An Indoor Positioning System based on Global Positioning System

by

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Abstract

GPS (Global Positioning System) has great demand in recent years and the use of GPS has increased widely in many areas like transportation, tracking, navigation, as well as being implemented in almost all of the smart phones for location based services to improve the quality of our daily life. GPS system communicates with the satellites which send the GPS signals to the earth to be able to provide needed information to the GPS receivers. GPS signals that reach to the earth is in low power and GPS receivers evaluate the position with respect to information in the signal. This position evaluation can be done with the error of 2.5 meters in today's technology. Despite this system is successful in outdoor areas, it is not so successful in indoor areas. Decoding GPS signals in the indoor areas is hard due to additional loss in the GPS signal because of interaction of the signals with physical obstacles. There is a need for increasing coverage of GPS signals in indoor areas like tunnels, undersea and buildings. In this thesis, an indoor positioning system based on GPS infrastructure is proposed and designed. Designed indoor positioning system consists of directional GPS antennas, downconverters, upconverter and IF antennas. For realizing the system, downconverters, upconverter and IF antenna are designed, manufactured and measured. The experiments show that indoor positioning can be done with our designed system by adding some hardware and updating in positioning algorithm to the conventional GPS receivers.

GPS Temelli İç Mekan Konumlandırma Sistemi

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Anahtar Kelimeler: GPS, İç Mekan Konumlandırma, Frekans Düşürücü, Frekans Yükseltici, Yönlü GPS Anteni, 433MHz IF Anten.

Özet

GPS (Küresel Konumlandırma Sistemi) günümüzde büyük talepe sahiptir ve günlük hayat kalitemizi artıracak konum temelli hizmetlerde kullanılan hemen hemen tüm akıllı telefonlarda olduğu gibi, ulaşım, izleme, navigasyon gibi birçok alanda çokça kullanılmaktadır. GPS sistemi, GPS alıcıları için gerekli olan bilgiyi sağlayabilmek için yeryüzüne GPS işaretlerini gönderen uydularla iletişim kurarak gerçeklenir. Yeryüzüne ulaşan GPS işaretleri düşük güçtedir ve GPS alıcıları işaretlerdeki bilgiyi değerlendirerek konumlandırmayı yaparlar. Günümüz teknolojisiyle bu konumlandırma 5m hata ile yapılabilmektedir. Bu sistem dış mekanlarda başarılı olmasına rağmen, iç mekanlarda çok başarılı değildir. İç mekanlardaki GPS işaretlerini çözümleme işaretlerin fiziksel engellerle etkileşimi dolayısıyla ortaya çıkan, işaretteki ek kayıplardan dolayı zordur. Tünneller, deniz altları, binalar gibi iç mekanlarda GPS işaretlerinin kapsama alanını artırmak gerekmektedir. Bu tezde GPS altyapısını kullanan bir iç mekan konumlandırma sistemi önerilmiş ve tasarlanmıştır. Tasarlanan iç mekan konumlandırma sistemi yönlü GPS antenlerinden, frekans düşürücülerden, frekans yükselticiden, IF antenden oluşmaktadır. Sistemi gerçekleme için, frekans düşürücü, frekans yükseltici ve IF anteni tasarlanmış, üretilmiş ve ölçülmüştür. Yapılan deneylere göre, sistemimiz sıradan GPS alıcılara ek bir donanım eklenerek ve yazılım güncellemesiyle iç mekan konumlandırmayı gerçekleştirebilmektedir.

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1 Introduction

In daily life, some form of navigation is always used by people with their common sense, eyes and landmarks while they are driving or walking to their destination. However, more accurate navigation systems are needed for obtaining more accurate position or transit time to be calculated. These may be in the form of a simple clock to determine the velocity over a known distance or an odometer in the car to keep track of the distance travelled. Some other navigation systems are more complex and they use radio-navigation technique which transmits electronic signals. Radio-navigation signals aid people to determine their position by providing the needed information to the receivers that will process these signals to calculate the position. These signals have the necessary information like range, bearing, estimated time of arrival to be able to navigate to a desired location. These signals form a basis for GPS systems which is a radio-navigation system.

1.1 History of GPS

Throughout time, people have improved many ways to figure out their position on earth and to navigate from one location to location. For example, the mariners in old times used angular measurements done by using the location of the sun and the stars for calculating their position. Radio-navigation, which is more advanced technique, allowed navigators to locate the direction of shore-based transmitters when in range in 1930s.[2] The marine radio-navigation aid LORAN (LOng Range Aid to Navigation) was important to the development of GPS because it was the first system to employ time difference of arrival of radio signals in a navigation system, a technique later extended to the NAVSTAR (NAVigation System with

Figure 1: 1st Boeing-built GPS IIF Satellite in 2010 [5]

Timing And Ranging Global Positioning System) satellite system.[3] After introduction of radio-navigation technique, artificial satellites were developed and these developed satellites made possible the transmission of more precise, line of sight radio-navigation signals and ushered a new era in navigation technology. Satellites were first used in position finding in a simple but reliable two-dimensional Navy system called Transit. This was the basis for the system that revolutionize navigation forever, GPS.[4]

NAVSTAR-GPS, which is a technique extended from LORAN, was developed by the U.S. Department of Defense (DoD) and can be used both by civilians and military personnel.[6] It was developed to meet military requirements but civilian world adopted it quickly. The first aim to develop this system was to use it in the precision of weapon delivery and to provide a capability that would reverse the proliferation of navigation systems in the military [7]. In the early 1960s, several U.S. government organizations including the military, the National Aeronautics and Space Administration (NASA), and the department of Transportation (DOT) were interested in developing satellite systems for position determination with the idea of developing a global, successful in all weather conditions, continuously available, highly accurate positioning and navigation system that address many of users. Later, by 1972, U.S. Navy and Air Force began to search realizing the concept of the transmission of the radio signals from satellites for navigation and positioning purposes. [7] The concept was developed and building blocks of the GPS system was designed. In 1978, the first operational GPS satellite was launched. In April 1995, the system had 24 fully operational satellites [8] and still they are present. Recently, there are 31 active GPS satellites [9] and the newest satellite can be seen in figure 3 which transmits protected civilian L5 band GPS signals to aid commercial aviation and safety-of-life applications. GPS satellites transmit the signals in five frequency bands for various applications. The frequency bands can be seen in table 1. While GPS has been developing in outdoors in that way, in indoors, there are coverage problems and today's researches mostly have intensified for solving this problem.

Table 1: GPS Frequency Bands and Usages

Band	Frequency(MHz)	Usage
L1	1575.42	civilian and military purposes
L2	1227.60	civilian and military purposes (2)
L3	1381.05	used for global alarm
L4	1379.913	no transmission, being studied for additional ionospheric correction
L5	1176.45	no transmission, safety-of-life data signal

1.2 Indoor GPS Overview

GPS (Global Positioning System) has great demand in recent years and the use of GPS has increased widely in many areas like transportation, tracking, navigation, as well as being implemented in almost all of the smart phones for location based services to improve the quality of our daily life.

GPS system communicates with the satellites which send the GPS signals to the earth to be able to provide needed information to the GPS receivers. GPS signals that reach to the earth is in low power and GPS receivers evaluate the position with respect to information in the signal. This position evaluation can be done with the error of 2.5 meters in today's technology with Differential GPS (DGPS)or Assisted GPS (AGPS) [10]. Despite this system is successful in outdoor areas, it is not so successful in indoor areas. Decoding GPS signals in the indoor areas is hard due to additional loss in the GPS signal because of interaction of the signals with physical obstacles. There is a need for increasing coverage of GPS signals in indoor areas like tunnels, undersea and buildings. In this thesis, an indoor positioning system based on GPS infrastructure is proposed and designed. Designed indoor positioning system consists of directional GPS antennas, downconverters, upconverter and IF antennas. For realizing the system, downconverters, upconverter and IF antenna are designed, manufactured and measured. The experiments show that indoor positioning can be done with our designed system by adding some hardware and updating in positioning algorithm to the conventional GPS receivers.

1.3 Applications of Indoor Positioning System

GPS (Global Positioning System) has great demand in recent years and the use of GPS has increased widely in many areas like transportation, tracking, navigation, as well as being implemented in almost all of the smart phones for location based services to improve the quality of our daily life. While the GPS system can be used in many applications in outdoor areas, it has become a necessity in indoor areas as well. There are some emergency applications such that the use of indoor GPS system can be of great help such as a firefighter trying to extinguish the fire in a building, or a patient trying to find his way in a hospital, or even may be an alive earthquake victim waiting to be rescued or a visually impaired person trying to navigate in a building or at an home/office environment.

The indoor positioning system can be used in health-care systems in many ways. For patients, the GPS system can be helpful in way finding and also people finding. Indoor GPS will enable visitors to navigate the facility, from their parking location to any specific department like nearest elevator or staircase. It is more valuable, if a patient is visually impaired or has alzheimer disease due to their physical disability to find their ways or for patients with motion impairment of any kind, and family members assisting them. It can be also used for people finding in a hospital without disturbing other patients by calling who you are looking for. In addition, it can be used in also hospital operations like staff finding or tracking and patient flow. Hospitals and healthcare facilities are dynamic environments, so pinpointing where staff members are at any time throughout the facility can be challenging, especially during the busiest hours. With the developed indoor positioning system, to find the staffs in the hospitals and track them by hospital administrators are realized easily.

With the developed indoor GPS positioning system, patient flow is also controlled readily. Having visibility of patient locations in real-time and historically over time can provide powerful insights as to quality of service, efficiency of the staff, availability of resources, and patient processing. This may be especially true of the emergency services, where the unexpected influx of patients into the Emergency Room may lead to long delays in service and poor patient flow. In these situations, patients may perceive a sub-standard service, staff may be stressed and frustrated and the hospital may be negatively impacted from a business reputation standpoint. Patient flow analysis may provide a clear picture of the situation, leading to improvements in the service processes and/or staffing changes.

Ambulatory patients under care at hospitals and healthcare institutions sometimes present special challenges for caregivers. For example, patients with cognitive disorders, dementia or under special medication may be at risk of walking away unnoticed or enter a location where they are not easily spotted, such as a service closet. As a result, time and resources are spent searching for patients that put themselves and others at risk. Indoor positioning system provide an easy solution for that problem.

For healthcare systems, lastly, it can be used for emergency response. One of aspects of emergency response is when patients who need immediate assistance are unable to be heard, ring a bell or use a phone. For example, a patient could fall down, unable to get up, in an area that is not visible to staff members. With the inactivity in GPS signals, it can be noticed. The other aspect is in ambulances. When an emergency call is done from an indoor area, there will be no need for giving address information to the ambulances. They can easily reach the address from GPS device of the phone and it saves time for patient and the patient can reach to hospital in time with higher chance to be rescued.

Indoor GPS positioning system is used also the applications other than health care system. As parallel in healthcare system, it can be used in security emergency situations. Polices can reach scene of accident or scene of crime with the help of the indoor GPS system without asking address to the witnesses like in ambulances.

Indoor positioning systems provide users automatic location detection. Real world applications depending on such automation are highly. For example, location detection of products stored in warehouse. Product organizations of the warehouses can be done effectively with indoor positioning system and controlled easily. In addition it can be useful in museums. When a visitor comes to an antiquity, his phone can give information about this antiquity by finding which antiquity he looks with the help of indoor GPS positioning.

Asset tracking and management is also on of the application of the indoor GPS positioning system. In airports, there are many lost bags and this makes dissatisfaction on the people in airports. Indoor positioning system can be also set up to the airports and the passengers can follow their bags with a GPS receiver.

There are many applications that needs the indoor GPS positioning system and researches on indoor positioning system is broad as well as outdoor positioning system. In next section, researches on indoor positioning system will be mentioned.

1.4 Researches on Indoor Positioning System

The popularity of indoor positioning systems has increased recently. There are many companies that want to use indoor positioning for their occupation. Some markets seek a way for tracking their products or wares and search availability of GPS systems in indoors. In today's technology, positioning can be done by using infra-red (IR), ultra sound, radio frequency identification (RFID), wireless local area network (WLAN), bluetooth, ultra-wideband (UWB), magnetic technology is presented. Each technology has it advantages and disadvantages in performing indoor positioning with respect to each other. For example, indoor positioning technique

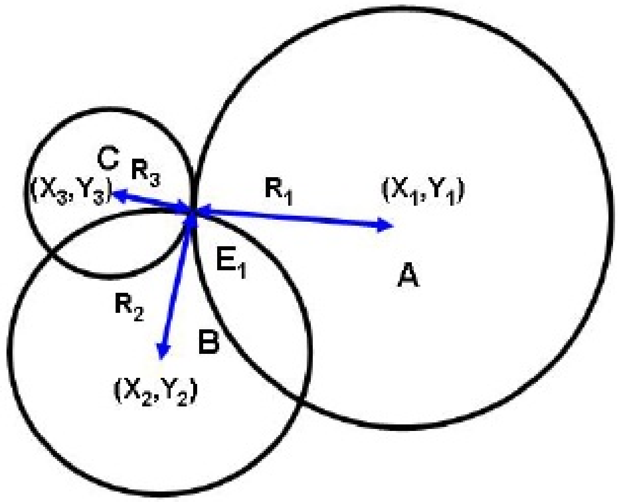


Figure 2: 2-D Triangulation Technique

using WLAN is no need of additional infrastructure, it uses wireless infrastructure which is recently present widely but this technology has limitations in itself due to deficiencies of wireless systems in indoor positioning. After deciding which technology will be used, there is also need for deciding which techniques will be used for localizing objects. Positioning is done in four techniques: Triangulation, fingerprinting, proximity and vision analysis. Proximity, scene analysis and triangulation with four measurement techniques. [11; 12] While proximity technique can only provide only proximity position information, triangulation, fingerprinting and visual analysis techniques can offer absolute, relative and proximity position information.

The 2-D triangulation technique can be seen at figure 2. In this technique, the positioning can be done with three methods: received signal strength (RSS), angle of arrival (AOA) and time of arrival (TOA) [13]. If the coordinates of three reference points; A, B and C are known, then the absolute position can be calculated by using either length or the directions of R_1, R_2 and R_3 shown in figure 2. Each method has advantages and limitations. Time of arrival method is the most accurate one which filters multi-path effects in indoor environments, but it is complex to implement. [11]

RSS and TOA uses at least three fix known locations for calculating the position of the target like A, B and C points shown in 2. AOA only uses two elements which measure position but if the target is far away, its error increases and accuracy is lower than the other methods. [14] In addition, this method needs expensive and calibrated antennas to set angles sensitively. [15] Generally, the distance between the target and the reference point is used instead of angle and this is done with RSS, TOA and TDOA methods. RSS method uses a receiver which measure received signal level and computes attenuation of the emitted signal level. Distance can be found in that way by calculating the attenuation by using propagation model. Because of multi-path fading and shadowing in indoors, RSS method is also prone to high error which makes it unreliable. [15]

Another technique is fingerprinting positioning. This technique aims to increase accuracy of the positioning by using pre-measured locations. It has two phases: Off-line training and on-line training phase. [12] In off-line phase, useful location data with respect to different locations is measured and collected for the position estimation. In the on-line phase, the before measured data inn off-line phase are compared with newly coming data. There can be always changes in indoor environments and this system will be needing an update always, its maintenance will be hard and expensive for that reason. If update is not done frequently, then the system will be unreliable due to unknowns changes in the indoor environment and old pre-measurements will include old data.

In proximity technique, there are many detectors placed indoor areas and if a movement occurs, closest detector will be activated and it will give information of whether the target in the environment or not instead of its position. This system needs many detectors and their maintenance that increase the cost of the system and have location problem for detectors. Therefore, it is not available for many indoor environment.

Last technique, vision analysis technique, guesses the position from the image of the indoor environment with the help of one or more than one cameras. Vision positioning is efficient by not bringing additional burden to the user with an extra track device. Generally, cameras are located to a fixed locations as whole place included, take picture real time of the place and pre-measurements are done like in fingerprinting method. The target can be identified from the images by looking the pre-measurement database.

Indoor positioning system can be classified as network based indoor positioning systems/non-network based indoor positioning system and with respect to system architecture. Network based indoor positioning system has advantage of not using any additional hardware infrastructure. Therefore, these types of indoor positioning systems have no problem of cost. Non-network based positioning systems use dedicated infrastructure in indoors while it has ability to the designer to design a positioning system higher accuracy. The other classification can be done with respect to architecture. Three types of architecture is present; self positioning architecture, infrastructure positioning architecture and self-oriented infrastructure assisted architecture. Self positioning finds the position by targets themselves and takes advantages of the infrastructures of the positioning systems. The infrastructure based positioning finds position by automatically tracking the target when the target is in the coverage area with the help of the designed infrastructures. In the self-oriented and infrastructure assisted technique, target wants to start positioning and gives order to the infrastructure to calculate its position and gets its position information from the system. [16] Another classification can be done based on medium used to positioning. In this classification, there are six categories such that infra-red signals, ultrasound waves, radio frequency (RF), electromagnetic waves, vision based analysis and audible sound. [16]

When the present systems compared, the comparing criteria can be with respect to security, cost, performance, robustness, accuracy, complexity, user preference, commercial availability and limitations. While infra-red positioning systems can calculate the position precisely and have advantages of cheap with not time consuming installation, small, light-weight, easy to carry by a person, it needs line-of-sight communication between transmitter and receiver without any powerful interference, it can damage from florescent or light of sun. [17] Therefore it is not preferable in indoors. Another way of positioning is ultra-sound wave positioning system. [18]. This system uses ultra-sound waves to calculate the distance between the target and the receiver. Altough this type of the positioning system is cheap, it is affected by the other noise sources. [16] Another positioning system is with magnetic positioning system. Magnetic positioning system has properties of high accuracy, no problem of line-of-sight when an obstacle is there between the target and the receiver, small sized, robust and cheap, provides multi-position tracking but has disadvantage of low coverage area. Another way is vision based positioning system. [19] This system uses cameras and firstly does pre-measurements and saves it. The system has a low price camera, no need to carry any location device. It is not reliable while using old data, not updated, due to change in the indoor environment and also privacy of the people is in danger in this system. In addition, this system is not efficient in dark, it needs light always.

An efficient way of indoor positioning system is using radio frequency (RF) technology. RF waves can penetrate through walls or physical obstacles like human bodies easily. So, the positioning system with RF waves increases coverage area by using less hardware than other methods. For example, this system can evaluate the signals with the help of access points of WLAN technology. Indoor positioning systems with radio frequency waves use widely triangulation and fingerprinting techniques. By using RF waves, there are eight types of indoor positioning system: RFID, WLAN, Bluetooth, UWB, pseudolites, high sensitive GPS, assisted GPS and GPS repeaters. [15; 16; 20] RFID positioning systems find the position with the help of RFID tags. In these systems, proximity technique is used and it needs many components. Another type of indoor positioning system is transmitting the information via WLAN. WLAN is used widely in all over the world, so its infrastructure is ready for use in numerous building and there is no need any additional infrastructure in this system. But, in some of this systems, fingerprinting method is used [16], so it not reliable due to a need for updating the previously saved data for calculating the position because of indoor environments can change in short time intervals. Some of these systems use TOA technique which gives more accurate results while it requires expensive access points that are synchronized with each other. Another type of indoor positioning system is via blutooth. This type of indoor positioning system also uses fingerprinting technique which is unreliable as in some of WLAN systems with the same causes. [21] In addition its coverage area is lower than WLAN, so it needs to be placed densely. UWB technology presents many advantages for indoor positioning systems like high accuracy, no need line-of-sight communication, not affected by multipath and can easily penetrate from physical obstacles. [20] But cost of this type of the system is high because it needs additional infrastructure, cannot use existed infrastructure. Pseudolite positioning system uses fake GPS satellites as like in its name combines with pseudo and satellites. In this system, a new GPS constellation system is installed for the indoor environment like the original GPS system in space. The transmitted information of this system is in similar way with standard GPS system, so standard receivers can detect and calculate position with these fake signals without any need for hardware updates. It is enough to update only the software of the system to be able to detect pseudo satellites. But the drawback of this system is installation of constellation. Another way of indoor positioning system is high sensitivity GPS (HS-GPS) and this system uses highly sensitive GPS receivers without any additional infrastructure to the standard GPS infrastructure. Despite great improvements in the performance of the receivers, evaluating the received GPS signal is very hard due to low power level of the signals. [20]

1.5 Proposed Indoor Positioning System

In this thesis, the indoor positioning is realized by updated repeater topology. In this topology, the GPS signals will be received by three directional GPS antennas and down converted to the free ISM band and transmitted to the indoors by a IF transmitter antenna. Later, the down converted signal will be picked up by the IF receiver antenna and up converted to the GPS L1 band to be able to decode the GPS signals with the GPS receivers. In this system, indoor position calculation will be an updated version of standard GPS algorithm and done with triangulation technique with time difference of arrival method. Firstly, the distance between the repeater and GPS receiver will be calculated and later the position will be calculated by drawing circles and intersecting these circles. The intersection is the actual position of the receiver. The designed hardware features:

1. Directed GPS Antenna

    - Resonance Frequency: 1575 MHz GPS L1 Band
    - 3 dB beam-width: 60 degrees
    - Antenna Gain: 9 dB

2. Down-Converter

    - Noise Figure: 2 dB
    - Gain: 53.3 dB
    - Linearity: Up to -57 dBm input power

3. Up-Converter

    - Noise Figure: 2.9 dB
    - Gain: 31 dB
    - Linearity: Up to -22 dBm

4. IF Antenna

    - Resonance Frequency: 422 MHz
    - Antenna Gain: -0.43 dB

5. Coverage

    - 20-500 meters

1.6 Organization

Chapter 2 presents the working principle of the GPS positioning system and an overview on indoor GPS positioning system. How can the GPS coverage area in indoors be increased with our topology will be mentioned in chapter 2. It was basically by down-converting the GPS signal to IF frequency and retransmitting to the indoors and later up-converting the detected signals in indoors with a up-converter circuit and transmit the signal to the GPS receiver and running the special GPS algorithm in indoors.

In chapter 3, The antennas used for receiving the GPS signals from outdoors and transmitting the down-converted signals into indoors will be introduced. Used GPS antenna is directional GPS antenna designed by Kerem Özsoy. [22] Additionally the IF antennas are designed to be able to transmit the down-converted GPS signals in indoors and receive these signals for transmitting to the up-converter circuit.

In chapter 4, down-converter and up-converter part of the system is presented. Down-converter and up-converter systems combine of low noise amplifiers, filters, mixer, oscillator and an antenna to be able to transmit the down-converted signals to the indoors and transfer it to the receiver by up-converting. The designed down-converter system has 53.3 dB gain and 2 dB noise figure by drawing 78mA current with 3V voltage. The designed up-converter system has 32 dB gain and 2 dB noise figure by drawing 66mA current with 3V voltage.

Chapter 5 presents overall system performance, analysis of path loss and how far the down-converted signals can be transmitted. The overall system performance will be analysed with minimum detectable signal, gain, noise figure and compression points.

Chapter 6 presents conclusion of indoor GPS system. This system will be used in indoors without needing an infrastructure and by easily realizing the positioning by linearly sending the signal to indoors by changing its frequency to IF frequency and evaluated by the receiver with a special algorithm developed after up-converting the down-converted signal before transmitting signals to the receiver.

2 Overview of GPS

2.1 Working Principle of GPS

Recently, GPS is fully operational and meets the needs in the outdoors. The system provides accurate, continuous, worldwide, 3-D position and can calculate velocity with the proper receivers. GPS calculates the position and velocity by communicating with the satellites which are man-made and turn around the world in a certain speed. Ground monitoring always controls the health and the status of the satellites. This control mechanism also updates the data in the satellites by communicating with the satellites. GPS receivers run passively, means that it is only receiving the signals which include the information that comes from the satellites, so unlimited number of people can use GPS system at the same time. Therefore, GPS system consists of the users, constellation satellites, ground control and has 3 segments can be classified in three segments, user segment, space segment,control segment shown in figure 3 [1].

Space segment is formed by satellites which provide navigation information to the users by the radio frequency signals. It consists of at least 24 satellites in 6 orbital planes. Each satellites are placed in the orbit in an abundant way which will provide highest coverage area and satellites turn around the world twice in each day. [20] As a summary, the space segment is used for transmitting the navigation messages by the RF signals. In addition there is a need for controlling satellite messages, for that reason, there are some ground stations that control these satellites which form the control segment of the system. Ground stations control the health of the GPS signals, clock biases, orbit configuration and ephemeris of the GPS satellites

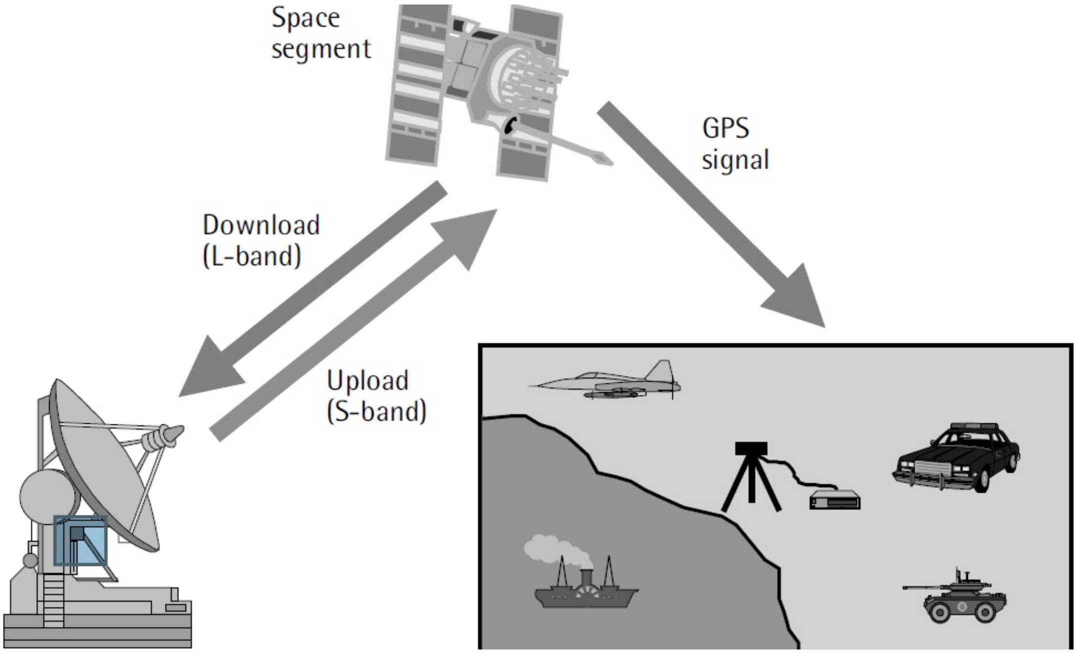


Figure 3: GPS Segments [1]

by making necessary changes in any situation. Ultimately, user segment is the last segment which uses receivers to calculate position and velocity.

GPS receivers calculate the position by measuring the distance between the receiver and satellites with the information in the GPS signals. Receivers know already the position of the satellites from the received signals and can calculate the distance accurately between receiver and the satellite. It will draw spheres with the diameter of the distance between receiver and the satellite. Three sphere is enough to calculate the position. By drawing the spheres with three different satellites and their distance to the receiver, the intersection point will be the position of the receiver as shown in figure 4.

There will be two intersection points and while one of them is actual position, the other one will be a distant point on the space. Receiver cannot be in space, so the actual position can be estimated precisely.

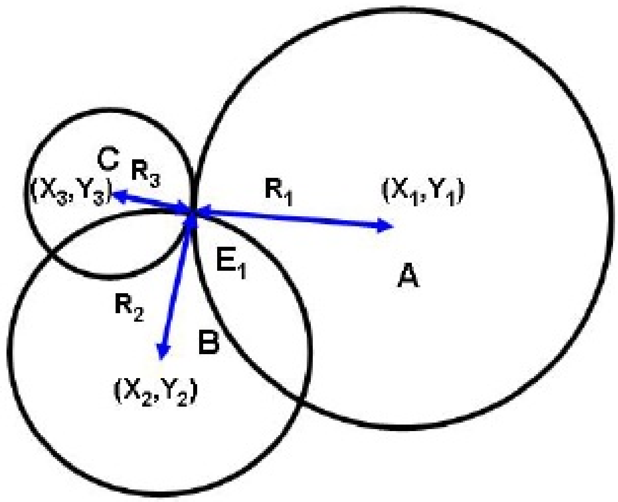


Figure 4: Intersection of the circles gives position of the receiver

2.2 Indoor Positioning using GPS

Altough GPS system is successful in outdoors, it is weak in indoors. Because, the GPS signals, that come from satellites, have additional loss due to the physical obstacles like walls. The signal power that reaches to earth is weak already due to high distance between satellites and earth, and also free space loss due to this high distance. These weak signals can be detected from the outsides but in indoors, they cannot be detected due to additional losses. Therefore, an indoor positioning system is designed by using GPS infrastructure without any other infrastructure.

In indoor environments, to be able to increase the coverage area of the GPS, there can be put some repeaters shown in figure 5 that transmits the GPS signals to the indoor environment by amplifying the signal linearly. Repeaters receive the GPS signals from three different satellites, amplify and retransmit to the indoor environment, so GPS receivers can detect these signals in indoors. However to repeat GPS signals are limited in many countries and so GPS signals cannot be transmitted to the indoors directly. Therefore, in our system, we will transmit the

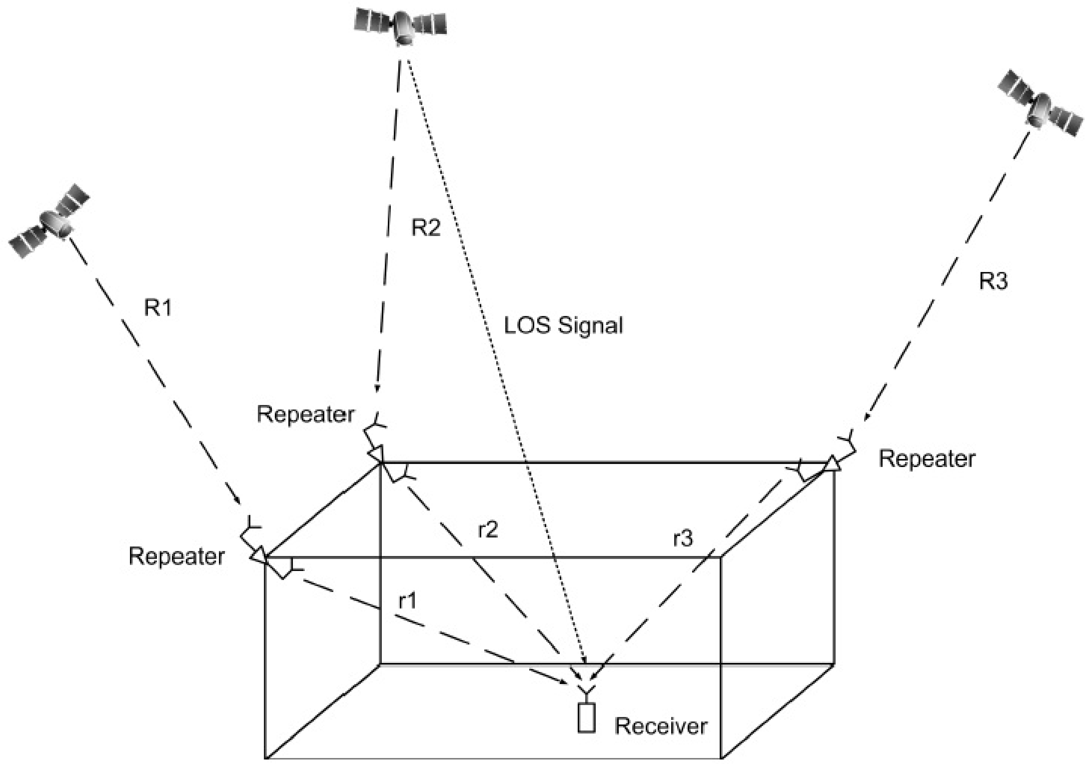


Figure 5: Indoor positioning system with repeaters

GPS signals by down-converting to the IF frequency which can be transmitted with higher power levels with respect to RF frequency power levels. The advantages of this system will be higher coverage area due to higher power level transmission and easier penetration of lower frequency signals to the physical obstacles. Updated system can be seen in figure 6.

While this updated system can provide increase in coverage area of the GPS system, it will decrease accuracy while increasing error in positioning because of non line of sight propagation. After transmitting GPS signals by down converting from glasses to the indoors, the signal will be refracted and this will cause an error in positioning shown in figure 6. The distance between target and satellites is not line of sight distance any more. GPS receivers calculate the position by finding line of sight distance which is R_i+r_i which is smooth in line of sight. This distance is

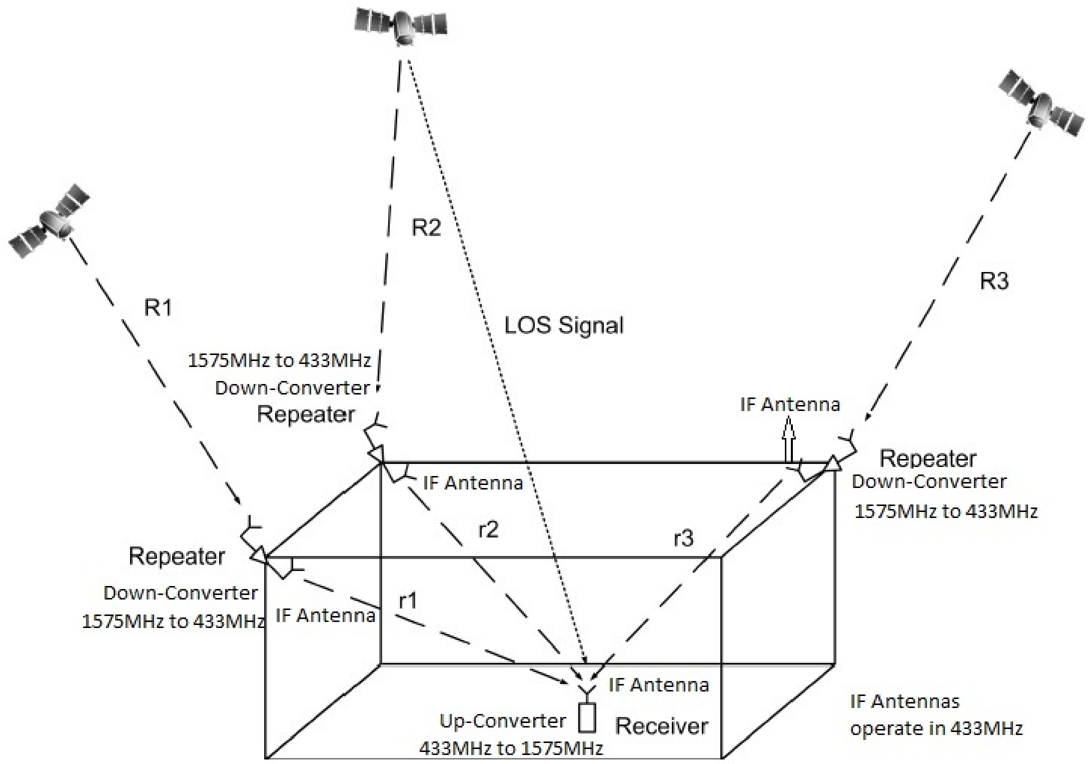


Figure 6: Indoor positioning system with updated repeaters

used in triangulation shown in figure 4. With some extra calculations, the error can be compensated.

GPS signals will be received by the directional antennas and there will be the positioning calculation here. The location of the GPS directional antennas is already known and the distance between satellites and antennas are known as R_i shown in figure 6. The distance between target and antennas need to be found. Total distance is also known from the speed of light and time of arrival. The total distance is given in equation 1 where b is the clock bias and c is the speed of light which is calculated as in equation 2 where x_tar, y_tar and z_tar are the coordinates of the target which will be found.

$$p_i = R_i + r_i + bc \tag{1}$$

$$R_i = sqrt((x_sat - x_tar)^2 + (y_sat - y_tar)^2 + (z_sat - z_tar)^2) \tag{2}$$

bc is added to be able to compensate the offset in clocks of receivers which are not synchronized with satellites clock. Repeaters location is fixed and found with equation 3 where x, y and z are the coordinate planes.

$$R_i = sqrt((x_sat - x_rep)^2 + (y_sat - y_rep)^2 + (z_sat - z_rep)^2) \tag{3}$$

R_i is known, total distance is known from speed of light and time of arrival, so the distance between target and antennas can be found easily as in equation 4 where P_i is the line of sight distance which is given in equation 5 where toa is time of arrival and c is the speed of the light.

$$r_i = P_i - R_i - bc \tag{4}$$

$$P_i = toa * c + bc \tag{5}$$

So, r_i can easily be found. After finding r_i, to be able to find the position, triangulation is done shown in figure 4. In 2D positioning system, triangulation needs three antennas and three circles to obtain intersection point while triangulation needs four antennas and four circles to obtain intersection point in 3D positioning. When looked again to 6, with three directional GPS antennas, the GPS signals will be received. The GPS antennas should be directional because the signal should be received from different satellites to be able to make triangulation. If two antennas see same satellite, triangulation will also have two circles and the intersection of two circles is not enough for calculating position. Received GPS signal by three directional GPS antennas, it will be down converted with the help of down-converter circuit. In this circuit, GPS signals frequency will be decreased to IF frequency, 433 MHz, and amplified. Down-Converted signals should be retransmitted to the indoors with an IF antenna. After transmitting the down-converted GPS signals, it should be received again by an IF antenna in indoor environment and up converted again to GPS frequency L1 band for GPS receivers can evaluate the received signals.

3 Antennas

In this section, used antennas for realizing the indoor positioning are presented. Three GPS receiver antennas are needed to be able to pick up the signals from three different satellites and for receiving the signals from different satellites, these antennas should be highly directional antennas. There is also a need for three transmitter 433 MHz antenna which will be transmitting the down-converted GPS signals to the indoors. At the receiver, a receiver 433 MHz antenna should be used to be able to get the signals in indoors and transmit it to the receiver for positioning. The antennas are reciprocal devices and so it is enough to use two types of antennas, one of them is in GPS L1 band and the other one is 433 MHz IF antenna.

3.1 GPS L1 Antenna

First of all, to be able to receive GPS signals from the satellites, there is a need for GPS antenna. 2-D GPS positioning is one with the signals which come from three different satellites. To be able to pick the signals from three different satellites, there is a need for three highly directional GPS antennas, so a directional L1 band, 1575.42 MHz, GPS antenna is used. The used antenna was designed by Kerem Ozsoy [22]. As GPS antenna, standard off the shelf GPS patch antenna was used and by adding conical reflectors to the antenna, the gain and beamwidth of the antenna is enhanced, so it is a reflective antenna which is simple to manufacture, compact, highly directive with higher gain than the standard GPS antenna and low cost. The used antenna can be seen in Figure 7. Its gain is 9dBi and beamwidth is 60 degrees.

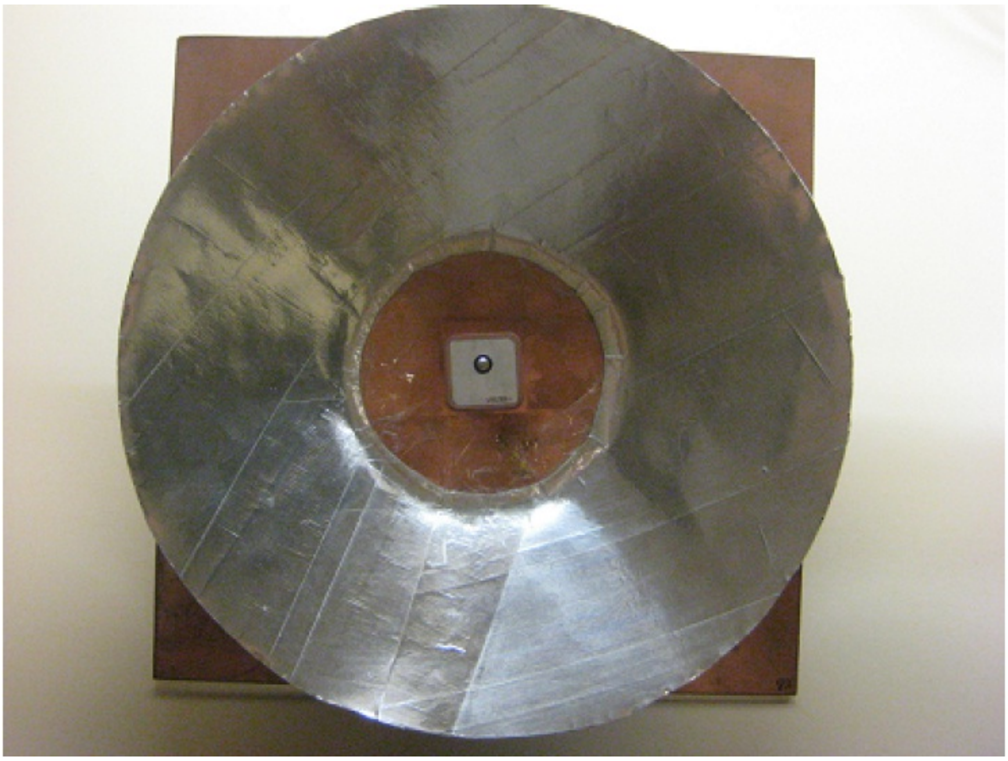


Figure 7: GPS Reflector Antenna

3.2 IF Antenna

Received GPS signals are down-converted to 433 MHz IF ISM band and it is needed to be transmitted to the indoors and also to receive the transmitted signal in indoors. To be able to transmit and receive these signals, there is a need for an IF antenna in 433 MHz. Wavelength of the signals in 433 MHz frequency is 69.284 cm and designed antenna would be in large sizes in this frequency. Antennas sizes should be as small as possible for effective usability of the system but in small sizes, gain of the antenna is lower. There are many topologies for designing an antenna like patch antenna, circular loop antenna, dipole antenna, helical antenna etc. When the design is done with square patch antenna, its sizes would be about 20.1 cm length and 20.1 cm width or with circular loop, it would be 10.5 cm radius. These dimensions is not integrable for today's small receivers Therefore, firstly a small antenna is designed with folded dipole antenna and measured. Although its

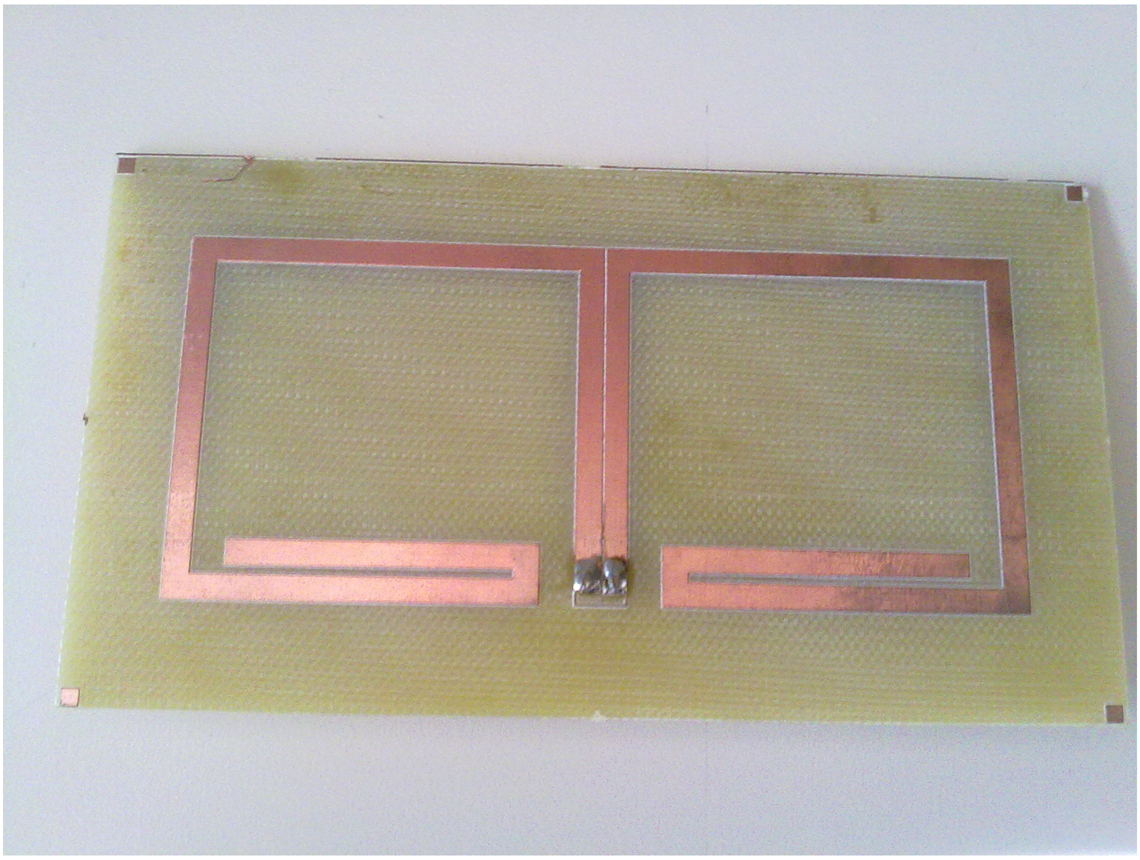


Figure 8: Folded Dipole Antenna on one sided FR4 PCB Board

sizes are small enough, we found a smaller antenna in 433 MHz, commercially and decided to use this antenna thanks to its easier integrability. The topology of this commercial antenna is helical antenna and its performance is close to the folded dipole antenna. They have same gain but helical antenna wider bandwidth and also lower directivity.

3.2.1 Folded Dipole Antenna

With the folded dipole topology, the size of the antenna is half of the dipole antenna by folding the dipole from half. The chosen PCB material was one sided FR-4 PCB board which has dielectric constant of 4.6 due to its low cost. Later, dimensions of the antenna were determined. Input impedance depends on the width of the wires shown in figure 10. To determine the antenna sizes, some calculations

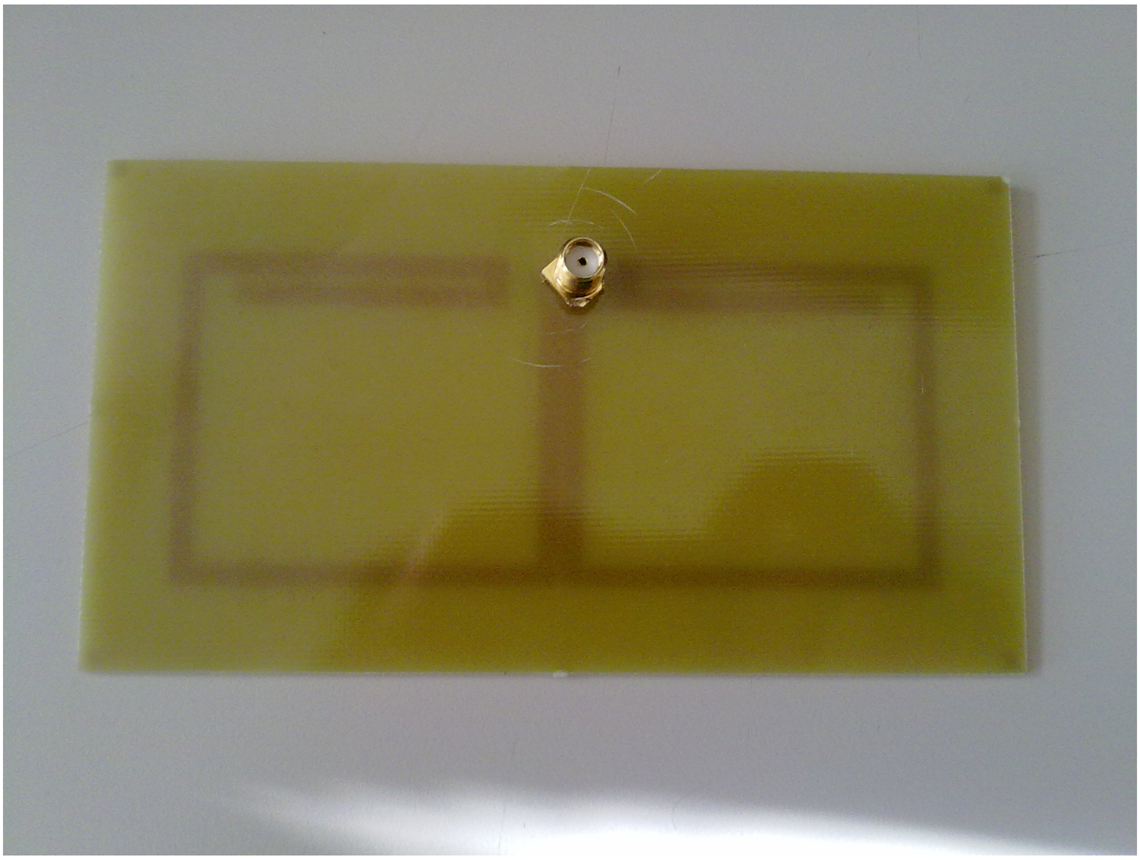


Figure 9: Reverse of Folded Dipole Antenna and its Feed

are needed. The resonance length of the antenna is given in the equation 6 where rd is resonant dipole length and λ is wavelength of the signal. Wavelength of the signal is given by the equation 7 where V is the speed of the wave on dielectric material and f is the frequency. Speed of the wave is found by the equation 8 where c is the speed of the light and ϵ_{eff} is effective dielectric constant. Effective dielectric constant is given by equation 9 where ϵ_r is the dielectric constant, h is the height of the substrate and w is the width of the antenna. The width can be determined by the equation 10 shown in figure 10. Ratio is the rate of folded dipole feed impedance with standard dipole feed impedance. When ratio is chosen 1, for standard dipole antenna impedance, $\underset{.}{1} = 2s$ and $\underset{.}{2} = s$ where s is the spacing between the folded wires. Here w is found as 0.6 mm and length is found as 9.25 cm. By using HFSS 13 simulation tool, it is matched to 50Ω input impedance by printing on the FR-4

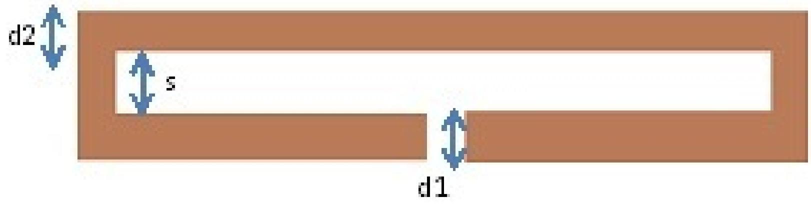


Figure 10: Folded Dipole Structure

board with 10.05 cm length and 5.5 cm width shown in figure 11. The manufactured antenna can be seen at figure 8 and figure 9. The input impedance and radiation pattern of the antenna can be seen at figures 13 and 15.

$$rd = 0.47\lambda \tag{6}$$

$$\lambda = V/f \tag{7}$$

$$V = c/\sqrt{\epsilon_e ff} \tag{8}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(\left(1 + \frac{12h}{w}\right)^{\frac{-1}{2}} + 0.04\left(1 - \frac{w}{h}\right)^2\right) \tag{9}$$

$$Ratio = \left(1 + \frac{\log(\frac{2s}{d1})}{\log(\frac{2s}{d2})}\right)^2 \tag{10}$$

The antenna was designed in HFSS 13 design tool and its results can be seen at figure 12 and 14. According to these results, the input impedance of the antenna is matched to 50Ω in 433 MHz and by looking the radiation pattern, its gain is about 0 dB and its pattern is like in figure 14.

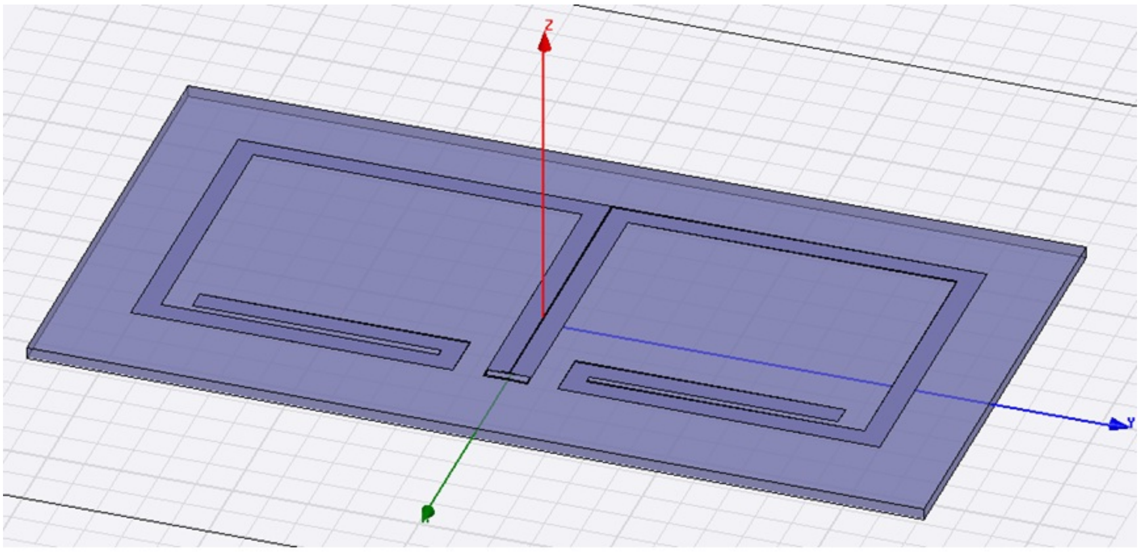


Figure 11: Designed Folded Dipole Antenna

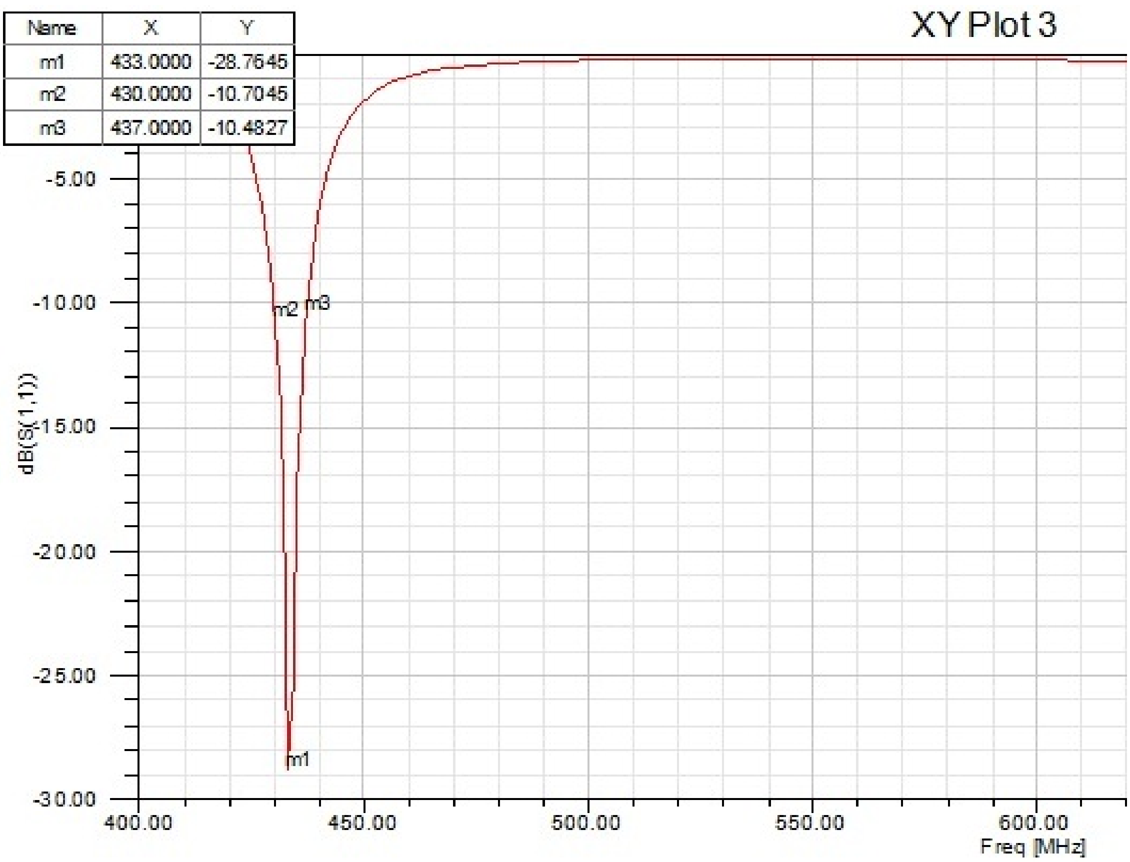


Figure 12: Simulated S11 of the Antenna

Radiation pattern measurements are done in an indoor area with many reflections. According to these measurements and Friis transmission equation in equation 11, free space loss is 25.17dB in 1m. 0 dBm power was transmitted with 6.5 dBi

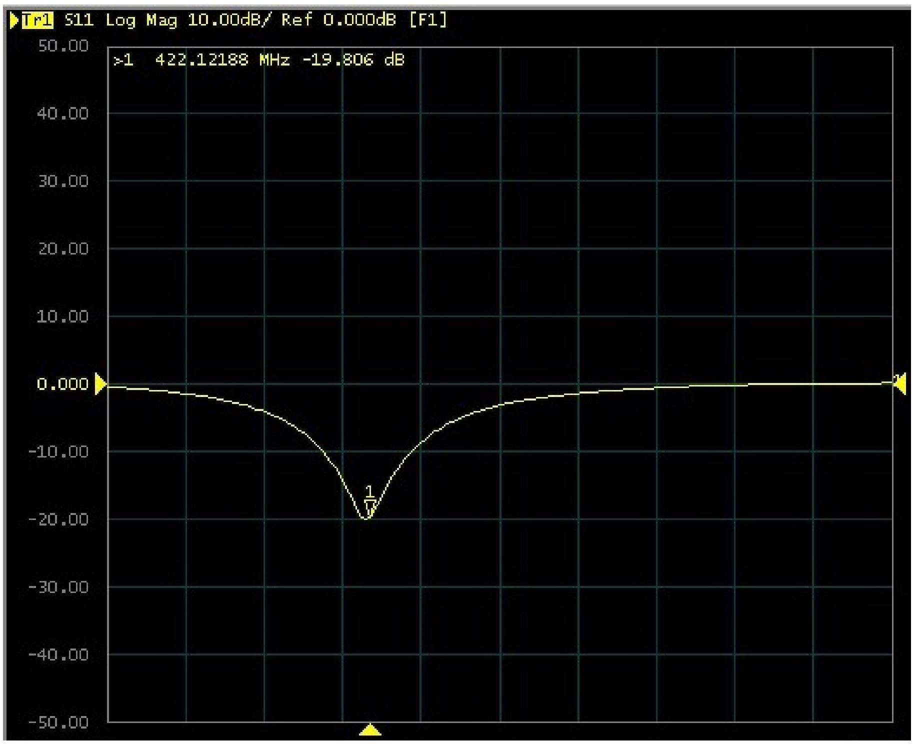


Figure 13: Input Impedance of the antenna

antenna gain with the commercial SAS-510-2 yagi uda antenna and so the signal power in 1m is -18.67 dBm. The received power with the designed IF antenna antenna was -19.1 dBm so the antenna gain is -0.43 dB. When simulated and measured S11 and radiation pattern of the antenna were compared, S11 is shifted about 11 MHz to the left from 433 MHz to 422 MHz which decreases antenna gain -0.43 dB instead of 2.07 dB. The shift in the resonance frequency may stem from the use of the cheap FR-4 PCB board which does not have actually the dielectric constant of 4.6.

$$P_R = \frac{P_T G_T G_R c^2}{(4\pi R f)^2} \tag{11}$$

$$Loss = (\frac{\lambda}{4\pi R})^2 \tag{12}$$

Table 2: Far Field Measurement Datas for IF Antenna

P_R	P_T	G_R	R
-19.1 dBm	0 dBm	6.5 dBi	1 m

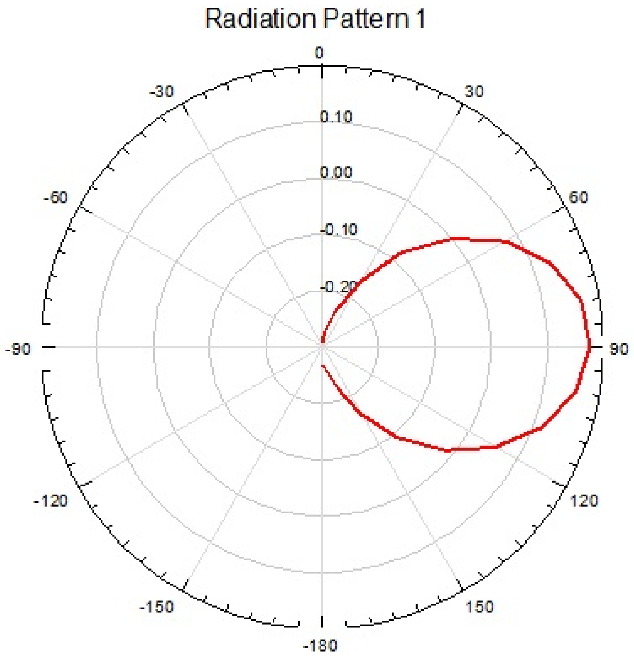


Figure 14: Simulated Radiation Pattern of the Antenna

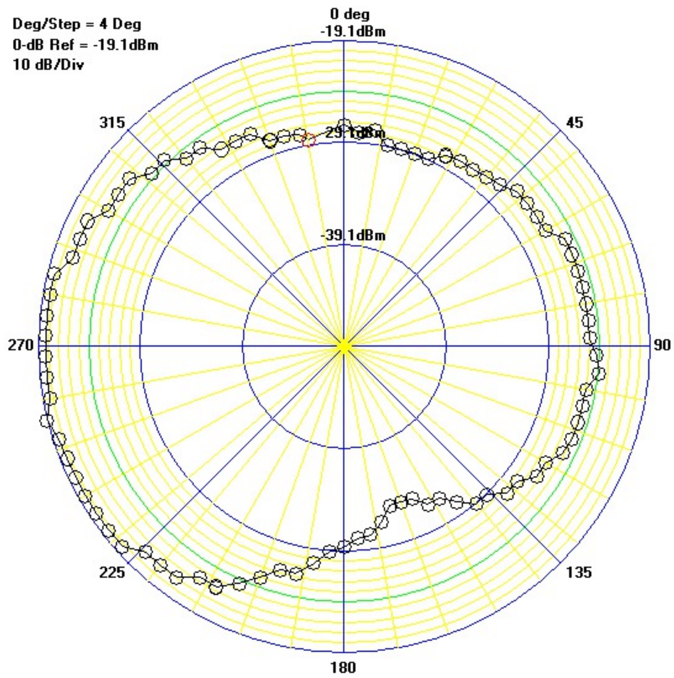


Figure 15: Measured Radiation Pattern of the antenna

4 Down-converter & Up-converter System Design and Measurements

In this chapter, the designed and measured down-converter and up-converter circuits for indoor GPS positioning is presented. After receiving GPS signals from the satellites, the signal will be down-converted with a mixer and an oscillator. The received signal frequency is 1575.42 MHz, GPS L1 band frequency. By multiplying this signal with an oscillator which produces the signal in 1142 MHz frequency and signal power of -5 dBm, free ISM signal will be obtained in 433 MHz frequency and after transmitting and receiving again in indoors, these signals will be again up-converted to GPS frequency to be able to calculate the position.

GPS signals reach to the earth with typically -128.5 dBm signal power. Standard GPS receivers have signal to noise ratio (SNR) up to -29 dBm. [23] Therefore, the signals up to -142 dBm are strong signal strength. Up to -150 dBm, the signal strength is weak while it is very weak from -150 dBm to -160 dBm. [23] The receivers in recent technology are able to detect the signals up to -160 dBm with high sensitivity GPS (HS-GPS) technology. As explained in chapter 5 in detailed, the down-converted GPS signals in 433 MHz needs to be transmitted about 20 meters distance in our assumption and for 20 meters, the outdoor signal loss for 433 MHz is 51.19 dB. In indoors, there will be 30 dB or more additional loss with respect to the number of physical obstacles like the walls, so we need to amplify the signal to compensate this 81.19 dB loss. GPS signals can be detected -142 dBm, so the transmitted signal power needs to be in -60.81 dBm signal power and the signal should be amplified as 62.19 dB. The directional antenna gain is about 9 dB shown in chapter 3, so above 53.3 dB gain is enough for 20 meters indoor GPS calculation. Above 20 meters distance, HS-GPS receivers can be used which will increase the coverage distance up to 160 meters with this 53 dB gain. Therefore, an amplifier with 53 dB gain is enough to design for down-converter part. To transmit the signal with minimum necessities is also important because there are many drawbacks of higher gained systems. First of all, the cost of the system increases with the number of elements of the system and for higher gain, the number of elements are increasing. Secondly, 433 MHz ISM band is free to use so there can be many devices that operates in this frequency with higher powers, so to transmit the GPS signals with higher power can harm their operation and also saturate the other electronic devices close to these frequencies. In addition, power consumption is also an important issue. The batteries of the circuits need to be as most as long duration and this can be handled with low power consumption. As the gain of circuit increases, the number of amplifiers will be increased which increases power consumption.

Noise floor at room temperature is -174 dBm and GPS receivers can pick up signals up to -142 dBm, so a 30 dB gain in up-converter is enough which will increase the coverage up to 500 meters in outdoors. However, it was placed to the system to be able to compensate possible additional losses more than 30 dB, so it is not included to the distance measurement.

4.1 Down-Converter

The signals received by directional antennas are the input of the down-converter circuit with -158.5 dBW power level. The reason for using directional antennas for receiving GPS signals is the need for receiving the signals from three different satellites for performing position calculation. GPS signals, reaching the earth with low power level, should be amplified and filtered firstly, later, down converted with the help of a mixer and a local oscillator. The signals which are down converted are filtered, amplified again and sent to the indoor areas with the help of 433 MHz antenna which will be connected to the output of the circuit. Designed system schematics are shown in figure 16.

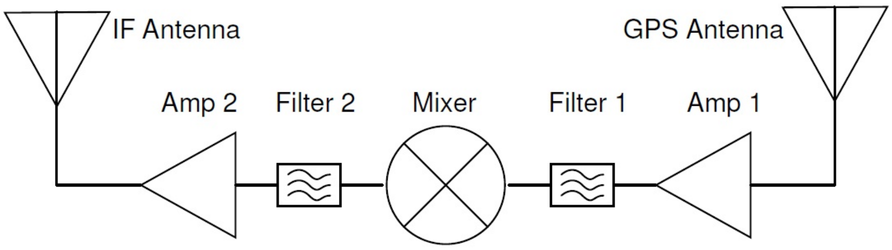


Figure 16: Down-Converter System Schematics

Down-Converter system is composed of low noise amplifiers, filters, a mixer, a local oscillator and power amplifiers. The system is designed on FR4 PCB board. The down-converter board can be seen at figure 17.

GPS signals are received firstly by a directional antenna and transmitted to the input of the circuit by coaxial cable with 50Ω input impedance. Transmitted low power GPS signals are amplified with an LNA which is shown in figure 16 with Amp 1. After the signal filtered with the help of the filter shown in Filter 1, it is down converted to the 433MHz ISM band by the mixer shown in Mixer in figure 16 with the help of the local oscillator shown at figure 18. Later, the signal is filtered by a filter shown in Filter 2 and amplified with 433MHz LNA shown in Amp 2 in figure 16. Lastly, with a 433MHz antenna, the down converted signal is retransmitted into the building.

For the first component of the system, an amplifier with low noise figure and high

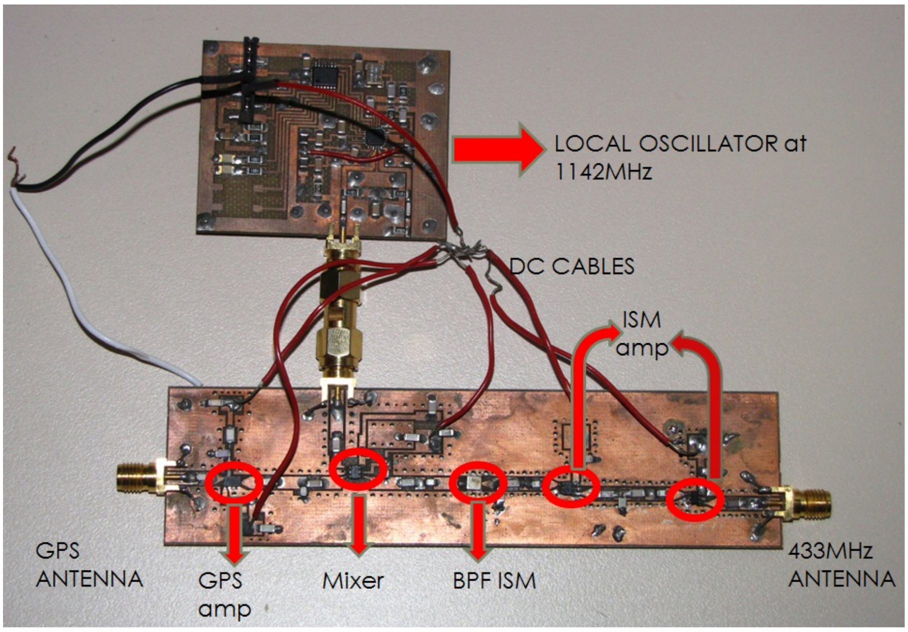


Figure 17: Down-Converter Board

gain should be chosen. To make lower the noise figure of a heterodyne system, it is very crucial that first amplifier should have very low noise figure. For the first step, an LNA, named ALM 1412 produced by Avago Technologies, in GPS frequency is chosen and the chosen LNA has a filter in it, so there is no need for second component

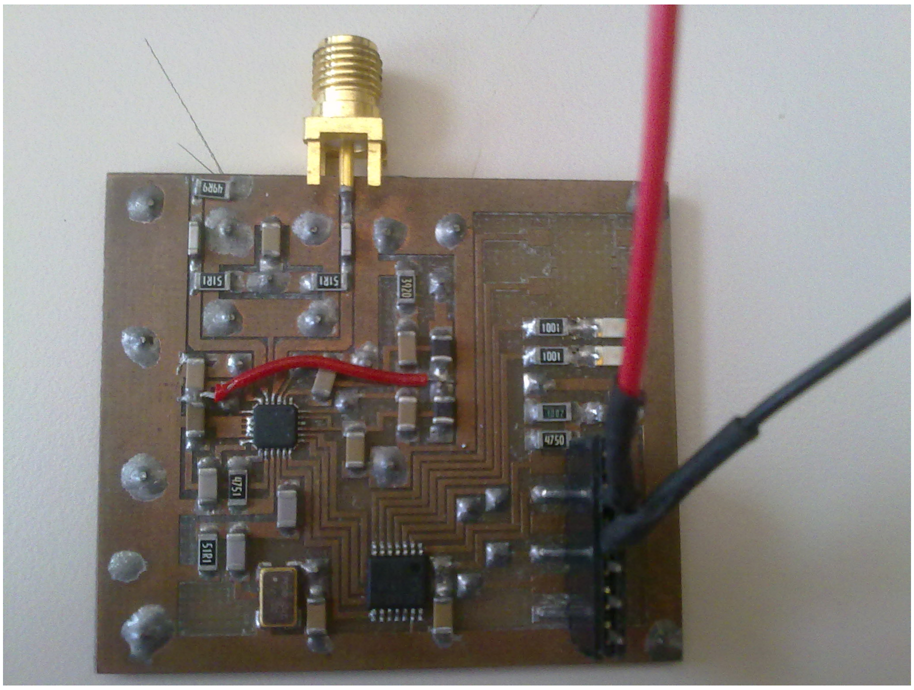


Figure 18: Oscillator Circuit

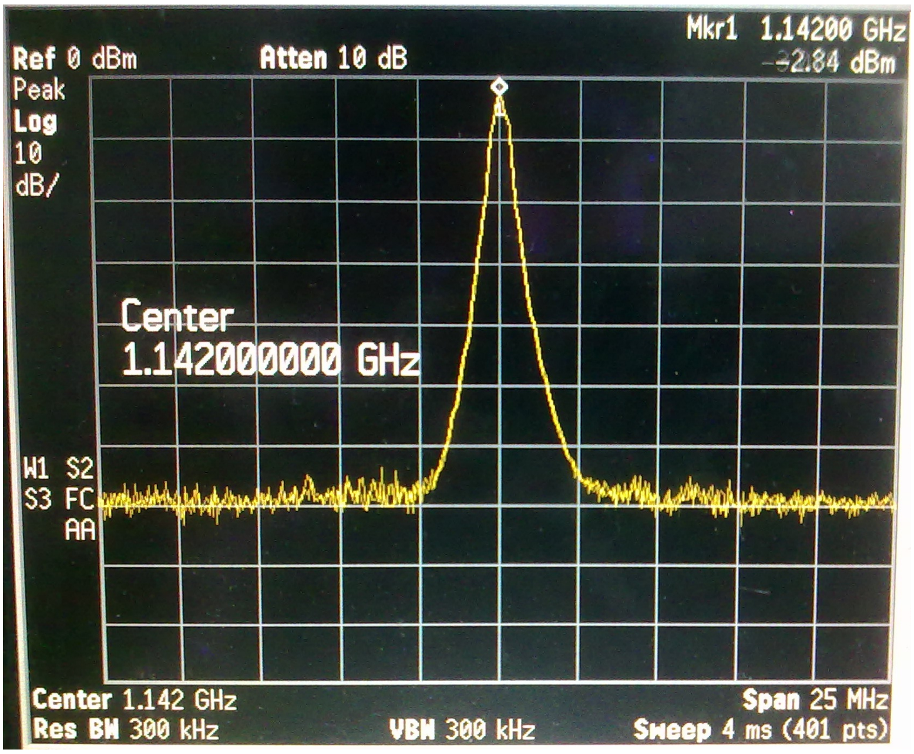


Figure 19: Oscillator Signal

in the figure 16. This would decrease the size of the board and also decrease the cost. The chosen LNA is drawing 8mA from 3V power supply. Its performance is 0.82dB noise figure and 13.5dB gain in its datasheet. Second component of the system is a filter in GPS frequency to eliminate the signals at the other frequencies and it should have low insertion loss. It is used within the first LNA, ALM 1412. For the third component of the system, a mixer with high conversion gain and a local oscillator at 1142 MHz for helping to the mixer should be chosen. This mixer down converts the GPS signal to 433 MHz by multiplying the signal with the signal produced by the local oscillator at 1142 MHz. The chosen mixer, named MAX 2682 produced by Maxim Company, draws 15mA current from 3V power supply. Its performance is 9.6dB noise figure and 11dB gain. The local oscillator oscillates at 1142MHz with -5dBm output power while it is drawing 50mA from 3V power supply. For the fourth component of the system is a filter to eliminate unwanted frequency components of the signal, comes out from mixer and it should have low insertion loss. The chosen filter, named B3710 produced by Epcos Company, has 2dB insertion loss and 1.7MHz bandwidth. Its pass band is between 433MHz and 434.71MHz. For the fifth component, an amplifier should be chosen with high gain. The LNA is chosen to be used in up-converter system, named MAX 2640 produced by Maxim Company. The reasons for choosing this LNA is to decrease the number of different components in the circuit and also decrease the power that the system consumes. The chosen LNA draws 3mA current from 3V power supply. Its performance is 0.9dB noise figure and 15.8dB gain with output 1dB compression point -6dBm. The LNA at the last stage is used twice for obtaining more gain and so the system has about 30dB gain after mixer stage. The system is realized on FR4 PCB board by using coplanar waveguide transmission lines. The reason for using coplanar waveguide topology is to enlarge the effective ground plane so as to increase isolation. Noise figure can be calculated by using well-known Friis equation in equation 13.

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \frac{F_5 - 1}{G_1 G_2 G_3 G_4} \tag{13}$$

Table 3: Datas for the noise figure calculation of the DownConverter Circuit

F_1	F_2	F_3	F_4	F_5	G_1	G_2	G_3	G_4	G_5
1.2	9.12	1.122	1.23	1.23	22.387	12.589	0.63	38	38

After calculation of noise figure of the system, expected noise figure is 1.56 dB. Expected total performance of the system is given in table 6.

The measured results can be seen in figure 20, and figure 21.

The produced board has 53.3dB gain and 2dB noise figure. The discrepancy between the expected and the measured noise figure may stem from the board

Table 4: Expected total performance of the system and comparison of performances of each building blocks for Down-Converter

	Amp 1	Mixer	Filter 2	Amp 2	Amp 2	TOTAL
Gain	13.5 dB	11 dB	-2 dB	15.8 dB	15.8 dB	54.1 dB
Noise Figure	0.82 dB	9.6 dB	0.5 dB	0.9 dB	0.9 dB	1.56 dB
Current	8 mA	65 mA	0mA	3 mA	3 mA	78 mA

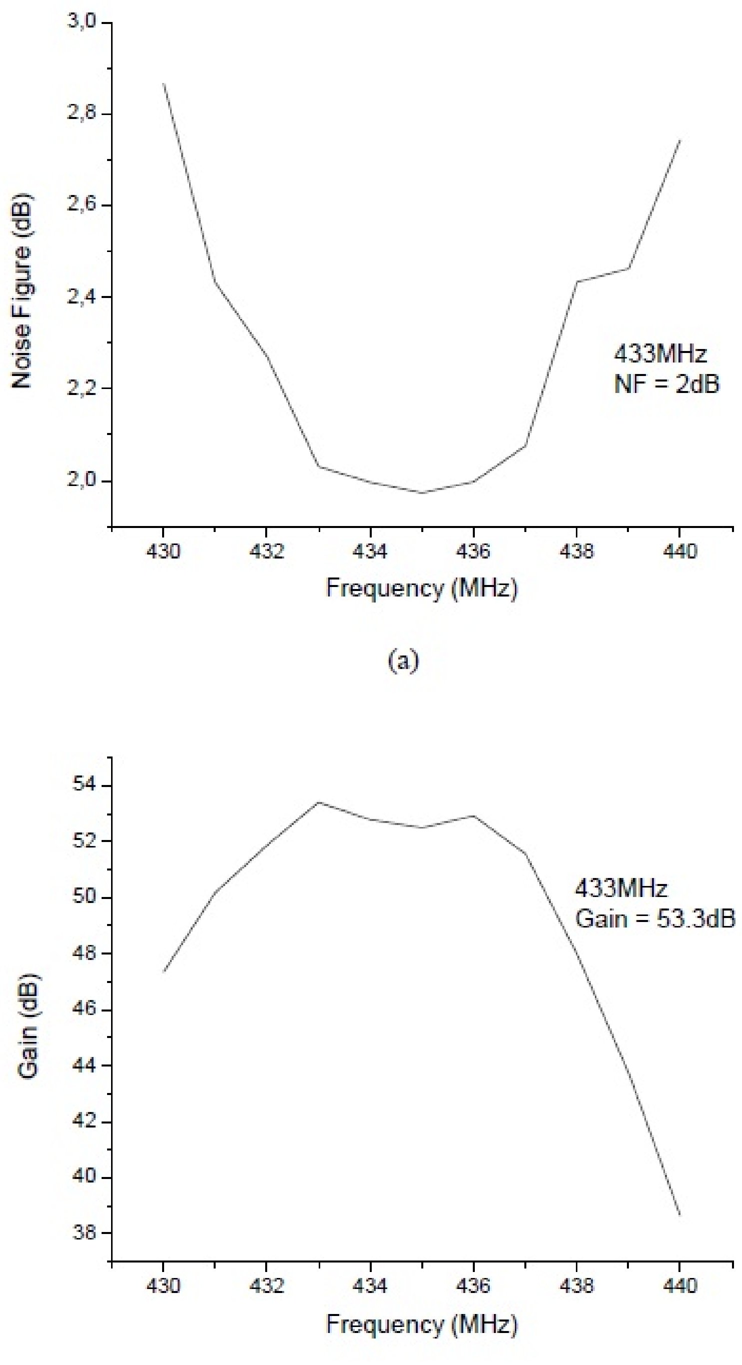
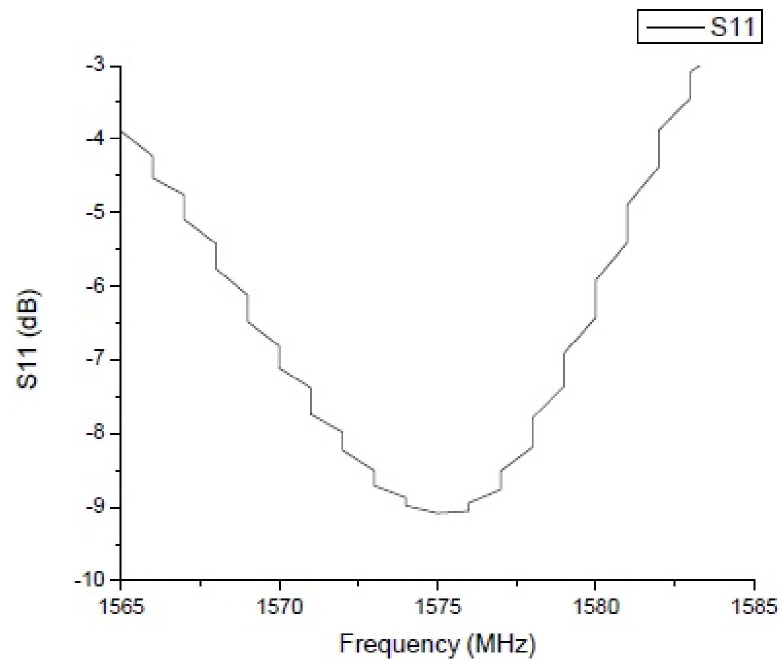


Figure 20: a. Down-Converter Noise Figure b. Gain



(a)

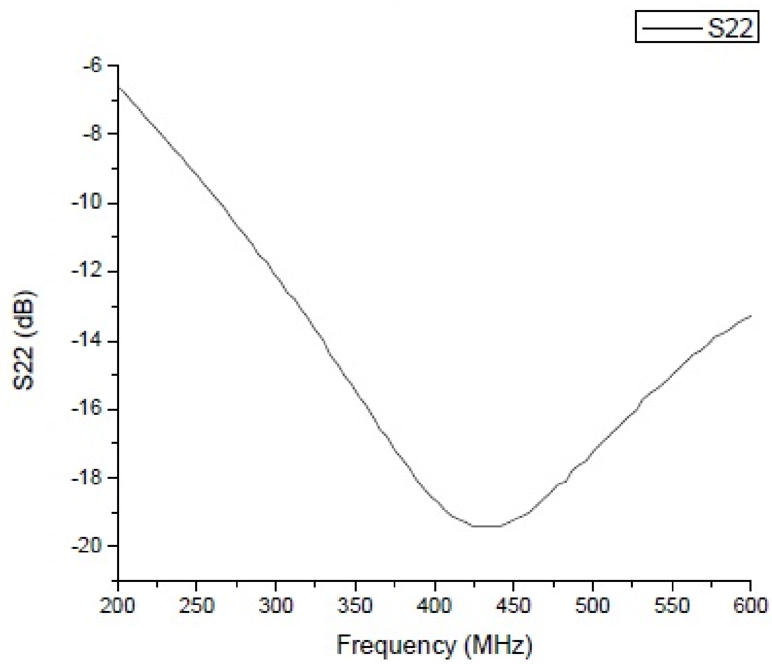


Figure 21: a. Measured S11 b. Measured S22

material, FR4 or error in measurement setup. The measured S11 is -9dB and S22 is -19dB. The S11 of the system is dominated by the S11 of the first LNA, Amp 1 in figure 16 and the S22 of the system is dominated by the S22 of the last LNA, Amp 2 in figure 16. The complete circuit is drawing 78mA current from 3V power supply and so consumes 234mW power.

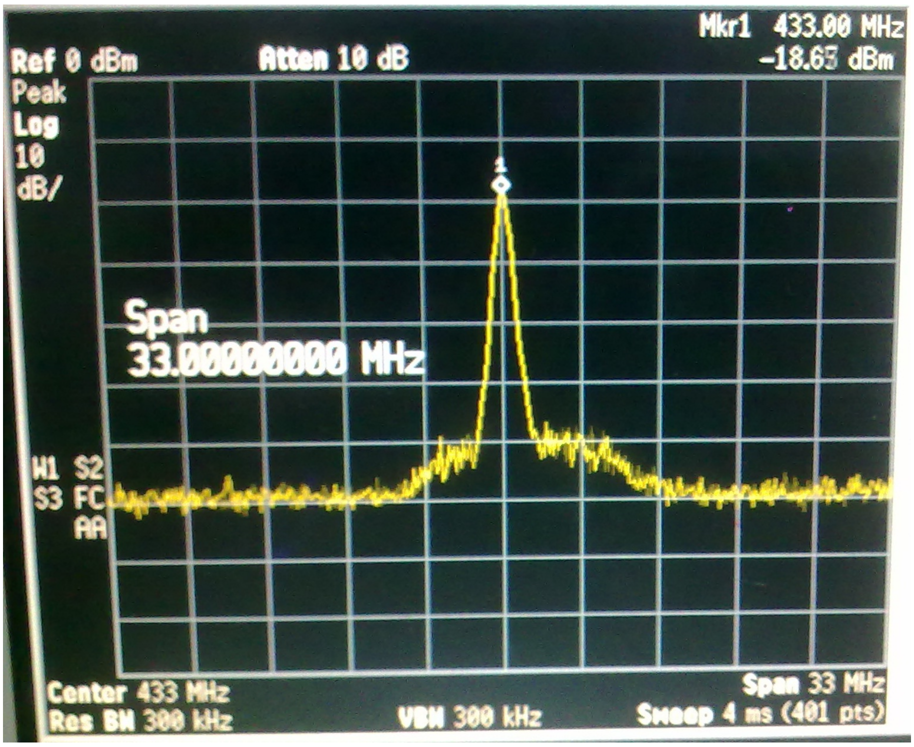


Figure 22: Down-Converter Test with -70 dBm Input Power

Firstly, -70 dBm power is generated with the signal generator, Agilent EE44376, in 1575 MHz GPS L1 band and the connected to the down-converter input. Down-converter output is connected to a spectrum analyser, Agilent E44078, shown in figure 22 Additional to these results, to be able to evaluate the performance better, cable loss analysis is done with 0 dBm input power. It can be seen at figure 23 and figure 24.

Cable loss for 1575 MHz is 2 dB and cable loss for 433 MHz is 1 dB.

4.2 Up-converter

The signals, received by IF antenna in indoors after transmitting the GPS signals by the down-converter and another IF antenna, are the input of the up-converter circuit. Received signals will be amplified firstly, later, up converted with the help of a mixer and a local oscillator. The signals which are up converted are amplified,

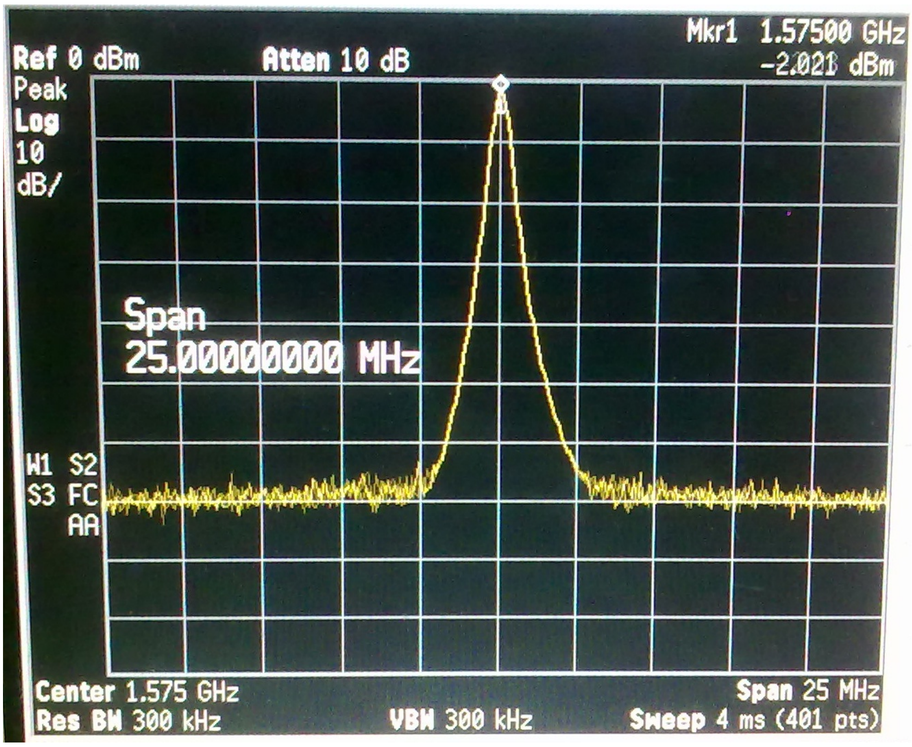


Figure 23: Cable Loss in 1575 MHz

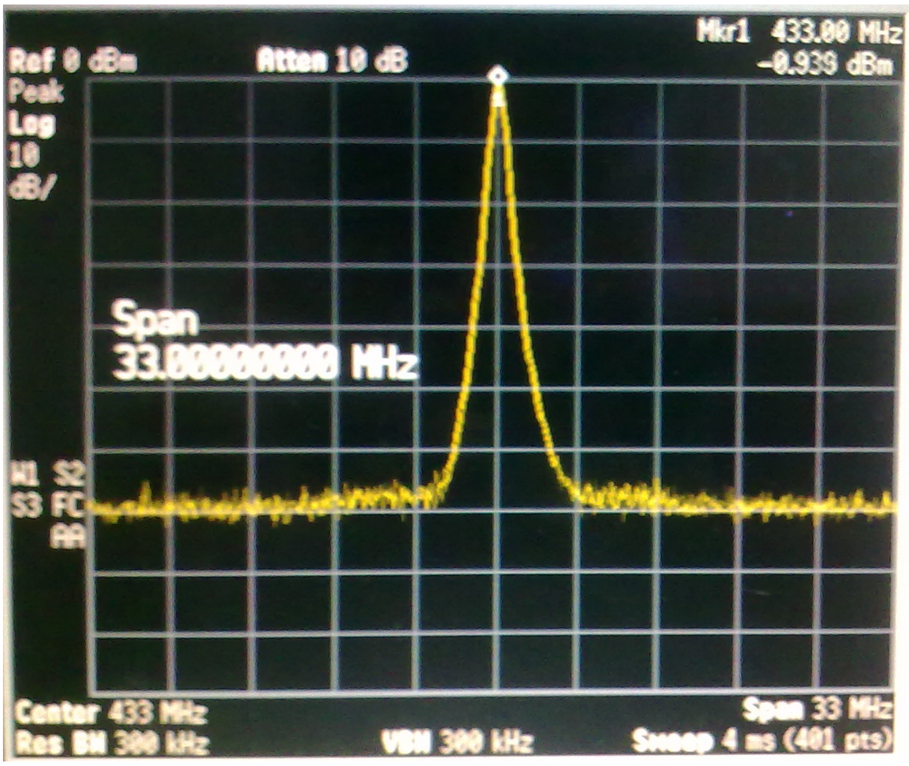


Figure 24: Cable Loss in 433 MHz

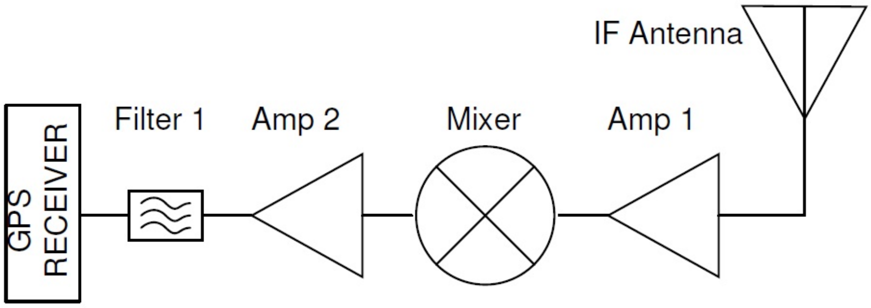


Figure 25: Up-Converter System Schematics

filtered and sent to the GPS receiver which will get data from the knowledge in the signals and calculate the position of the target by evaluating the position information in the signals. The Designed system schematic is shown in figure 25.

Up-Converter system is composed of low noise amplifiers, filters, a mixer, a local oscillator and power amplifiers. The up-converter circuit board can be seen in figure 26.

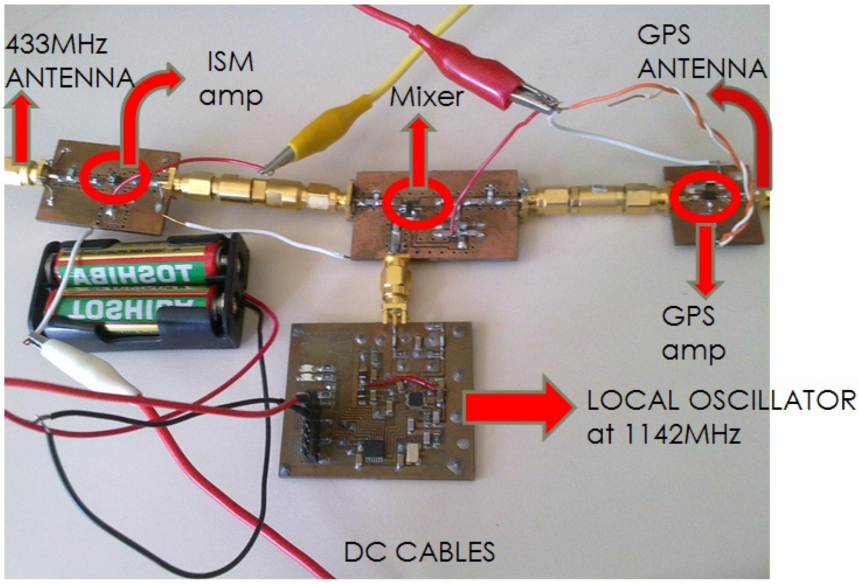


Figure 26: Up-Converter Board

The system is designed on FR4 PCB board. Down converted and transmitted GPS signals are received firstly by an IF antenna and transmitted to the input of the circuit by coaxial cable with 50Ω input impedance. Transmitted down converted

GPS signals are amplified with an LNA which is shown in figure 25 with Amp 1. Later, it is up converted to the 1575 MHz GPS frequency L1 band by the mixer shown in Mixer in figure 25 with the help of the local oscillator. Later, the signal is amplified with GPS L1 band LNA shown in Amp 2 in figure 25. Lastly, the signals which are up converted again to GPS frequency are transmitted to the GPS receiver which will evaluate the information in the signals and calculate the position. For the first component of the system, an amplifier with low noise figure and high gain should be chosen. To make lower the noise figure of a heterodyne system, it is very crucial that first amplifier should have very low noise figure. For the first step, an LNA in IF frequency is chosen and it is same low noise amplifier with the LNA in the last stage of the down-converter circuit, Max 2640. The chosen LNA is drawing 3 mA from 3V power supply. Its performance is 0.9 dB noise figure and 15.1 dB gain in its data-sheet. Second component of the system, a mixer with high conversion gain and a local oscillator at 1142 MHz for helping to the mixer should be chosen. This mixer up-converts the IF signal to 1575 MHz GPS frequency L1 band by multiplying the signal with the signal produced by the local oscillator at 1142 MHz. The chosen mixer, named Max 2660 produced by Maxim Company, draws 5 mA current from 3V power supply. Its performance is 12 dB noise figure and 4.6 dB gain. The local oscillator oscillates at 1142 MHz with -3 dBm output power while it is drawing 50 mA from 3V power supply. For the fourth component, an amplifier should be chosen with high gain. The LNA is chosen to be used in down-converter system, ALM 1412. The reasons for choosing this LNA is to decrease the number of different components in the circuit and also decrease the power that the system consumes. Its inner filter is also another advantage of using this LNA. The chosen

LNA draws 8 mA current from 3V power supply. Its performance is 0.82 dB noise figure and 13 dB gain with input 1 dB compression point +2.7 dBm.For the fifth component of the system is a filter to eliminate unwanted frequency components of the signal, comes out from mixer and it should have low insertion loss. The chosen filter is present in third component because the chosen amplifier is same with the first stage LNA of the down-converter circuit. So the circuit will be smaller and cheaper due to decrease in the number of the components. The system has 31 dB gain. The system is realized on FR4 PCB board by using coplanar wave-guide transmission lines. The reason for using coplanar wave-guide topology is to enlarge the effective ground plane so as to increase isolation. Noise figure can be calculated by using well-known Friis equation in equation 13 in down-converter part.

Table 5: Datas for the noise figure calculation of the UpConverter Circuit

F_1	F_2	F_3	G_1	G_2	G_3
1.23	15.85	1.12	38	3.16	22.387

After calculation of noise figure of the system, expected noise figure is 1.62 dB. Expected total performance of the system is given in table 6.

Table 6: Expected total performance of the system and comparison of performances of each building blocks for Up-Converter

	Amp 1	Mixer	Amp 2	TOTAL
Gain	15.8 dB	5 dB	13.5 dB	34.3 dB
Noise Figure	0.82 dB	9.6 dB	0.82 dB	1.62 dB
Current	3 mA	55 mA	8 mA	66 mA

The measured results can be seen in figure 27 and 28.

The produced board has 31 dB gain and 2.9 dB noise figure. The discrepancy between the expected and the measured noise figure may stem from the board material, FR4 or error in measurement setup. The measured S11 is -25 dB and S22 is -10 dB. The S11 of the system is dominated by the S11 of the first LNA, Amp

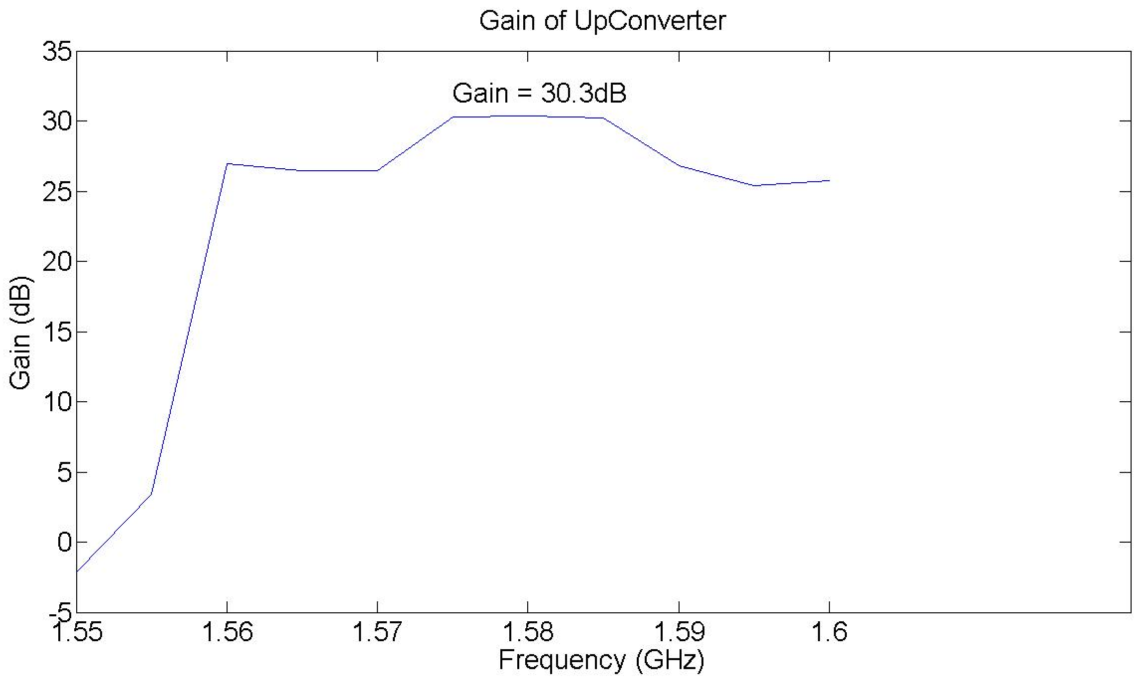


Figure 27: Up-Converter Gain

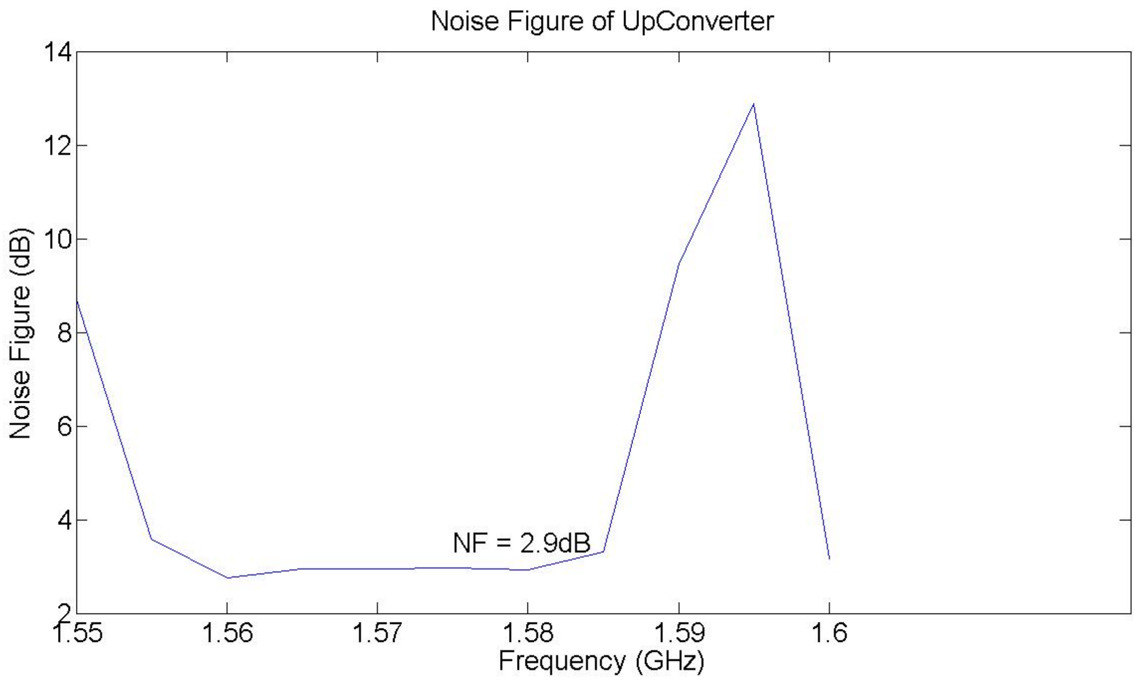


Figure 28: Up-Converter Noise Figure

1 in figure 16 and the S22 of the system is dominated by the S22 of the last LNA, Amp 2 in figure 16. The complete circuit is drawing 65 mA current from 3V power supply and so consumes 195 mW power.

For testing up-converter, firstly, -50 dBm power is generated with the signal

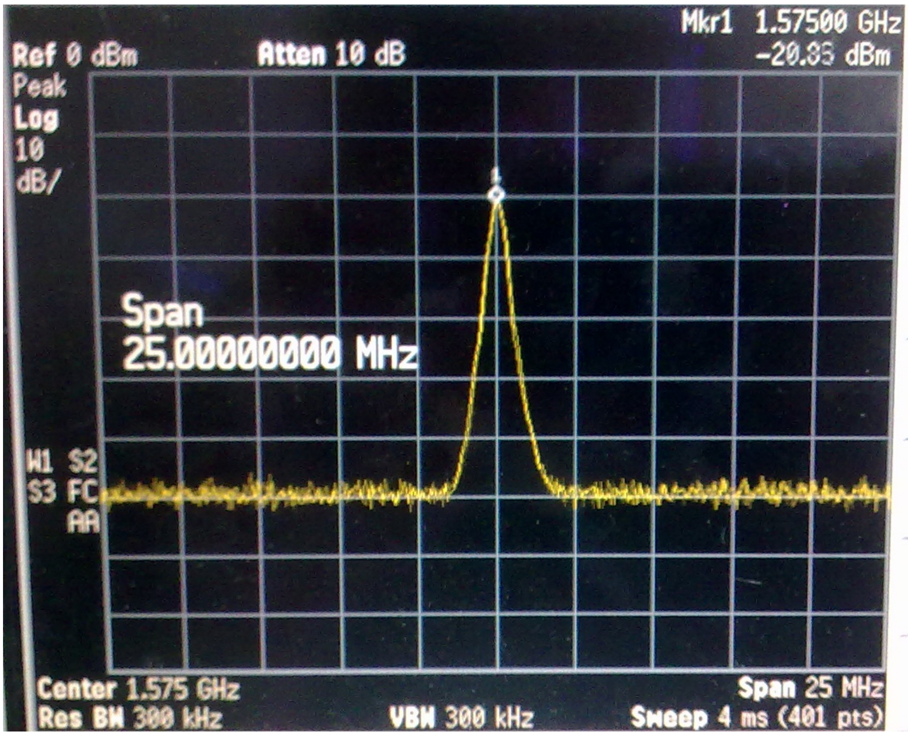


Figure 29: Up-Converter Test Output with -50 dBm Input Power

generator, Agilent EE44376, in 433 MHz free ISM band and connected to the up-converter input. Up-converter output is connected to a spectrum analyser, Agilent E44078, shown in figure 29 Measured output is -20.85 dBm and the gain is about 32 dB.

4.3 Down-converter & Up-converter System Components

4.3.1 Low Noise Amplifiers

4.3.1.1 ALM1412

"Avago Technologies' ALM-1412 is an LNA module, with integrated filter, designed for GPS band applications at 1.575 GHz. The LNA uses Avago Technologies' proprietary GaAs Enhancement-mode pHEMT process to achieve high gain with very low noise figure and high linearity. Noise figure distribution is very tightly controlled. A CMOS-compatible shutdown pin is included either for turning the LNA on/off, or for current adjustment. The integrated filter utilizes an Avago Technologies' leadingedge FBAR filter for exceptional rejection at Cell/PCSBand frequencies. The ALM-1412 is useable down to 1V operation. It achieves low noise figure, high gain and linearity even at 1V, making it suitable for use in critical low-power GPS applications or during low-battery situations." (Datasheet)

1. Features

   - Very Low Noise Figure: 0.82 dB typical
   - High Gain: 13.5 dB typical
   - High IIP3 and IP1dB
   - Exceptional Cell/PCS-Band rejection
   - Advanced GaAs E-pHEMT Technology
   - Low external component count
   - Wide Supply Voltage: 1V to 3.6V
   - Shutdown current: ¡ 0.1 μA
   - CMOS compatible shutdown pin (SD) current @ 2.8V: 0.1 mA
   - Adjustable current via single external resistor/voltage
   - Meets MSL3 and Lead-Free
   - ESD-protected RF input: 3kV HBM
   - Small package dimension: 3.3(L)x2.1(W)x1.1(H) mm3

2. Measurements

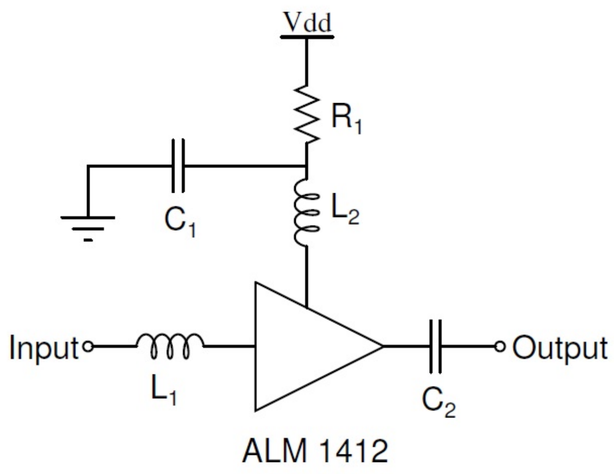


Figure 30: Schematics of ALM1412

Table 7: ALM 1412 Component Values

	L_1	L_2	C_1	C_2	R_1
UpConverter	5.6 nH	6.8 nH	10 pF	100 pF	12Ω
DownConverter	5.6 nH	6.8 nH	10 pF	100 pF	12Ω

The design schematic of the ALM1412 can be seen at figure 30 and also simulation results of S parameters can be seen at figure 32. L_1 is the input matching component for minimum noise figure, C_2 and L_2 form a matching network at the output of the LNA stage, which can be tuned to optimize gain and return loss. For example, higher gain can be obtained by increasing the value of C_2 but at the expense of stability. Changing the value of L_2 can improve the PCS rejection, but impacts output return loss. C_9 is the DC blocking capacitor and R_1 is the stability-enhancing resistor.

The circuit in the schematics is manufactured and tested. Measurement results can be seen in figure 35.

S parameters are shown in figures 35.

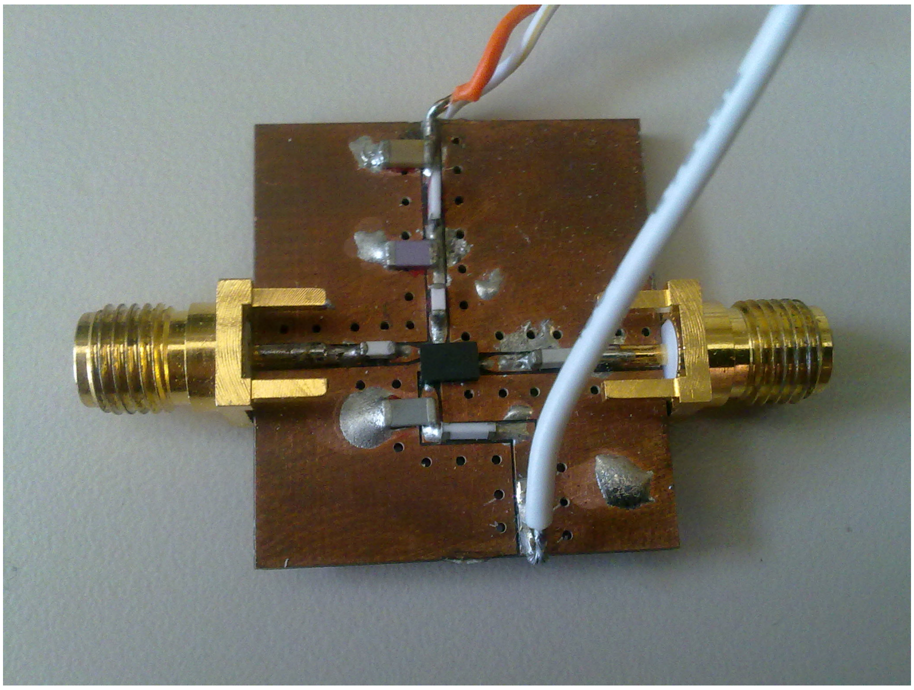


Figure 31: Board of ALM1412

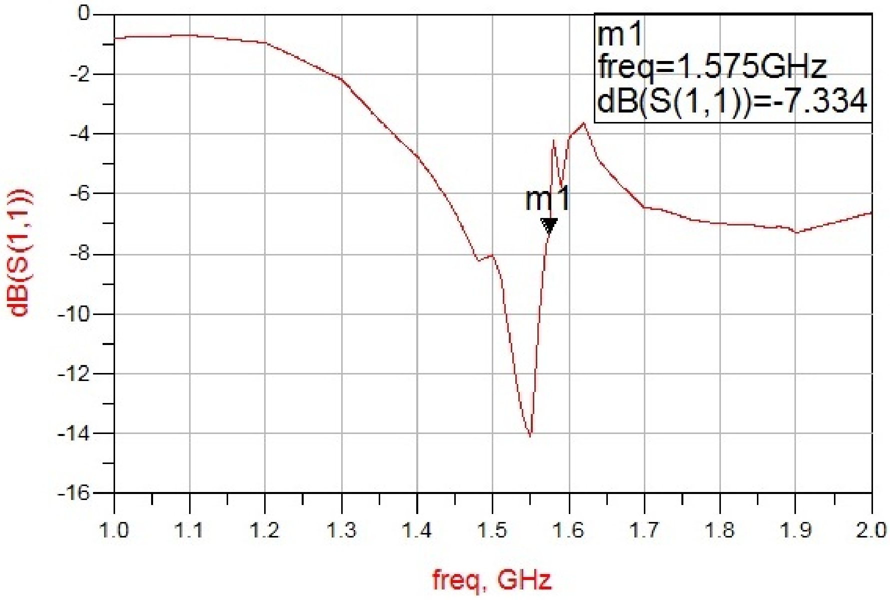


Figure 32: S11 Simulation of ALM1412

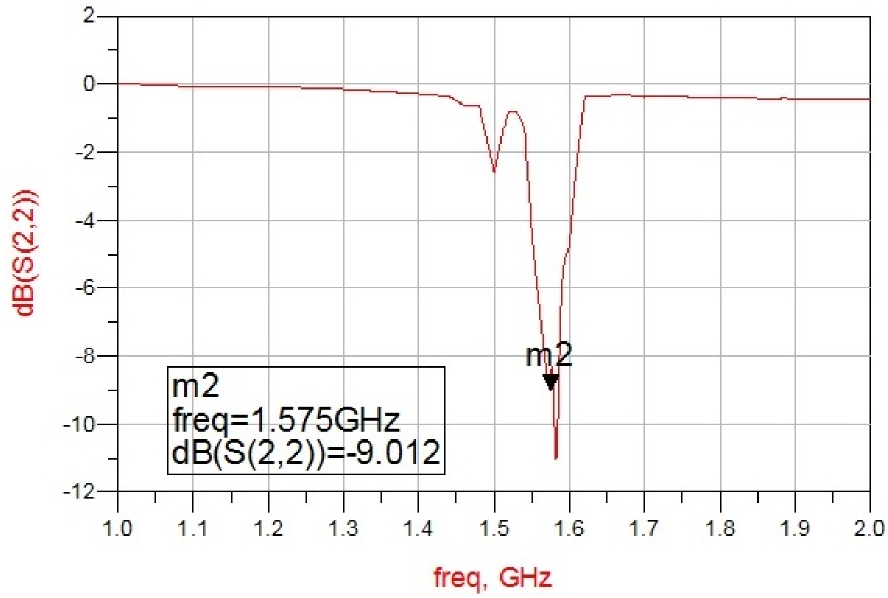


Figure 33: S22 Simulation of ALM1412

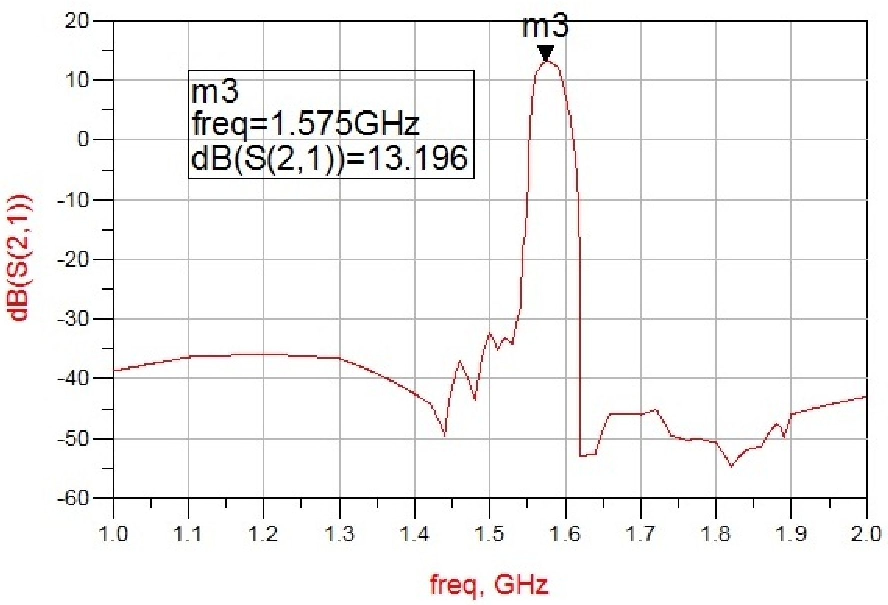


Figure 34: S21 Simulation of ALM1412

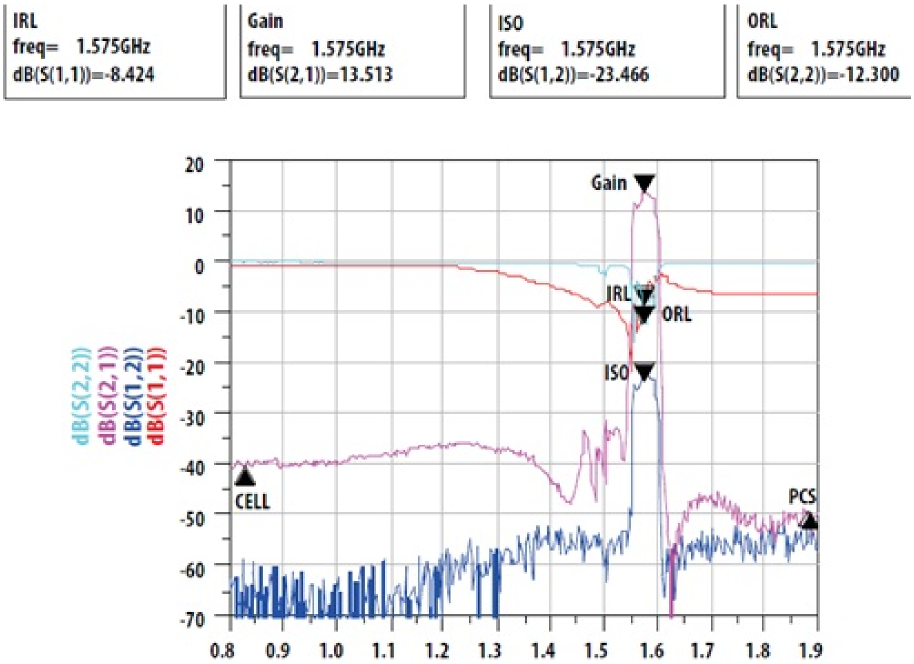


Figure 35: S Parameters of MAX2640

4.3.1.2 MAX2640

"The MAX2640 are low-cost, ultra-low-noise amplifier designed for applications in the cellular, PCS, GPS, and 2.4 GHz ISM frequency bands. Operating from a single +2.7V to +5.5V supply, this device consumes only 3.5 mA of current while providing a low noise figure, high gain, high input IP3, and an operating frequency range that extends from 400 MHz to 2500 MHz. The MAX2640 is optimized for 400 MHz to 1500 MHz applications, with a typical performance of 15.1 dB gain, input IP3 of -10 dBm, and a noise figure of 0.9 dB at 900 MHz. This device is internally biased, eliminating the need for external bias resistors and chokes. In a typical application, the only external components needed are a two-element input match, input and output blocking capacitors, and a VCC bypass capacitor. The MAX2640 is designed on a high-frequency, low-noise, advanced silicon-germanium process and are offered in the space-saving 6-pin SOT23 package." (Datasheet)

1. Features

    - Wide Operating Frequency Range: 400 MHz to 1500 MHz
    - Low Noise Figure: 0.9 dB
    - High Gain: 15.1 dB
    - High Reverse Isolation: 40 dB
    - +2.7V to +5.5V Single-Supply Operation
    - Low 3.5 mA Supply Current
    - Ultra-Small SOT23-6 Package

2. Measurements

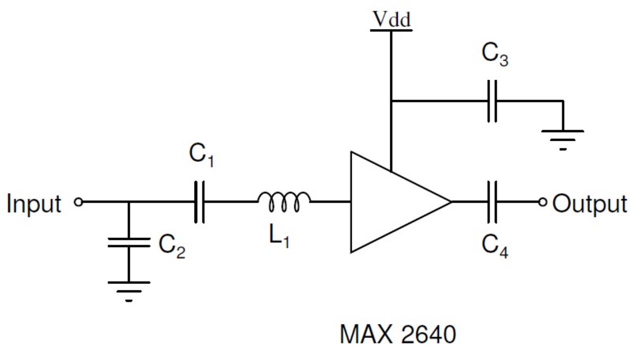


Figure 36: Schematics of MAX2640

Table 8: MAX 2640 Component Values

	L_1	C_1	C_2	C_3	C_4
UpConverter	39 nH	470 pF	6.8 pF	470 pF	15 pF
DownConverter	47 nH	1500 pF	0	470 pF	12 pF

The design board and schematic of the MAX2640 can be seen at figure 37 and figure 36. L_1 and C_2 is the input matching component for minimum noise figure for up-converter and maximum gain for down-converter, C_1 is the DC blocking capacitor,C_3 is AC couple capacitor and C_4 form a matching network at the output of the LNA stage, which can be tuned to optimize gain and return loss. Simulation results can be seen at figure 40.

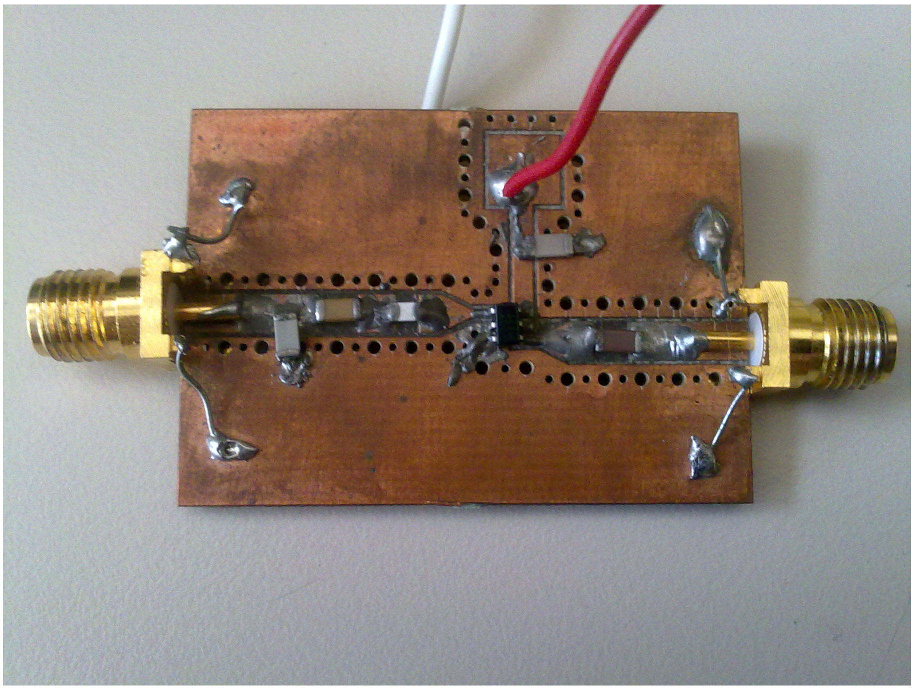


Figure 37: Board of MAX2640

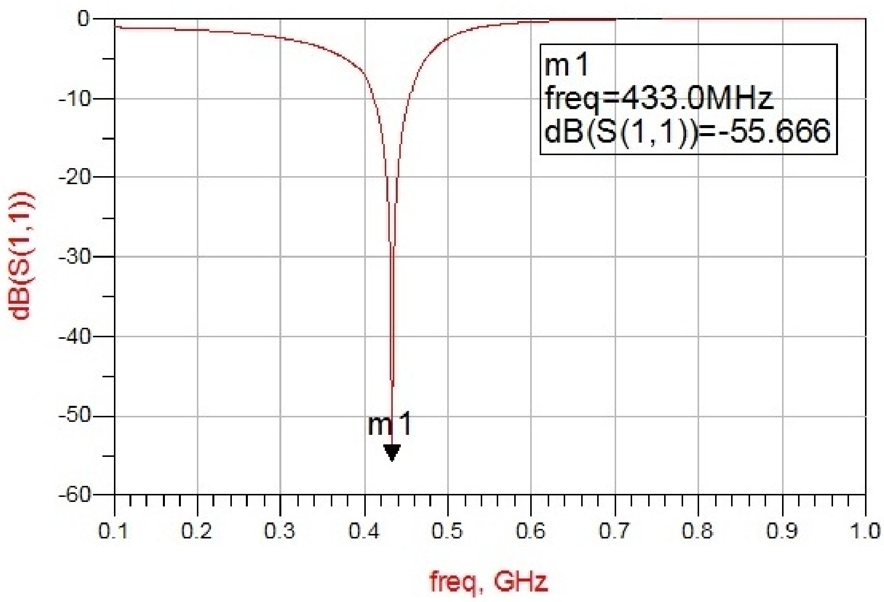


Figure 38: S11 Simulation of MAX2640

S parameters are shown in figures 41 and 42.

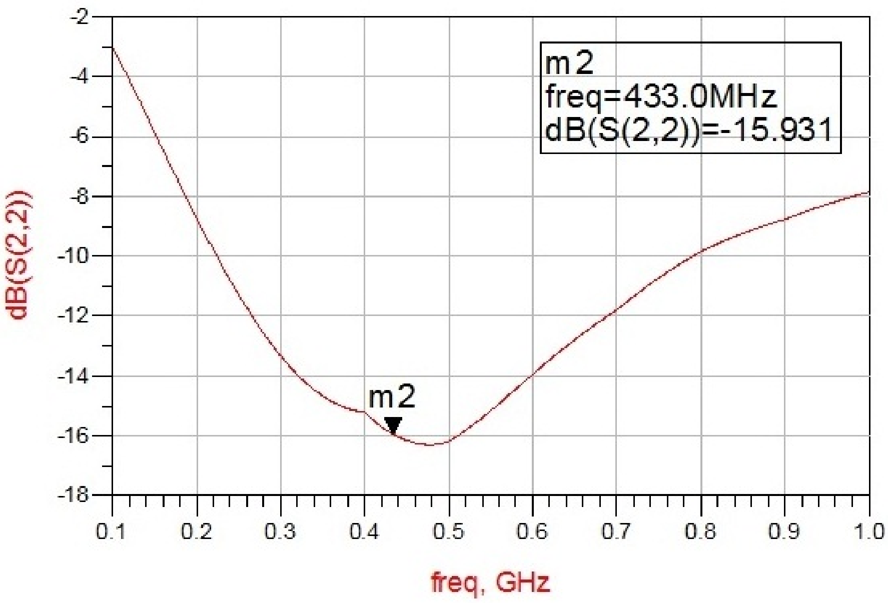


Figure 39: S22 Simulation of MAX2640

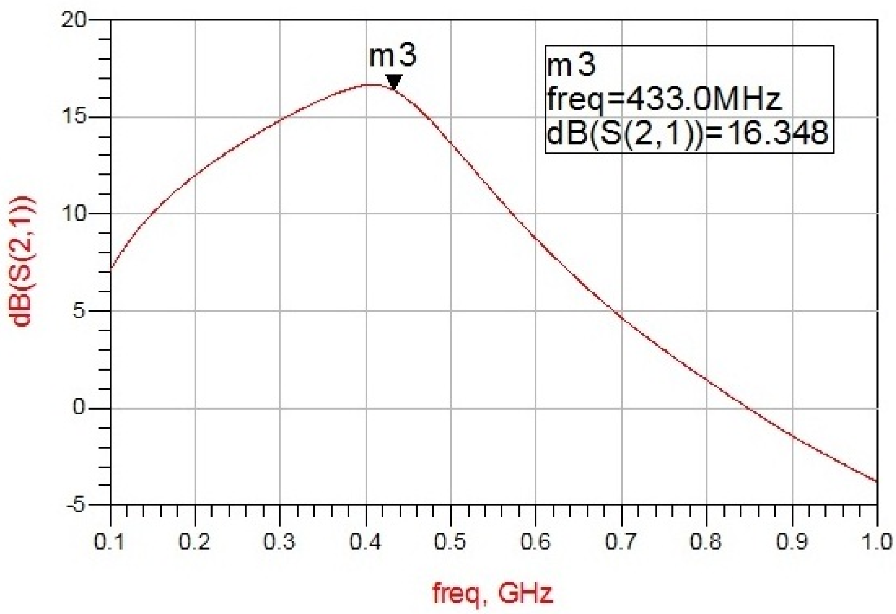


Figure 40: S21 Simulation of MAX2640

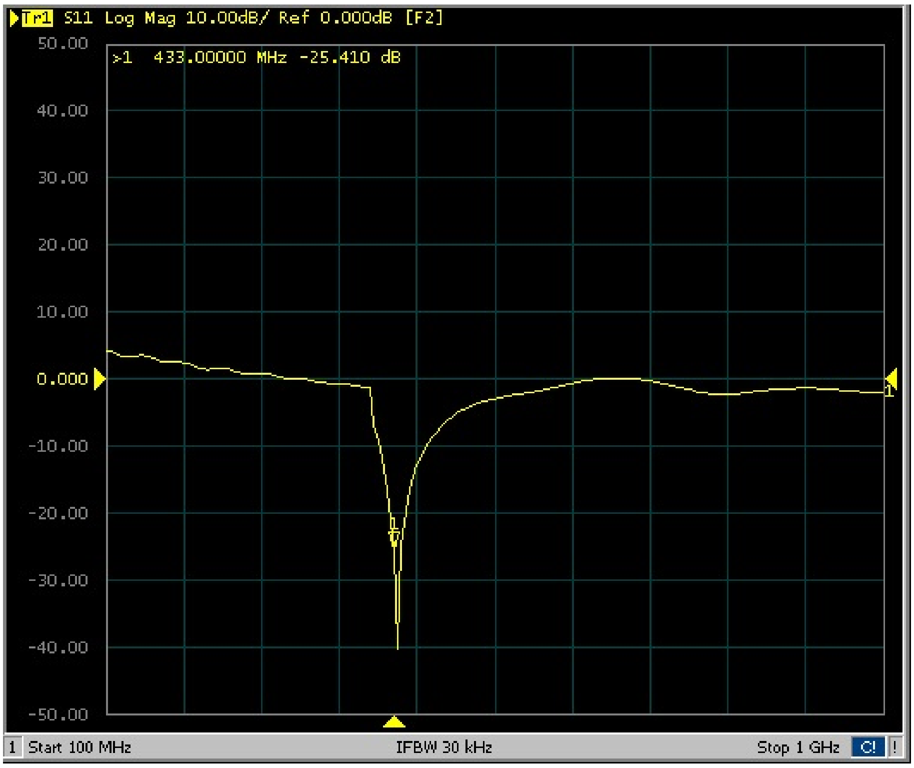


Figure 41: S11 of MAX2640

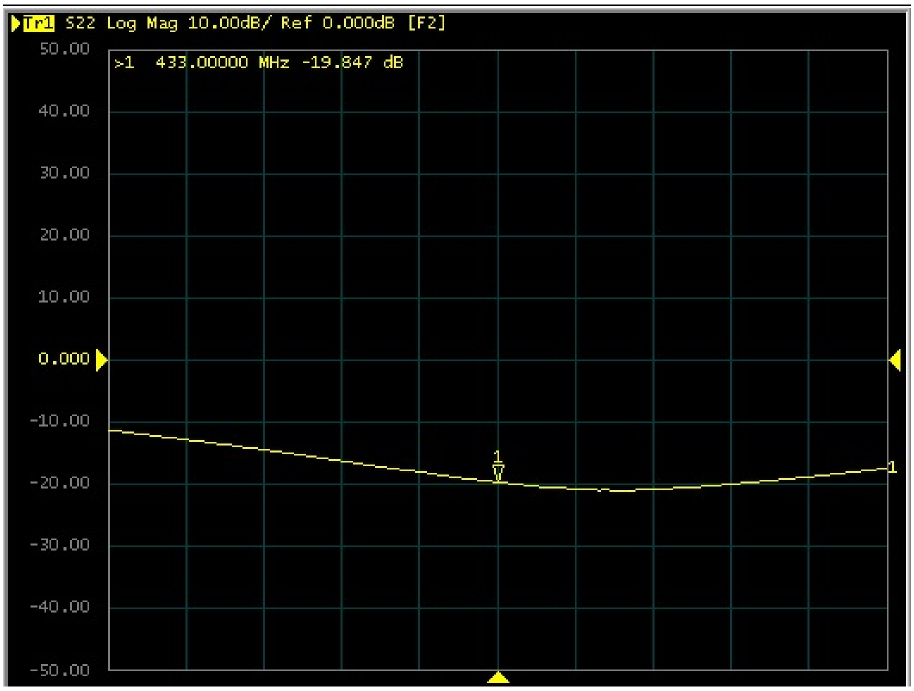


Figure 42: S22 of MAX2640

4.3.2 Mixers

4.3.2.1 MAX2660

"The MAX2660, miniature, low-cost, low-noise upconverter mixer is designed for low-voltage operation and are ideal for use in portable consumer equipment. Signals at the IF input port are mixed with signals at the local oscillator (LO) port using a double-balanced mixer. These upconverter mixers operate with IF input frequencies between 40 MHz and 500 MHz, and upconvert to output frequencies as high as 2.5 GHz. These devices offer a wide range of supply currents and output intercept levels to optimize system performance. Supply current is essentially constant over the specified supply voltage range. Additionally, when the devices are in a typical configuration with VSHDN = 0, a shutdown mode reduces the supply current to less than 1 μA. The MAX2660 is offered in the space-saving 6-pin SOT23 package." (datasheet)

1. Features

    - RF Output Frequencies: 400 MHz to 2.5 GHz
    - Low Noise Figure: 12 dB
    - +2.7V to +5.5V Single Supply
    - High Output Intercept Point (OIP3): 5.9 dBm at 4.8 mA
    - 1 μA Shutdown Mode
    - Ultra-Small Surface-Mount Packaging

2. Measurements

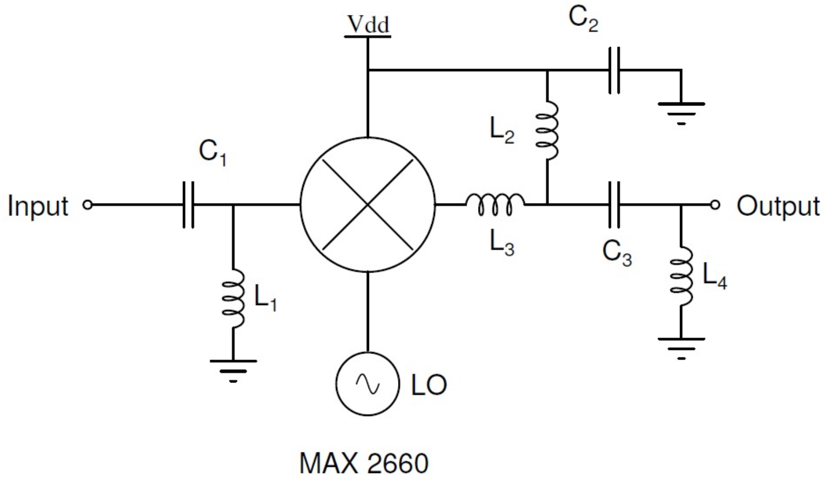


Figure 43: Schematics of MAX2660

Table 9: MAX 2660 Component Values

L_1	L_2	L_3	L_4	C_1	C_2	C_3
12 nH	2.2 nH	2.2 nH	5.6 nH	220 pF	47 pF	220 pF

The design board and schematic of the MAX2660 can be seen at figure 44 and figure 43. L_1 and C_1 is the input matching component for the mixer for maximum power transmission from input, C_2 is AC couple capacitor and L_2 is RF choke which eliminates AC current while passing DC current, C_3 is the DC blocking capacitor and, L_3 and L_4 form a matching network at the output of the LNA stage, which can be tuned to optimize gain and return loss.

S parameters are shown in figures 45 and 46.

4.3.2.2 MAX2682

"The MAX2682, miniature, low-cost, low-noise downconverter mixer is designed for low voltage operation and are ideal for use in portable communications equipment. Signals at the RF input port are mixed with signals at the local oscillator (LO) port using a double-balanced mixer. This downconverter mixer operates with RF input frequencies between 400 MHz and 2500 MHz, and downconvert to IF output

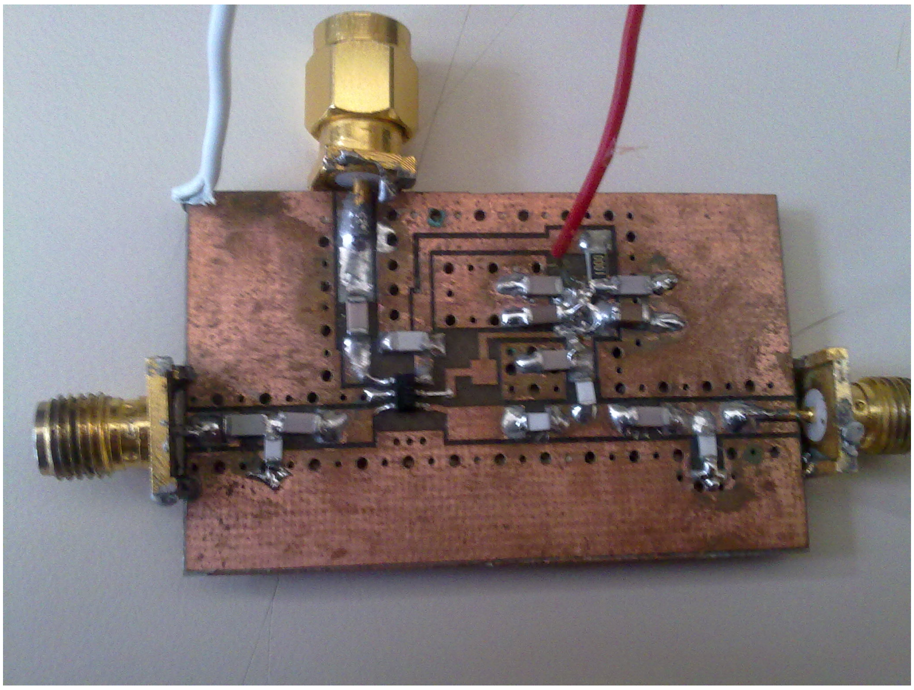


Figure 44: Board of MAX2660

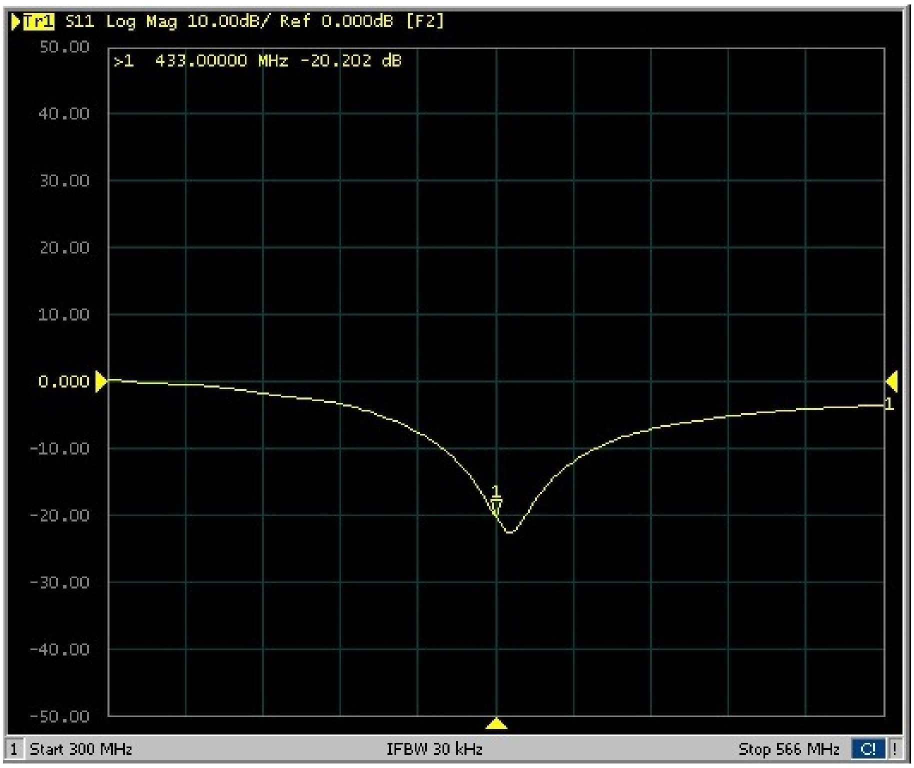


Figure 45: S11 of MAX2660

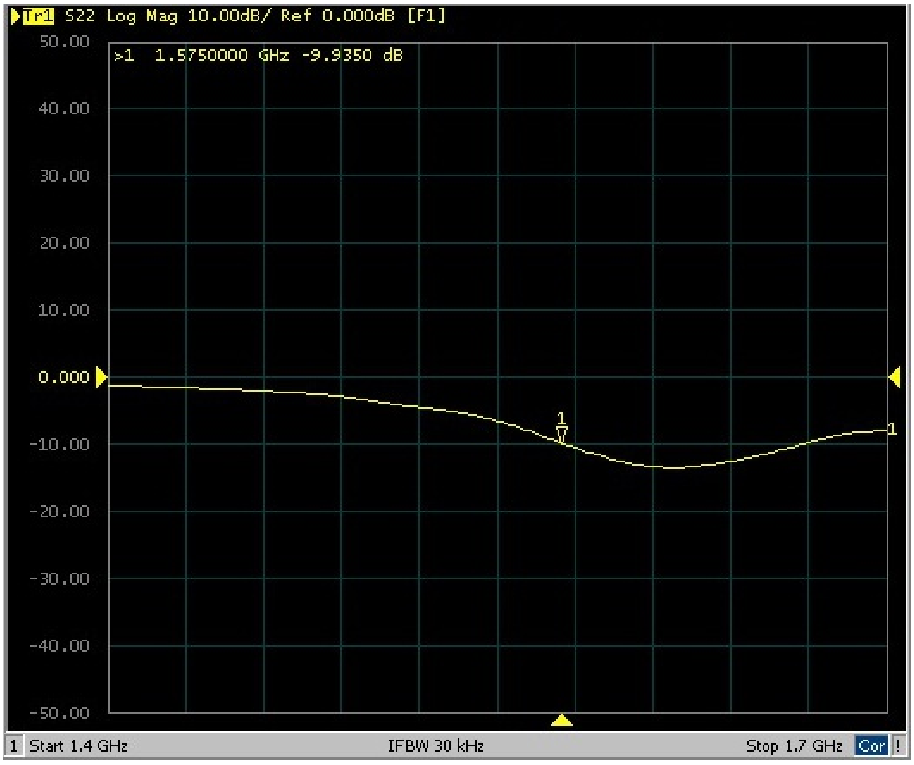


Figure 46: S22 of MAX2660

frequencies between 10 MHz and 500 MHz. The MAX2682 operates from a single +2.7V to +5.5V supply, allowing them to be powered directly from a 3-cell NiCd or a 1-cell Lithium battery. These devices offer a wide range of supply currents and input intercept (IIP3) levels to optimize system performance. Additionally, each device features a low-power shutdown mode in which it typically draws less than 0.1μA of supply current. The MAX2682 is manufactured on a high-frequency, low-noise, advanced silicon-germanium process and is offered in the space-saving 6-pin SOT23 package."(datasheet)

1. Features

  - RF Output Frequencies: 400 MHz to 2.5 GHz
  - Low Noise Figure: 9.6 dB
  - +2.7V to +5.5V Single Supply

- High Input Third-Order Intercept Point (IIP3):+3.2 dBm at 4.8 mA

- ¡0.1 μA Low-Power Shutdown Mode

- Ultra-Small Surface-Mount Packaging

2. Measurements

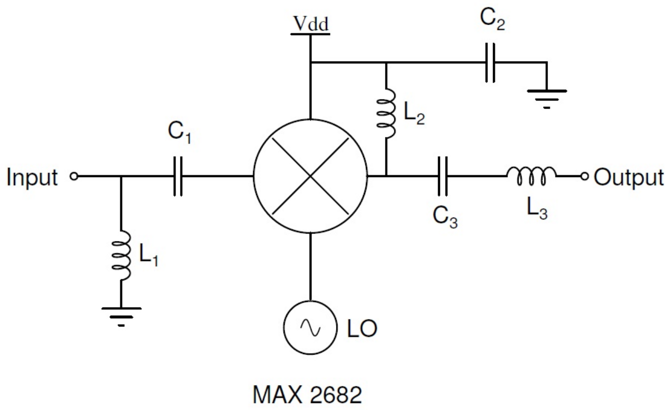


Figure 47: Schematics of MAX2682

Table 10: MAX 2682 Component Values

L_1	L_2	L_3	C_1	C_2	C_3
3.3 nH	56 nH	82 nH	270 pF	1000 pF	5.6 pF

The design board and schematic of the MAX2682 can be seen at figure 48 and figure 47. L_1 is the input matching component for the mixer which will be transmitting maximum power, C_2 is the AC couple capacitor and L_2 is RF choke which eliminates AC current, C_3 and L_3 form a matching network at the output of the LNA stage, which can be tuned to optimize gain and return loss while C_3 is also DC blocking capacitor like C_1.

S parameters are shown in figures 49 and 50. In spectrum analyser, -10 dBm power at 1575 MHz is transmitted and gain of max2682 is measured. Its

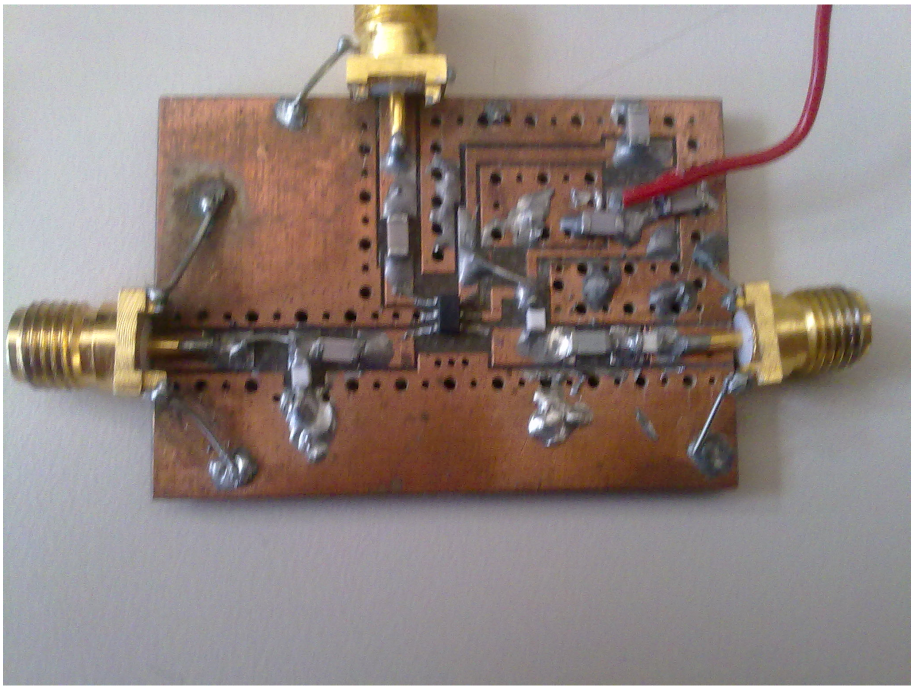


Figure 48: Board of MAX2682

output was -20 dBm as shown in figure 51 so its gain is 11 dB with 1 dB cable loss in measurement setup in 433 MHz.

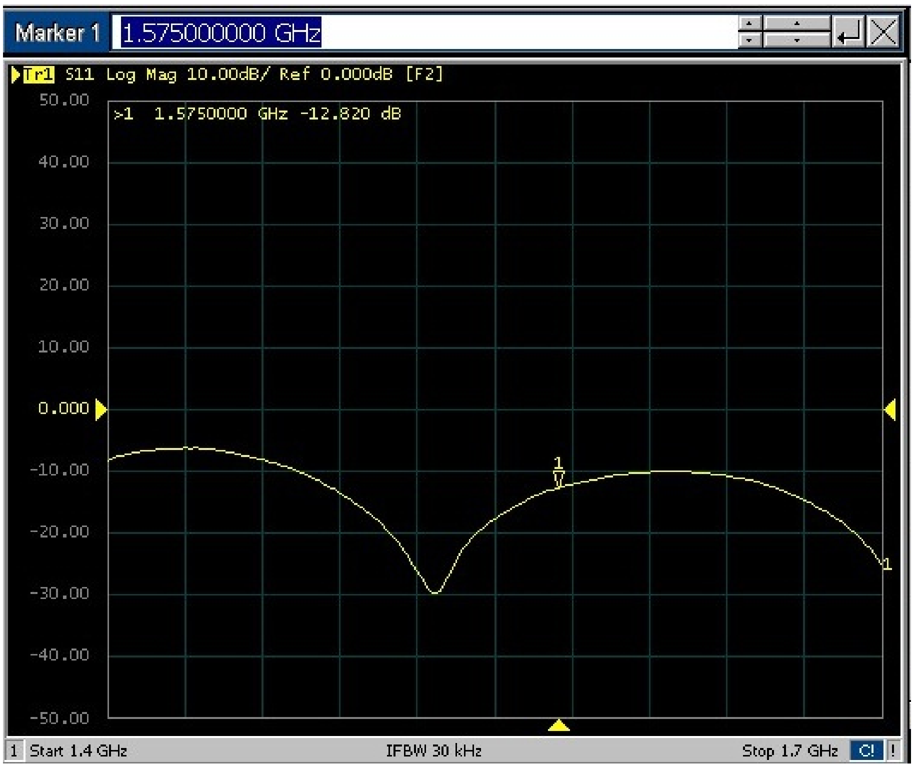


Figure 49: S11 of MAX2682

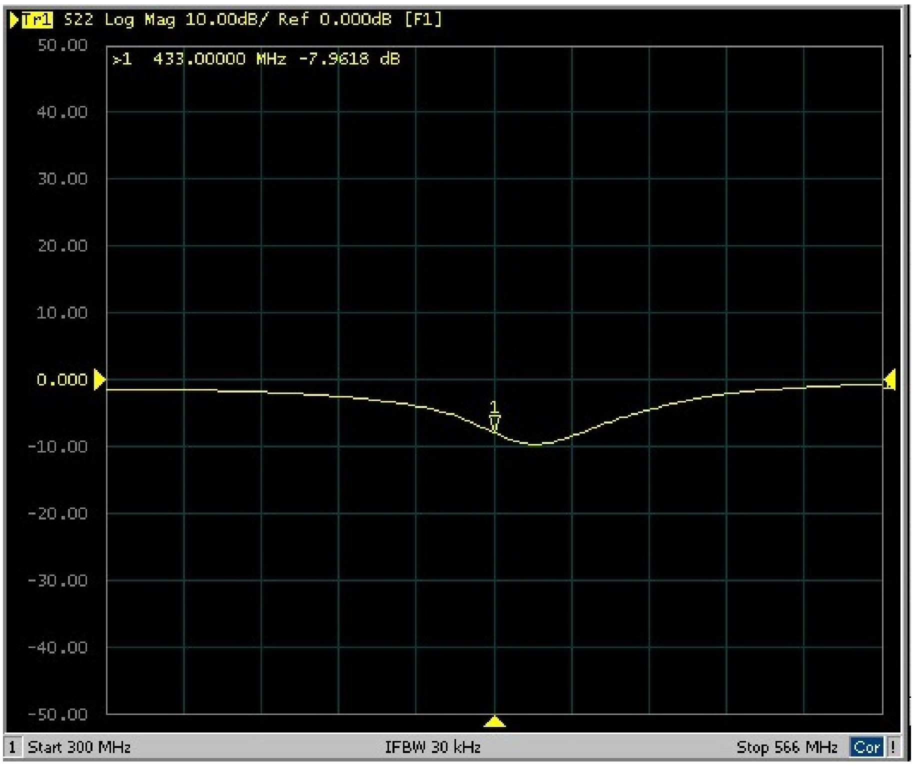


Figure 50: S22 of MAX2682

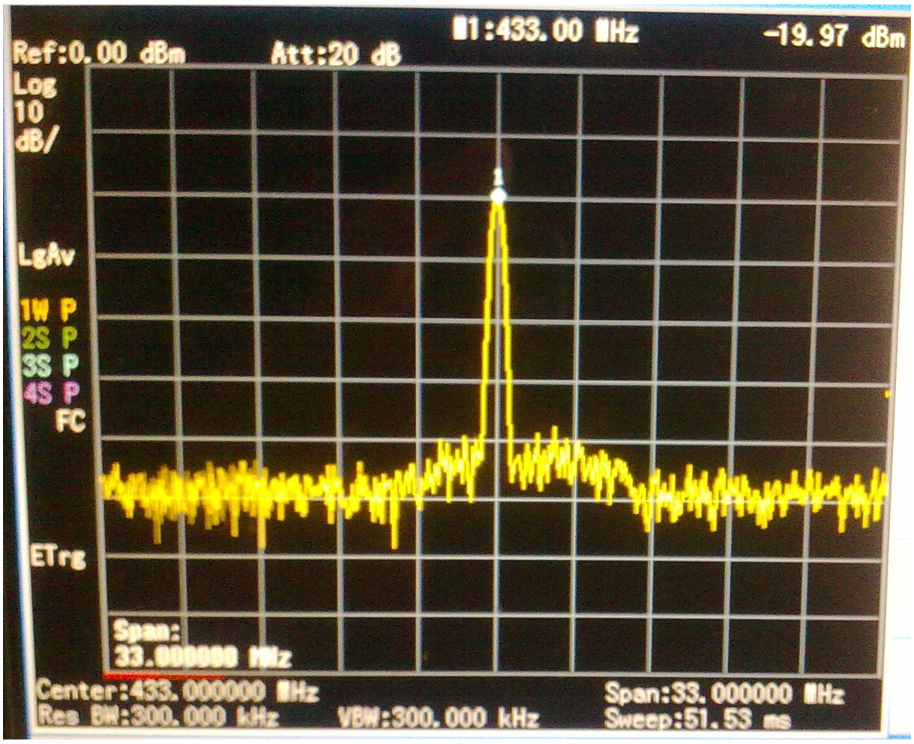


Figure 51: Output of MAX2682

5 Overall System Performance

5.1 Transmission of the signals

Signals can be transferred in the mediums with losses with respect to their refractive indexes. While outdoor areas have only air medium which can transmit the signals with maximum range after vacuum medium, in indoors, signals pass through walls and other physical obstacles by losing its power. In outdoor areas the lost power unit can be defined as in free space path loss equation 14.

$$Loss = 10 * log((\frac{4\pi R}{\lambda})^2) \tag{14}$$

With path loss equation, the signal power with various distances in the outdoors can be calculated. In this section, some measurements will be given by transmitting the signal from a corner of a room and receiving this signal from another corner of the room with an obstacle in front of the transmitter and also without an obstacle.

5.1.1 Transmission of the GPS signals in indoors

The frequency of the GPS signals is 1575 MHz. This frequency signals can be transmitted with a loss as -36.4 dB in one meter distance according to friis equation. The signal transmission was done with 10 dBm input power and 6.5 dBi transmitter antenna gain, SAS-510-2 yagi uda antenna, in three meters distance with an obstacle in front of the transmitter antenna. The transmitted signal power in air is 16.5 dBm. The receiver antenna is standalone GPS patch antenna which has 4 dBi antenna gain. Free space loss in three meters is 46 dB in 1575 MHz by using equation 14, so the expected received power is 16.5-46+4 = -25.5 dBm. The received signal power can be seen in figure 52.

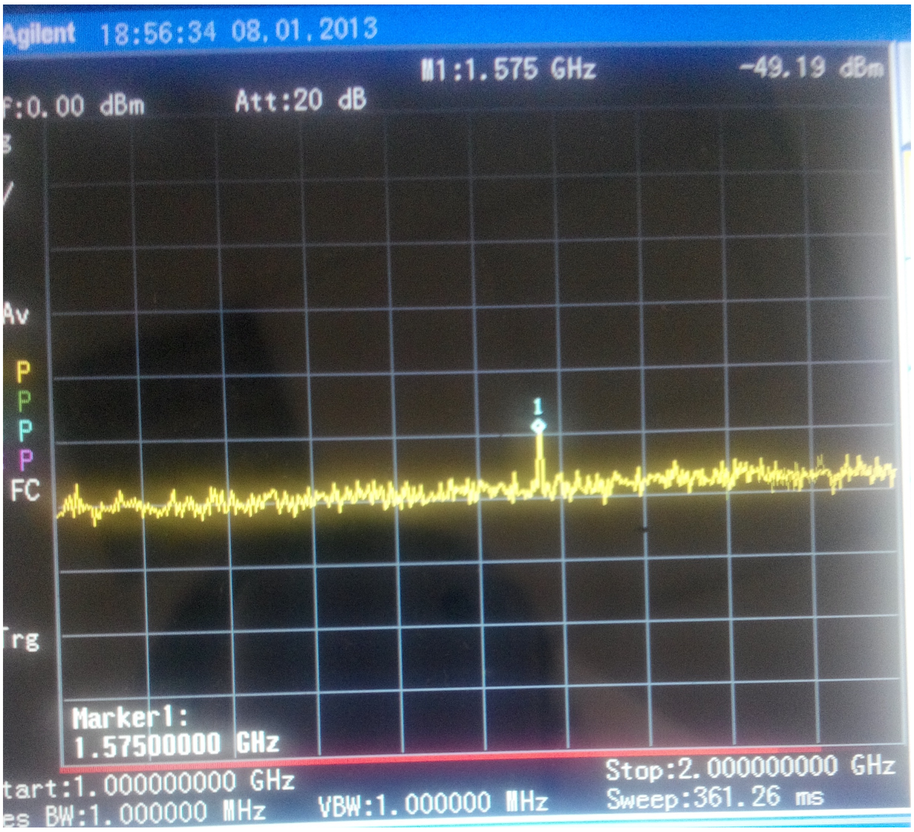


Figure 52: Received GPS Signal in Indoors

The received signal power is -49.2 dBm, so GPS signals loss about 23.7 dB power while hitting this physical obstacle.

5.1.2 Transmission of the IF frequency signal in indoors

The frequency of the IF signals is 433 MHz. This frequency signals can be transmitted with a loss as -25.2 dB in one meter distance according to free space path loss equation 14. The signal transmission was done with 10 dBm input power and 6.5 dBi transmitter antenna gain, SAS-510-2 yagi uda antenna, in three meters distance with an obstacle in front of the transmitter antenna. The transmitted signal power in air is 16.5 dBm. The receiver antenna is my IF antenna which has -0.5 dBi antenna gain and free space loss in three meters is 34.7 dB, so the expected received power is 16.5-34.7-0.5 = -18.3 dBm. The received signal power can be seen in figure 53.

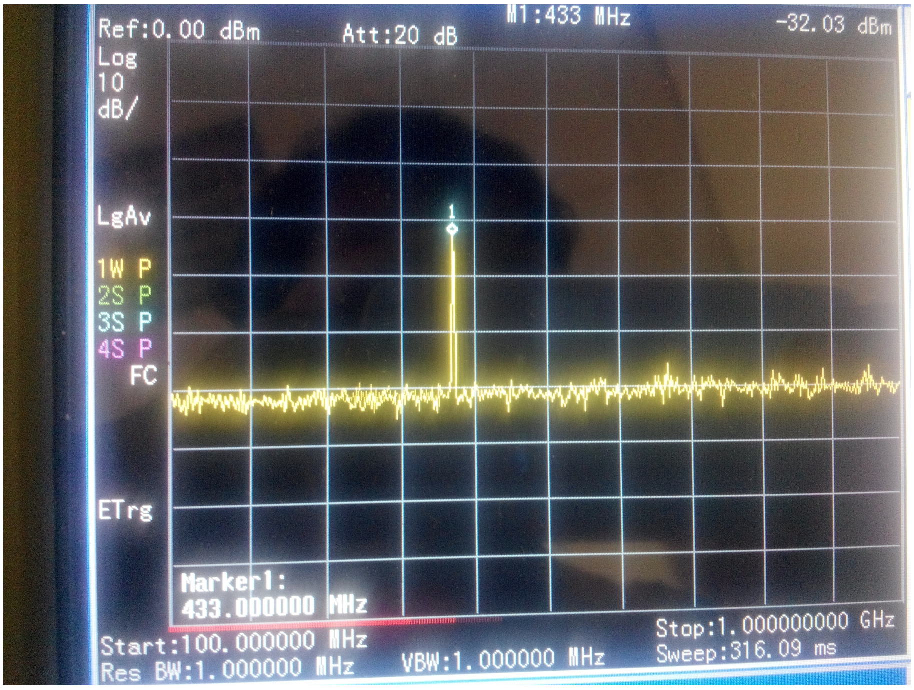


Figure 53: Received IF Signal in Indoors

The received signal power is -32 dBm, so IF signals loss about 13.7 dB power while hitting this physical obstacle. In GPS frequency, it was 23.7 dB so the penetration of the lower frequency signals to the obstacles is easier than higher frequency signals and has less loss. Therefore, lower frequency signals can be transmitted to the longer distances.

5.2 Overall System Analysis

When -50 dBm signal power generated in GPS frequency and connected to the output of the down-converter circuit, the transmitted power will be about this power plus down-converter circuit gain, so -50 + 51 = 1 dBm signal power. Down-converter will change the signal frequency from 1575 MHz to 433 MHz, so 433 MHz signals will be transmitted to the indoors. In three meters, free space loss will be 34.7 dB for 433 MHz. The next experiment was done with -50dBm input power, 6.5 dBi transmitter antenna gain and -0.5 dBi receiver antenna gain in three meters with 34.7 dB path loss and 13.7 dB obstacle loss. The expected signal power was -41.4 dBm and the measured received power can be seen at figure 54.

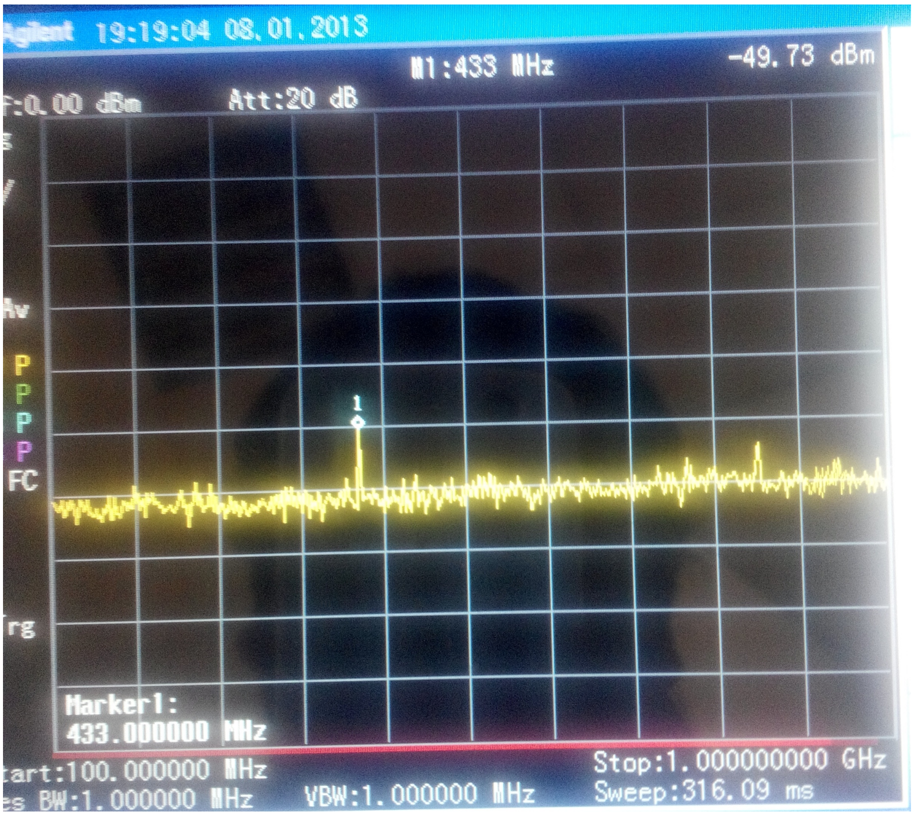


Figure 54: Received DownConverted Signal in Indoors

The measured signal power is -49.7 dBm and it is not -41.4 dBm as expected. Because we transmitted -50 dBm input power to the down-converter but down-converter circuit has last amplifier with -22 dBm input 1 dB compression point, so the system is not in linear region. The last stage input power level is -15 dBm and it is 6 dB higher than the linear region excluding the cable loss and the difference between expected received signal and measured received signal is 8.3 dB. The designed system can operate linearly up to -57 dBm input power with -22dBm for the input of last stage amplifier and 35 dB gain before this stage. The GPS signal power level that reaches to the earth is maximally -123 dBm, so when we add this 9 dBi antenna gain and 53 dB down-converter gain, we will be transmitting maximally -61 dBm power, so it will operate in linear region.

Noise floor for RF systems can be calculated with the equation ??mds) where MDS is minimum detectable signal in dBm, NF is noise figure in dB and BW is bandwidth in Hz.

$$MDS = -174dBm + NF(dB) + 10log(BW(Hz)) + SNR \tag{15}$$

Directional GPS antenna will take -123 dBm GPS signal power maximally and will transmit it to the down-converter with 9 dBi antenna gain and -114 dBm power. The designed down-converter will amplify this signal to the -60.7 dBm power level by decreasing its frequency to 433 MHz. By using equation 14, this signal will be transmitting up to 20 meters with 51.2 dB path loss and 30 dB estimated additional loss due to physical obstacles. With these, the signal power will be -141.9 dBm in 20 meters distance and GPS receivers can detect the GPS signals strongly up to -142 dBm. This can be found with the parameters of bandwidth of GPS signals is 1 MHz, SNR of the GPS receiver is -29 dBm and so -143 dBm minimum detectable signal power. The detectable signal will be lower than -143 dBm due to the GPS receiver has preamplifier in up-converter. Up-converter gain is 31 dB and noise floor is -174 dBm, so detectable signal level is 143 dBm. There can be additional loss more than 30 dB in indoors, but it is ignored due to the amplifier in the up-converter. Minimum detectable signal by the GPS receiver is -140.7 dBm with 1.7 MHz bandwidth, 2.9 dB noise figure and -29 dBm SNR. With pre-amplifier in up-converter, it will be receiving -171.7 dBm which is almost thermal noise floor for room temperature.

6 Conclusion

In this thesis, a new repeater model defined for indoor GPS applications is presented. The defined model also is manufactured and measured. Designed indoor positioning system can be used without any need of infrastructure by locating the system to the glasses of the buildings, entrance and exit of the tunnels, etc. It can be used for location detection of medical personnel or equipment in a hospital, location detection of firemen in a building on fire. There are many researches on handling the GPS positioning in indoor areas and this topic made this thesis. In the defined model, GPS signals will be received by three directional antennas, amplified, down-converted, filtered, re-amplified and transmitted to the indoor area by designed 433 MHz antenna. The signals sent to the indoor areas will be up-converted and amplified. Lastly, GPS receiver will detect these signals at GPS frequency and find the location of the receiver. For the down-converter system, a board which is composed of three LNAs, one oscillator, one mixer, two filters and transmission lines on FR4 PCB board is designed and the up-converter system, a board which is composed of three LNAs, one oscillator, one mixer, one filter. Down-converter system has measured 53.3 dB gain and 2 dB noise figure while it consumes 234 mW power. For the up-converter system, a board which is composed of two LNAs, one oscillator, one mixer, two filters and transmission lines on FR4 PCB board is designed and the up-converter system, a board which is composed of 2 LNAs, one oscillator, one mixer, one filter. Up-converter system has measured 30.1 dB gain and 2.9 dB noise figure while it consumes 200 mW power. For the designed IF antenna which will received and down-converted GPS signals to the indooors and receive these transmitted signals to up-convert and send it to the receiver, a small sized folded dipole antenna on FR4 PCB board is designed, manufactured and measured. The designed antenna has a good performance with respect to its frequency and size with -0.43 dB antenna gain.

The designed system has many advantages compared to the other topologies. First of all, there is no need for any additional infrastructure, it is enough to place three directional antennas with down-converter and update standard GPS algorithm. The designed system is not affected by the environmental conditions like rain, snow or any other obstacles like infra-Red technology. Its coverage area is enough for many indoor areas with its low noise figure and high gain. The up-converter is low power, so it can be used with batteries. In addition, the accuracy of this system is better than the other methods thanks to degradation in multi-path problem.

6.1 Future Work

Future work can be building 3-D positioning system by changing the system slightly which will give more accurate positioning by using four different satellites signal with four directional GPS antennas and also some visual effects can be added to the data output for showing the position. But before this advance, there is a need for review for this topology. In this topology, multi-path problem is a serious threat for operation of the system due to reflections in the building. The effects of multi-path problem can be lessened by adding antenna array and correlating the signal with a reference signal and with change in GPS algorithm with respect to the GPS data and reference data by comparing with the phase shifts of each antenna data. In addition to the future work, up-converter circuit will be built as a chip to be able to integrate it to the standard GPS receivers.

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