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Low Noise Amplifier for 2.45 GHz Frequency Band at 0.18 µm CMOS Technology for IEEE Standard 802.11 b/g WLAN

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Abstract— This paper presents the design of low noise amplifier (LNA) at 2.45 GHz and integrated at 0.18 µm RF CMOS process technology. This type of LNA at 2.45 GHz is use in the Bluetooth receiver. The proposed method is useful to optimize noise performance and power gain while maintaining good input and output matching. The amplifier is designed to be used as first stage of a receiver for wireless communication. The main aim of designer is to achieve low noise figure with improved gain with the help of CMOS technology by using single stage n-MOS amplifier. The simulation results show a forward gain of 14.0 dB, a noise-figure of 0.5 dB and stability factor is approximate unity, in which the circuit operates at 14.2 mA drain current with supply voltage of 3.5 V and biasing voltage of 1.5 V.

Index Terms— Advanced design system, Low noise amplifier, Input and output matching, RFIC, VLSI

I. Introduction

A low noise amplifier (LNA) requirement is important with regard to system performance due to growth of modern communication systems [1-4]. Low noise amplifier is use as the first block in front-end of receiver in wireless communication to amplify the desired band of signals without adding significant noise to the signal. This amplifier is a non-linear characteristic device and causes two main problems one is blocking and other is inter-modulation [5-7]. Low noise amplifier is used to reduce the external as well as internal noise [8]. The LNA can be designed and fabricated in user defined CMOS technology as topologies are the generalized schematic of circuit [9, 10]. The complete circuit can be designed using analog RF circuit designing procedure for desired frequency band and specifications. We have used an inductive source degenerated LNA topology for the application in WCDMA have minimum noise figure [11]. The design of matching network circuit is called the topology of LNA. The interference always occurs at the receiver end. Signal amplification is typically focused at the analog baseband stage.

The circuit requires current reusing and transformer feedback techniques to reduce the current consumption while optimizing the input matching and noise performance [12]. The common-gate transformer feedback transconductance boosting is used to minimize the current consumption then gain is doubled due to the sum of n-MOS and p-MOS transconductances. The main function of the LNA is mutually dependent on a set of design parameter values. LNA design with deep n-well into a fully integrated LNA with forward biasing exhibits better power gain and noise-figure performance [13]. The smallest signal that can be received at the receiver end whose defines the receiver sensitivity. The largest signal can be received by a receiver establish the upper power level limit whose can be controlled by the system while preserving voice quality.

The RF front-end circuit is shows in figure 1. The LNA follows the antenna and its output drives the mixer. It is first block after antenna in receiver front-end [14, 15]. Its main function is to amplify low signals without adding noise.

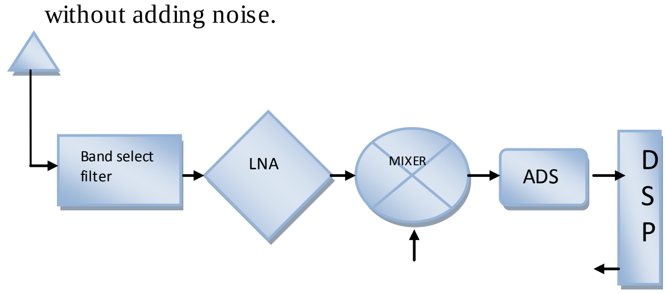

Fig.1 RF front-end circuit

In this paper, we have designed a single stage LNA circuit and input/output matching technique for IEEE 802.11 and Bluetooth standard over a frequency band of 2.45 GHz at 0.18 µm CMOS technology. Bluetooth supports a very short range approximately 10 meters. The proposed CMOS LNA is designed for IEEE standard 802.11(b) and 802.11(g). The organization of the paper is as follows: The IEEE standard WLAN are discussed in the Section II. The designs of LNA are given in the Section III and the simulated results are discussed in the Section IV. Finally, Section V concludes the work.

II. IEEE Standard (802.11b/g) WLAN

The Institute of Electrical and Electronics Engineers (IEEE) created the WLAN 802.11(b) standard in Sept. 1999. Standard 802.11(b) supports the bandwidth up to 11 Mbps. These have lowest cost, signal range is 35 meter indoor and 140 meter outdoor and not easily obstructed.

In June 2003, WLAN supports the standard 802.11(g). These standard attempts to combine the best of both 802.11(a) and 802.11(g). This standard 802.11(g) supports the bandwidth up to 54 Mbps [16]. These have fast maximum speed and signal range is also better. Table I summarizes the important specification of WLAN standards 802.11(b) and 802.11(g).

Table I Summarized WLAN 802.11 (b/g) Standards

	IEEE Standard 802.11(b)	IEEE Standard 802.11(g)
Release	Sept. 1999	June 2003
Frequency	2.4 GHz	2.4GHz
Max. data rate	11 Mbps / 5.5 Mbps	54 Mbps / 24 Mbps / 12 Mbps
Modulation	DSSS	DSSS, OFDM
Indoor range	35 meter	38 meter
Outputrange	140 meter	140 meter

III. LNA Circuit Design

The LNA have mainly three sections to be designed in complete circuit.

1. Input matching network
2. Main transistor section
3. Output matching network

The input matching network is used to make the input return loss (S_{11}) minimized without introducing additional noise. The input matching circuit that terminates the transistor to gamma optimum (Γ_{out}) which represents the input impedance of the transistor for the best noise matches. Attenuation is lowest at 77 Ω and power handling capability is highest at 30 Ω. So, the compromise between these two parameters gives the 50 Ω resistive input impedance to design a LNA [17].

Main transistor section ensures a high gain, high linearity and low noise factor at the time of input and output matching. The last step in LNA design involves output matching. The input and output impedance matching is required to maximize the power transfer and minimize the reflections. Smith chart is used for impedance matching. According to maximum power transfer theorem, maximum power delivered to the load when the impedance of load is equal to the complex conjugate of the impedance of source ($Z_S = Z_L^*$).

In the fully integrated two stages LNA, use the resistive shunt-feedback, simplified band-pass filter circuit to achieve wide input impedance matching [18, 19]. The cascoded CMOS topology is widely used in LNA designing to achieve the maximum gain. In the cascoded CMOS LNA, noise-figure (NF) and linearity of a low noise amplifier is directly affected by the gate width and gate-source voltage of common-source transistor. The circuit structure is shown in figure 2.

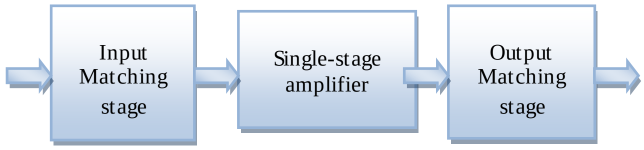

Fig.2 Low noise amplifier structure

This circuit structure of the proposed LNA consists of input matching stage, single stage amplifier and output matching stage. In this paper, we use the inductively degenerated common source topology as shown in figure 3.

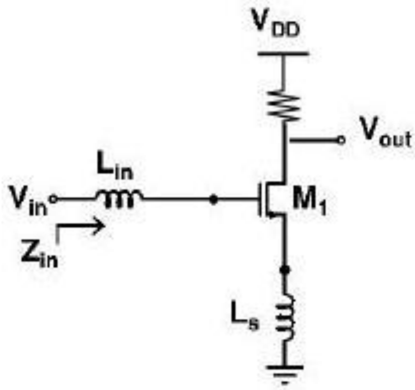

Fig.3 Single stage inductively degenerated common source configuration

This topology has been best choice for many frequency bands due to its noise and gain performance. By the use of changing the source degeneration inductor (L_S), we can be improved input matching (S_{11}). The input impedance of single-stage inductive degeneration CMOS LNA is expressed by ($L_{in}=L_g$):

$$Z_{in} = j\omega(L_g + L_s) + \frac{1}{j\omega C_{gs}} + \frac{g_m L_s}{C_{gs}} \quad (1)$$

For the input impedance matching, the gate-source capacitance (C_{gs}) of transistor is used. By the use of parallel LC network, it will neither increase power consumption nor degrade quality factor (Q_L) [19, 20]:

$$Q_L = \frac{1}{\omega_o C_{gs} z_o} \quad (2)$$

where ω_0 is the resonant frequency and is defined as in the following equation:

$$\omega_o = \frac{1}{\sqrt{(L_s + L_{in})C_{gs}}} \quad (3)$$

$$\omega_T = \frac{g_m}{C_{gs}} \tag{4}$$

After that condition, we can be drive output impedance of inductive degeneration CMOS LNA:

$$Z_O = \omega_T L_S \tag{5}$$

At resonance, the voltage across the capacitor and the short circuit output current is defined in equation:

$$V_{gs} = Q_L V_s \quad \text{and} \quad i_{out} = g_m V_{gs} \tag{6}$$

where g_m is the transconductance of the device.

A. Transconductance

The transconductance of the MOS transistor depends on the bias current and device geometry:

$$g_m = \sqrt{2k \frac{w}{L} I_D} \tag{7}$$

where $k = \mu_n C_{ox}$. The relationship of the input to the output of an amplifier usually expressed as a function of the input frequency is called the transfer function of the amplifier. The common-gate LNA achieves high gain and low noise-figure.

It realizes the input matching through a parallel LC network for fully integrated CMOS LNA with on-chip spiral inductors [3, 21, 22]. Inductive degeneration (L_S) also improves the linearity by use of a negative series feedback.

When we use current reuse topology in LNA then we can reduce the power consumption while preserve high-gain. But this topology requires a DC bias as well as biasing resistor then they will create extra noise and signal leakage [8]. The current reuse topology can be used with any circuit like common-source and common- gate.

B. S-parameters

It is refers to RF output voltage verses input voltage in the RFIC and describes the relationship between the two or more port network.

In the term of RFIC, $S_{11}$and S_{22} is called reflections coefficient. S_{21} and S_{12} are called transmission coefficient. S_{11} and S_{22} are used to calculate the input and output reflection in the circuits [23]. S_{21} and S_{12} are used to calculate the forward and reverse voltage gain in dB as shown in the figure 4.

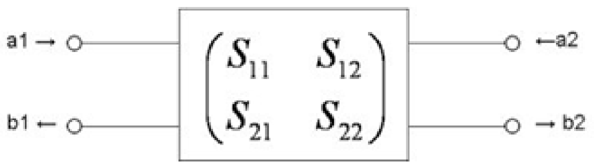

Fig.4 S-parameters of two port network

C. Impedance Matching

Impedance matching at input and output port done by using smith chart technique, by properly adjusting the value of inductance and capacitance at input and output side, we have managed to match impedance with the terminating resistance of 50 Ω. Γ_s and Γ_L is the source and load reflection coefficient respectively. Input and output reflection coefficient is Γ_{in} and Γ_{out} respectively shown in following equations:

$$\Gamma_{in} = s_{11} + \frac{s_{12}s_{21}\Gamma_L}{1 - s_{22}\Gamma_L} \tag{9}$$

$$\Gamma_{out} = s_{22} + \frac{s_{12}s_{21}\Gamma_s}{1 - s_{11}\Gamma_s} \tag{10}$$

D. Stability Factor (K)

Amplifier is not reliable when it is instable condition. The stability of a circuit is characterized by stern stability factor. The circuit is stable only when K>1 and Δ<1. When the input and output reflection coefficients are less than one then we determined the absolute stability factor:

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

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \tag{12}$$

When K<1, then Smith chart is stable but when the K<0, then the Smith chart is unstable [4].

E. Transducer Power Gain

It is the ratio of output signal to the input signal and also signals amplification capability of LNA. The CMOS LNA drives the transducer power gain whose power delivered to the load divided by power available from source:

$$G_T = \frac{1 - |\Gamma_s|^2}{|1 - s_{11}\Gamma_s|^2} |s_{21}|^2 = \frac{1 - |\Gamma_L|^2}{|1 - s_{22}\Gamma_L|^2} \tag{13}$$

F. Noise-Figure

It is the ratio of output SNR to the input SNR in dB:

$$NF(dB) = 10.\log \frac{SNR_i}{SNR_0} \tag{14}$$

In the cascaded form the noise-factor (F) is given as:

$$F_{total} = F_{LNA} + \frac{F_{after.LNA} - 1}{G_{LNA}} \tag{15}$$

G. Linearity

Linearity of LNA is most important in a wireless receiver to reduce the inter-modulation distortion. The linearity is expressed by the 1 dB compression point and inter-modulation product (IP_3). When the input signal is increased, a point is reached where the power of the signal is not amplified by the same amount as the smaller signal at the output. At this point where the input signal is amplified by an amount 1 dB less than the small signal gain, these are called 1 dB compression point. IIP_3 (input inter-modulation product) is proportional to the ratio of the first and third derivatives of the transfer characteristic. IIP_3 is expressed as:

$$IIP_3 = \sqrt{\frac{4}{3}\frac{|g_{m_1}|}{|g_{m_3}|}} \tag{16}$$

H. Spurious-free dynamic range (SFDR)

These are use as a specific measure of dynamic range between a lower bound and upper bound of the signal. The N_{oi} as the input referred noise power in dB. The input-referred IM_3 power N_0. SFDR is expressed as:

$$\begin{aligned} SFDR &= \frac{2}{3}[OIP_3 - N_o] \\ &= \frac{2}{3}[IIP_3 - N_{oi}] \end{aligned} \tag{17}$$

SFDR is bounded on one end by IIP_3 and on the other by the noise floor.

IV. Simulation Results

This simulation section presents the measured results of the single-stage inductive degenerated common source CMOS LNA whose operating at the 2.45 GHz frequency band. This is implemented based on 0.18 μm CMOS technology. The measured S-parameters are shown in figure 5 to figure 9.

The CMOS LNA was designed at 2.45 GHz. The forward gain (S_{21}) is 14.0 dB at 2.45 GHz frequency band shown in the figure 5. The designed LNA also shows a 0.5 dB noise-figure in figure 6. The input return loss (S_{11}) and output return loss (S_{22}) is -10 dB and -13 dB respectively shown in the figures 7 and figure 8. And the stability factor very closed to 1 dB is shown in the figure 9. The results shows that the $S_{11}<1$ and $S_{22}<1$ whose fulfils the stability condition. Figure the best impedance matching for high forward gain and low noise at 2.45 GHz frequency range.

The lowest F_{min} is 0.3 dB obtained at 2.7 GHz as shown in the figure 6. But we were working at 2.45 GHz so we use the value of noise-figure at 2.45 GHz.

A forward gain simulation was performed on the LNA, and results are shown in the figure 5. When we measured result better at frequency 2.6 GHz that is forward gain of approximately 15 dB and noise-figure of 0.3 dB. But we will see all result at 2.45 GHz, because this type of frequency used in many applications.

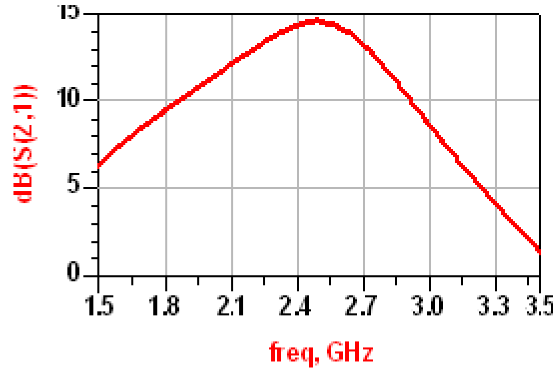

Fig.5 Power gain (S_{21}) of the LNA and achieves a forward gain (S_{21}) of 14.0 dB at 2.45 GHz.

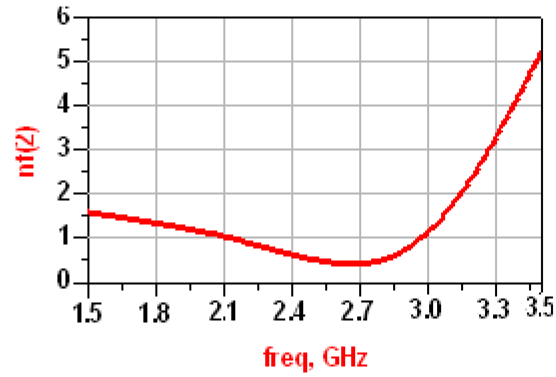

Fig.6 Noise figure of the LNA and achieves a NF of 0.5dB at 2.45 GHz.

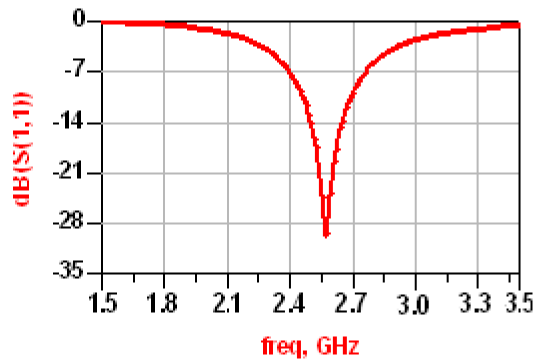

Fig.7 Input reflection coefficient (S_{11}) of the LNA. S_{11} is -10 dB at 2.45 GHz.

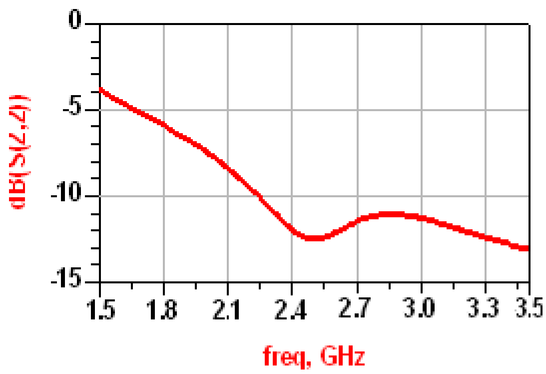

Fig.8 Output reflection coefficient (S_{22}) of the LNA. S_{22} is -13 dB at 2.45 GHz.

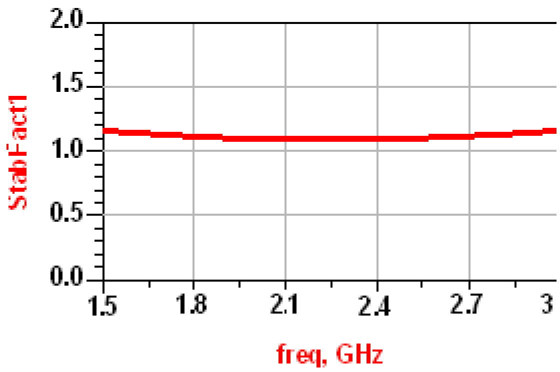

Fig.9 Stability factor (K) of an LNA at 2.45 GHz.

V. Conclusions

In this paper, design and implementation of a Low noise amplifier based on inductively degenerated common source topology at 2.45 GHz were presented. The LNA has been designed in a 0.18 µm CMOS technology. An ADS was used for circuit design and simulation and 0.18 µm CMOS technology are used. At 3.5 V supply, LNA achieves a forward gain, noise figure and reflection coefficient operating at 14.2 mA drain current. Summary of the proposed LNA performance is shown in Table II.

A better noise and gain performance were achieved. A power gain of 14.0 dB and noise figure of 0.5 dB were obtained for the proposed LNA. Input reflection (S_{11}) and output reflection coefficients (S_{22}) of -10 dB and -13 dB respectively were achieved. Low noise amplifier is used in IEEE 802.11b/g standards for wireless local area network. They are now also used for communication like Wi-Fi and Bluetooth applications [24-26].

Table II. Summary of the proposed LNA performance

Parameters	Measured Results
Frequency	2.45 GHz
Power gain (S_{21})	14.0 dB
Noise-figure (NF)	0.5 dB
Drain current	14.2 mA
Supply voltage	3.5 V

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