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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure (TOP) 6-3-040
DTIC AD No.:

20 July 2009

THERMAL IMAGING SYSTEMS

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1. SCOPE.

1.1 Purpose.

This TOP describes the instrumentation and procedures for measuring the optical and electro-optical characteristics of military thermal imaging systems.

1.2 Limitations and Assumptions.

This TOP comprises optical and electro-optical procedures that are predominantly for laboratory evaluation. However, some field test procedures are also included. The test procedures included in this TOP should be applied to the performance parameters specified for the test item. Not all of the procedures will be required for every test item. It is assumed that the operator has a working knowledge of laboratory practices and the principles of optics and thermal imaging. It is further assumed that the test operator is familiar with the test item's characteristics. It is essential that appropriate guidelines and standard operating procedures for safety are followed. This TOP is intended to cover both scanning and staring focal plane array military thermal imagers operating in the mid-wave infrared (3-5 μ m waveband) and long-wave infrared (8-14 μ m waveband) spectral regions. Applications of this TOP are subject to test equipment variations dependent upon the specific type of thermal imager. Collimator efficiencies are usually given or measured as radiometric quantities, but are typically implemented as a multiplying factor of the source temperature. This discrepancy is a common source of error which can be minimized by maintaining a constant ambient temperature. The field test procedures should be used when the thermal imaging sensor/subsystem cannot be separated from the host vehicle; however, the accuracy obtainable in field testing may not reach that obtainable in the laboratory. The references contained in Appendix C are for information purposes only and to aid understanding of the test methods to be applied.

2. FACILITIES AND INSTRUMENTATION.

Due to the significant number of procedures described in this TOP, the specific facilities and instrumentation guidance are covered within each associated test procedure.

3. REQUIRED TEST CONDITIONS.

3.1 Preliminary Remarks.

Although this section provides a general overview of the required test conditions, specific guidance for this subject is covered within each associated test procedure.

3.2 Pre-Test Planning.

a. Test Plan: Prior to initiating the test program a test plan must be prepared. The test plan shall:

- (1) Describe each test to be performed in sufficient detail to be understood by potential test personnel and approving authorities.
- (2) Describe the measurements to be made, the test criteria, verification method, data required, data reduction and analysis techniques to be used.
- (3) Describe the test set-up for each test and the instrumentation to be used.
- (4) Identify the required environmental conditions, profiles and limits for each test, as well as the number and location of environmental condition sensors.

b. The pre-test planning shall also include:

- (1) Adequate safety procedures for test personnel.
- (2) A brief to test personnel on all aspects of the test program, including the purpose of each test, the measurement requirements, and the preparation and operation of all test instrumentation.
- (3) Sufficient copies of all test item and instrumentation operating instructions and safety procedures.

3.3 Preparation.

3.3.1 Facilities.

Preparation of test facilities shall include:

- a. Adequate lead time to ensure the facility will be available for the duration of the test program.
- b. Assurance that facility environmental equipment is in proper operating condition.
- c. In terms of laboratory requirements, conformance to optical darkroom standards is essential, as is good floor stability, although extreme levels of vibration damping are not normally required. However, care must be taken to ensure that the levels of vibration, air turbulence, temperature variation etc, do not interfere with resolution measurements (e.g. MRTD, MDTD, and MTF). The working area should provide easy access to all parts of the system.
- d. If the laboratory area is clean and dry, clean room conditions (temperature, dust and humidity control) are not normally required. Unless otherwise specified, an ambient temperature of 20 °C to 25 °C and a relative humidity of about 50% are generally satisfactory. For some measurements, control of environmental conditions may be required to meet test plan requirements.

3.3.2 Instrumentation.

- a. Prior to initiating the test program:
 - (1) Ensure that all test instrumentation is in proper operating condition.
 - (2) Ensure that test personnel are adequately trained to operate the test instrumentation. For measurement of MRTD a trained observer should be used.
 - (3) Ensure all test instrumentation is available for the test program.
 - (4) Ensure that the calibration of all test instrumentation is current and will extend through the test period.
 - (5) Ensure that the accuracy of all test instrumentation will meet the test requirements. This is referred to as Test Accuracy Ratio (TAR) of the measurement parameter.
- b. The use of automated test instrumentation should be considered during the test planning process.

Specific test instrumentation requirements are listed in the individual test procedures.

3.4 Test Item.

- a. Prior to initiating the test program:
 - (1) Inspect the test item for damage, completeness, deterioration, or manufacturing defects and record any deficiencies.
 - (2) Ensure that the test item is in proper operating condition.
 - (3) Ensure that operating manuals for the test item are available.
- b. Provide a description of the test item(s). If available, the description should include, but not be limited to, the following:
 - (1) A description of the intended use of the test item.
 - (2) A description of each operating mode of the test item.
 - (3) Photographs of the test item mounted in the host vehicle and, if possible, outside the host vehicle.
 - (4) The test item specifications for each attribute to be measured.
 - (5) The physical characteristics (i.e. weight and dimensions) of the test item.

(6) A schematic diagram of the test item, its components and its interface to other sub-systems in the host vehicle.

(7) A description of all control features of the test item.

c. Test personnel shall be adequately trained to operate the test item and be familiar with all operating modes and controls.

4. TEST PROCEDURES.

Note: for any measurements where optical alignment or image resolution or quality is involved, the test item must be mounted in such a fashion that vibrations are dampened to normal field operational levels. In some cases, when sensors are hard mounted in lab environment, these vibrations are more pronounced than that found in operational environments and are of such a magnitude that they adversely impact the measurement values. This is especially true when dealing with sensors that have scanning mirrors or other vibration sources.

4.1 Minimum Resolvable Temperature Difference (MRTD).

4.1.1 Scope.

The purpose of this test is to measure the thermal resolution of a thermal imaging device as a function of spatial frequency for each test item field-of-view, in a laboratory environment (reference STANAG 4349^{1**}). Note that this reference is limited to analog or properly sampled thermal imaging sensors.

4.1.2 Facilities and Instrumentation.

a. Facilities.

<u>Item</u>	<u>Requirement</u>
Optical Laboratory	Standard Equipment
MRTD Thermal Targets	A differential blackbody source with a thermal range of -10 °C to + 30 °C from ambient and several 7:1 (height to width) aspect ratio 4-bar patterns bounding the published specification for MRTD when used with the below described collimator.

^{**} Superscript numbers/letters correspond to those in Appendix C, References.

<u>Item</u>	<u>Requirement</u>
Collimator(s)	Diffraction limited, capable of covering the span of spatial frequencies specified for the test item, using the MRTD thermal targets. The waveband of operation must accommodate the waveband of the test item. The average radiometric efficiency (collimator transmission/reflection and atmospheric transmission) in the waveband of the test item must be known. The collimator aperture must be sufficient to overfill the entrance pupil of the test item at the collimator/test item separation (collimator working distance).

b. Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Collimated MRTD Thermal Targets	Spatial frequency: $\pm 5\%$, Temperature: better than 10% of the thermal resolution specified for the test item, or 0.01 °C, whichever is larger.

4.1.3 Test Conditions.

a. The laboratory ambient temperature should be set at the recommended ambient background temperature for the test item and maintained to control residual drift. Steps must be taken, by shielding or by other means, to avoid significant local background temperature variations or transient fluctuations.

b. Mount the test item in a fixture so that an observer can view the image of the target. The test item is positioned so that it views the target through a collimator as shown in Figure 1. Ensure that the test item is within the collimator working distance. The target plate is placed in front of a blackbody source and positioned at the focal point of the collimator. The collimator shown in Figure 1 is an off-axis paraboloid (OAP). The temperature difference between the blackbody source (target) and the target plate (background) provides the thermal contrast. The temperature difference between the blackbody seen through the apertures in the target plate and the solid parts of the target plate is the target-to-background temperature difference. The fundamental spatial frequency of the bar target is defined by the period of the 4-bar target and collimator focal length.

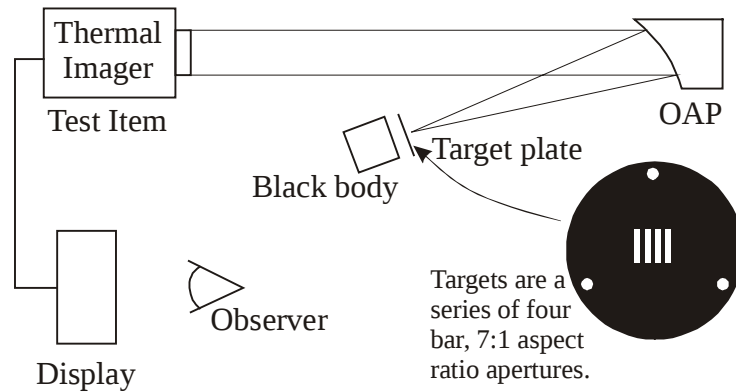


Figure 1. Typical MRTD Test Configuration.

c. The MRTD is the minimum target-to-background temperature difference at which the 4-bar target can just be resolved by a trained observer. A Forward MRTD is measured with the blackbody temperature above the background. A Reverse MRTD is measured with the blackbody temperature below the background.

d. The Forward and Reverse MRTD values are measured at different spatial frequencies by using a selection of standard 4-bar targets. The standard 4-bar target patterns range in size to represent spatial frequencies typically ranging from 0.1FN to just beyond FN, where FN = Nyquist frequency (cy/mr).

e. The temperature difference between the background and the blackbody is varied between -10 °C and 30 °C for the Forward and Reverse MRTD. The target plate is placed at the focus of a collimator so that the correct spatial frequency is presented. Forward and reverse measurements are required in order to null the effects of the emissivity of the background/target. Emissivity will be cancelled out if the measurements are averaged. Care must be taken to maintain the correct positive and negative values in all calculations.

f. The horizontal MRTD is measured with the vertical bar pattern placed in the on-axis position (OA) and, if required, in one or more off-axis FOV positions. These are defined in Figure 2, where OA = on-axis and UR = upper right, etc. The horizontal separation between positions UL and UR or LL and LR and the vertical separation between positions UL and LL or UR and LR will typically subtend 80% of the field-of-view.

g. If required, this measurement can also be made with horizontal bar patterns for Vertical MRTD.

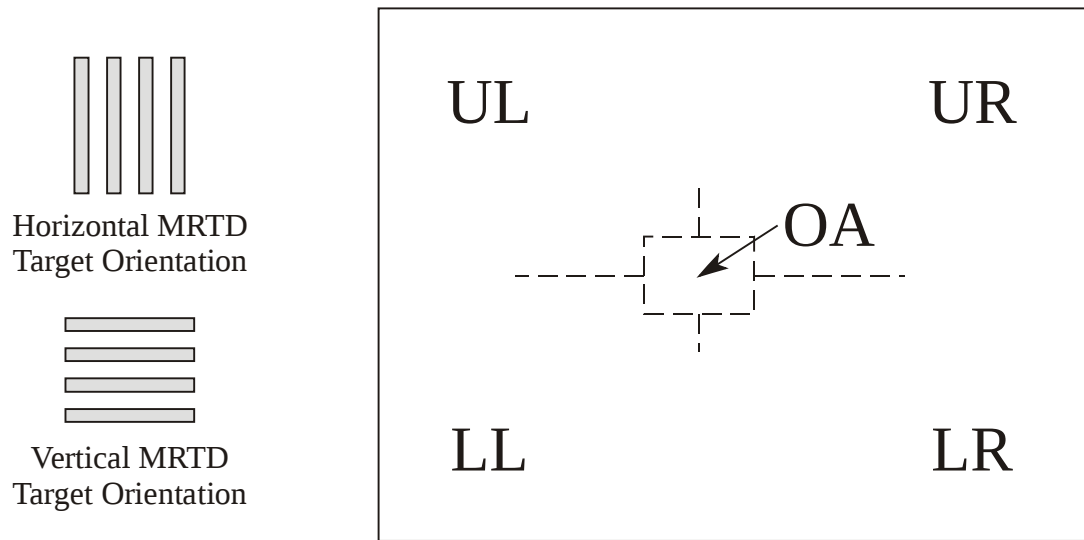


Figure 2. Horizontal and Vertical MRTD Target Orientations and MRTD FOV Positions.

4.1.4 Test Procedures.

a. Use an observer who is considered / recognized as trained in the area of resolving 4-bar targets to determine the MRTD. The observer's visual acuity shall be at least 3/6 or equivalent. While viewing the target on the display in a dark-adapted environment, permit the observer to adjust all control settings and background illumination conditions for optimum image quality. Once set, the white-hot/black-hot polarity setting should be recorded and retained for the duration of the test. The target plate (background) temperature shall be homogeneous and close to the laboratory ambient temperature. Record the laboratory ambient temperature and the target plate temperature (if different from ambient).

b. The criterion to be used for the MRTD measurements is that it should be possible to just resolve 75% to 100% of the area of the bars and spaces between the bars (not just some modulation) on the display, 50% of the time. It is not necessary that the whole of each bar be visible at the same time.

c. MRTD is calculated to give apparent temperature difference values and is given by $MRTD = \eta \Delta T$; where η is the radiometric efficiency and ΔT is the actual target-to-background temperature difference ($^{\circ}\text{C}$).

d. For each combination of target spatial frequency, orientation and field-of-view position (see Figure 2), perform the following operations to obtain values for Forward and Reverse MRTD.

(1) Adjust the temperature of the blackbody to make the target bar pattern temperature much higher than the target plate (background) temperature so that the bars are clearly distinguishable.

(2) Optimize the test item display controls to obtain the best image. The test item position may be slightly adjusted in pitch and/or yaw to obtain the maximum visibility of the image. Any aliasing effects (e.g. changes in bar width or spacing) should be noted and, if possible, photographed.

(3) Change the blackbody temperature towards the ambient temperature until the bars are clearly unresolvable.

(4) Slowly change the temperature of the blackbody away from the ambient temperature.

(5) Slowly increase the temperature until the bar pattern is just discernable and the top and bottom of the pattern can be identified and the relative width of the spaces and bars are approximately equal. This is the point where the measurement should be taken.

(6) Calculate and record the minimum apparent temperature difference between blackbody and background for which the target bar pattern is just distinguishable (Forward MRTD).

(7) Adjust the temperature of the blackbody to make the target bar pattern temperature much lower than the background and clearly distinguishable.

(8) Repeat steps 2 through 5, except record as the Reverse MRTD.

(9) Calculate the MRTD by taking half the difference of the Forward and Reverse MRTDs.

(10) Where multiple observations are made by a single observer, calculate and record the arithmetic mean MRTD of the observations.

e. If more than one observer is required, repeat the test as described in paragraph 4.1.4.d for each observer.

f. Calculate the geometric mean of the MRTD for the observers and record as the overall geometric mean MRTD at each combination of target spatial frequency, orientation and field-of-view position. (The geometric mean is used because the observer-to-observer variability typically follows a log-normal distribution.) Typical observer-to-observer variations in MRTD are shown in Figure 3.

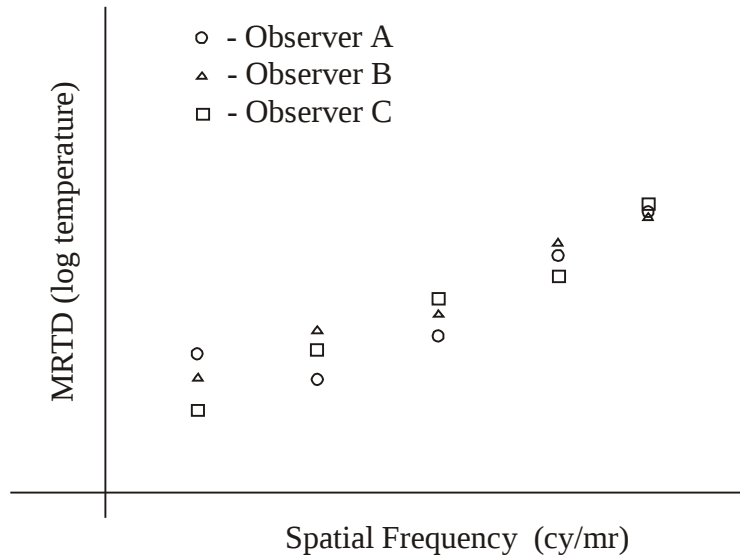


Figure 3. MRTD Observer Variation.

4.1.5 Data Required.

- Number of observers.
- Radiometric efficiency.
- Test item field-of-view.
- Target plate temperature (if different from ambient).
- Laboratory ambient temperature.
- Target orientation.
- Target spatial frequencies used.
- Calculated geometric mean of MRTD values for each combination (arithmetic mean if one observer).

4.1.6 Presentation of Data.

- For each target orientation, provide a table of the calculated MRTD values as illustrated in Table 1.

Table 1. MRTD Measurements.

MRTD MEASUREMENTS		
Number of Observers:		Target Plate Temperature:
Target FOV Position:		Test Item FOV:
Lab Ambient Temperature:		Radiometric Efficiency:
Spatial Freq (cy/mr)	Overall Mean MRTD at FOV Position	
	Horizontal MRTD	Vertical MRTD
0.1		
⋮		
10		

b. For each target field-of-view position, provide curves of the horizontal and vertical MRTD as a function of target spatial frequency, as illustrated in Figure 4. The curves are fitted to the overall mean values from Table 1.

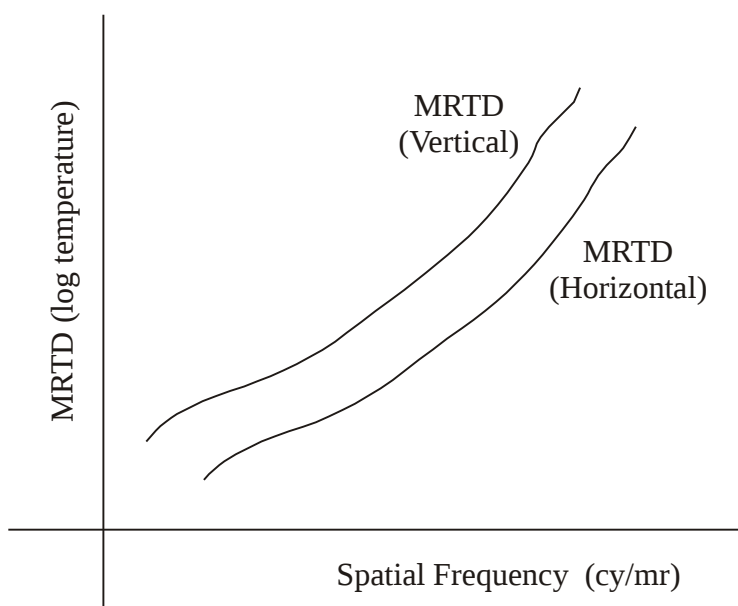


Figure 4. Typical MRTD Curves.

4.2 Minimum Detectable Temperature Difference (MDTD).

4.2.1 Scope.

The purpose of this test is to measure the thermal resolution of a thermal imaging device as a function of spatial frequency, for each test item field-of-view, in a laboratory environment.

4.2.2 Facilities and Instrumentation.

a. Facilities.

<u>Item</u>	<u>Requirement</u>
Optical Laboratory	Standard Equipment
MDTD Thermal Targets	A differential blackbody source with a thermal range of -10 °C to + 30 °C from ambient and several square, circular, or equilateral triangular targets.
Collimator(s)	Diffraction limited, capable of generating targets varying in size from 0.1 to 10 times the test item's detector angular subtense, using the MDTD thermal targets. The waveband of operation must accommodate the waveband of the test item. The average collimator efficiency (transmission/reflection) in the waveband of the test item must be known. The collimator aperture must be sufficient to overfill the entrance pupil of the test item at the collimator/test item separation (collimator working distance).

b. Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Collimated MDTD Thermal targets	Angular subtense: $\pm 5\%$, Temperature: better than 0.1 of the thermal resolution specified for the test item, or 0.01 °C, whichever is larger.

4.2.3 Test Conditions.

a. The laboratory ambient temperature should be set at the recommended ambient background temperature for the test item and maintained to control residual drift. Steps must be taken, by shielding or by other means, to avoid significant local background temperature variations or transient fluctuations.

b. Mount the test item in a fixture so that an observer can view the image of the target. The test item is positioned so that it views the target through a collimator as shown in Figure 1. Ensure that the test item is within the collimator working distance. The target plate is placed in front of a blackbody source and positioned at the focal point of the collimator. The collimator shown in Figure 1 is an off-axis paraboloid (OAP). The temperature difference between the target plate and the blackbody source provides the thermal contrast. The temperature difference between the blackbody seen through the aperture in the target plate and the solid part of the target plate is the target-to-background temperature difference. The angular subtense of the target is defined by the width (square), diameter (circle), or base-to-apex distance (triangle) of the target and the collimator effective focal length.

c. The temperature difference between the target plate (background) and the target blackbody is varied between -10 °C and 30 °C.

4.2.4 Test Procedures.

a. Use an observer who is considered / recognized as trained in the area of resolving targets to determine the MDTD. The observer's visual acuity shall be at least 3/6 or equivalent. While viewing the target on the display in a dark-adapted environment, permit the observer to adjust all control settings and background illumination conditions for optimum image quality. The background temperature of the MDTD target shall be homogeneous and close to the laboratory ambient temperature. Record the laboratory ambient temperature and the target plate temperature (if different from ambient).

b. The target extent should be varied between 0.1 and 10.0 times the Detector Angular Subtense (DAS).

c. Adjust the temperature of the blackbody to make the target temperature much higher than the background, so that the target is clearly distinguishable.

d. Optimize the test item display controls to obtain the best image. The test item position may be slightly adjusted in pitch and/or yaw to obtain the maximum visibility of the image.

e. Lower the blackbody temperature towards the ambient temperature until the target is clearly undetectable.

f. Increase the blackbody temperature above the ambient temperature at a rate which is easily controlled. Record the target temperature above background (Forward MDTD) at which the observer can just detect the target. Repeat the test for each target size.

g. If the forward MDTD for any target size is less than 1°C, then decrease the target temperature below the ambient, at a rate that is easily controlled. Record the target temperature below ambient (Reverse MDTD) at which the observer can just detect the target. Calculate the MDTD for the observer for the target size by taking half the difference of the Forward and Reverse MDTDs. Where multiple observations are made by a single observer, calculate and record the arithmetic mean MDTD of the observations.

h. If more than one observer is used, repeat the above test for each combination in paragraphs 4.2.4c to 4.2.4h.

i. Calculate and record the geometric mean MDTD of the observations. (The geometric mean is used because observer-to-observer variability typically follows a log-normal distribution.)

4.2.5 Data Required.

a. Number of observers.

- b. Radiometric efficiency.
- c. Test item field-of-view.
- d. Laboratory ambient temperature.
- e. Target Plate temperature (if different from ambient).
- f. Target description (square, circular or triangular).
- g. Target angular subtense used.
- h. Calculated geometric mean of MDTD values (arithmetic mean if one observer).

4.2.6 Presentation of Data.

- a. MDTD data for each target size shall be presented in tabular form as shown in Table 2.

Table 2. MDTD Measurements.

MDTD MEASUREMENTS		
Number of Observers:		Radiometric Efficiency:
Target Plate Temperature:		
Lab Ambient Temperature:		Test Item FOV:
Reciprocal Target Subtense (1/mr)	Target Description	Mean MDTD(°C)
...		

- b. The MDTD data will be graphically displayed as a function of target size as shown in Figure 5. The curve is fitted to the overall mean values from Table 2.

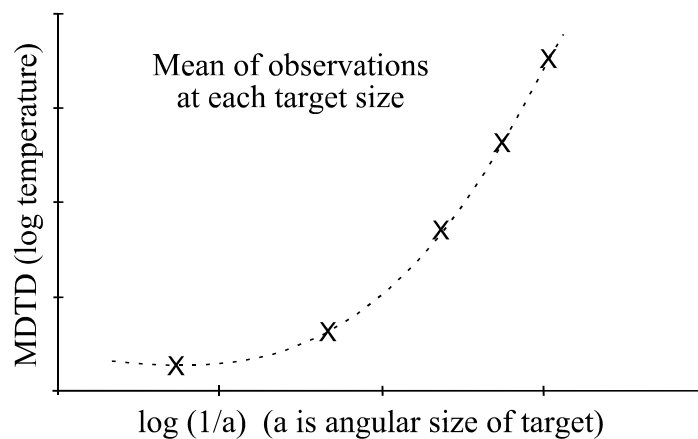


Figure 5. Typical MDTD Curve.

4.3 Signal Transfer Function (SiTF).

4.3.1 Scope.

The purpose of this test is to measure the relationship of the temperature difference between the target and the background, to either the test items analog or digital output video signal or display luminance.

4.3.2 Facilities and Instrumentation.

a. Facilities.

<u>Item</u>	<u>Requirement</u>
Optical Laboratory	Standard Equipment

b. Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Collimated thermal target	Size: approximately 0.1 of the test item field-of-view. Temperature: -10°C to +30°C relative to background.
Digital Data Acquisition Device (digital video output frame grabber)	Dynamic range > test item range. Bandwidth > test item bandwidth.
Digital Oscilloscope (for analog video signals)	Dynamic range > test item range. Bandwidth > 5 times test item bandwidth.
Photometer (for illuminance measurements)	Dynamic range > test item display range.

4.3.3 Test Conditions.

- a. Mount the test item in a fixture so that an observer can view the target.
- b. The thermal target will be heated to a sufficient temperature difference so that all observers can readily discern the target pattern.
- c. Where SiTF is measured as part of NETD (Section 4.4), this must be within one half hour before the NETD measurement.

4.3.4 Test Procedures.

- a. Present the collimated thermal target to the test item with the target image near the center of the raster. Measure and record the output video or luminance corresponding to the displayed target with a suitable data acquisition device or a photometer.
- b. Adjust the target temperature such that there are at least 5 data points over the linear unsaturated part of the SiTF curve. For each data point, permit the temperature to stabilize and record the peak output video signal.
- c. For cases where contrast and brightness controls are used to vary the video output, repeat for at least six combinations of contrast and brightness settings; three with variable brightness (min, mid, max) and fixed mid-point contrast, and three with variable contrast (min, mid, max) and fixed mid-point brightness. These combinations are illustrated in Figure 6.

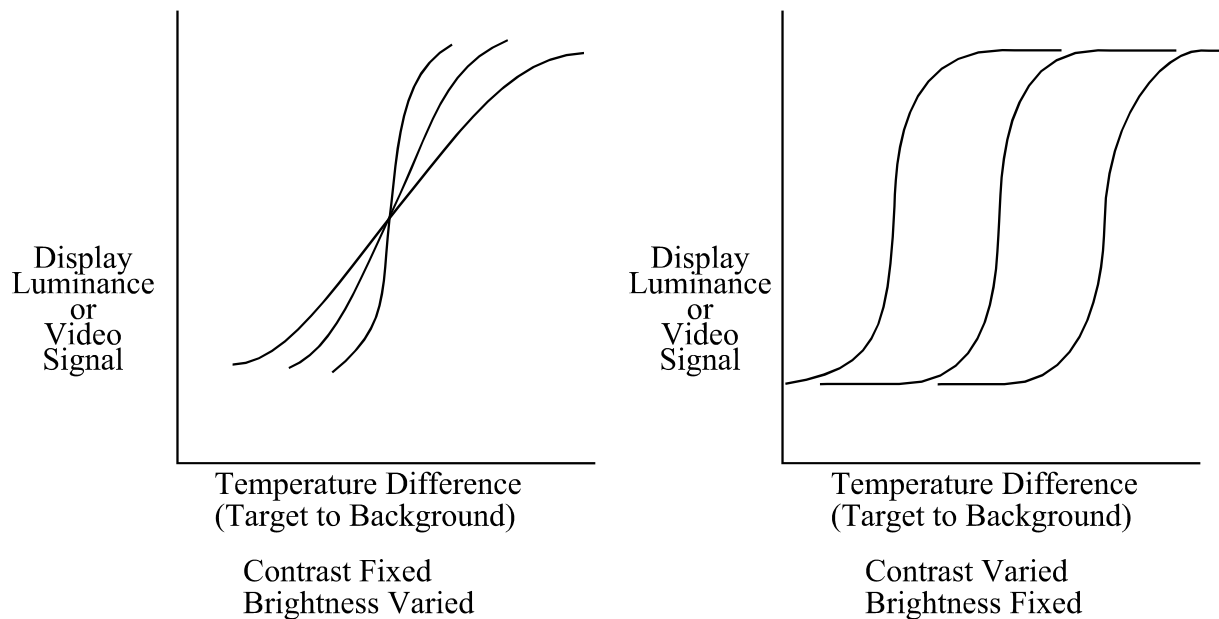


Figure 6. Variations in Video Output for SiTF.

4.3.5 Data Required.

- a. Test item brightness and contrast settings.
- b. Background temperature.
- c. Target temperatures relative to background temperature.
- d. Measured values for output video signal or the luminance of the display at each target temperature setting.

4.3.6 Presentation of Data.

a. Tabular presentation of required data for each combination as illustrated in Table 3. Note that Table 3a is for output video signal measurements and Table 3b is for luminance measurements.

Table 3a. SiTF Analog or Digital Video Measurements.

SiTF MEASUREMENTS		
Background temperature (°C):		
Brightness Setting:		Contrast Setting:
Trial	Target temperature relative to background temperature (°C)	Signal Voltage (V) or Digital Counts
1		
...		
N		

Table 3b. SiTF Luminance Measurements.

SiTF MEASUREMENTS		
Background temperature (°C):		
Brightness Setting:		Contrast Setting:
Trial	Target temperature relative to background temperature (°C)	Luminance (cd/m ²)
1		
...		
N		

b. For each combination, provide a graphical representation of the output video signal or the display's luminance as a function of the target's temperature difference relative to the background temperature. An example is shown for the voltage measurement in Figure 7.

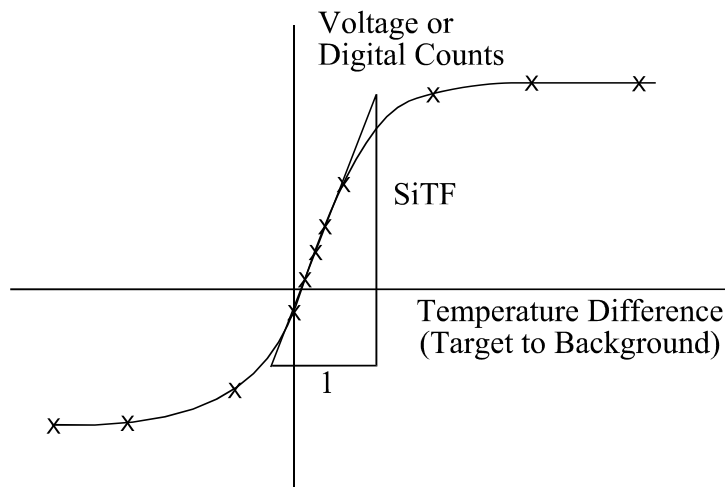


Figure 7. SiTF Curve.

4.4 Noise Equivalent Temperature Difference (NETD).

4.4.1 Scope.

The purpose of this test is to measure the high frequency component of the random temporal noise associated with the thermal imager output, relative to the SiTF. The SiTF value (the slope of the SiTF curve in the linear region of response as shown in Figure 7) obtained from section 4.3 is required. Depending on the thermal imager, the noise measurement can be made in at least one of the following three ways:

- a. Using the RMS voltage noise from the analog video output,
- b. Using the RMS digital count noise from the digital video output, or
- c. Using the RMS illuminance noise of the thermal imager's display.

The method chosen must coincide with the method chosen for the SiTF measurement. It should be noted that voltage or digital count measurements are preferred to display photometric measurements for RMS noise. The procedure is not suited to field testing.

4.4.2 Facilities and Instrumentation.

- a. Facilities.

<u>Item</u>	<u>Requirement</u>
Optical Laboratory	Standard Equipment

b. Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Felt or Foam Cover	Must be uniform in temperature and emissivity and large enough to cover the imager's entrance aperture.
Digital Data Acquisition Device (digital video output frame grabber)	Dynamic range > test item range. Bandwidth > test item bandwidth.
Digital Oscilloscope (for analog video signals)	Dynamic range > test item range. Bandwidth > 5 times test item bandwidth.
Photometer (for illuminance measurements)	Dynamic range > test item display range.

4.4.3 Test Conditions.

a. Mount the test item in a fixture so that a cover can be placed over the entrance aperture of the imaging system.

b. The SiTF must have already been measured (within the last one-half hour) and the SiTF value is readily available for the NETD calculation (see section 4.3). When calculating the NETD, the SiTF value is taken as the slope of the SiTF curve in the linear region of response (near the small signal temperature differential).

c. The region of interest within the test item FOV is specified or assumed for the NETD calculation processing (e.g. the center 1/3 x 1/3 of the field-of-view).

Note: Historically, NETD was defined at the output (analog) of the post amplifier. For this classical measurement, a simple filter was added with a 3-dB break frequency equal to the reciprocal of twice the detector dwell time. For *system* measurements as described in this TOP, NETD is defined at the analog video output to the monitor or the digital video output, where this classical external filter is not used.

4.4.4 Test Procedures.

a. Place the felt or foam cover over the entrance aperture of the test item to present a uniform out-of-focus source, so that the imager's output is a constant signal with maximum gain.

b. For voltage measurements, measure the RMS noise of the analog output video signal (e.g. RS-170, CCIR) of the test item using a digital oscilloscope.

- (1) Set up the digital oscilloscope to capture the first video line in the region of interest.
- (2) Set up the digital oscilloscope to capture only that portion of the video line corresponding to the region of interest for processing (the sync, reference, front porch, back porch, etc. signals must not be included).
- (3) Collect (capture or calculate) a time-averaged waveform of at least 256 frames of the video line region of interest and save this as the time-averaged waveform.
- (4) Subtract the time-averaged waveform from 4 consecutive waveforms, resulting in 4 pedestal removed waveforms.
- (5) Fit a 2nd order polynomial curve to each of the four pedestal removed waveforms and subtract it from each of the respective waveforms to remove the low frequency “trend” component of the video.
- (6) Calculate the standard deviation of the samples for each of the 4 waveforms that have been processed for pedestal and trend removal.
- (7) Calculate the average value of the 4 standard deviations and record this as the RMS voltage noise for the selected video line.
- (8) Repeat steps 2 through 7 for each video line in the region of interest.
- (9) Calculate the system RMS voltage noise by taking the average of the RMS voltage noise of all the video lines; recording this as $V_{\text{rms_noise}}$ [Volts].
- (10) Calculate and record the NETD using the RMS voltage noise and the corresponding SiTF value from paragraph 4.4.3b, using the equation:

$$\text{NETD} = \frac{V_{\text{rms_noise}} [\text{Volts}]}{\text{SiTF} \frac{[\text{Volts}]}{[\text{Deg C}]}} \quad \text{Celsius}$$

c. For digital count measurements, the RMS noise is measured on the digital output imagery of the test item.

- (1) Capture a minimum of one second of continuous digital frames from the region of interest and store in a three dimensional data set whose size is $T \times V \times H$. This data set is denoted UTVH. T is the number of frames captured, V is the number of vertical pixels and H is the number of horizontal pixels. V and H are determined by the specified region of interest, where V begins and ends with the first and last row of the region of interest respectively; and H begins and ends with the first and last column of the region of interest respectively.

(2) Calculate a two dimensional average in the T dimension (i.e. a frame average of the data set UTVH). Subtract the two dimensional average from each two dimensional VxH 'frame' of UTVH resulting in a new three dimensional data set with the temporal average removed. The size of the new data set is still T x V x H, and is denoted UtTVH.

(3) Calculate a two dimensional average in the V dimension on UtTVH. This two dimensional average shall be subtracted from each two dimensional TxH 'frame' of UtTVH resulting in a new three dimensional data set with the temporal and vertical averages removed. The size of the new data set is still T x V x H, and is denoted UtvTVH.

(4) Calculate a two dimensional average in the H dimension on UtvTVH. This two dimensional average shall be subtracted from each two dimensional TxV 'frame' of UtvTVH resulting in a new three dimensional data set with the temporal, vertical and horizontal averages removed. The size of the new data set is still T x V x H, and is denoted UtvhTVH.

(5) If necessary, remove the low frequency portion of UtvhTVH, which is sometimes referred to as trends. It is suggested that this be accomplished by subtracting UtvhTVH by a 2nd order least squares three dimensional fit to UtvhTVH.

(6) After removal of the low frequency trends, calculate the standard deviation of the data set UtvhTVH and record the value as $\sigma_{rms}[\text{Counts}]$.

(7) Calculate and record the NETD using the RMS digital counts noise and the corresponding SiTF value from paragraph 4.4.3b, using the equation:

$$\text{NETD} = \frac{\sigma_{rms} [\text{Counts}]}{\text{SiTF} \frac{[\text{Counts}]}{[\text{Deg C}]}} \quad \text{Celsius}$$

d. For luminance measurements, measure the RMS luminance of the display using a photometer that has a measurement spot of, at most, one-tenth of the impulse response width of the imager system displayed on the monitor.

(1) Record the RMS luminance as $L_{rms_noise}[\text{cd/m}^2]$

(2) Calculate and record the NETD using the RMS luminance noise and the corresponding SiTF value from paragraph 4.4.3b, using the equation:

$$\text{NETD} = \frac{L_{rms_noise} [\text{cd/m}^2]}{\text{SiTF} \frac{[\text{cd/m}^2]}{[\text{Deg C}]}} \quad \text{Celsius}$$

e. When calculating the Noise Equivalent Temperature Difference, the SiTF value (see paragraph 4.4.3b) is taken as the slope of the SiTF curve in the linear region of response (near the small signal temperature differential), for normal brightness and contrast settings usually specified or assumed. The specified combination of brightness and contrast settings should be recorded, if available.

4.4.5 Data Required.

- a. Test item settings.
- b. Region of interest within the FOV.
- c. Ambient temperature.
- d. System NETD.

4.4.6 Presentation of Data.

NETD is presented in tabular form as illustrated in Table 4.

Table 4. Noise Equivalent Temperature Difference (NETD).

NETD MEASUREMENTS	
Test Item Settings:	Region of Interest within the FOV:
Ambient Temperature (degrees C):	NETD (degrees C):

4.5 Operational Readiness Time (Warm-up Time).

4.5.1 Scope.

The purpose of this test is to measure the time interval between switch on and readiness for use for a thermal imaging system, in a laboratory environment.

4.5.2 Facilities and Instrumentation.

a. Facilities.

<u>Item</u>	<u>Requirement</u>
Optical laboratory	Standard Equipment
MRTD thermal targets	A differential blackbody source with a thermal range of + 30 °C from ambient and several 7:1 (height to width) aspect ratio 4-bar patterns.
Collimator	Diffraction limited, capable of covering the span of spatial frequencies specified for the test item, using the MRTD thermal targets. The waveband of operation must accommodate the waveband of the test item. The collimator aperture must be sufficient to overfill the entrance pupil of the test item.

b. Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Collimated MRTD thermal targets	Spatial frequency $\pm 5\%$.
Timer (stopwatch)	$\pm 0.1s$ over timed interval.

4.5.3 Test Conditions.

a. Ensure that the MRTD target source is adequately shielded to avoid local background temperature variations.

b. Mount the test item in a fixture so that the observer can view the image of the target through the collimator. Note that for image comparison purposes, one observer should be used throughout the test.

c. Ensure that the collimator aperture overfills the entrance pupil of the test item.

4.5.4 Test Procedures.

a. Switch on the test item and allow it to stabilize. Permit the observer to adjust all control settings to obtain an image.

b. Set the target condition to the specified spatial frequency and temperature difference. When there is no specification for these parameters, select a target pattern which is close to, but distinctly within the thermal resolution of the test item.

c. Present the collimated thermal target to the test item. Position the target at the center of the field-of-view. Adjust the test item control settings to achieve good display contrast without saturation.

d. With the image quality and position established as described, switch off the thermal target and the test item. Leave the test item in the off condition until the detector has reached ambient temperature (this is highly dependent on the test item and can range from several hours to overnight). Do not change the test item and laboratory conditions during this period.

e. Switch on the thermal target at the previous settings and allow the temperature to stabilize.

f. Verify that the ambient temperature is the same as at first switch on. Switch on the test item and use the timer to record the interval between switch on and the point at which the image quality reaches the level previously established at step c (the operator may adjust control settings if needed). The recorded period is the operational readiness time (maximum).

Note: If the test item has a standby mode of operation, the procedure may be repeated by timing the interval between this condition and the attainment of established image quality. The recorded period is the operational readiness time (standby).

4.5.5 Data Required.

- a. The spatial frequency of the selected thermal target pattern.
- b. The differential target temperature and the ambient temperature.
- c. The operational readiness time (maximum and/or standby).

4.5.6 Presentation of Data.

A tabular listing of the required data as shown in Table 5.

Table 5. Operational Readiness Time.

OPERATIONAL READINESS TIME (ORT)	
Ambient Temperature:	
Target Spatial Frequency (cy/mr)	
Differential Target Temperature (K)	
ORT Maximum/Standby* (seconds)	

* Delete as appropriate

4.6 Field-of-View (FOV).

4.6.1 Scope.

The purpose of this test is to measure the field(s)-of-view of a thermal imaging device. The test will be conducted in a laboratory environment when the test item is removable from the host vehicle. When the test item cannot be removed from the host vehicle, a procedure is outlined for field testing.

4.6.2 Facilities and Instrumentation.

a. Facilities.

<u>Item</u>	<u>Requirement</u>
Optical Laboratory and/or Test Range	Standard Equipment ≥500m line-of-sight

b. Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Collimated thermal point, edge or line source	Collimated beam > entrance pupil diameter of the test item. Distinguishable from background
Rotary Table (pitch and yaw)*	Sufficient size to support the test item or collimator Rotation ≥ 110% of test item FOV Resolution ≤ 2 arc min Accuracy ≤ 1 arc min
Distance measuring equipment	Target range ±0.5 m

*Note: It is possible to use a single axis rotary table that can be reconfigured to accommodate both pitch and yaw angles.

4.6.3 Test Conditions.

a. Laboratory Tests.

(1) Securely mount the test item or collimator on the rotary table. Position the test item and collimator such that the axis of rotation of the rotary table is perpendicular to their optical axes and is in the plane of the entrance pupil of the test item, as shown in Figure 8.

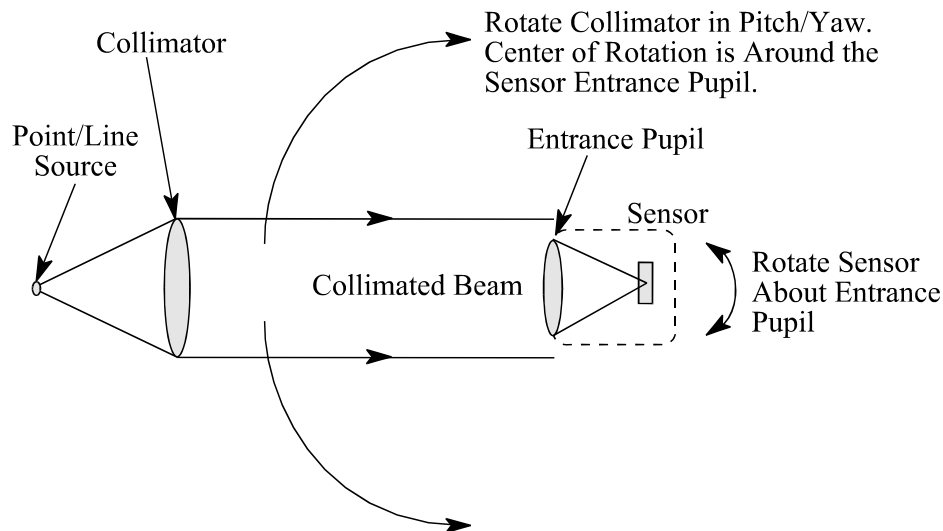


Figure 8. FOV Test Configuration.

(2) Position the collimator system such that the collimated beam overfills the entrance pupil of the test item under all rotation conditions.

(1) The point or line source must have a sufficient temperature difference so that the observer can readily discern the target from the background.

(3) The optics of the test item must be focused with the image at the center of one edge of the field-of-view.

b. Field Tests.

(1) If the test item cannot be removed from the host vehicle, then a test range is required where the observer can view a point source target at a range of 500 meters or greater.

(2) Position the test item using the host vehicle systems so that an observer can view the distant target.

(3) There should be a clear line of sight over the entire field-of-view of the test item.

(4) The optics of the test item must be focused with the image at the center of one edge of the field-of-view.

4.6.4 Test Procedures.

a. Laboratory Tests.

(1) Present a collimated thermal target to the test item. Either the collimator must be rotatable in pitch and yaw or the test item must be rotatable about its entrance pupil (see Figure 14).

(2) Rotate the collimator/test item to produce an image at the center of the left-hand edge of the test item field-of-view. Record the collimator/test item position (angles) as indicated in Figure 9.

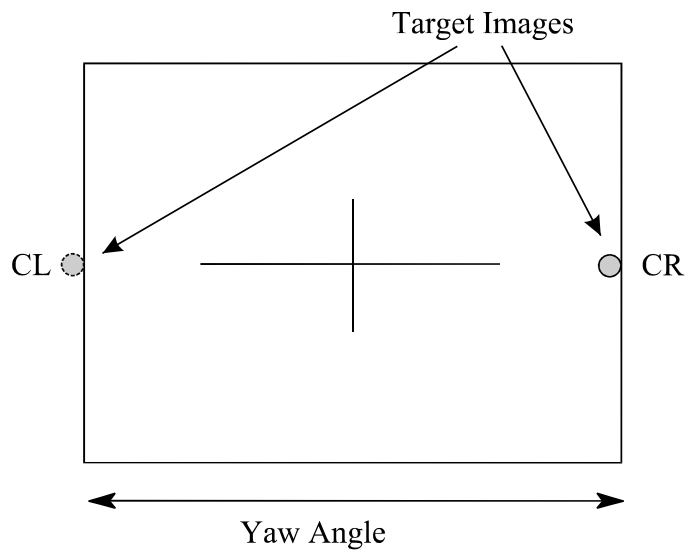


Figure 9. Image Positions for Horizontal FOV.

(3) Rotate the collimator/test item to produce an image at the center of the right-hand edge of the test item field-of-view. Record the collimator/test item position (angle) as indicated in Figure 9. The difference in the two recorded collimator/test item positions is the test item horizontal field-of-view (yaw angle).

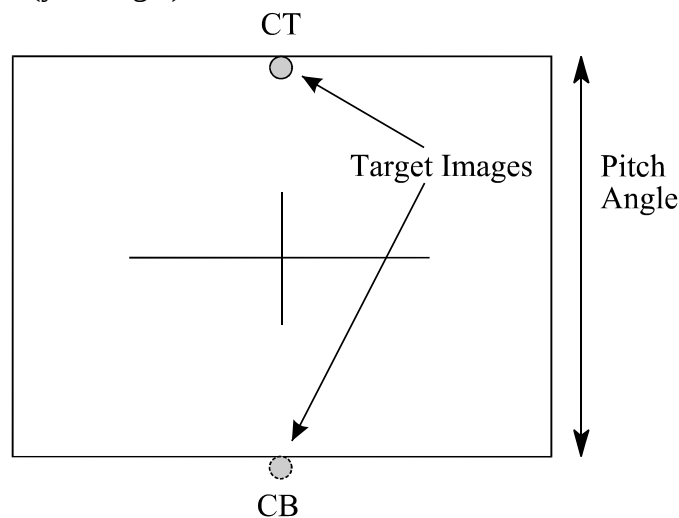


Figure 10. Image Positions for Vertical FOV.

(4) Repeat the procedures of b and c but with the image at the center of the top and bottom edges of the test item field-of-view, as shown in Figure 10. The difference in the two recorded collimator/test item positions is the test item vertical field-of-view (pitch angle).

(5) Repeat the procedure of b to d for each required field-of-view of the test item.

b. Field Tests.

(1) In-Vehicle Method

(a) Position a thermal target at a distance of $\geq 500\text{m}$ from the test item with the test item installed on the host platform. The host platform must be horizontal.

NOTE: This method assumes there is test item line-of-sight pitch and yaw control on the host platform/vehicle. It is further assumed that relative line-of-sight angle positions can be monitored.

(b) Rotate the test item to produce an image at the center of the left-hand edge of the test item field-of-view. Record the test item position (angle) as indicated in Figure 9.

(c) Rotate the test item to produce an image at the center of the right-hand edge of the test item field-of-view. Record the test item position (angle) as indicated in Figure 9. The difference in the two recorded test item positions is the test item horizontal field-of-view (yaw angle).

(d) Repeat the procedures of (2) and (3) but with the image at the center of the top and bottom edges of the test item field-of-view, as shown in Figure 10. The difference in the two recorded positions is the test item vertical field-of-view (pitch angle).

(e) Repeat the procedures of (2) to (4) for each required field-of-view of the test item.

(2) Remote Marker Method.

(a) Focus the test item on an object at a range between 1000 and 1500 meters. An observer, using the thermal imaging system under test, shall direct an assistant to place a reference marker at a point corresponding to the center of the system reticle.

(b) Establish a line perpendicular to the test item line-of-sight. At the direction of the observer, the assistant shall move to the right along the established line until he/she is at the edge of the field-of-view. The assistant shall mark this position. Record the distance from this position to the reference mark. Calculate the field-of-view right half-angle as shown in Figure 11.

(c) Determine the distance to the left edge of the field-of-view in the manner described above. Calculate the left half-angle field-of-view.

- (d) Record the system field-of-view as the sum of the right and left-half angles.
- (e) Repeat the procedure of (2) to (4) for each required field-of-view of the test item.

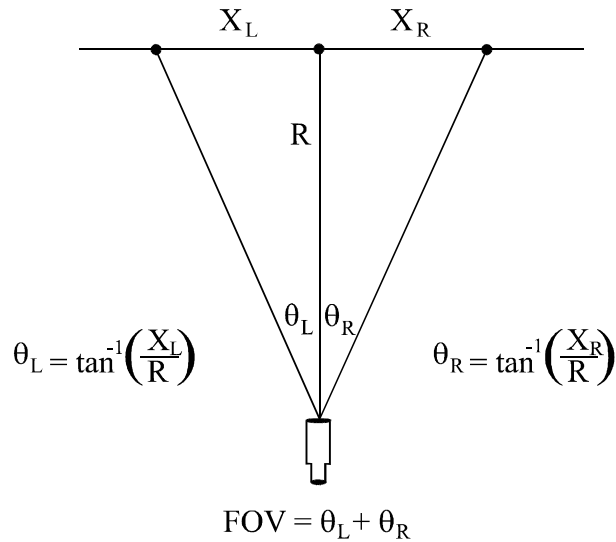


Figure 11. Remote Marker Method for FOV.

4.6.5 Data Required.

- a. Ambient temperature.
- b. Calculated values for each required horizontal and vertical field-of-view for each field-of-view of the test item.

4.6.6 Presentation of Data.

The field-of-view data shall be presented in tabular form as illustrated in Table 6.

Table 6. Field-of-view.

FIELD-OF-VIEW MEASUREMENTS	
Ambient Temperature:	
Axis	Field-of-View
Horizontal	
Vertical	

4.7 Coincidence of Fields-of-View.

4.7.1 Scope.

The purpose of this test is to measure the angular coincidence between the different fields-of-view of a thermal imaging system. Alternative methods are provided for this test. The test should be conducted in a laboratory environment when the test item is not installed in the host vehicle. When the test item is installed in the host vehicle, the alternative test method can be applied in the field environment. In any case, the most appropriate test method should be chosen.

4.7.2 Facilities and Instrumentation.

a. Facilities.

<u>Item</u>	<u>Requirement</u>
Optical laboratory and/or	Standard equipment
Test range with remote thermal target	500m - 1000m line-of-sight

b. Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Collimated thermal point or crosshair target	Collimated beam > entrance pupil diameter of the test item, temperature high enough to make target easily distinguishable from background but not high enough to cause detectable image spreading in the test item. Target subtense at test item to be just larger than central reticle or aiming mark, i.e. diameter of dot or width of crosshair.
Rotary table (pitch and yaw)*	Sufficient size to support test item. Rotation = ± 15 deg Resolution ≤ 30 arc sec Accuracy ≤ 15 arc sec

*Note: It is possible to use a single axis rotary table that can be reconfigured to accommodate both pitch and yaw angles.

4.7.3 Test Conditions.

a. Laboratory Test.

(1) Laboratory ambient temperature should remain constant within ± 1 °C, during the conduct of this test unless otherwise required by the test plan.

(2) Securely mount the test item on the rotary table. Position the test item so that the axes of rotation of the rotary table are perpendicular to the optical axis of the test item.

(3) Position the collimator system so that the collimated beam overfills the entrance pupil of the test item for all rotation conditions.

(4) If the test range target can be viewed from the optical laboratory and is to be used for the test, position the rotary table so that there is a clear and unobstructed line of sight between the test item and the target location.

(5) The observer must be able to easily discern the point or crosshair target source from the background in each field-of-view.

(6) For conditions where the test item reticle pattern can be repositioned, the central reticle marks for each required field-of-view must be symmetrically superimposed prior to the test.

b. Field Test.

(1) The test plan should identify the test item temperature range, profile and limits. It should indicate the number and the location of the temperature sensors used for the conduct of this test.

(2) Position the test item using the host vehicle systems so that an observer can view the distant target.

(3) The point or crosshair target source must have a sufficient temperature difference so that the observer can easily discern the target from the background in each field-of-view.

(4) For conditions where the test item reticle pattern can be repositioned, the central reticle marks for each required field-of-view must be symmetrically superimposed prior to the test.

(5) Exercise care to avoid movement of the host platform/vehicle during the test, e.g. rocking on its suspension.

4.7.4 Test Procedures.

a. Laboratory Test.

(1) Present the collimated thermal target or the test range target (> 500m from the test item) to the test item, as appropriate.

(2) Switch on the test item and permit the observer to adjust all control settings for optimum image quality. Verify that the central reticle marks of all required fields-of-view are aligned to the same target.

(3) Set the test item to its narrowest optical field-of-view. Using the rotary table, position the central reticle mark to be symmetrically superimposed on the target. If the test item is equipped with electronic zoom, then this feature may be used to optimize positioning. Note the readings (pitch and yaw) of the rotary table at this position.

(4) Without disturbing the set-up, change the test item setting to a wider field-of-view and observe the position of the central reticle mark relative to the target.

(5) If the center of the reticle mark in the wider field-of-view is displaced from the center of the target, use the rotary table to restore symmetrical superposition and note the new pitch and yaw readings. The difference in the respective recorded angular positions of the rotary table is the coincidence error of the fields-of-view of the test item.

(6) Repeat steps c to e five times to establish the variation of coincidence error (if any) due to the FOV switching process. Record the mean and standard deviation of the coincidence error in each axis.

(7) Repeat steps c to f for all specified fields-of-view.

b. Field Test.

(1) Present the test range thermal target (>500m from the test item) to the test item. Switch on the test item and allow the system to stabilize.

NOTE: This method assumes there is a test item line of sight pitch and yaw control on the host platform/vehicle. It is further assumed that the relative line of sight angular positions can be monitored.

(2) Switch on the test item and permit the observer to adjust all control settings for optimum image quality. Verify that the central reticle marks of all required fields-of-view are aligned to the same target.

(3) Set the test item to its narrowest optical field-of-view. Using the pitch and yaw controls on the host vehicle, position the central reticle mark to be symmetrically superimposed on the target. If the test item is equipped with electronic zoom, then this feature may be used to optimize positioning. Note the readings (pitch and yaw) of the encoders on the host vehicle at this position.

d. Without disturbing the set-up, change the test item setting to a wider field-of-view and observe the position of the central reticle mark relative to the target.

e. If the center of the wider field-of-view reticle mark is displaced from the center of the target, use the pitch and yaw controls on the host vehicle to restore symmetrical superposition and note the new pitch and yaw encoder readings. The difference in the respective recorded encoder readings from the host vehicle is the coincidence error of the fields-of-view of the test item.

f. Repeat steps c to e five times to establish the variation of coincidence error (if any) due to the FOV switching process. Record the mean and standard deviation of the coincidence error in each axis.

g. Repeat steps c to f for all specified fields-of-view.

4.7.5 Data Required.

- a. Ambient temperature.
- b. Test item temperature(s).
- c. Test item fields-of-view.
- d. The mean and standard deviation for the coincidence error in each axis.

4.7.6 Presentation of Data.

A tabular listing of the required data as shown in Table 7.

Table 7. Coincidence of fields-of-view.

COINCIDENCE OF FIELDS-OF-VIEW				
Ambient Temperature:				
Test Item Temperature(s):				
Narrowest Test Item FOV (angular):				
FOV	Vertical (pitch) Coincidence Error		Horizontal (yaw) Coincidence Error	
	Mean	Std. Dev.	Mean	Std. Dev.
1 st FOV (angular):				
2 nd FOV (angular):				
..				
Nth FOV (angular):				

4.8 Linearity.4.8.1 Scope.

The purpose of this test is to measure the linearity of the test item. Linearity describes the difference between the position of a point in the image space (measured as a fraction of image space half field-of-view) and its corresponding point in the object space (measured as a fraction of object space half field-of-view). Linearity is similar to distortion but the test for linearity does not require a measure of paraxial magnification. This procedure is not suited to field testing.

4.8.2 Facilities and Instrumentation.

a. Facilities.

<u>Item</u>	<u>Requirement</u>
Optical laboratory	Standard equipment

b. Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Collimated thermal point target	Collimated beam > entrance pupil diameter of the test item, temperature high enough to make target easily distinguishable from background but not high enough to cause detectable image spreading in the test item. Target subtense at test item to be > central reticle or aiming mark, i.e. diameter of dot or width of crosshair.
Rotary table (pitch and yaw)	Sufficient size to support test item. Rotation $\geq \pm 45$ deg. Resolution ≤ 30 arc sec. Accuracy ≤ 15 arc sec.
Low power telescope	x 3 to x 4.
Goniometer	Rotation: $\geq \pm 30$ deg. Resolution: ≤ 10 arc min. Accuracy: ≤ 5 arc min.
Traveling microscope with crosshair reticle.	Travel: > width of display monitor. Resolution: ≤ 0.2 mm. Accuracy: ≤ 0.1 mm. Magnification x 10 to x 15.

4.8.3 Test Conditions.

- a. Securely mount the test item on the rotary table. Position the test item such that the axes of rotation of the rotary table are perpendicular to the optical axis of the test item and in the plane of its entrance pupil (see Figure 14).
- b. For a test item which has a monocular eyepiece display, fit the low power telescope to the goniometer and securely mount this assembly to the test item. Position the assembly such that the plane of the entrance pupil of the low power telescope rotates about the exit pupil of the test item and is perpendicular to the optical axis of the test item.
- c. For a test item with a biocular display, fit the low power telescope to the goniometer and securely mount this assembly to the test item. Position the assembly such that the plane of the entrance pupil of the low power telescope is located at the normal viewing distance of the test item display and is perpendicular to the optical axis of the test item.
- d. For a test item with a relaxed view display (CRT or LCD), set up the traveling microscope so that the axis of the microscope tube is normal to the screen and can be traversed over the full width of the display.
- e. Position the collimator system such that the collimated beam overfills the entrance pupil of the test item.
- f. The target point source must have a sufficient temperature difference so that the observer can readily discern the target from the background.
- g. The horizontal and vertical field-of-view (in object space) of the test item must be known (see Section 4.6).

4.8.4 Test Procedures.

- a. Test Item with Monocular Eyepiece or Biocular Display.
 - (1) Present the collimated thermal target to the test item.
 - (2) Switch on the test item and adjust all controls to achieve optimum image quality. Use the rotary table to superimpose the central reticle mark (or the center of the field-of-view) symmetrically on the target. Record the scale readings from the rotary table as the reference position (object space).
 - (3) Rotate the goniometer until the crosshair of the low power telescope is centered on the target image. Record the goniometer scale reading as the reference position (image space).

(4) Rotate the test item on the rotary table to position the target at the edge of the field-of-view. Record the rotary table scale reading. Verify that the difference between this reading and the reference reading in paragraph b is the half field-of-view (object space) of the test item. Rotate the goniometer until the crosshair of the low power telescope is centered on the target image. Record the goniometer scale reading. The difference between this reading and the reference reading in paragraph c is the half field-of-view (image space). Return the rotary table and the goniometer to the reference positions and verify the crosshair of the low power telescope is again centered on the target.

(5) Rotate the test item on the rotary table by a known angle equivalent to about 20% of the half field-of-view. Record the scale readings from the rotary table and calculate the angular rotation of the test item from its reference position.

(6) Rotate the goniometer such that the crosshair of the low power telescope is again centered on the target. Record the goniometer reading and calculate the angular rotation of the goniometer from its reference position.

(7) Repeat the above test for at least five points, approximately equally spaced, out to at least 80% of the half field-of-view, on either side of the center of the field-of-view and above and below the central reference position.

(8) With prior knowledge of the field-of-view of the test item in the horizontal and vertical axes, express the rotation of the rotary table as a fraction of the half field-of-view in object space and express the rotation of the goniometer as fractions of the half field-of-view in image space.

(9) Calculate the linearity of the test item using:

$$L(\omega) = [\text{Fraction of half field-of-view (object space)} - \text{Fraction of half field-of-view (image space)}] \times 100(\%),$$

where $L(\omega)$ is the percent linearity at an off axis object space angle ω .

b. Test Item with Relaxed View Display.

(1) Present the collimated thermal target to the test item.

(2) Switch on the test item and adjust all controls to achieve optimum image quality. Use the rotary table to symmetrically superimpose the central reticle mark (or the center of the field-of-view) on the target. Record the scale readings from the rotary table as the reference position (object space).

(3) Move the slide of the traveling microscope to position the crosshair centrally over the screen image of the target. Record the scale reading from the microscope as the reference position (image space).

(4) Rotate the test item on the rotary table to position the target at the edge of the field-of-view. Record the rotary table scale reading. Verify that the difference between this reading and the reference reading in paragraph b is the half field-of-view (object space) of the test item. Calculate the tangent of this angle. Move the slide of the travelling microscope to position the cross hair centrally over the screen image of the target. Record the scale reading of the microscope. The difference between this reading and the reference reading in paragraph c is the half field-of-view (image space). Return the rotary table and the travelling microscope to the reference positions and verify that the crosshair is again centered on the target.

(5) Rotate the test item on the rotary table by a known angle equivalent to about 20% of the field-of-view. Record the scale readings from the rotary table and calculate the tangent of the angular rotation of the test item from its reference position

(6) Adjust the slide of the traveling microscope such that the crosshair is again centered on the target. Record the scale reading from the microscope and calculate the distance moved from the reference position.

(7) Repeat the above test for at least five points, approximately equally spaced, out to at least 80% of the field-of-view, on either side of the center of the field-of-view and above and below the central reference position.

(8) With prior knowledge of the field-of-view of the test item in the horizontal and vertical axes, express the tangent of the rotation angle of the rotary table and the linear movements of the traveling microscope as fractions of the half field-of-view.

(9) Calculate the linearity of the test item using:

$$L(\omega) = [\text{Fraction of tangent of half field-of-view (object space)} - \text{Fraction of half field-of-view (image space)}] \times 100\%,$$

where $L(\omega)$ is the percent linearity at an off axis object space angle ω .

4.8.5 Data Required.

a. Test Item with Monocular Eyepiece Display.

(1) Test item object space field-of-view (horizontal and vertical).

(2) Fraction of half field-of-view in object space (angular rotation of rotation stage divided by test item half field-of-view).

(3) Fraction of half field-of-view in image space (angular rotation of goniometer divided by test item half field-of-view).

b. Test Item with Biocular Eyepiece Display.

(1) Test item object space field-of-view (horizontal and vertical).

(2) Normal viewing distance used for measurement.

(3) Fraction of half field-of-view in object space (angular rotation of rotation stage divided by test item half field-of-view).

(4) Fraction of half field-of-view in image space (angular rotation of goniometer divided by test item half field-of-view).

c. Test item with Relaxed View Display.

(1) Test item object space field-of-view (horizontal and vertical).

(2) Fraction of half field-of-view in object space (tangent of angular rotation of rotation stage divided by tangent of test item half field-of-view).

(3) Fraction of half field-of-view in image space (linear movement of traveling microscope divided by half linear dimension of display field-of-view in that axis).

4.8.6 Presentation of Data.

a. A table of measured data as shown in Table 9.

Table 9. Linearity.

LINEARITY (HORIZONTAL/VERTICAL)			
Test Item Object Space FOV (Horizontal and Vertical):			
Position Number	Fraction Of Half FOV (Object Space)	Fraction Of Half FOV (Image Space)	Percent Linearity
1			
2			
3			
4			
5			
:			
N			

- b. A plot of linearity vs. object space half field-of-view as shown in Figure 12.

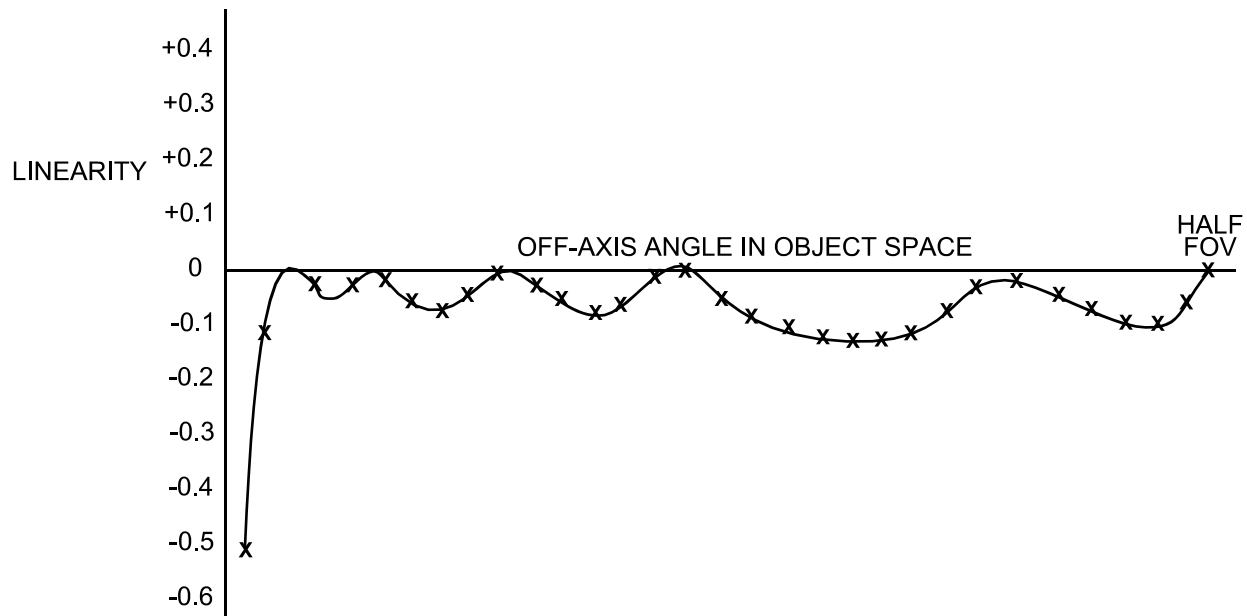


Figure 12. Linearity

4.9 Modulation Transfer Function (MTF).

a. The use of the Modulation Transfer Function (MTF) as a performance metric for thermal imaging systems provides information on the ratio of image-to-object contrast as a function of spatial frequency. However, this test is not typically applied to complete thermal imaging systems and is therefore excluded from this TOP.

b. For reference purposes, a description of MTF measurement principles is contained in STANAG 4161².

5. DATA REQUIRED.

5.1 General.

Due to the significant number of procedures in this TOP, the specific guidance for data required is covered within each associated test procedure section/paragraph.

a. Where applicable, the following general data requirements should be included for each test performed:

- (1) Laboratory and/or field environmental conditions.
- (2) Participating observers' names, identifiers and their visual acuities if necessary.

- (3) Test item manufacturer, type and serial number.
 - (4) Test item settings.
 - (5) Test item operating waveband, detector angular subtense, entrance pupil size and location for each field-of-view
 - (6) Measurement equipment information, manufacturer, model number, serial number, configuration and calibration date.
 - (7) Drawing of test set-up.
 - (8) Time and date of tests.
 - (9) Measurement uncertainty of the test data/results.
- b. The data requirements specific to individual tests are listed in the appropriate test procedure/paragraph.

5.2 Uncertainty Analysis.

- a. The measurement uncertainty is the result of a number of systematic and random sources of error. These include, but are not limited to, the following: the environment, the measuring equipment, the test item itself and relevant assumptions made during the test program.
- b. It is recommended that a text on uncertainty analysis, such as Chapter 12 of “Testing and Evaluation of Infrared Imaging Systems”^a, be consulted for further information.

6. PRESENTATION OF DATA.

Due to the significant number of procedures in this TOP, the specific guidance on presentation of data is covered within each associated test procedure section/paragraph.

APPENDIX A. DEFINITIONS.

Accuracy (Measurement Accuracy). The accuracy of a measurement refers to how close a measured value is to the true value or an accepted value. The difference between the measured value and the true or accepted value is the error. This error is a combination of all systematic and random sources of error in the measurement system. The accuracy of a measurement will be $\geq \pm$ half the resolution of the measuring equipment.

Aliasing. The result of a sampling frequency that is too low to preserve the spatial frequencies of the scene being sampled. When the frequency content in a scene is greater than half the sampling frequency, it appears in the sampled scene at a lower (aliased) frequency.

Ambient Temperature. The ambient temperature is the prevailing temperature in the immediate vicinity of an object or within defined surroundings.

Angular Subtense. The geometrical angle subtended by the edges of an object or image being viewed, or projected; usually expressed in milliradians.

Apparent Temperature Difference (Thermal Contrast). The apparent temperature difference is the apparent blackbody differential temperature between an unvignetted target and background, within the test item's spectral waveband. The distinction between "apparent" and "actual" temperature difference is used to take into account emissivity, atmospheric, environment and/or projection optic losses.

Atmospheric Transmission (radiometric, spectral). The atmospheric radiometric transmission, $\bar{T}_{\text{Atm}}$, over a specified range is defined by the equation:

$$\bar{T}_{\text{Atm}} = \frac{\int_{\lambda_1}^{\lambda_2} T_{\text{Atm,R}}(\lambda) F_s(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} F_s(\lambda) d\lambda}$$

Where $T_{\text{Atm,R}}(\lambda)$, is the atmospheric spectral transmission, given by the ratio of the power on a detector from a monochromatic, collimated source at range, R, to its value at zero range. $F_s(\lambda)$ is the spectral power of a polychromatic source and λ_1 and λ_2 define the waveband of interest.

Background Temperature. For the purposes of this TOP, the background temperature is the temperature of the target plate, used as part of a thermal target for the measurement of Minimum Resolvable Temperature Difference (MRTD) or Minimum Detectable Temperature Difference (MDTD). The background temperature will not necessarily be the same as laboratory ambient temperature, owing to the effects of thermal radiation from the blackbody source.

Biocular. The term "biocular" designates any optical instrument in which both eyes may be used to view an image through a single element to facilitate viewing.

Collimator. A collimator is an optical instrument consisting of a well-corrected objective lens or an off-axis parabolic reflector (typically a peak to valley wavefront error of less than $\lambda/8$). For many test applications, a collimator is used to make an object placed in its focal plane appear to be at infinity.

Collimator Radiometric Efficiency. The collimator radiometric efficiency, $\bar{R}$, is defined by the equation:

$$\bar{R} = \frac{\int_{\lambda_1}^{\lambda_2} R(\lambda) F_s(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} F_s(\lambda) d\lambda}$$

where $R(\lambda)$ is the collimator spectral transmission or reflection, $F_s(\lambda)$ is the spectral power of a polychromatic source and λ_1 and λ_2 define the waveband of interest.

Collimator Working Distance. The collimator working distance is the maximum distance at which the beam from the collimator fills the entrance pupil of the test item for all points in the test item's field-of view, as shown in Figure A-1.

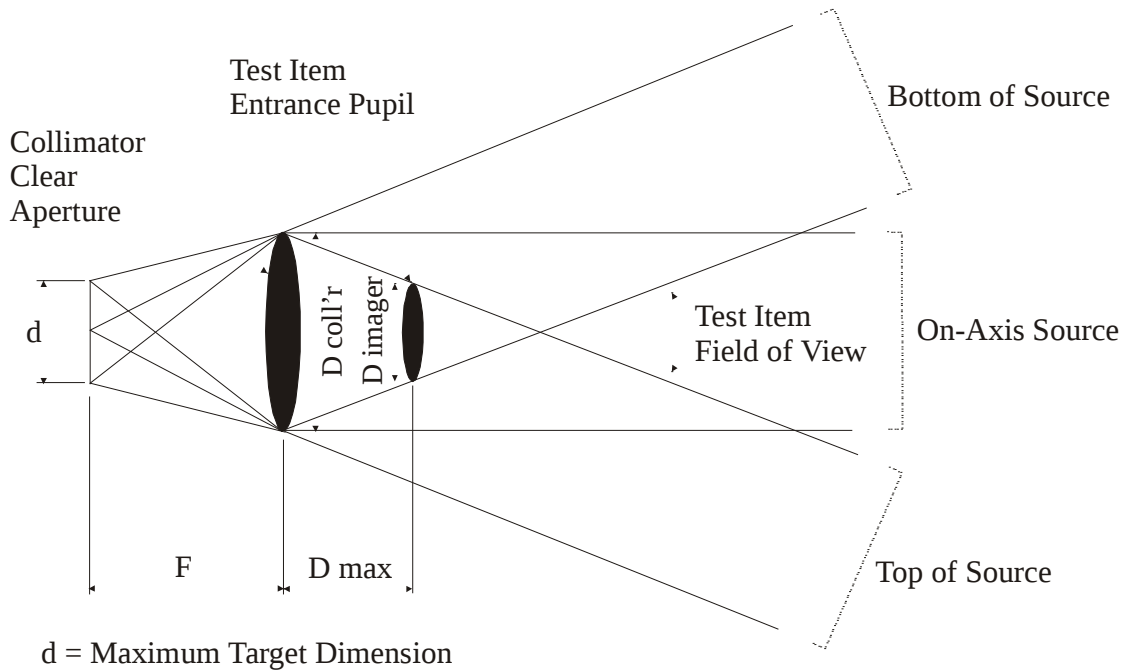


Figure A-1. Collimator Working Distance.

The collimator working distance in meters, $D_{\max}$, is given by:

$$D_{\max} = \frac{(D_{\text{coll'r}} - D_{\text{imager}}) * F}{d}$$

where $D_{\text{coll'r}}$ is the aperture diameter of the collimator (mm), D_{imager} is the aperture diameter of the test item (mm), F is the focal length of the collimator (m) and d is the maximum dimension of the collimator target (mm).

Cut-off Frequency. The spatial frequency at which the modulation transfer function falls to zero, or, for practical use, below some specified amount such as 3%. The cut-off frequency (f_{co}) for a diffraction limited optical system is given by:

$$f_{co} = \frac{1}{\lambda \text{ (mm)} * f_{no}} \text{ (cy/mm)} \quad \text{in image space, or}$$

$$f_{co} = \frac{D \text{ (m)}}{\lambda \text{ (mm)}} \text{ (cy/mr)} \quad \text{in object space}$$

where λ is the measurement wavelength, f_{no} is the f-number, and D is the entrance pupil diameter of the test item.

Derotation. In a panoramic optical system the image rotates about the optical axis as the system objective is rotated. The image rotation is compensated for, i.e. the image is de-rotated, by additional optical components in the system. The term derotation is a measure of the system's ability to correct for image rotation.

Detector Angular Subtense. The paraxial solid angle subtended by a single detector active area. For a rectangular detector active area of width, w and height, h, the detector angular subtense through an imager of effective focal length, f is given by:

$$DAS = \frac{w}{f} * \frac{h}{f} \text{ (rad}^2\text{)}$$

Typically, the width and height of the detector element are defined to be in the horizontal and vertical planes of the imager's coordinate system respectively. For this case, the horizontal and vertical one-dimensional detector angular subtenses are given by:

$$DAS_h = \frac{w}{f} \text{ (rad)} \quad \quad \quad DAS_v = \frac{h}{f} \text{ (rad)}$$

Diffraction Limited System. The term diffraction limited implies that the performance of an optical system is limited by the physical effects of diffraction rather than geometrical imperfections in either the design or fabrication.

Distortion. Distortion is an image defect (aberration) in which the magnification is not constant over the field-of-view. For radial distortions, the following polynomial can be used to describe the variation of magnification with field angle (ω):

$$M(\omega) = M_0 + A\omega + B\omega^2 + C\omega^3 + D\omega^4,$$

where M_0 is the paraxial magnification. Distortion indicates the percentage difference in magnification of an off-axis object compared to a paraxial object and can be expressed as:

$$D(\omega) = \frac{M(\omega) - M_0}{M_0} \times 100\%$$

For example, a negative radial distortion deforms a square grid object into a barrel shape (barrel distortion), a positive radial distortion deforms a square grid object into a pillow shape (pincushion distortion), and projecting an image onto a surface at an angle (keystone distortion). Figure A-2 shows the effect of different types of distortion on a square grid object.

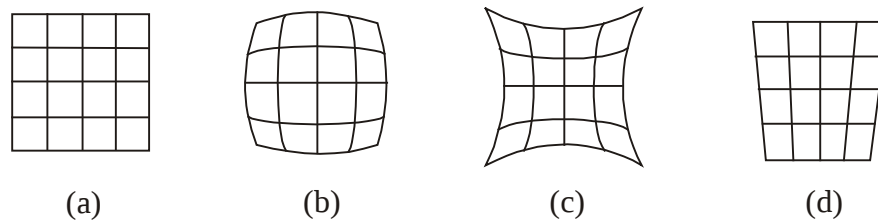


Figure A-2. Examples of Distortion.

(a) Object, (b) Barrel Distortion, (c) Pincushion Distortion, and (d) Keystone Distortion.

DRI. The acronym for Detection, Recognition, and Identification, where:

Detection is the determination of the presence of an object of interest. For example, the object is believed to be of military interest and warrants further investigation.

Recognition (classical) is the determination of the specific class to which a detected object belongs. For example, a detected object of military interest can be classified as a tank, as opposed to an armored personnel carrier, which are both within the general class of tracked vehicles.

Identification is the determination of the specific type within the class to which a recognized object belongs. For example, the object of military interest which was classified as a tank has been positively identified as a T-72.

Drift. Slow, large amplitude movement of the image that can be followed by the observer's eye.

Effective Focal Length. The effective focal length is the distance from the principal point to the focal point.

Effective Ranges (50% probability). The effective ranges are the distances at which 50 percent of the detection, recognition and identification (DRI) observations can be successfully conducted and are designated " R_{d50} ", " R_{r50} " and " R_{i50} ", respectively.

Emissivity. Emissivity is the ratio of an object's spectral radiance to that emitted by a blackbody radiator at the same temperature and at the same wavelength. Although emissivity is a function of wavelength, it is commonly stated as a broad-band average.

Entrance Aperture. The entrance aperture is the first physical aperture of the optical system that limits incoming rays parallel to the optical axis, typically the mechanical housing of the objective.

Entrance Pupil. The entrance pupil is the image of the aperture stop formed by the optical elements between the aperture stop and the object.

Entrance Window. The entrance window is the first optical element of the optical system intersected by a ray originating from a distant object. In some systems, the entrance window is a protective assembly without optical power.

f-number (f#, F or f_{no}). f-number is the ratio of the effective focal length of an optical system to the diameter of its entrance pupil. The f-number is also known as the aperture ratio.

Field-of-View (FOV). The limits of the field or area displayed by, or viewed through, an optical/electro-optical system. The field-of-view is usually expressed in angular terms.

Figure of Merit. Figure of merit is any parameter which is used to define the performance of a system against a standard metric. A figure of merit is typically defined to highlight (i.e. weight) or combine specific performance parameters into a single evaluation parameter. Figures of merit can be highly subjective and/or biased by the manner in which they are defined and must be used with caution.

Flicker. Flicker is intensity variations of the displayed image as a function of time. If the flicker frequency is above the frequency that is detectable by the human eye, no image degradation will be perceived. A low frequency flicker (20 Hz or below) can have a disturbing effect on the observer and thereby limit the effectiveness of the imaging system.

Focal point. The focal point is the point on the optical axis to which an incident bundle of parallel rays will converge.

Fourier Transform. The Fourier transform of a function $f(x)$ is defined as:

$$F(s) = \text{FT}\{f(x)\} \equiv \int f(x) \cdot e^{-i2\pi xs} dx$$

Goniometer. A goniometer is an opto-mechanical device used to measure angles. It typically comprises a low magnification telescope with an extended reticle for alignment, a remote entrance pupil about which it can rotate and a means of measuring its angle of rotation.

Image Space (IS). Image space is the region in which the image, formed by radiation which has passed through an optical system, exists.

Infrared Scene Projection (IRSP). IRSP is the capability to project collimated, in-band infrared scenes into the entrance aperture of a thermal imager under test. Note that IRSP is also used for Infrared Scene Projector, indicating a system of hardware and software configured to project infrared scenes.

Jitter. High frequency (i.e. usually beyond the frequency detectable by the human eye), small amplitude, lateral displacements of the image as represented in Figure A-3. If several frames are averaged (time domain averaging) to improve the signal-to-noise ratio, this can cause broadening of the averaged Line Spread Function (LSF). In this case it may be better to average a number of Modulation Transfer Functions (MTFs) (frequency domain averaging), by taking the Root Mean Square (RMS) and using the inverse Fourier transform to recover the LSF.

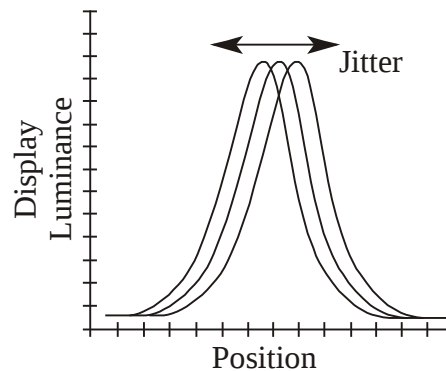


Figure A-3. Jitter – High Frequency Lateral Movement of the LSF.

Linearity. A function which describes the difference between the position of a point in the image space (measured as a fraction of image space half field-of-view) and its corresponding point in the object space (measured as a fraction of object space half field-of-view). It is related to distortion, but by definition is zero at the edge of the field-of-view. Magnification (M) as a function of off-axis angle (ω) can be described by the polynomial:

$$M(\omega) = M_0 + A\omega + B\omega^2 + C\omega^3 + D\omega^4$$

where M_0 is the paraxial magnification. Linearity as a function of object and image space field

$$L = 1 - \frac{\omega'}{\omega \bar{M}}$$

angles ω and ω' is given by:

where $\bar{M}$ is the average magnification over the field-of-view ($\bar{M} = (d/2f)/\tan(\text{FOV}/2)$) where $\text{FOV}/2$ is the angle from the optical axis of the test item to the edge of the field-of-view in object space, d is the diameter (or side) of the field-of-view in image space and f is the effective focal length of the optics.

Line Spread Function (LSF). LSF is the irradiance distribution function describing the image of a line, in the axis perpendicular to the line.

Magnification (Angular). Given an object on the optical axis which subtends an angle ω in object space and ω' in image space, the angular magnification of the object is:

$$M(\omega) = \frac{\tan(\omega')}{\tan(\omega)}$$

where ω and ω' are expressed in radians. For small angles, this expression may be approximated to ω'/ω .

Minimum Detectable Temperature Difference (MDTD). The MDTD is a subjective measurement of a thermal imager's ability to discriminate between a target and its immediate surroundings. It represents the minimum apparent temperature difference between a square or circular target and the background at which the target can just be detected, at a specified apparent background temperature. MDTD is usually performed over a range of target sizes.

Minimum Resolvable Temperature Difference (MRTD). The MRTD is a subjective measurement of the thermal resolution of a thermal imaging device, as a function of spatial frequency. It represents the minimum apparent temperature difference between target and background when a standard 4-bar target with a 7:1 aspect ratio of known fundamental spatial frequency is just barely resolvable, at a specified apparent background temperature. MRTD is usually performed over a range of vertical and horizontal spatial frequencies.

Modulation. In general, the system induced change in the properties of an input wave train as seen in the output wave train, (e.g. amplitude, frequency and phase). In optics, modulation is used as a synonym for contrast, especially when applied to a bar target imaged by an optical system.

Modulation Transfer Factor. The ratio of the image contrast to the object contrast for a sinusoidal object at a given spatial frequency.

Modulation Transfer Function (MTF). The MTF is a measure of an optical system's ability to transfer the contrast (i.e. modulation) of an object to its image. This function, usually represented graphically, shows the normalized modulation transfer factor of image-to-object contrast of a sinusoidal object plotted as a function of spatial frequency.

Noise Equivalent Temperature Difference (NETD). The NETD is the effective blackbody target-to-background temperature difference in a standard (low spatial frequency) test pattern (e.g. a large single bar target) which produces a peak signal to rms-noise ratio of one.

Nyquist Criterion. In image acquisition, the sampling frequency must be at least twice the highest frequency component in the image data being sampled.

Nyquist Frequency. Nyquist frequency is the highest spatial frequency which a sampled system can accurately reproduce, in accordance with the Nyquist criterion. This is given by: $F_N = 1/(2\alpha)$, where α is the detector angular subtense (mr) and F_N is the Nyquist Frequency (cy/mr).

Object Space (OS). OS is the region from which radiation enters the entrance pupil of an optical system and in which the object resides.

Objective. The objective of an optical system is the element, or combination of elements, that receives light from the object and forms the first or primary image.

Optical Axis. Optical axis is the line passing through both centers of curvature of the optical surfaces of a lens; the optical centerline for all the centers of a lens system.

Optical System. An optical system is a group of refractive and/or reflective components designed to perform a specific optical function.

Optical Transfer Function (OTF). The OTF is a functional relationship describing an optical imaging system's ability to transmit the spatial frequency components of an object to its image. The OTF is a complex function comprising modulation (real) and phase (imaginary) information. The respective parts are known as MTF and PTF, and are defined by:

$$\text{OTF}(\xi) = \text{MTF}(\xi)e^{-i\text{PTF}(\xi)}$$

where ξ is the spatial frequency in cycles/milliradian (cy/mr) or an equivalent measure.

Over-sampled Imager. A thermal imaging system is over-sampled when there are more than two samples per cycle at the highest spatial frequency transmitted by the system. Scanned imaging systems may be over-sampled in the line-scan direction.

Panoramic Telescope. A panoramic telescope is constructed such that the image remains erect and the eyepiece remains fixed as the line of sight is pointed in any horizontal direction.

Parallax. Parallax is the optical phenomenon that causes the apparent change in relative position between two objects when the eye point is displaced laterally. Parallax is observed in a telescope when the reticle is not located in the image plane and the image is observed along a line of sight that is not the optical axis of the system.

Paraxial Ray. A paraxial ray lies close to and almost parallel to the optical axis and obeys first-order, also called Gaussian, optics such that the ray's angle with the optical axis, μ (in radians), can be used in place of $\sin(\mu)$ or $\tan(\mu)$, in accordance with the small angle approximation.

Pedestal. A pedestal refers to the background signal level above zero reference.

Phase Transfer Function (PTF). The functional relationship describing the relative phase shifts of the spatial frequency components of an image relative to its object. A phase shift of 180 degrees corresponds to a contrast reversal.

Principal or Chief Ray. A principal or chief ray is the ray from an off-axis object point that passes through the center of the aperture stop. The principal ray enters the optical system passing through the center of the entrance pupil and exits the system passing through the center of the exit pupil. It is the effective axis of an oblique beam.

Principal Plane. The intersection of the projections of the incoming and exiting paraxial rays.

Principal Point. Principal point is the intersection of the principal plane with the optical axis.

Properly-sampled Imager. A sampled thermal imaging system can be described as properly-sampled when its imagery is adequate to perform the application for which it has been designed. For the purposes of this TOP, where the term is used in the MRTD measurement procedure, the effects of aliasing on the appearance of the bar targets shall be sufficiently small that the measured MRTD at the spatial frequencies of interest is not significantly worse than an analog imager with the same optics and electronics MTFs.

Radiometric Efficiency. The radiometric efficiency, η , is defined by the equation:

$$\eta = \frac{\int_{\lambda_1}^{\lambda_2} R(\lambda) T_{\text{Atm,R}}(\lambda) F_s(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} F_s(\lambda) d\lambda} \approx \bar{R} \times \bar{T}_{\text{Atm}}$$

where $R(\lambda)$ is the collimator spectral transmission or reflection, $T_{\text{Atm,R}}(\lambda)$ is the atmospheric spectral transmission, $F_s(\lambda)$ is the spectral power of a polychromatic source and λ_1 and λ_2 define the waveband of interest. It is usually approximated by the product of the atmospheric radiometric transmission, $\bar{T}_{\text{Atm}}$, and the collimator radiometric efficiency, $\bar{R}$.

Rayleigh Resolution Criterion. For a circular, diffraction-limited (i.e. aberration free) lens with effective focal length, f , and aperture, D , as shown in Figure A-4, the images of two points are just resolved when they are separated such that the center of the Airy diffraction pattern of one point falls on the first minimum of the Airy diffraction pattern of the other.

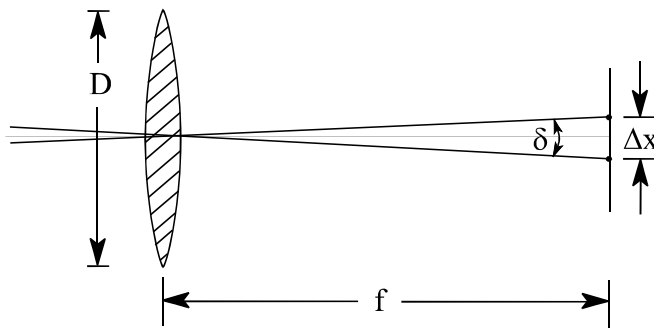


Figure A-4. Relation Between the Aperture, D , the Effective Focal Length, f , and the Image Separation, Δx , of Two Just Resolved Point Objects.

This resolution condition exists when the angular separation of the images of two object points, is:

$$\delta[\mu\text{r}] = \frac{1.22\lambda[\text{nm}]}{D[\text{mm}]} = \frac{\Delta x [\mu\text{m}]}{f [\text{m}]}$$

The corresponding spatial frequency is:

$$\omega_{\text{co}} \left[\frac{\text{cy}}{\text{mr}} \right] = \frac{1000.0D[\text{mm}]}{1.22\lambda[\text{nm}]} \approx \frac{819.7D[\text{mm}]}{\lambda[\text{nm}]}$$

and in the image plane is:

$$\omega_{\text{co}} \left[\frac{\text{lp}}{\text{mm}} \right] = \frac{1000000}{1.22\lambda[\text{nm}]} \frac{f[\text{mm}]}{D[\text{mm}]} \approx \frac{819700}{\lambda[\text{nm}]f_{\text{no}}}$$

where λ is the measurement wavelength and f_{no} is the f-number.

Reference Plane. The plane, generally perpendicular to the optical axis of the system, to which all spatial frequencies and position parameters are referred is the reference plane. The reference plane may be at infinity in object space and the spatial frequency expressed in cy/mr.

Relaxed View Display. A display that can be viewed from the operator's normal seated posture is the relaxed view display. Examples are a CRT monitor, flat panel display and a biocular display.

Resolution (Measurement Resolution). The resolution of a measuring instrument is the smallest positional or display increment that can be discerned by an observer. For a digital scale this will be one digit in the least significant position. In some cases, the ability to resolve can be enhanced by the use of aids that increase the measurement sensitivity.

Reticle. An optical element located at, or projected into, an image plane of an optical instrument that consists of a pattern (e.g. crosshair, linear or angular graduations) to assist the observer when pointing the instrument or measuring target characteristics.

Signal Transfer Function (SiTF) or System Intensity Transfer Function (SITF). The SiTF is the curve or the family of curves that describe the output luminance or output system voltage of a device as a function of the input blackbody target-to-background temperature difference in a standard test pattern.

Sinc Function. The mathematical function, denoted $\text{sinc}(x)$, is defined as:

$$\text{sinc}(x) = \frac{\sin(\pi x)}{\pi x}$$

Spatial Frequency (fundamental). Spatial frequency is the reciprocal of the period of a repetitive object such as a sine wave or series of equally spaced lines or bars. Figure A-5 shows a standard 4-bar target with a bar width equal to b , a bar spacing equal to b , and a bar height of $7b$. One cycle ($2b$) comprises one bar and one space. The spatial frequency is expressed in line-pairs/mm (lp/mm), $1/(2b)$, in an object or image plane or as cycles/milliradian (cy/mr) when viewing a distant object. Note: The spatial frequencies generated by a single slit can be represented by a sinc function, which theoretically has infinite angular spatial frequency content.

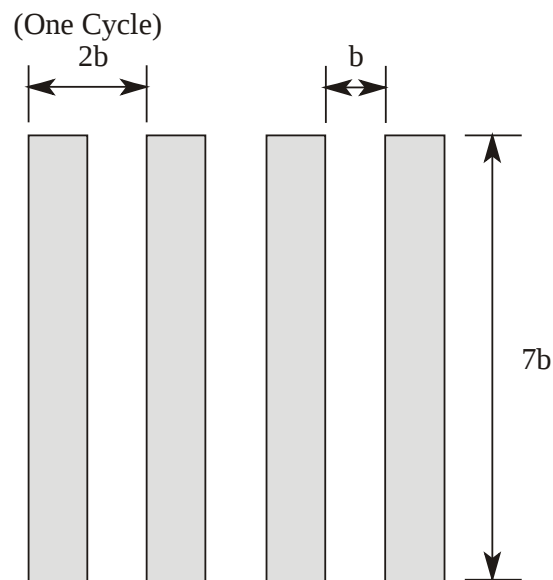


Figure A-5. A Standard Four Bar Target.

Square Wave. A square wave is a periodic function which can be reduced to an infinite series of sine waves in the following Fourier series:

$$Sq(x) = \sin(x) + (1/3)\sin(3x) + (1/5)\sin(5x) + \dots$$

When $0.6 < x < 0.9$ of the Nyquist limit, the aliasing of the third, and higher, harmonics of the series leads to an appearance of the image which contains false detail. Care should be taken when interpreting the appearance of 4-bar targets if the fundamental spatial frequency (x) of the target is in this range.

Stop. A stop is a physical aperture or diaphragm in an optical system that restricts the transmission of radiation through the system.

Target-to-background Temperature (or Differential Target Temperature). For the purposes of this TOP, the target-to-background temperature is the temperature difference between a blackbody source (i.e. 'target') and a target plate (i.e. 'background') in the type of thermal target used in MRTD and MDTD measurements.

Target Plate. For the purposes of this TOP, a target plate is a component of a thermal target used in MRTD or MDTD measurements. Typically, the target plate contains an aperture, or series of apertures, through which an observer can view a blackbody source, usually placed close to the target plate. The target plate is normally blackened to provide a high-emissivity, non-specular, homogeneous source at near-ambient temperature. Low-emissivity, specular target plates can be used where there are two blackbody sources, one seen through the target plate and the other reflected in the target plate.

Test Accuracy Ratio (TAR). The maximum permitted error of the unit to be measured or calibrated divided by the known error of the measuring or generating device used to perform the measurement. For example, if it is required that a system or equipment output parameter be accurate to 8% (maximum permitted error) and a known accuracy (maximum known error) of the measuring device used to measure the output parameter is 2%, then the TAR is 4.

Thermal Contrast. See Apparent Temperature Difference.

Tilt. Tilt is any angular deviation between the optical axis of an optical system and the axis of an element of the system.

Trends. A change in the background luminance of the raster caused, for example, by target inhomogeneities, shading, non-uniformity, floating baseline or, for scanning systems, 1/f noise, as illustrated in Figure A-6.

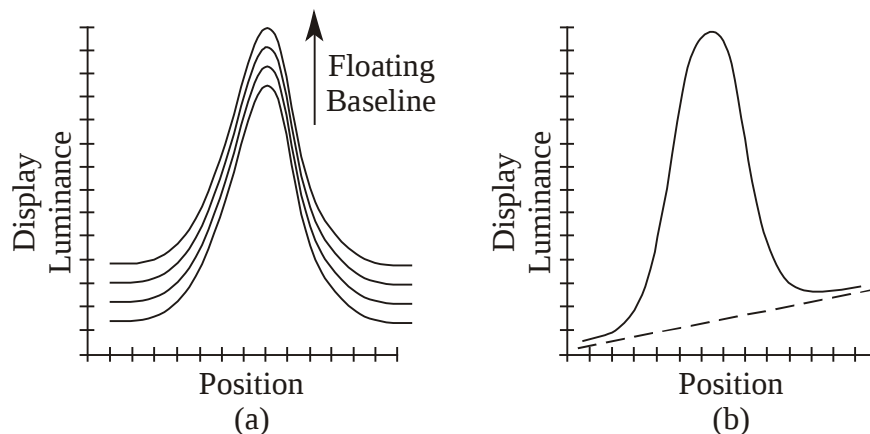


Figure A-6. Two Examples of Trends: (a) Floating Baseline (a Temporal Trend), and (b) Shading (a Spatial Trend).

Uncertainty Analysis. For the purposes of this TOP, Uncertainty Analysis is the analysis and evaluation of all sources of error that contribute to the overall measurement error of a system property. These include, but are not limited to; the effects of the environment, the measuring equipment, the test item itself, and the operator. Particular care must be taken to discriminate between sources of error that give a random distribution about the true value and those which introduce a systematic bias to the results.

Under-sampled Imager. A thermal imaging system is under-sampled when there are less than two samples per cycle at the highest spatial frequency transmitted by the system. Imagers using staring arrays, where the blur spot diameter of the optics is comparable with the detector linear dimension, are normally designed to be under-sampled.

Uniformity (display uniformity). The measure of the variation of the luminance over the display area while observing a thermal target of homogeneous radiant emittance.

Vignetting. The loss of image illuminance within an optical system as a function of increasing off-axis angle is vignetting. Any object that obstructs image forming rays can cause this effect.

APPENDIX B. ADDITIONAL PROCEDURES.

Dead, Strapped and Noisy Channels

1.1 Scope.

The purpose of this test is to determine and identify the location of any dead, strapped or noisy channels on a scanning thermal imaging system. The following definitions apply:

- a. A dead channel, the easiest to detect, consists of a dark thin horizontal line running across the entire field of view. This can be the result of an open detector, amplifier, or Light Emitting Diode (LED) wire thereby not providing any signal.
- b. A strapped channel is two adjacent channels that are shorted together providing the same signal on each channel. This can be determined by observing the “jaggies” that are reproduce when the thermal imaging system is viewing a diagonal bar target in the laboratory collimator. A long step would indicate strapped channels.
- c. A noisy channel is a channel that likely has a cold solder joint or the detector is not in physical contact with the cold finger of the detector Dewar assembly. A noisy channel appears as out of focus to the adjacent channels. To determine if the channel is bad, NEDT, as described in paragraph 4.4, is measured in the laboratory. If the channel passes the NEDT requirement the channel is good.

1.2 Facilities and Instrumentation.

1.2.1 Facilities.

<u>Item</u>	<u>Requirement</u>
Optical Laboratory	Standard Equipment

1.2.2 Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Optical Collimator	Entrance aperture must be large enough to completely flood fill the test item.
Diagonal Target	Target should be a narrow slit covering the test item from the lower left to upper right field of view (see Figure B-1). The target must be uniform in temperature and emissivity.

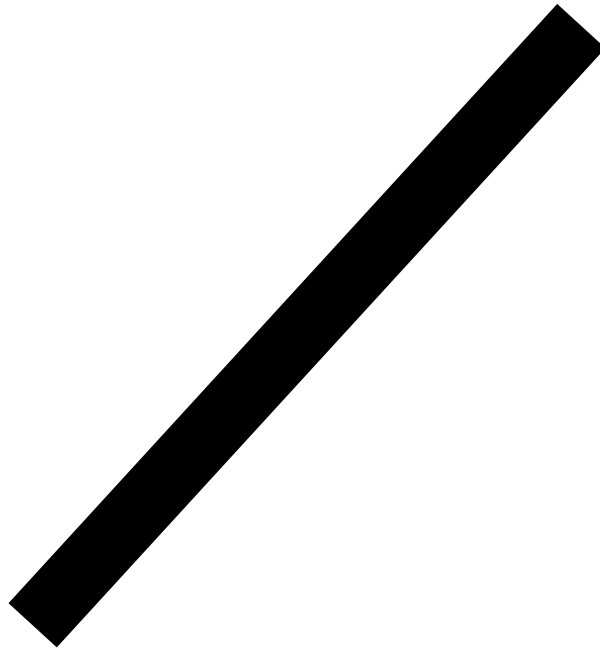


Figure B-1. Diagonal Bar Target

1.2.3 Test Conditions.

- a. Mount the diagonal bar target at the focal point of the optical collimator.
- b. Mount the test item in a fixture and position it to the optical collimator so that the diagonal bar can be observed by the test item.
- c. Radiance from the diagonal target is emitted through the optical collimator to the test item.
- d. The test item (scanning thermal imaging sensor) consist of several (typically 60 to 180) detectors mounted vertically to the cold finger at approximately 75 degrees Kelvin. The detectors represent the vertical portion of the field of view of the test item.
- e. The horizontal portion of the field of view is achieved by swiping the vertical detectors across the horizontal field of view using a scanning mirror. An image of the diagonal bar is created by converting the detector output to the visible wavelength.
- f. During this process there are many catastrophic failures that can render the thermal imaging sensor either not suitable for its intended mission or degraded performance. For example, open wires, burned out LEDs, shorted wires, etc.

- g. To determine if any problem exists with the channels the diagonal bar is analyzed.
- h. The diagonal bar target is projected at a 45 degree angle from the bottom to the top of the field of view subtending all vertical detector channels.
- i. A dead channel, the easiest to detect, consists of a dark thin horizontal line running across the entire field of view. This can be the result of an open detector, amplifier, or LED wire thereby not providing any signal.
- j. A strapped channel is two adjacent channels that are shorted together providing the same signal on each channel. This can be determined by observing the “jaggies” that reproduce the diagonal bar in the FLIR video. A long step would indicate strapped channels.
- k. A noisy or flashing channel appears to “flash” or “is out of focus” and is considered as an indeterminate state. The NEDT of the noisy or flashing channel is measured. If the channel passes NEDT then the channel is considered a good channel.

1.2.4 Data Required.

- a. Channel number.
- b. Condition of channel (dead, strapped, noisy).

1.2.5 Presentation of Data.

Dead, strapped, noisy channels are presented in tabular form as illustrated in Table 1.

Table B-1. Dead, Strapped, Noisy Channels.

Dead, Strapped, Noisy Channels MEASUREMENTS	
Test Item Channel Number:	Number starting from of top of FOV:
Condition of Channel:	Dead, Strapped, Noisy:

2.1 Boresight.

2.2 Scope.

Typically, a thermal imaging sensor is used to direct non-imaging sensors, such as a laser designator, to a desired target. In addition, to a lesser degree, the mounting holes or alignment pins align the thermal imaging sensor to a mechanical alignment.

2.3 Facilities and Instrumentation.

2.3.1 Facilities.

<u>Item</u>	<u>Requirement</u>
Optical Laboratory	Standard Equipment

2.3.2 Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Optical Collimator	Entrance aperture must be large enough to completely flood fill the test item.
Diagonal Target	Target should be a diagonal cross with the target having one pixel thickness (see Figure B-2). The target should be uniform in temperature and emissivity.

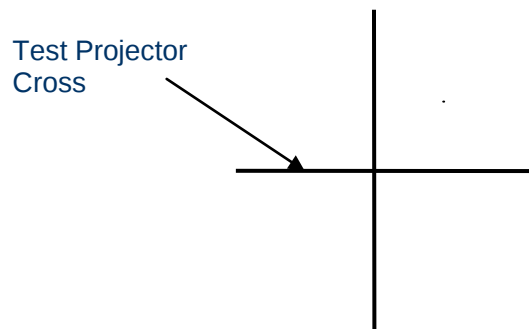


Figure B-2. Boresight Cross

2.3.3 Test Conditions.

- a. Mount the boresight cross target at the focal point of the optical collimator.
- b. Mount the test item in a precision pan and tilt fixture who's mounting points (i.e., mounting holes, alignment pins, etc.) have been aligned and positioned to the optical collimator's optical reference line so that the boresight cross can be observed by the test item.

c. Radiance from the cross target is emitted through the optical collimator to the test item.

d. Note the offset of the thermal imaging sensor by rotating the mount in both azimuth and elevation and note the amount of movement as read on the rotating mount.

2.3.4 Data Required.

Azimuth and elevation error.

2.3.5 Presentation of Data.

Boresight data is presented in tabular form as illustrated in Table 2.

Table B-2. Boresight.

Boresight MEASUREMENTS	
Azimuth Reading:	Angle in degrees:
Elevation Reading:	Angle in degrees:

3.1 Field-of-View to Field-of-View Boresight Retention.

3.2 Scope.

FOV switching of a thermal imaging sensor is accomplished by switching different optical elements in and out of the optical path. The detent which is the home position for each FOV can wear over time. A gunner on a mission that switches from narrow FOV to a wide FOV to possibly observe the surrounding area then switches back to narrow FOV expects the thermal imaging sensor to have the same direction of point. This can be checked with the FOV switching test.

3.3 Facilities and Instrumentation.

3.3.1 Facilities.

<u>Item</u>	<u>Requirement</u>
Optical Laboratory	Standard Equipment

3.3.2 Instrumentation.

<u>Device</u>	<u>Measurement Accuracy</u>
Optical Collimator	Entrance aperture must be large enough to completely flood fill the test item.
Diagonal Target	Target should be a diagonal cross with the target having one pixel thickness (see Figure B-2). The target should be uniform in temperature and emissivity.

3.3.3 Test Conditions.

- a. Mount the boresight cross target at the focal point of the optical collimator.
- b. Mount the test item in a precision pan and tilt fixture whose mounting points (i.e., mounting holes, alignment pins, etc.) have been aligned and positioned to the optical collimator's optical reference line so that the boresight cross can be observed by the test item.
- c. Select the narrow field-of-view on the thermal imaging sensor.
- d. Adjust the crosshairs of the thermal imaging sensor over the projected boresight cross target image by adjustment of the precision pan and tilt fixture. Note the precision pan and tilt fixture location.
- e. Switch the thermal imaging sensor to wide field-of-view then back to narrow field of view.
- f. Observe the location of the thermal imaging sensor's crosshair with respect to the projected boresight cross target. If there is miss alignment, realign the thermal imaging sensor's crosshair to the projected boresight cross target and log the precision pan and tilt fixture location.

3.3.4 Data Required.

Azimuth and elevation error.

3.3.5 Presentation of Data.

Field-of-View to Field-of-View Boresight Retention.

Table B-3. Field-of-View to Field-of-View Boresight Retention.

Field-of-View to Field-of View Boresight Retention MEASUREMENTS	
Azimuth Reading before FOV Switching:	Angle in degrees:
Elevation Reading before FOV Switching:	Angle in degrees:
Azimuth Reading after FOV Switching:	Angle in degrees:
Elevation Reading after FOV Switching:	Angle in degrees:

APPENDIX C. REFERENCES.

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