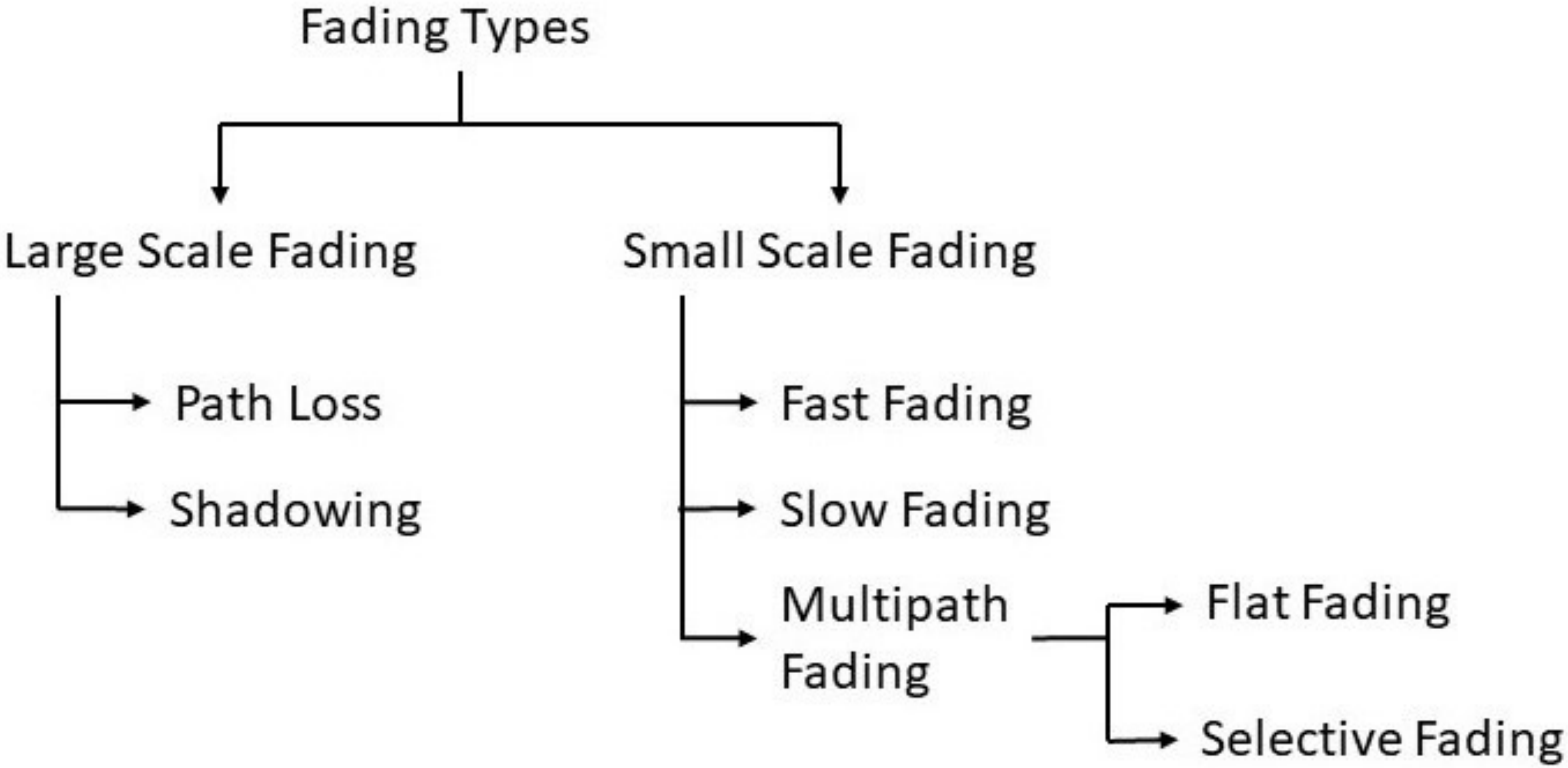
Unit 3 – Small Scale Fading


Fading Types
Large Scale Fading
Small Scale Fading
Path Loss
Shadowing
Fast Fading
Slow Fading
Multipath Fading
Flat Fading
Selective Fading

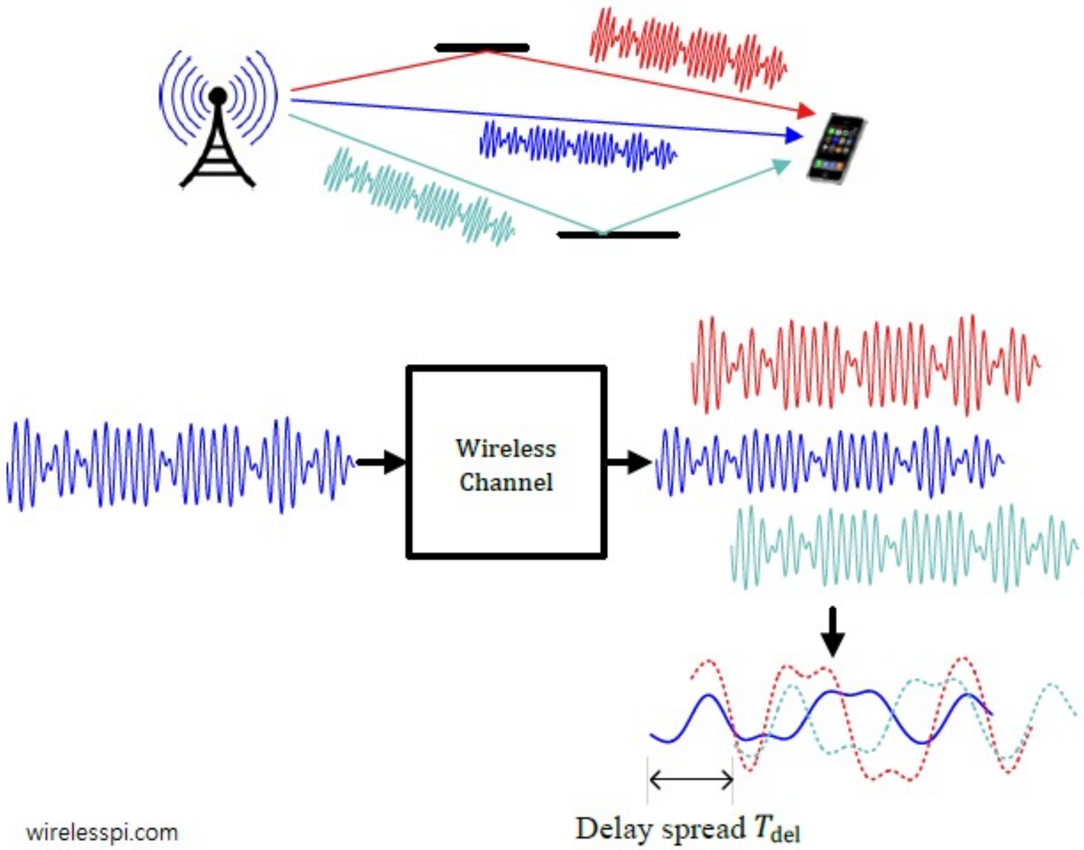
Small-Scale Multipath Propagation

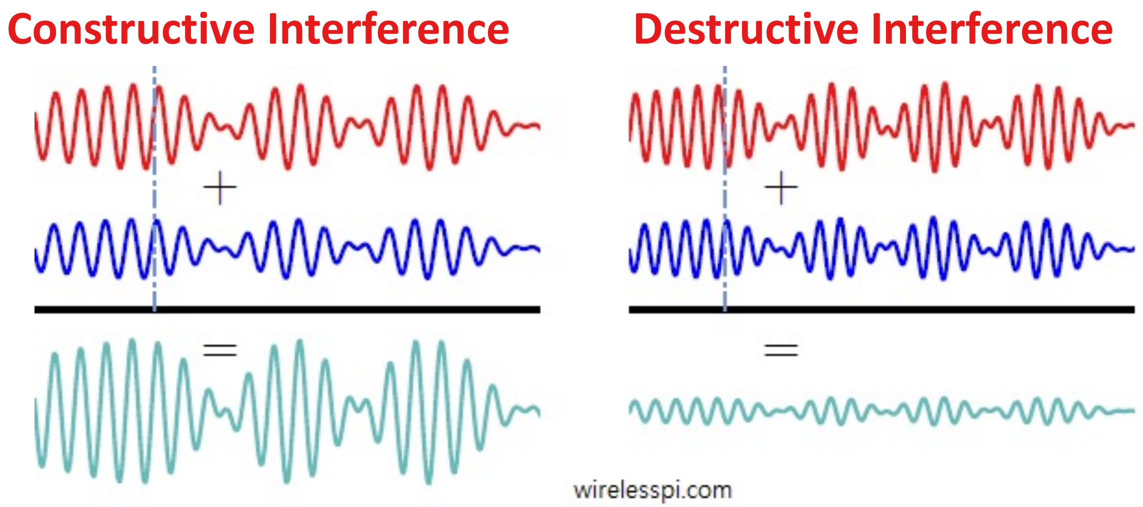
Multipath in the radio channel creates small-scale fading effects. The three most important effects are:

- Rapid changes in signal strength over a small travel distance or time interval
- Random frequency modulation due to varying Doppler shifts on different multipath signals
- Time dispersion (echoes) caused by multipath propagation delays.

Factors Influencing Small-Scale Fading

Multipath propagation

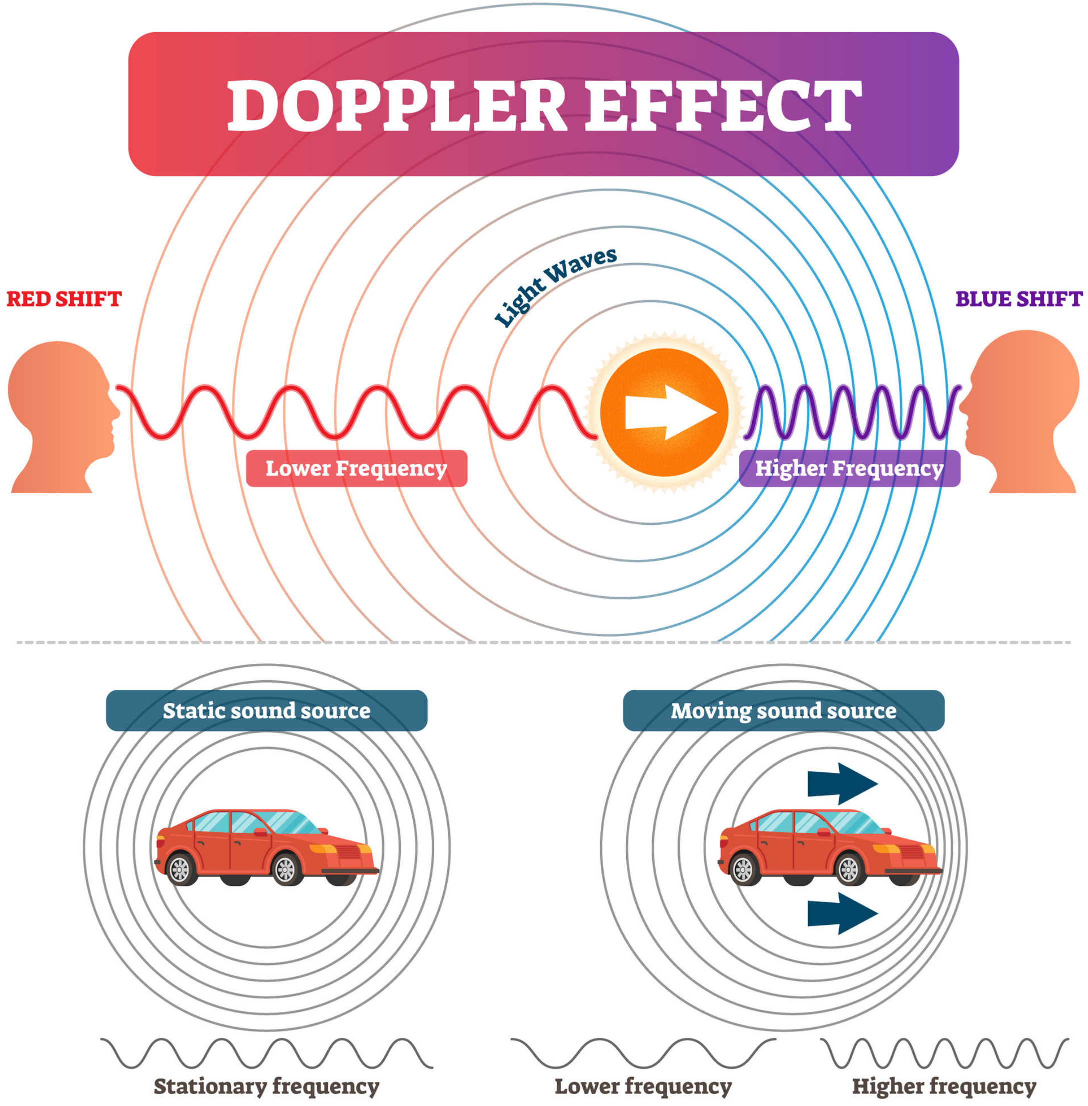




Factors Influencing Small-Scale Fading

Speed of the Mobile

Speed of the Surrounding Objects



Doppler Shift

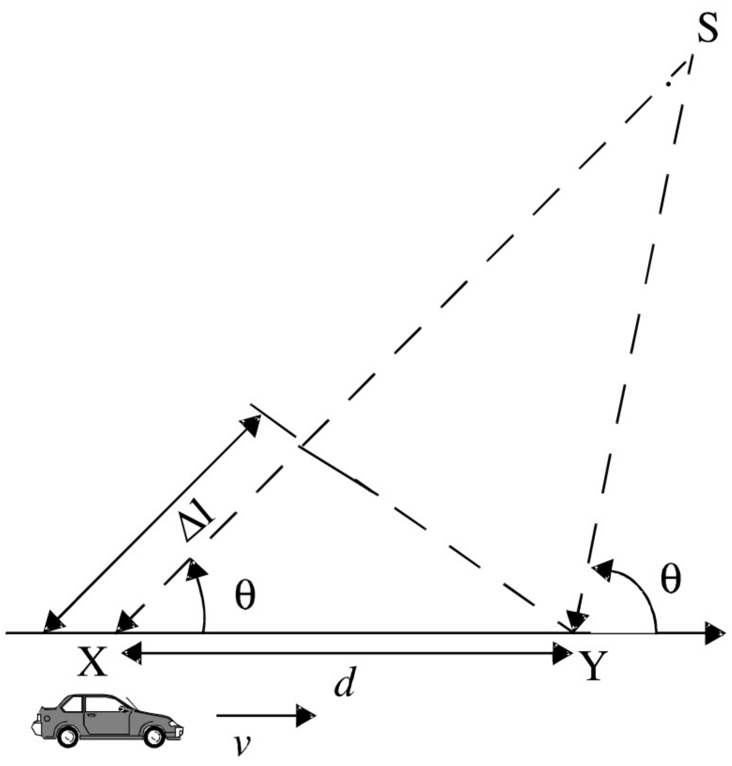


Illustration of Doppler effect.

The phase change in the received signal due to the difference in path lengths is therefore

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

Doppler shift, is given by *fd,* where

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

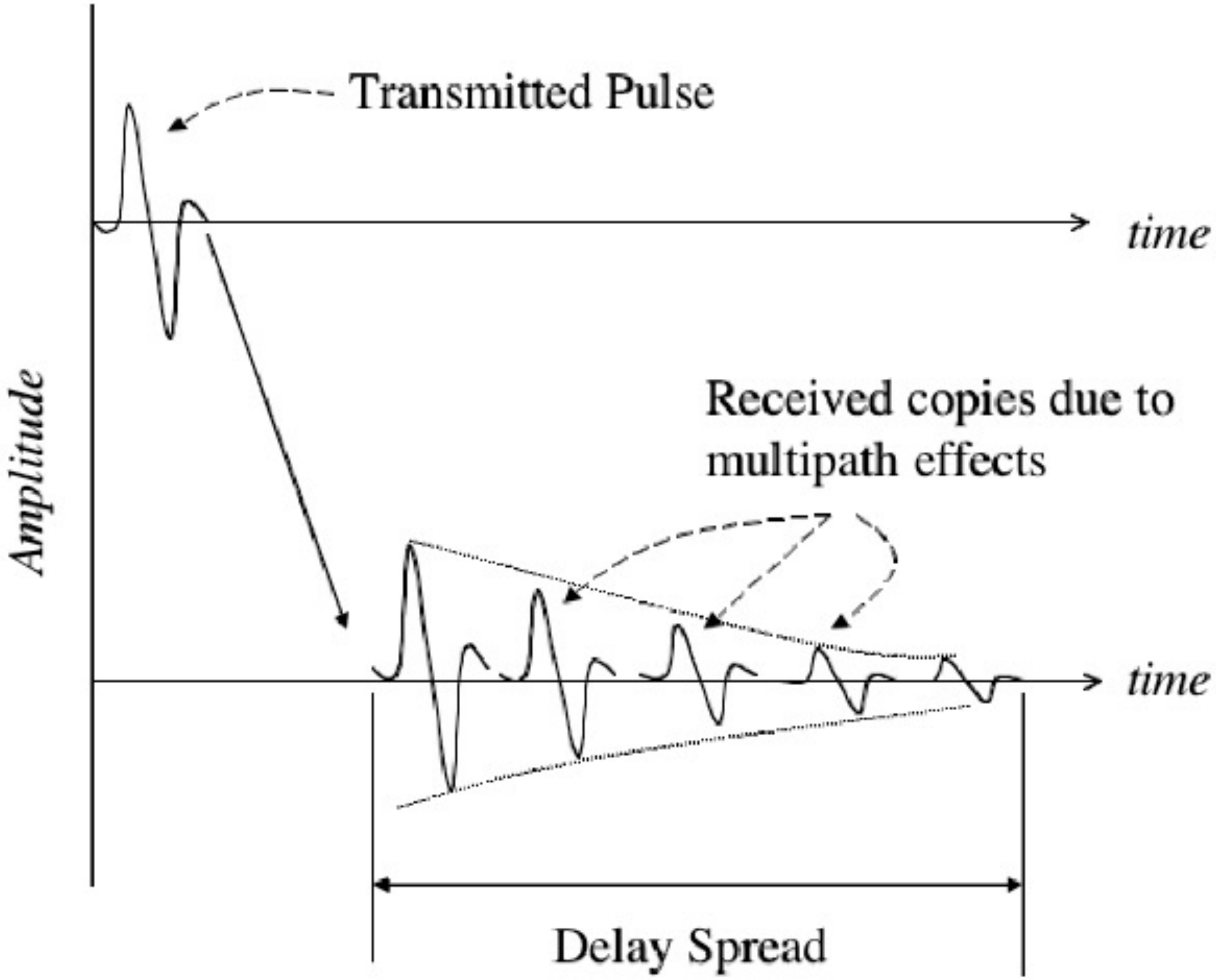
If the mobile is moving toward the direction of arrival of the wave, the Doppler shift is positive (i.e., the apparent received frequency is increased), and if the mobile is moving away from the direction of arrival of the wave, the Doppler shift is negative (i.e., the apparent received frequency is decreased)

Doppler Shift

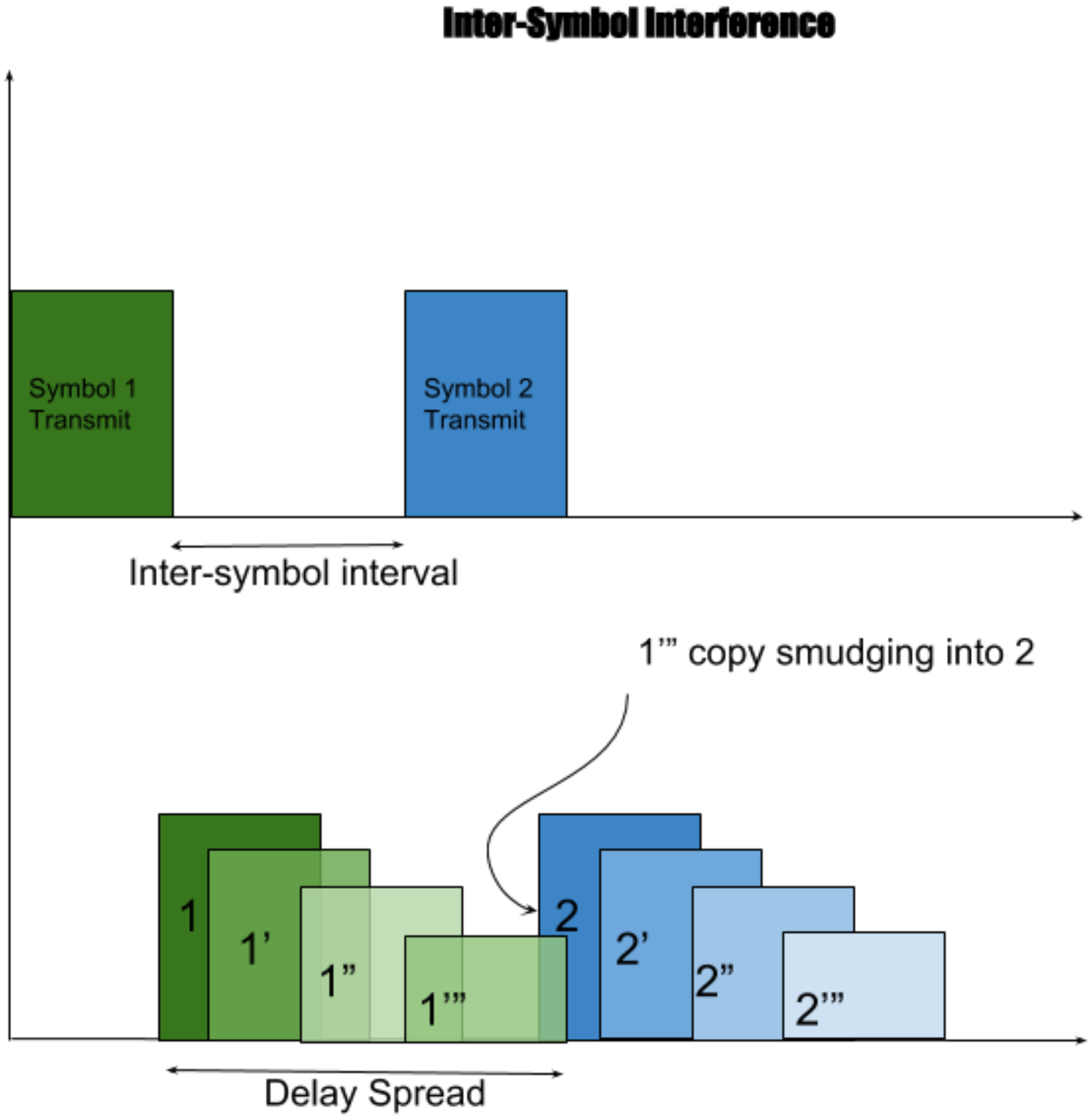
Example 5.1

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 toward the transmitter, (b) directly away from the transmitter, and (c) in a direction which is perpendicular to the direction of arrival of the transmitted signal.

Factors Influencing Small-Scale Fading



Factors Influencing Small-Scale Fading



IMPULSE RESPONSE MODEL OF A MUTIPATH CHANNEL

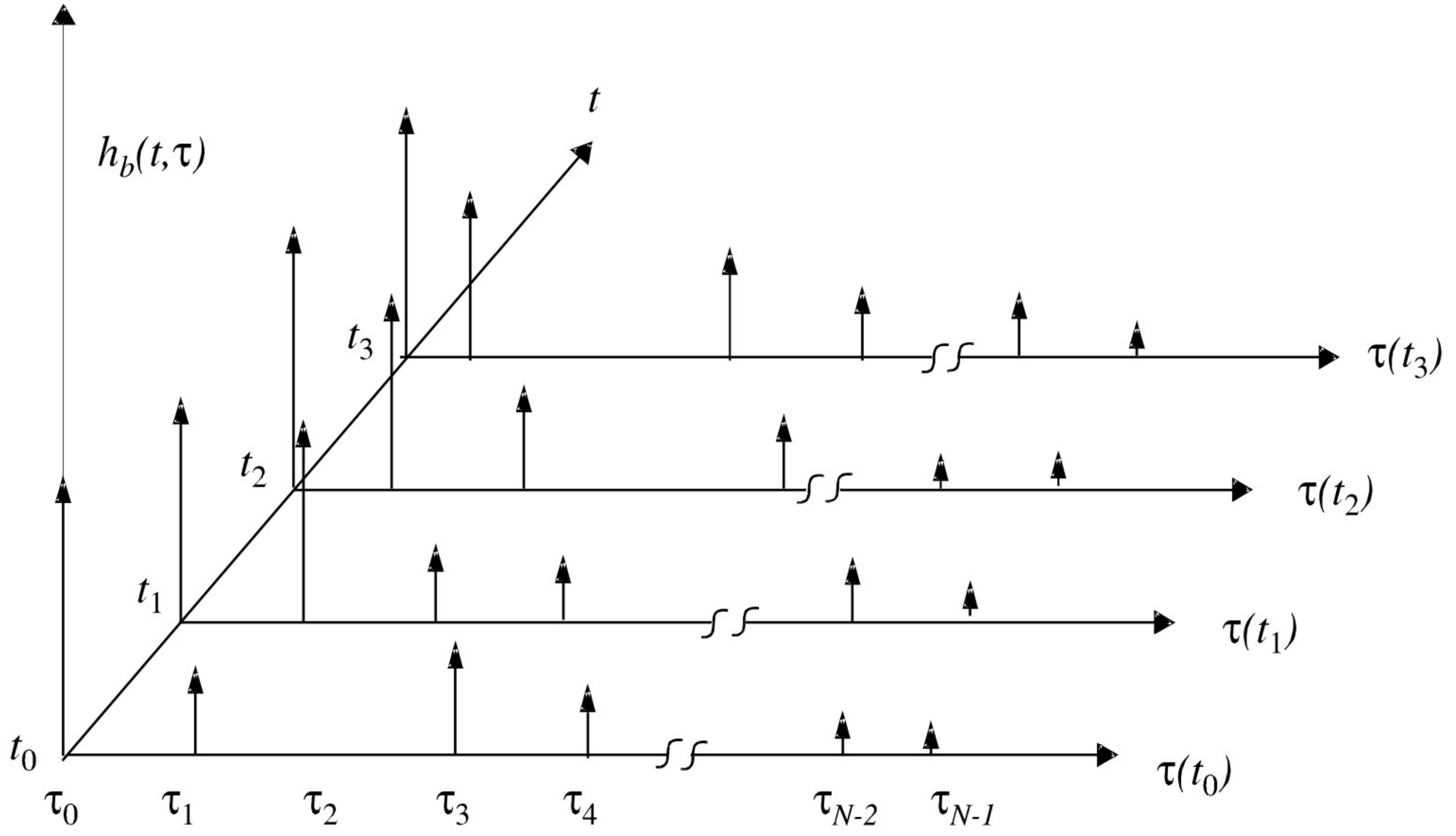


Figure 5.4 An example of the time varying discrete-time impulse response model for a multipath radio channel. Discrete models are useful in simulation where modulation data must be convolved with the channel impulse response [Tra02].

IMPULSE RESPONSE MODEL OF A MUTIPATH CHANNEL

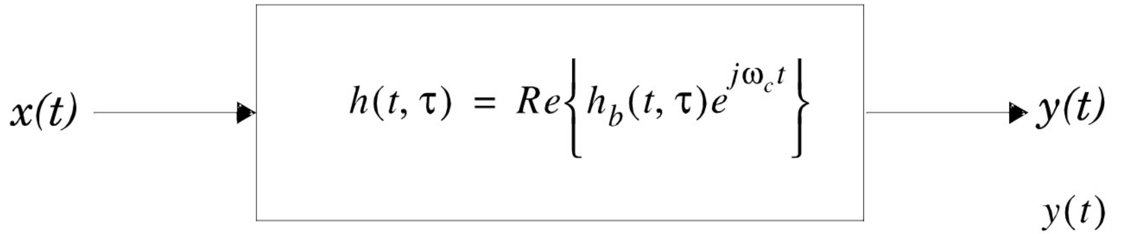
The baseband impulse response of a multipath channel can be expressed as

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

IMPULSE RESPONSE MODEL OF A MUTIPATH CHANNEL

The received signal $y(t)$ can be expressed as a convolution of the transmitted signal $x(t)$ with the channel impulse response

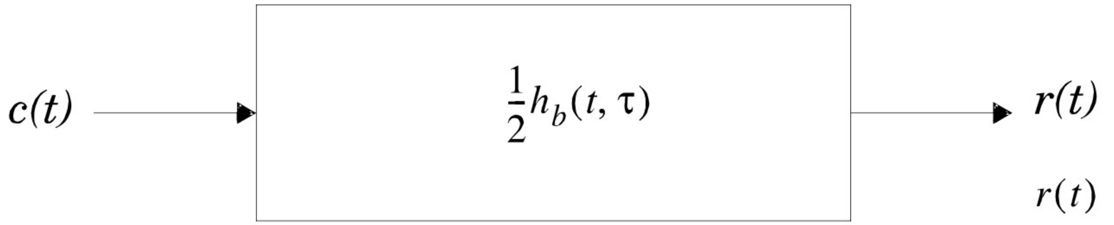
$$y(t) = \int_{-\infty}^{\infty} x(\tau)h(t,\tau)d\tau = x(t) \otimes h(t,\tau)$$



(a)

$$y(t) = Re\left\{r(t)e^{j\omega_c t}\right\}$$

$$y(t) = x(t) \otimes h(t)$$

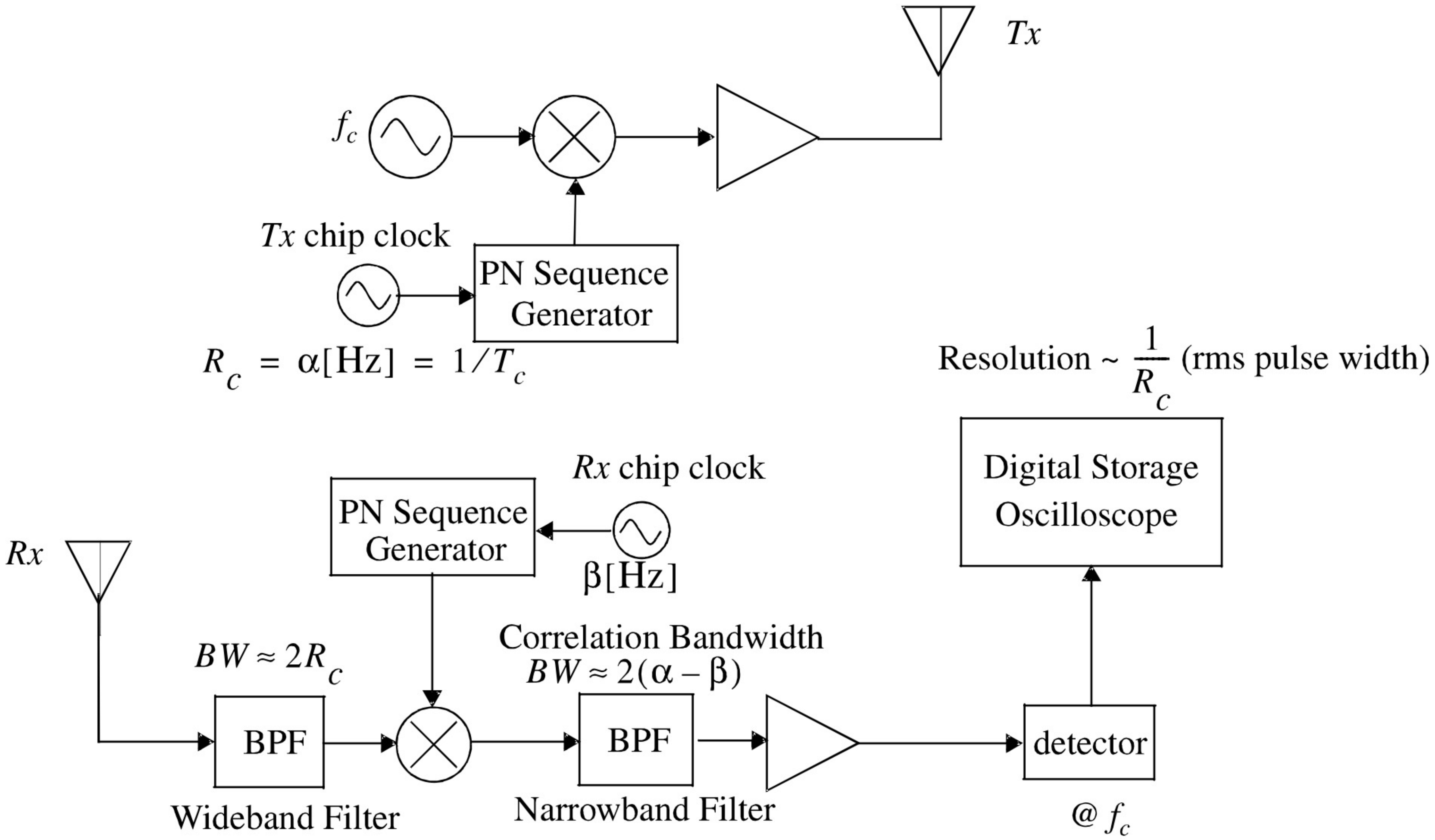


$$r(t) = c(t) \otimes \frac{1}{2}h_b(t)$$

(b)

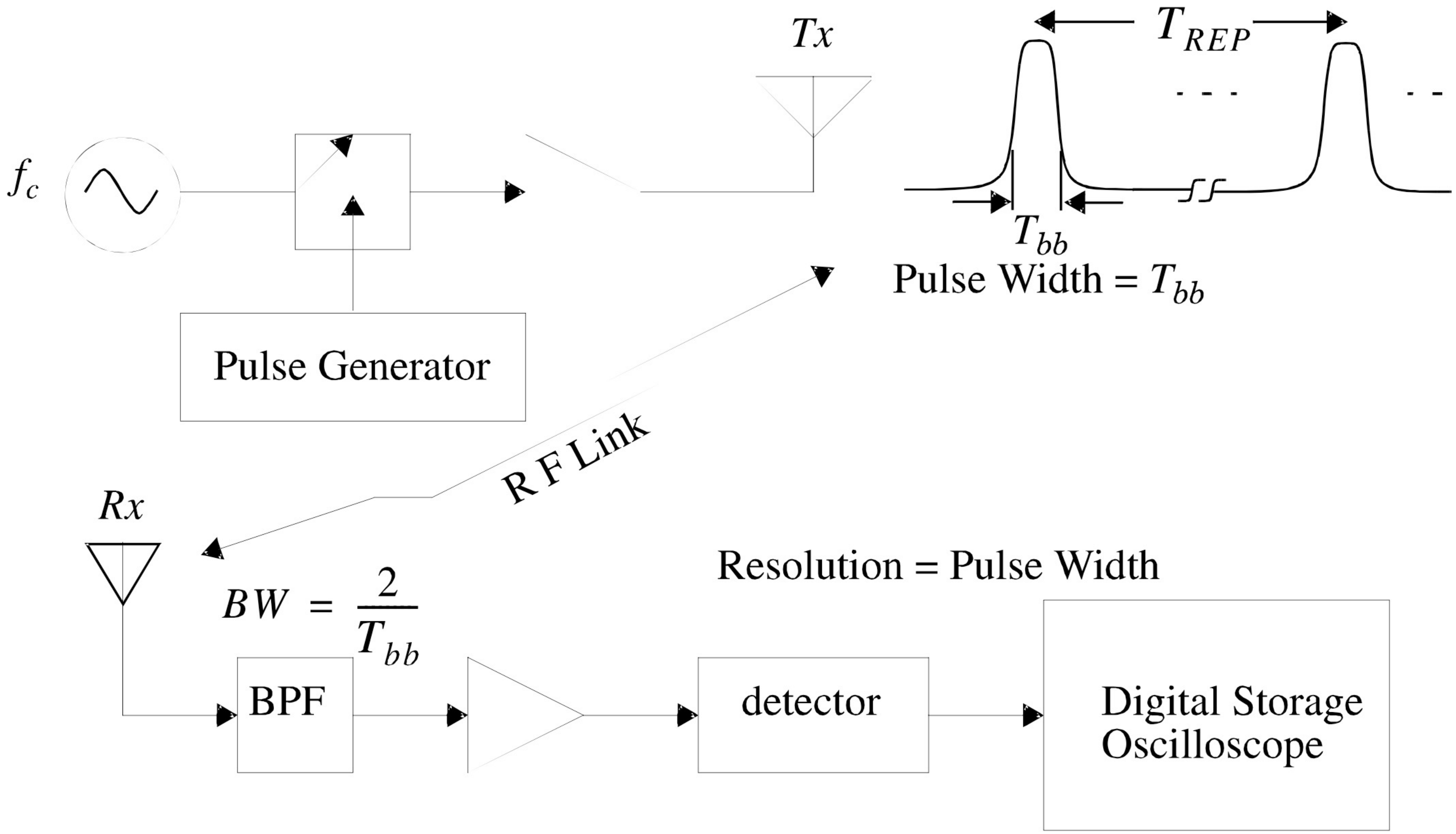
Small-Scale Multipath Measurements

Spread Spectrum Sliding Correlator Channel Sounding



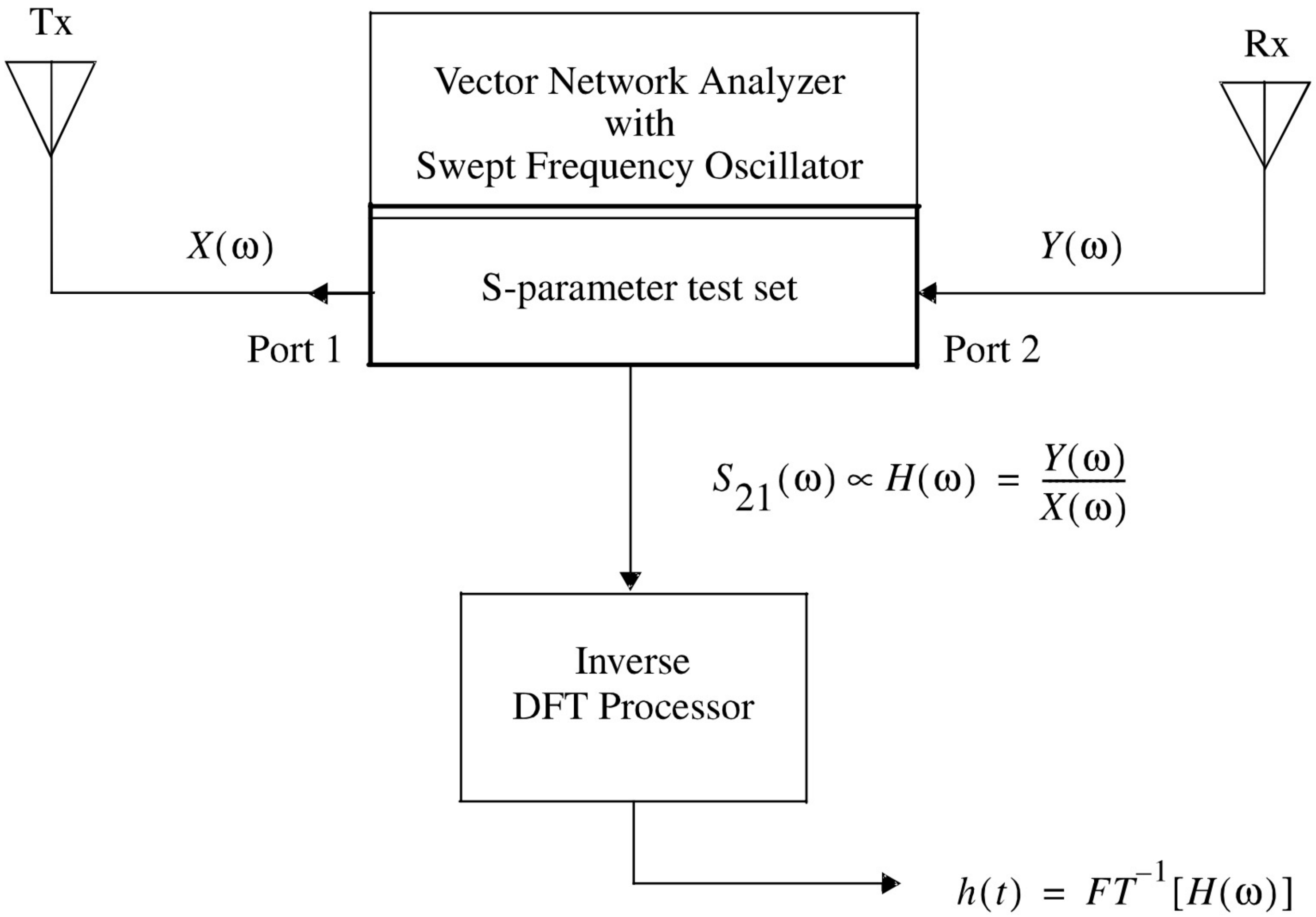
Small-Scale Multipath Measurements

Direct RF Channel Impulse Response Measurement System



Small-Scale Multipath Measurements

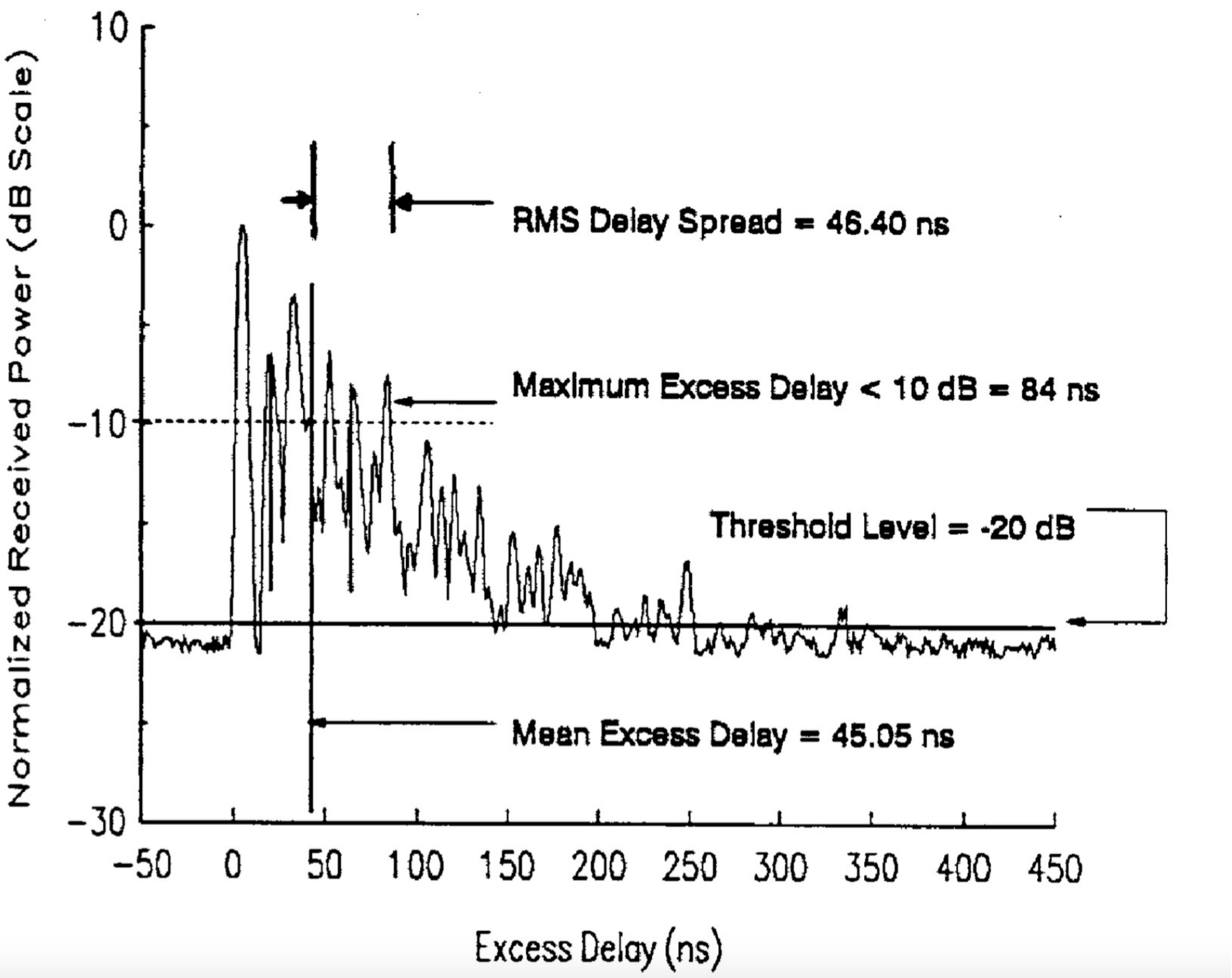
Frequency Domain Channel Sounding



Parameters of Mobile Multipath Channels

Time Dispersion Parameters

- mean excess delay
- rms delay spread
- excess delay spread



Parameters of Mobile Multipath Channels

Time Dispersion Parameters

- mean excess delay
- rms delay spread
- excess delay spread

Table 5.1 Typical Measured Values of RMS Delay Spread

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

Parameters of Mobile Multipath Channels

Coherence Bandwidth

Coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered "flat" (i.e., a channel which passes all spectral components with approximately equal gain and linear phase)

If the coherence bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.9, then the coherence bandwidth is approximately

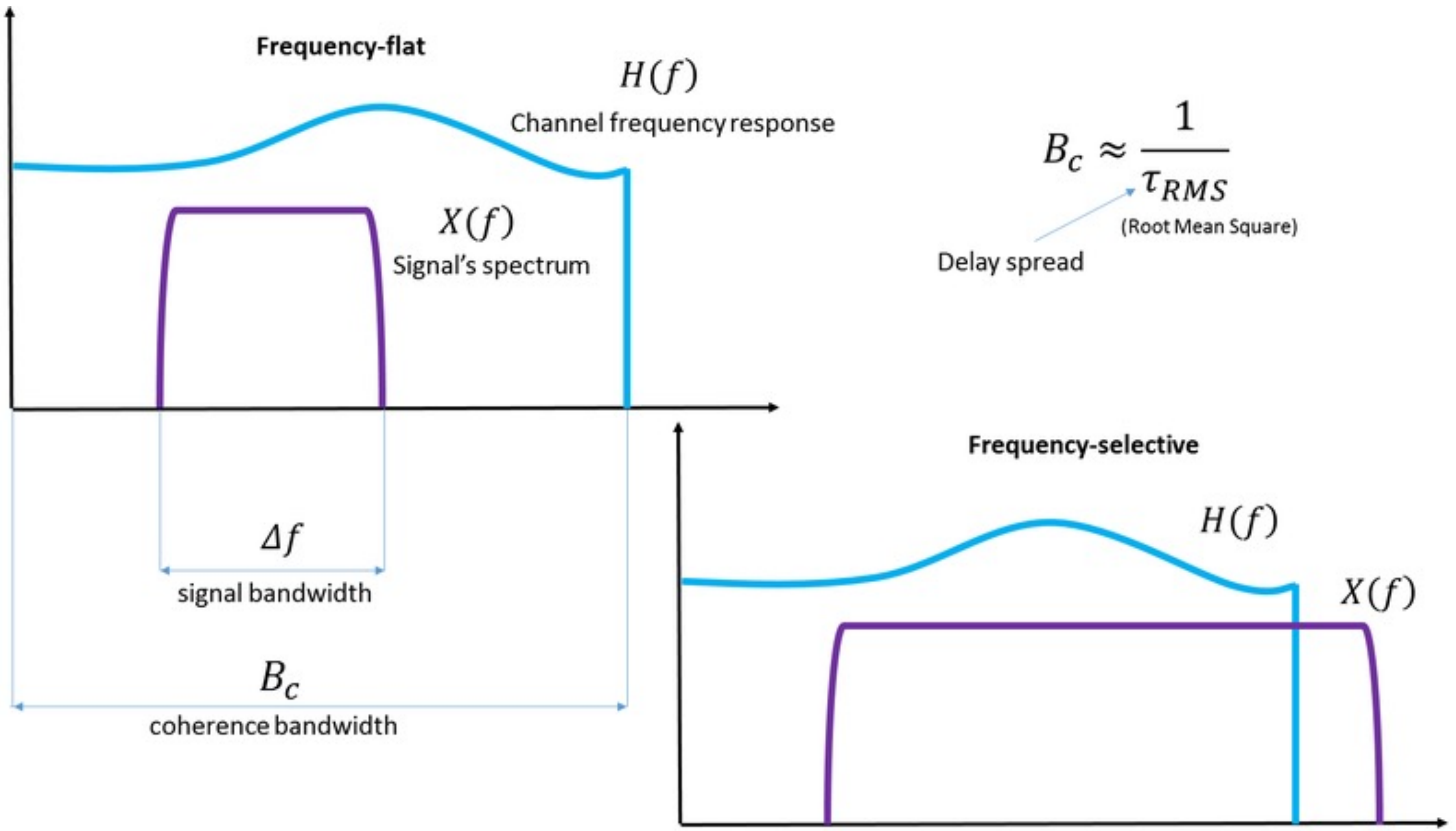
$$B_c \approx \frac{1}{50\sigma_\tau}$$

If the coherence bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.5, then the coherence bandwidth is approximately

$$B_c \approx \frac{1}{5\sigma_\tau}$$

Parameters of Mobile Multipath Channels

Coherence Bandwidth



Parameters of Mobile Multipath Channels

Doppler Spread and Coherence Time

Doppler spread and *coherence time* are parameters which describe the time varying nature of the channel in a small-scale region

Doppler Spread

Doppler spread B_D is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel and is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero

Parameters of Mobile Multipath Channels

Coherence Time

The Doppler spread and coherence time are inversely proportional to one another

$$T_C \approx \frac{1}{f_m}$$

Coherence time is actually a statistical measure of the time duration over which the channel impulse response is essentially invariant, and quantifies the similarity of the channel response at different times

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

Small-Scale Fading
(Based on multipath time delay spread)

Flat Fading
1. BW of signal < BW of channel
2. Delay spread < Symbol period

Frequency Selective Fading
1. BW of signal > BW of channel
2. Delay spread > Symbol period

Small-Scale Fading
(Based on Doppler spread)

Fast Fading
1. High Doppler spread
2. Coherence time < Symbol period
3. Channel variations faster than base-band signal variations

Slow Fading
1. Low Doppler spread
2. Coherence time > Symbol period
3. Channel variations slower than baseband signal variations

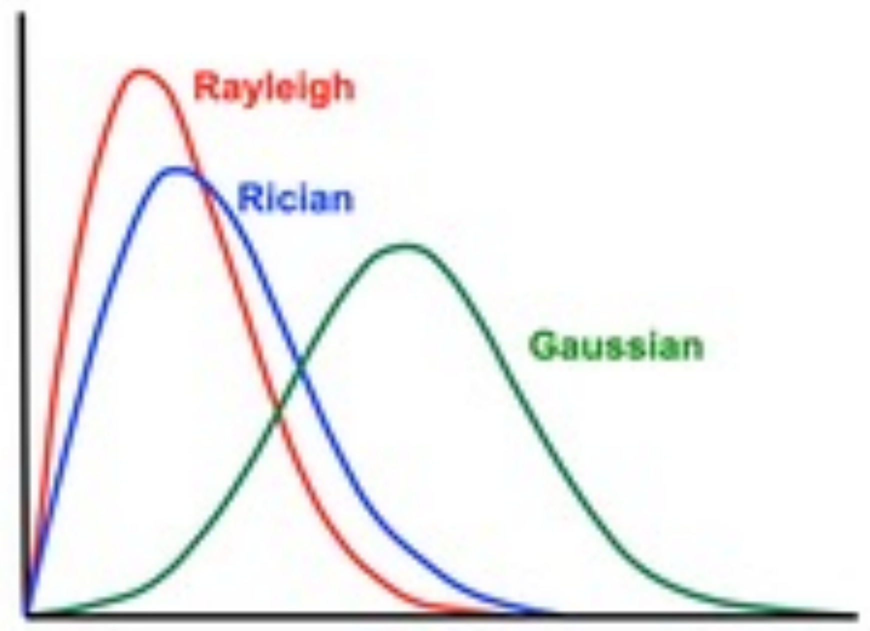
Rayleigh and Rician Fading

In communications theory, Nakagami distributions, Rician distributions, and Rayleigh distributions are used to model scattered signals that reach a receiver by multiple paths.

Depending on the density of the scatter, the signal will display different fading characteristics.

Rayleigh and Nakagami distributions are used to model dense scatters, while Rician distributions model fading with a stronger line-of-sight.

Rayleigh and Rician Fading



Rayleigh Distribution

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} \exp\left(-\dfrac{r^2}{2\sigma^2}\right) & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases}$$

Rician Distribution

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} e^{-\frac{(r^2 + A^2)}{2\sigma^2}} I_0\left(\dfrac{Ar}{\sigma^2}\right) & \text{for}(A \ge 0, r \ge 0) \\ 0 & \text{for}(r < 0) \end{cases}$$