Performance Analysis of Unilateral & Bilateral Methods of Microwave Amplifier Based On S-Parameters

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***Abstract* - This paper presents design aspects of transistor Low Noise Amplifier. Microwave amplifier providing desired gain is designed with the help of smith chart & S- parameters based techniques using unilateral figure of merit &bilateral figure of merit methods. The aim of proposed work is to present two methods of microwave amplifier designing comparatively starting from S-parameters on the other hand to use one of the methodology either unilateral or bilateral whichever is applicable for designing & development of LNA operating at frequency range 3.3 GHz to 3.8GHz & noise figure targeted less than 2 dB while gain is more than 10 dB for Wimax application. Also for optimum performance two techniques i.e. Feedback &Balanced Amplifier are used. The proposed amplifier is designed and simulated using AWR Microwave Office, AppCAD & RFSim99 softwares.**

***IndexTerms*-S-parameters,Gain,LNA,AWR,Wimax**

I. Introduction

Transistor amplifiers can be used at frequencies in excess of 100 GHz in a wide range of applications requiring small size, low noise figure, broad bandwidth, and medium to high-power capacity. The S parameters of a given microwave transistor can be derived from transistor equivalent circuit models based or they can be measured directly. The primary application for which amplifier is to be designed is WiMax. It stands for Worldwide Interoperability for Microwave Access. WiMAX is a second-generation protocol that allows for more efficient bandwidth use, interference avoidance, and is intended to allow higher data rates over longer distances.

1.1 Project Overview & Scheme of Implementation:

The final stage of design involves building matching networks around the transistor which optimize the transistor for best noise performance. Transistor ATF-54143 S parameter model from Avago Technology is used to design & simulate the LNA as it meet the specifications and recommended by Avago Technology .The combination of high gain, high linearity and low noise makes the transister ideal for low noise amplifier in the 450 MHz to 6 GHz frequency range. Amplifier can be considered as a two port network. The design goals for ideal microwave amplifier are as follows:

- To get stable gain (No oscillations).
- To get uniformity of gain over specified frequency range.
- To get maximum power gain.
- To get minimum noise figure.
- To get Input & output VSWR close to unity.

II. LITREATURE REVIEW

M.H. Misran, et al. [7] Presented the paper "Design of LNA for WiMax Application".He designed a single stage LNA by adding an input and output matching and DC bias in the transistor. The LNA design is test with two technique of broadband amplifier design which is a Feedback Amplifier and Balance Amplifier. For input and output matching of the component, microstrip stub element matching is used. The length and distance of the stub matching are found by calculation. The gain and noise figure are affected when the stub matching element is inserted in the design. From two of the design, the Feedback Amplifier design gave the best performance.Giancarlo Lombardi, et al. [1] Presented the paper "Criteria for the Evaluation of Unconditional Stability of Microwave Linear Two-Ports:A Critical Review and New Proof". A critical review of the different criteria used to verify the unconditional stability of active two-port networks has been presented. The problem of unconditional stability for active two-port networks has been widely discussed in literature. A geometrical condition involving the stability circles and the Smith circle is generally found.

George Fikioris, et al. [3] presented the paper "Analytical Studies Supplementing the Smith Chart". This paper is an analytical study focusing on formulas that can enhance understanding of transmission lines. In deriving the formulas, mathematical techniques that can benefit students are employed. Also smith chart & some basic problems connected to lossless terminated transmission lines were studied analytically. José R. Pereira, et al. [6] presented the paper" Bandwidth Analysis of a Single-Stub

Matching System Using the Smith Chart". The transmission-line examples of the matching and width of a single-stub impedance-matching system are explained. Also Matlab scripts developed by the author for stub matching are useful for graphical calculations.

III. FOUNDATION OF DESIGN: UNILATERAL VS. BILATERAL METHODOLOGY

3.1 S-Parameters

S-parameters are a valuable aid both for collecting data for a transistor and then using the data to predict performance and design an amplifier circuit. The values of S parameters depend not only upon the properties of the transistor but also upon the source and load circuits used to measure them. This is because they measure transmitted and the source and load used to test it. S-Parameters known as scattering parameters which are high frequency parameters. In two ports network load & source mismatch causes reflection; at that instant S-parameters comes into picture.
Scattered waves (i.e. reflected & transmitted wave amplitude) are linearly related to incident wave amplitude.The matrix describing the linear relationship is known as scattering matrix or [S]. If Reflection Coefficient $|\Gamma| > 1$ then this is the condition for oscillation. Also If $|\Gamma| < 1$ then this is the condition for amplification. If $\Gamma L\ \Gamma L = 0$ then this is the matched condition [3].

3.2 Actual Methodologies

The amplifier could be matched for a variety of conditions such as low noise applications, unilateral case and bilateral. The formulas for each condition are different.

A. Unilateral Assumption

$$U = \frac{|S11||S12||S21||S22|}{(1-|S11|^2)(1-|S22|^2)}$$

$$\frac{1}{|1+U|^2} < Gt\backslash Gtu(max) < \frac{1}{|1-U|^2} \text{........(3.2.1)}$$

If error lies in $\pm 0.5\ dB$ unilateral mode is valid otherwise its case of bilateral design. In the unilateral case, we set

$$S12 = 0$$

B. Bilateral Assumption

The relation for Γ_S is,

$$\Gamma_S = \frac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} \text{ .... (3.2.2)}$$

$$\text{Where, } B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \text{ .... (3.2.3)}$$

$$C_1 = S_{11} - \Delta S_{22}^* \text{ .... (3.2.4)}$$

Similarly, we obtain Γ_L as,

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} \text{ .... (3.2.5)}$$

$$\text{Where, } B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \text{ ....(3.2.6)}$$

$$C_2 = S_{22} - \Delta S_{11}^* \text{ ....(3.2.7)}$$

IV. DESIGN APPROACH OF LNA

To arrive at a balance between noise figure, gain the device drain source current was chosen to be 60 mA with a 3 V drain-to-source voltage, the gate-to-source voltage was 0.59 V. The S-Parameters for centre frequency 3.5 GHz from simulations of AWR,

$S_{11} = 0.59531 < 149.49^0$
$S_{12} = 0.084715 < 21.523^0$
$S_{21} = 4.4315 < 42.261^0$
$S_{22} = 0.09583 < -169.43^0$

$S_{12} \neq 0$ so we have to check unilateral assumption.

Step1:

$K - \Delta$ Test

$\Delta = S_{11}S_{22} - S_{12}S_{21}$
$\Delta = 0.373 < 107.4$

$$\Delta = 0.3735 < 107.4^0$$

$$K = \frac{1 + |\Delta|^2 - |S11|^2 - |S22|^2}{2\,|S12S21|}$$

K=1.033

As K>1, Δ<1 DUT is unconditionally stable.

Step2: Unilateral Assumption

$$U = \frac{|S11||S12||S21||S22|}{(1 - |S11|^2)(1 - |S22|^2)}$$

On Substitution values, we get

U=0.04

$\frac{1}{|1+U|^2}$=10log (0.90) = -0.59dB & $\frac{1}{|1-U|^2}$ = 10log (1.10) =0.63 dB

As error does not lie in $\pm 0.5\ dB$ .So unilateral mode is not valid .So it is the case of **bilateral design**.

Step3: Matching network designed using stub

So using bilateral method,
From equations (3.2.2) to (3.2.7),

Γ_L = 0.671<100.5

Γ_S = 0.847< -152.8

A microstrip stub element matching is used in both the input and output of the LNA. To design the stub matching, the length of the stub, *l* and the distance of the stub from the load, *d* need to be found.

Final values of stubs from chart calculations

1. For OMN(Output Matching Network)
   d=0.2422λ & l=0.3210 λ

2. For IMN(Input Matching Network)
   d=0.063λ & l=0.2120 λ

The λ can be found from FR4, dielectric constant is 4.6 and thickness d is 1.6mm.So λ is 0.045mm.

V. SOFTWARE ASPECTS: SIMULATIONS & RESULT ANALYSIS

After designing, verification of values is done by two tools i.e. RFSim99 & App CAD Provided by Agilent Technologies. Stability Circles are observed using RF Sim99 & Tabular values are verified by App CAD.

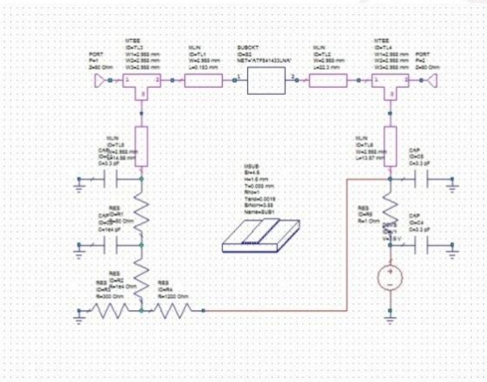

Fig 5.1: Single Stage LNA using AWR

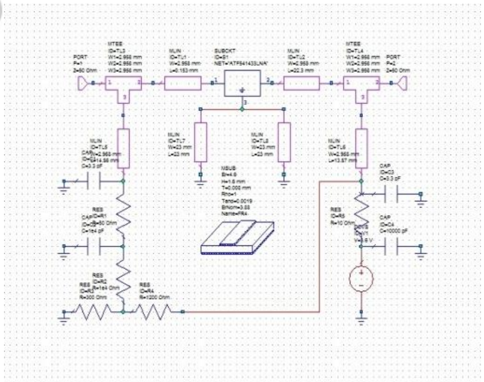

Fig 5.2: With Feedback Amplifier (Without VIA)

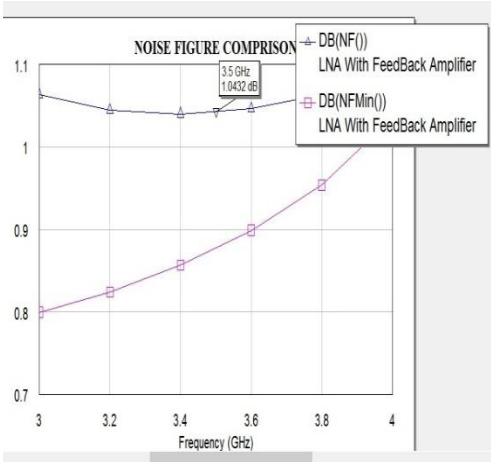

Fig 5.3: Without VIA NF Analysis

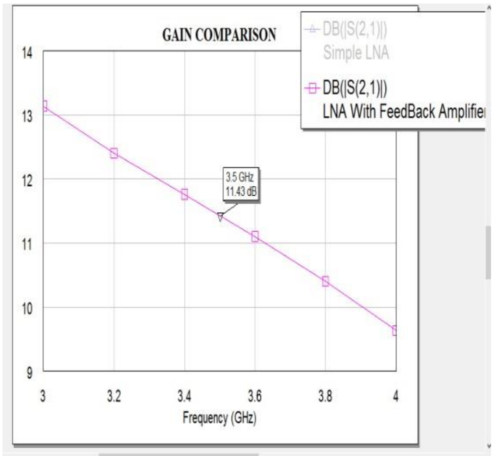

Fig 5.4: Without VIA Gain Analysis

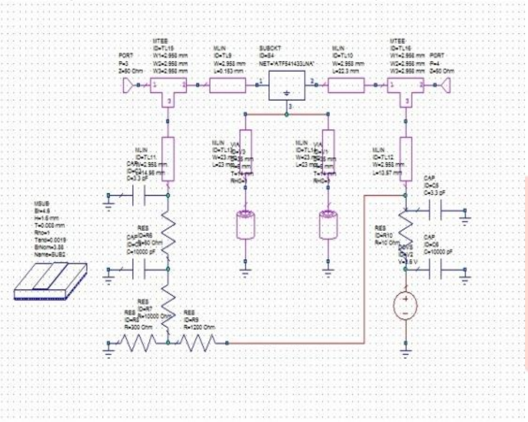

Fig 5.5: With Feedback Amplifier (With VIA)

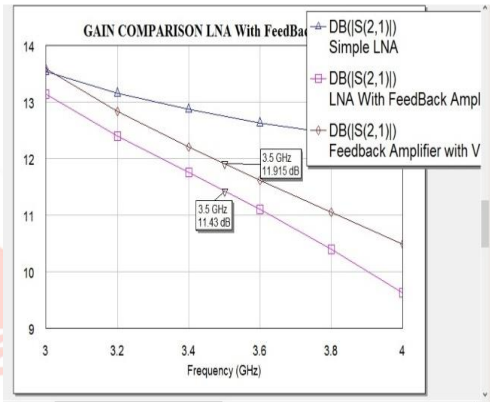

Fig 5.6: With VIA Gain Analysis

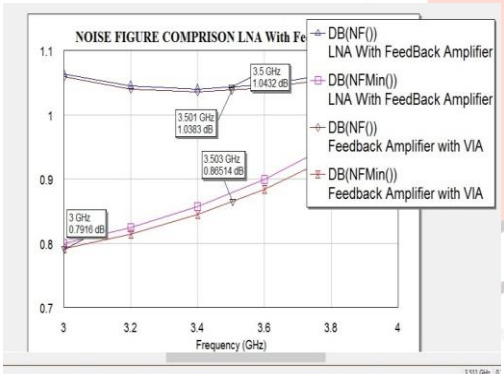

Fig 5.7: With VIA NF Analysis

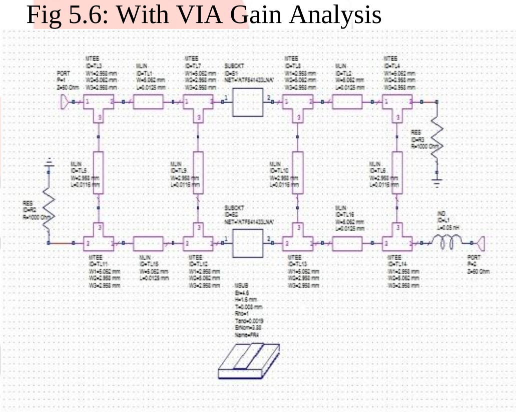

Fig 5.8: LNA with Balance Amplifier

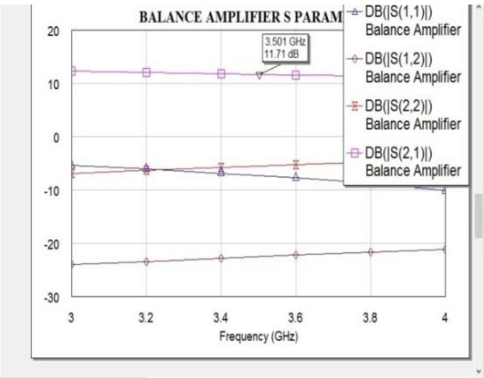

Fig 5.9: Gain Analysis Balance Amplifier

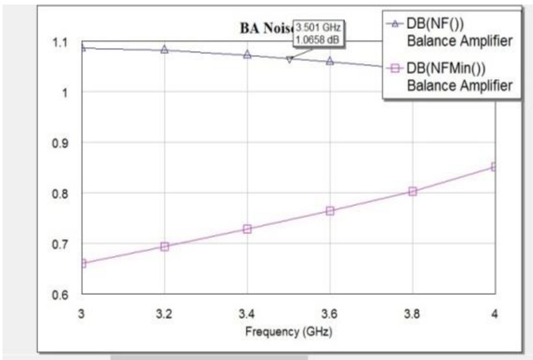

Fig 5.10: NF Analysis Balance Amplifier

Table 5.1: Comparison table of Gain & Noise Figure for optimum performance at 3.5GHz

Feedback Amplifier (without VIA)		Feedback Amplifier (with VIA)		Balance Amplifier	
Gain(dB)	Noise Figure(dB)	Gain(dB)	Noise Figure(dB)	Gain(dB)	Noise Figure(dB)
11.43	1.043	11.91	0.86	11.71	1.06

VI. CONCLUSION

The methods of the amplifier designing was studied & simulated. A single stage LNA is designed using bilateral figure of merit starting from S-parameters.For optimizing LNA performance two technique of broadband amplifier design which is a Feedback Amplifier and Balance Amplifier implemented. From these two designs, the best technique applied is Feedback Amplifier with VIA, which gives the most satisfactory results for its gain and noise figure. The Feedback Amplifier gives the gain as 11.91dB and Noise Figure as 0.86dB which satisfies the specification.

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