Project 8

Design of an amplifier with a potentially unstable FET transistor and LC matching circuits

This project focuses on the design of a narrow-band amplifier consisting of a potentially unstable FET and matching circuits from L and C elements.

Design two amplifiers based on a microwave FET. Find its type and operating frequency in the appended table.

As a design protocol note, please include:

A conditionally stable amplifier includes:
- a chosen FET and design frequency f_0,
- stability coefficient k of the transistor,
- stability circle Γ_L and a chosen gain circle,
- a solved stability problem in the output plane (with or without output matching circuit),
- a schematic of the final amplifier with matching LC circuit(s),
- S-parameters of the final amplifier in $f_0 \pm 50\%$ frequency band.

An absolutely stable amplifier includes:
- stability coefficient k of the transistor before and after stabilization,
- a calculated GM1 and GM2,
- a final schematic,
- final S-parameters in $f_0 \pm 50\%$ of the frequency band.

Transistor data can be found in: Libraries − AWR Web Site – Parts by Vendor – Avago – Data − FET – ATFxxxxx – MDIF.

Task No.	FET type	Design frequency (GHz)	Bias Point
1	ATF33143	3.6	3 V, 40 mA
2	ATF58143	1.7	3 V, 60 mA
3	ATF54143	2.2	4 V, 40 mA
4	ATF36163	7.6	2 V, 20 mA
5	ATF35143	5.7	4 V, 60 mA
6	ATF34143	1.9	3 V, 40 mA
7	ATF33143	3.0	3 V, 40 mA
8	ATF58143	1.7	3 V, 60 mA
9	ATF54143	2.2	4 V, 40 mA
10	ATF36163	8.1	2 V, 20 mA
11	ATF331H4	2.7	2 V, 40 mA
12	ATF531P8	2.1	4 V, 40 mA
13	ATF551M4	16.2	3 V, 20 mA
14	ATF34143	2.4	3 V, 40 mA
15	ATF35143	4.4	4 V, 60 mA
16	ATF331H4	3.2	2 V, 40 mA
17	ATF531P8	2.8	4 V, 40 mA
18	ATF551M4	5.1	3 V, 20 mA
19	ATF331H4	2.7	2 V, 40 mA
20	ATF531P8	1.8	4 V, 40 mA

Project solution procedure

The recommended design process is described by the following example:

- The ATF36077 (Agilent) transistor with a 1.5 V, 10 mA biasing point. The corresponding S-parameter data file is ATF36077_1P5V_10mA.s2p. The file can be found in Libraries – AWR Web Site – Parts by Vendor – Avago – Data – FET – ATF36077 – SPARAM library.
- At the 10 GHz design frequency, the transistor is potentially unstable. The stability problem will be solved in the output plane. The required matching circuits should be based on ideal LC elements.
- Create a new schematic called Transistor, load your transistor and connect both ports.

Plot the frequency dependence of stability coefficient *k* as a function of frequency (use the entire frequency band of your transistor):

- Create a new rectangular graph called Stability and add the measurement of stability factor *k* (Linear – Stability – K). The data source is the S-parameters file.
- Perform an analysis the results of which are to be shown in Fig. 1.
- Potential instability corresponds to the condition $k < 1$. Check if your transistor corresponds to this condition (if it is stable, contact your teacher).

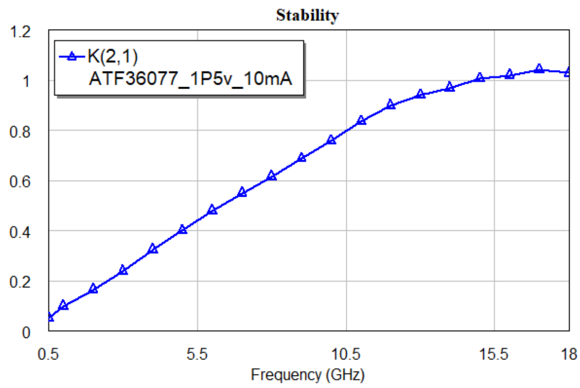

Fig. 1 Stability factor of the ATF-36077 transistor.

In our example $k = 0.74$ at 10 GHz, and the transistor is, therefore, truly, potentially unstable. An amplifier at 10 GHz based on this transistor cannot be simultaneously matched at both ports. Treat the stability problem in the output Γ_L plane (there can be a substantial reflection at the output) and ensure ideal impedance matching at the input:

- The maximum stable gain *MSG* is the decisive parameter for designing amplifiers with a potentially unstable transistor. Calculate the *MSG* of your FET (source schematic Transistor) at the design frequency.
- In PROJECT OPTIONS set a design frequency, 10 GHz in our example.
- Create a new graph of Tabular type.
- Plot *MSG* in dB into the table. It can be found under Liner – Gain – MSG.
- In our example at 10 GHz: *MSG* = 16.38 dB.
- The operational gain of the resulting amplifier must be about 1 – 3 dB lower than the *MSG* (otherwise $\Gamma_{in} = 1$ or $\Gamma_{out} = 1$). In our example, the operational gain should be somewhere between $G = 15$ dB and $G = 14$ dB.
- In parallel, it is necessary to solve the stability problems in the Γ_L plane. Stability can be ensured by finding a suitable Γ_{LZ} value in a stable region.
- For finding optimum transistor loading, it is necessary to plot an output stability circle (SCIR2) and constant power gain circle (GPCIR, gain 14 – 15 dB) into the Γ_L plane.
- Create a new graph of Smith Chart type and, at 10 GHz, plot the above stated circles which can be found in Liner – Circles. The 15 dB version can be seen in Fig. 2.

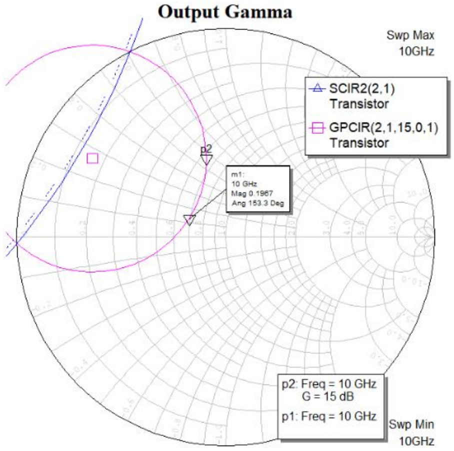

Fig. 2 Output stability circle and constant power gain circle.

- Suitable Γ_{LZ} loading must lie in the stable region (outside the blue stability circle) and on the red gain circle. Usually, the point closest to the center of the Smith Chart is chosen. In our example, $\Gamma_{LZ} = 0.2\angle 153º$ can lead to reasonable results. The output matching circuit should transform 50 Ω to this value.
- Another interesting version can be seen in Fig. 3. GPCIR corresponds to a 14 dB gain in this case.

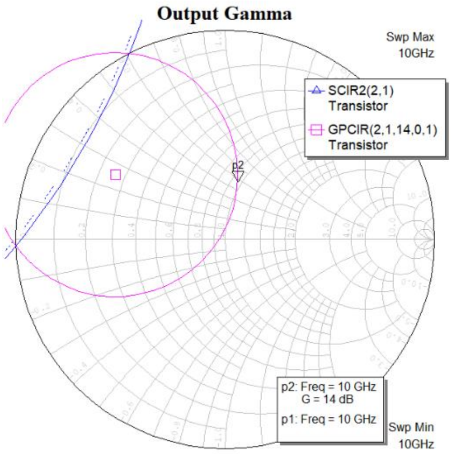

Fig. 3 Output stability circle and constant power gain circle crossing a 50 Ω load impedance.

- The GPCIR circle runs, in this case, approx. through the center of the Smith Chart. That is why $\Gamma_{LZ} = 0$ loading can be chosen and no output matching circuit is necessary.

Input and output matching circuits can now be designed. At first, the *G* = 14 dB and $\Gamma_{LZ} = 0$ case will be solved:

- There is no matching circuit at the output, the transistor is connected directly to the 50 Ω load. It is necessary to design the input matching circuit only.
- Create a new schematic Amplifier and place the Subcircuit Transistor in it. Also add both ports.
- In order to derive a suitable LC structure, plot S_{11} (source schematic Amplifier) into the Smith Chart, see Fig. 4.

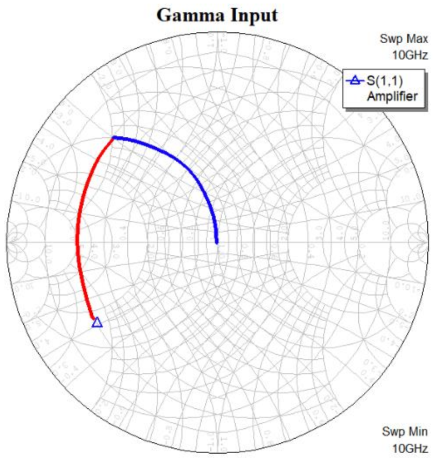

Fig. 4 Input reflection of a transistor with 50 Ω load and input matching circuit design procedure.

- In our example, the S_{11} point lies inside the g = 1 circle. That is why the matching circuit must start with an in-series connected element. In the first step, a series inductance was used and the impedance point was transformed to the g = 1 circle (red line).
- In our example, L1 = 0.55 nH inductance is required.
- From g = 1 it is possible to transform the input impedance to the Smith Chart's center using parallel capacitance C1 = 0.64 pF (blue curve). Use TUNE TOOL for these transformations. The resulting amplifier schematic can be seen in Fig. 5.

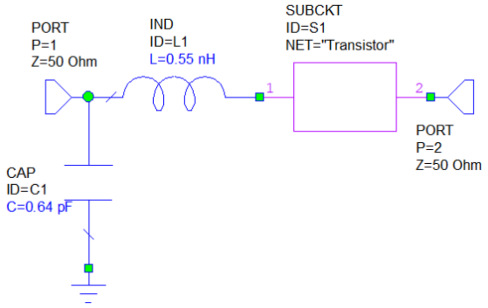

Fig. 5 Final schematic of the amplifier.

- Change the frequency range of the project to f_0 ± 50% and simulate the final amplifier parameters, see Fig. 6.

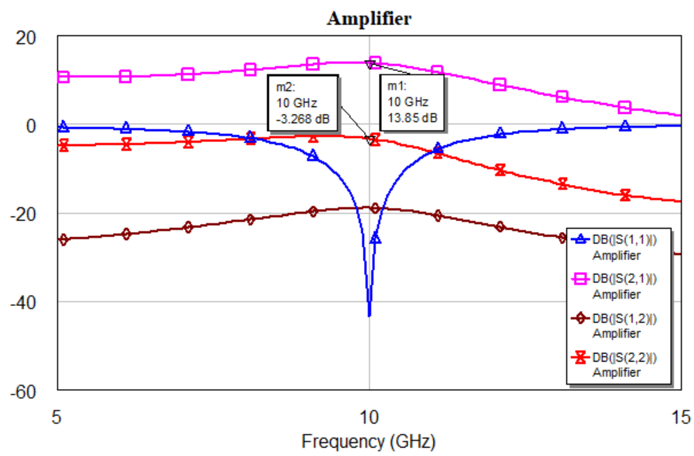

Fig. 6 S-parameters of the amplifier.

- At design frequency 10 GHz, the gain is 13.85 dB, and the amplifier is ideally matched at input. The output reflection is -3.3 dB, which is a consequence of using the potentially unstable transistor. The designed amplifier is conditionally stable.

The main advantage of the above-described solution is the fact that the amplifier does not have any output matching circuit and is, therefore, simpler and smaller. Nevertheless, this solution is not always applicable. In our example, when using the 15 dB-gain-circle, reflection coefficient $\Gamma_{LZ} = 0.2\angle 153º$ can represent a corresponding output loading. In this case, the output matching circuit transforms 50 Ω to $\Gamma_{LZ} = 0.2\ \angle 153º$ and the input matching circuit transforms 50 Ω to Γ_1.

- At first, the input matching circuit can be designed. Create a new schematic, add the Subcircuit Transistor, element LTUNER (can be found in ELEMENTS – GENERAL – PASSIVE – OTHER) to the output of the transistor and both ports. See Fig. 7.

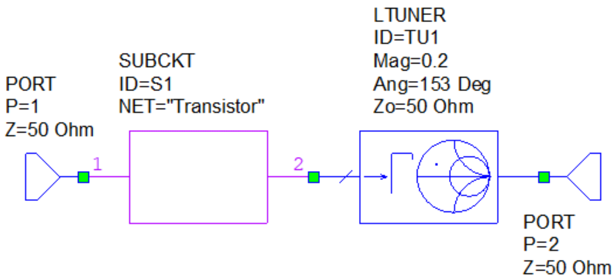

Fig. 7 Transistor loaded with an ideal load to produce gain 15 dB.

- Set the LTUNER to produce reflection $\Gamma_{LZ} = 0.2\angle 153º$ and show S_{11} of this circuit in the Smith Chart as shown in Fig. 8.

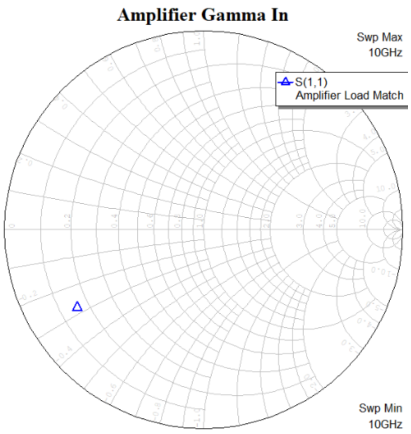

Fig. 8 Input reflection coefficient of the circuit from Fig. 7.

- The position of $S_{11} = \Gamma_1$ in the Smith Chart enables the employment of the same matching circuit as in the previous case (generally, it can be different). The resulting parameters are: L2 = 0.51 nH, C2 = 0.74 pF, as shown in Fig. 9.

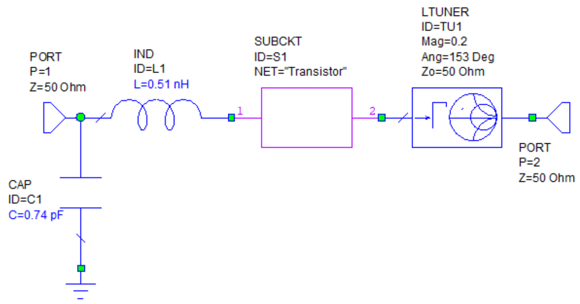

Fig. 9 Transistor with ideal output matching and designed input matching.

- It is necessary to design the output matching circuit separately. Again, use the LTUNER for this design. Create a new schematic and place the LTUNER there with values set to Γ^*_{LZ} = 0.2∠-153º. The matching procedure of S_{22} to 50 Ω is shown in Fig. 10.

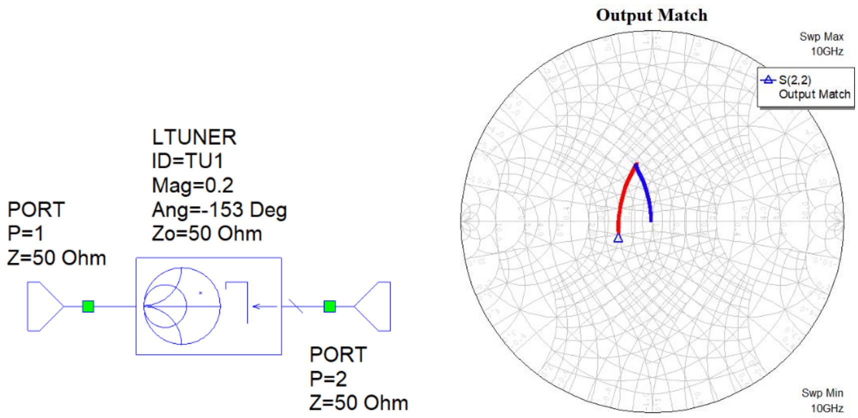

Fig. 10 Design procedure of the output matching circuit.

- The first element is a serial inductor (red curve) and the second is a parallel capacitor (blue curve). After the matching circuit is done move the LTUNER to the side of the circuit. The resulting structure can be seen in Fig. 11.

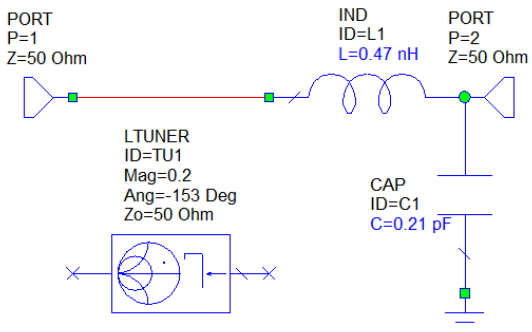

Fig. 11 Output matching circuit.

- Compile the resulting amplifier using sub-circuits. The resulting parameters of the final amplifier can be seen in Fig. 12.

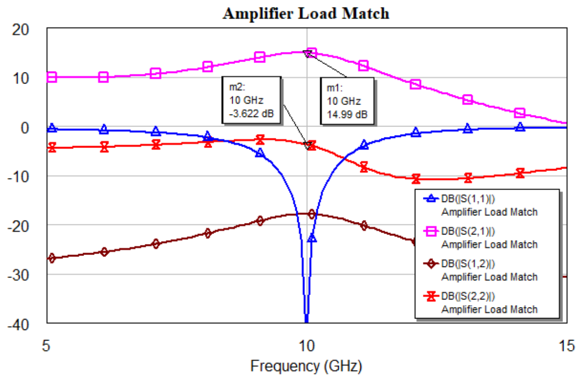

Fig. 12 Resulting S-parameters of the amplifier.

- The gain is 15 dB, meaning it is very well matched at the input, but the high reflection at the output results from using a potentially unstable transistor.
- The designed amplifier is conditionally stable.

As has been already stated, conditionally stable amplifiers cannot be matched simultaneously at both ports. In addition to this, under specific conditions, they can oscillate (and, in the case of power amplifiers, self-destruct). That is why the manufacturing and practical employment of conditionally stable amplifiers is problematic and why the stabilization of used transistors used, and subsequent design of absolutely stable amplifiers, can be recommended. To do so, use the following design steps:

- Create a new schematic and place your transistor there. Then connect ONE of the resistors (NOT all) as shown in Fig. 13.

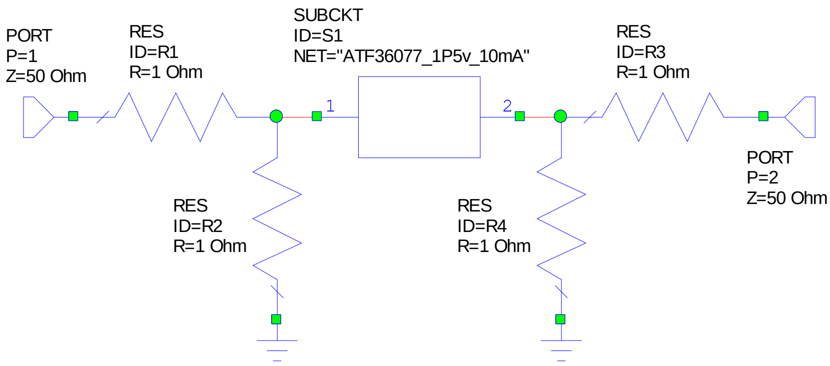

Fig. 13 All possible resistors potentially solving the instability of the transistors.

- In the case of FETs, the R1 resistor is usually suitable.
- Create a new rectangular graph and show stability factor *k*.
- Using TUNE TOOL, change the R1 value to set *k* in interval from 1.1 to 1.2 (not more) at the design frequency as shown in Fig. 14.

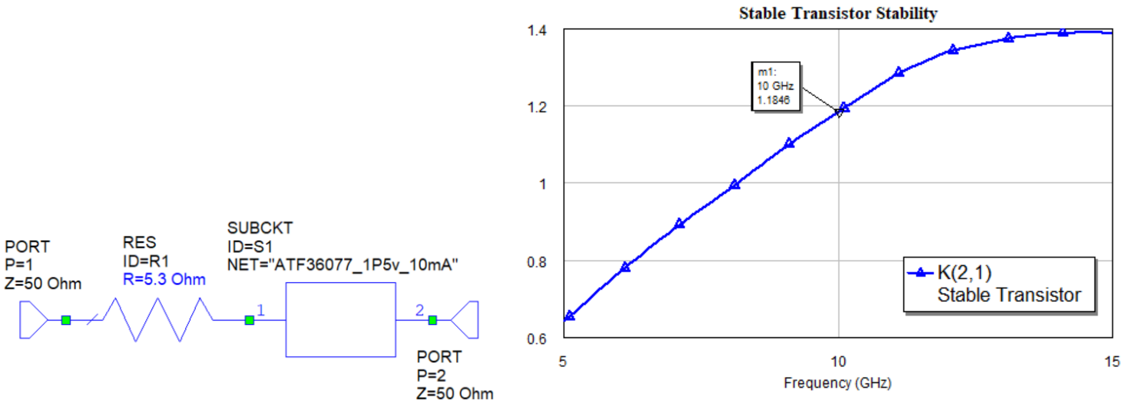

Fig. 14 Stabilized transistor with R1 resistor.

- In our example, R1 = 5.3 Ω leads to *k*=1.2 which is satisfactory.
- In the subsequent design, you can use the combination transistor+stabilizing resistor as a new absolutely stable transistor and then design an absolutely stable amplifier with simultaneous impedance matching both at the input and output.
- For designing matching circuits, the GM1 and GM2 parameters were calculated at design frequency 10 GHz as shown in Fig. 15.

Frequency (GHz)	|GM1(2,1)|[51] Stable Transistor	Ang(GM1(2,1))[51] (Deg) Stable Transistor	|GM2(2,1)|[51] Stable Transistor	Ang(GM2(2,1))[51] (Deg) Stable Transistor
10	0.7389	154.9	0.64848	139.66

Fig. 15 Calculated GM1 and GM2 parameters.

- Synthesize the input and output matching circuits using LC components.
- The resulting amplifier can be seen in Fig. 16.

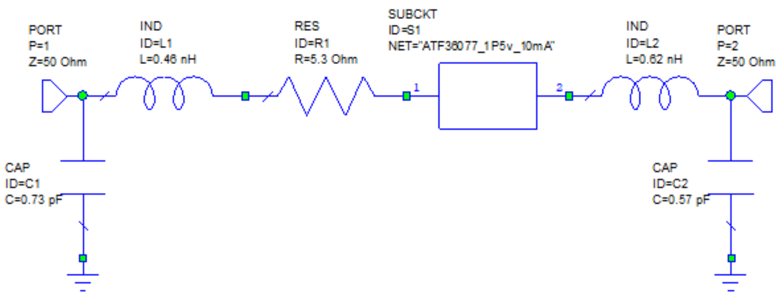

Fig. 16 Schematic of the final absolutely stable amplifier.

- The resulting parameters are shown in Fig. 17.

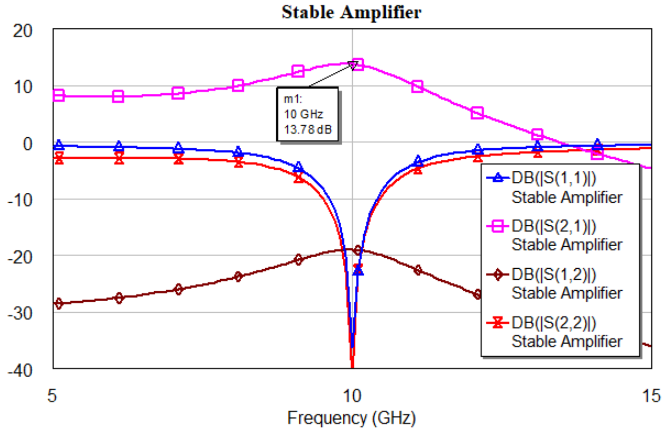

Fig. 17 S-parameters of the amplifier from Fig. 16.

- The amplifier's gain is 13.8 dB, which is only slightly lower than the gain of the conditionally stable amplifier. This amplifier is absolutely stable and ideally matched both at the input and output.