

**ETHER
WIRE**
& LOCATION, INC.

5950 Lucas Valley Road
Nicasio, CA 94946
Phone: (415) 662-2055
Fax: (415) 662-2056

**BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554**

In the Matter of)
) ET Docket 98-153
Revision of Part 15 of the Commission's Rules)
Regarding Ultra-Wideband Transmission Systems)

***Ex Parte* Notification**

On October 19, 2000, Robert Fleming and Cherie Kushner of Æther Wire & Location, Inc. (we) met with Karen Rackley, John Reed, and Mike Marcus of the Office of Engineering and Technology.

We discussed the major points that were made in our reply comments to the NPRM of the above-referenced proceeding. In particular, we advocated that operation of unlicensed Ultra-Wideband devices be permitted under the general emission limits contained in 47 C.F.R. Section 15.209, with the proviso that UWB devices be included in the exemption for intentional radiators of paragraph (d) of section 15.205.

To illustrate significant points, we used slides prepared for a recent DARPA Principal Investigators meeting. These slides are **included as part of this notice**.

We presented how 3D Relative Position (*i.e.* Localization) and low data rate sensor communication are the most compelling applications for UWB, because they utilize UWB's unique advantage of having gigahertz bandwidth at low frequencies. It is well understood that gigahertz bandwidth gives centimeter range resolution for position location and the ability to discriminate multipath signals. We stressed that operation at low frequencies below 2 GHz gives the ability to penetrate walls, and to use slower, cheaper (*i.e.* CMOS) integrated circuits. These attributes are critical for future applications, including pervasive Internet connectivity, because the cost, size, and power of wireless links must be fractionally proportionate to the items they connect. We reiterated that society will not enjoy the substantial benefits of these devices unless they are permitted to operate below 2GHz.

Other parties have commented that small, portable UWB devices will not need to operate below 2 GHz. We stated that this is a false presumption, which is probably due to the inability of others to radiate low frequency UWB signals from a small antenna, and to control their waveforms to avoid GPS frequencies. We showed time and frequency domain plots and an FDTD simulation of the baseband impulse that is radiated from a 4cm Large Current Radiator when driven by a Gaussian edge. In other words, a physically small antenna can effectively radiate low frequency (~200 MHz) signals.

We also showed time and frequency domain plots of an impulse doublet, which is our chip waveform using CDMA terminology. These plots illustrate how we can place deep 60 dB nulls

at the L1 and L2 GPS frequencies. We pointed out how the separation between impulses contributes to low frequencies in the spectrum of a doublet. Moreover, the separation allows the timing tolerances of the circuits to be relaxed, and thereby greatly reduce the cost of a transceiver.

We pointed out that tests of UWB interference using available laboratory generators will have pulse repetition factors that are much lower than our system and other UWB systems. As such, they may erroneously predict interference due to a PRF within the bandwidth of the victim receiver.

Our slides show how Autonomous Cargo Manifesting of intermodal cargo containers is a “killer” application that uses the accurate position location capability of UWB. The slides also show measurements of the electromagnetic environment within cargo containers, and how UWB is the only suitable RF technology.

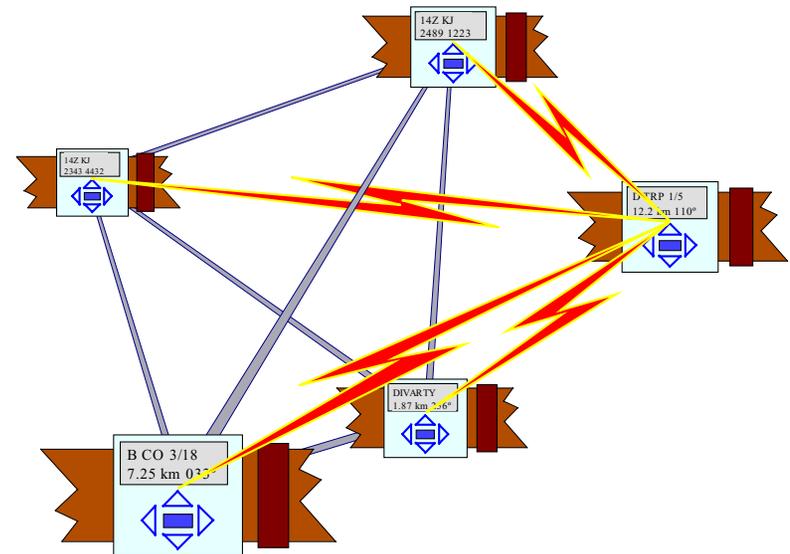
We received clarification from John Reed that the proposed limits on peak level set forth in paragraph 43 of the NPRM only apply for emissions above 1 GHz, and that the use of a CISPR quasi-peak detector is necessary and sufficient for measuring emissions below 1 GHz.

We concluded the meeting with an oral presentation of the history of UWB and the motivations of the various individuals and companies in the field. We also gave a copy of our CDROM “Archive of Ultra-Wideband Technology” to John Reed.



Ultra-Wideband Localizers

Aether Wire & Location, Inc.
Robert Fleming
Cherie Kushner

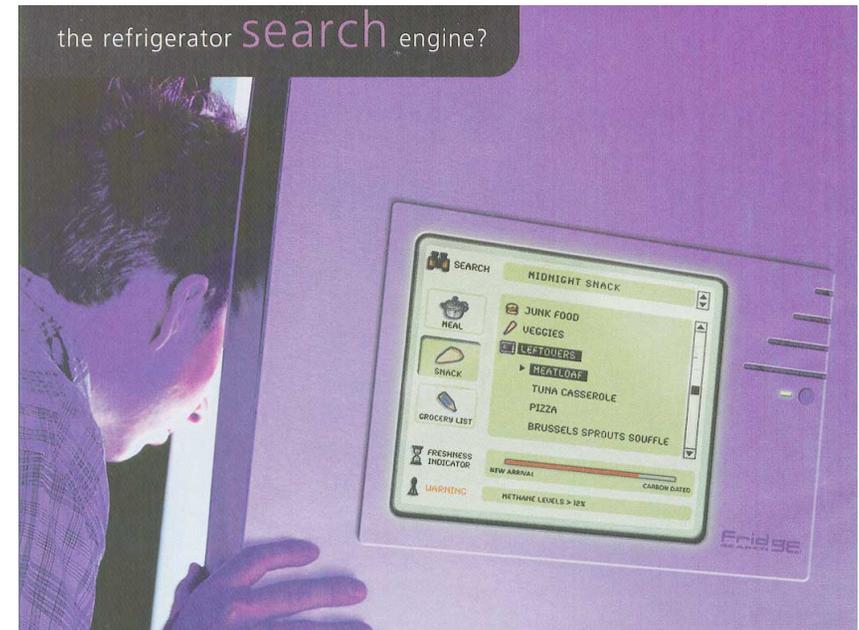




Position Location



- Permits intelligent machines to react to their environment
- Extends human senses beyond the limits of sight and hearing
- Enables automating tasks that now require a human for positioning
- Enables location-based Web services



- Resolution and range proportionate to size and mobility of object
- Most applications want relative location, not latitude and longitude



A Killer Application



- The Problem: Desert Storm
 - » First Major Regional Contingency (MRC) with ISO Containers
 - 40,000 Containers, Opened 25,000
 - Paper Manifests Were Inaccurate and Easily Lost
 - ISO Containers Hid the Stuff
 - Previous MRCs Used Break Bulk
 - Misplaced & Lost Stuff = \$3 Billion
 - GAO Report B-246015, Dec 1991
- Autonomous Manifesting
 - » The “Holy Grail of Logistics”
 - Multipath reverberation $\Rightarrow 1 \mu\text{s}$
 - Internal / stacked container blockage
 - RF leakage thru floor and doors
 - 1-3 inch resolution for inside vs. out





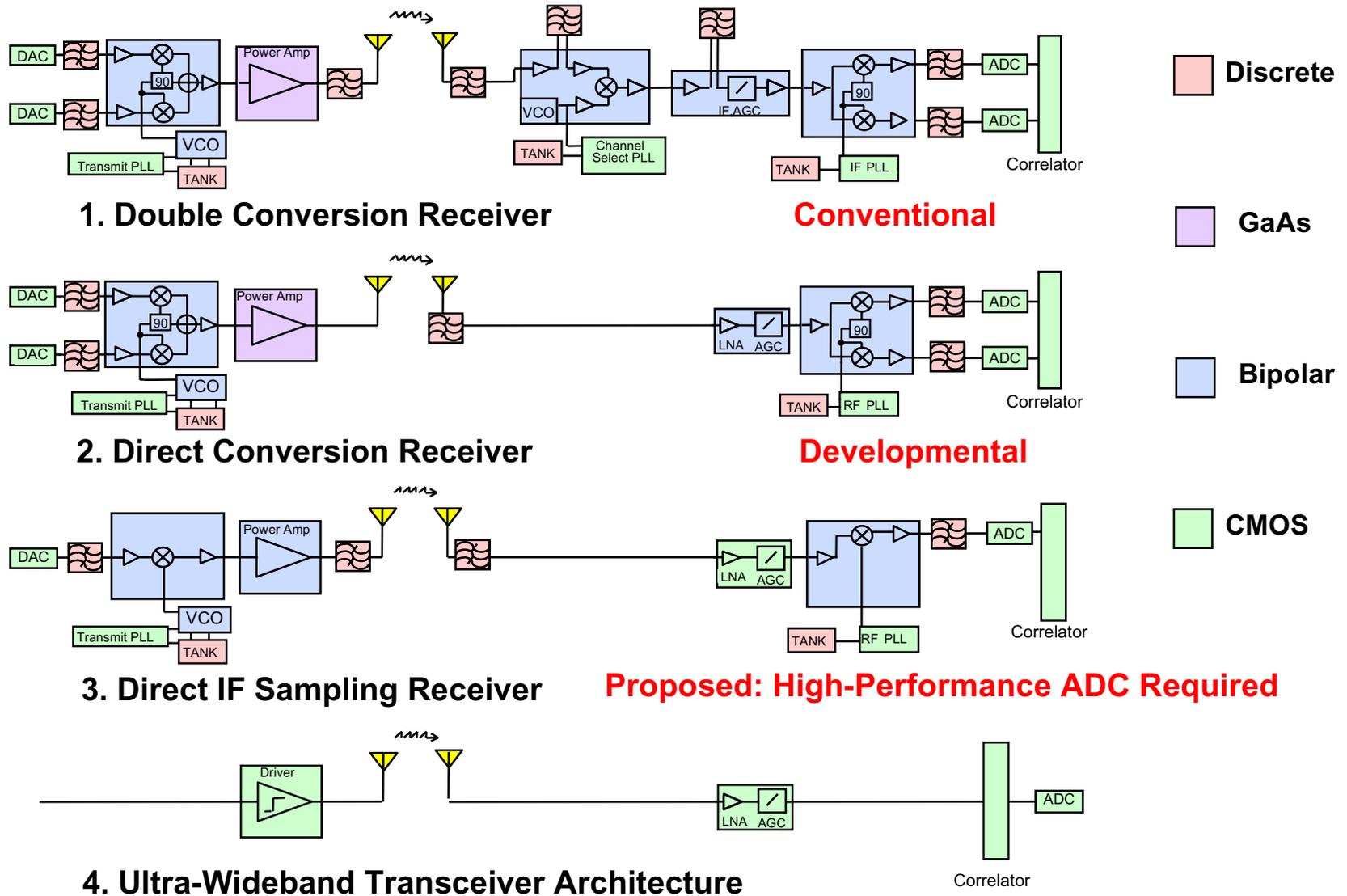
Advantages of Ultra-Wideband



- UWB Localizers are inherently cheaper, smaller, and lower-power
 - » Transceiver can be Integrated in single low-cost CMOS chip
- GHz bandwidth allows position location to Centimeter resolution
- Precise network-wide timing allows very low duty cycle operation
- Antennas are small because they are non-resonant (~ 2 cm)
 - » Current Mode Antenna can be driven directly by CMOS
- Operation within buildings, urban areas, forests, etc.
 - » Bandwidth at Baseband gives penetrating ability
 - » No deep fading nulls – reduces path loss from $1/r^4 \Rightarrow 1/r^2$
- Multipath signals can be time-resolved
 - » Direct sequence coding, short chip time, and accurate timing
- Ultra-Wideband maximizes Spectrum Reuse
 - » Non-interfering – energy is spread over GHz bandwidth
 - » Unlicensed spread spectrum bands are filling up



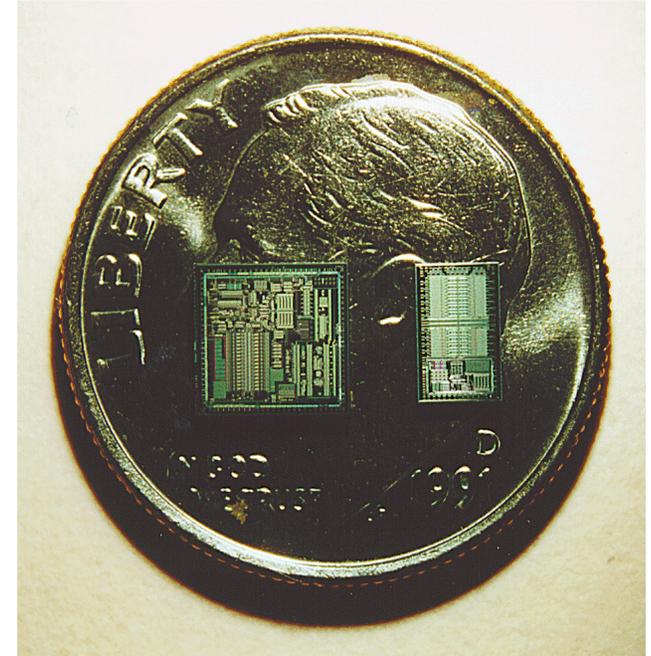
UWB versus Narrowband





Advantages of CMOS

- Small size & weight
 - » Estimated single chip transceiver die size using 0.18μ process is **8 mm^2**
 - Includes processor (1 mm^2), 512KB RAM (3 mm^2), and 128KB ROM (1 mm^2)
- Low cost
 - » Current estimated die cost is **50 cents**
- Low power – stand-alone battery use
 - » Extremely low static power
 - » No off-chip high current filters or SAWs
 - » Estimated networked idling power is **$30\ \mu\text{w}$**
- Rides the digital CMOS cost curve (Moore's law: $\frac{1}{2}$ every $1\frac{1}{2}$ yrs)
 - » Large complexity from high levels of integration
 - » "Software radio" – high functionality from processor/software control

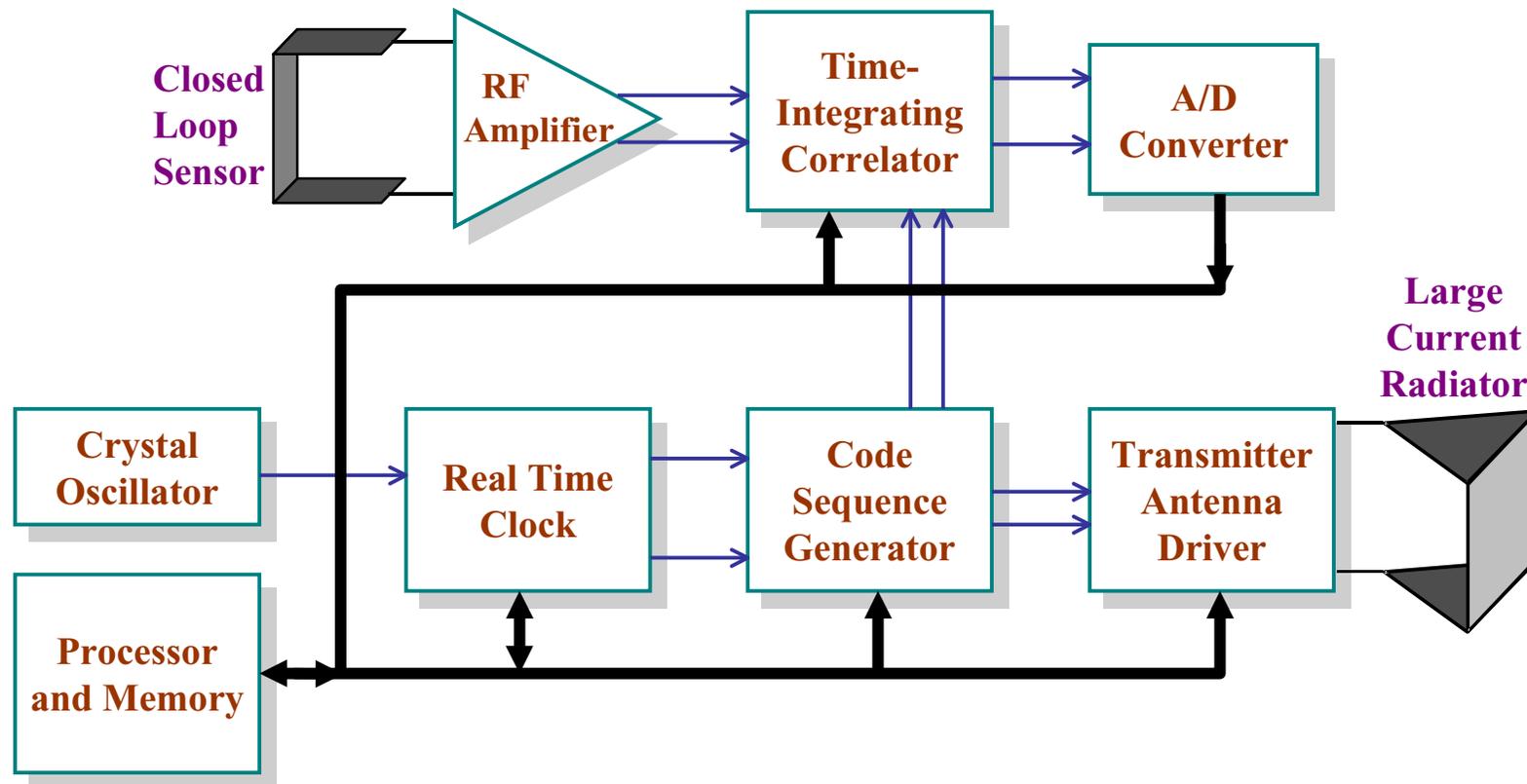




Localizer Block Diagram



- 3D Positions calculated from pair-wise Ranges with information distributed to all nodes within network of Localizers

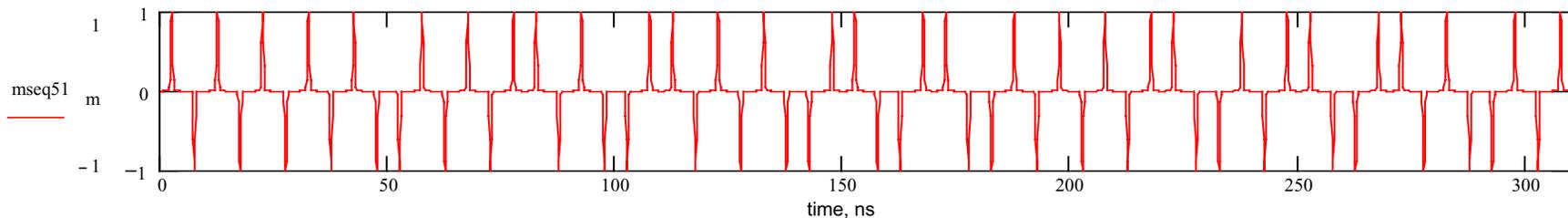




Transmission



- Episodic transmission of coded sequences of Impulse Doublets
 - » Impulse is launched when current is turn On or Off
 - » Bipolar signal (chip) allows use of CDMA PN code families which have both low autocorrelation sidelobes and low cross-correlation
 - Maximal sequences have ideal auto-correlation, but small families
 - Small & Large Kasami and Kasami-like codes have useful families
 - » Typical 1023-chip sequence of 10 ns chips lasts 10 μ s



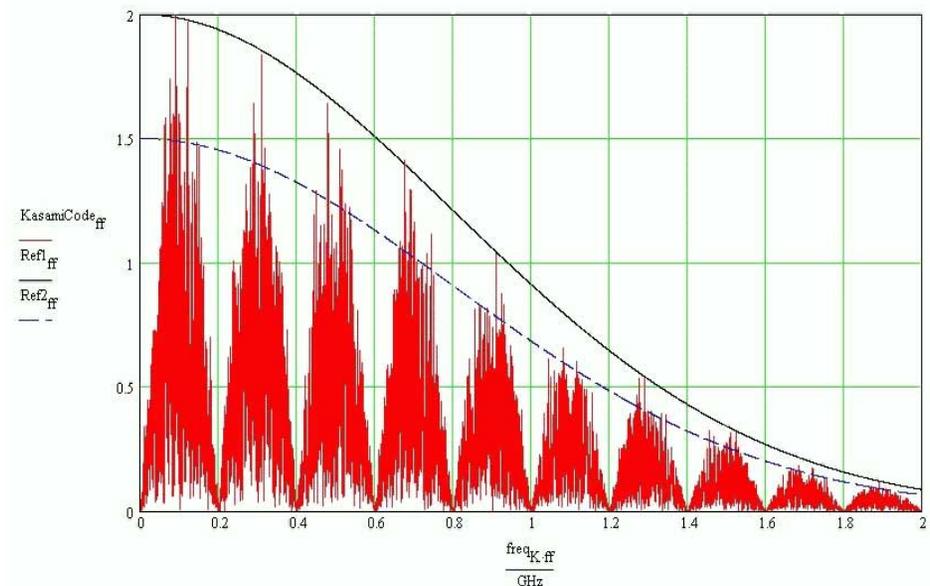
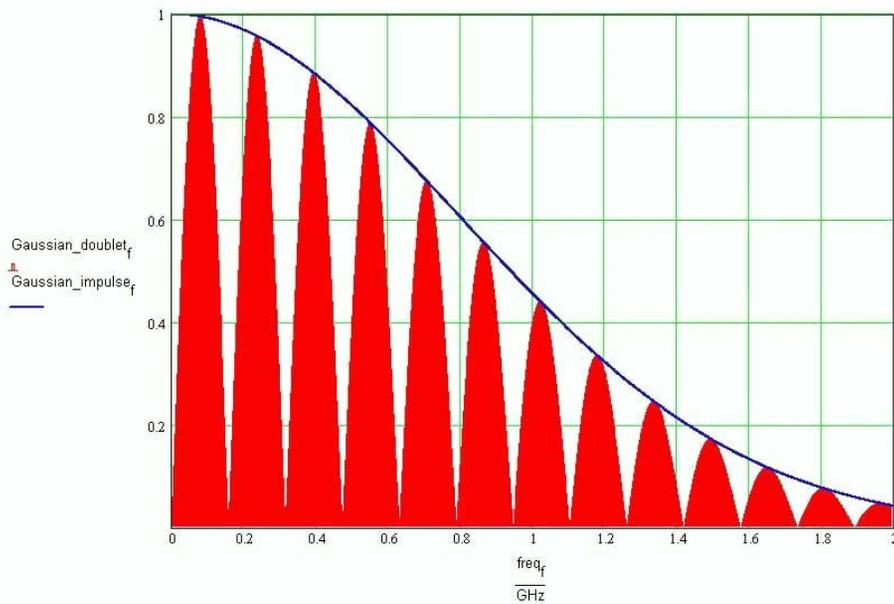
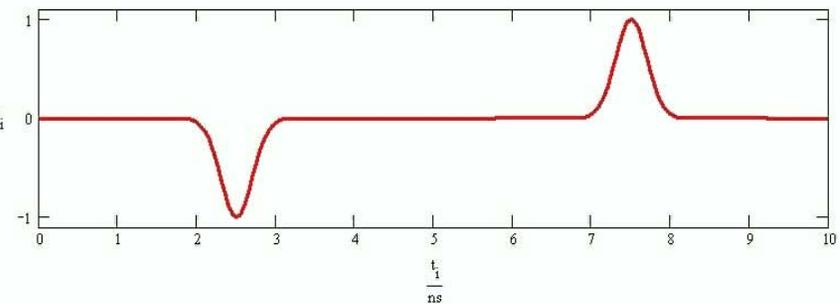
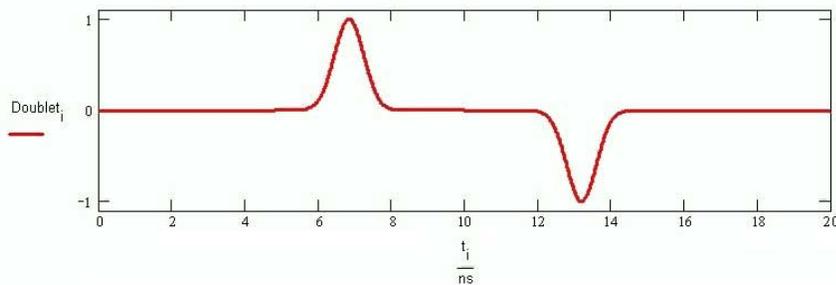
- » Very low power operation achievable with low duty-cycle
 - Typical 1% duty cycle with 1 ms cycle time
 - Network precise timing (~ 1 ppb) allows extended sleep mode (~ 40 s)



Signal Spectrum



- Spectral Nulls chosen by Impulse Separation to notch out selected frequency bands for transmission & reception (*i.e.* GPS)



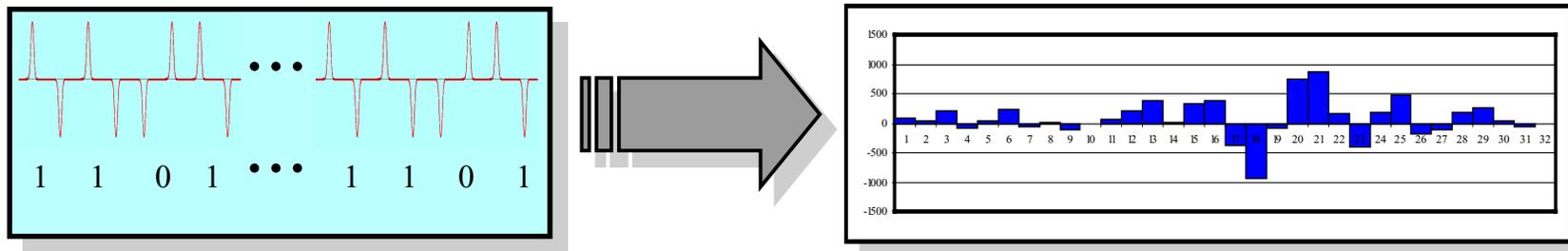


Reception



- Coherent Reception via Correlation

- » Time Integrating Correlator is a Matched Filter
 - Analog input signal is multiplied by Reference code & integrated
 - Each of 32 correlator phases represents a different time alignment of input signal & reference code
- » Typical 30 dB Process Gain with 1023-chip sequence



- Coherence maintained over typical $10\ \mu\text{s}$ reception window

- » Time compression spread $< 10\ \text{ps}$ with 1ppm timebase
- » Doppler shift insignificant for less than orbital velocity
- » Each reception starts with zero integrated noise



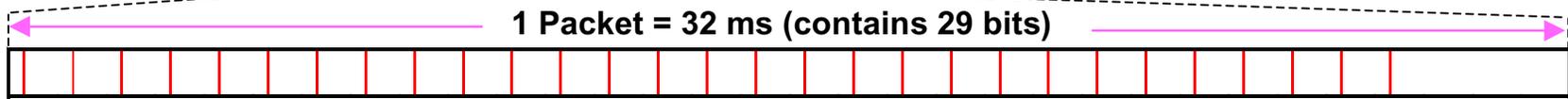
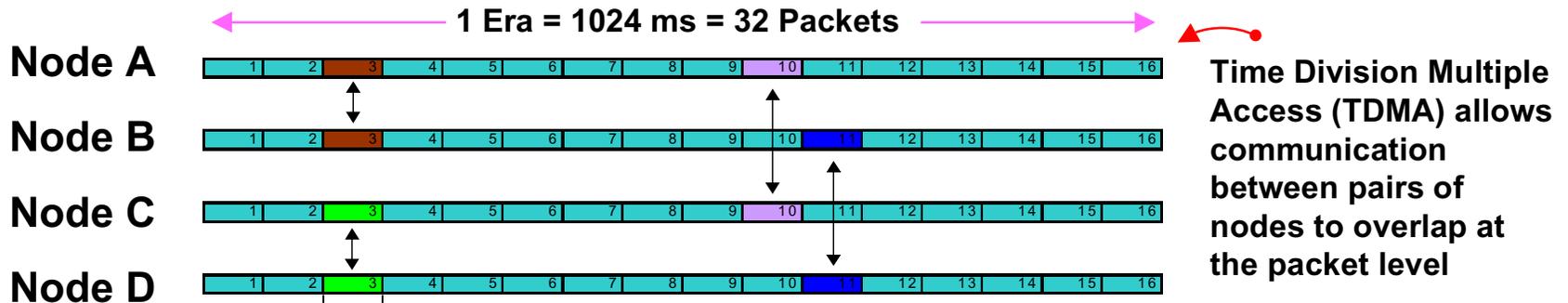
OSI Model - Data Link Layer



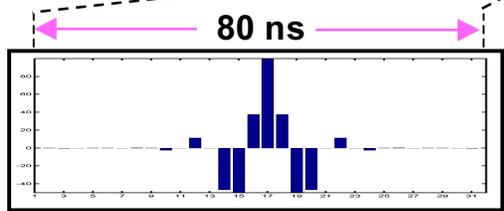
- Media Access Control
 - » Code-Division Multiple Access (CDMA) minimizes collisions between non-communicating units and between non- or weakly-linked clusters
 - 32 Small Kasami codes (or 32,800 Large Kasami codes)
 - » Time-Division Multiple Access (TDMA) within local cluster
 - 32 slots per Epoch, each 31.25 μ s long
 - » Duplex exchange of 1 Burst (1 or more bits) within 31 μ s slot
 - Allows short “moment arm” for round-trip ranging exchanges
- Logical Link Control
 - » 29-Bit Packet: preamble(1), header(5), payload(16), ECC(6), ranging(1)
 - Scheduled modulo reservation look-ahead cycle time (~32 packets)
 - Packet boundaries are negotiated between pairs of Localizers
 - TDMA allows packet exchanges between pairs of Localizers to overlap
 - Time-stamping for aging location fixes and tracking movement



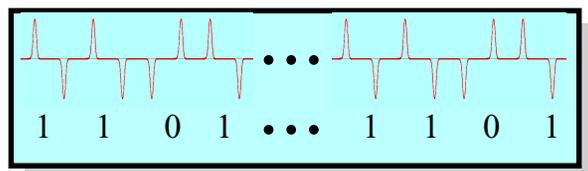
TDMA



Packets have 32 timeslots. Within a cluster, each timeslot is occupied by only one duplex exchange.



Correlator Reception Window

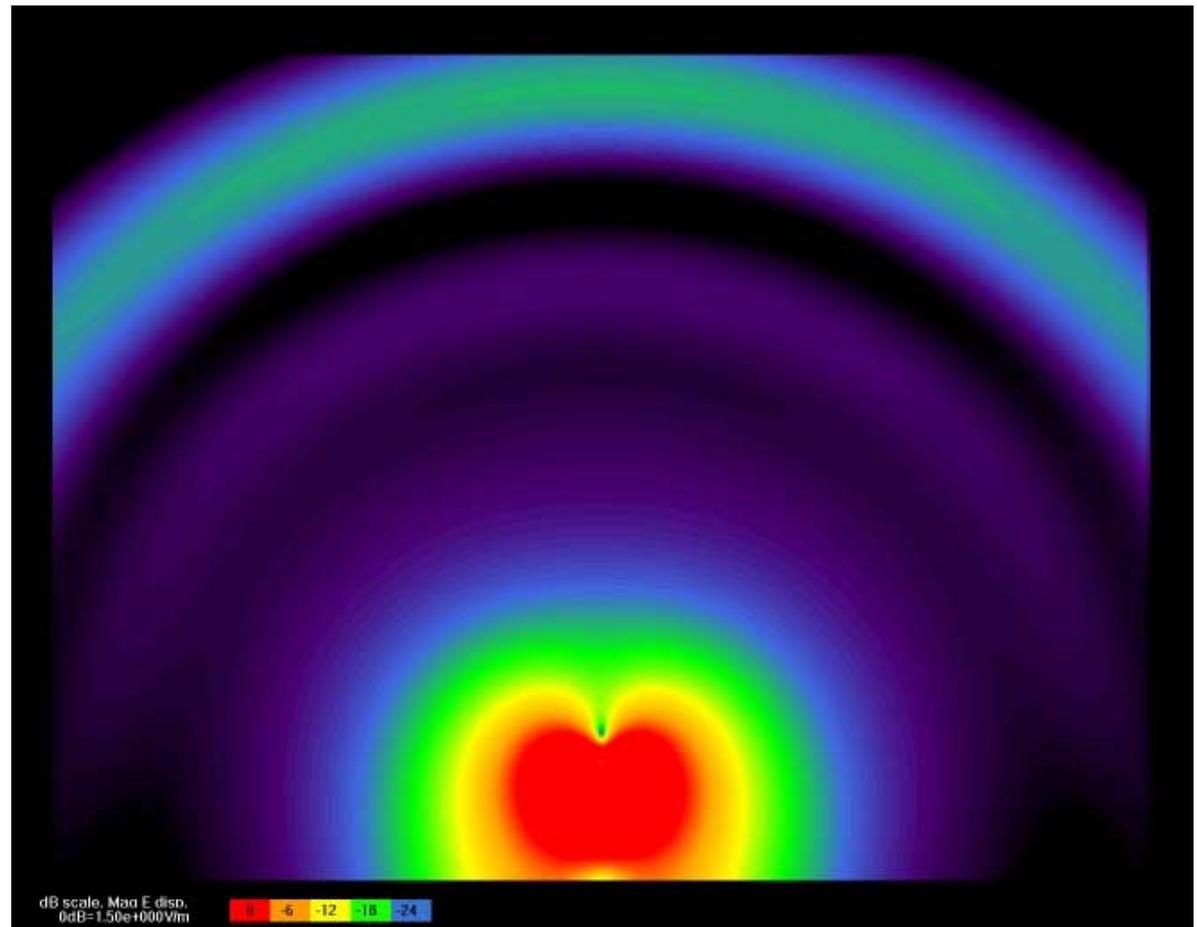
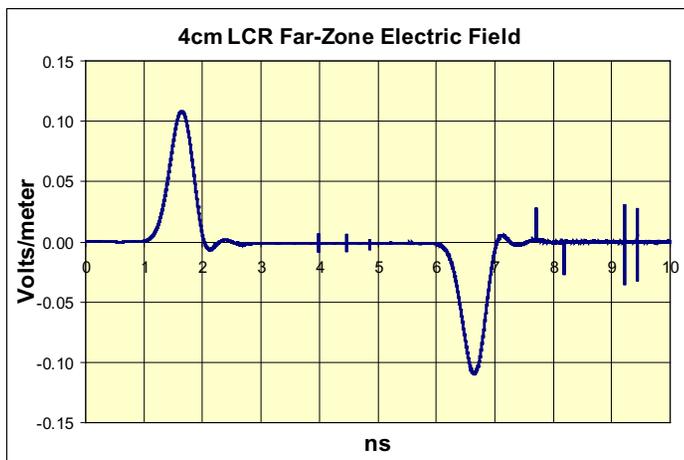
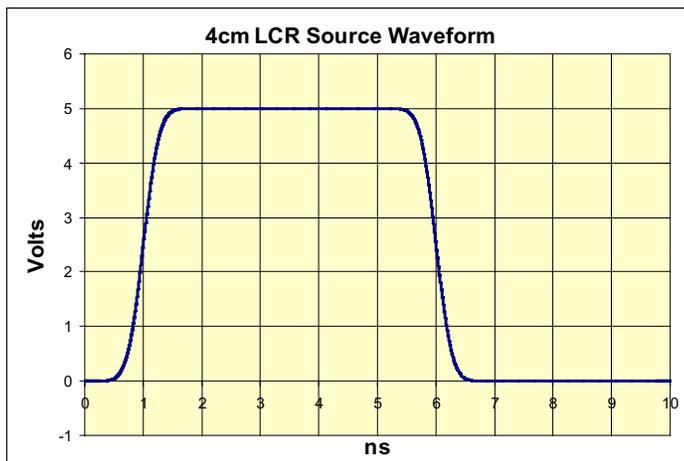




Large Current Radiator



Baseband impulses (<1GHz) can be effectively radiated from small (<4cm) Large Current Radiator (LCR) antenna (FDTD simulation)

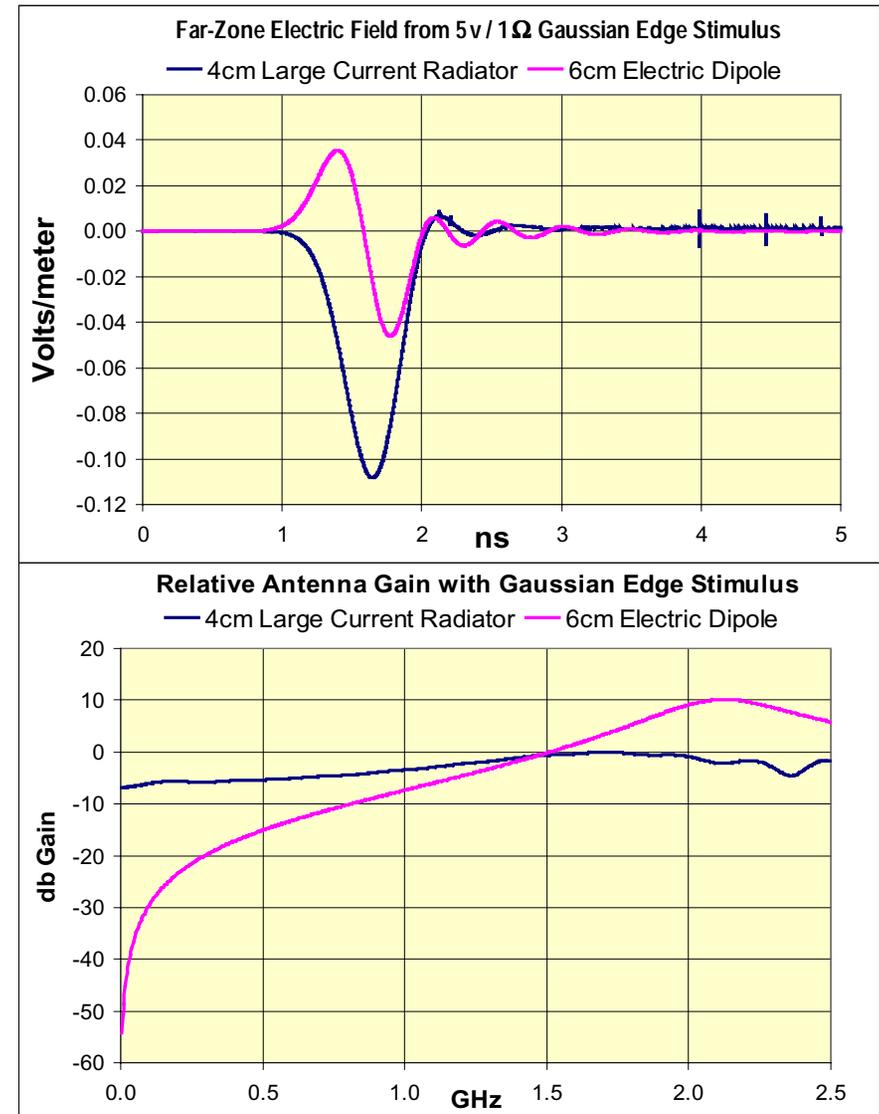




Antennas



- Large Current Radiator
 - » Preserves impulse shape
 - » Frequency response varies <6db from <100 MHz to >2.5 GHz
 - » Requires low (1Ω) source impedance
 - Direct drive from chip
 - No transmission line
 - » Requires balanced drive
 - Unbalanced drive causes oscillations
 - » New dual monopole configuration allows for unbalanced drive
- 6cm Electric Dipole (for comparison, 4cm LCR fits within 6cm sphere)
 - » Differentiates impulse shape
 - » Gain varies 40db from 100 MHz to 2.2 GHz





Rapid Acquisition



- Typical Time scales
 - » $t_w = 80 \text{ ns}$ – Correlator reception Window
 - » $t_p = 10 \mu\text{s}$ – Beacon transmission Period = Listener reception Period
 - » $t_c = 1 \text{ ms}$ – Beacon signal Cycle time
- **Exhaustive Search:** Listener steps its reception window in increments of $t_c + (\alpha \cdot t_w)$; $\alpha < 1$ for overlap $t_c / (\alpha \cdot t_w)$ receptions
 - » Beacon detected when correlation peak is within reception window
- **Rapid Acquisition:** Listener steps its reception window in increments of $t_c + (\beta \cdot t_p)$; $\beta < 2$ $(t_c / (\beta \cdot t_p)) \cdot (t_m / (\alpha \cdot t_w))$ receptions
 - » Beacon detected when Beacon Tx and Listener Rx periods overlap
 - » Beacon Code autocorrelation pattern has pyramidal shape
- **Speedup Factor**
 - » Exhaustive / Rapid = $(\beta \cdot t_p) / t_m = \beta \cdot (2^n - 1) / (2^{n/2} - 1) = \beta \cdot (2^{n/2} + 1)$
 - For 1023-chip codes, $n = 10$, and $\beta = 1$, speedup factor is **33**



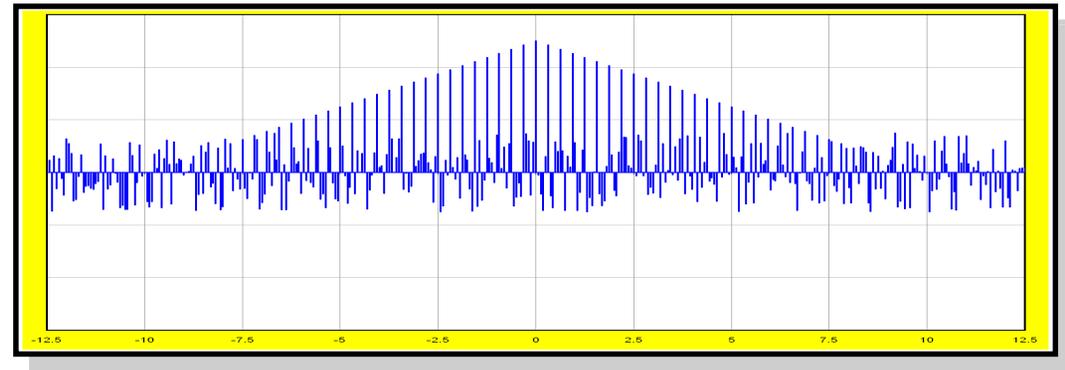
Rapid Acquisition



Received correlator output of **Beacon** signal plus noise.

Peaks exist every $t_m = 310$ nanoseconds.

Receptions are spaced $t_c = 1.024$ ms plus offset shown on Timeline.



20 μ s



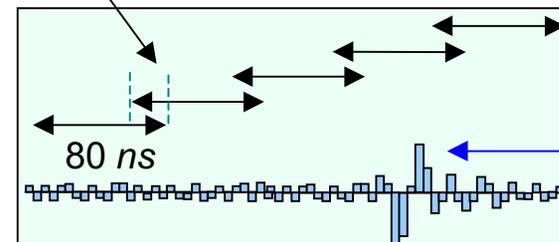
Scan Window

(Scan 320 ns, then jump 10 μ s)

First Detection Window

20 ns overlap

Correlator window
Size $t_w = 80$ ns



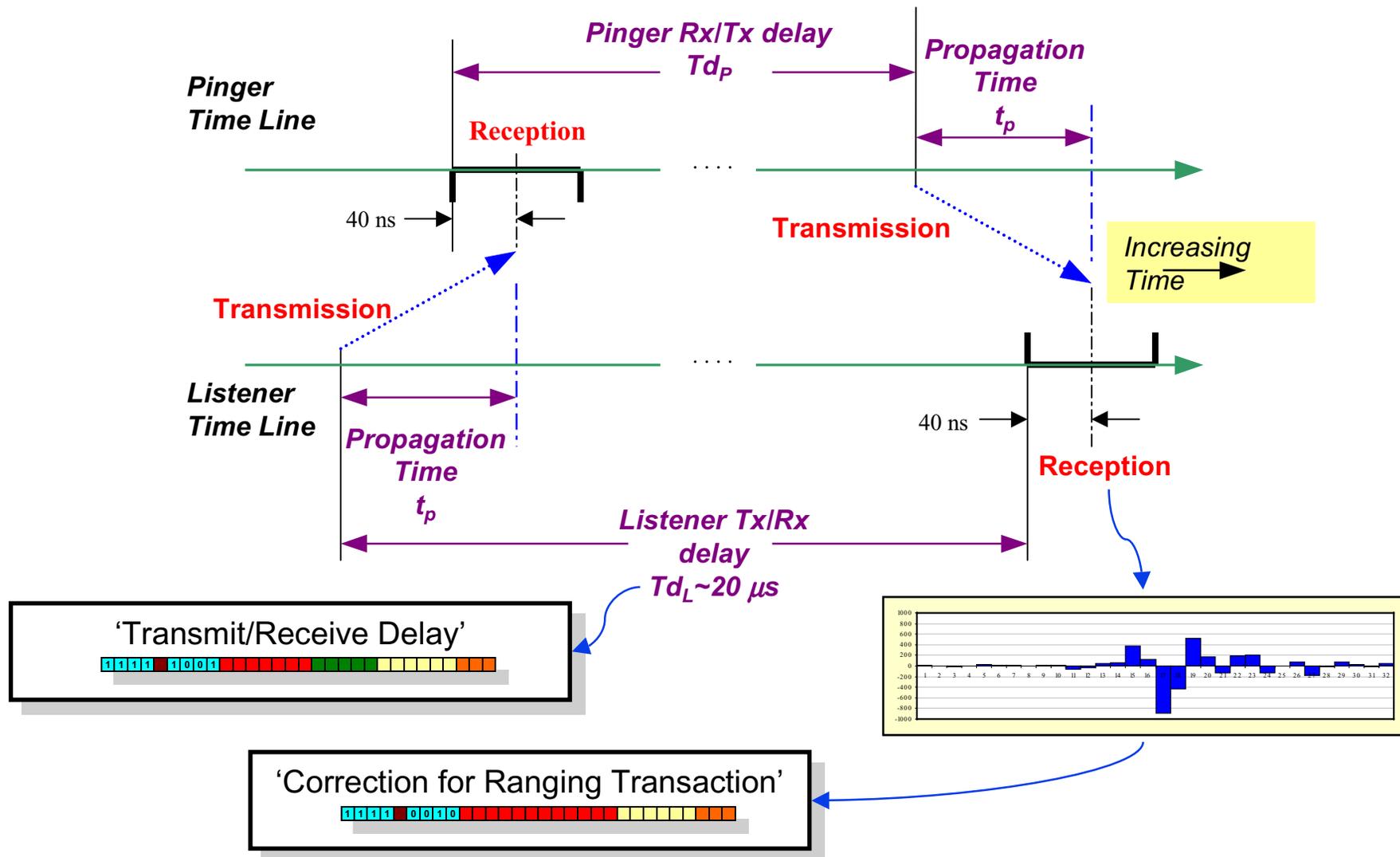
Five Receptions
Per Scan

First Detection

320 ns Scan Window



Ranging Transaction





Cooperative Networking



- Position location using inexpensive timebases
 - » Quartz crystal or MEMS oscillator
 - 1 ppm (10^{-6}) with on-chip software-mediated temperature compensation
 - Localizers track each other's clock frequencies for ppb (10^{-9}) matching
 - » Absolute position accuracy of entire network is raised to the absolute accuracy of the best oscillator or known distance
- Code & Time Division channelization for a million Localizers per km^2
- Peer-to-peer multi-hop Networking
 - » Defeats $1/r^n$ received power reduction ($n \geq 3$)
 - » Reduces probability of intercept
- Selective sharing of data over network
- Capable of hiding ranging information (for Security)
 - » Synchronization without giving range
 - » Spoofing for privacy



Autonomous Cargo Manifesting



Antennas: Farr Research TEM horns

Transmitter: Picosecond Pulse Labs model 2600 pulse generator

Receiver: Tektronix TDS694C 10 GS/s, 3 GHz digital storage oscilloscope



- Autonomous Manifesting of ISO Cargo Containers using Localizers
 - » DARPA-sponsored research applied to Navy problem
 - » Testing supported by ONR (Steve Gunderson, steve@nfesc.navy.mil)

– Initial Tests

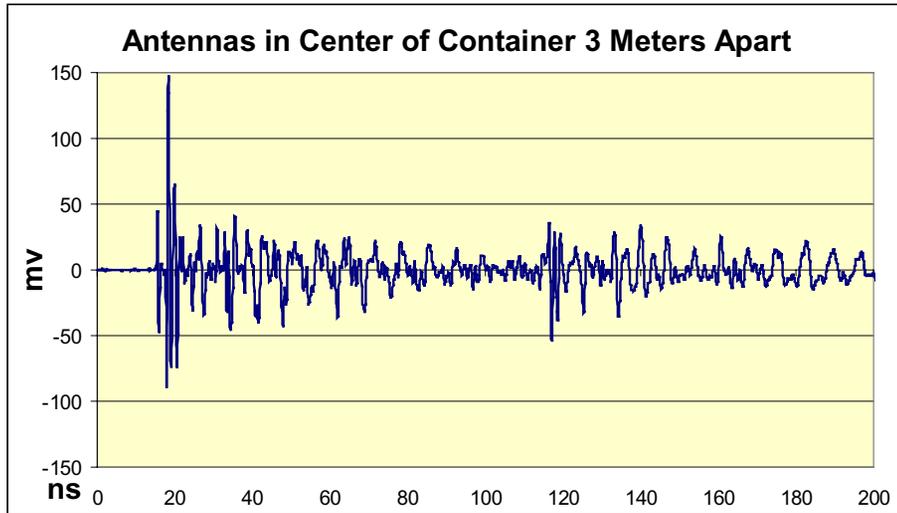
- Port of Oakland, 25 May 2000
- Characterize the RF environment
- Measure multipath delay spread
- Measure leakage and noise

– Demonstration

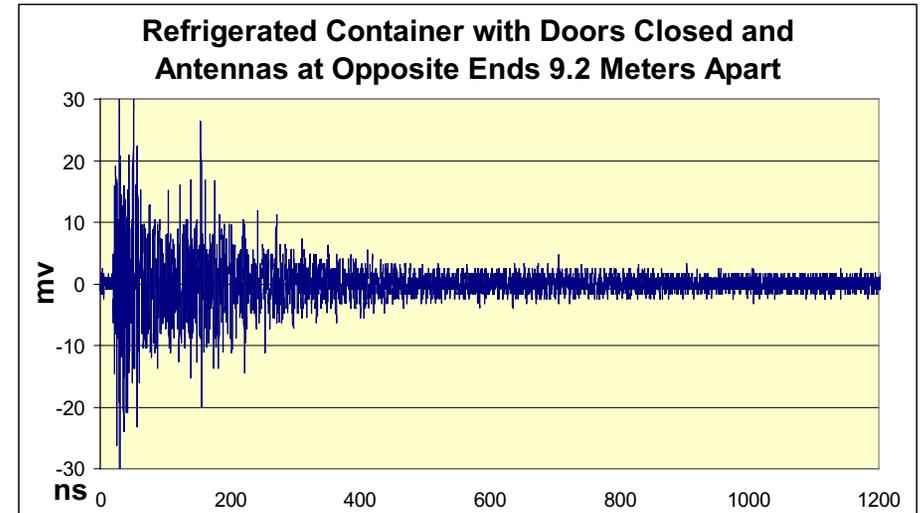
- Port of Oakland, Spring 2001
- Hide & Seek Localization Tests: which container has the asset
- Measure Localization accuracy



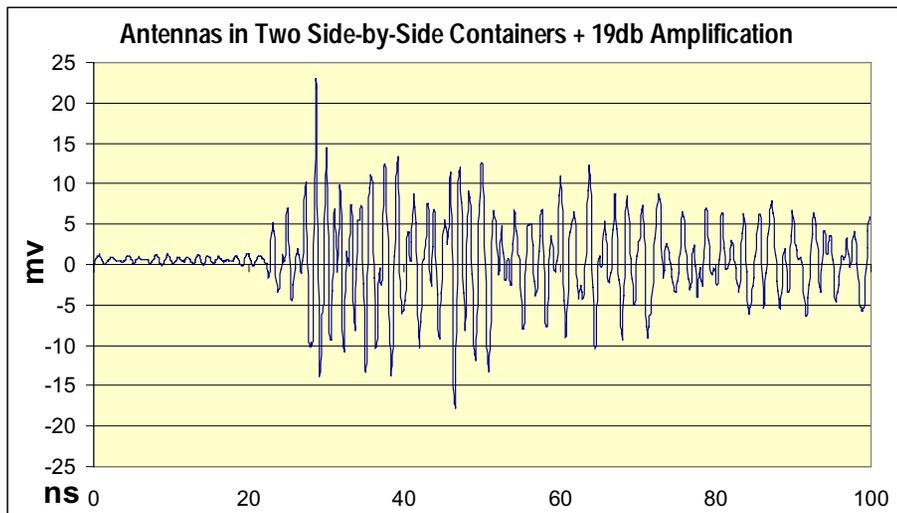
RF in ISO Containers



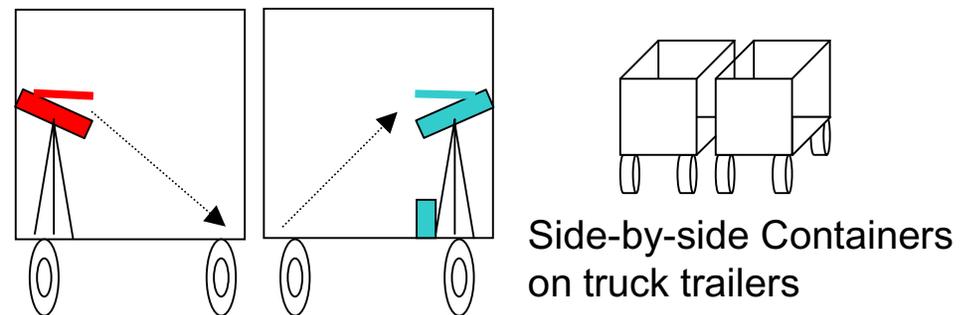
Direct path signal dominates multipath at 3 meters



Worst case delay spread $1 \mu\text{s}$ in Refrigerated Container with metal walls on all six sides



Warfighter Visualization PI Meeting



The leakage between containers thru the wooden floor is significant when they are not on the ground



Autonomous Cargo Manifesting



- The Challenge: ISO Containers
 - » Multipath delay spread $\Rightarrow 1 \mu\text{s}$
 - Direct path dominates multipath at short range (~ 3 meters)
 - More correlators / smaller windows
 - RAKE signal processing of multipath
 - » Absorption and blockage
 - Nearest neighbor communication
 - Projection of position determination using network linkages (*i.e.* a truss)
- ACM System Development
 - » System-on-chip to minimize cost
 - » Polarization diversity for orientation
 - » Battery life \Rightarrow months
 - Extremely low duty-cycle
 - Alternative wake-up modality



Measuring leakage thru wooden bottom and out between stacked containers



Hardware Prototype



- Pager-sized 4th Generation Prototype
 - » Transmit/Receive
 - Rx/Controller chip (Aether5)
 - Closed loop sensor
 - Low-noise TCXO
 - Tx Antenna Driver chip (Driver2)
 - Large Current Radiator
 - External RF amplifier & DAC
 - A-to-D converter
 - » Processor
 - Motorola ColdFire 5204
 - 1MB Static RAM
 - 512KB Flash RAM
 - » Power regulation





Hardware Prototype



- Low-Noise Logic family (to minimize Reception noise floor on-chip)
 - » $< 1 \mu\text{A}$ switching noise per gate on power supply
- Receiver/Controller chip (Aether5)
 - » 32-phase Time Integrating Correlator
 - » 60 dB variable gain RF amplifier (to adapt to large range of input signals)
 - » Real Time Clock (Tx/Rx event register & comparators)
 - 200 MHz low-jitter Phase-Locked Loop
 - » Tx/Rx code sequence generator (25-stage LFSR)
 - 1023 length Large Kasami codes (32,800-member families)
 - » 26 Independent Power Controls (for very low power operation)
- Transmit antenna driver chip (Driver2)
 - » H-bridge for producing Bipolar radiated impulses (+ or -)
 - Can Drive 8 amps with 450 ps edges (0.2Ω output impedance)
 - » Eight independent edge-delay controls



Key Resources



- Contract Title: Integrated, Low-Power, Ultra-Wideband Transceivers for Distributed Position Location and Communication
- Organization: Aether Wire & Location, Inc.
5950 Lucas Valley Road
Nicasio, CA 94946
tel: 415.662-2055 fax: 415.662-2056
- Principal Investigators: Robert Fleming - bob@aetherwire.com
Cherie Kushner - cherie@aetherwire.com
- Agent/Contracts: Richard Butler, AFRL/IFGA
315.330-1888
- Website: <http://www.aetherwire.com/>
- Archive of Ultra-Wideband Technology: <http://www.aetherwire.com/CDROM/Welcome.html>