

# Performance Analysis of Inductive Source Degeneration Low Noise Amplifier using Multi-finger Technique

Kusuma M. S., S. Shanthala, Cyril Prasanna Raj P.

**Abstract:** In the current paper, common source Low Noise Amplifier using inductively degenerated technique is designed to meet Radio Frequency (RF) range 2.45 GHz-2.85 GHz. The designed LNA is implemented using single and multi-finger transistor logic. The transistor geometry greater than 300  $\mu\text{m}$  has been split into multiple fingers using multi-finger technology. The schematic is captured using ADS. The performance of LNA for various technologies has been analyzed using PTM 180 nm, PTM 130 nm and PTM 90 nm models. The amplifier with single transistor achieves minimum noise figure of 0.178 dB noise figure and maximum gain of 20.045 dB using 130 nm model technology for Bluetooth applications. Similarly 0.288 dB of minimum noise figure and peak gain of 17.971 dB are obtained using multi-finger MOSFET of PTM 90 nm technology respectively. The reverse isolation ( $S_{12}$ ) below -50 dB is achieved.

**Index Terms:** Advanced Design System (ADS), Bluetooth, CMOS, Low Noise Amplifier, Multi-finger, RF frequency.

## I. INTRODUCTION

During last two decades, wireless telecommunication systems have great development both in hardware and software aspects. Systems for wireless data communications are becoming smaller and less power consumption to minimizing the number of external components required. These transceivers have to include multi-standard concepts to create new to meet design challenges like high performance, low power consumption and low cost. The development of CMOS technology supported for the development of wireless RF transceivers. The Low-Noise Amplifier (LNA) is the most essential component in the receiving path of RF receiver. In recent RFLNA architectures, the multi-standard has been reported in many works and various implementations. The LNA is responsible for strengthening of poor received signals while minimizing the noise and non-linear distortions at output end of amplifier. The characteristics of LNA set the overall performance of RF transceiver systems [1-2]. Design of LNA for a given requirement need to meet all the parameters such as noise figure, gain, linearity, impedance matching, power

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consumption and chip area. With the use of lumped components, in LNA design which are frequency dependent, the reactance of the LNA circuit changes with frequency [3].

LNA will increase the power of both the signal and the noise present at its input, the optimum design of LNA need to minimize the additional noise. LNA design and its behavior is characterized by five parameters such as Noise Figure (NF), gain, bandwidth, linearity and dynamic range. Designing an LNA that can meet all these parameters requires an understanding of the active device, impedance matching, and details of fabrication and assembly to create an amplifier that achieves optimal performance with the fewest trade-offs. There are several LNA topologies such as distributed amplifier topology, Common Gate (CG), Common Source (CS), cascade and Current Reuse (CR) topology [4]. The most frequently used topology for LNA design is the common source amplifier with inductive source degeneration.

The basic Inductively Degenerated Common Source (IDCS) LNA has typically been the best choice for narrowband applications due to its low NF, high gain and low power consumption with good performance [2]. The input matching circuit consisting of the source inductors and the gate to source capacitance resonates at a single frequency [5]. The Bluetooth systems need to operate on low power signals in ISM (Industrial, Scientific and Medical) band. Therefore LNA that can minimize interference noise is required for the Bluetooth system. Interference is one of the major challenges addressed in ISM band [6-8].

## II. THEORETICAL BACKGROUND

The LNA must provide good noise figure along with enough gain to overcome the noise in the successive stages of RF receiver. The design of critical component in LNA is the design of input impedance matching ( $50 \Omega$ ) circuit which provides source impedance for minimum noise figure ( $NF_{\min}$ ) which leads to poor gain. There are many techniques for  $50 \Omega$  input impedance matching in which inductive source degeneration circuit exhibited  $NF_{\min}$  [9]. The distributed amplifier reported by Ren-Chieh Liu et al., in [10], employs multiple narrowband LNAs to realize wideband matching. The distributed amplifiers guarantees good matching performance and high power gain over wide bandwidth 0.6 GHz to 22 GHz. However, it consumes large power and results in high noise figure up to 6 dB due to multiple amplifiers. So there is still chance for existing CMOS LNAs.

James Wilson and Mohammed Ismail in [11] presented an inductive source degenerated LNA with independently tuning center frequency and quality of input matching network. Such that the circuit provides the fast calibration and low power consumption. This IDCS technique approaches the input match to the desired center frequency in the presence of process shifts and parasitic elements. But the same calibration loop is used to tune the desired center frequency of load tank. The authors Kuo-Liang Yeh and Jyh-ChyurnGuo have described new approach for layout dependent parasitic capacitance and mobility extraction in [12] using multi-finger technique. The optimization method is used in measuring the S-parameters associated with the intrinsic channel and effective mobility in multifinger MOSFETs with narrow widths down to 0.125  $\mu\text{m}$ . An LNA with two stage CS-CG configuration and forward body bias technology was developed by Gh.R.Karimi in [13] with NF of 2.202 dB at 2 GHz frequency of operation while consuming 0.96 mW dc power.

The design of the LNA in this work was concentrated at an operating frequency of 2.45 GHz to 2.85 GHz for Bluetooth applications. The design and simulation results of LNA using IDCS topology is developed using a Berkeley Short-channel Insulated gate field effect transistor Model 3 (BSIM). Designing a LNA for Bluetooth applications and its implementation in Advanced Design System (ADS) tool are presented in Section 3 and in Section 4. Simulation results and Results discussion are reported in section 5 and section 6 provides the conclusion.

III. LNA DESIGN METHODOLOGY

The LNA with IDCS technique is shown in Fig. 1 and the corresponding specifications of the design is given in Table 1. The 50 Ohm resistor  $R_s$  is connected across the input terminal of LNA and hence provides the input matching. The bandwidth of the amplifier is determined by the input capacitance,  $C_{gs}$  of the transistor  $M_1$ . The inductance  $L_g$  at the gate of NMOS compensates the gate to source capacitance of  $M_1$  at the resonant frequency and hence making the impedance at the input of NMOS to be real i.e., only input resistance  $R_{in}$  [14].

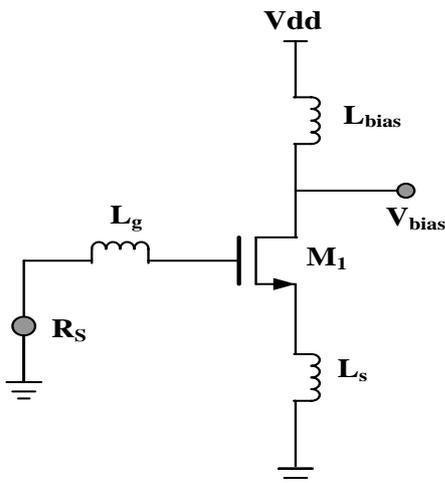


Fig. 1: Detailed circuit of CS LNA

Table 1: Narrow band LNA specifications

Parameters	Specifications
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Frequency (GHz)	2.45 - 2.85
Noise Figure (dB)	< 2.5
Gain (dB)	>10
Source/Load	50
Impedance (Ohms)	

A step by step algorithmic design methodology is developed for an IDCS LNA by considering PTM 180 nm, PTM 130 nm and PTM 90 nm models. The detailed design of LNA based on fundamental equations is presented in [15]. The circuit parameters of the proposed LNA are summarized in Table 2. The various process-dependent parameters for three different technologies such as 90 nm, 130 nm and 180 nm nodes were derived from the PTM model files [16].

Table 2: Circuit parameters for LNA design

Parameters	PTM 180	PTM 130	PTM 90
$C_{ox}$ (pF/ $\mu\text{m}^2$ )	8.6320E-3	10.463E-3	13.8122E-3
$L_g$ (nH)	7.52	7.52	7.52
$L_s$ (nH)	0.5	0.5	0.5
$W$ ( $\mu\text{m}$ )	434	496	489
$g_m$ (A/V)	0.045	0.045	0.045
$V_{eff}$ (V)	0.0618	0.0841	0.037
$I_D$ (mA)	1.39	1.894	0.832

IV. EXPERIMENTAL SETUP AND VALIDATION

The LNA design with circuit parameters summarized in Table 2 is modeled and simulated in ADS shown in Fig. 2. The current mirror based current reference circuit is designed to achieve constant load current flow for LNA circuit. The current mirror circuit is used to avoid extra voltage source in the circuit. The width of MOSFET  $M_2$  is  $\frac{1}{10}$  times width of  $M_1$ , with  $M_1$  width set to  $10M_2$ , the power overhead of the bias current is reduced.

A resistance R is selected so that its equivalent noise current can be ignored. This bias resistor isolates the current mirror from RF input. The capacitors connected between RF input and gate of  $M_1$  and that between drain and output terminal of  $M_1$  are used as DC blocking capacitors. The inductor between drain and supply isolates RF signal flowing into supply rail. The DC\_feed inductor is adjusted to obtain optimum gain.

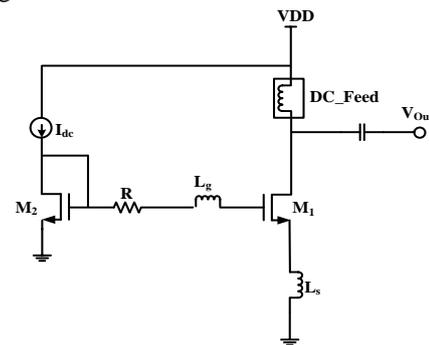


Fig. 2: ADS Simulation setup to analyze the basic LNA design

Implementation

Since the transistor geometry is larger, the recommended technology is to use multi-finger concept. MOSFETs with large dimensions are generally used in analog CMOS circuits and multiple-finger parallel devices are the most common method in such applications.

This method of implementation involves realizing a single transistor with larger width using multiple smaller width transistor connected in parallel. By having smaller transistor geometry, transistor matching is achieved meeting PVT corners and minimizing passive capacitance during layout design. This implementation is as shown in the Fig. 3. Multi-finger layout technique is extensively used in submicron CMOS circuit design due to increased circuit performance when compared to a single finger layout. In short channel MOSFETs, the gate resistance generates gate current noise which is significant to the thermal noise of the gate [17]. To overcome this, two methods are used to minimize the thermal noise. First method is silicide gate material which helps to reduce gate resistance ( $R_g$ ) and second is multi-finger technique where several devices (fingers) are connected parallel. Multi-finger technique allows lower gate resistance, less noise and improves the frequency performance [18]. The gate resistance is given in equation (1).

$$R_g = \frac{R_{sh}}{12 n_f^2} \cdot \frac{W}{L} \quad (1)$$

$R_{sh}$  is the sheet resistance of the gate material,  $n_f$  is the number of fingers and the factor of 12 is due to the distributed nature of the gate resistance when it is contacted on both ends [9][19]. However, keep reducing the transistor finger width  $W_F$  or increasing number of fingers  $N_F$  can result in larger gate capacitance [20]. Increase in signal quality and reduce in signal reflection is achieved with good impedance matching network. The multi-finger effect on single transistor is analyzed in this work.

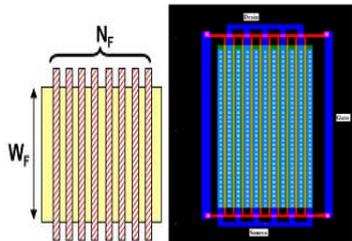


Fig. 3: Standard structure of multifinger MOSFET,  $W_{Tot} = W_F \times N_F$  [12]

The sample sets used for multi-finger circuit are summarized in the Table 3. There are three samples (S1, S2, and S3) to observe the variations of gate width.

Table 3: Summary of geometric information for test circuit

	S1 = 200	S2 = 300	S3 = 450
$W_F$ ( $\mu\text{m}$ )	66.66	100	150
$N_F$	3	3	3

The LNA design with circuit parameters summarized in Table 2 and sample sets used for multi-finger circuit in Table 3 is modeled and simulation environment is set in ADS software. The amplifying transistor  $M_1$  of Fig. 2 is divided into three fingers  $M_3$ ,  $M_4$  and  $M_5$  of equal finger width and their terminals are connected together as in Fig. 4. A detailed discussion on LNA results using single transistor and multi-finger technique is presented in next section.

## V. GAIN AND NF SIMULATION RESULTS DISCUSSION

The optimized design of LNA in terms of maximizing gain and minimizing NF is considered in this section. Plots of gain and NF with the typical frequency and transistor width with different PTM models are captured with all the

process corners for single transistor shown in Fig. 5 to Fig. 14 and multiple-finger technique shown in Fig. 15 and Fig. 16.

### A. Gain and NF Effects on Single Transistor Design

The ADS simulations of IDCS LNA of frequency versus width and NF versus width under different PTM technology with power gain greater than 14 dB are shown in Fig. 5 and Fig. 6 respectively. The transistor with narrow width has higher frequency of operation and lower noise figure values are achieved. Similar readings are obtained for power gain less than 14 dB, shown in Fig. 7 and Fig. 8 where lower noise figure values are reported for smaller transistor width with three different PTM models.

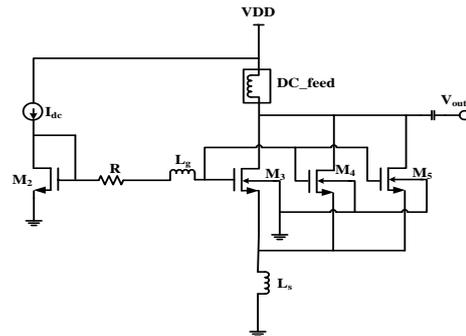


Fig. 4: Simulation setup to analyze the multi-finger LNA design

The simulation results of Fig. 5 to Fig. 8 indicate that there is an increase in noise figure of 11.78% for 180 nm model, 15.51% for 130 nm model and for 90 nm model technology 21.03% improvement in the noise figure with 85.11% of transistor geometry. The simulation results indicate that there is a frequency improvement of 79.51% for 180 nm model, 81.92% for 130 nm model and 69.66% for 90 nm model technology with 85.11% of transistor geometry.

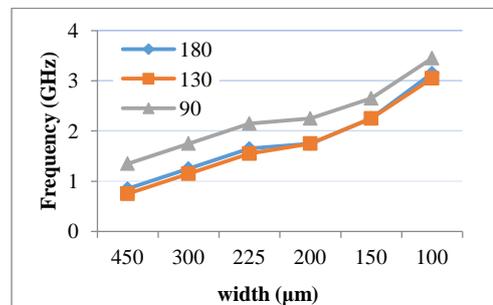


Fig. 5: Frequency versus width plot under different technologies (gain > 14dB)

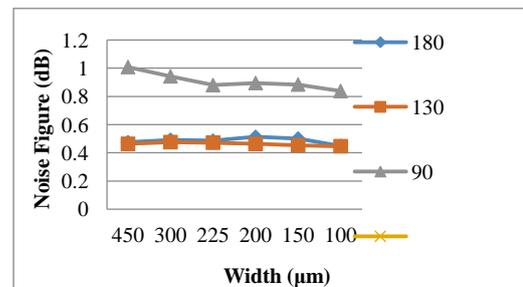


Fig. 6: Noise Figure versus width plot under different technologies (gain > 14dB)

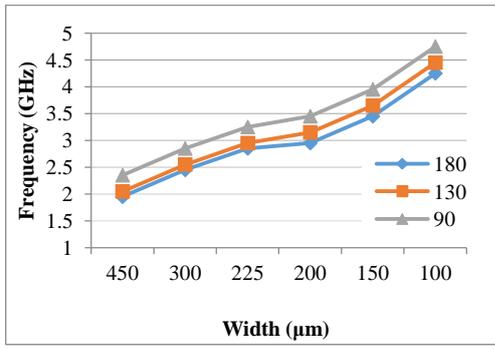


Fig. 7: Frequency versus width plot under different technologies (gain < 14 dB)

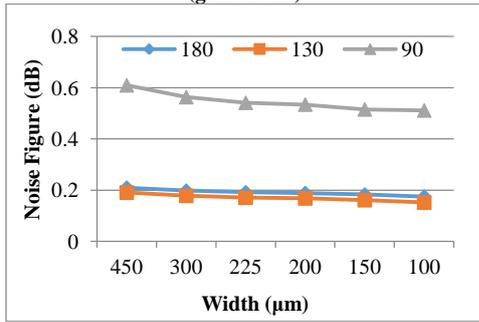


Fig. 8: Noise Figure versus width plot under different technologies (gain < 14 dB)

Fig. 9 and Fig. 11 are the plots of minimum noise figure of 0.169 dB for 66.66 μm transistor width with operating frequency of 5.15 GHz using 180 nm model and Fig. 10 indicates gain of 12.056 dB. The 130 nm model simulation results indicate 0.144 dB minimum noise figure at 5.45 GHz frequency of operation and gain of 12.439 dB with 66.66 μm transistor width. Similarly for 90 nm technology 0.505 dB of  $NF_{min}$  is obtained at 5.75 GHz frequency and gain of 11.179 dB for transistor geometry of 66.66 μm width.

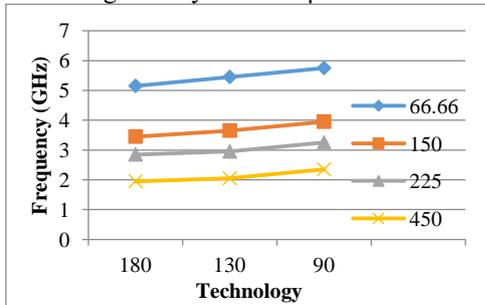


Fig. 9: Frequency versus technology plot under different widths W (μm), minimum NF

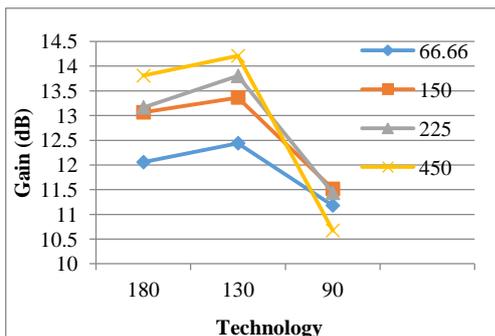


Fig. 10: Gain versus technology plot under Different widths W (μm), minimum NF

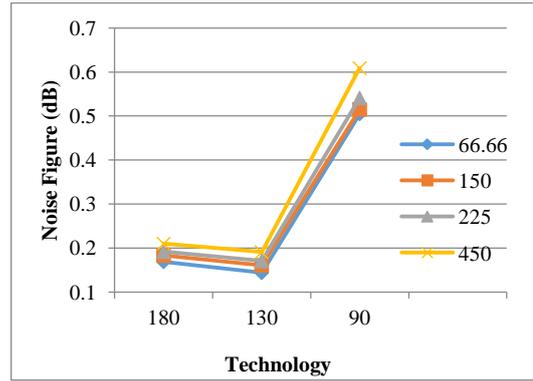


Fig. 11: Noise Figure versus technology plot under different widths, W (μm), minimum NF

Fig. 12 and Fig. 13 indicate the maximum gain of 18.746 dB for 450 μm width with operating frequency of 0.85 GHz using 180 nm technology and Fig. 14 shows NF of 0.475 dB. The 130 nm model simulation results indicate 20.045 dB maximum gain at 0.75 GHz operating frequency and noise figure of 0.464 dB with 450 μm transistor geometry. Similarly the maximum gain of 14.646 dB is obtained with operating frequency 1.35 GHz using 90 nm technology and NF of 1.008 dB. Therefore the LNA to operate at minimum noise figure the recommended technology is 130 nm and transistor width of 66.66 μm. Similarly the LNA to operate at maximum gain the 130 nm technology is preferred with transistor geometry of 450 μm width.

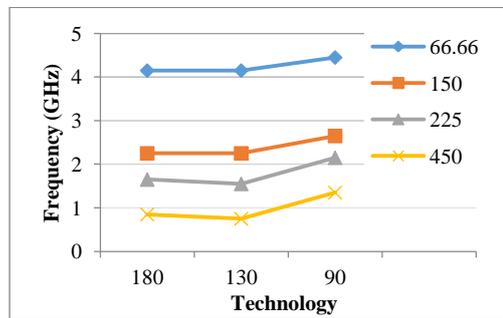


Fig. 12: Frequency versus technology under different widths, W (μm), minimum NF

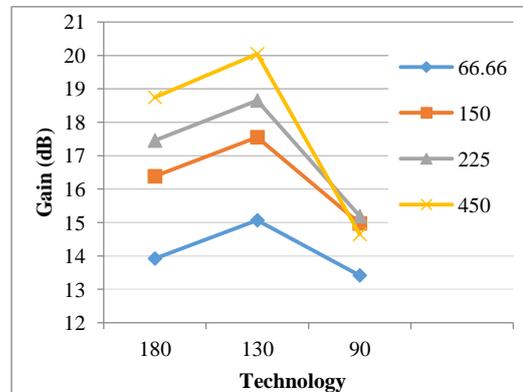


Fig. 13: Gain versus technology plot under different widths, W (μm)

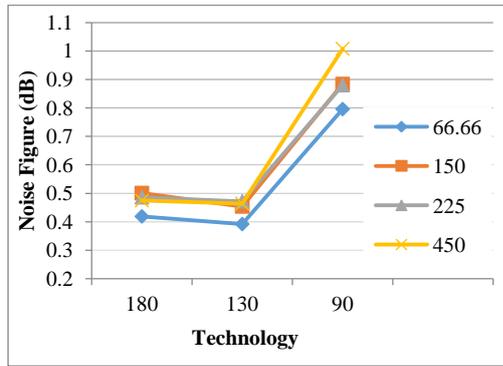


Fig. 14: Noise Figure versus technology plot under different widths, W (μm)

The LNA circuit to operate for Bluetooth applications, the required  $NF_{min}$  of 0.192 dB and gain of 13.166 dB using 180 nm technology are obtained with a transistor width of 225 μm. The  $NF_{min}$  of 0.178 dB and power gain of 13.941 dB using 130 nm model technology are obtained with 300 μm transistor geometry. Similarly the  $NF_{min}$  of 0.563 dB and gain of 11.132 dB are obtained using 90 nm model technology with a transistor geometry of 300 μm width. The maximum gain of 14.646 dB is obtained for 150 μm width and noise figure of 0.884 dB using 90 nm technology for Bluetooth applications of LNA circuit.

### B. Power Report for Single Transistor Technique

The 90 nm length design consumes less average power of 5 mW when compared with 180 nm design average power consumption of 10 mW and 7 mW for 130 nm length design with 1.5 V input supply voltage. The 450 μm width transistor design under 90 nm technology consumes less power of 4 mW whereas 66.66 μm width design consumes 6 mW power. The 450 μm width design consumes 11 mW power in 180 nm technology, 7 mW in 130 nm technology and 4 mW power consumption in 90 nm Technology. Similarly 66.66 μm width design consumes 11 mW power in 180 nm Technology, 9 mW in 130 nm and 6 mW power consumption in 90 nm technology. Therefore 90 nm process design can save more power when compare with the 180 nm and 130 nm length under 450 μm width.

### C. Gain and NF Effects on Multi-finger Transistor Design

The performance of LNA with gain and NF effects by multi-finger technique is tested with PTM 180 nm, PTM 130 nm and PTM 90 nm models. The NF and gain values are

remains unchanged with the number of fingers under the transistor width of 200 μm, 300 μm and 450 μm for PTM 180 nm and PTM 130 nm models. But in PTM 90 nm model NF and gain values are varied with the number of fingers for a particular transistor width which are captured in Fig. 15 and Fig. 16. Multi-finger technique is the most effective method to build a large size transistor because of lower RF noise and higher frequency of operation. When the number of fingers become smaller the frequency of operation of the circuit increases with decreasing the total transistor width for all the three different PTM models. The gain and NF simulation results for PTM 90 nm model are discussed in the following sections.

### D. Minimum NF Analysis of Multi-Finger Technique

Fig. 15 is the plot of  $NF_{min}$  of 0.534 dB for 200 μm transistor width and single finger with operating frequency of 3.45 GHz and gain of 11.428 dB as in Fig. 16. The two finger simulation results indicate 0.352 dB  $NF_{min}$  at 3.35 GHz and gain of 12.201 dB and three finger results indicate 0.288 dB of  $NF_{min}$  and gain of 12.270 dB at 3.35 GHz operating frequency for total transistor width of 200 μm. Similar results are captured for 300 μm and 450 μm total transistor width.

### E. Maximum Gain Analysis of Multi-Finger Technique

Fig. 16 indicates the maximum gain of 14.646 dB for 450 μm total transistor width and one finger with 1.35 GHz frequency of operation and noise figure of 1.008 dB. Two finger simulation results indicate 16.926 dB maximum gain at 1.15 GHz and 0.713 dB noise figure. Similarly 450 μm total transistor width with 3 fingers simulation results indicate 17.971 dB maximum gain at 0.95 GHz and 0.629 dB noise figure at this frequency of operation.

### F. Power Report for Multi-Finger Technique

The 90 nm simulation results under 200 μm width indicate 5 mW power consumption with single finger and 8 mW power consumption for 3 finger width. Similar results are obtained for 300 μm and 450 μm transistor width under different fingers. To improve NF and gain of common source amplifier with cascode topology can be considered. In addition the device characteristics such as carrier mobility and diffusivity can be considered for design analysis.

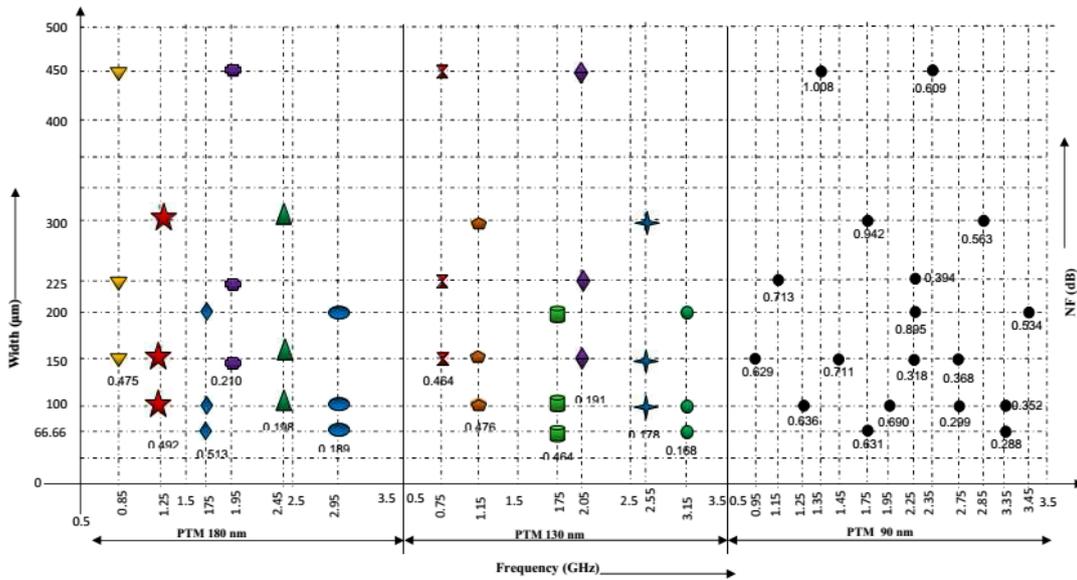


Fig. 15: Noise Figure performance of LNA with different fingers  $N_f$  under 200  $\mu\text{m}$ , 300  $\mu\text{m}$  and 450  $\mu\text{m}$  with three PTM models

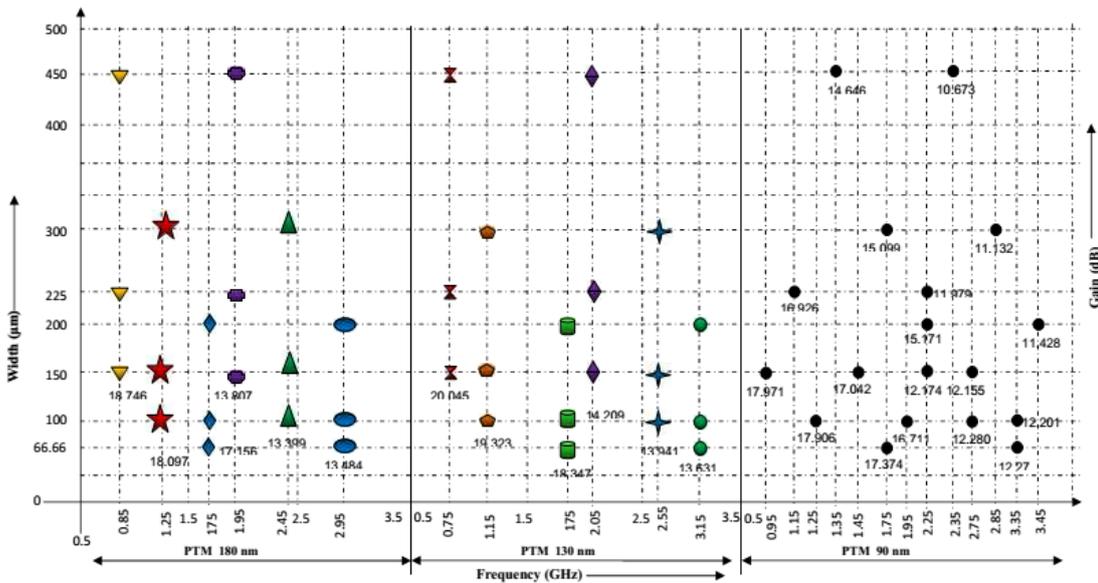


Fig. 16: Power gain performance of LNA with different fingers  $N_f$  under 200  $\mu\text{m}$ , 300  $\mu\text{m}$  and 450  $\mu\text{m}$  with three PTM models

IV. CONCLUSION

In this paper, the design of CS LNA with source degeneration is implemented in three different technologies such as PTM 180 nm, PTM 130 nm and PTM 90 nm models. The transistor geometry has been arrived for circuit schematic design and captured in ADS software. The simulation results obtained demonstrated that the designed LNA is suitable for Bluetooth applications of 2.45 GHz to 2.85 GHz with maximum power gain of 14.646 dB with 150  $\mu\text{m}$  transistor width using PTM 90 nm technology and minimum noise figure of 0.178 dB with 300  $\mu\text{m}$  transistor geometry using PTM 130 nm model technology.

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