Unit-1

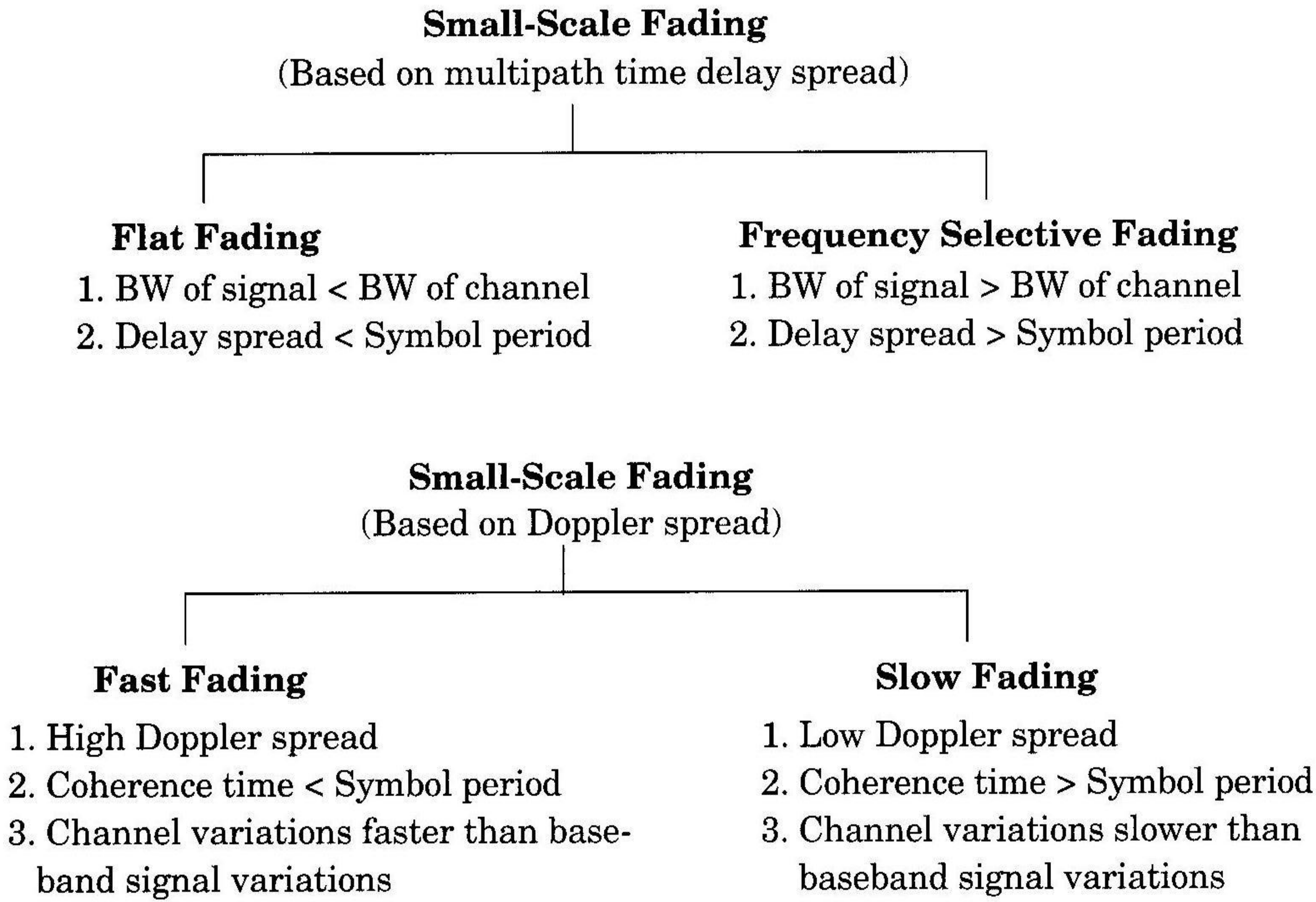
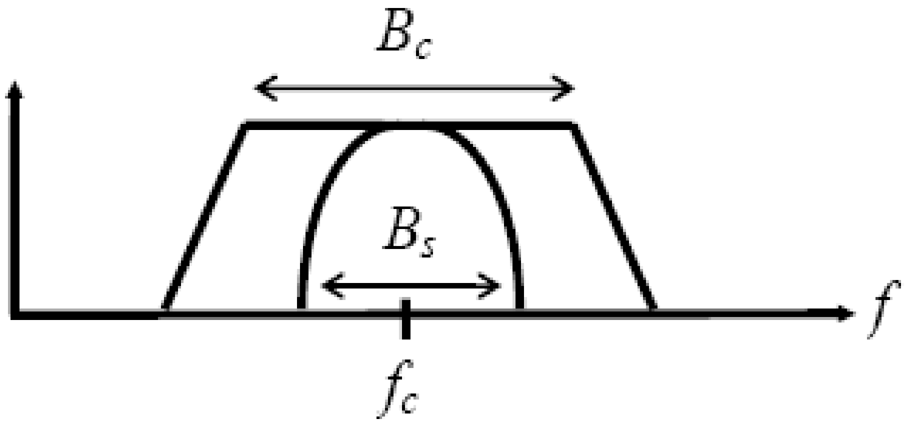


Figure 5.11 Types of small-scale fading.

1) Fading due to Multipath Delay

A) Flat Fading → $B_s << B_c$ or $T_s >> \sigma_\tau$

- $T_s \geq 10\sigma_\tau$
- signal fits easily within the bandwidth of the channel
- channel BW >> signal BW



- most commonly occurring type of fading

- spectral properties of Tx signal are preserved
  - signal is called a *narrowband* channel, since the bandwidth of the signal is narrow with respect to the channel bandwidth
  - signal is not distorted

- What does $T_s >> \sigma_\tau$ mean??
  - all multipath signals arrive at mobile Rx during 1 symbol period

  ∴ Little intersymbol interference occurs (no multipath components arrive late to interfere with the next symbol)

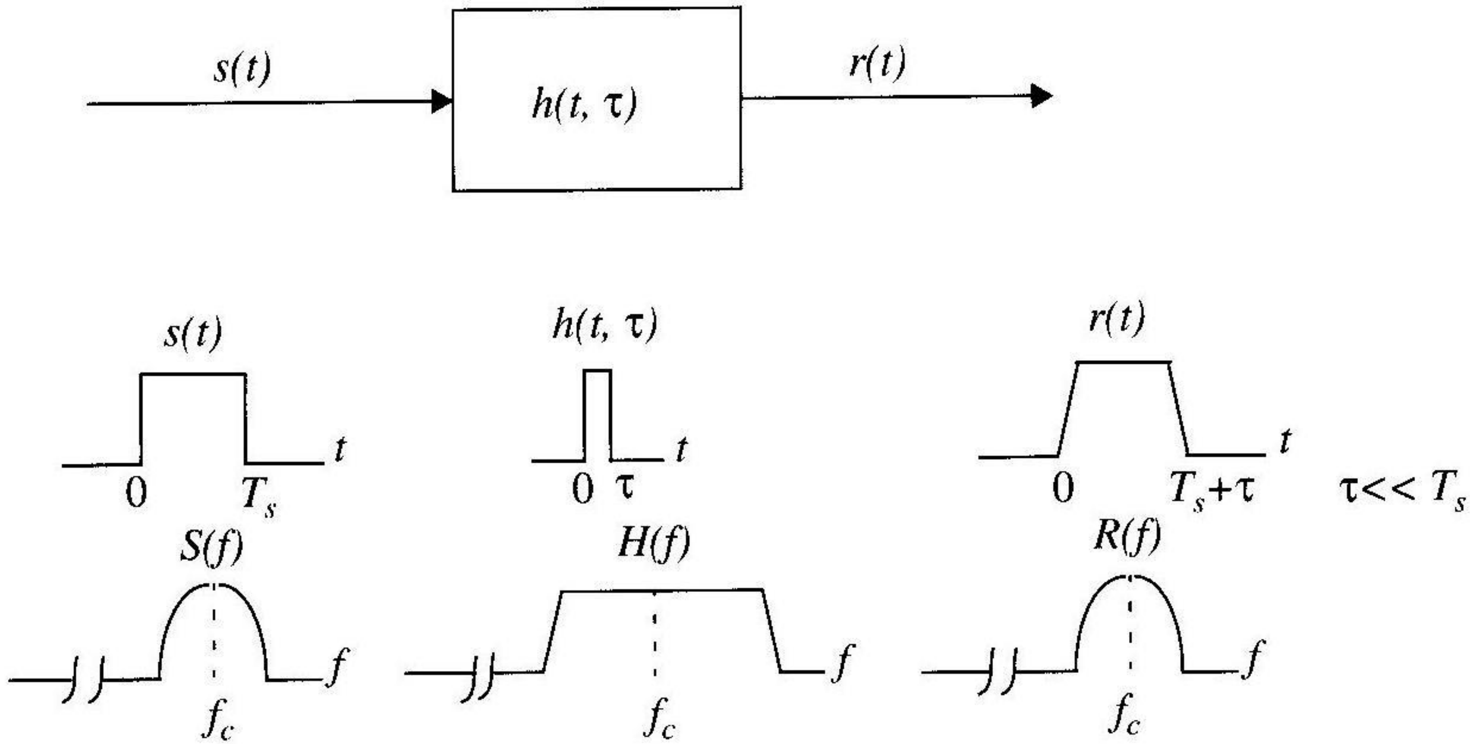
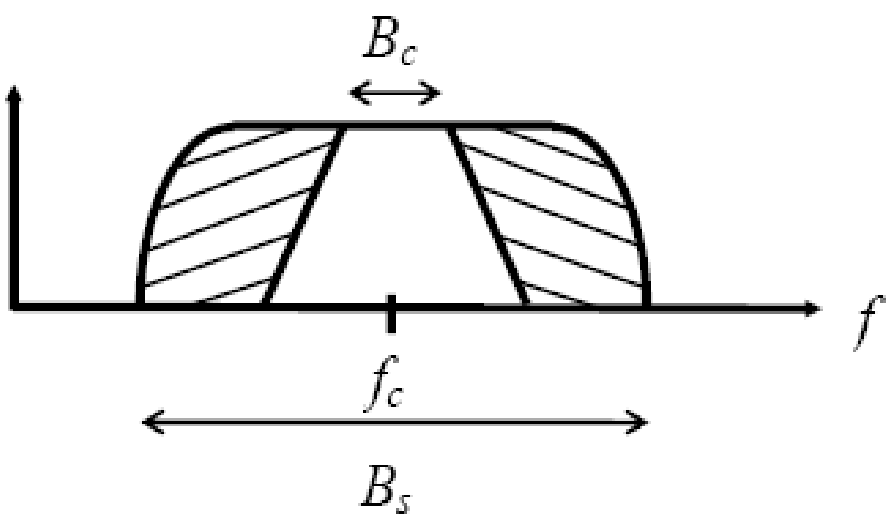


Figure 5.12 Flat fading channel characteristics.

- flat fading is generally considered **desirable**
  - Even though fading in amplitude occurs, the signal is not distorted
  - Forward link → can increase mobile Rx gain (automatic gain control)
  - Reverse link → can increase mobile Tx power (power control)
  - Can use diversity techniques (described in a later lecture)

B) Frequency Selective Fading → $B_s > B_c$ or $T_s <$ σ_τ

- $T_s \leq 10\sigma_\tau$
- $B_s > B_c$ → certain frequency components of the signal are attenuated much more than others



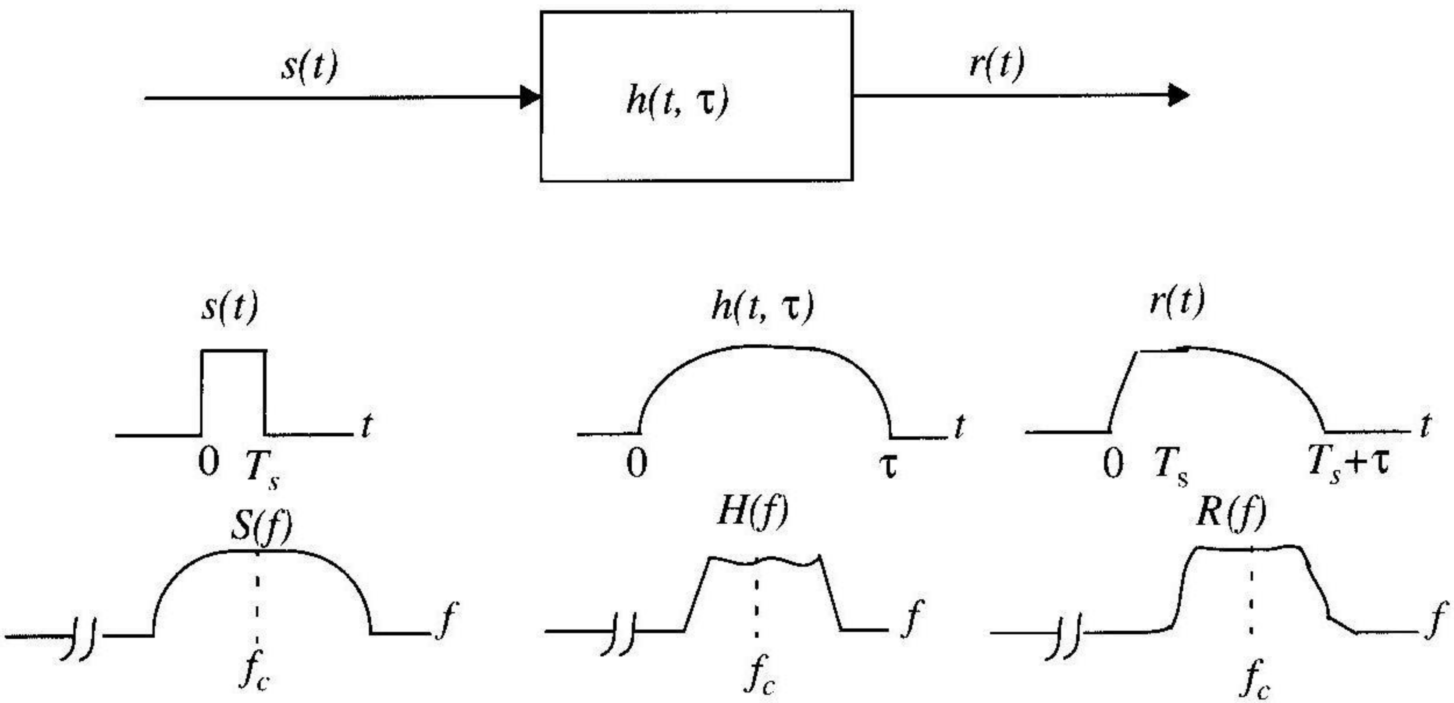


Figure 5.13 Frequency selective fading channel characteristics.

- *Ts* < σ_τ → delayed versions of Tx signal arrive during **different** symbol periods
  - e.g. receiving an LOS → “1” & multipath “0” (from prior symbol!)
  - This results in intersymbol interference (ISI)
  - Undesirable

- it is very difficult to predict mobile Rx performance with frequency selective channels

- But for high bandwidth applications, channels with likely be frequency selective
  - a new modulation approach has been developed to combat this.
  - Called **OFDM**

- One aspect of OFDM is that it separates a wideband signal into many smaller narrowband signals
  - Then adaptively adjusts the power of each narrowband signal to fit the characteristics of the channel at that frequency.
  - Results in much improvement over other wideband transmission approaches (like CDMA).

- OFDM is used in the new 802.11g 54 Mbps standard for WLAN's in the 2.4 GHz band.
- Previously it was thought 54 Mbps could only be obtained at 5.8 GHz using CDMA, but 5.8 GHz signals attenuate much more quickly.
- Signals are split using signal → FFT, break into pieces in the frequency domain, use inverse FFT to create individual signals from each piece, then transmit.

2) Fading due to Doppler Spread

- Caused by motion of Tx and Rx and reflection sources.

A) **Fast Fading** → $B_s < B_D$ or $T_s > T_c$

- $B_s < B_D$
  - Doppler shifts significantly alter spectral BW of TX signal
  - signal “spreading”
- $Ts > Tc$
  - MRC changes within 1 symbol period
  - rapid amplitude fluctuations
- uncommon in most digital communication systems

B) **Slow Fading** → $T_s << T_c$ or $B_s >> B_D$

- MRC constant over many symbol periods
- slow amplitude fluctuations
- for v = 60 mph @ f_c = 2 GHz → B_D = 178 Hz

  ∴ $B_s \approx$ 2 kHz $>> B_D$

  - B_s almost always $>> B_D$ for most applications

- ** NOTE: Typically use a factor of 10 to designate “>>” **

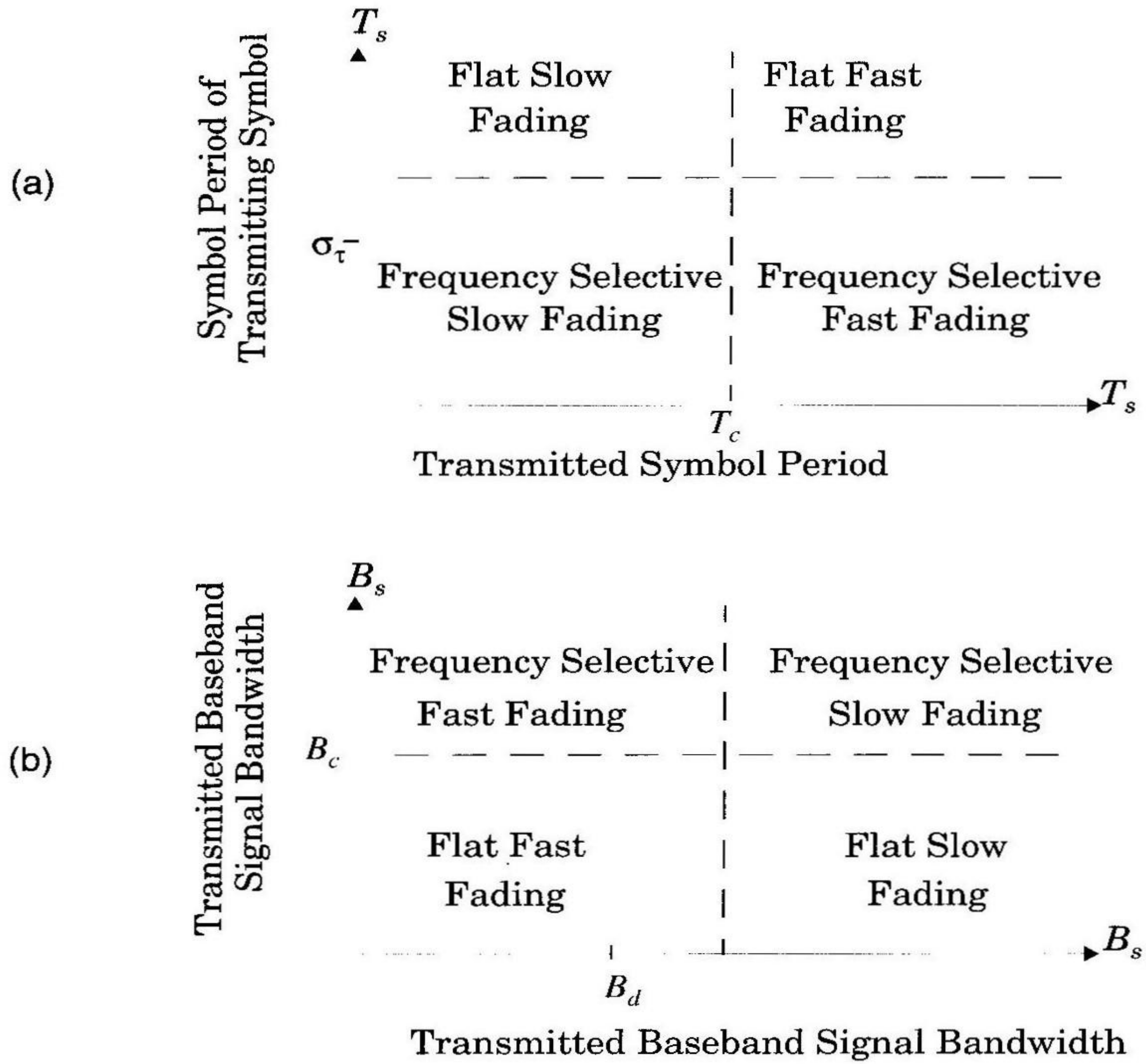


Figure 5.14 Matrix illustrating type of fading experienced by a signal as a function of: (a) symbol period; and (b) baseband signal bandwidth.

VI. Fading Signal Distributions

- Rayleigh probability distribution function →

$$P(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right) \qquad 0 \le r \le \infty$$

  - Used for flat fading signals.
  - Formed from the sum of two Gaussian noise signals.
  - σ : RMS value of Rx signal **before** detection (demodulation)
  - common model for Rx signal variation
    - urban areas → heavy clutter → no LOS path
  - probability that signal does not exceeds predefined threshold level *R*

$$P(R) = Pr(r \le R) = \int_0^R p(r)dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right)$$

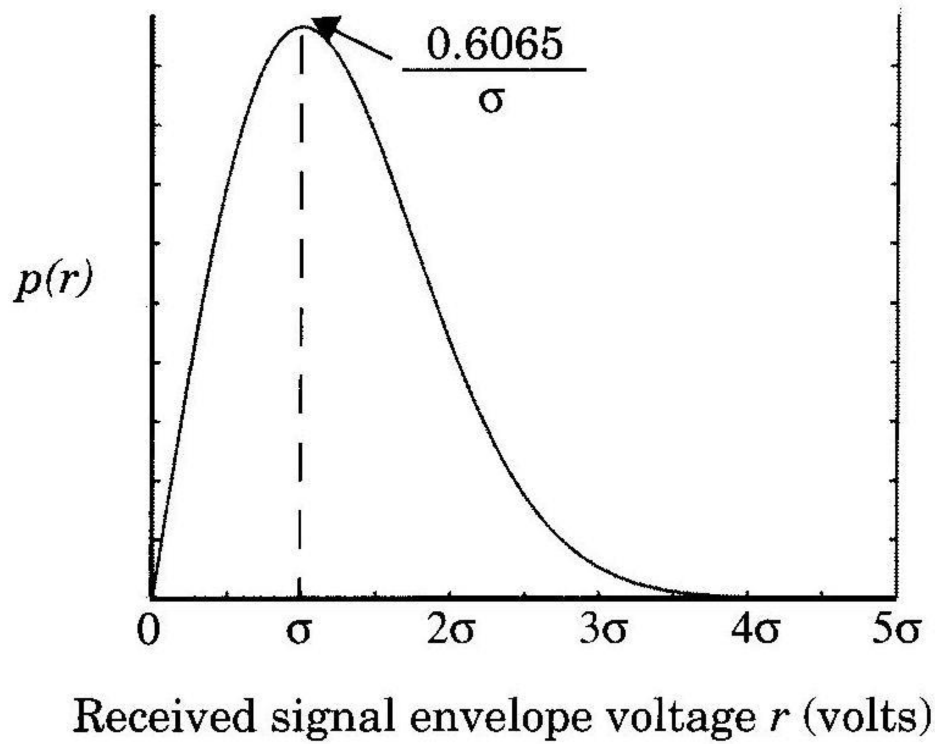


Figure 5.16 Rayleigh probability density function (pdf).

– r_{mean} : The mean value of Rayleigh distribution

$$r_{mean} = E[r] = \int_0^\infty r p(r) dr = \sigma\sqrt{\frac{\pi}{2}} = 1.2533\sigma$$

– σ_r^2 : The variance of Rayleigh distribution; ac power of signal envelope

$$\sigma_r^2 = E[r^2] - E^2[r] = \int_0^\infty r^2 p(r) dr - \frac{\sigma^2 \pi}{2}$$

$$= \sigma^2\left(2 - \frac{\pi}{2}\right) = 0.4292\sigma^2$$

- σ : RMS value of Rx signal **before** detection (demodulation)

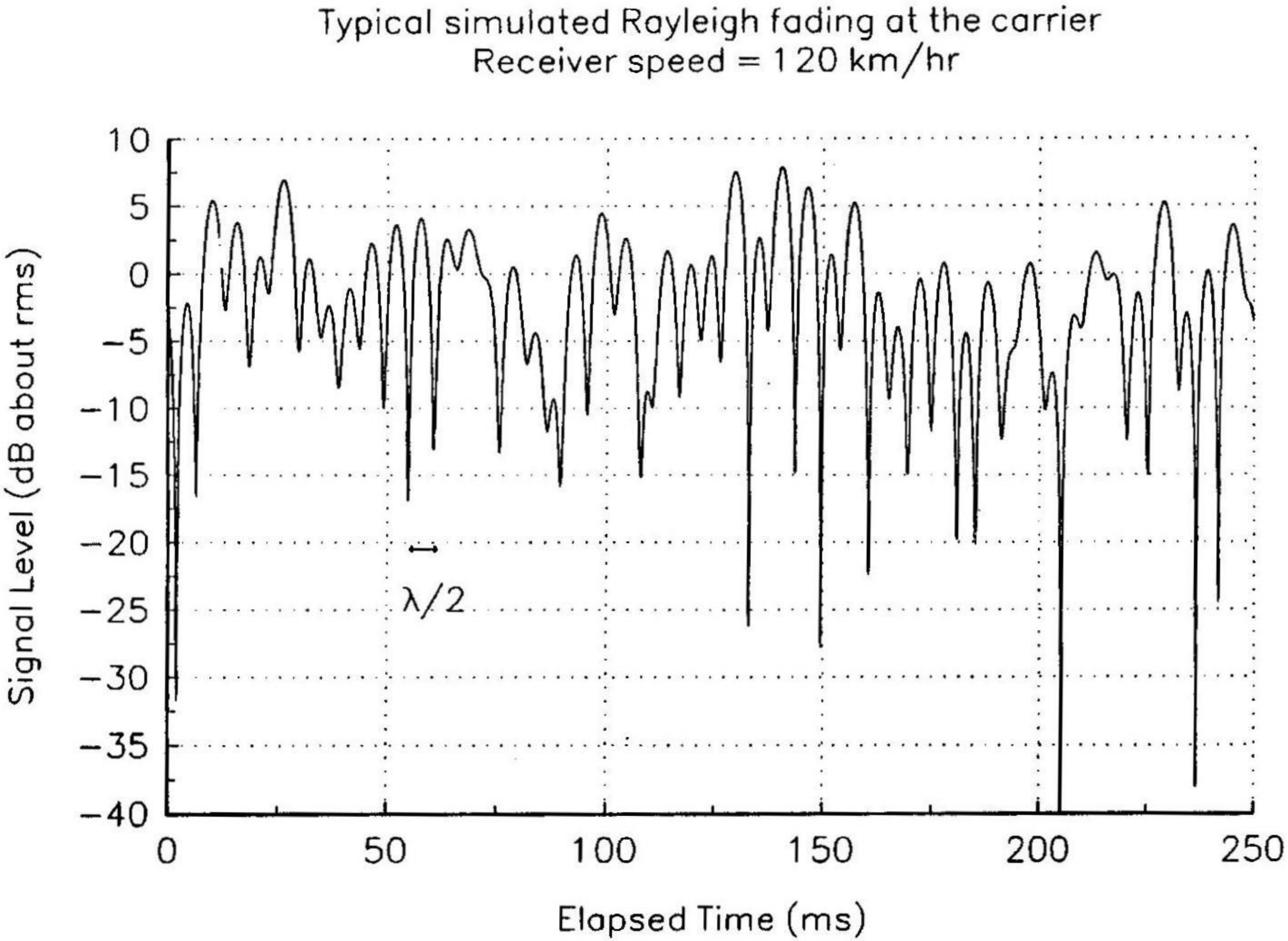


Figure 5.15 A typical Rayleigh fading envelope at 900 MHz [from [Fun93] © IEEE].

- Ricean Probability Distribution Function
  - one dominant signal component along with weaker multipath signals
  - dominant signal → LOS path
    - suburban or rural areas with light clutter
  - be[illegible] dominant co[illegible]

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

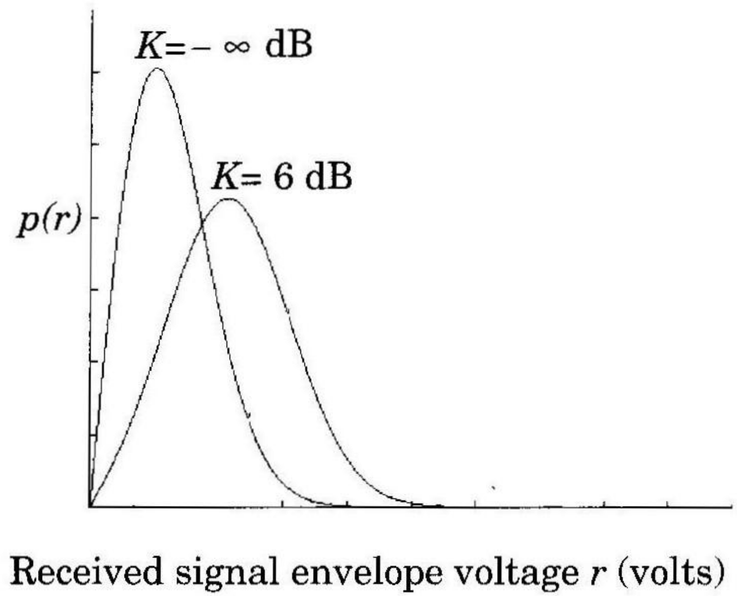


Figure 5.18 Probability density function of Ricean distributions: $K = -\infty$ dB (Rayleigh) and $K = 6$ dB. For K >> 1, the Ricean pdf is approximately Gaussian about the mean.