GNU RADIO BEACON RECEIVER FOR IONOSPHERIC STUDY

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Dedicated to my beloved parents

Tai Mok Lam

and

Tor Poo Chin,

siblings

and

all supported friends

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ABSTRACT

GNU Radio beacon receiver is a digital beacon receiver developed to receive beacon signals (150MHz and 400MHz) from LEO satellites for ionospheric study. This project is implemented based on software-defined radio (SDR) technology. Open source software GNU Radio is used with its friendly hardware USRP to perform real time reception. Some of the components like mixer, filter and demodulator are programed by GNU Radio, so greatly reduce the complexity of the circuit, thus, greatly reduce the cost of fabrication and maintenance compares to analog beacon receiver. Besides that, a satellite tracking program is developed to aim the reception of beacon signals. Satellite tracking program is developed by writing a python script that use PyEphem library for implementing astronomical algorithm.

ABSTRAK

GNU Radio beacon penerima adalah penerima beacon digital yang dibangunkan untuk menerima isyarat beacon (150MHz dan 400MHz) dari satelit LEO untuk kajian ionosfera. Projek ini dilaksanakan berdasarkan teknologi radio (SDR). Perisian GNU Radio digunakan dengan USRP untuk melaksanakan isyarat daripada satelit LEO. Beberapa komponen seperti mixer, penapis dan penyahmodulat diprogramkan oleh GNU Radio. Dengain ini, kerumitan litar dapat dikurangkan, Selain itu, ia juga mengurangkan kos fabrikasi dan penyelenggaraan berbanding dengan penerima beacon analog. Selain itu, program pengesanan satelit juga dibangunkan untuk mengesan satelit bagi tujuan penerimaan isyarat beacon yang Berjaya. Program pengesanan satelit dibangunkan dengan menulis skrip python yang menggunakan modul PyEphem untuk melaksanakan algoritma astronomi.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ADC	-	Analog To Digital Converter
DAC	-	Digital To Analog Converter
DDC	-	Digital Down Conversion
DSP	-	Digital Signal Processing
		Digital Signal Processor
DUC	-	Digital Up Conversion
EUV	-	Extreme Ultraviolet
FCC	-	Federal Communications Commissions
FPGA	-	Field Programmable Gate Array
GPMC	-	General Purpose Memory Controller
GPP	-	General Purpose Processor
GPS	-	Global Positioning System
GRC	-	Gnu Radio Companion
GUI	-	Graphical User Interface
IF	-	Intermediate Frequency
LEO	-	Low Earth Orbit
NF	-	Noise Figure
ppm	-	parts per million
QFH	-	Quadrifilar Helix
RF	-	Radio Frequency
SDR	-	Software-Defined Radio
STEC	-	Slant Total Electron Content
SWIG	-	Simplified Wrapper And Interface Generator
TEC	-	Total Electron Content
TLE	-	Two-Line Element Set

UHF	-	Ultra High Frequency
URL	-	Uniform Resource Locator
USB	-	Universal Serial Bus
USRP	-	Universal Software Radio Peripheral
UTC	-	Coordinated Universal Time
VHF	-	Very High Frequency
VTEC	-	Vertical Total Electron Content

LIST OF SYMBOLS

f_p	-	Plasma Frequency
h_{pp}	-	Height Of The Ionospheric Pierce Point
R_e	-	Radius Of The Earth
V_{pp}	-	Voltage Peak To Peak
f_{UHF}	-	Ultra High Frequency
f_{VHF}	-	Very High Frequency
f_c	-	Common Frequency
m_e	-	Mass Of Electron
n_f	-	Noise In Frequency Term
n_ϕ	-	Noise In Phase Term
v_{LOS}	-	Velocity Of The Slant Path
ε_0	-	Permittivity In Free Space
b	-	Receiver Clock Biases
B	-	Satellite Clock Biases
		Bandwidth
bps	-	Bit Per Second
D	-	True Range
dB	-	Decibel
e	-	Charge Of Electron
		Electronic Time Delay Within Receiver
E	-	Electronic Time Delay Within Satellite
f	-	Transmitted Frequency
I	-	Ionospheric Time Delay
km	-	Kilo Meter

L	-	Level
log	-	Logarithm
MHz	-	Mega Hertz
$Msps$	-	Mega Samples Per Second
N	-	Electron Density
		Final Noise Power Level
n	-	Refractive Index
		Bit Per Sample
s	-	Path Between Transmitter And Receiver
T	-	Tropospheric Time Delay
α	-	Elevation Angle
$L_{cable(dB)}$	-	Cable Loss in dB
$P_{t(dBm)}$	-	Transmitted Power
$P_{r(dBm)}$	-	Received Power
S	-	Final Signal Power Level
S_i	-	Received Signal Power Level
G	-	Gain
k	-	Boltzmann‟s Constant
T_0	-	Temperature in Kelvin
NF	-	Noise Figure
F_T	-	Total Noise Factor

CHAPTER 1

INTRODUCTION

1 Overview

This chapter presents overview of the project, problems that lead to the development of the project, objective of the project, scope of the project and thesis outline.

1.1 Project Overview

Ionospheric tomographic or beacon receiver used for ionospheric study is very important in radio communication system. It estimates the electron density in the ionosphere that brings great effect to radio propagation in the atmosphere. Total electron content (TEC) is the parameter and is measured in unit of TECU ($10^{16}m^{-2}$). This parameter images the ionosphere and helps to make correction of propagation effects due to ionosphere on the applied radio communication system [1, 2].

Radio link between satellite and ground station plays a vital role nowadays, this link used wisely in communication, navigation and surveillance. The radio propagates in free space encounters some changes. The phase advance and Doppler shift of a carrier, group retardation and time delay of a modulation, Faraday rotation of the polarization and wedge refraction of wave direction are all due to total electron content [2].

The development of software-defined radio (SDR) system has made a lot of analog signal processing to digital signal processing by only implement software on a general purpose computer. This allows the receiver software to be continuously improved and edited to adapt to the change of requirements and technologies. An implemented digital beacon receiver is described by Yamamoto [2008] [3]. In this study, a digital beacon receiver known as GNU Radio Beacon Receiver is built based on the work of Yamamoto.

Signals with different frequencies have different effects when encounter with ionosphere. Hence, a minimum of two downlink signals receptions from satellites is needed in order to study the ionosphere by comparing its differences. In this study, digital beacon receiver is designed to receive beacon signals (150MHz & 400MHz) from LEO satellites. It is developed based on a software toolkit known as GNU Radio and its friendly hardware called Universal Software Radio Peripheral (USRP), raising its name GNU Radio Beacon Receiver. The stored signals in binary data are saved for future development. Before developing GNU Radio Beacon Receiver, a program is developed to track the rise time and set time of satellites based on a high level language known as Python (version 2.7.6) with an astronomical algorithm library known as PyEphem (version 3.7.6.0).

1.2 Problem Statement

Previous beacon receivers are analog and this encounters a lot of problems. Analog beacon receivers are limited to only few operational transmitting platforms. Besides that, it is more costly due to fabrication and continuous maintenance. Moreover, it is not portable.

However, GNU Radio Beacon Receiver requires only few components, and most of the components are implemented by software, so greatly reduce the use of components and thus reduce the cost for fabrication. It doesn‟t require much maintenance as it has less components. Moreover, it can be further developed to extend or increase its ability for ionospheric study by simply changing the programming.

Furthermore, the available TEC map provided in internet network is a worldwide TEC image. It doesn‟t provide much about the information detail of ionosphere on a specific location on the Earth. Therefore, a beacon receiver should be owned by hobbyists and academics to extract detail information of the regional ionosphere.

The challenge in this project is to receive beacon signals from LEO satellites which do not appear on the sky all the time. LEO satellites have short orbital sidereal periods normally within 2 hours. The field-of-view is roughly 15 minutes on any location on the Earth. Therefore, a program used to track the visibility of the LEO satellites is developed.

1.3 Objectives

The main objective of this project is to develop a digital beacon receiver which can receive 150MHz and 400MHz signals and store them into a separated file for future development. Specifically, this project involves the following purpose:

i. To develop a low cost digital beacon receiver that is capable to receive 150MHz and 400MHz signals.
ii. To develop a program that is capable to track the visible time of the satellites.
iii. To demonstrate how the combination of USRP and GNU Radio can be used to realize digital beacon receiver.
iv. To reduce the complexity of beacon receiver by changing it from analog to digital.

1.4 Score of Project

This project studies only the ionosphere, one of the atmosphere‟s layers. This project implements the early technique which utilizes the beacon signals (150MHz and 400MHz) propagated from Low Earth Orbit or LEO satellites. Many parameters can be measured by existing beacon receivers. However, this project only receive beacon signals, measure of total electron content (TEC) is under future work.

This project can be divided into two parts. First, a program which is capable to track the visible time of satellites is developed using Python - a high level language with a PyEphem - a library for astronomical algorithm. Second, the beacon signals are received by the combination of the works of the USPR and the GNU Radio software.

This project includes the following works stated below:

i. Development of a program that is written using Python with an important library, PyEphem to interpret two line element (TLE) that contain satellite‟s information in order to track its rise time and set time for a particular earth station.
ii. Implementation of receiver based on SDR technology by using GNU Radio software and USRP hardware.
iii. Development of back end components using GNU Radio Companion (GRC) in GNU Radio

1.5 Thesis Outline

In this paper, software-defined radio technology, GNU Radio software and its friendly hardware USRP are discussed briefly in Chapter 2. Literature review on ionosphere and its effects on radio signal that propagate to ionosphere are discussed too in Chapter 2.

The methodology used to develop satellite tracking program and GNU Radio Beacon Receiver are described in Chapter 3. Overall operation is discussed, followed by the methodologies for satellite tracking program and GNU Radio Beacon Receiver. Besides that, flow of the project is described in detail.

Results and discussions are included in Chapter 4. Details discussions on the results are provided. Lastly, conclusion and plan of future work are made and are presented in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2 Overview

This chapter presents the review of Software-defined Radio (SDR), Ionosphere and LEO-based sources. Inside the topic of SDR, there are subtopics for Universal Software Radio Peripheral (USRP) and GNU Radio. The effect of ionosphere on signal and the main parameter of the ionosphere are reviewed. Furthermore, review on Leo-based sources for ionospheric study is included.

2.1 Software-defined Radio (SDR)

The idea of Software-defined Radio (SDR) was introduced by Joseph Mitola in 1991 and was developed firstly for military purpose [4]. Nowadays, this technology is being popular in commercial demand. SDR is a technology used in radio communication system to implement signal processing in software platform. There are two main parts in SDR technology: virtual module and hardware module. By having virtual module or software platform, hardware like filter, mixer, amplifier, modulator, demodulator etc can be implemented in the personal computer or specific embedding devices that are operated under certain software [5]. Software is a set of instructions that direct the computers or devices to operate. Meanwhile, by having a hardware module or RF frontend to receive/transmit signal from/to real world and converts the signal between analog and digital using ADC/DAC, we can reduce the complexity of an electronic device. Hence, reduce the cost of manufacturing.

In compliance with Federal Communications Commissions (FCC) regulation, certain frequencies are used by certain application. In response to the cost and this regulation, many devices are manufactured with the ability to transmit and receive certain frequencies only. Therefore, it is interest to have devices that can transmit and receive a variety of frequencies. SDR allows devices to process signals in variety of frequencies by simply changing its programming in software platform. Therefore, a lot of applications can be performed by using a single set of devices [4].

Digital signal processing (DSP) is an interest in SDR. By running software, programmable hardware performs the instruction and directs the digital signals to proper path way. There are some techniques not available in analog world but digital world. Indirectly, these techniques can solve the complex problems in analog world.

The virtual module in SDR technology is functioned based on programmable hardware. There are three types of programmable hardware: field programmable gate array (FPGA), embedded digital signal processor (DSP) and general purpose processor (GPP). The platforms based on FPGA and DSP satisfy requirements of most of the current wireless protocols. However, they are not very flexible. Contrarily, the platforms based on GPP are very flexible. Therefore, personal computer is widely used in SDR technology [6].

2.1.1 SDR Architecture

SDR is a technology in which some or all of the hardware are implemented in software platform. Field programmable gate arrays (FPGA), digital signal processor or any other specific programmable processors are the main devices used in SDR technology. Figure 2.1 depicts the interface of hardware and software platforms [7].