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Design of LNA for Weather RADAR

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***Abstract*: A weather RADAR operates both in S-band and C band. S-Band (2700-2900 MHz) is best used for detecting heavy rain in ranges up to 300 km while C-Band (5600-5650 MHz) can detect rain up to 200 km range. The C band RADAR represents a good compromise between range and reflectivity and cost and hence most widely used. The major parameters on which RADAR working depends is the sensitivity and selectivity which captures all the available signals. But the rain attenuates the EM waves which will distort the signals. This paper deals with the design of C band low noise amplifier using ADS simulation tool which improves the signal strength i.e. gain and reduces the noise figure for better RADAR weather detection. Various low noise amplifiers are designed using different stabilization techniques in this paper for determining the efficient and optimum LNA and found the parallel RLC drain LNA design to be efficient with a power gain of 14.003 dB and noise figure of 0.407 dB.**

Keywords: LNA, RADAR, VSWR, distributed components, power gain, noise figure,

I. Introduction

A Weather RADAR is used to detect the motion of rain droplets in addition to the intensity of the precipitation. Data analyzed is used to determine the structure of storms, its intensity, and wind pattern. It is used to locate precipitation, calculate its motion, and estimate its type (rain, snow, hail etc.). In a RADAR communication, the receiver receives all available signals which are normally weak and also contain noise. This signal is passed to RF Amplifier which is a low noise amplifier which eliminates the noise content and improves the signal strength. Arun Kumar Ray, Rathin Chandra Shit designed a low noise amplifier using fully stabilized InGaAs HEMT for RADAR receivers operating at 5.4 to 5.9 GHz with MMIC technology and obtained noise figure less than 1 dB, the power gain of 18 dB [1]. Z Hamaizia, N Sengouga, M Missous et al, designed low noise amplifiers for Radio Astronomy applications one with a cascode technique and another with a two-stage cascaded technology and obtained a maximum gain of 15dB and noise figure of 0.6dB for the first design, while 27 dB gain and 0.63dB noise figure for the second design [2]. R. Krithivasan, X. Li, et al, designed a low power X band SiGe HBT low noise amplifier that exhibits a gain of 11 dB and noise figure of 2.78 dB at 9.5 GHz [3]. Yashpal Yadav, CRS Kumar designed a low noise amplifier for RF applications in C band using Microstrip transmission components and obtained a power gain of 13.121 dB, the noise figure of 0.811 dB and VSWR approximately 1.5 both at the source and load side for 6 GHz center frequency [4]. Christina Lessi, Evangelia Karagianni designed a low noise amplifier for X band Marine Navigation RADARs operating at 9.1 GHz center frequency using lumped components and obtained a gain of 20.108 dB and noise figure of 6.92 dB [5]. This work implies that the power gain, noise figure, matching networks are the vital parameters that determine the performance of a low noise amplifier though there is a trade-off between the gain and noise figure of the design.

In this paper, we have managed to design a low noise amplifier for weather RADAR receiver system by balancing the trade-off parameters.

II. Design Aspects

In low noise amplifier, MAG (maximum available gain) and NFmin (minimum intrinsic noise) figure are the important parameters of active devices to be considered for LNA design, which in turn depends on the S parameters of the device. The S parameters determine the stability criteria of the device at various biasing points. The Low Noise Amplifier is designed using GaAs FET MGF 1303 of Mitsubishi with different techniques for improving the stability of the device and conclude for a better design with respect to noise figure, stability and gain of the amplifier.

Advanced Design System (ADS) simulation tool is used for designing the low noise amplifier. There are two different types of device libraries available in the ADS software namely S – parameter library and RF Transistor

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library. S – Parameter library works on fixed bias i.e. these parameters of the device are fixed for a particular bias point of the device and no separate biasing network is required to be connected with this device for providing supply [6]. In this work, the S – parameter library device is used.

Theoretically, the stability of the device is checked using K - |Δ| test where K said to be Rollet's Stability mathematically expressed as shown below.

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2\,|S_{12}S_{21}|} \quad (1)$$

Also, B is another parameter that is calculated for checking stability which should be positive for stable operation given by,

$$B = 1+|S_{11}|^2-|S_{22}|^2-|\Delta|^2 \quad (2)$$

And Δ is given by,

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \quad (3)$$

The condition for stability is that if K > 1, |Δ| < 1 and B = +ve, then the device is stable for certain conditions and if K < 1 then device is potentially unstable. This condition will tend the device to oscillate. In this case, the gain of the device will be a maximum stable gain (MSG) given,

$$MSG = \frac{|S_{21}|}{|S_{12}|} \quad (4)$$

If the device is stable then the gain will be a maximum allowable gain (MAG) given,

$$MAG = \frac{|S_{21}|}{|S_{12}|}(K \pm \sqrt{K^2-1}) \quad (5)$$

Here the circuit is designed using the distributed components i.e. transmission line equivalent of the lumped components because of the fact that at high frequencies in GHz range the lumped components posses parasitics which affect the system performance. The 50-ohm terminations are provided for calculating the S parameters of the network.

III. PROPOSED DESIGN

Different techniques are available to improve the stability of low noise amplifier [7]. Connecting a single passive element or combination of one or more components with the terminals of the active device (here GaAs FET) improves the stability of the device. These techniques are:

- Connecting a parallel RLC combination at the gate terminal of FET.
- Connecting a parallel RLC combination at the drain terminal of FET.
- Connecting a series RLC combination at the drain terminal of FET.

The first low noise amplifier designed for this application is shown in fig. 1 in which an RLC parallel network is connected at the gate terminal of FET.

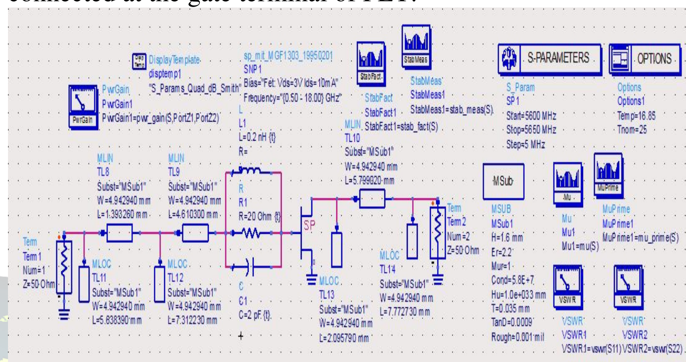

Fig. 1. Gate RLC LNA Design

In ADS Rollet's stability factor k (m9) and |Δ| (m10) obtained is shown above in fig. 2 which is obtained as 1.112 and 0.608 respectively.

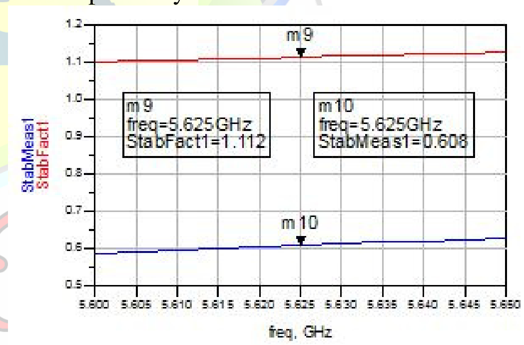

Fig. 2. Stability Curve of gate RLC

The second design deals with the resistor, inductor, and capacitor in parallel and this combined network connected to the drain terminal of the device as shown in fig. 3.

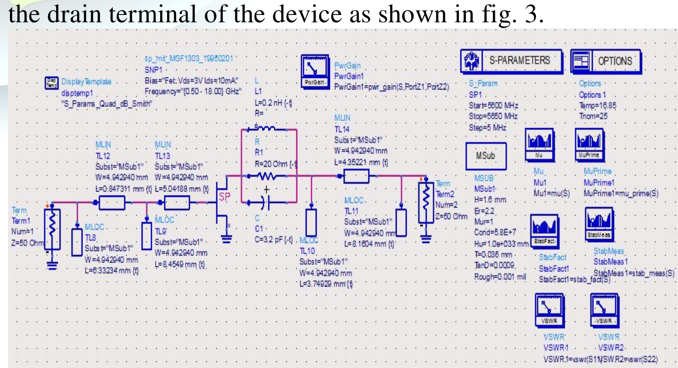

Fig. 3. LNA Design with drain RLC network

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The Rollet's stability factor k and |Δ| denoted as stabfact and stabmeas is shown in fig. 4 which is obtained as 1.043 and 0.450 respectively.

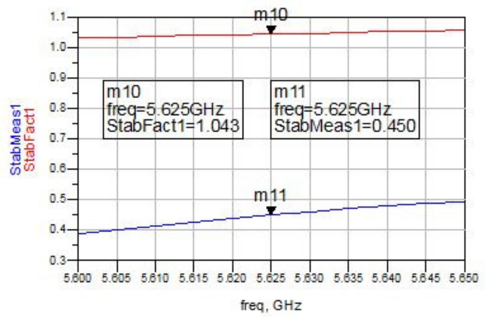

Fig. 4. Stability of drain parallel RLC

The third design deals with the RLC components connected in series and the combined network is connected to the drain terminal of the device as shown in fig. 5.

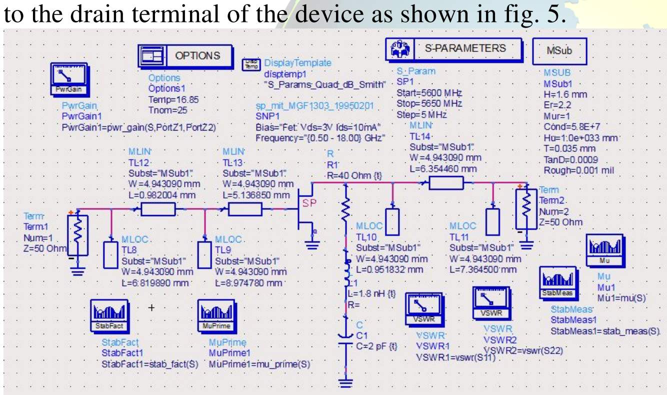

Fig. 5. Drain series RLC LNA Design

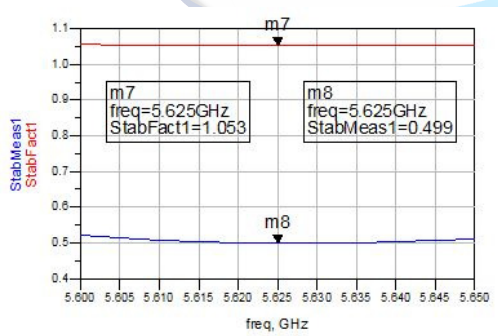

Fig. 6. Stability of drain series RLC

The Rollet's stability factor k and |Δ| denoted as stabfact and stabmeas is shown in fig. 6 which is obtained as 1.053 and 0.499 respectively.

IV. RESULTS

The power gain and noise figure obtained for the parallel gate RLC LNA are 13.271 dB and 3.146 dB as shown in fig. 7 and 8 respectively.

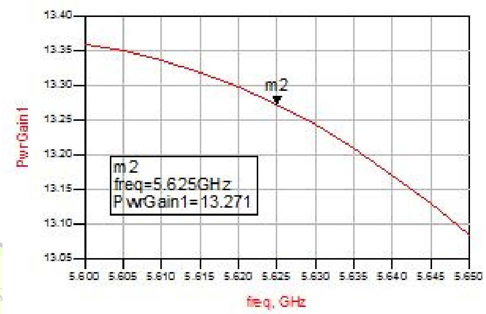

Fig. 7. Power Gain

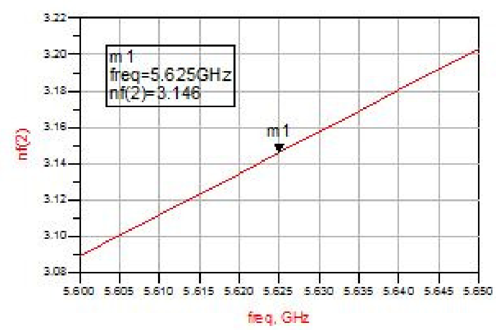

Fig. 8. Noise Figure

Standing wave ratio (VSWR) is another parameter which determines the amount of reflections that occurs in a microwave circuit due to improper impedance matching. It is represented in the form of reflection coefficient which is mathematically represented as

$$VSWR = \frac{V\max}{V\min} \quad (6)$$

OR

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (7)$$

Where $\Gamma = \frac{Vr}{Vi}$

The range of VSWR values is $1 < VSWR < \infty$ for the corresponding reflection coefficient of $0 < \Gamma < 1$ [8]. The VSWR obtained for the source (VSWR1) and load (VSWR2) matching is shown in fig. 9 which are 1.016 and 1.021 at

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input and output side respectively. The fewer values of VSWR i.e. nearby 1 signifies that the amount of reflections is very less i.e. negligible.

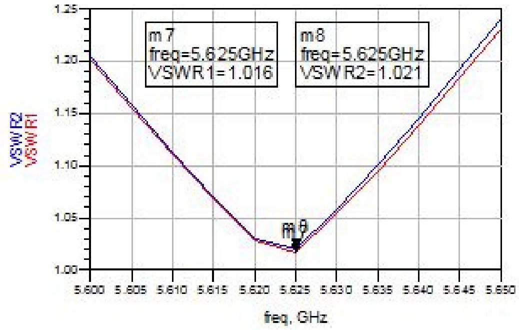

Fig. 9. VSWR

The S parameters of the designed LNA obtained are shown in fig. 10 and 11 respectively. The S_{11} is -41.861 dB, S_{21} is 13.271 dB, S_{12} is -17.339 dB and S_{22} is -39.753 dB.

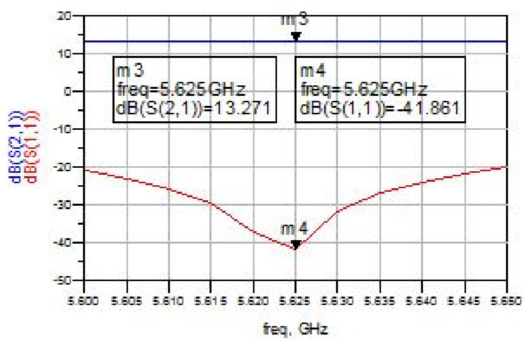

Fig. 10. S_{11} and S_{21} parameters

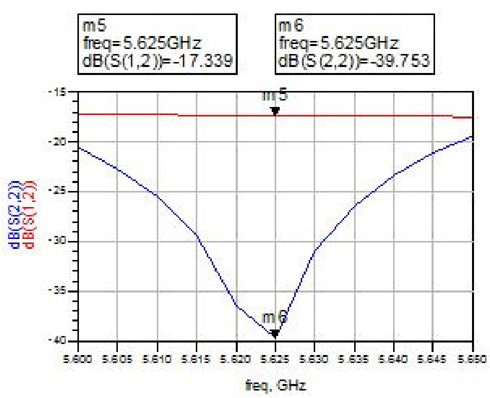

Fig. 11. S_{12} and S_{22} parameters

The second design with parallel RLC in drain terminal provide a power gain of 14.003 dB and noise figure of 0.407 dB as shown in fig. 12 and 13 respectively.

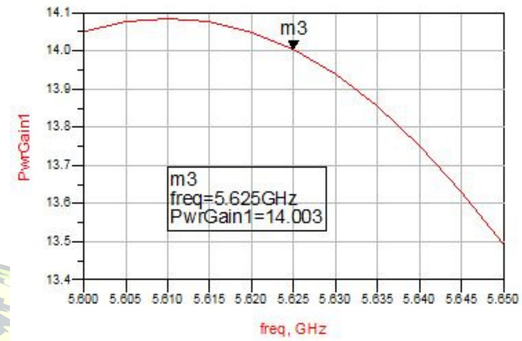

Fig. 12. Power Gain

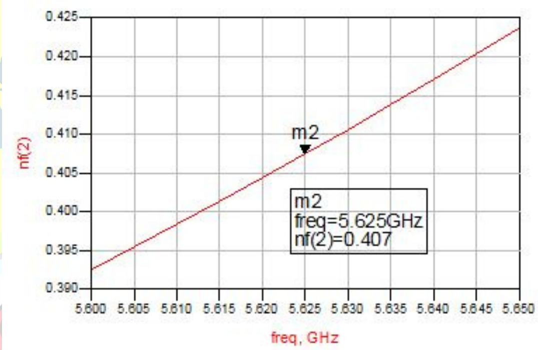

Fig. 13. Noise Figure

The VSWR obtained for the source (VSWR1) and load (VSWR2) matching is shown in fig. 14 which are 1.052 and 1.090 at input and output side respectively.

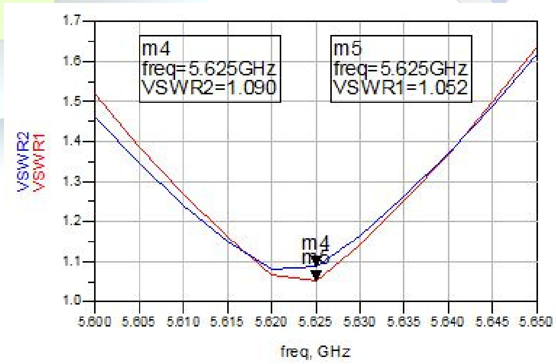

Fig. 14. VSWR

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The S parameters of the designed LNA obtained are shown in fig. 15 and 16 respectively. The S_{11} is -31.853 dB, S_{21} is 14.003 dB, S_{12} is -16.608 dB and S_{22} is -27.350 dB.

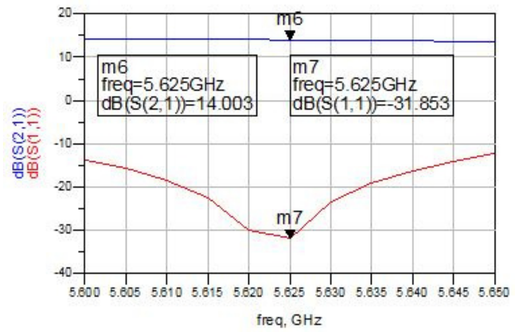

Fig. 15. S_{11} and S_{21} parameters

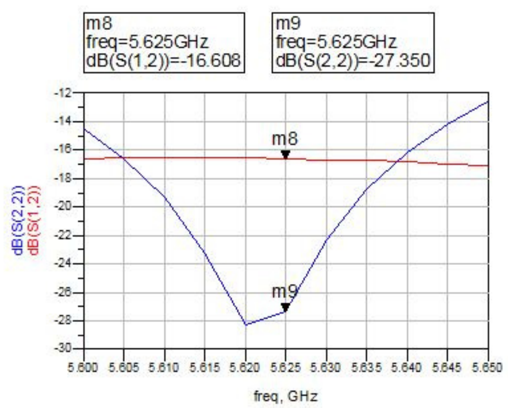

Fig. 16. S_{12} and S_{22} parameters

The third design with series RLC in drain terminal provide a power gain of 13.817 dB and noise figure of 0.579 dB as shown in fig. 17 and 18 respectively.

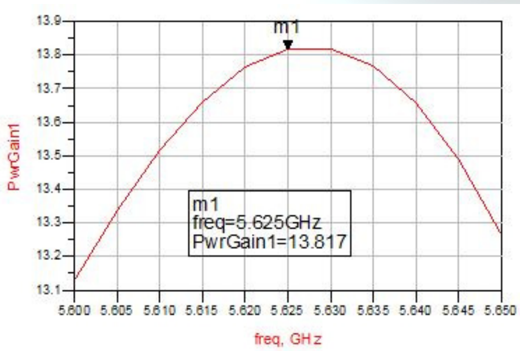

Fig. 17. Power Gain

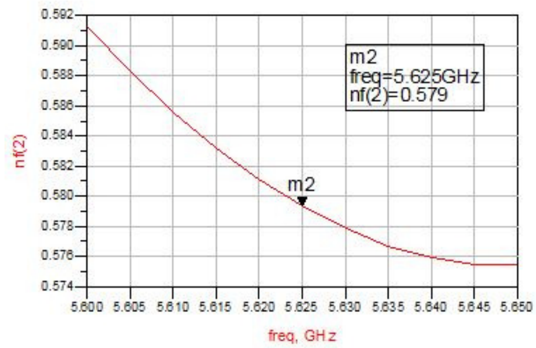

Fig. 18. Noise Figure

The VSWR obtained for the source (VSWR1) and load (VSWR2) matching is shown in fig. 19 which are 1.146 and 1.116 at input and output side respectively.

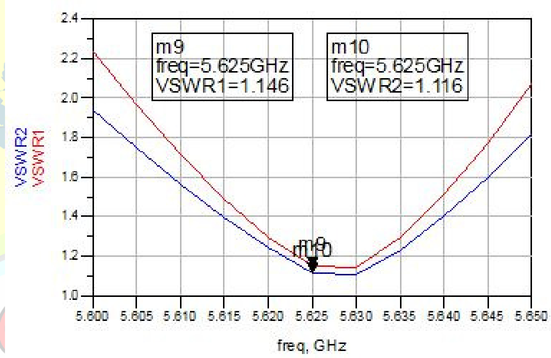

Fig. 19. VSWR

The S parameters of the designed LNA obtained are shown in fig. 20 and 21 respectively. The S_{11} is -23.324 dB, S_{21} is 13.817 dB, S_{12} is -16.794 dB and S_{22} is -25.228 dB.

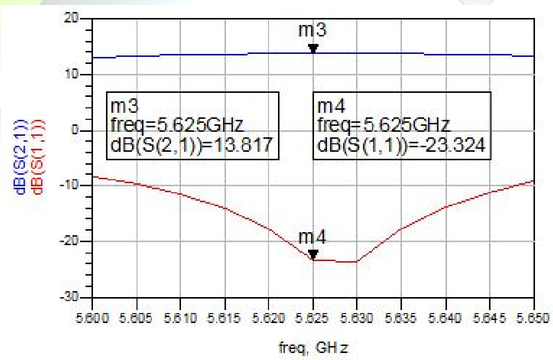

Fig. 20. S_{11} and S_{21} parameters

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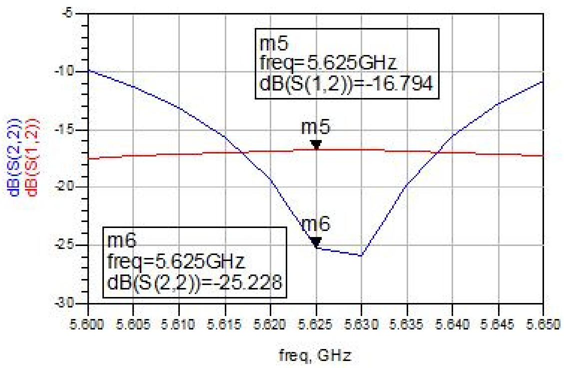

Fig. 21. S_{12} and S_{22} parameters

TABLE I: SIMULATION RESULTS OF PROPOSED DESIGNS

Parameters	Gate Parallel RLC	Drain Parallel RLC	Drain Series RLC
K	1.112	1.043	1.053
$\|\Delta\|$	0.608	0.450	0.499
S_{11} (dB)	-41.861	-31.853	-23.324
S_{12} (dB)	-17.339	-16.608	-16.794
S_{21} (dB)	13.271	14.003	13.817
S_{22} (dB)	-39.753	-27.350	-25.228
Gain (dB)	13.271	14.003	13.817
NF (dB)	3.146	0.407	0.579
VSWR	1.016 (I) 1.021 (O)	1.052 (I) 1.090 (O)	1.146 (I) 1.116 (O)

V. CONCLUSION

Different stability improvement techniques are discussed and analyzed to compare and determine the suitable LNA design for the Weather RADAR application. The results of implementation in ADS is presented in this paper. The LNA with parallel RLC at drain terminal proves to be efficient and optimum since the power gain of that LNA obtained is 14.003 dB. The S_{11} obtained is -31.853 dB and S_{12} is -16.608 dB. The VSWR obtained is 1.052 at the input side and 1.090 at output side which is comparatively less than the third design that shows the amount of reflections being less. Also, the noise figure obtained is 0.407 dB. Further to improve the gain of the amplifier and to reduce the noise figure cascading techniques can be used to implement multistage low noise amplifier and also use inductive degeneration method.

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