ISSN 2229-5518

Efficient Wideband High Gain Low Noise Amplifier in Modern Radars

Alaa El-Din Sayed Hafez, Mohamed Abd El-latif Mowad

Abstract— in this paper a wideband single stage pseudomorphic high electron mobility transistor (PHMET) amplifier has been designed at 5.8 GHz, the input and output matching circuits have a pi form.Noise cancelling principle and sensitivity analysis are performed .Simulation results have been compared with their correspondence in [10] give 2.71 dB improvement in amplifier gain at the same noise figure (N.F) and input, output returns loss. A new optimized low noise amplifier (LNA) using PHEMT at 3 GHZ have been designed to achieve an improvements of 3.3 dB in amplifier gain and 1.81 dB in noise figure.Also the two stages (common gate in cascaded with common source) LNA have been analyzed and optimized for (1-16) GHz full band application to achieve maximum gain over a wide frequency band. Simulation results carried out sever improvement in amplifier gain over the results obtained for the two structures in [16-17] respectively with no change in N.F value .The improvement in optimized gain for the first and second structures are (3.278, 2.82) dB. The comparative study between the traditional and optimized structures showing a superior performance of LNA making them sutiable to be used in modern radar systems.

Index Terms— Pseudomorphic High Electron Mobility Transistor (PHMET), Low Noise Amplifier (LNA), Cascaded Amplifiers, Noise figure (N.F).Radar receiver.

1 INTRODUCTION

IN the radar receiver the first stage is typically a low noise amplifier (LNA), which is designed to provide enough gain to overcome the noise effect of subsequent stages. Many researches have been introduced in complementary metal–oxide–semiconductor (CMOS) area within the frequency range from 9 MHz up to 9 GHz [1-4].In the literature there are several LNA design in GaAs and bipolar technology [5-8].In this paper, a low voltage, low power and wideband PHEMT LNA at 5.8 MHz is designed and simulated using (LINC2) simulation package. As a design tool , sensitivity analysis gives a measure of sensitivity for the LNA circuit performance due to the changing of active element to be PHEMT, also assisting the radar designer in choosing the adequate circuit elements tolerances [9].Such sensitivity analysis of LNA is very beneficial in making appropriate design trade- off . Four LNA have been designed using PHEMT with two operating conditions (Q1, Q2) .The first two LNA were designed using the same parameters as puplished in [10] while the second two LNA were optimized to achieve a minimum value of N.F with maximum amplifier gain.On the other side, the need of ultra wideband (UWB) circuits is steady rise for high data rate and multi-band applications. Many of (UWB) LNA have been reported with repectable performance. In UWB receiver, the LNA is realized by means of one or more (Really more than two) gain stages; therefore, the receiver noise performance depends relevantly on the N.F and the power gain of the LNA [11-12]. Many researches in wideband LNA have been provided [13-15]. Many limitions still exsists where the circuit structures on the privous studies were not optimized for frequencies with UWB. So; LINC2 simulation package and optimizer is again used to extract the optimum design of (UWB) LNA for frequencyband ranging between (1-16) GHz.

2 THEORTICAL DISCRIPTION

The beauty of the S-parameter amplifier design approach lies in its simplicity. The block diagram of RF amlifier is shown in figure.1.Where the active device is characterized by measured two- ports S-parameters instead of complex equivalent circuit model. It is very important to find the two terminations that satisfy our performance requirements. Restating the transducer power gain GT, [12].

$$G_T = \frac{\left(1-|\Gamma_S|^2\right)|s_{21}|^2\left(1-|\Gamma_L|^2\right)}{\left|\left(1-s_{11}\Gamma_S\right)\left(1-s_{22}\Gamma_L\right)-s_{12}s_{21}\Gamma_S\Gamma_L\right|^2} \quad (1)$$

The transducer power gain is function in the source and load terminations and the scattering parameters of the two port network shown in figure.1. If the amplifier produces the maximum small-signal power gain available from PHEMT device, we must find a unique solution for two terminations to impeadnce-match both ports simultaneously. Those two terminations are named $\Gamma_S = \Gamma_{MS}$ and $\Gamma_L = \Gamma_{ML}$, then,

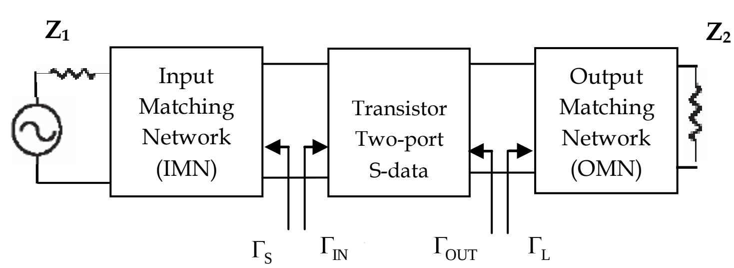

Fig. 1. Block diagram of RF amplifier with active device charaterrized by measured two-ports S-parameters

- *Alaa El-Din Sayed Hafez , Alexandria University , Senior Member IEEE E-mail: Alaahafez @ieee.org*
- *Mohamed Abd El-latif , Alexandria University, Member IEEE E-mail: Turbocode_2000@yahoo.com*

$$\Gamma_{MS} = \Gamma_{IN}^{*} = \left(s_{11} + \frac{s_{12}s_{21}\Gamma_{ML}}{1 - s_{22}\Gamma_{ML}} \right)^{*} \quad (2)$$

and

$$\Gamma_{ML} = \Gamma_{OUT}^{*} = \left(s_{22} + \frac{s_{12}s_{21}\Gamma_{MS}}{1 - s_{11}\Gamma_{MS}} \right)^{*} \quad (3)$$

Solving equations (2) and (3) for the two unknown Γ_{ML}, Γ_{MS} Where (*) is the complex conjugate gives,

$$\Gamma_{MS} = \frac{B_1 - \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} \quad (4)$$

$$\Gamma_{ML} = \frac{B_2 - \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} \quad (5)$$

where

$$B_1 = 1 + |s_{11}|^2 - |s_{22}|^2 - |\Delta|^2$$

$$C_1 = s_{11} - s_{22}^{*}\Delta$$

$$B_2 = 1 + |s_{22}|^2 - |s_{11}|^2 - |\Delta|^2$$

$$C_2 = s_{22} - s_{11}^{*}\Delta$$

$$|\Delta| = |s_{11}s_{22} - s_{12}s_{21}|$$

Equations (4) and (5) are valid for all unconditionally stable two ports. For potentially unstable device, we define the maximum stable gain (MSG), which is highest theoretically realizable gain with passive terminations, then the device stabilized by cascaded resistance to the border line stability, that is to achieve K=1.

$$MSG = \left| \frac{s_{21}}{s_{12}} \right| \quad (6)$$

$$K = \frac{1 - |s_{11}|^2 - |s_{22}|^2 + |\Delta|^2}{2 - |s_{12}s_{21}|} \quad (7)$$

We can define the standing wave ratio (SWR) as the maximum Ac voltage to the minimum AC voltage in the line and is quoted at the same time as the return loss of the load. For a line terminated in Z_o the SWR is equal to one.For an open or short circuit the SWR is infinite as V_{min} is zero.

$$SWR = \frac{V_{max}}{V_{min}} = \frac{|V^+| + |V^-|}{|V^+| - |V^-|} \quad (8)$$

The impedance a long a transmission line can be obtained by measuring both the magnitude and phase of V_{total} using a probe inserted into a slotted transmission line. The probe usually consisted of a diode detector operating in the square law region.

The noise figure (N.F) is defined as the ratio of the total available noise power at the amplifier output to the available noise power at the output that would result only from thermal noise in the source resistance so; N.F is a measure of the excess noise added by the amplifier.

2.1 Single Stage PHEMT Amplifier

The LNA is considered to be a narrow band amplifier when its bandwidth is less than 20% of the center frequency. Amlifieres discussed in [13] used in a military defence systems and test equipements over require a multidecade frequency range coverage. The complete schematic diagram of LNA circuit is shown in figure .2. The PHEMT transistor used is (Sirenza Micro-device SPT-2086T). It is a PHEMT Calluim Aresenide PHEMT with Schottky barrier gate. This device is ideally baised at 3v, 20 mA for lowest noise (Q_1) performance and battary powered requirmrnts at 5v, 40 mA (Q_2). The designed LNA is charactaresized in terms of S – parameters, input and output SWR, N.F and gain. On the other side a new LNA using single stage PHEMT and different circuit elements have been designed and optimized for maximum gain, minimum N.F and SWR.

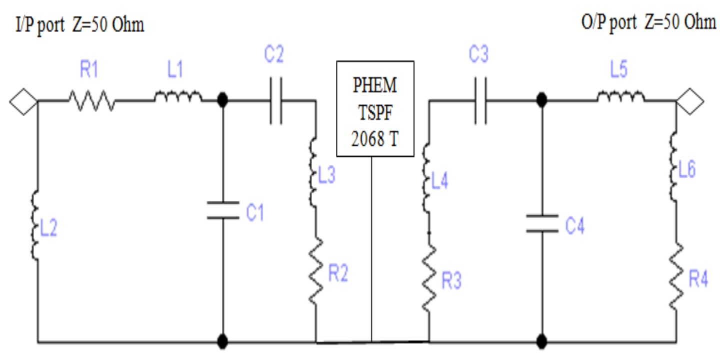

Fig. 2. Schematic digram of prposed PHEMT- LNA circuit

2.2 Wideband Multistage Amplifiers

The common gate topology is well known for its constant wideband input impedance of 1/gm where gm is the trans -conductance of the transistor. The common gate topology is known to have higher noise figure than common source or cascode LNA, especially at frequencies near 10 GHz or higher [17]. Figure -3 shows the first optimized LNA consists of common gate as a first stage with cascade second stage and a buffer. Figure-4 shows the second optimized LNA. Also, the wideband input matching is accomplished using a common gate stage .The LNA gain stage is realized using a common source transistor, which is loaded by a peaked inductor R2 and L2, in order to resonate with total equivalent capacitance at drain of M2 and provide a wideband gain. Hybrid RLC tank is used (R1 and L1) to compensate all the parasitic capacitances seen from drain of M1. For the LNA a cascade topology is used with a gain switching option for bypassing a strong level of input signals at the receiver. The gain switch is implemented with the help of bypassing n type-FETs, and a high gain cascode topology. It has the inherent advantage of separating the output and input optimization criteria in the LNA circuit. The input and output matching circuits are independent of each other. Amplifiers used in military defense systems and test equipments often require multi-decade frequency range coverage. The FET transistor used is (Sirenza Micro-device ATF-36136). This 300 µm device is ideally biased at 2V, 20 mA for lowest noise. The low noise amplifier designed is characterized in terms o S-parameters, input and output SWR, N.F and gain.

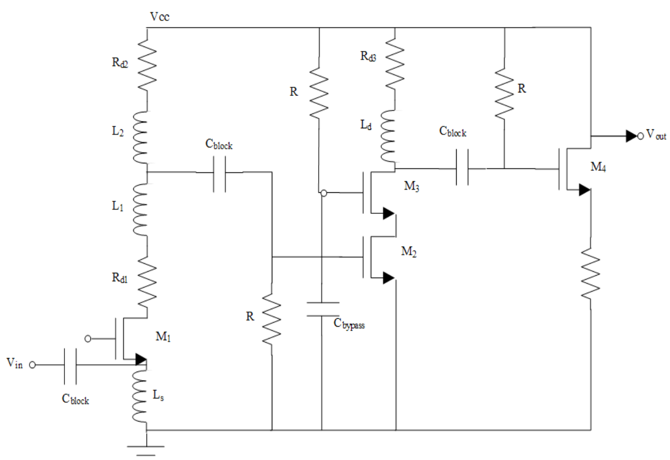

Fig. 3. Schematic circuit diagram for LNA1

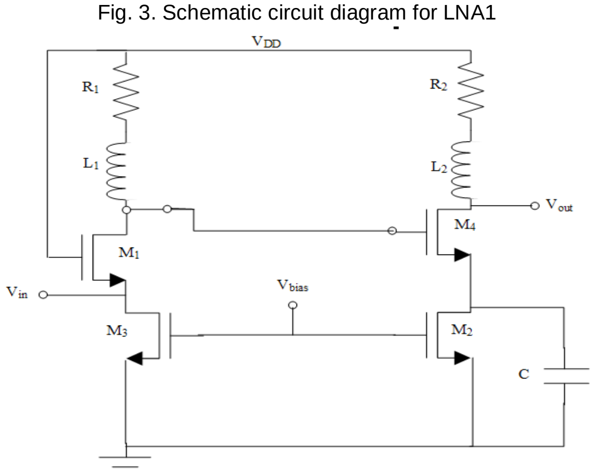

Fig. 4. Schematic circuit diagram for LNA2

3 SIMULATION RESULTS

The propsed LNA have been simulated using the same parameters used in [10] ,which can be briefed in 5.8 GHz frequency with N.F equal 2.463 dB, input and output SWR of (-15.35, -16.26) dB repectively. The unique change will be replacing the active device to be PHMET instead of CMOS transistor. The amplifier scattering parameters are shown in figs 5-8. Active device replacement provides about 23.42 % improment in amplifier gain as shown in figure-7, while keeping the same value of N.F as shown in table-1. Also .The new LNA circuit using single stage PHEMT which have been designed and optimized can also be characterized using the scattering parameters as shown in figs 9-12.The amplifier gain equals 16 dB as shown in figure -11 while the N.F equals 0.65 dB at 3 GHz frequency.Addtional 3.3 dB improvement in amplifer gain have been obtained compared with PHEMT LNA gain in figure -7 at 3 GHz frequency rather than 1.81 dB enhancement in N.F.The new designed PHEMT LNA also provides the advantages of high gain over a wide frequency band since the amplifier gain is greater than 10 dB within the frequency band(3- 6.8) GHz as shown in figure-11. On the other side, for wideband multistage the published LNA circuit structures [16, 17] have been simulated using schematic simulator (LINK 2) with identical components value. The first LNA circuit structure gives high gain over a wideband of frequencies from 1 to 16 GHz. The average achieved gain is 18.3 dB. Then all circuit components values are optimized to maximize the amplifier gain. The previous and optimum components values are listed in table-2. The gain achieved using the optimized parameters exceed the gain provided using the previous parameters by 15.5 % to be 21.15 dB average gain. Also the gain value of 15.3 dB has been achieved from the second optimized structure with average improvement of 18.4 %, the circuit components values are listed in table -3. Figure 13 shows the scattering parameter S21 over the whole frequency band for the first LNA circuit structure with the traditional and optimized parameters. Figure 14 shows also S21 for the second circuit structure. The two LNA are compared over a wideband of frequency, it is clear that the gain of the first structure exceeds the second one as shown in figure-15. Figure- 16 demonstrates the N.F for the two circuit structures and it is found that LNA1 have bad noise performance from 1-4 GHz with resepect to LNA2. At frequencies greater than 4 GHz, LNA1 perform the circuit structure of LNA2.

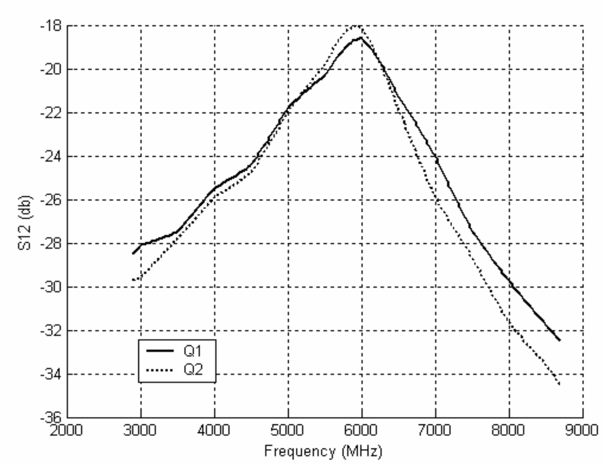

Fig.5. S11 for LNA with two operating conditions Q1 and Q2

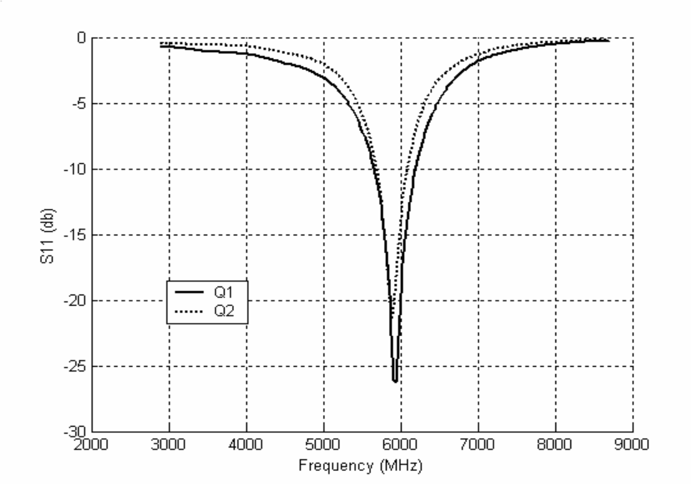

Fig.6. S12 for LNA with two operating conditions Q1 and Q2

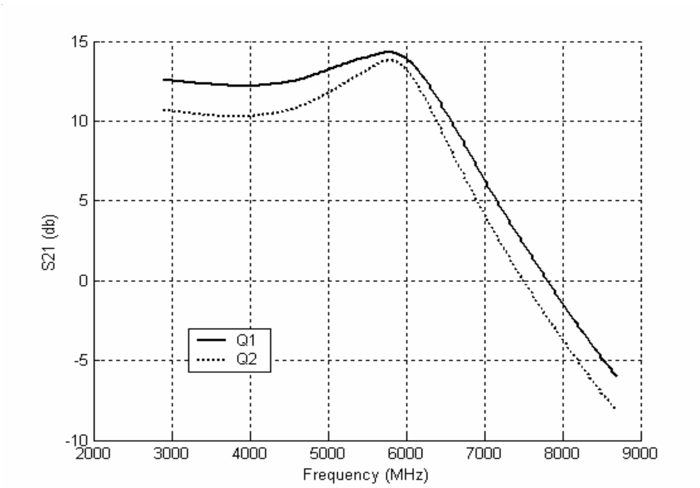

Fig. 7. S21 for LNA with two operating conditions Q1 and Q2

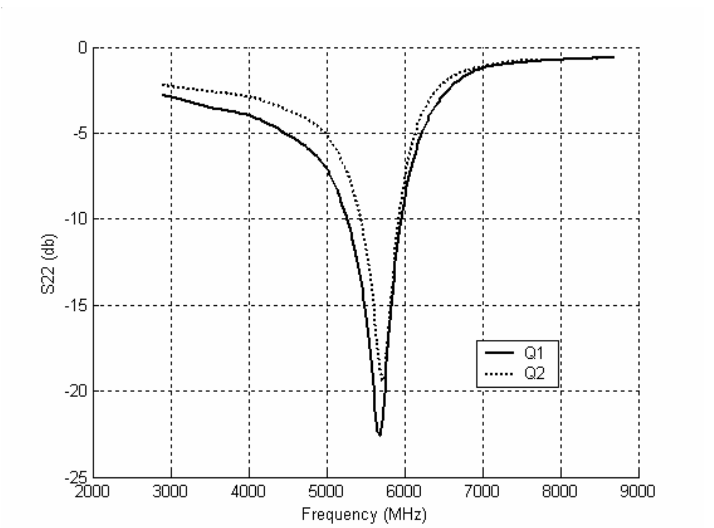

Fig. 8. S22 for LNA with two operating conditions Q1 and Q2

TABLE 1
PHEMT-CMOS LNA COMARESION

Parameter	Previous LNA	Present LNA	
Technology	0.18 µm CMOS	0.25 µm PHEMT	
Frequency	5.8 GHz	5.8 GHz	
		Q1	Q2
Gain (dB)	11.57 dB	14.28	13.8
Noise Figure (dB)	2.463 dB	2.463	2.463
Input SWR (dB)	-15.35	-15.22	-15.37
Output SWR (dB)	-16.26	-16.47	-16.18

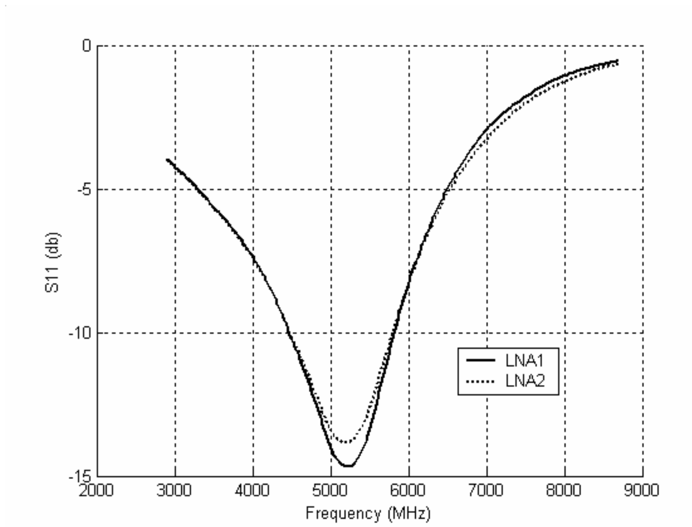

Fig. 9. S11 for optimized LNA with two operating conditions Q1 and Q2

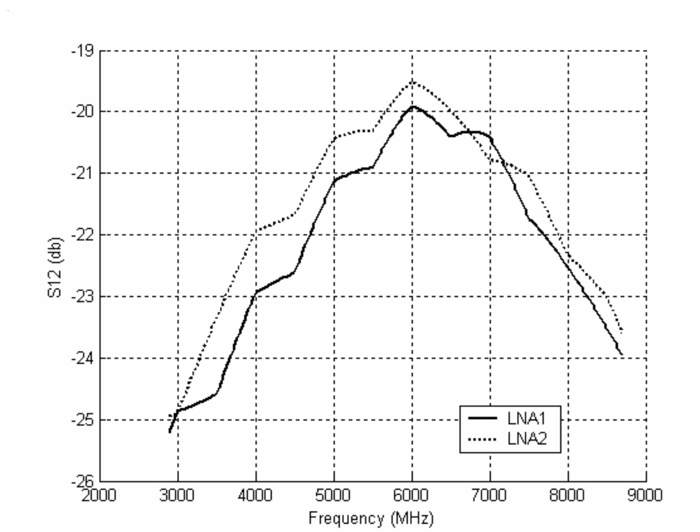

Fig.10. S12 for optimized LNA with two operating conditions Q1 and Q2

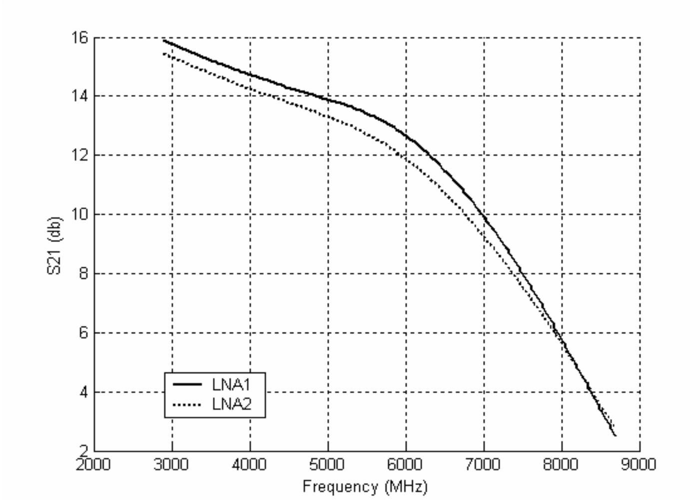

Fig.11. S12 for optimized LNA with two operating conditions Q1 and Q2

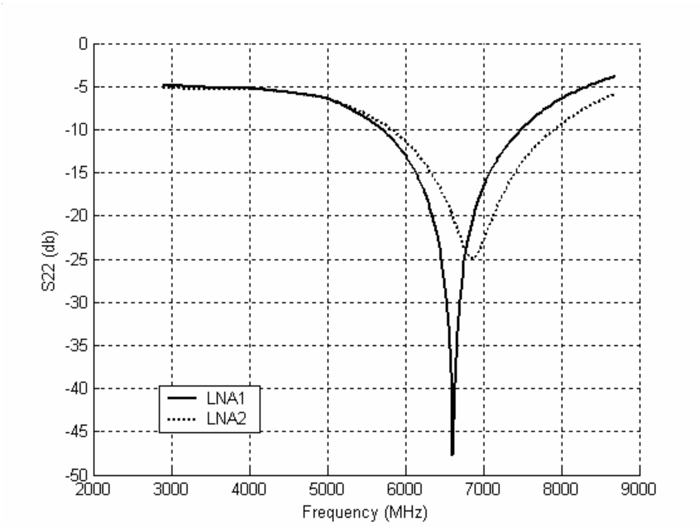

Fig.12. S22 for optimized LNA with two operating conditions Q1 and Q2

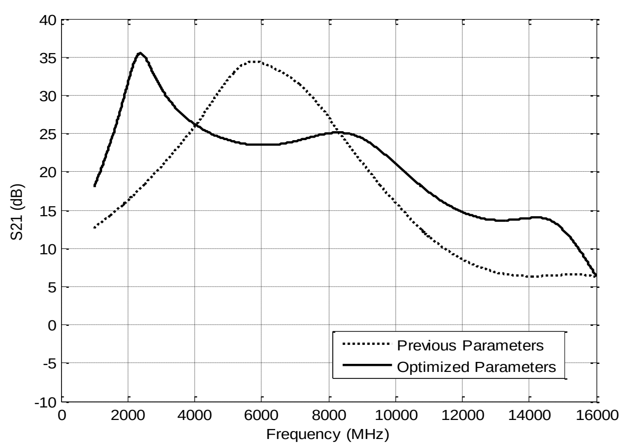

Fig.13. S21 against frequency for first LNA structure

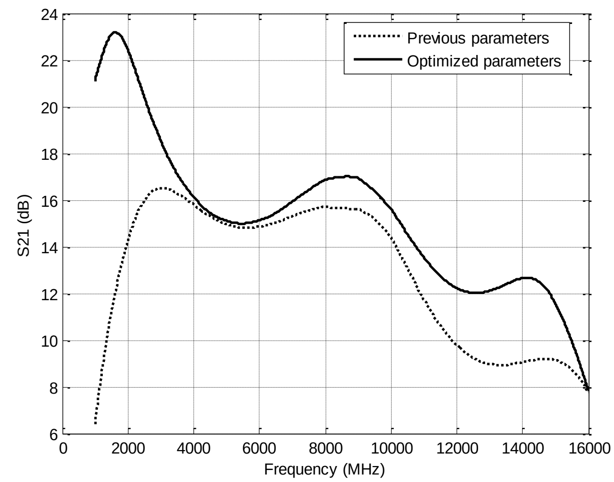

Fig.14. S21 against frequency for second LNA structure

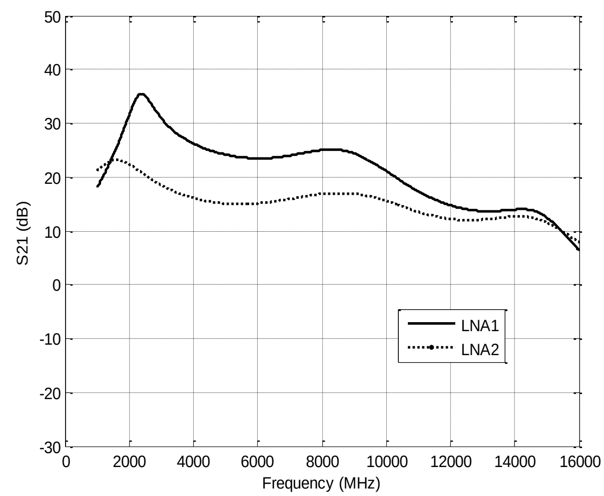

Fig.15 LNA gain comparesion between the two optimized structures

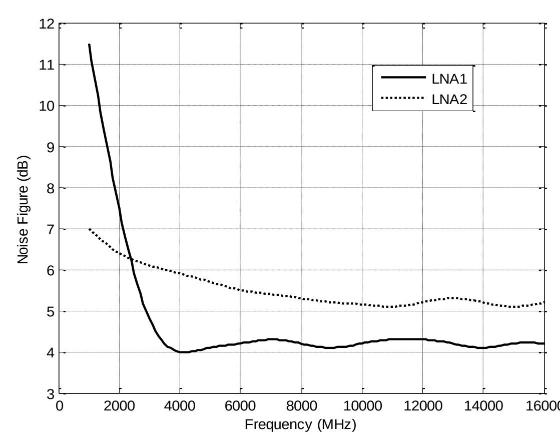

Fig.16. Noise fgure for both LNA structure

TABLE 2

PREVIOUS AND OPTIMIZED COMPONENTS VALUES FOR FIRST LNA CIRCUIT STRUCTURE

Component	Previous Values	Optimized Values
Rd_1, Rd_2, Rd_3 (Ω)	10, 100, 78	9.43, 100, 78.1
R_1, R_2 (KΩ)	20K, 20K	20K, 20K
L_1, L_2, L_d, Ls (nH)	1.8, 6.5, 2.2, 7	0.1, 7.76, 14.83
C_1, C_2, C_3 (pF)	10,10,10	5, 5, 10

TABLE 3

PREVIOUS AND OPTIMIZED COMPONENTS VALUES FOR SECOND LNA CIRCUIT STRUCTURE

Component	Previous Values	Optimized Values
R_1, R_2 (Ω)	80,20	110.57, 13.65
L_1, L_2 (nH)	2.2,2.5	10.62, 20
C_4 (pF)	10	17.67

4 CONCLUSION

In this paper a wideband single stage amplifier has been designed at 5.8 GHz using a PHEMT as an active device instead of CMOS amplifier.Simulation results have been compared with their correspondence in [10] give 2.71 dB improvement in amplifier gain at the same values of noise figure and input, output returns loss. A new optimized low noise amplifier (LNA) using PHEMT at 3 GHZ have been designed and optimized to achieve an addtioonal improvements of 3.3 dB in amplifier gain and 1.81 dB in noise figure.Also two stage (common gate in cascaded with common source) LNA have been analyzed and optimized in frequency band ranging between (1-16) GHz to achieve maximum gain over a wide frequency band. Simulation results carried out sever improvement in amplifier gain over the results obtained for the two structures in [16-17] respectively with no change in N.F value .The improvement values of optimized gain for the first and second structures are (3.278, 2.82) dB respectively . The comparative study between the traditional and optimized structures showing a superior performance of the designed wideband LNA making them sutiable to be used in modern radar systems.

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