Advanced Test & Calibration Systems for Integrated Multi-Sensor Platforms with IR, Visible, and Laser Range Finder/Designator Capabilities

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ABSTRACT

This paper discusses recent advances in the development of test and evaluation instrumentation for military laser range-finder (LRF) and designation systems. Recent strides have been made at Santa Barbara Infrared (SBIR) in the development of sophisticated active ranging simulation instruments for range accuracy and receiver sensitivity measurement, integrated measurement modules for laser pulse energy and temporal characteristics, and pulsed laser diode targets/sources for shared-aperture IR/laser sensor test and evaluation. In parallel with these activities, NAVSEA has led the development and validation of state-of-the-art reference standard radiometers used in the calibration of narrow-pulse laser systems at 1060 nm and 1550 nm. This paper will describe the application, capabilities, and performance of SBIR's active ranging, laser measurement, and pulsed laser source modules, and NAVSEA's high-performance 1060/1550 nm radiometric instrumentation.

Keywords: EO test & calibration, laser range finder/designator, laser receiver, laser transmitter, low-level power measurement.

1. INTRODUCTION

Current and emerging military electro-optical (EO) systems and weapons are incorporating increasing levels of sophisticated technology to perform active laser range-finding and target designation functions – combined with IR and visible (VIS) sensors and optical sights. Unit under test (UUT) technology is expanding to incorporate both separate aperture and coaxial LRF transceivers operating in the 1064 nm and 1540/1570 nm spectral regions. The high pulse energies and narrow pulse widths produced by today's UUTs give rise to high peak power levels, which require EO test system input attenuation, fairly high levels of simulated return pulse power, and accurate electro-optical pulse-shaping techniques. We discuss recent developments in EO test instrumentation for receiver and transmitter testing, and the requisite advances in calibration instrumentation and transfer standards.

2. LASER RANGE FINDER/DESIGNATOR TEST APPLICATIONS

Modern LRF test systems need to be capable of measuring UUT pulse amplitude (power, energy), amplitude stability, pulse width, pulse repetition frequency (PRF), beam divergence, satellite beams, range accuracy, and receiver sensitivity, in addition to performing laser/VIS/IR co-boresighting operations. While general-purpose test systems must accommodate a wide range of UUT performance parameters (pulse energy, width, PRF, divergence, maximum simulated range, etc), much of the basic test functionality can be standardized, with test program set (TPS) and tester-based attenuation providing compatibility on a per-UUT basis. Transmitter measurement typically employs combinations of joule meters/fast detectors, and has evolved somewhat over the past few years. Receiver measurement has historically used relatively simplistic laser sources and passive fiber spool-based ranging and pulse delay techniques. Recent developments in fast pulse shaping and modular system design have given rise to advanced techniques for flexible, active range simulation and receiver testing.

3. LASER RECEIVER MEASUREMENT

SBIR's active range module (ARM) provides the ability to measure LRF receiver sensitivity and range accuracy using standard table-top and modular IR/VIS target projection systems. The ARM allows programming of all key simulated pulse parameters (wavelength, amplitude, pulse width, PRF, etc). Derived from the basic electronic architecture of the ARM, the pulsed laser diode (PLD) source incorporates a single laser source mounted at focus, intended to provide pulsed periodic stimuli supporting internal and external sync modes.

3.1 Active Range Module (ARM)

SBIR's ARM provides the capability to test laser range finder/designator (LRF/D) range accuracy and receiver sensitivity. The ARM accomplishes this with a dual-channel architecture incorporating 1060 nm and 1550 nm laser diodes. The ARM output features programmable pulse delay (range), pulse energy, pulse width, 1060 vs 1550 nm spectra, single- vs. dual-pulse mode, and second pulse delay.

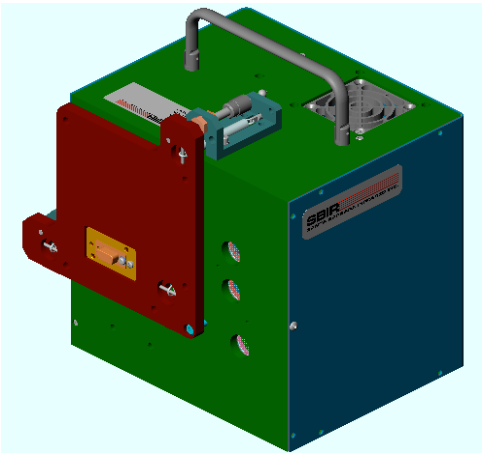

Figure 1a – ARM, Showing Optical & Mechanical Interfaces

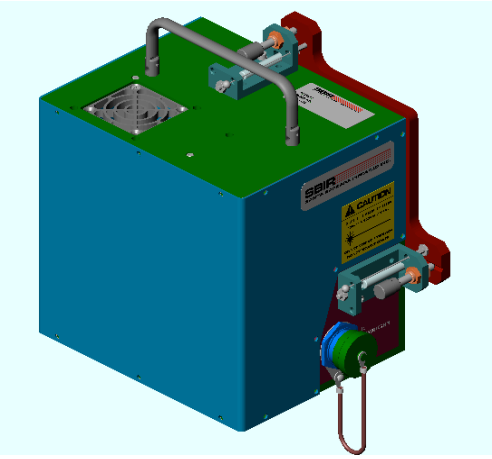

Figure 1b – ARM, Showing Azimuth/Elevation Adjustment & Electrical I/O

The ARM is typically used with a target projection/collimation system. The ARM optical interface views the collimator aperture, and projects a laser spot onto a diffusing surface in position at the target plane. Other configurations are possible, utilizing different positions in the optical path, and a variety of different diffusing surfaces and geometries.

For UUT range simulation applications, the UUT pulse is fired into the collimator, diffused, and detected by the ARM trigger detector. Depending upon simulated range, return pulse width, energy, and other parameters defined by the operator, the ARM provides an optical pulse back into the collimator, which then appears at the collimator output as a uniform simulated return to the UUT. The UUT's reported range is compared against the test condition to establish compliance.

Figure 2a shows the functional architecture of the ARM. The laser diode driver (LDD), pulse amplifier board (PAB), laser interface module (LIM), pulse control module (PCM), and trigger detector board (TDB) subassemblies have been developed to provide precise control, pulse shaping, photo-feedback, and triggering functions. The ARM optical bench assembly incorporates lenses, beam-splitters, spectral filters, attenuators, and photo-detectors as shown, in support of the dual-channel laser testing architecture. The model 925 controller allows adjustment of ARM output pulse parameters, trigger mode, channel selection, and calibration tables, and supports IEEE-488 communication.

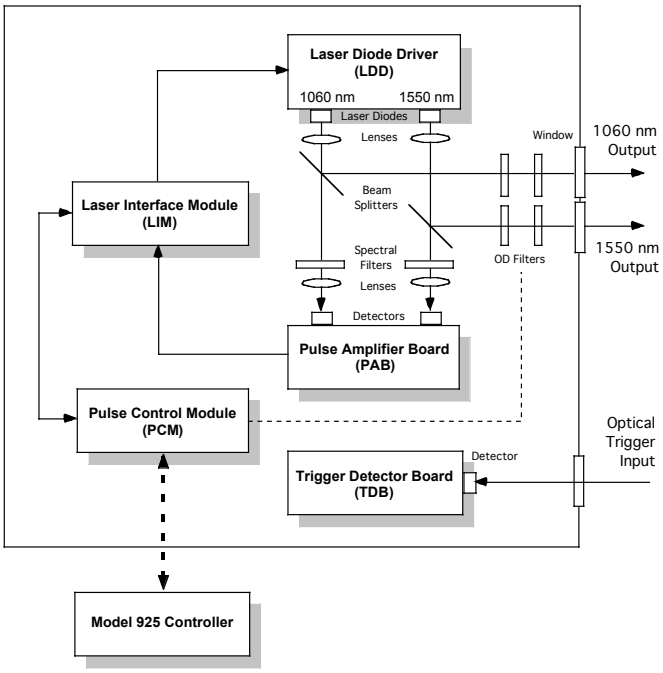

Figure 2a - ARM Functional Block Diagram

For UUT receiver sensitivity measurement, the ARM may be programmed to output a periodic optical laser pulse train of selectable frequency, pulse energy, and pulse width. Output power density is adjustable over a 10,000:1 dynamic range, and pulse width, delay, and second pulse delay are adjustable in increments of 10 ns. ARM performance specifications and key product features are summarized in Table 1.

Laser Output Wavelengths	1060 ± 5 nm 1550 ± 5 nm
Range Simulation Modes	single-pulse dual-pulse
Simulated Range	15 to 40,000 meters ±1.5 meter resolution ± 1.5 meter accuracy/repeatability
Output Power Density (into 50" FL projector)	0.5 to 5,000 nW/cm^2 (1060 nm) 0.5 to 4,000 nW/cm^2 (1550 nm)
Output Pulse Width	20 to 160 ns 10 ns resolution
Temporal Pulse Separation (dual pulse mode)	40 to 2,560 ns 10 ns resolution
Optical Interface	Trigger Detector Input 1060 nm output 1550 nm output
Optical Alignment	Azimuth Elevation
Primary I/O	Single D38999 connector
External Trigger	Optional
Safety Interlock	Electrical-Mechanical
Controller Type	Model 925

Table 1 – Active Range Module (ARM) Performance Specifications

3.2 Pulsed Laser Diode (PLD) Source

The PLD module is a pulsed laser source capable of providing laser spot stimulus at the focus of a collimator. The PLD system consists of a pinhole target backlit by a diffused laser diode source, and incorporates electronics derived from the ARM analog and digital circuit cards. Control is provided using a standard SBIR source controller with updated PLD control firmware, and pulse temporal characteristics are adjustable over the same range as that of the ARM. The optical front end of the PLD has been incorporated (as an option) into standard SBIR target wheels such as the model 312, as well as other modules allowing custom installation at focus of a wide range of projection systems. The PLD supports internal (free run) and external synchronization, and supports a variety of UUT receiver characterization tests. The operation of the PLD is illustrated in figure 2b.

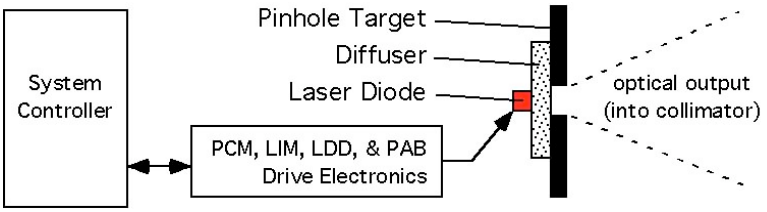

Figure 2b – Illustration of Pulsed Laser Diode (PLD) Operation

Preliminary PLD performance specifications and key product features are summarized in Table 2.

Laser Output Wavelength	1064 nm (other discrete wavelengths available)
Output Power Density (into 50" FL)	1E-14 to 1E-12 J/cm^2
Output Pulse Width	20 to 160 ns 10 ns resolution
Pulse Repetition Rate (PRR)	8 to 20 Hz
External Trigger	TTL, 50 Ω

Table 2 – Pulsed Laser Diode (PLD) Source Specifications

4. LASER TRANSMITTER MEASUREMENT

Laser transmitter measurements are accomplished in different ways for different test configurations. For standard laboratory projection systems, laser measurement hardware is incorporated at or near focus to characterize the input beam(s). For semi-custom and modular EO testers, laser components are integrated in dedicated modules such as the Laser Test Module (LTM), which is interchangeable with IR, VIS, and other modules to support re-configurable testing at the field and depot level.

4.1 Pulse Temporal Measurement

The latest systems accomplish pulse temporal measurements (width, pulse repetition frequency (PRF), etc) by using a fast detector/fiber optic to view the UUT pulse bounced off a diffusive surface. Modern PCI oscilloscope cards support sample rates up to 5 GHz, sufficient for characterization of pulse widths of several nanoseconds. With typical UUT pulse widths on the order of 10 ns, excellent test accuracy ratios are maintained during measurement of pulse width, PRF, and temporal stability.

4.2 Pulse Amplitude Measurement

For table-top projectors, pyroelectric joule meters are often employed, and provide good measurement range and increasing pulse rate capability. Modern devices support measurement of pulse amplitude for PRFs up to 20 kHz. Recent improvements in optical packaging, detection, and amplification have allowed use of fast detector-based amplitude measurement. UUT pulses are collected near focus in miniature integrating spheres, fiber-coupled to fast detector-amplifier modules, and captured by the PCI scope card. This approach allows a single fast detector/buffer to be used for both temporal and amplitude measurement (eliminating at least one component), and still provides excellent measurement accuracy and repeatability.

4.3 Beam Spatial & Angular Measurement

Beam divergence, diameter, and satellite beams are now handled using charge-coupled device (CCD), charge-injection device (CID), or NIR cameras/sensor engines mounted either at focus, or viewing a diffusive surface at focus. Attenuation is distributed between the projection aperture and intermediate points approaching focus, in order to maximize signal amplitude at the various measurement nodes, while maintaining margin below published damage thresholds for optical surfaces and devices.

VIS and IR-to-boresight procedures are accomplished by use of heated and front-illuminated boresight targets optically combined with the VIS/NIR sensor engine optical path, such that the boresight target feature maps to a known camera pixel on the 2-D array. VIS and IR components in the UUT view a single target, and UUT laser energy fired into the system appears on the camera display and is adjusted to the target camera location to align laser pointing with respect to VIS and IR.

4.4 Laser Test Module (LTM)

As discussed above, laser measurement hardware in standard laboratory projection systems is incorporated at or near focus to characterize the input beam(s). For semi-custom and modular EO testers, laser components are integrated in dedicated modules such as the Laser Test Module (LTM), which is interchangeable with IR, VIS, and other modules to support re-configurable testing at the field and depot level.

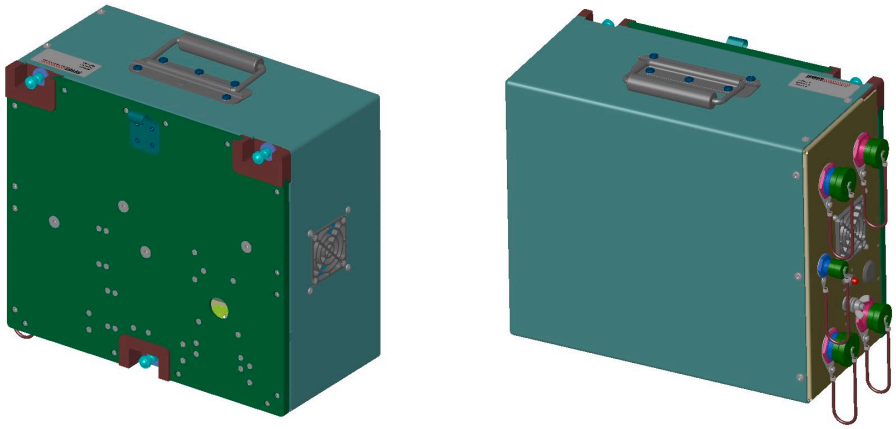

Figure 3 - LTM, Showing Opto-Mechanical Interfaces & Electrical I/O

Though the LTM was originally designed for modular compatibility with field-portable EO test stations, the underlying technology and much of the architecture is well suited to semi-custom laboratory applications. The table below summarizes the features and performance of the LTM.

Laser Input Wavelengths	850 – 1700 nm
Supported Tests	Boresight, Beam Divergence, Beam Alignment, Satellite Beams, Beam Profile, Pulse Rate, Pulse Width, Pulse Amplitude
Boresight	80 μrad accuracy
Beam Divergence	130 to 1000 μrad range ± 10 % accuracy
Beam Alignment	± 100 μrad accuracy ± 30 μrad repeatability
Satellite Beams	Up to 28 dB below peak 320 x 256 array, 30 μm pixel pitch
Beam Profile	Flexible, camera-based capability
Pulse Rate	Up to 20 Hz Accuracy limited by scope card
Pulse Width	> 5 ns capability ± 10 % accuracy
Pulse Amplitude	Input range driven by UUT attenuation (≥ 300 mJ typical with proper TPS) ± 10 % accuracy ± 5 % repeatability
Optical Interface	Laser Input/Output Port
External Camera Trigger	Optional

Table 3 - LTM Features & Performance Specifications

The LTM incorporates a 320 x 256 NIR camera, a heated/front-illuminated IR/VIS boresight target, and a fiber-coupled, buffered fast detector/amplifier channel to support measurement of all key laser transmitter parameters.

5. CALIBRATION STANDARDS

The Navy utilizes various laser rangefinders, trackers, and designators in the Fleet. These are used onboard aircraft to designate, detect, range, and bomb targets using laser technology. These systems utilize a laser receiver scheme capable of detecting extremely low-level 1064 nm and 1540-1580 nm laser energy. Receiver sensitivity is a verifiable parameter used to determine the laser system's ability to detect, track, and acquire laser-designated targets. These systems are currently tested on a variety of Test and Monitoring Systems (TAMS). These test sets generate low levels of fluence or irradiance for verification of the laser receiver's sensitivity. The Naval Surface Warfare Center (NAVSEA, Corona, CA) has led development of two radiometric transfer standards - the APD-800 and PLR-100 radiometers - for calibration and maintenance of LRF test systems.

5.1 APD-800 Low Level 1064 nm Laser Peak Power Radiometer

The Measurement Science Directorate at the Naval Surface Warfare Center (NSWC), Corona Division, initiated the development (through NIST, Boulder, CO) of the Low-Level Laser Peak Power Radiometer (APD-800) to satisfy LRF calibration requirements. The APD-800 was designed for on-site calibration of low-level laser test sets at the 1064 nm wavelength, for pulse widths as low as 20 ns. The APD-800 consists of the detector head and the high-voltage bias supply. The APD-800A version shown in Figure 4a is built with an internal bias supply. The output signal from the radiometer is proportional to the detected laser power or irradiance, and is measured by an oscilloscope. The amplitude of the signal represents the laser peak power, and the pulse width represents the laser pulse width. The detector head consists of two lenses, an aperture, a detector, coaxial switches, and amplifiers. Various apertures allow the radiometer to measure a wider range of fluence or irradiance. The detector is a commercial custom-fabricated Avalanche Photodiode (APD) detector. The detector surface is dimpled to increase

absorption of the incoming radiation. Temperature-control circuitry and a heater coil hold the detector package to (40 ± 1) °C. This improves the stability of the radiometer measurements in a non-laboratory environment.

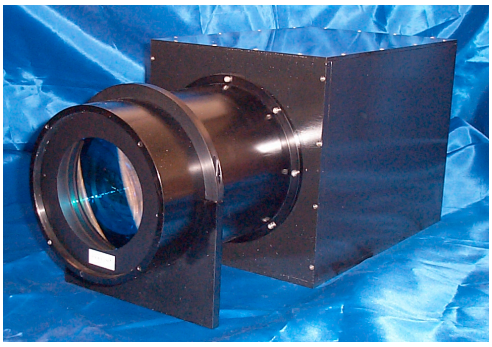

Figure 4a – APD-800A Radiometer

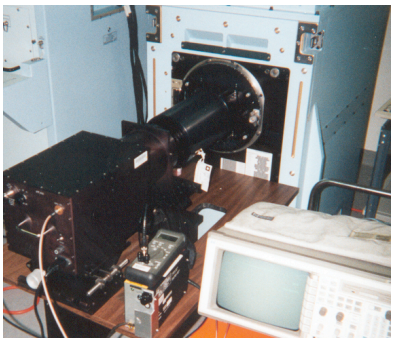

Figure 4b - Calibrating CASS/EOSS+

The calibration of the APD-800 is performed at NIST, through a basic comparison method to a laboratory transfer-standard calorimeter. An acousto-optic modulator generates alternately equal levels of pulsed and CW power from a 1064 nm laser beam. A characterized wedge beam splitter divides the laser beam into high- and low-power signals. The laboratory standard measures the CW power, and the APD-800 registers the pulsed signal with an oscilloscope. A comparison of the measured power and voltage levels provides a calibration factor. The impulse response of the APD-800 transfer standard is measured in a separate calibration procedure. These data are analyzed via computer to convolve the unit-area impulse response with unit-height Gaussian pulses of selected durations. From these data, correction factors of the pulse peak for observed pulse durations from 10 to 30 ns are determined.

The APD-800 has been used successfully under a variety of conditions in all parts of the world. It has been used as a development tool for the design, production, testing, and acceptance of low-level laser sources, as well as diagnostic and routine testing/calibration of EO test systems (see Figure 4b). System sensitivity varies between units and depends on the characteristics of the specific detector. Table 4 lists the typical APD-800 instrument specifications.

Measurement Range	
Fluence	$2x10^{-13}$ - $6x10^{-18}$ J/cm^2
Irradiance	$1x10^{-5}$ - $3x10^{-10}$ W/cm^2
Peak Power	$1x10^{-5}$ - $4x10^{-8}$ W
Accuracy	± 7 %
Wavelength	1064 nm
System Rise Time	3-6 ns
FOV	1.3^o (22 mr)
Collecting Optics Aperture	10.16 cm (4 inches) dia.
Pulse Width Range	15 - 300 ns

Table 4 – APD-800 Radiometer Specifications

5.2 PLR-100 Low Level 1550 nm Laser Peak Power Radiometer

The Optoelectronics Division of the National Institute of Standards and Technology (NIST) has constructed and calibrated a pulsed-laser radiometer (PLR-100) for use at a wavelength of 1550 nm. This instrument provides measurement support of peak-power irradiance as low as 130 nW/cm^2 with an expanded uncertainty of 8 percent, traceable to national standards for laser power. The PLR-100 was developed to provide calibration support for laser range finders, trackers, and designators operating in the 1540 to 1580 nm wavelength range.

The light collection for the PLR-100 radiometer is accomplished with two plano-convex lens spaced to provide a minimum focal spot on the photodiode. The two lens design allows the optical system to have a shorter focal length and reduces the spherical aberrations. The maximum aperture is 7.62 cm in diameter, providing an input area of 45.6 cm^2.

Light detection is achieved with a commercially available InGaAs photodiode. The photodiode has a PIN architecture with a diameter of 1 mm and is in a sealed container. A single-stage thermoelectric cooler is used to stabilize the temperature-dependent responsivity of the PIN photodiode to provide consistent performance outside the laboratory environment.

The current output of the photodiode is converted to voltage with a 150 MHz bandwidth transimpedance amplifier. The voltage signal is measured with a digitizing oscilloscope with a suitable bandwidth (400 MHz recommended as the minimum). The maximum linear output of the radiometer is about 2.5 V. The PIN photodiode limits the overall system bandwidth to approximately 75 MHz but still allows measurement of laser pulses with full-duration half-maximum as fast as 15 ns with less than 1.5 percent correction to the pulse amplitude.

Figure 5 – PLR-100 Radiometer

Calibration of the responsivity of the PLR-100 radiometer uses a technique similar to the comparative method for the APD-800. [1] An electro-optic modulator generates equal levels of pulsed and CW power from a 1550 nm laser beam. A characterized beam splitter divides the laser beam into high- and low-power signals. The laboratory standard measures the CW high-power beam, and the PLR-100 radiometer registers the pulsed signal with an oscilloscope. A comparison of the measured power and voltage levels using the beam splitter attenuation ratio provides a calibration factor in volts/watt.

In order to accurately measure laser pulses with durations less than 50 ns the limited electrical bandwidth of the PLR-100 radiometer must be accounted for. The measured impulse response of the radiometer is convolved with Gaussian pulses of unit height and durations of 5 to 25 ns. These data are used to generate correction factors for the observed pulse height and duration. The correction factors are to be used with the calibrated responsivity.

Irradiance Range	$1.1x10^{-5}$ to $1.3x10^{-7}$ W/cm^2
Peak Power	$6x10^{-4}$ to $5x10^{-6}$ W
Wavelength	1550 nm
System Impulse Response (FDHM)	4-5 ns
Maximum Input Aperture	7.62 cm (3 in.) diameter
Calibration Factor @ 1550 nm	$5x10^3$ V/W
Calibration Uncertainty	± 8 %

Table 5 – PLR-100 Radiometer Specifications

Products or companies named in this paper neither constitute nor imply endorsement by NIST.

6. SUMMARY

Significant advances are being made in the area of EO test instrumentation development for characterization of VIS-IR-laser UUTs. From an initial configuration of transmitter and receiver measurement tools, novel architectures are being developed and produced to address the test needs of emerging sensors in laboratory, depot, and field environments – with active range simulation at the forefront. With the evolution of UUT and test equipment laser capabilities, development of radiometric transfer standards is keeping pace, ensuring availability of appropriate calibration references.

REFERENCES

1. A.A. Saunders and A.L. Rasmussen, "A System for Measuring Energy and Peak Power of Low-Level 1.064 μm Laser Pulses," *National Bureau of Standards Technical Note 1058*, 1982, 39p.