MONOLITHIC INVARIANT OPTICAL ASSEMBLIES FOR LASER SYSTEM APPLICATIONS

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INTRODUCTION

PLX was founded in 1955 as Precision Lapping and Optical Company, producing highly accurate optical domes, lenses, prisms, and mirrors. In the 1970's the invention of the hollow retroreflector by PLX enabled work on mission-critical projects for military and space applications. PLX's proprietary technologies and manufacturing capabilities with high-performance optical systems are renowned for performing under the harshest environmental conditions such as extreme temperature, combat and deep space while maintaining near-perfect accuracy over time. In 2000 PLX invented the Monolithic Optical Structure Technology™ (M.O.S.T.) [1]. M.O.S.T is a unique optical innovation that combines all the elements of a complex optical design into a single monolithic unit - creating superb optical and thermal stability as well as unsurpassed shock and vibration resistance.

Today, PLX continues to push the boundaries of boresighting and targeting. With their exceptional stability, PLX's boresighting systems have been repeatedly proven in the field. This paper will expand upon the M.O.S.T. solution with case studies of M.O.S.T. designs and results for specific applications, such as laser delay line systems, boresighting, and telescope alignment systems. Other applications can utilize this novel technology, such as spectroscopy, interferometry, LIDAR, free space optics, laser tracking, laser cavities, satellites, boresighting, laser beam steering systems, alignment, or sensors.

1.1 Monolithic Optical Structure Technology™ (M.O.S.T)

PLX's patented Monolithic Optical Structure Technology™ provides a cost-effective, robust and compact solution for laser system applications. The M.O.S.T system has been developed to permanently incorporate multiple optical elements (such as mirrors, beam-splitters, lenses, freeform optics, diffractive elements, prisms, or active optical devices) of a complex optical configuration, into a compact, lightweight monolithic structure. The optical elements are made from CTE-matched optical materials such as fused silica, low expansion borosilicate, ULE, BK7, ceramics and/or metals. This combined with PLX's proprietary invariant optical technology, minimizes the beam deviation to sub arc second accuracy with minimal variation of optical specifications in the most extreme environments, where large thermal excursion, high shock and vibration are the typical operating conditions.

An integral part of the M.O.S.T. is the mounting to higher level assemblies without inducing any stresses, distortion or other forces to the M.O.S.T. unit. PLX has several techniques used for this, ranging from single point mounting/connection to the use of polymeric materials to provide isolation from stresses while still maintaining proper positioning of the assembly. The properties of the polymeric materials can vary depending on how they are incorporated, and this has to be carefully considered as part of the finite element analysis that is performed on these systems.

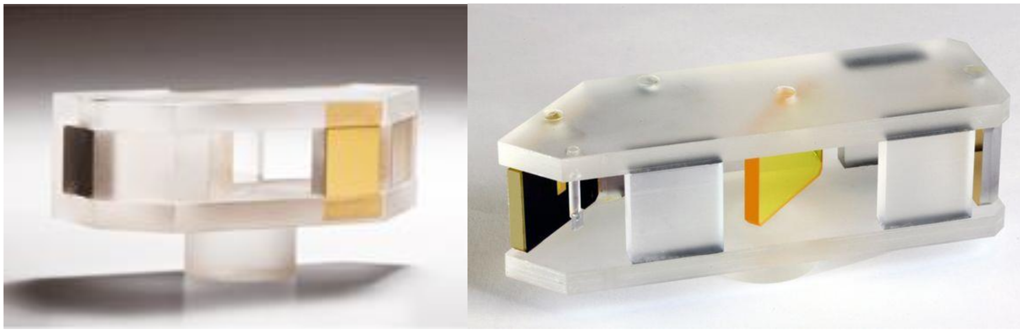


Figure 1 PLX Interferometer

1.2 Advantages over conventional design

The use of M.O.S.T for laser system applications results in several performance advantages over the conventional approach of a multi-element design, which requires mechanical assembly and has interfaces between components with differing materials and thermal expansion coefficients. This small form-factor assembly is permanently aligned and maintains its optical and thermal stability in the most demanding and complex applications. Invariant optical systems also maintain their input to output beam alignment even when the assembly is rotated or displaced relative to the beam. This allows the M.O.S.T sub-assemblies to be incorporated into complex photonic systems without the need for alignment mechanisms, reducing risk, complexity, and overall assembly time.

Hollow retroreflectors utilizing the M.O.S.T. Technology have significant advantages over solid-prism designs, which are often used as an alternative. As shown in Figure 2, for comparable retroreflectors with 1-inch clear aperture, the commercial solid-prism design can achieve at best 3 arc second beam deviation and weighs more than 36 g.
While PLX's patented hollow retroreflector can maintain below 1 arc second beam deviation and are less than half the weight at 17.4g

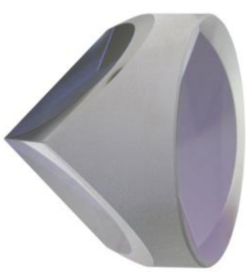


Figure 2 Solid Retroreflector, 36g Hollow Retroreflector,17.4g

1.3 **Analysis and testing of the system**

The M.O.S.T system is verified by both finite element analysis (FEA) and physical test, where the same wide range of temperature change and mechanical impact are applied to the objective unit.

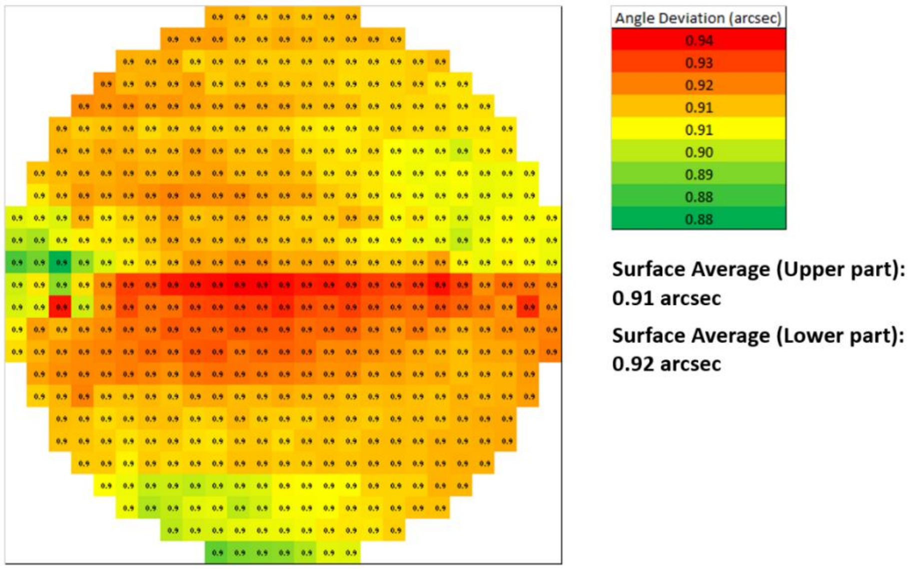
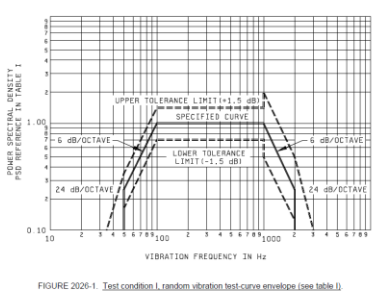


Figure 3 FEA results of a M.O.S.T structure

Figure 3 shows the FEA results of one of PLX's M.O.S.T structures under static load. As shown in the result, the system maintained an average beam deviation no larger than 1 arc second under this working condition.

During the structural test, shock and vibration levels are specific to the platform to which M.O.S.T. is applied. There is a frequency dependency so that a single number does not by itself describe the shock or vibration environment. Based on MIL-spec standards, M.O.S.T. units have been tested to MIL-STD-883H, Method 2026 condition K. Condition K is the most severe level for this test with an overall value of 44.8 Grms. Units have survived shock levels of up to 10,000 G.



Characteristics		
Test condition letter	Power spectral density	Overall rms G
A	.02	5.2
B	.04	7.3
C	.06	9.0
D	.1	11.6
E	.2	16.4
F	.3	20.0
G	.4	23.1
H	.6	28.4
J	1.0	36.6
K	1.5	44.8

Table 1 Test condition

The following figure shows the testing result of a M.O.S.T unit.

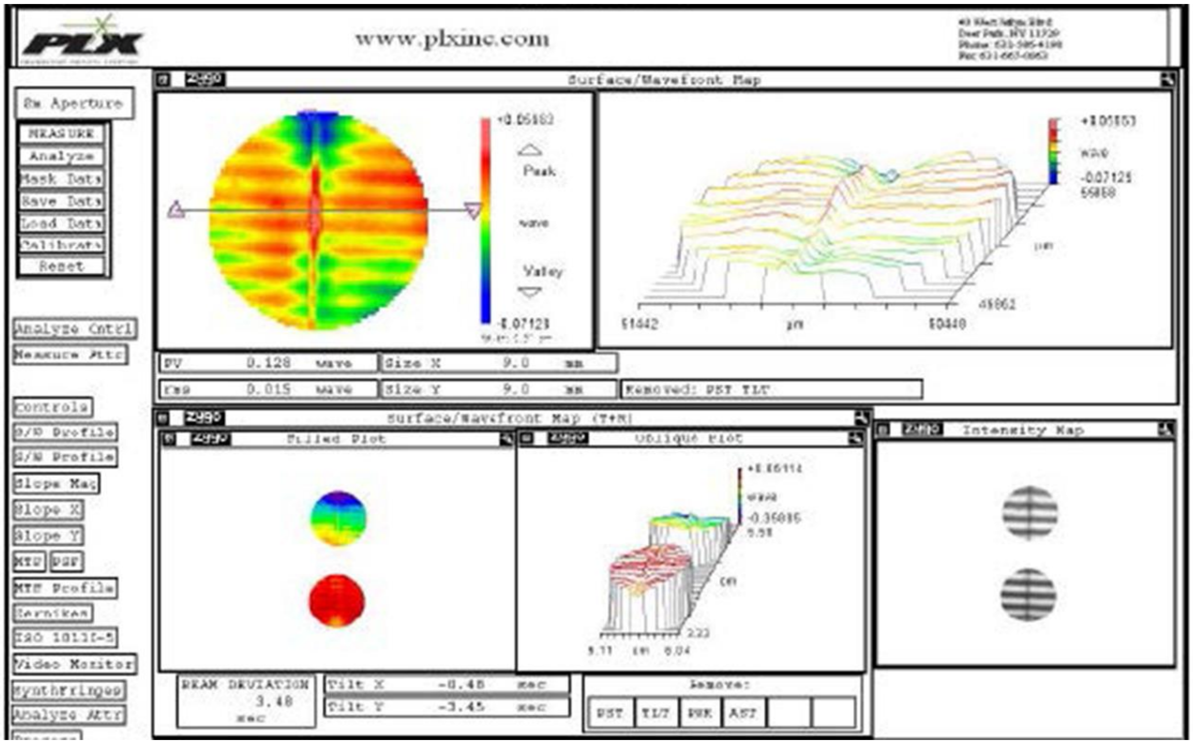


Figure 4 ZYGO testing result of a M.O.S.T unit

Figure 4 shows the angular accuracy testing result on the testing unit after all the qualification tests, which has a maximum beam deviation of 3.48 arc second. The testing description, condition and result is recorded in Table 2.

Test Description	Testing condition	Accuracy (arc second)	Accuracy change (arc second)
Initial Value	-	3.30	-
After Thermal test	-39 to +86°C	3.55	0.25
After Random Vibration Test	Overall Grms 13.88	3.43	0.13
After Quasi Static Load	35 g for 2 minutes in X, Y, Z axis	3.48	0.18
Final	-	3.48	0.18

Table 2 Testing records of the M.O.S.T unit

As shown in Table 2, the unit maintains sub arc second change of accuracy after extreme temperature cycle, harsh vibration, and shock test.

MONOLITHIC BORESIGHTING SOLUTIONS

Boresighting refers to the procedure of aligning hardware line-of-sight to an aiming device, or to the co-alignment of two or more optical axes, such as a laser and an imaging system. This technology can be implemented across a range of applications such as weaponry (from small rifles to artillery, tank and aircraft fire control systems), long-range cameras and laser/receivers, LIDAR and laser rangefinders fitted to satellites.

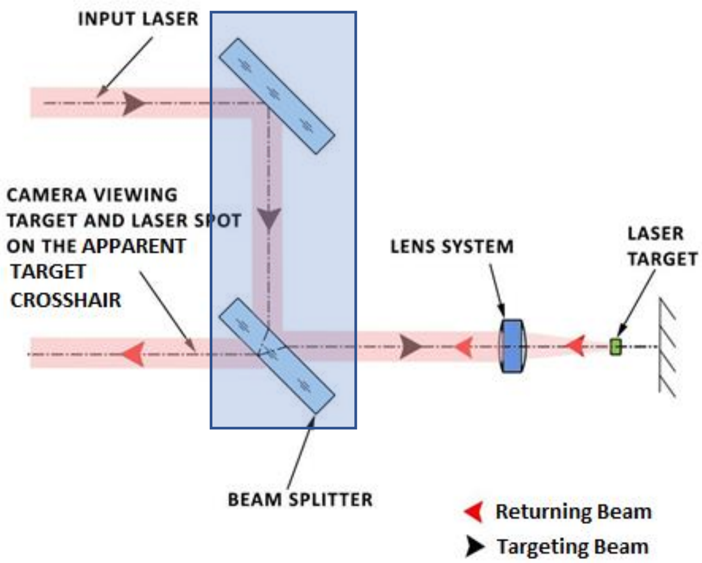


Figure 5 This is a schematic showing a long-range camera, such as an IR camera, which must be perfectly aligned to a laser designator.

In this application shown in Figure 5, the camera and the laser can be mounted on a gimbal that enables a wide field of view. For boresighting, the gimbal has a pre-determined position that enables the laser and the camera system to view the laser target through the boresighting system, in this case a periscope with a beamsplitter. The camera, focusing on a cross hair, must display the focused dot from the laser on the cross hair. Mechanical adjustment is required to tip and tilt the laser to bring the laser dot to the center of the cross hair. Alternately, this can be accomplished electronically. The camera captures a larger field of view than is displayed. The camera readout is adjusted to bring the laser dot to the center of the display.

1.4 **Case Study: Lockheed Martin – Arrowhead Targeting System**

PLX in cooperation with Lockheed Martin developed a Modernized Boresighting system (M-BSM) for the Apache Helicopter (AH-64D and AH-64E) based on PLX's patented Lateral Transfer Hollow Retroreflectors™ (LTHRs) technology[2]. Deliveries for the Apache (AH-64D) began in 2005 after an extensive development phase. To date, over two thousand of these modernized boresighting system assemblies have been delivered. The M-BSM utilizes a series of LTHRs to achieve simultaneous viewing of multiple lines of sight. The LTHRs in the M-BSM are configured in a rugged housing and maintain this accuracy under the combat conditions faced by the Apache.

The LTHRs in the M-BSM also enable simultaneous viewing of day and night vision through the primary gunner's sight. In addition, they achieve one arc second parallelism between the gunner's line of sight, the FLIR system and the target. This represents an improved accuracy of the previous system from 30 arc minutes to 1 arc second.

Figure 6 shows the angular accuracy testing result on a standard LTHR unit, which has a maximum beam deviation of 0.59 arc second after it went through all the qualification tests. LTHRs can be used in both commercial and defense applications.

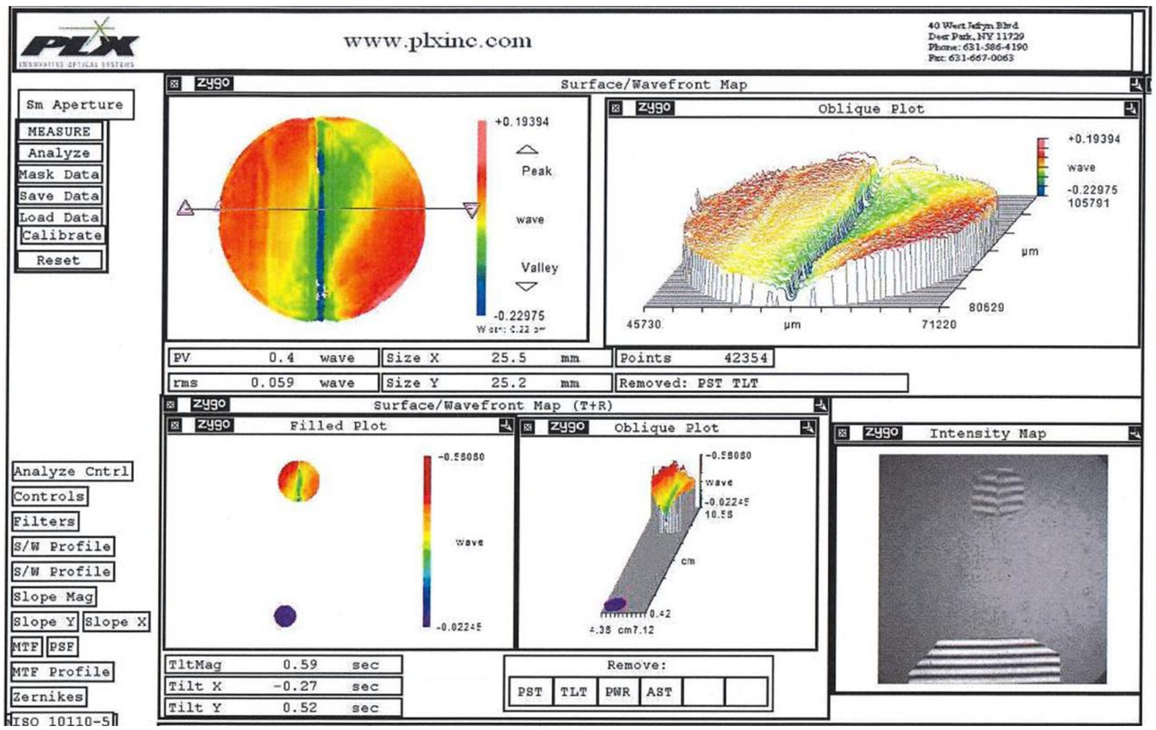


Figure 6 ZYGO result of a LTHR unit

What makes the Modernized Target Acquisition Designation Sight/Pilot Night Vision Sensor (M-TADS/PNVS) system so ground-breaking is that the pilot and targeting systems can operate simultaneously, where the targeting system is divided into two parts Modernized Night Sensor Assembly (M-NSA) and Modernized Day Sensor (M-DSA).

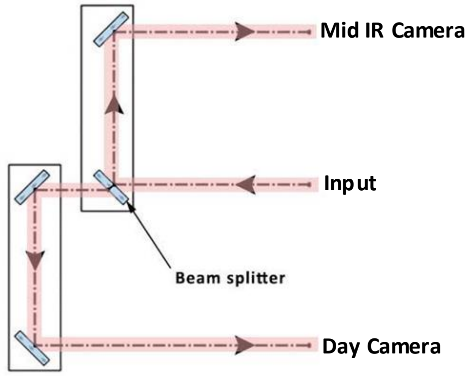


Figure 7 PLX's bore sighting system schematic. The input is a collimated multi-wavelength target source. The nightside output goes to a FLIR camera, and the dayside output goes to a high-resolution color camera.

PLX's boresighting technology offers three key benefits for the Apache Arrowhead as well as other fire control platforms:

1. The unit's ruggedness, high precision, optical and mechanical stability makes it possible to perform inflight boresighting as opposed to intermittent, ground-based boresighting at calibration points. Inflight boresighting allows in-situ, real-time calibration of the entire fire control system to overcome any mechanical errors due to drift of the cameras in the vehicle, be it a helicopter, a tank, or a jet. Also, the invariant nature of the system allows it to operate with undiminished accuracy in these high vibration environments. This enhances the dependability of the fire-control system and considerably reduces the repair cycle.
2. Because the boresighting module uses M.O.S.T, the unit never needs to be removed for its own recalibration.
3. The unit's compact form factor enables it to fit into the most tight and demanding space constraints.

CONCLUSION

PLX's patented Monolithic Optical Structure Technology™ (M.O.S.T) provides innovative solutions for a range of industries and operating environments. The above examples are by no means an exhaustive list of applications, with M.O.S.T. also being used for spectroscopy, interferometry, LIDAR, free space optics, laser tracking, laser cavities, satellites, targeting sights, laser beam steering systems, alignment, or sensors. As noted, the benefits of M.O.S.T assemblies are their superb optical stability and invariance in extreme operating conditions, their sub-arc second accuracy between the integrated optical elements and their permanent alignment so they will never require adjusting. M.O.S.T is fully customizable and is the first choice for optical alignment for mission-critical space and military missions as well as cutting edge commercial end uses.

[1] US Patent 6,141,101

[2]2US Patent 6,729,735

[3] https://icesat-2.gsfc.nasa.gov/