Non-optically Combined Multi-spectral Source for IR, Visible, and Laser Testing

Joe LaVeigne[a], Brian Rich[a], Steve McHugh[a],

Peter Chua[b]

[a]Santa Barbara Infrared, Inc., 30 S. Calle Cesar Chavez, #D, Santa Barbara, CA 93103
[b]Diverse Fabrications, P.O. Box 61444, Santa Barbara, CA 93160

ABSTRACT

Electro Optical technology continues to advance, incorporating developments in infrared and laser technology into smaller, more tightly-integrated systems that can see and discriminate military targets at ever-increasing distances. New systems incorporate laser illumination and ranging with gated sensors that allow unparalleled vision at a distance. These new capabilities augment existing all-weather performance in the mid-wave infrared (MWIR) and long-wave infrared (LWIR), as well as low light level visible and near infrared (VNIR), giving the user multiple means of looking at targets of interest. There is a need in the test industry to generate imagery in the relevant spectral bands, and to provide temporal stimulus for testing range-gated systems. Santa Barbara Infrared (SBIR) has developed a new means of combining a uniform infrared source with uniform laser and visible sources for electro-optics (EO) testing. The source has been designed to allow laboratory testing of surveillance systems incorporating an infrared imager and a range-gated camera; and for field testing of emerging multi-spectral/fused sensor systems. A description of the source will be presented along with performance data relating to EO testing, including output in pertinent spectral bands, stability and resolution.

Keywords: Multispectral, MSS, MRT, SWIR, MWIR, LWIR, UUT, LIDAR

1. INTRODUCTION

The emergence of fused IR and VIS/NIR/LASER sensor systems[1-4] has proven its versatility in enhancing performance in the battlefield, and reducing `stimulus overload'. This generation of fused or multi-spectral imagers necessitates more advanced test requirements that can validate their simultaneous, mixed-signal capabilities. SBIR's newly developed integrating sphere sources with integrated differential blackbodies are a novel means of providing multiple waveband stimulus to these systems.

SBIR has implemented the new combined source in two versions: The Multi-Spectral Source (MSS) system integrates diode lasers and an extended blackbody source in an integrating sphere to produce separate outputs at 1064 nm and 1550 nm laser wavelengths, concurrently with output in the MWIR and LWIR bands. The mixed outputs can be used for boresighting IR and SWIR cameras, provide back-illumination on small resolution targets, and perform range testing on gated SWIR cameras.

The Multi-Lambda Source (MLS) integrates a Quartz Tungsten Halogen source along with the blackbody source. This implementation was designed expressly for field-portable applications, as it removes the need to externally combine the sources using beamsplitters, as is the traditional approach. The result is a much smaller and lightweight tester for forward-deployed military electro optics support.

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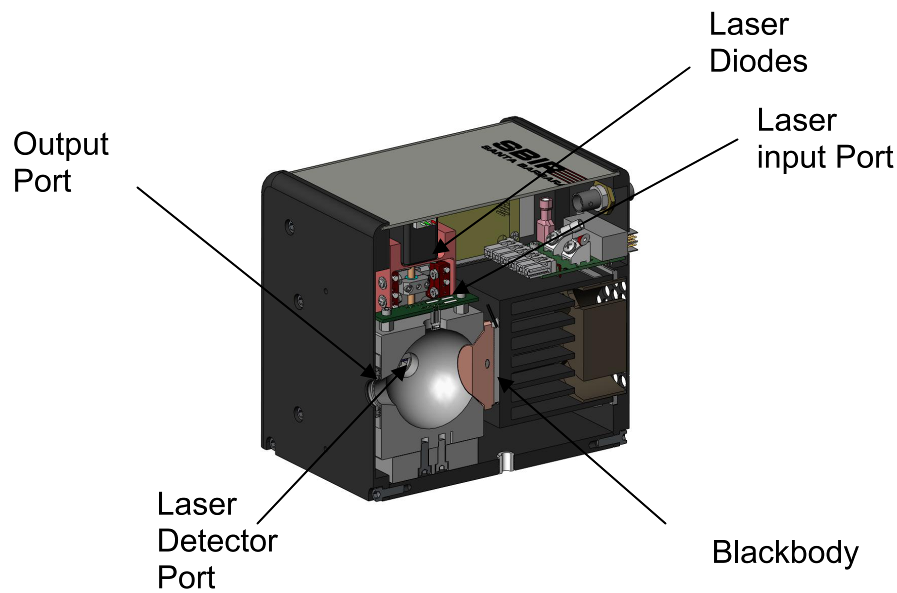

Figure. 1. Cross-section image of SBIR's Multi-Spectral Source (MSS). This section shows the blackbody, laser diode assembly, laser detector port and output port.

The component source inputs are combined inside an integrating sphere without use of a beamsplitter as shown in Figures 1 and 2. MWIR and LWIR outputs are provided by an extended blackbody source forming the rear wall of the modified sphere. The (circular) blackbody surface is directly viewable by the UUT through the sphere exit aperture, the centers of which define the optical centerline. The blackbody diameter is sized and fitted to the sphere to leave a slight gap between the blackbody surface and the surface of the sphere. This insulates the blackbody from added thermal loading of the integrating sphere. The blackbody overfills the viewable area of the sphere, so the gap is not "seen" through the exit aperture by the systems being tested.

To achieve high reflectance in the visible and NIR spectral bands, a special VIS/NIR white coating is applied on the blackbody source plate that also has high emissivity (i.e. is black) in the 3-5 µm (MWIR) and 8-12 µm (LWIR) bands. This "white blackbody" is a key element of the patent pending MSS and MLS. The high VIS/NIR reflectance nearly matches that of the rest of the integrating sphere, so integrating sphere performance – throughput and uniformity – are preserved. A similar coating with lower optical performance in the visible through short wave infrared (SWIR) bands, but with greater durability was chosen for use in the field deployed MLS.

Two ports at right angles to the optical axis of the sphere are used as inputs. One implementation of the MSS incorporates 1064 and 1550 nm laser diodes, for testing gated cameras (imaging LIDAR). These diodes are operated in a pulsed mode, and all of the pulse and timing electronics are incorporated into the source module. The timing circuitry simulates the transit time of an illuminating laser pulse in a gated camera system, so that optical testing can be performed with the gated camera operating normally. Input energy is varied through the use of a stepper-driven attenuating vane. The port opposite to the laser input port is the input for a visible source. SBIR's implementation of this source in a compact field-portable EO tester uses a quartz-halogen lamp with input power controlled by an attenuating vane, and the current control to the lamp to adjust and stabilize the color temperature.

Two ports, orthogonal to the input ports, are used for feedback detectors. In the case of the laser source implementation, a high speed InGaAs photodiode is used, with built-in transimpedance amplifier, integration circuitry, and analog to digital converter (ADC). For the visible source, a "smart" v-Probe is incorporated, which is a standard SBIR product that provides visible light detection over 9 orders of magnitude. The visible detector also has a built-in transimpedance amplifier with 4 gain stages and an ADC. The v-Probe keeps calibration data stored on an internal flash memory making it field replaceable without requiring re-calibration.

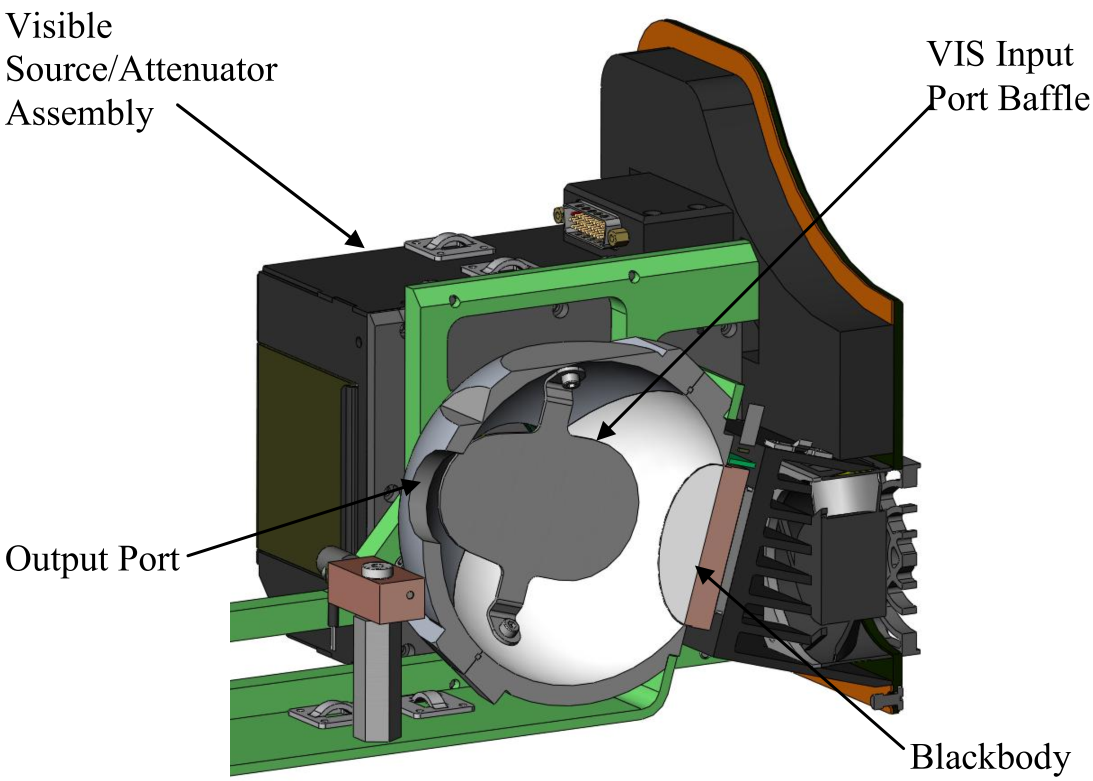

Figure 2. Cross section of the Multi-Lambda Source assembly. This section shows the sphere with the blackbody insert and luminance source baffle. The assembly behind the sphere is the lamp/attenuator.

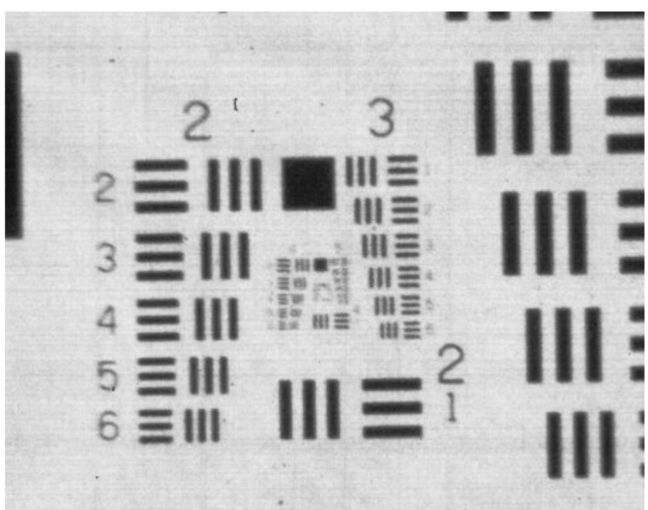

Figure 3. Image of a USAF resolution target produced by a gated camera using the MSS as a source. Wavelength 1.54 microns. Courtesy Curtis Webb, Northrop Grumman Corporation

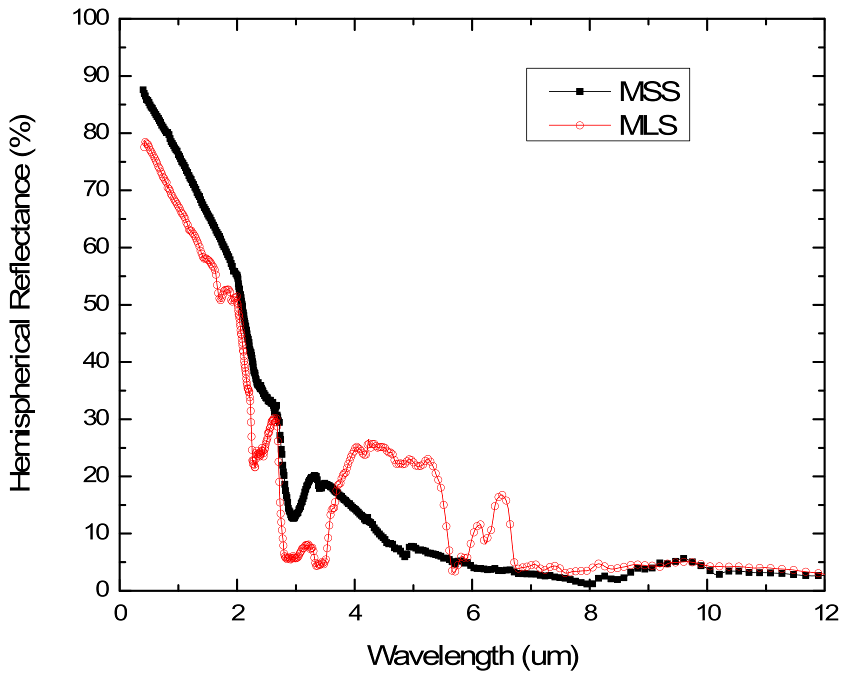

Figure 4. Reflectance spectra from white coatings used on the blackbodies for the two sources described.

2. MSS AND MLS IMPLEMENTATION

The MSS was built as a standalone source module, similar to SBIR's standard line of blackbodies and visible sources. These components are composed of two parts: a) the source "head" which is an enclosed unit typically behind a target wheel backlighting a projector system for presentation to a UUT; and b) the controller that either sits on a bench or is rack mounted in a test station. The controller interfaces to a test computer and has a front panel display for quick-check of status or intervention by the user. Figure 3 shows test imagery from a gated SWIR camera viewing an Air Force resolution target through a collimator with the MSS as a source.

The MLS, on the other hand, was specifically designed as part of a rugged, lightweight military test system. It has no external housing and is part of a source module that includes a target wheel. This module slips into the collimator housing itself, but is thermally isolated from the collimator by a bulkhead structure.

The MSS incorporates near infrared laser sources and a blackbody at the integrating sphere, while the MLS incorporates a visible source. Alternative implementations could include all three sources: IR, VIS and LASER, as either a laboratory unit or as part of a lightweight field-portable EO test set, with the ability to test laser receivers and rangefinders.

3. PERFORMANCE DATA

3.1 Blackbody:

The blackbody portion of the two sources described is derived from the SBIR Infinity line of standard sources. Temperature measurement and control is performed using an iProbe which stores calibration data on the probe itself. This allows an out-of-calibration unit to be calibrated by simply replacing the iProbe with one that is calibrated without returning the entire unit to the factory or some other center for calibration. The sources are driven by thermoelectric coolers and are capable of differential control from -15 to +60^{o}C from ambient. The blackbody portion of each sphere is covered with a custom coating that is reflective (i.e. "white") in the visible through SWIR portion of the electromagnetic spectrum while being highly emissive (i.e. "black") in the MWIR and LWIR portions. Figure 4 shows a hemispherical reflectance spectrum of the coatings used in the two sources. The coatings used were selected to best fit the intended use. The MLS is intended for field applications and requires a mechanically robust coating. The coating selected for the MLS exhibits a decrease in reflectance in the SWIR region. Although the reflectance is still reasonably high, the decrease has a significant effect on the efficiency of the sphere. Due to the multiple bounces of light before it exits the sphere, the decrease in reflectance will be multiplied every time light is reflected off the surface of the blackbody. Achieving adequate laser power output is a significant challenge in this source, so there is an incentive to use a coating with the highest possible reflectance in the SWIR spectrum while maintaining reasonably high emissivity in the MWIR and LWIR areas. Since the MSS is designed for laboratory applications, a less mechanically robust coating is acceptable. The MSS coating shown in Figure 4 provides approximately a 30% gain in laser output over the coating used in the MLS.

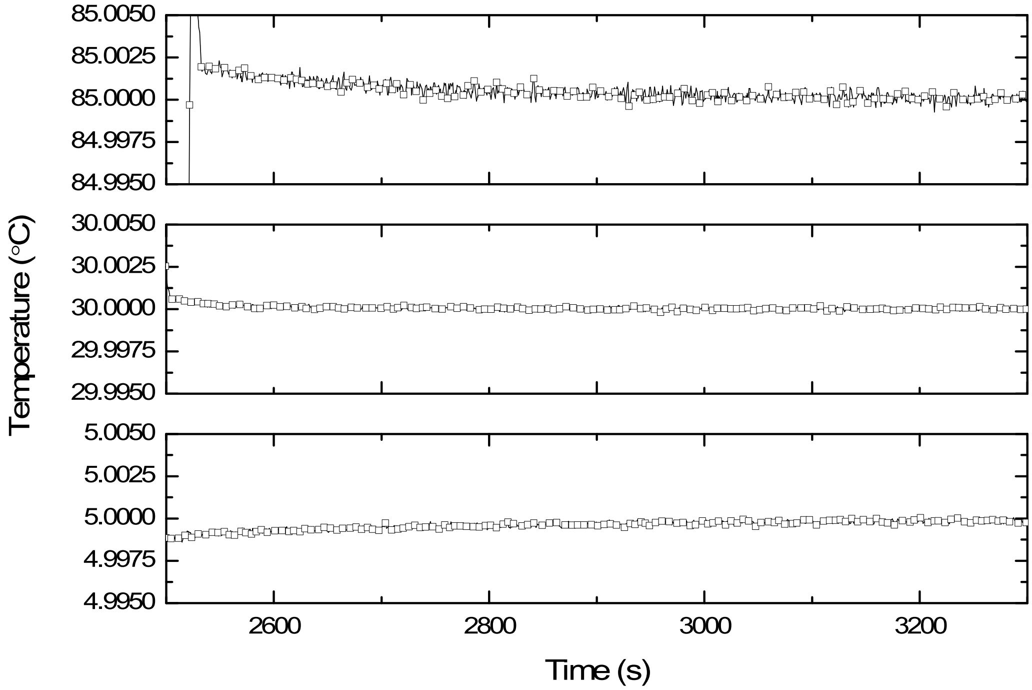

Figure 5. Stability plots from the MLS blackbody. This data shows sub-milliKelvin stability at the maximum and minimum temperatures as well as at slightly above ambient. Sigma, max and min are shown in Table 1.

Table 1. Statistics from stability data shown in Figure 5.

Set Point	5.0000	30.0000	85.0000
sigma	0.0001	0.0001	0.0003
max	5.0002	30.0002	85.0008
min	4.9995	29.9998	84.9993

The thermometric response of the blackbodies is comparable to others in the SBIR Infinity line of blackbodies. Test system performance is an important part of evaluating an infrared imager[5]. Fast transitions are desired with short settling times to reduce test time. In the case of minimum resolvable temperature measurements (MTR), preventing overshoot is extremely important. Overshoot can cause a viewer to mistakenly underestimate the MRT of a system. Stability is also a necessity with variations on the order of 1mK or less required for many tests. Data collected during design verification of the MLS is shown in Figures 5 through 7, and Table 1 show fast, well-behaved transitions with minimal overshoot and sub-milliKelvin stability.

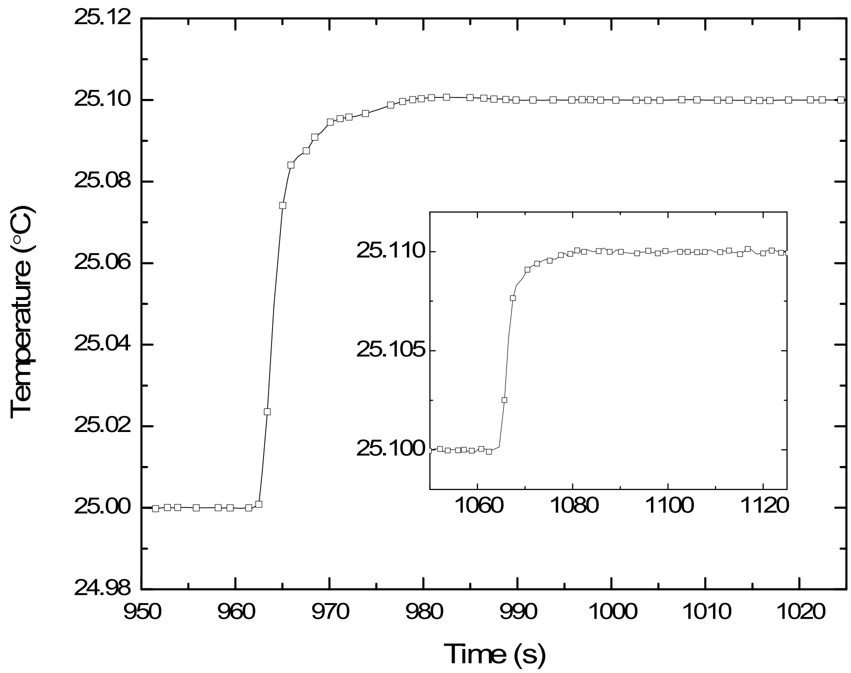

Figure 6. Small transitions. This figure shows 100 and 10 mK transitions. Overshoot in both cases is less than 1 mK and both are stable to within 1 mK in less than 15 seconds.

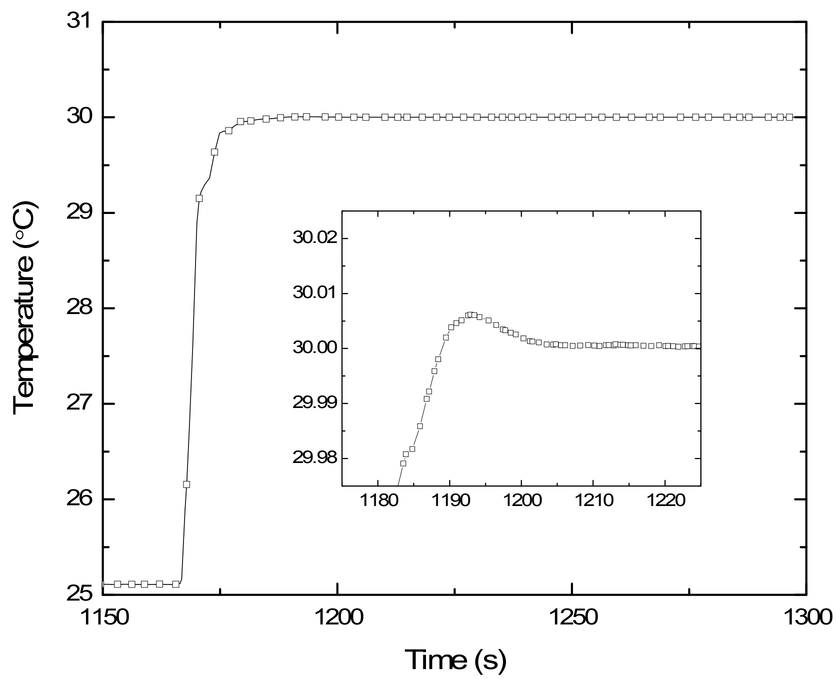

Figure 7. 5 K transition. This shows a 5 K transition from 25 to 30°C. The overshoot shown in the inset is 6 mK and the temperature is stable to 1 mK in 45 seconds.

3.2 Visible Source

The visible source on the MLS also makes use of components from SBIR standard products. The attenuator mechanism allows control over 8 orders of magnitude without requiring the addition of filters or other secondary attenuation devices. The attenuator is stepper-motor controlled and has resolution of better than 0.2% of the desired value over the entire range of operation (See Figure 8). The visible detector is similar to the iProbe mentioned earlier in that the calibration data resides on the probe. The detector has a built in shutter to allow dark current measurements for improving low light level performance. It is also temperature controlled, which reduces drift in dark current as well as gain (to a lesser degree). The detector automatically switches between 4 gain stages to achieve the best signal-to-noise without saturation. The detector allows measurement down to approximately 5E-6 ft-L. System accuracy is 2% or 5E-6, whichever is greater. Figure 9 shows the system stability over the set-point range of 1E-5 to 1000 ft-L.

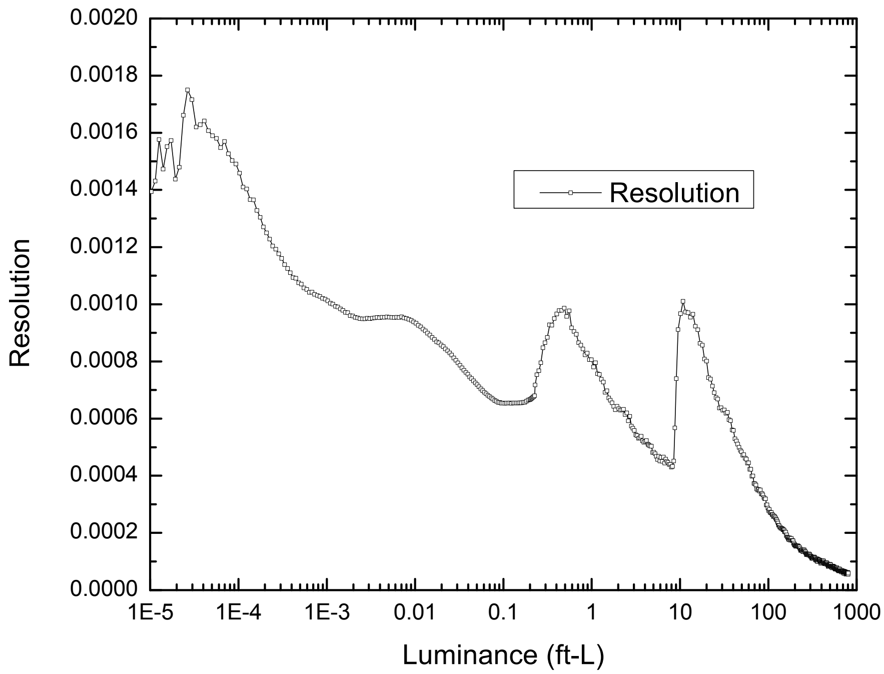

Figure 8. Luminance resolution in the MLS. This figure shows the resolution of the MLS luminance source as a fraction of the set-point value. The variations are due to the shape of the vane used.

3.3 Laser Source

The MSS contains two pulsed laser sources in addition to the blackbody. One source is 1064 nm wavelength, the other is 1550 nm. Both lasers input through the same entrance port in the sphere, and share a common attenuator. Only one of the lasers can be fired at a time. Before arming the laser, the user must choose the laser source wavelength, pulse width, trigger mode and trigger source, and output radiance.

The available laser power in a diode device with a narrow output band was one of the primary limits on the system. The MSS system is capable of pulse widths from 20 ns to 500 ns (see Figure 10.) The specification requires temporally-integrated output radiance from 0.4 to 85 nJ/cm^2/sr. To maximize the throughput of the sphere, it was made small (2 inches in diameter) just large enough to achieve nominal 2% uniformity over its half-inch exit port diameter.

The timing circuitry for the laser sources allows them to run in a free-run mode in which a continuous stream of output pulses is produced. This mode is useful for setup and alignment of the unit under test. When the system is set up, the usual timing mode is a ranging mode, where the MSS will create one return pulse for each trigger event. The return pulse can be delayed to simulate ranges from 100 m to 100 km, with a resolution of 5 m, and an accuracy of +/- 3 m. The MSS has a T_0 output, which allows for range testing without the need for firing the UUT laser. The T_0 signal is used to tell external test equipment that the UUT laser has been fired, and marks the start of the range delay.

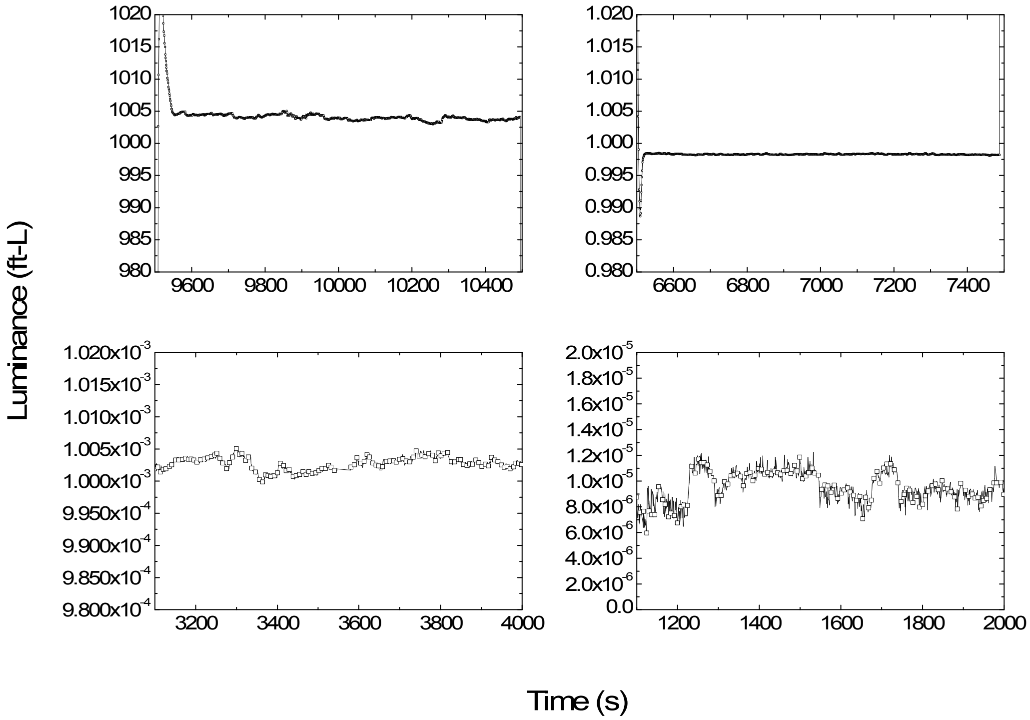

Figure 9. Luminance stability. Shows stability at 1E-5, 1E-3, 1, and 1000 ft-L. Sigma/mean is ~ 10% for the 1E-5 case and is < 0.5% for all the others.

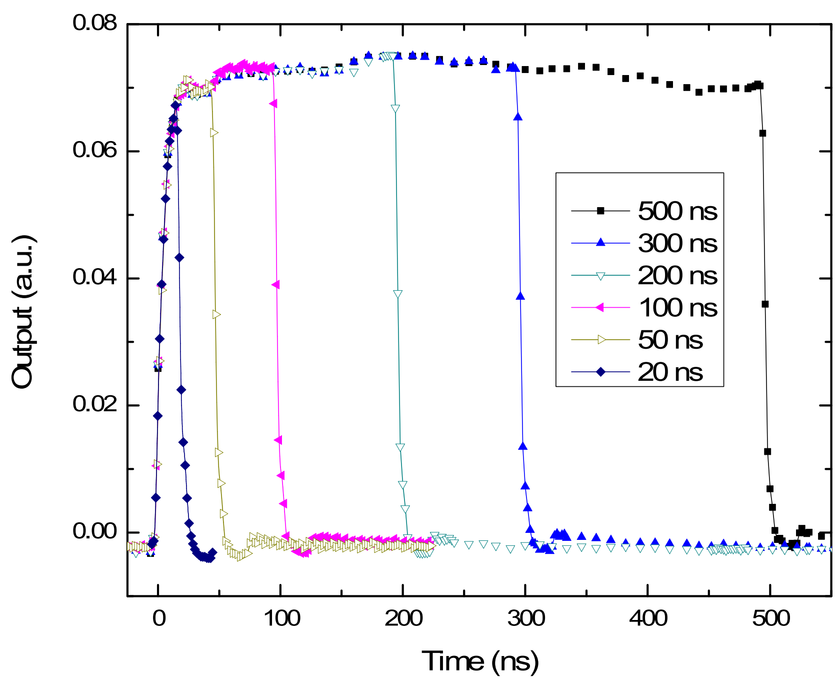

Figure 10. Variable pulse width in the MSS. This plot shows various pulse widths generated by the selectable pulse width of the MSS. The rise and fall times are on the order of 5 ns. The pulse shape is relatively flat after the first 20 ns and no undesirable artifacts are apparent with the increased pulse width.

4. SUMMARY

Current and future sensor technologies are utilizing broadband spectral sensitivity, as well as laser illumination and gating to provide better target discrimination and resolution. Testing of these devices requires new instrumentation with the ability to stimulate sensors with well characterized and controlled multi-spectral illumination simultaneously.

Santa Barbara Infrared, Inc., a HEICO company, has developed a novel multi-spectral uniform source design that combines visible, NIR, SWIR, MWIR, LWIR, and laser sources into a single unit without the use of combining optics. The design was driven by the need for a uniform large area pulsed laser illumination combined with MWIR/LWIR illumination that simultaneously back-illuminates resolution targets at the focus of a collimator. This initial design was adapted to support a requirement for combined MWIR/LWIR and visible illumination in a ruggedized, compact target projector used to test fused visible/IR sights and sensor systems.

On-going development includes the combination of laser, visible and IR sources into a single, fully integrated system, continued research into reflective and emissive coatings and materials, and development of new test methodologies.

REFERENCES

[1] Grasso, R., et al., "A novel low-cost targeting system (LCTS) based upon a high-resolution 2D imaging laser radar", Proc. SPIE, 5988, (2005)

[2] Estrera, J., et al., "Modern night vision goggles for advanced infantry applications" Proc. SPIE, 5079, (2003)

[3] Toet, A, and Hogervorst, M., "TRICLOBS portable triband color lowlight observation system", Proc. SPIE, 7245, (2009)

[4] Estrera, J., "Digital image fusion systems: color imaging and low-light targets", Proc. SPIE, 7298, (2009)

[5] Holst, Gerald C., [Testing and Evaluation of Infrared Imaging Systems], JCD Publishing, (2008)