The OSA Laser Systems Technical Group Welcomes You!

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OSA Laser Systems Technical Group

Technical Group at a Glance

- Focus
  - This group encompasses novel laser system development for a broad range of scientific, industrial, medical, remote sensing and other directed-energy applications.
- Mission
  - To benefit *YOU*
  - Webinars, e-Presence, publications, technical events, business events, outreach
  - Interested in presenting your research? Have ideas for TG events? Contact us at osa.lasersystechgroup@gmail.com.
- Find us here
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  - Facebook: https://www.facebook.com/groups/378463153017808/
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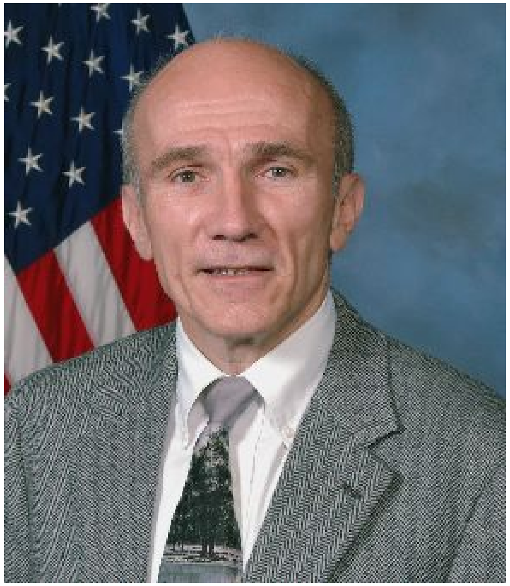
Today’s Webinar

An International History of Laser Radar/ LIDAR

Dr. Paul McManamon

Exciting Technology, LLC, University of Dayton, USA



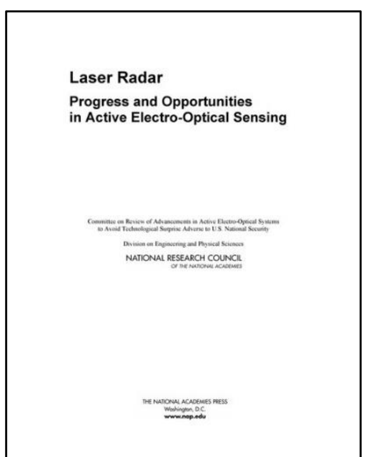
Speaker’s Short Bio:

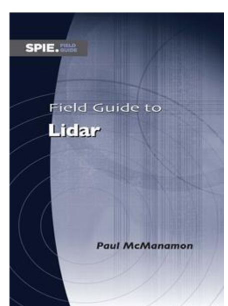
Dr. Paul F. McManamon is president of Exciting Technology LLC, Technical Director of the Lidar and Optical Communications Institute, LOCI, and chief scientist for Lyteloop, an innovation start up developing data storage using optical photons in motion. He chaired the US National Academy of Sciences, NAS, Study “Laser Radar: Progress and Opportunities in Active Electro-Optical Sensing” (2014), was co-chair of the US NAS study “Optics and Photonics, Essential Technologies for Our Nation” (2012), which recommended a National Photonics Initiative, NPI, and was vice chair of the 2010 NAS study “Seeing Photons: Progress and Limits of Visible and Infrared Sensor Arrays”. He is a Fellow of SPIE, IEEE, OSA, AFRL, DEPs, MSS, and AIAA. He received the IEEE WRG Baker award, was president of SPIE in 2006, and was on the SPIE board for 7 years. He received the Meritorious Presidential Rank Award, and was the co-recipient of the SPIE Presidents’ Award in 2013. He retired from being Chief Scientist for the Air Force Research Lab, AFRL, Sensors Directorate after 40 years of civil service. He was the main LiDAR expert witness for Uber in the lawsuit vs Google/Waymo.

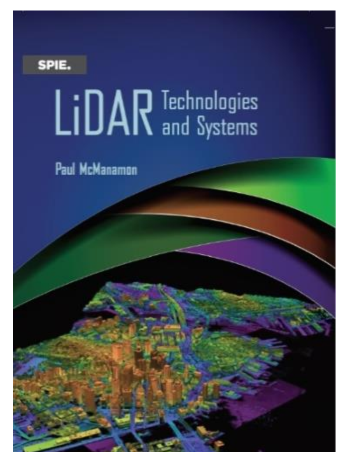
History of Lidar

By

Dr Paul McManamon







Lidar names

- LIDAR – Light Detection And Ranging
  - Generally used with atmosphere or chemical vapor detection
  - Used by the National Geospatial Intelligence Agency, NGA
  - Usually used for commercial applications
- LADAR – LAser Detection And Ranging
  - Historically used with hard targets
  - Adopted by NIST as the standard term for active EO Sensing
- Active EO Sensing, Laser Radar, Optical Radar, Laser Remote Sensing
- For Reference
  - RADAR – RAdio Detection And Ranging

Some References

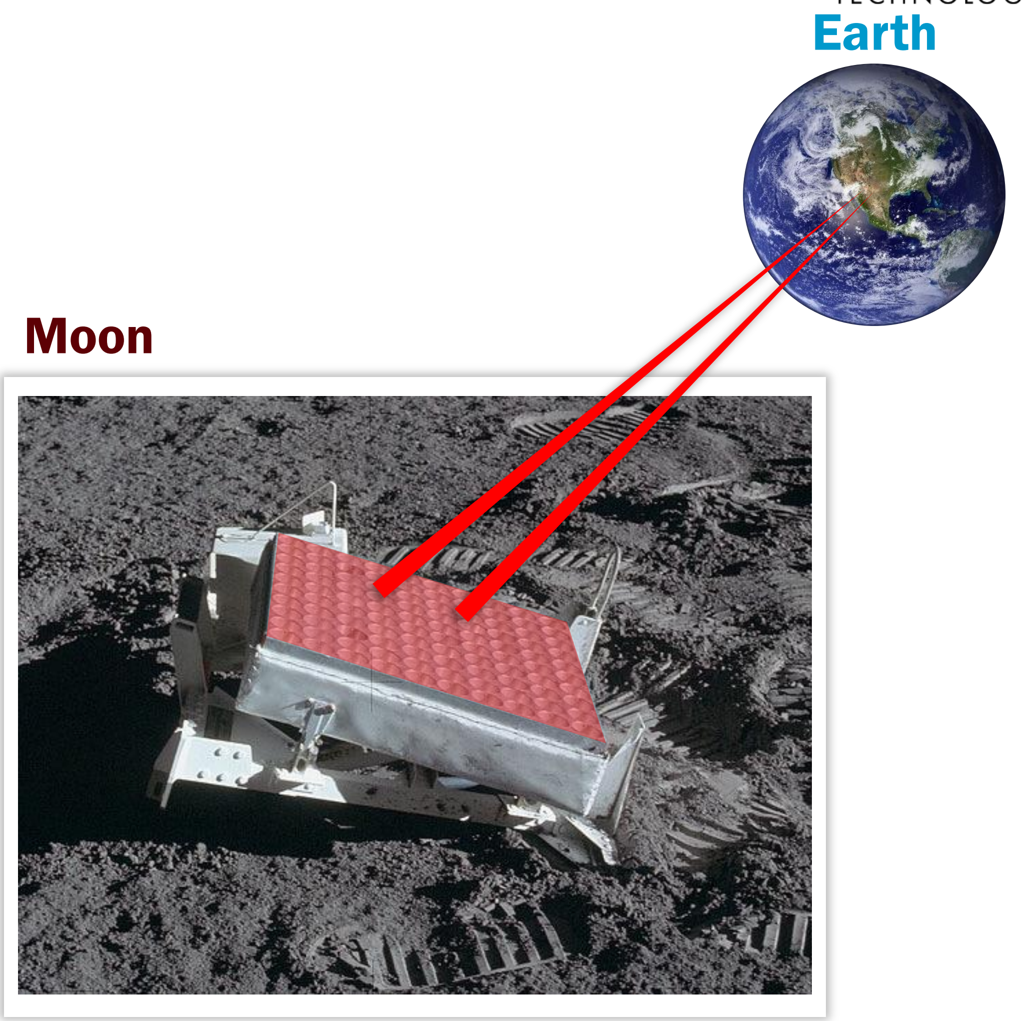
EXCITING TECHNOLOGY

- Laser radar: historical prospective—from the East to the West
  - Vasyl Molebny, Paul McManamon, Ove Steinvall, Takao Kobayashi, Weibiao Chen
  - Opt. Eng. 56(3),031220 (2016)
- Chapter 2 of “Lidar Technologies and Systems”
- A history of laser radar in the United States
  - PF McManamon, G Kamerman, M Huffaker - Laser Radar Technology and Applications XV, 2010
- **Laser radar: from early history to new trends**
  - Vasyl Molebny, Gary Kamerman, Ove Steinvall, 2010
- The dawn of optical radar: a story from another side of the globe
  - Vasyl Molebny, Peter Zarubin, Gary Kamerman, 2010

Early LiDAR – Ranging to the Moon

EXCITING TECHNOLOGY

MIT/LL Ranged to the moon with a 50 joule Ruby laser in May, 1962



- 1969 – with corner cube
- 60 Joule Ruby Laser
- 3 cm range precision

LASER TECHNOLOGY APPLICATION

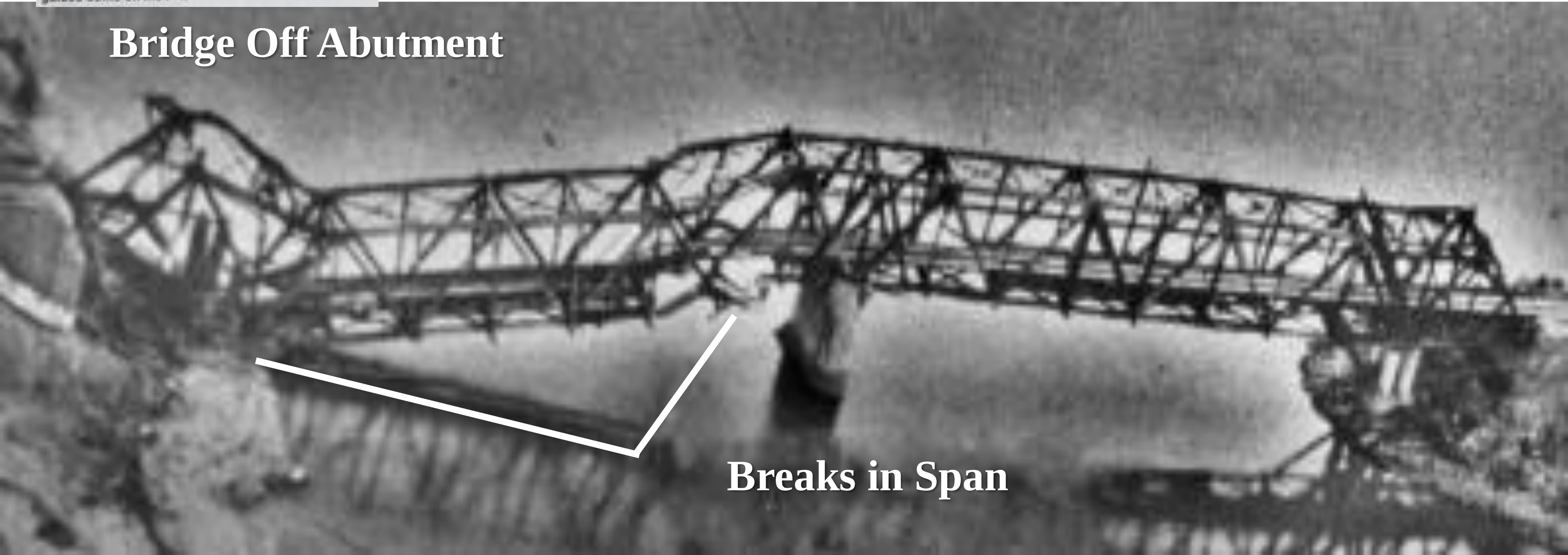
1st Laser Target Designator
Avionics Laboratory - 1969

Pave Way Laser Guided Bomb

Thanh Hoa Bridge (Dragon's Jaw) - Vietnam

Capt. Thomas Messett checks a 2,000-pound laser-guided bomb on his F-4.

Weapon	Sorties	Losses	Results
Unguided Bombs	871	11	Bridge standing
Laser Guided Bombs	4	0	Bridge destroyed



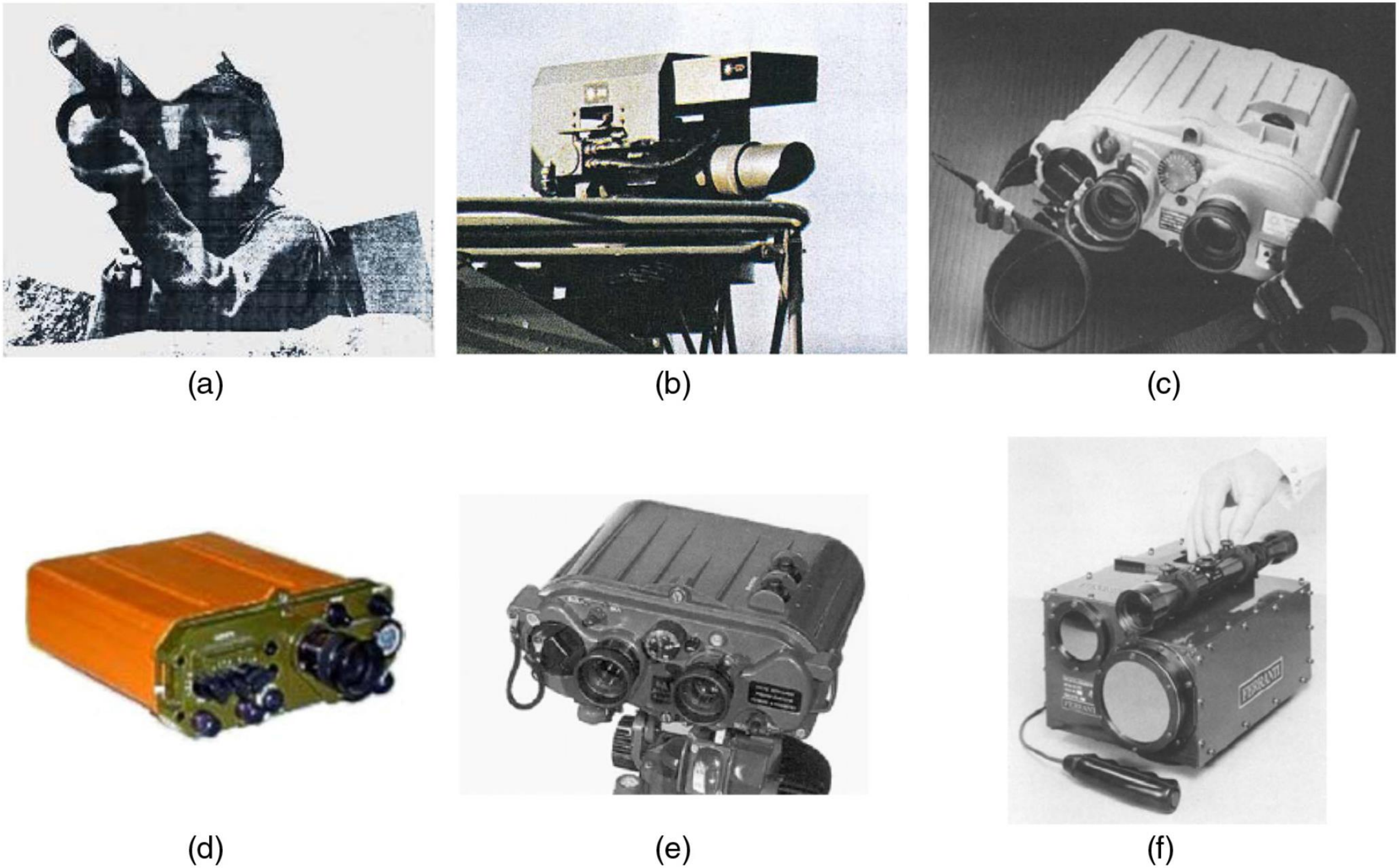


Fig. 1 Examples of early laser range finder (LRF) development. (a) Test equipment for the first Ericsson LRF (1965), (b) LRF for the Swedish Coastal Artillery (1968), (c) Simrad handheld LP-7, (d) LRF KTD 2-2 (Polyus, USSR), (e) LRF BD-1 (Institute # 801, USSR), and (f) Ferranti CO_2 TEA LRF.

Early Soviet range finders/designators

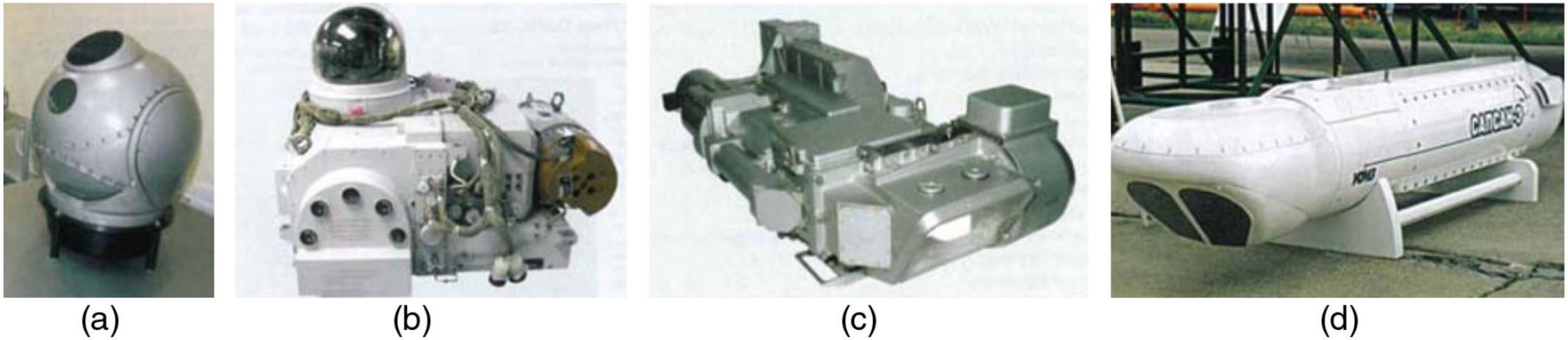


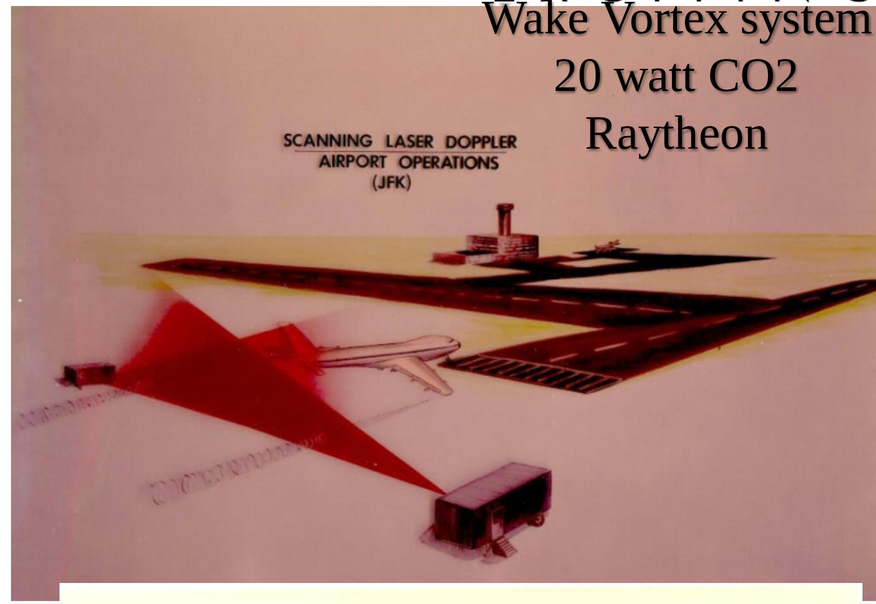
Fig. 2 Examples of the Soviet/Russian range finder/designator laser radars: (a) Samsheet-50 range finder/designator for Ka-52 helicopter, (b) 31E-MK electro-optic system for Su-30 fighter, (c) Shkval series for Su-25T, Su-25TM/Su-39, and Ka-50, and (d) pod mounted Sapsan-E for air-to-surface MiG and Su missions.

Early Argon-ion 1 watt, 3 forward scattering angle laser radar – Mid 60's

EXCITING TECHNOLOGY

Early Wind Sensing Laser Radar Work

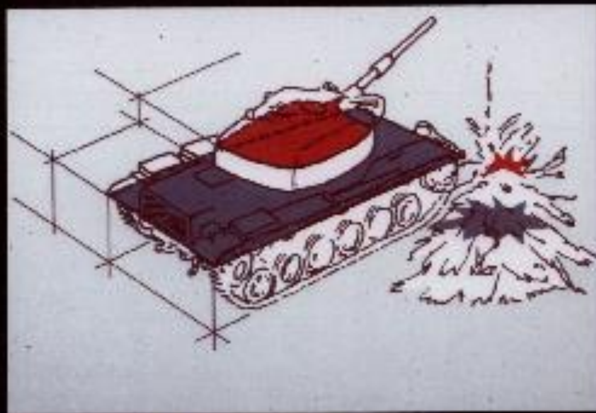
Early wind sensing
- Led by Milt Huffaker at NASA
- Clear Air Turbulence
- Wake Vortex detection



Wake Vortex system
20 watt CO_2
Raytheon

Clear Air Turbulence

NASA pulse CO_2
Laser Radar Test Aircraft
~1972



Processing Concept

Laboratory 3-DTC

Target Classification

- Neighborhood Processing
- Programmable Lab. Processor
- Real Time Classification
- Demo. Using Flight Test Data
- Multisensor Input Capability

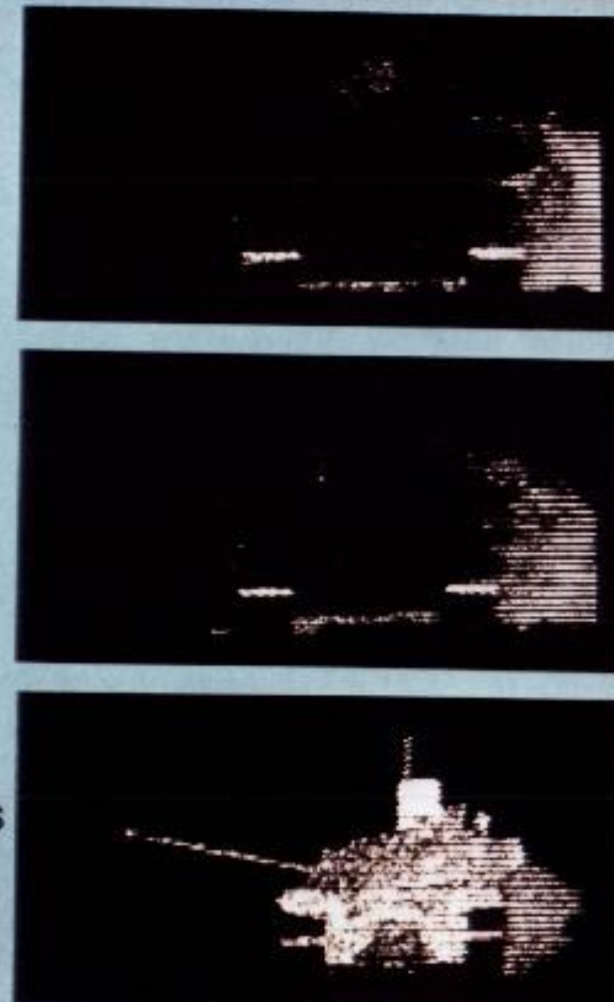
REAL TIME 3-D TARGET CLASSIFIER

. . . FLIGHT TEST RESULTS -- 1977 . . .

M-48 TANK

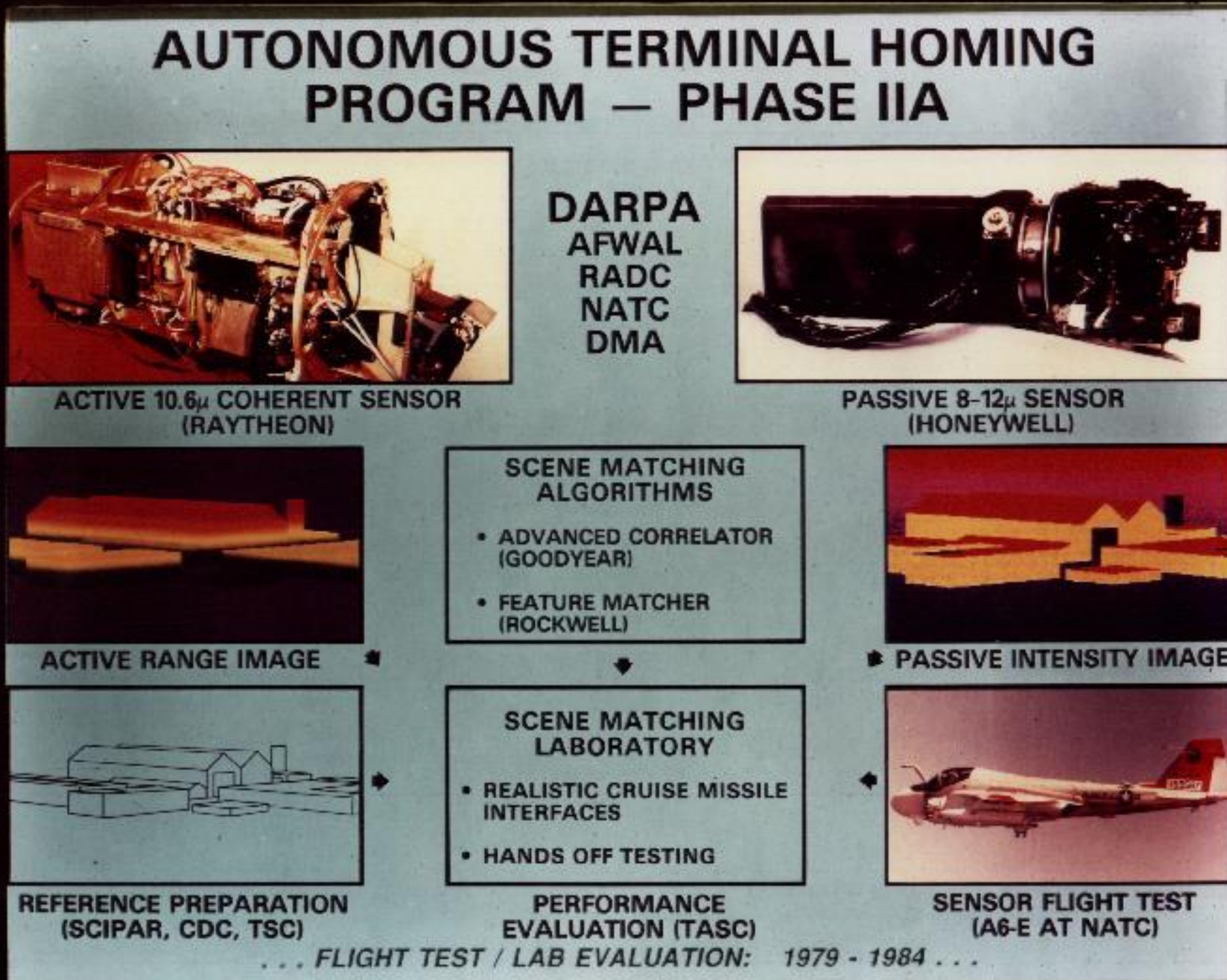
. . . *PIXEL-LEVEL DOPPLER IMAGERY* . . .

1978 RESULTS SHOWING SIGNATURES FOR VELOCITY GATE SETTINGS:
- -- ABOVE TANK VELOCITY
- -- BELOW TANK VELOCITY
- -- MATCHING TANK VELOCITY

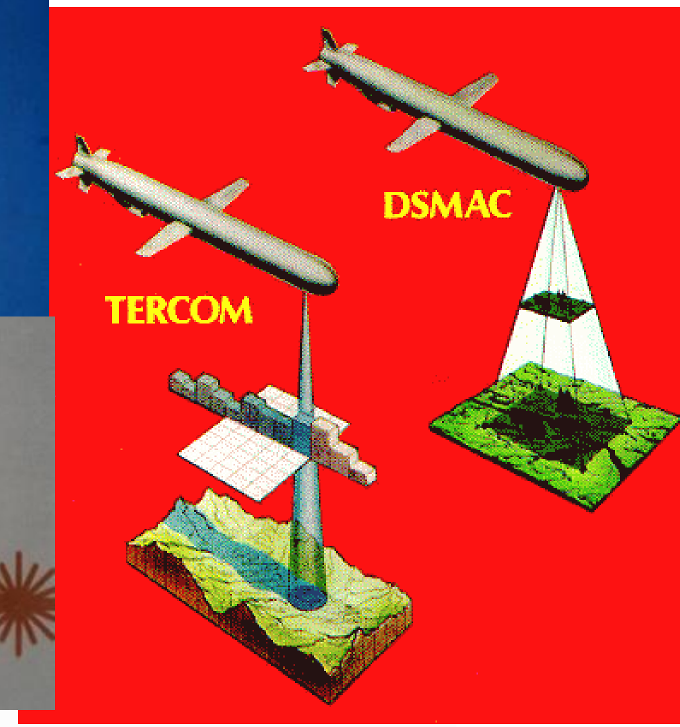


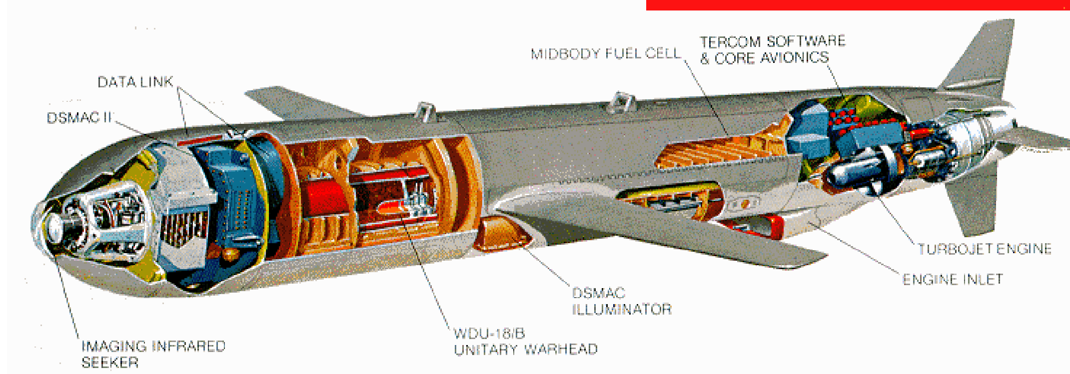
TARGET SIGNATURES UNIQUE TO LASER RADAR SENSORS
- -- TREADS ARE WITHIN VELOCITY GATES ONLY NEAR THEIR VERTICAL TRAVEL
- -- DUST CLOUDS UNIQUE TO EACH VELOCITY GATE SETTING

EO-474

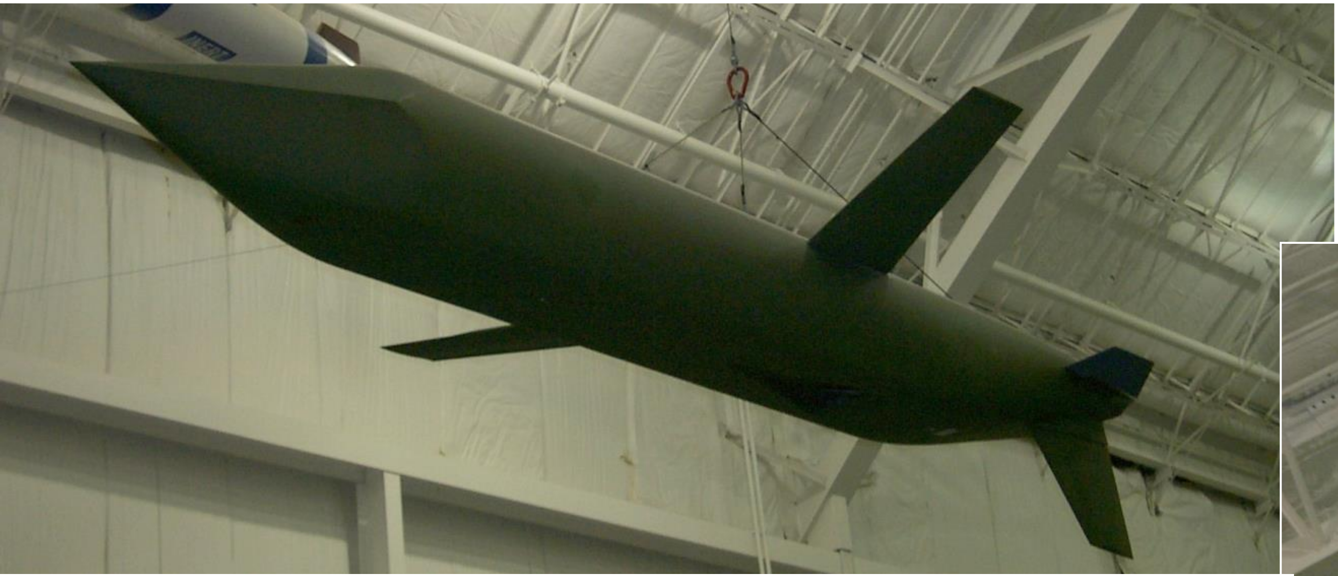

AUTONOMOUS TERMINAL HOMING
PROGRAM — PHASE IIA
DARPA
AFWAL
RADC
NATC
DMA
ACTIVE 10.6μ COHERENT SENSOR
(RAYTHEON)
PASSIVE 8-12μ SENSOR
(HONEYWELL)
SCENE MATCHING
ALGORITHMS
• ADVANCED CORRELATOR
(GOODYEAR)
• FEATURE MATCHER
(ROCKWELL)
ACTIVE RANGE IMAGE
PASSIVE INTENSITY IMAGE
SCENE MATCHING
LABORATORY
• REALISTIC CRUISE MISSILE
INTERFACES
• HANDS OFF TESTING
REFERENCE PREPARATION
(SCIPAR, CDC, TSC)
PERFORMANCE
EVALUATION (TASC)
SENSOR FLIGHT TEST
(A6-E AT NATC)
. . . FLIGHT TEST / LAB EVALUATION: 1979 - 1984 . . .

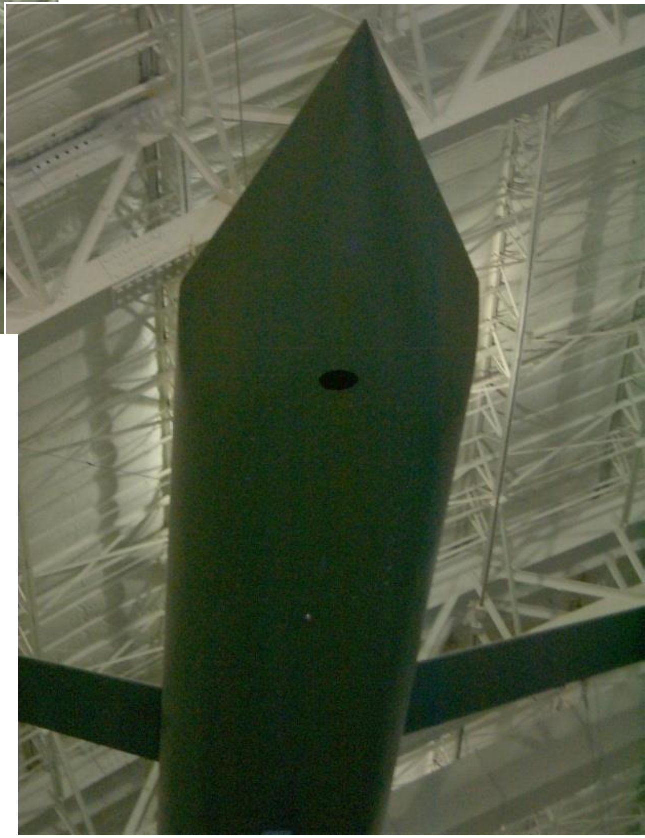
Cruise Missile Guidance





AGM-129A

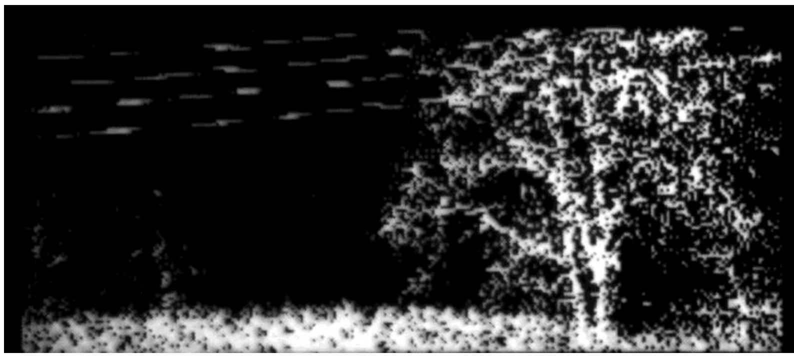




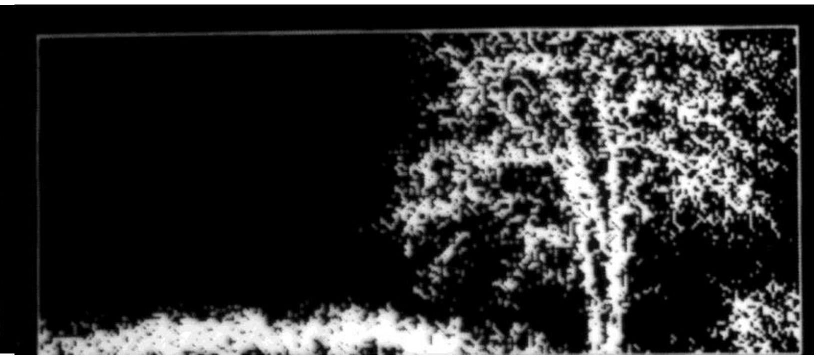
The ACM is an air-to-ground cruise missile developed to provide the Strategic Air Command (now Air Combat Command) with a long range, highly survivable, strategic standoff weapon. The ACM uses laser sensor updates to give it high navigation accuracy and "stealth" technology to give it a low radar cross section and increased chance to penetrate enemy defenses. The distinctive forward swept wing is an example of the application of stealth technology. Up to 12 ACMs can be carried by a B-52H bomber, allowing the bomber to attack multiple targets without penetrating enemy airspace. Full-scale development of the ACM began in 1983, and the first production missile was delivered in 1987. Production contracts for ACMs were awarded to General Dynamics and McDonnell Douglas.

Early 3D Imaging CO2 Field Trials

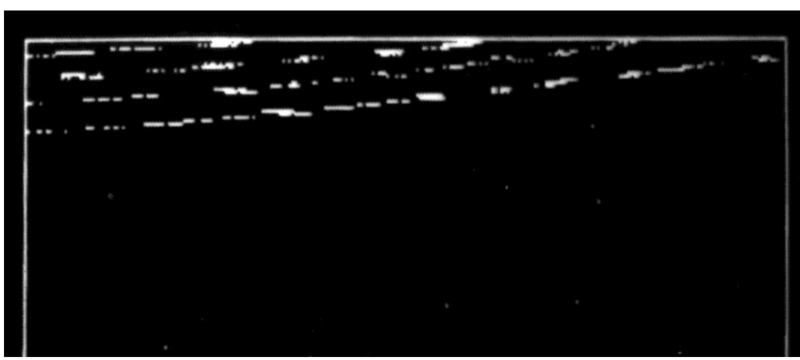
Original Image



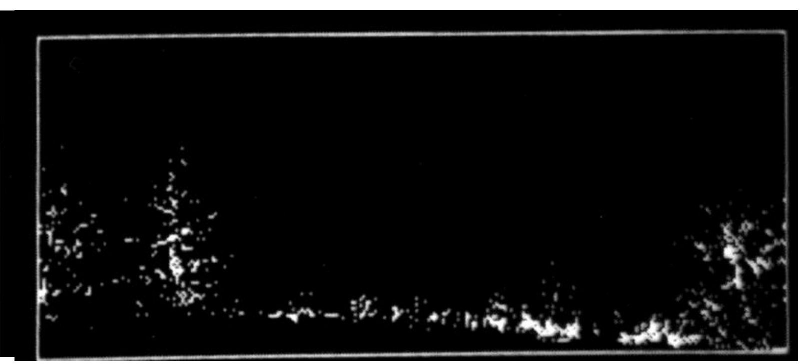
First Range Gate



Second Range Gate



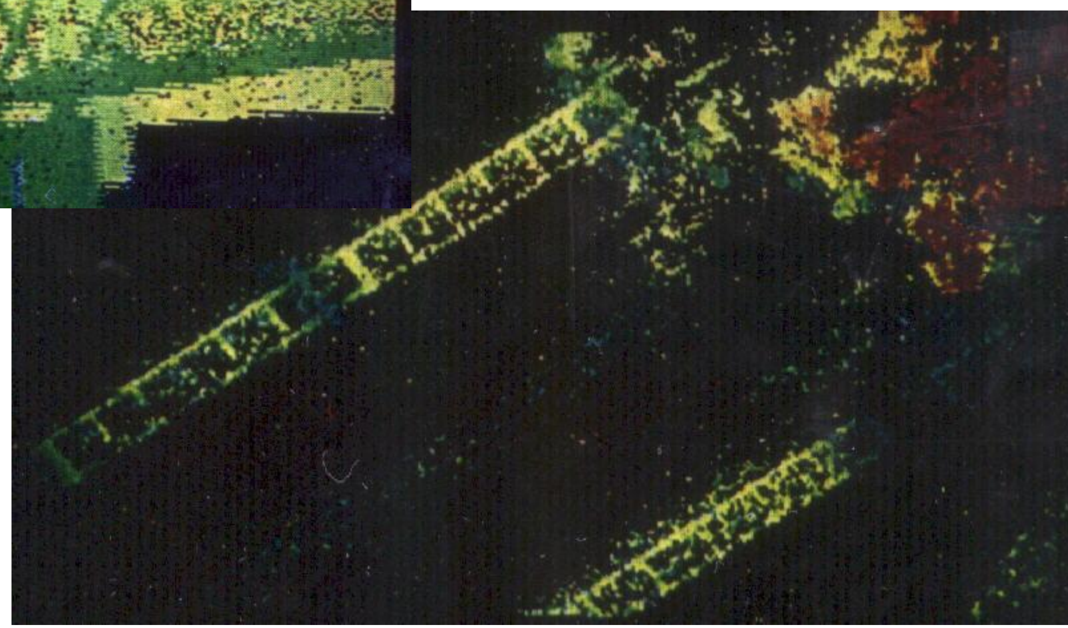
Last Range Gate



~1983

River Bridge Complex

Pseudo-Color Range Image



Top Down Projection

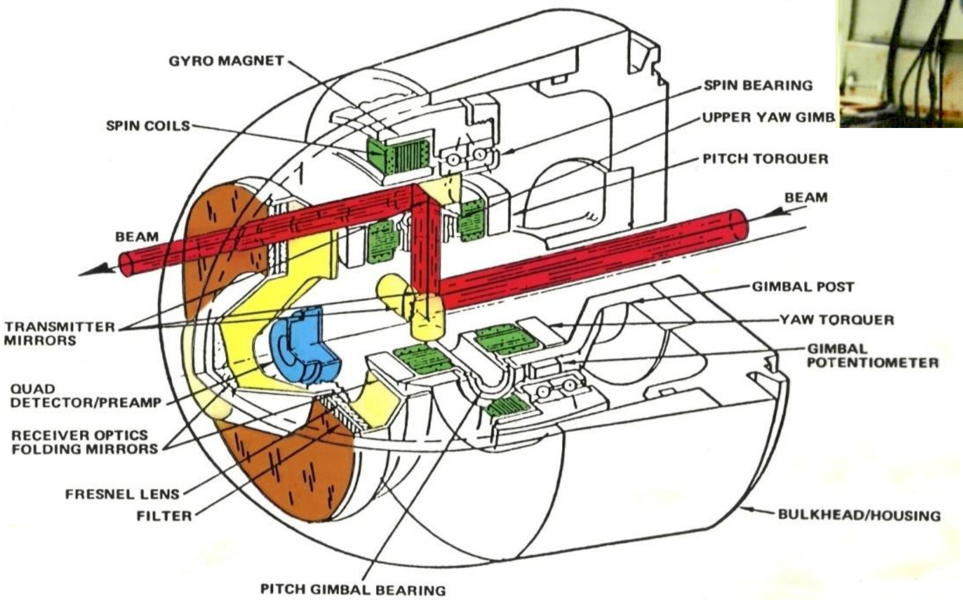
~1983

*

Seeker Schematic

-Schematic of the first air-to-air missile seeker.
- external diameter of 5”
-1.064 microns
- field of regard of ±45°
- track at angular rates up to 45° /sec.

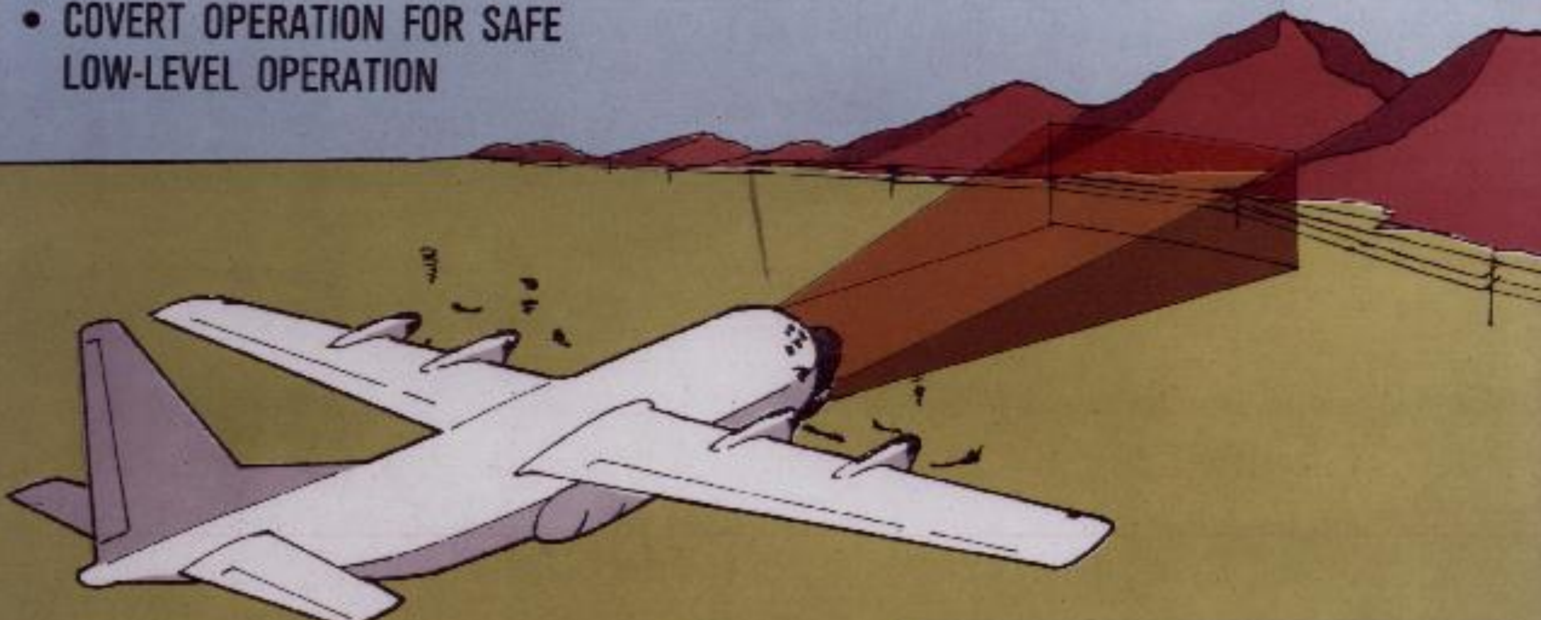
Photo of the air to air missile seeker in ground tests at China Lake.



LASER RADAR
QUIET KNIGHT

PROVIDES .....

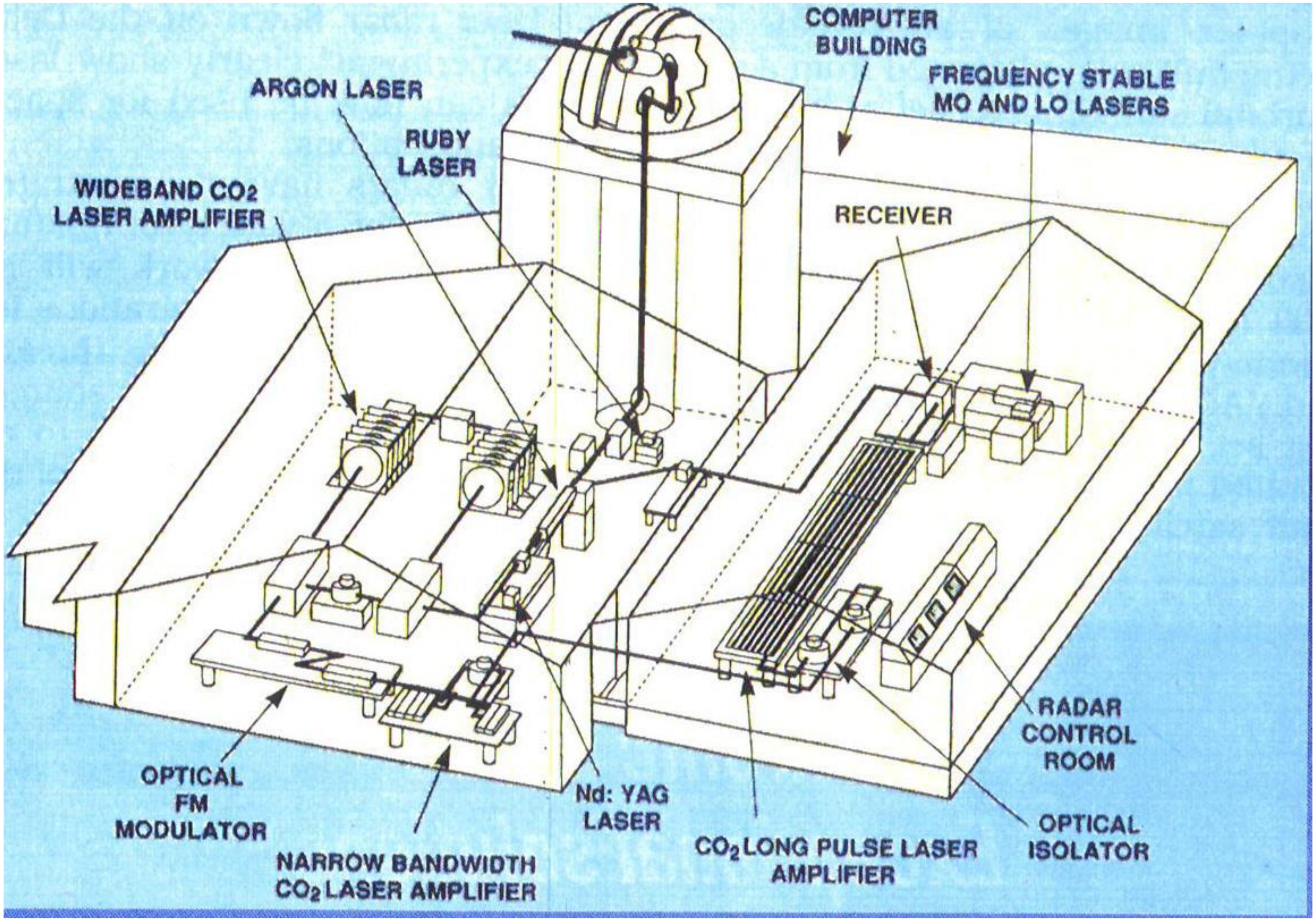
- TF / TA / OA IN ADVERSE WEATHER
- COVERT OPERATION FOR SAFE LOW-LEVEL OPERATION



TF REFERENCE	2-15 NMi
OBSTACLE DETECTION	2-5 NMi
WIRE DETECTION	1-2 NMi

PROGRAM INITIATED -- 1988

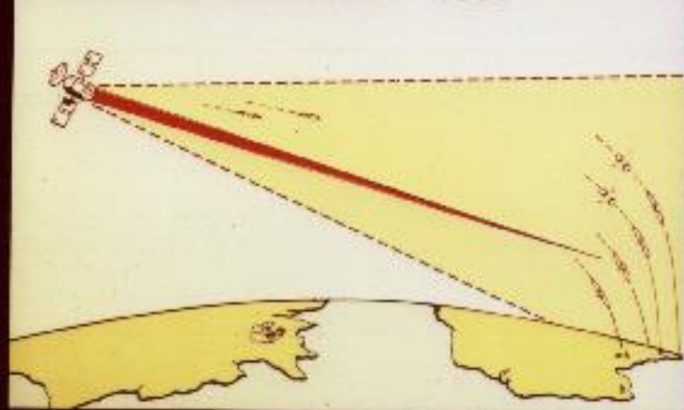
MIT/LL Firepond Laser Radar



20 Watt P22 636 (11.15 µm) master oscillator, mechanically chopped @ 4 to 10 Hz to 35 µsec pulses of 700 µJoules (each)

LOW WEIGHT KEW ACTIVE TRACKER
(LOWKATER)

PROGRAM INITIATED: 1988



OBJECTIVE

DEMONSTRATE CARBON DIOXIDE LASER RADAR TECHNOLOGY FOR SPACE - BASED WEAPONRY DISCRIMINATION AND TRACKING FUNCTIONS

APPROACH

- O PRELIMINARY AND DETAILED DESIGN AND PLATFORM ANALYSES
- O FABRICATION OF GROUND - BASED AND SPACE - CAPABLE UNITS AND TESTING
- O SPACE FLIGHT EXPERIMENT

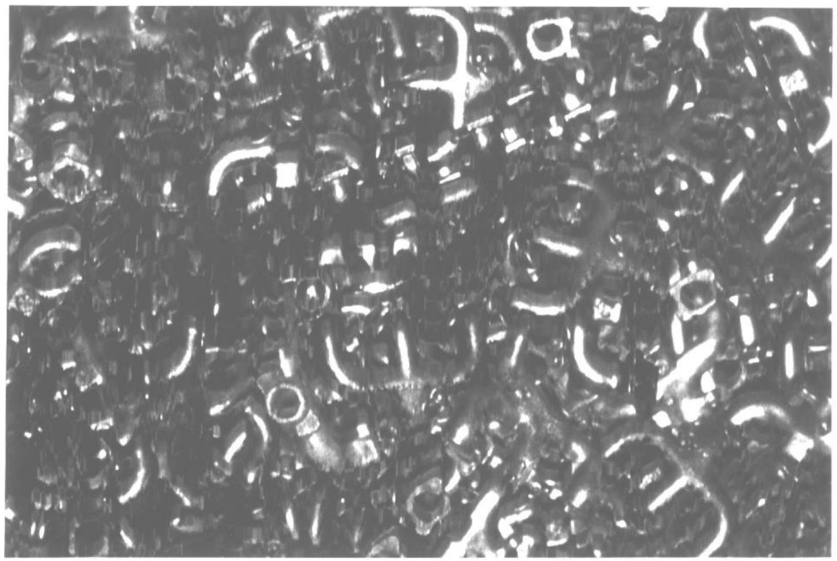
Delta 180

- First Laser Radar In Space
  - Launched: 5 Sep 1986
  - High Power Pulsed Nd:YAG
    - 100 milliJoule/pulse
    - 100 Hz PRF
- On-Orbit Tracking & Terminal Guidance
- Kinetic Kill Intercept for SDIO

3-D Imaging in Manufacturing

V6 Exhaust Manifolds

Intensity



Range

Courtesy of Perceptron

Images from a scanned laser radar system build by Perceptron for Ford Automobile Company

-3D image of a pile of exhaust manifolds is on the right

-matching panchromatic photograph is on the left

-prominent objects in an ordinary photograph are seldom the ones on top

FLIR/ERASER (2D) Breadboard Side-by-Side Comparison – mid 90's

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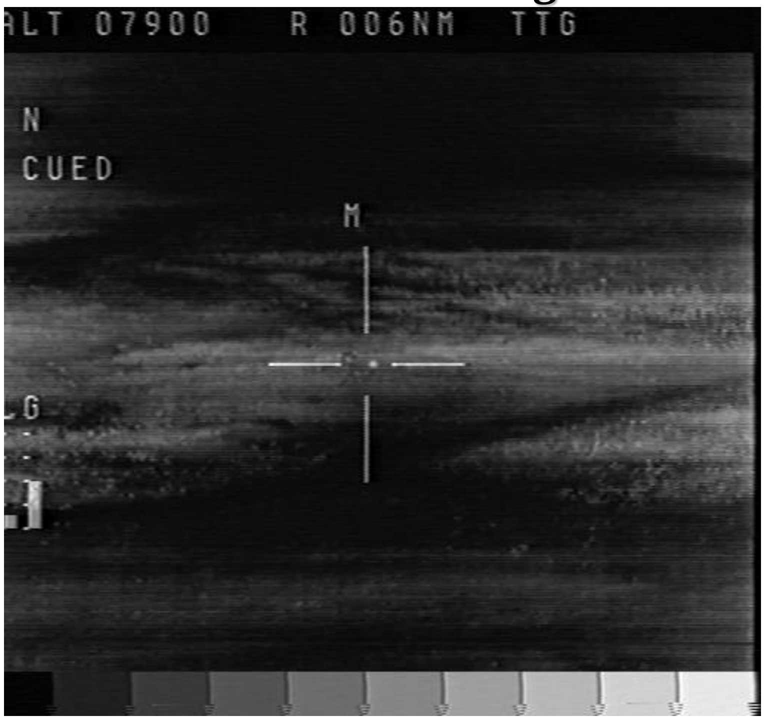
Imagery Collected With Identical Range / Targets (Different Dates)

NFOV FLIR Image



ERASER Breadboard Image

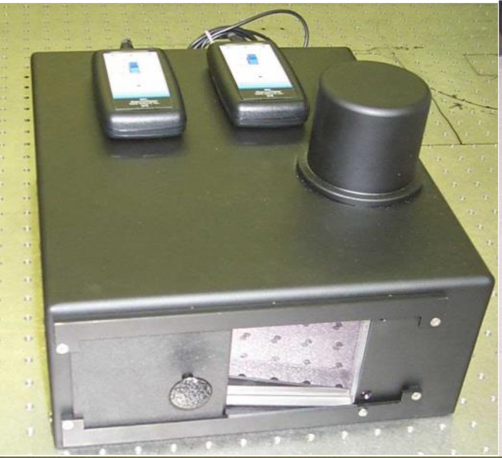
- 8-inch Aperture
- State-of-the-Art FLIR
- 8 - 12 micron waveband
- 6 nmi Range (WSMR)

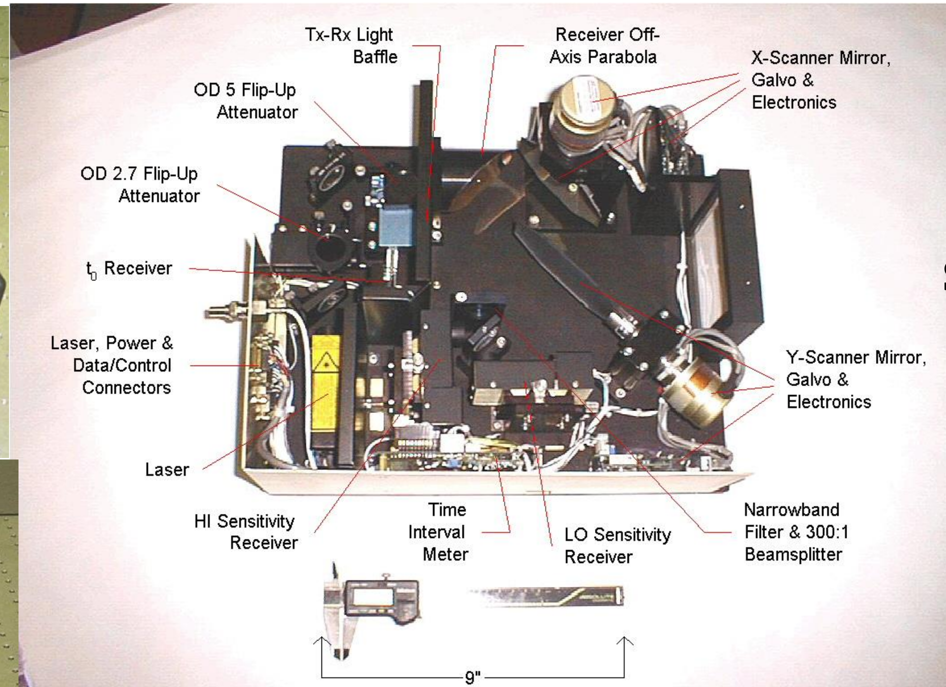
- 8-inch Aperture
- 6 nmi Range (WSMR)

- **Ground threat ID at > 20 km**

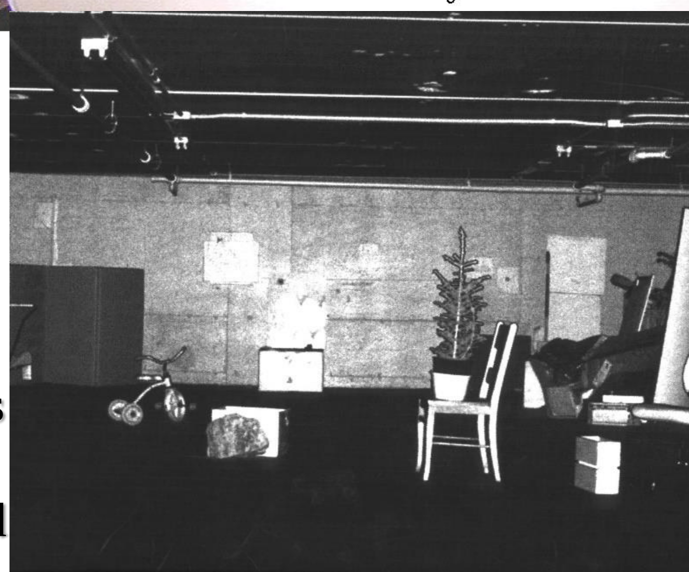
Champollion/DS4 Breadboard

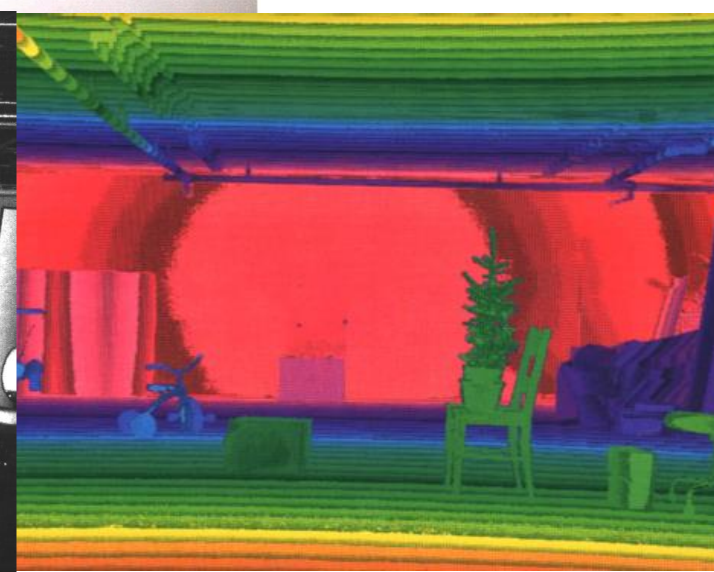
EXCITING TECHNOLOGY





For autonomous landing of a deep space probe on the comet Tempel 1 - Late 90's





Intensity (left) and 3D laser radar (right) images collected by the Champollion Breadboard

Shuttle Inspection

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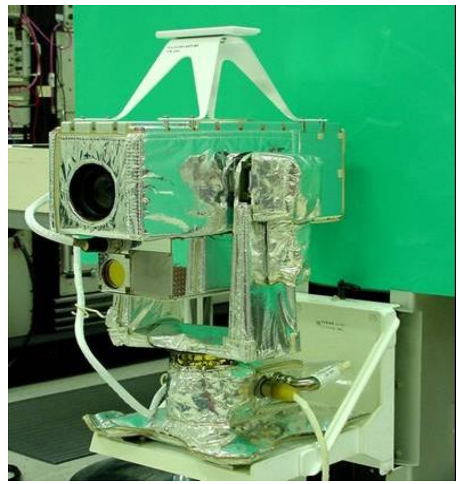
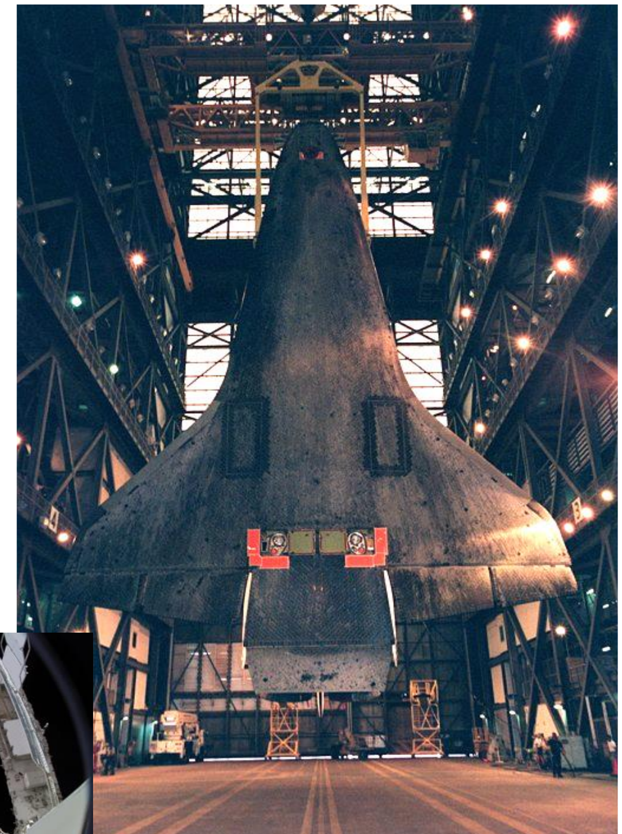
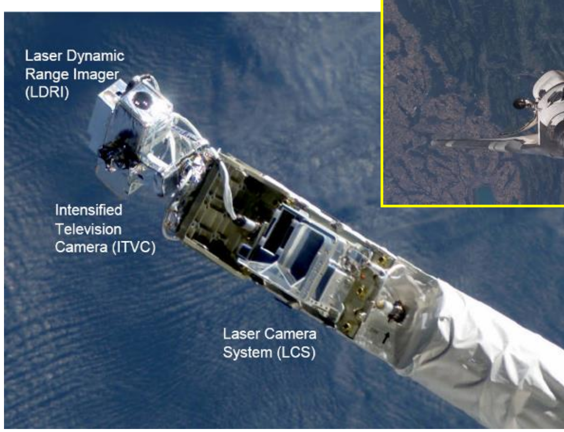
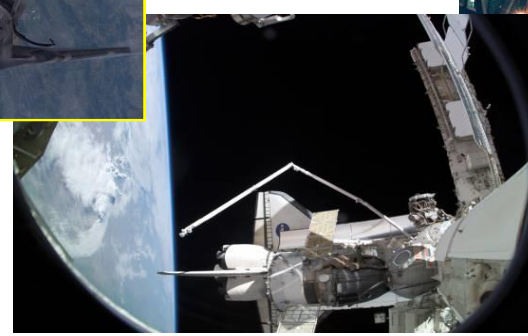
TECHNOLOGY









Damage is routinely detected by the laser radars and then the High Def pictures are shown to the media

History of Recent Wind Sensor Developments

NASA Optical Air Turbulence Sensor

2 µm, 1 mJ, 1 kHz, 5 cm aperture, chiller

NASA ACLAIM Turbulence Warning

2 µm, 8-10 mJ, 100Hz, 10 cm aperture, chiller

MAG-1 WindTracer

2 µm, 2 mJ, 500Hz, 10 cm aperture heat exchanger

MAG-1A WindTracer

2 µm, 2 mJ, 500Hz, 10 cm aperture, heat exchanger

WTX Derivative of CAT IR

1.6 µm, 2-5 mJ, 200-1000Hz, 12.7 cm aperture

↑ NextGen Wind Sensor

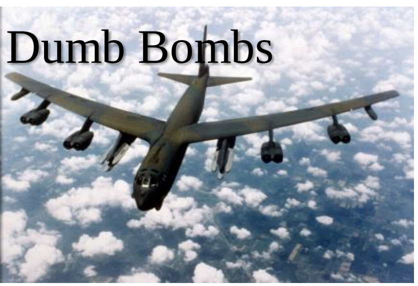
1995 — 1998 — 2001 — 2004 — 2006 →

BALLISTIC WINDS

EXCITING TECHNOLOGY

Applications

Dumb Bombs



Gunship

115 cu ft, 2014 lbs

Solid state, 3.5mJ

(Aug 95)

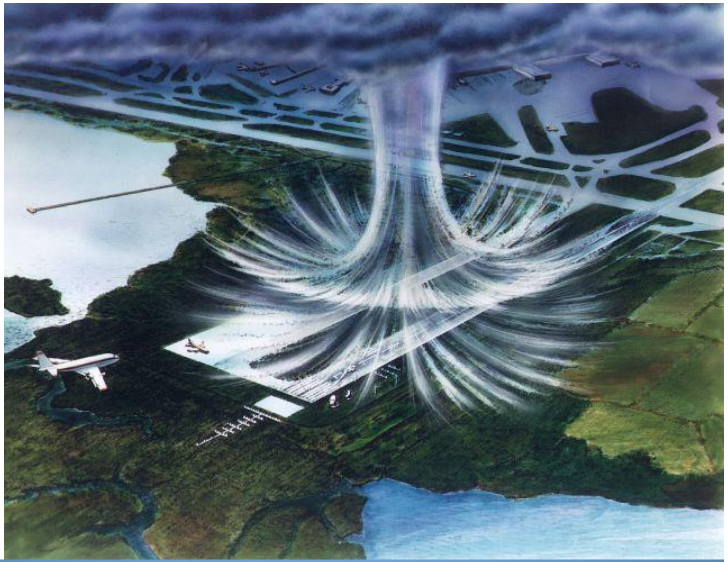
Near Prototype C-130 Pod System

(Jun 97 15 cu ft, 1000 lbs, Solid state, 15 mJ

Wind Sensing

- Microburst

https://upload.wikimedia.org/wikipedia/commons/4/4e/Microburstnasa.JPG?downloaded May 23, 2018



- Wind Farms

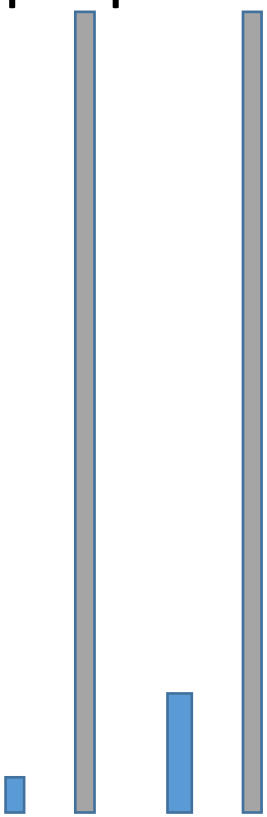
By Steve Wilson from Orpington, UK - flickr: More Windmills......, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=22777884

3D Mapping lidar

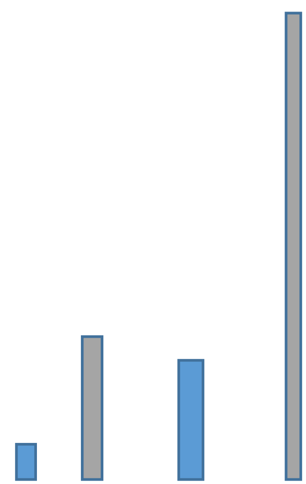
- Has been around since the 90's
  - Single detector systems fly at 3-6 Kft altitude
- Has been used in many application
- In 2010 or so DOD flew a high altitude 3D mapping system in Afghanistan
  - The HALOE system
  - GMAPD based
- About 2013 Harris introduced a GMAPD based mid altitude 3D mapping system
- Someone could make a 3D mapping system using an array of LMAPDs, but no one has yet.

Gieger Mode vs. Linear Mode APDs

- Geiger Mode always has the same # of electrons out – a large #
- For linear mode the number of electrons is linearly proportional to the number of input photons



Geiger Mode

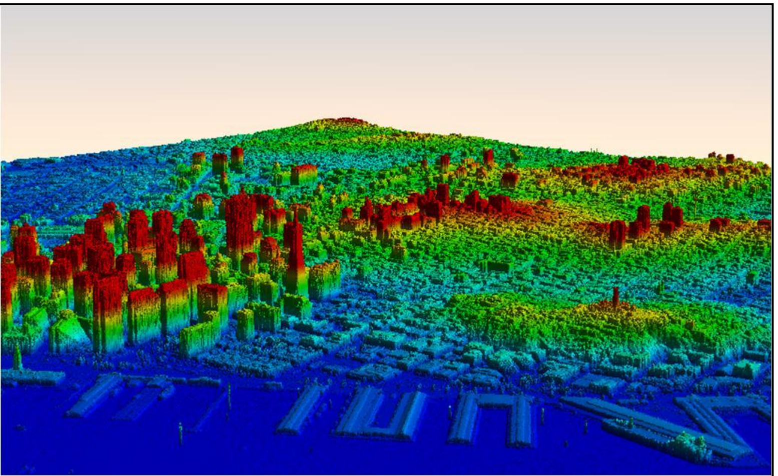


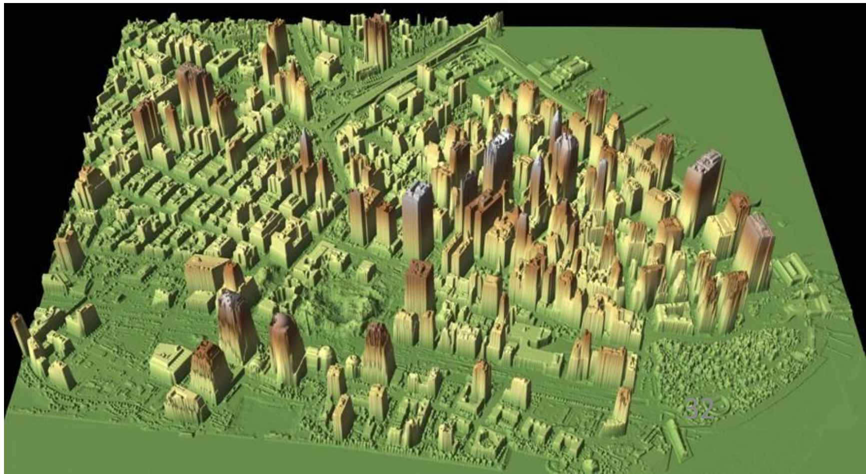
Linear Mode

3D Ladar

Scanning ladar

- Use a single detector, or small array of detectors.
- Laser only illuminates where the detector array is viewing
- Requires stabilization to a fraction of the detector angular sub-tense, DAS
- Has relatively high rep rate
  - For pulsed diode pumped, lidars this can mean you buy fewer laser diodes
- Most commercial lidars are still scanning





3D Mapping Applications

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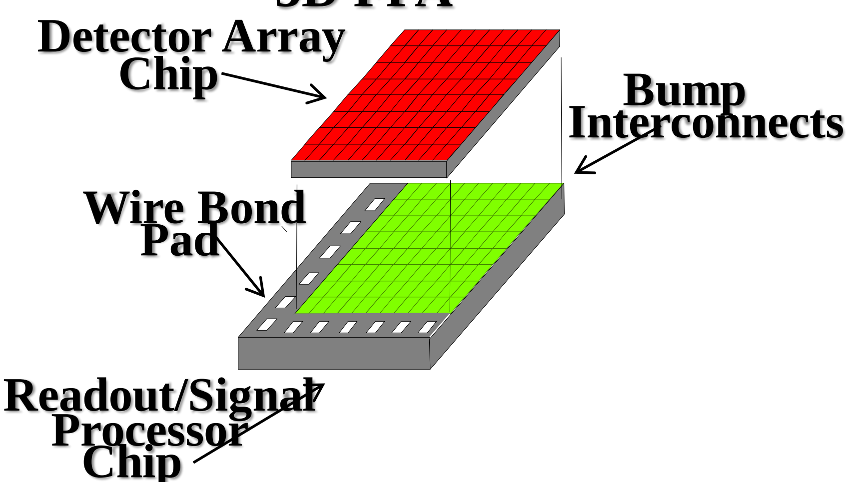
- GNSS Position Data Collection
- Ground Surveys
- Mapping Land Topography
- Mapping Utility Assets and Vegetation Encroachment
- Mapping Transportation Assets
- Mapping 3D Urban Infrastructure and Modeling
- Mapping Hazards and Emergency Management
- Forest Inventory Management
- Mapping Ancient Archeological Sites

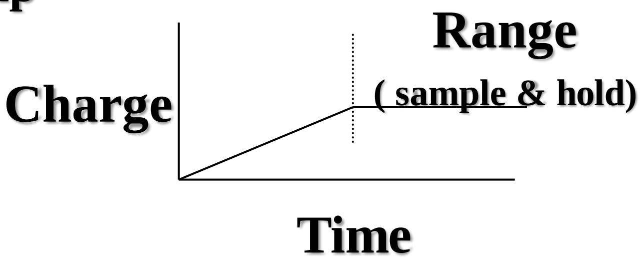
3D "Flash" Ladar

(3D Image on a Single Pulse)

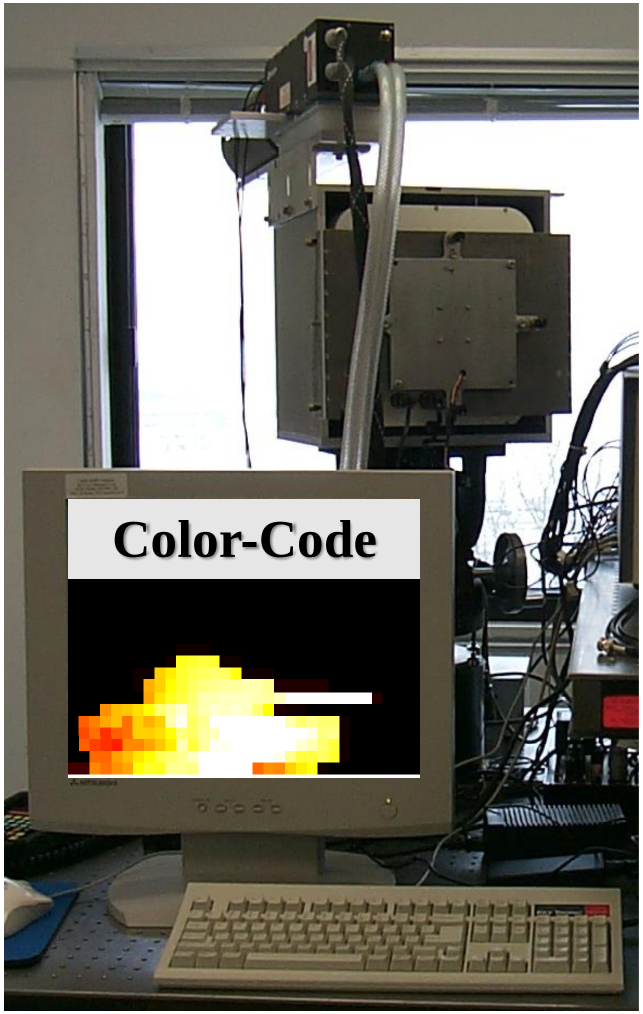
This is linear gain
Geiger mode APDs also have
Come into prominence

3D FPA



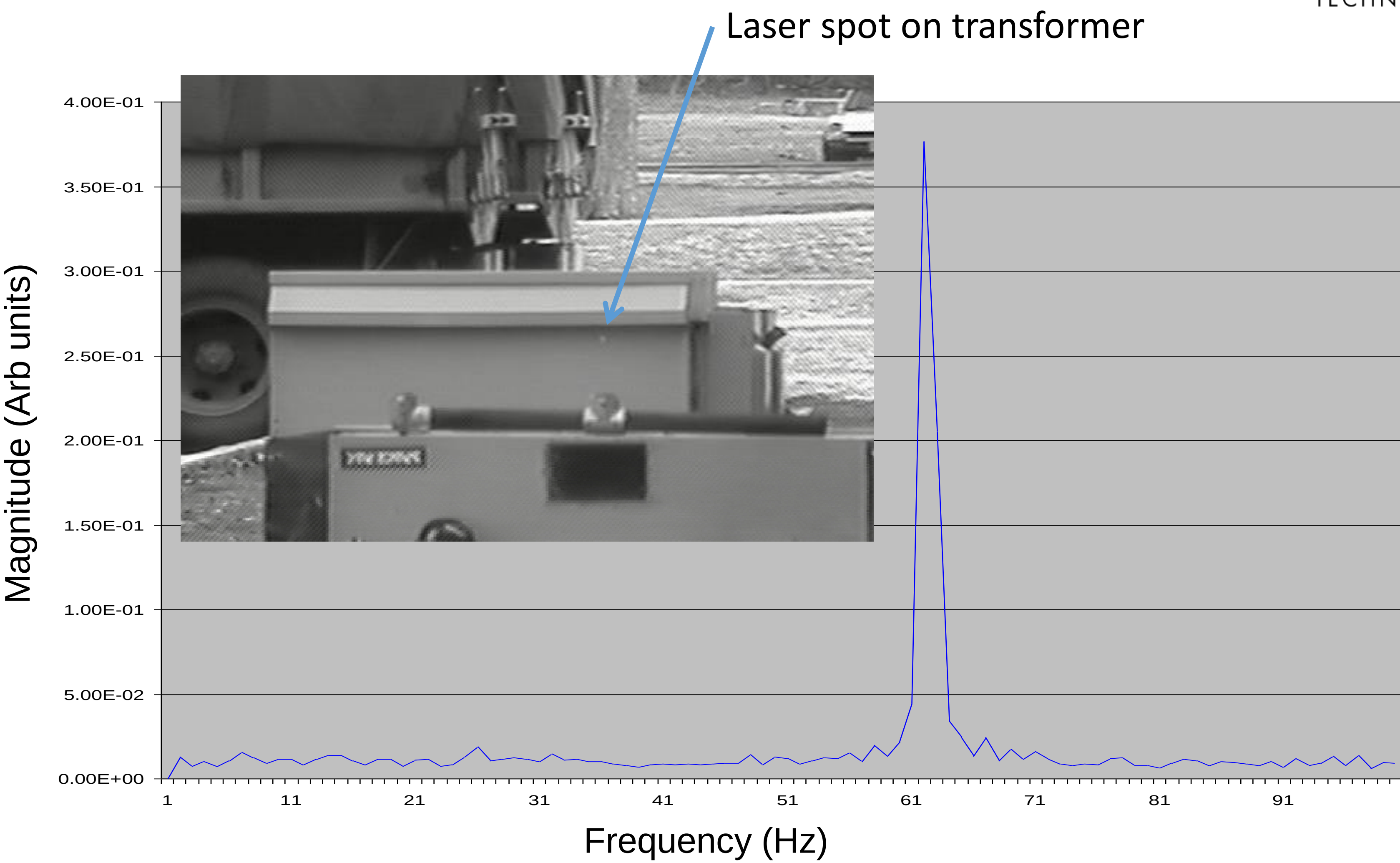


3D Laser Radar



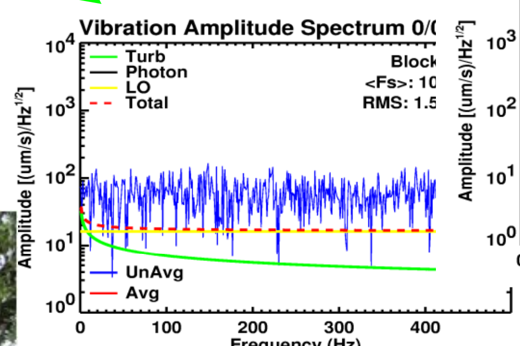
Ladar vib Measurements of a transformer

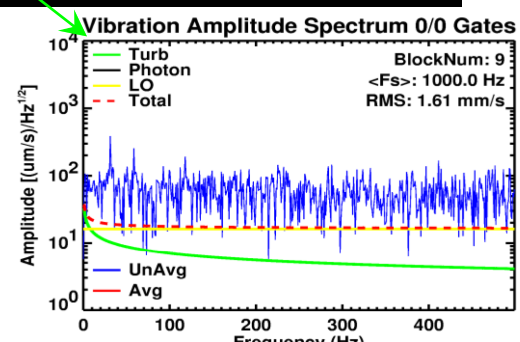
EXCITING
TECHNOLOGY

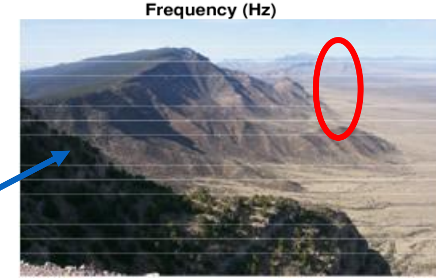


Vibration Measurement Campaign at White Sands –May 2002

Vibration Signature Through a Tree at 11 km







What if you could hear targets from long ranges?

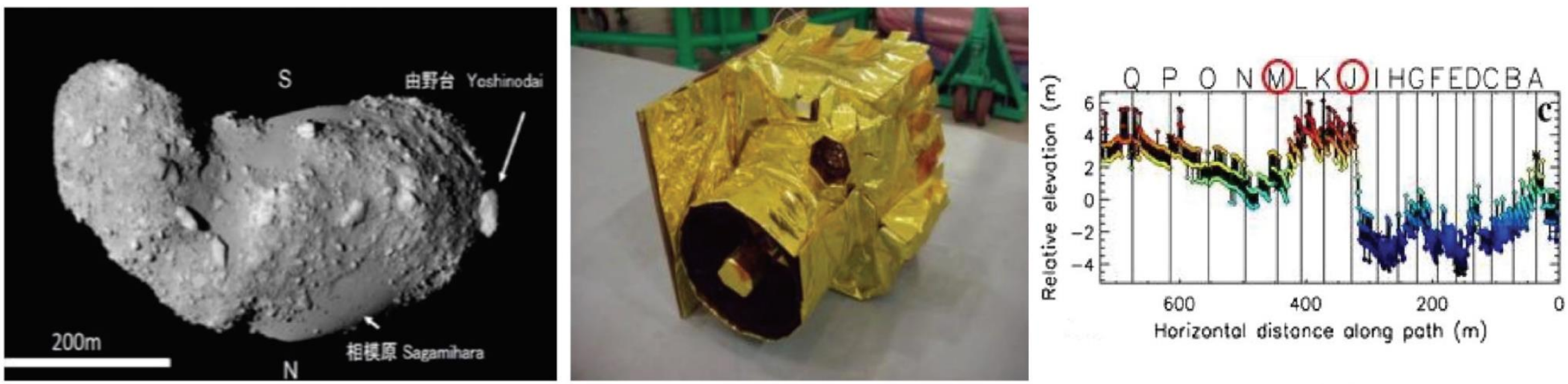
View from Tank

52Km A/A Range

Hayabusa Mission

EXCITING TECHNOLOGY

- Launched by Japan in 2005
- It operates at 1064 nm with 8 mJ, 1 Hz, 12.5 cm aperture, 3.7 kg, 24 cm, 23 cm , 25 cm).
- Range resolution of ±1 m



(a) (b) (c)

Figure 2.5 Hayabusa mission using the Hayabusa LiDAR: (a) a photo of the asteroid Itokawa taken by an imager; (b) a flight model; and (c) relative elevation and horizontal distance measured by the Hayabusa LiDAR (reprinted from Ref. 14).

Early LiDAR– 1980s NavLab (DARPA)

Photo 1: *The NAVLAB autonomous navigation test-bed vehicle and the road used for trial runs.*

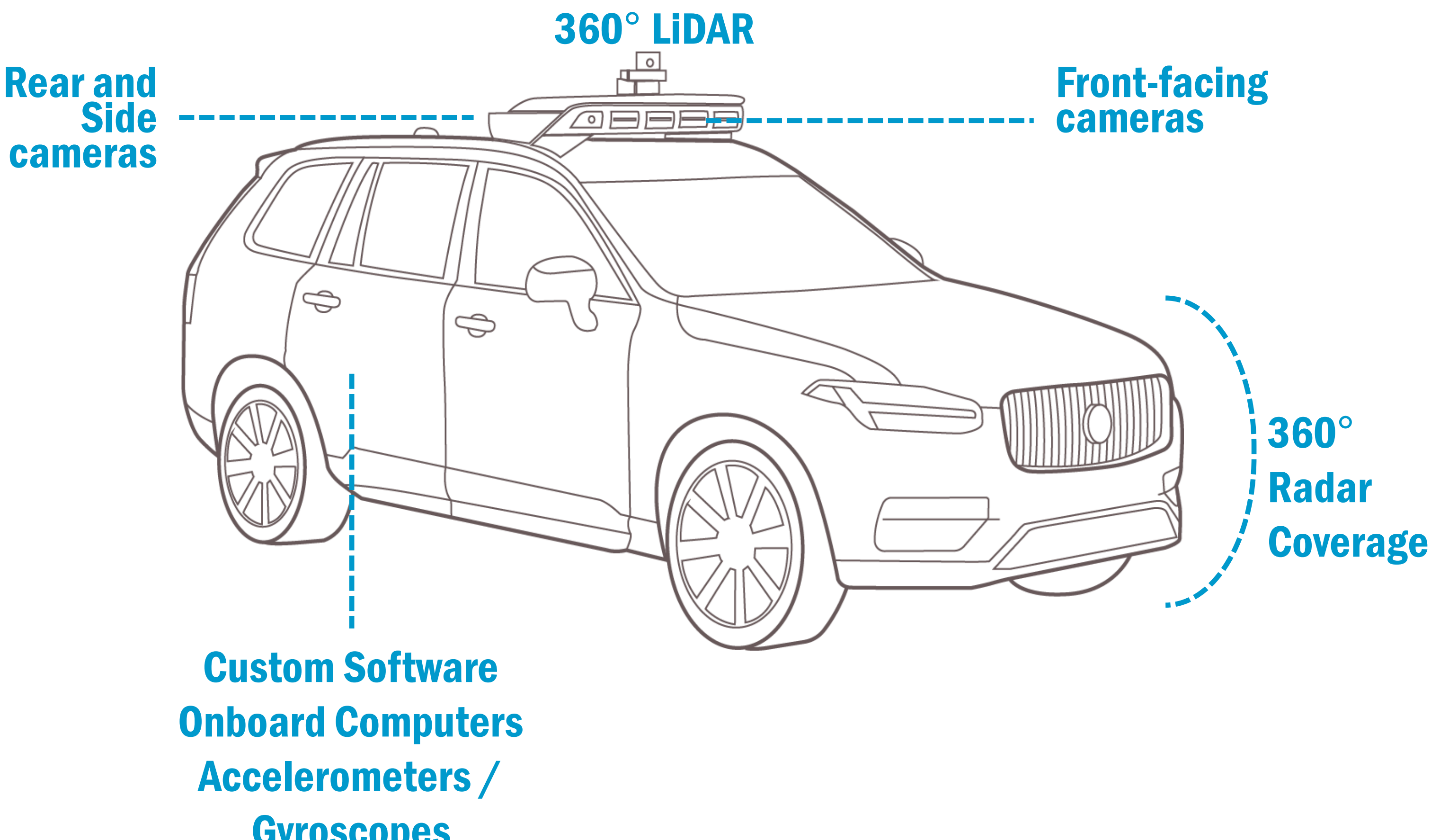
Lidar was from ERIM

2007 Urban Challenge

Velodyne
HDL 64
LiDAR

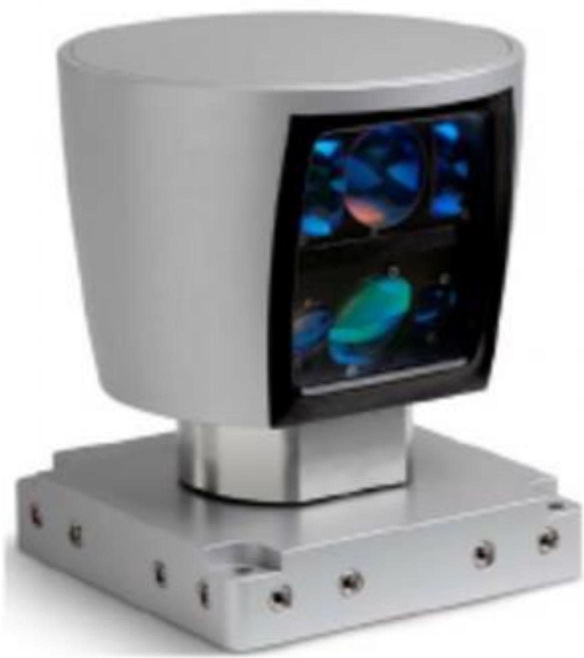
Autonomous Vehicles

- Lidar will be a critical Sensor, but not the only one
- Radar, and visible Sensors, and maybe acoustic sensors, will be used



Velodyne HDL64

- 5 of 6 finishers in the 2007 DARPA urban Challenge used the HDL 64
- Used a single Rotating Lidar on the roof, with 360 deg azmuth coverage



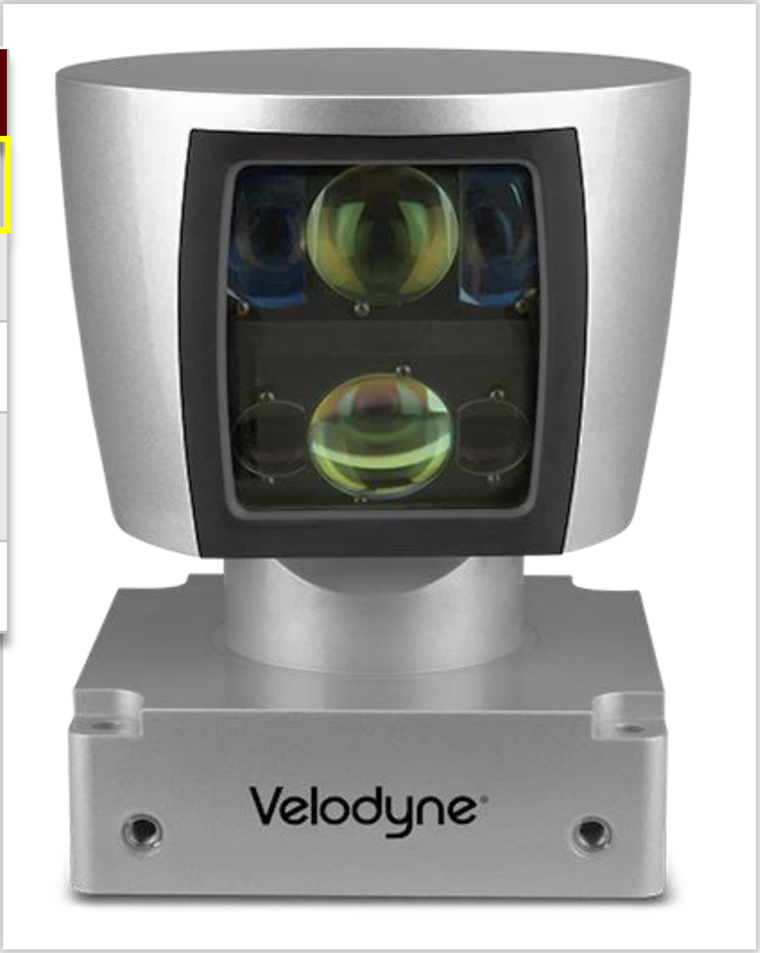
(a)

(b)

Velodyne HDL-64
Commercially available 2007

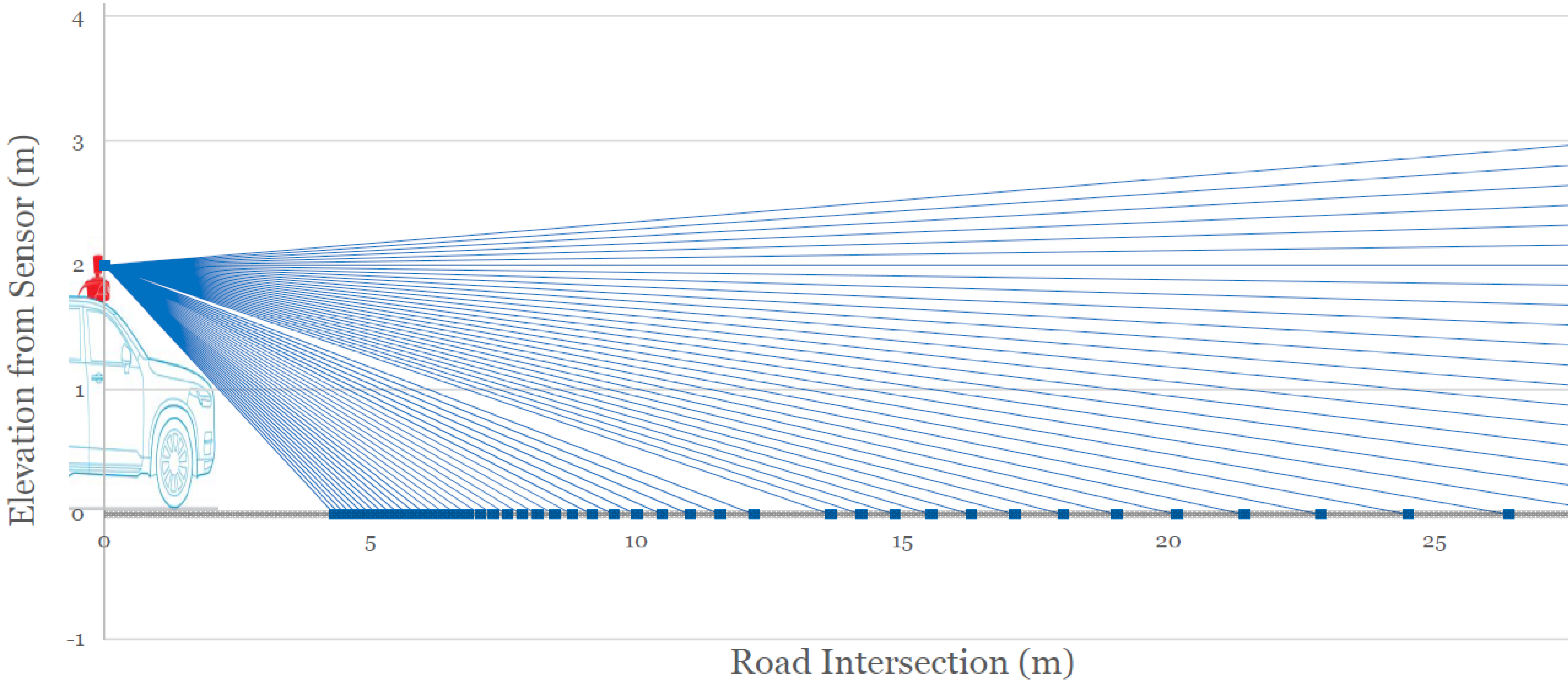
EXCITING TECHNOLOGY

Feature	Velodyne HDL-64
Number of lasers	64 laser diodes
Number of detectors	64 detectors
Horizontal Field of View	360 degrees
Vertical Field of View	+2 degrees to -24.8 degrees

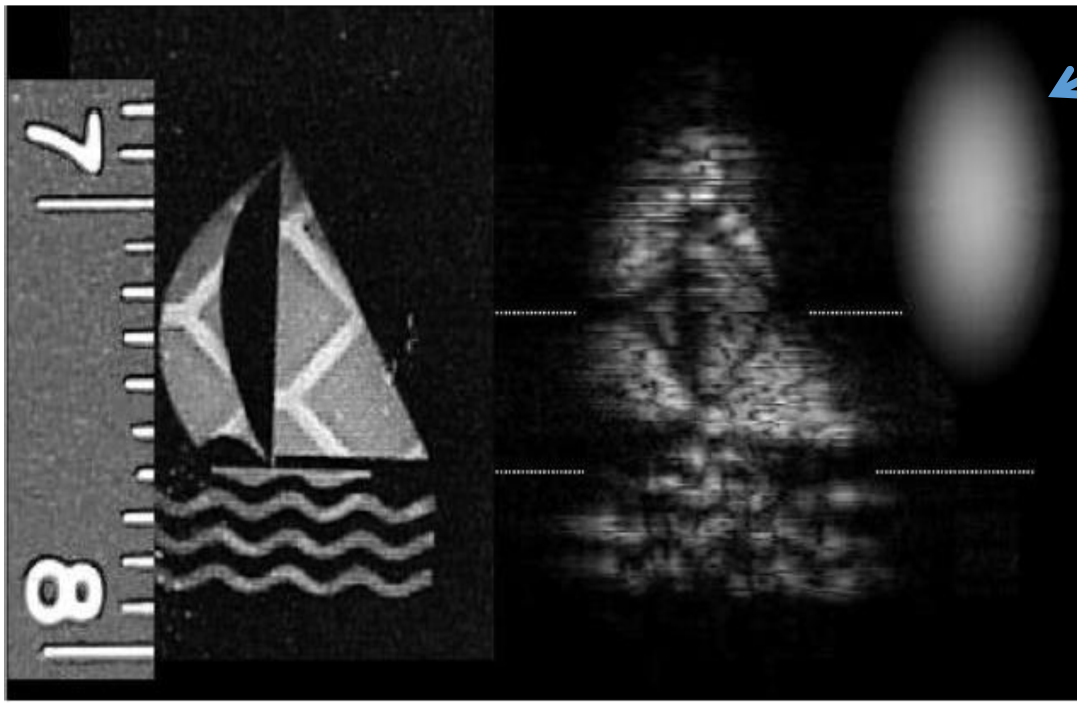


Velodyne HDL-64 (Vertical Field of View)

The Elevation coverage shown below would be for the lidar mounted 2 meters above a flat road

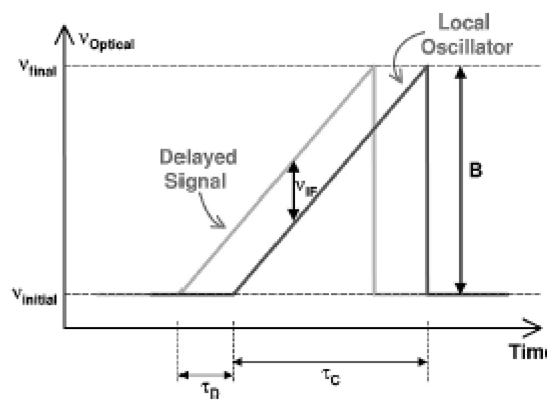


Aerospace "SAIL", Synthetic-Aperture Imaging Ladar, Image*



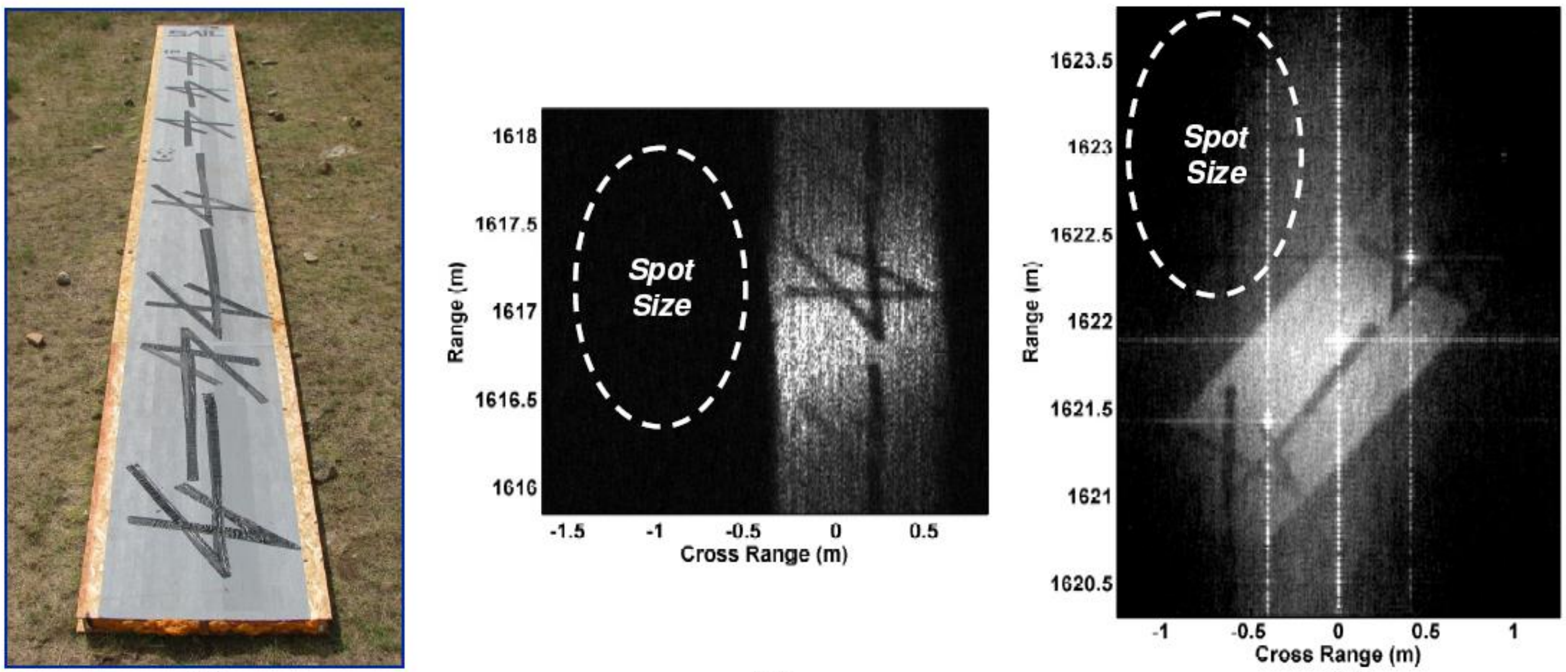
Real aperture diffraction limited spot size

Used FM chirp of LO
For enhanced range resolution



* Synthetic-aperture imaging laser radar: laboratory demonstration and signal processing", Steven M. Beck, Joseph R. Buck, Walter F. Buell, Richard P. Dickinson, David A. Kozlowski, Nicholas J. Marechal, and Timothy J. Wright, 10 December 2005 Vol. 44, No. 35 APPLIED OPTICS, p7621-7629

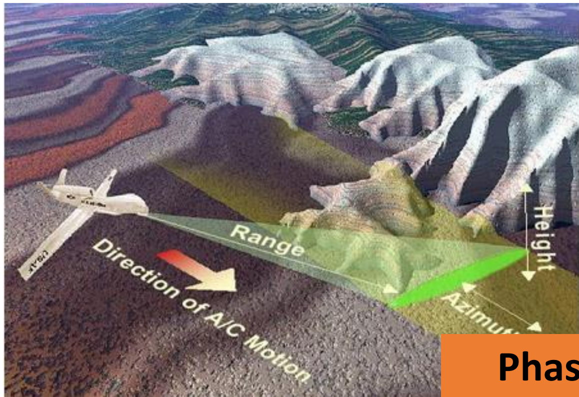
Lockheed Martin Published SAL Flight test results



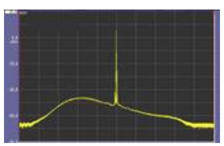
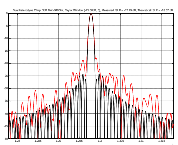
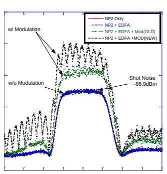
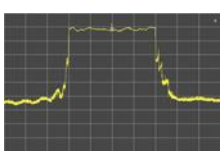
(a) (b) (c)

: SAL demonstration images. (a) Photograph of the target. (b) SAL image, no corner cube glints. Cross range resolution = 3.3 cm, 30x improvement over the spot size. Total synthetic aperture = 1.7 m, divided into 10 cm sub-apertures and incoherently averaged to reduce speckle

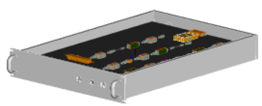
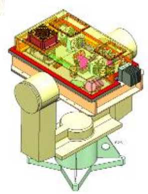
SAL Timeline & Achievements



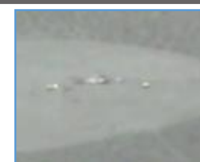
Phase 1A (FY03-04)
Basic Science

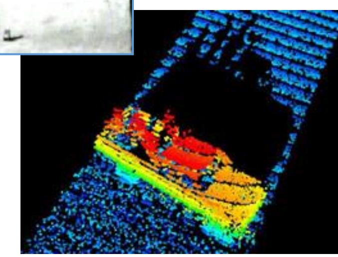
Phase 1B (FY04-05)
Design & Integration

Phase II (FY05-06)
Desert Campaigns




Phase III (FY06-07)
Water & Urban Campaigns

Simulated Images

Feb 16, 2006: ***World's first***
Synthetic Aperture Ladar Image
from an Airborne Platform.

Building Blocks for the Future:
Raytheon has successfully transitioned SALTI from basic laboratory science to a TRL4 sensor with 25+ imaging missions in various climates

History of Laser Radar Summary

EXCITING TECHNOLOGY

- ♦ Laser Radar has a rich history covering > 60 years
- ♦ Early Laser radars used misc lasers - argon, Ruby
- ♦ NdYag Laser designators became widely used
- ♦ CO2 became popular
  - Wind Sensing
  - 3D ladar
  - Navigation
- ♦ Solid State Laser radar came into vogue, replacing CO2
  - Wind sensing
  - 2D laser radar
  - 3D scanning and flash Ladar
- 3D mapping started in the 90's
- Autonomous vehicles
  - Early work in the 80's
  - DARPA grand Challenge in 2005 kicked off the major push
- Synthetic Aperture Lidar in the 2000's