**ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY**

# DESIGN AND REALIZATION OF KU-BAND MICROSTRIP PATCH ANTENNA WITH LNA FOR SMALL SATELLITES

**M.Sc. THESIS**

**Lida KOUHALVANDI**

**Department of Electronics and Communication Engineering**

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**Thesis Advisor: Dr. H. Bülent YAĞCI**

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**İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ**

# KÜÇÜK UYDULAR İÇİN KU BAND MİKROŞERİT YAMA ANTEN DİZİSİ VE DÜŞÜK GÜRÜLTÜLÜ KUVVETLENDİRİCİ TASARIMI VE GERÇEKLEMESİ

**YÜKSEK LİSANS TEZİ**

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**Lida-Kouhalvandi**, a **M.Sc.** student of ITU **Institute of Science Engineering and Technlogy** student ID **504121368**, successfully defended the **thesis** entitled "**DESIGN AND REALIZATION OF KU-BAND MICROSTRIP PATCH ANTENNA WITH LNA FOR SMALL SATELLITES** ", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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|---|---|---|
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**Date of Submission : 4 May 2015**
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***I dedicate this thesis work to my loving grandparents. You are my heart forever and have never left my side. Your endless love, words of encouragement and push for tenacity, ring in my ears and drive me to move forward.***

***I also wish to dedicate this thesis to my adored parents who encourage and support me at every stage of my life. Your greetings and cares always stay with me on my way to success and happiness.***

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June 2015 Lida KOUHALVANDI

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## ABBREVIATIONS

| | |
|---|---|
| **LNA** | **:** Low Noise Amplifier |
| **LEO** | **:** Low Earth Orbit |
| $I_{DSS}$ | **:** Saturated Drain Current |
| **NF** | **:** Noise Figure |
| $G_a$ | **:** Associated Gain |
| **Ref** | **:** Reference |

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**DESIGN AND REALIZATION OF KU-BAND MICROSTRIP PATCH ANTENNA WITH LNA FOR SMALL SATELLITES**


## SUMMARY

This dissertation is concerned with both investigation of a well-characteristic microstrip array antenna which is specially designed with three slits with ground plane structure and a high-gain wideband low noise amplifier (LNA) which are appropriate for the Ku-band application to fulfil the demand of radar, satellite, and communication. This thesis is divided into four parts. First part is a short and brief introduction about the works and designs that have been done in order to realize the design in the desired band frequency for small satellites.

The second part deals with the theory behind Ku-band slotted rectangular patch array design. For designing this array patch antenna, firstly unit patch element over a Taconic TSM-30-0600-C1/C2 ($\varepsilon r$=3) with the height of 1.52mm. Obtained single element radiation pattern is directional with good amount of radiated power with negligible backward radiation. The 3D radiation pattern shows maximum power flowing in the z-direction ($\Theta=0^0$). After simulation, the single element antenna has about 7dBi gain and linear polarization at $\phi= 90^0$ degree direction and 10dB back lobe ratio has been achieved. Then 2×2 array structure is developed by using array feed circuit. Dimension of array antenna is 16mm × 18 mm and feed of array antenna combines with 100Ω and 50Ω T-junctions over Taconic-TSM substrate with the height of 0.76mm on the reverse top side layer. For 2×2 array antenna, maximum measured gain of 10.9 dBi has been achieved in 11.9 GHz to 12.9 GHz band frequency. Furthermore, for array antenna, linear polarization is at $\phi = 90^0$ degree direction.

The third part is related to LNA design. In this contribution , single transistor LNA by utilizing bias and matching networks which are modeled in AWR, has been designed and simulated at Ku-band for the potential employment in the satellite RF subsystems. Substrate used is Rogers material ($\varepsilon r$=3) and thickness of substrate and metal are H=0.762 mm and t=17.5 µm ,respectively. The design employs an N-CHANNEL HJ-FET transistor from NEC, NE3511S02. Designed LNA has ~10.5dB peak gain and 1.5dB NF.

**KÜÇÜK UYDULAR İÇİN KU BAND MİKROŞERİT YAMA ANTEN DİZİSİ VE DÜŞÜK GÜRÜLTÜLÜ KUVVETLENDİRİCİ TASARIMI VE GERÇEKLEMESİ**

**ÖZET**


Uzay teknolojileri yarışı, resmi anlamda Sovyetler Birliğinin, Sputnik'i 4 Ekim 1957'de yörüngeye oturtmaları ile ivme kazanmıştır. 58 cm çapındaki küreye benzeyen yapısıyla, ilk telsiz işareti dünyaya ulaştığında insalık için de önemli ve yeni bir alan doğuyordu. Uydu teknolojileri, birçok mühendislik alanının uyumlu ve başarılı bir şekilde çalışmasının ürünüdür.

İnsan yapımı uydular günümüzde çok çeşitli amaçlar için kullanılmaktadır. Hava tahmin uyduları, iletişim uyduları, radyo-tv yayını uyduları, bilimsel gözlem uyduları ve askeri gözlem uyduları gibi. Uydunun görevi ne olursa olsun, bütün uydular için vazgeçilmez en önemli özellik, uydunun haberleşme birimidir. Veri alınamayan ya da komut gönderilemeyen bir uydu kaybedilmiş sayılır ve uzay çöpünün bir parçası olur.

Uydu teknolojileri denince akla genelde büyük haberleşme uyduları gelse de, günümüzde giderek kullanımı artan uydular, kütle ve hacim olarak daha küçük uydulardır. Alt yörüngeye konumlandırılan ve bu bölgede görev alan ve 500kg den hafif olan küçük uydular, üretim maliyeti ve düşük işletme gideri gibi özelliklerinden dolayı tercih edilmektedir.

Gelişen elektronik ve malzeme bilimi sayesinde, küçük uyduların yetenekleri de artmıştır. Daha küçük alana daha fazla ve daha verimli elektronik donanımların yerleştirilmesiyle, daha fazla veri toplama imkanı da doğmuştur. Toplanan bu verilerin dünyaya aktarılması da küçük uyduların görevlerinin önemli bir parçasıdır.

Alçak yörüngede konumlandırılmaları sebebiyle küçük uyduların hızları oldukça yüksektir (5-10 km/saniye). Yüksek hız sebebiyle, dünya üzerinde sabit durumda bulunan yer istasyonları için haberleşme penceresi çok dar olmaktadır. Artan veri aktarımı ihtiyacı, bu kısıtlı geçiş zamanı içerisinde çoğu zaman yeterli olmamaktadır. Bu nedenle yer istasyonu sayısı arttırılmakta, ya da birkaç geçişte verinin tamamı alınabilmektedir. Örneğin yüksek çözünürlüklü fotoğraflar, sensör verileri, pozisyon bilgisi kayıtları gibi. Bu nedenle küçük uydularda da geniş bantlı haberleşme sistemlerine olan ihtiyaç artmaya başlamıştır. Geniş bantlı haberleşmeye uygun yer istasyonlarının da küçük uydulara uyarlanmasıyla birlikte küçük uydularda kullanılabilecek sistem tasarımları önemli bir araştırma alanı haline gelmiştir.

Küçük uydulardaki yüksek hızlı haberleşme için, yüksek verimli, küçük boyutlu, uzay şartlarına dayanıklı devre ve sistemler gereklidir. Uydu dışına yerleştirilebilecek şekilde uygun geometriye sahip, yüksek kazançlı anten de haberleşme sisteminin önemli bir parçasıdır.

Bu tez çalışmasında, yüksek hızda iletişimi sağlayabilmek için Ku bandında çalışacak bir anten ve bu antene yakın bir şekilde konumlandırılacak bir düşük gürültülü kuvvetlendirici tasarımı hedeflenmiştir.

Sınırlı bant genişliği problemini aşabilmek için, uydu haberleşme sistemlerinde dizi anten sürecinin uygulanması son zamanlarda önerilmiştir. Kanallı parça dizi antenleri kapsamlı olarak anten sistemlerinin çoğunda kullanılmaktadır. Bunun nedeni ise; kullanışlı bir bant genişliği, uygun bir polarizasyon, düşük maliyet, sadelik, kolay üretim ve kalitedir. Bahsedilen ihtiyaçların doğrultusunda,bu tip antenler Ku-Band için elverişli çözümler sunabilir.

Mikrodalga ve kablosuz haberleşme RF ön uç alıcılarında, sistemin toplam gürültüsü sayısını belirleyen en önemli bileşen, sistem girişindeki ilk devredir. Bu nedenle, bu yapının kazançlı ve mümkün olduğunca düşük gürültülü olması istenir. Yüksek hızda haberleşebilen sistemlerde, düşük gürültülü kuvvetlendirici tasarımında, geniş bant boyunca kazancın yüksek olması, gürültünün düşük olması önemli bir ihtiyaç olmakla birlikte tasarımcıyı zorlayan en önemli şartlardır. Transistör kazancının frekans düştükçe azalması da, ilk katta yüksek kazanç elde etmenin önündeki kısıtlardan birisidir. Bunun için birden fazla transistör içeren yapılar kullanılmakta, ancak bu da güç tüketimini ve devre boyutunu arttırmaktadır.

Bu yüksek lisans tez çalışmasında küçük uyduların yüksek hızda haberleşebilmesine imkan sağlayacak ve Ku bantta çalışacak 3 yarıklı ve topraklanmış metal tabanlı bir anten yapılı anten dizisi ve geniş bantlı düşük gürültülü kuvvetlendirici tasarımı ve gerçeklemesi sunulmuştur.

Tez 4 ana başlıkta incelenmiştir. İlk kısımda küçük uydularla ilgili kısa bir bilgi verilmiş, çeşitli uygulamalar sunulmuştur.

2. kısımda Ku bantta çalışan anten dizisinin teorik altyapısı anlatılmıştır. Anten dizisi tasarımından önce, ilk olarak tek anten tasarlanmıştır. Tek antenli yapı için 1.52mm kalınlığında Taconic TSM-30-0600-C1/C1 ($\varepsilon r$=3) taban tercih edilmiştir. Tasarım için Ansoft HFSS bilgisayar destekli tasarım ve analiz yazılımı kullanılmıştır. Benzetim sonuçlarına göre, yansıma katsayısı dikkate alındığında (S11<-10dB) en yüksek kazanç için antenin ışıması doğrusal olup ters yöndeki ışıma miktarı ihmal edilebilecek seviyededir. Tasarlanan antenin benzetim sonucuna göre en yüksek kazancı 7dBi'dir. Tek antenli yapının tasarımının ardından dizi anten tasarımına geçilmiştir. Bunun için 2×2 şeklinde 4 antenli bir yapı tercih edilmiştir. 4 anten, uygun bir besleme yapısı ile birbirine bağlanmıştır. Anten dizisinin boyutu 16x18mm$^2$ olup birleştirme yapısı 50

ve 100 Ω T birleştiriciler ile 0.76mm kalınlığındaki Taconic TSM taban üzerine, antenlerin baktığı yönün tersinde yer alacak şekilde yapılmıştır. Birleştirici ve anten dizisi uygun şekilde birleştirilerek dizi anten yapısı tek noktadan beslenebilir hale getirilmiştir. Tasarlanan antenin ölçülen çalışma aralığı (S11<-10dB) yaklaşık olarak 11.9-12.9 GHz'dir. Ölçülen tepe kazancı da 10.9 dBi'dir.

3. kısımda düşük gürültülü kuvvetlendirici sunulmuştur. Alt kısmı topraklanmış olarak tek yüzeye tasarlanan düşük gürültülü kuvvetlendirici antenin çalıştığı aralığı kapsayacak şekilde tasarlanmıştır. Tasarımda NI AWR Microwave Office kullanılmıştır. 0.76mm kalınlığındaki Rogers RO3003 taban ($\varepsilon r=3$) kullanılmıştır. Tasarımda NEC firmasının N kanallı HJ-FET'i olan NE3511S02 kullanılmıştır. Üretici firma tarafından sağlanan S parametreleri ile tasarım yapılmıştır. Tasarlanan kuvvetlendiricinin ölçülen en yüksek kazancı 10.5dB olup çalışma bandı içindeki toplam gürültüsü de 1.5dB'den küçüktür.

# 1. INTRODUCTION

Artificial satellites are being used for many kinds of purpose. Today, a lot of broadcasting and communication satellites are operated for commercial and military missions. Additionally, scientific satellites are under operation for space research. The main requirement for all satellites is communication with the earth.

Small satellites, which operate at low earth orbit (LEO) and lighter than 50kg, are preferred for many applications due to low operating and manufacturing cost. The fascinating world of small satellites began when Sputnik, the first artificial Earth satellite, launched the Space Age on 4 October 1957 and surprised the world with the knowledge that humans could lift artificial satellites into Earth orbit. It was a 58 cm (23 in) diameter polished metal sphere, with four external radio antennas to broadcast radio pulses [1].

Minimum mass and power consumption, minimum complexity, minimum cost, maximum reliability and lifetime, maximum performance, and radiation tolerance are specific requirements in order to be suitable for space applications. Small satellites are usually simpler but use the same technologies as larger satellites.

Speed of small satellites are quite high (5-10 km/second) because of the low altitude. Although communication window is very small for small satellites, high data rate is required to transfer big amount of data such as high resolution photograps, detailed sensor records, etc. Therefore, small satellites require high data rate communication systems. As an example, a high-data-rate (typically over 300Mbps @8.2GHz) communication system is applied to small satellite of 50 kg class in LEO. System will be demonstrated on orbit by "Hodoyoshi" small Satellite project [2].

Figure 1.1 shows down link data rates of LEO satellites and their mass. The figure indicates that down link data rates are proportional roughly to linear or square of satellite mass.

The demand increasment of data rate for satellite communication on small satellites has driven the growing need for novel antenna designs that can be packed with RF circuits like LNAs. Today, Ku-band is getting more popular for satellites to increase data rate which requires higher bandwidth in the recent years.

The application of array antenna processing has been suggested recently for satellite communication systems to deal with the problem of limited bandwidth. Slotted patch array antennas are extensively used in many antenna systems because of their reasonable bandwidth, polarization purity, low cost, simplicity, easily fabrication, and power-handling capability. In the light of mentioned characteristics, these antennas may be a suitable solution for Ku band.  Most of the antenna features, including radiation pattern and input-impedance remain unaffected by the insertion of the slits [3].

In most of the microwave and wireless communication RF front end receivers, wideband LNAs are the first block, which are efficient to extend capacity and performance. They amplify the wanted signals and provide maximum gain with minimum noise figure and also appropriate input and output matching  under stable conditions within the required band [4].

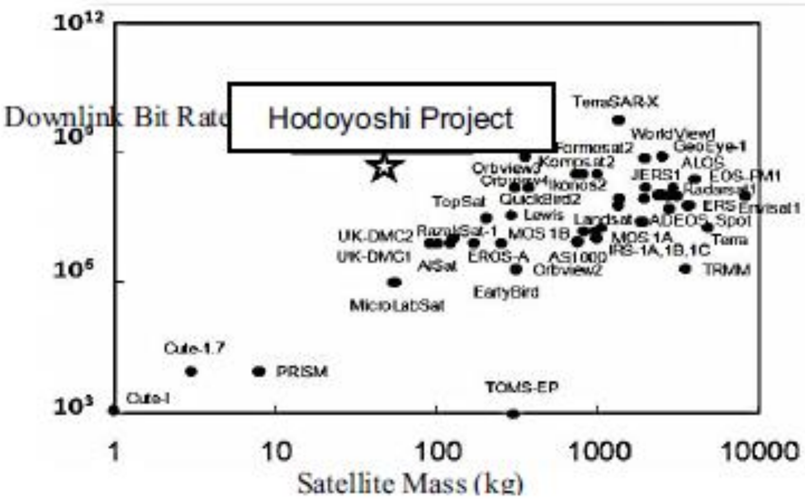


**Figure 1. 1 :** Down link bit vs. satellite mass [2].

Taking advantage of smartphones and other consumer technologies, tiny satellites are changing the space business. Small satellites benefit from the constant improvements in price and perforemance being achieved by consumer-electronics industry.

Low cost and tolerance of less-stringent standards allow multiple nanosats to be built faster.

## 1.1 Statement of the Problem

As modern small satellite communication systems have developed rapidly in recent years, the microstrip antennas may be a good solution due to their efficient fabrication in to arrays. An antenna as a front component is required to have a wide band and good radiation performances for wideband communication.

The main drawback of microstrip patch antenna that will be used in satellite communication is suffered from narrow bandwidth, low gain, and limited power capacity. To overcome its limitations, many techniques have been suggested such as using suitable substrate and feeding, changing shape or size of antenna, etc.[1].

To reduce insertion loss between antenna and LNA, designed LNA is located behind the antenna. Final structure is similar to an active antenna.

For array antenna design, firstly, a single antenna design with three slots is applied in both sides of rectangular patch and via feed with ground plane is used for resolving the problem of low gain. Then 2×2 array patch antenna is designed by using four single antennas and an appropriate feed circuit. Secondly, an LNA is designed by using microstrip lines and NE3511S02 transistor.

In this work, slotted rectangular patch array antenna and then low noise amplifier for Ku-band are designed, respectively.

## 1.2 Literature Review

In the recent years, microstrip antennas have quickly developed from a research novelty to a practical reality with applications in a wide range of communication systems that must thank to their numerous appreciated features. They have been playing a key role for small satellite service requirements and have more advantages and better prospects comparing with the conventional satellite antennas such as dishes. Rapid and cost effective fabrication is especially important when it comes to prototyping of antennas for their performance evaluation. These antennas have characteristics like low cost and low profile which are well suited for small satellites application systems [7][8].

Microstrip patch antenna is attractive for their well-known efficient features such as compatibility with microwave circuits like LNAs, lightweight, less fragile, low profile, etc.

A microwave amplifier is one of the RF system that becomes the most important part and extremely advanced, and is placed very close to the antenna in order to amplify very weak RF signals. LNA has been the topic research due to its different performance requirements for different standards. Gain, NF, linearity, and low power consumption are the major specifications in the design of LNA, and the most important paramerter is NF [9]. The NF must be minimized with high-gain, sufficient linearity and establishing the compatibility to other transceiver blocks (i.e. impedance matching).

In order to maximize the RF low-noise amplifier power transfer from source to load, impedance matching is required. In this case, the maximum power transfer will occur when the reactive components of impedances cancel each other, and that is when they are complex conjugates.

Selection of the appropriate transistor is crucial important for the microwave system design and realization in order to design a high-performance RF low-noise component with an accurate matching network.

The stability of the intended amplifier is a very important consideration in a design, and can be determined from S-parameters, the matching networks, and the terminations.

### 1.3 Objectives

This study presents a four elements microstrip array antenna with high-gain wideband low noise amplifier (LNA) using HJ-FET transistor, applicable for Ku-band in small satellite communications.

In the first part, a low nature slotted microstrip antenna with ground plane structure for Ku-band satellite communications is designed. Firstly, a single Ku-band slotted patch antenna designs and then 2×2 array structure models and simulates by using Ansoft HFSS 3D electromagnetic simulation tool. High directivity of antenna has been realized by using full ground plane and via has fed array elements. Array feed circuit places behind of antenna in the third layer. The measured gain of array antenna is about 10.9dBi and according to lower than-10dB reflection, it is usable between 11.9 GHz and 12.9 GHz band frequency. The configuration of the proposed antenna shows the way to fabricate and make it appropriate for Ku-band applications in satellite communications.

In the second part, a typical single-transistor amplifier including input and output matching networks is designed. Substrate used is Rogers material ($\varepsilon r=3$) and thickness of substrate and metal are H=0.762 mm and t=17.5 μm respectively. Many high gain amplifier topologies have been proposed as a way to satisfy the requirement for low power dissipation as well as good performances. The design employs a high-performance very low noise amplifier N-CHANNEL HJ-FET transistor NE3511S02.

After putting slotted rectangular patch array antenna with LNA, the simulated results have been compared with measurements by Istanbul Technical University (ITU) RF labrotary and show good agreements which are reported in the thesis.

# 2. MICROSTRIP ANTENNA

## 2.1 Introduction

An antenna, which is essential component of all communication devices, is a specialized transducer that converts radio-frequency (RF) fields into alternating current (AC) or vice-versa. It can send and receive signals such as microwave, radio or satellite signals often through transmission lines to the receiver or transmitter in all horizontal directions equally, or preferentially in a particular direction[10] .There are two basic types: the receiving antenna, which intercepts RF energy and delivers AC to electronic equipment, and the transmitting antenna, which is fed with AC from electronic equipment and generates an RF field. A transmitting antenna, in general, must be able to handle much more electrical energy than a receiving antenna. An antenna must be tuned to the same frequency band of the radio system to which it is connected, otherwise the reception and the transmission will be impaired. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern [11].

With the advent of communication engineering, the necessity of size reduction and improved bandwidth with the slotted patch radiator are essential to meet the requirement for practical applications. For decades, the microstrip antennas have been intensively used in electronic circuits, communication systems like satellite communication, radar, countermeasure ,etc., due to their low-profile, low-weight, low-cost ,and easy fabrication [12][13].

Nevertheless, do microstrip antennas typically suffer from narrow radiation (a few percent of center frequency), low gain, poor polarization purity, tolerance problem, and limited power capacity, by selecting suitable substrate, changing the antenna shape or size, using a variety of feeding techniques and impedance matching methods, the problems can be solved.

## 2.2 Design

In this section, the antenna model is introduced briefly, and then the simulated results are provided in details. Several performance parameters of this antenna, such as input port reflection coefficient and radiation pattern, are discussed respectively.

Figure 2.1 shows the main design of antenna. It consists of two substrates. The array antenna design is over sub1 and combiner is on sub 2.

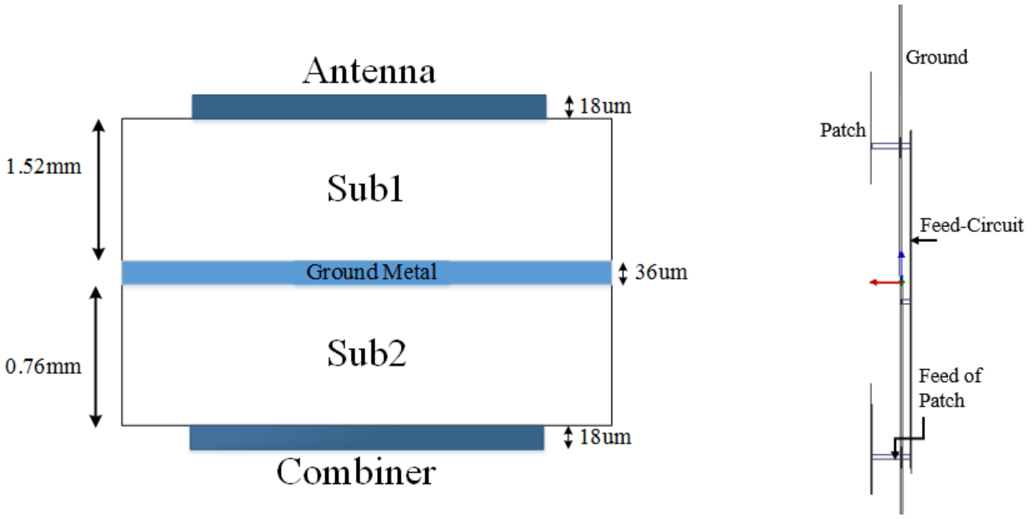


**Figure 2. 1 :** Main design of antenna.

In this work, in order to resolve the weakness of microstrip antennas and increase the bandwidth, three slots are applied in both sides of rectangular elementary patch. By using via feed and ground plane, gain of patch element has been developed [14][15]. After getting suitable gain and bandwidth, highly directive slotted patches are substituted in 2×2 array by using wide band feeding circuit in other side of ground plane. Array structure has been designed over Taconic TSM-30-0600-C1/C2 ($\varepsilon r$=3) with the height of 1.52mm for the design frequency of 13.2 GHz and array feed circuit , over Taconic-TSM substrate with the height of 0.76 mm on the reverse top side layer. This design has been modelled and simulated by using Ansoft HFSS 3D electromagnetic simulation.

Based on the theory of microstrip array antenna, numerical and simulation are realized. An efficient and new compact layered coaxial feed rectangular slotted microstrip patch antenna for Ku-band satellite applications with reduced size is proposed.

### 2.2.1 Single – element antenna design

The design of main patch antenna which is designed at 13.2GHz is shown in Figure 2.2. By using (2.1)-(2.4) equations, the length (Wy), and width (Wx) for unit element antenna are obtained [16].

$$w_x = \frac{1}{2f_{r\sqrt{\mu_{0\varepsilon_0}}}} \times \sqrt{\frac{2}{\varepsilon_{r+1}}} \qquad \textbf{(2.1)}$$

$$w_y = \frac{1}{2f_{r\sqrt{\varepsilon_{eff}\,\varepsilon_{0\mu_0}}}} - 2\Delta L \qquad \textbf{(2.2)}$$

Where

$$\Delta L = 0.41h \frac{\varepsilon_{eff+0.3}}{\varepsilon_{eff-0.258}} \times \frac{\frac{w_x}{h} + 0.264}{\frac{w_x}{h} + 0.8} \qquad \textbf{(2.3)}$$

And

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{w_x}}} \qquad \textbf{(2.4)}$$

Where $f_r$ (in Hz) is the resonant frequency, Wy and Wx are the length and width of the patch element in mm, respectively and $\varepsilon_r$ is the relative dielectric constant.

To increase bandwidth some deflections on the antenna can be done [17] and to find best fitting values for the required antenna, optimization has been done.

The calculated dimensions of the proposed antenna for the preferred substrate is 6.3mm × 5.7mm.

Table 2.1 describes the appropriate size values of slotted patch antenna shown in Figure 2.2.

Simulation results of three slotted antenna for a single antenna such as 3D radiation pattern , radiation pattern for $\phi = 90^0$ degree plane,and input reflection coefficient which are done in HFSS, are shown in Figures 2.3, 2.4 ,and 2.5 respectively.

The results show that this small-sized antenna has a wideband frequency and high gain in required range frequency which is suitable for small satellites.

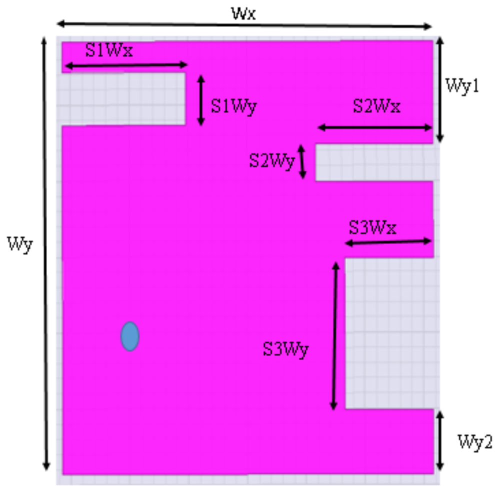


**Figure 2. 2 :** Novel shape of  single slotted patch antenna for Ku-band systems.

**Table 2. 1 :** Dimensions of the designed antenna.

| Symbol | Value(mm) | Symbol | Value(mm) |
|---|---|---|---|
| Wx | 6.3 | S1Wy | 0.7 |
| Wy | 5.7 | S2Wx | 2 |
| Wy1 | 1.35 | S2Wy | 0.5 |
| Wy2 | 0.85 | S3Wx | 1.5 |
| S1Wx | 2.1 | S3Wy | 2 |

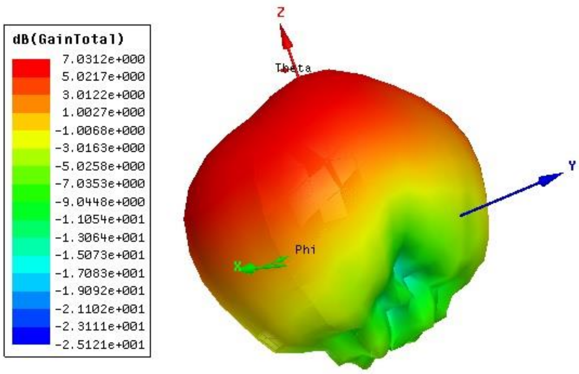


**Figure 2. 3 :** 3D radiation pattern of single slotted patch antenna at 12.3GHz.

According to the Figure 2.2 , the maximum gain of the single patch is 7dBi and 10dB back lobe ratio has been achieved. Furthermore, it can be mentioned that slotted patch antenna acts as linear polarization and more than %10 frequency bandwidth is calculated for the listed values in Table 2.1.

Figure 2.4 shows that the antenna has linear polarization and it is appropriate for satellite applications.Figure 2.5 shows that the range frequency for antenna is about 1500 MHz which is wideband.

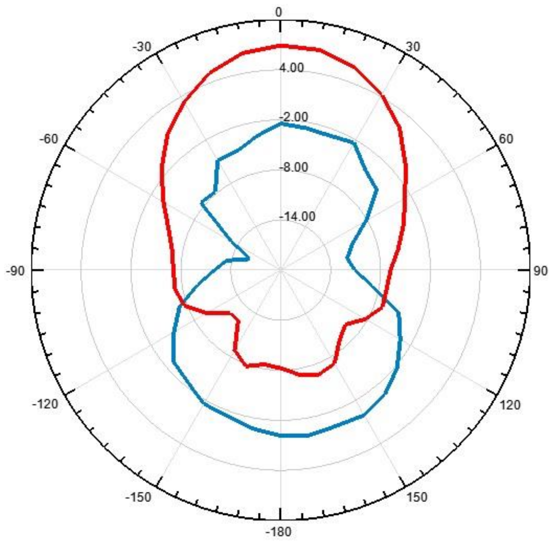


**Figure 2. 4 :** Radiation pattern of single slotted patch antenna at 12.3 GHz for $\phi = 90^0$ degree plane (Red line is Gain Phi and blue line is Gain Theta).

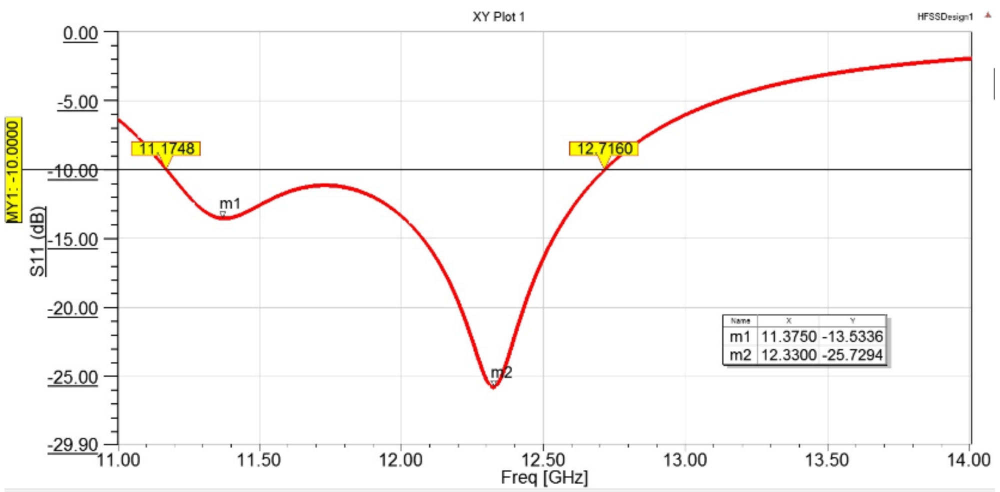


**Figure 2. 5 :** Input reflection coefficient of single slotted patch antenna versus frequency ($S_{11}$ in dB).

### 2.2.2 2×2 array structure

2×2 array antenna structure is preferred to increase gain and to keep area small that antenna size should be smaller as possible in order not to decrease total area of the solar panels that surface of the small satellites are covered by them. Optimized array structure which is 2×2 uniformly plane array is shown in Figure 2.6 by considering the requirements of direct broadcast satellite to antenna gain. The feed of each antenna element has constant amplitude and the same phase [18][19][20]. Table 2.2 describes the appropriate values for the array design. By simulation in HFSS software, 3D radiation pattern, radiation pattern of 90 degree and input reflection coefficient in dB are obtained in Figures 2.7, 2.8, and 2.9 orderly.

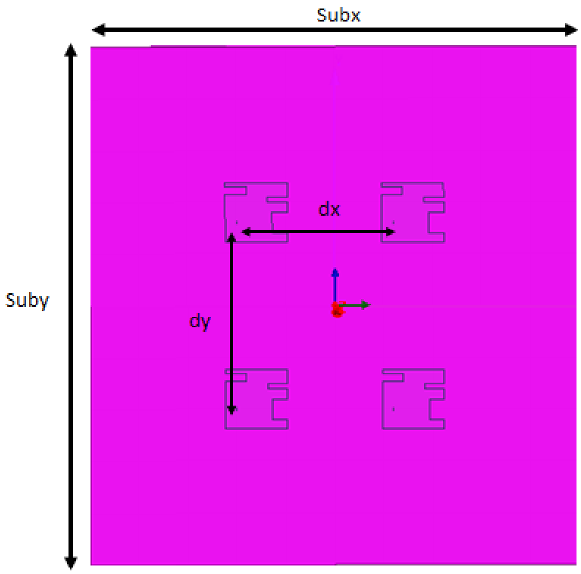


**Figure 2. 6 :** Top perspective view of 2×2 array antenna.

**Table 2. 2 :** Dimensions of array antenna.

| Symbol | Value(mm) |
|---|---|
| Subx | 50 |
| Suby | 50 |
| dx | 16 |
| dy | 18 |

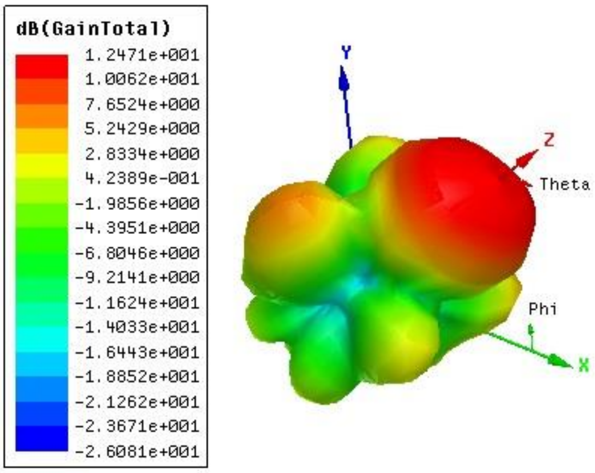


**Figure 2. 7 :** 3D radiation pattern of 2×2 Array antenna at 12.3 GHz.

Figure 2.8 shows that like single antenna which has been introduced previously, array antenna has linear polarization. And figure 2.9 shows that the range frequency is about 900 MHz.

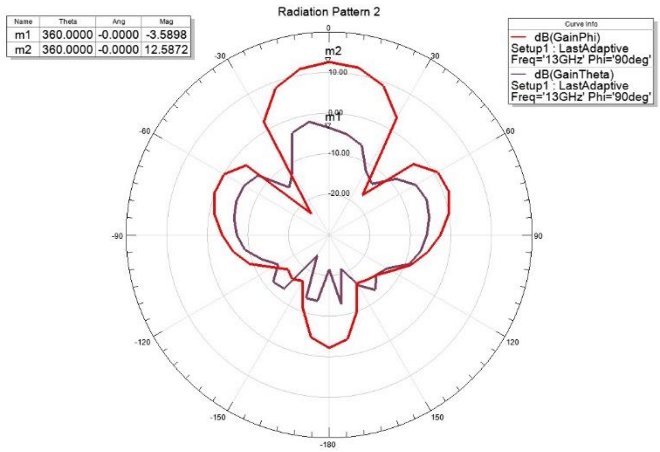


**Figure 2. 8 :** Radiation pattern of 2×2 array antenna for $\phi = 90^{o}$ degree plane.

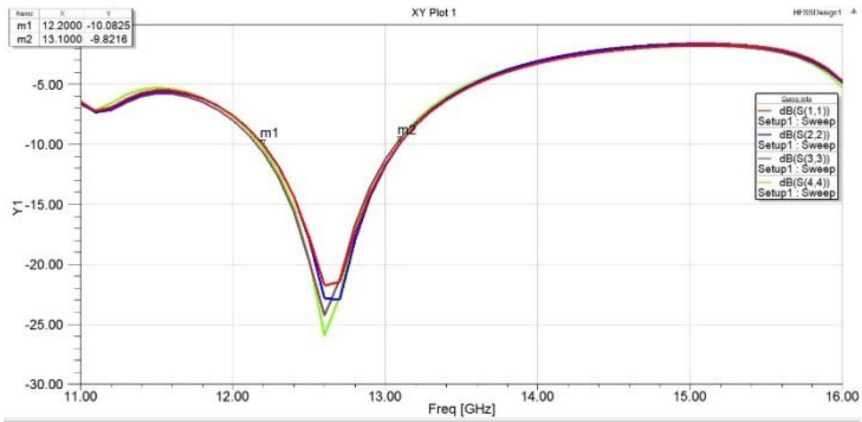


**Figure 2. 9 :** Input reflection coefficient of 2×2 array antenna versus frequency ($S_{11}$,$S_{22}$ ,$S_{33}$ ,$S_{44}$ in dB).

### 2.2.3 Array feed circuit

In Figure 2.10, the configuration of the feeding circuit is shown. Two Vertical antennas combine to two 100Ω T-junctions by using narrow width transmission line (fw1=1.6mm) and the antennas' via feed impedance matches to 50Ω microstrip line with fw2=0.6mm over Taconic-TSM substrate with the height of 0.76mm on the reverse top side layer.

For choosing appropriate feeding circuit, some techniques have been tested and at last this feeding circuit is chosen in order to get the best results.

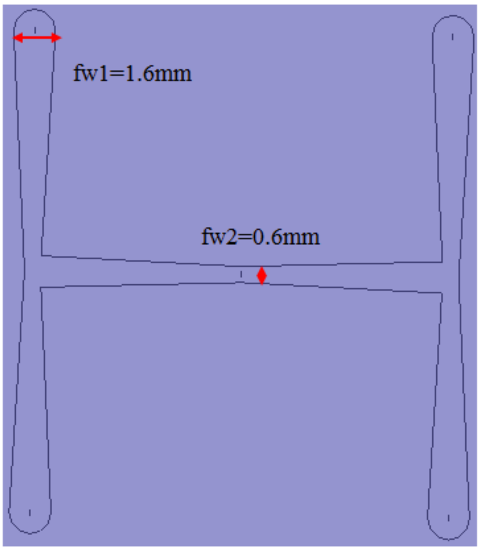


**Figure 2. 10 :** Feed circuit of 2x2 array antenna.

The performance of the array antenna is summarized in Table 2.3.

**Table 2. 3 :** Performance of the array antenna.

| Parameter | Value |
|---|---|
| Gain | 12.4 dBi |
| -10dB BW | 900 MHz |
| $S_{11}$ | < -10 dB |

Table 2.4 and 2.5 compare the simulated performances of this work with other reported designs. Having high gain in wide band frequency with total reduced size of array antenna are significant characteristics of the designed array antenna.

**Table 2. 4 :** Comparison of single antenna with other reported designs.

| Ref. | Frequency [GHz] | Bandwidth [MHz] | Gain [dBi] | Dimension [mm$^2$] |
|---|---|---|---|---|
| [17] | 15.63-15.7 | 70 | 6.3 | 5 × 5.7 |
| [19] | 14.13-14.65 | 520 | 7.771 | 7.6 × 10 |
| This work | 11.2-12.7 | 1500 | 7 | 6.3 × 5.7 |

**Table 2. 5 :** Comparison of array patch antenna with other reported designs.

| Ref. | Frequency [GHz] | Bandwidth [MHz] | Gain [dBi] | Dimension [mm$^2$] |
|---|---|---|---|---|
| [27] | 15.5-16.5 | 100 | 13.62 | 50.14×10.48 |
| [28] | 15.5-16.5 | 100 | 7.771 | 19.4 × 32.2 |
| This work | 12.2-13.1 | 900 | 12.4 | 25 × 25 |

## 3. LOW NOISE AMPLIFIER (LNA)

### 3.1 Introduction

Practically, when designing an amplifier, the input and output matching networks are consider to obtain the required stability, gain, and bandwidth. In this section, a design methodology of LNA for Ku-band has been described. Figure 3.1, shows a typical single-stage amplifier including input and output matching networks[21].

The basic concept of high frequency amplifier design is to match input and output of a transistor at high frequencies using S-parameters frequency characteristics with source impedance and load impedance. Input and output matching circuit is essential to reduce the unwanted reflection of signal and to improve efficiency of the transmission from source to load.

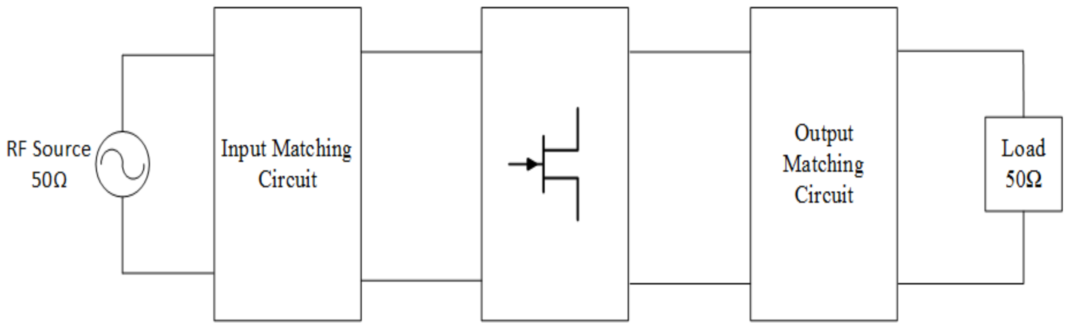


**Figure 3. 1 :** Typical amplifier design.

Friis's formula is used to calculate the total noise factor of cascade stages, each with its own noise factor and gain (assuming that the impedances are matched at each stage)[22]. The total noise factor can then be used to calculate the total noise figure. Basic RF block is shown in Figure 3.2 and the total noise factor is given as definition (3.1). An important consequence of this formula is that the overall noise figure of a radio receiver is primarily established by the noise figure of its first amplifying stage. Subsequent stages have a diminishing effect on signal-to-noise ratio. For this reason, the first stage amplifier in a receiver is often called the low-noise amplifier (LNA).

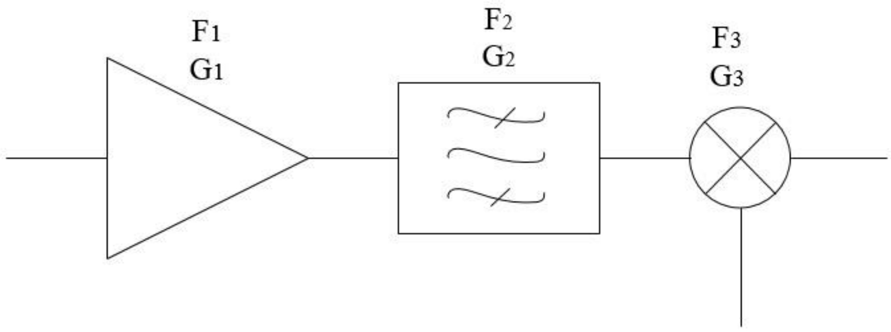


**Figure 3. 2 :** Basic RF block.

In equation (3.1), F and G show noise figure and gain respectively.

$$\mathrm{F_{total}} = \mathrm{F_1} + \frac{\mathrm{F_2} - 1}{\mathrm{G_1}} + \frac{\mathrm{F_3} - 1}{\mathrm{G_1 G_2}} + \frac{\mathrm{F_4} - 1}{\mathrm{G_1 G_2 G_3}} + \cdots + \frac{\mathrm{F_n} - 1}{\mathrm{G_1 G_{2\ldots} G_{n-1}}} \qquad \textbf{(3.1)}$$

### 3.2 Choice of transistor

A first step for the choice of transistor is to define the amplifier topology that best suits the design requirements. Parameters S, MAG (Maximum Available Gain) and Rollet factor (k) ,which are found in the device data sheet, allow a first feasibility analysis of the design with a specific transistor. For the case of study, the chosen is the NE3511S02 and some characteristics under $T_A = +25^{\circ}$ are as Table 3.1.

**Table 3. 1 :** Specifications of the Transistor ($\mathbf{V_{DS} = 2v}$ and f= 12 GHz).

| Symbol | Test Conditions | MIN. | TYP. | MAX. |
|---|---|---|---|---|
| $\mathrm{I_{DSS}}$(mA) | $\mathrm{V_{GS} = 0v}$ | 20 | 40 | 70 |
| NF(dB) | $\mathrm{I_D = 10mA}$ | - | 0.30 | 0.45 |
| $\mathrm{G_a}$(dB) | $\mathrm{I_D = 10mA}$ | 12.5 | 13.5 | - |

Minimum noise figure and associated gain of transistor versus frequency in 12 GHz to 14 GHz by simulation in AWR, are shown in Figures 3.3 and 3.4 respectively.

These results show that the transistor has a high gain and low noise in required band frequency. And it will be suitable for combining with array antenna.

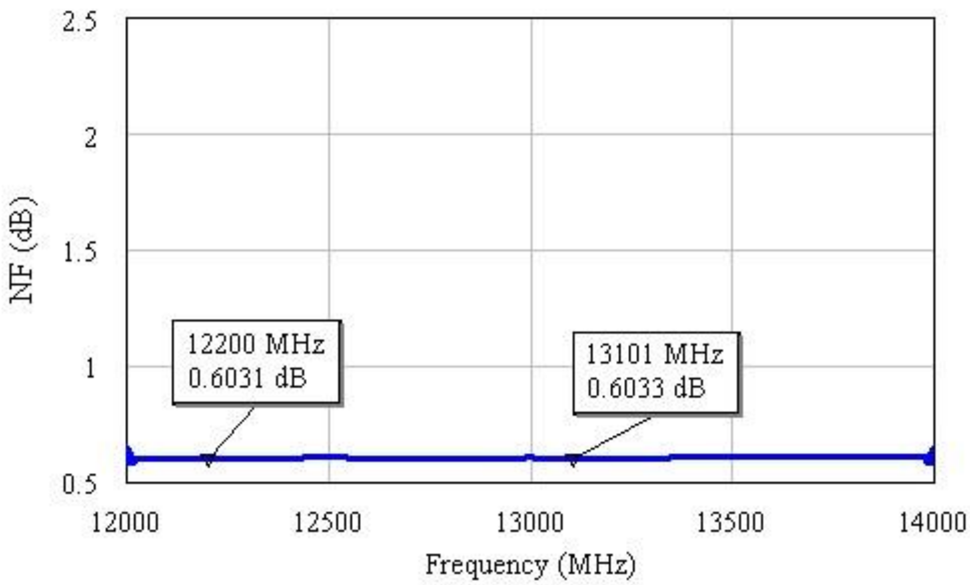


**Figure 3. 3 :** Minimum noise figure of transistor.

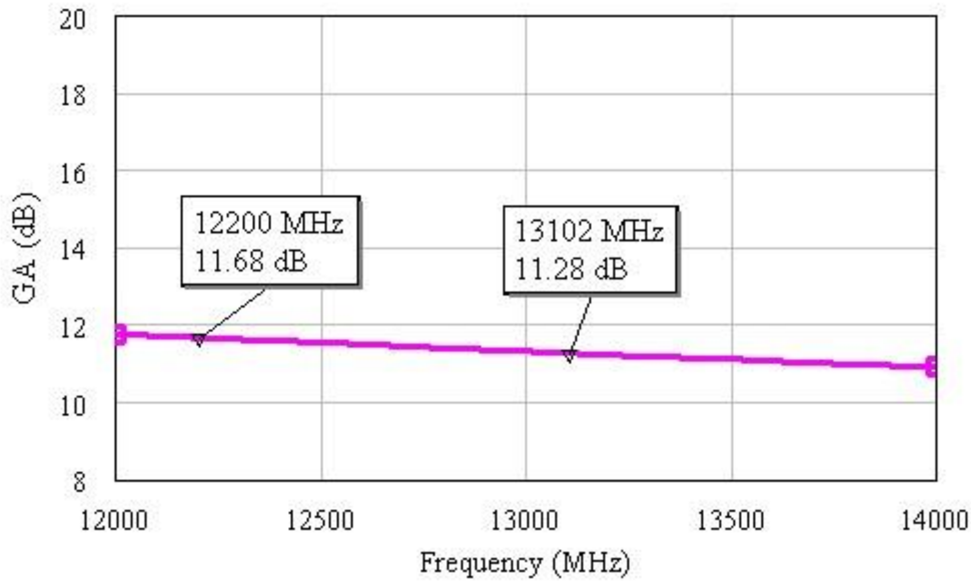


**Figure 3. 4 :** Associated gain of transistor.

### 3.3 Design

To accurately realize the Ku-band microwave LNA, the design and simulation procedures have been thoroughly conducted. Microstrip transmission lines were used to get a more accurate simulation of the performance of the amplifier design. Then, by inserting substrate properties to the TXLine Calc. in AWR the widths and lengths of the microstrip lines can be obtained.

A test bench created in AWR is shown in Figure 3.5.

The biasing circuit provides the desired voltage level for the intended RF performance, based on a low DC resistance in order to ensure that the microwave circuit is not loaded, and signals do not flow onto the supply lines; based on using a radial stub after λ/4 high impedance biasing line, which helps to achieve the proper isolation at the desired frequency.

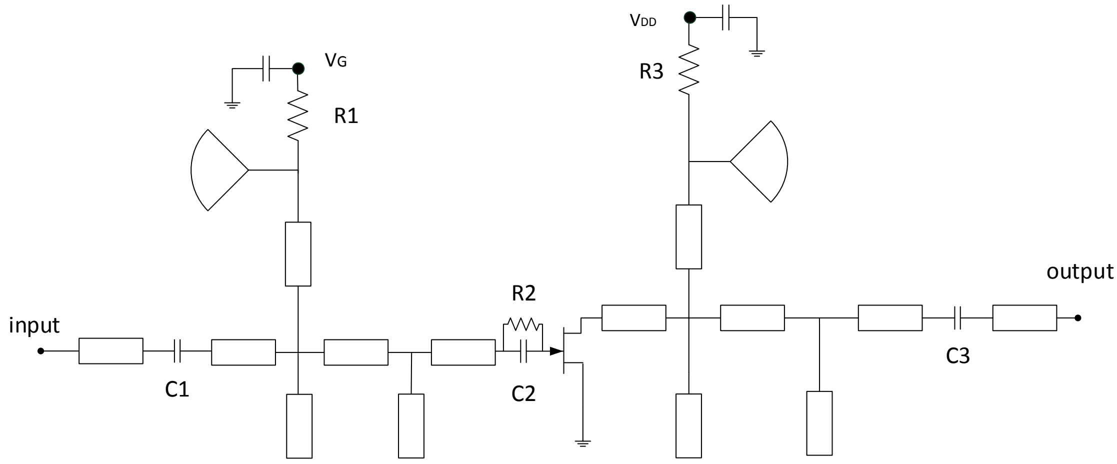


**Figure 3. 5 :** Structure of designed LNA.

The basic formula for transducer power gain and stability are as equations (3.2) and (3.3) respectively [22]. C1 and C3 are DC blocking capacitors (1pF). R2 (2kΩ) and C2 (0.2pF) are used to decrease lower frequency gain and increase stability. R1 and R3 are 10Ω and 470Ω respectively.

$$G_T = \frac{P_L}{P_{avs}} = \frac{|S_{21}|^2 (1-|\Gamma_s|^2)(1-|\Gamma_L|^2)}{|1-\Gamma_s\ \Gamma_{in}|^2\ |1-S_{22}\Gamma_L|^2} \quad \textbf{(3.2)}$$

When both the input and output are matched for zero reflection (in contrast to conjugate matching), then $\Gamma_L = \Gamma_s = 0$ and $G_T = |S_{21}|^2$.

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+\Delta^2}{2|S_{12}||S_{21}|} > 1$$

$$|\Delta| = |S_{11}\ S_{22} - S_{12}S_{21}| < 1 \quad \textbf{(3.3)}$$

Practically, Figure 3.6 is designed in AWR.

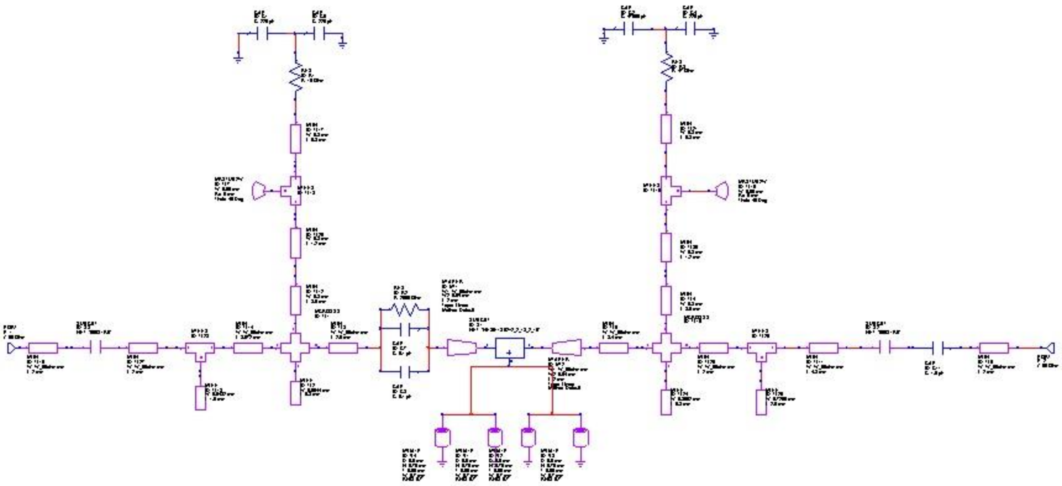

**Figure 3. 6 :** Detailed structure of LNA.

The exact places of input matching, output matching, biasing circuit, radial stub, and transistor are shown in Figure 3.7 which is the layout of LNA.

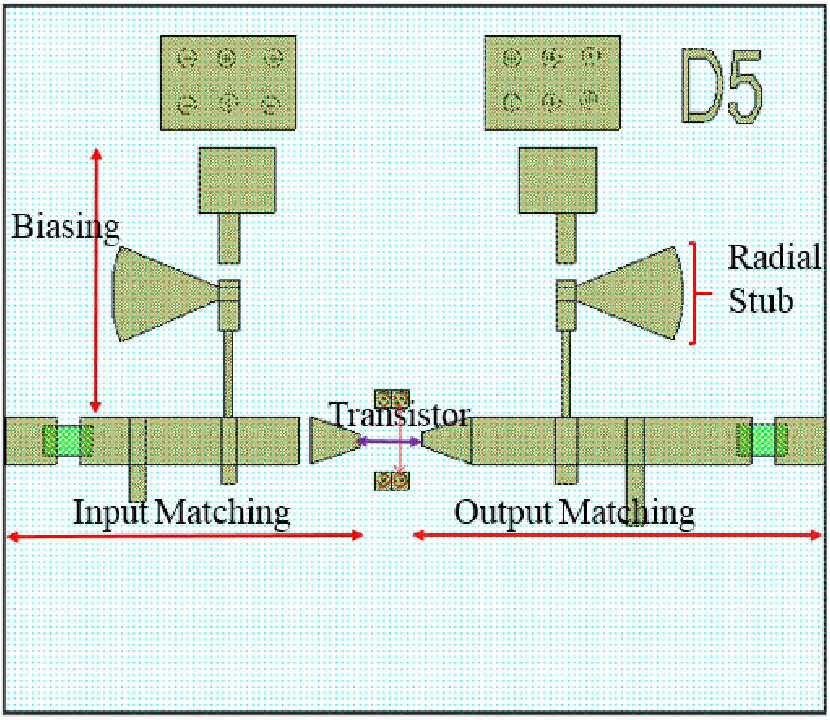


**Figure 3. 7 :** Layout of LNA.

By using Figure 3.8, different values including lenghts and widths of microstrip lines ,and also total dimension of LNA are shown in Tables 3.2 , 3.3 and 3.4 respectively.

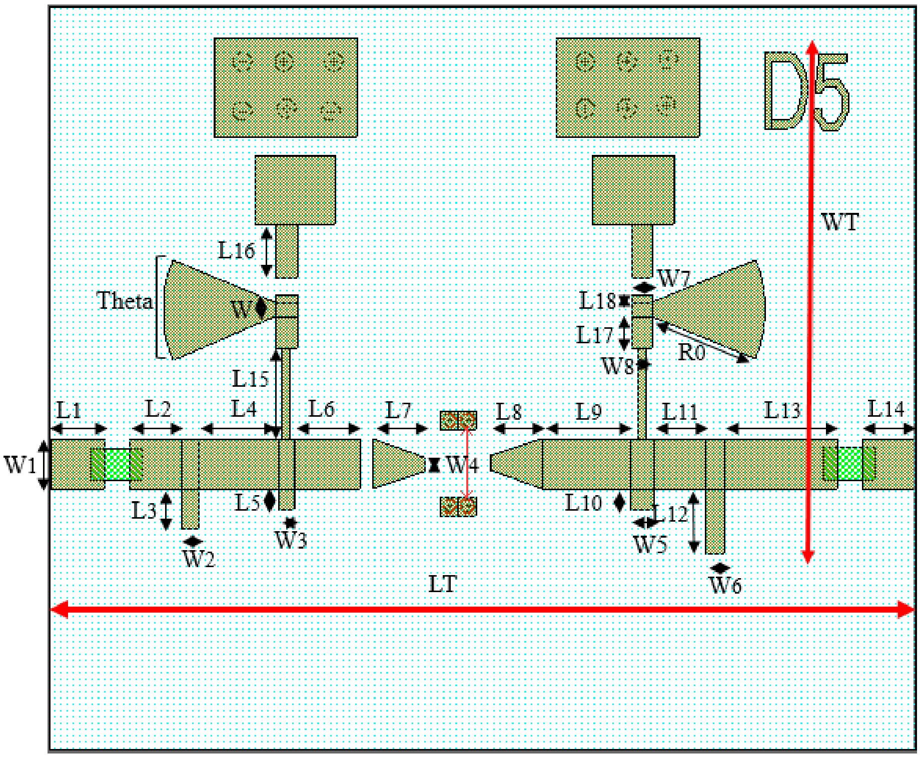


**Figure 3. 8 :** Layout of LNA indicating the dimensions.

**Table 3. 2 :** Lenght values of transmission lines.

| Lenght | Value(mm) | Lenght | Value(mm) |
|---|---|---|---|
| $L_1$ | 2 | $L_{10}$ | 0.8 |
| $L_2$ | 2 | $L_{11}$ | 2 |
| $L_3$ | 1.5 | $L_{12}$ | 2.5 |
| $L_4$ | 3.072 | $L_{13}$ | 4.3 |
| $L_5$ | 0.8 | $L_{14}$ | 2 |
| $L_6$ | 2.5 | $L_{15}$ | 3.5 |
| $L_7$ | 2 | $L_{16}$ | 2 |
| $L_8$ | 2 | $L_{17}$ | 1.2 |
| $L_9$ | 3.4 | $L_{18}$ | 0.3 |

**Table 3. 3 :** Width values of transmission lines.

| Width | Value(mm) |
|---|---|
| $W_1$ | 1.93 |
| $W_2$ | 0.65 |
| $W_3$ | 0.65 |
| $W_4$ | 0.54 |
| $W_5$ | 0.8 |
| $W_6$ | 0.72 |
| $W_7$ | 0.8 |
| $W_8$ | 0.3 |

**Table 3. 4 :** Dimension of LNA.

| Symbol | Value(mm) |
|---|---|
| LT | 33 |
| WT | 20 |

As it is seen from Figure 3.7 , radial stubs are used in order to have wider bandwidth capacitance.

Figure 3.9, shows the main design of microstrip radial stub (MRSTUB) [29]. Different values of radial stub's parameters in the LNA design are shown in Table 3.5.

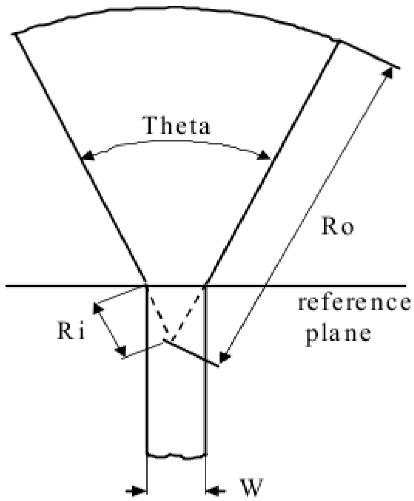


**Figure 3. 9 :** Main design of radial stub.

**Table 3. 5 :** Different values of radial stub.

| Parameter | Value |
|---|---|
| $R_0$ | 5 mm |
| W | 0.55 mm |
| Theta | 45 Deg |

The gain performance, satbility, noise figure, input refelection, and output reflection of LNA in 12.0-13.5GHz range frequency are shown in Figures 3.10, 3.11, 3.12, 3.13,and 3.14 respectively.

The results show that the whole design has high gain and low noise and it is working in the required band as the same as array antenna.

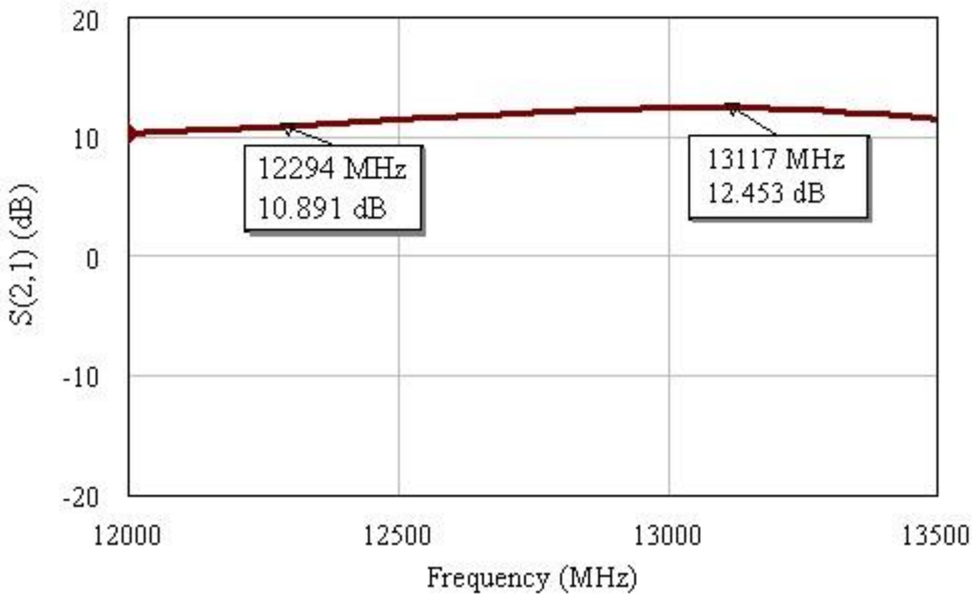


**Figure 3. 10 :** Gain of LNA.

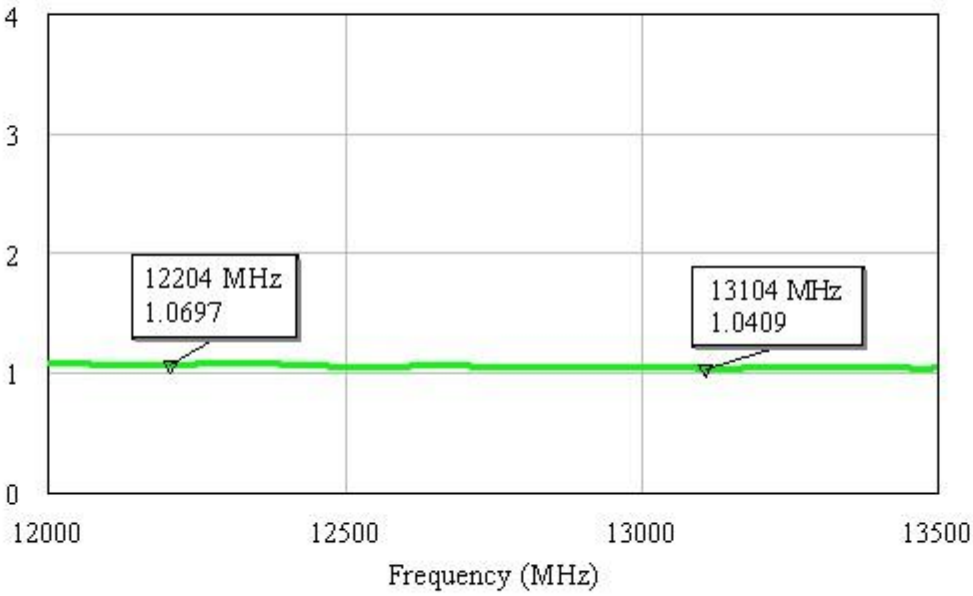


**Figure 3. 11 :** Stability of LNA.

S-parameters have earned a prominent position in RF circuit design, analysis, and measurement. As it is shown in figure 3.10, $S_{21}$ is the forward and return gain (or loss) when the network is terminated with the reference impedance.

While designing any amplifier, it is important to check the stability of the device chosen, or the amplifier may function as an oscillator. Figure 3.11 shows that the designed LNA has a good stability in the range frequency between 12-13.5 GHz beacuse with regard to Rollet's Stability factor , K>1.

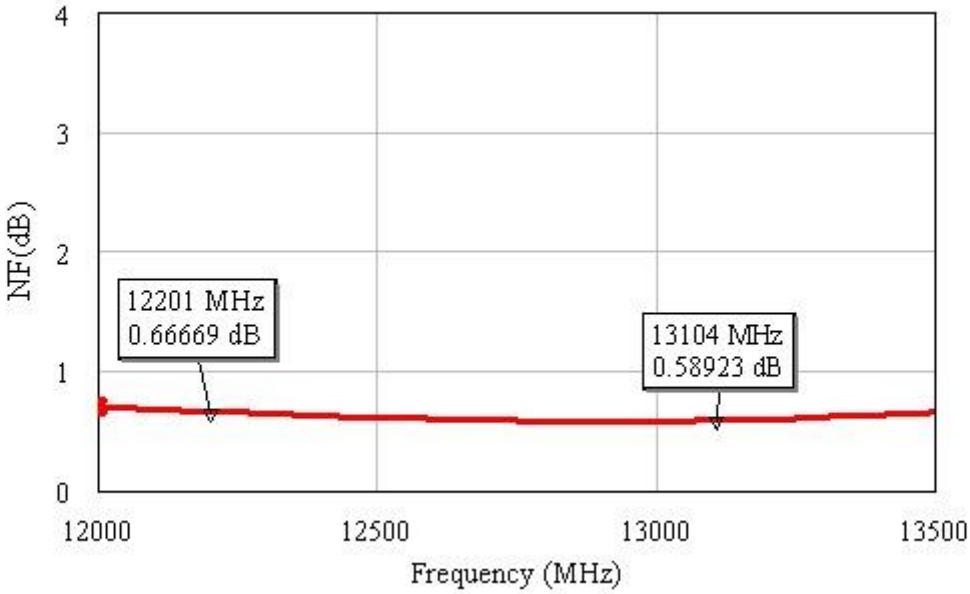


**Figure 3. 12 :** Noise of LNA.

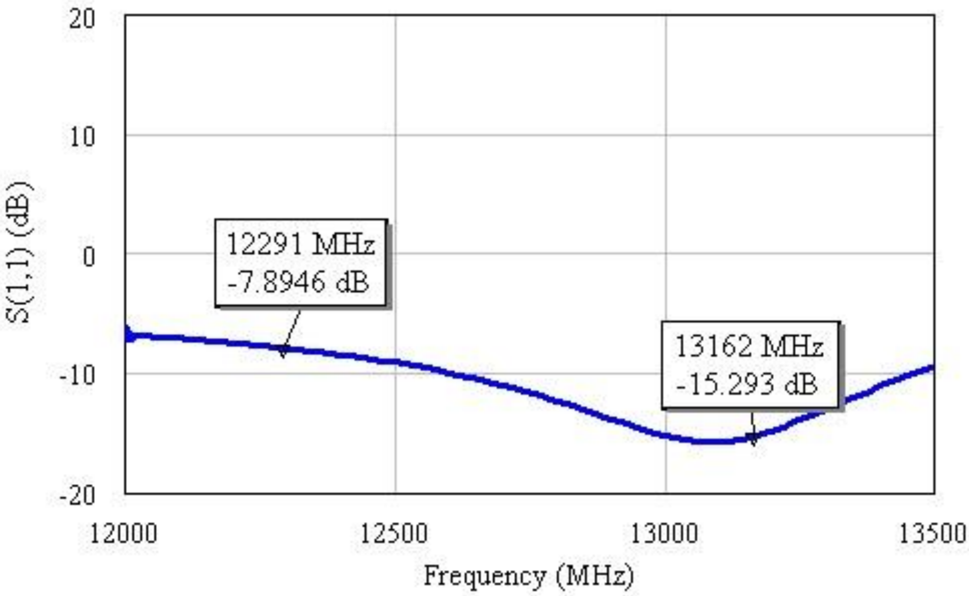


**Figure 3. 13 :** Input refelection of LNA.

Figure 3.12 shows that the noise of whole design is about 0.6 dB which is low and best.

Figure 3.13 shows the simulation result of S11 which is input reflection coefficient of LNA in 12-13.5 GHz range frequency.

This results show that when we realize the LNA it will work suitably and we will obtain the required specifications.

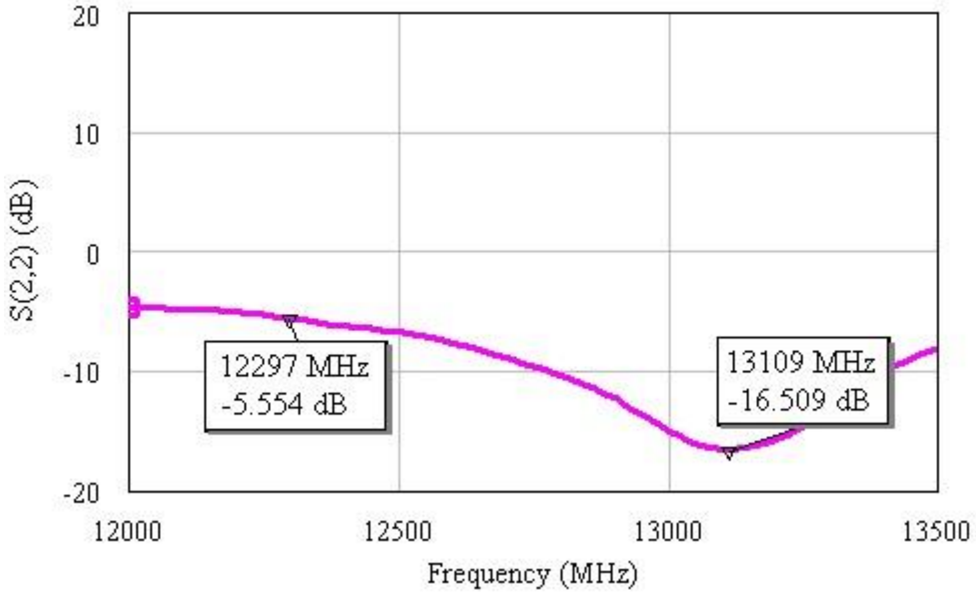


**Figure 3. 14 :** Output reflection of LNA.

Simulation results of noise figure, stability, and S parameters such as S11, S22, and S21 are shown in Figures 3.15, 3.16, and 3.17 between 1GHz to 20GHz band frequency as wideband simulation results.

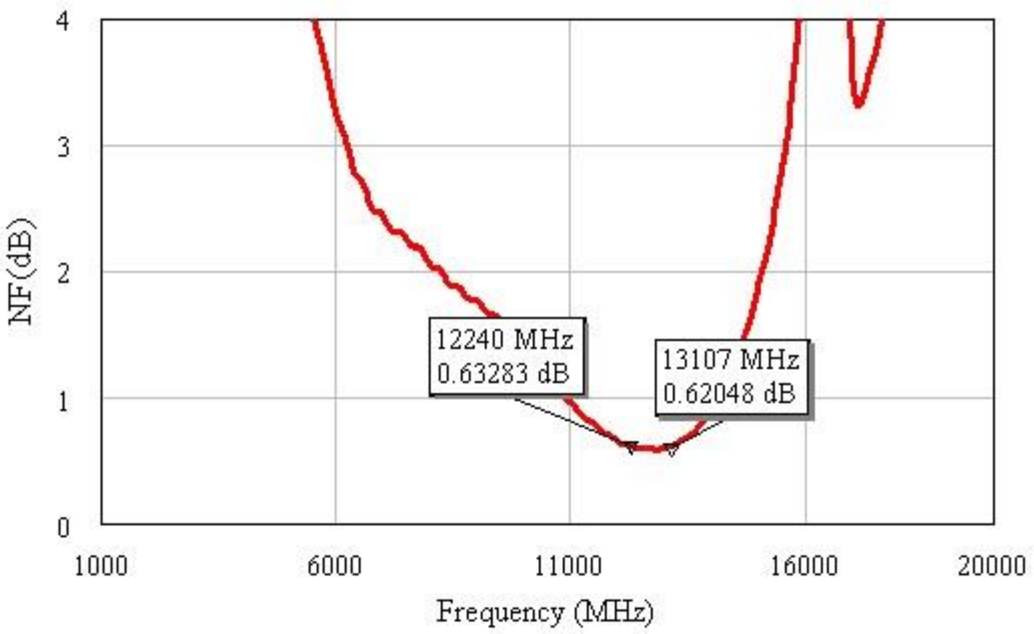


**Figure 3. 15 :** Wideband noise figure of LNA.

In order to be certain that the LNA will not oscillate in wide range frequency and the we will get the required results when we make the LNA practical , wide range simulation is done.

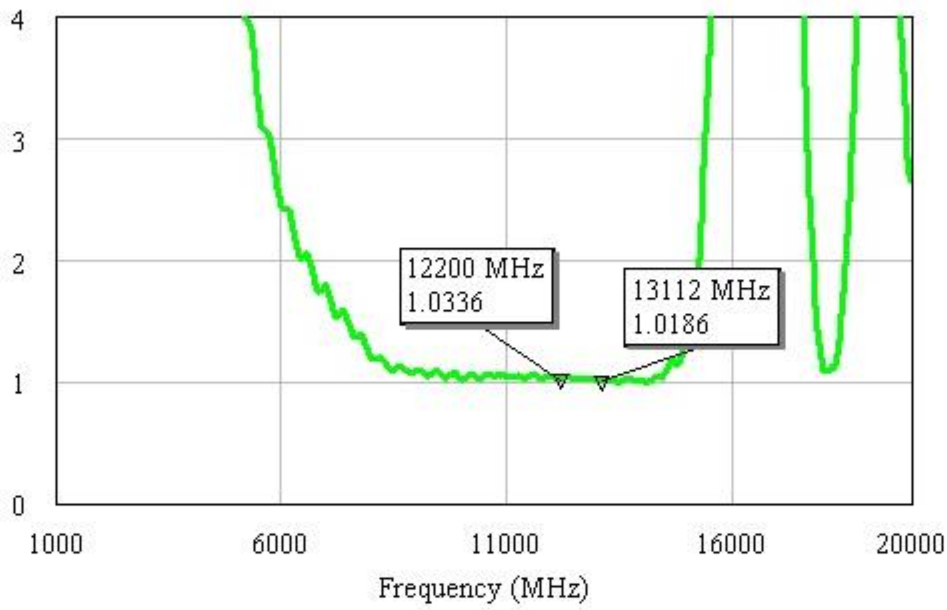


**Figure 3. 16 :** Wideband stability of LNA.

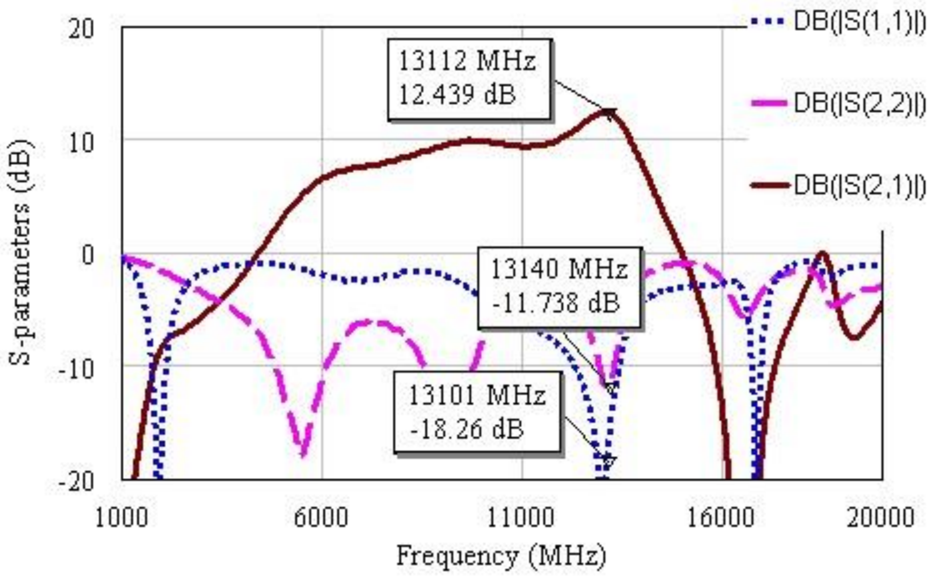


**Figure 3. 17 :** Wideband S-paramerts of LNA.

The performance of the LNA design is summarized in Table 3.6 for 20 mW power consumption.

**Table 3. 6 :** Parameters of the designed LNA.

| Parameter | Specifications |
|---|---|
| S11 | < -8 dB |
| S22 | < - 6 dB |
| Gain | 11-12.5 dB |
| Noise | > 0.6 dB |

Table 3.7 compares the simulated performances of this work with other reported designs. Having low noise and also high gain in one stage LNA are the most remarkable specifications of the designed LNA in this work.

**Table 3. 7 :** Comparison with other reported designs.

| Ref. | Number of satges | $f_0$ [GHz] | Vds/Ids [V]/[mA] | Gain [dB] | NF [dB] |
|---|---|---|---|---|---|
| [24] | 2 | 16 | 1.5/ 10 | 20.57 | 1.9 |
| [25] | 2 | 24.125 | 2/ 10 | 15.37 | 1.78 |
| This work | 1 | 12.65 | 2/ 10 | 12.5 | 0.6 |

Some commercial products of TriQuint in the range frequency similar to the designed LNA in this thesis, are shown in Table 3.8.

**Table 3. 8 :** Commercial products of TriQuint.

| Product | Frequency [GHz] | NF [dB] | Gain [dB] | Voltage [v] | Current [mA] |
|---|---|---|---|---|---|
| TGA2227 | 2 to 22 | 2 | 15 | 8 | 125 |
| TGA2511 | 6 to 14 | 1.3 | 20 | 5 | 160 |
| TGA2512 | 5 to 15 | 1.4 | 27 | 5 | 160 |
| TGA2513 | 2 to 23 | 2 | 17 | 5 | 75 |
| TGA2525 | 2 to 18 | 2 | 17 | 5 | 75 |
| TGA2526 | 2 to 20 | 2 | 17 | 5 | 75 |

## 4. MEASUREMENTS

In this section, fabricated antenna and LNA circuit is presented. Printed circuit boards for the antenna were prepared with milling method. LNA board is manufactured with laser prototyping because of soft substrate structure.

### 4.1 Antenna

Figure 4.1 shows the array patch antenna (top view) over Taconic TSM-30-0600-C1/C2 ($\varepsilon r=3$) with the height of 1.52mm and Figure 4.2 shows array feed circuit , over Taconic-TSM substrate with the height of 0.76 mm on the reverse top side layer. The total area of array antenna is 50 mm × 50 mm.

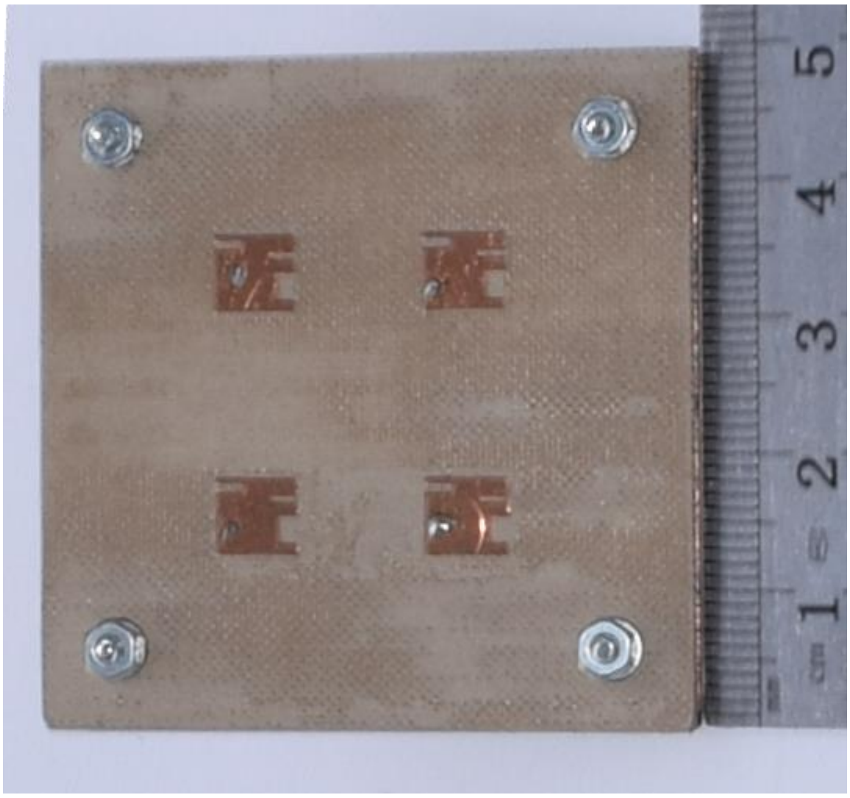

**Figure 4. 1 :** Top view of antenna.

As it is shown in Figure 4.1, four single antennas are placed in array.

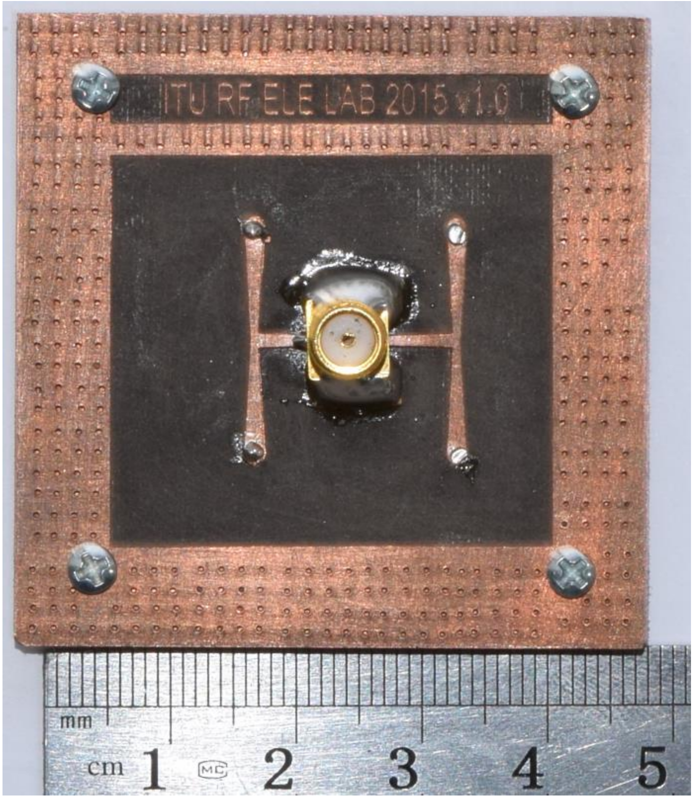


**Figure 4. 2 :** Array feed circuit with SMA(F) connector.

After using SMA connector, main antenna design (Figure 2.1) is fabricated as Figure 4.3.

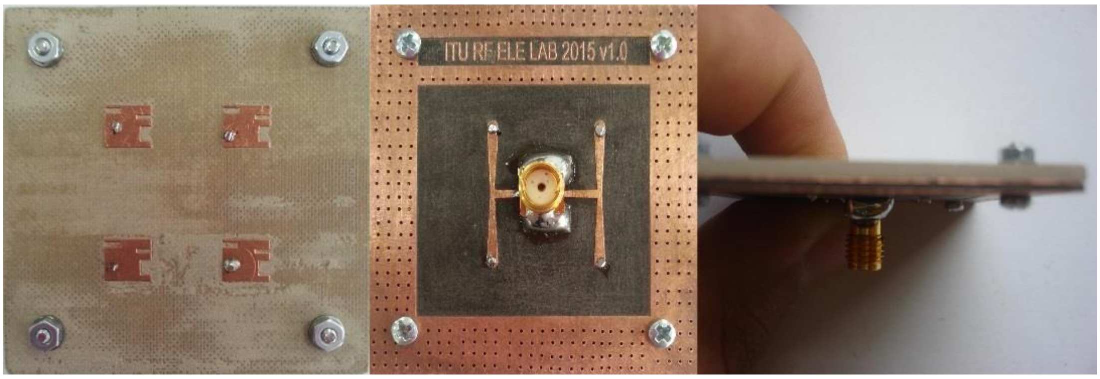


**Figure 4. 3 :** Main fabricated array antenna (top, bottom and side view).

Input reflection coefficient ($S_{11}$) and gain of array patch antenna have been measured by Agilent N5245A PNA-X Microwave Network Analyzer. Measured peak gain between 11.9-12.9 GHz is 10.9dBi.

Figure 4.4, shows the simulation and measurment results of input reflection coefficient of array antenna.

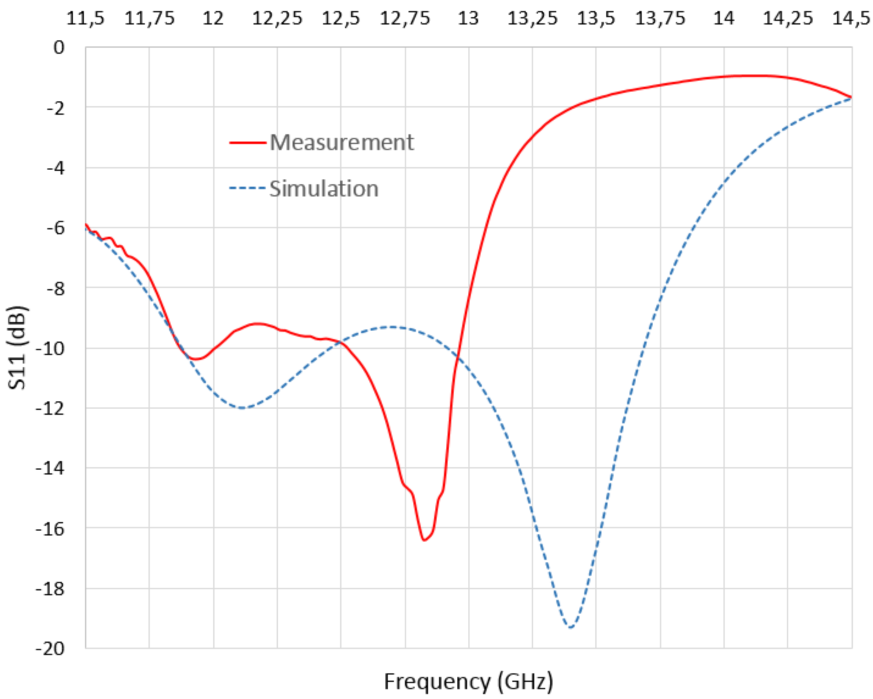


**Figure 4. 4 :** Simulation and measurement results of input reflection coefficient of array antenna.

### 4.2 LNA

Figure 4.5 shows the fabrication of Figure 3.7. Substrate used is Rogers material ($\varepsilon_r$=3) and thickness of substrate and metal are H=0.762 mm and t=17.5 µm respectively.

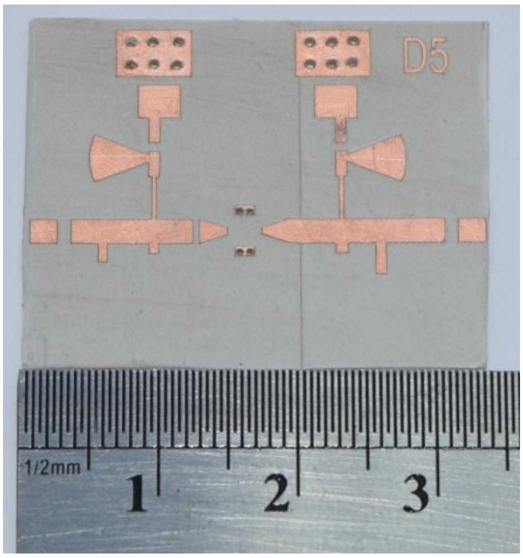


**Figure 4. 5:** Main fabricated LNA.

After soldering a transistor, capacitors and resistors , the suitable fabricated LNA for measuring is ready. Figure 4.6 shows the exact fabrication of Figure 3.6.

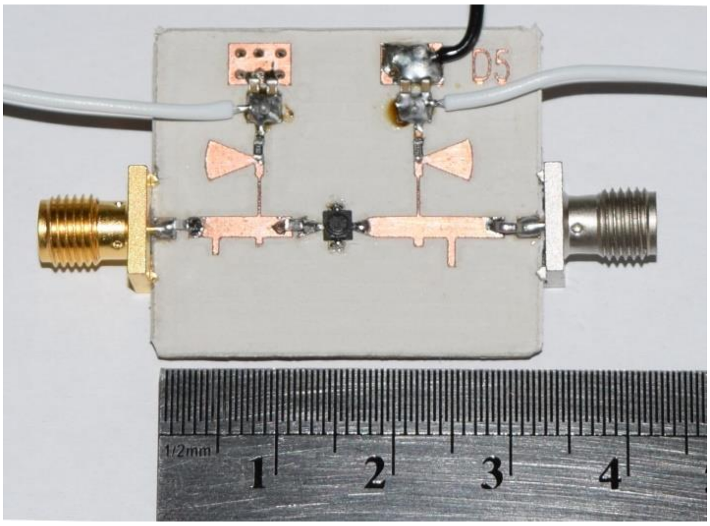


**Figure 4. 6 :**Total fabricated LNA after soldering elements.

Gain and noise figure of LNA have been measured by R&S FSUP, Signal Source Analyzer (Figure 4.7). S parameters of the LNA are measured by Agilent N5245A PNA-X Microwave Network Analyzer. Figures 4.8 and 4.9 , show the realted results of fabricated LNA.

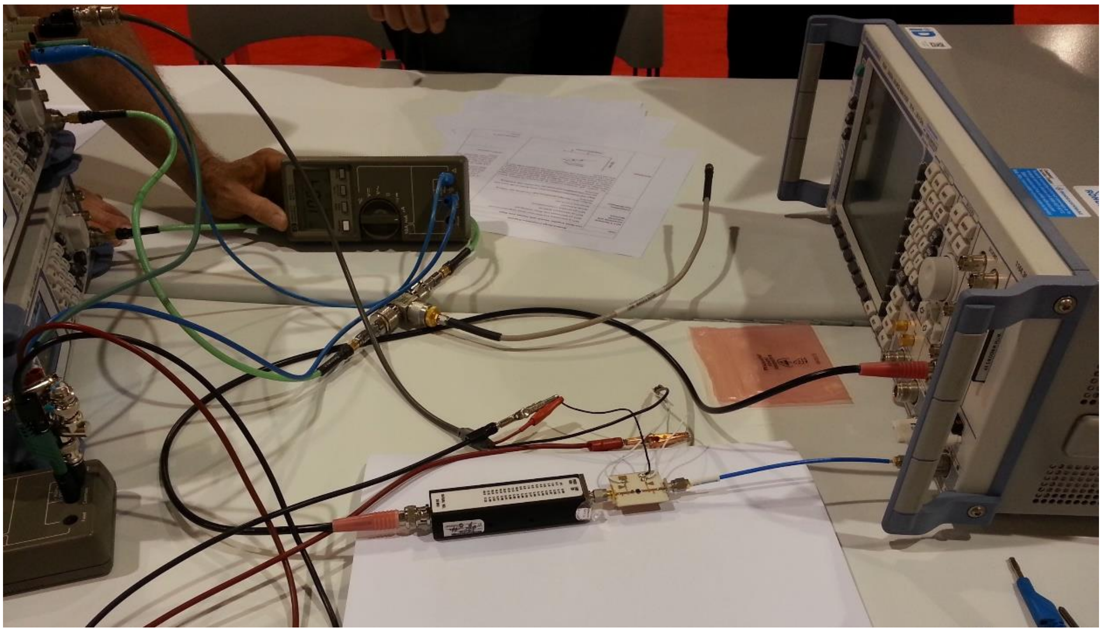

**Figure 4. 6:** Measurement setup for the gain and NF of LNA.

Measurment results such as gain and NF are shown in Figures 4.7 and 4.8 respectively for LNA, which are showing good agreements to simulated results in AWR.

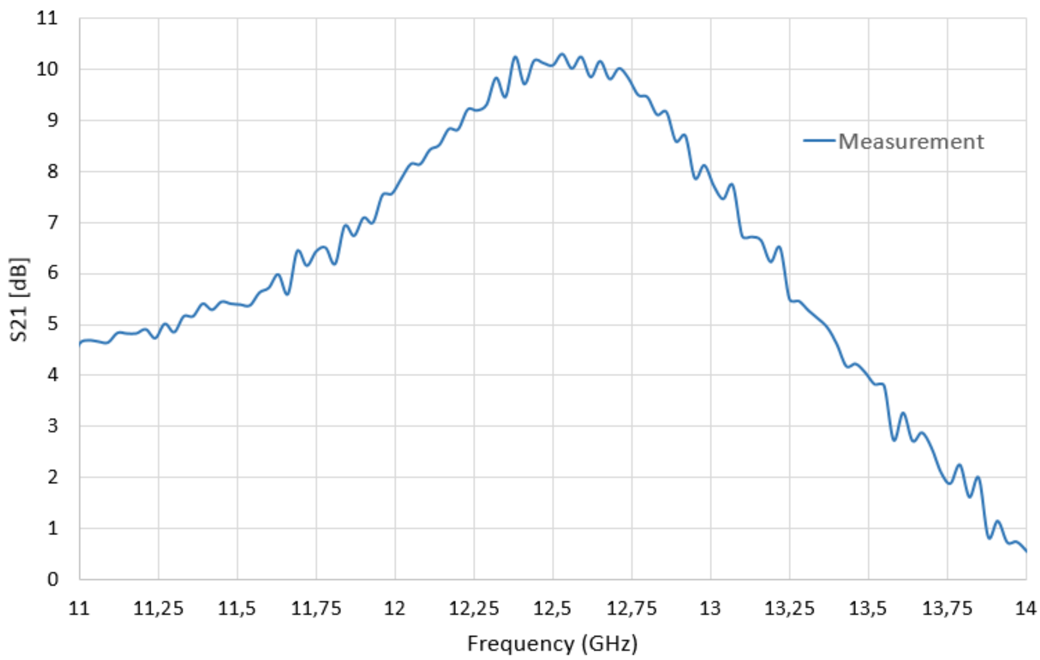


**Figure 4. 7:** Measured gain of LNA.

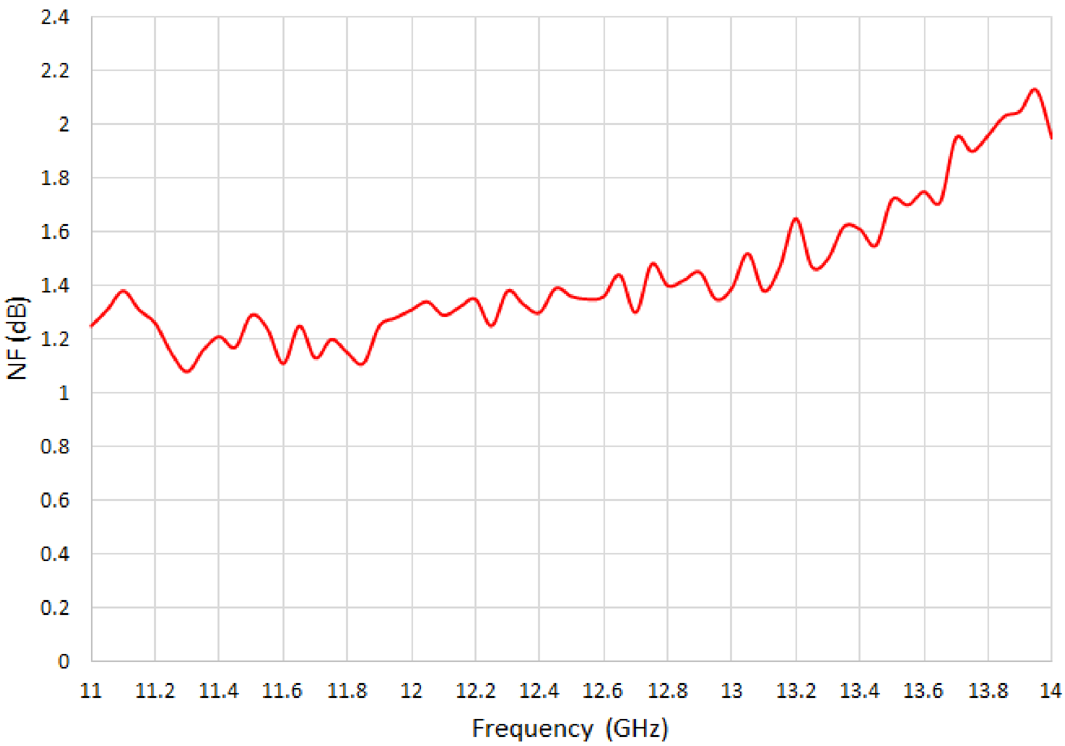


**Figure 4. 8 :** Measured NF of LNA.

Figures 4.9 and 4.10 are showing measurment results of input reflection coefficient and output reflection coefficient of LNA which are two important specifications of low noise amplifiers.

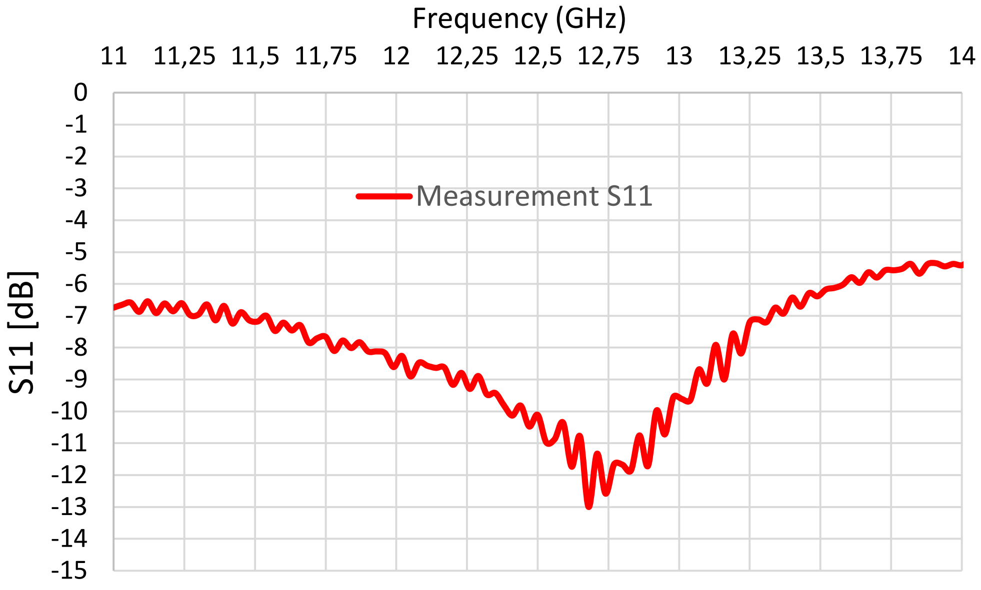


**Figure 4. 9 :** Measured S11 of the LNA.

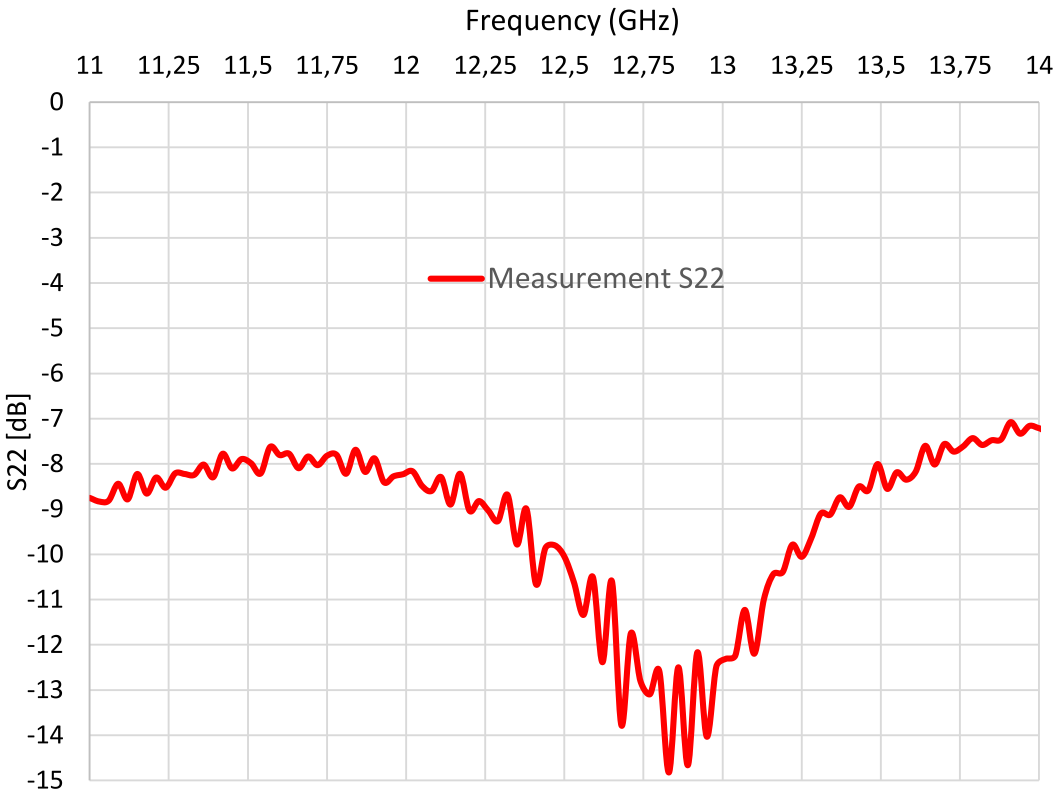


**Figure 4. 10 :** Measured S22 of the LNA.

Table 4.1 shows the measurement summary of the LNA which are showing great results and good agreements for 11.9-12.9 GHz range frequency and where the fabricated antenna is working perfectly.

**Table 4. 1:** Measurement Results of the LNA (for 11.9-12.9GHz).

| Measurements [dB] | Min [dB] | Max [dB] |
|---|---|---|
| S21 | 7 | 10.3 |
| S11 | -13 | -8 |
| S22 | -14.8 | -8 |
| NF | 1 | 1.6 |

## 5. CONCLUSION

In the recent years, microstrip antennas have quickly developed from a research novelty to a practical reality, with applications in a wide range of communication systems that must thank to their numerous appreciated features. The present work proposes a low nature slotted microstrip antenna with ground plane structure which is combined with LNA for Ku-band satellite communications. Firstly, a single Ku-band slotted patch antenna designed and then 2x2 array structure modelled and simulated by using Ansoft HFSS 3D electromagnetic simulation tool. High directivity of antenna has been realized by using full ground plane and via has fed array elements. Array feed circuit placed behind of antenna in the third layer. The configuration of the proposed antenna shows the way to fabricate and make it appropriate for Ku-band applications in satellite communications.

The design has demonstrated its applicability for combining with other RF circuits like LNAs because it is specially designed with three slits in the rectangular grounded patch antenna which is used to fulfil the demands of radar, satellite and communication systems.

In the second part of this thesis, one stage LNA by utilizing active bias networks which are modeled in AWR, has been designed and simulated at Ku-band for the potential employment in the satellite RF subsystems. Measured maximum gain of the LNA is around 10.3dB. S11 and S22 are acceptable for the antenna.

The designed array antenna and LNA at Ku-band, are fabricated by Istanbul Technical University (ITU) RF Laboratory and the meaurment results show great agreements with simulated results.

In summary, it can be mentioned that the whole work is designing and realizing an active planar array antenna for Ku-Band small satellite communications.

As a future work, system will be tested under space conditions such as very high and low temperature, vacuum.

Additionally, some mechanical stress tests may be required such as vibraton and high acceleration.

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**PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:**

- Lida Kouhalvandi, Selcuk Paker, H.Bulent Yagci: Ku – Band Slotted Rectangular Patch Array Antenna Design; SİU 2015 IEEE 23. Sinyal İşleme ve İletişim Uygulamaları Kurultayı, 16 – 19 May 2015, Malatya, Turkey.

- Lida Kouhalvandi, Osman Ceylan, Selcuk Paker, H. Bulent Yagci: Design and Realization of an Active Novel Planar Array Antenna for Ku – Band Satellite Communications, submitted to Microwave and Optical Technology Letters.

**OTHER PUBLICATIONS, PRESENTATIONS AND PATENTS :**

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