Summary of Baseband Transmission

Line Coding
- On-Off
- NRZ
- RZ
- Manchester

M-ary baseband signals
\[ r_b = \frac{1}{T_b} \]
\[ \gamma \text{ bits/symbol (binary case } \gamma = 1) \]
\[ T_s = \gamma \times T_b \]
\[ r_s = \frac{1}{T_s} = \text{symbol rate} \]
\[ B_0 = \frac{\gamma}{2} = \text{minimum baseband bandwidth} \]

Symbol detection
- Minimum distance decision algorithm
- Integrate & dump is the same as filter & sample
- Decision based on the output of the Integrate & dump (or filter & sample)
- One symbol error can cause multiple bit errors

ISI
- Pulse shaping
- Criteria for no ISI, \( p(0) = 1 \) (constant) and \( \sum_{k=0}^{\infty} p(t - kT_s) = 0 \)
- Raised cosine pulse shaping,
  \( B_r = B_0(1+\alpha) = \text{baseband bandwidth with pulse shaping} \)
- Eye-diagram

Analog-to-Digital (A/D) conversion
- PAM
- PCM
- \( (S/N)_Q \approx 6\gamma \) (dB)
Summary of Time Division Multiplexing

Time frame
Time slot & number of time slots/frame
Number of bits/time slot

Bit rate = \( \frac{\# \text{bits/frame}}{\text{Frame Time}} \)

TDMA
TDD
Uplink and downlink
Frame synchronization
TDM/PAM

Minimum baseband bandwidth = \( \frac{C}{2} \) with no pulse shaping (with raised cosine pulse shaping, multiply by 1+\( \alpha \))

TDM/PCM

Minimum baseband bandwidth = \( \frac{C}{2} \) with no pulse shaping (with raised cosine pulse shaping, multiply by 1+\( \alpha \))
Summary of DSB-SC

\[ x_{\text{DSB-SC}}(t) = A_c x_{\text{bb}}(t) \cos(2 \pi f_c t) \]

\[ B_{\text{RF}} = 2 B_{\text{bb}} \]

Spectrum of DSB-SC signals

In general requires a synchronous (coherent) receiver, carrier recovery is needed

DSB-SC is a linear modulation

ASK is a digital modulation using DSB-SC with a specific digital baseband signal, \( x_{\text{ON-Off}}(t) \)

\[ B_{\text{RF}} = r_b \]

Spectral efficiency = (1b/s)/Hz

BPSK is a digital modulation using DSB-SC with a specific digital baseband signal, \( x_{\text{NRZ}}(t) \)

\[ B_{\text{RF}} = r_b \]

Spectral efficiency = (1b/s)/Hz

Power in the DSB-SC signal, \( A_c x(t) \cos(2 \pi f_c t) \), is

\[ P_{\text{DSB-SC}} = \frac{A_c^2 P_x}{2} \]
Summary of Quadrature Modulation and Multiplexing

Quadrature Multiplexing allows two signals to use (share) the same RF spectrum, one signal on the I-channel and one on the Q-channel.

Carrier recovery is required to demodulate quadrature modulated signals.

Quadrature modulation is used to transmit digital signals.

One baseband digital signal (NRZ or M-ary) transmitted on the I-channel and one on the Q-channel.

Constellation (signal-space) diagrams

Minimum distance detection of transmitted symbols-in two dimensions.

Transmitter block diagram

Receiver block diagram

Relationships:

\[ \gamma \text{ bits/symbol} \]

Symbol time \( T_s = \gamma T_b \)

QPSK \( 2 \) bits/symbols, \( \gamma = 2 \)

M-QAM; \( M = 2^\gamma \)

M-ary PSK; \( M = 2^\gamma \)

Maximum spectral efficiency = \( \gamma \text{ (b/s)/Hz} \)

<table>
<thead>
<tr>
<th>Modulation Type</th>
<th>Maximum Spectral Efficiency (b / s) / Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASK</td>
<td>1</td>
</tr>
<tr>
<td>BPSK</td>
<td>1</td>
</tr>
<tr>
<td>QPSK</td>
<td>2</td>
</tr>
<tr>
<td>8 – ary PSK</td>
<td>3</td>
</tr>
<tr>
<td>16 – QAM</td>
<td>4</td>
</tr>
<tr>
<td>64 – QAM</td>
<td>6</td>
</tr>
<tr>
<td>256 – QAM</td>
<td>8</td>
</tr>
<tr>
<td>1024 – QAM</td>
<td>10</td>
</tr>
</tbody>
</table>

Representations of RF Signals

\[ y(t) = y_c(t) + jy_s(t) \]

\[ \text{Re}(y(t)e^{j2\pi f_c t}) \]

\[ V(t) \cos(2\pi f_c t + \Theta(t)) \]

\[ y_c(t) \cos(j2\pi f_c t) - y_s(t) \sin(j2\pi f_c t) \]
Summary of Frequency Division Multiplexing (FDM) and Orthogonal Frequency Division Multiplexing (OFDM)

FDM enables sharing of spectrum
Guard bands are placed between the channels to prevent adjacent channel interference.
FDM can support independent transmitters and receivers, i.e., the broadcast case.
Composite baseband signals can be constructed using FDM then modulated to RF.
Bandwidth of FDM signals.
FDD
FDMA
Combined TDMA and FDMA
OFDM
No explicit sidebands
\[ \frac{1}{T_s} = \Delta f \text{ (subcarriers are orthogonal)} \]
N=Number of subcarriers
\[ B_{RF} \approx (N+1)\Delta f \text{ (Not a function of the QAM modulation on each subcarrier)} \]
\[ r_b = N \times \Delta f \times \gamma \text{ (} \gamma = \text{bits/symbol, assumes same QAM on all N subcarriers)} \]
Transmitter/receiver use IDFT/DFT

OFDM combined with TDMA
Time/Frequency Resource Grid
\[ T_f = \text{Frame time} = \text{Number of slots} \times \left( \frac{\text{Number of OFDM symbols}}{\text{time slot}} \right) \times T_s \]
\[ r_b = \frac{\text{Number of bits in a } T_f}{T_f} \]