Discussion of IR Testing Using IRWindows™2001

This paper is the result of a joint effort by two companies.

Santa Barbara Infrared, Inc. (SBIR)

SBIR designs and manufactures the most technologically advanced Electro-Optic Test Equipment available in the world. SBIR is the leading supplier of standard and custom instrumentation for FLIR testing, Visible sensor testing, Laser Range Finder/Designator testing, IR detector testing, IR simulation and multi-sensor boresighting. SBIR instrumentation and software is an integral part of most of the current commercial and military test sets in use today, spanning laboratory, production, depot, and field applications.

FLIR Systems, Inc. (FLIR)

FLIR Systems is a leading global manufacturer of high performance IR thermal imaging systems. Serving the commercial thermography market as well as a wide range of commercial, airborne law enforcement and military imaging segments, FLIR's experience in thermal imaging systems is quite extensive. Over the past several years, FLIR has been upgrading its capabilities in IR systems testing and improving its production / QA ATP processes to better ensure the performance of its wide range of high quality imaging products. Several SBIR IR test stations (HW and SW) are presently in service at FLIR, in the R&D engineering group as well as both the Ground and Airborne/Maritime production lines.

TESTING OF IR STARING SENSORS

IR sensor testing theory, image quality metrics, and measurement methodologies have received much attention over the past 15 years, yielding the writing of many texts and technical papers on the subject. It is not the intention of this paper to restate this work but rather to present useful information on a new tool-set (IRWindows™2001) that incorporates this work into an automated and highly flexible test environment.

Categories of IR Testing, Suitability and Test Interdependence

System-level testing of infrared imaging sensors can be grouped into the following general categories: (1) gain response and noise equivalent sensitivities, (2) geometric resolution metrics, (3) general image quality, and (4) subjective observer response. Each category encompasses a large number of specific test metrics that are used to fully characterize the operation and performance of an IR imager. Table 1 summarizes a comprehensive list of tests, all of which can be performed within the framework of the IRWindows™2001 package. These tests are used throughout the IR sensor development process to characterize and validate component and system level performance.

Figure 1 illustrates the general hierarchy of test execution and interdependence of test results. Some tests are performed manually, that is the user interactively commands the IRWindows™2001 blackbody source and target wheel assets and may utilize other external devices such as a motorized stage, digital oscilloscope, etc. to perform the specific measurement. Examples include FOV/IFOV mapping, Bar Target CTF, Narcissus and ghost images assessments, etc. Other tests are both objectively quantifiable and fully automated such as SiTF, NETD (temporal, spatial, 3-D), MTF, Radiometric tests, etc. There is a third class of tests that are carried out in a semi-automated fashion. These tests make use of defined test procedures in the IRWindows™2001 software, but also require active user participation in the execution and acquisition of the measurements. Examples in this category include SRF where the user interactively adjusts the slit widths, and MDTD and MRTD where the user is a "trained observer" subjectively determining the discernable limits.

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	

The priority of test execution and interdependence of results is also important to consider when establishing a test measurement plan. The following generic IR imager setup is typically used as a pretest procedure before any lab measurements of system performance are conducted:

- Setup IR imager, UUT (unit under test), and configure it accordingly:
  - Manual mode
    - No AGC or automatic level control, extraneous image processing, etc.
  - Usually set for maximum user gain (most sensitive setting)
  - Adjust level for signal output in the linear range of the UUT
    - For an RS-170 video signal, this is typically between 200mV and 600mV
  - Focus on the target, usually a test target viewed through a collimator
  - Perform a single-point, Non-Uniformity Offset Correction (NUC) on the UUT

From this stage, the test engineer may choose to perform a series of manual tests such as the visual inspection of image quality or observable noise issues or narcissus checks. Alternatively, the engineer may start with automated tests such as SiTF or MTF. For the purposes of this discussion, we will focus on automated and semi-automated measurements performed with the

IRWindows^{TM}2001 package. Subjective image quality assessments (i.e., illumination non-uniformities, discernable noises, narcissus and ghost images, etc.) are critically important, aided by the IRWindows^{TM}2001 interactive environment, but performed manually.

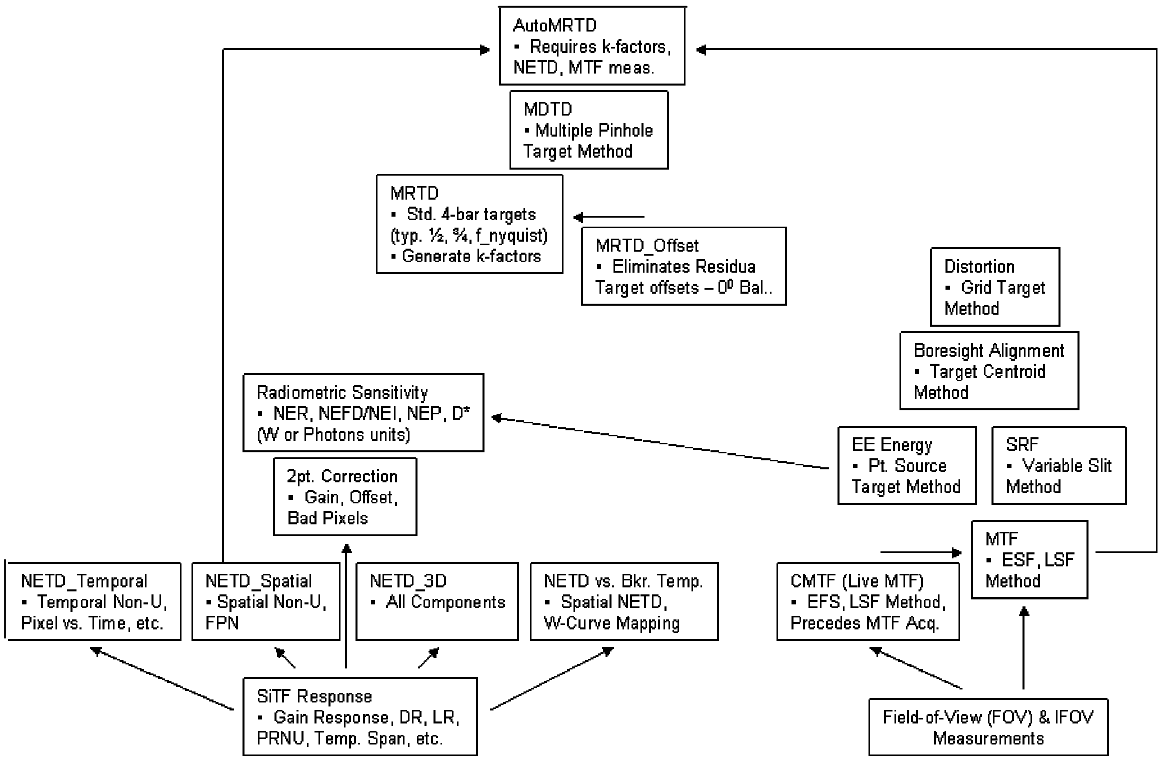

Figure 1: IRWindows2001^{TM} General Test Hierarchy and Interdependence

The most common starting point in the performance characterization of thermal imaging surveillance sensors is the determination of the basic SiTF response of the imager. SiTF provides a measure of the imager's sensitivity to changes in object scene temperature. The usual units are mV/deg C, specified at a unique scene background temperature. Given the SiTF results, the NETD (temporal, spatial, and 3-D) performance values can be measured and computed. Also, from the SiTF and NETD data the response linearity, linear display temperature span, dynamic range, photo-response non-uniformity and fixed pattern noise are derived. Radiometric sensitivities are also measurable in the new Radiometric Test Module (described in a later section). Radiometric information is of general interest to scientific users and in special military applications where target phenomenology is described in terms of radiometric quantities (i.e., IR search and track applications, detection of missile plume signatures, etc.).

Geometric resolution measurements are usually the next category of interest to the IR system developer and end-user customers. Usually, the FOV and IFOV are known, by design - however, it is easily measured by a goniometer stage or by pixel measurements of a known target dimension viewed through a collimator. Imager resolution is another key performance metric. New tests have been added to the IRWindows^{TM}2001 package to allow the performance of ensquared energy and slit response function tests, which provide the ability to critically evaluate the actual geometric resolution profile of the sensor system. This provides the user with the flexibility to describe the resolution of the imager by a variety of industry-accepted metrics (i.e., IFOV, imaging resolution, measurement resolution, etc.). System-level Modulation Transfer Function (MTF) measurements are also performed to evaluate the sensors ability to reproduce scene contrast as a function of target spatial frequency. An invaluable new test, Continuous MTF (real-time MTF), has been added to IRWindows™2001 to allow the user to optimally peak the focus MTF of the UUT prior to collecting archival MTF data.

Subjective observer response tests, MDTD and MRTD, are very common FLIR imager measurements. These tests account for both the resolution and sensitivity performance of the FLIR. MDTD is a measure of the observer's ability to detect the presence of thermal target, whereas the MRTD is specifically associated with the observer's ability to discretely resolve the complete detail of a 4-bar pattern at particular spatial frequencies. Both of these tests require specialized targets, trained observers, take a reasonable amount of time to perform (relative to other automated tests) and should have multiple observations made to reduce measurement uncertainty. In general, these measurements are useful in terms of sensor-to-sensor comparisons, yet they are easily subject to ± 20% uncertainty margins.

AutoMRTD is test methodology, typically used in a high volume production environment that attempts to determine the MRTD response of an imager by an objective means. The basic approach is to acquire quantifiable NETD and MTF data sets along with manual MRTD measurements on a large sample set of camera's (i.e., 50 – 100 systems). Then a proportionality constant, "K", can be computed at the same discrete spatial frequencies that the manual MRTD is performed, according to equation 1.

(1) $$K_f = \frac{MRTD_f \, MTF_f}{NETD}$$

Based upon the reliability of the statistical results of these "K" values, subsequent imagers would only require their NETD and MTF to be measured and then the MRTD's could be predicted according to equation 2. The main benefits of this approach are to increase production ATP throughput (reduce measurement time), reduce measurement uncertainty margins (due to multiple test personnel and their individual subjectivity levels), and maintain product quality. FLIR is currently evaluating this process for inclusion in its production QA ATP process.

(2) $$MRTD_f = \frac{K_f \, NETD}{MTF_f}$$

Engineering Qualification vs. Production QA ATP

Engineering development and qualification of IR imaging products typically involves performing all of the tests described in Table 2.1-1. Using the IRWindows™2001 test platform, a complete characterization of IR sensor performance can be easily achieved. Since the test methodology remains constant, the effects of product design changes and component variations can be accurately identified and parametrically assessed.

In addition to the value of the test data, many of the *output* results from IRWindows™2001 are useful as *inputs* to predictive sensor modeling codes such as FLIR92 and NVTHERM2002. Among these are 3-D noise parameters, detector D*, EE, MTF, and SRF results. The wide scope of measurements acquired with the IRWindows™2001 package (i.e., NEDT, MTF, MRTD, etc.) can be correlated with modeled results in an iterative fashion to further refine and validate these models against actual sensor performance.

In a production QA role, accurate, repeatable, well-documented results are readily achieved . A performance record for each system establishes its performance against the ATP requirements and may then be used to establish trends as the number of systems produced increases. This can provide valuable insight into the production process, surfacing possible problems with components or assembly procedures. IRWindows™2001 provides a tool for seamless transfer of test procedures developed in engineering to the production floor. Finally, the performance record for each system, as built, is available to the customer service/repair department. A given system returned for repair may be measured and compared against its original performance. This comparison can provide indications to the service technician of the possible problems. Then after repair, the unit's original capabilities can be easily verified.

Figure 2 illustrates the range of typical tests appropriate for different levels of end users and mission applications, ranging from basic commercial surveillance to high-end military fire control and Infrared Search and Track (IRST) applications. The provided time estimates are representative of average production ATP validation processes performed at FLIR for its handheld thermal imaging cameras, using the IRWindows™2001 package.

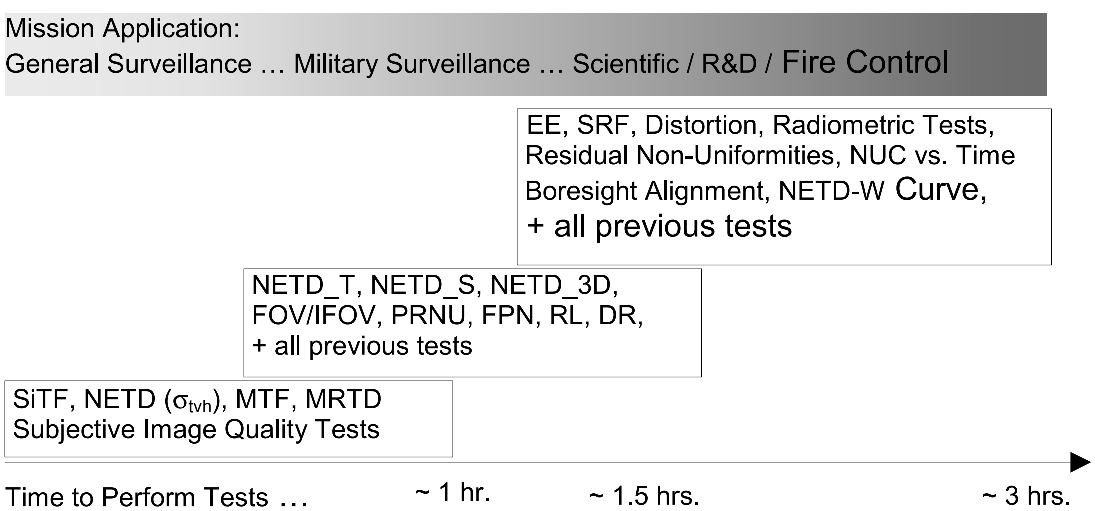

Figure 2: Typical ATP Test Requirements for End-user Mission Applications

SBIR TEST HARDWARE AND SOFTWARE - OVERVIEW

General Hardware Description

SBIR has developed a high-end commercially available turnkey IR test station consisting of both the hardware and software components required to perform all of the tests outlined in Table 1. The basic hardware components include an infrared target projector (blackbody source and digital controller, multi-position motorized target wheel and test targets), optical collimator (typical size; 60" EFL, F/5), and computer with a data acquisition frame grabber. Figure 3 illustrates a basic schematic diagram of the IR test station concept. Figures 4 and 5 show two implementations currently being used at FLIR.

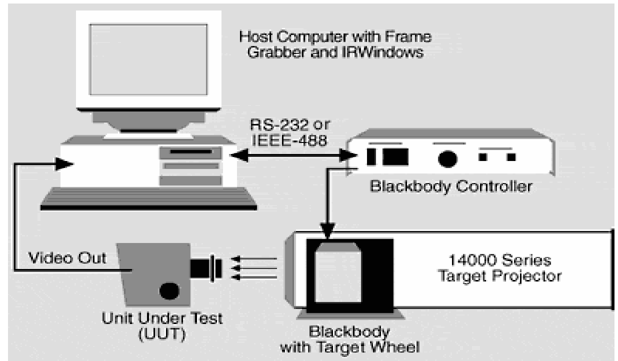

Figure 3 IR Test Station Components

Other implementations incorporating all-reflective targets, requiring two independent blackbody sources, are also available. This implementation approach, while more sophisticated, does offer a further enhanced capability to simulate targets and backgrounds over a wide scene temperature span and dynamic range.

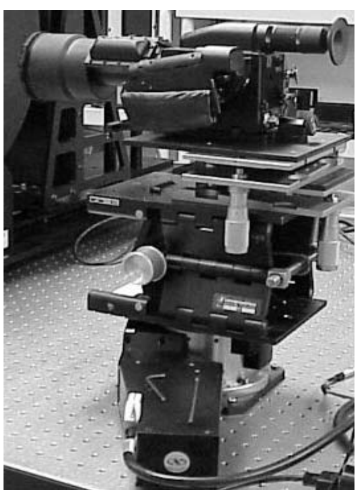

Figure 4: FLIR's MilCAM RECON MWIR Camera on a 3-axis Alignment Stage in front of the Engineering SBIR IR Test Station.

Figure 5: FLIR, SBIR Engineering IR Test Station: Includes: 60" EFL, F/5 collimator, 4" Ext. BB, 1" 1000deg C Cavity BB, 16-position target wheel, multi-source slide, range focus option, IRWindow ^{TM} 2001 Software, 1000TVL Monitor, Digital Scope, 3-axis UUT motion stage

The SBIR hardware is fully controlled by IRWindows^{TM}2001 via the IEEE-488 and/or RS-232 interfaces. Command and control of all SBIR assets, test definition, execution, data analysis, and data storage is all provided by IRWindows^{TM}2001. Data acquisition of the UUT video signal is accomplished by frame-grabbing the RS-170 (50 or 60Hz) output video at either 8 or 10-bit levels. In FLIR's configuration, all signals from the sensor are also fed to a digital scope, to ensure that video levels are always within range (i.e., linear output of the camera) and set to specific dc offset levels to help ensure repeatable and meaningful data collection with the SBIR equipment.

In FLIR's production QA ATP process, the SBIR test equipment is implemented along with FLIR's existing 250", optical collimator. In this configuration, a more basic target set is installed providing the necessary targets to perform the four basic imaging sensor tests: SiTF, NETD, MTF, and MRTD.

FLIR has implemented two SBIR IR test stations in this area; one servicing ground products and the other the airborne/maritime gimbal-based products. Each IR test station has similar test capabilities and each has product-specific optimized target sets.

General Software Description and Architecture

IRWindows™2001 is an advanced windows-based software tool that automates the setup, execution, data collection and results analysis of industry standard performance tests for IR imaging sensors, visible sensors, and laser systems. It can be utilized in an interactive fashion from a standard PC Windows interface to remotely control all IR test equipment assets. Operated in this mode, the IR system developer can use the software as a general purpose test environment to setup and assess UUT performance such as the ability to detect and discern thermal targets, assess general focus quality, capture, store and analyze image properties.

The real power of the software, however, is in its general architecture to accommodate automated testing of IR imaging systems. IRWindows™2001 can perform over twenty unique types of standardized thermal imager tests or test procedures (TP's), as listed in Table 1. Each TP can have uniquely defined test configurations (TC's) that contain the details of the test to be performed, such as the blackbody temperature, data acquisition parameters and unique test notes. Multiple TC's afford the test engineer the capability to store unique and rapidly accessible test templates that may correspond to different thermal imagers, or may be appropriate for testing different modes of a thermal imager. A set of TC's from one or more TP's can be grouped together into a test macro (TM). Macro programming capability is a powerful feature in a production QA environment as a test engineer can develop a TM that can further streamline or automate the overall ATP process.

TC's are structured in the same general fashion, requiring many common configuration inputs from test to test. Some of the most common configuration parameters include test configuration name, target selection, blackbody set-point temperatures, signal region-of-interest (ROI) location and size, number of frames to acquire, number of frames to average, A/D conversion units, and pass/fail criteria. In addition to these common parameters, each type of test will have its own set of unique setup parameters relevant to the particular test measurement.

The basic work environment of the IRWindows™2001 software is depicted in Figure 7. A standard Windows menu bar provides access to the interactive features as well as all test modules and macro capabilities. A UUT setup screen is established upon boot-up as a worksheet for the test engineer to store key information about the UUT along with a holding area to place TC's for subsequent execution and another holding area for the completed tests results – itemized in list format. In general, the user selects TC's from the various test modules and places them in the "tests-to-be-performed" section. By selecting the view option, the user can interactively do a final check of the TC parameters and acquire a live video snapshot from the UUT to ensure the target is properly aligned in the test ROI. Then the user would run the test and subsequently click on the completed test to view the results (i.e., graphs, tables, pass/fail results, etc.).

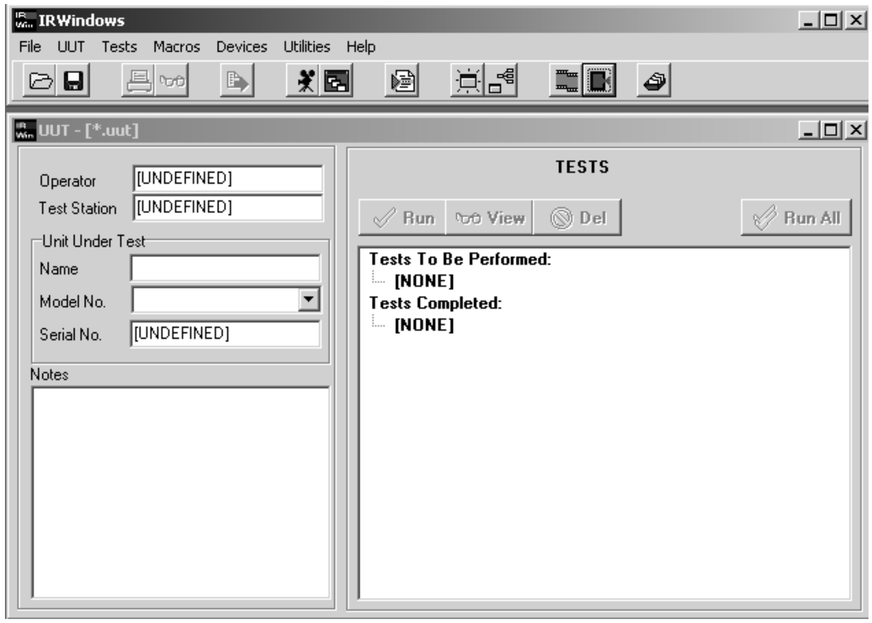

Figure 7: UUT Setup/Summary Screen

In addition to the automated tests, several interactive features of the IRWindows™2001 are noteworthy. These are found in the **Devices** and **Utilities** menus. Table 2 lists these features along with a brief description.

Figure 8 shows the IRWindows™2001 Asset Control Panel (ACP) menu. The most common assets to control are the differential blackbody source and target wheel, as shown in page 1 of the ACP. T1 and T2 are calibrated thermistors attached to the wheel and blackbody, respectively. The user can select to operate in a dT or absolute T2 set-point mode as well as establish the settling or ready window (Rdy Window) for the blackbody controller. Many different options are available on the ACP pages depending upon the assets installed with the system.

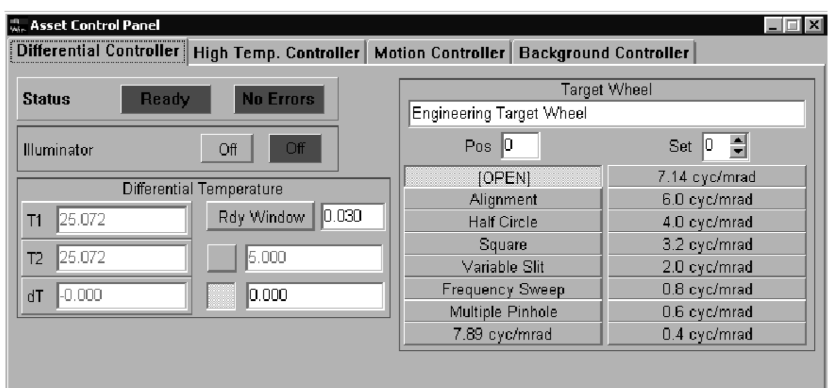

Figure 8: Asset Control Dialog

Table 2: Global Setup Functions and Interactive User Features in **Devices** and **Utilities** Menus.

Menu / Function / Feature	Brief Description / Utility
Devices	
Device Options	Allows the user to select the hardware assets (i.e., blackbody sources, stages, target wheels, etc.) to be controlled by IRWindows^{TM}2001. Assets selected will show up in the Asset Control Panel. An asset emulation option is available to simulate the function of any asset (that may not be attached) thereby allowing a TP to be performed for debug purposes
Select Image Capture	Maintains a list of all available video-driver files accessible to the frame grabber.
Asset Control Panel	Provides a user menu for the control and current status of all selected hardware components attached to the IR test station. The ACP can be accessed manually by the user or automatically by defined TP's. An image of this panel is shown in Figure 8.
Image Capture	Interactive image capture and analysis feature significantly enhanced for IRWindows^{TM}2001. Details of this feature are described in a later section.
Utilities	
Collimator Optics and Blackbody Emissivity	Allows user input of collimator EFL and average in-band transmittance factor. The EFL is used to convert target dimensions into angular units and the transmittance is used to correct for collimator losses, thereby reporting results as referred to the sensor input. User input blackbody emissivity (for both cavity and differential type) is also specified to account for non-ideal properties of these sources (typically 0.99 for cavity and 0.95 for differential.).
K-value Worksheet	This is a statistic worksheet editor that can log all AutoMRTD K-factors (sorted by discrete spatial frequency points), providing a running statistical summary of K-factors. Statistical calculations include Min, Max, Mean, Median, Std., Std/Mean* 100%.
Event Log File	A feature of the original IRWindows^{TM} that provides a log-style sequential listing of commands sent to the assets during test execution. Useful as a debug tool and allows the user to monitor the status of test execution as it is occurring.
Operator Menu	This utility allows the user to easily develop a graphical operator's window for display of macro-style commands. It is useful in a simple production QA role where only simple button commands may be desired.
Template Values	This module contains blank or default TC templates for all available TP's. The user can configure default TC's from this menu for easier setup of subsequent TC's.
Wheel Editor	This utility contains the configuration information for the targets installed in the target wheel asset. The user can input and modify the details of each target by using this editor.
Model Editor	Used in conjunction with the new IRWindows^{TM}2001 Radiometric Test Module, the detailed model editor allows the user to define key sensor design parameters for use in radiometric calculations that support the test results for the Radiometric Tests. Details of this feature are described in a later section.
Password Protection	Provides the user the ability to establish password access to IRWindows^{TM}2001 startup, editing of a TC or editing of a TM.

IRWindows^{TM}2001 Product Enhancements

The fundamental IRWindows^{TM} architecture established in early releases of the program has endured as the product has evolved over the past several years. Version 2.0 of the application, released in 1999, provided the user with a basic set of core IR test modules (i.e., SiTF, Spatial NETD, MTF, and MRTD), basic image capture capability, and macro programming functionality. At the time, it was well received by the user community and well suited in a production QA role for general IR imaging products.

The new IRWindows^{TM}2001 release represents a substantial improvement and evolution of the product, expanding its utility deep into the R&D / engineering development sector while refining its appeal to the more general high-volume production marketplace. IRWindows™2001 has evolved in several major areas:

- Addition of more than ten new IR test modules, improvements in many existing test modules and more test execution options (i.e., use of differential or absolute source, default units, options, etc.)
- Upgrade of its image capture, analysis, and data storage capabilities
- Addition of a Radiometric Test Suite and a comprehensive Radiometric Model Editor
- Addition of a wide range of units selection options, data analysis and display options, statistical calculations, enhanced graphical labeling, and improved output report capabilities

In general, throughout the software upgrade development process, the IRWindows™2001 application has been systematically restructured and streamlined, making it more efficient and flexible.

New Test Modules

Coupled with the IRWindows™ v.2.0 test suite, the new test modules incorporated into IRWindows™2001 provide the means to completely and comprehensively test almost all aspects of a high-performance IR imaging sensor. Table 3 lists the new test modules along with a brief summary of their function and utility.

NETD is one of the most common and well-known FLIR performance specifications can easily be misinterpreted or incorrectly specified. Four distinct NETD test modules (Temporal NETD, Spatial NETD, 3-D Noise, and Spatial NETD vs. Background) have been developed for IRWindows™2001 to allow the user to comprehensively characterize a FLIR's NETD performance. Measurements of NETD may be performed against any background temperature within the range of the blackbody thermal source, and testing does not require the use of any specialized targets.

Resolution tests such as EE and SRF require the use of specialized custom targets to measure these UUT optical performance parameters. The EE test requires a 1/10th IFOV (or smaller) pinhole target while the SRF requires a calibrated movable vertical slit. Both targets are available from SBIR and can be tailored to the customer's specific requirements. These types of resolution measurements are of key interest to both the commercial thermography community as well as high-end military customers. The test results are plotted along with theoretical diffraction-limited performance labels and several other industry-accepted resolution definitions, providing the user with a meaningful data analysis and useful interpretations to aid in assessing UUT performance to meet various mission applications.

The live CMTF feature added to IRWindows™2001 has proven itself as an invaluable tool for providing the user with the ability to "peak" systems focus and MTF response prior to collecting archival MTF data. This ensures measurement accuracy and repeatability.

Table 3: IRWindows^{TM}2001, New Test Modules

Test	**Brief Description / Utility**
Temporal NETD	This module can measure the temporal NETD of a single-pixel or a group of pixels in a specified ROI. Pixel Amplitude vs. time (sequential frame) and NPSD plots are available.
Spatial NETD vs. Background. Temperature (W-Curve Mapping)	Allows for the measurement of UUT spatial noise (σ_{tvh} or σ_{vh}) as a function of varying blackbody source temperature. SiTF vs. Bkgrnd. Temperature is also determined (as required). A W-curve response can be obtained.
3D-Noise	An image cube of N-frames is acquired and subsequently processed according to NVESD's 3D-noise algorithm. Seven component noise levels and an RSS total noise are reported. This data is useful as input data in std. FLIR92 and NVTHERM modeling codes.
Ensquared Energy (EE)	Point source ensquared energy is measured for the UUT. A simple 1/10th IFOV target is required to perform this test. This data result is processed for several ROI sizes (3x3, 5x5, 7x7, and 9x9). EE is subsequently used in the Radiometric tests for NER-to-NEFD conversion.
Slit Response Function (SRF)	This module maps out the SRF of the UUT. The user manually adjusts the discrete slit positions during the test execution (as prompted by the IRWindows^{TM}2001 program). This test requires a specialized micrometer adjustable vertical slit target (available from SBIR). Several industry-accepted resolution definitions are plotted along with the data results.
(Updated) MDTD	A new version of the MDTD test has been implemented that utilizes a specialized multiple pinhole target (available from SBIR) and automated procedure to measure and map the MDTD response of the UUT. An output plot of MDTD (deg C) vs. Angular subtense (mrad) is plotted.
Continuous MTF	A live (near real time, ~ 2-3 updates/sec) MTF measurement has been implemented. This CMTF test has all of the same features and functionality available to the standard MTF test. An ESF/LSF/MTF methodology is used. The main benefit of this test is to allow the user to "peak' the focus response of the UUT relative to maximum MTF response prior to collecting archival MTF data.
Gain, Offset, Bad Pixel (GOBP)	This module acquires a set of high and low temperature images and computes the standard 2pt. Correction (gain and offset) coefficients within the specified ROI. It also defines several criteria for finding so-called "bad-pixels" in the UUT. Bad Pixel criteria include gain range, offset range, noise range and criteria for variable frequency blinking pixels.
MRTD Offset	Simple test module to determine the small residual level of temperature error that may exist between the indicated 0 deg dT level set on the blackbody controller and the actual observed thermal contrast of a 4-bar target. The MRTD offset value is then used by the Manual MRTD test to help balance all of the test results about 0 deg dT.
Radiometric Test Suite	This is a single test module that computes the following radiometric sensitivities of the UUT: Noise Equivalent Radiance (NER), Noise Equivalent Flux Density (NEFD) / Irradiance (NEI), Noise Equivalent Power (NEP) and D*. The later two measurements can be system or FPA referred. The Radiometric Model Editor

Image Capture Module (ICM)

The acquisition and storage of imagery during the QA ATP process is critical to the proper documentation and testament of the systems operation. The adage, "A picture is worth a thousand words", is very true. Stored images serve to document the observable image quality of the UUT, such as the presence of bad pixels, image non-uniformities, noise, general focus quality, etc.

IRWindows™2001 now provides a newly enhanced image capture module to aid in this process (illustrated in Figure 9).

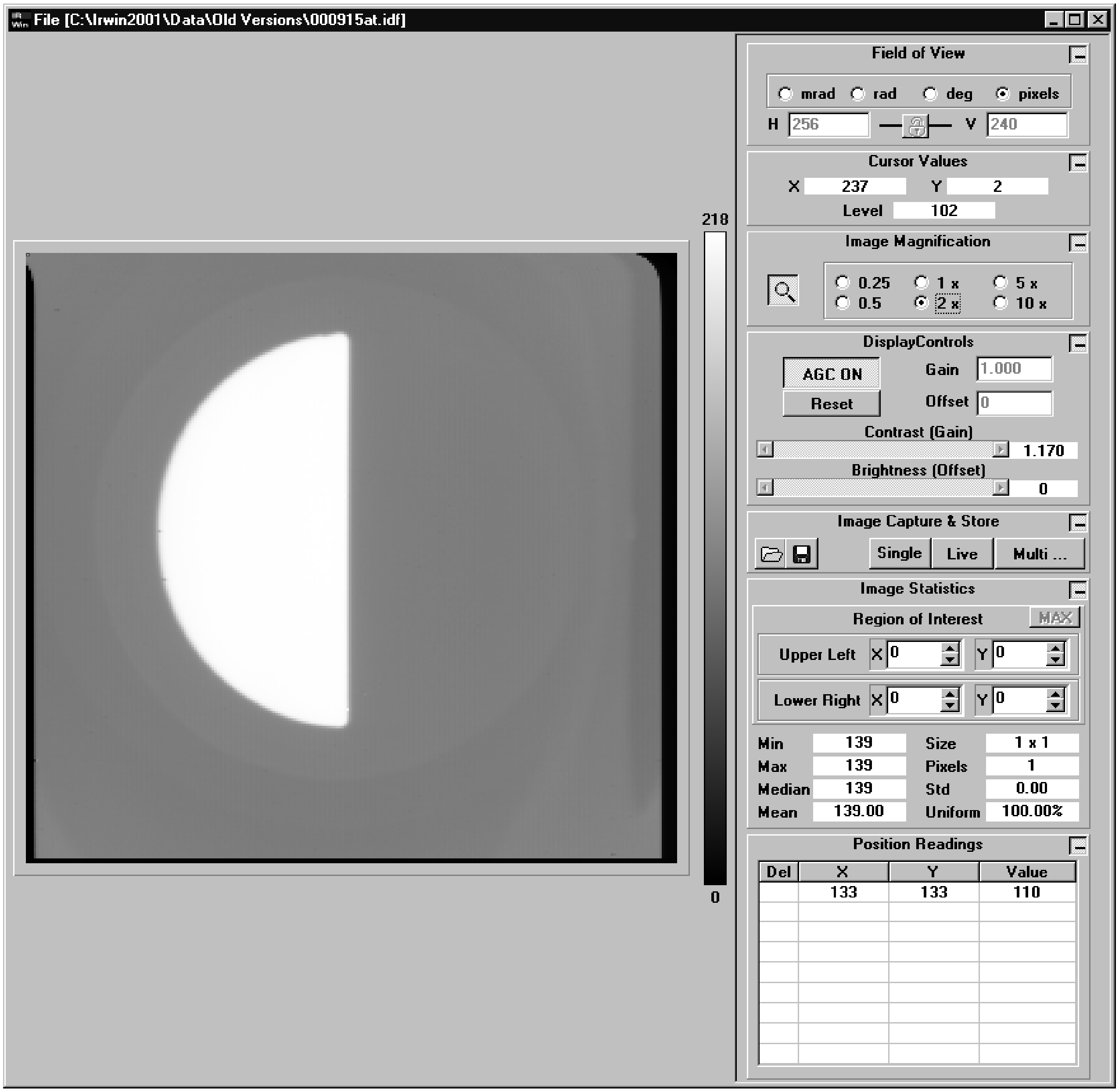

Figure 9: Enhanced Image Capture Module (EICM)

The ICM can be accessed from the **Devices** menu or directly from within the tests results screen for any test module that collects imagery as part of the test process. As can be seen in Figure 9, the ICM provides a set of interactive user tools to quantify many aspects of an acquired image. Target features can be measured by using the mouse-cursor and displayed in several forms of units (mrad, rad, deg, or pixels). Pixel intensities in ADC counts are continuously displayed. The image can be magnified and panned to aid in the observation of small details. While at this time only grayscale display is supported, the user can make use of an AGC display function to quickly establish a suitable image contrast or can manually adjust the displayed image contrast and brightness. These manual adjustments are very useful to observe very subtle image anomalies by means of increasing the gain of the image and reducing the brightness (offset level) to reveal high levels of image contrast and subtle image details.

Image capture and storage capabilities have been significantly improved. IRWindows™2001 supports live image display (near real time, ~ 5-10 Hz update rate), single and multi-frame image capture, frame averaged image capture, and variable frame sampling rates (to acquire non-sequential frames widely spaced in time). The latter is useful in assessing NUC stability as a function of time by means of computing spatial noise for images stored over an extended period of time.

Images may be loaded or stored from this module in a variety of formats. Standard formats include: *.idf (IRWindows™2001 proprietary format), *.bmp (generic windows format), and *.csv (comma-separated-value). The *.csv format is directly importable into Microsoft Excel™ worksheet or can be read into MATLAB™ using the "dlmread" command.

The image statistics feature provides basic statistical details for the user-specified ROI. The ROI can be sized from 1-pixel to the entire extent of the 2-D image. This feature is useful to get quick estimates of pixel values, non-uniformity, and min/max levels. Another useful feature is the pixel-position-readings capability. This feature allows the user to specify the use and location of up to nine pixel sampling points within the 2-D image. When selected, pixel intensities are sampled at the specified XY coordinates (in real time, if the live button is activated). This feature is useful to align finely focused, small point sources by monitoring the intensity in a center pixel along with surrounding neighbor pixels in real time. This type of process is used to prepare for an Ensquared Energy or Slit Response Function test where the alignment of sub-pixel sources is critical.

Radiometric Test Capability and Radiometric Model Editor

While describing IR camera performance in terms of temperature differences (mainly an outgrowth of the commercial thermography industry), infrared photon detectors actually respond to changes in object scene radiant flux. In fact, most high-end military IR sensor systems are more commonly defined by their radiometric noise equivalent sensitivities rather then NETD or MRTD metrics. This is largely because modeling codes quantitatively predict target and background thermal signatures as well as infrared detector performance by means of exact radiative transport theory, which employs radiometric quantities and units. The new IRWindows™2001 package can measure radiometric sensitivity of thermal imagers and work with different types of radiometric units.

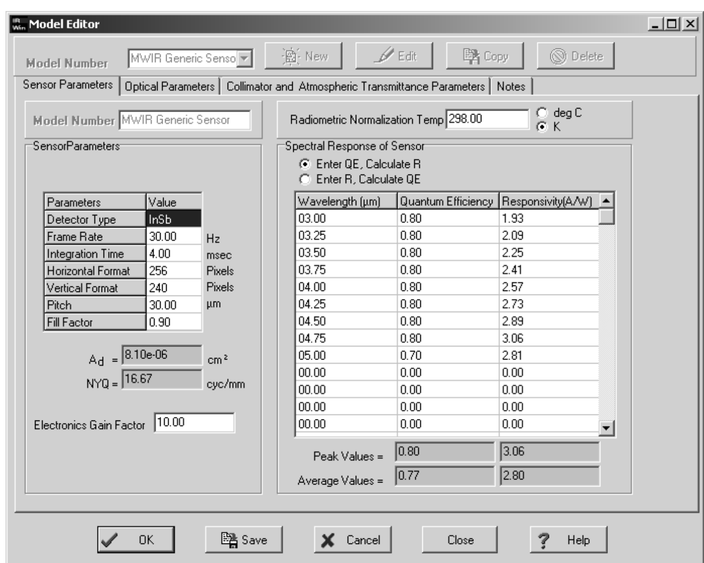

Figure 10: Page 1 of RME

IRWindows™2001 Radiometric test module can measure the following parameters: NER, NEFD, NEI, NEP and D*. The basic test procedure is simple and straightforward, only requiring the acquisition of (2) image frames (or frame-averaged composites) taken at two temperatures within the linear dynamic range of the IR sensor, yet spaced far enough apart to yield a reasonable dc response difference between the two. From this delta in output response, a host of radiometric calculations is performed by IRWindows™2001 to arrive at the various radiometric sensitivities. Total image noise levels (σ_{TVH}) are determined in the specified image to provide the necessary data to convert these sensitivities into radiometric noise equivalent sensitivity results.

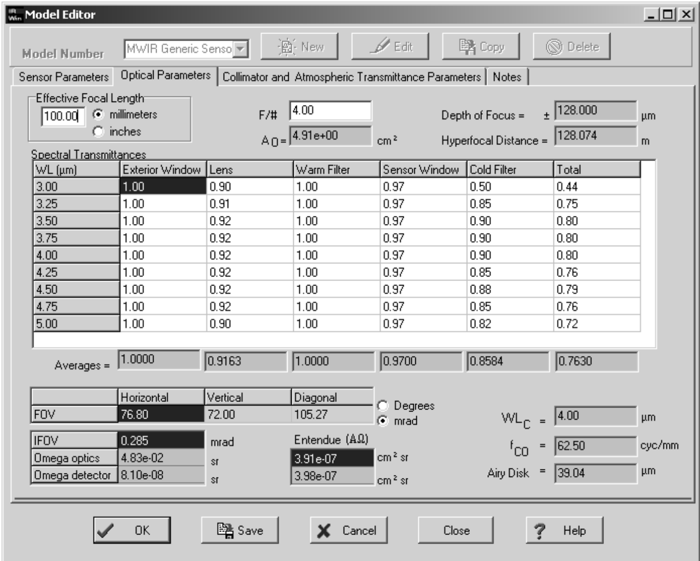

Figure 11: Page 2 of RME

The key to IRWindows™2001 ability to conduct these tests is the new Radiometric Module Editor (RME). In order to compute the different radiometric performance factors, all of the key design details of the IR sensor must be properly specified. The RME is the data entry module to accomplish this and is found under the **Utilities** menu. Users can define, edit and store uniquely named models that correspond to different type sensors that may be measured on the IRWindows™2001 equipment. Prior to executing a radiometric test, the user must first select a model from the list on the UUT display page that is appropriate to the sensor under test.

The RME consists of three main data entry pages: FPA detector, optics, and source-collimator details. A systems engineer would typically be responsible to enter the detailed technical model data for the sensor. In addition to the data entry fields, the RME performs basic back-of-the-envelope calculations on relevant systems parameters to provide the user with additional useful modeling information. Figure's 10 through 12 illustrate the RME with some sample model information (this data is representative of a generic MWIR camera and does not correspond to a particular camera model).

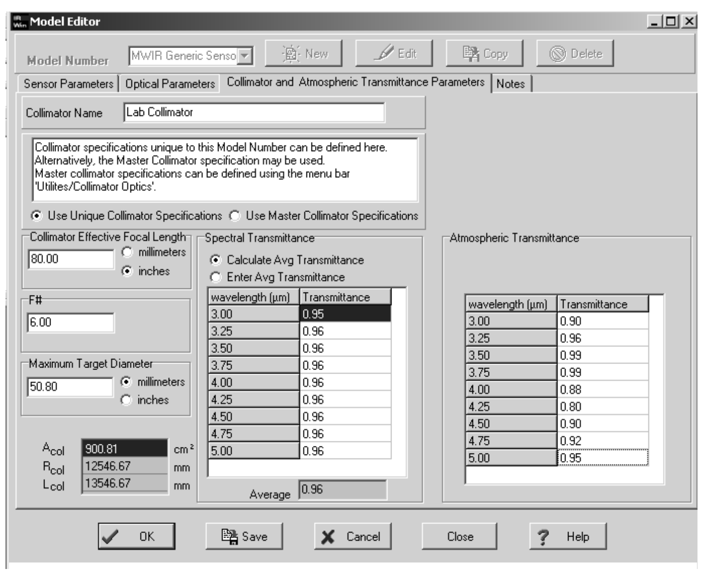

Figure 12: Page 3 of RME

Page 1 of the RME requires that the user enter information about the detector FPA that is used in the UUT. Here also the total wavelength range and wavelength increment is determined by the user (subsequent pages will use this specified range). A global electronics gain factor can be entered. This provides a means to later compute the NEP and D* as either end-to-end system results or specifically referenced to the detector FPA (the latter is typically required by FLIR modeling codes).

The incorporation of a radiometric normalization temperature allows the detector response to be appropriately weighted by a Planck function (computed at that temperature) appropriate to the sensors intended target scene. This is usually set at the 298K default value.

Page 2 of the RME is the optical parameters entry page. It requires the user to enter basic optical details of EFL, F/# and transmittance factors. The transmittance factors are organized to accommodate typical IR camera optical elements. IRWindows™2001 computes all fields indicated by the light-gray boxes. Many of these calculations are useful to the systems engineer.

The optical transmittance factors are used by IRWindows™2001 to convert the input-referred radiometric sensitivities (NER, NEFD) to the detector-referenced quantities (NEP, D*), accommodating the optics response. In addition, data on this page is used to compute the area and solid angle terms as well as the diffraction EE estimates needed to derive the NEFD/NEI values from the NER result.

Page 3 of the RME contains details of the collimator used by the SBIR equipment. The user can optionally utilize this page to further describe the collimator transmittance or simply utilize a single transmittance factor. An additional spectral attenuation factor, accounting for atmospheric losses, can be entered. The user would typically acquire the information for this factor from a MODTRAN™ atmospheric model. Typically, these losses are small, yet available for specification.

Based upon the values of collimator and UUT entrance aperture, the standard working distances of the collimator are computed for reference, R_{COL} and L_{COL}.

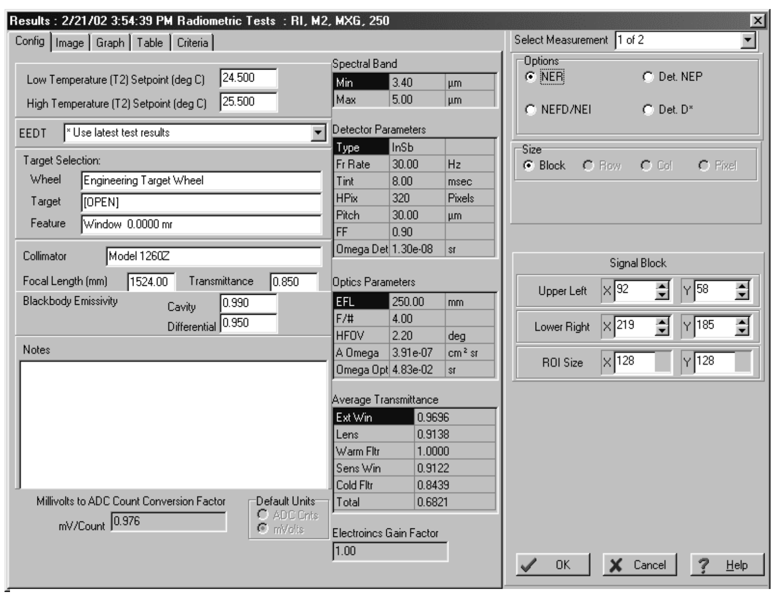

Figure 13: Test Results Screen with Radiometric Results

The values entered on this page (and the other pages) are appropriately spectrally factored into the equations for the radiometric sensitivity calculations performed by the Radiometric Test Module. The output results from the Radiometric Test Module are similar to many of the other IRWindows™2001 modules. However, since this test attempts to critically describe the quantitative performance of the sensor in scientific units, it is important to augment the output results with a detailed summary of sensor design details. To that end, the first page of the radiometric test results screen contains sensor information extracted from the RME as illustrated in Figure 13.

General Enhancements

Over the course of the IRWindows^{TM}2001 development program, many new and/or upgraded features were designed into the package. These enhancements, taken as a group along with the comprehensive test list, serve to elevate the IRWinwdow2001 product into the "high-end" category making it a flexible research tool. These major improvements were made in several categories. These are summarized in Table 4.

In addition to the enhancements described above, each module of the IRWindows^{TM} 2001 release has been renovated with a multitude of usability and readability improvements.

Table 4: Major General Enhancements to IRWindows^{TM}2001

Enhancement	**Brief Description / Utility / Benefits**
Test Functionality	
dT and T2 Source Options	Each test module can be operated by means of specifying a target differential temperature (dT) or by directly setting an absolute temperature value of the blackbody (T2). This adds flexibility to conduct tests at specific target scene backgrounds (i.e., NETD, SiTF, etc.) and without the need for a differential target.
H and V FOV Fields	Both horizontal and vertical FOV specifications. for a UUT can now be incorporated in the tests. This provides additional flexibility and allows for vertical MTF's to be performed.
SiTF User Data Fits	The SiTF test has been enhanced with several new data analysis features. User specified SiTF data fits, statistical information, photo-response non-uniformity (PRNU), and dynamic range values are now included.
10-bit A/D Functionality	Full 10-bit A/D functionality has been implemented in all test displays and analysis capabilities. SBIR can supply 8 or 10-bit video driver files as needed. Extended 10-bit acquisition capability reduces the A/D quantization noise floor of the test equipment.
Digital Camera Interface	Several digital interface cards have now been integrated into IRWindows^{TM}2001 allowing selection of digital camera interfaces that eliminate signal transfer losses
Collimator Specification	The user can choose to define the collimator with a single transmittance factor or a more detailed spectral transmittance profile (including separate atmospheric factors).
Units Display	
mV or ADC Counts	Each test module now includes an mV/ADC Count factor and default units selection option to allow the user to display the test results in both units. This capability is very useful when comparing results with oscilloscope readings (in Volts), interpreting data in units familiar to electronic engineers.
Watts or Photons/sec	The radiometric test module can display test results in W/sr/cm^2, W/cm^2, Photon/sec/sr/cm^2, Photon/sec/cm^2, etc. The user can select to work with the most appropriate units set, to ease interpretability with modeling codes, customer requirements…
cyc/mrad, cyc/mm, Nyquist Normalized	For the MTF, CMTF, and MRTD tests, the user can select between three units, with the default set to cyc/mrad. Image space units (cyc/mm) are useful to optics designers and design codes, and Nyquist Normalized units are also available. In this case, the spatial frequency axis is normalized to (2*ifov). A model from the RME must be available and selected to switch into image space units, as the EFL of the optics is required.
Deg C or Kelvin	Wherever appropriate, the graphical displays in all tests that plot a temperature axis can report the units in a Celsius or Kelvin scale.
Graphical Displays	
Bar Histograms, User-defined Bin Sizes	Bar histogram graphical displays have been added to almost all tests to help describe measurement results in a useful manner. User defined fields for setting minimum andand maximum graph endpoints and bin size have been incorporated. Default bin specifications can be set in the TP templates.
ROI Size Indicator	An ROI size field has been added below the ROI thumbnails.
Image Statistics Calculations.	Image statistics have been incorporate in almost all output test results wherever appropriate. These include min, max, mean, std., std/mean*100%. Provides useful additional info.
Informative Data Labels (measured and theoretical)	Many of the tests now include several types of informative data labels on the graphical output results screens. Several tests show diffraction-limited theoretical estimates and ancillary definitions that are meaningful to the test (i.e., EE, SRF, MTF and MDTD).
Axis Grids and log-linear plotting options	Axis grids, linear and semi-log graphing options and other such plotting options have been implemented in this new release. All to provide the user with more data presentation options.
Other	
Macro and Operator menu editor improvements	The user interface and editor features in the Macro and Operator functions have been augmented and improved. New save options and editing capabilities were implemented.

EXAMPLES OF IR MEASUREMENTS USING IRWINDOWS™2001

In mid 2001, FLIR introduced the MilCAM RECON handheld IR imager. Figure 14 shows a picture of the handheld camera. A subset of relevant performance specifications is described in Table 5.

FLIR has used the IRWindows™2001 IR test package extensively during the engineering development and qualification process for the RECON. Production RECON's undergo final ATP testing on the IRWindows™2001 test equipment. In this section, many of the key IR tests available in IRWindows™2001 are demonstrated using camera systems from FLIR's Ground production line.

Figure 14: FLIR's MilCAM RECON

Table 5: Relevant FLIR MilCAM RECON InSb Specifications

Parameter	**Specification**
FPA Type	InSb, snapshot mode
FPA Format	320 x 240 pixel, 30um pitch
Spectral Response	3.4 – 5.0um (cold filter)
Optics	50 / 250mm, F/4 Dual Field-of-View Optics (2x extender option)
FOV	WFOV (50mm) - 11.0 deg x 8.25 deg NFOV (250mm) – 2.2 deg x 1.65 deg
Operational Modes and Sensitivity	Mode 1: Med-Sensitivity Short Integration Time Daytime Optimized Mode 2: High Sensitivity Long Integration Time Nighttime, Low bkgrnd Optimized.
Mode 2 Temporal NETD @ 23 deg C. MRTD @ Nyquist Frequency	 < 25 mK < 75 mK

SiTF

One of the most basic test measurements is the SiTF response. Figures 15 through 17 illustrate the results of an SiTF test for the RECON IR camera, operated in its most sensitive integration mode and highest user gain settings. IRWindows™2001 provides five output results screens for each test: a *test configuration summary (Config)*, *image display (Image)*, *graphical results (Graph), tabular results (Table), and a criteria page (Criteria*). The criteria page contains an optional user- defined pass/fail summary for the test. On the right hand side of each Results display are user adjustable selections for the type of results to be viewed or analyzed, including the ability for the user to modify the original Region of Interest (ROI). For brevity, this is shown only in Figure 15. Most subsequent figures will show only in the left-hand section. The *image page* (shown in Figure 16) allows the user to view the captured test images. If desired, the user may expand the image and use the enhanced Image Capture Module (ICM) to further examine image properties. The *graph page* shows the main test results along with useful data labels that contain key result values. Histogram displays of data values are used throughout IRWindows™2001 graphical displays.

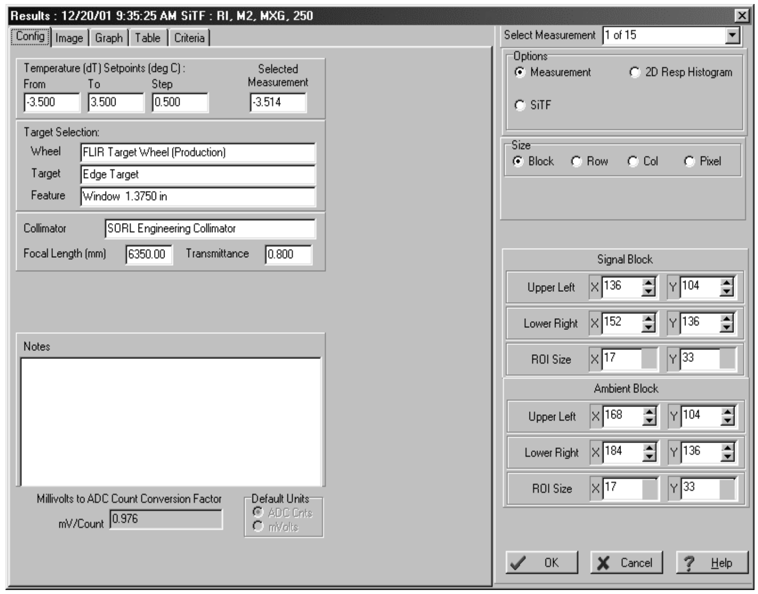

Figure 15

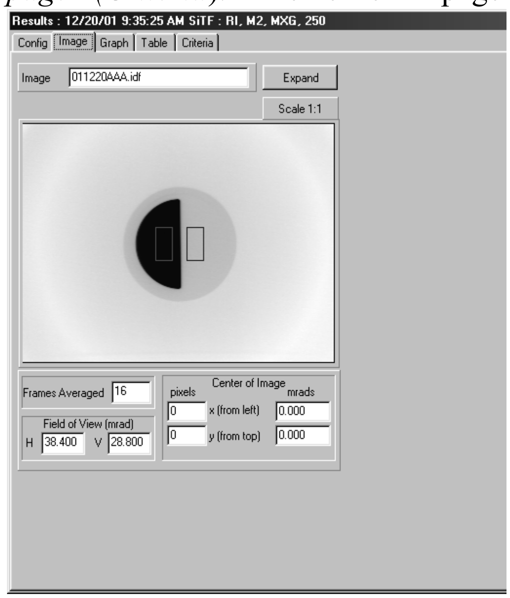

Figure 16

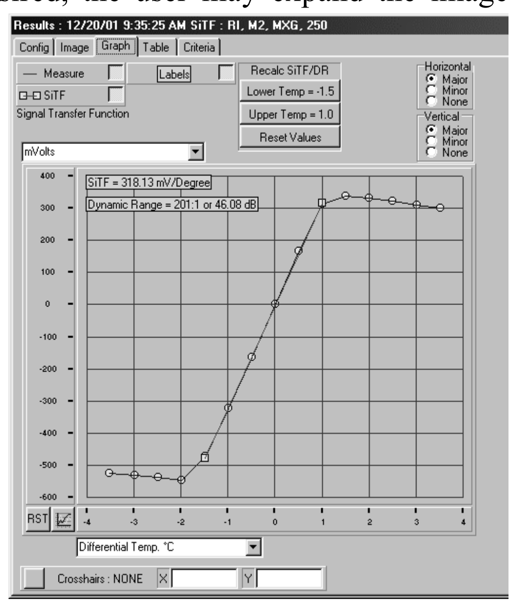

Figure 17

The SiTF response, typically an S-shaped curve, is plotted in Figure 17. The mean gain response is shown to be 318 mV/deg, as determined from a user defined fit range between -1.5 deg dT and + 1.0 deg dT, and centered about T2 ~ 23 deg C. This fit region is used to compute the dynamic range value. A histogram plot of the individual pixel gain responses, within the specified ROI, is also available. From these results, the photo-response non-uniformity (PRNU) is computed.

Temporal NETD

A portion of the results from a temporal NETD test is illustrated in Figure 18. The image was collected from the uniform extended blackbody surface at 23^o C. For this test, a 64-frame image data set (image cube) was collected and the individual pixel temporal NETD's (within a specified ROI) were computed. The graph shows a histogram plot of the NETD's indicating a mean temporal NETD at 18 mK.

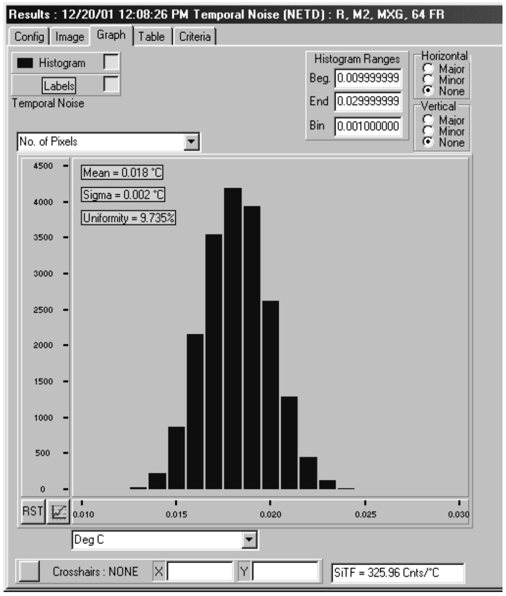

Figure 18

Spatial NETD

The spatial NETD is typically determined from a frame-averaged data set (time averaged to reduce temporal noise effects) and unlike the temporal NETD, results in a single NETD value. In addition, the imager's fixed pattern noise or spatial offset non-uniformity is measured. Although not shown in these figures, the spatial NETD for this RECON is 8 mK (which is less than the temporal NETD, typical of this type of imager).

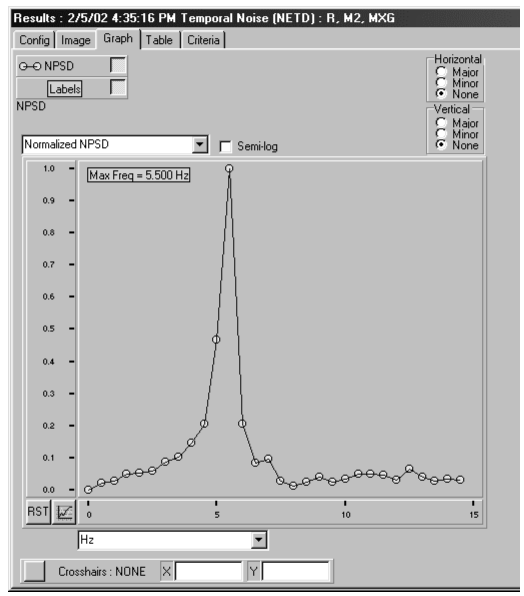

Figure 19

Temporal NPSD

Figure 19 illustrates another useful measurement capability of the Temporal NETD module. For illustrative purposes, a slit target was placed in front of the cavity blackbody source with a built-in chopper. The chopped frequency was set for approx. 5 Hz and a 64-frame data set was collected by running the temporal NETD test. Figure 19 shows the noise-power-spectral-density (NPSD) of this temporal signal, clearly indicating the peak energy content around the 5 Hz band. In general, NPSD tests are useful to help determine the frequency content of noise or periodic signals.

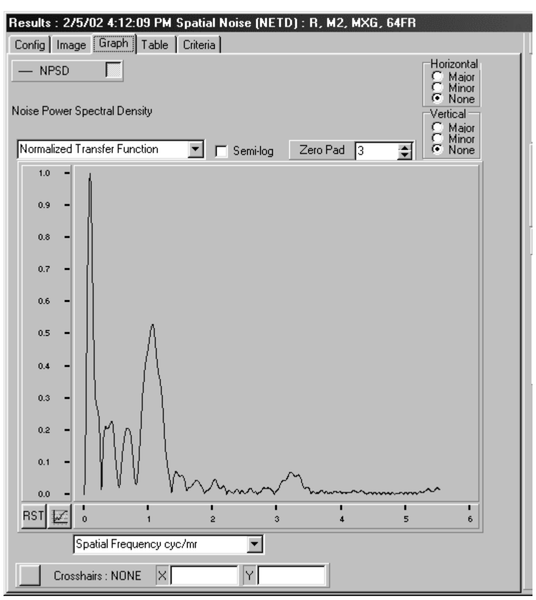

Figure 20

Spatial NPSD

In a similar manner, and for illustrative purposes, a spatial NPSD result is shown in Figure 20. Here, a MRTD 4-bar target was placed in the FOV of the RECON and imaged. This bar had a spatial frequency at approximately 1 cyc/mrad. A spatial NETD test was performed and the results were analyzed for a single row. From this, the spatial frequency content of the 4-bar pattern was observed in the NPSD plot depicted in Figure 20. Again, this type of analysis is useful in the assessment of spatial noise frequency content in the UUT.

3-D Noise

The 3-D Noise test requires the same type of data set as the temporal NETD test (a typical data set would be 64 frames for a 30 Hz interlaced imager). The images may be collected against any background temperature. The ROI may be any 2-D image region. Figure 21 illustrates the tabular display format for the 3-D noise component results. The results may be displayed in ADC counts, mV, or deg C. As previously discussed, these results are directly useful as inputs to government standard FLIR modeling codes such as FLIR92 and NVTHERM. In addition, the 3-D noise component, σ_{VH} is the same as the Spatial NETD. The σ_{TVH} value is typically a worst-case noise level, referred to as the single-frame random spatio-temporal noise level. This is the value used by the radiometric test to compute noise equivalent sensitivities. 3-D Noise measurements are very effective in helping to separate and identify different types of noise characteristics or sources among different types of infrared sensors.

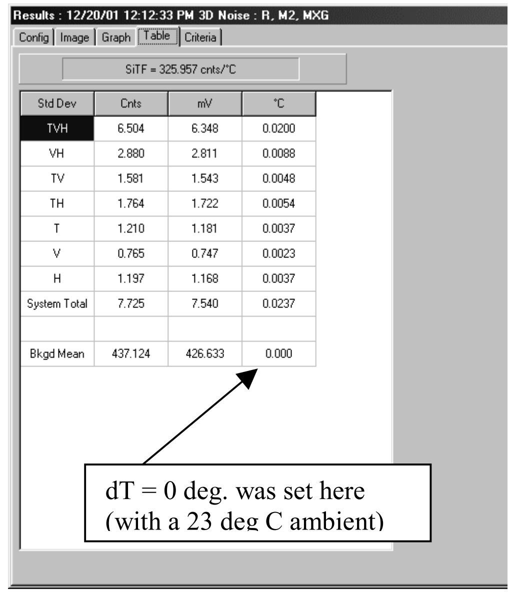

Figure 21

MTF

The IRWindows™2001 package supports the Edge Spread Function (ESF) methodology for MTF measurements. Figures 22 and 23 illustrate the basic measurement process. A critically focused image of an edge target is acquired for this test. Horizontal line cuts across this edge (as defined by the ROI) are differentiated to arrive at the line spread function (LSF), which is further processed by means of a Fourier Transform to develop the end-to-end Modulation Transfer Function response of the sensor. Although negligible, the MTF loss due to the collimator optics is also included in this result. Tilting the edge target (by means of finely adjusting the sensor in the roll-axis) can aid in the accuracy of the measurement by improving the sampling of the edge response. The user may choose to view the ESF or LSF in addition to the final MTF result. Pedestal (LSF offset removal) and Smoothing (LSF fitting) can be modified by selecting values other than zero in these data entry fields. Adjustment of these parameters will directly affect the MTF result profile. In some cases, it is appropriate to modify these values, but typically, these are set at 0.

In general, measurement accuracy is best achieved for a high SNR image. To achieve this, the sensor should be placed in its lowest gain mode (typically lowest noise) and the edge target should have a high dT setting. The image must be within the linear dynamic range of the sensor. Frame averaging can be beneficial but should be used with caution as any possible motion of the sensor can result in a blurred or reduced MTF response.

The frequency axis scaling for the MTF plot is derived from the user's entry of the horizontal FOV value (or vertical FOV, in the case of a vertical MTF measurement) and the pixel format information contained in the frame grabber video driver file. The user may switch the MTF graphical display into <cyc/mm> units (provided a model from the RME is specified and selected) or Nyquist frequency normalized units <0 – 1>.

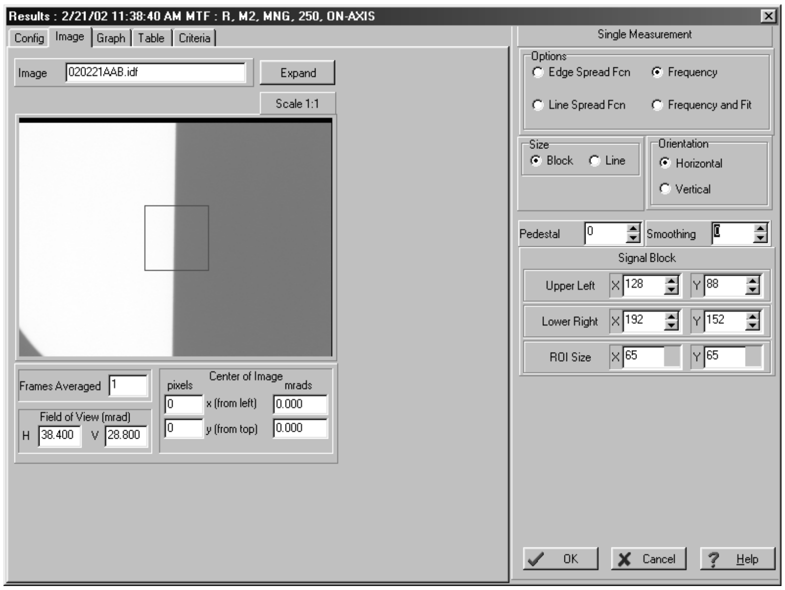

Figure 22

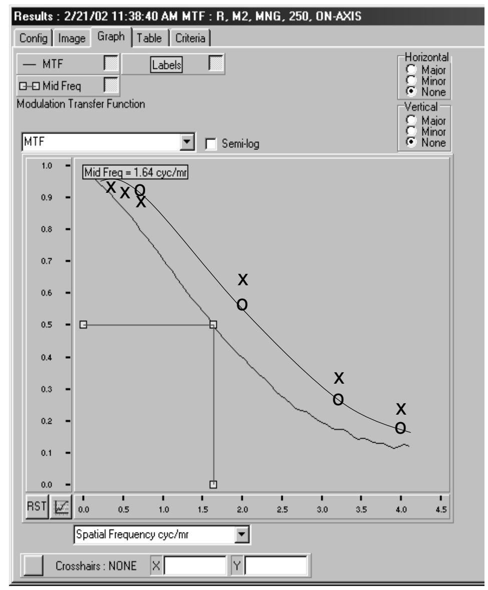

Figure 23

An informative parameter, the spatial frequency corresponding to the 50% MTF value, is provided on the MTF plot. This is useful for a quick spot check on MTF performance, especially when operating in the live or Continuous MTF module (CMTF) where the user is getting MTF updates in near real time. In fact, the CMTF module looks IDENTICAL to the MTF output results with the added benefit that the data is displayed live and in near real time so that the user can finely focus the sensor, observing the performance improvement live. A CMTF test usually precedes the MTF test to ensure that "peak" focus has been achieved prior to archival storage of MTF data.

Many other techniques exist to evaluate MTF of imaging sensors. A simple bar-target (or square wave response) contrast transfer function test (CTF) can easily be performed with IRWindows^{TM}2001 and an oscilloscope, sampling the video output of the sensor. For the same camera, a CTF was performed using six discrete spatial frequency bar targets and the results were plotted in Figure 23 with "x" curve. CTF measurements always have a higher modulation response than MTF, yet provide a good sanity check on system performance results. Since the ESF methodology is inherently under-sampled, these results can often under-predict staring sensor MTF performance. Manual adjustment of the user selectable pedestal levels can counter this effect to some extent and in many cases provide a more accurate indication of the absolute MTF response (the effect of pedestal shift on the MTF profile is indicated in Figure 23, ref. "o" curve).

Manual MRTD, K-Factors, AutoMRTD

Figure 24 shows the results of a typical Manual MRTD test. MRTD response vs. spatial frequency can be displayed on a linear or semi-log scale. Tabular data reports on the ± temperature observation points for each discrete spatial frequency bar target. The MRTD value is computed from this data, taking into account the total collimator transmittance.

If both NETD and MTF test results are present prior to making Manual MRTD measurements, then the user can choose to select the “K-values” option in the MRTD test results screen. If selected, the K-values are computed and can be displayed in both a graphical or tabular format.

If both NETD and MTF results are available and IRWindows™2001 has a stored set of “K-values” in the K-worksheet editor, then the user can run the AutoMRTD test to quickly and automatically generate a set of MRTD results (without the need to perform a standard manual MRTD test).

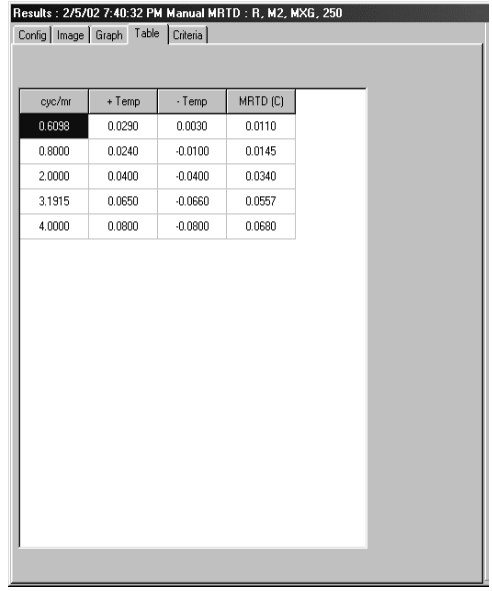

Figure 24

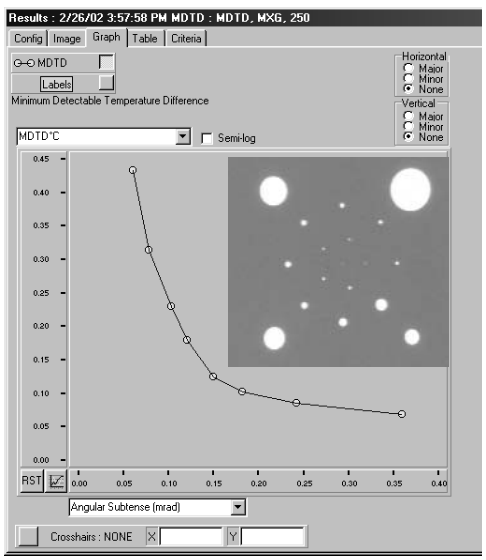

Figure 25

MDTD

The MDTD test provides a basic measure of a human observer’s ability to just detect the presence of a particular size target with a specified dT. IRWindows™2001 allows the user to determine MDTD as a function of target angular subtense. Figure 23 illustrates an example MDTD measured response using a custom multi-pinhole target plate (also shown in the figure). Eight of the sixteen circular targets were observed at measurable threshold temperatures. Since the MDTD response is a subjective observer metric, it is important to further document the viewing conditions for the test such as monitor size, viewing distance, and background lighting.

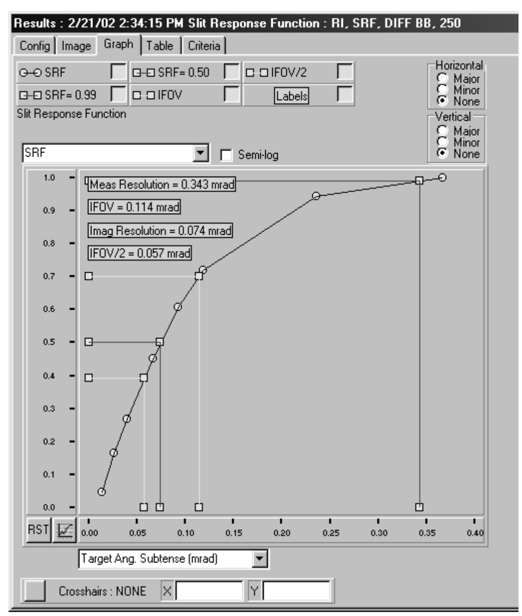

Figure 26

Slit Response Function (SRF) Test

The SRF test requires a custom movable slit target (available from SBIR). Prior to test execution, the user critically aligns the slit image (typically set to approximately the ifov width) along a single column of the imager (the ICM is used to support this setup work). Presently, up to eight discrete slit widths are supported in the SRF test. Typical slit values may be: 1/10th, ¼, 1/3, ½, ¾, 1, 2x, and 3x of the imager’s basic IFOV angular width. This spread of targets provides for a good range over which to map out the SRF profile. During test execution, the user is prompted to adjust the calibrated slit micrometer manually, prior to each measurement point. Figure 26 illustrates a SRF profile mapped for the RECON imager in its NFOV mode. Several useful definitions of imaging metrics are plotted in the graph as well. Tabular values report all of the key measurement information about the SRF profile.

During the setup of the SRF test, the user must ensure that the amplitude of the sensors output response for the widest slit setting (i.e., 3x ifov) is still within the linear, non-saturating, response of the imager. Frame averaging is also recommended to improve the overall SNR of the measurement yielding better overall accuracy.

Radiometric Test Module (RTM)

The RTM requires that the sensor view an extended blackbody source at two temperatures within its linear dynamic range. It also requires that a radiometric model of the sensor be specified and selected from the Radiometric Model Editor prior to test execution. Figure 27 shows the configuration settings and key radiometric parameters for a typical radiometric test performed on the RECON imager. Figure 28 shows the NEFD results of all of the pixels in the specified ROI. The results that can be selected are NER, NEFD, NEP, and D*. The user, as indicated in Figure 28 may select units of Watts or Photons (per unit area and solid angle). The NER and NEFD are input referenced at the sensor aperture, whereas the NEP and D* are referenced to the output of the sensors FPA detector.

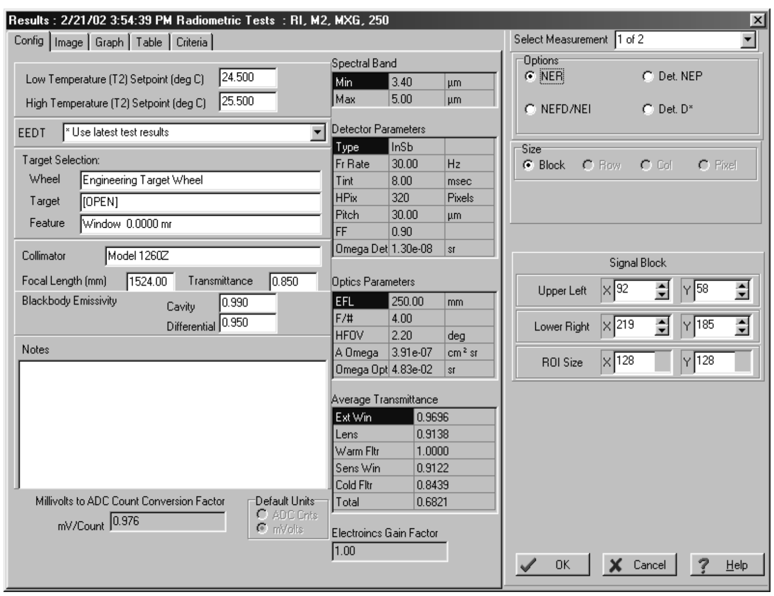

Figure 27

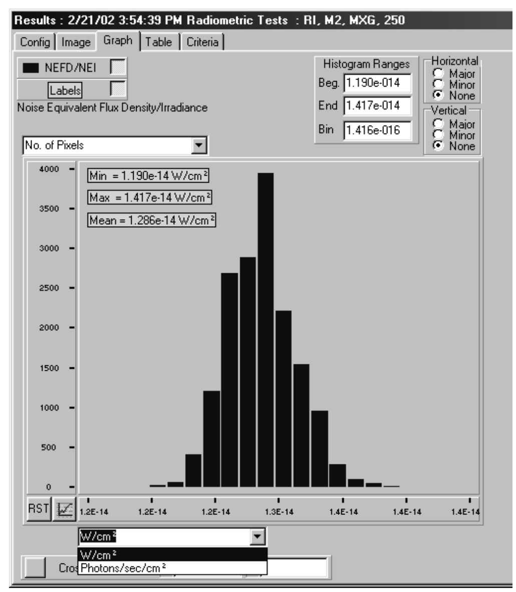

Figure 28

Spatial NETD vs. Background Temperature

Performance of a thermal imager as a function of scene background temperature is an important characterization to evaluate since real systems need to contend with a wide range of environmental conditions and target scene variations. This test module *extends* the capabilities of the NETD modules and SiTF module to evaluate imager performance as a function of scene temperature. The test requires the use of the extended blackbody typically ramped across a wide range of set-point temperatures (each of which becomes a background temperature evaluation point). Two temperature profiles are configured for this test: (1) the overall min/max/step increment profile (similar to a SiTF test) and (2) the smaller dT setting for a local SiTF profile. Four analysis graphs are available from this measurement: raw measurement profile (output counts vs. scene temperature), SiTF gain response (i.e., ADC counts / deg C), noise counts, and Spatial NETD (σ_{TVH} or σ_{VH} depending upon frame-averaging selection). All analyses are plotted as a function of background (blackbody) temperature.

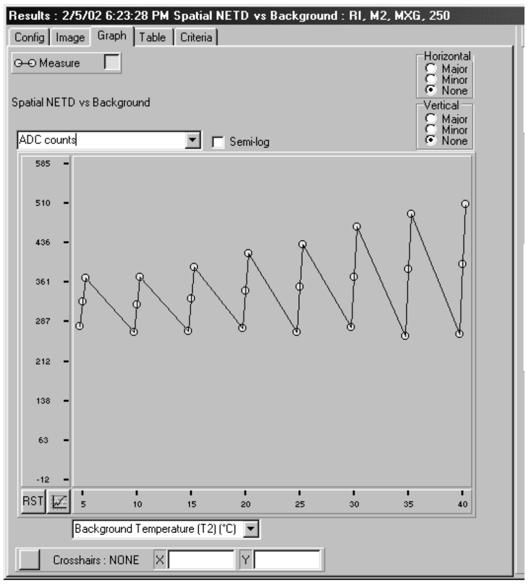

Figure 29

Since this test is performed over a wide temperature span (typically *much* wider than the instantaneous dynamic range of the sensor), an optionally checked "pause to adjust UUT offset" feature has been implemented. At each main temperature setpoint, the user is prompted to manually adjust the sensor-offset level to a specified video level prior to the noise and SiTF data acquisition at that background temperature. This allows the user to collect valid data across the total dynamic range of the imager, not just its instantaneous range. The end-user would typically set the sensors dc-coupled offset level to accommodate the conditions of the scene being viewed. The test engineer also has the option to perform a NUC during this period-of-pause, prior to collecting the data at that specific temperature. This has an effect on the end noise results and may be desirable to be measured.

The temperature range measured for this example was 5 deg C to 40 deg C in 5 deg C increments. At each temperature setting, an SiTF data set was collected (using the absolute SiTF method, not requiring a target) by a user defined ± 0.25 deg C temperature difference about each main set-point temperature. For example, at the 10 deg C point, the SiTF was determined from a computer automated linear curve fit of the sensor output response at three temperatures (9.75, 10.0, and 10.25 deg C).). This acquisition profile is observed in Figure 29. From this raw data set, the SiTF as a function of background temperature is determined and plotted in Figure 30. The resulting gain response is typical of MWIR InSb sensors, with the sensitivity of the imager decreasing with lower temperature backgrounds – yielding an equivalent increase in the resulting NETD of the sensor.

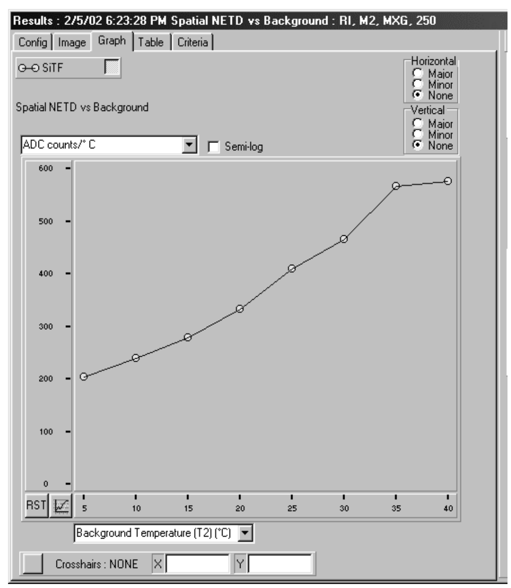

Figure 30

The noise counts are derived from the image acquired at the center temperature setpoints for each background temperature. Specifically either the noise is the σ_{TVH} value or if frame averaging is used, the noise value can approximate the σ_{VH} value. Figure 31 plots the noise results over the measured temperature span. At higher background temperatures, background photon noise and residual photo-response non-uniformity noise primarily drive the sensor's noise counts. At the lower background temperature, typically the dominant noise source is residual fixed pattern noise and other focal plane or electronics noise floor limits.

The resulting Spatial NETD is hence the noise divided by the SiTF at each of the background temperature setpoints. This is illustrated in Figure 32. Depending upon the noise processes at hand, the resulting spatial NETD curve may take on a W-shape or U-shape – both indicative of the 2-D staring sensor performance as a function of scene or background temperature.

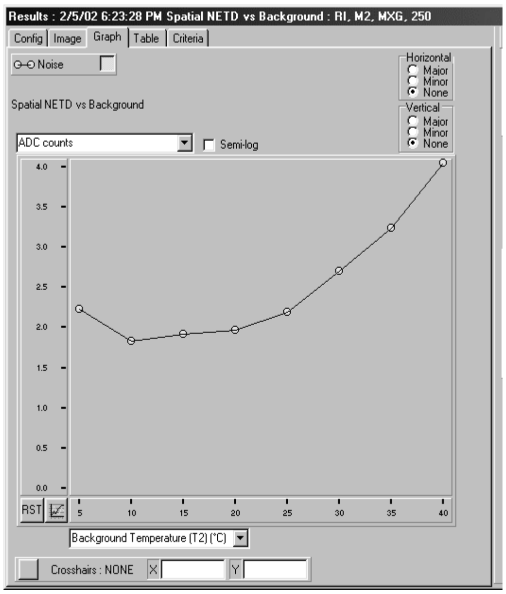

Figure 31

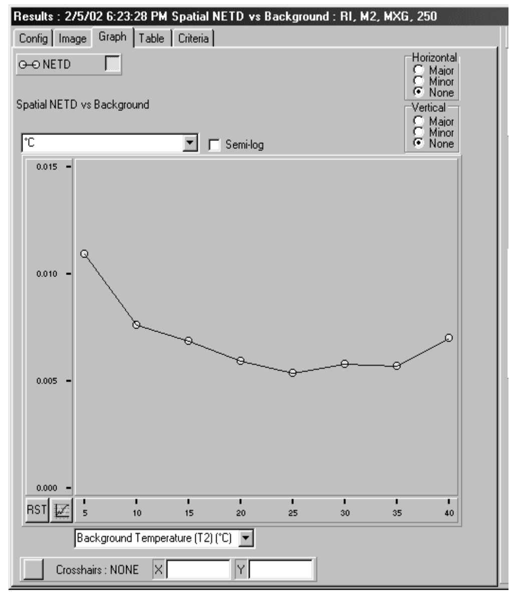

Figure 32