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Electrochemical Power Generation/Storage

Army Research Laboratory

Sensors & Electron Devices Directorate

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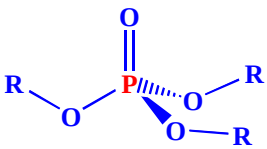
Prototype Batteries

Spin-Airgun



Fire-Retardant Electrolyte Additives

Prototype Fuel Cell

Objectives:

To develop new concepts, materials, and processes for reliable, high-energy, high-power electrochemical devices (i.e., active and reserve batteries, capacitors, fuel cells) that will provide the power for the individual soldier, future combat systems and smart munitions The new power sources will provide longer operating time for equipment at higher power levels under all-weather conditions.

Synopsis:

ARL is working in four basic thrust areas to improve future power sources:

- High-energy batteries for the individual soldier. Current research is on electrode and electrolyte materials for improved storage characteristics, lower temperature performance, and higher power and energy densities.
- Electrochemical capacitors for burst communications and Army vehicles. Research is addressing improved organic electrolytes for increased power and energy densities.
- Fuel cells for individual soldier applications and future combat systems. Research is being conducted on hydrogen generation, improved protonic membranes and electrocatalysts for proton exchange membrane (PEM) fuel cells.
- Munitions batteries. The current effort addresses improvement of thermal design of thermal batteries and the development of miniature liquid reserve batteries for smart munitions.

Payoff to the Soldier:

The development of new and improved compact power sources will give the soldier increased mobility and reduce the logistics tail. Superior power sources will enable current and future information systems to function reliably and efficiently during lengthier battlefield missions.

Publications:

K.Xu, S. Zhang, T.R. Jow, W. Xu, and C. A. Angeli, “LiBOB as Salt for Lithium-Ion Batteries”, J. Electrochem. And Solid State Letters, **5** (1) A26-A29 (2002)

J. Read, A. Driedger, D. Foster, J./ Wolfenstine and W. Behl, Electrochemical and Solid State Letters, **4** A162 (2001)

D. Chu and R. Jiang, “Polymer Electrolyte Membrane Fuel Cells for Communication Applications”, J. Power Sources, 96 (2001)

Connections:

DoD: Army Research Office; Communications-Electronics Command Research, Development and Engineering Center; Tank-Automotive Research, Development and Engineering Center; Army Missile Research, Development and Engineering Center, Department of Energy; Defense Advanced Research Projects Agency; National Security Agency; U.S. Special Operations Command; Naval Surface Warfare Center

Academia: Johns Hopkins University, Case Western Reserve University, Arizona State University, Ilinois Institute of Technology, Penn State

Industry: KTI Co., Lynntech, Maxpower, Eag;e-Picher, Motorola, Precision Combustion, Innova Tek, Maxdem, Giner, Inc., Yardney, SAFT, Honeywell

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MATRIX CONVERTERS

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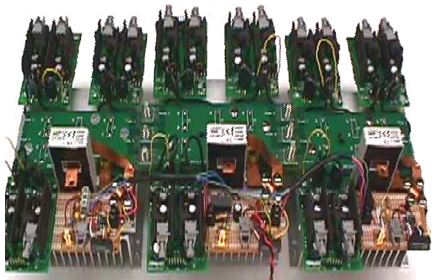

Switches and Drivers for 10 kW Generator Matrix Converter

100 kW Matrix Converter

Objectives:

To develop compact (<10% volume of conventional DC link converters) converters capable of operating AC-AC, DC-AC, AC-DC or DC-DC as required by the application. Applicable to field power and combat vehicle applications.

Synopsis:

ARL is working in two basic thrust areas in matrix converters:

- Fielded Power. Working with CECOM RDEC (Ft. Belvoir) in support of PM Mobile Electric Power. Designing converter for next generation 10 kW Army field generator. Generator produces power at a variable frequency around 400 Hz, which reduces overall system size. Matrix converter stabilizes output voltage and frequency, the latter selectable as DC, 50 Hz, 60 Hz and 400 Hz, with additional frequencies possible.
- Vehicular applications. A 100 kW class matrix converter has been demonstrated as a motor drive. This is the highest power ever demonstrated in a matrix converter. The unit can fit in a 19" electronic equipment rack behind a 6U panel. New developments in controller circuitry promise a further reduction in size by reducing the size of the input filter, which protects the power source from converter switching harmonics. An Inter-Service demonstration of the converter has been proposed, on the Navy's DDX ship simulator facility at NSWC-Philadelphia

Payoff to the Soldier:

Matrix converters will reduce the size and weight of vehicles and mobile generators, and permit multiple functions to realized with a single converter. This combines to reduce the logistics trail by lightening the load and reducing the number of spare parts needed to be brought into the field.

Publications:

Pat W Wheeler, Jon C Clare, Dimos Katsis, Tom Podlesak, Michael Bland, Lee Empringham," A 150KVA Matrix Converter Induction Motor Drive", to be presented at the EPE Power Electronics and Motion Control Conference

Dimosthenis Katsis, Lee Epringham, Mike Bland, Patrick Wheeler, Jon Clare and Pericle Zanchetta, "A Three-Phase Utility Power Supply Based on the Matrix Converter", submitted to IEEE 2004 Industrial Application Society Annual Meeting

T.F. Podlesak, D. Katsis, P. W. Wheeler, J. C. Clare, M. Bland, L. Empringham, "A 150KVA Vector Controlled Matrix Converter Induction Motor Drive," submitted to IEEE 2004 Industrial Application Society Annual Meeting

Connections:

DoD: Communications-Electronics Command Research, Development and Engineering Center; Tank-Automotive Research, Development and Engineering Center; Naval Surface Warfare Center

Academia: University of Nottingham, UK, Texas A&M University, University of South Carolina

Industry: Rockwell, International Rectifier, Dynex

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Directed Energy for Force Protection

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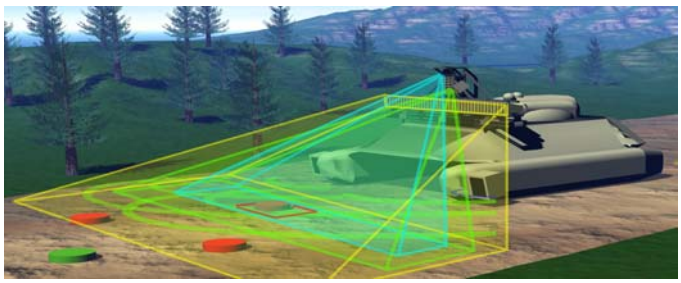

Conceptual FCS HPM System

Objective:

ARL is investigating the technologies necessary to use Radio Frequency (RF) Directed Energy (DE) to neutralize the electronics in various threat systems, including explosive devices such as on and off route mines/booby traps. This technology provides "speed of light" engagement, stand off range, wide area of coverage resulting in a high probability of hit and an infinite magazine. Adjustable power levels allow for scalable effects to minimize collateral damage.

Synopsis:

ARL is investigating RF models and techniques to determine RF parameters required to cause neutralization of these devices. This investigation includes identifying mission critical components in mines and booby traps, utilization of electromagnetic coupling and effects models to determine most effective source parameters, and RF effects testing. The knowledge gained from these investigations will be used to design efficient, effective, and affordable RF DE countermine/booby trap systems.

Payoff to the Soldier:

One of the greatest threats to life in current operations is the use of electronically fuzed explosive devices. By providing stand off distance and high probability of engagement, a RF DE system in combination with other techniques to neutralize explosive devices will allow the Future Force to conduct operational tempo mounted operations in areas that have mine and booby trap systems in place.

Collaborations:

Academia: *University of Maryland*
Government: CERDEC, ARDEC, NSWC, NRL, AFRL

References:

1. Mark Berry, Benson King, John Tatum, "Countering Potential Remote Triggering Devices Using RF DE," Sixth Annual Directed Energy Symposium Proceedings, 22 Oct 2003.
2. Classified reports, contact John Tatum or Todd Turner for more information

Prototype Pick-up Truck Mounted HPM System

Prototype 2.5 Ton Truck Mounted HPM System

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Alternative Energy Sources

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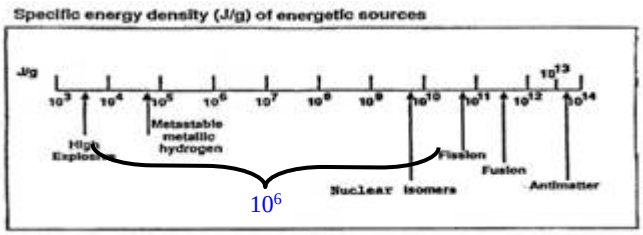

The energy density stored in spinning excited states of nuclei exceed the chemical energy densities by at least 5 orders of magnitude

Objective:

Investigate technologies to develop energy dense fuels that would reduce or eliminate the need for warfighters to be re-supplied during a campaign.

Develop a capability within the army to exploit clean, high-energy-density (HED) materials as sources of non-fissionable nuclear energy. These technologies can produce intense localized bursts of energy. Alternatively, they can be triggered so as to provide a long cascade of small energy states producing lower levels and longer lasting power for force sustainment.

Alternative energy solutions and appropriate energy conversion techniques must be matched to the application.

Synopsis:

The US participates in joint/coalition regional conflicts taking our forces worldwide for undetermined periods of time. An opponent, unable to match strength with our forces can still achieve victory by employing an energy denial strategy.

More than 50% of the carbon based fuels have been discovered. Alternative energy sources must be considered in reference to the long-term future and availability of these fuels.

The Alternative Energy Team is evaluating series of long live isomeric materials. These include americium, lutecium, silver, holmium, and hafnium. The materials are compared for energy stored, ease of triggering, energy level of trigger, availability of isotope, form of energy ouput. The concept design continues with identifying the optimum energy conversion technique. This depends on the mix of energy released by the isomers, which may encompass alpha particles, betas, gammas, or heat. Thermoelectric conversion is the least efficient, and therefore we look to harvesting the energy from (thermo) photovoltaics, beta conversion (semiconductor junctions) and alpha converters (ionization chambers).

Isomers hold tremendous potential, but the field is still in the basic research phase.

- Material burnup experiments, currently underway are evaluating and comparing the cross-section for trigger interaction of the different materials
- Numerical calculations addressing concept designs and configuration are in progress.
- Produce samples of the isomeric materials with sufficient ratio to ground state to make measurements producing unambiguous cross section measurements and clear conclusions.

We are investigating ways to control the release and better characterize the process.

Payoff to the Soldier:

We must be prepared to deploy rapidly, sustain indefinitely, and re-supply rarely. This work will lead to concept design of compact, long-lived, high-energy density nuclear power sources for unattended sensors, UAVs, and soldier full-mission time-frame individual power.

Providing compact, long-lived, high-energy density power sources will contribute to sustainability, deployability, and survivability of the objective force.

Connections:

Government: Naval Surface Warfare Center-CD, Army CECOM, Army NSC, NSA, DIA, Air Force Research Laboratory; Naval Research Laboratory, NASA

Academia: Youngstown State University, Alabama A&M

Industry: SRS, BTG

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Battlefield Acoustic Sensors

Army Research Laboratory

Sensors & Electron Devices Directorate

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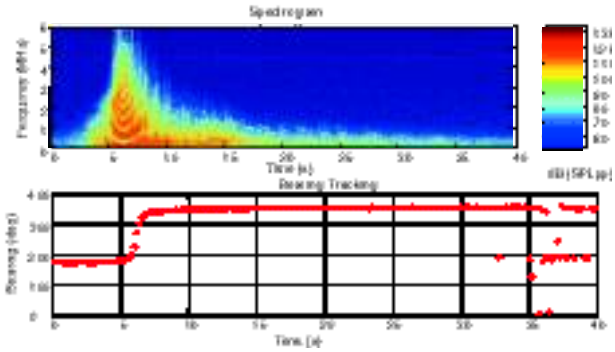
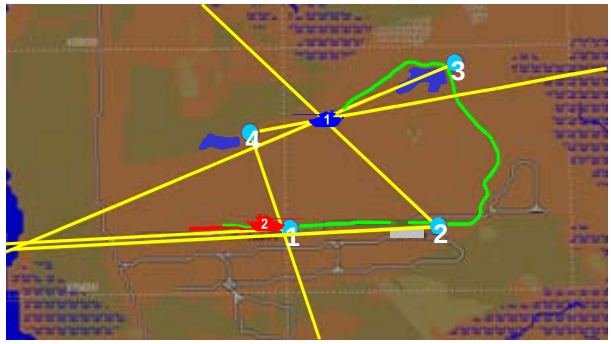


Signature and bearing plot of a cruise missile.



Lines of bearing and target tracks from two tracked vehicles.

Objective:

To provide the underlying technology needed to make acoustic sensors practicable for future Army systems. Acoustic sensors placed on the ground or mounted onboard robotic vehicles are passive and can provide real-time, non-line-of-sight tracking and identification of battlefield targets at very low cost. Infrasonic sensors have been implemented for long range event detection and localization. ARL is performing both basic and applied research in target location and identification, sensor designs, and sensor performance assessment.

Synopsis:

Acoustic technology offers the potential for very small, extremely low-cost, non-line-of-sight battlefield sensors that would significantly add to the soldier's awareness of the battlefield. ARL is focused on such key technical areas as beamforming , target classification and identification algorithms, target tracking, sensor designs, signature modeling and field validation of results. This research enables systems to track helicopters, locate gunshots, and identify ground vehicles.

Payoff to the Soldier:

Applications of battlefield acoustic sensor technology include

- individual soldier alert sensors,
- unattended ground sensors,
- sniper localization, and
- infrasonic localization of missiles and artillery.

The work is coupled to ARL's Advanced Sensors Collaborative Technology Alliance (CTA) and to Training and Doctrine Command (TRADOC) users.

Connections:

Army: Communications-Electronics Command/Night Vision and Electronic Sensors Directorate; Tank-Automotive Command; Armaments Research, Development and Engineering Center; TRADOC/Dismounted Battlespace Battle Lab; Army Research Office; Engineering Research and Development Center (ERDC-CRREL); INSCOM; Project Manager for Close Combat Support

Navy: Office of Naval Research, Naval Undersea Warfare Center, Naval Surface Warfare Center, Marine Corps Commandant's Warfighting Laboratory

Industry: AAI, BAE Systems, BBN, C. S. Draper Labs, Textron, Signal System Corporation

Academia: University of Maryland, University of Washington, Boston University, Pennsylvania State University, University of Mississippi, Johns Hopkins University/Applied Physics Laboratory, Morgan State University, Bucknell University, University of Southern California, Ohio State, Georgia Tech, Clark Atlanta, University of Florida, Massachusetts Institute of Technology

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EO/IR Imaging Processing

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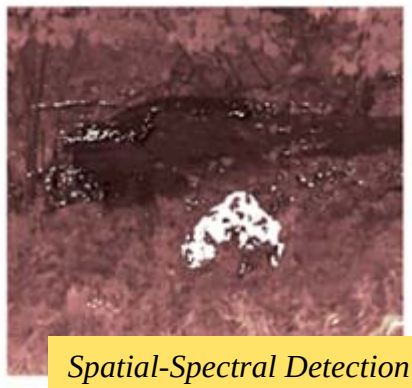
Hyperspectral Image



Spatial-Spectral Detection

Objective:

To research & develop innovative techniques & algorithms for maximizing the detection, clutter rejection and identification capability of emerging sensors & missile seekers.

Synopsis:

Detecting targets in challenging battlefield operating conditions- such as partial occlusion and obscuration- requires advanced techniques that use available information, including spatial & spectral information, images from reconnaissance platforms, moving targets, or information from other sensors. The need for algorithms that are compatible with affordable and power-constrained processors adds to the challenge. This research program is an in-house capability that delivers algorithms & answers to Army customers using broadband and multi-spectral passive infrared sensors, and imaging laser sensors on standard Army platforms or subsystems of networked sensors or robotic sensors.

Payoff to the Soldier:

Image processing offers the potential to dramatically reshape the future fighting force by reducing operator/analyst overload. Leveraging current and projected investment in ATR to enhance conventional munitions will greatly increase weapons lethality while potentially decreasing fratricide.

Publications:

Lipchen Alex Chan, Sandor Z. Der, Nasser M. Nasrabadi, Automatic Target Detection, Encyclopedia of Optical Engineering 2003, Marcel Dekker.

H. Kwon, S. Der, and N. Nasrabbadi, “Adaptive multisensor target detection using feature-based fusion,” Opt. Eng., 41(1) 69-80, January 2002 .

H. Kwon, S. Der, and N. Nasrabadi, “Adaptive anomaly detection using subspace separation for hyperspectral imagery,” Opt.Eng. 42(11) 3342-3351, 2003.

Connections:

DoD: CERDEC-NVESD, AMRDEC, ERDC-TEC, SMDC

Academia: University of Maryland, Duke University, Clark Atlanta University, Georgia Institute of Technology

Industry: BAE Systems, Northrop Grumman

Point of Contact:

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SYDET - XM153
Sympathetic Detonator / Timer

Army Research Laboratory
Sensors & Electron Devices Directorate

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Objective:

Develop a system to simultaneously detonate numerous unlinked explosive charges through the command and control of only one.

Approach:

SYDET will have two modes of operation:

- Sympathetic: Munition detects nearby explosions (via acoustic sensor) and, if verified by on-board algorithms, will detonate its charge.
- Time Delay: At a pre-set time, the munition will detonate its explosive. Similar to M147 TDFD. However, both relative and Absolute timers can be used.

SYDET will consist of three variants:

- Open-Air
- Underwater
- Surf-Zone

Point of Contact:

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aladas@arl.army.mil

Payoff to the Soldier:

The XM153 SYDET provides the soldier with a small, effective, safe and affordable munition system. It will eliminate the need for connecting explosive charges together which will lighten the soldier's load and will decrease his "time-on-target." It is compatible with existing demolition munitions and allows pre-assembled demolition packages because only "secondary" explosives are used in the fire train.

Status:

Open-Air Variant:

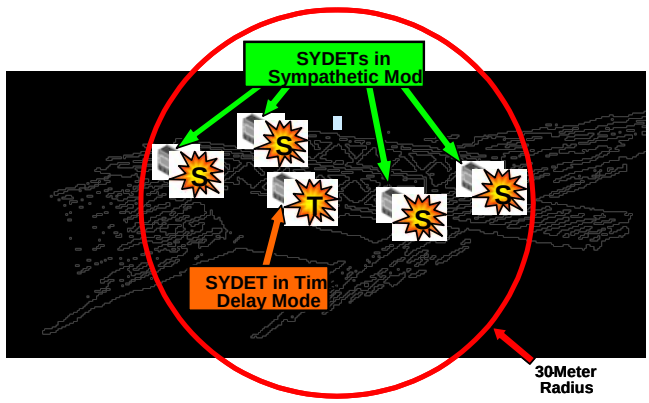
- Design completed; DT Testing underway
- Type-Classification planned for FY04

Underwater Variant:

- Currently in early development

Surf-Zone Variant:

- Currently in concept stages



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M152 Remote Activation Munition System (RAMS)

Army Research Laboratory
Sensors & Electron Devices Directorate

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SSG David Sander with RAMS in An Najaf

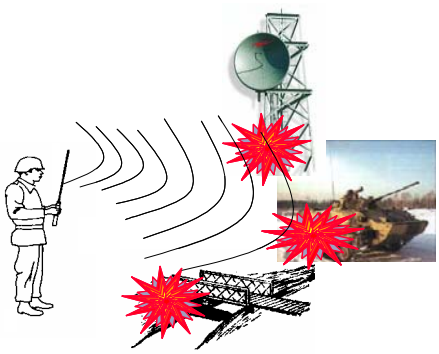
Objective:

Develop a system that provides a capability to remotely control the detonation of demolition charges or the operation of other electronic items such as beacons, laser markers, radio functions, weapons, etc.

Approach:

RAMS consists of four major components:

- Transmitter – Transmits coded rf signals to 1 or more receivers.
- M16 Receiver – Electrical output initiates M6 caps or electrical items.
- M17 Receiver– Explosive output initiates M7 & secondary caps.
- Auxiliary Power Pack – Extends transmission range to 5+ km.



Payoff to the Soldier:

The M152 RAMS provides the soldier with a system that provides extended range; enhanced safety; and increased mission capabilities as compared to the previously-used M122 remote control system.

Status:

- M152 was "Type-Classified" in FY98
- M152 is being used in the field today by SOF, USMC & Army EOD.
- M17 was "Type-Classified" and is in production.
- ARL / SEDD provides production & PM support.
- ARL / SEDD is developing system enhancements for shock tube initiation and magneto-inductive transmissions in urban and subterranean environments.

Impact:

The user has praised this system as a "vital advance in technology for the Special Operations Forces in their missions ranging from Humanitarian Assistance to Counter-Insurgency to Low Intensity conflict to Full Scale War."

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Currently in use by USSOCOM

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HMMWV Auxiliary Weapons Mount (HAWM)

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Objective:

Design and fabricate a low-cost Auxiliary Weapons Mount for HMWWV's so that an additional weapon may be used in a combat mission.

Approach:

Providing a rapid response to a real field need, ARL designed a HMMWV Auxiliary Weapons Mount (HAWM). To meet the urgent requirements of Operations Iraqi Freedom and Enduring Freedom, AMC-FAST Activity and ARL installed HAWMS on HMMWV's of the 173rd Airborne Brigade for Operations and later delivered several HAWM's to other military units.

Payoff to the Soldier:

The HAWM provides the soldier a second weapon of choice for rapid deployment into a wider range of missions and eliminates the need to re-mount desired weapons. It also allows the turret to rotate more easily because weapons are offset to balance weight distribution.

The 173rd Airborne Brigade stated that they "employed the [HAWM] in combat and it's capability already saved lives."

Design Features:

Provides a platform for an additional weapon:

- M249 SAW
- M240 60-mm Machine Gun
- M2 .50-cal Machine Gun
- MK19 40-mm Grenade Launcher.

- Provides a counter-balance on the turret to balance weight distribution.
- Reduces cost and increases reliability over previously designed systems

Status:

67 HAWM's were delivered to units in Baghdad including the 173rd Airborne Brigade; 501st MP Co; 82nd Airborne Division; 101st Airborne Division and Maryland National Guard.

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Rapid Technology Transition to the Soldier

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AOTF Sensor Development

Army Research Laboratory
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Dr. Zoltan G. Sztankay; (301) 394-3130 sztankay@arl.army.mil

Objective:

To develop the technology to produce the Army's next generation of hyperspectral/polarization imaging sensors by insertion of an acousto-optical tunable filter (AOTF) cell in the optical train of a high-sensitivity focal plane array (FPA). Several such imagers are being designed to cover the full optical spectrum. These sensors will be field-portable, low cost, low maintenance, and smart. They will demonstrate better recognition ability, more efficient data collection, faster decision times, and greater ability to function in all environments.

Synopsis:

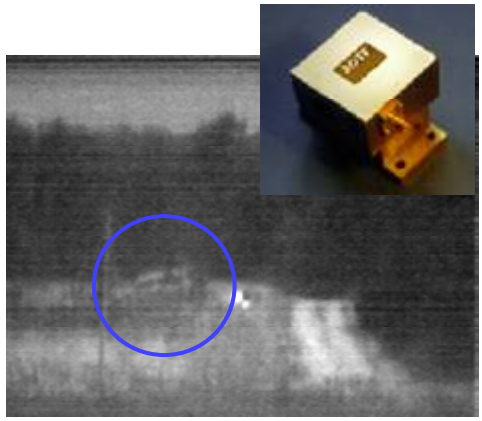
Research into AOTF technology is aimed at improving AOTF cell materials and design as well as transducer design. For AOTF imagers, there are two research goals: (1) making AOTF cells that operate over a wider spectral range, operate at low power, and have high throughput and low sidelobes, and (2) designing better infrared (IR) AOTFs. Mating such cells with higher sensitivity, larger FPAs will allow us to carry out better target discrimination and operation in all battlefield conditions.

ARL performs AOTF design and characterizations as well as imager design, fabrication, and testing. Currently, ARL is developing the following AOTF-based sensors:

1. UV visible (UVVIS 220-450 nm), visible near-IR (VNIR, 400–1000 nm), short-wave IR (SWIR, 800–1700 nm), mid-wave IR (MWIR, 2–4.5 µm), and long-wave IR (LWIR, 8–12 µm) hyperspectral/polarimetric imagers that use off-the-shelf FPAs and optics, as well as electronically tunable retarders. The first imager above uses KDP AOTF cell, imagers 2 to 4 use tellurium dioxide (TeO_2) cells, and the last uses a thallium arsenic selenide (TAS) cell.
2. Computer-controlled, high-resolution, high-sensitivity AOTF spectrometers for chemical/biological detection operating in the 260–430 nm, 400–800 nm, 1.1–2.2 µm, and 2.0–4.5 µm ranges.

Payoff to the Soldier:

This work will yield the capability to passively detect tactical targets in foliage and camouflage. It will also provide the underlying technology for a field-portable chemical/biological agent detection system.



Hyperspectral image at 660 nm revealing truck hidden under camouflage net. Insert shows an AOTF cell.

Publications:

1. "Object detection with a field-portable spectropolarimetric imager," App. Opt. 40, pp. 6626-6632, 2001.

2. "Acousto-optic tunable filter based visible-to-near-infrared spectropolarimetric imager," Opt. Eng. 41, pp. 1033-1038, 2002.

Connections:

DoD: Communications-Electronic RDEC / Night Vision and Electronic Sensors Directorate, Aviation and Missile RDEC, Edgewood Chemical and Biological Center, Space and Missile Defense Command, Defense Advanced Research Projects Agency, Topographic Engineering Center, Tank and Armaments RDEC.

Academia: Carnegie Mellon University, Moscow State University, University of Maryland

Industry: Northrop Grumman, Raytheon, BAE, SE-IR, Advanced Materials Corporation, Coherent Technology Incorporated.

Points of Contact:

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FM/cw Laser Radar R&D for Battlefield Applications

Army Research Laboratory
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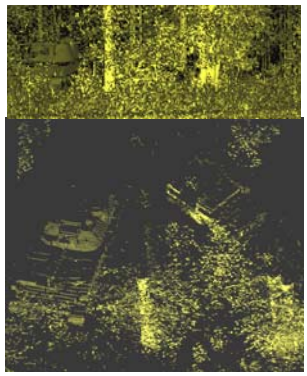

Image showing the power of a ladar sensor to separate targets from clutter. The top figure shows a ladar image collected in the field from the ladar viewpoint. The bottom figure shows the same data set rotated in the computer to expose a HumVee hidden behind thin intervening foliage.

Objective:

To develop designs for low-cost ladar (laser detection and ranging) for smart munitions and robotics, and long-range ladar for reconnaissance/surveillance. These ladar designs are staring array imagers, i.e., not mechanically scanned and therefore will provide a compact, low-cost, and high-resolution, 3-D imager required for a wide range of Army missions. ARL's research focuses on a novel direct detection ladar architecture employing frequency-modulated/continuous-wave (FM/cw) ranging techniques, photonic mixing detector arrays, and cw lasers. Research topics include developing wideband amplitude-modulated laser sources, novel photonic mixing detector arrays, high-speed computationally efficient signal processors, and automatic target recognition (ATR) algorithms.

Synopsis:

The ARL ladar measures range and intensity by applying conventional FM/cw radar techniques to direct detection ladar. The modulated laser floodlights the battlefield and the receiver lens images the backscattered light onto a detector array. The original modulation signals are mixed with the target return signals in the photonic mixing detectors to produce signals from which the target range and intensity image is extracted by a temporal Fourier transform.

With low signal-processor bandwidths and modest signal-to-noise ratios (SNRs), the ARL FM/cw ladar can achieve a range resolution of less than 30 cm and simultaneously resolve multiple target returns in one pixel. This capability enables imaging targets obscured by camouflage, foliage, or smoke. By comparison, pulsed ladars need wide signal-processing bandwidths and high SNRs to resolve such target returns, increasing system cost and complexity. Previous FM/cw ladars used coherent detection requiring precise alignment and phase coherent lasers, also increasing cost and complexity.

Payoff to the Soldier:

Under Technology Planning Annexes with the Armament Research, Development and Engineering Center (ARDEC) and the Aviation and Missile Research, Development and Engineering Center (AMRDEC), ARL is adapting its ladar for deployment on projectiles and missiles to detect targets deep behind enemy lines and for terminal guidance.

In the ARL CTA program, ARL will demonstrate how a ladar integrated with passive infrared sensors can provide reliable high-resolution battlefield surveillance and target identification on a military platform. In a joint project with the Communications and Electronics Command (CECOM) for the Army's 3rd generation of infrared imagers, ARL's integrated passive and ladar sensor will be the precursor to advanced integrated sensors for future combat systems.

Since unmanned robotic vehicles can perform missions in hazardous areas without endangering soldiers, ARL is adapting its ladar for robotic vehicle navigation and surveillance in a joint program with the National Institute of Standards and Technology (NIST).

Publications:

B. Stann, W. Ruff, and Z. Sztankay, "Intensity-modulated diode laser radar using frequency-modulation/continuous-wave ranging techniques," Opt. Eng. 35 (1996), 3270–3278.

W. Ruff, et. al., "Characterization of a 32-element linear self-mixing detector array for an FM/cw ladar," Proc SPIE Laser Radar Technology and Applications VII, Vol. 4723, (2002).

B. Stann, et. al.,"Research progress on a focal plane array ladar system using a laser diode transmitter and FM/cw radar principles," Proc SPIE Laser Radar Technology and Applications VII, Vol. 4723, (2002).

Connections:

Gov't.: AMRDEC, ARDEC, CECOM, DARPA, NIST

Academia: University of New Mexico, University of DE

Industry: BAE Systems, PyramidTech Inc., MIT/Lincoln Labs

Points of Contact:

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Chirped AM Laser Radar R&D for Battlefield Applications

Army Research Laboratory
Sensors & Electron Devices Directorate

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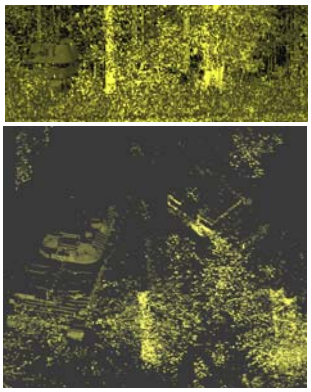
Image showing the power of a ladar sensor to separate targets from clutter. The top figure shows a ladar image collected in the field from the ladar viewpoint. The bottom figure shows the same data set rotated in the computer to expose a HumVee hidden behind thin intervening foliage.



Objective:

To develop designs for low-cost ladar (laser detection and ranging) for smart munitions and robotics, and long-range ladar for reconnaissance/surveillance. These ladar designs are staring array imagers, i.e., not mechanically scanned and therefore will provide a compact, low-cost, and high-resolution, 3-D imager required for a wide range of Army missions. ARL's research focuses on a novel direct detection ladar architecture employing frequency-modulated/continuous-wave (FM/cw) ranging techniques, photonic mixing detector arrays, and cw or long-pulse lasers. Research topics include developing wideband amplitude-modulated laser sources, novel photonic mixing detector arrays, high-speed computationally efficient signal processors, and automatic target recognition (ATR) algorithms.

Status:

A recently developed 32x32 pixel breadboard of the ARL staring ladar is shown in the accompanying photo. Here a semiconductor diode laser flood illuminates the receiver's field of view. Laser light reflected from the target is collected with a camera lens and focused onto a 32x32 pixel detector array researched and built at ARL. Photocurrents from each detector are captured with read-out electronics and then fed into a PC which computes the range to each pixel in the field of view and displays the data in three-dimensions. A photo of a target scene shows a cardboard "A" followed by a poster board and a some cardboard boxes as a backdrop. The three-dimensional image captured by the breadboard shows a clear image that displays the respective range differences between the objects in the scene. The image quality is equal to or better than obtained by other groups researching staring ladars.

Payoff to the Soldier:

Under Technology Planning Annexes with the Armament Research, Development and Engineering Center (ARDEC) and the Aviation and Missile Research, Development and Engineering Center (AMRDEC), ARL is adapting its ladar for deployment on projectiles and missiles to detect targets deep behind enemy lines and for terminal guidance.

In the ARL CTA program, ARL will demonstrate how a ladar integrated with passive infrared sensors can provide reliable high-resolution battlefield surveillance and target identification on a military platform. In a joint project with the Communications and Electronics Command (CECOM) for the Army's 3rd generation of infrared imagers, ARL's integrated passive and ladar sensor will be the precursor to advanced integrated sensors for future combat systems.

Since unmanned robotic vehicles can perform missions in hazardous areas without endangering soldiers, ARL is adapting its ladar for robotic vehicle navigation and surveillance in a joint program with the National Institute of Standards and Technology (NIST).

Publications:

B. Stann, et. al.,"Research progress on a focal plane array ladar system using a laser diode transmitter and FM/cw radar principles," Proc SPIE Laser Radar Technology and Applications VIII, Vol. 5086, (2003).

Points of Contact:

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Passive Infrared Detection and Imaging

Army Research Laboratory
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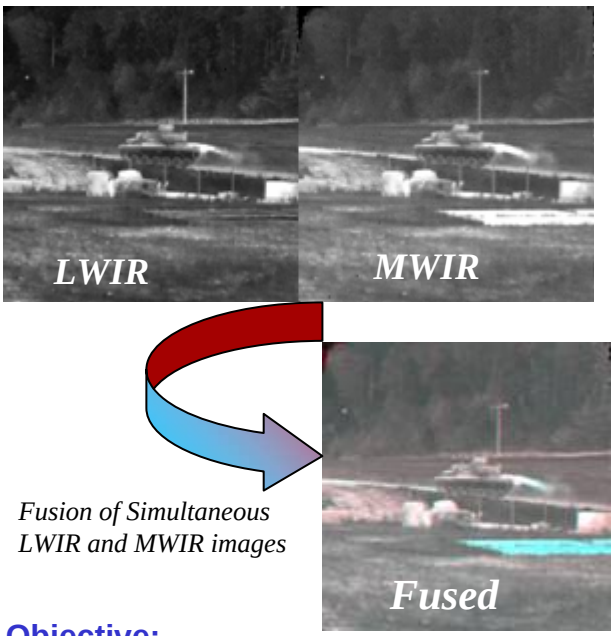


Fusion of Simultaneous LWIR and MWIR images

Objective:

To test and evaluate candidate detectors for the Army's next generation of infrared sensors. These sensors will allow the development of night-vision devices that will be highly sensitive, low cost, low maintenance, smart, multispectral, and multifunctional. They will demonstrate better recognition ability, faster decision times, higher operating temperature, and better ability to function in all environments over currently available IR sensors

Synopsis:

ARL is working to evaluate new infrared detector and focal plane arrays (FPAs) in both laboratory and field environments.

- Laboratory evaluation of dual-band quantum well infrared photodetector (QWIP) Mercury cadmium telluride (MCT) photodetectors produced under the Advanced Sensors Collaborative Technology Alliance program.
- Field data collections for DoD customers using single-band and dual-band IR camera systems.
- Measurements of the performance of advanced infrared detector structures such as quantum dots and Type II Superlattices.

Payoff to the Soldier:

This work will lead to the production of infrared sensors that will provide enhanced situational awareness on the battlefield in all ambient conditions including greater effectiveness in defeating IR countermeasures such as smoke, camouflage, and flares. It is a critical component of the Army Science and Technology Objective "Third Generation Infrared Imaging Technology." Other dual-band IR sensors may be used to exploit the spectral signature of disturbed soil to remotely detect minefields.

Connections:

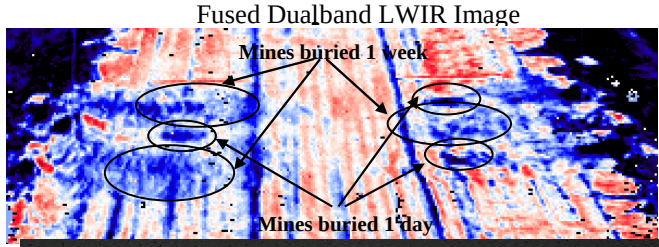
DoD: Army NVESD, AMCOM, TACOM, SMDC, Missile Defense Agency; Air Force Research Laboratory; Naval Research Laboratory, NASA

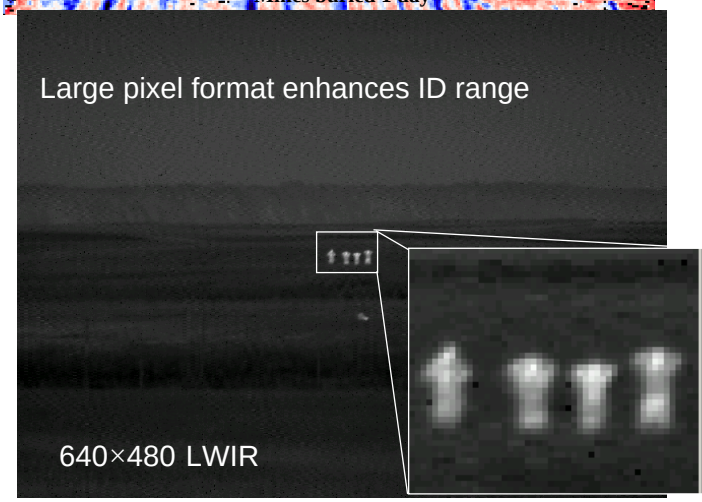
Academia:

University of New Mexico, University of Maryland, Northwestern University, University of Hawaii.

Industry: DRS, Inc.; BAE Systems ; Indigo Systems

Fused Dualband LWIR Image





Points of Contact:

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Cold Atom Research

Army Research Laboratory
Sensors & Electron Devices Directorate

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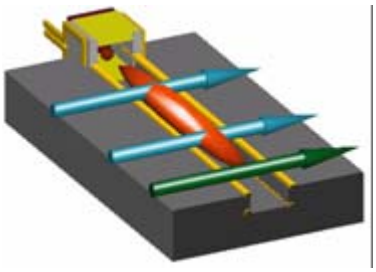
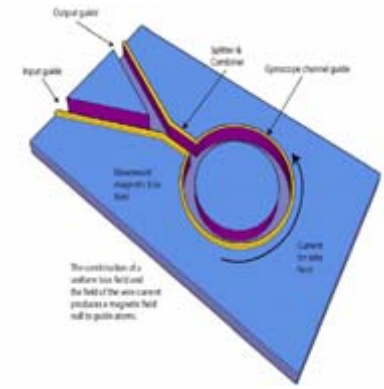
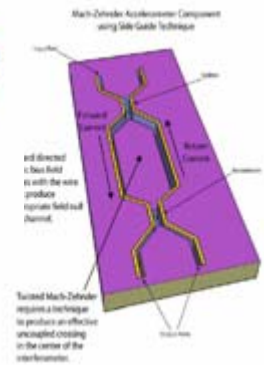
Dr. Tom Bahder 301-394-2044
Dr. Z. G. Sztankay 301-394-3131







Some Atom chip devices: Clockwise from the upper left, an atomic clock concept using a guided cold atom beam, an atomic clock prototype chip including fiber optic channels and a MEMS produced atomic waveguide, concept drawing for an atom chip based gyro, concept drawing for an atom chip accelerometer.

Objective:

To explore techniques for manipulating cold atom clouds and Bose-Einstein condensates (BEC) on miniature devices called atom chips. New types of atomic interferometric sensors for the detection of accelerations, gravity gradients, and rotations will be studied. A new class of miniature atomic clocks using atom chip technology will be explored. In addition, the possibility of cold atom delay lines using BEC filled atom waveguides and slow light will be studied. To support the idea of an atom chip sensor, this program will also explore the development of supporting technologies such as techniques for maintaining ultra-high vacuums on the atom chip using MEMS based vacuum techniques.

Synopsis:

ARL is working to understand, construct and experimentally demonstrate various cold atom devices based on cold atom chip techniques.

- Development of a Cold Atom Laboratory for flexible experimental testing of various atom chip devices.
- Design and construction of atom chip devices at the ARL clean room facility.
- Theoretical and experimental studies of techniques for guiding, splitting and detecting cold atom matter waves for use in atom chip interferometry.

Payoff to the Soldier:

It is expected that this work will lead to a new class of highly sensitive, reprogrammable, miniature sensors of gravitational and electromagnetic fields that will be of use on the battlefield. The inherent miniaturization involved in these devices will allow inexpensive production of these atomic devices using available techniques from the microelectronics industry.

Collaborations:

Academia*:* George Washington University, University of Colorado JILA (ARO MURI), Stanford University (ARO MURI), University of Maryland

Government:

Naval Research Laboratory, National Institute of Standards and Technology

Points of Contact:

Dr. Mike Golding 301-394-1535
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Interband Cascade Laser Development

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Richard L. Tober (301) 394-5756 richt@arl.army.mil

Objectives:

Develop high-efficiency semiconductor lasers emitting in the 3-5mm spectral region (IRCM Bands II & IV) capable of operating under cw conditions at TE-cooler temperatures (>240K) or higher. Achieve greater than 50% reductions in IRCM system weight, volume, and prime power requirements over present-day solutions.

Synopsis:

ARL has made significant strides in the development of efficient mid-IR semiconductor lasers during the past two years based on the interband cascade laser design in the InAs/GaSb material system ; these include world records for mid-IR semiconductor laser output power (>6W/facet peak), wall-plug efficiency (>20% at 80K), and operation at room temperature. The program is currently focussing on developing improved laser designs, MBE growth procedures, and device fabrication procedures that will further enhance device performance to meet ARL-03 STO objectives.

Payoff to the Soldier:

Improved efficiency mid-IR semiconductor lasers will significantly enhance the ability of IRCM systems to defeat IR-guided missile threats to FCS mobile ground platforms and fixed- and rotary-wing aircraft. This will enhance FCS survivability and lethality. Additionally, if cw performance at TE cooler temperatures can be achieved, these lasers will provide new practical tools for the sensitive detection of RDX for mine/explosives detection and the detection of bio-agents. They will also enable the development of high-bandwidth battlefield communications over rapidly deployable, all-optical, secure communication networks.

Publications:

Rui Q. Yang, John L. Bradshaw, J. D. Bruno, J. T. Pham, and D. E. Wortman, “Power, Efficiency, and Thermal Characteristics of Type-II Interband Cascade Lasers”, IEEE Journ. Quant. Electron. 37, (2)282 (2001).

J. D. Bruno, J. L. Bradshaw, R. Q. Yang, J. T. Pham, D. E. Wortman, “Low-Threshold Interband Cascade Lasers with Power Efficiency Exceeding 9%”, Appl. Phys. Lett. 76, 3167 (2000).

J. L. Bradshaw, J. D. Bruno, J. T. Pham, D. E. Wortman, R. Q. Yang, “Continuous Wave Operation of Type-II Interband Cascade Lasers”, IEE Proceedings- Optoelectronics 147, 177 (2000).

J. L. Bradshaw, J. D. Bruno, J. T. Pham, D. E. Wortman, R. Q. Yang, “Midinfrared Type-II Interband Cascade Lasers”, J. Vac. Sci. Technol. B 18, 1628 (2000).

R. Q. Yang, J. D. Bruno, J. L. Bradshaw, J. T. Pham, D. E. Wortman, “Interband Cascade Lasers: Progress and Challenges”, Physica E 7, 69 (2000).

Connections:

DoD: CECOM, ARFL

Academia: MIT/LL, Univ. of Maryland, State Univ. of New York, Stony Brook

Industry: Maxion Technologies, Inc.

Point of Contact:

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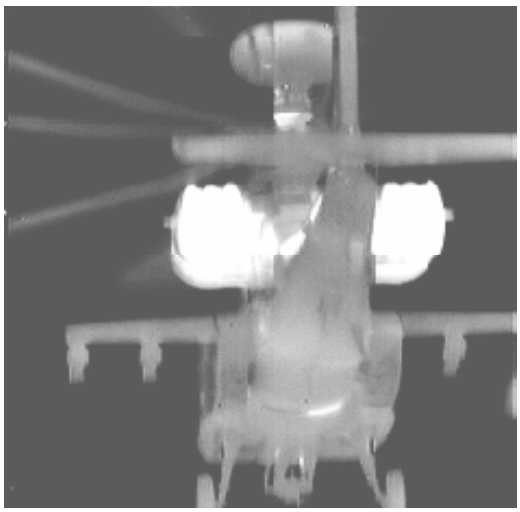
Infrared Detector Development

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Nibir K. Dhar (301) 394-0947 ndhar@arl.army.mil



IR image of Apache helicopter

Objective:

To develop the technology to produce the Army's next generation of infrared sensors. These sensors will allow the development of night-vision devices that will be highly sensitive, low cost, low maintenance, smart, multispectral, and multifunctional. They will demonstrate better recognition ability, faster decision times, higher operating temperature, and better ability to function in all environments.

Synopsis

ARL is working in two basic thrust areas to improve future IR sensors:

- **Semiconductor quantum structures for infrared detection**. Currently based on GaAs and related III-V compound semiconductors, nanoscale structures such as quantum wells, superlattices, quantum wires, and quantum dots exhibit entirely new modes of infrared detection and are compatible with optoelectronic device technologies for smart sensor applications.
- **Mercury cadmium telluride (MCT) photodetectors**. MCT detectors use the II-VI material system and are the foundation of current Army high performance infrared sensors. The development of alternative substrates and improved material growth techniques will advance the state-of-the-art of thermal imagers for Army applications.

The research goals in both of these thrust areas are multispectral operation for better target discrimination and operation in all battle field conditions, larger focal plane arrays for higher resolution, and higher operating temperature for lower power consumption. ARL performs detector design, material growth and evaluation, device fabrication, and focal plane testing.

Payoff to the Soldier:

This work will form the basis for the next generation forward looking Infrared (FLIR) imagers, missile seekers, and general surveillance devices. It is a critical component of the Army Science and Technology Objective "Third Generation Infrared Imaging Technology."

Publications:

J. W. Little, S. W. Kennerly, R. P. Leavitt, M. L. Lucas, and K. A. Olver, "A New Two-Color Infrared Photodetector Design Using InGaAs/InAlAs Coupled Quantum Wells," Proc. Of the 2000 IRIS Specialty Group on Detectors, 2000.

R. Ashokan, N. K. Dhar, B. Yang, A. Akhiyat, T. S. Lee, S. Rujirawat, S. Yousuf, and S. Sivananthan, "Variable Area MWIR Diodes on HgCdTe/Si Grown by Molecular Beam Epitaxy," J. Electron. Mater., Vol. 26, No. 6 (2000).

Y. Chen, G. Brill and N.K. Dhar,"MBE growth of CdSeTe/Si composite substrate for Long-wavelength IR HgCdTe applications", J. Cryst. Growth, 2003

Connections:

DoD: Communications-Electronics Command/Night Vision and Electronic Sensors Directorate; Aviation and Missile Command; Armaments Research, Development and Engineering Center; Defense Advanced Research Projects Agency, Ballistic Missile Defense Organization

Academia: University of Illinois, West Virginia University, Princeton University, University of Maryland, Catholic University

Industry: EPIR, Inc.; Raytheon; Rockwell Science Center; DRS, Technologies; Lockheed Martin, BAE Systems

Point of Contact:

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Materials Characterization

Army Research Laboratory
Sensors & Electron Devices Directorate

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wsarney@arl.army.mil

Infrared Materials and Devices Branch

TEM image of two InAs quantum dots grown on GaAs

Objectives:

To enhance the quality of research in the Infrared Materials & Devices branch by detecting and solving critical materials science problems through chemical and structural microanalysis. Major projects include quantum-well infrared photodetectors (QWIPs), mercury cadmium telluride (MCT) photodetectors, strained layer superlattice detectors (SLSL), quantum-dot infrared photodetectors (QDIPs), and interband cascade lasers (ICLs).

Synopsis:

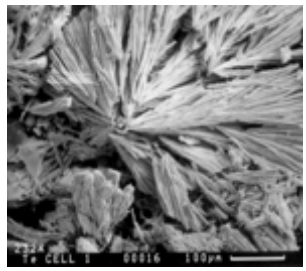
The Materials Characterization Team conducts joint research with materials and device growers primarily within the IR Materials and Devices branch, but also throughout ARL and our extended workforce. We study materials-related issues related to lasers and detectors under development at ARL. Examples include:

- QWIPs and SLSL detectors: Study interfacial bonding as related to total structural quality and device performance.
- MCT Photodetectors: Examine the defect morphology of the MCT films as related to the molecular beam epitaxy growth conditions.
- QDIPs – Develop a controlled process for independently manipulating the lateral and vertical dot dimensions.
- ICLs – Structural quality studies as related to growth conditions and final device performance.

The Materials Characterization Team uses a vast inventory of microanalysis tools in its research, including

- Scanning Electron Microscope (SEM) with Energy-Dispersive X-ray (EDX), Wavelength-Dispersive X-ray (WDX), Electron-beam Induced Conductivity (EBIC), and Cathodoluminescence (CL).
- Transmission Electron Microscopy (TEM) with EDX
- Secondary Ion Mass Spectroscopy (SIMS)
- Scanning Auger Spectroscopy (AES)/X-ray Photoelectron Spectroscopy (XPS)

CAMSCAN SEM



Secondary electron image of II-VI MBE system Te effusion cell residue

- Scanning Probe Microscopy (SPM)
- Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Payoff to the Soldier:

Microstructural and chemical analysis facilitates the development of the best possible materials for integration into high performance devices for the Army. These devices are critical components of the Army's Future Combat System and Objective Force.

Publications:

Sarney WL, Salamanca-Riba L, Bruno JD, and Tober RL, "Strain relaxation in AlSb/GaSb heterostructures", SOLID STATE ELECTRONICS 46(10): 1643-9, OCT 2002.

Xu K, Lee U, Zhang SS, Wood M, Jow TR, "Chemical analysis of graphite/electrolyte interface formed in LiBOB-based electrolytes, Electrochemical and Solid State Letters", 6 (7): A144-A148 2003.

Dhar NK, Boyd PR, Martinka M, et al, "CdZnTe heteroepitaxy on 3-inch (112) Si: Interface, surface, and layer characteristics" J ELECTRON MATER 29 (6): 748-753 JUN 2000.

Connections:

DoD: Night Vision and Electronic Sensors Directorate

Academia: Univeristy of Maryland, Howard University, Morgan State University

CRADA: Maxion, DRS

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Optical Detection of Chemical and Biological Agents

Army Research Laboratory
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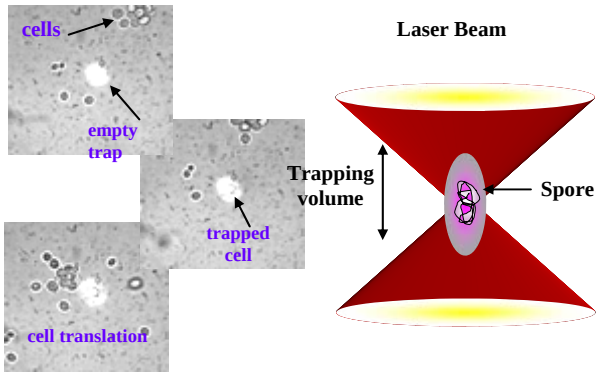
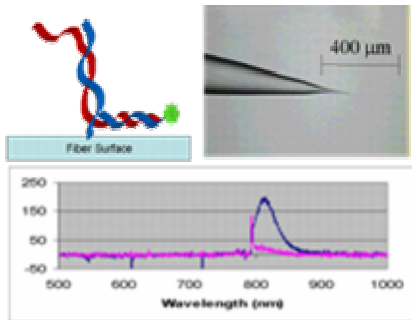


Cell manipulation using optical tweezers



Optical signature and micrograph from tapered-fiber DNA hybridization project

Objective:

To investigate and develop new methods for rapid detection of chemical and biological agents, one of the most serious threats faced by the U.S. military.

Synopsis:

Because of the requirements for detection, identification, analysis time, and desired concentration limits, the chem/bio (CB) threat is a multidisciplinary problem involving the integration of several sensor technologies. Our research focuses on rapid optical techniques for both point and standoff detection.

Optical technology applied to the CB threat offer the potential to outperform the current technology, while reducing the logistics load of the sensors. ARL has focused on such key technology areas as surface-enhanced Raman scattering (SERS), fiber optic DNA hybridization, Micro-electromechanical (MEMS) photoacoustics, optical tweezers and broadband bioaerosol Lidar. These technologies not only enable development of a new generation of sensor, but foster investigations into the fundamental aspects of the multi-disciplinary CB problem.

Payoff to the Soldier:

-Applications of battlefield optical sensor technology include

- Unattended remote chemical sensors (M21)

- Platform based chem/bio sensor suites (JBPDS)

ARL is performing innovative basic and applied research for development of next generation chemical and biological sensors. The research is supported by the Edgewood Chemical and Biological Center (ECBC), the Defense Threat Reduction Agency (DTRA), and DARPA.

Recent Publications:

P.M.Pellegrino, N.F. Fell, Jr, and J.B.Gillespie, “Enhanced spore detection using dipicolinate extraction techniques” Anal Chim Acta 455, Jan 2002, pp167-177

J.B. Gillespie, P. M. Pellegrino, D. A. Ligon, N. F. Fell, Jr.,and N. J Wood, “Development of a broadband lidar system for remote determination of aerosol size distrib-utions”, Meas. Sci. Technol. 13, Feb2002, pp383-389

T.A. Alexander, J.B. Gillespie, P.M. Pellegrino, N.F. Fell, G.L. Wood and G. Salamo “Near-infrared Surface-Enhanced-Raman-Scattering (SERS) mediated identification of single, optically trapped, bacterial spores”, SPIE proceedings Vol. 4876 (in press).

Connections:

DoD: ECBC, DARPA, DTRA, MASINT

Academia: University of Maryland, University of Arkansas, Northwestern, Hampton U., Boston U., USMA

International: QinetiQ (UK), TTCP

Point of Contact:

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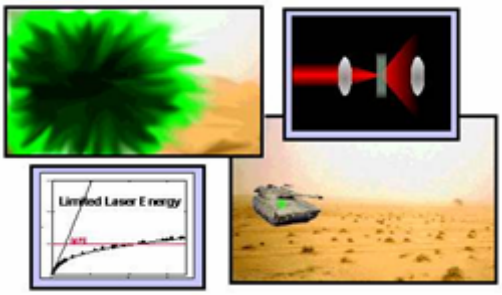
Nonlinear Optics for Eye/Sensor Protection

Army Research Laboratory
Sensors & Electron Devices Directorate

POC: Mr. Andy Mott; (301) 394-0942 amott@arl.army.mil
Dr. Gary Wood; (301) 394-0942 gwood@arl.army.mil



Eye/Sensor protection gives the soldier the ability to "see through" a laser threat.

Objective:

To develop passive optical limiting devices through the utilization of nonlinear optical properties of materials to protect electro-optic sensors and eyes from damaging levels of laser radiation.

Synopsis:

Sensor protection is necessary to protect optical systems such as tank periscopes, gunner's sights, FLIRs and soldier's eyes from damaging or debilitating laser radiation from enemy lasers on the battlefield. A protection device for any given sensor type must be capable of limiting incident energy to safe levels from a variety of laser sources across it's entire operating spectrum. Conventional electronics attached to shutters are not fast enough to respond to the short pulse widths of threat lasers. Devices that respond in a fraction of a nanosecond are necessary to provide protection from current and future threats.

We are investigating nonlinear materials and device designs which can be utilized in current and future optical systems. Nonlinear materials are substances who's optical properties change with increasing light intensity. We study the nonlinear changes in absorption, refractive index, and or scattering of these materials and exploit these features in the design of optical limiters. Our research program includes the nonlinear characterization of a large class of materials such as two-photon absorber (TPA) dyes, dendrimers, bi-chromophores, reverse saturable absorbing (RSA) dyes, nanocomposite materials and ladder polymers. Optical limiting performance of these materials and devices is demonstrated in simulated army sight testbeds with different focusing geometries.

Payoff to the Soldier:

Optical devices based on nonlinear materials for sensor protection will eventually be retrofitted into current optical systems throughout the Army. Future optical systems will be designed to incorporate these protection concepts directly. ARL is working closely with the Tank Automotive RDEC (TARDEC) and the Natick Soldier Center (NSC) in a well coordinated Army program to achieve these stated goals. The inclusion of sensor protection devices will enhance the survivability and functionality of the soldiers' eyes and sensor systems in the face of laser threats.

Publications:

Timothy M. Pritchett, "Diffractive Effects in the Determination of Damage Thresholds Using Focused Top Hat Beams," ARL Technical Report ARL-TN-200. (2003)

Timothy M. Pritchett, Robert C. Hoffman and Andrew G. Mott, "*Z*-scans with excited-state reverse saturable absorption," in OSA *Trends in Optics and Photonics (TOPS), Vol. 79, Nonlinear Optics*, OSA Technical Digest, Postconference Edition, pp. 286-288. (2002)

Timothy M. Pritchett, "Models for Saturable and Reverse Saturable Absorption in Materials for Optical Limiting," ARL Technical Report ARL-TR-2567. (2002)

Timothy M. Pritchett and Andrew G. Mott, "Interoferometric determination of laser power," in *Nonlinear Optics: Materials, Fundamentals and Applications*, OSA Technical Digest, pp. 276-278.(2000).

I.C. Khoo, P.H. Chen, M.V. Wood, M.Y. Shih, M.J. Miller, A.G. Mott, M.J. Ferry,"Nanosecond and picosecond studies of an extremely nonlinear optical fiber core liquid for limiting applications," Proceedings of SPIE, vol 3798 (July 1999).

Connections:

DoD: TARDEC, NSC, CECOM, Air Force Research Lab, Naval Research Laboratory, USMA

Academia: University of Alabama, Hampton State University, University of Central Florida-CREOL, Penn State University

International: UK, Sweden

Points of Contact:

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Dr. Gary Wood; (301) 394-0942; gwood@arl.army.mil

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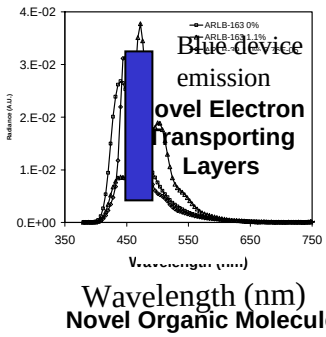
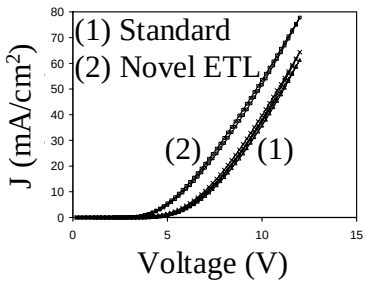
Flexible Displays

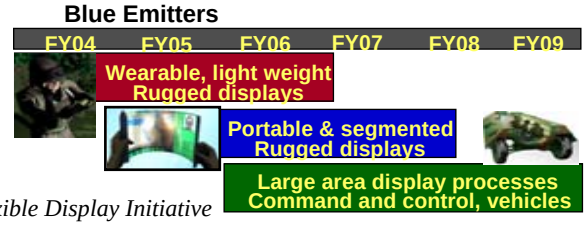
Army Research Laboratory
Sensors & Electron Devices Directorate

POC: Dr. David Morton
(301) 394-1916 dmorton@arl.army.mil





Novel Organic Molecule for Blue Emitters



Flexible Display Initiative

Objectives:

Develop the flexible pixel driver electronics, electro-optic devices, and environmental barrier structures required to enable affordable production of lightweight, rugged, flexible displays. Displays are based on two classes of electro-optic imaging (EO): reflective technologies that are bi-stable and emissive technologies that have high light conversion efficiency.

Synopsis:

The US Army ARL and NSC are working in the following areas to improve future flexible display technologies:

- The Army has established a Flexible Display Center at Arizona State University to develop and integrate the driver electronics, electro-optic devices and barrier structures for the manufacturing of flexible displays in a pre-competitive environment. The Center will partner closely with industry, academic partners and the Army through this cooperative agreement. This program is managed by ARL with NSC.
- ARL is developing novel electro-optic materials and devices based on the synthetic chemistry of blue emitting molecules and device design for highly efficient emissive flexible display devices.
- Inorganic phosphor materials, device structures and processing for near IR emitting display applications
- Novel flexible electronics based on ARL materials for n-type thin film transistors and flexible solar cells

Payoff to the Soldier:

Lightweight, low power, rugged flexible displays that provide the warfighter with increased situational awareness in daylight, night, and adverse weather for increased lethality and survivability.

Publications:

US Patent filed 3-2004 J. Shi, E. Forsythe, D. Morton "*ORGANIC LUMINESCENT MATERIALS*"

US Patent filed 3-2004 J. Shi, E. Forsythe, D. Morton "*ORGANIC LUMINESCENT DEVICES*"

"*Role of film formation on Disorder states in Alq*", E. Forsythe, D. Morton, D. Chiu, accepted for publication J.SID, (2002)

"*Anthracene derivatives for stable blue-emitting organic electroluminescence devices*" Shi J., Tang C.W., APL 80 3201(2002)

"*Flexible Displays for Military Use*", E. Forsythe, D. Morton, G. Wood, SPIE Aerosense Proceedings, Proceedings of the SPIE-Int. Soc. Opt. Eng V4712, pg. 262 (2002)

Connections:

DoD: Army's Flexible Display Initiative and the Flexible Display Center at Arizona State University; Natick Soldier Center; Communications-Electronics Command Research, Development and Engineering Center. The Flexible Display Initiative has received endorsements from PM Soldier Warrior; PM Tech Carol Fitzgerald, FFW. DARPA Photovoltaic Program

Academia: Arizona State University, Lehigh U., Princeton U., Penn State U., U. Florida, U. Cincinnati, U. Kentucky, U. North Texas, U. Texas, Dallas

Industry: All major US display companies connect through the partners with the US Army's Flexible Display Center.

Point of Contact:

Dr. David Morton; (301) 394-1916
dmorton@arl.army.mil

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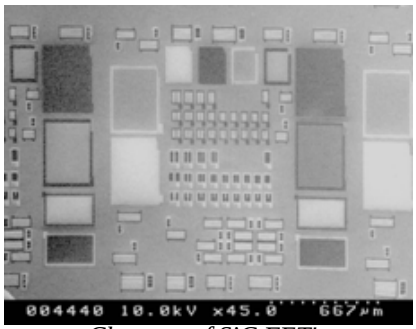
Electronic Materials & Structures

Army Research Laboratory

Sensors & Electron Devices Directorate



Close-up of SiC FET's

Scanning electron micrograph of ion implanted SiC FET's after they have been annealed with a cap showing the anneal can be done with no damage to the devices.

Objective:

Develop new processes and material systems for improving device performance by improving the quality of the material. Improve current methods and develop new ones for determining the morphological, chemical, structural, and electrical characteristics of electronic materials and semiconductor devices.

Synopsis:

The Electronic Materials and Structures Group at ARL supports R&D within the Army by growing and characterizing emerging electronic materials and device structures, developing new methods for processing them into devices, and analyzing devices. The group has a metal organic chemical vapor deposition (MOCVD) system for growing material, ultra-high vacuum (UHV) system for depositing contact metals, and a high temperature furnace (1800°C) for annealing; scanning electron microscope (SEM), scanning Auger microscope (SAM), quadrupole and magnetic based secondary ion mass (SIMS), x-ray diffraction (XRD) and triple crystal x-ray systems, transmission electron microscopes (TEM), a focused ion beam (FIB) system for analyzing the material and device structures; and Hall, CV and TLM systems for electrical measurements, a mixed mode drift-diffusion model semiconductor device simulator, and the capability to measure steady state and transient current and voltage characteristics of devices for validating the models used in the device simulations.

Pathway to the Soldier:

The team works on emerging materials and device technologies essential to the soldier of today and tomorrow. On-call Failure Analysis of material systems and devices provides DoD fast and accurate material and device characterization of failed systems from the field.

Collaborations:

Academia: U. of Maryland, Howard U., RPI,WesternKentucky U., George Mason U.

Industry: Peabody Scientific, Cree Research, Sterling

Government: TARDEC, AFRL, NRL

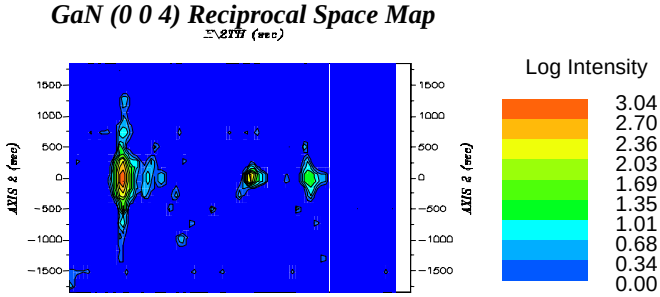
References

[1] P.B. Shah, B.R. Geil, M.E. Ervin, T.E. Griffin, s. Bayne, K.A. Jones, and T. Oldham; "Advanced Operational Techniques and pn-pn-pn Structures for High Power SiC GTO's", IEEE Trans. Power Electronics 17, 1073-79, (2002).

[2] K.A. Jones, M.A. Derenge, P.B. Shah, T.S. Zheleva, M.H. Ervin, K.W. Kirchner, M.C. Wood, C. Thomas, and M.G. Spencer, "A Comparison of Graphite and AlN Caps Used for Annealing Ion Implanted SiC, J. Electron. Mat. 31, 568-75, (2002).

[3] K.A. Jones, M.A. Derenge, M.H. Ervin, P.B. Shah, J. A. Freitas, R.D. Vispute, R.P. Sharma, and G.J. Gerardi; "Annealing SiC Implanted with Al and Al and C Using an AlN Cap", to be published.

GaN (0 0 4) Reciprocal Space Map



Triple crystal x-ray reciprocal lattice map of a GaN/AlGaN HEMT structure grown on a SiC substrate.

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Nano and Micro Electro Mechanical System (N-MEMS) Technology for Multifunction RF

Army Research Laboratory
Sensors & Electron Devices Directorate

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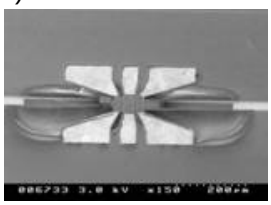
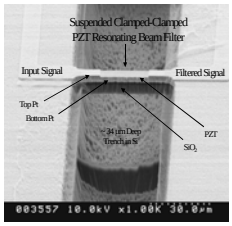
e-mail: tkipp@arl.army.mil

Objective:

Model, design, fabricate, integrate and evaluate smart materials (e.g. Lead Zirconate Titanate PZT, AlN, AlAs, SiC) and Si N-MEMS devices for multifunction RF, UAV, unattended sensors network, and IMU for Future Combat Systems (FCS).



PZT MEMS Switch



PZT MEMS Resonator

Synopsis:

Nano and Microelectromechanical structures and systems are miniature devices that enable the operation of complex systems. Smart Piezoelectric MEMS devices have created a unique class of intelligent sensors and actuators that was not possible with other materials. PZT, AlN, ZnO, Si and glass based MEMS devices are currently being developed in the MEMS fabrication facility at ARL.

1**. PZT MEMS Resonator for RF Filter:**
Piezoelectric MEMS resonant filters for VHF applications**.**

2. Nano Mechanical Array Signal Processors:
Direct E-Beam write lithography to fabricate Nanoscale piezoelectric NEMS resonator arrays for high frequency filters to operate in the MHz-GHz frequency regime.

3. PZT MEMS Switches:
Piezoelectric MEMS switches are free from stiction, capacitance charging, and temperature effects associated with electrostatic switches.

4. Extremely Sensitive PZT MEMS Magnetometer:
An orientation sensor for high-accuracy inertial guidance applications in IMU and magnetic field detection in the nT range.

5. PZT N-MEMS Modeling:
ANSYS Finite Element Analysis and MATLAB™ analytical and numerical methods for modeling, design, and validation of RF MEMS filters, switches and cantilevers. Measured mechanical and physical properties of thin films used for MEMS modeling**.**

Pathway to the Soldier:

Objective Force (OF) and Future Combat Systems (FCS) need low cost, low power, compact, and intelligent networked sensors; and precise lethal ammunitions. N-MEMS networked Sensor systems overlaying the battlespace will be integral to ensuring the survivability of the lightweight Future Warriors.

Collaborations:

Academia*:* Caltech, Pennsylvania State Univ**.,** Univ. of Maryland, Johns Hopkins Applied Physics Lab, MIT, Cornell Univ., Washington State Univ., and University of Colorado.

Government*:* DARPA, CECOM, TACOM, AMCOM, NRL, STRICOM, NSA, Sandia Lab, NASA, and Navy-SPAWAR.

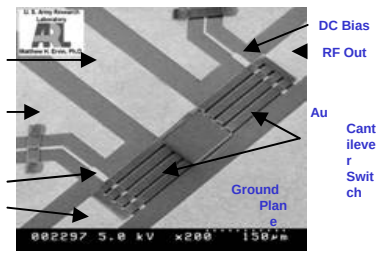
References:

[1] "Sol-gel PZT for MEMS Applications", B. Piekarski, M. Dubey, E. Zakar, R. Polcawich, D. DeVoe, and D. Wickenden, Integrated Ferroelectrics, 42, 25-37, (2002).

[2] "Piezoelectric MEMS for RF Filter Applications", A.E. Wickenden, B. Piekarski, L. Currano, J. Pulskamp, R. Polcawich, E. Zakar, R. Piekarz, D. Washington, J. Conrad, and M. Dubey, AVS 49th International Symposium, November 3-8, 2002, Colorado, Abstract# MM-ThA9 (To be published in J. Vac. Sci. Technol - 2003).

[3] "Nanoscale Electromechanical Systems (NEMS) for RF Filter Applications," A.E. Wickenden, B. Piekarski, M. Dubey, and Donald DeVoe, Accepted to the Workshop on Nano and Microsystems Technology and Metrology, Redstone Arsenal, AL, 3-5, December 2002.

[4] "FEA Modeling of Piezoelectric Clamped-Clamped Beam Microresonators," L. Currano, B. Piekarski, D. DeVoe, ASME International Mechanical Engineering Congress and Exposition, Nov. 17-22, 2002, Louisiana, Manuscript 33324. (To Be Published in Proc. of the IMECE 2002).



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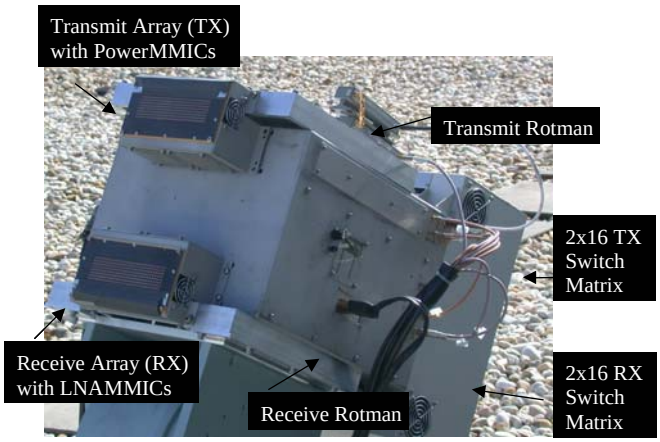
Electronically Scanned Antennas

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Mr. Edward Burke 301-394-4375



Dual Aperture Rotman lens ESA

Objective:

ARL is developing the technologies necessary to integrate Radar & Communications functions into a single, compact, and affordable package. This low cost approach to multi-function RF sensing employs a single electronically scanned antenna (ESA) shared between all of the sensors, thus reducing cost and weight. The integrated sensor functions include active/passive target acquisition, combat identification, weapons guidance, secure point-to-point communications, active protection, networks for situational awareness, and signal intercept.

Synopsis:

The benefit of ESAs over traditional mechanically scanned antennas is the ability to reposition the antenna beam instantly to any position within the coverage area of the sensor without physically moving the antenna. ARL is pursuing a full spectrum approach to ESA technology employing phased array and true-time-delay approaches. For phased array antennas, ARL is developing ferroelectric phase shifters, MEMS phase shifters, millimeter wave integrated circuits (MMICs), and optical control of microwaves. For true-time-delay antennas, we are developing Rotman lens beam forming capabilities. The advantage of this true-time-delay architecture is that multiple simultaneous beams can be generated which cover a broad band of the RF spectrum making it ideal for multi-function RF sensing.

Pathway to the Soldier:

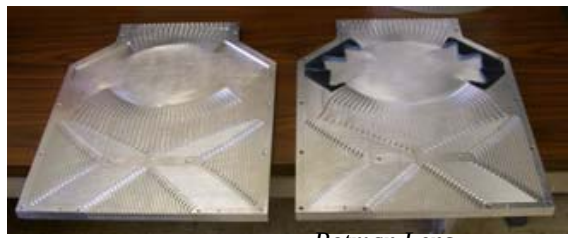
A Multifunction RF system will be beneficial in three ways: It will reduce the number of antennas and interfaces required on a military platform to perform multiple functions, it will enhance the interoperability of the various functions, and it will enable the inclusion of multiple functions on a platform by making them more compact and affordable.

Collaborations:

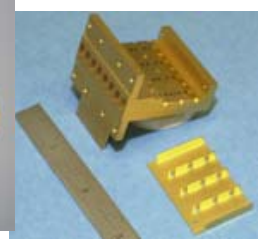
Academia*:* University of Michigan, University of Florida
Government*:* CERDEC, AMRDEC, ARDEC, TARDEC
Industry*:* BAE, Northrop Grumman

References:

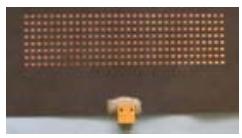
1. S. Weiss, E. Adler, Ozlem Kilic, E. Viveiros, R. Dahlstrom, “A Multifunctional Ka-Band Electronic Scanning Antenna (ESA)”, 2003 IEEE International Symposium on Phased Array Systems, Oct 2003
2. R. Dahlstrom, S. Weiss, E. Viveiros, A. Bayba, and E. Adler, “A K_a-Band Electronically Scanned Antenna for Multi-function RF Applications”, Antenna Applications Symposium, Sept 2003



Rotman Lens



2x16 Pin diode Switch



Patch Antenna

MMICS & Module

S. Weiss, E. Adler, R. Dahlstrom,O. Kilic, E. Viveiros, “Measured Performance of an Electrically Scanned Antenna”, GOMACTech, M

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Ka-Band Monopulse Polarimetric Instrumentation Radar

Army Research Laboratory
Sensors & Electron Devices Directorate

POC: Kwok Tom, (301)394-2612
ktom@arl.army.mil

Objective:

ARL has designed and developed a Ka-Band Monopulse, Polarimetric Instrumentation Radar in support of Guidance Integrated Fuzing (GIF) and MMW seeker based tracking. The goal is to improve aimpoint selection in missile systems. This radar is used as a tool to collect signatures to characterize endgame performance, develop and evaluate seeker based fuzing algorithms and assist in the validation of computer backscatter models.

Synopsis:

The radar was designed to obtain Ka-band target andbackground signature data. This radar is u sed to measure the Radar Cross Section of air and ground targets. It has the resolution necessary to measure real world effects, such as gaps, discontinuities, cavities, shadowing, and traveling wave effects on RCS. These effects can impact monopulse tracking systems that exist on missile seeker system. Basic system characteristics are:

- Operating frequency 32 – 36 GHz
- Bandwid th 4 GHz
- Integration 8 pulse
- Number of channels 12 channels
- A/ D resolution 12 bits (min)
- PRF 1MHz (max)
- Monopulse, fully polarimetric
- Coherent and widebandwidth
- Polyphase coding of illuminating waveform
- PRF: 1 MHz (typical)
- Pulse width: 100 nSec
- Frequency Steppable: 512 – 5.86 MHz steps
- Peak Power: 10 W
- Antenna beamwidth (one way): 2,5,8 or 12 degrees (selectable) • Polarization agile: RHCP/ LHCP or V/ H (selectable)
- Phase coding resolution: 1.4 d egrees
- Data recording: 12 channels/ pulse, simultaneous sampling

Payoff to the Soldier:

This work provides a unique measurement capability to support GIF and seeker programs. Target signatures provide detailed knowledge of target backscatter that is crucial to theGIF designs. It provides for valid ation of target models, development and evaluation of seeker based fuzing algorithms and can support target measurements necessary for missile engagement assessments using hardware and/ or software simulations saving the time and expense of actu al flight-testingof missiles or other seeker based munitions in statistically significant quantities.

Collaboration:

Government*:* AMCOM

Point of Contact:

Kwok Tom, (301)394-2612, ktom@arl.army.mil

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MMW Signature and Analysis

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Ms. Suzanne R. Stratton 410-278-3942

Objective:

ARL is conducting research and development in MMW signature measurement and analysis techniques. The ability to make calibrated measurements of the increasingly small radar signatures of targets is the impetus behind this work. These target signatures, which provide detailed information on the radar scattering properties of armored vehicles and other targets, are used to examine phenomenology for sensor systems and for assessing the baseline system performance requirements for smart munitions and other sensors under development. These signatures also aid in designing or modifying U.S. vehicles to obtain a desired/required signature. These data are also used in simulations of situations that are too difficult or expensive to script.

Synopsis:

ARL has developed a tri-band millimeter wave

polarimetric inverse synthetic aperture instrumentation radar and analysis software that have become invaluable tools for a broad range of MMW research, including ground and air vehicle signature measurements.

The tri-band instrumentation radar, located at the ARL Signature Research Facility at Aberdeen Proving Ground, includes: 8-18, 34 and 94 GHz systems with bandwidth of 1.6 GHz, which provide high-resolution imagery on the order of 0.09 m in downrange and crossrange. Fully polarimetric images are available for linear or circular polarizations. Radar cross section (RCS) plots and histograms with statistical information concerning the RCS of the target are also produced. Vehicles measured include the BMP-2, ZSU-23-4, 2S3, T- 62, T-72, T-80 and BTR-80.

W-Band and Ka-Band monopulse polarimetric radars are also available for acquiring ground target signatures and clutter backgrounds and for evaluating detection and tracking algorithms. The Ka-Band system has a 4 GHz bandwidth capable of giving high-resolution imagery on the order of 0.04 m.

The ARL/TECOM Signature Research Facility consists of a 22-ft-diameter in ground turntable placed that is positioned 153 ft from a 125-ft tower to allow depression angles of 0 to 35 degrees. A portable turntable placed closer to the tower allows for depression angles of 40 to 65 degrees.

Through the use of a portable overhead rail structure, 90- degree look-down angles are achieved. The facility has a large secure building located on the grounds for the storage of vehicles and materials. Vehicle/materials handling, storage and security can all be provided on site. A meteorological station is on the grounds to characterize the ambient conditions.

Pathway to the Soldier:

This research is crucial to battlefield information dominance. The increased understanding of radar phenomenology will allow for more timely, cost effective, systematic, robust simulations to be run for missile systems which employ the use of radar. This research will not only provide for better detection of enemy forces, but it will also be useful in the concealment our vehicles by reducing their signatures through various measures. This, in turn, will increase both the lethality and survivability of our future forces.

Collaborations:

Government: TECOM, TARDEC

References:

[1] Robert Bender and Suzanne Stratton, “Radar Cross-Section Measurements of the 2S3 Howitze

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Passive Millimeter-Wave Video Image Processing

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Dr. Joseph D. Silverstein 301-394-3170

Objective

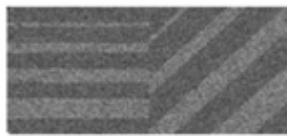
The object of this work is to find efficient means of processing passive millimeter-wave (PMMW) images. These images afford the Army a means of observing scenes vital to military intelligence which will complement PMMW imaging capabilities at optical and IR wavelengths under adverse weather conditions. A major difficulty posed by PMMW imagery, however, is its limited ability to resolve key objects in some scenes at ranges at a kilometer or greater. This ability is limited by sensor size, weight, and complexity which are governed by the nature of army platforms.

Synopsis:

ARL has demonstrated improvements in the resolution of objects in PMMW images by processing them with various restoration algorithms. The linear algorithm used, Two Mu, was modified to reduce computer times. The nonlinear algorithms used, Maximum Likelihood (ML) and Maximum a Priori (MAP), are statistical in nature and require hundreds to thousands of iterations for convergence. After executing 1000 iterations, ML and MAP achieve a maximum resolution improvement of $\times 2.4$, on simulated images of a "two-squares" pattern, compared to $\times 1.8$ for the non-iterative Two-Mu. However, computation time for Two-Mu was 0.09 sec, whereas that for ML and MAP was 2.8 sec.

ARL is also investigating the integration of consecutive frames of video streams in order to reduce their effective signal-to-noise ratio (SNR) to help in discerning objects in low-contrast scenes which would be difficult to discern in a single frame. The images shown are portions of a simulated pattern of stripes at temperatures of 280 K and 290 K. They are displayed on a grayscale ranging from 243 K to 343 K. The top-most image and the two just below it on the left and right are a single frame without any noise and after the addition of noise with a signal-to-noise ratio (SNR) of 10 dB and 18 dB, respectively. The added noise, especially that with the 10-dB SNR, is seen to degrade the contrast. The bottom two images are the result of integrating 25 frames. The integration is seen to increase the SNR and improve the contrast. ARL is now investigating methods of combining the registration, integration, and restoration of measured PMMW video images into one processing operation.

One frame; no noise; Grayscale: 243 K-343K
T_{low} = 280K T_{high} = 343K



One frame; SNR = 10 dB

One frame; SNR = 18dB

25-frame integration
Resultant SNR = 17 dB

25-frame integration
Resultant SNR = 25 dB

Pathway to the Soldier:

This work is applicable to sensors for reconnaissance and surveillance and for pilotage and navigation for rotary wing aircraft. The results of this work can transition directly to Army PMMW camera development.

Collaborations:

Academia*:* University of Arizona
Government*:* AMCOM

References:

[1] J. Silverstein, "Alternative Implementations of the Two- Mu Algorithm", *JOSA* , 18, No. 8 (Aug 2001), pp 1853-1861.
Improvement By Linear and Non-Linear Algorithms, SPIE 4373, (April 2001), pp 132-153.

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Passive Millimeter-Wave Camera

Army Research Laboratory
Sensors & Electron Devices Directorate
POC: Dr. Joseph Nemarich 301-394-3172

Objective:

The object of this work is to develop a passive millimeter-wave (MMW) camera that is useful for varied military applications. Passive MMW imagery affords a means of observing terrain scenes in limited visibility conditions that is vital to operation with Army aircraft. It enhances the overall imaging capabilities of the aircraft beyond optical and IR wavelengths. Passive MMW imaging sensors have been limited in the past by their inability to achieve sufficiently large images (many pixels) with low-noise at video frame rates for a reasonable cost. This work aims to overcome these obstacles by pushing the required technology, thereby reducing cost and achieving the goal of having a useful sensor.

Synopsis:

Many passive MMW system architecture approaches have been tried or demonstrated over the years. Rather costly focal plane arrays, which require one MMW receiver circuit per pixel, have been demonstrated, although engineering issues remain to be solved. Clever scanning systems that use fewer receivers have also been shown to work but not without image artifacts and other mechanical problems. The approach that ARL is pursuing with its contractor, Trex Enterprises, utilizes a pupil-plane architecture that is comprised of a far fewer number of MMW receivers than a focal plane array. This is accomplished by using a flat antenna that frequency scans in one dimension and acts as a phased array in the other. This architecture allows one to build a system that can much more easily be adapted to a variety of platforms and applications.

A microwave Rotman-type processor behind a 3-foot square planar antenna/receiver was used in the first generation passive MMW camera (PMC-1). During a helicopter flight test with the camera, 30-Hz frame-rate passive MMW movies of scenes in and around Mojave, CA. were obtained. The flight test showed that the system was not only able to collect video frame-rate imagery but that it could do this with enough thermal resolution to follow a highway while flying above a fog bank and to detect moving vehicles on the road.

PMC-2 concept drawing and rear view under assembly

A second version of the PMC (PMC-2) has been designed and development is nearly complete. This system has a 2-foot square antenna and will have a field of view three times larger than PMC-1 with lower system noise, lighter weight (150 lbs.), and lower cost. To accomplish this, the system uses a planar dielectric antenna and advanced Rotman-type processors to sort 94-GHz image signals using low-cost, low-loss stripline technology.

Pathway to the Soldier:

This type of sensor could be used in any scenario where it is required that imagery be collected from aircraft through clouds, fog, dust, or smoke. Examples are surveillance, navigation, landing, and search and rescue operations. Currently there are plans to flight test the PMC-2 on an Army helicopter in 2004. ARL is working with CECOM (Ft. Belvoir) to accomplish this task.

Collaborations:

Academia*:* Caltech
Government*:* AMCOM, CECOM

References:

[1] S. E. Clark, et al, "Passive millimeter-wave imaging technology for phased-array systems," *Proc. SPIE, Passive MMW Imaging Technology VII, Vol. 5077,* April, 2003.

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Passive Millimeter-Wave Imaging for Concealed Weapons Detection

Army Research Laboratory
Sensors & Electron Devices Directorate

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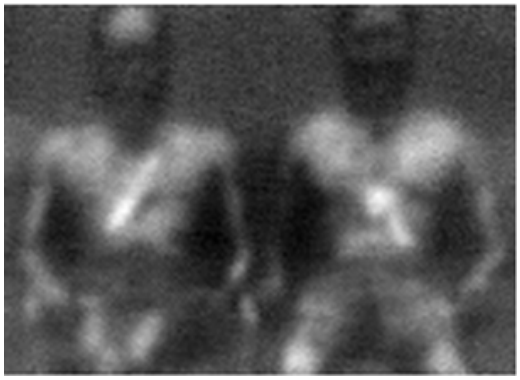

Passive MMW Concealed Weapons Image

Objective:

Develop the technology and measurement techniques required to enable video-frame-rate passive millimeter-wave (MMW) imaging systems to detect weapons/explosives underneath clothing.

Approach:

The concealed weapons problem is envisioned in three different scenarios:

- Portal: People entering a military installation pass through a portal that images plastic or metal weapons under clothing.
- Outdoor Checkpoint: People passing through an outdoor checkpoint can be searched from a safe standoff distance for explosives or weapons.
- Crowd Scanning: The most challenging scenario involves scanning people at various ranges on the street as they pass by the sensor.

Point of Contact:

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Payoff to the Soldier:

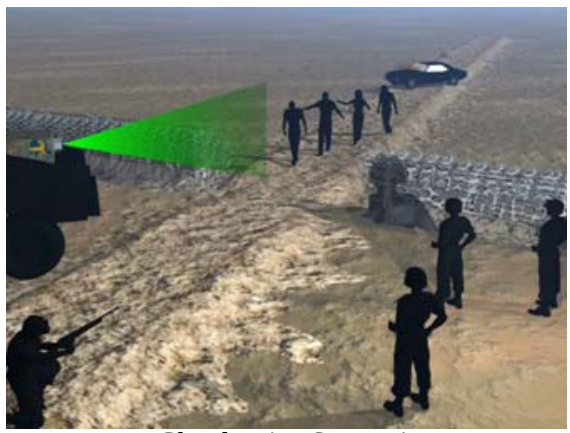
Passive MMW imaging has the potential to improve the security of military installations, increase the safety of soldiers manning checkpoints where suicide bombers are a possibility, and to allow the scanning of potentially hostile crowds by detecting weapons (metal and plastic) through clothing.

Status:

A second-generation passive MMW camera (PMC-2) is being built that will be able to demonstrate this technology at a 30-Hz frame rate.

Low cost MMW detectors are being researched to enable inexpensive ~30,000 pixel cameras.

A session is being held at this year's SPIE Defense and Security Symposium on passive MMW imaging for security applications.



Checkpoint Scenario

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MMW Monopulse Fully Polarimetric Signature Measurement Radars

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Mr. Ronald J. Wellman 301- 394- 3171

Objective:

ARL is developing the technology for millimeter wave (MMW) target acquisition & low angle tracking for anti-armor weapon systems.

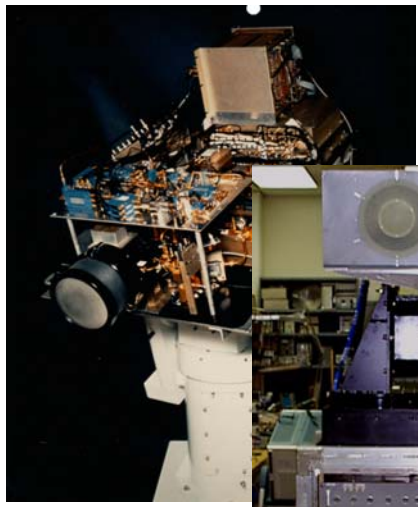
Synopsis:

To support these efforts, ARL has developed both 35- and 95-GHz fully polarimetric wide band coherent monopulse radars. The radars are portable and designed to be mounted on a tower and make signature measurements of targets placed on a turntable. In addition, these radars have been used to determine the characteristics of MMW target signatures of stationary and moving armored vehicles at low depression angles and to characterize clutter statistics for the same depression angles. Analysis of this data is used to develop improved target detection, classification and tracking algorithms, which are then tested using ARL assets in a realistic battlefield environment.

Radar Characteristics:

35GHz, 95 GHz

- Center frequency: 34.7 GHz, 95.32 GHz
- Bandwidth: 2.2 GHz, 640 Mhz
- Integration: 8 pulse, variable
- Number of channels:12 channels
- A/D resolution:12 bits
- PRF: 1MHz (max), 20 Khz
- Monopulse, fully polarimetric
- Coherent and widebandwidth
- Fully Polarimetric: RHCP, LHCP, V, H selectable
- Phase coding: Polyphase code, none
- PRF: 1 MHz(typical), 10 Khz
- Pulse width: 100 nSec
- Frequency Steppable: 512 – 5.86 MHz, steps
- Peak Power: 10 W, 45 W
- Antenna beamwidth (one way): 2-12, 1.6- 6.3 degrees (selectable)
- Data recording:12 channels/pulse, simultaneous sampling



95 GHz Radar

35 GHz Radar

Pathway to the Soldier:

The data collected with these radars is used to characterize the end-game performance of various proposed seeker/tracker configurations as well as to develop and evaluate seeker-based fuzing algorithms. Detailed knowledge of the target backscatter characteristics is crucial to the design of seeker guidance, control, fuzing, and warhead. Fine grain data are also invaluable for validation of the computer models of target backscat-ter that are needed for hardware-in-the-loop simulations. These radars are ideal for evaluating the detection and tracking algorithms for fire-control radar, smart munitions, or missile seekers. These capabilities support advanced radar or munitions system design for future Army needs.

Collaborations:

Academia*:* University of Michigan.
Industry*:* Simulation Technologies
Government*:* ARDEC, AMCOM, TARDEC, PM-BAT

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Ka-Band Monopulse Polarimetric Instrumentation Radar

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Kwok Tom, (301)394-2612 ktom@arl.army.mil

Objective:

ARL has designed and developed a Ka-Band Monopulse, Polarimetric Instrumentation Radar in support of Guidance Integrated Fuzing (GIF) and MMW seeker based tracking. The goal is to improve aimpoint selection in missile systems. This radar is used as a tool to collect signatures to characterize end-game performance, develop and evaluate seeker based fuzing algorithms and assist in the validation of computer backscatter models.

Synopsis:

The radar was designed to obtain Ka-band target and background signature data. This radar is used to measure the Radar Cross Section of air and ground targets. It has the resolution necessary to measure real world effects, such as gaps, discontinuities, cavities, shadowing, and traveling wave effects on RCS. These effects can impact monopulse tracking systems that exist on missile seeker system. Basic system characteristics are

- Operating frequency 32 – 36 GHz
- Bandwidth 4 GHz
- Integration 8 pulse
- Number of channels 12 channels
- A/D resolut 12 bits(min)
- PRF 1MHz (max)
- Monopulse, fully polarimetric
- Coherent and widebandwidth
- Polyphase coding of illuminating waveform
- PRF: 1 MHz (typical)
- Pulse width: 100 nSec
- Frequency Steppable: 512 – 5.86 MHz steps
- Peak Power: 10 W
- Antenna beamwidth (one way): 2,5,8 or 12 degrees (selectable)
- Polarization agile: RHCP/LHCP or V/H (selectable)
- Phase coding resolution: 1.4 degrees
- Data recording: 12 channels/pulse, simultaneous sampling

Payoff to the Soldier:

This work provides a unique measurement capability to support GIF and seeker programs. Target signatures provide detailed knowledge of target backscatter that is crucial to the GIF designs. It provides for validation of target models, development and evaluation of seeker based fuzing algorithms and can support target measurements necessary for missile engagement assessments using hardware and/or software simulations saving the time and expense of actual flight-testing of missiles or other seeker based munitions in statistically significant quantities.

Collaboration:

Government: AMCOM

Point of Contact:

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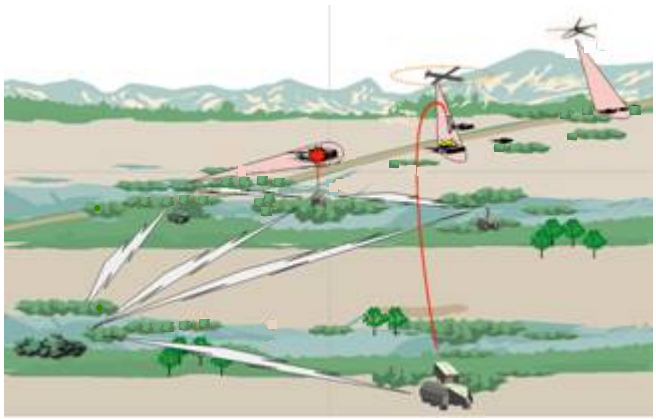
Multi-Function RF Sensor Technology

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Mr. Edward Burke 301-394-43



Objective:

This program will develop and demonstrate the technologies required to integrate the multi-function RF concept into systems so that simultaneous target acquisition, combat ID, and communications can be performed by the same electronics. The primary outcome of this effort is not a system concept but the technology required to integrate RF concepts into future army platforms in a single system, thereby making these enhanced capabilities more affordable.

Synopsis:

The transformation of the Army from heavy forces to lighter, faster forces places a heavy burden on current sensor systems to provide engagement lethality and survivability. This increased requirement will be met by implementing surveillance, active protection, communications, command guidance, and combat identification systems within reduced space requirements and tight budgetary constraints. This cannot be achieved with multiple, independent systems. The objective of a Multi-Function Radio Frequency Sensor for application to Future Combat Systems and other Objective Force platforms is to develop the architecture, subsystems, and algorithms to meet these requirements in an integrated sensor suite. Our program is investigating the key technical issues that are prerequisites for a multi-function system; among them two-dimensional electronically scanned antennae, integrated receiver/exciters, flexible waveform synthesizers, high-throughput common signal processors, and system tradeoffs that impact the architectural design. Through intelligent sensing and achieving near-perfect situational awareness, we will enable future objective forces to be more survivable and lethal than current heavy force.

Pathway to the Soldier:

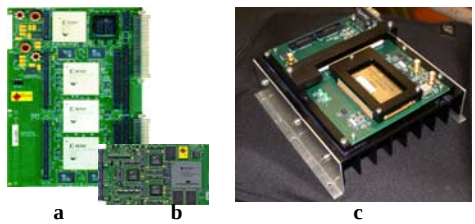
A Multifunction RF system will be beneficial in three ways: It will reduce the number of antennas and interfaces required on a military platform to perform multiple functions, it will enhance the interoperability of the various functions, and it will enable the inclusion of multiple functions on a platform by making them more compact and affordable.

Collaborations:

Academia: University of Florida, University of Michigan
Government: CERDEC, AMRDEC, ARDEC, TARDEC
Industry: BAE, Northrop Grumman

References:

1. M. Conn, F. Koenig, G. Goldman, E. Adler, "Waveform Generation and Signal Processing for a Multifunction Radar System", IEEE Radar, April 2004
2. R. Wellman, E. Adler, T. Pizzillo, "Demonstration of a Multifunction RF Concept for Ground Vehicle Survivability, Ground Vehicle Surviability Symposium, March 2004



a b c

a)Field Programmable Gate Array Processing,
b)1.5 GHz A/D c) 1 GHz Direct Digital Synthesizer

E. Adler, J. Silvious, J. Clark, M. Conn, R. Wellman, "Multifunction RF Fielded Demonstration", GOMACTech, March 2004

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Polarimetric Millimeter-wave Radiometry

Army Research Laboratory
Sensors & Electron Devices Directorate
POC: David Wikner 301-394-0865

Objective:

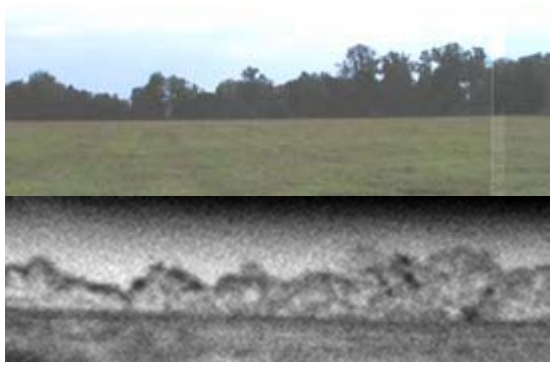
The objective of this program is to explore the polarimetric phenomenology associated with millimeter-wave (MMW) radiometry. This exploration is intended to increase the understanding of passive MMW imagery and find new uses for the technology. The results of this work will provide unique data and analyses of MMW imagery that can be used by both the applied technology and research communities.

Synopsis:

The Army Research Laboratory (ARL) has developed a fully polarimetric Stokes-vector radiometer at 94 GHz. This radiometer is a tool that has been and will be used to collect polarimetric data. Various applications, such as helicopter navigation and pilotage through fog/smoke/dust, missile terminal guidance through fog and smoke, and surveillance, have been identified as being appropriate for this technology. To gauge the expected performance of a 94-GHz radiometer for these scenarios, it is necessary to collect a complete polarimetric set of data that includes many material types at various aspect angles. The Stokes radiometer built by ARL is able to assist in this task because it is highly accurate when used to measure the absolute brightness temperature of a material. (The radiometer has a precision of 0.4 K and an accuracy of $\pm$ 1 K.)

94 GHz Stokes-vector Radiometer

The processing of imagery is also an important part of the radiometry program. This processing is used to extract the physics behind the imagery as well as enhance the display of the data. Statistical methods are being used to determine ways of improving detection of low-flying-aircraft obstacles such as trees and buildings. Other processing work involves using registered multi-frame integration to enhance passive MMW video streams. These techniques can enhance the quality of MMW video data as it is collected from a moving platform.



Passive 94-GHz Imagery of aTreeline

Pathway to the Soldier:

The information generated by this work will feed the government research establishment in two main ways. Firstly, the information we accumulate will be shared with government organizations, inside and outside the Army that are interested in determining how passive MMW technology can help their missions. Secondly, the work supports and guides another effort within the Army to develop a passive MMW camera.

Collaborations:

Government: AMCOM, NVESD

References:

[1] D. Wikner, R. Dahlstrom, “Millimeter-wave radiometry of deciduous trees at low-depression angle,” Radio Science, Volume 33, Number 6, Nov-Dec 1998.

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Ultra-Wideband Foliage & Ground Penetrating Radar Programs

Army Research Laboratory

Sensors & Electron Devices Directorate

POC: Mr. Karl A. Kappra 301394-0848

Motivation:

Low-frequency imaging radar offers the potential for dramatic new capabilities on the battlefield. It may provide the ability to reliably detect stationary vehicles concealed beneath foliage and subsurface targets such as buried mines and unexploded ordnance. In addition, the utility of this technology to detect negative (ditches) and positive obstacles (rocks) is being evaluated to enhance robotic vehicle perception. Significant national initiatives in foliage penetration radar, countermine, humanitarian demining, robotics, and detection of unexploded ordnance for environmental remediation provide the conduits to advance this emerging technology for the Theater Commander.

The ARL Program:

The ARL effort has established the following program components to support our concealed target detection studies: (1) an instrumentation grade radar that spans from 20 to 1100 MHz in a single coherent collection interval; (2) ground penetration radar test sites of national significance; (3) a measurement program aimed at collecting a substantial quantity of foliage and ground penetration target and clutter data; (4) a high-performance computing laboratory for signal processing and synthetic aperture radar (SAR) image formation; (5) a computational electromagnetic signature modeling program and (6)an automatic target detection (ATD) visualization and assessment environment to be used at ARL and at our research partners' sites.

The Radar:

The radar is mounted atop a unique telescoping boom lift (figure 1). This setup allows the system to emulate the imaging geometry of either an airborne radar or a vehicle mounted system at a fraction of the cost. Further, it provides a high degree of control in the design and execution of test scenarios.

Collaborations:

Academia*:* Duke University, Ohio State University
Industry*:* Lockheed-Martin Arizona, Mission Research Corporation
Government*:* CECOM:Ft. Monmouth, NVESD
Countermine, Army Research Office, Air Force Research Laboratory
International: TTCP Sensors Action Group 3

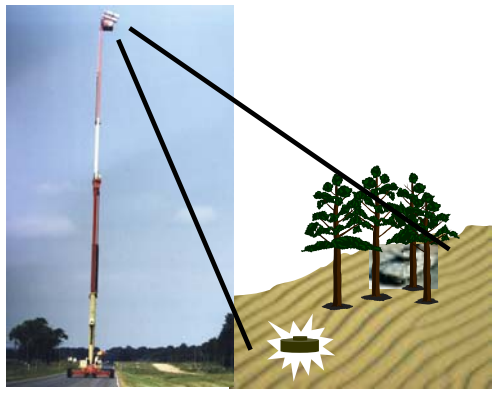

Figure 1. Army Research Laboratory BoomSAR System

References:

[1] L. Carin, et al, Duke University, J. Sichina and L. Nguyen, "Ultra-Wideband Synthetic Aperture Radar for Mine Field Detection," IEEE Antennas & Propagation Magazine, February 1999.

[2] L. Nguyen, et al., "A Mine Field Detection Algorithm Utilizing Data from an Ultra-Wideband Wide Area Surveillance Radar," *Proceedings of SPIE, Detection and Remediation Technologies for Mines and Minelike Targets III, Vol 3392, pp 627-643*, April 1998.

[3] J. Sichina, et al., "Using Models and Measurements to Describe Ultra Wideband Radar Scattering Phenomena," *SPIE, Algorithms for Synthetic Aperture Radar Imagery VII, Vol. 4053, pp 220-228*, April 2000.

[4] S. Vitebskiy, et al., "Ultra-Wideband Short-Pulse Ground Penetrating Radar: Simulation and Measurement," IEEE Trans. Geosci. Remote Sens., Vol. 35, No.3 , May 1997, pp. 762-772.

[5] A. Sullivan, et al, "Detection of above-ground and subsurface unexploded ordnance using ultra-wideband (UWB) synthetic aperture radar (SAR) and electromagnetic modeling tools, " *Proceedings of SPIE, Detection and Remediation Technologies for Mines and Minelike Targets V, Vol. 4038, pp 983-992*, April 2000.

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Mine/Booby Trap Detection and Neutralization

Army Research Laboratory
Sensors & Electron Devices Directorate

POC: Jeff Sichina 301-394-2533
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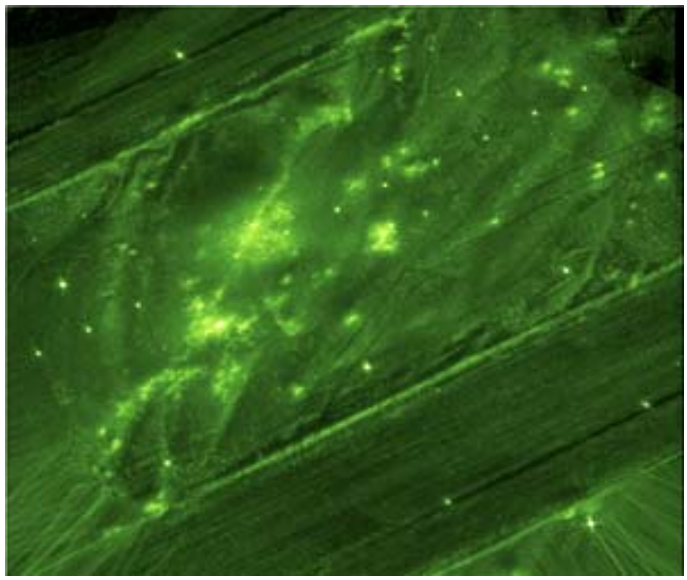
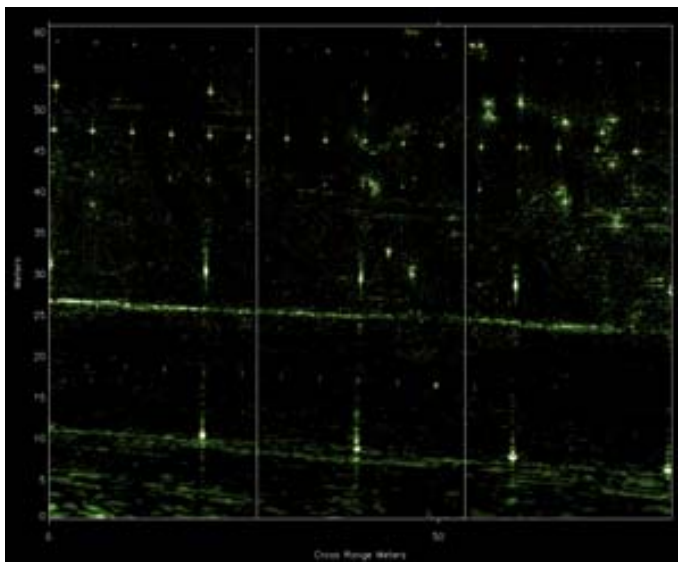
Objective:

Determine the utility of imaging radar to detect and locate mines and/or booby traps. Given item location, determine likelihood of neutralization with High Power Microwave (HPM) stimulus.



Approach:

In partnership with NVESD, use predictive models and available measurements to assess mine/booby trap radar scattering and determine performance in complex clutter. Utilize specialized test chambers to characterize and determine susceptibility of devices to HPM and develop proposed system parameters.



Pay off to the Soldier:

Point Detection and Neutralization of explosive hazards (IED's, mines) is TRADOC's number one priority shortfall.

Point of Contact:

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Ultra-Wideband Radar for Sensing Through the Wall

Army Research Laboratory
Sensors & Electron Devices Directorate

POC: Traian Dogaru; 301-394-1482
Tdogaru@arl.army.mil

Objective:

Examine the effectiveness of ultra-wideband radar technology for the through the wall sensing mission.

Approach:

Use electromagnetic models to characterize the signatures of people and objects concealed by diverse materials. Analyze data to define the performance boundaries for UWB radar for this application. Collaborate with the international community to compare measurements to model predictions and develop processing techniques to maximize performance.

TTCP Sensor Technical Panel #6

Pay off to the Soldier:

Provides the capability to detect people and weapons in buildings for military operations in urban terrain.

Point of Contact:

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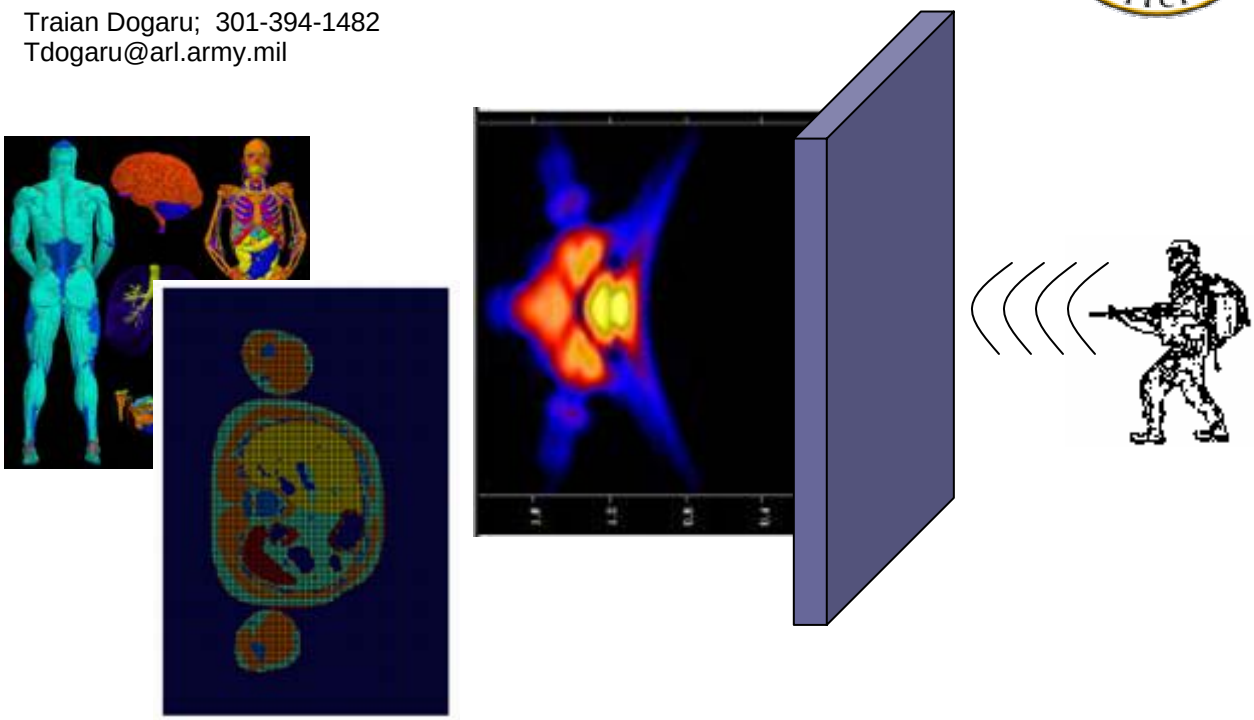

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Vacuum Electronics

Army Research Laboratory
Sensors & Electron Devices Directorate
POC: Mr. Romeo del Rosario 301-394-3562

Microwave Power Module (MPM)
Size: 7x6x1/2 inches
Weight: 3.6 lbs
Frequencies: 6-18 GHz
Output Power: 100 W

Objective:

Develop high power RF, microwave and millimeter wave devices with vacuum electron device and hybrid vacuum-solid state technologies. Such devices comprise traveling wave tubes (TWTs), microwave power modules which make use of a solid-state driver cascaded with vacuum power boosters (such as a TWT), as well as analogous millimeter-microwave power modules (MMPM.) Development entails specification, design, setup, testing and integration of vacuum electronics into Army laboratory and end products.

Synopsis:

While semiconductor devices now account for the vast majority of electronics in military and commercial systems, vacuum tubes remain the only alternative for applications that require high power. For radar, electronic warfare (EW), countermeasures (ECM), and long range radio transmitters (e.g. base-station to satellite), the superior power handling capabilities of vacuum electron devices present a distinct advantage.

Nonetheless, the strengths of semiconductors, namely light weight, lower power consumption, and superior small signal amplification cannot be ignored.

With these diverse strengths in mind, ARL is developing a highly modularized and integrated power amplifier capable of providing low noise, broadband 30-40GHz amplification with 100W continuous wave (CW) maximum output power. In addition, a 43.5 to 45.5 GHz 50W amplifier is being developed using a similar architecture. Applications for the two amplifiers are ECM and satellite communication, respectively. These devices incorporate a Solid State Amplifier (SSA) for better low noise performance, a miniature Vacuum Power Booster (VPB) for higher output power, and an Integrated Power Conditioner (IPC) to further decrease package size. By utilizing the strengths of each technology, the MMPM achieves a combination of high efficiency, power density, reliability, and small size that are not attainable by solid-state or VE alone.

Pathway to the Soldier:

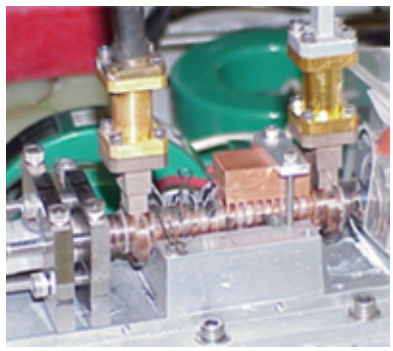
Hybrid solid state-vacuum devices utilize the most advantageous characteristics of both technologies to achieve performance that could not be duplicated individually. Such architectures are resulting in higher power and superior frequency response for military applications such as radar, electronic warfare and electronics countermeasures. Most significantly, the lighter weight and smaller volume, further enhancing military mobility, augment these improvements.

Collaborations:

Academia: University of Maryland

Industry: L3 Electron Devices, Communications and Power Industries

Government: CECOM-I2WD, MILSATCOM, Naval Research Laboratory



Miniature Ka band TWT for Millimeter Wave Power Module

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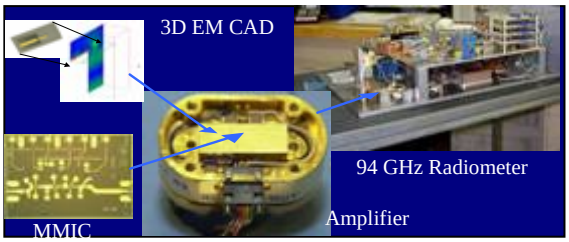
Millimeter-Wave Technology

Army Research Laboratory
Sensors & Electron Devices Directorate
POC: Ed Viveiros 301-394-0930



Objective:

Research new design methodology, materials, devices, integration technologies and characterization techniques for millimeter-wave (mmW) circuits and multi-chip assembly (MCA) modules. The resulting technologies are being demonstrated through the development of single and multifunction mmW components that are directly applicable to Army systems.

Synopsis:

GaAs- and InP-based MMIC (monolithic microwave & millimeter-wave integrated circuit) research has provided improved performance for their consideration in various Army systems. ARL is currently engaged in research in InP MHEMT technology for cost effective manufacturing and InP HBT circuits for signal generation and processing. In addition, new devices based on GaN HEMTs and associated material characteristics are being studied for high power density and high dynamic range applications. One limitation to fully exploit the performance of these MMIC technologies remains in their current integration with systems at mmW. Improved and innovative designs and associated implementation will result in high performance components, ready for a wide spectrum of system insertions.

We are presently extending our experience in the 3-D electromagnetic simulations, module fabrication technology, and thermal designs to research new waveguide structures and integration topologies. Recent accomplished results include Ku-band power modules (>4W), Ka-band power amplifier (>4W) and low-noise amplifier (1.4dB NF at 32 GHz), and W-band power amplifier (>400mW) and low-noise amplifier (<4dB). Multi-functions components include Ka-band transmit/receive modules and switched amplifiers. We are continuing to explore new design topologies for novel waveguide-to-microstrip transitions, power divider and combiner circuits, and multi-channel transmit/receive modules to achieve high output power and low noise-figure, high dynamic range performance. In addition, 3-D integration techniques, MCA architecture, and multi-layer substrate technology are being explored for multi-function phased-array system integration where compact size is a critical requirement. Large- and small-signal, mmW automated measurement systems have been implemented to achieve reliable, accurate characterization and data-collection of devices and modules. Capabilities include on-wafer probing, s-parameters, power, and noise figure measurement. In addition, on-wafer source/load pull characterization system for new device structures such as GaN HEMTs at mmW frequencies has recently been added.

Pathway to the Soldier:

Advanced mmW MCA components are enabling technologies for future radar and phased-array systems. They offer performance, size and reliability benefits. The new technology/components developed are applicable to systems, such as TUAV, MMR for CECOM, seeker applications for AMCOM, and comm./radar for FCS. Internally, the power and low-noise units have also been inserted in demos for programs such electronic-scan antenna (e-scan) to enable multi-function RF operation, Tri-band radar, and Active Protection Radar. The W-band modules are used to enhance passive mmW imaging system, e-scan radar and other future systems.

Collaborations:

DoD: CECOM, AMCOM, NRL, AFRL, and DARPA.
Academia: U. of Michigan, Cornell U., and Boston U.
Industry: BAE Systems, Northrop Grumman, Raytheon, TRW, and AMCOM-Communications

References:

[1] E. Viveiros, J. Speulstra, E. Adler, and H. A. Hung, “Ka–Band MMIC Technologies for an Electronic–Scan Antenna System”, *GOMAC Dig. of Papers*, Mar. 2001.
[2] E. Viveiros, D. Wikner, J. Speulstra, and H. A. Hung, “W-band low-noise amplifiers for a polarimetric stokes radiometer,“ *GOMAC Dig. of Papers*, pp.320-323, Mar. 2000.

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Electric-Field Tunable RF Devices

Army Research Laboratory

Sensors & Electron Devices Directorate

Ferroelectric phase shifters provide electronic scanning capabilities to (a) the 1x4 element C-band antenna and are being developed for electronic scanning of broadband aperture fed antennas at (b) X-band and Ka-band.

Objective:

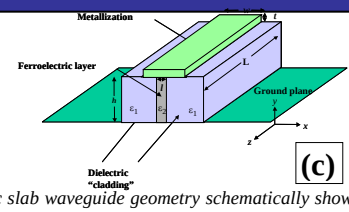
Develop and demonstrate low cost, temperature insensitive, high performance, electric-field tunable device prototypes such as phase shifters to enable affordable electronic scanning antennas; true time delay devices to enable affordable, broadband, single aperture, multi-mode RF systems; tunable filters for digital receivers; and, tunable impedance transformers to reduce losses due to impedance mismatch.

Synopsis:

Present technology, ferrite phase shifters are relatively narrow band, require large amounts of current to control the phase angle, and are relatively bulky and expensive.

Ferroelectrics are electric-field (voltage) tunable materials that provide the potential for low cost, low power (low current) consuming tunable high performance RF and microwave devices. Such devices can be used for electronic scanning antenna technology including secure communications as well as for enabling broadband/multi-mode platforms that will utilize fewer antennas and device components thus reducing the size, weight, and power consumption of the overall system compared with the total from individual antenna systems.

The U.S. Army Research Laboratory is currently developing new materials and device structures to overcome some of the short falls of present ferroelectric phase shifter technology so that high performance RF and microwave tunable device prototypes can be realized and demonstrated in system level architectures. Low loss device structures, to provide tunable true time delay, are being developed to overcome the short fall of relatively narrowband phase shifters. Temperature insensitive ferroelectrics are being developed in order to eliminate the need for temperature compensating circuitry.



The ferroelectric slab waveguide geometry schematically shown in (c) has been used to demonstrate true time delay behavior through X-band. In addition, new electric field tunable materials have been demonstrated that provide significantly less temperature sensitive dielectric properties in the temperature range –50 to 100 °C.

Pathway to the Soldier:

Tunable RF components including true time delay devices that utilize paraelectric materials potentially allow for a relatively low cost high performance broadband/multi-mode platform that affords the soldier on the battlefield the ability to simultaneously perform secure communications, multi-target acquisition and tracking, etc., using a single lower cost, smaller, lighter weight, lower power consuming electronic scanning antenna platform.

Collaborations:

Government*:* CECOM (TPAs CE-SE-2002-05 and CE-SE-2002-06) Supporting STOs: Advanced RF Components and Multi-Function RF Sensor Technology

References:

[1] F.J. Crowne and S.C. Tidrow, "The Ferroelectric Slab Waveguide: a Geometry for Microwave Components that Incorporate Ferroelectric Materials", Mat. Res. Soc. Symp. Proc., 720, 185-190(2002).

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RF Frequency Control

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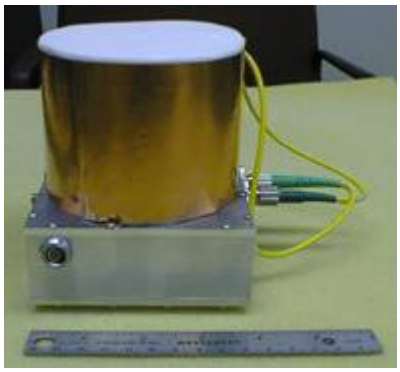


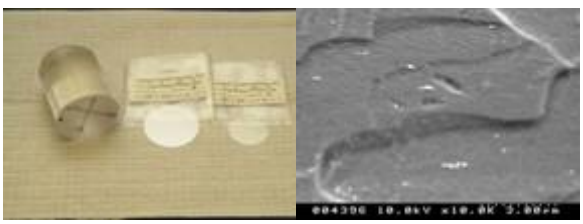
Opto-Electronic Oscillator (OEO) at 10 GHz has an improved phase noise of 20 to 30 dB compared with conventional technology.

Objective:

Apply advanced frequency control measures to meet the Army's Future Combat Systems (FCS) requirements, leading to high-G smart munitions, high data rate rf network links, higher immunity against rf jamming, more effective navigation and better radars capable of detecting slow moving targets and better synchronization for radios needing longer radio silence periods.

Synopsis:

Modeling and simulation and development of new piezoelectric materials are used to design improved and novel resonators for more stable and accurate clocks/oscillators with considerably lower power consumption, lower sensitivity to vibration, higher-G survivability, and lower jitter/phase noise.



(a) (b)

(a) Single crystal boules of LGS, LGN, LGT are cut and polished for use as substrates. (b) SEM photograph showing step-bunch-flow-growth mode of LGS film. LGS and LGT epitaxial films have been grown on the temperature compensated Y-cut of LGS ad LGT substrates by liquid phase epitaxy for use in thin film resonator devices.

These key features will lead to higher-performance communications permitting longer periods of radio silence, better radar systems for detecting lower doppler speed targets, more reliable IFF and rf networking links, very high-G smart munitions and more effective anti-rf jam modules.

Pathway to the Soldier:

Improved frequency control measures are key factors for obtaining better communications, effective rf anti-jam measures, high data rate rf networks, high-G smart munitions, and improved radar doppler target detection. These technology advances will help reshape the Army battlefield environment of the future and will help reduce the exposure of the future US soldier to hostile forces by providing an effective strike capability for initial engagements.

Collaborations:

Academia*:* University of Central Florida, State University of New York (DOE Brookhaven)
Industry*:* Northrop-Grumman, Q-Tech Inc., Vectronics Inc., Crystal Photonics Inc.
Government*:* JPL/NASA, NIST/Boulder, CERDEC.
International*:* Swiss Federal Institute of Technology

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