Mobile Radio Propagation

Small Scale Fading and Multipath

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Wireless Communications

Principles and Practice

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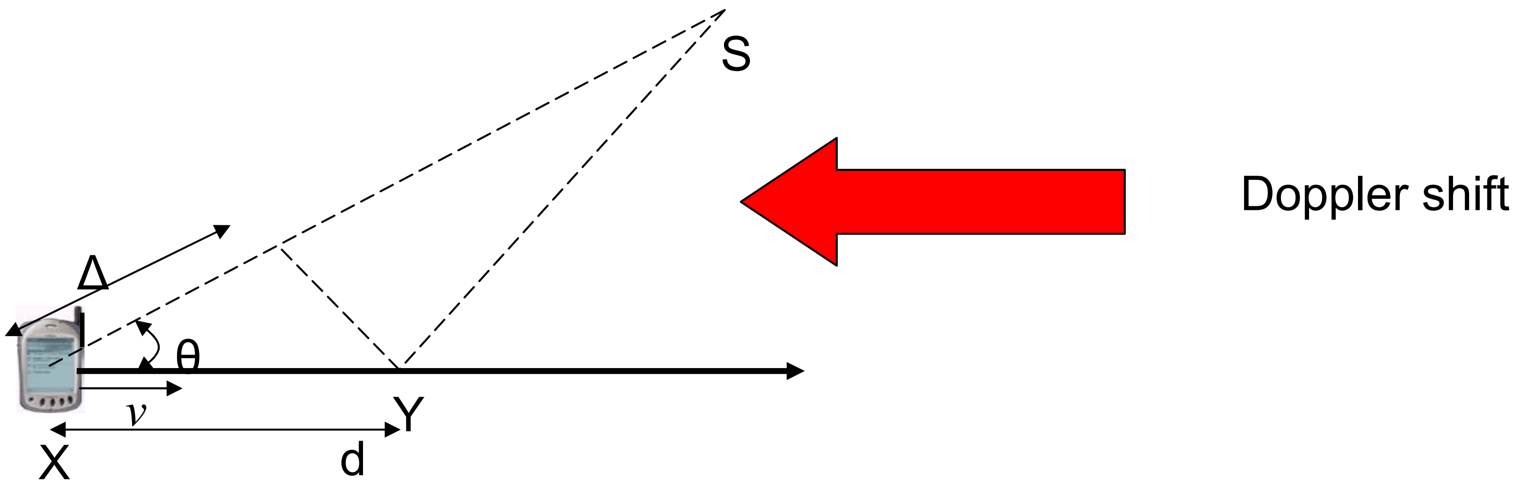
Small Scale Fading and Multipath

- Small scale fading is used to describe the rapid fluctuations over a short period of time or distance (*either amplitude or phase and multipath delay*)
- Fading is caused by interference between two or more signals which arrive at the receiver at a slightly different time (*multipath waves*)

Small Scale Fading and Multipath

- Due to the multipath, the small scale fading effects could by summarized as
  - Rapid change in signal strength over a small travel distance or time
  - Random Frequency modulation due to varying Doppler shifts on different multipath signals
  - Time dispersion (echoes) caused by propagation delays



Small Scale Fading and Multipath

- **Doppler shift**
  - As illustrated in the figure
  - The difference in path lengths, Δl, equals dcos(θ) = vΔtcos(θ),

where Δt is the time required to Y from X

- The phase change in the received signal due to Δl is therefore

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

- And the change in frequency, Doppler shift, is given by

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

If the Doppler shift is positive ⇒ the apparent frequency is increased and the mobile is moving toward the direction of arrival of the wave

Small Scale Fading and Multipath

Example 4.1

Consider a transmitter which radiates a sinusoidal carrier frequency of 1850 MHz. For a vehicle moving 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.

Solution to Example 4.1

Given:

Carrier frequency $f_c = 1850\,\text{MHz}$

Therefore, wavelength $\lambda = c/f_c = \dfrac{3 \times 10^8}{1850 \times 10^6} = 0.162\,\text{m}$

Vehicle speed $v = 60$ mph $= 26.82$ m/s

(a) The vehicle is moving directly towards the transmitter.

The Doppler shift in this case is positive and the received frequency is given by equation (4.2)

$$f = f_c + f_d = 1850 \times 10^6 + \frac{26.82}{0.162} = 1850.00016 \text{ MHz}$$

(b) The vehicle is moving directly away from the transmitter.

The Doppler shift in this case is negative and hence the received frequency is given by

Small Scale Fading and Multipath

$$f = f_c - f_d = 1850 \times 10^6 - \frac{26.82}{0.162} = 1849.999834 \text{ MHz}$$

(c) The vehicle is moving perpendicular to the angle of arrival of the transmitted signal.
In this case, $\theta = 90°$, $\cos\theta = 0$, and there is no Doppler shift.
The received signal frequency is the same as the transmitted frequency of 1850 MHz.

Small –Scale Multipath Measurements

In order to determine the small-scale fading effects, a number of wideband channel sounding techniques have been developed:

-Direct pulse measurements

-Spread spectrum sliding correlator measurements, and

-Swept frequency measurements

Direct RF Channel impulse Measurements

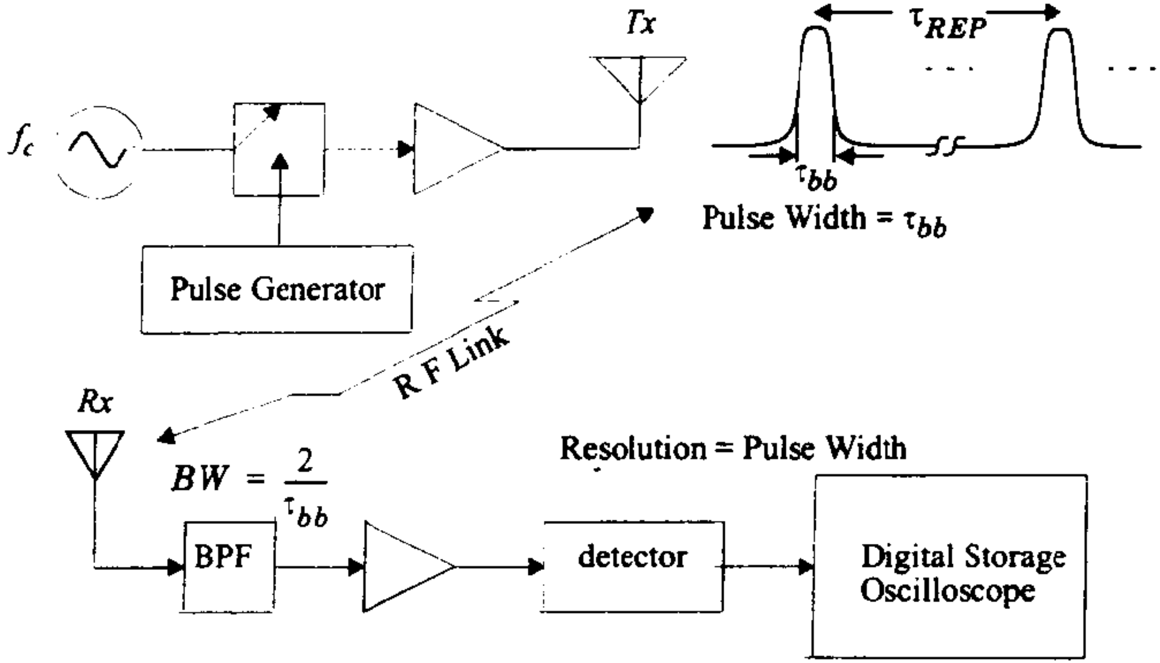


Figure 4.6
Direct RF channel impulse response measurement system.

- The system is simple but the main problem with systems is that it is a subject to interference and noise, due to the wide passband filter.
- The individual multipath components are not received, due to the use of envelope detector

Spread Spectrum Sliding correlator Channel Sounding

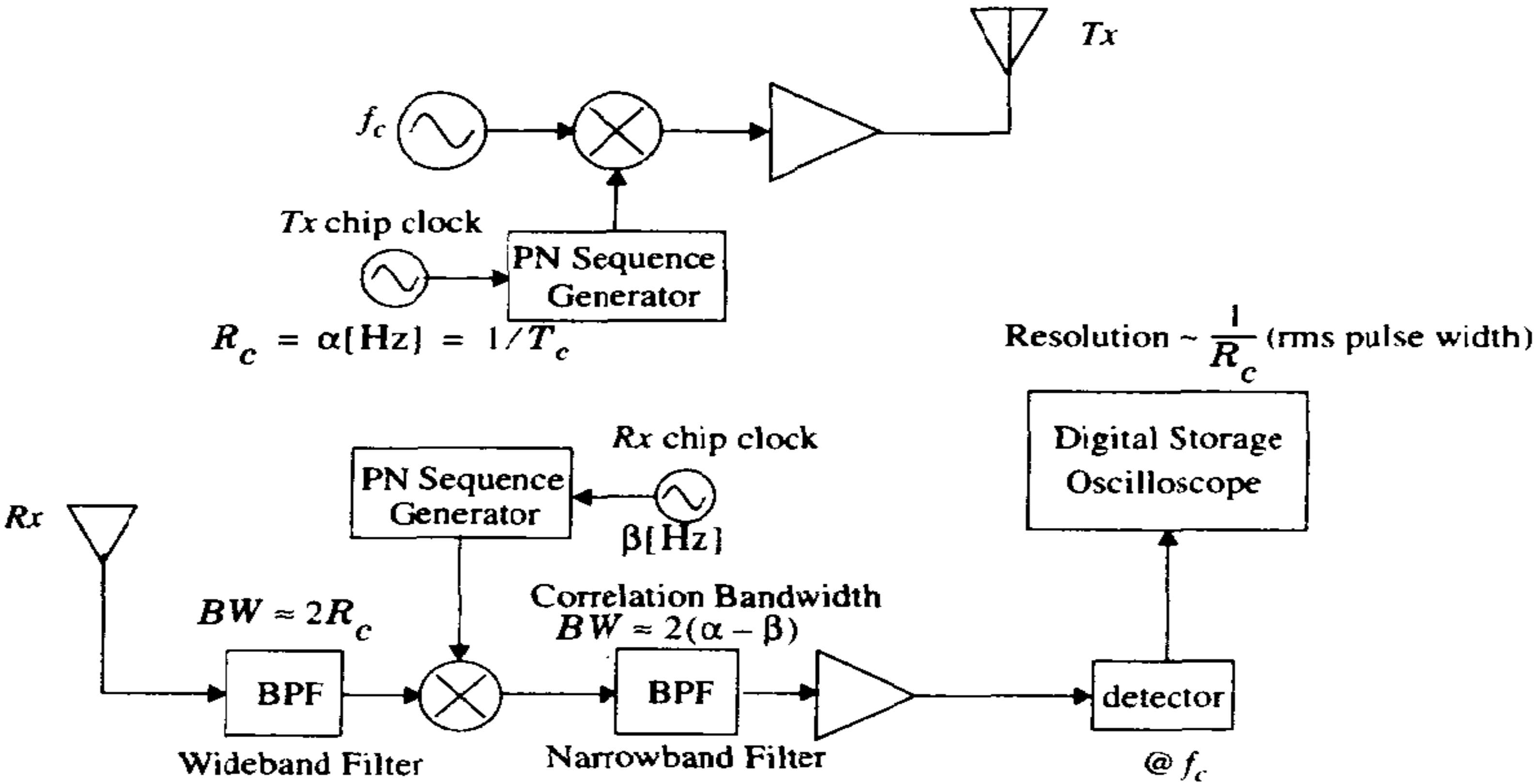


Figure 4.7
Spread spectrum channel impulse response measurement system.

Spread Spectrum Sliding correlator Channel Sounding

- In this system, we use a narrowband filter to improve the dynamic range of the system.
- The carrier is spread over a large bandwidth by mixing it with a binary PN generator having a chip duration T_C and chip rate $R_C=1/T_C$
- The power of transmitted spread spectrum signal is

$$S(f) = \left[\frac{\sin \pi (f - f_c) T_c}{\pi (f - f_c) T_c}\right]^2$$

The time resolution of multipath components is

$$\Delta\tau = 2T_c = \frac{2}{R_c}$$

Spread Spectrum Sliding correlator Channel Sounding

The sliding correlation process gives equivalent time measurements that updated every time the two sequences are maximally correlated. The time between maximal correlations (T) can be calculated as

$$\Delta T = T_c \gamma l = \frac{\gamma l}{R_c}$$

where T_c = chip period (s)
R_c = chip rate (Hz)
γ = slide factor (dimensionless)
l = sequence length (chips)

The slide factor is defined as

$$\gamma = \frac{\alpha}{\alpha - \beta}$$

where α = transmitter chip clock rate (Hz)
β = receiver chip clock rate (Hz)

Spread Spectrum Sliding correlator Channel Sounding

The narrowband processing, eliminating much of passband noise and interference. The bandwidth of narrowband filter

$$(BW = 2(\alpha - \beta)).$$

$$\text{Actual Propagation Time} = \frac{\text{Observed Time}}{\gamma}$$

The sequence length must have a period which is greater than the longest multipath propagation delay. The PN sequence period is

$$\tau_{PNseq} = T_c l$$

Spread Spectrum Sliding correlator Channel Sounding

Advantages:

1- The ability to reject passband noise.

2- Sensitivity is adjustable by changing the sliding factor and the post-correlator filter bandwidth.

3- low power compared to direct pulse systems.

Disadvantages:

1- Measurements are not made in real time, but they are complied as the PN codes slide past one another.

2- Noncoherent detector is used, so that phases of individual multipath components can not be measured

Parameters of Mobile Multipath Channels

- Time Dispersion Parameters
- Coherence bandwidth
- Doppler Spread and Coherence Time

Time Dispersion Parameters

- **Mean excess delay**
- **rms delay spread**
- **Excess delay spread (X dB)**

Mostly; mean excess delay and rms delay spread quantified the time dispersive properties

Time Dispersion Parameters

- Mean excess delay

It's the first moment of the power delay profile

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

- rms delay spread

It's the square root of the second moment of the power delay profile

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

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