ICT course:

Mobile Wireless Communications

Lecturers:
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Course Schedule

- Lectures:

1. Introduction
2. Characteristics of mobile radio environment:
    - Propagation
    - Fading and mitigations
3. Cellular concept
4. Channel assignment (optional)
5. Modulation techniques
6. Multiple Access techniques
7. Coding for error detection and correction
8. Applications – Mobile network Generations:
    - GSM
    - 3G/LTE-4G
    - 5G and future of mobile networks (discussion)

- Exercises
- References:

[1]. Mischa Schwartz: Mobile Wireless Communication, CAMBRIDGE UNIVERSITY PRESS, 1st Edition (2005)

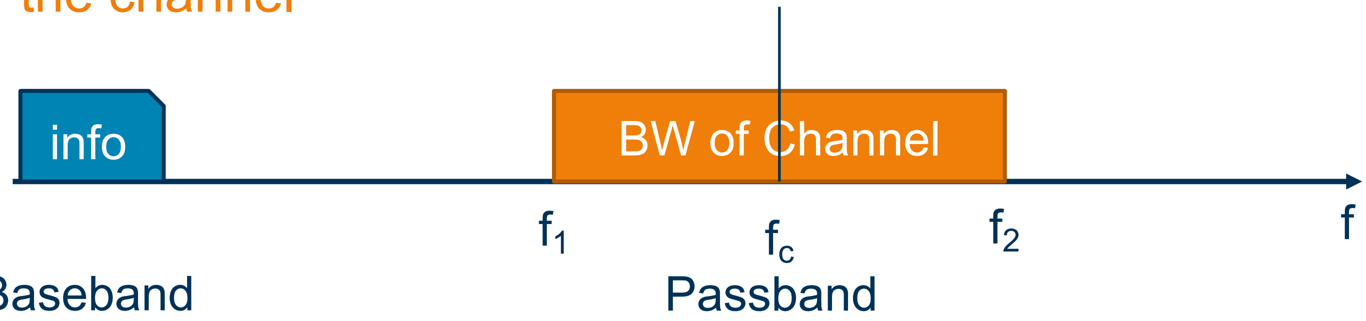
[2]. Wireless Communications: Principles and Practice (2nd Edition) by Theodore S. Rappaport

[3]. Widjaja, Indra, and Alberto Leon-Garcia. "Communication Networks Fundamental Concepts and Key Architectures." *Mc GrawHill: USA* (2004).

Lecture 4: Modulation techniques

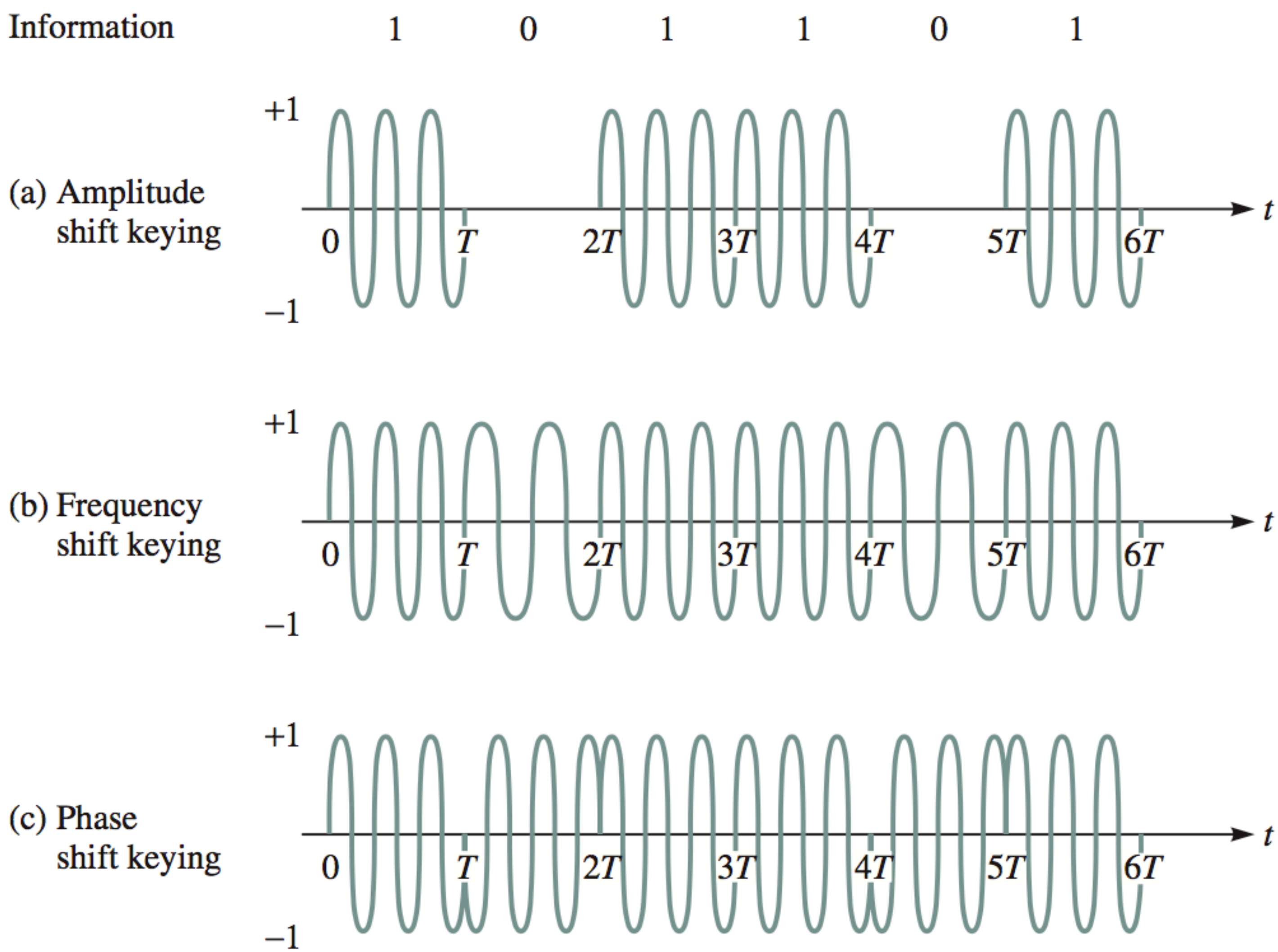
- Introduction to digital modulation techniques
- Modulation in wireless systems:
  - QPSK, 8-PSK
  - MSK, GMSK
  - QAM
  - OFDM
- Signal shaping

- Introduction to digital modulation:
  - Modulation:
    - Function: producing a signal that contains the information sequence and that occupies frequencies in the range passed by the channel



    - The various types of modulation schemes involve embedding the information into the transmitted signal by varying, or modulating, some attribute of the carrier signal
    - Carrier signal: sinusoidal signal has all of its power located precisely at f_c

$$\cos(2\pi f_c t)$$



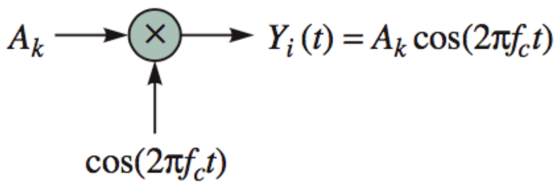
Information
1
0
1
1
0
1
+1
−1
(a) Amplitude shift keying
0
T
2T
3T
4T
5T
6T
t
(b) Frequency shift keying
(c) Phase shift keying

- Digital modulation
  - How:
    - Transmitting b bits at a time: b bits ≡ a symbol → a waveform $s_i(t)$
    - Number of waveforms: $M = 2^b$
  - Conveying above information-bearing waveforms into carrier signal

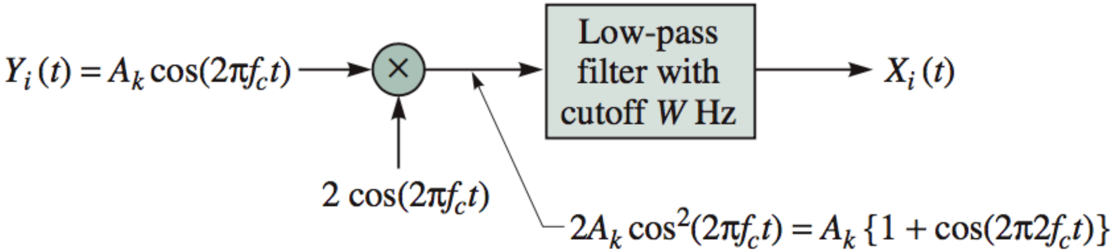
- Modulation techniques in wireless system:
  - Phase Shift Keying (PSK)
    - In a T-second segment:

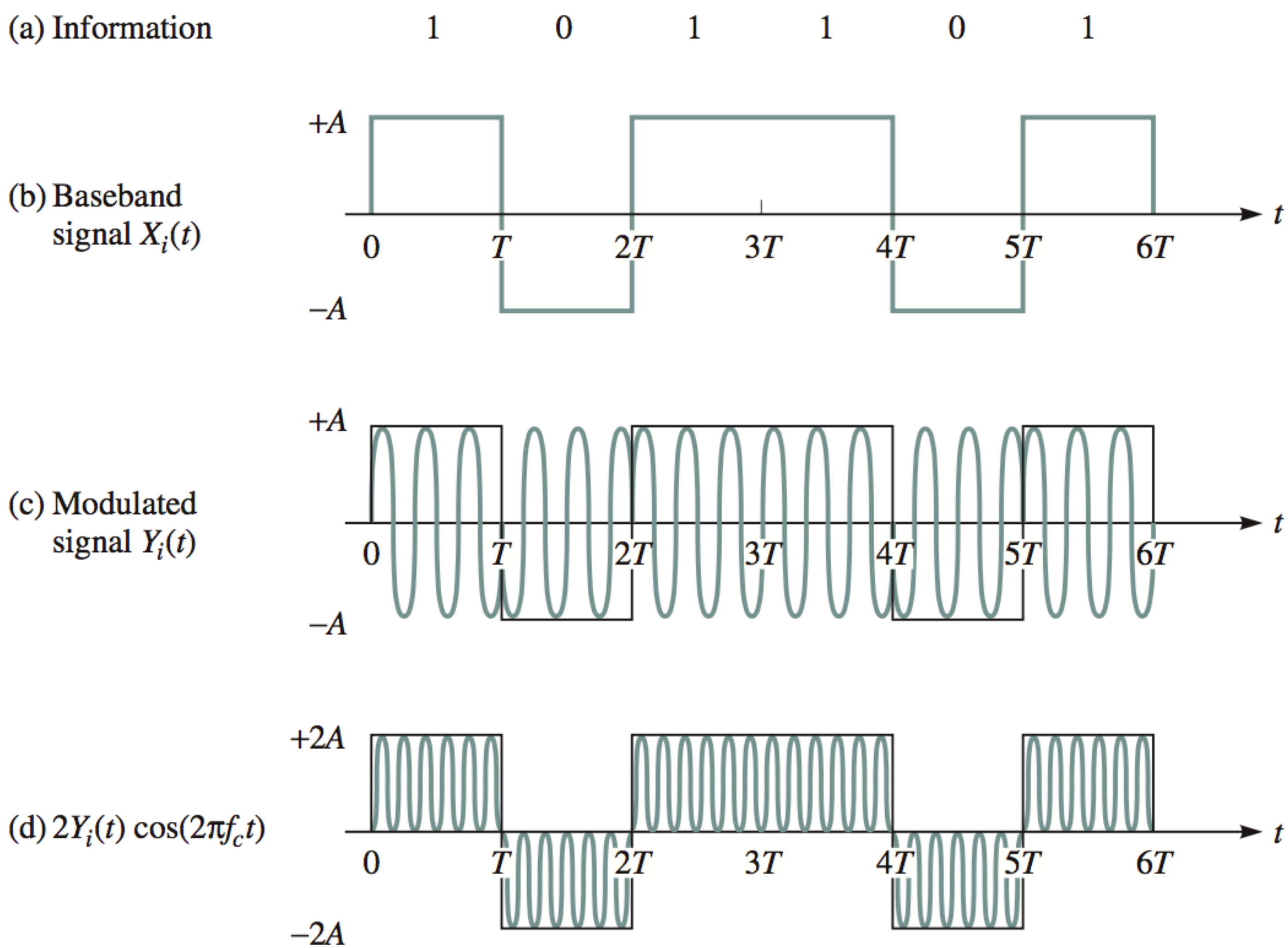
$$\begin{cases} A\cos(2\pi f_c t) & \text{if the information symbol is 1} \\ -A\cos(2\pi f_c t) & \text{if the information symbol is 0} \end{cases}$$

(a) Modulate $\cos(2\pi f_c t)$ by multiplying it by A_k for $(k\text{-}1)T < t < kT$:



(b) Demodulate (recover) A_k by multiplying by $2\cos(2\pi f_c t)$ and low-pass filtering:





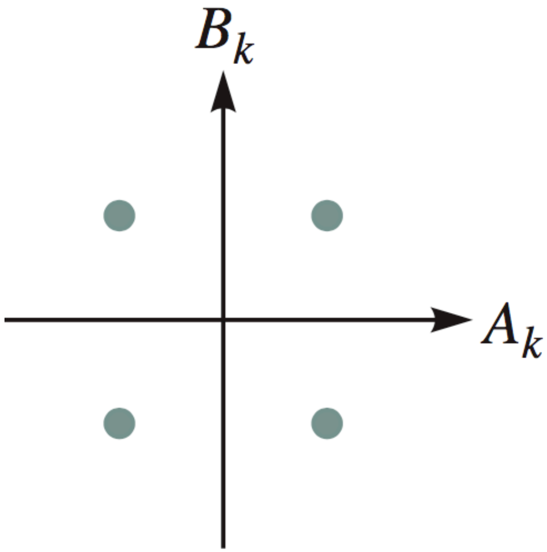
Transmit W pulses/seconds

2-D signals:

- Using 2 quadrature carriers
- Splitting the original sequence into two sequences

$$Y_i(t) = A_k \cos(2\pi f_c t) + B_k \sin(2\pi f_c t)$$

- System can transmit 2W bits/seconds*:
  - At a given T-second interval: transmitting 2 bits/pulse
- Signal Constellation: representation of signal in 2-D plane

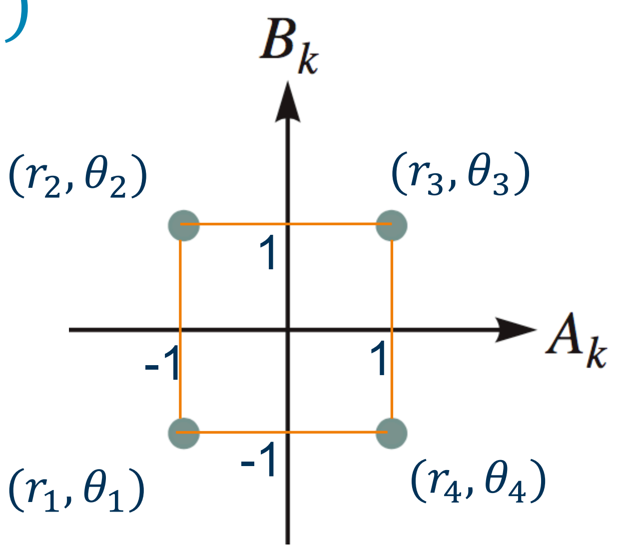


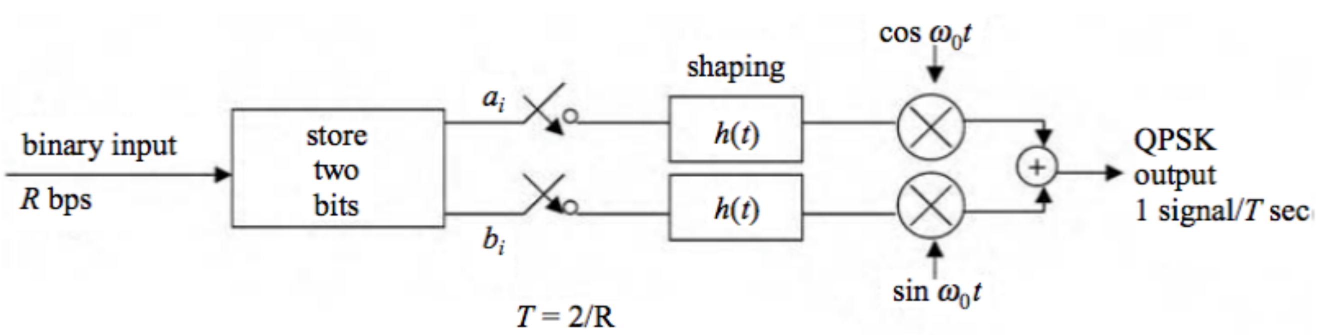
A_k : In-phase component
B_k : Quadrature component

* The Nyquist rate is the maximum signaling rate that is achievable through an ideal low-pass channel with bandwidth W and no ISI.

▫ Quadrature Phase Shift Keying (QPSK)

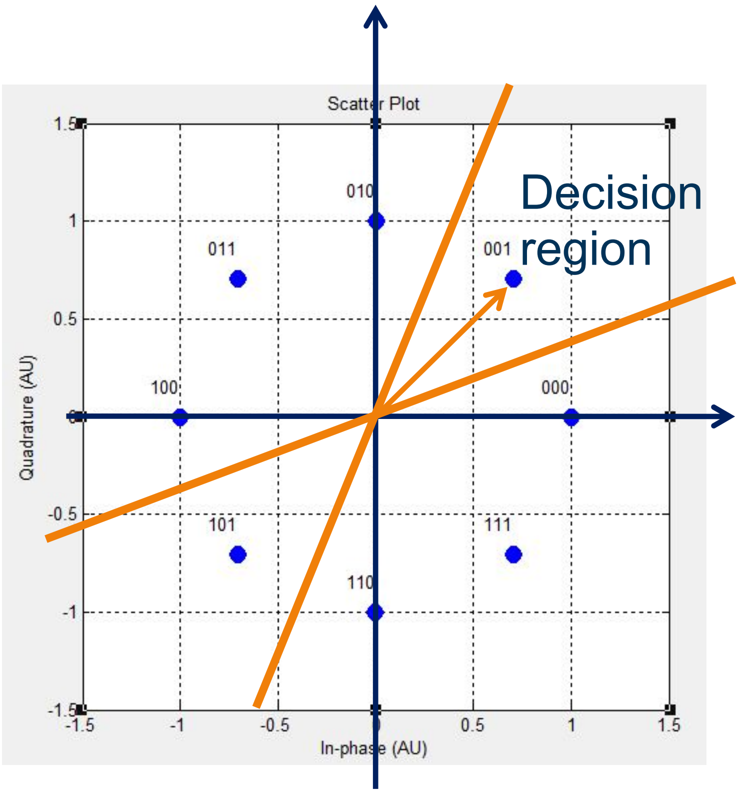
$$Y_i(t) = a_i \cos(2\pi f_c t) + b_i \sin(2\pi f_c t)$$
$$= r_i \cos(2\pi f_c t + \theta_i)$$





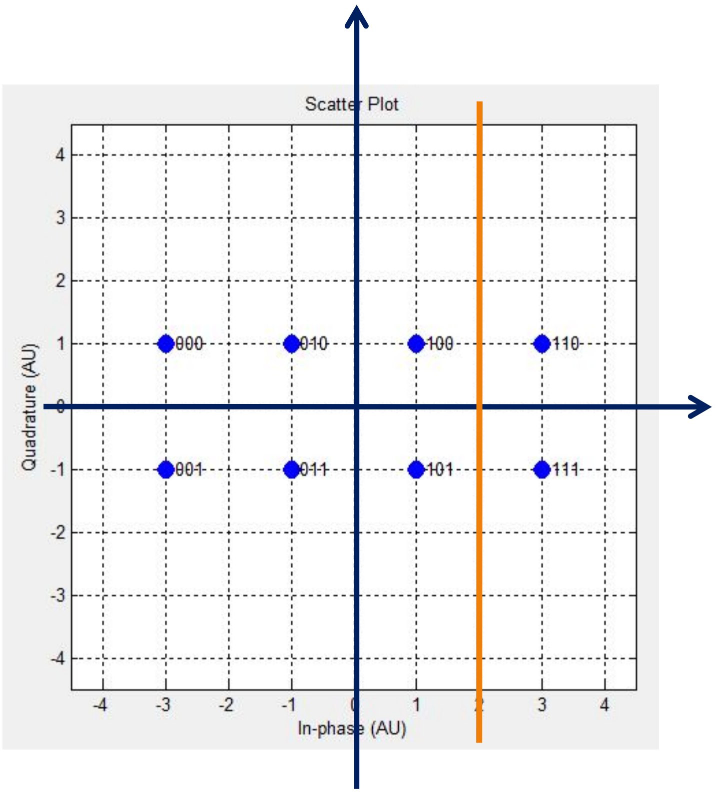
QPSK Modulator

- M-PSK



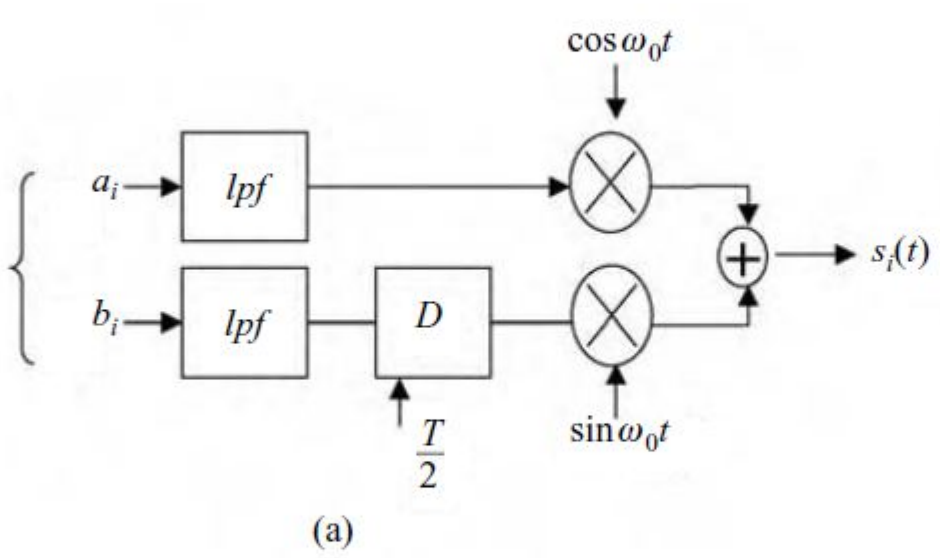
8-PSK
Signal points arranged on a circle, no amplitude variation

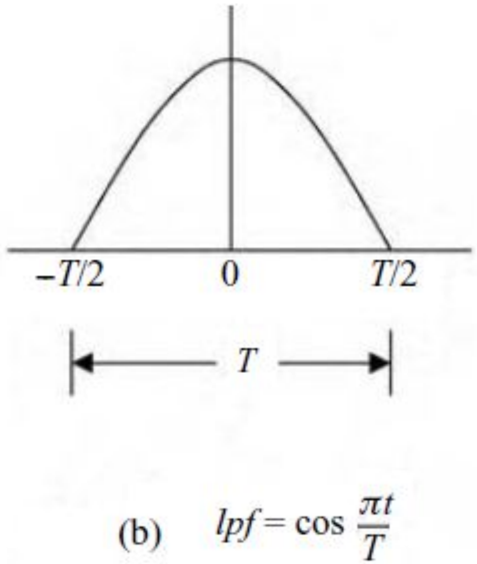
- Quadrature Amplitude Modulation (QAM)



8-QAM
Amplitude and phase modulation

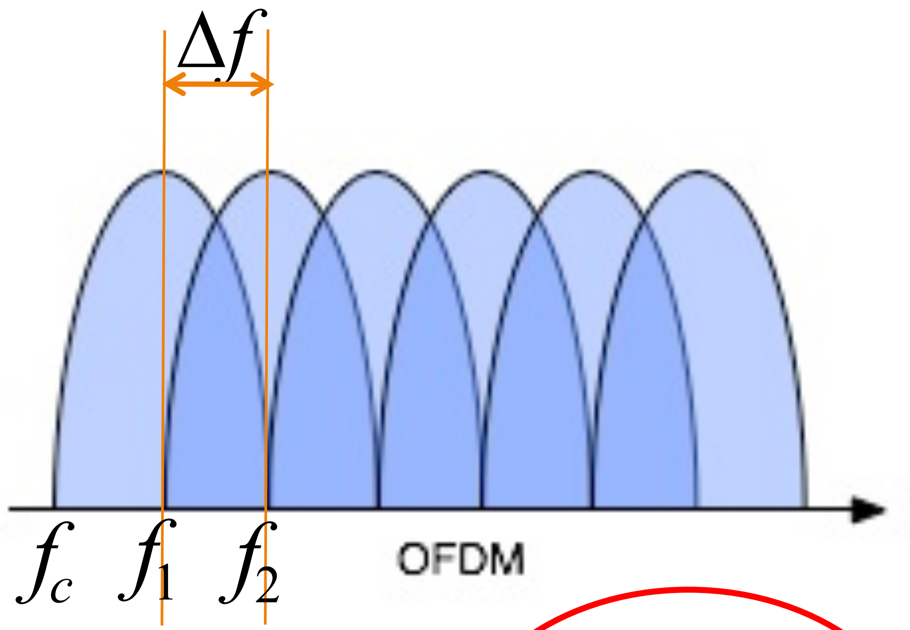
- Minimum Shift Keying (MSK)
  - Is continuous phase **frequency shift keying (FSK)**
  - The quadrature component is delayed by half of a symbol interval
  - Each bit is encoded as a half sinusoid
  - Gaussian MSK (GMSK): lpf is gaussian shaping filter





- Orthogonal Frequency Division Multiplexing (OFDM)
  - N carriers: transmit N sequences of bits at once
  - a_k: symbols

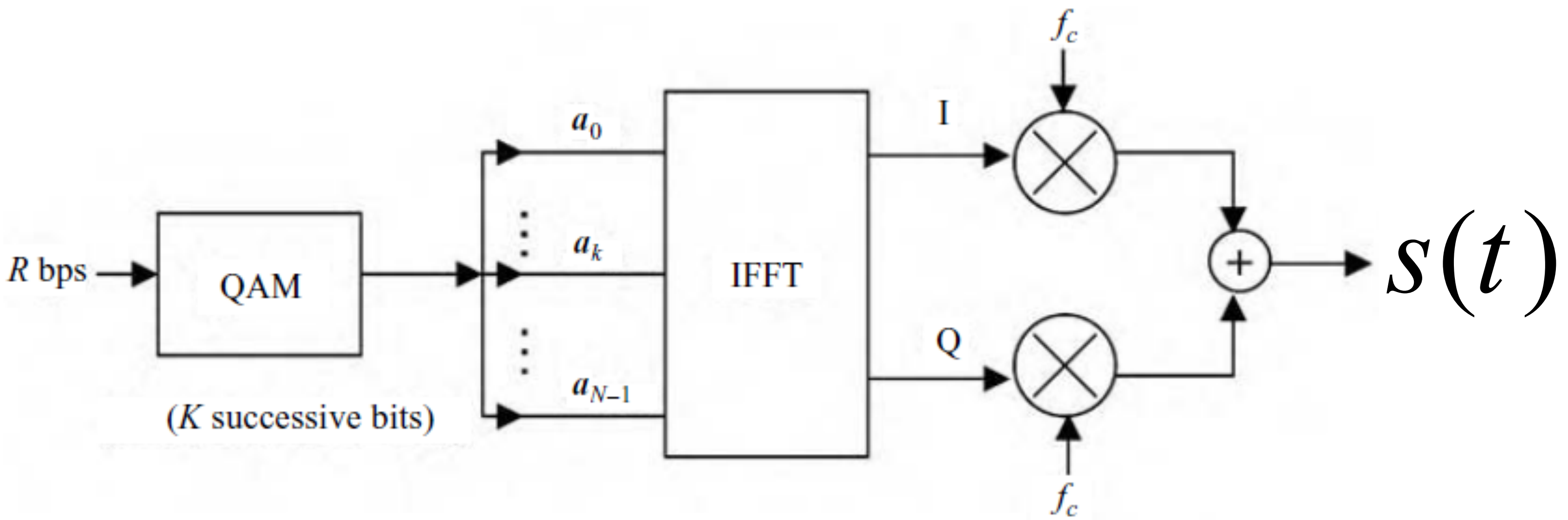
$$f_k = f_c + k.\Delta f$$



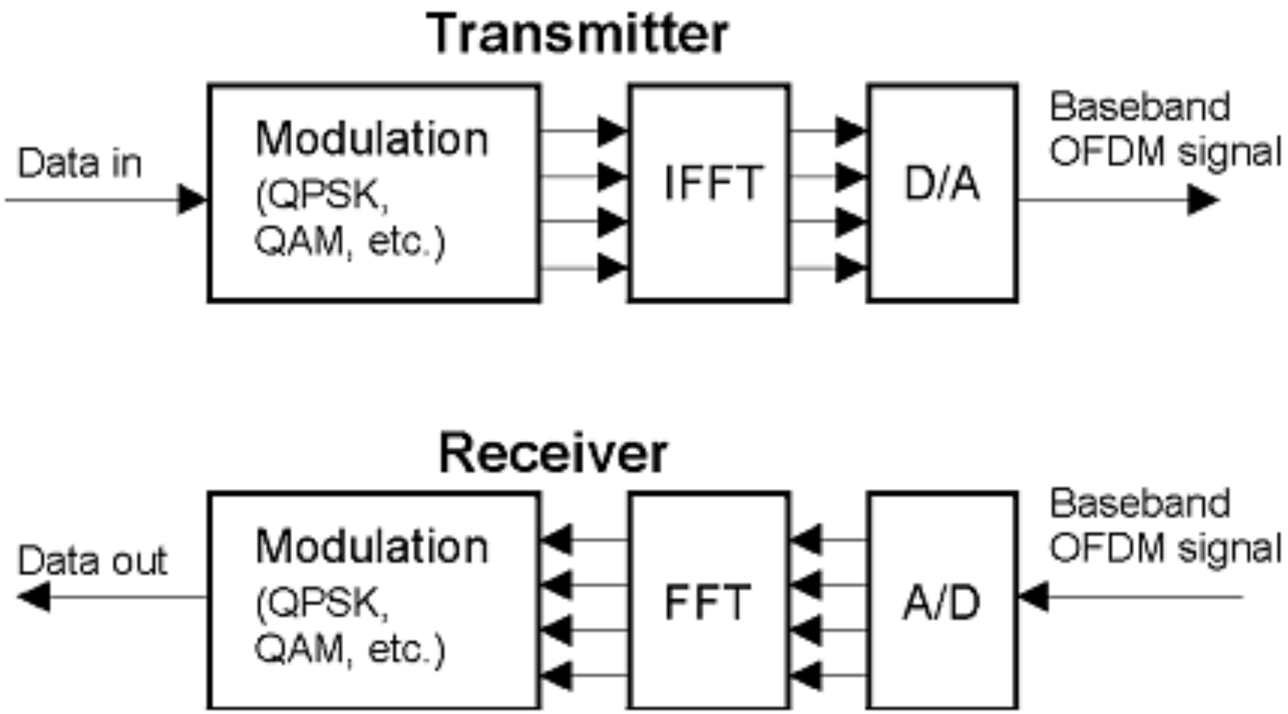
$$s(t) = \mathrm{Re}\left[\sum_{k=1}^{N} a_k e^{j2\pi f_k t}\right] = \mathrm{Re}\left[e^{j2\pi f_c t}\sum_{k=1}^{N} a_k e^{j2\pi k\Delta f t}\right]$$

IFFT

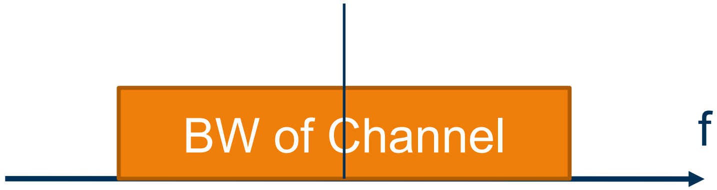
- Using Inverse Fast Fourier Transform



- OFDM and Demultiplexing



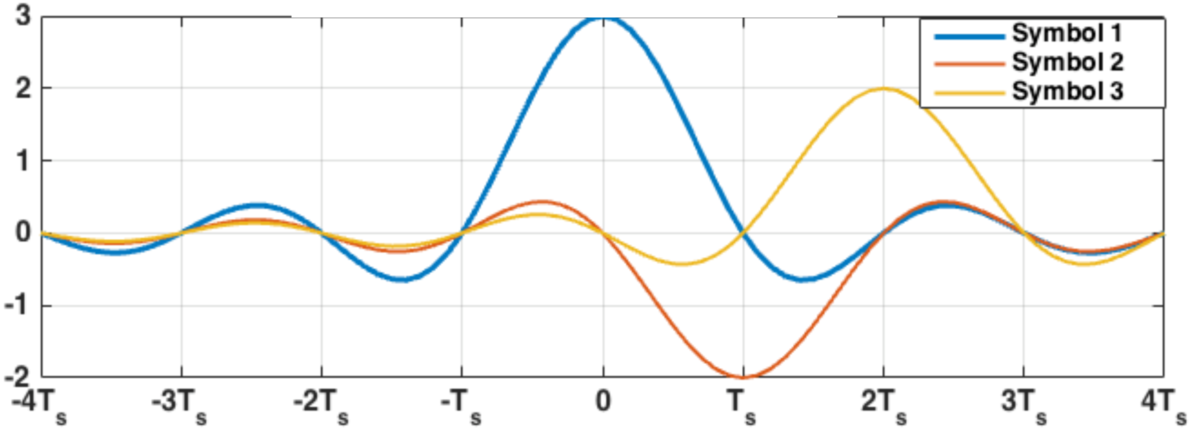
- Signal shaping
  - Keep the modulated signal within the bandwidth of the channel



  - the impulse response of the band-limited channel causes a transmitted symbol to be spread in the time domain →ISI

- Nyquist pulse-shaping criterion (condition for zero ISI):
  - Impulse response of the filter must satisfy:

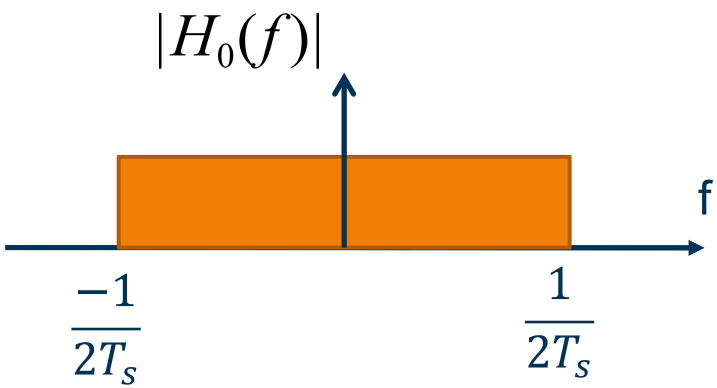
$$h(t) = \begin{cases} 1 & when \quad t = 0 \\ 0 & when \quad t = kT_s \end{cases}$$



T_s : Symbol interval (s) (period of the periodic transmitted signal)

- Transfer function of the filter must satisfy:
  - Minimum channel bandwidth: $W = \frac{1}{T_s}$

$$H_0(f) = \begin{cases} 1 & |f| < W \\ 0 & otherwise \end{cases}$$



-Hard to create this filter (unrealizable)

- Mistiming error in sampling at the demodulator → infinite ISI component

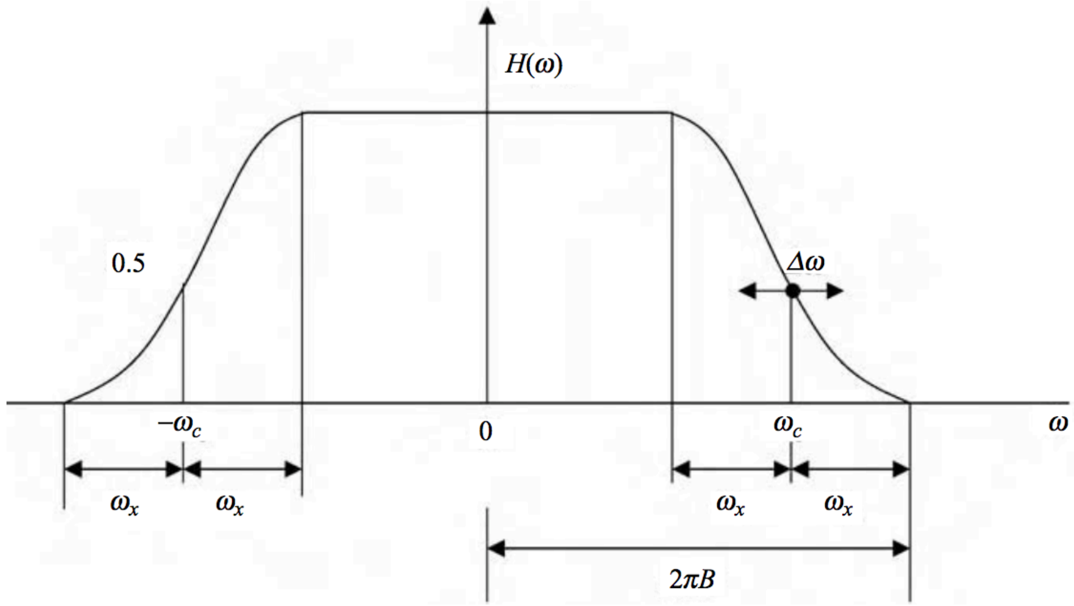
Sinusoidal rolloff shaping:

Raised cosine shaping function:

- Transfer function:

$$|H(f)| = |H_0(f)| + RO(f)$$

$RO(f)$: Roll off function



- Bandwidth of the signal after shaping:

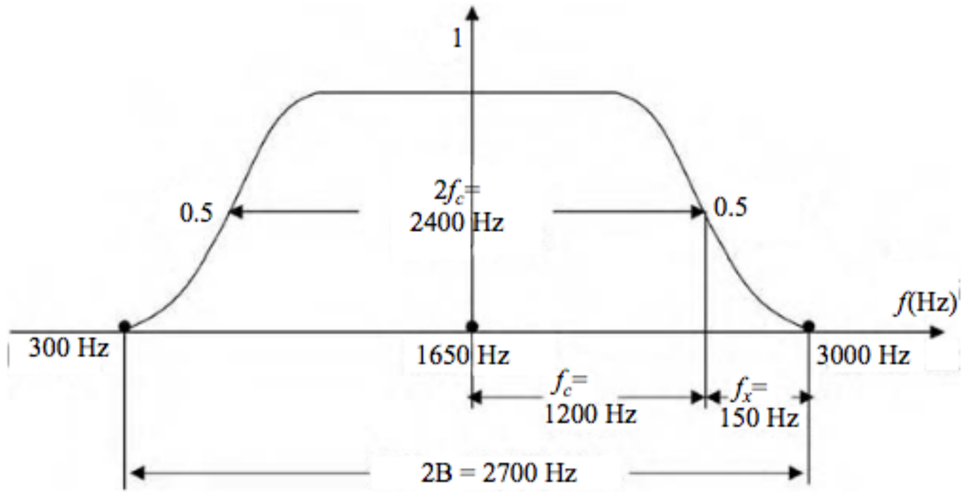
$$B_T = 2B = 2f_c(1 + f_x/f_c) = \mathrm{R}(1 + \mathrm{r})$$

$f_c = \frac{1}{2T_s}$; R: transmission rate

Example 1

1. 14.4 kbps transmission is desired. If sinusoidal rolloff shaping and PSK modulation are used, if a rolloff factor of 0.5 is used. Determine the required transmission bandwidth.
2. Uses sinusoidal rolloff shaping, with a rolloff factor *r* = 0.35. Frequency band: 30 kHz per user. If PSK modulation were to be used, determine the maximum binary transmission rate.

Example 2: Telephone modem



- Telephone modem operates at above bandwidth
- 16-QAM is to be used to carry binary information over this channel
- 12.5% rolloff shaping is used
- Determine bit rate achievable for this scheme
- Repeat for 64-QAM

Exercise 1:

1. Let the transmission bandwidth be 1 MHz. Say a rolloff factor of $r = 0.25$ is used.

- Determine:
  - Achievable rate of data traffic
  - Delay spread that no ISI occurs
- Repeat for following cases:

2. Let OFDM with $N = 16$ equally spaced carriers be used.
3. If 16-QAM is now utilized for the OFDM system

Exercise 2

- Transmission bandwidth: 1 MHz
- It is desired to transmit at a 4.8 Mbps data rate, but with no inter-symbol interference for delay spreads up to 25 msec. QAM and OFDM are used.
- Select appropriate modulation technique and number of subcarriers to accommodate required above delay spread of 25 msec.

Exercise 3

- A transmission bandwidth of 2 MHz is available. Nyquist rolloff shaping is used in transmitting data.
  (a) Find the bit rates that may be transmitted over this channel using PSK for rolloff factors of (1) 0.2, (2) 0.25, and (3) 0.5.
  (b) Nyquist roll off shaping of 0.25 is used. It is desired to transmit at a rate of 6.4 Mbps over this channel. Show how this may be done. Repeat for 9.6 Mbps.

Exercise 4

Successive binary pairs	a_i	b_i
0 0	−1	−1
0 1	−1	+1
1 0	+1	−1
1 1	+1	+1

- Choose an input sequence of ten or more binary digits to be applied to a QPSK modulator. Map them to the five appropriate QPSK signal pairs using above Table. Let the carrier frequency be some multiple of $1/T$. Sketch the corresponding output QPSK signals.
- Note the times at which $\pi\ radian$ and $\frac{\pi}{2}\ radian$ phase shifts occur. Correlate these with the input bit pairs.