Introduction to Communication Engineering
SSY121, Lecture # 1

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Outline

1. Course Organization
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   - Literature and Information
   - Contents and Elements
   - Examination and Rules
2. Brief Signals and Systems Review
   - The Fourier Transform
   - Linear and Time Invariant (LTI) Systems
   - The Sampling Theorem
3. The Digital Communication System
   - Models for Digital Communications
   - Spectrum Regulation
   - Designer's Dilemma

Part I

Course Organization

Course Organization

Course Staff

- **Fredrik Brännström**, Professor,
  Communication Systems, *Lecturer and Examiner*
- **Mohammad Farsi**, PhD Candidate,
  Communication Systems, *Teaching Assistant*
- **Azadeh Tabeshnezhad**, PhD Candidate,
  Communication Systems, *Teaching Assistant*
- **Erik Svenske**, Management Consultant,
  Ekan Management AB, *Guest Lecturer*

For more info

Communication Systems Group (CS)
Department of Electrical Engineering (E2)

Fredrik Brännström, short bio

- **MSc** in Electrical Engineering, 1998,
  Luleå University of Technology
- **LicEng** and **PhD** in Communication Theory, 2000 and 2004
  Department of Computer Engineering, Chalmers
- **Post Doc**, Communication Systems, 2004 – 2006
  Department of Signals and Systems, Chalmers
- **Principal Design Engineer** for Wi-Fi 802.11a/b/g/n, 2006 – 2010
  Quantenna Communications, Fremont, CA
- Communication Systems Group (CS)
  Department of Electrical Engineering (E2)
  - **Assistant Professor**, Sept 2010 – Oct 2013
  - **Docent** in Communication Systems, Nov 2012
  - **Associate Professor**, Nov 2013 – Sept 2016
  - **Professor**, Oct 2016 –
  - **Head of Communication Systems Group**, Oct 2018 –
- **Research Scientist** (part time) at Neural Propulsion Systems, Inc.
  A CA startup in autonomous sensing platforms, (www.nps.ai), 2018–

CS – Sweden's largest group in its field

8 Base-funded Faculty (BFF)

Professor (full)
Erik Ström
Head of CAOS
Vehicular Comms.
Channel estimation, synchronization, positioning, vehicular communication

Professor (full)
Erik Agrell
Optical Communications
Optical communications, modulation, coding, and information theory

Professor (full)
Thomas Eriksson
Hardware-Constrained Communications
Modeling and compensation of amplifiers, oscillators, and other hardware components

Professor (full)
Tommy Svensson
Wireless Systems
Coded modulation, medium access, resource allocation, cooperative communications, mm-wave/sub-THz communications, moving networks, satellite networks

Professor (full)
Henk Wymeersch
Cooperative Systems
Optical communications, radio localization and sensing

Professor
Fredrik Brännström
Head of ComSys
Vehicular Comms.
Coding and modulation, uncoordinated multiple access, vehicular communications

Professor (full)
Giuseppe Durisi
Fundamentals
Information theory applied to machine-type, massive MIMO and mm-wave comm.; Information-theoretic methods in machine learning

Professor (full)
Alexandre Graell i Amat
Distributed Information Systems
Coding theory with application to distributed computing, edge computing and caching, privacy, optical communications, and uncoordinated multiple access

Assistant Professor
Christian Häger
Data-Driven Comm. Systems
Deep learning for nonlinear equalization, physics-based machine learning, end-to-end autoencoder learning

2 Adjunct Prof, 1 Researcher, 12 Postdocs, and 21 PhD students

Students (today)

- 20 Information and Communication Technology (MPICT)
- 3 Embedded Electronic System Design (MPEES)
- 1 Biomedical Engineering (MPBME)
- 1 Sustainable Electric Power Engineering and Electromobility (MPEPO)
- 1 PhD student
- 3 unknown (extra courses)
- **29 students in total**

Course Literature and Information Resources

- Course Memo, 2023
- Course book: J. B. Anderson, *Digital Transmission Engineering*, 2nd ed., Wiley, 2005 (STORE or eBook for loan at Chalmers library)
- Supplementary literature will be posted on the course website
  - Comments on Digital Transmission Engineering
  - E. Ström, Notes on Signals and Systems
  - Formula Sheet
  - Introduction to Matlab slides
  - Project Memo
  - P. Mattisson, Working in Projects
  - Request for Proposal (RFP), Thu Sept. 7
  - Lecture slides, weekly
  - Exercises and homeworks, weekly
  - Old exams
  - A few selected articles
- Course website: www.canvas.chalmers.se/courses/25262
- Course staff (email)

Do you need a quick answer?

Take a look at www.wikipedia.org or see what www.google.com says.

Do you want to learn more?

- Proakis, Digital Communications.
- Ziemer and Tranter, Principles of Communications.
- Viterbi and Omura, Principles of Digital Communication and Coding.

Learning Outcomes (abbreviated)

After completion of this course, the student should be able to:

- Explain the purpose of each of the main blocks in the Shannon communication model
- Choose signal waveforms and receiver filters for digital transmission
- Synchronize the frame, symbol timing and phase of a received signal
- Describe the functions in some modern communication standards
- Derive and calculate the uncoded bit and symbol error rate, including bounds and approximations, for transmission over the additive white Gaussian noise channel (AWGN)
- Convert continuous-time signals to a discrete constellation using orthonormal basis (Gram-Schmidt procedure)
- Solve a complex task as a member of a project team, by planning and organizing subtasks, establishing roles and common values, reporting and delivering results and self-evaluating the process
- Characterize a typical development project in industry

Course Elements

- **Lectures**: maximum 14 sessions. Voluntary!
- **Computer exercises**: 3 sessions. Voluntary!
- **Tutorial exercises**: 5 sessions, including exam practice. Voluntary!
- **Homework exercises**: 4 homeworks that give extra points towards the final grade. Voluntary!
- **Project**: Continuous over course weeks 2–8. Mandatory!
- **Wrap-up workshop:** Wed. Oct. 18, 13:15–16:30, hosted by Ericsson. Voluntary but very nice!
- **Written examination**: Mon. Oct. 23, 14:00–18:00 Mandatory! (reexam Jan. 4 and Aug. 20, 2024).

Lectures Voluntary!

- The lectures cover the essentials but not the full course contents. Read the book!
- A combination of slides and whiteboard will be used.
- Lecture slides (like this) reflect the content of the lecture, but not the details.
- Are more intensive during weeks 1–4 to help the project preparation.
- Guest sessions provide the industrial view on project development and teamworking. Details in Course Memo.

Computer Exercises Voluntary!

- Mondays at 08:00 in the 3 coming weeks.
- MATLAB (that has to be used in the projects) will be introduced.
- MATLAB exercise to help the project development.
- Even experienced MATLAB users are welcome!
- Check out MATLAB tutorial and online training!

Exercises Voluntary!

- Tutorial Exercises in weeks 1, 3, 5, and 7:
  - Short theory review.
  - Solution of selected problems.
  - Take a look at the problems before the session.
- Homework Exercises in weeks 2, 4, 6, and 8:
  - Discussing the homework assignment.
  - 4 homeworks with 3 problems each (maximum 12 points).
  - Discussing homework assignments is allowed, but individual solutions are required!
- Last Tutorial Exercise in week 8: solving previous exam problems.
- The level of the problems is often, but not always, similar to the level of the exam's problems. Details in Course Memo.

SSY121: 2023

2023	Week 1 Mon 28/8	Week 1 Wed 30/8	Week 2 Mon 4/9	Week 2 Wed 6/9	Week 3 Mon 11/9	Week 3 Wed 13/9	Week 4 Mon 18/9	Week 4 Wed 20/9	Week 5 Mon 25/9	Week 5 Wed 27/9	Week 6 Mon 2/10	Week 6 Wed 4/10	Week 7 Mon 9/10	Week 7 Wed 11/10	Week 8 Mon 16/10	Week 8 Wed 18/10	Week 9 Mon 23/10
08:00-09:45			C1: AT E-studion		C2: AT E-studion		C3: AT E-studion										
10:00-11:45		L1: FB ED	L3: FB EE	L4: FB EA	L6: FB EE	L7: FB EE	L8: FB EE	L9: FB EE	L10: FB EE	L11: FB EE	L12: FB EE	L13: FB EE	E4: MF EC	L14: FB ED	H4: MF EE	E5: MF ED	
LUNCH																	
13:15-15:00		L2: FB ED		L5: ES ED		E2: MF ED		H2: MF ED		E3: MF ED		H3: AT ED				Ericsson	EXAM 14:00-18:00
15:15-17:00		E1: MF ED		H1: MF ED													
Project tasks:			Mon 12: Project reg Mon 18: Teams are formed Thu 12: Common Values Thu 12: RFP handed out Fri 12: Time report 1		Tue 18: Proposal Wed 15:30-18:30: Hearings Fri 12: Time report 2		Fri 12: Status report 1 Fri 12: Time report 3		Fri 12: Status report 2 Fri 12: Time report 4 Mon-Fri 17-21: 5225		Fri 12: Status report 3 Fri 12: Time report 5 Mon-Fri 17-21: 5225		Mon-Thu 17-21: 5225 Wed 10: Quiz Wed: 12-17: Demo sign up Fri 12: Project deadline Fri 12: Time report 6 Fri 17-20: Demo (5225)		Mon 12: Experience report Mon 17-20: Demo (5225) Tue 17-20: Demo (5225)		

Lecture | Guest Lecture | Computer Exercise | Excersise | Homework | Block A

Fredrik Brännström (FB), Erik Svenske (ES), Mohammad Farsi (MF), Azadeh Tabeshnezhad (AT)

Schedule

- A recommendation is to use all the grey slots for project, since you have no other courses in these slots.
- Computer lab (room 5225) booked on Mon–Fri between 17:00-21:00 during week 5, 6, and 7 (unsupervised).

Project Mandatory!

- **Summary**: Work in a complex project spanning the entire course.
- Technical contents:
  - Design a digital communication link.
  - Use of a real hardware channel.
  - Preparation of software for transmitter and receiver.
- Nontechnical contents:
  - Simulate an industrial development project.
  - Learn professional teamworking.
- **Examination**: Continuous over weeks 2–8.
- Parts: Customer approval 10 points + Teamworking 8 points + Deliverables 6 points + Quality 6 points + Individual Quiz 10 points = 40 points.
- MATLAB-based... Matlab introduction/training is recommended!
- Register in Canvas no later than noon Mon. Sept. 4.
- Answer Former Knowledge Survey no later than noon Mon. Sept. 4.
- Details in Course Memo, Project Memo, and Working in Projects

Wrap-up Workshop Voluntary but very nice!

- Hosted by Ericsson.
- Wed. Oct. 18, 13:15–16:30 (exact times coming later).
- Demo of selected project solutions.
- Reflections on the project experience.
- Comments by industry experts.
- Demo of modern telecom products.
- A great opportunity for asking questions to Ericsson managers!

Written Exam Mandatory!

- **Understanding** communication engineering is rewarded. The emphasis is not on memorizing facts or solving standard problems.
- Aim for understanding **during the course**. The earlier the preparation starts, the better.
- Chalmers' rules apply. See link in Course Memo.
- You may bring:
  - Chalmers-approved calculator.
- A formula sheet, included in Exercises and Exams, will be attached to the exam. Ask us if you want some additional formula to be included.
- The **solution** is more important than the **answer**:
  - A good solution with a minor error usually gives close to full points, even if the answer is incorrect.
  - An answer without a clear motivation usually gives 0 points, even if it is correct.

Passing Requirements and Grades

- Both the project and the written exam need to be passed.
- Project points P at least 20 (out of maximum 40).
- Exam points E at least 12 (out of maximum 48).
- Homework assignment points H (maximum 12).
- The final course grade $G = P + E + H$ is

$$\begin{aligned} 0 \leq & G < 40 \quad \text{FAIL} \\ 40 \leq & G < 60 \quad \text{grade 3} \\ 60 \leq & G < 80 \quad \text{grade 4} \\ 80 \leq & G \leq 100 \quad \text{grade 5} \end{aligned}$$

- Project points earned in 2023 are valid until after the second reexam in Aug. 2024.

Rules and Policies in This Course

- **Questions** are always very **welcome**
- Only **English** please!
- **Late arrivals** in the lectures or exercises are **not welcome**.
- **Active** participation in the classroom is highly appreciated.

Acknowledgment

- Some of these slides have been created and/or modified by Alex Alvarado, Erik Agrell, Erik Ström, Johan Lassing, and Patrik Bohlin. Their contribution is much appreciated.
- Thanks to **Ericsson** and **Ekan Management AB** for supporting this course in various ways!

Plagiarism

- All deliverables are submitted through the course website Canvas and are automatically checked for plagiarism.
- All deliverables, including text, figures, tables, MATLAB code, etc., must be authored by the student/team itself.
- Copying any material (from other teams, students, publications, the Internet, or elsewhere) is considered cheating and will result in disciplinary action.
- **Do not include any copied material** in your project deliverables. This will be reported as cheating!
- This applies to all courses at Chalmers!

Part II

Introduction to Digital Communication Systems

Brief Signals and Systems Review

The Fourier Transform $\mathcal{F}\{\cdot\}$

The Fourier Transform pair is defined as

$$X(f) = \mathcal{F}\{x(t)\} = \int_{-\infty}^{\infty} x(t)\mathrm{e}^{-\jmath 2\pi f t}\,dt \Longleftrightarrow x(t) = \int_{-\infty}^{\infty} X(f)\mathrm{e}^{\jmath 2\pi f t}\,df,$$

or alternatively,

$$X(\omega) = \int_{-\infty}^{\infty} x(t)\mathrm{e}^{-\jmath\omega t}\,dt \Longleftrightarrow x(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(\omega)\mathrm{e}^{\jmath\omega t}\,d\omega.$$

Properties

- Linearity, i.e., $\mathcal{F}\{ax_1(t) + bx_2(t)\} = aX_1(f) + bX_2(f)$
- Signal energy (using Parseval's theorem):

$$E = \int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-\infty}^{\infty} |X(f))|^2 df$$

- Convolution:

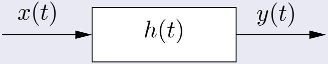
$$x_1(t) * x_2(t) = \int_{-\infty}^{\infty} x_1(\tau)x_2(t-\tau)d\tau$$

- Transform of a convolution:

$$\mathcal{F}\{x_1(t) * x_2(t)\} = X_1(f) \cdot X_2(f)$$

- If $x(t)$ is symmetric respect to zero, i.e., $x(-t) = x(t)$, its transform is real, $\mathcal{F}\{x(t)\} \in \mathbb{R}$

Linear and Time Invariant (LTI) System



- The impulse response of the LTI system is given by $h(t)$
- In the time domain, $y(t) = x(t) * h(t)$
- In the frequency domain, $Y(f) = X(f)H(f)$

The Sampling Theorem

Let $x(t)$ be a signal with Fourier transform $X(f)$ such that $x(t)$ is band-limited, i.e., $X(f) = 0$ for $|f| \geq B$. If the signal $x(t)$ is sampled at uniformly spaced time instants using a sampling frequency $f_\mathrm{s} = 1/T_\mathrm{s}$, $x(t)$ can be completely recovered if $f_\mathrm{s} \geq 2B$.

And how?

By interpolating, i.e.,

$$x(t) = \sum_{n=-\infty}^{\infty} x(nT_\mathrm{s}) \mathrm{sinc}\left(\frac{t - nT_\mathrm{s}}{T_\mathrm{s}}\right),$$

where $\mathrm{sinc}\,(x)$ is the normalized sinc function

$$\mathrm{sinc}\,(x) = \frac{\sin \pi x}{\pi x}.$$

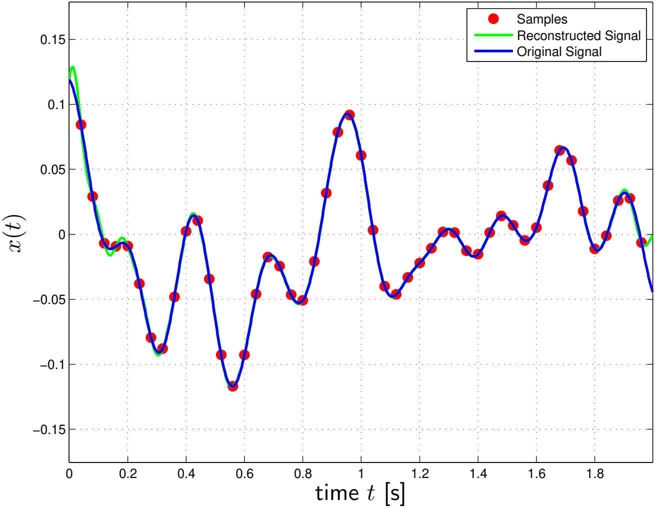


Figure: The band-limited signal $x(t)$ is reconstructed using samples. The BW of $x(t)$ is $B \approx 10$ Hz and $f_s = 25$ sample/s.

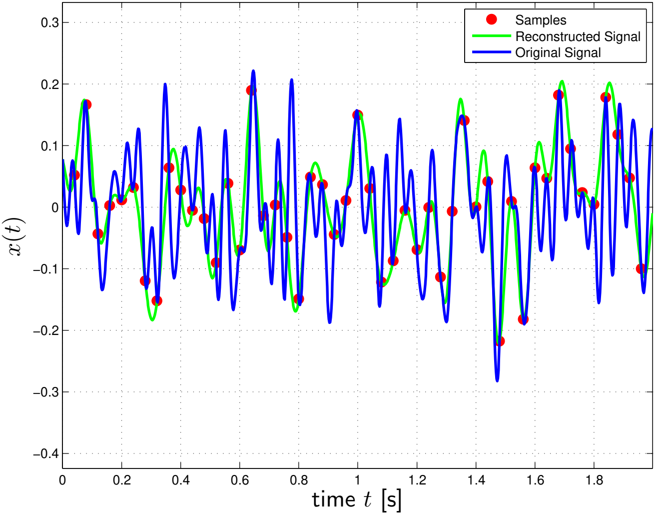


Figure: The band-limited signal $x(t)$ is reconstructed using samples. The BW of $x(t)$ is $B \approx 100$ Hz and $f_s = 25$ sample/s.

The Digital Communication System

System Modeling

1. We will look at models of communication systems
2. Simplification of reality in order to predict aspects of real world behavior
3. We will look at *digital* systems

Why digital?

1. Cheap hardware (due to the transistor)
2. Quality control (error rates, detection and correction)
3. Compatibility and flexibility (packeting, routing)
4. Efficient utilization of the resources (source coding)
5. Security can be easily implemented

Two Communication Models

1. Shannon's communication model
   - ~ 1948
   - Point-to-point communication
   - Application-specific
2. The Open System Interconnection (OSI) reference model
   - ~ 1977
   - Packet-switched networks
   - Shared between many types of traffic

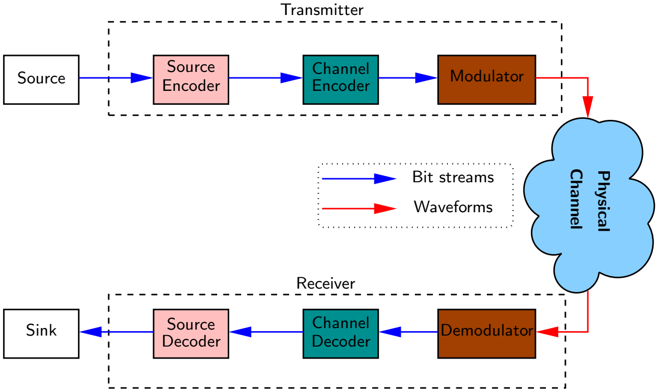


Figure: Shannon's communication model.

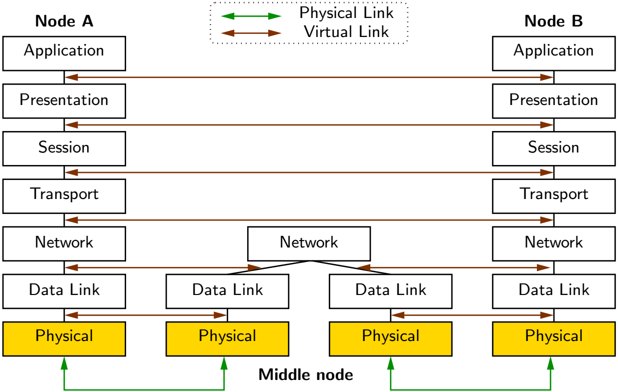
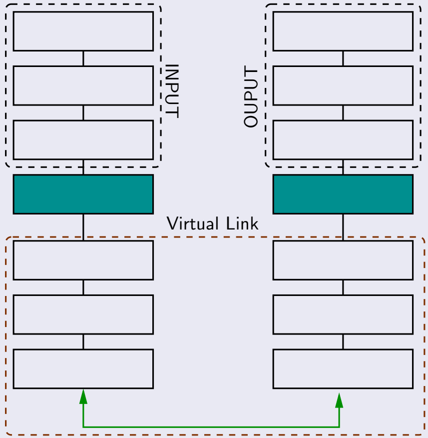


Figure: OSI Layered communication model.

Why layered?

- Modern systems are too complex
- Layers can be designed in parallel
- Layers can be tested separately
- Designers can specialize

The System

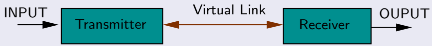


Designing the highlighted layer

- The upper interface tells us which service we should provide
- The lower interface offers us a service
- Upper/lower levels implementations become unimportant

The simplified version

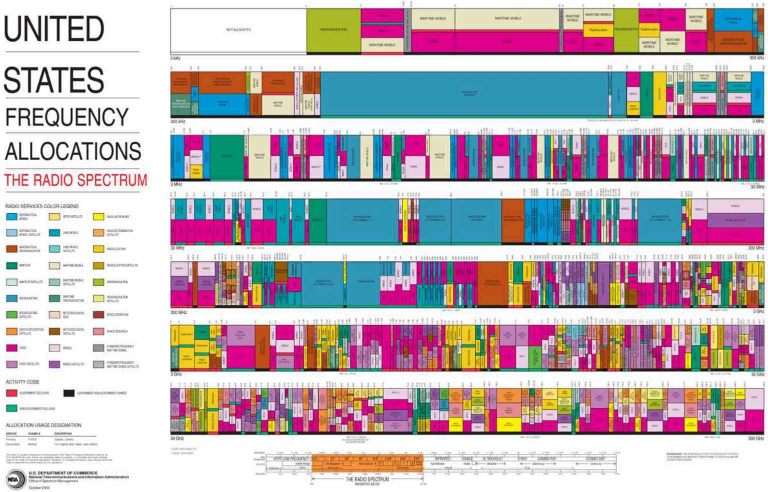
All the designer needs to know is the following model:



This will work well if and only if the interfaces and the other layers were properly defined.

Spectrum Regulation

- The electromagnetic spectrum is a very costly resource
- Spectrum regulation is needed to minimize interference and optimize the overall utilization of the radio spectrum
- Licensed bands are reserved for singular operators or functions
- Unlicensed bands may be used by anyone, but under strict conditions
- The global spectrum allocation is managed by the International Telecommunications Union (ITU)
- Each country has their own local administration, e.g.,
    - The Swedish Post and Telecommunications Agency (PTS)
    - The US Federal Communications Commission (FCC)
    - The Canadian Radio–Television and Telecommunications Commission (CRTC)
- Spectrum regulation is a slow process


UNITED
STATES
FREQUENCY
ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
ACTIVITY CODE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz
THE RADIO SPECTRUM

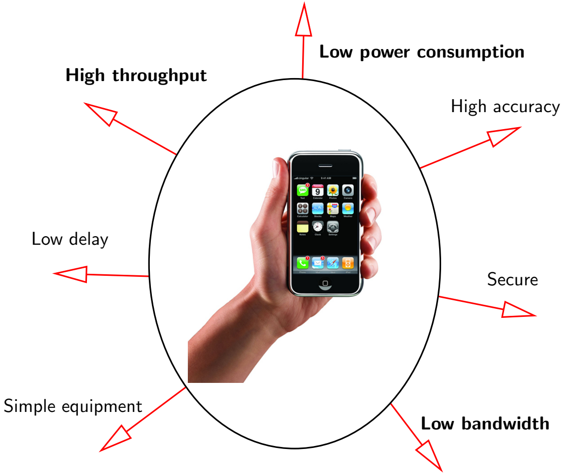


Figure: The designer's dilemma.

Constraints

The design is limited by

- Theoretical bounds
- Laws and regulations

Confused?

- Read the course memo
- Read the project memo
- Visit the course website
- Ask the course staff