Defense Advanced Research Projects Agency
“Bridging the Gap”

Dr. Robert F. Leheny
Deputy Director
**Report Documentation Page**

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

<table>
<thead>
<tr>
<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
<th>3. DATES COVERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>05 MAR 2007</td>
<td>N/A</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. TITLE AND SUBTITLE</th>
<th>5a. CONTRACT NUMBER</th>
<th>5b. GRANT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bridging the Gap</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6. AUTHOR(S)</th>
<th>5c. PROGRAM ELEMENT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</th>
<th>8. PERFORMING ORGANIZATION REPORT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>DARPA</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</th>
<th>10. SPONSOR/MONITOR’S ACRONYM(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>12. DISTRIBUTION/AVAILABILITY STATEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approved for public release, distribution unlimited</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>13. SUPPLEMENTARY NOTES</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>14. ABSTRACT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>15. SUBJECT TERMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>16. SECURITY CLASSIFICATION OF:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. REPORT</td>
</tr>
<tr>
<td>unclassified</td>
</tr>
<tr>
<td>b. ABSTRACT</td>
</tr>
<tr>
<td>unclassified</td>
</tr>
<tr>
<td>c. THIS PAGE</td>
</tr>
<tr>
<td>unclassified</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>17. LIMITATION OF ABSTRACT</th>
<th>18. NUMBER OF PAGES</th>
<th>19a. NAME OF RESPONSIBLE PERSON</th>
</tr>
</thead>
<tbody>
<tr>
<td>UU</td>
<td>44</td>
<td></td>
</tr>
</tbody>
</table>

*Standard Form 298 (Rev. 8-98)*
Prescribed by ANSI Std Z39-18
DARPA Role in Science and Technology

Science and Technology Programs for the Armed Services

Fundamental Research, Leading Edge Discovery, System Concept Invention
DOD Investments in Science & Technology
(circa 1957)

July, 1957 - Dec, 1958
International Geophysical Year

Limited Funding!
NRL’s Vanguard
Planned 3.5 lbs

Fundamental Research Focus

No Program of Record to create a Space Capability

Service Requirements Focused Investments

Near
Mid
Far

Science & Technology Investments
$
DOD Investments in S&T

Sputnik- A wake-up call

Science & Technology Investments $

No Program of Record to create a Space Capability

Near

Mid

Far

Time to Market

- Sputnik- 1 Oct 1957 186 lbs
- Sputnik- 2 Nov 1957 1120 lbs (live dog payload)
- Sputnik- 3 May 1958 3000 lbs (1,327 lbs payload)

Limited
Money

NRL’s Vanguard Planned 3.5 lbs
DARPA Investments: Innovation Driving New Capabilities

Service Requirements Focused Investments

Focus on “capabilities to meet future needs”

6.1 Research Focus

Application Time Horizon

Science & Technology $ (FY07)
DARPA Investments: Innovation Driving New Capabilities

ARPA Responds
(August 15, 1958)

30 December 1957
Saturn I first proposed. Von Braun produces 'Proposal for a National Integrated Missile and Space Vehicle Development Plan'. First mention of 1,500,000 lbf booster (Saturn I)

29 July 1958
ARPA gives Von Braun team contract to develop Saturn I (called 'cluster's last stand' due to design concept)

15 August 1958 ARPA launches Saturn I project ARPA provided the Army Ordnance Missile Command (AOMC) with authority and initial funding to develop the Juno V (later named Saturn launch vehicle).

Go/NoGo - a Rocket with the largest Payload Capability possible

Science & Technology $ (FY06)

10B -

5B -

0 -

Application Time Horizon

NEAR

MID

FAR

Focused on “capabilities to meet future needs”

10B -

5B -

0 -

Saturn

Pres. Kennedy commits US to send a man to the moon

6.1 Research Focus

Saturn

DARPA

Innovation Driving New Capabilities

DARPA Investments:
DARPA Business Model

Projects (Programs) agency:

Typical projects are 3-5 years with multiple contracts-

- Projects are phased,
  - Well-defined milestones (Go-NoGo) for progression between phases.
  - Timing of Go/No-Go decisions are dependent upon effort and not pre-determined

- Projects with fieldable prototypes as deliverables typically require MOUs with operators (end users) to go forward to final phase.

- Funding in any technology area beyond end of project contract dependent on ideas
DARPA’s New Initiative Process

**Phase I**
- Evaluate “Go / No Go” Accomplishment

**Phase II**
- Continue Development
- Solicit Partnership & Transition Path

**Source Selection**
- Evaluate Responses
- Select Performers

**Broad Agency Announcement**
- Establish “Go / No Go” Criteria
- Approve Broad Agency Announcement (BAA)

**Contract**

**Feasibility Study**

**Idea**

Individuals from:
- Industry
- Universities
- Entrepreneurs
- Government

DARPA Program Manager

DARPA Office Director
DARPA’s Strategic Thrusts

*Investments Today Create Future Capabilities*

- Detection, Precision ID, Tracking & Destruction of Elusive Targets
- Networked Manned & Unmanned Systems
- Robust, Secure Self-Forming Tactical Networks
- Urban Area Operations
- Location and Characterization of Underground Structures
- Assured Use of Space
- Cognitive Systems
- Bio-Revolution
- Core Technologies (Biology / Materials / Electronics / IT)
Future Icons

• Low-cost titanium to enable routine use ($3.5/lb military grade alloy)
• Accelerate Development & Production of Therapeutics & Vaccines from 12+ yrs to 12 wks
• Alternative Energy Sources – Jet Fuel from plants
• Prosthetics to enable return to units without loss of capability
• Networks - Self-forming, Robust, Self-defending
• Chip Scale Atomic Clock to replace reliance on GPS time signal
• Networked Sensors – Determine, track, and neutralize elusive threats
• Real time language translation to replace linguists (Defense Language Institute, III Æ IV)
• High-productivity computing system – peta scale computer
• Air Vehicles - Fast Access, long loiter for military operations
• High Energy Liquid Laser Area Defense System as a penetration aid to replace stealth
• Space capabilities to enable global military operations
• Grand Challenge – Accelerated development of autonomous ground vehicle technology
Opportunities

Microsystems Technology Advances
Enable Future ICONS

- Sense
- Process
- Communicate
- Actuate
- Energize
Opportunities

Applications Create Challenges

Innovations Create Capabilities

Core Technologies

Digital-Analog/RF Mixed Signal

MEMS RF Resonator

ME MS Opto-Steering

A/D Wafer

Deep Via Cross Sectional SEM

MEMS Wafer

Digital Electronics

Analog/RF

Photonics

Digital-Analog/RF

Mixed Signal

Core Technologies for Chip-Scale Microsystems

Opportunities

MEMS

Photonics

Digital-Analog/RF

Mixed Signal
Chip-Scale Atomic Clock

**Atomic Clock Concept**

- **Laser**
  - 852.11 nm
  - \(^{133}\)Cs vapor at 10\(^{-7}\) torr

- **Vapor Cell**

- **VCSEL**

- **Substrate**

- **Resonator**
  - in Vacuum

- **MEMS and Photonic Technologies**

- **Physics Package**

---

**Chip-Scale Atomic Clock**

- Vol: 1 cm³
- Power: 30 mW
- Stab: \(1 \times 10^{-11}\)

**Stability data**

- Overlapping Allan Deviation, \(\sigma(\tau)\)

**Goal:**

- Miniature, low-power atomic timing and frequency references with
  - Allan deviation < \(10^{-11}\) over 1 hour (1 μs/day)
  - Size <1 cc
  - Power Consumption < 30 mW

---

**Precision Time for Every Radio and Network Node**
WASP - Hand Launched UAV

- 2 Color video cameras & GPS
- Weigh: 13 oz.
- Endurance: 30-40 min
- Speed: 20-34 knots

- Hand Launched
- Autonomous Flight
- Auto-Navigation
- Auto-Land
Opportunities

Microsystems Technology Advances
Enable Future ICOns

– Sense
– Process
– Communicate
– Actuate
– Energize
Sense

Focal Plane Arrays

SHORT-WAVE

MEDIUM-WAVE

LONG-WAVE

THz

DUVAP
(0.5 µm)

HOT-MWIR
(3-5 µm)

PCAR
(1-2 µm)

VISA
(8-12 µm)

TIFT
(THz)

MIATA
(mm-Wave)

UV
SWIR
MWIR
LWIR

λ (µm)

THz
mm-Wave

0 1 3 5 8 10 12 300 3000
Exploiting materials to achieve reliable, high performance devices and MMICs with
- higher power
- higher efficiency & bandwidth
- superior thermal performance

Achieve rapid insertion into DoD RF systems

Revolutionizing RF systems performance through increases in solid state amplifier power, efficiency, linearity, noise figure, and robustness

The Future of RF Electronics for Radar, EW, and Comms
Chip Scale Gas Analyzers (MGA)

Remote detection of chemical agents via tiny, ultra-low power, fast, chip-scale gas analyzers that greatly reduce the incidence of false positives
- Achieve 4 sec analysis time in <2 cc
- Minimum detectable signal < 1 ppt
- Energy per analysis < 1 Joule
Opportunities

Microsystems Technology Advances Enable Future ICONS

– Sense
– Process
– Communicate
– Actuate
– Energize
Exploiting Moore’s Law

Minimum Feature Size (nm) (DRAM Half/Pitch)

YEAR

193nm Litho
157nm Litho
157nm Immersion
CMOS/SOI
SiGe HBT
CVD Copper
Laser anneal
C-doped SiGe
ABCS, EPIC
UNIC, NEMS, STEEP
DARPA Sponsored
Critical World Leading Demonstrations

Heat Generation Is Roadblock to Continued Scaling

Scaling Trend

DARPA
Discipline

Heat Generation

Critical World Leading Demonstrations

DARPA Sponsored

Critical World Leading Demonstrations

YEAR

22
Supercomputer on a Chip

Intrinsic Transistor Performance versus Circuit Speed

X86 (52% / year)
Moore’s Law (74% / year)
19% / year

Perf (ps/Inst)
Delay/CPUs

Intrinsic Device Speed not Exploited at Circuit Level:
Thermal Limitation
Architecture
Global Interconnects

Source: ISAT Summer 2001 Study- Last Classical Computer;
Prof. Bill Dally (Stanford U) Study Lead
Impact of Supercomputer on a Chip

From Hans Moravec, Carnegie-Mellon University
http://www.transhumanist.com/volume1moravec.htm
Cognitive Computing Challenges

- Autonomous Robots
- Massive Sensor Streams
- Information Integration
- Rapid Planning & Decision Making
Machine Translation

In Near Real Time

Global Autonomous Language Exploitation (GALE)

- Multiple media, sources, and languages
- Speech translation
- Text translation
- Content distillation

Continuous translation of formatted speech with content distillation

Phraselator to TRANSTAC
A Major Leap Forward

Handheld translation systems for spontaneous two-way speech communications under real world conditions

- Phraselator-deployed today
- TRANSTAC-Tomorrow's Solution

Real-time two way speech within a limited contextual domain

- Begin with limited two-way system
- Constrain the domain
- Enhance performance through iterative testing - robustness to noise, context-driven ASR, etc.
Opportunities

Microsystems Technology Advances Enable Future ICONS

- Sense
- Process
- Communicate
- Actuate
- Energize
network centric operations
1. **Network Centric Enterprise**

*Strategic and operational level of deployment and warfare*

- Cleared Personnel – TS/SCI
- Links air, ground and naval campaigns
- Engages by operational maneuver and strategic strikes
- Provides information, resources, and sustainment connectivity
- Large C4ISR backbone and infrastructure
  - Rides on GIG and Extensions
  - Can leverage commercial info systems
  - IPv6 early adopter
  - Susceptible to many IA threats

2. **Network Centric Warfare**

*Tactical level of deployment and warfare*

- Uncleared Personnel
- Links effects to targets
- Engages directly with the enemy
- Must be agile, adaptive and versatile
- Minimal, “portable” C4ISR infrastructure
  - Rides on tactical communications
  - Requires LPD/LPI transmission security
  - NCW weapons susceptible to IA attack
Networked Wireless Communications

A Dual-Rate, Mobile Ad-Hoc Network for the Maneuver Force

Mobile ad-hoc network dynamically reconfigures during operations to automatically maintain network connectivity

System automatically schedules non-interfering communications for increased network capacity

Networked vehicles automatically communicate when within range – no manual configuration

Vehicles automatically leave and join the network – no manual entry
Optical & RF Combined Link Experiment

Links to forces fixed and on the move

Objective: Develop a hybrid free space optical/radio frequency communications system

Air-to-Air Crosslink
FSO/RF
>200 km
99% Availability
2 Gbps (average)

FSO/RF
All Weather
Surface to 10 km
>95% Availability
2 Gbps (average)

Optical Retro Reflector
Clear Air
>45 Mbps
Uplink/Downlink

GIG / Fiber Optic
Point of Presence
Next Generation Core Optical Networks

Goal: Increased Optical Network Throughput with Reduced Latency & Cost

1. Ultra-High-Capacity, Long-Reach Transmission
2. All-Optical Switching and Circuit-Based Grooming
3. All-Optical Bursts or Flow Grooming in Edge Networks
4. Network Control and Management

<table>
<thead>
<tr>
<th>Network Requirement</th>
<th>Today’s State of the Art Networks</th>
<th>Next-Gen Core Optical Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate Capacity</td>
<td>10 Tb/s</td>
<td>100 Tb/s</td>
</tr>
<tr>
<td>Maximum Fiber Capacity</td>
<td>1.6 Tb/s</td>
<td>16 Tb/s</td>
</tr>
<tr>
<td>Bit Rate per Wavelength</td>
<td>10 to 40 Gb/s</td>
<td>40 to 160 Gb/s</td>
</tr>
<tr>
<td>Speed of Provisioning</td>
<td>Minutes to Hours</td>
<td>&lt; 100 msec</td>
</tr>
<tr>
<td>Speed of Restoration</td>
<td>Seconds to Minutes</td>
<td>&lt; 100 msec</td>
</tr>
<tr>
<td>Speed of Protection</td>
<td>50-200 msec</td>
<td>&lt; 50 msec</td>
</tr>
</tbody>
</table>

Approved for Public Release (DARPA Case #7528 21JUL2006)
Photonic Data Links

Network Scale:

MTO Program: (active/complete)

Photonic Technologies:

Accessing Quantum Systems

Chip

CS-WDM, C2OI, EPIC

• Heterogeneous O/E Integration
  • Dense 2-D
  • Waveguide & Free Space
  • WDM

Board

VLSI-P

• GaAs based O/E
  • Si electronics
  • Freespace
  • 2-D arrays
  • DOE/VCSELs

Platform

OMNET,

• GaAs based O/E
  • VCSELs
  • mm Fiber/POF
  • Gb/s
  • Serial/parallel

Global

BIT

OCDMA, DODAR

• InP based O/E
  • SM-glass Fiber
  • Very high speed TDM
  • WDM

1Å 10 Å 100 Å 1000 Å

VLSI Today (2005): 1B transistors/cm²

Projected Limits to CMOS (2015: 10B transistor/cm²)

Atomic Scale
Integration of photonic functions with standard high performance CMOS electronics and fabricated in a standard CMOS foundry.

Moore’s Law

- Feature size (nm)
  - Photon λ (~350-400 nm)
  - Electron λ (~10 nm)

Quantum Regime


20 Gb/s Transceiver
- 4 λ x 5 Gb/s into single fiber
- >100 photonic devices
- + > 5,000 electronic devices

8.02 mm x 9.17 mm die

Seamless Interface between Photonics and Electronics

Optical Data Transceiver Chip in Silicon

- Silicon 10G Modulators: driven with on-chip circuitry, highest quality signal, low loss, low power consumption
- Flip-chip bonded lasers: wavelength 1550 nm, passive alignment, non-modulated = low cost reliable
- Silicon Optical Filters - DDM: electrically tunable, integrated on-chip control circuitry

CMOS Photonics Technology

The Toolkit is Complete
- 10Gb modulators and receivers
- Integration with CMOS electronics
- Cost effective, reliable light source
- Standard packaging technology

Seamless Interface between Photonics and Electronics
Opportunities

Microsystems Technology Advances
Enable Future ICONS

- Sense
- Process
- Communicate
- Actuate
- Energize
Actuate

Creating the MEMS Frontier

1950
The First IC (Fairchild)

1960
Pressure Sensor (Honeywell)

1970
Si Pressure Sensor (Motorola)

1980
SFB Pressure Sensor (NovaSensor)

1990
PolySi Micromotor (Tai, Muller)

2000
DMD (TI)

2010
RF MEMS

Fabrication plus Basic Sensors

Surface Micromachined Sensors, RF-MEMS

Modified from a slide from YC Tai, Caltech
Understanding the Language of the Brain

State of the Art: Utah arm

- Closed loop nervous system integration
- Full DOF, range-of-motion
- Proportional tactile & force receptors
- Human-like endurance and actuation

Revolutionizing Prosthetics
Opportunities

Microsystems Technology Advances
Enable Future ICONS

- Sense
- Process
- Communicate
- Actuate
- Energize
High Energy Liquid Laser Area Defense System (HELLADS)

**Offensive Targets**
- Air defense systems
- Aircraft

**Defensive Targets**
- Cruise missiles
- Aircraft
- UAVs
- Low-altitude missiles
- SAMs

- *Novel Design That Combines the Energy Density of a Solid State Laser with the Improved Thermal Management Qualities of a Liquid Laser*
- *System Goals: 150 kW Laser Output, 5 kg/kW*
- *Enables Laser Weapon Systems Integration with Tactical Platforms*
All Diode-Pumped Lasers Have the Same Basic Components and Issues

Efficiency, power supply, thermal management and beam quality
Opportunities

Core Technologies

Innovations Create Capabilities

Applications Create Challenges

MEMS

Photonics

Digital-Analog/RF Mixed Signal

Digital-Electronics

Analog/RF

MEMS

Photonics

Applications Create Challenges

Innovations Create Capabilities

Opportunities

Core Technologies
Future Challenges

Sensing
- Single photon detection over SW/MW/LW IR
- Room temperature broadband sensing
- Create chip-scale hyperspectral sensing
- Small aperture mm wave/THz imager
- Subwavelength-size pixel focal planes

Processing
- Eliminate thermal dissipation road block
- Eliminate data throughput and memory access bottleneck
- Overcome the growing complexity in circuit design
- Theoretical limit analog to digital converters

Communication
- Complete chip scale radios
- Reduced latency
- “internet over RF”
- mm-wave communications
- Coherent optical communications

Actuation
- Chip scale avionics
- Universal MEMS packaging
- Chip-scale RADAR
- Ultra-stable, lower power timing devices
- Tunable directionality antennas
- Miniature GPS systems
- Micro-scale gas and liquid analyzer

Energize
- Laser diode bar lifetime and reliability
- Diffraction-limited, coherent high-power diode laser arrays
- Smart power management
- Long endurance micro-power generation
DARPA

Always Interested in Innovative Ideas

- For information on current solicitations & doing business with DARPA access
  www.darpa.mil

- Or, talk to a DARPA Program Manager

- Or, attend DARPATech 2007

DARPA’s Industry Outreach

DARPA’s Strategic Plan
Available online at

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
STRATEGIC PLAN
FEBRUARY 2007
If you have an idea you can’t get done where you are, consider joining us.

We just might help that dream to come true.

Give us a call.

Visit www.darpa.mil/PoweredbyIdeas for more details

Submit resumes and ideas to callus@darpa.mil