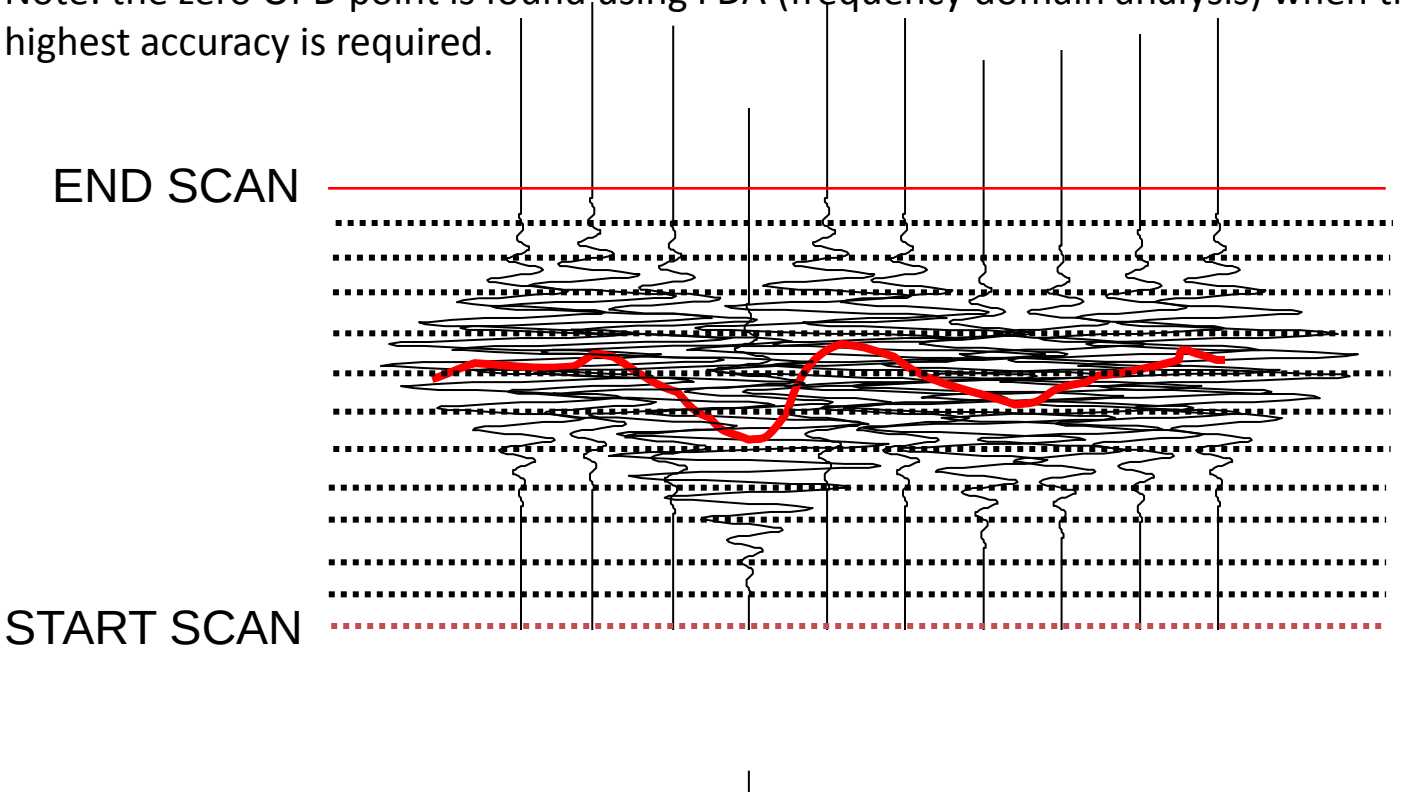


Scanning White Light Interferometry

Doing this scan for every point (pixel) in the field of view allows us to create a relative height map of the entire FOV.

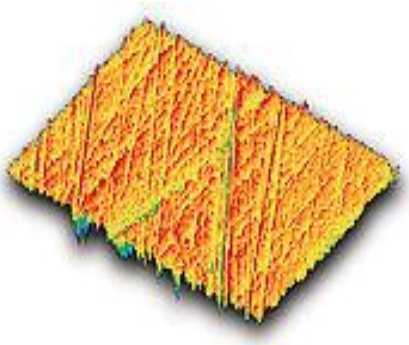
The zero OPD points map the surface of the test part.

Note: the zero OPD point is found using FDA (frequency domain analysis) when the highest accuracy is required.

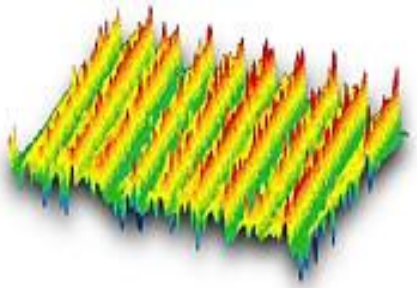


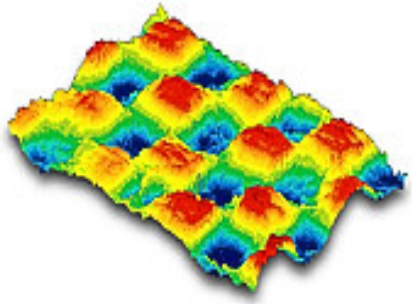
Examples of Applications

Valve Stems



Diamond-turned Surfaces





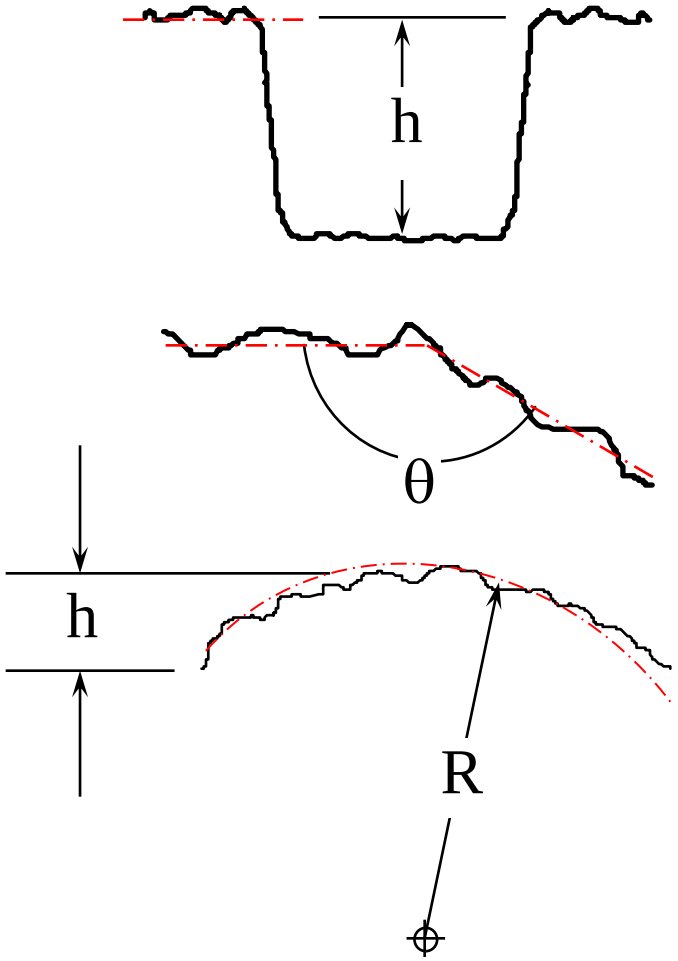
Embossed Paper

Anything that might look cool.

Examples of Applications: Microgeometry

Critical Dimensions

- Step Height, Coplanarity
- Angle
- Power, Curvature



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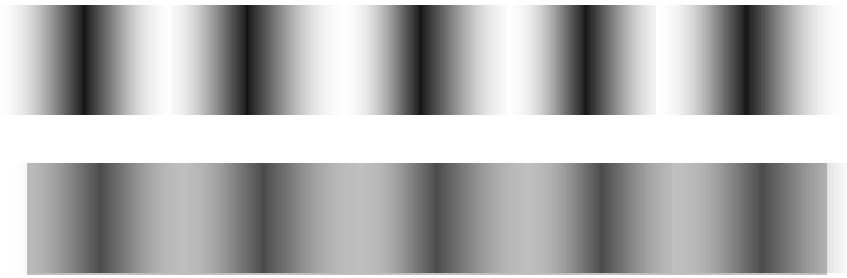
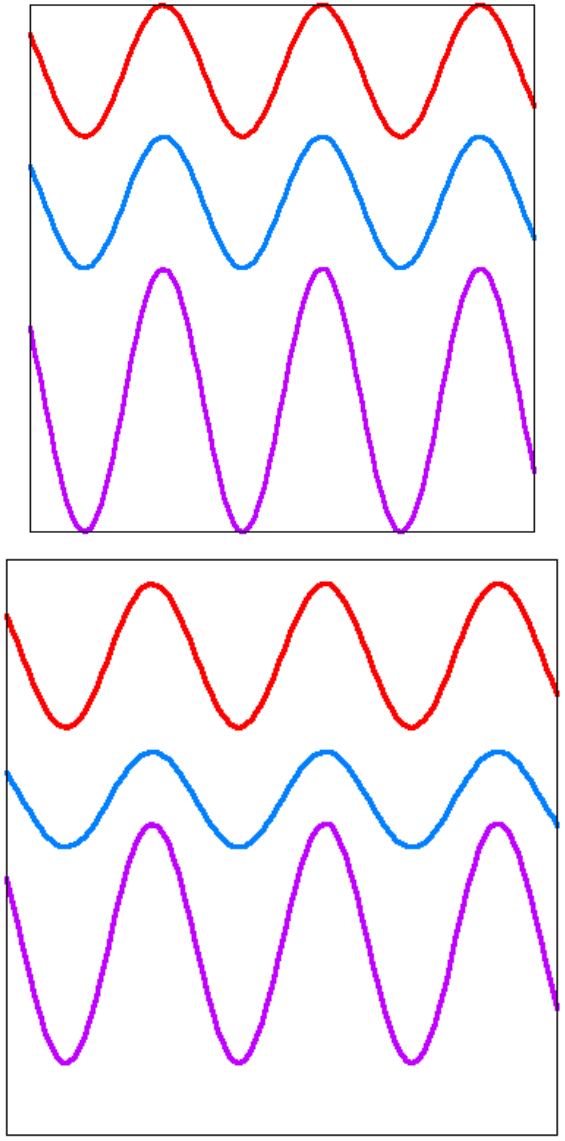
Fringe Contrast

Fringes are caused by the interference of light – but what if the two interfering beams are not of equal intensities?

Fringes end up in low contrast, varying between shades of grey rather than sharp black and white.

Low contrast fringes are usually caused by either reflective mismatches or aliased fringes.





Reflectivity Mismatch

If the light:

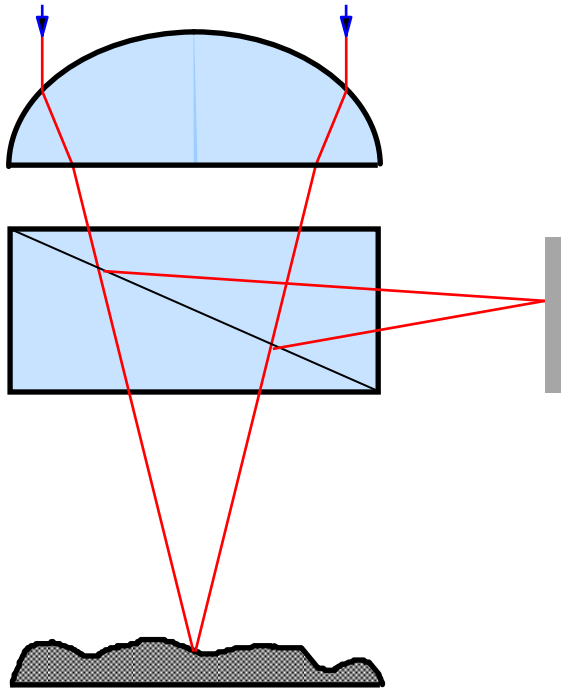
- is evenly split along each path (bad assumption!!),
- and a perfect mirror is used for the reference surface (also a bad assumption),

the reference beam will return at ½ the initial intensity.

The test beam will return at ½ times whatever the reflectivity of the test part is, so a low reflectivity part will cause low contrast fringes.

(In reality the objectives are in more of a middle ground, realizing that few parts are perfectly reflective!)

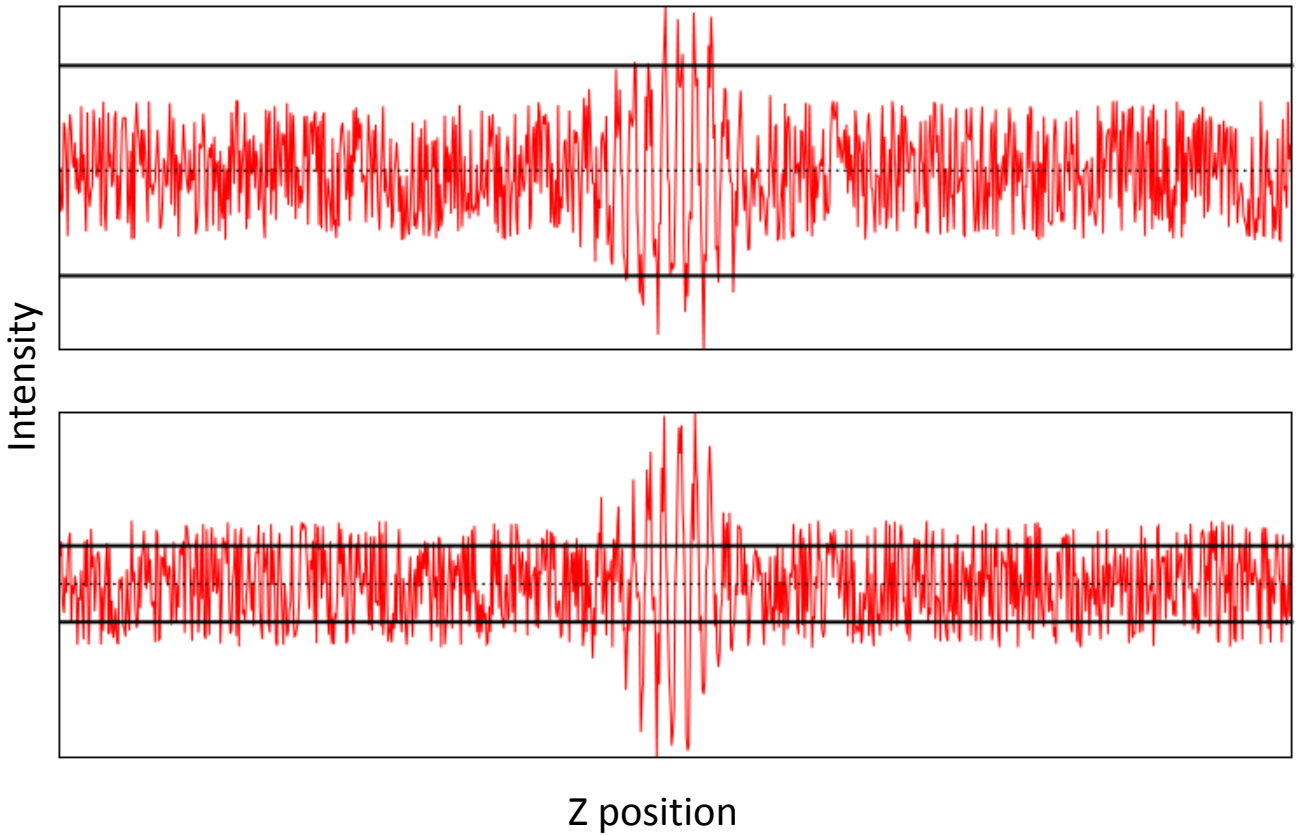
So what can we do?



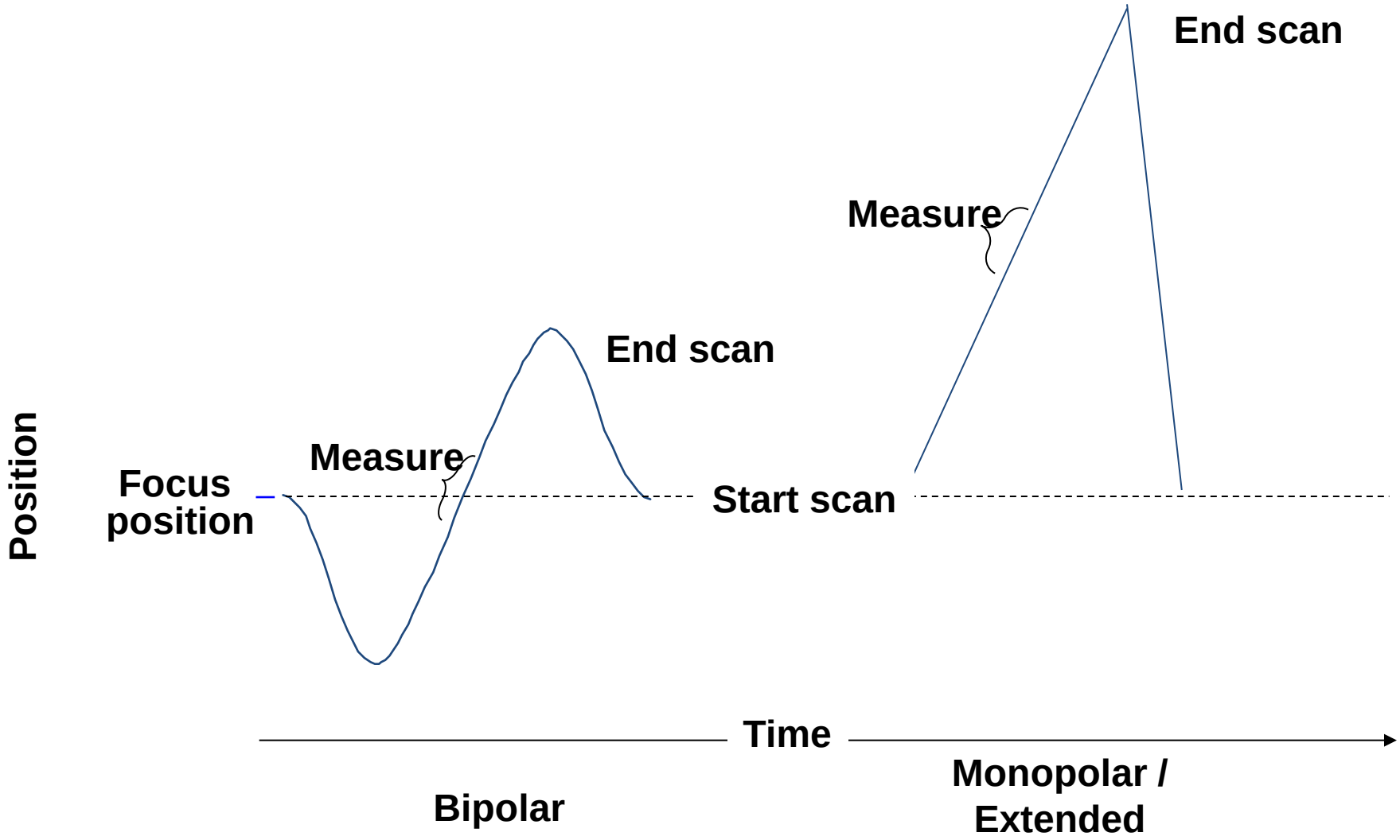
Minimum Modulation (Min Mod%)

The MinMod% control specifies how much oscillation is required for data to be accepted.

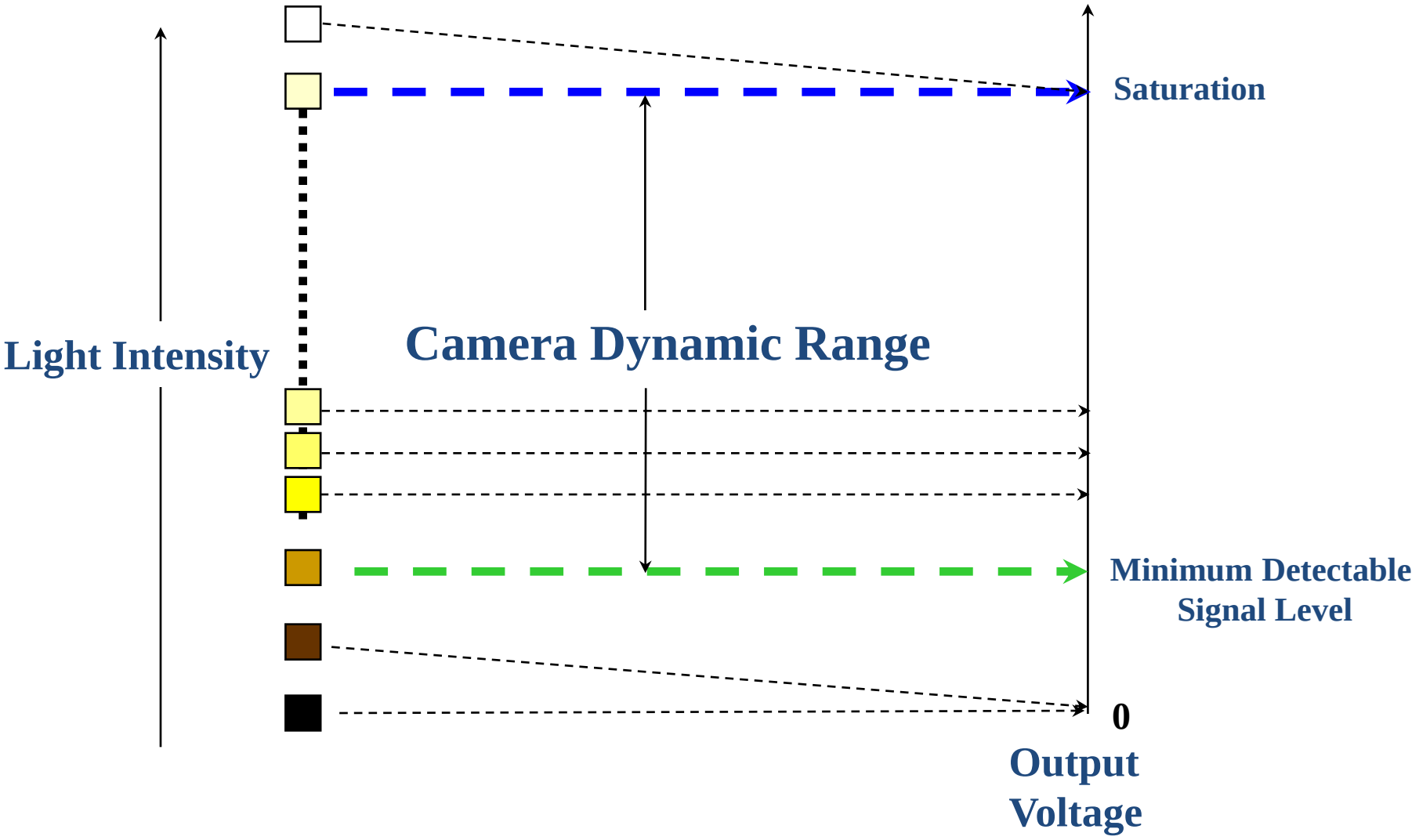
Poorly modulating signals (low contrast fringes) will be excluded if this control is set too high, but noise can be misinterpreted as data if the control is set too low.



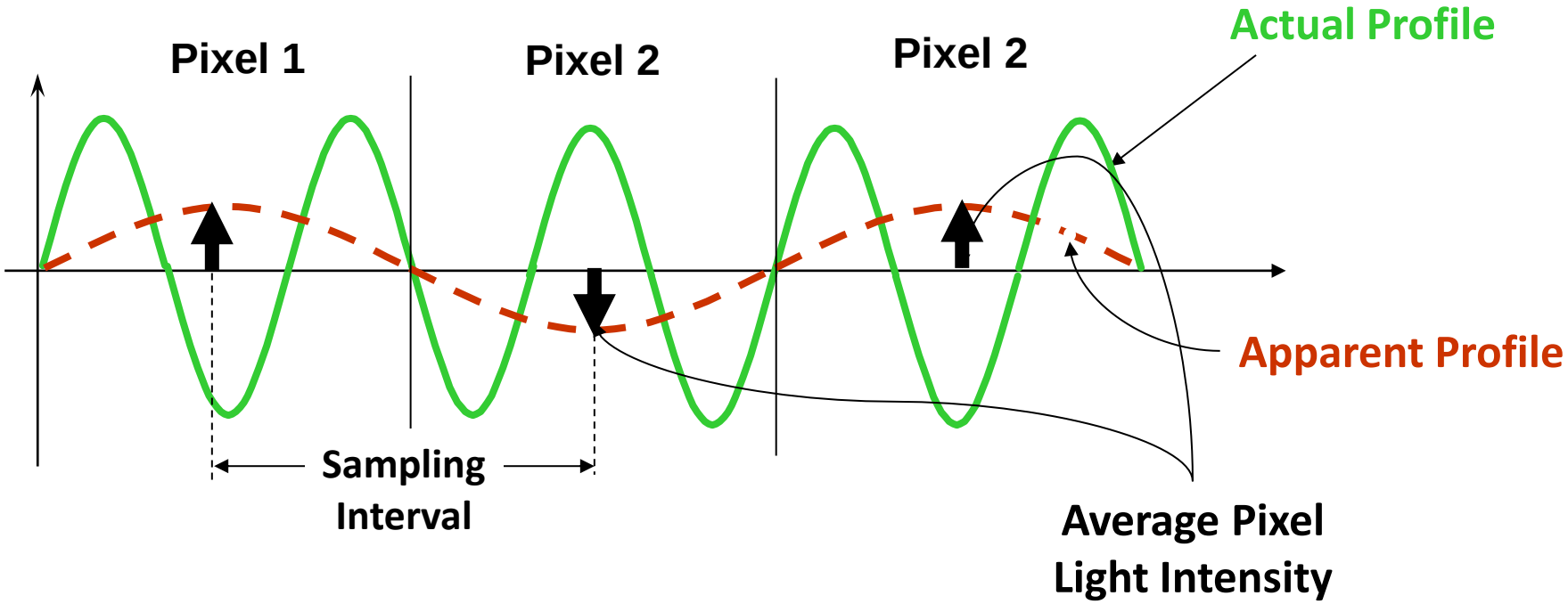
Scan Types



Camera Dynamic Range

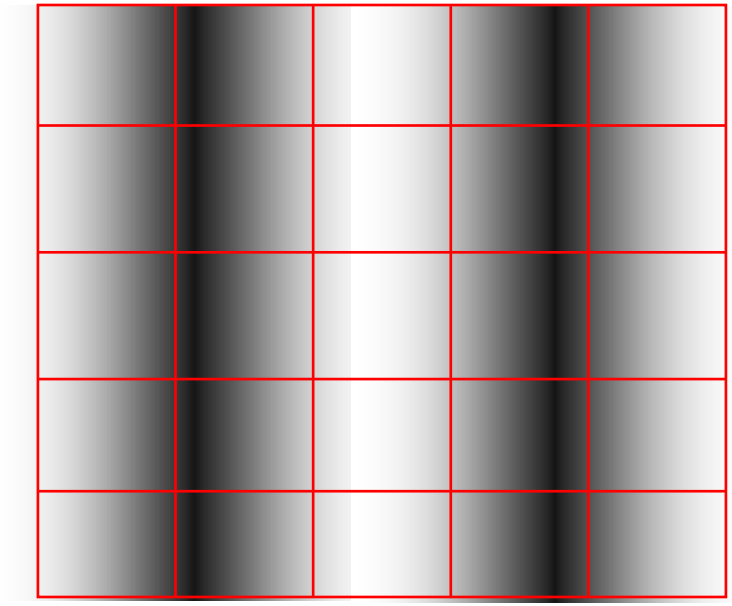


Aliasing

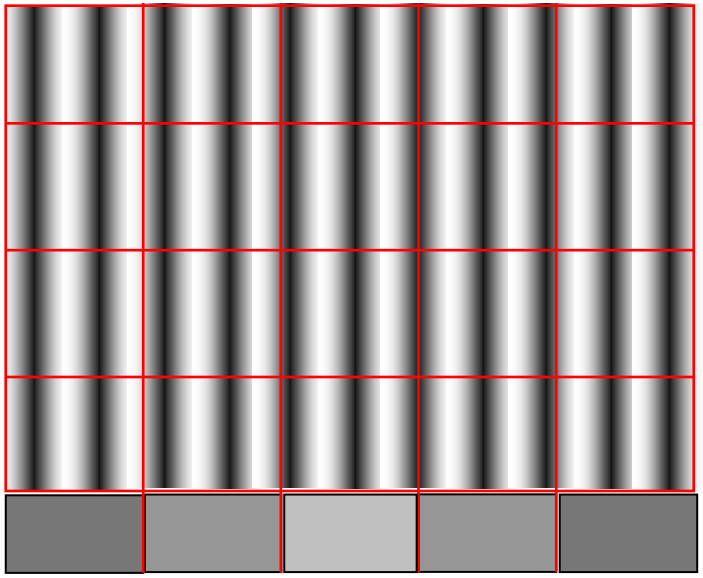


Nyquist Limit -- the shortest detectable wavelength for a given sampling interval or rate (pixel spacing or filter window size)

Aliased Fringes



Nyquist Limit



Aliased Fringes

(Average Light Intensities)

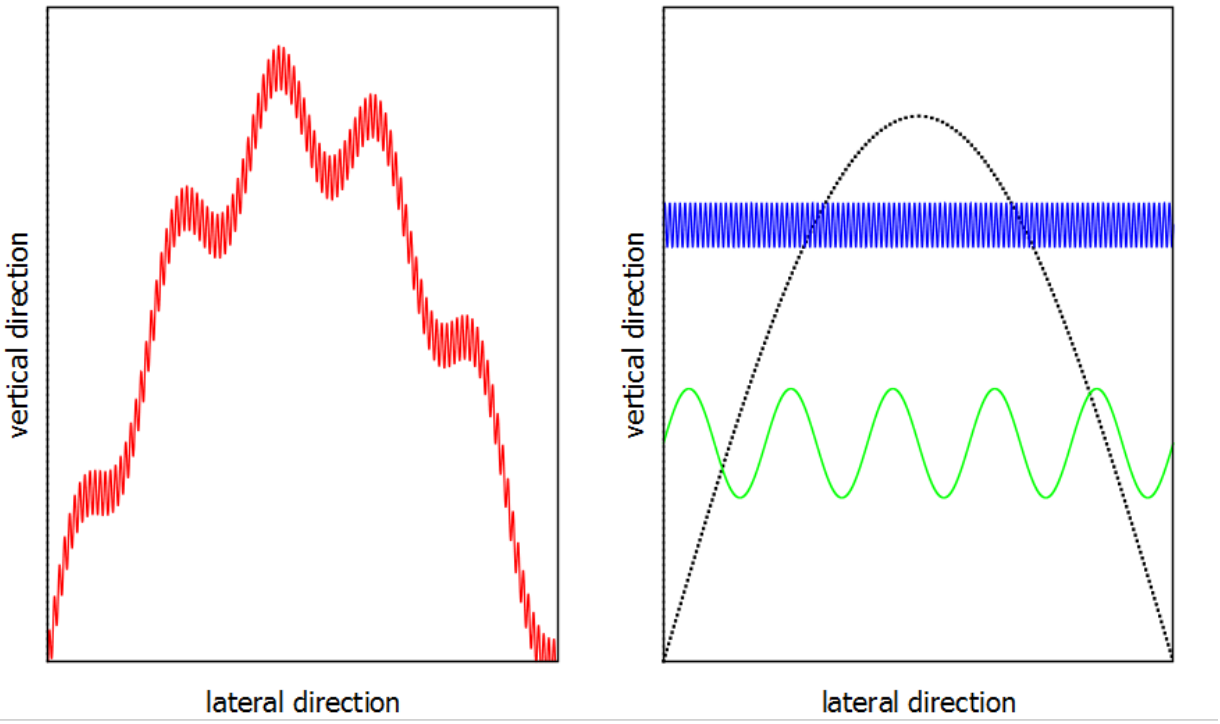
MetroPro Surface Texture Parameters

Frequency Domain Analysis (FDA)

Surface structure analysis is discussed in **frequency (or wavelength) space**.

The **Fourier Decomposition** of a function is its expression as a series of sine and cosine functions of different frequencies (or wavelengths).
General form:

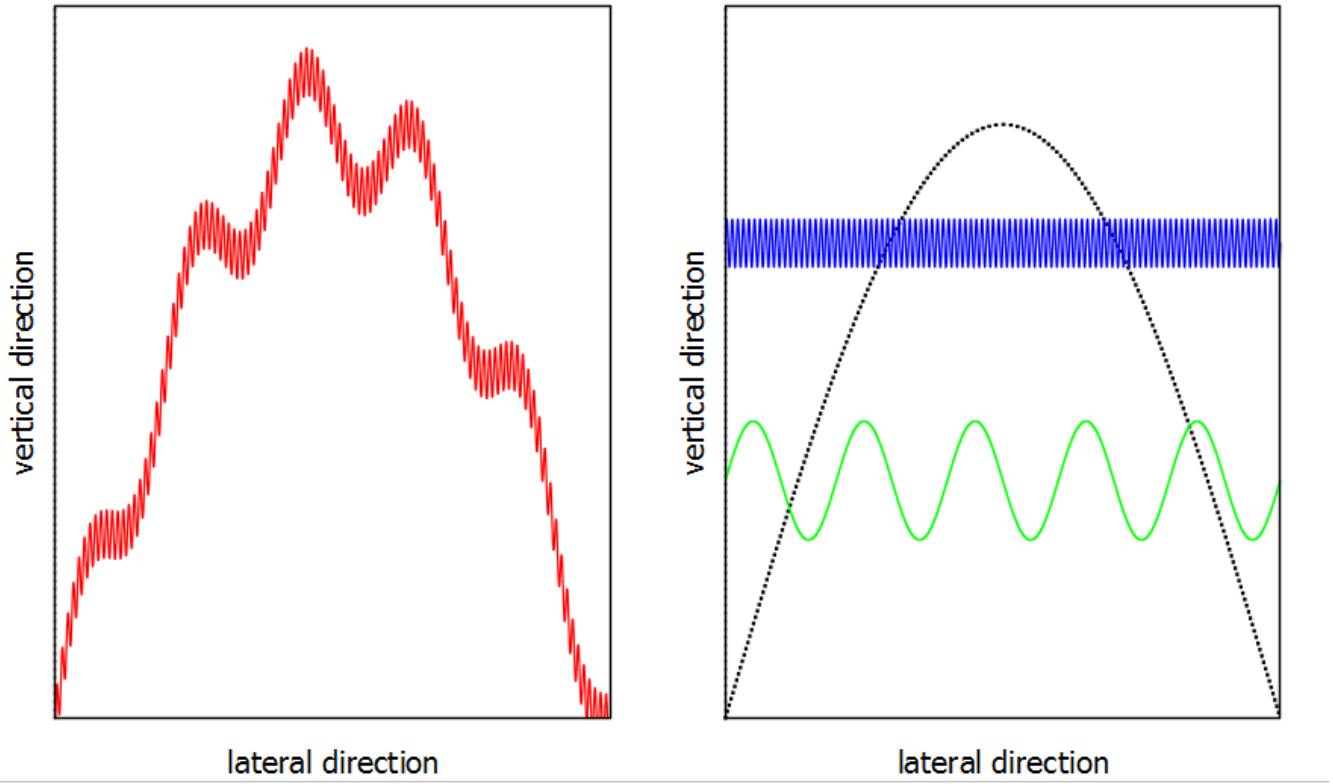
$$f(x) = \Sigma(a_j \cos[k_j x] + b_j \sin[k_j x])$$



Form and Texture

Surface characteristics are often grouped by wavelength. A part measurement (in cross-section) may look like the graph on the left.

- Long wavelength features, i.e. the general shape of a part, are called **form**. (Black dashed line.)
- Mid-wavelength features are called **waviness**. (Green line; vertically offset for clarity.)
- Short wavelength features are **roughness**. (Blue line; vertically offset for clarity.)
- Waviness and roughness are jointly called **surface texture**.

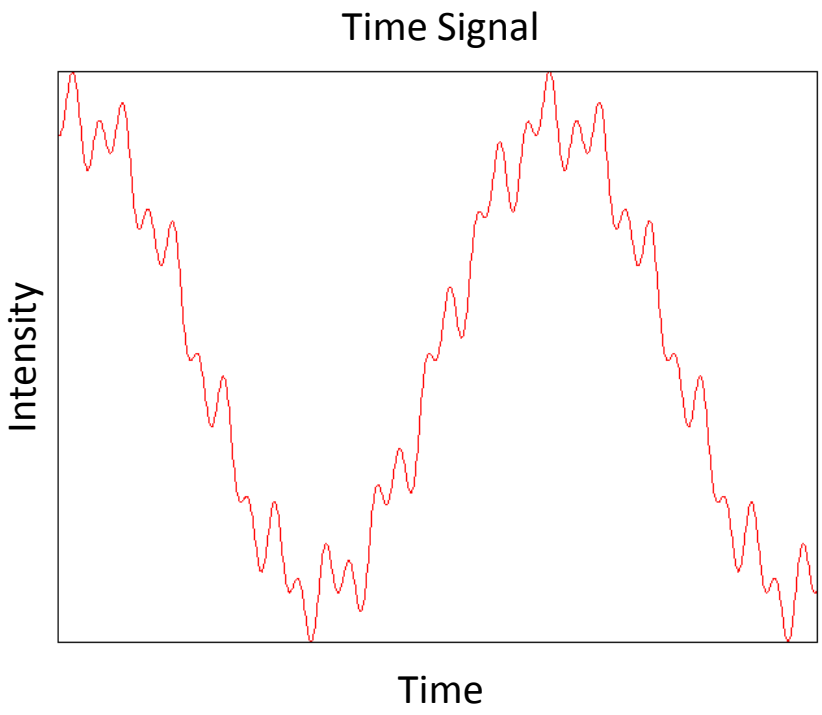


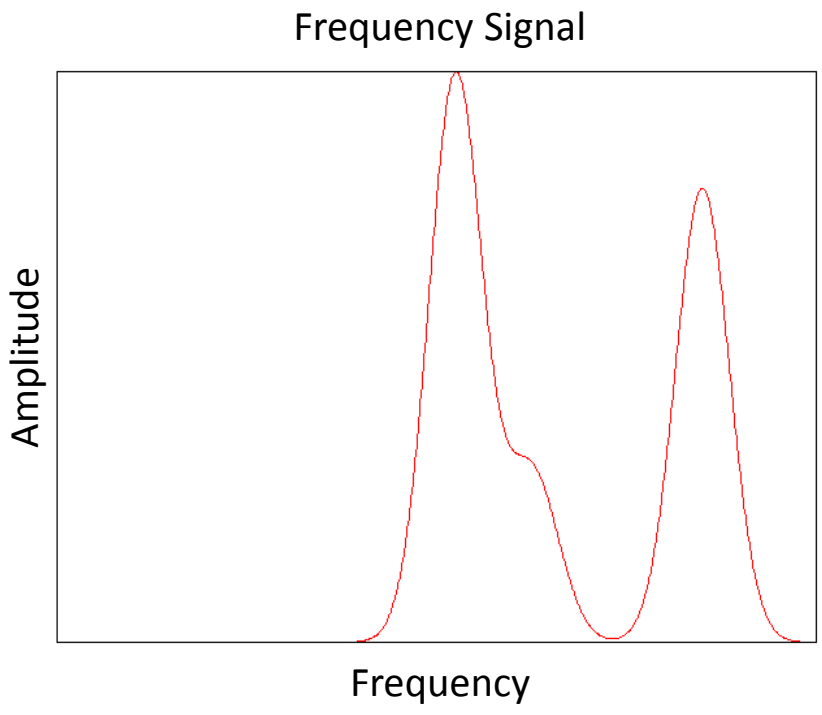
Power Spectrum

The Power Spectrum is a way to visualize the amount of each frequency in a signal.

In real signal processing, the signal is discrete, and has values only at points determined by the sampling frequency.

Filtering can be understood easily in terms of the power spectrum / Fourier transform!





Terminology (1 of 2)

- Surface Texture
  - The topography of a surface composed of certain deviations that are typical of the real surface. It includes roughness and waviness.
- Profile
  - A two dimensional slice through an area.
- Areal
  - A three dimensional surface area.
- Roughness Parameters
  - The non-periodic finer irregularities in the surface texture which are inherent in the production process. These are a measure of the vertical characteristics of the surface. Sampling Length- The area selected for assessment and evaluation of the roughness parameter having the cutoff wavelength. Any surface irregularities spaced farther apart than the sampling length are considered waviness. Also known as cutoff length.

Reference: Zygo OMP-514, Surface Texture Parameters

Terminology (2 of 2)

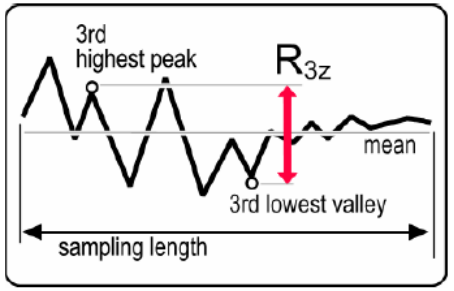
- Waviness Parameters
  - A larger component of surface texture upon which roughness is superimposed.
- Cutoff Filter
  - Determines the wavelength at which the surface structure is differentiated between roughness and waviness data. Proper selection of the correct filter cutoff in software is critical to measurement accuracy. (λc)
- Hybrid Parameters
  - These parameters are combinations of spacing and roughness parameters.
- Evaluation Length
  - The area from which data is obtained. It is a three dimensional area that corresponds to the instrument field of view, or a two dimensional profile that corresponds to the length of the slice as defined in the filled plot.

Reference: Zygo OMP-514, Surface Texture Parameters

Roughness Parameters

Examples

R_{3z} Base roughness depth. The distance between the third highest peak and the third lowest valley. A peak is a portion of the surface above the mean line and between center line crossings. Available for profile and areal data.



R_t (PV) Maximum peak-to-valley height. The absolute value between the highest and lowest peaks. Available for profile and areal data.

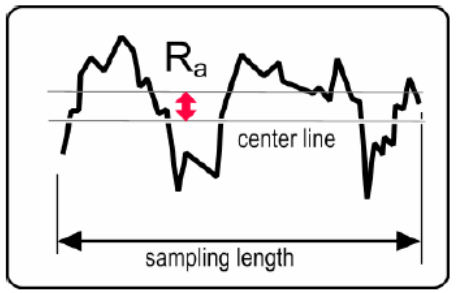
$R_t = R_p + R_v$

Reference: Zygo OMP-514, Surface Texture Parameters

Roughness Parameters

Examples

R_a Arithmetical mean deviation. The arithmetic average of the absolute values of the roughness profile. Available for profile and areal data.



$$R_a = \frac{1}{L}\int_0^L |z(x)|dx$$

R_q (rms) Root-mean-square (rms) roughness. The average of the measured height deviations taken within the evaluation length or area and measured from the mean linear surface. Available for profile and areal data. Rq is the rms parameter corresponding to Ra.

$$R_q = \sqrt{\frac{1}{L}\int_0^L z^2(x)\,dx}$$

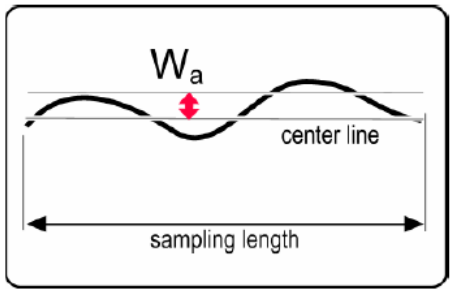
Reference: Zygo OMP-514, Surface Texture Parameters

Waviness Parameters

Examples

W_a Arithmetical mean deviation. The arithmetic average of the absolute values of the waviness profile.

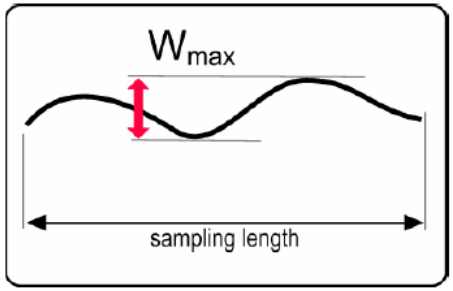
$$W_a = \frac{1}{L}\int_0^L |z(x)|dx$$



W_q The root-mean-square (rms) roughness of all points from a plane fit to the waviness data.

$$W_q = \sqrt{\frac{1}{L}\int_0^L z^2(x)\,dx}$$

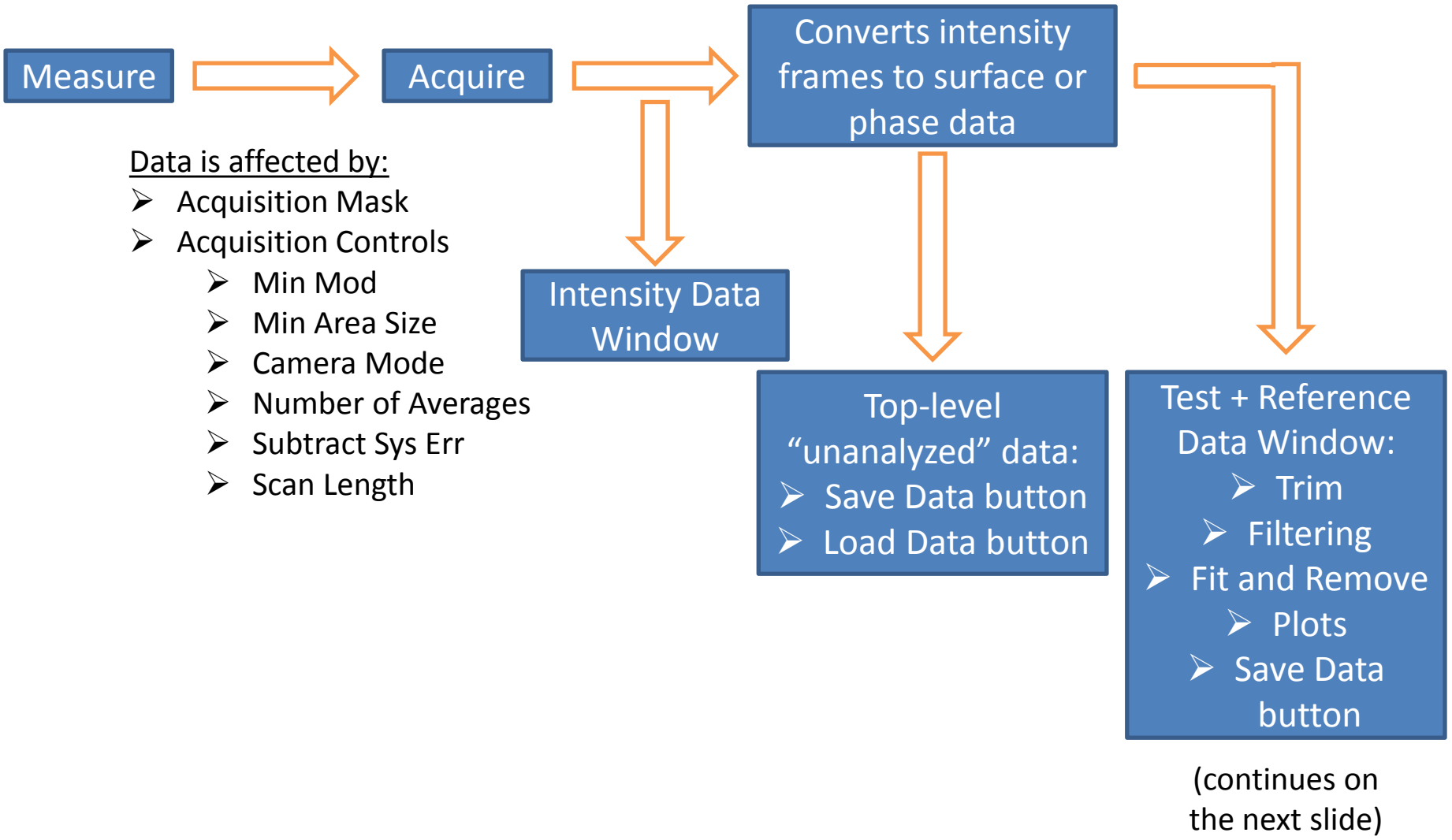
W_y (W_{max}) The maximum height of the waviness data.



Reference: Zygo OMP-514, Surface Texture Parameters

MetroPro Data Flow

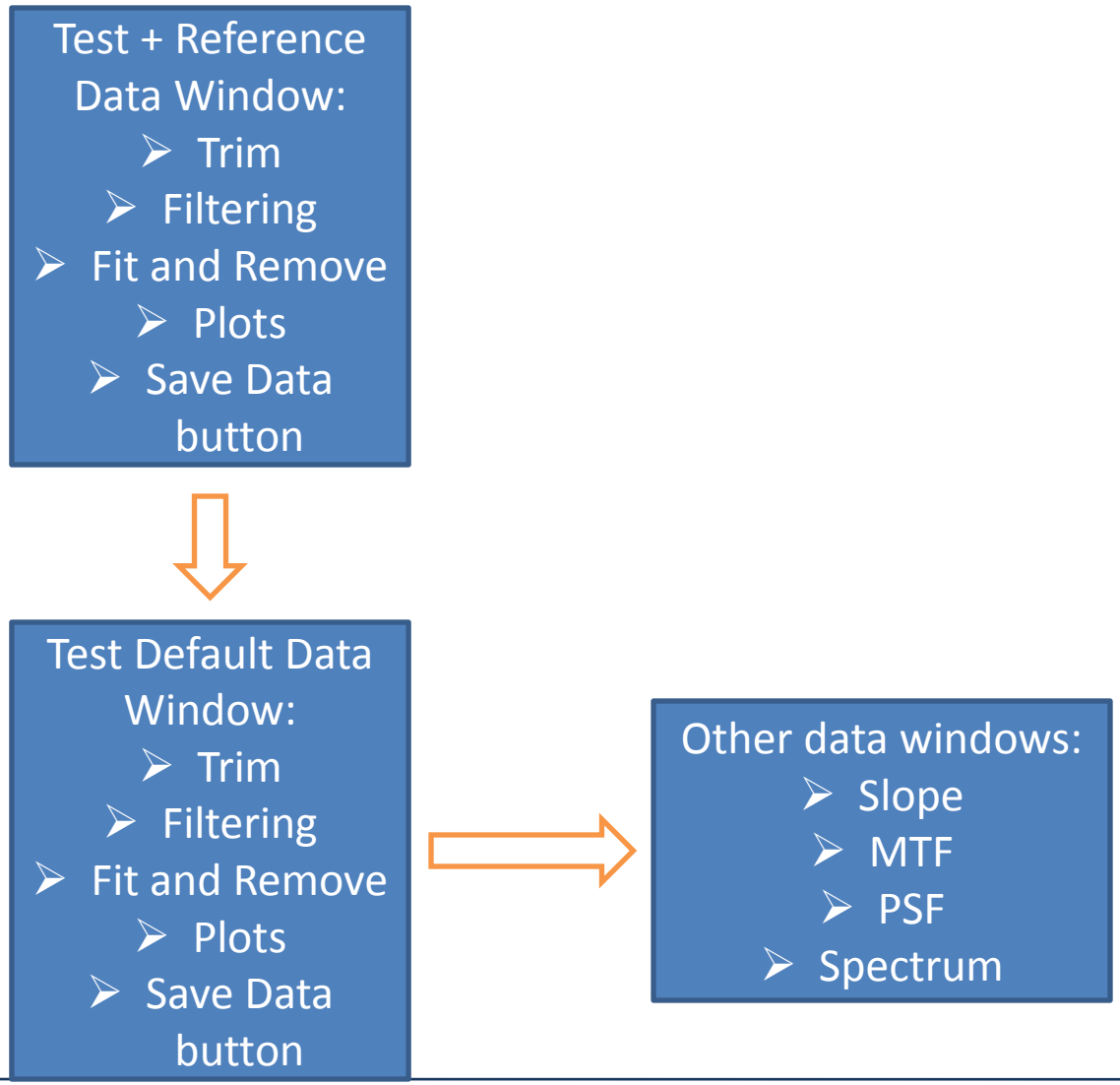
MetroPro Data Flow



(continues on the next slide)

MetroPro Data Flow (continued)

(continued from the previous slide)



Noise, Its Effects, Its Sources, and Countermeasures

Noise Categories

- Noise that can compromise metrology
  - Vibration
    - Seismic
    - Acoustic
  - Air turbulence
  - Thermal stresses

Noise Sources

- Foot traffic
- Machinery
- Building modes or harmonics
- Air circulation systems
- Closing doors
- Paging systems

Minimizing Seismic Vibrations

- Isolate floor
  - Select room away from vibration sources, put saw cuts in the slab
- Locate optical table on ground floor
- Place optical table near wall
  - May avoid building modes to some degree

- Always use a commercially available vibration isolation table
  - Make sure it is floating properly, strain relieve cables

Minimizing Acoustic Vibrations

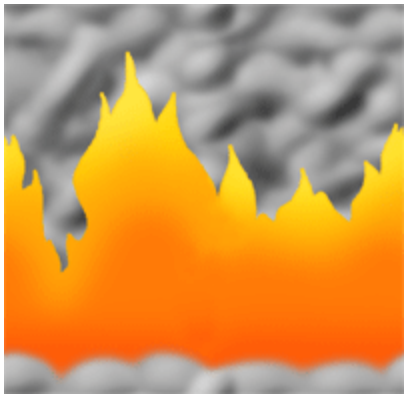
- Locate optical table in a quiet area
- Use acoustic absorbing material on the walls, floor and ceiling
- Construct a tent of soft material or screen mesh around the optical table
  - Plexiglass boxes are not very effective
- Replace doors with curtains
- Mechanically de-couple the ventilation system from the room structure
- Reduce noise during data acquisition

Noting and Minimizing Air Turbulence

- Air turbulence will appear as “smoke” in a nulled interference pattern

- Sources that vary the index of refraction of the air
  - Normal room air flow
  - Heat sources/sinks near the interferometric cavity
  - Equipment fans

- Combating air turbulence
  - Remove equipment with fans from the immediate area
  - Cover ventilation ducts near the interferometer
  - Install diffusing baffles in the ventilation ducts
  - Tent the cavity and/or curtain the table area



Minimizing Thermal Stress

- Fabrication generates heat
- Thermal stresses will deform the cavity
- Allow the system to come to equilibrium
- Use equipment in a controlled environment

End Part I

Questions, comments, concerns?

Dan Russano - drussano@zygo.com
Jennifer Chen - jenchen@zygo.com
Zygo Corp. – inquire@zygo.com

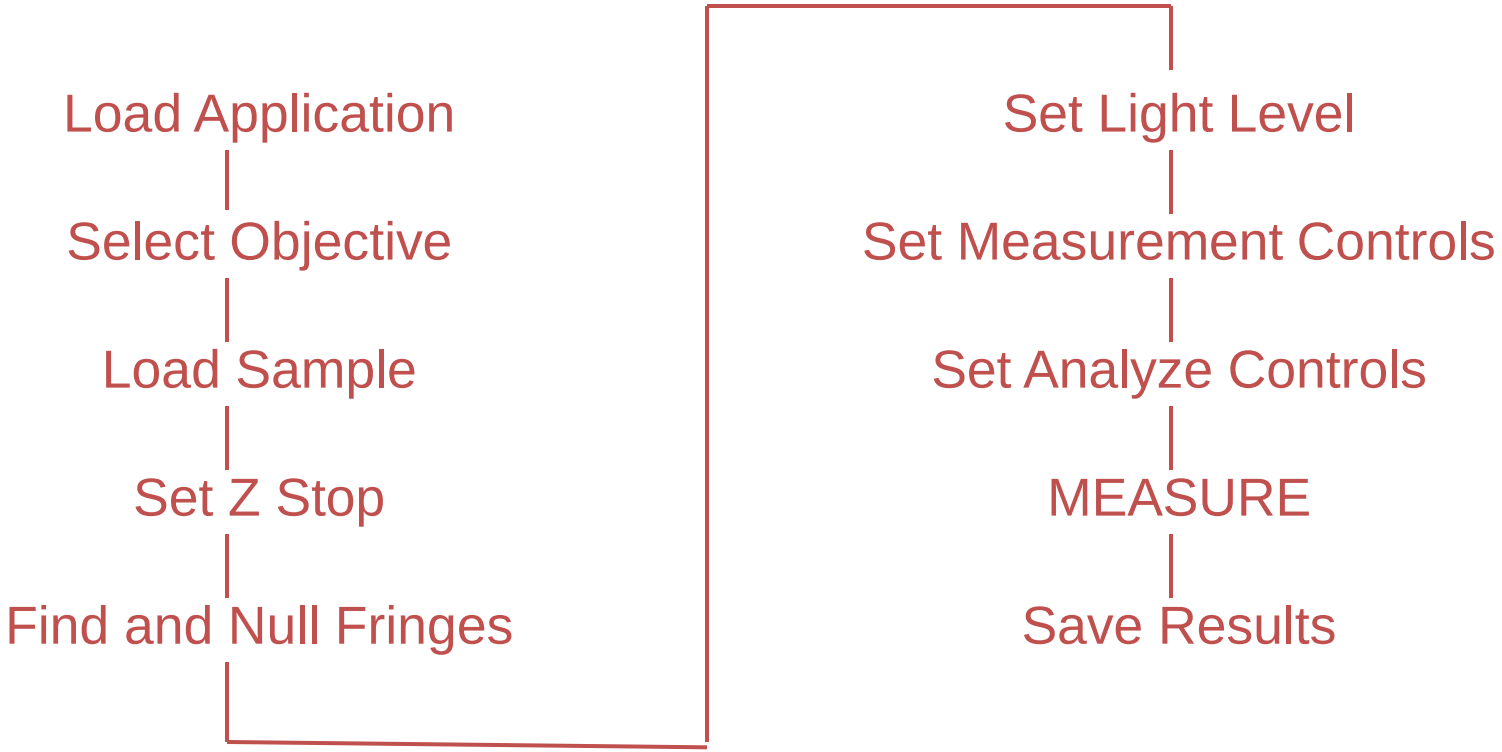
Further Reading: Wikipedia is an excellent place to start, and MIT-OCW can be very helpful for select topics. For further information,

- Born & Wolf, Principles of Optics / Garg, Classical Electromagnetism in a Nutshell / Hecht, Optics
- Hariharan, Optical Interferometry / Malacara, Optical Shop Testing
- Oppenheim, Discrete-Time Signal Processing / Butz, Fourier Transformation for Pedestrians
- Leach, Characterisation of Areal Surface Texture
- ISO Standards and their various guides

Some images courtesy Wikipedia under Attribution-share alike license: (Michelson Interferometer, slides 9&10, Airy Disk slides 14&15)

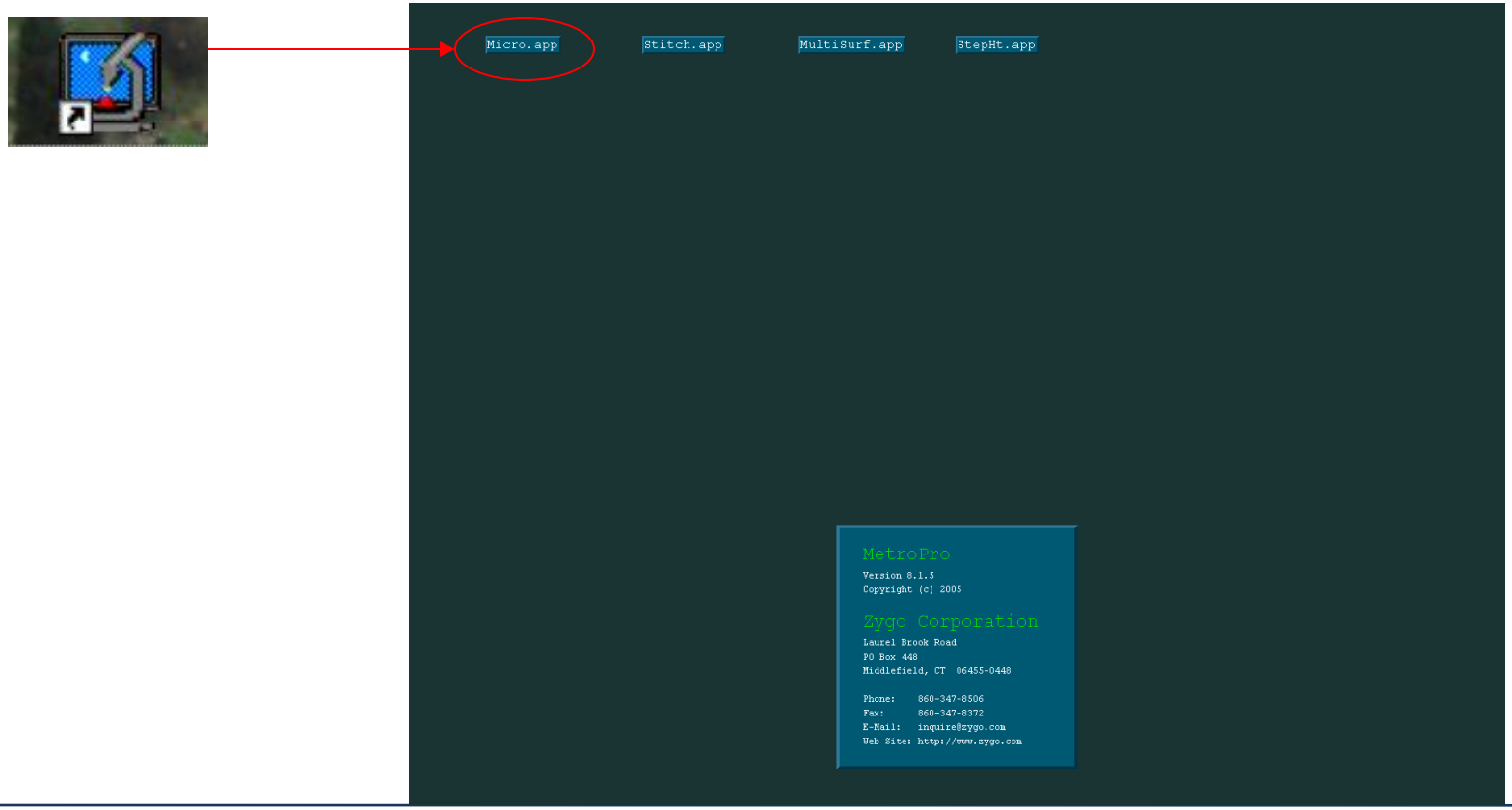
MetroPro Operation

Overall Operator Process Flow



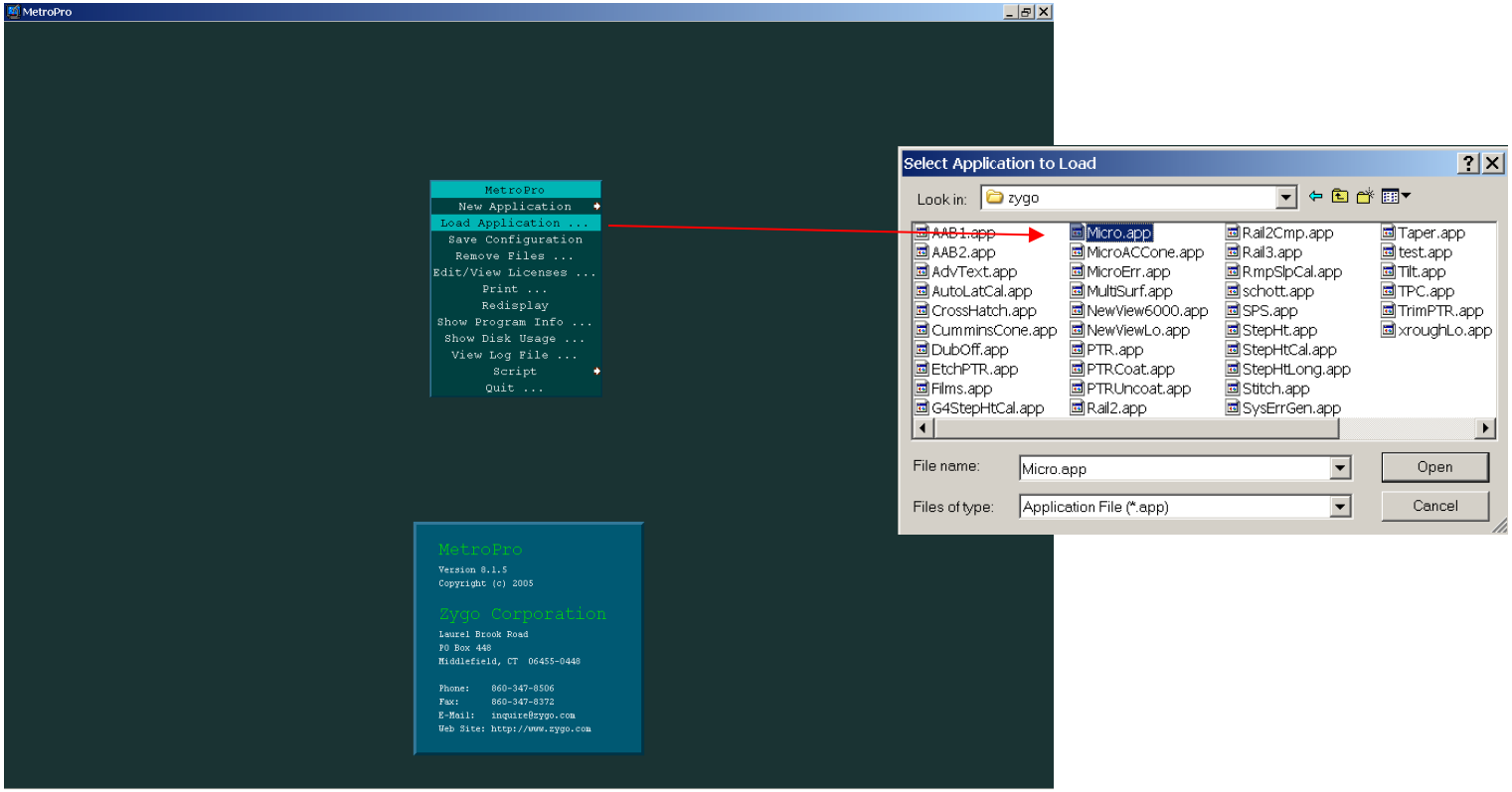
Load Application

- Open the MetroPro Shortcut on the Desktop
- Click on the desired application to open



Load Application

- If application not on desktop, right-click to “Load Application”



NewView Procedure

Step by step

- Select and mount appropriate objective
- Mount part
- Move slightly closer than objective working distance; set “z” stop
- Set light level for viewing
- Focus; observe fringes
- Broaden fringes by tipping and tilting stage
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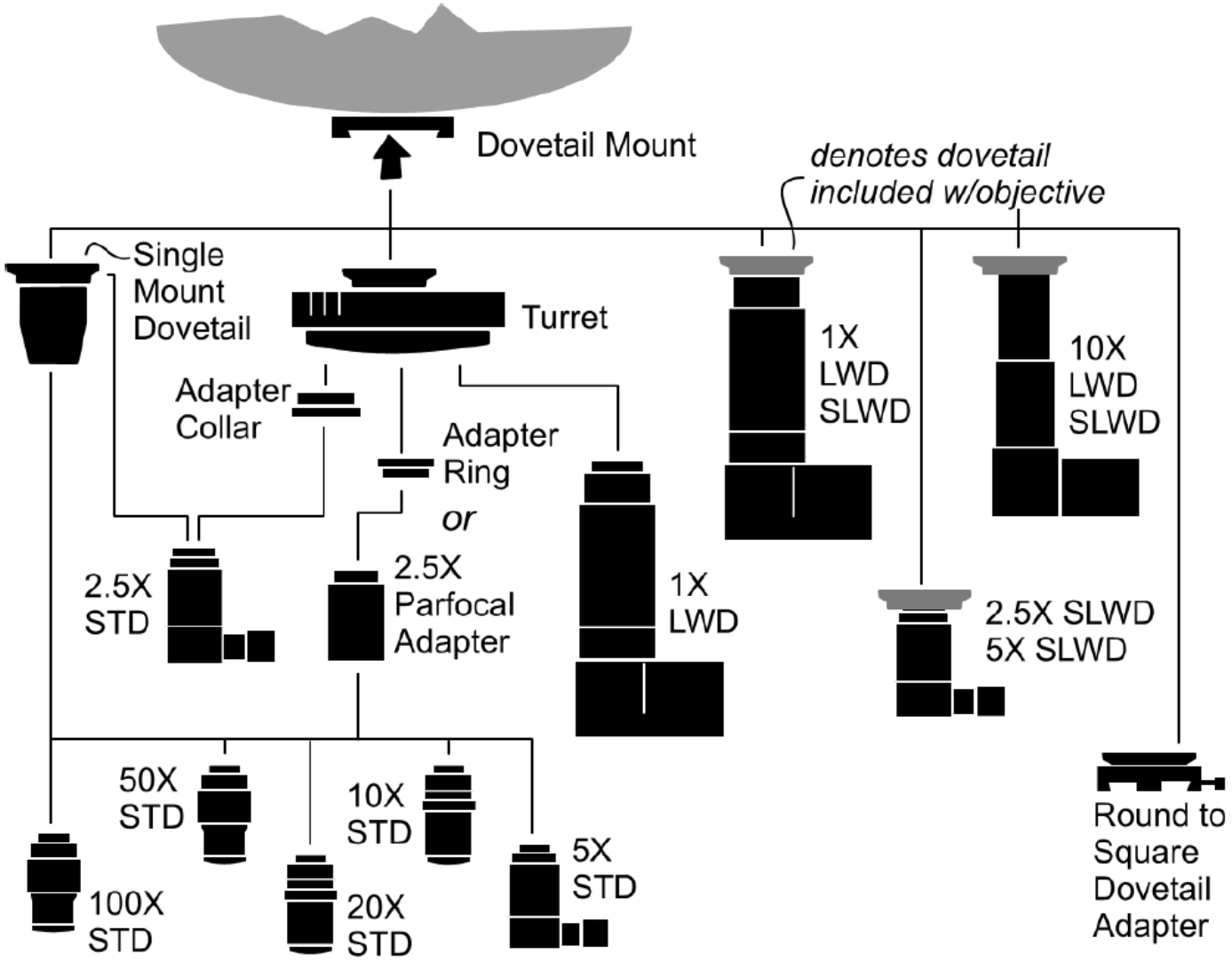
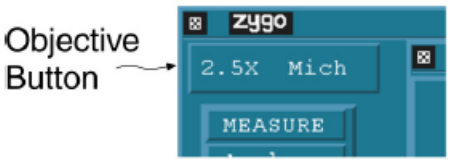
NewView Accessory Guide



Select Objective

- Click the Objective Button to select the objective
- For automated turret, ensure sample stage is clear first
- Choose objective based on resolution and desired field of view
  - Tradeoff: Lower magnification yields a wider field of view but provides coarser lateral resolution



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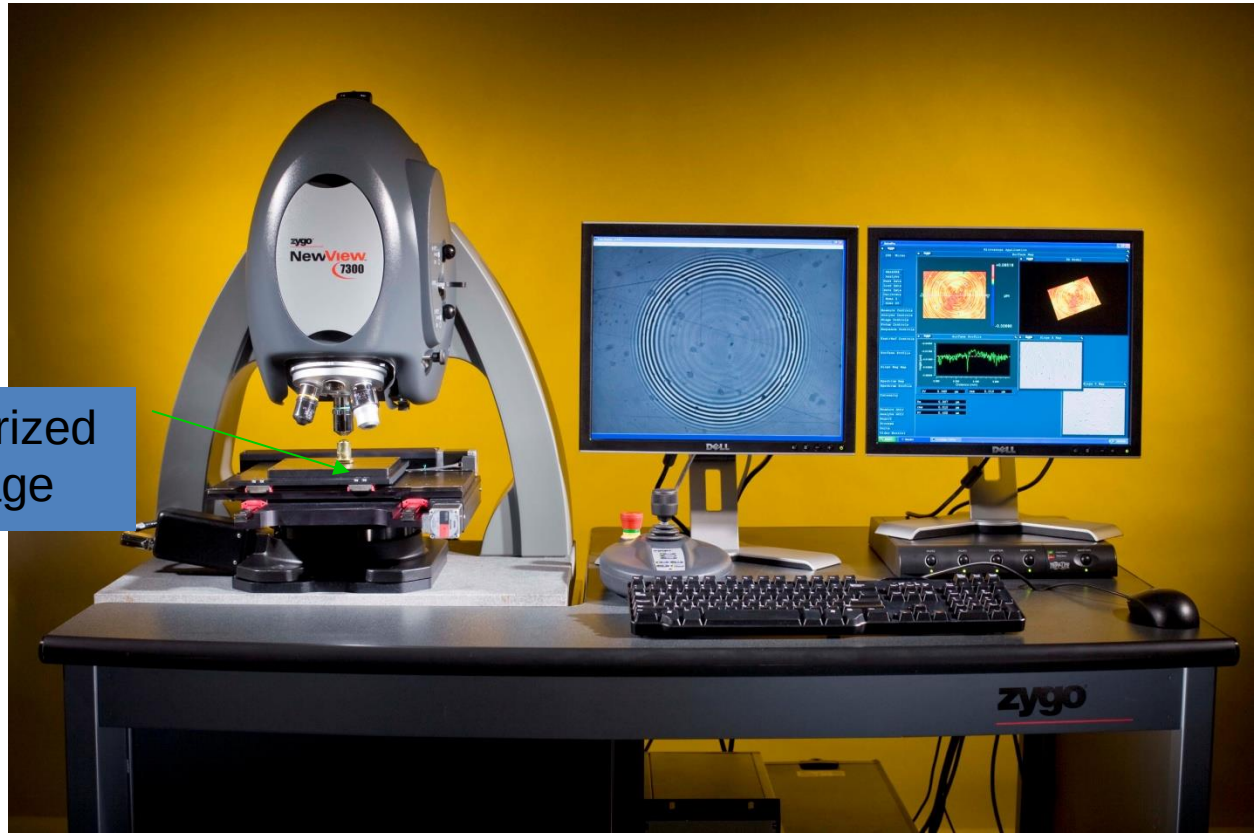
NewView 7300 System Overview

- Place part on motorized stage



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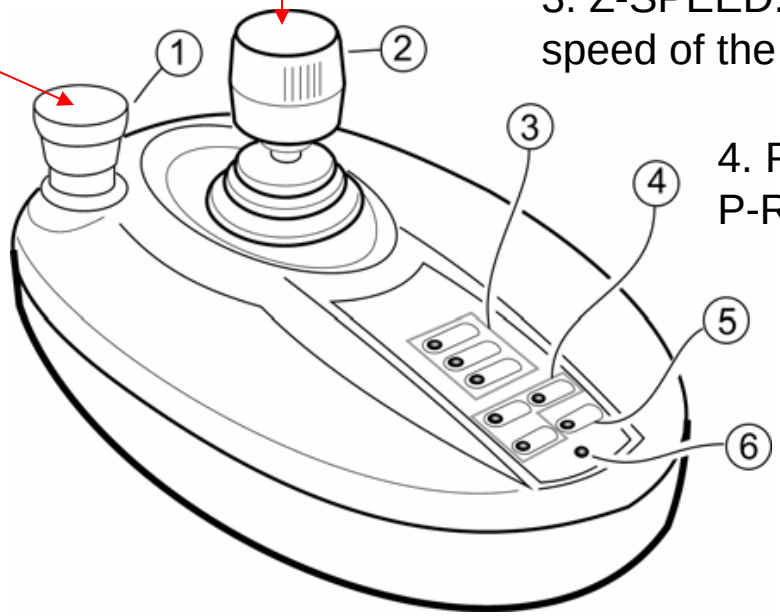
Motion Controller/Joystick

2. Turn Twist Knob to drive z-axis.
- Clockwise - away from part stage
- Counterclockwise - towards the part stage

Push joystick to drive selected part stages.
- Up/Down for y-axis or pitch (tilt).
- Left/Right for x-axis or roll (tip)

1. Press MOTION STOP to halt motion in case of emergencies



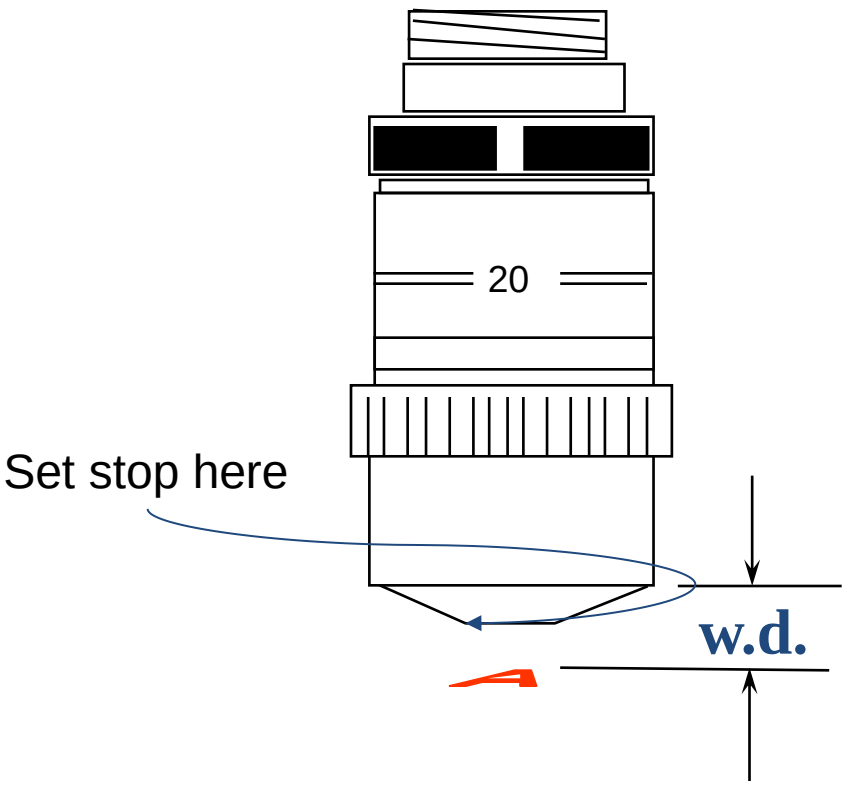
3. Z-SPEED. Choose speed of the z-axis (focus)

4. Push to activate the X-Y or P-R

5. Set Z STOP
To avoid crashing objective into sample

6. HOST. Red when motion system is controlled by software

Setting “Z” Stop



Indicator Light

Solid Green -- Safe; stop set, objective above stop level

Flashing Red -- DANGER! Stop not set

Solid Red -- Stop set, objective at stop level

NewView Procedure

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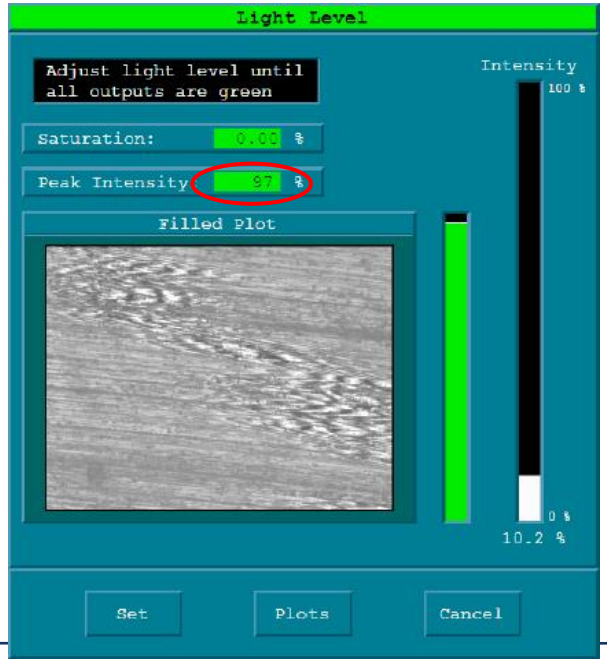
Set Light Level

- Set **automatically** by pressing “F5”
  - Must be centered on the brightest fringe
- Set **manually** by pressing “F4”
  - Use numeric keypad to set peak intensity to approx 90 – 99 %
  - Make sure there is no saturation (red)

Key	Function
/ *	Coarse down (/) and up (*).
- +	Fine down (-) and up (+).
1 2 ... 9	Adjust level in 10% steps, 1 = 10%, 3 = 30%, 9 = 90%
Tab	Toggle between last two light settings.
Esc	Cancel current action and abort measurement.



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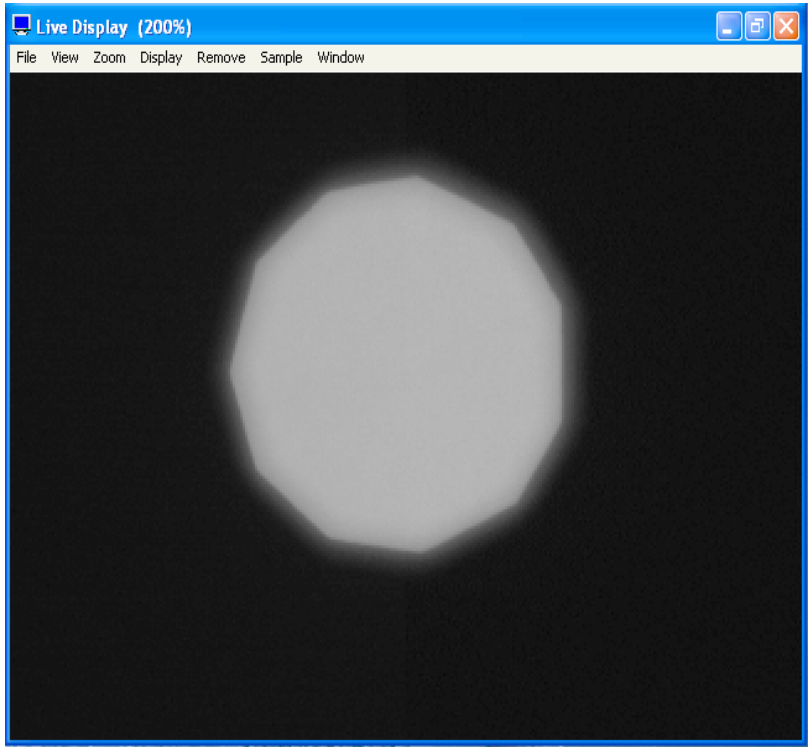
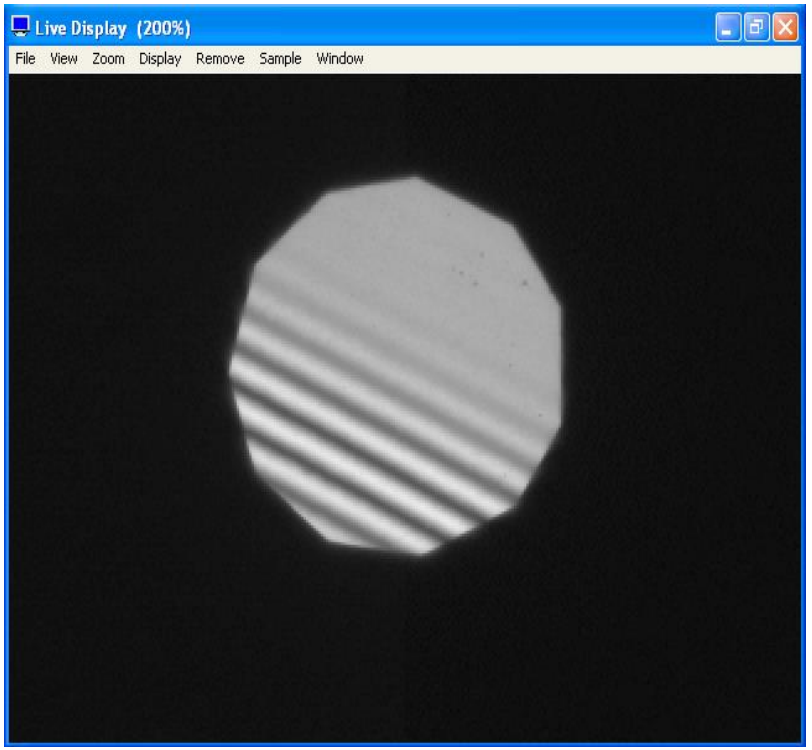
Field Stop Employment

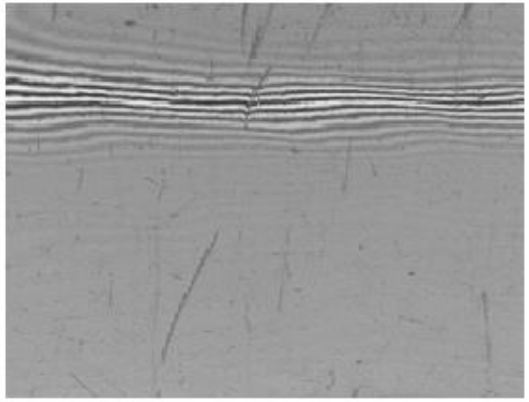
- For a highly reflective part, it is easiest to use an edge to find focus
- The field stop can be used as a focus aid
  - A “halo” will appear near focus





Focus Sample

- Adjust z using the focus joystick until sample is focused
- Focus is found when fringes appear on Live Display
  - Fringes are the light and dark bands produced by the interference of light
- *Hints:* if having trouble focusing, press “F5” to set the light level automatically for viewing, or try using the field stop



Example: Part focused with fringes

NewView Procedure

Step by step

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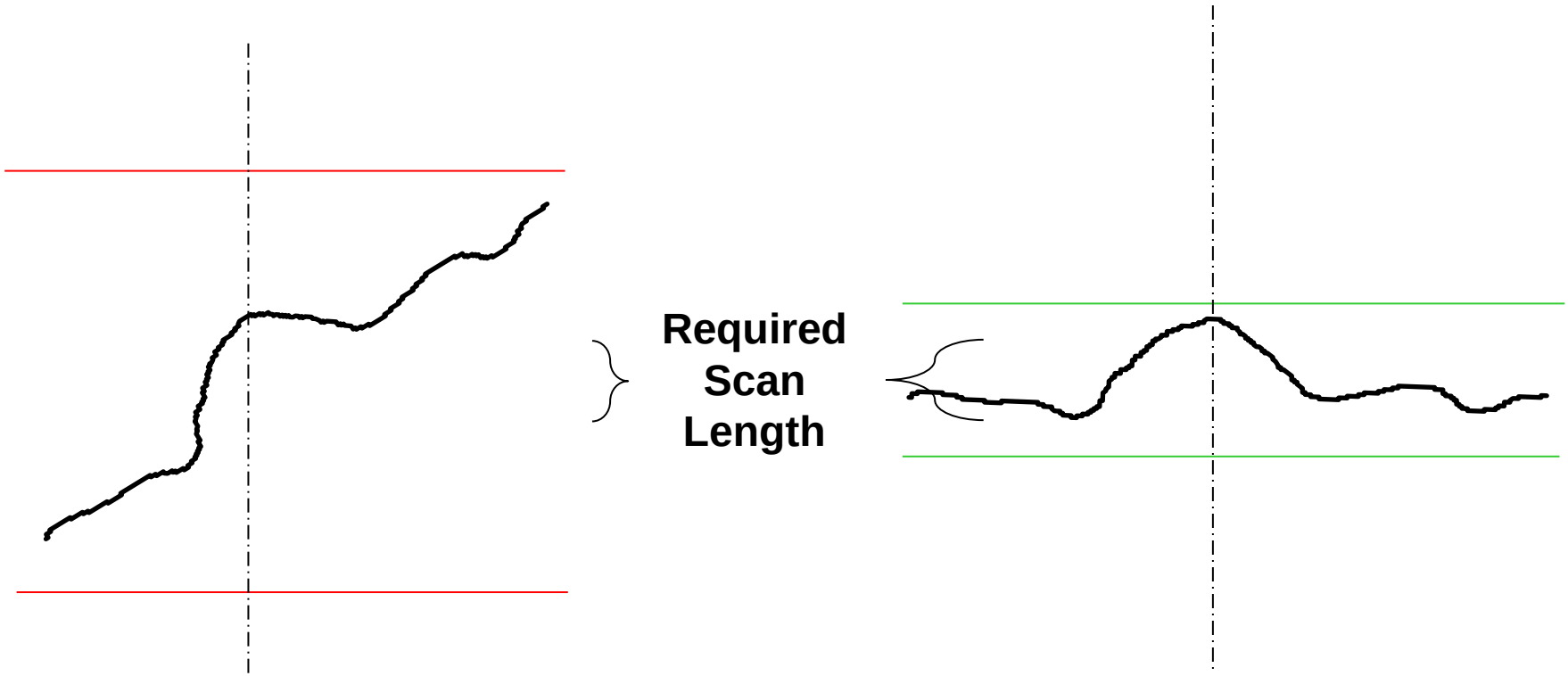
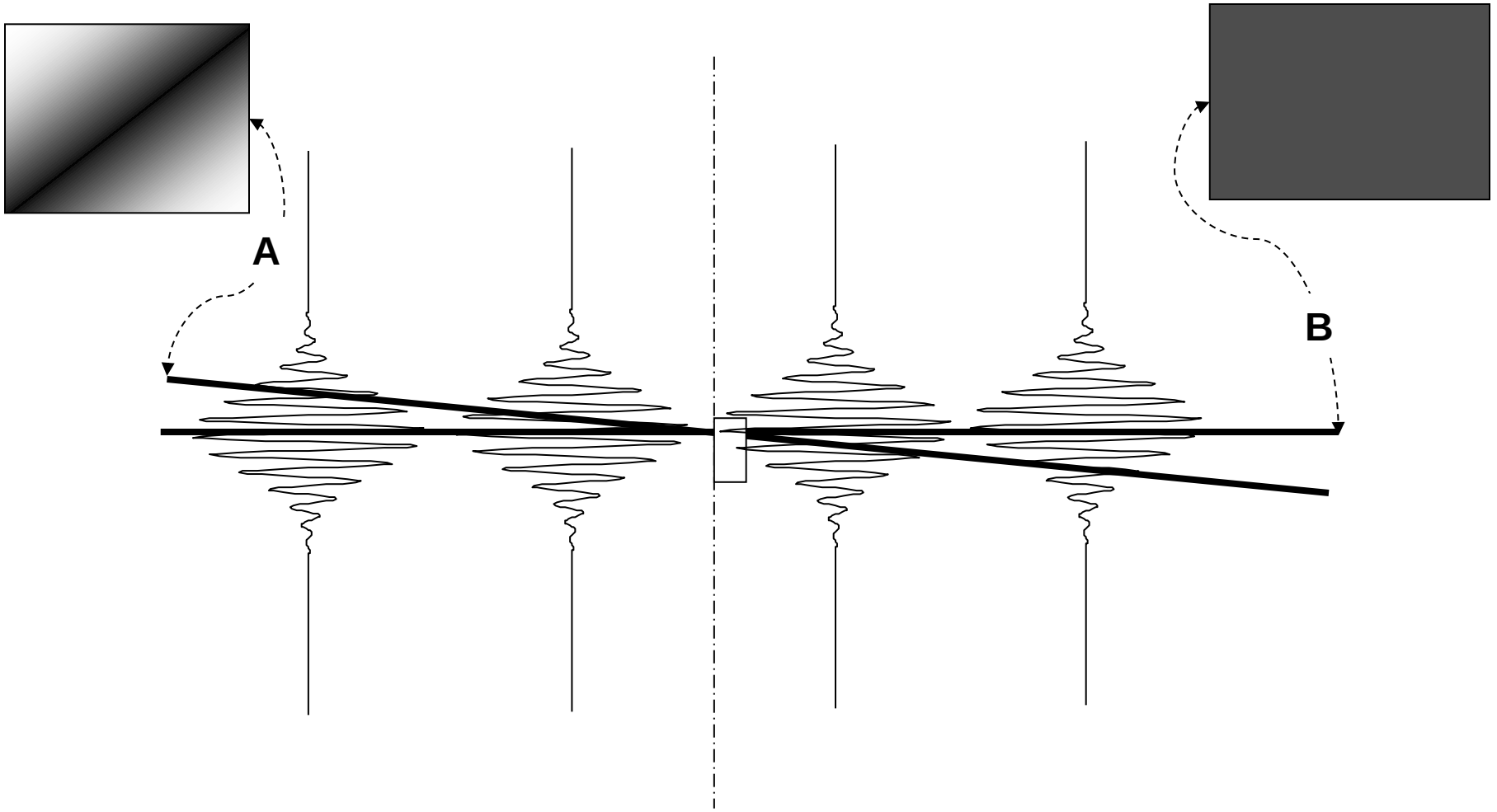
Roll & Pitch to Minimize Scan Length



“Nulling” the Cavity

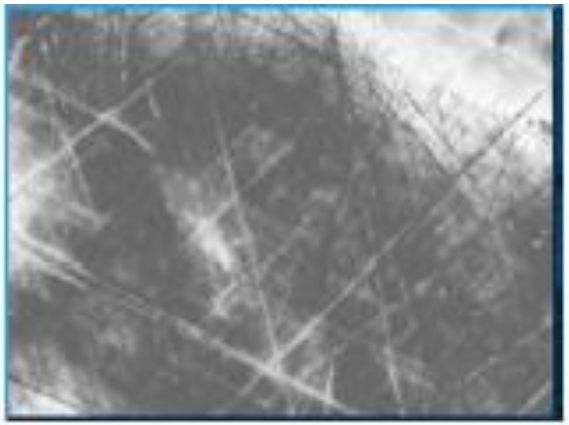


Null Fringes

- Nulling is the process of minimizing the number of fringes
- Null sample by adjusting tip/tilt or “R P” using the joystick
- As the tip/tilt is adjusted, it may be necessary to make fine z-adjustments to keep the fringes viewable on the live display monitor

Fringes due to Tilt
NOT NULLED

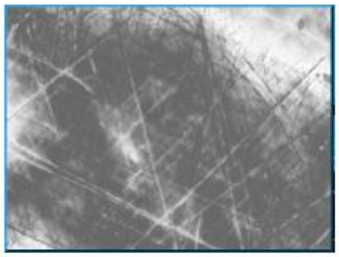
Minimum Fringes
NULLED



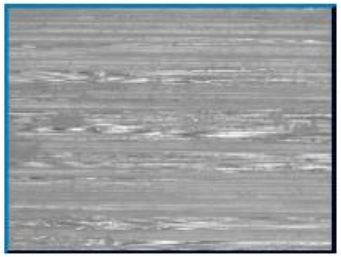
Null Fringes

- *Note:* The null fringe location will look different depending on the part
  - in most cases, think of "spreading out" the fringes
  - for a spherical part, center the bulls eye

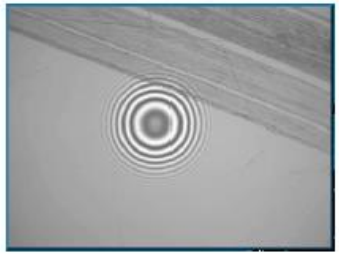
Example of Nulled Parts



Smooth Flat Part
Adjust for high contrast and the least number of fringes.



Rough Flat Part
The fringes are in smaller isolated areas. Center the fringes and adjust focus between the high and low fringes.



Spherical Part
Adjust the stage and focus to center the circular fringe pattern.

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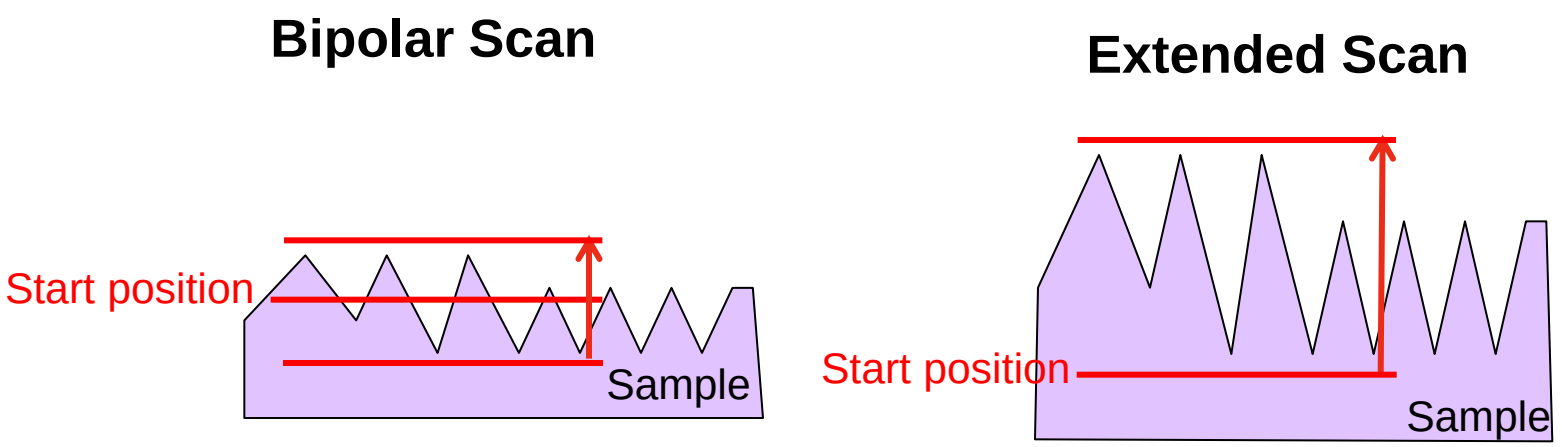
Set Measurement Controls

Measurement Controls

- Image Zoom to increase or decrease field of view, if available
  - 1X standard; 0.5X, 0.75X, 1.5X and 2.0X optional
- FDA Res control sets how the software processes the data collected
  - "High 2G" for smooth surfaces
  - "Normal" for rough surfaces, typically > 75 nm Ra
  - "Low" required for extended scans
- Camera Mode
  - Selects effective camera size for collecting data
  - More pixels resolve smaller details but result in increased processing time

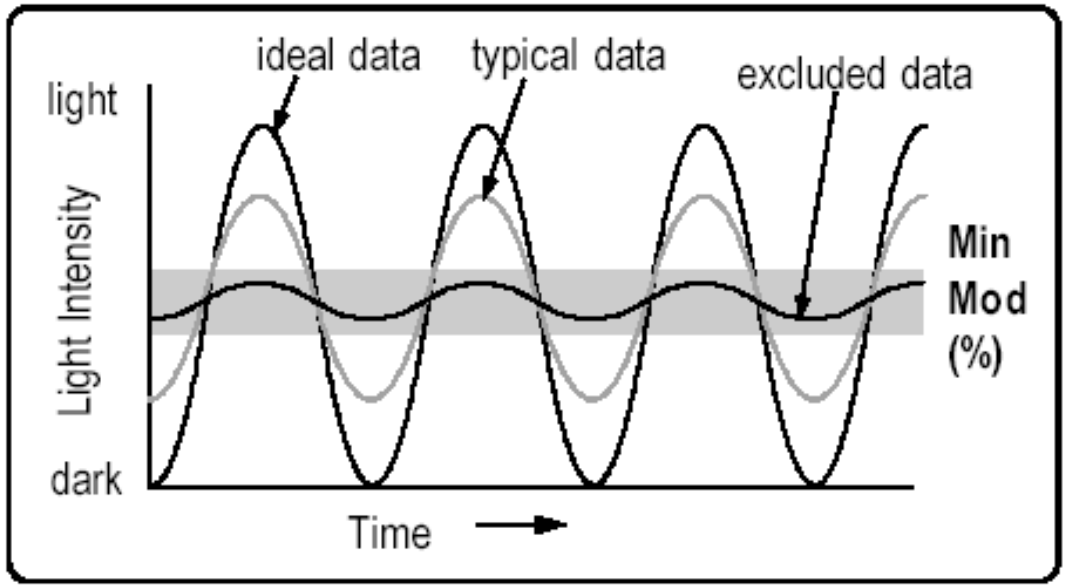
Measurement Controls

- Scan Length
  - Select length of measurement scan
  - Ranges from 5 um to 15 mm
  - Longer scan = Longer acquisition time
  - Bipolar Scan: from initial position, objective moves down half the scan length and then scans upward
  - Extended Scan scans upward only



Measurement Controls

- Min Mod (%)
  - Specifies minimum modulation or intensity range for a valid data point
  - Setting can range from 0 to 100 %



NewView 7000 Camera Modes

Camera Mode Setting	Maximum Number of Pixels	Pixel Spacing (um)	Scan Speed (um/sec)	Comments
640x480 210 Hz	307,200	44		Most common use case
320x240 380 Hz	76,800	22		Can use for stitching larger regions
160x120 380 Hz	19,200	11		Not commonly used
640x160 515 Hz	102,400	44		“Strip mode” primarily used by Zygo personnel for diagnostics

The Importance of Fringe Visibility

No Fringes,

No Data.

No Fringes

- **Part out of focus**
- **Incorrect part tip/tilt**
- **Part too rough**
- **Part reflectivity is low**
- **2.5x and 5x objectives -- Beam block blocking reference path**

NewView Vertical (“z”) Resolution

- **LOW FDA Res -- 25 nm**
- **NORMAL FDA Res -- 3 nm**
- **HIGH FDA Res / Phase1 / Phase 2 -- 0.1- 0.3 nm**

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- Set **automatically** by pressing “F5”
  - Must be centered on the brightest fringe
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  - Use numeric keypad to set peak intensity to approx 90 – 99 %
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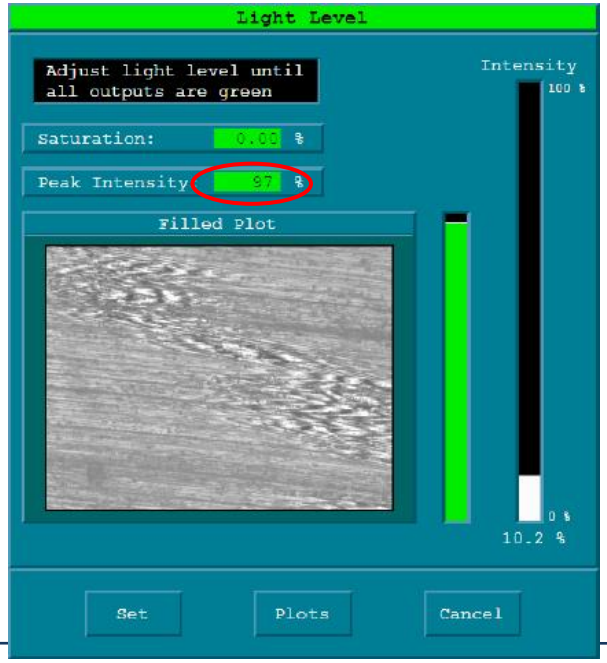

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Measure

- Press “F1” or click 

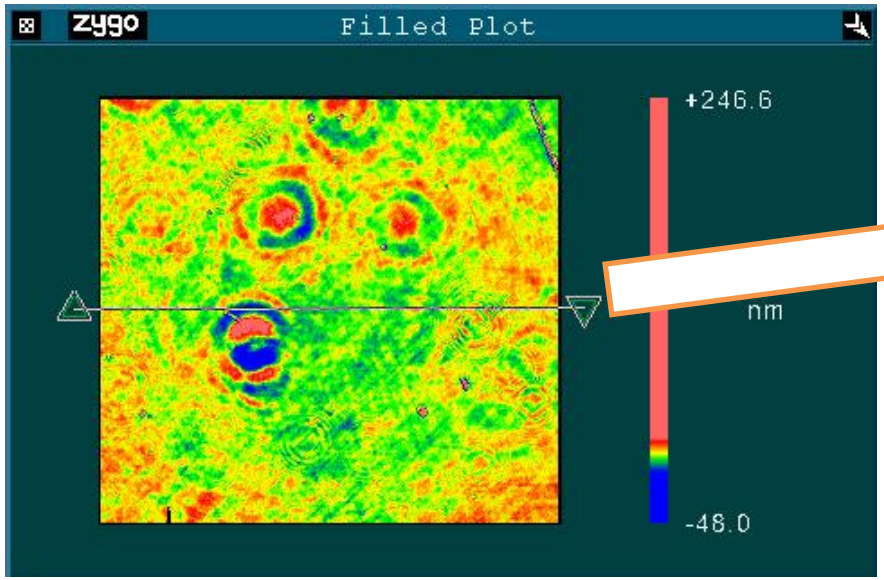
button to measure
- System will scan then display results
  - Do not touch vibration isolation table or sample stage until measurement is complete

MetroPro Plots, Displays, and Results

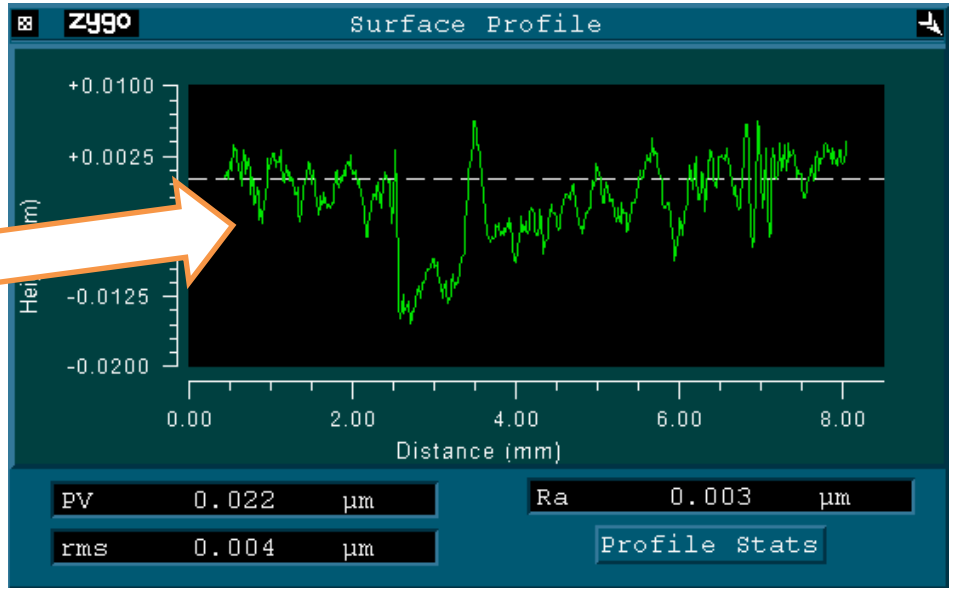
MetroPro Plots, Displays, and Results

- The two most common plots are the Filled Plot and the Profile Plot, which work in tandem
- The Filled Plot is a two-dimensional areal plot representing the height data
- The Profile Plot is a one-dimensional linear plot representing the height data across the line drawn on the Filled Plot

Filled Plot

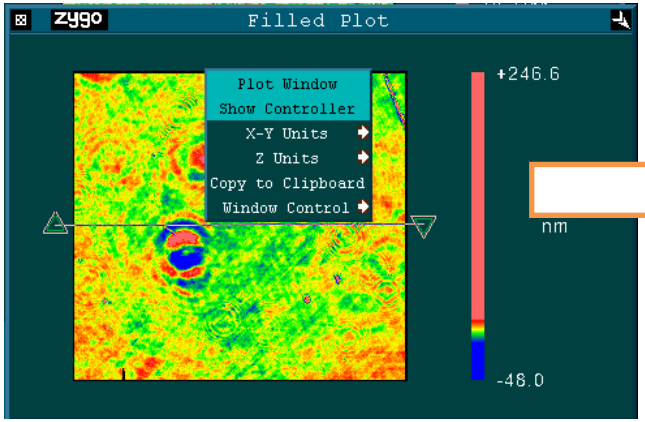


Profile Plot



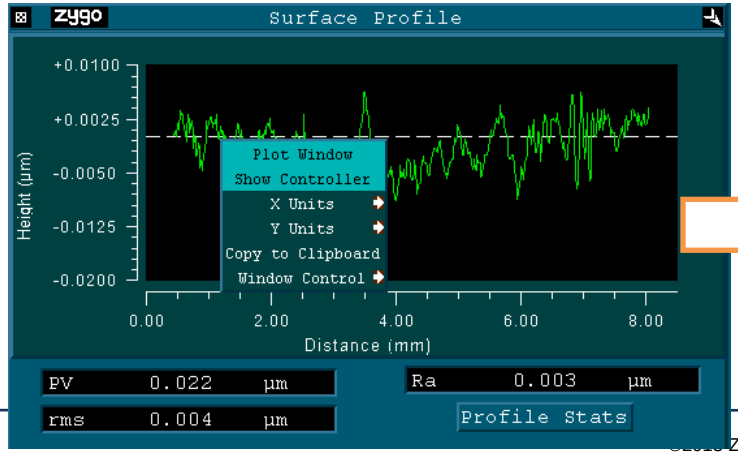
Plot Controller

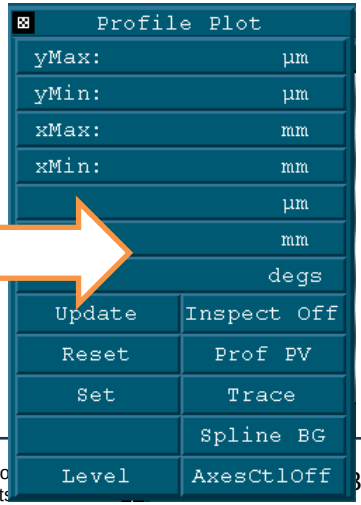
- Each plot has a Controller which is used to manipulate the plot
- The Plot Controller can be brought up by right-clicking on the plot or by clicking on the map using the center mouse button



The plot controller can be used to rescale the axes and allow the operator to select what to display and how to display it

The plot controller varies based on which plot the operator is manipulating





NewView Procedure

Step by step

- Select and mount appropriate objective
- Mount part
- Move objective slightly closer than working distance; set “z” stop
- (F5) Set light level for viewing
- Focus; observe fringes
- Broaden fringes by tipping and tilting stage
- Set Measurement controls
- (F4) Set light level for measurement
- MEASURE
- Examine surface data on MetroPro displays and plots
- Set Analyze controls
- ANALYZE

Analyze Controls

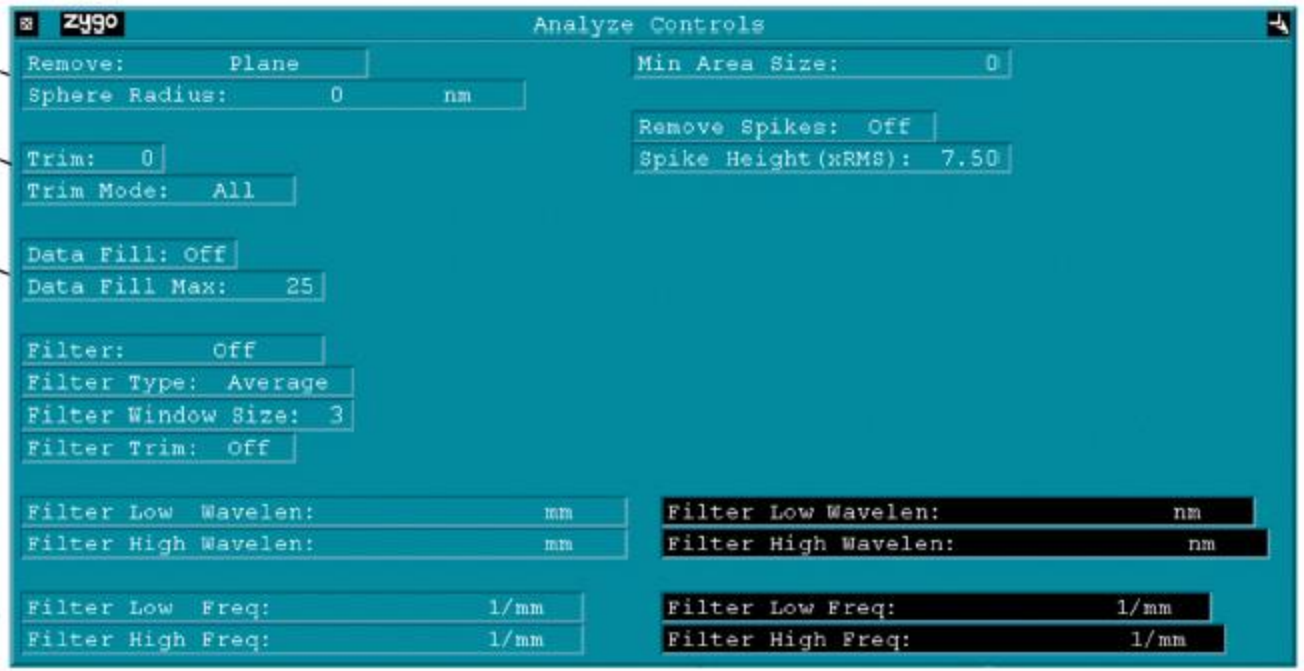
- *Note:* Changes to these controls can be made after

Removes "form" from the data

Removes edge effects

Fill holes in the data

Filtering controls are used to select and analyze the various spatial frequency components that make up the test part.



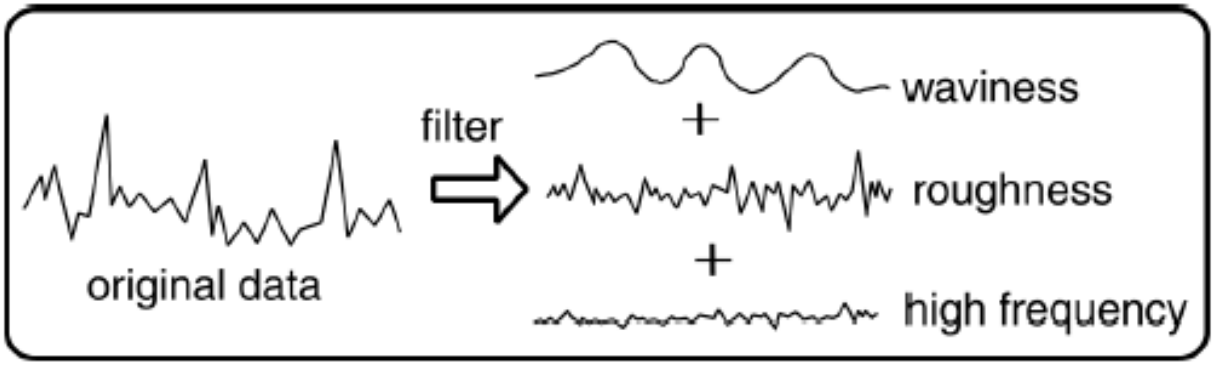
Analyze

Analyze Controls

- Remove specifies the surface to remove to minimize form
  - As a general rule of thumb, remove a plane for flatness or a cylinder for roughness
- Turn Data Fill On to fill missing data points; The maximum number of pixels that will be filled is based on the Data Fill Max control
- If Remove Spikes is On, a pixel will be removed if its height is greater than the surrounding pixel heights by the Spike Height value

Analyze Controls

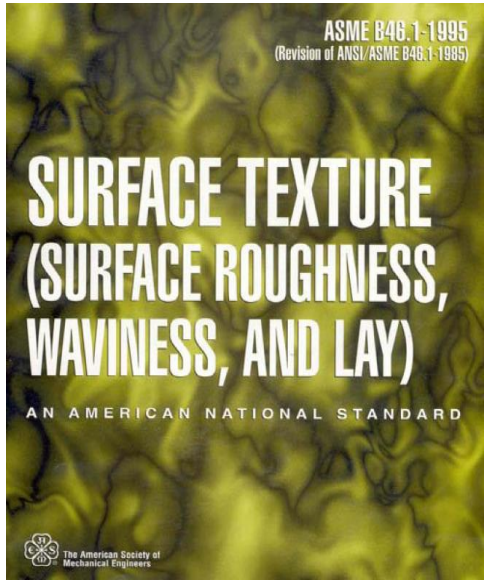
- Filtering
  - Low pass, high pass, band pass or band reject filters are available in the Filter control (Off by default)
    - Low pass highlights waviness or form; high pass highlights roughness
  - Use Filter Type to choose an average, median, 2 sigma, FFT or Gaussian type filter
  - For FFT fixed, enter cutoff values in the high and low wavelength (or frequency) controls

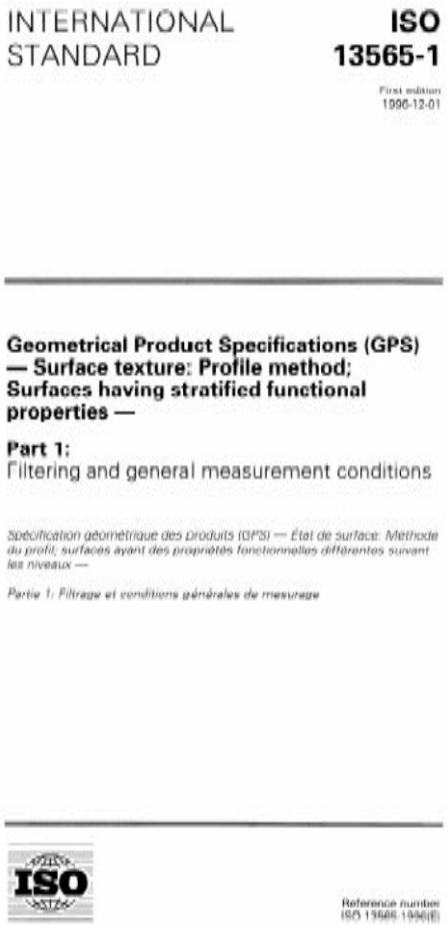


Fundamentals of Spatial Data Filtering

Standards based filtering

- Where are the filters defined
  - Worldwide ISO 13565-1
  - USA ASME B46.1
  - Japan JIS B0601




INTERNATIONAL STANDARD

ISO 13565-1

First edition
1996-12-01

Geometrical Product Specifications (GPS) — Surface texture: Profile method; Surfaces having stratified functional properties —

Part 1: Filtering and general measurement conditions

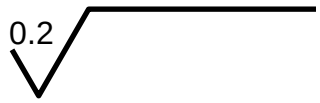
Spécification géométrique des produits (GPS) — État de surface: Méthode du profil; surfaces ayant des propriétés fonctionnelles différentes suivant les niveaux —

Partie 1: Filtrage et conditions générales de mesurage

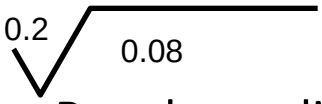
ISO

Reference number
ISO 13565-1:1996(E)

Standard Nomenclature

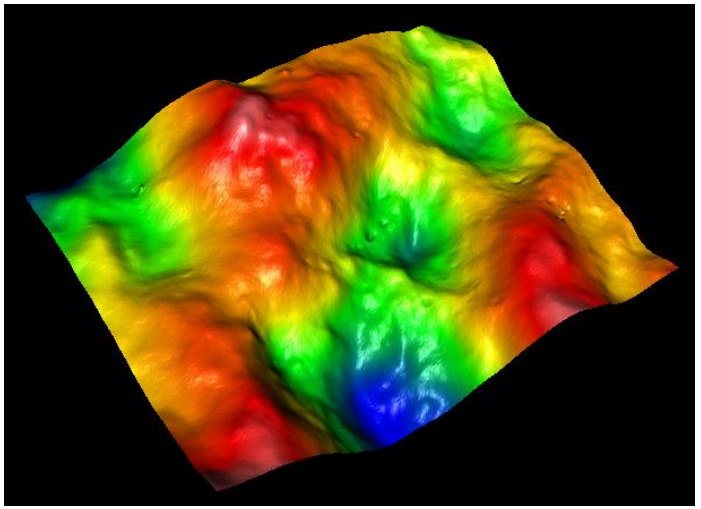
- If this 

  - 0.2um Roughness limit
  - 0.8mm filter cutoff

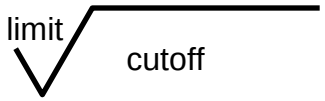
- If this 

  - 0.2um Roughness limit
  - 0.08mm filter cutoff

- ISO Default
  - Roughness = Ra
  - Cutoff = 0.8mm



- Unless otherwise specified
  - Roughness is Ra
  - Units are um for limit
  - Units are mm for cutoff



Why do we filter?

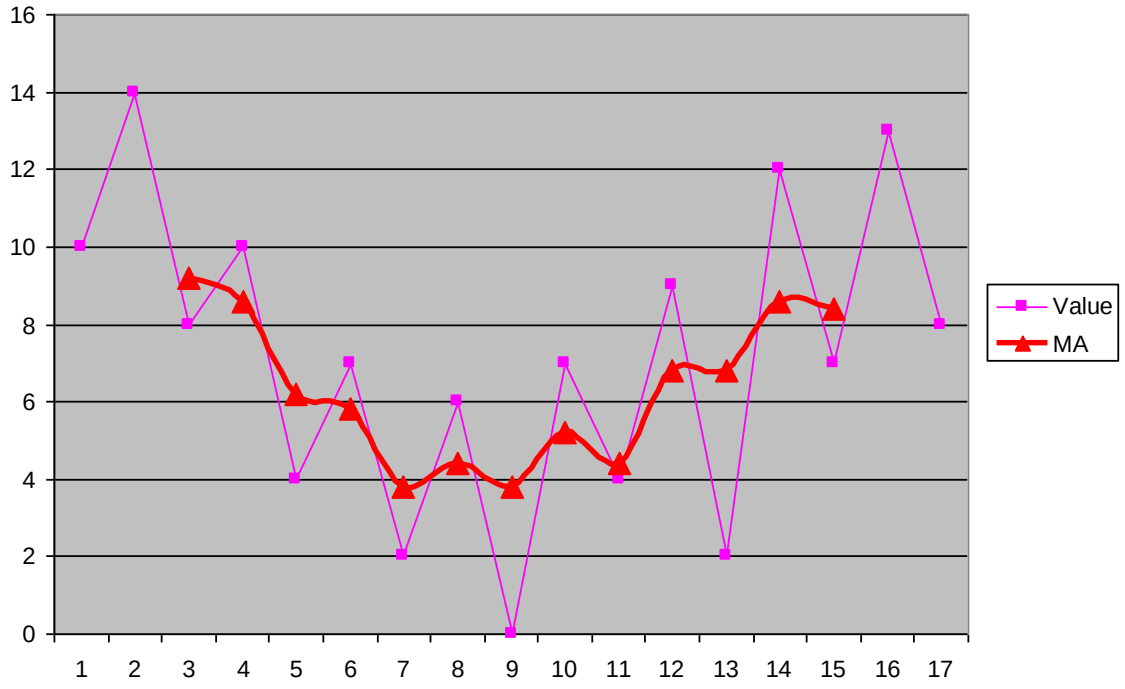
- Filters are used to separate the long wavelengths from the short wavelengths
  - Long wavelengths are “Form” or “Shape”
  - Mid wavelengths are “Waviness”
  - Short wavelengths are “Roughness”

- In the simplest sense, a filter can be thought of as a “moving average”.
  - As the moving average is run through the data, the extreme, local peaks and valleys are “smoothed out”.

Simple Example

Low Pass Average Filter

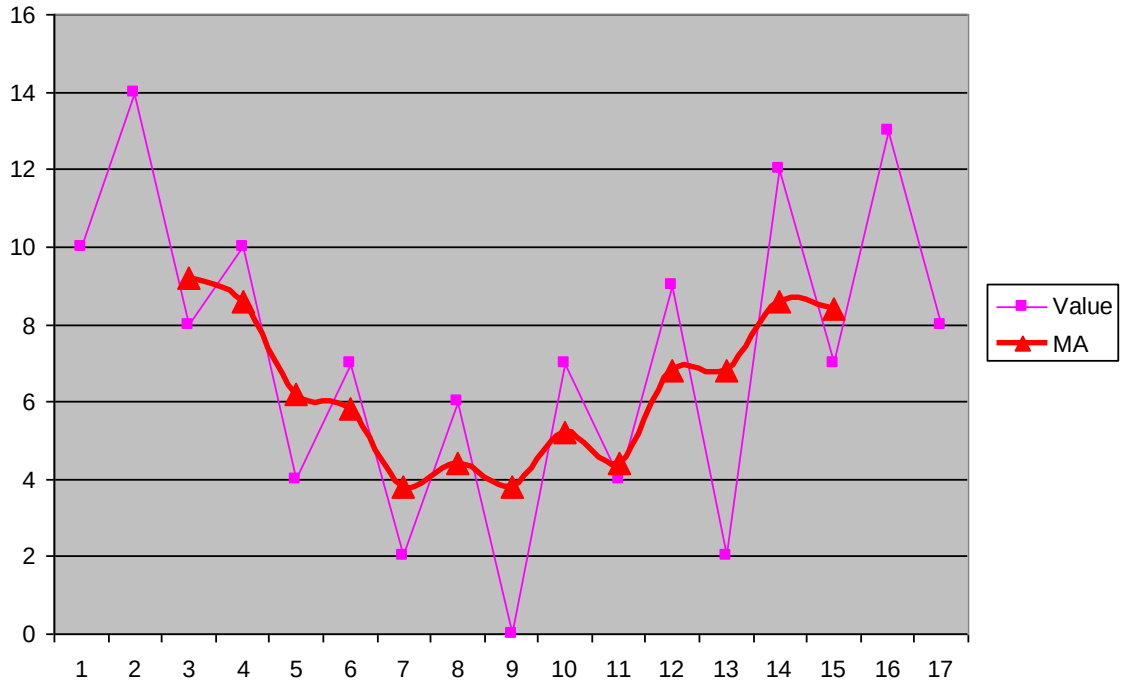
- Average Every 5 data points
  - Averages can be plotted to form the “waviness” profile



Simple Example

Low Pass Average Filter

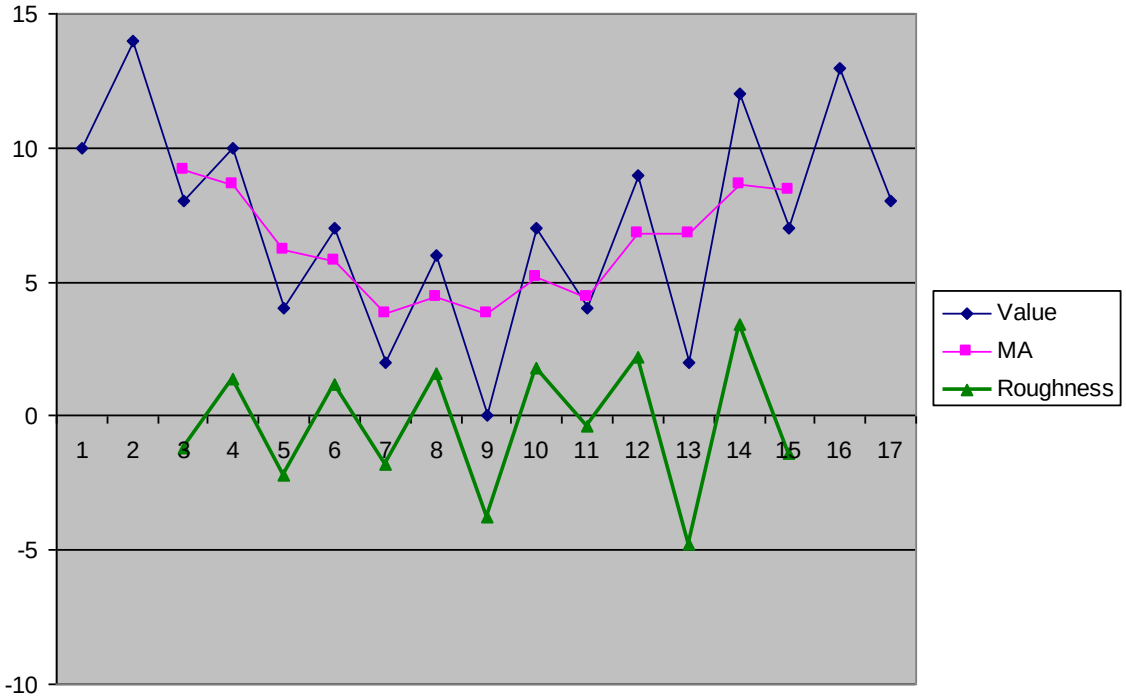
- Average Every 5 data points
  - Averages can be plotted to form the “waviness” profile



Simple Example

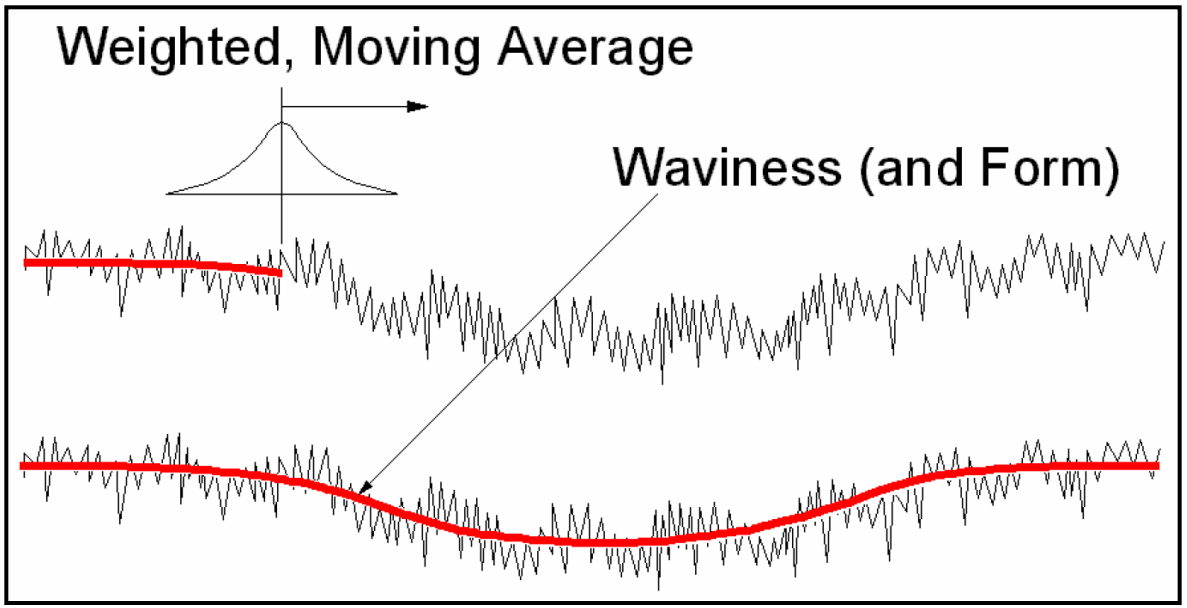
Low Pass Average Filter

- The difference between the measured (Value) data and the waviness (MA) data is the roughness data



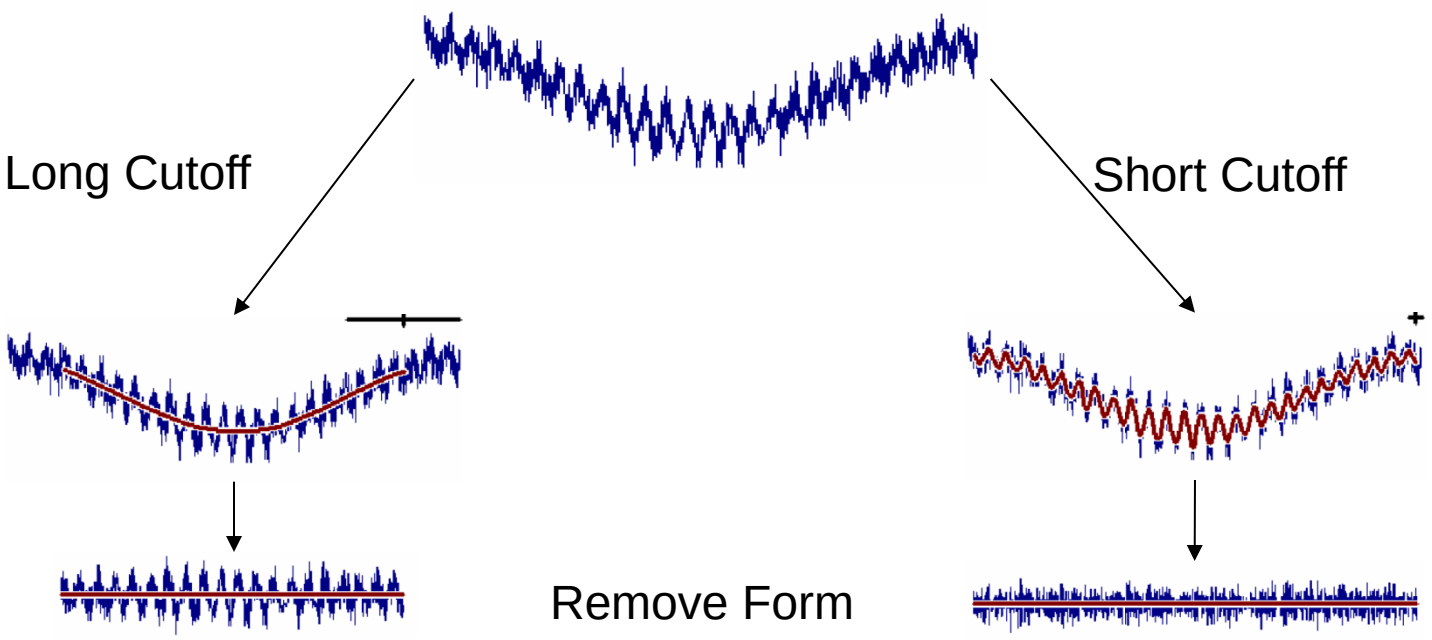
A better moving average

- A Gaussian and FFT weighted average
  - The standard filter type (ISO and ASME)



Changing the cutoff

- Changing the cutoff of the moving average changes the separation between roughness and waviness.



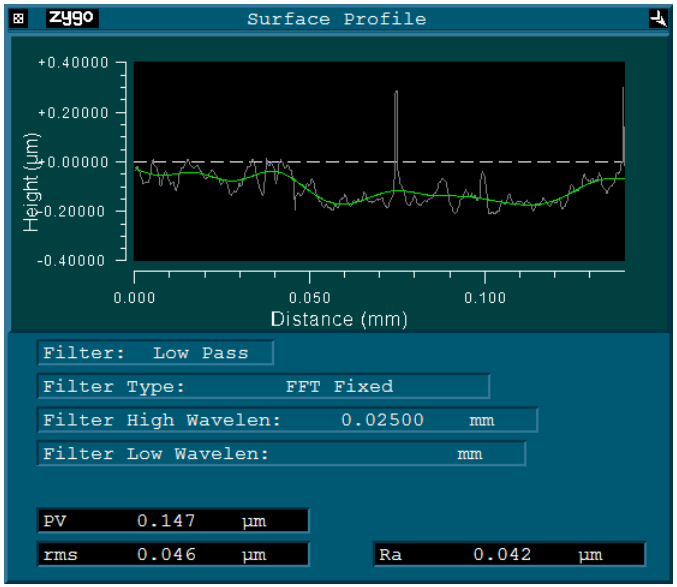
Implementing ISO filters in MetroPro

- You can quite closely match the ISO requirements using standard filter controls in MetroPro

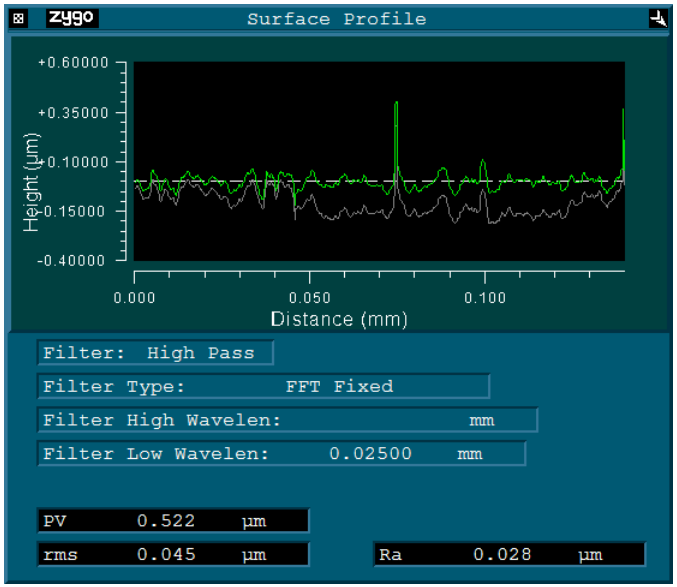
- Basics
  - Filter is of type FFT Fixed
    - in many cases Gaussian Spline is also accepted
  - Filter Cutoff is of type Gaussian for FFT
    - Old versions of MetroPro used a sinusoidal cutoff – this should not be used now
  - High and low wavelengths are used to set the cutoffs

Implementing ISO filters in MetroPro

- λ_c = 0.025mm
  - Roughness use High Pass with Low Wavelength
  - Waviness use Low Pass with High Wavelength



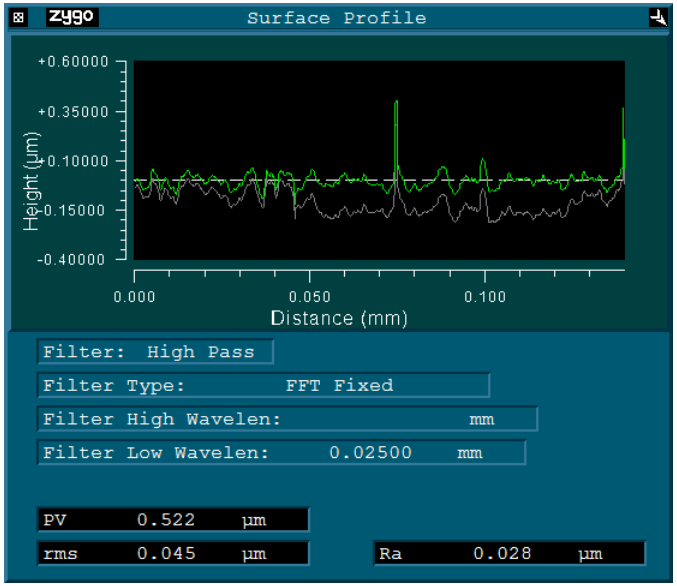
Waviness



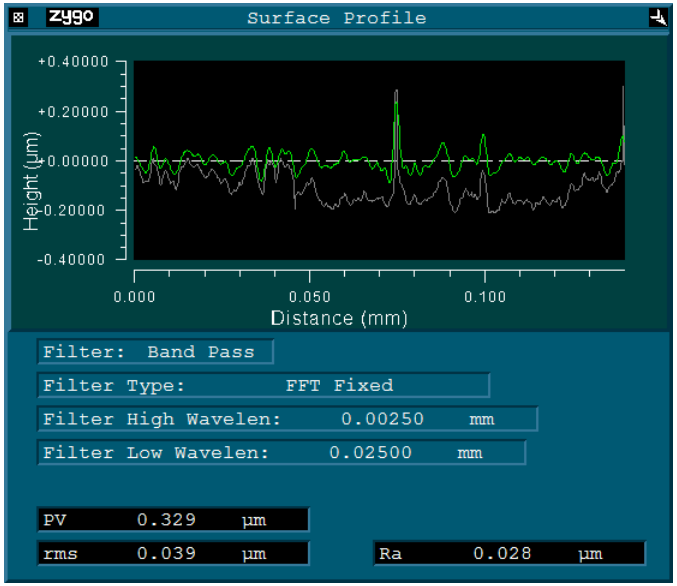
Roughness

Implementing ISO filters in MetroPro

- λ_c = 0.025mm and λ_s = 0.0025mm
  - Roughness profile is maintained, while noise is removed by the λ_s cutoff



Roughness



Roughness with Noise cutoff

There are more options than ISO…

- Some applications or customers will require ISO filtering
- There are other ways to apply filtering
  - How you filter depends on the part, the application, and the expectations of the customer
- There are other types of filters you can use
  - Simple smoothing filters
  - Complex form removal
  - Limit measurement to optical resolution
- More!

Basic Filtering Guidelines

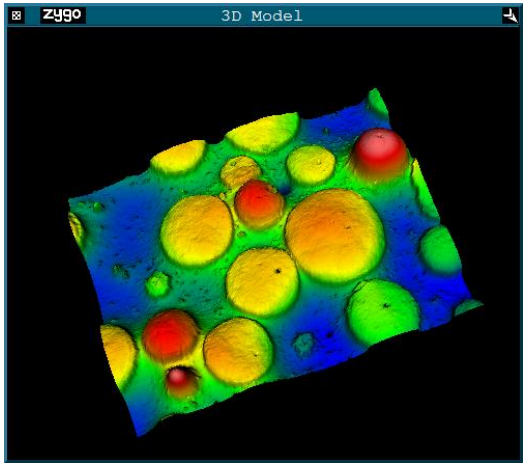
- **Roughness**
  - You need to remove form – either through the Remove control, or through a bandpass / high pass filter
    - Usually you want to remove the primary waviness too
  - High pass or band pass filter is generally used
    - High pass by itself may remove too much structure
    - Sometimes just a low pass filter is still ok when you are measuring areal roughness – it all depends on the application and the sample

Basic Filtering Guidelines

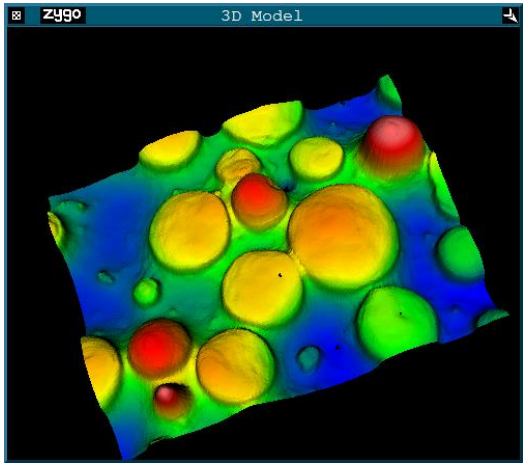
- **Waviness**
  - You want to at least level the data
    - Usually on NewView this is remove plane – higher order form may be a part of the waviness.
      - This depends on the sample
  - You may want to remove the roughness component
    - Residual roughness will have less impact on waviness results than form
  - Usually, a low pass or band pass filter is used to isolate waviness

Simple Smoothing filters

- Low Pass filter
  - Median, Average, 2Sigma
- All of these apply a ‘moving average’ style filter over a user defined window size
- Usually used to ‘remove noise’ or ‘smooth’ data
  - These filters ‘knock down’ the noise



No Filtering

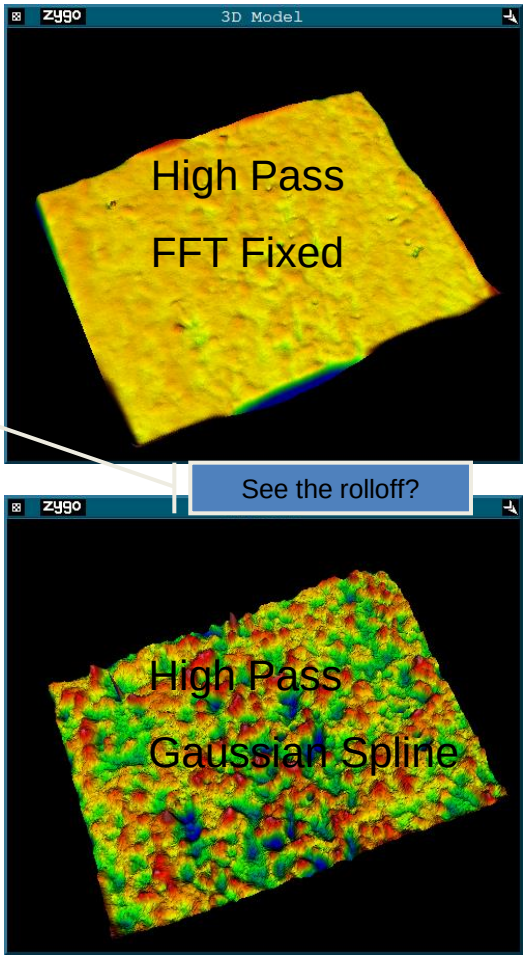


Low Pass

Median

Gaussian Spline Filters

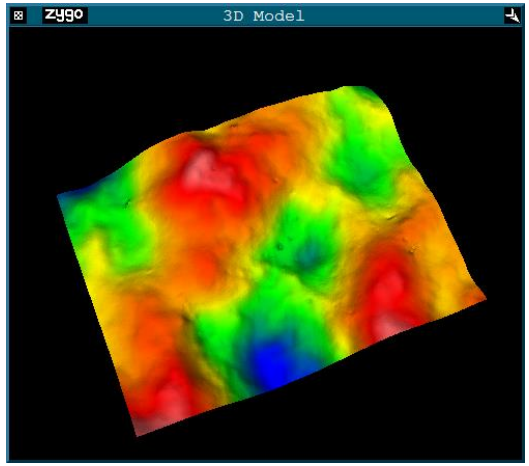
- Spline filters behave similarly to FFT filters
  - They can be used for band pass and band reject filters, as well as Low and High pass
- Advantage over FFT filters is that they do not ‘ring’ or ‘roll off’ at the edge of the data
  - They can sometimes have problems with holes in the data though, which can usually be fixed using a specific MetroPro setting
    - Spline Fill = -2
- When might I use a GS filter?
  - Remove Complex form
  - Band Pass filtering
  - Anytime you might otherwise use an FFT and want to avoid roll off at the edge of the data



Gaussian Spline Filters

- You can use Gaussian Spline filters to remove complex form that the bulk “Remove” control will not eliminate

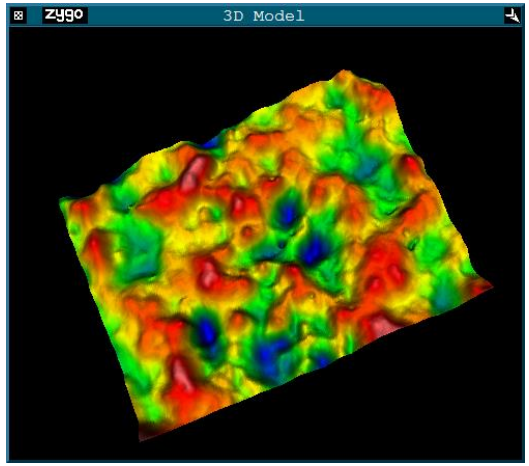
- Rules of thumb for measuring texture on a complex form
  - Band pass Gaussian spline
  - High wavelength
    - 3x camera resolution if pixel limited
    - Optical resolution if diffraction limited
      - Optical res = 0.5 λ / N.A.
  - Low wavelength
    - HFOV/4



No Filtering

HFOV = 60um

CR = 0.2um



BandPass

λh = 0.6um

λ_l = 15um

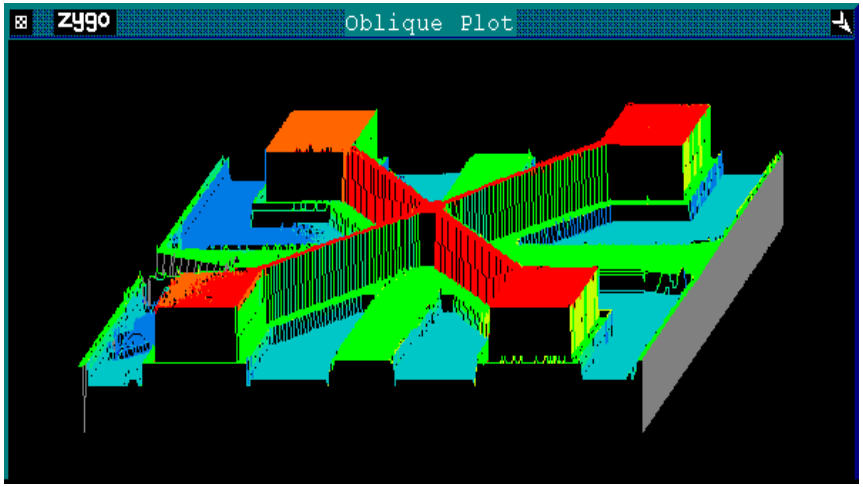
How to Customize MetroPro Applications

How to Customize MetroPro Applications

- MetroPro applications are highly customizable depending on the need

Surface Segmentation Fundamentals

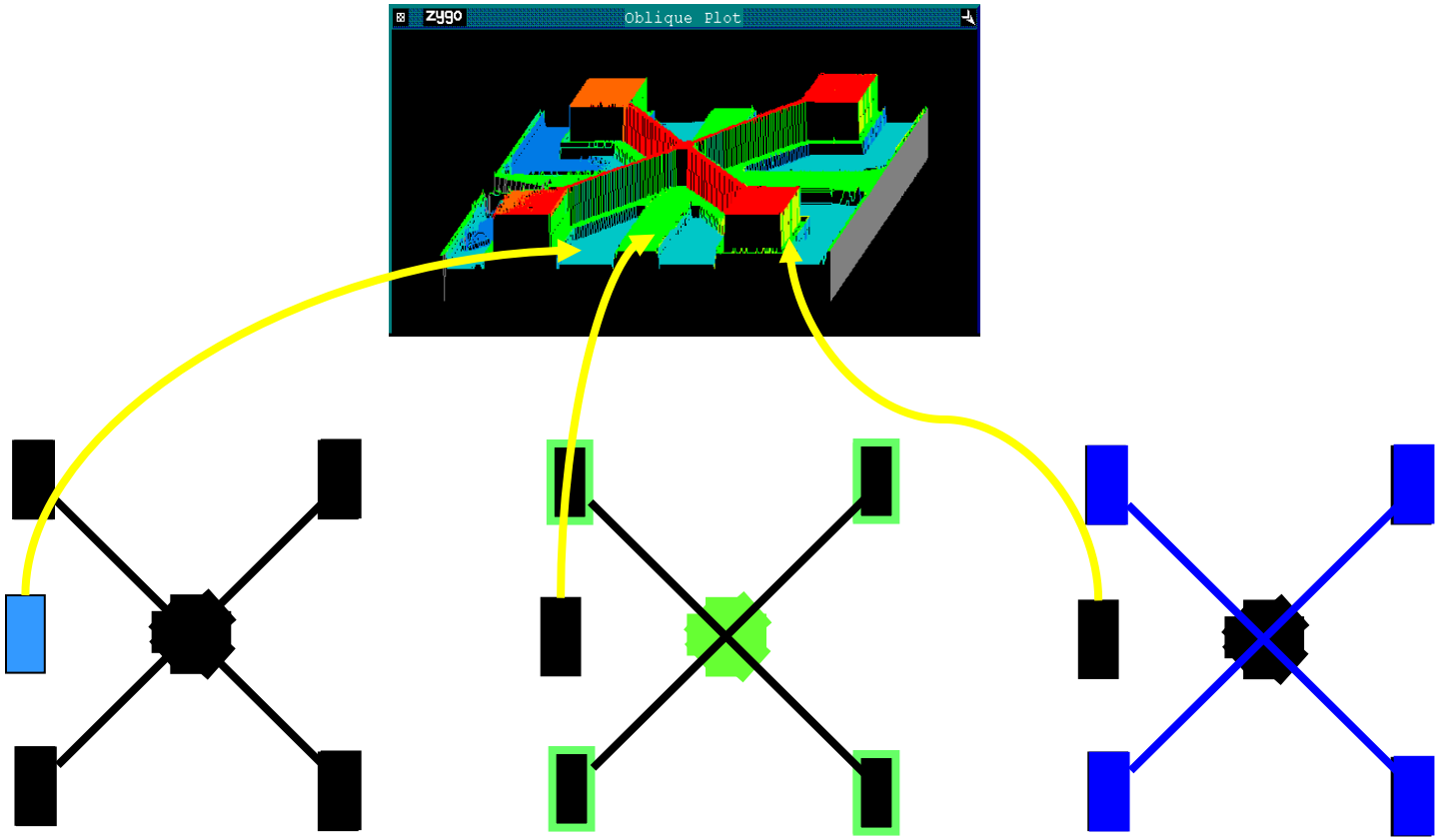
MultiSurf Application



- Isolate areas of interest
- Divide a single data set into multiple individual (“Test”) areas

Segmentation

- Separation of data into areas of interest --



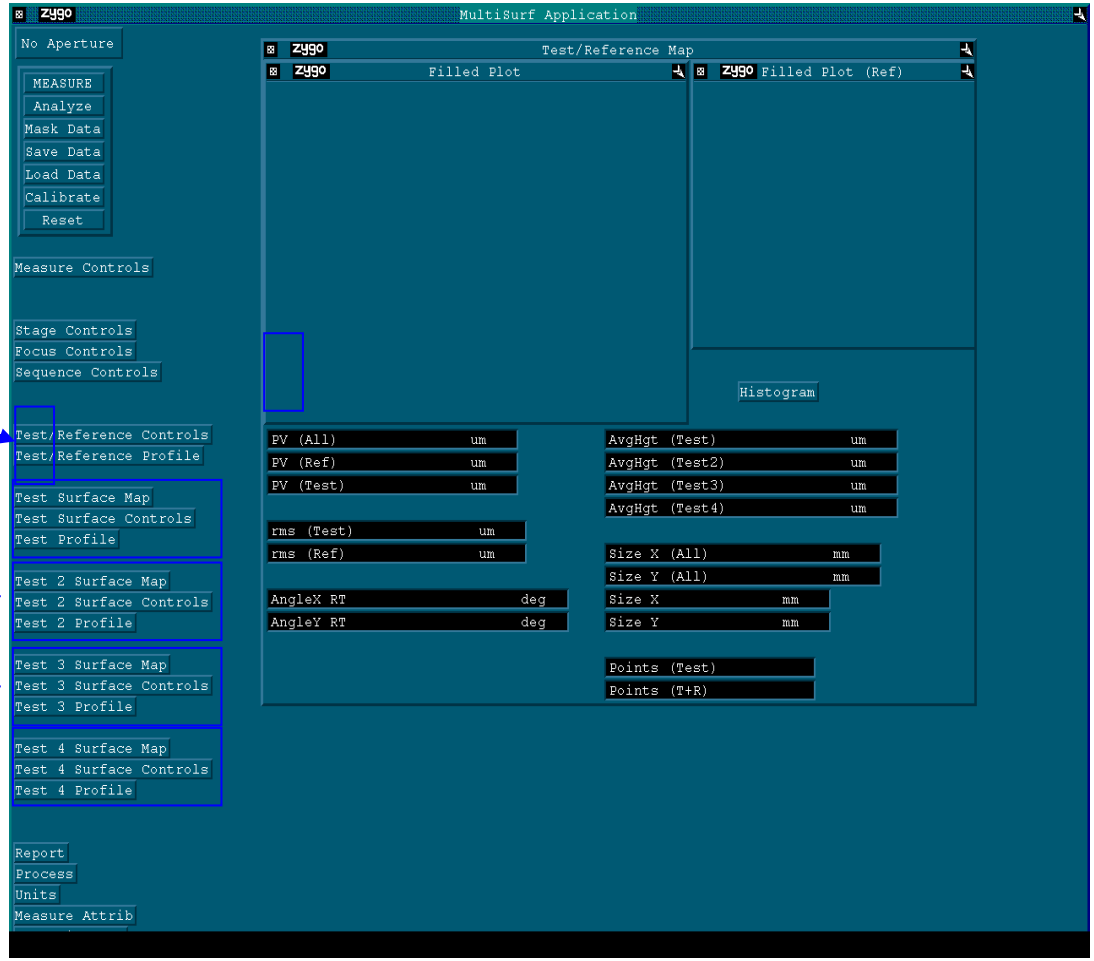
MultiSurf Key Features

- Up to four unique test surface windows
  - Separate analysis controls for each test surface
- Multiple segmentation methods
  - By height
  - By lateral area
- Height methods overcome mask alignment difficulties

MultiSurf Application Window

Test/Ref Controls

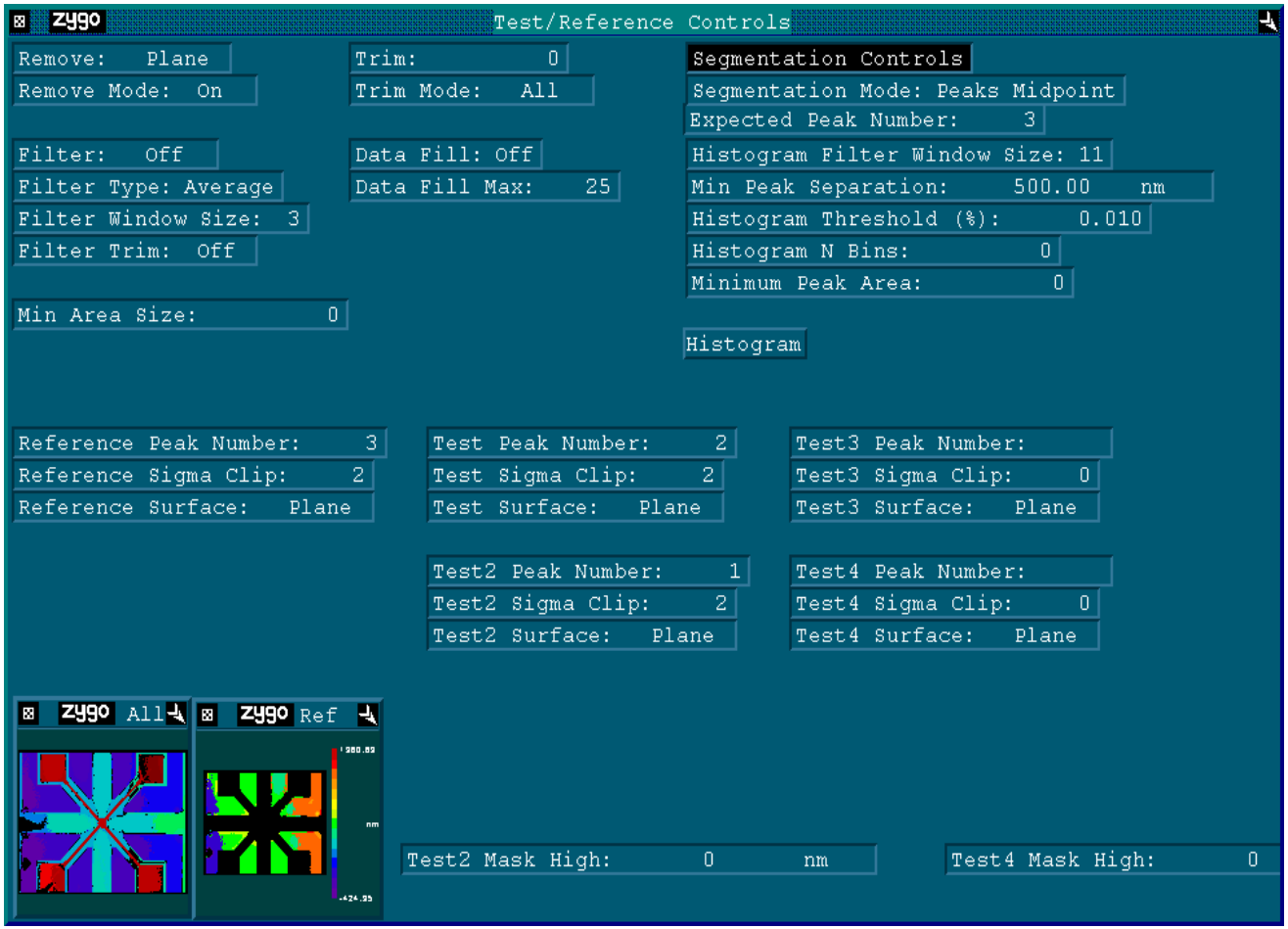
Test Surface Analysis Windows
- Map
- Controls
- Profile



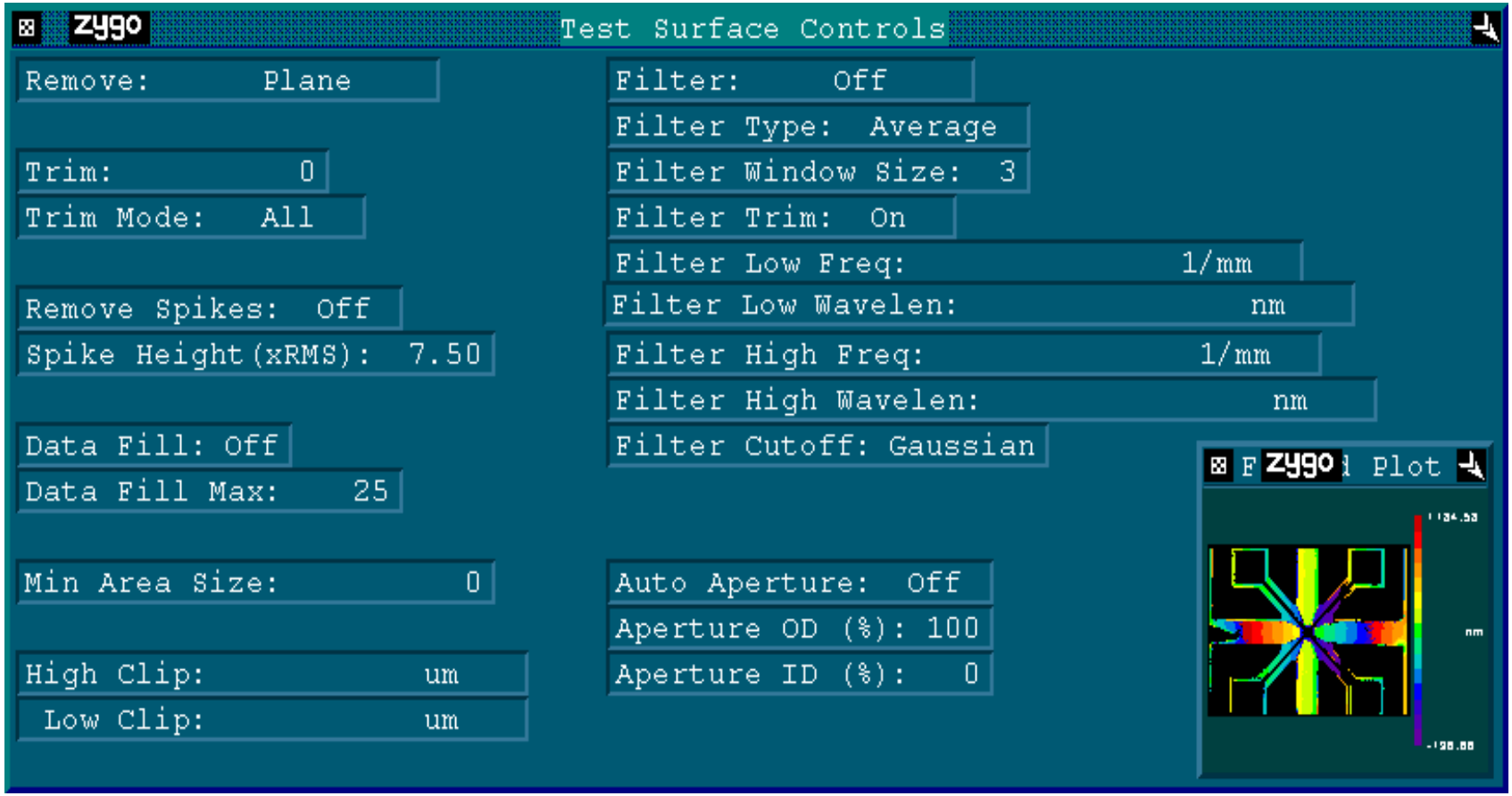
Segmentation Guidelines

- Use non-segmented data to determine proper settings
- Base segmentation mode on part characteristics
- Know what surfaces you want to isolate
- Experiment

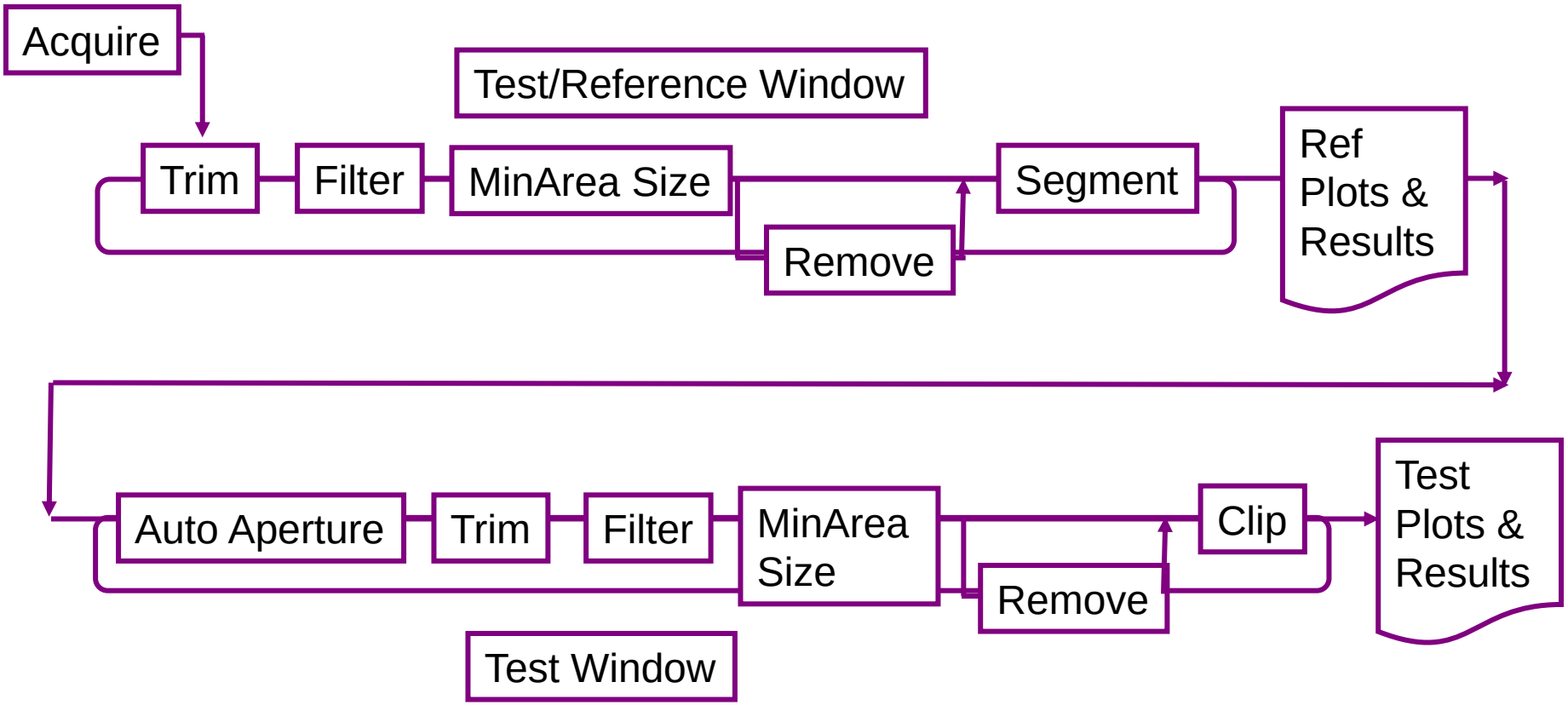
Test/Reference Controls



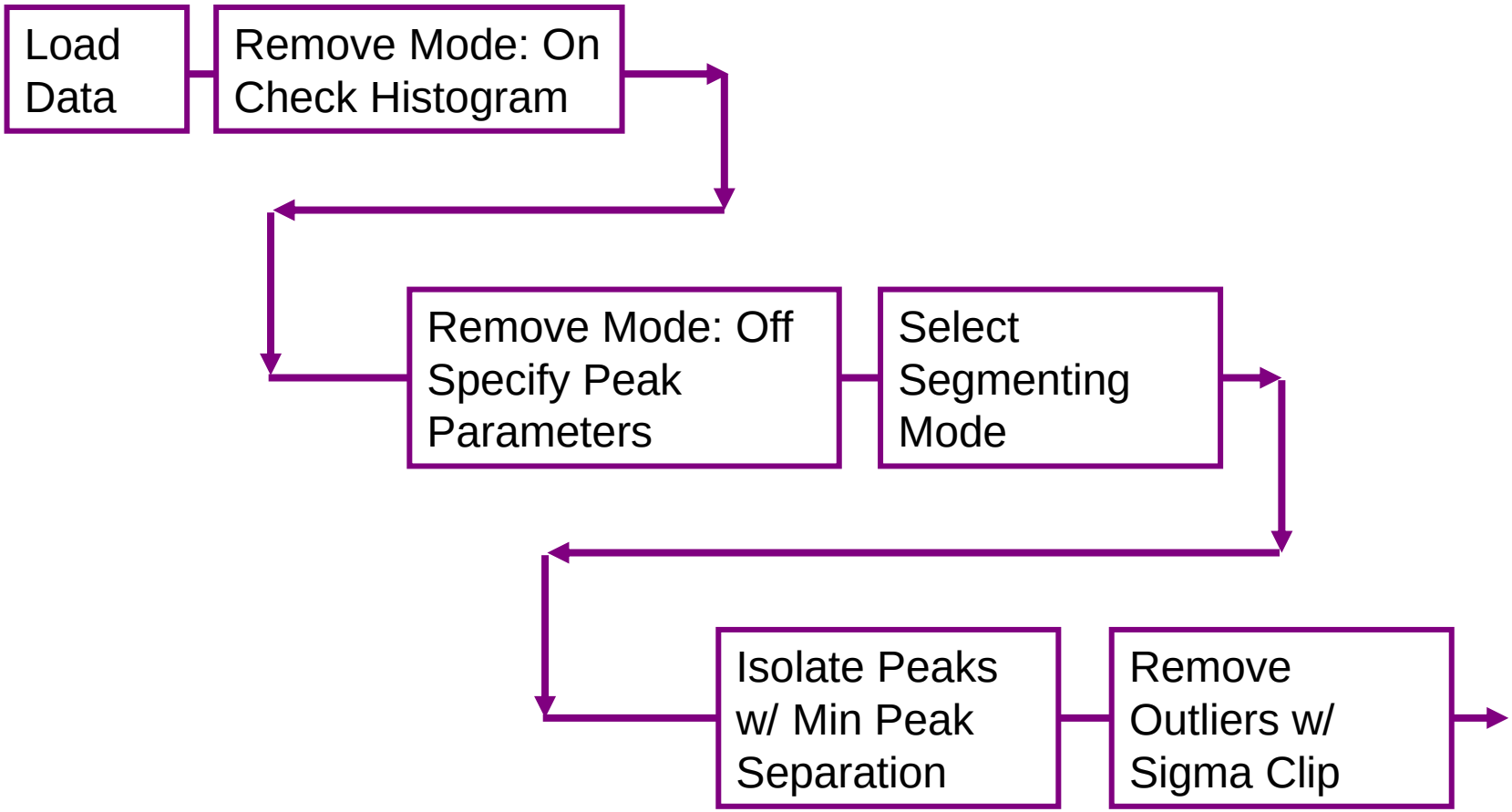
Test Surface Controls



Segmentation Data Flow



Segmentation Process



Segmentation Modes

- Manual:
  - Editor
  - Histogram
  - Peaks Relative
- Automatic:
  - Peaks Midpoints
  - Full Width, Half Maximum (FWHM)
  - Islands

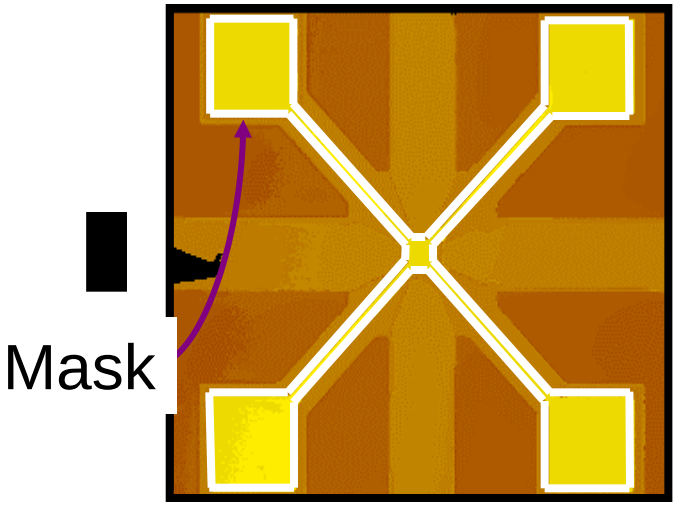
Segmentation Mode: Editor

- Selects areas of interest based on location
- Requires user-drawn reference and test masks

Segmentation Mode: Editor

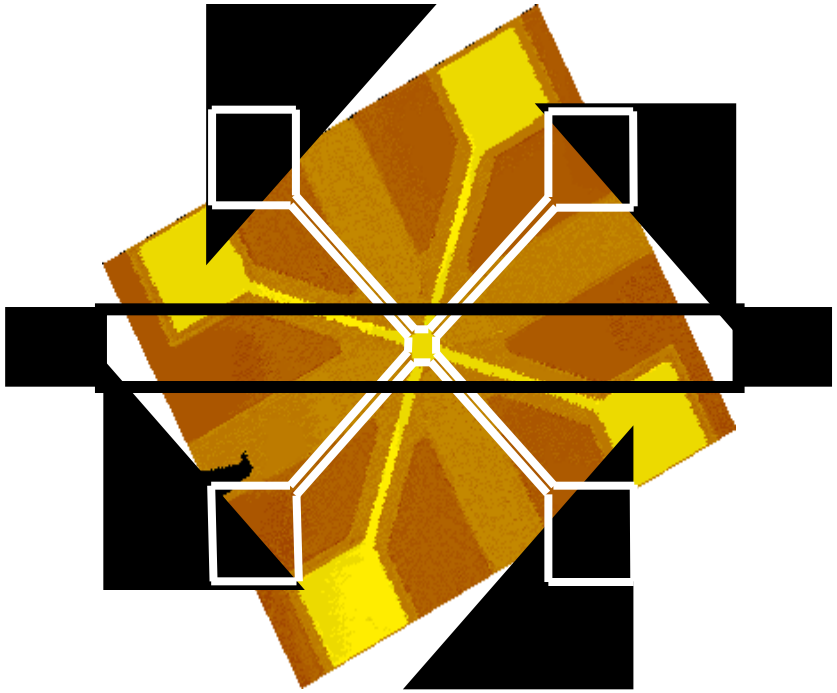
- Strictly manual
- Selects areas of interest based on location

- Advantage: segmented surfaces are guaranteed to be those defined by the masks



Segmentation Mode: Editor

- Disadvantages:
  - Part must be precisely aligned in the field of view each time
  - Only one Test Mask allowed



Editor Mode Procedure

- Set Mask Mode control to Editor
- Open Mask Editor window
- Locate surfaces visually
- Choose shapes
- Draw masks onto part
- Define Test and Reference regions
- Analyze

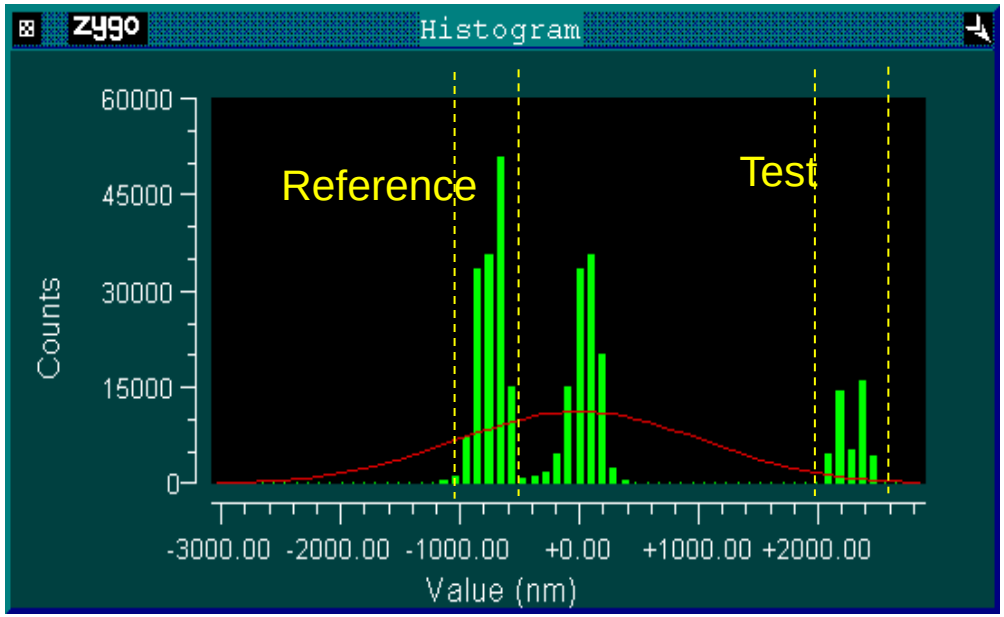
Note: Test and Reference regions may include some, or even all, of the same data cells / pixels

Segmentation Mode: Histogram

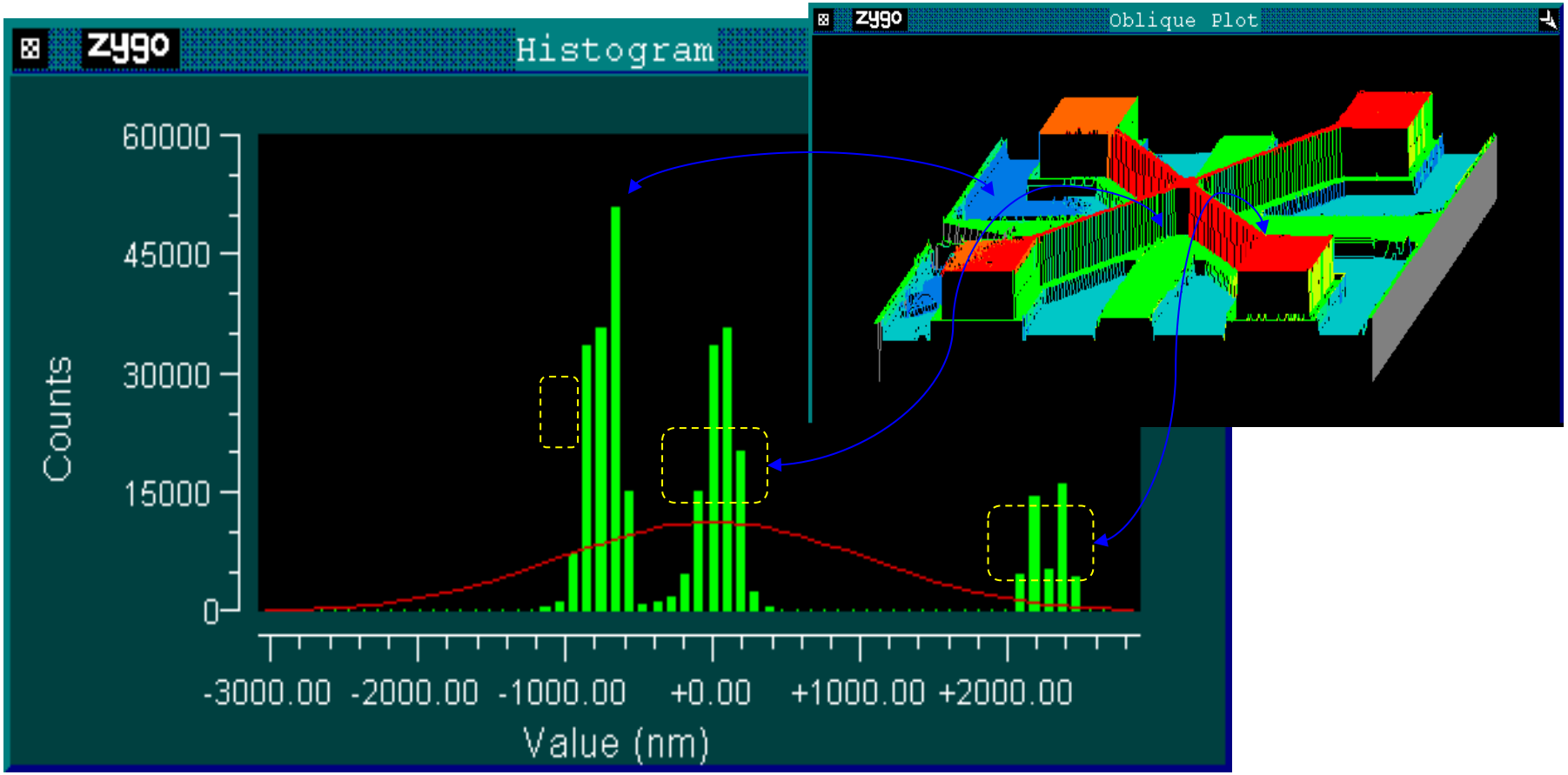
- Selects areas of interest based on heights
- Manual segmenting technique that defines reference and test areas based on control settings
- Control settings are relative to the best fit surface specified by the “Remove” control

Segmentation Mode: Histogram

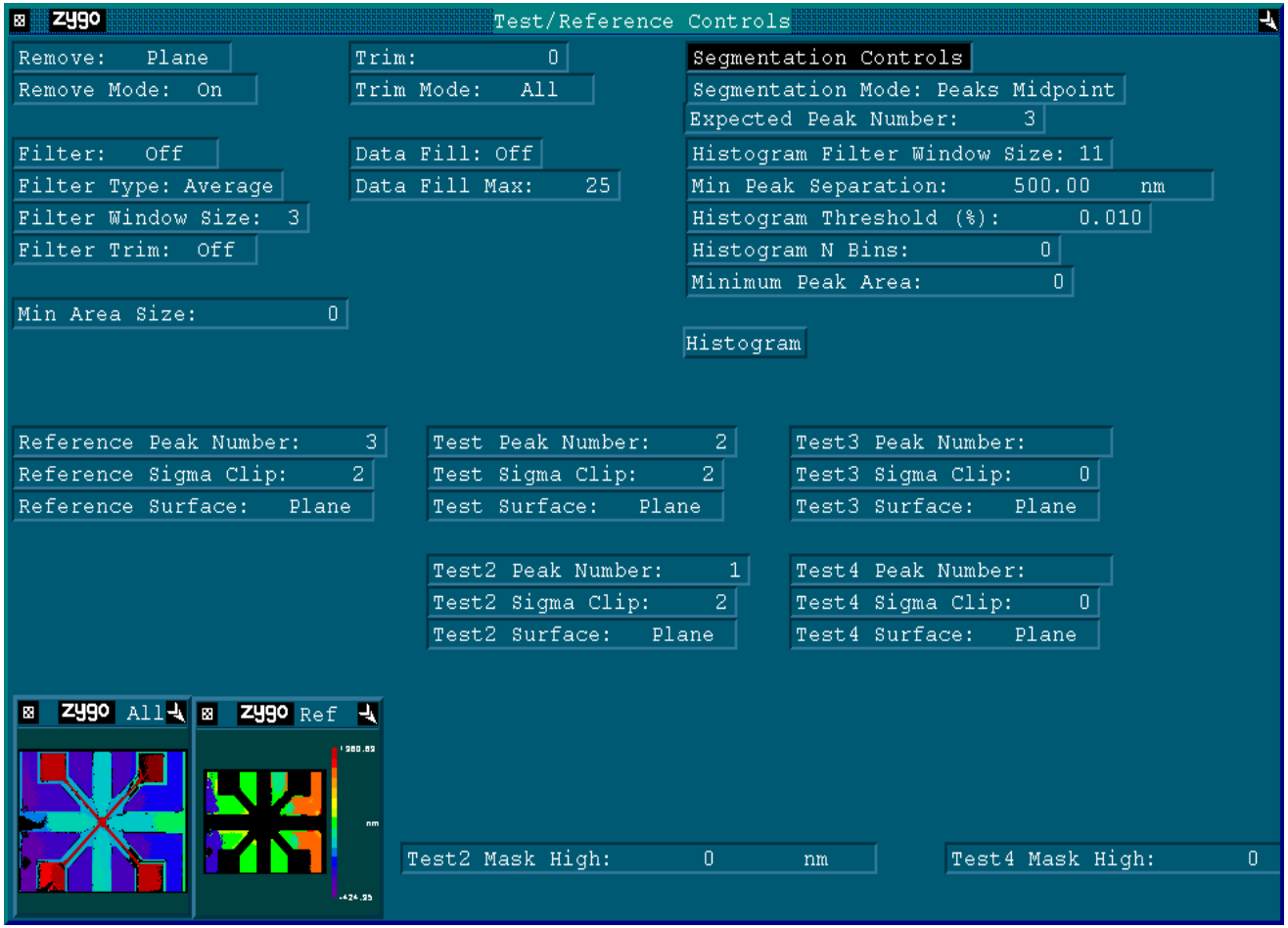
- Manual
- Advantage: Surfaces are segmented more accurately than with the Editor mode -- does not depend on operator manual dexterity and hand-eye coordination



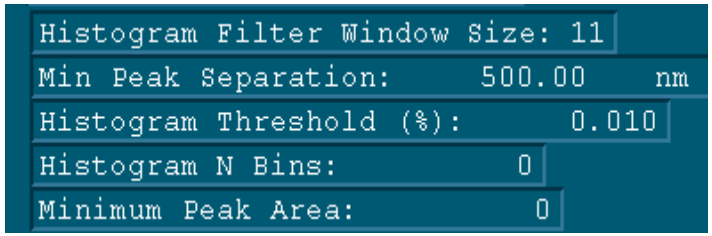
Histogram

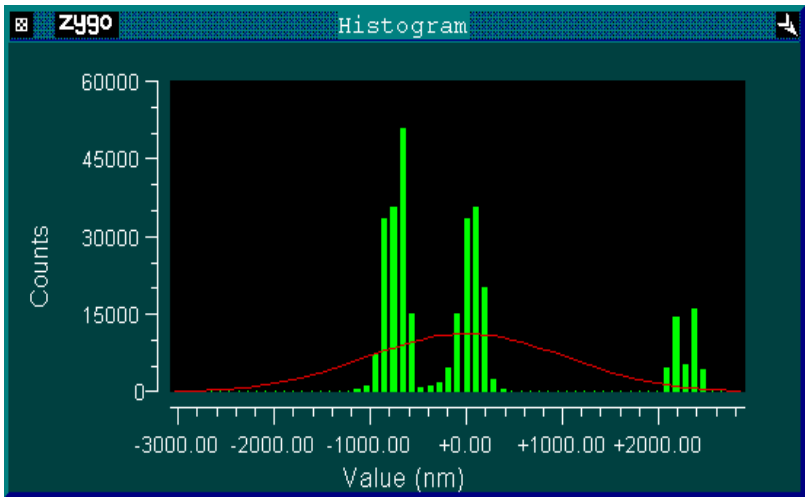


Histogram Controls



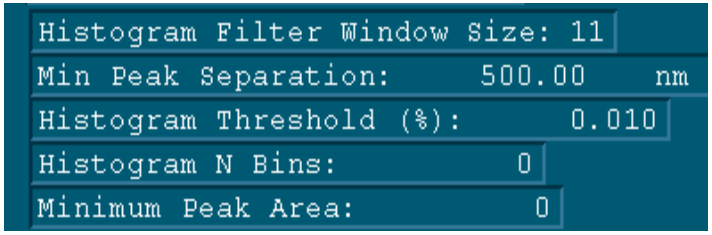
Histogram Controls

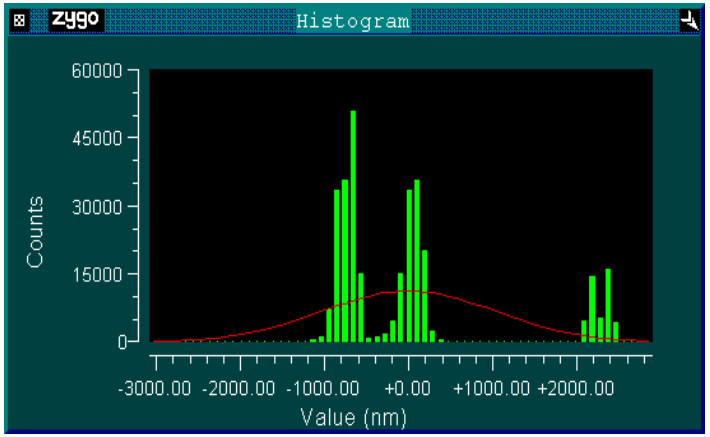




- Histogram Filter Window Size
  - Smooths the histogram
  - User-specified
  - The value of a bin
- Minimum Peak Separation -- Forces close peaks to be counted as one when the minimum separation is set to a high value
- Histogram Threshold (%) -- Sets a minimum size for any bar on the histogram; any single bin in the histogram must have at least as much as the specified percentage of the TOTAL number of data points to be included in a peak.

Histogram Controls

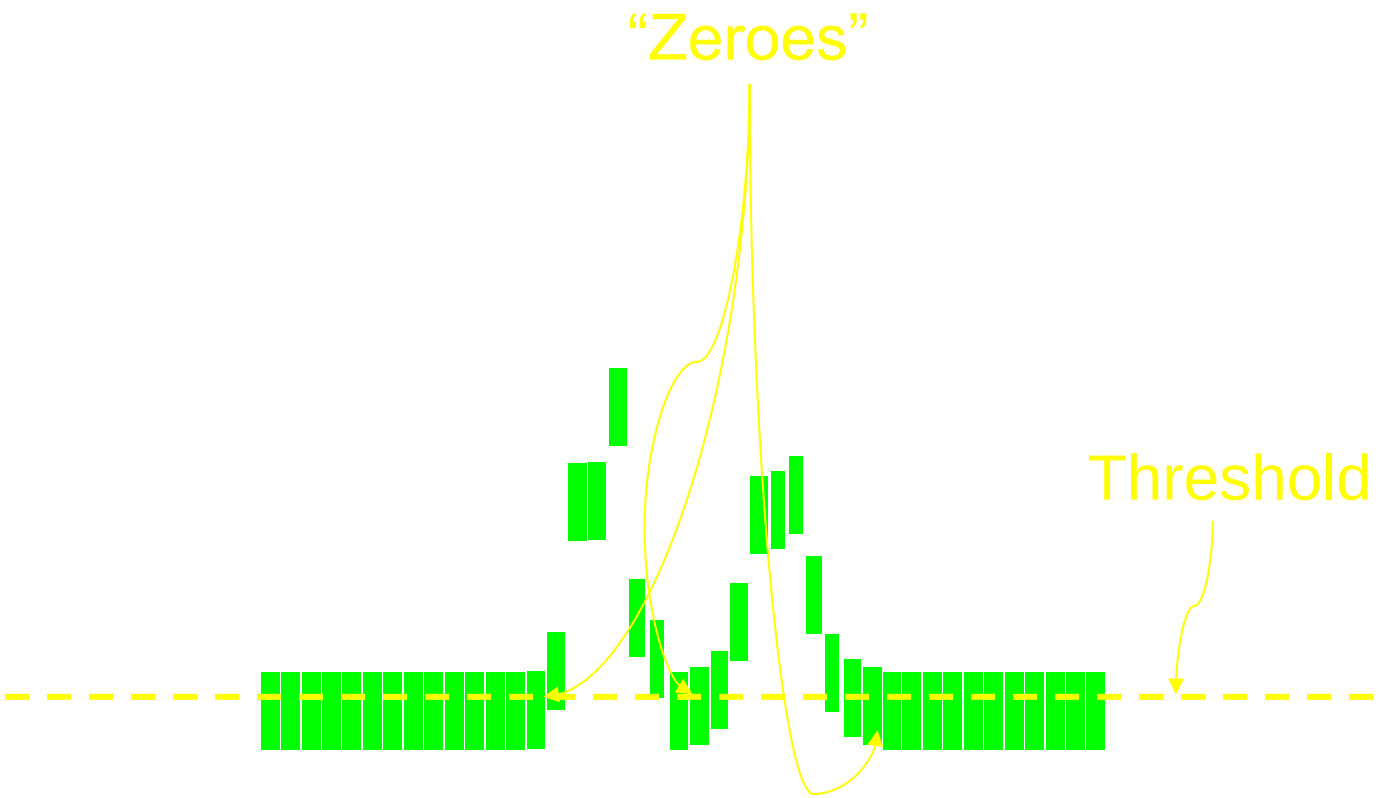




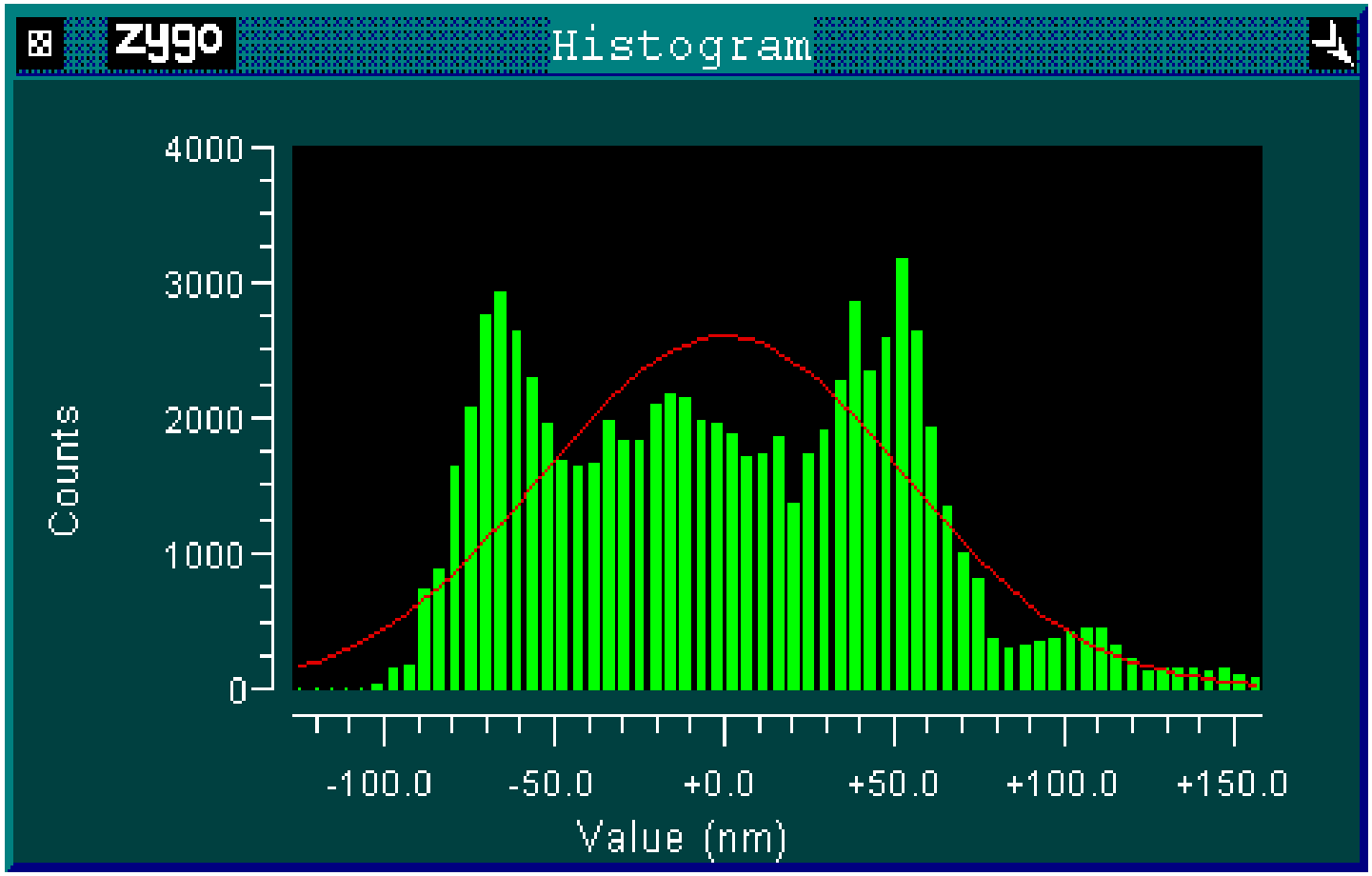
- Histogram N Bins -- Height values are separated into bins of size N/PV; multiple steps with wide range on each step require a larger number of bins:
  - Default: 64
  - Max: 1024

- Minimum Peak Area -- Sets minimum number of data points to define a level (histogram peak); sum of all the bars to be included in a peak; bars are counted only if they meet the threshold criterion.

Peak Definition

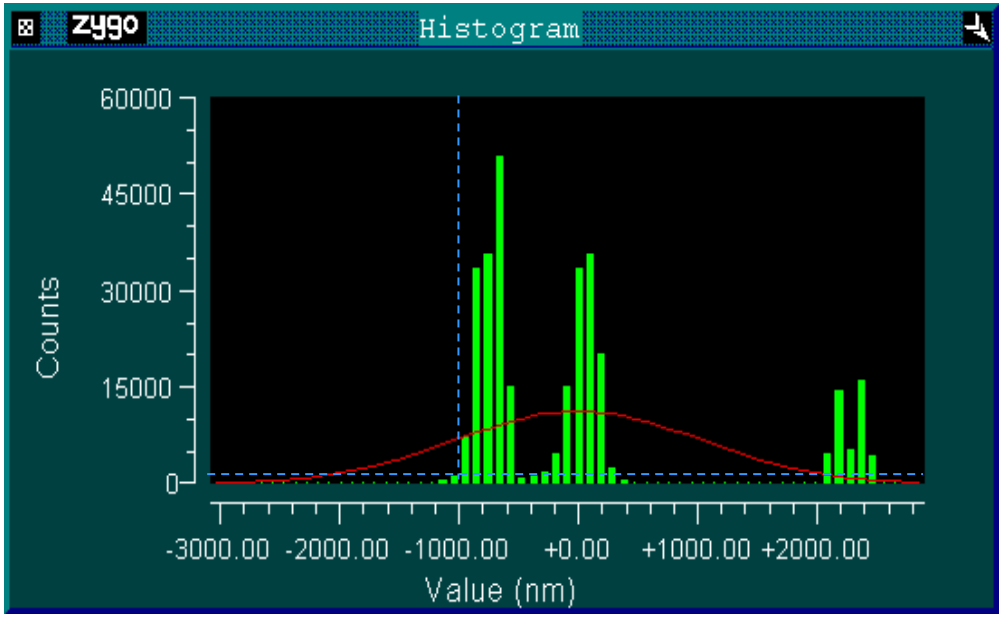


Non-segmentable surface



Peaks Not Well-Defined!! (No Zeros)

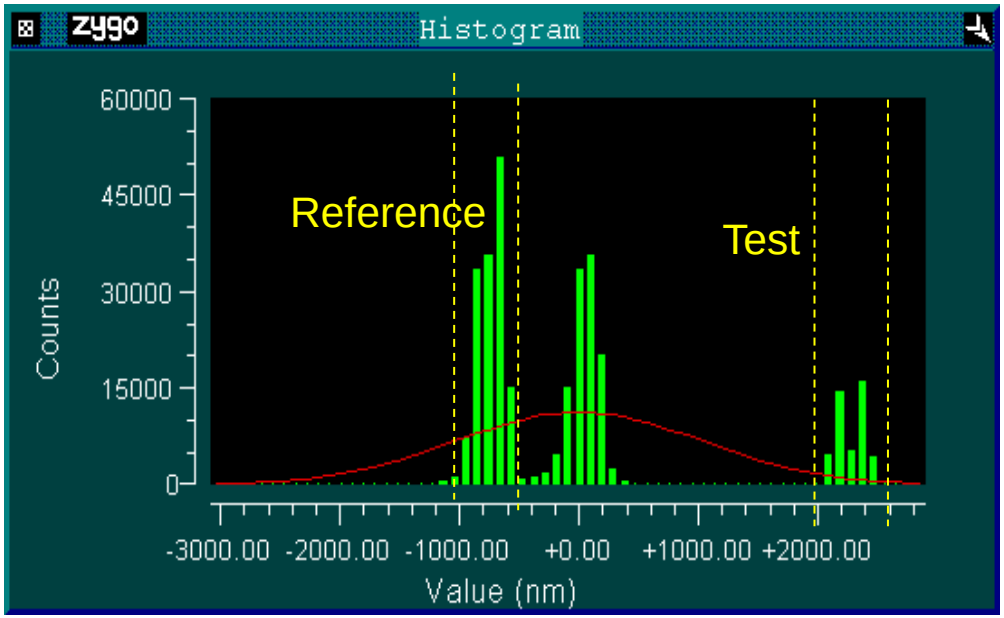
Histogram Mode Procedure



- Set Segmentation Mode control to Editor
- Set Remove control to shape of Reference Surface
- Open Histogram plot; use inspectors to determine the heights for each surface
- Set Segmentation Mode control to Editor

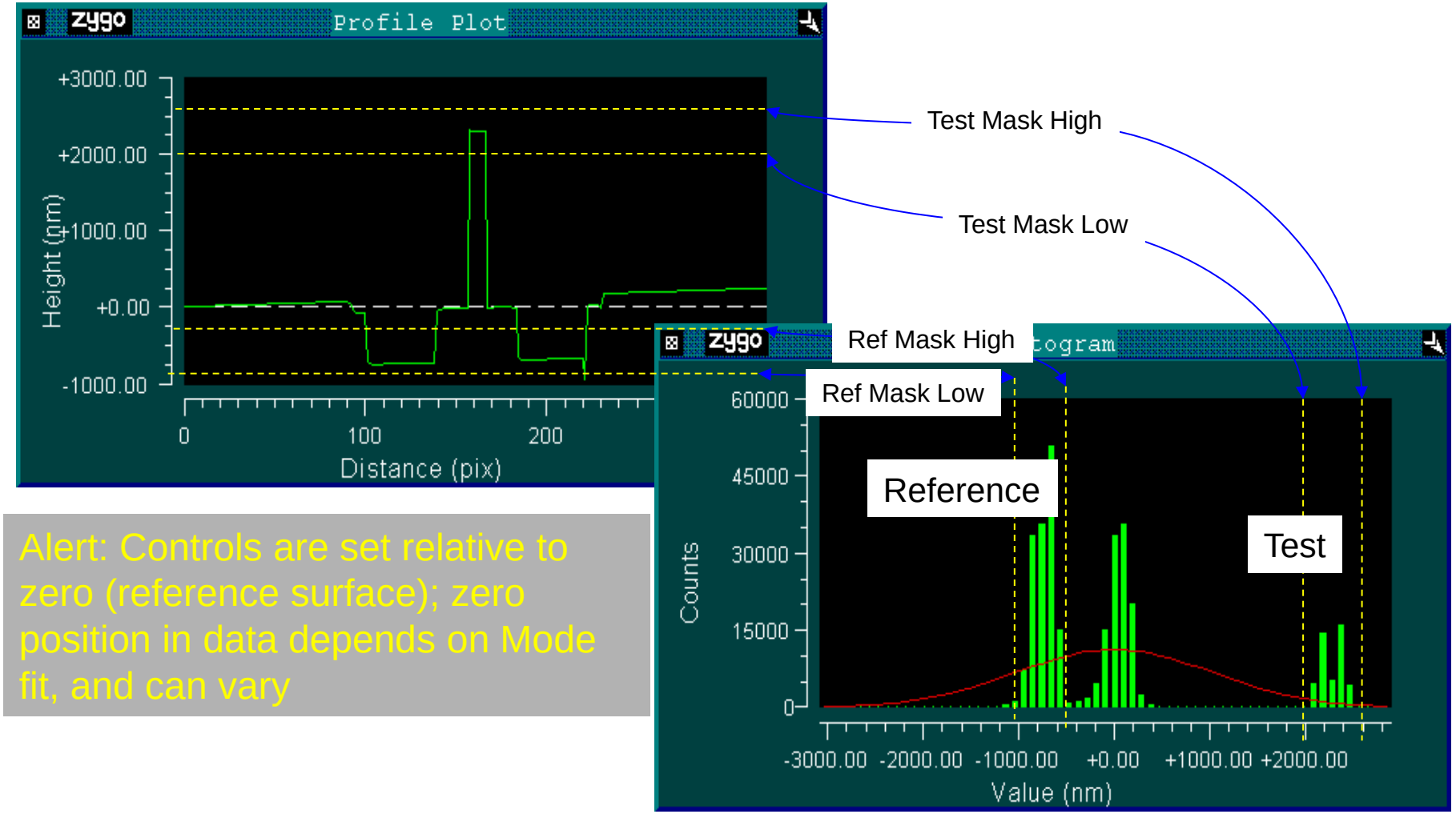
Note: Test and Reference regions may include some, or even all,of the same data cells / pixels

Histogram Mode Procedure



- Set Test & Reference Mask High and Low limit controls
- Set Test & Reference Mask Mode controls (Fill)
- Set Segmentation Mode control to Histogram
- Analyze

Histogram Mode



Alert: Controls are set relative to zero (reference surface); zero position in data depends on Mode fit, and can vary

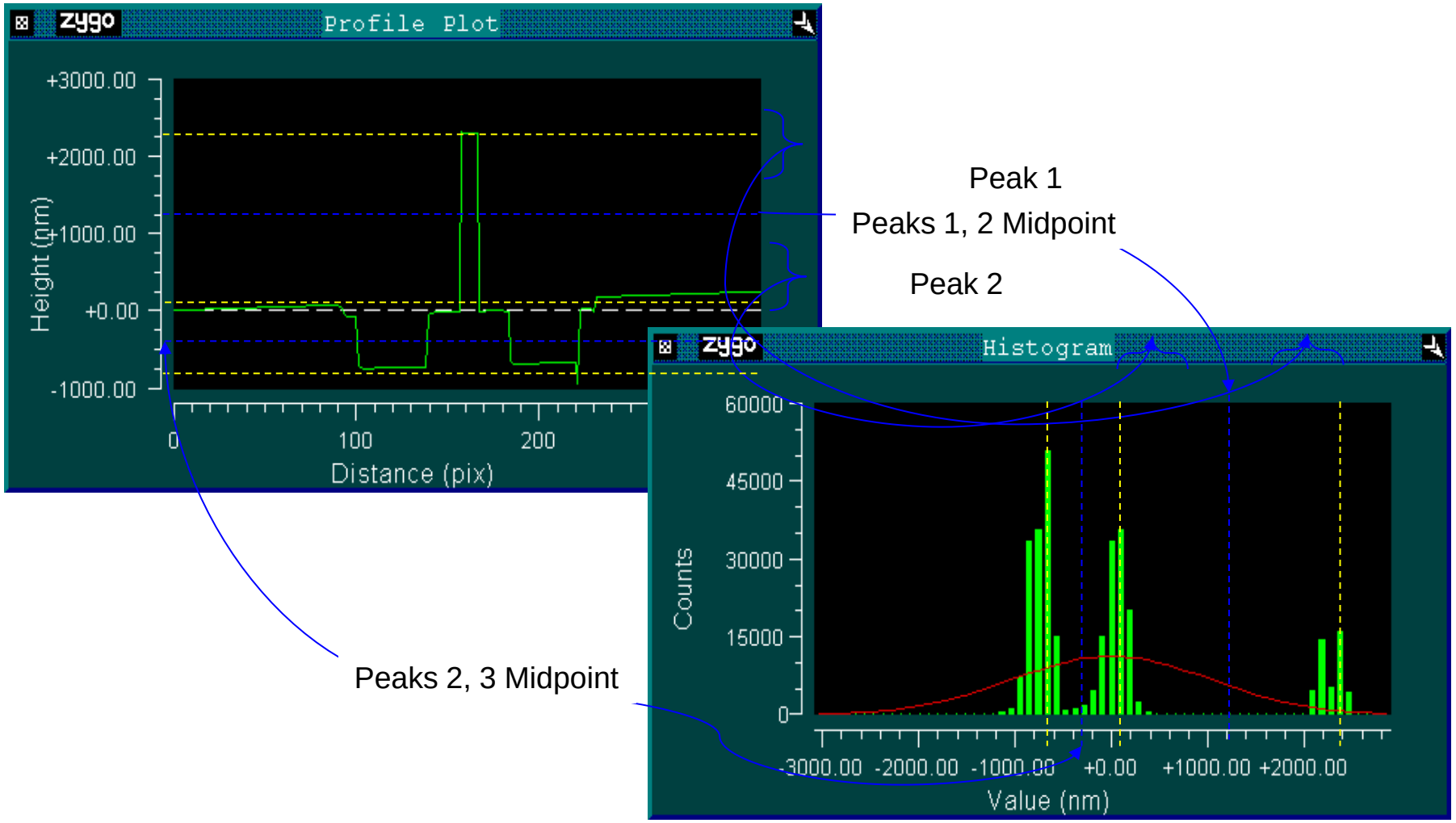
Segmentation Mode: Peaks Midpoint

- Selects areas of interest based on heights
- Designed for relatively smooth parts with clearly separated height areas
- Not recommended for rough surfaces or surfaces with slopes

Segmentation Mode: Peaks Midpoint

- Advantage:
  - Segmentation is automatic
  - Works well on relatively smooth parts with clearly separated height areas
- Disadvantage: Not recommended for rough parts or parts with slopes

Peaks Midpoint Mode



Peaks Midpoint Mode Procedure

- Set Segmentation Mode control to Editor
- Set Remove control to shape of Reference Surface
- Set ExpectedPeak Number control to the number of surfaces/levels you expect to find
- Set Segmentation controls
- If the surfaces are not distinct or the data is noisy, you may want to help the algorithm by entering a Minimum Peak Separation value
- Set Peak Number controls
- Set Reference and Test Sigma Clips -- imperative for surfaces connected by slopes
- Analyze

Note: Test and Reference regions may include some, or even all, of the same data cells / pixels

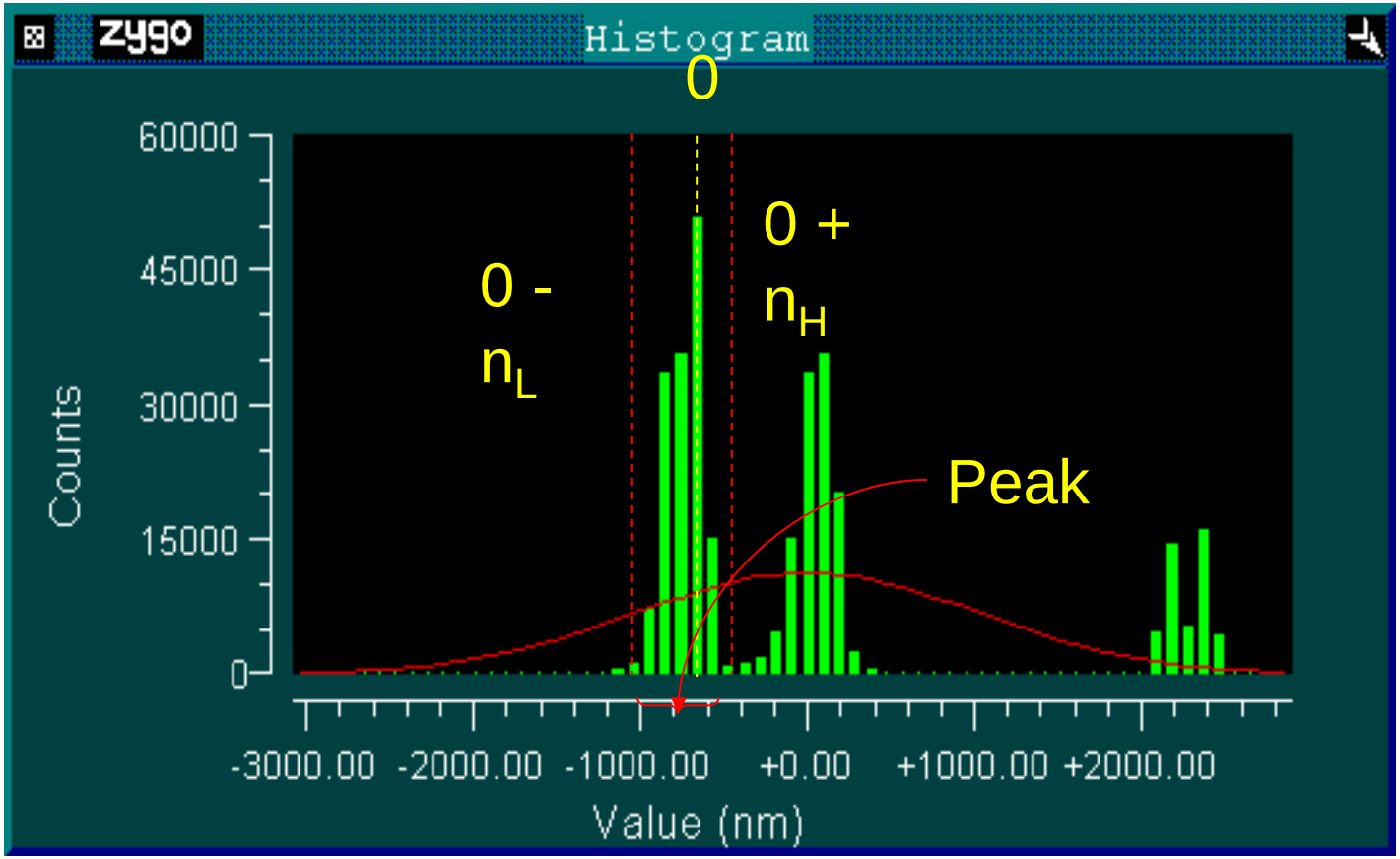
Segmentation Mode: Peaks Relative

- Selects areas of interest based on heights
- Designed for parts with steps and and parts with slopes between steps
- Control settings are relative to the histogram peak at a given vertical level

Segmentation Mode: Peaks Relative

- Advantage:
  - Segmentation is automatic
  - Recommended for steps on rough parts
  - Recommended for parts with slopes between steps

Peaks Relative Mode



Peaks Relative Mode Procedure

- Segment using Peaks Midpoint mode
- Slice data set
- In Test/Reference Control Window, add:
  - Ref Mask Low & Ref Mask High
  - Test Mask Low & Test Mask High
  - Test2 Mask Low & Test2 Mask High
  - Test3 Mask Low and Test3 Mask High
  - Test4 Mask Low & Test4 Mask High
- Use Profile Plot Inspectors to set these values
- Set Expected Peak Number control
- Set Reference and Test Peak Number controls
- Set Reference and Test Sigma Clips
- Analyze

Note: Test and Reference regions may include some, or even all, of the same data cells / pixels

Segmentation Mode: Peaks Relative

- Selects areas of interest based on heights

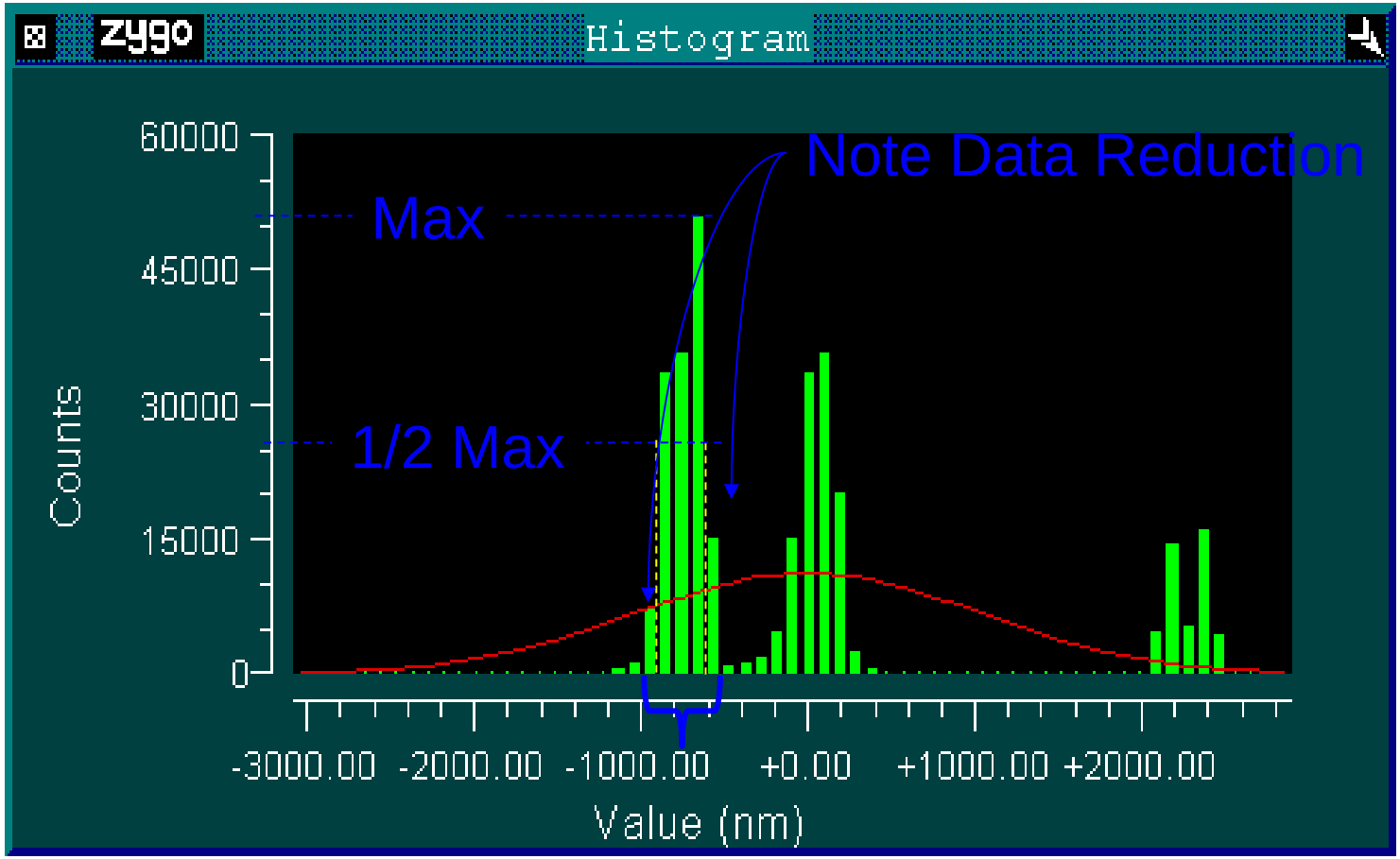
- Ref/Test Mask High/Low values determined automatically at Full Width Half Maximum of a given peak

Segmentation Mode: Peaks FWHM

- Advantages:
  - Surfaces are segmented automatically, as in Peaks Midpoint mode
  - Differentiation between adjacent peaks is clearer than with Peaks Midpoint mode

- Disadvantage:
  - It is likely that less data will be available for each surface

Peaks FWHM Mode



Peaks FWHM Procedure

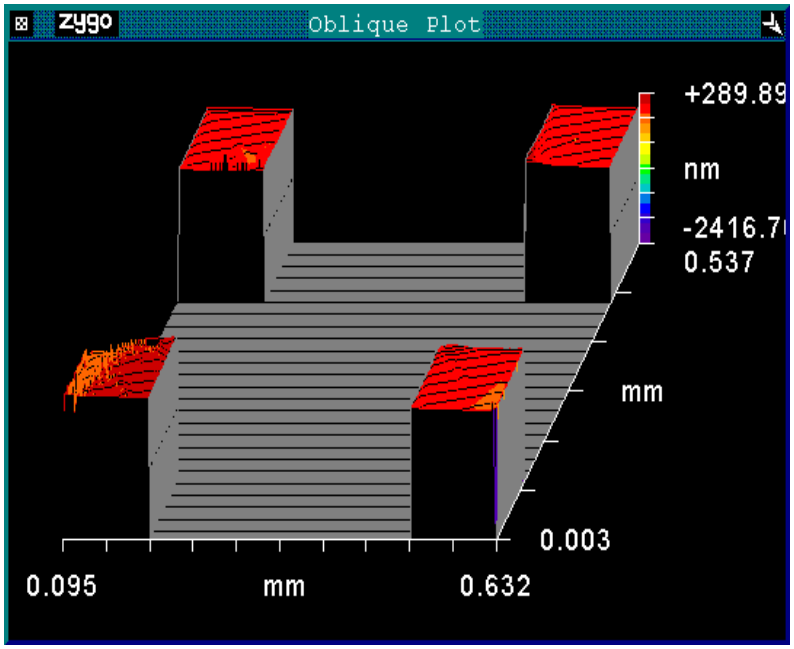
- Set Segmentation Mode control to Editor
- Set Remove control to shape of Reference Surface
- Open Histogram plot
- Set Expected Peak Number control
- Set Reference & Test Peak Number controls
- Set Reference and Test Sigma Clips
- Set Segmentation Mode control to FWHM
- Analyze

Note: Test and Reference regions may include some, or even all, of the same data cells / pixels

Segmentation Mode: Islands

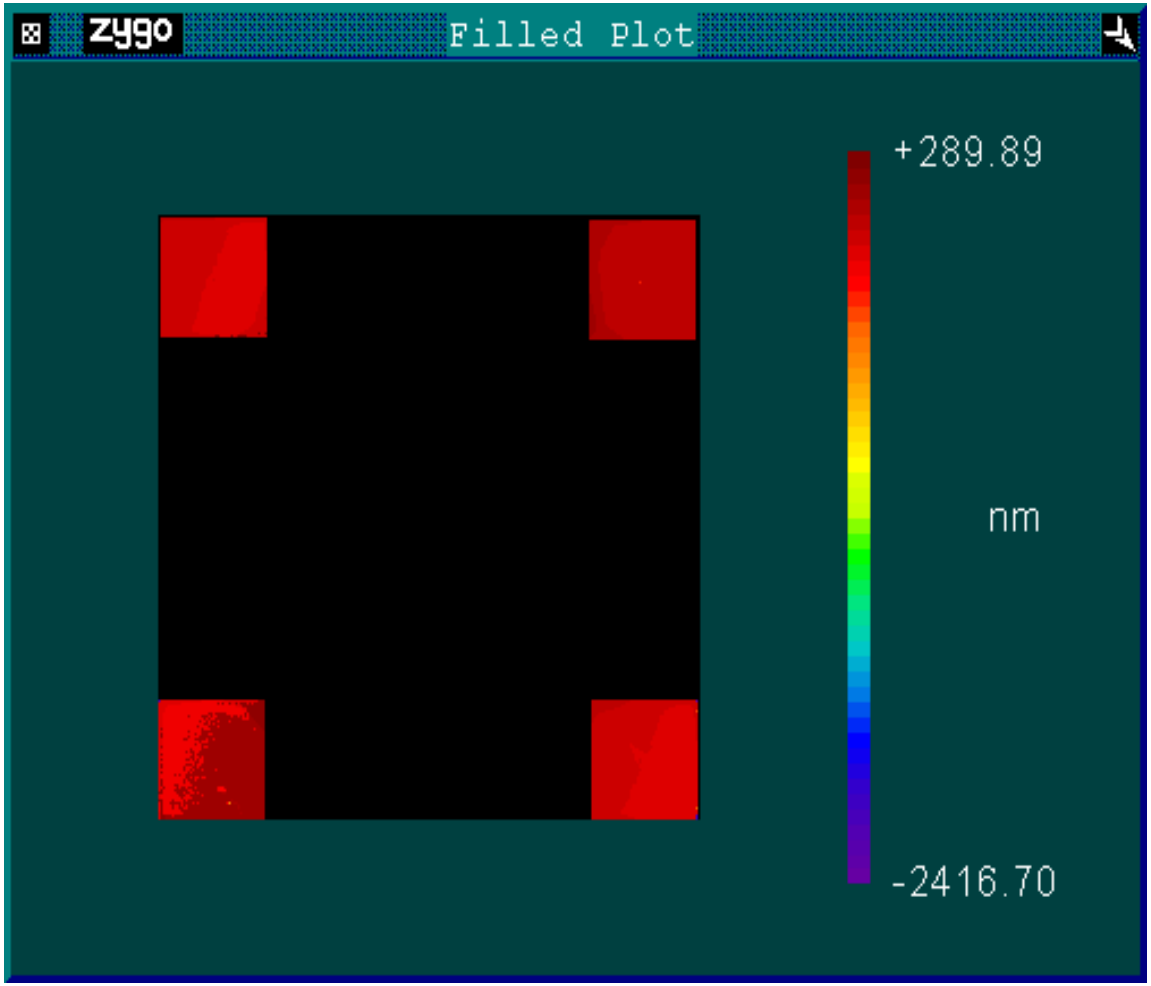
- Selects areas of interest based on size; does not use Histogram
- Designed only for parts with discontinuous or isolated islands of data
- Automatically numbers islands from largest (1) to smallest (N)

Segmentation Mode: Islands

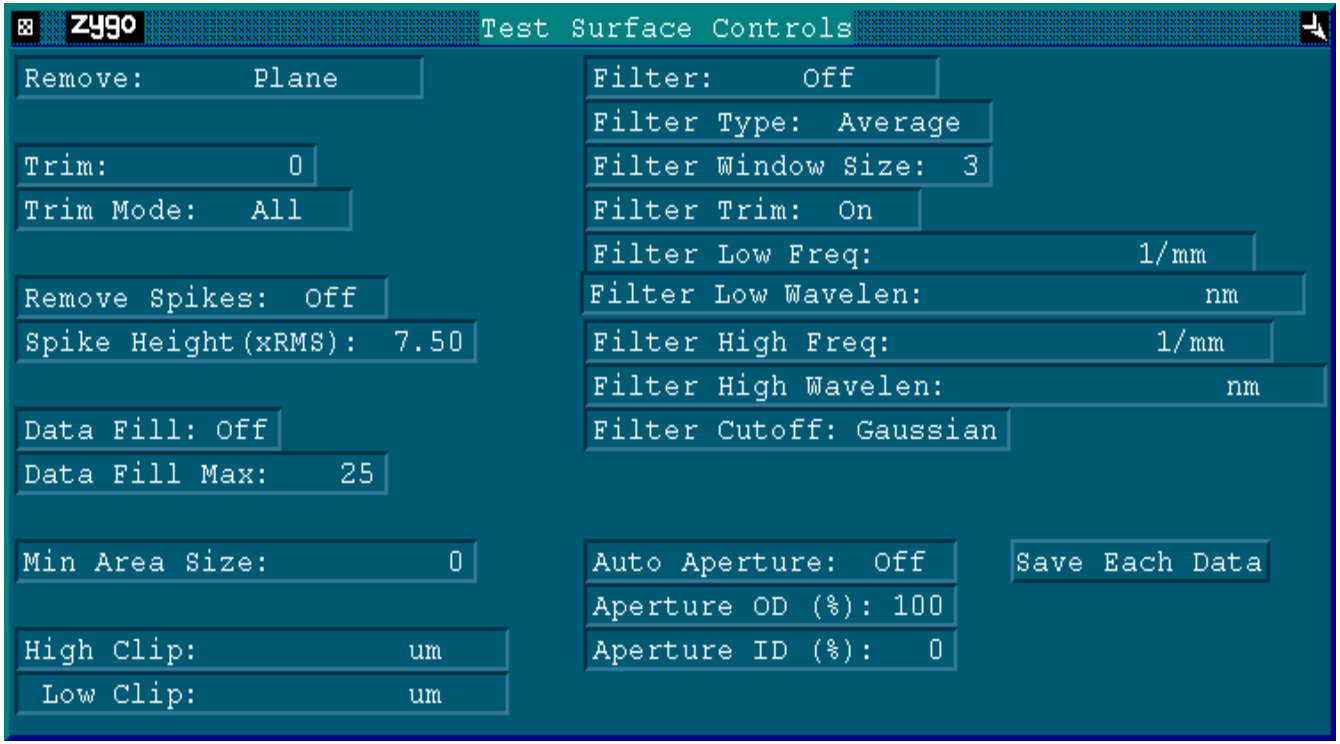


- Advantage: Enables you to analyze discontinuous regions that may or may not be at the same height

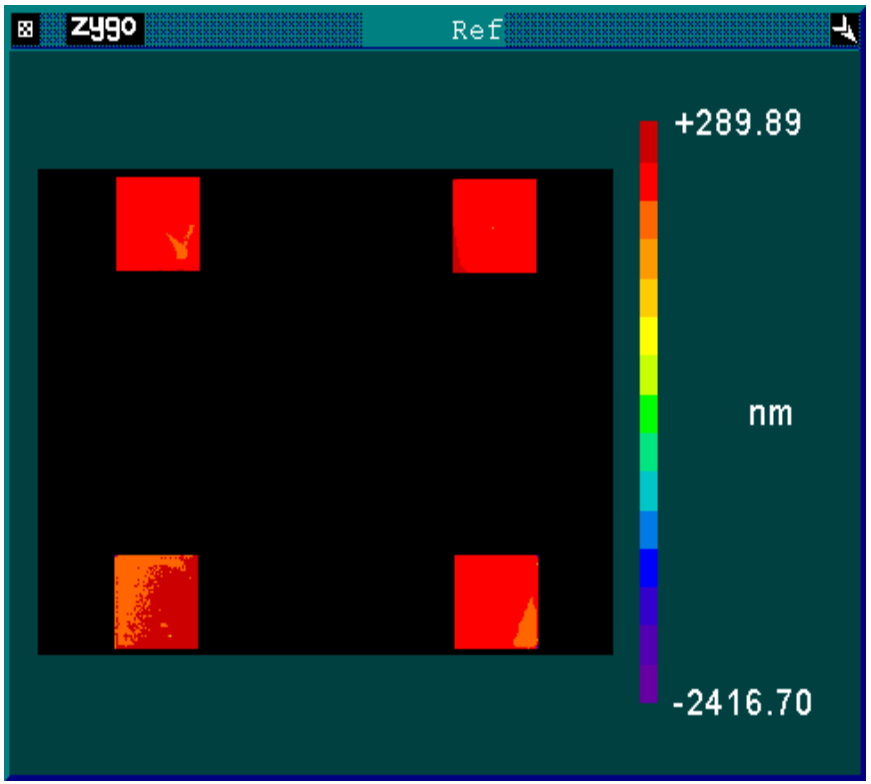
Segmentation Mode: Islands

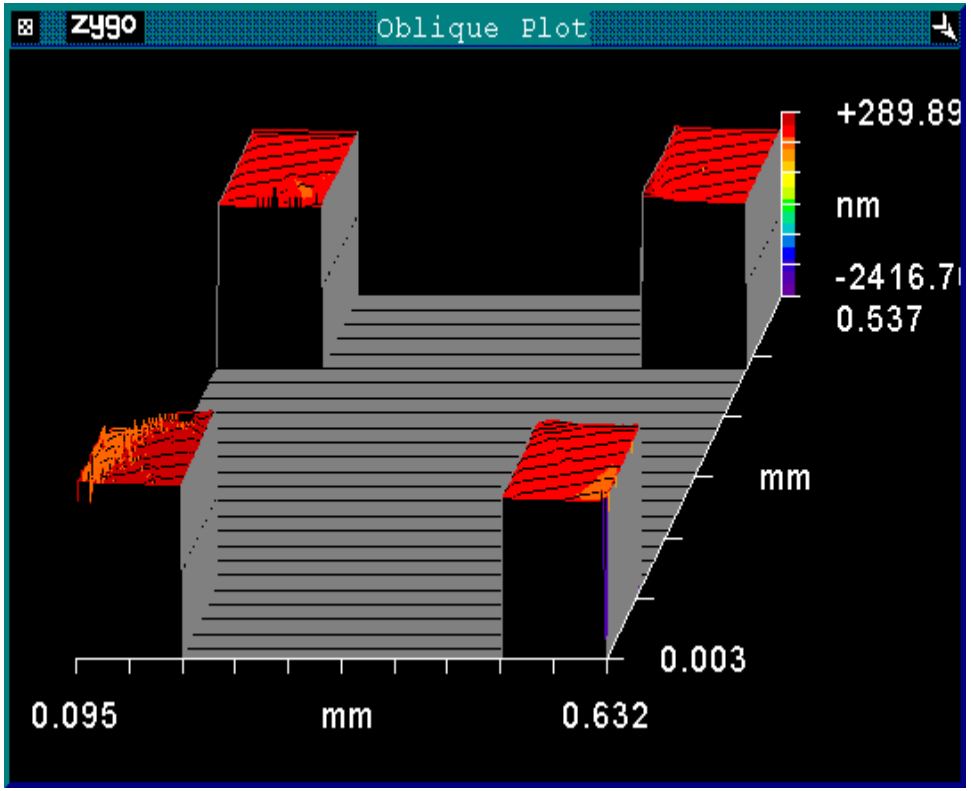


Test Surface Controls



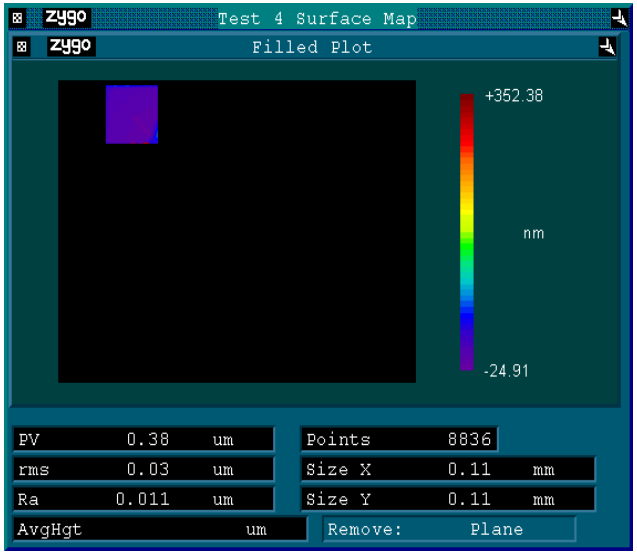
Islands Reference Surface

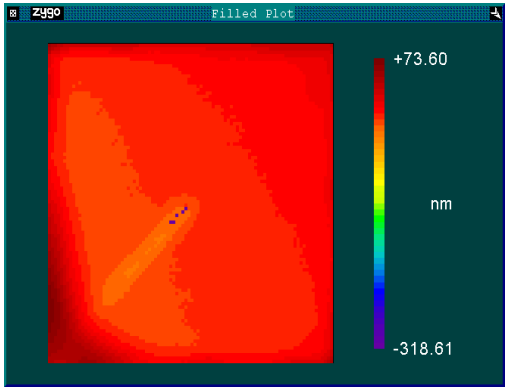




Islands Surfaces

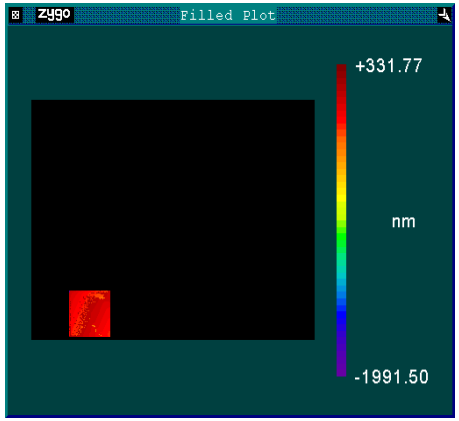
Test 4

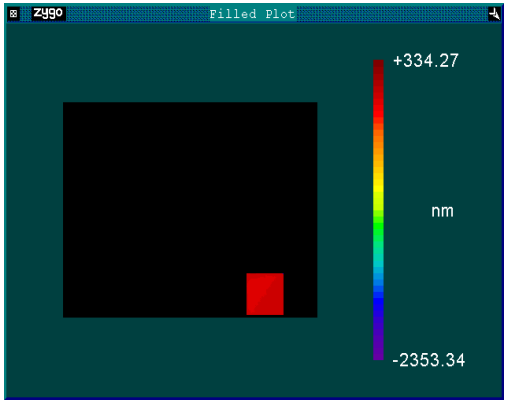




Test

Test 2





Test 3

Islands Mode Procedure

- Set Segmentation Mode control to Editor and Analyze
- Set Remove control to "None."
- In the Test Controls window, add and press the Save Each Data button
- Press the Load Data button
  - Look for data sets named "area0," through "area*n*," where *n* is the number of discontinuous areas of data
  - Area 0 is the entire data set; areas 1 through *n* are the individual regions in order of size
- Set the Segmentation Mode control to Islands
- For each Test area you'd like to analyze, enter the area number ("*n*") into the appropriate Test Peak Number control.
- You may enter any number *n* for the reference area, or 0, in which case all the areas combined will be the reference.

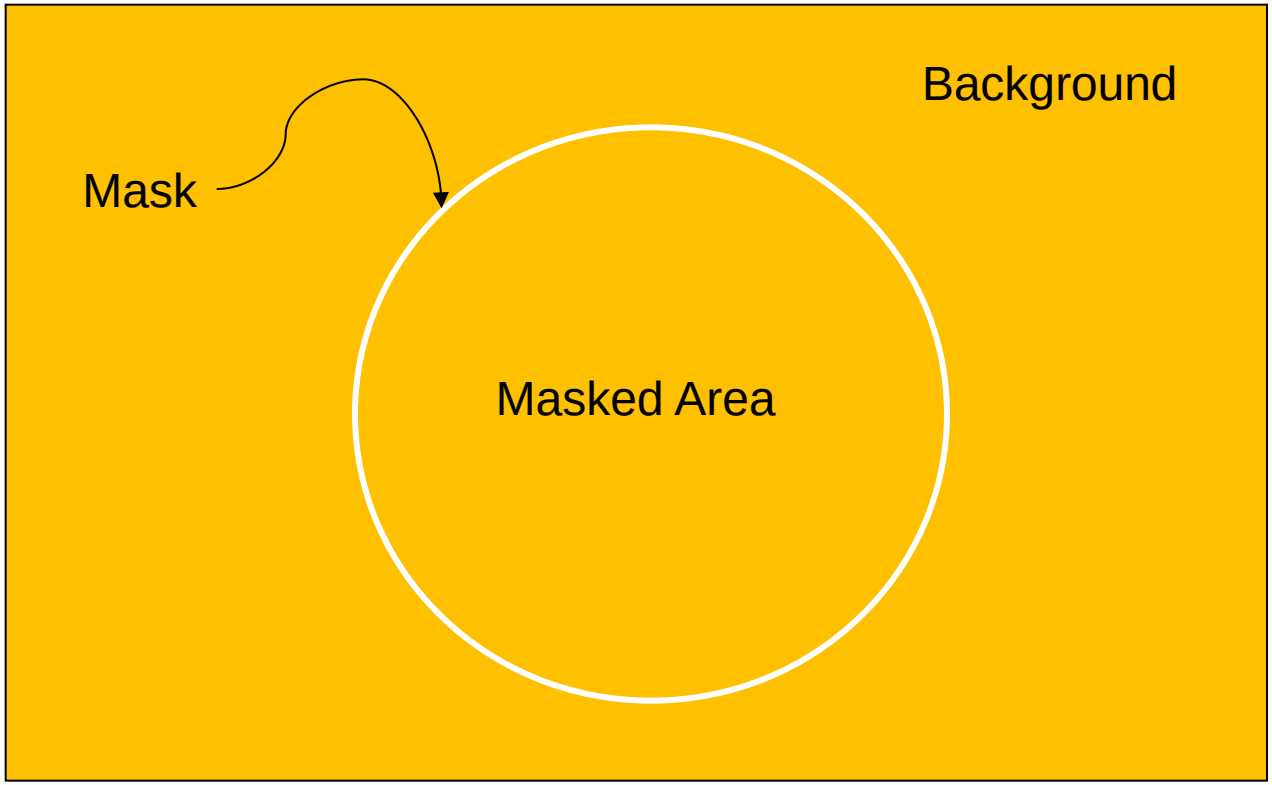
Note: Use of "Save Each Data" control is necessary only if the number of islands is greater than four

Segmentation Concepts

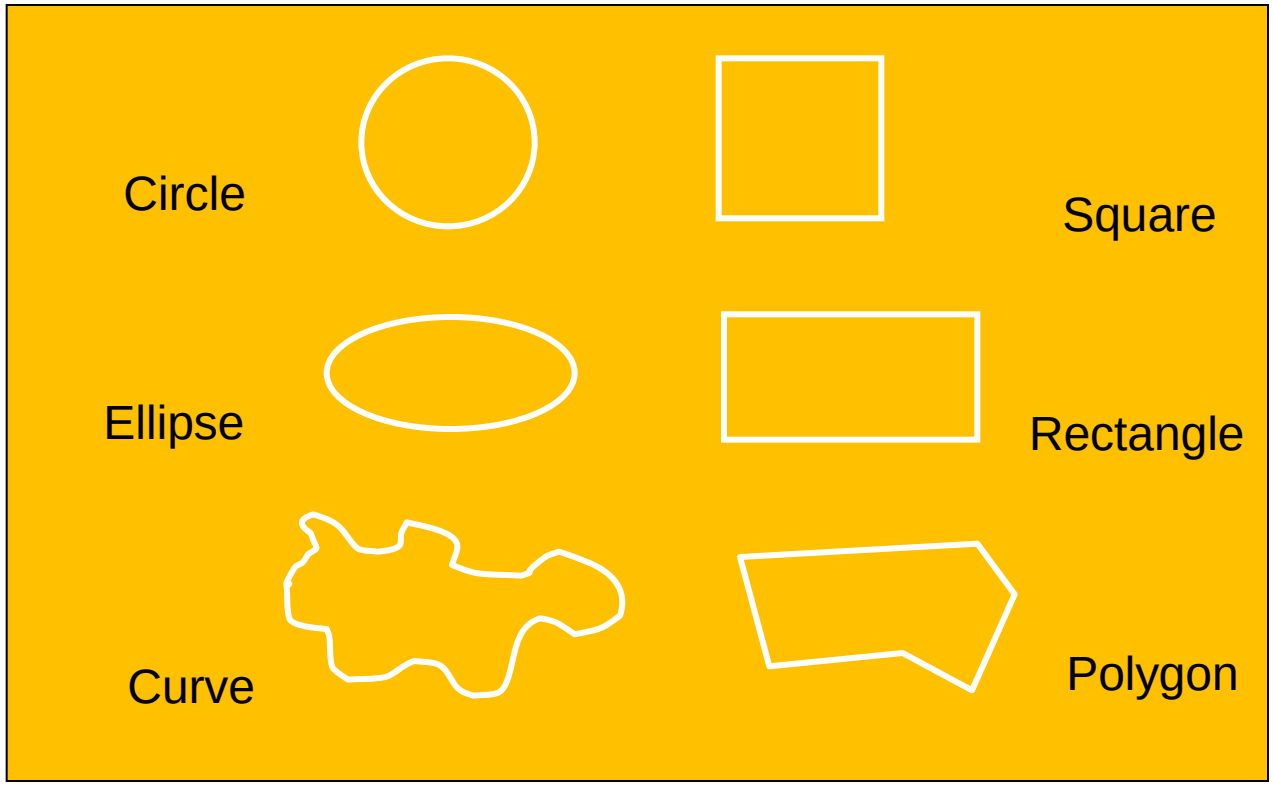
- Masks
- Fill / Unfill / Fill No Holes
- Sigma Clip
- Remove Mode

Masks

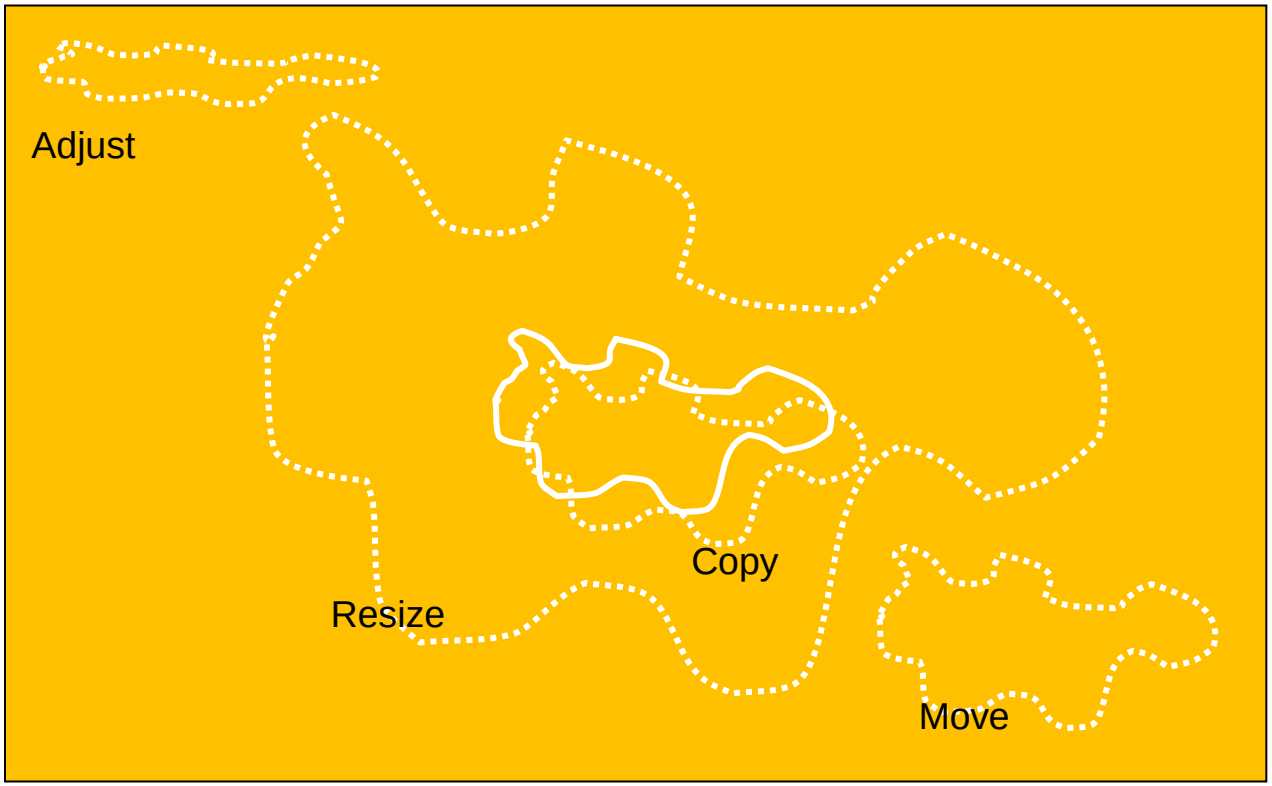
- Closed lines that separate areas of the data / field of view
- NOT the enclosed area



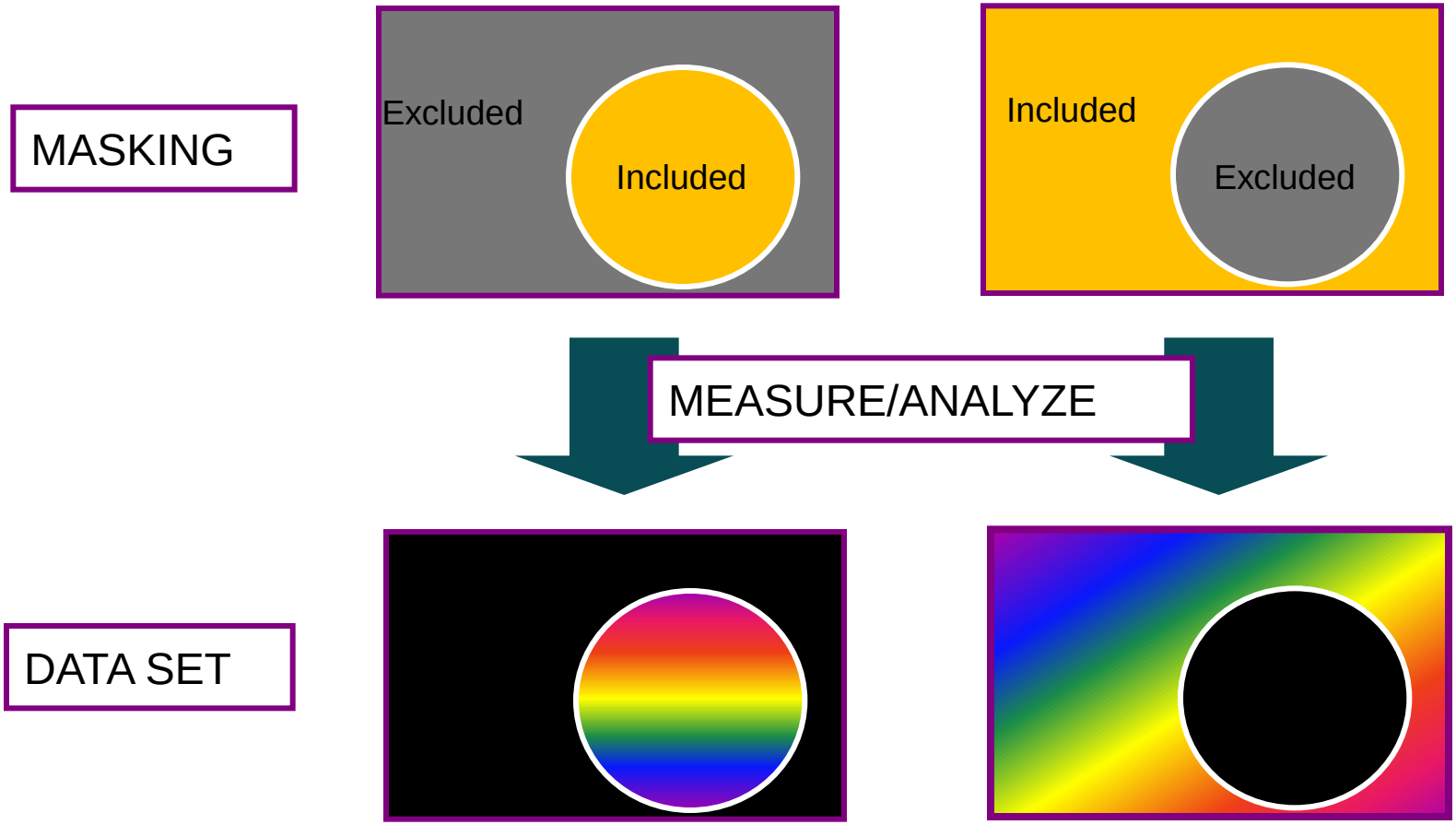
Mask Editor Shapes



Mask Editor Manipulations

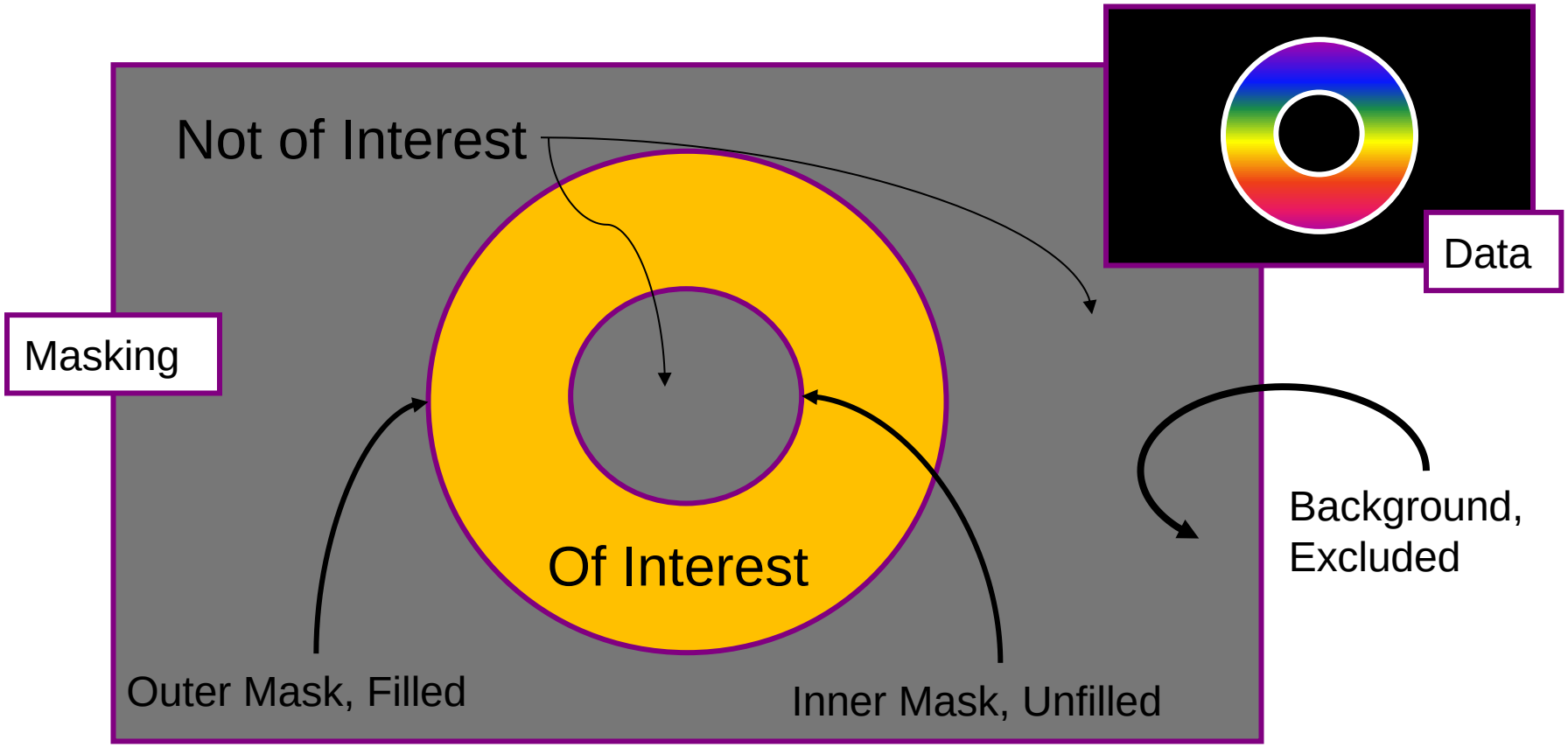


Fill and Unfill with Color



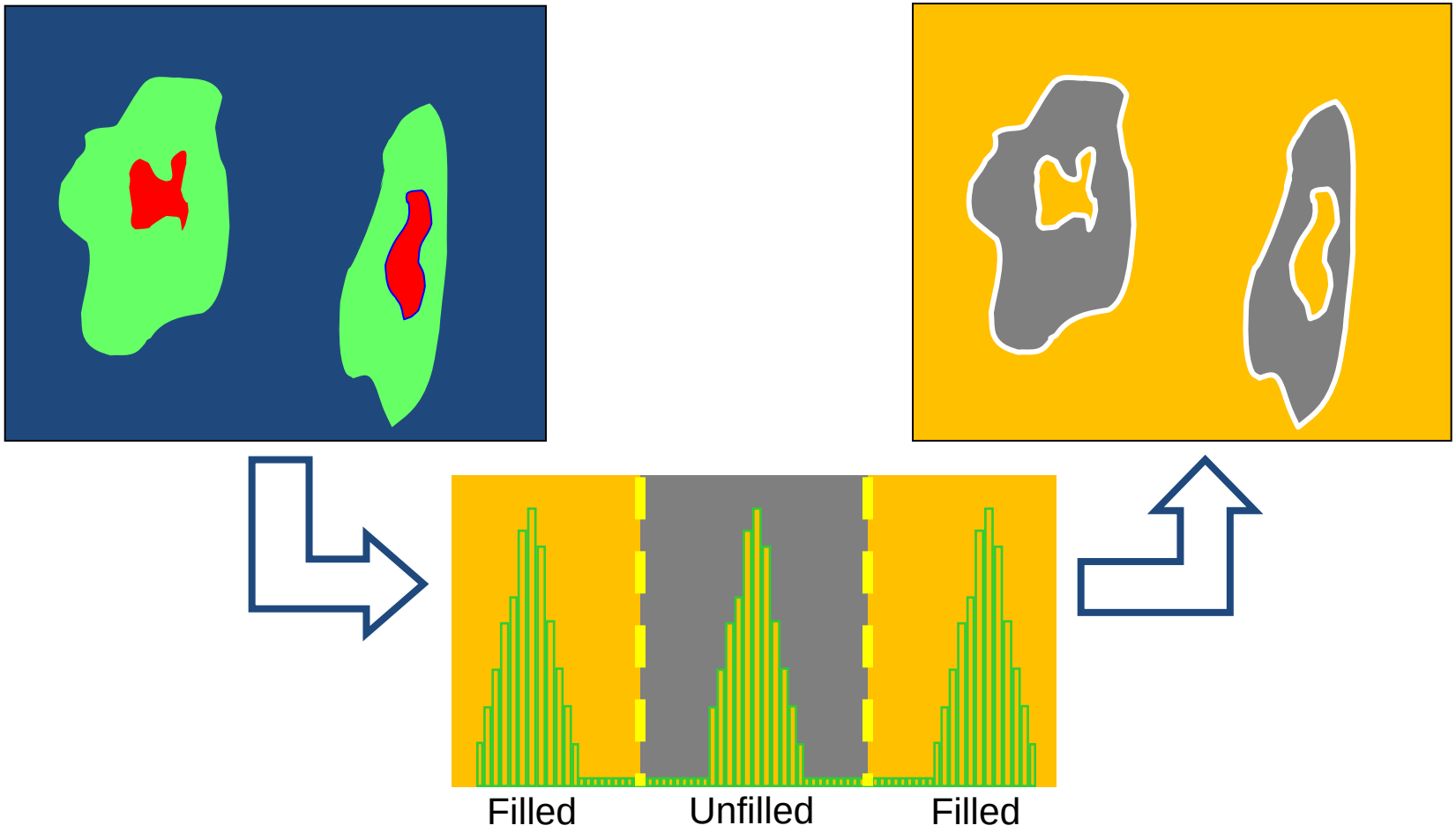
Masking More Complex Areas

- Use multiple masks
- Fill and unfill each as necessary to eliminate undesired data

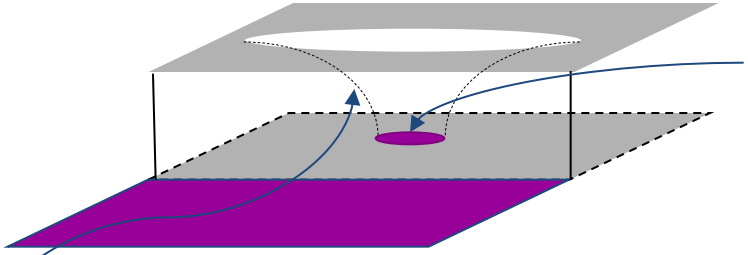


Fill / Unfill Using Histogrammed Data

- Allows definition of even more complicated areas, even areas discontinuous laterally and in height



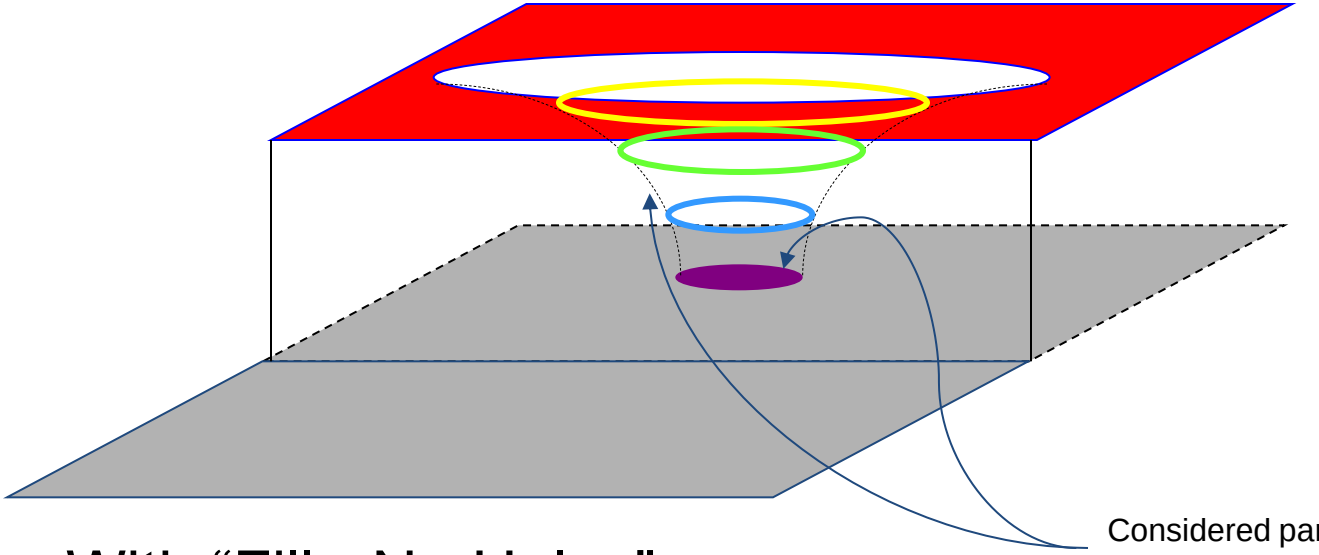
Fill – No Holes



Considered part of lower surface

Without “Fill - No Holes”

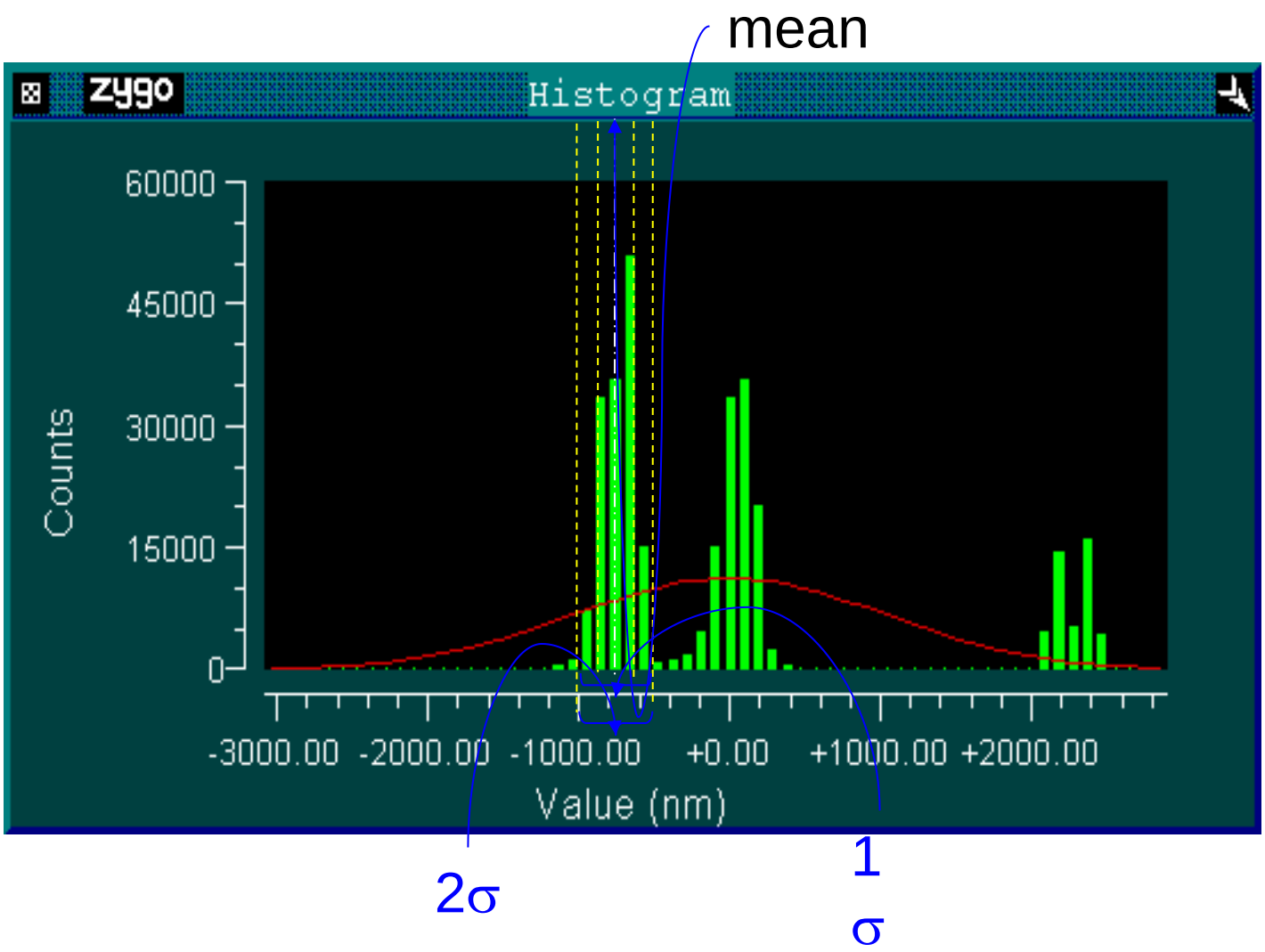
Not considered part of either surface



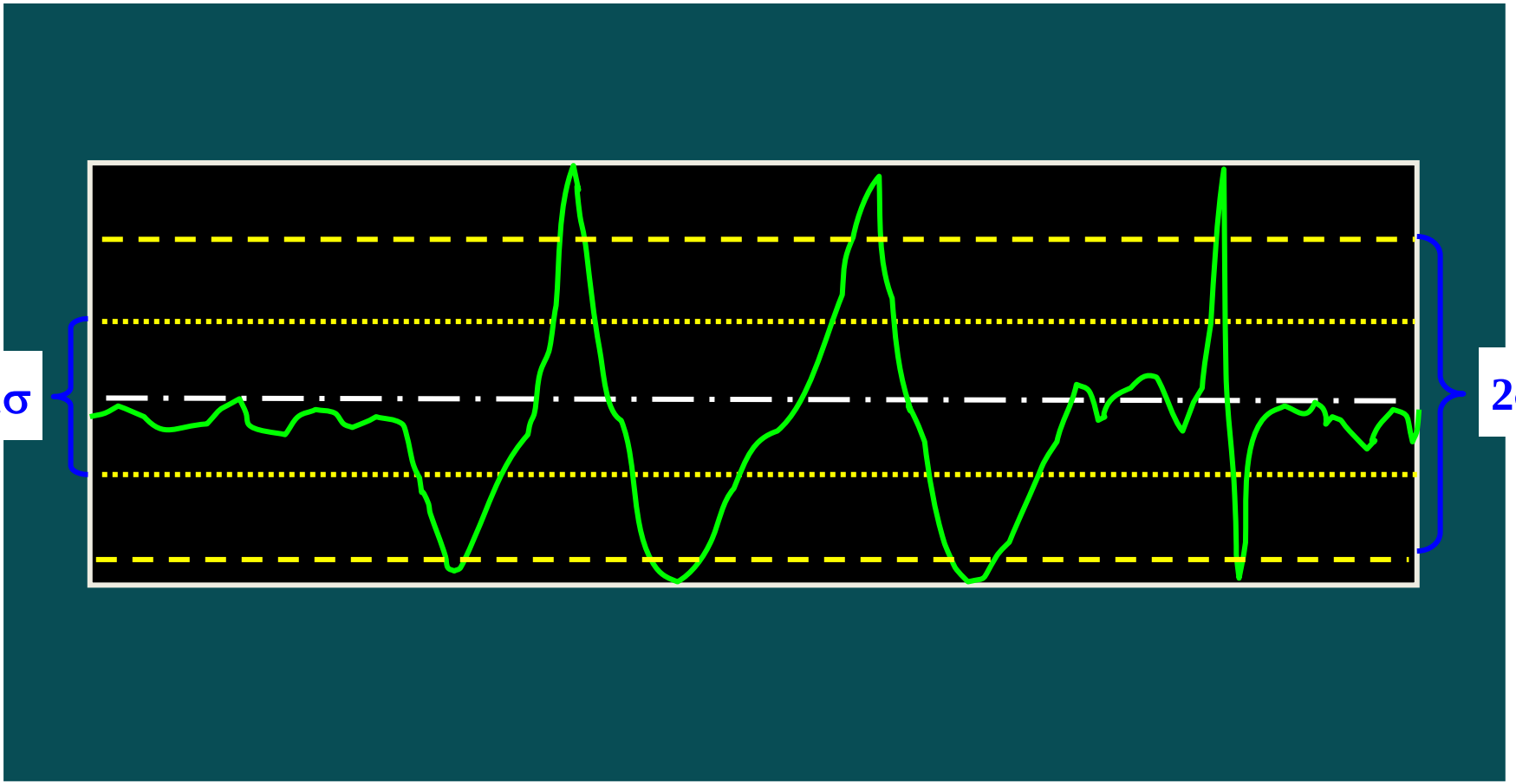
Considered part of upper surface

With “Fill - No Holes”

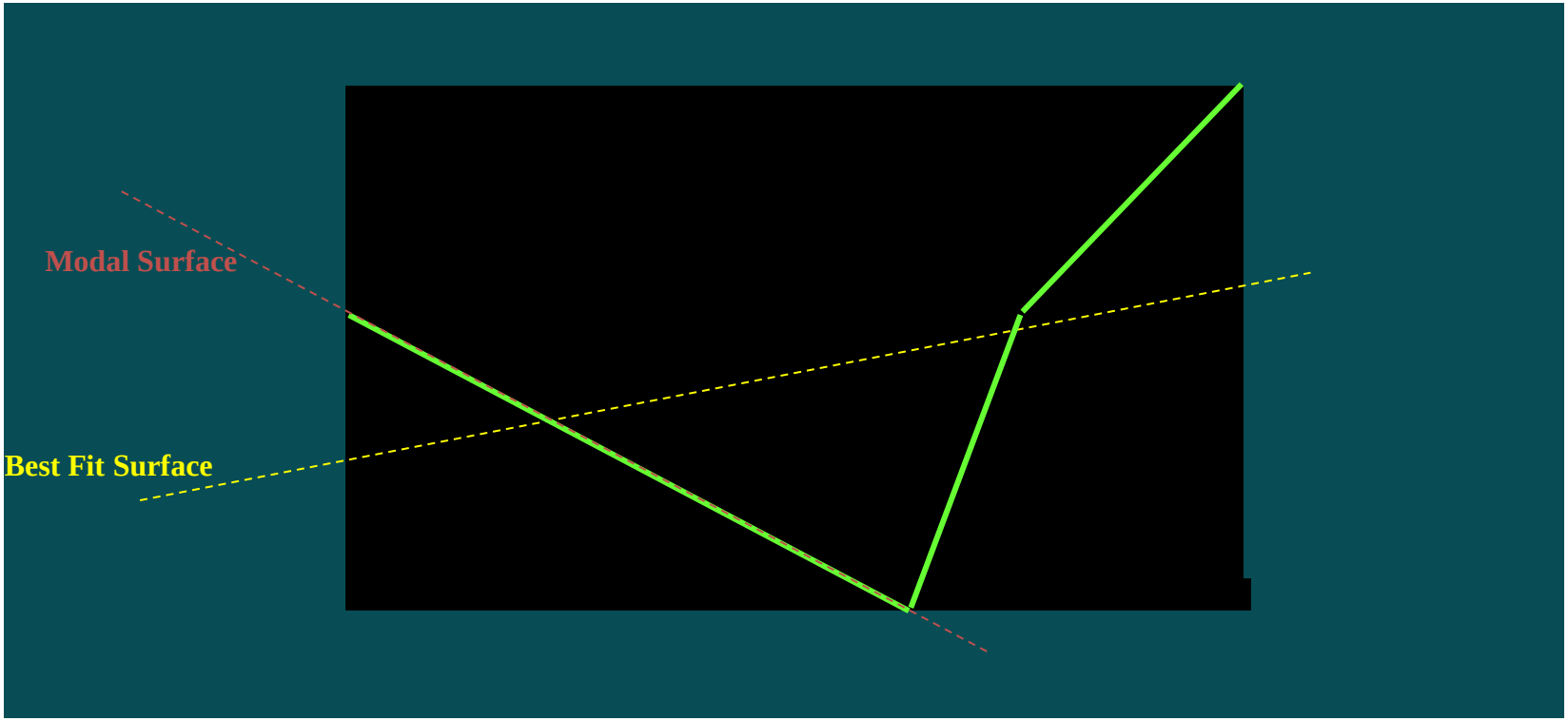
Sigma Clipping



Sigma Clipping

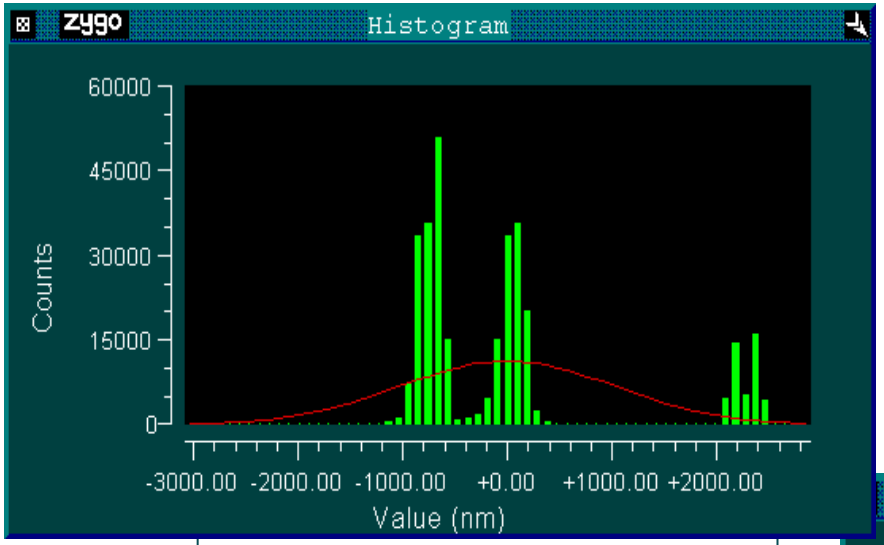


Modal Surface Removal



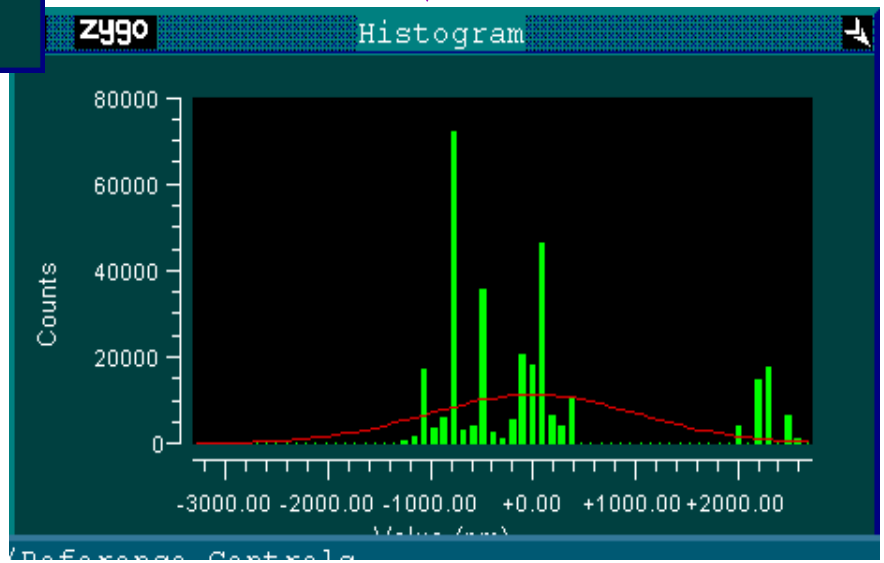
Leave "Remove Mode" OFF unless in Editor Segmentation Mode

Modal Surface Removal

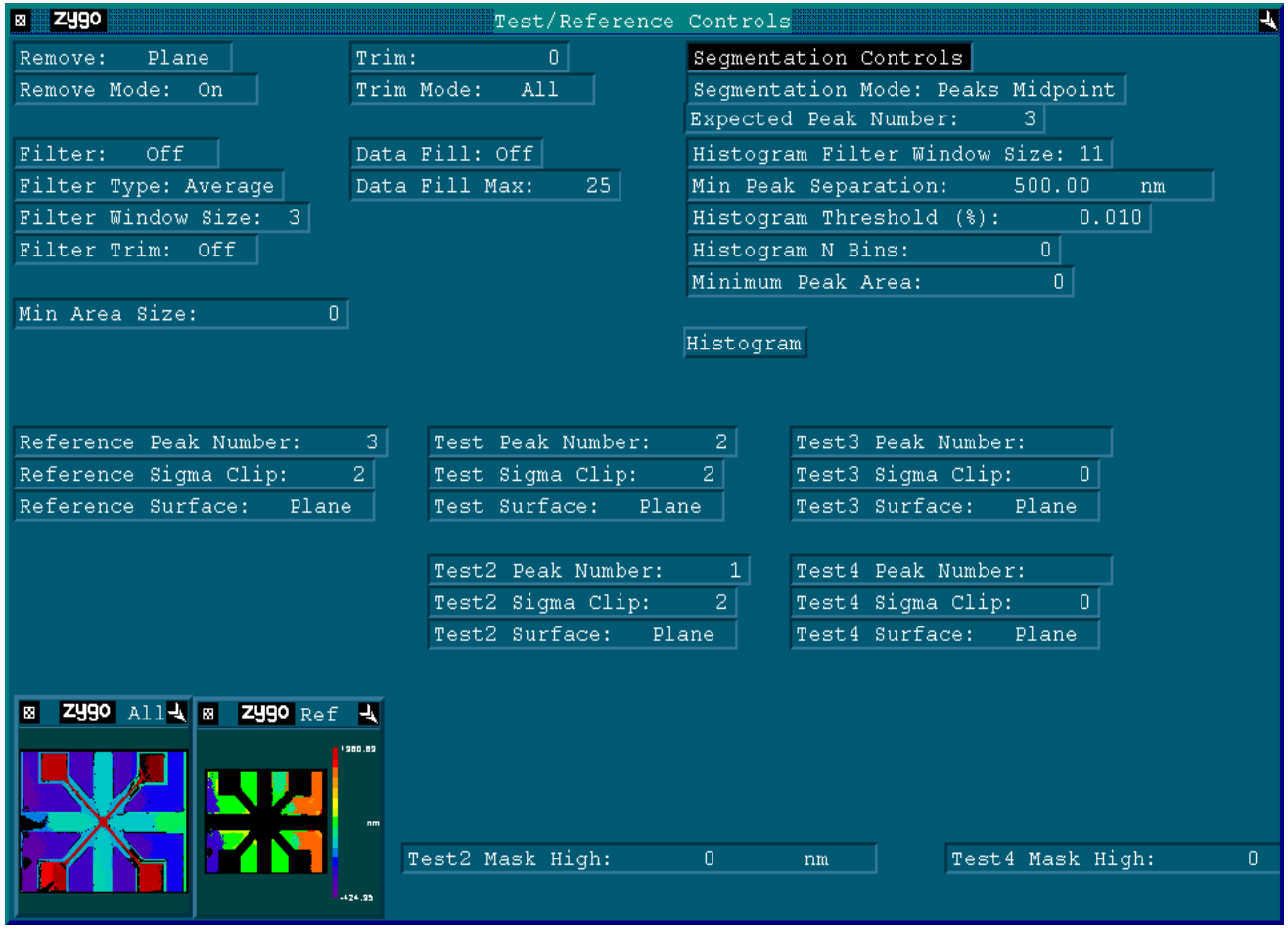


Remove Mode: Off

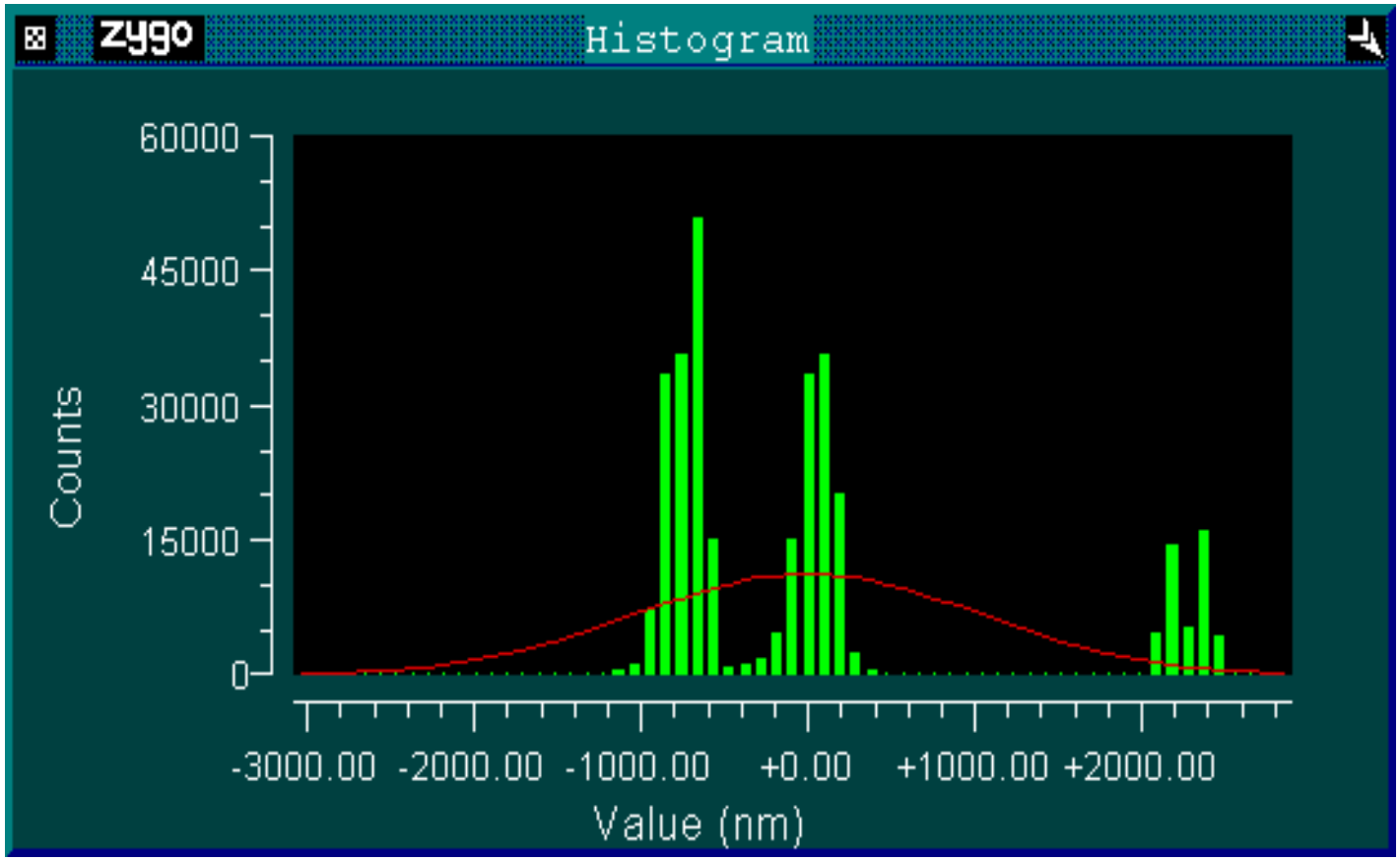
Remove Mode: On



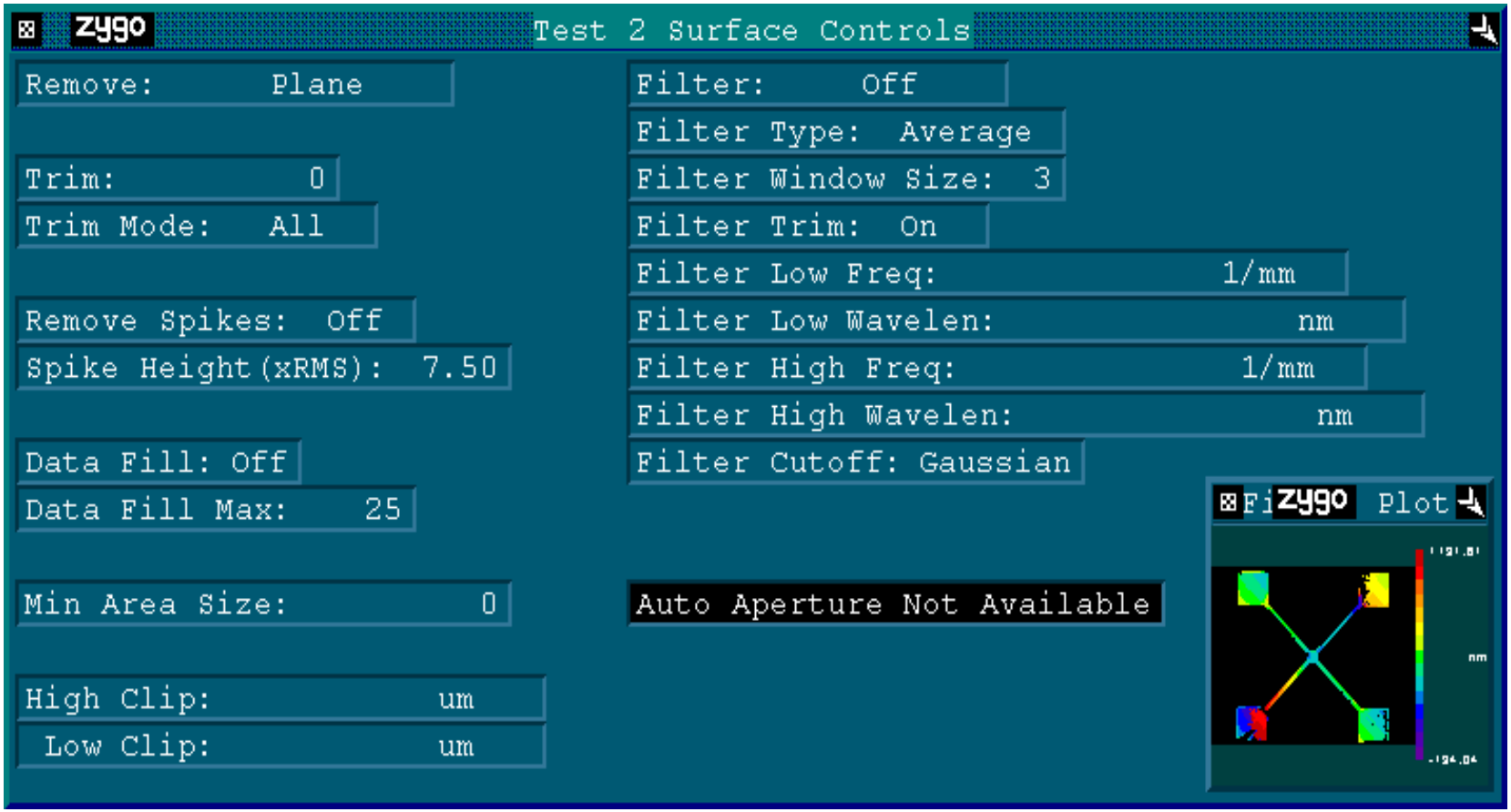
Test/Reference Controls



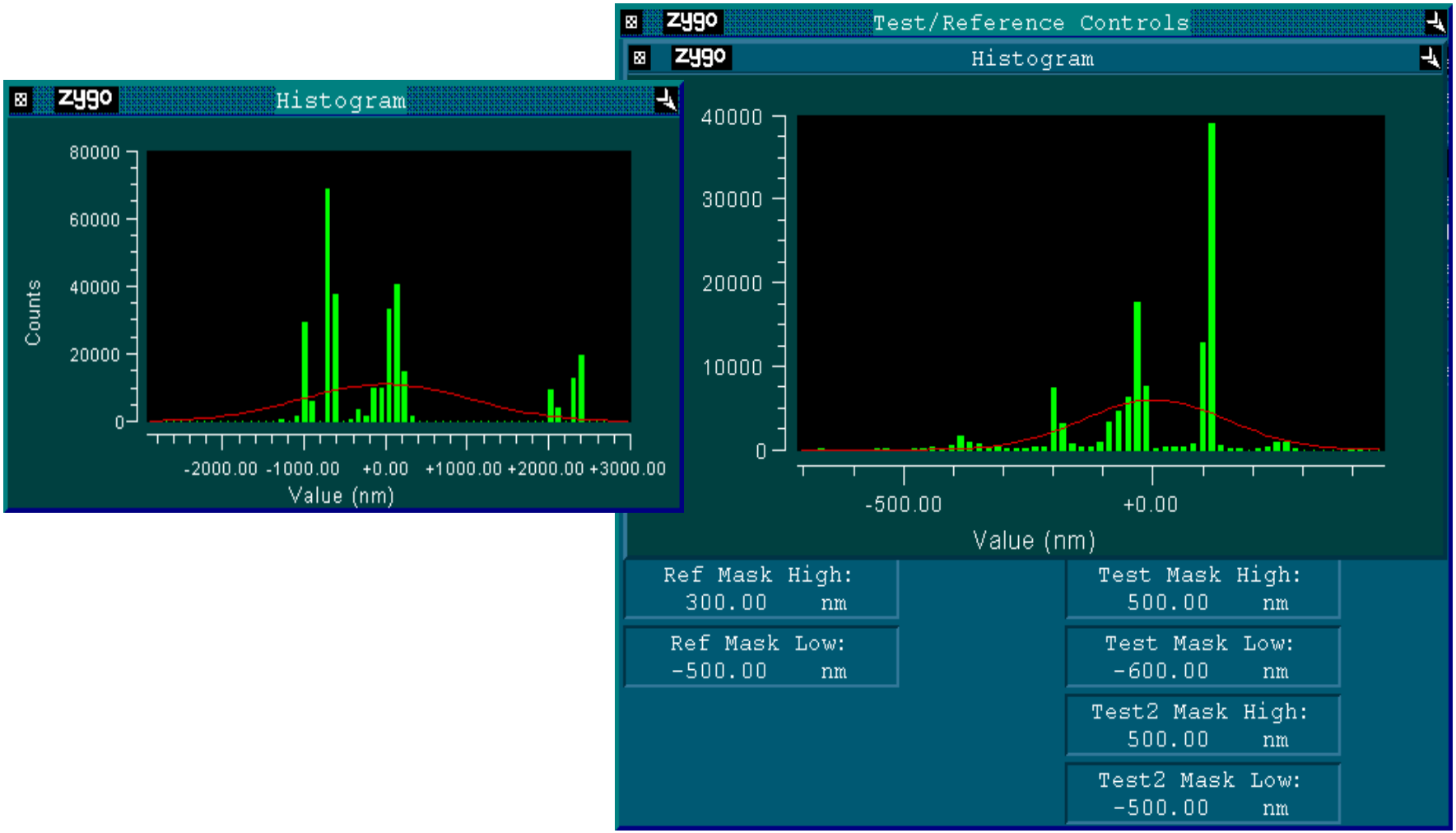
Raw Surface Data



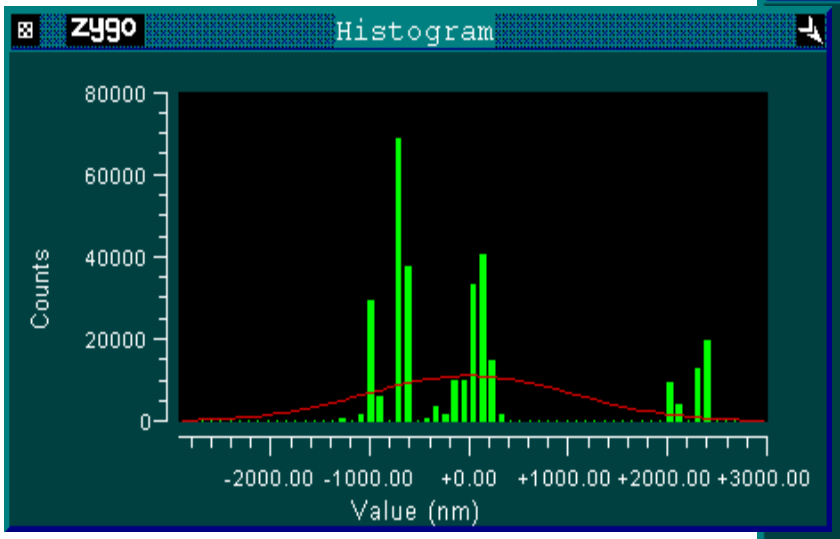
Test Surface 2 Controls

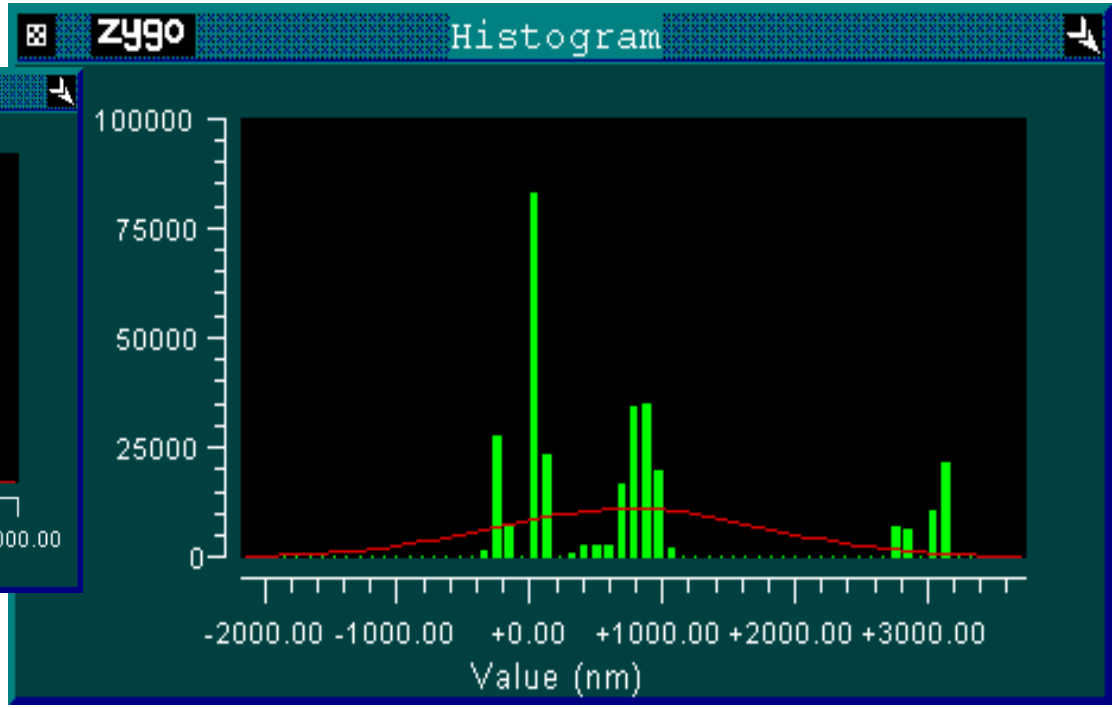


Histogram Plot

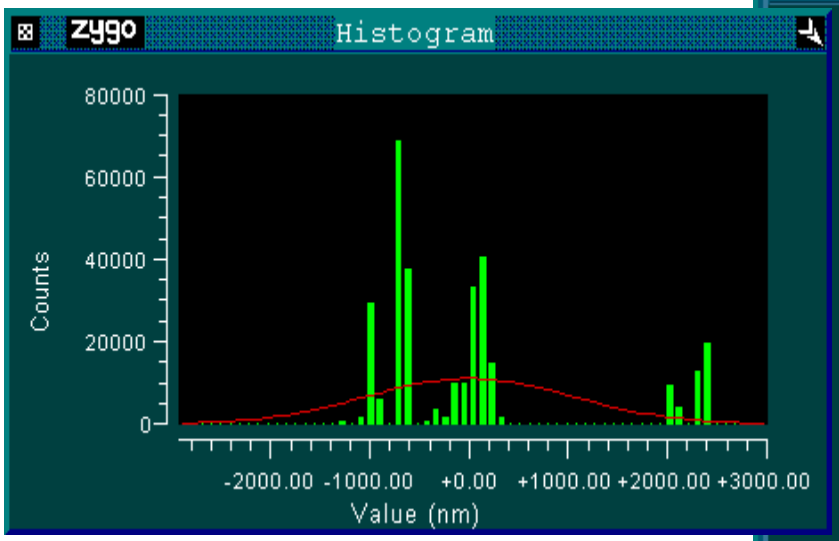


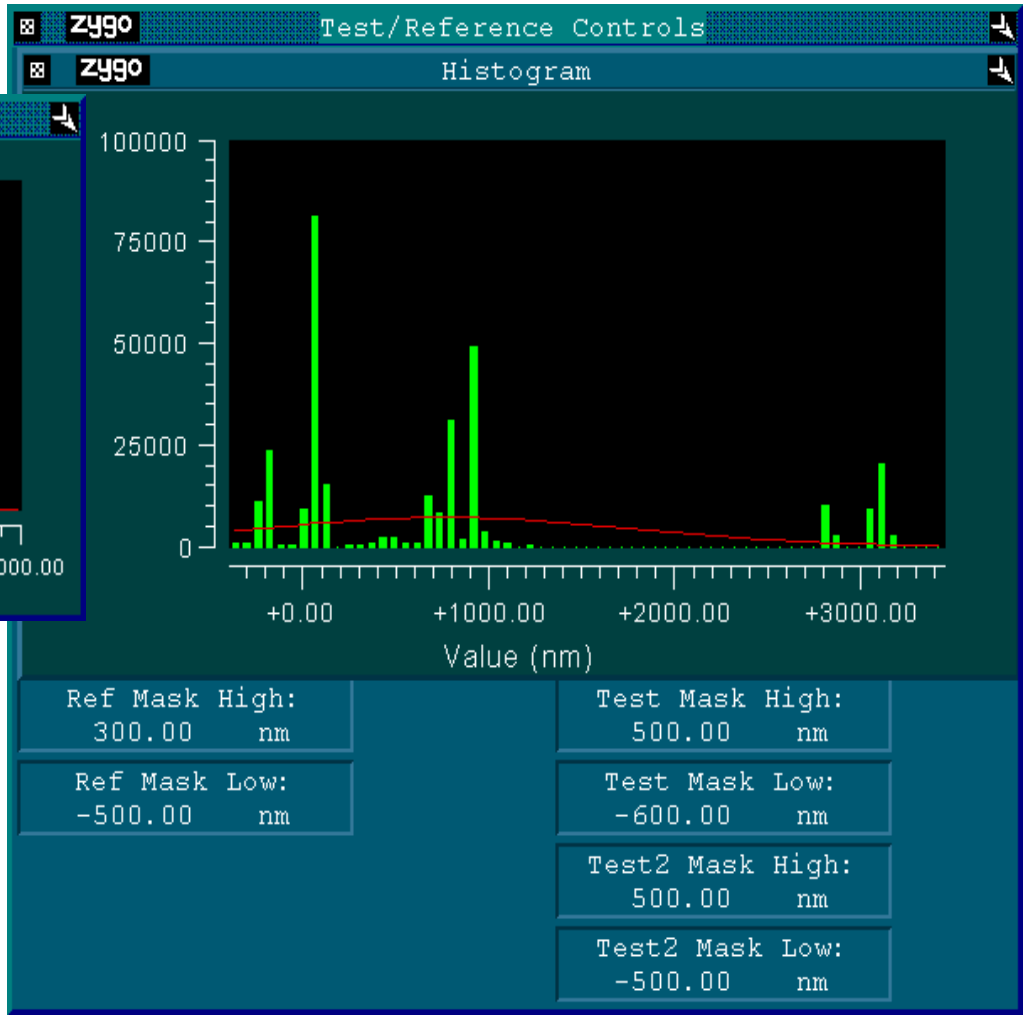
Peaks Midpoints Product



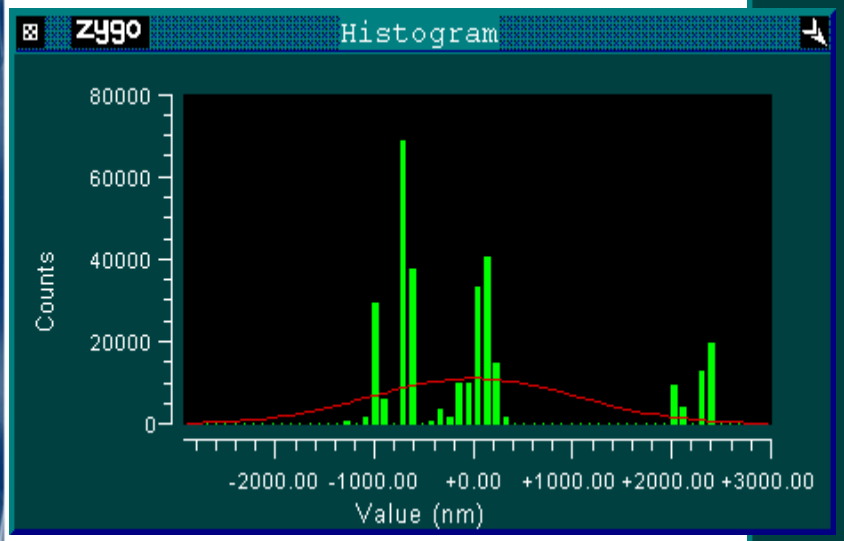


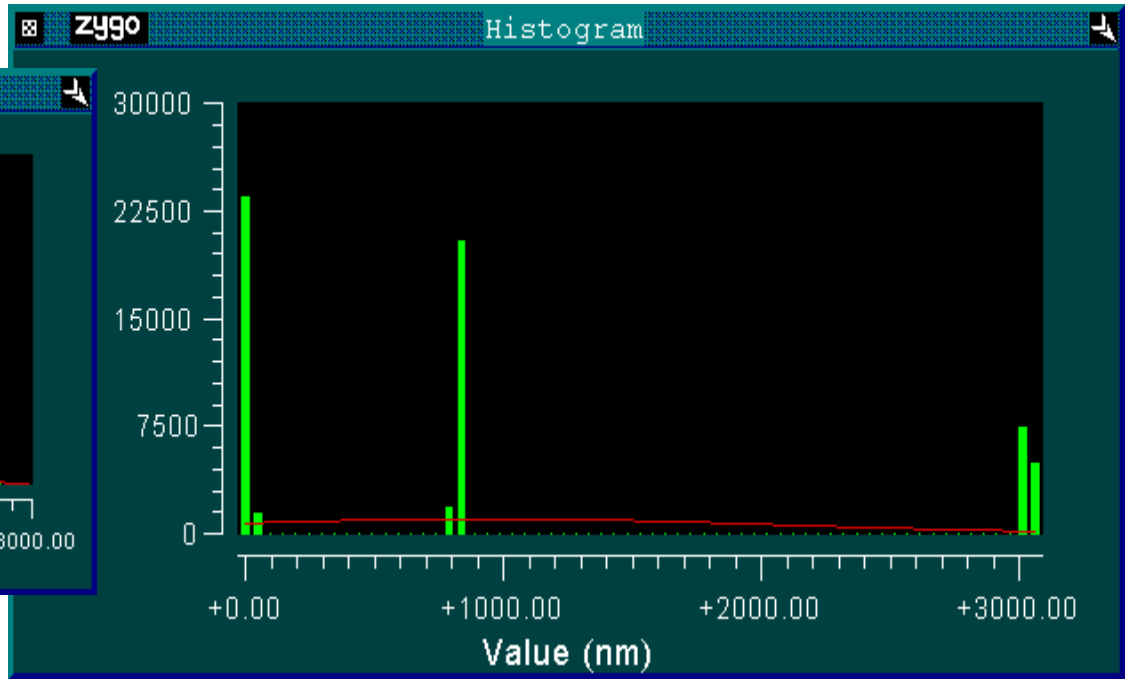
Peaks Relative Product





Peaks FHWM Product

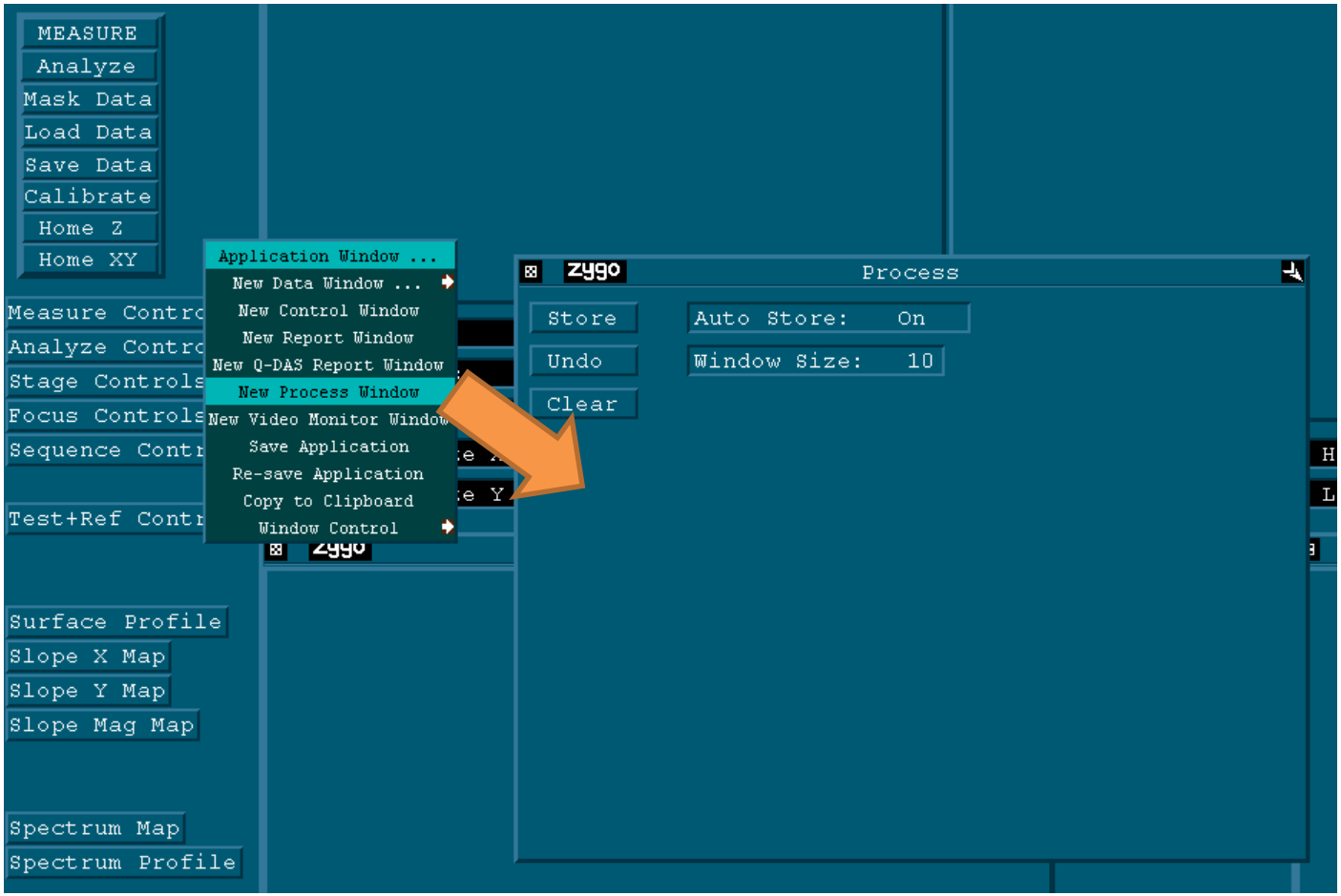




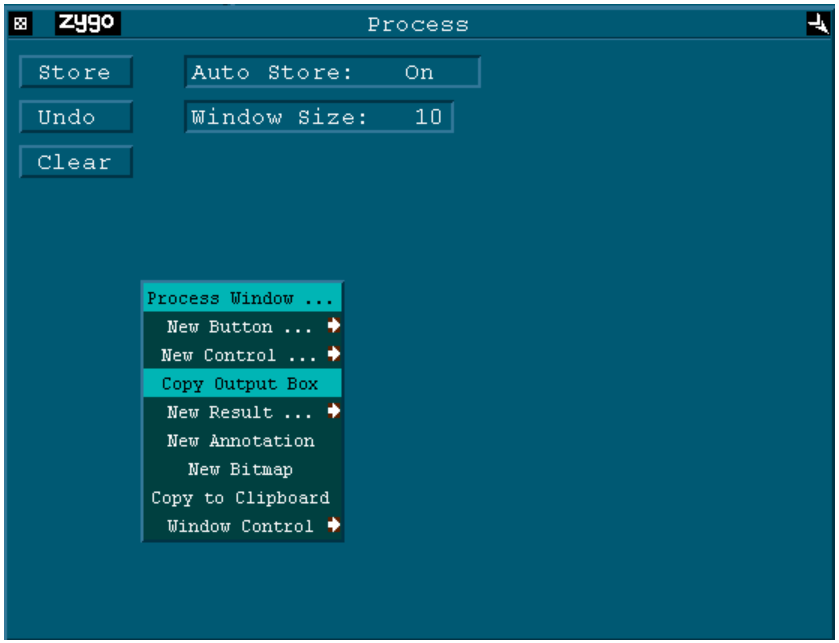
MetroPro Process Statistics Recording

MetroPro Process Statistics Recording

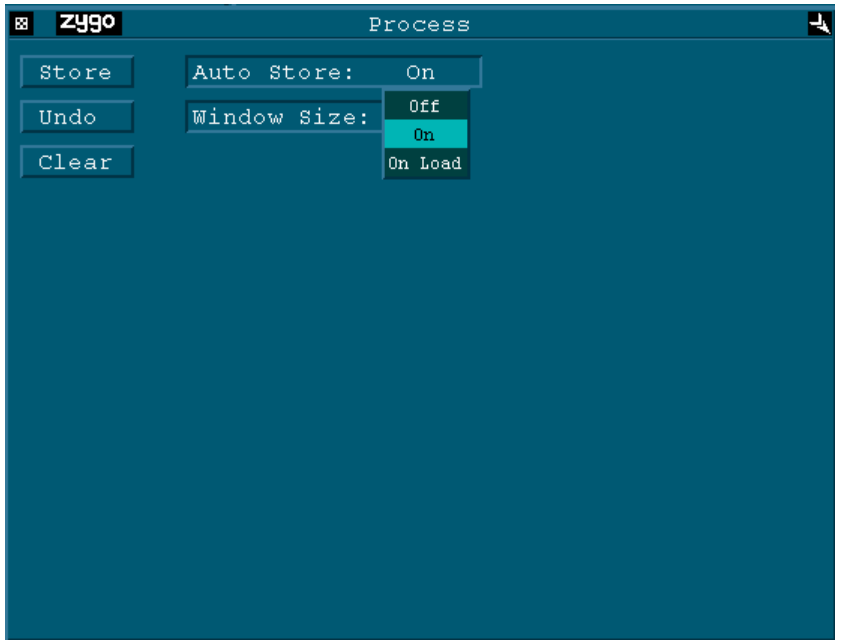
To create a new process statistics window, right-click in the application-level window and navigate to New Process Window.



MetroPro Process Statistics Recording



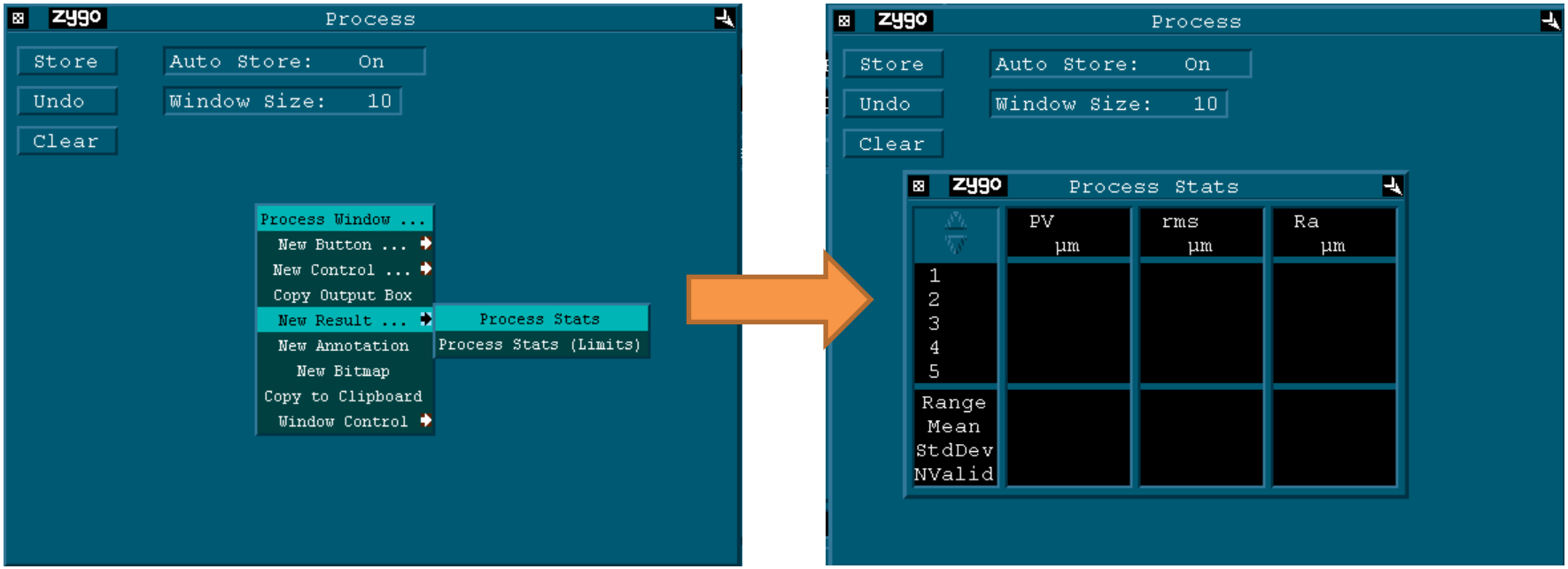
Right-click in the Process Statistics window and select “Copy Output Box” to add results. An asterisk (*) will appear next to the mouse; click on the individual results to add them to the window.



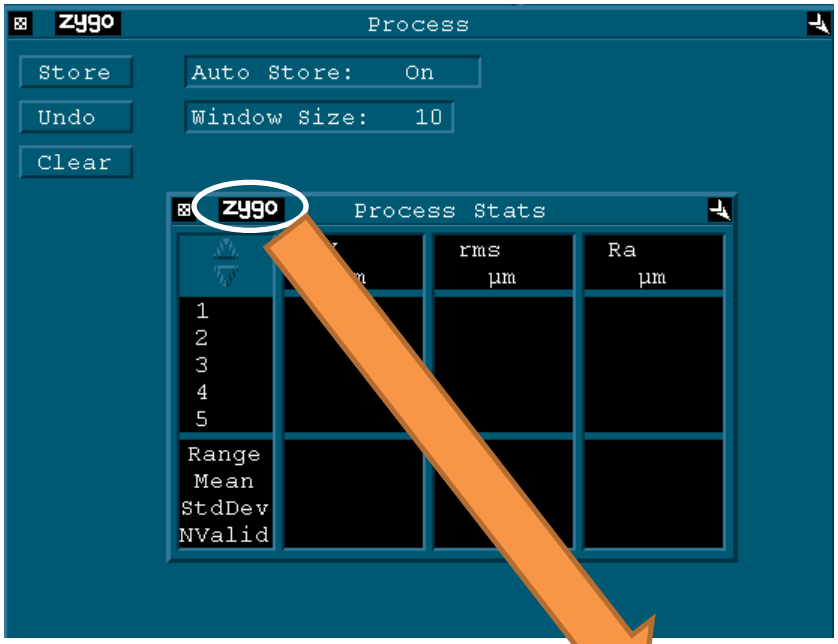
Options for storing results in the Process Stats window are “Off” (no logging), “On” (Measure or Analyze operations), or “On Load” (for the operation of loading data)

MetroPro Process Statistics Recording

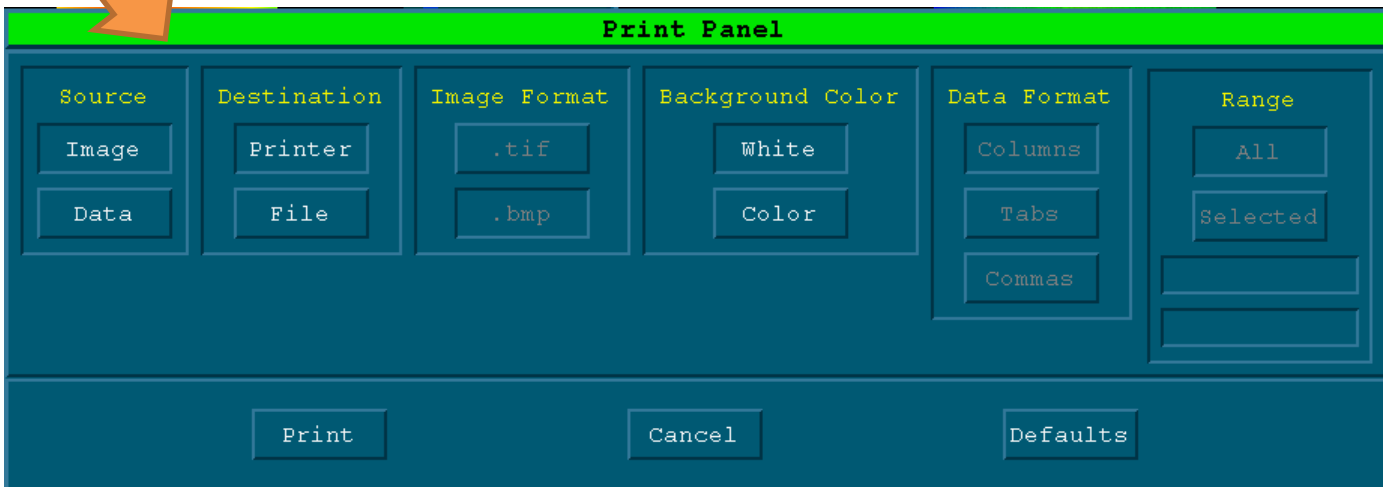
Right-click and navigate to New Result > Process Stats
to create a new table for logging results.



MetroPro Process Statistics Recording

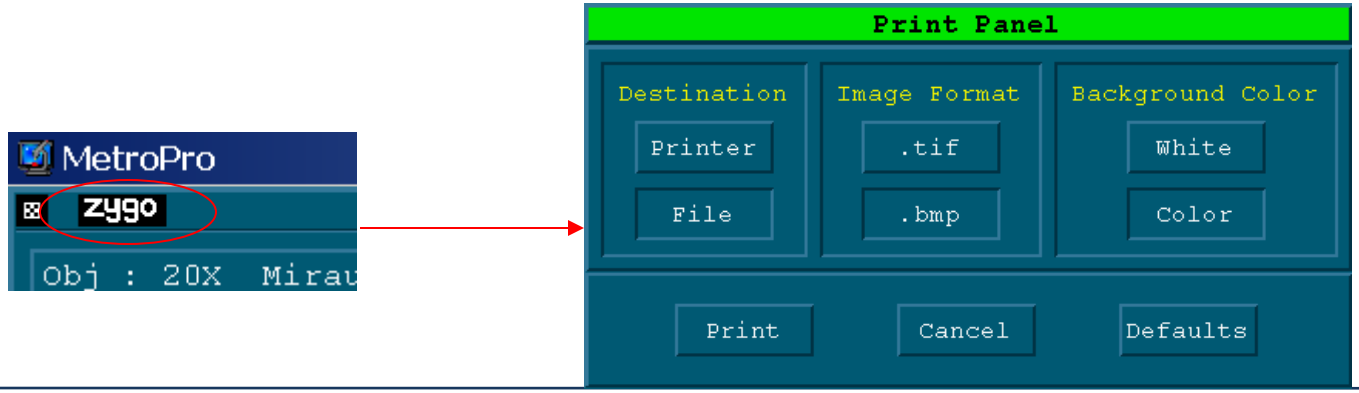


To save the tabulated results, click on the ‘zygo’ icon in the upper left-hand corner of the window. This will bring up a dialog box, allowing users to save the table in a column-, tab- or comma-delineated file.



Save Data: Store screenshot

- Options to Save Data: Save a screenshot, save the raw data or save process stats
- To acquire a screenshot from MetroPro
  1. Click on the Zygo button on the upper left corner of the application
  2. Choose File, .bmp, Color from the Print Panel then click Print
  3. Save the file with a .bmp extension



Save Results: Data

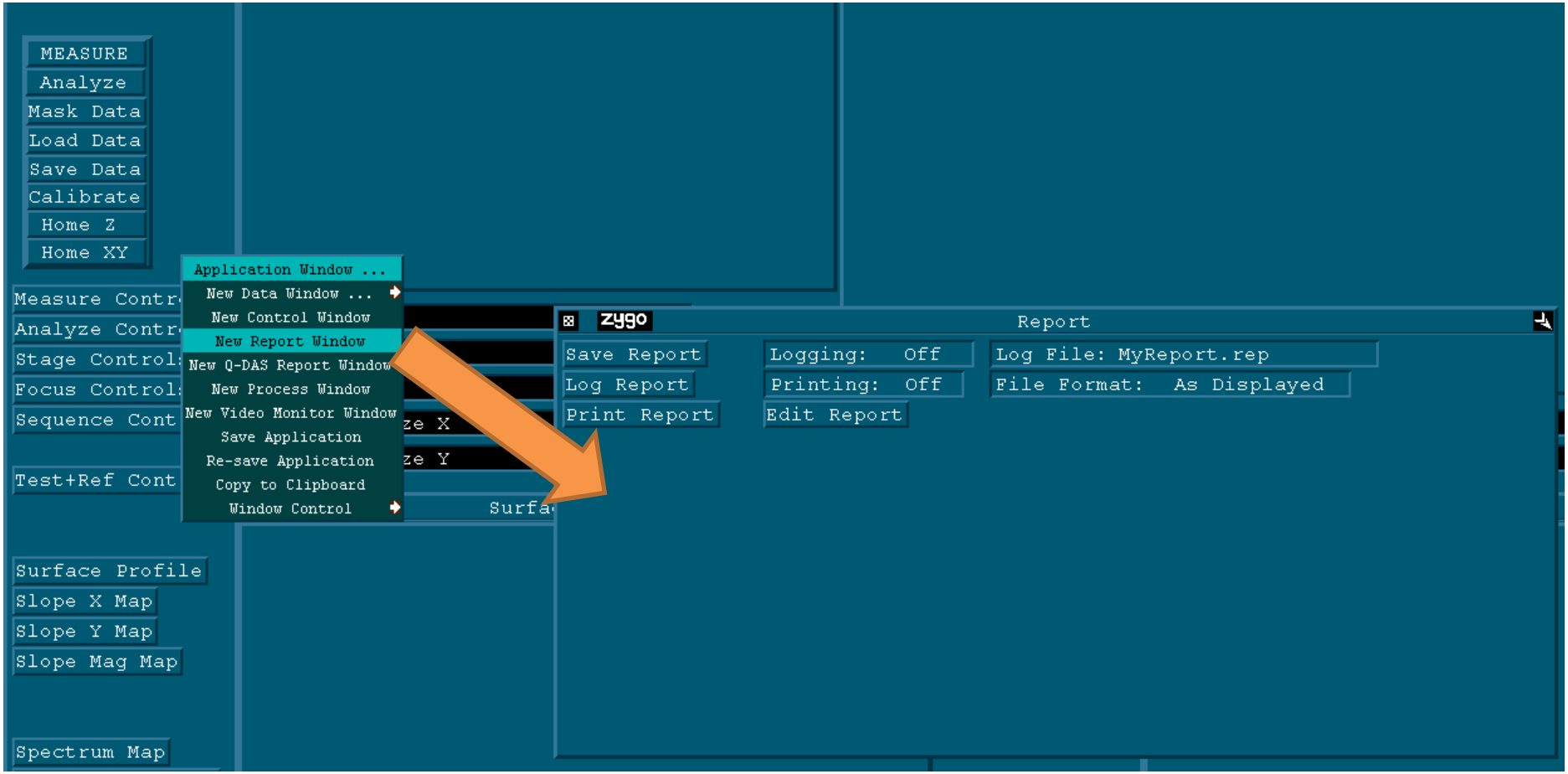
- Press 

button
- In the file handler, enter a name for the file ending with ".dat"
- Raw data is saved; Can be post-analyzed

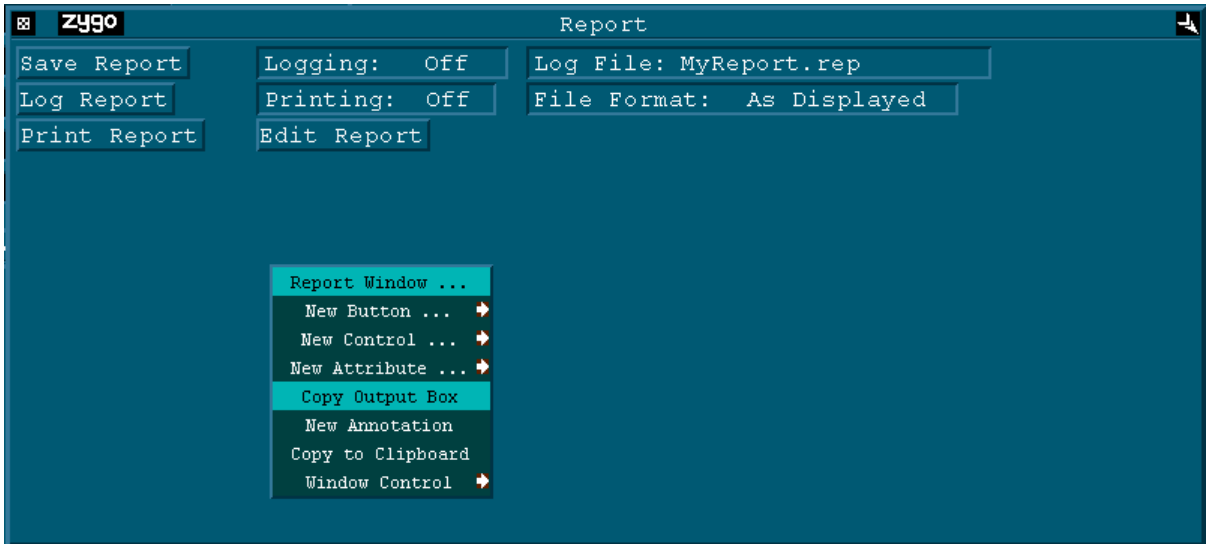
MetroPro Metrology
Report Generation

MetroPro Metrology Report Generation

To create a new Report window, right-click in the application-level window and navigate to New Report Window.

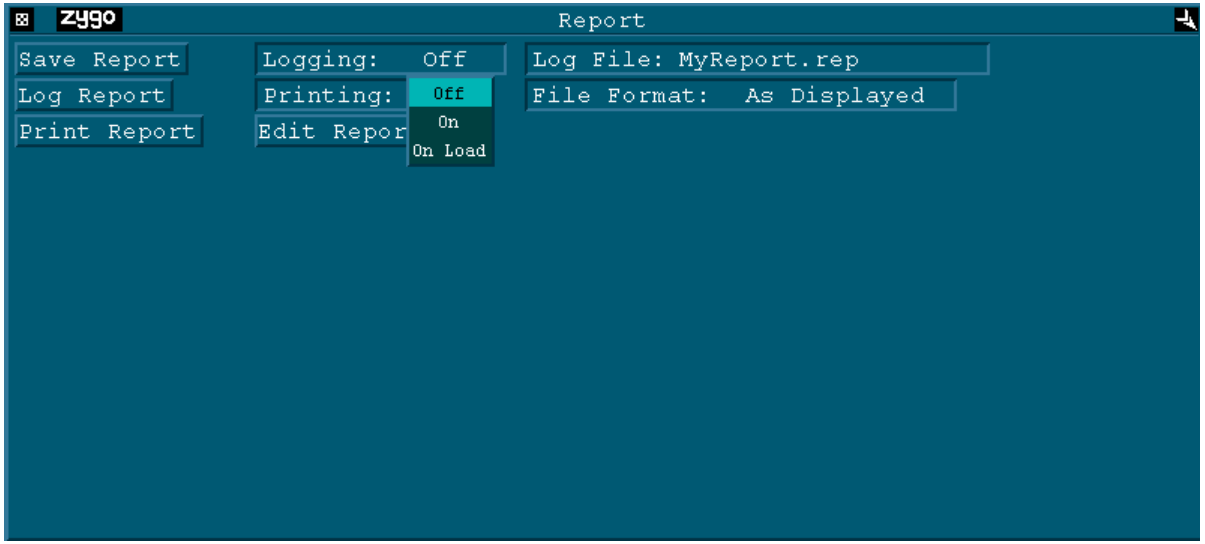


MetroPro Metrology Report Generation



Right-click in the Report window and select “Copy Output Box” to add results. An asterisk (*) will appear next to the mouse; click on the individual results to add them to the window.

Options for storing results in the Report window are “Off” (no logging), “On” (Measure or Analyze operations), or “On Load” (for the operation of loading data)



Troubleshooting

- What to do if MetroPro returns “No Valid Data” error or if there is too much data dropout
  - Check Focus: Do you see fringes and are they nulled? (Or for an extended scan, are you positioned below focus?) 3 or fewer fringes is a good rule of thumb
  - Check Scan Length: Is your scan long enough? Do you see all of the fringes go by?
  - Check Light Level (F4): Is light level in green zone?
  - Check Min Mod %: Does it need to be lowered?

Resources

- NewView 7200/7300 Operating Manual, OMP-0536
- NewView Microscope Application Booklet, OMP-0360
- MetroPro Reference Guide, OMP-0347

Additional References

Surface Roughness and Trade/Professional Journals

- Surface Roughness
  - Automotive Handbook; Bosch
  - Exploring Surface Texture; Dagnall
  - Computational Surface and Roundness Metrology; Muralikrishnan & Raja
  - Surface Texture Analysis, The Handbook; Mummery
  - The Development of Methods for the Characterisation of Roughness in Three Dimensions; Stout, et al
  - ASME B46.1-2002, Surface Texture (Surface Roughness, Waviness, and Lay); Malburg et al
- Trade/Professional Journals
  - Laser Focus World
  - Photonics Spectra
  - Biophotonics
  - Microscopy and Analysis
  - Physics Today

Additional References

General/Optics and Optical Testing

- General
  - Guide to the Expression of Uncertainty in Measurements (GUM); Estler
  - Handbook of Optical Metrology; Yoshizawa
  - Introduction to Statistical Quality Control; Montgomery
  - Measurement Systems Analysis -- MSA; Automotive Industry Action Group
  - An Introduction to Error Analysis; Taylor
  - Schaum's Outline of Engineering Economics; Sepulveda
- Optics & Optical Testing
  - Introduction to Modern Optics; Fowles
  - Principles of Optics; Born & Wolf
  - Modern Optical Engineering; Smith
  - Lens Design Fundamentals; Kingslake
  - An Introduction to Fourier Optics; Goodman
  - Field Guide to Geometrical Optics; Grievenkamp
  - Optical Shop Testing; Malacara
  - Fabrication Methods for Precision Optics; Karow

Summary

Zygo NewView profilers can support metrology for a variety of applications

Most common

- Surface texture
  - Smooth surfaces
  - Rough surfaces
- Form

More unique

- Microgeometry
  - Critical dimensions
- And beyond!

Zygo products are sophisticated yet versatile with significant capabilities

- Access appropriate support materials to assist with your work (OMP's, Tech Notes, spreadsheets, presentations, etc.)
- When you need further assistance or have additional questions, contact support@zygo.com or 800-ZYGO-NOW (800-994-6669)

Questions?