Our purpose is designing an LNA with a Noise Figure of 2 dB at 10 GHz using BFP720 transistor manufactured by Infineon. This transistor is an ultra-low-noise Silicon Germanium BJT which can perform its task up to 12 GHz. The biasing points we have chosen is V_{CE}=3.0 V and I_C=13 mA. For this set of operating points, the minimum noise figure can be 1.05 dB as can be seen in Figure 1.

```
BEGIN NDATA
# GHZ S MA R 50
%F nfmin n11x n11y rn
0.450 0.59 0.25 1 0.17
1.800 0.65 0.23 16 0.13
2.400 0.70 0.21 29 0.37
5.500 0.86 0.09 -13 0.17
10.000 1.05 0.42 -76 0.26
END
```

Figure 1. Minimum Noise Figure Data Table for the biasing point

From the data table, we can also see the extracted S parameters as shown in Figure 2.

```
7.800 0.6051 114.5 4.466 2.4 0.0636 11.9 0.2076 -174.2
7.900 0.6086 113.0 4.416 0.9 0.0644 11.4 0.2092 -179.0
8.000 0.6125 111.5 4.369 -0.6 0.0653 10.9 0.2122 176.3
8.500 0.6393 102.9 4.050 -8.5 0.0682 8.0 0.2181 159.2
9.000 0.6748 95.0 3.730 -15.9 0.0715 5.1 0.2530 142.4
9.500 0.7202 88.5 3.421 -23.1 0.0740 1.6 0.3090 129.2
10.000 0.7643 82.8 3.105 -30.0 0.0748 -2.0 0.3735 119.0
10.500 0.7879 78.7 2.799 -35.1 0.0756 -4.0 0.4282 112.0
11.000 0.8023 77.2 2.603 -39.0 0.0780 -5.8 0.4707 108.2
11.500 0.8334 76.8 2.483 -44.2 0.0811 -8.6 0.5157 106.3
12.000 0.8614 75.2 2.334 -50.8 0.0824 -12.5 0.5599 103.8
```

Figure 2, Extracted S parameters for the biasing point at f=10GHz, I_C=13 mA and V_{CE}=3 V

In polar form, we obtain the following S parameters:

For our design purposes, we have to find the stability region so that when optimal Γ_S circle for the desired noise figure is drawn, we make sure that the amplifier will not oscillate. It would be great if the transistor is unconditionally stable for the desired frequency because it would give us the benefit of choosing Γ_S everywhere we want in the Constant Noise Figure Circle. For that purpose, we applied the K – Δ test for unconditional stability.

Since the K – Δ test is satisfied the transistor is stable for every selection of the input and output passive loads. In order to confirm our results, we can also perform a simulation which finds the input and output stability circles in Microwave Office. As can be seen if Figure 3, the circles indicate the stable region to be the whole Smith Chart.

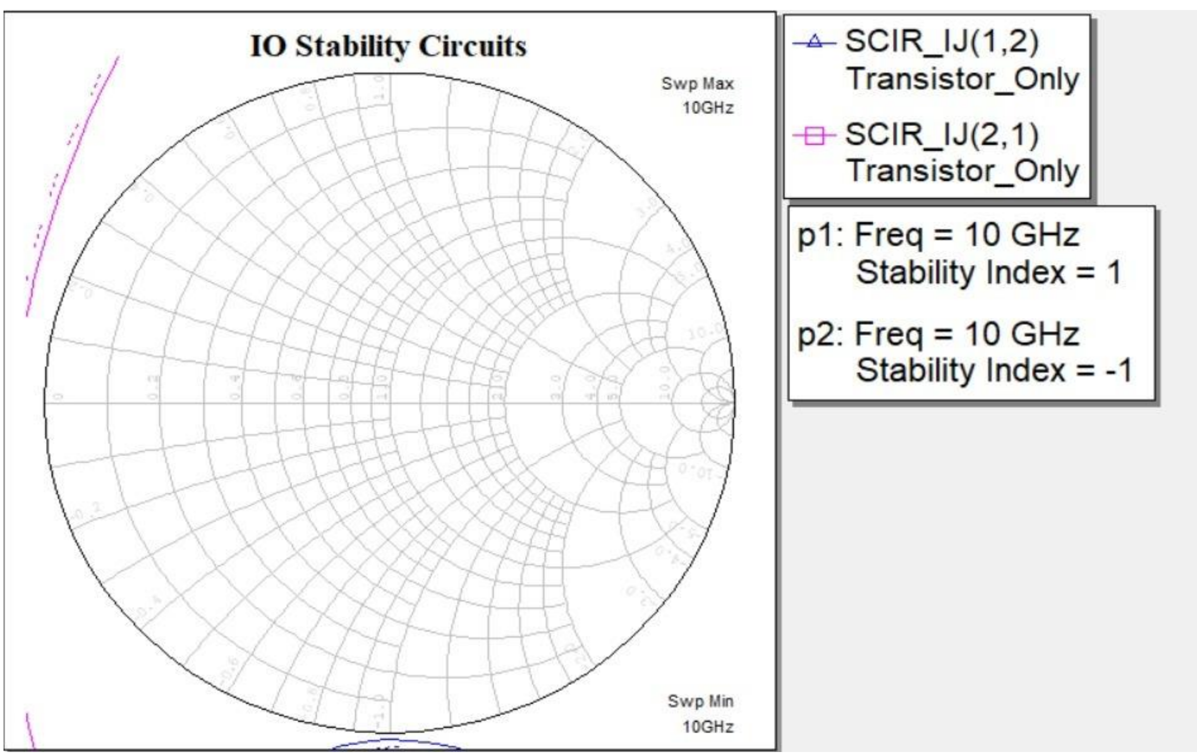

Figure 3 Input and Output Stability Circles at 10GHz

The blue circle in the Figure 3 represents the input stability circle while the red one represents the output stability circles. The blue circle does not intersect the Γ=1 circle. Since $|S_{22}|<1$, this means that every selection of passive Z_s will lead to stability. The same can be said for the output stability circle. From the Figure 3, we deduce that it encloses the Smith Chart entirely. Thus, both Z_S and Z_L can be chosen anywhere in the Smith Chart.

Now, we can proceed with our low-noise amplifier design. From the component sheet, we obtain the following graph shown in Figure 4:

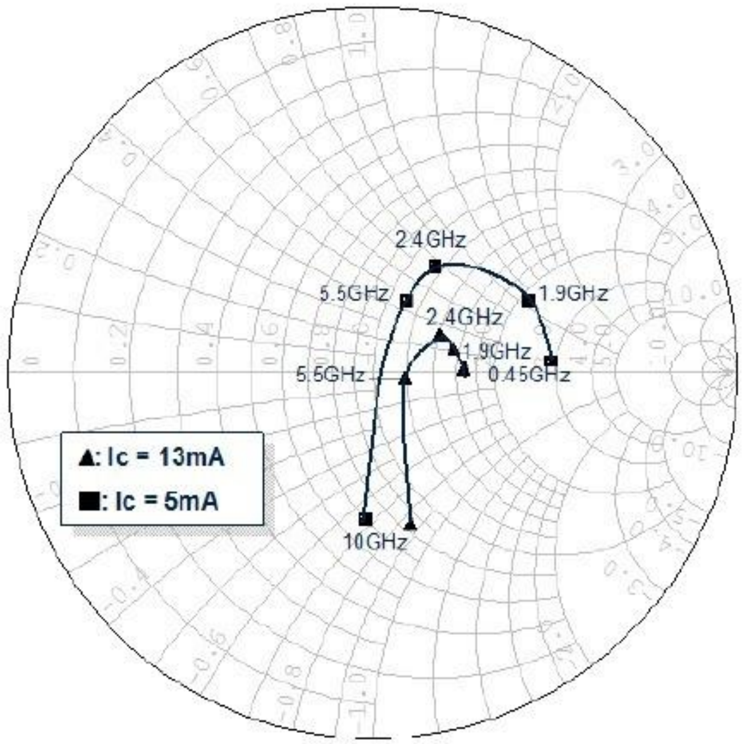

Figure 4. $\Gamma_{S,opt}$ plot for various frequencies and various biasing currents

It seems that for an I_C=13 mA and at f=10GHz, the normalized $z_{S,opt}$ =0.846-j*0.83. We find the $Z_{s,opt}$=42.3 - 41.5j. In our design, we need a noise figure of 2 dB. Hence, we need to draw the constant noise figure circle associated with this value. The calculation for the noise figure circle is as shown below:

We can plot this in Microwave Office as well indicated in Figure 5. This circle complies with our Noise Figure Circle shown in the next page.

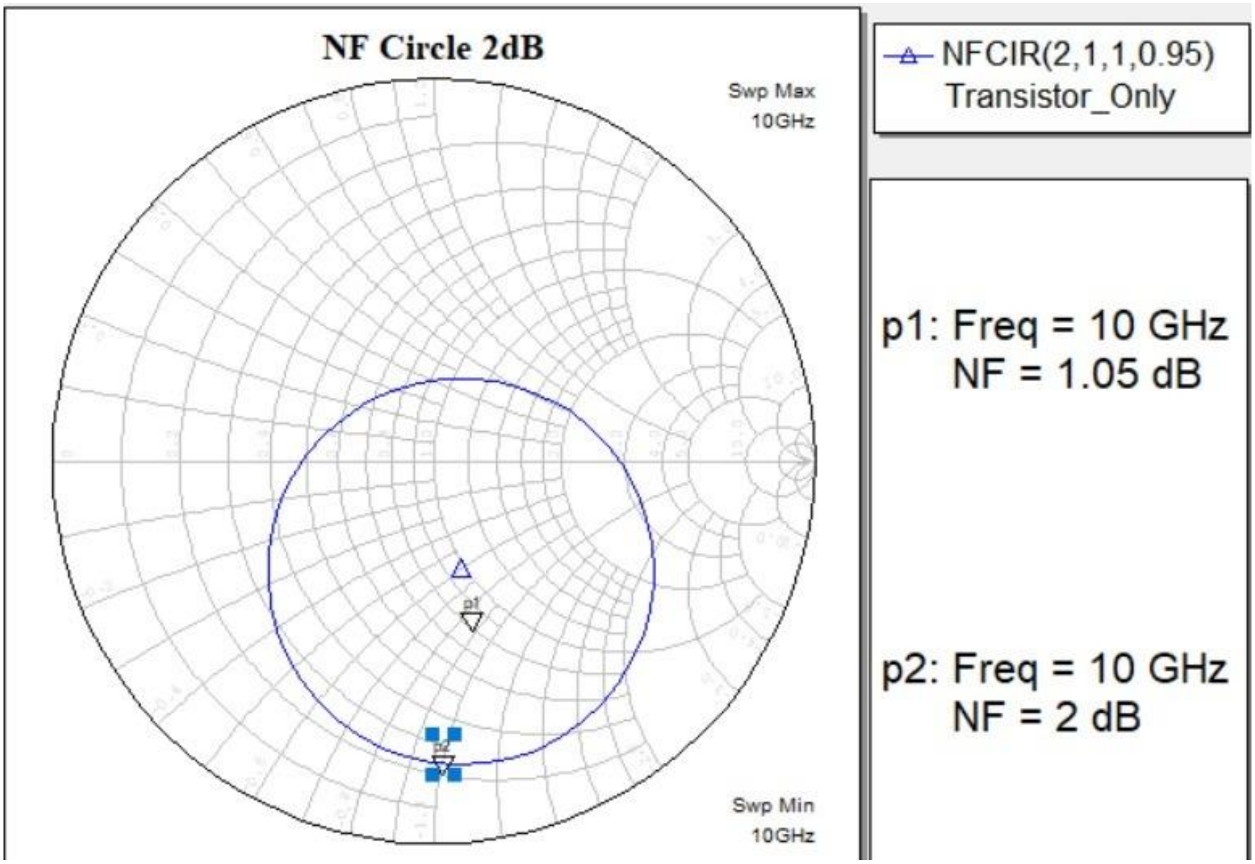

Figure 5. $\Gamma_{S,opt}$ and NF=2 dB circle

For the next step, we intend to select the Γ_S which will yield the maximum available gain possible. The reason why we are plotting maximum available gain is because it is easier in Microwave Office to plot the available gain circles. If we assume the transistors to be unilateral (because $|S_{12}|$ is small enough) and if we consider maximum power transfer at the output at the same time, the available power gain and transducer power gain will reduce to the same formula as shown below:

Because of this approximation that we are making, there will be some error introduced but it won't be significant. The constant available gain circles, plotted in Microwave Office are as shown below:

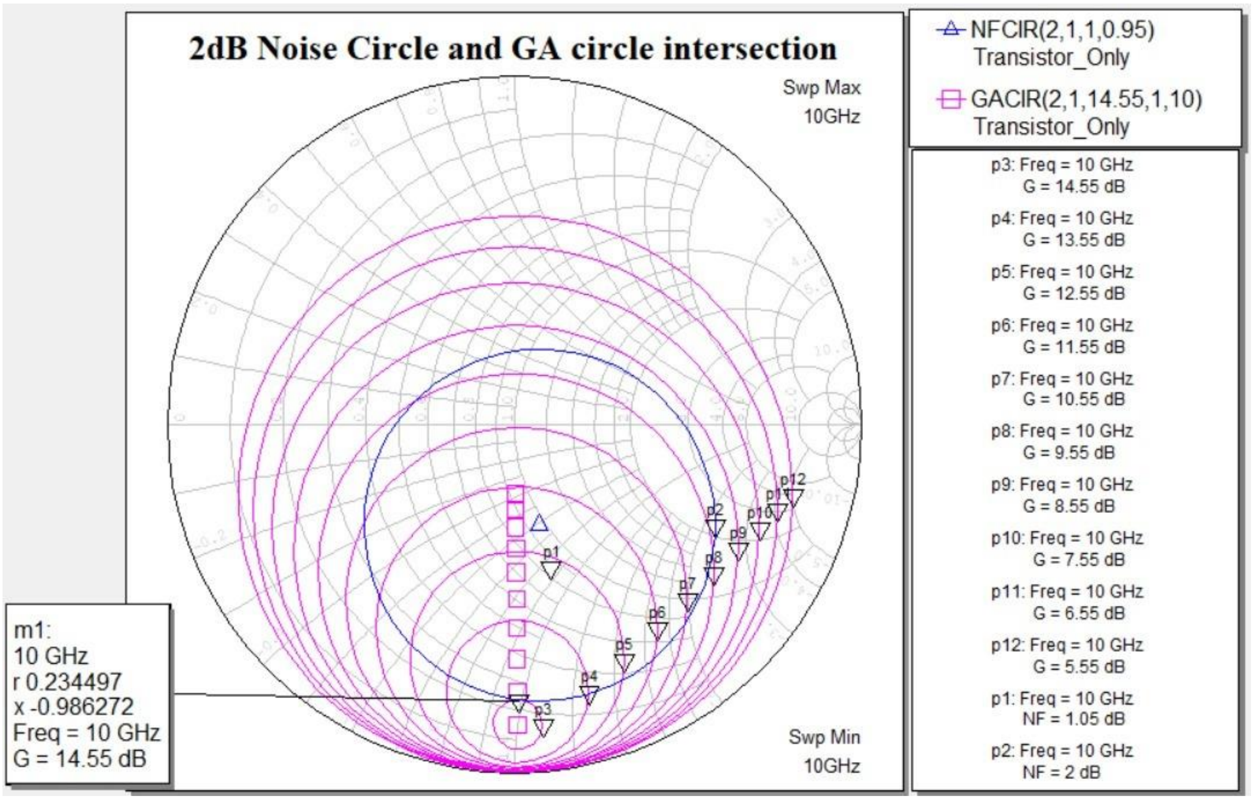

Figure 6. Constant Available Gain Circles

The maximum available gain is achieved when the G_A circle is tangent to the 2-dB noise figure circle we have calculated before. Clearly, the maximum available gain is achieved at a normalized z_S=0.2345-0.986j. This corresponds to Γ_S=0.79$\angle(-89.2\,°)$. For this value of Γ_S, maximum power transfer at the output is achieved at $\Gamma_L = \Gamma_{out}^*$=0.478$\angle(178°)$. The calculations are as shown below:

We plot the S parameters of the LNA in Figure 7:

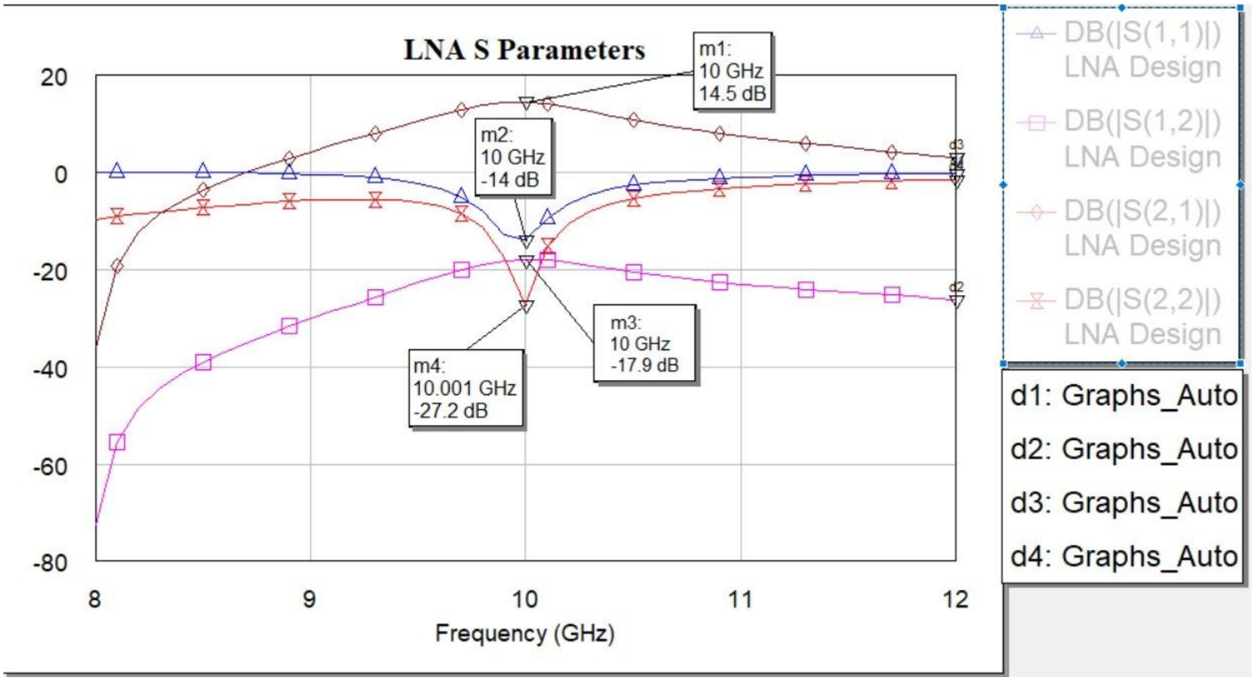

Figure 7. S-parameters of the LNA

We can see that for our design frequency we obtain a local minimum for both $|S_{11}|$ and $|S_{22}|$ meaning that we have minimum reflections at 10 GHz. Furthermore, the transducer gain obtained, $20\log|S_{21}|$ is maximum at this design frequency as expected.

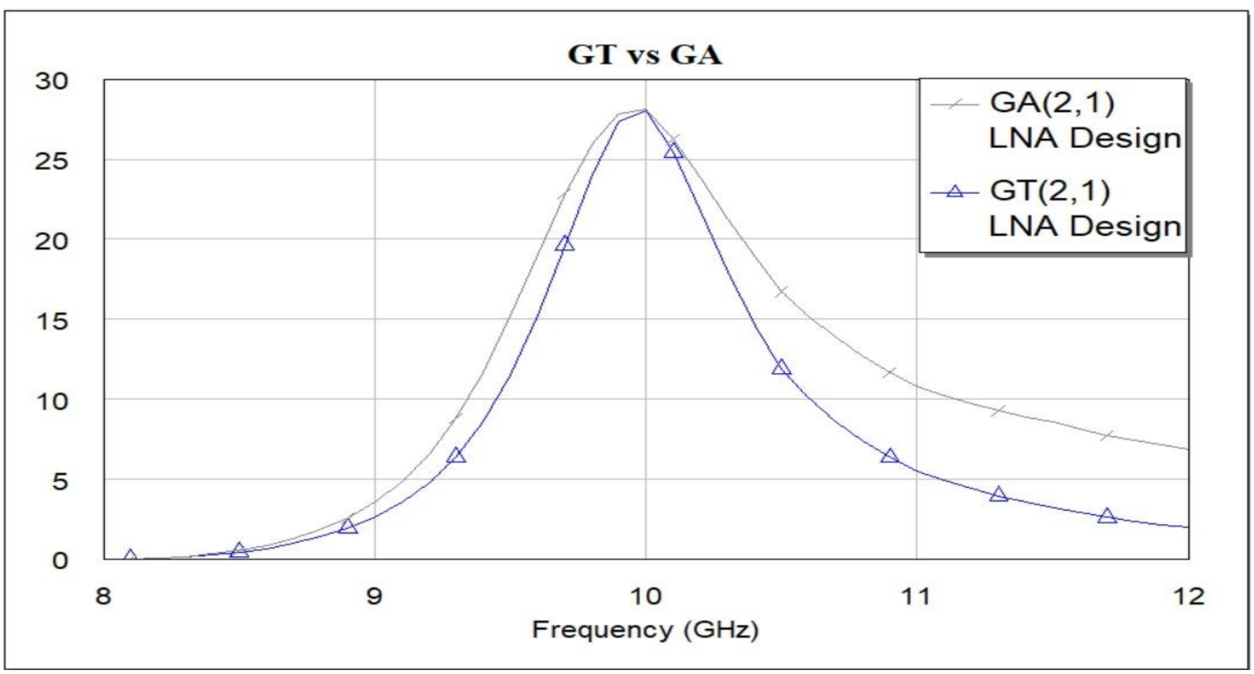

Figure 8. Transducer Gain and Available Gain

In Figure 8, we also plot the available gain and compare it with the transducer gain in order to check our previous assumption regarding the negligible difference between them. Indeed, for the design frequency, the difference is very small.

We can also calculate the bandwidth. As can be seen in Figure 9, the 3-dB Bandwidth is approximately 1 GHz.

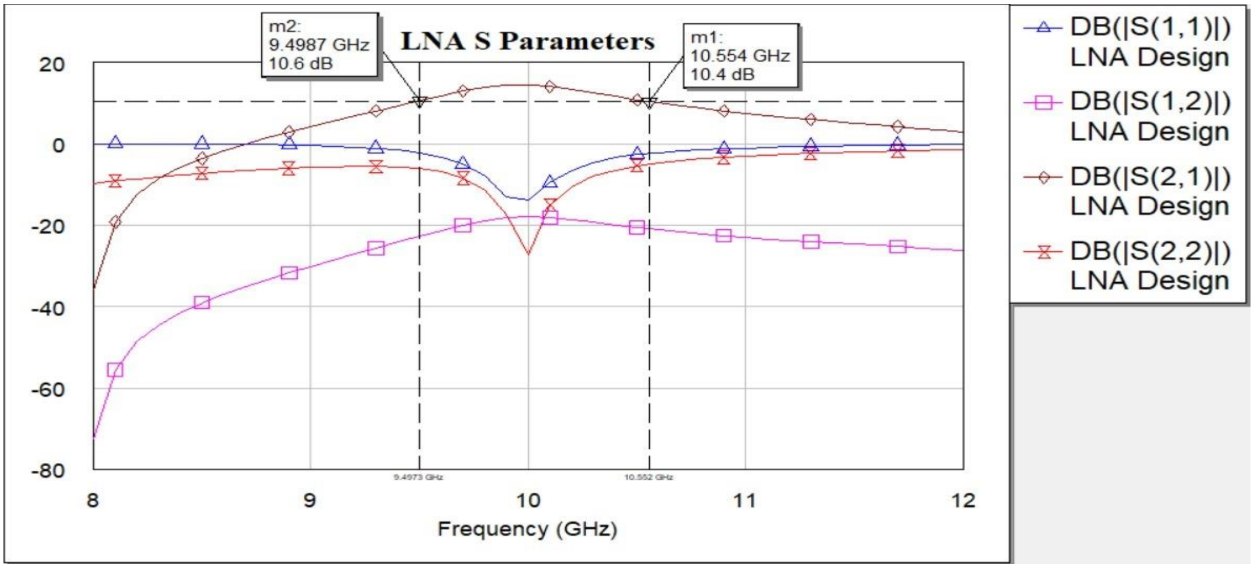

Figure 9. 3 dB Bandwidth Boundaries

Last, we need to make sure that our circuit will not be unstable for frequencies close to our design frequency. Hence, we can sweep the frequency, to obtain the stability circles once again. We obtain the following results shown in Figure 10. Again, the stability region for the selection of Γ_S and Γ_L is the entire Smith Chart.

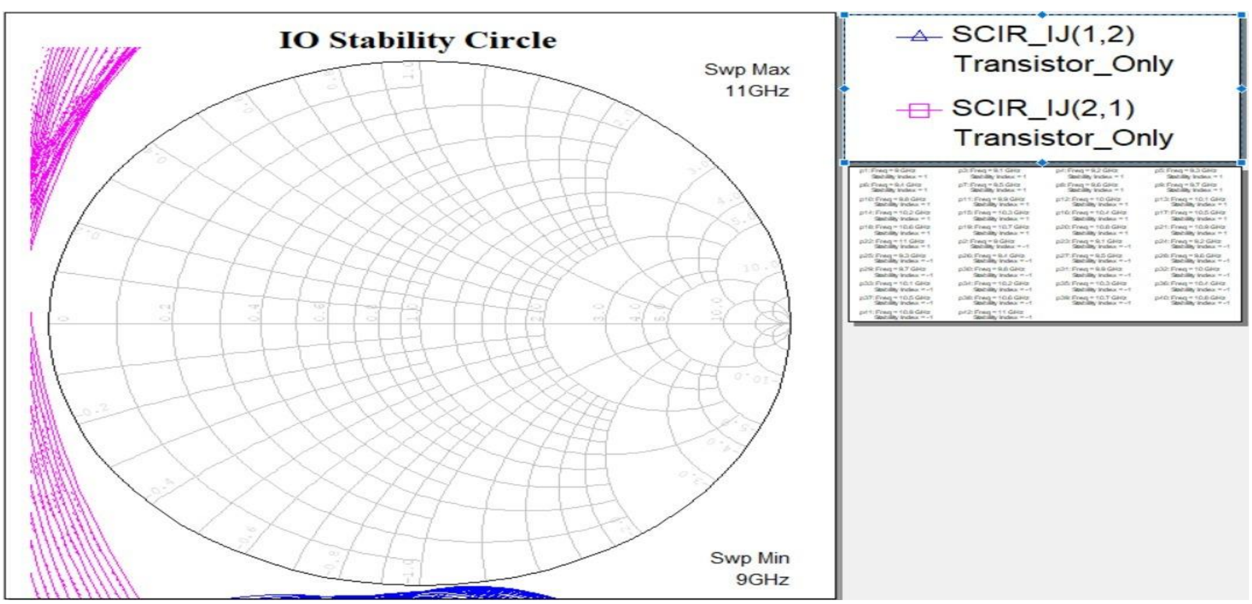

Figure 10. Stability Circles for a 9 GHz to 11 GHz frequency range

The last part is about designing for the DC operating point. For that purpose, we implement the circuit shown in Figure 11. For maximum power transfer to the transistor, we need to employ very high resistors at the input. If they are very high, they are effectively open circuits so it does not disturb the previous calculations that we have done. In Figure 11, we have chosen R1 to be 340 kΩ. After that, we created a variable R_{SWEEP} in order to sweep R2, so that we generate the required I_C. The target I_C is 13 mA and target V_{CE} is 3 V. The selected DC supply is 12 V so we should have 9V over the resistance R3. Since the required current is 13 mA, it makes sense to choose R3 692.3 Ω. In Microwave Office, to generate the sweep operation, we need to create a circuit element called SWPVAR.

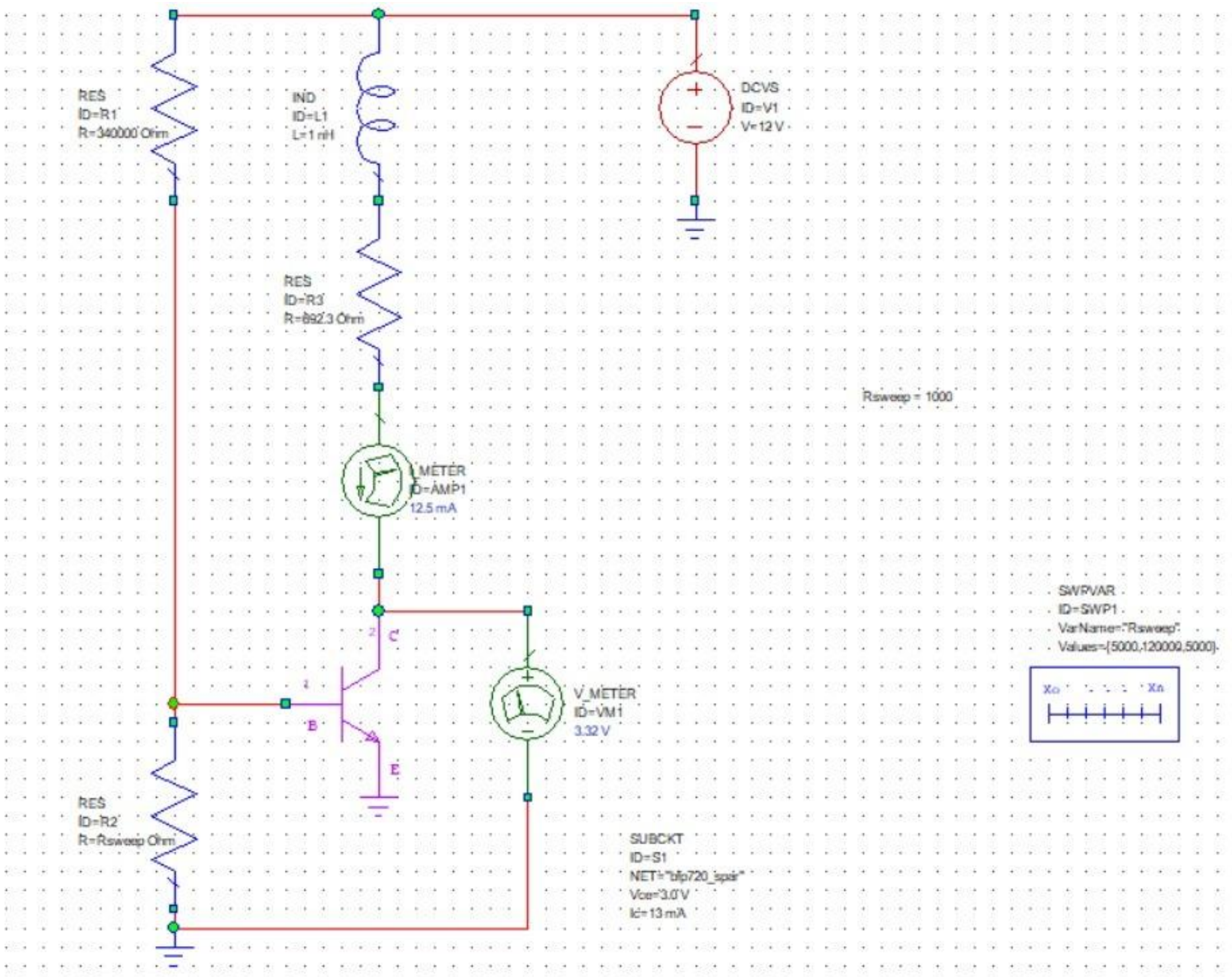

Figure 11. Circuit Configuration for proper DC biasing

We swept the variable Rsweep from 5 kΩ to 120 kΩ. As shown in Figure 12, for a current of 13mA, the required R1 value is approximately 119 kΩ.

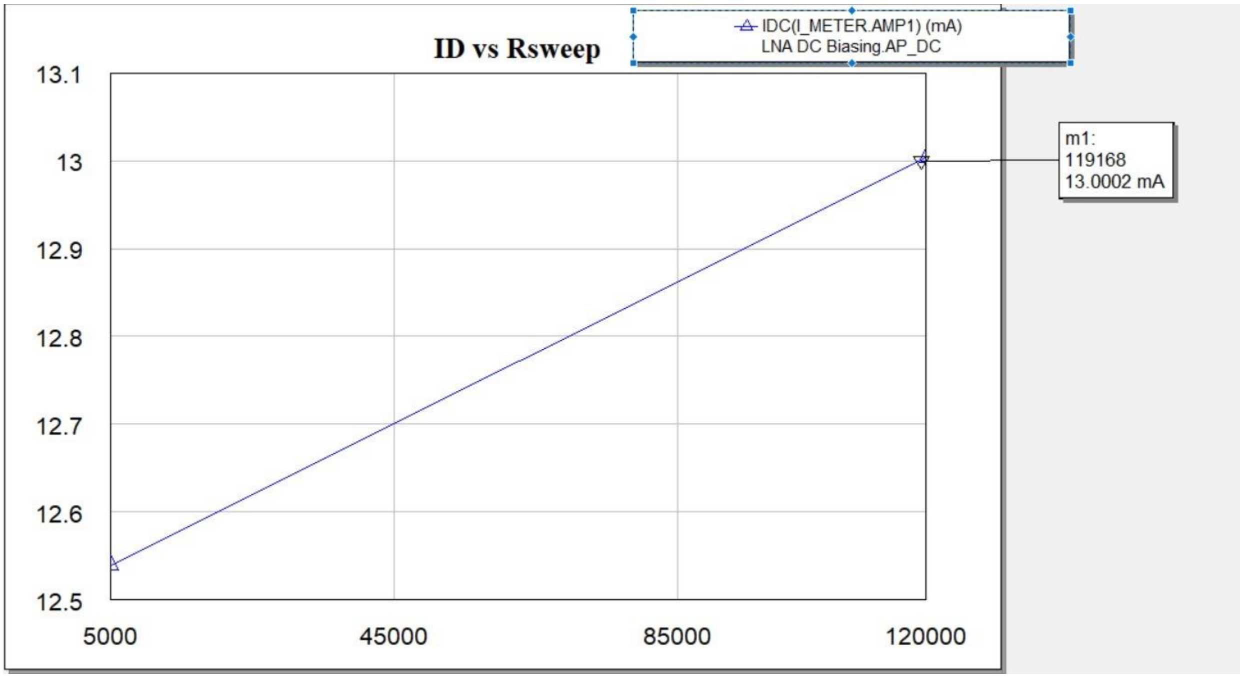

Figure 12. I_D versus R1 sweep

We put an inductor in series with our R3 so that in the desired operating frequency, the equivalent impedance of R3 and L is nearly open circuit in the desired operating frequency. Above 9 GHz, that equivalent resistance is greater than 500 kΩ which can be considered an open circuit and therefore does not affect our AC operation. We will also have to use high capacitors to connect the input and load impedance matching circuits. Those capacitors need to be high enough to block the DC and at the same time to not affect the AC operation. Since the intended operating frequencies are from 9.5 GHz to 11.5 GHz we are selecting a capacitance of C=10 µF which will give us an equivalent series resistance of 1.77 µΩ. Since this value does not affect the DC and AC operation, it is appropriate for our amplifier design.

To conclude, our final schematic which includes the required noise figure, the associated maximum allowable available gain, the correct biasing circuitry, is shown in Figure 13.

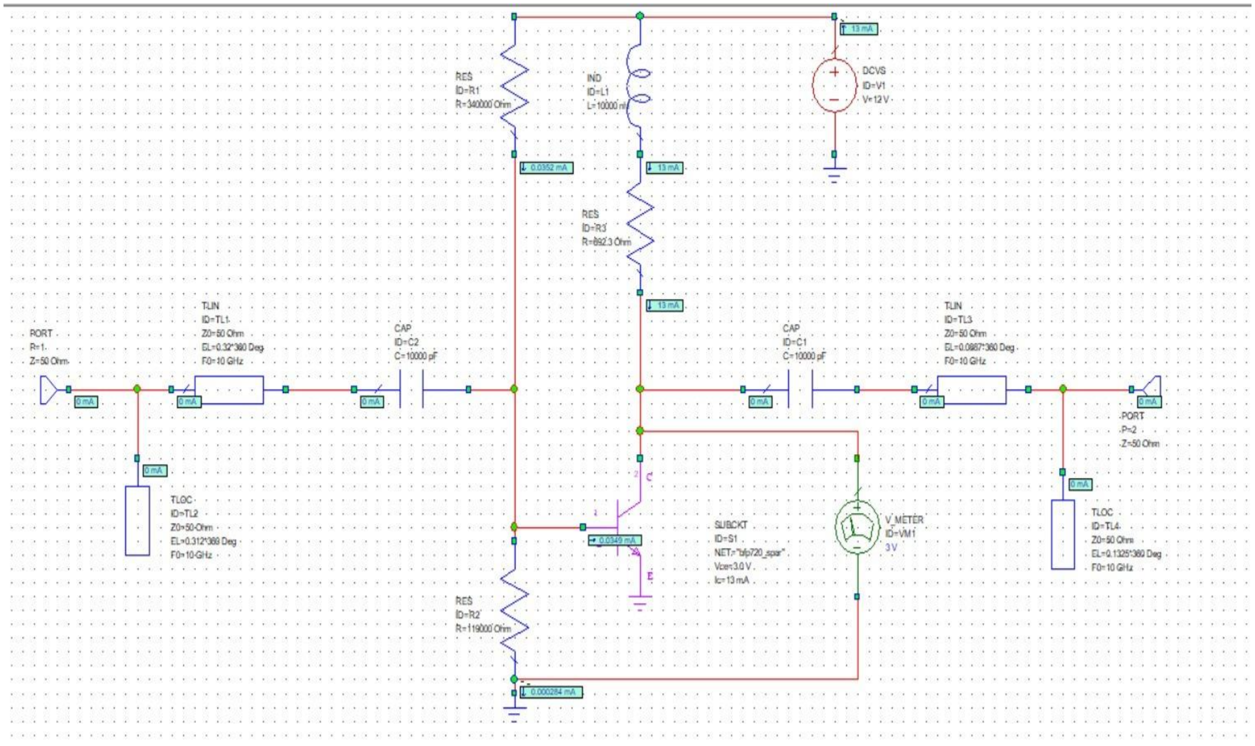

Figure 13. Full LNA Design