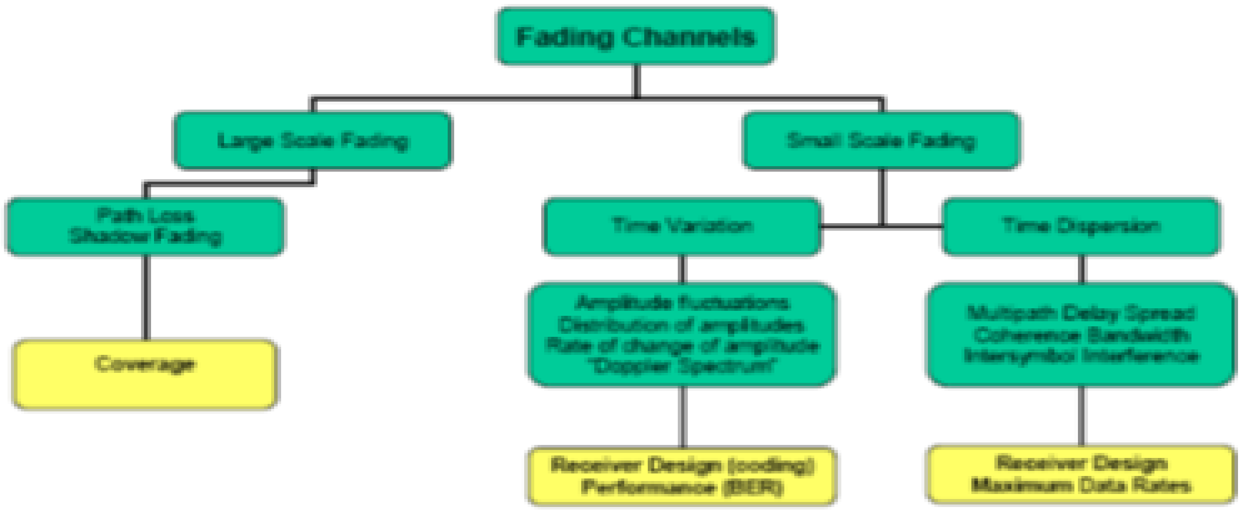
Communication Issues and Radio Propagation



❖ Small Scale Propagation or fading

Characterization of the rapid fluctuations of the received signal strength over very short travel distances

Small Scale or Fading Models: characterize rapid fluctuations of received signal over

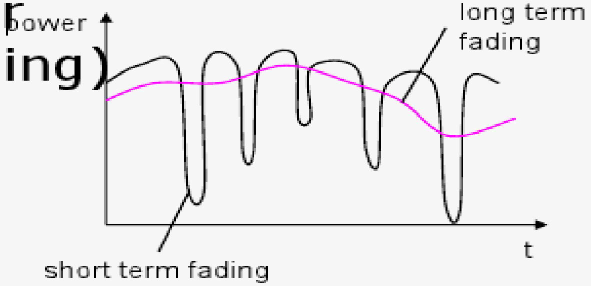
- short distances (*few* λ) or
- short durations (*few seconds*)

with **mobility** over short distances

- instantaneous signal strength fluctuates
- received signal = sum of many components from different directions
- phases are random → sum of contributions varies widely
- received signal may fluctuate 30-40 dB by moving a fraction of λ

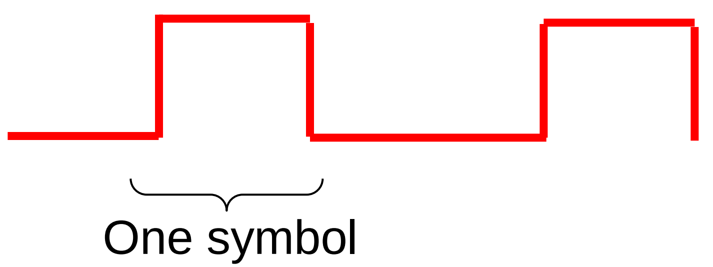
Fading

- Channel characteristics change over time & location
  - e.g., movement of receiver and/or scatters
- ➔ quick changes in the power received (short term/fast fading)
- Additional changes in
  - distance to sender
  - obstacles further away
- ➔ slow changes in the average power received (long term/slow fading)



Relationship between Bandwidth and Receiver Power

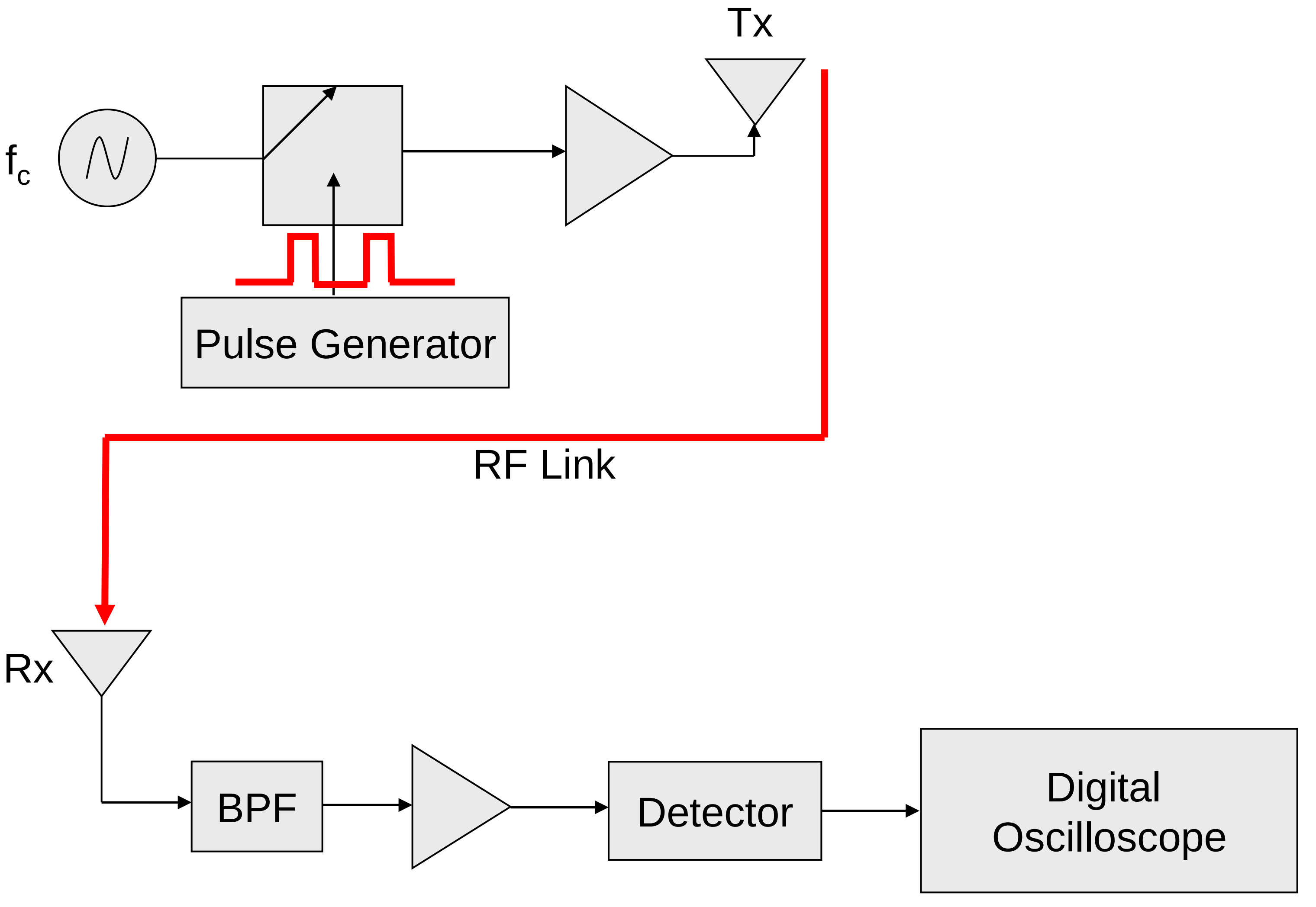
- What happens when two different signals with different bandwidths are sent through the channel?
  - What is the receiver power characteristics for both signals?
- We mean the bandwith of the baseband signal
  - The bandwidth of the baseband is signal is inversely related with its symbol rate.



Small-Scale Multipath Measurements

- Several Methods
  - Direct RF Pulse System
  - Spread Spectrum Sliding Correlator Channel Sounding
  - Frequency Domain Channel Sounding
- These techniques are also called channel sounding techniques

Direct RF Pulse System



Parameters of Mobile Multipath Channels

- Time Dispersion Parameters
  - Grossly quantifies the multipath channel
  - Determined from Power Delay Profile
  - Parameters include
    - Mean Access Delay
    - RMS Delay Spread
    - Excess Delay Spread (X dB)
- Coherence Bandwidth
- Doppler Spread and Coherence Time

Measuring PDPs

- Power Delay Profiles
  - Are measured by channel sounding techniques
  - Plots of relative received power as a function of excess delay
  - They are found by averaging *intantenous* power delay measurements over a local area

Timer Dispersion Parameters

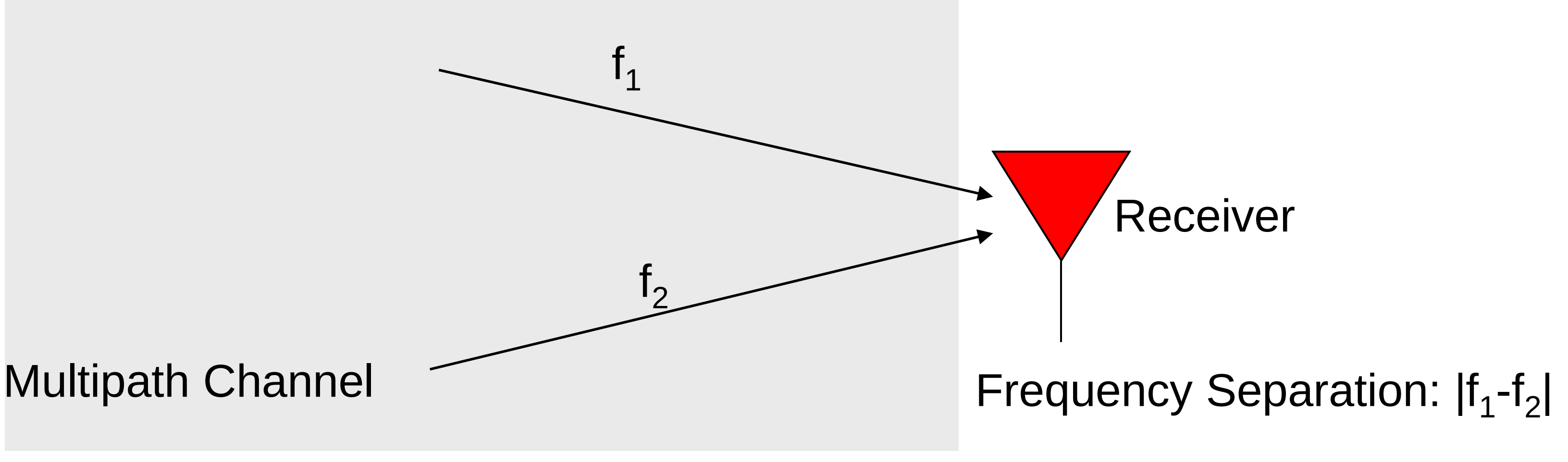
Maximum Excess Delay (X dB):

Defined as the time delay value after which the multipath energy falls to X dB below the maximum multipath energy (not necesarily belonging to the first arriving component).

It is also called *excess delay spread*.

Coherence Bandwidth (B_C)

- Range of frequencies over which the channel can be considered flat (i.e. channel passes all spectral components with equal gain and linear phase).
  - It is a definition that depends on RMS Delay Spread.
- Two sinusoids with frequency separation greater than B_c are affected quite differently by the channel.



Coherence Bandwidth

Frequency correlation between two sinusoids: $0 <= C_{r1, r2} <= 1$.

If we define Coherence Bandwidth (B_C) as the range of frequencies over which the frequency correlation is above 0.9, then

$$B_C = \frac{1}{50\sigma}$$

σ is rms delay spread.

If we define Coherence Bandwidth as the range of frequencies over which the frequency correlation is above 0.5, then

$$B_C = \frac{1}{5\sigma}$$

This is called 50% coherence bandwidth.

Coherence Bandwidth

- Example:
  - For a multipath channel, σ is given as 1.37μs.
  - The 50% coherence bandwidth is given as: $1/5\sigma$ = <u>146kHz</u>.
    - This means that, for a good transmission from a transmitter to a receiver, the range of transmission frequency (channel bandwidth) should not exceed 146kHz, so that all frequencies in this band experience the same channel characteristics.
    - Equalizers are needed in order to use transmission frequencies that are separated larger than this value.
    - This coherence bandwidth is enough for an AMPS channel (30kHz band needed for a channel), but is not enough for a GSM channel (200kHz needed per channel).

Coherence Time

- Delay spread and Coherence bandwidth describe the time dispersive nature of the channel in a local area.
  - They don't offer information about the time varying nature of the channel caused by relative motion of transmitter and receiver.
- Doppler Spread and Coherence time are parameters which describe the time varying nature of the channel in a small-scale region.

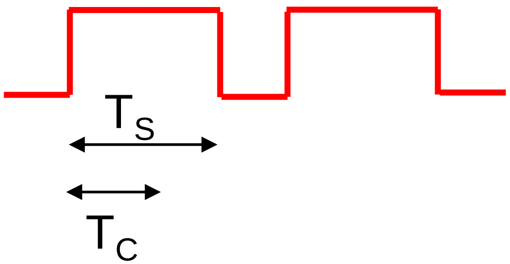
Doppler Spread

- Measure of spectral broadening caused by motion
- We know how to compute Doppler shift: f_d
- Doppler spread, B_D, is defined as the maximum Doppler shift: $f_m = v/\lambda$
- If the baseband signal bandwidth is much greater than B_D then effect of Doppler spread is negligible at the receiver.

Coherence Time

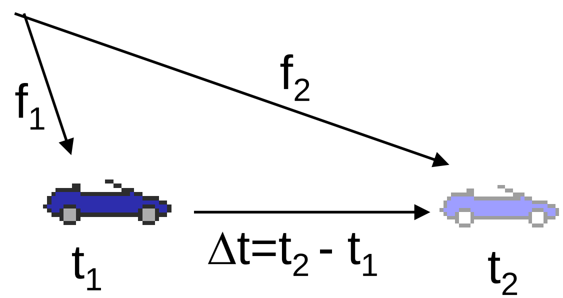
Coherence time is the time duration over which the channel impulse response is essentially invariant.

If the symbol period of the baseband signal (reciprocal of the baseband signal bandwidth) is greater the coherence time, than the signal will distort, since channel will change during the transmission of the signal .



Coherence time (T_C) is defined as:

$$T_C \approx \frac{1}{f_m}$$

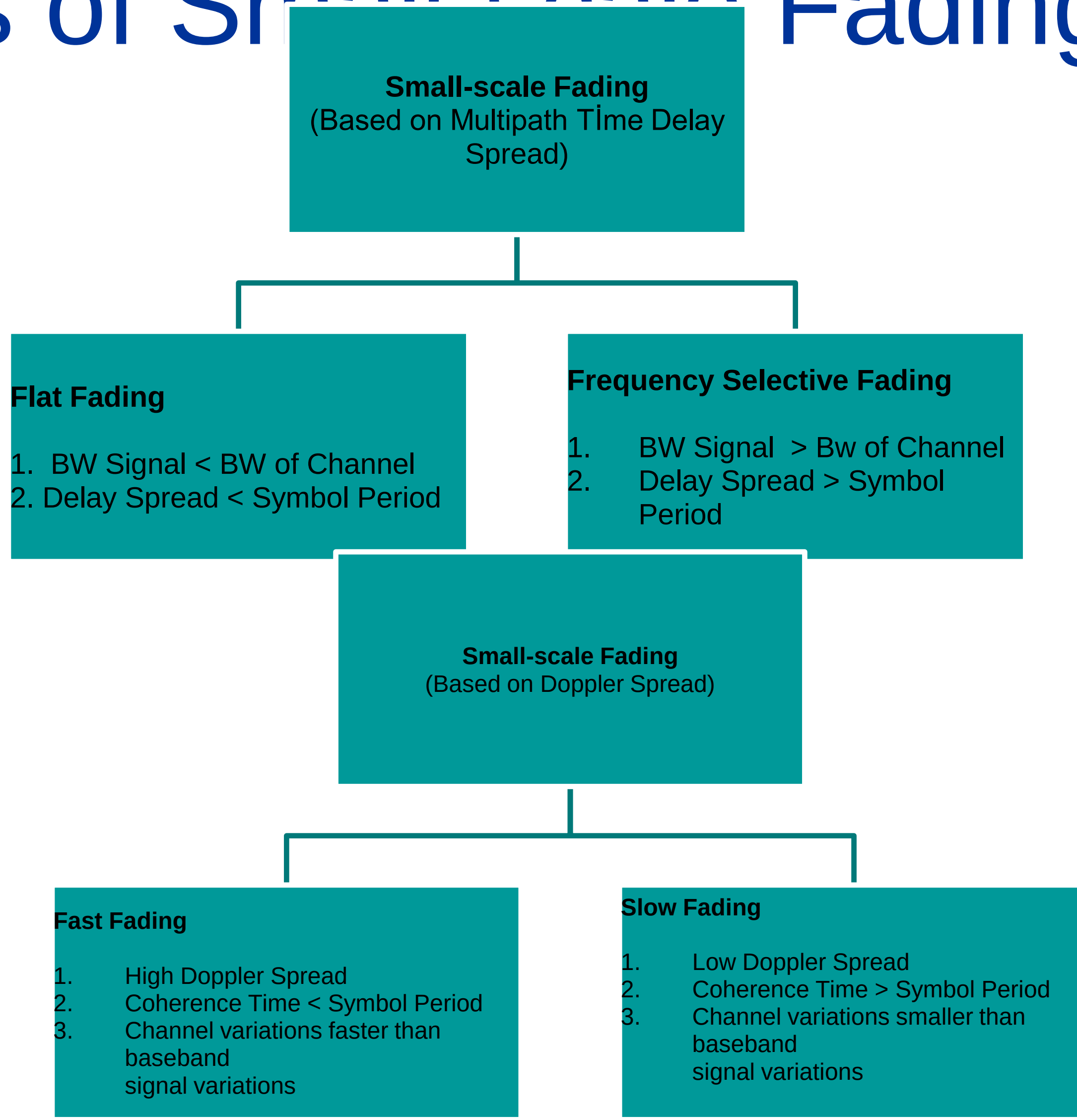


Coherence Time

Coherence time is also defined as: $$T_C \approx \sqrt{\frac{9}{16\pi f_m^2}} = \frac{0.423}{f_m}$$

Coherence time definition implies that two signals arriving with a time separation greater than T_C are affected differently by the channel.

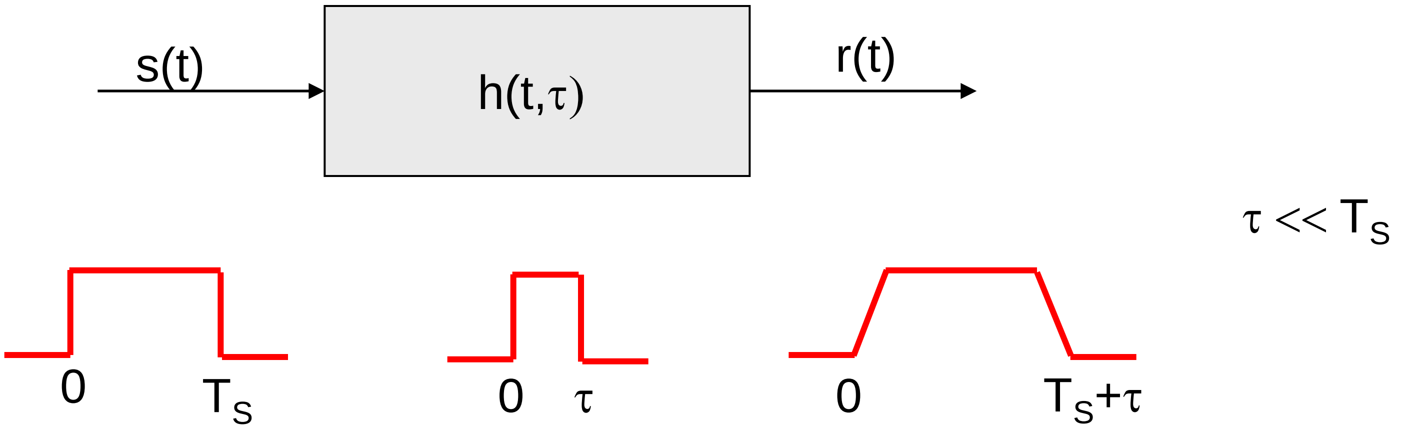
Types of Small-scale Fading



Flat Fading

- Occurs when the amplitude of the received signal changes with time
  - For example according to Rayleigh Distribution
- Occurs when symbol period of the transmitted signal is much larger than the Delay Spread of the channel
  - Bandwidth of the applied signal is narrow.
- May cause deep fades.
  - Increase the transmit power to combat this situation.

Flat Fading



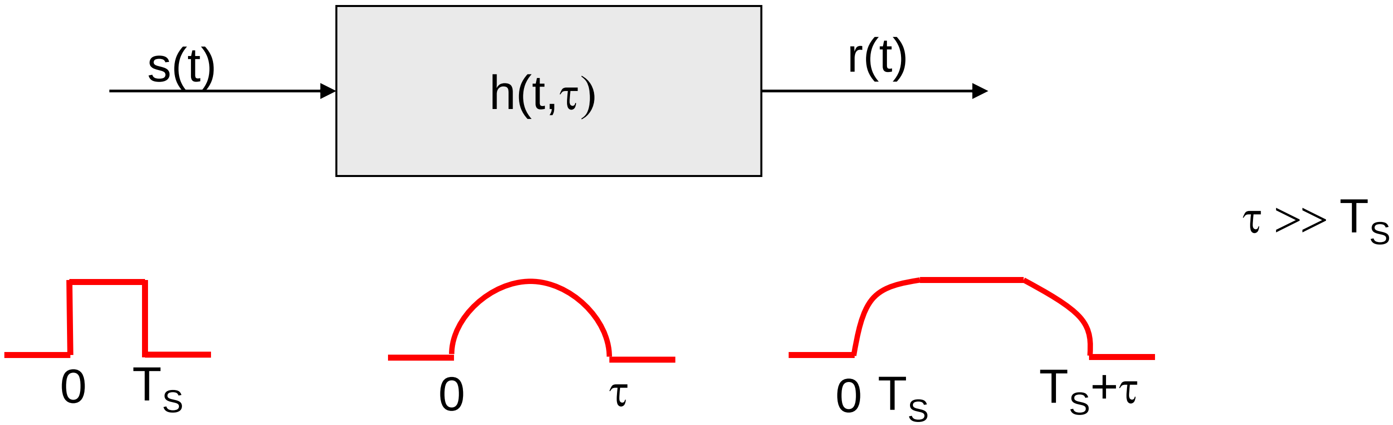
Occurs when:
$B_S << B_C$
and
$T_S >> \sigma_\tau$

B_C: Coherence bandwidth
B_S: Signal bandwidth
T_S: Symbol period
σ_τ: Delay Spread

Frequency Selective Fading

- Occurs when channel multipath delay spread is greater than the symbol period.
  - Symbols face time dispersion
  - Channel induces Intersymbol Interference (ISI)
- Bandwidth of the signal s(t) is wider than the channel impulse response.

Frequency Selective Fading



Causes distortion of the received baseband signal

Causes Inter-Symbol Interference (ISI)

Occurs when:
$B_S > B_C$
and
$T_S < \sigma_\tau$

As a rule of thumb: $T_S < \sigma_\tau$

Fast Fading

- Due to Doppler Spread
  - Rate of change of the channel characteristics
    is **larger** than the
    Rate of change of the transmitted signal
  - The channel changes during a symbol period.
  - The channel changes because of receiver motion.
  - Coherence time of the channel is smaller than the symbol period of the transmitter signal

Occurs when:
$B_S < B_D$
and
$T_S > T_C$

B_S: Bandwidth of the signal
B_D: Doppler Spread
T_S: Symbol Period
T_C: Coherence Bandwidth

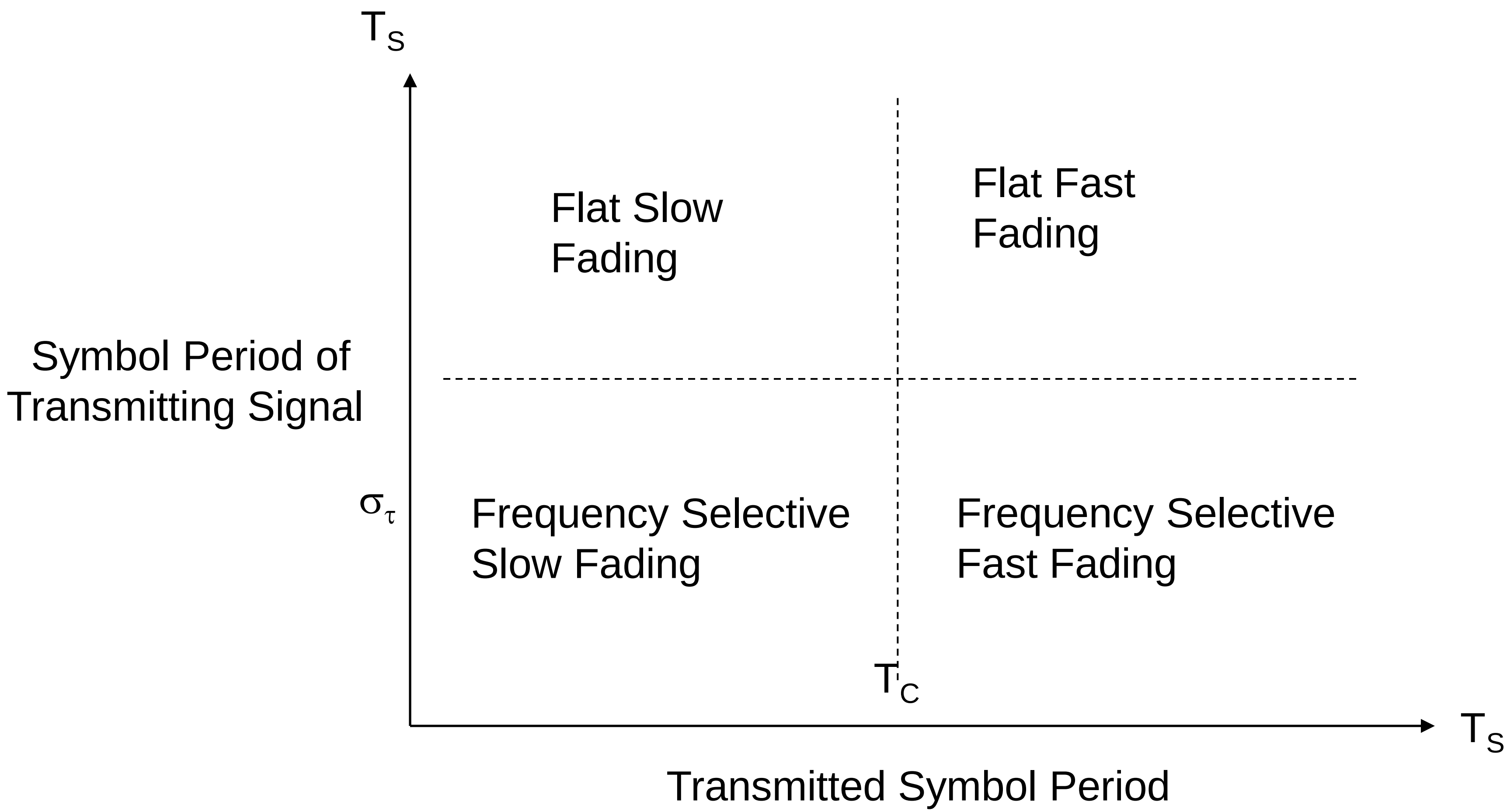
Slow Fading

- Due to Doppler Spread
  - Rate of change of the channel characteristics
    is **much smaller** than the
    Rate of change of the transmitted signal

Occurs when:
$B_S >> B_D$
and
$T_S << T_C$

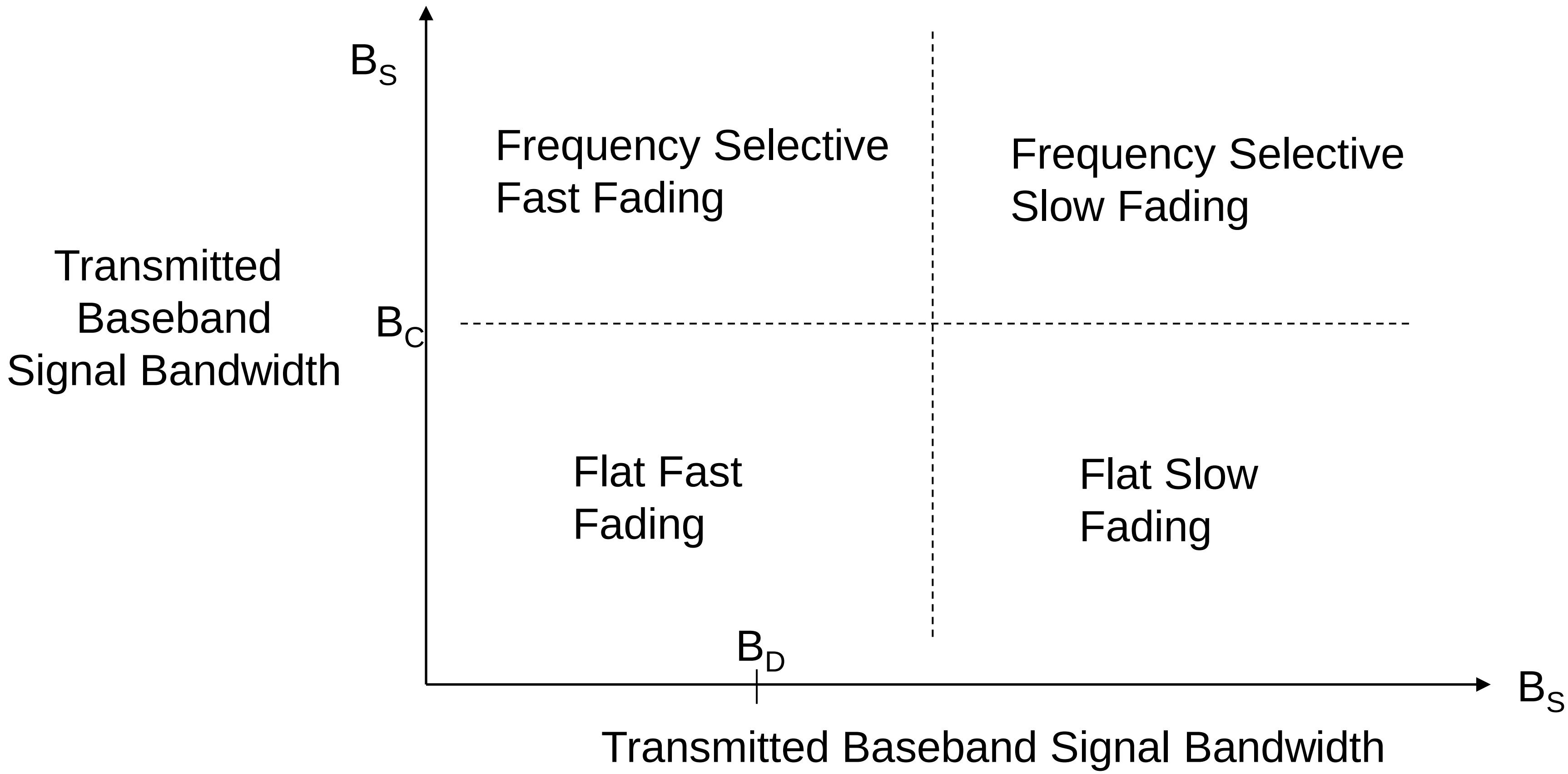
B_S: Bandwidth of the signal
B_D: Doppler Spread
T_S: Symbol Period
T_C: Coherence Bandwidth

Different Types of Fading



With Respect To SYMBOL PERIOD

Different Types of Fading



With Respect To BASEBAND SIGNAL BANDWIDTH

Fading Distributions

- Describes how the received signal amplitude changes with time.
  - Remember that the received signal is combination of multiple signals arriving from different directions, phases and amplitudes.
  - With the received signal we mean the baseband signal, namely the envelope of the received signal (i.e. r(t)).
- Its is a statistical characterization of the multipath fading.
- Two distributions
  - Rayleigh Fading
  - Ricean Fading

Rayleigh and Ricean Distributions

- Describes the received signal envelope distribution for channels, where all the components are non-LOS:
  - i.e. there is no line-of–sight (LOS) component.
- Describes the received signal envelope distribution for channels where one of the multipath components is LOS component.
  - i.e. there is one LOS component.

Ricean Distribution

- When there is a stationary (non-fading) LOS signal present, then the envelope distribution is Ricean.
- The Ricean distribution degenerates to Rayleigh when the dominant component fades away.