

# ***High-End Infrared Imaging Sensor Evaluation System***

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## **ABSTRACT**

The development and manufacture of high performance Infrared imaging sensors requires more than just the tools to design and build them – it also requires the tools to accurately characterize their electro-optical performance and further utilize this data to better optimize the product as well as monitor many systems in serial production. Santa Barbara Infrared (SBIR) in cooperation with FLIR Systems, Inc. (FLIR) has completed a project to significantly enhance the capabilities of their IRWindows<sup>TM</sup> software package, now *IRWindows<sup>TM</sup>2001*, to meet the needs of *all levels* of IR system developers. This paper will discuss both hardware and software requirements for IR staring sensor testing and performance evaluation. Key aspects of the new IRWindows<sup>TM</sup>2001 software will be described and their utility will be demonstrated with FLIR's MilCAM RECON InSb handheld IR camera.

**Keywords:** IR Testing, IRWindows2001, Imaging Sensor, Radiometric, FLIR, SBIR

## **1.0 INTRODUCTION**

Infrared sensor testing is an important part of engineering development as well as a necessary part of product quality assurance. In the late 80's and early 90's, much work ensued to formally develop test metrics for the comprehensive characterization of modern-day thermal infrared imaging sensors (TI's, FLIR's, etc.). In particular, many new concepts and test metrics related to the performance characterization of 2-D Focal Plane Array (FPA) staring sensors were developed and refined, for example 2-D MRTD, 3-D Noise, Spatial and Temporal image properties. In the mid-90's, commercially available semi-automated FLIR test equipment included user-friendly test software capable of executing basic infrared sensor performance tests in a repeatable and accurate manner. Santa Barbara Infrared (SBIR) was one of several leading IR test equipment manufacturers to develop such computerized test equipment for FLIR sensor characterization. With its initial release of IRWindows<sup>TM</sup> in 1996, followed by IRWindows<sup>TM</sup> v2.0 in 1998, automated FLIR testing was made available to mainstream commercial manufacturers of high-volume infrared sensor/camera systems.

In 1999, FLIR conducted a survey of commercially available IR test equipment and determined that while there were several basic platforms available, none had the full feature set to meet the wide scope of needs for FLIR's diverse range of IR camera systems. SBIR's IRWindows<sup>TM</sup> platform did offer a solid foundation for basic FLIR testing metrics with a proven track record and had an intuitive user interface that was well suited to a production ATP. SBIR was also interested in extending the product into a more powerful and useful R&D tool that would aid both researchers and high-end system developers in the field. FLIR was interested in investing in a single IR test and evaluation tool that would support both engineering product development and production QA in a compatible manner. As a result, FLIR engaged SBIR in a joint development effort to significantly enhance the IRWindows<sup>TM</sup> package. Both organizations critically contributed to the technical development of the IRWindows<sup>TM</sup>2001 package through the incorporation of more than *ten new tests, major feature enhancements, new data analyses' and improved user displays*. Extensive beta testing, on a variety of IR camera products, was performed by FLIR throughout the entire development cycle. This effort culminated with the full commercial release of the IRWindows<sup>TM</sup>2001 product in Q1, 2002.

This paper starts out with a brief review of the scope of IR sensor testing. Applicability of tests in an R&D engineering role as well as production QA roles is discussed. From this foundation, SBIR's IR test hardware and enhanced IRWindows<sup>TM</sup>2001 software are described. The capabilities of the IRWindows<sup>TM</sup>2001 test environment are demonstrated using a range of example measurements with FLIR's handheld IR camera, the MilCAM RECON (Mid-wave InSb version). Future product enhancements and a complementary EO (visible sensor) capability are also discussed.

### **1.1 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.

### **1.2 FLIR Systems, Inc. (FLIR)**

FLIR Systems is a leading global manufacturer of high performance IR thermal imaging systems. Serving both 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.

## **2.0 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 countless technical papers on the subject<sup>1-5</sup>. It is not the intention of this paper to restate this work but rather to present useful information on a new toolset (IRWindows<sup>TM</sup>2001) that incorporates this work into an automated and highly flexible test environment.

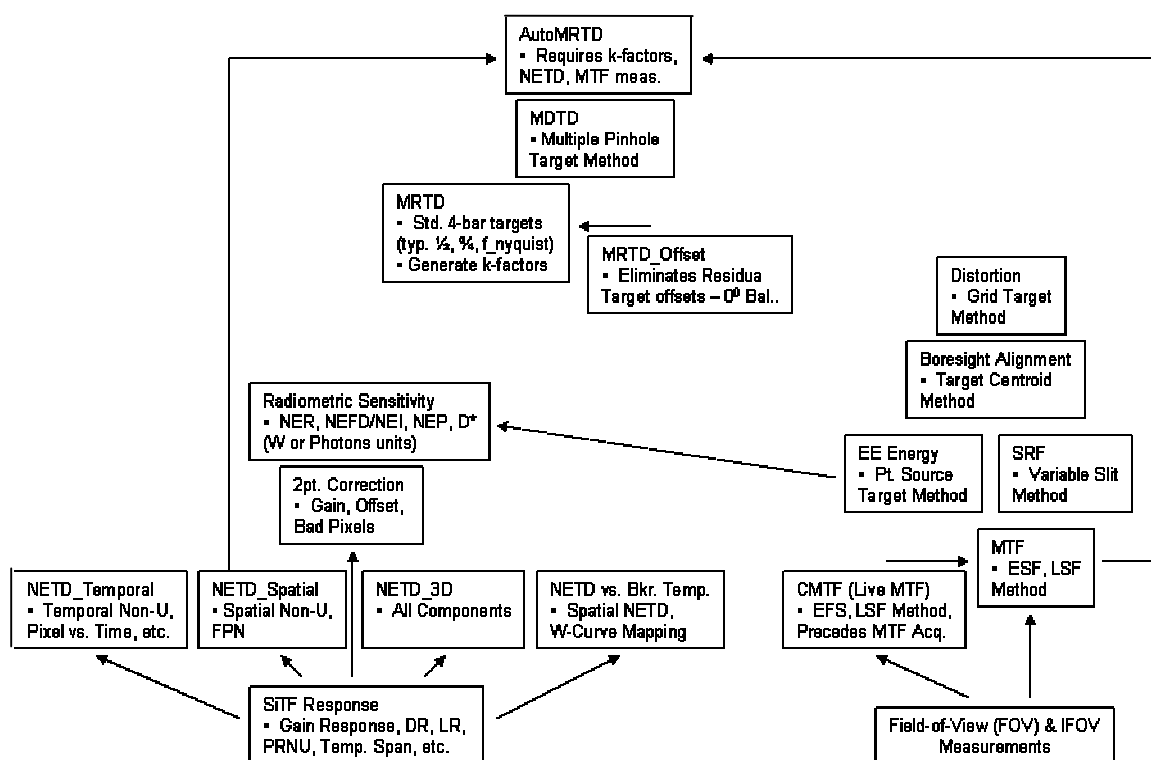
### **2.1 Categories of IR Testing**

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 2.1-1 summarizes a comprehensive list of tests, all of which can be performed within the framework of the IRWindows<sup>TM</sup>2001 package. These tests are used throughout the IR sensor development process to characterize and validate component and system level performance.

Figure 2.1-1 illustrates the general hierarchy of test execution and interdependence of test results. A complete discussion of test execution priorities and interdependence is beyond the scope of this paper, however a discussion is available in a supplementary document on IR sensor testing with IRWindows<sup>TM</sup>2001, available from SBIR.<sup>6</sup>

**Table 2.1-1: 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) <ul style="list-style-type: none"> <li>• Response Linearity (RL)</li> <li>• Dynamic Range (DR)</li> <li>• Photo-Response Non-Uniformity (PRNU)</li> </ul>	Field-of-View (FOV)  Instantaneous FOV (IFOV)	Illumination Non-Uniformity and Image Statistics <ul style="list-style-type: none"> <li>• Min, Max, Mean, Std/Mean, etc...</li> </ul>	Minimum Resolvable Temperature Difference (MRTD)
Temporal NETD and NPSD	Slit Response Function (SRF)	Visually Discernable Temporal Noise	Auto-MRTD <ul style="list-style-type: none"> <li>• Req'd: NETD, MTF, K-coef's</li> </ul>
Spatial NETD and NPSD <ul style="list-style-type: none"> <li>• Offset Non-Uniformity, or Fixed Pattern Noise (FPN)</li> </ul>	Ensquared Energy (EE)	Visually Discernable Spatial Noise <ul style="list-style-type: none"> <li>• NUC vs. Time</li> </ul>	Minimum Detectable Temperature Difference (MDTD)
3-D Noise (NETD) <ul style="list-style-type: none"> <li>• All (7) components</li> </ul>	Contrast Transfer Function (CTF)	Narcissus Images and Ghost Images	MRTD Offset <ul style="list-style-type: none"> <li>• Null's Target dT Errors</li> </ul>
NETD vs. Background Temperature (NETD-W curve) <ul style="list-style-type: none"> <li>• SiTF vs. Temp. Background</li> <li>• Noise vs. Background.</li> </ul>	Modulation Transfer Function (MTF) <ul style="list-style-type: none"> <li>• ESF, LSF</li> <li>• Live MTF Module</li> </ul>	Residual Non-Uniformity <ul style="list-style-type: none"> <li>• Gain</li> <li>• Offset</li> </ul>	
Radiometric Tests: <ul style="list-style-type: none"> <li>• Noise Equiv. Radiance (NER)</li> <li>• Noise Equiv. Flux Density (NEFD)</li> <li>• Noise Equiv. Power (NEP)</li> <li>• D-Star (D*)</li> </ul>	Distortion (DIST)  Boresight Alignment (BA)	Bad Pixels Finder <ul style="list-style-type: none"> <li>• Gain</li> <li>• Offset</li> <li>• Excessive Noise</li> <li>• Blinking</li> </ul>	



**Figure 2.1-1: IRWindows2001™ General Test Hierarchy & Interdependence**

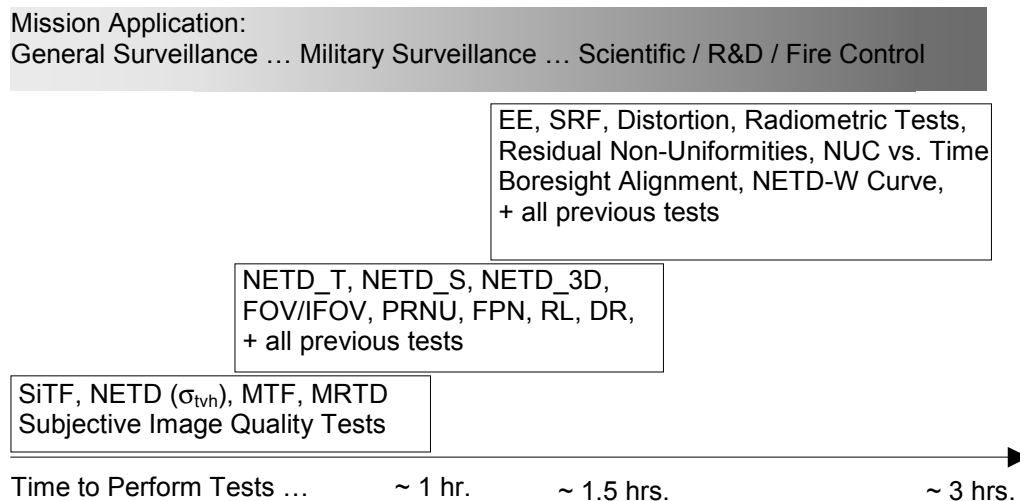
## 2.2 IRWindows™2001 Utility in Engineering Qualification and Production QA ATP Roles

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., NETD, 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<sup>7</sup>. 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 and, after repair, it is easy to verify that the unit is performing to its original capability.

Figure 2.2-1 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 time estimates provided are representative of average production ATP validation processes performed at FLIR for its handheld thermal imaging cameras, using the IRWindows™2001 package.

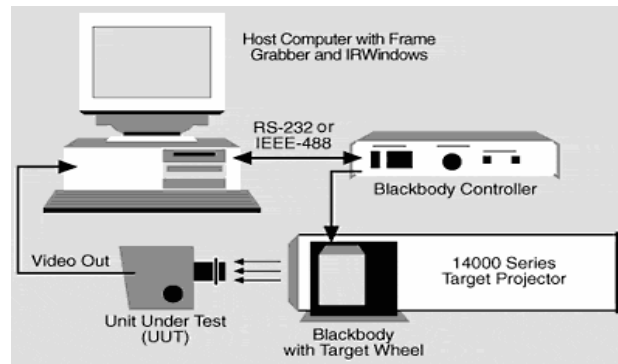


**Figure 2.2-1:** Typical ATP Test Requirements for End-user Mission Applications

### 3.0 SBIR TEST HARDWARE AND SOFTWARE - OVERVIEW

#### 3.1 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 2.1-1. 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 3.1-1 illustrates a basic schematic diagram of the IR test station concept. Figures 3.1-2 and 3.1-3 show two implementations currently being used at FLIR.



**Figure 3.1-1** IR Test Station Components



**Figure 3.1-2a:** FLIR's MilCAM RECON MWIR Camera on a 3-axis Alignment Stage in front of the Engineering SBIR IR Test Station.



**Figure 3.1-2b:** 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, IRWindow2001™ Software, 1000TVL Monitor, Digital Scope, 3-axis UUT motion stage

The SBIR hardware is fully controlled by IRWindows™2001 via the IEEE-488 and RS-232 interfaces. Command and control of all SBIR assets, test definition, execution, data analysis, and data storage is all provided by IRWindows™2001. Data acquisition of the UUT video signal is accomplished by framegrabbing 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.

### 3.2 General Software Description and Architecture

IRWindows™ 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 GUI 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 is that it is an all-in-one test platform doing system level testing. IRWindows™ 2001 can perform over twenty unique types of standardized thermal imager test procedures as found in table 2.1-1. Each procedure can have user defined test configurations. Multiple configurations 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 configurations from one or more tests can be grouped together into a test macro. Macro programming capability is a powerful feature in a production QA environment. A test engineer can develop a macro consisting of all the appropriate tests for a particular model IR imager, thus allowing a full suite of tests to be performed with a simple press of a button.

In addition to the automated tests, there are several interactive features of IRWindows™ 2001. These features include: a control panel for monitoring and operating all the hardware components attached to the test system; an interactive image capture and analysis feature that has been significantly enhanced from previous versions; configuration screens for defining the characteristics of the target projection system; and worksheets for calculating the parameters used in Automatic MRTD (the K factors) and radiometric tests.

### 3.3 IRWindows™2001 Product Enhancements

The new IRWindows™2001 release represents a *substantial improvement* 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. *A complete discussion of the enhancements incorporated into the IRWindows™2001 system would exceed the limits of this paper and are discussed in detail in SBIR's IRWindows™2001 Testing Document* <sup>6</sup>. However, a brief set of highlights includes:

- Addition of more than (10) new IR test modules, improvements in many existing test modules with more test execution options, such as use of differential or absolute source and the ability to select different units for display.
- Significant upgrade of the Image Capture Module (ICM) features and capabilities in image acquisition, image interrogation and analysis, and data storage options.
- Addition of a wide range of units selection options, data analysis and display options, statistical calculations, enhanced graphical labeling, and improved output report capabilities.
- Addition of a Radiometric Test Module (RTM) and a comprehensive Radiometric Model Editor (RME).

The RTM is a powerful new test that can measure the radiometric sensitivity of thermal imagers and report their noise equivalent sensitivities in a variety of radiometric units. Output results from the RTM include: NER, NEFD or 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 ( $\sigma_{TVI}$ ) are determined in the specified image to provide the necessary data to convert these sensitivities into radiometric noise equivalent sensitivity results.

The key to IRWindows™2001 ability to conduct these tests is the new Radiometric Module Editor (RME). The RME is a data entry module that contains key design details and technical data specific to the sensor including: FPA detector parameters, optics, and relevant SBIR asset details. The RME also acts as a back-of-the-envelope systems engineering worksheet for routine systems calculations that are useful to the test engineer or scientist. Users can define, edit and

store unique models for different sensors. Prior to performing a radiometric test, the user would select the appropriate sensor model. A detailed discussion of this feature is further provided in SBIR's IR Testing Document. <sup>6</sup>

### 3.2.1 IRWindows™2001 New Test Modules

**Table 3.2.1-1: IRWindows™2001, New Test Modules**

Test	Brief Description / Utility
Temporal NETD	This module measures 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 Temp. (W-Curve Mapping)	Measures UUT spatial noise ( $\sigma_{tvh}$ or $\sigma_{vh}$ ) as a function of varying blackbody source temperature. SiTF vs. bkr. Temp. 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 EE is measured with a simple 1/10 <sup>th</sup> IFOV target. 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)	The user manually adjusts the discrete slit positions as prompted by the IRWindows™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.
MDTD	A new version of the MDTD test has been implemented to use 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 (with ~ 2-3 updates/sec) MTF measurement with all of the same features and functionality available to the standard MTF test. An ESF/LSF/MTF methodology is used. Used 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 in the specified ROI. It also defines several criteria for finding 'bad-pixels' in the UUT: gain range, offset range, noise range and a criteria for variable frequency blinking pixels.
MRTD Offset	Used 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 with respect to 0 deg dT.
Radiometric Test Suite	Computes the following radiometric sensitivities: 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 (RME) is required for this test as it contains all of the needed sensor specification details.

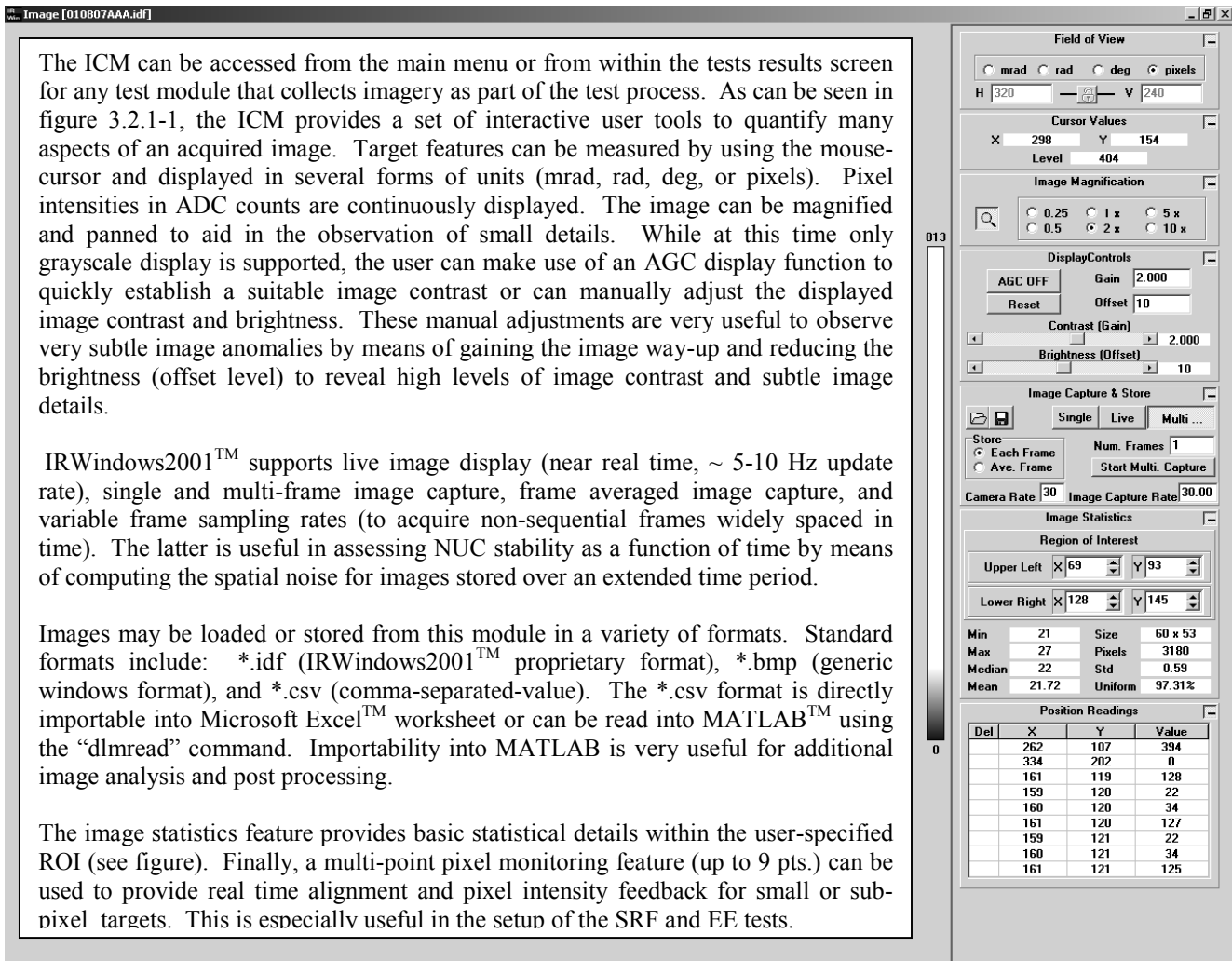
Over the course of the IRWindows™2001 development program, many new and/or upgraded features were designed into the package. These enhancements, taken as a group along with the comprehensive test list, serve to elevate the IRWinwindow2001™ product into the “high-end” category making it an extremely flexible and appealing research tool. These major improvements were made in several categories and are summarized in Table 3.2.1-2.

**Table 3.2.1-2: Major Feature Enhancements to IRWindows™2001**

<b>Enhancement</b>	<b>Brief Description / Utility / Benefits</b>
<b><i>Test Functionality</i></b>	
dT and T2 Source Options	Target differential temperature (dT) or absolute temperature value of the blackbody (T2) can be selected. This adds flexibility to conduct tests at specific target scene backgrounds (i.e., NETD, SiTF, etc.) without the need for a differential target.
H and V FOV Fields	Horizontal and vertical FOV spec's. 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.
Collimator Specifications	The user can choose to define the collimator with a single transmittance factor or a more detailed spectral transmittance profile (including separate atmospheric factors).
<b><i>Units Display</i></b>	
mV or ADC Counts	Each test module now includes a 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)
Watts or Photons/sec	The radiometric test module can display test results in W/sr/cm <sup>2</sup> , W/cm <sup>2</sup> , Photon/sec/sr/cm <sup>2</sup> , Photon/sec/cm <sup>2</sup> , etc. The user can select to work with the most appropriate units.
cyc/mrad, cyc/mm, F_Nyq. Normalized	For MTF, CMTF, and MRTD tests, the user can select between these three units: cyc/mrad (default), cyc/mm (Image space units, useful for optics designers and design codes), and Nyquist. Normalized (spatial frequency axis is normalized to $(2 \cdot \text{ifov})^{-1}$ ). A model from the RME must be available and selected to switch into image space units because the EFL of the optics is required.
Deg C or Kelvin	Where appropriate, the graph and table results display temperature axis units in Celsius or Kelvin.
<b><i>Graphical Displays</i></b>	
Bar Histograms, User Bin Sizes	Where appropriate, the graph results display Bar Histogram data. The user can set minimum and maximum graph endpoints and bin size. In addition, default bin specifications can be set in the TP templates.
Region of Interest (ROI) Size Indicator	An ROI readout has been incorporated to provide the user with a quick reading on the ROI size
Image Statistics Calculations	Where appropriate, image statistics have been incorporated. These include: minimum, maximum, mean, standard deviation (std), std/mean*100%.
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).



### 3.2.2 Enhanced Image Capture Module (ICM)



**Figure 3.2.2-1: ICM Module** (Note: Image is Normally Displayed Under the Text Box in the Figure).

## 4.0 EXAMPLES OF IR MEASUREMENTS USING IRWINDOWS™2001

In mid 2001, FLIR introduced the MilCAM RECON handheld IR imager. The RECON is available in both mid-wave InSb and long-wave QWIP versions. Figure 4-1 shows a picture of the handheld camera. A subset of relevant performance specifications is described in Table 4.1.

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™ are demonstrated using camera systems from FLIR's Ground production line.



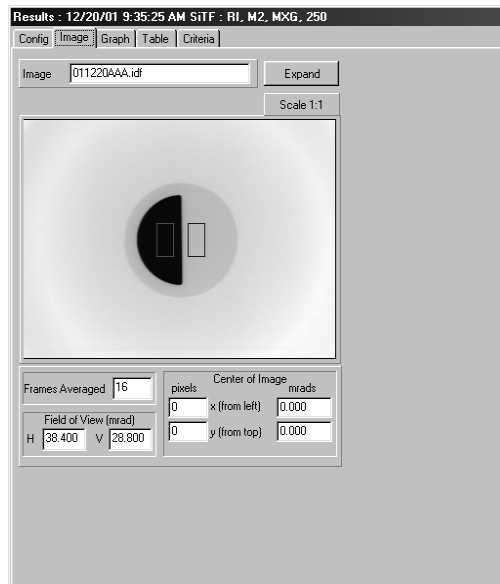
**Figure 4.1: FLIR's MilCAM RECON Imager**

**Table 4.1:** Relevant FLIR MilCAM RECON InSb Specifications

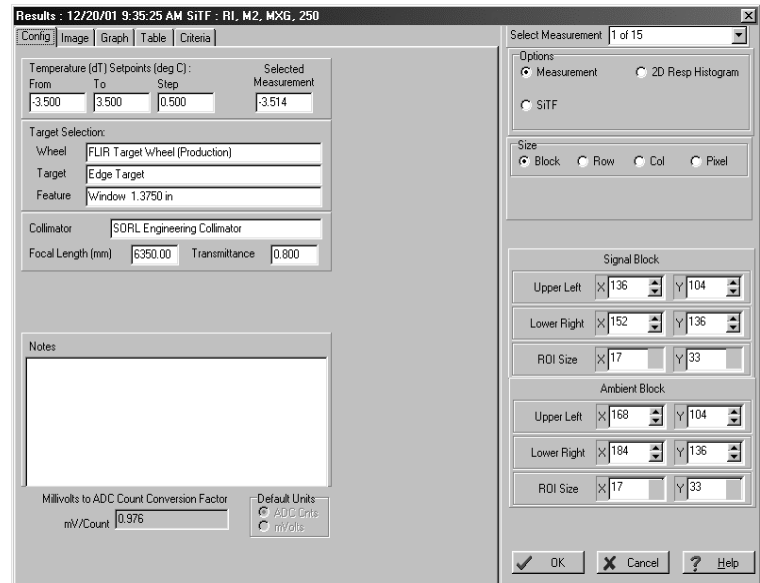
Parameter	Specification
FPA Type	InSb, snapshot mode
FPA Format	320 x 240 pixel, 30um pitch
Spectral Response	3.4 – 5.0um (coldfilter)
Optics	50 / 250mm, F/4 Dual Field-of-View Optics (2x extender option)
FOV	WFOV (50mm) - 11.0 deg x 8.25 deg NFOV (250mm) – 2.2 deg x 1.65 deg
Operational Modes and Sensitivity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

## SiTF

One of the most basic test measurements is the SiTF response. Figures 4.2 through 4.4 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



**Figure 4.3**



**Figure 4.2**

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 4.2. Most subsequent figures will show only in the left hand section. The *image page* (shown in figure 4.3) 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.

The SiTF response, typically an S-shaped curve, is plotted in figure 4-4. 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 computer.

## Temporal NETD

A portion of the results from a temporal NETD test is illustrated in figure 4-5. The image was collected from the uniform extended blackbody surface at 23° 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.

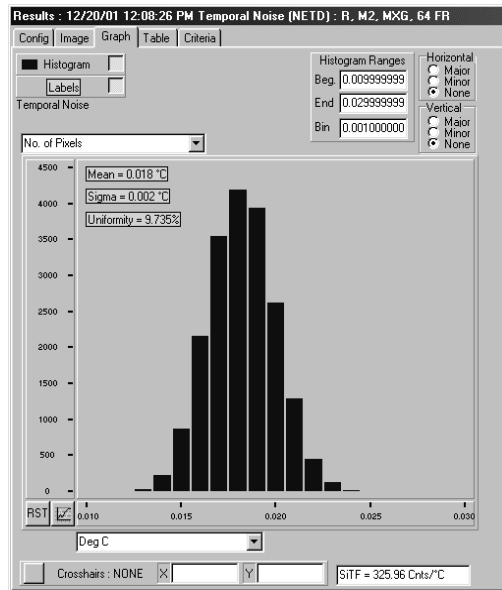


Figure 4.5

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 4-6 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,  $\sigma_{VH}$  is the same as the Spatial NETD. The  $\sigma_{TVH}$  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.

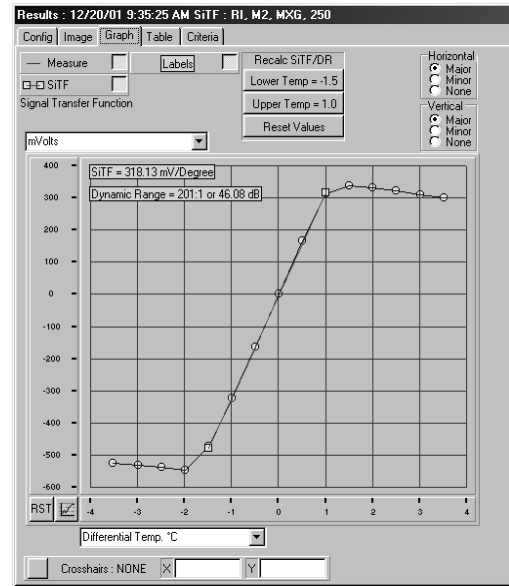


Figure 4.4

## 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. Also, in this test module, the imager fixed pattern noise or spatial offset non-uniformity is measured. Although not shown in these figures, the spatial NETD for this RECON was 8 mK (which is less than the temporal NETD, typical of this type of imager).

## 3-D Noise

The 3-D Noise test requires the same type of data set as the temporal NETD test (a typical data set

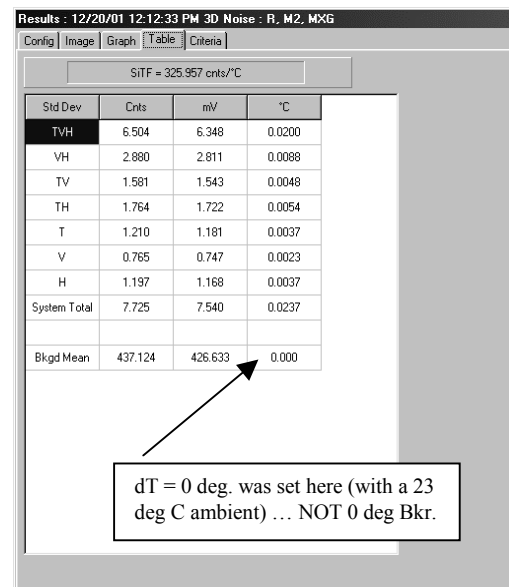


Figure 4.6

## MTF

The IRWindows<sup>TM</sup> 2001 package supports the Edge Spread Function (ESF) methodology for MTF measurements<sup>8,9</sup>. Figures 4.7 and 4.8 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 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 0,0.

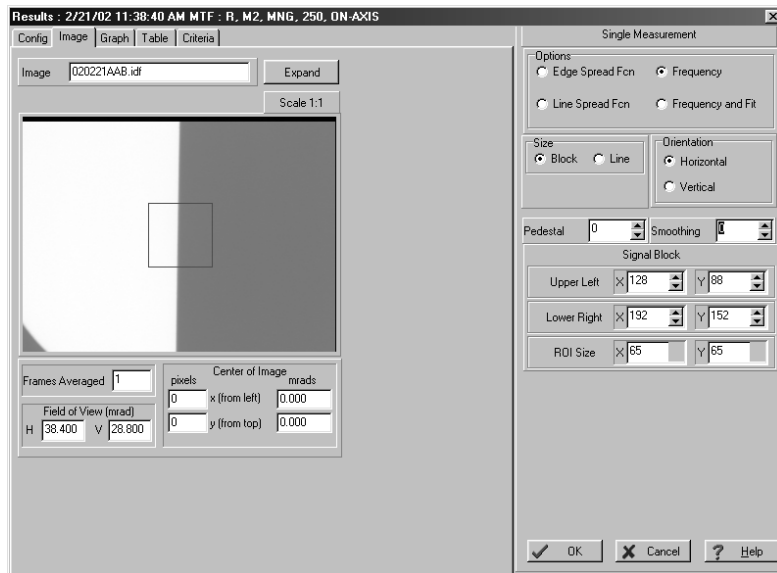


Figure 4.7

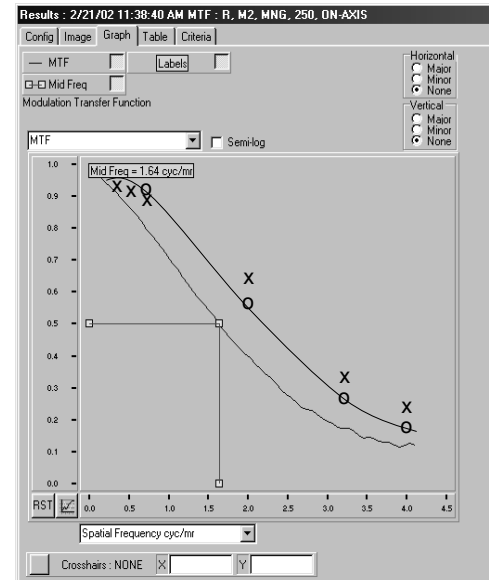


Figure 4.8

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 is 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 framegrabber 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>.

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<sup>TM</sup>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 4.8 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 somewhat and in many cases provide more accurate indications of the absolute MTF response (the effect of pedestal shift on the MTF profile is indicated in figure 4.8, ref. “o” curve).

### Manual MRTD, K-Factors, AutoMRTD

Figure 4-9 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<sup>TM</sup>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).

### 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<sup>TM</sup>2001 allows the user to determine MDTD as a function of target angular subtense. Figure 4-10 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.

### 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:  $1/10^{\text{th}}$ ,  $1/4$ ,  $1/3$ ,  $1/2$ ,  $3/4$ , 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

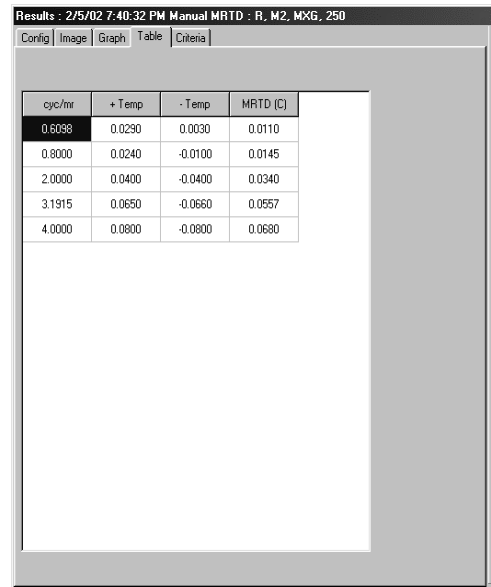


Figure 4.9

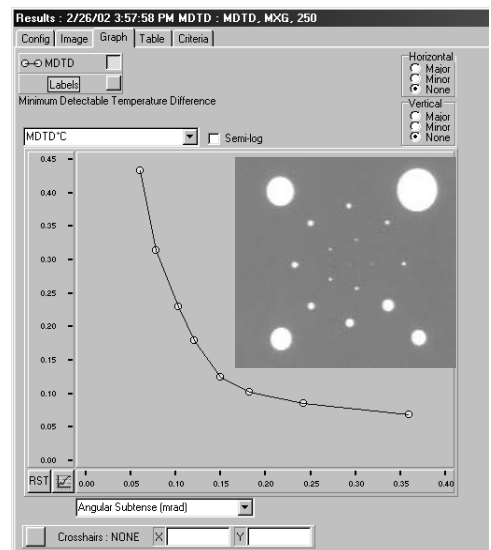


Figure 4.10

measurement point. Figure 4-11 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 is specified and selected from the Radiometric Model Editor prior to test execution. Figure 4-12 shows the configuration settings and key radiometric parameters for a typical

radiometric test performed on the RECON imager. Figure 4-13 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\*. Units of Watts or Photons (per unit area and solid angle) may be selected by the user, as indicated in figure 4-13. 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.

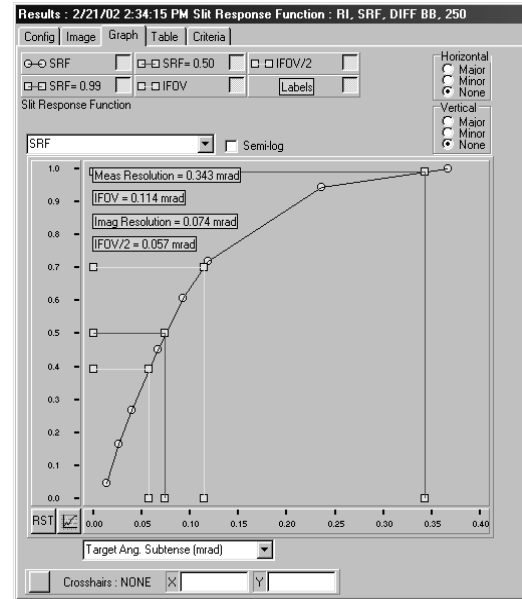


Figure 4.11

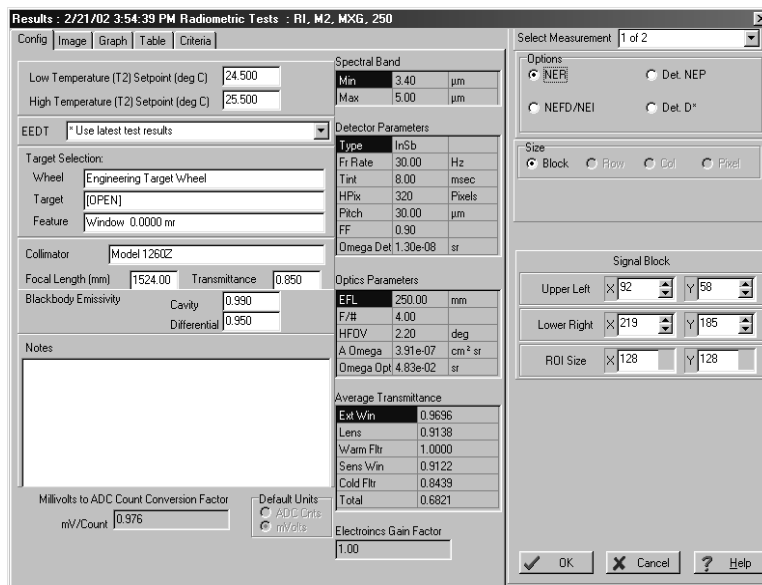


Figure 4.12

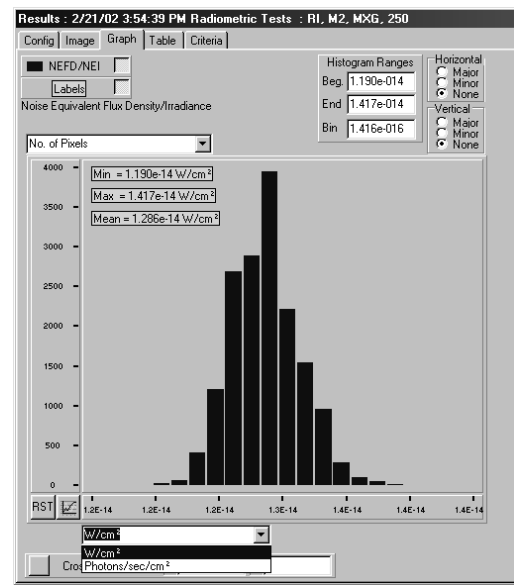


Figure 4.13

### 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 ( $\sigma_{TVH}$  or  $\sigma_{VH}$  depending upon frame-averaging selection). All analyses are plotted as a function of background (blackbody) temperature.

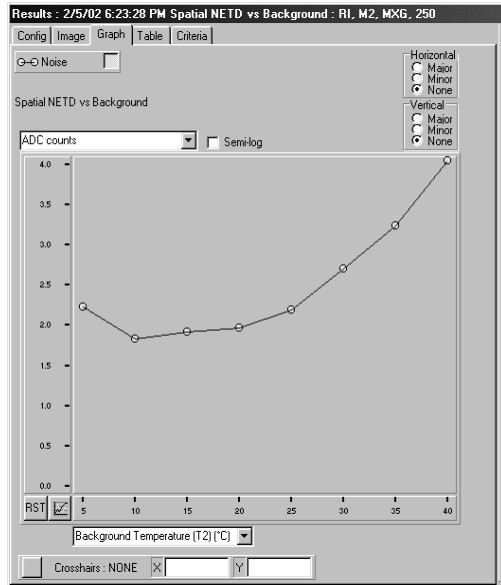


Figure 4.15

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 (3) temperatures (9.75, 10.0, and 10.25 deg C). From this raw data set, the SiTF as a function of background temperature is determined and plotted in figure 4-14. 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.

The noise counts are derived from the image acquired at the center temperature setpoints for each background temperature. Specifically either the noise is the  $\sigma_{TVH}$  value or if frame averaging is used, the noise value can approximate the  $\sigma_{VH}$  value. Figure 4-15 plots the noise results over the measured temperature span. At higher background

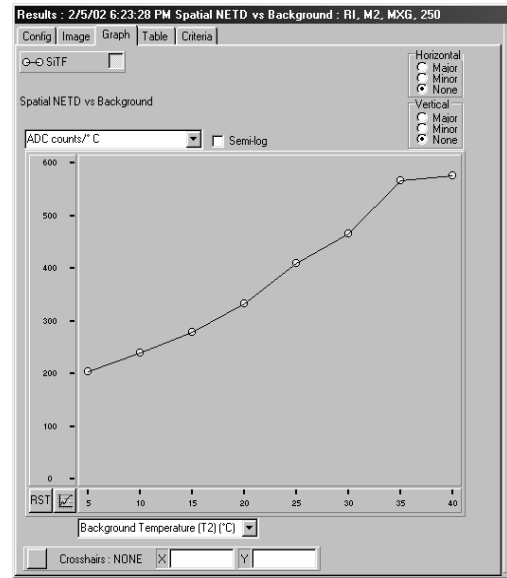


Figure 4.14

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.

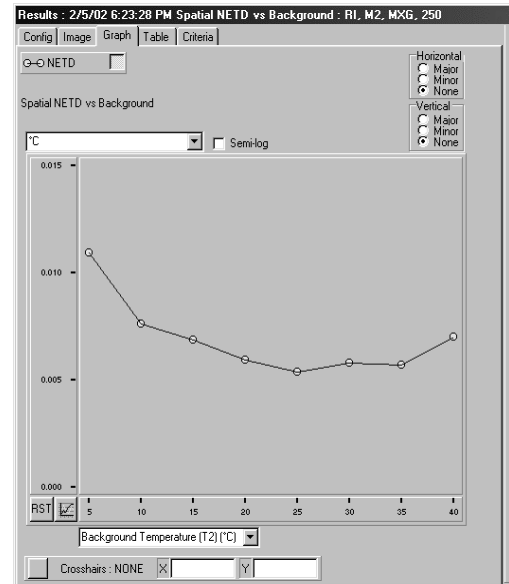


Figure 4.16

temperatures, the sensor's noise counts are primarily driven by background photon noise and residual photo-response non-uniformity noise. 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 4-16). 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.

## **5.0 SUMMARY**

This paper has presented a summary of the capabilities of a new generation of IR imager test software and hardware, IRWindows<sup>TM</sup>2001. A general framework for types of IR testing performed on modern day FPA-based IR cameras was presented along with actual production sensor test data from FLIRs MilCAM RECON product line.

For FLIR, IRWindows<sup>TM</sup>2001 has met and exceeded the goals that motivated the original expansion of the existing testing tool. FLIR is utilizing IRWindows<sup>TM</sup>2001 in its engineering group for testing and evaluating all of its new Imaging Products). In its production area, Acceptance Test Procedures (ATP's) for all its Ground imaging products (MilCAM, RECON, Ranger) are performed using IRWindows<sup>TM</sup>2001. By the end of Q1, many of the ALE/Maritime products (U7500, SeaFLIR, etc.) will be evaluated with this type of test equipment as well.

In addition to the many standard performance measures for IR imagers (i.e., SiTF, NETD, MTF and MRTD, etc.), the IRWindows<sup>TM</sup>2001 package has been upgraded with its first round of radiometric performance assessment capabilities with the inclusion of the RTM and RME. This results in a tool that is very useful to specialized military-program-oriented system designers and scientific users.

The extensive set of organized and automated features built in to the software platform such as user configurable test procedures, test configurations, and macro programming not only reduce the amount of time necessary to collect the data of interest on a given system, but also conveniently provide archival data for trend analysis by a manufacturer's QA department. Selected test results are further easily imported into a given system's final acceptance test report.

This two year joint development program between FLIR and SBIR has established a new level of synergy between the IR imager manufacturer and the test equipment provider resulting in a more flexible and powerful tool for OEM IR sensor developers, research scientists, and other IR enthusiasts. Ongoing work in both organizations will further validate the IRWindows<sup>TM</sup>2001 package and extend it into the Visible Sensor test arena.

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