COMPUTER ENGINEERING

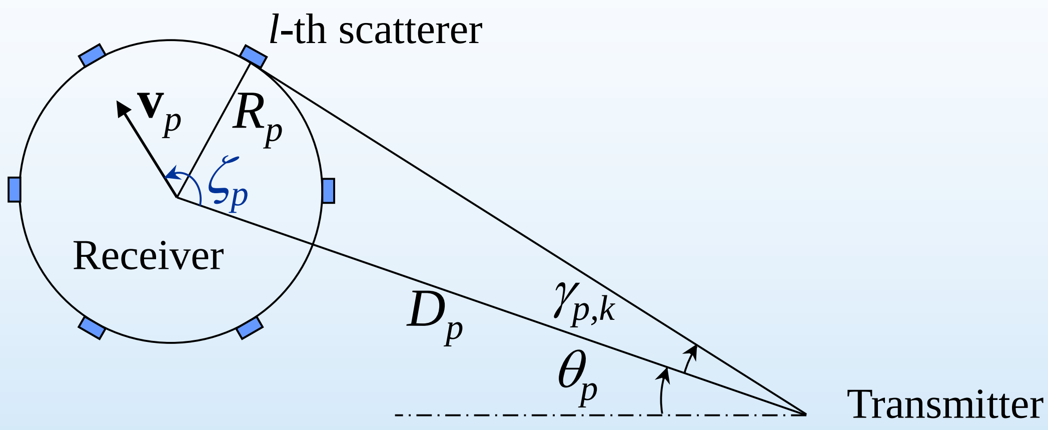
Digital transmission on the wireless channel

Mobile Wireless Channel

- Open transmission medium (broadcast)
  - Resource sharing (TDM, FDM, CDMA)
  - Disturbances
  - Interference
  - Interception

- Mobility
  - Channel characteristics that vary over time
  - Fading
  - Shadowing
  - Coverage and continuity of service

Multi-path Channel



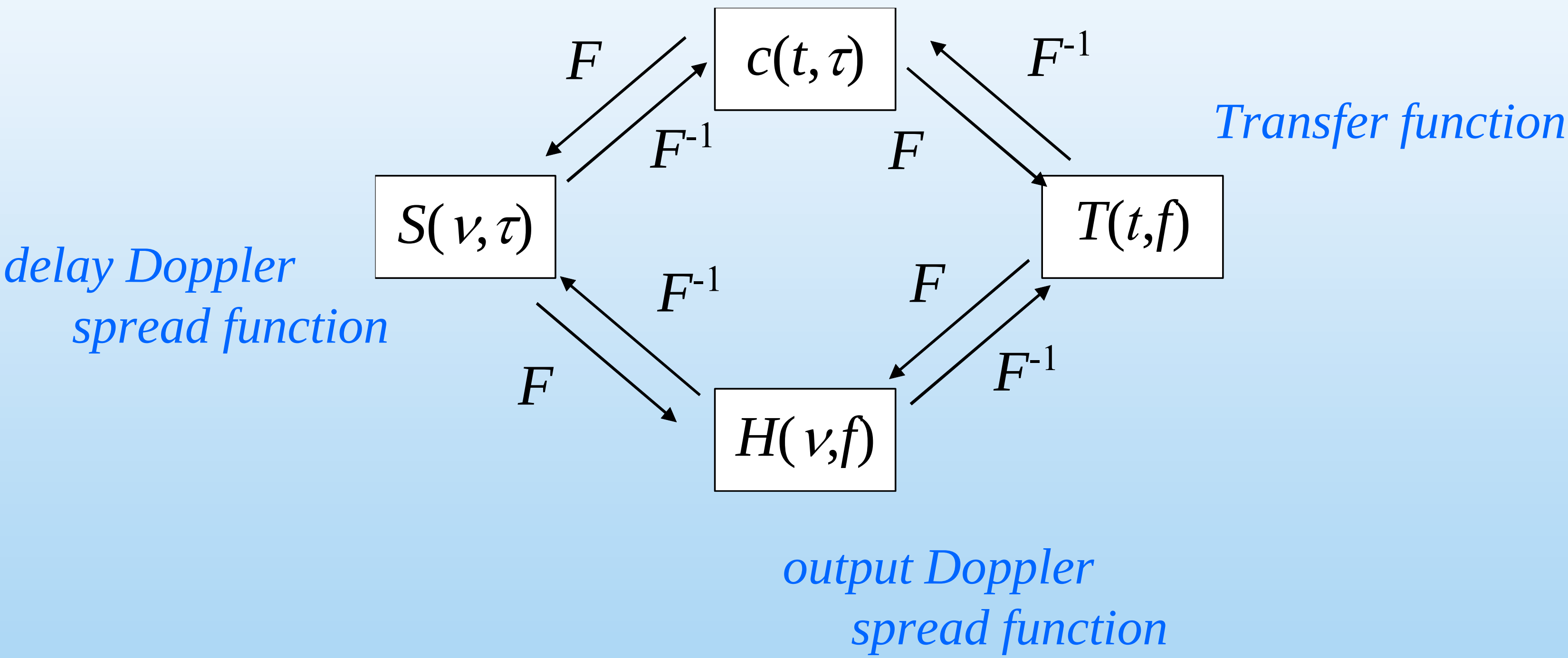
- Defined by the impulse response (input delay spread function): $c(t,\tau)$ (channel response evaluated at t to an impulse applied at t-τ).

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

- Effects of mobility:
  - Doppler effect (variable delay: frequency variation).
  - Random combination of phases of multiple paths varying in time.

The functions of Bello (1)

- Fourier transforms



The functions of Bello (2)

- $S(\tau, \nu)$: delay Doppler spread function: provides an indication of the channel dispersion with respect to the Doppler frequency ν as the delay τ varies.

- $T(f,t)$: time varying transfer function

$$y(t) = \int_{-\infty}^{+\infty} X(f) T(f,t) e^{j2\pi f t} \mathrm{d}f$$

- $H(f, \nu)$: output Doppler spread function: provides an indication of the channel dispersion with respect to the Doppler frequency ν as the frequency f varies.

$$Y(f) = \int_{-\infty}^{\infty} X(f-\upsilon) H(f-\upsilon, \upsilon) \mathrm{d}\upsilon$$

Correlation functions

- $\Phi_c(t,s;\tau,\eta)=\mathrm{E}[c(t,\tau)c^*(s,\eta)]/2;$
- $\Phi_T(t,s;f,m)=\mathrm{E}[T(t,f)T^*(s,m)]/2;$
- $\Phi_H(\nu,\mu;f,m)=\mathrm{E}[H(\nu,f)H^*(\mu,m)]/2;$
- $\Phi_S(\nu,\mu;\tau,\eta)=\mathrm{E}[S(\nu,\tau)S^*(\mu,\eta)]/2.$

  – They are connected to each other by a double Fourier transform.

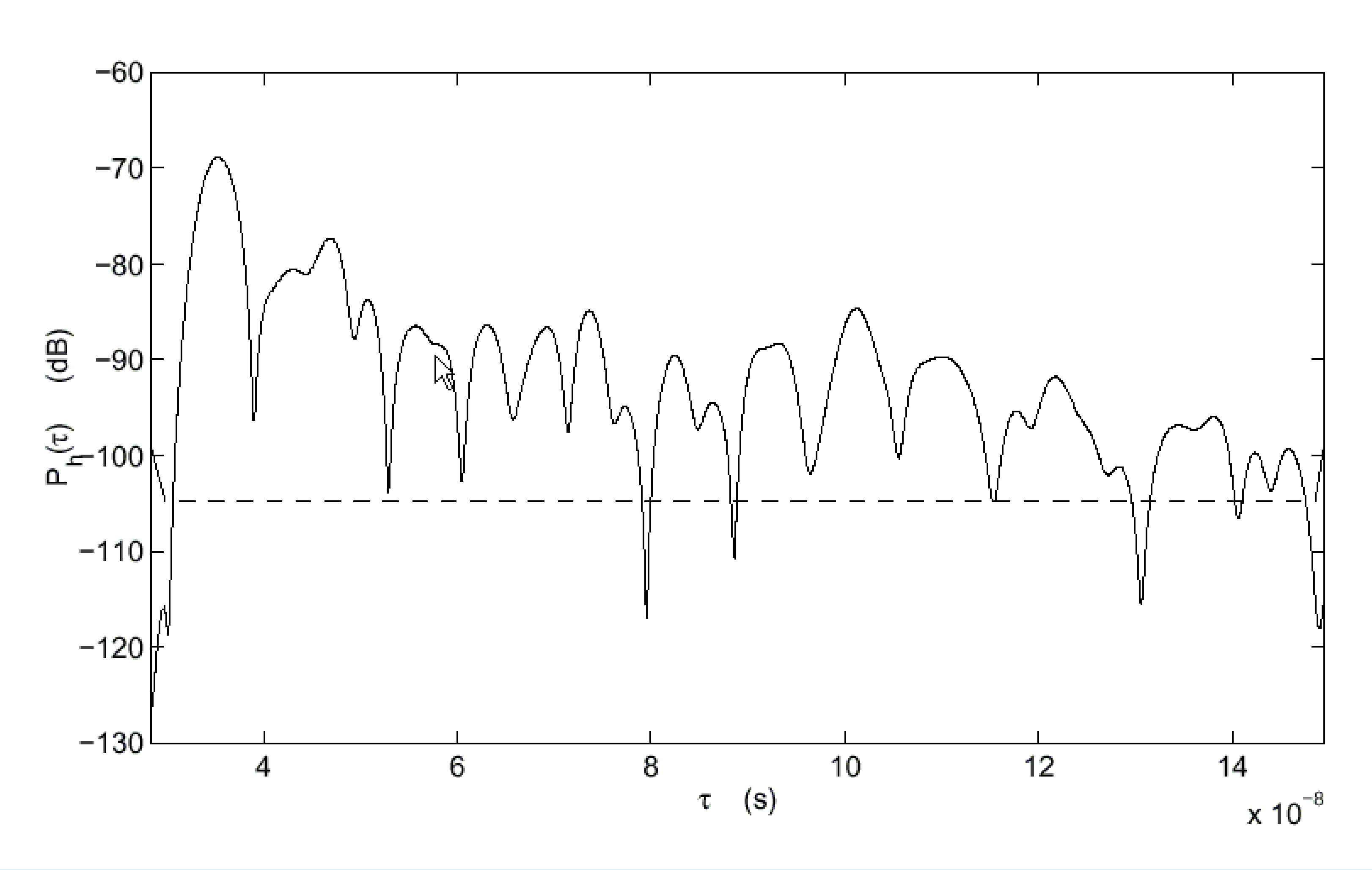
$$\Phi_S(\nu,\mu;\tau,\eta)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\Phi_c(t,s;\tau,\eta)e^{j2\pi(\nu t-\mu s)}\mathrm{d}t\mathrm{d}s$$

$$\Phi_c(t,s;\tau,\eta)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\Phi_S(\nu,\mu;\tau,\eta)e^{-j2\pi(\nu t-\mu s)}\mathrm{d}\nu\mathrm{d}\mu$$

Wide Sense Stationary Uncorrelated Scattering (WSSUS) channel

- The attenuation and phase shift associated with the delay τ_1 are uncorrelated with those associated with the delay τ_2. The same holds for Doppler frequencies. ν_1 and ν_2.
- $\Phi_c(t,t+\Delta t;\tau,\eta)=\Phi_c(\Delta t,\tau)\delta(\eta-\tau);$
- $\Phi_T(t,t+\Delta t;f,f+\Delta f)=\Phi_T(\Delta t;\Delta f);$
- $\Phi_H(\nu,\mu;f,f+\Delta f)=\Phi_H(\nu,\Delta f)\delta(\nu-\mu);$
- $\Phi_S(\nu,\mu;\tau,\eta)=\Phi_S(\nu,\tau)\,\delta(\eta-\tau)\delta(\nu-\mu).$
- The function $\Phi_c(0,\tau)=\Phi_c(\tau)$ is said power delay profile, and provides the average power (averaged over all values of the Doppler spread ν) at the output, as a function of the delay τ.

Power delay profile (an indoor example)



Delay spread

- Average delay: $$\mu_\tau = \frac{\int_0^\infty \tau \phi_c(\tau)\mathrm{d}\tau}{\int_0^\infty \phi_c(\tau)\mathrm{d}\tau}$$

- Delay spread: $$\sigma_\tau = \sqrt{\frac{\int_0^\infty (\tau - \mu_\tau)^2 \phi_c(\tau)\mathrm{d}\tau}{\int_0^\infty \phi_c(\tau)\mathrm{d}\tau}}$$

- Macrocells: 1-10 μs
- Indoor (open space): 300 ns
- Indoor (rooms): 30-60 ns

Coherence bandwidth

- The function $\Phi_T(\Delta t=0,\Delta f)= \Phi_T(\Delta f)$ measures the frequency correlation of the channel.

- It is called coherence bandwidth, B_c, the frequency separation, Δf, for which $\Phi_T(\Delta f)$ assumes a given value (usually 0.5).

- The coherence bandwidth is proportional to the reciprocal of the delay spread.

$$B_c \equiv \frac{1}{\sigma_\tau}$$

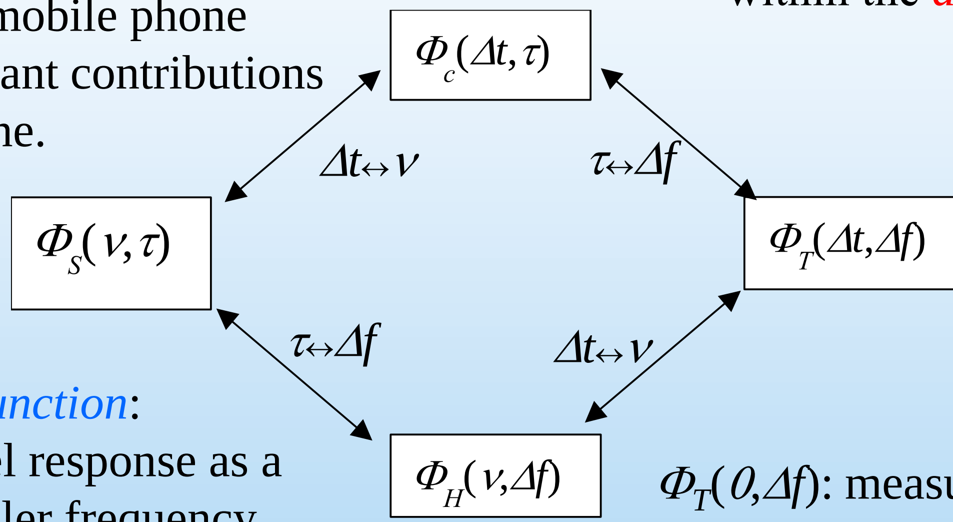
Coherence Time

- The function $\Phi_H(\nu,\Delta f=0)= \Phi_H(\nu)$ provides the behavior of the output power as a function of the Doppler frequency, ν.
- The bandwidth, B_d, within which this function assumes significant values is called Doppler spread.
- The inverse of this bandwdth is called coherence time (the time interval in which a significant correlation between the channel characteristics remains).
- Observe that B_d is proportional to the mobile spees, V, $B_d \equiv V/\lambda=Vf_c/c$, being f_c the carrier frequency and c the speed of light in the vacuum.

Summary

$\Phi_c(\Delta t, \tau)$: assumes values close to $\Phi_c(0, \tau)$ for $\Delta t < T_c$ (coherence time). *Doppler Spread*: $B_d = 1/T_c$; bandwidth within which a mobile phone receives significant contributions from a single tone.

$\Phi_c(0, \tau)$: *delay power spectrum*: takes on significant values within the *delay spread*.



Spaced time spaced frequency correlation function.

$\Phi_S(\nu, \tau)$: *scattering function*: Measures channel response as a function of Doppler frequency and time variation.

$\Phi_T(0, \Delta f)$: measures channel coherence in the frequency domain. It takes on significant values within the coherence band (inversely proportional to the delay spread).

$\Phi_H(\nu, 0)$: *Doppler power spectrum*: takes on significant values within the *Doppler spread*.

Discrete delay channel

- Assume we have N distinct paths, each of which is characterized by attenuation. α_i and delay τ_i. We have:

$$c(t,\tau)=\sum_{i=1}^{N}\alpha_i(t)e^{-j2\pi f_c\tau_i(t)}\delta(\tau-\tau_i(t))$$

- Generic path weight:

$$p_i=\alpha_i^2\Big/\sum_{n=1}^{N}\alpha_n^2$$

- Average delay and delay spread:

$$\mu_\tau=\sum_{i=1}^{N}p_i\tau_i \qquad \sigma_\tau=\sqrt{\sum_{i=1}^{N}p_i(\tau_i-\mu_\tau)^2}$$

6-path channel model (macrocells) (COST 207)

Urban typical		Urban (worst case)	
delay, μs	weight	delay, μs	weight
0.0	0.189	0.0	0.164
0.2	0.379	0.3	0.293
0.5	0.239	1.0	0.147
1.6	0.095	1.6	0.094
2.3	0.061	5.0	0.185
5.0	0.037	6.6	0.117