Multipath, mobility and selectivity in wireless communications:

An introduction

EE161: Digital Communication Systems

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Multipath and frequency selectivity

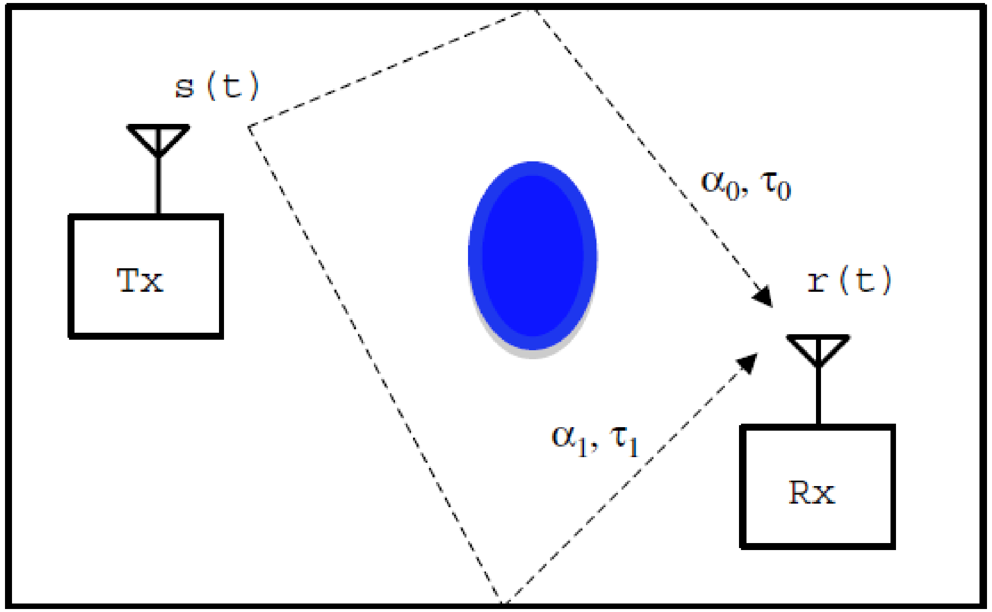
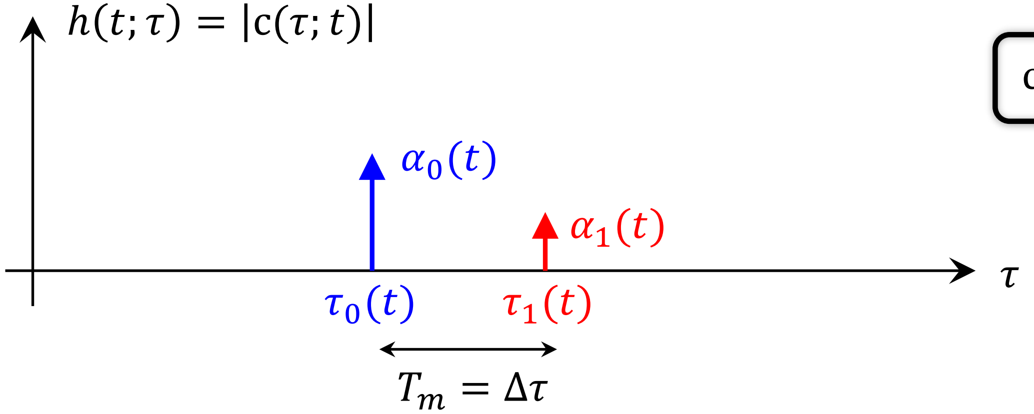


Figure 1: A wireless two-path channel.

$$h(t) = \alpha_0\,\delta(t-\tau_0) + \alpha_1\,\delta(t-\tau_1),$$

where, for $i = 0, 1$, the attenuation α_i is inversely proportional to the n-th power (for some value of ~~an integer~~ n) of the path distance d_i between transmitter and receiver, and the delay of an electromagnetic wave is $\tau_i = d_i/c$, where $c = 3 \times 10^8$ (m/s) is the speed of light.



$$c_i(\tau;t) = \alpha_i(t)e^{-j2\pi f_c \tau_i(t)}$$

$$h(t) = \alpha_0\,\delta(t-\tau_0) + \alpha_1\,\delta(t-\tau_1)$$

$$|H(f)|^2 \quad = \quad \alpha_0^2\,\left[1+\beta^2+2\beta\cos(2\pi f\Delta\tau)\right]$$

$$\beta \stackrel{\Delta}{=} \alpha_1/\alpha_0$$

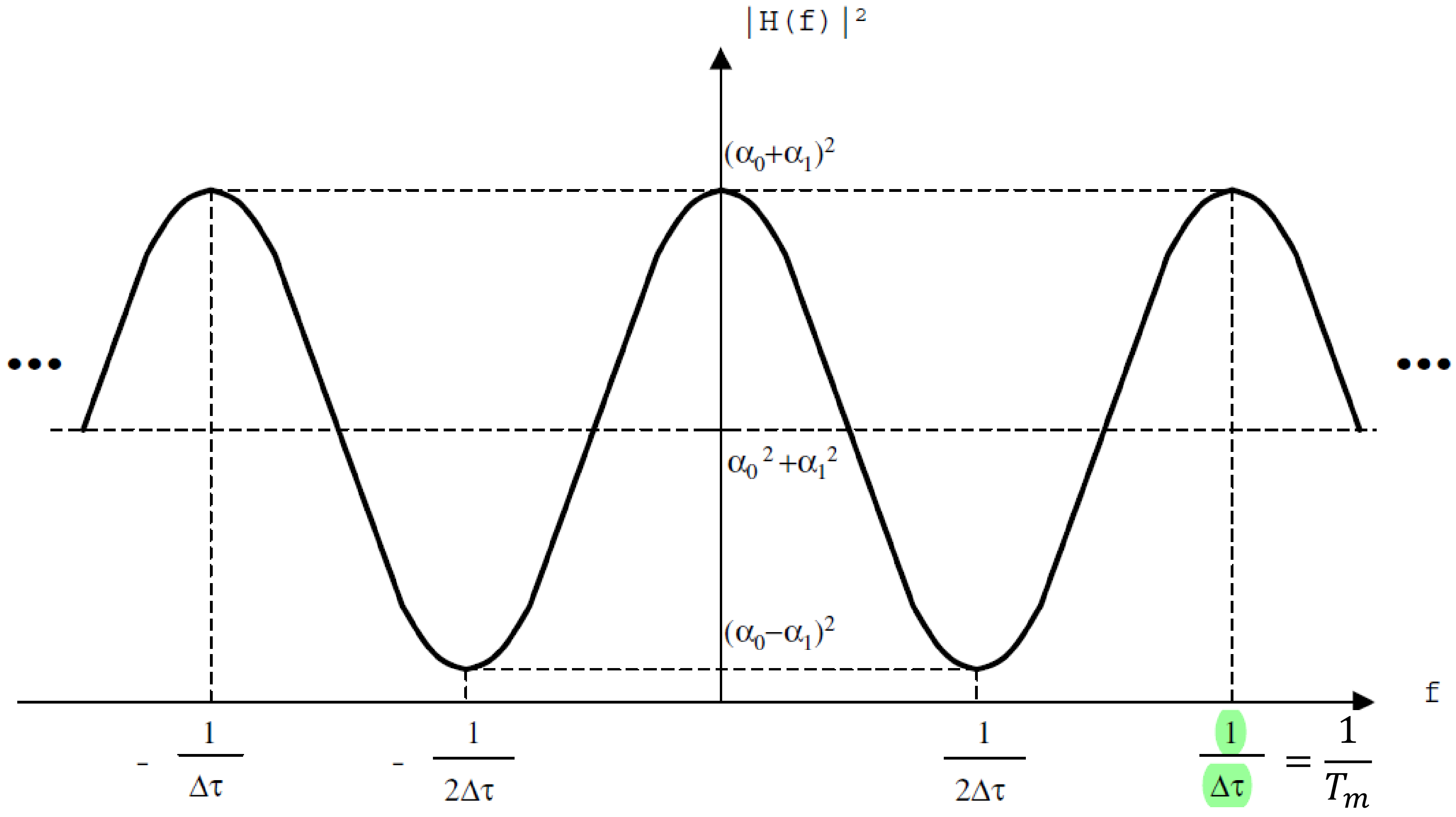
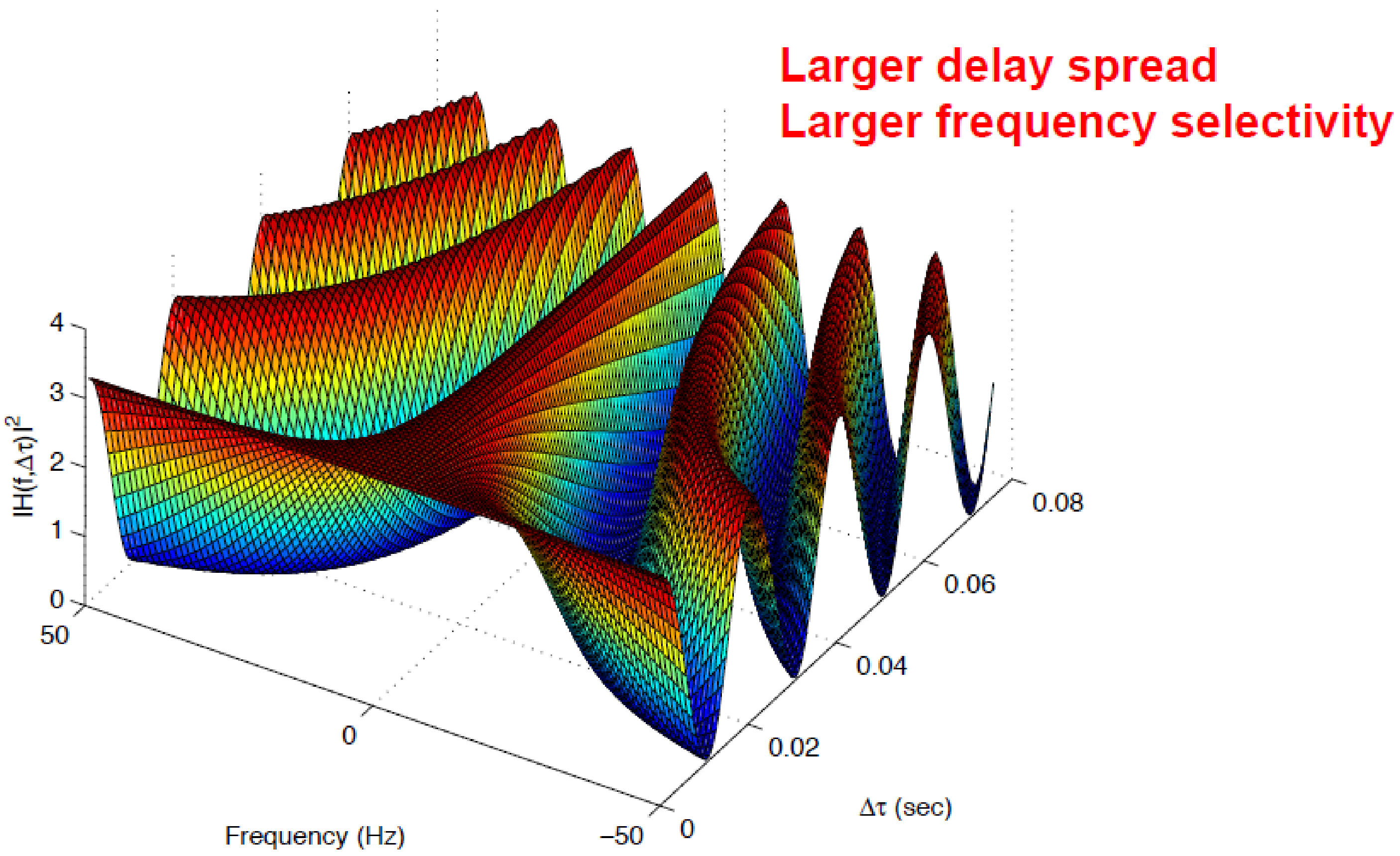


Figure 2: Sketch of $|H(f)|^2$.

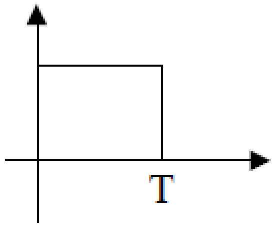
We say that this channel is *frequency selective* in that the transfer function is no longer flat (constant). This means that some frequency components are severely attenuated while others are accentuated. In addition, the frequency values where the low values of the transfer function occur (known in the literature as *nulls*) are a function of the delay $\Delta\tau$ between the two paths. The PSD $|H(f,\Delta\tau)|^2$ of the channel as a function of both frequency f and delay spread $\Delta\tau$ is depicted

PSD of a wireless two-path channel

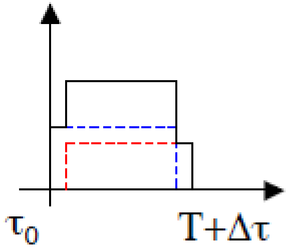


Wireless two-path channel response to rectangular pulses

Narrowband pulses, $T > \Delta\tau$ $(\Delta\tau = \tau_1 - \tau_0)$



Input

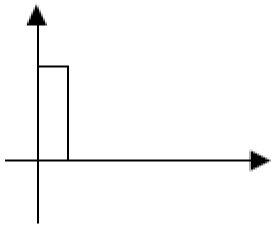


Output

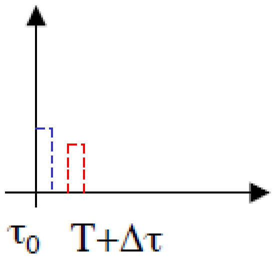
- Amplitude variation:
  Fading
- Distortion

FLAT FADING

Wideband pulses, $T < \Delta\tau$



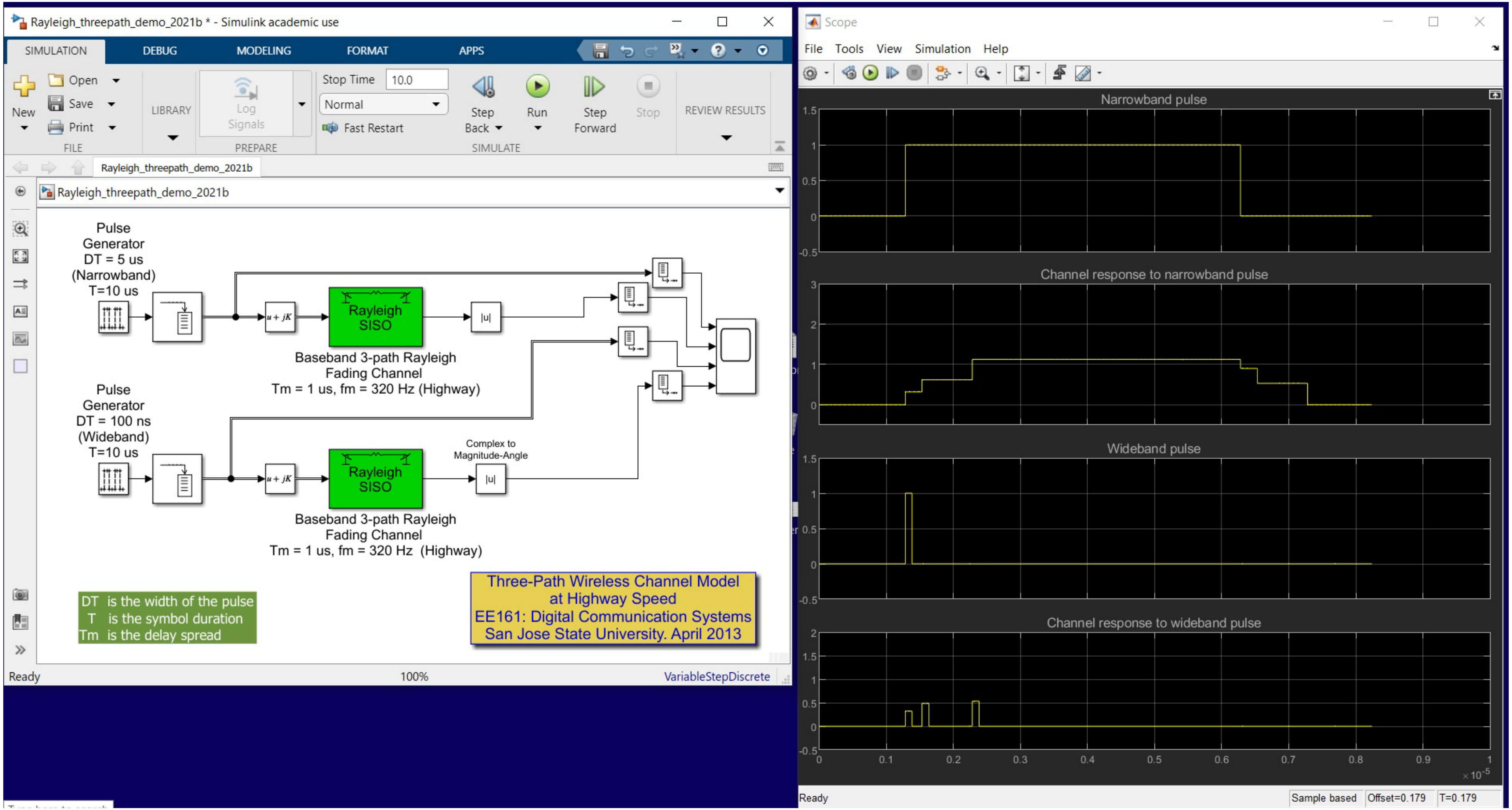
Input



Output

- Amplitude variation:
  Fading (less)
- No distortion
- Overlap to next pulse:
  Interference

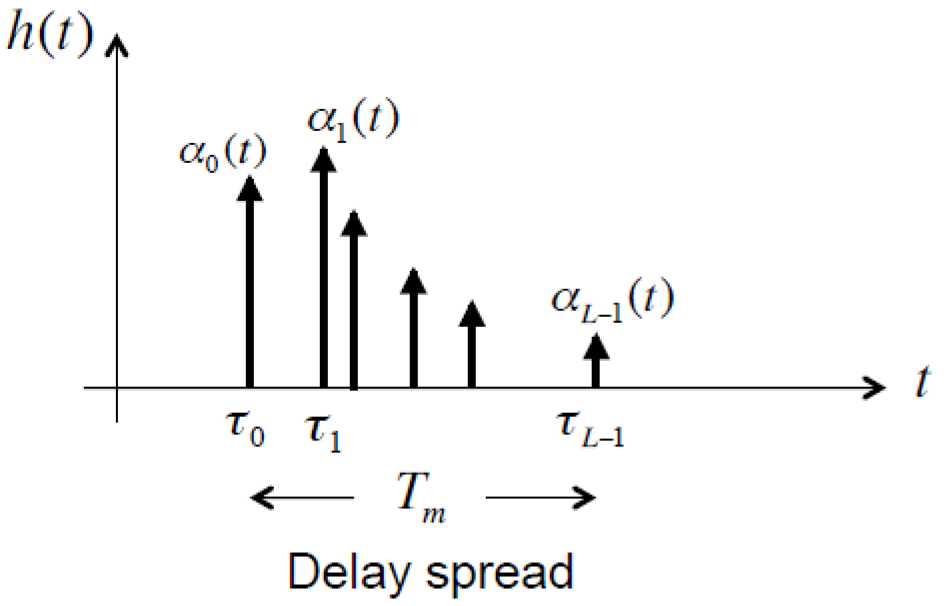
FREQUENCY-SELECTIVE FADING



MATLAB Simulink model: *Rayleigh_threepath_demo_2021b.slx*

Multipath effects

- Reflections (paths) of the transmitted electromagnetic signal on objects
- *L*-path channel impulse response:



Coherence bandwidth:

$$\boxed{B_c = \frac{1}{T_m}}$$

Phase rotation:

$$\boxed{\phi_i(t) = 2\pi f_c \tau_i(t)}$$

Basic types of fading

- Flat fading:

$$\boxed{B << B_c \quad \text{or} \quad 2\mathrm{W} << \frac{1}{T_m}}$$

  – **Narrowband** signaling

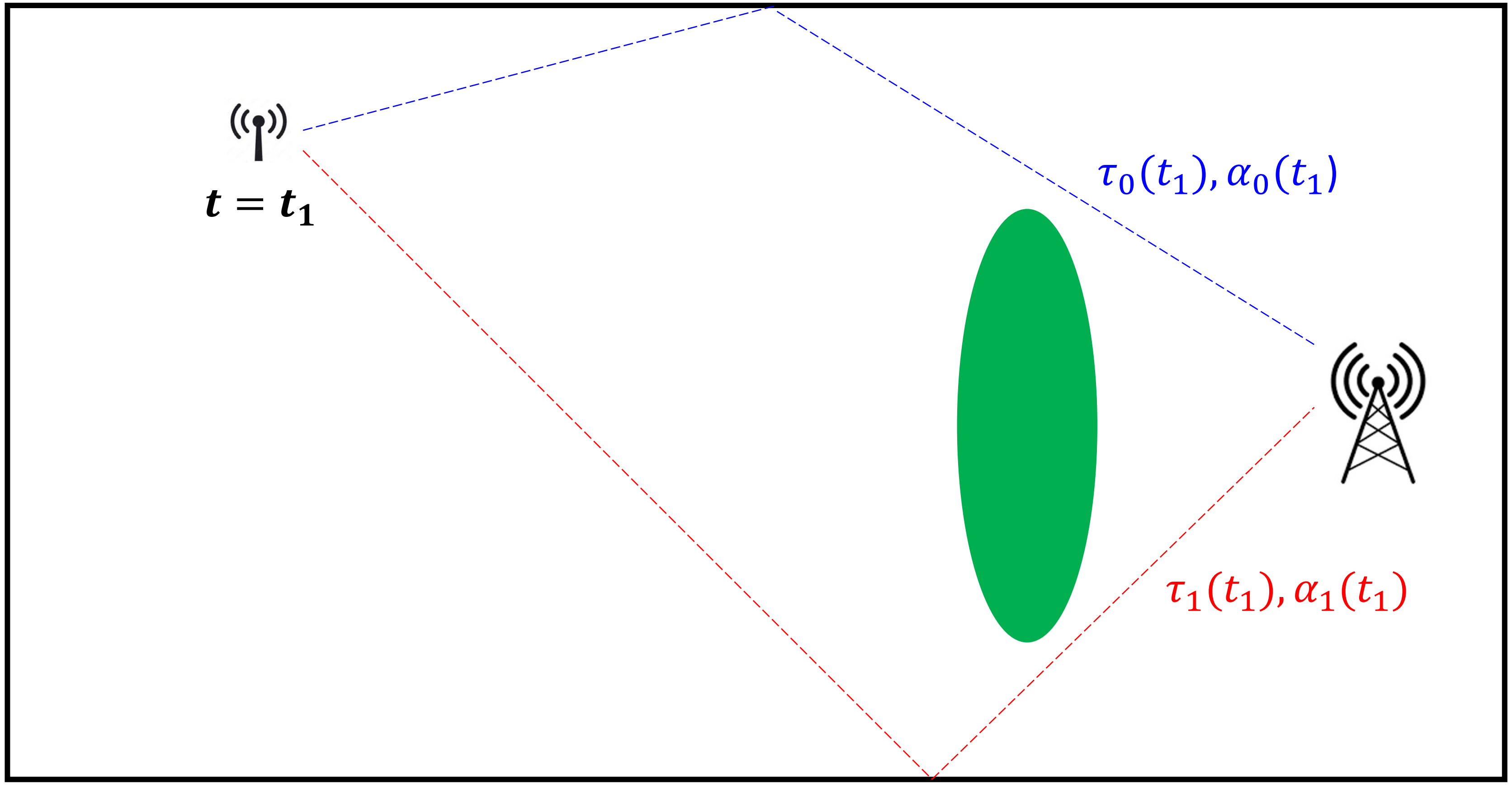
B=2W is the signal bandwidth

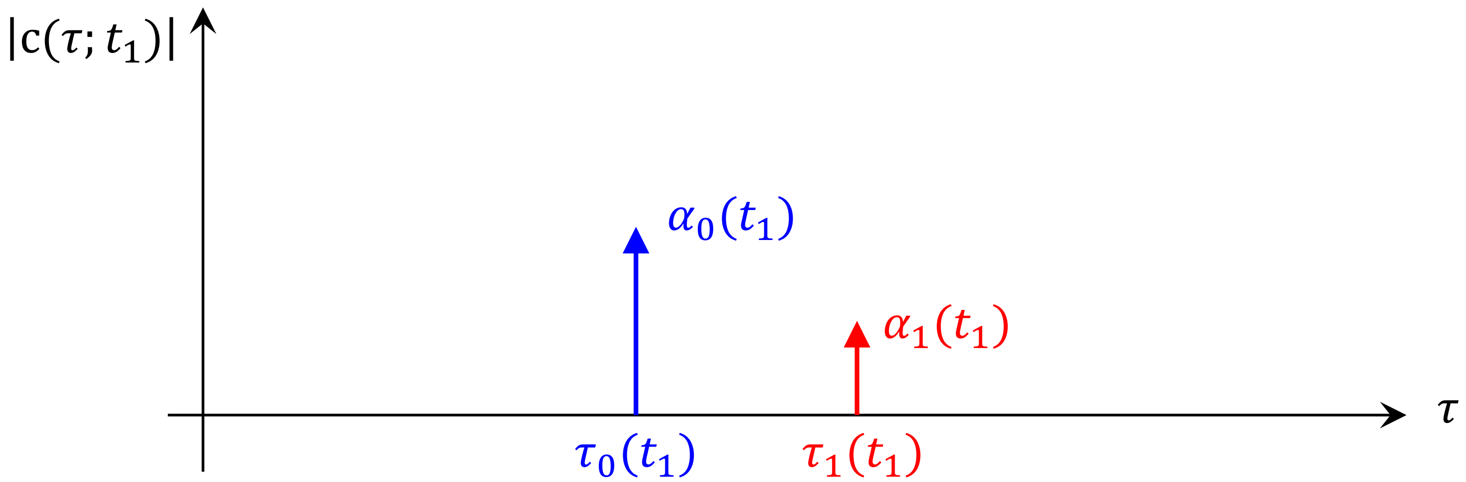
- Frequency-selective fading:

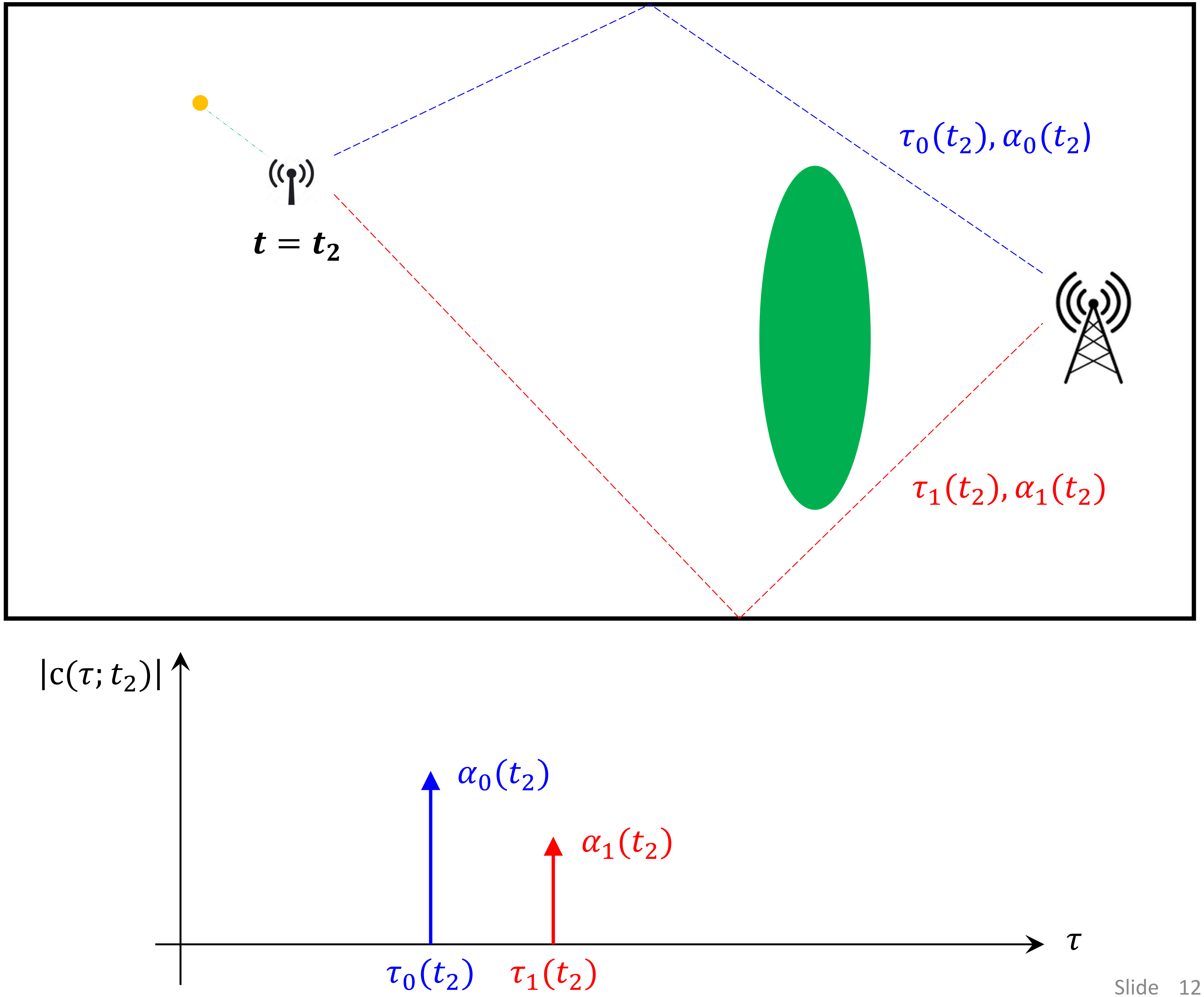
$$\boxed{B >> B_c \quad \text{or} \quad 2\mathrm{W} >> \frac{1}{T_m}}$$

  – **Wideband** signaling

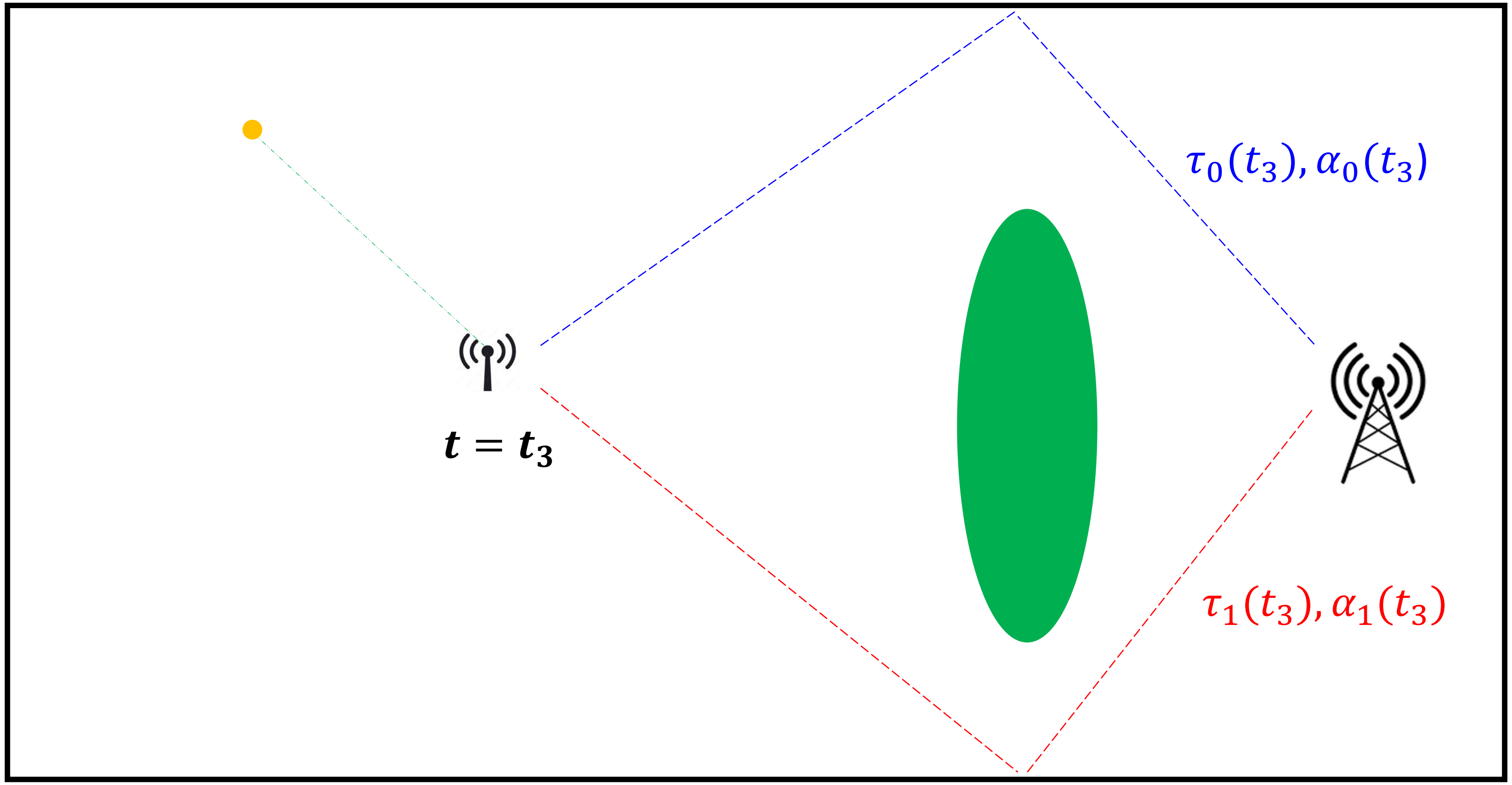
Mobility and time selectivity


$t = t_1$
$\tau_0(t_1), \alpha_0(t_1)$
$\tau_1(t_1), \alpha_1(t_1)$

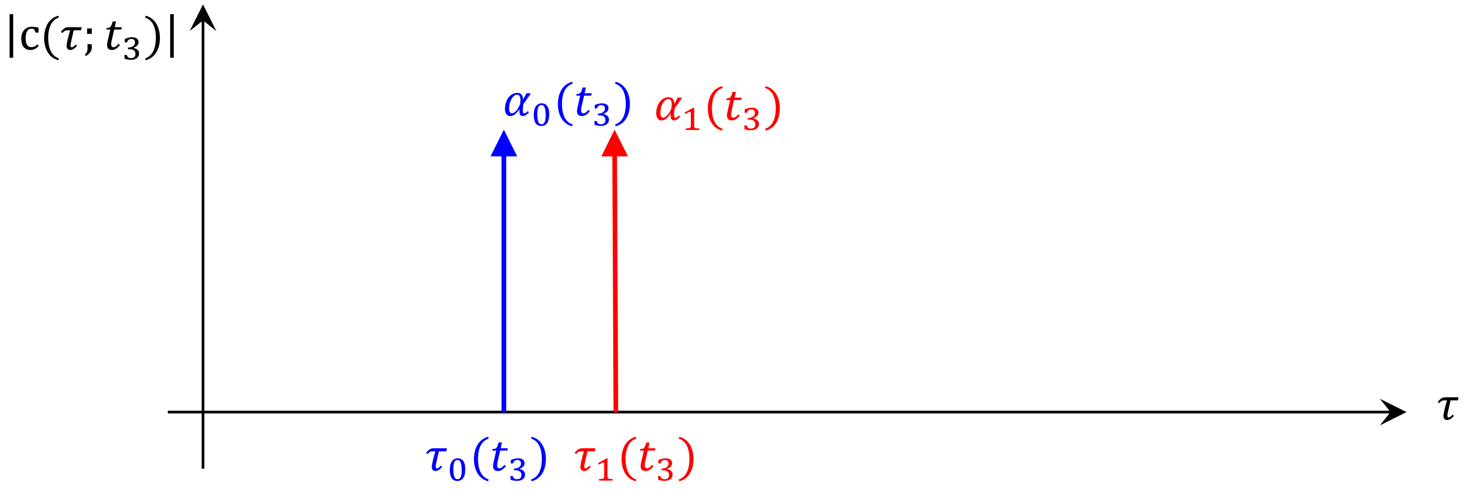

$|c(\tau; t_1)|$
$\alpha_0(t_1)$
$\alpha_1(t_1)$
τ
$\tau_0(t_1)$
$\tau_1(t_1)$



$t = t_2$
$\tau_0(t_2), \alpha_0(t_2)$
$\tau_1(t_2), \alpha_1(t_2)$
$|c(\tau; t_2)|$
$\alpha_0(t_2)$
$\alpha_1(t_2)$
τ
$\tau_0(t_2)$
$\tau_1(t_2)$



$t = t_3$
$\tau_0(t_3), \alpha_0(t_3)$
$\tau_1(t_3), \alpha_1(t_3)$

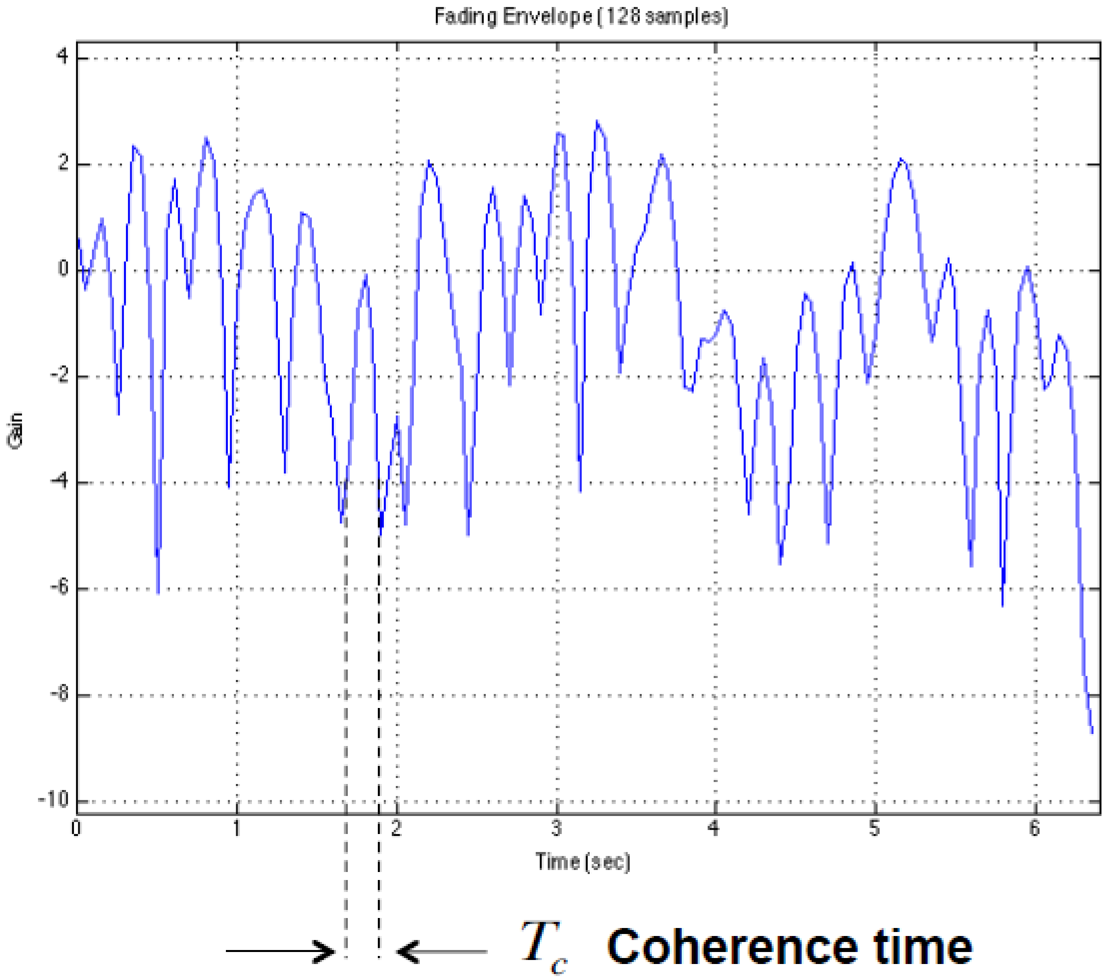


$|c(\tau; t_3)|$
$\alpha_0(t_3)$ $\alpha_1(t_3)$
τ
$\tau_0(t_3)$ $\tau_1(t_3)$

Fading and time variations

- Variations in received power due to movement (Doppler):

$|c_i(\tau; t)|$



T_c **Coherence time**

$$T_c = \frac{1}{B_D}$$

B_D : Doppler bandwidth

$$B_D = 2vf_c / c$$

Slow fading: $T < T_c$

Fast fading: $T > T_c$

T is the symbol duration

Summary

- **Multipath** due to reflections may cause a non-flat or *frequency selective* channel response. Classification:

    1. Flat channel: $T > T_m$ or $B < B_c$
    2. Frequency-selective channel: $T < T_m$ or $B > B_c$

- **Mobility** may cause a (*time selective*) variation (*fading*) in the received amplitude of each path. Classification:

    1. Slow fading: $T < T_c$ or $B > B_D$
    2. Fast fading: $T > T_c$ or $B < B_D$