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Bluetooth Indoor Localization System

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Outline

- Motivation
- Principles of time measurement for localization
- System description and components
- First measurement results

Motivation

- **Indoor localization enables location-aware services**
  Guidance in complex facilities using handheld devices
  Finding the location of particular persons and objects
  Tracking and watching of active badges and tags

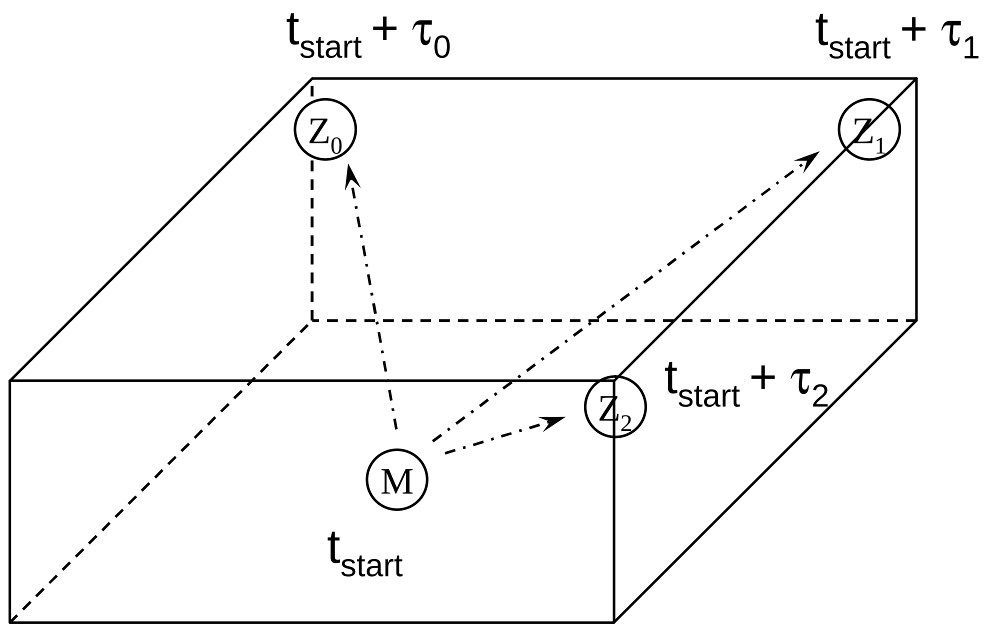
- **Indoor localization system is hard to achieve**
  GPS, DGPS doesn't work with sufficient reliability
  Cellular phone systems (GSM) haven't required accuracy
  Embedding in a widely spread radio system desired

- **Existing solutions require changes on mobile device**
  Dedicated hardware for phase measurement, not standard conform
  System based on RSSI or BER determination need calibration

- **Bluetooth indoor localization system with ± 1 meter accuracy**
  Allows to localize any Bluetooth device, no changes on mobile
  Localization by time-of-arrival measurement using cross correlation IC

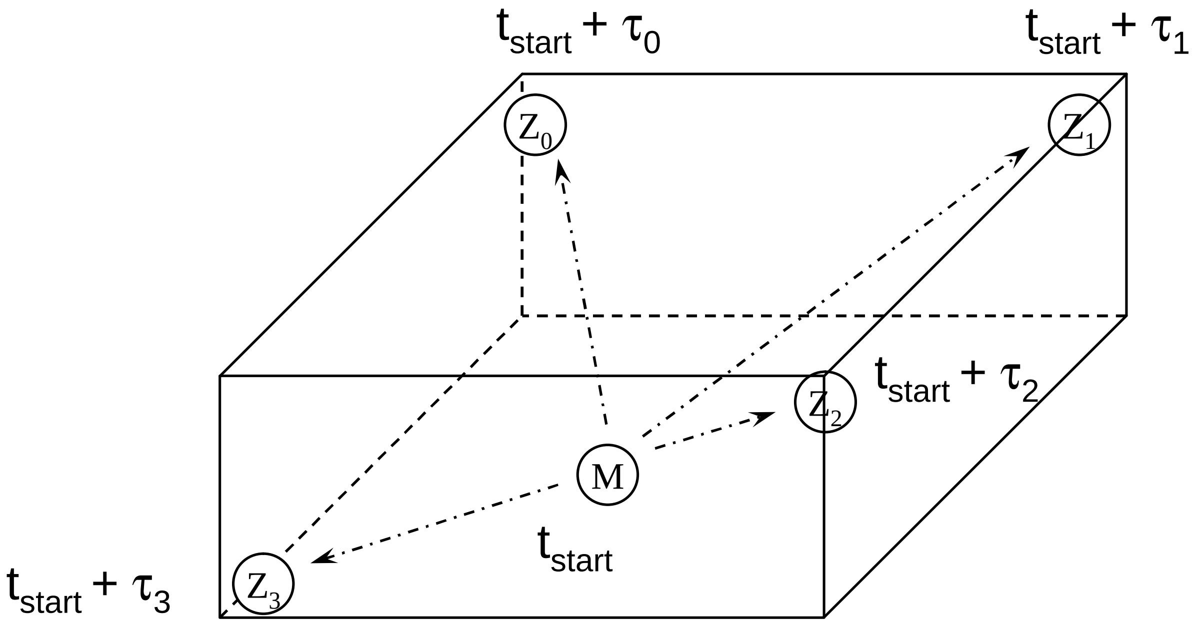
Principles of Time Measurement - TOA

- **Measurement of propagation time of electromagnetic waves**
  Transmitter (mobile) sends signal at known time
  Measurement of individual times of arrival at the base stations
  Calculation of three distances from three propagation delays



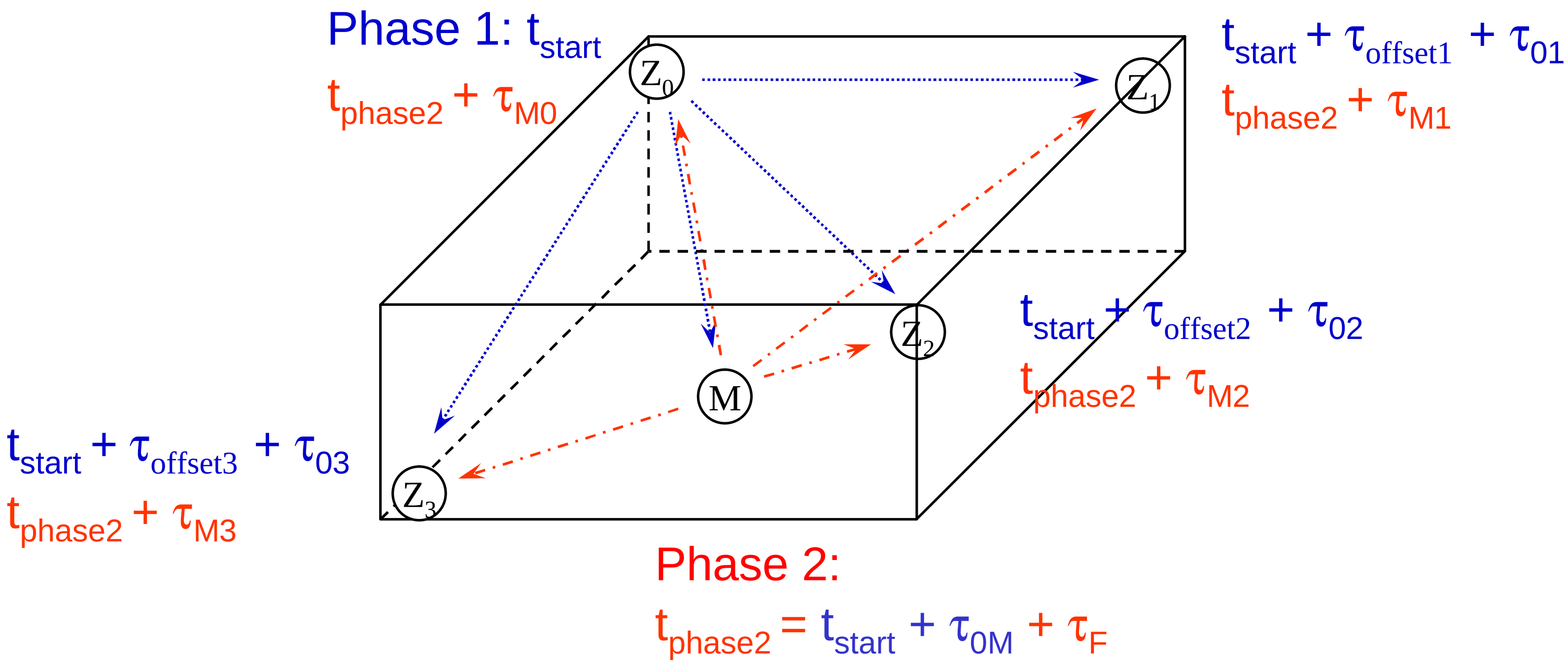
Principles of Time Measurement - DTOA

- **Omit knowledge of start time**
  Introducing additional base station at known position (one off plane)
  Still needs synchronization between base stations
  Calculation of three distances from four propagation delay differences



Principles of Time Measurement - DTDOA

- **Omit base station synchronization: differential measurement**
  Master base stations transmits first signal starting counters, mobile answers stopping the counters on the time measurement stations
  Calculation of three distances from four propagation delay differences



Differential Time Difference of Arrival

Phase 1:

$$t_{1Z_i} = t_{start} + t_{offset_i} + t_{Z_0 Z_i}$$

Phase 2:

$$t_{2Z_i} = t_{start} + t_{offset_i} + t_{Z_0 M} + t_F + t_{MZ_i}$$

Offset elimination:

$$\Delta t_i = t_{2Z_i} - t_{1Z_i} = t_{Z_0 M} + t_F + t_{MZ_i} - t_{Z_0 Z_i}$$

Propagation time differences:

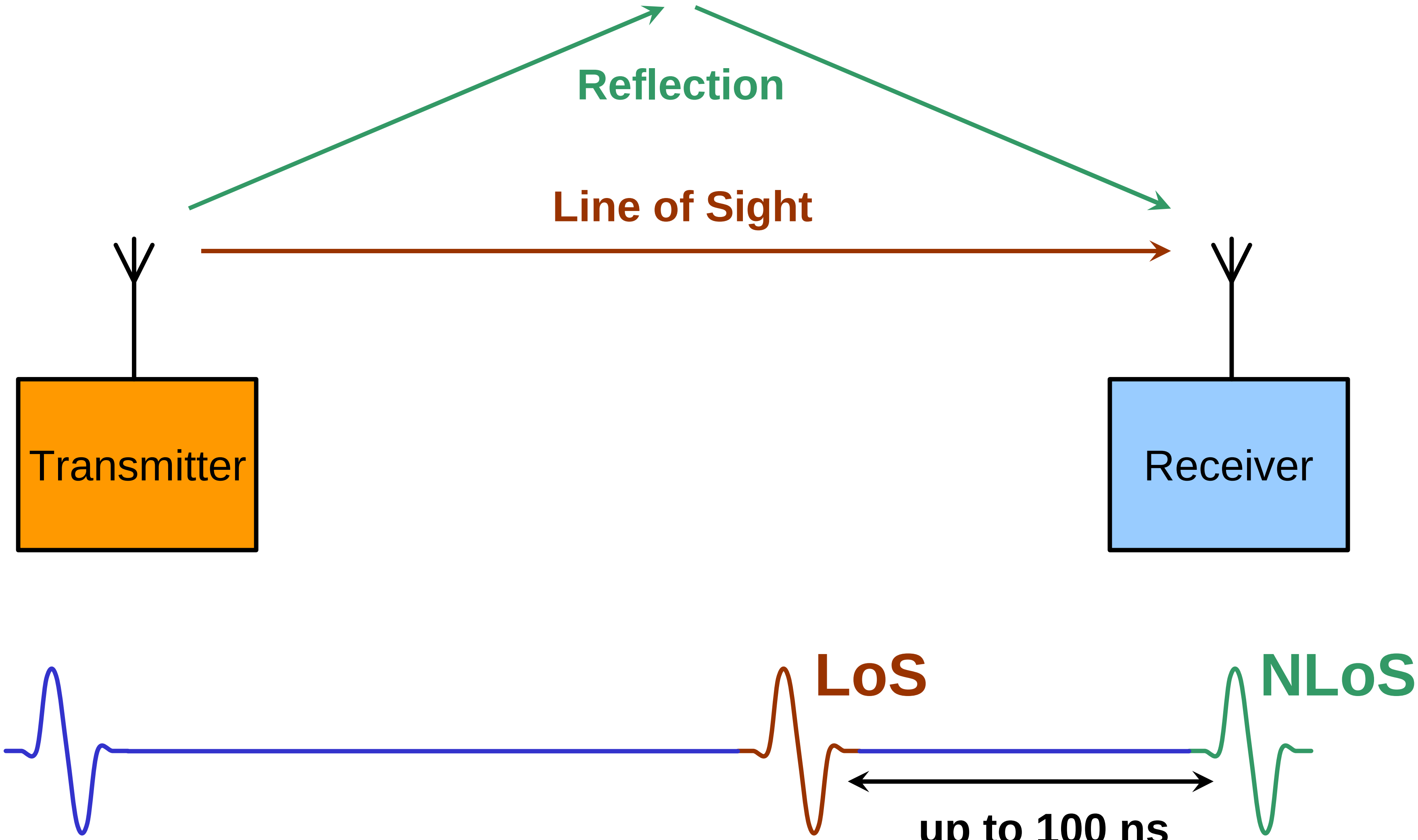
$$\Delta t_{ij} = \Delta t_i - \Delta t_j = t_{MZ_i} - t_{Z_0 Z_i} - t_{MZ_j} + t_{Z_0 Z_j}$$

Distance differences:

$$t_{MZ_i} - t_{MZ_j} = \Delta t_{ij} + t_{Z_0 Z_i} - t_{Z_0 Z_j}$$

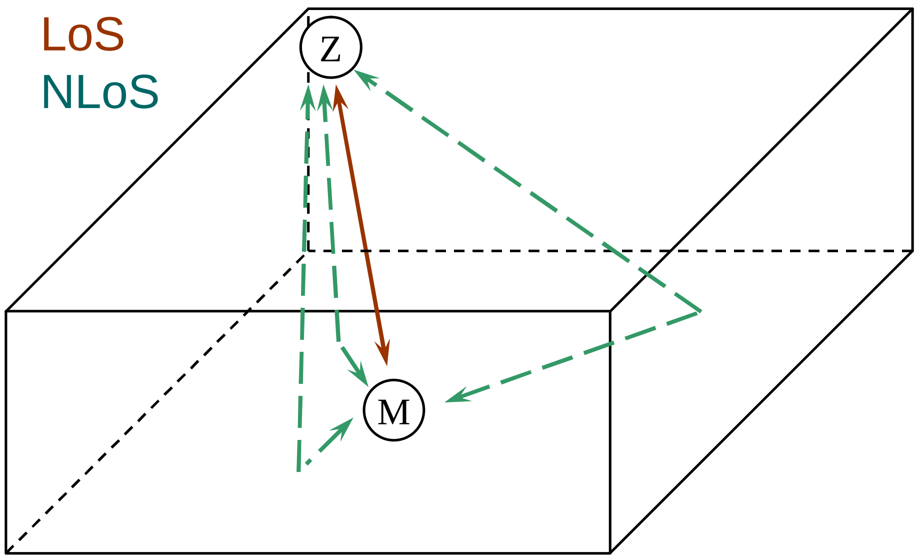
$$\Delta dij = c \cdot (t_{MZ_i} - t_{MZ_j})$$

Multipath Propagation

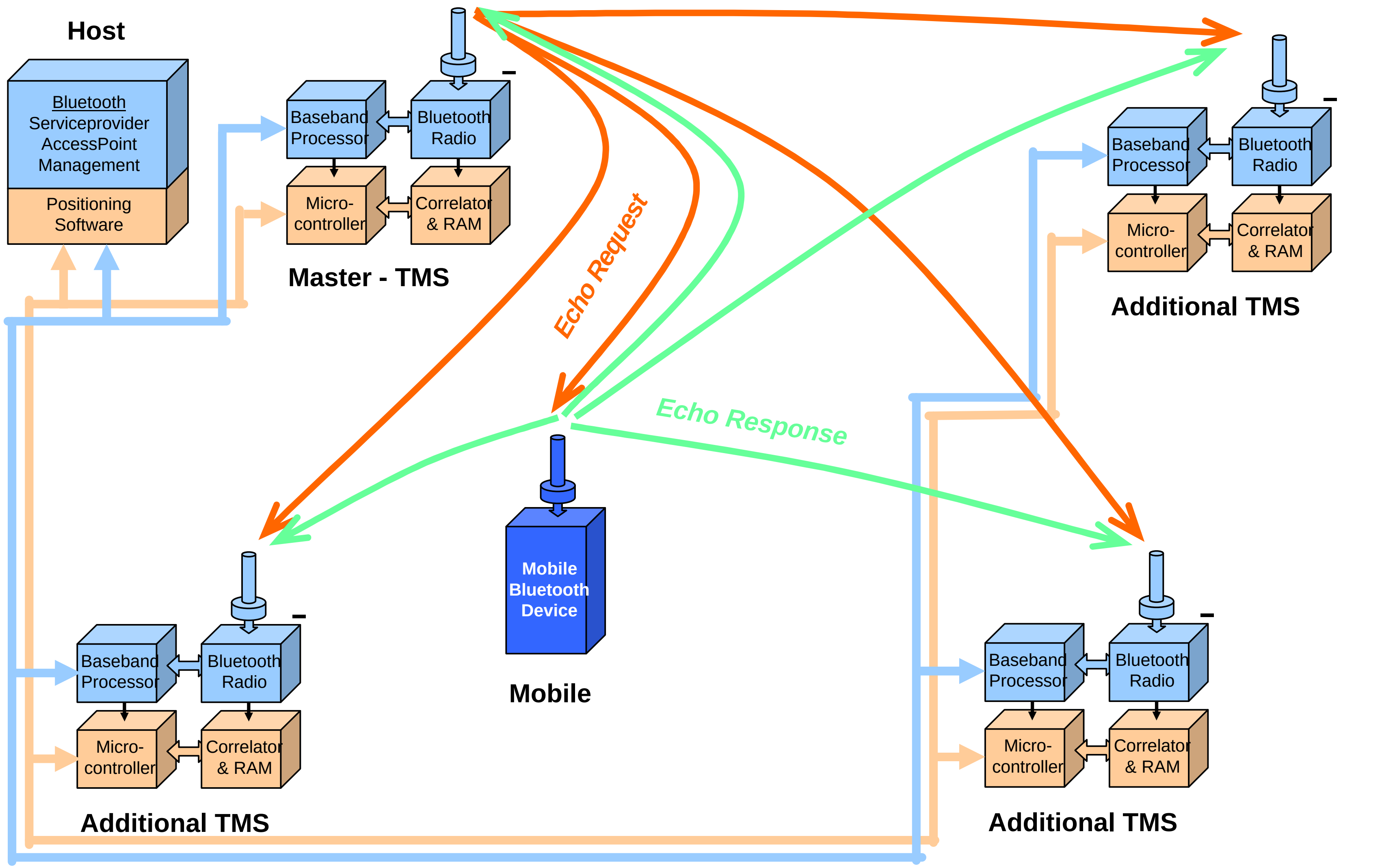


Reduction of Reflected Signals

- **Base stations installed in upper corners, usage of directed antennas**
  Good LoS conditions for almost all positions
  No reflections from adjacent walls and ceiling
  Reflected signals from opposite walls might have much smaller power than the LoS signal

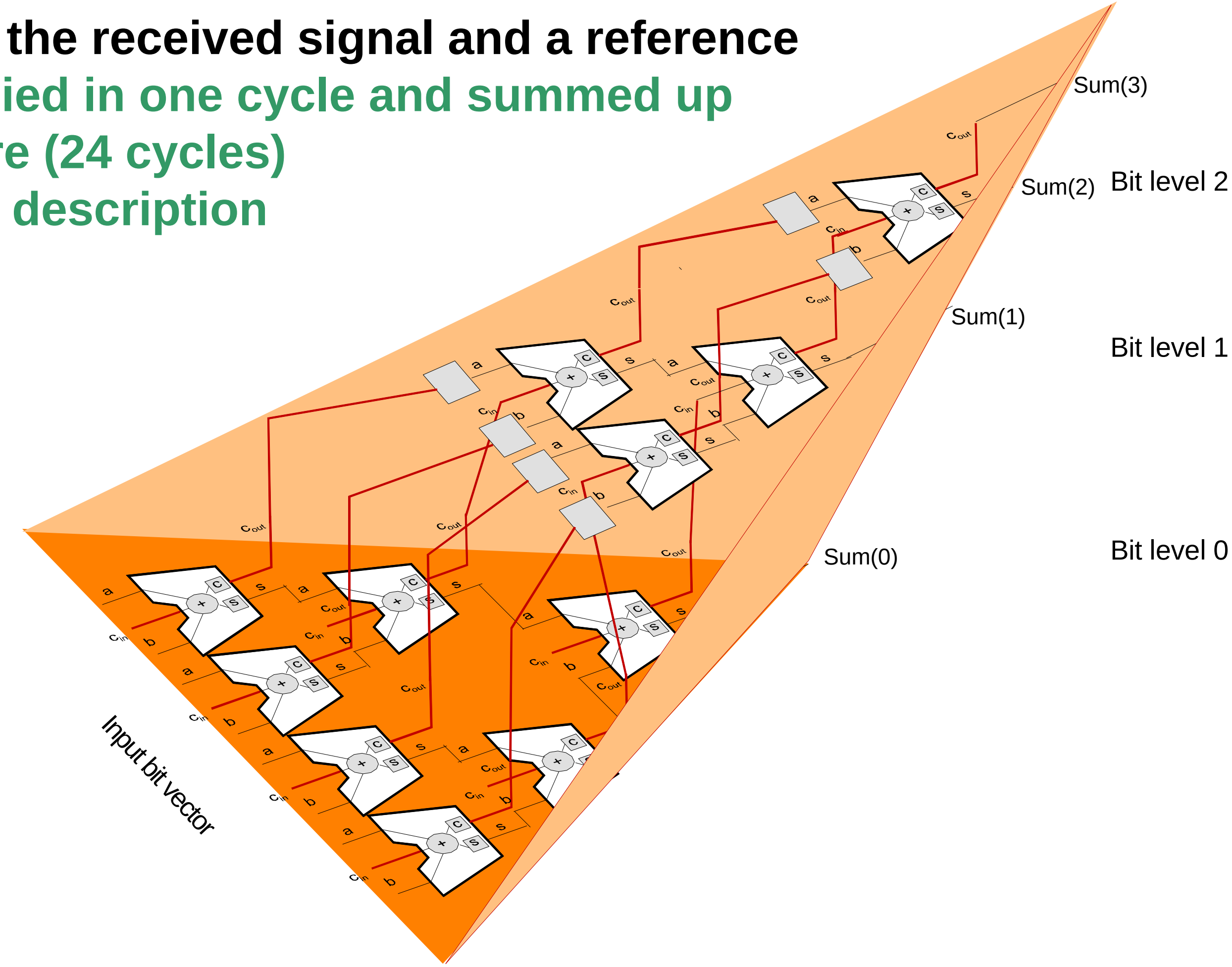


System Overview



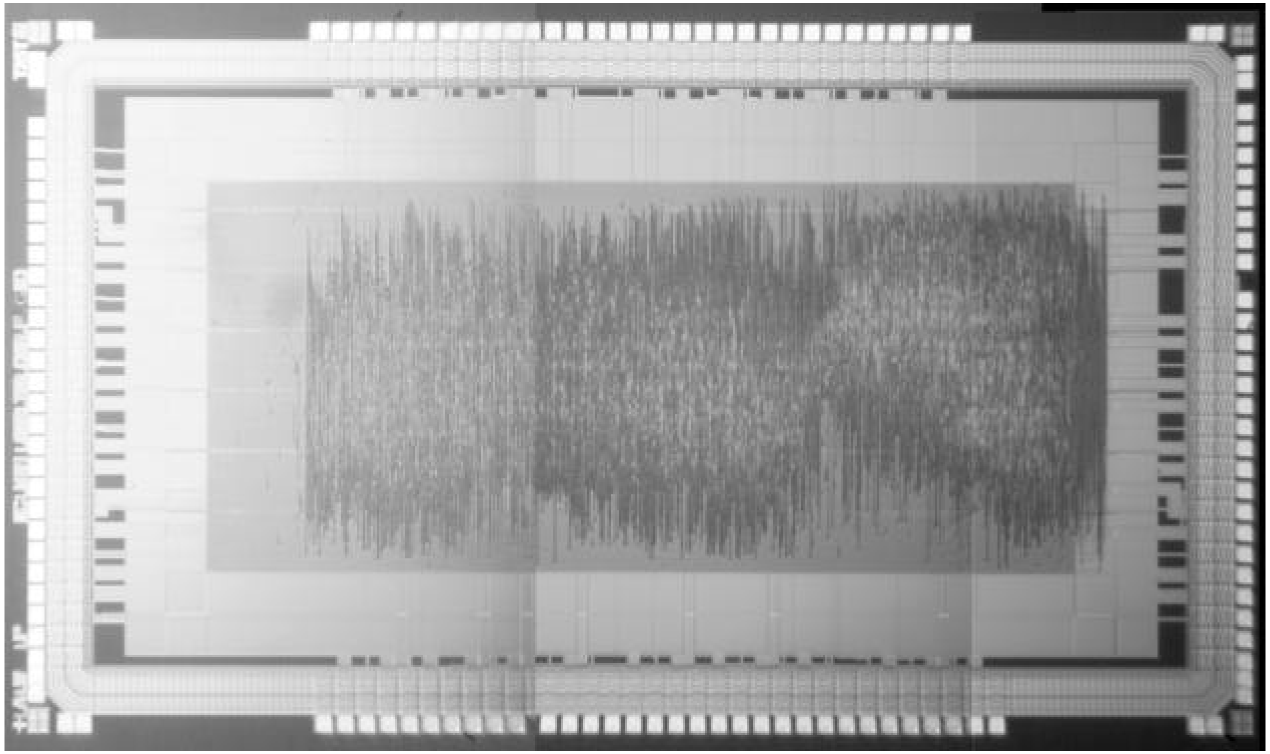
Cross Correlation IC

- **Multiplication of the received signal and a reference**
  4096 bits multiplied in one cycle and summed up
  Pipeline structure (24 cycles)
  Recursive VHDL description



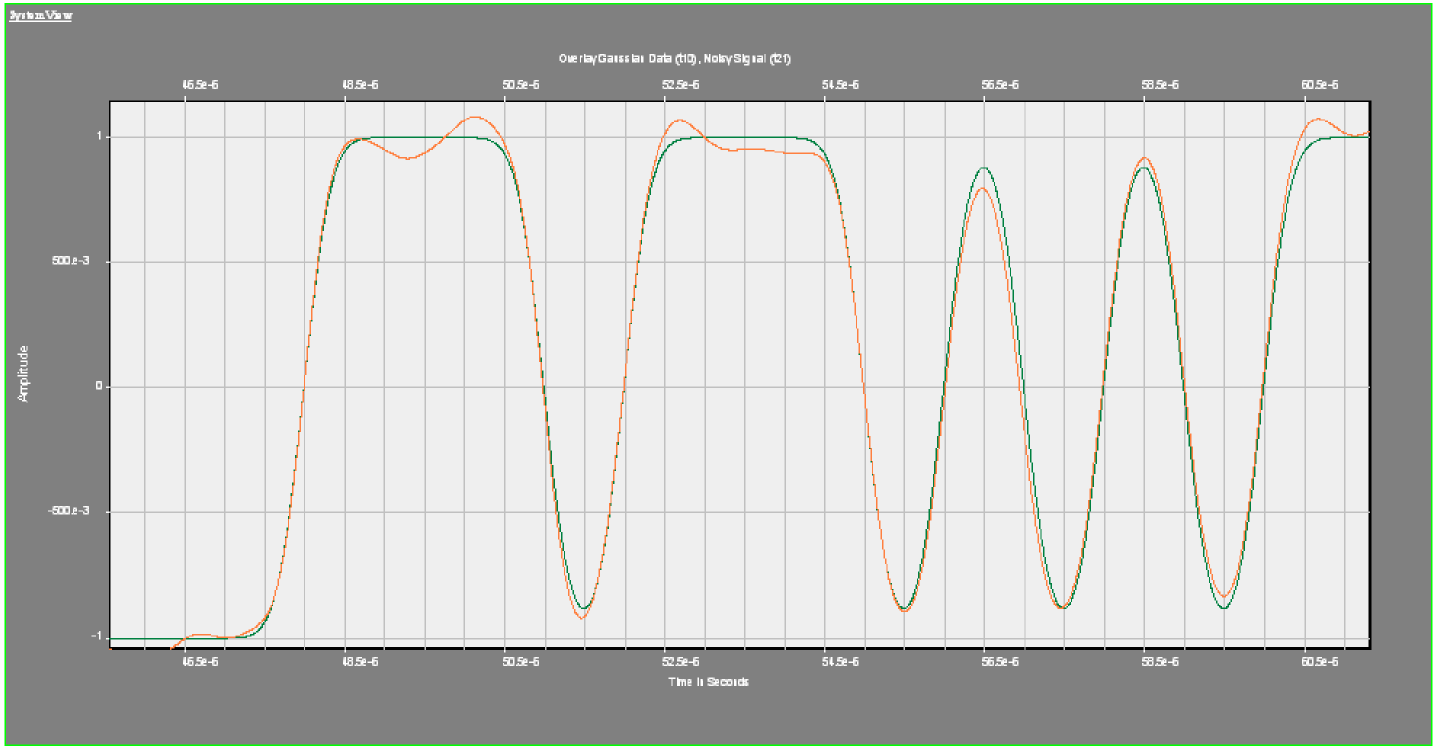
Correlation IC

- **Logo design in 0.25µm CMOS**
  Cooperation with Humboldt University Berlin, Germany
  Clock rate programmable, code length 4096 bits, 3.5 x 6.7 mm²

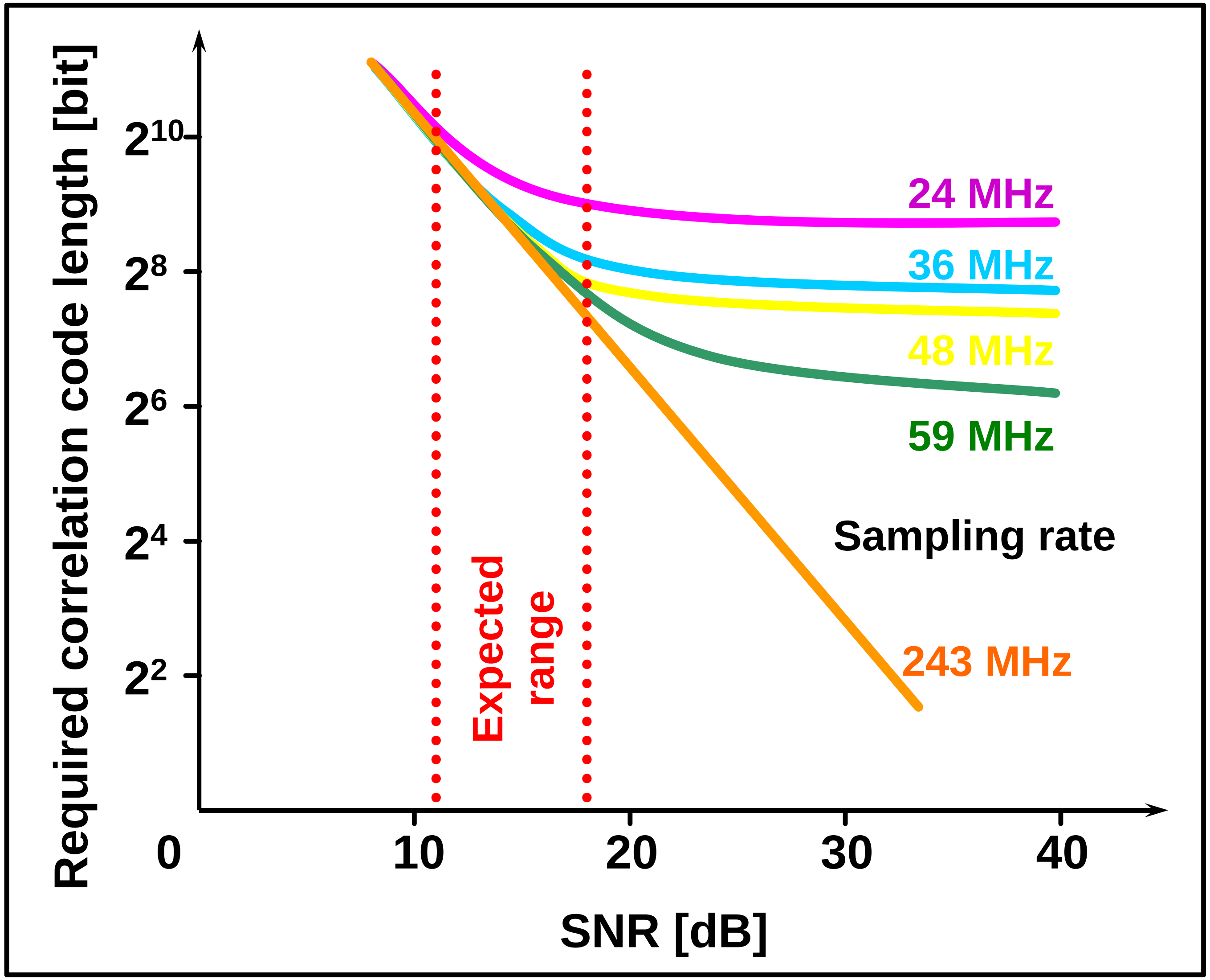


Demodulated Signal

- **Signal-to-noise ratio typically between 12 to 18 dB**
  Signal and noise are low pass filtered
  Cycle-to cycle jitter in the order of several 10 ns

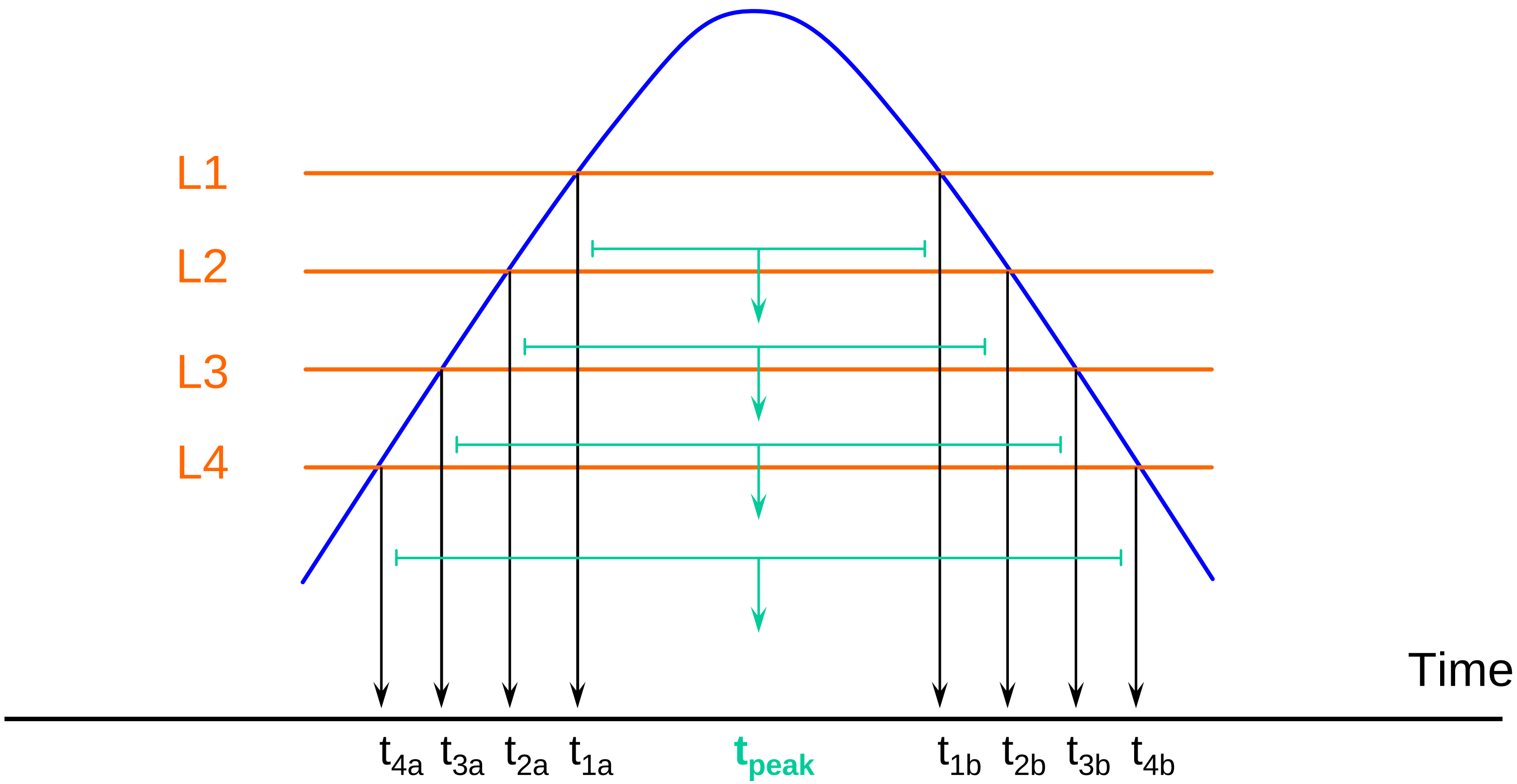


System Simulations

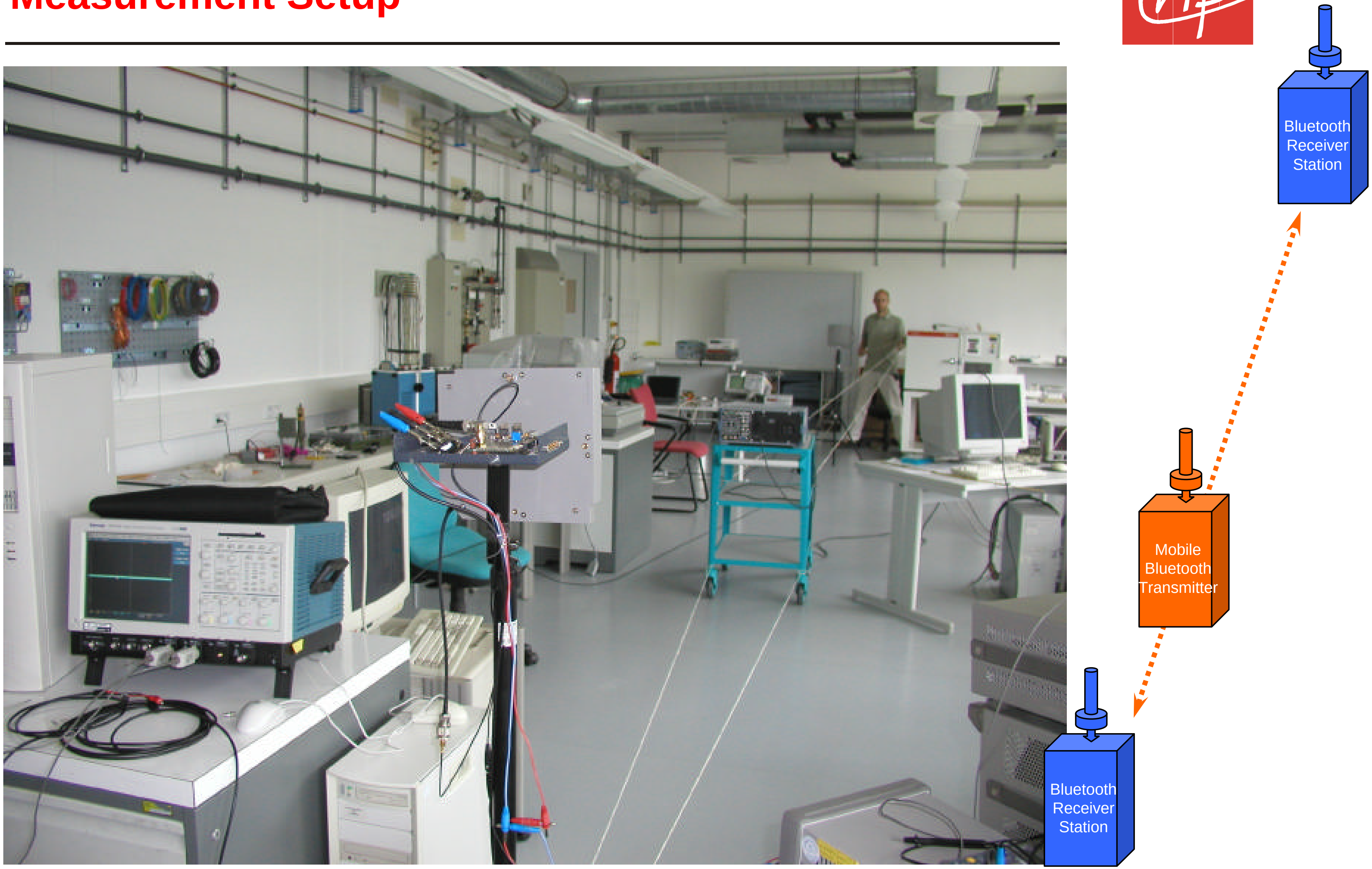


Evaluation of the Correlation Peak

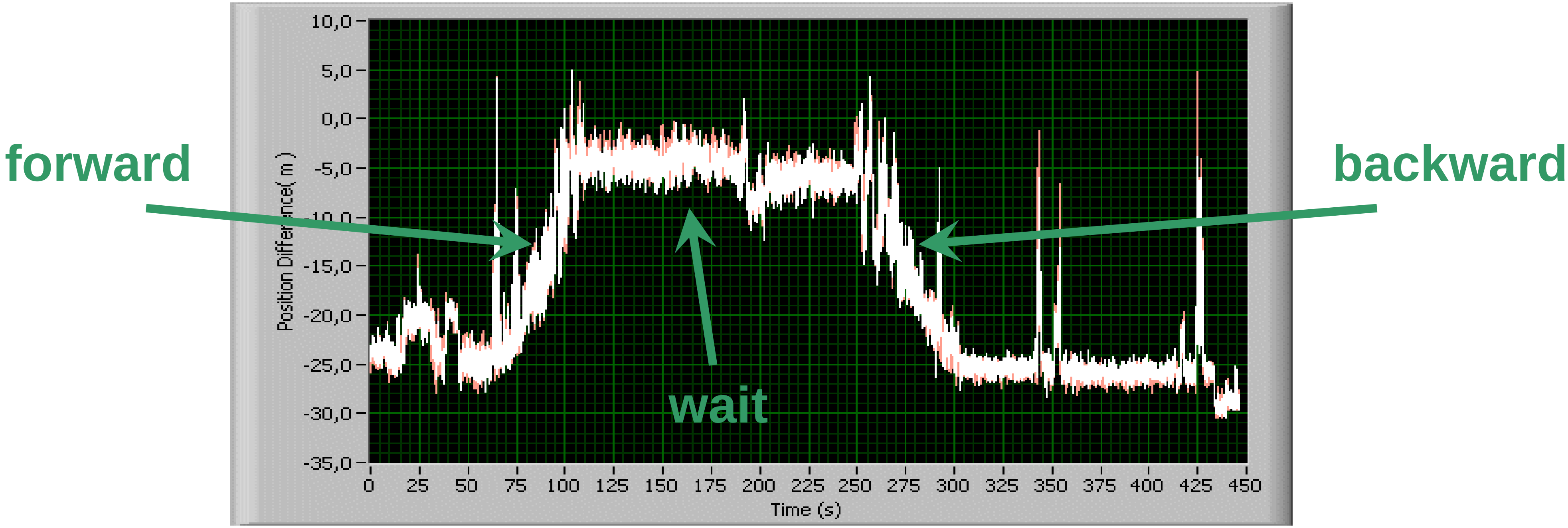
- **Time resolution better than sampling rate**



Measurement Setup



Measurement Results



Summary

- **Bluetooth localization system with ± 1 meter accuracy presented**
  No changes on mobile device required
  Only one data packet necessary for localization

- **Differential time difference of arrival scheme used**
  Base stations don't needed to be synchronized

- **Dedicated cross correlation IC fabricated and tested**
  Made in 0.25µm standard CMOS technology
  Multiplication of 4096 bits in parallel and summation within 1 clock cycle (pipeline structure), works fine with 64 MHz clock rate

- **System implementation is a challenge**
  In essence line-of-sight conditions required
  Best solution is a common integration of the correlation IC with a microcontroller in cooperation with Bluetooth chip manufacturer