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Design of an Active Inductor based Low Noise Amplifier using 180nm Cmos Technology for RF Receivers

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Abstract: In this paper three types of 3.1-10.6GHz low noise amplifiers are analysed for RF receivers. Common gate LNA with differential active inductor is used capacitor cross coupled technique to improve nonlinear distortions, noise performance, in-band gain flatness, linearity, frequency response and derivative super position technique is used to overcome capacitor cross coupled induced linearity deterioration. UWB CMOS LNA with presence of active inductor basis input matched network is presented. UWB CMOS LNA has 3 stages; a gm-boosted CG input stage, a common source stage, and a common drain stage. Cascode CS LNA is designed in the absence of active inductor. These LNA's were designing under 1.8v supply.
Index terms: Derivative superposition, capacitor cross couple, low noise amplifier, common gate, active inductor, UWB, CMOS, RF, CG, CS

I. INTRODUCTION

LNA is key component in the receiver front end. UWB technology gives the ability to deliver and collect message in a widespread frequency spectrum, partitioned into the lower frequency (3-5 GHz) and the upper frequency band (6-10.6 GHz). Advantages of UWB network are its capability to transmit digital signals in high date rate with low power consumption, low complexity, and high immunity. LNA maintain low noise figure and high gain of amplify weak input RF signal, low power consumption, low chip area, high stability, high linearity. Enhancement of CG LNA's noise figure technique is capacitor cross coupled. Basis on the noise performance and input matching network characteristics common source, common gate LNA's. Main disadvantage in CS LNAs is their high quality factor of their input matching network at resonance frequency, while this later should low to satisfy the UWB matching requirements in terms of bandwidth.

Inductive source degeneration method suffers from high noise figure. Input termination method suffers from higher noise figure due to noise contribution of an added resistor at the input port of LNA Inductive source degeneration method is suitable for narrow band applications and current reuse approach occupies a large chip area. Shunt series feedback technique needs high power consumption and creates bigger noise figure. Because of parallel resonant network and knowing that gate to source capacitance is proportional to transistor size, quality factor of input matching network of CG LNA would decrease when the technology should be scaled down and bandwidth show wideband behaviour. So CG LNA has a constant wideband input impedance matching without using additional components, while preserving area consumption and avoiding from more resistance losses of on chip inductors. In addition to providing a simple input match network in a wide bandwidth, the CG-LNA has more linearity and stability performance, low power consumption, better input-output isolation, more immunity to PVT variations.

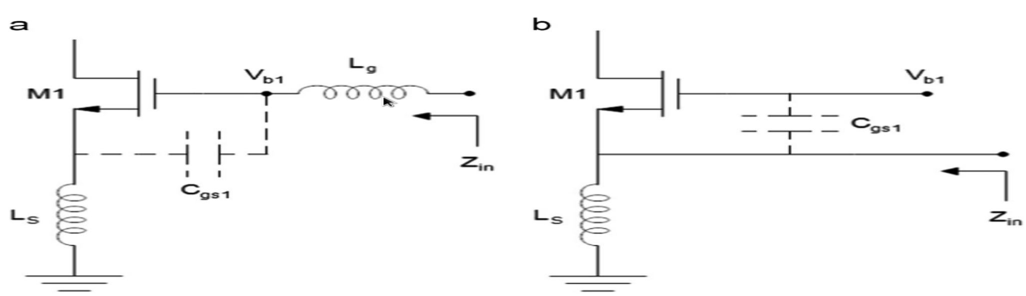


Fig. 1. Popular topologies for LNA input transistor. (a) common-source. (b) common-gate.

Other point of view is noise figure of CS-LNA is linearly proportional to operating frequency and increases when frequency reaches gigahertz range. Noise figure in CG-LNA is approximately independent of operating frequency. It depends on device size and process parameters, and has a inseparable link with input matching resistance. The device trans conductance has fixed by set input match resistance to 50ohms, noise performance of CG-LNA will be limited by input matching condition and noise figure characteristic such as resistive feedthrough, gm-boosting technique, combination of CG-CS amplifiers with single input differential output structure can improve performance of CG-LNA.
As for the matching network itself aforementioned LNAs mainly use on chip passive spiral inductors. These inductors are bulky with low and fixed inductance, low quality factor, self-resonant frequency, and incompatible with low cost standard CMOS processes. It is then preferable to use gyrator-based active inductors makes them very attractive in multichannel communications, as it can be applied in the input matching network of LNA, create an active input matching network with tunable resonance frequency.

II. GM-BOOSTING MECHANISM IN LNA

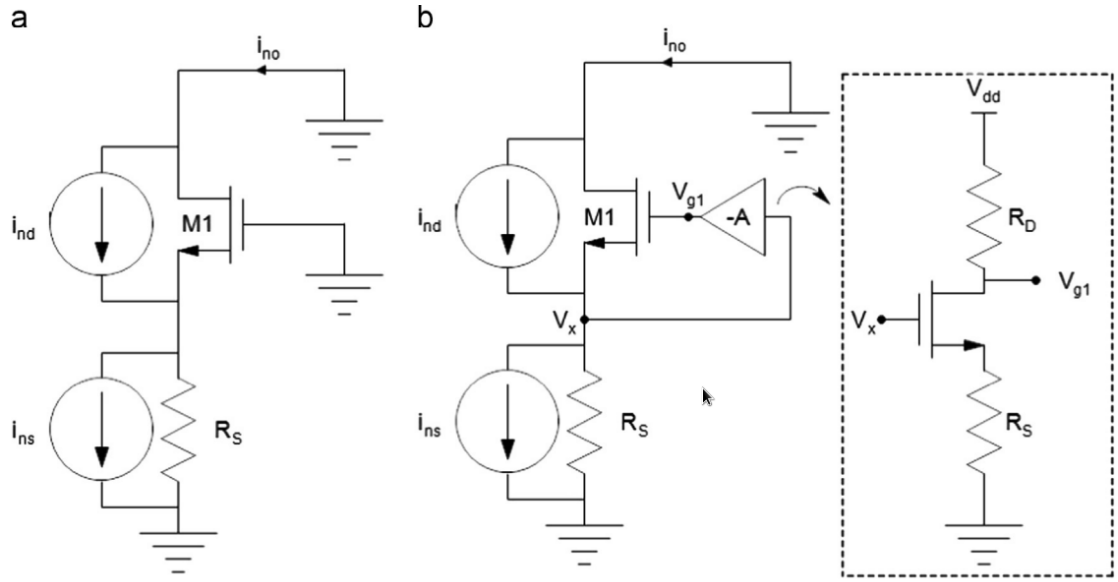
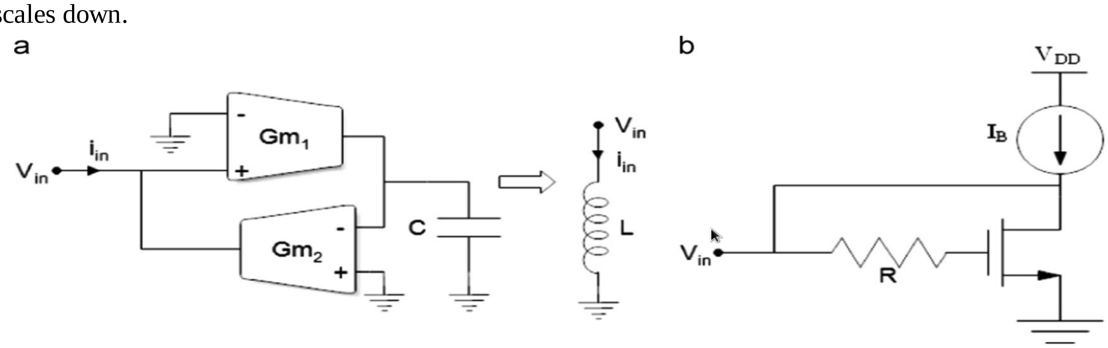


Fig 2. CG-LNA configuration (a)conventional,(b)with g_m-boosting

To maintain benefits of common gate topology and overcome its limitations a g_m-boosting technique[1] has applied to CG-LNA to disconnect the strong coupling between input matching and noise figure characteristic, causing a reduction in both noise and power losses. As mentioned before the noise factor of CG-LNA is confined by $1/g_m$ due to input matching condition. Fig.2(a) shows a basic CG-LNA configuration with its noise sources. As the gate-induced noise is insignificant and usually negligible in CG-LNA[5] the dominant noise sources are the thermal channel noise of transistor, i_{nd}, and the noise current of source resistance i_{ns},. The conductance is equal to 1/R. The parameter g_m / g_{do} is equal to unity for long channel devices and has a lower values when the channel length scales down.



Due to the input matching condition expressed as $g_m * R=1$, g cannot be increased arbitrarily to reduce the noise factor. Nevertheless it is still possible to enhance noise performance by decoupling input matching and noise figure. As shown this aim can be achieved

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by increasing the effective transconductance of the device at the source terminal. It is clear that the noise factor is reduced by a factor of (1+A).

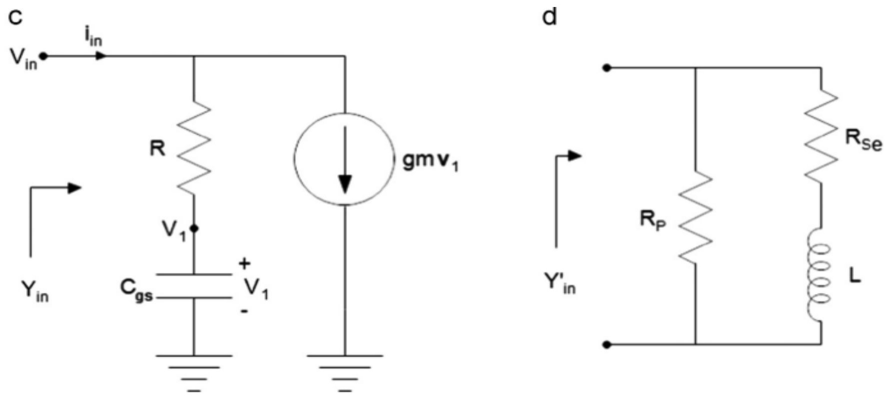


Fig. 3. Gyrator-C based active inductor and its equivalent circuits.

Additionally a lower bias current is needed in the g-boosted CG-LNA in comparison to the conventional one, results in less channel noise of the input transistor. One way to achieve the inverting gain would be using a pair of cross coupling capacitors. However it requires a differential configuration. Thus although this approach has low noise contribution due to use passive reactive components it needs a differential structure for LNA and hence a differential RF input signal has to be generated through a balun stage which will occupy a large chip area .A common source amplifier used as inverting gain block.

III. ACTIVE INDUCTOR

Passive spiral inductors suffer from drawbacks such as low and non tunable self-resonant frequency, low and fixed inductance value and large silicon area. On the other hand gyrator basis active inductors offer a number of unique advantages are small area, large and tunable inductance value, self-resonant frequency and compatibility with standard CMOS technology. Block diagram of active inductor[5,6,7] consisting of two back to back connected positive and negative transconductors and a capacitor at the output terminal as a gyrator-C network. This network exhibits an inductive behaviour at its input terminal, but due to the parasitic capacitance and finite output impedance of the transconductors this behaviour remains inductive only within a narrow frequency range.

IV. LNA CIRCUIT TOPOLOGIES

A. Cascode CS LNA
B. Differential active inductor based Common Gate LNA
C. LNA with acive inductor input matching network

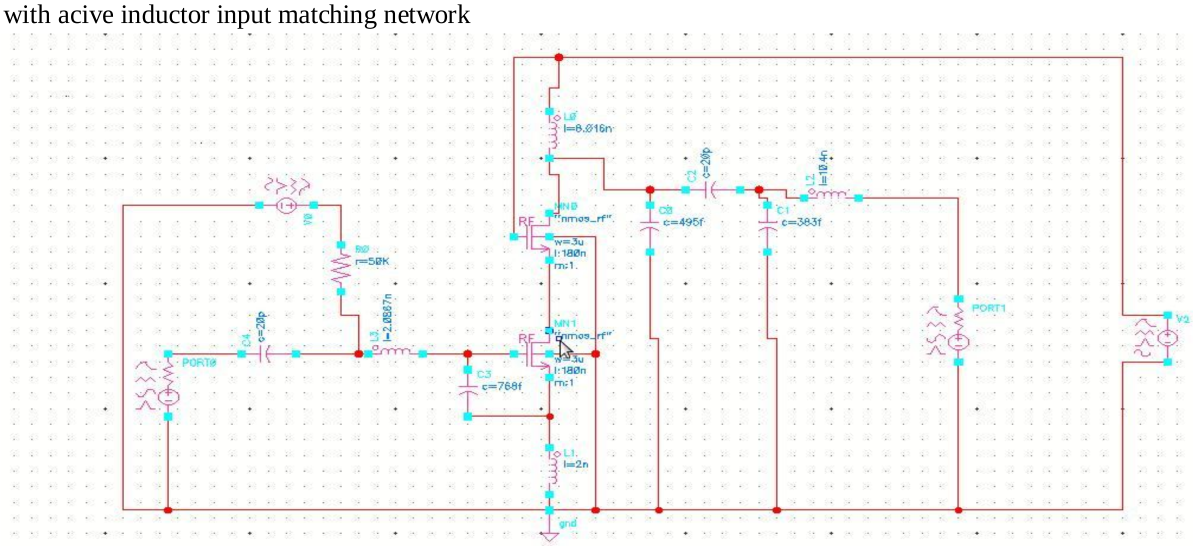


fig 4. cascode CS LNA

The Capacitor Cross Coupled (CCC) technique is proven effective in improving noise performance and reduces power consumption. The CCC technique will deteriorate the CG-LNA's linearity, and the conventional gm-boosting technique also has this problem. It is assumed that the overdrive voltage of input NMOS aspect ratio of CG-LNA due to the gm-boosting amplifier. In a CCC-CG LNA the third order intermodulation product will increase 4 times and hence the IIP3 will decrease by 6dB. To improve the iip3 of the CCC-CG LNA the third order nonlinear coefficient should be minimized. The IIP3 of a MOS transistor can be improved by increasing the overdriving voltage.

However the power consumption will increase dramatically. An interesting characteristic of MOS transistor can be improved by increasing the overdriving voltage. However the power consumption will increase dramatically. An interesting characteristic of MOS transistor is that the g changes from positive to negative when the transistor is biased from weak inversion region to strong inversion region. Therefore a g3 close to zero can be achieved by two parallel transistors which are biased at the subthreshold and saturation regions. The advantage of DS method[4] is that small extra power consumption is needed.

The circuit schematic of the proposed gm-boosted LNA[2,3]. It consists of two stages along with a buffer, the first one the input stage is a common gate configuration with a gm-boosting approach and active input impedance matching network. The common a gate transistor with low input impedance provides a relatively frequency independent noise factor. Also cancelling the Miller effect of its gate-drain capacitance provides better isolation against output return signal. The common source transistor with resistor forms the inverting gain block between gate and source terminals of m to boost its trans conductance with a factor of A without increasing the bias current and transistor size. The active inductor of the active inductor of the input matching network has been realized.

According to it is the increased R will increase the inductance value and therefore use a tunable component like a voltage controlled resistor allows changing the resonance frequency the attractive portion for multichannel communications.

It has to be noted that the matching condition is achieved by a conjugation between active inductor and CG-stage, the active inductor is used to cancel the capacitive effects at the input terminals and the gm-boosted CG structure guaranties the real part matching.

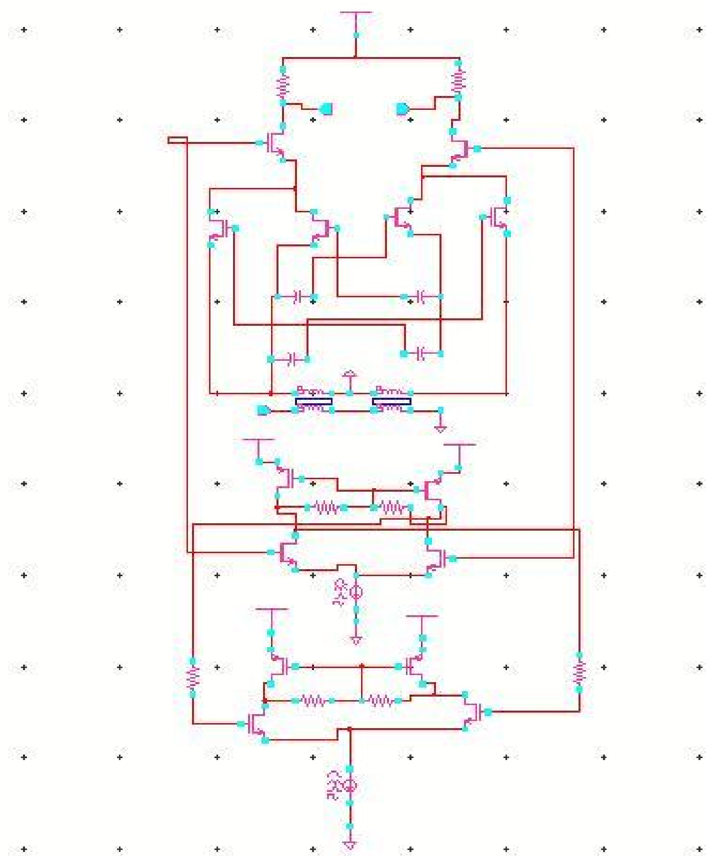


fig 5. CCC-CG LNA

The second stage of the LNA[5,6,7] the gain stage includes a common source transistor to increase the power gain and source follower transistor to act as buffer stage. Due to UWB bandwidth requirements it is very important to have a flat power gain over the frequency range. Therefore resistor and inductor have been added as a shunt peaking to improve the bandwidth and gives a smooth gain.

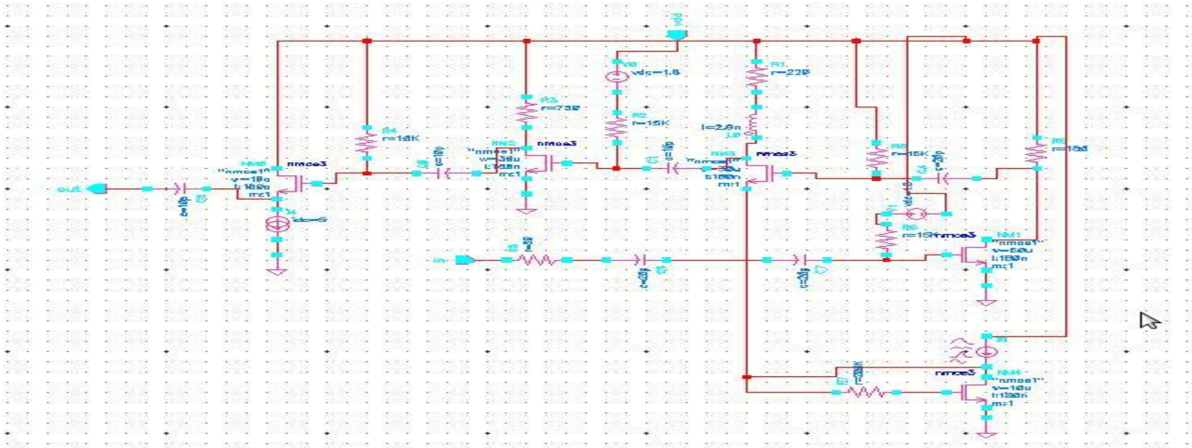
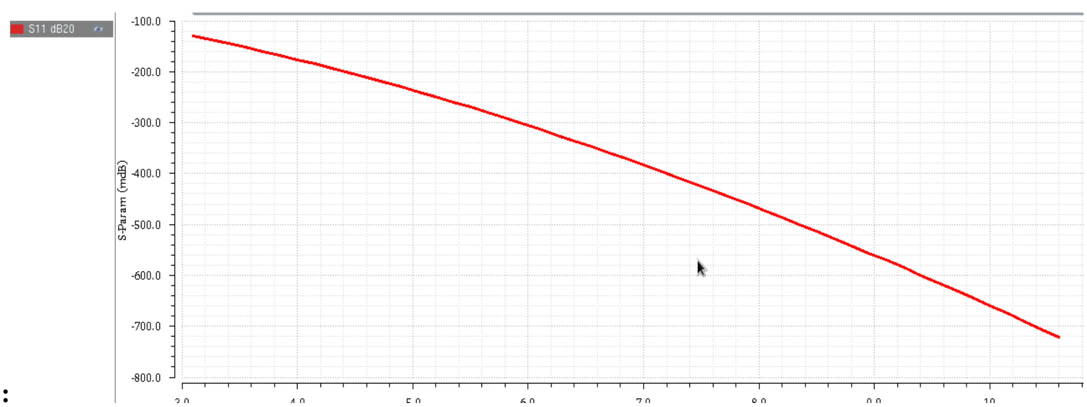


fig 5. g_m – boosted LNA

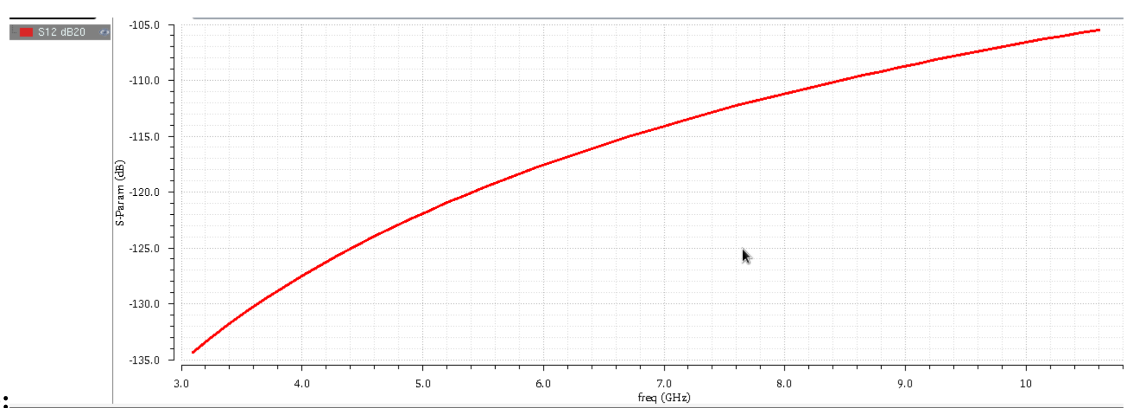
V. SIMULATION RESULTS OF GM BOOSTED LNA CIRCUIT

A. Parameter Values

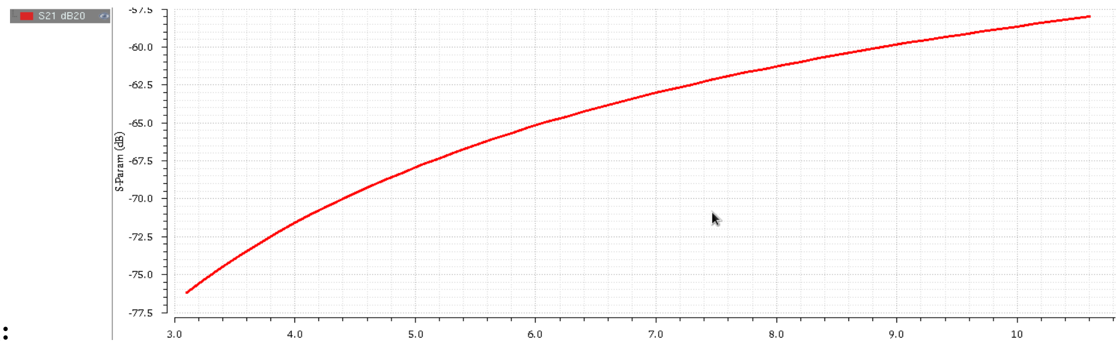
Transistor W/L(um/um)	Resistor(Ω)	Capaitor(F)	Inductor
NM2,NM3=30/0.18	R0,R2,R6=15K	C1,C6,C7=20p	L=2.9n
NM1=50/0.18	R3=750,R7=200,R8=180	C5,C0=10p	
NM0,NM4=10/0.18	R1=220,R4=10K,R5=50	C2=10P	



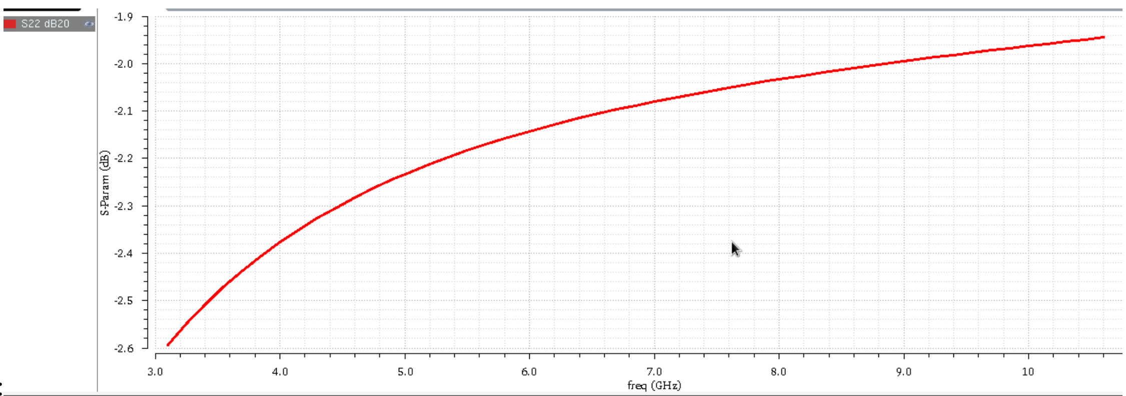
S_{11}:



S_{12}:

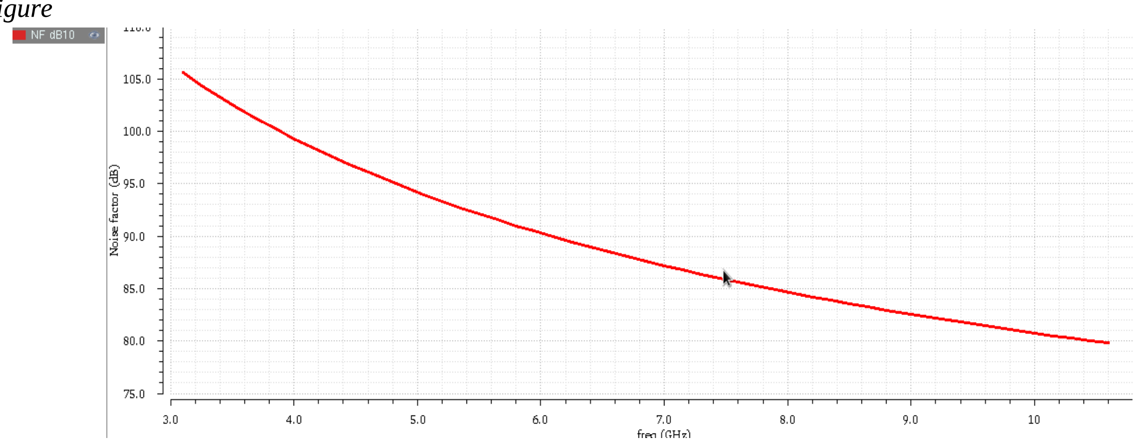


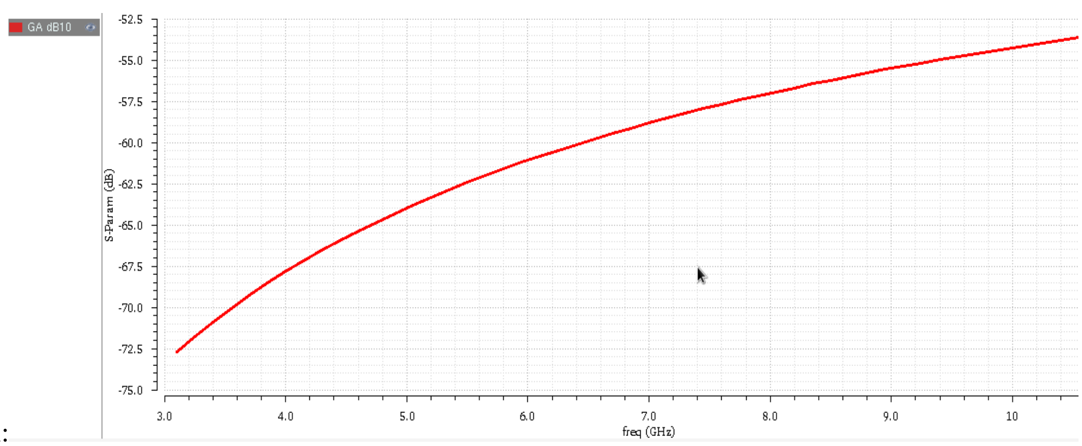
S_{21}:



S_{22}:

B. Noise Figure





Gain:

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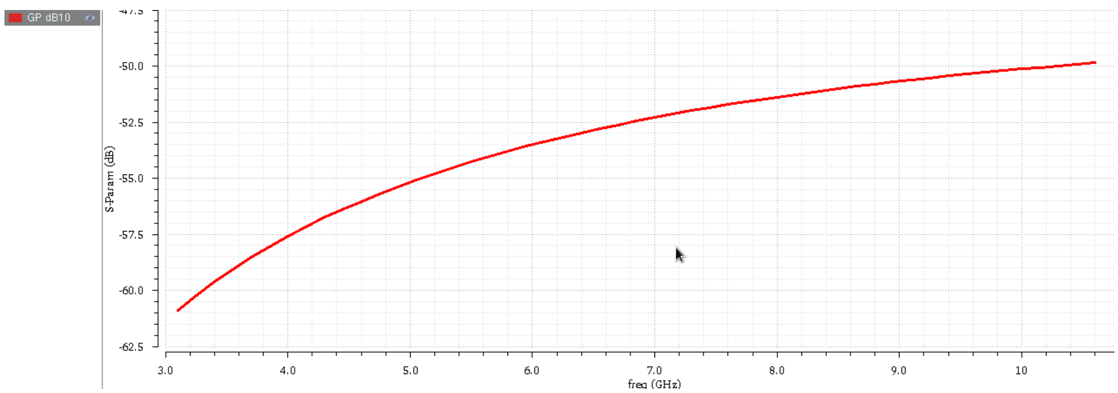
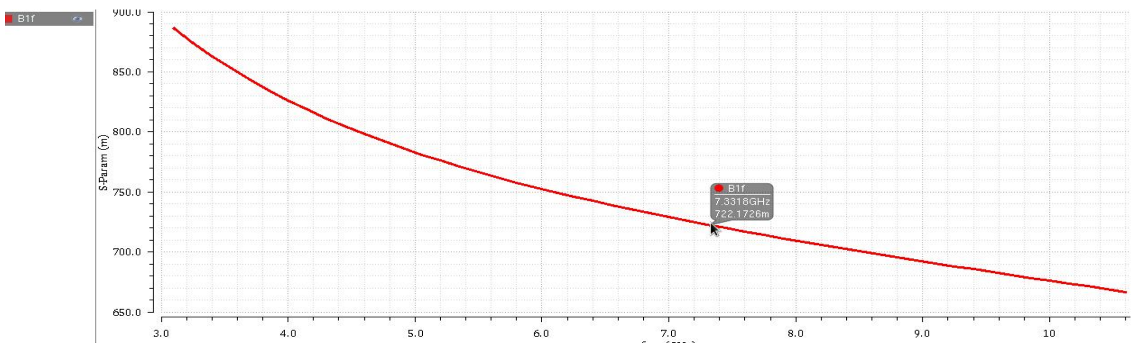
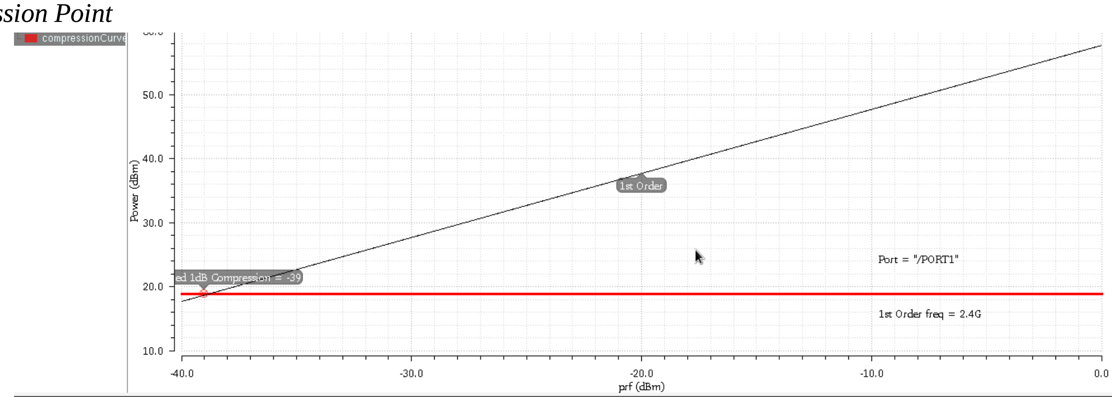
C. Power Gain



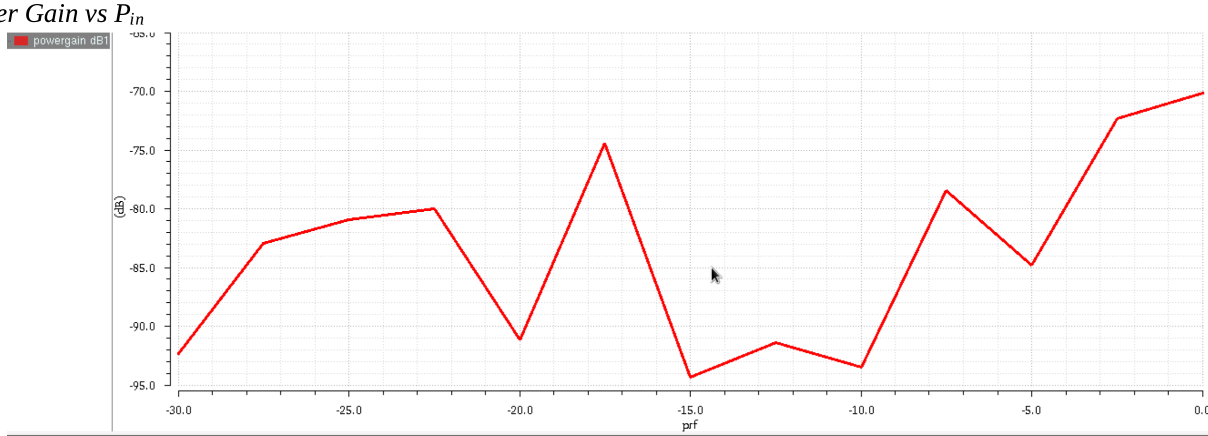
D. Stability Factor



E. Compression Point



F. Power Gain vs P_{in}



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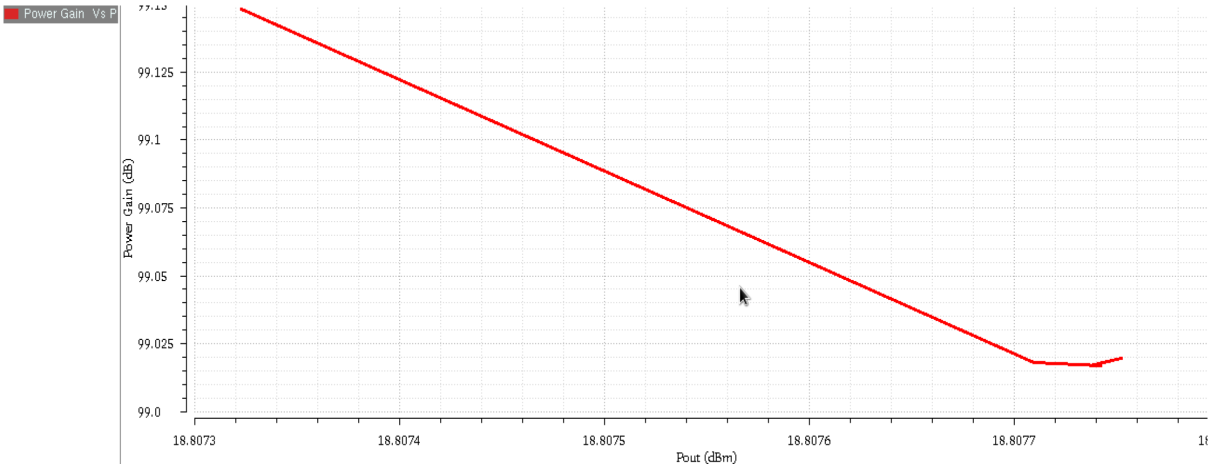
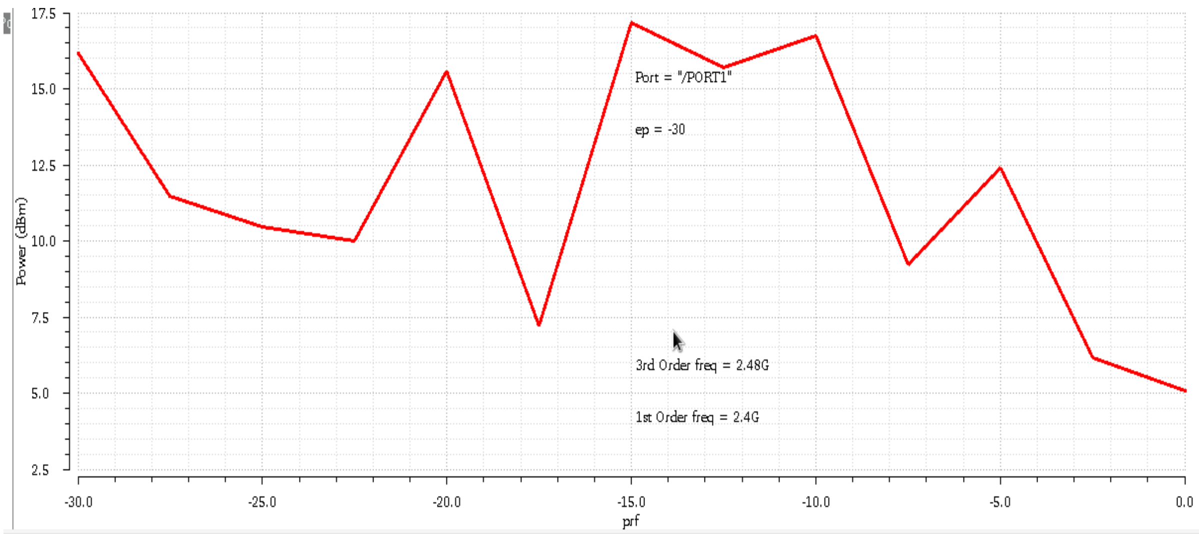
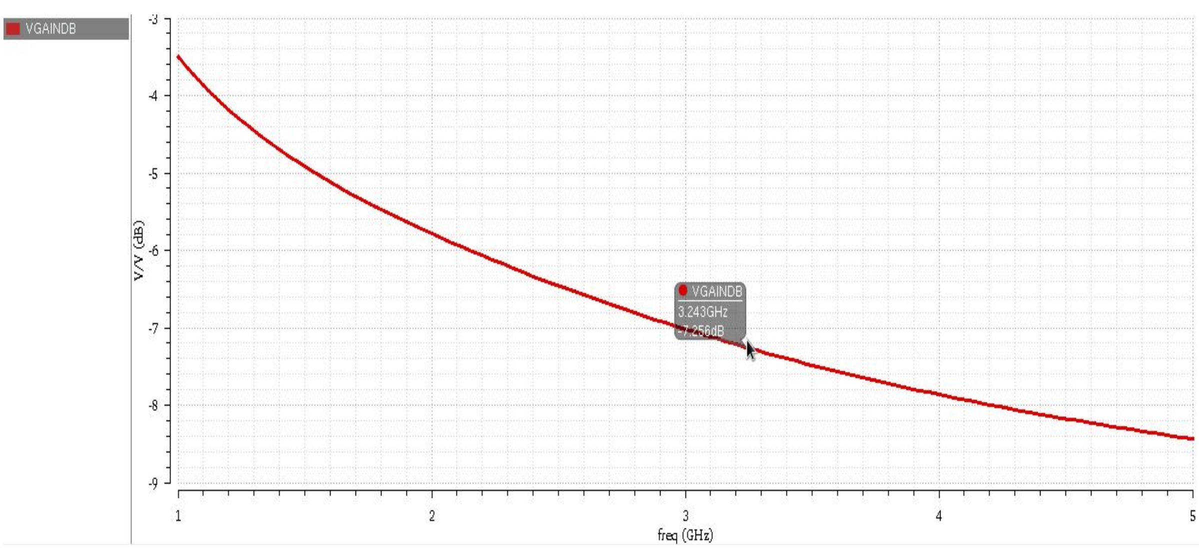
G. Power Gain vs P_{out}



H. P_{out} vs P_{in}:



I. $VSWR_1$



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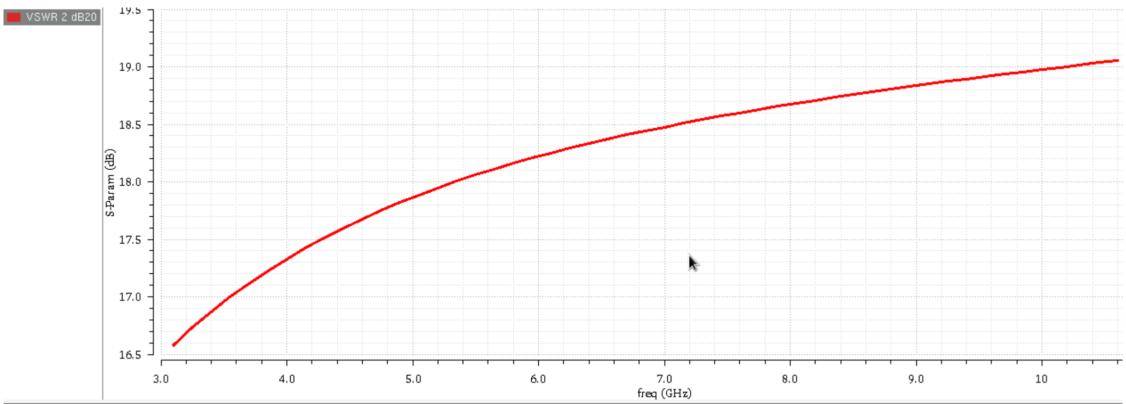
J. SWR_2



VI. COMPARISON TABLE OF LNA TOPOLOGIES

Parameter	Cascode CS LNA	CCC-CG LNA	Gm-boosting LNA
S11(dB)	-2.676m_-265.5m	-1.80561_-1.80563	-130.715m_-721.79m
S12(dB)	-8.429_-31.5436	-74.07_-74.44	-134.304_-105.4702
S21(dB)	-8.429_-31.5436	-74.07_-74.43	-76.168_-58.0125
S22(dB)	-844.133_-5.924	-870.261m_-793m	-2.591_-1.945
NF(dB)	928.904m-2.962	66.8_66.81	105.57_79.80
BW(GHz)	3.1_10.6	100M_1000M	3.1_10.6
P(W)	138.36a	13.34z	2.83n

VII. CONCLUSION

An ultra-wideband CMOS LNA utilizing an active inductor in the input matching network presented. A common gate structure with g_m boosting approach has been used as core of LNA due to its input matching characteristic in ultra-wideband and relatively frequency independent noise figure. A common source amplifier has used as feedback path to boost g_m of the common gate stage to reduce noise specification of LNA. With the presence of active inductor based g_m-boosting LNA shows good performance compared to cascode CS LNA. g_m-boosting LNA power is 2.83nW. g_m-boosting LNA can be used for Radio frequency receivers.

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