Telecommunicatie A (EE2T11)

Lecture 1 overview:

General
Introduction Telecommunications A
Homework exercises in MapleTA

What is information?
Analogue v.s. digital communication
Characterization information source
Channel capacity (Shannon)
Modulation - demodulation
Signal characteristics
Decibels

EE2T11 Telecommunicatie A

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Telecommunicatie A (EE2T11)

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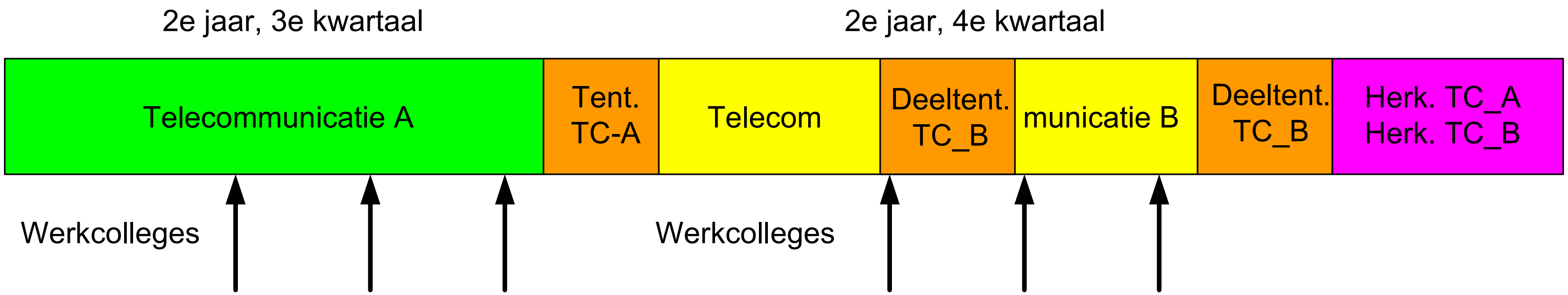
Boek: L.W. Couch, *"Digital and Analog Communication Systems"*,
8th edition, Prentice Hall, 2013

TC_A: Beginselen van signaaloverdracht en basisbandtransmissie
& lab courses
TC_B: Banddoorlaattransmissie: analoge en digitale modulatie technieken
& Telecommunicatienetwerken

Telecommunicatie A: 7 x 2 uur college
3 x 2 uur werkcollege

Tentamen: donderdag 14 april 2016, 13:30 – 16:30 uur
Herkansing: vrijdag 22 juli 2016, 13:30 – 16:30 uur

Telecommunicatie A en B



Telecommunicatie A

De theoretische basis van communicatiesystemen: signaalbeschrijving, signaalpropagatie, ruis en systeemruisberekeningen, basisbandtechnieken, modulatietheorie → analoge pulsmodulatie, analoog/digitaalomzetting.

& lab courses

Telecommunicatie B

Banddoorlaatsystemen: modulatietechnieken voor analoge en digitale signalen. Maten voor de kwaliteit van detectie van signalen met ruis: berekening van de signaal-ruis verhouding en bitfoutenkans.

& Telecommunicatienetwerken

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Collegerooster

Collegestof Telecommunicatie A EE2T11 voor de 8e editie van Couch **3e kwartaal 2015-2016**

Col./Instr	Datum	Hfdst	Onderwerp	Blz.
Telecommunicatie A: Beginselen van signaaloverdracht en basisbandtransmissie				
Col. 1	8-2		**Introduction**	
		1.1 - 1.6	General introduction	25 - 32
		1.9, 1.10	Ideal communication systems	39 - 42
		2.1	Power relations, decibel	56 - 66
Col. 2	15-2		**Signaal descriptions**	
		2.6	Linear systems, filtering, distortion	104 - 111
		2.7	Bandlimited signals and noise	111 - 119
		2.9-2.10	Bandwidth of signals and noise	127 - 134
Col. 3	22-2		**Received signal power and noise**	
		1.7-1.8	Propagation of e.m. waves	32 - 39
		8.6	Received signal power	619 - 622
		8.6	Thermal noise sources	622 - 629
Instr. 1	**29-2**			
Col. 4	1-3		**System noise calculation and analog transmission components**	
		8.6	System noise calculation and link budget evaluation	629 - 640
		4.8 - 4.12	Selection of communication system components: filters, amplifiers, limiters and mixers	276 - 295
Col. 5	7-3		**Baseband techniques: sampling and pulse code modulation**	
		3.1, 3.2	PAM, Flat-top PAM	154 - 163
		3.3	PCM: sampling, encoding, bandwidth	163 - 174
		7.7	Output Signal-to-Noise ratio for PCM	547 - 552
Instr. 2	**14-3**			

Blackboardpagina EE2T11, tab “Course information”

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Colleges en Werkcolleges Telecommunicatie A

Colleges:

Maandag	8-2, 15-2, 22-2, 7-3, 21-3	5^e en 6^e uur, EWI-Pi
Dinsdag	1-3, 15-3	7^e en 8^e uur, EWI-Pi

Werkcolleges:

Maandag	29-2, 14-3, 4-4	5^e en 6^e uur, EWI-Pi

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Huishoudelijk

- Mededelingen komen op de Blackboard pagina van het vak Telecommunicatie A (EE2T11)

- Overzicht van de collegestof-per-week op Blackboard

- Wekelijks verschijnt er een MapleTA huiswerkopgave op Blackboard behorende bij de stof van die week.

- College responsiegroep

"Bonus" verdienen met de Huiswerkopdrachten

Maken van de huiswerkopdrachten levert een bonus op voor het tentamen en de herkansing:

Tentamencijfer = TT + 2*HW*(10-TT)/100

Het resultaat van de huiswerkopdrachten, zijn alleen geldig voor dit collegejaar: dus t.m. de herkansing in juli.

Huiswerkopdrachten met MapleTA (1)

De MapleTA opgaven staan onder "Assignments".

- Je kunt de opgaven printen en vervolgens eerst maken voordat je de antwoorden in MapleTA invult
- Als de opdracht uit meerdere vragen bestaat, vul je eerst alle antwoorden in voordat je de "Grade" knop gebruikt.
- "Grade" is:
  * antwoorden inleveren,
  * je krijgt een cijfer
  * einde opdracht.
- Je kunt de opdracht maar één keer maken!!!
- Als je met Quit/Save de opdracht verlaat kun je later terugkomen.

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Huiswerkopdrachten met MapleTA (2)

- De vragen staan open van/tot:
  * vanaf 30 minuten na het college
  * tot 's ochtends 3:00 uur op de dag van het eerstvolgende (werk)college
- Geef de antwoorden op twee decimalen nauwkeurig.

- **LET OP!!! Het decimaalteken in MapleTA is een "PUNT".**

- Er wordt nagekeken met een absolute antwoordnauwkeurigheid van +/- 0.2 dB, of een relatieve nauwkeurigheid van +/- 2%

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Voorbeeld van een huiswerkopgave

<u>Opgave 1.</u>

Een basisband communicatiesysteem zendt iedere [1.a] msec één van [1.b] mogelijke berichter door middel van een digitaal woord over het kanaal. De kans op verzending is voor elk bericht ev groot.

a. Wat is de woordlengte die nodig is voor het overzenden van een bericht?

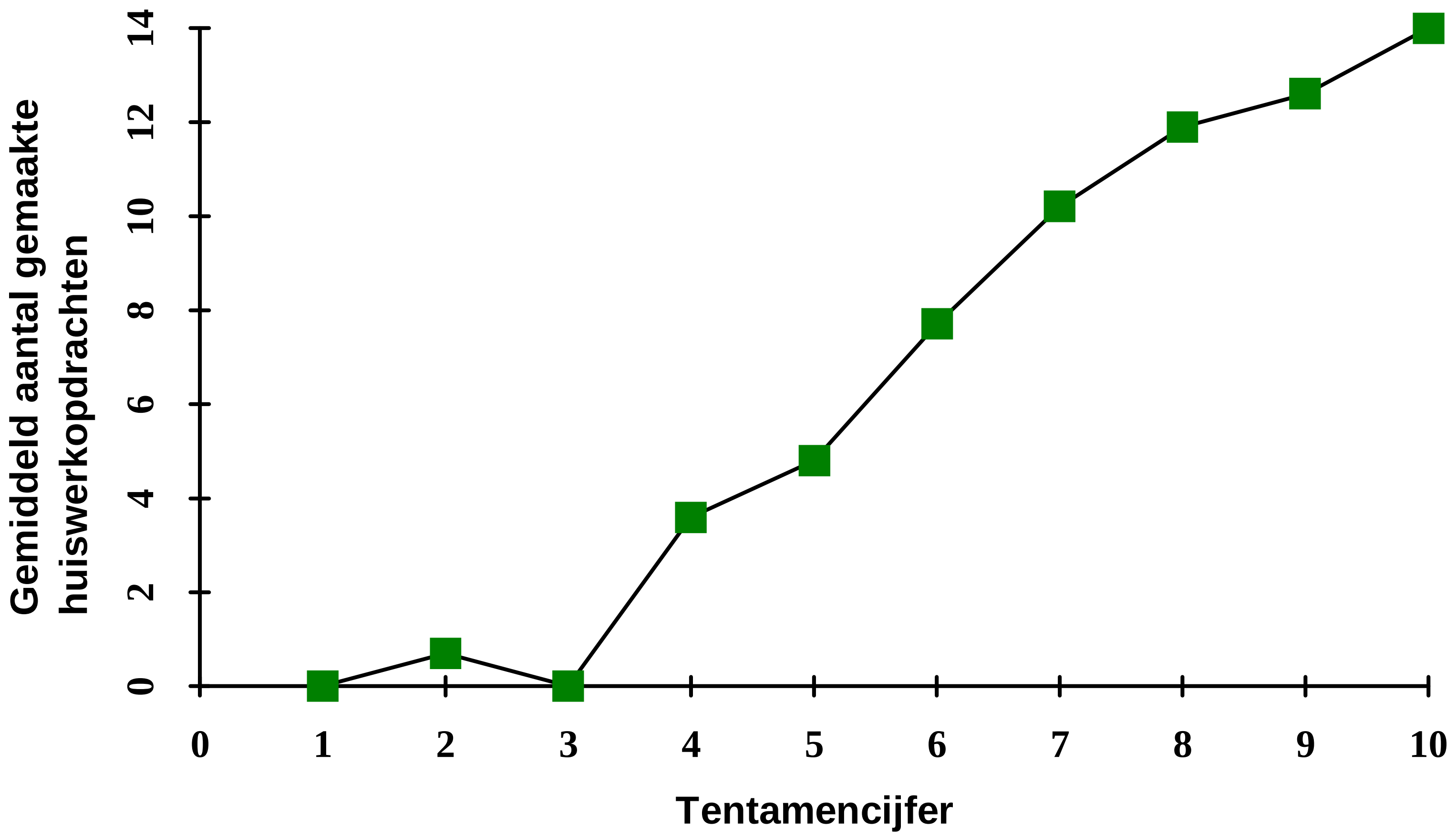
De woordlengte is $\boxed{}$ bits.

b. Wat is de bitrate van het systeem? De bitrate bedraagt $\boxed{}$ kbits/sec.

c. De beschikbare bandbreedte voor verzending van bovengenoemd signaal is B = 750 Hz. Bereken de minimale signaal-ruis verhouding die vereist is voor foutloze overdracht.

$S/N_{min} = \boxed{}$

Tentamencijfer v.s. aantal gemaakte huiswerkopdrachten.



Telecommunicatie A (EE2T11)

Lecture 1 overview:

What is information?
Analogue v.s. digital communication
Characterization information source
Channel capacity (Shannon)
Modulation - demodulation
Signal characteristics
Decibels

Telecommunications

What is telecommunications?

- transport and distribution of information from a source to (a) destination(s)
- collection and extraction of information by observation.

Importance of telecommunications?

- it like "greasing oil" in our society
- largest electro-technical sector
- (second) largest sector based on turnover
- largest part of turnover is generated by services
- important area for the electrical engineer

Some of the services that use telecommunications techniques

- *speech communication* (telephony)
- *data communication* (internet)
- *broadcast* (radio, TV)
- *electronic positioning and navigation*
  (GPS, future Galileo, radar, air traffic control)
- *telemetry* (control systems)
- *remote sensing*
  (weather satellites, environmental research, military applications)

Telecommunications in EE curriculum

Telecommunications spans a broad field of research activities:
- applications
- systems
- signals

How is it treated in the lectures:
- based on models (meta-systems)
- in Telecommunication A & B, good knowledge of Signals and Systems (EE2S11) and Signal Processing (EE2S31) is important

Because telecommunications is so important in our society, basics of telecommunications are obligatory topics in the bachelor's program EE of TU-Delft.

Meta-system

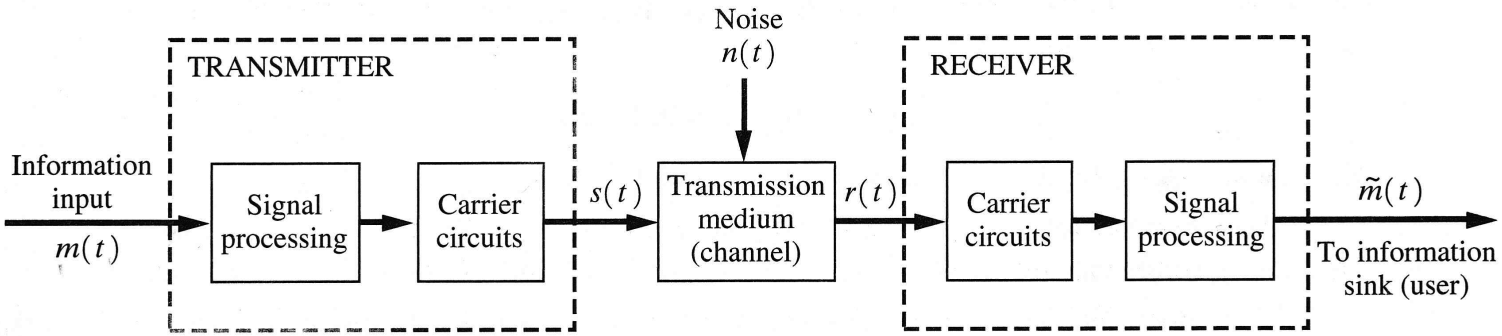


Figure 1–1 Communication system.

1. **Source and destination of the message are at different locations.**
2. **Transfer of the signal via an electro-magnetic channel: i.e. using a cable, radio (wireless) or an optical fiber.**
3. **The information signal is converted into an e.m. signal: i.e. a waveform that can propagate over the available channel.**
   Messages need to be converted into suitable waveforms for transmission over the channel, and from which the original information can be retrieved at the destination with as low as possible distortion/error probability.
4. **At the destination, we should be able to distinguish the desired signal from other signals and distortions like noise and interference.**

Information source: analog sources

An analog source generates an analog message:
continuous in level and continuous in time

Examples:

- a microphone
- a video camera

By means of analog-to-digital conversion (ADC), an analog signal can be digitized (e.g. PCM) and be digitally processed, transported or stored on a CD-ROM or DVD.

Information source: digital sources

A digital source generates a digital message:
a finite set of discrete symbols, discrete in time

Examples:
- computer data: 0011010100110 $\rightarrow$ 2 possible symbols

- key board message:
  Helaas studeren nog te weinig meisjes elektrotechniek $\rightarrow$ 26 symbols

- morse: . . . - - - . . . $\rightarrow$ 2 basic symbols

Characteristics of a digital source

1. The alphabet from which the messages are drawn as symbols (M possible symbols)

2. The source rate R [symb/sec, baud]

3. The probability of occurrence of the respective symbols (e.g. Pr(e) = 0.124 in the Dutch language).

Analog and digital transmission systems

1. Analog transmission system

Transmits information generated by an analog source as an analog signal: continuous values continuous in time.

2. Digital transmission system

Transmits information generated by a digital source: a finite set of time discrete symbols.

Advantages of digital communication:

1. transparent for different types of information
2. data from different sources can be jointly transmitted (multiplexing)
3. cheap electronics
4. relatively insensitive to noise
5. error detection/correction possible
6. easy encryption

Disadvantages:

1. more bandwidth needed than for analog signals
2. synchronization required

What is information?

Some details on a holiday location:

1. The sun will come up every day.

2. From time to time rain showers.

3. Tomorrow a hurricane is expected.

A bigger surprise $\rightarrow$ more information

Definition of information content?

A less probable message contains more information!

Information content: $I_j \triangleq \log_2 \frac{1}{P_j} = -\log_2 P_j$

- this is a technical definition
- unit of information: [bit]
- the information content does not depend on a possible interpretation, it only depends on its probability of occurrence

Information is additive

Informations are additive:

$$I_{ij} \triangleq \log_2 \frac{1}{P_i P_j} = -\log_2 P_i - \log_2 P_j$$

$$= I_i + I_j$$

iff the messages are independent!

So, two *independent messages* will give you more information.

Source entropy

Source entropy = the average information per symbol.

$$H \triangleq \sum_{j=1}^{M} P_j I_j = \sum_{j=1}^{M} P_j \log_2 \frac{1}{P_j} \quad \text{[bit/symbol]}$$

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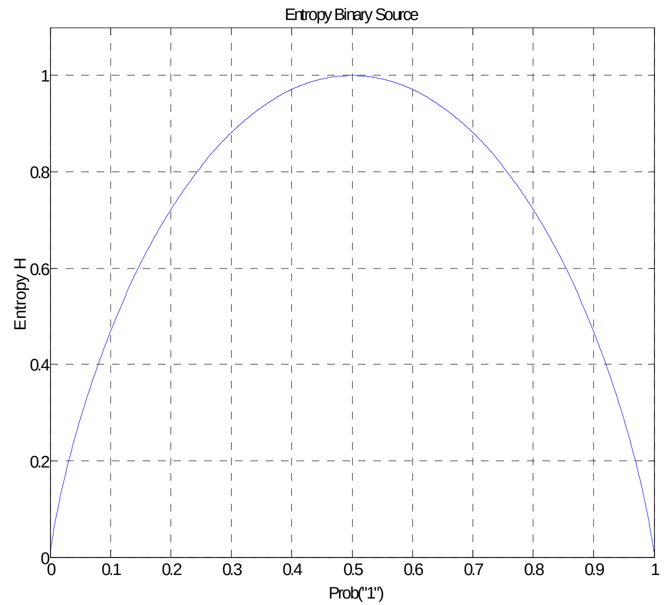
Binary source

Bericht "1": $P_1 = p$

Bericht "0": $P_0 = 1 - p$

$$H = -p\log_2 p - (1-p)\log_2(1-p)$$

- The best source (maximum H) has equi-probable symbols: $P_1 = P_0 = 0.5$
  The *surprise effect* for each of the symbols is the same and maximum.
- A useless source has very likely "0" or "1", there is no need to communicate
- A *known pattern* can be very useful for training!



The speed of a source: $R \triangleq \dfrac{H}{T}$ [bit/s]

where T is the duration of a symbol/message.

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Example: Telex (1)

A telex machine can generate 26 letters + 6 special characters.

The source-encoder generates the equivalent bit stream.

What is the bit rate of this system in case we send 10 char/s, and assuming that the symbols are equally-likely?

Example: Telex (2)

For the telex $\Rightarrow$ 26 letters + 6 special characters

$\Rightarrow$ alphabet = 32 symbols

In case we send 10 char/s $\Rightarrow$ T = 100ms.

For equally likely symbols: $P_j = \frac{1}{32} \quad \Rightarrow \quad I_j = -\log_2 P_j = 5 \text{ bits}$

Now we find for the source rate:

$$R = \frac{H}{T} = \frac{1}{T}\left(\sum_{j=1}^{32} -P_j \log_2 P_j\right) = 10\left(\sum_{j=1}^{32} \frac{5}{32}\right)$$

$$= 10 \text{ symbols/s of 5 bits each} = 50 \text{ bit/s}$$

Channel capacity (Shannon)

The capacity C of a transmission channel: $C \geq R$
(R = bit rate)

$$C = B \cdot {}^{2}\log\left(1 + \frac{\mathrm{S}}{\mathrm{N}}\right) \quad \text{[bit/s]}$$

C = capacity [bit/s] is the maximum error-free bit rate for a channel with Additive White Gaussian Noise (AWGN)
B = bandwidth [Hz] of the channel
S/N = ratio of signal power to the noise power

Increase of capacity:
- increase the bandwidth B
- increase of the S/N

Shannon is the founder of the Information Theory (1948).

Example: Telephone modem (1)

The useful frequency band of the telephone voice channel is $300 < f < 3400$ Hz.

The quality of the telephone channel: $S/N = 1000$ (30 dB)

Calculate the Capacity of this channel.

What SNR is required for a capacity of 56.6 kbit/s?

Example: Telephone modem (2)

Bandwidth telephone speech channel: 300 - 3400 Hz $\Rightarrow$ B = 3100 Hz
Quality telephone channel: S/N = 1000 (30 dB)

Capacity $C = B \cdot \log_2(1 + S/N) = 3100 \cdot \log_2(1001) \simeq 31000 \text{ bit/s}$

For a 56k6 modem: $C \geq 56600 \text{ bit/s} = 3100 \cdot \log_2(1 + S/N)$

$$\Rightarrow \quad \frac{S}{N} \geq 2^{\frac{C}{B}} - 1 = 2^{\frac{56600}{3100}} - 1 \approx 313500 \equiv 55 \text{ dB}$$

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Modulation (1)

Modulation $\rightleftarrows$ Demodulation (MODEM)

Modulation: manipulation of a carrier-signal parameter according to a message such that it can be transmitted over the fysical channel (taking into account the available frequency / bandwidth)

Demodulation: retrieval of the message from the received modulated carrier-signal.

Modulation (2)

Modulation: manipulation of a signal waveform to carry information

Such a signal is called a carrier. A modulated sine-carrier:

$$s(t) = R(t)\cos(2\pi f_c t + \phi(t))$$

CW: continuous wave modulation

f_c = carrier frequency

$R(t)$ = instantaneous amplitude

$\phi(t)$ = instantaneous phase

information signal

$R(t) = \mathfrak{L}\{\mathrm{m(t)}\}$ linear modulation, e.g. AM, DSB and SSB

$\phi(t) = \mathfrak{L}\{\mathrm{m(t)}\}$ (exponential) angle modulation, e.g. PM, FM

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Why modulation?

1. Optimal adaptation to the available transmission channel.
2. Different signals can be transmitted on different carrier frequencies

   → by tuning: select the individual transmitters

   → multiplexing (stacking of signals in the frequency domain)
3. Choose the frequency which contains least noise/interference
4. At high frequencies, the relative bandwidth of a signal decreases

   → in the higher frequency bands more similar signals can be located

Sources of interference and distortion

1. Noise: a stochastic (unpredictable) process
   - cannot be removed, in principle.
2. Interference: distortion due to signals not of interest
   a. intentional,
   b. system related, } suppression is possible in principle
   c. by accident.
3. Distortion:
   - linear distortion = filtering (echos, phase shifts)
     $\rightarrow$ can be compensated for by equalization,
   - non-linear distortion: due to non-linear components
     (e.g. a limiting amplifier) $\rightarrow$ cannot be removed
   Vanishes when the signal is removed

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Task Telecommunications Engineer:

To make an optimum trade-off in the choices of:

- signal waveform (modulation)
- signal bandwidth and power
- sensitivity to noise/interference (robustness)
- cost

$$C = B \cdot {}^{2}\log\left(1 + \frac{S}{N}\right)$$

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Signals and waveforms

Received signal = desired signal + undesired signals

Unknown waveform

Deterministic transmitted waveform unknown to the receiver

Stochastic waveform: noise + interference

The waveform $w(t)$ is a function of time.

In the telecommunication, a signal is usually represented by a voltage $v(t)$ or a current $i(t)$, but also other physical quantities are possible.

Practical signal waveforms

$\rightarrow$ must be physically realisable

1. finite duration and finite energy
2. finite bandwidth
   (no infinitely fast changes possible)
3. time-continuous
4. finite peak value
5. real

Usually, but not necessarily, practical waveforms in telecommunications are available as a voltage or a current.

Physical v.s. mathematical signals

Often we will use idealized signals to allow for simple modeling and mathematical manipulations.

Although physical signals are always **real**, we will see that the complex signal representation is very useful in the telecommunications (e.g. when we evaluate filtering, bandpass systems and modulation).

Physical waveform:
Limited: - duration
- bandwidth
- energy
- continuous in time

Mathematical waveform:
Unlimited: - duration
- bandwidth
- energy
- discontinuous in time

Mathematical and physical waveforms

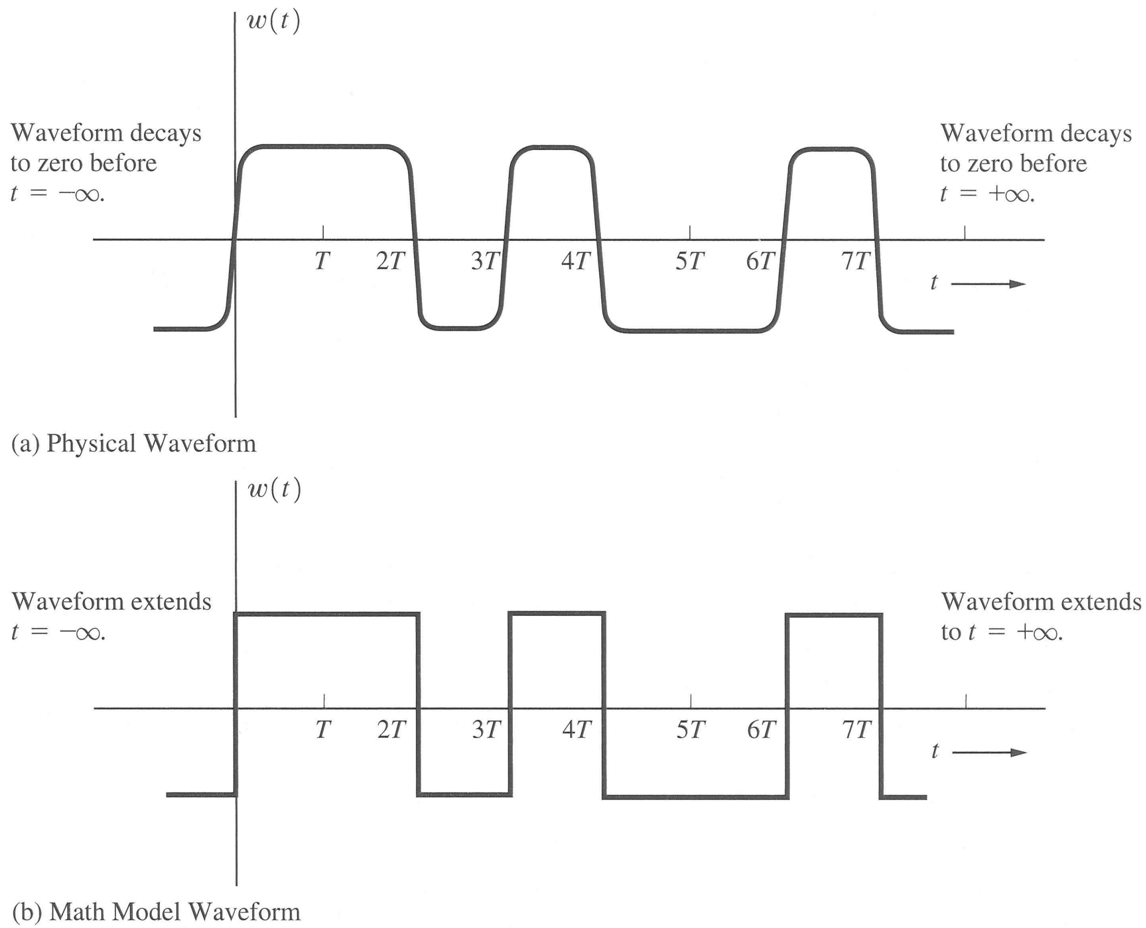

Figure 2–1 Physical and mathematical waveforms.

Signal characteristics (1)

1. DC-value, mean value: $w_{DC} = < w(t) > = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} w(t)dt$
2. Instantaneous power: $p(t) = v(t) \cdot i(t)$
3. Average power: $P = < p(t) > = < v(t) \cdot i(t) >$

   For ergodic processes, the time average can be replaced by the ensemble average: $P = < p_i(t) > = \overline{p_i}(t)$
4. RMS-value: root-mean-square or effective value.

   $w_{rms} \triangleq \sqrt{< w^2(t) >}$

   For a resistive load:

   $$P = v_{rms} i_{rms} = \frac{< v^2(t) >}{R} = < i^2(t) > R$$

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Signal characteristics (2)

5. Normalized power = power in a 1 Ω load.

$$P = \langle w^2(t) \rangle = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} w^2(t)dt \quad [\mathrm{W}] = [\mathrm{J/s}]$$

   with $w(t)$ a real voltage or current.

   $w(t)$ is a power waveform iff $0 < P < \infty$.

6. Normalized energy = energy dissipated in a 1 Ω load.

$$E = \lim_{T\to\infty} \int_{-T/2}^{T/2} w^2(t)dt \quad [\mathrm{J}]$$

   $w(t)$ is an energy waveform iff $0 < E < \infty$.

A signal $w(t)$ cannot be a *power waveform* as well as an *energy waveform*. A physically realisable waveform is always an energy waveform.

Decibel [dB]

The decibel is a logarithmic measure:

$$X_{\mathrm{dBx}} \triangleq 10 \cdot \log_{10} X$$ dBx w.r.t. the unit of X

Why? $\Rightarrow$ Calculations simplify substantially!
- multiplications and divisions $\Rightarrow$ sums and differences of dB values: e.g. when cascading different components like amplifiers, filters, etc.
- very large and very small numbers become easy to use/imagine

The other way around, we find X [x] from X_{dBx} as:

$$X = 10^{\frac{X_{\mathrm{dBx}}}{10}} \; [x]$$

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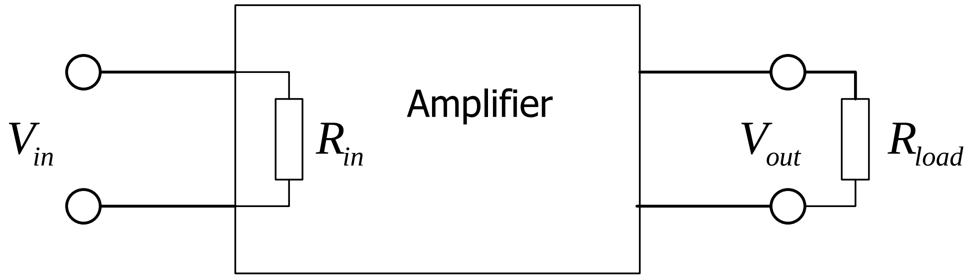
Decibel and power amplification

The power gain of an amplifier is:

$$G = \frac{P_{out}}{P_{in}} = \frac{\overline{V_{out}^2} / R_{load}}{\overline{V_{in}^2} / R_{in}}$$



and it follows:

$$G_{dB} \triangleq 10 \log_{10} \frac{P_{out}}{P_{in}}$$

$$= 20 \log_{10} \frac{V_{rms\_out}}{V_{rms\_in}} - 10 \log_{10} \frac{R_{load}}{R_{in}}$$

Power amplification without voltage amplfication possible.

Inverse: $G \triangleq 10^{G_{dB}/10}$

Often the last term is neglected, even when we do not refer to the *normalized power.* This is only allowed when $R_{load} = R_{in}$.

The dB is usually related to power.

Other decibel notations (1)

- Signal-to-Noise Ratio (SNR)

$$\frac{S}{N} \triangleq \frac{P_{signal}}{P_{noise}} \Rightarrow \left.\frac{\mathrm{S}}{\mathrm{N}}\right)_{dB} = 10\log_{10}\frac{P_{signal}}{P_{noise}}$$

$$= 10\log_{10}\frac{< s^2(t) >}{< n^2(t) >}$$

$$= 20\log_{10}\frac{V_{rms\_signal}}{V_{rms\_noise}}$$

$$= P_{signal\_dBW} - P_{noise\_dBW} \ \ [\mathrm{dB}]$$

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Other decibel notations (2)

A reference value in dB-notations is indicated by adding a unit.

Some definitions:

- Power: $\text{dBm} \triangleq 10\log_{10} P\ [\text{mW}] = 10\log_{10} \frac{P\ [\text{Watt}]}{10^{-3}}$

$$= 30 + 10\log_{10} P\ [\text{Watt}]$$

$$0\ \text{dBm} = 1\ \text{mW}$$

$$\text{dBW} \triangleq 10\log_{10} P\ [\text{Watt}]$$

$$0\ \text{dBW} = 1\ \text{W}$$

- Bandwidth: $\text{dBHz} \triangleq 10\log_{10} BW\ [\text{Hz}]$

Examples decibel notations

Telephone: $\text{dBpW} = 10\log_{10} P\ [\text{pW}] = 10\log_{10}\dfrac{P\ [\text{W}]}{10^{-12}} = \text{dBm} + 90$

Cable television: reference is 1 mV over a 75Ω load

$$\text{dBmV} = 20\log_{10}\left(\frac{V_{rms}}{10^{-3}}\right)$$

$$0\ \text{dBmV} \equiv \frac{(10^{-3})^2}{75} = \frac{10^{-6}}{75} = 1.33\cdot 10^{-8}\ \text{W} = -48.75\ \text{dBm}$$

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