Develop a GPS/GNSS receiver:
Design of Correlators for GNSS Receivers Based on VHDL

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I hereby declare that this dissertation is all my own work, except as indicated in the text:

Signature _____

Date _____ / _____ / _____

I hereby declare that I have all necessary rights and consents to publicly distribute this dissertation via the University of Nottingham's e-dissertation archive.

Abstract

Giving a short overview of the work in your project.

Acknowledgements

Acknowledgements here. [1]

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Chapter 1

Introduction

In an era where precise positioning, navigation, and timing have become fundamental requirements for numerous applications, the *Global Navigation Satellite System* (GNSS) has emerged as a transformative technology. *Global Positioning System*, commonly known as GPS, has revolutionized the way we navigate, communicate, and interact with our surroundings. As the demand for accurate and reliable GNSS positioning continues to grow, there is an increasing need to explore innovative methods to develop advanced GNSS receivers capable of handling diverse and challenging environments.

The aim of this project is to design and develop a GPS/GNSS receiver, focusing on the critical component of correlators, which form the backbone of any GNSS receiver. Correlators play a vital role in the tracking part of the GNSS positioning process, making them a key element in the overall receiver architecture.

1.1 Background

The GNSS has become an integral part of modern life, transforming how we navigate, communicate, and interact with the world around us. As the demand for accurate and reliable positioning information continues to grow, there is a constant need for advance-

ments in GNSS receiver technology. The receiver's tracking module, responsible for extracting precise positioning data from satellite signals, plays a critical role in ensuring the accuracy and robustness of the overall GNSS positioning process.

- Increasing Reliance on GNSS: In recent years, there has been a substantial increase in the reliance on GNSS technology across various sectors and industries. From commercial transportation and aviation to precision agriculture, emergency response, and scientific research, GNSS has become a ubiquitous tool in countless applications. The accurate positioning and timing information provided by GNSS have not only improved operational efficiency but have also enabled the development of innovative services and solutions.

- Importance of the Tracking Module: The tracking module is a vital component of any GNSS receiver, responsible for acquiring and locking onto the weak satellite signals and maintaining their synchronization. Efficient tracking algorithms can increase SNR (*Signal-to-Noise-Ratio*) which are essential for accurate and real-time positioning, especially in dynamic environments where satellite signals may be temporarily obscured or weakened. Optimizing the tracking module's performance is crucial to enhancing the overall receiver's sensitivity, accuracy, and responsiveness to varying environmental conditions.

- Opportunities for Hardware Optimization: As the demand for high-performance GNSS receivers increases, there are opportunities to explore hardware optimization techniques to improve tracking capabilities. Implementing the tracking module using VHDL (*Very High-Speed Integrated Circuit Hardware Description Language*) offers advantages such as parallel processing and hardware acceleration, allowing for real-time tracking and reduced power consumption. The utilization of VHDL enables the development of customized *Application-Specific Integrated*

Circuits (ASICs) or *Field-Programmable Gate Arrays* (FPGAs) tailored to the tracking function, leading to more efficient and specialized GNSS receivers.

1.2 GNSS/GPS

GNSS consists of a constellation of satellites orbiting the Earth, transmitting continuous signals containing precise timing and positioning information. Each GNSS satellite is equipped with atomic clocks, ensuring high accuracy in the signals it emits. The GNSS constellation comprises multiple satellites, typically in *Medium Earth Orbit* (MEO), providing global coverage to ensure that a sufficient number of satellites are visible from any point on Earth at any given time.

1.2.1 Functioning of GNSS

A GNSS receiver on the ground intercepts signals from multiple satellites in the constellation. By analysing the timing and phase information in these signals, the receiver can calculate the distance between itself and each satellite. By triangulating the distances from multiple satellites, the receiver can determine its precise three-dimensional position (latitude, longitude, and altitude). Additionally, the receiver can synchronize its internal clock with the highly accurate satellite atomic clocks, providing precise timing information.

1.2.2 Key Components of GNSS/GPS

Satellites: The heart of GNSS is the constellation of satellites orbiting the Earth. Each satellite broadcasts signals carrying unique identification information and precise timing data.

GNSS Receivers: GNSS receivers are devices that intercept and process the satellite sig-

nals to calculate the user's position, velocity, and time. These receivers can be integrated into various devices, such as smartphones, car navigation systems, aviation equipment, and scientific instruments.

Control Segment: The control segment consists of ground-based monitoring stations and control centres responsible for monitoring the health of the satellites, maintaining their orbits, and ensuring accurate timing information.

User Segment: The user segment encompasses the GNSS receivers used by individuals, industries, and organizations to access positioning, navigation, and timing services.

1.2.3 Applications of GNSS/GPS

The applications of GNSS are diverse and far-reaching, permeating nearly every aspect of modern life. Some key applications include:

- Navigation: GNSS enables precise and real-time navigation for land, sea, and air transportation, making it a critical component of navigation systems in vehicles, ships, and aircraft.

- Surveying and Mapping: GNSS is widely used in geodetic surveying, mapping, and cartography to obtain accurate geographic data for urban planning, construction, and land management.

- Precision Agriculture: GNSS-based systems optimize agricultural processes by providing precise positioning for automated machinery, crop monitoring, and targeted application of resources like fertilizers and pesticides.

- Emergency and Disaster Response: GNSS aids emergency services in locating and coordinating responses during disasters, enabling efficient search-and-rescue operations.

- Timing and Synchronization: GNSS provides highly accurate timing information, essential for the synchronization of critical infrastructure, such as power grids, telecommunication networks, and financial systems.

- Scientific Research: GNSS data is used in scientific research, including the study of tectonic movements, sea level changes, atmospheric monitoring, and climate research.

In conclusion, GNSS/GPS has transformed the way we navigate and interact with our environment. By leveraging signals from a constellation of satellites, GNSS provides precise positioning, navigation, and timing services, powering applications across diverse sectors and enriching various aspects of modern life. As technology continues to evolve, GNSS is expected to play an increasingly critical role in shaping our interconnected world.

1.3   FPGA

FPGA is a type of integrated circuit that allows users to configure its hardware functionality after manufacturing. Unlike ASICs, which are designed for specific tasks and cannot be reconfigured, FPGAs offer flexibility and programmability. This characteristic makes FPGAs suitable for a wide range of applications, including digital signal processing, communication systems, image and video processing, and in this case, GNSS receiver design.

Here are the advantages of using FPGA in the project:

- Hardware Customization: FPGAs allow customization of hardware functionality, tailoring specific algorithms and designs for the GNSS tracking module. This flexibility optimizes hardware resources, resulting in a specialized and efficient GNSS receiver.

- Real-Time Processing: FPGAs excel in parallel processing, enabling real-time data processing with low latency. This is crucial for continuous and accurate GNSS positioning, especially in dynamic environments with intermittent satellite signals.

- Power Efficiency: FPGA designs can be optimized for high performance with low power consumption. This is essential for battery-operated GNSS devices, extending battery life and improving overall device usability.

- Rapid Prototyping and Iteration: FPGA development allows quick prototyping and iterative design refinement. Changes can be implemented and tested rapidly, speeding up development and performance improvements.

- Adaptability and Future Upgrades: The programmable nature of FPGAs allows easy updates and future upgrades. GNSS algorithms can be incorporated without hardware changes as technology advances.

- Cost-Effectiveness: FPGAs offer a cost-effective solution for custom hardware design compared to ASICs. They are suitable for smaller-scale projects or research without requiring expensive fabrication.

1.4 Aims and Objectives

1.4.1 Aims

The project has three aims: first, to design a tracking processor for GNSS receivers using VHDL; second, to verify the results using MATLAB; and third, to learn about GNSS signal acquisition and tracking by reading papers, books, etc.

1.4.2 Objectives

- Literature survey on GNSS signal processing and tracking

- Be familiar with the principles of correlation functions, correlators, VHDL and Vivado

- Write a literature review

- Create and verify a set of correlators model in MATLAB

- Write the RTL (*Register Transfer Level*) code of the correlator in VHDL

- Write the testbench code of the correlator in VHDL

- Instance several times (e.g. three times) of the correlator VHDL code to implement the tracking part of the GNSS receiver

- Write the testbench code of the project

- Compare the results from VHDL with those from MATLAB

- Record and analyse the VHDL results against the MATLAB results

- Complete the final dissertation

1.5   Description of the work

I will design the correlators of the receiver using VHDL.I plan to design a set of correlators in an FPGA. The correlators can be used to capture GNSS signals to allow subsequent devices to perform ranging and positioning. My front-end device will acquire the GNSS signal and transmit it to me. During the acquisition process I can receive at least one GNSS signal. I will extract the ranging code from it and compare it with the ranging code generated by the receiver, i.e. using a correlator.

Chapter 2

Literature Review

The literature review chapter serves as a critical foundation for this project, offering an in-depth exploration of the existing research, developments, and advancements in the field of GNSS receivers, with a particular focus on the tracking module. This chapter aims to identify the key theories, methodologies, and technologies that have shaped the evolution of GNSS tracking and provide valuable insights for the design and development of the FPGA-based GNSS tracking module.

Chapter 3

Design

Containing a comprehensive description of the design chosen, how it addresses the problem, and why it is designed the way it is.

Chapter 4

Implementation

Containing a comprehensive description of the implementation of your software, including the language(s) and platform chosen, problems encountered, any changes made to the design as a result of the implementation, etc.

Chapter 5

Evaluation

Explaining how your software was tested (using different datasets or in different environments), statistical evaluation of performance, results of user evaluation questionnaires, etc.

Chapter 6

Summary and Reflections

Including a discussion of results in a wider context (considering other work).

6.1 Project management

Covering the tasks as a part of your work plan and progress as well as how time and resources are managed.

6.2 Contributions and reflections

Providing the details of your achievements and contributions including innovation, creativity and novelty (if there is any) as well as a personal reflection on the plan and your experience of the project (a critical appraisal of how the project went).

Bibliography

[1] Y. Li, "University of nottingham thesis and dissertation template," https://github.com/imyueli/NottinghamThesisTemplate, 2017.

Appendix A

User Manuals

Appendix B

User Evaluation Questionnaire