NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

MEEC/MIEEC

Radio Frequency Electronics

Low Noise Amplifier - Part I

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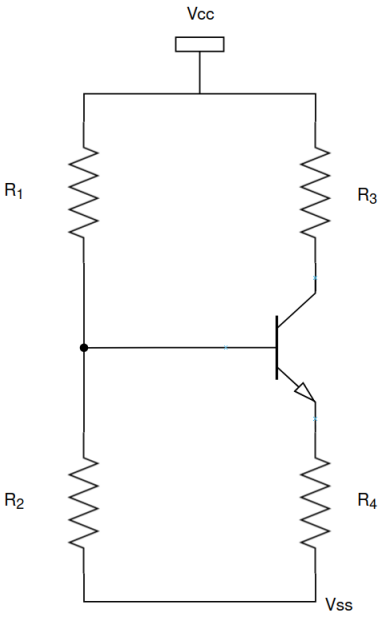
1 Introduction

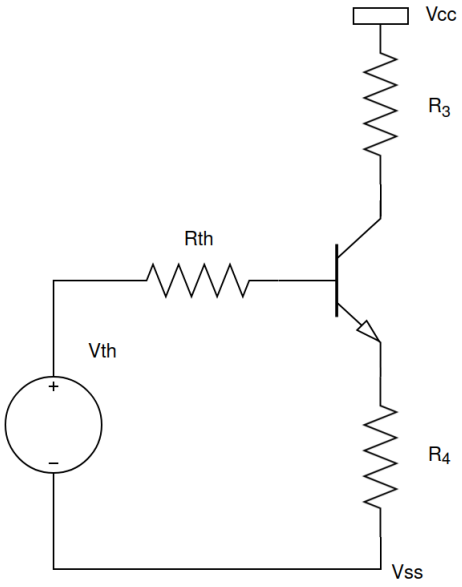
2 Design of the LNA

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	$1\,\text{k}\Omega$
R_4	$100\,\Omega$
β	72.534
I_C	$9\,\text{mA}$
V_{CC}	$10\,\text{V}$
V_{BE}	$1\,\text{V}$
V_{CE}	$5\,\text{V}$

Resulting in $R_1 = 4\,\text{k}\Omega$ and $R_3 = 454\,\Omega$.
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2.2 S-parameters with packaging effects

2.3 Transistor validation for the given bias point

2.4 Stability

2.5 Input and output matching networks

2.6 Gain and Noise Factor

3 Simulation

In this section, the simulations of the LNA and the corresponding matching networks will be presented.

3.1 Validation of the LNA design

First, using the LTSpice, the T502 transistor was added and the parasites capacitance and inductance of the package were considered, resulting in the simulated real transistor circuit in Figure 2.

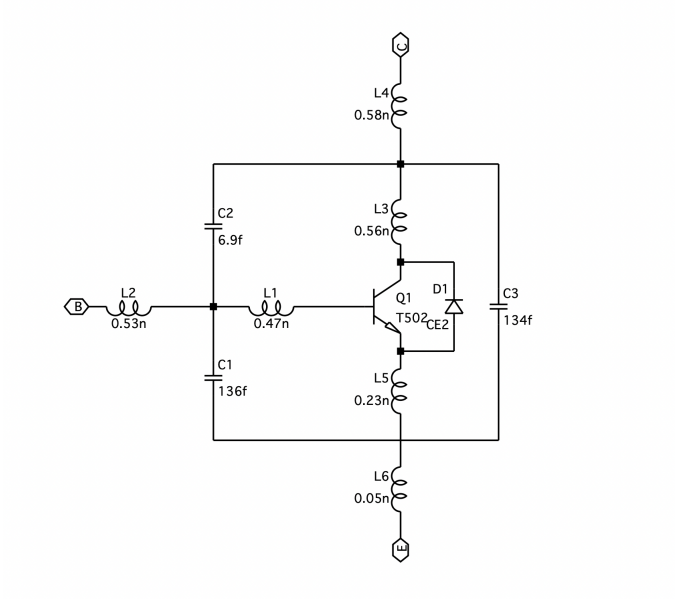


Figure 2: Transistor with package effects

After this, the biasing circuit of the transistor for the required parameters is present in Figure 3.

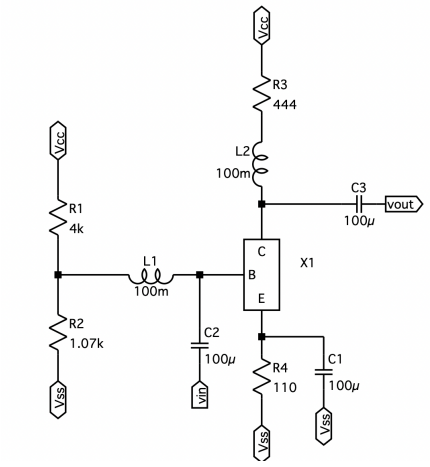


Figure 3: Biasing circuit simulated

After simulating the operation point of the previous circuit, the result for the required parameters is shown in Figure 4.

Figure 4: Result of the operation point simulation

After analyzing the previous graphic, it is possible to confirm that result parameters of the biasing circuit are within the required.

At the same time, the same circuit was implemented in Cadence, to ensure greater reliability of the results obtained. So, this circuit can be seen in Figure **??**.

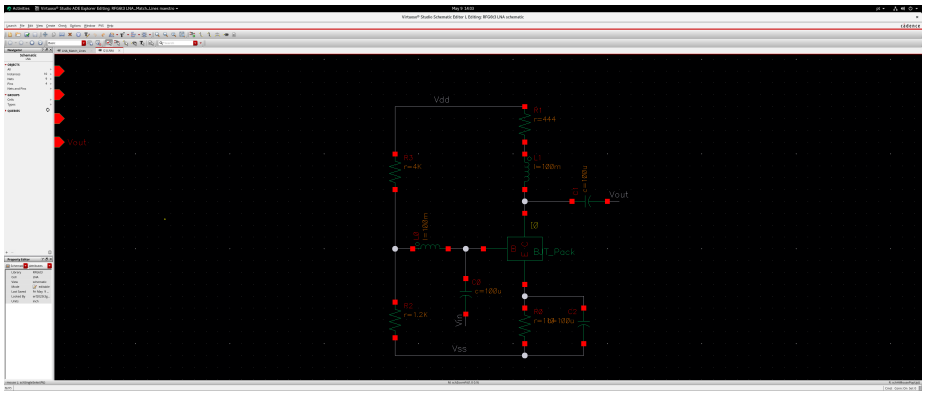


Figure 5: Biasing circuit simulated in Cadence

So the matching networks for the source and the load, both with an impedance of 50Ω, can be implemented.

3.2 Input and output matching networks design simulation

As mentioned before, the first step in designing a matching network in an LNA is to know the S-parameters of the amplifier circuit, so, switching to an AC analysis of the LNA circuit,

and adding both the source and the load, the simulated circuit is shown in Figure 6.

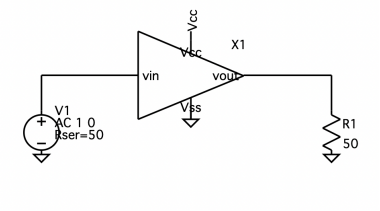
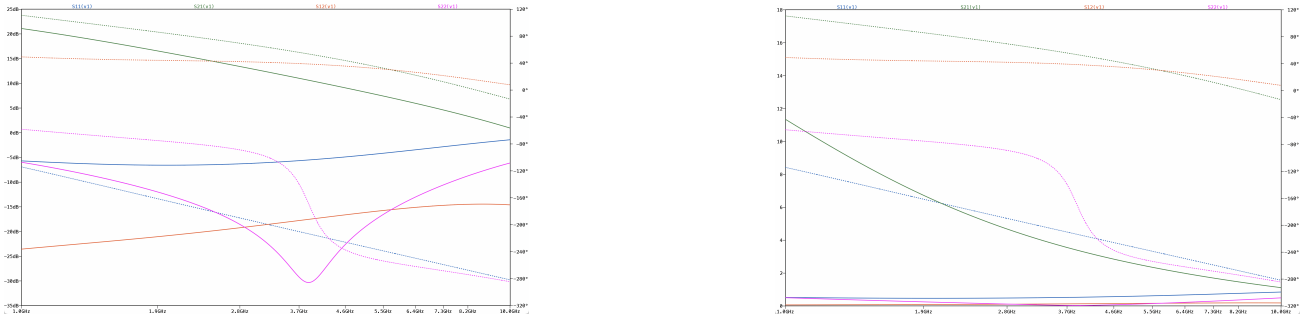


Figure 6: Circuit for the S-parameters

The resulting S-parameters can be seen in Figure 7.



(a) S-parameters in dB

(b) S-parameters in linear

Figure 7: S-parameters of the LNA

After assuming a working frequency of $4GHz$, the resulting matching networks using capacitors and inductors is exhibit in Figure 8.

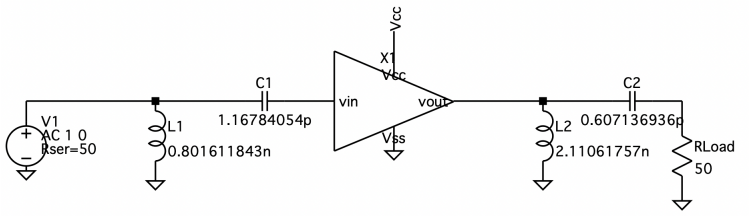


Figure 8: Matching networks using inductors and capacitors

Using again the same AC analysis, the S-parameters of new circuit using the capacitors and inductors matching networks is displayed in Figure 9.

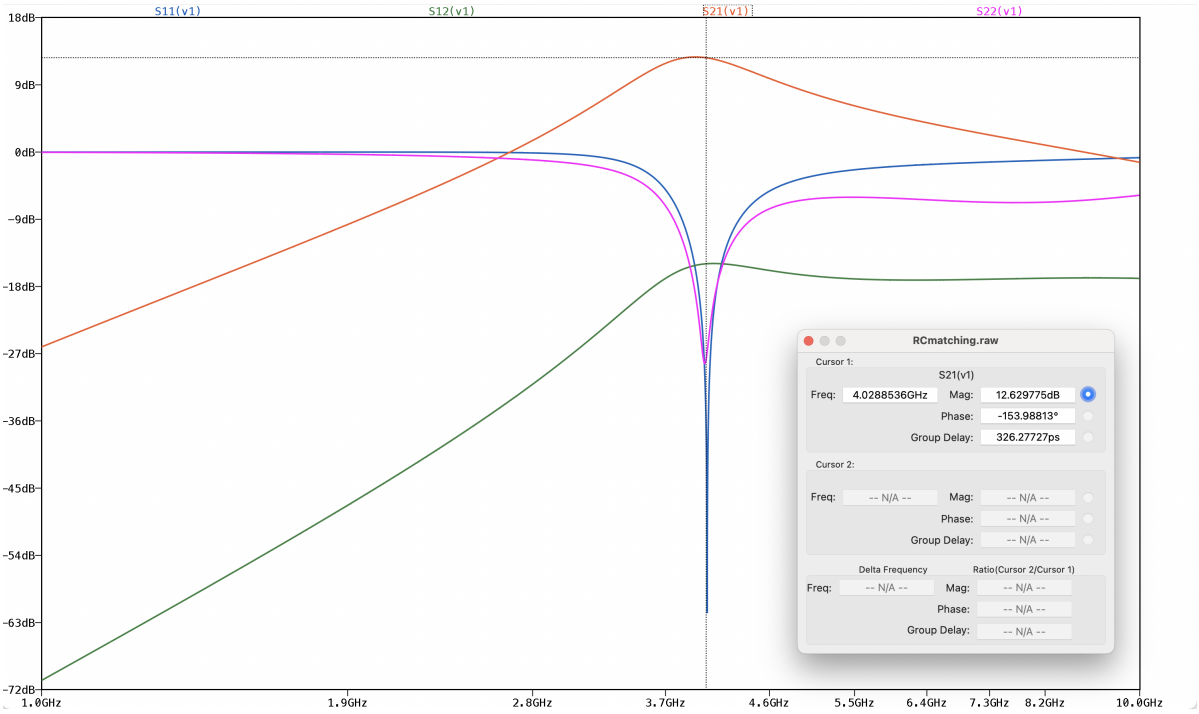


Figure 9: S-parameters for the matching networks using inductors and capacitors

After looking at the graphic above, it is possible to conclude that this matching network is working properly, since there is a sharp drop in both $S11$ and $S22$ ate the desired frequency of $4GHz$ as well as a high point in the $S21$ curve.

In cadence, the circuit for the matching using inductors and capacitors is the following.

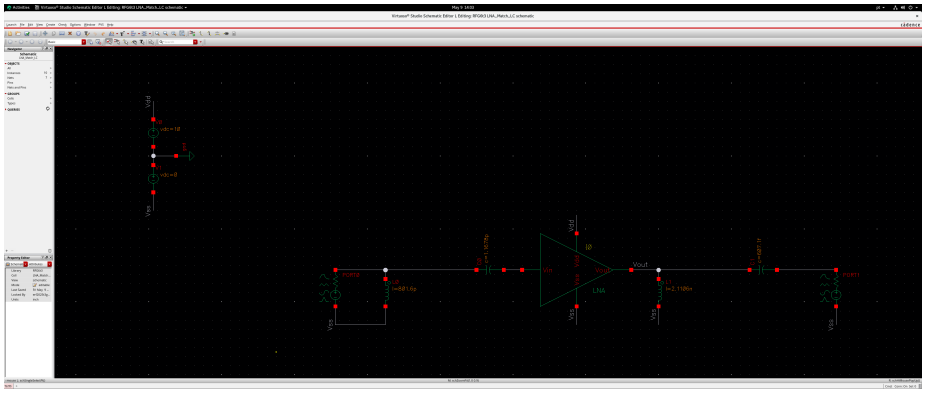


Figure 10: Matching networks using inductors and capacitors in Cadence

Simulating, the S-parameters of this circuit with the mentioned matching networks is visible in Figure 11.

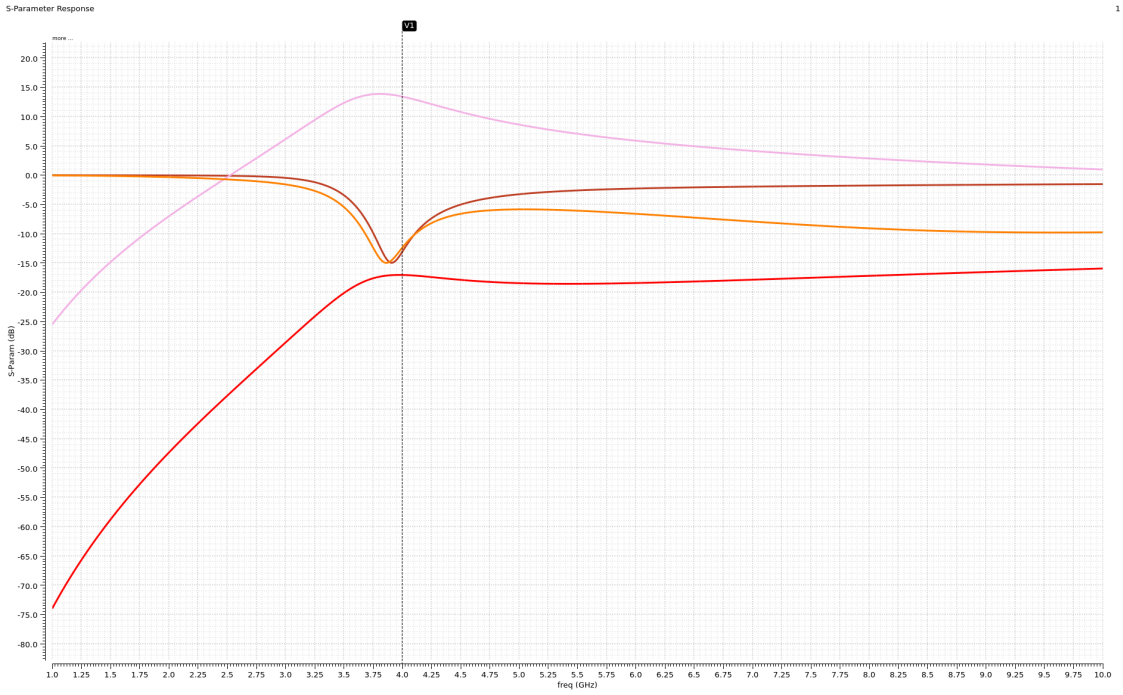


Figure 11: S-parameters for the matching networks using inductors and capacitors in Cadence

Passing to the matching networks using transmission lines and stubs, and using the same working frequency, the new LNA circuit is shown in Figure 12.

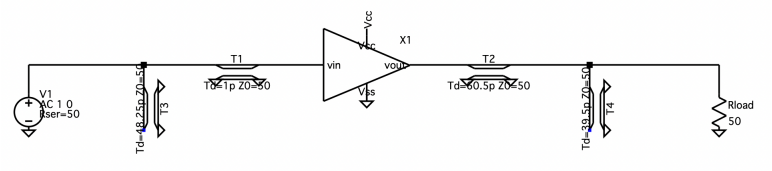


Figure 12: Matching networks using transmission lines and stubs

The S-parameters for this new matched circuit can be seen in Figure 13.

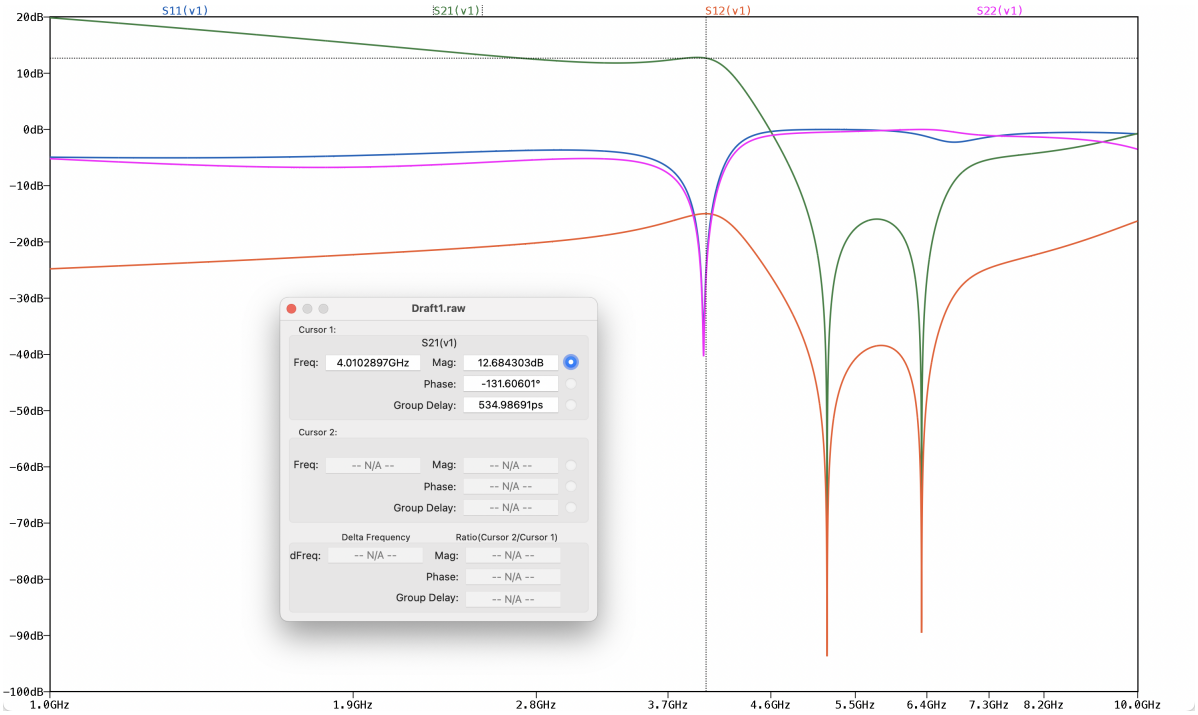


Figure 13: S-parameters for the matching networks using transmission lines and stubs

Similarly to the first matching networks, the drop in both $S11$ and $S22$ can also be seen, as well as the same approximated value of $S21$, so, this matching network using transmission lines and stubs is correctly working.

In cadence, the circuit for the matching using transmission lines and stubs is the following.

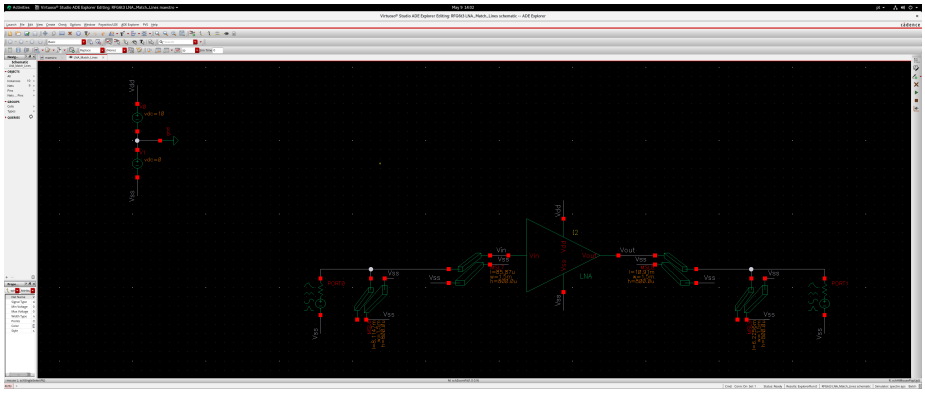


Figure 14: Matching networks using transmission lines and stubs in Cadence

Simulating, the S-parameters of this circuit with the mentioned matching networks is visible in Figure 15.

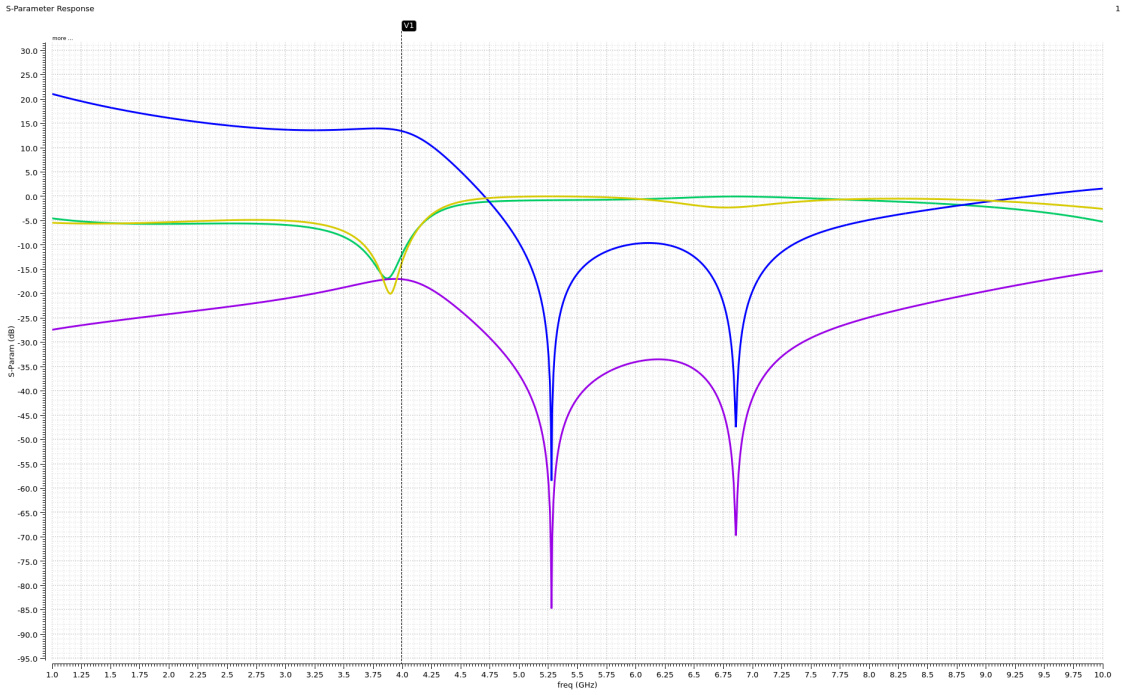


Figure 15: S-parameters for the matching networks using transmission lines and stubs in Cadence

3.3 Noise

To simulate the noise of each matching network, the Cadence was used, resulting in the graphic shown in Figure 16 for the inductors and capacitors.

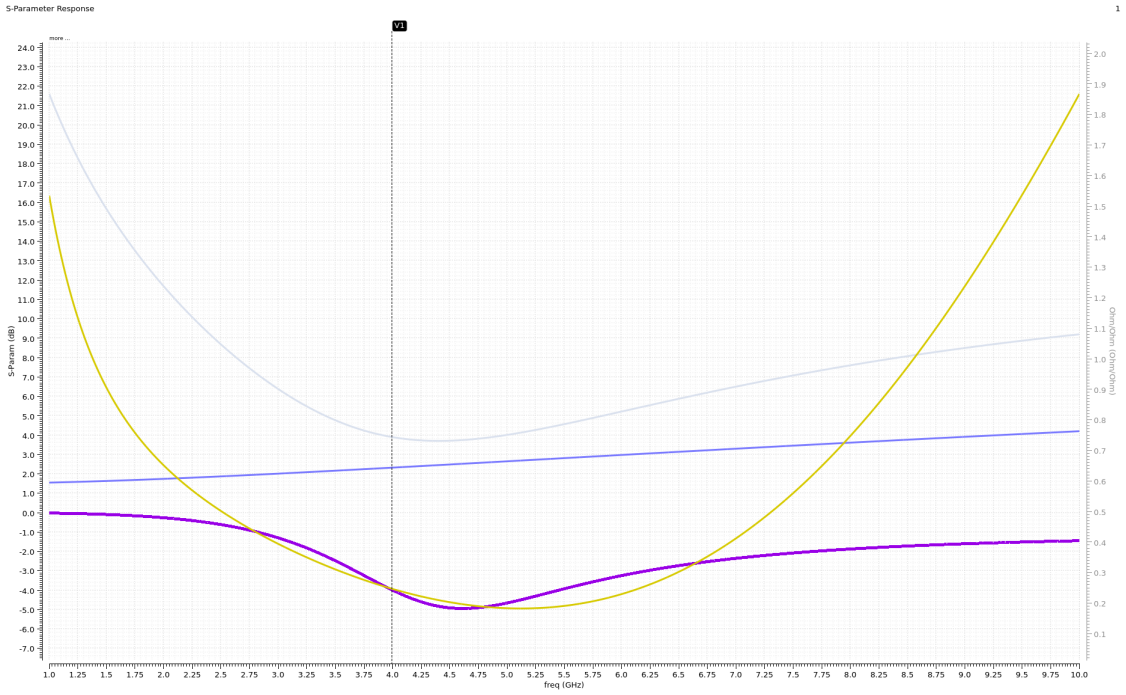


Figure 16: Noise for the matching networks using capacitors and inductors in Cadence

And for transmission lines and stubs in Figure 17.

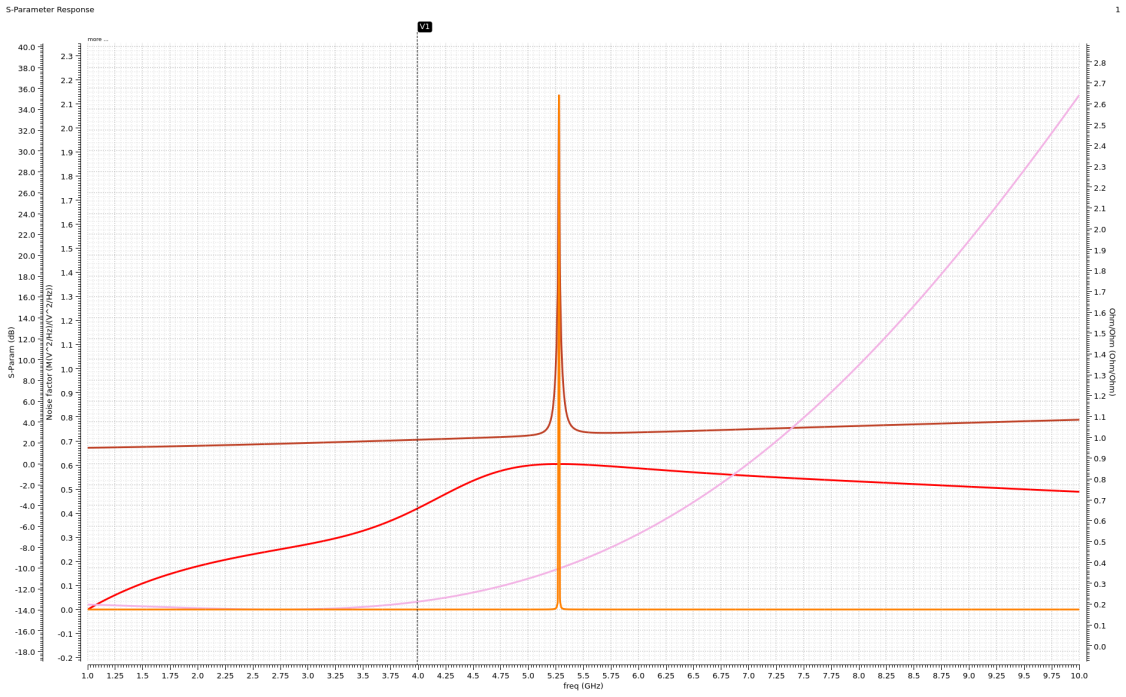


Figure 17: Noise for the matching networks using transmission lines and stubs in Cadence

4 Conclusion