Laboratory 5 (w11-14)

2020/2021

Microwave Devices and Circuits

MDC Project

Assignment

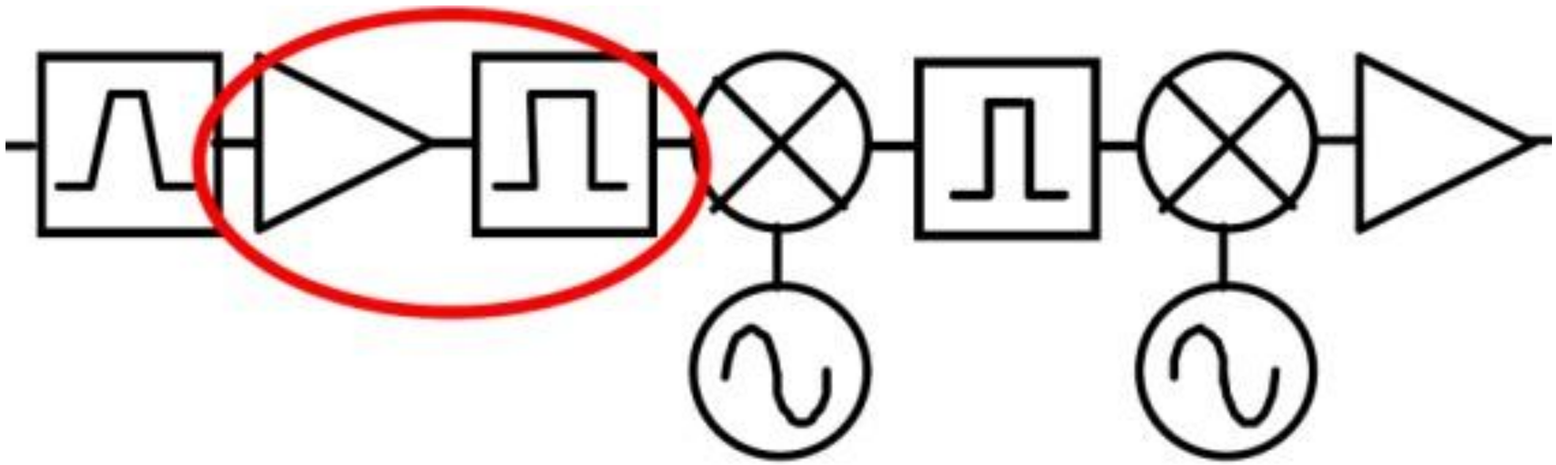
- Design a low-noise multi-stage transistor amplifier required to provide a power gain of **G [dB]** and a noise factor of **F [dB]** at the design frequency **f [GHz]**.
- At the output of the amplifier insert a order **N** bandpass filter with fractional bandwidth of the passband **B [%]** around the design frequency.

Assignment

- The matching networks and filter must be implemented with transmission lines (stubs: L7-L8).
- The use of the transistors we used in lectures and laboratories examples is not permitted (NE 71084, ATF 34143)
- Delivery deadline: last day of the semester (06.06.2021, 23:59:59)

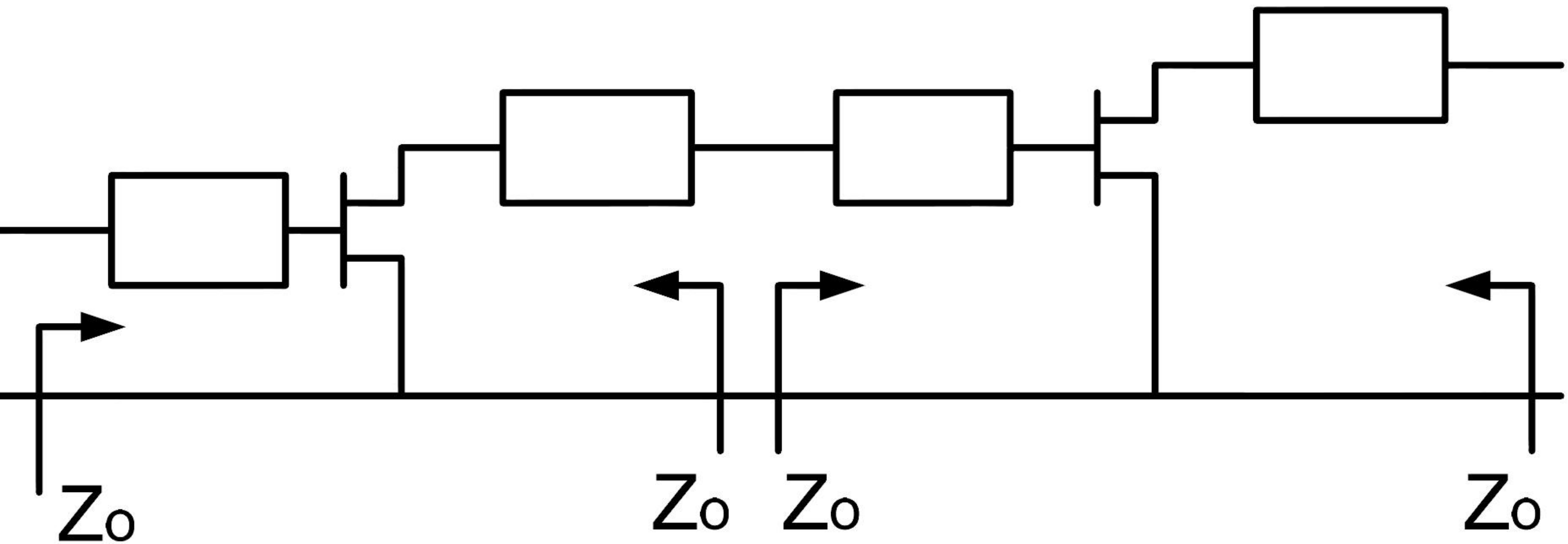
Assignment

- this structure is frequently encountered in radiocommunication systems

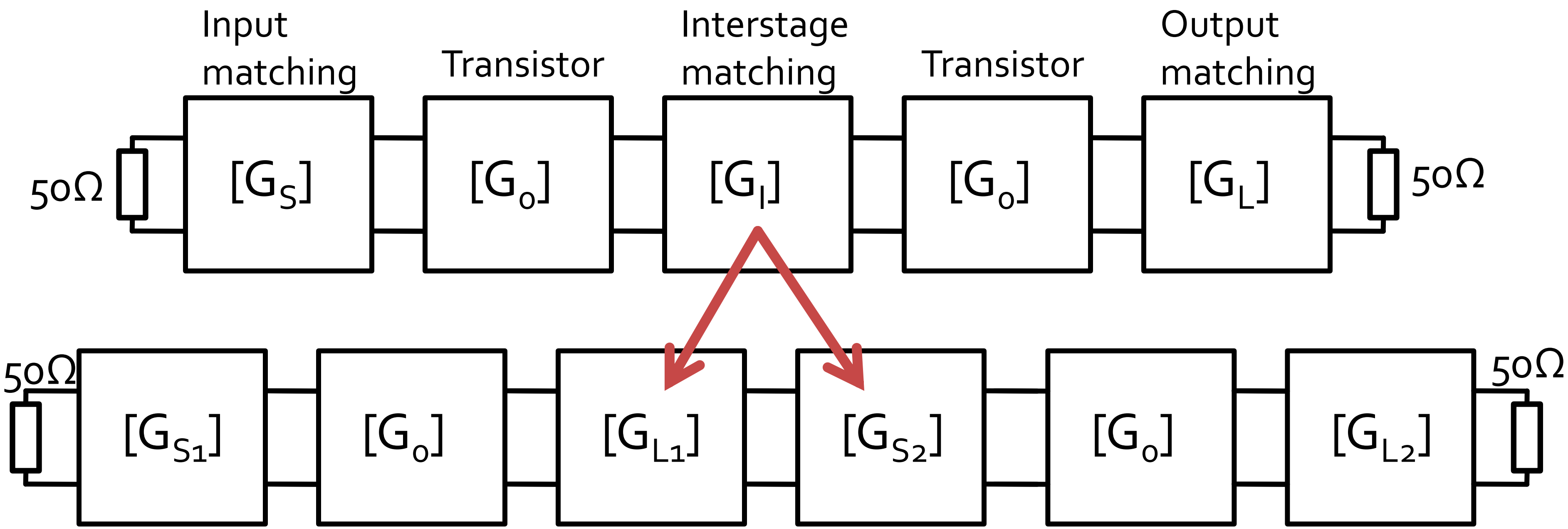


Multistage amplifiers

- Interstage matching can be designed in two modes:
  - Each stage is matched to a virtual Γ = 0



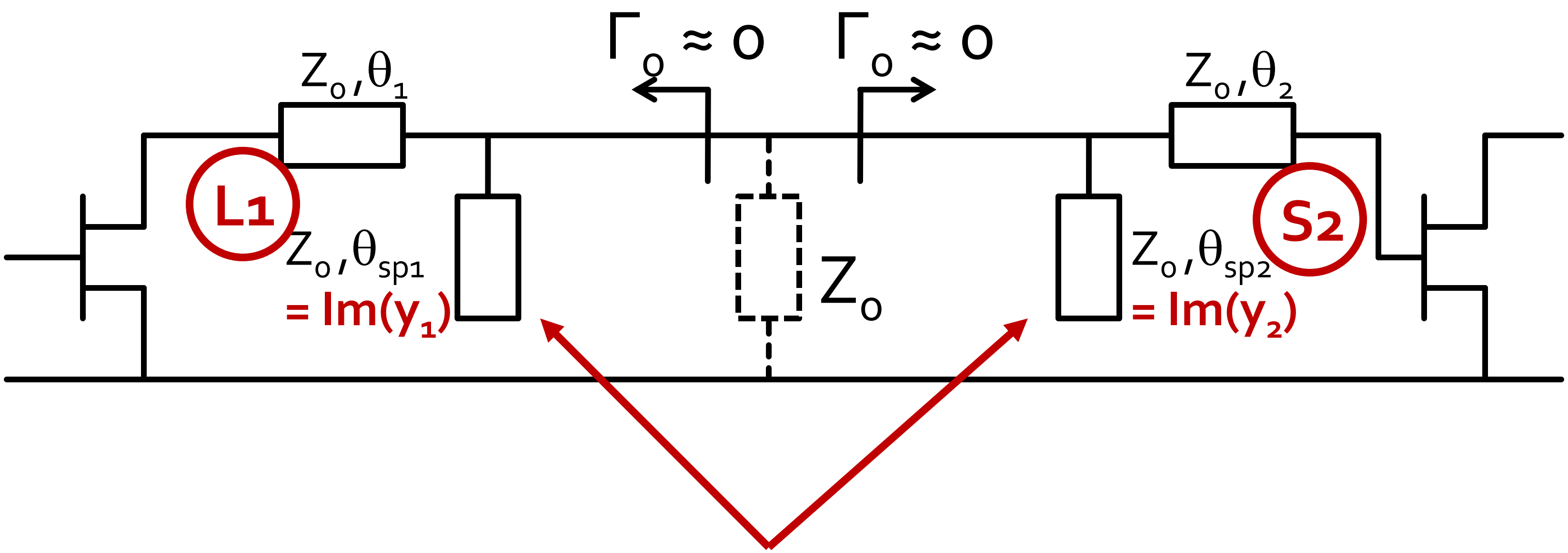
Multistage amplifier design



- The design for input and output matching must be achieved on a single transistor schematic (recommended: easier)

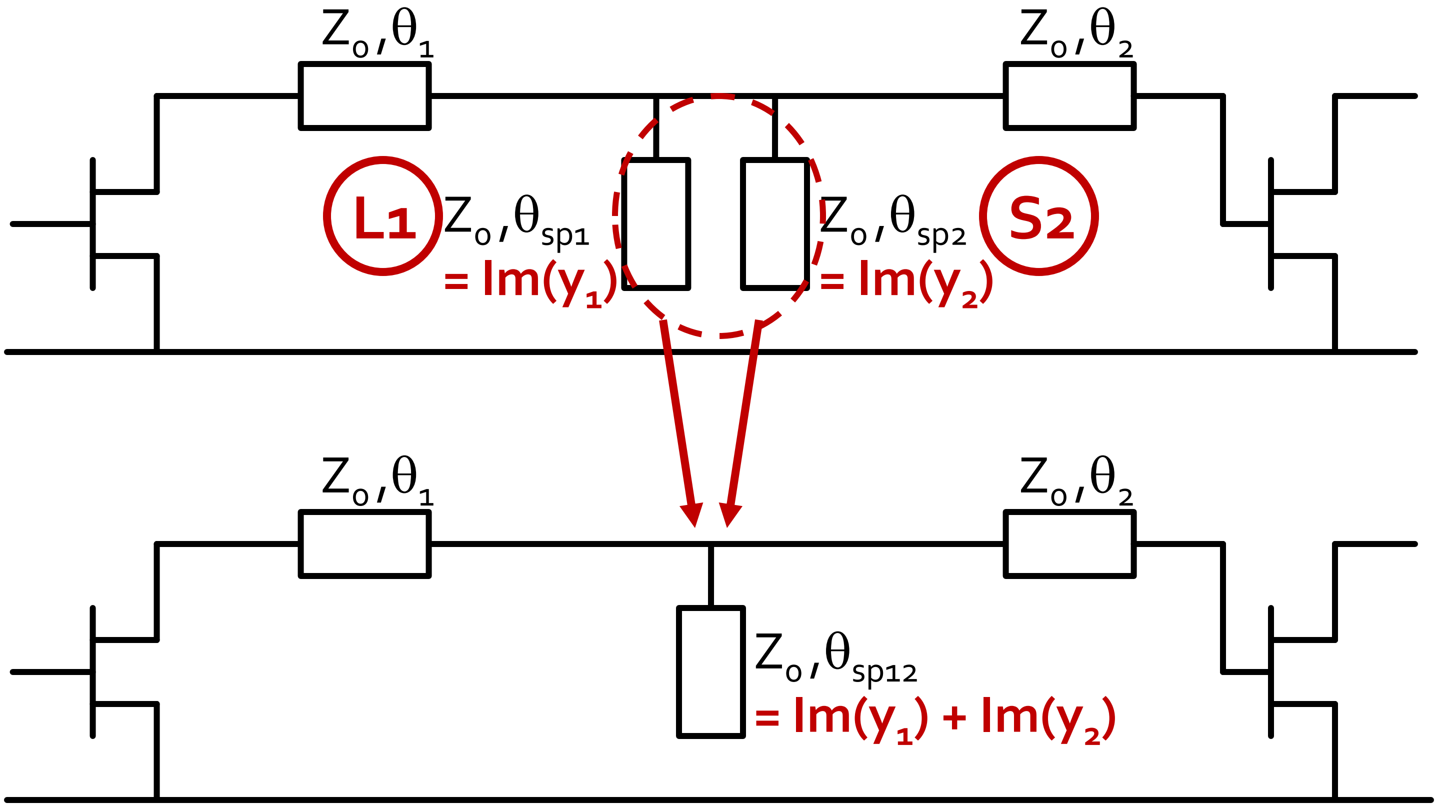
Interstage matching

- One of the stages creates through its matching network a refflection coefficient Γ=o towards which the other stage is matched



Interstage matching

- The two shunt stubs combine into a single one



Step - 1

- Split performance parameters on the 2 stages
  - G
  - F
- Uses Friis formula
- Pt. 3 example

$$G_{cas} = G_1 \cdot G_2 \qquad\qquad F_{cas} = F_1 + \frac{1}{G_1}\left(F_2 - 1\right)$$

- 2 equations, 4 unknowns, multiple solutions

Friis Formula (noise)

$$G_{cas} = G_1 \cdot G_2 \qquad F_{cas} = F_1 + \frac{1}{G_1}\left(F_2 - 1\right)$$

- Friis formula
  - first stage: low noise factor, probably resulting in a smaller gain
  - second stage: high gain, probably resulting in higher noise factor
- It's essential to introduce a design margin (reserve: ΔF, ΔG)
  - $G = G_{design} + \Delta G$
  - $F = F_{design} - \Delta F$
- Interpretation of the design target
  - $G > G_{design}$, better, but it's not required to sacrifice other parameters to maximize the gain
  - $F < F_{design}$, better, the smaller the better, we must target **the smallest possible noise** factor as long as the other design parameters **are met**

Friis Formula (noise)

- Friis formula
  - first stage: low noise factor, probably resulting in a smaller gain
  - second stage: high gain, probably resulting in higher noise factor
- Division between the two stages (Estimated!)
  - input stage: F1 = 0.7 dB, G1 = 9 dB
  - output stage: F2 = 1.2 dB, G2 = 13 dB
- To verify the result apply Friis formula
- First transform to **linear scale !**

$$F_1 = 10^{\frac{F_1[dB]}{10}} = 10^{0.07} = 1.175 \qquad G_1 = 10^{\frac{G_1[dB]}{10}} = 10^{0.9} = 7.943$$

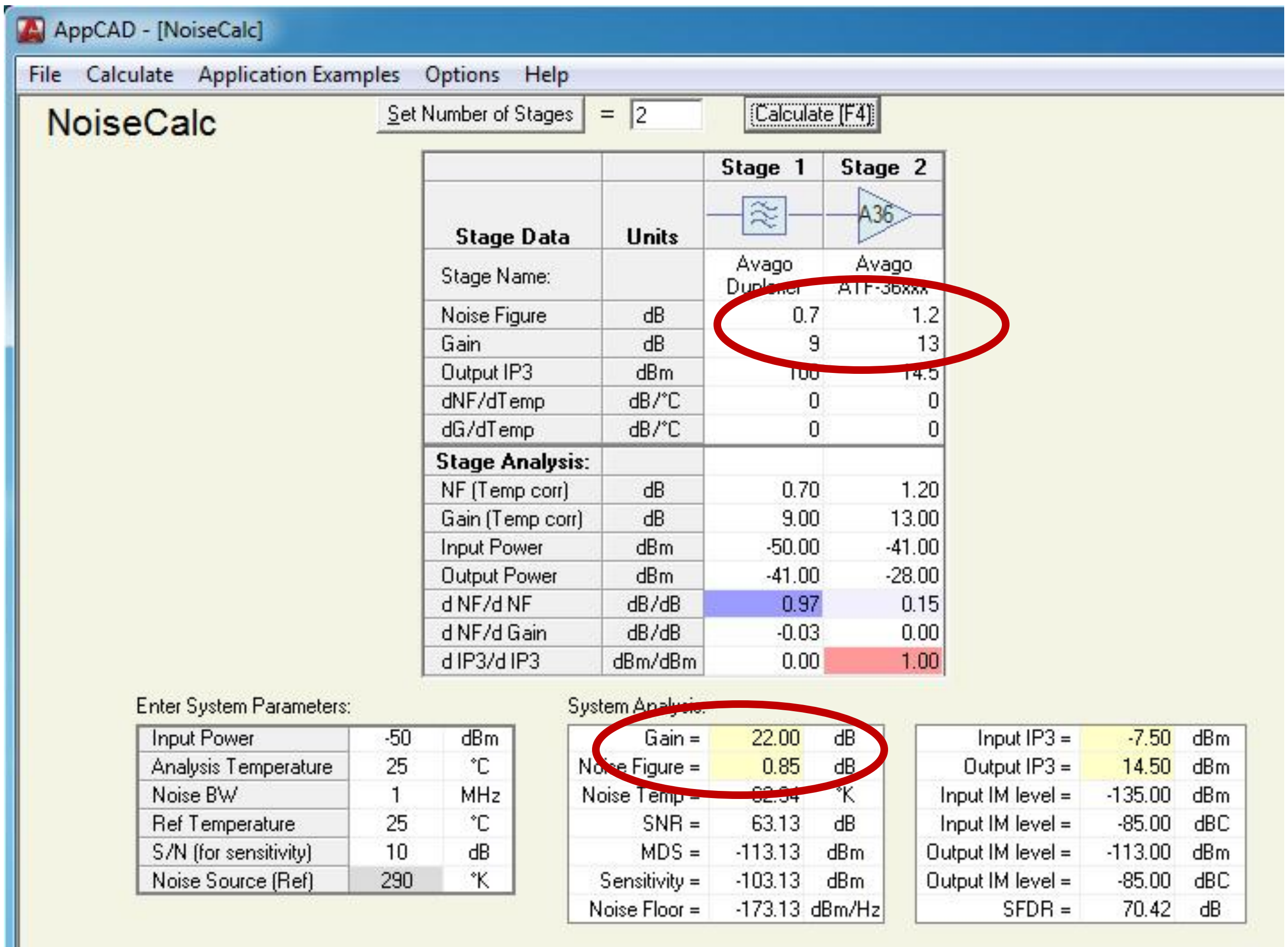
$$F_2 = 10^{\frac{F_2[dB]}{10}} = 10^{0.12} = 1.318 \qquad G_2 = 10^{\frac{G_2[dB]}{10}} = 10^{1.3} = 19.953$$

$$F_{cas} = F_1 + \frac{1}{G_1}(F_2 - 1) = 1.215 \qquad G_{cas} = G_1 \cdot G_2 = 158.49$$

$$F_{cas} = 10 \cdot \log(1.215) = 0.846\ dB \qquad G_{cas} = 10 \cdot \log(158.49) = 22\ dB$$

Friis Formula (noise)

- Avago/Broadcom AppCAD



Step - 1

- Result:
  - first amplifier **G_1/F_1**
  - second amplifier **G_2/F_2**

Step - 2

- Choose appropriate transistor(**s**) (Gi/Fi)
- Time consuming
- Depending on the design frequency :
  - bipolar
  - unipolar
- Starting from selection guides **recommended**
- Pt. 5 example

Step - 2

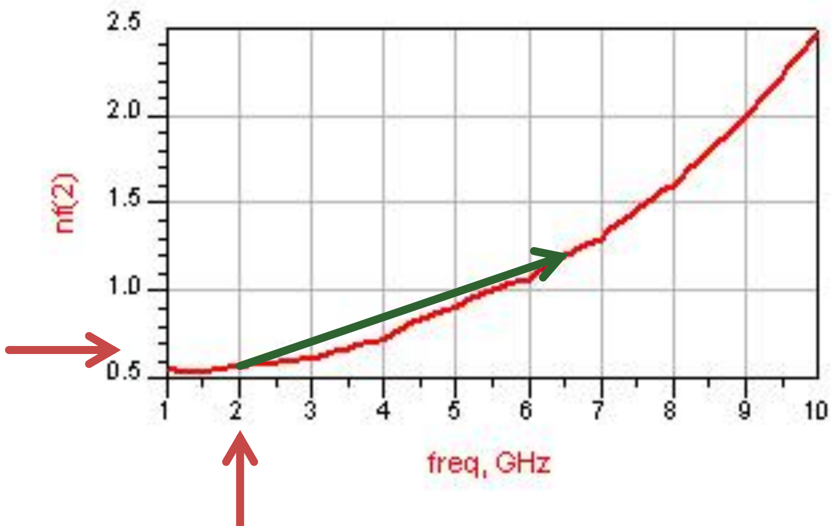
- Few selection guides available on rf-opto
- -> Google: microwave/rf transistor, low noise, LNA

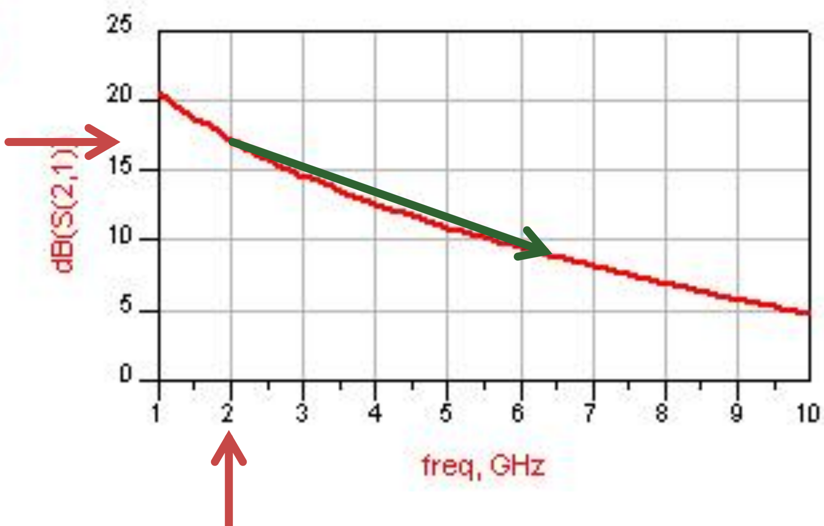
Low Noise pHEMTs (Typical Specifications @ 25°C Case Temperature)

Part Number	Gate Width (µm)	Frequency Range (GHz)	Test Freq. (GHz)	V_{dd} (V)	I_{dd} (mA)	NF_o (dB)	G_a (dB)	OIP3 (dBm)	$P_{1\,dB}$ (dBm)	Package
ATF-33143	1600	0.45 - 6	2	4	80	0.5	15.0	33.5	+22	SOT-343 (SC-70)
ATF-331M4	1600	0.45 - 6	2	4	60	0.6	15.0	31	+19	MiniPak[2]
ATF-34143	800	0.45 - 6	2	4	60	0.5	17.5	31.5	+20	SOT-343 (SC-70)
ATF-35143	400	0.45 - 6	2	2	15	0.4	18.0	21	+10	SOT-343 (SC-70)
ATF-38143	800	0.45 - 6	2	2	10	0.4	16.0	22	+12	SOT-343 (SC-70)
ATF-36077	200	1.5 - 18	12	1.5	10	0.5	12.0	—	+5	70 mil SM
ATF-36163	200	1.5 - 18	12	1.5	15	1.2	10.0	—	+5	SOT-363 (SC-70)

Step - 2

- Take into account the typical variation of the parameters to estimate from test frequency to design frequency
  - Noise factor **increases** with increasing frequency
  - Gain **decreases** with increasing frequency



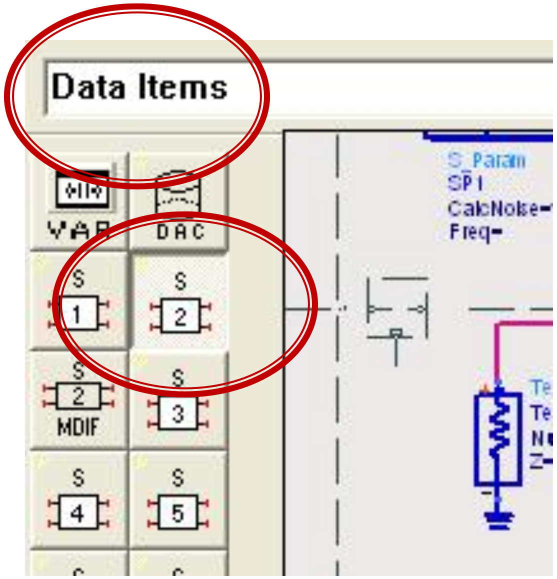


Step - 2

- Result
  - candidate T1: **ATF34143**
  - candidate T2: **NE71084**

Step - 3

- Obtain model data for the candidate transistor(**s**)
- Most often S parameter files (Touchstone)
- Google, manufacturer site: S2p files, S parameters etc.

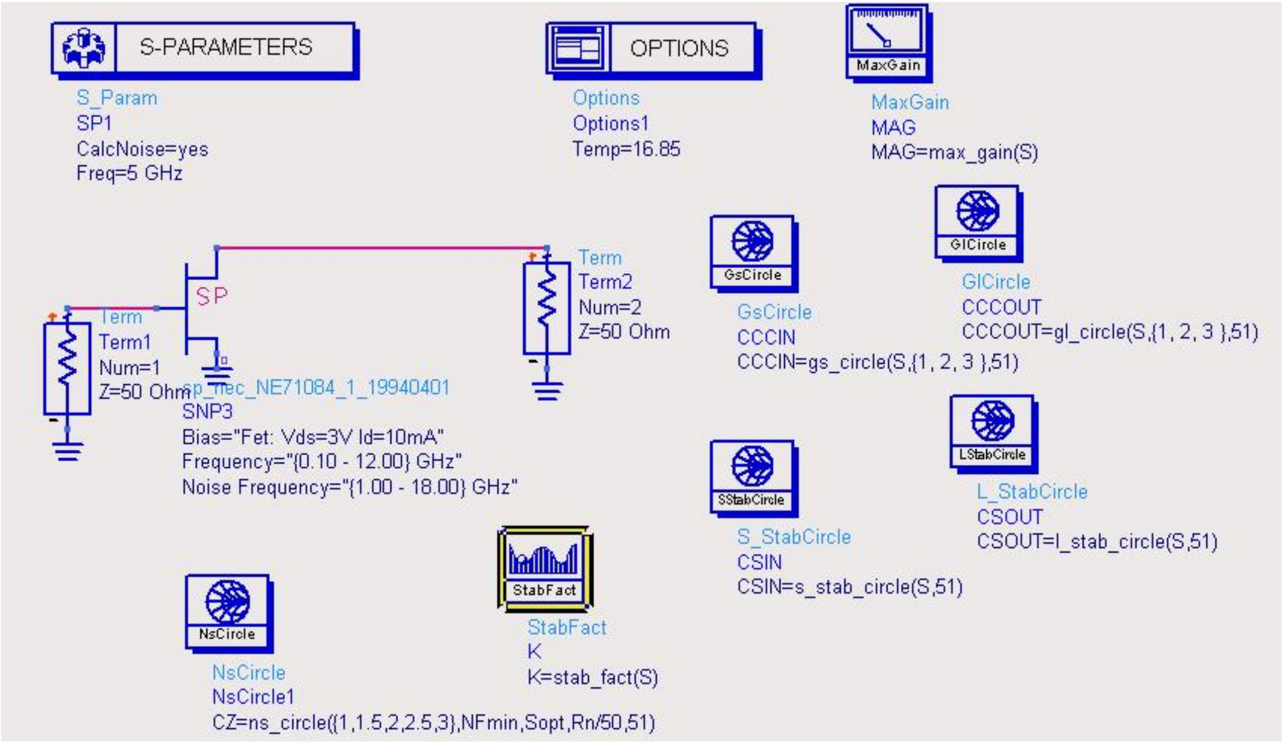


Step - 4

- Investigate the transistor
  - schematic 1/lab 3-4
  - compute some values (check G/F at design frequency)
  - compute some circles (position, diameter)
  - estimate/choose GS/GL
    - similar to lab3-4
    - for each transistor
- Pt. 7 example

Step - 4

- introduce a succession of multiple S parameter files and simulate (**repeatedly**)



Step - 4

- Result
  - candidate T1: **ATF34143 la 3V, 20mA, GS1 = ~ ... dB, GL1 = ~ ...dB**
  - candidate T2: **NE71084 la 3V, 1mA , GS2 = ~ ... dB, GL2 = ~ ...dB**

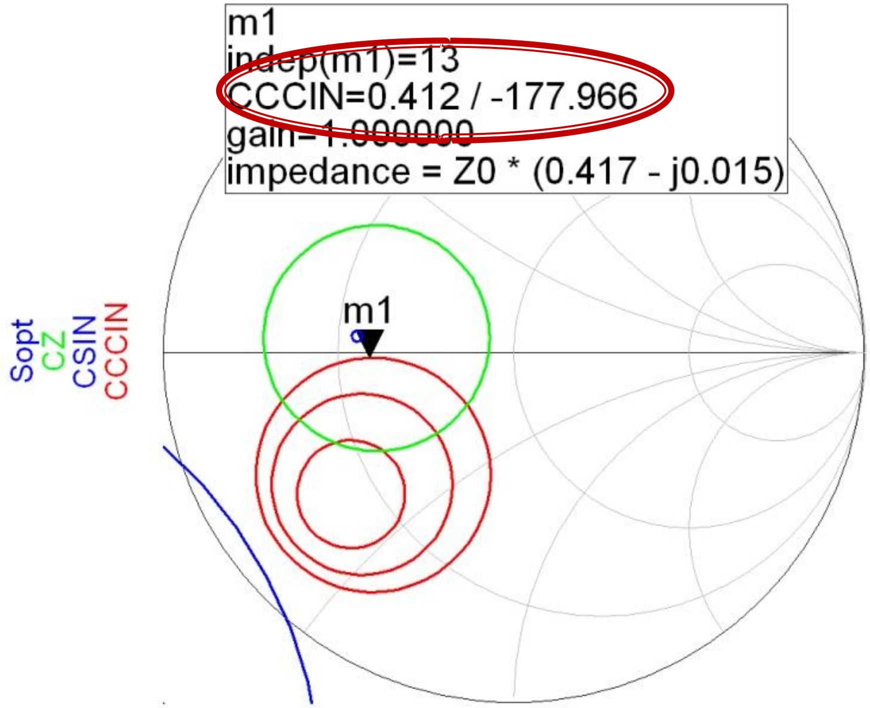
Step - 5

- For each transistor:
- Design of the input matching network
  - schematics 1~2/lab 3-4
- circles on the Smith Chart
  - stability circle
  - noise circle(**s**) (~chosen F)
  - gain circle(**s**) (~chosen GS)

- Pt. 8 example

Step - 5

- Use a marker to get the value of the reflection coefficient Γ_S
  - draw a dummy circle to have a point for the marker



Step - 5

- Calculate the electrical lengths of the two series/parallel lines according to the examples in the course/project
  - write down (on paper) the computation (**!!"andrei" factor**)

$$\boxed{\cos(\varphi + 2\theta) = -|\Gamma_S|}$$

$$\boxed{\theta_{sp} = \beta \cdot l = \tan^{-1} \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}}$$

Step - 5

- Result:
  - electrical length **E1, E2**
  - for each transistor

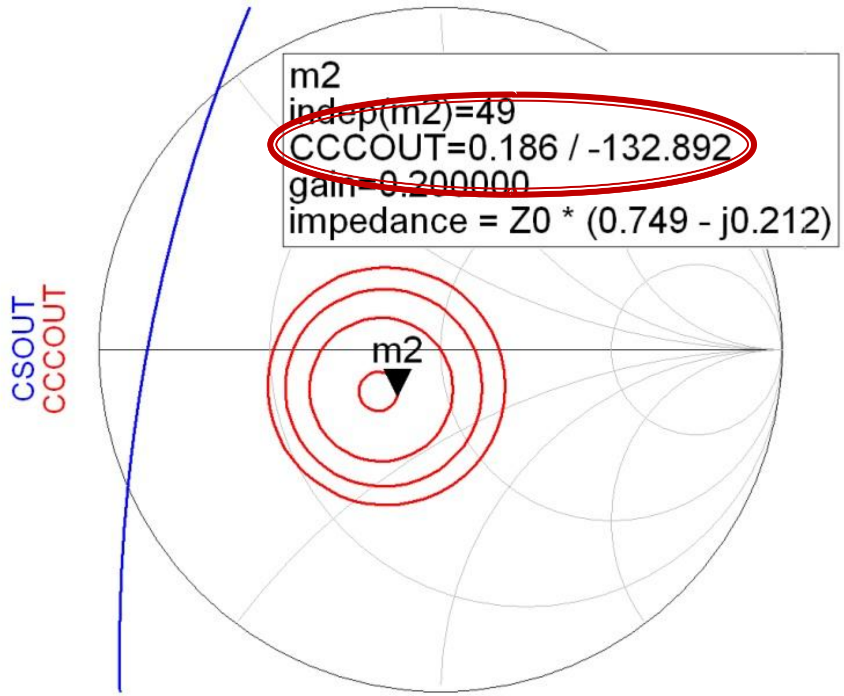
Step - 6

- For each transistor:
- Design of the output matching network
  - schematics 1~2/lab 3-4
- circles on the Smith Chart
  - stability circle
  - ~~noise circle(**s**) (~chosen F)~~
  - gain circle(**s**) (~chosen GL)

- Pt. 9 example

Step - 6

- Use a marker to get the value of the reflection coefficient Γ_L



Step - 6

- Calculate the electrical lengths of the two series/parallel lines according to the examples in the course/project
  - write down (on paper) the computation (**!!"andrei" factor**)

$$\boxed{\cos(\varphi + 2\theta) = -|\Gamma_L|}$$

$$\boxed{\theta_{sp} = \beta \cdot l = \tan^{-1} \frac{\mp 2 \cdot |\Gamma_L|}{\sqrt{1 - |\Gamma_L|^2}}}$$

Step - 6

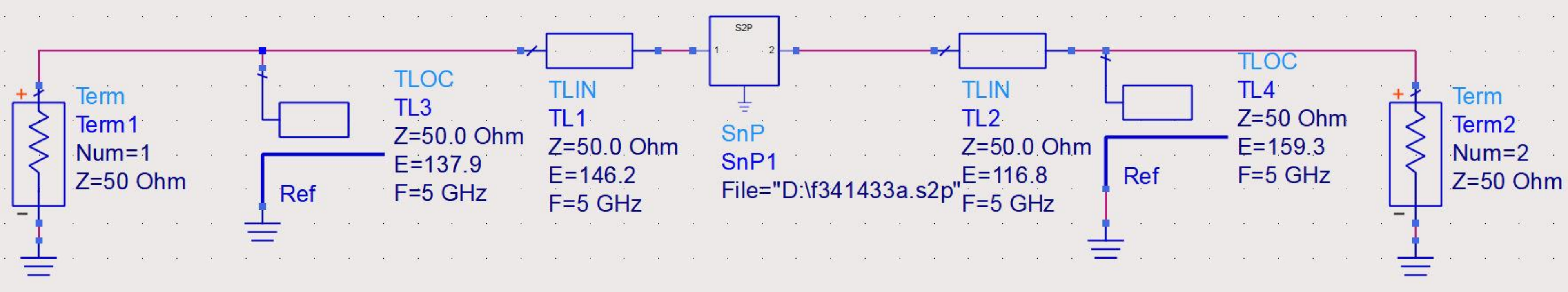
- Result:
  - electrical length **E_3, E_4**
  - for each transistor

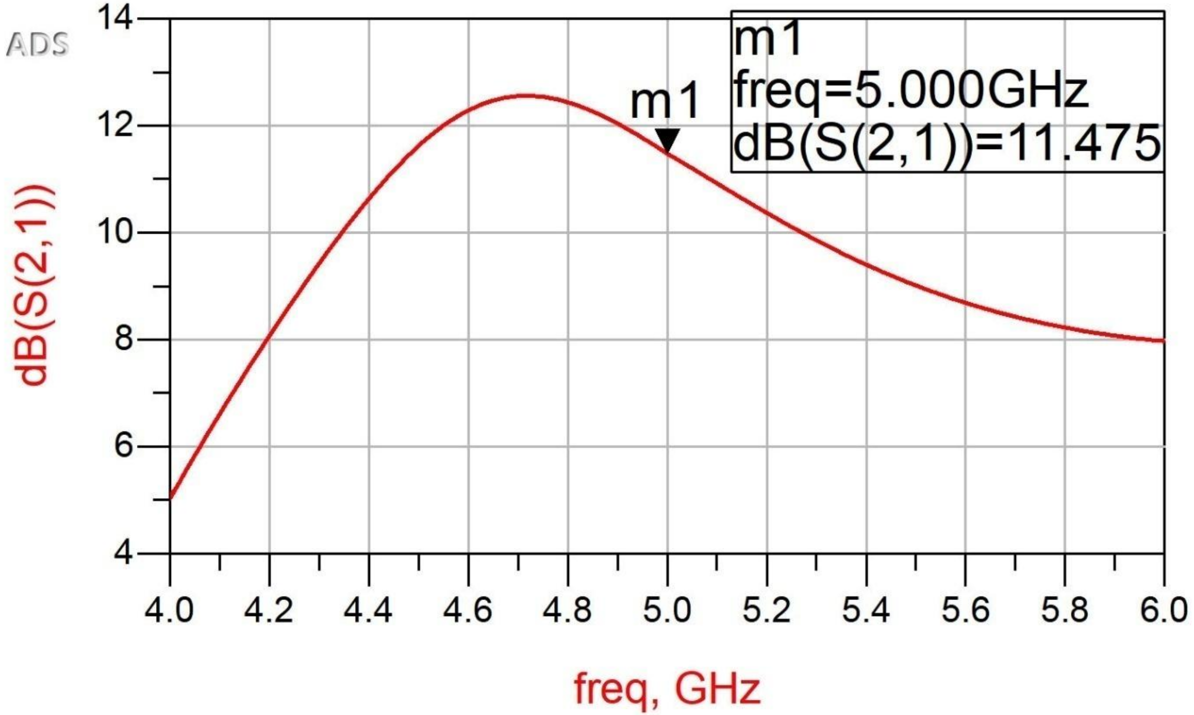
Step - 7

- For each transistor
- Check E_1, E_2, E_3, E_4
- Insert lines E_1, E_2 as the input network and E_3, E_4 as the output network and check if the proposed G / NF results are obtained.
  - Check and repeat the calculations

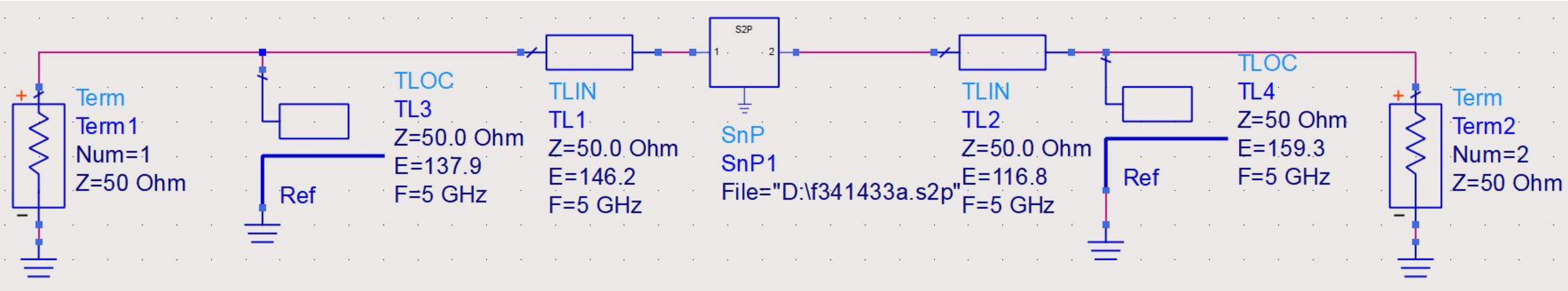
- Point non-existent in the example

Step - 7

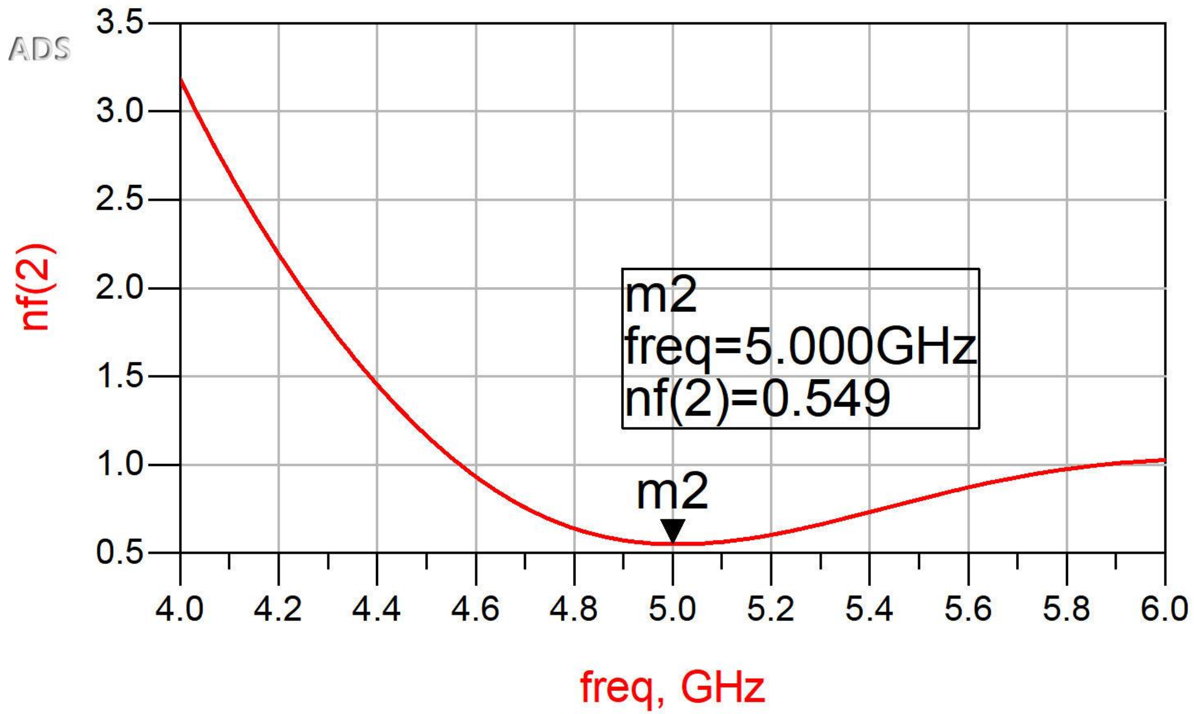

S2P
1
2
Term
Term1
Num=1
Z=50 Ohm
Ref
TLOC
TL3
Z=50.0 Ohm
E=137.9
F=5 GHz
TLIN
TL1
Z=50.0 Ohm
E=146.2
F=5 GHz
SnP
SnP1
File="D:\f341433a.s2p"
TLIN
TL2
Z=50.0 Ohm
E=116.8
F=5 GHz
Ref
TLOC
TL4
Z=50 Ohm
E=159.3
F=5 GHz
Term
Term2
Num=2
Z=50 Ohm


ADS
m1
freq=5.000GHz
dB(S(2,1))=11.475
m1
dB(S(2,1))
14
12
10
8
6
4
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
freq, GHz

Step - 7



Term
Term1
Num=1
Z=50 Ohm
Ref
TLOC
TL3
Z=50.0 Ohm
E=137.9
F=5 GHz
TLIN
TL1
Z=50.0 Ohm
E=146.2
F=5 GHz
S2P
1
2
SnP
SnP1
File="D:\f341433a.s2p"
TLIN
TL2
Z=50.0 Ohm
E=116.8
F=5 GHz
Ref
TLOC
TL4
Z=50 Ohm
E=159.3
F=5 GHz
Term
Term2
Num=2
Z=50 Ohm



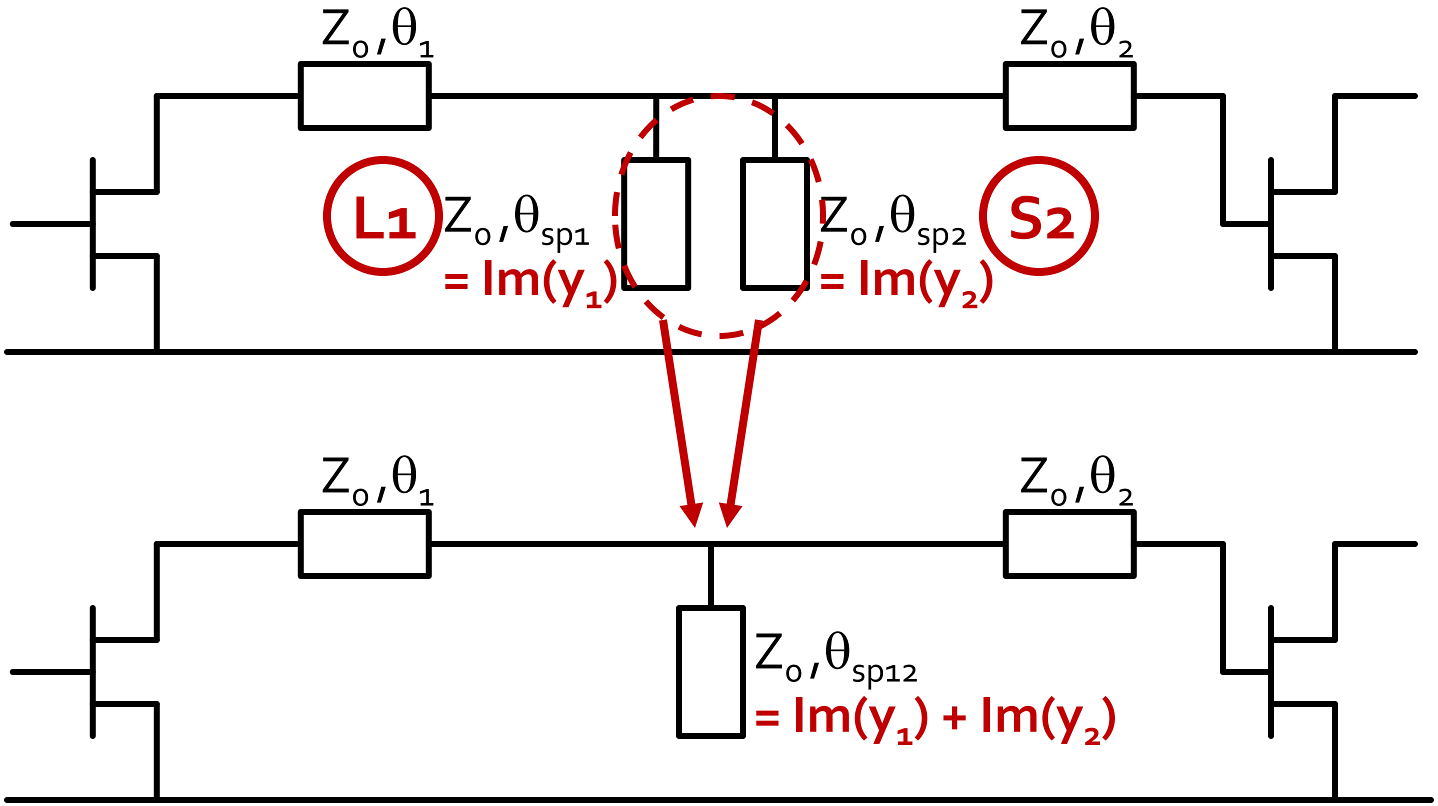
ADS
nf(2)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
m2
freq=5.000GHz
nf(2)=0.549
m2
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
freq, GHz

Step - 7

- Result
  - adopted T1: **ATF34143 la 3V, 20mA, GS1 = ... dB, GL1 = ...dB**
  - adopted T2: **NE71084 la 3V, 1mA , GS2 = ... dB, GL2 = ...dB**

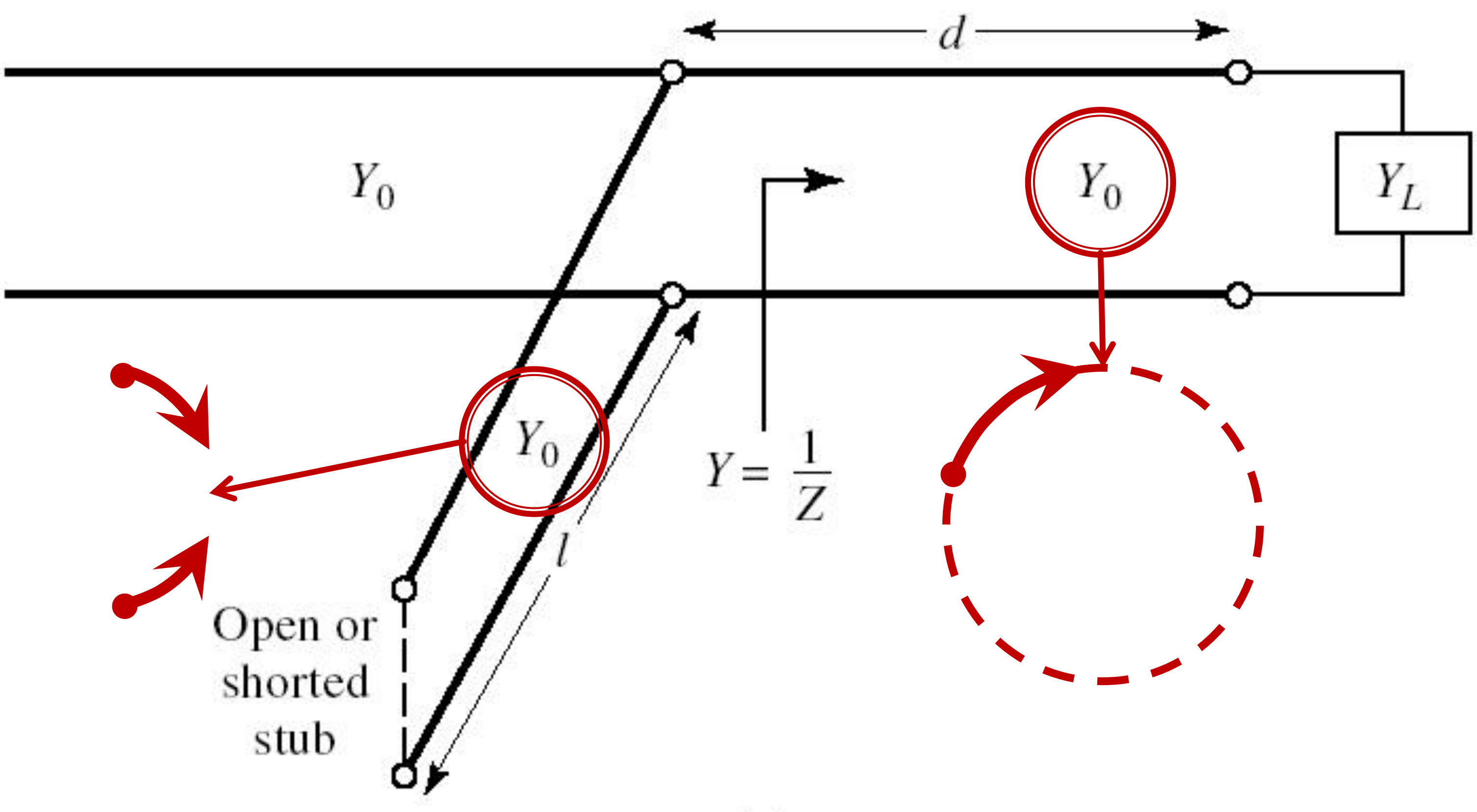
Interstage matching

- The two shunt stubs combine into a single one

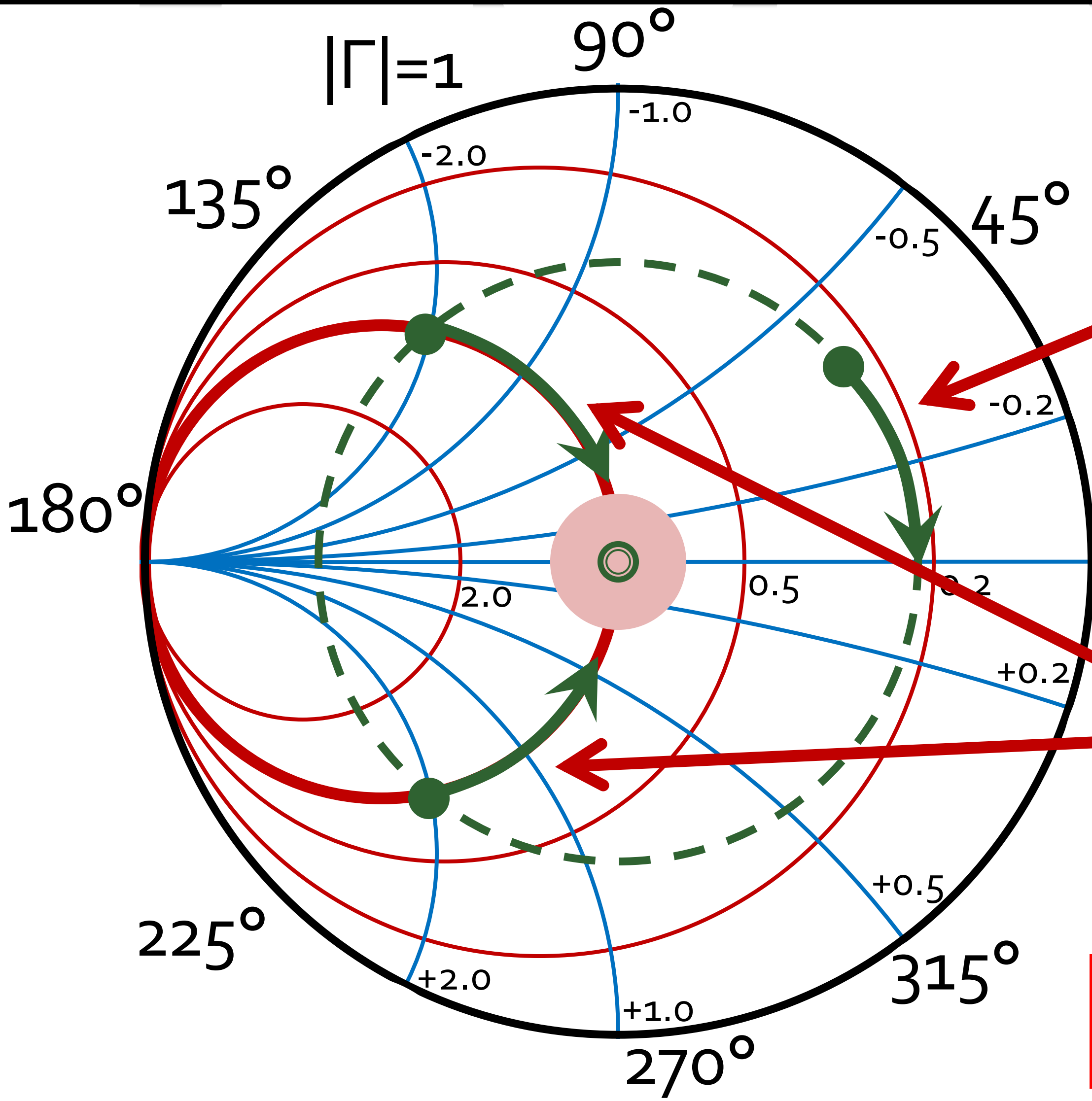


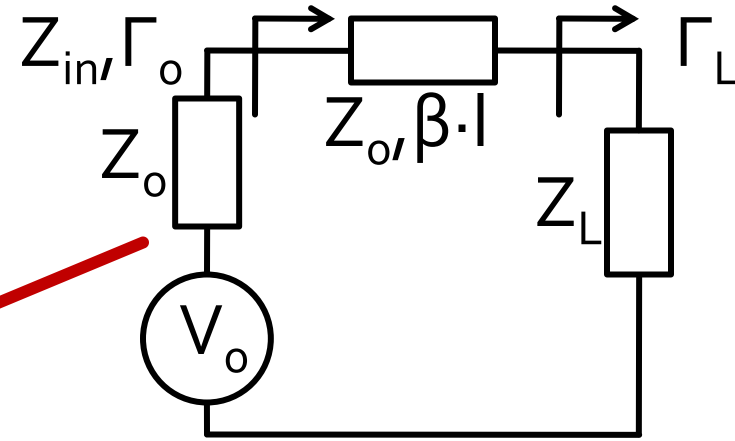
Case 1, Shunt Stub

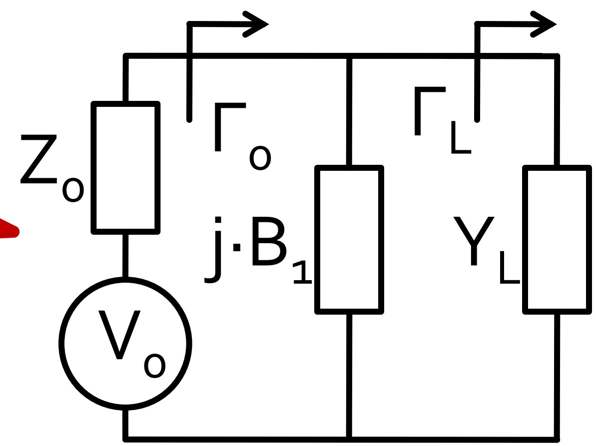
- Shunt Stub



Shunt stub matching, L7







$$\boxed{|\Gamma_{in}| = |\Gamma_L|}$$

$$\boxed{g_{in} = 1}$$

Analytical solution, usage

$$\boxed{\cos(\varphi+2\theta)=|\Gamma_S|}$$

$$\boxed{\theta_{ss}=\beta\cdot l=\cot^{-1}\frac{\mp 2\cdot|\Gamma_S|}{\sqrt{1-|\Gamma_S|^2}}}$$

$$\Gamma_S=0.555\angle-29.92°$$

$$|\Gamma_S|=0.555;\quad \varphi=-29.92°\qquad \cos(\varphi+2\theta)=0.555\Rightarrow(\varphi+2\theta)=\pm 56.28°$$

- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **series stub** equation
  - **"+" solution**

    $$(-29.92°+2\theta)=+56.28°\qquad \theta=43.1°\qquad \mathrm{Im}\,z_S=\frac{+2\cdot|\Gamma_S|}{\sqrt{1-|\Gamma_S|^2}}=+1.335$$

    $$\theta_{ss}=-\cot^{-1}(\mathrm{Im}\,z_S)=-36.8°(+180°)\rightarrow\theta_{ss}=143.2°$$

  - **"-" solution**

    $$(-29.92°+2\theta)=-56.28°\qquad \theta=-13.2°(+180°)\rightarrow\theta=166.8°$$

    $$\mathrm{Im}\,z_S=\frac{-2\cdot|\Gamma_S|}{\sqrt{1-|\Gamma_S|^2}}=-1.335\qquad \theta_{ss}=-\cot^{-1}(\mathrm{Im}\,z_S)=36.8°$$

Analytical solution, usage

$$(\varphi+2\theta)=\begin{cases}+56.28^\circ\\-56.28^\circ\end{cases}\quad \theta=\begin{cases}43.1^\circ\\166.8^\circ\end{cases}\quad \mathrm{Im}[z_S(\theta)]=\begin{cases}+1.335\\-1.335\end{cases}\quad \theta_{ss}=\begin{cases}-36.8^\circ+180^\circ=143.2^\circ\\+36.8^\circ\end{cases}$$

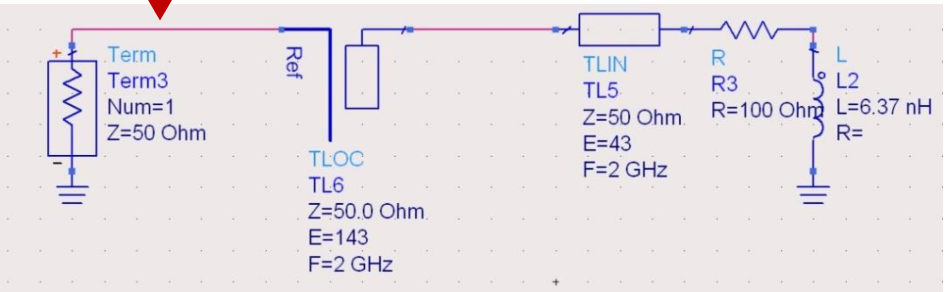
- We choose **one** of the two possible solutions
- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **series stub** equation

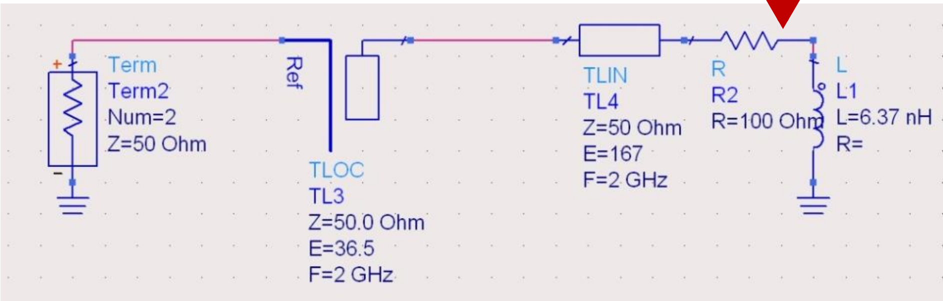
$$l_1=\frac{43.1^\circ}{360^\circ}\cdot\lambda=0.120\cdot\lambda$$

$$l_2=\frac{143.2^\circ}{360^\circ}\cdot\lambda=0.398\cdot\lambda$$

$$l_1=\frac{166.8^\circ}{360^\circ}\cdot\lambda=0.463\cdot\lambda$$

$$l_2=\frac{36.8^\circ}{360^\circ}\cdot\lambda=0.102\cdot\lambda$$





Contact

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