



Electrical, Electromagnetic, and Optical Characterization of the InP/InGaAs Alloy System

A Thesis
Presented to the Faculty of the
Department of Electronics and Communications Engineering
Gokongwei College of Engineering
De La Salle University

In Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Electronics and Communications Engineering

by
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September, 2018



De La Salle University

ORAL DEFENSE RECOMMENDATION SHEET

This thesis, entitled **Electrical, Electromagnetic, and Optical Characterization of the InP/InGaAs Alloy System**, prepared and submitted by :

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in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electronics and Communications Engineering (BS-ECE)** has been examined and is recommended for acceptance and approval for **ORAL DEFENSE**.

Dr. Francisco D. Baltasar
Adviser

September 24, 2018



ABSTRACT

Keep your abstract short by giving the gist/nutshell of your thesis. Use the following checklist questions to help you in crafting your abstract.

- ☐ Did you briefly state what you intend to do?
- ☐ Did you concisely discuss the problem statement?
- ☐ Did you tersely mention the objectives in general terms?
- ☐ Did you succinctly describe the methodology for the target audience?
- ☐ Did you strongly describe your significant results and your conclusions?

Index Terms—alloy system, characterization, InP, InGaAs.



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ABBREVIATIONS

AC	Alternating Current.....	58
HTML	Hyper-text Markup Language	58
CSS	Cascading Style Sheet	58
XML	eXtensible Markup Language	58



NOTATION

\mathcal{S}	a collection of distinct objects	60
\mathcal{U}	the set containing everything	60
\emptyset	the set with no elements	60
$ \mathcal{S} $	the number of elements in the set \mathcal{S}	60
$h(t)$	impulse response	50
$x(t)$	input signal represented in the time domain	50
$y(t)$	output signal represented in the time domain	50

Throughout this thesis, mathematical notations conform to ISO 80000-2 standard, e.g. variable names are printed in italics, the only exception being acronyms like e.g. SNR, which are printed in regular font. Constants are also set in regular font like j . Functions are also set in regular font, e.g. in $\sin(\cdot)$. Commonly used notations are t , f , $j = \sqrt{-1}$, n and $\exp(\cdot)$, which refer to the time variable, frequency variable, imaginary unit, n th variable, and exponential function, respectively.



GLOSSARY

matrix

a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements

Functional Analysis

the branch of Mathematics concerned with the study of spaces of functions



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Chapter 1

INTRODUCTION

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1.1 Background of the Study

Aside from the usual text descriptions of the background, put here figures that will cast images to your audience about the context of your work.

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1.2 Prior Studies

Put here a summary of your literature review. Preferably, a table showing the summary would be helpful.

Prior Studies or Literature Review (expansion of the Prior Studies) is basically about competition. Competition.

So the goals are:

1. to mention briefly the problem;
2. to show the features of the existing literature in solving the problem
3. to show the weakness of the solutions of existing literature
4. to show how your solution is better (can be better (for proposals))

For the table that is placed here, please discuss it in light of the above-mentioned goals. The main difference between the Prior Studies and Literature Review is that the Prior Studies is done in a concise manner.

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1.3 Problem Statement

The problem statement needs to be very clear and to the point.

A persuasive problem statement from a contextualized and intended-audience-awareness perspective consists of:

1. PS1: description of the ideal scenario for your intended audience
 - Describe the goals, desired state, or the values that your audience considers important and that are relevant to the problem.
2. PS2: reality of the situation
 - Describe a condition that prevents the goal, state, or value discussed in PS1 from being achieved or realized at the present time.
 - It is imperative to make the audience feel the pain point.
3. PS3: consequences for the audience
 - Using specific details, show how the situation contains little promise of improvement unless something is done.

After the above-mentioned items, succinctly describe your approach/solution ("approach" for proposal theses; "solution" for "final" theses). You must be terse here because your



approach/solution is like a seed/kernel in terms of its description here, which you expand more through your objectives, and it grows larger in your description and methodology, and its full explanation in the Methodology chapter.

A well constructed problem statement will convince your audience that the problem is real and worth having you solve it.

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1.4 Objectives

Your objectives are the states that you desire to achieve in solving the problem. The general objective is the main state to be achieved whereas the specific ones are sub-states to be achieved.

1.4.1 General Objective(s)

To ...;



1.4.2 Specific Objectives

1. To ...;
2. To ...;
3. To ...;
4. To ...;
5. To ...;

1.5 Significance of the Study

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1.6 Assumptions, Scope and Delimitations

Bulletize your assumptions in one group, and then bulletize the scope in another, and do the same for your delimitations.



1.6.1 Assumptions

1. ...;
2. ...;
3. ...;

1.6.2 Scope

1. ...;
2. ...;
3. ...;

1.6.3 Delimitations

1. ...;
2. ...;
3. ...;

1.7 Description and Methodology

A purpose of the description here is to re-steer/remind the panelist/reader again by tersely describing what your thesis is about (i.e. its problem and the main goal you want to achieve). Your methodology is your means of achieving your stated objectives.

Note that each stated objective should have a corresponding methodology.



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1.8 Estimated Work Schedule and Budget

Gantt chart or project network diagram is to be part of this section.

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1.9 Overview

Provide here a brief summary and what the reader should expect from each succeeding chapter. Show how each chapter is connected with each other.



Chapter 2

LITERATURE REVIEW

Contents

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2.2	Lacking in the Approaches	14
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2.1 Existing Work

Cite and summarize here relevant and significant literature (dissertations, theses, journals, patents, notable conference papers) through a table and descriptions to prove that no one has done your work yet. Your focus here is what has been done.

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2.2 Lacking in the Approaches

You can summarize the weaknesses of existing approaches by a tabular comparison of the literature. Your focus here is what has not been done, and/or what features were missed, and then introduce the necessity for doing your proposed solution.

Briefly include here the following in order to remind the reader why you are highlighting the weakness of the solutions of existing literature.

- mentioning of the problem
- showing how your solution is better (can be better (for proposals))

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2.3 Summary



Chapter 3

THEORETICAL CONSIDERATIONS

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Before starting the first section, provide an overview of the purpose of this chapter and its contents, and how they are relevant to your methodology.

This chapter is for providing the context to your panelist/reader. It is actually an expanded form of the Background of the Study that you have put in Chapter 1.

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Fig. 3.1 A quadrilateral image example.

3.1 Summary



Chapter 4

DESIGN CONSIDERATIONS

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Before starting the first section, provide an overview of the purpose of this chapter and its contents, and how they are relevant to your methodology.

Your primary goal in the Design Considerations is to describe to your panelist/readers the key topics that fall under Theoretical Considerations. These key topics are those that you have directly adopted in making your solution/methodology.

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4.1 Summary



Chapter 5

METHODOLOGY

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5.2	Evaluation	28
5.3	Summary	30



Mention here your methodology flow through a figure (preferably) and provide an overview of it and how your methodology achieves your objectives. How your methodology achieves each of your specific objective is what your panelists/examiners will be looking for. Also make sure that you refer clearly to the chapters on the Literature Review, Theoretical Considerations, and Design Considerations showing how your methodology ties with those that you have discussed in those chapters.

5.1 Implementation

Summarize the process used to create/set-up the work with an explanation of such process, instruments, and materials that you used if any. If the description is lengthy, use condensed bullet points.

Rule of thumb: Implementation is how you made your work; (keywords: implemented, created, made, soldered, programmed, etc.).

If you wrote a program or made a simulation, you must state how the program or simulation functions in this section. An algorithm or a pseudocode as shown in Table B.2 is a good example.

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5.2 Evaluation

Describe the procedures for evaluating the correct behavior and outcome of your work, including what information you need to gather and how you will obtain or measure it.

Rule of thumb: Evaluation is how you tested your work; (keywords: measured, tested, compared, simulated, etc.).

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5.3 Summary



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De La Salle University

Appendix A
ANSWERS TO QUESTIONS TO THIS
THESIS



How important is the problem to practice?

A possible answer to this question is the summary of your Significance of the Study, and that portion of the Problem Statement where you describe the ideal scenario for your intended audience.

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How will you know if the solution/s that you will achieve would be better than existing ones?

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How will you measure the improvement/s?

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What is/are your basis/bases for the improvement/s?

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Why did you choose that/those basis/bases?

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How significant are your measure/s of the improvement/s?

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What is the difference of the solution/s from existing ones?

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How is it different from previous and existing ones?

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What are the assumptions made (that are behind for your proposed solution to work)?

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Will your proposed solution/s be sensitive to these assumptions?

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Can your proposed solution/s be applied to more general cases when some of the assumptions are eliminated? If so, how?

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What is the necessity of your approach / proposed solution/s?

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**What will be the limits of applicability of your proposed solution/s?**

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What will be the message of the proposed solution to technical people? How about to non-technical managers and business men?

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How will you know if your proposed solution/s is/are correct?

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Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

Will your results warrant the level of mathematics used (i.e., will the end justify the means)?

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Is/are there an/_ alternative way/s to get to the same solution/s?

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Can you come up with illustrating examples, or even better, counter examples to your proposed solution/s?

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a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

Is there an approximation that can arrive at the essentially the same proposed solution/s more easily?

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If you were the examiner of your Thesis, how would you present the Thesis in another way? Give your remarks, especially for your methodology and the results and discussions.

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What are the weaknesses of your Thesis, specifically your methodology and the results and discussions?

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Appendix B

USAGE EXAMPLES



The user is expected to have a working knowledge of \LaTeX . A good introduction is in [4]. Its latest version can be accessed at <http://www.ctan.org/tex-archive/info/lshort>.

Equations

The following examples show how to typeset equations in \LaTeX . This section also shows examples of the use of `\gls{ }` commands in conjunction with the items that are in the `notation.tex` file. **Please make sure that the entries in `notation.tex` are those that are referenced in the \LaTeX document files used by this Thesis. Please comment out unused notations and be careful with the commas and brackets in `notation.tex`.**

In (B.1), the output signal $y(t)$ is the result of the convolution of the input signal $x(t)$ and the impulse response $h(t)$.

$$y(t) = h(t) * x(t) = \int_{-\infty}^{+\infty} h(t - \tau) x(\tau) d\tau \quad (\text{B.1})$$

Other example equations are as follows.

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (\text{B.2})$$

$$\frac{1}{2} < \left[\text{mod} \left(\left\lfloor \frac{y}{17} \right\rfloor 2^{-17\lfloor x \rfloor - \text{mod}(\lfloor y \rfloor, 17)}, 2 \right) \right], \quad (\text{B.3})$$

$$|\zeta(x)^3 \zeta(x + iy)^4 \zeta(x + 2iy)| = \exp \sum_{n,p} \frac{3 + 4 \cos(ny \log p) + \cos(2ny \log p)}{np^{nx}} \geq 1 \quad (\text{B.4})$$



The verbatim L^AT_EX code of Sec. B is in List. B.1.

Listing B.1: Sample L^AT_EX code for equations and notations usage

```

1 The following examples show how to typeset equations in \LaTeX. This
  section also shows examples of the use of \verb| \gls{ } | commands
  in conjunction with the items that are in the \verb| notation.tex |
  file. \textbf{Please make sure that the entries in} \verb| notation.
  tex ||\textbf{ are those that are referenced in the \LaTeX \
  document files used by this \documentType. Please comment out
  unused notations and be careful with the commas and brackets in} \
  verb| notation.tex |.
2
3 In~\eqref{eq:conv}, the output signal \gls{not:output_sigt} is the
  result of the convolution of the input signal \gls{not:input_sigt}
  and the impulse response \gls{not:ir}.
4
5 \begin{eqnarray}
6   y\left( t \right) = h\left( t \right) * x\left( t \right)=\int_{-\infty}^{+\infty}h\left( t-\tau \right)x\left( \tau \right) \, \mathrm{d}\tau
7   \label{eq:conv}
8 \end{eqnarray}
9
10 Other example equations are as follows.
11
12 \begin{eqnarray}
13   \left[ \, \dfrac{V_{1}}{I_{1}} \, \right] =
14   \begin{bmatrix}
15     A & B \\
16     C & D
17   \end{bmatrix}
18   \left[ \, \dfrac{V_{2}}{I_{2}} \, \right]
19   \label{eq:ABCD}
20 \end{eqnarray}
21
22 \begin{eqnarray}
23   \dfrac{1}{2} < \left\lfloor \mathrm{mod} \left( \left\lfloor \dfrac{y}{17} \right\rfloor 2^{-17} \lfloor x \rfloor - \mathrm{mod}(\lfloor y \rfloor, 17) \right) \right\rfloor, 2 \right) \right\rfloor,
24 \end{eqnarray}
25
26 \begin{eqnarray}
27   | \, \zeta(x)^3 \, \zeta(x + iy)^4 \, \zeta(x + 2iy) \, | =
28   \exp{\sum_{n,p} \frac{3 + 4 \cos( ny \log p) + \cos( 2ny \log p)}{np^{nx}}} \, \ge 1
29 \end{eqnarray}

```



Notations

In order to use the standardized notation, the user is highly suggested to see the ISO 80000-2 standard [5].

See https://en.wikipedia.org/wiki/Help:Displaying_a_formula and https://en.wikipedia.org/wiki/List_of_mathematical_symbols for L^AT_EX maths and other notations, respectively.

The following were taken from `isomath-test.tex`.

Math alphabets

If there are other symbols in place of Greek letters in a math alphabet, it uses T1 or OT1 font encoding instead of OML.

<code>mathnormal</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathit</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathrm</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathbf</code>	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \mathbf{f}, \mathbf{f}, \mathbf{\beta}, ^\circ, !, v, w, 0, 1, 9$
<code>mathsf</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathtt</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \uparrow, \downarrow, \beta, ^\circ, !, v, w, 0, 1, 9$

New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.

<code>mathbfit</code>	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathsf</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathsfbit</code>	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$

Do the math alphabets match?

$\alpha x \alpha \omega \mathbf{a} x \alpha \omega \mathbf{a} x \alpha \omega \quad T C \Theta \Gamma T C \Theta \Gamma T C \Theta \Gamma$

Vector symbols

Alphabetic symbols for vectors are boldface italic, $\lambda = e_1 \cdot \mathbf{a}$, while numeric ones (e.g. the zero vector) are bold upright, $\mathbf{a} + \mathbf{0} = \mathbf{a}$.

Matrix symbols

Symbols for matrices are boldface italic, too:¹ $\mathbf{A} = \mathbf{E} \cdot \mathbf{A}$.

¹However, matrix symbols are usually capital letters whereas vectors are small ones. Exceptions are physical quantities like the force vector \mathbf{F} or the electrical field \mathbf{E} .

**Tensor symbols**

Symbols for tensors are sans-serif bold italic,

$$\boldsymbol{\alpha} = \boldsymbol{e} \cdot \boldsymbol{a} \quad \Longleftrightarrow \quad \alpha_{ijl} = e_{ijk} \cdot a_{kl}.$$

The permittivity tensor describes the coupling of electric field and displacement:

$$\boldsymbol{D} = \epsilon_0 \boldsymbol{\epsilon}_r \boldsymbol{E}$$



Bold math version

The “bold” math version is selected with the commands `\boldmath` or `\mathversion{bold}`

<code>mathnormal</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathit</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \mathfrak{B}, \mathfrak{^}, \mathfrak{!}, v, w, 0, 1, 9$
<code>mathrm</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \mathfrak{B}, \mathfrak{^}, \mathfrak{!}, v, w, 0, 1, 9$
<code>mathbf</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \mathfrak{B}, \mathfrak{^}, \mathfrak{!}, v, w, 0, 1, 9$
<code>mathsf</code>	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \mathbf{\mathfrak{f}}, \mathbf{\mathfrak{f}}, \mathbf{\mathfrak{B}}, \mathbf{\mathfrak{^}}, \mathbf{\mathfrak{!}}, \mathbf{v}, \mathbf{w}, \mathbf{0}, \mathbf{1}, \mathbf{9}$
<code>mathtt</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \uparrow, \downarrow, \mathfrak{B}, \mathfrak{^}, \mathfrak{!}, v, w, 0, 1, 9$

New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.

<code>mathbfi</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathsfi</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathsfbfi</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$

Do the math alphabets match?

$\alpha x \alpha \omega a x \alpha \omega a x \alpha \omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma$

Vector symbols

Alphabetic symbols for vectors are boldface italic, $\lambda = e_1 \cdot a$, while numeric ones (e.g. the zero vector) are bold upright, $a + 0 = a$.

Matrix symbols

Symbols for matrices are boldface italic, too:² $\Lambda = E \cdot A$.

Tensor symbols

Symbols for tensors are sans-serif bold italic,

$$\alpha = e \cdot a \iff \alpha_{ijl} = e_{ijk} \cdot a_{kl}.$$

The permittivity tensor describes the coupling of electric field and displacement:

$$D = \epsilon_0 \epsilon_r E$$

²However, matrix symbols are usually capital letters whereas vectors are small ones. Exceptions are physical quantities like the force vector F or the electrical field E .



The verbatim L^AT_EX code of Sec. B is in List. B.2.

Listing B.2: Sample L^AT_EX code for notations usage

```

1  % A teststring with Latin and Greek letters::
2  \newcommand{\teststring}{%
3  % capital Latin letters
4  % A,B,C,
5  A,B,
6  % capital Greek letters
7  %\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
8  \Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Phi,\Psi,\Omega,
9  % small Greek letters
10 \alpha,\beta,\pi,\nu,\omega,
11 % small Latin letters:
12 % compare \nu, \omega, v, and w
13 v,w,
14 % digits
15 0,1,9
16 }
17
18
19 \subsection*{Math alphabets}
20
21 If there are other symbols in place of Greek letters in a math
22 alphabet, it uses T1 or OT1 font encoding instead of OML.
23
24 \begin{eqnarray*}
25 \mbox{\mathnormal} & & \mbox{\teststring} \\
26 \mathit & & \mathit{\teststring} \\
27 \mathrm & & \mathrm{\teststring} \\
28 \mathbf & & \mathbf{\teststring} \\
29 \mathsf & & \mathsf{\teststring} \\
30 \mathtt & & \mathtt{\teststring}
31 \end{eqnarray*}
32 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
33 italic.
34 \begin{eqnarray*}
35 \mathbf\it & & \mathbf\it{\teststring} \\
36 \mathsf\it & & \mathsf\it{\teststring} \\
37 \mathsf\bf\it & & \mathsf\bf\it{\teststring}
38 \end{eqnarray*}
39 %
40 Do the math alphabets match?
41 $
42 \mathnormal {a x \alpha \omega}
43 \mathbf\it {a x \alpha \omega}
44 \mathsf\bf\it {a x \alpha \omega}
45 \quad
46 \mathsf\bf\it {T C \Theta \Gamma}
47 \mathbf\it {T C \Theta \Gamma}
48 \mathnormal {T C \Theta \Gamma}
49 $
50
51 \subsection*{Vector symbols}
52

```



```

53 Alphabetic symbols for vectors are boldface italic,
54  $\vec{\lambda} = \vec{e}_1 \cdot \vec{a}$ ,
55 while numeric ones (e.g. the zero vector) are bold upright,
56  $\vec{a} + \vec{0} = \vec{a}$ .
57
58 \subsection*{Matrix symbols}
59
60 Symbols for matrices are boldface italic, too:%
61 \footnote{However, matrix symbols are usually capital letters whereas
    vectors
62 are small ones. Exceptions are physical quantities like the force
63 vector  $\vec{F}$  or the electrical field  $\vec{E}$ .%
64 }
65  $\Lambda = E \cdot A$ .
66
67
68 \subsection*{Tensor symbols}
69
70 Symbols for tensors are sans-serif bold italic,
71
72 \[
73   \text{\tensorsym{\alpha}} = \text{\tensorsym{e}} \cdot \text{\tensorsym{a}}
74   \quad \Longleftrightarrow \quad
75   \alpha_{ijl} = e_{ijk} \cdot a_{kl}.
76 \]
77
78
79 The permittivity tensor describes the coupling of electric field and
80 displacement: \[
81 \vec{D} = \epsilon_0 \text{\tensorsym{\epsilon}}_{\text{\mathrm{r}}} \vec{E} \]
82
83
84
85 \newpage
86 \subsection*{Bold math version}
87
88 The ‘‘bold’’ math version is selected with the commands
89 \verb+\boldmath+ or \verb+\mathversion{bold}+
90
91 {\boldmath
92   \begin{eqnarray*}
93     \mbox{\mathnormal} & & \text{\teststring} \\
94     \mbox{\mathit} & & \text{\mathit{\teststring}} \\
95     \mbox{\mathrm} & & \text{\mathrm{\teststring}} \\
96     \mbox{\mathbf} & & \text{\mathbf{\teststring}} \\
97     \mbox{\mathsf} & & \text{\mathsf{\teststring}} \\
98     \mbox{\mathtt} & & \text{\mathtt{\teststring}}
99   \end{eqnarray*}
100   New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
    italic.
101   \begin{eqnarray*}
102     \mbox{\mathbfit} & & \text{\mathbfit{\teststring}} \\
103     \mbox{\mathsfit} & & \text{\mathsfit{\teststring}} \\
104     \mbox{\mathsfbfit} & & \text{\mathsfbfit{\teststring}}
105   \end{eqnarray*}
106   %
107   Do the math alphabets match?

```



```

108 $
109 \mathnormal {a x \alpha \omega}
110 \mathbf{fit} {a x \alpha \omega}
111 \mathsf{fbfit}{a x \alpha \omega}
112 \quad
113 \mathsf{fbfit}{T C \Theta \Gamma}
114 \mathbf{fit} {T C \Theta \Gamma}
115 \mathnormal {T C \Theta \Gamma}
116 $
117
118 \subsection*{Vector symbols}
119
120
121 Alphabetic symbols for vectors are boldface italic,
122 $\vec{\lambda}=\vec{e}_1\cdot\vec{a}$,
123 while numeric ones (e.g. the zero vector) are bold upright,
124 $\vec{a} + \vec{0} = \vec{a}$.
125
126
127
128
129 \subsection*{Matrix symbols}
130
131 Symbols for matrices are boldface italic, too:%
132 \footnote{However, matrix symbols are usually capital letters whereas
133 vectors
134 are small ones. Exceptions are physical quantities like the force
135 vector $\vec{F}$ or the electrical field $\vec{E}$.%
136 }
137 $\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}$.
138
139 \subsection*{Tensor symbols}
140
141 Symbols for tensors are sans-serif bold italic,
142
143 \[
144 \quad \matrixsym{\alpha} = \matrixsym{e}\cdot\matrixsym{a}
145 \quad \Longleftrightarrow \quad
146 \quad \alpha_{ijl} = e_{ijk}\cdot a_{kl}.
147 \]
148
149 The permittivity tensor describes the coupling of electric field and
150 displacement: \[
151 \quad \vec{D}=\epsilon_0\matrixsym{\epsilon}_{\mathrm{r}}\vec{E}\]
152 }

```



Abbreviation

This section shows examples of the use of \LaTeX commands in conjunction with the items that are in the `abbreviation.tex` and in the `glossary.tex` files. Please see List. B.3. **To lessen the \LaTeX compilation time, it is suggested that you use `\acr{ }` only for the first occurrence of the word to be abbreviated.**

Again please see List. B.3. Here is an example of first use: alternating current (ac). Next use: ac. Full: alternating current (ac). Here's an acronym referenced using `\acr` : hyper-text markup language (html). And here it is again: html. If you are used to the `glossaries` package, note the difference in using `\gls` : hyper-text markup language (html). And again (no difference): hyper-text markup language (html). Here are some more entries:

- extensible markup language (xml) and cascading style sheet (css).
- Next use: xml and css.
- Full form: extensible markup language (xml) and cascading style sheet (css).
- Reset again.
- Start with a capital. Hyper-text markup language (html).
- Next: Html. Full: Hyper-text markup language (html).
- Prefer capitals? Extensible markup language (XML). Next: XML. Full: extensible markup language (XML).
- Prefer small-caps? Cascading style sheet (CSS). Next: CSS. Full: cascading style sheet (CSS).
- Resetting all acronyms.
- Here are the acronyms again:
- Hyper-text markup language (HTML), extensible markup language (XML) and cascading style sheet (CSS).
- Next use: HTML, XML and CSS.
- Full form: Hyper-text markup language (HTML), extensible markup language (XML) and cascading style sheet (CSS).



- Provide your own link text: style sheet.

The verbatim \LaTeX code of Sec. B is in List. B.3.

Listing B.3: Sample \LaTeX code for abbreviations usage

```

1 Again please see List.~\ref{lst:abbrv}. Here is an example of first use:
   \acr{ac}. Next use: \acr{ac}. Full: \gls{ac}. Here's an acronym
   referenced using \verb| \acr |: \acr{html}. And here it is again: \
   acr{html}. If you are used to the \texttt{glossaries} package, note
   the difference in using \verb| \gls |: \gls{html}. And again (no
   difference): \gls{html}. Here are some more entries:
2
3 \begin{itemize}
4
5   \item \acr{xml} and \acr{css}.
6
7   \item Next use: \acr{xml} and \acr{css}.
8
9   \item Full form: \gls{xml} and \gls{css}.
10
11  \item Reset again. \glsresetall{abbreviation}
12
13  \item Start with a capital. \Acr{html}.
14
15  \item Next: \Acr{html}. Full: \Gls{html}.
16
17  \item Prefer capitals? \renewcommand{\acronymfont}[1]{\
   MakeTextUppercase{#1}} \Acr{xml}. Next: \acr{xml}. Full: \gls{xml}
   }.
18
19  \item Prefer small-caps? \renewcommand{\acronymfont}[1]{\textsc{#1}}
   \Acr{css}. Next: \acr{css}. Full: \gls{css}.
20
21  \item Resetting all acronyms.\glsresetall{abbreviation}
22
23  \item Here are the acronyms again:
24
25  \item \Acr{html}, \acr{xml} and \acr{css}.
26
27  \item Next use: \Acr{html}, \acr{xml} and \acr{css}.
28
29  \item Full form: \Gls{html}, \gls{xml} and \gls{css}.
30
31  \item Provide your own link text: \glslink{[textbf]css}{style}
32
33 \end{itemize}

```



Glossary

This section shows examples of the use of `\gls{ }` commands in conjunction with the items that are in the `glossary.tex` and `notation.tex` files. Note that entries in `notation.tex` are prefixed with “not:” label (see List. B.4).

Please make sure that the entries in `notation.tex` are those that are referenced in the \LaTeX document files used by this Thesis. Please comment out unused notations and be careful with the commas and brackets in `notation.tex`.

- Matrices are usually denoted by a bold capital letter, such as \mathbf{A} . The matrix’s (i, j) th element is usually denoted a_{ij} . Matrix \mathbf{I} is the identity matrix.
- A set, denoted as \mathcal{S} , is a collection of objects.
- The universal set, denoted as \mathcal{U} , is the set of everything.
- The empty set, denoted as \emptyset , contains no elements.
- Functional Analysis is seen as the study of complete normed vector spaces, i.e., Banach spaces.
- The cardinality of a set, denoted as $|\mathcal{S}|$, is the number of elements in the set.

The verbatim \LaTeX code for the part of Sec. B is in List. B.4.

Listing B.4: Sample L^AT_EX code for glossary and notations usage

```

1 \begin{itemize}
2
3   \item \Glspl{matrix} are usually denoted by a bold capital letter,
      such as  $\mathbf{A}$ . The  $\mathbf{A}$ 's  $(i,j)$ th element is
      usually denoted  $a_{ij}$ .  $\mathbf{I}$  is the
      identity  $\mathbf{I}$ .
4
5   \item A set, denoted as  $\mathbf{S}$ , is a collection of objects.
6
7   \item The universal set, denoted as  $\mathbf{U}$ , is the
      set of everything.
8
9   \item The empty set, denoted as  $\emptyset$ , contains no
      elements.
10
11  \item  $\mathbf{FA}$  is seen as the study of complete
      normed vector spaces, i.e., Banach spaces.
12
13  \item The cardinality of a set, denoted as  $\mathbf{card}(S)$ , is
      the number of elements in the set.
14
15 \end{itemize}

```




Figure

This section shows several ways of placing figures. PDFL^AT_EX compatible files are PDF, PNG, and JPG. Please see the `figure` subdirectory.

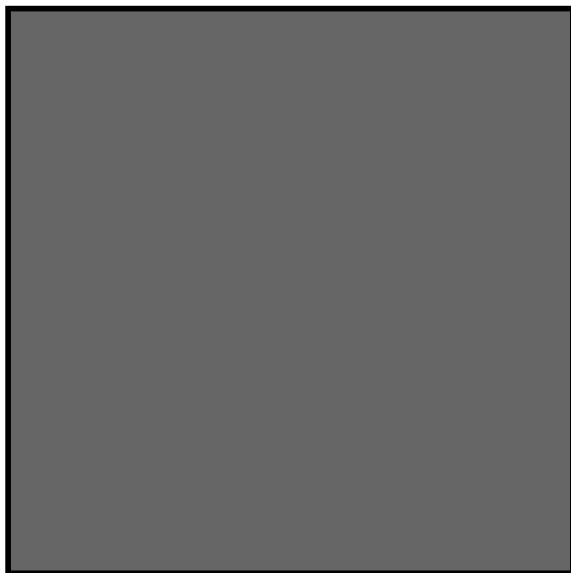


Fig. B.1 A quadrilateral image example.



Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding \LaTeX code.

Listing B.5: Sample \LaTeX code for a single figure

```
1 \begin{figure}[!htbp]
2   \centering
3   \includegraphics[width=0.5\textwidth]{example}
4   \caption{A quadrilateral image example.}
5   \label{fig:example}
6 \end{figure}
7 \cleardoublepage
8
9 Fig.~\ref{fig:example} is a gray box enclosed by a dark border. List.~\
  ref{lst:onefig} shows the corresponding  $\text{\LaTeX}$  \ code.
10 \end{figure}
```



(a) A sub-figure in the top row.



(b) A sub-figure in the middle row.



(c) A sub-figure in the bottom row.

Fig. B.2 Figures on top of each other. See List. B.6 for the corresponding \LaTeX code.

Listing B.6: Sample L^AT_EX code for three figures on top of each other

```
1 \begin{figure}[!htbp]
2 \centering
3 \subbottom[A sub-figure in the top row.]{
4 \includegraphics[width=0.35\textwidth]{example_gray_box}
5 \label{fig:top}
6 }
7 \vfill
8 \subbottom[A sub-figure in the middle row.]{
9 \includegraphics[width=0.35\textwidth]{example_gray_box}
10 \label{fig:mid}
11 }
12 \vfill
13 \subbottom[A sub-figure in the bottom row.]{
14 \includegraphics[width=0.35\textwidth]{example_gray_box}
15 \label{fig:botm}
16 }
17 \caption{Figures on top of each other}
18 \label{fig:tmb}
19 \end{figure}
```



(a) A sub-figure in the upper-left corner.



(b) A sub-figure in the upper-right corner.



(c) A sub-figure in the lower-left corner.



(d) A sub-figure in the lower-right corner

Fig. B.3 Four figures in each corner. See List. B.7 for the corresponding \LaTeX code.

Listing B.7: Sample L^AT_EX code for the four figures

```

1 \begin{figure}[!htbp]
2 \centering
3 \subbottom[A sub-figure in the upper-left corner.]{
4 \includegraphics[width=0.45\textwidth]{example_gray_box}
5 \label{fig:upprleft}
6 }
7 \hfill
8 \subbottom[A sub-figure in the upper-right corner.]{
9 \includegraphics[width=0.45\textwidth]{example_gray_box}
10 \label{fig:uppright}
11 }
12 \vfill
13 \subbottom[A sub-figure in the lower-left corner.]{
14 \includegraphics[width=0.45\textwidth]{example_gray_box}
15 \label{fig:lowerleft}
16 }
17 \hfill
18 \subbottom[A sub-figure in the lower-right corner]{
19 \includegraphics[width=0.45\textwidth]{example_gray_box}
20 \label{fig:lowright}
21 }
22 \caption{Four figures in each corner. See List.\ref{lst:fourfigs} for
23 the corresponding \LaTeX \ code.}
24 \label{fig:fourfig}
25 \end{figure}

```



Table

This section shows an example of placing a table (a long one). Table B.1 are the triples.

TABLE B.1 FEASIBLE TRIPLES FOR HIGHLY VARIABLE GRID

Time (s)	Triple chosen	Other feasible triples
0	(1, 11, 13725)	(1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0)
2745	(1, 12, 10980)	(1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0)
5490	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
8235	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
10980	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
13725	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
16470	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
19215	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
21960	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
24705	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
27450	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
30195	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
32940	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
35685	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
38430	(1, 13, 10980)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
41175	(1, 12, 13725)	(1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
43920	(1, 13, 10980)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
46665	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
49410	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
52155	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
54900	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
57645	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
60390	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
63135	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
65880	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
68625	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
71370	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
74115	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
76860	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
79605	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
82350	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
85095	(1, 12, 13725)	(1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
87840	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
90585	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
93330	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
96075	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
98820	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
101565	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
104310	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
107055	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
109800	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
112545	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
115290	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
118035	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
120780	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
123525	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)

Continued on next page



Continued from previous page

Time (s)	Triple chosen	Other feasible triples
126270	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
129015	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
131760	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
134505	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
137250	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
139995	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
142740	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
145485	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
148230	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
150975	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
153720	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
156465	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
159210	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
161955	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
164700	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)



List. B.8 shows the corresponding \LaTeX code.

Listing B.8: Sample \LaTeX code for making typical table environment

```

1 \begin{center}
2 {\scriptsize
3 \begin{tabularx}{\textwidth}{p{0.1\textwidth}|p{0.2\textwidth}|p{0.5\textwidth}}
4 \caption{Feasible triples for highly variable grid} \label{tab:triple_
   grid} \\
5 \hline
6 \hline
7 \textbf{Time (s)} &
8 \textbf{Triple chosen} &
9 \textbf{Other feasible triples} \\
10 \hline
11 \endfirsthead
12 \multicolumn{3}{c}{\textit{Continued from previous page}} \\
13 \hline
14 \hline
15 \textbf{Time (s)} &
16 \textbf{Triple chosen} &
17 \textbf{Other feasible triples} \\
18 \hline
19 \endhead
20 \hline
21 \hline
22 \multicolumn{3}{r}{\textit{Continued on next page}} \\
23 \endfoot
24 \hline
25 \endlastfoot
26 \hline
27
28 0 & (1, 11, 13725) & (1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0) \\
   & \\
29 2745 & (1, 12, 10980) & (1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0) \\
   & \\
30 5490 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
31 8235 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
   & \\
32 10980 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
   & \\
33 13725 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
   & \\
34 16470 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
35 19215 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
   & \\
36 21960 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
   & \\
37 24705 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
   & \\
38 27450 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
   & \\
39 30195 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
40 32940 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
41 35685 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
42 38430 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0)

```



```

43 41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
    0) \\
44 43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
45 46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
46 49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
47 52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
    0) \\
48 54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
49 57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
50 60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
51 63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
52 65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
53 68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
54 71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
55 74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
56 76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
57 79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
58 82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
59 85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
    0) \\
60 87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
61 90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
62 93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
63 96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
64 98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
65 101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
66 104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
67 107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
68 109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
69 112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
    1, 0) \\
70 115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
71 118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
72 120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
73 123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
74 126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
    1, 0) \\
75 129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
76 131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
77 134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
78 137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
79 139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
80 142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
81 145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
    1, 0) \\
82 148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
83 150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
84 153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
85 156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
86 159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
87 161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
88 164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
89 \end{tabularx}
90 }
91 \end{center}

```



Algorithm or Pseudocode Listing

Table B.2 shows an example pseudocode. Note that if the pseudocode exceeds one page, it can mean that its implementation is not modular. List. B.9 shows the corresponding \LaTeX code.

TABLE B.2 CALCULATION OF $y = x^n$

Input(s):	
n	: n th power; $n \in \mathbb{Z}^+$
x	: base value; $x \in \mathbb{R}^+$
Output(s):	
y	: result; $y \in \mathbb{R}^+$

Require: $n \geq 0 \vee x \neq 0$

Ensure: $y = x^n$

```
1:  $y \leftarrow 1$ 
2: if  $n < 0$  then
3:    $X \leftarrow 1/x$ 
4:    $N \leftarrow -n$ 
5: else
6:    $X \leftarrow x$ 
7:    $N \leftarrow n$ 
8: end if
9: while  $N \neq 0$  do
10:  if  $N$  is even then
11:     $X \leftarrow X \times X$ 
12:     $N \leftarrow N/2$ 
13:  else  $\{N \text{ is odd}\}$ 
14:     $y \leftarrow y \times X$ 
15:     $N \leftarrow N - 1$ 
16:  end if
17: end while
```

Listing B.9: Sample L^AT_EX code for algorithm or pseudocode listing usage

```

1 \begin{table}[!htbp]
2   \caption{Calculation of  $y = x^n$ }
3   \label{tab:calcxn}
4   {\footnotesize
5     \begin{tabular}{lll}
6       \hline
7       \hline
8       {\bfseries Input(s):} & & \\
9       $n$ & : & $n$th power; $n$ \in \mathbb{Z}^{+}$ \\
10      $x$ & : & base value; $x$ \in \mathbb{R}^{+}$ \\
11      \hline
12      {\bfseries Output(s):} & & \\
13      $y$ & : & result; $y$ \in \mathbb{R}^{+}$ \\
14      \hline
15      \hline
16      \\
17    \end{tabular}
18  }
19  \begin{algorithmic}[1]
20    {\footnotesize
21      \REQUIRE $n \geq 0$ \vee $x \neq 0$
22      \ENSURE $y = x^n$
23      \STATE $y \leftarrow 1$
24      \IF{$n < 0$}
25        \STATE $X \leftarrow 1 / x$
26        \STATE $N \leftarrow -n$
27      \ELSE
28        \STATE $X \leftarrow x$
29        \STATE $N \leftarrow n$
30      \ENDIF
31      \WHILE{$N \neq 0$}
32        \IF{$N$ is even}
33          \STATE $X \leftarrow X \times X$
34          \STATE $N \leftarrow N / 2$
35        \ELSE[$N$ is odd]
36          \STATE $y \leftarrow y \times X$
37          \STATE $N \leftarrow N - 1$
38        \ENDIF
39      \ENDWHILE
40    }
41  \end{algorithmic}
42 \end{table}

```

```

1  /* fibo.c -- It prints out the first N Fibonacci
2  *          numbers.
3  */
4
5  #include <stdio.h>
6
7  int main(void) {
8      int n;          /* Number of fibonacci numbers we will print */
9      int i;          /* Index of fibonacci number to be printed next */
10     int current;     /* Value of the (i)th fibonacci number */
11     int next;        /* Value of the (i+1)th fibonacci number */
12     int twoaway;     /* Value of the (i+2)th fibonacci number */
13
14     printf("How many Fibonacci numbers do you want to compute? ");
15     scanf("%d", &n);
16     if (n<=0)
17         printf("The number should be positive.\n");
18     else {
19         printf("\n\n\tI\t\tFibonacci(I)\n\n\t===== \n");
20         next = current = 1;
21         for (i=1; i<=n; i++) {
22             printf("\t%d\t\t%d\n", i, current);
23             twoaway = current+next;
24             current = next;
25             next = twoaway;
26         }
27     }
28 }
29
30 /* The output from a run of this program was:
31
32 How many Fibonacci numbers do you want to compute? 9
33
34 I      Fibonacci(I)
35 =====
36 1      1
37 2      1
38 3      2
39 4      3
40 5      5
41 6      8
42 7      13
43 8      21
44 9      34
45
46 */

```



List. B.11 shows the corresponding \LaTeX code.

Listing B.11: Sample \LaTeX code for program listing

```
1 List.~\ref{lst:fib_c} is a program listing of a C code for computing  
   Fibonacci numbers by calling the actual code. Please see the \verb|  
   code | subdirectory.
```



Referencing

Referencing chapters: This appendix is in Appendix B, which is about examples in using various \LaTeX commands.

Referencing sections: This section is Sec. B, which shows how to refer to the locations of various labels that have been placed in the \LaTeX files. List. B.12 shows the corresponding \LaTeX code.

Listing B.12: Sample \LaTeX code for referencing sections

```
1 Referencing sections: This section is Sec.~\ref{sec:ref}, which shows
   how to refer to the locations of various labels that have been
   placed in the \LaTeX \ files. List.~\ref{lst:refsec} shows the
   corresponding \LaTeX \ code.
```

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A subsection

Referencing subsections: This section is Sec. B, which shows how to refer to a subsection. List. B.13 shows the corresponding \LaTeX code.

Listing B.13: Sample \LaTeX code for referencing subsections

```
1 Referencing subsections: This section is Sec.~\ref{sec:subsec}, which
   shows how to refer to a subsection. List.~\ref{lst:refsub} shows the
   corresponding \LaTeX \ code.
```

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A sub-subsection

Referencing sub-subsections: This section is Sec. B, which shows how to refer to a sub-subsection. List. B.14 shows the corresponding L^AT_EX code.

Listing B.14: Sample L^AT_EX code for referencing sub-subsections

```
1 Referencing sub-subsections: This section is Sec.\ref{sec:subsubsec},
   which shows how to refer to a sub-subsection. List.\ref{lst:
   refsubsub} shows the corresponding \LaTeX \ code.
```

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.



Citing

Citing bibliography content is done using BibTeX. It requires the creation of a BibTeX file (.bib extension name), and then added in the argument of `\bibliography{ }`. For each .bib file, separate them by a comma in the argument `\bibliography{ }` without the extension name. Building your BibTeX file (references.bib) can be done easily with a tool called JabRef (www.jabref.org).

The following subsections are examples of citations.

Books

- [6]
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Booklets

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In proceedings

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**Journals**

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Technical Reports and Others Miscellaneous

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| • [125] | • [140] |
| • [126] | • [141] |
| • [127] | • [?] |
| • [128] | • [142] |
| • [129] | • [143] |
| • [130] | • [144] |
| • [131] | • [145] |
| • [132] | • [146] |
| • [133] | • [147] |
| • [134] | • [148] |
| • [135] | • [149] |
| • [136] | • [150] |
| • [137] | • [151] |
| • [138] | • [152] |
| | • [153] |
| | • [154] |



Index

For key words or topics that are expected (or the user would like) to appear in the Index, use `\index{key}`, where `key` is an example keyword to appear in the Index. For example, Fredholm integral and Fourier operator of the following paragraph are in the Index.

If we make a very large matrix with complex exponentials in the rows (i.e., cosine real parts and sine imaginary parts), and increase the resolution without bound, we approach the kernel of the Fredholm integral equation of the 2nd kind, namely the Fourier operator that defines the continuous Fourier transform.

List. B.15 is a program listing of the above-mentioned paragraph.

Listing B.15: Sample \LaTeX code for Index usage

```
1 If we make a very large matrix with complex exponentials in the rows (i.
  e., cosine real parts and sine imaginary parts), and increase the
  resolution without bound, we approach the kernel of the \index{
  Fredholm integral} Fredholm integral equation of the 2nd kind,
  namely the \index{Fourier} Fourier operator that defines the
  continuous Fourier transform.
```



Adding Relevant PDF Pages

Examples of such PDF pages are Standards, Datasheets, Specification Sheets, Application Notes, etc. Selected PDF pages can be added (see List. B.16), but note that the options must be tweaked. See the manual of `pdfpages` for other options.

Listing B.16: Sample \LaTeX code for including PDF pages

```
1 \includepdf[pages={8-10},%  
2 offset=3.5mm -10mm,%  
3 scale=0.73,%  
4 frame,%  
5 pagecommand={},]  
6 {./reference/Xilinx2015-UltraScale-Architecture-Overview.pdf}
```



Virtex UltraScale FPGA Feature Summary

Table 6: Virtex UltraScale FPGA Feature Summary

	VU065	VU080	VU095	VU125	VU160	VU190	VU440
Logic Cells	626,640	780,000	940,800	1,253,280	1,621,200	1,879,920	4,432,680
CLB Flip-Flops	716,160	891,424	1,075,200	1,432,320	1,852,800	2,148,480	5,065,920
CLB LUTs	358,080	445,712	537,600	716,160	926,400	1,074,240	2,532,960
Maximum Distributed RAM (Mb)	4.8	3.9	4.8	9.7	12.7	14.5	28.7
Block RAM/FIFO w/ECC (36Kb each)	1,260	1,421	1,728	2,520	3,276	3,780	2,520
Total Block RAM (Mb)	44.3	50.0	60.8	88.6	115.2	132.9	88.6
CMT (1 MMCM, 2 PLLs)	10	16	16	20	30	30	30
I/O DLLs	40	64	64	80	120	120	120
Fractional PLLs	5	8	8	10	15	15	0
Maximum HP I/Os ⁽¹⁾	468	780	780	780	650	650	1,404
Maximum HR I/Os ⁽²⁾	52	52	52	104	52	52	52
DSP Slices	600	672	768	1,200	1,560	1,800	2,880
System Monitor	1	1	1	2	3	3	3
PCIe Gen3 x8	2	4	4	4	5	6	6
150G Interlaken	3	6	6	6	8	9	0
100G Ethernet	3	4	4	6	9	9	3
GTH 16.3Gb/s Transceivers	20	32	32	40	52	60	48
GTY 30.5Gb/s Transceivers	20	32	32	40	52	60	0

Notes:

1. HP = High-performance I/O with support for I/O voltage from 1.0V to 1.8V.
2. HR = High-range I/O with support for I/O voltage from 1.2V to 3.3V.



Virtex UltraScale Device-Package Combinations and Maximum I/Os

Table 7: Virtex UltraScale Device-Package Combinations and Maximum I/Os

Package ⁽¹⁾⁽²⁾⁽³⁾	Package Dimensions (mm)	VU065	VU080	VU095	VU125	VU160	VU190	VU440
		HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY
FFVC1517	40x40	52, 468 20, 20	52, 468 20, 20	52, 468 20, 20				
FFVD1517	40x40		52, 286 32, 32	52, 286 32, 32				
FLVD1517	40x40				52, 286 40, 32			
FFVB1760	42.5x42.5		52, 650 32, 16	52, 650 32, 16				
FLVB1760	42.5x42.5				52, 650 36, 16			
FFVA2104	47.5x47.5		52, 780 28, 24	52, 780 28, 24				
FLVA2104	47.5x47.5				52, 780 28, 24			
FFVB2104	47.5x47.5		52, 650 32, 32	52, 650 32, 32				
FLVB2104	47.5x47.5				52, 650 40, 36			
FLGB2104	47.5x47.5					52, 650 40, 36	52, 650 40, 36	
FFVC2104	47.5x47.5			52, 364 32, 32				
FLVC2104	47.5x47.5				52, 364 40, 40			
FLGC2104	47.5x47.5					52, 364 52, 52	52, 364 52, 52	
FLGB2377	50x50							52, 1248 36, 0
FLGA2577	52.5x52.5						0, 448 60, 60	
FLGA2892	55x55							52, 1404 48, 0

Notes:

1. Go to [Ordering Information](#) for package designation details.
2. All packages have 1.0mm ball pitch.
3. Packages with the same last letter and number sequence, e.g., A2104, are footprint compatible with all other UltraScale architecture-based devices with the same sequence. The footprint compatible devices within this family are outlined. See the [UltraScale Architecture Product Selection Guide](#) for details on inter-family migration.



Virtex UltraScale+ FPGA Feature Summary

Table 8: Virtex UltraScale+ FPGA Feature Summary

	VU3P	VU5P	VU7P	VU9P	VU11P	VU13P
Logic Cells	689,640	1,051,010	1,379,280	2,068,920	2,147,040	2,862,720
CLB Flip-Flops	788,160	1,201,154	1,576,320	2,364,480	2,453,760	3,271,680
CLB LUTs	394,080	600,577	788,160	1,182,240	1,226,880	1,635,840
Max. Distributed RAM (Mb)	12.0	18.3	24.1	36.1	34.8	46.4
Block RAM/FIFO w/ECC (36Kb each)	720	1,024	1,440	2,160	2,016	2,688
Block RAM (Mb)	25.3	36.0	50.6	75.9	70.9	94.5
UltraRAM Blocks	320	470	640	960	1,152	1,536
UltraRAM (Mb)	90.0	132.2	180.0	270.0	324.0	432.0
CMTs (1 MMCM and 2 PLLs)	10	20	20	30	12	16
Max. HP I/O ⁽¹⁾	520	832	832	832	624	832
DSP Slices	2,280	3,474	4,560	6,840	8,928	11,904
System Monitor	1	2	2	3	3	4
GTY Transceivers 32.75Gb/s	40	80	80	120	96	128
PCIe Gen3 x16 and Gen4 x8	2	4	4	6	3	4
150G Interlaken	3	4	6	9	9	12
100G Ethernet w/RS-FEC	3	4	6	9	6	8

Notes:

1. HP = High-performance I/O with support for I/O voltage from 1.0V to 1.8V.

Virtex UltraScale+ Device-Package Combinations and Maximum I/Os

Table 9: Virtex UltraScale+ Device-Package Combinations and Maximum I/Os

Package (1)(2)(3)	Package Dimensions (mm)	VU3P	VU5P	VU7P	VU9P	VU11P	VU13P
		HP, GTY	HP, GTY	HP, GTY	HP, GTY	HP, GTY	HP, GTY
FFVC1517	40x40	520, 40					
FLVF1924	45x45					624, 64	
FLVA2104	47.5x47.5		832, 52	832, 52	832, 52		
FHVA2104	52.5x52.5 ⁽⁴⁾						832, 52
FLVB2104	47.5x47.5		702, 76	702, 76	702, 76	624, 76	
FHVB2104	52.5x52.5 ⁽⁴⁾						702, 76
FLVC2104	47.5x47.5		416, 80	416, 80	416, 104	416, 96	
FHVC2104	52.5x52.5 ⁽⁴⁾						416, 104
FLVA2577	52.5x52.5				448, 120	448, 96	448, 128

Notes:

- Go to [Ordering Information](#) for package designation details.
- All packages have 1.0mm ball pitch.
- Packages with the same last letter and number sequence, e.g., A2104, are footprint compatible with all other UltraScale devices with the same sequence. The footprint compatible devices within this family are outlined.
- These 52.5x52.5mm overhang packages have the same PCB ball footprint as the corresponding 47.5x47.5mm packages (i.e., the same last letter and number sequence) and are footprint compatible.