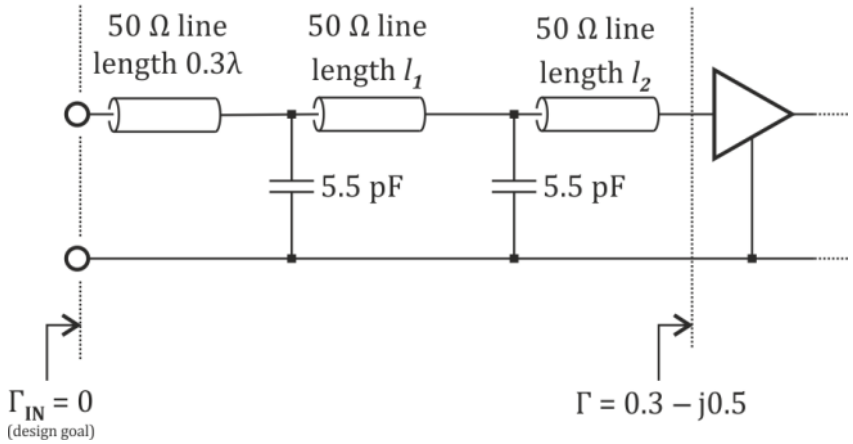
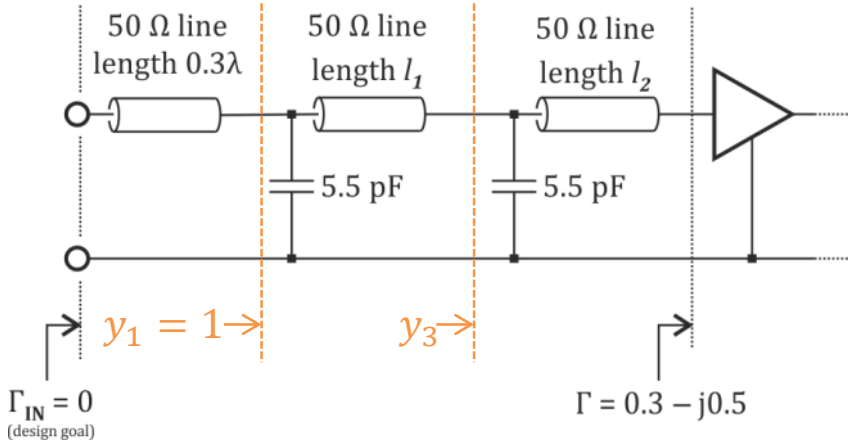
5. Matching of an RF Amplifier Module - Reference Solution

The input of an RF amplifier module operating at $f_c = 1\,\text{GHz}$ shows a reflection coefficient $\Gamma = 0.3 - j0.5$. By means of two 5.5 pF capacitors, placed along a lossless 50 Ω line, the input of the entire circuit shall be matched to 50 Ω.



By using the Smith-chart determine the transmission line lengths l_1 und l_2 (as a ratio of the wavelength λ)!

5. Matching of an RF Amplifier Module - Reference Solution



<u>50 Ω line (with length 0.3 λ) at the input can be ignored…</u>

…because it has the same impedance as the desired input impedance.

<u>Solution approach:</u>

1. divide the network into two parts by a reference plane located in between the adjustable elements
2. determine the set of admittances y_3 which can be matched to $y_1 = 1$ (equ. 50 Ω) by the left-hand side network (5.5pF + line 1)
3. determine the set of admittances y_3 which can be realized by the right-hand side network (5.5pF + line 2 + amplifier)
4. intersect both sets to find a solution for y_3
5. based on the solution for y_3 determine the lengths of line 1 and line 2

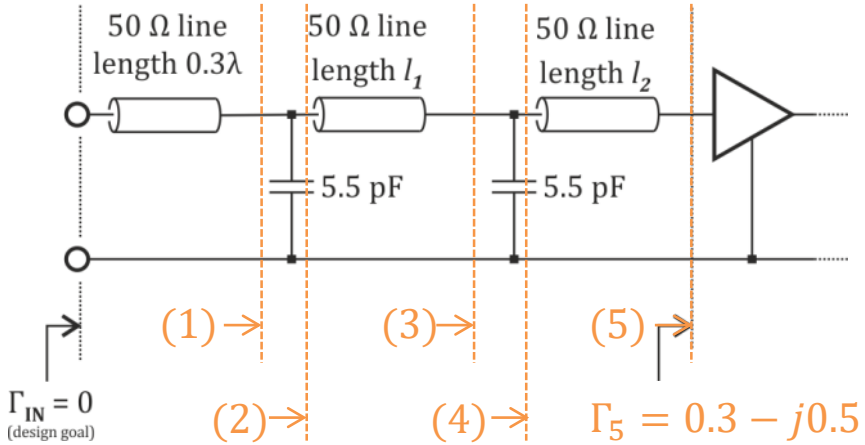
<u>Info:</u> Because all lines (of which the reference planes are shifted along) have a wave impedance of 50 Ω, the Smith-chart used for the solutions is referenced to 50 Ω as well.

5. Matching of an RF Amplifier Module - Reference Solution

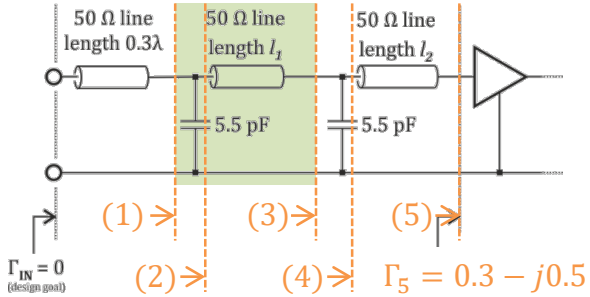
The following notation will be used in the Smith-charts:

- impedances are marked in **BLUE**
- admittances are marked in **RED**
- construction steps are marked in **ORANGE**
  (sometimes other colors might also be used for clarity)
- the reference impedance is indicated in to upper left corner
- pastel colors are used for preceding construction steps, impedances, and admittances

- reference planes are denoted by (1),(2),(3),(4) and (5);
  they are located at the following positions and use the following orientations:



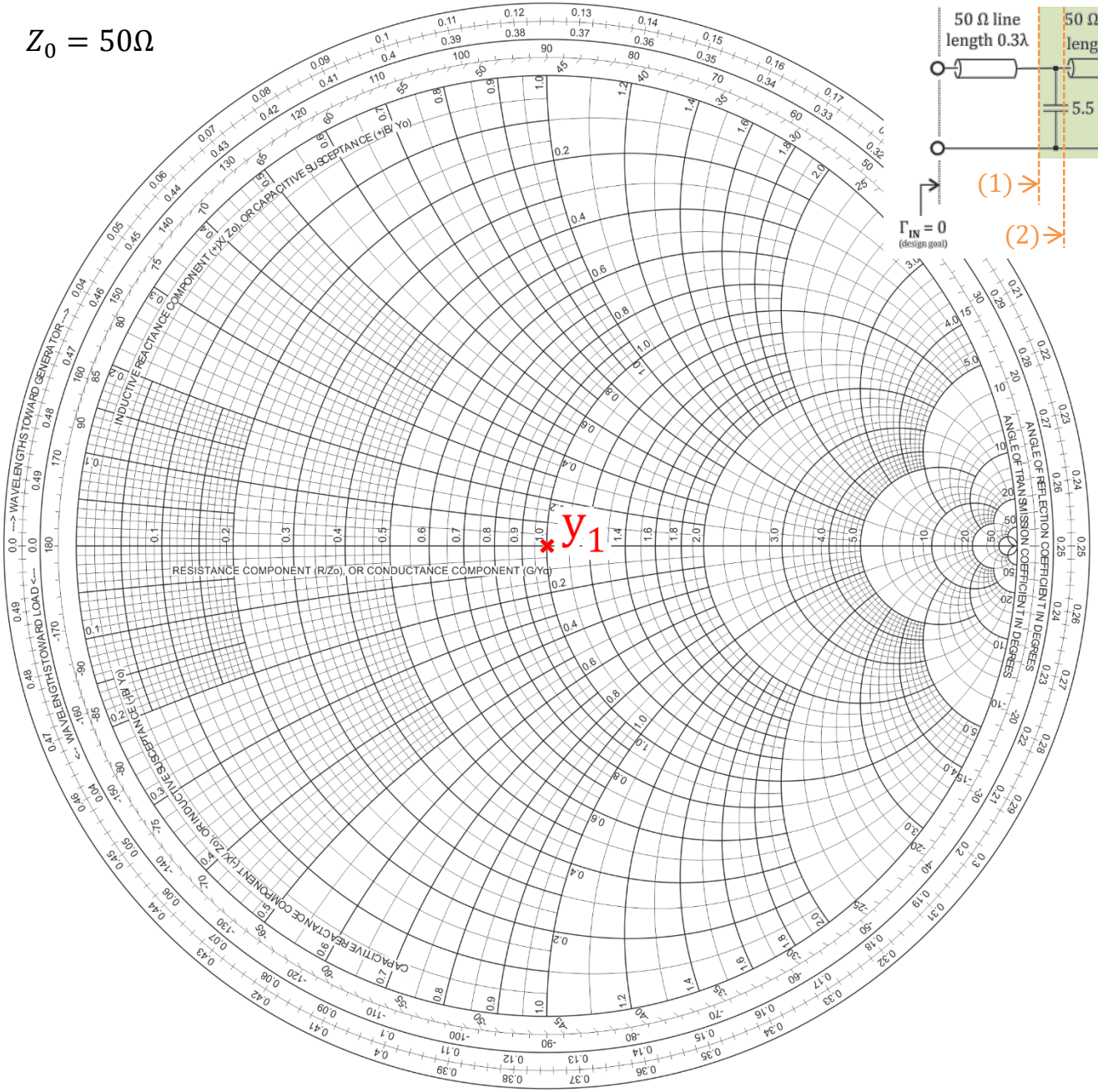
5. Matching of an RF Amplifier Module - Reference Solution

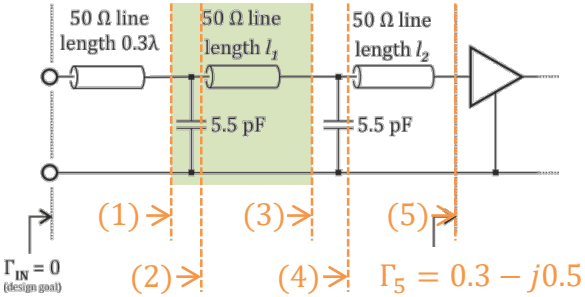


We start by determining the set of admittances y_3 which can be matched to $y_1 = 1$ (equ. 50 Ω) by the network marked in green (5.5pF + line 1)…

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$





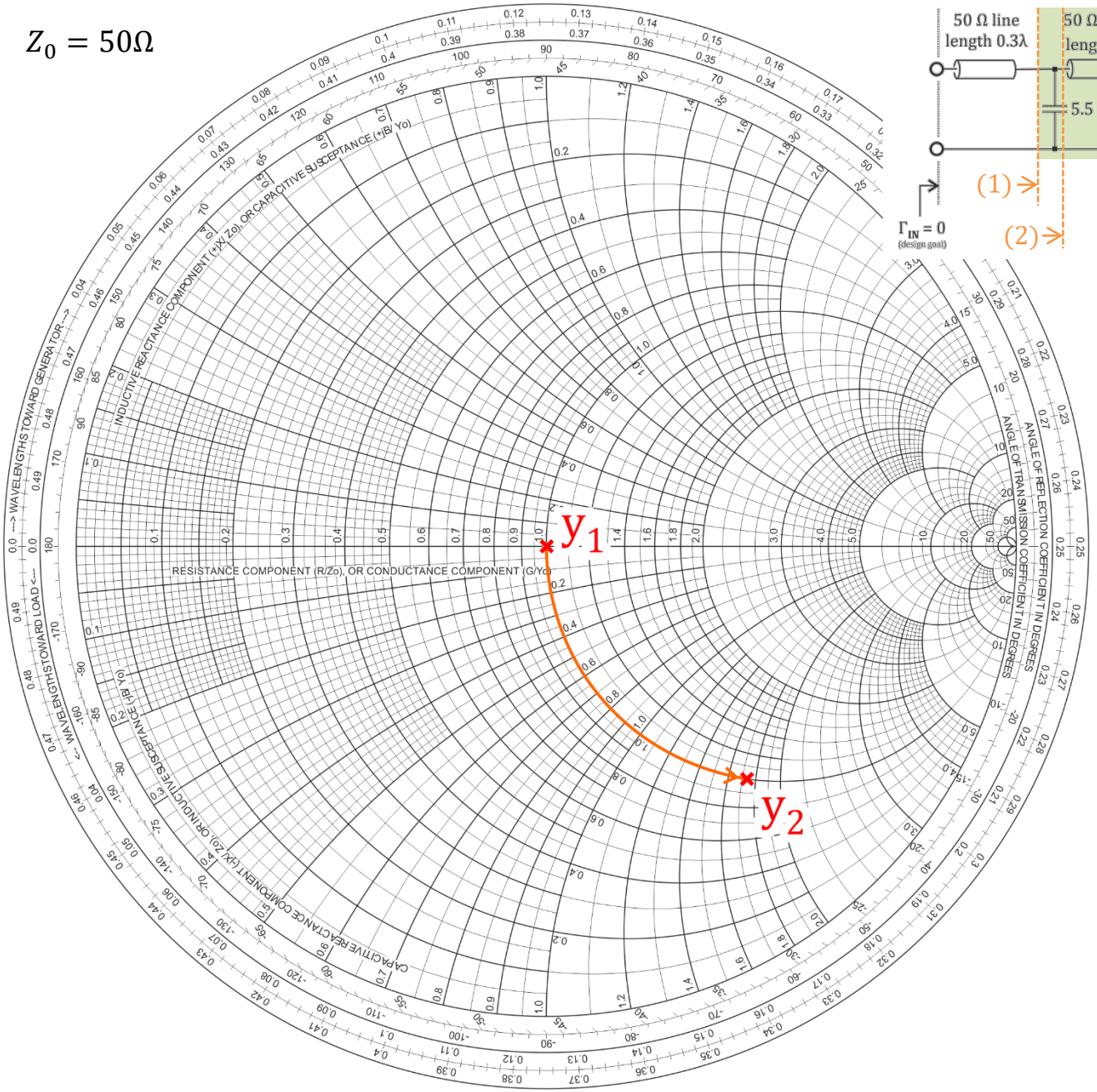
Solution for left part (5.5pF + line 1):

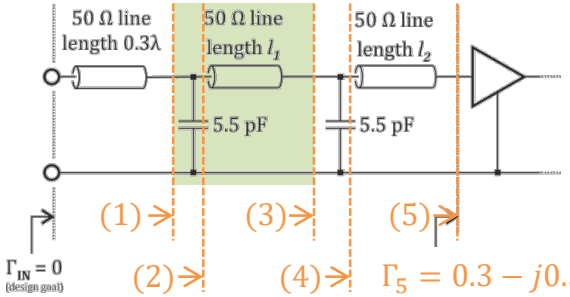
- **enter y_1** (use admittance plane because when shifting the reference plan to y_2 we have to deal with a parallel connection of the 5.5pF capacitor)

RF Techniques

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$





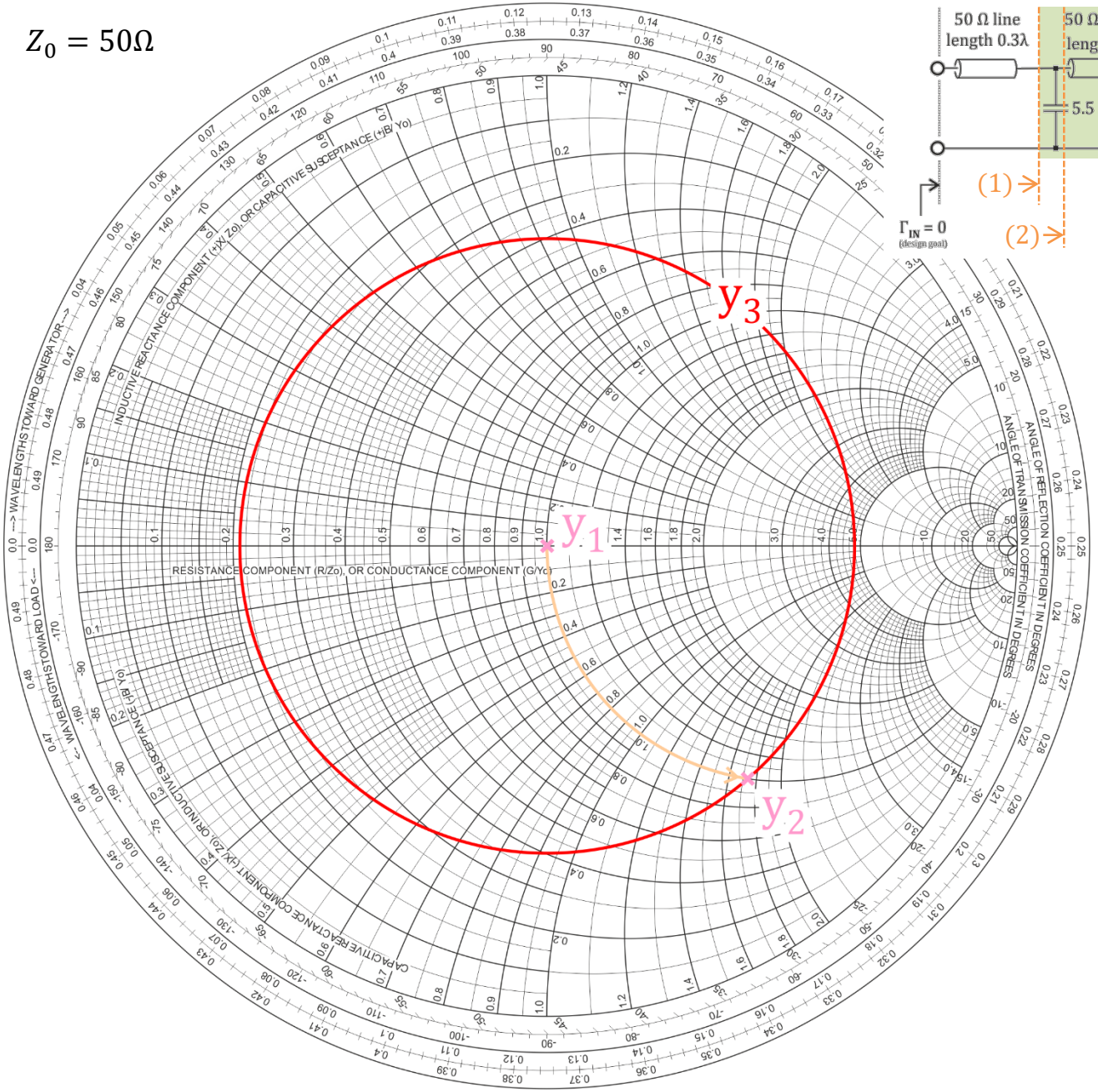
<u>Solution for left part (5.5pF + line 1):</u>

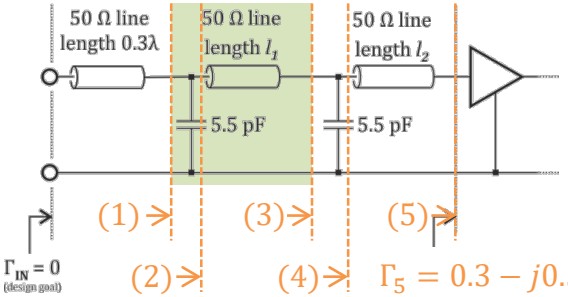
- enter y_1
- **shift reference plane y_1 to y_2 by removing the 5.5pF capacitor** (this equals a subtraction of the admittance!)
- $y_C = \frac{z_0}{z_C} = j\omega C Z_0 = +j1.73$

RF Techniques

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$

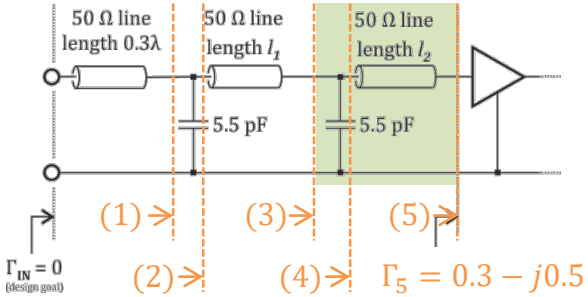




<u>Solution for left part (5.5pF + line 1):</u>

- enter y_1
- shift reference plane y_1 to y_2 by removing the 5.5pF capacitor
- **shift reference plane y_2 to y_3** (this is done by rotating y_2 towards the load along a circle)
- any admittance on the circle y_3 can be matched to $y_1 = 0$ by choosing an appropriate line length l_1

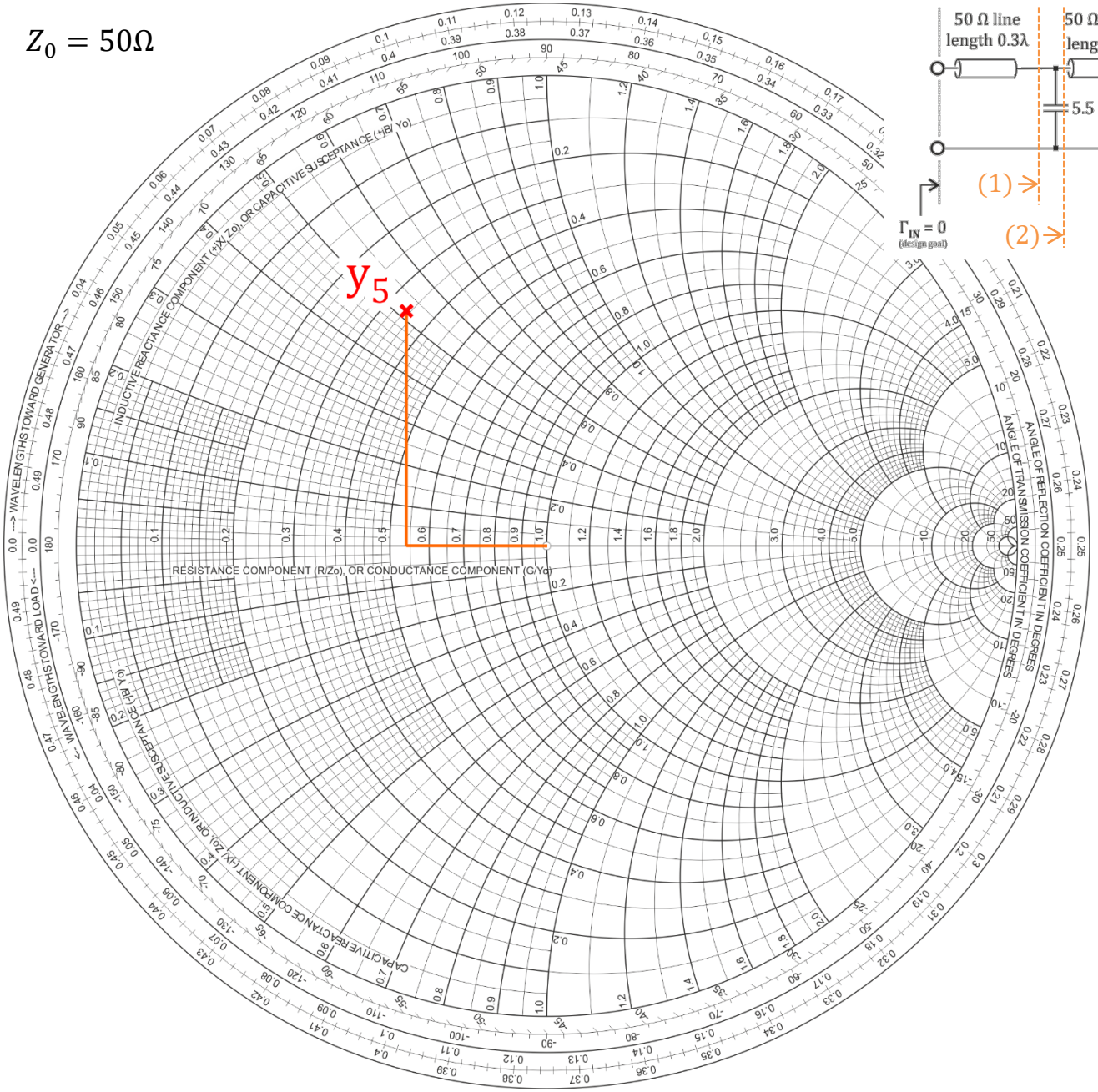
5. Matching of an RF Amplifier Module - Reference Solution

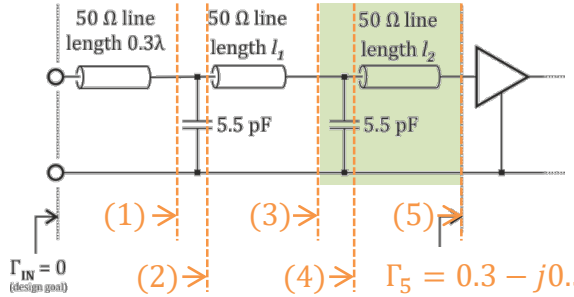


Next, we determine the set of reflection coefficients y_3 which can be realized by the network marked in green (5.5pF + line 2 + amplifier)…

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$





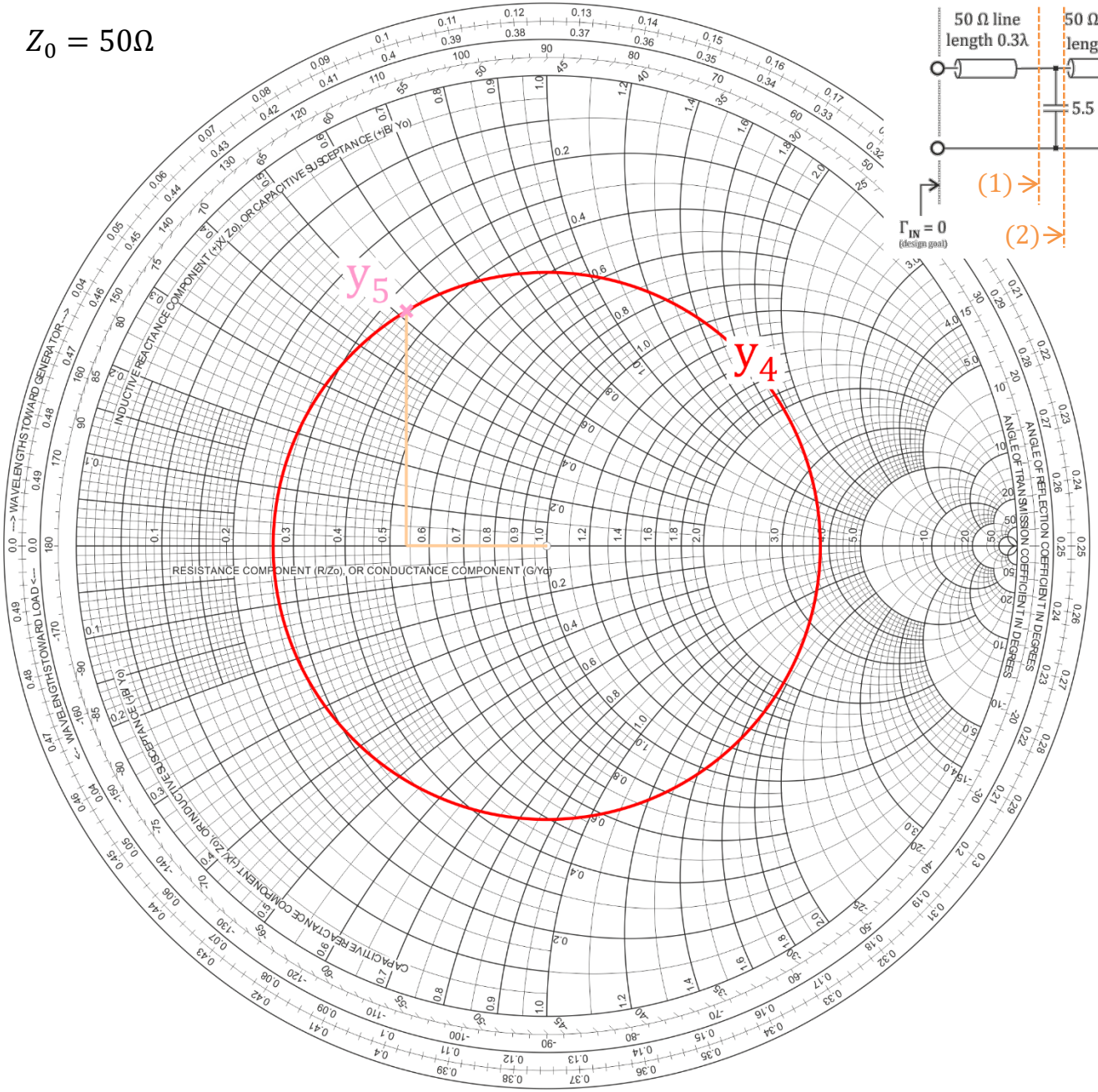
Solution for right part (5.5pF + line 2 + amp):

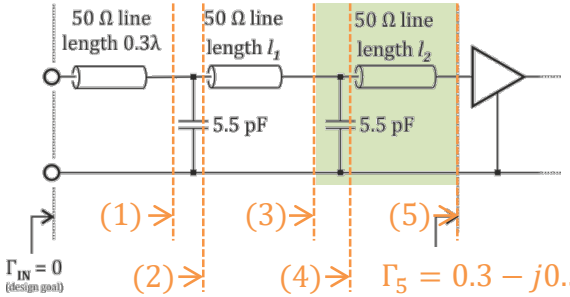
- **enter y_5** ($\Gamma_5 = 0.3 - j0.5$) again, use admittance plane because later on we have to deal with a parallel 5.5pF capacitor

RF Techniques

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$





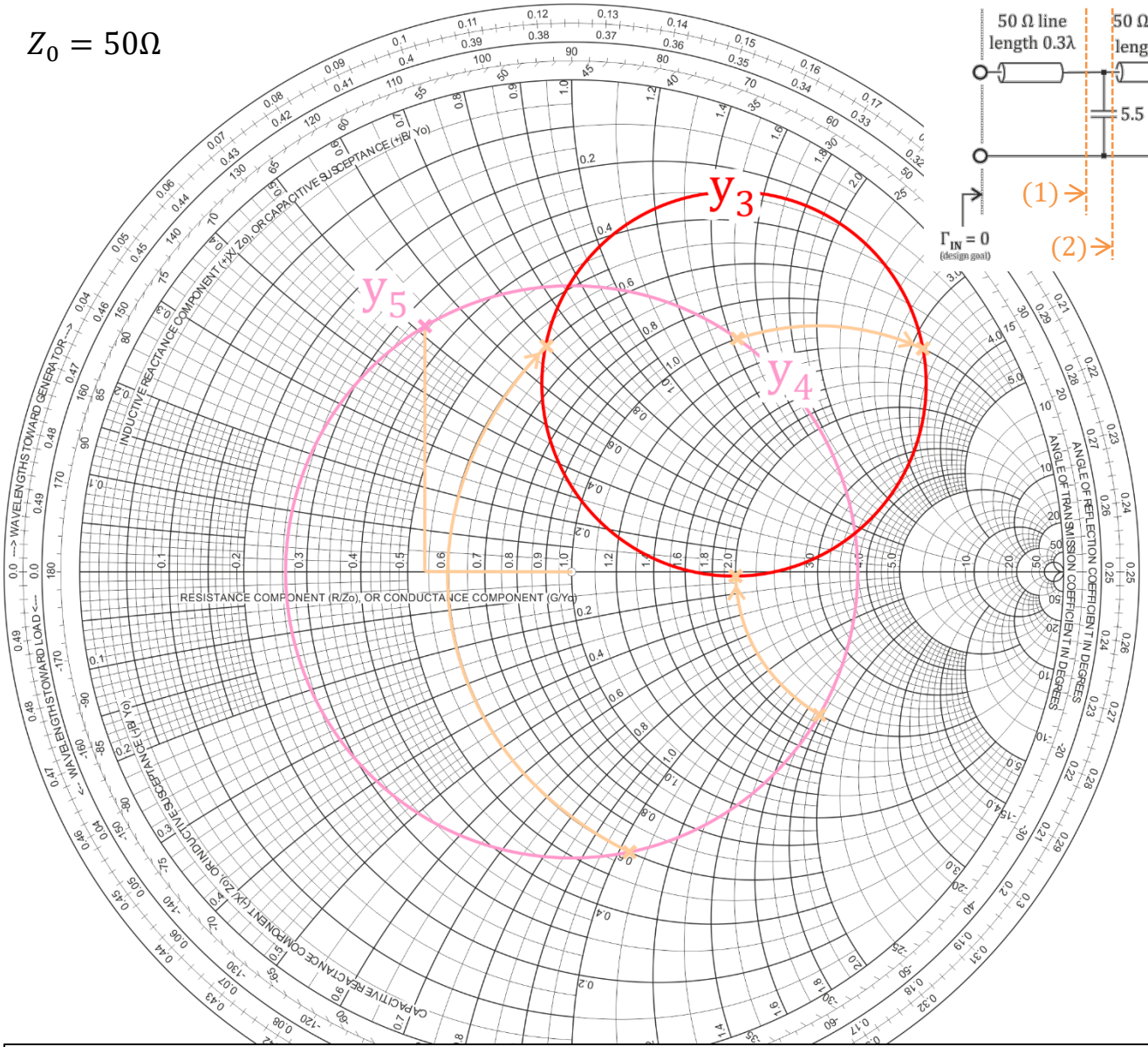
Solution for right part (5.5pF + line 2 + amp):

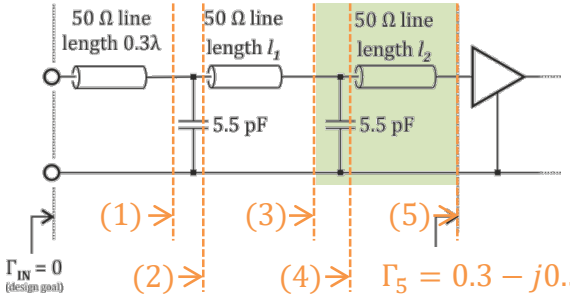
- enter y_5
- **shift reference plane y_5 to y_4** (this is done by rotating y_5 towards the generator along a circle)
- any admittance on the circle y_4 can be realized by choosing different line lengths l_2

RF Techniques

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$



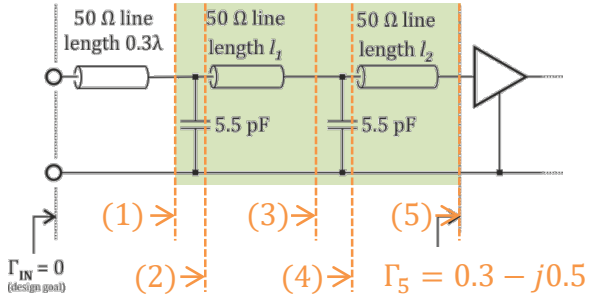


Solution for right part (5.5pF + line 2 + amp):

- enter y_5
- shift reference plane y_5 to y_4
- **add the 5.5pF capacitor's admittance in order to determine the set of possible y_3's**
- By knowing that this will result in a circle*, three arbitrary points on the y_4 circle are chosen, the capacitor's admittance is added, and the y_3 circle is constructed then

* The Smith-chart is a conformal mapping between Γ-plane (reflection coefficients) and the Y/Z-plane (= it preserves angles). Circles will be transformed into circles. When adding constant imaginary values to the reflection coefficient this corresponds to a parallel movement of the circle in Y-plane and, therefore, results in a circle in the Γ-plane again.

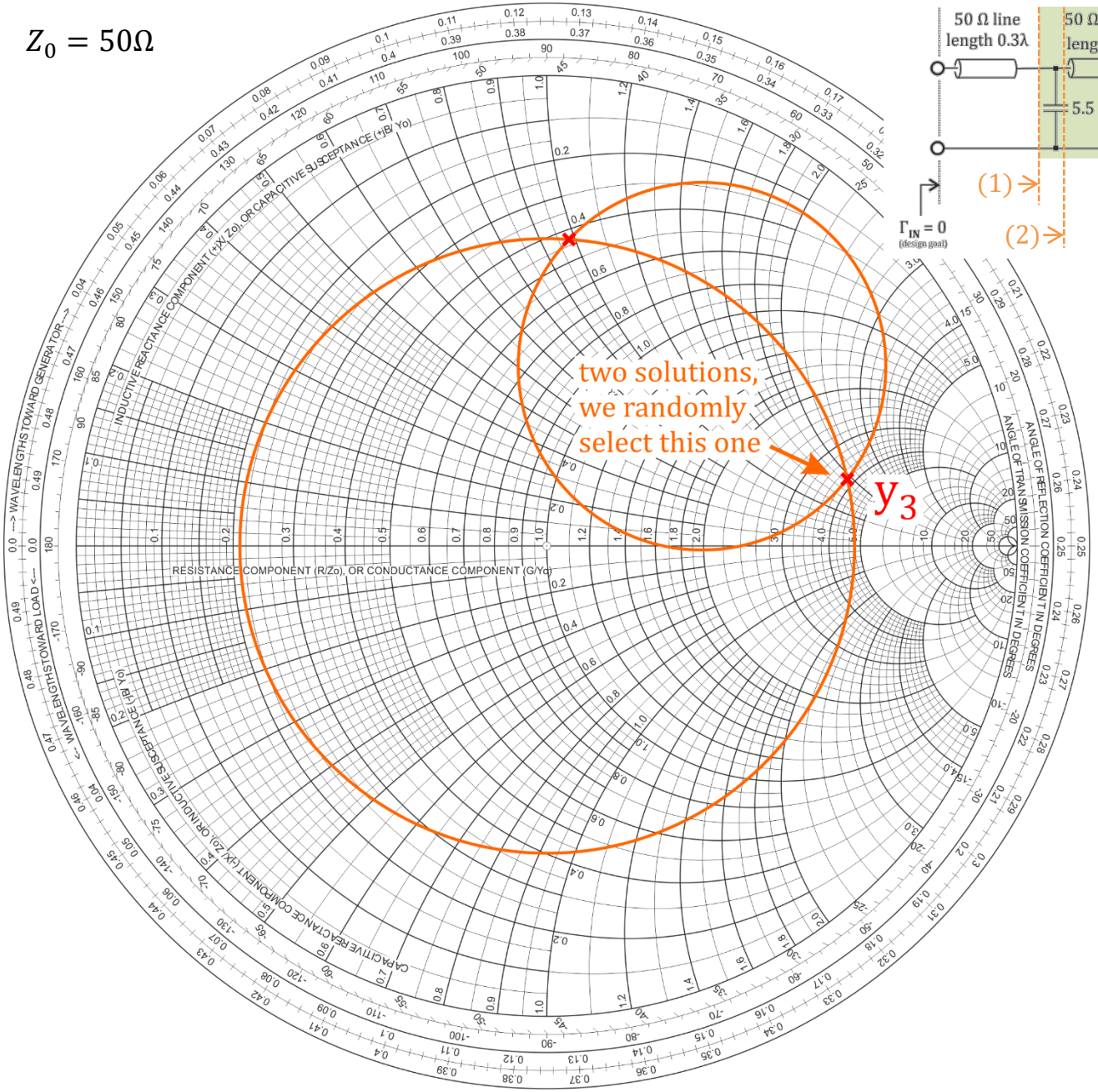
5. Matching of an RF Amplifier Module - Reference Solution

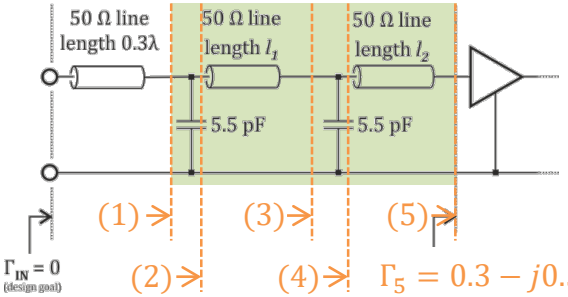


Now, as we have solutions for y_3 based on the left and right half of the circuit, we determine a y_3 which can be matched by the left circuit to 50 Ω and can be realized by the right one…

5. Matching of an RF Amplifier Module - Reference Solution

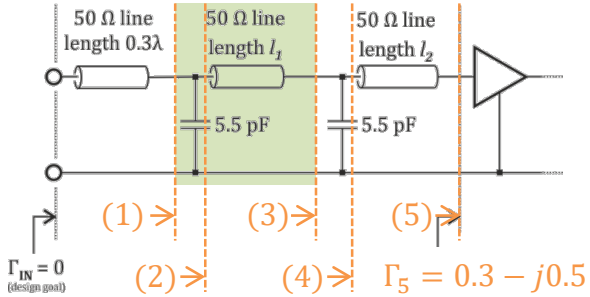
$Z_0 = 50\Omega$





- **intersect the solution-sets** of y_3 (the one for the left and the one for the right half) **to find a solution for y_3**
- two solutions!
- both solutions are valid, we decide to go for the depicted one

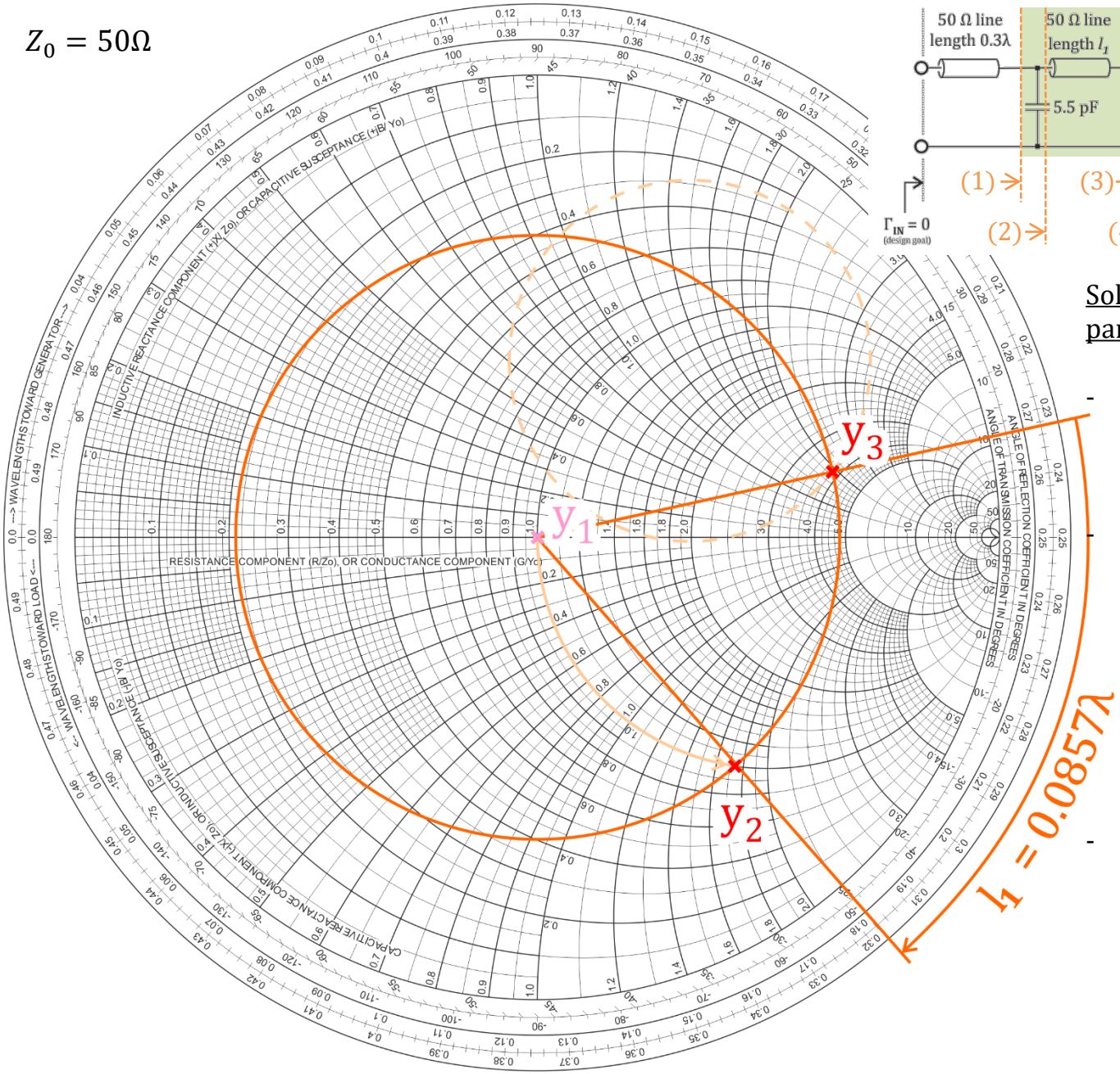
5. Matching of an RF Amplifier Module - Reference Solution



Next, as we know the value y_3 we get back to the solution of the left-hand circuit and determine the length of line 1…

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$

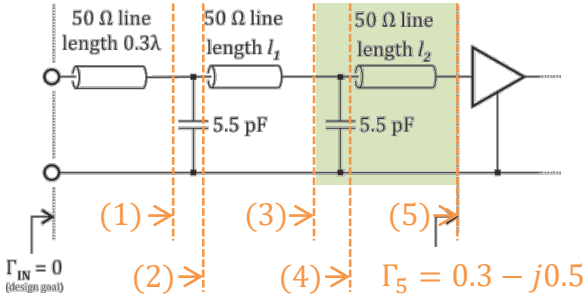


Solution for the left part (5.5pF + line 1):

- **enter y_3** in the solution for the left circuit half (5.5pF + line 1)
- **determine the length of line 1** by the required rotation of y_3 along the line 1 towards the generator in order to achieve y_2
- **➔ $l_1 = 0.0857\lambda$**

RF Techniques

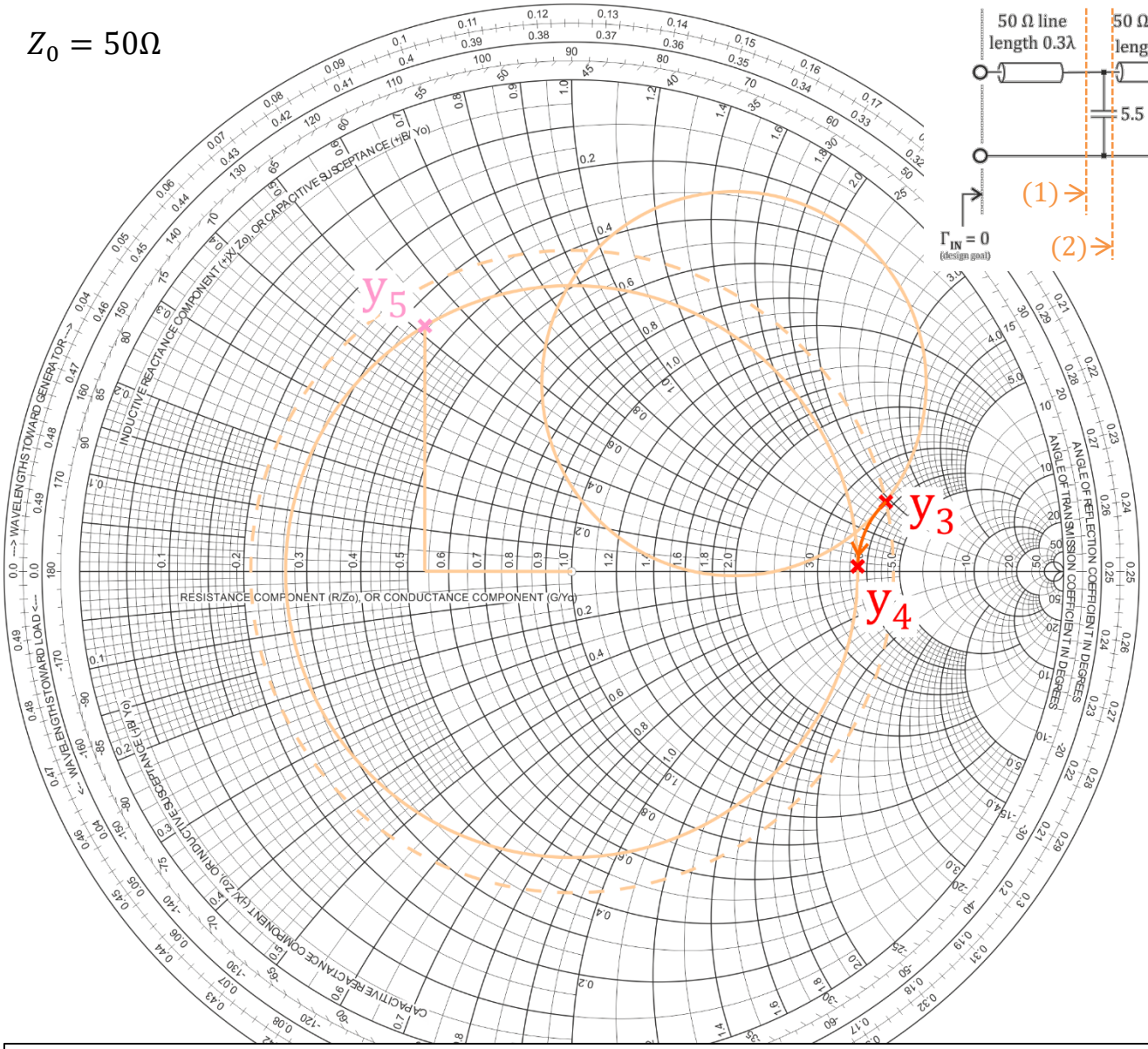
5. Matching of an RF Amplifier Module - Reference Solution

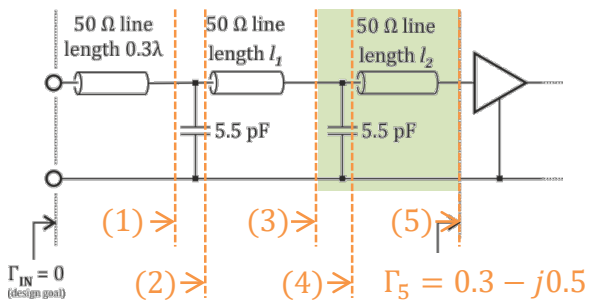


Now, we determine the length of line 2 by entering the found y_3 value in the solution of the circuit's right half…

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$





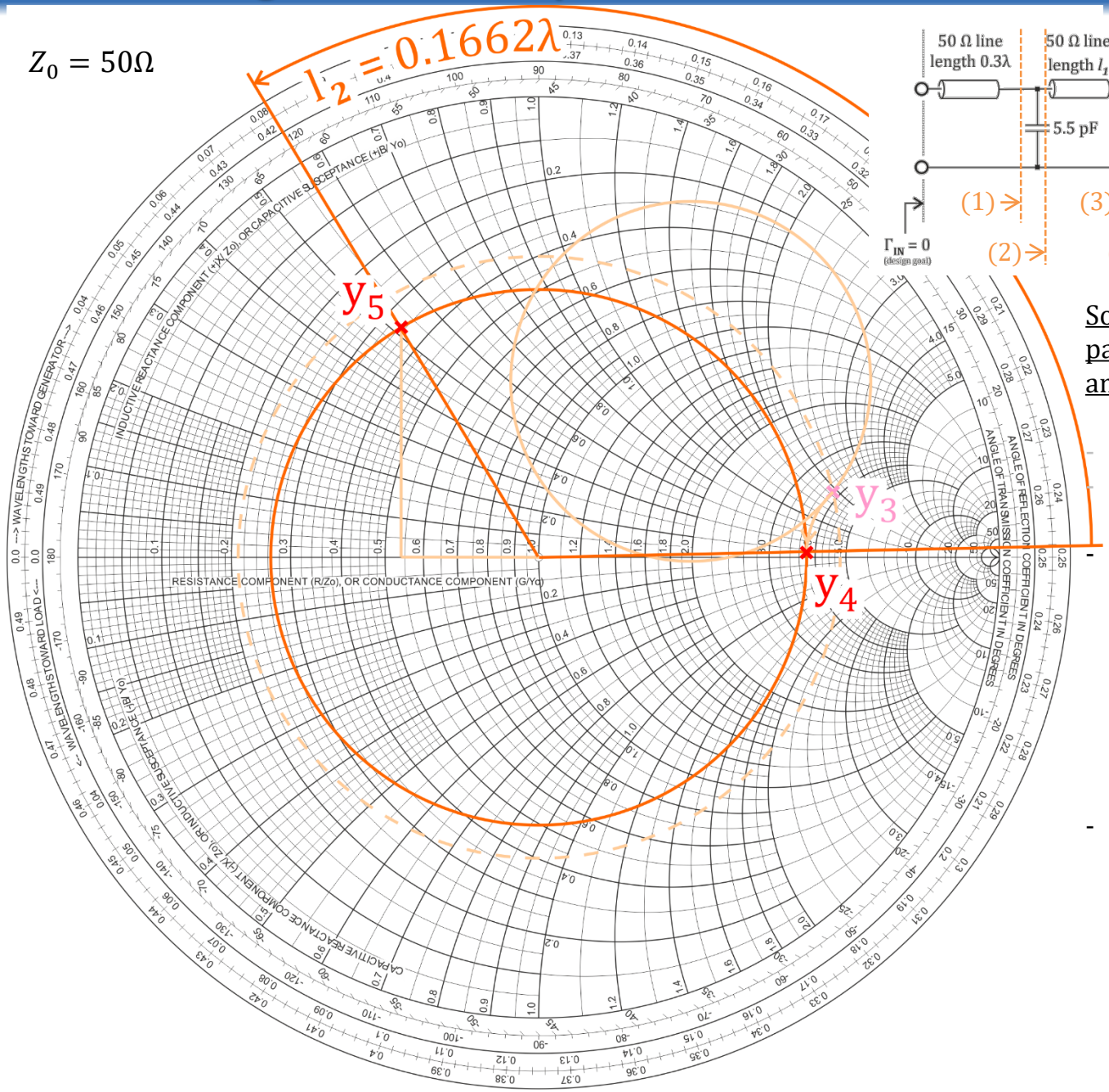
<u>Solution for the right part (5.5pF + line 2 + amp):</u>

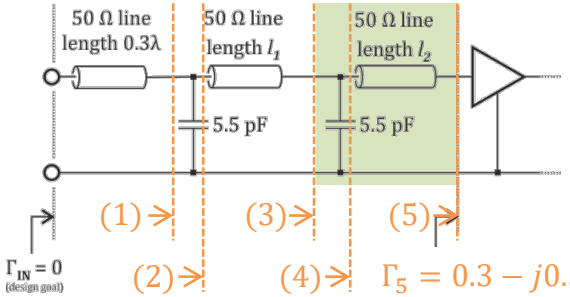
- **enter y_3** in the solution for the right circuit half
- **determine y_4 by subtracting* y_C from y_3**
- In case you forgot: $y_C = \frac{z_0}{z_C} = j\omega C Z_0 = +j1.73$

* You need to subtract y_C from y_3 out of the following reason: When measuring y_3 the capacitor is included in the circuit. But when measuring y_4 the capacitor needs to be removed. / Or think the other way round: If you know y_4 you would have to add y_C in order to determine y_3. As we know y_3 already, y_C needs to be subtracted.

5. Matching of an RF Amplifier Module - Reference Solution

$Z_0 = 50\Omega$





<u>Solution for the right part (5.5pF + line 2 + amp):</u>

- enter y_3
- determine y_4 by adding y_C to y_3
- **determine the length of line 2** by the required rotation of y_3 along the line 2 towards the load in order to achieve y_4
- **➔ $l_2 = 0.1662\lambda$**

That's it, you survived the tutorial!

Questions?
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Room: CF0131