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Design Of A Broadband LNA

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Abstract

The design of a broadband Low Noise Amplifier (LNA) having the following specifications is presented.

Bandwidth of operation = 9-17 GHz
Noise Figure < 1.4 dB
VSWR < 2
Gain > 10 dB
Source Impedance = 50 Ω
Load Impedance = 50 Ω
Relative permittivity of substrate = 2.2
Thickness of substrate = 20 mil
Impedance matching = Chebyshev transformer
Transistor = Avago ATF-36077.

1. Introduction

The Low Noise Amplifier as its name suggests is an amplifier to amplify very weak signals captured by an antenna. Since the LNA is the first circuit block in a receiver chain, its noise performance dominates the system sensitivity. Using an LNA, the effect of noise from the subsequent stages of the receive chain is reduced by the gain of the LNA, while the noise of the LNA itself is injected directly to the received signal. Thus it is necessary for an LNA to boost the desired signal power while adding as little noise and distortion as possible, so that the retrieval of this signal is possible in the later stages in the system.

Broadband LNAs find applications in communication systems and instrumentation equipment. The primary objective of this work is to achieve low noise figure and VSWR as well as maximum gain over the wide frequency range of operation. Other considerations include large range of source and load impedances for which the amplifier remains stable.

While minimum noise figure in narrow band amplifiers can be obtained with a single frequency impedance matching network, achieving close-to-minimum noise figure across a wide frequency band is significantly more complicated.

Inductive degeneration has been used in narrow-band amplifiers to achieve simultaneous matching for high gain and low noise. Similarly, using inductive degeneration in our wideband application we achieve close to minimum noise figure and reduced input VSWR.

When designing a broadband LNA one can minimize the noise figure at every frequency point, or require that the noise figure is lower than some upper bound. The second approach allows the noise figure to be higher than the minimum at low frequencies and gives a wider band of operation. Both types of wide-band LNAs find applications, but the first option was chosen for design. Here we have used the method of inductive degeneration, resistive stabilisation and Chebyshev matching for broadbanding the LNA.

2. Source Peaking

At the beginning of LNA design, it is necessary to give a thorough analysis of the low noise FET. Source-Peaking, a feedback method, will be applied. Connect an inductor between the source and the ground and select an appropriate value of the inductor. This series process can change the S parameter and noise parameter of the FET and a little change in the noise figure. These adjusted parameters make the design process easy to implement. We can get low noise and good VSWR simultaneously. From the curves in the Smith Chart of the two ground methods, it can be seen that the optimal noise impedance curve and the conjugate s11 curve is overlapped after source-peaking processing. We also get the circuit more stable through source-peaking. However, the inductor that connects ground and the source of FET is very small. It is hard to find a lumped inductor with so small value. We have to use a fine microstrip line and via hole to achieve an equivalent inductor.

3. Stability

The stability of an amplifier or its resistance to oscillate is a very important consideration in a design and can be determined from the S parameters, the matching networks, and the terminations. In a two-port network, oscillations are possible when either the input or the output port presents a negative resistance. This occurs when $|\Gamma_{in}| > 1$ or $|\Gamma_{out}| > 1$, which for a unilateral device ($s_{12} \cong 0$) is when $|s_{11}| > 1$ or $|s_{22}| > 1$. But in practical cases $s_{12} \neq 0$ and unilateral assumption cannot be made.

A two-port network is said to be unconditionally stable at a given frequency if the real parts of Z_{IN} and Z_{OUT} are greater than zero for all passive load and source impedances. For bilateral cases ($s_{12} \neq 0$) the condition $K > 1$ is only a necessary condition for unconditional stability where K is the Rollet's factor or stability factor.

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$K=(1-|s_{11}|^2-|s_{22}|^2+|\Delta|^2)/(2|s_{12}.s_{21}|) > 1$
where $|\Delta| = |s_{11}.s_{22}-s_{12}.s_{21}|$

4. Gain

In a two-port network as shown in figure the three types of power gains are:

Power Gain

$G=P_L/P_{in}$ is the ratio of power dissipated in the load to the power delivered to the input of the two-port network. The gain is independent of source impedance.

Available Gain

$G_A=P_{avn}/P_{avs}$ is the ratio of the power available from the two-port network to the power available from the source. This assumes conjugate matching of both the source and the load, and depends on source impedance but not load impedance.

Transducer Power Gain

$G_T=P_L/P_{avs}$ is the ratio of the power delivered to the load to the power available from the source. This depends both on source and load impedance.

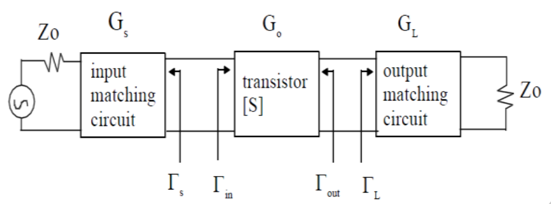

Figure 1. Transistor Gain

5. Noise Figure

The noise figure (NF) describes quantitatively the performance of a noisy microwave amplifier. The noise figure of a microwave amplifier is defined as the ratio of the total available noise power at the output of the amplifier to the available noise power at the output due to the thermal noise from the input termination. NF can also be defined as the ratio of the available signal-to-noise power (SNR) ratio at the input to the available signal-to-noise power ratio at the output. A minimum noise figure is obtained by properly selecting the source reflection coefficient of the amplifier. For the single stage amplifier, its noise figure is seen as follows:

$$NF = NF_{min} + \frac{4r_n|\Gamma_s - \Gamma_{opt}|}{(1-|\Gamma_s|^2).|1+\Gamma_{opt}|^2}$$

In the formula, NF_{min} is the minimum noise figure which is decided by the transistor itself, Γ_{opt}, r_n, Γ_s are the best source reflection coefficient, the equivalent noise resistance of the transistor and the input reflection coefficient of the transistor when NF_{min} is obtained.

6. Voltage Standing Wave ratio

In a transmission line voltage standing wave ratio is given by
$VSWR = (1+|\Gamma_0|)/(1-|\Gamma_0|)$
Alternatively, $\Gamma_0 = (VSWR-1)/(VSWR+1)$
Where Γ_0 is the load reflection coefficient.
Since the power delivered to the load in a transmission line, excited by a source impedance Z_0 is given by
$P_L=P_{AVS}(1-|\Gamma_0|^2)$
Where P_{AVS} is the power available from the source.
From the above equations we can find out what portion of P_{AVS} is delivered to the load if we know the VSWR.
In our design the VSWR is around 1.5, it follows that $|\Gamma_0| = 0.2$ and the ratio of the incident to the reflected from the load is $|\Gamma_0|^2 = 0.04$ or 4%. Hence 4% of the incident power is reflected by the load or 96% of the incident power is delivered to the load.

7. Impedance Matching

Impedance matching is important for the following reasons:

→Maximum power is delivered when the load is matched to the line and power loss in the feed line is minimized.

→Impedance matching sensitive receiver components (such as antenna, low noise amplifier, etc.) improves the signal-to-noise power ratio of the system.

Factors that may be important in the selection of a particular matching network include:

→Complexity – A simpler matching network is usually cheaper, more reliable, and less lossy than a more complex design.

→Bandwidth – Any type of matching network can ideally give a perfect match at a single frequency but in many applications it is desirable to match a load over a band of frequencies.

In our design we use microstrip to design the input and output matching networks.

8. Microstrip

Microstrip line may well be the most popular transmission line structure. Ease of fabrication by photolithographic techniques and a good range of impedances and couplings allow it to be used for a wide variety of circuit components. A conductor of width W is printed on a thin grounded dielectric substrate of thickness h and relative permittivity ϵ_r with t<<h.

Due to the presence of dielectric and its absence above the strip, microstrip has some of its field lines in the dielectric region, concentrated between the strip conductor and the ground plane, and some fraction in the air region above the substrate. Hence the effective dielectric constant satisfies the relation

$1 < \epsilon_e < \epsilon_r$,

and is dependent on the substrate thickness, h, and conductor width W.

The exact fields of a microstrip line constitute a hybrid TM-TE wave and require more advanced analysis which we don't need to consider. Here we consider the fields as quasi-TEM (fields same as static case) where the phase velocity is given by $v_p=c/\sqrt{\epsilon_e}$.

We use the substrate RT DUROID 5880 for the microstrip with $\epsilon_r=2.2$ and thickness 20 mil.

9. Selection of the type of design

In ADS there are two types of devices, (1) S-parameter & (2) normal device. S-parameter device is an in-built device with S-parameters loaded from the data sheet. There is no need of applying external bias to it., because it has fixed S-parameters (i.e. fixed biasing). On the other hand normal device is just like any transistor device to which any bias value can be applied. For the LNA design, S-parameter device is chosen in general.

10. Selection of the transistor

The selection of the transistor also plays a crucial role in the LNA design. As of course we are designing a LNA we should look for as much low NF_{min} as possible in the transistor datasheet. We should also see that the current draw of the transistor is very low so as to get a lower NF and high gain and also see that the bandwidth of operation should meet our requirements. Other parameters should also be considered like bandwidth of stability in case of broadband LNA. For example in our design we selected ATF-36077 (which is implemented in our design) and ATF-36163. Although 36077 had all the factors better than 36163 (low NF, high gain, low current draw) but the bandwidth of stability of 36077 was 15-18 GHZ as compared to 12-18 GHZ of 36163 (both without the insertion of any resistance) which is required in design of an broadband LNA. So we stabilised both the circuit by adding input series resistance of required values so as to work within the frequency of 9-17 GHz and we found that 36077 has low NF, high gain when both had the same bandwidth of stability. So we selected ATF-36077 for our design.

11. Inductive degeneration

This is the first thing that we should do for designing a broadband LNA. As we are designing a broadband LNA we need to consider such a matching network which provides a proper match over a broad bandwidth. This was only possible by multisection quarter-wave transformers. But for matching with a quarter wave transformer we need to have real impedances. So we use the method of inductive degeneration (addition of an inductor of appropriate value between the source and ground terminals) so as to get a real input impedance (obviously at a particular frequency). So we tried to get a real impedance at 13 GHz which is the centre frequency. For that the appropriate value of inductance was 25 pH. Inductive degeneration does not introduce noise in the circuit and also improves the stability of the amplifier. Simultaneously we can get low noise and good VSWR using this process.

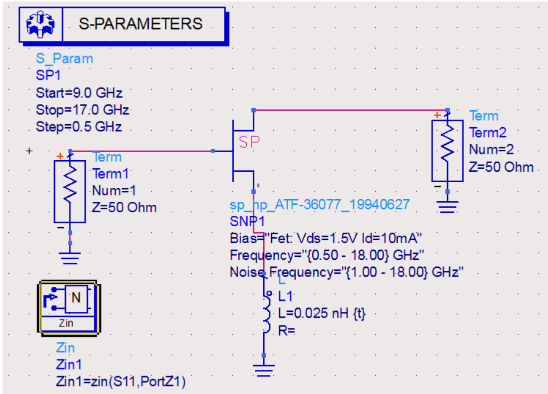

Figure 2. Inductive Degeneration

12. Stabilization

Although there are many methods of stabilising the amplifier for a desired frequency range, we use the method of stabilising by a series input resistor because this helps in reducing the VSWR which is required for better performance of the amplifier. Here in this case the VSWR was 4.2 and after adding the resistance of 3 ohm we got a VSWR of 3.3 without affecting the gain and noise figure much, which was not possible in any other cases. This does not mean that we need to add more resistance in order to reduce the VSWR. We must add a certain value of resistance which is available and stabilises the circuit. Reducing the VSWR is just an extra advantage. This should not be the primary cause for adding resistance as adding a resistance increases the NF as well as reduces the gain both of which are undesirable. Hence a trade of should be maintained among the 4 parameters i.e stability, gain, NF and VSWR while adding the resistance. A series resistance at the output gives a NF of 0.7(not flat) and VSWR of 2 with the same stability and gain as a series resistance at the input would give with a NF of 1.1(flat) and VSWR of 1.6. But as this is the case of a broadband amplifier we would require the output parameters to be as flat as possible over the working frequency range. So we choose the option of adding a series resistance at the input.

13. Impedance Matching

In this design we are using Chebyshev multisection matching transformers for input impedance matching. This transformer optimizes bandwidth at the expense of passband ripple. Here we use 3 sections for impedance matching. We tried to match the circuit with 5 and 7 sections also but there was not such a remarkable difference so as to implement them. Moreover using lower number of sections will ease the process of tuning which is the most important part of impedance matching in broadband amplifier design. We could also have used tapered lines for matching but they are not feasible to be tuned.

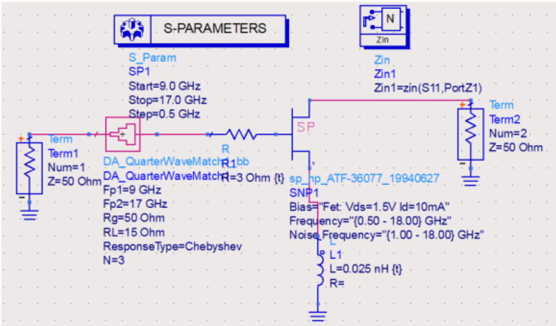

Figure 3. Impedance Matching

After matching the input impedance the responding output circuit was obtained by using the optimization tool of ADS.

Finally the whole circuit was tuned to get the best performance in stability, gain, NF, VSWR.

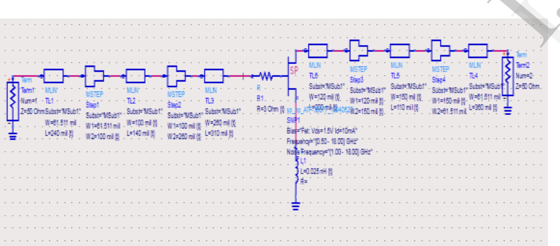

Figure 4. The complete circuit

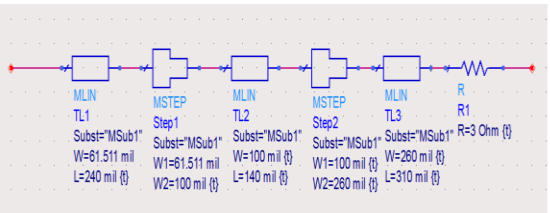

Figure 5. Input matching circuit

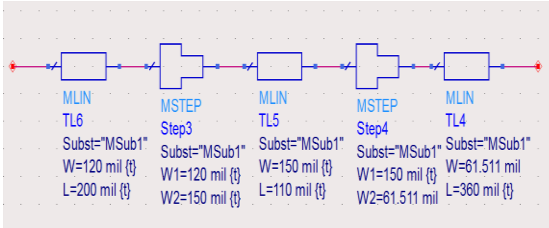

Figure 6. Output matching circuit

14. Simulation Results

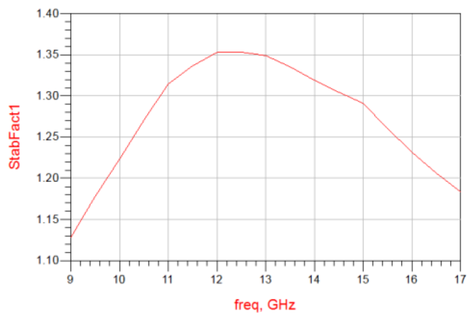

Figure 7. Stability Factor

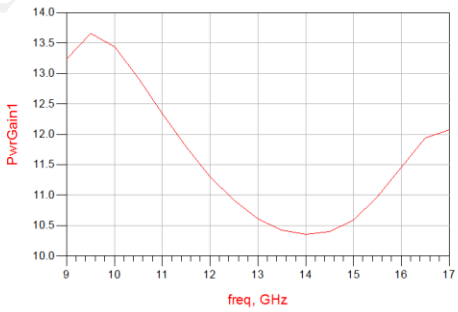

Figure 8. Power Gain

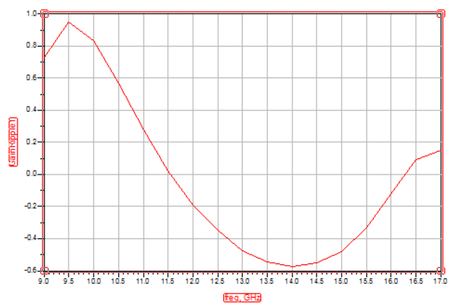

Figure 9. Gain Ripple

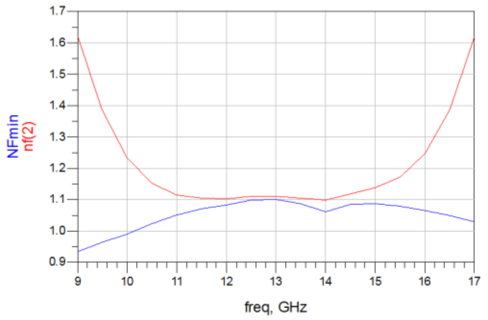

Figure 10. Noise Figure

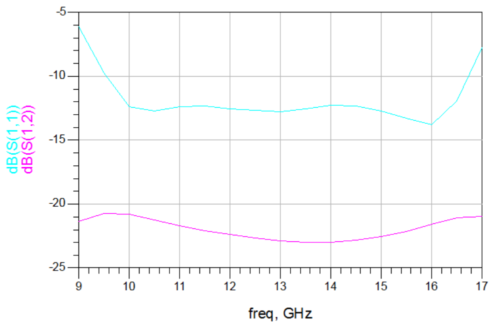

Figure 11. Reflection & transmission coeff

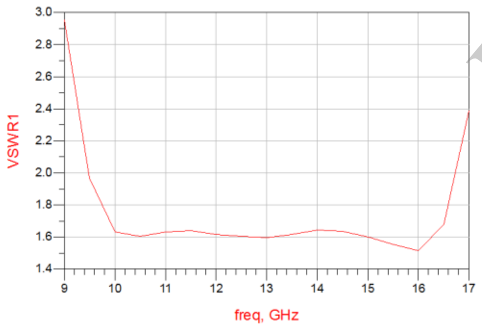

Figure 12. Voltage Standing Wave Ratio

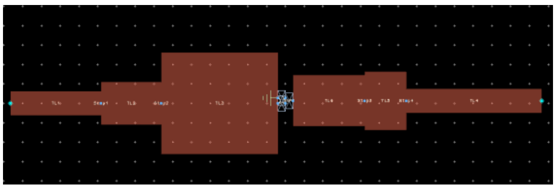

Figure 13. Layout

15. Acknowledgement

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