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Low Noise Amplifier Circuit Design for C-band Satellite Transponder Model

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Abstract: This paper presents the low noise amplifier (LNA) circuit design for 6GHz in communication satellite transponder. To amplify the received signal in a communication satellite system, a LNA is required. An LNA design in RF circuits requires many important characteristics such as maximum available gain (MAG), noise figure (NF), stability, power consumption and complexity. The goal of the paper is to design a low noise amplifier with stability, lowest NF and highest gain possible. Advance Design System (ADS) is used to simulate the designed performances.

Keywords: Biasing, Matching, Noise Figure (NF), MAG, and Stability.

I. INTRODUCTION

Low noise amplifiers are essential elements for any radio frequency receiver. In order to design a low noise devise, firstly choose a transistor component. The transistor should be biased to be lowest the minimum noise figure. Then test the transistor stability. LNA reduces the noise in the signal received from the BPF and amplify the gain. In LNA design, the most important factors are low noise, moderate gain, matching and stability. Besides, power consumption and layout design size also needed to be considered in design work [1].

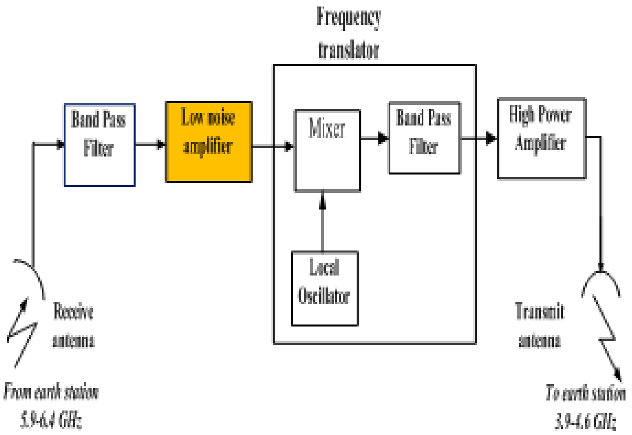

Fig.1. Block diagram of C-band satellite transponder.

Block diagram of C-band satellite transponder model is shown in Fig.1. In a satellite transponder, transmit and receive antennas, BPF (Band Pass Filter), LNA (Low Noise Amplifier), Frequency converter and HPA(High Power Amplifier) sections are included. Selection of the transistor is the crucial stage in LNA design.

II. DESIGN PROCEDURE AND CALCULATION FOR LNA

A. Transistor selection and stability Considerations

Transistor selection is the first and most important step in an LNA design. Choosing a transistor for an RF amplifier is more complicate than choosing it for other application. It involves choosing one in the right package having an adequate current rating, with gain and noise figure capability that meets the requirements of the intended application. It is also important submit manuscript electronically for review that the selecting of a transistor has breakdown voltages which will not be exceeded by the dc and RF voltages that appear across the various junctions of the transistor and that permit the gain at frequency objectives to be met by the transistor [2]. A first step for the choice of transistor is to decide the frequency range, because it may affect other specifications. Understanding data sheet specifications can help selecting and using *RF* devices for specific application. It describes the transistor's behavior at RF frequencies. The parameters found in the device data sheet typically are: *S*-parameters, MAG (Maximum Available Gain), and Rollet factor (*k*). These parameters allow a first feasibility analysis of the design with a specific transistor.

B. DC Biasing

Biasing a Transistor amplifier is the process of setting the dc (Biasing) operating voltage and current to the correct level so that any ac input signal can be amplified correctly by the transistor. That is by setting its Collector current (I_C) to a steady state value without an input signal applied to the transistors Base, and by the values of the *dc* supply voltage (V_{CC}) and the value of the biasing resistors connected the transistors Base terminal. The goal was to select an operating point that would give sufficient output power. The correct bias Operating point of the transistor is generally somewhere between the two extremes of operation, that is halfway between cutoff and saturation. This mode of operation allows the output current to increase and decrease around the amplifiers Q-point without distortion as the input signal swings through a complete cycle [3].

C. Input and Output Matching

The last step is to take the values of the reflection coefficients at the input and the output, and to design for these values their corresponding input and output matching couplers. Input and output return losses (S_{11} and S_{22} respectively) are important properties in RF circuits, because they will affect the gain and noise figures and tell about how well the circuit is matched. The lower S_{11} and S_{22} are, the better is the matching. An improvement in gain can always be achieved [4].

III. DESIGN CALCULATION

A. Transistor stability calculation

Unconditional stability of the circuit is the goal of the LNA design. Unconditional stability means that with any load present to the input or output of the device, the circuit will not become unstable. The main way of determining the stability of a device is to calculate the Rollett's stability factor (K), which is calculated using a set of S-parameters for the device at the frequency of operation. Rollet Stability Factor, K is derived as follows:

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

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

The S-parameters of ATF34143 are as follow:

$$S_{11} = 0.66\angle 87$$
$$S_{21} = 2.506\angle -26$$
$$S_{12} = 0.124\angle -41$$
$$S_{22} = 0.24\angle 86$$
$$\Delta = 0.4134$$
$$K = 1.09$$

When K-factor is greater than unity, the circuit will be unconditionally stable for any combinations of source and load impedance. The parameters must satisfy $K > 1$ and $|\Delta| < 1$ for a transistor to be unconditionally stable.

B. Biasing Calculation

The following diagram shows the Schematic diagram of DC Biasing.

$$V_{DD} = I_{DS}R_D + V_{DS} + I_{DS}R_S \quad (3)$$

Where,

V_{DD} = supply voltage

V_{DS} =Drain to source voltage

I_{DS} =Drain to source current

V_{DD} =5V

V_{DS} =4V

I_{DS} =40mA

$R_{D,}R_S$ = 12.5 Ohm

$$V_G = V_{DD}\left(\frac{R_1}{R_1 + R_2}\right) \quad (4)$$

$$R_2 = R_1\left(\frac{V_{DD} - V_G}{V_G}\right) \quad (5)$$

$R_2 \geq 10R_1$, set R_1=1MΩ.

R_2 =11.5MΩ

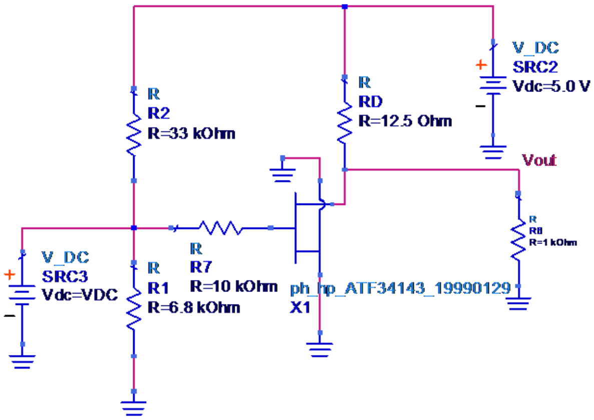

Fig.2. Schematic diagram of DC Biasing.

C. Calculation for Input and Output Matching

The last step in LNA design involves input and output matching of the transistor (see fig 3 and 4). An additional resistor, either in series or parallel, has been placed on the collector of the transistor for circuit stabilization. Conjugate matching has been exclusively used for narrow band LNA design to maximize the gain out of the circuit [5]. The impedances of source and load are calculated from the S-parameters of selected component.

$$\Gamma_S = \left[S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - (S_{22}\Gamma_L)}\right] \quad (6)$$

$$\Gamma_L = \frac{B_2 - \sqrt{{B_2}^2 - 4|C_2|^2}}{2|C_2|} \quad (7)$$

The intermediate quantity B2, C2 must be first calculated

$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \quad (8)$$

=0.45

$$C_2 = S_{22} - (\Delta S_{11}) \quad (9)$$

$C_2 = 0.47 < 61$

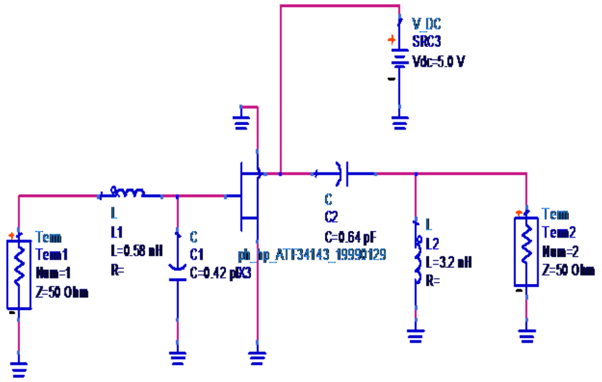

Fig.3. Input Output Matching Circuit for 6GHz LNA.

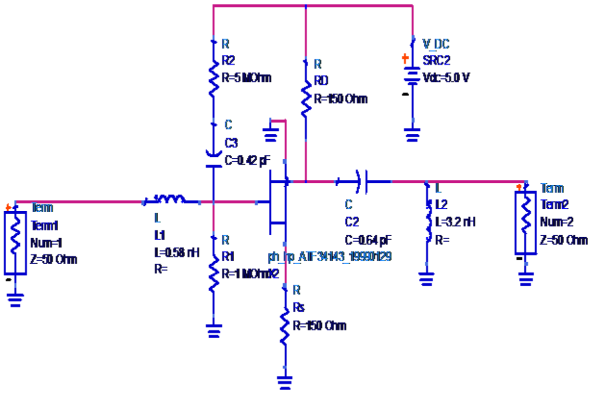

Fig.4. Schematic diagram of complete LNA circuit.

Then reflection coefficients of source and load are calculated. The input impedance and output impedance values are set on Smit-Chart and read directly from it. The reactance values are gained for input/output matching [6].

D. Calculation of MAG and Noise Figure

The main task of the LNA design is to reduce the noise and amplify the gain.

$$MAG = 10\log\left|\frac{S_{21}}{S_{12}}\right| + 10\log\left|K \pm \sqrt{K^2-1}\right| \qquad \textbf{(10)}$$

$$MAG = 11.23dB$$

Noise factor, F is the numerical ration of noise figure where it can be expressed in dB. Thus, the noise figure is:

$$NF = 10\log F \qquad \textbf{(11)}$$

$$F = F_{min} + \frac{4R_n}{Z_0}\frac{\left|\Gamma_S - \Gamma opt\right|^2}{\left(1-\left|\Gamma_S\right|^2\right)\left|1+\Gamma opt\right|^2} \qquad \textbf{(12)}$$

Noise parameters F_{min}, $\frac{R_n}{Z_o}$ and Γ_{opt} are gained from datasheet of selected component[7].

IV. SIMULATION RESULTS

The LNA design at 6GHz has been implemented using Advanced Design System (ADS) tool. As shown in Fig.5, primary S-parameters model of selected transistor ATF34143 is used throughout the LNA design process.

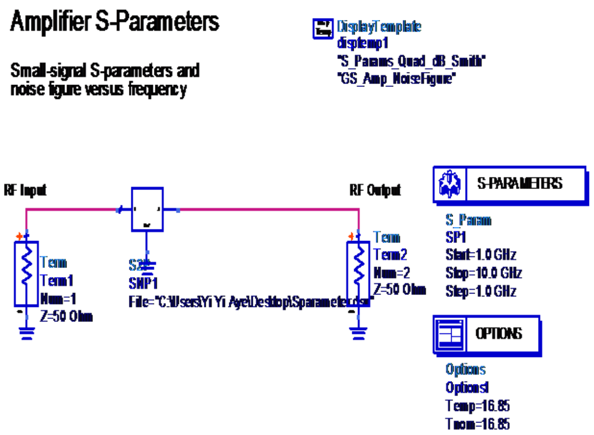

Fig.5. Simulation for S-parameters model of ATF34143.

The Rollett's stability factor of the model being stable or unstable within the operating frequency is presented in Fig.6. The stability factor K at 6GHz is (1.09). The simulation result and calculation result are the same. Different simulation results are presented in figures 7, 8 and 9.

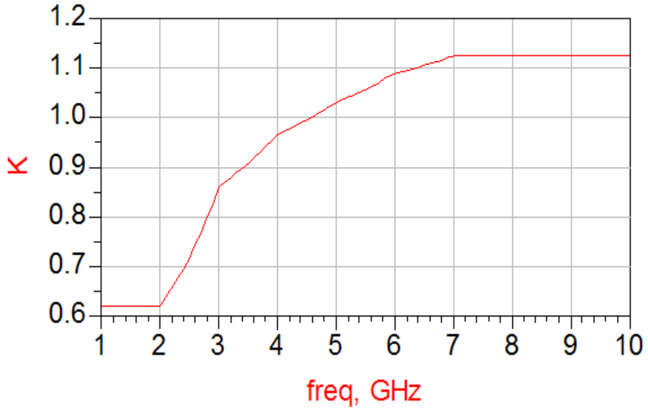

Fig.6. Simulation result for stability K factor.

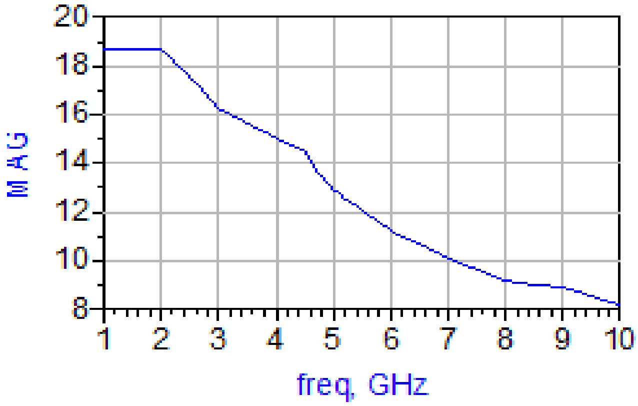

Fig.7. Simulation result for MAG.

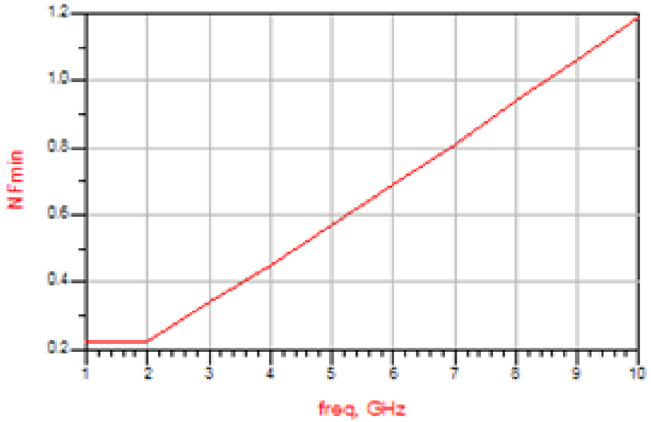

Fig.8. Simulation results of Noise Figure(min).

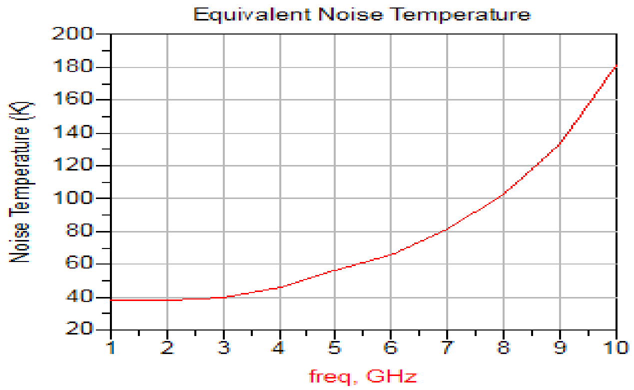

Fig.9. Simulation results of Noise temperature.

V. CONCLUSION

In this paper, a LNA at 6GHz for satellite transponder has been designed with HEMT (Low noise pseudomorphic) ATF34143. The simulation for design process has been carried by using the Advanced Design System (ADS) tool from Agilent Technologies. The presented LNA design is able to provide the maximum available gain (MAG) 11.23dB and minimum noise figure NF (min) is 0.7dB. The simulation result of minimum noise figure is less than calculation result. So simulation results are satisfied. Transistor selection is the most important step in an LNA design. The simulation result shows that the stability factor (K) is greater than 1 with the desired frequency 6GHz. It can be said that the selected component is unconditionally stable at 6GHz. This LNA design provide minimum noise and maximum gain

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