Ain Shams University
Faculty of Engineering

Electronics and Communications Engineering Department

Signal Simulator for Global Navigation Satellite System

A Thesis
Submitted in partial fulfillment of the requirements of the degree of
Master of Science in Electrical Engineering

Submitted by

Mohamed Ibrahim Ahmed Mahmoud EL Hawary

B.Sc. of Electrical Engineering
(Electronics and Communications Engineering)
Thebes Higher Institute of Engineering, 2008

Supervised by

Prof. Dr. ABDELHALIEM ZEKRY

Prof. Dr. ISMAEEL M. HAFEZ

Dr. GIHAN GOMAH HAMZA

Cairo, 2014

Examiners Committee

Name: Mohamed Ibrahim Ahmed Mahmoud EL Hawary

Dissertation: Signal Simulator for Global Navigation Satellite System

Degree: Master of Science in Electrical Engineering

Title, Name, and Affiliation **Signature**

Prof. Dr. Talaat Abdel Latief Ibrahim El Garf
(Professor in Higher Technological Institute
in tenth of ramadan)

Title, Name, and Affiliation **Signature**

Prof. Dr. Wagdy Refaat Anis
Ain Shams University,
Faculty of Engineering
Electronics and Communications Department

Title, Name, and Affiliation **Signature**

Prof. Dr. Abdel-Halim Zekry
Ain Shams University,
Faculty of Engineering
Electronics and Communications Department

Title, Name, and Affiliation **Signature**

Prof. Dr. Ismail Mohamed Hafez
Ain Shams University,
Faculty of Engineering
Electronics and Communications Department

STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Electrical Engineering, Electronics and Communications Engineering.

The work that was included in this dissertation was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this dissertation was submitted for a degree or a qualification at any other university or institution.

Name: Mohamed Ibrahim Ahmed EL Hawary
Date: January, 2014

Curriculum Vitae

Name of Researcher	Mohamed Ibrahim Ahmed Mahmoud El Hawary
Date of Birth	15/2/1986
Place of Birth	Egypt
First University Degree	B.Sc. in Electrical Engineering
Name of University	Thebes High Institute of Engineering
Date of Degree	June 2008
Affiliation:	Research assistant in the National Institute for Standards.

ACKNOWLEDGEMENT

الحمد للة رب العالمين

I would like to take the opportunity to acknowledge the direct and indirect help of many people who made this thesis possible.

I would like to express my sincere appreciation to Prof. Dr. Abdel Haleem Zekry and Dr. Gihan Gomaa for their continuous support and valuable guidance. I can't express my deep appreciation to Prof. Dr. Abdelhaliem Zekry. I am proud to belong to his very distinctive school. In this school the students not deal only with a distinctive and modest scientist but also with a wise father. He introduces a full scientific support for me and gave me the trust that made me discover more research capabilities in myself.

Thanks a lot to Prof. Dr. Zekry.

I can't express my deep appreciation to Dr. Gihan Gomaa. She introduces a full scientific support for me and gave me the trust that made me discover more research capabilities in myself. I think that without Dr. Gihan's support I couldn't start research in this vital field.

Thanks a lot to Dr. Gihan Gomaa.

I would like to thank Prof.Dr. Ismail Hafez for his help.

I would like to thank my parents, without their help, this degree would not have been possible.

Mohamed EL Hawary

2014

ABSTRACT

For the time being there are many Global Navigation Satellite Systems (GNSSs) in the world that have both navigation and timing capabilities. Most of the GNSSs share a great part in the design of both the transmitter and receiver. So, it became necessary to use flexible tools in the system design to facilitate both the modernization plans of the current systems and the launching of new systems. This thesis introduces a new look for the simulation and implementation of Galileo signals using a graphical programming language; which is Simulink.

Galileo is the European independent GNSS that provids a highly accurate and guaranteed global positioning and timing services under civilian control. It is inter-operable with the American GNSS, which is the Global Positioning system (GPS), and the Russian GNSS; which is the GLONASS.

The successful design and implementation of the Galileo receiver strongly depends on to which extent we could simulate the Galileo signals to test the functionality of the receiver. During the design stage of the receiver it is preferable to use simulated signals than real signals to be able to control the properties of the received signal. Moreover, the Interface Control Document (ICD); which defines the main requirements of the Galileo system, recommends introducing flexible designs because the system is still under development and is subject to modifications.

So, this thesis adds a step on the route toward a clear, easy and transparent simulation and implementation of Galileo transmitter implemented with the Software Defined Radio (SDR) technology. In general, the graphical environment makes the relation between the system modeling, system simulation, and system implementation clearer and easier to debug, because we

can put test points everywhere and obtain immediate results. Also, using a graphical programming language enables the designer to finish the simulation of the complete system in a relatively short time. This will facilitate the simulation and implementation of the Galileo receiver.

Contents

List o f Figures…… *IV*

List of Tables……... *VII*

Abbreviations…….. *VIII*

Introduction…….. *IX*

CHAPTER ONE: Background on Galileo System

1.1 Introduction…… 1

1.2 Other Global Navigation Satellite Systems (GNSS)…….. 3

1.3 Galileo Segment……. 7

1.3.1 Space Segment…… 7

1.3.2 Ground Segment …… 8

1.3.3 User Segment…….. 11

1.4 Galileo Services…….. 11

1.4.1 Open Service (OS)…….. 11

1.4.2 Safety of Life (SoL)…… 12

1.4.3 Commercial Service (CS)……... 13

1.4.4 Public Regulated Service (PRS)……. 13

1.4.5 Search And Rescue (SAR)……. 14

1.5 Galileo Signals…… 14

1.5.1 E1 signal…….. 15

1.5.2 E6 signal…….. 16

1.5.3 E5a signal…… 16

1.5.4 E5b signal…… 16

CHAPTER TWO: Spread Spectrum Techniques

2.1 Introduction…… 19

2.2 Types of spread spectrum techniques…… 21

2.2.1 Direct Sequence Spread Spectrum (DS-SS)…….. 21

2.2.2 Frequency Hopping Spread Spectrum (FH-SS)…… 22

2.3 Generation of Pseudo-Noise (PN) Sequences……... 22

2.3.1 Maximal Sequence (m-sequence) length codes……. 23

2.3.2 Gold Sequences…….. 24

2.4 Multiple Access Techniques…….. 25
2.5 Code Division Multiple Access (CDMA) technique……. 26
2.6 Galileo spreading codes……. 27
2.6.1 Implementation of primary code ……... 30
2.6.1.1 Optimized Pseudo-Noise sequences (memory code)……. 30
2.6.1.2 Linear Feedback Shift Registers (LFSR) based Pseudo-Noise sequences……. 30
2.6.2 Galileo secondary code……... 31
2.7 Galileo spreading codes of E1 signal…….. 31
2.8 Galileo spreading codes of E6 signal…….. 31

CHAPTER THREE: Modulation Techniques used in Galileo System

3.1 Introduction……. 33
3.2 Binary Phase Shift Keying (BPSK) Modulation…… 34
3.3 Binary Offset Carrier (BOC) modulation…….. 37
3.4 Alternate BOC (AltBOC)…….. 43
3.5 Coherent Adaptive Subcarrier Modulation (CASM)…….. 45

CHAPTER FOUR: Simulation of Galileo Signals using Simulink

4.1 Introduction……. 53
4.2 E1 signal Simulator……. 56
4.2.1 E1 Ranging Codes……... 60
4.2.2 Generate random data stream of E1 signal……..…….. 62
4.2.3 Binary Offset Carrier (BOC) and CBOC Modulation…… 64
4.2.3.1 Power Spectral Density of BOC Modulation……. 65
4.2.3.2 Autocorrelation Function of BOC Modulation…….. 71
4.2.4 Coherent Adaptive Subcarrier Modulation of E1 signal…… 80
4.3 E6 signal Simulator…… 87
4.3.1 E6 Ranging Codes……. 88
4.3.2 Generate random data stream of E6 signal……. 92
4.3.3 BOC Modulation for E6 signal…….. 95
4.3.4 Coherent Adaptive Subcarrier Modulation of E6 signal…… 99

CHAPTER FIVE: Implementation of Galileo Transmitter signals on DSP through Simulink

5.1 Introduction…… 102
5.2 Hardware and Software background…….. 104
5.2.1 The DSK board with TMS320C6713DSP…… 104

5.2.2 The Real Time Data Exchange Technology……... 106
5.3 Implementation of E1 signal……..…. 108
5.3.1 Implementation of SE1 signal……..….. 108
5.3.2 Implementation of sL1 signal……. 111
5.4 Implementation of E6 signal……... 112
Conclusion……... 113
References…… 114

List of Figures

Fig.(1.1):Galileo is moving from the development phase to the deployment phase…….. 3
Fig.(1.2):Galileo implementation plan..... 3
Fig.(1.3):All GNSS frequancy bands…….…….... 6
Fig.(1.4):Galileo System Architectur……. 7
Fig.(1.5):Galileo space segment……. 7
Fig.(1.6):Ground control station at fucino…….. 9
Fig.(1.7):Galileo Map……. 10
Fig.(1.8):Galileo services…… 12
Fig.(1.9):Galileo frequancy plan…… 15
Fig.(1.10):Space Vehicle/Navigation user interface……... 16
Fig.(1.11):Galileo frequancy spectrum……... 17
Fig.(1.12):E1\L1signal frequancy spectrum……... 17
Fig.(1.13):E6 signal frequancy spectrum…… 18
Fig.(2.1):Spreading operation spreads the signal energy over a wider frequancy bandwidth…… 20
Fig.(2.2):Direct Sequance Spread Spectrum (DSSS)……. 21
Fig.(2.3):Frequancy Hopping Spread Spectrum (FHSS)…… 22
Fig.(2.4):PN Sequance with generator polynomial…… 23
Fig.(2.5):Maximal length pseudo random sequance generator……... 24
Fig.(2.6):Generating Gold codes by combing two preferred pairs of m-sequances……... 25
Fig.(2.7):Multiple access schems…… 26
Fig.(2.8):Tiered codes generation……... 28
Fig.(2.9):Simplified diagram that rerpresent the tiered code generation…… 29
Fig.(2.10):LFSR based code generator for combined m-sequances……... 31
Fig.(3.1):BPSK signal constellation diagram..... 35
Fig.(3.2):BPSK signal sequance……. 35
Fig.(3.3):Amplitude spectrum of the BPSK …….. 36
Fig.(3.4):BPSK Modulator……. 36
Fig.(3.5):Normalized base band PSD of BPSK modulated signal……. 36
Fig.(3.6):BPSK modulator without subcarrier generator block ……. 38
Fig.(3.7):BOC modulator with subcarrier generator block……. 38
Fig.(3.8):PSD of BOC(1,1) and BPSK modulated signals……. 39
Fig.(3.9):BOC(1,1) and BOC(15,2.5) waveforms…….. 41
Fig.(3.10):PRN Spreading code, subcarrier, carrier, and signal as result of the BOC modulation principle……... 41
Fig.(3.11):BOCsin and BOCcos waveforms…….. 42
Fig.(3.12):Alternate BOC modulation…… 43
Fig.(3.13):The constellation diagram of CASM…… 51
Fig.(4.1):Modulation Scheme for the E1 CBOC Signal……. 57
Fig.(4.2):Simulink model that represent SE1 signal using CBOC Modulation…….. 57
Fig.(4.3):Simulink model that represent the ranging code of component A…….. 60
Fig.(4.4):Generated Ranging code of component A……... 60
Fig.(4.5):Simulink model that represent the ranging code of component…….. 61
Fig.(4.6):Generated Ranging code of component B……... 61
Fig.(4.7):Simulink model that represent ranging code for component C……... 62
Fig.(4.8):Generated Ranging code of component C……... 62
Fig.(4.9):Simulink model that generat random data stream of component B……. 63
Fig.(4.10):generated random data of component B…… 63

Fig.(4.11):Simulink model that generat random data stream of component A…….. 64
Fig.(4.12):Generated random data of component A……... 64
Fig.(4.13):PSD of BOCsin(1,1)…….. 66
Fig.(4.14):PSD of BOCcos(1,1)…… 66
Fig.(4.15):PSD of BOCsin(6,1)…….. 67
Fig.(4.16):PSD of BOCcos(6,1)…… 67
Fig.(4.17):PSD of BOCsin(10,5)…… 68
Fig.(4.18):PSD of BOCcos(10,5)……... 68
Fig.(4.19):PSD of BOCsin(15,2.5)…… 69
Fig.(4.20):PSD of BOCcos(15,2.5)…… 69
Fig.(4.21):PSD of BOC(1,1) , BOC(6,1) , BOC(10,5) and BOC(15,2.5)…….. 70
Fig.(4.22):PSD of BOCcos(1,1) , BOCcos(6,1) , BOCcos(10,5) and BOCcos(15,2.5)…. 70
Fig.(4.23):Normalized ACF BOC(1,1)……... 72
Fig.(4.24):ACF of BOC(1,1) with sine and cosine phased…… 72
Fig.(4.25):ACF of BOC(10,5) with sine and cosine phased……... 73
Fig.(4.26):ACF of BOC(15,2.5) with sine and cosine phased…… 73
Fig.(4.27):CBOC sub-carrier of component B with BOC(1,1) and BOC(6,1)…….. 75
Fig.(4.28):CBOC sub-carrier of component C with BOC(1,1) and BOC(6,1)…….. 76
Fig.(4.29):PSD of SE1 signal…… 77
Fig.(4.30):The SE1 signal with generated data and ranging code with PSD…….. 78
Fig.(4.31):Simulink model that represent Component A signal and its PSD……. 78
Fig.(4.32):PSD of component A…… 79
Fig.(4.33):Component A signal with generated data and ranging code with PSD……. 81
Fig.(4.34):Multiplexing scheme for $s_{L1}(t)$ by using CASM……... 81
Fig.(4.35):Simulink model that represent the CASM of A,B and C components…….. 81
Fig.(4.36):Simulink model for CASM…… 82
Fig.(4.37):The L1 CASM PSD……... 82
Fig.(4.38):Constellation for L1 signal…… 83
Fig.(4.39):Normalized ACF BOCcos(15,2.5) of component A at eL1A……... 84
Fig.(4.40):Normalized ACF BOCsin(1,1) of component B at eL1B…….. 84
Fig.(4.41):Normalized ACF BOCsin(1,1) of channel C at eL1C……... 84
Fig.(4.42):sL1 signal with generated data and PRN code with its ACF and PSD…….. 86
Fig.(4.43):Modulation Scheme for the E6 Signal……... 87
Fig.(4.44):The E6 Simulink Model…… 88
Fig.(4.45):simulink model of Component B ranging code…… 90
Fig.(4.46):The generated ranging code for Component B…….. 90
Fig.(4.47):Component A ranging code simulink model…… 90
Fig.(4.48):The generated ranging code for Component A…….. 91
Fig.(4.49):Simulink model for ranging code of Component C……... 91
Fig.(4.50):Simulink model for Primary code of Component C…….. 91
Fig.(4.51):Simulink model for Secondary code of Component C…….. 92
Fig.(4.52):The generated ranging codes for Component C……..... 92
Fig.(4.53):Simulink model that generat random data stream of component B……... 93
Fig.(4.54):The generated random data of component B…… 93
Fig.(4.55):Simulink model that generat random data stream of component A…….. 93
Fig.(4.56):The generated random data of component A…… 94
Fig.(4.57):Modulation the S_{E6} signal using BPSK modulation…….. 95
Fig.(4.58):Modulation the S_{E6} signal using BPSK modulation Simulink Model……... 95
Fig.(4.59):PSD ofsE6 signal……... 96
Fig.(4.60):Model of PSD of component A signal……... 96

Fig.(4.61):PSD of component A signal…….. 96
Fig.(4.62):Normalized ACF BPSK(5) of components B and C at sE6…….. 97
Fig.(4.63):Normalized ACF BOCcos(10,5) of component A…… 97
Fig.(4.64):The SE6 signal with generated data and ranging code with PSD…….. 98
Fig.(4.65):Simulink model that represent the CASM SE6 signal……... 99
Fig.(4.66):Simulink model that represent the E6 CASM……... 99
Fig.(4.67):Constellation for CASMsE6 signal……... 100
Fig.(4.68):The SE6 signal and component A signal with generated data and ranging codes with ACF and PSD for each signal……... 101
Fig.(5.1):TMS320C6713-based DSK Board…….. 105
Fig.(5.2):Block diagram of the C6713 DSK……... 105
Fig.(5.3):RTDX data flow…….. 106
Fig.(5.4):Target to host communication……. 107
Fig.(5.5):Host to target communication…….. 107
Fig.(5.6):The implementation of SE1 signal in simulink……... 108
Fig.(5.7):The modified simulink model of ranging code of component B…… 108
Fig.(5.8):The modified simulink model of ranging code of component C…… 109
Fig.(5.9):The modified simulink model of ranging code of component C show the modified on oversampling subsystem block……... 109
Fig.(5.10):PSD of SE1 signal that simulated…….. 109
Fig.(5.11) :PSD of SE1 signal that implemented in the DSP kit…… 110
Fig.(5.12):The implemented of sL1 signal in simulink…….. 111
Fig.(5.13):Simulated sL1 CASM PSD……... 111
Fig.(5.14):Implemented sL1 CASM PSD…….. 111
Fig.(5.15):The implementation of sE6 signal in simulink……. 112
Fig.(5.16):The simulated PSD of sE6 signal…….. 112
Fig.(5.17):The implemented PSD of sE6 signal……. 112

List of Tables

Table (1): Comparison of the most important properties of GPS, GALILEO and GLONASS 5
Table (2): Main Specifications of Galileo space segment…… 8
Table (3): Main Characteristics of Galileo Spreading Code…….. 28
Table (4): The different combinations of the three binary channels $s_1(t)$, $s_2(t)$ and $s_3(t)$……... 51
Table (5): Galileo E1 signal technical characteristics…… 59
Table (6): The technical characteristics of Galileo E6 signal…… 88
Table (7): The code generators for component B…….. 89
Table (8): The code generators for component C…….. 89

Abbreviations

ACF	Autocorrelation Function.
AltBOC	Alternate Binary Offset Keying.
BOC	Binary Offset Carrier.
BPSK	Binary Phase Shift Keying.
CASM	Coherent Adaptive Sub-Carrier Modulation.
CBOC	Composite Binary Offset Carrier.
CCS	Code Composer Studio.
CDMA	Code Division Multiple Access.
CS	Commercial Service.
DS-SS	Direct Sequence Spread Spectrum.
FDMA	Frequency Division Multiple Access.
FH-SS	Frequency Hopping Spread Spectrum.
FOC	Full Operational Capability.
GCC	Galileo Control Center.
GIOVE-A	Galileo In-Orbit Validation Element-A.
GIOVE-B	Galileo In-Orbit Validation Element-B.
GMT	Greenwich Mean Time.
GNSS	Global Navigation Satellite System.
GPS	Global Positioning System.
GSS	Galileo Sensor Stations.
GST	Galileo System Time.
GUI	Graphical User Interface.
ICAO	International Civil Aviation Organization.
INRIM	Istituto Nazionale di Ricerca Metrologica.
IOV	In Orbit Validation.
IRNSS	Indian Regional Navigational Satellite System.
LFSR	Linear Feedback Shift Register
NAVSTAR	NAVigation System with Timing And Ranging.
OS	Open service.
OS SIS ICD	Open Service Signal in space Interface Control Document
PRN	Pseudorandom Noise.
PRS	Public Regulated Service.
PSD	Power Spectral Density.
PTF	Precise Timing Facility.
QZSS	Quasi Zenith Satellite System.
RTDX	Real Time Data Exchange.
RTW	Real Time Workshop.
SAR	Search and Rescue.
SARSAT	Search And Rescue Satellite Aided Tracking.
SDR	Software Defined Radio
SoL	Safety of Life.
TC6	Target Support Package.
TDMA	Time Division Multiple Access.
ULS	Uplink Station.
UMTS	Universal Mobile Telecommunications System.
UTC	Co-ordinated Universal Time.