National Defense Industrial Association

Small Arms Symposium

Sensors for Small Arms Munitions

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CECOM Bottom Line: THE WARFIGHTER

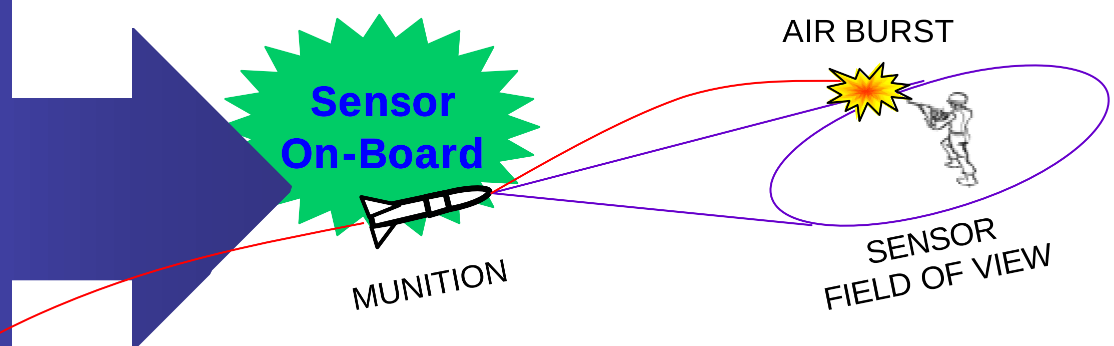
Sensor Integration for Small Arms Smart Munitions

What advantages can a Small Arms Smart Munition offer to the 21st Century Soldier?

- **Increased Lethality (High Probability of Incapacitation, P(I))**
- **Simplicity in Operation (Locate Target, Point, Fire and Forget, not laser designated)**
- **Effective For Multiple Enemy Positions (Moving, Stationary, in Defilade)**
- **Lightweight Weapon System (Soft-launched autonomous munition)**

<u>Projectile Sensor Requirements</u>

Small Size, Low Weight
Passive Operation in Day & Night
Sensitivity *(Range dependent)*
Response Time *(Velocity dependent)*
Autonomous Target Detect and Engagement
Low Power
Easy to Manufacture



Concept of Operation For Small Arms Smart Munition

Sequence of Events on the Fire Control System (individual weapon)

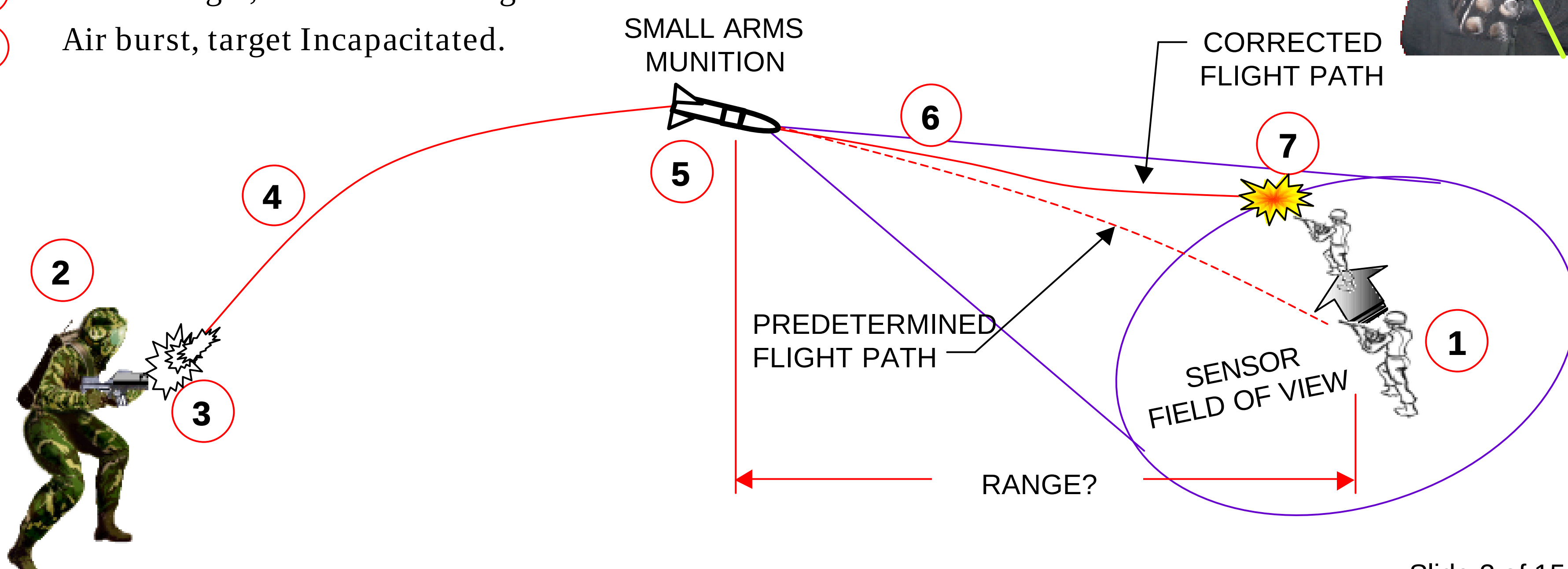
- Detect target and Acquire target location information.
- Compute flight trajectory, target image(s), Download to munition.
- Elevate weapon, Soft-launch munition.

Sequence of Events on the Small Arms Munition

- Follow predetermined flight path to known target location.
- Activate sensor and Look for target.
- Detect target, Maneuver to target.
- Air burst, target Incapacitated.

21st Century Visionary Soldier

- Individual Weapon
- Electronic Compass
- Laser Rangefinder
- Infrared Sensor

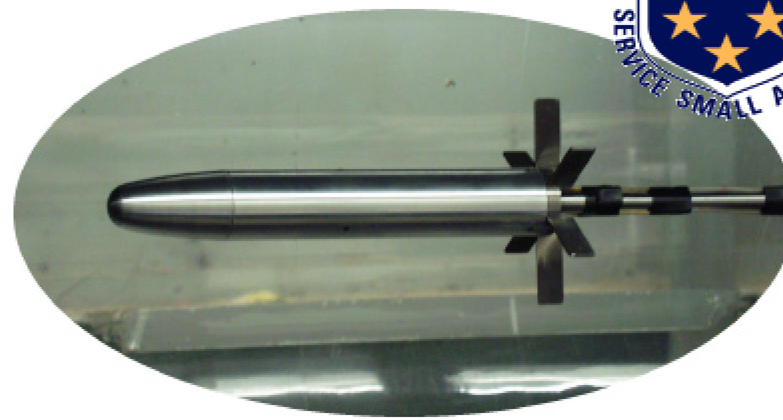


Light Fighter Lethality (LFL)
Small Arms Smart Projectile Example

Need Munition Characteristics to Focus Sensor Development / Specifications

Propose the Light Fighter Lethality (LFL) Seeker Projectile being developed by JSSAP

- Fin Stabilized – Maximum Spin Rate: 6 Hz
- Diameter: 25.0 mm
- Length: 165 mm (6.1”) unfolded
- Weight Goal: 0.5 lbs
- Maximum Flight Velocity: 160 m/s
- Maximum Engagement Range: 500 m
- Time of Flight: 4 s
- Target Type: Personnel in Body Armor



Based on above, Propose Using a 8-12 micron Uncooled Staring Microbolometer Sensor

Advantages:

+ Small Size (no scanning)
+ Low Weight, Low Power (with no TE cooler)
+ Passive, All Weather Operation
+ Medium to High Sensitivity
+ Manufacturing Processes Improving

Disadvantages

- Not Spin Insensitive (current pixel design)
- Non-Uniformity Correction (Calibration)
- Sensor Noise
- Thermoelectric (TE) Cooling currently

Sensor Development Outline

GOAL: Detect a personnel target with high probability early in projectile flight to provide adequate range and time for maneuvering.

FIRST: Determine the suitable Field of View (FOV) for the optics to fully contain the target based on projectile flight path. Concurrently, design external profile to satisfy aerodynamic stability. (slide 6&7)

SECOND: Optimize sensor array size for the given FOV and determine appropriate focal length to satisfy projectile physical constraints. (slide 8)

THIRD: Determine thermal time constant to minimize image degradation induced by projectile spin rate. (slide 11)

FOURTH: Determine detector sensitivity required to resolve target at sensor turn-on range. (slide 12)

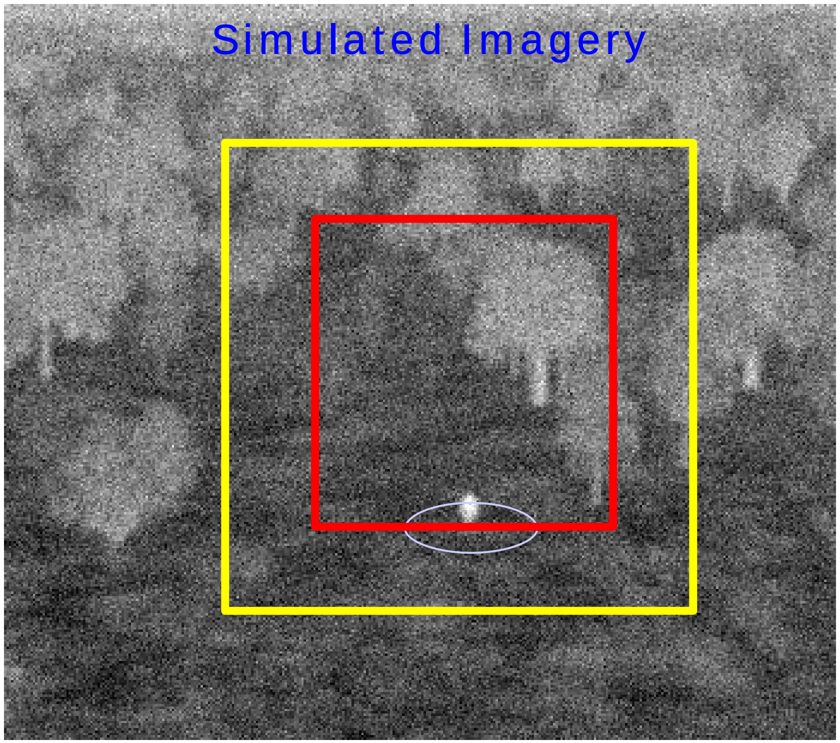
FIFTH: Predict detector sensitivity and thermal time constant values necessary to achieve a 70% probability of detection for a personnel target to satisfy the LFL application. (NVTherm Model) (slide 13)

SIXTH: Identify any issues associated with the sensor development results. (slide 14)

Field Of View (FOV) Analysis at Sensor Turn-On

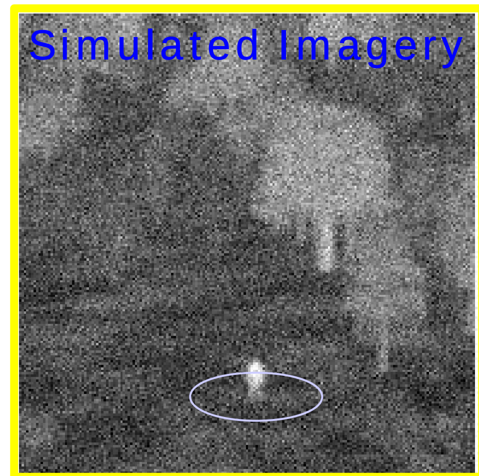
(Range: 265m, Altitude: 16.8m, -0.11°, TOF: 2.2sec)

Range to Target is 235 m



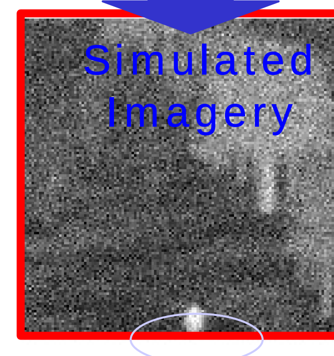
~10º Field of View

Circle is how far target could have run in the elapsed time from initial target acquisition to sensor turn-on.



8º Field of View

Requires Decreasing Projectile Altitude Or Later Turn-On!



6º Field of View

Field of View Must Encompass

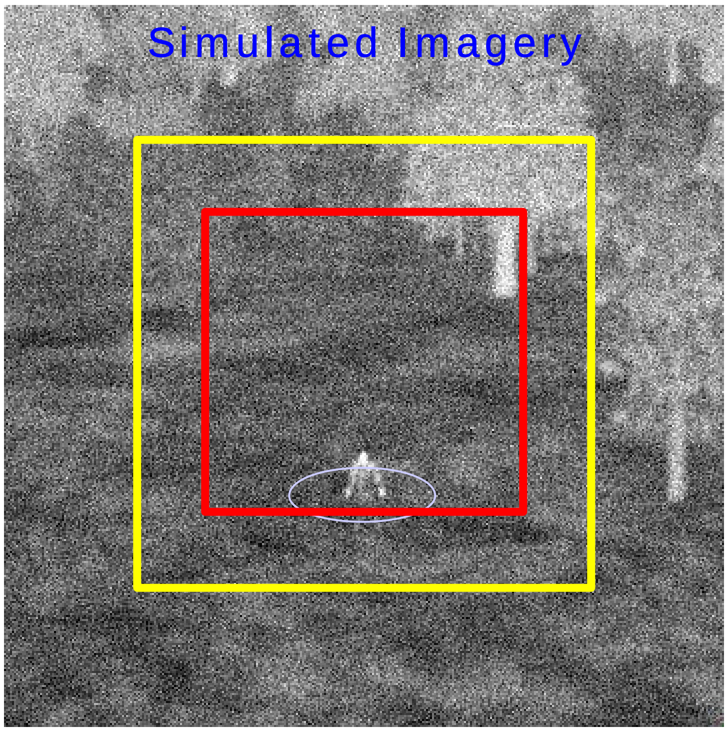
- Target upon turn-on without affecting projectile flight.
- Distance the target can run in available time.
- Errors associated with the targeting devices (such as the laser rangefinder, digital compass).
- Errors associated with projectile flight trajectory.

10° Is Excessive, 6° Is Too Small in Azimuth, 8° Is Sufficient.

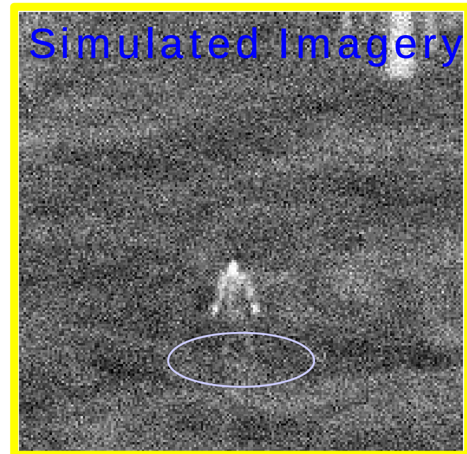
Field Of View (FOV) Analysis at Closer Range to Target

(Range: 413m, Altitude: 10.8m, -4.7°, TOF: 3.3sec)

Distance to Target is 87 m
Time to Impact is 0.7 sec



~10º Field of View

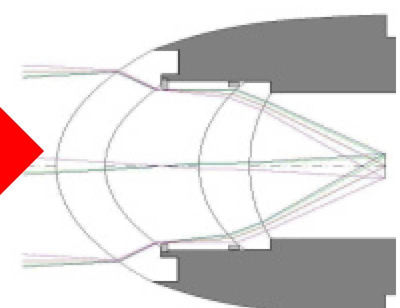


8º Field of View

6º Field of View

Circle indicates how far the target can run before the projectile reaches the target.

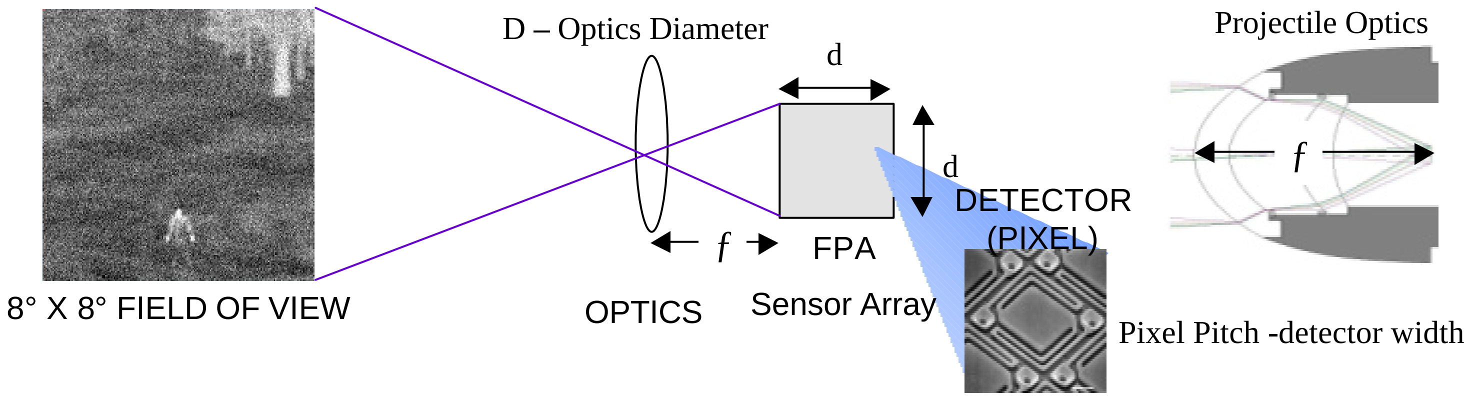
External Profile Satisfies Aerodynamic Stability Factors



Shorter Range to Target Reduces Amount of Scene Coverage

In Addition to Time Available for Projectile Course Correction

Focal Plane Array (FPA) Optimization Analysis



$$FOV = 2\tan^{-1}\left(\frac{d}{2f}\right)$$

$$IFOV = \left(\frac{FOV}{\#Pixels}\right)$$

$$F\# = \left(\frac{f}{D}\right)$$

Determine Appropriate Focal Plane Array Size to Best Resolve the Required Field of View.

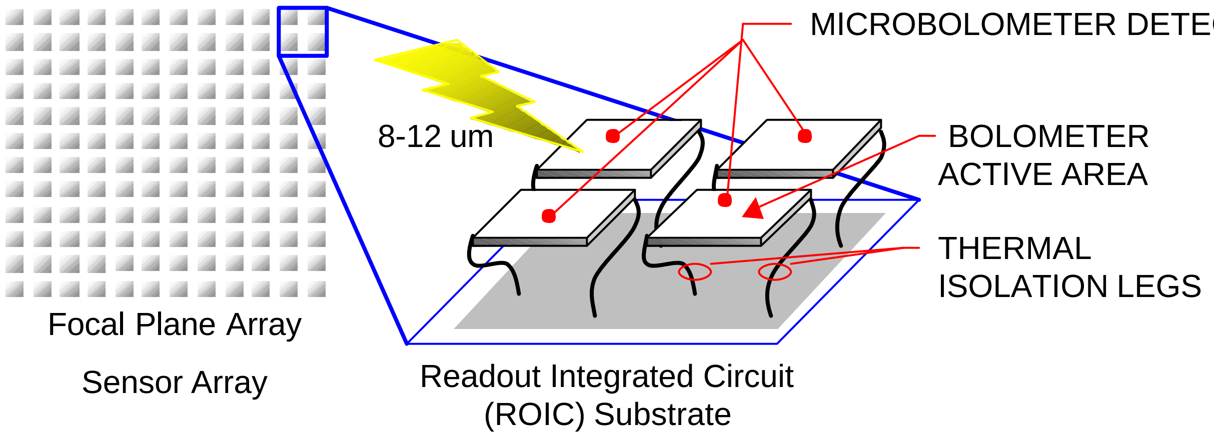
Dependent On:

• Number of Detectors	Many	Higher Resolution, Small IFOV
	Few	Lower Resolution, Large IFOV
• Pixel Pitch	Large	Large FPA Size, Long Focal Length (f)
	Small	Small FPA Size, Short Focal Length (f)
• Processing Consideration	Many Pixels	More Image Processing per pixel
	Few Pixels	Less Image Processing per pixel

Desire The Most Compact Optical System That Sufficiently Resolves The Target.

Result: 64 x 64 FPA, 25 µm pixel pitch, 11.5 mm (0.45”) focal length, 0.13° IFOV, 0.9 F#.

Microbolometer Detector Operation and Characteristics



Microbolometer Detector Operation

- Active Area absorbs incoming Infrared (IR) energy.
- IR energy produces a change in detector resistance across legs.
- Resistance change is sensed by integrating bias current or voltage.
- Resulting detector signal is read out and digitized.

The larger the change in resistance, the more IR energy was absorbed, and the thus the "hotter" the target.

Sensitivity

Determines the smallest temperature difference.

How far can you see?

Thermal Time Constant

Determines detector speed of response by the following equation:

$$t_{th} = C / G$$

where C = Thermal Heat Capacity (J/K)

G = Thermal Conductance (W/K)

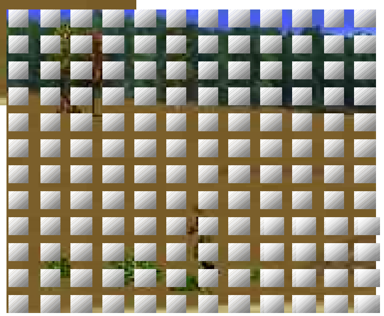
How fast can you see it?

Sensitivity and Thermal Time Constant are Inversely Proportional Based on Material Properties, Thermal Mass and Physical Geometry.

Issue of Projectile Spin on Sensor Effectiveness

NO PROJECTILE SPIN

Visible Scene



Scene Imaged by Static FPA

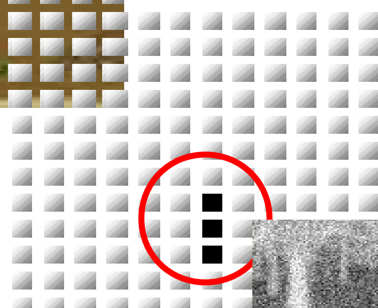
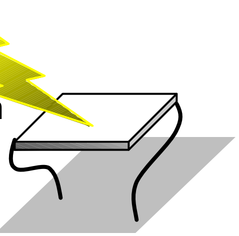


Image Readout

Thermal Image



IR Energy Contained within the IFOV is Absorbed by the bolometer.

PROJECTILE SPIN

6 Hz Spin = 2160º rotation/second

For single detector with τ_{th} = 10ms, scene IFOV rotates by **21.6°!!!**

Target Contrast Decreased !

Aspect Ratio Changes !

Visible Scene

Scene Imaged by Rotating FPA

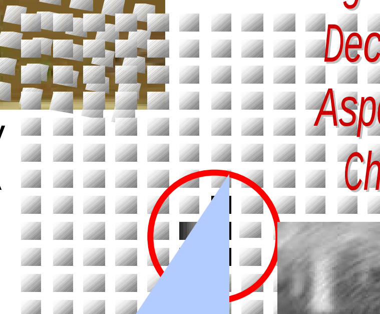
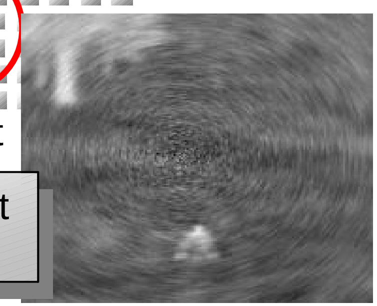


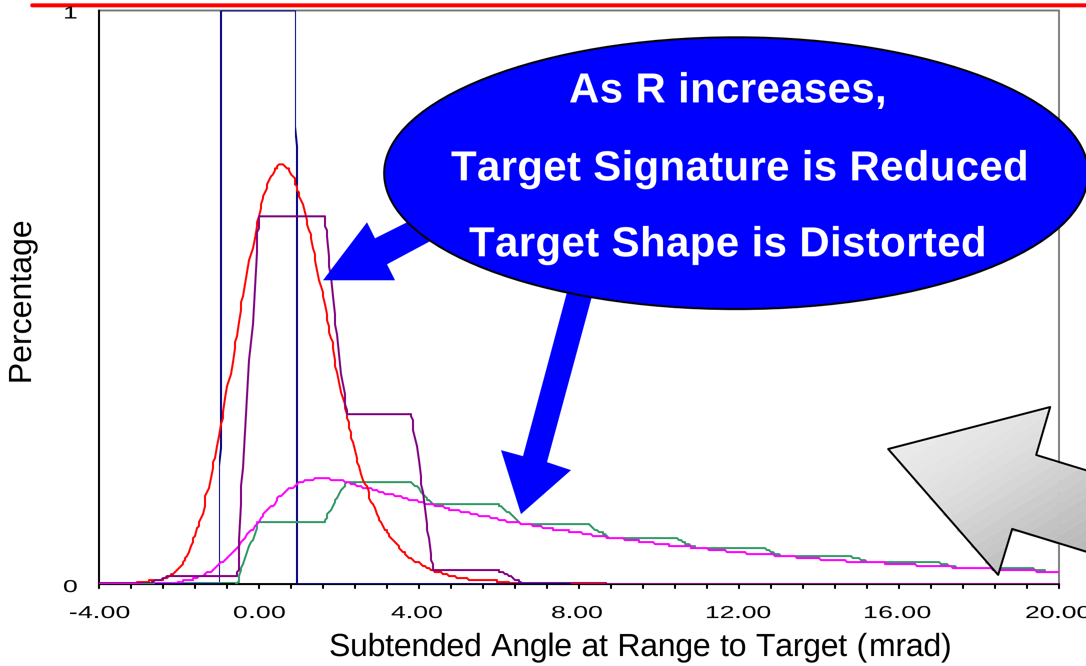
Image Readout

Effect worsens at FOV extremes.



Thermal Image

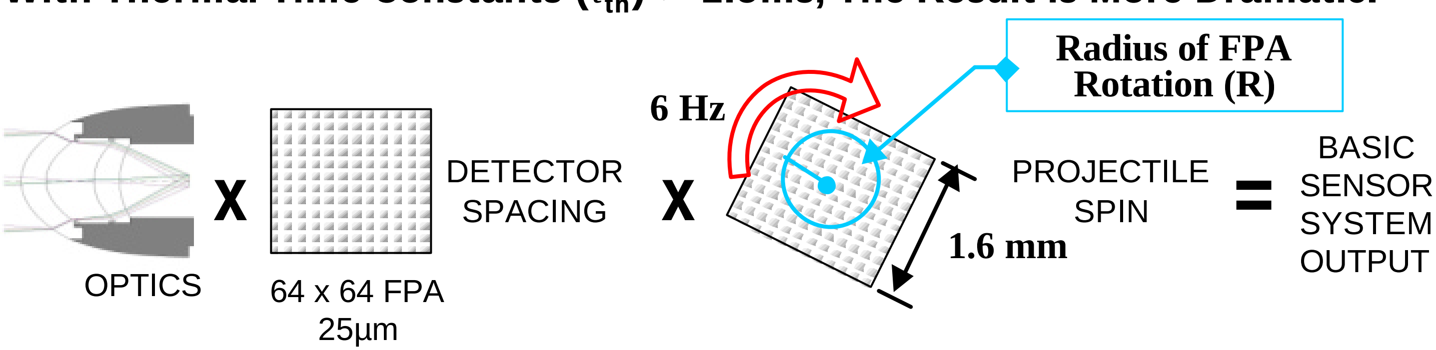
Projectile Spin Analysis (cont'd)

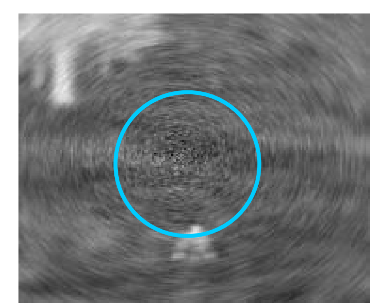


Sensor Parameters:
Field of View: 8° x 8°
Array Size & Pixel Pitch: 64 x 64, 25µm
Thermal Time Constant = 1.5ms
Range of Target = 234m

As Seen Above, Effect Worsens With Larger Radii of FPA Rotation (R).

With Thermal Time Constants (t_{th}) > 1.5ms, The Result is More Dramatic.

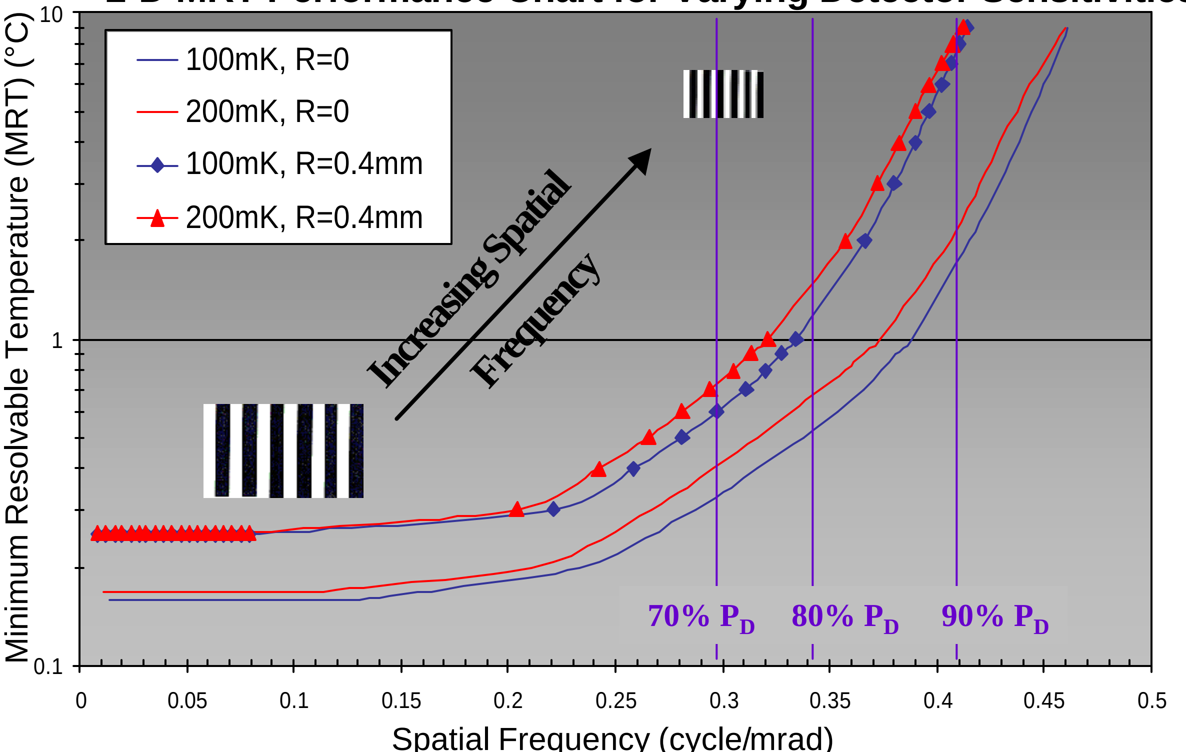




Thermal Image Representation

Required Sensor Performance at Sensor Turn-On Range
(234m to target)

2-D MRT Performance Chart for Varying Detector Sensitivities



MRTD is the minimum temperature difference between a standard target and the background that is required in order for a standard observer to just fully resolve the target. It is the best overall indicator of thermal imager system performance.

- FLIR92 Thermal Imaging Systems Performance Model, NVESD, Fort Belvoir, VA, Jan 1993.

Sensor 2-D MRT

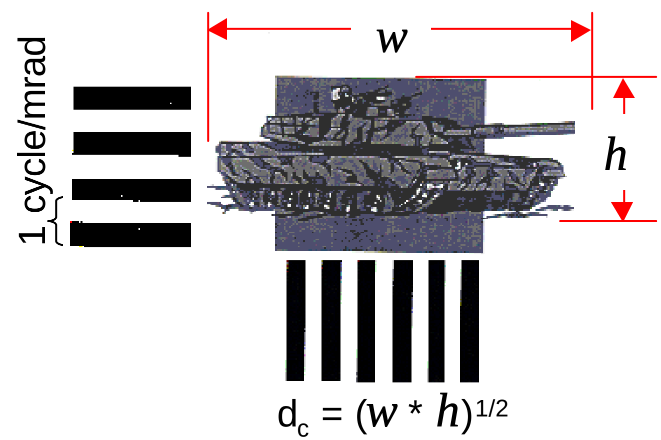
Atmospheric Transmission (0.7km^{-1})

Target-to-Background ? T (1.25° C)

Target Critical Dimension (d_c) (0.75m)

Plug into NVTherm Model, Output is a Range Performance Estimate for Probability of Detection

Johnson Criteria



Verify Sensor Parameters Through Sensor Performance Modeling

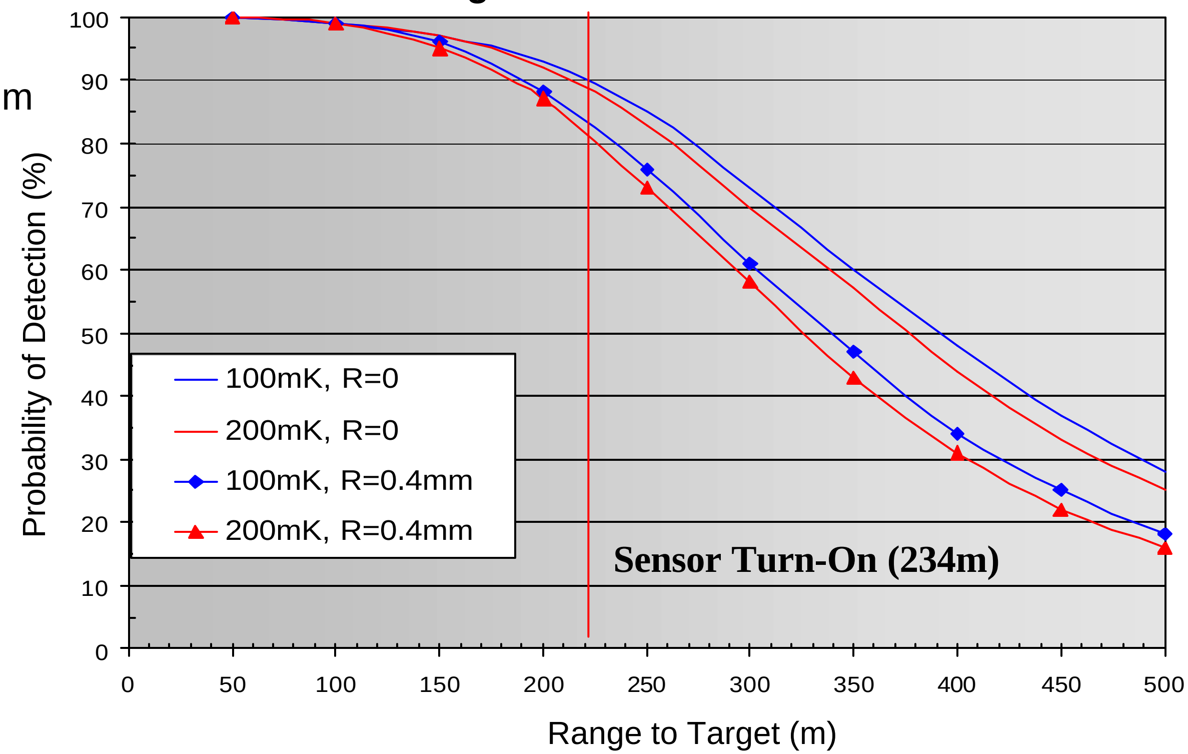
Sensor Parameters	
Focal Plane Array Size	64 x 64 pixels
Detector Sensitivity	100-200mK (f/1@30Hz)
Thermal Time Constant	1.5ms (minimum)
Pixel Pitch	25µm
Field of View	8° x 8°
Focal Length	11.5 mm
F#	0.9

Range Performance Estimates

Prob. of Detection	100mK	200mK
70%	270m-312m	260m-300m
80%	217m-233m	225m-262m

NVTherm is a computer model that is used to estimate the performance of thermal imaging systems. It was developed by the CECOM RDEC Night Vision & Electronic Sensors Directorate (NVESD), Fort Belvoir, VA.

Sensor Range Performance from NVTherm



Sensor Development Issues

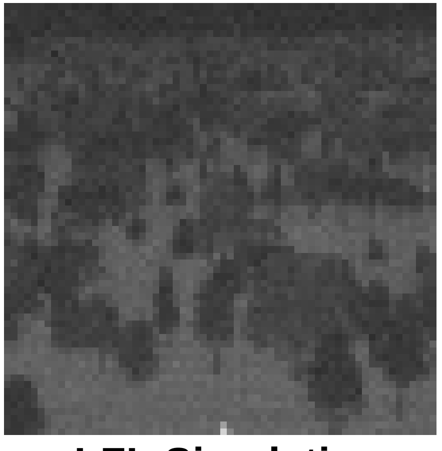
Factors Not Accounted For in Current Sensor Development:	**Impact**
• Software-in-the-loop operation for personnel target detection.	Moderate to High
• Verify operational timelines can be satisfied through the interaction of the guidance and control unit to the automatic target detection process.	Moderate
• Noise considerations(non-uniformity, fixed pattern noise).	Moderate to Low
• LFL Seeker Projectile flight errors on FOV optimization.	Moderate to Low
• Target aspect ratio based on projectile Angle of Attack (AoA).	Low (<5° AoA)

Factors Associated with NVTherm Range Performance Results	
• Does not account for software-in-the-loop target detection.	Moderate to High
• 70% Probability of Detection is conservative estimate for **man-in-the-loop.**	Moderate

Software-in-the-Loop Design Integration Will Be Addressed In Future Analysis. However, The Analysis To Date Still Proves That Sensor Parameters Can Be Adjusted To Satisfy The LFL Seeker Projectile Application.

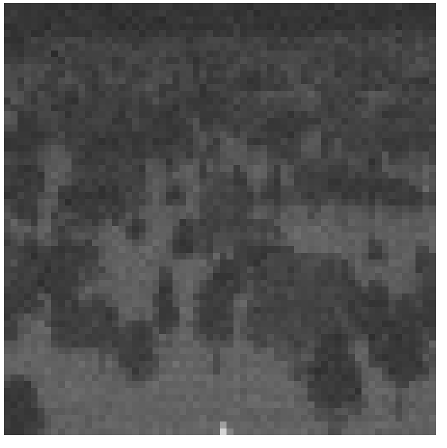
Summary and Future Work

- Investigate Prototype Development of an Uncooled, Small Array Sensor for Use in Smart Munitions.
  - Revise Sensor Parameters To Consider Munition Guidance and Control Capabilities.
  - Uncooled Detector Technologies Have Improved In Recent Years (assuming reasonable temporal response and sensitivity requirements).
  - Electronics Required to Readout the Sensor Images Can Be Produced.
- Investigate Issues Associated with the Software-in-the-Loop issue for Automatic Target Detection.
- Continue Development of the LFL Seeker Projectile Sensor Simulation as a Sensor Analysis Tool.



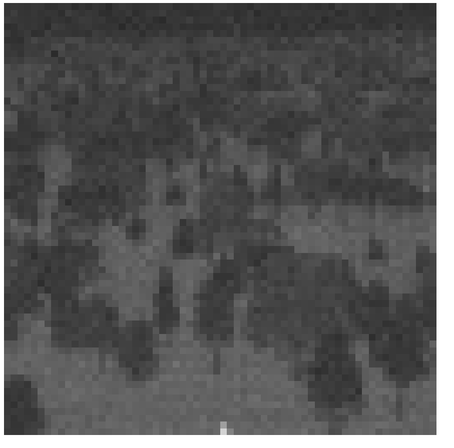
LFL Simulation

Real-Time Speed



LFL Simulation

1/3 Speed



LFL Simulation

1/10 Speed