Design and Comparison of Different Matching Techniques for Low Noise Amplifier Circuit

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Abstract

This paper describes the design of Low Noise Amplifier (LNA) circuits with different types of matching circuits at the input side and output side at 6 GHz. This paper compares the results of all possible combinations of 'T' and 'L' type matching circuits. The designed circuit is simulated with Advanced Design System (ADS) software. Each circuit is simulated for, with and without stabilizing circuit and feedback circuit. RLC series circuit is applied as feedback circuit and to improve the stability of the LNA circuit. Of all LNA matching circuits the T- L matching gives better results in the stabile region than L-L matching, L-T matching and T-T matching. Under stability condition forward gain and noise figure of T-L match is 14.14 dB and 1.81 dB which is better than L-L match as 10.39 dB and 2.15 dB , L-T match as 5.237 dB and 2.47 dB and T-T match as 6.468 dB and 3.9 dB.

Keywords- Advance Design System (ADS), Low Noise Amplifier (LNA), Noise Figure (NF), T-matching network, L-matching network.

I. INTRODUCTION

Designing amplifiers for a minimum noise figure then becomes simply a matter of setting the optimum condition for a particular transistor. Based on S-parameters of the transistor and certain performance requirements, a systematic procedure is developed for the design of the LNA. In LNA design, the most important factors are low noise, moderate gain, matching and stability. In the designed LNA of this paper, different types of matching sections have been designed and simulated using Advanced Design Software (ADS).

II. LITERATURE SURVEY

Recently, Low Noise Amplifiers (LNAs) were designed and simulated by many researchers [1]-[8].In [1] a novel method is used for isolation of DC circuits from AC signals. Radial stubs are used for this isolation. Since radial stubs have low impedance at low frequencies and it generates high impedance at higher frequency.

Design of wide band Low Noise Amplifier (LNA) with a novel feedback mechanism using intrinsic gate- drain capacitor is dealt in [2]. By means of a fine tuning of the transistors output RC loading impedance and source inductance, a transistor's input reflection coefficient and noise temperature can be greatly improved over broad bandwidth.

In paper [3] presents an analysis and design of wide band Low Noise Amplifier (LNA) based on cascade configuration with resistive feedback. Wideband input matching was achieved using a shunt –shunt feedback resistor in conjunction with a proceeding π-match network.

A symbolic approach and an optimization algorithm for the optimal design of Low Noise Amplifiers (LNAs) through S-parameters have been discussed in [4]. This paper gives the idea of computing automatically the symbolic expression of S-parameters using coates diagraph technique.

A novel method of designing low power wide band Low Noise Amplifier (LNA) using a sub threshold technique is discussed in paper [5]. The Low Noise Amplifier (LNA) is built with common-gate (CG) input stage for wideband input matching and a common source (CS)- common gate (CG) cascade stage for gain boosting and the power reduction is achieved by driving the front end common gate(CG) transistor in sub-threshold (low current) region and here the input matching is done by LC circuit.

In [6] the effect of gate inductance on noise figure of designed Low Noise Amplifier (LNA) is dealt. In this paper [6] the effect of L_g is considerably less to noise figure of Low Noise Amplifier (LNA) designed based on the noise optimization technique.

In [7] the noise figure in low noise radio frequency cascade amplifiers using narrow band input impedance matching is analyzed. The matching network is as inherently belonging to the low noise amplifier. A parallel-series matching network has been proposed in [7] which allows dominant noise contributions to be reduced and very low noise figure is to be achieved.

In [8] a new technique has been employed for improving the stability of the Low Noise Amplifier (LNA). A RLC series circuit has been employed to make the LNA stable. Also a RLC feedback circuit is used between the gate terminal and drain terminal operating the LNA in the stable region.

III. EQUIVALENT CIRCUIT OF MICROWAVE MESFET

Most microwave amplifiers today use Gallium Arsenide (GaAs) Field-Effect Transistor (FETs). They can presently be used at frequencies up to 100 GHz in a wide variety of applications requiring low noise figure, broad band width and medium power capacity [9] [10]. Knowledge of the equivalent circuit of a MESFET is very useful for the device performance analysis (gain, noise, etc…) in designing of microwave circuits. In this paper low noise GaAs MESFET NE 76000 has been used for the design of LNA. The NE 76000 provides a low noise figure and high associated gain though K-Band. Fig.1 show the equivalent circuit of this transistor which has been recovered by NEC Company for frequency range of 1 GHz to 26 GHz [11].

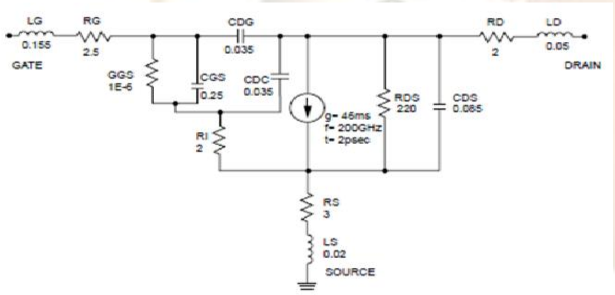

Fig. 1 Linear Model of NE 76000 Transistors [15]

IV. DC BIASING

In order to design a low noise device, the transistor must be DC biased at an appropriate operating point. These depends of the application (low noise, high gain, high power), and the type of the transistor (FET, HEMT, etc) [12]. Accounts both source and load mismatch. Thus from [13], can be define separate effective gain factors for the input (Source) matching network, the transistor itself and the output (load) matching network as follow . Fig 2 shows model of a DC biasing circuit.

V_d (drain voltage) = 3V and I_{ds} (drain-Source current) = 10 mA. The biasing point is obtained by using a Vg (Gate Voltage) range from -0.6 V to -0.3 V and it gives -0.4V as DC operating point by using the circuit shown in Fig 2.

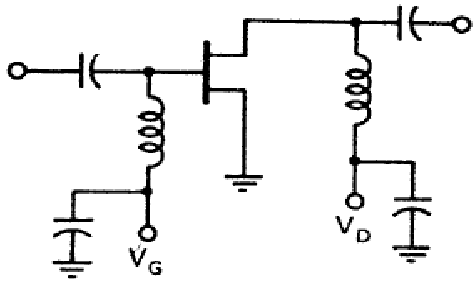

Fig. 2 Basic DC biasing network [12]

A. Single Stage Amplifier

A single stage microwave transistor amplifier can be modeled by the circuit in Fig. 3, where a matching network is used both sides of the transistor to transform the input and output impedance Z_0 to the source and load impedance Zs and ZL. The most useful gain definition for amplifier design is the transducer power gain, which accounts both source and load mismatch. Thus from [13], can be define separate effective gain factors for the input (Source) matching network, the transistor itself and the output (load) matching network as follow:

$$G_S = \frac{1 - |\Gamma_s|^2}{1 - |\Gamma_{IN}\Gamma_s|^2} \tag{1}$$

$$G_0 = |S_{21}|^2 \tag{2}$$

$$G_L = \frac{1 - |\Gamma_L|^2}{1 - |S_{22}\Gamma_L|^2} \tag{3}$$

Then the overall transducer gain is $G_T = G_s G_0 G_L$. The effective gains from GS and GL are due to the impedance matching of the transistor to the impedance Z_0.

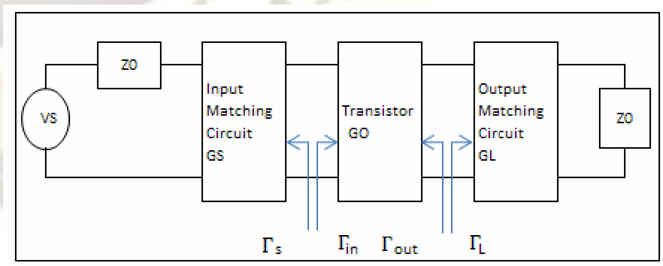

Fig.3 The General Transistor Amplifier Circuit [12]

B. Stability Consideration

The stability of an amplifier, or its resistance to oscillate, is a very important consideration in a design and can be determined from the S parameters, the matching networks, and the terminations. In the circuit Fig. 3, oscillations are possible when either the input or output port presents a negative resistance. This occurs when in $|\Gamma_{IN}| > 1$ or $|\Gamma_{OUT}| > 1$. These because of in and out depend on the source and load matching networks. While, the stability of the amplifier depends on S and L as presented by the matching networks. Alternatively, it can be shown that the amplifier will be unconditionally stable if the following necessary and sufficient conditions are met [14]:

$$K = \frac{1-|S_{11}|^2 - |S_{11}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} > 1 \qquad (4)$$

$$\text{and} \qquad |\Delta| > 1 \qquad (5)$$

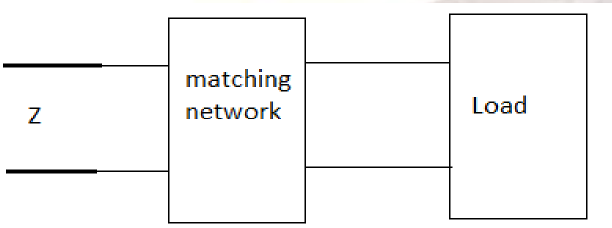

Fig. 4 A lossless network matching networks arbitrary load impedance to a transmission line [12]

In this paper an RLC series circuit is used as stability circuit for LNA circuit in bringing it to the stable region.fig.5 shows a sample of RLC series stability circuit.

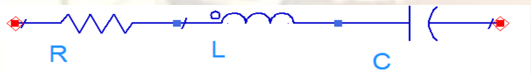

Fig.5 Stabilizing Circuit for LNA.

V. MATCHING NETWORK

The basic idea of the impedance matching is illustrated in Fig. 4, which shows an impedance matching network placed between load impedance and transmission line. The need for matching network arises because amplifiers, in order to deliver maximum power to a load, or to perform in a certain desired way, must be properly terminated at both the input and output ports. The matching network is ideally lossless to avoid unnecessary loss of power and is usually designed so that looking into the matching network is Z_0. Several types of matching network are available, however factors likes complexity, bandwidth, implementation and adjustability need to be considered in the matching network selection. In this paper different matching circuits is discussed such as 'L'
Matching, and 'T' matching circuits and its all possible combinations.

Case: I 'L' Type Input Matching and 'L' Type Output Matching LNA Circuit

In Fig.7 the 'L' type matching is used at the input as well as on the output side. RLC series circuit is designed and used to improve the stability of the circuit. For feed back again a RLC series resonance type is used.

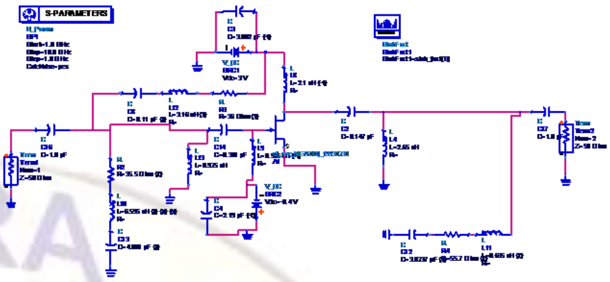

Fig. 6 'L' Type Input Matching and 'L' Type Output Matching LNA Circuit

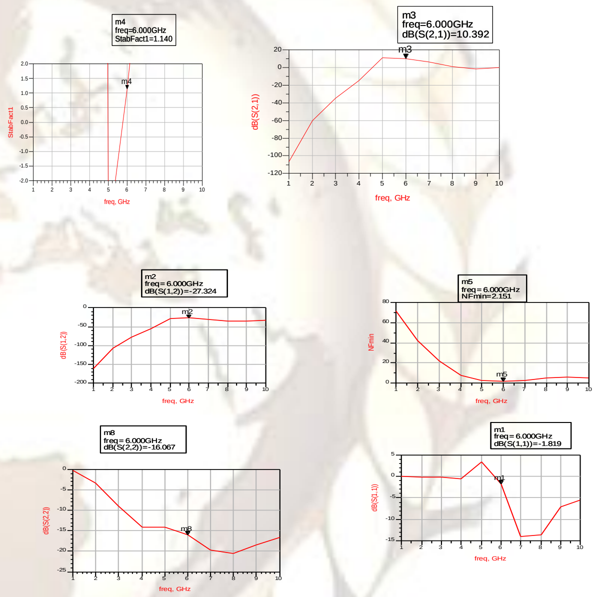

Fig.7 S_{11}, S_{22}, S_{12}, S_{21}, NF_{min} Vs freq for L-L Matching

After the simulation of the circuit shown in Fig 6, the results are shown in Fig 7. The stability and forward gain are as 1.14 and 10.392 dB. The output reflection coefficient is -16.067 dB and reverse transmission coefficient is -27.324 dB, input reflection coefficient is -1.819 dB and the stability of the transistor amplifier is as 1.14 which satisfies the equation (4).Thus the stability is maintained at more than one as per equation (4) with noise figure touches slightly more than two decibel point and the forward gain reduced to 10.394 dB.

Case: II 'L' Type Input Matching and 'T' Type Output Matching LNA Circuit

In Fig 8 the 'L' type matching is used at the input and on the output side the 'T' type matching is used.

RLC series circuit is designed and used to improve the stability of the circuit. For feed back again a RLC series resonance type is used.

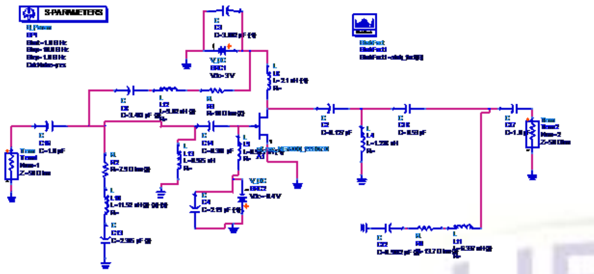

Fig. 8 'L' Type Input Matching and 'T' Type Output Matching LNA Circuit

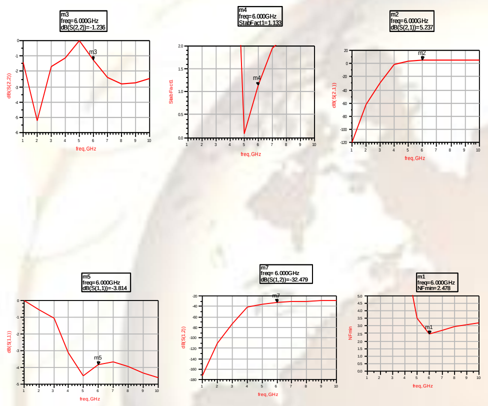

Fig.9 S_{11}, S_{22}, S_{12}, S_{21}, NF_{min} Vs freq for L-T Matching

After the simulation of the circuit shown in Fig 8, the results are shown Fig 9. The stability, output reflection coefficient and forward gain are shown in Fig 4.50 as 1.133, -1.236 dB and 5.237 dB. The input reflection coefficient is -3.814 dB, reverse transmission coefficient is -32.479 dB and minimum noise figure is 2.478 dB. The stability of the transistor amplifier is as 1.133 which satisfies the equation (4).Thus the stability is maintained at more than one as per equation (4) with noise figure touches almost two and half decibel point while the forward gain drastically reduced to 5.237 dB.

Case: III 'T' Type Input Matching and 'L' Type Output Matching LNA Circuit

In Fig 8 the 'T' type matching is used at the input and on the output side the 'L' type matching is used. RLC series circuit is designed and used to improve the stability of the circuit. For feed back again a RLC series resonance type is used.

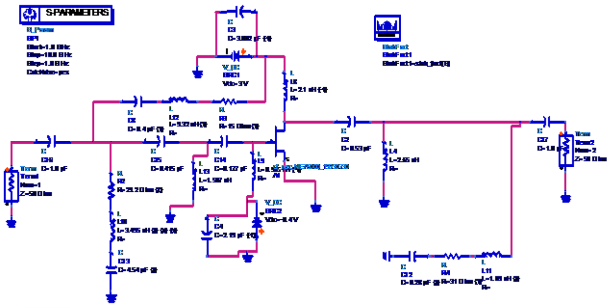

Fig. 10 'T' Type Input Matching and 'L' Type Output Matching LNA Circuit

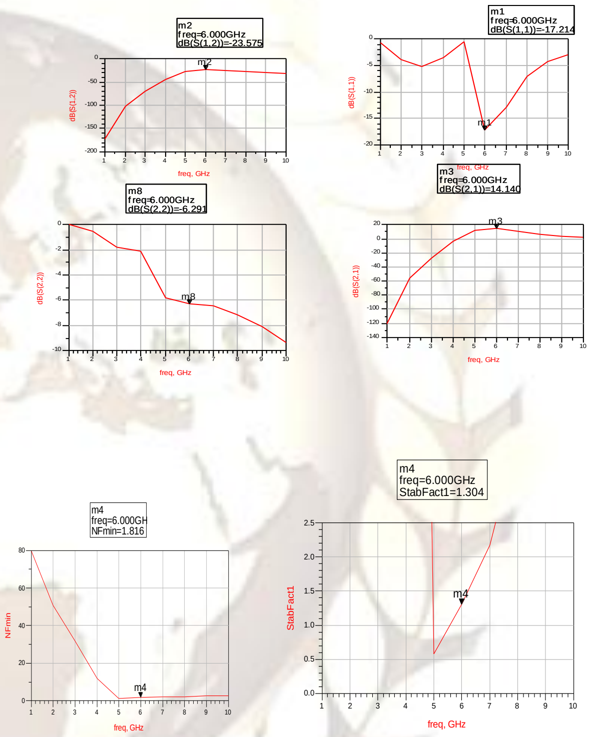

Fig.11 S_{11}, S_{22}, S_{12}, S_{21}, NF_{min} Vs freq for T-L matching

After the simulation of the circuit shown in Fig 10, the results are shown in Fig 11.The forward gain is 14.14 dB, the output reflection coefficient is -6.291 dB and reverse transmission coefficient is -23.575 dB and also the input reflection coefficient is -17.214 dB. The stability and minimum noise are as 1.304 and 1.816 dB. Thus the stability is maintained at more than one as per equation (4) with almost double increasement in noise figure.

Case: IV 'T' Type Input Matching and 'T' Type Output Matching LNA Circuit

In Fig 7 the 'T' type matching is used at the input as well as on the output side. RLC series circuit is designed and used to improve the stability of the circuit. For feed back again a RLC series resonance type is used.

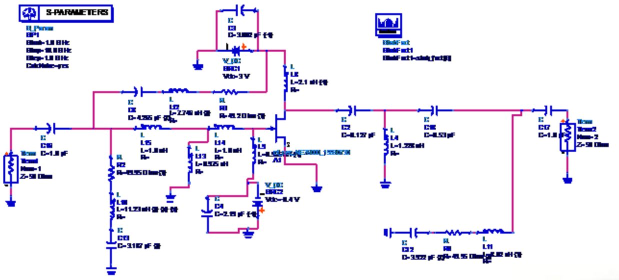

Fig 12 'T' Type Input Matching and 'T' Type Output Matching LNA Circuit

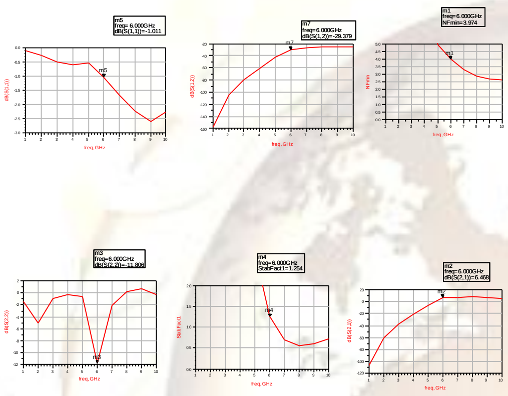

Fig.13 S_{11}, S_{22}, S_{12}, S_{21}, NF_{min} Vs freq for L-L matching

After the simulation of the circuit shown in Fig 12, the results are shown in Fig 13. The stability, output reflection coefficient and forward gain are as 1.254, -11.808 dB, and 6.468 dB. The input reflection coefficient is -1.011 dB, reverse transmission coefficient is -29.379 dB and minimum noise figure is 3.974 dB. The stability of the transistor amplifier is as 1.254 which satisfies the equation (4).Thus the stability is maintained at more than one as per equation (4) with noise figure touches almost four decibel point while the forward gain drastically reduced to 6.468 dB.

VI. SIMULATION RESULTS

In this paper, combination of different input and output matching networks have been developed for a Low Noise Amplifier (LNA) circuit for 6 GHz range and simulated using ADS software [13] and the results are shown in Table I.

Table .I Comparative Results of LNA Circuit (with and without Stabilizing circuit) using different matching techniques.

	L-L		L-T		T-L		T-T	
	WO. SC	W. SC	WO .SC	W. SC	WO. SC	W. SC	WO. SC	W. SC
S_{21}	16.280	10.39	13.539	5.237	16.296	14.14	13.588	6.468
S_{12}	-14.17	-27.3	-16.91	-32.5	-14.15	-23.5	-16.864	-29.4
S_{22}	-4.370	-16.1	-1.79	-1.24	-5.537	-6.29	-2.120	-11.8
S_{11}	-2.922	-1.82	-11.25	-3.81	-2.937	-17.2	-11.923	-1.01
K	0.409	1.14	0.409	1.133	0.409	1.304	0.409	1.254
NF	0.906	2.15	0.906	2.478	0.906	1.816	0.906	3.974

VII. CONCLUSIONS

The simulation results of all possible combinations of 'L' and 'T' type matching circuits are shown in Table I for with(W) and without(WO) stabilizing circuit(SC). From Table I the 'T' type input matching with 'L' type output matching gives better results without much degradation in terms of forward gain, noise figure, stability point of view. It gives gain as 16.3 dB, noise figure 1.8 dB while improving stability from 0.41 to 1.3. Other parameters like output reflection coefficient (S_{22}) is -6.3 dB, input reflection coefficient (S_{11}) is -17.2 dB and reverse transmission coefficient (S_{12}) is -23.5 dB also comparatively better than other matching sections. Whenever there is an improvement in stability other matching circuits exhibits much degradation in gain and more than double increments in noise figure from the results of LNA without stabilizing circuit.

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