NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

# MEEC/MIEEC

## Radio Frequency Electronics

### Low Noise Amplifier - Part I

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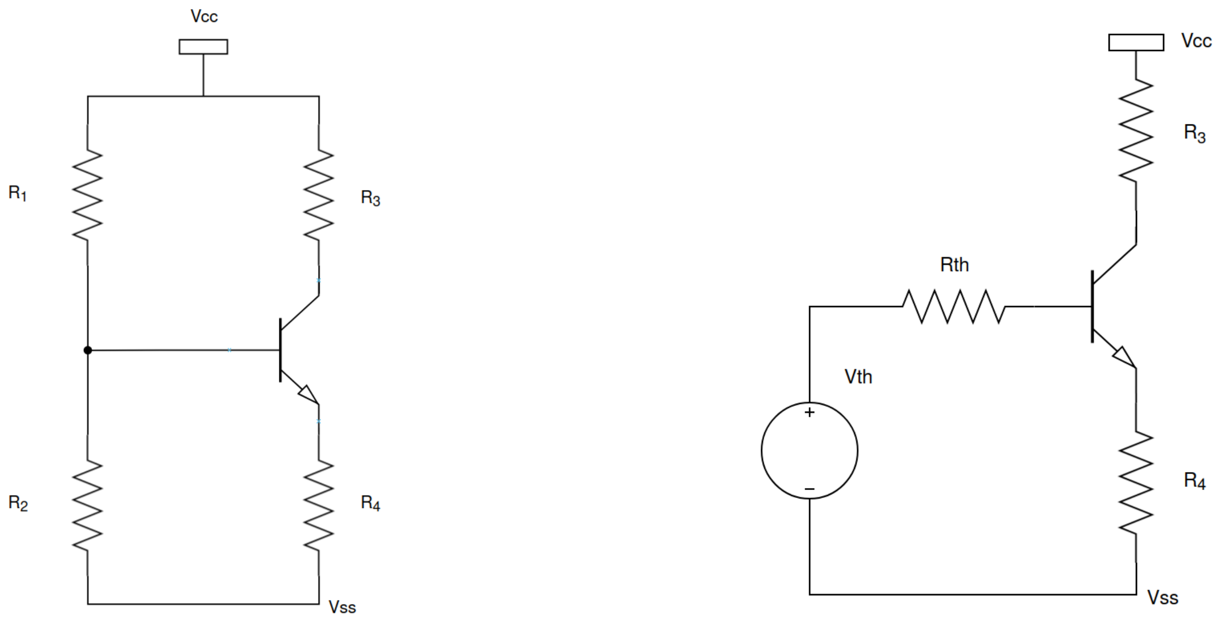
## 2.1 Transistor Bias Network

The DC bias point of a transistor directly influences its small-signal S-parameters, and hence the gain, noise figure and stability of the LNA. This makes this step crucial. Figure ?? shows the biasing circuit and its Thévenin equivalent used to simplify analysis.




**(a)** Transistor DC biasing circuit

**(b)** Bias circuit equivalent circuit

As shown in Figure 1b the Thévenin equivalent is given by the equations 1, replacing the $R_1$, $R_2$ voltage divider.

$$\begin{aligned} R_{TH} &= R_1 // R_2 \\ V_{TH} &= V_{cc} \frac{R_2}{R_1 + R_2} \end{aligned} \tag{1}$$

Using Kirchhoff voltage law, the equations 2 are derived, the first starts at $V_{TH}$ goes through $R_{TH}$, $V_{BE}$ and $R_4$. The second goes from $V_{CC}$ through $R_3$, $V_{CE}$ and $R_4$.

$$\begin{cases} 0 = V_{TH} - I_b \cdot R_{TH} - V_{BE} - I_E \cdot R_4 \\ 0 = V_{CC} - R_3 \cdot I_C - V_{CE} - I_E \cdot R_4 \end{cases} \tag{2}$$

Solving the system of equations, assuming fixed values for $R_2$ and $R_4$, originates the equations 3.

$$
\begin{aligned}
R_1 &= \frac{R_2\left(-I_C R_4 \beta - I_C R_4 - V_{BE}\beta + V_{CC}\beta\right)}{I_C R_2 + I_C R_4 \beta + I_C R_4 + V_{BE}\beta} \\
R_3 &= \frac{-I_C R_4 \beta - I_C R_4 + V_{CC}\beta - V_{CE}\beta}{I_C \beta}
\end{aligned}
\tag{3}
$$

The Table 1, shows the provided values for the biasing circuit and the fixed values for $R_2$ and $R_4$.

**Table 1:** Transistor biasing parameters

| Parameter | Value |
|---|---|
| $R_2$ | $1\,\mathrm{k\Omega}$ |
| $R_4$ | $100\,\Omega$ |
| $\beta$ | 72.534 |
| $I_C$ | $9\,\mathrm{mA}$ |
| $V_{CC}$ | $10\,\mathrm{V}$ |
| $V_{BE}$ | $1\,\mathrm{V}$ |
| $V_{CE}$ | $5\,\mathrm{V}$ |

Resulting in $R_1 = 4\,\mathrm{k\Omega}$ and $R_3 = 454\,\Omega$.

## 2.2 S-parameters with packaging effects

With the biasing circuit designed, the next step was to simulate the S-parameters of the transistor in LTSpice. The S-parameters were taken for a frequency range of 1 GHz to 10 GHz, Figure 2 shows the S-parameters of the transistor without any matching network.

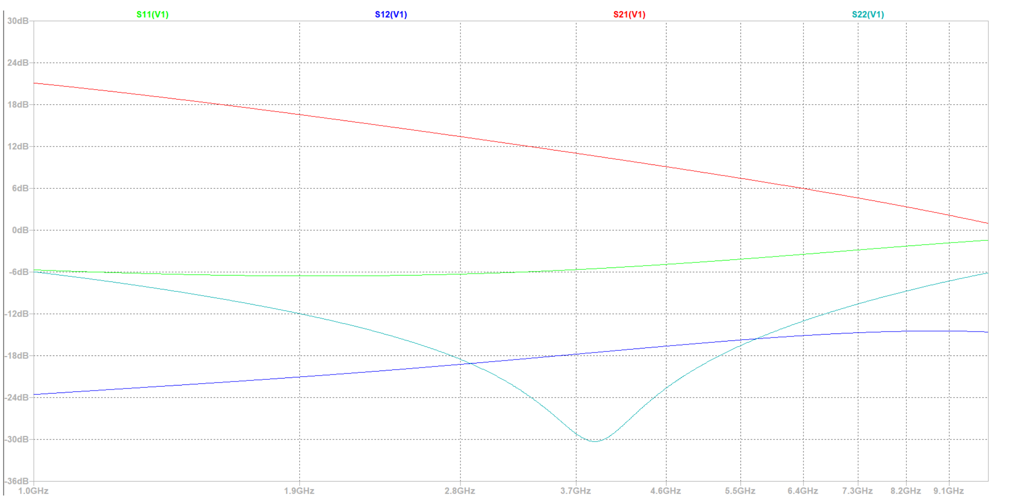



**Figure 2:** S-parameters of the transistor without matching network

## 2.3 Stability

Ensuring that the LNA remains stable is critical for reliable operation. The network is unconditionally stable for a frequency if for any source impedance value, $|\rho_{in}| < 1$ and for the load impedance $|\rho_{out}| < 1$. The stability circles can be used to determine regions for $\rho_{in}$ and $\rho_{out}$ where the amplifier circuit will be conditionally stable, but simpler tests can be used to determine unconditional stability.

Defining $K$ as:

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12} \cdot S_{21}|} \tag{4}$$

If:

- $K > 1$ and $|\Delta| < 1 \rightarrow$ unconditionally stable
- $K > 1$ and $|\Delta| > 1$ or $K < 1 \rightarrow$ potentially unstable or always unstable

Another criteria is the $\mu$ factor,
Defining $\mu$ as:

$$\mu = \frac{1 - |S_{11}|^2}{|S_{22} - \Delta S_{11}^*| + |S_{12} \cdot S_{21}|}$$

if $\mu > 1 \rightarrow$ unconditionally stable In addition, it can be said that larger values of $\mu$ imply greater stability.

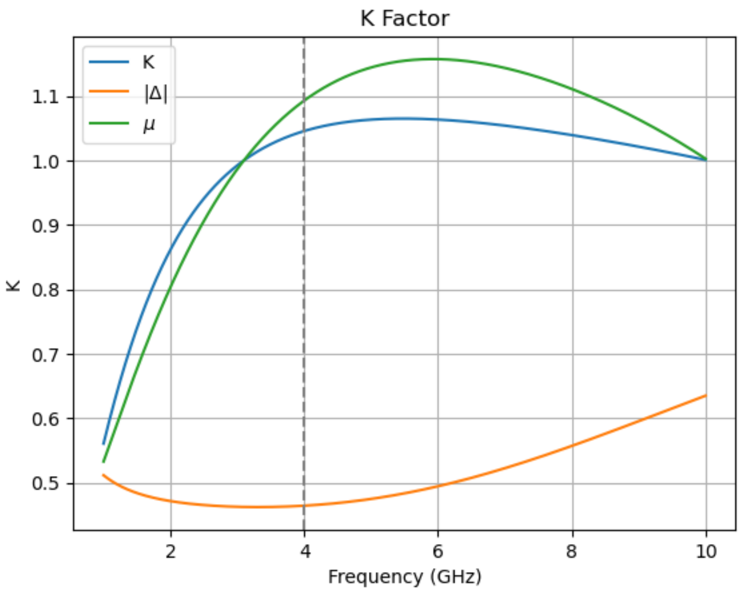



**Figure 3:** Stability tests

Figure 3, shows that the LNA is stable for frequencies above 3.1 GHz and above 10 GHz loses stability again.

At this stage another important figure is the Maximum Available Gain, $MAG$, which for the bilateral case can be expressed as the equation 5.

$$MAG = \left|\frac{S_{21}}{S_{12}}\right| \cdot \left[K \pm \sqrt{K^2 - 1}\right] \tag{5}$$

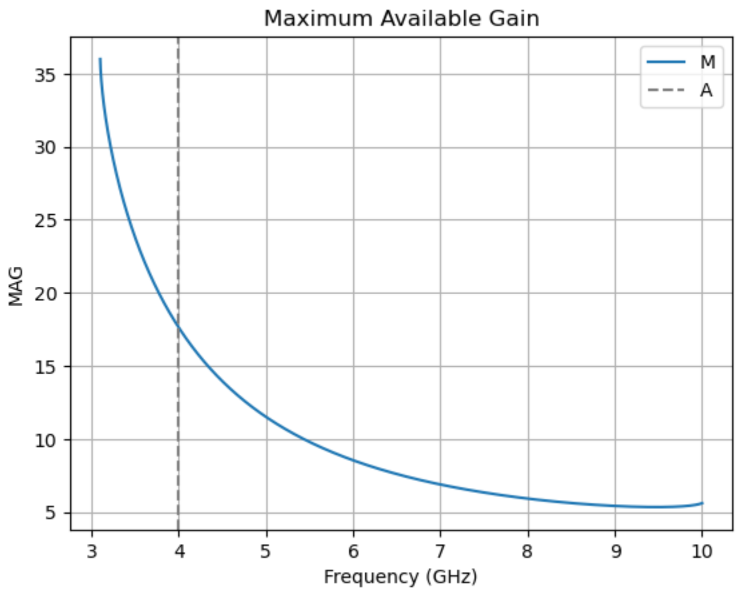



**Figure 4:** Maximum Available Gain

Now having the full picture of the LNA characteristics, an operating frequency can be decided. It is a compromise between stability and gain. The frequency chosen was 4 GHz.

## 2.4 Input and output matching networks for maximum gain

The adaptation for maximum gain is done using the line impedance transformation method. The input and output matching networks are designed to transform the input and output impedances of the transistor to the desired values, which are 50 Ω in this case. In the Smith chat, the matching is done with inductors and capacitors and lines and stubs.

### 2.4.1 Matching with lumped elements

The matching networks are designed using the Smith chart, which allows for the visualization of the impedance transformation. The input and output impedances of the transistor are transformed to 50 Ω using a combination of inductors and capacitors. The values of the components are also calculated using the equations for impedance transformation.

The matching using the Smith Chart for the input and output are shown in Figures 5 and 7, where the input and output impedances of the transistor are transformed to 50 Ω using a combination of inductors and capacitors.

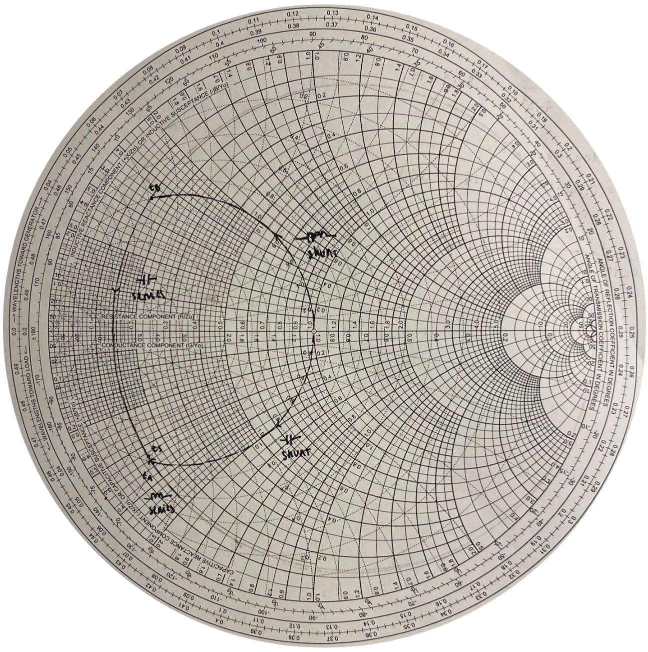


**Figure 5:** Smith chart for input matching with lumped elements

The adaptation mesh for the input was done with a shunt inductor and a series capacitor and the equivalent circuit is shown in Figure 6. The values of the components were also calculated using the equations for impedance transformation as a form of validation.

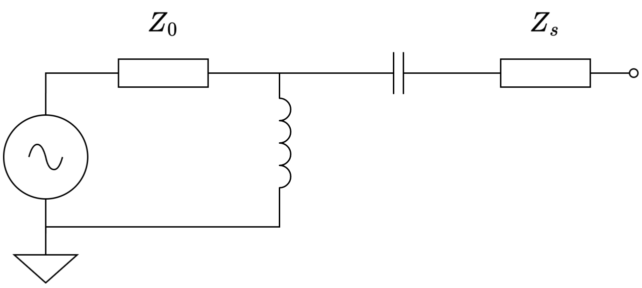



**Figure 6:** Matching circuit for input

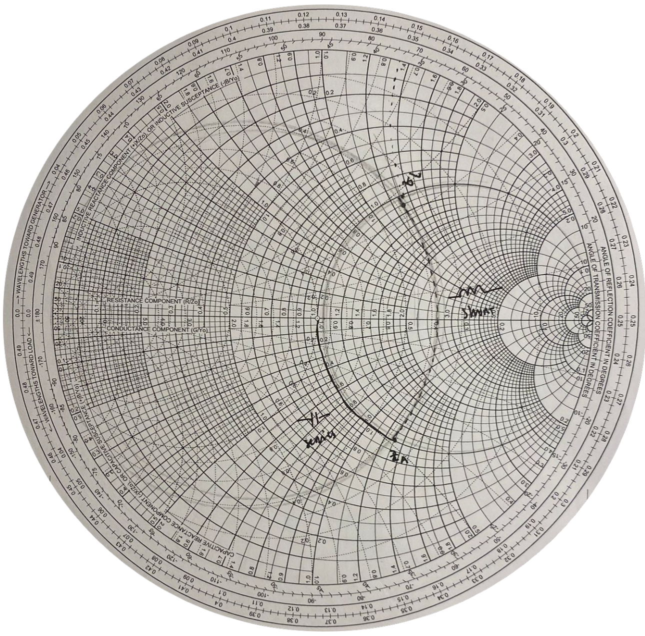


**Figure 7:** Smith chart for output matching with lumped elements

The adaptation mesh for the output is done with a series capacitor and a shunt inductor and the equivalent circuit is shown in Figure 8. The values of the components were also calculated using the equations for impedance transformation as a form of validation.

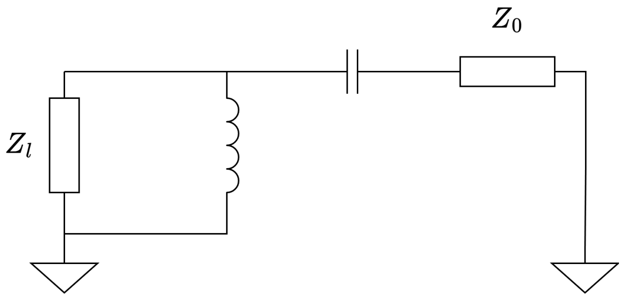



**Figure 8:** Matching circuit for output

The resulting circuit is shown in Figure 9, where the input and output matching networks are designed using a combination of inductors and capacitors.

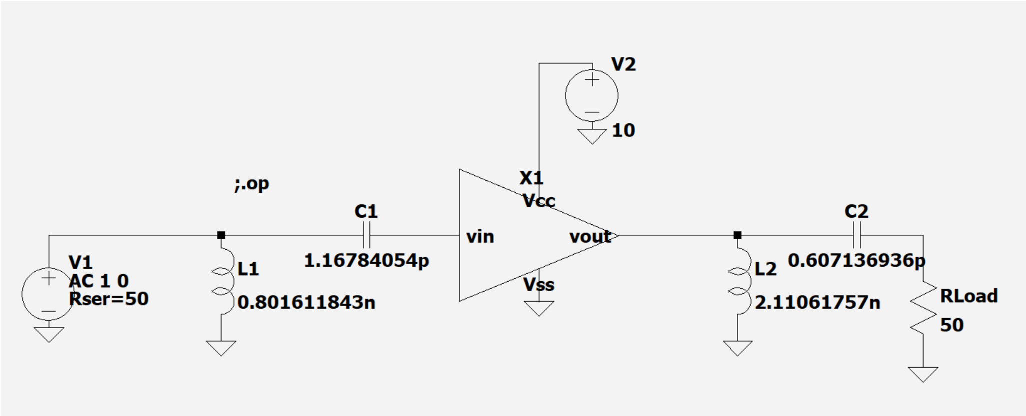



**Figure 9:** Matching circuit for input and output with values

### 2.4.2 Matching lines and stubs

The matching networks were also designed using transmission lines and stubs, this type of adaptation allows greater frequencies (more than 1 GHz) in real conditions. The input and output impedances of the transistor were transformed to 50 Ω using a combination of transmission lines and stubs. The values of the components were also calculated using the equations for impedance transformation to validate the results.

The matching using the Smith Chart for the input and output are shown in Figures 10 and 11.

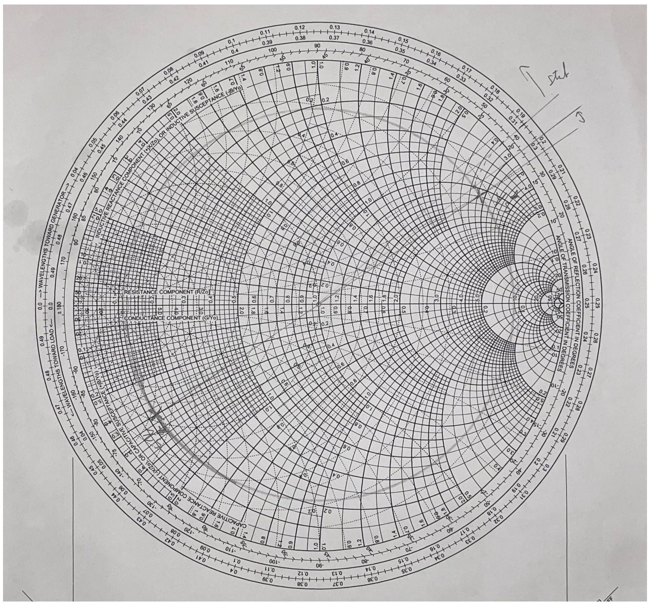


**Figure 10:** Smith chart for input matching with lines and stubs

The adaptation mesh for the input was done with an open circuit shunt stub and a series line.

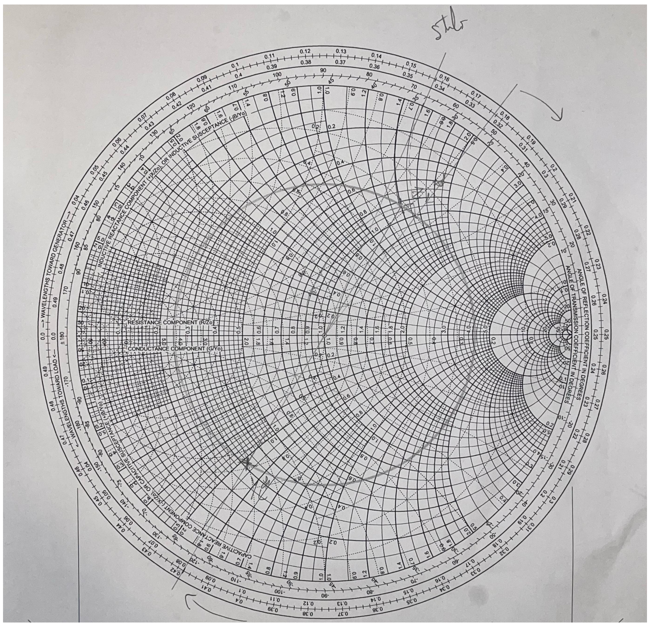


**Figure 11:** Matching circuit for input with lines and stubs

The adaptation mesh for the output is done with a series line and an open circuit shunt stub.

The final circuit is shown in Figure 12, where the input and output matching networks are designed using a combination of transmission lines and stubs.

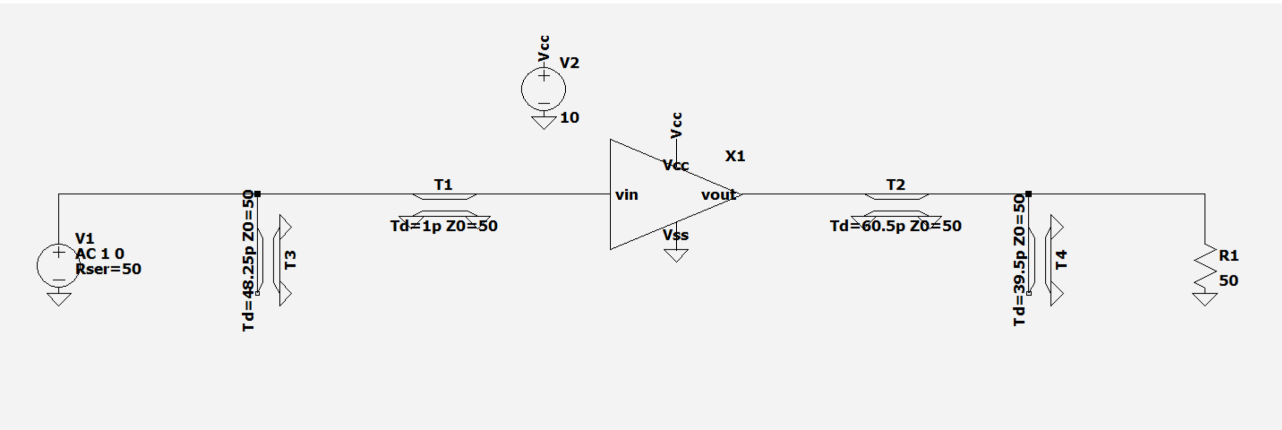



**Figure 12:** Matching circuit for input and output with values

# 3 Simulation

## 3.1 Validation of the LNA design

## 3.2 Input and output matching networks design optimization

# 4 Conclusion

# References