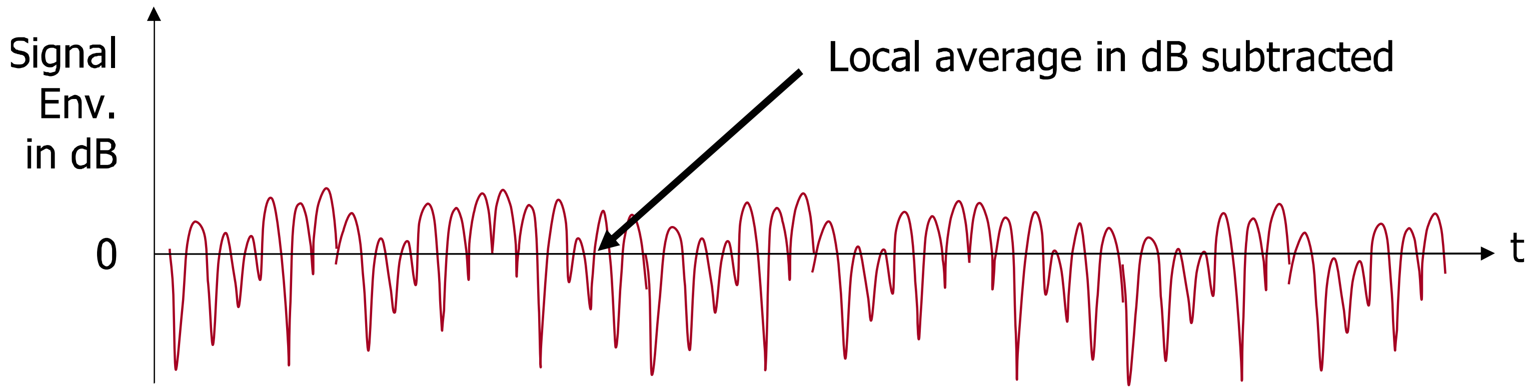
LEVEL CROSSING RATE AND AVERAGE FADE DURATIONS

Normalized Fading Process

- Begin with the channel fading process, normalized to the local rms signal level

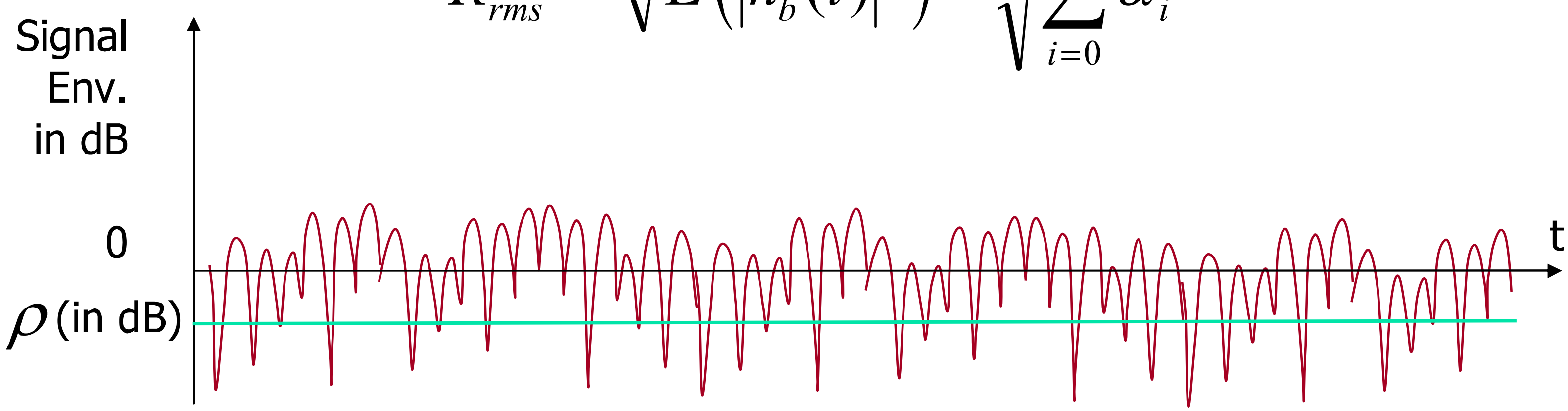


[not real data]

Normalized Threshold Level

- Pick a level or threshold $\rho = R / R_{rms}$, where R is the unnormalized threshold and

$$R_{rms} = \sqrt{E\left(\left|h_b(t)\right|^2\right)} = \sqrt{\sum_{i=0}^{N-1} \overline{\alpha_i^2}}$$



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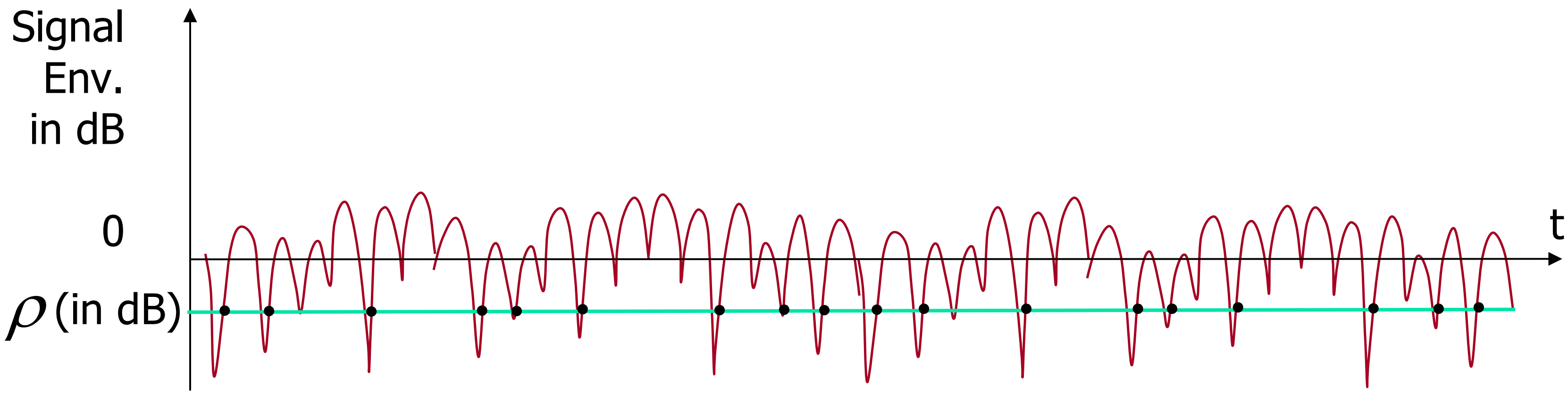
Level Crossing Rate

- The LCR at threshold ρ is the expected rate at which the normalized envelope passes the value ρ with a positive slope



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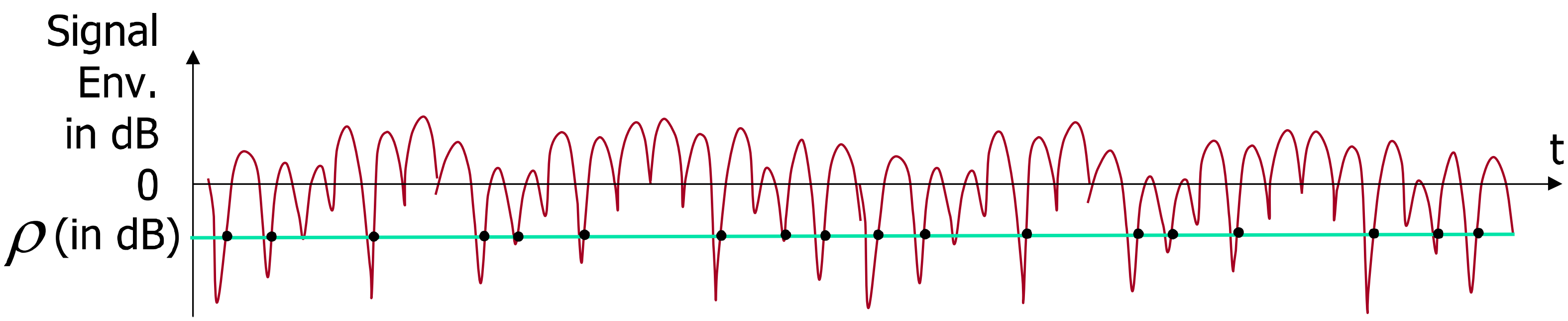
Trends

- We expect the highest rate around ρ =0 dB, tapering off gently for lower thresholds and abruptly for higher thresholds
- The maximum Doppler frequency just scales the horizontal axis and therefore the rate



[not real data]

LCR for Rayleigh Fading

- For Rayleigh fading and isotropic scattering (Clarke's Model), the LCR is given by

$$\sqrt{2\pi}\, f_d \rho e^{-\rho^2}$$

where f_d is the maximum Doppler frequency

LCR for Ricean Fading

- If we assume isotropic scattering plus a non-random component, then the LCR can be approximated as

$$\sqrt{2\pi(K+1)}\, f_d \rho e^{-K-(K+1)\rho^2} I_0\left(2\rho\sqrt{K(K+1)}\right)$$

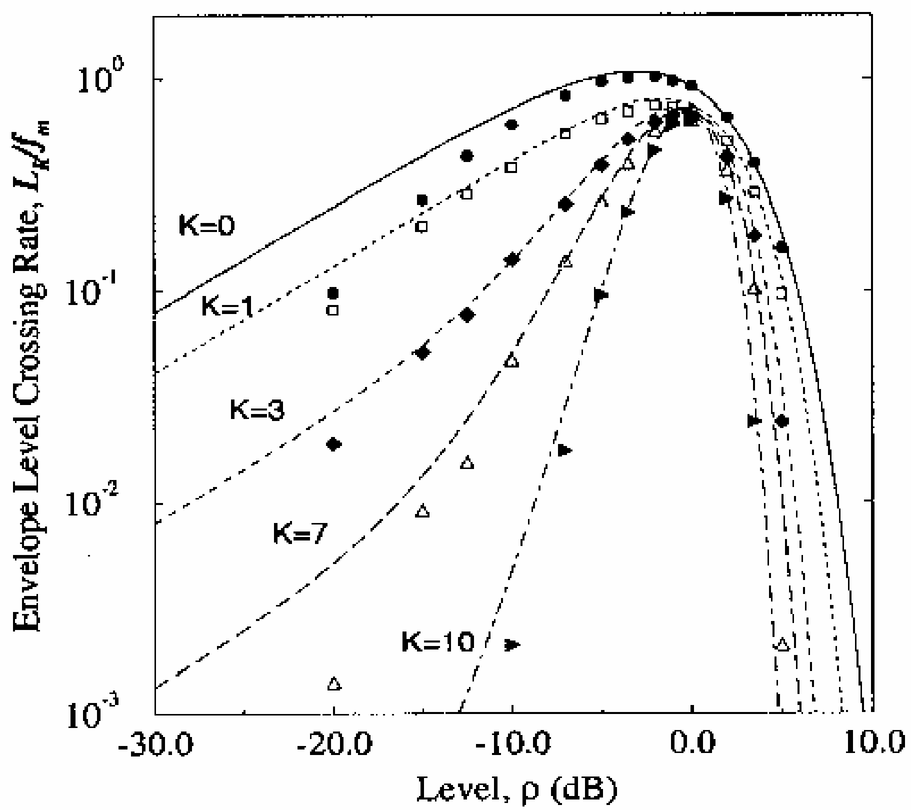
where I_0 is the modified Bessel Function of the first kind, zero order:

$$I_0(x) = \frac{1}{2\pi}\int_0^{2\pi} e^{-x\cos\theta}\, d\theta$$

LCR for Isotropic Scattering and a non-random component

Lines are theoretical results assuming a constant AOA power distribution plus a non-random component

Symbols represent simulation results using a multipath fading simulator

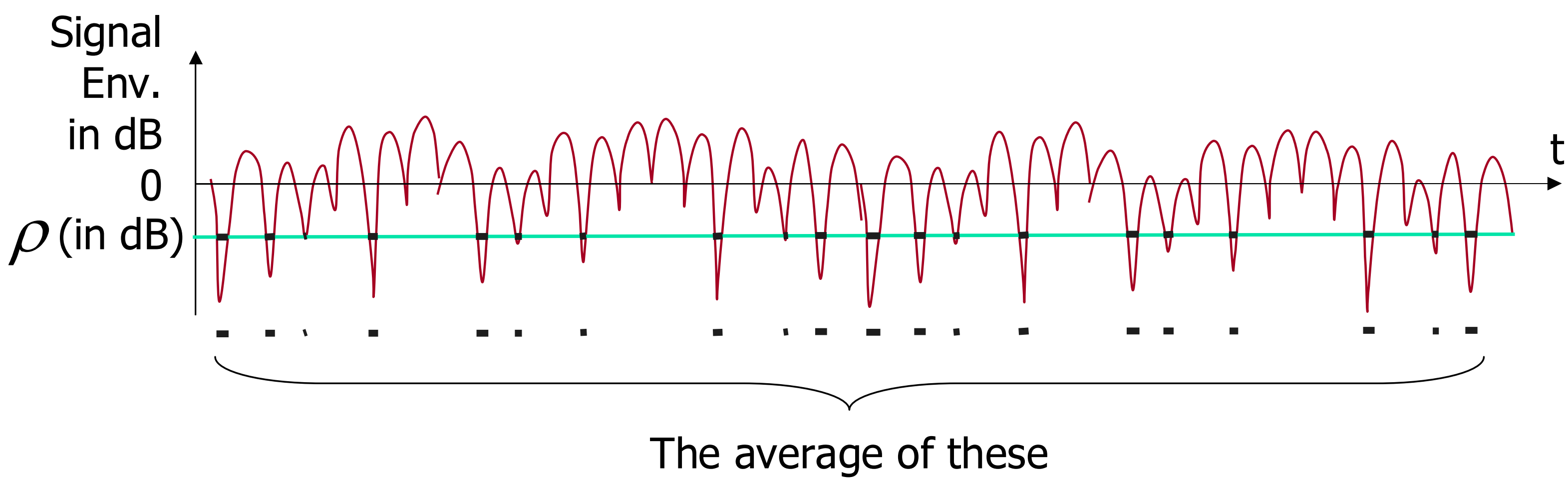


Speed Estimation

- The LCR can be used to estimate the speed of a mobile

Average Fade Duration

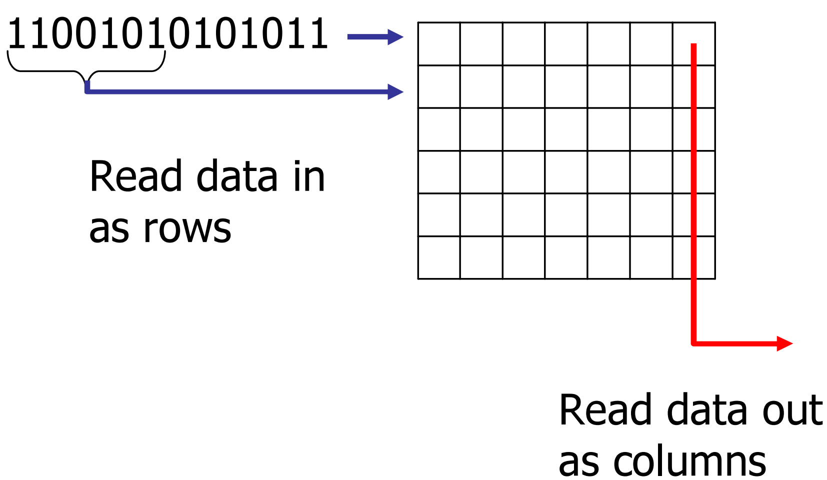
- The average fade duration is the average period of time the normalized envelope is below a level ρ



Average Fade Duration Impacts Interleaver Depth

- The interleaver breaks up the fade so that forward error correction (FEC) codes can correct errors from fading

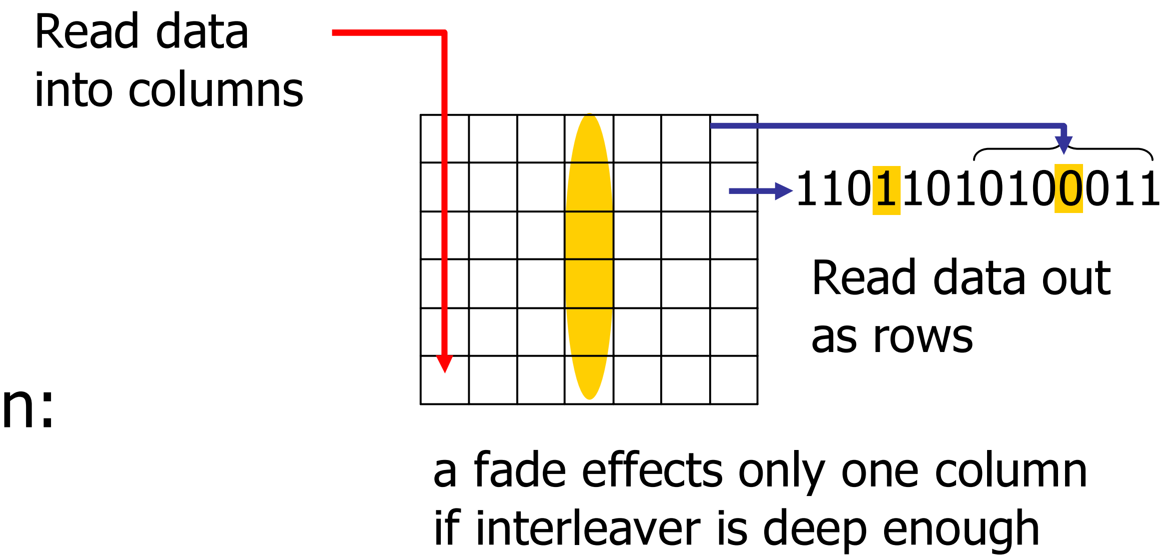
At the Transmitter just before modulation:



De-Interleaving

- At the receiver, the reverse operation is performed

At the Receiver just after demodulation:



Average Rayleigh Fade Duration

- For Rayleigh fading and isotropic scattering, the average fade duration below a level ρ is

$$\bar{\tau} = \frac{e^{\rho^2} - 1}{\sqrt{2\pi} f_d \rho}$$

Average Ricean Fade Duration

- Assuming isotropic scattering with one non-random component,

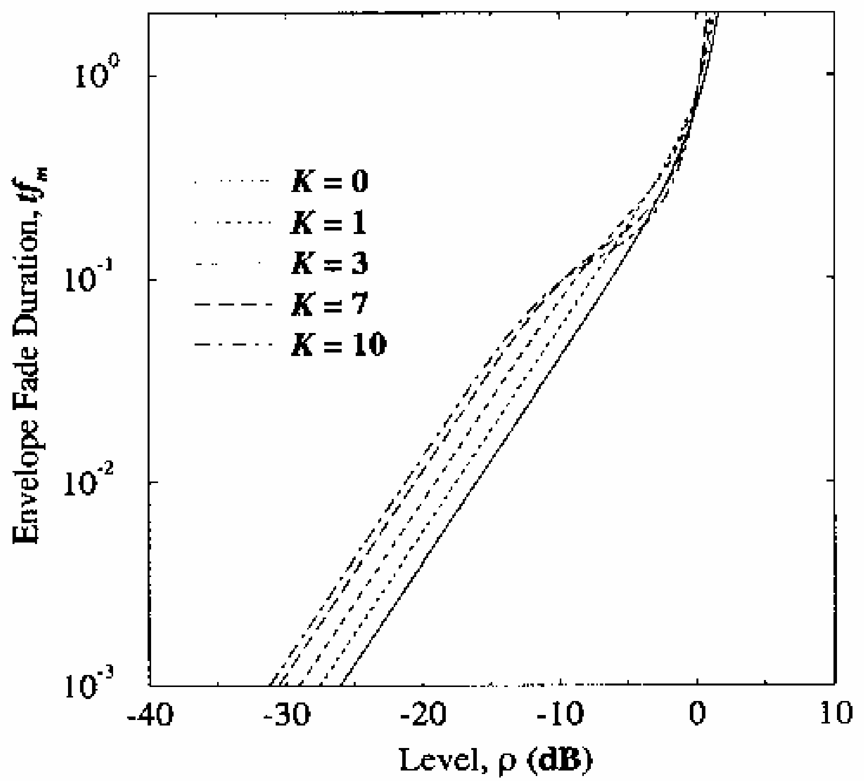
$$\bar{\tau} = \frac{1 - Q\left(\sqrt{2K}, \sqrt{2(K+1)\rho^2}\right)}{\sqrt{2\pi(K+1)}\, f_d\, \rho e^{-K-(K+1)\rho^2} I_0\left(2\rho\sqrt{K(K+1)}\right)}$$

where $Q(a,b)$ is the Marcum Q function

Average Rice Fading Duration

Lines are theoretical results assuming a constant AOA power distribution plus a non-random component

Symbols represent simulation results using a multipath fading simulator



Example

- For a mobile traveling 60 mph, with RF frequency 900MHz, the maximum Doppler frequency is f_d =88Hz

  At the threshold of 0 dB, the average fade rate is 81 fades/s with average duration of 7.8ms

Summary

- Level crossings can be used to estimate mobile speed
- Fade duration must be considered for interleaver design