Highly Linear Band Limited LNA for S-Band T/R Module

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***Abstract*:**

Low Noise Amplifier (LNA) plays a vital role in deciding the quality of any Transmit/Receive Module particularly sensitivity. The key design constraints in designing LNA especially for T/R Module are Power Consumption, Single supply operation, Linearity and most important the Noise Figure. Often achieving these specifications all at once is quite challenging.

This paper explains the design of an LNA with sub 1dB Noise Figure based on Avago E-pHEMT technology for S-Band T/R Module. The proposed design is attempted for higher S-Band TR Module with 12% Fractional Bandwidth. The developed LNA has resulted in Noise Figure of less than 1dB, OIP3 of 37 dBm with typical Small Signal Gain of 13 dB and Gain flatness of ±0.5 dB .It occupies an approximate area of 28mm X 16 mm and requires a single +5V supply. In order to get Band Limited performance, gain at lower frequency is attempted to reduce by using high pass lumped element matching at input and output side.

The complete design is carried out using ADS tool, with ATF 54143 transistor nonlinear model and performance verified using s2p file. Complete circuit is fabricated using Rogers's 5880 substrate of 20 mil thickness

***Keywords*:**
Low Noise Amplifier, OIP3, T/R Module, S-Band, E-pHEMT, Noise Figure, Lumped Element Matching, Microstrip

I. INTRODUCTION

The very purpose of Low Noise Amplifier (LNA) is to amplify low level signal while maintaining very low Noise Figure. Thus LNA is critical element of any Receiver module which boost signal without adding significant noise which sets the Noise Figure of the system.

In order to maximise the sensitivity of any Receiver Module, every effort is to be made to locate the LNA as close as possible to the antenna to minimize noise figure of receiver system. LNA has dominant effect on the noise performance of the overall system. It amplifies extremely low signals without adding noise thus Signal to Noise Ratio (SNR) of the system is preserved. For designing LNA especially for T/R Module of Active Phase Array Radar, it is necessary to compromise among its simultaneous multi constraints like high gain, low noise figure, low power consumption, linearity.

In this paper of LNA design, Avago ATF- 54143 E-pHEMT GaAs FET with high dynamic range, low noise, high linearity which requires single supply of +5V is used. Device equivalent circuit is shown in Fig.1.

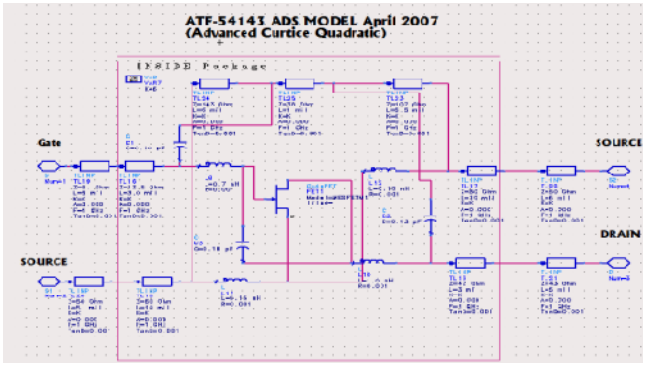

Figure 1: Equivalent circuit of ATF 54143

As part of the design, the following design goals are set to ensure that the designed LNA will meets system requirements.

1. Operating Bandwidth : 400MHz in upper S-Band
2. Gain : 12 dB ± *0.5 dB*
3. Noise Figure : less than 1dB
4. I / O Return Loss : better than10 dB

II. LOW NOISE AMPLIFIER DESIGN

After selecting the device, the main steps that need to be followed in the design are selection of Device Bias Point, Stability Consideration, Input and output Matching Circuit design. . LNA design is carried out as per the design flow shown below in Fig 2 and simulation is carried out using ADS Software.

Input matching circuit needs to terminate the transistor to gamma optimum (Γopt) which represents the impedance at the input of the transistor for the optimum noise match. Output matching circuit is required to maximize the power transfer and minimize the reflections. Smith chart is used for matching.

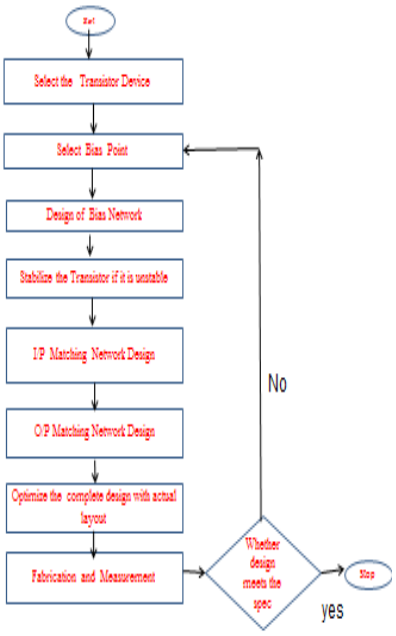

Figure 2: Design flow of LNA

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The various parameters like Gain, Input/output Return Loss, Noise Figure and Stability are all interdependent and equally important hence a tradeoff is needed to be exercised among them to optimize the design.

OPERATING POINT SELECTION:

Transistor must be biased at appropriate operating Bias point so that transistor can provide optimum performance and achieve less power consumption. In the given design, passive biasing method is adopted and reference has been taken from device datasheet.

Passive biasing of the ATF-54143 is accomplished by the use of a voltage divider consisting of resistors R1and R2. The voltage for the divider is derived from the drain voltage which provides a form of voltage feedback through the use of R3 to help keep drain current constant. Resistor R5 (approximately 10kΩ) provides current limiting for the gate of enhancement mode devices such as the ATF-54143. R4 of 49.9Ω provides low frequency termination which improves low frequency stability.

By using different sweeps for given DC Bias point, Vds = 4V and Ids = 80mA has been chosen because it can give optimum gain and noise figure. With Vgs = 0.6V, VDD=5V IBB=2mA, Vds = 4V and Ids = 80mA.

$$R1 = \frac{\text{Vgs}}{\text{IBB}} = 300\Omega$$

$$R2 = \frac{(\text{Vds}-\text{Vgs})\text{R1}}{\text{Vgs}} = 1700\Omega$$

$$R3 = \frac{\text{VDD} - \text{Vds}}{\text{Ids} + \text{IBB}} = 12.19\Omega$$

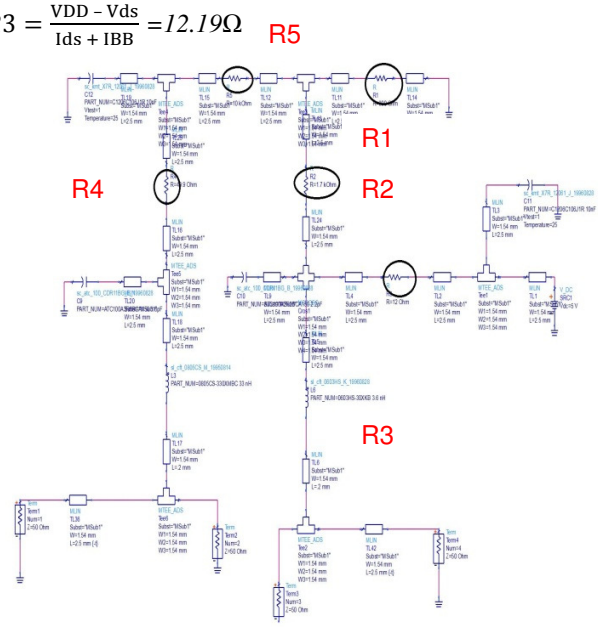

Figure 3: Biasing circuit for ATF 54143 device

STABILITY COSIDERATION:

The stability of an amplifier or its resistance to oscillate is an important consideration in a design. It can be determined from the *S* parameters. Oscillation occurs when $|\Gamma in| > 1$ or $|\Gamma out| > 1$. An amplifier is said to be unconditionally stable if the auxiliary condition along with *Rollet's condition*, defined as in equations below, are simultaneously satisfied.

$$K = \frac{1 - |S11|^2 - |S22|^2 + |\Delta|^2}{2|S21 - S12|} > 1$$

$$|\Delta| = |S11S22 - S12S21| < 1$$

The ATF 54143 transistor is unconditionally stable since its K constant is more than 1 up to 6 GHz by adding stub at source pad of the transistor as shown in Fig.4.

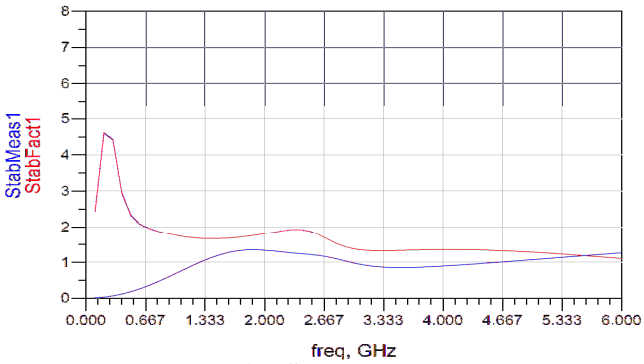

Figure 4: Rollet Constant K

GAIN AND NF COSIDERATION:

LNA with its matching can be modeled as shown in below figure:

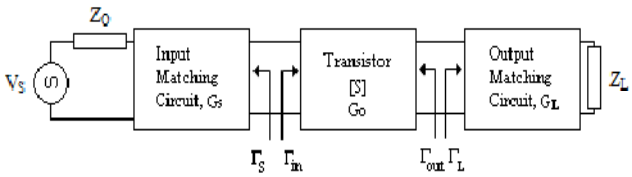

Figure 5: Block Diagram of LNA

There are different Gain terminologies as defined below:

Power Gain, G

$$G = \frac{|S21|^2(1-|\Gamma L|^2)}{(1-|\Gamma in|^2)|1-S22\Gamma L|}$$

Available Gain, GA

$$GA = \frac{|S21|^2(1-|\Gamma s|^2)}{|1-S11\Gamma s|^2(1-|\Gamma out|^2)}$$

Transducer Gain GT

$$GT = \frac{|S21|^2(1-|\Gamma s|^2)1-|\Gamma L|^2)}{|1-\Gamma s\Gamma in|^2|1-S22\Gamma L|^2}$$

Besides the stability and gain requirement, noise figure is another important consideration for a microwave LNA. The noise figure of the completed amplifier is equal to the noise figure of the device plus the losses of the matching network preceding the device. The noise figure of the device is equal to F_{min} only when the device is presented with gamma optimum (Γopt). If the reflection coefficient of the matching network is other than gamma optimum (Γopt), then the noise figure of the device will be greater than F_{min} based on the following equation.

$$NF = Fmin + \frac{4Rn}{Zo}\frac{|\Gamma s - \Gamma opt|^2}{|1+\Gamma opt|^2(1-|\Gamma s|^2)}$$

Where R_n/Z_o is the normalized noise resistance, gamma optimum (Γopt) is the optimum reflection coefficient required to produce F_{min} and ΓS is the reflection coefficient of the source impedance actually presented to the device. The losses of the matching networks are non-zero and they will also add to the noise figure of the device creating a higher amplifier noise figure.

Since **GA = f (Γs, [S]),** available gain and NF are function of source reflection coefficient Γs, both needs to considered simultaneously to trade-off Gain and NF in the design.

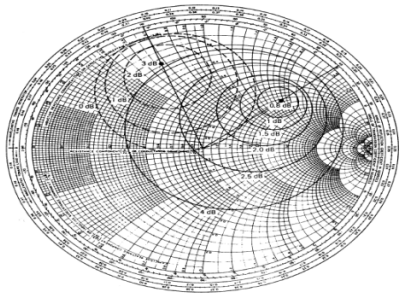

Figure:6 Constant NF Circles (solid curves) and Constant Available Gain Circles (dashed curves)

INPUT/ OUTPUT MATCHING CIRCUIT DESIGN:

The impedance matching basic idea is presented in Fig. 5, which ensembles that an impedance matching network placed between the load/ source impedance and device. Matching network is made to ideally avoid the unnecessary loss power. Input matching circuit needs to terminate the transistor to gamma optimum (Γopt) which represents the impedance at the input of the transistor for the optimum noise match. Output matching circuit is required to maximize the power transfer and minimize the reflections so output impedance needs to be conjugate matched to the impedance presented to device including its biasing and stability networks . There are variety of factors that needed to be considered in the matching network selection e.g. complexity, implementation and adjustability. In this paper, the LNA is designed by using lumped elements matching.

III. SIMULATED RESULTS

A. BEFORE MATCHING

The parameters of Gain, Input and Output Return Loss, Stability of device along with biasing network are simulated in ADS tool. The simulated results for the device are shown as below.

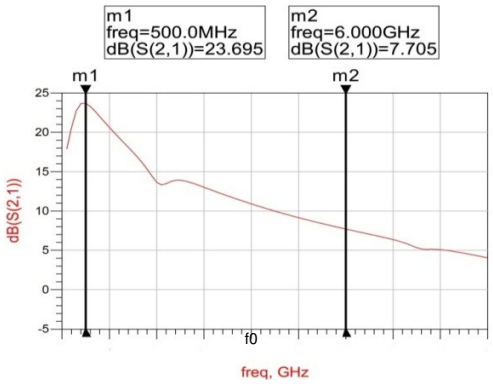

Figure 7: S21 (dB) before matching

It can be seen from Fig.7 that device is having Gain of 12 dB at centre frequency (f0) of the desired bandwidth but at the same time it is having high gain at lower frequency.

I/O return loss at centre frequency can be seen in Fig.8. It is found input return loss to be less than 3 dB against the requirement of 10 dB. Device is already unconditionally stable in the operating frequency band.
While designing the matching circuit it has been attempted to lower down low frequency gain in order to get band limited characteristics.

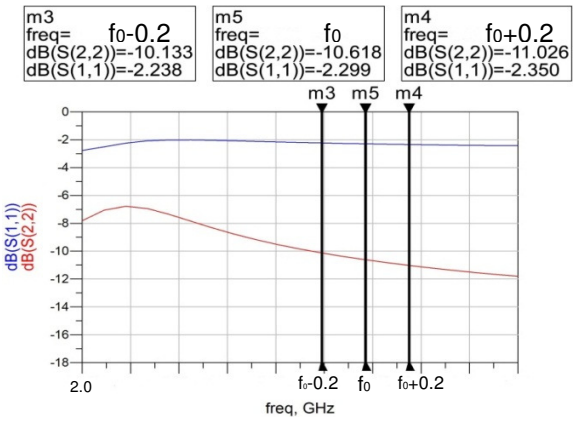

Figure 8: S11 (dB) and S22 (dB) before matching

B. AFTER MATCHING

To match input and output impedance, lumped elements matching is added into LNA circuit .After matching gain at lower frequency also reduced due to high pass matching topology. Both input and output impedance to which matching needs to be done is calculated using S parameter simulation as shown in the Fig.9.

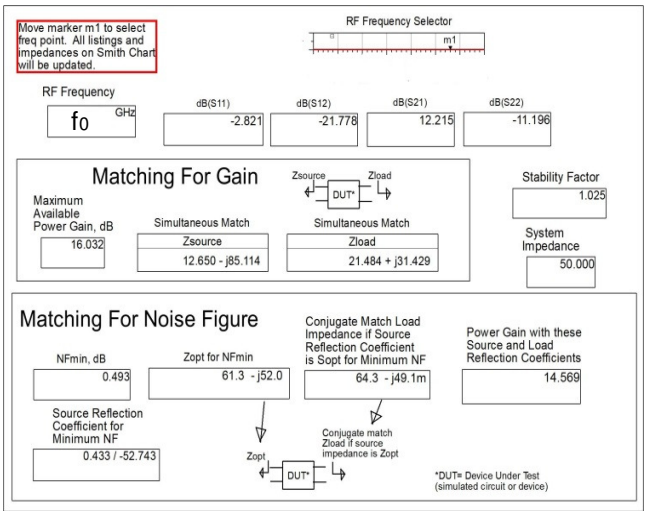

Fig 9: Input and output matching impedance

After completion of design with ideal lumped passive components, same design is simulated with models of real passive components. There happens to be some mismatch, which is taken into consideration. Thus, the whole LNA circuit after matching is shown in the Fig.10. The microstrip substrate used in the design is Rogers RT/Duroid 5880 laminate (Relative dielectric constant of 2.2) with the substrate thickness of 20 mil.

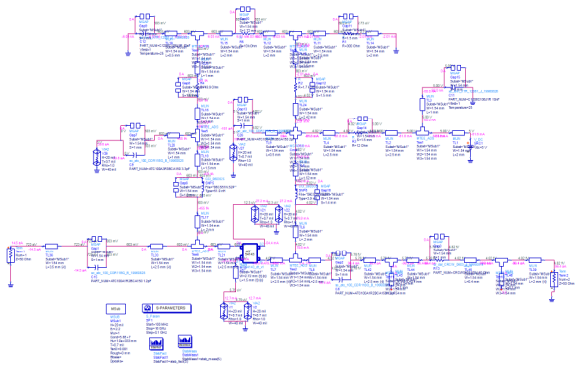

Figure 10: complete LNA schematic with Matching

After the completion of schematic design, the layout was generated in ADS momentum and planar EM simulation was carried out to take parasitic layout coupling into account . Finally, EM Co-simulation was performed through schematic control including all the models of real passive components and some fine tuning was performed. Complete circuit including layout is shown in Fig 11.

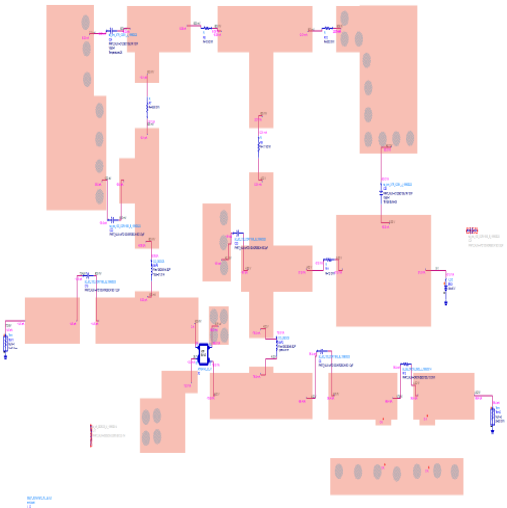

Figure 11: EMCosim circuit diagram

The simulated results for Gain, Input and Output Return Loss, OIP3, and Noise Figure of the complete design is shown below in Fig12, 13 and 14.

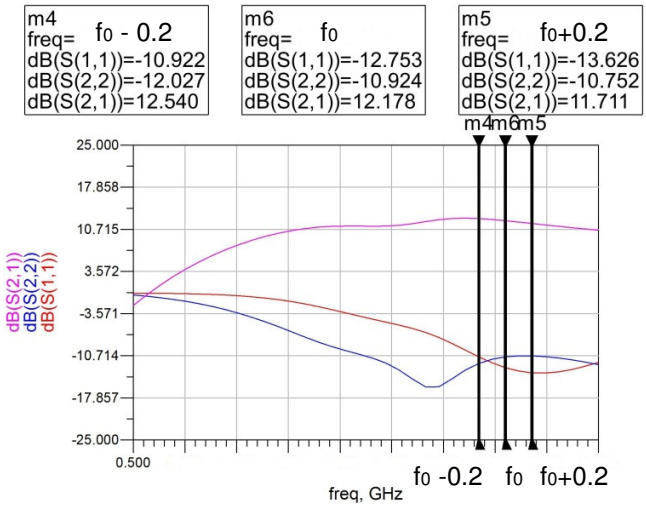

Figure 12: S11 (dB), S21 (dB) and S22 (dB) after matching.

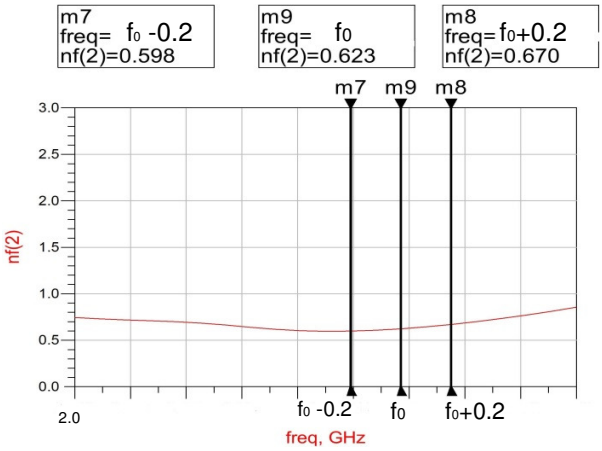

Figure 13: Noise Figure (dB) after matching

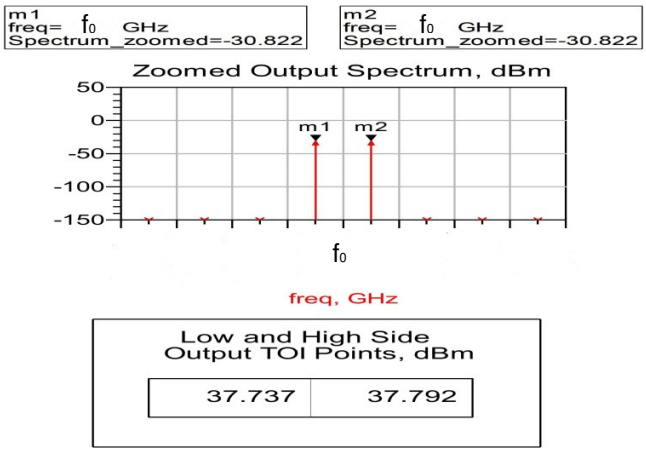

Figure 14: OIP3 (dBm) after matching

For the result obtained at centre frequency f0 from the simulation, the power gain is 12.178dB and the noise figure is 0.623dB, while the return loss for source and return loss for load is -12.753dB and -10.442dB respectively. It can be seen that LNA has OIP3 of 37dBm. The results obtained from the LNA simulation have achieved the requirements that have been set.

IV. LNA FABRICATION AND COMPARISION OF MEASURED AND SIMULATED PARAMETERS.

The complete layout is fabricated in-house. The Fabricated unit is shown in Fig15.

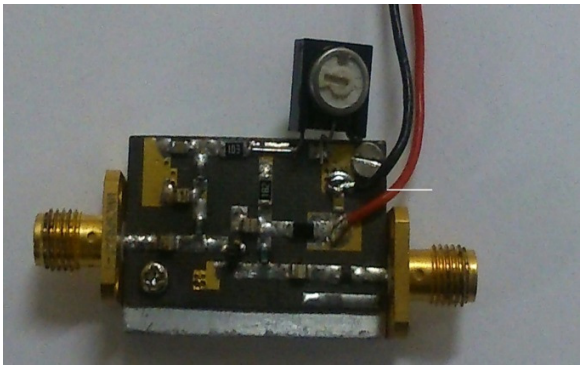

Figure 15: Fabricated Low Noise Amplifier

The parameters of Gain, Input and Output Return Loss, of fabricated unit are measured using Vector Network Analyzer and Noise Figure using NF Analyzer. The measured results are shown below.

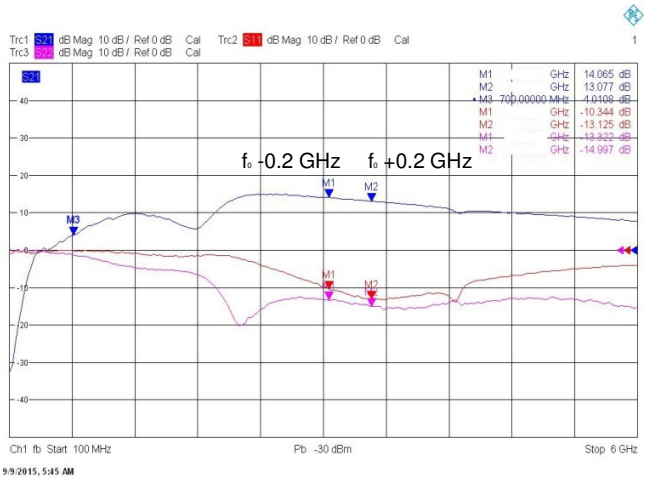

Figure 16: S11 (dB), S21 (dB) and S22 (dB) of fabricated LNA.

Parameters	Simulated Result	Measured Result
S11(dB)	-10.922 max.	-10.344 max.
S22(dB)	-10.752 max.	-13.322 max.
S21(dB)	11.711 min.	13.077 min.
NF(dB)	0.670 max.	0.90 max.
K	>1	>1

Table1: Comparison of Simulated Results and Measured Results

V. CONCLUSION AND FUTURE SCOPE

Low Noise Amplifier with desired characteristics has been designed and developed. From the comparison of the Simulated and Measured result it can be seen that there is a slight difference in values which may be due to device model and actual device differences.

Design needs to be improved using better techniques like filter matching in order to achieve better band limited response to eliminate pre-selector BPF filter before LNA in the TR Module receive chain.

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