

Performance Comparison of Reflective and Emissive Target Projector Systems for High-Performance IR Sensors

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ABSTRACT

This paper presents qualitative and quantitative comparisons between emissive and reflective target technologies used in the application of IR target projection for thermal imager test and evaluation. Comparison of target projector performance in MRTD, SiTF, and other areas will be presented. Relative advantages and disadvantages of emissive and reflective systems will be shown, in addition to requirements placed upon test laboratory environment by the different projector technologies. Discussion of software-based compensation techniques for mitigating reflected ambient effects, environmental ambient drift, and other anomalies will also be provided.

Keywords: IR test and evaluation, target projection, reflective target, emissive target, thermal imager, sensitivity, resolution, MRTD, spatial NETD, SiTF, non-uniformity.

1. INTRODUCTION

Minimum Resolvable Temperature Difference (MRTD) is a key figure of merit used to characterize the performance of thermal imaging systems. It is a subjective test providing a combined measure of system thermal sensitivity and spatial resolution. The test requires the operator to determine the temperature difference resolvable at various spatial frequencies, typically using 4-bar target patterns.

Consistency of MRTD test results is dependent upon the stability and repeatability of the target projection system. With thermal imagers now tested in a variety of conditions (laboratory, production, depot, field, etc), recent tests have shown that as the ambient temperature varies, some test systems may fail to maintain a stable and repeatable differential target image. As UUT spatial and thermal resolution continues to evolve, these test issues become more significant.

1.1 Target Stability, Uniformity, & Repeatability

Typical target projectors can maintain differential temperatures of ± 0.001 °C, but as ambient temperature varies, the target temperature can drift, resulting in an unstable image – forcing the operator to adjust the UUT’s temperature window offset and affecting consistency of the test results. Other effects such as thermal gradients at target and source surfaces also introduce errors. The magnitude of these errors is dependent on the rate of change of the ambient temperature, and other system-specific factors such as target and blackbody emissivity, optical baffling, and target edge characteristics.

Thermal imagers do not directly measure temperature differences (ΔT), but rather sense radiance (L) and differential radiance (ΔL). Since radiance is a nonlinear function of temperature, a given thermometric DT does not always produce the same ΔL . This effect is small in laboratory conditions but readily detected by many modern thermal imagers.

The differential radiance seen by a UUT looking at an ideal target/blackbody system may be expressed as the difference between blackbody and target radiance:

$$\Delta L = L_{bb} - L_{tgt}$$

For real-world blackbody and target surfaces with non-unity emissivity (ie, $e < 1.0$), the reflected ambient components of the radiance must be included. The differential radiance can then be expressed as a sum of the Planck terms for each emitted and reflected radiance source:

$$\Delta L = \epsilon_{bb} \int_{\Delta} W(T_{bb}) d\lambda + (1 - \epsilon_{bb}) \int_{\Delta} W(T_{amb}) d\lambda + \epsilon_{tgt} \int_{\Delta} W(T_{tgt}) d\lambda + (1 - \epsilon_{tgt}) \int_{\Delta} W(T_{amb}) d\lambda$$

The non-linearity of the Planck function gives rise to a variation in differential radiance with ambient temperature change - even when thermometric ΔT is maintained. This variation is known as a “radiometric ΔT ” error. The graph(s) below displays typical differential radiance error for a range of ambient temperatures.

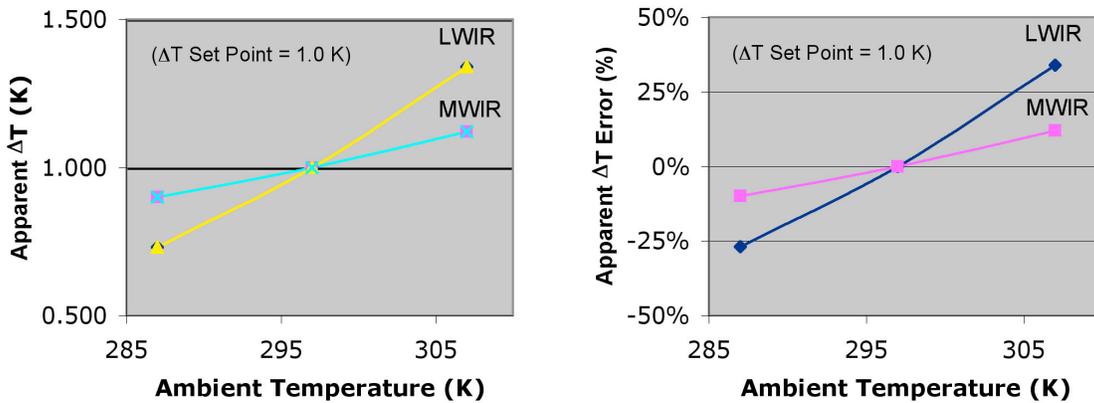


Figure 1 – Typical Apparent Temperature Error vs. Ambient Temperature

In lab environments, this error equates to 5 % imager response variation in the LWIR and 2 % in the MWIR. Under field and depot conditions, the error increases to 25 % response variation in the LWIR and 10 % in the MWIR. Depending upon UUT thermal resolution and other performance specs, these errors may be problematic in characterizing system MRTD.

1.2 “Radiometric ΔT ”

SBIR differential blackbody systems provide a “radiometric ΔT ” (R ΔT) feature to preserve differential radiance in the presence of varying ambient temperature. Implemented in software and firmware, the R ΔT algorithm adjusts blackbody temperature in real time – based upon ambient temperature and system optical properties – to provide constant ΔL over varying ambient temperature.

1.3 Test System Design Improvements

Target non-uniformity caused by changes ambient temperature can be removed by utilizing a “reflected background” target projector configuration as shown in figure 2.

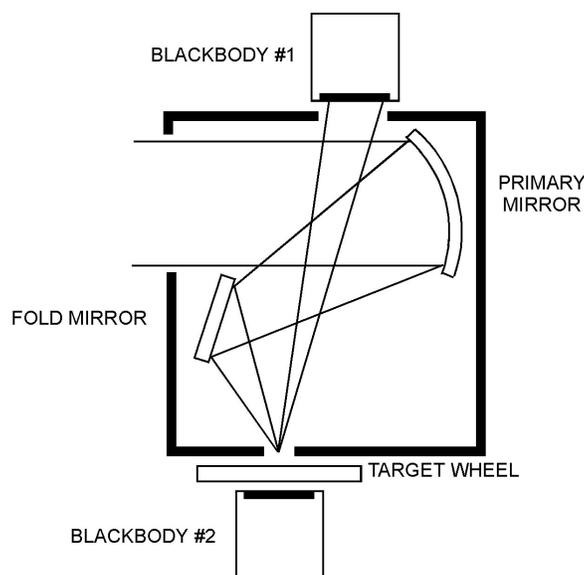


Figure 2 – Reflected Background Target Projector with Dual Blackbody Sources

Reflected background target projectors include precision reflective gold target surfaces, and two blackbodies – for both target and background.

The ability to control both target and background temperature minimizes the effect of ambient drift upon target stability and uniformity, allowing measurement of very low level MRTD at user-selectable background temperatures, without the need for continual readjustment of thermal imager offset. With careful optical baffling and ambient temperature control, these state-of-the-art reflective target projection systems provide a stable, repeatable MRTD measurement capability over spatial frequency ranges resolvable by modern high-performance thermal imagers.

2. TARGET PROJECTOR DESIGN

2.1 System Configuration

In order to begin to quantify the differences between the performance achievable with laboratory-grade projection systems employing emissive and reflective targets, SBIR has configured an internal “house” projector system. This system will not only enable in-depth technical comparisons between candidate targets, optics, and measurement components, but also support the demonstration and optimization of emerging laser measurement and characterization products for a variety of customers’ UUTs and subsystems.

This new projection system uses an unfolded Newtonian optical form with a 12” diameter OAP and 60” focal length, and includes dual blackbody sources, a target wheel capable of holding a variety of emissive and reflective target configurations, and an IR Windows system for source/target control and data acquisition. The target wheel is adjustable via a kinematic mount to achieve both a “normal” and “tilted” focal plane for use of emissive and reflective targets, respectively – and all optical components are mounted to an optical table for maximum stability and flexibility. The system is housed in a dedicated room in the new SBIR facility, which will eventually allow independent control of ambient temperature and dramatic reduction of stray light effects.

Figure 2 illustrates the system configuration, and its use with both emissive and reflective target technologies.

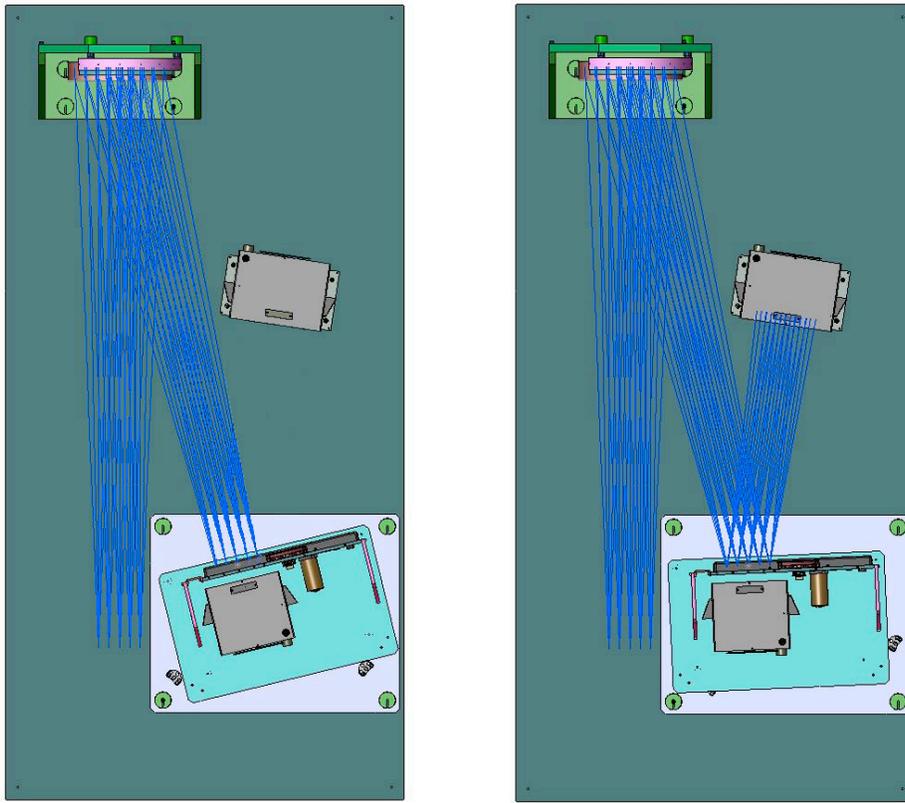


Figure 2 – Target Projector System with Kinematically-Adjustable Target Wheel and Dual Blackbody Sources, Supporting Both Emissive (left) and Reflective (right) Target Configurations

The OAP mount, target wheel, and background/target blackbody sources are comparable to those utilized on a variety of open-air projector systems. Several views of the assembled system are shown in figure 3.



Figure 3 – SBIR's In-House Target Projector System

2.2 Target Selection & Construction

For this initial target comparison, we selected a basic target set enabling measurement of signal transfer function (SiTF) and MRTD. This consisted of a single square target (for SiTF) and a low-frequency four-bar target (for MRTD), fabricated in both emissive and reflective formats. The MRTD target had a bar pitch of 0.72 inches, which corresponded to 0.083 cycles/mrad using our 60" FL. For an IR camera with a pixel pitch of $\sim 30 \mu\text{m}$ and a lens FL of 25 mm, this equates to 0.2 times the Nyquist spatial frequency – a sensible design point to assess low frequency MRTD performance.

The emissive targets used a high-emissivity coating ($\epsilon = 0.97 \pm 1.5\%$) deposited on knife-edge cut metal substrates. The reflective targets were manufactured by etching the aperture pattern into a thin, gold-coated, bi-metallic layer mounted to a rigid substrate and mounting ring.



Figure 4 – Four-Bar Emissive (left) & Reflective (right) Targets

A variety of novel reflective target manufacturing technologies are under development, with prototypes to be evaluated in summer 2003.

3. TEST RESULTS

This first round of testing utilized a Merlin Lab camera. This configuration uses a high-performance 320 x 256 InSb-based FPA mounted in a pour-fill dewar, with an $f/2.5$ cold shield and a 25 mm IR lens. Testing was performed to determine the relative merits of reflective versus emissive targets for Thermal Imager (TI) testing. The Indigo Merlin TI was allowed to athermalize in the test environment for 1 hour prior to testing. The targets had been in place in the target wheel for 48 hours prior to testing.

3.1 Test Methodology

Using the SiTF routine in IR Windows 2001, the temperature window of the TI was set to approximately 1.00°C after a single point NUC was performed. The ambient temperature of the room was recorded per the T1B probe - the ambient temperature thermistor on the background blackbody source. Spatial NETD was measured using the four bar target with $\Delta T = 0$ in an attempt to assess target uniformity. After NETD measurement, two single-point MRTD runs were conducted in quick succession. Another SiTF was performed to make sure the sensitivity of the TI had not significantly changed during the test. Results of these SiTF, spatial NETD, and MRTD tests are summarized in Table 1 and Figure 5.

Performance measurements were repeated after a 12-hour dwell period to check for repeatability. Test equipment was left switched-on but the imager was turned off.

The TI temperature Window was then decreased (sensitivity or responsivity increased) to 0.75°C to see if a better MRTD could be obtained. Results are discussed below.

Finally, a localized heat source was introduced in proximity to the target plane, to demonstrate the effects on the uniformity of the two types of target.

3.2 Data Summary & Observations

Table 1 summarizes performance measurements made using the different targets and thermal imager gain settings.

Target Type	SiTF (mV/K)	NETD (mK)	MRTD (°C)	Ambient (°C)
DAY ONE				
Emissive	631	17	0.0090	22.200
	649	22	-	22.275
Reflective	684	10	0.0055	22.866
	698	10	0.0050	23.142
			-	23.352
DAY TWO				
Emissive	676	17	0.0085	23.407
	702	18	-	23.470
Reflective	692	10	0.0050	23.512
	699	11	-	23.356
DAY TWO, INCREASED RESPONSIVITY				
Reflective	950	12	0.0045	23.299
			0.0045	23.322
Emissive	981	21	0.0100	23.590
			0.0095	23.611

Table 1 – Summary of Measurements Performed Using Emissive & Reflective Targets

Figure 5 shows selected imagery from MRTD testing for each target type.

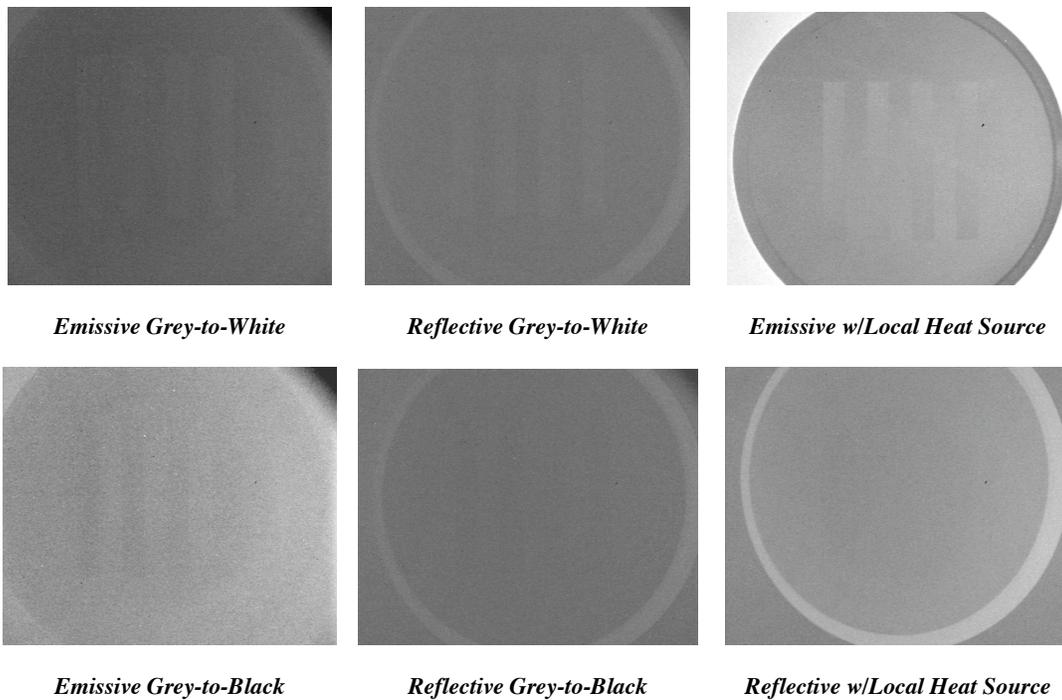


Figure 5 – Selected Imagery from MRTD Testing

The following observations were made during testing:

1. NETD & MRTD – Substantially improved NETD and MRTD was achievable using the reflective targets. Performance measured with the reflective target represents the performance limit of the UUT. This is likely due to the fact that the background blackbody source non-uniformity is spatially integrated since the source is not at focus.
2. HEAT SENSITIVITY - Any local source of heat near the emissive target created an increase in non-uniformity across the target plate, which affected the MRTD and spatial noise measurements. Reflective targets were immune to effects of local heat, as long as the heat source remained outside of the light path for the background Black Body.
3. UUT ADJUSTMENT - As the ambient temperature of the room increases, adjustments to the TI offset are necessary to compensate for changes seen on the emissive target (TI drift). This effect is not seen with the reflective target since the background temperature (TIB) is held constant by the second blackbody.
4. FOV UNIFORMITY - With reflective targets, it was possible to achieve a more uniform scene across the TI FOV by adjusting the background source temperature to match that of the target wheel. This made MRTD testing subjectively easier due to reduced distraction to the observer.

3.3 Ambient Drift

When observing an emissive 4-bar target with a thermal imager, the background comes from the surrounding black surface on the target face. This black surface is constructed from a highly emissive surface to provide an efficient transfer of target thermometric temperature into the radiometric domain. With emissive target projectors, the background temperature is not actively controlled. The target surface is highly emissive and its behavior approaches that of a blackbody; it absorbs ambient temperature and re-emits from its surface so it relies on the ambient environmental temperature to provide a “stake” in the ground. If ambient temperature drifts, the target temperature will follow - thus causing its background to be at a different temperature. The target blackbody will track these changes and maintain the desired thermometric (or radiometric) ΔT . However, the image displayed on the imager will have changed. As the target temperature increases, the background on the imager display will move away from mid-gray, and towards white (assuming “white hot” setting).

Initially, this provides a distraction to the MRTD observer as there is a finite time while the blackbody temperature adjusts to maintain the differential. The appearance of the image will have also changed, as it now appears lighter. If the temperature continues to increase, the operator must then adjust the imager’s offset to compensate and bring the background to mid-gray. With high performance imagers, the temperature window setting for MRTDs will be small, meaning that even very small changes in target temperature will require adjustment of the imager’s offset. For example, a TI with an 8-bit video output will require only a 100 mK change in temperature to result in a change in gray level of about 25 shades, with temperature window set to 1°C. This places a time constraint on the test, to avoid constant re-adjustment of the imager’s offset control. In extreme cases the test may prove impossible to perform with any consistency.

Reflective targets are largely insensitive to ambient, relying primarily upon a constant background blackbody temperature to ensure stable reflected target background radiance. Using precision blackbody sources, target backgrounds can be held to a few mK over long periods of time. This results in an easier test for the operator to perform, and a test that will provide more consistent results. The stability that dual blackbody reflective target systems can provide supports automated testing as there is no longer the need for operator adjustment to correct for target temperature drifts during the test sequence.

3.4 Thermal Uniformity

As previously discussed, the background portion of the target plate is approaching the behavior of a blackbody. Therefore, any localized heat source placed near a portion of the target causes a change in temperature on the portion of the plate nearest to the heat source. Over time, the rest of the target will slowly change as it tries to approach the temperature of the portion nearest the heat source. As this happens, an error in the reading of the temperature probe monitoring the target plate temperature will occur, because the target plate is now no longer at one even temperature, making the ΔT reading inaccurate.

This temperature change across the target will cause a gradient in the emitted radiation and will be clearly visible by a TI observing the target. The effect is seen at its worst when the ΔT is closest to zero, i.e. when performing MRTDs, the result is that the four bars will either have different ΔT s, or the bars may change from white (positive ΔT) at one side of the target to black (negative ΔT) at the other.

Because the reflective target has very low emission, it does not radiate a significant amount of energy due to its own temperature and emissivity, maintaining integrity of the test.

4. SUMMARY

Reflective target technology offers improvements in spatial NETD and MRTD measurement, target stability, target uniformity, and ease of test operation. Though performance improvement in these areas is dependent upon the type of thermal imager being evaluated, most test applications will benefit from use of reflected background target projection, compared with traditional emissive approaches.

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