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Design of Low Noise Amplifiers at 10 GHZ and 15 GHZ for Wireless Communication Systems

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Abstract: *In this study, design and simulation of 15GHZ and 10GHZ Low Noise Amplifiers (LNA) have been explored. The simulation has been performed by using the Agilent Advanced Design System (ADS) Software. Tuning and optimization tools of ADS software have been used to optimize results. The minimum Noise Figure (NF_{min}) of the High Electron Mobility Transistor (HEMT) device in our simulation, is lower than previous works. We have designed a 15GHZ LNA based on three design methods basing on the lumped, the distributed and the radial stub elements. The scattering parameters of 15GHZ designed amplifier in the following manner, input return loss (S11), output return loss (S22), forward gain (S21), and isolation (S12) are -17.15dB, -16.92dB and 14.35dB as follow as -17.023 dB, respectively. Furthermore, noise figure of the 15GHZ designed amplifiers is 0.92 dB. Furthermore, the simulation results show that the scattering parameters and noise figure of 10GHZ LNA amplifiers are improved noticeably with respect to the previous works.*

Keywords: *Low Noise Amplifier (LNA), noise figure, forward gain, lumped element, distributed element*

I. Introduction

Wireless communication system is now very important as an essential part of any wireless communication system and has fast development in recent years. LNA is the first part in any RF receiver system [1]. The common topology of the LNA contains of three stages: the input matching circuit, the amplifier and output matching circuit. Input matching circuit is used for making balance between gain and noise figure. Output matching circuit is used for improving gain, gain flatness, and input voltage standing wave ratio (VSWR) [2, 3].

The simultaneous requirement of maximum gain with minimum noise figure, good input and output matching and stability should be considered in LNA design [2]. LNA with a noise figure of 2.1 dB and forward gain of 12.5 dB at 15 GHz was reported [8]. Where a 90 nm RF-CMOS technology and cascode topology is implemented in its design. LNA at 17.5 GHz has demonstrated a noise figure of 2.12 dB and forward gain of 17.62 dB [9]. The RF-CMOS 130 nm technology and cascode topology with source inductive degeneration is used for designing LNA in [9] reference. LNA with a noise figure of 4.2 dB and forward gain of 10.8 dB at 15 GHz was reported [10]. Where a 130 nm RF-CMOS technology is implemented for designing LNA in [10] reference. The LNA showed a noise figure of 2.29 dB and forward gain 9.11 dB at 10 GHz [11]. GaAs high frequency transistor and common source topology has been implemented for designing circuit in [11]. Also, distributed and radial stub elements are used for designing input and output matching as well as biasing circuits. LNA with a noise figure of 2.72 dB and forward gain of 11.040 dB at 11 GHz were reported [12]. 180 nm RF-CMOS technology and two stage cascode topology is used for designing circuit in [12].

The ADS software has high strong capability in microwave circuit design and simulation analysis. The noise figure, gain and stability circle of the circuits information have been achieved by the S parameter analysis [3]. In this paper, design and simulation of 15 GHz and 10 GHz LNAs is presented. Three different structures are implemented for preparing a novel structure of LNA at 15 GHz. Lumped, distributed and radial stub elements are used for designing these structures, but lumped elements are not suitable for designing LNA above 5GHz, hence the distributed and radial stub elements are more appropriate. LNA exhibited a noise figure 0.92 dB and forward gain 14.35 dB at 15 GHz. Furthermore LNA in 10 GHz has been designed. Radial stub element is implemented for designing biasing network. Current LNA exhibited significantly lower noise figure and higher forward gain.

The main task of this paper is explained completely in the following manner. The first part of this paper explains the performance of a 15GHz LNA. In this section, the lumped and distributed elements are implemented for circuit designs. In the second part of this paper, the 15GHz simulation results are explained. In the third part, the performance of a 10GHz LNA explained based on distributed and radial stub elements. In the next part of this paper, the 10GHz simulation results are presented. In the final part, the complete conclusion of this paper is explained.

II. 15 ghz lna design

Agilent ATF-36077 has been implemented for designing LNA at 15GHZ. It is ultra-low-noise pseudomorphic high electron mobility transistor (phemt), packaged in a low parasitic, surface-mountable Ceramic package. ATF-36077 suitable for use in KU-band direct broad-cast satellite (DBS) television system, c-band television receiver only (TVRO) LNAS, or other low noise amplifiers operating in the 2-18GHZ frequency range [4]. Stability is a very important factor for designing microwave amplifiers. Stability can be defined by the S parameters of the device , the matching networks, the source and load terminations [5,6]. The adequate and essential situation for being unconditional stability are in the following manner [5, 6]:

$$K = \frac{1-|S11|^2 - |S22|^2 + |\Delta|^2}{2|S21.S12|} > 1 \quad (1)$$

$$|\Delta| = |S_{11}.S_{22} - S_{12}.S_{21}| < 1 \quad (2)$$

The ADS software to analysis stability of LNA is used, because the calculation stability figure by the data sheet is impossible. There are three factors in ADS software for calculation stability of amplifier such as Stab Meas, Stab fact, and mu. Where,

$$Stab\_fact = K \quad (3)$$

$$Stab\_meas = 1-|S_{11}|^2 - |S_{22}|^2 + |S_{11}.S_{22} - S_{12}.S_{21}|^2 \quad (4)$$

$$MU = \frac{1-|S_{11}|^2}{|S_{22} - Conj(S_{11}).\Delta| + |S_{12}.S_{21}|} \quad (5)$$

For being unconditional stable: Stab_fact>1 and Stab_meas>1 or MU>1
The simulation result is shown in Fig. 1. According to the fig. 1 stab fact and stab meas are greater than 1, so the transistor is unconditional stable in working frequency.

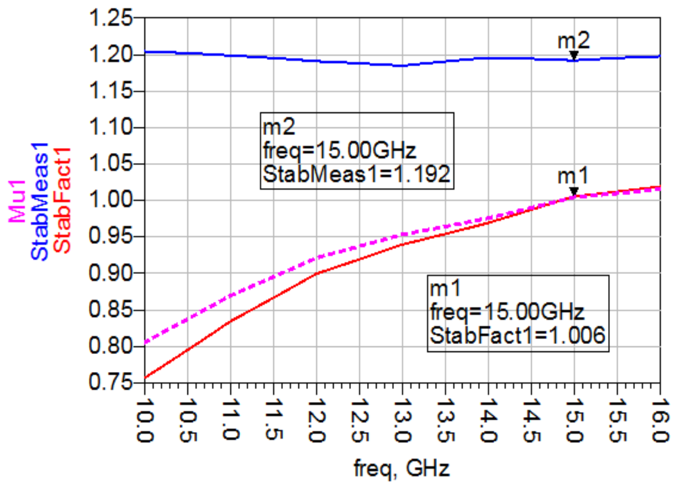

Fig. 1. Stability figure for active part of 15 GHz amplifier

Three LNAs have been designed. The first LNA, design is based on lumped element for matching and bias networks as shown in fig. 2. The second LNA, design employs distributed element for matching network and lumped element for biasing network as shown in fig. 3. As shown in fig. 4, in the third design, it has been used a radial stub as a biasing network. Smith chart tools of ADS software is implemented for designing matching networks, also line calculation tools of ADS software is implemented for designing length and Width distributed elements.

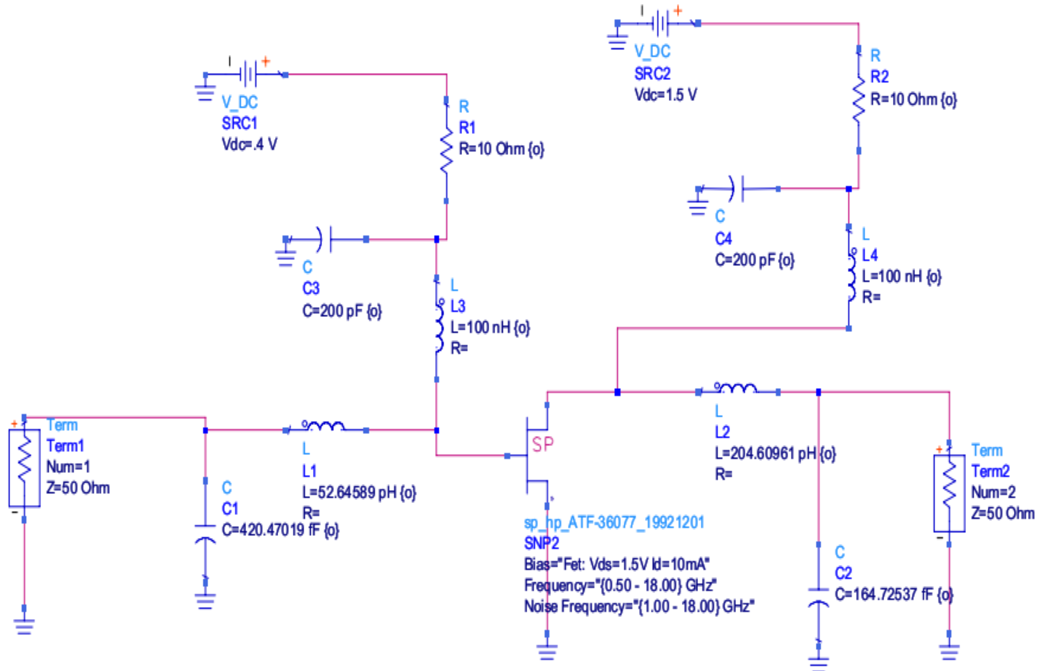

Fig. 2. LNA with lumped element in matching and biasing networks

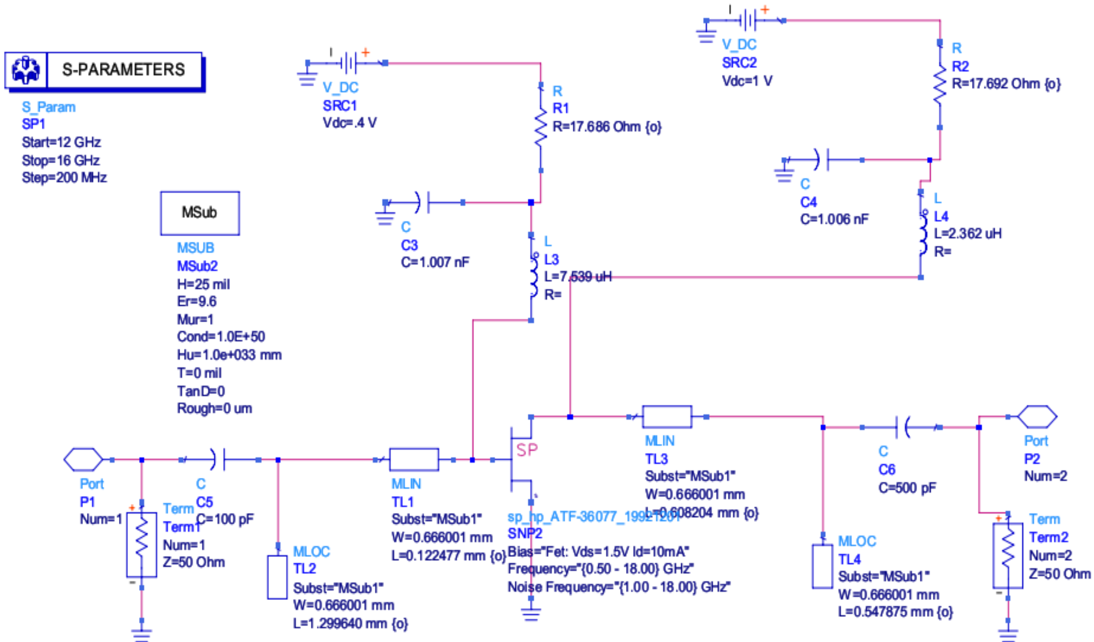

Fig. 3. LNA with distributed element in matching network and lumped element in biasing networks

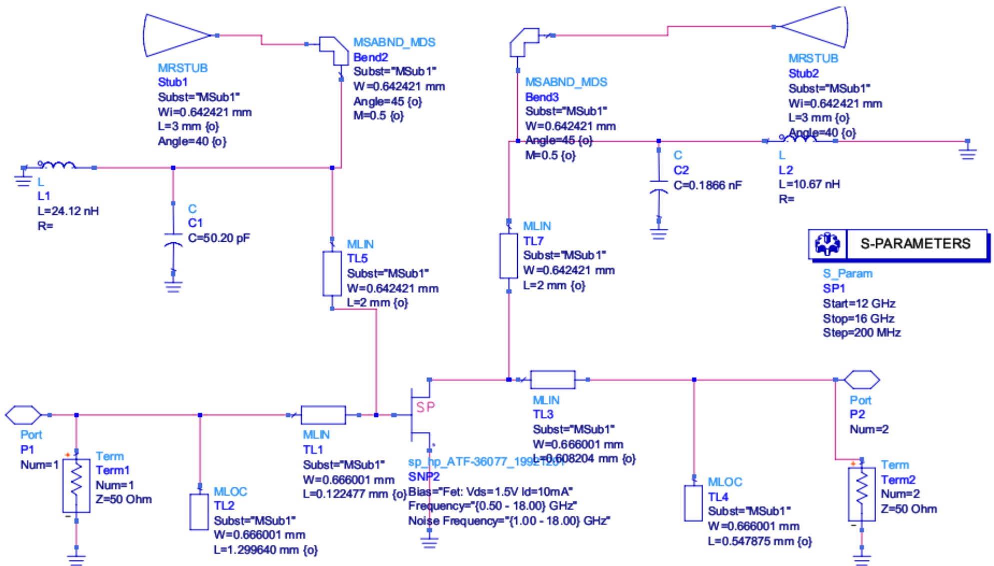

Fig. 4. LNA with distributed element in matching network and radial stub in biasing networks

III. Simulation results of 15 ghz lnas

Table I presents the summary of simulation results of a 15 GHz LNAs. The obtained results show that the forward gain and noise figure of these designs is almost 14.3 dB and 0.92 dB respectively in 15 GHz, also input and output return loss is almost -17dB. Input impedance of these structures are nearly 50 ohm. Since the characteristic impedance is equal to 50 ohm, this result indicates that design of input matching network has been accurate.

Table I. Comparison between the designs of 15 GHz LNAs

LNA type's	Gain [dB]	Noise figure [dB]	Input reflection coefficient [dB]	output reflection coefficient [dB]	Zin [Ω]
Fig. 2	14.34	0.927	-16.95	-16.93	54
Fig. 3	14.31	0.924	-16.97	-16.99	52
Fig 4	14.33	0.91	-16.99	-17.02	52.55

Table II indicates a comparison between the simulated results with other works. According to table II, Noise figure in [8], [9] and [10] is equal to 2.1 dB, 2.12 dB and 4.2 dB respectively. but noise figure in our study is equal to 0.92 db. This result indicates noise figure is reduced fifty-seven percent in compare with prior literature [8, 9, and 10]. Forward gain (S21) is higher than [8, 10] and lower than [9]. Also, input and output reflection coefficient (S11, S22) of these structures are improved noticeably. To our knowledge, these are the best noise figure performance of any LNAs ever reported at 15 GHZ.

Table II. Comparison with to other reported designs

reference	F0 [GHz]	Gain [dB]	Noise Figure [dB]	Input reflection coefficient [dB]	output reflection coefficient [dB]
This work	15	14.33	0.91	-16.99	-17.02
[8]	15	12.5	2.1	-9	-15
[9]	17.49	17.62	2.12	-13.3	-8.7
[10]	15	10.8	4.2	-18	-11

IV. 10 ghz lna design

FHX04LG has been implemented for preparing a novel structure of LNA in 10GHZ. FHX04LG is high electron mobility transistor (HEMT), low noise and high gain amplifier in the 2-18 GHz frequency range [7].

The biasing network design based on radial stub, inductor and capacitor is shown in fig. 5. Also, biasing network performance is shown in fig. 6.

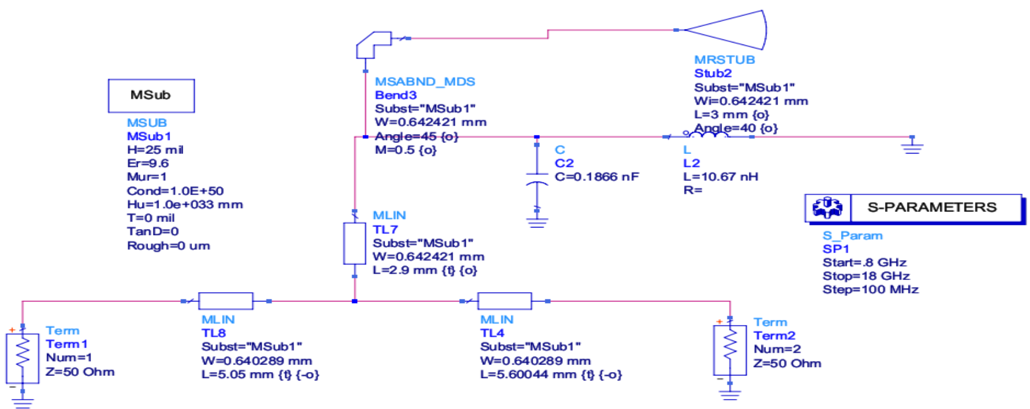

Fig. 5. Biasing network in ADS

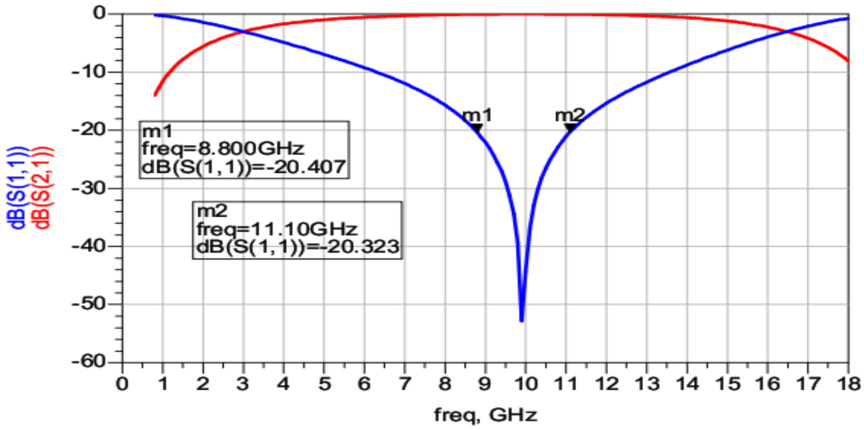

Fig. 6. Biasing network performance

According to the fig. 6 S11 is less than -40 dB and S21 confined to 0 dB, this result indicates that biasing network performance is satisfactory.

The designed LNA along with biasing and matching networks is shown in fig. 7. Distributed elements have been used for designing input and output matching networks.

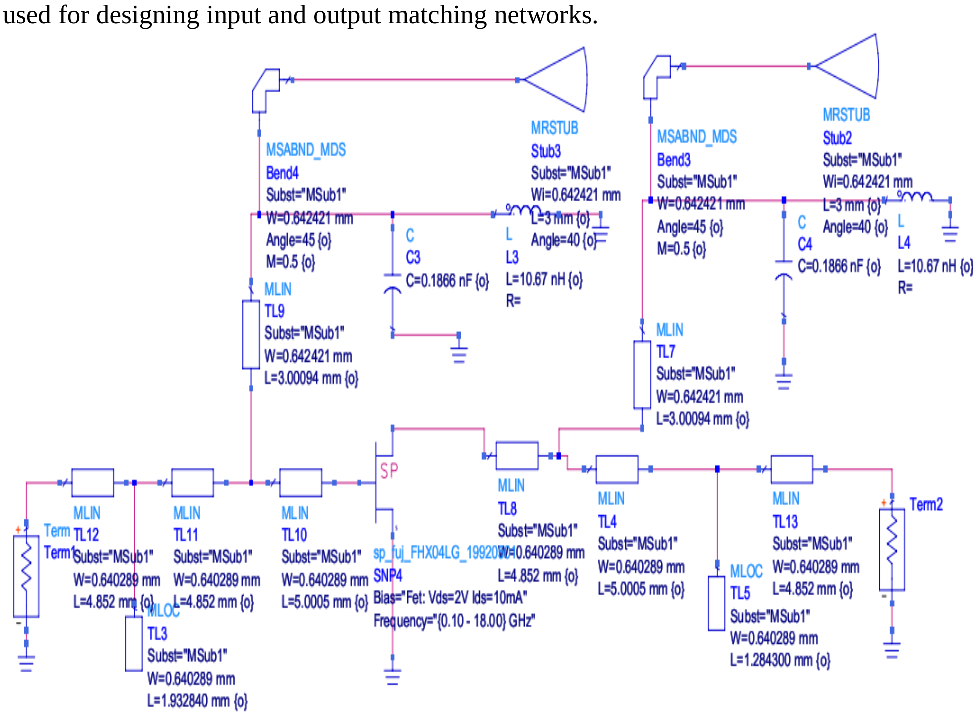

Fig. 7. Designed LNA

V. Simulation results of 10 ghz lna

The simulation result are shown in fig. 8, to fig. 11. The designed LNA provides, forward gain 13.14 dB, noise figure 1.18 dB, input reflection coefficient -18 dB and output reflection coefficient -8.87 dB which are shown fig. 8, fig. 9, fig. 10, fig. 11 respectively. Optimization and tuning tools of ADS software have been used for optimize the whole circuit.

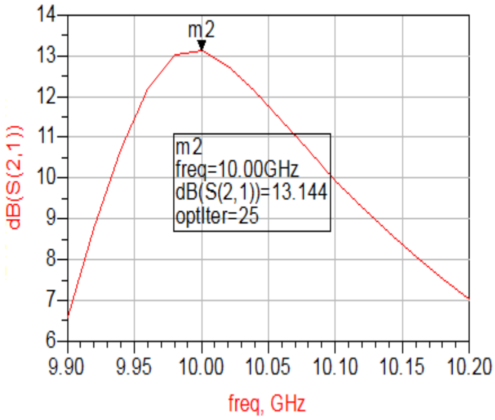

Fig. 8. Forward gain

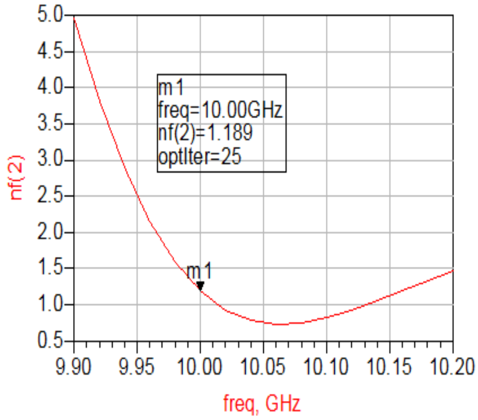

Fig. 9. Noise figure

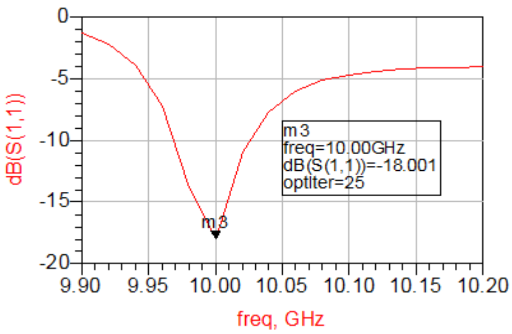

Fig. 10. Input reflection coefficient

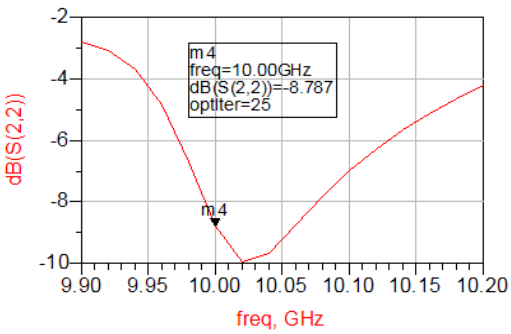

Fig. 11. Output reflection coefficient

Table III presents a comparison between simulated results of LNA with other works in [11], [12]. According to table III, Noise figure in [11] and [12] is equal to 2.29 dB and 2.72 dB respectively. But noise figure in our study is equal to 1.18 db. This result indicates noise figure is reduced forty-eight percent in compare with prior literature [11, 12]. Forward gain in [11] and [12] is equal to 9.11 dB and 11.04 dB respectively. But forward gain in our article is equal to 13.14. This result indicates forward gain is increased nineteen percent in compare with prior literature [11, 12].

Table III. Comparison to other reported designs

reference	F0 [GHz]	Gain [dB]	Noise Figure [dB]	Input reflection coefficient [dB]	output reflection coefficient [dB]
This work	10	13.14	1.18	-18	-8.78
[11]	10	9.110	2.293	-10.002	-13.019
[12]	11	11.040	2.720	-15.000	-----------

VI. Conclusion

In this paper, LNAs at 15 GHz and 10 GHz for communication system has been designed and simulated. We used three different structures for design of LNA at 15GHz. It is observed that the forward gain and noise figure of these designs is almost 14.3 dB and 0.92 dB respectively in 15 GHz. In the second part, a LNA based on distributed elements and radial stub at 10 GHz was designed along with forward gain greater than 13 dB and noise figure less than 1.2 dB. LNAs designed in this paper show low noise figure in compared to previously works. The simulation results have good assent with desired demand.

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