Project 6

Design of an amplifier based on BJT with LC matching circuits

This project focuses on the design of a narrow-band amplifier with a bipolar transistor and matching circuits created by ideal L and C elements.

Design an amplifier with a BJT and LC-based matching circuits. Your transistor type can be found in the appended table and all files are placed in Libraries – AWR web site –Parts By Vendor –Infineon –High Linearity Si-, SiGe:C-Transistors up to 6 GHz.

As a design protocol note, please include:

- choice of a BJT, bias point and design frequency f_0,
- stability coefficient k ,
- calculate GM1 and GM2 values,
- schematic of matching circuits,
- analysis of the resulting amplifier in the $f_0 \pm 1$ GHz (or wider) frequency band, *i.e.*, plot the absolute values of parameters S_{11}, S_{21}, S_{12} and S_{22}.

List of transistors:

Task No.	Transistor type	Bias point
1	BFP650	3 V, 30 mA
2	BFP650	3 V, 70 mA
3	BFP450	3 V, 50 mA
4	BFP450	3 V, 90 mA
5	BFR380F	3 V, 8 mA
6	BFR380F	3 V, 40 mA
7	BFP760	3 V, 10 mA
8	BFP760	3 V, 30 mA
9	BFR380L3	3 V, 10 mA
10	BFR380L3	3 V, 40 mA

Project solution procedure

The recommended design steps are described in the following example:

- We show the solution for the AT-31625 (Agilent) transistor with a 4.8 V, 50 mA biasing point. Its S-parameters can be found in the T316255A file (which can be found in the Libraries – AWR web site – Parts Obsoleted – Agilent – Data – BJT Data Files library).
- Create a circuit schematic Transistor, drag your transistor into it and connect both PORTs.
- Find the available frequency band of your transistor. It can be viewed using PROJECT – DATA FILES by clicking the left mouse button at the S-parameter filename (the data file can also include noise parameters).

The stability of the transistor used is one of the most important design parameters. Plot stability coefficient k against the available frequency band of your transistor:

- Create a new graph by right clicking on GRAPHS – NEW GRAPH.
- Select Rectangular type and name it Stability.
- As a measurement, define k which can be found in LINEAR – STABILITY – K.
- As a data source, define the file containing the S-parameters of the transistor.
- Run an analysis.
- The best resulting parameters can be obtained using absolutely stable transistors; absolute stability corresponds to $k \geq 1$. In the case of your transistor, choose a design frequency where the condition $k \geq 1$ is fulfilled. In our example (the AT-31625 transistor), the 1 GHz design frequency was chosen, as shown in Fig. 1.
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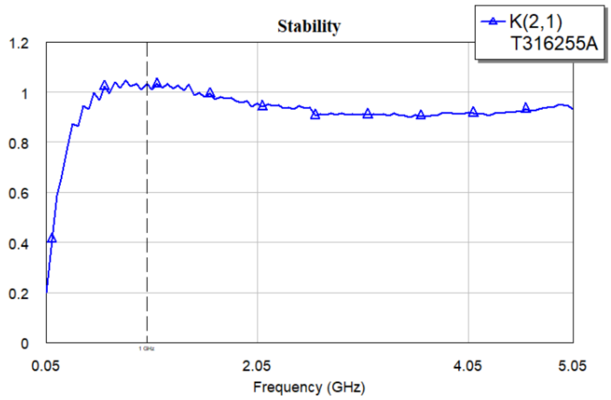

Fig. 1 Stability factor of the AT-31625 transistor.

If the BJT is absolutely stable, optimum reflection coefficient GM1, “seen” by the transistor base, and optimal reflection coefficient GM2, “seen” by the transistor collector, can be calculated:

- The Transistor schematic consists of the BJT and PORTs.
- Using PROJECT OPTIONS set the design frequency (one frequency only). In our example this is 1 GHz.
- Also set the default units of the project as GHz and pF.
- Create a new graph of TABULAR type and name it GM.
- GM1 and GM2 measurements can be found in the LINEAR folder.
- Plot into the table graph: mag(GM1), angle(GM1), mag(GM2) and angle(GM2).
- Set the data source of the measurement of the Transistor schematic.
- Resulting parameters for the AT-31625 transistor at 1 GHz are shown in Fig. 2.

Frequency (GHz)	|GM1(2,1)| Transistor	Ang(GM1(2,1)) (Deg) Transistor	|GM2(2,1)| Transistor	Ang(GM2(2,1)) (Deg) Transistor
1	0.89229	-163.72	0.64625	103.49

Fig. 2 Reflections GM1 and GM2 of the AT-31625 transistor at 1 GHz.

- The calculated GM1 and GM2 values can be verified by connecting two LTUNER elements and the transistor into a new schematic called Ideal Match. The schematic is shown in Fig. 3. The LTUNER, which can be found in the ELEMENTS – GENERAL – PASSIVE – OTHER folder, is a virtual element which transforms 50 Ω impedance to a defined reflection coefficient (Mag, Ang). The input LTUNER renders GM1 and the output LTUNER renders GM2.

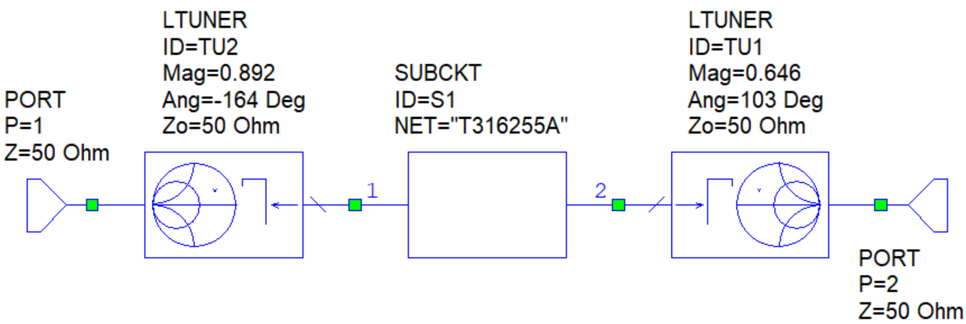

Fig. 3 Schematic of the ideally matched transistor using two LTUNER elements.

- Analyzing the Ideal Match schematic, the amplifier should be ideally matched both at the input and output at the design frequency. The resulting parameters are shown in Fig. 4.

Frequency (GHz)	DB(|S(1,1)|) Ideal Match	DB(|S(2,1)|) Ideal Match	DB(|S(2,2)|) Ideal Match	DB(|S(1,2)|) Ideal Match
1	-30.797	11.896	-31.694	-14.164

Fig. 4 Resulting parameters of the ideally matched transistor using two LTUNER elements.

With GM1 and GM2 values known, it is possible to separately design an input matching circuit, which transforms 50 Ω to GM1, and an output matching circuit, which transforms 50 Ω to GM2. To design both matching circuits, use ideal LC components.

- Create the new schematic Input Match with LTUNER and the GM1* reflection value connected to PORT 1. Also create a new Smith Chart graph and show S_{11} reflection. Both are shown in Fig. 5.

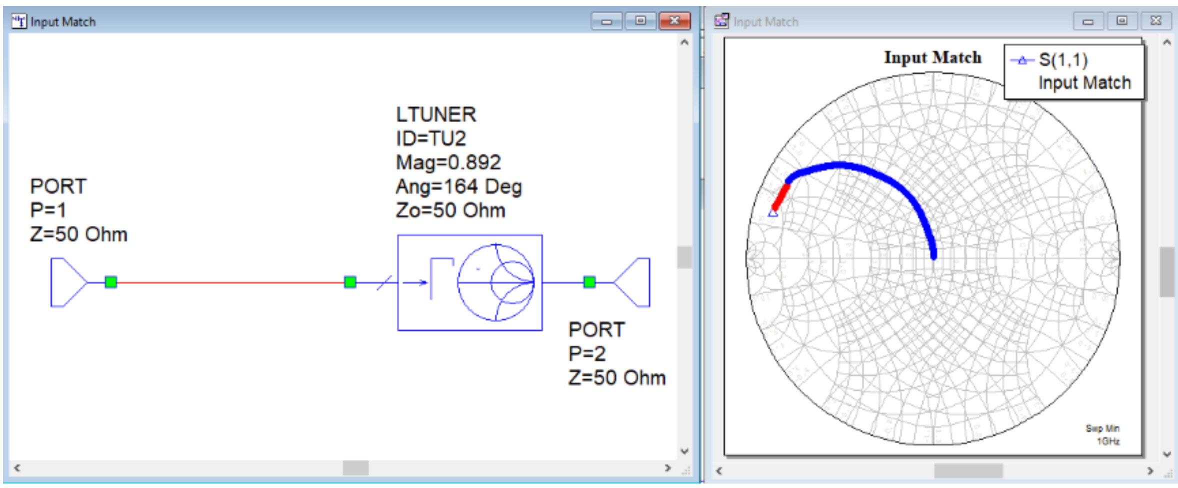

Fig. 5 Schematic with LTUNER with GM1 reflection and a Smith Chart with intended matching.*

- An input matching circuit can be synthesized as a matching circuit placed between the LTUNER and PORT 1 which matches impedance GM1* to 50 Ω. In the Smith Chart in Fig. 5 the red color represents reflection transformation by adding inductance in series and the blue color a capacitor connected in parallel.
- Add both lumped elements and use TUNE TOOL to set their proper values to reach the center of the Smith Chart, as shown in Fig. 6.

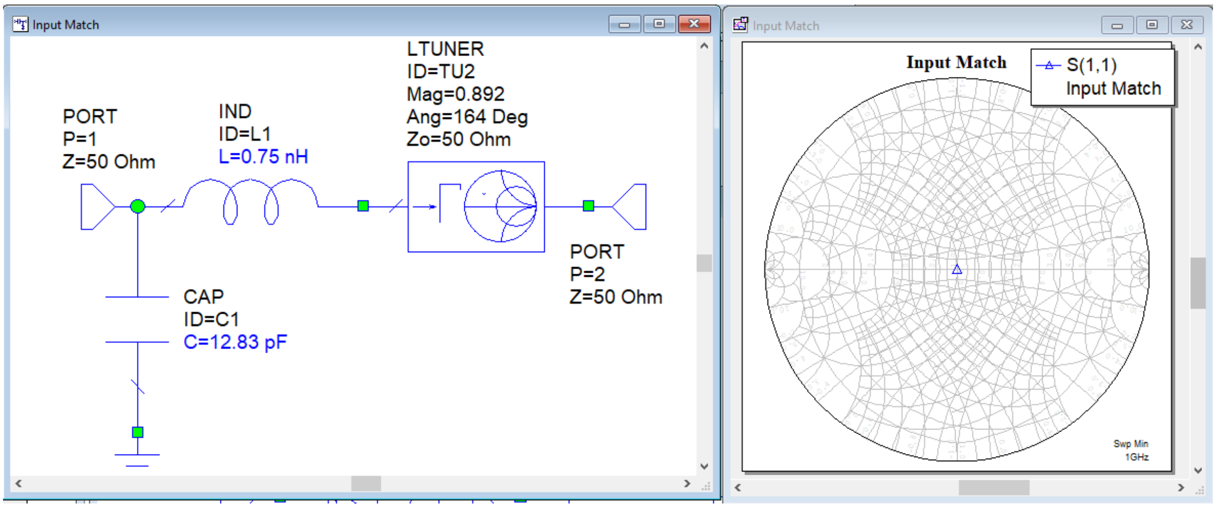

Fig. 6 Input matching circuit and resulting reflection coefficient.

- After finishing the input matching circuit place the LTUNER aside the circuit, so the circuit is not affected, as shown in Fig. 7.

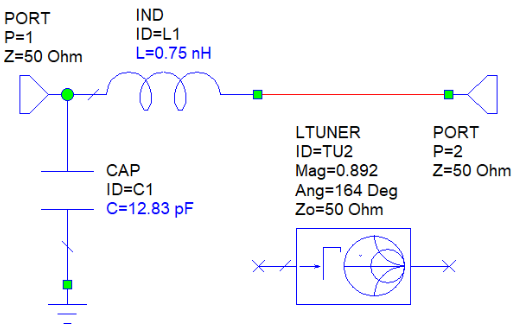

Fig. 7 Input matching circuit.

- In a similar way create an Output Matching schematic and place in it LTUNER with GM2* reflection and two ports, as shown in Fig. 8.

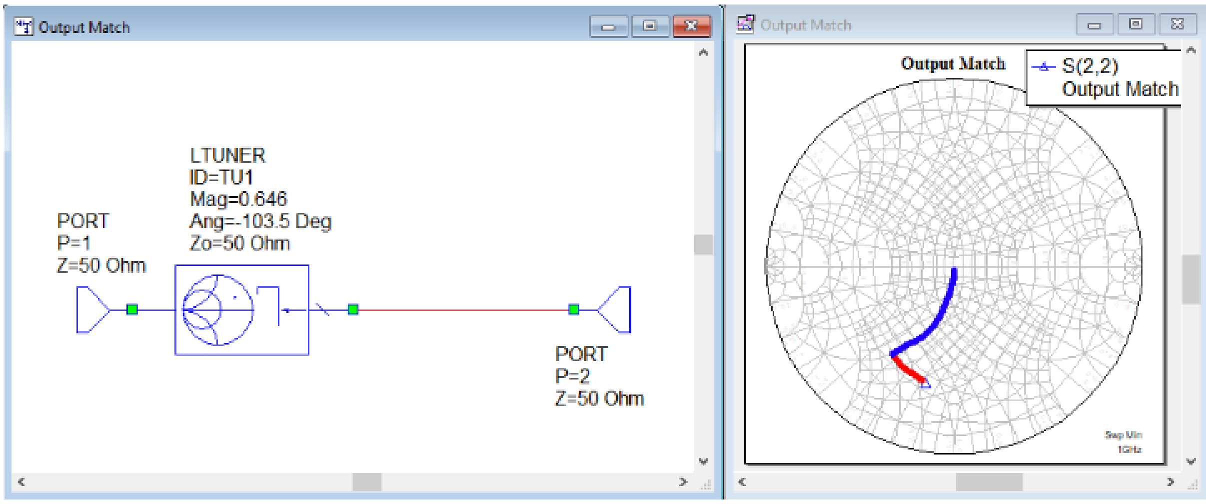

Fig. 8 Schematic with LTUNER with GM2 reflection and a Smith Chart with intended matching.*

- Moving the reflection coefficient to the center of the Smith Chart can be done by, first, connecting the inductor in series (red curve) and the second inductor connected in parallel (blue curve). The matching circuit and resulting reflection coefficient is shown in Fig. 9.

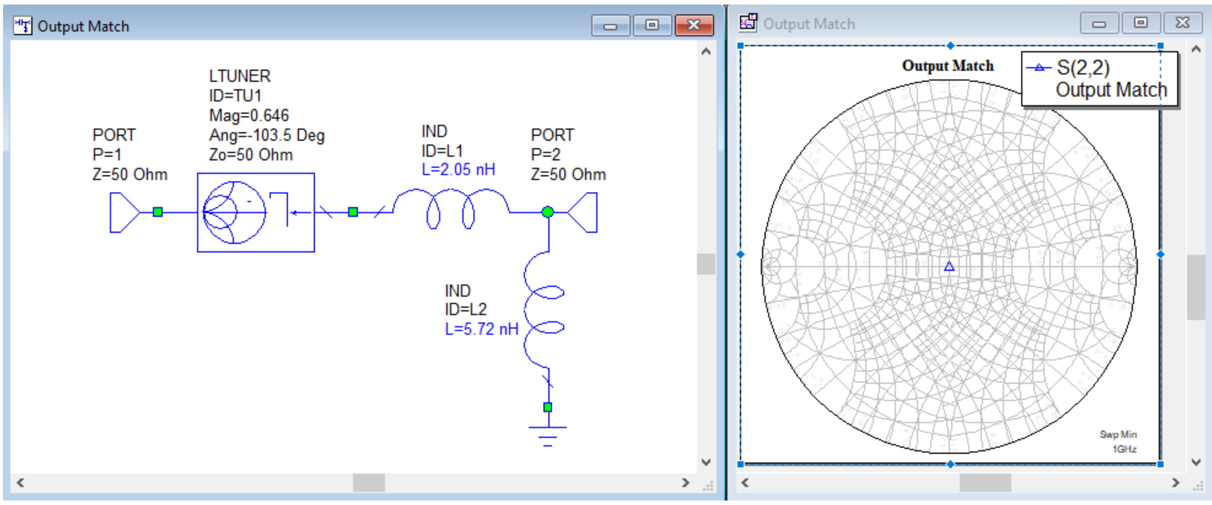

Fig. 9 Output matching circuit and resulting reflection coefficient.

- After tuning the output matching circuit, move the LTUNER element aside to not disturb the circuit.

After designing the input and output matching circuits, it is possible to compile the resulting amplifier and analyze its parameters:

- The resulting amplifier can be compiled using SUBCIRCUITS (folder ELEMENTS, on the bottom).
- Create a new schematic called Amplifier and insert (from the left) the schematics Input Match, Transistor and Output Match, and connect both PORTs. The resulting schematic with subcircuits is shown in Fig. 10.

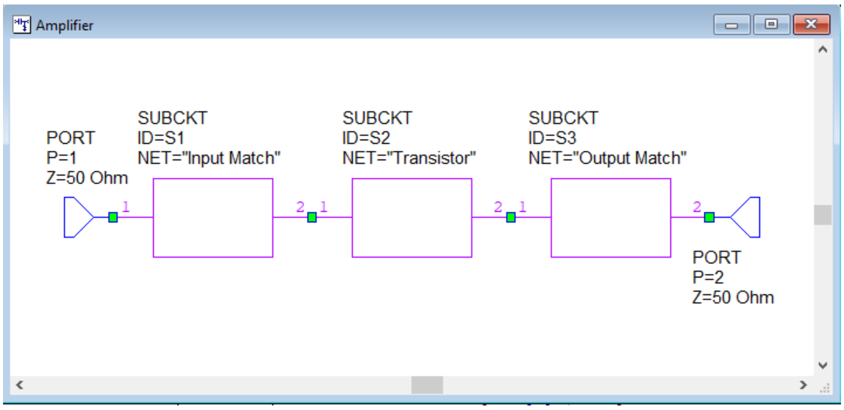

Fig. 10 Schematic of the final amplifier formed by subcircuits.

- Set the frequency band of the project from 0.1 to 3 GHz, step 0.05 GHz.
- Create a new graph of rectangular type and add the measurements from the Amplifier schematic dB(abs(S11)), dB(abs(S21)), dB(abs(S12)) and dB(abs(S22)). Perform an analysis of the resulting amplifier. Results corresponding to our example can be seen in Fig. 11.

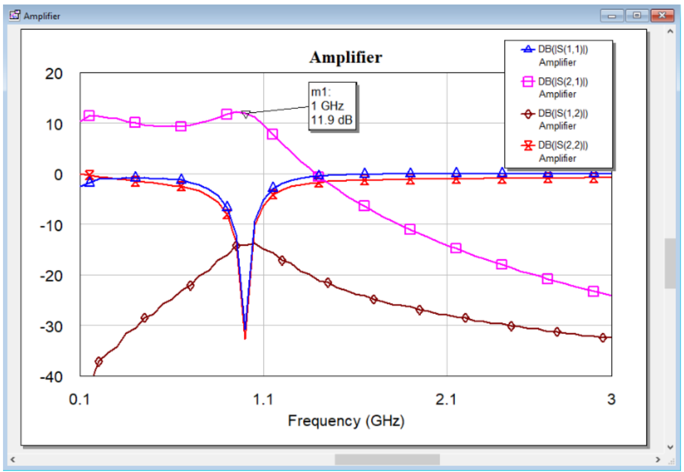

Fig. 11 Resulting parameters of the final amplifier.

- The resulting amplifier is ideally matched (*RL* < −30dB), both at the input and output, and its gain is 12 dB which is the maximum available.