

DEPARTMENT OF TECHNOLOGY AND BUILT ENVIRONMENT

***“Design of RF Front End for Multi-Band Multi-System GNSS
Receivers”***

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Abstract

Design of RF Front ends for multi-band multi-system GNSS Receiver

The up growing wireless communication field always need such a system which is simple but more reliable for multiple applications. To fulfill these demands the modern receiver RF front-end can play an important role. ‘A successful design could be a better solution, not only simple but also modern receiver architecture topology is necessary’.

The main objective of this dissertation is to design a simple RF-Front end for both multi-band multi-systems Global Navigation Satellite System (GNSS i.e. GPS and Galileo) receiver which will provide civil signals on multiple frequencies, similar to those currently available for only military purpose and finally implement and test the receiver front end. Different topologies have been investigated and finally the direct digitization RF front end receiver topology is chosen for simplicity, cost and performance. The entire RF front receiver consists of a broad band LNA, a broad band pass filter and a band stop filter. This kind of receiver needs a minimum feasible sampling frequency which is 434 MHz for designed methodology.

A simple receiver RF front end for GNSS application is designed to demonstrate and it has been implemented and tested. The receiver is yield the minimum power consumption which is 26mA current from 3V power supply.

Although, there are no such a specifications for combined future GPS/Galileo receiver, the simple design performance is satisfactory and it will be an interesting future work from commercial point of view.

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List of Acronyms

AD	Analog to Digital
ADC	Analog to Digital Converter
ARNS	Aeronautical Radio Navigation Services
AltBOC	Constant envelope modulation scheme for combining two sidebands each consisting itself of two binary signals (in I- and Q- channel)
ADS	Advance Design System
BPSK	Binary Phase Shift Keying
BOC	Binary Offset Coding with sine shaped subcarrier
BW_I	Information Band Width
CDMA	Code Division Multiple Access
CAD	Computer Aided Design
C/A Code	Coarse/ Acquisition Code
DSSS	Direct-Sequence Spread-Spectrum
DS	Direct-Sequence
DCR	Direct Conversion Receiver
DC	Direct Current
DSP	Digital Signal Processing
DoD	Department of Defense
Data	A data channel is the result of modulating ranging code, sub-carrier (if present) and secondary code with a navigation data stream. Data Channel transmitted in-phase component.
3D	3 Dimension
ESD	Electro Static Discharge
ESA	European Space Agency
E-pHEMT	Enhancement mode pseudomorphic High Electron Mobility Transistor
EM	Electro Magnetic

FHSS	Frequency Hopping Speared Spectrum
FPGA	Field Programmable Gate Array
FBW	Fractional Band Width
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
GLONASS	GLOBal NAVigation Satellite System
GFSK	Gaussian Frequency Shift Keying
HTS	High Temperature Superconducting
IF	Intermediate Frequency
ISM	Industrial Scientific and Medical
I	In-Phase Component
IRNSS	Indian Regional Navigation Satellite System
IP₃	3rd Order Intermodulation Product
IC	Integrated Circuit
LNA	Low Noise Amplifier
LO	Local Oscillator
LTCC	Low Temperature
MMIC	Monolithic Microwave Integrated Circuit
MEMS	Micro-Electro-Mechanical Systems
MDS	Minimum Discernable Signal
NF	Noise Figure
NAVASTAR	NAVstar System with Timing And Ranging
NUDET	Nuclear Detonation
Pilot	A pilot channel (or data less channel) is made of ranging code, sub-carrier (if present) and secondary code only, not modulated by a navigation data stream. Pilot Channel transmitted in-Quadrature component.
P(Y) Code	Precision Code
P_{in.min}	Minimum Input Power
QPSK	Quadrature Phase Shift Keying
Q	In-Quadrature Component

QZSS	Quasi-Zenith Satellite System
RF	Radio Frequency
Rx	Receiver
RNSS	Radio Navigation Satellite System
RLC	Resistor Inductor Capacitor Network
SAW	Surface Acoustic Wave
SAR	Specific Absorption Rate
SNR	Signal to Noise Ratio
SFDR	Spurious Free Dynamic Range
SoL	Safety of Life
U	User
US	United State
WLAN	Wireless Local Area Network

Chapter-1

1.1 Motivation and Goal

It is quite common that RF front-end receiver projects have multiple targets, only some or one of which are actually known for the designer. Nowadays, the exponentially increasing wireless communication system has highly demands for multiple applications from simple system. There are lots of challenges for software radio receiver at each level or layer. From the RF- front end receiver designer's point of view to complete the physical layer or air interface protocol, the challenge is to design a receiver that supports all future standards with backward compatibility. The multi standard receiver is essential for future all-in one system. The standards that should be included in the receiver differ for different areas. For example in Europe, it is more reasonable to develop a multi-standard receiver covering both the GPS and the Galileo system.

Global Navigation Satellite System (GNSS) receiver designs have been exposed since last twenty years from analog to digital architectures. At present, super heterodyne digital receiver architectures are available in commercial GNSS receiver. Due to the technological progress in software radio, especially the direct sequence spread spectrum Code Division Multiple Access (CDMA), it is possible to design a simple multi-band multi-system RF front end for GNSS receiver using direct digitization architecture, which has reduced significantly the size, weight, cost and power consumption of a GNSS receiver.

Usually, the traditional receiver RF front end includes amplifiers, mixers, local oscillators and band pass filters. Due to the analog nature of these components, there are some impairments like oscillator phase noise, mixer non-linearities that affect the overall performance. On the other hand a direct digitization RF front end can just include amplifiers and band pass filters minimizing the number of components.

GNSS has been introduced from last several years and the two primary systems currently in operation are the United States GPS and the Russian Global Orbiting Navigation

Satellite System (GLONASS) but at present, the Global Positioning System (GPS) is the only fully functional and fully available global navigation satellite system. Both satellite navigation systems are based on DSSS techniques and the future GNSS in Europe called Galileo is also on these DSSS techniques.

However, within the last few years only several papers on direct digitization DS spread-spectrum GNSS receiver architectures have been published [1, 2 etc.] and even very few papers on combined GPS/Galileo receiver have been published [3, 4, 5]. In [3], a dual gain ESD protected LNA with integrate antenna sensor RF front end has been proposed. In this paper, the low-IF receiver architecture has been used for the RF front end implementation. However, the front end presented in this paper was only one band L1. In [4], a combined GPS/Galileo receiver design has been proposed using direct RF sampling and antenna arrays. In this paper, most of the GPS/Galileo combined frequency band has been discussed except the E6 band for the Galileo system. However, there was no such a discussion regarding the RF chain. In [5], the direct digitization receiver architecture has been used but there were some extra component presented in the RF front end.

The author's point of view is to design a modern RF front end which is simple, easy to implement and gives best performance for the combined GPS/Galileo system.

The main goal of this dissertation is to investigate and design the modern 'Broadband instead of Narrowband' RF front end which will work on combined GPS/Galileo direct digitization/ band pass sampling receiver architecture and finally, implementation and measurement.

1.2 Thesis Overview

In chapter-2, there will be overall basic concept on different receiver architectures including their advantages and disadvantages and the receiver design considerations. Chapter-3, describes the introduction of Global Navigation for Satellite System (GNSS), focus on the GPS and Galileo system. In chapter-4, the proposed Direct Digitization Receiver for GNSS will be described in details. Chapter-5 will be focused in the receiver RF front end design and implementation. Chapter-6 will be devoted on the measurement results. And finally the conclusion and the future work consideration for the thesis appear in Chapter-7.

Chapter-2

2.1 Introduction

The first advent of the wireless communication system was the Marconi's demonstrated viable radio system in 1895, now more than 100 years later the radio systems which are being used today bear no similarity to the early equipment that was used. The early equipment was crude and very insensitive; at present the receivers are very sensitive and they offer wide variety of applications. The world of wireless communication has grown enormously over the past few years and has created high demand for radio frequency transceivers. Low cost, low power and small size are the major demands for the modern receivers. To accomplish these requirements the receiver architecture plays an important role. From the beginning to till now different receiver architecture, such as Super heterodyne receivers, Zero-IF receivers, Low-IF receivers, Zero-IF/Low-IF Multi-standard receivers, Wideband IF Double conversion receivers, Digital-IF receivers and Direct Digitization receivers have been proposed. At present, very few of these architectures are being used in the actual product. This chapter will explore in brief the important features of different architectures. A more detailed discussion can be found in reference [6].

2.2 Receiver Architectures

2.2.1 Super heterodyne receivers

The Super heterodyne receivers were first invented in 1918, during the First World War. The Super heterodyne receivers are the most famous architecture due to its huge popularity of RF application in the world today. As shown in Figure- 2.1, a super heterodyne receiver down converts the RF signal to low frequency signal using some basic elements. ``In practice, all the design will not consist of these elements but the essential elements of a local oscillator and mixer followed by a filter and IF amplifier are common to all super heterodyne receivers``. In the case of multiple down conversions, the total required amplification can be divided across several frequencies, which is an aid for the stability of the amplifier stages and increase the total possible amplification. The super heterodyne receiver is constantly popular due to its ability to cope up narrow band high frequency signal from the surrounding back ground interferences outside the frequency band of interest, which has been major problem for the other receivers. Thus, the super heterodyne receives has good performance in terms of sensitivity and selectivity.

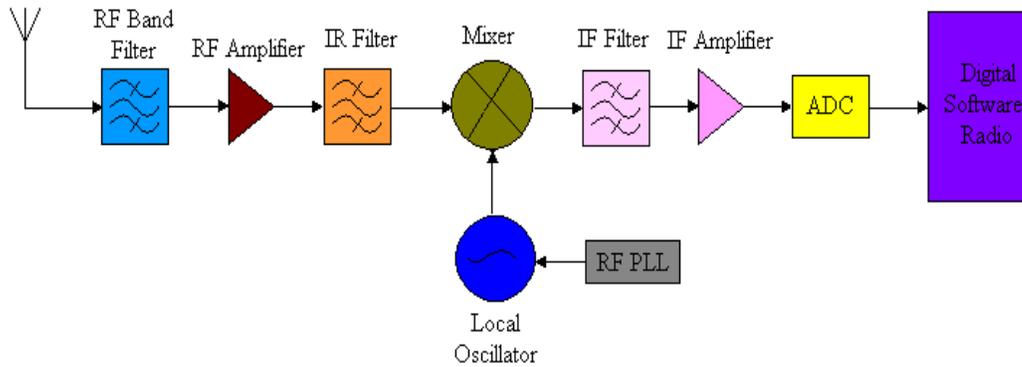


Figure-2.1 Block diagram of typical super heterodyne receiver

Nevertheless, the super heterodyne receivers have some drawbacks. Firstly, during the multiple down conversions, the receivers generate many spurious or inter modulation components, some of these components fall in to the desired channel band which has great impact on overall receiver's performance. Secondly, several filters are required at RF and IF to reject images and interferences. These kinds of filter can not be suitable for today's on chip technologies. As a result, external filters have to be used which greatly increases the cost and the size of the receivers. Another important drawback of heterodyne receiver is that the LNA must have 50 ohms load because the IF filter is placed off-chip. Otherwise, it will degrade the filtering transfer function. Moreover, the substantial power will be consumed by the on-chip blocks. However, in terms of frequency plan, super heterodyne receivers are not feasible for single chip multi standard application.

2.2.2 Zero-IF receivers

Image problem is quite common for super heterodyne receivers, therefore to completely eliminate the image the IF is set to be zero frequency. This kind of receiver architecture is called 'Zero-IF' receiver. It is also called the 'Direct Conversion Receiver (DCR)' or homodyne receiver. This is the natural approach to down convert the signal from RF to base band. DCR have several advantages over heterodyne receiver. Firstly, there is no image problem because of IF is set to zero. Secondly, the LNA must not have 50 ohms load because of no image rejection filter. Finally, there is no IF SAW filter and other stage has been replaced by low pass filter which has resulted highly integrated on-chip with very low power consumption. This receiver architecture is fully feasible for single chip modern multi standard application. The block diagram of typical 'Zero-IF' receiver' is shown in Figure-2.2.

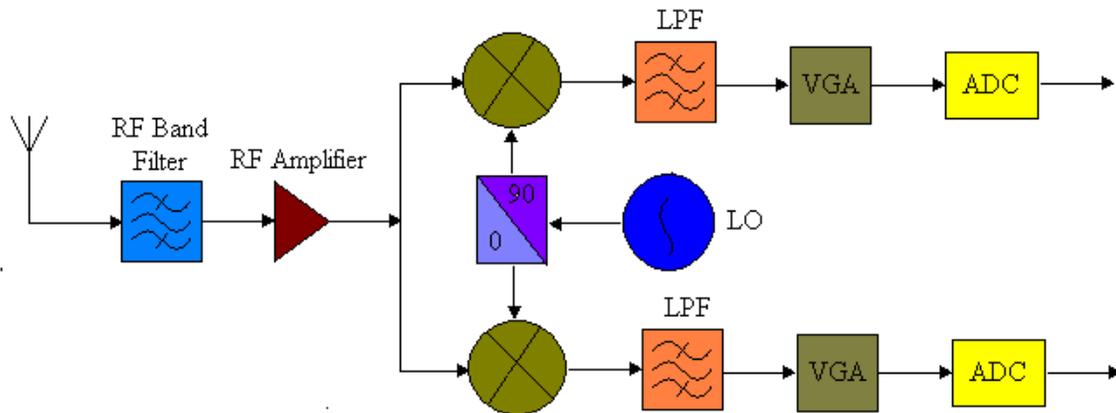


Figure-2.2 Block diagram of typical Zero IF receiver

After having all of these advantages over super heterodyne receiver, there are few drawbacks of ‘Zero- IF’ receiver as well. The main drawbacks of ‘Zero- IF’ receiver are DC offset problem, Flicker noise problem, even order distortion, LO leakage and self mixing. However, the ‘Zero- IF’ receiver architecture is most promising architecture due to its low power and high integration for future wireless communication.

2.2.3 Low-IF receivers

The Low-IF receiver is very similar to Zero-IF receiver, a Low-IF receiver down-convert the signal to a low IF, instead of DC whereby an on chip band pass filter can be used to channel selection. The block diagram of typical Low-IF receiver is shown in Figure-2.3

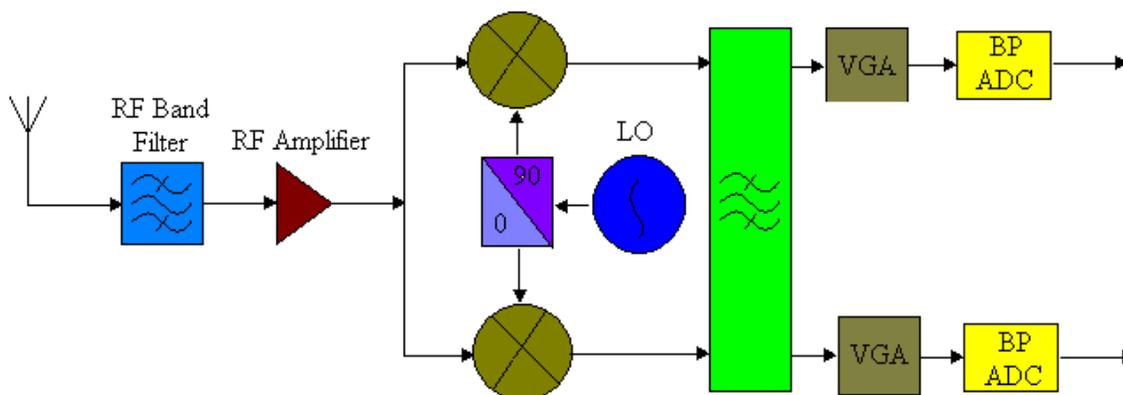


Figure-2.3 Block diagram of typical Low-IF receiver

This receiver architecture eliminates the problem of DC off-set and flicker noise over the Zero-IF receiver while maintaining the same high level of integration. An important draw back of Low-IF receiver is that the image comes up again. Nowadays, it is quite hard to implement the image rejection filter, therefore the image rejection mixer could be a solution to eliminate this problem but this is also quite hard to implement either on-chip or off-chip design. However, this Low-IF receiver architecture is suitable for specific modulation technique and easy to make.

2.2.4 Zero-IF/ Low-IF Multi-standard receivers

2.4 GHz short range wireless local area network (WLAN) standards can be classified in two types. One type uses direct sequence spread spectrum (DSSS) and QPSK modulation techniques and the other one uses frequency hopping spread spectrum (FHSS) and GFSK modulation techniques. From the above discussion it is clear that multi standard receiver can be developed by combining the Zero and Low IF receiver. The typical block diagram of multi standard ISM band receiver by combining the Zero-If and Low-IF receiver is shown in Figure-2.4

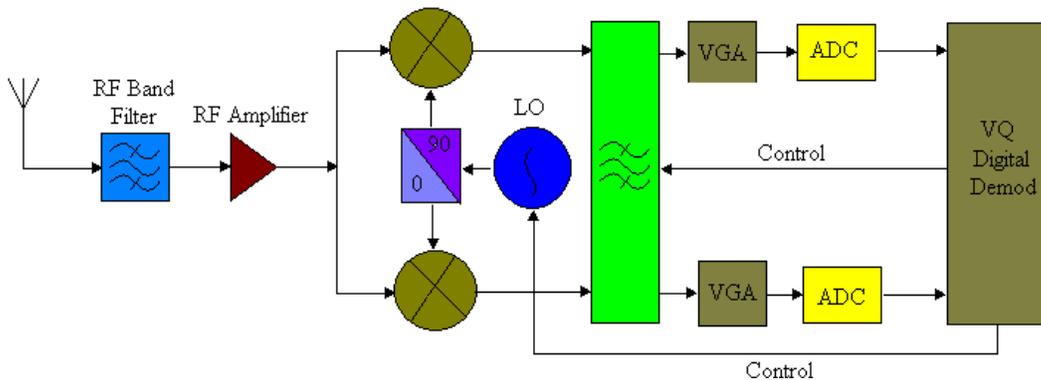


Figure-2.4 Block diagram of typical Zero-IF/Low-IF multi standard receiver

In this receiver digital base band is suitable for both WLAN standard and except for the analog filter part, most of the analog components are shared to each other as a result this receiver consume low power and cost- effective for the multi standard ISM band receiver.

2.2.5 Wideband IF Double conversion receivers

Newly alternative Wideband IF double conversion receiver architecture has been well suited in the wireless communication system. This receiver is similar to super heterodyne receiver. In this receiver, all possible channels are down converted from RF to IF by using a fixed frequency LO1 and a low pass filter is removed any up converted frequency components, with passing all

channels to the second stage mixers. And again all the channels down converted from IF to base band, using tunable channel selecting frequency synthesizer LO2. A baseband filtering is performed to remove the unwanted adjacent channel energy. The typical block diagram of wideband IF double conversion receiver is shown in Figure-2.5 [6]

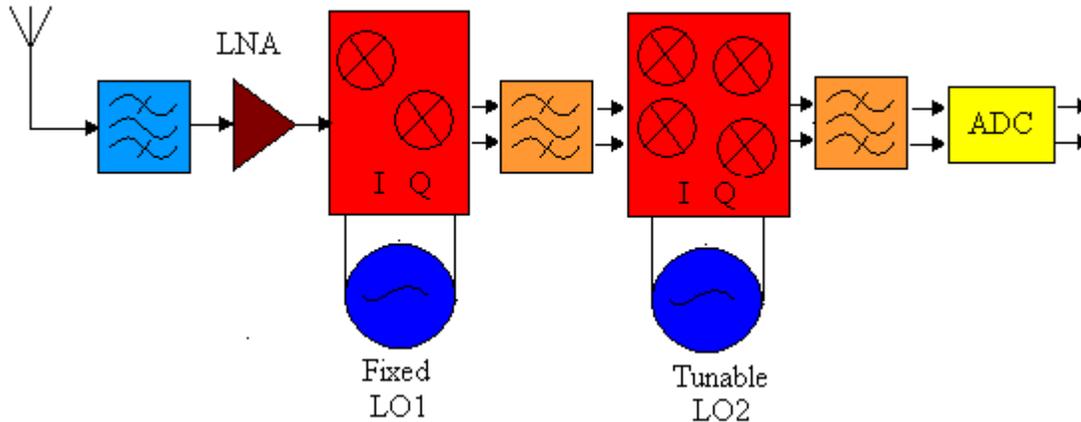


Figure-2.5 Block diagram of typical Wideband IF Double conversion receiver

The advantages of the Wideband IF double conversion receiver architecture are: highly desirable for monolithic integration, the radiation of LO1 does not affect to the antenna due to its fixed frequency, by tuning the LO1 multi-band multi standard application is possible, the first local oscillator can be designed with very good phase noise which is better for overall phase noise performance, but this receiver also suffers from using six high performance mixer to perform the complete down conversion which increases the system noise figure, distortion and power consumption.

2.2.6 Digital-IF receivers

Greatly improvement of digital signal processor (DSP) enhance that, the function of radio blocks moves to the digital domain. The Figure- 2.6 is an example for digital-IF receivers where the first IF signal is digitized and all other baseband processing is done by excellent programmable powerful DSP. This is why it is called Digital-IF receivers.

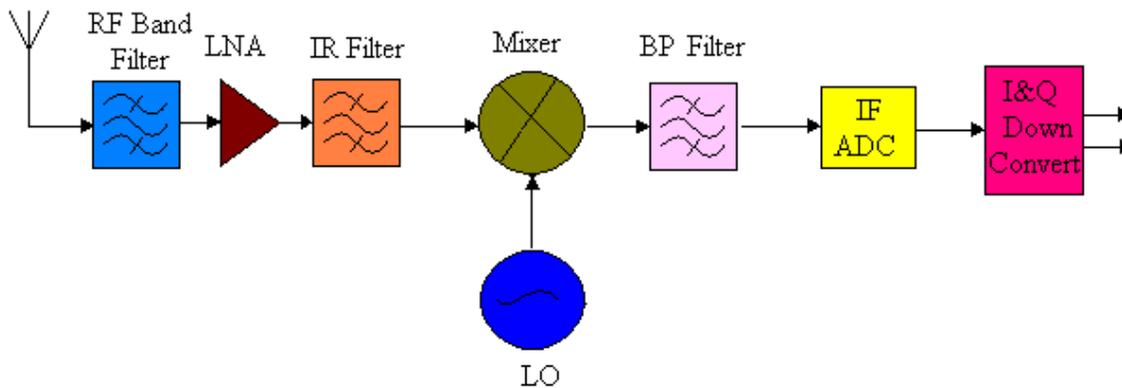


Figure-2.6 Block diagram of typical Digital-IF receiver

The Digital-IF receiver architecture is widely used in base station receiver. And it is also a strong candidate for future radio software receivers. The I and Q mismatch is completely eliminated by digital signal processing. AD converter performance is the main issue for Digital-IF receiver architecture. The high power consumption is the draw back for Digital-IF receiver architecture. However, it is the good solution for baseband software radio system, if the AD conversion reaches the desired performance.

2.2.7 Direct Digitization receivers

Due to exponential development of wireless communication multiple standards are needed. Nowadays the software radio contribution for whole communication systems whose main goal is facilitates multi standard system with considering less RF components in the receiver chain. Direct Digitization receiver architecture is the most promising candidate for these kinds of receiver. This architecture is also called ‘Band Pass Sampling’ architecture. The band-pass sampling some time referred to as harmonics sampling uses the intentional aliasing technique to provide frequency down conversion from RF to baseband directly and is able to reconstruct the information. The sampling rate is based on the information bandwidth of the signal rather than the RF carrier[14]. For more detail on band sampling see appendix-B. The block diagram of Direct Digitalization receiver is shown in Figure-2.7

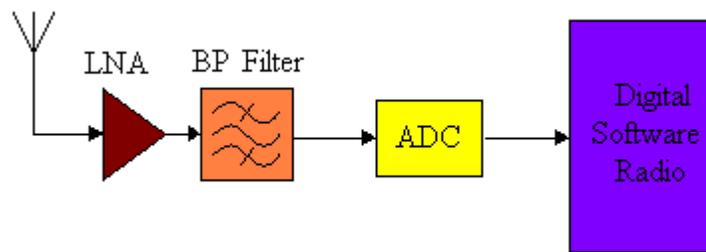


Figure-2.7 Block diagram of typical Direct Digitization receiver

The key advantage of Direct Digitalization receiver architecture is that it is much simpler than other architectures which have been presented in previous sections and supports more multi-band multi-mode systems. This receiver's RF analog includes only filters and low noise amplifiers before the ADC. Such kinds of receiver require unique hardware architecture such as the high dynamic range of ADC and selectivity of the filter, especially in the case of high frequency narrow band signal, this may be considered as draw back. However, this receiver architecture is the most efficient and popular architecture ``with respect to all considerations`` in the modern wireless communication world.

2.3 Design Considerations

The Specifications of a radio receiver is fundamental criteria, which is defined by the system parameters. The system parameters include sensitivity, selectivity, baseband performance, frequency range, inter modulation characteristic and tuning speed (if applicable) and so on. Some of these are discussed in the following sections:

2.3.1 Sensitivity and Noise figure

Sensitivity is the key specification for a receiver. Receiver sensitivity means, the ability to cope up the minimum signal level with the acceptable signal-to-noise ratio, which is defined by the receiver's modulation scheme. There is no such a measurement standard for measuring the sensitivity. However, we can measure the sensitivity with the help of noise figure. The noise figure, NF is a measure of the reduction in signal-to-noise ratio (SNR) between the input and output of the component or the receiver. The relation between NF and sensitivity, $P_{in,min}$ is expressed as:

$$P_{in, \min} = -174dB_m / Hz + NF + 10 \log B + SNR_{\min}$$

Where, B is the channel bandwidth, thermal noise power density $-174dB_m / Hz$ is known and SNR_{\min} is determined by the modulation and demodulation scheme. Therefore, $P_{in, \min}$ is only determined by NF.

2.3.2 Selectivity

Selectivity is also another key specification for a receiver. Selectivity was originally defined as the attenuation characteristics of IF filter, but in the sense of modern receiver, selectivity is the ability to reject all unwanted signals which enter through the antenna interface. IF filter is still a strong candidate for selectivity but additional blocks like pre selecting filters, mixers and amplifiers have selectivity as well. Therefore, at least two characteristics must be considered simultaneously for selectivity. The selective components should be sharp enough and on the other hand they should be broad enough to pass the highest side band frequencies with acceptable distortion in amplitude and phase. Filters are very vital elements for Rx performance, because they have a role for both sensitivity and selectivity issues. But different architectures and different frequency plan have different filtering problems. Therefore, better selection of receiver architecture and frequency plan will bring better selectivity.

2.3.3 Nonlinearity and Inter-modulation

Active devices have both a linear and a non-linear operating region but they have large inherent nonlinear region. When the input signal is large enough or internal signal become larger the active devices are no longer in linear region. Though oscillators, comparators and limiters are necessary building active components for a receiver, their nonlinearity always does not impact the system. But the amplifiers and the active filters, whose function is to linearly amplify or attenuate the signal, therefore this component's nonlinearity is unwanted. Besides the mixer's nonlinearity also gives rise to a number of undesired harmonics and mixer products. These products increase the mixer's conversion loss and also distort the desired signal, which results reduction of the system dynamic range.

2.3.4 Dynamic range

Dynamic range is defined as the ratio between the maximum input level to the minimum input level at which the system can tolerate and able to provides the reasonable signal quality. This definition is applied in different way to different application. Usually, in analog circuits such as an amplifier and ADC the dynamic range is defined by both the signal-to-noise ratio (SNR) and the spurious free dynamic range (SFDR). The SFDR is the maximum relative level of interferences that a receiver can tolerate while producing an acceptable quality from a small input level. The lower end of the dynamic range is defined by the sensitivity of the receiver and the upper end of the dynamic range is defined by the maximum input level that the system can tolerate without distorting the signal.

Chapter-3

3.1 Introduction

The advent of satellite-based navigation starts in the early 1970s. Global Navigation Satellite System is satellite system that is used to identify the geographic location of the user's anywhere in the world. A GNSS is small electronic receiver which is able to determine the user's location (longitude, latitude and altitude) to within a few meters using time signal transmitted from the satellites. At present, there are different GNSS in the world such as United States NAVSTAR (NAVstar System with Timing And Ranging) Global Positioning System (GPS), Russian GLONASS, European Union's Galileo Positioning System, China Beidou Global Navigation System, India IRNSS and Japan Quasi-Zenith Satellite System (QZSS) [12]. While the GPS is the only fully operational GNSS, Galileo will provide high accuracy and guaranteed global positioning services under civilian control and is under development of European nations and industry. This chapter will explore the features of GPS and Galileo GNSS only.

3.2 US Global Positioning System (GPS)

The GPS program was approved in 1973 which is developed by the Department of Defense (DoD) of USA. The first satellite was launched in 1978. In August 1993, GPS had 24 satellites in the orbit and in December of the same year the initial operational capability was established. Now the system has 29 satellites in the orbit [7, 8]. Although, the main purpose of GPS was for military applications, now it is widely used in civilian services. The applications are mainly 3D positioning, velocity, attitude and time calculations for the surveying, mapping, constructing works and civilian applications such as aviation, marine and automobile navigation and so on. The following section will discuss briefly the GPS system

3.2.1 Basic Concept of how a GPS receiver determines its position?

To understand how the GPS receiver determines its position, let's have a look some examples. First, very simple example is in a one dimensional case. A user position is in the X-axis defined by U, in Figure-3.1. If the satellite position S_1 and its distance to the satellite x_1 both are known, the user position can be at two places, either to the left or right of S_1 . Therefore, to determine the

user position, the known distance x_2 from user to another satellite S_2 must be required. The Figure-3.1 shows the user position.

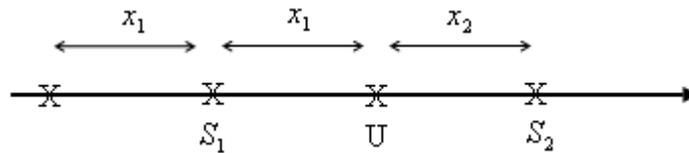


Figure-3.1 One-dimension user position

In the case of two dimensional, to determine the user position three satellites and three distances are required. In Figure-3.2 shows the two dimensional user positions. In Figure-3.2 (a) two satellites (S_1, S_2) and two distances (x_1, x_2) gives two possible solutions because two circles intersect two points. Therefore, a third satellite (S_3) and its distance x_3 is required to specify the exact position of the user U. Figure-3.2 (b) shows the correct two dimensional user position.

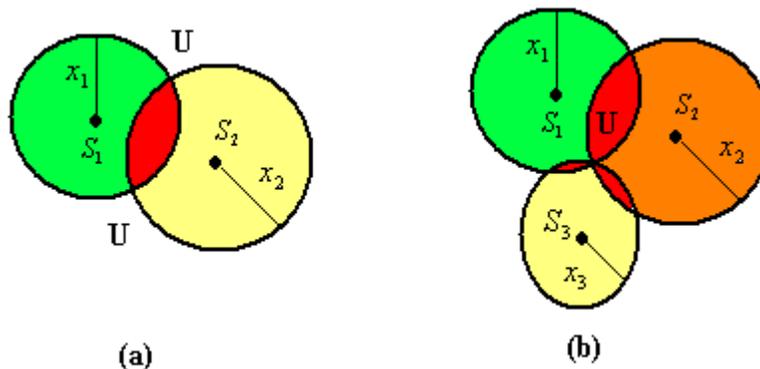


Figure-3.2 Two-dimension user position

From the above two examples, it is easy to understand that in the case of three dimensional. It is difficult to show graphically. In this case four satellites and its four corresponding distances are required. A sphere supposes to be three dimensional cases. Two spheres intersect to make a circle and this circle intersects another sphere to make two points, similar to two dimensional cases. Finally, to determine the exact user position one more sphere will be needed. Thus, a GPS receiver needs minimum four satellites to determine the user position. More detail can be discussed in appendix-A.

3.2.2 Global Positioning System Segmentation

The GPS consists of three segments such as Space segments, Control segments and User segments. The function of the space segments is to carry stable clocks and the signal, L1(1575.42 MHz) that includes the Coarse Acquisition (C/A) code which is used for civilian and the encrypted precision P (Y) code which is used for authorized users. These satellites also carry the signal, L2 (1227.60 MHz) that include the precision P (Y) code for correcting the ionospheric propagation delays. The function of the control segment is to monitor and track the signal from the space segment, estimate the orbits and clock behavior of the satellites and send this information to the satellites. Finally, the satellites transmitted the information to the user segments. There are two measurements that are performed by using GPS signal in the users segments. One is the measurement of pseudo-range which compares the receiving C/A and P code with the locally generated by the receiver itself in order to compute the transmission delay between the satellites and the receiver. And the second one is the carrier phase measurement which compares the difference of the phase between received carrier signal and self generating signal by the receiver at the same frequency. The common observation of GPS satellite is show in Figure-3.3

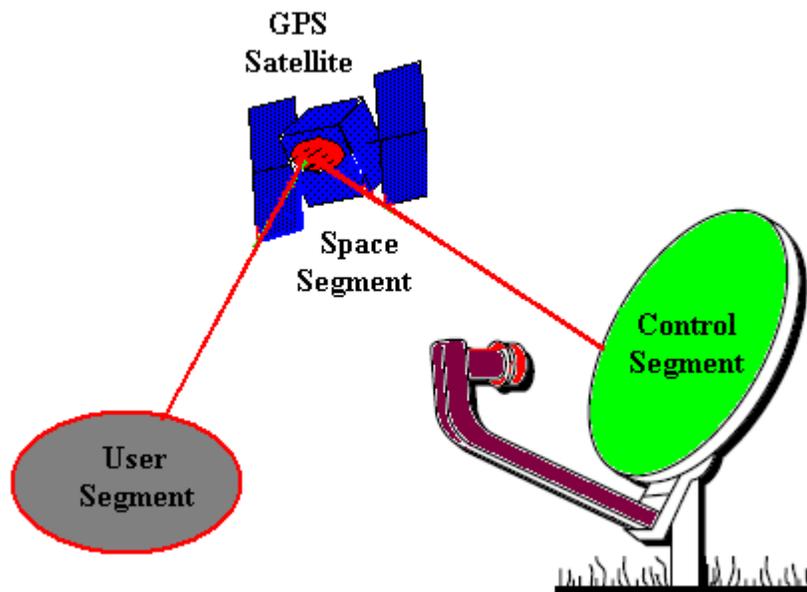


Figure-3.3 The common observation of GPS satellite

3.2.3 Modern Global Positioning System

In order to increase the user demands of GPS for last two decades and the development of some other satellite navigation system, especially GALILEO, the US authority has made available the performance improvement of GPS. The modern GPS includes a third civil signal, L5 (1176.45 MHz), whose main purpose Safety-of-Life (SoL) for the civilian uses. A detailed discussion can be found in reference [9]. There are two signals more in modern global positioning system, L3(1381.05 MHz) which is used by the Nuclear Detonation (NUDET) Detection System Payload (NDS) to signal detection of nuclear detonations and L4 (1379.45 MHz), which is investigating for additional ionospheric correction [12].

3.3 Europe Global Positioning System (Galileo)

It is definitely true that in order to get more facilities from a system such as GNSS, a new system with high accuracy and guarantee service is needed. This is what, the European government thought in early 1994. That was the time of first journey of European Global Positioning System Galileo. The first major program concerning Galileo satellite system had been brought together between the European Union and European Space Agency (ESA) [8]. Galileo is a global positioning system which will give highly accurate and precise global positioning for the civilian users. It will be the same technology like US GPS and higher degree of precision rather than US GPS. There will be 30 satellites (27 operational + 3 active extra) in the orbit. The first satellite had been launched in late 2005. In 2010, the system will be worked under the civilian control and the full operation like US modernize GPS, will be in 2012[12].

3.3.1 Why Galileo Global Positioning System ?

The European Government has been realized that there are plenty of contributions in the satellites navigation system, especially in the civilian services such as political, economical and technological terms, While, the GPS is mostly controlled by the military forces. Besides, it will provide integrity message in case of user errors, more reliable and secure in modern business, guarantee in real public services and able to receive the signal in such a region which is located in extreme latitudes.

3.3.2 Galileo Signal for services

Each and every Galileo satellite will continuously transmit microwave L-band navigation signals. The Galileo signals are divided into four frequency bands such as E1 (1575.75 MHz), E6 (1278.75 MHz), E5a (1176.45 MHz), E5b (1207.14 MHz) and combine E5 (1191.795 MHz). The mentioned frequencies are at the center frequency of each band. The Galileo signal is designed for providing overall services in urban areas about the 95% of them, whereas in US GPS is 55 percent. The Galileo signal applications are shown in Table-3.1 [10]

Table-3.1: Galileo signal applications

Name of Signal	Applications
E1	Commercial services, Open services and Safety-of- life services.
E6	Commercial services.
E5a	Open services.
E5b	Commercial services, Open services and Safety-of- life services.

3.4 Conclusion

Though the most important advantages of Galileo system is that it will give more facilities over US GPS system but the existence of both independent satellites will be the role off in terms of security. Therefore, taking in to account considerations combined GPS/Galileo receivers would be the dominant device for the GNSS users, which will be more beneficial for the fast and accurate positioning.

Chapter-4

4.1 Introduction

Before starting a project there are some important considerations, which must be taken care of by the system designer, such as technical and financial, time, manpower and so on. There are some rare cases, where the goal may be as less as ‘Try to do the best, whatever the cost is!’ Besides this only research work can take the advantages partially of freedom of schedule. It is definitely true that RF systems projects have multiple targets, and the engineer must be capable of making some trade-offs. Therefore, every effort must be taken to speed up the project and its evaluation. It must be kept in mind that each and every system design has specific plan, that will lead the designer towards success In the Figure-4.1 shows the flow chat for this project followed by the designer

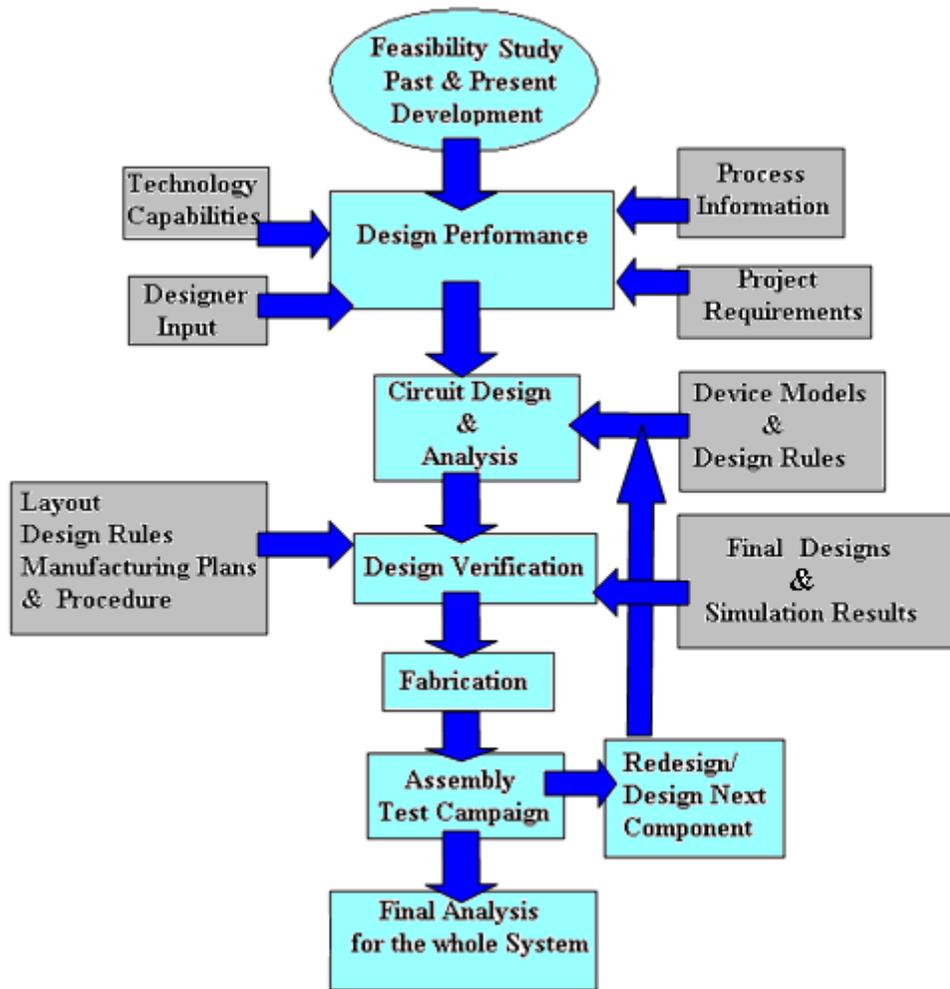


Figure-4.1 Flow chart of the project

4.2 GPS/Galileo Frequency Bands

There are three US GPS Signal frequency bands that are transmitted. These are L5, L2 and L1 band. There are four Galileo Navigation Signal frequency bands are transmitted. These are E5 (E5a+E5b), E6 and E1 band. These frequency bands and the allocated spectrum for Radio Navigation Satellite Services (RNSS) and Aeronautical Radio Navigation Services (ARNS) is shown in Figure-4.2

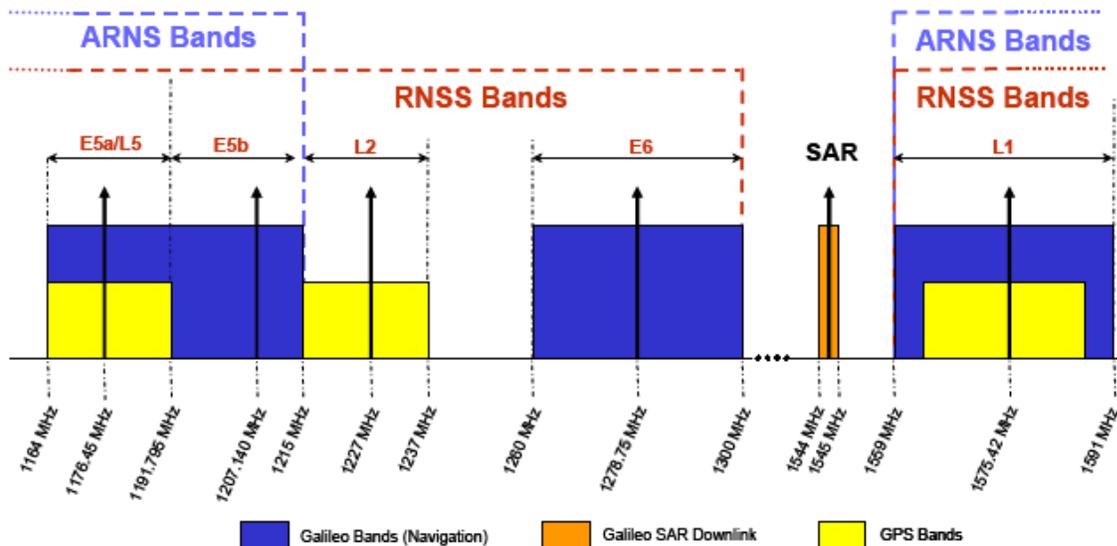


Figure-4.2 GPS/Galileo Frequency Bands [10]

4.2.1 Summary of the GPS/Galileo Standard

The summary of GPS and Galileo frequency bands and carrier frequencies that have been reported in Figure-4.2, the Rx reference bandwidth, modulation type and channel/code are given in Table-4.1

Table-4.1 Summary of the GPS/Galileo Standard [9,10]

Signal		Frequency Band (MHz)	Carrier Frequency (MHz)	Rx Reference Bandwidth (MHz)	Modulation Type	Channel/Code
Galileo	E5a	1164 - 1191.795	1176.450	27.795	AltBOC	E5a data
	E5b	1191.795 - 1215	1205.140	23.205		E5a pilot
	E5 (E5a+E5b)	1164 -1215	1191.795	51.150		E5b data
	E6	1260-1300	1278.750	40.920	BPSK	E5b pilot
	E1	1559-1591	1575.420	24.552	BOC	E6-B data E6-C pilot
GPS	L5	1164-1191.795	1176.450	27.795	BPSK	E1-B data E1-C pilot
	L2	1215-1237	1227	22	BPSK	P (Y) code
	L1	1559-1591	1575.420	32	BPSK	P (Y) code C/A code

4.2.2 GPS/Galileo Minimum Discernable Signal (MDS)

The minimum signal which can be decoded by the receiver is called Minimum Discernable Signal (MDS). The minimum received power level for the GPS users and the Galileo users are given in Table-4.2

Table-4.2 GPS/Galileo Minimum Received power level [10]

Signal		Minimum received Power level
Galileo	E5(E5a+E5b)	- 125 dBm
	E6	- 125 dBm
	E1	- 127 dBm
GPS	L1	-133 dBm (P-code)
		-130 dBm (C/A-code)
	L2	- 136 dBm (P-code)

4.3 Direct Digitization Receiver (DDR) and RF front end architectures

Considering the numerous amount of modern wireless communication technologies, it is desirable to have a multi standard system. At present, the combined GPS/Galileo multi band GNSS system is a major demand. Multi standard system means more and more frequencies are involved, which made the RF front end more complex. These complexities come from various kinds of mixing stages in the traditional receiver design. There is another complexity for multi band system, which is the equivalent propagation delay for each frequency band. Having all of these complexities and tremendous development of soft radio technology a unique technique to the multiple frequencies front end design is ‘Direct Digitization’, where RF signals are directly sampled. As a result intentional aliasing occurs in information bands. Using this technique, there are no mixing stages required and even the frequency translation happens with the help of aliasing of the desired input through the sample processing. More detail for this technique see appendix-B. In this paper the author has proposed three different RF front end direct digitization architectures which are given below

The Figure-4.3 shows the first proposed direct digitization receiver architecture which includes a broad band(1.164 GHz- 1.591 GHz) LNA, a broad band (1.164 GHz- 1.591 GHz) band pass filter and a band stop filter (1.3 GHz- 1.559 GHz). The entire frequency band is specified according to Figure-4.2 rectangular frequency band.

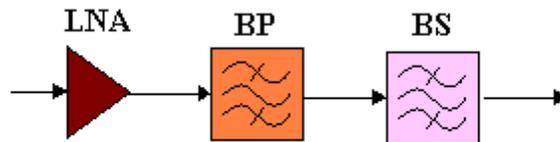


Figure-4.3 The first proposed combined GPS/Galileo Receiver

The Figure-4.4 shows the second proposed direct digitization receiver architecture which includes a broad band(1.164 GHz- 1.591 GHz) LNA, a three-way power divider, three band pass filter (1.164- 1.237 GHz, 1.260- 1.300 GHz and 1559-1591 GHz) and a combiner. The entire frequency band is specified according to figure-4.2 rectangular frequency band.

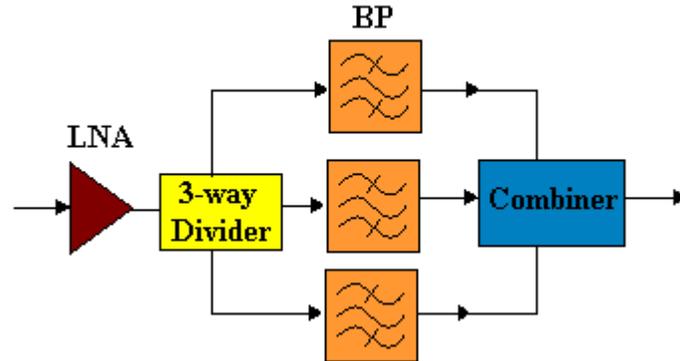


Figure-4.4 The second proposed combined GPS/Galileo Receiver

The Figure-4.5 shows the third proposed direct digitization receiver architecture which includes a broad band (1.164 GHz- 1.591 GHz) LNA, a two-way power divider, two band pass filter (1.164-1.300 GHz and 1559-1591 GHz) and a combiner. The entire frequency band is specified according to figure-4.2 rectangular frequency band.

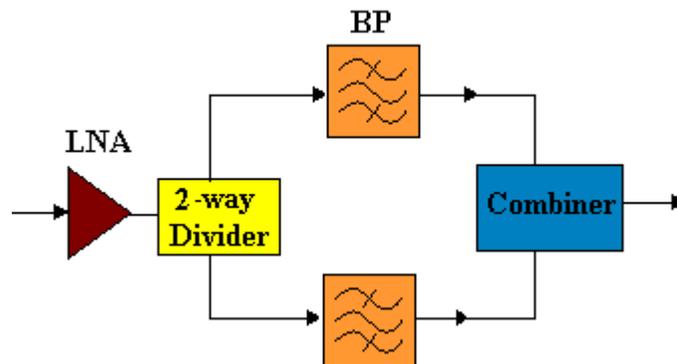


Figure-4.5 The third proposed combined GPS/Galileo Receiver

Among the three different proposed RF front end receiver architectures, the first architecture has been designed, implemented and measured. The first architecture is quite straight forward and less components. Although the first architecture will consider frequency band 1.237-1.260 GHz (23 MHz), which is not band of interest. In the second and third architecture it is clear that more components will be required as well as more insertion loss will be added to the system due to presence of three-way divider and combiner. The following next chapter-5, will present the design and implementation and chapter-6, will present the final measurement.

4.4 Choice of sampling frequency

In order to design the direct digitization receiver, selection of sampling frequency is one of the important considerations. Although there is a straightforward solution for the software radio that is just increase the sampling frequency, in the presence of multiple signals. Always must kept in mind that more sampling frequency requires wider dynamic range of the ADC's as well as high performance of FPGA, which will increase the computational cost. The simple technique of the choice of minimum sampling frequency is the sum of the band width (BW_f) of the desired signal. However, in some cases it may be consider increasing the sampling frequency rather than theoretical sampling frequency. In this project, as depicted in Figure-4.2 the E1 and L1 bands is located 1.559-1.591 GHz (32 MHz) and the E5 (E5a+E5b)-L5-L2-E6 is located 1.164-1.300GHz (136 MHz). Therefore, the theoretical minimum sampling frequency of the system will be 168 MHz.

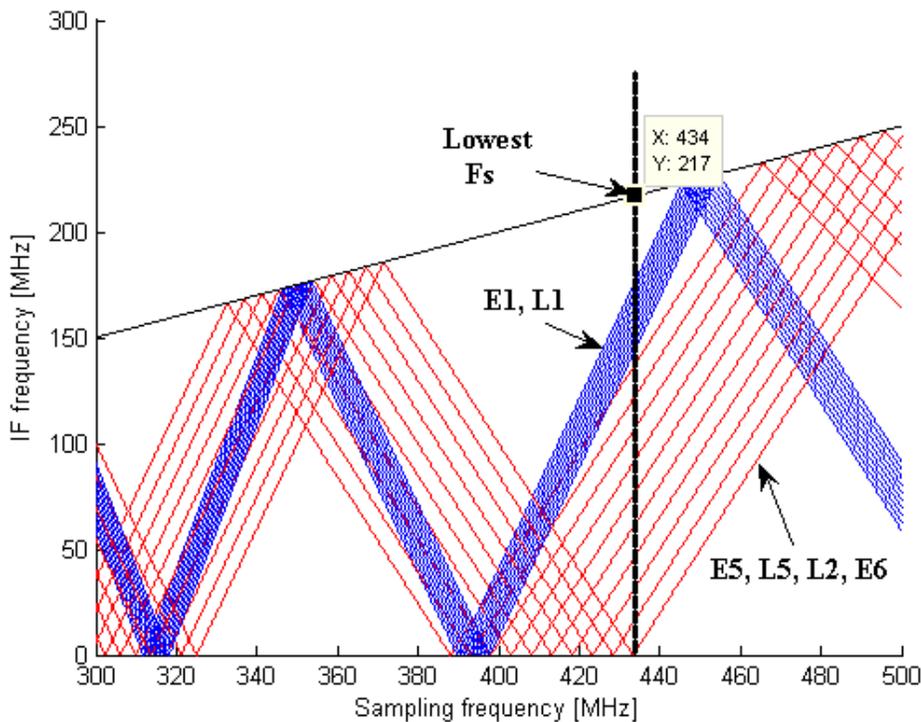


Figure-4.6 Ladder Diagram for combined GPS/Galileo Receiver

As shown in above Figure-4.6, the Ladder diagram for combined GPS/Galileo receiver, the lowest feasible sampling frequency is 434 MHz. The choice of sampling frequency using Ladder diagram, there are some basic relation between intermediate frequency and sampling frequency which is addressed in appendix-B. The programming code of this ladder diagram is given in appendix-C.

Chapter-5

5.1 Introduction of Low Noise Amplifier (LNA)

The low noise amplifier (LNA) is a special type of electronic amplifier used in communication systems to dig up and amplify very weak signals from the noisy signal captured by an antenna. It is often located very close to the antenna. That is why the first stages of a receiver have a great impact on the overall NF. The well known Frii's formula is the best understanding of the importance of LNA, because the overall noise figure of the receiver front-end is dominated by the first stage.

Using a LNA, the noise of all the subsequent stage is reduced by the gain of the LNA and the noise of the LNA is injected directly into the received signal. That's why it is essential for a LNA to pick up the desired signal power while adding as small noise and distortion as possible in order to optimize the receiver sensitivity. Though LNA gain needs to be high to reduce the noise contribution from the mixer and later stages, but too high gains degrade the overall system linearity as well. If the system requires dynamic range for large incoming signal, LNA's are often designed as a variable gain amplifier (VGA) to reduce the dynamic range and linearity requirements of the later stages. To sum up, there are some key features to design a LNA, which are given below [11]

- Low noise figure
- Sufficient gain
- Good linearity
- Good Impedance matching
- Minimum power consumption
- Minimum number of components
- Distortion behaviour (IP_3)
- Maximum out put power (mainly 1dB compression point)

There are also some design trade-offs that are closely related to each other such as gain, noise and distortion and power consumption. For multi-band system there are several ways to design LNA. The straight forward way to design a wide band LNA that will be covered the overall bandwidth of all the standards. Recently, the monolithic ICs (MMIC) have enough compliance, of course with reasonable limits. Basically, there are two types of choice for the designer, one is standard design and other one is custom design. In this project, the standard LNA design has to be followed.

5.2 LNA design and Specifications

There is no such a specification for designing combined GPS/Galileo front end receiver's LNA, but no design is completed without some desired goals or specification. In this project a commercial current adjustable E-pHEMT process GaAs MMIC (MGA-61563) low noise amplifier is used and the main specifications which are followed for designing the combined GPS/Galileo LNA's are given in Table-5.1

Table-5.1 Specifications of the Low Noise Amplifier

Specifications of the LNA	
Frequency Range	1.1-1.65 GHz
Noise Figure	< 1.2 dB
Gain	>15 dB (as maximum as possible)
Return Losses (S_{11} and S_{22})	≥ 15 dB
Power consumption	Minimum
OIP ₃	> 25 dB _m
P _{1dB}	> 15 dB
Stability	Unconditional stable ($\mu > 1, \mu' > 1, k > 1, \beta > 0$)

The Substrate specifications are given in Table-5.2

Table-5.2 Substrate Specifications for the LNA

Substrate specifications	
Relative dielectric constant, ϵ_r	3.38
Dielectric loss tangent, $\tan \delta$	0.0027
Substrate thickness, H	0.76 mm
Conductor thickness, T	35 μ m

5.2.1 LNA Simulation results

In this project, the Agilent's Advanced Design System (ADS) simulation tool has been used. The final circuit layout and simulation results are shown in Figure-5.1, Figure-5.2 and Figure-5.3 respectively and the summarized results is given in Table-5.3

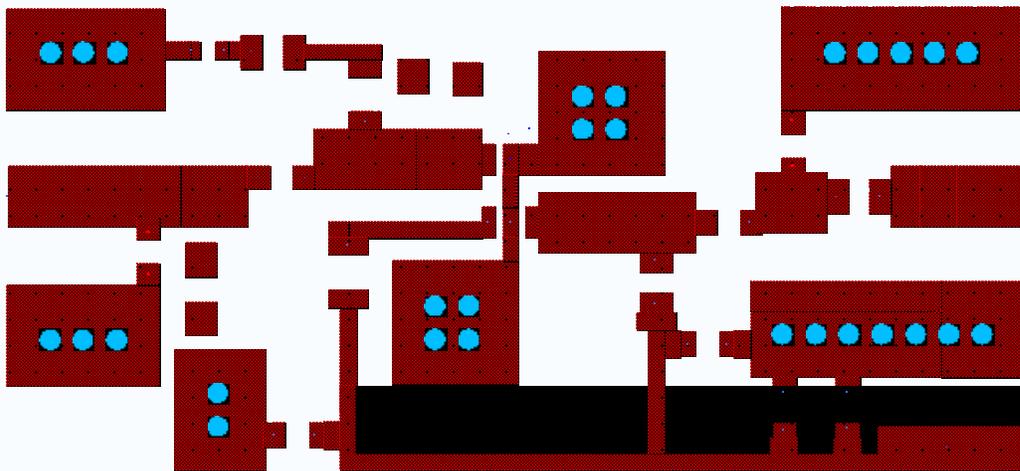
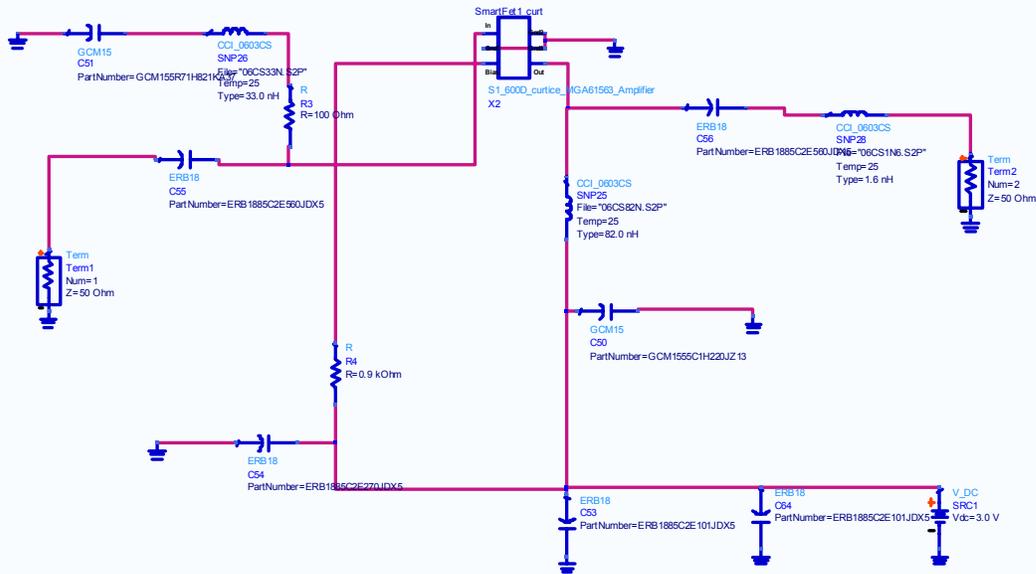


Figure-5.1 Final circuit components arrangement and layout of LNA

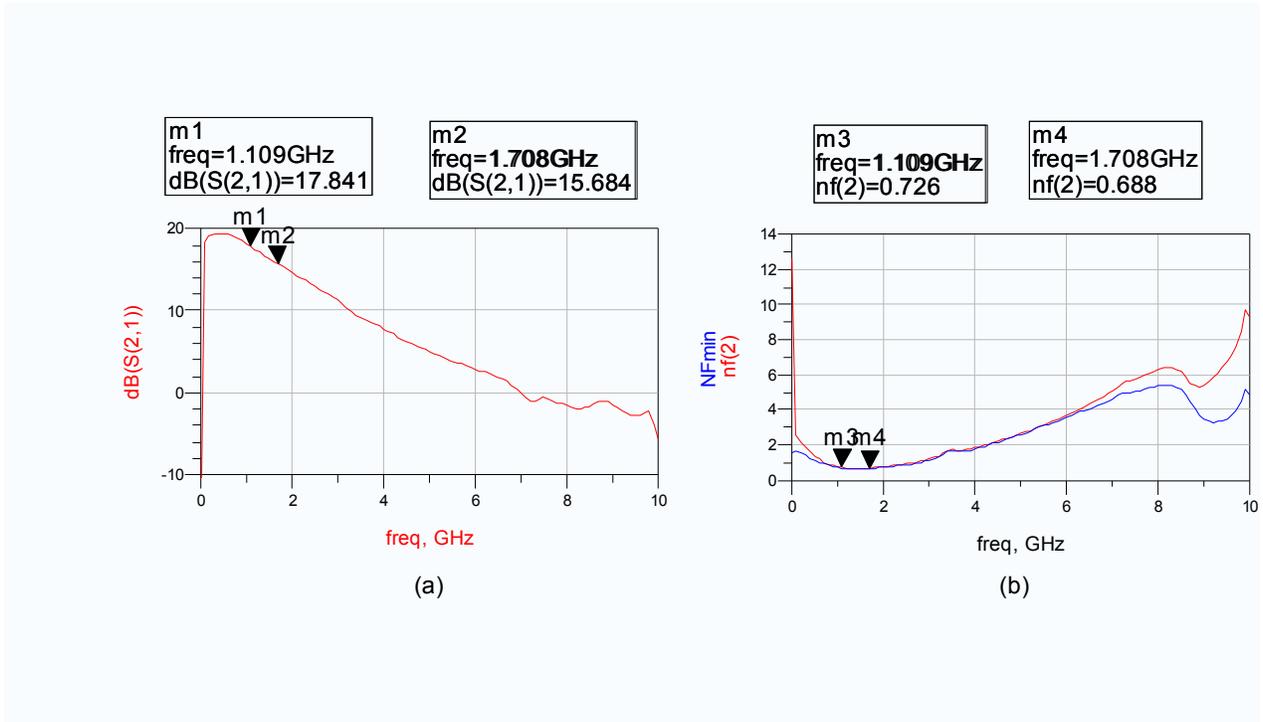


Figure-5.2 Final Layout Simulation result of LNA (a) Gain & (b) Noise figure (NF)

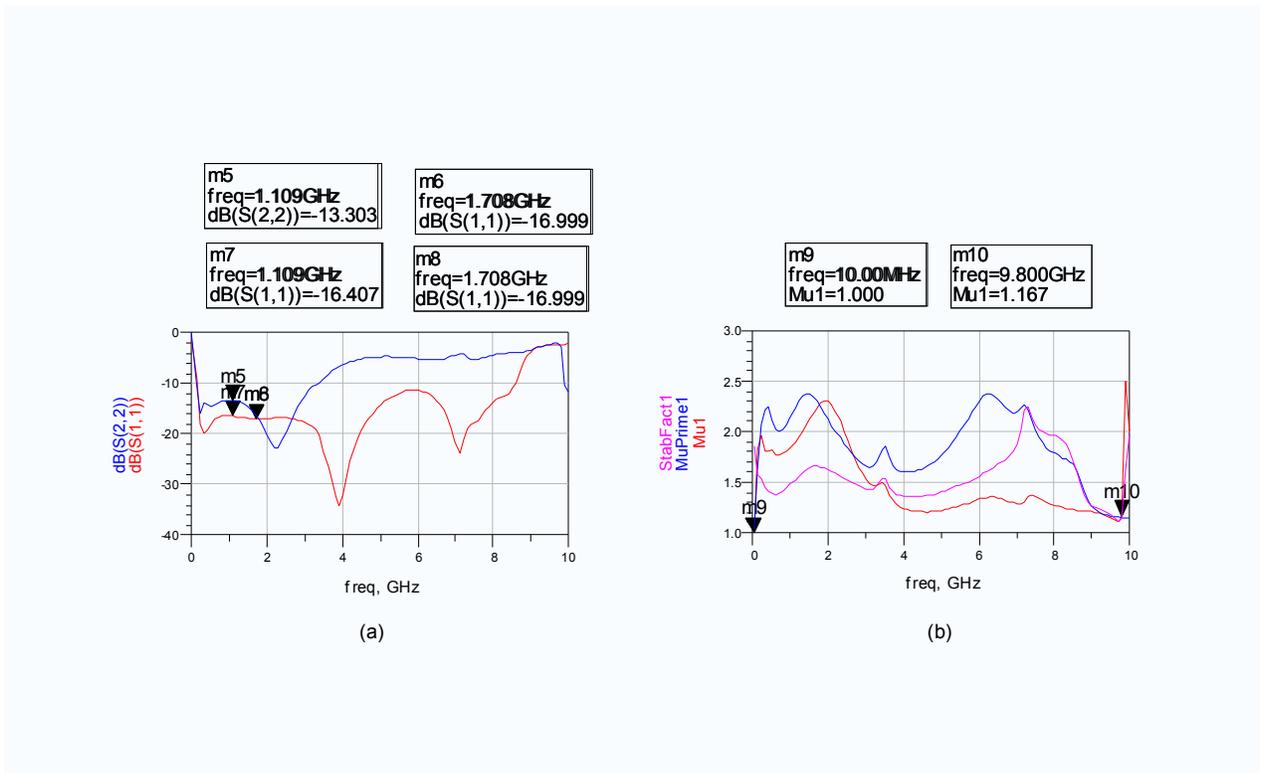


Figure-5.3 Final Layout Simulation result of LNA (a) Return losses & (b) Stability factors

Table-5.3 LNA final layout simulation results

LNA final layout simulation results	
Frequency Range	1.109-1.708 GHz
Noise Figure	0.71 dB
Gain	16.76 dB
Return Losses	16.7 dB (S_{11})
	14.8 dB (S_{22})
Power consumption	55 mW
OIP ₃	25.69 dBm
P _{1dB}	15.14 dBm
Stability	Unconditionally stable from 0-10 GHz

5.3 Introduction of Filter

A filter is an electrical device that alters the frequency spectrum of signals passing through it. Filter plays an important role in RF/Microwave applications. A RF/Microwave filter is a two-port network used to control the frequency response at a certain point in a RF/Microwave system by providing transmission at frequencies within the pass band of the filter and attenuation in the stop band of the filter. A filter's primary purpose is to differentiate between different bands of frequencies and therefore frequency selectivity is the most common method of classifying filters. Names such as lowpass, high pass, band pass and band stop are used to categorize filters. If a circuit passes all signals from dc through its cut off frequency but stop the rest of the spectrum, it is known as a low pass filter. If a circuit stops all the signals up to cut off frequency and passes those at higher frequencies is known as high pass filter. If a circuit passes only a finite frequency band and does not include zero(dc) and infinite frequency, it is called a band pass filter. Similarly a band stop filter passes all signals except a finite band.

The increasing demand of high quality wireless communication continue to challenge RF/Microwave filters with requirements, such as high performance, small size, low cost and less weight etc. Due to the requirements and situations, the RF/Microwave filters can be designed either lumped elements or distributed elements circuits. The most recent development of materials and fabrication technologies such as MMIC, MEMS, HTS and LTCC, has forwarded the filter design in to new microstrip technologies. Advance computer aided

design (CAD) tools especially EM full-wave simulation have influenced the microstrip technology. Besides, sometimes making filters using lumped components at specific frequency band for an

instance L band could be difficult due to more lumped elements which has increased the influence of different parasitic effects. In this project the designer has faced this kind of problem and finally the microstrip technology has been chosen by the designer. To sum up , there are two key considerations to design a filter, which are given below [11]

- Frequency response (Both attenuation and group delay)
- Impedance matching.

In this project, one broad band traditional hairpin band pass filter and one hairpin band stop filter is designed. The following section will present the filter design and its simulated frequency response.

5.3.1 BP Filter design and Specifications

There are different kinds of conventional microstrip band pass filter such as coupled line filter, Comb line filter, Inter digital filter, Hairpin filter, Hairpin-Comb filters, Stepped impedance filter, stub line filters, Zig-Zag coupled line filters, half wave length coupled line filters and so on, are extensively used in many RF/Microwave applications. In this project, the fractional bandwidth (FBW) of the band pass filter is 41%. Usually, in the conventional RF/ Microwave micro strip filter design where the band width is greater than 10% of the centre frequency design is quite hard. For instance, coupled line or inter digital filters have better performance where the band width is less than 10% of the centre frequency. Besides, with in the L frequency band the wave length of the resonator is quite large and increases the filter size. Again, the comb line and inter digital filters need good ground connection which is difficult. Therefore, it's better to choose such a simple filter which can be easily implemented and has good response. This is why the designer is motivated to design a half wave-length Hairpin-Filter for this project. Nowadays, there are several types of Hair-pin filters; in this project a traditional fifth order Hair-pin filter is designed. A more detail discussion can be found in reference [13].

The specifications of the filter which have been followed for designing the combined GPS/Galileo Band pass filter are given in Table-5.4

Table.5.4 Band Pass filter specifications

Band Pass Filter specifications	
3 dB band width	550 MHz
Insertion loss, IL	≤ 1 dB
Input & output return Loss, RL	>15 dB
Source Impedance	50 Ω
Load Impedance	50 Ω

The Substrate specifications are given in Table-5.5

Table-5.5 Substrate Specifications for the BP

Substrate specifications	
Relative dielectric constant, ϵ_r	10.30
Dielectric loss tangent, $\text{Tan } \delta$	0.0023
Substrate thickness, H	0.76 mm
Conductor thickness, T	35 μm

5.3.1.1 BP Simulation results

In this project, the Agilent's Advanced Design System (ADS) simulation tool has been used. Final circuit layout of band pass filter and the full wave EM simulation performance of the filter are shown in Figure-5.4 and Figure-5.5 respectively and the summarized results is given in Table-5.6

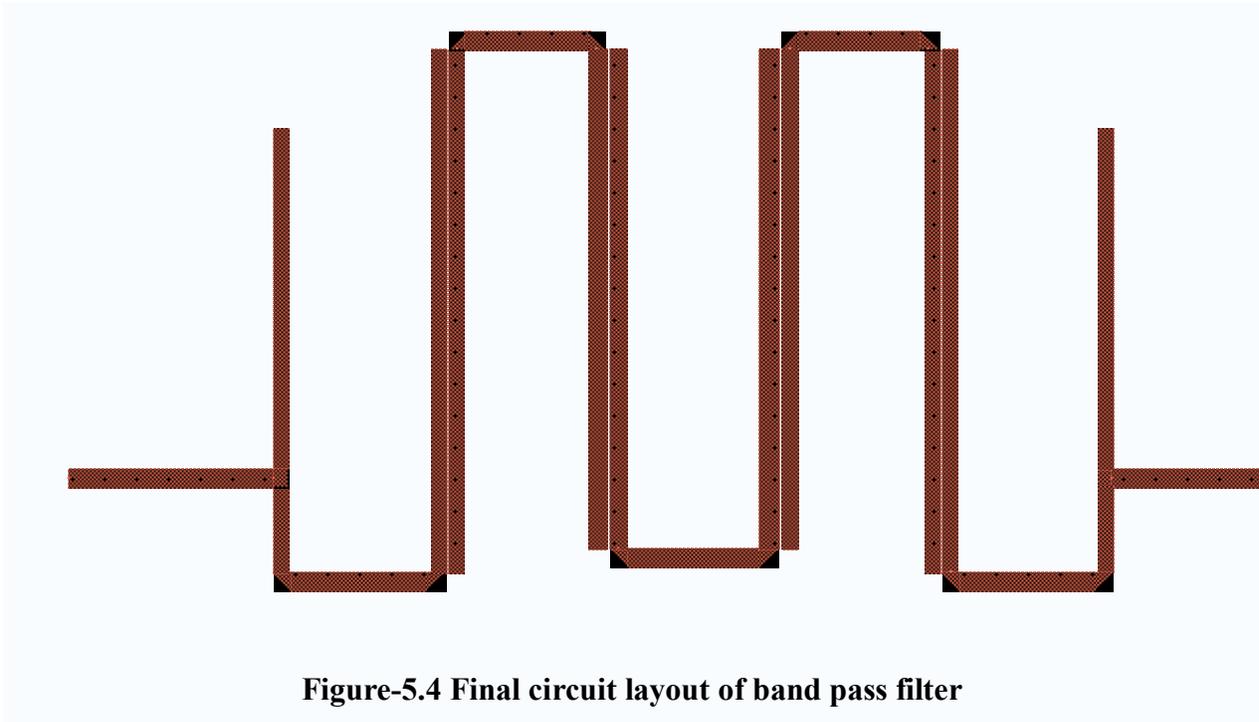


Figure-5.4 Final circuit layout of band pass filter

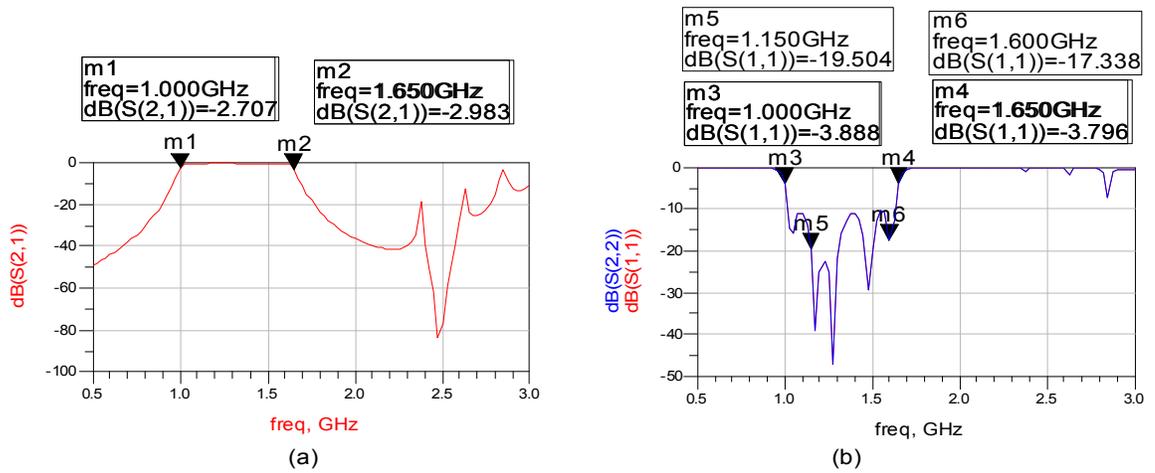


Figure-5.5 Full wave EM Simulation performance of the Band Pass filter (a) S_{21} (b) S_{11}

Table.5.6 Summarized result of Band Pass filter

Summarized result of Band Pass filter	
3 dB band width	650 MHz
Insertion loss, IL	≤ 0.5 dB
Return Loss, RL	> 15 dB @ GPS/Galileo operating band
Source Impedance	50 Ω
Load Impedance	50 Ω

5.3.2 BS Filter design and Specifications

There are different kinds of conventional microstrip band stop filter such as Open circuited stub band stop filters, L-shape resonator band stop filters, Spiral resonator band stop filters, Open loop (Hairpin) resonator band stop filters and Improved Hairpin band stop filters and so on, are widely used in many RF/Microwave applications. In this project a traditional third order Hair-pin band stop filter is designed. A detailed discussion can be found in reference [13]. The specifications of the filter which is followed for designing the combined GPS/Galileo LNA is given in Table-5.5

Table-5.7 Band Stop filter specifications

Band Stop Filter specifications	
3 dB band width	260 MHz
Centre frequency	1429.5 MHz
Input & output return losses	> 10 dB
Source Impedance	50 Ω
Load Impedance	50 Ω

The Substrate specifications are given in Table-5.6

Table-5.8 Substrate Specifications for the BS

Substrate specifications	
Relative dielectric constant, ϵ_r	10.30
Dielectric loss tangent, $\text{Tan } \delta$	0.0023
Substrate thickness, H	0.76 mm
Conductor thickness, T	35 μm

5.3.2.1 BS Simulation result

In this project, the Agilent's Advanced Design System (ADS) simulation tool has been used. Final circuit layout of stop band filter and the full wave EM simulation performance of the filter are shown in Figure-5.6 and Figure-5.7 respectively and the summarized results is given in Table-5.7

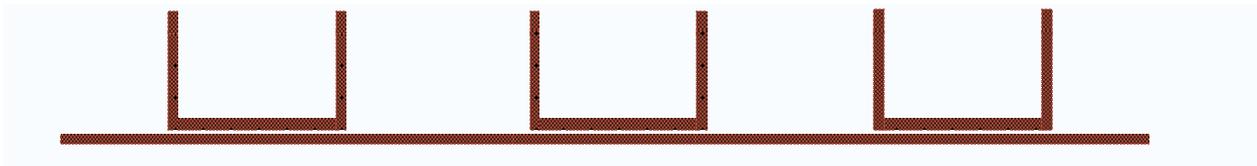


Figure-5.6 Final circuit layout of stop band filter

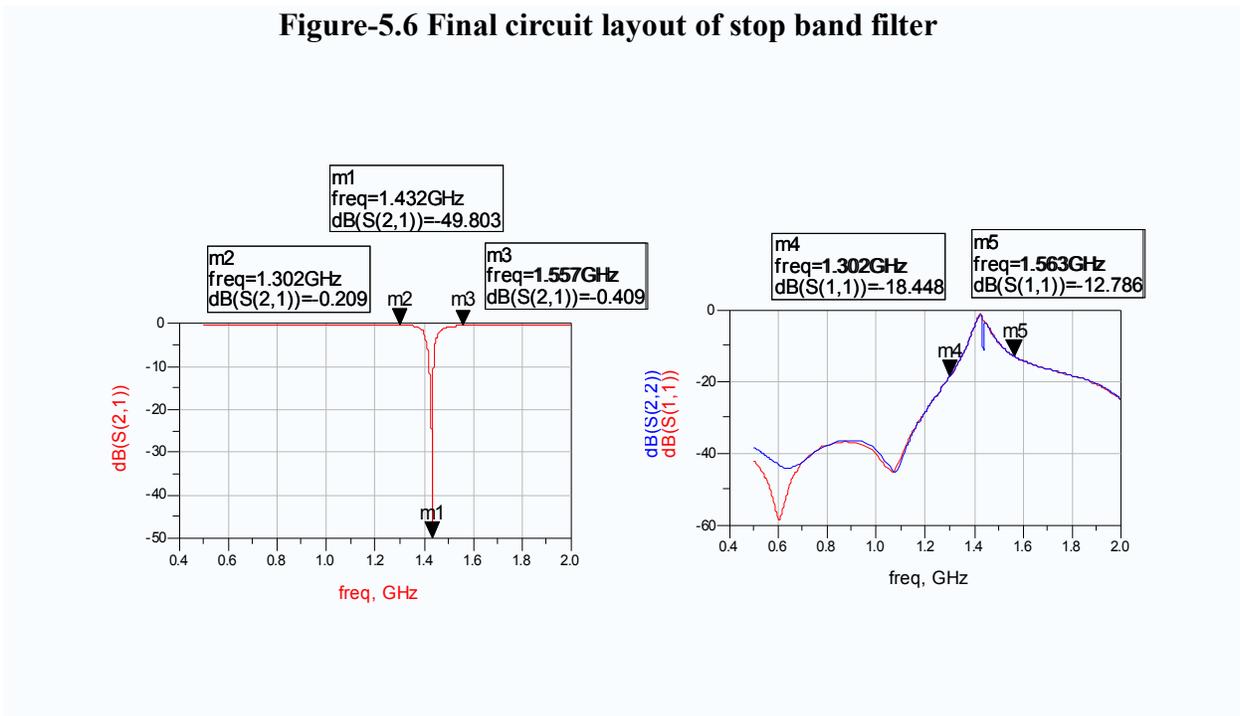


Figure-5.7 Full wave EM Simulation performance, (a) S_{21} (b) S_{11} & S_{22} of the Band Stop filter

Table-5.9 Summarized result of Band Stop filter

Summarized result of Band Stop filter	
3 dB band width	255 MHz
Centre frequency	1432 MHz
Input & output return losses	> 10 dB
Source Impedance	50 Ω
Load Impedance	50 Ω

5.4 Conclusion

There are always some design constraints between theoretical and simulation. To compromise these constraints and go further towards the design goal is the best option for the designer. During this project, the designer has also faced some problems in the specific component. In the LNA design, the curtsie model of LNA IC was not stable with in the whole band (0-10 GHz), there were oscillation in low frequency and high frequency as well, to solve this problem a RLC series notch network is added to the source side of the LNA. Besides, there were low return losses of the LNA IC's and to improve the return losses an inductor is added to the load side of the LNA. However, the final simulation responses of the LNA are complying with the specifications. In the band pass and the stop band filter design, there were always two things have to be considered. One is wider band width and the second is the frequency band (L-band). L- band has larger wave length and it has also suffered spacing between the resonators. In the band stop filter since the spacing is too small, so the electric coupling will be decreased faster, that is why, to balance the electric coupling and magnetic coupling the separation between 50 ohms characteristic impedance line and coupled line are made a bit higher which has effect less band width but good performance. However, the full wave EM simulation performances for both filters are complying with the specifications.

Chapter-6

6.1 Introduction

This chapter will show the measurement performances of the implemented LNA, Band Pass filter and Band Stop filter separately and then the measurement performances of RF front end for combined GPS/Galileo receiver.

6.1.1 Measurement results of LNA

The LNA is implemented on Rogers RO4003 (3.38) substrate and Murata (0603) capacitors, Coil craft (0603) inductors and Neohm (0603) resistors are used. For measuring the LNA gain and return losses Rohde & Schwarz VNA is used and for noise figure Agilent Series Noise Figure Analyzer (NFA) is used. The complete implemented LNA is show in Figure-6.1 and the measurement results are shown in Figure-6.2 and Figure-6.3 and the summarized results is given in Table-6.1

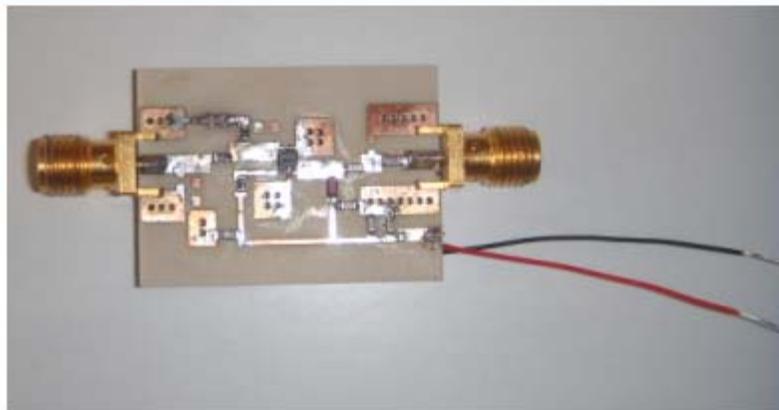
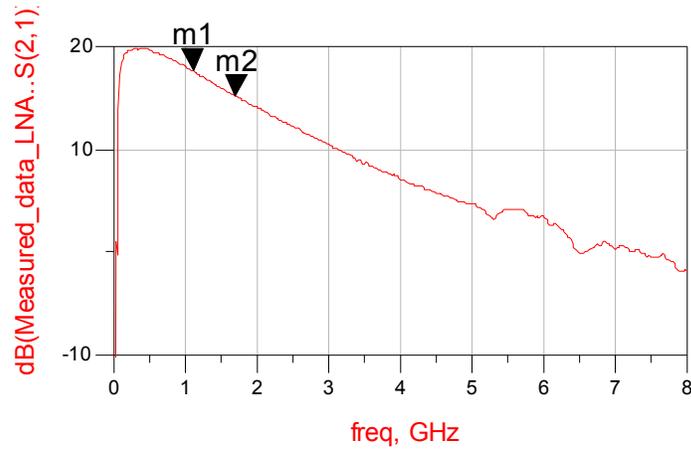


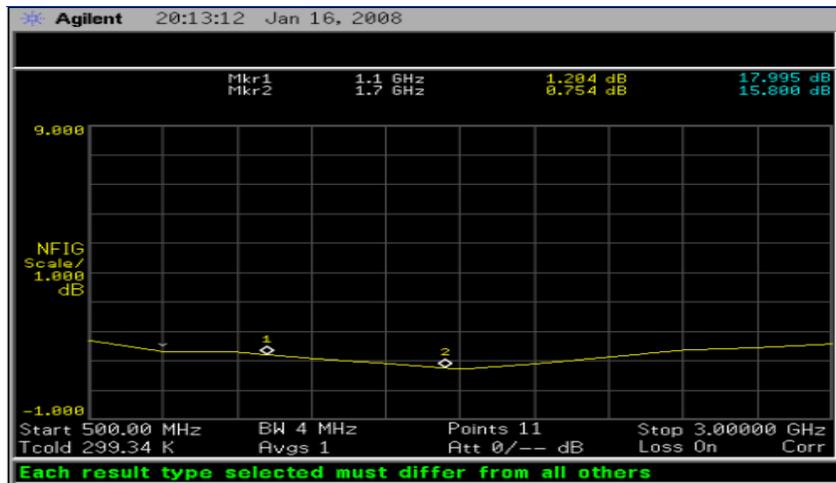
Figure-6.1 The implemented LNA

m1
 freq=1.100GHz
 dB(Measured_data_LNA..S(2,1))=17.639

m2
 freq=1.700GHz
 dB(Measured_data_LNA..S(2,1))=15.185



(a)



(b)

Figure-6.2 (a) Measurement performance of LNA's (a) Gain & (b) Noise figure (NF)

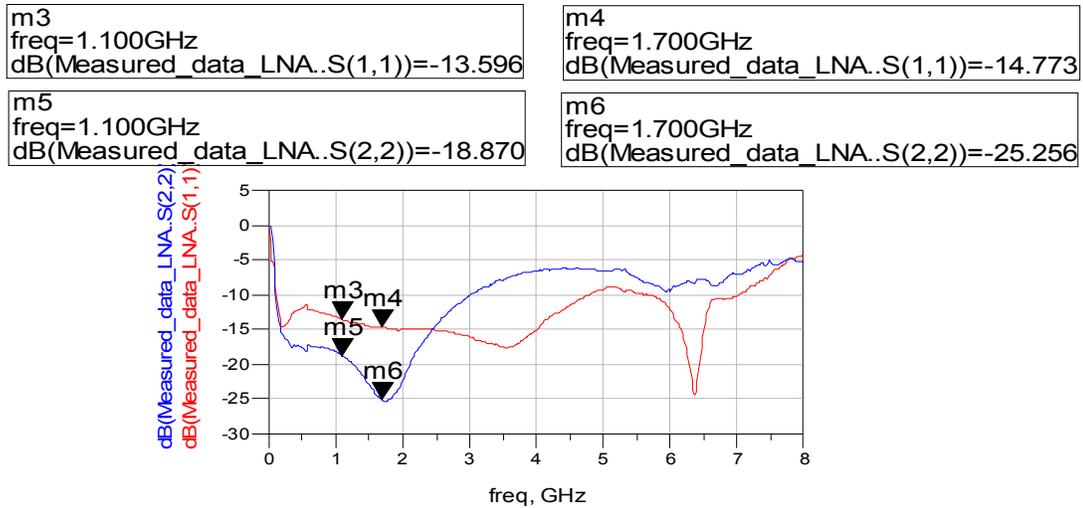


Figure-6.3 Measurement performance of LAN's input and output return losses

Summarized Average measurement results of LNA	
Frequency Range	1.1-1.7 GHz
Noise Figure	1.01dB (1.1-1.6 GHz)
Gain	16.42 dB
Return Losses	14.74 dB (S ₁₁)
	22 dB (S ₂₂)
Power consumption	78 mW
OIP ₃	30.25 dBm
P _{1dB}	16.14 dBm
Stability: Unconditionally stable up to 20 GHz (Spurious response with an Spectrum Analyzer)	

Table-6.1 Summarized measurement results of LNA

6.1.2 Measurement result of Band Pass filter

The Band pass filter is implemented on ARLON AD1000 (10.30) substrate and LPKF (laser & Electronics) machine is used. For measuring the performance of the Band pass filter Rohde & Schwarz VNA is used The implemented Band pass filter is show in Figure-6.4 and the measurement results are shown in Figure-6.5 and the summarized results is given in Table-6.2

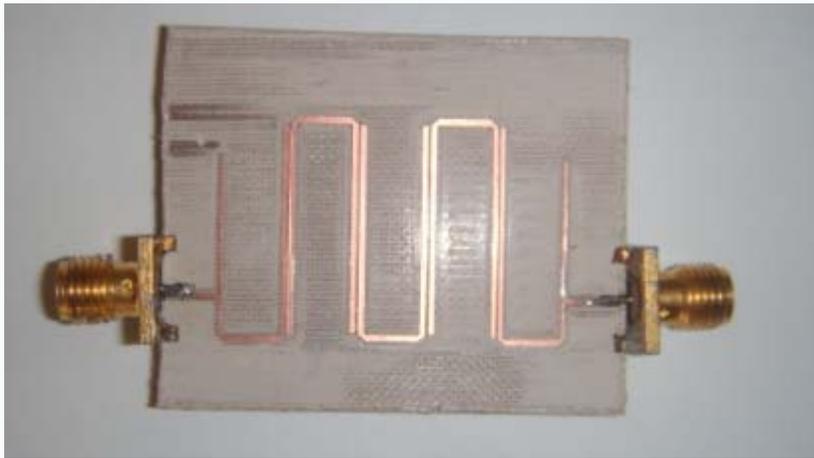


Figure-6.4 The implemented Band pass filter

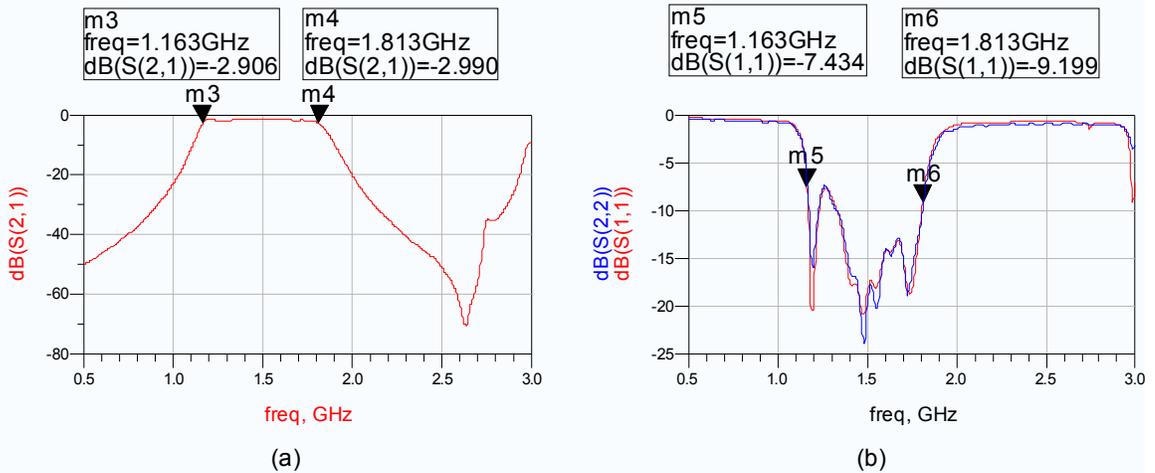


Table-6.2 Summarized measurement results of Band pass filter

Summarized Average Band Pass filter performance	
3 dB band width	650 MHz
Insertion loss, IL	< 2 dB
Return Losses, RL	> 10 dB
Source Impedance	50 Ω
Load Impedance	50 Ω

6.1.3 Measurement result of Band Stop filter

The Band pass filter is implemented on ARLON AD1000 (10.30) substrate and LPKF (laser & Electronics) machine is used. For measuring the performance of the Band stop filter Rohde & Schwarz VNA is used The complete implemented Band stop filter is show in Figure-6.6 and the measurement results are shown in Figure-6.7 and the summarized results is given in Table-6.3

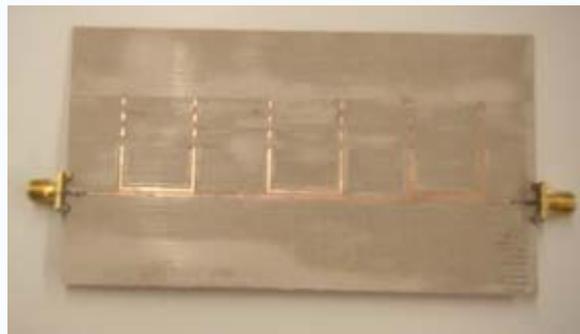


Figure-6.6 The implemented Band stop filter

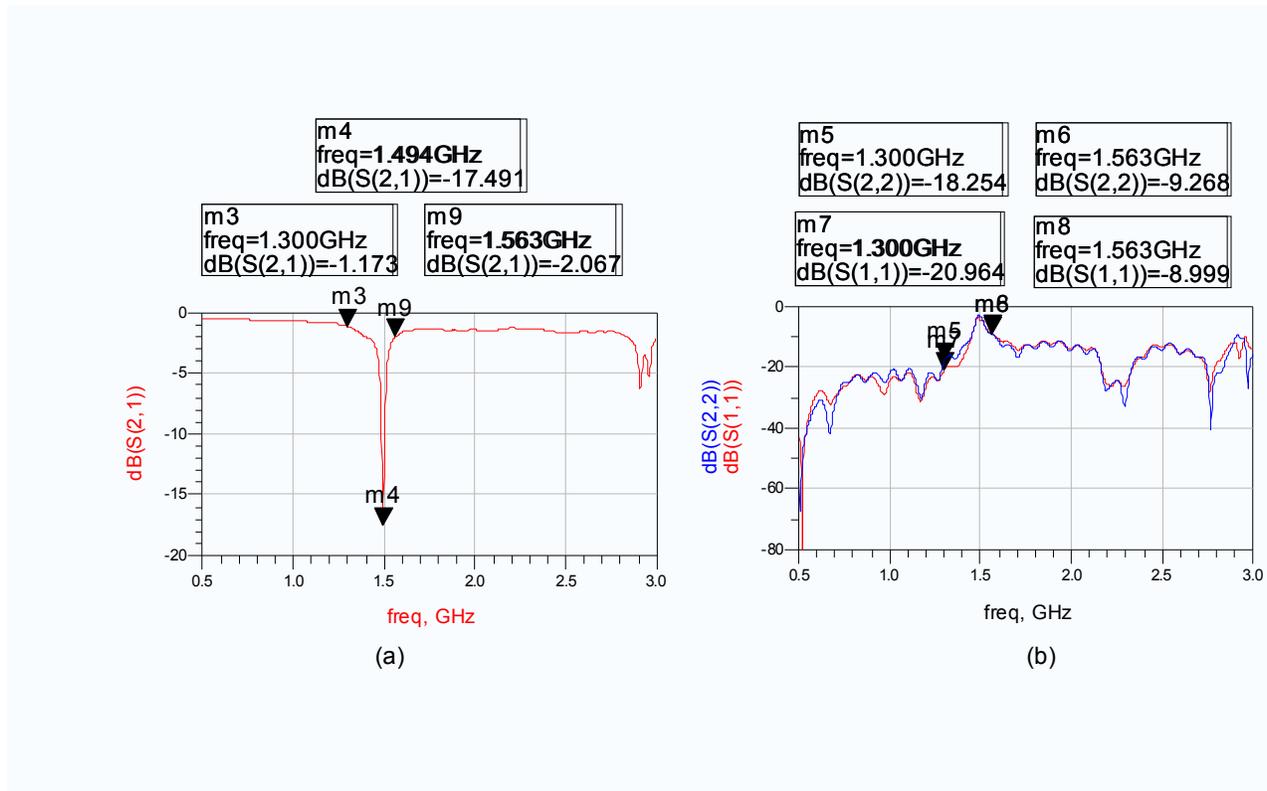


Figure-6.7 Measurement performance of the Band Stop filter, (a) S_{21} (b) S_{11} & S_{22}

Table-6.3 Summarized measurement results of Band Stop filter

Summarized Band Stop filter performance	
Band width	263 MHz
Centre frequency	1494 MHz
Input & output return losses	> 10 dB (Average)
Source Impedance	50 Ω
Load Impedance	50 Ω

6.2 Summarized performance of RF front end

The implemented RF front end is shown in Figure-6.8 and the summarized performance of the front end is given in Table-6.4

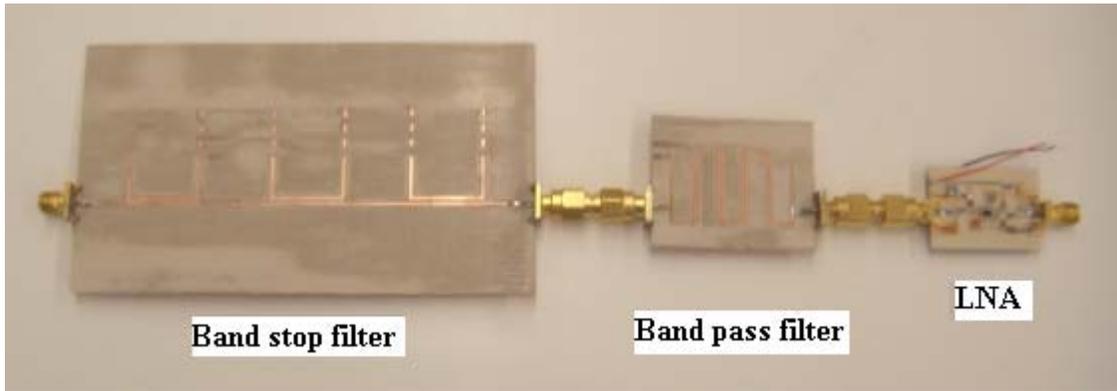


Figure-6.8 The implemented RF front end

6.2.1 Test setup and measured performance of RF front end

A . RF front end Gain and Input return loss

When measuring the RF front end gain and input return loss, the network analyzer is used. The test setup is shown in Figure-6.9 and the response of the front end is shown in Figure-6.10

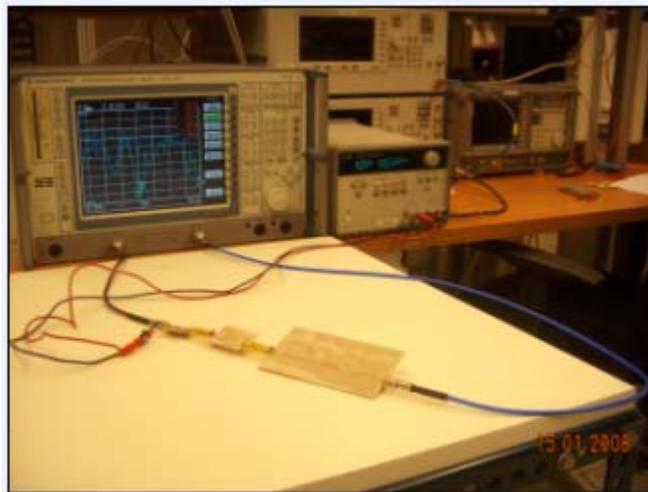


Figure-6.9 The test set up for gain and input return loss of implemented RF front end



Figure-6.10 The Gain and input return loss response of implemented RF front end

B . RF front noise figure

When measuring the noise figure of the implemented RF front end, the Series Noise Figure Analyzer (NFA) is used. The test setup and measurement performance is shown in Figure-6.11 and Figure-6.12 respectively.

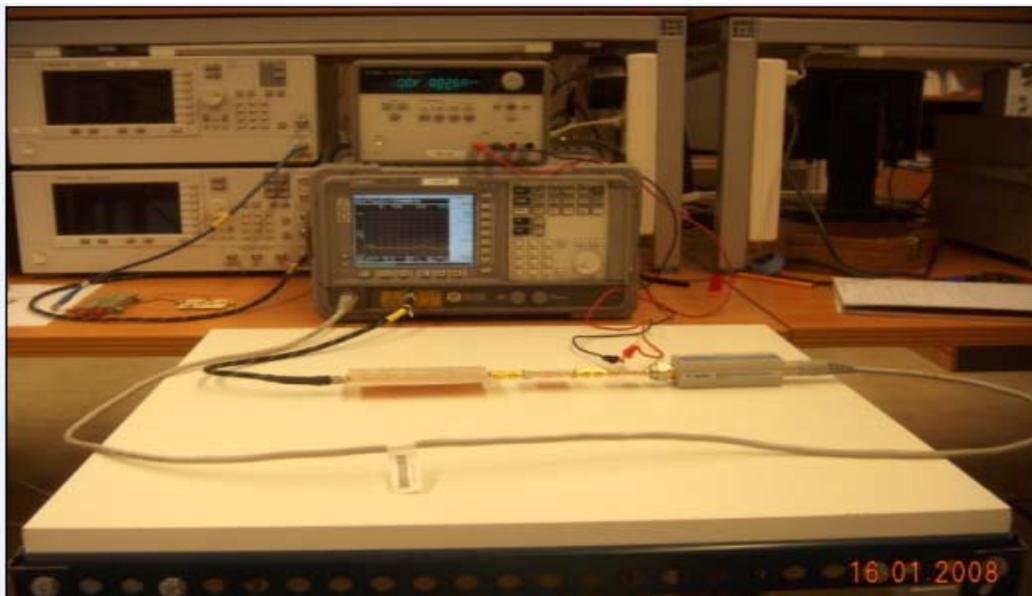


Figure-6.11 The test set up for noise figure of implemented RF front end

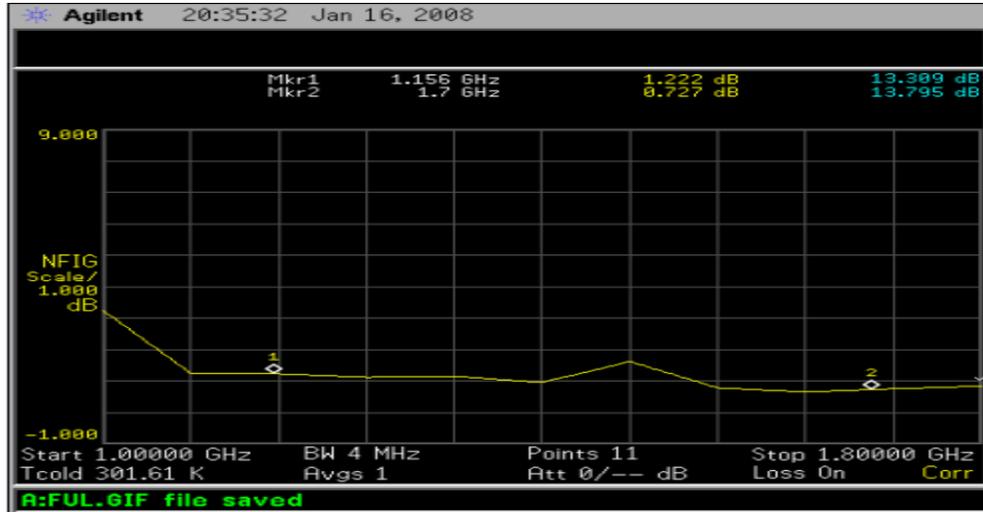


Figure-6.12 The noise figure response of implemented RF front end

Table-6.4 Summarized measured results of RF front end

Summarized average RF front end performance	
Noise Figure, NF	1 dB
Gain	12 dB
Input return loss	> 10 dB
Power consumption	78 mW

6.3 Comparison between Implemented and Commercial GPS RF front end

Since, there is no commercial product for combined GPS/Galileo RF front end yet, therefore the author's point of view is that it's better to have a look with commercial available GPS RF front end. In this section the integrated GPS receiver RF front end (SE4100L) manufactured by SiGe Semiconductor is used for basic comparison. The comparison between the implemented RF front end and the commercial GPS RF front end is given in Table-6.5

Table-6.5 Basic comparison between implemented and commercial RF front end

Basic comparison		
Parameter	Commercial RF front end	Implemented RF front end
Operating Frequency Band	L1(1575.42 MHz)	L1&E1(1575.42 MHz),E6(1278.75 MHz), L2,L5 & E5(1207.140 MHz)
Front end components	LNA, Mixer, Oscillator, Filtres etc	LNA, Filters
Power consumption	38 mW	78 mW
Noise figure, NF	12.5 dB	1 dB

6.4 Discussion

Each and every RF designer should have faced the reality which gives the unexpected results for what has been designed. RF circuit design is really challenging task that requires considering RF fundamentals, active and passive models, and knowledge about RF versus DC behaviors, understanding the semiconductor device physics and CAD techniques as well. After having all of this, practical experience is a most important thing which will give a successful product design. During this project, the designer has also faced some problems in the specific component. In the implemented LNA, the measurement results are almost complying with the simulation results but the remarkable change is the noise figure and the power consumption. Both the noise figure and the power consumption have increased. The most important issue is the non-ideal component effects. In RF testing, surface mounted component is suitable because of the smaller parasitic effects but still they are not 100% perfect. Most of the surface mounted capacitors have parasitic inductance which can be higher than 1 nH and most of the surface mounted inductors have resonance effects. Besides, the ADS model can not be a perfect model and the connector and soldering the components on PCB is also the reason for increasing the noise figure. Usually the noise figure measurement should be in the shielded room because near the RF from base station will not give the accurate result. This could be one of the reasons for high noise figure.

In the implemented band pass filter, the measured and the simulated 3 dB band width both are same but the measurement 3 dB band widths has sifted to the higher frequency and the insertion loss is also higher than the simulated result. As mention it before the bandpass filter is in L-band and it is a broad band design. Therefore, spacing is the key consideration for changing the filter response. In the implemented band stop filter, the measured and the simulated band width and the center frequency both are shifted. The filters are made by using the LPKF machine. For the perfect design, the LPKF machine positioning accuracy is very important, to maintain the necessary precision for both x-y axis dimensions and the depth of the penetration of the substrate. Since the filter's coupled line spacing is very small (0.1 mm) for the band pass filter and the LPKF machine's micro cutter drill pin diameter is also 0.1 mm, therefore it is quite difficult to make the spacing 0.1 mm by using the LPKF machine. Besides, the machine drill pin has also some tolerances.

In the implemented RF front end, the measurement performance is depicted in Figure-6.10 and Figure-6.12 and the result is summarized in the Table-6.4 and the basic comparison between a commercial GPS RF front end and the implemented RF front end is given in Table-6.5. In Figure-6.10, the front end average gain is 12 dB in the band of interest but it has also same gain up to 1.75 GHz which is not band of interest. This is due to imperfection filter response of band pass filter and in Figure-6.12 the noise figure a bit high due to the shift of center frequency and the exact stop band filter response. The degradation of the filter responses is discussed above. Test-bench is an important issue for measuring the RF performance. Since, the test-bench is not used during the RF measurement this could be an issue for degrading the RF front end performance.

Chapter-7

7.1 Conclusions

To design RF circuits is quite challenging and it requires a better combination between the theoretical knowledge and practical experience. In this dissertation, several kinds of RF front end receiver architecture have been investigated and finally, the direct digitization RF front end receiver architecture has been chosen for multi-band multi system GNSS receiver. And then, it has been designed, implemented and tested. The implemented RF front end is able to perform 1 dB noise figure, 12 dB Gain, input return loss is higher than 10 dB and the power consumption is 78 mW. The power consumption is quite higher than the commercial RF front end which is used for GPS (L1) band, but the implemented RF front end is able to perform both the GPS and Galileo band. It is apparent that to design broad band system requires more power compare to the narrow band system. Not only the broadband but also gain and noise figure is a tradeoff with the power consumption. From the Figure-6.10, it is obvious that the band width of the receiver front end is increased in the high frequency. Since, the navigation spread-spectrum signals are below the thermal noise floor and in the digital software is used a special technique during the correlation which is high processing gain in the band of interested , therefore non of band interest in the RF front end will have not too much impact to the performance of the whole receiver. In the whole system there are two possible way to good filtered the signal. One is the analog part and the other one is in the digital part. Actually, there is a trade off between these two filtering. If the analog part is not well filtered the signal then we needs the signal more filtered in the digital part which will increase the computational cost.

The main contribution of this dissertation is to propose a simple multi-band multi-system combined GPS and Galileo receiver RF front end.

7.2 Future works

In future, to capture the real satellite signal and play with digital software radio and RF front end by using the MATLAB Simulink to analyze how the RF front ends response impact on the satellite detection and positioning accuracy. A custom LNA design is required to analyze. Instead of designing the microstrip filter, SAW or BAW filter is required to analyze. In this dissertation there are three models has been proposed but only the first proposed model is analyzed. Rest of the two models required to analyze. In future there are two more satellites band L3 & L4 which is discussed in section 3.3.2 and SAR (1544-1545 MHz) could be possible to design in this architecture. Last but not least, a MMIC combined GPS/Galileo RF front end will be an open future work for all.

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Appendices

Appendix-A

In chapter-3, the author has given clear explanation concerning the basic concept of how a GPS receiver determines the user's position. Basically, a GPS receiver is used to determine the 3D position. The 3D determination is very easy to understand by theoretically but it is really quite hard to understand figuratively. Here in appendix-A the author will try to give some theoretical concept of how a GPS receiver determine the 3D position. As mentioned it before in chapter-3, for finding the 3D user position four satellites are needed. Some times it seems that three satellites are sufficient for determining the 3D position. Suppose if we see the three dimensional axis in Figure- A1 and analyze the following given equations

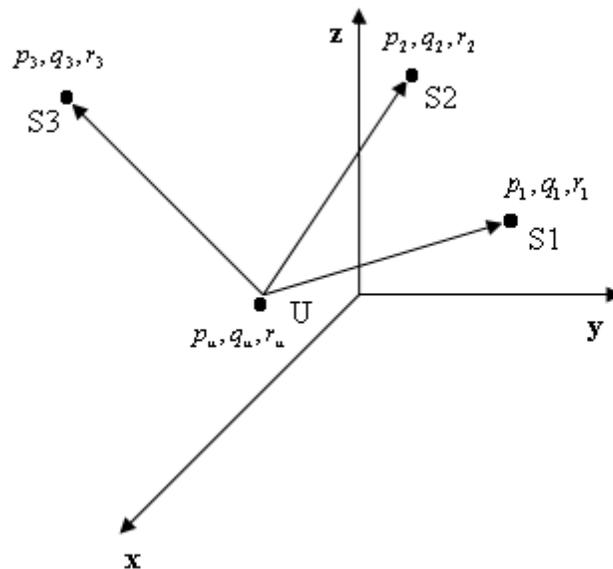


Figure-A1 Three-dimension user position using three known satellites position

From the above Figure-A1, assumed that there are three known satellite's position (S1, S2, S3) with the known three distances (d_1, d_2, d_3) and an unknown user position (U). Therefore, there are three equations whose has three unknown (p_u, q_u, r_u) can be solved by using the following given equations below

$$d_1 = \sqrt{(p_1 - p_u)^2 + (q_1 - q_u)^2 + (r_1 - r_u)^2}$$

$$d_2 = \sqrt{(p_2 - p_u)^2 + (q_2 - q_u)^2 + (r_2 - r_u)^2}$$

$$d_3 = \sqrt{(p_3 - p_u)^2 + (q_3 - q_u)^2 + (r_3 - r_u)^2}$$

After solving the above three equations, there should have two possible solutions. In theoretically one solution can not determine the user position because between two solutions, one is in the space and another one is closed to the earth's surface. Since the user is on the earth's surface, it will be the only solution for user position. Basically, Ephemeris data and pseudoranges can be obtained from the navigation data. Ephemeris data are used to determine the position of the satellites, which are transmitted by the satellite and by using the satellite positions and the pseudoranges the user position can be calculated.

Normally, Each and every satellite sends a signal at a specific time and the receiver (user) receives the signal at a later time. It is true that there are some differences between the user clock and the GPS clock. Therefore, there is always a unknown constant bias error, which will not give the exact user position. To solve this problem it is apparent that in the above three equations it should require a constant (b_u). Now if the equation is rewritten with a constant (b_u) and for resolving these equations one more equation will be needed. Thus, in order to find the user position at least four satellites are required. The equations are given below

$$d_1 = \sqrt{(p_1 - p_u)^2 + (q_1 - q_u)^2 + (r_1 - r_u)^2} + b_u$$

$$d_2 = \sqrt{(p_2 - p_u)^2 + (q_2 - q_u)^2 + (r_2 - r_u)^2} + b_u$$

$$d_3 = \sqrt{(p_3 - p_u)^2 + (q_3 - q_u)^2 + (r_3 - r_u)^2} + b_u$$

$$d_4 = \sqrt{(p_4 - p_u)^2 + (q_4 - q_u)^2 + (r_4 - r_u)^2} + b_u$$

However, from the above discussion it is clear that how the three dimensional user positions can be determined by the GPS receiver. A more detail discussion regarding on GPS fundamental can be found in reference [7].

Appendix-B

Band pass Sampling

In chapter-2 and chapter-4, the author has discussed little bit about band pass sampling technique for the direct digitization receiver architecture. Here the appendix-B will explore the fundamental concept of the band pass sampling technique and its mathematical expression for choosing the sampling frequency. The main purpose of the software radio technique is to place the ADC as close the antenna as possible. To accomplish this, high performance ADC should be required because the ADC will work at RF sampling frequency greater than the twice of the carrier frequency of interest and after that processed by Field Programmable Gate Array (FPGA). Such a high rate processing sample with reasonable power consumption is still under developing. Therefore, right now band pass sampling technique could be the righteous alternate solution.

Band pass sampling is such a technique where under sampling rate of a modulated signal is used to achieve frequency conversion via intentional aliasing. The ratio of the RF carrier to the under sampling rate is not too high because the noise density at the presence ADC's operating at RF being high and increase the harmonic order with increase the of sampling rate. This sampling frequency is not based on the frequency of the carrier, but rather on the interested band width of the signal. Basically, an ADC will operate at higher than twice the largest carrier frequency of interest, therefore the resulting information bandwidth (BW_I) will contain the frequencies from DC to $F_s/2$. Thus, the resulting processing rate can be significantly reduced. [14]

There is a mathematical expression which will translate the carrier frequency F_C to the resulting low intermediate frequency F_{LIF} as a function of sampling frequency F_S is given below

$$F_{LIF} = \begin{cases} odd, F_s - rem(F_C, F_s) \\ even, rem(F_C, F_s) \end{cases} \quad \text{if } (2F_C / F_s)$$

Where $rem(a, b)$ is the remainder after division of a/b . There are also some mathematical expressions, which can be ensured that each entire desired band fall with in the resulting bandwidth. Those inequalities of the lower and upper constrain are given below:

$$0 < F_{LIF_1} - \frac{BW_I}{2} \quad \text{And} \quad \frac{F_S}{2} > F_{LIF_1} + \frac{BW_I}{2}$$

Where BW_I is the information band width. Moreover, for multiple band pass sampling, the information bands must not overlap in the frequency spectrum of the resultant sampled bandwidth. Therefore, the another constrain of mathematical expression for multiple (N information bands) band pass sampling is expressed as [14]

$$|F_{LIF_a} - F_{LIF_b}| \geq \frac{BW_{I_b} + BW_{I_a}}{2}, \quad \text{For } a=2\dots N, b=1\dots, a$$

A detailed discussion can be found in reference [14]. Using those above equations, it would be possible to get the lowest feasible sampling frequency with the help of Ladder diagram which has already discussed in chapter-4 and shown in Figure-4.6.

In order to get clear understandings of band pass sampling technique, it could be the frequency domain representation. A frequency domain presentation, based on the direct digitization front end from Figure-2.7, is presented as a four-stage process is shown in Figure-B.1

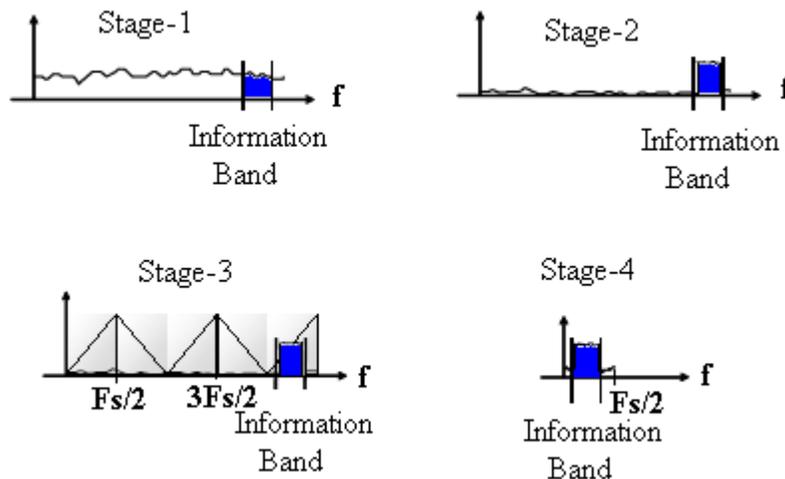


Figure-B.1 Frequency domain presentation of band pass sampling

Stage-1: When the signal enters through the antenna and then by the LNA all the frequencies within the band will be amplified.

Stage-2: The amplified signal then passes through the band pass filter and attenuates the signal out side the interested band.

Stage-3: In stage-3, the sampling frequency F_s is selected, which will define the resulting sampled bandwidth from 0 to $F_s/2$ and the aliasing triangles.

Stage-4: After sampling the information band and noise from each aliasing triangle within the analog input bandwidth of the ADC, the resulting sampled bandwidth will be folded. For the multiple signals, the frequency domain presentation of band pass sampling is shown in Figure-B.2

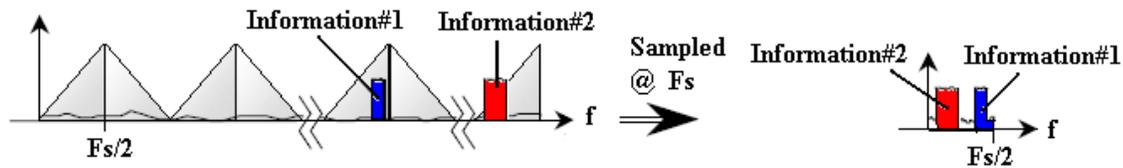


Figure-B.2 Multiple signals frequency domain presentation of band pass sampling

Appendix-C

% Programming code for choosing sampling frequency

```

% LadderDiagram
BW1=136*10^6;
BW2=32*10^6;
fc1=1232*10^6;
fc2=1575*10^6;
fs=(300:0.1:500)*10^6;
figure;
hold on
Nscan=10;
f_scan1=linspace(0,BW1,Nscan);
f_scan2=linspace(0,BW2,Nscan);
for i=1:Nscan,
    fc1_scan=fc1-BW1/2+f_scan1(i);
    fc2_scan=fc2-BW2/2+f_scan2(i);
    f_IF1=calculate_IF(fc1_scan,fs,BW1);
    f_IF2=calculate_IF(fc2_scan,fs,BW2);
    plot(fs*10^-6,f_IF1*10^-6,'r')
    plot(fs*10^-6,f_IF2*10^-6,'b')
end
plot(fs*10^-6,(fs*10^-6)/2,'k')
plot(434,0:275,'k')
xlabel('Sampling frequency [MHz]')
ylabel('IF frequency [MHz]')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function f_IF=calculate_IF(fc,fs,BW)
slope=fix(fc./(fs/2));
is_odd=rem(slope,2);

```

```
N=length(is_odd);  
for i=1:N,  
    if is_odd(i),  
        f_IF(i)=fs(i)-rem(fc,fs(i));  
        %disp('a')  
    else  
        f_IF(i)=rem(fc,fs(i));  
        %disp('b')  
    end  
end  
end
```