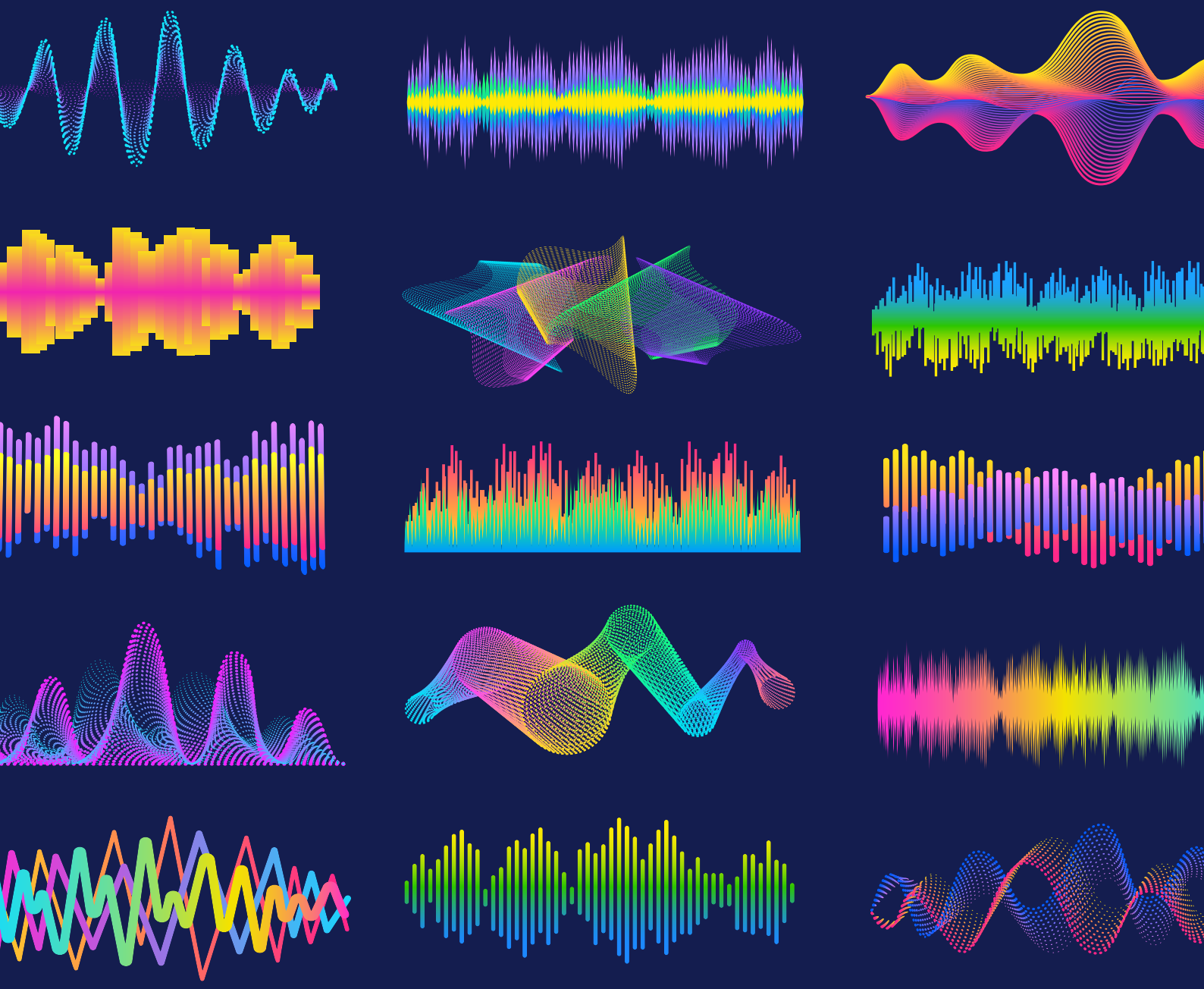
DTU Electrical Engineering
Department of Electrical Engineering
KAIST EE
전기 및 전자공학부

Portable Ultrasound System for Blood Velocity Estimation

Jeppe Hinrichs

Master Thesis



Portable Ultrasound System for Blood Velocity Estimation
Project Report

Master Thesis
April, 2023

Author:
Jeppe Hinrichs

Advisor(s):
Hyunjoo Lee, Associate Professor, School of Electrical Engineering, KAIST
Xenofon Fafoutis, Associate Professor, Department of Applied Mathematics and Computer Science, DTU
Tiberiu Gabriel Zsurzsan, Associate Professor, Department of Electrical Engineering, DTU

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Approval

This thesis has been prepared over six months at the Brain/Biomedical Microsystems Laboratory, School of Electrical Engineering, at the Korean Advanced Institute of Science and Technology, KAIST, and the Department of Electrical Engineering, Technical University of Denmark, DTU. This thesis is in partial fulfilment for the joint-degree Master of Science in Electrical Engineering, MSEE from KAIST and DTU.

It is assumed that the reader has a basic knowledge in the areas of electrical engineering and circuit analysis.

Jeppe Hinrichs - s163555

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Signature

.....

Date

Abstract

Abstract

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Resumé

Hej, her er noget tekst uden mening. Denne tekst skal vise, hvordan en trykt tekst vil se ud på dette sted. Hvis du læser denne tekst, får du ingen information. Virkelig? Er der ingen information? Er der forskel på denne tekst og noget nonsens som "Huardest gefburn"? Kjift – slet ikke! En blindtekst som denne giver dig information om den valgte skrifttype, hvordan bogstaverne er skrevet og et indtryk af udseendet. Denne tekst skal indeholde alle bogstaver i alfabetet, og den skal være skrevet på originalsproget. Der er ikke behov for særligt indhold, men længden af ord skal passe til sproget.

요 약

안녕하세요, 여기 의미 없는 문자가 있습니다. 이 텍스트는 이 플레이스에서 인쇄된 텍스트의 모양을 보여줘야 합니다. 이 텍스트를 읽으면 정보를 얻을 수 없습니다. 정말? 정보가 없나요? 이 텍스트와 "Huardest gefburn"과 같은 말도 안 되는 내용 사이에 차이가 있나요? Kjift – 전혀 그렇지 않습니다! 이와 같은 블라인드 텍스트는 선택한 글꼴, 글자의 작성 방법 및 모양에 대한 정보를 제공합니다. 이 텍스트는 알파벳의 모든 문자를 포함해야 하며 원래 언어로 작성되어야 합니다. 특별한 내용은 필요 없지만, 단어의 길이는 언어와 일치해야 합니다.

Contents

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Acronyms

Notation	Description
DC	Direct Current
DSP	Digital Signal Processor
MCU	Microcontroller Unit
MRI	Magnetic Resonance Imaging

Glossary

Notation	Description
LTspice	A freeware -based circuit simulator from Linear Technology/Analog Devices
MATLAB	Computing environment used for matrices, plotting and simulation interfacing

Nomenclature

Category	Name	Unit	Description
Preamplifier	V_{ref}	V	Reference voltage
	C_{hp}	F	High pass filter capacitor
	R_{hp}	Ω	High pass filter resistor
	f_{hp}	Hz	High pass cut-off frequency
	C_{lp}	F	Low pass filter capacitor
	R_{lp}	Ω	Low pass filter resistor
	f_{lp}	Hz	Low pass cut-off frequency
	A_v	1	Amplification factor
Modulator	R_1	Ω	AIM voltage divider resistor
	R_2	Ω	AIM voltage divider resistor
	R_{in}	Ω	AIM input resistor
	R_{fb}	Ω	AIM feedback resistor
	C_1	F	AIM capacitor
	V_{in}	V	Input signal voltage
	V_{span}	V	Voltage range of input signal
	V_{pwm}	V	PWM signal
	V_H	V	V_{pwm} high level voltage
	V_L	V	V_{pwm} low level voltage
	V_{out}	V	V_{pwm} voltage range $(V_H - V_L)$
	V_{hys}	V	Hysteresis voltage
	V_{hw}	V	Hysteresis width
	V_{th_H}	V	Hysteresis threshold upper voltage
	V_{th_L}	V	Hysteresis threshold lower voltage
	V_c	V	PWM carrier voltage
	V_{c_H}	V	PWM carrier upper voltage
	V_{c_L}	V	PWM carrier lower voltage
	f_{sw}	Hz	PWM signal frequency
	D	1	PWM signal duty cycle
	t_H	s	PWM carrier charge time
	t_L	s	PWM carrier discharge time
	τ	1	PWM carrier charge constant
	R_{th}	Ω	PWM carrier thevenin resistance
	f_{idle}	Hz	PWM signal idle switching frequency
	k_2	1	R_{fb}, R_{in} voltage divider
Gate driver	D_{dt}	1	Dead-time circuit diode
	R_{dt}	Ω	Dead-time circuit resistor
	C_{dt}	F	Dead-time circuit capacitor
	V_C	V	Dead-time circuit supply voltage
	V_s	V	IC supply voltage
	t_c	s	Charging circuit time
Power stage	V_{DD}	V	Power supply voltage
	Q_1, Q_2, Q_3, Q_4	1	Power stage switches

Category	Name	Unit	Description
	V_g	V	Gate driver signal
	V_o	V	Output voltage
	I_o	A	Output current
	R_{BTL}	Ω	Speaker equivalent load resistance
Output filter	R_f	Ω	Output filter single-ended load
	C_{BTL}	F	Output filter differential capacitance
	C_f	F	Output filter single-ended capacitance
	L_f	H	Output filter inductance
	ΔI_L	A	Output filter ripple current
	Q	1	Output filter quality factor
	f_c	Hz	Output filter cut-off frequency
	ω_n	$\mathrm{rad\,s^{-1}}$	Output filter natural frequency
	ζ	1	Output filter damping ratio
Shunt regulator	R_{sh}	Ω	Shunt current limiting resistor
	I_K	A	Shunt cathode current
	$I_{K_{\max}}$	A	Shunt maximum cathode current
	$I_{K_{\min}}$	A	Shunt minimum cathode current
	I_{su}	A	Shunt supply current
	R_{A1}	Ω	Shunt adjust resistor 1
	R_{A2}	Ω	Shunt adjust resistor 2
	C_L	F	Shunt load capacitance
	$V_{\mathrm{ref_{IC}}}$	V	Shunt internal reference voltage

Report structure

This section of the report will explain to the reader how to reference this document and explain the fundamental structure of the project as well as the report. Throughout the report, the reader will be assumed to be knowledgeable of basic circuit analysis and familiar with standard abbreviations typically used in electrical engineering. If not, readers can refer to the denotation section at the beginning of the report.

Please refer to Acronyms, Glossary, and Nomenclature pages for explanations to terms found within the report.

Furthermore, as a notation convention, large-signal Direct Current (DC) quantities are denoted by uppercase letters with uppercase subscripts. Small-signal quantities are denoted using lowercase letters with lowercase subscripts. Quantities composed of both large-signal and small-signal elements are denoted using lowercase letters and uppercase subscripts.

Sources

Calculus expressions present in the report will typically have a reference explaining their origin. All references are prominently displayed with square brackets and a number, directing to the appendix in the last section of the report.

Chapters

The report is divided into five chapters, where the first part is an introduction to the project. The second chapter will focus on explaining the theory of the topic of the project. The third chapter focuses on the synthesis of a circuit for experimental testing. The fourth chapter explains the production of the hardware. The fifth chapter will explain the testing methodology performed on the hardware. Finally, additional documentation of testing, code, circuit diagrams, and of laboratory setups can be found in the appendix.

1 Introduction

The progress of imaging internal organs has advanced significantly during the 20th century. Three major technologies used are X-ray, Magnetic Resonance Imaging (MRI), and ultrasound. Each of the technologies have distinct advantages and disadvantages in biomedical imaging, thus are still relevant for modern medicine. With x-rays, an important drawback is that patients are exposed to ionizing radiation [1], [3], [4], [6] [2], [5] A class-D audio amplifier is a typology of audio amplifiers that utilizes transistors as switches instead of gain devices as in other amplifier systems. As the transistors are operating non-linearly, the input signal is converted into a stream of pulses that resemble the input signal through a pulse-width modulation scheme. The time-averaged power of the modulated pulses is directly proportional to the input signal, so after amplification, the signal can be converted back into an analog signal through a passive low-pass filter. The purpose of this filter is to reduce high-frequency components in the amplified signal and thereby restore the audible spectrum frequency signal.

DC LTspice MATLAB MRI Digital Signal Processor (DSP)

1.1 Project scope

As this project deals with a synthesis of a peculiar design and an analytical examination of a class-D system, this initial design will determine the specific direction of the qualitative analysis. The project is focused on the output stage of the system. Therefore analysis will comprise of distinctive variations of parasitic element combinations in the chosen output filter topology.

1.1.1 Learning objectives

See below for an outline of the project activities

Project specification
Learn a class-D amplifier topology, calculate component values
Understand and design a self-oscillating modulator amplifier
Investigate and test open loop output filter
Investigate and test closed loop output filter
Investigate output filter parasitic elements affects control loop
Make quantifiable performance measurements on system
Write a technical report documenting the project work

Table 1.1: Project specification table

2 Colours

The design guide define 3 primary colours (dtured, white and black) and 10 secondary colours https://www.designguide.dtu.dk/#stnd-colours. Below are codes for the various colour modes. RGB is used for web and Office Programmes. CMYK is used for print. HTML is used for HTML-coding. If you know anything about colour codes you might notice that the RGB codes are ranging from 0-1 instead of the usual 0-255.

color	rgb	cmyk	HTML
dtured	0.77 0 0.05	0 0.91 0.72 0.23	C4000D
white	1 1 1	0 0 0 0	FFFFFF
black	0 0 0	0 0 0 1	000000
blue	0.12 0.24 1	0.88 0.76 0 0	1F3DFF
brightgreen	0.31 1 0.34	0.69 0 0.66 0	4FFF57
navyblue	0 0 0.4	1 0.9 0 0.6	000066
yellow	0.95 0.83 0.18	0.05 0.17 0.82 0	F2D42E
orange	1 0.35 0.14	0 0.65 0.86 0	FF5924
pink	1 0.65 0.74	0 0.35 0.26 0	FFA6BD
red	1 0.14 0.35	0 0.86 0.65 0	FF2459
green	0 0.78 0	0.89 0.05 1 0.17	00C700
purple	0.33 0.04 1	0.67 0.96 0 0	540AFF

The default colour mode for this template is cmyk. The current colour model is cmyk which is also illustrated by the underlined numbers in the colour test table above. If you which to change the colour model to rgb go to Setup/Settings.tex and change `targetcolourmodel` to rgb. In Setup/Settings.tex it is also possible to change the background colour of the front and back page. The colours are primarily used for diagrams (the plotcyclelist DTU) and the front and back page.

Lighter colours can be achieved as written in the LaTeX code below. For example to get a tint of 50% you would write colourname!50.

Normal dtured 80% dtured 70% dtured 60% dtured 50% dtured

For more information about colours in LaTeX read the `xcolor` manual. I want to use the MCU [7] for the MCU part of the project. Microcontroller Unit (MCU)

3 Examples of figures, tables, equations and listings

In the following a bunch of examples of figures and tables have been made. There are advantages to using `tikZ` diagrams over excel diagrams. 1) the font and font size perfectly matches the document 2) the styling and colours are pre-defined to follow the design guide 3) the plots uses vector graphics which reduces the file size, reduces the compile time and looks sharp when zooming in. The possibilities are endless, look at the `pgfplots` gallery for inspiration: http://pgfplots.sourceforge.net/gallery.html. However there are still cases where I would recommend to insert a plot as a picture. For example if the plot contains a lot of data: a line graph with 1000 points takes a long time to compile.

Some tips if you want good looking diagrams or graphs which will be inserted as pictures (e.g. in a figure environment with \includegraphics): The main font is Arial. Use DTU colours as described in chapter 2. Use high quality pictures. Try to scale the diagram (picture) so the text size of the axis legends match the text size in this document.

Remember to change the label of your figures so there are no duplicate labels. A label should be placed below a caption or after a heading (fx after a \chapter).

3.1 Graphs and charts

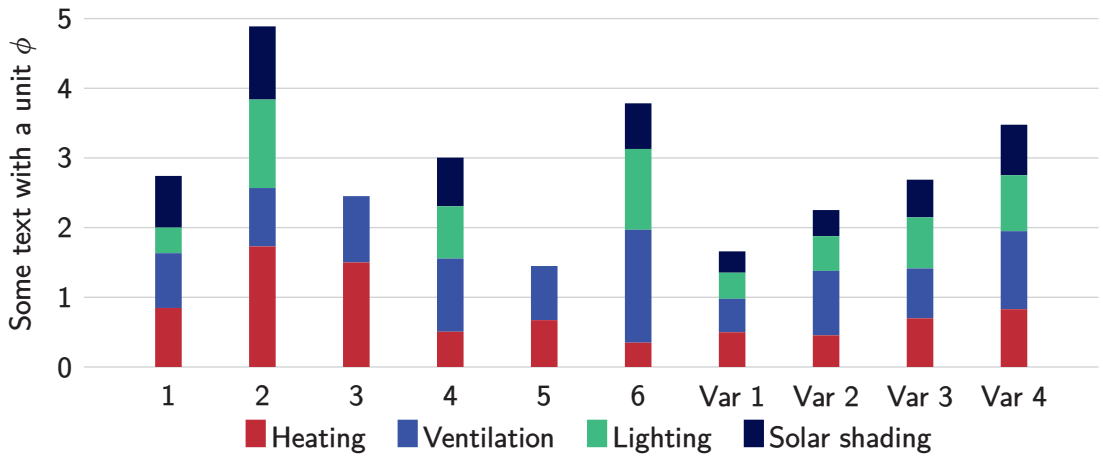

Figure 3.1: Stacked column chart

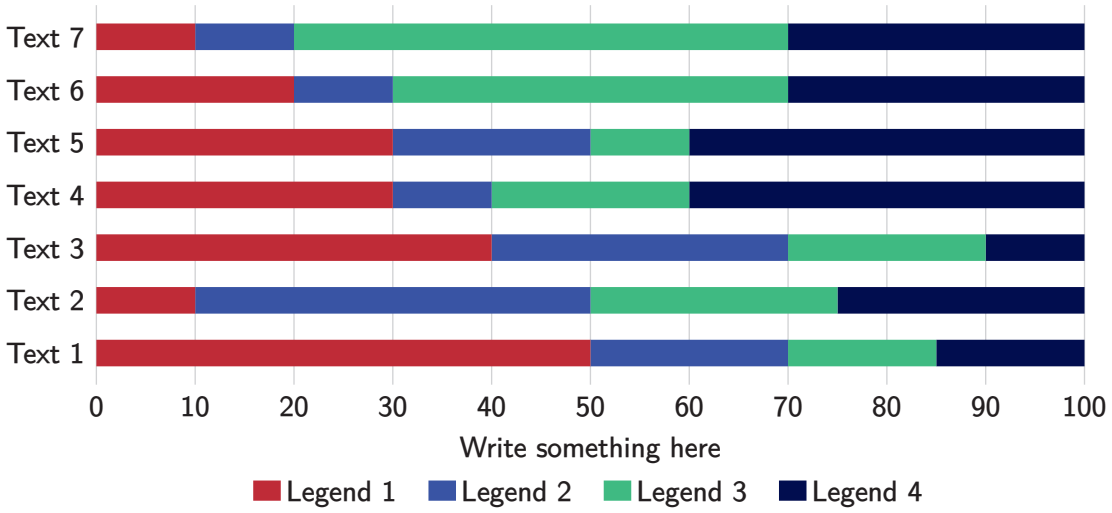

Figure 3.2: Stacked bar chart

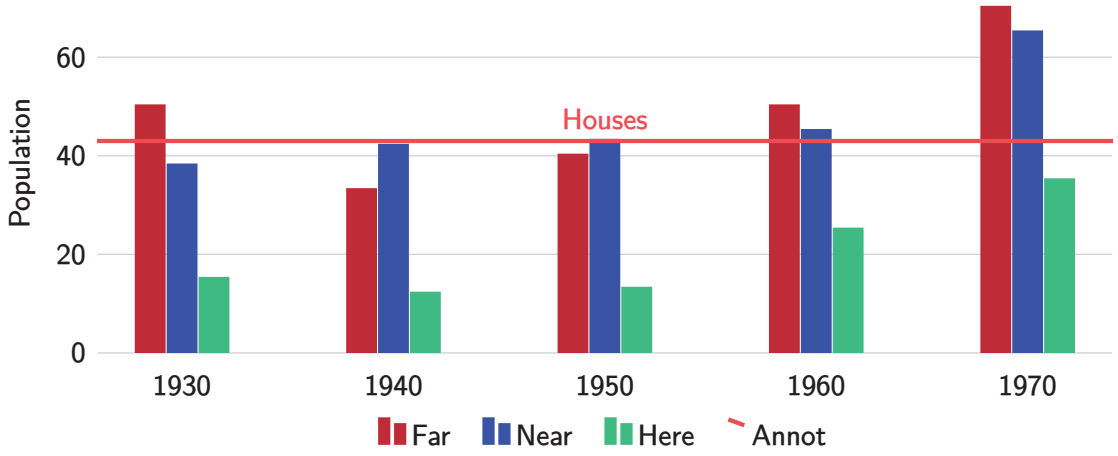

Figure 3.3: Grouped column chart

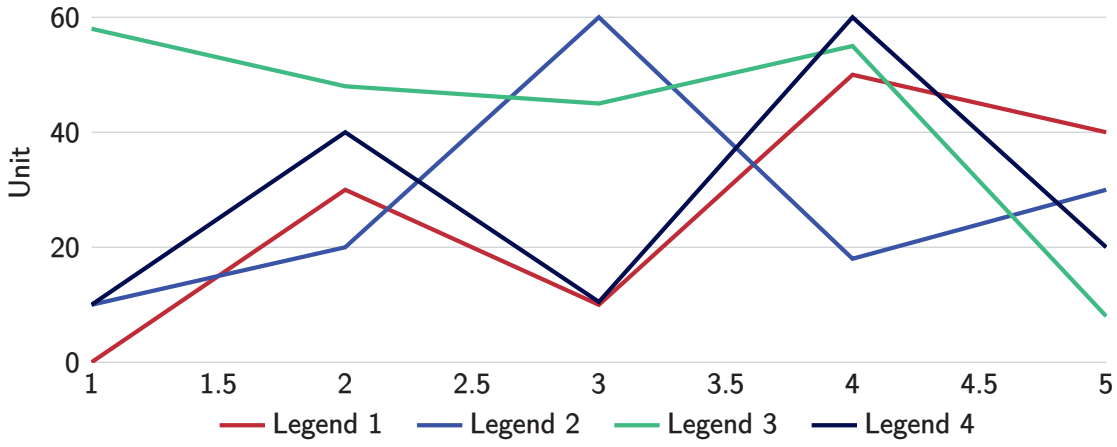

Figure 3.4: Line graph

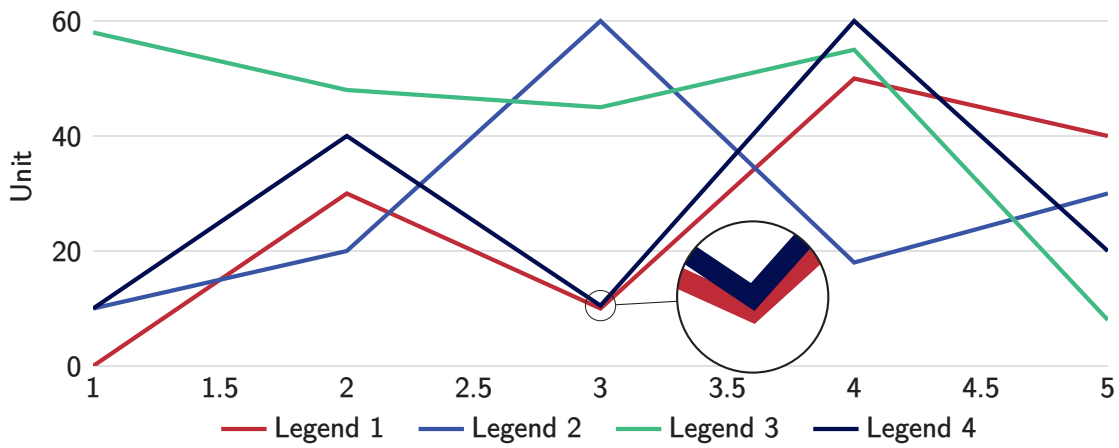

Figure 3.5: Line graph with magnifying glass

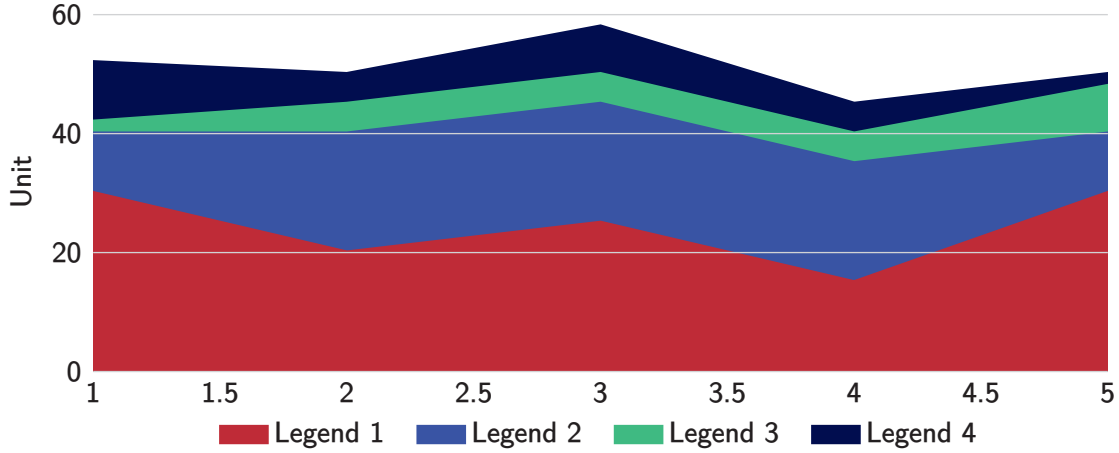

Figure 3.6: Area graph

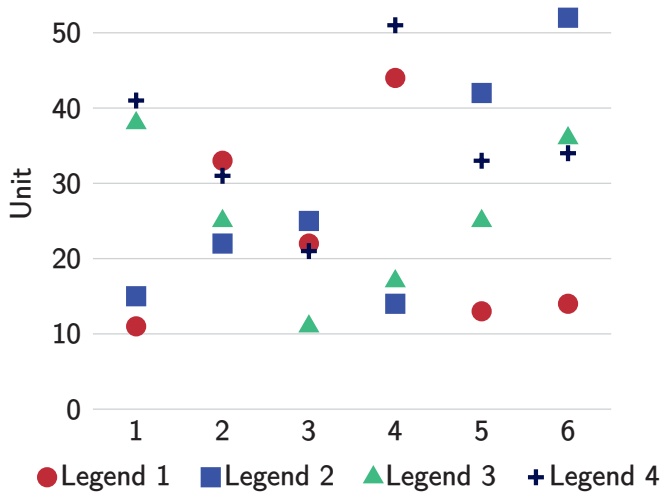

Figure 3.7: Scatter plot

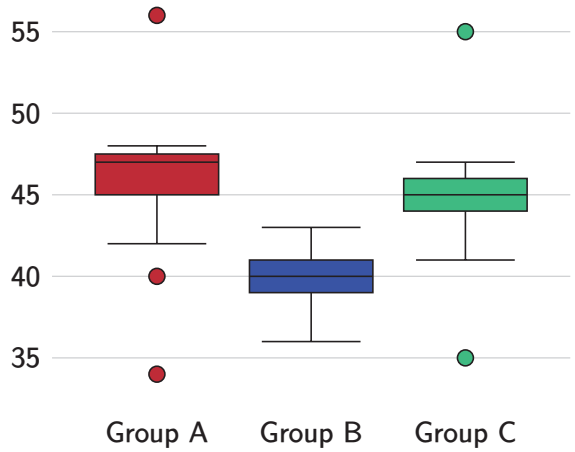

Figure 3.8: Boxplot

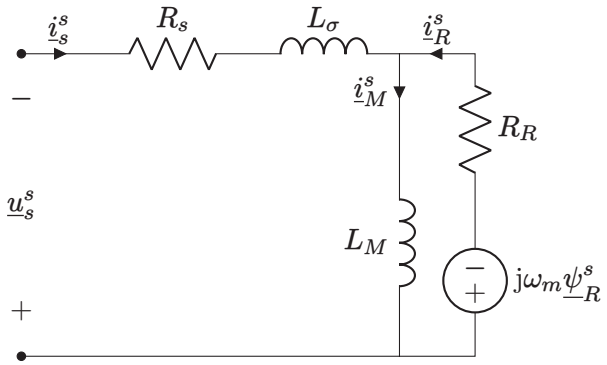

Figure 3.9: The nodes short, V, R and L are presented here, but there a lot more

3.2 Tables and figures

Table 3.1: This is a `booktabs` table

Animal	Description	Price ($)
Gnat	per gram	13.65
	each	0.01
Gnu	stuffed	92.50
Emu	stuffed	33.33
Armadillo	frozen	8.99

`Booktabs` tables don't use any vertical lines. Only horizontal lines are used. Table 3.1 begins with a `\toprule`, ends with a `\bottomrule` with `\midrule` in between. The table has 3 columns formatted as `@{}llS@{}`. `@{}` is cropping the horizontal lines of the table to fit the content (removes column spacing at the left and right edges). `l` aligns the column to the left and `S` aligns the column according to the decimal point (`siunitx` package). You can of course also use `r` to align right or `c` to center the contents of the column.

Table 3.2: Wrongly formatted table

	Voltage V	Current A	Power W
Transformer input	234.4	0.50	117.4
Transformer output	25.86	2.72	70.3
Efficiency			60%

Table 3.3: Correctly formatted table

	Voltage V	Current A	Power W
Transformer input	234.4	0.50	117.4
Transformer output	25.86	2.72	70.3
Efficiency			60 %

Table 3.2 and table 3.3 have the same comtents but there are some subtle differences in formatting which makes table 3.3 the superior table of the two. The most obvious change is removing the midrule between the transformer input and output rows. The efficency row is the odd man out and a midrule has been used to emphasise the difference between the transformer rows and the efficiency row. The delimiters in the voltage, current and power columns are aligned. The horizontal lines (rules) fits to the content and instead of protruding. The spacing between 60 and the percentage sign is correctly adjusted.

Figure 3.10: Just a normal figure

(a) A subfigure

(b) A subfigure

Figure 3.11: A figure with two subfigures

(a) A subfigure

(b) A subfigure

(c) A subfigure

(d) A subfigure

Figure 3.12: A figure with four subfigures

Referring to the figure as a whole fig. 3.12 or to an individual sub figure fig. 3.12a is done the normal way with `\cref{}` commands.

3.3 Equations

In-line math is easy. Anything surrounded by dollar signs becomes a math field. Here is an example: $f(x) = 2x - 1$. Also anything inside the "\begin{equation}" and "\end{equation}" environment is also a math field. Examples are shown below.

All equations use the default latex font. Some might say it looks weird with a serif font for equations and a sans-serif font for the body text. However, it is very unpractical to change the math font in latex which is the exactly the reason why this has not been done. One benefit of the serif style math font is the clear distinction between symbols (variables) and units.

On the subject of units, those are all taken care of by the `siunitx` package. Whenever there is a number followed by a unit one should write \SI{number}{unit}. Note this command is case sensitive. If a unit should follow a variable use the command \si{unit} (also case sensitive).

The ideal gas law is shown in eq. (3.1).

$$p \cdot V = n \cdot R \cdot T \tag{3.1}$$

$$\frac{\partial}{\partial t}\int_0^\delta U dy = -\delta\frac{1}{\rho}\frac{\partial P}{\partial x} - U_f(t)^2 \tag{3.2}$$

$$d_{step} = \sqrt{\frac{\delta}{\frac{dw}{dp_v}} \cdot t} = \sqrt{\frac{1.0 \times 10^{-11}\,\mathrm{kg/(m\,s\,Pa)}}{\frac{5.4\,\mathrm{kg/m^3}}{233.82\,\mathrm{Pa}}} \cdot 7200\,\mathrm{s}} = 0.001\,766\,\mathrm{m} = 1.766\,\mathrm{mm} \tag{3.3}$$

$$x = \mathrm{x}, \mathrm{x}, \mathrm{x}, x_{1_{2_{3_4}}}^{1^{2^{3^4}}} \cdot hello * \text{hello world} \cdot \text{equation without number}$$

Notice how the `aligned` environment can be used to align the equilibrium arrows in eq. (3.4). Only one equation number is generated using this method. Alternatively if you want an equation number for each line see eqs. (3.5) to (3.6).

$$\begin{aligned} CH_3COOH + OH^- &\rightleftharpoons CH_3COO^- + H_2O \\ H_2O &\rightleftharpoons H^+_{(aq)} + OH^-_{(aq)} \end{aligned} \tag{3.4}$$

$$f(x) = 1 + x - 3x^2 \tag{3.5}$$

$$g(x) + y = 3x - \frac{1}{2}x^3 \tag{3.6}$$

3.4 Listings (code)

Listing 3.1 is a nicely formatted block of code. A listing will automatically continue on the next page if it encounters a page break. Many different programming languages can be highlighted. Check the `listings` package documentation for a list of supported programming languages.

```
%% Monte Carlo simulation, estimation of pi
m=1E7;

x=rand(m,1);
y=rand(m,1);

g = x.^2+y.^2-1;

%dots outside
Pf = sum((g)<=0)/m

pi = 4*Pf
```

Listing 3.1: Monte Carlo simulation to estimate the value of π

Bibliography

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[7] *STM32F411xE High-performance access line, Arm Cortex-M4 core with DSP and FPU, 512 Kbytes of Flash memory, 100 MHz CPU, ART Accelerator*, December 2017. [Online]. Available: https://www.st.com/resource/en/datasheet/stm32f411re.pdf.

A Title

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DTU Electrical Engineering
Technical University
of Denmark

Ørsteds Plads, Building 348
2800 Kgs. Lyngby
Tel. (+45) 4525 3800

www.elektro.dtu.dk

KAIST EE
Korea Advanced Institute
of Science & Technology

E3-2, 291 대학로 유성구
34141 대전
Tel. (+82) 042-350-2114

www.ee.kaist.ac.kr