MONOLITHIC INVARIANT OPTICAL ASSEMBLIES FOR LASER SYSTEM APPLICATIONS

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INTRODUCTION

PLXs Monolithic Optical Structure Technology M.O.S.T.℠ pushes the boundaries of boresighting and targeting technology. 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, targeting sights, laser beam steering systems, alignment, or sensors.

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

M.O.S.T.™ is like the Swiss Army Knife of optics. The technology is cost-effective, robust, and offers a significant saving in time and resources.

The M.O.S.T.™ patented assembly is a single sandwich like structure which incorporates a number of optical elements (such as mirrors, beamsplitters, lenses, freeform optics, diffractive elements, prisms, etc.). What makes the system unique is the integration of multiple types of glass combined with other exotic CTE-matched materials (such as fused silica, low expansion borosilicate, ULE, BK7, ceramics and/or metals), to create a lightweight structure with superb stability (Figure 1). The result is a small form-factor assembly with robust sub-arcsecond performance with minimal variations of optical specifications to large thermal, vibration and shock conditions compared to conventional systems.

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.

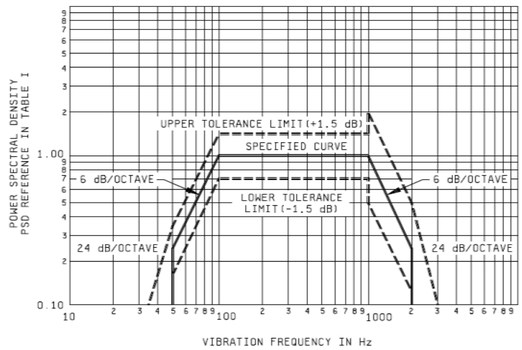

FIGURE 2026-1. Test condition I, random vibration test-curve envelope (see table I).

TABLE I. Values for test condition I. 1/

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

Figure 1 PLX Interferometer

These assemblies provide easy initial alignment with a plug-and-play style approach and do not need to be removed for re-calibration. For the initial set-up the beam just needs to be aligned within the clear aperture path of the invariant system. It is permanently aligned to sub-arcsecond accuracy so it will never need to be adjusted and it lasts indefinitely. Invariant optical systems maintain their input to output beam alignment even when the assembly is tilted relative to the beam.

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. In military and aerospace terms, this can apply to applications such as weaponry, from small rifles to artillery, tank and aircraft fire control systems, or long-range cameras and laser/receivers mounted on satellites. PLX solutions have been used for a number of boresighting applications.

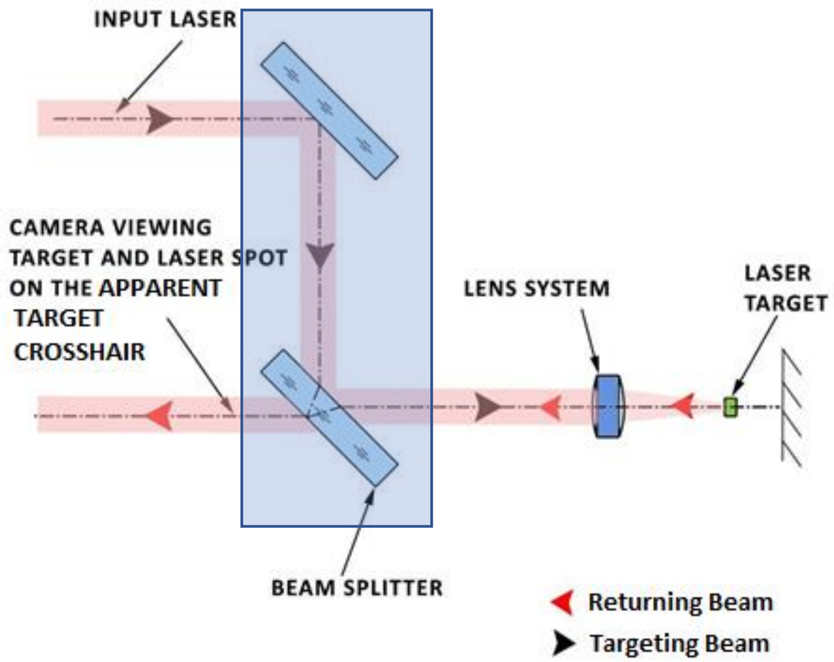

Figure 2 This is a schematic showing a long-range camera, such as an IR camera, which must be perfectly aligned to a laser designator.

In this application shown in Figure 2, the camera and the laser can be mounted on a turret that enables viewing in all possible coordinates in space. For boresighting, the turret 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.

1.2 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). Deliveries for the Apache (AH-64D) began in 2005 after an extensive development phase. The M-BSM system is designed to allow simultaneous viewing of multiple lines of sight. The M-BSM utilizes a series of PLX Lateral Transfer Hollow Retroreflectors (LTHRs℠) [2]. The LTHRs℠ in the M-BSM enable the 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.
The LTHRs℠ in the M-BSM are configured in a rugged housing and maintain this accuracy under the combat conditions faced by the Apache.
To date, over two thousand of these modernized boresighting system assemblies have been delivered.
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).

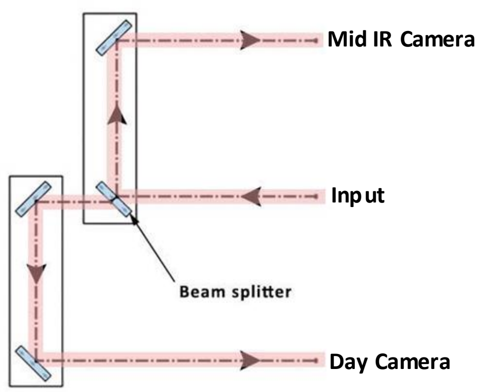

Figure 3 PLX's boresighting system schematic. The input is a collimated multi-wavelength target source. The nightside output goes to a FLIR camera, and the dayside output goes to a high-resolution color camera.

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 tightest and most demanding space constraints.

MONOLITHIC OPTICAL DELAY LINES

Light sources have become critical for a variety of scientific measurements. These are employed in many different industries to characterize properties of a material or system. These measurements often involve light delay or light interference and require the use of what are called optical delay lines (ODL). PLX has utilized laser optical delay lines in many of their product collaborations.

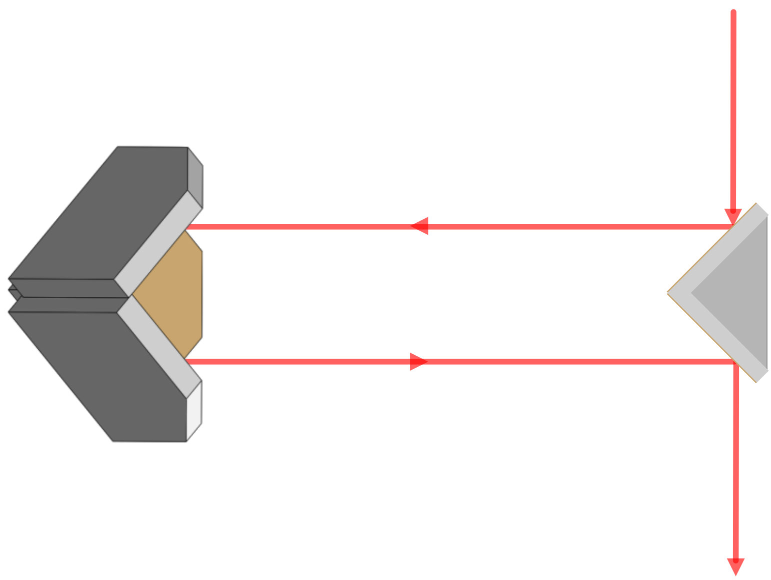

Figure 4 Laser Optical delay line. Figure 4 shows a simple assembly where incoming laser light is reflected by a reverse roof mirror as well as a retroreflector to ultimately return to the original path. This added path provides the delay. The retroreflector can be translated (left to right in the figure) to vary the optical delay, without affecting the optical alignment of the system.

1.3 Case Study: PLX Interferometer

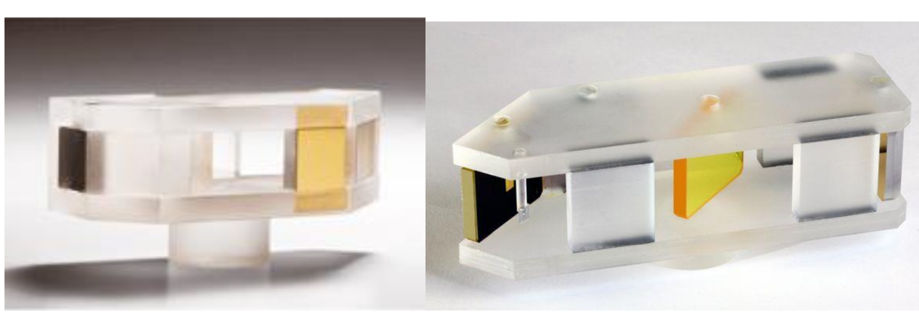

Figure 5 left INT05-N Monolithic Michelson Interferometer, right INT10-M Monolithic Michelson Interferometer.

Figure 5 shows a monolithic, Michelson interferometer designed to be extremely rugged and never need adjustment. The unit has two mirrors, a beamsplitter and compensator. A moving retroreflector is added to one arm to complete the interferometer and allow for the variation of the optical path difference around zero OPD. The retroreflector is a critical part of the interferometer. The modulation efficiency of the interferometer is greatly affected by any tilt between the two beams in the interferometer [3]. To maintain good performance the tilt should be kept at less than 0.25 λ, where λ typically refers to the 633nm wavelength of the HeNe laser. Maintaining that degree of angular tolerance on a moving flat mirror under all conditions is a difficult feat. This is keeping the edge of a 1-inch mirror not moving more the 6 micro inches out of line while being translated back and forth. The hollow retroreflector relaxes mechanical requirements on the translation as it is insensitive to tilt. The interferometer shown in figure 5 has a thermal performance dependence of less than 0.15%/°C.
The INT05-Series NIR interferometers are suitable for the most demanding NIR analyzer applications, whereas the INT10-M Monolithic Michelson Interferometer is especially suited for FTIR machine architecture operating from 2.5 to 15 microns. Other beamsplitters and coatings can be used to cover different wavelength ranges.

MONOLITHIC TELESCOPE ALIGNMENT SYSTEMS

PLX has a long history of working in the space industry, with applications for satellite missions for Mapping and Topography, Environmental and Atmospheric or pure science applications.

1.4 Case Study: ICESat 2 – ATLAS [4]

ICESat-2 is part of NASA's Earth Observing System. Its mission is to deploy a space borne sensor to collect altimetry data of the Earth’s surface optimized to measure ice sheet elevation change and sea ice thickness, while generating an estimate of global vegetation biomass. Ball Aerospace contracted PLX to work on the Advanced Topographic Laser Altimeter System (ATLAS) program. The Telescope alignment system uses 4 Laser spots emanating from the telescope part of the Telescope Alignment Monitoring System (TAMS). The light from the TAMS is directed via an LTHR into the Laser Reference System (LRS) camera. Meanwhile, a second LTHR samples a portion of the outgoing illumination laser beam aimed at Earth and directs this to the LRS as well. The twin LTHRs can keep the illumination laser and telescope directed to the same location and together they serve as the “brains” of the TAMS.

CONCLUSION

The Monolithic Optical Structure Technology™ (M.O.S.T.™) has many uses in 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 8,851,689

[2] US Patent 6,729,735

[3] P.R. Griffiths and J.A. de Haseth, *Fourier Transform Infrared Spectrometry*, 2nd ed. John Wiley & Sons, Inc, 2007.

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