Stanford Center for Position, Navigation & Time - (*SCPNT*)

Per Enge, Mark Kasevich, Umran Inan,

Tom Kenny, Jim Spilker, Jr., Brad Parkinson,

Sebastian Thrun, Ahmad Bahai, Tom Langenstein

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- **The implementation of GPS in 1973 began this technology revolution, this technology is just in its infancy; "*We have only passed the end of the beginning*" of a new era in technology. (W. Churchill)**

- ***"Navigation & time technology will benefit billions of people, millions of businesses and most nations in a life altering manner in the next 20 years - much as is the Internet"*** **(Jim Spilker)**

- **Stanford University Departments in AA, EE, ME, CS and Physics are each contributing exciting, novel new technologies, and together can play a leading role in this technology revolution which necessarily crosses many department boundaries**

SCPNT - Technology Vision

- **Trajectory determination at the centimeter level – anywhere, anytime.**
  - **Low-cost**
  - **Compact**
  - **Easy-to-integrate**
  - **Authenticated**
  - **Secure**
  - **Low-power**

- **Guidance, navigation & control for swarms of intelligent, autonomous airborne drones, ground and undersea robots**

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Stanford Technology
Difficult Navigation Environments

- **Difficult environments:**
  - **Indoor, urban canyons**
  - **Space**
  - **Remote**
  - **Mountainous terrain**
  - **Jungle/Foliage**
  - **Undersea**
  - **Underground**
  - **EMI & Malevolent Jamming or Spoofing**

- **Ubiquitous, precision, reliable navigation & time technology is currently not available in all of these environments.**

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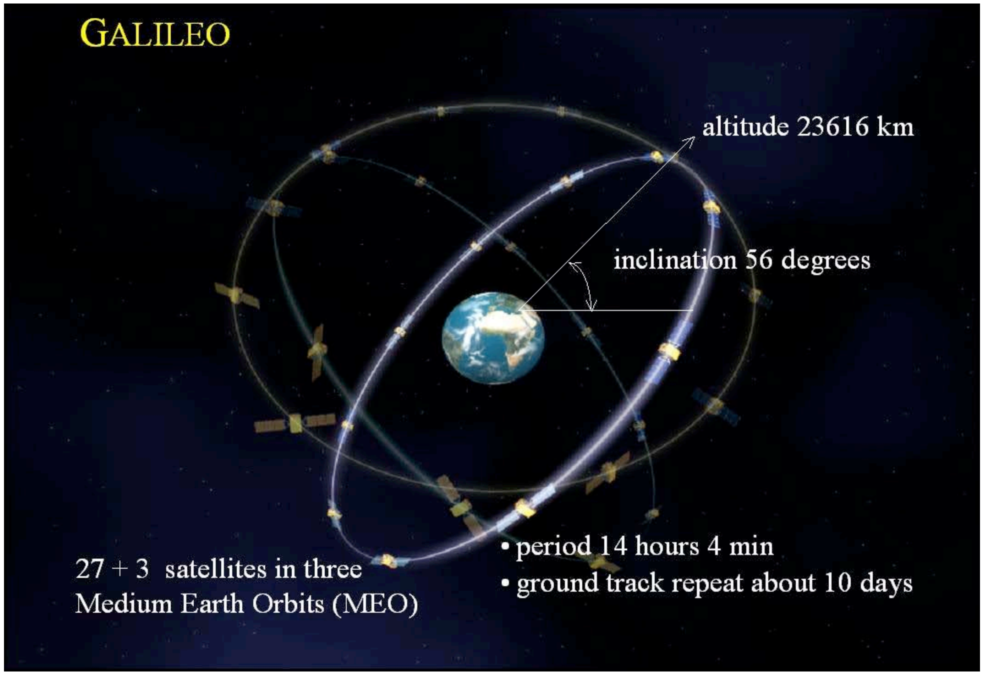
Europe, Russia, India & Japan Share Our Sense of the Future

- Other nations have recognized the importance of navigation & time.
- The European Union is designing the Galileo system of 30 satellites (10B ECU)
- Russia and India are planning to rejuvenate the GLONASS system
- Japan is also active with QZSS.



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Outline

A. Navigation & time technology will impact billions of people:

- Millions of cars, trucks, motorcycles, boats, ships, private and commercial aircraft, robotic vehicles, shipping, digital telecom networks, energy grids, security, seismic & sensor monitoring. New location based services (LBS) will emerge world-wide.

B. Stanford Position, Navigation & Time technology:

- Stanford has substantial ongoing research in Position, Navigation & Time in 5 separate departments

- Technology advancements include next generation GPS, Galileo, atomic based clocks, gyros, inertial units & their integration with mobile telecom & new semi-conductor technology.

Outline

C. Stanford Center for Position, Navigation & Time

- **Central themes:**
  - New advanced sensors integrated for the next generation of applications.
  - Target projects with major benefit to Government and industry.
  - Enable interdisciplinary work between key departments.
  - Hands-on emphasis on hardware design, development & testing
  - Provides a new level of interaction between University researchers, Government, and industry.

- **Led by key faculty from AA, EE, ME, CS & Physics.**
  - Interconnectivity & continuity with new Prof. (Res) & Asst Prof.
  - Center management to reduce faculty administrative load.

- **Funded by:**
  - New & existing Government contracts ($10M today)
  - Industry donations from Center Members and Associates.

A. Position, Navigation & Time Technology Critical to the global economy

Time Technology

- **Broadband communications/Internet networks rely on precision timing at each nodal point for digital synchronization and timing.**

- **Cellular & wireless base-stations rely on time synchronization**

Survey, Geodesy, & Seismic Monitoring

- **Precision survey, mapping, geodesy and seismic monitoring of earthquake faults.**

- **Future advancements will improve precision & reduce costs**

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New Era in General Aviation

Business jets flying in virtual tunnel highways in the sky with high integrity and all weather precision navigation to/from small runways.

Disarm Unexploded Ordinance (UXO)

In the U.S. alone, UXO is spread over 10 million acres at 1400 sites. Current DoD budget is $200M/year.

UXO Search at Camp Bonneville

- **Centimeter accuracy under foliage requires integration with new clock technology & local radio beacons**

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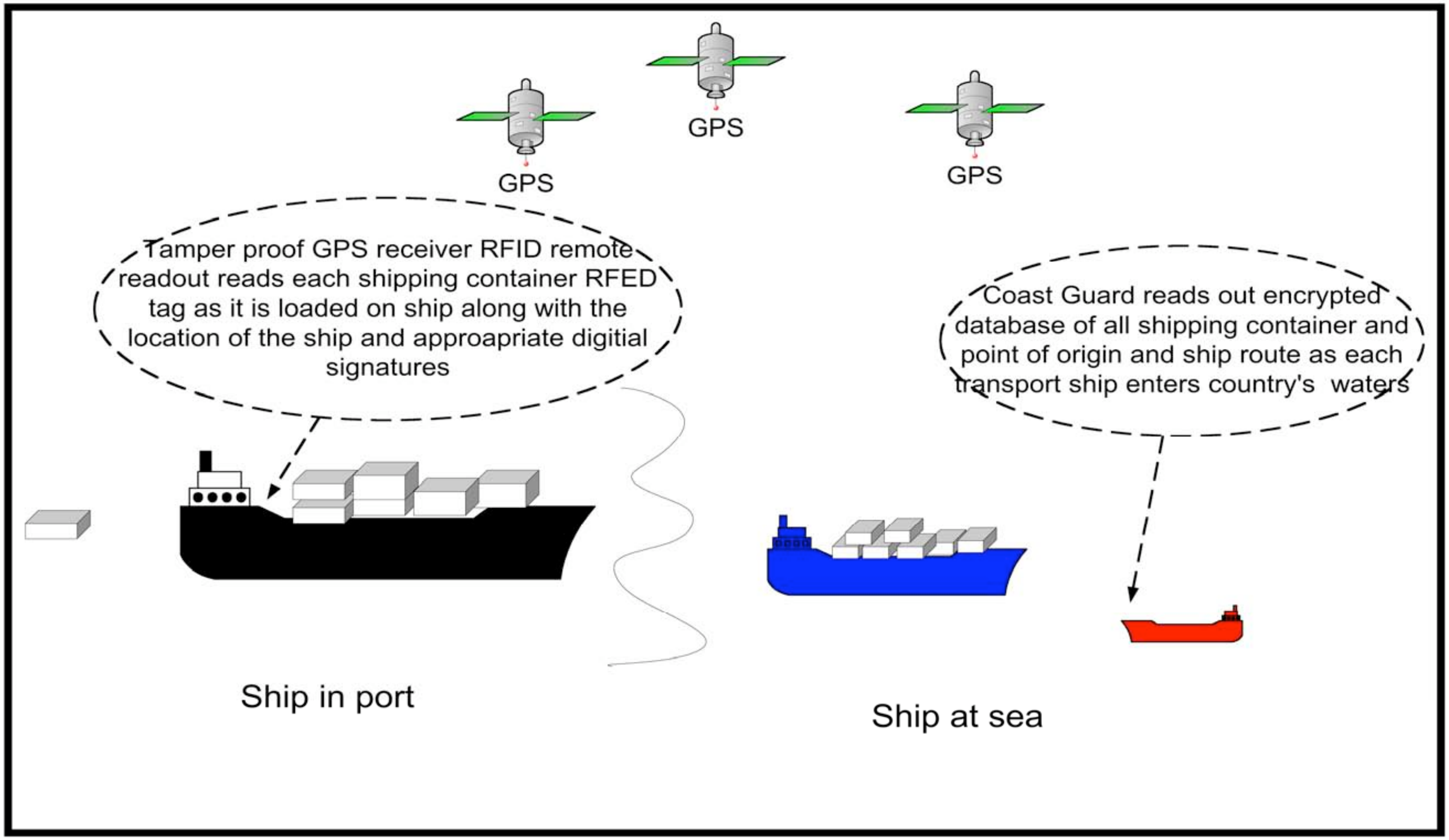
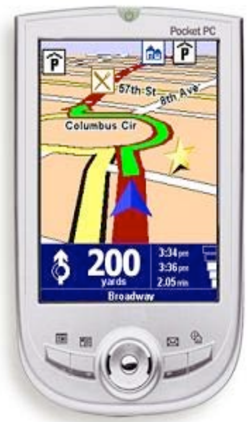
Location Aided Ship Transport Security



Wireless Devices-distress warnings

- **Wireless cellphones, PDAs, laptops with position/maps/ thumbprint readers provide E911 emergency service & theft security**

- **New location based services (LBS) for travel, meetings, shopping**



Military
Aircraft Carrier Landing

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Military
Unmanned Air Vehicles (UAVs)

- **Future military with thousands of UAVs flying in formation with aerial refueling protecting borders, performing reconnaissance, dangerous military missions**
- **Secure reliable navigation is key, especially with jamming**

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GPS and Sensor Networks

- Future applications will require 100's of interconnected, heterogeneous mobile sensors and clusters
- Low power embedded GPS can enhance sensor network efficiency
  - New applications
  - Higher reliability
- Accurate timing and localization will increase throughput and reduce total power consumption
- Ultra clean clock reference can improve accuracy of mixed signal and timing recovery in communication systems

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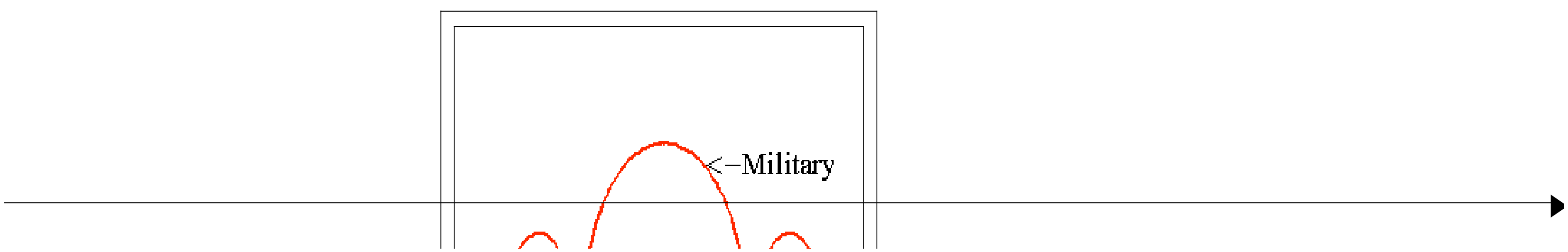
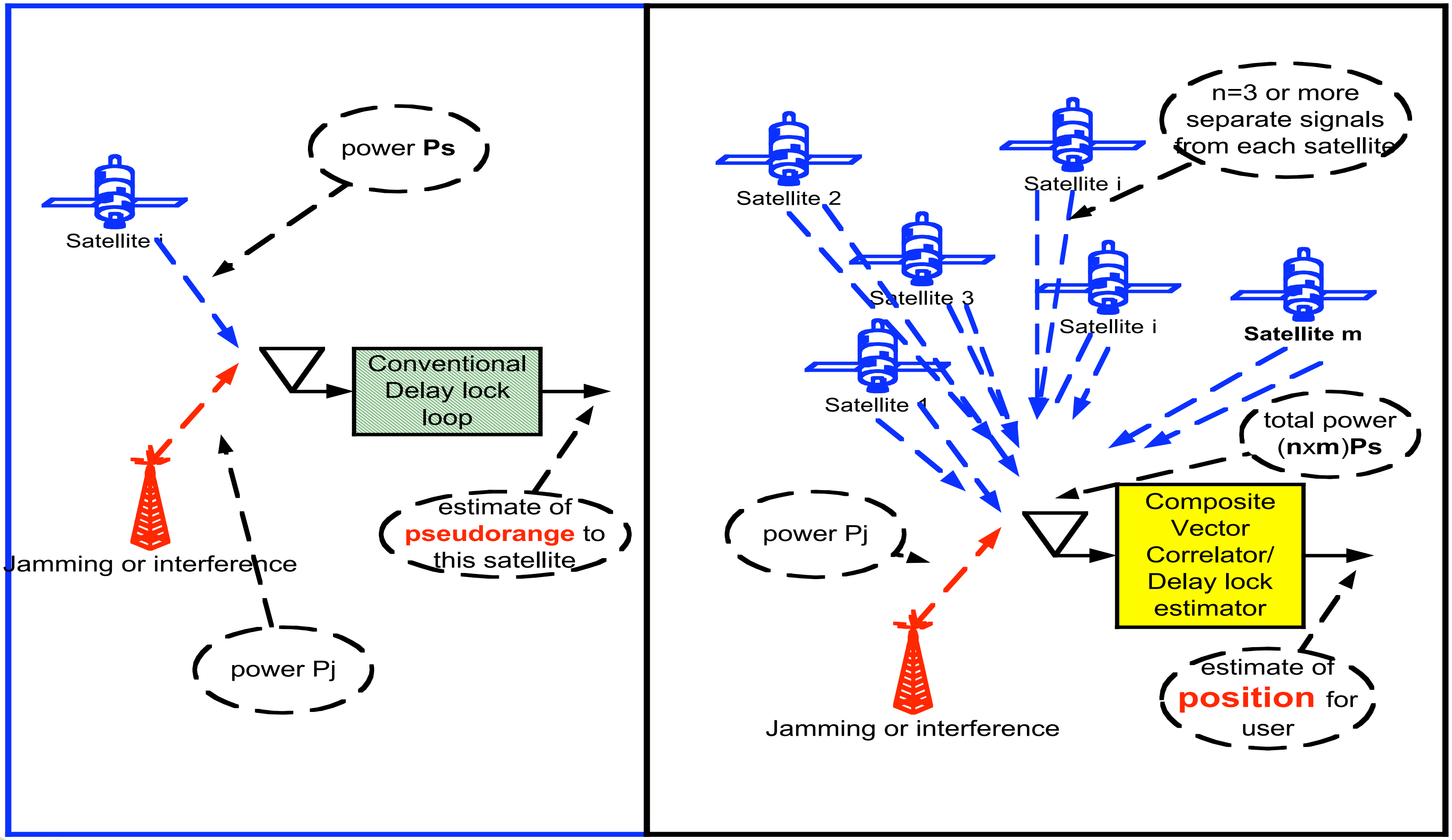
GPS Signals: Present and Future
L1, L2, and L5—L5 in Block 2F satellites

New satellites launched
near the end of the decade



Composite Signal Vector Correlation/Tracking



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B. Stanford Technology Strengths

- Navigation system design & analysis
- Satellite design & orbital analysis
- Adaptive multi-beam and nulling antenna design
- Generalized vector navigation sensor processing
- Space science & ionospheric modeling
- Radiation-hardened sensors
- Navigation system integrity
- GPS augmentation, WAAS, LAAS, Loran
- Precision atomic accelerometer/gyro & clocks
- Silicon chip clocks & MEMS accelerometers
- Working systems!

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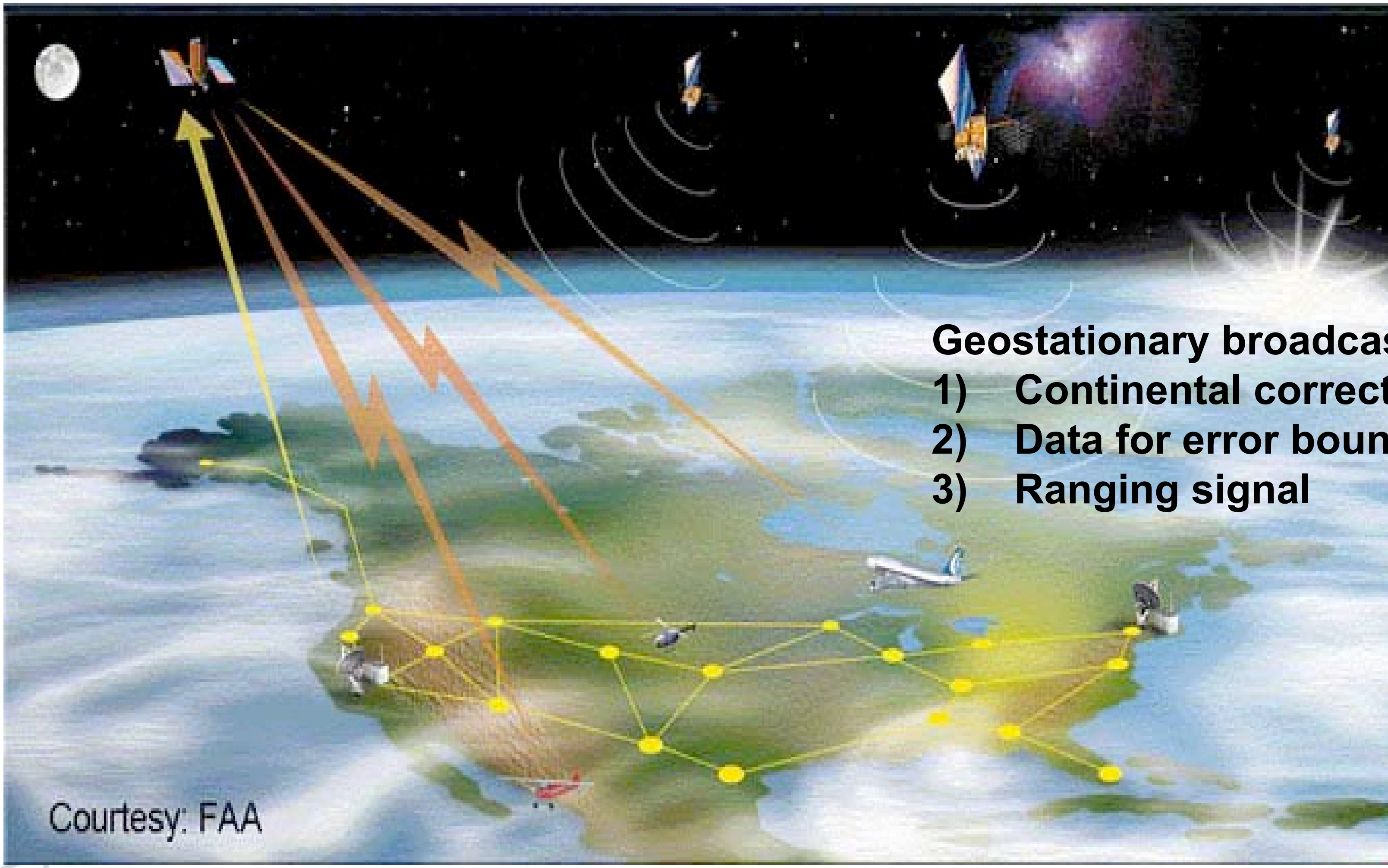
Wide Area Augmentation System WAAS



Geostationary broadcast of:

1) **Continental corrections**
2) **Data for error bounds**
3) **Ranging signal**

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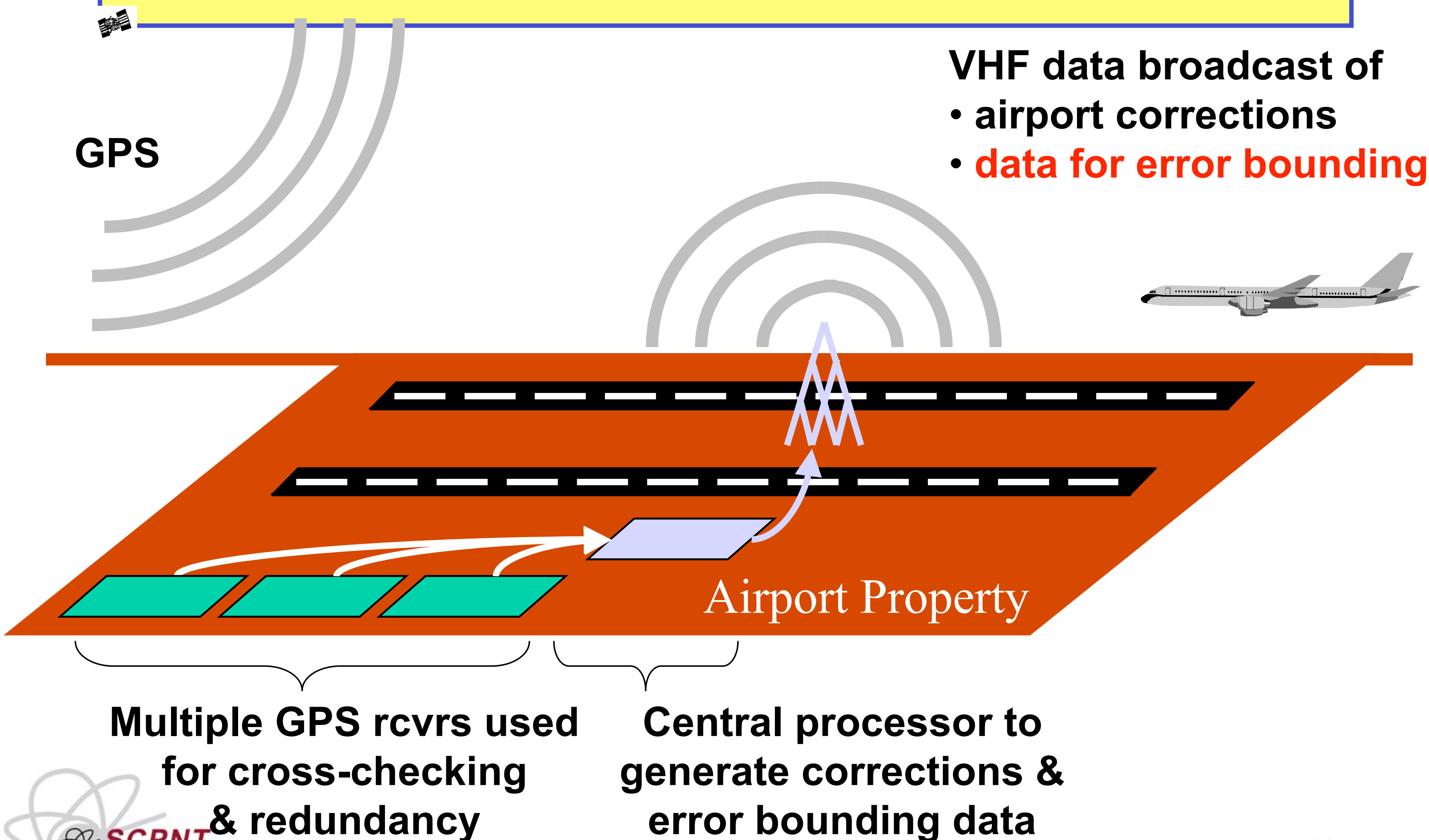
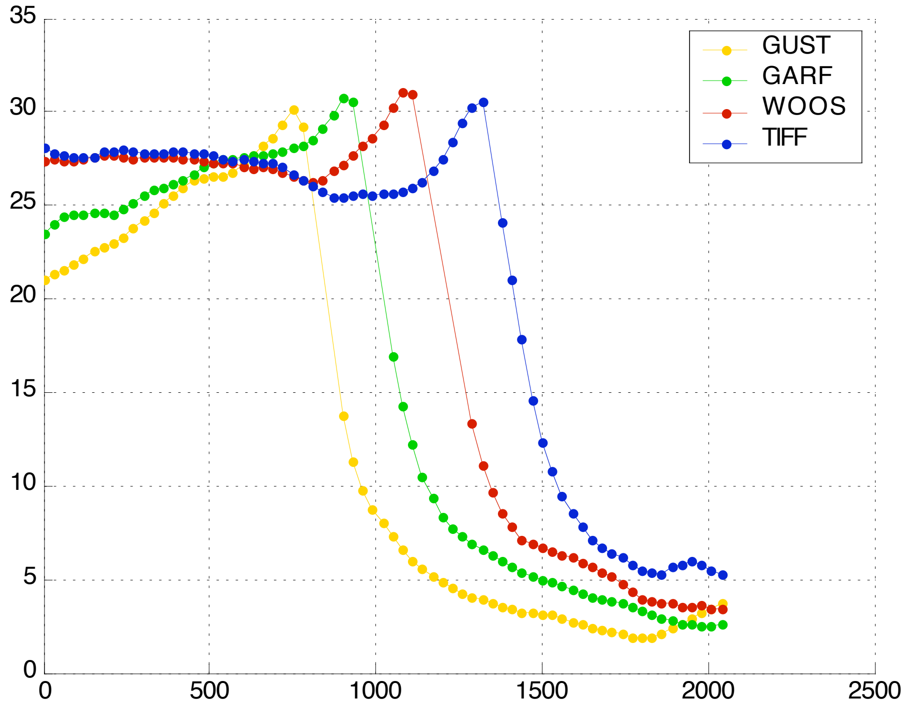
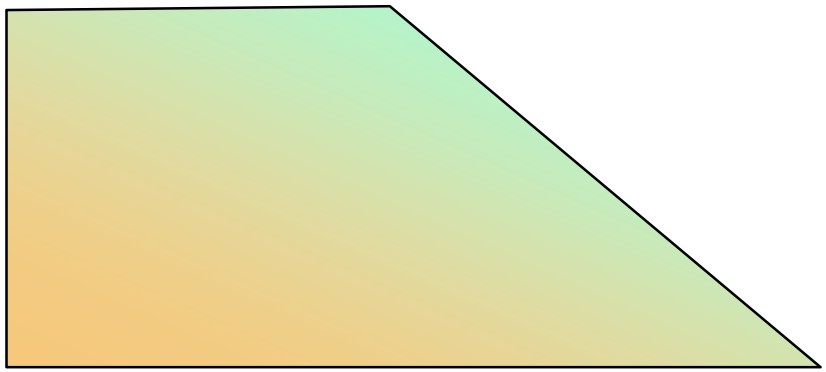
Local Area Augmentation System

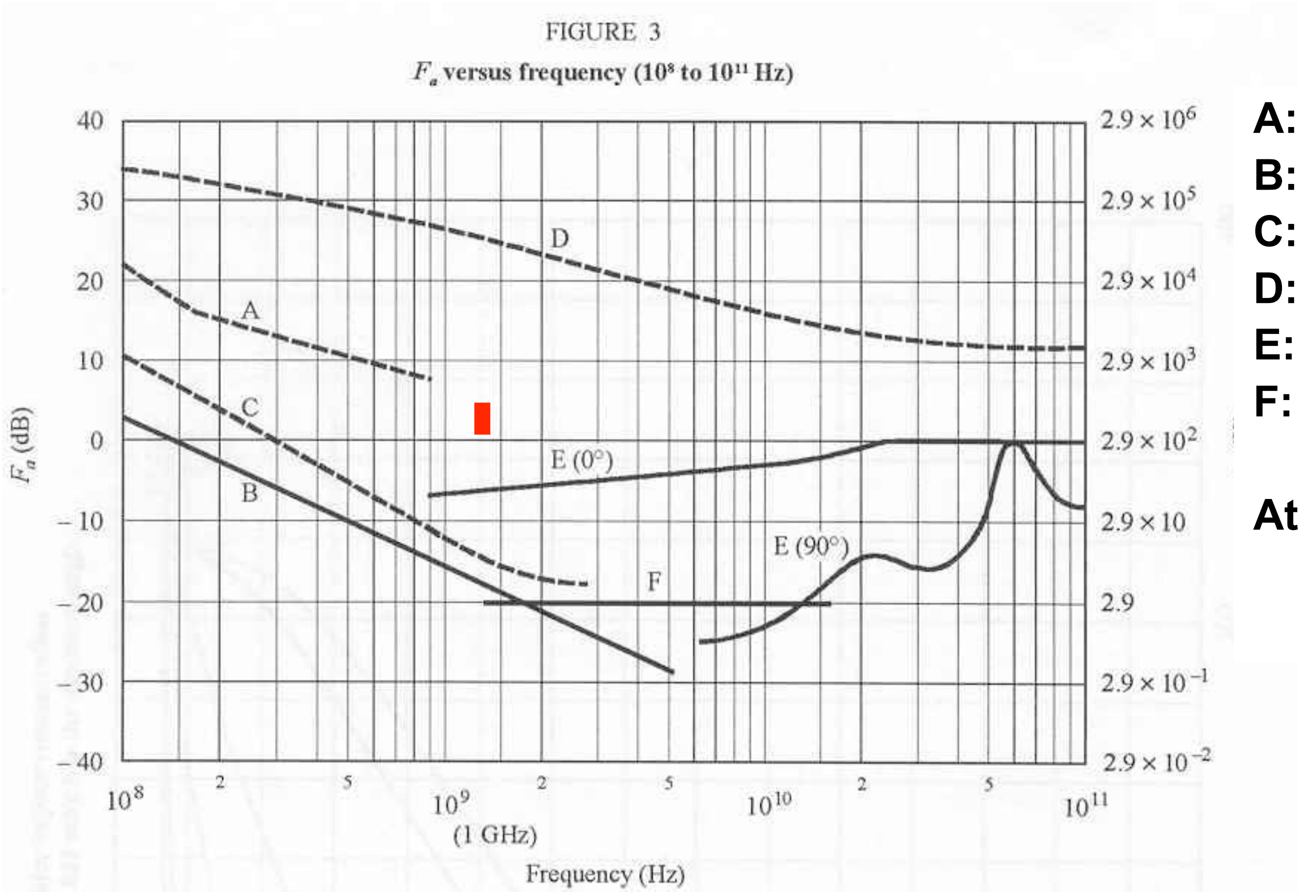


Ionospheric Gradients from Ohio (11/20/03) Along with the Associated Threat Model





Vulnerability: GPS or Galileo Noise Floor



A: man-made, business
B: galactic
C: galactic center
D: quite Sun
E: sky noise (O_2, H_2O)
F: black body (2.7 K)

At GPS frequency:

$-1 < F_a < 3$ dB
239 K< T_a < 565 K

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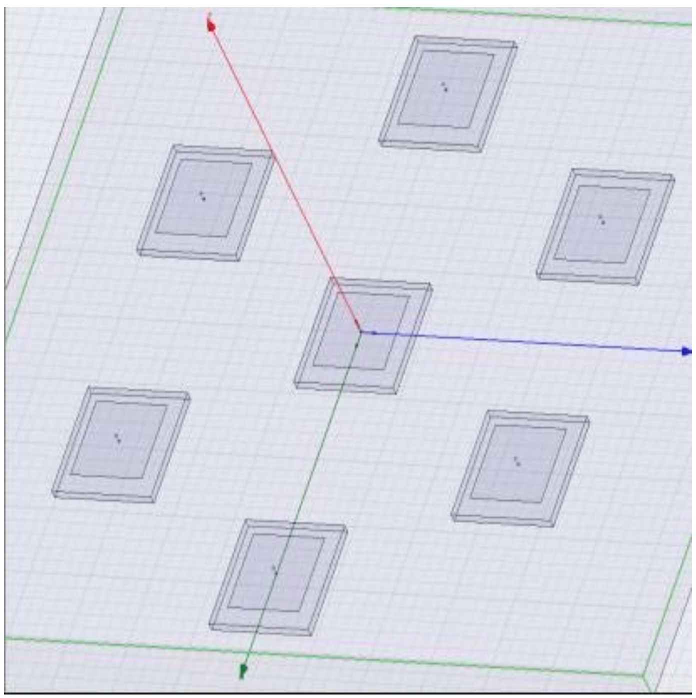
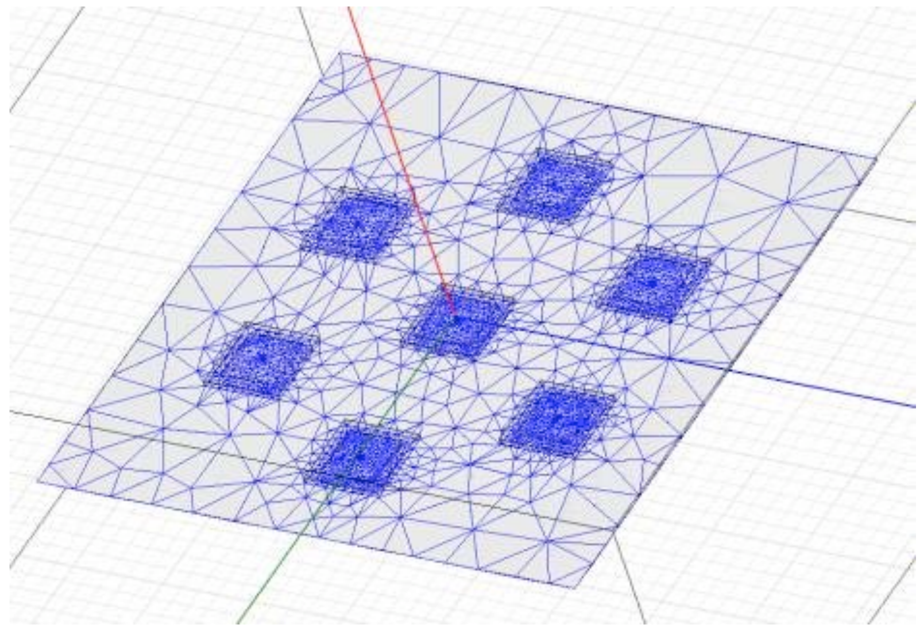
Stanford Technology
Prototype of a Controlled Radiation Pattern Antenna
Beam steering for Jam resistance





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Next Generation Software Receiver
DSP chips with embedded high speed correlators

- Present day DSP chips enable software receiver for the 1.023 Mcps GPS C/A code. However they are not sufficiently fast for either the GPS military signal or the new GPS L5 civil code at 10.23 Mcps.

- New research can design next generation high volume low cost DSP chips with embedded high speed correlators to permit new very low cost receivers on a single chip.

- Advantage: many PDAs, cellphones already have DSP chips

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Light-pulse atom sensors

Mark Kasevich, Physics Department, Stanford University
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- Atom is in a near perfect inertial frame of reference (no spurious forces).
- Laser/atomic physics interactions determine the the relative motion between the inertial frame (defined by the atom deBroglie waves) and the sensor case (defined by the laser beams).
- Sensor accuracy derives from the use of optical wavefronts to determine this relative motion.
- Like GPS, sensor is kinematic.

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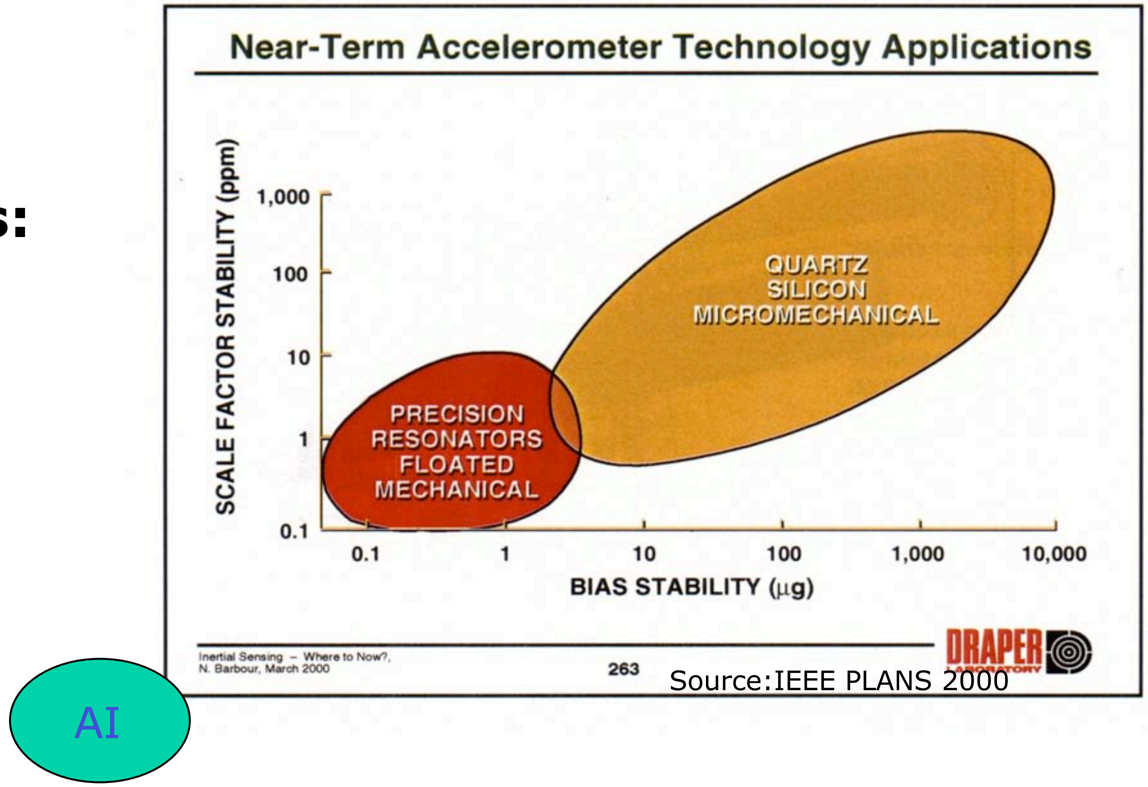
Accelerometer technology

Light-pulse AI accelerometers:

Scale Factor stability: 10^{-12}

Bias stability: $<10^{-10}$ g



Source:IEEE PLANS 2000

1000x improvement over state-of-the-art in these key sensor parameters.

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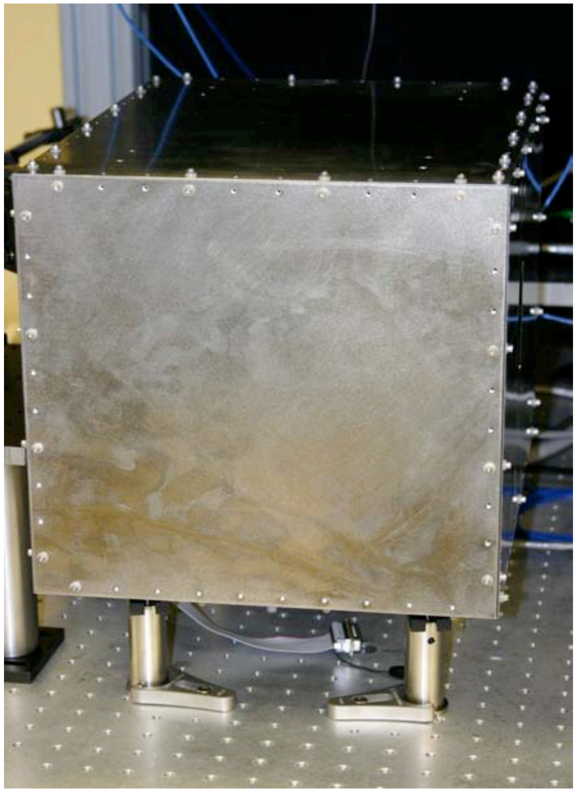
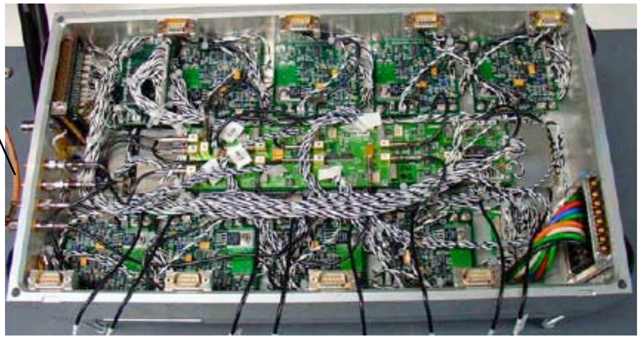
Field-ready prototype sensor



Sensor head (1 of 6)

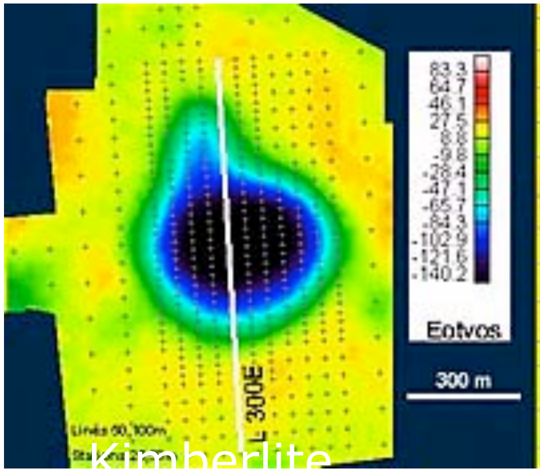
Laser and control electronics, supports multiple (4 to 6) sensor heads.

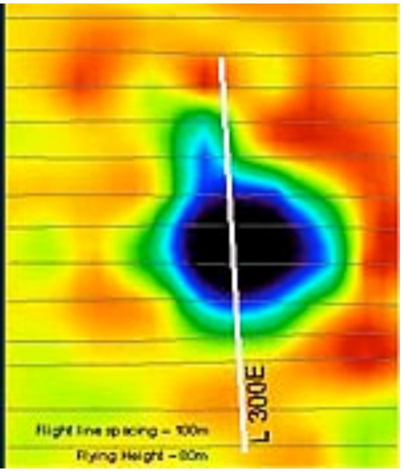


Sensor performance approaches, and in some cases exceeds that of laboratory sensors.

Airborne Gravity Gradiometer: BHP FALCON Program

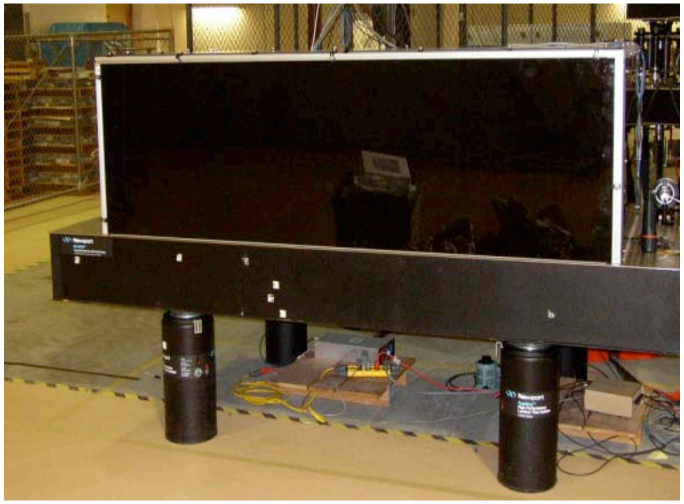
Existing Technology | **Land: 3 wks.** | **Air: 3 min.**

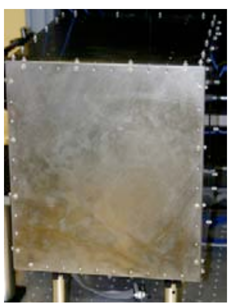




AI sensors potentially offer 10 x – 100 x improvement in detection sensitivity at reduced instrument costs.

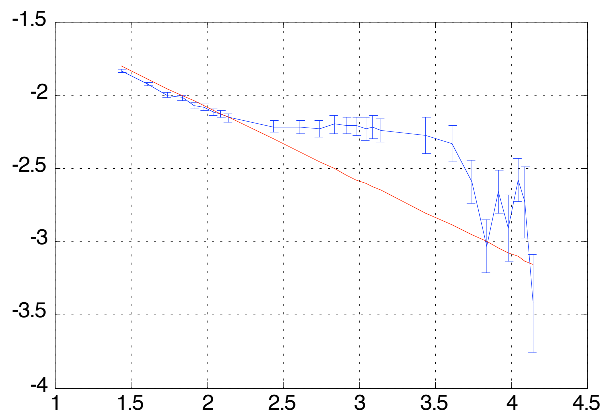
Field-ready prototype gravity gradiometer





Sensor hardware

Stanford AI gravity gradiometer: Allan deviation for 10/02/2004 data run

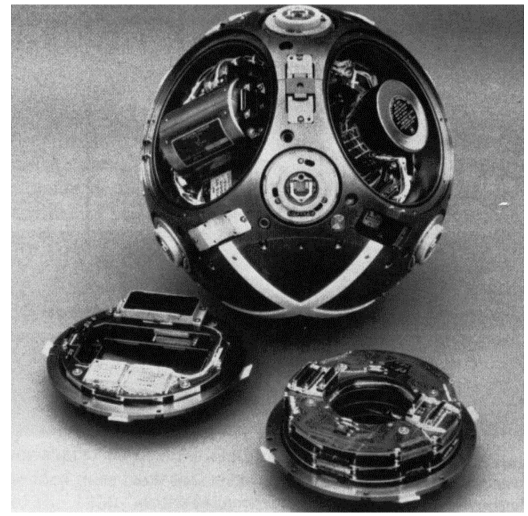


Testing

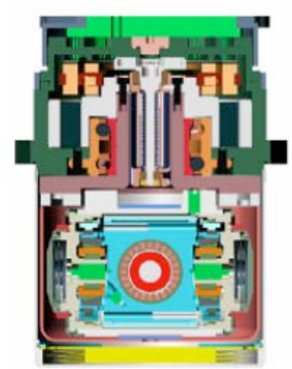
Atom sensors for GN&C

- Navigation
  - High accuracy gyroscope
  - Gravity gradiometer
  - Benign platform

- Geodesy
  - Moving base gravity gradiometery
  - Low cost absolute gravimeters



PRP 10 PIGA

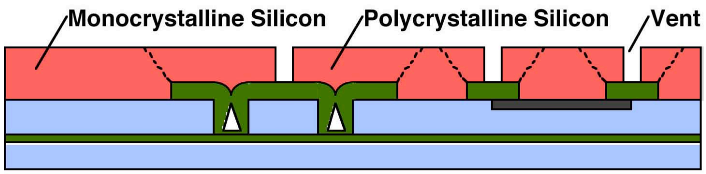


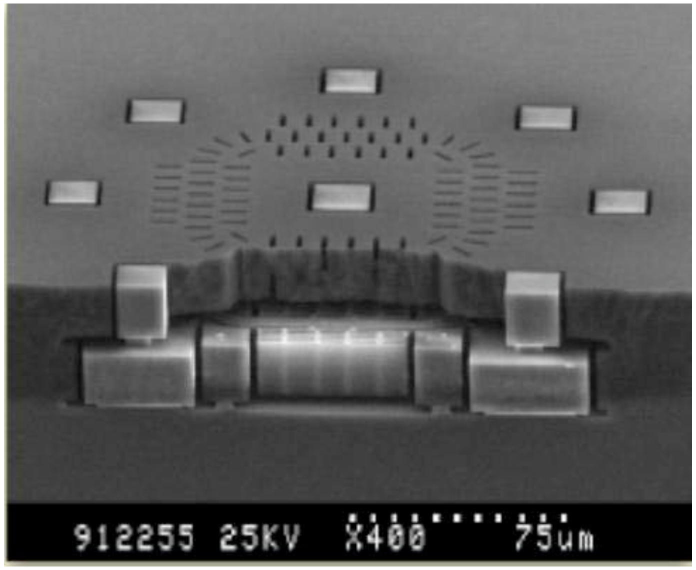
Superior atom sensor?

Stanford Wafer Scale Silicon Oscillators and Inertial Sensors for PNT

Thomas Kenny, Department of Mechanical Engineering, Stanford University
kenny@cdr.stanford.edu , www.mems.stanford.edu

- MEMS Devices have not made impact on navigation and timing systems.
- Performance, size, integration, and cost have been barriers.
- Current research at Stanford on Encapsulated MEMS may be providing a path around these problems.
- SCPNT provides an opportunity to integrate MEMS navigation and timing systems for the first time.





MEMS Packaging Example : Bosch

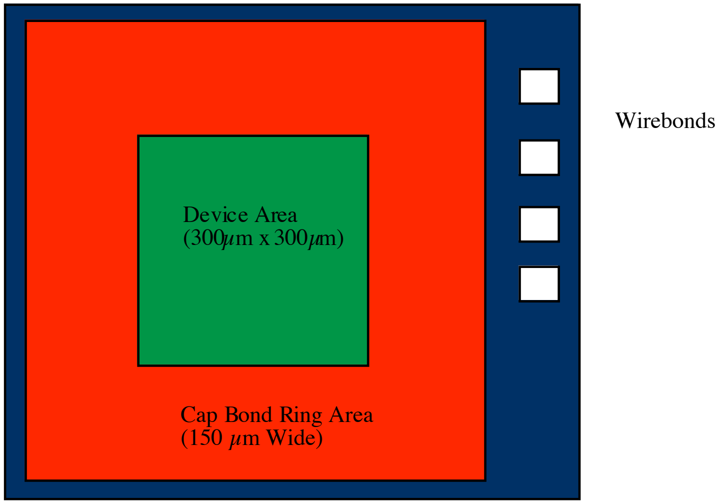
Another option is to develop a wafer-scale post-process bonded package.

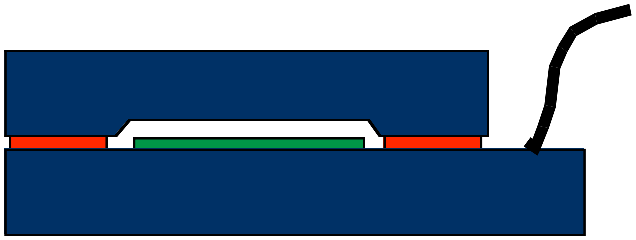
This approach is widely used in industry, but suffers from significant disadvantages.

- **Lost Die space**
- **Yield**
- **Temperature budget**
- **Cost**

Device <20% of Die,

Bond Ring is 60% of Die





Example numbers Adapted from Bosch Accelerometer

MEMS Packaging Example : Bosch

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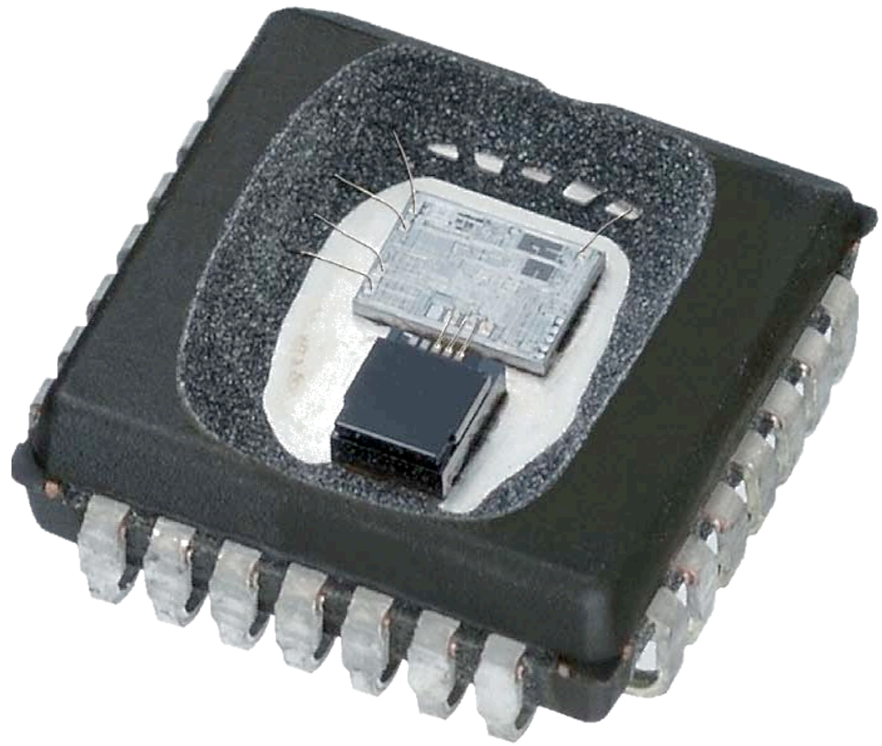

Example numbers Adapted from Bosch Accelerometer

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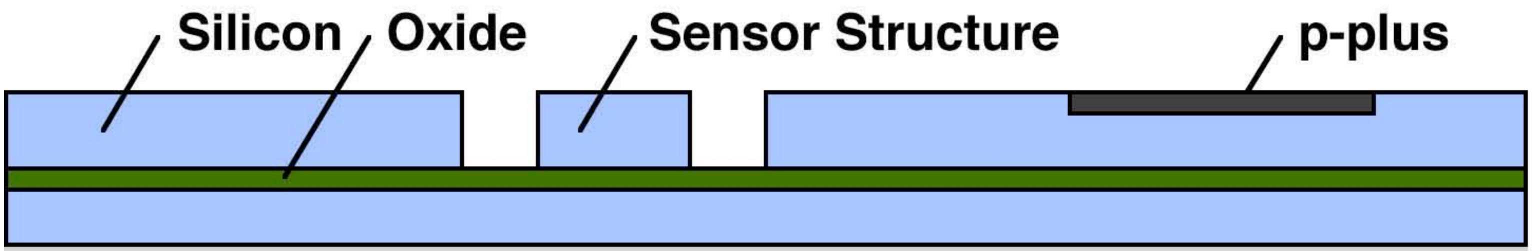
BOSCH

MEMS is a Packaging Technology

We propose:

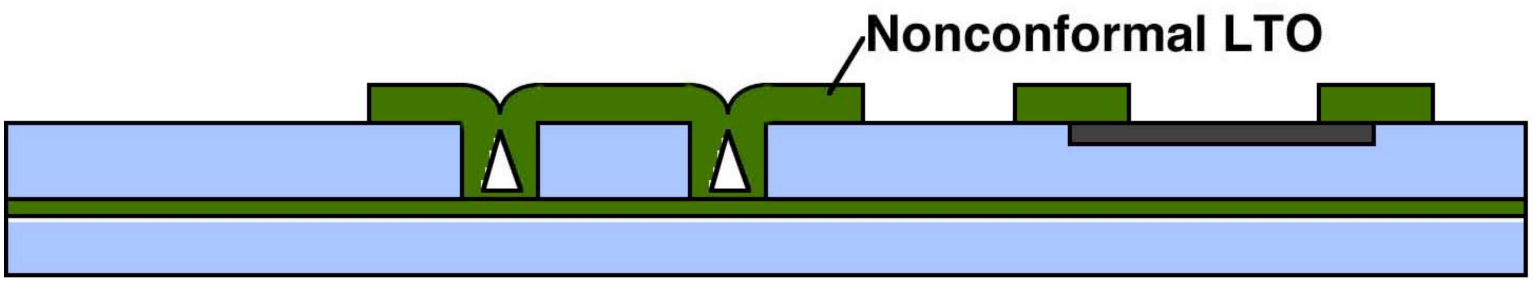
- **Integrate packaging into the MEMS fabrication process.**
- **Develop and optimize designs to overcome package process compromises.**
- **Leverage opportunities that come from a package-integrated process for performance improvements.**
- **Avoid all back-end custom handling and packaging. Move back towards conventional chip packaging approaches.**
- **Deliver unique MEMS capabilities without the usual baggage, and with some new features.**

Wafer-Scale Package

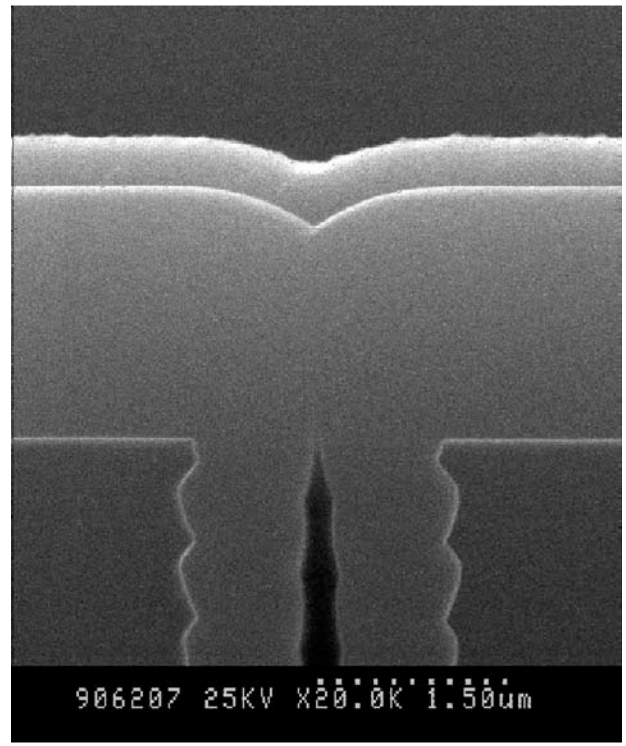


Start with a "generic" MEMS device made from silicon, prior to being released from the substrate by HF. Silicon layer may be single crystal (SOI), or poly-si (Bosch epi-poly structural material, for example).

Wafer-Scale Package



Deposit a thick (3-5 µm) non-conformal Low-Temperature oxide. This oxide fills and seals structures around the device, producing a complete sacrificial encapsulation.



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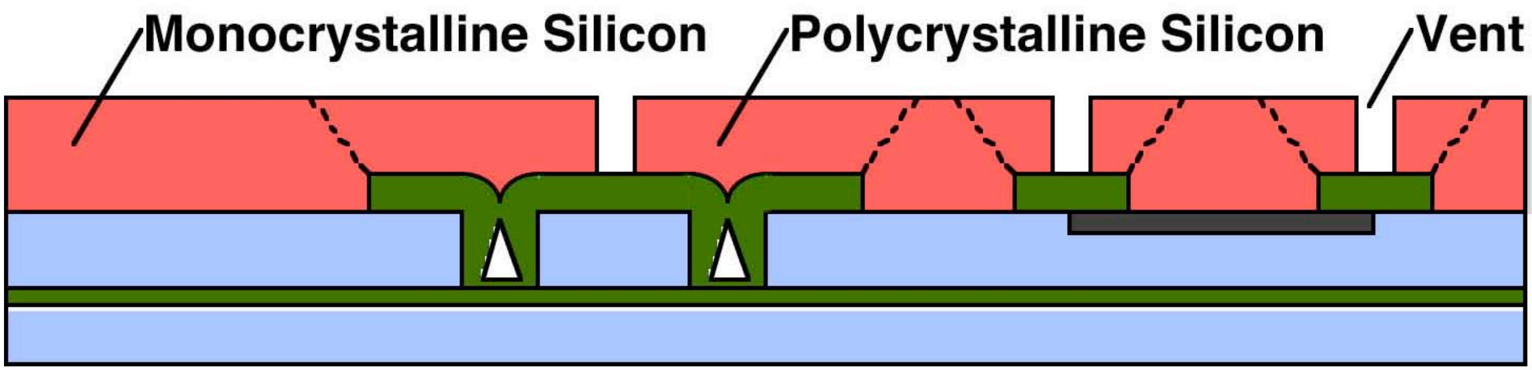
STANFORD Micro Structures & Sensors Lab

BOSCH

Wafer-Scale Package



Deposit Thick Epi-Poly. This forms poly where grown over LTO, and forms single-crystal Si where grown over single-crystal Si.

Deposition rates of up to 3 µm/min achieved in conventional Epi-Si reactor at Stanford, and in a production environment at Bosch.

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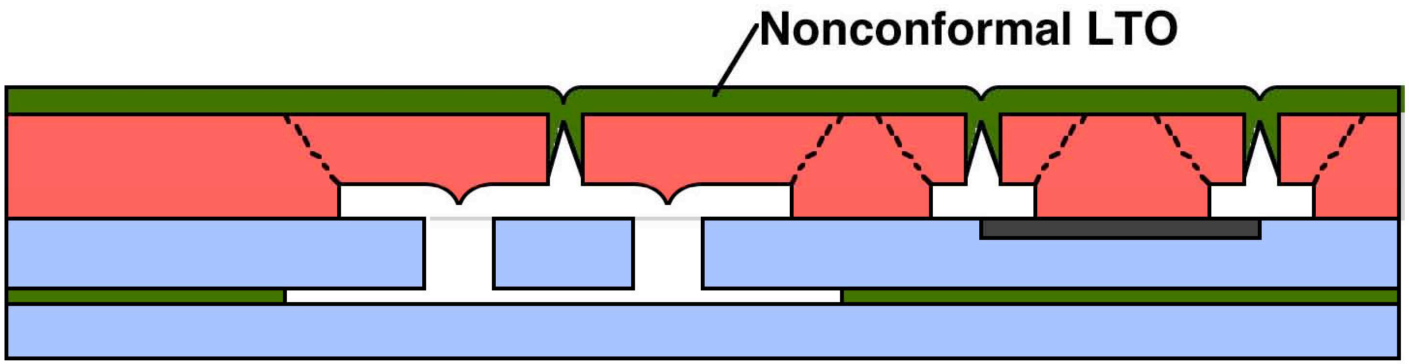
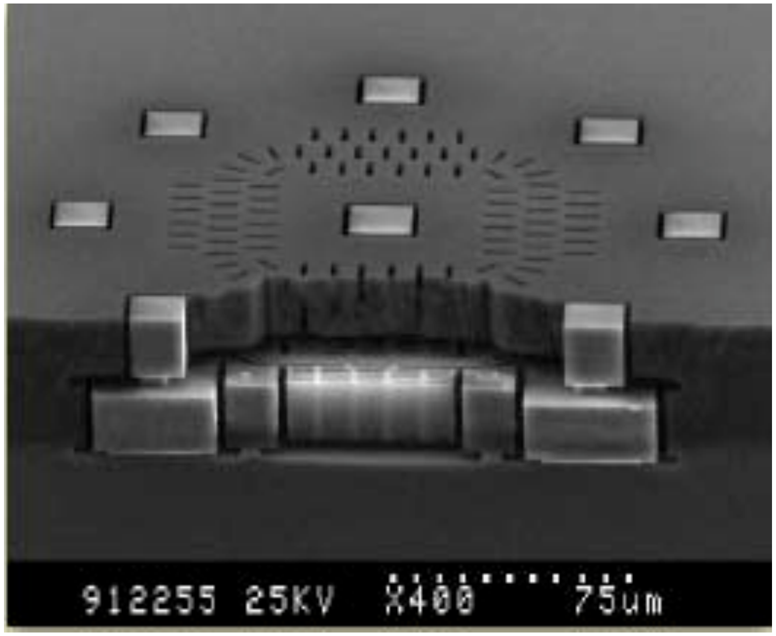
Wafer-Scale Package



The encapsulation oxide is removed in a Vapor HF etcher, developed by Bosch (Prototype installed at Stanford), and the device is sealed by a second non-conformal LTO. TEOS and other thick oxide processes being explored



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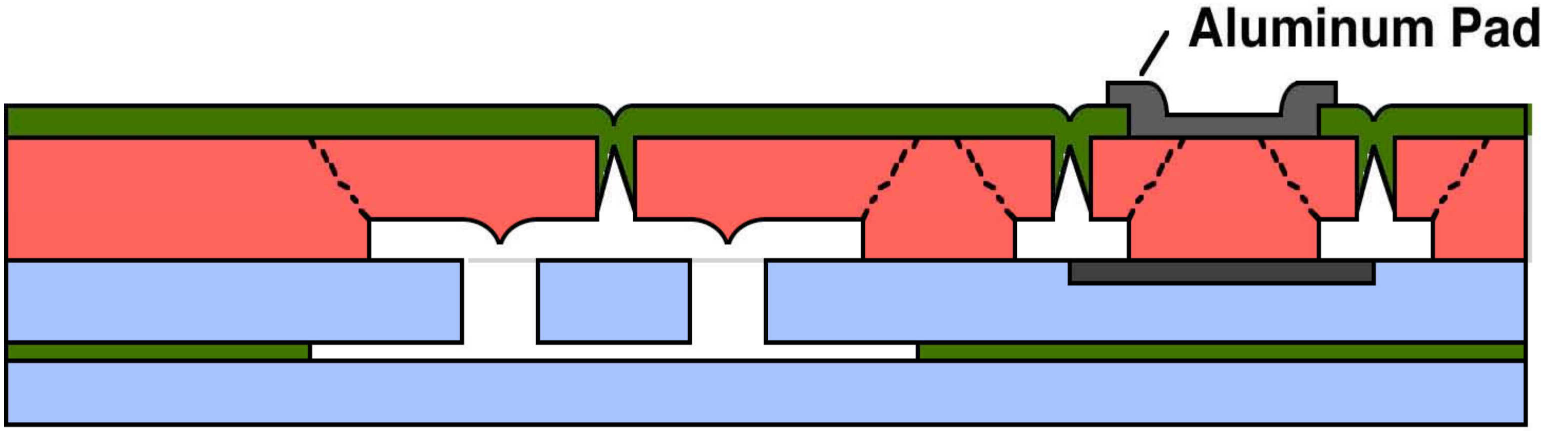
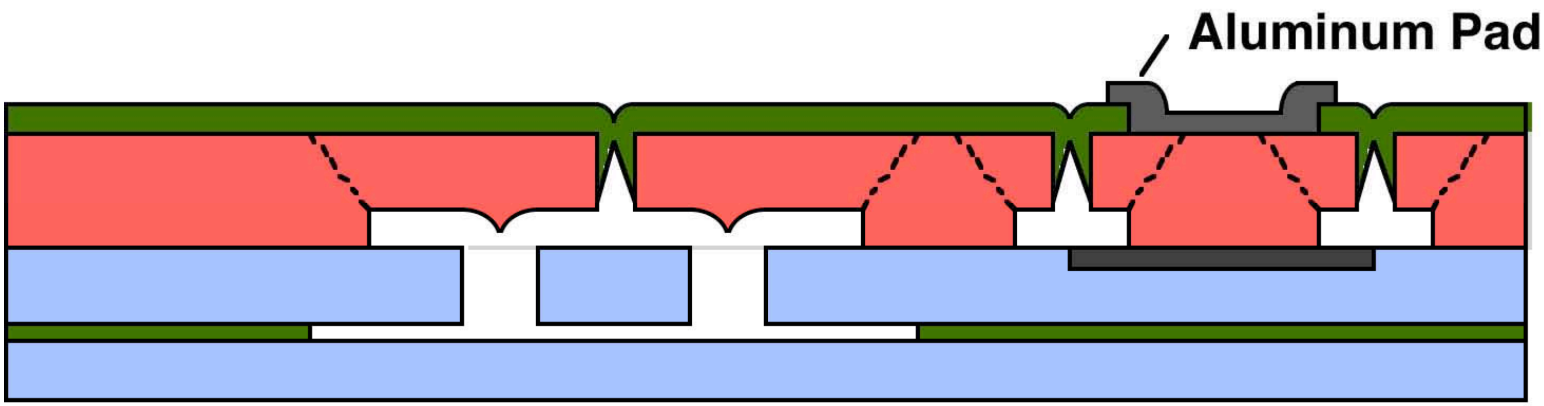
Wafer-Scale Package



- An opening in the oxide over the interconnect allows formation of a bond pad.
- The interconnect structure is isolated from the surrounding Epi-Si layer by an annular oxide seal, and makes electrical contact to a doped layer on the device level of the structure.
- Interconnects of this architecture can be fabricated with 5:1 aspect ratio, and may be as small as 20 μm in diameter.

Wafer-Scale Package



Package can withstand high pressures

- **25 μm cap can withstand 100 ATM for Injection Mold Packaging**

Very Little Lost Die Space

- **Only 10-20 μm needed for "bond ring"**
- **Surface over device may be used for wire-routing.**
- **Entire process can be pre-CMOS**

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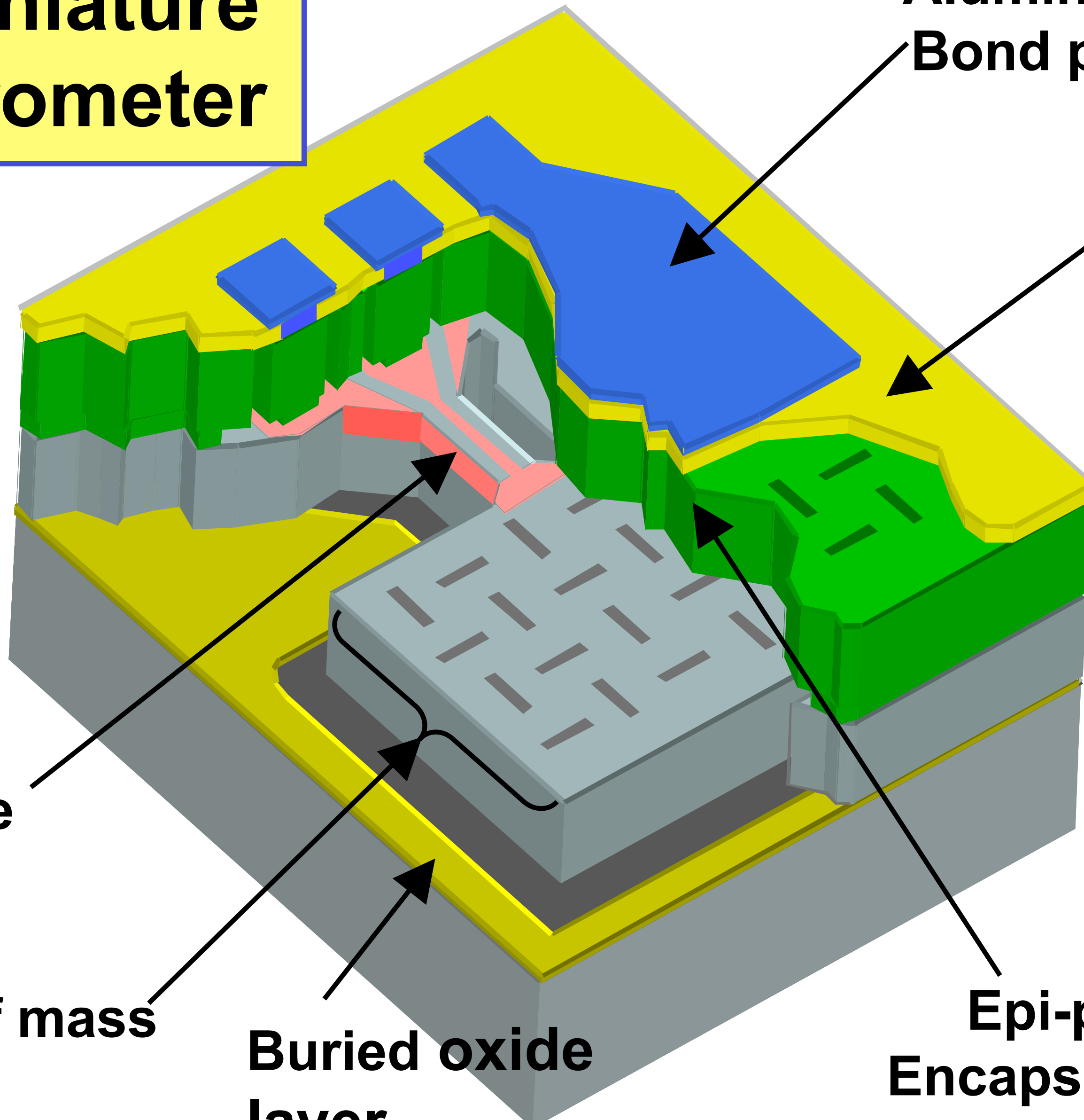
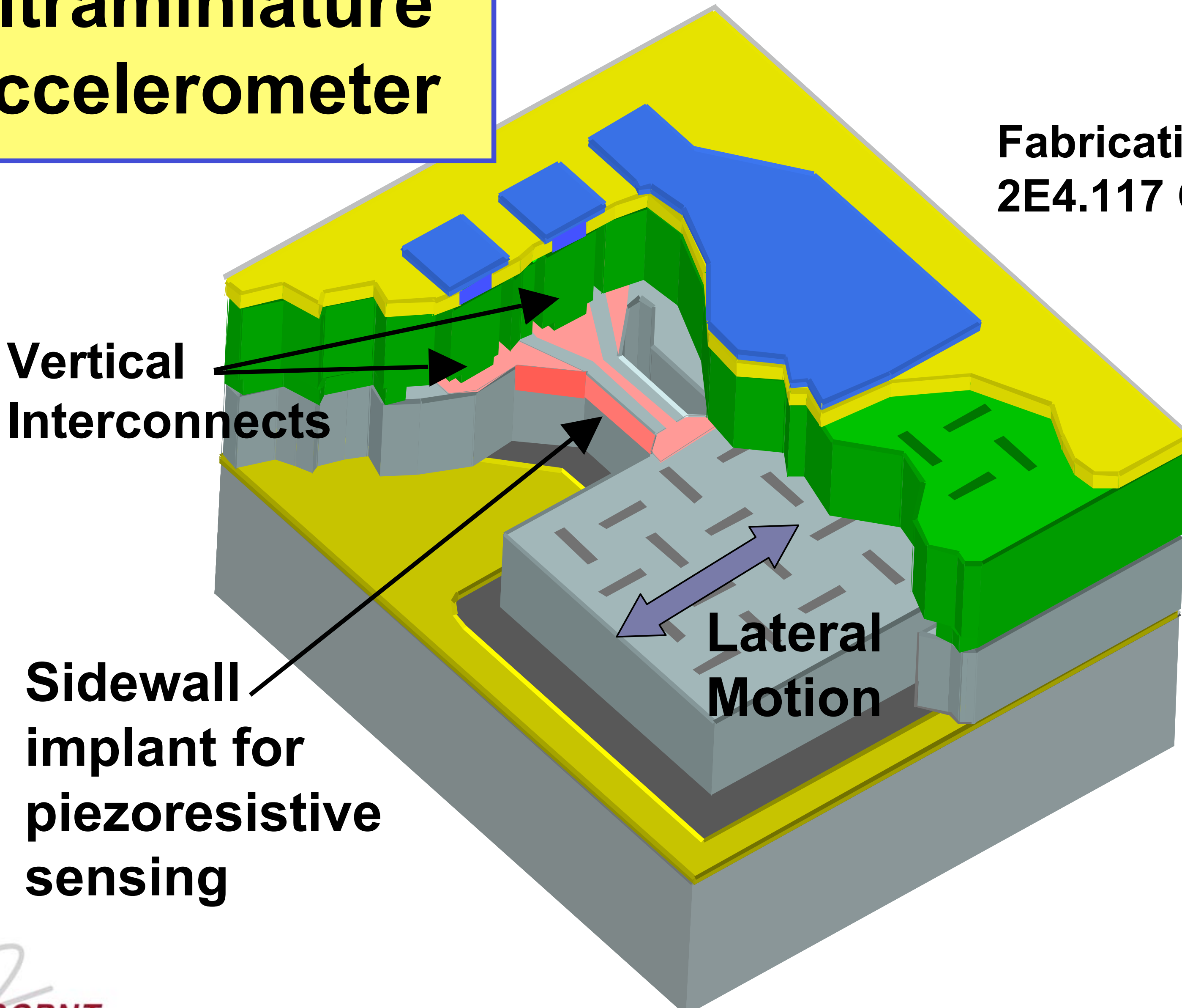
BOSCH

Ultraminiature Accelerometer

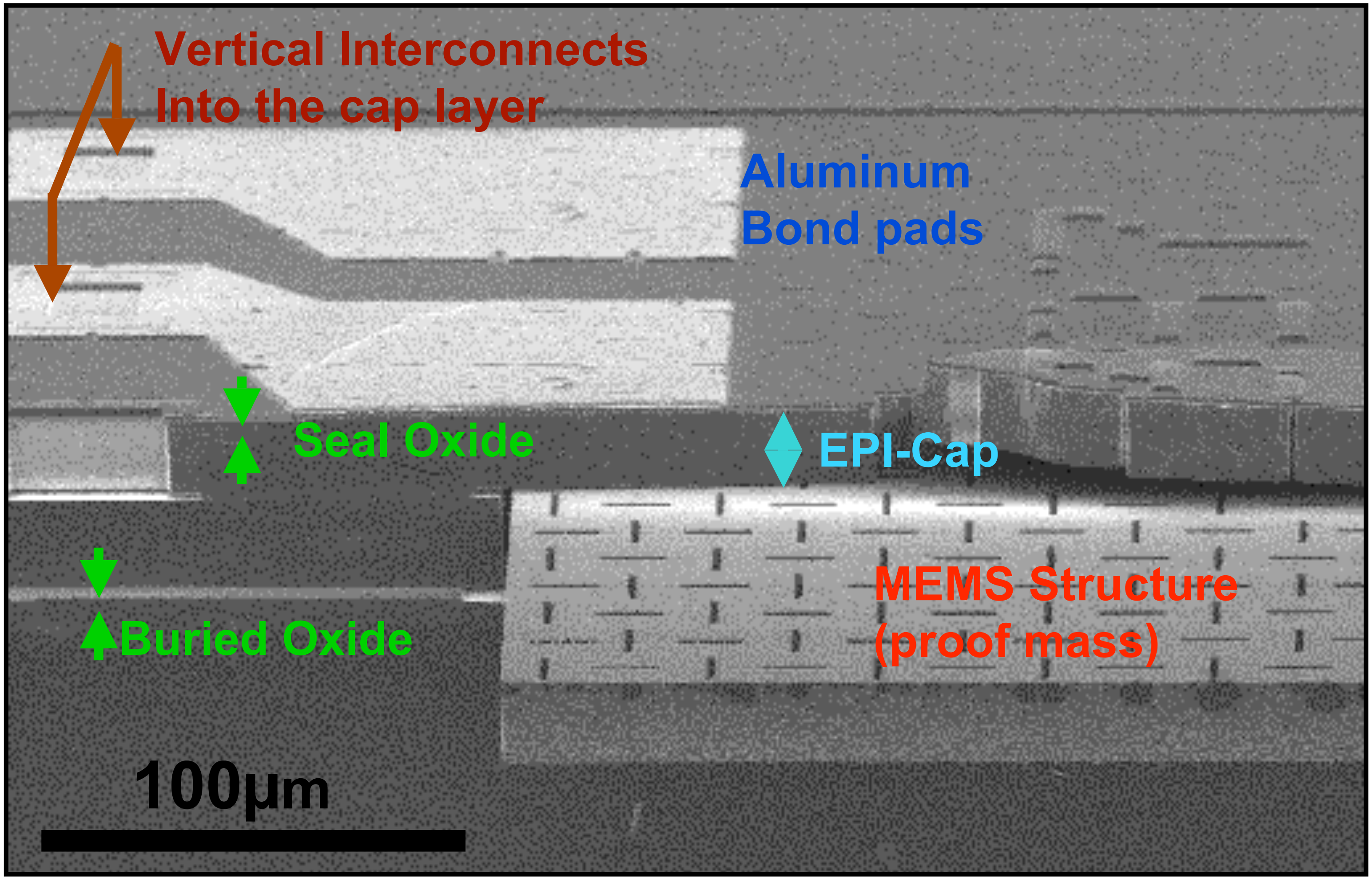


Ultraminiature Accelerometer

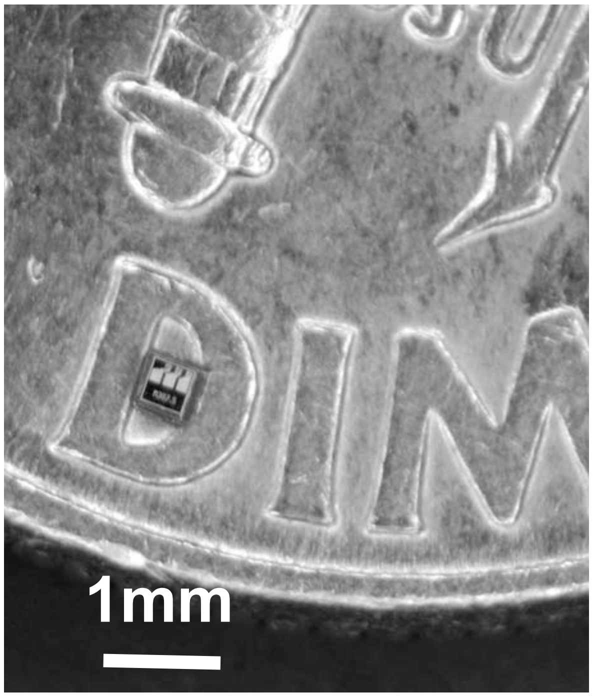
Fabrication details
2E4.117 Candler *et al.*

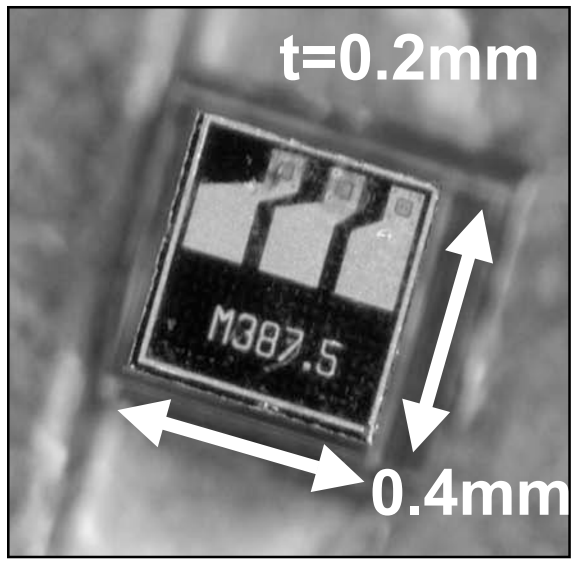


Ultraminiature Accelerometer



Status of this Work





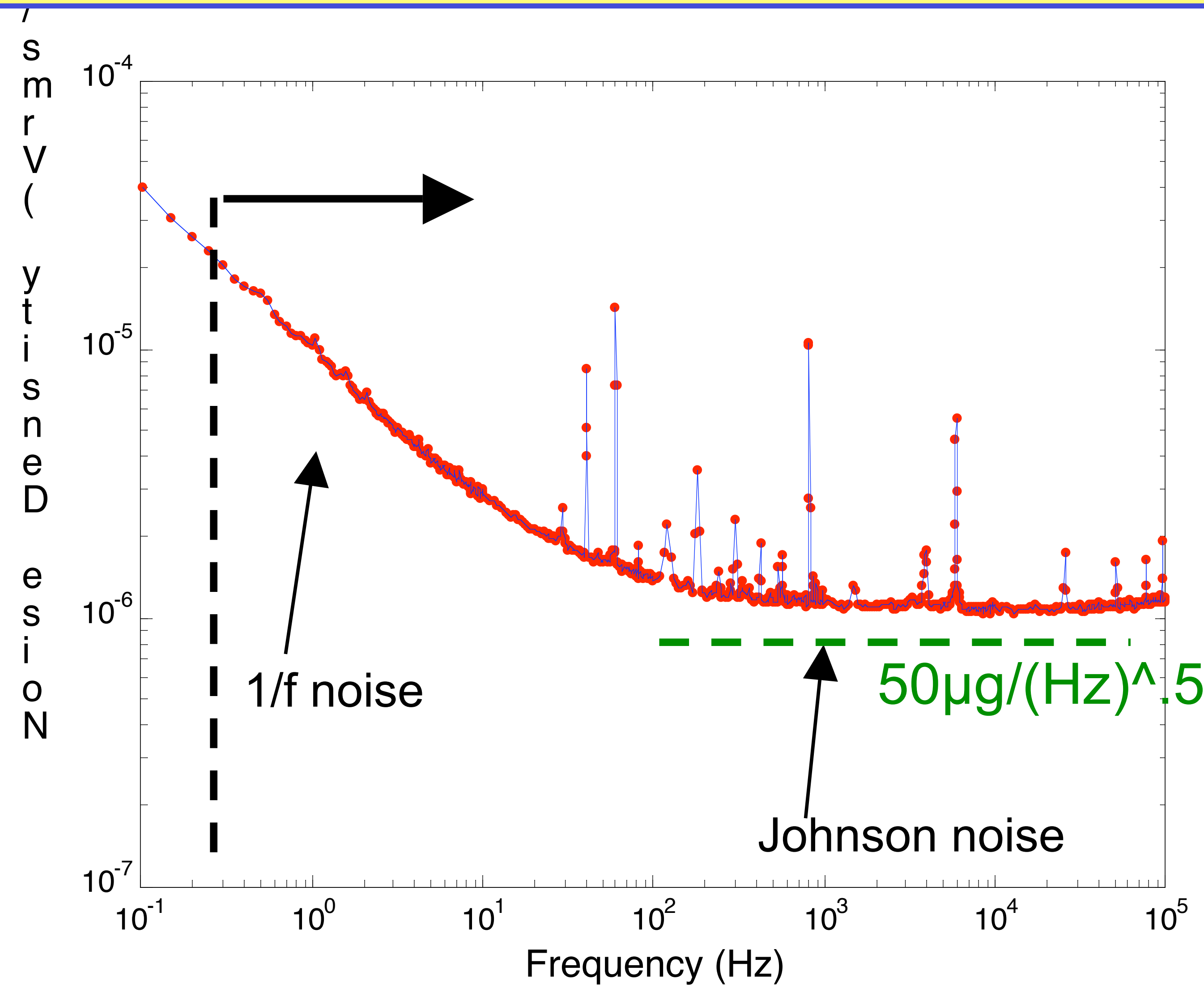
Volume
0.034mm^3

Mass
< 100µg

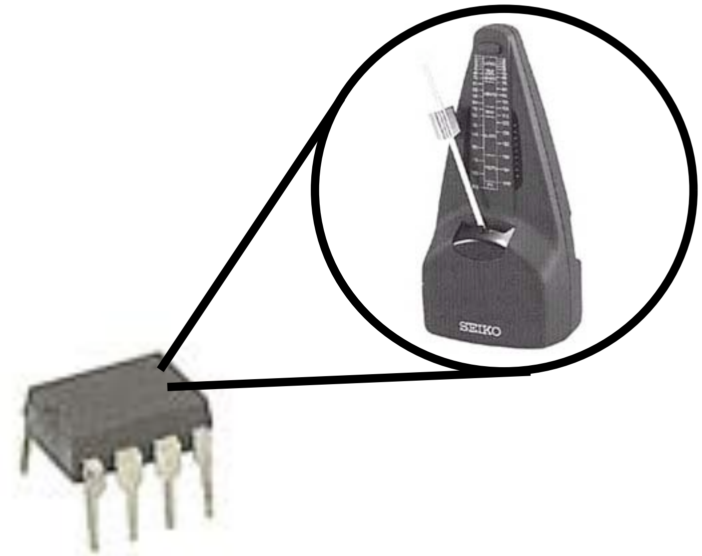
Resolution
0.25mg/(Hz)^5.

CMOS
Compatible

Noise characteristics



MEMS Resonator Motivation



In-Chip Frequency Reference

CMOS compatible MEMS Resonators have potential to be integrated into IC chip

Expected Benefits of MEMS Resonators:

- **Volume reduction**
- **Cost reduction**
- **Low power consumption**
- **Make circuit design simpler**

Frequency stability of silicon MEMS resonators has not been sufficiently characterized.

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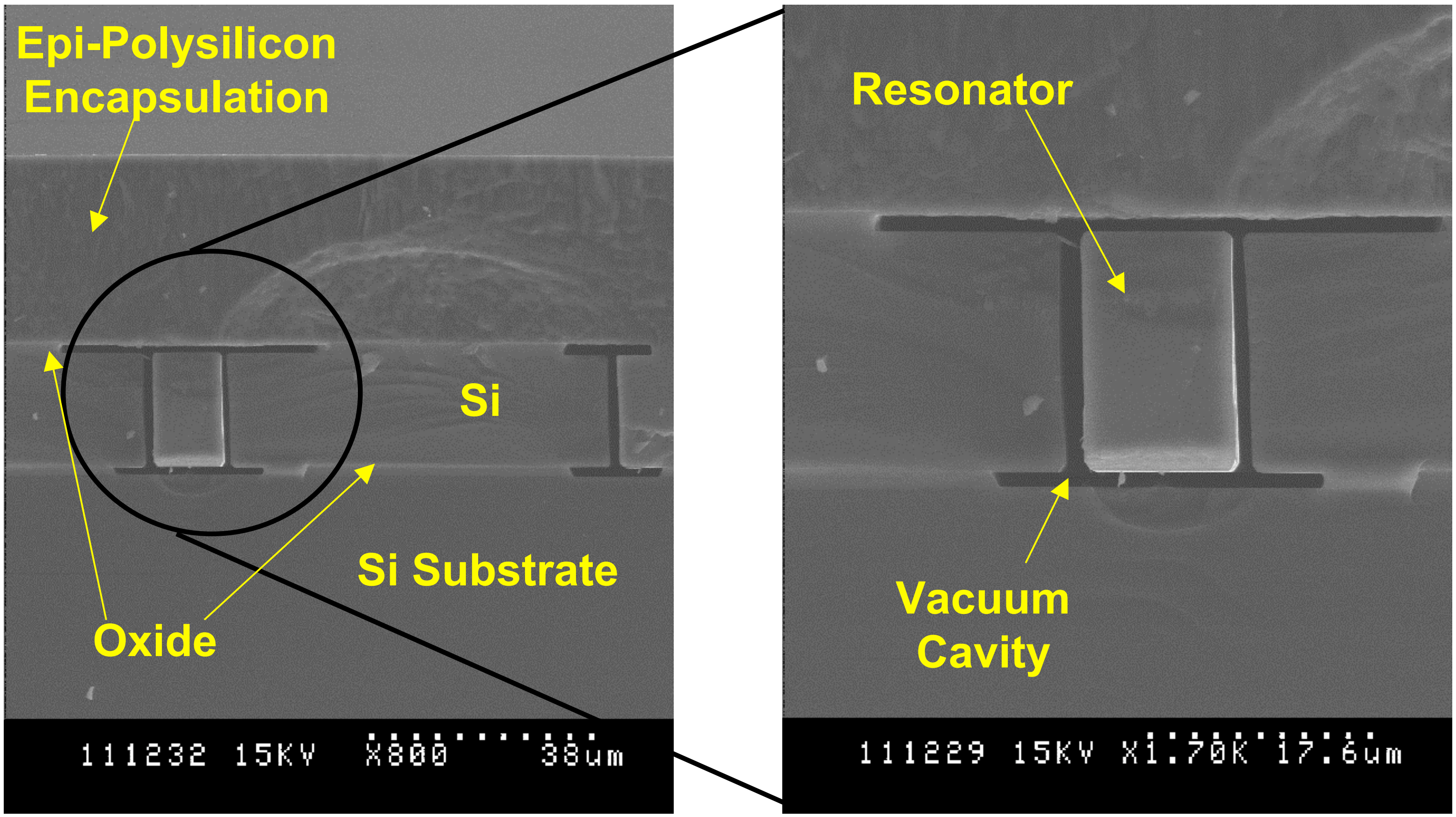
SEM Cross Section View of Vacuum Encapsulated MEMS Resonator



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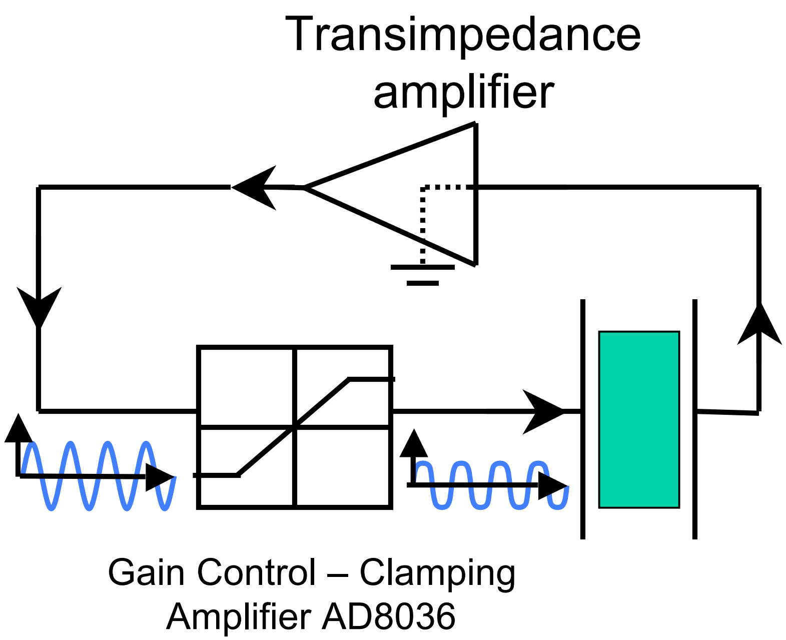
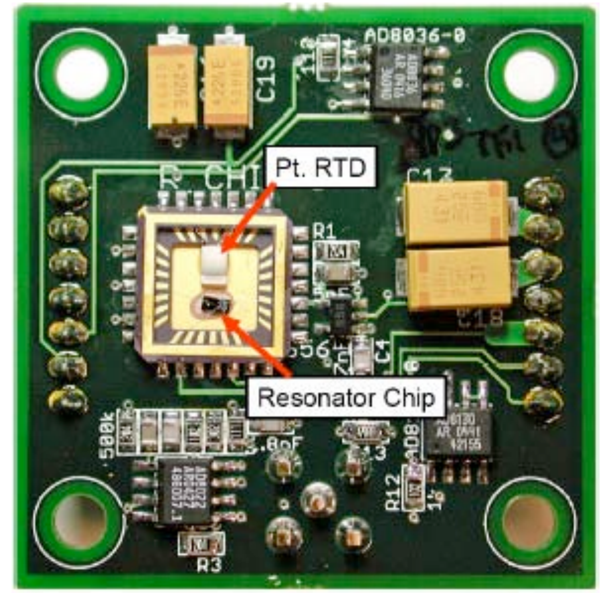
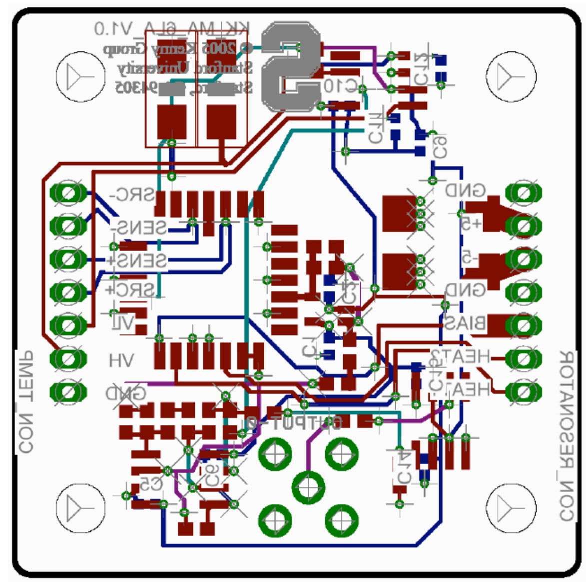
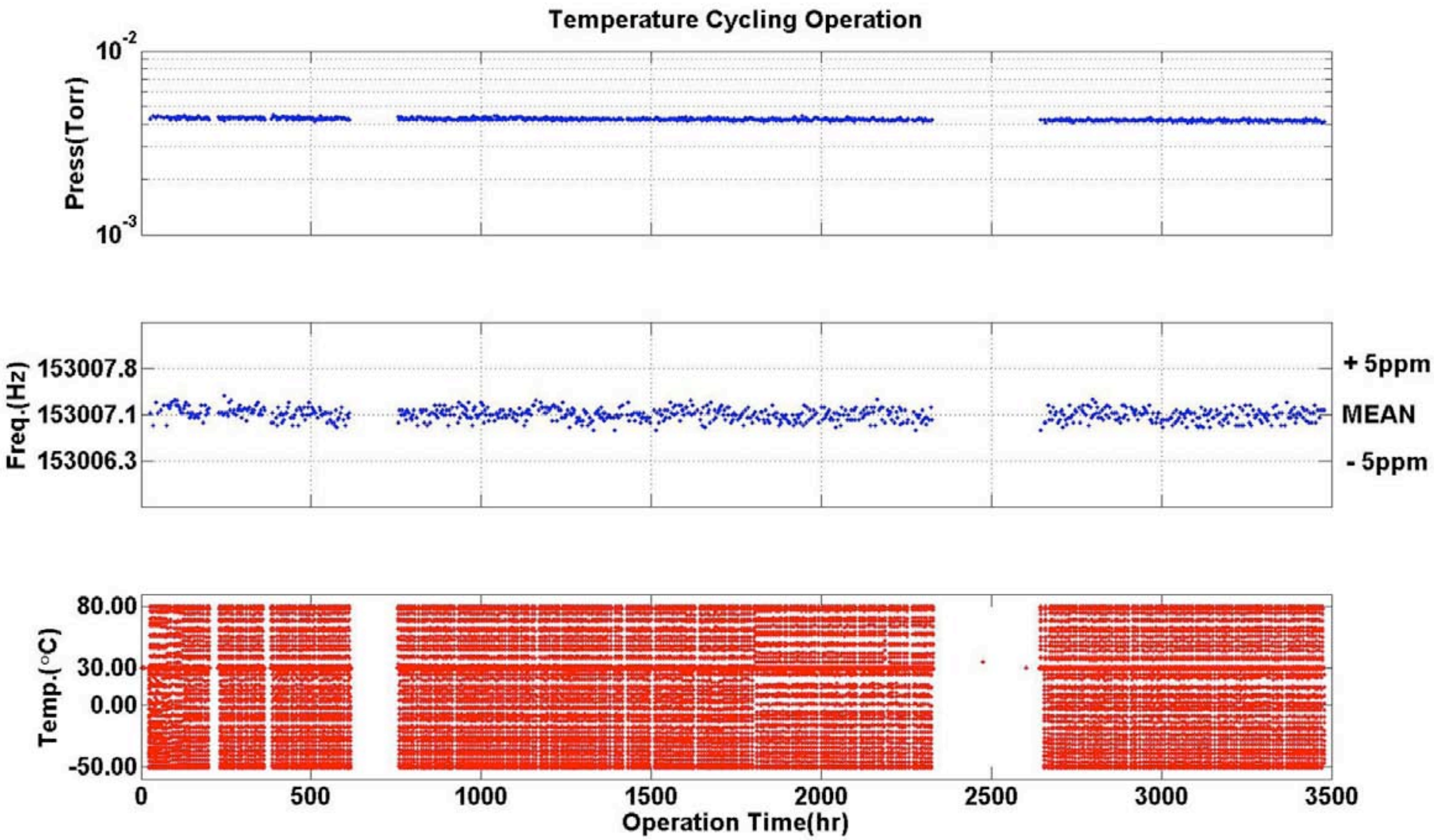
Oscillator Design







Long-Term Stability during Temperature Cycles from -50C to +80C



As with fixed-temperature tests - no evidence for leakage through encapsulation.

MEMS Conclusions : Integrated Inertial Sensors and Resonators

- **MEMS devices have not been successful as primary navigation or timing systems. However, they can provide support navigation and timing information - especially on short timescales.**

- **For the first time, MEMS sensors and resonators are truly CMOS-compatible.**

- **The combination of miniaturization and encapsulation has enabled integration, and has also provided some performance enhancements.**

- **SCPNT can leverage a significant DARPA investment in this capability. Additional Venture Capital Investments being made in a commercial provider of this capability.**

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Location Aware Communication Services & Optimization

Prof. James Spilker, Jr.
EE Department
Stanford University

- Location based Wireless Communication Optimization
- Supply Chain Management and Security
- Location Based Communications services

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Location Optimized Wireless Communications

- **Digital maps of user signal strength can optimize channel capacity and more efficiently use power.**
- **Diversity antennas can provide substantial improvement and provide improved performance maps.**
  - **Movements of a meter can cause a 20 dB increase in channel attenuation if diversity antennas are not employed.**
- **Optimize time of transmission as well as location to minimize interference & maximize throughput. Transmit at higher rates during time of low interference**
- **Higher dimensional digital maps compare the signaling performance of cellphone vs. various wireless LAN systems. 802.11, a, b, g etc., Wi-Max.**

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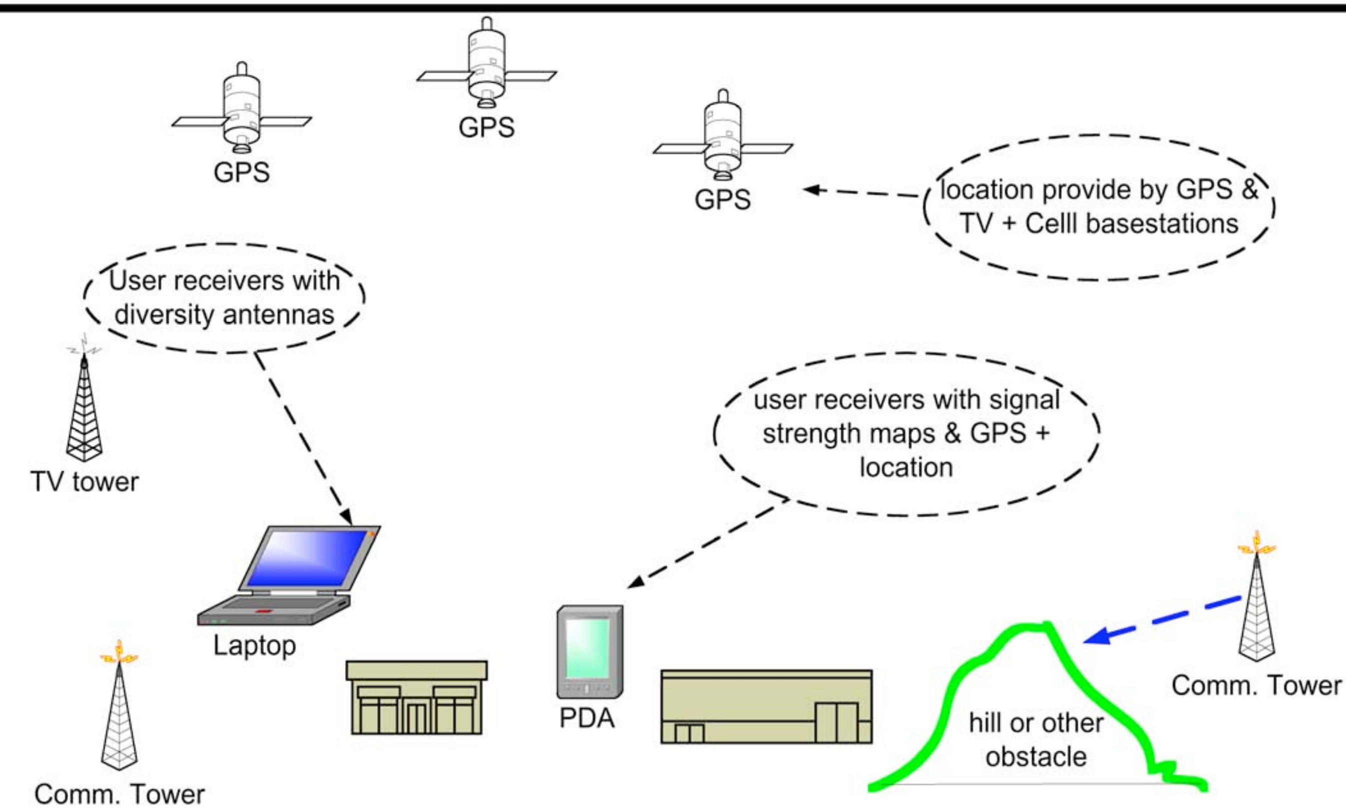
Location Aided Communications



User sets adjust power i& select media in accord with location maps.
Users also adjust time of transmission to optimize performance/reduce interference

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Location, GPS, and Sensor Communication Networks

- Future sensor networks will employ 100s- 1000s of interconnected, heterogeneous mobile sensors and clusters of sensors
- Low power embedded GPS can enhance sensor network efficiency
- Accurate timing and localization will increase throughput and reduce total power consumption
- Ultra clean clock reference can improve accuracy of mixed signal and timing recovery in communication systems

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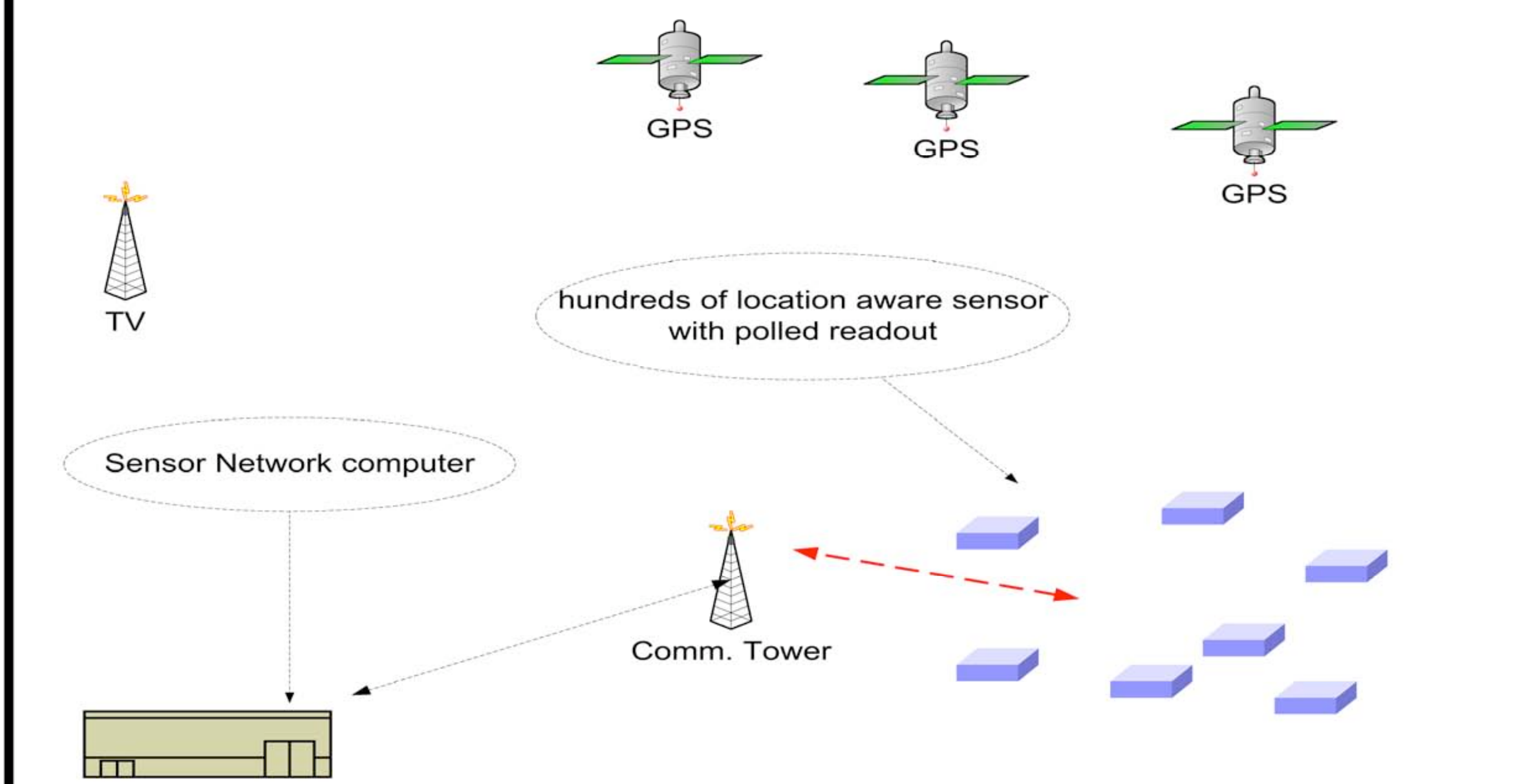
Location Aware Sensor Communication



Location Aware Sensor Network

Supply Chain Management

- Ground delivery systems to millions of individual customers.
- Integrated RFID/GPS systems to identify location of every package delivered.
- Avoids need for RFID readers at every home/office.
- Next generation of RFID and GPS with order of magnitude decrease in price will increase power and universality of efficient supply chain management.
- Hitachi integrated RFID/antenna chip.
- GPS receivers on a <$5 chip. New forms of higher performance DSP chips with on multiple on-chip correlators and software receivers.

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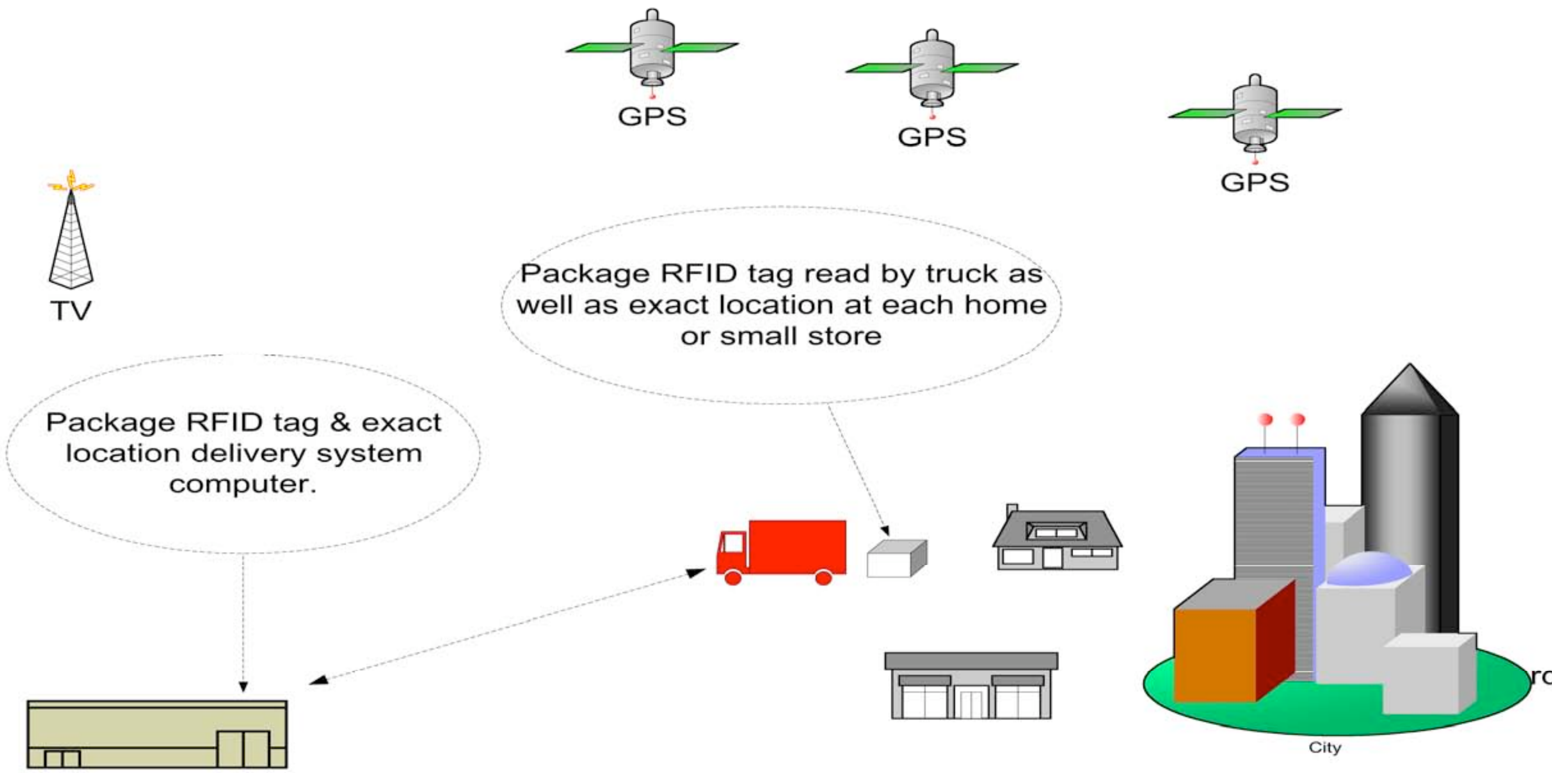
Location Aided Supply Chain Consumer/Retail stores



Package delivery to millions of consumers retail stores Delivery truck identifies location of each RFID package delivered without need for RFID reader at each store or home.

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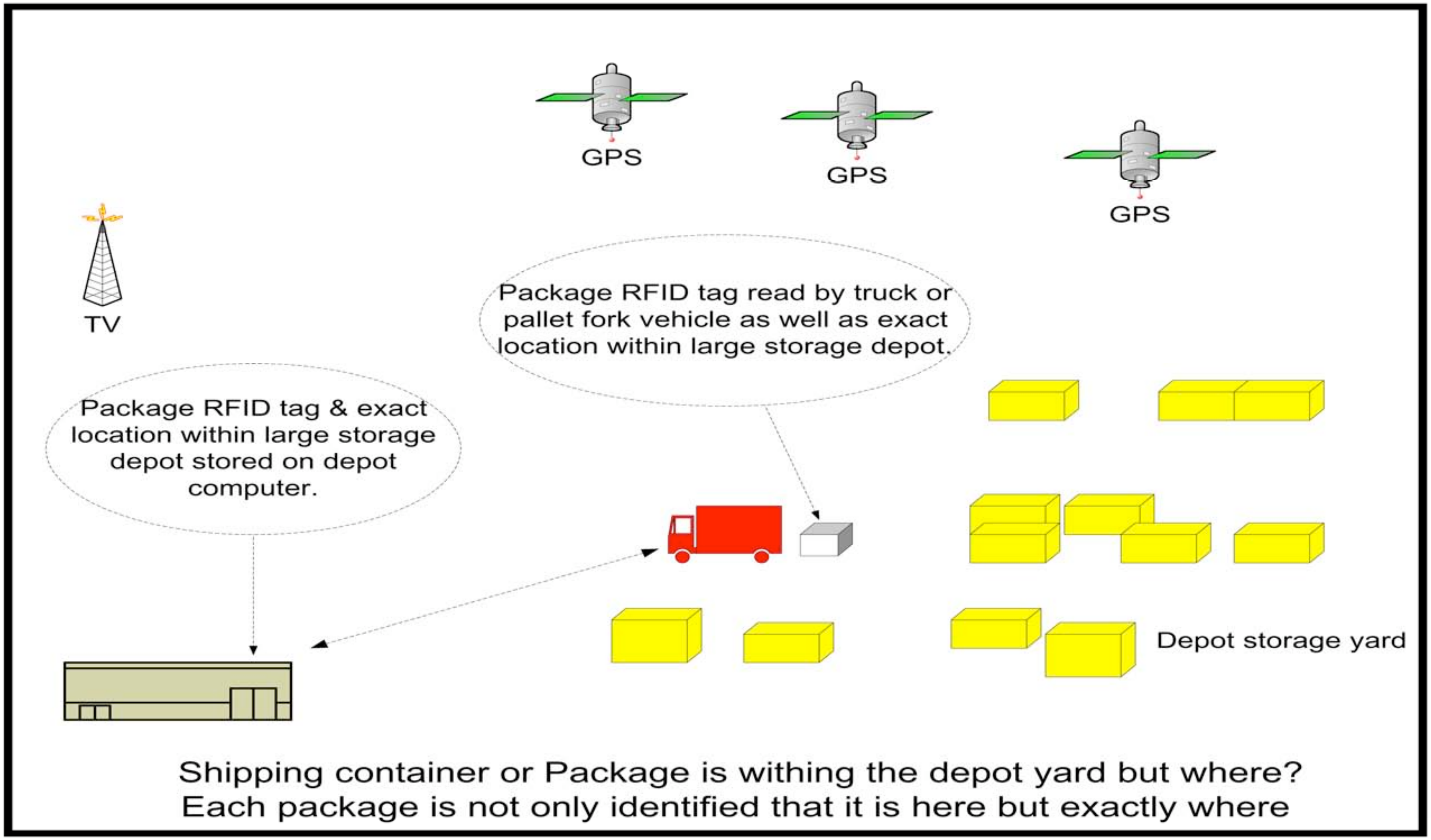
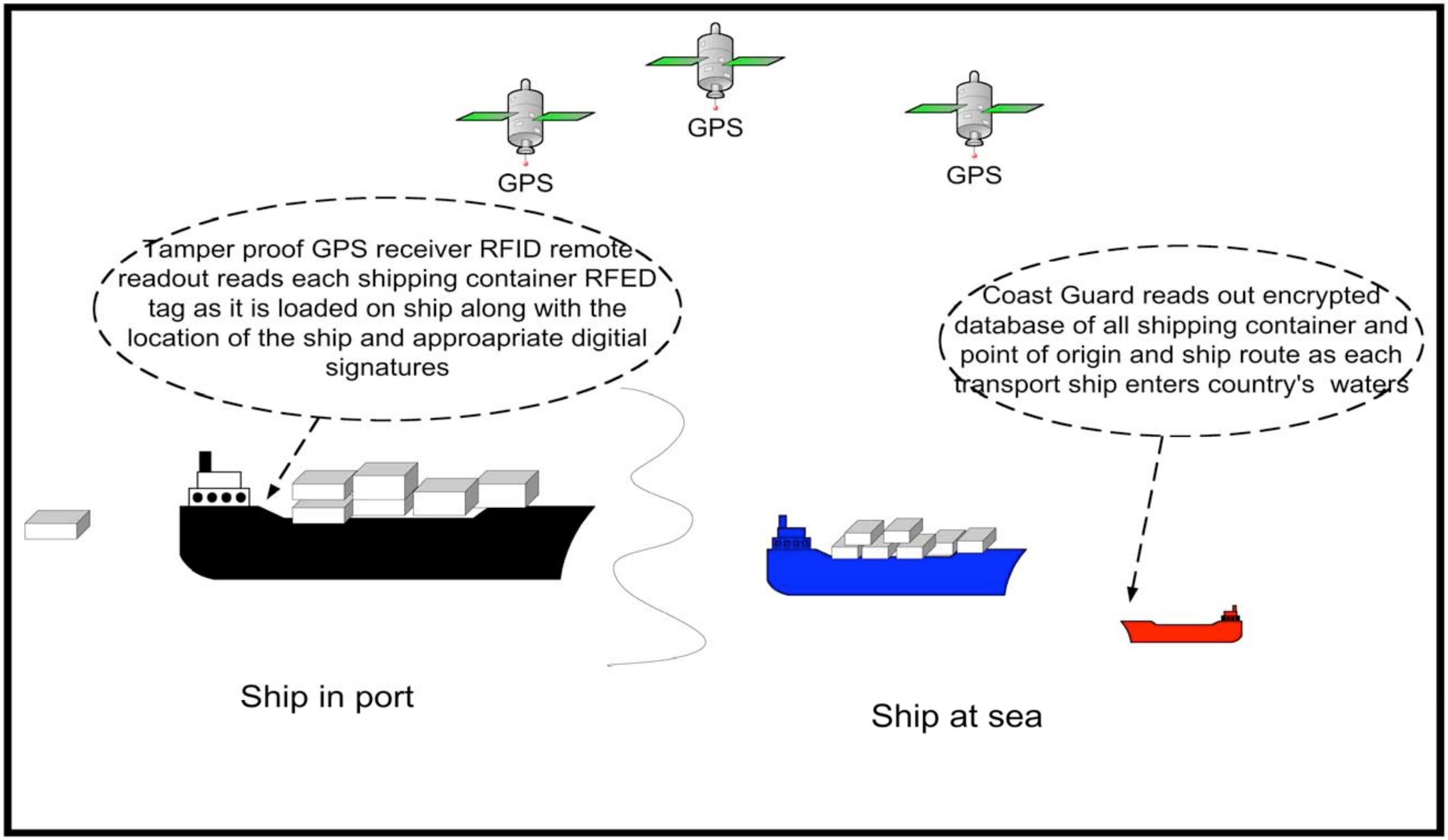
Location Aided Supply Chain to Depot Asset Tracking



Location Aided Ship Transport Security



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Shipping/Transport Location Management

- **World-wide shipping location management**
- **Time updated world wide map of all major ships, location direction, destination.**
  - **Mimic the maps presently in use for commercial air transport by FAA and other government organizations**
- **Collision prevention communication to the ships from the regional tracking centers via satcom links.**

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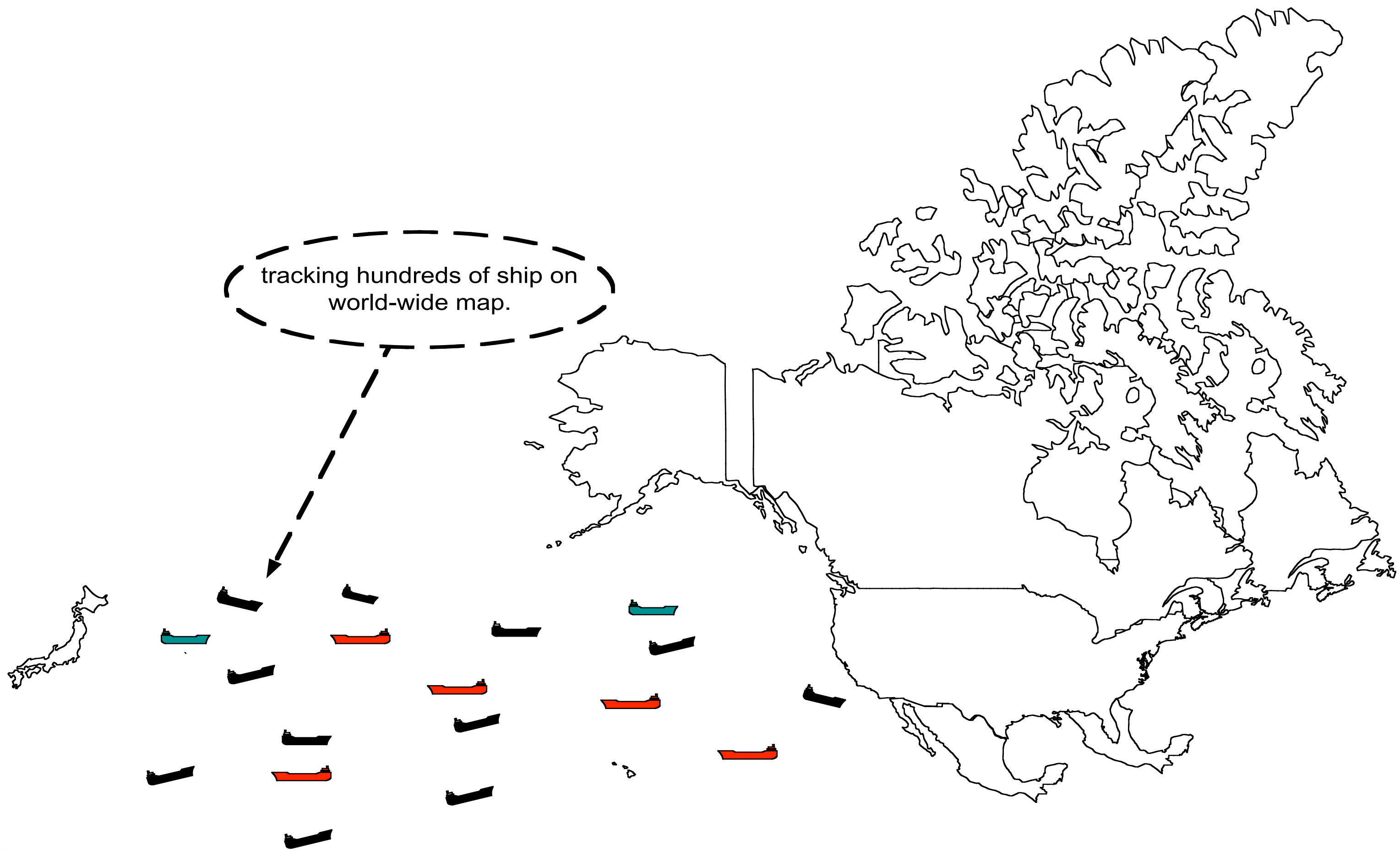
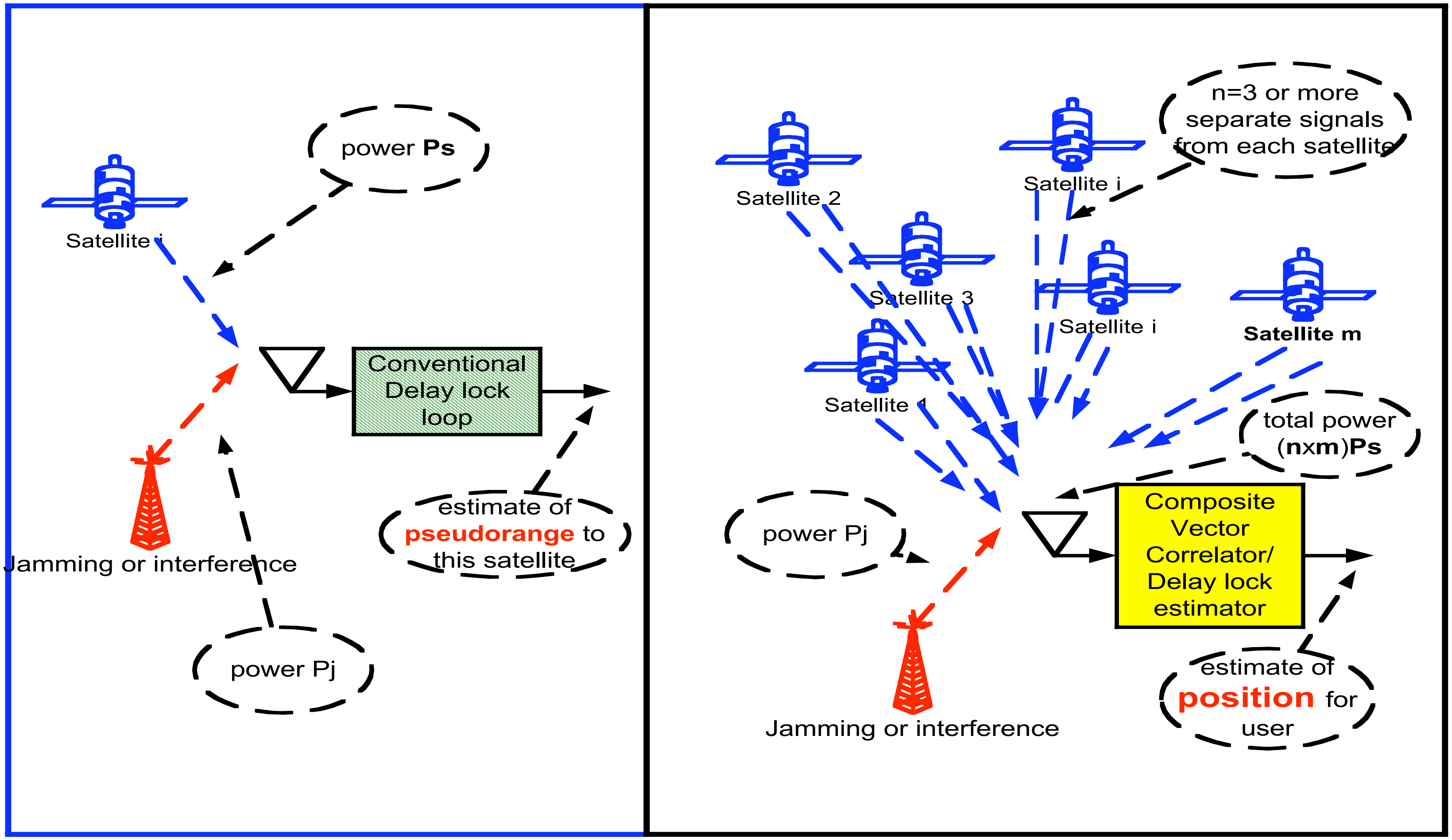
Tracking of Thousands of ships traffic patterns around the World



Composite Signal Vector Correlation/Tracking



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Location Based Services (LBS) Location Aware Search Engines

- **User laptop/PDA with integrated location technology automatically can perform detailed search of Database for that location**
  - **Geographical/historical information for that location for tourists, business**
  - **Complete information on restaurants, hotels, shopping for that site**
  - **Universal addressing/mapping data base**
  - **Image database of photos related to location**

Location based Communication Services Automated Location Based Search Engines

- **Future laptops, PDAs, and advanced cellphones will have built-in software location sensors**
- **GPS augmented with WAAS, Japan QZSS, EGNOS, TV, WiMax etc. provide accurate location at near zero cost using software receivers.**
- **Present location search for restaurants and other services just a beginning, orders of magnitude improvement in location oriented database are needed to bring location based services real value to the consumer.**

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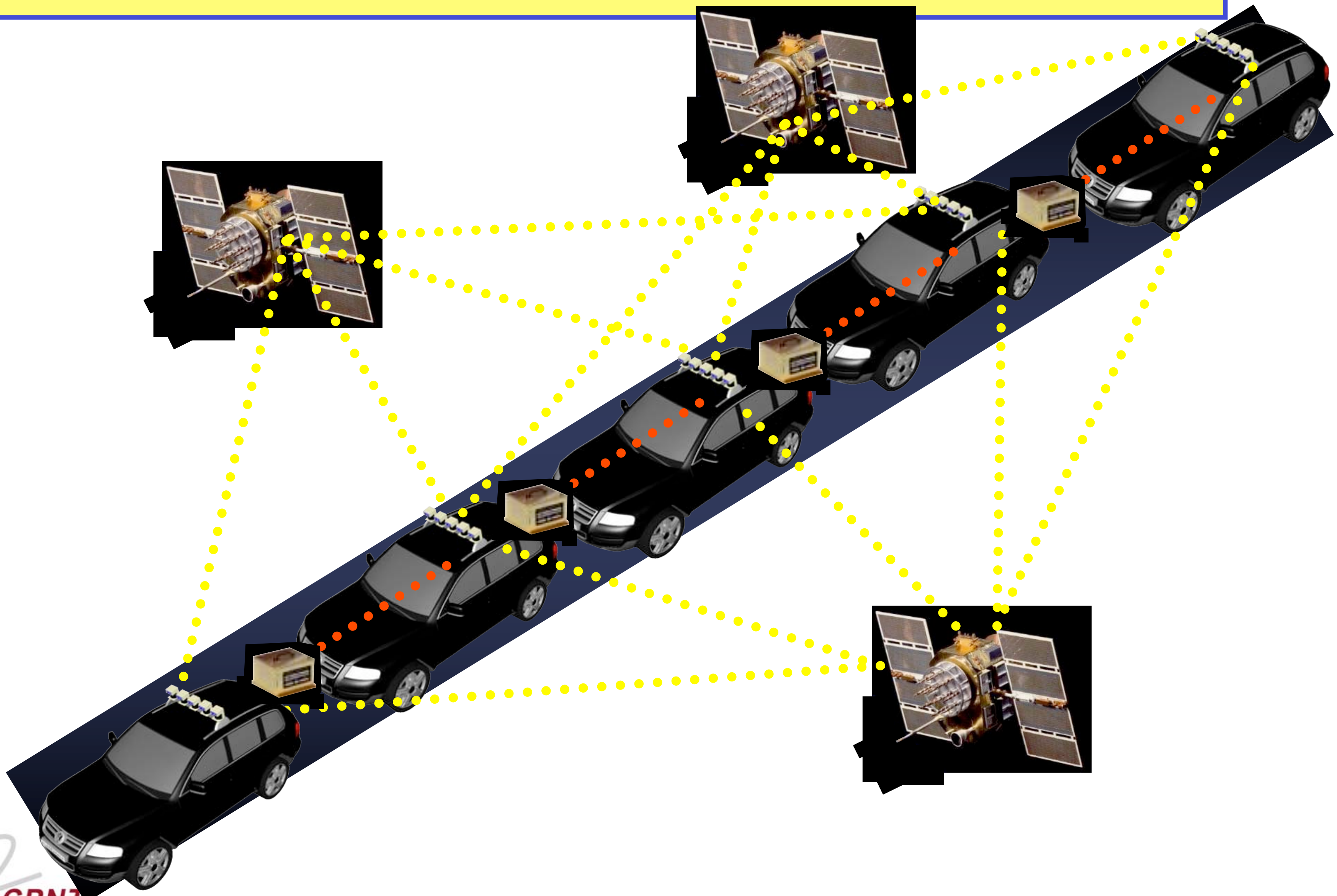
Stanford Artificial Intelligence Lab

Sebastian Thrun, Computer Science Department, Stanford University
thrun@stanford.edu

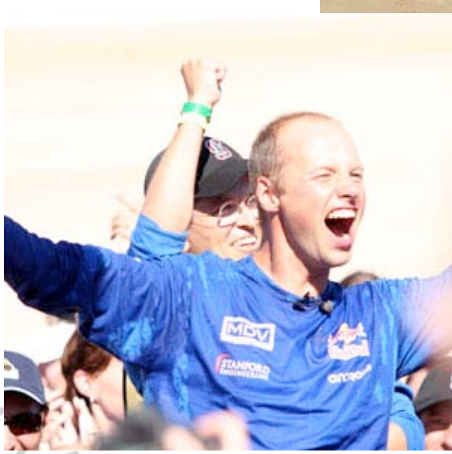
Winning The DARPA Grand Challenge

Stanford Racing Team   www.stanfordracing.org

Position Estimation



Finish Line Pictures



Societal Perspective

- **Traffic Accidents (USA)**
  - 42,636 dead (2004)
  - 2,788,000 injured (2004)
  - Leading cause of death, age 3-33
- **Commuting (USA)**
  - 1.25 hours per day and working person

Towards Autonomous Cars for Everyone

- Goal: Build Cars that can drive autonomously in Traffic
- Long-Term Impact
  - Save lives, money
  - Make people more productive
  - Improve quality of life of aging population
  - Increase highway throughput
  - Change urban real-estate

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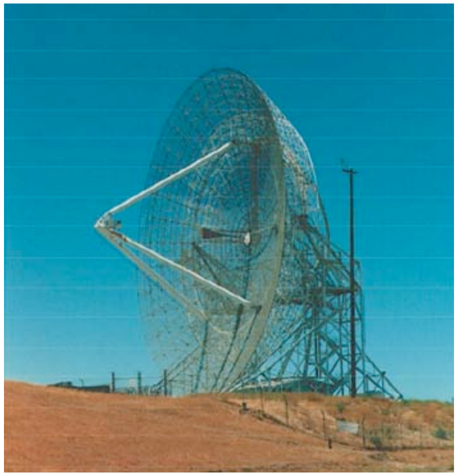
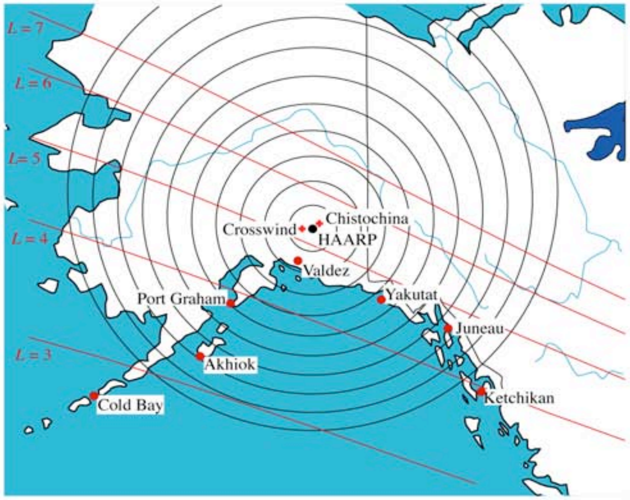
Space, Telecommunications and Radioscience (STAR) Laboratory

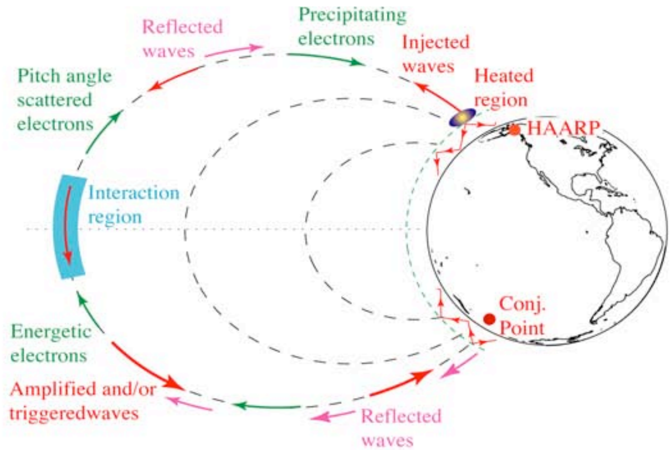


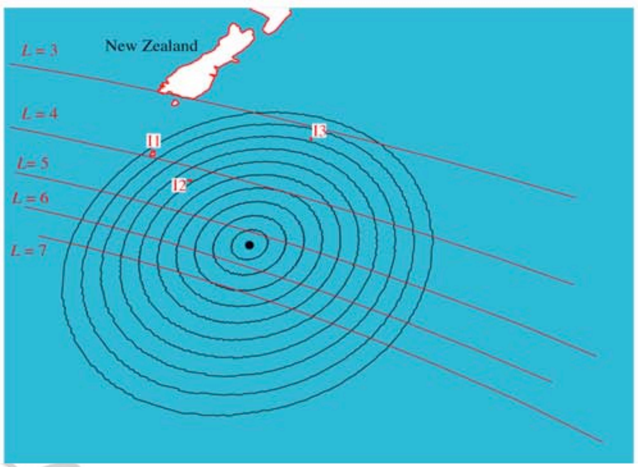
Faculty:	**Cioffi, Cox, Goldsmith, Inan, Kahn, Kazovsky, Tyler, Zebker**
Emeriti:	**Fraser-Smith, Bracewell, Eshleman, Helliwell, Carpenter**
Consulting:	**Bahai, Hashemi, Leeson, Narasimha,Walt**
Senior Staff:	**Bell, Hinson, Linscott, Simpson**
Director:	**Umran Inan, Packard 355** **inan@stanford.edu, 723-4994**

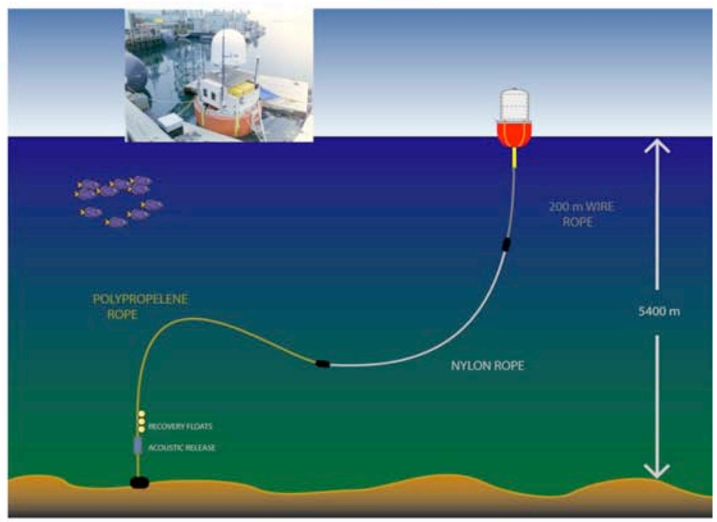
- **Electromagnetics and remote sensing**
- **Focused on the natural environment, including planets**
- **Utilizes radio propagation, radar, and optical measurements**
- **Theoretical modeling, ground- and spacecraft-based instrument development**
- **Field observations around the world, including Antarctica, Alaska, and Greenland**
- **Telecommunications**
- **Focused on engineering implementations**
- **Emphasize wireless and optical fiber systems as well as physical layer and DSL**
- **Channel modeling, signal processing, coding, propagation, modulation, networks, systems, circuits & architectures, multiple access, performance limits**
- **WDM, fiber nonlinearities, coherent detection with MEMs, lasers, optical networks**

ELF/VLF Wave-Injection Experiments with HAARP *(Inan)*

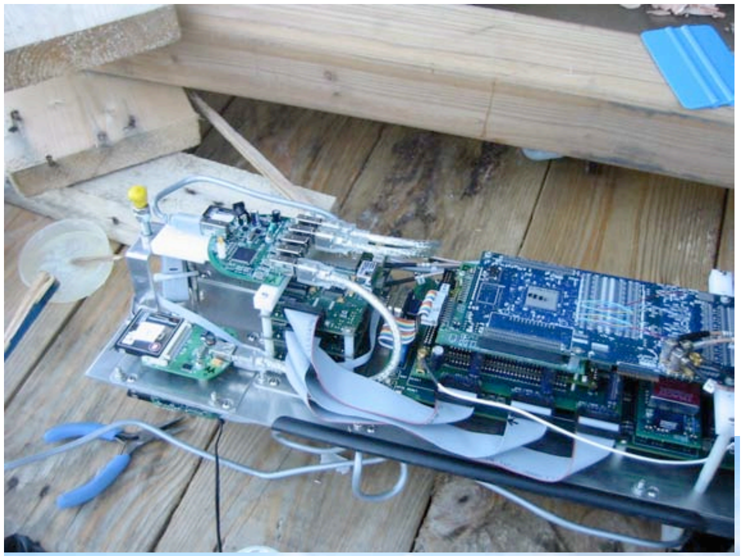


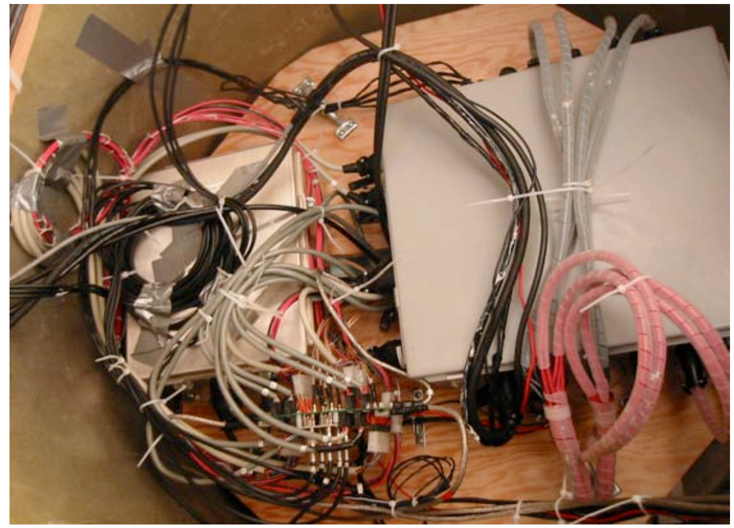




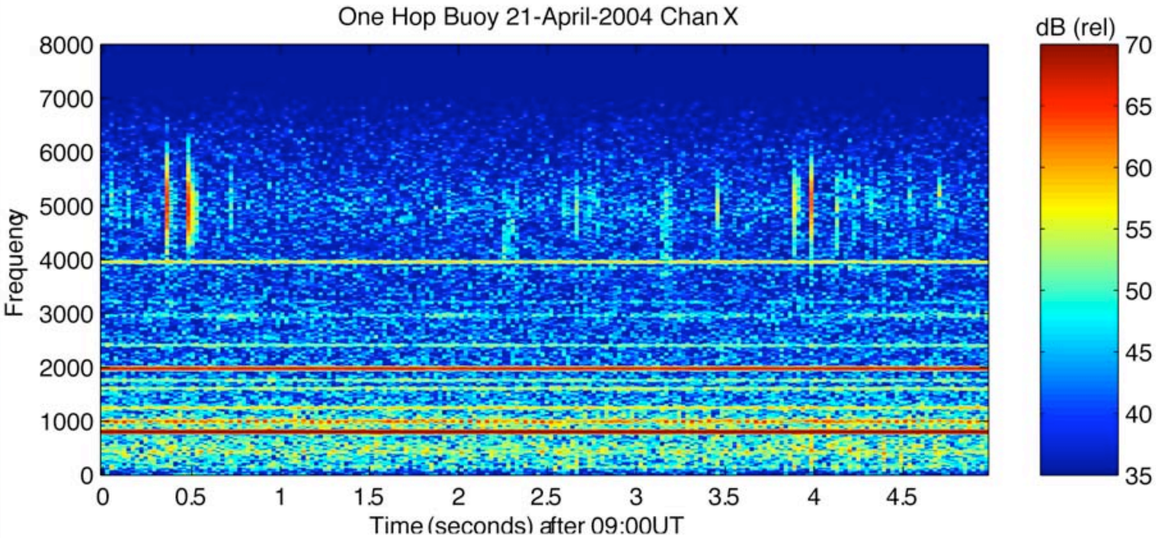


Stanford VLF Buoy in New Zealand: Integration & Launch





Stanford VLF Buoy
“First Light”



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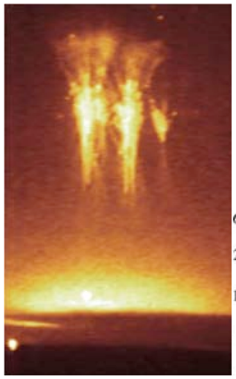
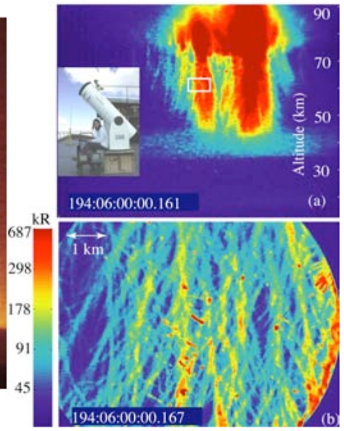
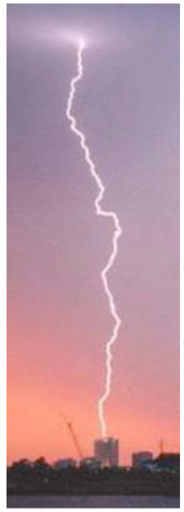
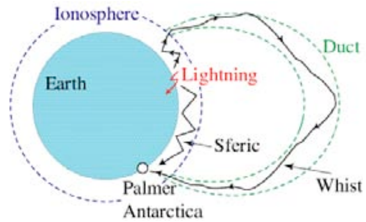
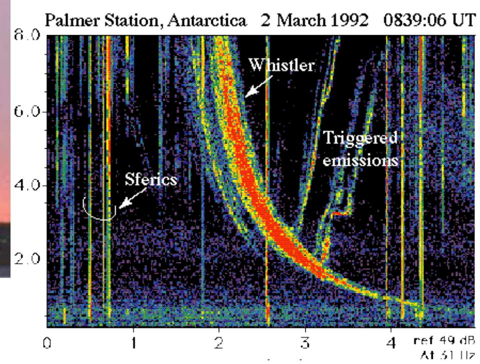
Stanford at Palmer & South Pole Stations, Antarctica *Prof. U. S. Inan*

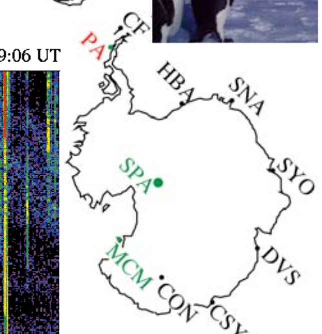


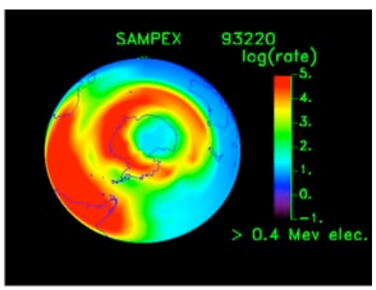


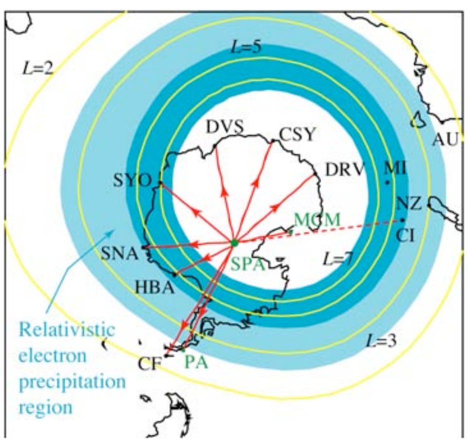












Stanford VLF Buoy at Sea and back in New Zealand

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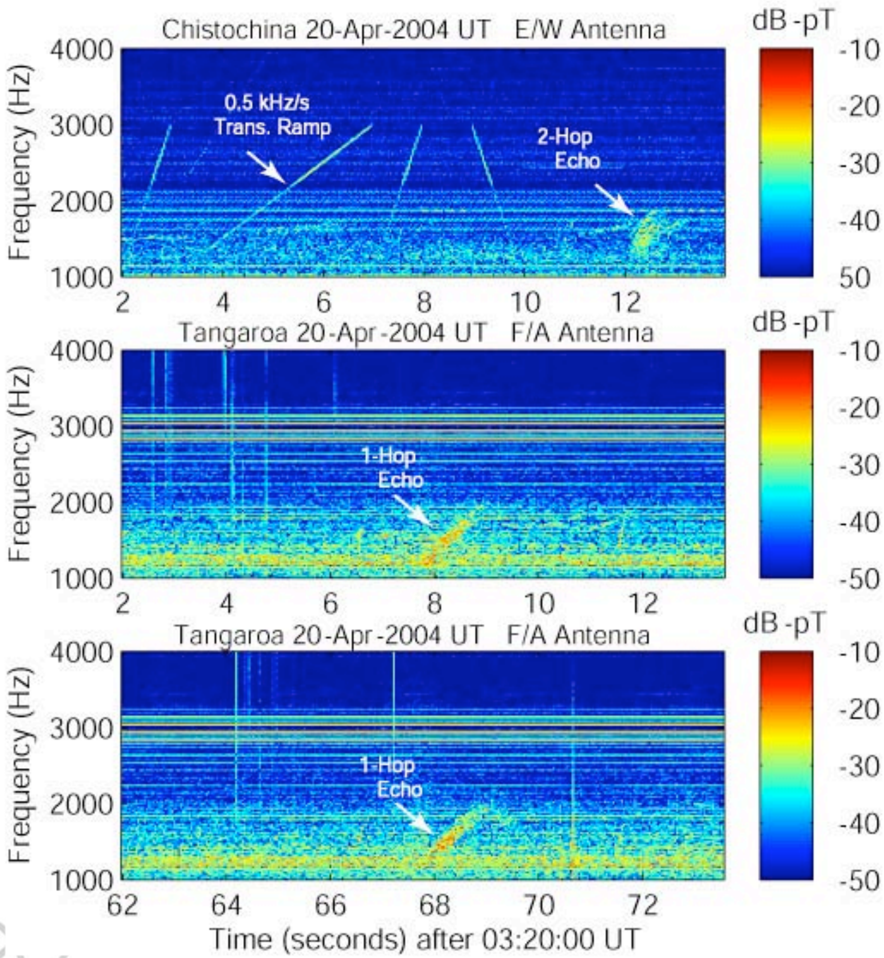
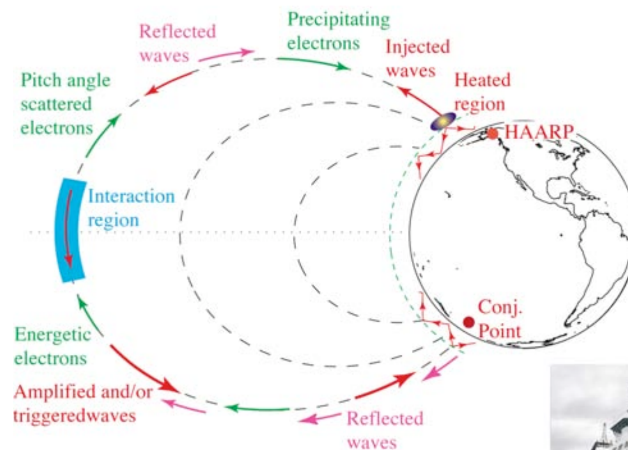
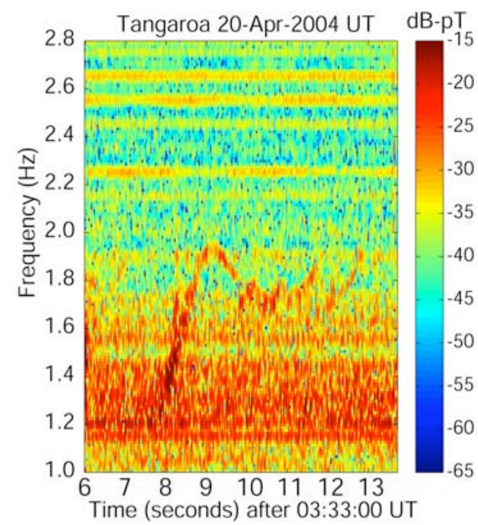
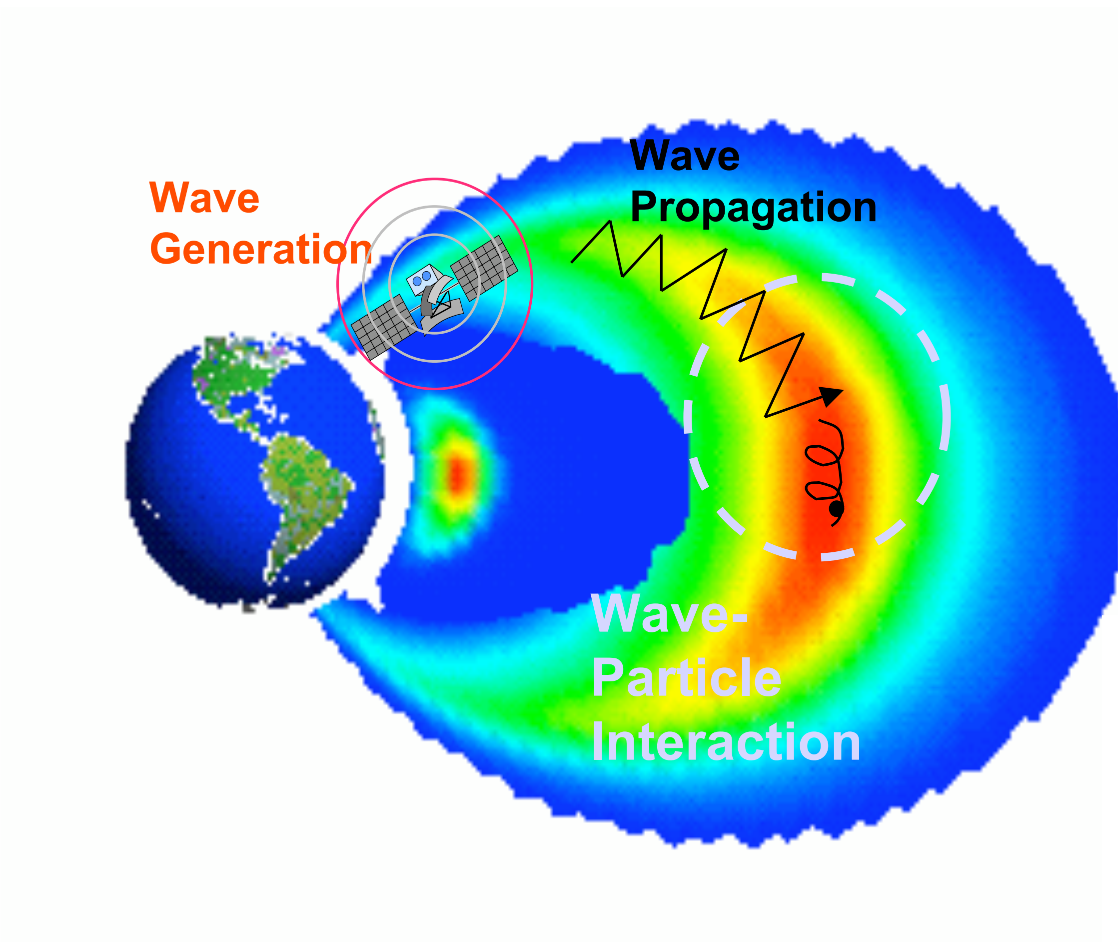
Amplified Signals and Triggered Emissions on Tangaroa & Alaska

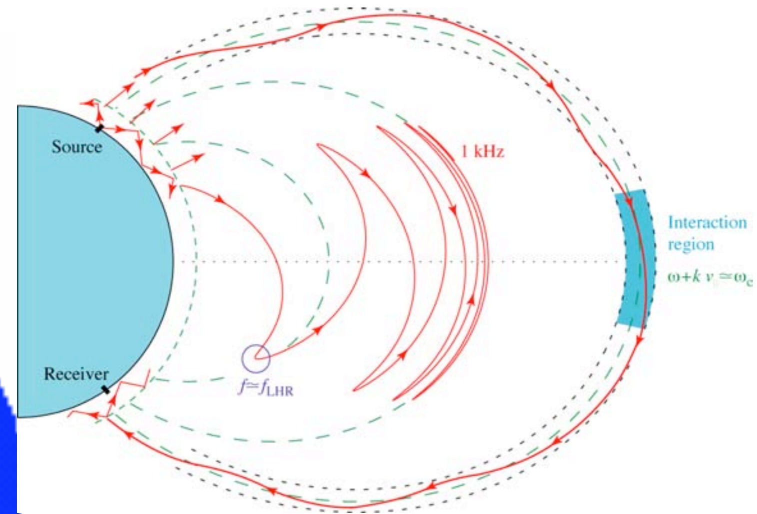


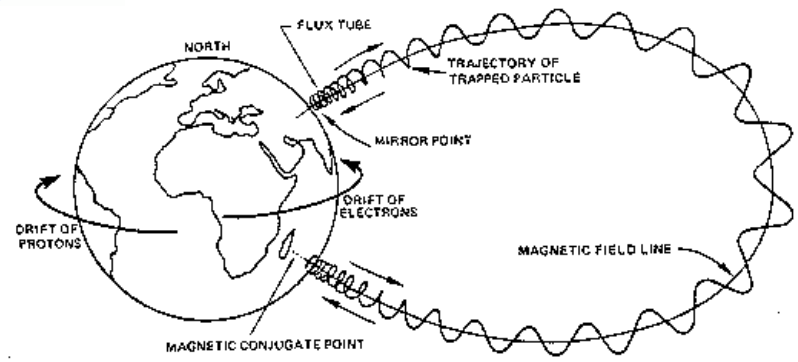




Wave-Particle Interactions & Radiation Belts *(Prof. U. S. Inan)*







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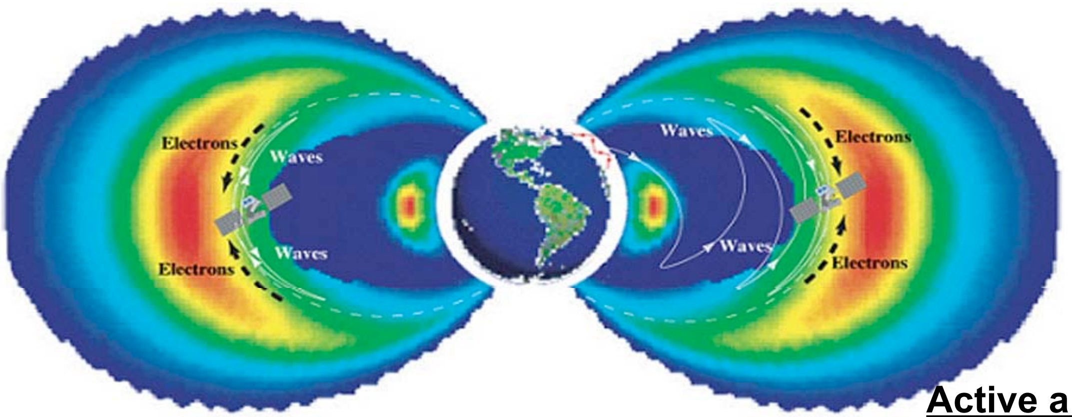
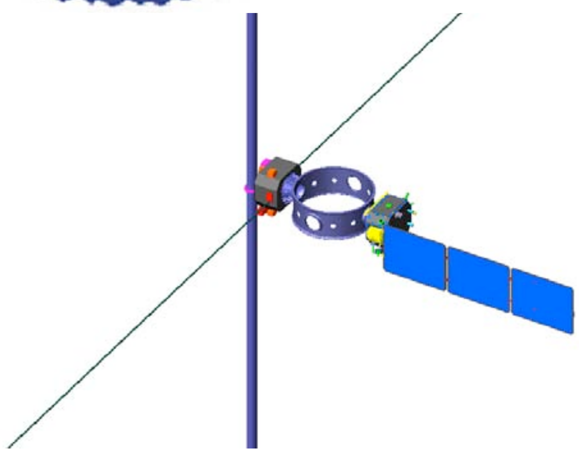
DSX / WIPER Spacecraft Mission
(Prof. U. S. Inan)





DSX Spacecraft

Active and Passive Observation Objectives

i) Characterize naturally occurring VLF signals
   a. In the inner radiation belt
   b. Slot region
   c. Inner edge of the outer belt.

ii) In-situ injection of VLF waves
   a. Efficiency in injection
   b. Propagation characteristics
   c. Effect on energetic particles

iii) Quantify pitch angle scattering
   a. Energetic electrons by whistler-mode waves
   b. Naturally occurring or injected.

WIPER: Wave-Induced Precipitation of Electron Radiation

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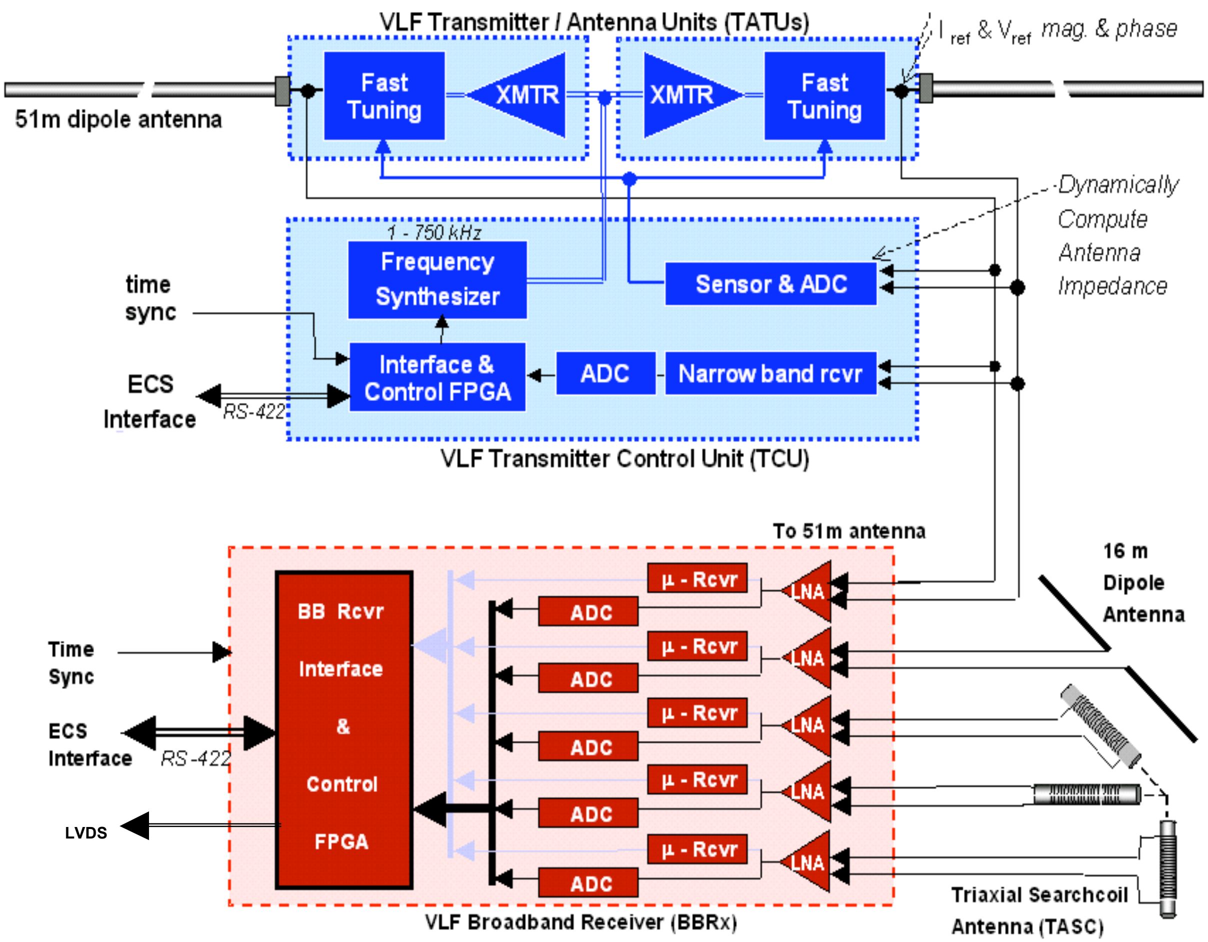
WIPER Block Diagram



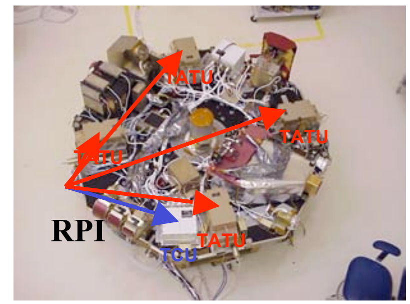
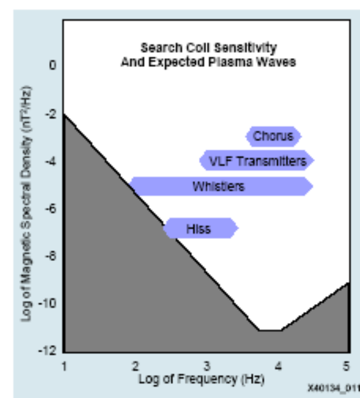


IMAGE Spacecraft Instrument Deck



Receiver sensitivity vs. frequency

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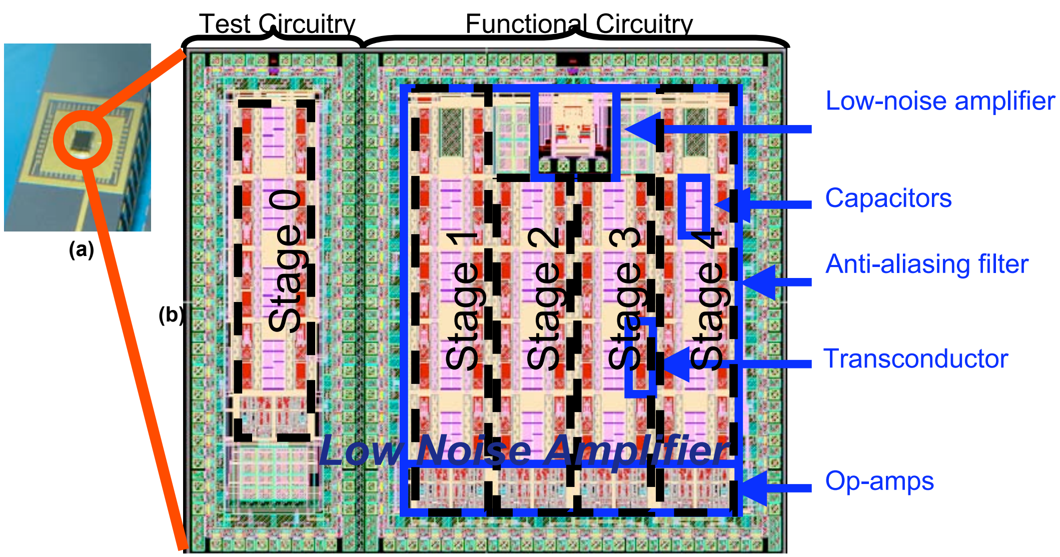
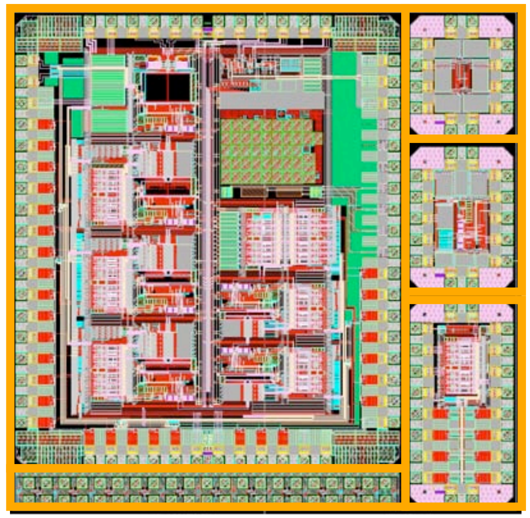
Stanford VLF Microelectronics Plasma Wave Receiver, LNA + ADC





PARX ADC Die Layout

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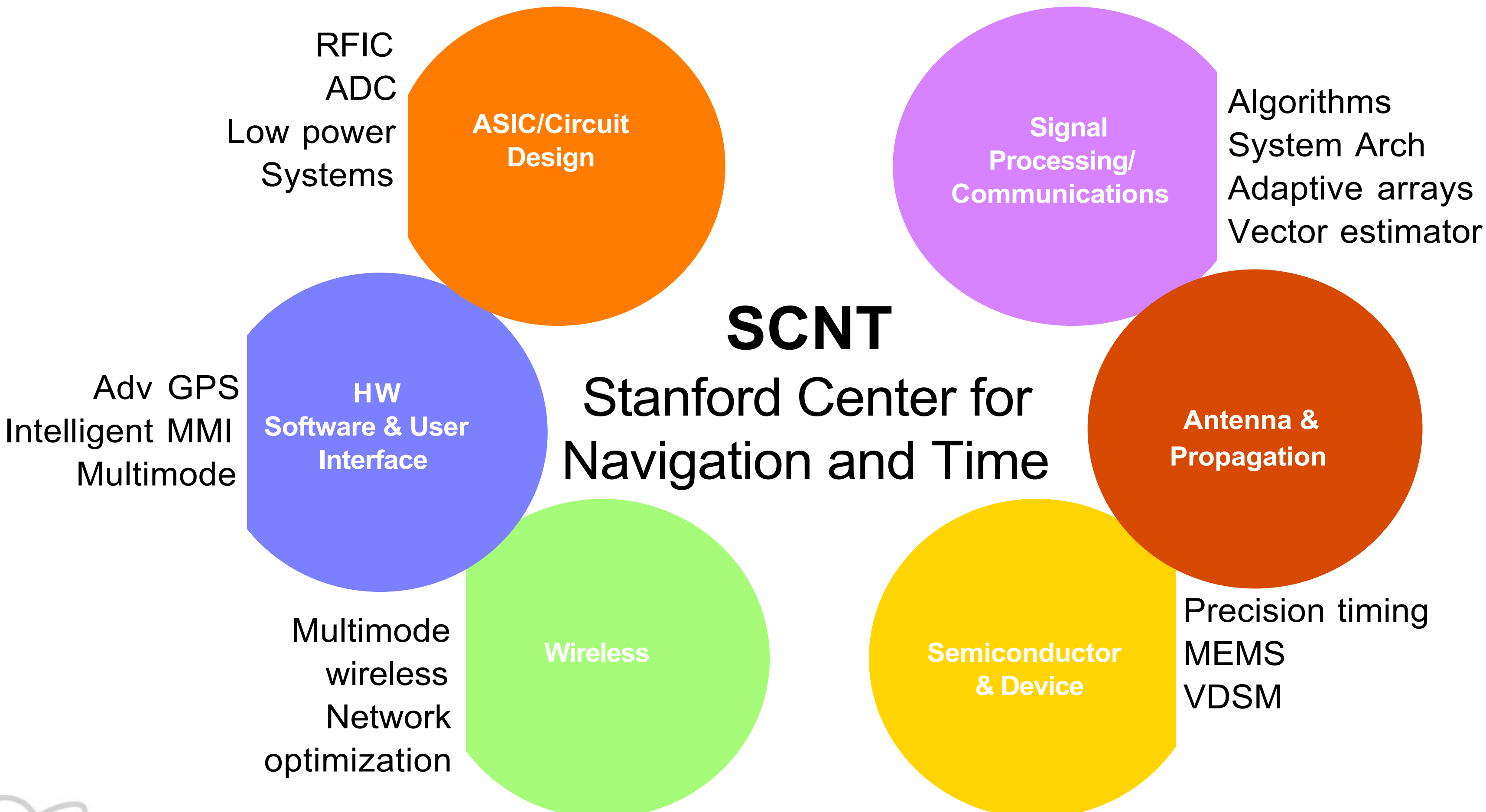
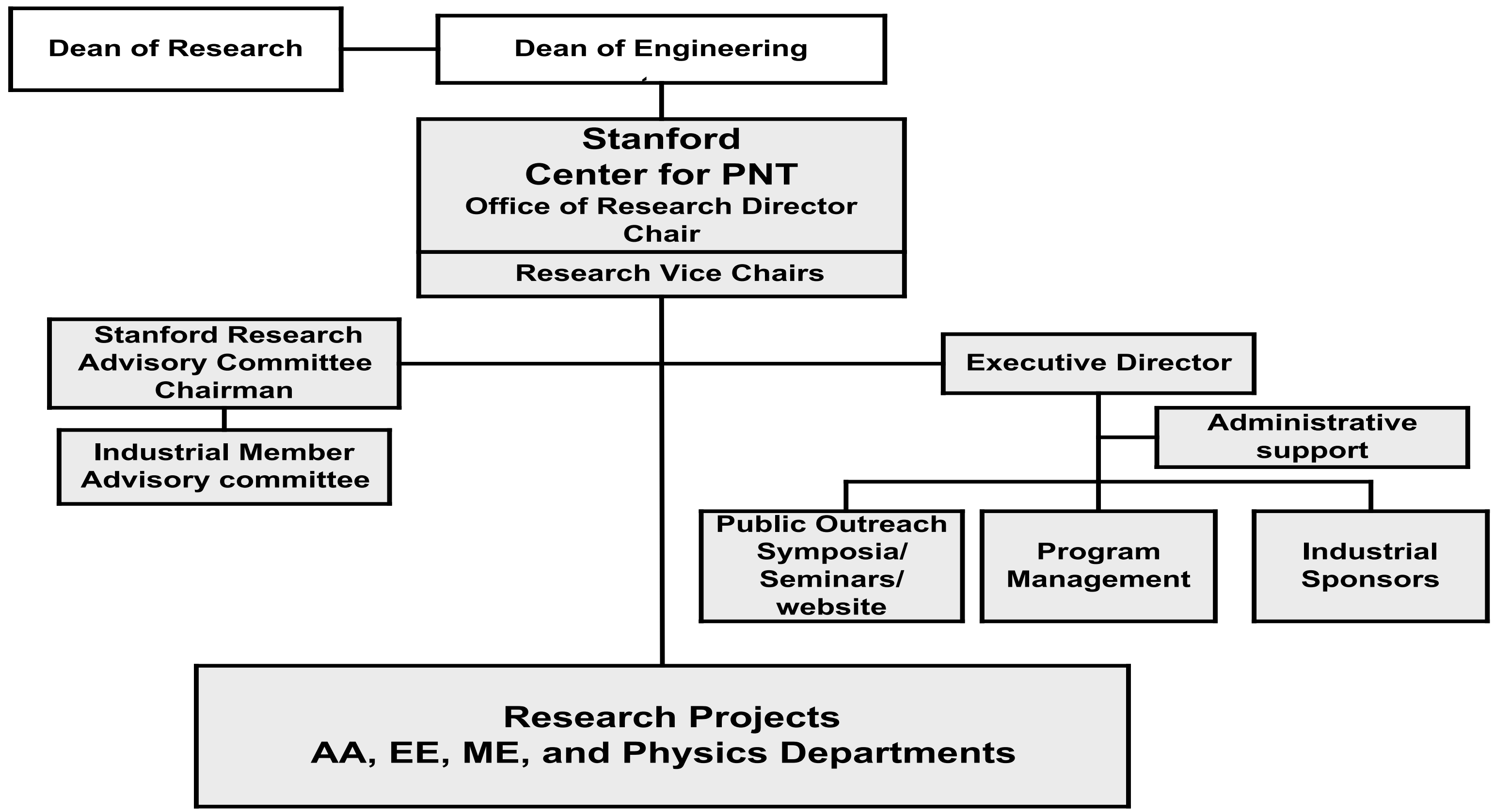
Multi-Disciplinary Research



SCPNT Management Plan
Center Relevance

- Navigation industry can no longer sustain cross disciplinary R&D teams required for progress.
- Nation is rapidly losing a generation of navigation system engineers, while few organizations are training younger generations.
- Navigation technology will continue to play a central role in security and economic prosperity.
- Stanford is uniquely positioned with excellence in Aeronautics/Astronautics, Electrical Engineering, Physics, and ME departments.

C. SCPNT
Management Plan & Organization



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SCPNT - Goals, Funds and Timeline

- Two new faculty positions next year:
  - Professors of Research
- 10+ Grad Students funded yearly in addition to contract funding
- Industrial Associates Program:
  - Different Membership Levels & Benefits
  - 1st year goal: $1.0M
- Funding for the Center:
  - University provided startup funds for AY ‘05/’06
  - SCPNT to be self-sustaining by AY ‘06/’07
- Center began operation Fall Q, 2005

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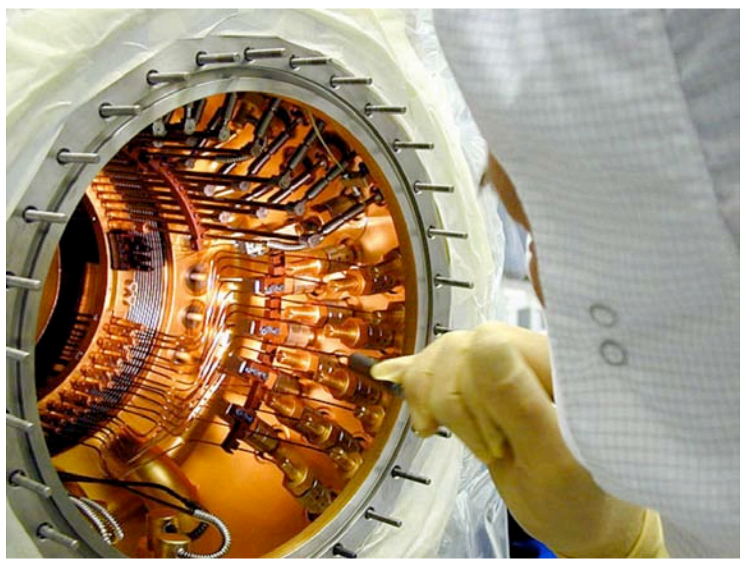
SCPNT: Center-level Government Support

- **Federal Aviation Administration**
- **U.S. Navy**
- **NASA**
- **DARPA Contracts and Prizes**
- **National Geospatial-Intelligence Agency**
- **Other government agencies have inquired about the new center.**



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SCPNT - Industrial Associates Program

Benefits / Sponsorship Levels	Founding Member	Senior Member	Associate Member	Affiliate Member
	One time donation of $950K (funds and/or equipment) - Donation covers first 3 years Senior Membership	$150K/year	$50K/year	$25K/year
1. Memberships in Industrial Advisory Committee	2	1	No	No
2. Graduate Student Research Sponsorships	2 Students/yr	1 Student/yr	No	No
3. Visiting Fellow on-campus at SCPNT	9 months/year	3 months/year	1 month/year	No
4. Facilitiated Recruiting of Grad Students	Yes	Yes	Yes	Yes
5. SCPNT Annual Symposium - Free Registration	No limit	Up to 4 people	2 people	1 person
6. Invitation to annual Project Reviews Presentations	Yes	Yes	Yes	Yes
7. Access to Technical Reports including PhD Thesis	Yes	Yes	Yes	Yes
8. Access to weekly (for credit) Seminar Series	Yes	Yes	Yes	Yes
9. Recognition on printed materials, web site, etc.	Yes	Yes	Yes	Yes
10. Early exposure to SCPNT Intellectual Property	Yes	Yes	Yes	Yes

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SCPNT - Membership Benefits (1)

- Industrial Advisory Committee
  - Composed of Representatives from Founding (2 per) and Senior (1 per) Members and SCPNT Directors
  - Provides Policy Guidance for Major Research Initiatives
  - Selects Graduate Students for Research Sponsorships
- Graduate Student Research Sponsorships
  - Named in Honor of Sponsor
  - Sponsor’s suggested research, if possible
  - Mentoring type relationship encouraged
- Industrial Affiliates Research ~30% less expensive
  - Sponsored research (Grad student +) @ ~$120K/yr
  - Affiliates research (Grad student +) @ ~$90K/yr

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SCPNT - Membership Benefits (2)

- Visiting Fellows Program
  - Members send staff to work at Stanford
  - Topics of Interest - SCPNT Faculty and Students
  - New skills, insights, contacts from experience
  - Office space and access to all facilities
  - Founding Member - 9 months/year
  - Senior Member - 3 months/year

- Facilitated Recruitment of Students
  - Members sent resumes of SCPNT students
    - Summer or Permanent employment
  - Member's Position Descriptions Posted

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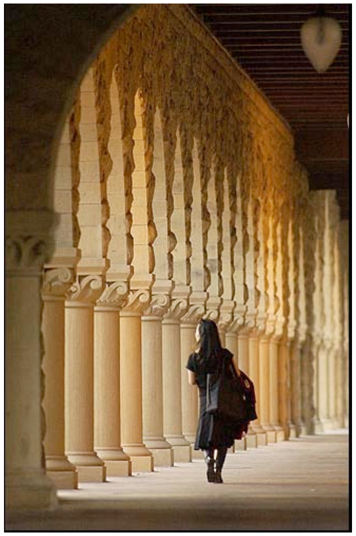
SCPNT - Membership Benefits (3)

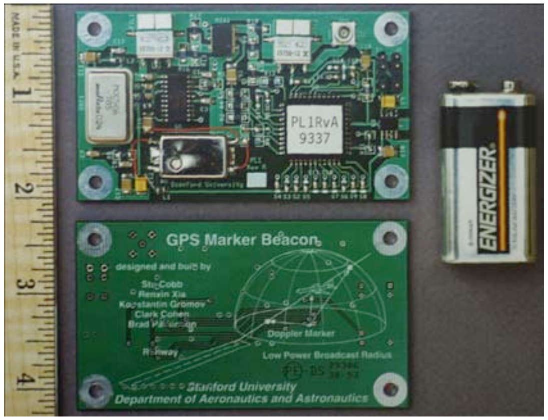
- Annual Symposium and Project Reviews
  - Mixture of In-depth Lectures and Workshops
  - Government and Industry Participation
  - Founding Members - Unlimited Attendance
  - 1st Symposium in December ‘06



- Technical Reports and PhD Theses
  - Reports & Theses posted on Web site
- Weekly SCPNT Seminar Series
  - Every Friday at noontime or Wednesday afternoon
  - Presenters include:
    - Visiting Researchers, Faculty, Staff, Students
  - Email list, web site posting, web site presentations
  - All Members invited to attend

SCPNT - Membership Benefits (4)

- **Early exposure to Center's Intellectual Property**
  - **Members have facilitated early access to Centers' IP**
    - **Meetings, Workshops, Grad Student Sponsorships, Visiting Fellows Program, Seminars, Etc.**
  - **Exclusive or Non-exclusive IP licensing through Stanford's Office of Technology Licensing (OTL)**
    - **OTL has long history of mutually successful arrangements**



SCPNT
Stanford Center for Position, Navigation and Time