Kursombud

Kontakta mig i pausen!

Course Programme

Digital Communications (ETT051), 7.5 hp, 29/8 – 24/10 2016

The homepage of this course: http://www.eit.lth.se/kurs/ett051

Introductory lecture: Tuesday, 30 August (calendar week 35), 08.15 – 10.00 in room MA:5.

Laboratory lesson: LAB (4 hours) starts Monday 3 October (calendar week 40=study week 6).

Application to the laboratory lesson is made on the homepage of this course where you book one available time-slot. Applications to the lab can be made from Monday 19 September (maybe even earlier, **check Messages!!**).

Messages will be distributed on the homepage of this course. **Check messages at least twice a week!!**

Written Examination: 1:st opportunity: Monday 24 October 2016, 14.00-19.00, room MA 10:E-I

2:nd opportunity: Thursday 22 December 2016, 08.00 – 13.00, room MA 9:A

3:rd opportunity: Monday 14 August 2017, 14.00 – 19.00, room E:2311

Course Literature:

- "Introduction to Digital Communications", compendium August 2006.
- Instructions for the laboratory lesson.

The compendium can be bought at KFS book store, located at LTH Studiecentrum.

The instructions for the laboratory lesson will be available on the homepage of this course (they are not available yet).

You are allowed to use the compendium during the written examination.

This course is defined by the pages and problems given in the course outline given below in this course program, and by the laboratory lesson.

__Lectures__

The lectures are given in English and there are two lectures each week.

Lecturer: Göran Lindell, Room E:2360, email: Goran.Lindell@eit.lth.se

Tuesdays: 08.15 – 10.00 in room MA:5 (**except** in study week 6: then in MA:6)

Thursdays: 10.15 – 12.00 in room MA:7

Problem solving (exercise) classes

Teacher: Göran Lindell, Room E:2360, email: Goran.Lindell@eit.lth.se

Each student belong to one of two exercise groups (denoted A and B below). Each group has two exercises each week :

Group A (C3, D, E, F, **in Swedish**): Two exercises each week:

Wednesdays 10.15 – 12.00 in room E:3316

Thursdays 13.15 – 15.00 in room E:2311

Group B (MWIR1, Erasmus, **in English**): Two exercises each week:

Tuesdays 10.15 – 12.00 in room E:3316

Fridays 08.15 – 10.00 in room E:3336

Preliminary Course Outline for the course Digital Communications (ETT051), 2016.

Calendar Week	Contents
35	<u>Lecture 1 (30/8):</u> Chapter 1, 2.1 – 2.4.1 (pages 1 – 32). <u>Lecture 2 (1/9):</u> 2.4 – 2.4.3.1 (pages 31 – 42), 2.4.4 – 2.4.7.1 (pages 43 – 55). <u>Exercise 1:</u> Problems 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8. <u>Exercise 2:</u> Problems 2.11, 2.12, 2.13, 2.14a, 2.28, 2.15.
36	<u>Lecture 1(6/9):</u> 2.5 -2.5.1.1 (pages 61-69), 2.5.2 (pages 70 -72), 2.5.2.2 – 2.5.4.2 (pages 77 – 88). <u>Lecture 2 (8/9):</u> 2.5.5 – 2.5.8 (pages 88 – 102). <u>Exercise 1:</u> 2.18, 2.16, 2.17a, 2.19a, Example 2.17 on page 64. <u>Exercise 2:</u> 2.21a,b, 2.22, 2.23, 2.25, 2.29.
37	<u>Lecture 1 (13/9):</u> 3 – 3.2 (pages 117 – 136), 3.3 – 3.3.1 (pages 139-147), 3.3.2 (pages 147-152). <u>Lecture 2 (15/9):</u> 3.4.3 (pages 167-170), 3.5.3-3.5.3.1 (pages 174-184), 4.1 – 4.3 (pages 227-244). <u>Exercise 1:</u> 2.26, 2.27 (only 2,3,4,7), 2.30, Example 3.1 on page 121, 3.1, 3.2, 3.3. <u>Exercise 2:</u> 3.5, 3.6, Example 3.7 on page 135, 3.9, 3.10b, 3.19, 3.7, 3.22.
38	<u>Lecture 1 (20/9):</u> 4.3.1 – 4.4.1.3 (pages 244 – 272). <u>Lecture 2 (22/9):</u> 4.5-4.6 (pages 272-293), 5.1-5.1.1 (pages 329-331), 5.2 – 5.2.1 (pages 360-366). <u>Exercise 1:</u> 3.11c, Example 3.19 on page 168, 3.23, 4.1, 4.2, 4.6. <u>Exercise 2:</u> 4.7, 4.8, 4.27, 4.10, 4.17c, 4.20, 4.29, Example 4.12 on page 260, 4.32.
39	<u>Lecture 1 (27/9):</u> Figure 5.17 on page 369, 5.4.3 (pages 395 – 396), 5.4.5 (pages 400 – 403), 6 – 6.1 (pages 435 – 446). <u>Lecture 2 (29/9):</u> 6.2 – 6.2.2 (pages 446 – 453), 6.2.4 (pages 455 – 459). <u>Exercise 1:</u> 4.19, 4.21, Example 4.19 on page 279, 4.13, 4.12, Example 4.4 on page 242, 4.18. <u>Exercise 2:</u> 4.22, 4.28, 4.30b, Example 4.22 on page 285, 4.35, 4.36.
40	**Observe that the LAB starts in this week!** <u>Lecture 1 (4/10):</u> 7.1 – 7.1.3 (pages 471 – 476), 8.1 (pages 501 – 505). <u>Lecture 2 (6/10):</u> Summary of this course. <u>Exercise 1:</u> 6.1a, 6.1c, 6.2, 6.3a, 6.4, 6.7a, 6.9a, 6.8. <u>Exercise 2:</u> 6.10, 6.5, 6.6, 6.11b.
41	<u>Exercise 1:</u> 7.5, 7.7, 8.1, 8.2, 2.32a,b, 8.4. <u>Exercise 2:</u> Time for questions.
43	Written Examination on Monday 24 October 2016, 14.00-19.00, room MA 10:E-I

(You are allowed to use the compendium during the written examination.)

Digital Communications - ETT051

We are in **a global digital (r)<u>evolution</u>**.

- Mobile broadband & telephony (GSM, EDGE, 3G, 4G, 5G,....)
- Internet
- Modem (e.g. ADSL, optical fibers,….)
- WLAN (Wireless Local Area Network)
- Digital TV
- GPS (Global Positioning System)
- Bluetooth
- Home electronics (CD, DVD, remote controls, etc etc)

Digital Communications - ETT051

- Mobile <u>digital</u> communications started **1992** (GSM).
- The transition from analog to digital TV was finished in February **<u>2008</u>** in Sweden.
- Fiber optic <u>digital</u> communications is well established.
- 1976 1996 **2016** 2036 2056

  ? ??

Digital Communications - ETT051

- Digital communication systems require state-of-the-art technical solutions, both in software and in hardware.

- These systems belong to the most advanced technical systems that exist today.

Digital Communications - ETT051

- You will in this course get knowledge about how these systems work, their performance and limitations.
- Practical questions are studied such as:

How is high bit rate communication implemented in practice, and when is high bit rate communication possible?

What is meant by ”digital communication”?

Digital Communications

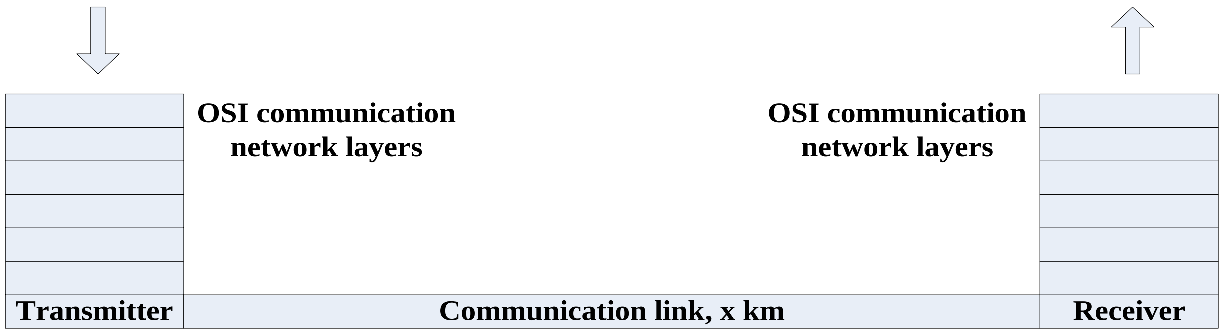
Data + Speech + Music
+ Images + Video

Users

OSI communication network layers

OSI communication network layers

”A”



”B”

”Bits to signals”

Wireless
Wireline
Optical fiber

”Signals to bits”

Link quality: Signal – to – Noise - Ratio

Requirement: High bit rate

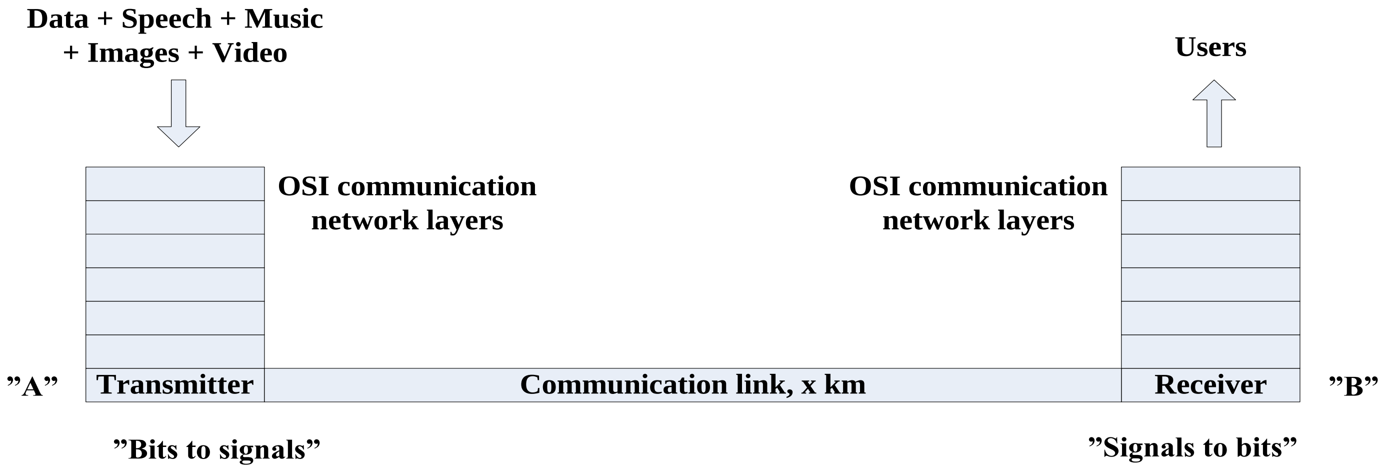
Efficient use of:
Signal power
and
Communication bandwidth

Requirement: Low bit error probability

Digital communications

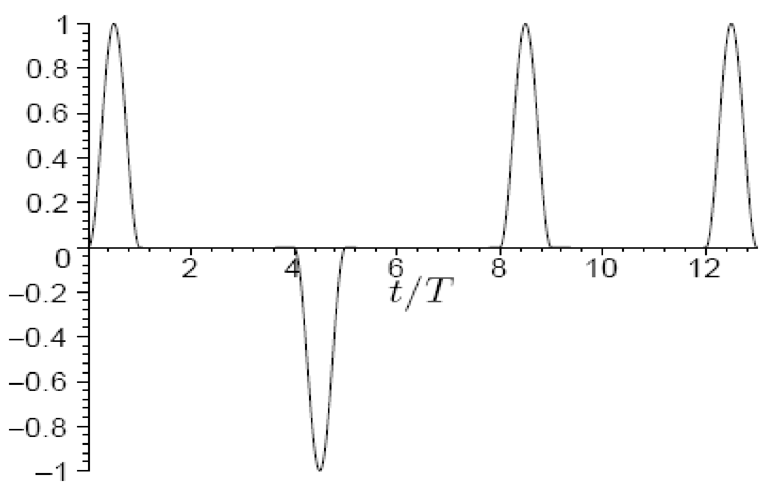
- Transmitter principles (”bits to analog signals”)
- Characteristics of the communication link
- Receiver principles (”analog noisy signals to bits”)
- Technical challenges
- Limitations

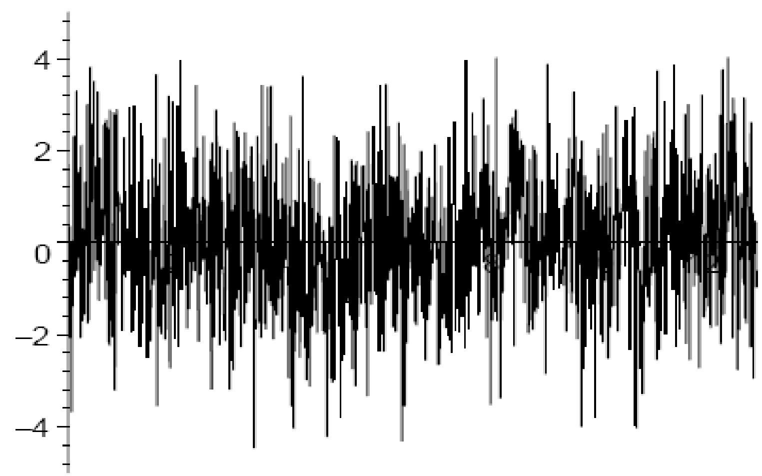
Digital Communications



Link quality: Signal – to – Noise - Ratio

Requirement: Low bit error probability





Example of analog communication?

Requirements on a communication link:

- ”Most” bits should be correct after the receiver.
- High bit rate.
- Efficient use of signal power and bandwidth (Hz).

- Technical solutions/challenges?

Chapters and contents

Transmitter Channel Receiver

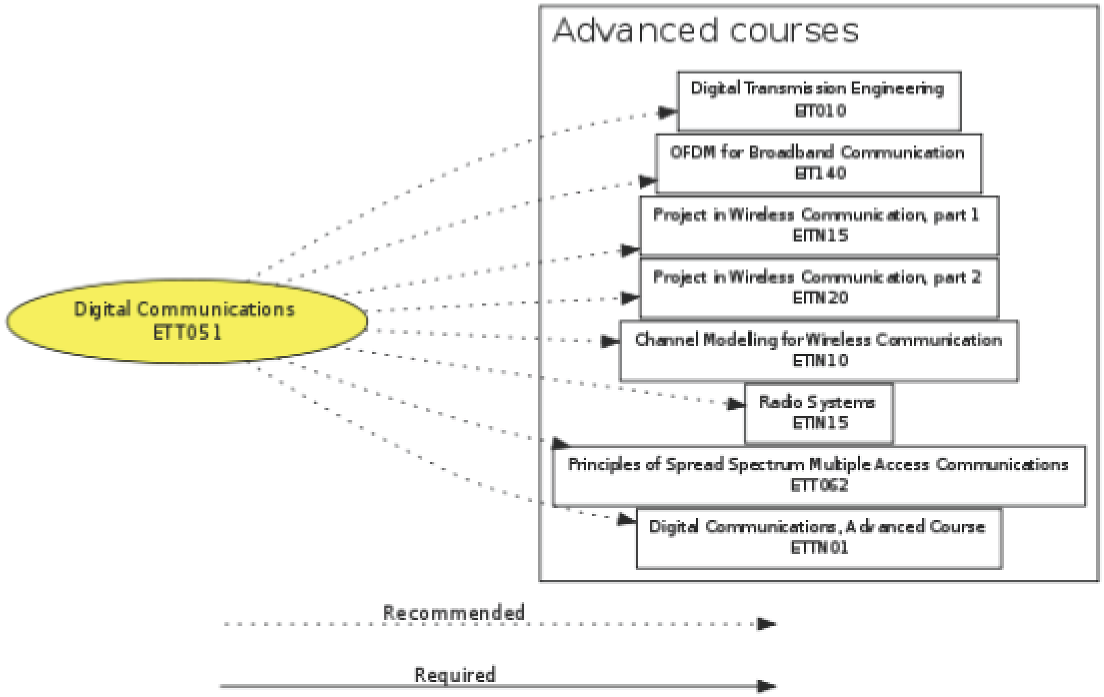
Chapter 2 Chapter 3 Chapter 4+5

Chapter 6 (isi)

Chapter 7 (opt. fiber)

Chapter 8 (trellis)

Course dependencies



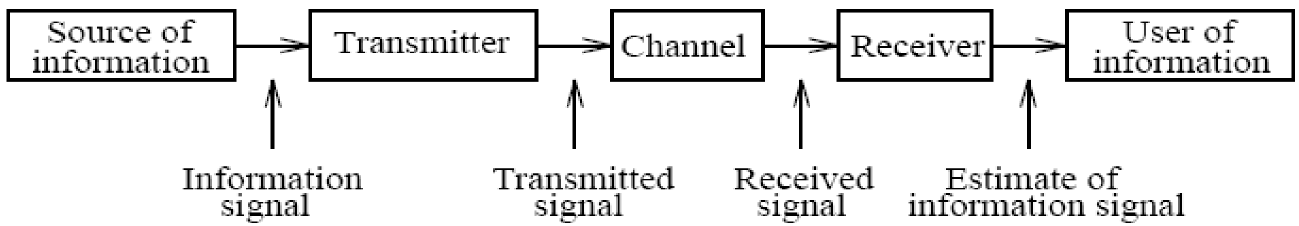


Figure 1.1: Basic elements of a communication system.

1.2 Some Important Events in the Development of Communication Techniques

Communication is nothing new, only the methods vary from time to time. As examples of early methods of communication we have beacons, smoke signals and traveling messengers. Today, however, ***we are in the beginning of the so-called "global digital (r)evolution".*** Below, a selected list of important events in the development of communication techniques is given. For a more complete and thorough historical review the reader is referred to [43], [44], [46] and references therein.

1794. C. Chappe: Constructed an optical telegraph.
1837. S. Morse: Demonstrated the electric telegraph.
1864. J. C. Maxwell: Basic theory for electromagnetic radiation.
1876. A. G. Bell: The invention of the telephone was patented.
1895. G. Marconi: Demonstrated the transmission of radio signals.
1920. AM radio broadcasting initiated.
1928. H. Nyquist: Fundamental theory on digital communication.
1929. V. Zworykin: Demonstrated a television system.
1933. E. Armstrong: Demonstrated an FM radio communication system.
1942. N. Wiener: Basic estimation theory, the optimum linear filter.
1947. W. Brattain, J. Bardeen, W. Shockley: Invention of the transistor.
1948. C. E. Shannon: The "birth" of information theory.
1950. R. W. Hamming: Basic theory on error-detection and error-correcting codes.
1953. Transatlantic cable between the United States and Europe (telephony).
1962. The satallite Telstar 1 was launched.
1965. J. M. Wozencraft, I. M. Jacobs: Basic theory based on a geometrical approach to digital communications.
1967. A. J. Viterbi: Developed an optimal decoding algorithm, nowadays referred to as the Viterbi-algorithm (VA).
1970. Breakthrough for the production of optical fibers. Glass with an attenuation of 20 dB/km was produced.
1982. G. Ungerboeck: Developed trellis-coded modulation, a (signal) power and bandwidth efficient technique.
1988. A fiber optical transatlantic cable between the United States and Europe, TAT-8.
1992. The European GSM system, for mobile digital telephony, started.
1993. C Berrou, A. Glavieux, and P. Thitimajshima: The development of so-called "turbo" codes.
1998. G.J. Foschini, M.J. Gans: Pioneering work within the concept of so-called MIMO systems (multiple-input-multiple-output systems).

:

Examples of transmitter output analog signals that represent information bits.

A ”1” is here represented by a short positive voltage pulse, and a ”0” by a short negative voltage pulse.

T is the pulse duration.

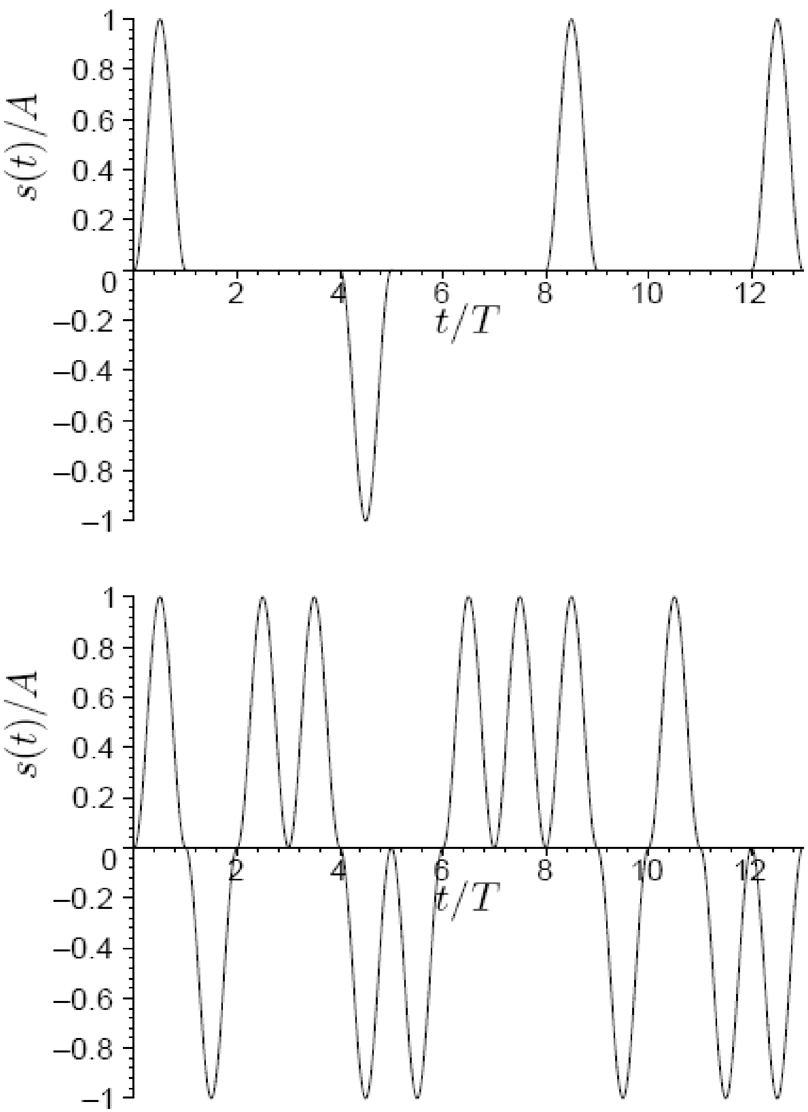


Figure 2.3: Examples of an information carrying transmitted signal $s(t)$. The underlying sequence of bits is in the upper plot 1011, and in the lower plot 1011001110100.

Noise:

Received noisy signal:

Received noisy signal:

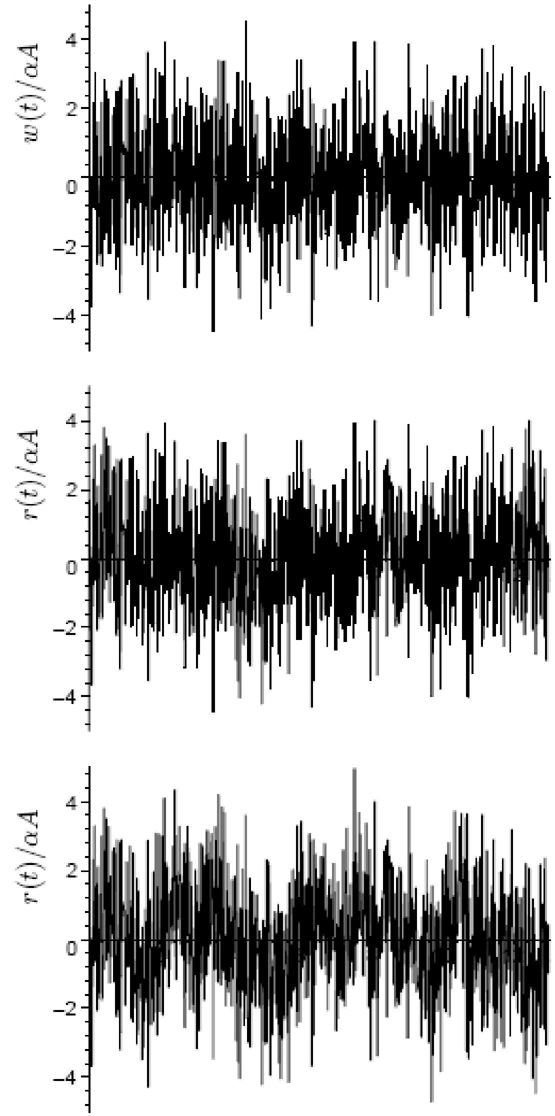


Figure 2.4: The upper plot shows the normalized additive noise $w(t)/\alpha A$.
The middle plot shows the normalized received noisy signal $r(t)/\alpha A$, see (2.11), where $s(t)/A$ is given in Figure 2.3 (upper plot).
The lower plot shows $r(t)/\alpha A$ if the transmitted signal $s(t)/A$ in Figure 2.3 (lower plot) is sent.

Bit error probability: $$P_b = E\{B_{err}\}/B \quad (2.12)$$

Information bit rate in bps: $$R_b = B/\tau \quad (2.1)$$

Information bit time in s: $$T_b = 1/R_b \quad (2.2)$$

Assume 10 bit errors per hour on the average, and that the bit rate is 1 Mbps.
What is the bit error probability?

Total number of bits in an hour=B=1000000*60*60
Gives us
the bit error probability =10/B= 2.78*10^-9

How is this obtained in practice?
Computer simulation is not realistic here!

f [Hz]

| W |

W is the bandwidth in Hz that is used.

Example:
For a specific pulse with duration T it is given that W=2/T.
This means that the bandwidth is W=2 MHz if the duration T of the pulse is T=10^-6.

$$\rho = R_b/W \tag{2.21}$$

A challenge is to make this parameter large (bandwidth efficiency)!!

”Bits to analog signals”

k is the number of bits carried by each analog signal!

M is the number of signal alternatives, and M=2^k.

Binary signaling: M=2, k=1

”0” ↔ s0(t), energy consumption E0

”1” ↔ s1(t), ” ” E1

M=4 (4-ary (quaternary) signaling), k=2

”00” ↔ s0(t), energy consumtion E0

”01” ↔ s1(t), ” ” E1

”10” ↔ s2(t), ” ” E2

”11” ↔ s3(t), ” ” E3

”Bits to analog signals”

<u>M=8 signal alternatives, k=3</u>

”000” ↔ s0(t),	**energy**	**consumtion**	**E0**
”001” ↔ s1(t),	**”**	**”**	**E1**
”010” ↔ s2(t),	**”**	**”**	**E2**
”011” ↔ s3(t),	**”**	**”**	**E3**
”100” ↔ s4(t),	**”**	**”**	**E4**
”101” ↔ s5(t),	**”**	**”**	**E5**
”110” ↔ s6(t),	**”**	**”**	**E6**
”111” ↔ s7(t),	**”**	**”**	**E7**

NOTE! A new signal alternative is here sent after each 3-tuple of information bits!

If M=16384 signal alternatives then k=14.

"Bits to analog signals"

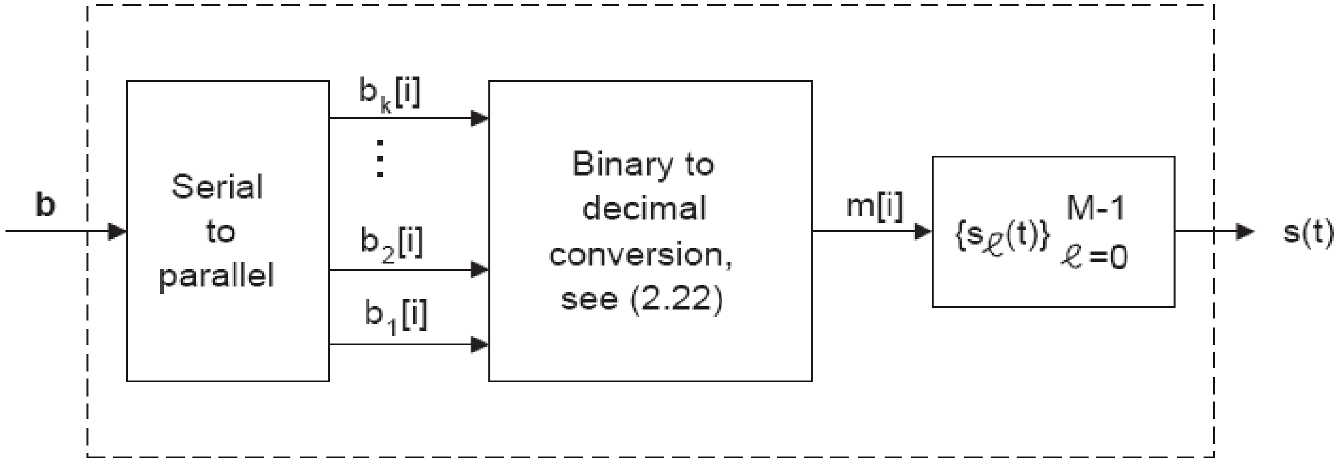


Figure 2.6: Basic structure of the transmitter.

A **k-tuple of information bits** is represented by a unique signal alternative.

If m=5 then signal alternative s5(t) is sent.
So, **the number of the sent signal alternative is the same as m**.
m is often referred to as the **message number**.

EACH WEEK:

1. Get a good overview of the content in the current pages in the compendium.

2. Start to solve problems.

3. Interactive learning procedure: problems <=> text.

4. Then you will learn where the most important and useful pages are located.
   These pages are also stressed in the lectures!

A new signal alternative is sent every Ts.
Ts = the signaling (or symbol) time.

t

| new signal sent | new signal sent | new signal sent |

0 Ts 2Ts 3Ts

The signaling (or symbol) rate = Rs = 1/Ts [symbols/s].

A signal alternative carries k information bits, and

$$\boxed{T_s = kT_b} \qquad (2.23)$$

$$\boxed{R_s = 1/T_s = R_b/k} \qquad (2.24)$$

Note: **t=time variable,**
T=pulse duration,
Tb=bit time,
Ts=signaling (symbol) time=k*Tb

Signal energy:

$$E_\ell = \int_0^{T_s} s_\ell^2(t)dt < \infty \qquad (2.29)$$

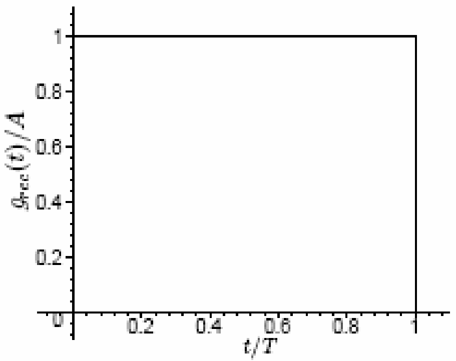


Figure D.1: $g_{rec}(t)/A$.

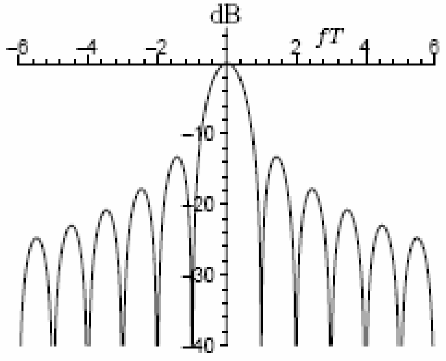


Figure D.2: $\frac{|G_{rec}(f)|^2}{E_g T}$ in dB.

1. The rectangular pulse:

$$g_{rec}(t) = \begin{cases} A & , \quad 0 \le t \le T \\ 0 & , \quad \text{otherwise} \end{cases} \qquad (D.1)$$

$$E_g = \int_0^T g_{rec}^2(t)dt = \int_{-\infty}^{\infty} |G_{rec}(f)|^2 df = A^2 T \qquad (D.2)$$

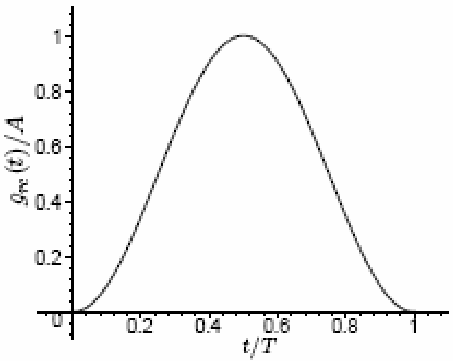


Figure D.9: $g_{rc}(t)/A$.

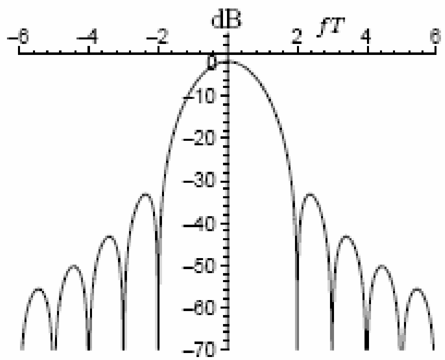


Figure D.10: $\frac{|G_{rc}(f)|^2}{E_g T}$ in dB.

5. The time raised cosine pulse:

$$g_{rc}(t) = \begin{cases} \frac{A}{2}\,(1 - \cos(2\pi t/T)) & , \quad 0 \le t \le T \\ 0 & , \quad \text{otherwise} \end{cases} \tag{D.18}$$

$$E_g = 3A^2T/8 \tag{D.19}$$

Signal energy:

$$E_\ell = \int_0^{T_s} s_\ell^2(t)dt < \infty \qquad (2.29)$$

If a sent signal s(t) has signal energy E, how much signal energy is it then in the received signal α*s(t), if α = 0.001?

Average signal energy and signal power

Equally likely information bits are desired and common in practice.

The **average transmitted signal (or symbol) energy $\bar{E}_s$** over a symbol interval T_s is a very important system parameter,

$$\bar{E}_s = \sum_{\ell=0}^{M-1} P_\ell E_\ell \tag{2.30}$$

The **average transmitted signal energy per information bit, $\bar{E}_b$**, is especially important. Since a signal alternative carries k information bits we have,

$$\boxed{\bar{E}_b = \bar{E}_s / k} \tag{2.31}$$

and the **average transmitted signal power $\bar{P}$** is then given by (compare also with (2.16))

$$\boxed{\bar{P} = R_s \bar{E}_s = \frac{R_b}{k} \cdot k\bar{E}_b = R_b \bar{E}_b} \tag{2.32}$$

$$\boxed{r(t) = \alpha s(t) + w(t)} \tag{2.6}$$

The parameter α, together with the noise/disturbances, determine the quality of the communication link!

The parameter α typically <u>decreases</u> as the communication range increases!

At a long communication range, α is typically very small!

$$\bar{P}_z = \alpha^2 \bar{P} = \alpha^2 R_b \bar{E}_b \tag{2.17}$$

$$\mathcal{E}_b = P_z / R_b = \alpha^2 \bar{P} / R_b = \alpha^2 \bar{E}_b \tag{2.19}$$

If α=0.001 then the received signal power is reduced a factor 10^-6.
This will increase the bit error probability!

How different are two signals?

$$\boxed{\begin{aligned} D^2_{i,j} &= \int_0^{T_s} (s_i(t) - s_j(t))^2 dt = \\ &= \int_0^{T_s} (s_i^2(t) + s_j^2(t) - 2s_i(t)s_j(t))dt = \\ &= E_i + E_j - 2\int_0^{T_s} s_i(t)s_j(t)dt \end{aligned}} \qquad (2.33)$$

Two signal alternatives $s_i(t)$ and $s_j(t)$ are said to be **antipodal** if,

$$s_i(t) = -s_j(t), \quad 0 \le t \le T_s \qquad (2.34)$$

and they are said to be **orthogonal** if,

$$\int_0^{T_s} s_i(t)s_j(t)dt = 0 \qquad (2.35)$$

M=2: “Antipodal signals are better then orthogonal signals”

Case 1: M=2 and on-off signaling

s1(t) =A in the time interval t=0 to t=Tb.
s0(t) = 0 in the time interval t=0 to t=Tb.

gives D^2 = 2Eb

Case 2: M=2 and antipodal signaling

s1(t) =A in the time interval t=0 to t=Tb.
s0(t) = -A in the time interval t=0 to t=Tb.

gives D^2 = 4Eb (**much** better!!)

Digital communication standard methods:

- Pulse Amplitude Modulation (**PAM**)
- Phase Shift Keying (**PSK**)
- Frequency Shift Keying (**FSK**)
- Pulse Position Modulation (**PPM**)
- Quadrature Amplitude Modulation (**QAM**)
- Orthogonal Frequency-Division Multiplex (**OFDM**)

2.4.1 Pulse Amplitude Modulation (PAM)

Pulse amplitude modulation with M signal alternatives (M-ary PAM) means that the information is placed in the amplitude only. Alternatively, this signaling technique is also referred to as M-ary amplitude shift keying (M-ary ASK).

In $0 \leq t \leq T_s$ the ℓ:th signal alternative, $s_\ell(t)$, may be expressed as,

$$\boxed{s_\ell(t) = A_\ell g(t)} \quad \ell = 0, 1, \ldots, M-1 \tag{2.38}$$

$$\boxed{\boxed{A_\ell = -M + 1 + 2\ell\ , \quad \ell = 0, 1, \ldots, M-1}} \tag{2.39}$$

$$\boxed{\{A_\ell\}_{\ell=0}^{M-1} = \{\pm 1, \pm 3, \pm 5, \ldots, \pm(M-1)\}} \tag{2.45}$$

4-ary PAM (only the amplitude depends on the information bits)

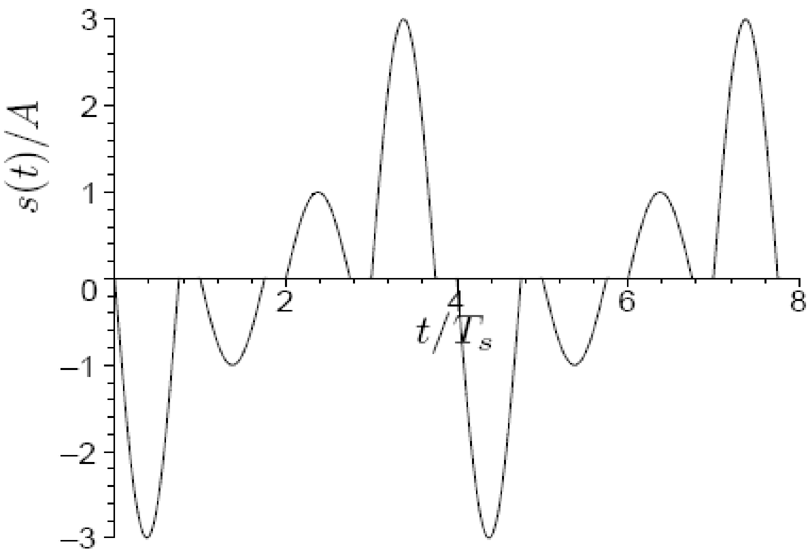


Figure 2.7: An example of a sequence $s(t)$ of 4-ary PAM signal alternatives (see (2.44)). The pulse shape is $g_{hcs}(t)$ (defined in (D.13)) with amplitude A and duration $T = 3T_s/4$. The time axis shows the time interval $0 \leq t \leq 8T_s$.

$$
\begin{aligned}
\bar{E}_s &= E_g \frac{M^2-1}{3} \\
\bar{E}_b &= \frac{\bar{E}_s}{k} = E_g \frac{M^2-1}{3k} \\
E_{\max} &= E_g (M-1)^2 \\
\bar{P} &= \bar{E}_b R_b = \bar{E}_s R_s = E_g \frac{M^2-1}{3k} R_b \\
D_{i,j}^2 &= 4E_g (i-j)^2
\end{aligned}
\tag{2.50}
$$

2.4.1.3 Bandpass M-ary PAM

In many applications it is necessary to use high-frequency signals. This means that the PAM signals are placed around a so-called **carrier frequency f_c** in the frequency domain. A practical way to generate such a bandpass signal $s_{bp}(t)$ is to multiply the original M-ary baseband PAM signal $s(t)$ with a high-frequency sinusoidal signal as below,

$$s_{bp}(t) = \underbrace{\left(\sum_{i=-\infty}^{\infty} A_{m[i]} g(t - iT_s) \right)}_{\substack{\text{Original low-pass} \\ \text{M-ary PAM signal } s(t)}} \cdot \underbrace{\cos(2\pi f_c t + \varphi)}_{\substack{\text{high-frequency} \\ \text{carrier}}}, \quad -\infty \leq t \leq \infty \qquad (2.53)$$

We will consider the frequency domain properties of this kind of signals in Subsection 2.5.1.1 and in Chapter 3 (see, e.g., Example 3.1 on page 121).

4-ary PSK (only the phase depends on the information bits)

$$\boxed{s_\ell(t) = g(t)\cos(2\pi f_c t + \nu_\ell)} \qquad \ell = 0, 1, \ldots, M-1 \qquad (2.54)$$

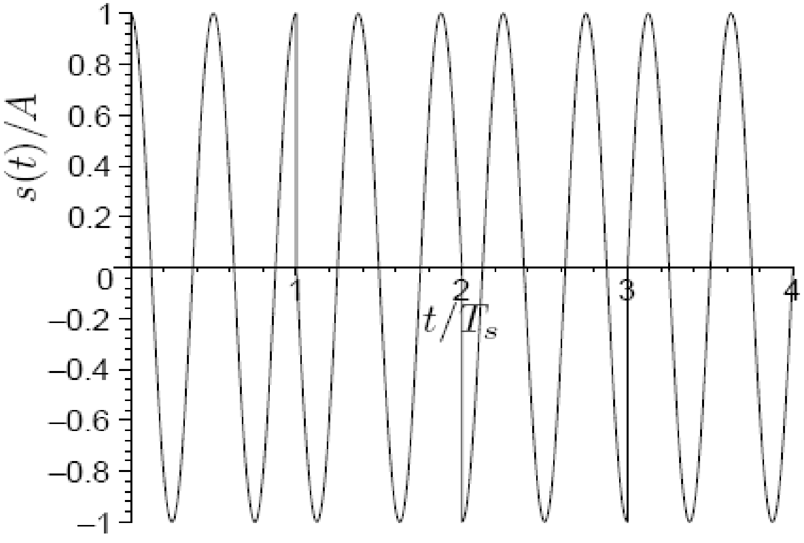
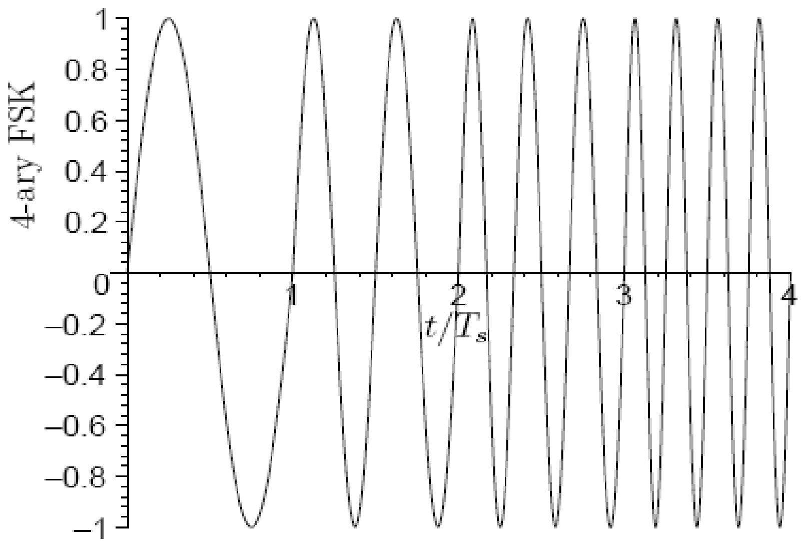


Figure 2.8: An example of a sequence of 4-ary PSK (QPSK) signal alternatives. The pulse shape is $g_{rec}(t)$ (defined in (D.3)) with amplitude A and duration $T = T_s$. The time axis shows the time interval $0 \leq t \leq 4T_s$.

4-ary (orthogonal) FSK (only the frequency depends on the information bits)

$$\boxed{s_\ell(t) = A\cos(2\pi f_\ell t + \nu)} \qquad \ell = 0, 1, \ldots, M-1 \qquad (2.68)$$

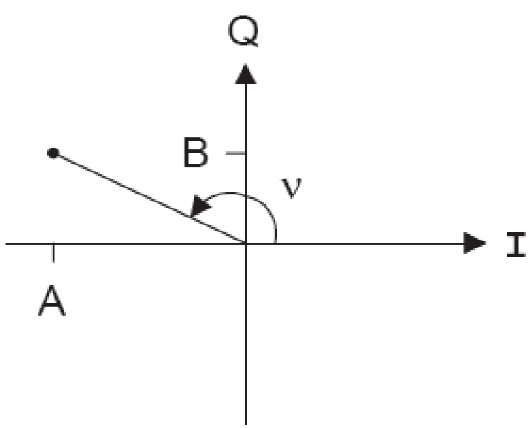


□

2.4.5 Quadrature Amplitude Modulation (QAM)

$$\boxed{s_\ell(t) = A_\ell g(t)\cos(2\pi f_c t) - B_\ell g(t)\sin(2\pi f_c t)} \quad \ell = 0, 1, \ldots, M-1 \qquad (2.87)$$

$$\boxed{s_\ell(t) = g(t)\sqrt{A_\ell^2 + B_\ell^2}\cos(2\pi f_c t + \nu_\ell)} \quad \ell = 0, 1, \ldots, M-1 \qquad (2.89)$$



64-ary QAM

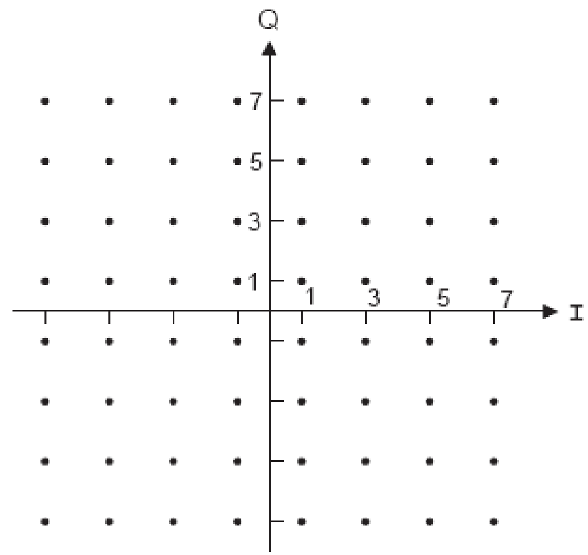
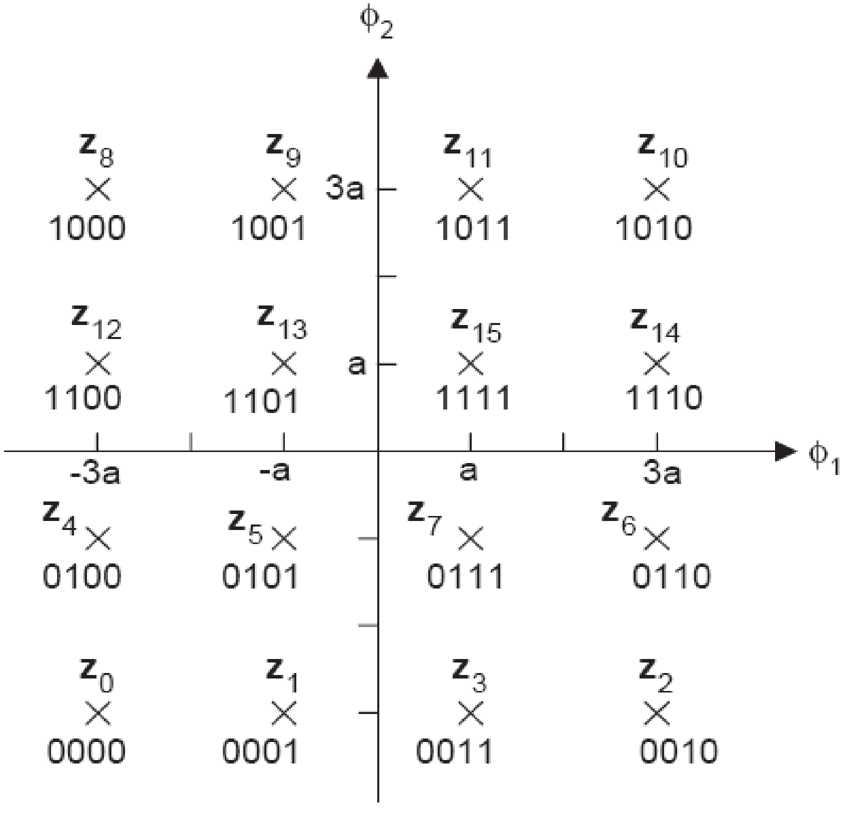


Figure 2.10: Illustrating the $M = 2^6 = 64$ possible pairs of I-Q message amplitudes $\{A_\ell, B_\ell\}_{\ell=0}^{63}$.

16-ary QAM with so-called Gray-coding



Orthogonal Frequency-Division Multiplex (OFDM)

$$x(t) = \sum_{n=0}^{N-1} (a_I[n]g(t)\cos(\omega_n t) - a_Q[n]g(t)\sin(\omega_n t)),\ 0 \le t \le T_s \qquad (2.106)$$

OFDM = the sum of N orthogonal QAM signals.

Example: N=6000
64-ary QAM in each QAM signal

Then an QFDM signal carries 36000 bits!

How can this be built in practice?

An OFDM signal alternative?

OFDM (N=16, 16-ary QAM in each sub-channel)
In this case, an OFDM signal then carries 16x4=64 bits.

$$x(t) = \sum_{n=0}^{N-1} (a_I[n]g(t)\cos(\omega_n t) - a_Q[n]g(t)\sin(\omega_n t)), \ 0 \le t \le T_s \qquad (2.106)$$

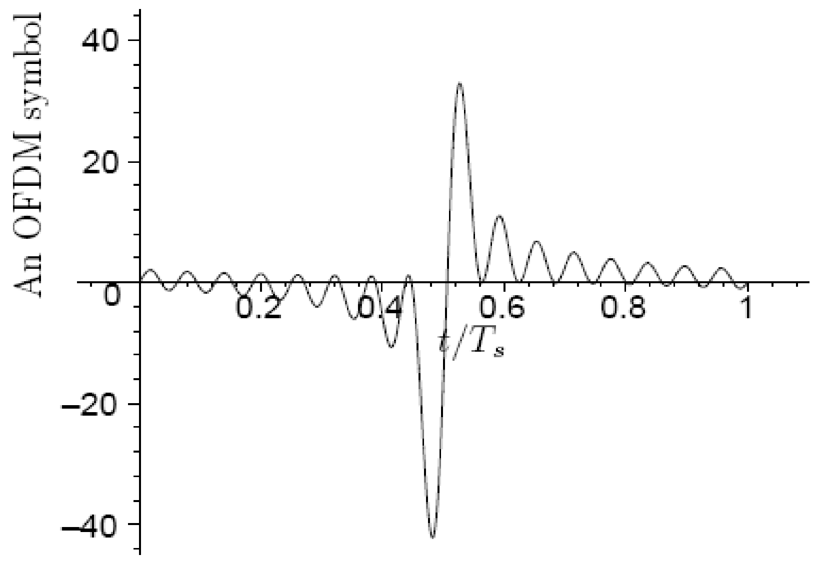


Figure 2.11: An example of a specific OFDM symbol $x(t)$ given in (2.115). The figure shows $x(t)/A$ over the symbol interval $0 \le t \le T_s$.

A clever implementation of a practical OFDM transmitter

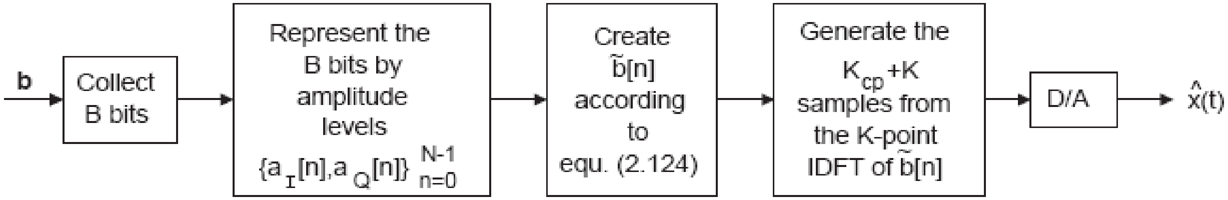


Figure 2.12: Illustrating the generation of $x(t)$ by using the IDFT.

A short summary of some important parameters/concepts in this course during **study-week 1:**

Chapters 1+2:

Pages 1-4 are recommended as an introduction to this course.

Study the basic definitions of: bit rate (page 6), bit time (page 6), bit error probability (page 15), decibel (page16), and bandwidth efficiency (page 19).

Try to understand the connection between Figure 2.3 and Figure 2.4.

Study Figure 2.6 in detail. Furthermore, the number of sent bits (k) in a transmission , the number of signal alternatives in the transmitter (M), and the signaling (or symbol) time (Ts) are basic parameters.

Since k bits are sent in Ts seconds, the bit rate must be k/Ts bps.

The average signal energy and power consumption is found on page 26.

Examples of some signals (pulse shapes) are found in Appendix D.

The squared Euclidean distance tells us how "different" two signals are (page 28).

Pages 31-55 covers the basic signal constellations PAM, PSK, FSK, PPM, QAM, PWM, OFDM.