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Research paper

Inductive source degenerative LNA for radar altimeters

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Abstract

This paper deals with the design of Low Noise Amplifier with inductive source degeneration technique using ADS simulation tool. The major parameters on which RADAR Altimeter working depends is the sensitivity and selectivity of the first RF amplifier after receiving antenna which captures all the available signals. But the rain attenuates the propagating EM waves which results in a distorted signal being received by the antenna. The LNA designed will improve the signal strength i.e. the gain and reduces the noise figure for better detection of earth's surface reflected radio signal at the receiver of aircraft. The low noise amplifier designed is with inductive source degeneration which is a stability improvement technique that proved to be an efficient and optimum design resulting in power gain of 14.735 dB and noise fig-ure of 0.132 dB.

Keywords: *Altimeters; Inductive Source Degenerative LNA; Noise Figure; Power Gain; VSWR.*

1. Introduction

A RADAR altimeter is a radio navigation equipment available in the aircraft which helps in determining the distance between the air-craft and the earth's surface. It operates in 4.2 - 4.4 GHz frequency band with the bandwidth of 200 MHz at a center. Due to the limited availability of bandwidth, the accuracy and resolution of these al-timeters are typically a few feet.

Makesh Iyer, T. Shanmuganantham designed low noise amplifiers with different stabilization techniques for RADAR Altimeters ap-plication and obtained the drain resistance LNA to be an efficient and optimum design getting a gain of 11.856 dB and noise figure of 0.339 dB [1]. A. Iji, X. Zhu, et al, A 4.5 mW 3–5 GHz Low-Noise Amplifier for Power - Constraint application using CMOS technol-ogy and obtained gain of 10.3 dB and 2 dB noise figure [2]. Jyh Chyurn Guo and Ching Shiang Lin designed an ultra-wide band CMOS low noise amplifier using resistive feedback under forward body bias condition and obtained the noise figure of 3.3 dB, gain of 13 dB at 4.3 GHz [3]. Syed Mubashir, Vikram Singh designed a UWB 2 – 10 GHz CG LNA using body bias technique and obtained a noise figure of 4 dB and power gain of 11 dB at 4.3 GHz [4]. D. Senthilkumar, Santosh Jagtap et al, designed various low noise am-plifiers with different matching networks with and without stability improving networks and concluded that T – L matching network provided better impedance matching obtaining power gain of 14.14 dB and noise figure of 1.816 dB [5]. This work implies that the good power gain, optimum noise figure and minimum VSWR are the vi-tal parameters that determine the performance of a low noise am-plifier though there is a trade-off between the gain and noise figure of the design [6].

In this paper, we have managed to design a low noise amplifier for RADAR Altimeters receiver system by balancing the trade-off pa-rameters.

2. Design aspects

The general block diagram of a microwave amplifier is shown in fig. 1. It comprises of an active device which is GaAs FET, input matching network and output matching network.

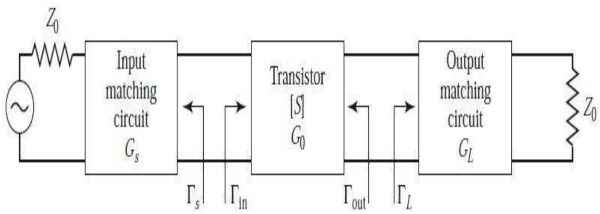

Fig. 1: General Block Diagram of Microwave Amplifier

The various parameters shown in fig. 1 are G_S the source gain of the input matching network, G_O the gain of the active device (tran-sistor) used, G_L the gain of the output matching network called the load gain, Z_O characteristic impedance. If there is no proper match-ing between the matching networks and the active device then, re-flections of the incident input signal will be generated which will return to the input side. This reflections are measured as reflected voltage and it's ratio in comparison with the incident voltage is called the reflection coefficient. Hence, the various reflection coef-ficients involved in the design of an amplifier are Γ_s called as source reflection coefficient, Γ_{IN} the input reflection coefficient, Γ_L load reflection coefficient, Γ_{OUT} output reflection coefficient of the de-vice [7].

Advanced Design System (ADS) simulation tool is used for design-ing the low noise amplifier. There are two different types of device libraries available in the ADS software namely S – parameter li-brary and RF Transistor library.

S – Parameter library works on fixed bias i.e. these parameters of the device are fixed for a particular bias point of the device. In this work, the S – parameter library device is used.

The Low Noise Amplifier is designed using GaAs FET MGF 1303 of Mitsubishi. In a low noise amplifier, the vital parameters to be considered are, maximum gain provided by the active device which is termed as MAG (maximum available gain) and NFmin (minimum intrinsic noise) figure which in turn depends on the S parameters of the device. The S parameters determine the stability criteria of the device at various biasing points which is mathematically described in section 3.
Theoretically, the stability of the device is checked using Rollet K - |Δ| test where K said to be Rollet's Stability factor is given by,

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

Also, B is another parameter that is calculated for checking stability which should be positive for stable operation given by,

$$B = 1 + |s_{11}|^2 - |s_{22}|^2 - |\Delta|^2 \quad (2)$$

In addition, Δ is given by,

$$\Delta = S_{11}\, S_{22} - S_{12}\, S_{21} \quad (3)$$

The condition for stability is that if K > 1, |Δ| < 1 and B = +ve, then the device is unconditionally stable and if K < 1 then device is potentially unstable. This condition will tend the device to oscillate and the maximum available gain will be no more valid due to unstable condition.
Hence, the maximum gain produced by the device will now be said as MSG (maximum stable gain) which is mathematically expressed as,

$$MSG = \frac{|S_{21}|}{|S_{12}|} \quad (4)$$

If the device is unconditionally stable i.e. K > 1, then the gain obtained will be maximum available gain which is expressed as,

$$MAG = \frac{|S_{21}|}{|S_{12}|}(K \pm \sqrt{K^2 - 1}) \quad (5)$$

In later stages, there was another parameter introduced to check the stability of the active device for stable operation given by,

$$\mu = \frac{1-|s_{11}|^2}{|S_{22} - \Delta S_{11}^*| + |S_{12}S_{21}|} \quad (6)$$

For the device to operate in unconditionally stable region the value of μ should be greater than 1 (μ > 1) and if it's less than 1 then the device is potentially unstable. This condition will tend the device to oscillate which degrades the noise immunity and distort the signal.
Hence, to improve the stability of the active device there are various techniques available which are described in [8]. One such technique is to connect an inductor in series to the source terminal of the active device i.e. here GaAs FET and this technique is said to be inductive source degeneration technique. This technique not only improves the stability of the amplifier but also improves the signal strength i.e. the power gain without much affecting the noise immunity [9].
Once the stability of the device is taken care off next step is to calculate the gain and noise figure of the amplifier. This calculation involves various other parameters like F_{min} which is the minimum noise figure that will be generated for a particular frequency, Γ_{opt} that is the optimum reflection coefficient, which is available in the data sheet of the active device we use.
The noise figure for a single stage LNA is given as,

$$NF = F_{min} + \frac{4_{rn} - |\Gamma_S - \Gamma_{opt}|^2}{(1-|\Gamma_S|^2)(|1+\Gamma_{opt}|^2)} \quad (7)$$

The overall noise figure of multistage amplifier is given as,

$$NF = F_1 + \frac{F_2 - 1}{GA_1} + \frac{F_3 - 1}{GA_1 GA_2} + . \quad (8)$$

Initially, for the first stage the condition to be assumed for minimum noise figure is $\Gamma s = \Gamma_{opt.}$ Once Γs is calculated then Γ_L has to be calculated which is given by,

$$\Gamma_L^* = \Gamma_{out} = S_{22}\frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S} \quad (9)$$

This will result in Γ_L and the value can be used to calculate the transducer power gain which is the combination of device gain, source gain and load gain given as,

$$G_T = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2} \cdot |S_{21}|^2 \cdot \frac{1}{1-|\Gamma_L|^2} \quad (10)$$

Here the circuit is designed using the distributed components i.e. transmission line equivalent of the lumped components because of the fact that at high frequencies in GHz range the lumped components possess parasitics which affect the system performance. The 50 ohm terminations are provided for calculating the S parameters of the network.
The substrate used for designing the Microstrip matching components is RT Duroid 5880 of Rogers Corporation which has following parameters shown in table 1.

Table 1: RT Duroid 5880 Parameters

Parameters	Values
εr	2.2
tanδ	0.0009
substrate height (h)	1.6 mm
metal thickness (t)	0.035 mm
conductivity (σ)	5.8 x e7

Voltage Standing wave ratio (VSWR) is another parameter which determines the amount of reflections that occurs in a microwave circuit due to improper impedance matching. It is represented in the form of reflection co-efficient which is mathematically given as,

$$VSWR = \frac{V_{max}}{V_{min}} \quad (11)$$

Or

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (12)$$

Where

$$\Gamma = \frac{V_r}{V_i}$$

The VSWR values theoretically ranges from $1 < VSWR < \infty$ for the corresponding reflection co-efficient of $0 < \Gamma < 1$.
The LNA is designed using RF chokes both at the gate and drain terminal of the active device in order to achieve a very high isolation between the RF input signal and the DC biasing of the transistor. High impedance λ/4 transformer is connected in RF choke which creates a high impedance path for the RF signals with the large value capacitors that acts as an open circuit to restrict RF signal flow that may leak in the DC circuit.

3. Proposed design

The low noise amplifier is designed with source inductive degeneration for this application is shown in fig. 2.
The various icons shown in fig 2 are the parameters of measurement which are described below.

- S-parameter icon in the figure is used to measure the S-parameters of the amplifier which are S_{11}, S_{12}, S_{21}, and S_{22}.
- The MSUB icon is used to set the substrate parameters which includes the substrate height, metal thickness, metal conductivity, loss tangent (tanδ), relative permittivity also called dielectric constant (ε_r), etc.
- Two VSWR icons namely VSWR1 and VSWR2 are used for calculating the voltage standing wave ratio at the input and output side of the amplifier after connecting the matching network
- which implies how perfectly the impedance is matched with the source and load.
- PwrGain is the function used to find the available power gain of the amplifier.
- Stabfact1 indicates the Rollet stability factor 'K', stabmeas1 indicates delta (Δ), and Mu1 indicates factor 'μ'.

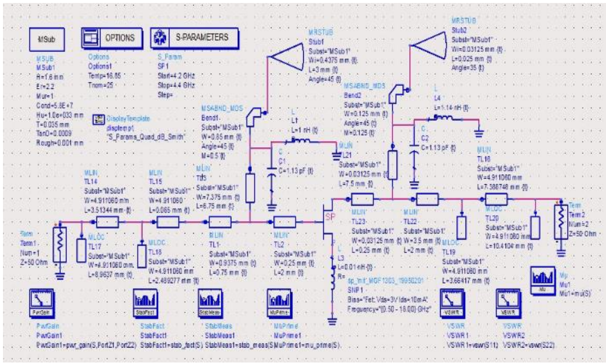

Fig. 2: Proposed LNA.

K - |Δ| test, B and μ are calculated for the above design with the help of the obtained s parameters,

$S_{11} = 0.467\angle{-28.542}$

$S_{12} = 0.067\angle 63.391$

$S_{21} = 3.552\angle 99.111$

$S_{22} = 0.628\angle{-84.9}$

$\Delta = [(0.467\angle{-28.542}) \times (0.628\angle{-84.9}) - (0.067\angle 63.391) \times (3.552\angle 99.111)] = 0.334\angle{-157.116}$

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

$$K = \frac{1-|0.467|^2-|0.628|^2+|0.334|^2}{2*0.237} = 1.052$$ that's greater than 1.

$B = 1+|S_{11}|^2-|S_{22}|^2-|\Delta|^2 = 1 + |0.467|^2 - |0.628|^2 - |0.334|^2 = 0.712$ that's +ve

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

can be obtained as follows, $\Delta S_{11}^* = [(0.334\angle{-157.116}) \times (0.467\angle 28.542)] = 0.155\angle{-128.574}$.

$|S_{22} - \Delta S_{11}^*| = 0.5055$

$$\mu = \frac{1-|0.467|^2}{0.5055+0.237} = 1.053$$ that's > 1.

The Rollet's stability factor K and |Δ| obtained for the complete designed amplifier including the matching network is shown above in fig. 3 which is obtained as 1.157 and 0.667 respectively.

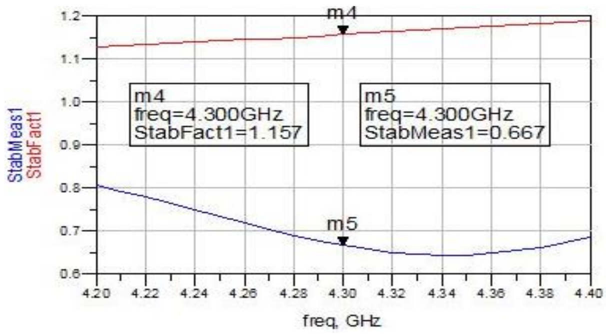

Fig. 3: Stability of Proposed LNA.

Therefore, the above obtained values of K > 1, B = +ve, |Δ| < 1 and μ > 1 proves that the device is unconditionally stable.

4. Results

The power gain and noise figure obtained for the source degenerative LNA are 14.735 dB and 0.132 dB as shown in fig. 4 and 5 respectively.

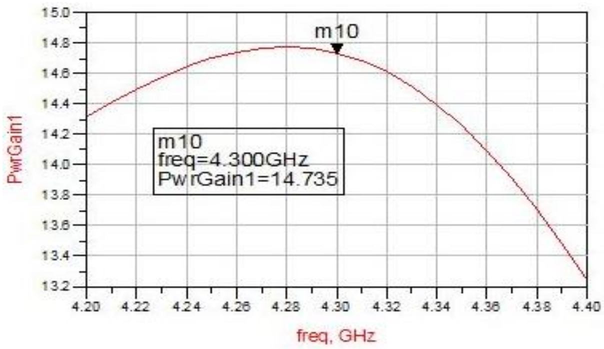

Fig. 4: Power Gain of LNA.

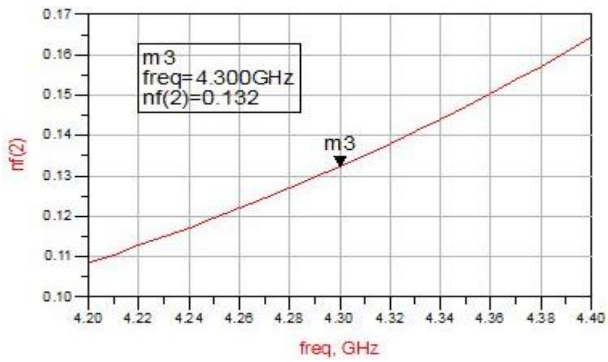

Fig. 5: Noise Figure of LNA.

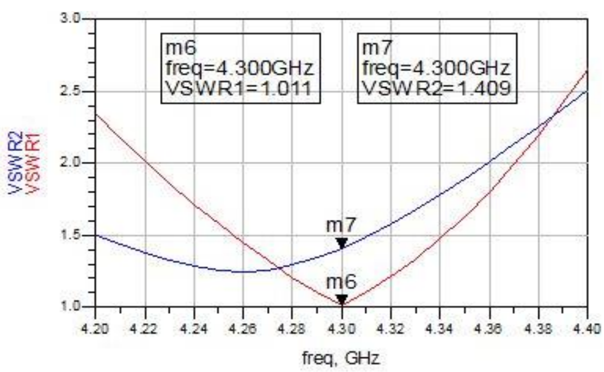

Fig. 6: VSWR of LNA.

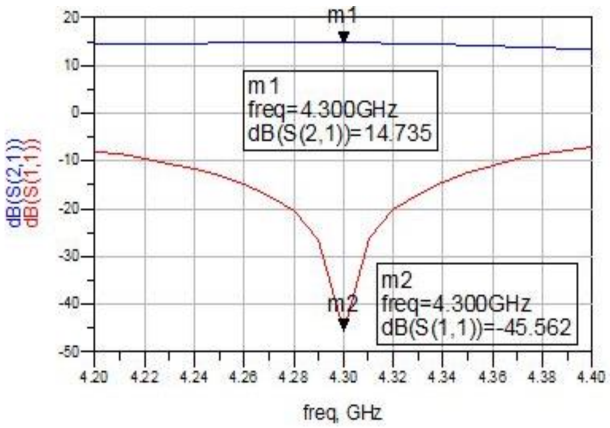

Fig. 7: S_{11} and S_{21} of LNA.

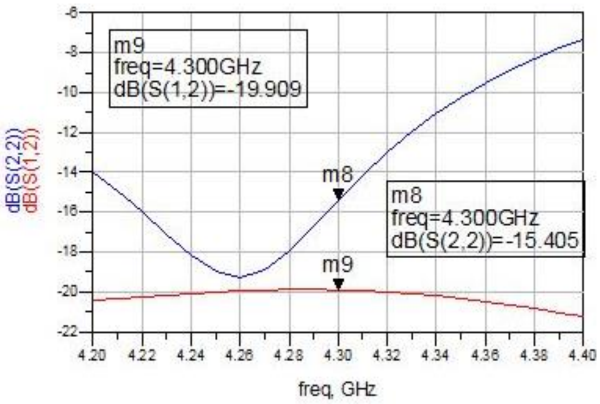

Fig. 8: S_{12} and S_{22} of LNA.

The VSWR obtained for the source (VSWR1) and load (VSWR2) matching is shown in fig. 6 which are 1.011 and 1.409 at input and output side respectively. These less values of VSWR i.e. nearby 1 signifies that the amount of reflections is very less and hence maximum input power can be transferred to the output side of the amplifier.

The S parameters of the designed LNA obtained are shown in fig. 7 and 8 respectively. The S_{11} is -45.562 dB, S_{21} is 14.735 dB, S_{12} is -19.909 dB and S_{22} is -15.405 dB.

Table 2: Comparative Results

Parameters	[1]		[3]	Proposed LNA
	R_F LNA	R_D LNA		
K	1.395	1.512	NM#	1.157
S_{11} (dB)	-30.941	-25.466	-15	-45.562
Gain/S_{21} (dB)	8.781	11.856	13	14.735
S_{12} (dB)	-16.310	-20.485	< -27.36	-19.909
S_{22} (dB)	-26.378	-19.572	-23	-15.405
NF (dB)	1.680	0.339	3.3	0.132
VSWR	1.113 (I) 1.235 (O)	1.058 (I) 1.101 (O)	NM#	1.011 (I) 1.409 (O)

NM# - Not Measured, NF – Noise Figure.

5. Conclusion

The results of inductive source degeneration LNA after implementation in ADS is presented in this paper which proves to be efficient and optimum LNA since its power gain obtained is 14.735 dB. The VSWR obtained is 1.011 at input side and 1.409 at output side which is nearby value equal to one that shows the amount of reflections being less and maximum power can be transferred. Also the noise figure obtained is 0.132 dB that shows very high noise immunity. Further, to improve the bandwidth of the amplifier with minimal trade-off of noise figure and more gain cascading techniques can be used to implement multistage low noise amplifier.

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