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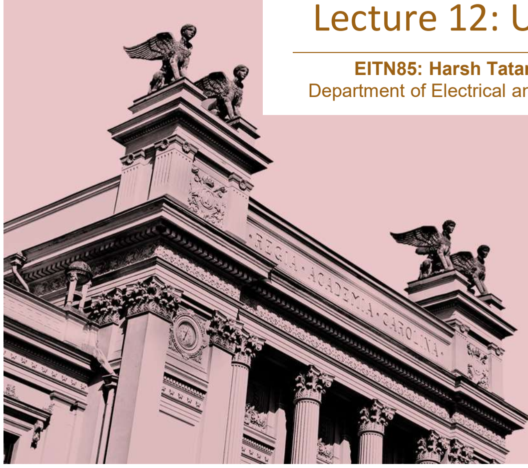

Wireless Communications Channels
Lecture 12: UWB Channel Models

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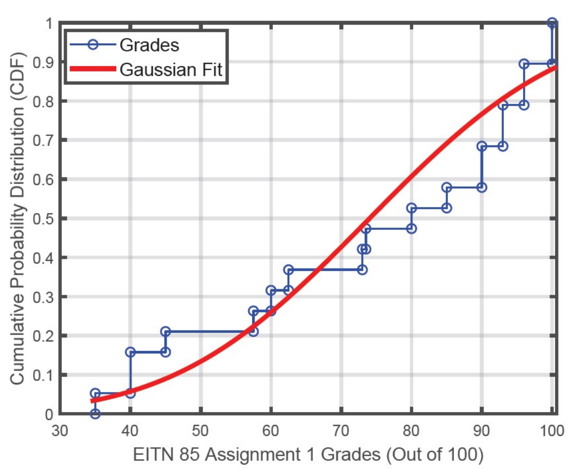
Assignment 1 Grades of EITN85



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Clarrifications in Assignment 2

- In Part II, Section 3.3: **H**(Rx,nTx,f) is size 8x8x201.
- Received signal is given by: **y=Hx+n**

(at a given frequency f)

8x1 received signal

8x1 data vector with all ones as entries

8x1 additive white Gaussian noise vector at the RX array modelled as a Gaussian distribution with mean zero and variance one.

- **r**(t)=**y**(t), and **y**(t) is the channel **impulse response** in the time domain, at a given time t, which is also size 8x1.
- **R**rr is a 8x8 matrix at a given time t, and since there are 201 frequency bins, there are 201 time instances, which the expectation is performed over (201 realizations of **H**).

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Overview

- What is Ultra-Wideband (UWB)?
- Why do we need UWB channel models?
- UWB channel modeling
- Standardized UWB channel models
- Summary

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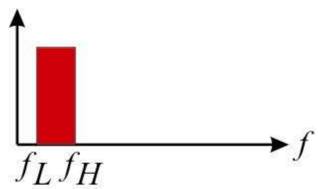
What is Ultra-Wideband (UWB)?

- Transmitted power is spread over an extremely large bandwidth
- Definition: Signals having $f_H - f_L > 500 \text{ MHz}$

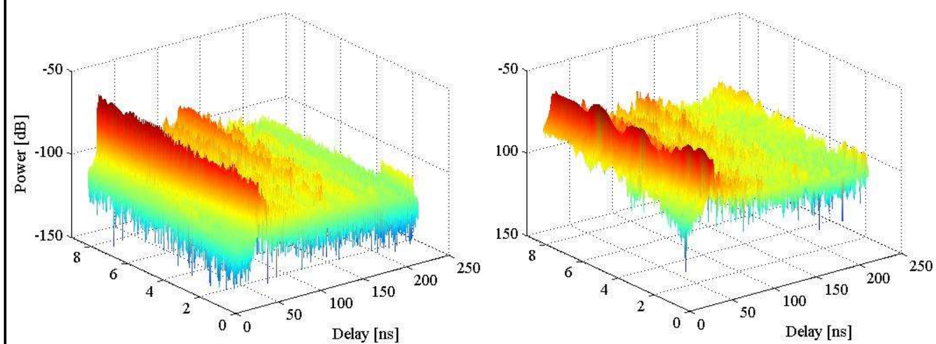


Large Bandwidth Implications

- High resistance to fading
  - Fine delay resolution; impulse response resolved into many delay-bins
  - Fading within each delay-bin is smaller
  - Sum of all bins have even less fading
- Good ranging capability
- Good wall and floor penetration (for some frequency ranges)
  - Low-frequency components can go through material

A Measured Impulse Response

BW = 7.5 GHz   BW = 500 MHz



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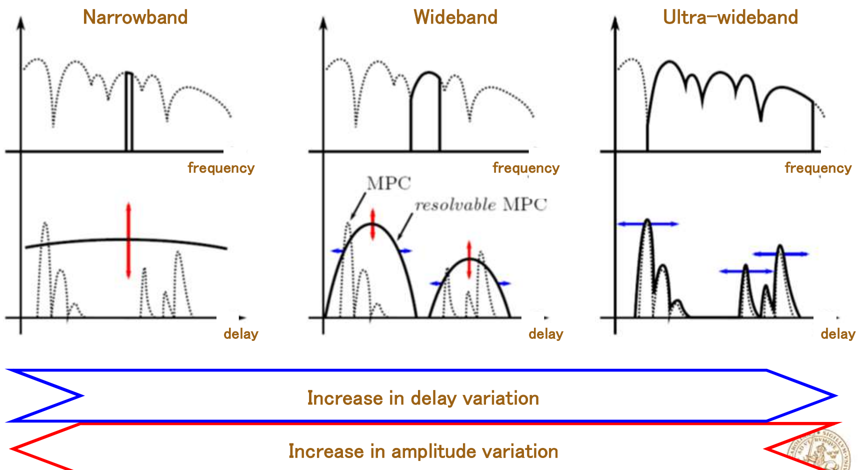
Wireless Channel Bandwidth



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Two Possible UWB Techniques

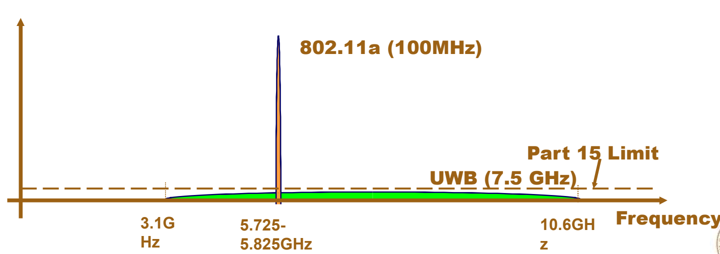
- **Pulse based UWB (impulse radio)**
  - Transmission through ultra short time domain pulses in the baseband
  - Evolution of the radar concept
  - Time hopping codes (Pulse Position Modulation)
- **Multiband OFDM**
  - OFDM-principle with frequency hopping in predefined subbands
  - Generation of UWB signals within carrier based systems
  - Especially for high data rate systems

Basic Principle

UWB makes use of same spectrum as existing services:

1. Information spread over wide spectrum; low power spectral density
2. Very low power

   ⇨ Small interference – looks like noise to other systems



Applications

- Personal area networks
  - Small range
  - Home networks (residential and office environments)
  - Consumer electronics
- Positioning, sensor networks
- Other
  - Military applications (frequency range < 1GHz)
  - Through-wall radars

A Fundamental Question

Q: Why do we need UWB Channel Models?

A: UWB channels are fundamentally different from narrowband channels.

Narrowband channel measurements and modeling cannot be directly reused!

Narrowband vs. UWB Channel Models

- Assumptions about standard wireless channels:
  - "Narrowband" in the RF sense (bandwidth much smaller than carrier frequency
  - WSSUS assumption
  - Complex Gaussian fading (Rayleigh or Rice) in each delay tap
- Specialties of UWB channel:
  - Bandwidth comparable to carrier frequency
  - Different frequency components can "see" different reflection/ diffraction coefficients of obstacles
  - Few c … orem (Gaussian fading) not valid anymore

New channel models are needed!!

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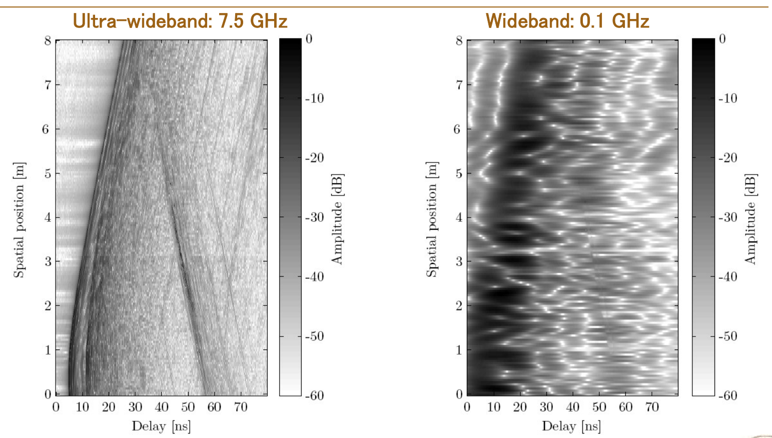
Bandwidth Effect on Delay Tap Amplitude



Ultra–wideband is immune to multipath.

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Propagation Processes

Fundamental propagation processes:

- Free space propagation
- Reflection and transmission
- Diffraction
- Diffuse scattering

All are frequency dependent!

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Free-Space Propagation

Path gain of free-space propagation:

$$G_{\text{path}}(d,f) = \frac{P_{RX}}{P_{TX}} = G_{TX}(f)\,\eta_{TX}(f)\,G_{RX}(f)\,\eta_{RX}(f)\left(\frac{c_0}{4\pi f d}\right)^2$$

where the antenna gain is given by

$$G_{RX}(f) = \frac{4\pi f^2}{c_0^2} A_{RX}(f)$$

Frequency dependent!

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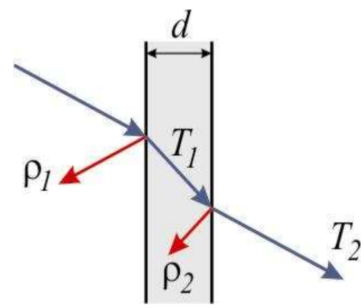
Reflection and Transmission

- Dielectric properties of materials vary with frequency
- Transmission (through two layered structure):

$$T = \frac{T_1 T_2 e^{-j\alpha(f)}}{1 + \rho_1 \rho_2 e^{-j2\alpha(f)}}$$

where the electrical length is given by

$$\alpha(f) = \frac{2\pi}{c_0} f \sqrt{\varepsilon_r} d_{\text{layer}} \cos\theta$$



Frequency dependent!

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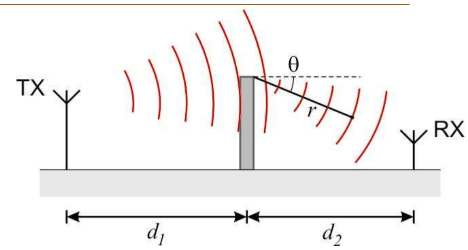
Diffraction

Diffraction from single screen:



Total electric field:

$$E_{\text{total}} = \left(\frac{1}{2} - \frac{e^{j\pi/4}}{\sqrt{2}} F(\nu_F)\right) e^{-jk_0 r}$$

where $F(\nu_F) = \int_0^{\nu_F} e^{-j\pi t^2/2} dt$ and $\nu_F = \theta \sqrt{\frac{2 f d_1 d_2}{c_0 (d_1 + d_2)}}$

Frequency dependent!

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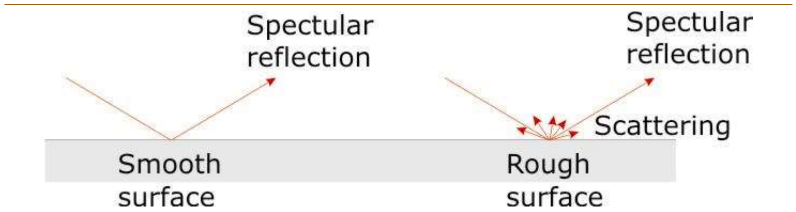
Scattering



Rough scattering according to Kirchoff theory:

$$\rho_{\text{rough}} = \rho_{\text{smooth}} \exp\left[-2\left(k_0 \sigma_{\text{h}} \sin\psi\right)^2\right]$$

Frequency dependent!

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Frequency Dependency of UWB

Propagation phenomina:

Narrowband: 1 MHz
Wideband: 100 MHz
Ultra–wideband: 7500 MHz

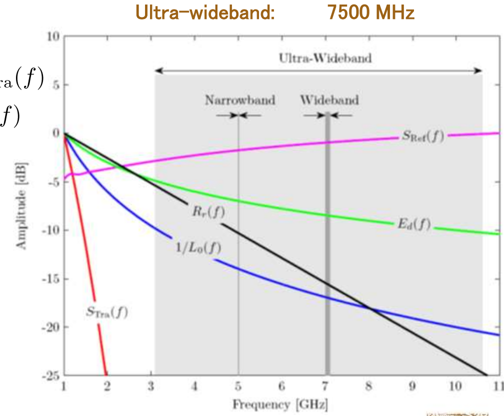
Free–space path–loss $L_0(f)$

Dielectric layer transmission $S_{\text{Tra}}(f)$

Dielectric layer reflection $S_{\text{Ref}}(f)$

Edge diffraction $E_d(f)$

Rough surface scatte$R_r(f)$



all propagation phenominas have a frequency dependency.

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UWB Channel Modeling

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Generic Channel Representation

- Tapped delay line model:

$$h(t,\tau) = \sum_{i=1}^{N} a_i(t)\,\delta(\tau - \tau_i)$$

- For UWB, each MPC show distortion:

$$h(t,\tau) = \sum_{i=1}^{N} a_i(t)\,\chi_i(t,\tau) \otimes \delta(\tau - \tau_i)$$

where $\chi_i(t,\tau)$ is the distortion function.

- Adjacent taps are influenced by a single physical MPC ⇨ WSSUS assumption violated.

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Deterministic Modeling for UWB

- Interaction processes now all depend on frequency and/or direction
- Suggested solutions:
  - perform ray tracing at different frequencies, combine results
  - compute delay dispersion for each interaction process (possibly different for different directions), concatenate
- Combine deterministic rays with diffuse clutter (statistically described)

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Statistical Channel Models

- Modeling of:
  - Pathloss (total power)
  - Large-scale effects
    - Shadowing
    - Delay dispersion (decay time constant)
    - Rice factor
    - Mean angle of arrival
    - "Parameters describing small-scale fading"
  - Small-scale effects
    - Small-scale fading

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Modeling Path Gain

- Narrowband path gain:

$$G_{\text{path}}(d) = \frac{E\{P_{RX}(d, f_c)\}}{P_{TX}} = E\left\{|H(d, f_c)|^2\right\}$$

- For UWB channel, define frequency-dependent path gain:

$$G_{\text{path}}(d, f) = E\left\{\int_{f-\Delta f/2}^{f+\Delta f/2} \left|H\left(\tilde{f}, d\right)\right|^2 d\tilde{f}\right\}$$

- Simplified modeling:

$$G_{\text{path}}(d, f) = G_{\text{path}}(f)\, G_{\text{path}}(d)$$

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Modeling Path Gain (cont'd)

- Distance dependent path gain:

$$G_{\text{path}}(d)|_{\text{dB}} = G_{\text{path}}(d_0)|_{\text{dB}} - 10n\log_{10}\left(\frac{d}{d_0}\right)$$

  - Path loss exponent varies from building to building → can be modeled as a random variable

- Frequency dependent path gain:

$$\sqrt{G_{\text{path}}(f)} \propto f^{-\kappa}$$

  - κ varies between 0.8 and 1.4 (including antennas) and -1.4 and 1.5 (excluding antennas)

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Modeling Large-Scale Fading

Defined as the variations of the local mean around the path gain

- Commonly described as exhibiting a log-normal distribution
- Since large-scale fading is associated with diffraction and reflection effects, a frequency dependence would seem likely
- So far, measurements indicate no frequency dependence of shadowing variance

Multi-Cluster Models

- How is a cluster determined?
- Definition: components of cluster undergo same physical processes
- Extraction from continuous measurements
- Visual extraction from looks of (small-scale-averaged) power delay profile
- Fitting to measurement data
  - Very sensitive to small changes
- Better resolution when spatial information is taken into account

Saleh-Valenzuela Model

- Originally not for UWB [A.M. Saleh, R.A. Valenzuela, 1987]
- MPCs arrive in clusters
- Impulse responses given by

$$h(t) = \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \beta_{kl} e^{j\theta_{kl}} \delta(t - T_l - \tau_{kl})$$

$$\overline{\beta_{kl}^2} \equiv \overline{\beta^2(T_l, \tau_{kl})} = \overline{\beta^2(0,0)} e^{-T_l/\Gamma} e^{-\tau_{kl}/\gamma}$$

- Path interarrival times given by Poisson-distributed arrival process
- Different occurance rates for clusters (Λ) and rays (λ)

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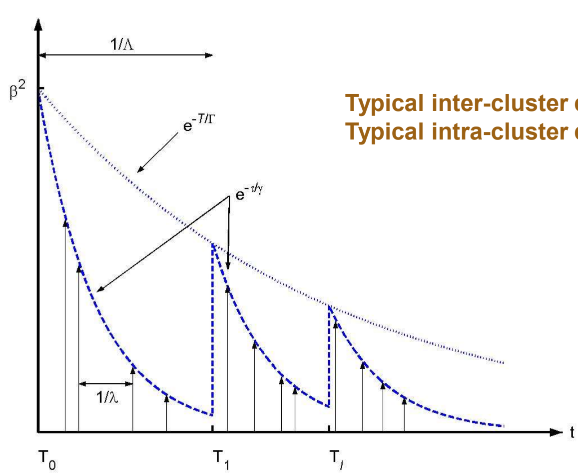
Saleh-Valenzuela Model (cont'd)



Typical inter-cluster decay: 10-30 ns
Typical intra-cluster decay: 1-60 ns

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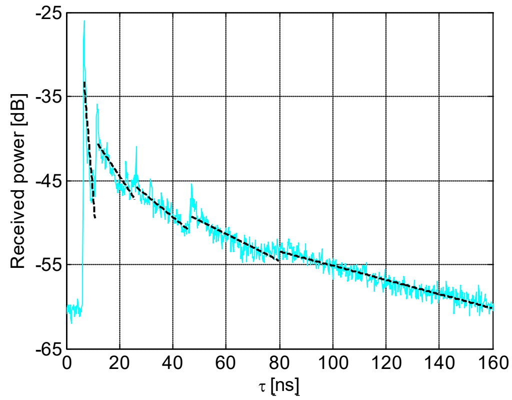
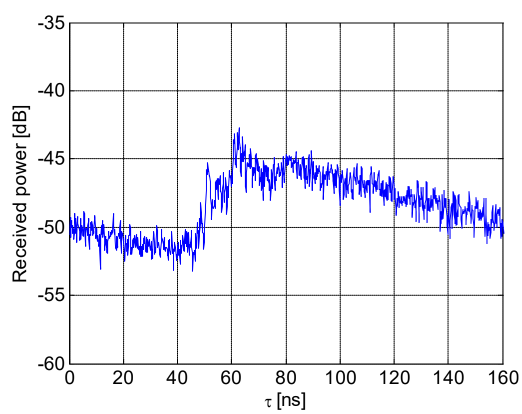
Measured Power Delay Profile (LOS)

From 2m LOS measurement in factory hall:



Measured Power Delay Profile (NLOS)

From NLOS measurement in factory hall:



Generalizations

- Number of clusters as a random variable
- Cluster decay constants and arrival rates change with delay
- Ray arrival rates change with delay
- Cluster power varies due to shadowing
- Path interarrival times
  - Dense channel model - regularly spaced arrival times
  - Sparse channel model - Poisson arrival times

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Small-Scale Fading Statistics

- Measurements report power within each bin being Gamma-distributed, amplitude is m-Nakagami distributed:

$$p(x) = \frac{2}{\Gamma(m)} \left(\frac{m}{\Omega}\right)^m x^{2m-1} \exp\left(-\frac{m}{\Omega} x^2\right)$$

  where m-factors are modeled as random variables

- Fading of delay bins is modeled as uncorrelated

- Phases modeled as uniformly distributed

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Summary

UWB is a promising area for
- home networks (consumer electronics)
- Positioning, sensor networks
- military applications

Fundamental differences of UWB channels to narrowband channels
- Propagation mechanisms processes are frequency dependent
- Different small-scale statistics of fading
- Sparse impulse responses occur

Standard channel models will not work for the UWB channel!