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RF Front End Analysis for the Damage Rate of Low Noise Amplifiers

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ABSTRACT
The first real signal processing element just after the antenna that determine the noise performance and linearity of the overall system in RF receiver is Low Noise Amplifier (LNA) which makes it one of the most important and sensitive block of a RF receiver that can improve the performance of the circuit. The RF front end is the most significant part and any electronic warfare can damage the entire circuit performance. It is not possible to analyze theoretically under conditions such as change in input power, frequency, and design parameters. It is mandatory to propose the relationship between damage rate and the power absorbed in order to reduce the damage rate. This paper analyzes the power absorbed by the non-linear element present in the LNA circuit. The power absorption is verified by varying the input and output impedances. Hence, this paper identified the parameters that increase the damage rate of LNAs and suggested designs to reduce the damage rate.

I. Introduction

Low noise amplifiers (LNA) are devices capable of amplifying extremely weak signals and provide voltage levels suitable for analog to digital conversion or further analog processing. They are employed in applications involving low amplitude sources like many types of transducers and antennae. When dealing with weak sources, the performance of the measurement system is dominated by the gain and noise introduced by the first stage. Thus the selection of proper LNA is important for the good operation of the circuit. The circuit faces the electronic failure during interference, upset and damage or burn-out. A very high input power causes the burn out. After the occurrence of any electronic warfare, it can take few days to recover or may never return to normal operation. The probability of occurrence of damage can be related to certain variables such as the microwave pulse width, pulse frequency, transient responses of the bipolar junction transistor and pseudomorphic high electron mobility transistors(PHEMTs). It is also possible to visually examine the damage conditions and mechanisms of the PHEMT by using scanning electron microscopy and X-Ray spectroscopy. However, these methods are expensive and time consuming. So, here the damage modeling of LNA was realized in National Instruments Design Suite Multisim. The simulation includes the damage mechanisms in addition to the variables of hybrid parameters which defines the damage boundary. An LNA consists of semiconductor devices and passive circuit elements. Here, in this paper we analyze the parameters that affect the LNA failure. The relationship between the peripheral circuit and nonlinear element is analyzed here. It also identifies the variables determining the damage rate of an LNA. In an electric circuit, a nonlinear element or nonlinear device is an electrical element which does not have a linear relationship between current and voltage. The power absorbed by the non-linear elements such as BJTs, MOSFETs, and HEMTs is used to determine the damage rate of LNA in the circuit. When the power absorbed by the non-linear elements is very high, it leads to breakdown due to heat focusing and in turn affects the circuit.

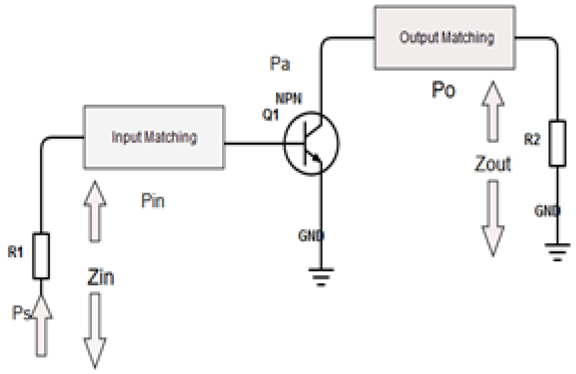

Fig 1. Power flow of an LNA

The power absorbed by the circuit is related to the input and output impedances of the LNA as shown in the Fig 1. The power absorption Pa is defined by considering the small power losses.

$P_a = P_{in} - P_{out}$

Even though the loss of matching is considered to be small, the above relation cannot be used to determine the power loss and this is due to the reason that the input power is very high. This, paper proposes an another definition of the power by considering the high input power. Let us take three cases for analyzing the power absorption. The analysis is made for both the resistive and inductive LNA.

II. Damage rate

A. Resistive LNAs

Based on the application, the circuit can either be a resistive LNA or inductive LNA. There is a major difference between the resistive and inductive structure with respect to input frequency.

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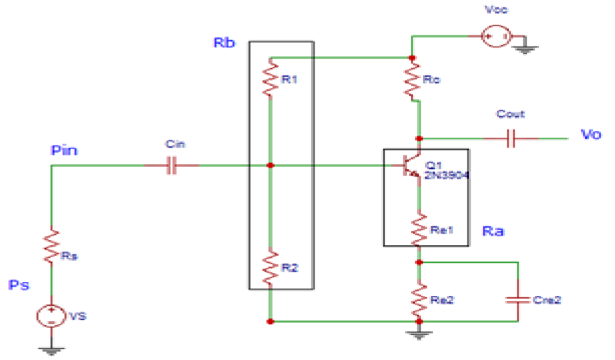

Fig 2.Resistive LNA

As shown in the Fig 2 the input side of the RF Front end consists of the input source Vs and the source impedance Rs. Rb is the matching impedance at the input side and divides the bias voltage. Ra is the internal impedance of the BJT. The output resistor Rc affects the output impedance and output power. The input and output capacitors Cin and Cout remove the dc components of the input and output signals.

B. Power absorption

Here in order to define the power absorption of an abnormally operating transistor, the only input side is considered. Let us consider the input circuit as follows as shown in the Fig.3.

The input side concentrated on the internal and the matching impedance of the circuit alone.

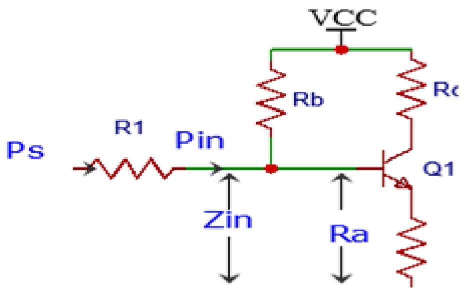

Fig 3.Input Side

The input impedance of the above defined LNA is given as

$$Zin = \frac{Rb\ X\ (r\pi+(\beta+1)(Re1+re))}{Rb+(r\pi+(\beta+1)(Re1+re))}$$

Here, Rb is calculated as R1|| R2 and Ra is defined as $(r\pi+(\beta+1)(Re1+re)$, the input impedance Zin is calculated from a parallel of the matching impedance of the input side Rb and the internal impedance of the BJT(Ra). It is to be noted that Ra includes Re1 for easier calculation. The internal impedance consists of the hybrid parameters that are changed by the collector current and temperature. The input side can also be expressed by an equivalent circuit as shown as below in Fig 4.

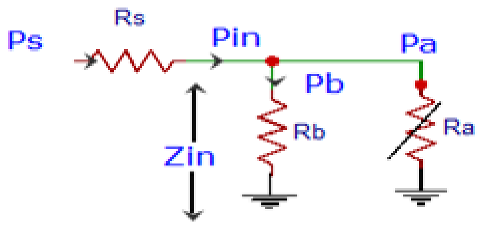

Fig 4. Equivalent Circuit

The equivalent circuit is given as shown above. The power absorbed to the BJT is given as

Pa = Pin – Pb

As we have related the damage rate with that of the power absorption, lesser power input to Ra results in lower damage rates.

There are two factors which increase the damage rate of LNA.

1. High matching impedance of the input side
2. Low internal impedance of the BJT.

The high matching impedance can be incurred by the impedance change of the inductors as the input frequency changes. The internal impedance of a BJT varies with its characteristic curves of hybrid parameters.

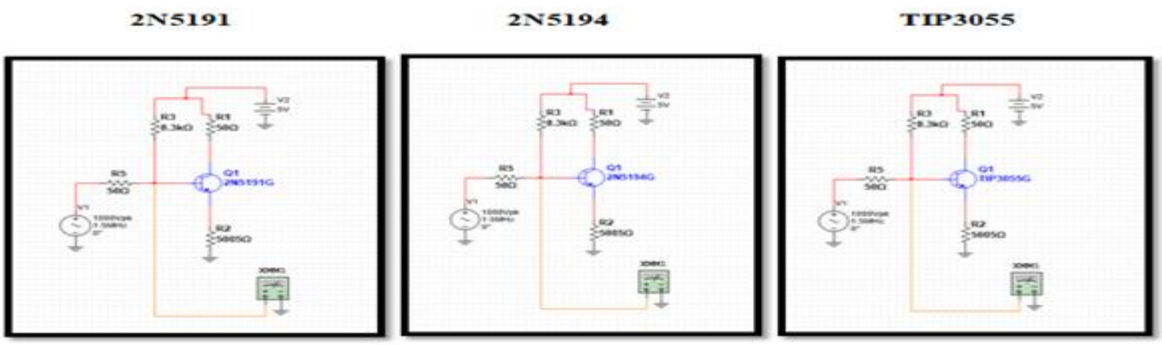

Fig 5. Case 1 analysis for 2N5191, 2N5194, TIP3055

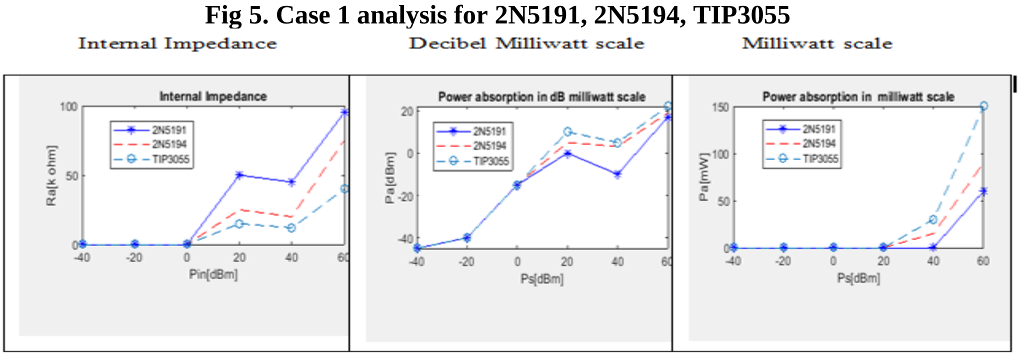

Fig 6. Output Graphs obtained for the 2N5191, 2N5194, TIP3055

III. Modes of LNA

Usually the LNA has four unique modes. They are, Saturation , Reduction, Increase and Breakdown. The Kirk effect ruptures the depletion layer and makes it unlikely to return to normal operation. This effect is possible to occur after the increase mode. Hence, it is defined that the high power absorption after the increase mode can breakdown LNAs more faster than the usual.

Three cases are considered here to analyze the damage rate of variously desgined LNAs.In each case, we have observed the performances with an NPN, PNP and a complementary power transistor.

A. Case 1

In this case, the LNAs differ only in the BJTs used. Each LNA consists of a fixed matching impedance of the input side and a BJT, but every BJTs have different characteristic curve. Reducing Ra increases the power absorption of a BJT.

B. Case 2

Same BJTs with different input impedances are analysed. Here, in this case matching impedance is varied in the input side. The LNAs differ only in the peripheral circuits. The different input impedances has a situation in which the inductor impedance is changed by the wide frequency range of an HPEM pulse. The internal impedance changes with the input power. When the matching impedance of the input side is different, the input power is different for the same power source. Thus when the internal impedance is the highest, the power absorbed will be the lowest.

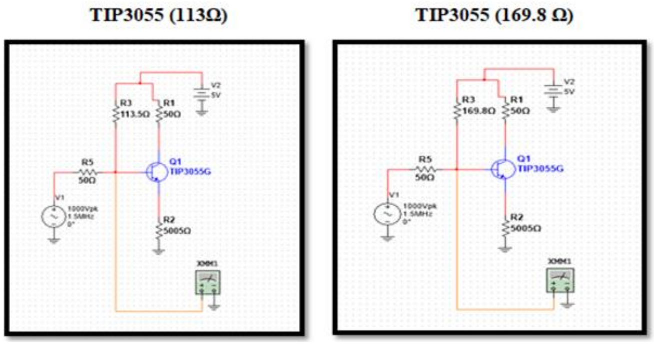

Fig7. Case 2 analysis for the different matching impedances

C. Case 3

Case III is of three LNAs having different matching impedances and different BJTs, in order to compare which condition dominantly affects the BJT damage rate. The results in Cases I and II are predictable by the proposed equivalent circuit, but Case III is not. So, Case III makes an LNA having a high internal impedance (R_a) also has a high matching impedance of the input side (R_b). Generally, R_a is higher than R_b. Thus, the input impedance (Z_{in}) converges on R_b, which is shown in Table I. It can be predicted that the power absorbed to a BJT will be mainly affected by R_b. Increasing Rb increases the power absorption of BJT. The power absorption of 2N5191 is the highest.

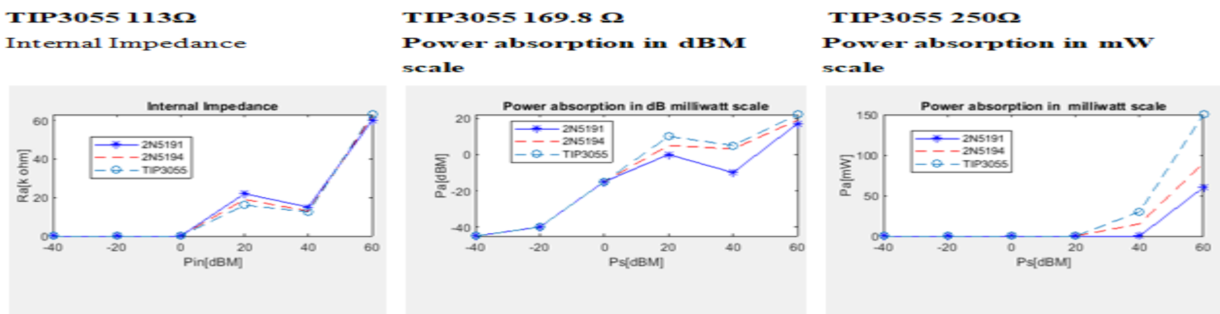

Fig 98.

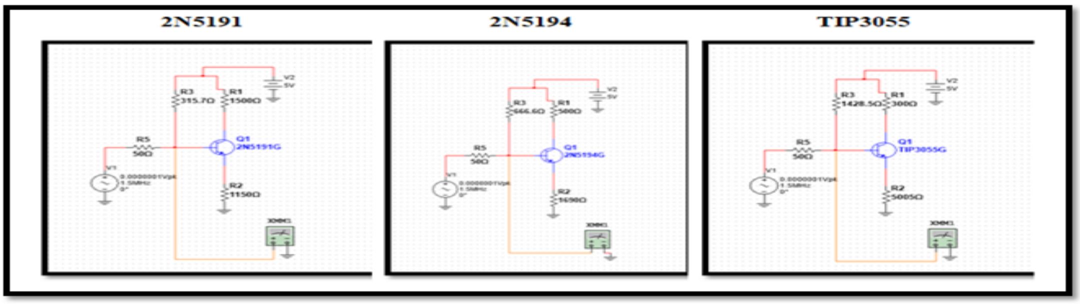

Fig.9. Case III Analysis for different BJTs with different matching impedances.

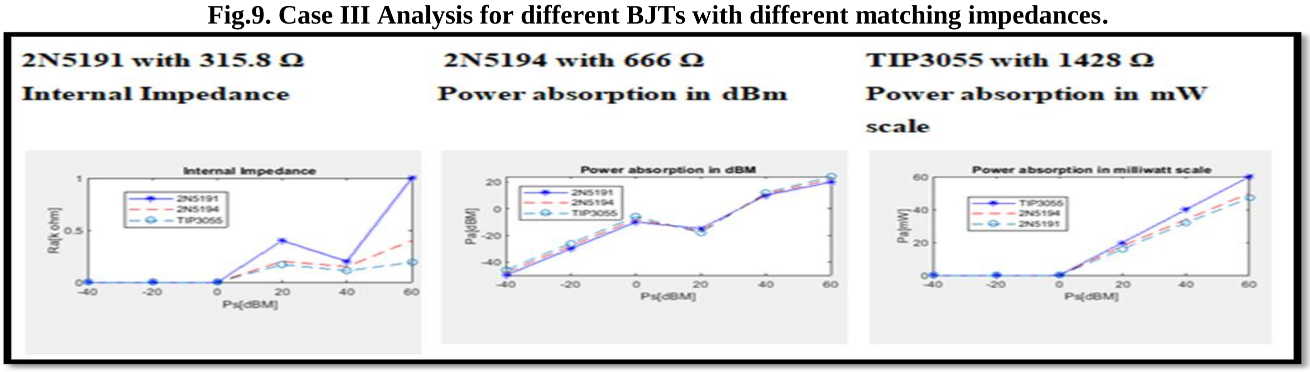

Fig.10. Output Graphs obtained for the Case III.

Low matching impedance with the low internal impedance is the most vulnerable case, this is because the highest matching impedance increases the power input to internal impedance while the lowest matching impedance increases the overall input current and the collector current of the BJT increases. The increasing collector current further increases the internal impedance, which consists of the hybrid parameters.

IV. Inductive LNA

The LNA types used for frequencies in the order of giga-hertz are resistive or The proposed method to predict the damage rate of such an LNA can be effectively employed to analyze an inductive structure. The figure shows a basic inductive LNA. The peripheral circuit of both the emitter and the base affects the input impedance.

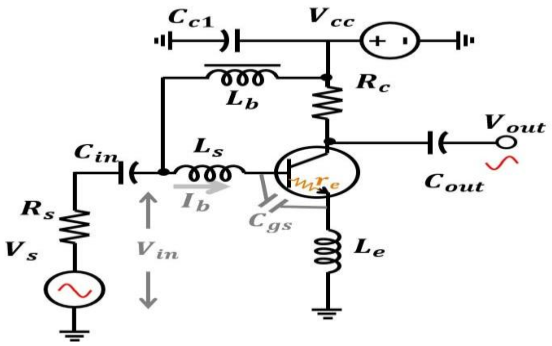

Fig.11. Inductive LNA Circuit

Table 1. Parameter specification for Resistive LNA

Name	Case 1	Case2		Case 3		
	2N5191,2N5194,TIP3055	TIP3055with 113Ω	TIP3055 with 315.8 Ω	2N5191with 315.8Ω	2N5194 with 666Ω	TIP3055with 1428 Ω
R1	1000Ω	2000 Ω	3000 Ω	1500 Ω	2000 Ω	5000 Ω
R2	60Ω	120 Ω	180 Ω	400 Ω	1000 Ω	2000 Ω
Rb	56.6 Ω	113 Ω	169.8 Ω	315.8 Ω	666 Ω	1428 Ω
Rc	50 Ω	50 Ω	50 Ω	1500 Ω	500 Ω	300 Ω
Re1	5 Ω	5 Ω	5 Ω	30 Ω	30 Ω	30 Ω
Zin	51 Ω	94 Ω	129 Ω	286 Ω	552 Ω	1009 Ω
Z0	50 Ω	50 Ω	50 Ω	1449 Ω	493 Ω	297.7 Ω
Vcc	5 V	5V	5 V	5V	5V	5V
Rs	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω
RL	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω
Re2	5000 Ω	5000 Ω	5000 Ω	1120 Ω	1600 Ω	950 Ω
Cin	20pF	20pF	20pF	6.4pF	1.77pF	0.9pF
Cre2	10pF	10pF	10pF	2pF	900pF	90pF

Here, g_m is the reciprocal of the transresistance r_e. The inductor on the emitter performs the role of eliminating oscillation and increasing the linearity of the output; this is called emitter degeneration (L_e). The damage rate of the inductive LNA can be inferred from circuit theory. The big difference between the resistive and inductive types of LNAs is in the frequency term and the parasitic capacitance. The input impedance of an inductive LNA increases with increasing input frequency; thus, the input power to the base decreases, which in turn leads to low power absorption of the BJT, thereby decreasing the damage rate. This prediction also corresponds with the experimental results.Comparatively the performance of inductive LNA is superior to that of the resistive LNA i.e the power absorbed is very less even in the vulnerable cases of the resistive LNA. The graph above shows that the power absorbed is nearly -10dBM to the maximum here and hence the power absorbed by the transistors in Inductive LNA configuration is less.

It is observed that the power absorbed in the inductive LNA is very less when compared to the resistive LNAs. The power is very low in the order of about -30 dBM. This is because the inductors improve the linearity of the system and control the oscillations in the circuit.The results prove that the proposed inductive LNA circuit can be effectively employed to reduce the damage rate of LNAs, and this approach is expected to contribute to design that protect RF front ends from HPEM pulses.

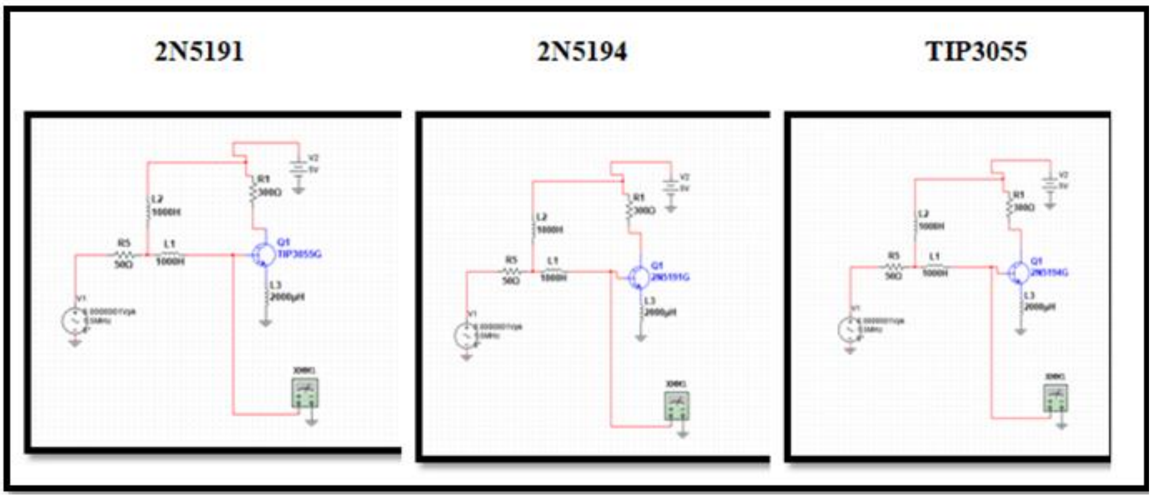

Fig12. Inductive LNA Circuits

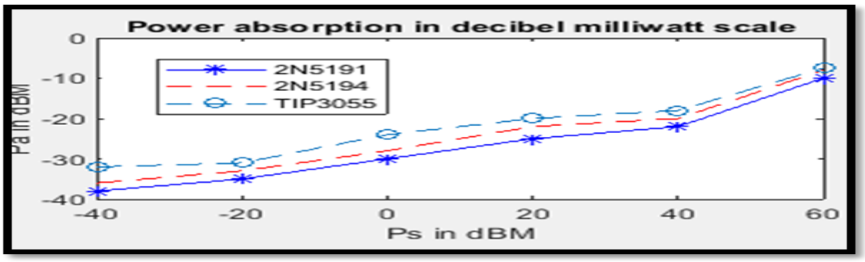

Fig.13 .Output Graph for the Inductive LNA circuit.

Table 2.Parameter Specification for Inductive LNA

Nam	**Case 1**	**Case2**		**Case 3**		
	2N5191,2N5194,TIP305	**TIP3055 with 113**	**TIP3055 wit 315.8 Ω**	**2N5191 with 315.8**	**2N5194 with 666**	**TIP3055 with 1428**
R1	1000Ω	2000 Ω	3000 Ω	1500 Ω	2000 Ω	5000 Ω
R2	60Ω	120 Ω	180 Ω	400 Ω	1000 Ω	2000 Ω
Rb	56.6 Ω	113 Ω	169.8 Ω	315.8 Ω	666 Ω	1428 Ω
Rc	50 Ω	50 Ω	50 Ω	1500 Ω	500 Ω	300 Ω
Re1	5 Ω	5 Ω	5 Ω	30 Ω	30 Ω	30 Ω
Zin	51 Ω	94 Ω	129 Ω	286 Ω	552 Ω	1009 Ω
Z0	50 Ω	50 Ω	50 Ω	1449 Ω	493 Ω	297.7 Ω
Vcc	5 V	5V	5 V	5V	5V	5V
Rs	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω
RL	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω
Re2	5000 Ω	5000 Ω	5000 Ω	1120 Ω	1600 Ω	950 Ω
Cin	20pF	20pF	20pF	6.4pF	1.77pF	0.9pF
Cre2	10pF	10pF	10pF	2pF	900pF	90pF

V. Conclusion

Low Noise Amplifiers when get unwell can damage or degrade the entire performance of the circuit. Hence, this paper made an analysis for all the possible values of matching and internal impedances. It is inferred that the Low internal and matching impedance is the most vulnerable combination. Hence to safeguard the front end of the RF circuit, it is necessary to cross check the value of the internal and matching impedance. Also, the inductive LNA circuit is analyzed and it is observed that the power absorption is drastically reduced compared to the resistive LNA. The power absorption is even 10 times less than that of the resistive LNA. Hence, the relationship between the internal and matching impedance matters a lot in the analysis.

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