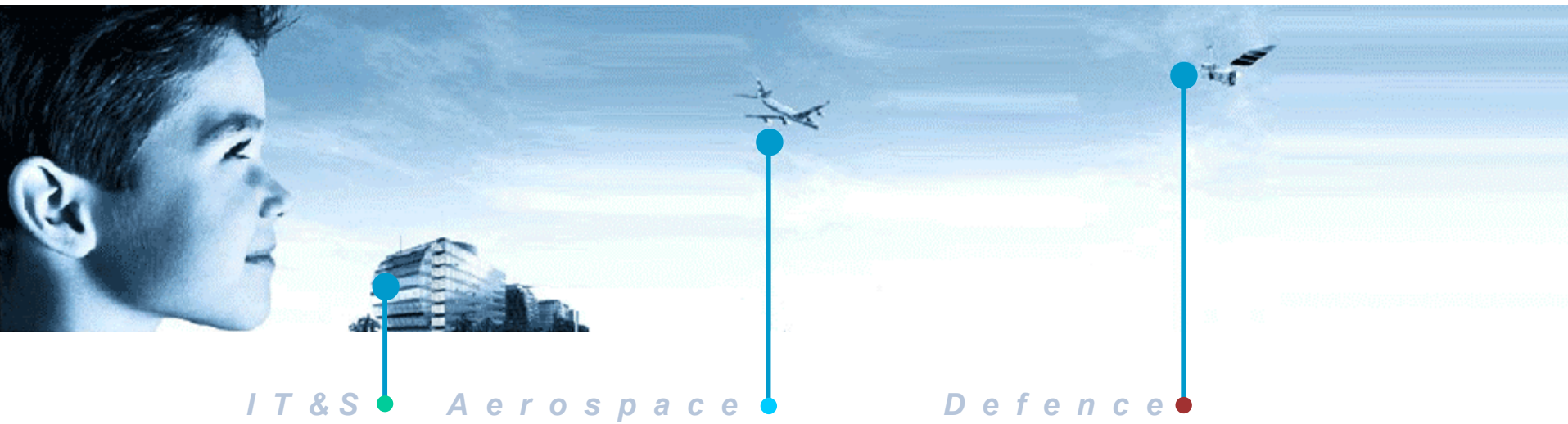
Ultra Wide-Band (UWB) Indoor Positioning



Dave Harmer
Thales Research and Technology UK Ltd

- ARTES 4 Project
- ESTEC December 2004

THALES

Presentation Overview

- Brief Overview of TRT
- What is UltraWideBand (UWB)?
- UWB applications - Why Use UWB?
- Summary of ARTES 4 Indoor Positioning Project
  - Project Overview
  - System Overview
  - Summary of Performance Results
  - Recorded Demonstration
  - Regulatory & Standards Issues
- Brief Summary of FH-UWB Indoor Positioning Project
- TRT UWB Antenna - Brief Overview

Thales Research & Technology - Overview

- Corporate Research Laboratory for the Thales Group
  - Based in France, UK, Netherlands
  - Serves all parts of the Group
- TRT (UK) Ltd - 3 Main groups
  - Navigation
  - Sensors & Signal Processing
  - Networking

Thales Research & Technology - Key applications

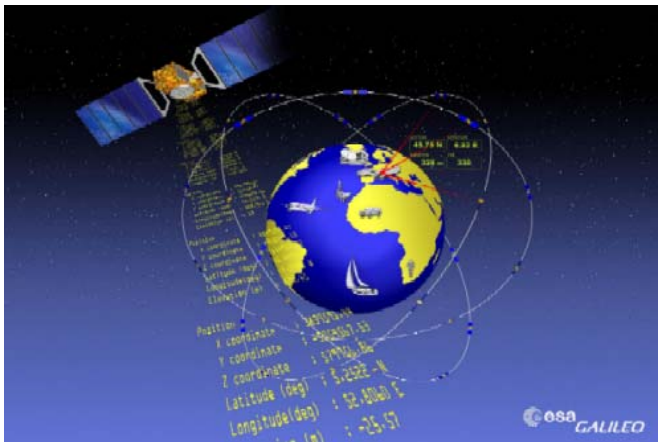
- Homeland security

- Multi-national coalition operations in the littoral (military and peacekeeping)

THALES

Thales Research & Technology - Key applications

- GALILEO exploitation and location based services



- Virtual Collaboration

THALES

Definition: Any radio signal with a fractional bandwidth >20% or an absolute bandwidth > 500MHz

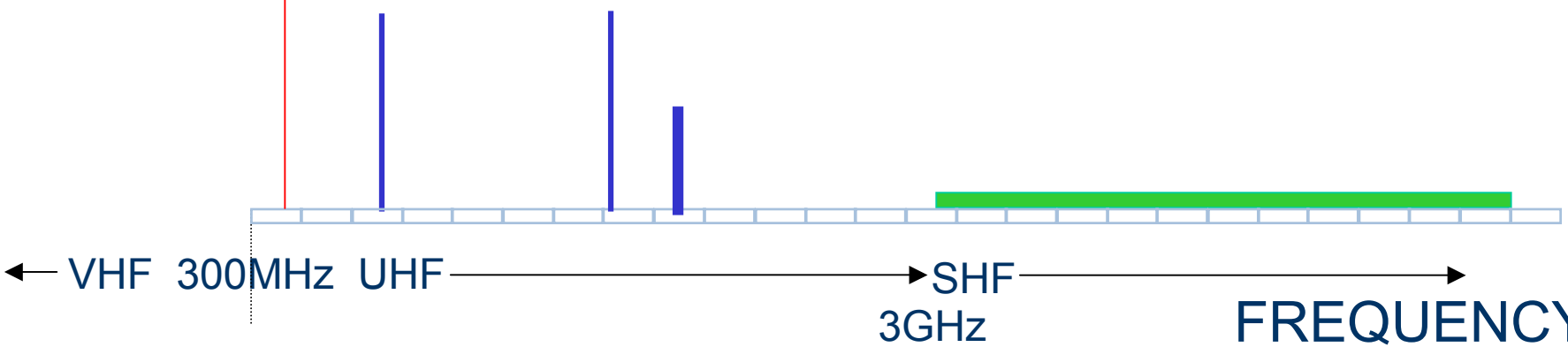
RADIO SPECTRUM

NOT TO SCALE

TYPICAL EMERGENCY SERVICES COMMUNICATIONS SIGNAL (TETRA 25 kHz BANDWIDTH)

TYPICAL MOBILE PHONE (GSM/PCN/3G) SIGNALS

TYPICAL UWB SIGNAL

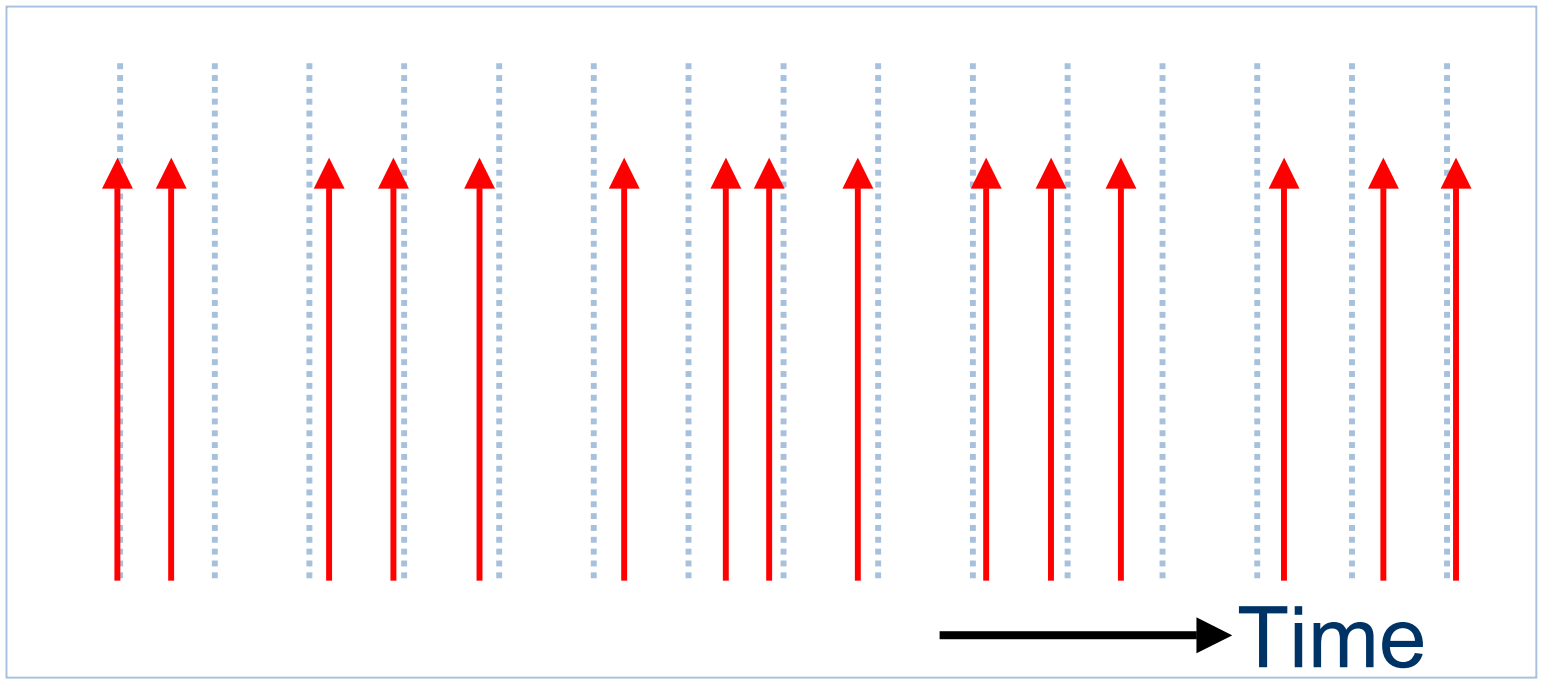


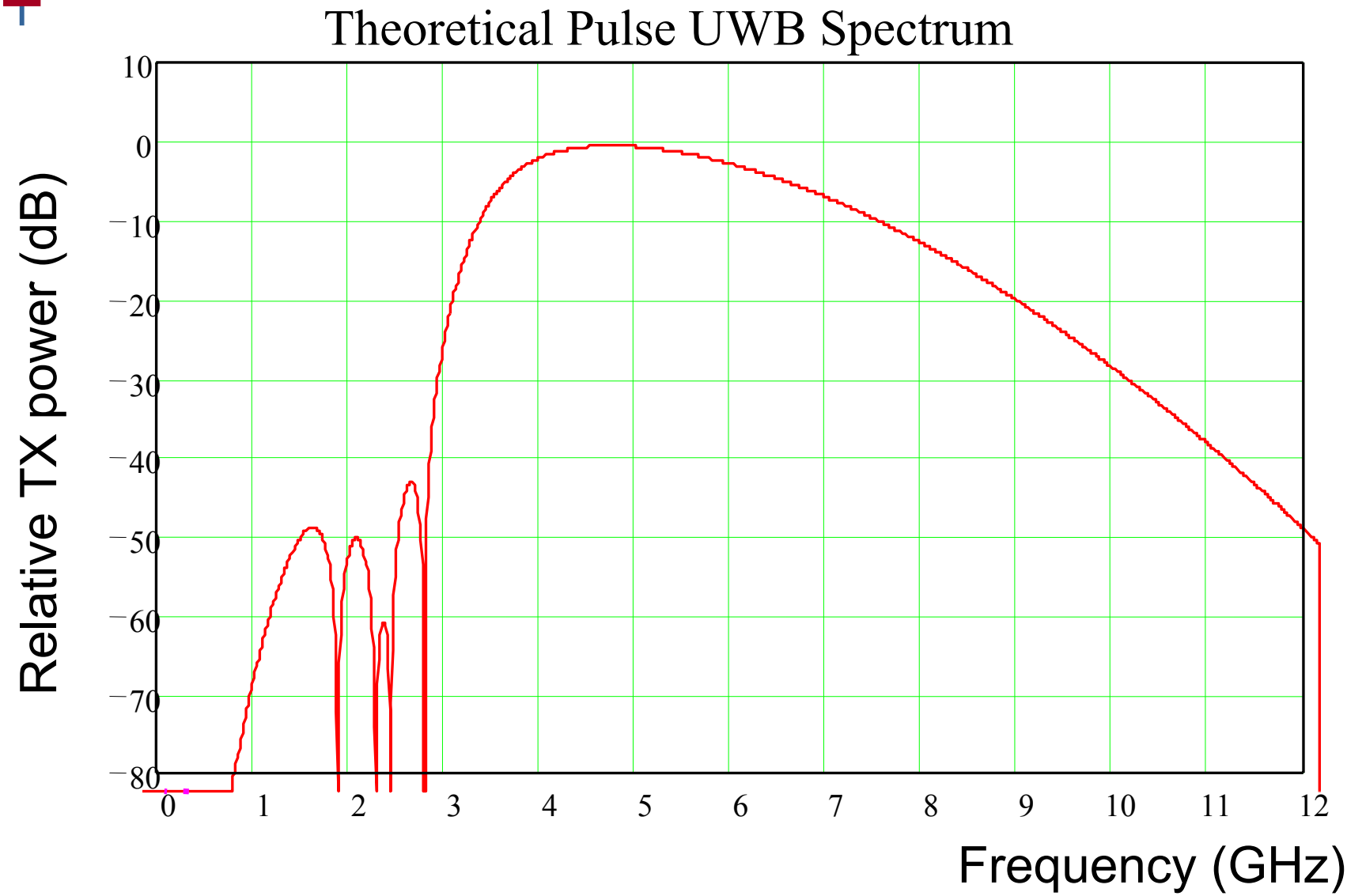
THALES

Two of a number of methods of generating UWB:

- Pulse UWB
  - Very short (sub nanosecond) pulses tens of nanoseconds apart
  - Inherently wide band
  - Used for ARTES 4 Project
- Frequency Hopped UWB
  - Typically a Direct Sequence Spread Spectrum Signal of about 10 to 20MHz bandwidth, hopped over around 1GHz at 10k to 100k hops per second
  - Used for another indoor positioning project, supported by BNSC

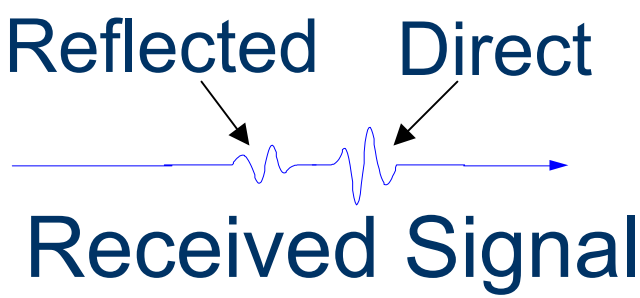
- ‘Pulse Generated’ UWB - continuous sequence of pulses (pseudo-randomly distributed about nominal repetition rate)

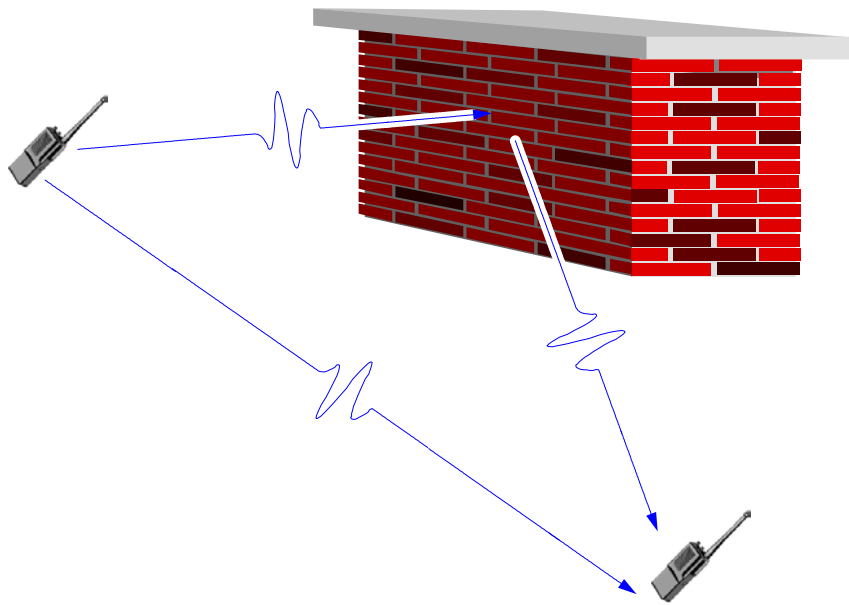



Theoretical Pulse UWB Spectrum
Relative TX power (dB)
10
0
−10
−20
−30
−40
−50
−60
−70
−80
0
1
2
3
4
5
6
7
8
9
10
11
12
Frequency (GHz)

MULTIPATH TOLERANCE

- Multipath common in buildings
  - INTERFERENCE BETWEEN DIRECT & REFLECTED PATH CAUSES FADING
- Short pulse - reflections suppressed
  - THEY ARRIVE LATER





THALES

UWB APPLICATIONS - WHY USE UWB? (2)

- High timing accuracy
  - CONSEQUENCE OF WIDE BANDWIDTH
  - REJECTION OF MULTIPATH

- With UWB it is possible to achieve:
  - HIGH ACCURACY POSITIONING (and Radar)
  - POTENTIALLY HIGH DATA RATE - COMMUNICATION

RELIABLE EVEN IN ENVIRONMENTS TRADITIONALLY CONSIDERED VERY HOSTILE TO RADIO, E.G. INSIDE BUILDINGS

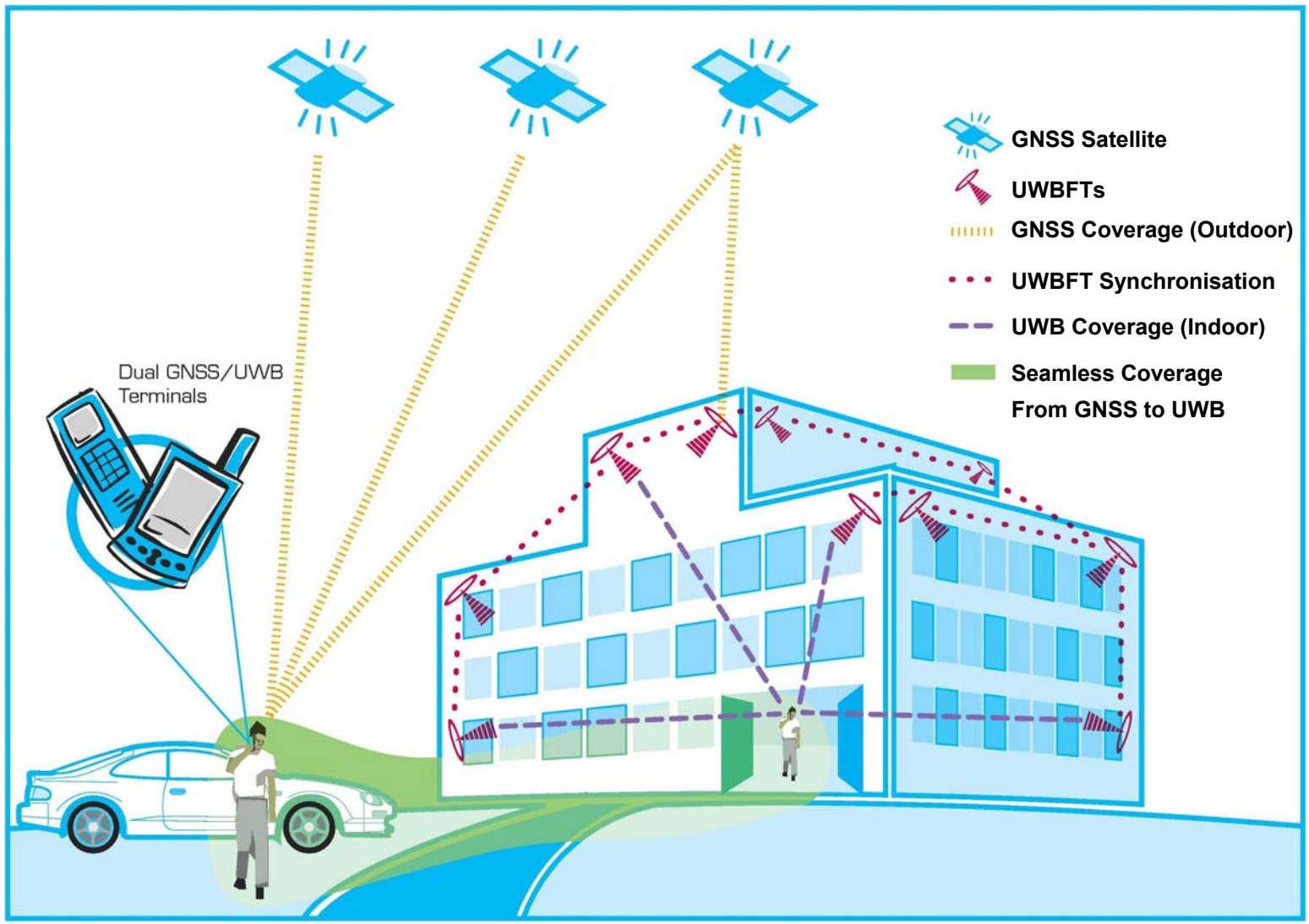
UWB APPLICATIONS - WHY USE UWB? (3)

- UWB Adhoc networks
  - Combined comms & positioning
  - Civil Defence (Homeland Security)
  - Soldier Radios (enabling better situational awareness both at a headquarters and for each soldier)
- Short Range Radar
  - Ground Penetrating Radar
  - Earthquake victims
  - Anti-terrorist and Military (Through Wall Radar)

UWB APPLICATIONS - WHY USE UWB? (4)

- Indoor (and outdoor) extension to GNSS
  - Precision location
  - Guidance around offices, malls and urban canyons
  - Lone worker protection
  - Monitoring/Locating lost children
- High data rate WLAN/PANs
  - Home Networks
  - Office Networks

UWB APPLICATIONS - WHY USE UWB? (5)



THALES

INDOOR POSITIONING: PROJECT OVERVIEW

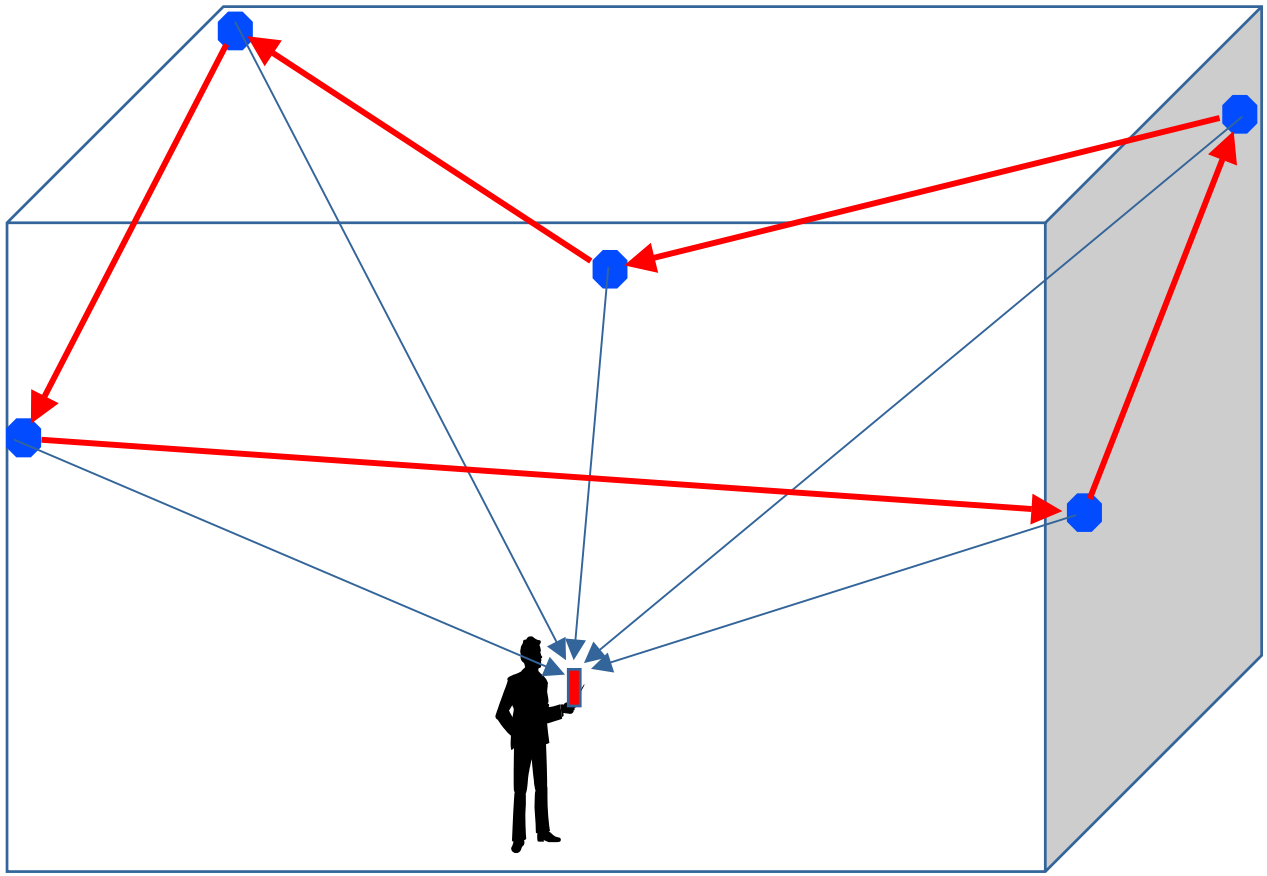
- Aim: To show the viability of indoor coverage as an extension to the Galileo (or GPS) capability
  - Implement Indoor Positioning demonstrator system
  - Evaluate potential System Performance
  - Identify main issues to be overcome for a product
- Project Overview
  - Two Phases
    - System Design & Analysis
    - Demonstrator Implementation & Trials
  - Delay between the phases due to problems with UWB chip design at Time Domain Corporation
    - Necessitated compromise on system design aspects
    - FCC UWB Spectrum Allocation introduced

Project showed that Accurate Indoor Positioning can be achieved using UWB

SYSTEM OVERVIEW (1)

- Demonstrator based on Pulse UWB technology
  - Sourced from US company (Time Domain)
- Requirements aligned with Hospital Lone Worker Application. Main Aims:
  - Accuracy 1m (95%),
  - Update Rate >1Hz
  - Scalability
- System based on several fixed UWB transceivers
  - Known (surveyed) locations
  - Fixed Units transmit in sequence around a (logical) ring
  - Mobile calculates Time Difference of Arrival (TDOA) from pairs of fixed nodes to determine its position
  - Automated survey technique for fixed transceivers

SYSTEM OVERVIEW (2)

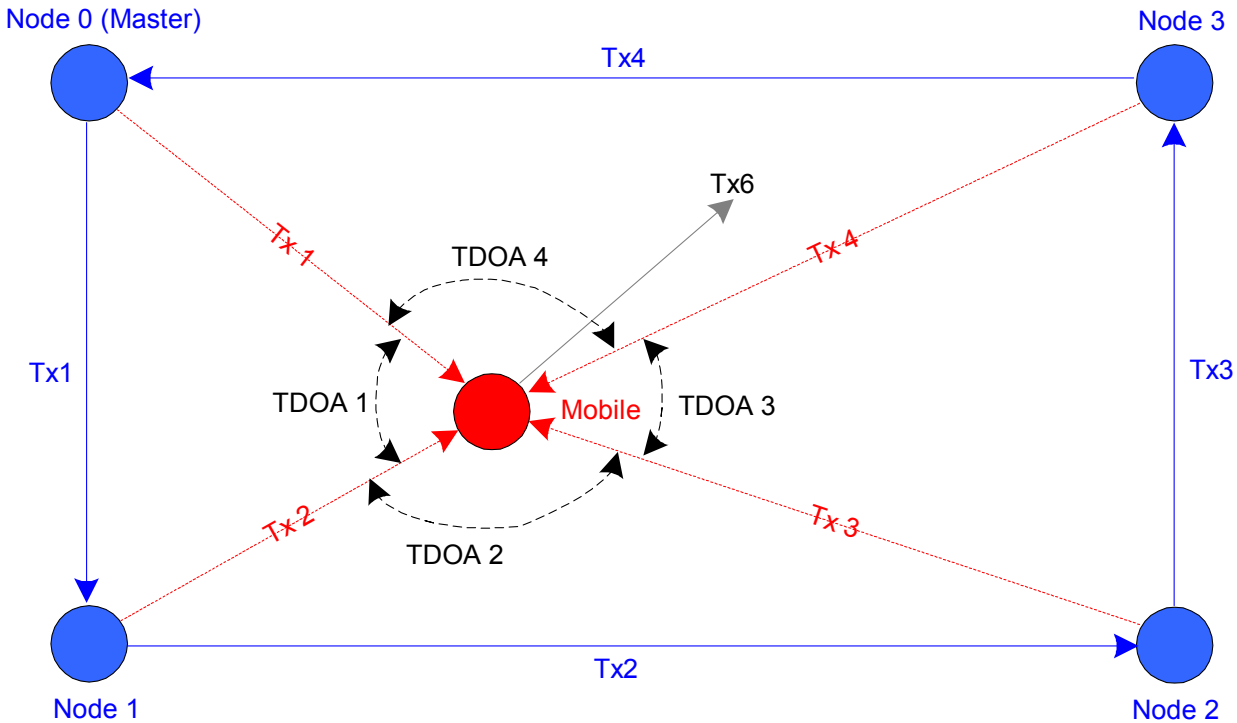


Fixed (Surveyed) UWB transceiver

Mobile UWB transceiver

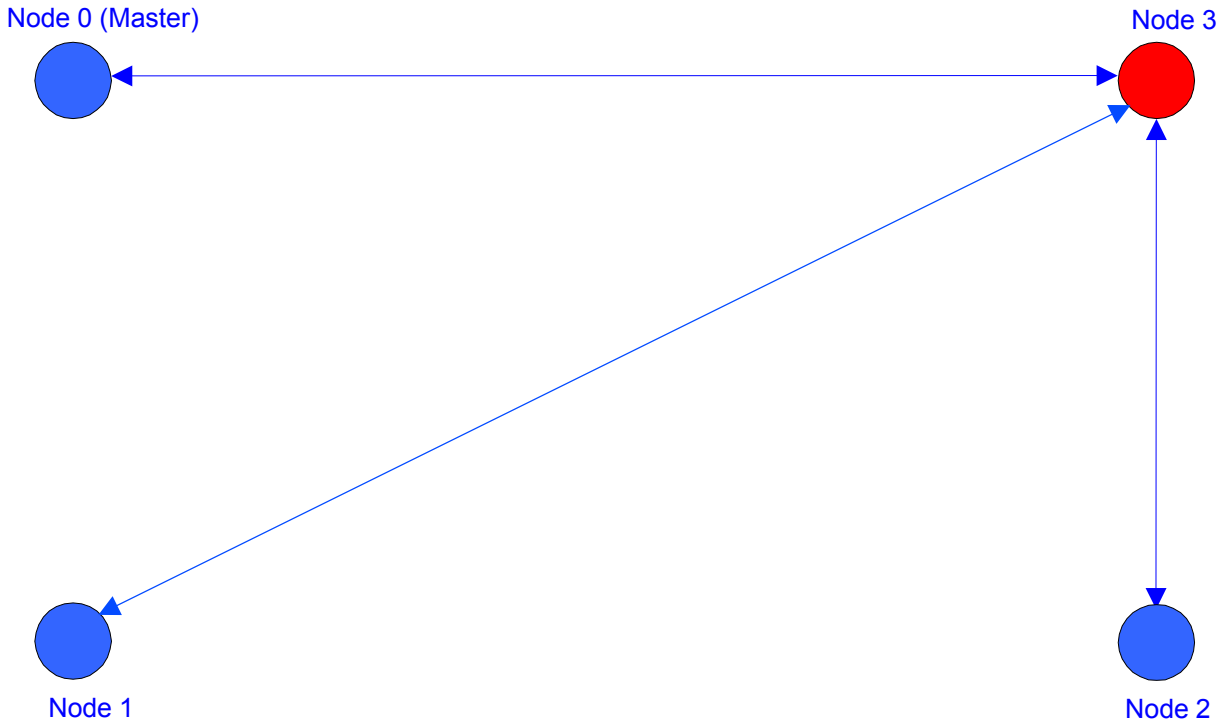
THALES

SYSTEM OVERVIEW (3)



Passive Positioning (Main mode)

- Fixed Nodes transmit a packet to the next fixed node in a ring format.
- Mobile unit also receives these transmissions and measures the TDOA between pairs of fixed nodes.
  - Using four TDOA measurements the Mobile can locate itself in 3 dimensions.
- No transmission required from mobiles (scalable)



Active Positioning (Used for fixed node auto-location)

- Node positions 0,1,2 known
- Node position 3 calculated from ranges (found by ‘ping-pong’ transmissions)
- Use for Automatic survey of New Nodes

- Packet Structure
  - Payload and the number of Scan Ramps are programmable, the rest is fixed by Time Domain kernel.

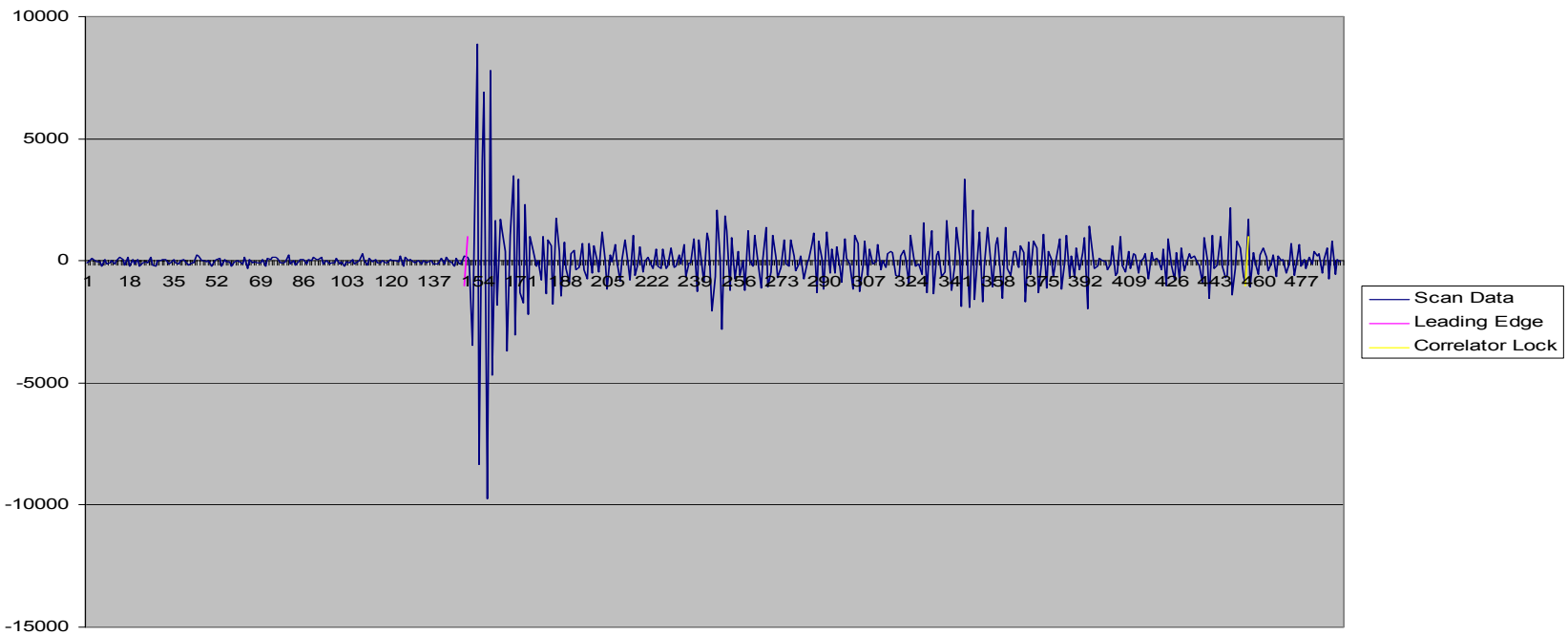
476	96	96	1500 bits
Acquisition Ramps	Header	Payload	Scan Ramps

- Packet Payload
  - Contains:

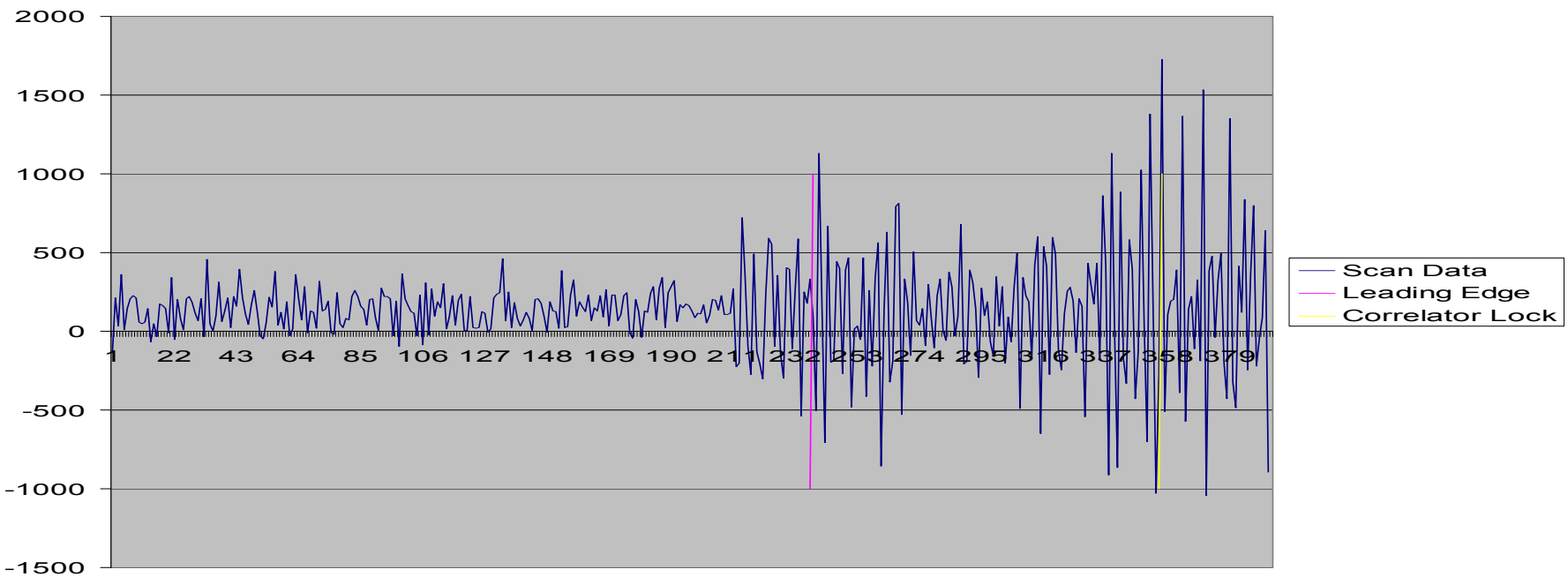
32				32		32	
4	4	8	16	16	16	16	16
Src Id	Flag	Epoch	Bias Bins	PL CoOrd.X (cm)	PL CoOrd.Y (cm)	PL CoOrd.Z (cm)	CRC16

    - Source Id - Identifies which fixed node originated the transmission
    - Flags - Various control bits such as Panic Alarm status
    - Epoch - System Time Stamp
    - Bias Bins - Used by mobile to make TDOA measure more accurate
    - Coordinates - The system coordinates of the originating node
    - CRC16 - 16 Bit Cyclic Redundancy Check code

- Scan Ramps
  - Scan Ramps are just a series of transmitted 1's
  - They allow the receiver to build up the impulse response
  - We can then locate the leading edge of the pulse and use this to determine the correct TDOA value so that multipath reflections are ignored.



- Example of pulse scan in non-line of sight conditions.
  - Correct leading edge is much harder to locate reliably.



SUMMARY OF PERFORMANCE (1)

- Summary of Main Trials
  - Outdoor Range
  - Attenuation of Test Walls
  - Indoor Range
  - Interference to & from the system
  - Outdoor Positioning Accuracy
  - Indoor Positioning Accuracy

Outdoor Range Tests

Integration (header, data, signal optimisation, acquisition)	Max range obtained with approximately 25% packet loss on master (m)
128	107
256	200
512	375
1024	404

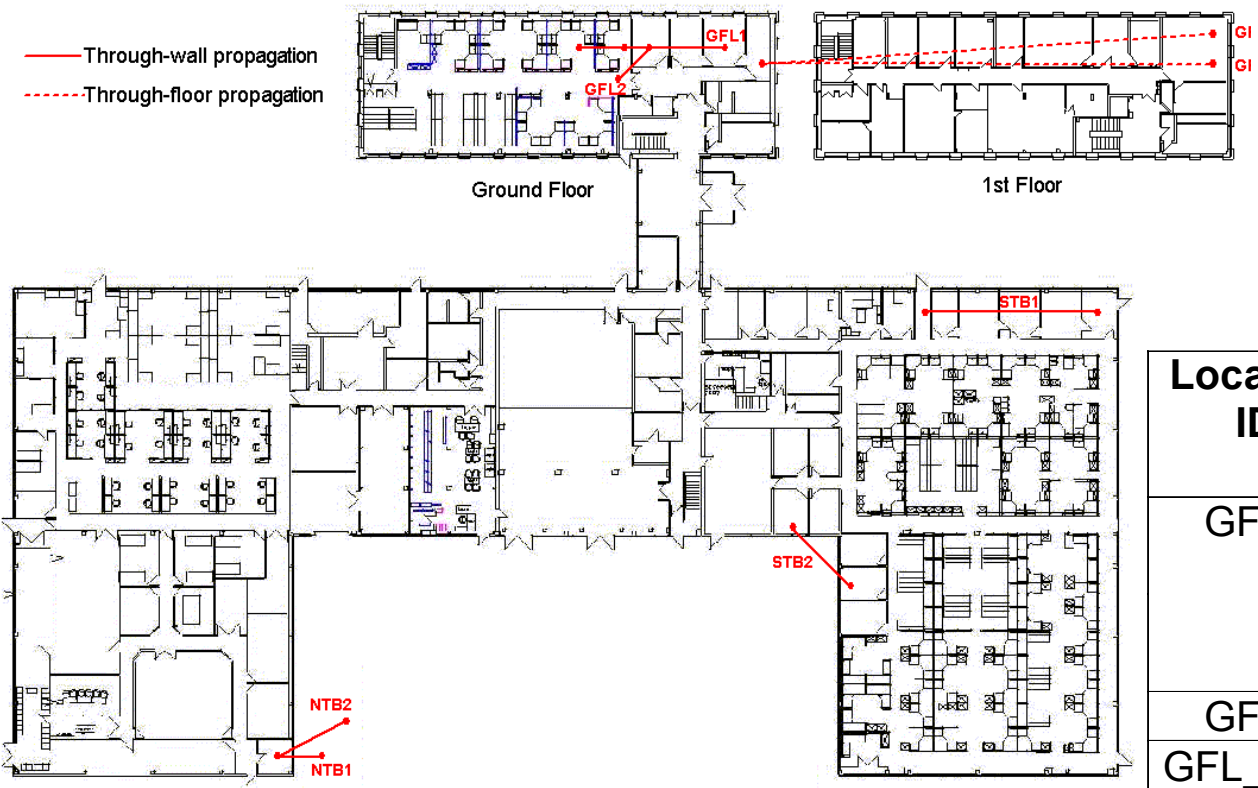
SUMMARY OF PERFORMANCE (2)

Walls used for attenuation tests

Summary of Attenuation Test Results

Material description	Transmission loss at 0 degrees (dB)	Transmission loss at 60 degrees (dB)
Engineering brick (100mm thick)	8.7	13.8
Concrete block (100mm thick)	6.9	12.3
Thermalite block (100mm thick)	8.6	11.1
Plasterboard sheet (14mm thick)	1.1	6.4
Internal Glass (3mm thick)	1.8	6.6
Annealed stopsol glass (6mm thick)	3.3	8.2

SUMMARY OF PERFORMANCE (3)



Location ID	Predicted propagation loss (dB)	Actual propagation loss (dB)
GFL1	9.25m path: 33.8	33
	12.85m path: 36.6	34
GFL2	13.9	15 to 17
GFL_MF L1	18.6	19 to 21
GFL_MF L2	26.9	30
STB1	18.8	21
STB2	16.9	19 to 21
NTB1	17.9	18 to 19
NTB2	26.7	24

SUMMARY OF PERFORMANCE (4)

- Interference to the system
  - No significant problems encountered from interference during the trials
  - Tests on a number of actual and simulated intentional emitters
    - Most significant: WLAN transmissions in 5GHz band - in principle this could be improved by interference nulling
  - Tests on a number of unintentional emitters
    - Personal computer, Fluorescent lighting, Laser printer, Vending machine, Microwave oven, Lighting dimmer control, Workshop lathe, Workshop pillar drill, Television.
    - Microwave oven caused 50% packet loss at 0.2m
    - Laser printer caused 5% packet loss at 0.1m
    - Vending machine compressor caused 5% packet loss at 1m (unable to get closer than this)

SUMMARY OF PERFORMANCE (5)

- Interference from the system - Devices tested
  - APC Medical's external pacemaker - most RF sensitive device found in report by UK government agency
  - PMRs at TRT-UK (868 MHz)
  - Mobile phone O2 network, dual-band (GSM 900 and DCS1800)
  - Television
  - Radio FM/AM
  - Handheld GPS unit (1.57542 GHz)
  - WLAN 802.11a (5.15 GHz - 5.825 GHz)
- Results: No significant effects except for 5GHz WLAN
  - A 30m WLAN link showed 60% capacity reduction when the UWB transmitter was 1.5m from the receiver.

SUMMARY OF PERFORMANCE (6)

- Interference Excision and Spectrum Shaping
  - A number of ideas proposed during Design Phase
  - Limitations of the Time Domain Hardware prevented implementation of some of the ideas
    - Limits on Pulse positioning for Transmit shaping
    - Interference nulling on receive only possible during the data portion of the signal.
  - Performance of Interference Excision was limited in the end by the performance of the Time Domain hardware (Dynamic range and Cross-coupling between correlators)
    - Around 14db Max Null depth shown to be achievable

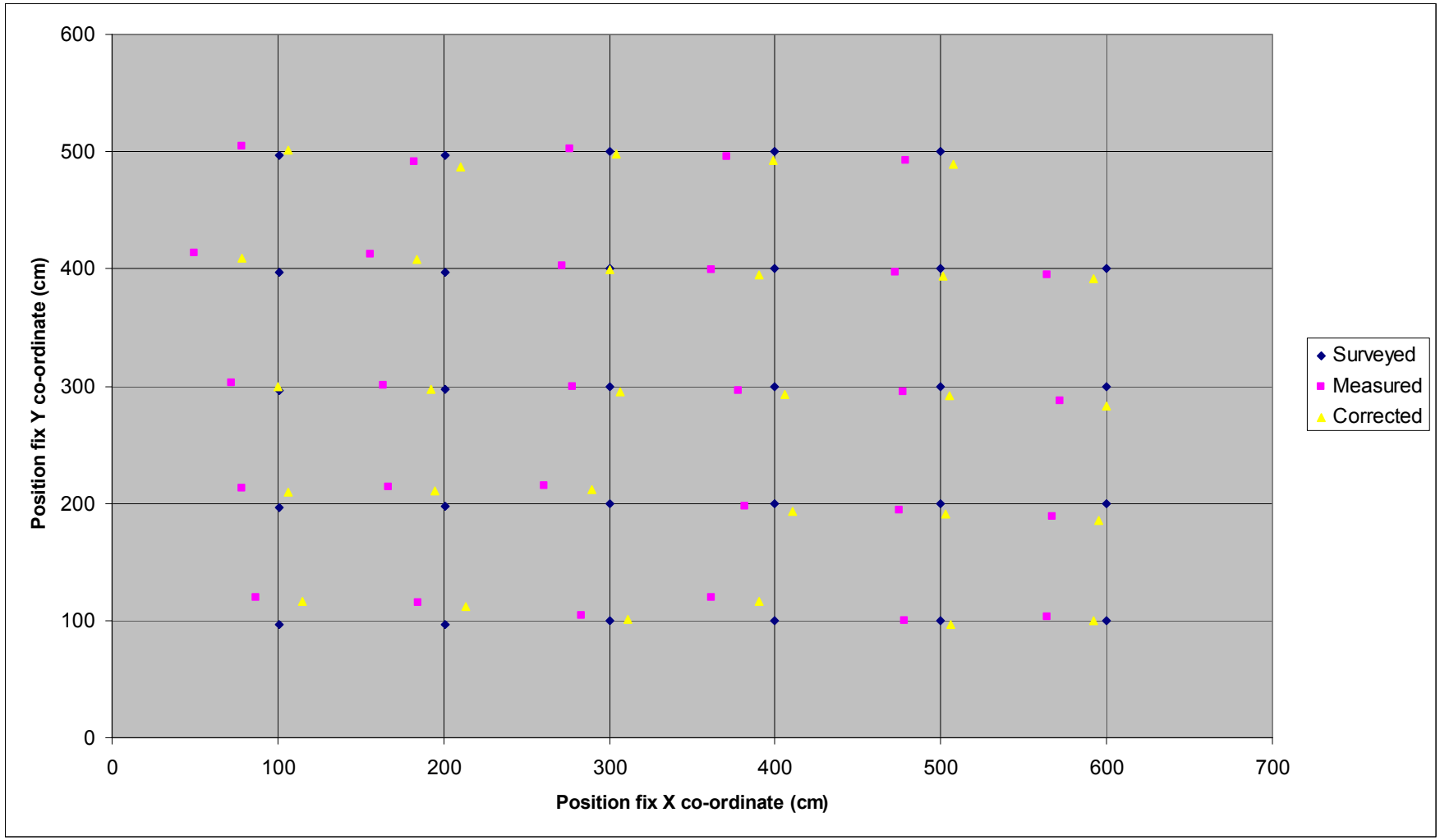
SUMMARY OF PERFORMANCE (7)

- Stationary position fixes:
  - Averaged position errors over 25-point grid for 2m User Terminal height (x, y, z): -3.56cm, -13.76cm, 4.44cm
  - Averaged position errors over 9-point grid for 1m User Terminal height (x, y, z): -1.78cm, -21cm, -3.11cm

User Terminal height	Circular error prob. (CEP) at 50%	Circular error prob. (CEP) at 95%
1m	15cm to 45cm	25cm to 70cm
2m	10cm to 30cm	25cm to 125cm

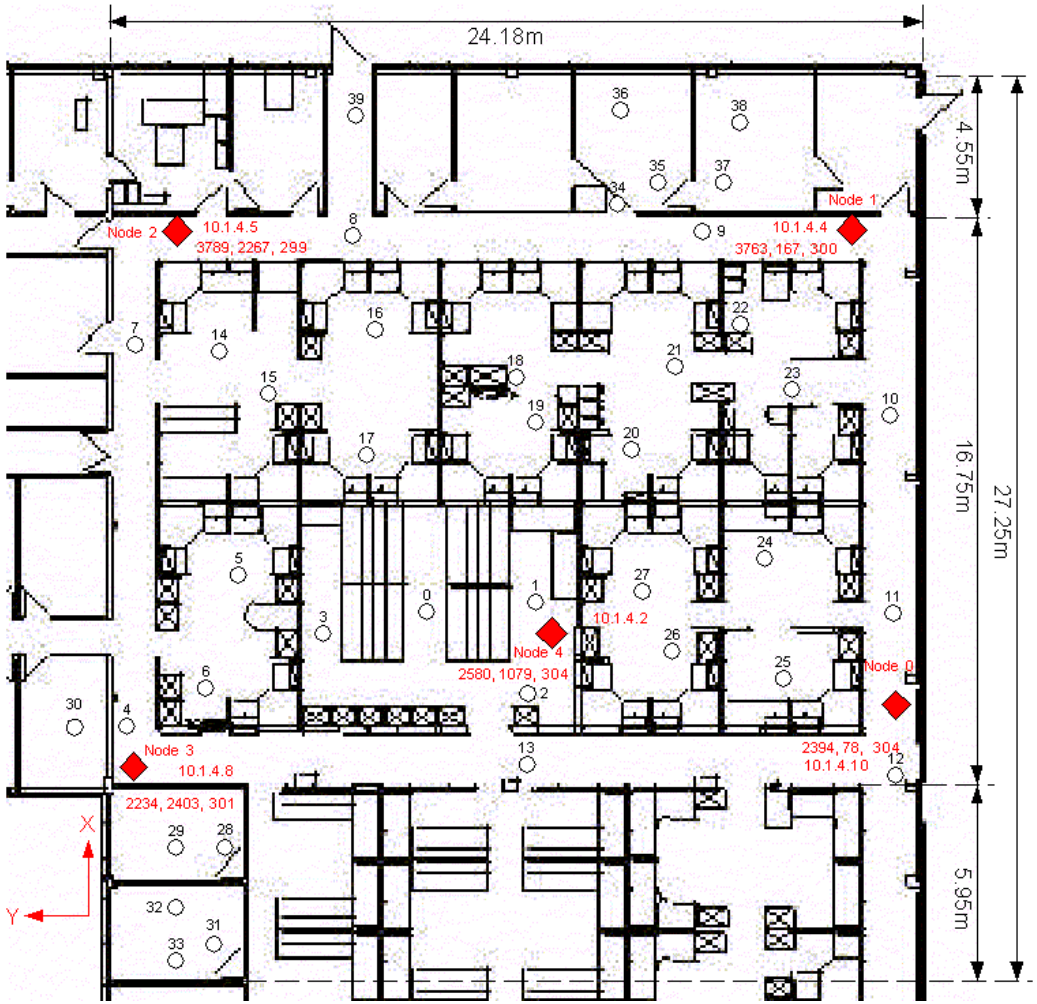
CEP for 1m and 2m User Terminal heights

INDOOR POSITION FIX ACCURACY (Single Room)



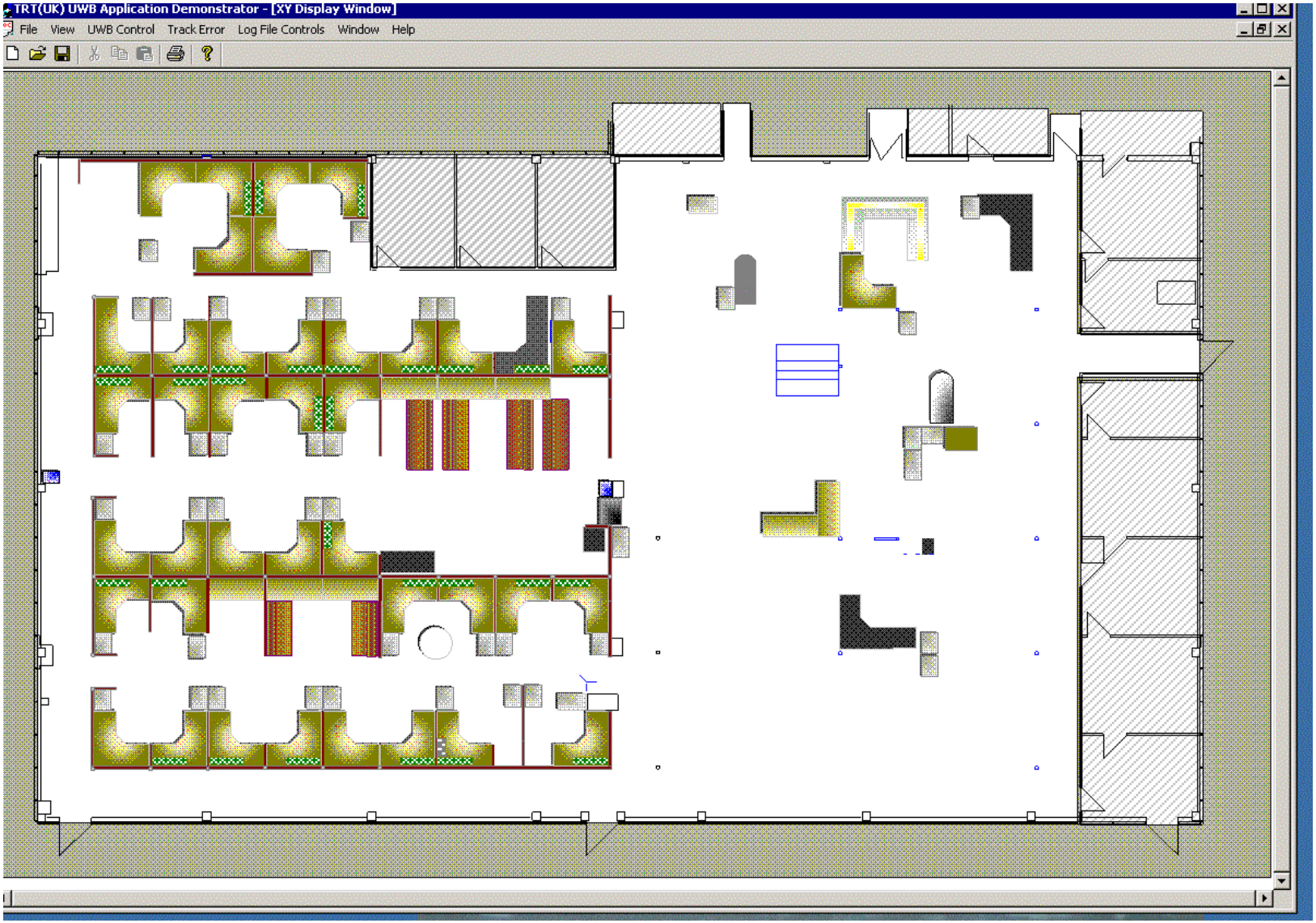
SUMMARY OF PERFORMANCE (9)

INDOOR POSITION FIX ACCURACY



User Terminal height	Circular error probable (CEP) at 50%	Circular error probable (CEP) at 95%
1.5m	25cm to 245cm	50cm to 505cm
2m	15cm to 70cm	25cm to 110cm

LABORATORY DEMONSTRATION

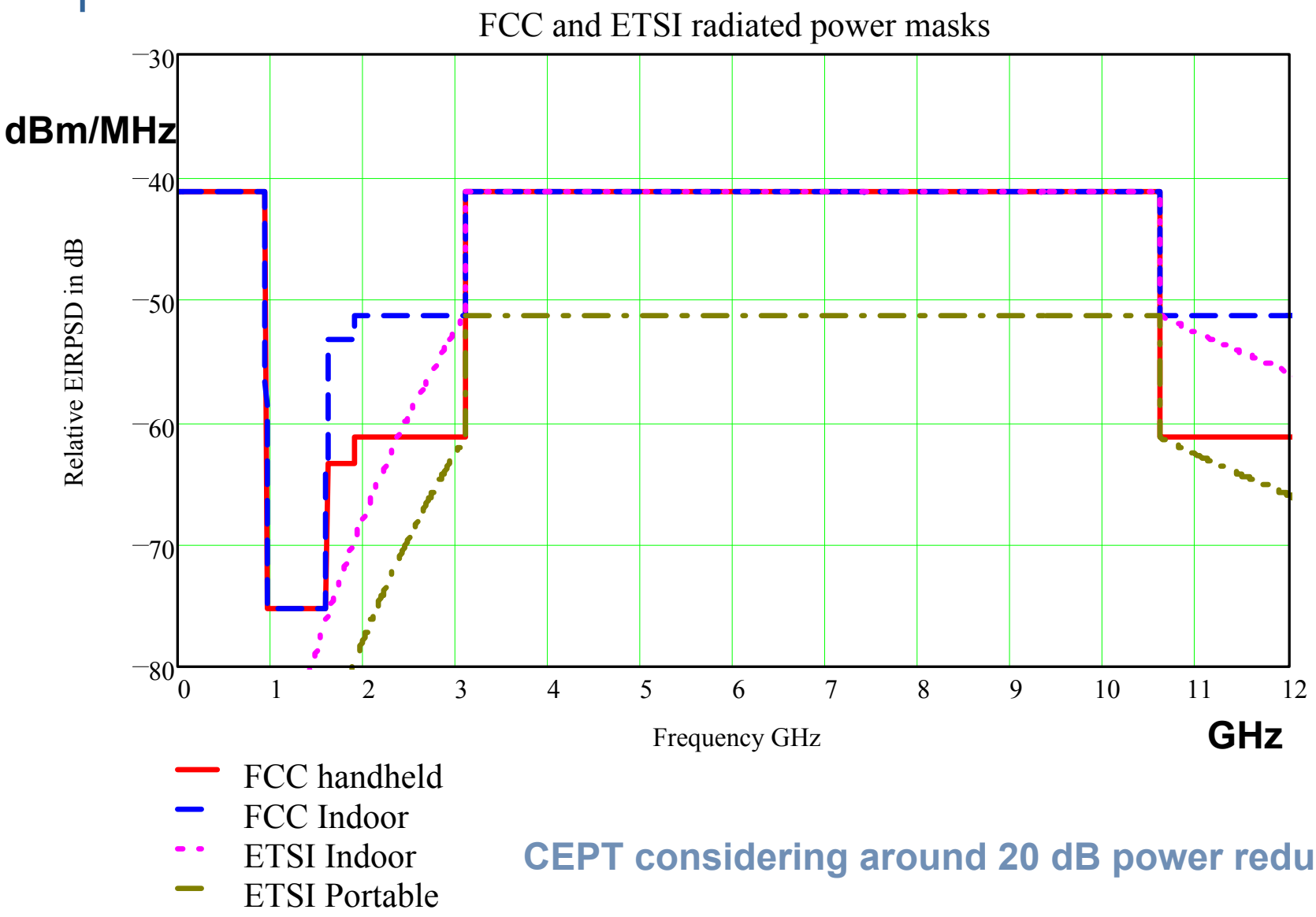


REGULATORY/STANDARDS ISSUES (1)

- REGULATION
  - System Used in ARTES Project is within the US FCC regulations
    - FH-UWB system may not be permitted under current FCC regulations
  - Europe and the ITU are still debating UWB regulations

- STANDARDS
  - IEEE are looking at standards in the US, but none have yet been agreed
    - For very high data rate, very short range, OFDM and Direct Sequence Spread Spectrum are the competing options
      - Chips sets being developed (unlikely to be suitable for positioning application)
    - Discussion ongoing: waveform for lower data rate & positioning
  - ETSI have some draft standards under consideration

REGULATORY/STANDARDS ISSUES (2)



CEPT considering around 20 dB power reduction

THALES

FH UWB DEMONSTRATOR PROJECT (1)

- Positioning Technique
  - Designed to use a set of synchronised fixed nodes with passive mobile nodes (i.e. similar to GPS)
  - Similar active technique to Pulse UWB demonstrator for positioning additional fixed nodes

Why FH UWB:

- Same accuracy as Pulse UWB for same bandwidth covered
- Greater immunity to interference
- More flexibility to shape the transmit spectrum to avoid interference to other systems
- Potential for smaller size and lower power
- Easier to share spectrum between nets (Orthogonal hop & spread codes)

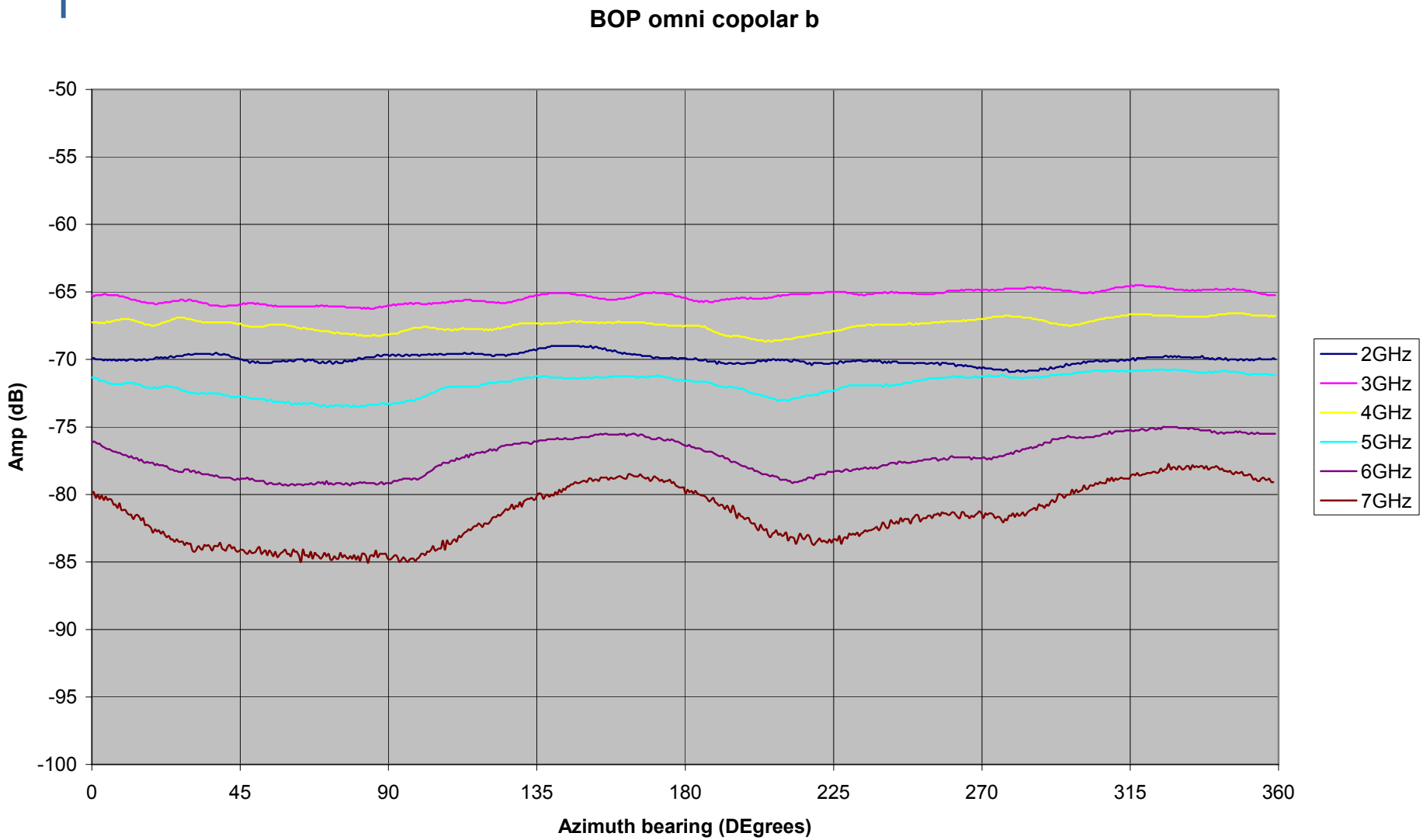
Issues:

- Not covered by current FCC regulations
- Potentially more interference possible from single emitters (though aggregate issues are the same as Pulse)

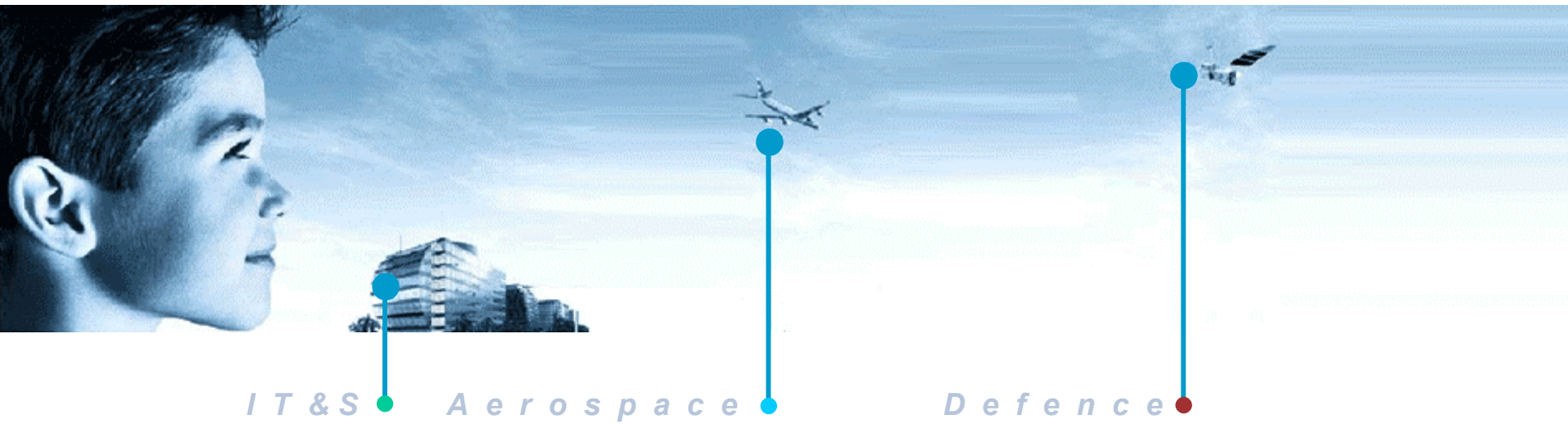
FH UWB DEMONSTRATOR PROJECT (2)

- RESULTS
  - Improved accuracy over Pulse system
  - Range and hence coverage poorer with current hardware
    - Up to 20dB shortfall in current receiver performance
    - Most of the problems causing this identified

- Main Specification Points:
  - Omni-Directional (<2dB variation in azimuth)
  - Low Ringing Time (< -50dBc after 0.8ns)
  - Wide Bandwidth (E.g. 3.5 - 8GHz, though this can be scaled.)
  - Small size
    - 20 x 30 x 1.6mm, (H x W x D) excluding 40 x 30mm ground plane, for the example frequency range
  - Low cost simple construction
  - Gain (0dBi at 3.5 GHz for the example)
  - Uni- directional version also possible (5dB gain)


BOP omni copolar b
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
Amp (dB)
0
45
90
135
180
225
270
315
360
Azimuth bearing (DEgrees)
2GHz
3GHz
4GHz
5GHz
6GHz
7GHz

Ultra Wide-Band (UWB) Indoor Positioning



Dave Harmer
Thales Research and Technology UK Ltd

- ARTES 4 Project
- ESTEC December 2004

THALES