Short-Range Ultra-Wideband Systems

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Principal Investigator

A MURI Team Effort between

University of Southern California
University of California, Berkeley
University of Massachusetts, Amherst

Features of a Rationale

FCC Compliance ➠ Low Power Applications
➠ Short-Range and/or Low Data Rate Applications

For a Given Center Frequency:
"Ultra-Wide Bandwidth" ➠ Very Large Bandwidth
➠ Fine Time Resolution
➠ Ranging is a Killer Application

For a Given Bandwidth:
"Ultra-Wide Bandwidth" ➠ Very Low Center Frequency
➠ Good Propagation through Materials

These are comparative/relative statements.

More Consequences of UWB Constraints

Fine Time Resolution ➠ T_{unc}/T_{res} Large
➠ Long Acquisition Times

"Ultra-Wide Bandwidth" ➠ Channel Distortions
➠ Matched Filter Design Problems
➠ Receiver Design for Efficient Energy Capture

Very Large Bandwidth ➠ Large Frequency Diversity
➠ Multipath Mitigation

FCC Compliance ➠ Power Optimization Requirements
➠ Design for Spectral Flatness/Shaping

High-Level Questions

Are answers for UWB questions simply bandwidth-scaled from narrowband designs, or is there a paradigm shift in approach/viewpoint?

Is UWB radio the best choice for a given application?

Is asynchronous UWB radio an effective use of the RF spectrum?

Overview of the Proposal

The Research Team

University of Southern California
Bob Scholtz, Keith Chugg, Won Namgoong
(propagation, systems, circuits)
UltRa Lab

University of California, Berkeley
Bob Brodersen, David Tse
(circuits, information theory)
Berkeley Wireless Research Center

University of Massachusetts, Amherst
Dave Pozar, Dan Schaubert, Dennis Goeckel
(antennas, systems)
Antennas Laboratory

Goals

- Channel Characterization: UWB propagation and interference models for short-range propagation scenarios
- Antenna Design: Basic limits on radiation and reception of UWB signals; time-domain characterization; practical antennas for integrated UWB tagging systems.
- System Design: Issues uniquely affected by large bandwidth, fine time resolution, large frequency diversity, e.g., rapid sync acquisition, designs and architectures for efficient recovery of signal energy, low power-density modulation, ranging in dense and resolvable multipath.
- Implementation: UWB architectures and topologies for single-chip implementation in CMOS; simultaneous optimization of antennas, algorithms, and circuits for performance and power consumption.
- Test Beds: Hardware and simulation test beds for UWB systems and components; cooperate with government agencies in testing efforts.

Focus

• The study of UWB systems that require both position location and communication as operational requirements.

•To ground research in reality, environments in which we can perform measurements and experiments will be pursued.

•Parameters for design related to RF tags, e.g., IFF systems, shipping and logistic systems, status monitoring, battlefield asset tracking, traffic monitoring, medical tagging.

Impact on Universities and Education

Five meetings so far

- New Relationships between Team Members
- New Relationships with Industry
- Improved Infrastructure and Capabilities of Labs
- Training of Graduate Students in UWB Technology
- Annual Workshops on UWB Technology
- Student Exchange

Fall 2002 workshop jointly sponsored with Intel

Where We Want To Be In Two More Years

Understand the issues, answer questions posed in proposal

MURI Team

(basic research and cross-fertilization)

Characterize, optimize, construct, and test critical/novel parts of a UWB radio (fabrication feasibility)

Brodersen

Namgoong

Have the ability to do reasonable sanity checks on a design:

- Develop good performance prediction techniques
- Produce believable link budgets
- Produce reasonable battery power budgets

Scholtz

(system feasibility)

For more information, copies of papers, etc., visit the UltRa Lab's web site at

http://ultra.usc.edu/New_Site/

The MURI team has a page at this web site.

FCC Regulations

UltRa Lab @USC

FCC Decision 2/14/02

THURSDAY, FEBRUARY 14, 2002 C3

FCC Expected to Deal Blow to Ultra-Wideband

Telecom: Faster wireless may face constraints. Some worry the technology could cause airwave interference.

By JUBE SHIVER Jr.
TIMES STAFF WRITER

WASHINGTON—In a setback to computer and consumer product makers, federal regulators today are expected to tightly constrain a breakthrough wireless technology that backers had hoped would usher in a new era of wireless networking and tracking.

Proponents had boasted that the TimeDomain Corp., a Huntsville, Ala., company that has been developing the technology.

In addition, the FCC staff is expected to oppose most commercial and consumer applications of ultra-wideband tracking technology out of fear it might fall into the wrong hands.

"We think a conservative approach is appropriate at the outset," a top administration official said. "We can make adjustments later."

Although military and public safety personnel will be able to use ultra-wideband's radar capabilities to see through walls and other obstructions, the FCC staff wants to limit commercial applications to

FCC Approves New Wireless System

Federal regulators approved the use of a new wireless technology that could help rescue workers find people buried in rubble or locate stresses in the side of a bridge, overcoming fears it would interfere with important navigation aids.

The Federal Communications Commission voted unanimously to approve limited use of ultra-wideband technology for hand-held wireless communications, ground-penetrating radar and vehicle collision avoidance systems.

The FCC approved the marketing and operation of products using UWB technology but limited it to the range above the 3.1-gigahertz frequency and, in some cases, restricted use to law enforcement, scientific researchers and certain industries such as construction.

Reuters

FCC UWB Device Classifications

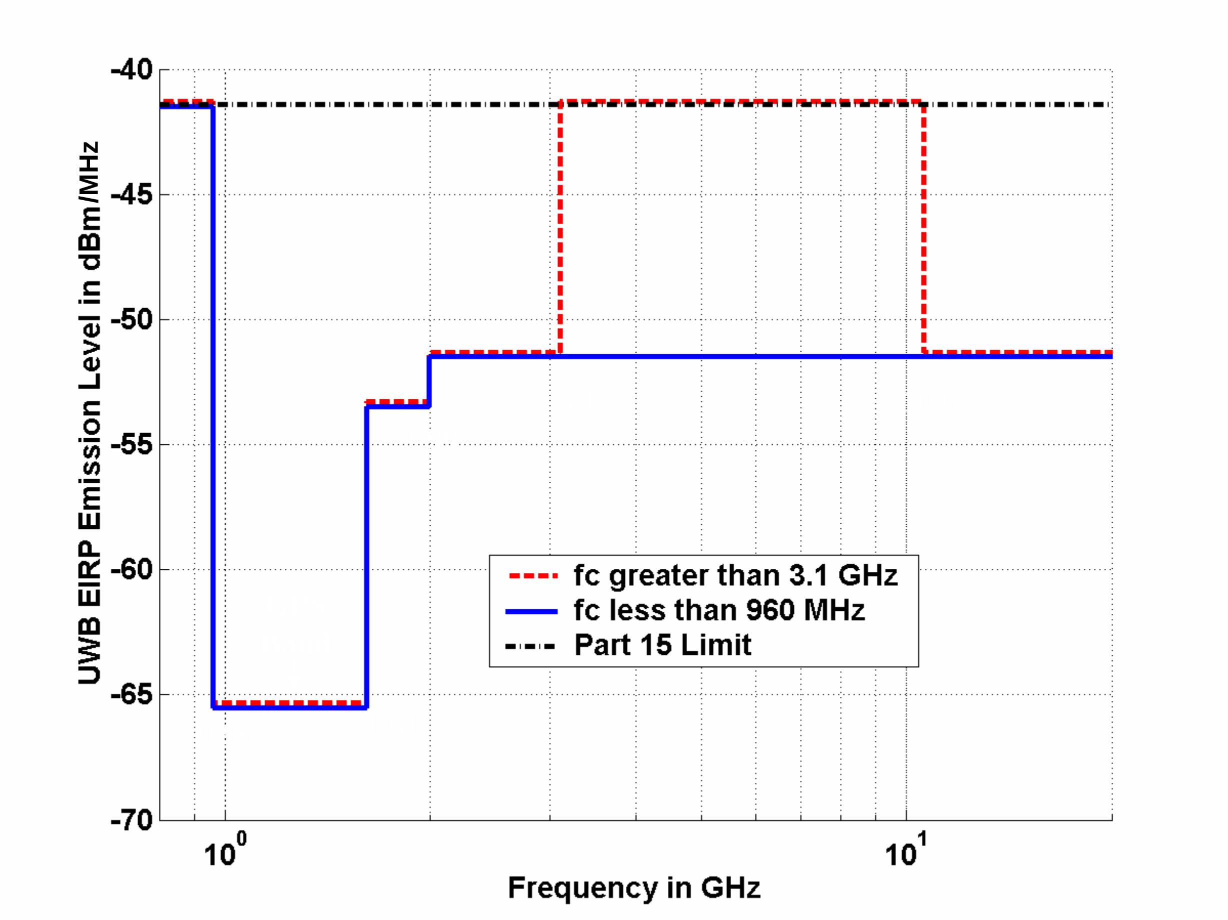
Authorizes five classes of devices – different limits for each:

- **Imaging Systems**
  1. Ground penetrating radars, wall imaging, medical imaging
  2. Thru-wall Imaging & Surveillance Systems
- **Communication and Measurement Systems**
  3. Indoor Systems
  4. Outdoor Hand-held Systems
- **Vehicular Radar Systems**
  5. Collision avoidance, improved airbag activation, suspension systems, etc.

FCC First Report and Order Authorizes Five Types of Devices

Class / Application	*Frequency Band for Operation at Part 15 Limits*	*User Limitations*
Communications and Measurement Systems	**3.1 to 10.6 GHz** **(different "out-of-band" emission limits for indoor and outdoor devices)**	**No**
Imaging**: Ground Penetrating Radar, Wall, Medical Imaging**	**<960 MHz *or* 3.1 to 10.6 GHz**	**Yes**
Imaging: **Through-wall**	**<960 MHz *or* 1.99 to 10.6 GHz**	**Yes**
Imaging: **Surveillance**	**1.99 to 10.6 GHz**	**Yes**
Vehicular	**24 to 29 GHz**	**No**

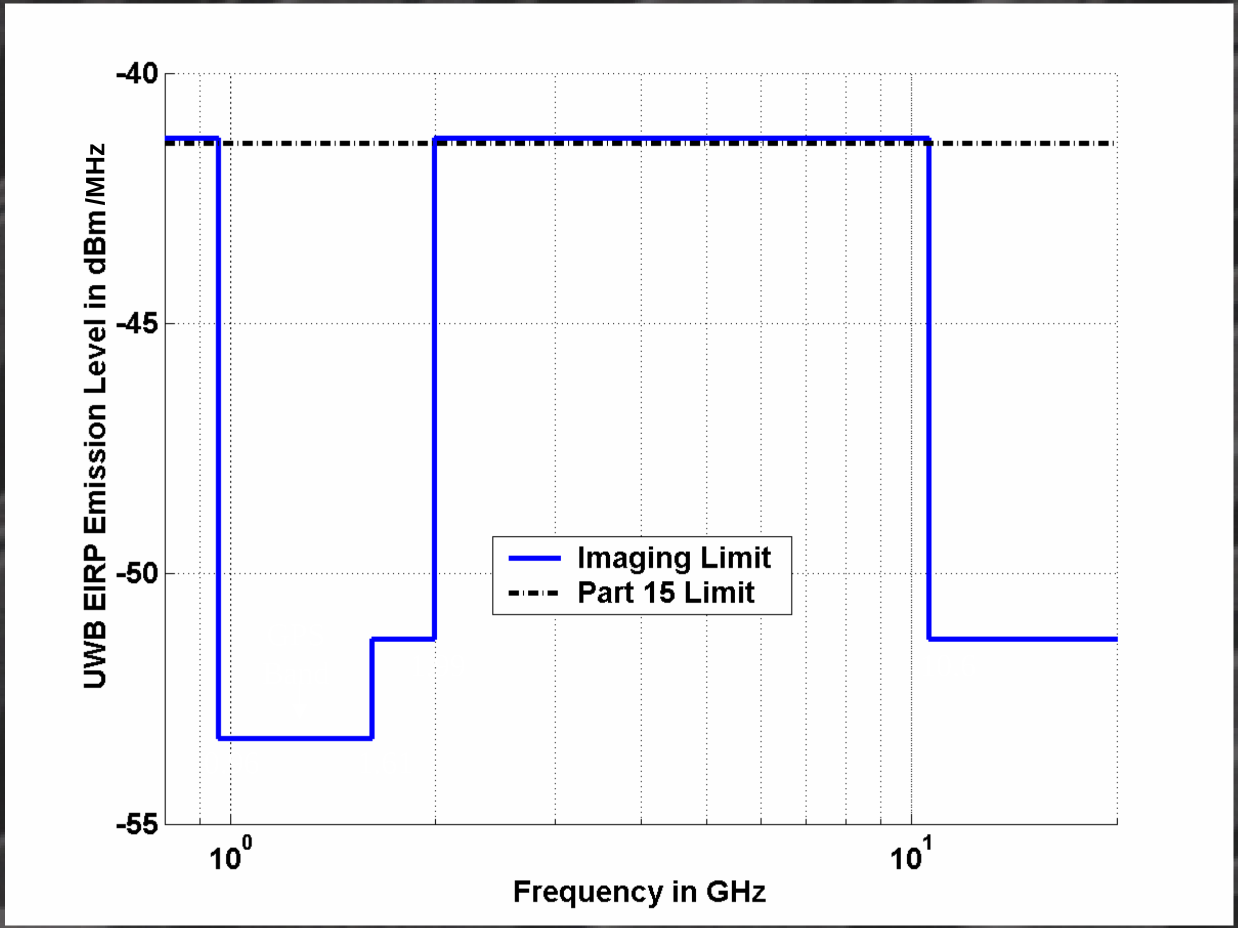
UWB Emission Limits for GPRs, Wall Imaging, & Medical Imaging Systems



Operation is limited to law enforcement, fire and rescue organizations, scientific research institutions, commercial mining companies, and construction companies.

Source: www.fcc.gov

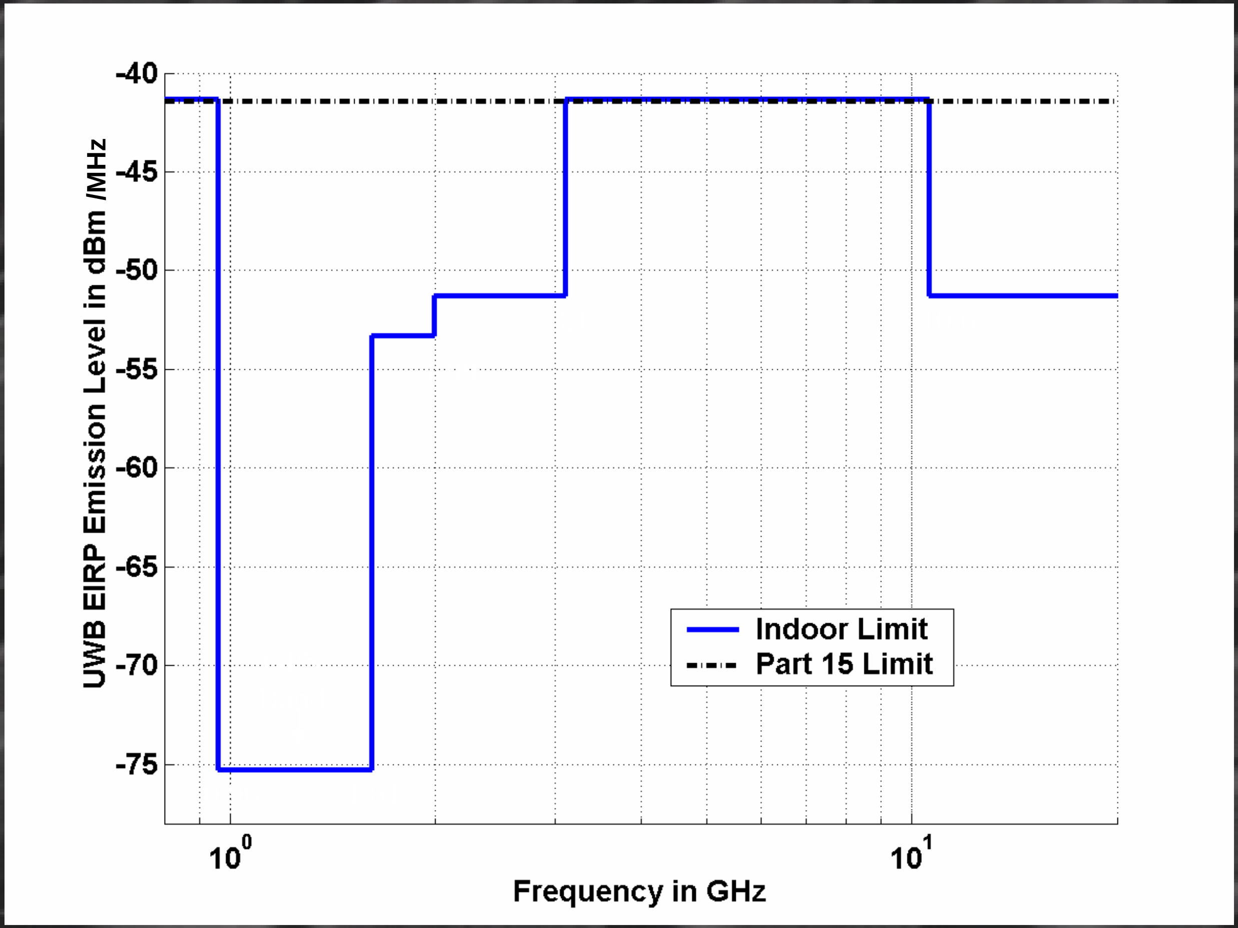
UWB Emission Limits for Thru-wall Imaging & Surveillance Systems



Operation is limited to law enforcement, fire and rescue organizations. Surveillance systems may also be operated by public utilities and industrial entities.

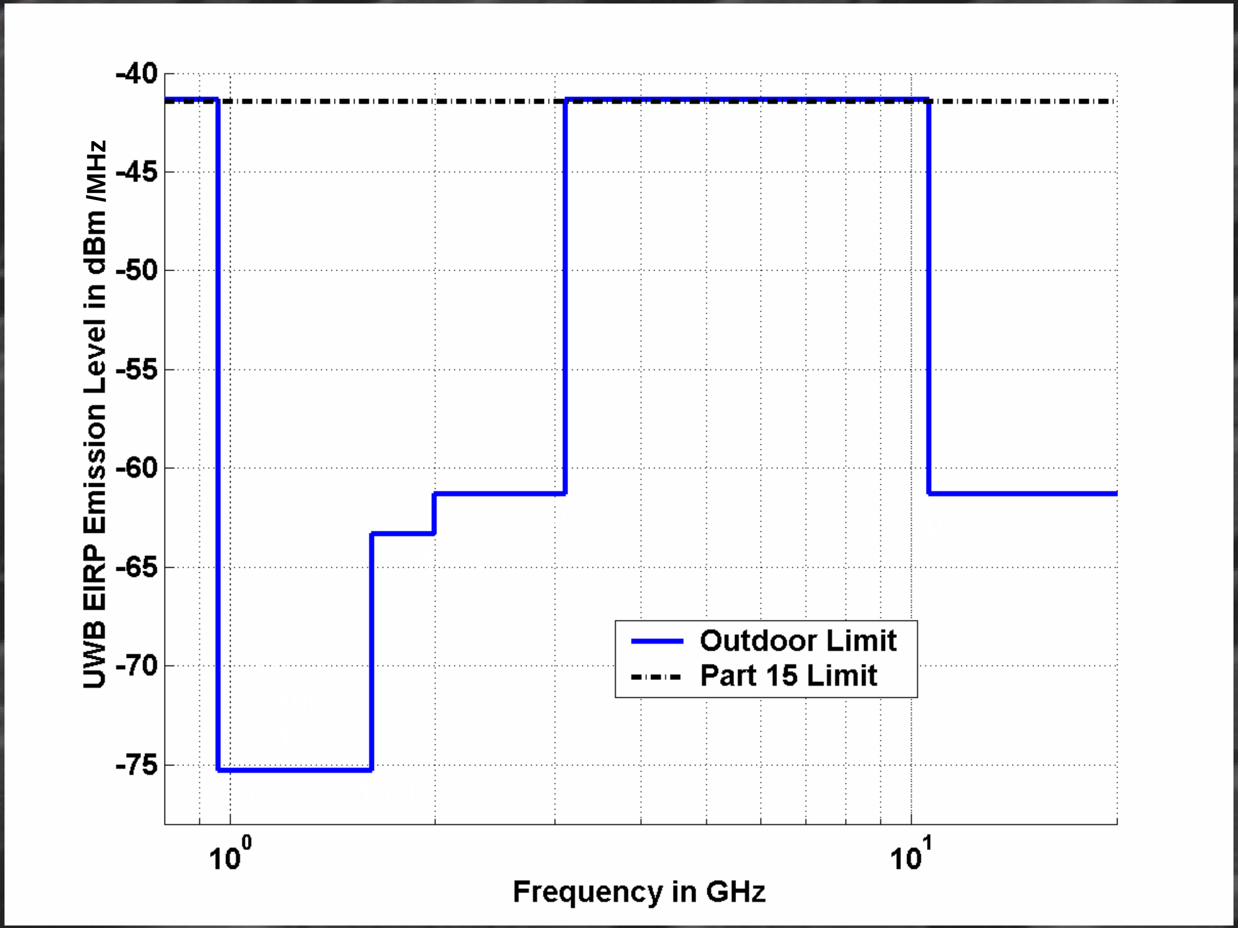
Source: www.fcc.gov

UWB Emission Limit for Indoor Systems



Source: www.fcc.gov

UWB Emission Limit for Outdoor Hand-held Systems



Source: www.fcc.gov

Basic Power Computations

FCC bound: 500 microvolts/meter/(MHz)$^{1/2}$ @ 3 meters
= -41.25 dBm/MHz EIRP

FCC band: 3.1 GHz to 10.6 GHz = 7500 MHz

➠ -41.25 + 38.75 = -2.5 dBm EIRP (bound)

Bit energy to noise density ratio

<.56 mw

Effective receiving aperture?

Receiver efficiency

$$R_b(E_b/N_{tot}) = (P_tG_t)(1/L_{prop}4\pi R^2)(G_r\,\lambda^2/4\pi)\eta_{rec}/(N_o+I)$$

Bit Rate

Propagation losses and spreading

Noise+interference density

UWB Band: Power Comparison

Center Frequency	500 MHz		5GHz
Relative bandwidth	1		10
Relative EIRP/MHz	1		6.25
Relative power gain	1		0.01
Net power advantage	2 dB		
Unknowns:			
Interference		?	
Propagation	Advantage	?	
Time Resolution	1		0.1

Assumptions: same fractional bandwidth, identical (scaled) antennas

Sanity Check:
Link Budgets

Sanity Check: Comparative Communication Link Budgets (1)

EIRP: same

Data Rate: same

Frequency: NB carrier at UWB center frequency

Antenna pattern: dipole

Antenna losses: same

Propagation: free space

External interference: none

Reception: Matched filter/correlator in both

Receiver noise temperature: same

Modulation: same binary antipodal

⇨ Approximately equal bit error rates

UWB advantage in range/time resolution

Sanity Check: Comparative Communication Link Budgets (2)

EIRP: same

Data Rate: optimized

Frequency: NB carrier at UWB center frequency

Antenna pattern: dipole

Antenna losses: same

Propagation: free space

External interference: none

Reception: Matched filter/correlator in both

Receiver noise temperature: same

Modulation: optimized

⇨ UWB advantage: Higher data rate and/or lower bit error rate

UWB advantage : Range/Time resolution

Sanity Check: Comparative Communication Link Budgets (3)

EIRP: same

Data Rate: same

Frequency: NB carrier at UWB center frequency

Antenna pattern: dipole

Antenna losses: same

Propagation: free space

External interference: other CDMA users

Receiver: Matched filter/correlator in both

Receiver noise temperature: same

Modulation: optimized CDMA

⇨ UWB advantage in number of users

UWB advantage in Range/Time resolution

Sanity Check: Comparative Communication Link Budgets (4)

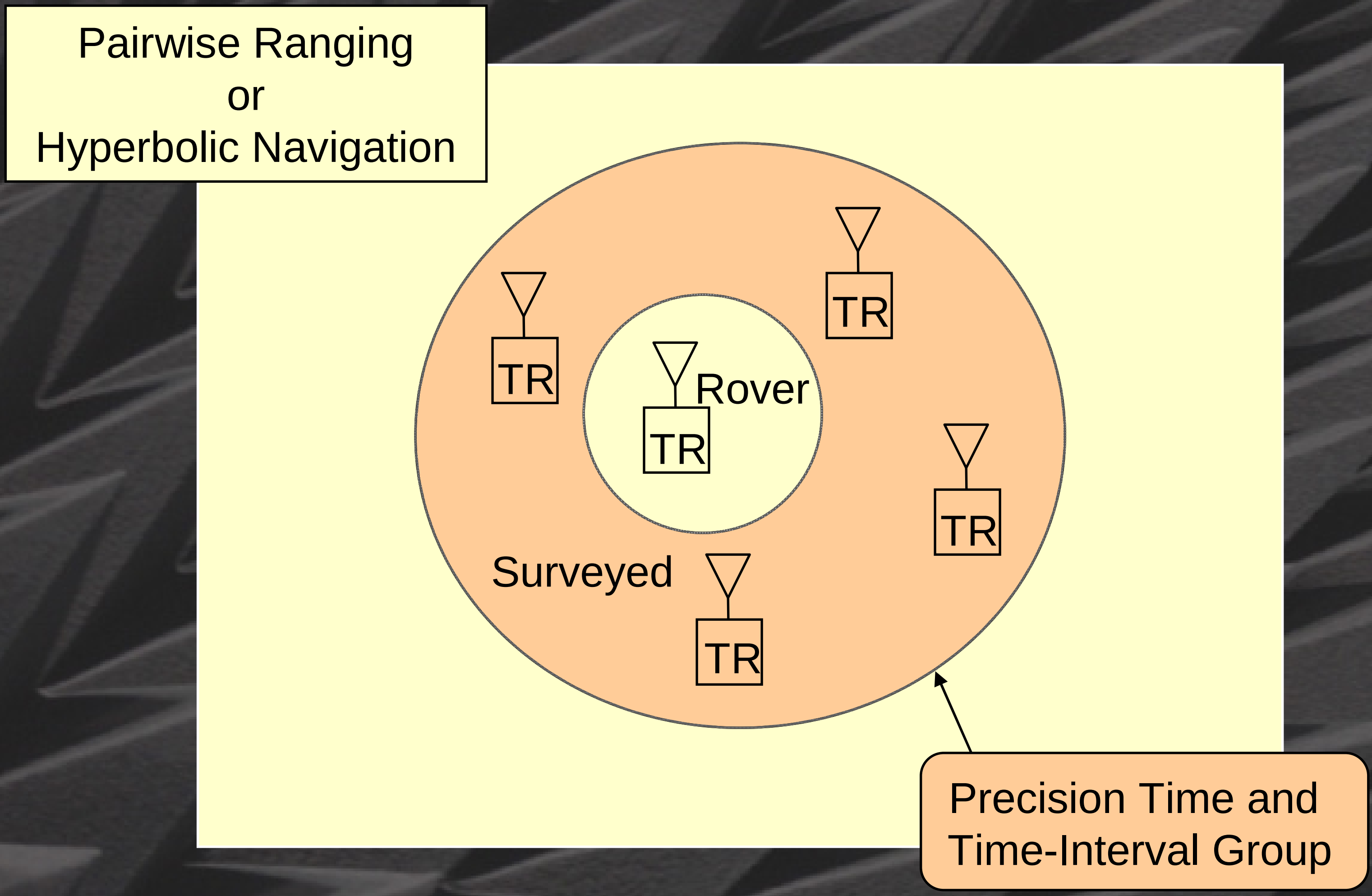
EIRP: FCC regulation ➪ NB+
Data Rate: same
Frequency: NB carrier at UWB center frequency
Antenna pattern: dipole
Antenna losses: mismatch problems ➪ NB+
Propagation: terrestrial indoor
Fading Margin ➪ UWB + (propagation)
Receiver Mismatch ➪ NB+ (receiver design)
External interference: other radio systems ➪ NB+
Interference mitigation: SS PG and excision ➪ UWB+
Receiver noise temperature: same
Modulation: optimized spread spectrum
➪ UWB advantage in Range/Time resolution

Research Directions

Research Motivators

- UWB antennas and impedance matching
- UWB propagation modeling and measurements
- Interference excision over ultra-wide bandwidths
- Handling on-chip interference
- Efficient receiver processing
- Computationally efficient ranging algorithms
- UWB link and network synchronization
- Realistic position location schemes for UWB emitters
- UWB node teaming for long-distance transmission

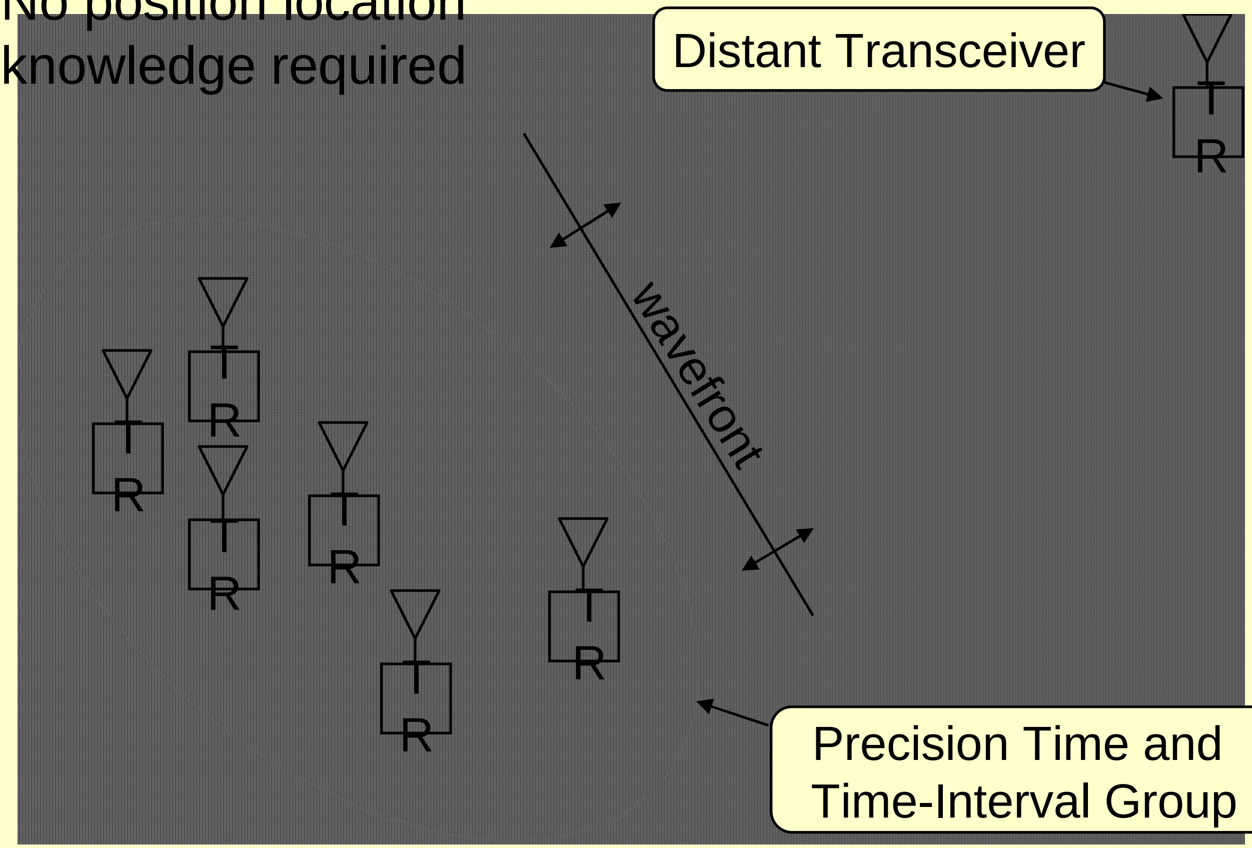
Precision Location



Retrodirective Timing Issues

The UWB Equivalent of Phase Conjugation

No position location knowledge required



Timing Issues

- What is the effect of multipath and blockages on position location and retrodirective array processing using UWB signals?
- What is the effect of multipath and blockages on precision time and time-interval systems?
- What is the effect of UWB time duplexing on PTTI systems?
- How can we characterize the timing noise on voltage-controlled clocks?

Propagation-Related Efforts

- Propagation Data Base on Web - Intel supported
- Polarization measurement efforts
- Upgrading equipment to the 3.1-10.6 GHz band
- Folded dipole antenna study
- Development of response envelope models

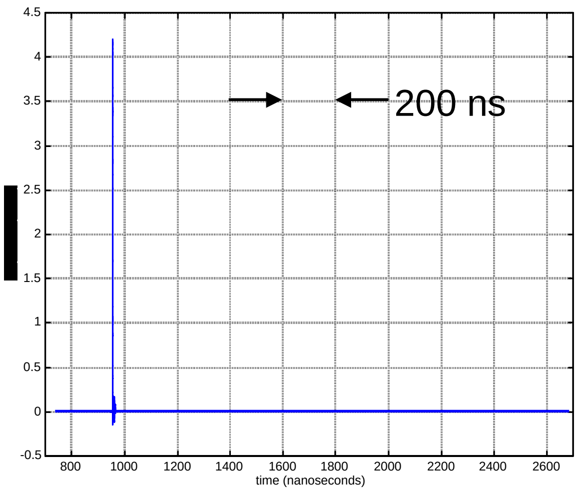
<u>Propagation models needed by</u>

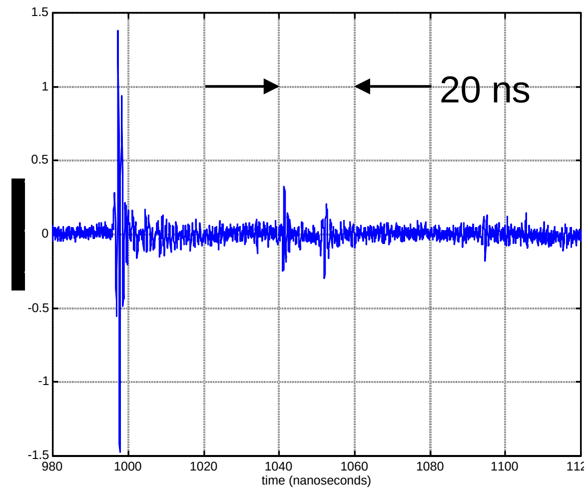
NETEX program

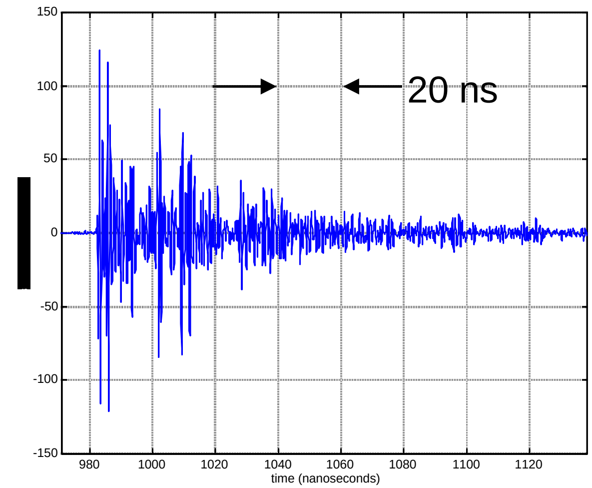
IEEE 802.15 UWB standard effort

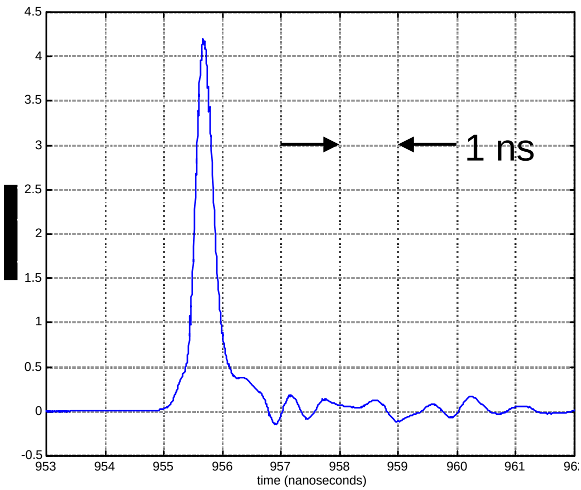
Representative Measurements I

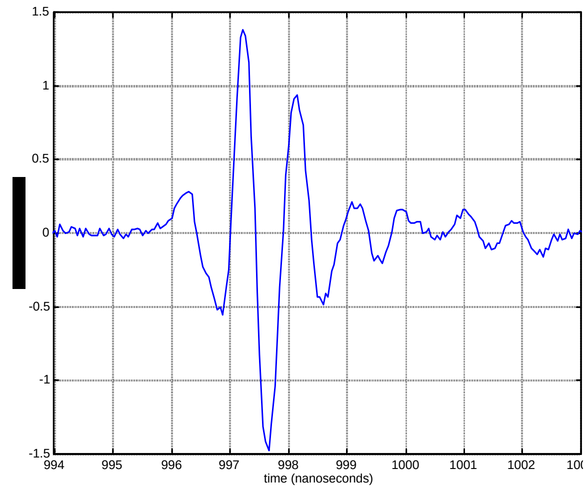
Transmitted Signal	Outdoor Rcvd Clear LoS	Office Rcvd Clear LoS

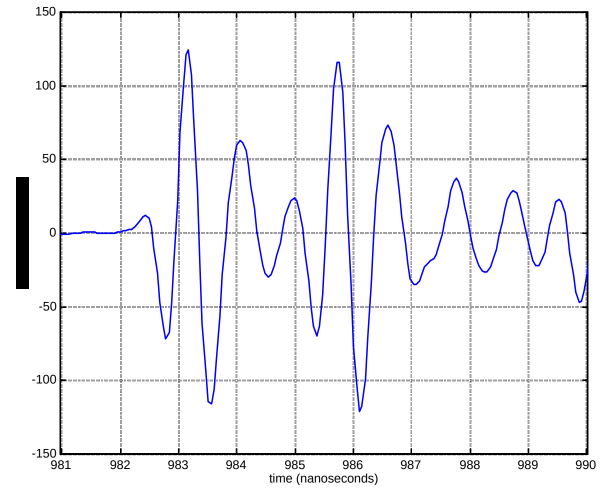






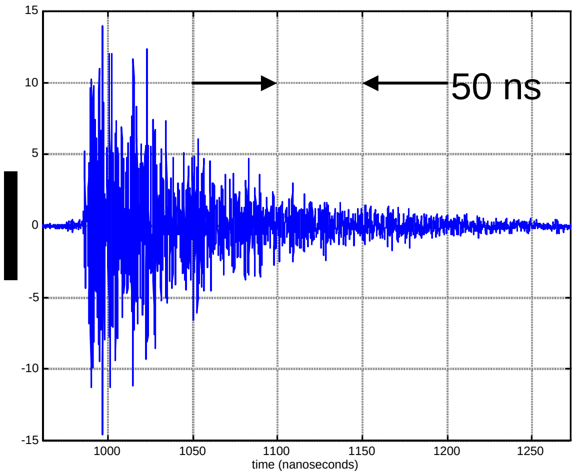


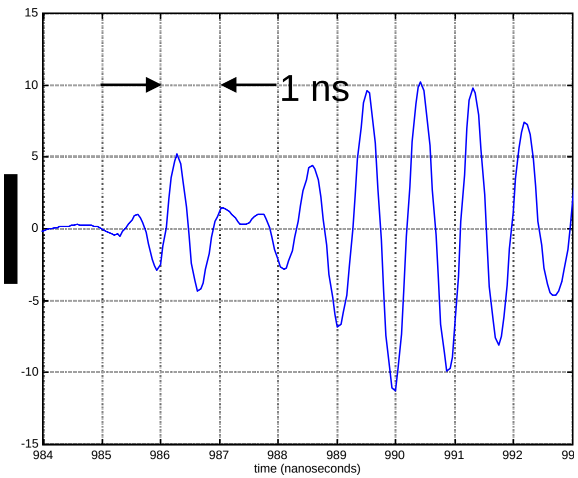




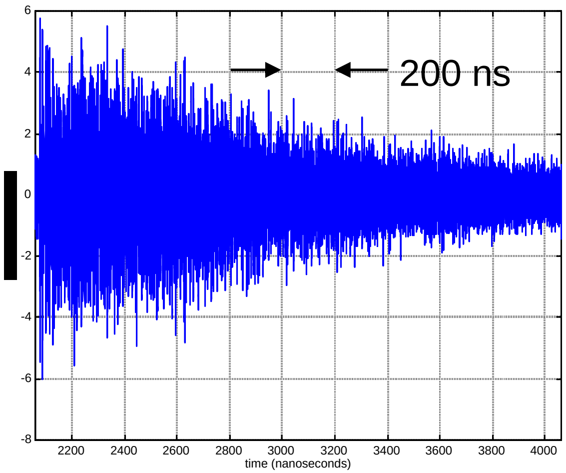
Representative Measurements II

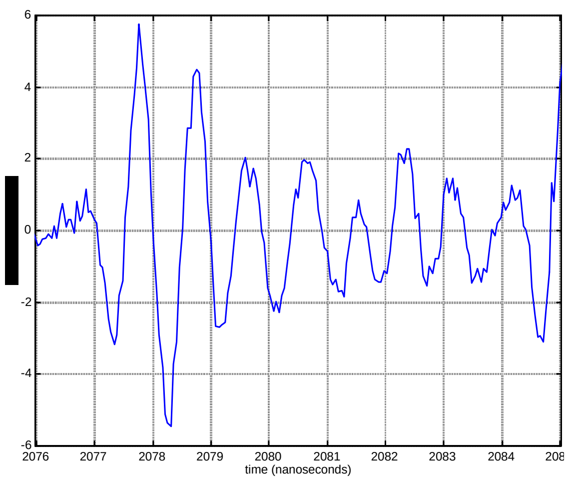
Office Rcvd Blkd LoS



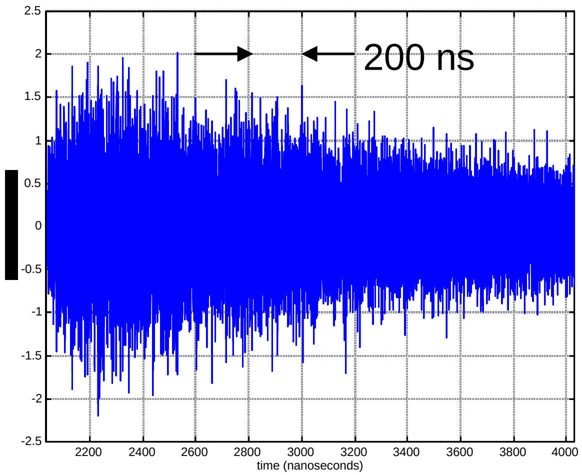


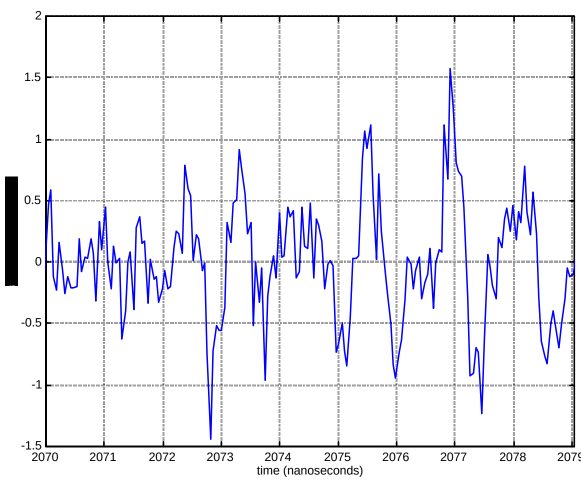
Hold Rcvd Clear LoS



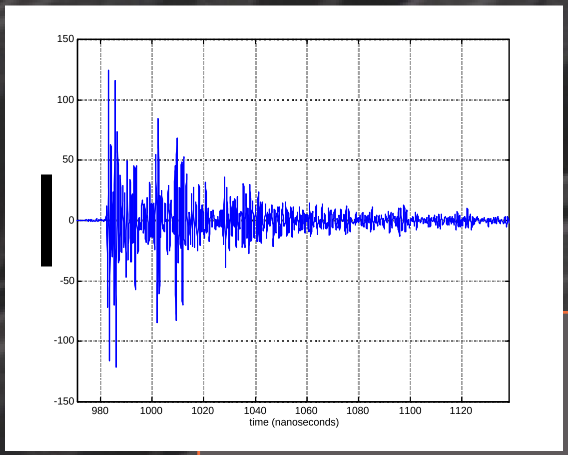


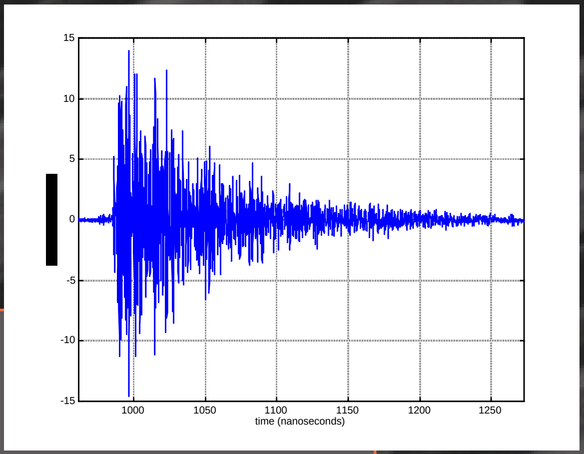
Hold Rcvd Blkd LoS





Energy Response Functions





Source room

Space #1	Space #2
Energy $E_1(t)$	Energy $E_2(t)$

Adjacent room

$$E_1(t+dt)=E_1(t)-a_1E_1(t)dt-x_{10}E_1(t)dt-x_{12}E_1(t)dt+x_{21}E_2(t)dt$$

$$E_2(t+dt)=E_2(t)-a_2E_2(t)dt-x_{20}E_2(t)dt-x_{21}E_2(t)dt+x_{12}E_1(t)dt$$