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A New Cascode Low Noise Amplifier (LNA) with Double Feedback Technique Architecture for Long Term Evolution (LTE) Application

Abu Bakar Ibrahim[1,*], Nurul Husna Kahar[1], Hafizul Fahri Hanafi[1], Ashardi Abas[1], Shamsul Arrieya Ariffin[1]

[1] Department of Faculty of Art, Computing and Creative Industry, Universiti Pendidikan Sultan Idris, 35900 Tanjung Malim Perak, Malaysia

ABSTRACT

The paper aims at designing a new cascode low noise amplifier (LNA) by using double feedback technique architecture for long term evolution (LTE). The objectives of this article is to display the improvement performance of gain with minimizing noise figure with innovative technique for realization of Long Term Evolution (LTE). The innovation technique with implementation double feedback technique architecture outline the possibility to improve the performance in various parameters such as bandwidth, stability, gain, noise figure, power consumption and complexity. The realization using cascode LNA is verify by using FHX76LP Super Low Noise HEMT that operate at 5.8 GHz in compliant with LTE standard. The Advance Design System (ADS) software is used to obtain characteristics for collecting data in smith chart and s-parameter generated by simulation. The cascode LNA with double feedback technique achieve average gain (S_21) of 20.887 dB with noise figure of 0.341 dB. The input return loss (S_11) and output return loss (S_22) are – 14.354 dB and – 11.879 dB respectively. The outcome of this work will contribute in providing a better wireless signal receiver especially for the LTE standard and it potentially in addressing wireless communication issues in rural area.

Keywords:
Cascode, LNA Double Feedback Technique, Long Term Evolution (LTE)

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1. Introduction

Powered by the unpredictability of the development of wireless communication especially radio frequency in the wireless industry, imploring the unrestricted internet connectivity and encouraging high data rates to be achieved are significantly advanced. Consequently, by employing wireless receiver for certain standard which open the way to establish new frequency standard lead to an escalation number of LNA as receiver resulting rise of design complexity imposing hassle on cost and power consumption. Solution for transceivers can be meticulously implemented by paying attention to different architectures, circuit design and accessible technology. Wireless networking devices

Corresponding author.
E-mail address: bakar@fskik.upsi.edu.my

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including Long Term Evolution (LTE), Wireless Local Area Network (WLAN), Wi-Fi and WIMAX are also distinct.

There is endless demand of Low Noise Amplifier (LNA) that continue to keep driving the innovation for the high rate data of communication system in today's world. Technology today's requires high speed transmission efficiency with less power consumption and LNA is one of remarkable product that can satisfy all the parameters. LNA are core components in the receiving end of the communication system providing promising performance of RF receiver which observe in term of sensitivity, selectivity or propensity for error in reception of receiver according to Iniewski [1]. The LNA have five features that directly influence the design and affect directly the sensitivity of receivers which are linearity, bandwidth, noise, gain estimations and dynamic operating range. To monitor these parameters, adequate knowledge of active devices, impedance matching and amplifier assembly and manufacturing methods is needed and optimum output with less trade offs is achieved. As stated by Muhammad Arsalan and Falin Wu [2], the LNA used in communications system amplify very weak signals that captured by an antenna playing an important position to recover data in communication system with minimal noise figure plays as important role in the architecture.

As claimed by Azzouni et al [3], LTE's functional to provide an upstream and downstream broadband, reducing the time accessing network for end user, flexibility of the bandwidth and incorporating with current network contributing rapid development in communication system. As the license-free 5.8 GHz frequency manage to provide broad spectrum frequency allowing covering higher data rates which is an alternative way without needed to ask permission to uses and low cost to meet any communication prospect to penetrate channel. The advantages of LTE are it can experience overwhelming range between 100 mm – 10 mm to connect with users compared with Wi-Fi which is range between 10 m – 100 m besides having more network capacity as it open for everyone use to continue keep up with demands of existing services. Based on Shayea Ibraheem et al. [4], in line with International Telecommunication Union (ITU) prediction the demand of mobile data traffic in 2020 would be increase dramatically to four times more than in 2015 that lead to rapid mass-market adaptation to access high speed data which corresponds to either increase in bandwidth (BW) or signal to noise ratio (SNR) or both.

Several block diagrams are included when designing the LNA such as input matching network, biasing network and output matching network as shown in Figure 1 which is essential to establish technique to be used.

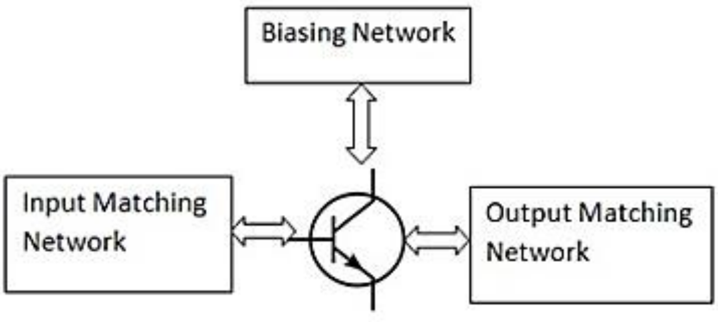

Fig. 1. LNA block diagram

Previously, design of cascode LNA with various techniques such as current-reused technique, inductive source degeneration, feedback technique and utilizing feedback body biasing (FBB) to evaluate the capability of LNA for reducing noise while maintaining the gain and surpass the crucial problem of stability to improve the performance. The outline of this paper will be arranged as follows. A brief overview of the previous studies and topology is portrayed in Section II. The design detail and simulation achieved includes analysis results are mentioned in Section III. Meanwhile, comparison of recorded work with other published works are discussed in IV. In section V conclusion of research finding are provided

2. Related Works

Cascode topology is a common method used to design the LNA as it is the most versatile with input and output by having better isolation which improve the stability of circuit. Cascode topology offer better stability, stabilize noise figure, higher signal gain, good reverse isolation and unbiased of input and output matching impedance. The method for maximizing the gain of the amplifier by amplifying the trans-conductance and increasing power gain of RF LNA by implementing negative resistance obtained by combination of cascode would affecting the noise and gain simultaneously as mention by Bansal and Srivastava [5]. On the report of Radha et al. [6], when designing LNA an entangled task of exchange between certain parameters where’s one is able to do high gain, low noise with low linearity able to handle at desired signals adopted the resistive feedback and gain peaking LNA at 2.4 GHz without much distortion. The efficiency of LNA strongly depends on the input impedance and the selection of impedance matching topologies to minimize total noise figure including effective amplifiers. There L-type, T-type and Pie-type matching are the various types of matching methods. This paper implemented T-matching techniques at the input and output impedance of cascode LNA as according to Ibrahim et al [7], comparing the matching network, the T-matching indicated better gain and noise in order to achieved key demands of LTE receiver characteristics. In contrast according to Lee and Yang [8], limited matchable impedance ranges and lack of freedom making the L-type matching network only depends on $\mathrm{R_L}$ and $\mathrm{R_S}$ meanwhile Pie-type matching only enhance small impact in linearity which become not suitable for high frequency range.

The assimilation between LNA and communication device of LTE influence each other in term of incredible growth of communication technology which led to affect in radio frequency (RF) of microwave electronic circuit. Several designs of LNA have been proposed previously by using cascode with various techniques such as current-reused technique by Khosravi et al. [9], employed to reduce power consumption and provide a flat gain over wide bandwidth in the 2.4 GHz and 5.2 GHz frequency bands that suitable for applications in multi-band WLAN receivers. The inductive source degeneration used to achieve simultaneous noise contribution and input matching such that the antenna has optimal power transfer which commonly matched with off-chip components as claimed by Muhammad Waqas Qadir et al. [10]. Meanwhile, utilizing CG feedback body biasing (FBB) technique at input transistor leads to a further decrease in the supply of power (VDD) due to a decrease in the threshold voltage resulting from a decrease in the use of power consumption for 3.1 – 10.6 GHz frequency wideband matching as stated by Vikram Singh et al [11]. Meanwhile, as reported by Wu and Yang [12], feedback technique proposed utilized improvement in the bandwidth and employed compensation on gain and become major factor to surpass the crucial problem of stability and gain flatness besides capable of solving problem low breakdown voltage and achieve high power performance.

Desirable performance level, high linearity, efficiency with high gain and minimal noise figure are the key feature in considerations as it is potentially impacts on low noise amplifier with various methods and techniques used as clarified by published research. Therefore, in this work, by addressing the issues implementing cascode LNA by using double feedback technique for LTE adopting T-matching for input and output impedance running for 5.8 GHz frequency band exposure the potential for improving the gain to maximum, minimizing noise figure with targeted number, better reverse isolation, and improved linearity as the objective of this paper.

3. Circuit Design

The propose LNA is to be designed such that to comply with the LTE specifications whereby the LNA needs to provide a high gain of greater than 20 dB with a noise figure of lower than 3 dB and operating at low power at 5.8 GHz. The input and output reflection coefficient should ideally be lesser than -10 dB in order to have good input and output matching including circuit stability. The architecture of this design is presented and utilize the targeted S-parameter specification as shown in Table 1.

Table 1
Design specification of targeted S-parameter for cascode with double feedback LNA

Design Parameter	Design Specification
Input reflection coefficient $\mathbf{S_{11}}$ (dB)	-10
Return loss $\mathbf{S_{12}}$ (dB)	-10
Forward Gain $\mathbf{S_{21}}$ (dB)	-20
Output reflection coefficient $\mathbf{S_{22}}$ (dB)	-10
Noise Figure (dB)	< -3
Stability (K)	>1

Pseudomorphic High Electron Mobility Transistor (PHEMT) FHX76LP is used to design cascode with double feedback LNA where the S-parameter obtained from datasheet for 5.8 GHz and the simulation are conducted by using Advance Design System (ADS) technologies to meet the designation result illustrated in Table 2.

Table 2
S-parameter acquired from datasheet FHX76LP provided

S-parameter	$\mathbf{S_{11}}$	$\mathbf{S_{12}}$	$\mathbf{S_{21}}$	$\mathbf{S_{22}}$
Magnitude	0.192	0.075	11.075	0.225
Angle	93.830°	21.513°	76.337°	157.977°

Cascode LNA is selected to put into action for LTE application. This topology was chosen to yield appealing gain with minimum noise figure besides have good input and output isolation that can boost the stability. The T-matching network has been adopted at the input and output port for excellent maximum power transfer when impedance between two circuits match at load and source which can improve the performance. To acquire better certainty Smith Chart tools in ADS is being used to design T-matching network. Double feedback techniques has been purpose in RF circuit design which tolerate in stability distortion and maintain the flatness of gain with low noise interruption. In this case, cascode amplifier can control the gain limitation from negative feedback and positive feedback in double loop transformation feedback but affecting minor noise figure to enhance other parameters. Considering the 50 ohms at the input and output in simulation can reduce the reversei solation with positive feedback placing in between output and source cascode LNA and negative feedback in between source to reduce the issuing of noise figure. On the side, the inductor peaking was added placed in series to conjoin with output passive network to improve the nonlinearity of LNA. The optimum reflection coefficient (Γ_{opt}) obtained for 5.8 GHz were 20.209 – j 36.711 and Γ_L as 171.121 + j 24.457 for purpose design LNA. Figure 4 shows the complete schematic diagram of cascode LNA with negative feedback.

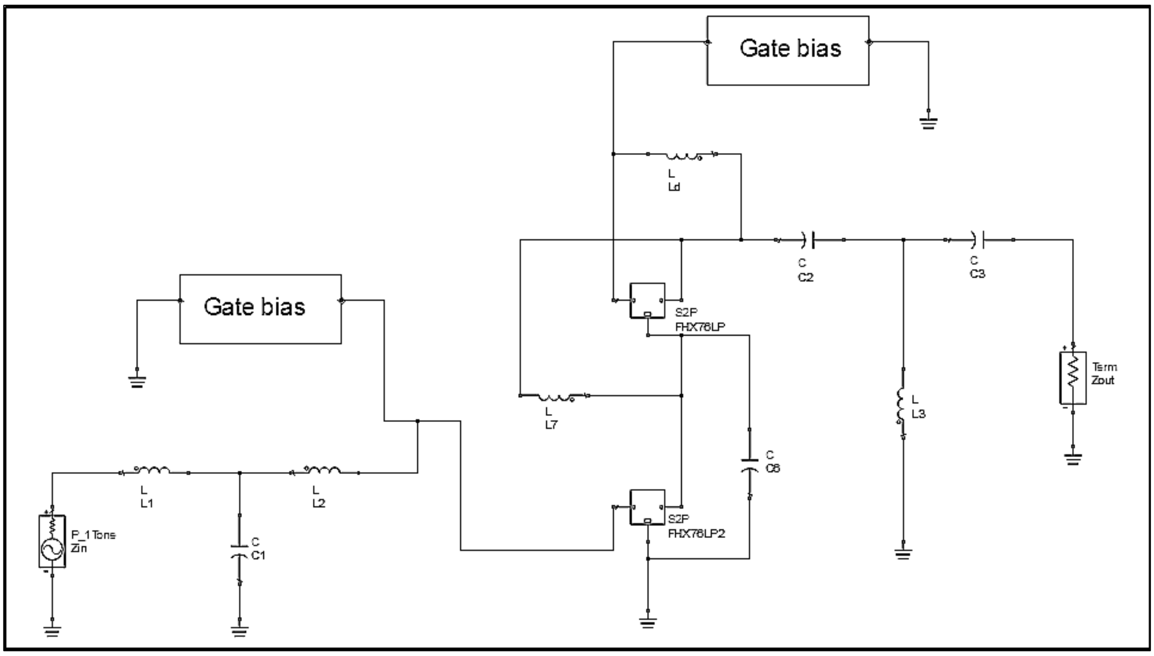

Fig. 2. Circuit diagram of proposed LNA

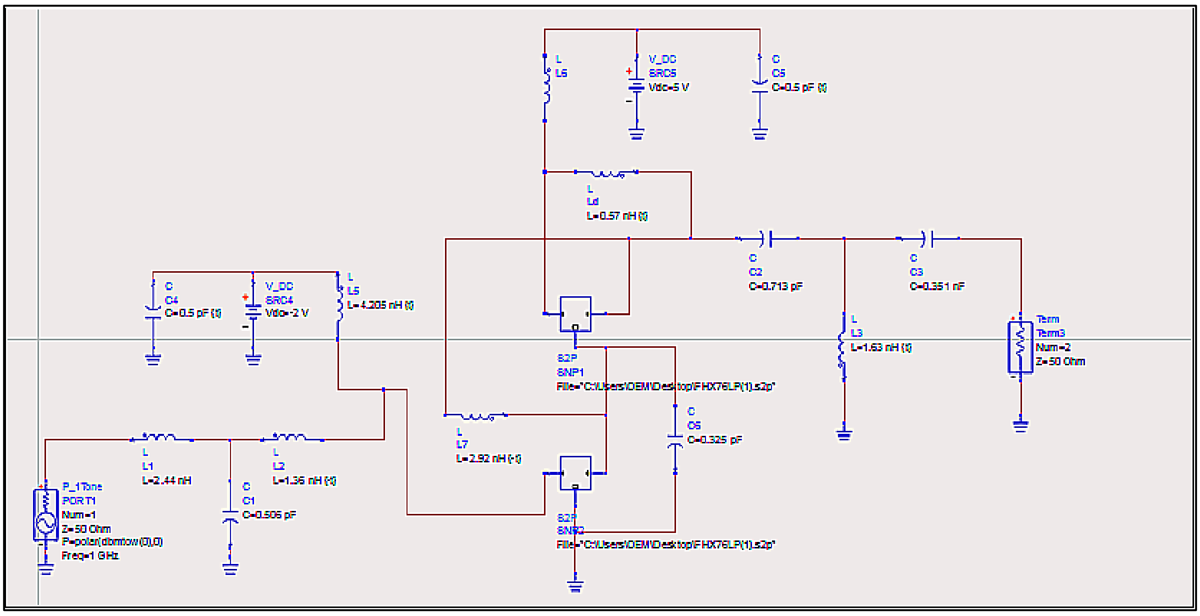

Fig. 3. Schematic diagram of proposed LNA

4. Simulation Results and Analysis

The analytic analysis and simulation results of low noise amplifier build at 5.8 GHz are shown in this section. Analytic analysis, DC biasing, design matching network and S-parameter of ADS simulation are three key stages. The design employ high-performance low noise Pseudomorphic High Electron Mobility Transistor (PHEMT) FHX76LP developed by Eudyna Devices with reduced noise resistance, which lower noise performance sensitivity to distinct in matching input impedance. With the aid of Smith Chart, the the impedance matching network in this paper can be modelled graphically or mathematically. The design cascode Low Noise Amplifier with matching network at 5.8 GHz was obtained. From the simulation it resulting, the input reflection coefficient (S_{11}) obtained -14.354 dB meanwhile output reflection coefficient (S_{22}) is -11.879 dB indicate the values acquire is better than the targeted which is adequate to the research. The output of S_{11} and S_{22} displays in Figure 4. In the meantime, the forward gain (S_{21}) achieve 20.887 dB with return loss (S_{12}) of -22.465 dB which is acceptable and much better than targeted parameter. The output of S_{21} and S_{12} displays in Figure 5.

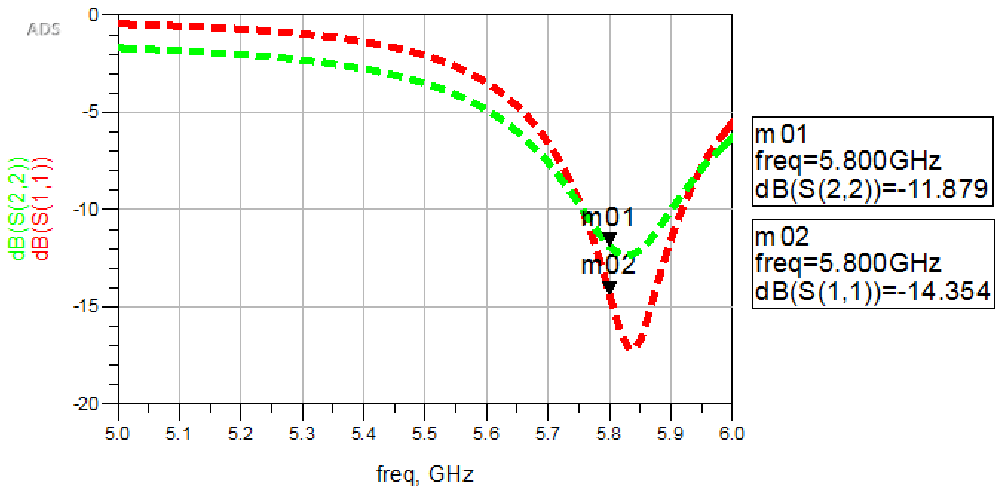

Fig. 4. The input and output of reflection coefficient of S_{11} and S_{22} in S-parameter impedance simulation

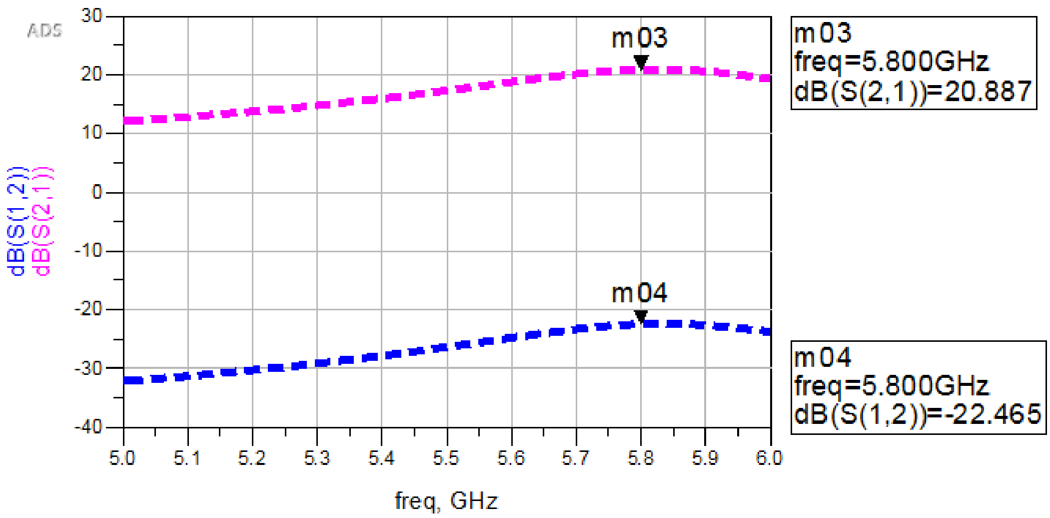

Fig. 5. Return loss and gain of S_{12} and S_{21} in S-parameter impedance simulation

The minimum noise figure is desired in order to secure maximum gain. Figure 6 shows the noise figure obtain which is 0.341 dB lower than targeted specification. Along with the frequency increase, the NFmin value is affected by being reduced.

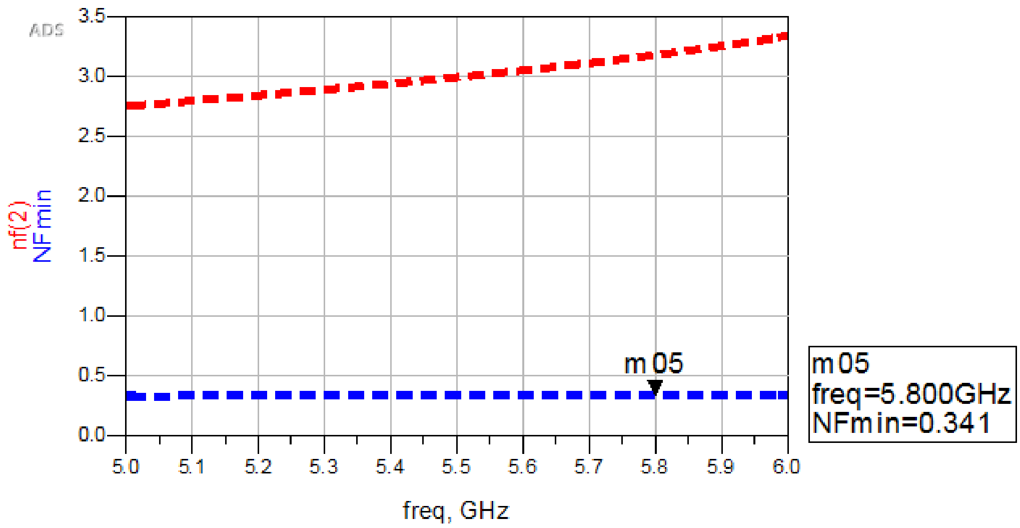

Fig. 6. The noise figure (NF)

After matching occur at the load, stability factor (K) obtained is 1.001 at 5.8 GHz frequency range established in Figure 7. The value acquired is more than 1 which is in unconditionally stable state with no isolation occur which compatible with targeted result.

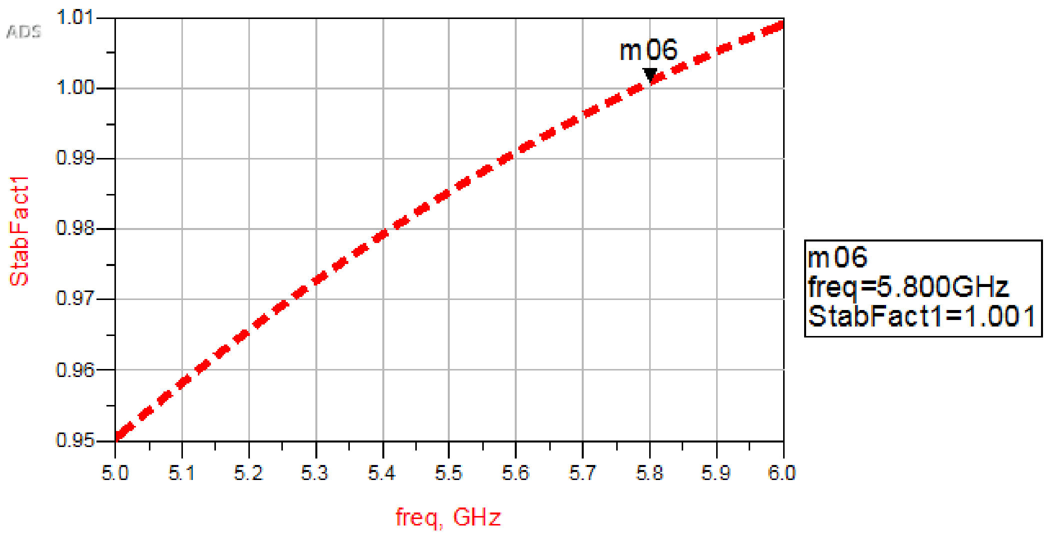

Fig. 7. Stability Factor

From Table 3, it can be concluded the aggregated throughput represent the comparison of output obtained from simulation with targeted specification for cascode LNA with double feedback performance. After the simulation of the circuit the stability, output reflection coefficient and forward gain are as 1.001, −11.879 dB, and 20.887 dB. The input reflection coefficient is −14.354 dB, reverse transmission coefficient is −22.465 dB and minimum noise figure is 0.341 dB. The stability of the transistor amplifier is as 1.001 which satisfies the equation (1) which determined by Rollett stability factor K>1 for unconditional stability. The stability is therefore maintained as the oscillations arise where the output impedance and load impedance or at the source end are incorrectly aligned with forward gain drastically achieved more than needed.

Table 3
Comparison of performance parameters

Design Parameter	Targeted	Simulation
Input reflection coefficient S_{11} (dB)	−10	−14.354
Return loss S_{12} (dB)	−10	−22.465
Forward Gain S_{21} (dB)	20	20.887
Output reflection coefficient S_{22} (dB)	−10	−11.879
Noise Figure (dB)	<3	0.341
Stability (K)	>1	1.001

$$\text{Stability factor, k} = \frac{1-(|S_{11}|)^2 - (|S_{22}|)^2 + (\Delta)^2}{2\,(|S_{12}|)\ (|S_{21}|)} > 1 \quad (1)$$

where

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

Several authors have previously focused on refining and study of low noise amplifier. Following the references Cen and Song [13], Ibrahim and Ali [14], Ibrahim et al [15] and Cen and Song [16] authors working on LNA optimization. However, according to the cited reference, the works reaches minimal noise figure with maximum power gain besides concludes that the input (S_{11}) and output (S_{22}) return loss coefficient are matching based on S-parameter resulting from ADS simulation. The authors have been worked to gives minimal noise figure within frequency band of 5 – 6 GHz. Comparing with other cited LNAs, Table 4 illustrated the results overview of this designed LNA.

Table 4
Comparison of performance summary of designed LNA with other cited LNAs

Author (Year)	Topology	Frequency (GHz)	Gain, S_{21} (dB)	Noise Figure (dB)	Input Return Loss, S_{11} (dB)
[13]	Two stage cascade with inductive degeneration	5.8	17.04	0.972	-17
[14]	Single stage with ladder matching network	5.8	17.2	0.914	-19
[15]	Single stage with resistive shunt feedback	6	15.16	0.801	-15
[16]	Cascode with positive feedback	5.8	18.66	2.03	< -13
Proposed	Cascode with double feedback	5.8	20.887	0.341	< -10

Conclusion

The cascode LNA with double feedback technique has been proposed, design and stimulated with long term evolution (LTE) standard for frequency 5.8 GHz by using ADS. Observation from the results, the proposed amplifier has meet the specification to obtain maximum power gain with minimum noise figure with implementation of T-matching at the input and output port and uses of double feedback technique. Based on tabulated values, this LNA achieves parameters target with forward gain (S_{21}) of 20.887 dB, input return loss (S_{12}) of -23.585 dB, input reflection coefficient (S_{11}) of -11.101 dB, output reflection coefficient (S_{22}) of -22.465 dB. Meanwhile, the noise figure (NFmin) 0.341 dB and stability 1.001 obtained respectively. To summarize, this research is a good candidate for low power and low noise wireless applications and there is scopes for any improvement to fulfil performance satisfactory.

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