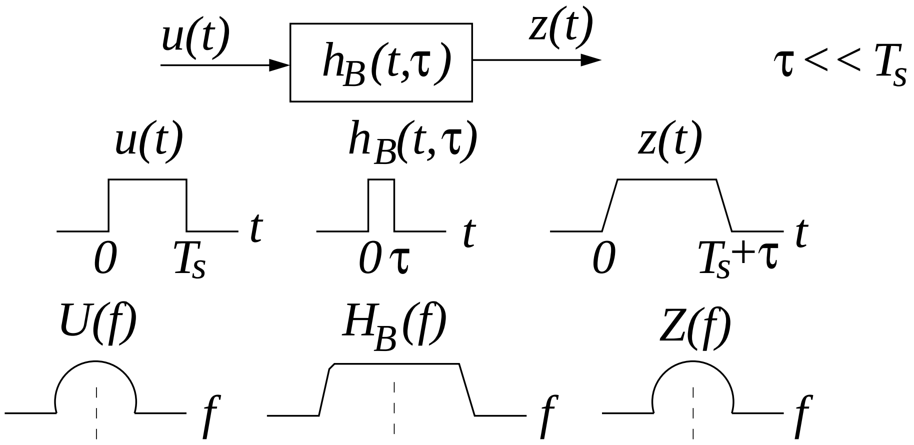
Revision of Lecture Three

- We have an indepth look into **wireless mobile channels**
- Doppler spread which causes frequency dispersion
  - Physical dimension **Doppler frequency**, effects of which are characterised by Doppler power spectrum with parameters Doppler spread/coherence time
- Multipath which causes time dispersion
  - Physical dimension **excess delay**, effects of which are characterised by power delay profile with parameters mean excess delay, root mean square delay spread/coherence bandwidth
- Similar spatial dimension characterised by angle power spectrum with parameters mean angle, root mean square angle spread/coherence distance

This lecture we use first two physical dimensions to further classify channels, in particular, channel impulse response

Narrow-Band Channels

- **Narrow-band** channels: also called **flat fading**, occurs when $B_S \ll B_C$ or $T_S \gg \sigma_\tau$



- Transmitted signal bandwidth B_S is **much smaller** than channel coherence bandwidth B_C, or symbol period T_S is **much larger** than rms delay spread $\sigma_\tau \Rightarrow$ All the transmitted frequency components encounter nearly identical propagation delay, and received signal sampled at symbol rate is given by

$$r(k) = (a_I + ja_Q) \cdot s(k)$$

where $s(k)$ is transmitted symbol at sample k, and $r(k)$ received signal sample

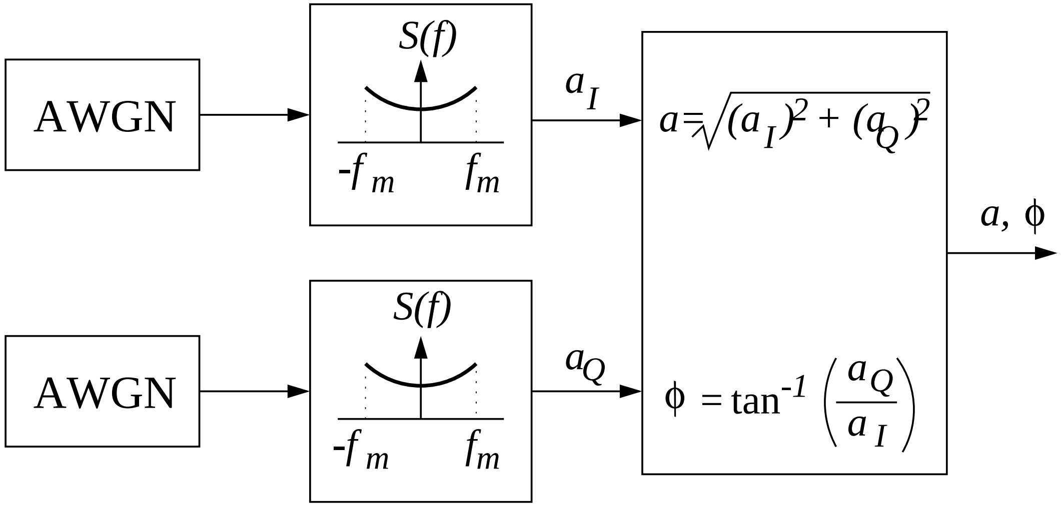
Narrow-Band Channels (continue)

- There is **no ISI** for a narrow band channel, but the channel can be time varying, that is, a_I and a_Q are time varying (fading)
- **Time varying nature** of a_I and a_Q is characterised by **Doppler spectrum** $S(f)$, and $a = \sqrt{a_I^2 + a_Q^2}$ is Rayleigh distributed (fading)
- Baseband **Rayleigh fading channel** simulator:

An white Gaussian process with unit variance convoluted with a filter having specified Doppler spectrum yields real part a_I of channel tap

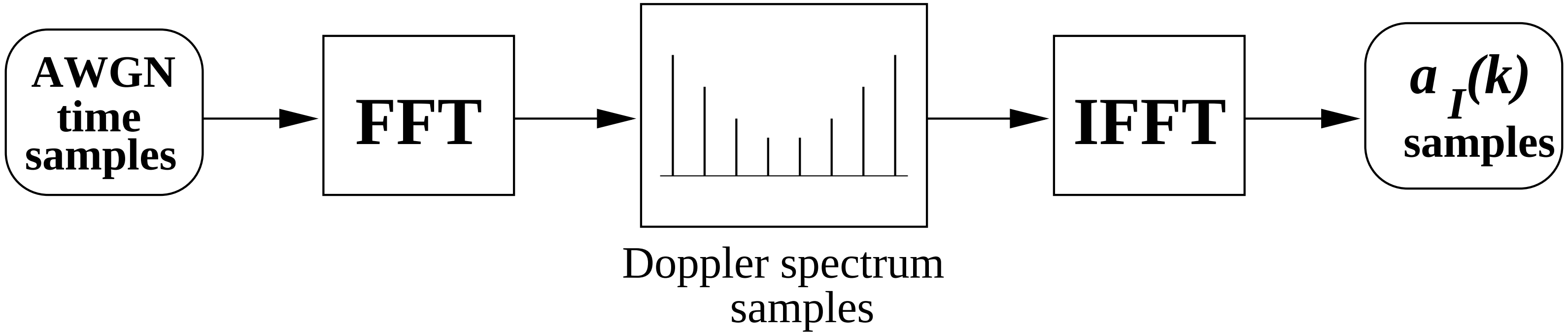
Similarly, imaginary part a_Q is generated

$a = \sqrt{a_I^2 + a_Q^2}$ is then the required Rayleigh process



Generating Flat Rayleigh Channel

- Method of generating Rayleigh channel can be time-domain based, but **frequency-domain** based is more convenient
  - Given carrier frequency f_c and mobile speed v specifies Doppler frequency f_m
  - Symbol rate or symbol period T_s determines how you should sample AWGN process, and T_s and f_m specify required normalised Doppler frequency $\bar{f}_m$



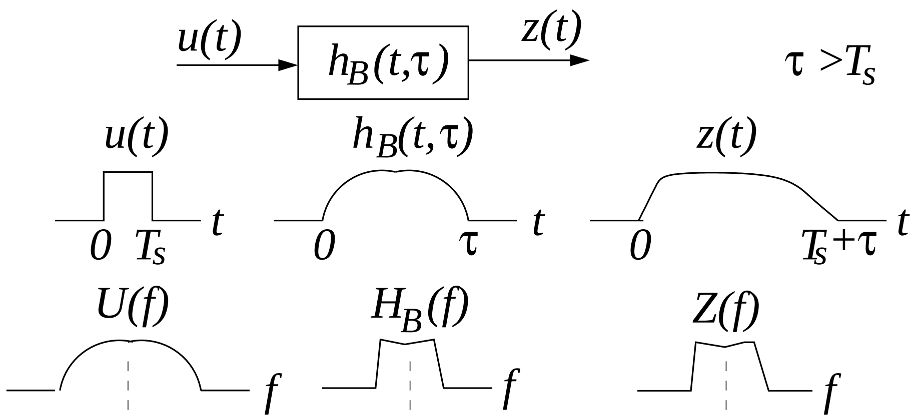
Block of AWGN time samples is FFT → frequency samples are convoluted with Doppler spectrum samples → Doppler spectrum shaped frequency samples are IFFT to yield block of real-part channel tap time samples $\{a_I(k)\}$

Similarly, $\{a_Q(k)\}$ are generated

$a(k) = \sqrt{a_I^2(k) + a_Q^2(k)}$ is the required Rayleigh process time sample

Wideband Channels

- **Wideband channels**: also called **frequency selective**, occurs when $B_S > B_C$ or $T_S < \sigma_\tau$



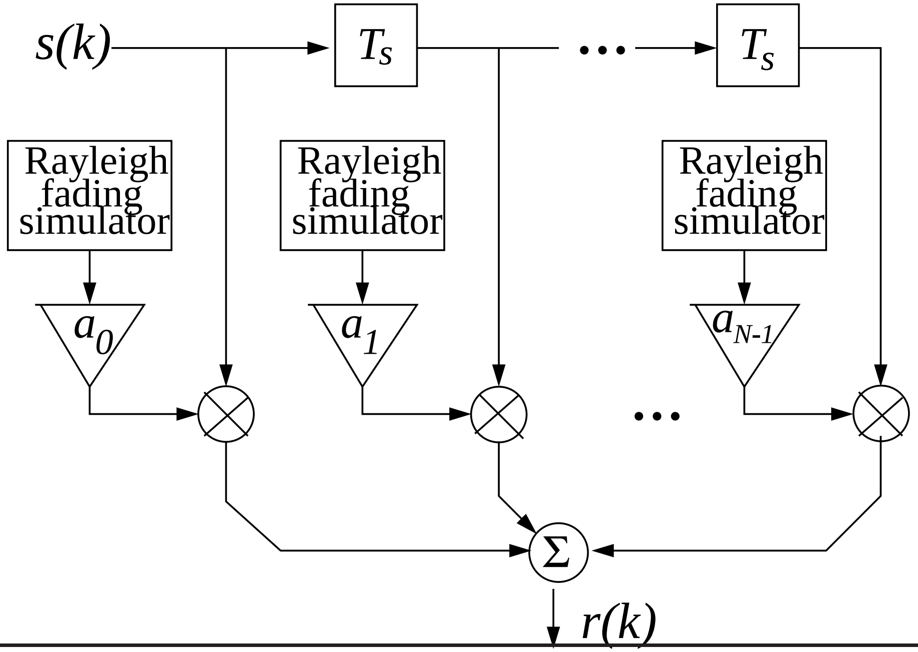
- Signal bandwidth B_S is **larger** than channel coherence bandwidth B_C, or symbol period T_S is **smaller** than rms delay spread σ_τ $\Rightarrow$ Channel has different gains and delays for different frequency components, and symbol-rate received signal sample is given by

$$r(k) = \sum_{i=0}^{N-1} (a_{I,i} + j a_{Q,i}) \cdot s(k-i)$$

where $s(k)$ is transmitted symbol at sample k and $r(k)$ received signal sample

Wideband Channels (continue)

- A frequency selective channel introduces **ISI**, and an equaliser is required at receiver
- Each $a_{I,i} + j a_{Q,i}$ represents a Rayleigh fading multipath component, with $a_i = \sqrt{a_{I,i}^2 + a_{Q,i}^2}$ Rayleigh distributed
- How fast time varying the channel is depends on Doppler spread
- Baseband channel simulator:



Channel Classification

- **Time-varying rate** depends on T_S/T_C or B_S/B_D

  Slow fading: $T_S \ll T_C$ or $B_S \gg B_D$

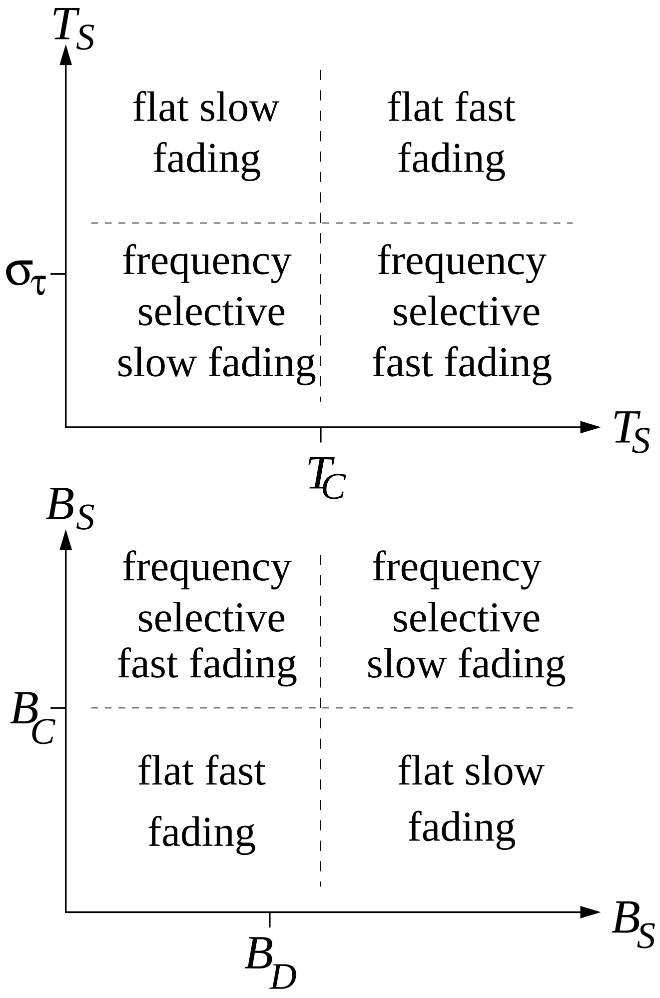
  Fast fading: $T_S > T_C$ or $B_S < B_D$

- **Frequency selective** depends on T_S/σ_τ or B_S/B_C

  Flat: $T_S \gg \sigma_\tau$ or $B_S \ll B_C$

  Selective: $T_S < \sigma_\tau$ or $B_S > B_C$

- Most difficult case is frequency selective and fast fading



T_S: symbol period

T_C: coherence time

σ_τ: rms delay spread

B_S: signal bandwidth

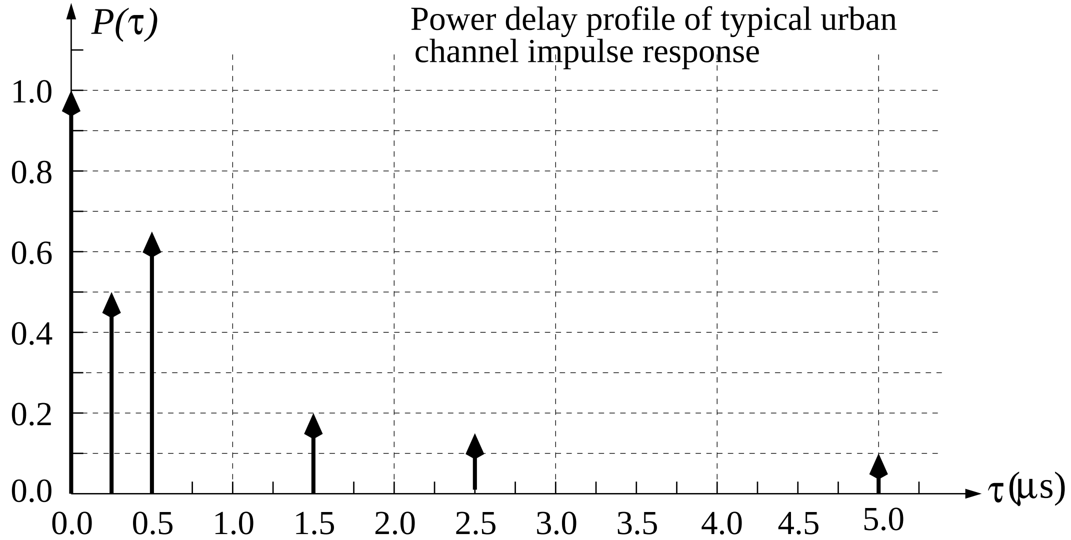
B_D: Doppler spread

B_C: coherence bandwidth

Further consider rms angle spread σ_θ / coherence distance D_c, classification $\Rightarrow$ three-D regions

Fading Channel Example

The power delay profile of a typical urban mobile radio channel is given below:



1. Estimate the 50% coherence bandwidth of the channel. **2**. Will this channel be suitable for AMPS (which has a baseband signal bandwidth $B_S = 30$ kHz) and GSM (which has a baseband signal bandwidth $B_S = 200$ kHz) service without the use of an equaliser?

In a GSM system with the carrier frequency $f_c = 1.8$ GHz, a mobile moves at a speed of $v = 120$ km/hr. **3**. Estimate the Doppler spread of the corresponding channel. **4**. Is this channel classified as being slow or fast fading?

Note: AMPS – Advanced mobile phone system; GSM – Global system for mobile communications

Solution: **1**. RMS delay spread σ_τ and coherence bandwidth B_C

$$\sum P(\tau_i) = 1 + 0.5 + 0.65 + 0.2 + 0.15 + 0.1 = 2.6$$

$$\sum P(\tau_i)\tau_i = 1\times 0 + 0.5\times 0.25 + 0.65\times 0.5 + 0.2\times 1.5 + 0.15\times 2.5 + 0.1\times 5 = 1.625\ (\mu\mathrm{s})$$

$$\sum P(\tau_i)\tau_i^2 = 1\times 0^2 + 0.5\times 0.25^2 + 0.65\times 0.5^2 + 0.2\times 1.5^2 + 0.15\times 2.5^2 + 0.1\times 5^2 = 4.08125\ (\mu\mathrm{s})^2$$

$$\bar{\tau} = \frac{\sum P(\tau_i)\tau_i}{\sum P(\tau_i)} = 0.625\ (\mu\mathrm{s}), \quad \bar{\tau^2} = \frac{\sum P(\tau_i)\tau_i^2}{\sum P(\tau_i)} = 1.5697115\ (\mu\mathrm{s})^2$$

$$\sigma_\tau = \sqrt{\bar{\tau^2} - (\bar{\tau})^2} = 1.086\ (\mu\mathrm{s}), \quad B_C \approx \frac{1}{5\sigma_\tau} = 184\ (\mathrm{kHz})$$

2. For AMPS, as $B_S = 30\ \mathrm{kHz} \ll B_C$, the channel is flat, and an equaliser is not required. For GSM, as $B_S = 200\ \mathrm{kHz} > B_C$, the channel is frequency selective, and an equaliser would be required.

3. For single carrier frequency $f_c = 1.8$ GHz, $v = 120$ km/hr and $c = 3 \times 10^8$ m/s, the maximum Doppler frequency deviation is

$$f_m = \frac{v f_c}{c} = \frac{1.2\times 10^5 \times 1.8 \times 10^9}{3600 \times 3 \times 10^8} = 200\ (\mathrm{Hz})$$

Since the signal bandwidth is very small in comparison to the the carrier frequency, the Doppler spread

$$B_D \approx f_m = 200\ (\mathrm{Hz})$$

4. Since $B_S = 200\ \mathrm{kHz} \gg B_D$, the channel is slow fading.

Comments

- We have finished **mobile radio channels**. To understand mobile communication technologies, you need an understand of **mobile communication media**

- Two main sources of hostility in mobile media are **Doppler spread** and **multipath**. Many techniques developed are counter measures for **fading and frequency selective**

- Consider a simple example. Channel coding is very good in detecting and correcting isolated bit errors. When a channel is in a deep fade, bursts of bit errors will occur, and this causes problem for channel decoding. A simple interleaver will do the trick: it mixes up bit sequence for transmission. At receiver, de-interleaver will break up bursts of bit errors into isolated ones.

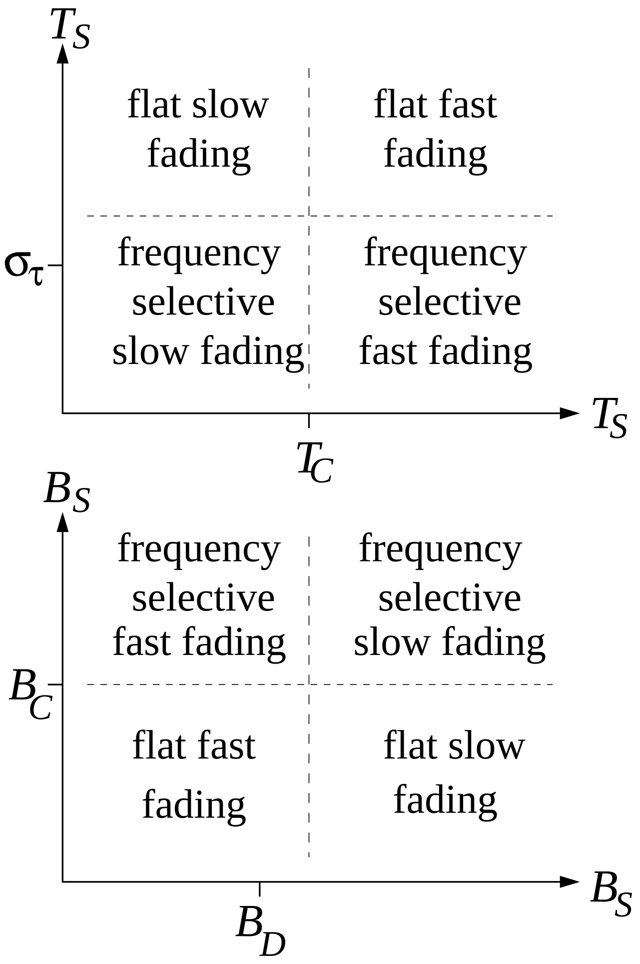
- There are many examples. It is useful in the subsequent parts of study that a connection with mobile radio media is made

- ST processing is powerful, as it exploits a whole new spatial (angle) dimension

Summary

- Narrow-band (flat) channels and wideband (frequency selective) channels

- Classification of channels:
  - Slow fading:
    $T_S \ll T_C$ or $B_S \gg B_D$
  - Fast fading:
    $T_S > T_C$ or $B_S < B_D$
  - Flat:
    $T_S \gg \sigma_\tau$ or $B_S \ll B_C$
  - Frequency selective:
    $T_S < \sigma_\tau$ or $B_S > B_C$



T_S: symbol period

T_C: coherence time

σ_τ: rms delay spread

B_S: signal bandwidth

B_D: Doppler spread

B_C: coherence bandwidth

- Sources of (time) fading and frequency selective: Doppler spread and multipath

- Spatial dimension can also be exploited