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# Photonics Chip Level Test Strategies in High Vibration Production Environments

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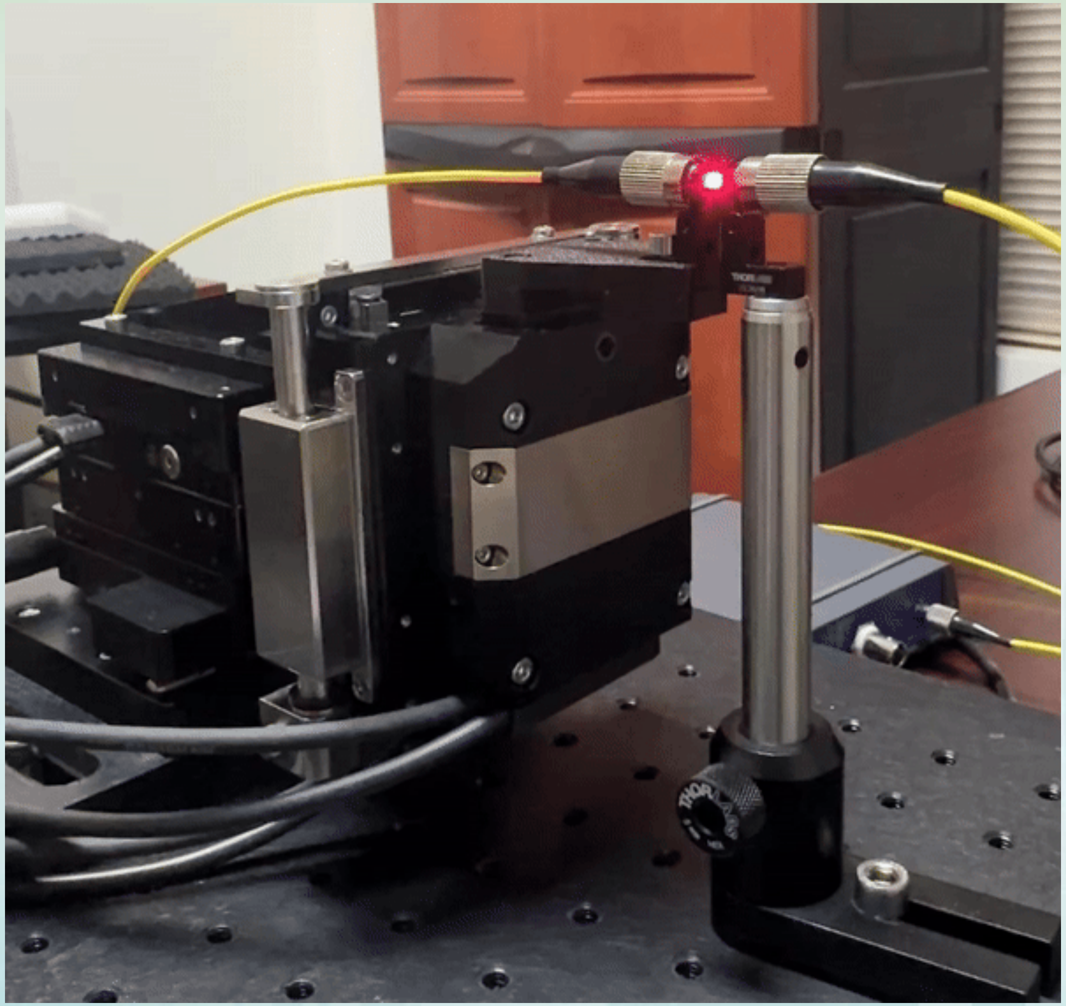
# *Photonics Chip Level Test Strategies in High Vibration Production Environments*

- **An Anatomy of Design (Photonics Test Automation)**
- **Production Scale Photonics Probe Dynamics**
- **Direct Vibration Disturbance Injection**
- **Indirect Vibration Disturbance Injection**
- **Measurement and Analysis**

# An Anatomy of Design
# (Photonics Test Automation)



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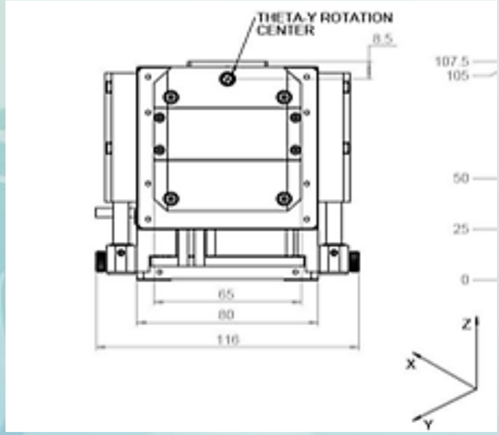
# *Important Aspects of Precision Photonics Test Robotics:*

- **Compact (100 mm x 100 mm x 100 mm) with minimum probe arm reach required**
- **6-Degrees of freedom w/ minimal wear under high duty-cycle repetitive motions**
- **Short stroke in linear and angular travel (25 mm/10 deg)**
- **Supporting light applied loads(at <500 g) w/ adjustable magnetic counterbalance**
- **High dynamics (especially in higher order terms-$\ddot{\mathbf{r}}, \dddot{\mathbf{r}}$) to 2g, accelerations**
- **Optical axis roll is highly dynamic and responsive to 1,000 deg/s^2**
- **Pitch/Yaw are highly stable, adjustable and lockable**
- **Minimal position adjustment and stability at ~ 30 nm**
- **Inherent damping of high-frequency resonances w/ minimal crosstalk**



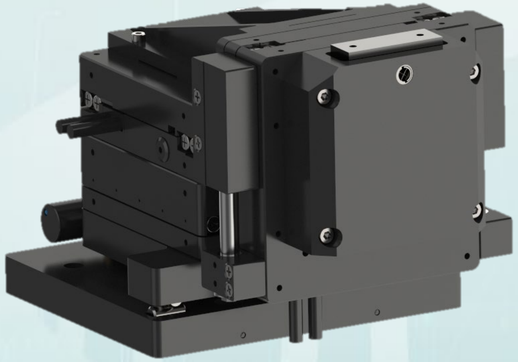



**Figure 1. Forward facing, oblique view of NovAlign42 Robotic Photonics Aligner**

**Figure 2.** Rear Facing Oblique view of NovAlign42 Robotic Photonics Aligner

# Component Level Considerations-Linear Motor

- **Halbach Array Linear Motor**
  - Klaus Halbach of LBNL independently invented this magnet arrangement for particle accelerators.
  - Strong concentrated magnetic field produces:
  - Increased Force Density
  - Improved Motor Efficiency
  - Ideal for space constrained systems
  - B-Field simulation (shown below)

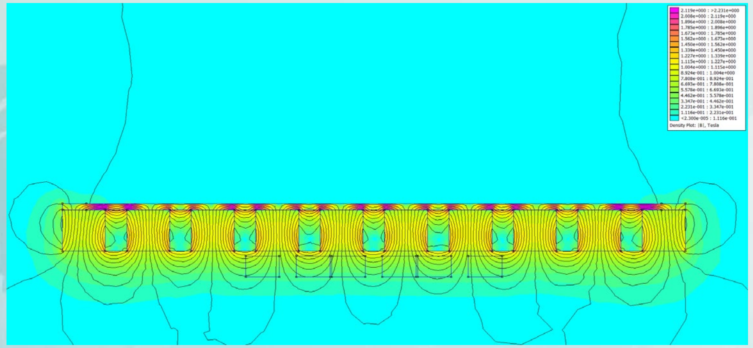


**Figure 4. Halbach Array Motor B-Field Simulation using Finite Element Analysis**

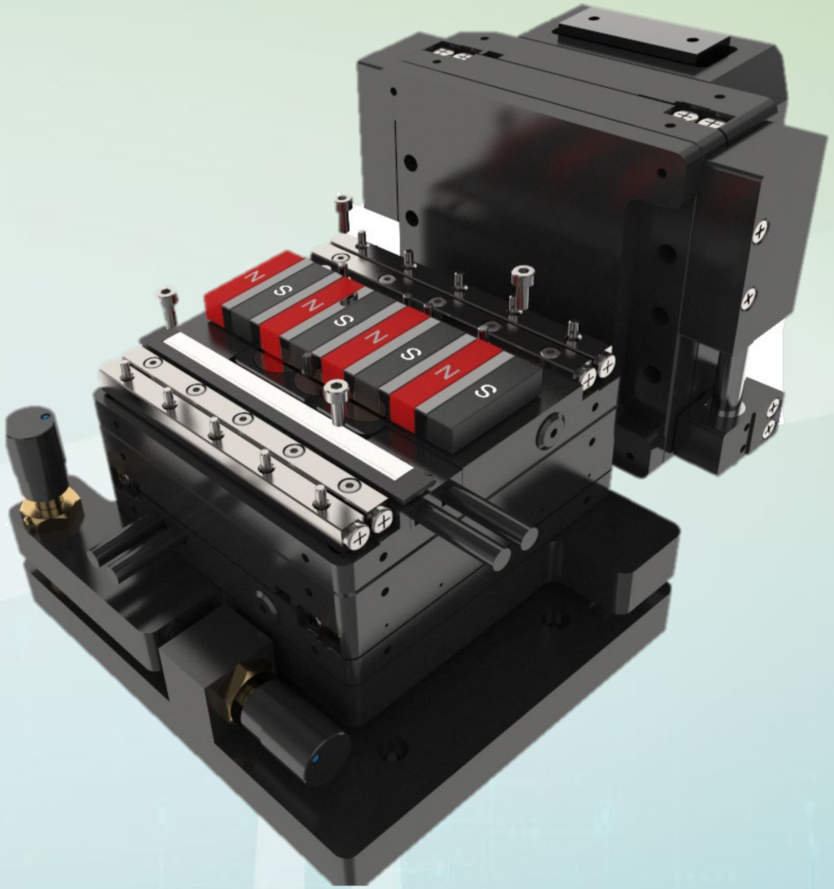


**Figure 3.** Halbach Array Motor Concept in NovAlign42 Robotic Photonics Aligner

# Component Level Considerations-Glass Scale Linear Encoder

- **Glass Scale Linear Encoder**
  - Provides direct position feedback
  - Optical linear encoder with direct measurement at the load
  - Glass encoder scale attached to carriage with readhead integrated on body
  - 20 µm, signal period with SIN/COS output (1 V, PTP)
  - 14-bit interpolation at the drive yields about 1 nm, position resolution

**Figure 5.** Optical Linear Encoder location for direct position feedback on NovaAlign42 Robotic Photonics Aligner (X-Axis)

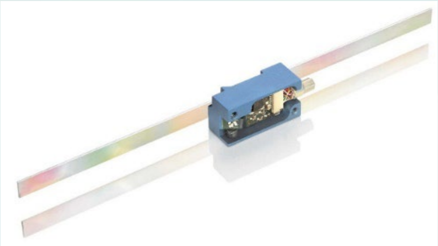


**Figure 6**. PI One Linear Encoder

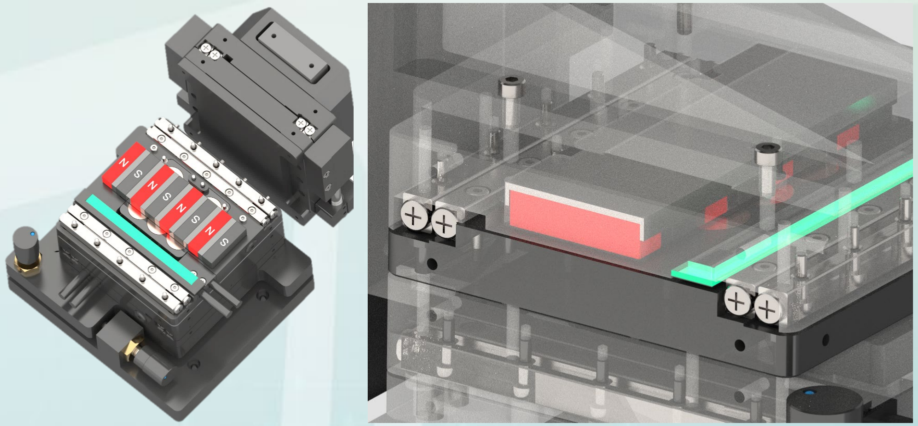


**Figure 7.** Internal views of NovAlign42 Robotic Photonics Aligner optical linear encoder (X-Axis)

# Component Level Considerations-Body and Bearings

- Light, stiff “Aerospace Grade “ anodized aluminum alloy body using 6061-T6
- Good strength-to-weight ratio
- Good fatigue resistance
- Provides stiff structure with low moving mass for photonics loads (FAU, lensed fibers, fixtures)
- High-rigidity, precision machined, preloaded, low-friction high carbon steel, anti-creep, crossed roller bearing guides
- Good repeatable guiding over short range with extended operating lifetimes under photonics loads

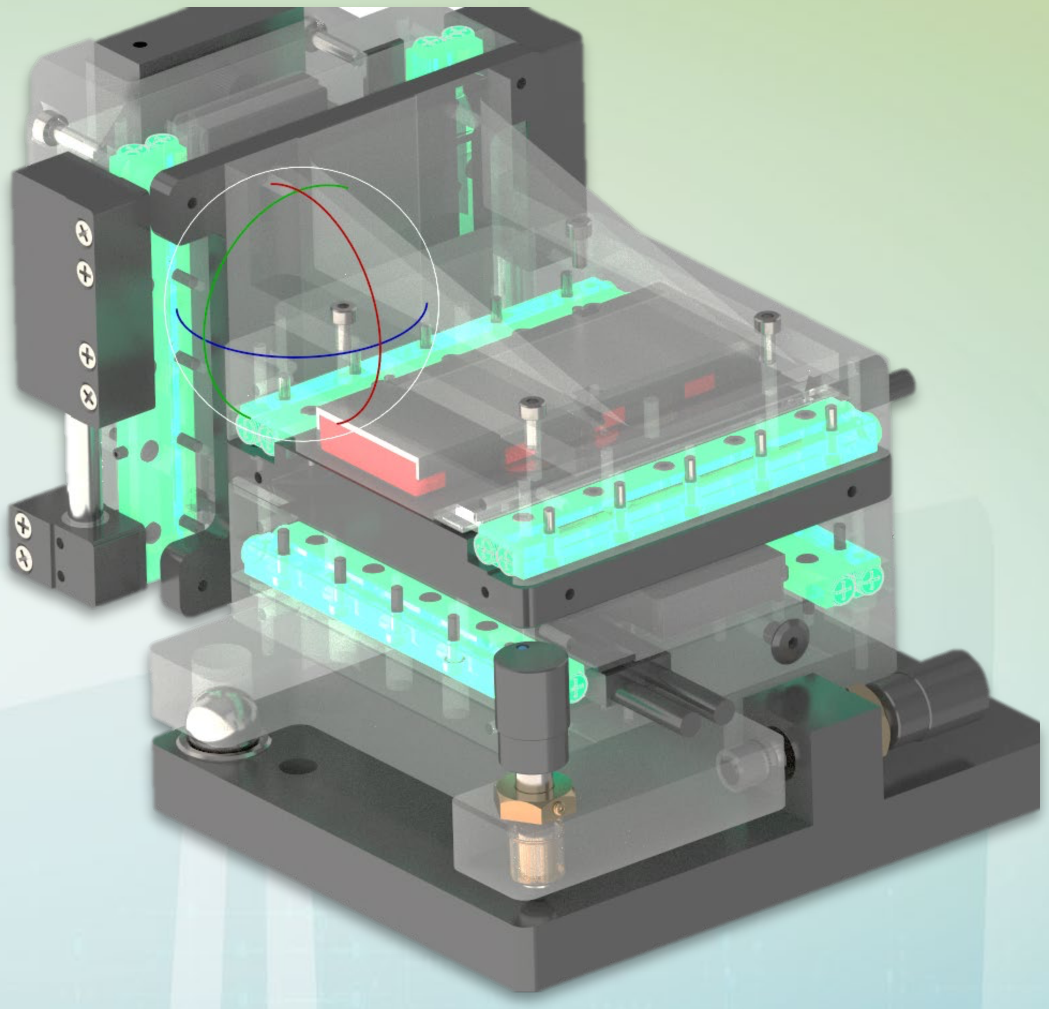


**Figure 8.** Crossed Roller Bearings in NovAlign42 Robotic Photonics Aligner

# Evaluating Photonic Probe Dynamics Performance

- Algorithmic search and optimization is pumped with high dynamic, periodic motion
- We evaluate dynamics performance in terms of achievable operating frequency
- There is a balance of injected dynamics, disturbance, stability and error characteristics (& Pathing)

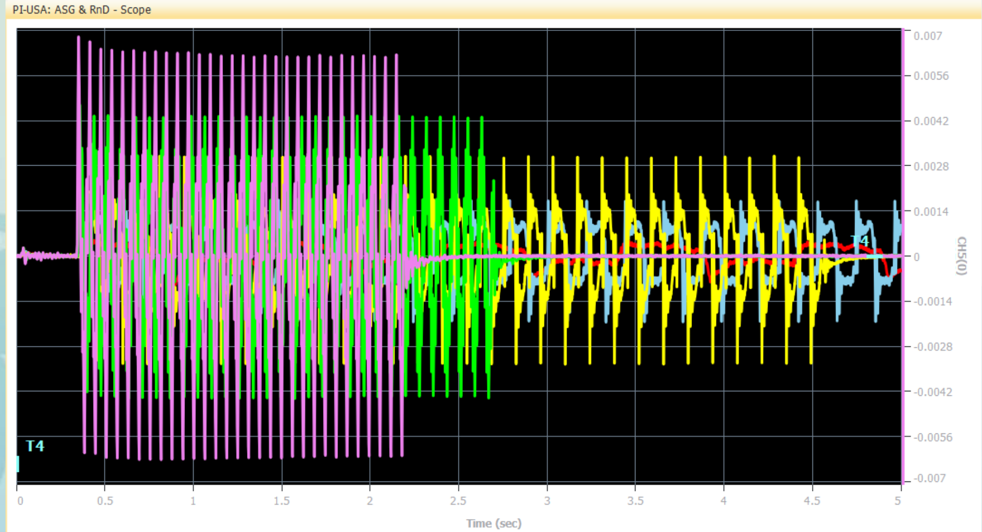



**Figure 9.** Comparative Positioning Error for Algorithmic Signal Search at different frequencies

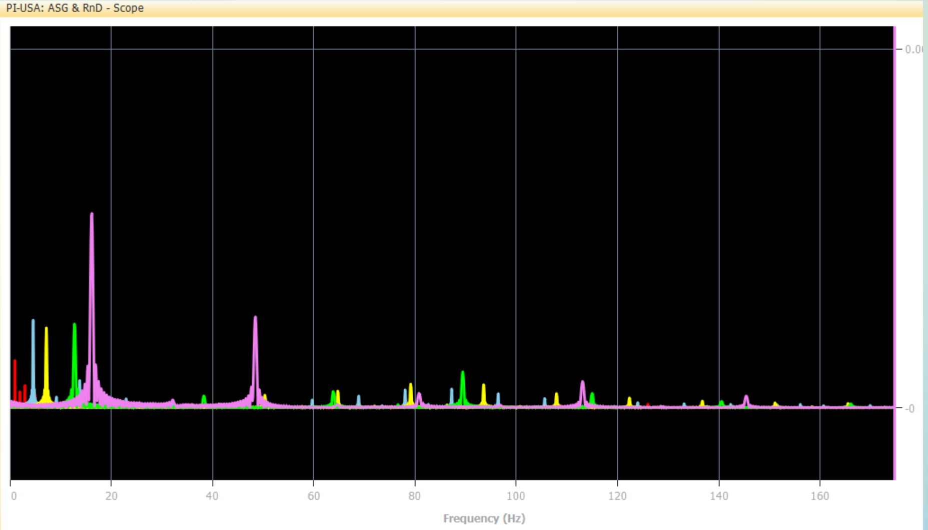



**Figure 10.** Fast Fourier Transform (FFT) of Positioning Error at different operating frequencies

# Evaluating Photonic Probe Dynamics Performance

- **Here, the NovAlign42 system operates at: 1 Hz, 5 Hz, 10 Hz, 20 Hz, 40 Hz**
- **Respective positioning error at these frequencies (PTP) are: ±0.7 µm, ±1.5 µm, ±3.5 µm, ±4.5 µm, ±6.0 µm**
- **The relative strength of contribution to error observed from the FFT demonstrates symmetry breaking injected disturbance at 40 Hz (with pumped error growing significantly on that frequency)**

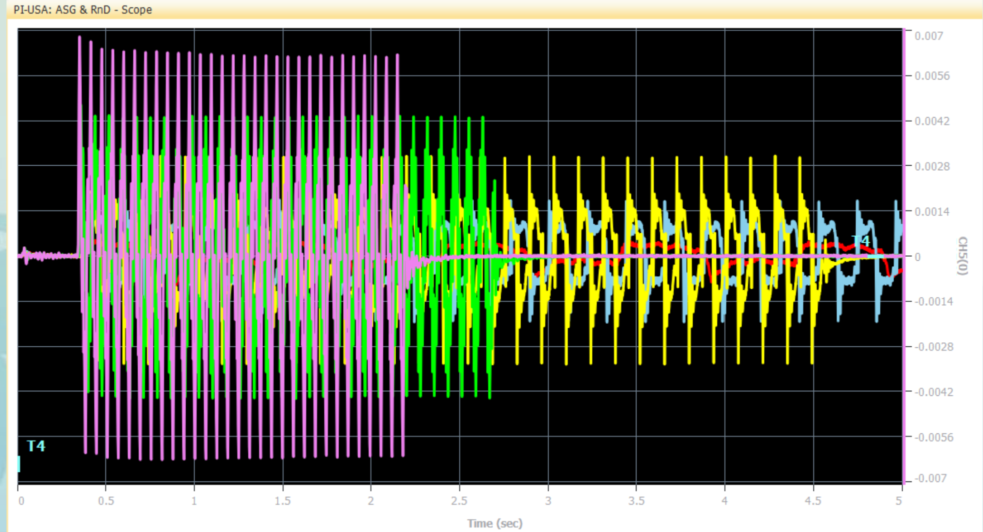



**Figure 9.** Comparative Positioning Error for Algorithmic Signal Search at different frequencies

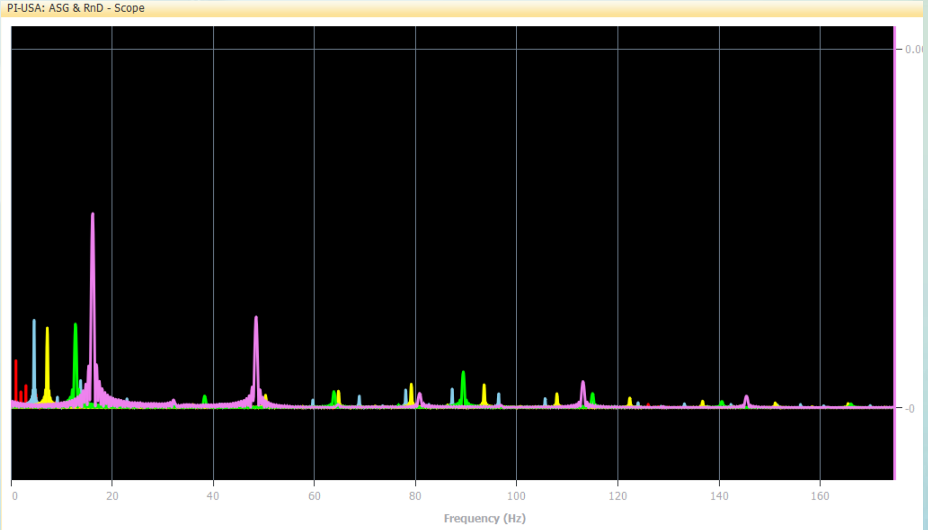
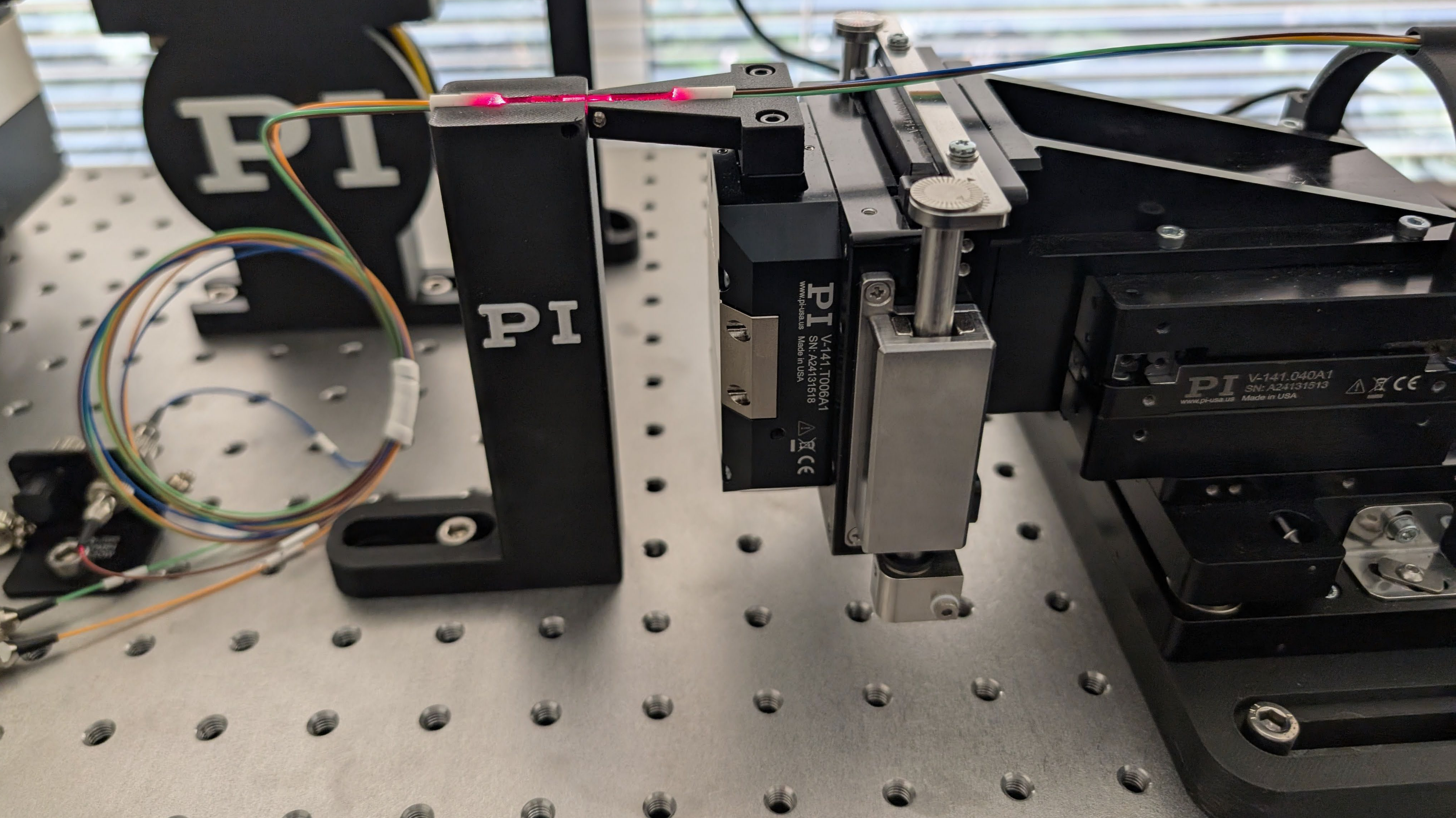



**Figure 10.** Fast Fourier Transform (FFT) of Positioning Error at different operating frequencies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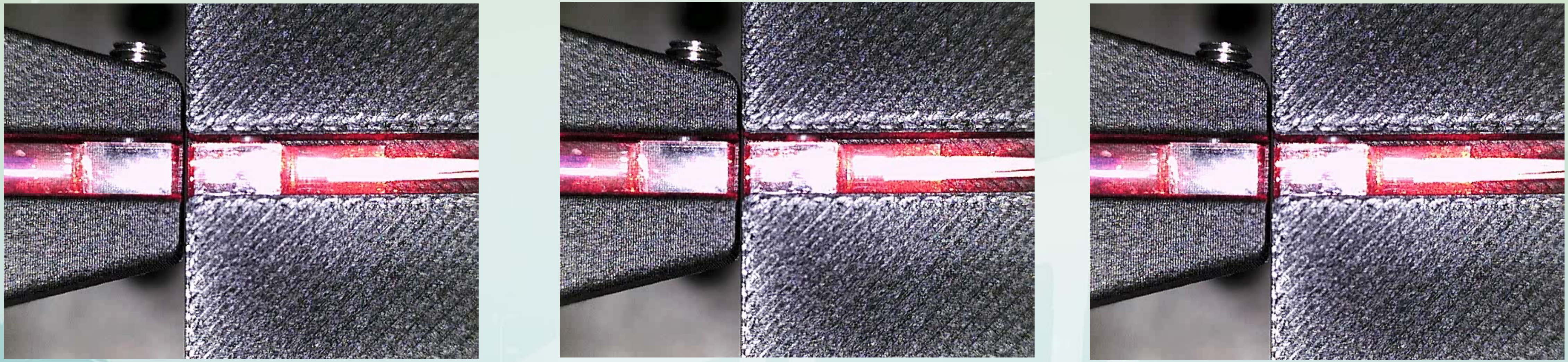
# Production Scale Photonics Probe Dynamics

Dynamic Path Degradation as Function of Operating Frequency

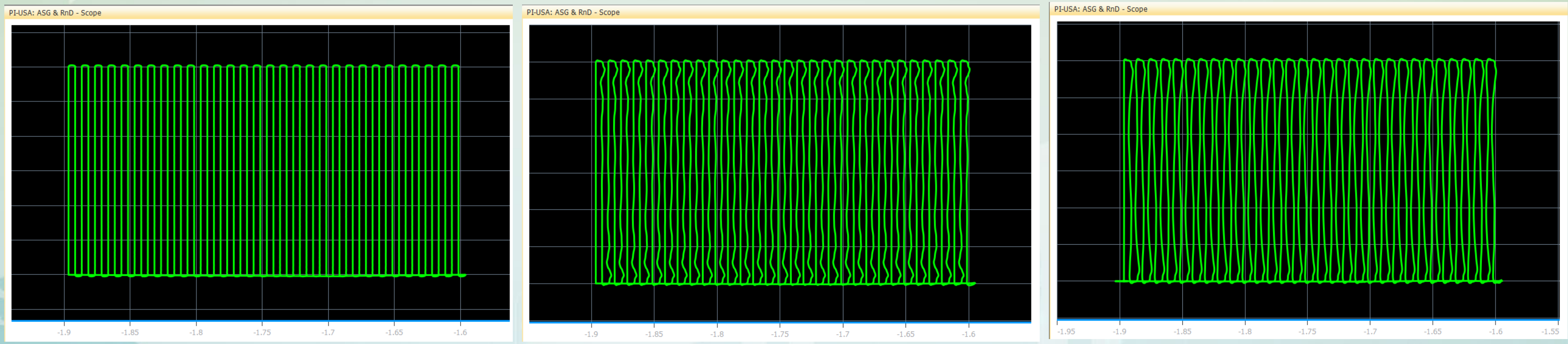


**1 Hz** **(X-Scan Area Search)** | **10 Hz** **(X-Scan Area Search)** | **40 Hz** **(X-Scan Area Search)**

**Figure 11.** Algorithmic signal search at ascending frequencies with direct imaging of edge coupling of 4-channel fiber arrays (50 µm (core), 250 µm (spacing))

# Production Scale Photonics Probe Dynamics

## Dynamic Path Degradation as function of Operating Frequency




**1 Hz**
**(X-Scan Area Search)**

**10 Hz**
**(X-Scan Area Search)**

**40 Hz**
**(X-Scan Area Search)**

**Figure 12.** Algorithmic signal search at ascending frequencies with direct measurement of path characteristics

# *Direct Vibration Disturbance Injection*

# Transfer Function Characterization

## Evaluating Resonance Signatures of Precision Robotic Alignment Systems

- The linear motor, robotic aligner has an inherent frequency response that is a function of intrinsic design and engineering attributes as well applied operating environment and control module
- The frequency response function can be characterized with selective application of ascending frequency current excitation sweeps (alternative methods include white noise injected excitation)
- The gain and phase relationship (between excitation signal and response) is characterized in the open loop transfer function and can be used to identify first mode resonance and gain and phase margins impacting stability
- Otherwise, the responsiveness of the servo and gains need to be balanced for instability with appropriate margins (6 dB and 30-degree, phase margin) based on design and environmental variability

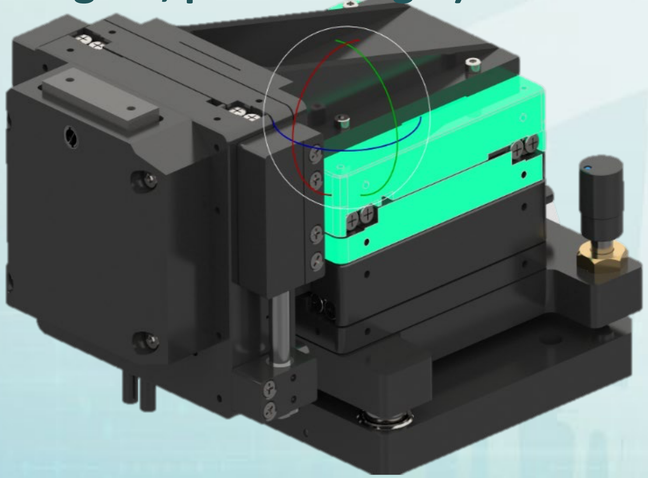


**Figure 13.** Axis characterized in Transfer Function in Figure 12.

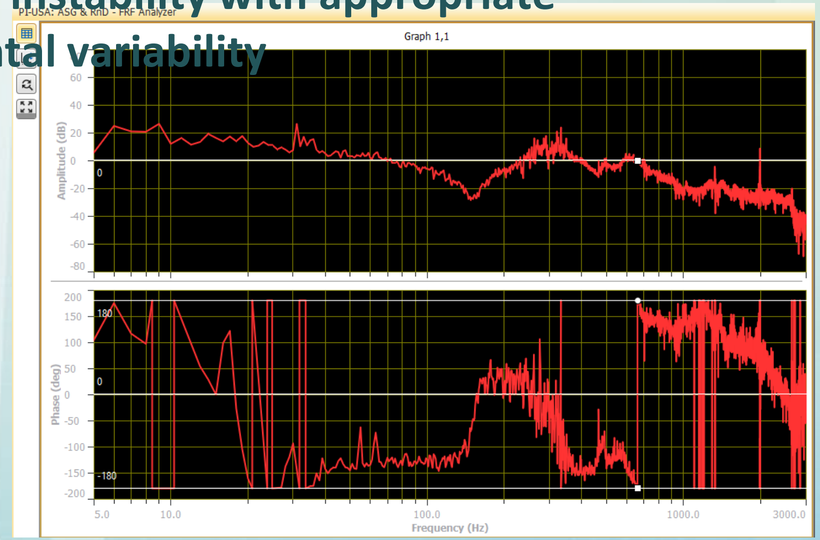



**Figure 14.** Algorithmic Signal Search at Ascending Frequencies with direct measurement of path characteristics

# Mitigation Strategy

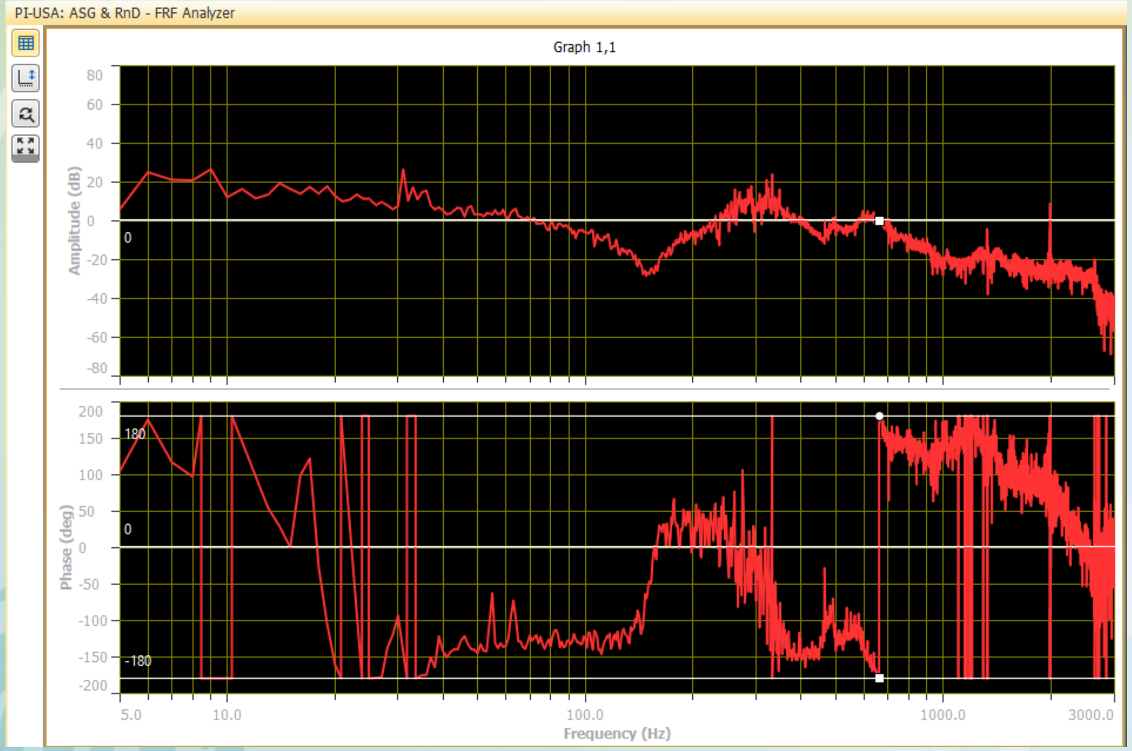



**Figure 15.** Transfer Function of X-Axis prior to application of notch filter at first-mode resonance observed at 315 Hz and generally observed poor stability characteristic

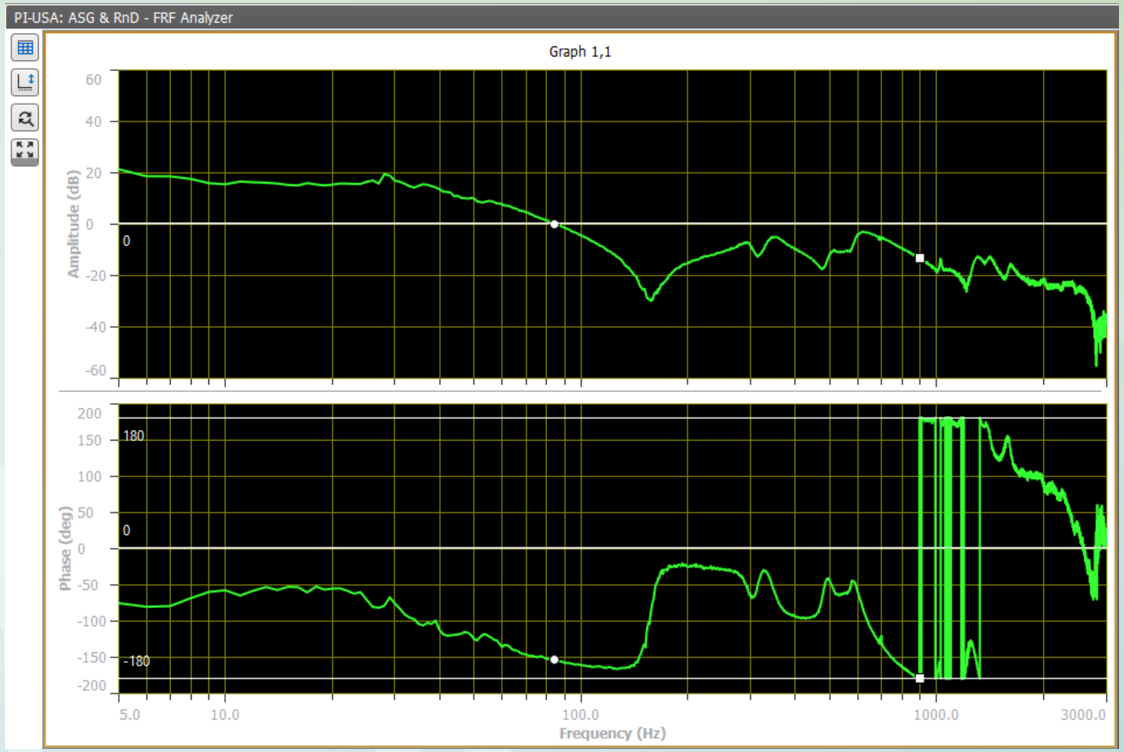
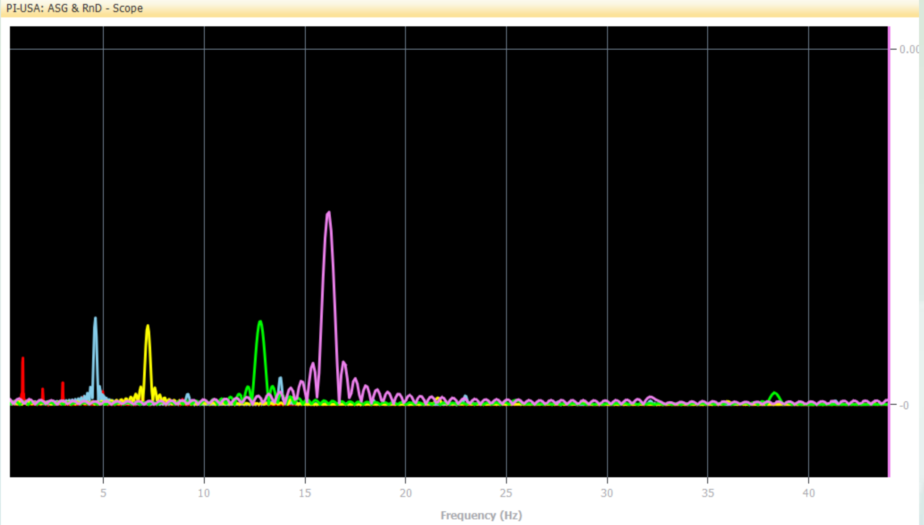



**Figure 16.** Transfer function of X-Axis with notch filter applied to servo with PIV gains optimized

# Production Scale Photonics Probe Dynamics

## Dynamic Path Degradation as function of Operating Frequency

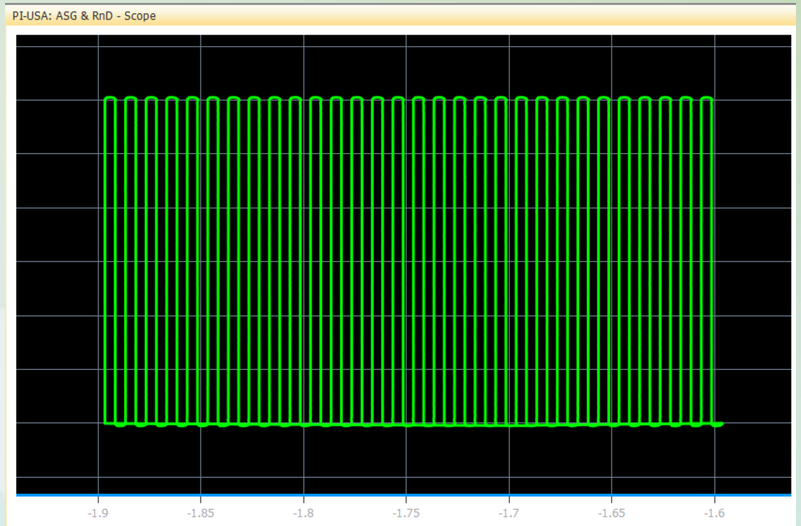




**Figure 17.** Transfer Function Characterization

No Notch (Red)

Notch Filter Applied (Yellow)

Notch + Gains Optimized (Green)

**Figure 18.** FFT characterization of position error frequency contributions at different operating frequencies:

1 Hz (red)

5 Hz (blue)

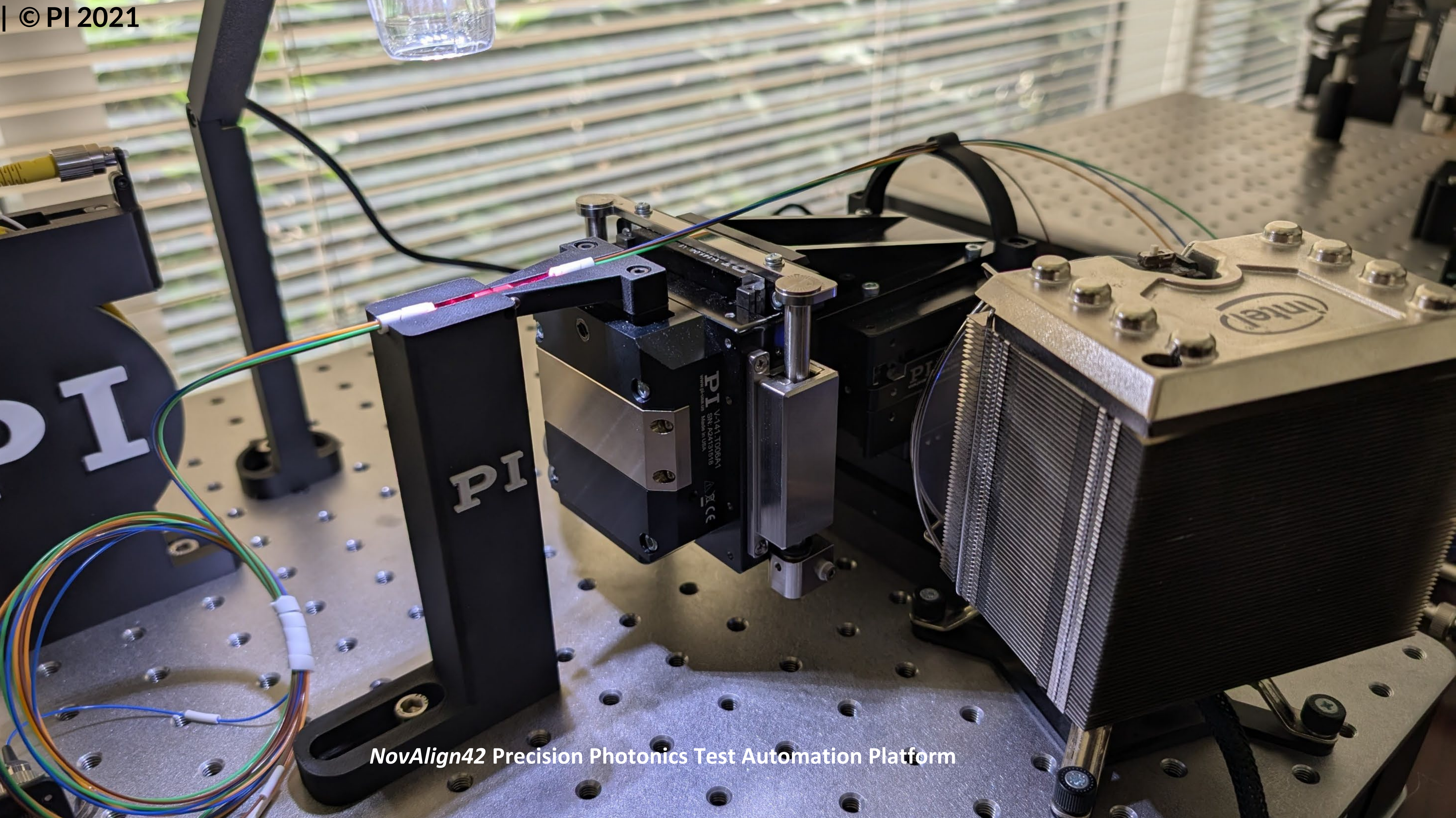
10 Hz (yellow)

20 Hz (green)

40 Hz (magenta)

**Figure 19.** Fixed frequency rounded search paths that minimize direct disturbance injection or excitation of structural resonances

# *Indirect Vibration Disturbance Injection*




*NovAlign42* **Precision Photonics Test Automation Platform**

# Environmental Vibrations Unrelated to Direct Robotic Aligning Action

***Photonic Probe and Test Production Tools***

- ***Include structural and peripheral components that must support robotic photonic alignment systems that balance:***
  - *Cost*
  - *Size and Volumetric Constraints*
  - *Accommodate Integration of additional sensors, instrumentation, and electrical probe or other physical contact or inertial influences from wafer or chip handlers/fixtures*
  - *Provide sufficient environmental regulation with forced heating and cooling elements including vacuum pumps, compressors, fans, heaters, chillers, etc..*
  - *Materials aspects such as probe arms, holders, aluminum base plates, steel welded frames, granite and aluminum suspended structures*
- ***All while allowing for machine handlers (robots) and human operators to interface and operate the tools as a part of a dedicated process tool or a part of hybrid system performing assembly or other process actions***
- ***This comes typically with robotic alignment precision to support stable coupling at <100 nm tolerances fully inclusive of both direct and indirect disturbances***
- ***Both highly dynamic and highly stable***

# *Impact of Localized Forced Cooling*

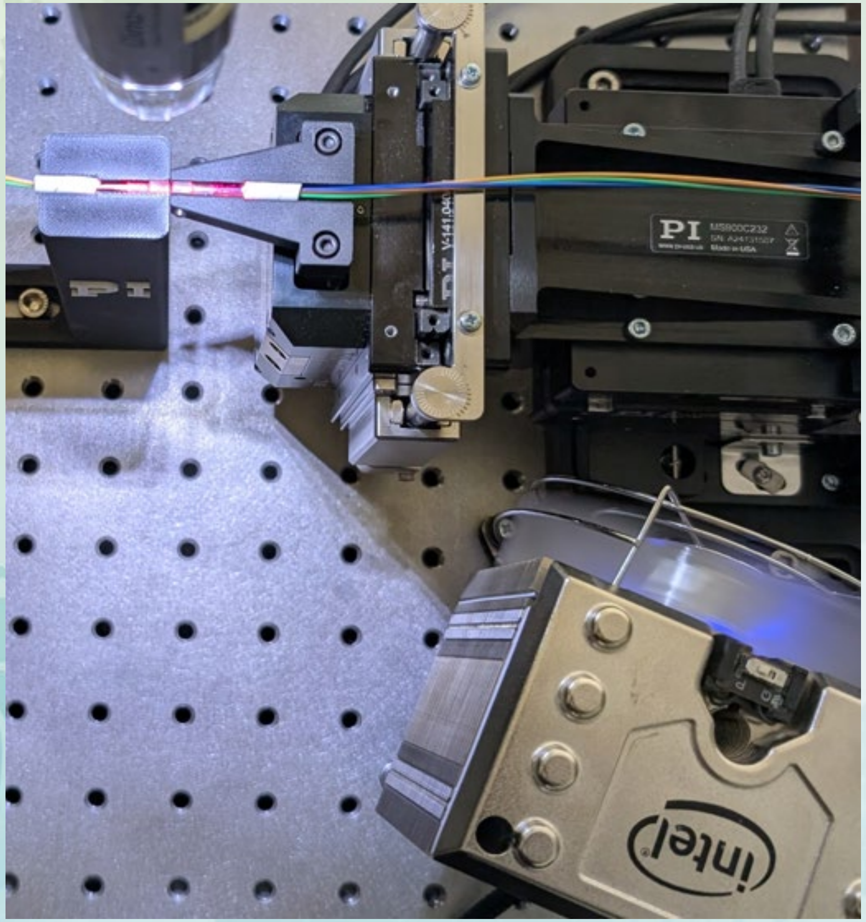



**Fig 20. Forced cooling fan coupled to structure positioned near NovAlign42 precision robotic aligner to understand influence of localized fan on edge-coupled fiber array coupling using 4-channel, 50 µm core MM fiber with loopback circuit (250 µm channel spacing)**

# Impact of Localized Forced Cooling

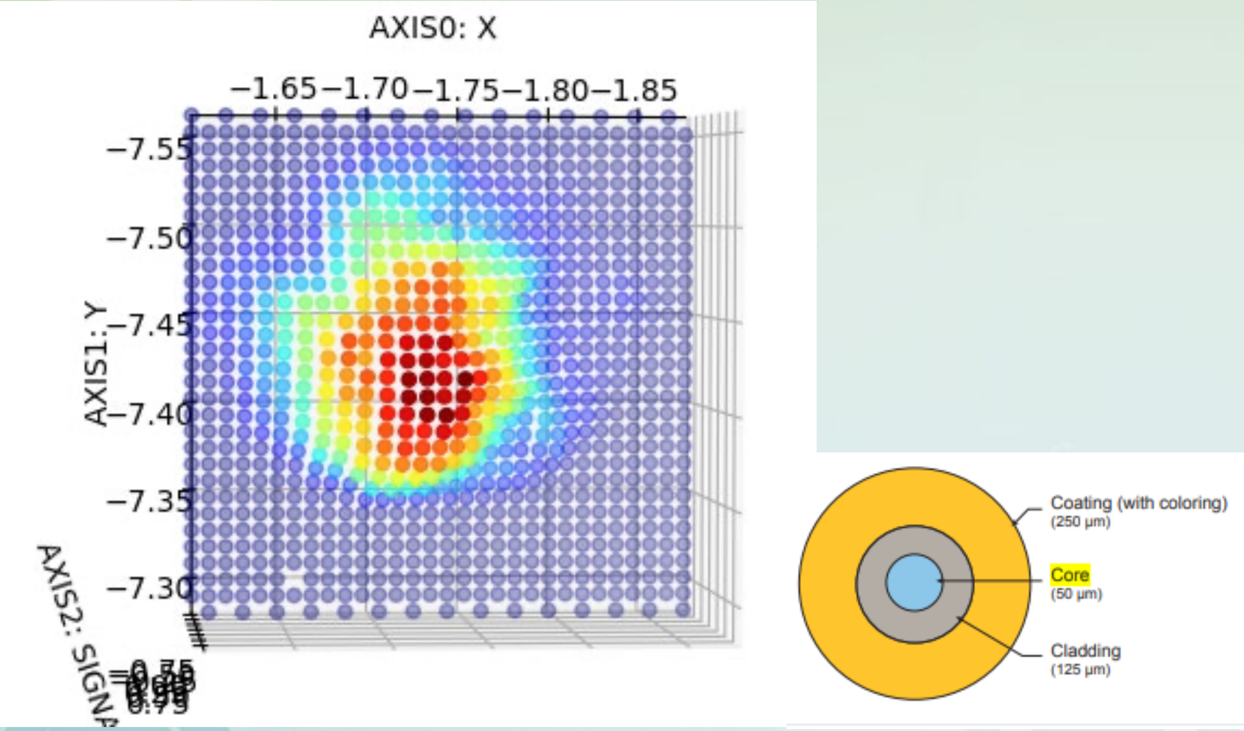



**Figure 21.** Profiling data from characterization algorithm with fiber array to fiber array coupling through 4-Channel, FAU with loopback circuit (50 µm-core, 250 µm-Spacing )

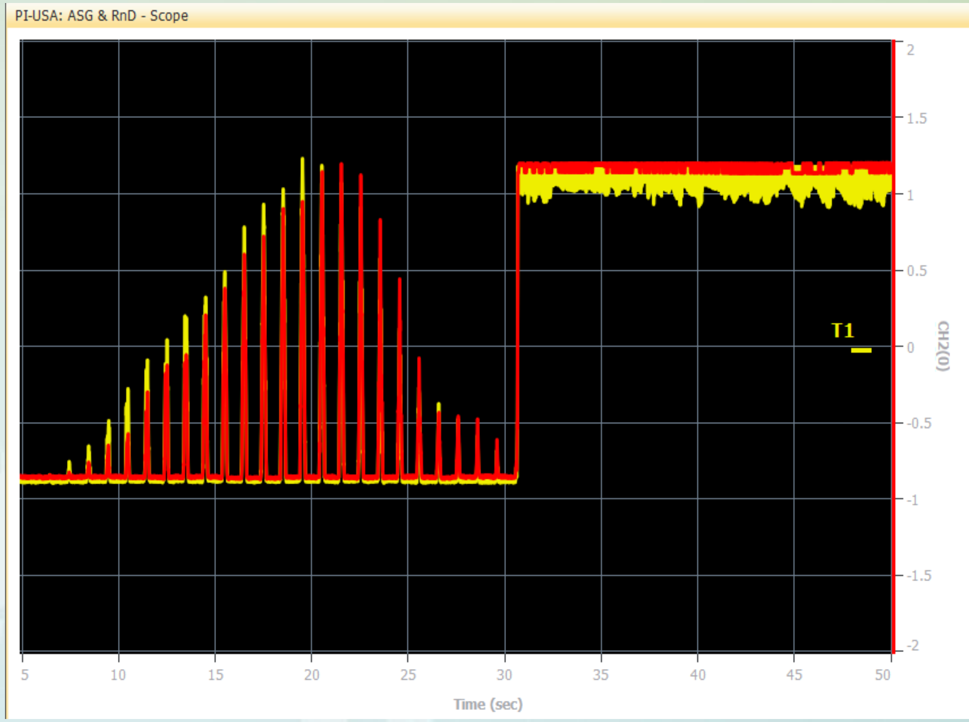



**Figure 22. 1 Hz, X-Scan algorithmic signal search with move to peak coupling position and hold position stable for 4 seconds (no active track). Red Signal represents fan-off state and yellow is fan-on state . Show clear impacts to coupling stability metrics, insertion loss.**

# *Measurement Analysis and Review*

# Measurement Analysis and Review

## Structurally-Coupled Fan Assembly Impact on Setup

- *Introduction of elastomer interfaces at structural coupling of fan to minimize impact of forced cooling on fiber array photonics edge coupling using four-channel, multi-mode fiber array.*
- *Here we present three cases:*
  - *X-Scan area signal search operated at 20 Hz for peak signal finding with no fan present (red trace)*
  - *X-Scan area search operated at 20 Hz, with direct structural coupling of fan to robotic aligner ( yellow trace)*
  - *X-Scan area search operated at 20 Hz, with structural coupling of fan using elastomeric interfaces on structural coupling to robotic aligner ( blue trace)*
  - *Normalized insertion loss and coupling stability are affected*

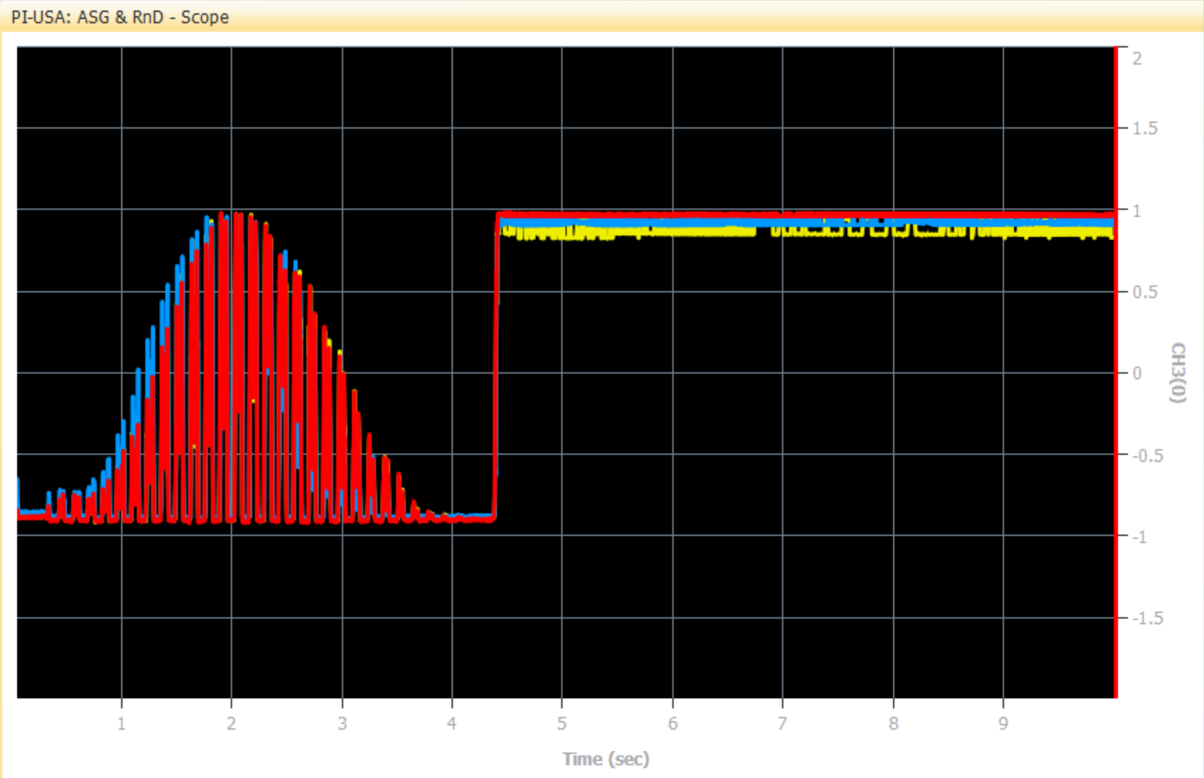



**Figure 23.** Plot showing alignment signal characteristics using fixed frequency algorithmic signal search on the NovAlign42 in different vibration environments with structural fan coupling (with and without elastomer interface) and no fan present.

# Measurement Analysis and Review

## Structurally-Coupled Fan Assembly Impact on Setup

*Normalized Insertion Loss:*

*Mean Coupling (No Fan):* -
*Mean Coupling (Fan w/elastomers):* 0.49 dB
*Mean Coupling (Fan):* 0.79 dB

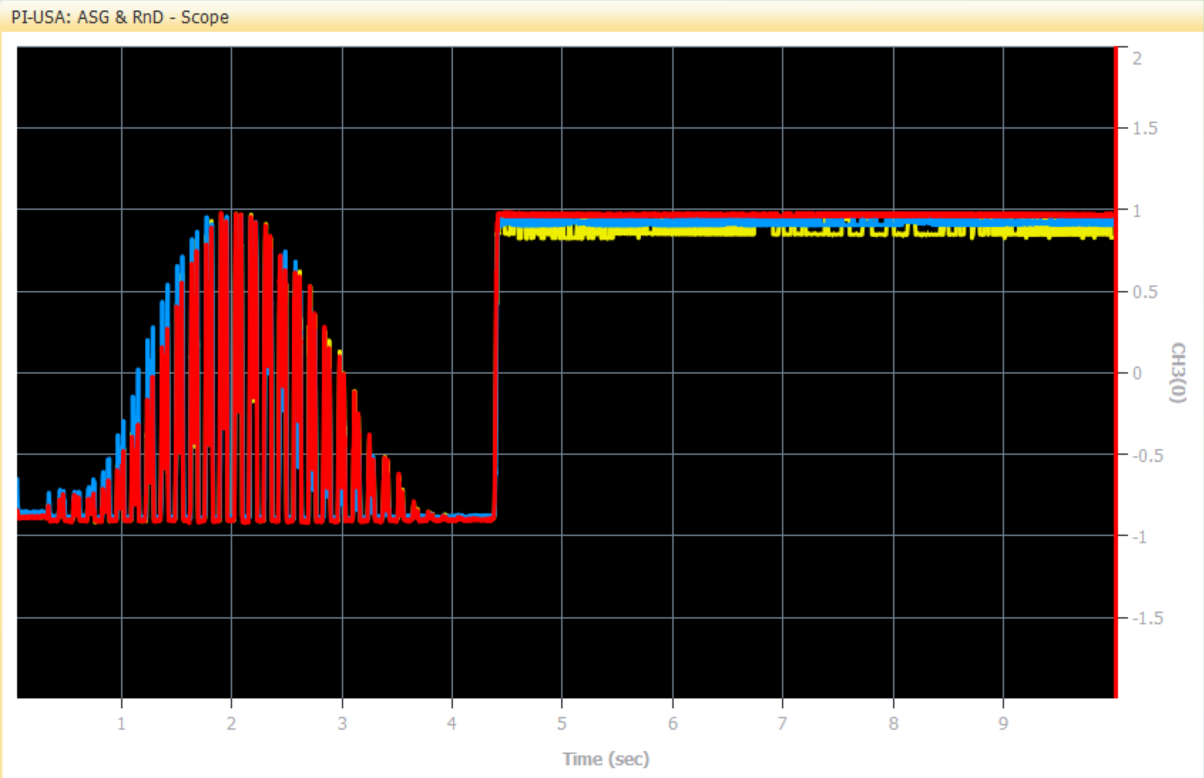



**Figure 23.** Plot showing alignment signal characteristics using fixed frequency algorithmic signal search on the NovAlign42 in different vibration environments with structural fan coupling (with and without elastomer interface) and no fan present.

# Measurement Analysis and Review

**Summary**

- *Frequency sweep transfer function characterization allows for an understanding of first mode resonances of robotic aligners informing both design and application of notches and servo gains for best stability*
- *Algorithmic implementations and applications need to be applied with a full-understanding of injected resonances from robotic aligners to prevent excitation of system structural harmonics*
- *This includes time and frequency domain analysis (i.e. Fast Fourier Transform-FFT)*
- *Aggressive dynamics should be tuned to the particular use case and environment and selectively applied with understanding of structural excitations*
- *Integration of active cooling mechanisms with indirect disturbance injection should not be directly coupled to robot aligning platforms*
- *There is clear evidence of degradation of key coupling metrics with application of forced cooling in local environment*
- *Elastomeric damping can improve these metrics potentially substantially*