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Verification of third party components to the Road Telematics Communicator

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The author declare that he is the sole author of this thesis and have not used any sources other than those listed in the bibliography and identified as references. He further declare that he have not submitted this thesis at any other institution to obtain a degree.

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Abstract

The Road Telematics Communicator (RTC) as it is called in Scania. It is the device responsible to keep the vehicle connected and send the vehicle data to the off board system. It uses data from different sources such as GNSS signals, CAN signals and wireless Telecom signals. Connected vehicles provide real-time information on positioning, fuel consumption and vehicle diagnostics. There are acceptance and regression test suites that verify the functionality of RTC. Third party components such as GNSS module are not a part of the tests due to technical limitations. Hence RTC lacks automated tests for important features. Due to lack of complete verification in automated test suites, time consuming tests must be performed on the road. And trouble reports from the field are difficult to analyze.

This thesis provide testing the location accuracy of the GNSS module in vehicles used for telematics applications in the automotive industry, by using a GPS vector signal generator in a controlled lab environment. GNSS consists of GPS, GALILEO, GLONASS, BEIDOU. We are using GPS in this research. The GPS receiver is put under test in a controlled lab environment for testing the, Time to First Fix, Location accuracy of GPS receiver and analysing the performance with the given inputs. Test cases were created similar to field tests on the signal generator.

At this stage, an experiment is performed on the GPS receiver which is connected to the signal generator via RF connector and to a computer via LAN. An input data is sent to the signal generator in the form of SCPI commands. The signal generator processes these commands and generates a signal accordingly. This generated signal is fed to the receiver. With the help of signal generator we can generate field like inputs and verify the behavior of the GPS module. By verifying the behavior of the module, we can develop test cases that shows the functionality of the receiver.

Keywords: Telematics, Global positioning system, Vecotr signal generator, Signal analyzer, RF Communication, Signal processing, Quality assurance

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Finally I thank the Connected Platform (ECPP) team for their useful information and interesting insights in this research.

List of Abbreviations

RTC	Road Telematics Communicator
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
UHF	Ultra High Frequency
BPSK	Binary Phase Shift Keying
RF	Radio Frequency
TCS	Test Case Selection
LAN	Local Area Network
ANOVA	Analysis of Variance
ITS	Intelligent Transport System
CAN	Control Area Network
SDR	Software Defined Radio
HIL	Hardware In Loop
DUT	Device Under Test
PPS	Pulse Per Second
TTFF	Time To First Fix
FFT	Fast Fourier Transform
CCDF	Complementary Cumulative Distribution Function
HDOP	Horizontal Dilution of Precision
ART	Adaptive Random Testing
SCPI	Standard Commands for programmable Instruments
TOW	Time of Week
NMEA	National Marine Electronics Association
GNGGA	Global Positioning system fix data
GPGSV	GPS satellites information
RQ	Research Question

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Chapter 1

Introduction

Telecommunications and Informatics systems known as Telematics are being introduced in vehicles. From the ABI research, the telematics market is expected to grow from USD 2.5 billion dollars in 2004 to USD 98.27 billion dollars by 2026 [42]. Telematics is referred as wireless technology with location based services.

In automotive industry vehicle telematics consists of positioning device, entertainment device, communication device, theft detection, user interface and vehicle interface. One of the key elements is positioning which provides all the solutions to the location based services such as emergency assistance, road side assistance, routing information, vehicle tracking, accident warning messages and vehicle diagnostics[2].

There are many factors that effect the received GPS signals such as antenna height, cable loss, interference from embedded hardware devices, obstruction and multi-path. Therefore the industry have to develop particular specifications and provide the services to improve the customer satisfaction. Test cases should be developed to confirm the specifications, test cases can be developed for the whole system or for individual features. From the above drawbacks the GNSS signal simulator comes into play. It can generate different scenarios in different working conditions and help the testers to validate the results. The main advantage of the signal generator is that, we can generate signals in a controlled limited space environment for various environmental scenarios, which helps in reducing on-field testing time and cost. [2, 41].

1.1 GPS Overview

The global positioning system is a radio navigation system managed by the US air force[18]. First it was developed for the purpose of military, later it was provided for civilians as it has many benefits. Such as GPS in cars, boats and mobile phones. The GPS has 24 satellites and transmits the signals in two carrier frequencies L1/L2, which are transmitted in ultra high frequency (UFH) band. The frequency values are:
$f_{L1} = 1575.42$ MHz
$f_{L2} = 1227.60$ MHz

The L1 frequency is used for civilian purposes, while L2 frequency is used for military purposes. We are using L1 frequency in this research. The frequencies L1 and L2 have GPS navigation message stored in them and spreading sequences. The navigation message is used by GPS receivers to calculate the position. To ensure secure communication and less interference, the spreading sequence is used. It is a

modulation technique that spreads the signal bandwidth in the frequency domain. The modulation technique is Binary Phase Shift Keying (BPSK). Every satellite generates 1.023 Mchips BPSK (Binary phase shift keying). The spreading sequence of satellites uses a pseudo-random code called as C/A (Coarse acquisition) code, which is most widely used for civilian applications. At first the GPS receivers would receive the accuracy up-to 30-40m because of an error timing code added by the US military for security reasons. Now a days the consumer grade GPS receivers achieve an error of maximum 5m [31]. The measured power level of L1 signal at the receiver is -130 dBm. There are three levels in the GPS as shown in the below figure 2.

- The space level have 24 satellite constellations and transmit the signal one-way to get the current GPS position fix.
- The control level, monitors the satellites. Keeps them in orbit and adjusts the clock by sending the commands occasionally. It also monitors the satellite constellation and the performance.
- In the user level, the GPS receivers receive the signals from the satellite to acquire a 3-D positional fix.

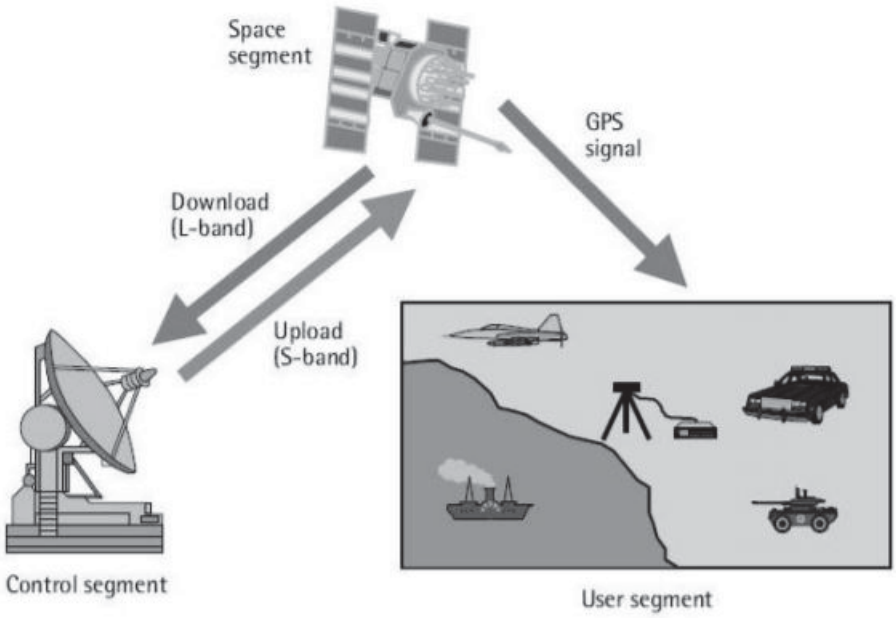

Figure 1.1: GPS levels
[31]

1.1.1 Binary Phase Shift Keying

It is very important signal used in satellite navigation, as it is very robust and can handle signals with highest levels of noise[50]. In BPSK modulation we know that the phase of the carrier wave is modulated by binary symbols "1" and "0". When digital signal changes from "0" to "1" there is a phase shift of π. A sin wave with a

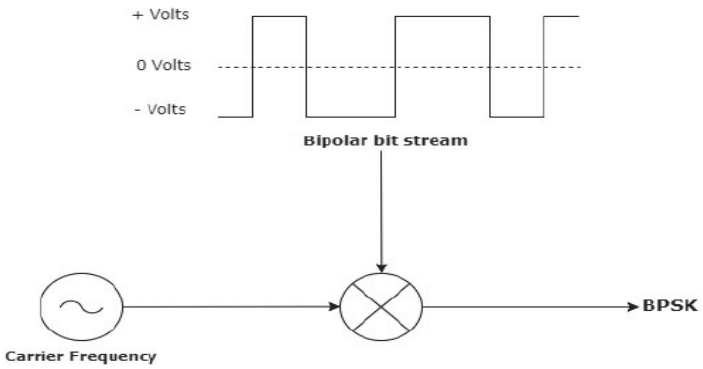

Figure 1.2: Generation of BPSK
[35]

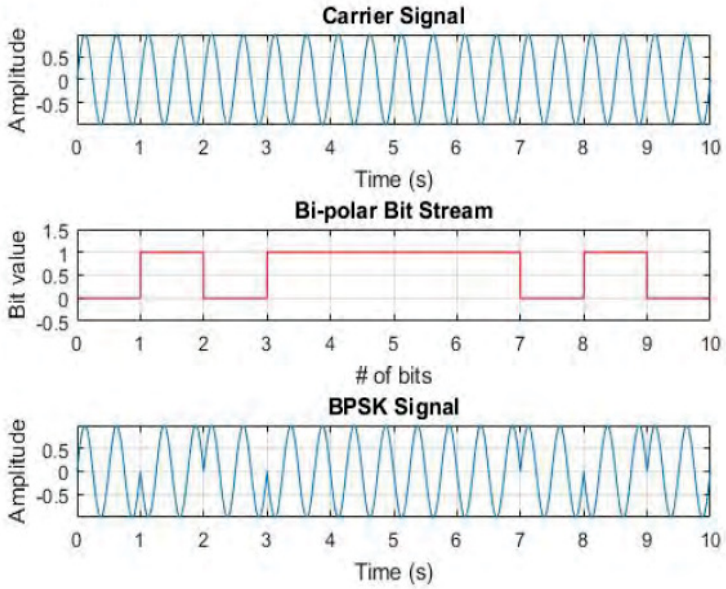

Figure 1.3: BPSK Modulation
[35]

carrier frequency is modulated with bi-polar bit stream, this will change the polarity of sine wave as shown in the figure (1.2).
From the figure (1.3) observe the BPSK signal, the symmetry is caused due to addition of Bi-polar bit stream to the carrier frequency. In GPS the bi-polar bit stream contains the navigation message transmitted by satellite.

1.1.2 GPS receiver output format

The output of a GPS receiver is a NMEA format. Which is a standard data format supported by all the GPS receivers at present. Table 1.1 and 1.2 explains each and every field in the received messages. The output of the GPS receiver are presented in chapter 4 section 4.4.

GNGGA message

Field	Contents	Meaning
0	*GNGGA*	Message ID
1	hhmmss.sss	(UTC) hh:[hour], mm:[minute], ss.sss:[second]
2	ddmm.mmmm	Latitute - dd:[degree], mm.mmmm:[minute]
3	a	"N" (North) or "S" (South)
4	dddmm.mmmm	Longitude - ddd:[degree], mm.mmmm:[minute]
5	a	"E" (East) or "W" (West)
6	x	Fix Quality - "0" (No Fix), "1" (Fix), "6" (Dead Reckoning)
7	xx	Number of satellites in use
8	xx	Horizontal dilution of precision
9	xx	Antenna altitude
10	M	Units of antenna altitude
11	xx	mean sea level below ellipsoid
12	M	Units of Geoidal separation, meters
13	xx	Checksum, alaways begins with *

Table 1.1: *GNGGA* Message Format

GPGSV message

Field	Meaning
0	Message ID *GPGSV*
1	Total number of messages of this type in this cycle
2	Message number
3	Total number of satellites visible (SV)
4	SV PRN number
5	Elevation, in degrees, 90 degrees max
6	Azimuth, degrees from true North, 000 degrees through 359 degrees
7	C/No
8-11	Information about second SV, same format as fields 4 through 7
12-15	Information about third SV, same format as fields 4 through 7
16-19	Information about fourth SV, same format as fields 4 through 7
20	The checksum data, always begin with *

Table 1.2: *GPGSV* Message Format

Dead-Reckoning

It is a technology that provides 2-D position fix when there is a loss of GPS signals. The user location is updated based on the user's last location fix, heading and velocity information, before the signal was lost [1].

Fix Quality Indicator

- 0 - Invalid (no fix)
- 1 - GPS Fix
- 6 - Dead reckoning
- 2 - DGPS fix (differential GPS)

The DGPS provides improved location accuracy. It uses a network of fixed ground-based reference stations to broadcast the difference between the positions indicated by GPS satellite system and the known fixed positions.

In this paper we are testing only the fix, no fix and dead reckoning. The DGPS is not considered as it requires a fixed ground-base reference station.

1.1.3 Dilution of Precision

It is used for calculating the precise positioning. It describes the strength of number of available satellites and their configurations [32]. As a rule of thumb, lower Dilution of Precision (DOP) results in good positioning. If the value is above 5, it is not acceptable for applications that require maximum precision.

Horizontal dilution of precision (HDOP)

This describes the affect of DOP on HDOP. If there are more satellites in view, better the HDOP and latitude and longitude values are.

1.2 Concepts

This section will discuss the main concepts which are used in this research.

1.2.1 Telematics

When the module is activated inside a vehicle, the related information is displayed on the instrument cluster. The vehicles information i:e vehicle identification number and location information from the GPS receiver and all the related data are sent to the host via cellular network. Thus the data sent over the cellular network should be reliable to identify the location of vehicle. For Example: The off board service team plots the coordinates on the map and directs the emergency team to the vehicle in case of an emergency[47].

The below figure 1.4 shows a basic working example of the telematics.

1.2.2 GNSS Vector Signal Generator

Introduction

In the present day there is an increasing demand for GNSS technology in a wide range of civilian applications. So it is very important that the GNSS technologies

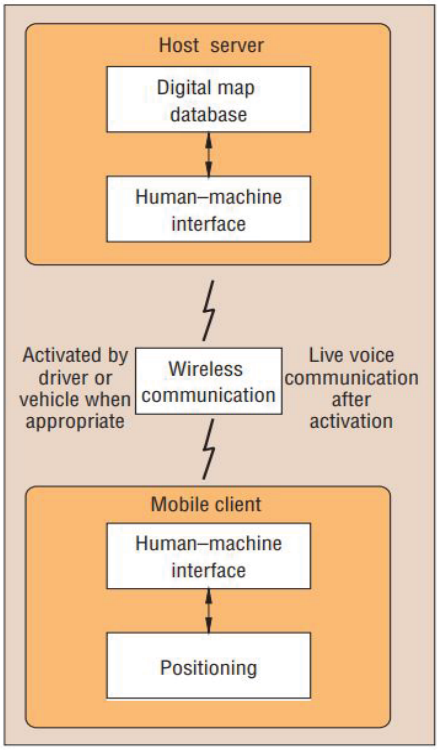

Figure 1.4: Basic Architecture of Telematics [47]

meet the requirements for specific applications[40]. To implement these requirements we have to focus on the product development life cycle from development to testing to production. This paper discusses the RF simulation testing, which is considered as a standard testing method over the past decade. This paper also provides benefits of using GNSS simulator for developers, testers and designers. And point out the cost benefits to project managers for improving business that involves GNSS.

Signal Analyzer

It is an instrument that measures the magnitude and phase of the input signal at a single frequency. We test the RF output signals, frequency domain characteristics and modulation domain characteristics [40].

RF Shielding Box

Used for reliable testing radio interfaces. RF test boxes enable reliable and reproduce-able measurements when a shielded test environment in needed [40].

What is a GNSS RF simulator?

The GNSS stands for Global Navigation Satellite System. A generator generates virtual satellite signals, and the RF output of the generator is given as input to the receiver, to process the signals and determine the location, time and speed. The GNSS include GPS, GLONASS, Galileo. A simulator provides an efficient and

effective way to test the receiver, it emulates a real world environment of a GNSS receiver by modelling the vehicle speed, satellite motion and signal characteristic. The receiver will process these signals in the same way as from a real GNSS satellite signal.

A signal generator provides a different way of testing when compared to testing with live GNSS signals. With the help of a generator a tester can have full control over the test and the tester can run various test scenarios.

1. **Date, time and location:** We can select any time of the day or year to generate a signal and test the receiver in a controlled lab environment.

2. **Vehicle Motion:** A simulator can model a vehicles motion and trajectory without moving the hardware, that is being tested.

3. **Error and inaccuracy:** A simulator provides control over the satellite constellation and the tester can test how the hardware behaves when certain constellation errors are occurred.

Why simulate?

Let us consider a fully operational GPS system. To test the receiver we can connect it to a antenna and place it on the roof of the vehicle and check, is it tracking the signals or not. This type of test is called as "Live Sky" which would verify the operations of RF and processing circuits inside the receiver. But we are interested in testing rather than checking the operation, so the "Live Sky" method is not the one to be relied upon when testing a products life cycle from concept-design-development-production and integration.
Below we will discuss about more reasons in detail.

1. **Multipath:** The GNSS signals are direct line-of-sight and reflected signals from the reflective surfaces. The receiver cannot differentiate between the direct signal and the reflected signal, so it uses both the signals. Due to error in the reflected signal there will be an error in the receivers position estimate. Therefore with the help of a simulator we can totally eliminate multipath and apply multipath models to the simulated signals in a controlled environment and analyze the performance of the recevier in the presence and absence of multipath.

2. **Repeatability:** All the test scenarios run on a simulator have similar signals with same date, time and satellite constellation. We can assure that the receiver is being simulated with the exact same signals every time a test scenario is run. In this way we can verify the receiver performance and any design modifications made.

3. **Controllability:** One of the main important points while testing is accurate control over the test. As mentioned above in the "Live Sky" we have very little control over the test, we only have control over the antenna and the location. To have complete control over the test, we need to control date,time and satellite signals, which cannot be done in the case of "Live Sky" testing.

4. **Accuracy:** The important parameters of accuracy is quality and reliability. Signal's generated from a simulator are reliable and have better quality than real GNSS signals and allows to perform rigorous testing in a lab environment. The noise generated from simulator is much less than the thermal noise, so the noise factor is negligible during the test.

5. **Capability:** A simulator have the capability to simulate a motion of a vehicle beyond it's characteristics, for a particular application. Therefore we can test the receiver's maximum performance beyond it's intended need something that cannot be done by any other means.

1.3 Test Case Selection

Time and resources are very important in software testing and improving the test suites is very crucial in software development process. The test suites aims at eliminating redundant data to improve testing procedure. For a reliable software, testing is crucial and there are limitations in its execution such as time, automated tools, increasing costs and poor planning [25].

In software testing a detailed specification about a test is called as test case [38]. A valid test case includes a detailed specification of input parameters, execution environment and expected results. And one or more test cases are know as test suites. As the software requirements increase, running the test suites will be very difficult with limited resources and time.

Test case selection comes into picture that selects test cases based upon specific criteria that helps eliminating redundant data and maximise fault detection. This approach provides solution for developing testing strategies.

Yoo and Harman [44] wrote a survey that discussed various methods to minimize test suites, test case selection, and prioritization.

A systematic review is conducted for the test case selection. Our main objective is to provide accurate information by analyzing the data from scientific papers.

1.4 Motivation/Problem

There are acceptance and regression test suites that verify the functionality of RTC. Third party components such as the GNSS module are not a part of the tests due to technical limitations in the test method. Hence RTC lacks automated tests for important features.

To verify the GPS receivers, extensive testing is done in real world conditions. This requires vehicles and excessive hardware, which results in time consuming and very expensive. And the introduction of the new telematics products can be delayed. So this scenario which motivated me to do this research provides a methodology to verify the GNSS module in a controlled environment and repeatable manner. This methodology consists of various test cases that were developed on a GNSS vector signal generator in a controlled lab environment.

1.5 Aim and Objectives

The aims and objectives of this thesis are:

- Aim
  - To investigate and analyze how to best verify the GNSS module.
  - Black box tests and exploratory tests have to be created that show functionality of GNSS module.
  - To verify the functionality of RTC in a controlled environment.
- Objectives
  - Setting up the GNSS signal generator.
  - Connecting the signal generator to the RTC by using a radio frequency connector.
  - Establishing a connection between signal generator and computer via LAN.
  - Implementing the Hardware In Loop (HIL) testing.
  - Initialize the HIL operation.
  - Sending SCPI commands from the computer to signal generator to test different scenarios.
  - Receiving the output logs from the RTC (C300).
  - Verifying the output logs with the given input data.

1.6 Research Questions

This research focuses on the following research questions:

- **RQ1:** How to use the signal generators to give field-like input to the RTC and verify the behavior of GNSS module?
  - **Method used:** To answer this research question a HIL (hardware in loop) experiment is performed.
- **RQ2:** How to integrate the test cases in the automatic test suites to extend the regression testing to include all components of RTC?
  - **Method used:** To answer this research question a literature review is conducted, to identify the required method.

1.7 Outline

This thesis document consists of six chapters. Chapter one gives a brief introduction on the topic and the concepts involved in the research and problems related to GPS receiver testing. Chapter two describes the related work that is implemented in the field of testing GPS receivers and its technologies. Chapter three provides a detailed methodology that is implemented in order to answer the research questions. chapter four gives us an analytical knowledge of the results, obtained from the implemented methodology. In Chapter five the research questions are answered and threats to validity are defined. And in chapter six conclusions are provided by summarizing the results and future work is also highlighted for further improving the research topic and to identify new topics in this area of research.

Chapter 2

Related Work

> Research is to see what everybody else has seen, and to think what nobody else has thought.
>
> Albert Szent-Gyorgyi

An architecture on smart healthcare services based on cellular mobile communication and GPS is proposed in the research [4]. The main aim of this study is to provide emergency healthcare services to patients in the hospitals. By measuring the vitals values of the patient and comparing them with the standard values and if found outside the range of standard values, an emergency SMS is sent with patients name, body temperature, heart rate to the concerned doctor with the exact location and time stamp. Thus provides quick intervention in hospitals in emergency situations. Therefore in many situations the receives GPS signal may not be accurate due to weakening of GPS signal. From this paper we have addressed the above problem and used signal generator to simulate this scenario. These results will be helpful in further improving the GPS receivers.

Vehicle Positioning with GPS in urban canyon environment is investigated in the paper[15]. Which discuss the problems faced by the GPS receivers in urban canyon environments, where the signals are blocked by tall structures and due to less number of satellite signals we cannot estimate the position fix. This means for a particular journey, point-wise positioning accuracy is not available. To solve this, the proposed method is by approximately modelling the path of the vehicle with straight lines and curves. As the vehicle travels in a certain path i:e section of road, modelling the path with straight lines and curves which actually resembles the section of the road is known as "priori". With this the position information can be obtained with a few satellites as the number of satellite signals reduces to less than 3. As most of the cities have detailed maps information, we can obtain the vehicles path from the maps. But the approximated model will differ from the actual path, so it has to be estimated. From this paper, the Kalman filtering technique and the state augmentation method are used simultaneously to approximate the location accuracy and the actual path.

Performance of GPS under forest canopies is studied from the research [48]. Which discuss the performance evaluation of GPS receiver under different canopy densities. The GPS provides the GPS receiver with satellite signals which enables

the receiver to calculate the position, velocity and time. To get the position fix it requires signals from at-least four satellites, these signals have to travel a long distance to reach the receiver on the earth. One of the main errors caused in the forest is multi-path propagation due to trees. This results in secondary paths and obstructs the original signal and manipulate the phase and amplitude. The error in position caused by multi-path propagation can be as high as 60-80 meters. Because of this the receiver update time is longer than usual, and causes problems for applications that require constant positioning updates[2]. From this paper, Image processing techniques such as Otsu's Algorithm was used to classify the canopy density into three levels and position errors were calculated using ANOVA.

Estimation of GPS receivers using Re-reference system is investigated in the research [26]. With the Re-reference system we can test the satellite system in lab environment with the receiver. Setting up the Re-reference system we can receive the satellite signals in the room environment. The Re-reference diagram is shown in the figure (2.1). The accuracy of the receiver is calculated by knowing the exact location of the receiving antenna. The test results from the proposed solution show that the errors take place during signal distribution which is caused due to location of satellites. This paper gives an idea on how the Re-reference system can be used to determine the average errors which are caused due to location of satellite and signal distribution.

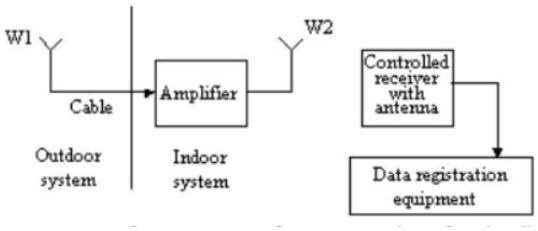

Figure 2.1: Re-reference system
[26]

GNSS receiver performance, challenges and test approaches have been studied from the research [14]. The research is discussed on providing position accuracy to Intelligent transport system (ITS) in the automotive industry using a hybridized GNSS receiver. The GNSS receiver based on software defined radio (SDR) is discussed. In the cases where the vehicle does not receive the GNSS signals such as tunnels or closed parking garages, to avoid such scenarios navigation accuracy is measured by integrating the measurements of GNSS receivers and sensors (Internal Measurement Unit) connected to the vehicle. Integration is done at different levels, depending on the final application. Loosely coupled process is used where the GPS and internal data are combined to provide the performance at low cost. Tightly coupled process is used where internal data comes from different sensors controlled by control area network (CAN).This paper provides the benefits of using GNSS receiver based on SDR. At the first level raw satellite signals are received and converted. Level two consists of information to calculate the location and third level consists of final location and time calculated by the receiver. The test results show that the

sensors are able to store the data at level 2 and level 3. Level 2 is used to design the loosely coupled algorithms and verify the performance of the algorithm. The data stored at low level 1 verifies the quality of received signal and also analyze the GNSS receiver.

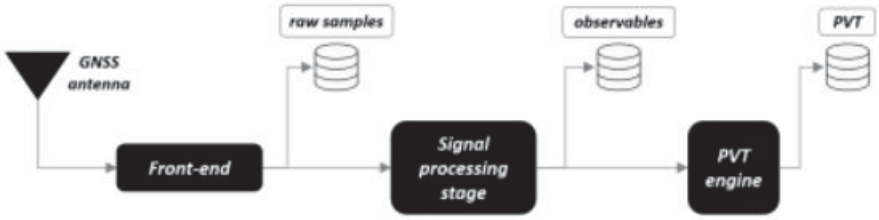

Figure 2.2: Data output levels
[14]

We can create large test suites with help of software tools such as Tobias[12], TRUST[28]. But running these large test suites is not efficient because of time and resources. So we have to take the required steps to decrease the test cases.

Reducing the test suites means removing the redundant data for testing, that decreases the test cases. There are two options that can be used, minimizing the test suites and test case selection. Minimizing consists of reducing the test criteria, that reduces the test cases this is explained with partitioning. An example is shown in the figure 2.3.

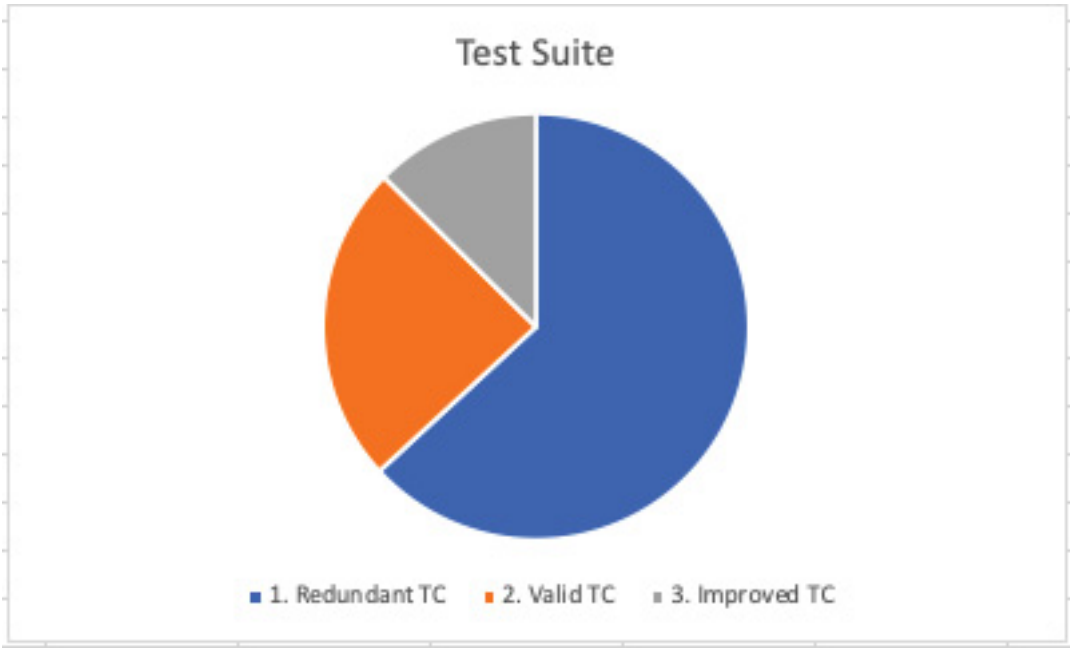

Figure 2.3: Partitioning test suite

From the test suite partitioning Qu et al. [37] considered only the test cases that are associated with the latest configuration changes in the testing program. Where as

Zeng et al. [46] adopted the partitioning, based on the importance and partitioning is done and verified through data correlation.

On the other hand test case selection uses the approach of selection based on the similarity. If two test cases are dissimilar then detecting the faults becomes easy. Hemmati et al. [24] said that the purpose of using similarity concept is to detect faults in a test suite that contains maximum number of test cases. There is another approach known as prioritizing of test cases. Here only those test cases are selected for execution, which are most appropriate to the test data, to detect faults and fasten the debugging process.

- The test suites are permanently reduced in minimization, unlike test case selection [44].
- We cannot select pre-established test cases for execution in minimization, which is a dis-advantage when compared to test case selection [23].

Chapter 3

Methodology

This chapter describes the procedure that was used to implement on the GNSS/GPS satellite signal generator, to create radio frequency scenarios and evaluate/verify the performance of the GPS receiver.

3.1 Environment setup

The below figure describes the laboratory setup of the satellite signal generator. Hardware in loop is a testing method used where the device under test (DUT) is placed inside a simulator that simulates a real-world environment for the DUT in real-time. Here the device under test is the GNSS receiver. It is controlled via inputs and outputs.

- A processor that converts the simulated virtual environment into real-time using mathematical models.
- To interact with the receiver analog and digital inputs are given.
- A user interface to provide commands and to monitor the operation.

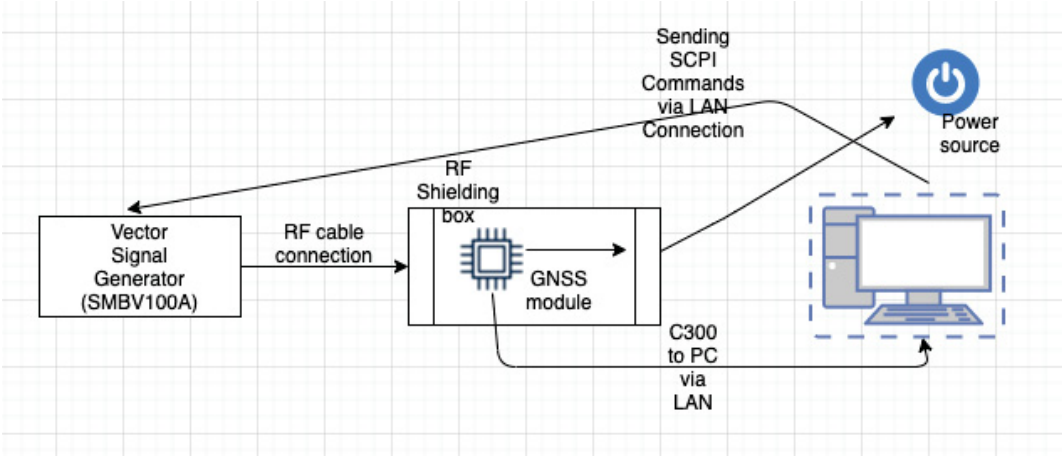

Figure 3.1: Experiment Setup

In the HIL testing the receiver receives inputs from the signal generator that consists of sensors and various components used for signal generation, and emulates

a real world scenario without any difference from the virtual reality. We use CLI to check the output logs from the GNSS module. Testing the GNSS receiver with signal generators is beneficial because we can analyse its performance, functionality and errors in a controlled and repeatable lab environment. The HIL testing is widely used in automobiles and aviation.

3.2 Signal Power Level Calculation

- The minimum power received at the earth's surface is -160dBW/Hz assuming clear sky.
  - The satellite uses 478.6 Watts Tx power transmitter (26.8dBW).
  - The average range is 2 $\times 10^7$ m and free-space path loss (L) is given by

    L = $10.Log_{10}$ $(\lambda/4\pi R)^2$ [7]
    λ = Wavelength (19cm for 1575.42Mhz L1 carrier), and R is the range.
  - We have L = -182 dBW.
  - Due to atmospheric loss we get around -160 dBW value. This is further reduced due to multi-path from tall buildings and trees.
- Carrier-to-noise-ratio (C/No) calculation:
  - The C/No is defined as ratio of received carrier power to noise power per unit bandwidth. Expressed in decible-hertz (dB-Hz).
  - If C/No is higher it results in reduced carrier and bit error rate, that in-turn results in reduced noise and accurate positioning.
  - C/No is estimated as:
    C/No = $S_r + G_a - 10.Log_{10}(K) - 10.Log_{10}(T_{sys}) - L(dB - Hz)$ [36]

Typical values of GPS L1 C/A code are:

- S_r is received GPS L1 signal power = -130 dBm
- G_a is receiver antenna gain to satellite = 0dBi
- K is Boltzman's constant = 1.38 $\times$ 10$^-$23 Watt-sec/K
- T_{sys} is system noise temperature = source noise + receiver noise
- The noise from an antenna is around 100k and with a signal generator the noise is at 290k and the receiver noise is around 420k. From all the above values considering receiver noise and noise from signal generator, the C/N0 value is 40.9 dB-Hz.
- The system noise is dominated by receiver, but we also have to consider noise at source, i:e antenna noise or noise from signal generator.
- For GPS L1 with open view of sky, the C/N0 values ranges from 35 to 55 depending on the angle of transmitting antenna and gain of receiving antenna.

3.3 Verification of the Generated signal

For evaluating the receivers performance the signal generated from the simulator should have accuracy, stability, precision and wide range. Generally the simulated signals are spreading signals, buried in thermal noise and are difficult to measure using regular techniques. The RF output port of the simulator is considered in the testing and to obtain the black-box performance test results of the simulator by using a vector signal analyzer. This approach minimizes the testing design requirements of the simulator and focuses on the internal implementation of RF output. We test the RF output signals frequency domain characteristics and modulation domain characteristics. The RF output results are discussed in the next chapter(4).

3.4 Performing a simulator test

Setting up a GPS receiver to test with a simulator is very straight forward and can be categorised into:

1. **Explanation:** At this stage all the required specifications on the simulator are set-up using the simulator software. The following points should be considered.
    - Understand the receiver application and the operating situation.
    - Perform the required necessary tests.
    - present the detailed test scenario with effects.
    - Connect the receiver to the simulator for a good RF reception.
2. **Run-Time:** Here the test scenario is running on the simulator to produce a required RF signal. The following points should be considered.
    - Monitor the receiver and change the settings on the simulator accordingly.
    - Analyze the receiver. This can be done in real time or by analyzing the data, by logging the output data into a file and comparing it with the actual simulation data.

3.5 The methodology of simulation

The signal generator simulates real world conditions for the GNSS receiver. It generates positioning data and given as input to the receiver. To communicate and give inputs to the signal generator we can use the GUI or LAN connection and send SCPI commands, a programmable command language for the hardware components. The signal generator processes these commands and generates a GNSS signal accordingly and this generated GNSS signal is given as input to the receiver, and the receiver calculates a fixed position data, and it is delivered at the output port of the receiver. Now the loop continuous. The user sends a new position data and the signal generator processes the data in real time and generates a updated signal. This updated signal is given as input to the receiver, and the loop continuous.

3.5.1 Initializing the HIL operation

There are 2 types of simulation modes present in the signal generator "Auto Localization" and "User Localization". The Auto localization mode automatically adjusts to the standard frequency of the GPS L1 signal, number of satellites in view and their power levels. Where as in User localization mode we can decrease or increase the number of satellites in view, frequency and power levels. Here we have to select "Auto localization" mode.

Figure 3.2: Step 1
[40]

With the GPS Auto Localization mode in the signal generator, the frequency of the GPS signal and the satellite power levels are set to standard values. So testing in this mode will give us accurate results. Where as in User Localization mode, all the frequency values and satellite signal power levels can be changed according to the user's requirement. This will result in inconsistent data generation and ultimately there will be changes in the output values, which are not acceptable.

The type of the vehicle is selected as "HIL"

Figure 3.3: Step 2
[40]

Positioning data is sent as shown in the below figure (3.4).

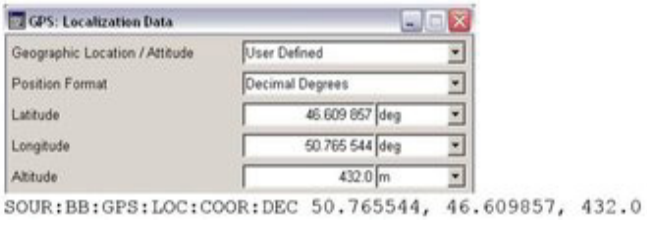

Figure 3.4: Step3
[40]

3.6 Synchronise

The input SCPI command should be synchronized with the elapsed time in the signal generator. The signal generator evaluates the received signal with a 100PPS signal which is present internally, not visible externally.

3.6.1 Input command is synchronized with simulator

The input command is sent in synchronous with the 100PPS signal. The time taken to process the received command is 5ms. The execution is synchronous with 100PPS signal. And the output is obtained in the next 100PPS pulse signal. As shown in the below figure (3.5).

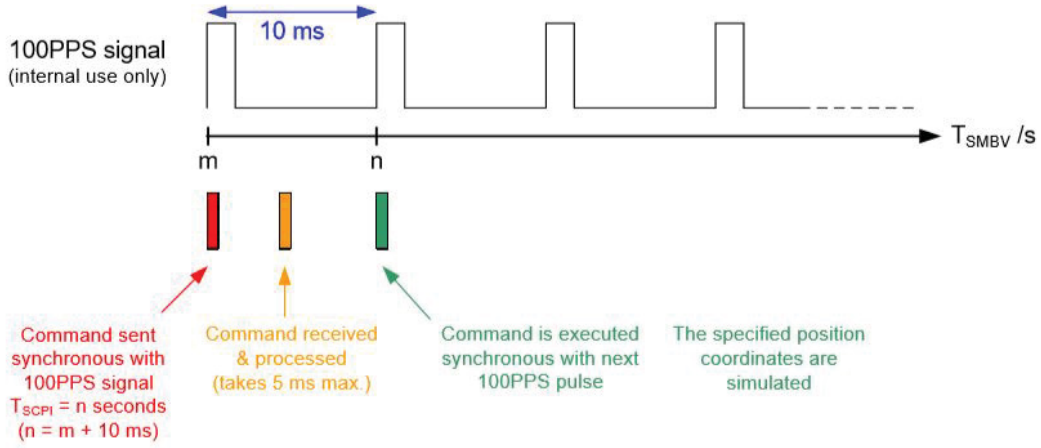

Figure 3.5: Synchronized command
[40]

3.6.2 Delay in input command

Let us assume when a input command is sent to the signal generator, the input command "m" is not synchronised with internal 100PPS signal "n". Then the signal generator extrapolates the data using a specific prediction algorithm internally. Extrapolated position coordinates are simulated at every 100PPS signal until a new command is sent. As shown in the below figure(3.6).

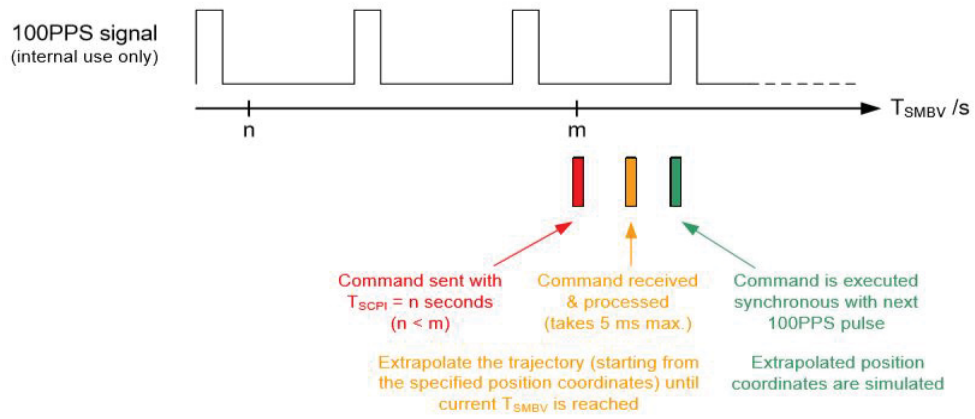

Figure 3.6: Command is not synchronized
[40]

3.7 Latency

The term latency describes how fast the satellite signal generator can respond to the given input values. Three major points are discussed in this section.

- Processing Latency
- Output Latency
- Updating Latency

3.7.1 Processing Latency

This is described as, how fast the signal generator process the input commands. The minimum processing time of the signal generator is 5ms, including sending of commands via the USB/LAN.

3.7.2 Output Latency

This is a hardware error, as it takes approx 20ms to transfer the processed data at RF output port.

3.7.3 Updating Latency

How fast the signal generator can update the simulated position coordinates. The minimum update time of the signal generator is 10ms.

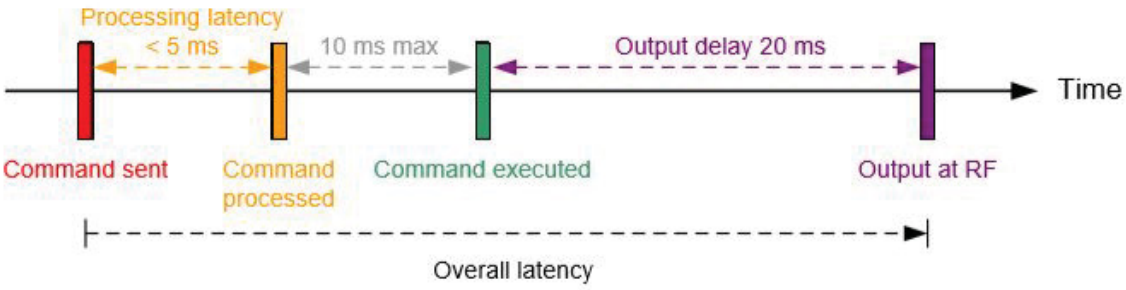

Figure 3.7: Latency
[40]

3.8 Standard Tests

For the laboratory testing of the GPS receiver a range of standard tests should be conducted to verify the functionality of the receiver under normal and special conditions. The tests carried out individually or combined are listed below.

3.8.1 Time to First Fix (TTFF)

The time to first fix is a very important parameter for validating the GPS receivers. The time taken by the receiver to acquire its actual position is very important in consumer grade GPS receivers. The GPS receivers must download the almanac data from the satellites through a navigation message (the almanac data file is present internally in the signal generator) , in cold start TTFF condition it takes 30-60sec for the receiver to download the GPS frame and get a position fix. The TTFF measurements should be taken under various conditions as the GPS satellites revolve around the earth every 12 hours[29]. There are three TTFF conditions which are discussed below.

Cold Start:

The GPS receivers need to download the almanac data and get a position fix. Most modern day consumer grade GPS receivers get a position fix in 30-60sec depending on the receiver in cold start conditions.

Warm Start:

In this condition the GPS receiver have some almanac data stored from the previous weeks. Most modern day consumer grade GPS receivers get a position fix in less than 10 sec in warm start conditions.

Hot Start:

In this condition the GPS receivers have the latest almanac data and require the timing information of satellite to acquire the position fix. Most modern day consumer

grade GPS receivers get a position fix in less than 5 sec in hot start conditions.

Apart from personal use GPS is used as an application for the logistics industry to optimize their operations. The start up time of the GPS receiver is very important for the industry, this is when the first position fix should be accurate without any delay. This is where TTFF is a very important measurement. Garmin et al said that the first position fix have a large error than the following fixes[20].

The formula to evaluate the arithmetic mean of the measured TTFF values is:
$T = \frac{1}{k} \sum_{i=1}^{k} T_i$
n is the total number of measurements and T_i is the i times of TTFF values.

The standard deviation is:
$S = \sqrt{\frac{1}{k-1} \sum_{i=1}^{k} (T_i - T)^2}$

The range of values can be taken as $T \pm 2S$

3.8.2 Re-acquisition Time

The GPS receivers are tested for navigation and position accuracy, but the speed at which these signals are received and processed is also tested which is known as re-acquisition time. The time to re-acquire a signal after a loss for a short period of time is gaining more importance due to increase in signal loss in urban areas and due to high rise buildings. There is no standard measurement for the re-acquisition time but it varies from one manufacturer to another.

A simulator can be used to generate GPS signals without any atmospheric or multi-path errors (Perdue et al. 2015). GPS signal simulator receives the input parameters as location and time and generates the signal accordingly for the GPS receiver to process these signals. The receiver's internal clock is synchronised with the simulated GPS signals. Even if the signals are received again after the signal loss, the internal clock is not synchronised immediately as the re-acquisition is not occurred yet. For example, when a vehicle enters a tunnel all the signals are lost, and we check how fast the receiver can get a position fix when the signals are restored.

3.9 Methodology for test case selection

A systematic review is an accurate and solid methodology for collecting relevant research, evaluating the data, and estimating the results [16]. This paper follows the three phases, planning, execution, and data collection as mentioned by Kitchenham [6]. This section provides planning and execution and the next section provides results. The keywords used for searching are "test case selection", "test suites", "test case prioritization". The following scientific databases were searched to get an insight into the on-going research.

- IEEE Digital Library

- Scopus Digital Library
- ACM Digital Library

Inclusion and exclusion criteria in a systematic review are meant to minimize the study based on qualitative evaluations and to ensure primary objective is reached.

Inclusion criteria

- Studies that include practical results on TCS (Test case selection)
- Qualitative studies on TCS.

Exclusion criteria

- Studies that include practical results without analyzing.
- Studies focusing on test suite minimization, test case generation.

3.9.1 Execution of systematic review

The below table shows the following search process. A total of 214 papers resulted from the search, and all are in English. We considered the search from 2006-2012. After excluding duplicates, it narrowed down to 160 papers.

Step	Process	Result
1	Search	214 Papers
2	Duplicates, Inclusion and Exclusion criteria	160 Papers
3	Removed by title	58 Papers
4	Reading Abstracts	24 Papers
5	Reading Full paper	24 Papers included

Table 3.1: Search process

In the third step papers were manually screened based on title and abstract, this resulted in 58 papers. And in the next step, reading the abstracts and applying inclusion criteria resulted in 24 papers, which are included. The below table shows number of papers screened from each database.

Database	Result	Included
IEEE	71	7 Papers
Scopus	68	6 Papers
ACM	75	11 Papers
Total	214	24 Papers

Table 3.2: Papers screened from each database

Chapter 4

Results and Analysis

4.1 RF output results

The below figure (4.1) represents the FFT spectrum analyzer, the Orange wave indicates the maximum power, the green wave indicates the average power and the blue wave indicates the minimum power. It calculates the Fast Fourier Transform of the measured RF signal to achieve the frequency domain representation. The power measured in the below figure for a GPS L1 frequency is in the required acceptable range.

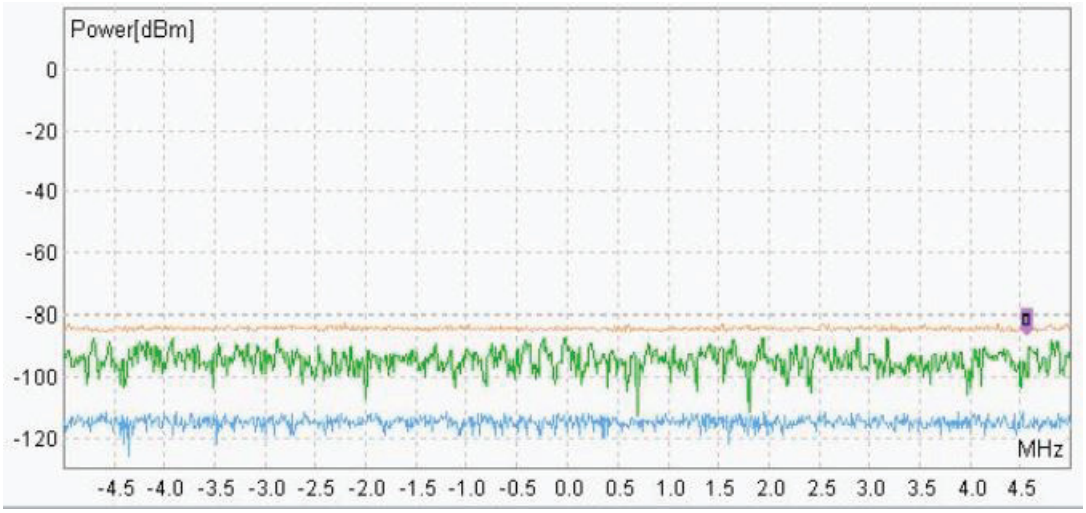

Figure 4.1: FFT Spectrum

The below figure (4.2) represents the CCDF curve captured on the RF channel. To extract useful information from a signal that has noise, we need statistical description of power levels in the signal. X-axis is the above the average signal power and Y-axis is amount of time a signal spends above the average power level. The CCDF curve indicates peak-to-average deviation. As seen in the figure at 1% of the time, the average power exceeds by 7.2 dB. We can say that the generated signal have very less noise, which is negligible.

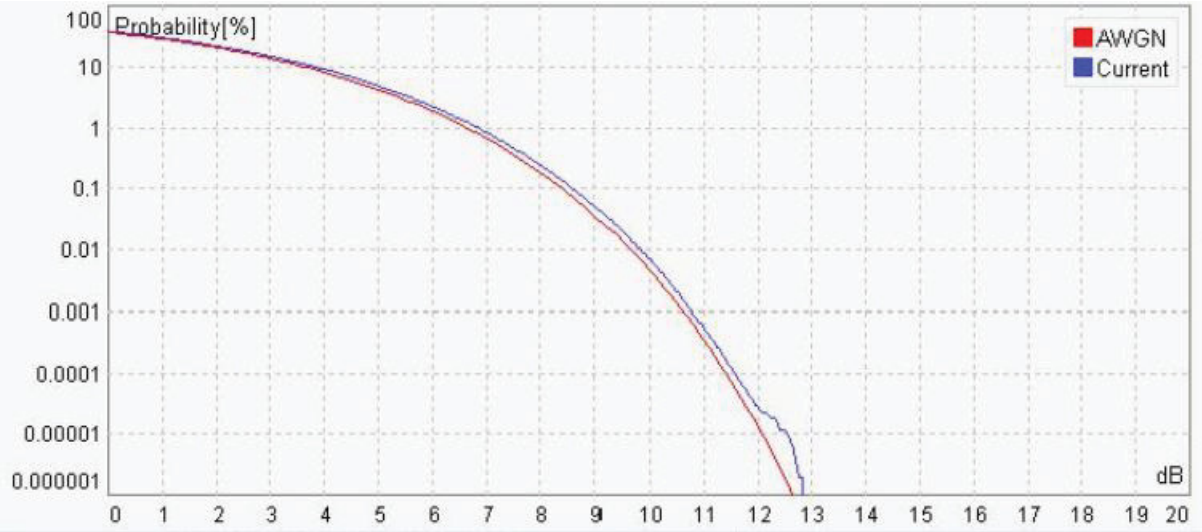

Figure 4.2: CCDF

The below figure (4.3) represents the IQ data plot of the generated signal. On X-axis we have t/transient recorded samples and on Y-axis we have amplitude. In BPSK modulation we know that the phase of the carrier wave is modulated by binary symbols "1" and "0". When digital signal changes from "0" to "1" there is a phase shift of π, which is seen in the diagram.

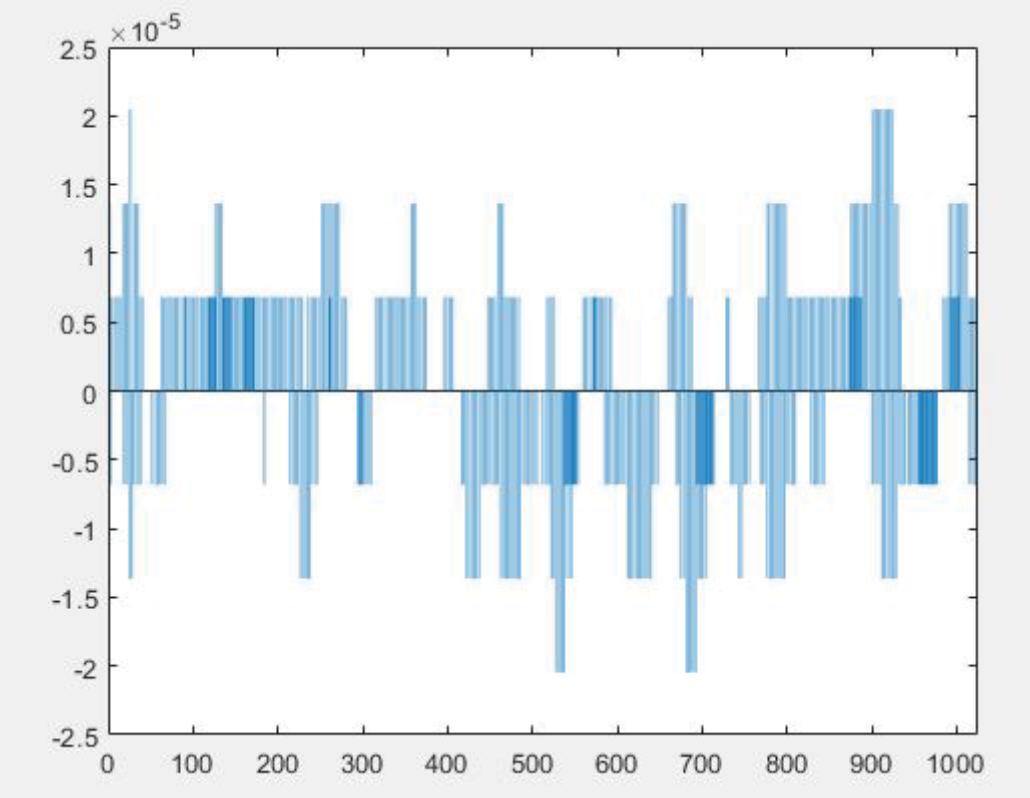

Figure 4.3: IQ Data

4.2 Results for Time To First Fix in Cold, Warm, and Hot start conditions.

The table 4.1 provides the TTFF values for four different simulation scenarios with same Latitude, Longitude and Altitude. It is crucial to test TOWs because the available satellites changes substantially even over the course of several hours. The values are chosen randomly, as different times in a day.

Date	Time of Week	Cold TTFF	Warm TTFF	Hot TTFF	Max SATS
Simulation 1	301096	38.3	2	1	12
Simulation 2	376424	37.1	2.5	0.8	12
Simulation 3	488024	35.7	3	1	12
Simulation 4	124424	36	3	1.1	12
Average	NA	36.775	2.625	0.975	NA
STDEV	NA	1.18145391	0.47871355	0.12583057	NA

Table 4.1: TTFF Values

In addition to the TTFF values, the accuracy of Longitude, Latitude and Altitude is also measured at various TOW because the availability of satellites changes with time. The results are provided in the table 4.2.

Date	Time of Week	Latitude	Longitude	Altitude	HDOP (m)
Simulation 1	301096	50.765545	46.60985	429.4	0.8
Simulation 2	376424	50.76554	46.609846	430	0.8
Simulation 3	488024	50.76555	46.609855	426	1
Simulation 4	124424	50.765545	46.60985	430	1.2
Average	NA	50.765545	46.60985025	428.85	0.95
STDEV	NA	0.000006	0.000012	1.92093727	0.9148542
Simulated	NA	50.765544	46.609857	432	NA

Table 4.2: Accuracy at different TOW

The availability of satellites change with respect to time, so to verify the GPS receiver we can test the receiver at same time with number of trails. This also verifies weather the RF output adds uncertainty to the GPS signal or not. The table 4.3 shows the similar results when the same simulation scenario is used multiple times.

No of trials	Time of Week	Latitude	Longitude	Altitude	HDOP (m)
Simulation 1	301096	50.765545	46.60985	429.4	0.8
Simulation 2	301096	50.765545	46.60985	430	0.8
Simulation 3	301096	50.765545	46.60985	426	0.8
Simulation 4	301096	50.765545	46.60985	430	0.8
Average	301096	50.765545	46.60985	428.85	0.8
STDEV	0	0	0	0.6942622	0
Simulated	NA	50.765544	46.609857	432	NA

Table 4.3: Number of trials

4.3 Results from GPS receiver test cases

Test Case 1: Input signal with minimum satellites in view

To acquire a position fix the minimum number of required satellites is 4. Minimum satellites considered in the test cases are 4. The DOP values describe the current strength of satellite configuration (geometry). In the figure (4.4) the Horizontal dilution of precision value is 32. The effect of the DOP on the horizontal position value. The more good visible satellites in the sky, the better the HDOP and the horizontal position (Latitude and Longitude) are. As a rule of thumb, DOP values above 5 are not acceptable to meet the requirements of all the sensitive applications.

Figure 4.4: Test Case - 1

Test case 2: Input signal with maximum satellites in view

GPS constellation have 24 satellites. Maximum satellites considered in the test cases are 12. From the figure (4.5) the strength of satellite configuration (geometry) is good when maximum satellites are available, so we observe the Horizontal dilution of precision (HDOP) value obtained is in the range of 1-2. And C/No values are in the required range. These values describe the highest possible position accuracy, for applications that demand highest precision at all time.

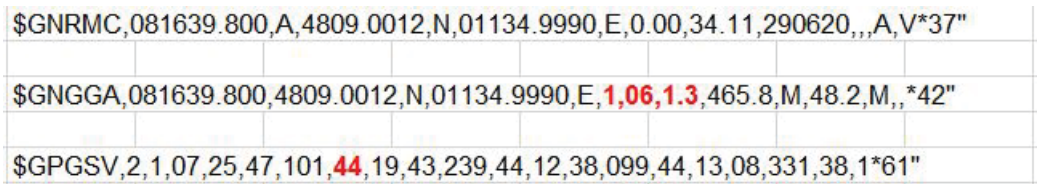

Figure 4.5: Test Case - 2

Test case 3: Input signal changes from >4 sats to <4 (signal lost test)

The figure (4.6) describes, when there are maximum number of satellites(max satellites given 12) we get a position fix denoted by (TC-2). The C/N0 is (51) as highlighted, which indicates a good GNSS signal reception. When the signals from satellites changes from maximum to less than minimum required (2 satellites given). The dead reckoning is activated (approx time to activate 15sec, i:e indicated by 6). Tracks the position of the vehicle for 9 sec (as measured during the test). And ultimately the position fix changes to (0) when there are no signals available, it extrapolates the last available position co-ordinates.

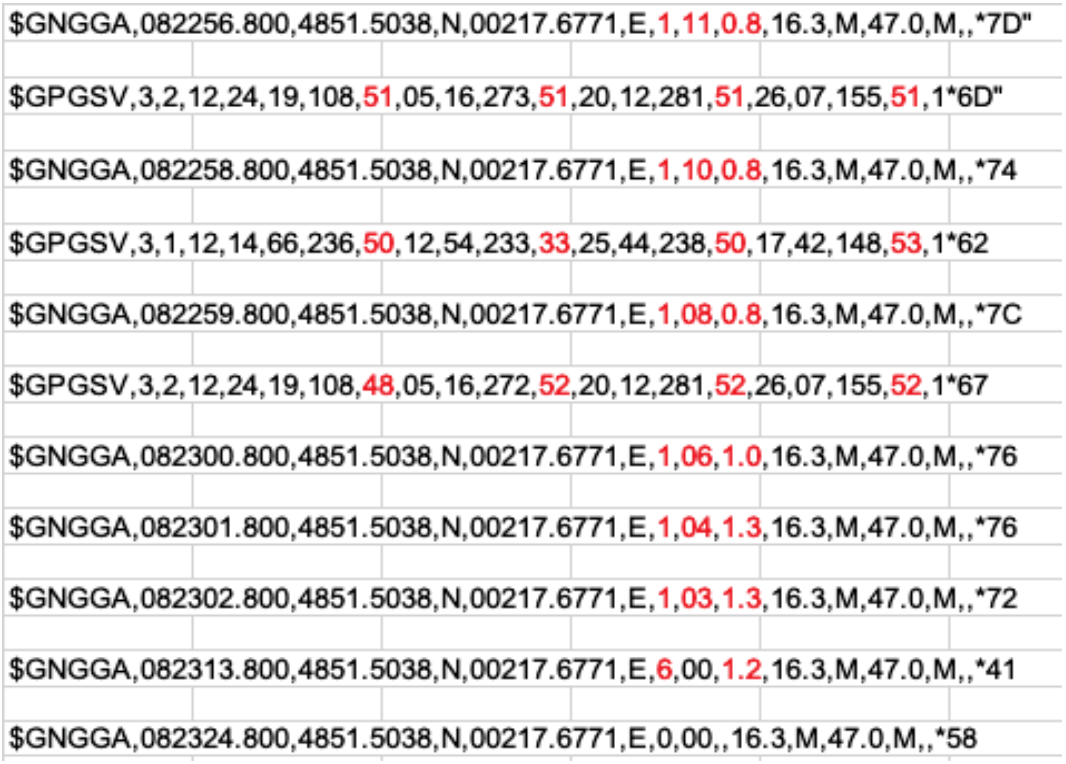

Figure 4.6: Test Case - 3

Test case 4: Input signal changes location Big time

The figure (4.7) presents the result where the module has the fix at location (1) and when new signal is sent with location (2) co-ordinates, the dead reckoning feature is activated for 15sec (as measured during the test), and then looses the fix and extrapolates the location (1) coordinates, until the GNSS module acquires the location (2) fix. In this test we are testing the GNSS module with a sudden change in location co-ordinates and checking the output.The C/No ration is 54 dB-Hz which indicates a good reception of the signal.

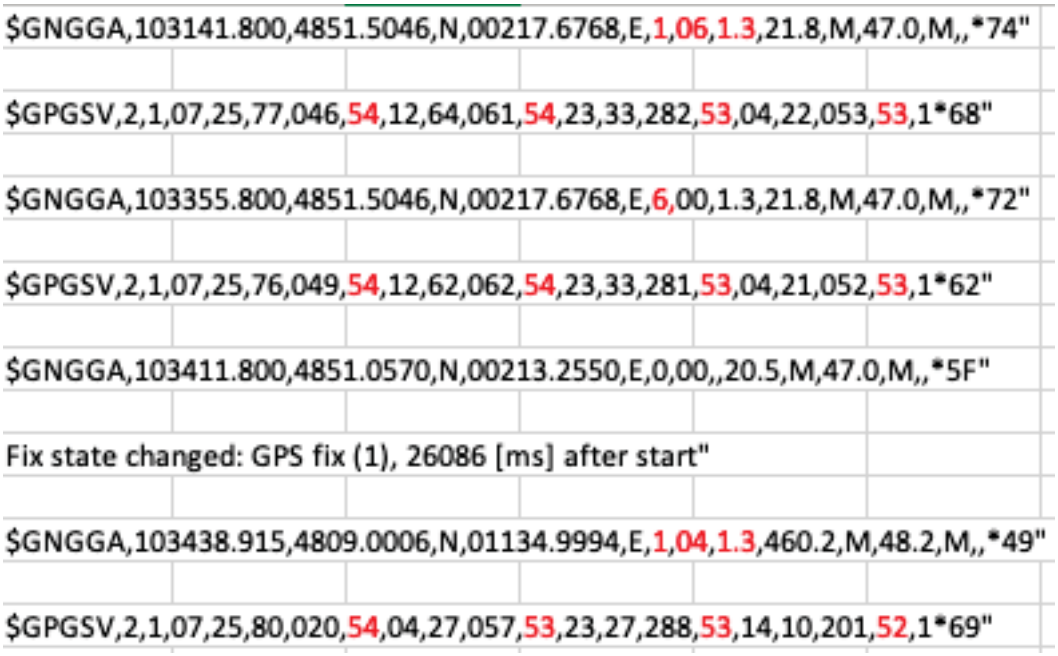

Figure 4.7: Test Case - 4

Test case 5: Input signal at location 1 and close GNSS module and set location 2 and start GNSS module

The figure (4.8) presents the result where the module have a fix at position (1) and then switching off the module and updating the new position (2). The GNSS module extrapolates the position (1) co-ordinates until the new position (2) fix is obtained. The C/No ration is 52 dB-Hz which indicates a good reception of signal.

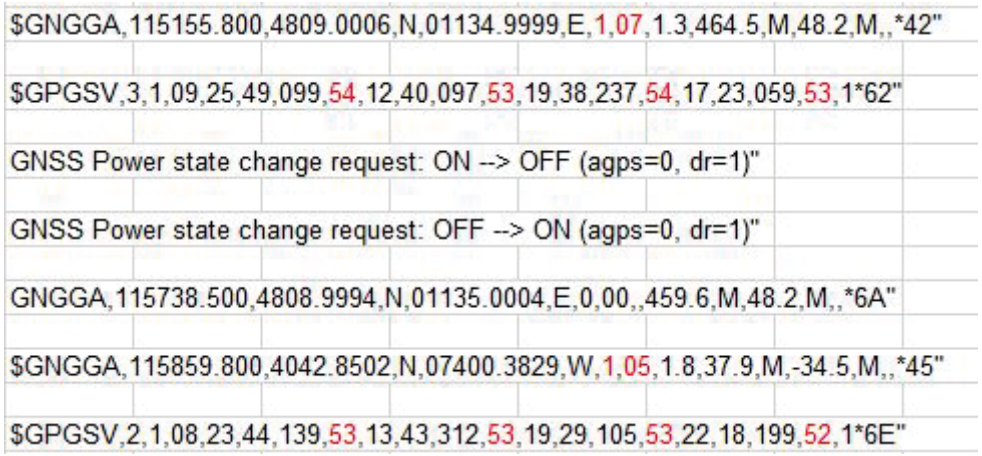

Figure 4.8: Test Case - 5

Test case 6: Input signal at location 1 and close GNSS module and set location 2 and start GNSS module (set no of satellites <4)

The figure (4.9) presents the results where the module have a fix at position (1) and then switching off the module and updating the new position (2), when the GNSS

module is switched ON with less than 3 satellites in view, it does not loose the co-ordinates position completely but instead it extrapolates the co-ordinates of position (1).

Figure 4.9: Test Case - 6

Test case 7: Input signal at location 1 and close GNSS module and set location 2 and start GNSS module (set no of satellites <4 and gradually increase)

The figure (4.10) presents the results where the module have a fix at position (1) and then switching off the module and updating the new position (2), when the GNSS module is switched ON with less than 3 satellites and gradually increasing the number of the satellites, it does not loose the co-ordinates position completely but instead it extrapolates the co-ordinates of position (1) until it acquires a fix for position (2). The C/No ration is 41 dB-Hz which indicates a good reception of the signal.

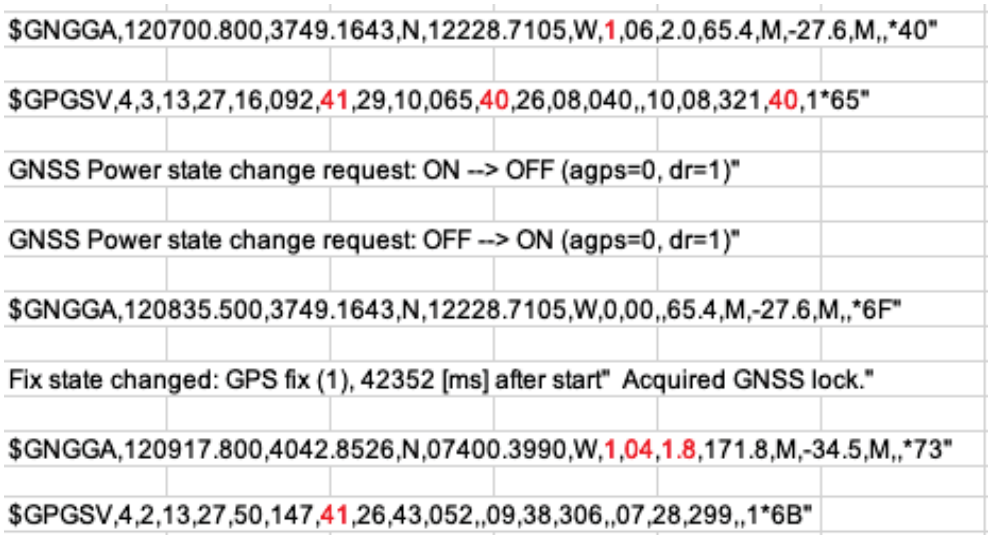

Figure 4.10: Test Case - 7

4.4 Results for Test case selection

In the selected papers, mostly empirical study is suggested for test case selection. Published by more than 70 different researchers. The below table shows the area of research by different researchers.

Author	Publication	Research area
Liu, H	4	Adaptive random testing
Huang, H.D	2	Adaptive random testing
Chen, Y.T	7	Adaptive random testing
Mayor, J	3	Adaptive random testing
Hemmati, H	4	Similarity based TCS
Arcuri, A	2	Similarity based TCS
Yoo, S	2	Multi-objective TCS

Table 4.4: Authors and their publications

To check the quality of papers, we searched weather the papers include related work, limitations, applications, and future work. And all the papers provide these topics, these topics should be included in the scientific papers because they provide information regarding the continuation of reported works and selected methods.

Papers	Software Domain	Selection Method
[8]	Embedded Applications	Adaptive Random Testing
[13, 27]	Simulation	Adaptive random testing
[33, 34, 39]	Simulation	Adaptive random testing
[5]	Embedded Application	Adaptive Random Testing
[21, 23, 24]	Reactive Systems	Greedy Algorithms
[3, 23, 24]	Reactive Systems	Genetic Algorithms
[49]	Replace and Space	Adaptive random testing
[10, 11, 33]	Numerical Computation	Adaptive Random Testing
[3, 21, 23, 24]	Reactive Systems	Random Testing
[17]	Mobile Devices	Random Testing
[21, 22, 24]	Reactive Systems	Adaptive Random Testing
[22]	Video-conference system	Adaptive Random Testing
[30]	Vending Machine	Genetic algorithms
[38]	Vending coffee machine	Clustering
[9]	Mobile phone and desktop	Model-based testing
[45]	Financial purpose	Statistical

Table 4.5: Software Domain Analysis

Table (4.5) presents the software domains studies and the selected methods. More than 22 papers are included and we found various software domains. The studies indicate that the selected methods target a particular software domain, so we could

not differentiate which selection method is best when compared with other selection methods.

Engstrom et al. [19] observed that the researchers propose a new test case selection study, rather than continuing the research work of other researchers. The figure (4.11) indicates the most commonly used method in test case selection.

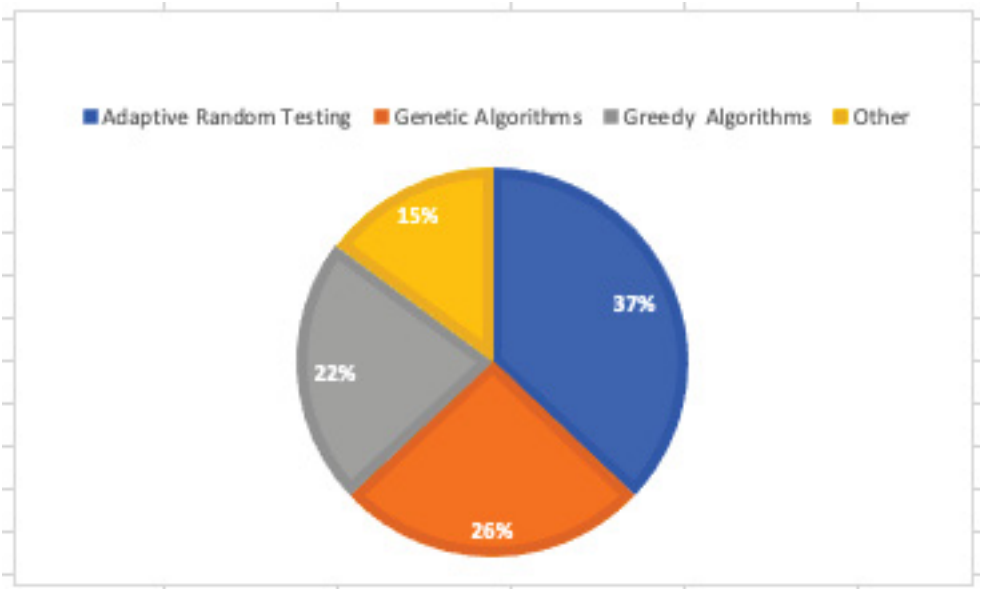

Figure 4.11: Commonly used test case selection methods

Several researchers use more than one method in experiments that include comparison and validation. Briand and Hemmati [23] used Adaptive random testing and Genetic algorithms to check the similarity and compared with Greedy algorithms to determine the faults.

From the above results of the systematic review, in this paper for our experiment, we have selected the ART (Adaptive Random Testing) method, as it is most commonly used in software testing and it is in the related software domain.

Adaptive Random Testing

This method is an extension of random testing. It focuses on detecting faults in a software at a particular input domain. Chen et al. said that by spreading the test cases at input, the capability of detecting faults increases [12].

The basic idea of adaptive random testing is, similar test data show similar failures. Based on this ART calculates difference between test data and presents only required data at input. Test cases are selected from a test suite and this difference criteria is applied to all the test cases, and only those are included which satisfy this criteria. This method has proven effective for testing with input domain, whose main focus is spreading the test data evenly at input [27, 39]. Therefore adaptive random testing uses similarity function to show difference between test cases. And selects only those test cases that have a greater dissimilarity for execution.

For the current scenario this is best suited, as these test cases are different from standard test cases. These include communication with the hardware equipment (signals generator). The code (The code contains different inputs to the signal generator) is different for each and every test case. Whenever a test suite is run, the commands are executed and the required changes are made in the signal generator. No two similar test cases can be added to the test suites, in this way the test suite is utilized to its maximum efficiency.

Chapter 5

Discussion

5.1 Answers to Research Questions

RQ1: How to use signal generators to give field-like input to the RTC and verify the behaviour of GNSS module?

A: The RF output results obtained in the section (4.1), by analyzing the generated signals in the signal analyzer and the obtained signal parameters were in the required range. These generated signals were used to test the GNSS receiver for various test scenarios, and the output results are presented in section 4.4, the output satisfies with the given inputs.

RQ2: How to integrate the test cases into the automatic test suites to extend the regression testing to include all components of RTC?

A: From the analysis of the results, Adaptive Random Testing is used as it is the most common test case selection method used by the researchers in the software domain of our experiment and for black-box testing. As we can see in Figure 4.11. Therefore only test cases that meet the criteria are selected for execution, in this way all the components are included and can be tested in a controlled environment with maximum efficiency.

5.2 Threats to Validity

This section discusses the validity of threats. The threats are classified as internal validity, external validity and conclusion validity as mentioned by Wohlin and Runeson [43].

5.2.1 Internal Validity

Internal validity refers to the influence of factors on research, which may affect the validation of results [43]. The threat can be a possibility of inconsistent frequency level, power levels, and noise at the simulator. To mitigate this, a signal analyzer is used that takes the RF output of the signal generator as input and analyzes the signal for various parameters, this way we can verify the generated signal parameters.

5.2.2 External Validity

External validity refers to which extent the results from our research can be generalized [43]. This research is based on GPS receiver testing with a simulator. The approach used in the study is interesting as the test cases used to evaluate the GPS receiver are not seen in any related work and helps in further evaluating the receivers in researches that involve GPS testing. As this experiment is done in a controlled lab environment at Scania, the conclusions are relate-able to other testing environments, where some large-scale projects can be improved using this approach.

5.2.3 Conclusion Validity

Conclusion validity refers to whether the data and results obtained from our experiment are true and justified. The validity threats arise when the experiment and literature review are carried out without following correct procedures and methods. This can be mitigated by following correct procedures and methods while conducting the experiment and literature review. By configuring the signal generator with the correct values and analyzing the generated signal to test the GPS receiver. And using the correct keywords for searching and precisely apply the inclusion and exclusion criteria and screening the papers by reading the abstracts.

Chapter 6

Conclusions and Future Work

Validation of GPS receiver performance in automotive telematics applications is very crucial for customer satisfaction. At present, the validation is done with extensive field testing. But some level of field testing should be done for any validation, this paper presents a methodology of evaluating the GPS receivers performance in a controlled lab environment with the help of a multi-channel GPS satellite signal simulator. Test scenarios were emulated based on the field testing scenarios developed by Scania and were simulated in the signal generator. The receiver output was acceptably good with the given inputs. This methodology can be executed at any time of the day and year, to test the receivers positioning performance. This will result in reducing cost for validation and less time for the application to reach the market which is based on telematics.

There are many more aspects to be considered in future study such as, atmospheric modeling, multi-path modeling, GPS L2 signal, GLONASS, Galileo..etc which can be configured in the signal generators, all these aspects are needed to be considered in the future work. The results obtained from these will help designers and developers further improve the receivers and telematics applications. There is still a great deal to be done in the field of testing with signal generators. We certainly believe that this research will provide more opportunities and information for the industries that use telematics applications. And we encourage more researchers for testing GPS applications with signal generators, that will significantly help reduce the cost for industries.

In this paper a systematic review is performed to select a method, to add the test cases to the test suites. After an empirical evaluation we came to the conclusion that firstly, commonly used methods are ART, greedy algorithms, genetic algorithms. And secondly, the metric used for the selection of test cases is fault detection. During the research, we also found that researchers perform empirical studies on new approaches rather than continuing the research work by other researchers. Lastly, the methods are based on software domain and context, so we could no evaluate the superiority between methods. In the future, we can work on evaluating the selected methods for scalability, efficiency, and develop frameworks that can assist TCS.

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Appendix A

Supplemental Information

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