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Final Briefing Report

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SURVEY OF LADAR SENSORS FOR WARHEAD FUZING

JUNE 1993

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Submitted to:
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Redstone Arsenal, AL 35898

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TITLE PAGE

The "Survey of LADAR sensors for Warhead Fuzing" study was conducted by the Environmental Research Institute of Michigan (ERIM) for the Army Materiel Command, Smart Weapons Management Office, Redstone Arsenal, AL. The study was accomplished as a special task under the technical scope of the Technical Area Task provision of the Infrared Information and Analysis (IRIA) contract, DLA900-88-D-0392. The Government Contracting Officer's Technical Representative (COTR) for the IRIA Center is Dr. John M. MacCallum, and the Smart Weapons Management Office COTR is Mr. Donald V. Rubin, U.S. Army Material Command, ATTN: AMSMI_SW, Redstone Arsenal, AL 35898, phone (205) 842-8079. The ERIM principle investigators were Mr. William L. Cesarotti and Mr. David M. Zuk.

93-21039 R1

Survey of LADAR Sensors for Warhead Fuzing

for

Army Materiel Command Smart Weapons Management Office

ERIM

EXECUTIVE SUMMARY

This chart provides an top level overview of the "Survey of LADAR Sensors for Warhead Fuzing" task with key elements highlighted. The survey primary objective was accomplished and LADAR technology was assessed as being sufficiently mature and offering needed performance to be considered as a fuzing sensor for guided munitions.

SURVEY OF LADAR SENSORS FOR WARHEAD FUZING

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Objective

- Survey LADAR sensor technology for fuze applications
- Identify promising concepts

Background

- Improve weapon performance by: Improved aim-point resolution,
- Increased stand-off range, and narrowed fuze range tolerance

Methodology

- Tailored signal-to-noise equation analyses
- Technology assessment

Benefits

- Improved understanding of LADAR technology
- Identification of potentiai fuzing LADARs

OBJECTIVE

The survey task had a tripartite objective as shown. The focus was to identify a number of infrared LADAR sensors that would be suitable as warhead fuzing sensors for new anti-vehicular weapons. The selection of an optimal LADAR for a particular weapon would be the result of activities subsequent to this survey.

OBJECTIVE

For Selected Weapon Concepts

- Survey
  Applicable LADAR sensor and processing technologies
- Select
  Most promising concepts
- Recommended
  Demo plan for selected concepts

PROGRAM APPROACH

The approach to accomplishing the program is schematically depicted on this chart. After a brief overview (this chart), each of the major areas are discussed in detail in subsequent charts.

The program starts with a definition of 1) LADAR characteristics and assumptions (principally, the method the investigators chose to categorize the candidate LADAR concepts); 2) weapon(s) concept, and fuzing function requirements (primary sponsor inputs); and 3) sensor algorithm and weapon guidance assumptions necessary to analyze the LADAR concepts as fuzing sensors. After establishing the above initial criteria, a Signal-to-Noise Ratio (SNR) performance analysis was conducted to identify the applicability of a matrix of LADAR concepts to the fuzing concept(s) specified. The performance analysis consisted of calculating key performance values using the signal-to-noise equation tailored to the LADAR category (initiating condition) and the warhead fuzing problem. Curves showing required laser power vs range to target are used to identify relative performance of the LADAR concepts. The survey results present the LADAR concepts that dominate the matrix of choices to accomplish the fuzing function. Principally, the assessment is based on identifying lasers of sufficient power and size to support the weapon mission definition. Selected data supporting this assessment is presented in this report. After candidate LADARS have been identified, design reviews accomplished through and assessments of component technology and countermeasures provide a priority list of the most promising LADAR concepts and a suggested demonstration plan.

LADARS FOR WARHEAD FUZING

PROGRAM APPROACH

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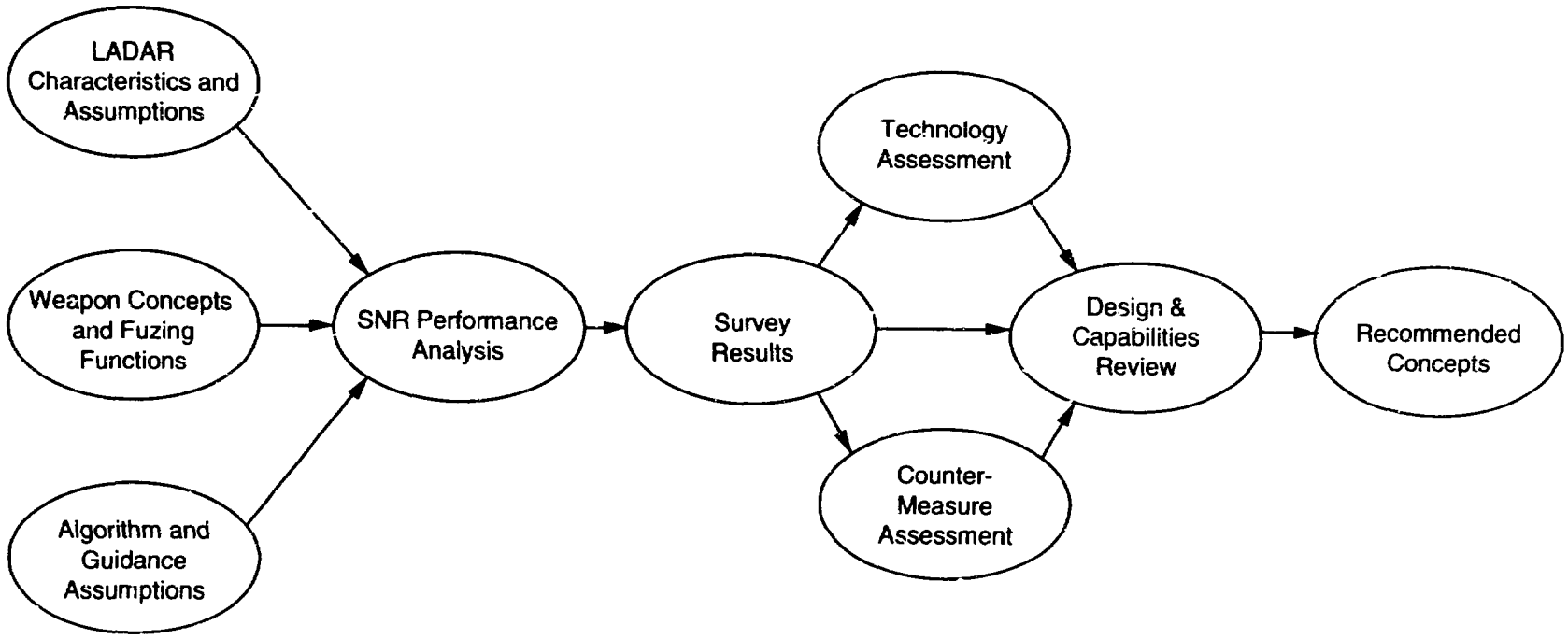

INITIATING CONDITIONS

The initiating factors; LADAR characteristics and assumptions used for the survey; weapon(s) concept and fuzing functions, i.e., weapon characteristics and fuzing requirements dictating LADAR design limits, and algorithm and guidance assumptions impacting LADAR design parameters are presented first.

LADARS FOR WARHEAD FUZING

INITIATING ASSUMPTIONS

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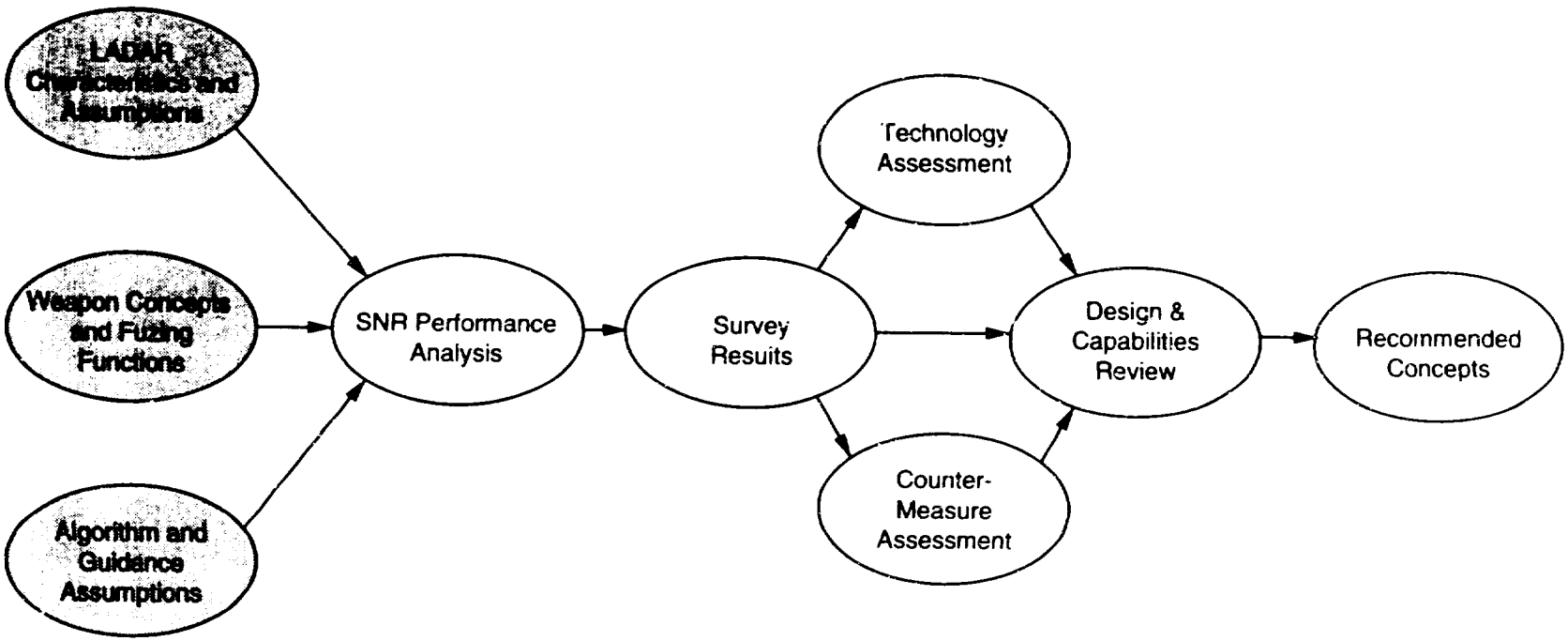

LADAR ASSUMPTIONS FOR SURVEY

These assumptions have been made to support the definition of LADARs to be consider in the survey. First, all LADARs being considered are Infrared LADARs and each LADAR will be of a single wavelength, i.e., multispectral LADARs will not be considered. Second, key phenomenology related parameters are nominally invarient within a waveband and can be treated as constants with each waveband. Third, the LADAR concepts being considered produce three dimensional information as a information output, i.e., other phenomenology such as polarization, doppler, etc. will not be investigated. Fourth, the LADARs are not constrained to meet eye safety requirements. Other assumptions, that will be used in the recommendation of concepts include the relative availability of components, practicality, and cost.

LADAR ASSUMPTIONS FOR SURVEY

- LADAR definition
  - IR, single wavelength
  - Singular characteristics within wavebands
  - 3-dimensional geometry
  - Eye safety not an issue
- Key components available
- Practicality and cost important

LADAR CHARACTERISTICS

The characteristics of the LADAR fuzing concepts considered for the designated representative weapon concept are presented on this chart. For the four selected IR bands, a laser(s) representative of that band was chosen. For each of the selected lasers, pulsed and continuous-wave waveforms are investigated using both direct (non-coherent) and heterodyne (coherent) detection. For each of the above combinations, three scanning techniques were considered: scanning a single detector, scanning an array detector, and a non-scan focal plane array. The combinations of these characteristic represent over 50 LADAR concepts.

LADAR CHARACTERISTICS

- Waveband
  - NIR (< 1.1 μm - GaAs and YAG)
  - SWIR (1.1 μm ⇒ 2.5 μm - Ho)
  - MWIR (3.0 μm ⇒ 5.0 μm - DF)
  - LWIR (8.0 μm ⇒ 12.0 μm - CO_2)
- Pulsed / CW—Modulated wave forms
- Direct / Heterodyne detection
- Scanning technique
  - Single detector
  - Array detector
  - Focal plane array (non-scan)

NOMINAL WEAPON CHARACTERISTICS

Five conceptual anti-vehicular (ground vehicles and helicopters) weapons were identified and a nominal list of LADAR design driving characteristics and requirements were selected to represent the five weapon concepts. A LADAR fuze designed to satisify these requirements would satisify the needs of any of the five weapon concepts.

NOMINAL WEAPON CHARACTERISTICS

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- 375 m/sec maximum engagement velocity
- Fuzing range ≤ 7 m with minimum tolerance of ± 0.2 m
- Aimpoint variation from centroid of a turret to centroid of a vehicle
- Space available for lens ≤ 8 cm

FUZING FUNCTION CONCEPTS

Two functional fuzing concepts were used to specify LADAR parameters: a "best aim-point solution" and a "select and guide to an aim-point". With both concepts, it is assumed that the weapon is on an trajectory that will intersect the target. For the best aim-point solution, the LADAR fuze would scan the predetermined target and select the "best" aimpoint the weapon will intersect and fuze on that aim-point at the designated range. The "best" aim-point is a selected priority as shown: 1) a turret centroid, 2) an engine compartment, and 3) a vehicle centroid. The fuze processor, using algorithm templates, would identify the aim-points, determine which selected aim-points will be reached on the weapon trajectory, select the "best" aim-point and fuze at the required range for the selected aim-point. The second fuze function concept is similar to the "best" aim-point concept, but instead of selecting the the best aim-point that will be intersected, the fuze will select the best aim-point that can be "reached" within the weapon maneuver envelope and provide offsets to the guidance and control section the steer the weapon to the selected aim-point. The guide to an aim-point concepts requires the LADAR to operate at a longer range.

FUZING FUNCTION CONCEPTS

- Best aim-point solution
  - Weapon trajectory fixed
  - Aim-point priority
    - Turret centroid
    - Engine compartment
    - Vehicle centroid
  - Fuze at predetermined range
- Guide to aim-point
  - Acquire aim-point with priority
  - Provide guidance coordinates
  - Fuze at predetermined range

GUIDANCE AND ALGORITHM ASSUMPTIONS

These assumptions have been made to provide initial conditions for the performance analysis. Generally, the comparison of LADARs will be insensitive to the guidance assumptions. The algorithm assumptions are based on community accepted standards and/or ERIM experience. The use of a "detection theoretical signal processor" or "optimum processor" provides the theoretical best possible processor; therefore, comparison of processor types or claims will not influence the LADAR comparison.

GUIDANCE AND ALGORITHM ASSUMPTIONS

For weapon guidance

- Weapon directed at target prior to LADAR operation
- Nominal 10:1, range cross range maneuver capability

For algorithm/processor

- Two pixels/line pairs on target for detection
- Range-precision is 1/5 critical dimension of target
- Detection theoretical signal processor

PROCESSOR CONSIDERATIONS

To this point, the focus has been on the sensor element of a seeker. To complete a seeker system the processor must be addressed. For the purposes of this survey, the processor element will be defined in Millions-of-Instructions per Second (MIPS) using the optimum processor theory. Basically, this theory provides the minimum size processor that could meet the data rate requirements. The defined processor is the theoretical best that can be achieved, and as a best case solution if the "optimum" processor cannot be shown to support the data through-put needs the seeker concept would be judged "not-viable". This chart identifies the inputs to the optimum processor model.

PROCESSOR CONSIDERATIONS

IFOV (Pixel)

FOV (Frame)

Size of Target (in Pixels)

Functions

Weapon Velocity (Frame Rate)

MIPS ⇒ Processor Size

SNR ANALYSIS METHODOLOGY

The methodology used to accomplish the performance analysis follows.

LADARS FOR WARHEAD FUZING

SNR ANALYSIS METHODOLOGY

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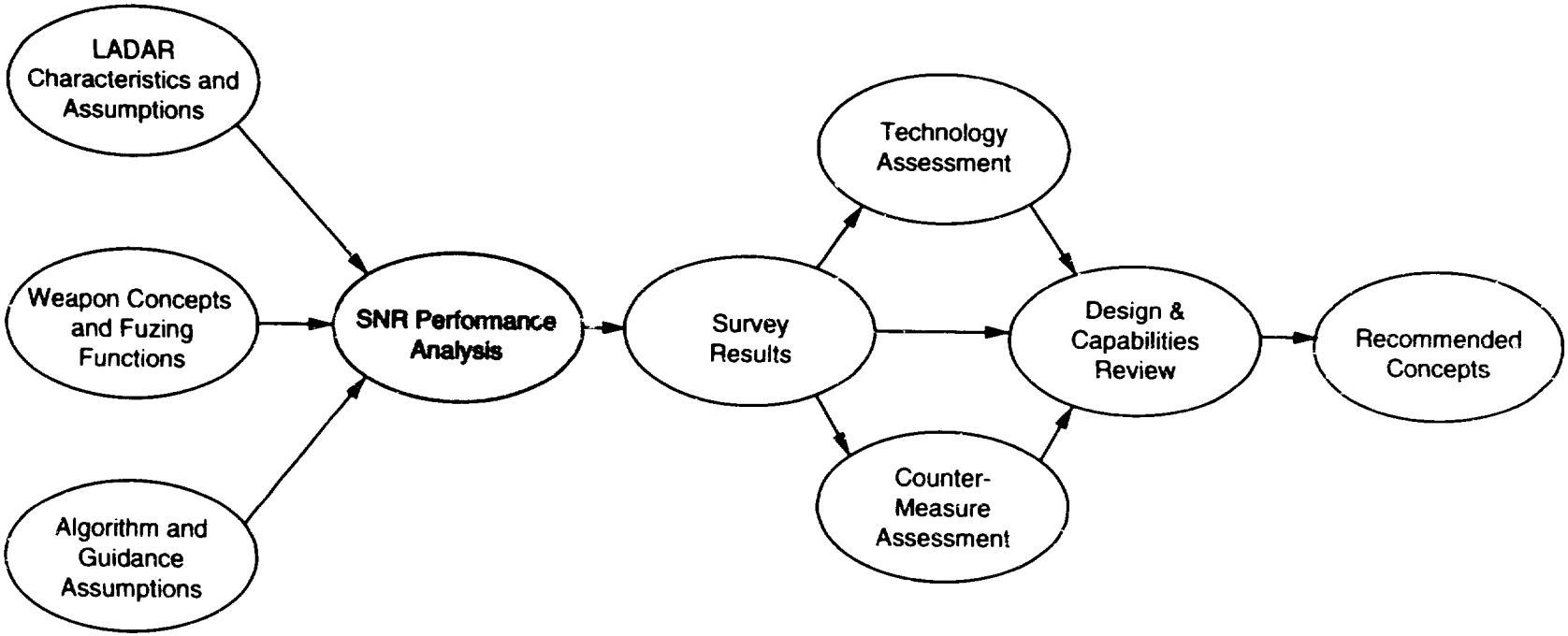

SNR EQUATION

The Signal-to-Noise Ratio (SNR) based on power is shown for direct (non-coherent) and heterodyne (coherent) detection. These equations represent the starting point of the performance analysis. The parameters of the equation are identified and defined on the follow chart. Subsequent charts will present the transformation of these equations into the LADAR performance equations used for this survey.

SNR EQUATION

- For direct detection

$$S/N = \frac{(\text{Signal Current})^2}{(\text{Signal Shot Noise Current})^2 + (\text{Solar Shot Noise Current})^2 + (\text{System Noise Current})^2}$$

$$S/N = \frac{2S(w)\left[\beta P_L \frac{\rho}{\pi} \frac{A_r}{R^2} T_t T_r T_A{}^2\right]^2}{2eFB\beta P_L \frac{\rho}{\pi} \frac{A_r}{R^2} T_t T_r T_A{}^2 + 2eFB\beta\rho A_r \frac{\Theta_r^2}{4} E_\lambda \Delta\lambda T_r T_A + NEP^2\beta^2 B}$$

- For Heterodyne detection

$$S/N = \frac{(\text{Signal Current})^2}{(\text{Signal Shot Noise Current})^2}$$

$$= \frac{2S(w)\ P_L \frac{\rho}{\pi} \frac{A_r}{R^2} T_t T_r T_A{}^2 \eta\eta_H}{h\upsilon B}$$

SNR EQUATION TERMS

The parameters of the SNR equations presented on the previous chart are identified, along with the factors that define the parameters, on this chart.

LADARS FOR WARHEAD FUZING

SNR EQUATION TERMS

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Variable	Description	Defining Factor
$S(w)$	Modulation Coefficient	Modulation Waveform
β	Responsivity	Quantum Efficiency
ρ	Scene Reflectivity	Phenomenology
A_r	Receiver Aperture	Munition Size
R	Range	Range/Cross Range Decision
T_t	Transmitter Transmission	Experience 0.8
T_r	Receiver	Experience 0.6
T_A	Atmospheric Transmission	System/Constraints
e	Electron Change	Defined
F	Excess Noise Factor	Detector Type
B	Bandwidth	FOV, IFOV, Frame Rate, Sample Rate
Θ_r	IFOV	Algorithm/Feature
E_λ	Background Spectral Irradiance	Estimated by Plank Curve
$\Delta\lambda$	Optical Bandwidth	Experience
NEP	Noise Equivalent Power	Experience, Quantum Efficiency & Resistor Noise
σ_r	Range Precision	Target, Penomenology, Decision Algorithm
R_a	Ambiguity Interval	Target Attack Geometry
P_L	Laser Power	Bounded by Available Technology
η_H	Heterodyne Efficiency	Extra Term for Mismatch in Optics
η	Quantum Efficiency	Detector Characteristics
ν	Optical Frequency	Selected Laser

LADAR SNR EQUATION DEVELOPMENT

This chart presents the approach to tailoring the basic SNR equation to a form appropriate to the objective of this program. Using the assumption that certain parameters are primarily invariant with the selected wavebands, the SNR equation can be simplified into a series of constants and easily recognized sensor parameters. The definition of the constants is presented on the following chart.

LADAR SNR EQUATION DEVELOPMENT

- Simply SNR

  $SNR = f(K_u, K_{WB}, SP)$

  Where K_u = Universal constants
  K_{WB} = Invariant parameters within waveband
  SP = Sensor system parameters

- SNR equation becomes

  For direct detection $$SNR = \frac{K_1 \left[P_L \frac{Ar}{R^2}\right]^2}{K_2 B}$$

  For Heterodyne detection $$SNR = \frac{K_3 \left[P_L \frac{IFOV^2}{R^2}\right]}{K_4 B}$$

SURVEY SNR EQUATION CONSTANTS

This chart presents the SNR equation parameters established as constants (both true constants and phenomenology related constants in the chosen wavebands) in tailoring the general SNR equation to the warhead fuzing function.

SURVEY/SNR EQUATION CONSTRAINTS

Universal Constants

h—Plank's Constant

k—Boltzman's Constant

e—Charge of an Electron

c—Velocity of Light

Waveband Constants

ρ —Reflectivity

T_t —Transmission of Transmit Optics

T_r —Transmission of Receive Optics

σ —Atmospheric Extinction

η —Quantum Efficiency

E_λ—Background Spectral Radiance

$\Delta\lambda$—Optical Bandwidth

F —Excess Noise Factor

G —Detector Gain

R_L—Load Resistance

COMPARISON OF WAVEBAND CONSTANTS

Shown are the different values used for the waveband constants by waveband. The values selected are based on experience and should be considered conservative, i.e., sensors developed using these design parameters should be expected to exceed performance requirements.

Reflectance values selected are representative of low reflectances for the spectral band. NIR of 0.1 is significantly lower than one would expect for a vegative matching paint, but it includes paint covered by dirt or mud. The 0.01 value for LWIR is representative of paints for viewing angles of 45 degrees or more. The transmit and receive optics transmission is lower for the MWIR and LWIR to account for the higher index materials that must be used in those spectral regions. Atmospheric extinction coefficients are representative of a 1 km visibility. Quantum efficiency is representative of values that can be expected. For solar background, a 6000 degree K black body was used to represent solar illumination in the NIR and SWIR bands. For the MWIR and LWIR bands, a value that was 2 times less than theoretical D star was used for background illumination. The optical bandwidth of the system is larger at longer wavelengths because of the problem of manufacturing narrower bandpasses at the longer wavelengths. The excess noise factor is not unity only for the NIR where SiAPDs (Silicon Avalanche Photo Diodes) are available. Similarly, the gain term exists only for the NIR where the Si APD provides internal gain. The final term represents the load resistor value that must be used to obtain the necessary frequency response. The load resistor is determined by the stray capacitance which was selected to be 10 picofarads and the pulse width (pulsed waveforms) or period of modulation (cw waveforms).

LADARS FOR WARHEAD FUZING

COMPARISON OF WAVEBAND CONSTANTS

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Constant	Symbol	NIR	SWIR	MWIR	LWIR
Reflectivity	ρ	0.1	0.1	0.1	0.01
Transmission of Transmit Optics	T_t	0.8	0.8	0.7	0.7
Transmission of Receive Optics	T_r	0.6	0.6	0.5	0.5
Atmospheric Extinction	σ	2.0	1.4	0.9	0.15
Quantum Efficiency	η	0.5	0.5	0.5	0.5
Background Spectral Radiance	E_λ	Black Body		D*	
Optical Bandwidth	Δ_λ (µm)	0.001	0.05	0.05	0.1
Excess Noise Factor	F	3	1	1	1
Detector Gain	G	100	1	1	1
Load Resistance	R_L	$\frac{t}{2\pi C_d}$			

DEVELOPMENT OF PERFORMANCE EQUATIONS

The SNR equation is used to analyze the performance of a sensor; however, accomplishing a sensor parametric design, requires the SNR to be expressed as a given value or function of sensor parameters. Nominally, this can be accomplished in one of two ways. First, a given or required value for SNR can be established based on a required probability-of-detection and probability-of-false-alarm using standard probability-of-detection curves for direct and heterodyne detection. Second, the SNR can be expressed as a function of required range precision. The requirement or dominance of the requirement, detection or range precision, dictates the technique to be used. For the purpose of this survey, the range precision requirement dominates, and the expressions for range precision in term of power SNR are shown. Substituting the equations for range precision into the SNR equation yield the presented performance equations for direct and heterodyne detection and pulsed versus continuous wave waveforms.

DEVELOPMENT OF PERFORMANCE EQUATION

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- Use range precision (σ_R) requirement to set SNR

Pulse $$\sigma_R = \frac{C}{2\,B\,\sqrt{SNR_\Phi}}$$

CW $$\sigma_R = \frac{R_a}{2\,\pi\,\sqrt{2\,SNR_\Phi}}$$

- Substituting with SNR equations

Direct detection, Pulse $$P_L{}^2 = K_5\,\frac{R^4}{B\sigma_R{}^2 A_r{}^2}$$

Direct detection, CW $$P_L{}^2 = K_6\,\frac{BR_a{}^2 R^4}{\sigma_R{}^2 A_r{}^2}$$

Heterodyne, Pulse $$P_L = K_7\,\frac{R^2}{B\sigma_R{}^2 IFOV^2}$$

Heterodyne, CW $$P_L = K_8\,\frac{BR^2 R_a{}^2}{\sigma_R{}^2 IFOV^2}$$

PERFORMANCE EQUATION VARIABLES

The key variables in the performance equations are presented on this chart along with the factors that determine the numerical value of the variables. The Area of the Receiver variable is dictated by the size, diameter, or other physical constraints of the munition. Range-to-Target and Field-of-View (FOV) are parameters usually constrained by the maneuver envelope of the weapon. The IFOV, Ambiguity Interval, and Range Precision are usually dictated by the mission needs, e.g., target, aimpoint size and location, CEP, etc.

LADARS FOR WARHEAD FUZING

PERFORMANCE EQUATION VARIABLES

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Variable	Definition	Constraint/Source
A_r	Area of Receiver	Largest Lens That Can Be Used
B	Bandwidth	IFOV, FOV, Data Rate-CW, Range Precision-Pulse
IFOV	Instantaneous-Field-of-View	Nominally, determined by detection need for two lines on target
R_a	Ambiguity Interval	Nominally, 2 Times Extent of Target
σ_r	Range Precision	Nominally, 1/5 of Critical Dimension
R	Range to Target	Mission Dictates / Maneuver
P_L	Laser Power / Detector Element	Technology Availability

PULSED LADAR BANDWIDTH AND IFOV DETERMINATION

Presented is the development of the values used for bandwidth and Instantaneous Field of View (IFOV) for the pulsed LADAR concepts using state-of-the-art components and previously address assumptions for the detection algorithms. Technology state-of-the-art or component availability is addressed under a subsequent heading: "Technology Assessment".

PULSED LADAR BANDWIDTH AND IFOV DETERMINATION

- Bandwidth

  Let pulse width = t_p

  Then for Q–switched pulses which are in the range of 10 - 100nsec.

  Select 20ηsec as generally achievable number

  $$B \simeq \frac{1}{t_p} = 50\text{MHz}$$

- IFOV

  Two lines required for detection, and using 7m as maximum vehicle dimension
  FOV = 14m

  With a range - cross range variation of 10:1
  IFOV(θ) ≃ 10mrad

CW LADAR BANDWIDTH DETERMINATION

Presented is the development of the value used for bandwith of the CW LADAR concepts.

CW LADAR BANDWIDTH DETERMINATION

Tolerance of range measurement determines
Fuze Window (F_w) = ± 0.15m

Velocity (v) of munition 0.5M $\mapsto$ 1.2M using
375m/sec as worse case

Time (t_w) for munition to move through Fuze Window

$$t_w = \frac{F_w}{v}$$

To ensure fuzing occurs in Fuze Window select
sample time or dwell time $(t_d) = \frac{t_w}{10}$

Therefore, $t_d = 40\mu$sec

For a 50% duty factor (scan) $B = \frac{1}{t_d} = 25{,}000$Hz

Note: PRF of pulse laser equals CW bandwidth

INITIAL SURVEY RESULTS

Following are the findings from the SNR performance analysis. Performance for direct and heterodyne detection, continuous-wave (CW) and pulsed waveforms, and representative wavelengths in each of the wavebands is displayed as graphs of range versus average laser power in a variety of combinations. Two wavelenghts, 0.8 and 1.06 micrometers (GaAs and NdYAG) were selected to represent the near infrared band as in this region highly efficient silicon photo-avalanche diode (SiAPD) detectors can be used.

For reasons that will become apparent during the presentation of the results, the scan versus non-scan issue can be held in abeyance until the number of potential LADAR concepts is reduced.

LADARS FOR WARHEAD FUZING

INITIAL SURVEY RESULTS

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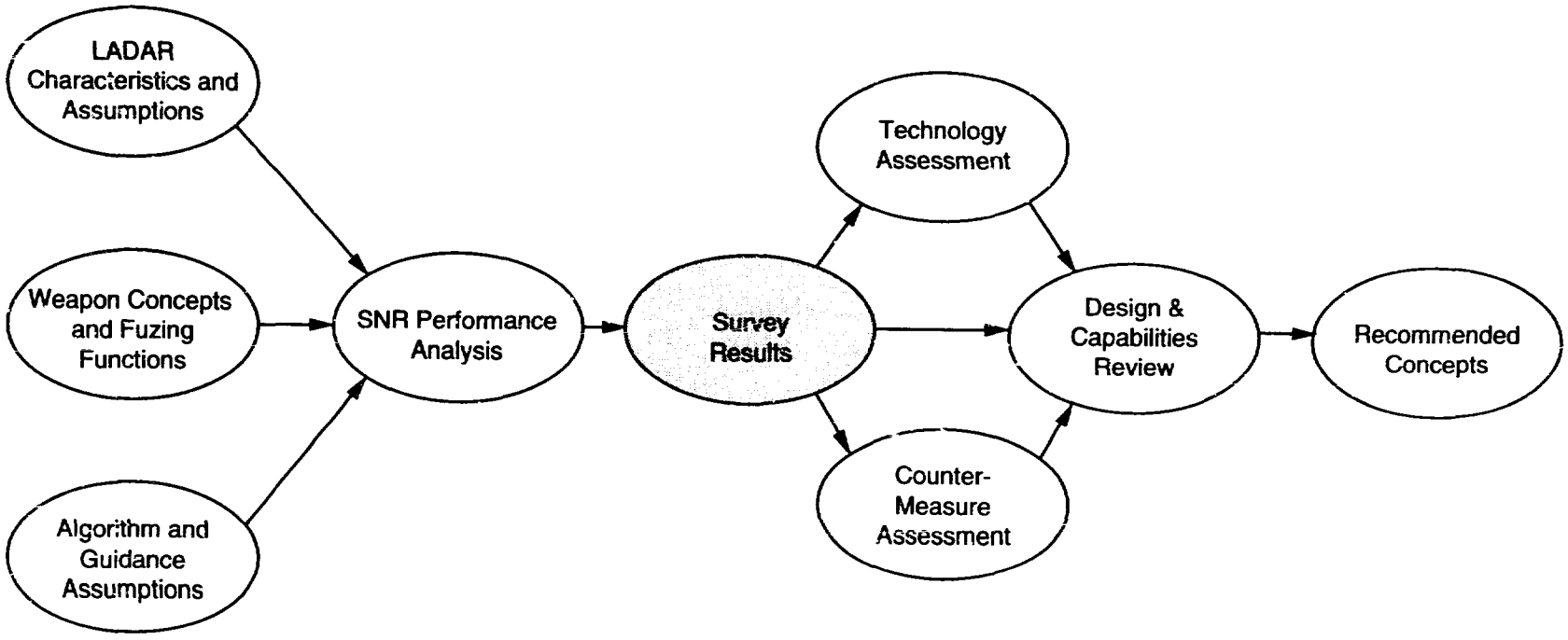

DIRECT DETECTION WAVELENGHT VARIATIONS

The direct detection performance for CW and pulse LADARs is presented on this chart. From these charts, it can readily be seen that the 0.8 and 1.06 micrometer LADAR performance dominates the performance of LADARs in the other wave bands for the range parameters of interest. Conclusions cannot be reached in comparing CW versus pulsed LADARs from these charts even thought the apparent power requirements appear to favor a pulsed LADAR. The ability and techniques for producing the required pulse power compared to direct transmission will be addressed in a subsequent dersign review of the candidate LADARs.

LADARS FOR WARHEAD FUZING

DIRECT DETECTION WAVELENGTH VARIATIONS

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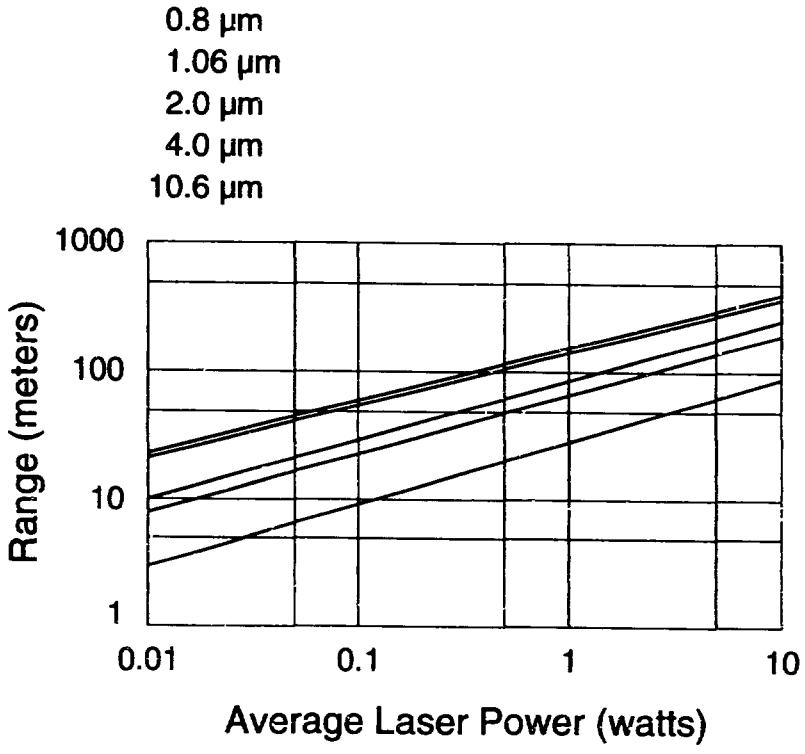
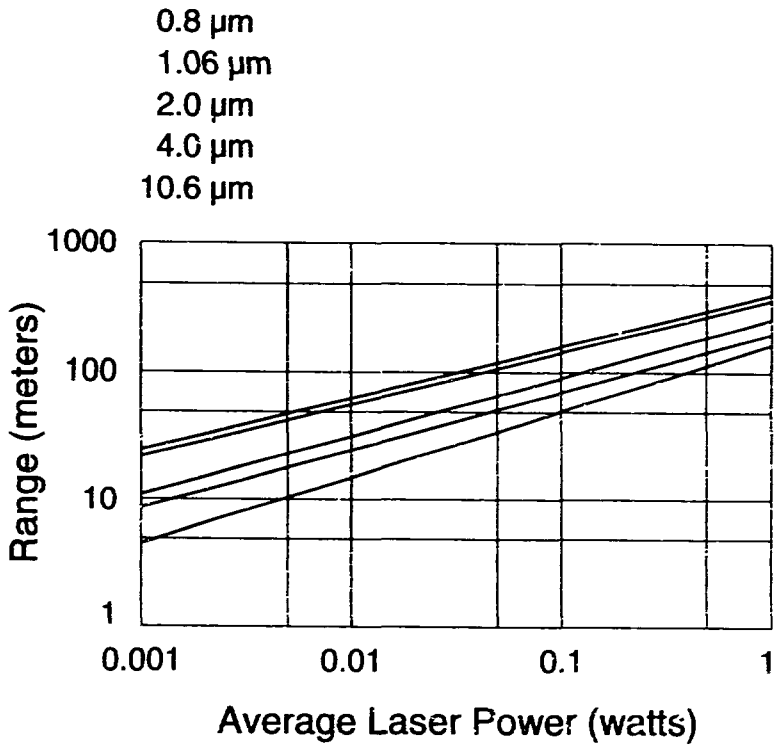


(a) CW



(b) PULSED

HETERODYNE DETECTION WAVELENGHT VARIATIONS (10mr IFOV)

The heterodyne detection performance for CW and pulse LADARs with a 10mr instantaneous-field-view (IFOV) is presented on this chart. The 10mr IFOV was selected based on detection requirements (see previous chart: PULSED LADAR BANDWIDTH AND IFOV DETERMINATION). For heterodyne detection, CO_2 LADAR (10.6 micrometers) performance dominates the performance of LADARs in the other wavebands. As IFOV is a major parameter in the SNR equation for heterodyne detection (see previous chart titled; LADAR SNR EQUATION DEVELOPMENT), the performance for a heterodyne LADAR with a smaller IFOV is presented on the next chart.

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HETERODYNE DETECTION WAVELENGTH VARIATIONS (10 mr IFOV)

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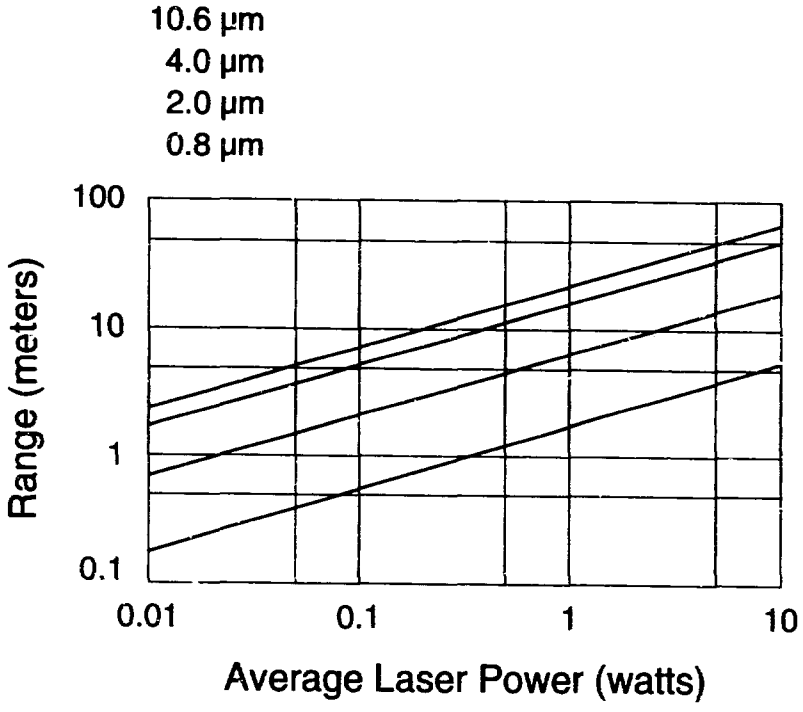
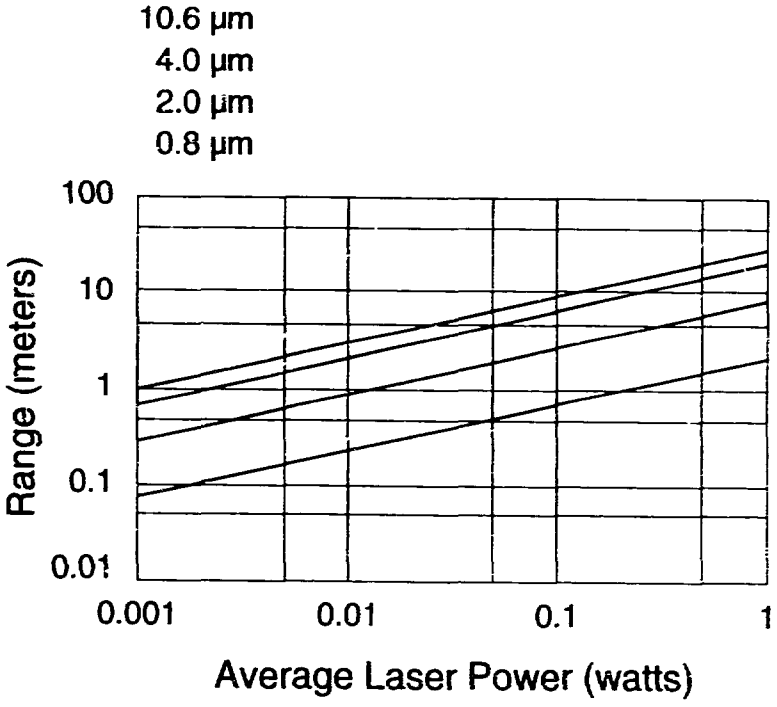


(a) CW



(b) PULSED

HETERODYNE DETECTION WAVELENGHT VARIATIONS (1mr IFOV)

Using a smaller IFOV, the performance improvement is significant; however, other sensor items would have to be changed to accommodate a smaller IFOV and maintain required performance. Also, note that CO_2 LADAR (10.6 micrometers) performance still dominates the performance of LADARs in the other wavebands.

LADARS FOR WARHEAD FUZING

HETERODYNE DETECTION WAVELENGTH VARIATIONS (1 mr IFOV)

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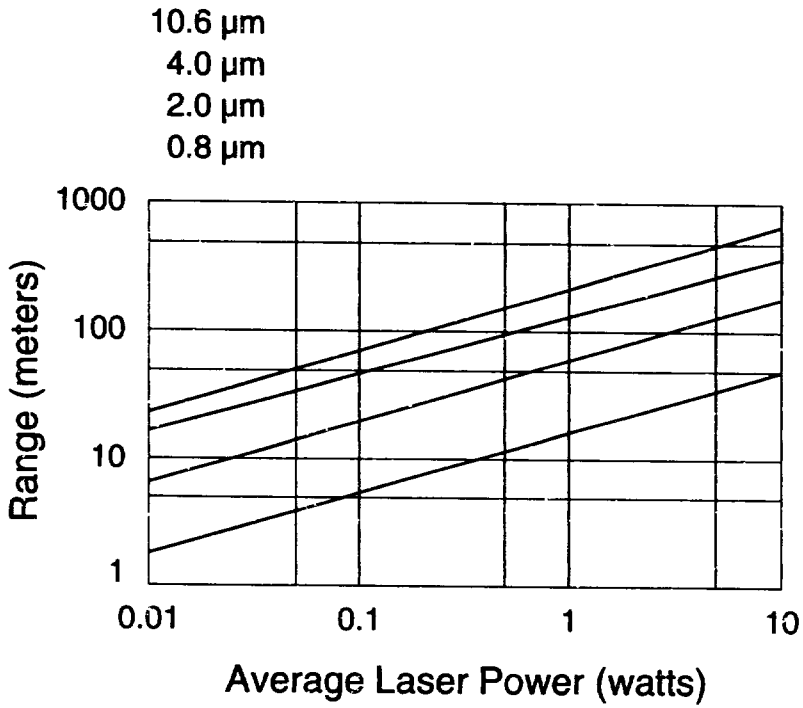
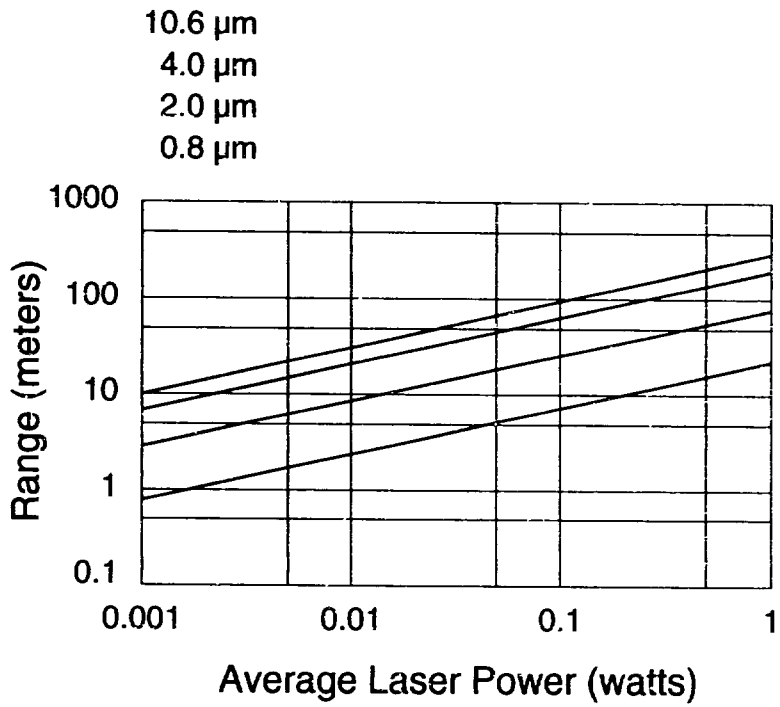


(a) CW



(b) PULSED

HETERODYNE/DIRECT DETECTION COMPARISON (CW)

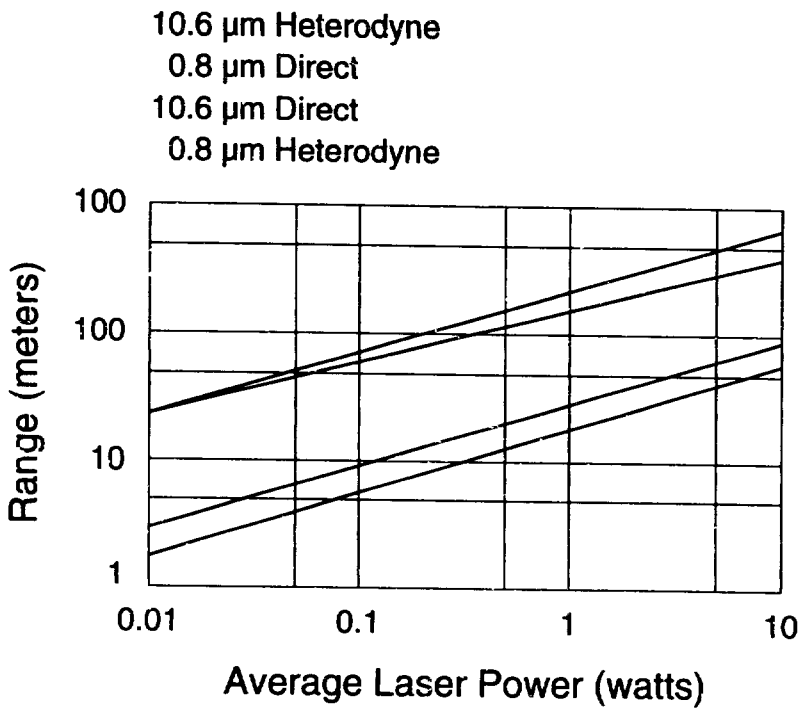
This chart presents a performance comparison of detection techniques for LADARs using continuous-wave (CW) waveforms. The comparison is presented for the two IFOVs shown on the previous chart for heterodyne detection. Only, the LADAR wavelengths that dominated the respective detection techniques are shown. For the smaller (1mr) IFOV the performance of heterodyne 10.6 micrometer and direct 0.8 micrometer LADAR are approximately equal over the range of interest. As the IFOV is increased, direct detection proves superior.

LADARS FOR WARHEAD FUZING

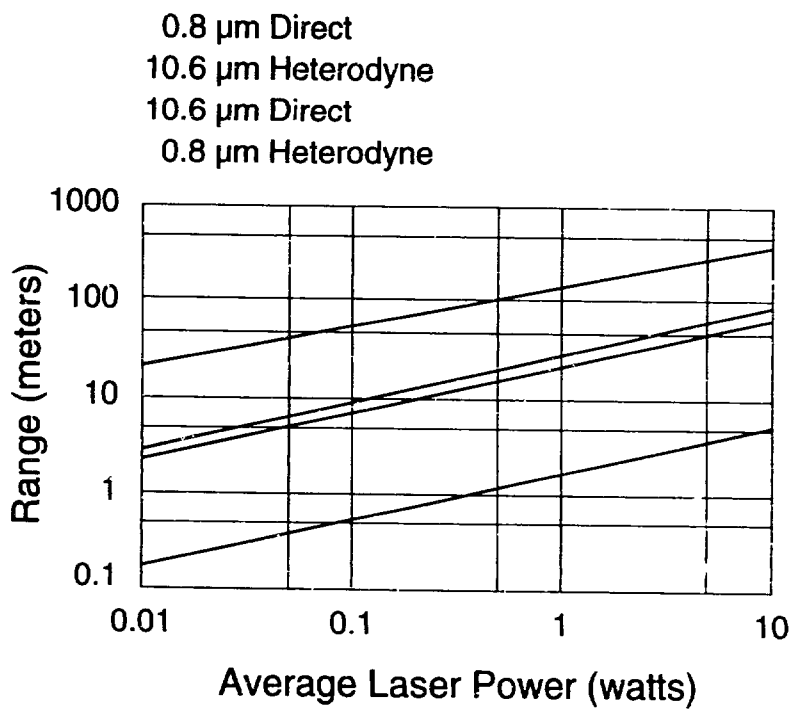
HETERODYNE—DIRECT DETECTION COMPARISON (CW)

ERIM

93-21344 R1



(a) 1 mr IFOV



(b) 10 mr IFOV

HETERODYNE/DIRECT DETECTION COMPARISON (PULSED)

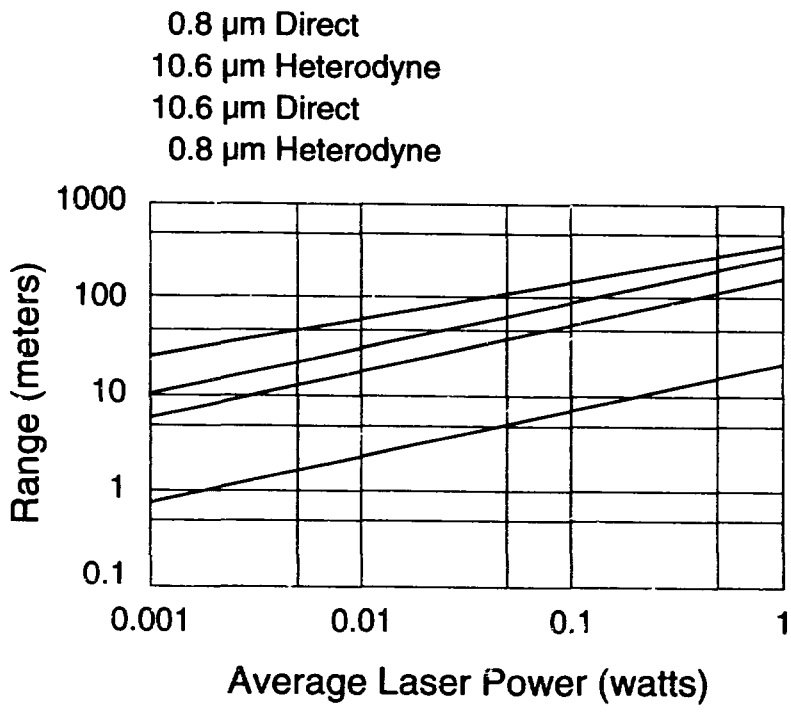
Similarily, this chart presents a performance comparison of detection techniques for LADARs using pulsed waveforms. For pulsed LADARs, the heterodyne 0.8 micrometer LADAR appears to fail as a potential candidate warhead fuze candidate.

LADARS FOR WARHEAD FUZING

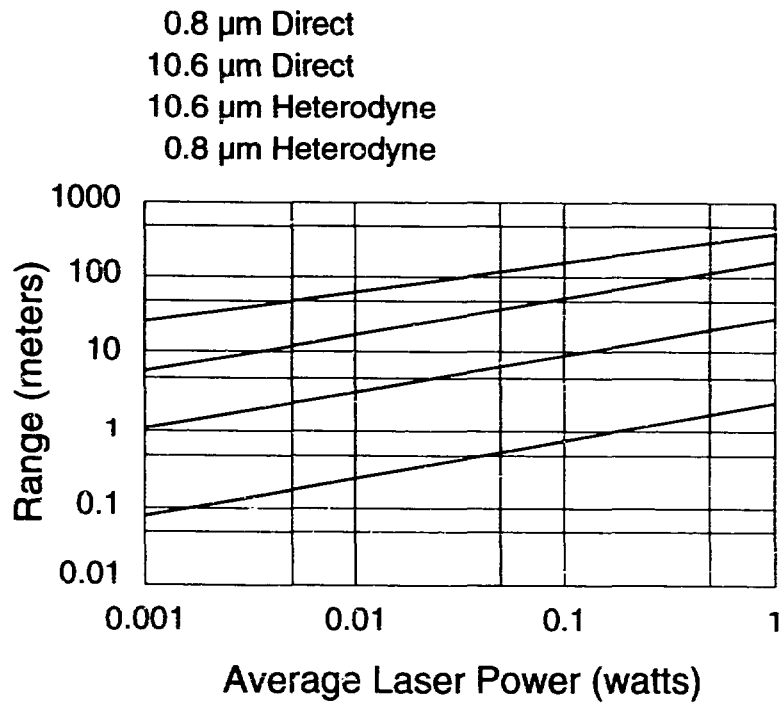
HETERODYNE—DIRECT DETECTION COMPARISON (PULSED)

ERIM

93-21345 R1



(a) 1 mr IFOV



(b) 10 mr IFOV

PULSED/CW COMPARISON

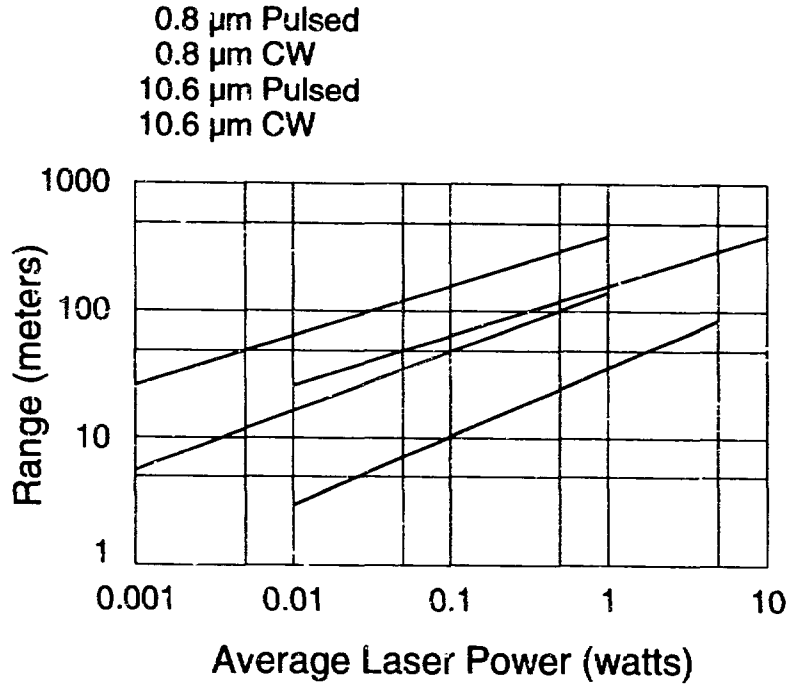
This chart presents a performance comparison of pulsed and CW waveforms. The comparison is presented for direct and heterodyne detection (1mr IFOV). Again, only, the LADAR wavelengths that dominated the respective detection techniques are shown. As in previous charts, the 0.8 micrometer LADAR dominates for direct detection and the 10.6 micrometer LADAR dominates for heterodyne detection.

LADARS FOR WARHEAD FUZING

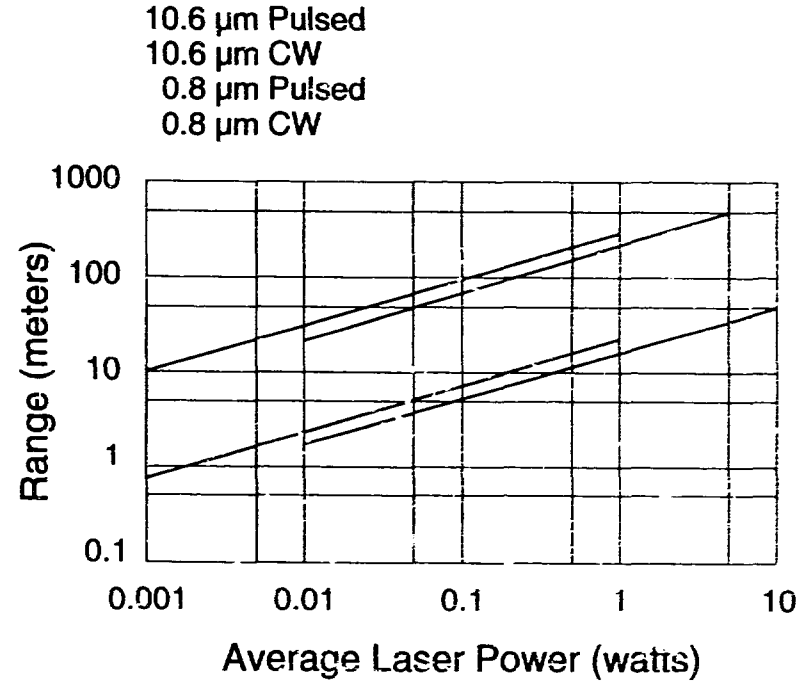
PULSED-CW COMPARISON

ERIM

93-21346 R1



(a) DIRECT



(b) HETERODYNE (1 mr IFOV)

SNR ANALYSIS CONCLUSIONS

The Singal-to-Noise Ratio (SNR) analysis lead to the conclusions shown. The survey proceeds to a more detailed review with the number of candidate LADARs reduced to six.

SNR ANALYSIS CONCLUSIONS

ERIM
93-21299

- For direct detection, CW and Pulsed;

  GaAs (8.0μm) and NdYAG (1.06μm) dominate

- For Heterodyne detection, CW and Pulsed;

  CO_2 (10.6μm) dominates

- Continue survey with above

TECHNOLOGY ASSESSMENT

A brief review of major components for the candidate LADARs selected from the SNR analysis follows. The review will address the source (laser) and detector combinations, scanning concepts and scan mechanisms, processors considerations, and observations on LADAR technology as a whole.

LADARS FOR WARHEAD FUZING

TECHNOLOGY ASSESSMENT

ERIM

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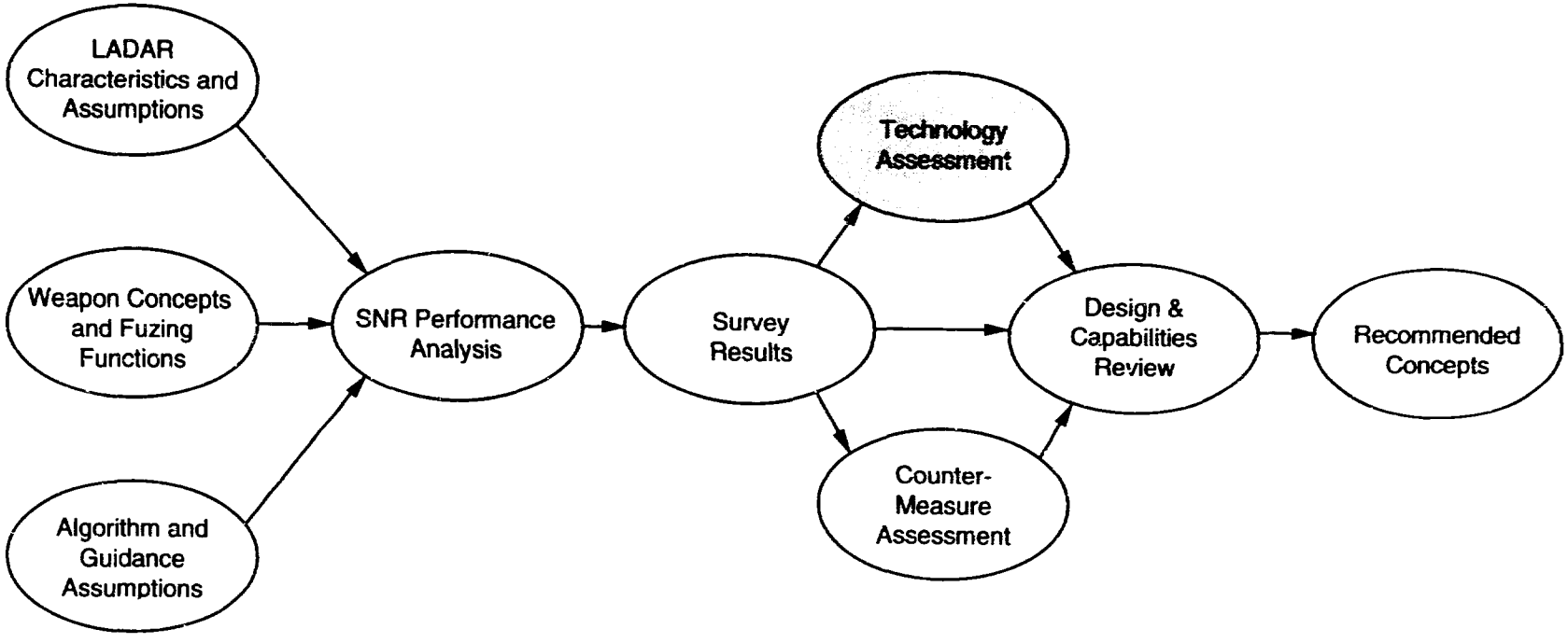

SOURCE-DETECTOR COMPARISONS

This chart addresses the technology availability or limitations of available source (laser) - detector combinations of the remaining candidate LADAR concepts. The symbols used are as follows: GaAs, Galium Arsenide; NdYAG, Neodymium-YAG or "YAG"; SiAPD, Silicon Avalanche Photo Diode; HgCdTe, Mercury-Cadimum-Telluride "Merc-cad-telluride". For packaging considerations, the size of potential LADARs as a relative measure with the smallest unit equated to 1.0. An absolute size or volume estimate would require a detailed point design; however, a GaAs laser can be considered less than one cubic centimeter in size. To show a power requirement comparison, the relative efficiency measured as optical power out to electrical power in (based on manufacturer claims) of the lasers sources is shown with the most efficient, CW-GaAs, being set equal to 1.0. The GaAs laser operating in a CW mode can have power efficiencie as high as 30%.

Technology limitations based on the operating parameters derrived in the SNR analysis section are addressed in the remarks column. In general, LADAR component technology is readily available; however, available GaAs technology limits are reached in the area of generating the pulses at a rate sufficient to satisify the short fuzing ranges (and related ranging toleraces) for high speed weapons. YAG lasers can be pulsed at the desired PRF; however, most YAGs are power rated at 1.0kHz, and at the PRF required for a LADAR fuze a YAG will provide much less peak power than at the peak power specified at 1.0 kHz.

The source lasers are listed in order of increasing complexity, and for the purposes of this survey complexity is directly related to cost.

LADARS FOR WARHEAD FUZING

SOURCE-DETECTOR COMPARISONS

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Source Laser	Recommended Detector	Relative Size	Relative Efficiency	Remarks
GaAs Diode (direct)				0.8 μm–0.9 μm band
CW	SiAPD	1.0	1.0	Requires more power than pulsed
Pulsed	SiAPD	1.0	0.4	Near tech. limit for PRF, i.e., required samples; slightly more complex
NdYAG (direct)				Single wavelength 1.06 μm
CW	SiAPD	2.0	0.4	
Pulsed	SiAPD	2.0	0.3	For Required PRF, peak power much less than 1 kH_z peak power (conventional spec)
CO_2 (heterodyne)				cryogenic cooled detectors; possible storage issues
CW	HgCdTe	5.0+	0.1	
Pulsed	HgCdTe	5.0+	0.2	Required pulsed-width near tech. limit; possible storage issues; requires second laser for optical local oscillator

Note: Sources listed in order of increasing complexity

STARE OR SCAN IMAGING

This chart summarizes the techniques for collecting a LADAR image.

A staring sensor would illuminate the entire FOV and have a detector for each required pixel. In order to maintain the same SNR, a staring sensor requires a laser power increase by the square root of the number of detectors. In addition, the detector array requires that each detector have its own signal processing electronics to measure pulse arrival time. The laser PRF for a pulse system is reduced to the frame rate rather than the pixel rate.

A one dimensional scanner uses a linear array of detectors which is scanned in one dimension. (A linear array of detectors is used in the Common Mod FLIR.) As above, the linear array requires the laser power to increase by the square root of the number of detectors to maintain the same performance. The number of signal processing electronics is equal to the number of detectors. The PRF of a pulse laser system is reduced to the number detectors times the frame rate instead of the pixel rate.

A two dimensional scanner requires only a single detector and signal processing electronic unit. There is no additional laser power required, but a two dimensional scanner does require two scan units to produce an image.

The maturity of the technology involved, the power required, and simplicity indicate that a scan (one or two dimensional) imaging sensor would be the best choice for an Aimpoint Fuzing Sensor.

STARE OR SCAN IMAGING

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93-21824

- Stare mode
  - Number of detectors equal number of pixels in frame
  - Laser power increases by sq. root of number of detectors
  - N signal processing circuits required for N detectors
- One-dimensional scan
  - Linear array of L detectors
  - Laser power increases by sq. root of number of detectors
  - L signal processing circuits required for L detectors
- Two-dimensional scan
  - Single detector
  - Dual scan mechanisms
  - Single signal processing circuit
- Technology maturity, power requirements, and simplicity suggest scan imaging

SCAN OPTIONS

This viewgraph presents the three scan group options available to the sensor designer. Counter rotating wedges were not considered because of the difficulty in generating a raster type of scan.

Acousto-optic scanners use an ultrasonic wave to deflect a light beam in a solid media. Acousto-optic scanners have no moving parts, modest power requirements, and can be scanned rapidly. They are however limited to scanning relatively small angles, but the scan angles should be suitable for this application.

Holographic scanners use a single low inertia moving part to produce scanning in two dimensions. They have a relatively low power requirement, modest scan rates, and can cover small or large deflection angles.

Scanners based on moving mirrors represent the most mature technology. Scan mirrors have moderate inertia, power requirements, and scan rates.

SCAN OPTIONS

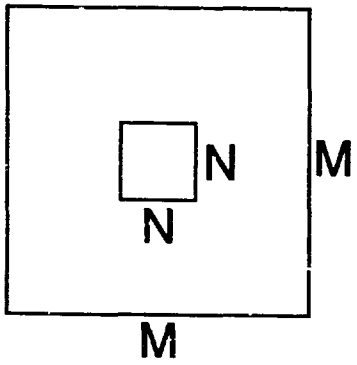
- Acousto-optic
  - No moving parts
  - Small angles
  - Low power requirements
  - Rapid scanning possible
- Holographic
  - Singular, low inertia moving parts
  - Small or large angles
  - Low power requirement
  - Moderate scan rates
- Mirror(s)
  - Moderate inertia moving part(s)
  - Small or large angles
  - Moderate power required
  - Moderate scan rates

PROCESSOR ACCESSMENT

The size of the processor can be estimated from the number of mathematical operations that are required to make the decision as to where the aimpoint is located. Given the FOV dimensions in pixels, the data rate, and the template size, the number of integer operations required to determine the best aimpoint can be calculated. The number of operations will vary according to the ratio of template pixels to FOV pixels, but will peak when the number of template pixels is half the number pixels in the FOV. The approximation of 3 times n squared operations for template matching is a good estimate, and three additional operations to compare the computed results to the previous best match. The M - N locations squared gives the number of times the template matching must occur to cover the FOV. The number of frames per second is calculated from the square of the number of pixels in the FOV divided into 25000 pixels per second data rate of the study. The product of the frames per second, and the number of integer operations per frame provides the number of integer operations per second. No allowance has been made for reduction of the computational burden due to information carried over from the previous frame.

Even with the worst case scenario presented, the computation rate is only 17 million integer calculations per second which doesn't even strain the computational abilities of current off the shelf CPU's and DSP's.

PROCESSOR ASSESSMENT



M = Size of FOV in Pixels
N = Size of Template in Pixels

For each location of the template there will be $3N^2$ operations to compute the goodness of a match and 3 operations to compare to previous match

There are $(M - N)^2$ locations to check the template giving $3(N^2 + 1)(M - N)^2$ operators per frame

FOV in Pixels	Template Size in Pixels	Frames Per Second Based on 25,000 Pixels/Second	Number of Integer Operations	Number of Integer Operations Per Second
12	6	174	4.0×10^3	0.7×10^6
30	15	28	1.5×10^5	4×10^6
60	30	7	2.4×10^6	17×10^6

TECHNOLOGY ASSESSMENT SUMMARY

The assessment summary concludes:

1) LADAR technology is sufficiently mature to support a low risk development program as sources and detectors in the wavebands that show the most promise are virtually catalog items,

2) The production to cost issue of high power lasers is an issue yet to be addressed by industry; however, the issue is a tractable problem that can be solved within exiting technology as low power lasers (CD players, grocery store scanners, etc.) are readily available at very low cost , and

3) Based on the fuzing requirements use in this survey, processing requirements are well within processor state-of-the-art of current processing technology. There isn't any single processor and/or algorithm that would be selected as being superior at the level of the study.

TECHNOLOGY ASSESSMENT SUMMARY

- Technology sufficently mature for low risk development
- Production to cost a solvable issue
- Any of a number of processors and algorithms could be used

COUNTERMEASURE ASSESSMENT

It is important to address the countermeasures as early as possible in concept development as potential countermeasures may well influence the design selection. A tailored countermeasure vulnerability assessment is present in this portion of the survey.

LADARS FOR WARHEAD FUZING

COUNTER-MEASURE ASSESSMENT

ERIM

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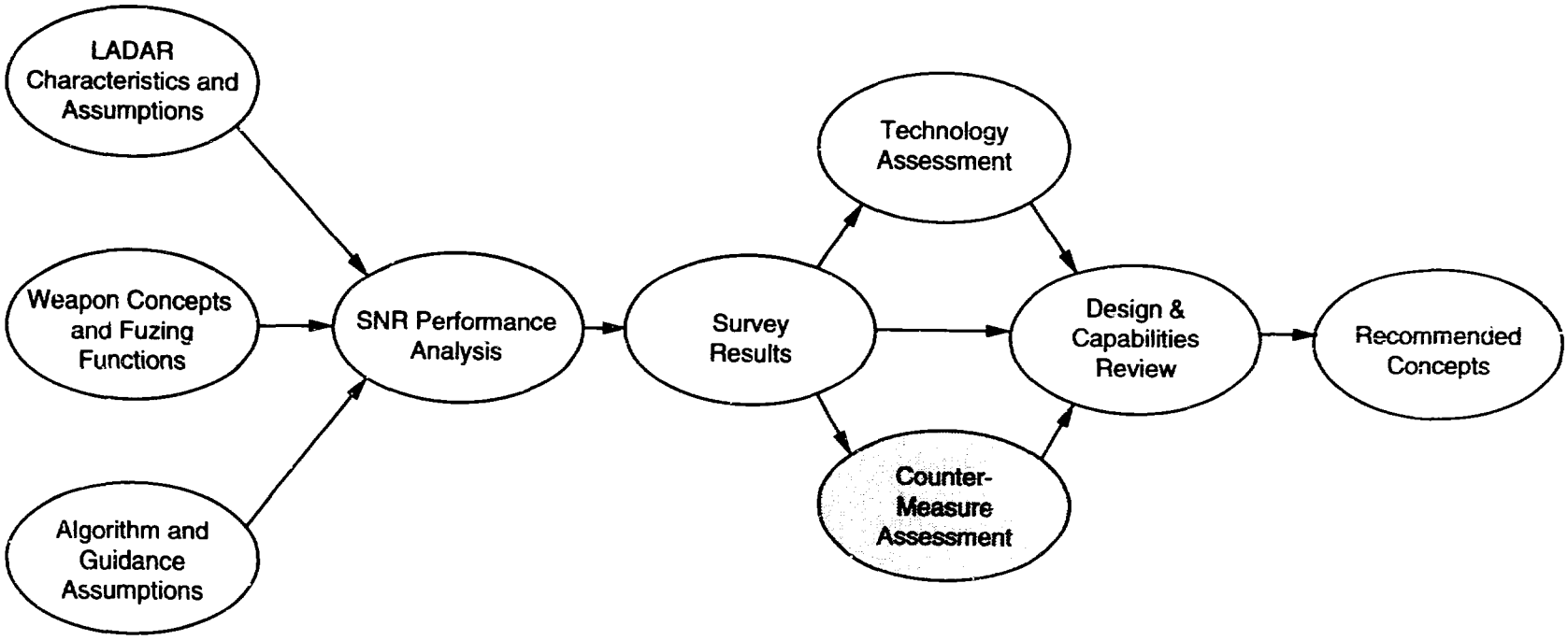

COUNTERMEASURES

This chart shows the countermeasures that will be addressed in the countermeasure assessment. With the exception of "decoys/deception", the list is common to all sensors. Because the LADARs being considered in this survey will operate on three-dimensional information, only three-dimensional models similar in size and geometry to a target would be useful as decoys. For this countermeasure assessment, it is important to remember that the LADAR is the fuzing sensor only; therefore, a weapon could be countered by CM techniques against other sensors in the system.

COUNTERMEASURES

- Signature Alteration
  - Nets
  - Foliage, etc.
- Decoys / Deception

  3-dimentional mockups
- Obscurants
  - Smoke
  - Dust
- Active
  - Power
  - Deception

CM VULNERABILITY

This chart displays the classical definition of the vulnerability of a system to countermeasures. These definitions have been used to assess potential countermeasures to the LADAR fuzes.

LADARS FOR
WARHEAD FUZING

CM VULNERABILITY

ERIM

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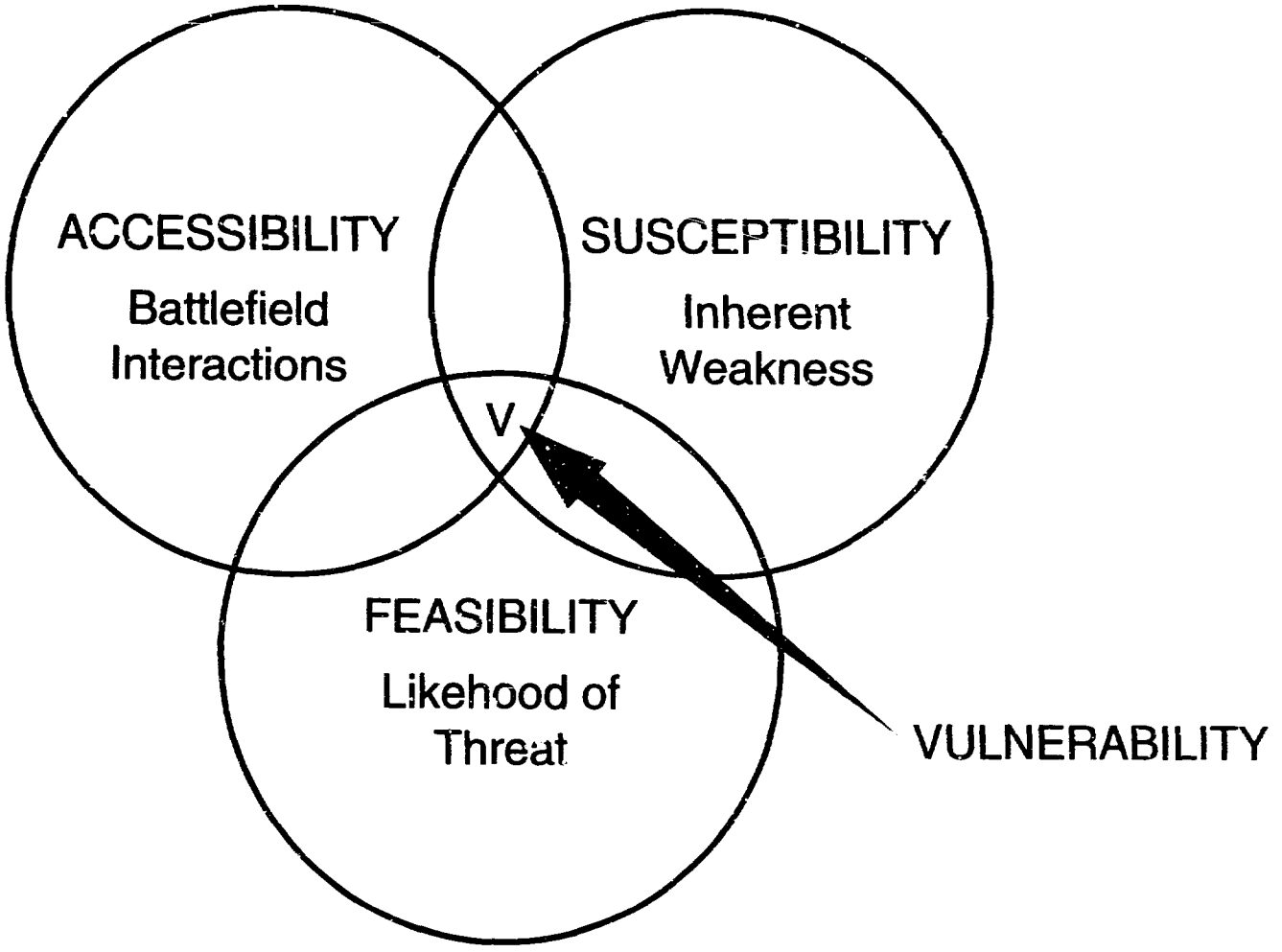

CM ASSESSMENT APPROACH

The approach to the survey countermeasure assessment is shown on this chart. As stated, for each category of countermeasure previously identified, i.e., signature alteration, decoys/deception, obscurants, and active countermeasures, this survey addresses the vulnerability factors as follows:

1. Susceptibility of the LADAR to the identified CM and possible Counter-Counter Measures (CCMs) that could be incorporated to harden the LADAR in question;

2. Suggest how the identified CM would have to be deployed to be accessable to the LADAR; and

3. Estimate the technical complexity of the proposed CM to address feasibility.

If differences in the candidate LADARS, e.g., wavelength, modes, etc., suggest different vulnerability, these differences are noted in the category discussions.

CM ASSESSMENT APPROACH

- For each category of countermeasure
  - Identify susceptibility and possible CCM
  - Suggest CM deployment for accessibility
  - Estimate CM technical complexity for feasibility
- Identify wavelength/mode differences where applicable

SIGNATURE ALTERATION

Nets, foliage, and sandbags, items in use, are characteristic of this category of countermeasure, and without developing signal processing techniques to counter these countermeasures a LADAR fuze could be highly susceptible to these items as described on this chart. As a LADAR fuze uses three dimensional information altering the viewed shape can create a situation in which the fuze would function on the return signals from the net and items under the net. Foliage or sandbags could alter the signature to degrade aimpoint determination, e.g., from our aimpoint priority list the fuze may not be able to "read" a key feature and function on the target centroid. For these countermeasures to be most effective they should be deployed as suggested on this chart.

Fortunately, these countermeasures are not new and a variety of signal processing techniques, that reduce the LADAR's susceptibility to these countermeasures, have been developed by several LADAR developers. The following two charts show imagery examples of one ERIM developed and patented signal processing technique "Range Dispersion (RD) Sensing" that would be useful against this category of countermeasure.

SIGNATURE ALTERATION

- Susceptibility

  Nets: High probability of fuzing on net, may miss target
  (Signal processing can improve)

  Foliage: Moderate probable fuze on foliage (if dense), or
  degrade aimpoint selection
  (Signal processing can improve)

- Accessibility

  Nets, ideally much larger than the target should be deployed at a height above the target that renders the warhead ineffective.

  Foliage, sandbags, etc. should be placed at critical key feature positions to degrade or mask target signature.

- Feasibility: In use

IMAGE THROUGH NET

The photos on this chart show an ERIM experiment using RD sensing. The tank is a commercial plastic model which was covered by a "net" with 50% transmissivity. As can be seen in the final photograph, a signature is very evident and centroid fuzing could be accomplished.

LADARS FOR
WARHEAD FUZING

IMAGE THROUGH NET

ERIM

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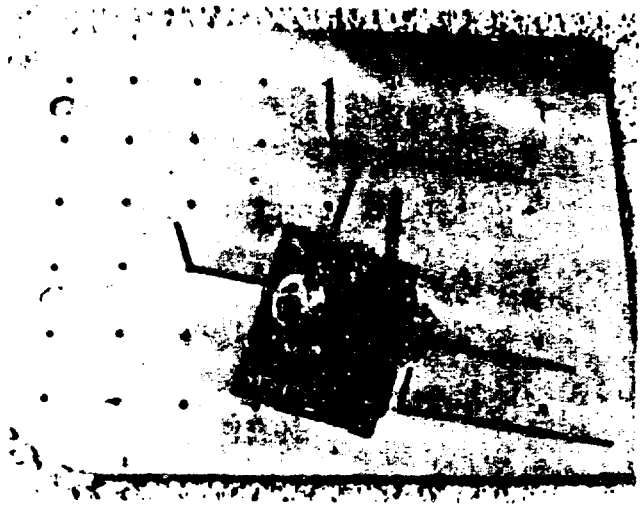
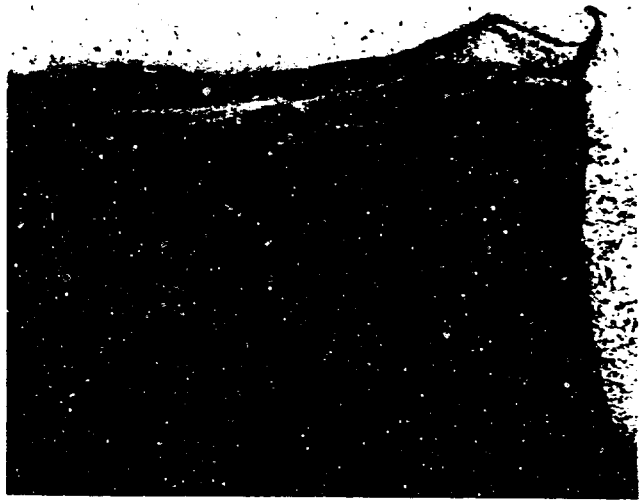


88-12065-17A



93-12065-25A

88-12066-3A

STAFF RD TESTS

An ERIM sensor employing Range Dispersion Sensing was tested with Aerojet Ordinance in 1989. In these tests the RD sensor was attached to an articulating arm that was moved near horizontally over a full size tank to emulate the flight path of a STAFF muntion. The images shown are direct output images, no data reduction or post processing, from the sensor as recorded on a strip-chart. The first image is of a bare tank with folliage to the side (top of the image). The image is very sufficient for an algorithm to select virtually any desired aimpoint. The stripe at the very top of the image is a noise strip created when the sensor was "looking" at or above the horizon and no signal was returned. In the second image, the tank was densely covered with tree branches. It is highly probable that there is a sufficent tank signature in this image for an algorithm to select a specific aimpoint.

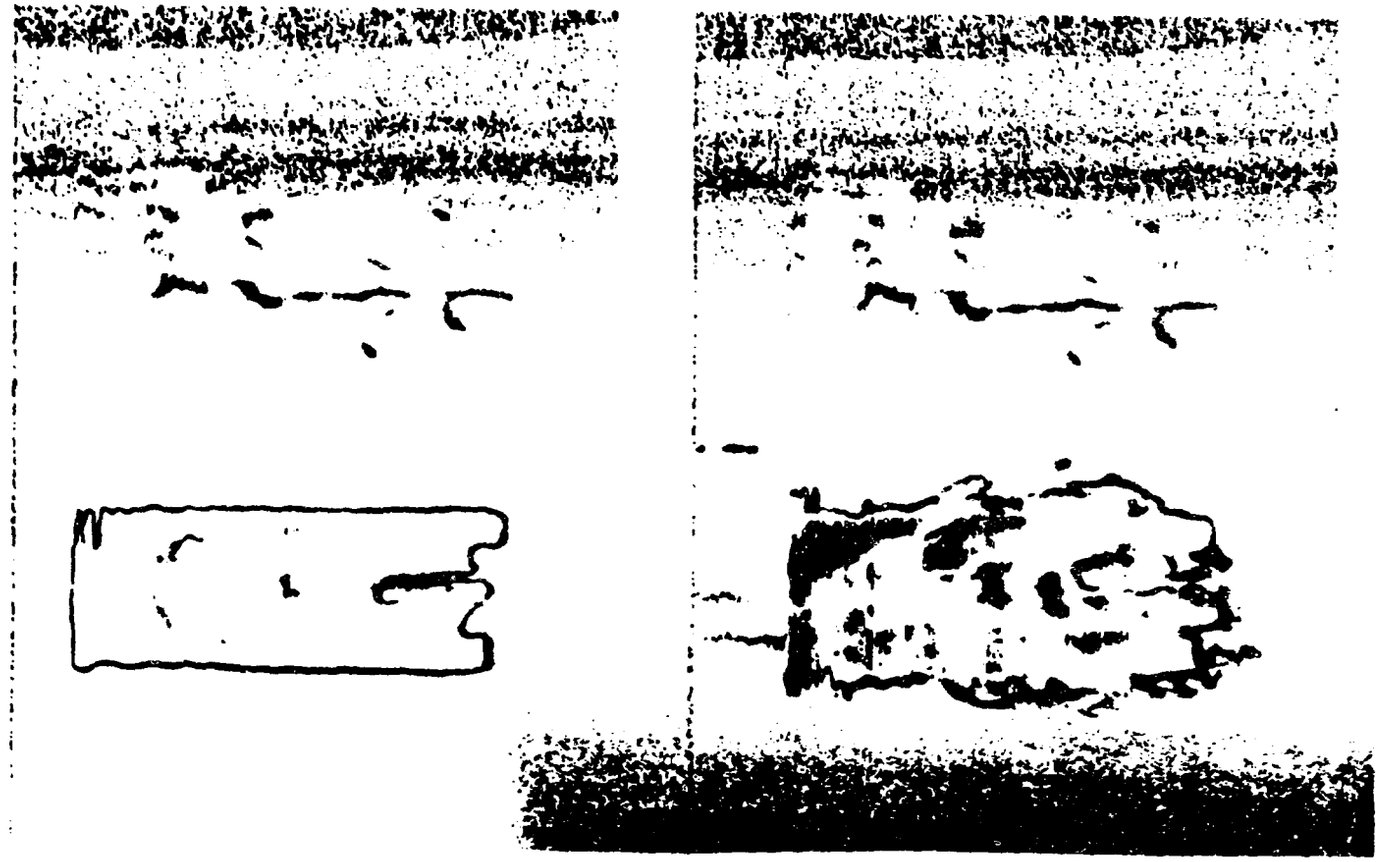
This and the previous chart are singular examples of what signal processing can do to reduce susceptibility to signature altering countermeasures.

LADARS FOR
WARHEAD FUZING

STAFF RD TESTS

ERIM

93-21315



DECOYS

A LADAR fuze using three-dimensional information to select an aimpoint will be susceptible to a reasonably accurate three-dimensional decoy. The key element is that the decoy must be three dimensional; however, the quality of the decoy is actually moot. If the weapon was fired at and will pass within fuzing range it makes little difference if the LADAR fuze is "fooled" as the weapon has already been committed to the decoy. If in the future the LADAR would be the terminal guidance sensor for an autonomous sensor, a LADAR's ability to rapidly discriminate fine detail could be a useful tool against less than high quality three dimensional decoys. Then the issue would be one of logistics complexity rather than technical complexity.

DECOYS

- Susceptibility

  As the selected target is a decoy, the LADAR will fuze on the 3-dimensional decoy.

- Accessibility

  Decoy must be 3-dimensional

- Feasibility

  Logistics issue, not technically difficult

OBSCURANTS

Smoke and dust can degrade LADAR performance; however, at the short fuzing ranges considered in this survey the smoke and dust would have to be extremely dense. If the sensor used to guide the weapon to the target can see the target, the LADAR fuze should have no difficult selecting and firing on an aimpoint. A rule of thumb is if you can see the target the LADAR can see the target. Actually, a LADAR can see a target better than the human eye and CO_2 heterodyne sensors have demonstrated excellent haze penetrability. Continuous-wave wave forms should perform better than pulsed wave forms in obscurants as the scattering from the continuous return should cancel.

OBSCURANTS

- Susceptibility

  Smoke and dust can degrade aimpoint selection. CO_2 can be less susceptible.

- Accessibility

  At short fuzing range, need dense obscurants at target to mask target features.

- Feasibility

  In use

ACTIVE COUNTERMEASURES

LADARs like all other electronic sensors are susceptable to power and deception jamming; however, LADARs generally have a small receive beam and no "sidelobes"; therefore, LADARs are much less susceptable to jamming than radars as the jamming signal must be in the receive beam to be effective. A "YAG" sensor would be easier to jam as NdYAG lasers transmit a singular wavelength. GaAs and CO_2 lasers have a waveband in which to operate. The singular YAG wavelength issue would have to be addressed if several weapons (fuzes) were operating with close proximity as fratricide would be an issue.

Laser jamming remains in the development stage as power jamming would have to be virtually omni-directional, thus requiring very high power lasers which are not currently available. While several high classifed programs have investigated laser deception jamming, these type of laser jammers are technically complex and may never be practical.

ACTIVE CM

- Susceptibility

  Power jamming: Burnout detector or raise noise to mask target. (Burn-through probable if detector intact; Home on jam possible)

  Deception jamming: Create false returns to detonate warhead

- Accessibility

  Jamming signal in receive beam. Omni-directional jamming located on target. NdYAG singular wavelength eases power jamming requirements.

- Feasibility

  Omni-directional jamming with necessary power complex. Omni-directional deception jamming very complex.

DESIGN AND CAPABILITIES REVIEW

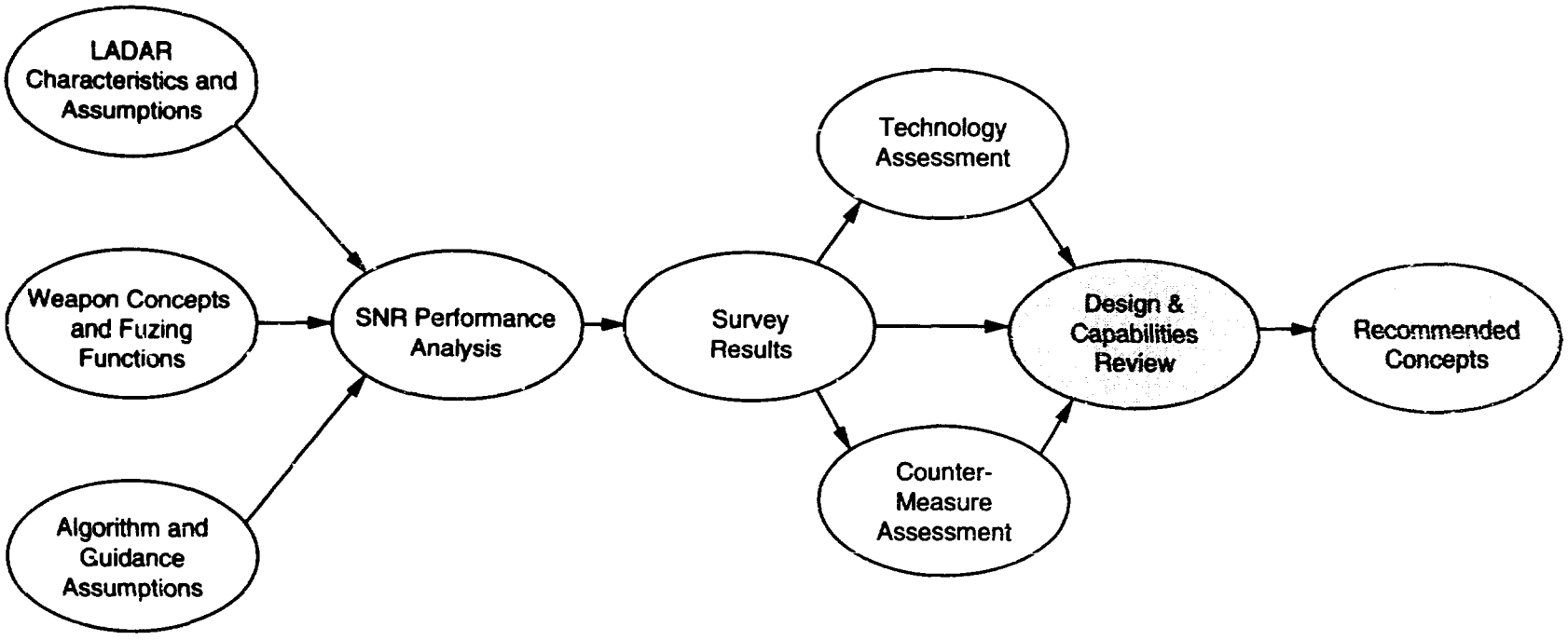
Following is a design considerations discussion and review of the candidate LADAR fuzes selected from the SNR analysis. The discussion and review are based initiating fuzing requirements, the technology assessment, and ERIM design experience. Following a review of each of the selected concepts, general conclusions about using LADARs are presented, as well as recommended fuze concepts and a suggested program approach to develop a prototype fuze.

LADARS FOR WARHEAD FUZING

FINAL REVIEW AND RECOMMENDATION

ERIM

93-21340 R1



GaAs DIRECT DETECTION DESIGN REVIEW

The source wavelength matches the peak of the detector responsivity which results in maximum performance. The GaAs laser diode is an efficient means of converting electrical energy to optical energy, and has the smallest volume of any laser. GaAs laser diodes can be specified with an optical output emission in the spectral region from 0.8 μm to 0.9 μm. This spectral diversity coupled with narrow band interference filters provide a number of distinct spectral bands which reduces the potential for fratricide and makes counter measures significantly more difficult. Of the technologies examined, the GaAs laser diode and the Si APD detector are the most mature. The system design does not require optics that have diffraction limited performance nor is the alignment as critical as with a coherent or heterodyne sensor.

Modulated CW provides potential expansion to higher data rates if the detailed system design requires more pixels per second. Other modulation waveforms could be used to improve the efficiency of the system and simultaneously provide additional information that can be used to eliminate the ambiguity interval. "Zero" range fuzing can be accomplished directly without special signal processing.

Pulse modulated systems may be limited by the availability of laser diodes that can provide a high enough data rate or PRF for the specified pixel rate. GaAs laser diodes can produce shorter pulses by narrowing the current drive pulse, but peak powers can not be increased without the potential for damage. "Zero" range fuzing with a pulse that is longer than the fuzing range is difficult to handle.

GaAs-DIRECT DETECTION DESIGN REVIEW

- General
  - Detector response peaks at source wavelength
  - Most efficient source
  - Smallest volume
  - Multiple source wavelengths possible
  - Most mature technology
  - Diffraction limited optics not required
  - Simple opto-mechanical alignment
- CW
  - Higher data rates possible
  - Alternate waveforms can improve efficiency and eliminate ambiguity
  - "Zero" range fuzing
- Pulse
  - High data rates limited by PRF technology limits
  - Shorter pulses possible
  - "Zero" range fuzing a signal processing issue

Si APD's are still the best detector for this spectral region, but the responsivity is only 20 % of the peak value which reduces the performance compared to a GaAs system. The Nd:YAG source is the second most efficient when it comes to electrical to optical power conversion providing one uses laser diodes as the source. If an arc, flash, or filament lamp is used, the efficiency is orders of magnitude less. A Nd:YAG system requires more volume than a GaAs system because of the extra space required for the laser rod, cavity, and modulator. The wavelength of the source is fixed by the crystal which could present a problem with fratricide and countermeasures. The technology is as mature as GaAs if diode pumping is used and more mature if other pump sources are employed. As with GaAs the design does not require diffraction limited optics, and alignment is simpler than for a coherent or heterodyne system.

Modulated CW provides potential expansion to higher data rates if the detailed system design requires more pixels per second. Other modulation waveforms could be used to improve the efficiency of the system and simultaneously provide additional information that can be used to eliminate the ambiguity interval. "Zero" range fuzing can be accomplished directly without special signal processing. The external modulator required for modulated CW operation results in the electrical conversion efficiency of the system to drop by a factor of 2 because only lossy modulators are available.

Pulse modulated systems are limited by the availability of lasers that can provide a high enough Q-switch data rate or PRF for the specified pixel rate. Another factor that must be considered in the specification of the source is that the peak power available from a Q-switched Nd:YAG laser is usually specified for PRF's of less than 1 kHz, and the available peak power will be reduced if the PRF is increased beyond the specified PRF. Q-switched Nd:YAG lasers can produce shorter pulses but only by about a factor of 2 than those used in the study. (Mode locked Q-switched operation could produce shorter pulses, but the addition of a mode locker, and a lengthened cavity make it unrealistic at this time.) "Zero" range fuzing with a pulse that is longer than the fuzing range is difficult to handle.

Nd:YAG-DIRECT DETECTION DESIGN REVIEW

ERIM
93-21828

- General
  - Detector spectral response 20% of peak
  - Second most efficient (assuming diode pumping)
  - Volume larger due to extra cavity and modulator
  - Single source wavelength
  - Mature technology
  - Diffraction limited optics not required
  - More complicated opto-mechanical alignment
- CW
  - Higher data rates possible
  - Alternate waveforms can improve efficiency and eliminate ambiguity
  - "Zero" range fuzing
  - Modulation reduces available power by a factor of 2
- Pulse
  - Data rates limited by maximum Q-switch frequency
  - Can decrease pulse width only by a factor of 2
  - "Zero" range fuzing a signal processing issue

CO_2 HETERODYNE DETECTION DESIGN REVIEW

The electrical to optical power conversion efficiency is lower than GaAs systems. The physical size of the laser will be larger than either the GaAs or Nd:YAG systems. The very narrow effective optical bandwidth of a heterodyne system will reduce fratricide and compound the countermeasure problem. Diffraction limited optics are required as the optical wavefronts must be matched at the receiver for efficient operation of the sensor. Similarly, alignment and opto-mechanical design considerations will be much more stringent. Speckle which will produce "holes" in the data must be handled in data processing which will increase the computational load on the processor which will require more power and possibly more hardware.

Modulated CW provides potential expansion to higher data rates if the detailed system design requires more pixels per second. Other modulation waveforms could be used to improve the efficiency of the system and simultaneously provide additional information that can be used to eliminate the ambiguity interval. "Zero" range fuzing can be accomplished directly without special signal processing. The external modulator required for modulated CW operation results in the electrical conversion efficiency of the system to drop by a factor of 2 because only lossy modulators are available.

Pulse modulated systems may be limited by the availability of lasers that can provide a high enough Q-switch data rate or PRF for the specified pixel rate. Another factor that must be considered in the specification of the source is that the peak power available from a Q-switched Nd:YAG laser is usually specified for PRF's of less than 10 kHz, and the available peak power will be reduced if the PRF is increased beyond the specified PRF. Q-switched CO_2 lasers are limited to pulse widths of approximately 20 nanoseconds. (Mode locked Q-switched operation could produce shorter pulses, but the addition of a mode locker, and a lengthened cavity make it unrealistic at this time.) "Zero" range fuzing with a pulse that is longer than the fuzing range is difficult to handle.

CO_2-HETERODYNE DETECTION DESIGN REVIEW

ERIM
93-21829

- General
  - Lower efficiency
  - Larger volume
  - Heterodyne gives effect of multiple wavelength for fratricide and CM
  - Diffraction limited optics required
  - Critical opto-mechanical alignment
  - Speckle must be handled in data processing
- CW
  - Higher data rates possible
  - Alternate waveforms can improve efficiency
  - "Zero" range fuzing
  - Modulation reduces available laser power by a factor of 2
- Pulse
  - Data rates limited by maximum Q-switch rate
  - 20 ns near minimum pulse width limit
  - "Zero" range fuzing a signal processing issue

CAPABILITIES SUMMARY

Packaging considerations put GaAs on the top of the list with the smallest volume and the lowest power requirements. The Nd:YAG follows a close second with slightly larger volume and power requirements. The CO_2 system is feasible, but due to larger volume, increased power, and much tighter manufacturing and alignment requirements is considered to be less practical.

Performance considerations favor a modulated CW system as they should be less susceptible to countermeasures because the modulation frequency would be interpreted as either an unmodulated signal, or something with an unrealistically high PRF. The modulated CW system is less susceptible to smoke/haze than pulsed systems because the returns from an aerosol tend to cancel each other where a pulse system must make a decision as to which part of the return signal is the target when there could be multiple returns from the smoke/haze, and the background. Pulsed systems are more energy efficient, but fuzing at ranges shorter than the pulse width are an unresolved issue. If the platform performance is reduced by using a lower velocity or narrowing the maneuver window, the data rate would be lowered, and the pulsed systems energy efficiency would be more favored. Heterodyne systems have speckle which will produce "holes" in the data that must be handled in data processing. The additional data processing requirement increases the computational load on the processor and will require more power and possibly more hardware. Addressing speckle will definitely add another layer to the detection and aimpoint algorithms.

CAPABILITIES SUMMARY

- Packing considerations
  - GaAs, most size and power efficient
  - NdYAG, slightly larger and slightly less efficient
  - CO_2 feasible, but much less practicable
- Performance considerations
  - CW could be less susceptible to smoke/haze
  - Pulsed is more energy efficient, but "zero" range fuzing is an issue
  - Constrained vehicle performance, i.e., velocity, maneuverability favors pulsed
  - Heterodyne detection requires additional processing

RECOMMENDATIONS

The aimpoint fuzing sensors listed in order of highest to lowest potential are:

GaAs Modulated CW

GaAs Pulsed

Nd:YAG Modulated CW

Nd:YAG Pulsed

Possible, but not highly recommended aimpoint fuzing sensors are:

CO_2 Heterodyne Modulated CW

CO_2 Heterodyne Pulsed

RECOMMENDATIONS

- High potential
  - GaAs, CW
  - GaAs, pulsed
  - NdYAG, CW
  - NdYAG, pulsed
- Possible
  - CO_2, heterodyne, CW
  - CO_2, heterodyne, pulsed

DEMONSTRATION PLAN

This chart presents a recommend plan for a competitive development to demonstrate the potential of LADARs for fuzing.

First, the requirements should be stated at the system level,i.e., specify the job to be done, where it is to be done, under what conditions, and what time frame (technology availability).

Second, provide system level guidelines to constrain the design to practical applications. To avoid conflicting and difficult to prove claims of performance, the program should require the demonstration consist of an optical train built to size and production quality lens otherwise it would be virtully impossible to evaluate concepts as potential production systems. The processor and electronics can be of a size that minimizes the program cost as the miniturization of electronics is well understood (but expensive) and will not be an issue in evaluating the concept as a production system.

Third, since the suggested program is a concept development program multiple concepts and contractors should be considered. This survey identified several LADAR fuze concepts that could be practical LADAR fuzes. Final requirements and insights of the designers may well produce more that one viable concept that will require testing to validate and compare. A demonstration program could be accomplished within 18 months with time for government controlled, side-by-side testing and comparison. As the program would be pursuing technical ideas not a low cost contract, a technical competition where the value of the contract(s) is fixed and contractors are asked for their ideas within that contract value. This ensures the competition is technically driven not contract cost driven. To minimize the time to continue the development of a LADAR fuze, the program could have an option for the prototype develop of the concept. The option would save the contract, RFP, evaluation, negotiation, etc time during which no technical work is being done and key personnel are reassigned to other projects.

DEMONSTRATION PLAN

- System level requirements
  - Minimum functions to be performed
  - Scenarios
    - Environment
    - CMs and battlefield considerations
- Practical design and demonstration
  - Limits on fuze parameters, e.g., size, power available, location, etc.
  - Optical train to size and production quality lens
  - Require realistic time lines for collection and processing
  - Static, full-scale-target Government tests
- Multiple concepts / contractors
  - 18 months 6.3A type program
    - 15 month contractor design, fab, and test
    - 3 month Government test period
  - Technical not cost competition
  - Option for prototype development

CONCLUSIONS

LADARS can provide aimpoint fuzing for all of the munitions scenarios examined in this study. Low risk development can be assured by relying on existing technology, and the fact that several technologies support aimpoint fuzing.

CONCLUSIONS

- LADAR can provide aimpoint fuzing
- Technology available for low risk development
- Several technologies support fuzing requirements