ECEN 5104

Two Stage Amplifier

Semester Project

Spring 2000

Reto Zingg

1 Itroduction

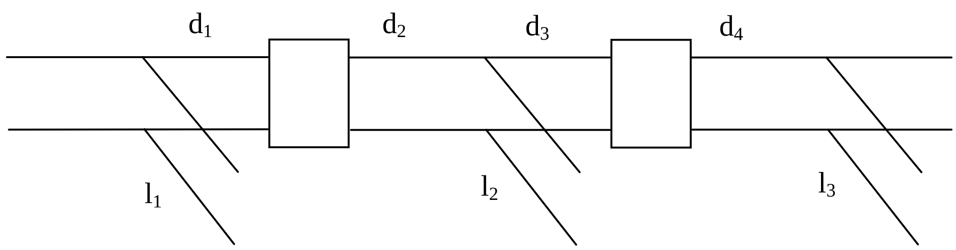
For this term paper a two-stage amplifier has been designed and simulated. Table 1 shows the detailed specifications.

Table 1 Secifications

Center Frequency	8 GHz
Bandwidth	15% (3 dB)
Z_{in}	50 Ω
Z_{out}	50 Ω
Gain	12 dB
Device	HP ATF-26884

2 Problem Analysis

For a maximum gain we would try to match all the sections of the amplifier conjugate complex. But this will result in a narrow bandwidth. To achieve a wider bandwidth, we need to leave the amplifier not perfectly matched. A first design is to match the input with a single parallel stub. The intermediate matching network consists of a length of transmission line, an open parallel stub and again a length of transmission line. The output matching circuit is again a simple single stub matching network.



3 Design

3.1 Bilateral / Unilateral

As the device is not unilateral we calculate the figure of merit and determine of witch order the error is if we assume S_{12} to be zero (unilateral). From (11.47) [1] we get

$$U = 0.15113 \quad \textbf{(3-1)}$$

$$0.755 < \frac{G_T}{G_{TU}} < 1.388 \quad \textbf{(3-2)}$$

or

$$-1.22dB < \frac{G_T}{G_{TU}} < 1.42dB \quad \textbf{(3-3)}$$

This shows that the error is too large to be accepted. Anyway we'll take the unilateral approach and then refine the design.

3.2 Stability

The stability analysis is performed on a single transistor. All S-parameters are taken from the data sheet (see Figure 16, [3]).

Table 2 Parameters of stability circles

Frequency	C_S	R_S	C_L	R_L
2 GHz	1.145 ∠55.4°	0.339	1.790 ∠62.90°	1.224
4 GHz	1.454 ∠106.8°	0.6014	1.673 ∠67.80°	0.8545
6 GHz	1.823 ∠142.9°	0.7865	1.519 ∠70.91°	0.4918
8 GHz	1.935 ∠177.6°	0.9011	1.440 ∠83.29°	0.4189
10 GHz	1.948 ∠-141.8°	0.9567	0.480 ∠149°	0.5331
12 GHz	1.986 ∠-110.5°	1.001	0.490 ∠108°	0.7959

3.2.1 Input

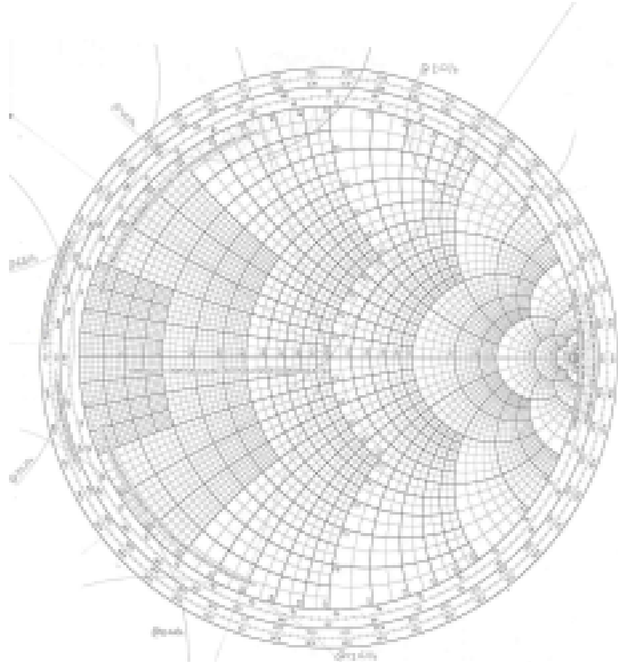


Figure 1 Input Stability

3.2.2 Output

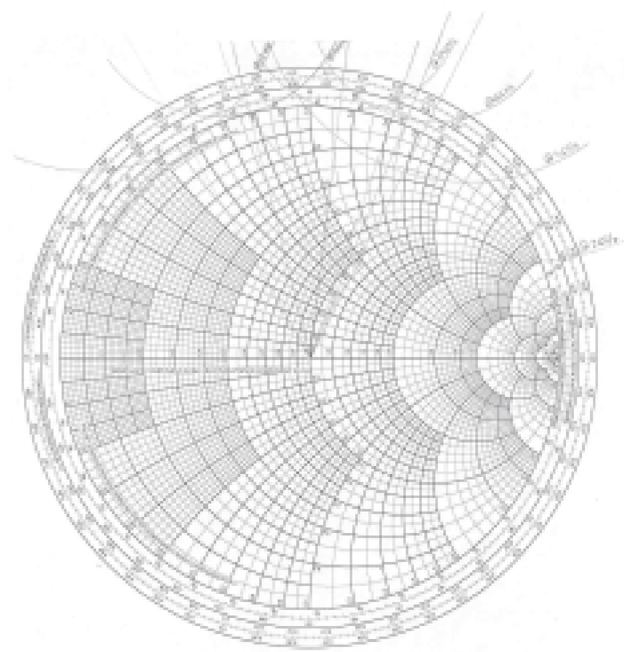


Figure 2 Output Stability

3.3 Matching

The matching design is based on data from the data sheet (see Figure 16, [3]).

3.3.1 Input

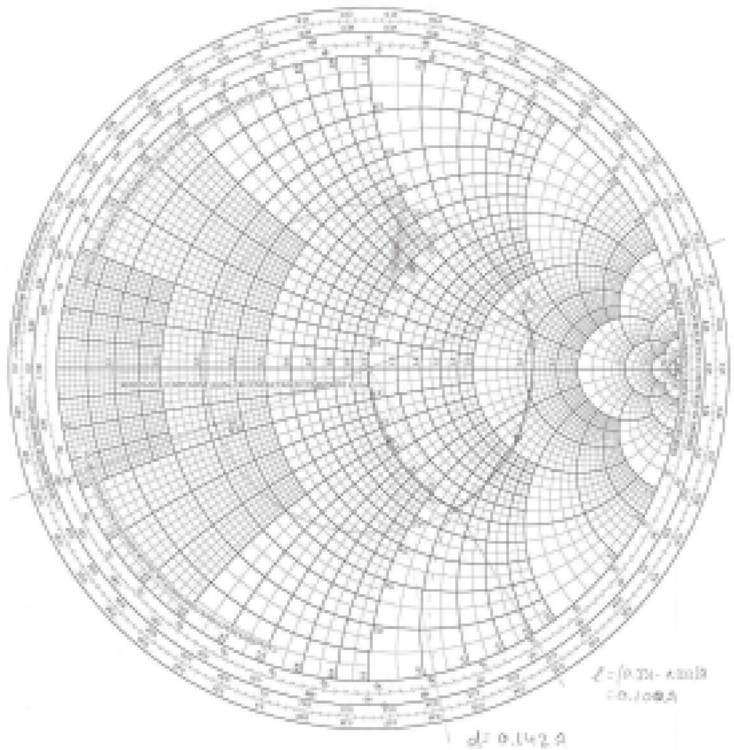


Figure 3 Input Matching

$$
\begin{aligned}
{}_1 &= 0.109 \cdot \lambda \\
d_1 &= 0.142 \cdot \lambda
\end{aligned}
\qquad \textbf{\textit{(3-4)}}
$$

3.3.2 Output

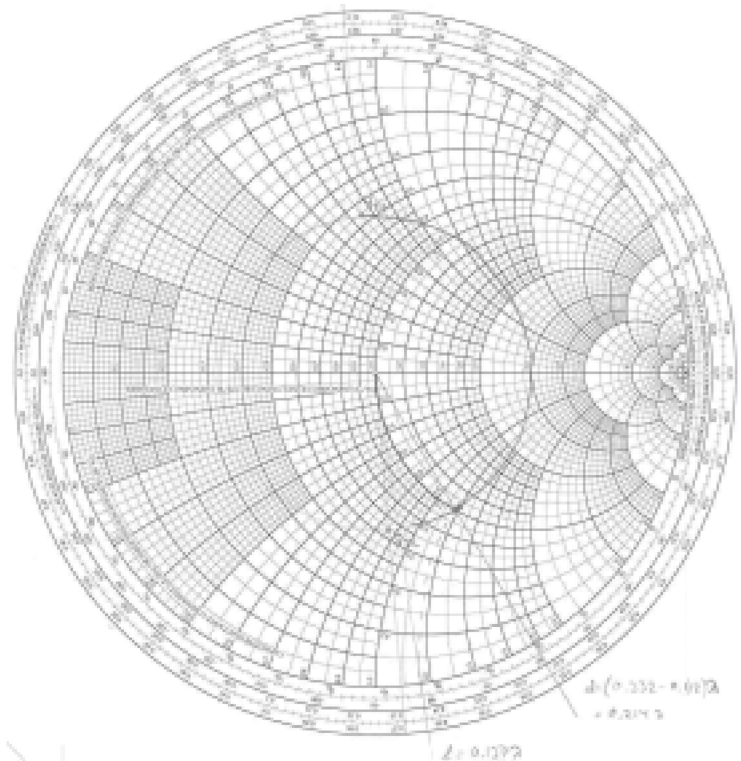


Figure 4 Output Matching

$$
\begin{aligned}
{}_{3} &= 0.137 \cdot \lambda \\
d_4 &= 0.214 \cdot \lambda
\end{aligned}
\qquad \textbf{(3-5)}
$$

3.3.3 Interstage

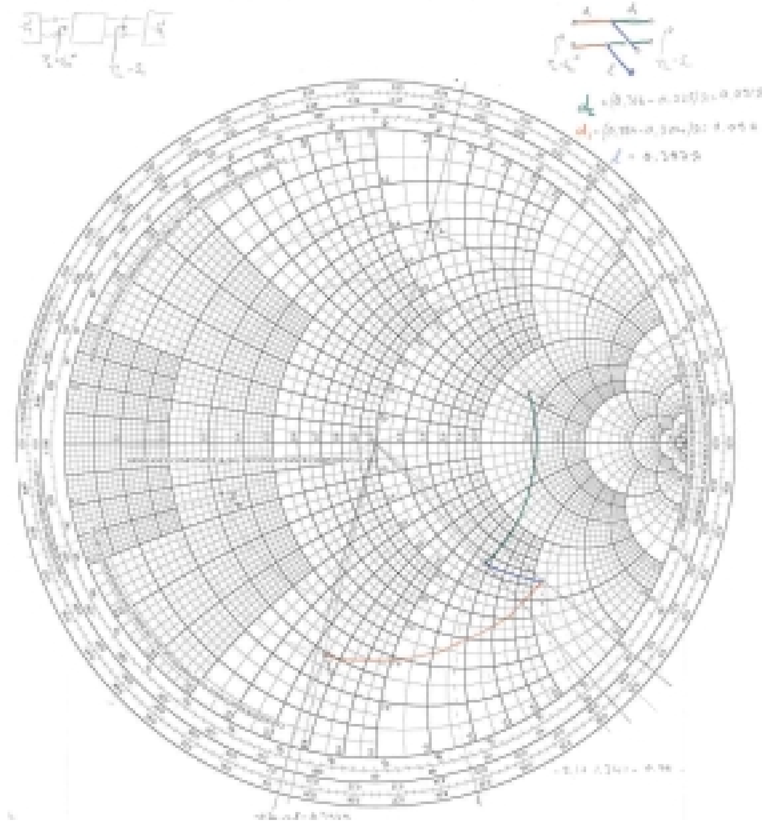


Figure 5 Interstage Matching

$$
\begin{aligned}
{}_{2} &= 0.397 \cdot \lambda \\
d_{2} &= 0.09 \cdot \lambda \\
d_{3} &= 0.09 \cdot \lambda
\end{aligned}
\qquad \textit{(3-6)}
$$

4 Simulation

This first design was used to perform a simulation. As we assumed unidirectionality and the S parameters of the simulation model also don't correspond well to the values from the datasheet the result is expected to be not very accurate.
A substrate of 31 mil thickness and an ε_r of 2.2 was used.
To feed the transistors with their appropriate DC current, a biasing structure had to be added.
Based on these first Parameters, a tuning process was used to achieve the desired values.

4.1 Transistor

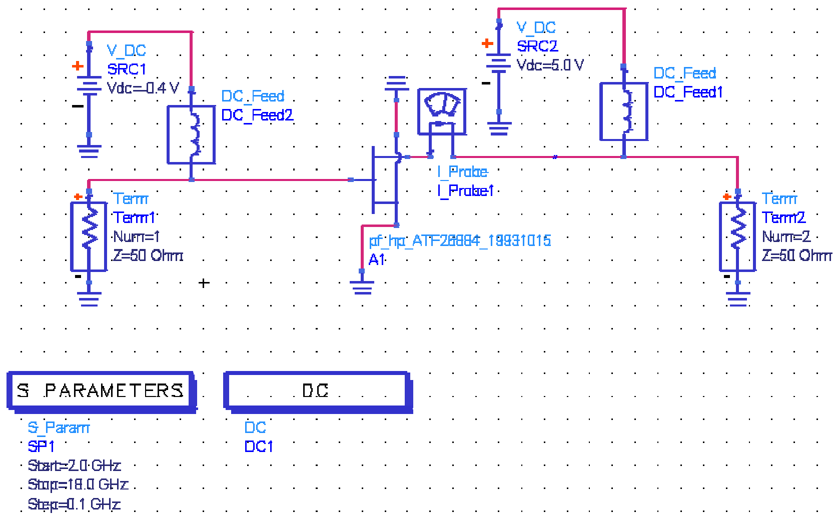


Figure 6 Single Transistor (bias adjustment)

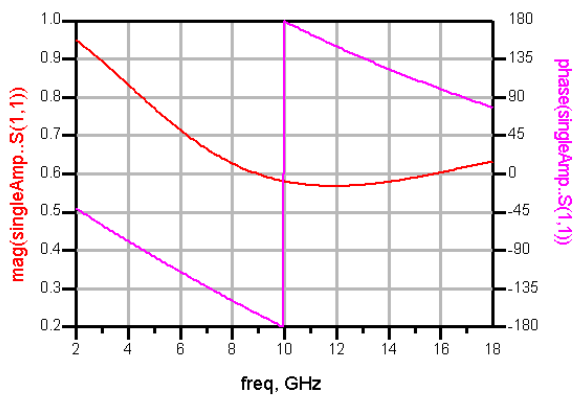


Figure 7 Transistor S_{11}

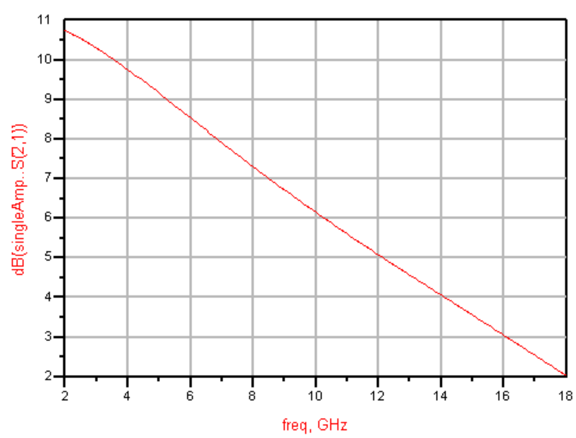


Figure 8 Transistor S_{21}

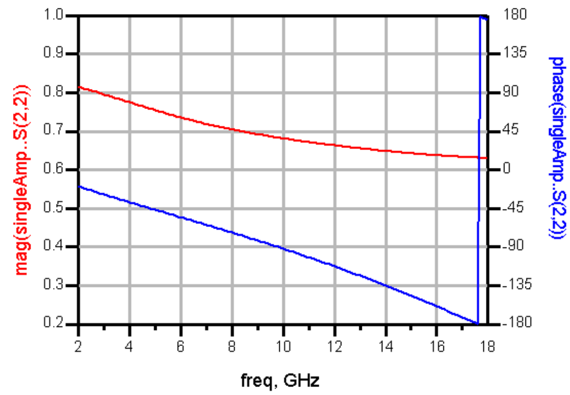


Figure 9 Transistor S_{22}

4.2 Single Stage Amplifier

To be able to compare the performance of the two-stage amplifier first a single stage amplifier was built, simulated and tuned.
As it turned out a single stage amplifier with the chosen device can achieve the desired specification!

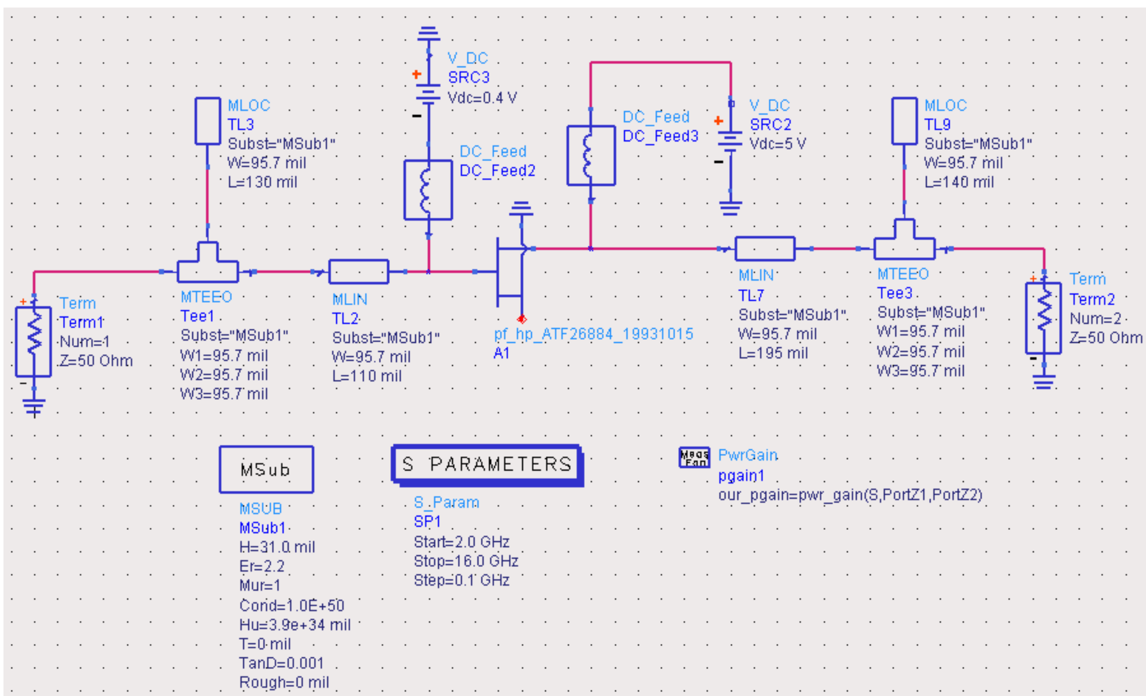


Figure 10 Circuit of the single stage amplifier

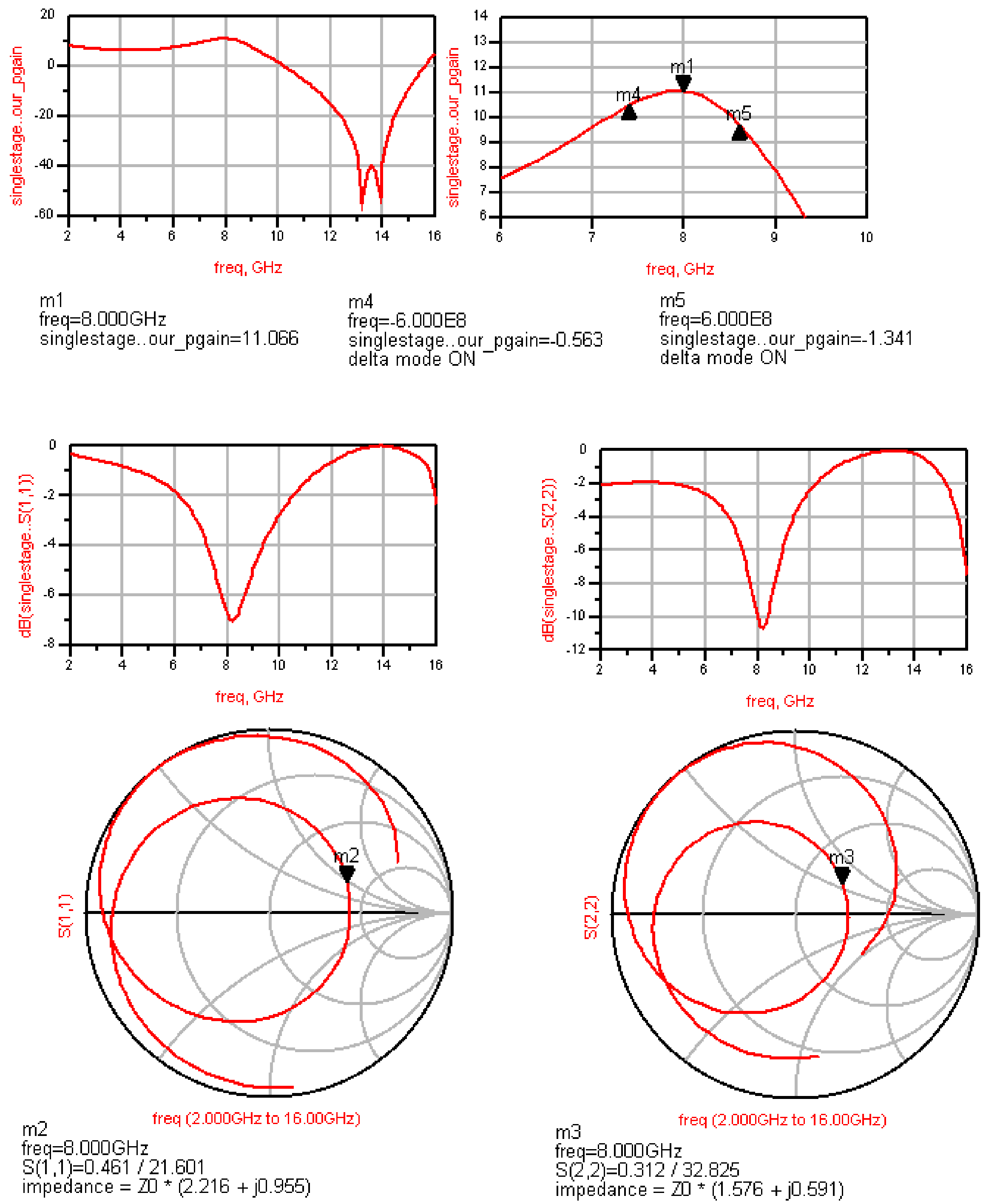


Figure 11 Simulation results from the single stage amplifier

With this design we have a gain of 11.066 dB at 8 GHz and a roll off of –0.563 dB at 7.4 GHz and a roll off of –1.341 dB at 8.6 GHz. This fully satisfies the requirements.

4.3 Two Stage Amplifier

Even though the single stage amplifier satisfies the requirements a two-stage amplifier was built, simulated and tuned. Figure 12 shows the circuit and Figure 15 shows the power gain. A gain of 13.53 dB at 8 GHz, a roll off of –0.057 dB at 7.4 GHz and a roll off of +0.084 dB at 8.6 GHz was achieved.

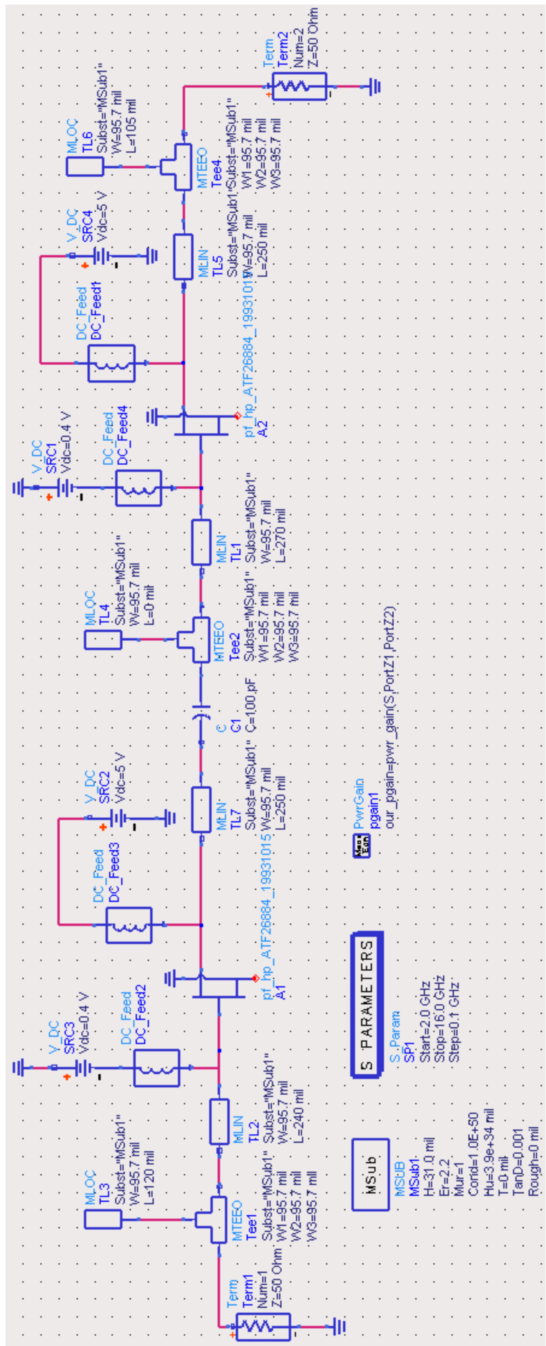


Figure 12 Two-stage amplifier simulation circuit

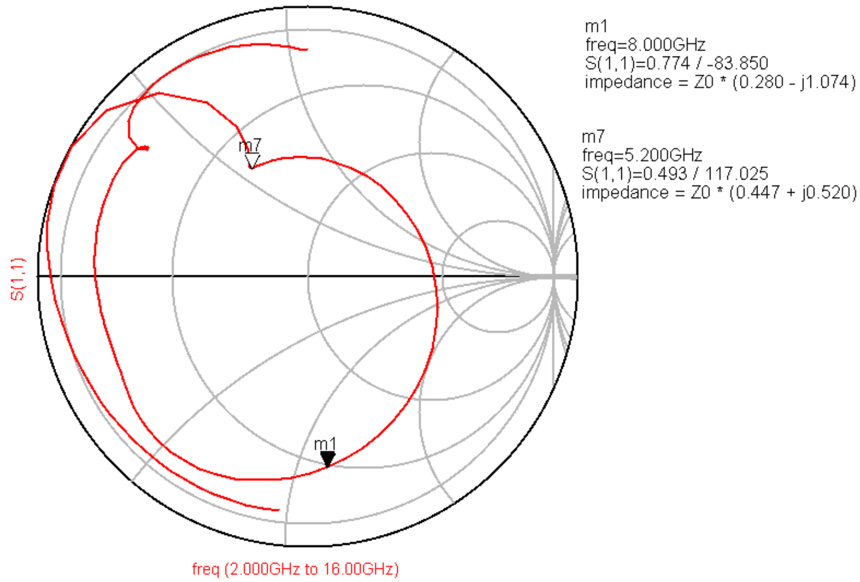


Figure 13 Two-stage amplifier S_{11}

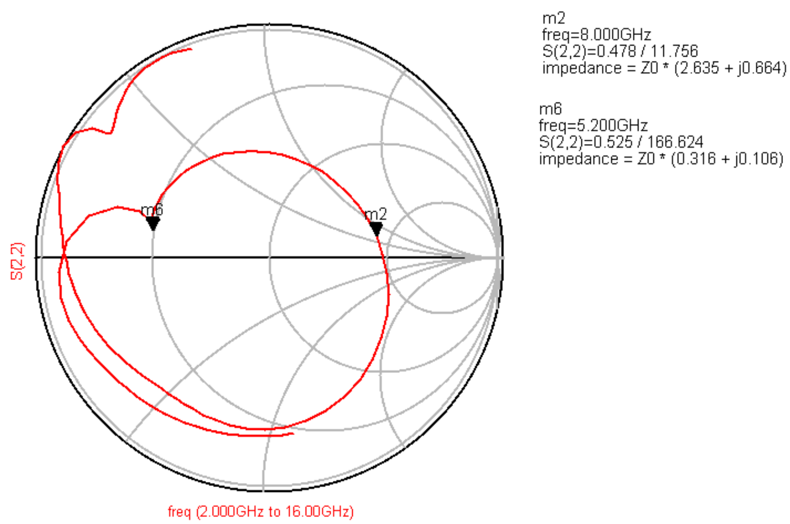


Figure 14 Two-stage amplifier S_{22}

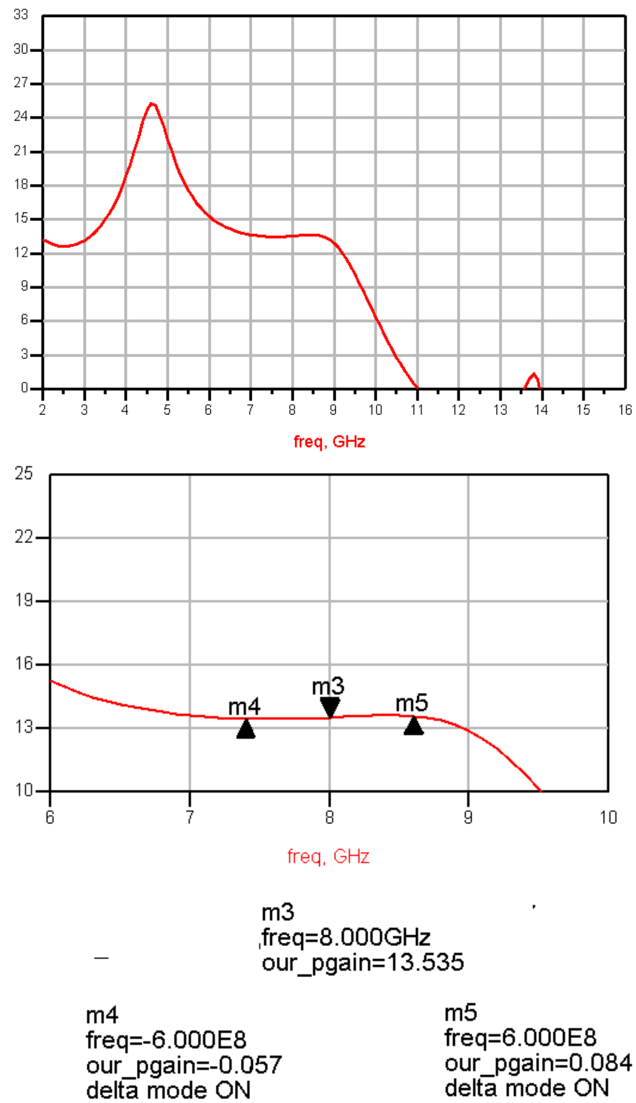


Figure 15 Two-stage amplifier power gain

5 Conclusion

For this project the author tried to design a two-stage amplifier with a simple theoretical approach and using CAD software to refine the design by tuning the design parameters. A good result was achieved, but after tuning the circuit it can not be known if this is the optimum design and how sensitive the design is to manufacturing tolerances.
The use of design rules for two stage amplifiers is desirable.

6 Datasheet

Typical Scattering Parameters, Common Emitter, $Z_O = 50\ \Omega$, $T_A = 25°C$, $V_{DS} = 5$ V, $I_{DS} = 30$ mA

Freq.	S_{11}		S_{21}			S_{12}			S_{22}	
GHz	Mag.	Ang.	dB	Mag.	Ang.	dB	Mag.	Ang.	Mag.	Ang.
2.0	.94	-41	9.2	2.88	138	-30.8	.029	65	.84	-23
3.0	.87	-65	9.5	2.97	118	-27.3	.043	51	.80	-34
4.0	.79	-89	9.3	2.93	97	-25.5	.053	40	.74	-44
5.0	.71	-109	8.7	2.73	79	-24.9	.057	35	.71	-53
6.0	.64	-126	8.1	2.54	64	-24.4	.060	33	.69	-60
7.0	.57	-142	7.5	2.38	50	-24.0	.063	31	.69	-67
8.0	.52	-162	7.2	2.30	35	-23.1	.070	30	.69	-76
9.0	.48	174	6.9	2.21	18	-21.9	.080	28	.67	-87
10.0	.48	149	6.5	2.11	1	-20.4	.095	24	.63	-100
11.0	.48	130	5.9	1.97	-14	-19.7	.104	22	.57	-114
12.0	.49	108	5.6	1.91	-25	-18.1	.125	20	.55	-122
13.0	.53	88	5.2	1.82	-39	-16.2	.155	18	.54	-132
14.0	.57	69	4.7	1.71	-55	-15.2	.173	5	.52	-146
15.0	.62	56	4.1	1.60	-75	-14.8	.182	-1	.52	-165
16.0	.70	44	3.7	1.53	-87	-13.8	.205	-16	.52	165
17.0	.75	33	3.0	1.41	-103	-12.9	.226	-28	.54	135
18.0	.74	24	2.3	1.30	-117	-13.6	.210	-44	.63	114

Figure 16 S-Parameters of ATF-26884 transistor

7 Reference

[1] "Microwave Engineering", David M. Pozar, Second Edition
John Wiley 1998, ISBN 0-471-17096-8

[2] Design of Amplifiers, George D. Vendelin
John Wiley and Son

[3] Agilent ATF-26884 transistor datasheet
http://ftp.agilent.com/pub/semiconductor/rf/4_downld/products/xrs/atf26884.pdf