Advanced Target Projector Technologies For Characterization of Staring-Array Based EO Sensors

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ABSTRACT

This paper describes recent developments in the area of target projection technologies for measurement of staring IR sensor image quality. In addition to the latest reflective target techniques, we describe a novel Variable Slit Target (VSTa) device, which allows extremely precise slit, edge, and rectangular features to be generated at the focus of a reflective target projection system, and stepped across a UUT's FOV with a high degree of sub-pixel resolution. We also present the Collimator Line of Sight Alignment Techniques (CLOSAT) as a means of both precisely aligning the target projector and adding dynamic capability to static targets. The discussion includes a review of the applicability of VSTa and CLOSAT to current and emerging UUTs incorporating advanced staring focal plane technologies.

Keywords: EO test & evaluation, MTF, MPETS, staring FPAs, VSTa, CLOSAT.

1. INTRODUCTION

The typical, modern electro-optical test station consists of the following elements: The Unit Under Test (UUT), the Target Projection System, a source controller, and a system controller that can perform data analysis. Figure 1 shows a typical IRWindows^{TM}2001system distributed by Santa Barbara Infrared, Inc. (SBIR).

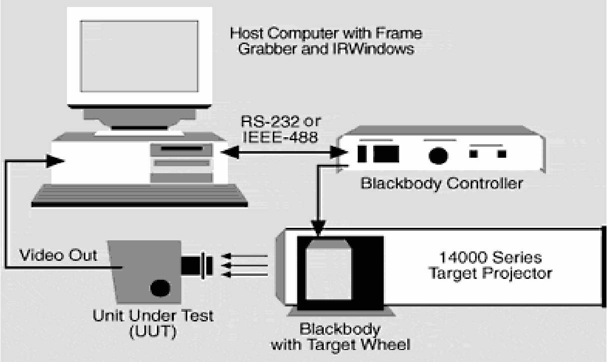

Figure 1 Test Station Configuration

Advances in the capabilities of the data analysis and test control system have been discussed elsewhere[1], and further advances in the source control will be discussed in future references. This paper will be focusing on some of the advances made in the target projector, and in particular its target feature and LOS pointing capabilities.

SBIR has been following two trends in thermal image sensor testing that have had a significant impact on target projector requirements.

The first is the advances in thermal sensors, specifically the requirements necessary to support third generation staring array sensor testing. The increase in sensor count (1024 x1024 array sizes), decrease in sensor pitch (25 µm), and decrease is system noise require continual improvements in the design of target projection systems.

The second trend is the requirement for more flexible testing stations capable of supporting the wide variety of configurations, capabilities and combinations of sensors. A UUT may consist of a stand alone thermal imager or a pod/turret with multiple sensors. Systems with more than one Field of View (FOV) are becoming more commonplace along with widely differing aspect ratios and data rates. Field test stations and depot repair sites must meet the testing demands for all the various sensor systems that could potentially be presented for test/repair/maintenance, and they must be able to perform these tests with a minimal footprint.

To meet these requirements, improvements in target projector technologies have continually advanced the characteristics of the signals presented to the sensors during testing. Reflective targets, improved target feature creation, athermal and lightweight collimator structures, and thermal source advances have all made incremental improvements in the quality of thermal images.

This paper will discuss two significant advances in target projector capabilities developed by SBIR. The Variable Slit Target (VSTa) and the Collimator Line of Sight Alignment Technique (CLOSAT) improve both the flexibility and image characteristics of the target projector.

2. OVERVIEW

Variable Slit Target - VSTa

VSTa is a device for dynamically generating a variety of target images (see Figure 2). Located at the focal plane of the collimator, the device consists of two reflective, knife edge surfaces on a precision motion control system. Each surface resides on an independent linear stage, and both sides are joined on a rotating stage.

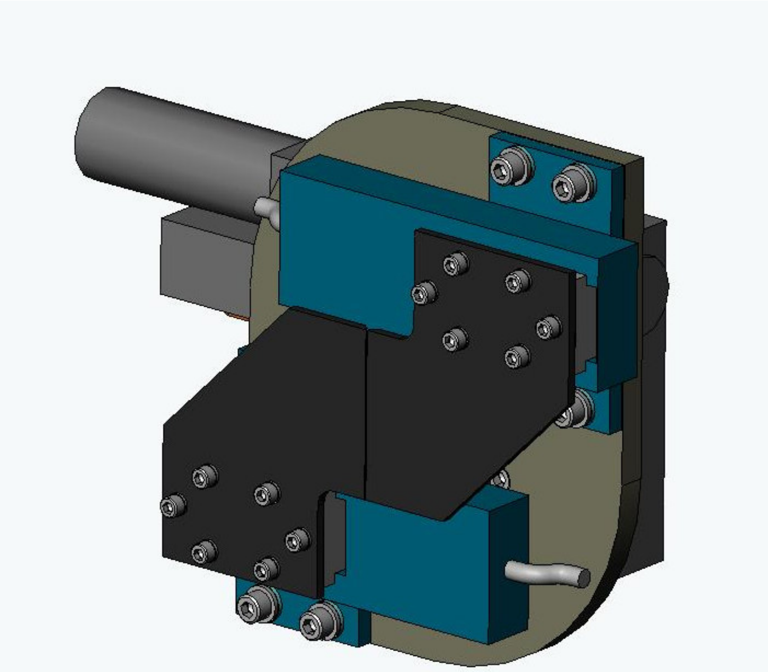

Figure 2 VSTa Diagram

This design allows a range of target configurations, as shown in Figure 3. An edge, a slit, or an open aperture can be presented to the UUT. The slit width and angle are programmable by the user to optimize projected features for the UUT under evaluation.

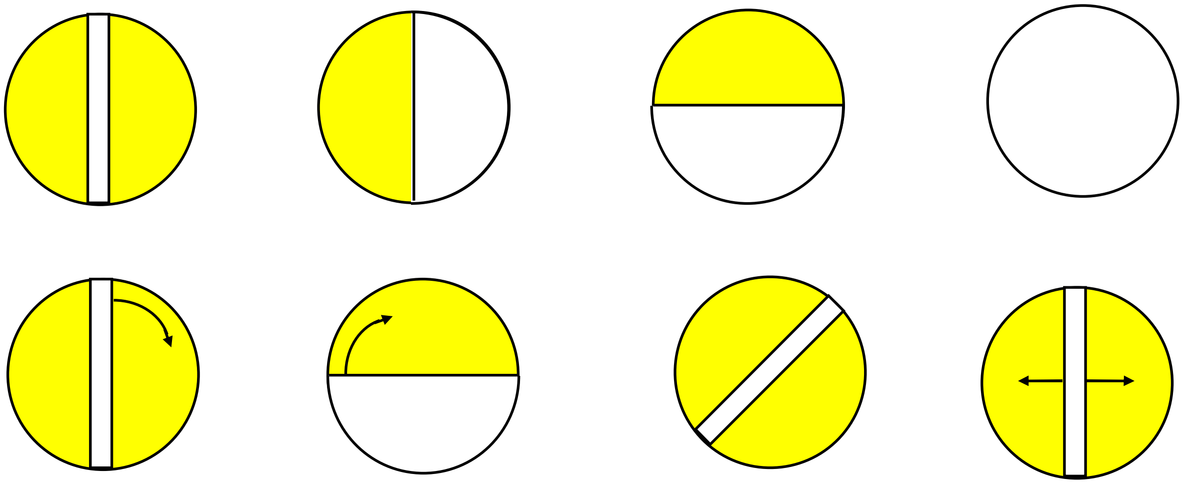

Figure 3 VSTa Target Configurations

Currently, the design provides a resolution of 0.625 µm for the gap size. In a 55 inch focal length collimator, this translates into an angular subtense resolution of 0.4 µrad for the gap size. Each linear stage has a one inch range of motion in a 1.6 inch diameter target field. Each stage extends the range of its knife edge fully off the target at one limit and past the center of the target at the other limit. This allows a constant gap width to be moved across the center of the target for a total range of approximately one quarter the target width.

For example, a third generation staring array with a 25 µm pitch in a system with a 25 mm focal length lens would have a Detector Angular Subtense (DAS) of about 1 mrad. In the 55 inch focal length target projector system described, a slit with a gap width of 0.1 mrad (0.1 x DAS) can be moved approximately 7.2 mrad across the center of the projected FOV (+3.6 mrad to -3.6 mrad) in 0.4 µrad step size (18 000 steps). Typically, the motion of interest would be limited to the DAS and only measured at 10 evenly spaced steps, although the system would be capable of measuring over 2500 steps across the detector.

The tilt angle has a resolution of 0.5 degrees. The range of motion is limited to just over 90 degrees. Due to the symmetry of the design, this allows the edge/slit feature to achieve any presentation angle. Since the linear stages are attached to the rotation stage, the gap width stays constant when rotating.

Collimator Line of Sight Alignment Tool - CLOSAT

The CLOSAT mechanism allows for precise motion of the primary collimating mirror in two orthogonal axes. This is illustrated in Figure 4, below. The system consists of the collimator housing on a 2-axis gimbal system driven by 2 orthogonal linear stages and a unique optical feedback fixture mounted at the exit aperture of the collimator. A precision camera provides feedback for the motion control system.

The precision stages have a 50 µinches/step resolution and a range of 4 inches. With a 53 inch moment arm on the target projector housing, the primary mirror can be rotated with a resolution of approximately 0.94 µrad. The range of motion and optical feedback allow for +/- 37 mrad from the nominal center, and may be easily expanded in azimuth and elevation.

The primary purpose of this range of motion is to allow for optimal alignment between the target projection system and the UUT before any geometric tests are performed (boresight/LOS, distortion, etc). To measure the alignment of the primary mirror to the UUT mount, the CLOSAT ring provides optical feedback to a built-in, precision, VIS-CCD sensor.

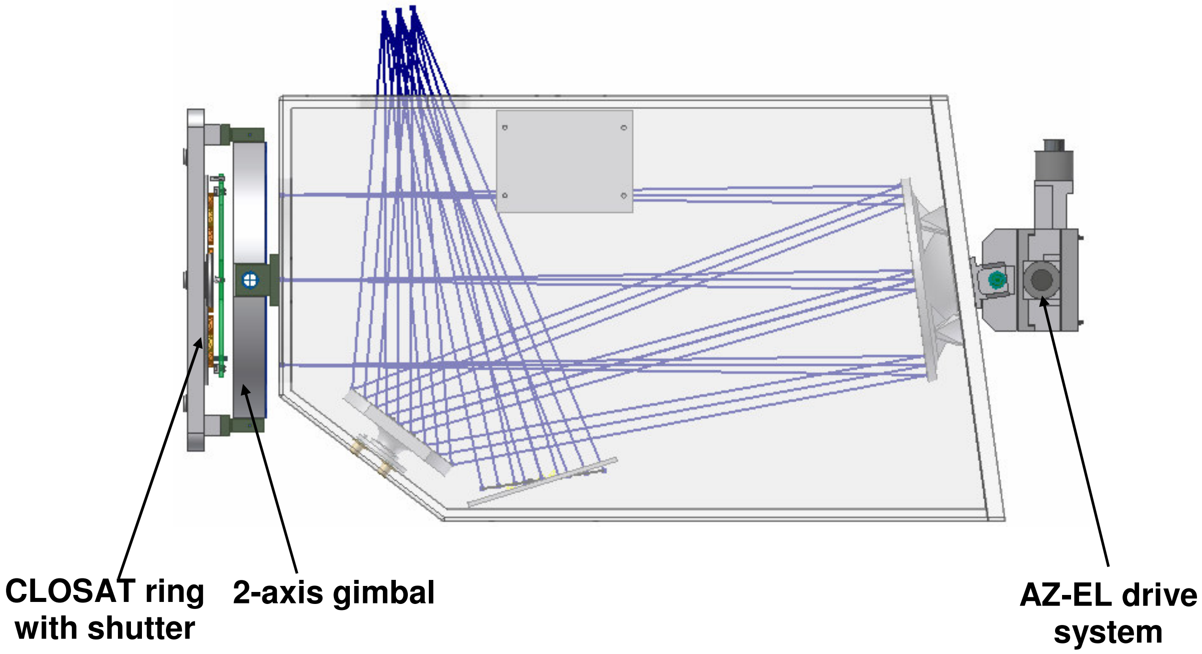

Figure 4 Components in the CLOSAT

The CLOSAT ring mechanism is a patented alignment tool mounted to the UUT mounting fixture at the exit aperture of the collimator. The ring consists of a set of 18 aluminum facets, 1 inch in diameter, bonded to an aluminum ring. The angles cut into the facets are a set of compound angles needed to cover a 4x4 matrix of facet positions projected into the focal plane of a VIS-CCD sensor. When a visible source illuminates the CLOSAT ring from the focus of the primary mirror, the angular reflection of each facet places a spot in the collimated FOV corresponding to the angle of the facet. The angles have been set to cover the full range of motion of the Az-El drive system with no gaps in coverage.

A precision VIS-CCD sensor is placed at the focus of the collimator, sensing the spatial placement of the spots reflected back by the CLOSAT ring. The sensor has a 2048 x 2048 array configuration with 14 x 14 µm pixel size. This corresponds to an FOV of 19 mrad for the camera, and a DAS of 9.3 µrad. During operation, the spot from at least one of the CLOSAT facets will appear in the camera's FOV, allowing precise determination of the collimator angle relative to the UUT mount.

In Figure 5, below, a diagram of the field coverage is shown. Each box represents the FOV of the VIS-CCD sensor, and the CLOSAT return spots are shown. The drive stages on the CLOSAT allow the system to re-zero the alignment between the target projector and the UUT mount.

Also shown in Figure 5 is a TPS return. When a TPS fixture is used to attach a UUT to the target projector housing, any angular offsets need to be measured for correction of geometric test results. A reference flat on the TPS fixture can be used by the CLOSAT reference camera to measure the TPS offset.

Although the primary function of the CLOSAT is to improve the pointing accuracy of the target projector system, a secondary feature is the ability to move any of the projected target images through the angular range of the Az-El drive system. This feature adds a limited dynamic capability to any static target, as well as target alignment capability when testing UUT/detector phase effects.

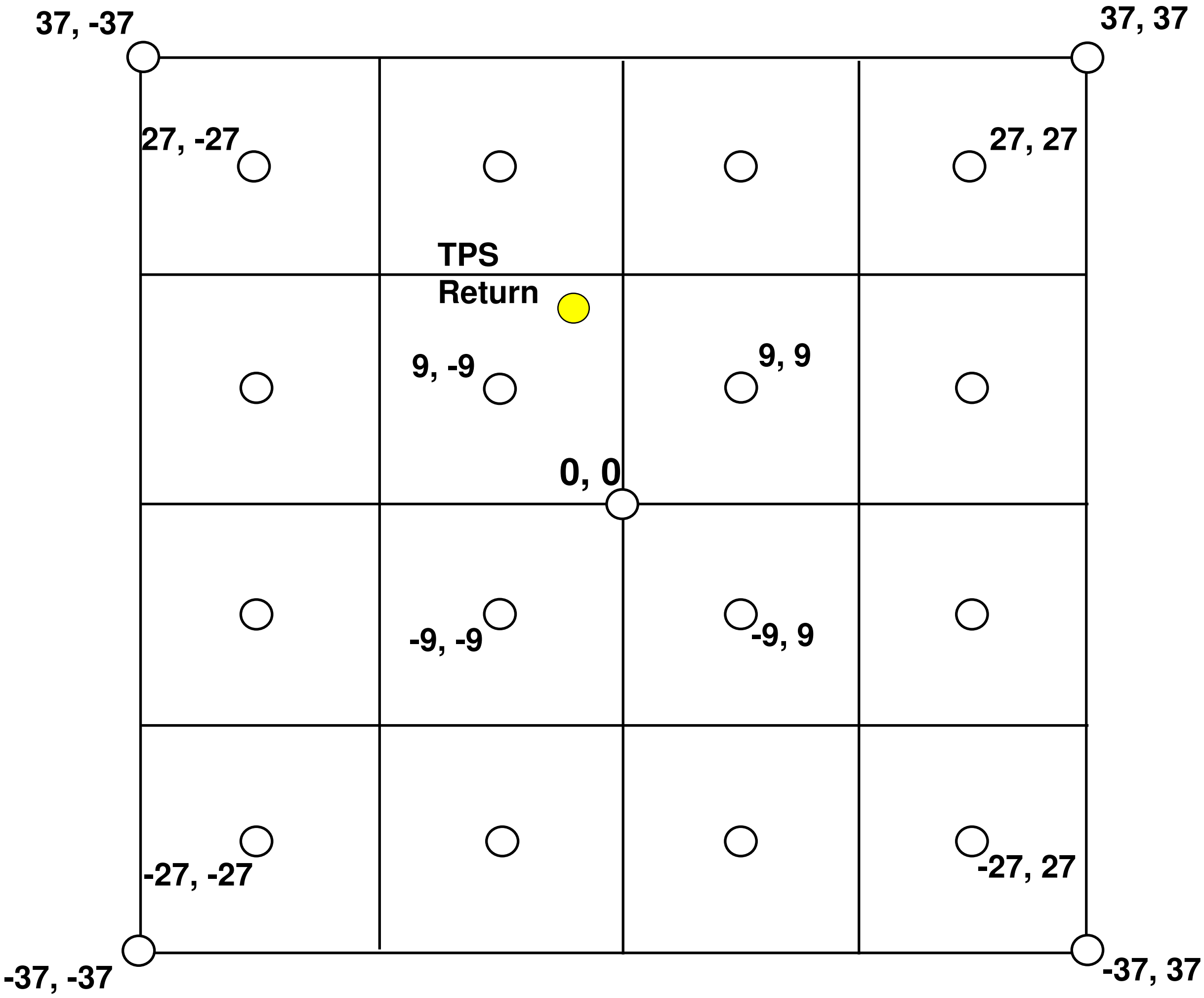

Figure 5 CLOSAT Field Coverage

3. TESTING APPROACHES

Soel[1] has defined 4 general categories of IR testing that can also be applied to any imaging system: (1) Gain Response and Noise Equivalent Sensitivities, (2) Geometric Resolution, (3) General Image Quality and (4) Subjective Observer Response. Some of the tests that fall into these categories are shown in Table 1, below.

For tests in the first category, Gain Response and Noise Equivalent Sensitivities, and the third category, General Image Quality, the VSTa capability allows the target to be configured into an appropriate, static configuration. The blades can either open completely for an unobstructed view of the source, close completely for a uniform, reflective surface, or provide a ‘half-moon’ configuration, where half the target image is reflecting a background value and half is open to the controlled source. These are the configurations typically used for SiTF, NETD, 3D Noise, uniformity, and all other standard tests measuring noise, responsivity, or general image quality.

Geometric Resolution tests (the second category) are often dependent on the pointing accuracy of the target projection system relative to the UUT. As the requirements on advanced imagers and targeting systems have increased, so has the need to both prevent and correct stress and thermal movement in the structural supports of the test system. LOS correction becomes a more difficult and critical part of highly accurate geometric testing. Advanced, composite materials used in the construction of the housings and structural supports minimize these effects, and the CLOSAT system has been designed to make adjustments, removing any long term changes in the system.

Table 1 General Categories and Test Listings Applicable to 2-D Staring Infrared Sensors

Gain Response and Noise Equivalent Sensitivities	**Geometric Resolution**	**General Image Quality**	**Subjective Observer Response**
Signal Transfer Function (SiTF) • Response Linearity (RL) • Dynamic Range (DR) • Photo-Response Non-Uniformity (PRNU)	Field-of-View (FOV) Instantaneous FOV (IFOV)	Illumination Non-Uniformity and Image Statistics • Min, Max, Mean, Std/Mean, etc…	Minimum Resolvable Temperature Difference (MRTD)
Temporal NETD and NPSD	Slit Response Function (SRF)	Visually Discernable Temporal Noise	Auto-MRTD • Req'd: NETD, MTF, K-coef's
Spatial NETD and NPSD • Offset Non-Uniformity, or Fixed Pattern Noise (FPN)	Ensquared Energy (EE)	Visually Discernable Spatial Noise • NUC vs. Time	Minimum Detectable Temperature Difference (MDTD)
3-D Noise (NETD) • All (7) components	Contrast Transfer Function (CTF)	Narcissus Images and Ghost Images	MRTD Offset • Null's Target dT Errors
NETD vs. Background Temperature (NETD-W curve) • SiTF vs. Temp. Background • Noise vs. Background.	Modulation Transfer Function (MTF) • ESF, LSF • Live MTF Module	Residual Non-Uniformity • Gain • Offset	
Radiometric Tests: • Noise Equiv. Radiance (NER) • Noise Equiv. Flux Density (NEFD) • Noise Equiv. Power (NEP) • D-Star (D*)	Distortion (DIST) Boresight Alignment (BA)	Bad Pixels Finder • Gain • Offset • Excessive Noise • Blinking	

MTF is a measure of the spatial frequency response of an imager, including focus. It is typically displayed as a curve plotting the transfer function of the system vs. spatial (or angular) frequency. A more thorough discussion of MTF can be found in Holst[2].

The MTF test has unique requirements that influenced many of the design advances in VSTa. Beyond the pointing accuracy of the collimator, the spatial resolution demands of MTF testing are challenging. This is especially the case when a UUT with multiple FOVs must be tested, or when multiple UUTs with different spatial resolutions or sensors must be tested.

There are two general methods of MTF measurement: direct and derived. Direct measurement characterizes the response of the system at discrete frequency modulations using either sinusoidal or bar targets. Derived measurement characterizes the frequency response using Fourier analysis of a signal response function.

The direct method suffers from low speed and inflexibility. A bar pattern at a fixed spatial frequency is presented to the imager and its response is measured. The measured response is used to calculate the transform at the presented frequency, and the transform is one point of the MTF curve. Several additional bar patterns at varying frequencies are individually presented to the imager, and the response to each frequency is measured, the transform calculated, and the MTF graph is created. The approach is slow since each discrete frequency used to generate the MTF curve must be individually presented to the imager (ideally in the same position within the FOV), measurements taken, and data reduced. The method is also inflexible since the targets are at fixed spatial frequencies and must range across the expected MTF curve of the UUT. If the expected spatial response of a new UUT is significantly different than the original, it may require additional bar targets.

The derived method of calculating MTF performs a Fourier transform over the data collected from a Line Spread Function (LSF), or a Point Spread Function (PSF). An Edge Spread Function (ESF) can also be measured and the result differentiated to get an LSF. One advantage of this method is its speed. A single image (or a single average image calculated from a series of images) is used to calculate a detailed MTF curve. A typical desktop computer can calculate a Fourier Transform much quicker than a mechanical target change can occur.

As with direct methods, LSF and PSF methods typically require a new target for each UUT with a significantly different spatial response. These targets have exacting requirements, with the width having an angular subtense significantly smaller that the DAS.

The ESF method has the advantage of being more flexible since a single edge can support a variety of UUTs with varying spatial responses. The disadvantage of an edge response is that the differentiation step accentuates any noise seen in the image. This impacts the final MTF curve.

An additional problem with the derived method of MTF calculation is under sampling across the edge and the related problem of the position of the edge as it's projected onto a detector, also known as the phase problem. To effectively reproduce any of the spread functions from discrete measurements, multiple points should be measured across the transitions (see Figure 6, below). However, modern imaging systems typically have PSFs with widths on the order of the DAS. This presents a problem of trying to effectively sample the PSF in a way that retains critical spatial frequency response information.

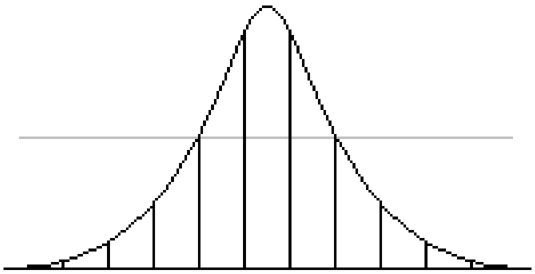

Figure 6 Sampling a PSF

There have been several approaches to solving this problem. One general category of solutions involves sampling several different detectors with the edge or slit centered at different offsets from the detector edge. For instance, a regular pattern of slits offset by a non-integral multiple of the DAS will center each slit at a different position over a detector.

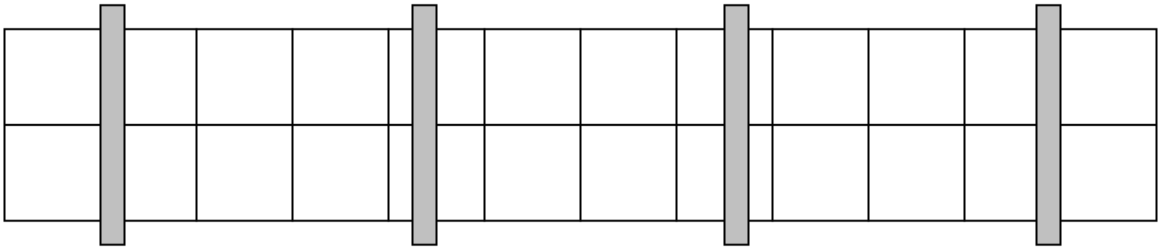

Figure 7 Periodic Slit Pattern

Another method puts the edge or slit at an angle to a column of detectors. Then, each detector in the column has the edge crossing at a different position relative to the detector edge. One implementation of this method has been made into a standard by the ISO Committee[3].

One of the problems with this multiple detector method is that the response of each detector must be normalized for the system to effectively reconstruct the ESF, LSF, or PSF. Furthermore, with the multiple-slit method, each slit must be accurately reproduced, or the variance reduced by some normalizing calculation.

An alternative method is to scan the edge or slit across a detector as the detector is measured in time. This temporal sampling effectively reproduces the spatial response without the need for normalization between multiple detectors or image sources.

The VSTa mechanism allows the angled edge or slit method as well as the scanning edge or slit. The angular rotation of the VSTa allows a better fit between the spatial characteristics of the UUT and the number of complete phase rotations measured in the static, slanted edge method (the ISO 12233 standard requires an integral number of phase rotations in the measurement).

VSTa also supports the scanning edge or slit method. In addition to controlling the motion of the slit across the detector, the slit width can be varied to best match the DAS of the UUT. This flexibility allows the test engineer to best match the VSTa configuration to the UUT, and also allows CLOSAT to provide accurate relative motion between slit (or edge) and UUT.

For the fourth category of testing, Subjective Observer Response, the MRTD test is the classic example. MRTD is a measure of spatial resolution versus temperature sensitivity. It plots the minimum temperature necessary to resolve an image at a particular spatial resolution. The most important aspect of performing the test is that it requires the use of one or more human observers to determine image quality. A more thorough discussion of MRTD can be found in Holst[4].

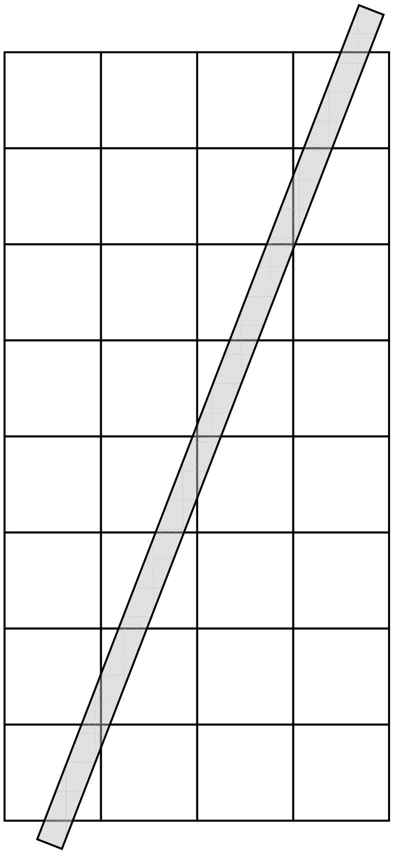

Figure 8 Angled Slit

MRTD is typically performed by presenting a 4 bar target at a discrete spatial frequency to the UUT and having a human observer determine the minimum temperature differential at which the bars of the target are resolved by the UUT. This test has been subject to a wide variety of critiques and criticisms over the years, often focusing on the subjective nature of the observer's measurements and the resulting variance in responses. Despite these criticisms, the test has continued to be used, which is a testament to its value as a metric of image quality.

More recently, problems with the MRTD test have been identified when used on staring arrays[5]. These problems are based on relative offset between the image and the staring array, as shown in Figure 9 and Figure 10. Several alternatives have been proposed, and one is the Dynamic MRTD (DMRTD). Webb and Halford experimented with DMRTD by rotating the sensor in collimated space[6].

The CLOSAT system provides a way to implement DMRTD by moving the projected image of the 4 bar target across the FOV of the UUT. The rate and the range of the image motion can be controlled to best fit the recommended practices.

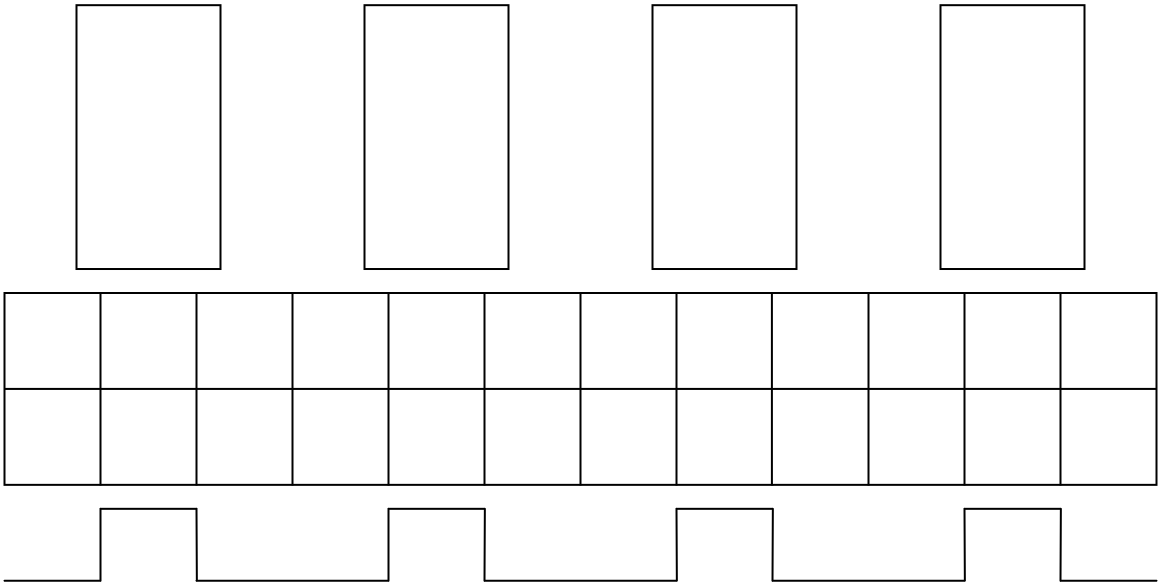

Figure 9 MRTD Phasing Alignment 1

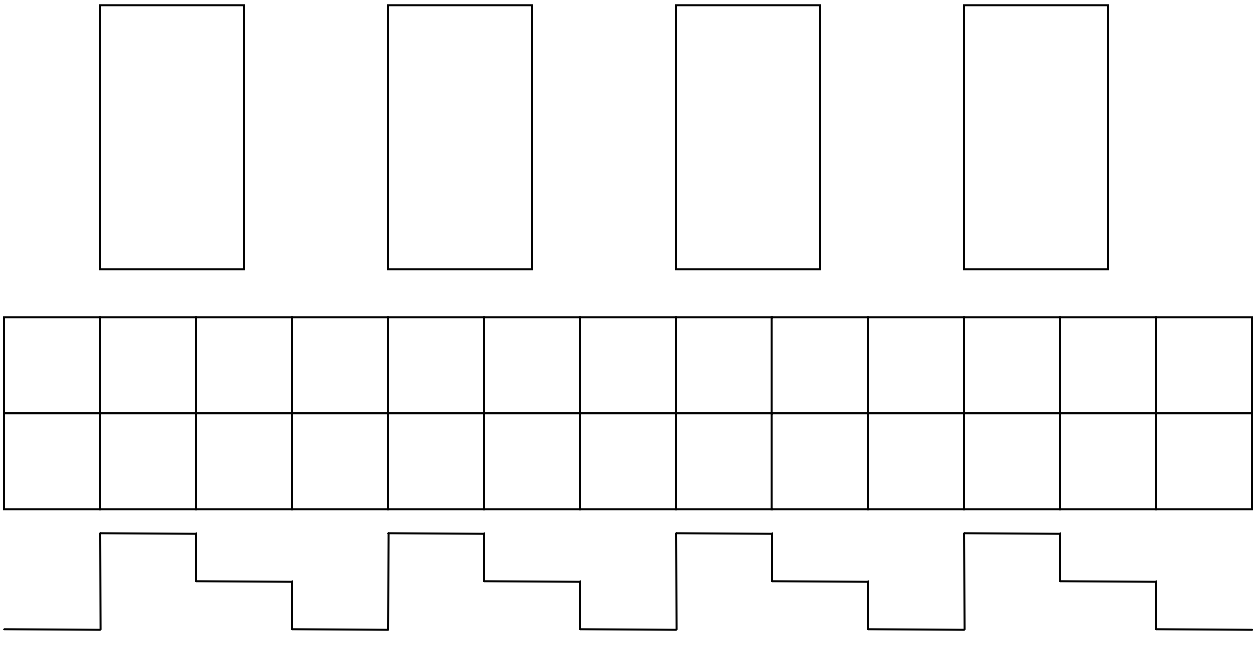

Figure 10 MRTD Phasing Alignment 2

4. CONCLUSIONS

CLOSAT and VSTa technologies have been developed by SBIR to improve the performance and flexibility of target projector systems. The demands of third generation thermal imagers, as well as the need for facilities that can test a variety of devices, multi-sensor pods, and variable magnifications are met by these devices.

The initial implementation of both CLOSAT and VSTa addresses the Navy's Man-Portable EO Test Station (MPETS) program. Testing is currently underway.

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