Wireless Communications

EENG 5820

Lecture 6

Shengli Fu

University of North Texas

Dept. of Electrical Engineering

Today

- Small-scale Multipath Propagation
- Impulse Response Model of a Multipath Channel
- Small-scale Multipath Measurements
- Parameters of Mobile Channels

5.1 Small-scale Multipath propagation

What is Multipath Propagation

- Assume that the signal from a mobile user propagates isotropically (equally in all directions).
- When it hits a reflector (building, ground, tree, person, car, etc.) it reflects. *There are likely to be MANY such reflections*.
- The signal received at any point is the sum of the incident and reflected signal(S), each with a different delay and attenuation.
- MOTION: Either the reflector or mobile or both will probably be moving, so the multipath will be constantly changing.
- These signals may interfere *constructively* or *destructively*, and the result will be a combination of large and small magnitudes, depending on the location. (FADING)

5.1.1 Small-scale Multipath Propagation

Factors affect multipath

- Reflectors in the channel
- Speed of mobile
- Motion of reflectors
- Bandwidth of the signal
  - BW_sig > BW_ch: distortion dominates
    - Coherence bandwidth: maximum frequency for which signals are still correlated in amplitude
  - BW_sig < BW_ch: fading dominates

5.1.1 Small-scale Multipath Propagation

- **What are the effects of Multipath?**
  - Fading: rapid changes in signal strength over small change in distance or time
    - Both mobile and/or environment may be moving
  - Doppler shift: random change in frequency modulation because of motion
    - Coherence time: staticness of the channel
  - Echoes: time delay (dispersion) of signals, ISI

5.1.2 Doppler Shift

$$\Delta l = d\cos\theta = v\Delta t\cos\theta$$

$$\Delta\phi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}$$

$$f_d == \frac{1}{2\pi}\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cos\theta$$

Doppler Shift

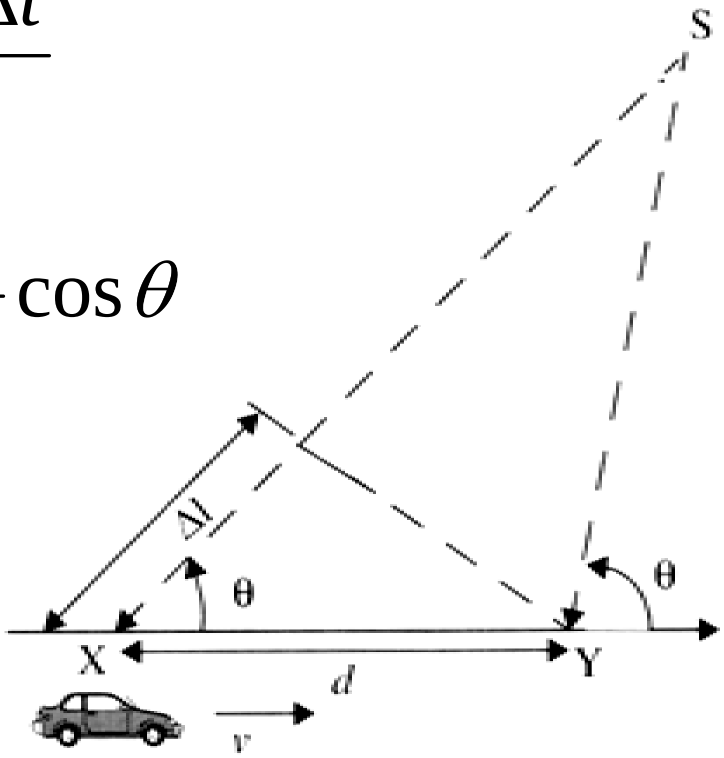


Figure 5.1 Illustration of Doppler effect.

5.1.2 Doppler Shift

- **Example 5.1**

  TX with $f_c = 1850$ MHz, vehicle speed 60 mph, compute the received carrier frequency if the mobile is moving

  a) directly towards the transmitter

  b) directly away from the transmitter

  c) in a direction which is perpendicular to the direction of arrival of the transmitted signal.

  d) How about $f_c = 915$ Mhz

5.1.2 Doppler Shift

Significance

- Higher frequencies: more problems with Doppler shift
- This is Not too much trouble for tuning/electronics, because it is small frequency change
- This IS a problem for the modulation schemes
- Narrow band systems (all the same Doppler shift) have more trouble than broad band (spread spectrum) (different Doppler shifts) systems, in general

5.1.2 Doppler Shift

Echoes

- Time delay of signal produces echoes.
- It is possible for the echo to be as large or larger than the original signal.
- Analysis: same as for Doppler shift, except this is TIME instead of DOPPLER shift.

Significance

- In an analog system, the echo will be "heard" directly as an echo.
- In a digital system, the echo (which is copy of bit streams) can mess up bits and completely distort the signal (garble).
- The echo is particularly troublesome when trying to synchronize systems (like CDMA).
- Echo cancellation software can be used.

5.2 Impulse Response Model of a Multipath Channel

Linear Filter

- The channel can be modeled as a linear filter that changes with time (and location of the TX, RX)

$$y(d,t) = x(t) \otimes h(d,t) = \int_{-\infty}^{t} x(\tau)h(d,t-\tau)d\tau$$

What can linear filters (the channel) do

- Delay signals (multipath)
- Attenuate signals (fading)
- Amplify signals (constructive)

5.2 Impulse Response Model of a Multipath Channel

- **Discrete channel impulse response**
  - Rather than considering a continuous variation in time between waves, they are divided into discrete "bins" of excess time delay for convenience.

$$y(d,t) = x(t) \otimes h(d,t) = \int_{-\infty}^{t} x(\tau) h(d, t-\tau) d\tau$$

$$y(d,t) = \int_{-\infty}^{t} x(\tau) h(vt, t-\tau) d\tau = x(t) \otimes h(vt,t)$$

- **The impulse response of *$h(t,\tau)$* is a function of t and τ (adjustment of time)**

$$y(t) = \int_{-\infty}^{\infty} x(\tau) h(t,\tau) d\tau = x(t) \otimes h(t,\tau)$$

5.2 Impulse Response Model of a Multipath Channel

Power received

- Received power is the sum of the received power from each multipath signal. This is true for both narrowband (pulsed) and CW systems.
- If the bandwidth of the TX is LARGER than the bandwidth of the channel (filter), the channel WILL reduce the signal (it will be filtered). You can think of this as "some of the TX power is reflected away from the RX.” BUT this affect does not vary significantly over space. All points in space have about the same RX power (though it would not have arrived at the same TIME). There are no deep nulls.
- If the bandwidth of the TX is SMALLER than the bandwidth of the channel (a CW signal, and most cell phone signals), the signal will still be filtered, and this filtering WILL vary strongly with location. There will be deep fading nulls.

$$y(t) = \int_{-\infty}^{\infty} x(\tau)h(t,\tau)d\tau = x(t)\otimes h(t,\tau)$$

$$h_b(t,\tau) = \sum_{i=0}^{N-1} a_i(t,\tau)\exp\left[j(2\pi f_c\tau_i(t)+\phi_i(t,\tau))\right]\delta(\tau-\tau_i(t))$$

5.3 Small-scale Multipath Measurements

- **In practice, channels are more often measured than predicted. There are too many parameters to be considered for predication models unless the scope of the location is very localized.**
- **Three Types of Measurements:**
  - Direct RF Pulse
  - Spread Spectrum Sliding Correlator Channel Sounding
  - Frequency Domain Channel Sounding

5.3.1 Direct RF Pulse System

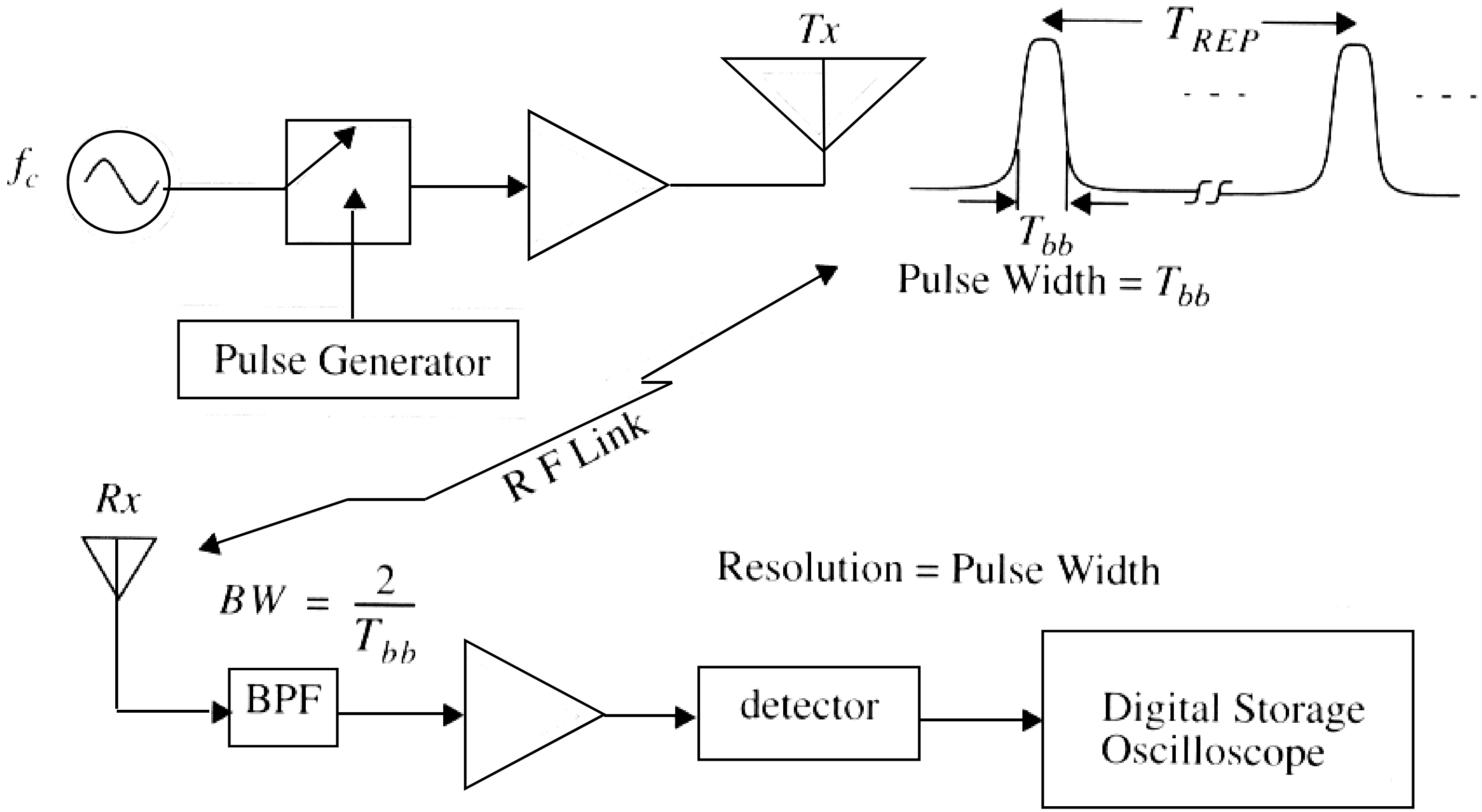


Figure 5.6 Direct RF channel impulse response measurement system.

5.3.1 Direct RF Pulse System

Advantages

- Immediate measurement
- Simple, equipment readily available

Disadvantages

- Wide band band pass filter (BPF) also picks up noise and interference (imagine trying to measure a cell phone channel in downtown LA with everyone else's cell phone turning on and off at random. The other cell phones are not part of the channel, yet they are definitely going to corrupt the measurements. Consequently, this system can only be practically used in isolated environments (inside buildings where users can be controlled, in an area without present coverage, etc.)
- The ability to trigger the oscilloscope on the first arriving signal

5.3.2 Spread Spectrum Sliding Correlator Channel Sounding

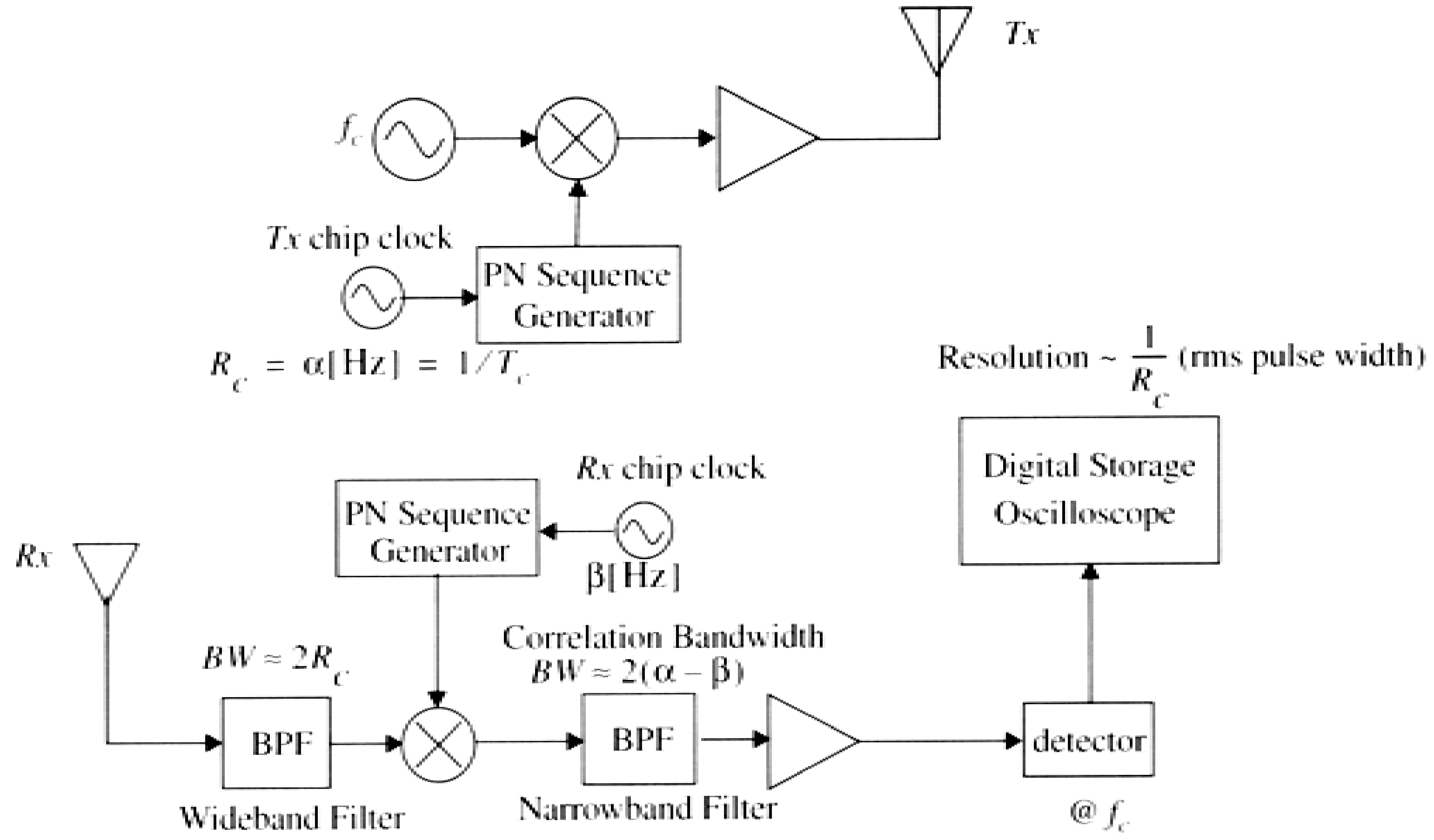


Figure 5.7 Spread spectrum channel impulse response measurement system.

5.3.2 Spread Spectrum Sliding Correlator Channel Sounding

- **TX: Frequency Hopped Spread Spectrum.**
- **The Data is modulated (as in FSK) at baseband and will be mixed with the carrier wave.**
- **The total frequency band available for the phone is divided into hundreds or thousands of subbands. The carrier wave will be "pseudo-randomly" HOPPED around these subbands.**
    - Fast hopping means it hops within the time one bit of data is transmitted.
    - Slow hopping means it sends several bits of data on each of its frequency hops.
- **The PN (pseudo noise) code generator determines which of these subbands the frequency is hopped to.**
- **The CODE CLOCK determines how fast the PN code generator changes (fast or slow hopping).**
- **IF the code clocks on RX and TX are synchronized, the system will pick up ONLY the primary signal, no multipath. (Assuming the multipath elements are delayed by more than a clock cycle.)**

5.3.3 Frequency Domain Channel Sounding

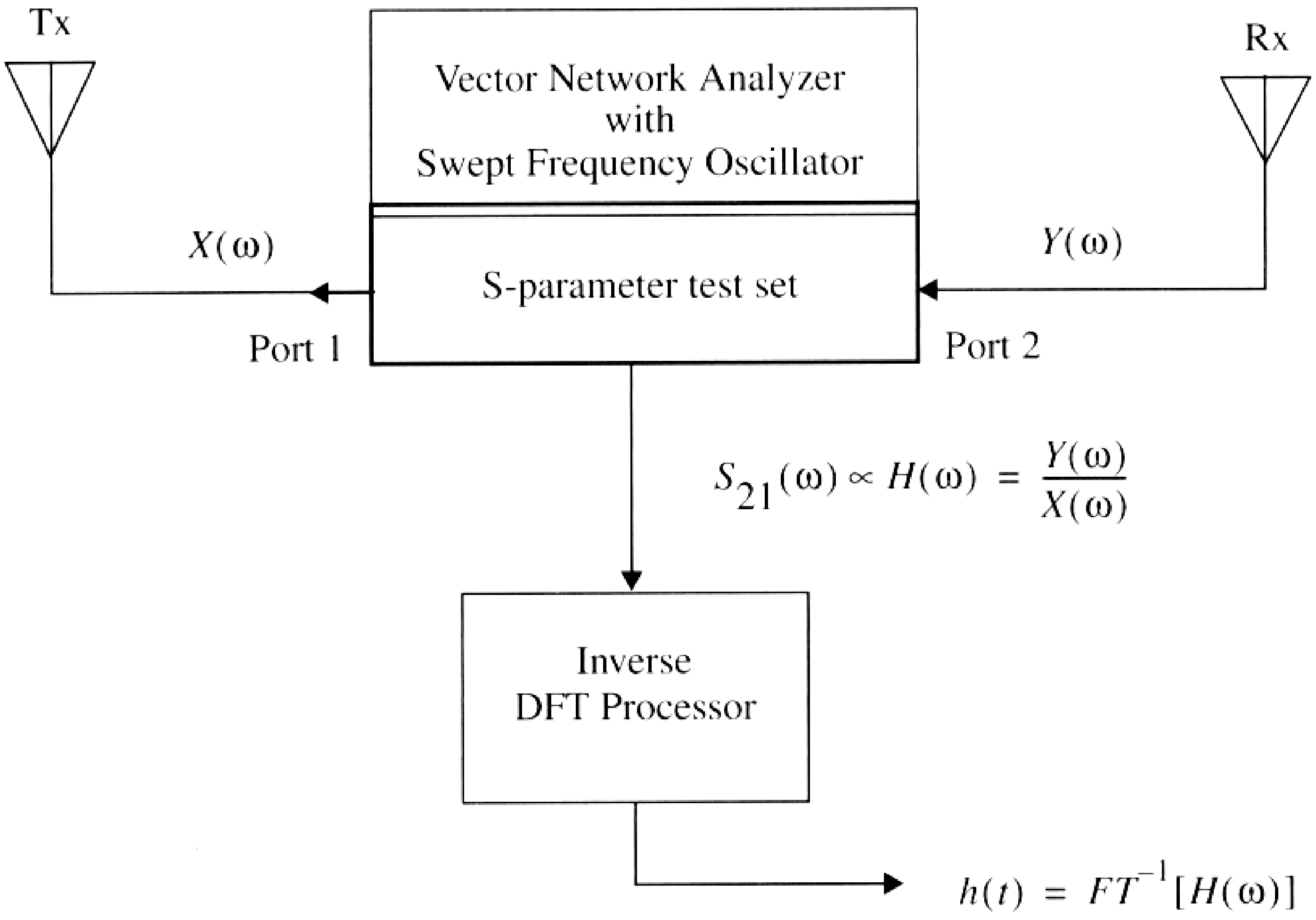


Figure 5.8 Frequency domain channel impulse response measurement system.

5.3.3 Frequency Domain Channel Sounding

- **Advantages**
  - Most common method for indoor channel sounding
  - Vector network analyzer
- **Disadvantages**
  - Requires hard-wired synchronization between RX and TX
  - Time-varying channel will not be correctly analyzed (missed waiting for the stepped frequencies in the network analyzer: fast sweep)

Rohde&Schwarz ZVB Vector Network Analyzer

5.4 Parameters of Mobile Multipath Channels

Time dispersion parameters

$$h_b(t,\tau)=\sum_{i=0}^{N-1} a_i(t,\tau)\exp\left[j(2\pi f_c\tau_i(t)+\phi_i(t,\tau))\right]\delta(\tau-\tau_i(t))$$

Mean excess delay

$$\tilde{\tau}=\frac{\sum_k a_k^2\tau_k}{\sum_k a_k^2}=\frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

rms excess delay

$$\sigma_\tau=\sqrt{\bar{\tau}^2-(\tilde{\tau})^2}$$

$$\bar{\tau}^2=\frac{\sum_k a_k^2(\tau_k)^2}{\sum_k a_k^2}=\frac{\sum_k P(\tau_k)(\tau_k)^2}{\sum_k P(\tau_k)}$$

Maximum excess delay (dB): $\tau_X - \tau_0$: within X dB of the strongest arriving path signal

5.4.1 Time Dispersion Parameters

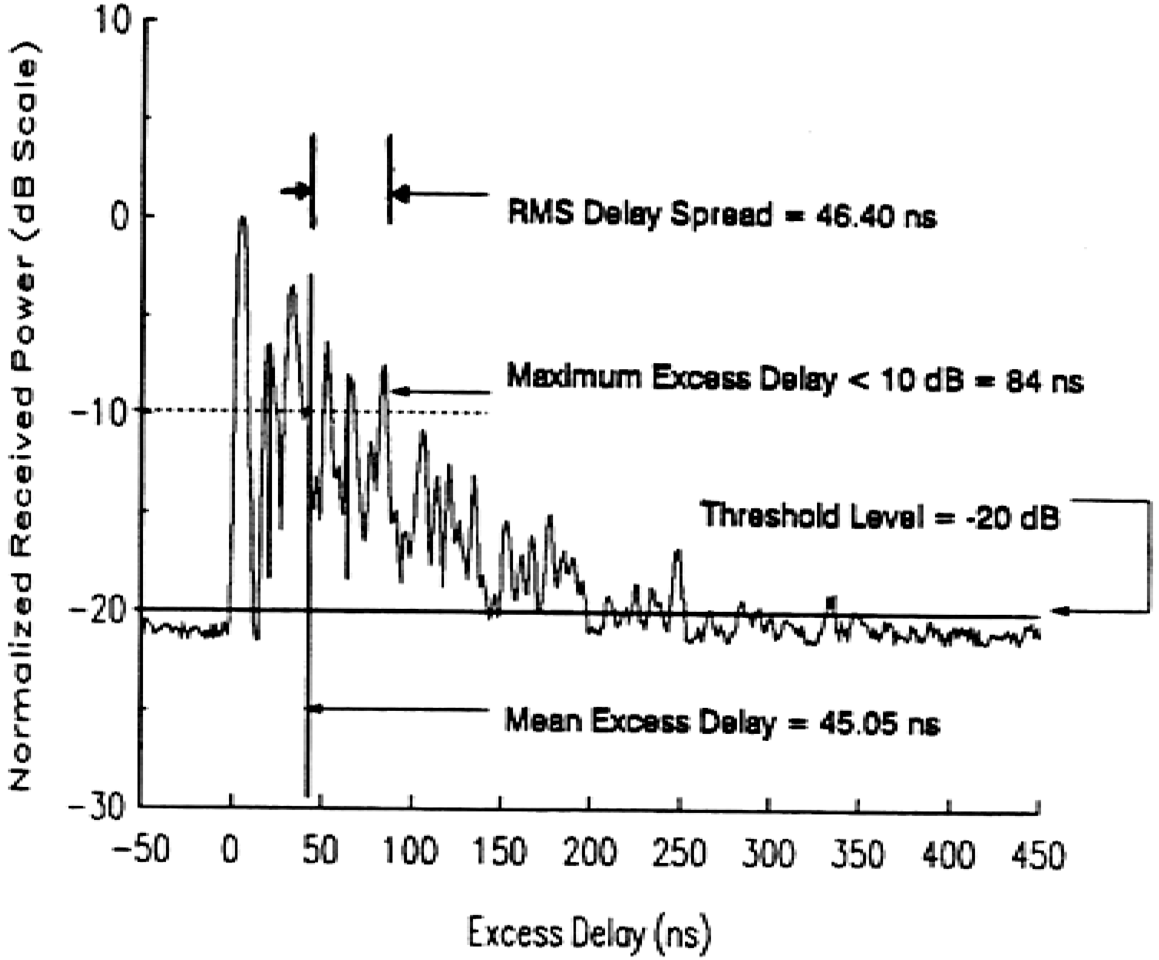


Figure 5.10 Example of an indoor power delay profile; rms delay spread, mean excess delay, maximum excess delay (10 dB), and threshold level are shown.

5.4.1 Time Dispersion Parameters

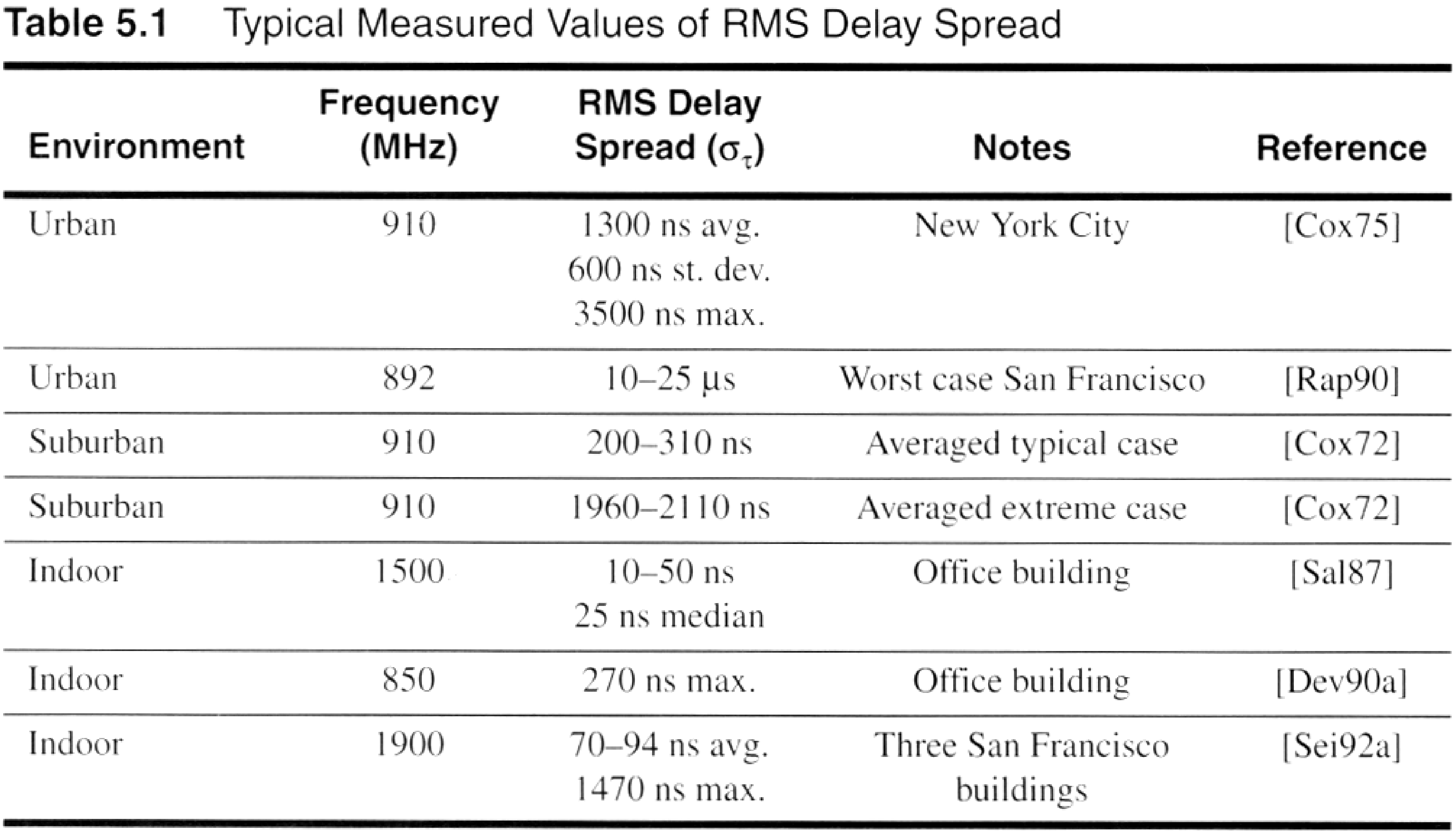


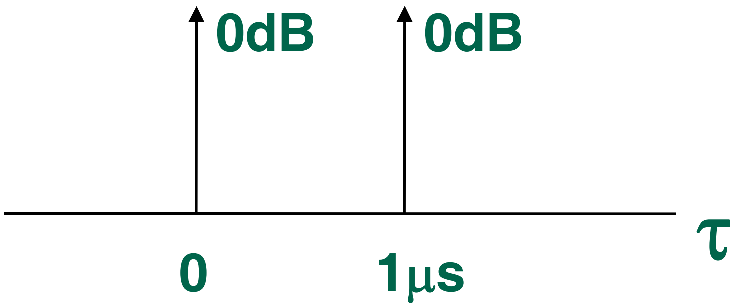
Table 5.1 Typical Measured Values of RMS Delay Spread

Environment	Frequency (MHz)	RMS Delay Spread (σ_τ)	Notes	Reference
Urban	910	1300 ns avg. 600 ns st. dev. 3500 ns max.	New York City	[Cox75]
Urban	892	10–25 μs	Worst case San Francisco	[Rap90]
Suburban	910	200–310 ns	Averaged typical case	[Cox72]
Suburban	910	1960–2110 ns	Averaged extreme case	[Cox72]
Indoor	1500	10–50 ns 25 ns median	Office building	[Sal87]
Indoor	850	270 ns max.	Office building	[Dev90a]
Indoor	1900	70–94 ns avg. 1470 ns max.	Three San Francisco buildings	[Sei92a]

5.4.1 Time Dispersion Parameters

Example 5.4

a) Compute RMS delay



5.4.2 Coherence Bandwidth

- Coherence bandwidth: a statistical measure of the range of frequencies over which the channel can be considered as “flat” (equal gain and linear phase)
- Frequency correlation = 0.9: $1/(50\sigma_\tau)$
- Frequency correlation = 0.5: $1/(5\sigma_\tau)$

5.4.3 Doppler Spread and Coherence Time

- **Doppler Spread B_D**

$$f_d == \frac{1}{2\pi}\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cos\theta = B_D$$

- **Coherence Time: *T_c***
  - Measure of length of time that channel impulse response is almost invariant
- **For a time correlation of 0.5**

$$T_C \cong \frac{9}{16\pi f_m}$$

Homework

- 5.1, 5.2, 5.5, 5.6, 5.16, 5.27, 5.28