

Curs 8

2025/2026

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2025/2026

- 2C/1L (+1), **DCMR (CDM)**
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
 - Vineri 10-12/**Video (istoric)**, C1, corp C
 - E – **50%** din nota
 - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
 - primul test L1: ~01.10.2025 (t2 si t3 neanuntate la **curs**)
 - 3pz (C) $\approx$ +0.5p (**2p** max)
 - toate materialele permise

Disciplina 2025/2026

- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
 - L – **25%** din nota
 - ADS, 4 sedinte aplicatii
 - prezenta + **rezultate personale!**
 - P – **25%** din nota
 - ADS, 3 sedinte aplicatii (-1? 21-22.12.2022)
 - tema personala

Documentatie

■ <https://rf-opto.etti.tuiasi.ro>



Microwave and Optoelectronics Laboratory
Faculty of Electronics, Telecommunications and Information Technology
Gheorghe Asachi Technical University of Iasi

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[English](#)[Romana](#)

Microwave Devices and Circuits for Radiocommunicati

Course: DCMR (2024-2025)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DOS412T
Discipline Type: DOS; Alternative, Specialty
Credits: 4
Enrollment Year: 4, **Sem.** 7

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assoc.P. Dr. Radu-Florin Damian, 1 Hours/Week, Group, Timetable:

Evaluation

Type: **Exam**

A: 50%, (Test/Colloquium)
B: 25%, (Seminary/Laboratory/Project Activity)
D: 25%, (Homework/Specialty papers)

Grades

[Aggregate Results](#)

Bibliografie

- <https://rf-opto.etti.tuiasi.ro>
- Irinel Casian-Botez: "Microunde vol. 1: Proiectarea de circuit", Ed. TEHNOPRES, 2008
- David Pozar, Microwave Engineering, Wiley; 4th edition , 2011, ISBN : 978-1-118-29813-8 (E), ISBN : 978-0-470-63155-3 (P)

Examen: Reprezentare logaritmică

$$\text{dB} = 10 \cdot \log_{10} (P_2 / P_1)$$

$$0 \text{ dB} = 1$$

$$+ 0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$+ 3 \text{ dB} = 2$$

$$+ 5 \text{ dB} = 3$$

$$+ 10 \text{ dB} = 10$$

$$-3 \text{ dB} = 0.5$$

$$-10 \text{ dB} = 0.1$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dB} = 0.001$$

$$\text{dBm} = 10 \cdot \log_{10} (P / 1 \text{ mW})$$

$$0 \text{ dBm} = 1 \text{ mW}$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$5 \text{ dBm} = 3 \text{ mW}$$

$$10 \text{ dBm} = 10 \text{ mW}$$

$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dBm} = 100 \mu\text{W}$$

$$-30 \text{ dBm} = 1 \mu\text{W}$$

$$-60 \text{ dBm} = 1 \text{ nW}$$

$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

$$[\text{dBm/Hz}] + [\text{dB}] = [\text{dBm/Hz}]$$

$$[x] + [\text{dB}] = [x]$$

Examen: Reprezentare logaritmică

- $P_0 = 1\text{mW}$
 - $P[\text{dBm}] = 10 \cdot \log \left(\frac{P}{P_0} \right)$
 - $P = P_0 \cdot 10^{\frac{P[\text{dBm}]}{10}}$
- Cu unitati de masura
 - $P[\text{mW}] = 1[\text{mW}] \cdot 10^{\frac{P[\text{dBm}]}{10}} = 10^{\frac{P[\text{dBm}]}{10}}$
 - $P[\mu\text{W}] = 1000[\mu\text{W}] \cdot 10^{\frac{P[\text{dBm}]}{10}} = 10^3 \cdot 10^{\frac{P[\text{dBm}]}{10}}$
 - $P[\mu\text{W}] = 10^{\frac{30+P[\text{dBm}]}{10}}$

Examen: Reprezentare logaritmică

- Relatii empirice

- $\lambda[\mu\text{m}] = \frac{1.240}{E_g[\text{eV}]}$

- uneori cu corespondenta fizica $E_g = h\nu; \lambda = \frac{hc}{E_g}$

- Puteri

- $1\text{mW} = 10^3\mu\text{W}; 1\mu\text{W} = 10^{-3}\text{mW}$

- Empiric

- $P[\mu\text{W}] = 10^3 \cdot P[\text{mW}]!!$

- Ex: $P = 1.2\text{mW} = 1200\mu\text{W}$

Examen

- Operatii cu numere complexe!
- $z = a + j \cdot b ; j^2 = -1$

Linii de transmisie in mod TEM

Cuprins

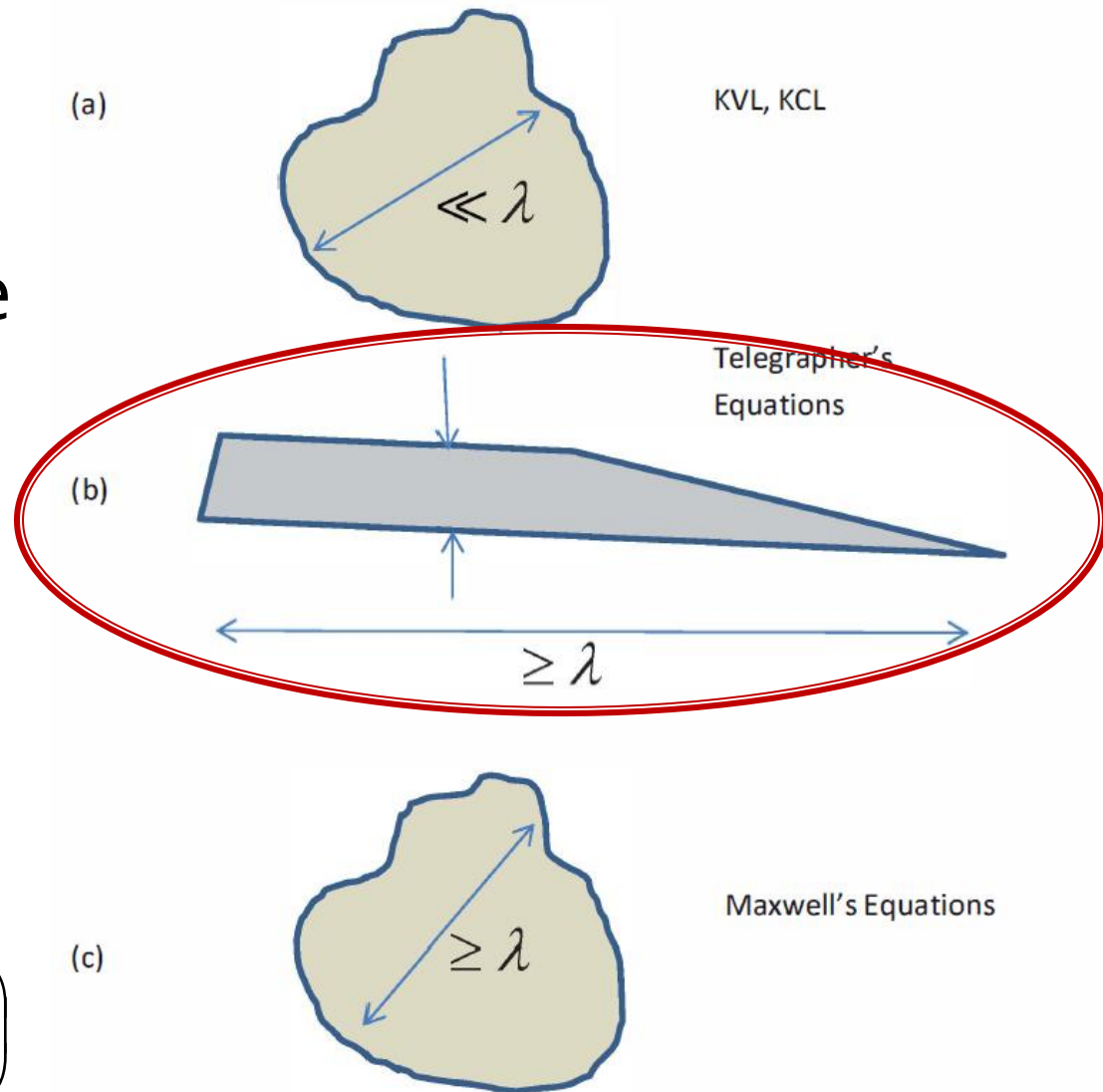
- **Linii de transmisie**
- **Adaptarea de impedanță**
- **Cuploare direcționale**
- **Divizoare de putere**
- **Amplificatoare de microunde**
- **Filtre de microunde**
- **Oscilatoare de microunde ?**

Lungime electrica

- Comportarea (descrierea) unui circuit depinde de lungimea sa electrica la frecventele de interes

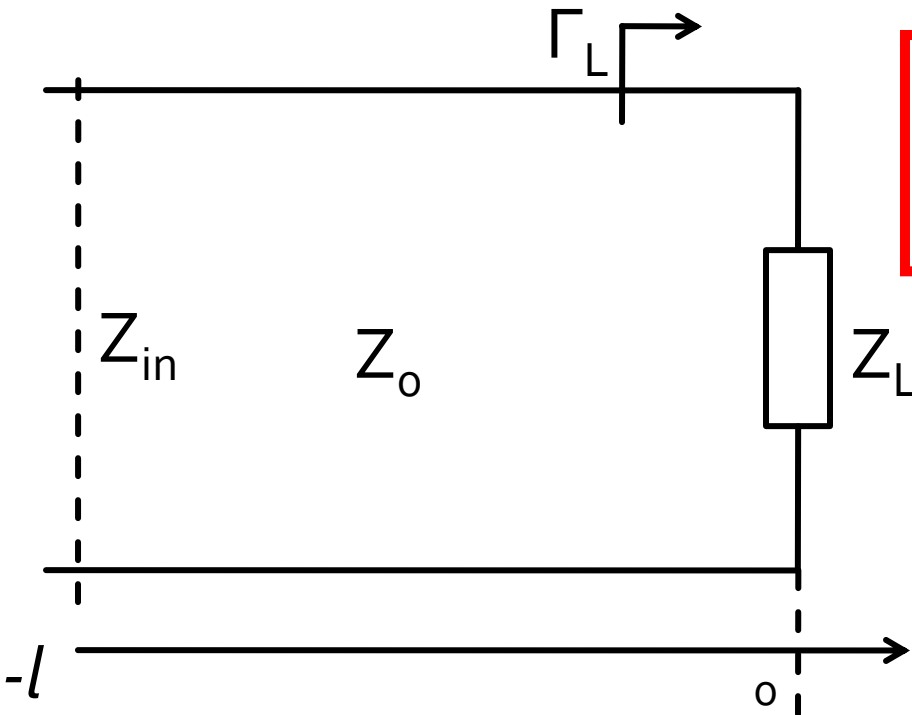
- $E \approx 0 \rightarrow$ Kirchhoff
- $E > 0 \rightarrow$ propagare

$$E = \beta \cdot l = \frac{2\pi}{\lambda} \cdot l = 2\pi \cdot \left(\frac{l}{\lambda} \right)$$



Linie fara pierderi

- impedanta la intrarea liniei de impedanta caracteristica Z_0 , de lungime l , terminata cu impedanta Z_L



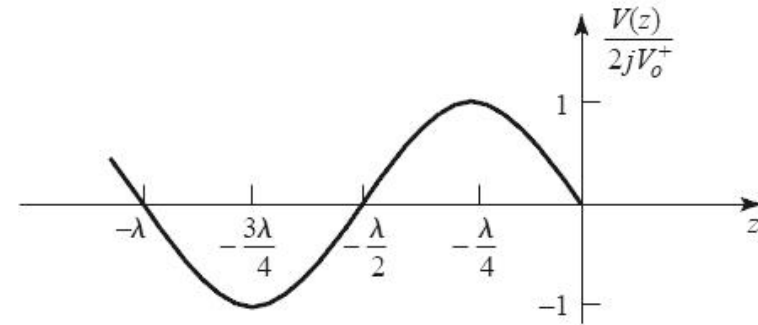
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Linie în scurtcircuit

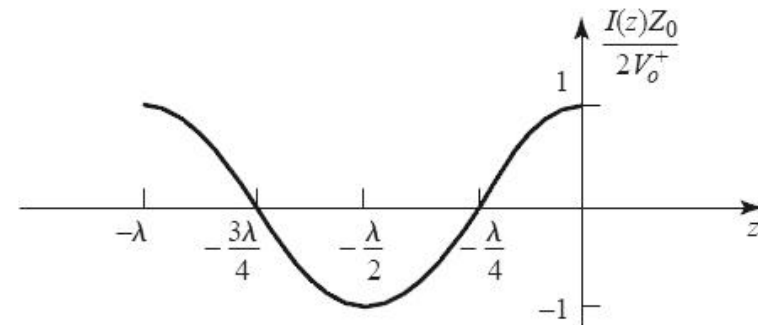
- $Z_L = 0$
- reactanța pură
 - +/- → în funcție de l

$$Z_{in} = j \cdot Z_0 \cdot \tan \beta \cdot l$$

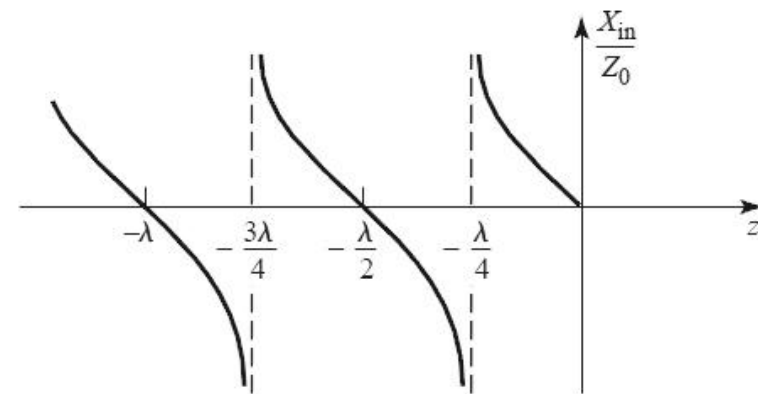
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan(\beta \cdot l)}{Z_0 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$



(a)



(b)



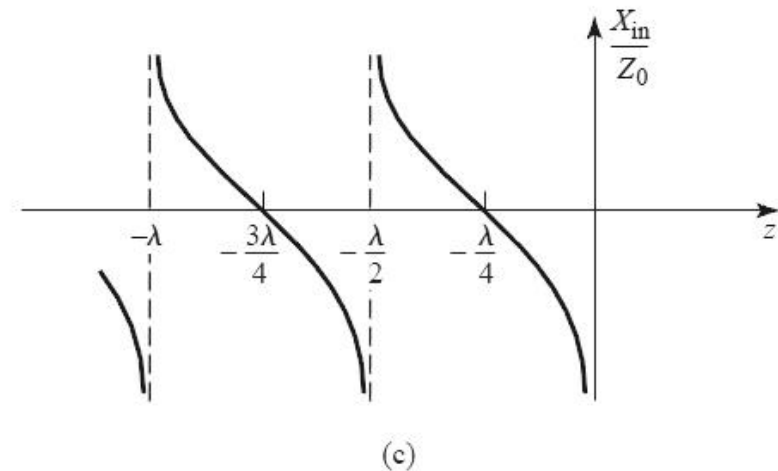
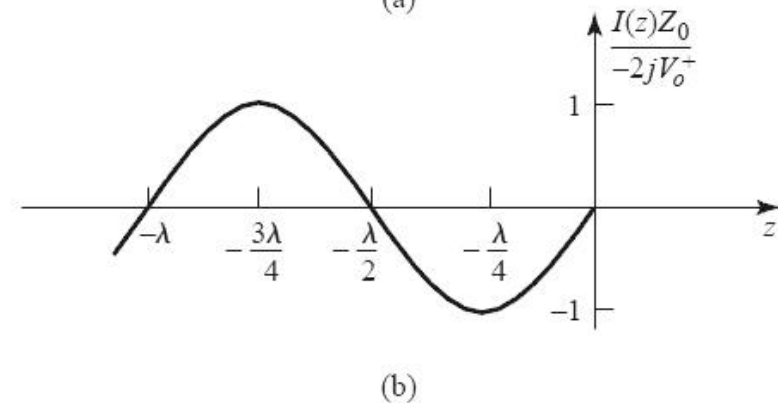
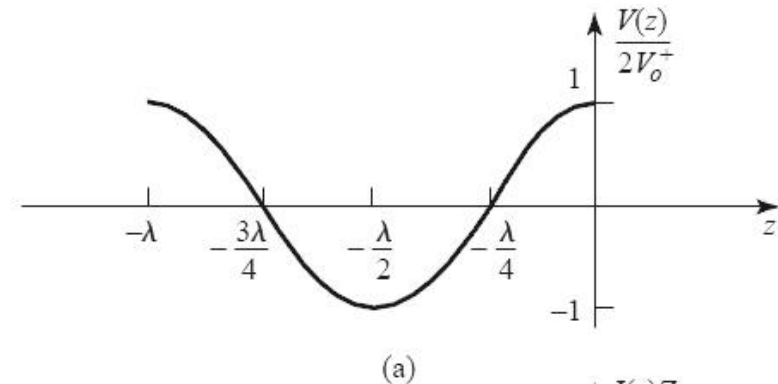
(c)

Linie în gol

- $Z_L = \infty \rightarrow 1/Z_L = 0$
- reactanța pură
 - +/- $\rightarrow$ în funcție de l

$$Z_{in} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan(\beta \cdot l)}{Z_0 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$



Adaptarea de impedanță

Diagrama Smith

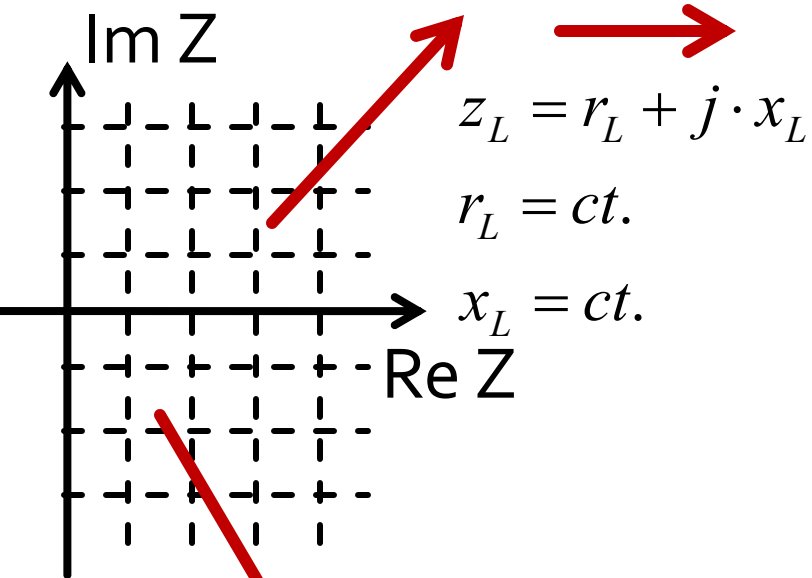
Cuprins

- Linii de transmisie
- **Adaptarea de impedanță**
- Cuploare direcționale
- Divizoare de putere
- Amplificatoare de microunde
- Filtre de microunde
- Oscilatoare de microunde ?

[illegible]

Diagrama Smith

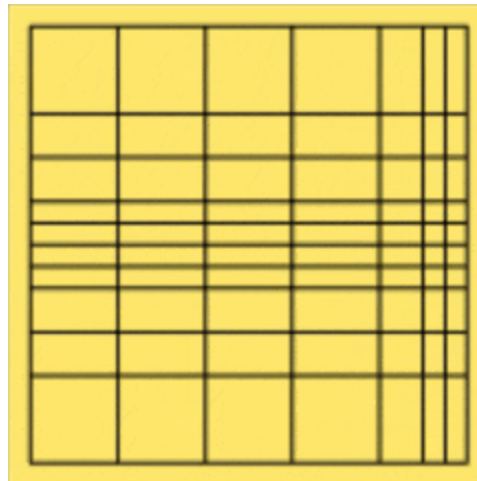
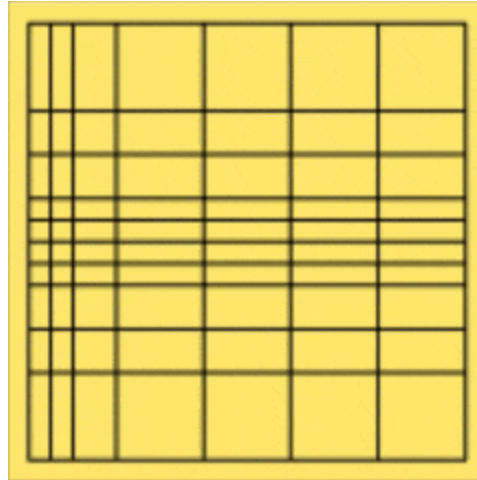
$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1}$$



$$z_L = r_L + j \cdot x_L$$

$$r_L = ct.$$

$$x_L = ct.$$



$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{Y_0 - Y_L}{Y_0 + Y_L} = \frac{1 - y_L}{1 + y_L}$$

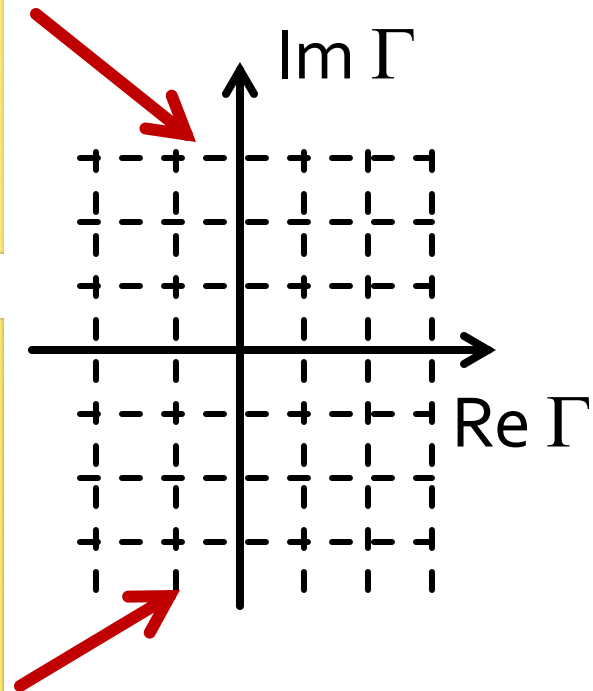


Diagrama Smith

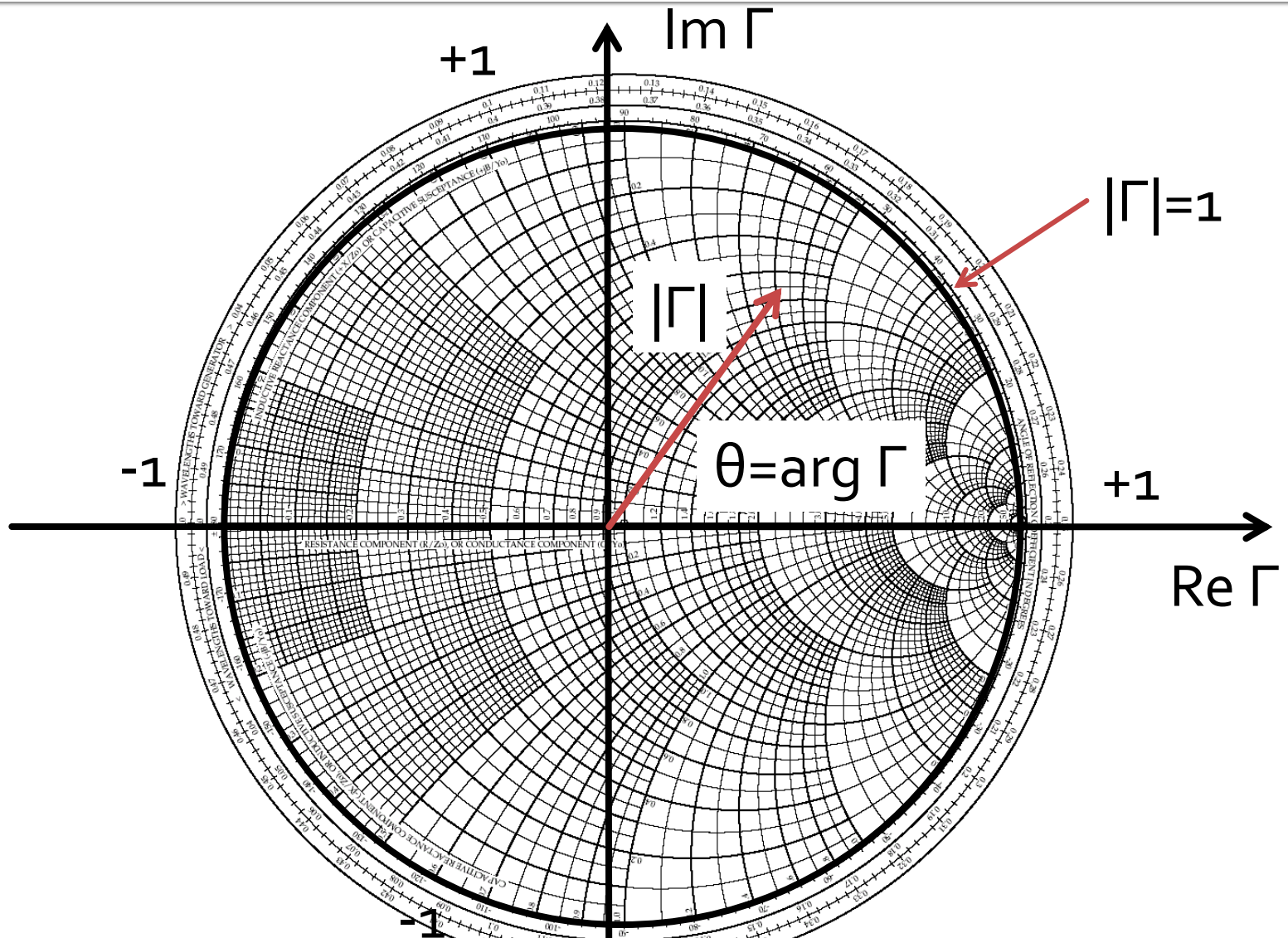


Diagrama Smith

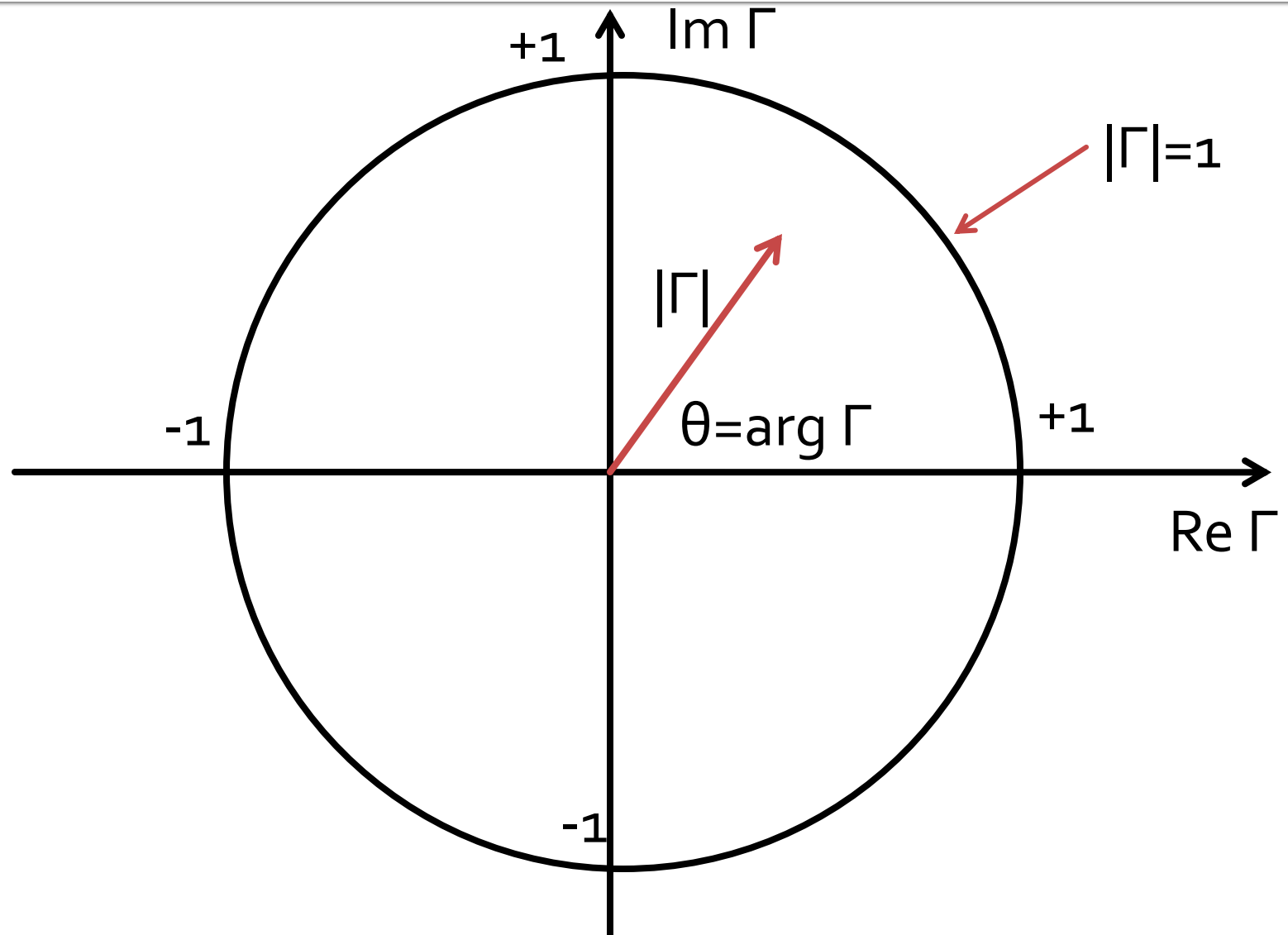


Diagrama Smith, rezistentă

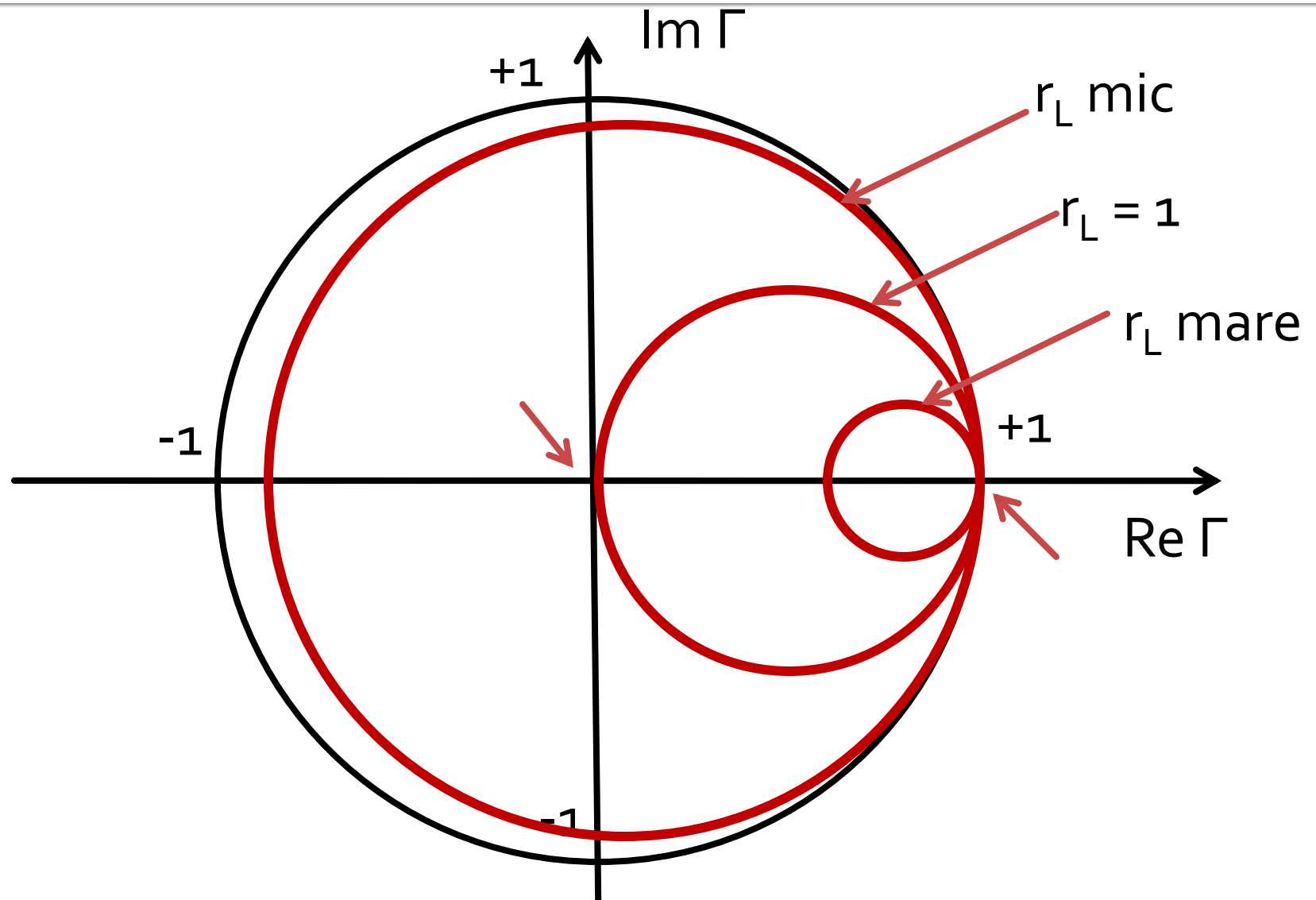


Diagrama Smith, reactanta

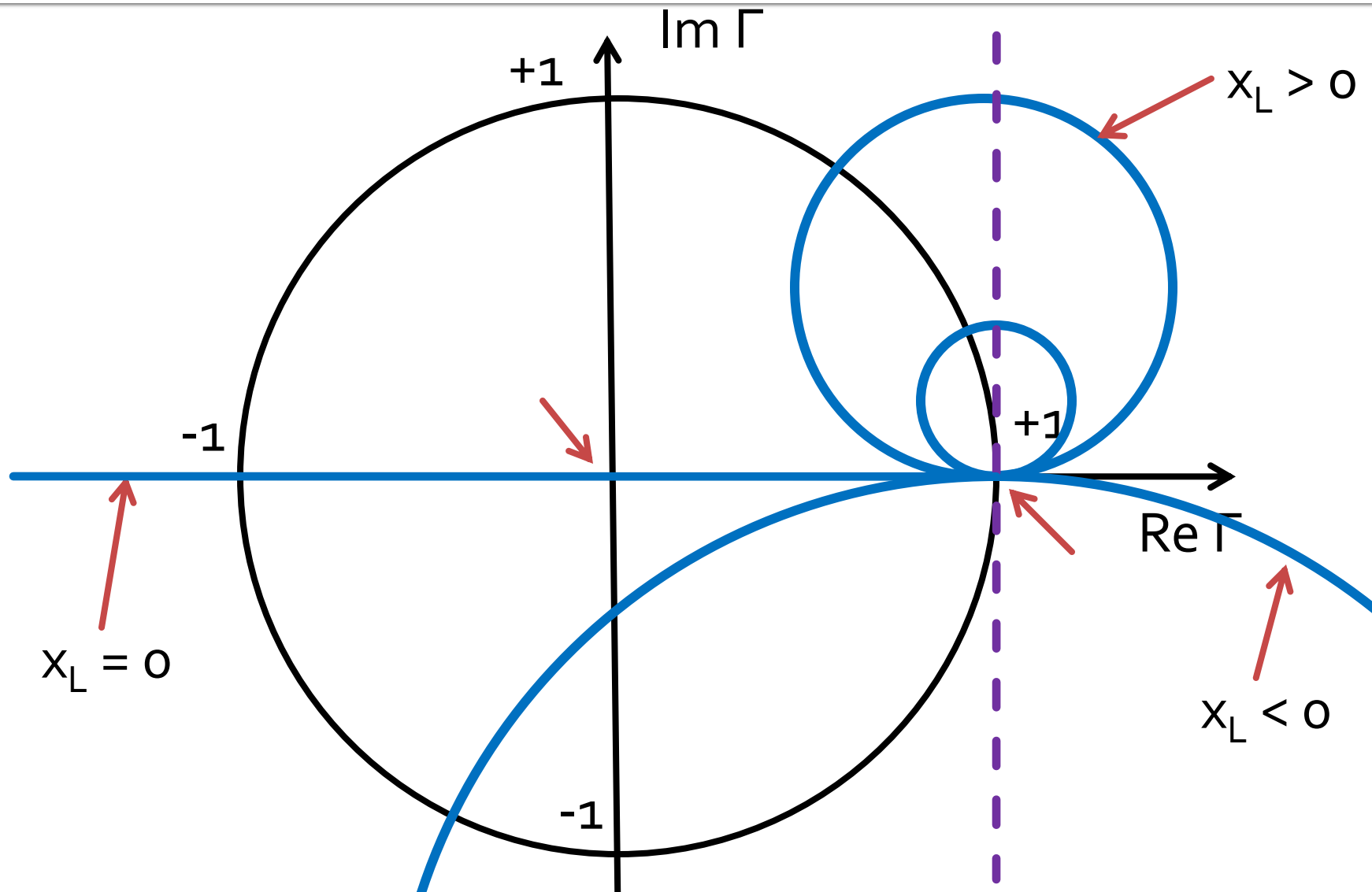


Diagrama Smith, impedanta

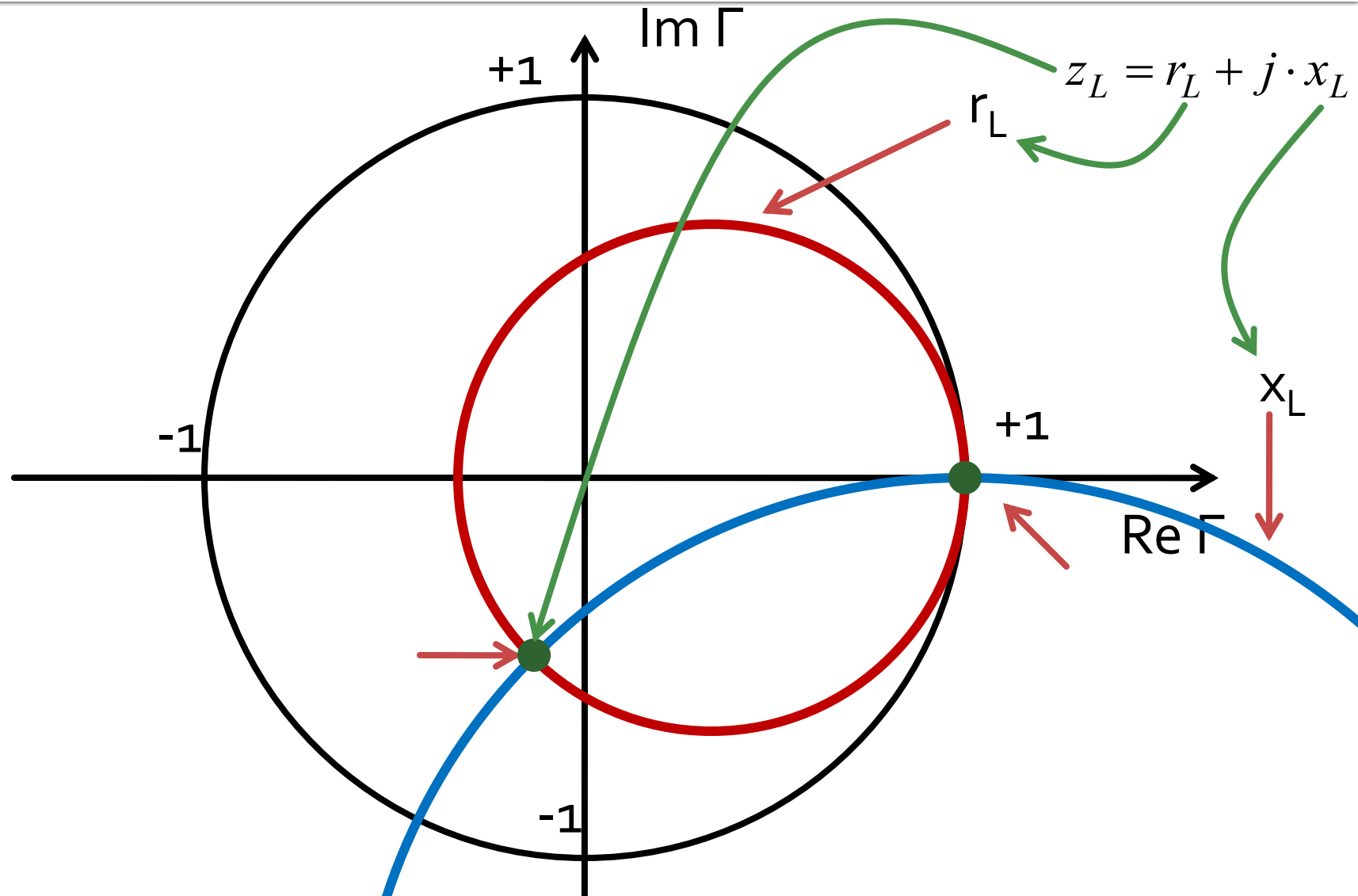
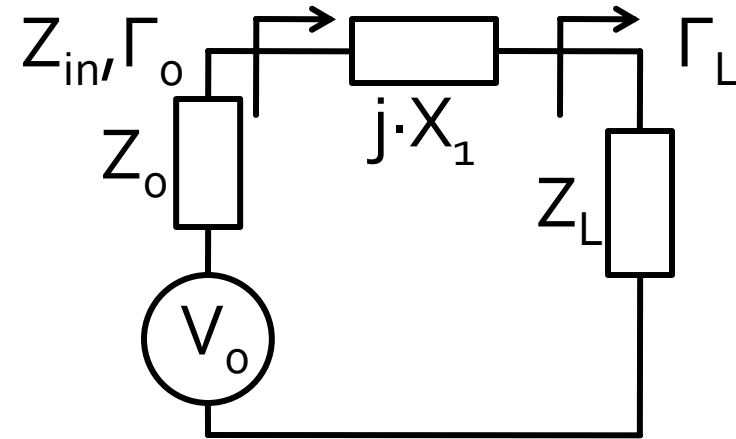
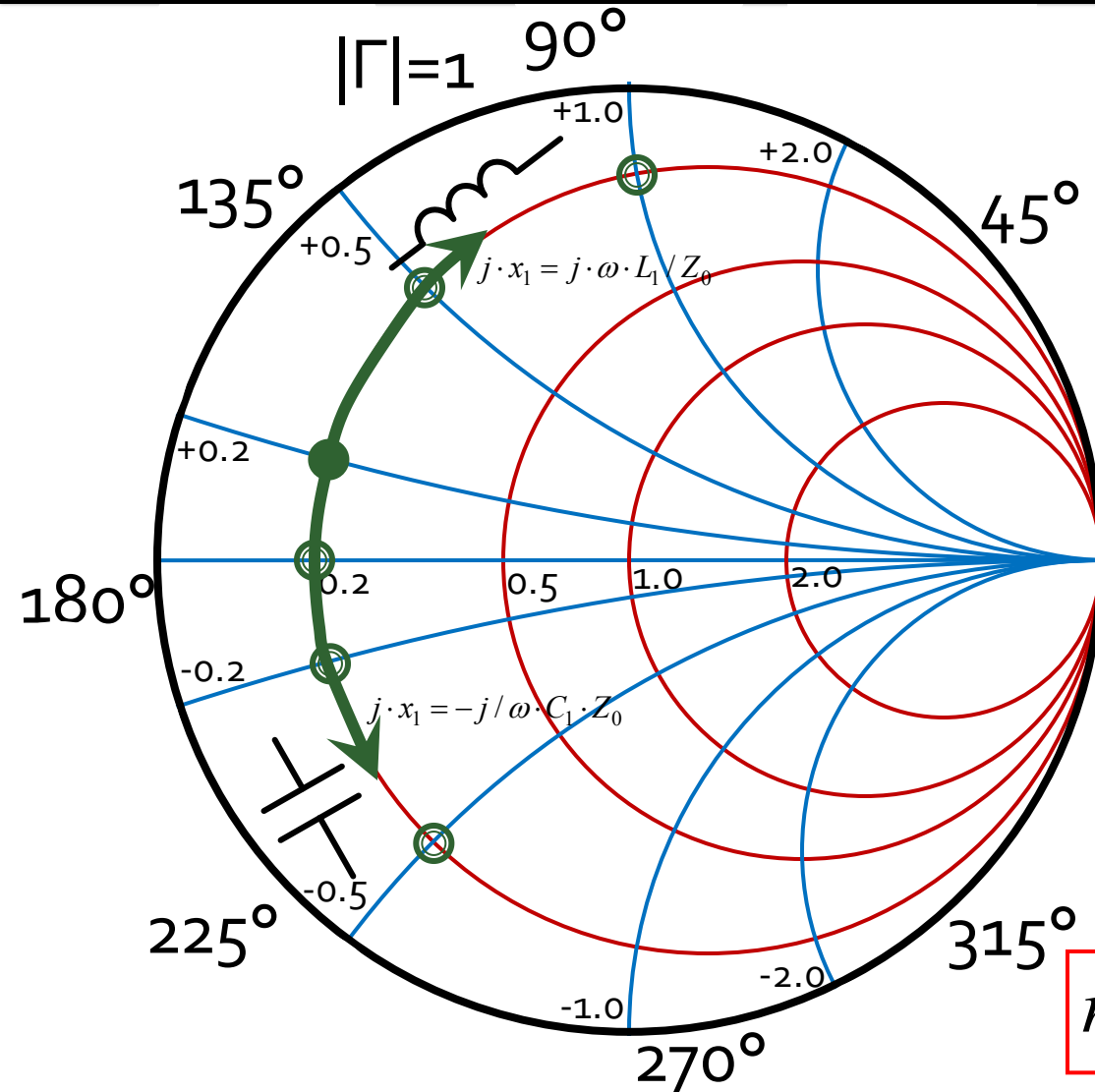


Diagrama Smith, coeficient de reflexie, reactanta in serie



$$Z_0 = 50\Omega$$

$$Z_L = R_L + j \cdot X_L = 10\Omega + j \cdot 10\Omega$$

$$z_L = r_L + j \cdot x_L = 0.2 + j \cdot 0.2$$

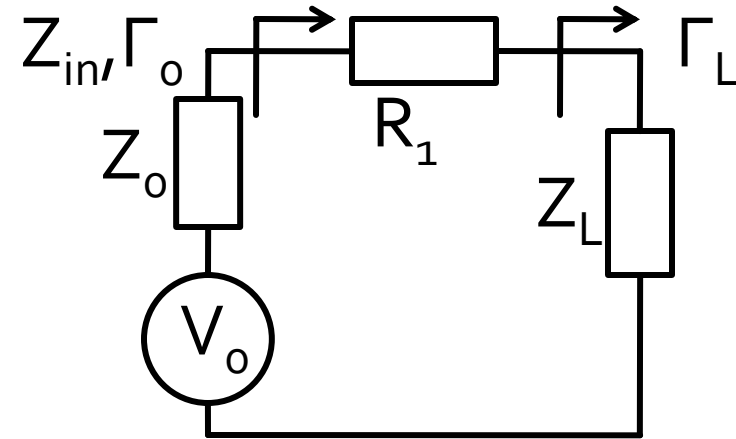
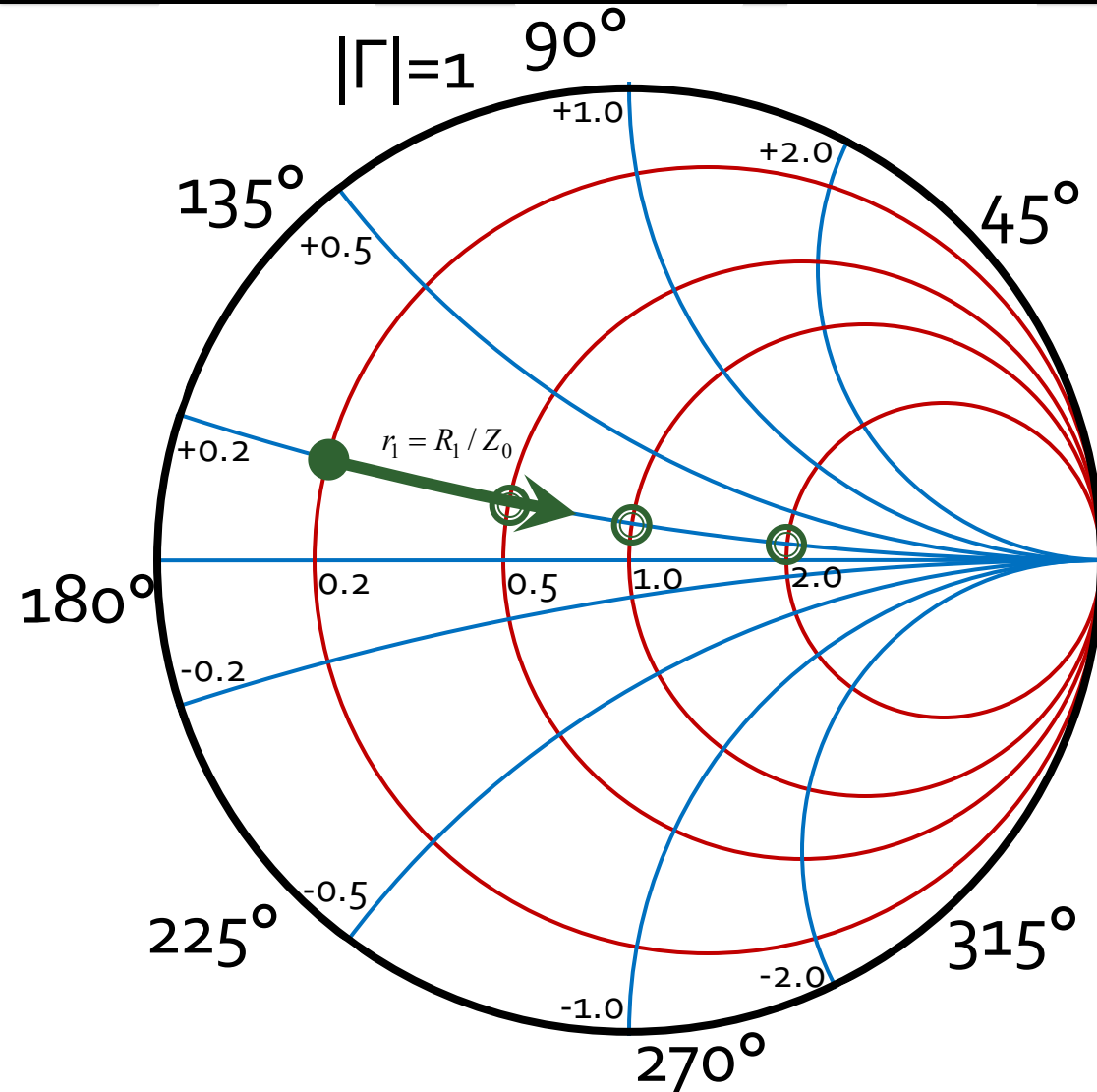
$$\Gamma_L = 0.678 \angle 156.5^\circ$$

$$Z_{in} = Z_L + j \cdot X_1 = R_L + j \cdot (X_L + X_1)$$

$$z_{in} = r_L + j \cdot (x_L + x_1)$$

$$r_{in} = r_L \quad \begin{aligned} j \cdot x_1 &= j \cdot \omega \cdot L_1 / Z_0 > 0 \\ j \cdot x_1 &= -j / \omega \cdot C_1 \cdot Z_0 < 0 \end{aligned}$$

Diagrama Smith, coeficient de reflexie, rezistenta in serie



$$Z_0 = 50\Omega$$

$$Z_L = R_L + j \cdot X_L = 10\Omega + j \cdot 10\Omega$$

$$z_L = r_L + j \cdot x_L = 0.2 + j \cdot 0.2$$

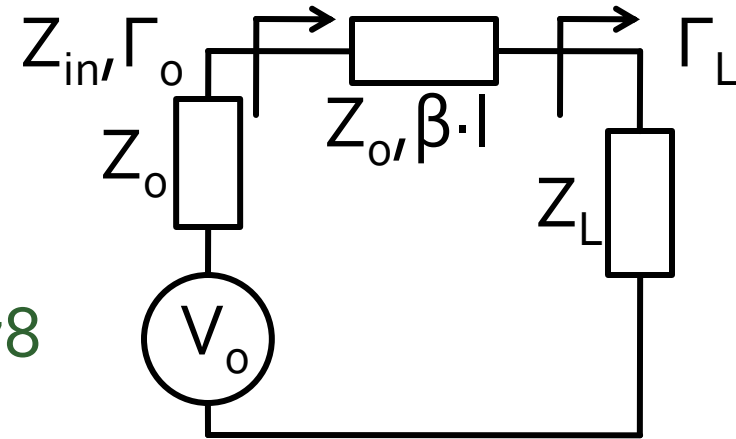
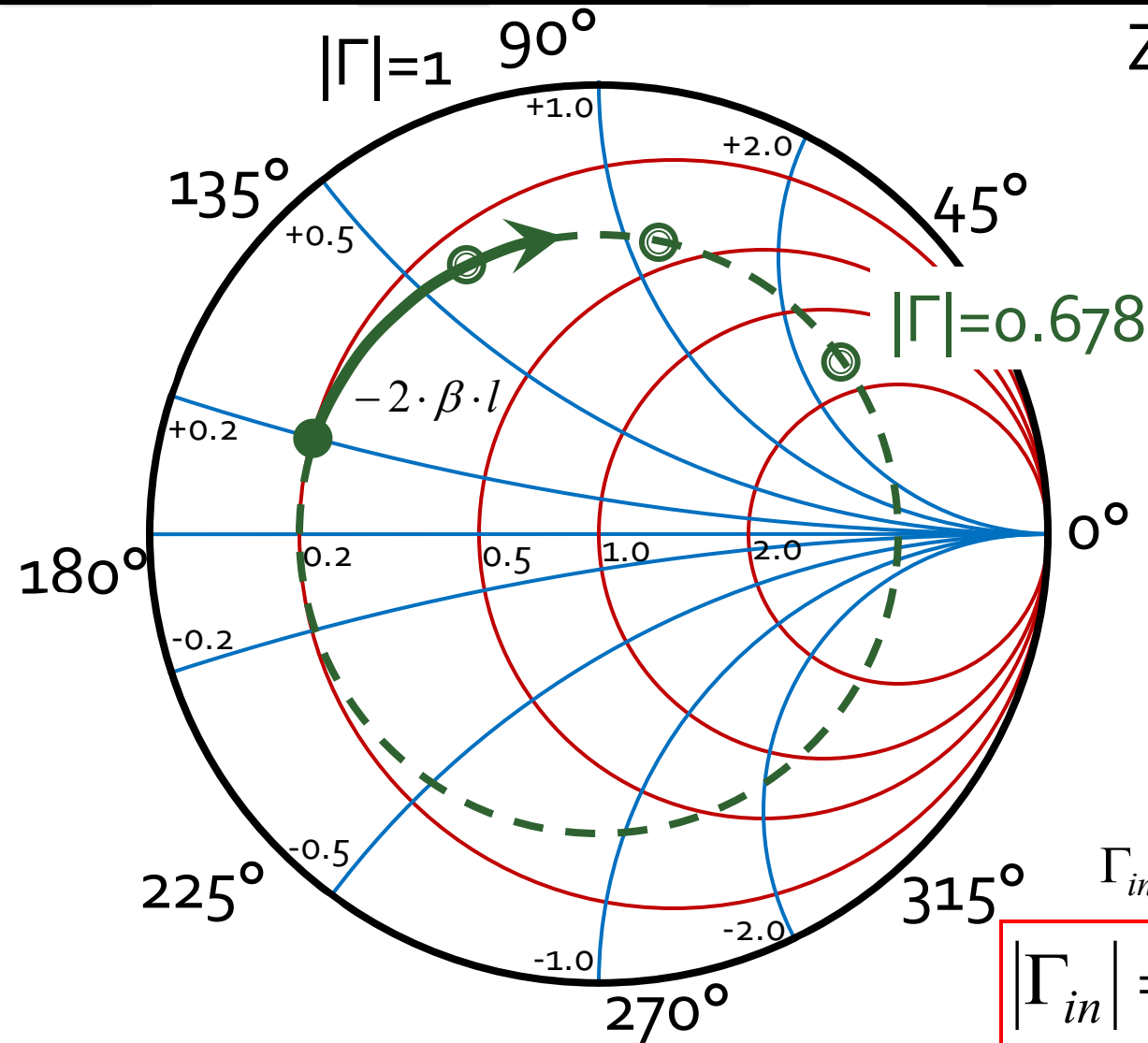
$$\Gamma_L = 0.678 \angle 156.5^\circ$$

$$Z_{in} = Z_L + R_1 = (R_L + R_1) + j \cdot X_L$$

$$z_{in} = z_L + r_1 = (r_L + r_1) + j \cdot x_L$$

$$x_{in} = x_L \quad r_{in} = r_L + R_1 / Z_0$$

Diagrama Smith, coeficient de reflexie, linie de transmisie in serie



$$Z_0 = 50\Omega$$

$$Z_L = R_L + j \cdot X_L = 10\Omega + j \cdot 10\Omega$$

$$z_L = r_L + j \cdot x_L = 0.2 + j \cdot 0.2$$

$$\Gamma_L = 0.678 \angle 156.5^\circ$$

$$Z_{in} = Z_0 \cdot \frac{1 + \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}}{1 - \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}}$$

$$\Gamma_{in} = \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}$$

$$|\Gamma_{in}| = |\Gamma_L| \quad \arg(\Gamma_{in}) = \arg(\Gamma_L) - 2 \cdot \beta \cdot l$$

Diagrama Smith, conductanta

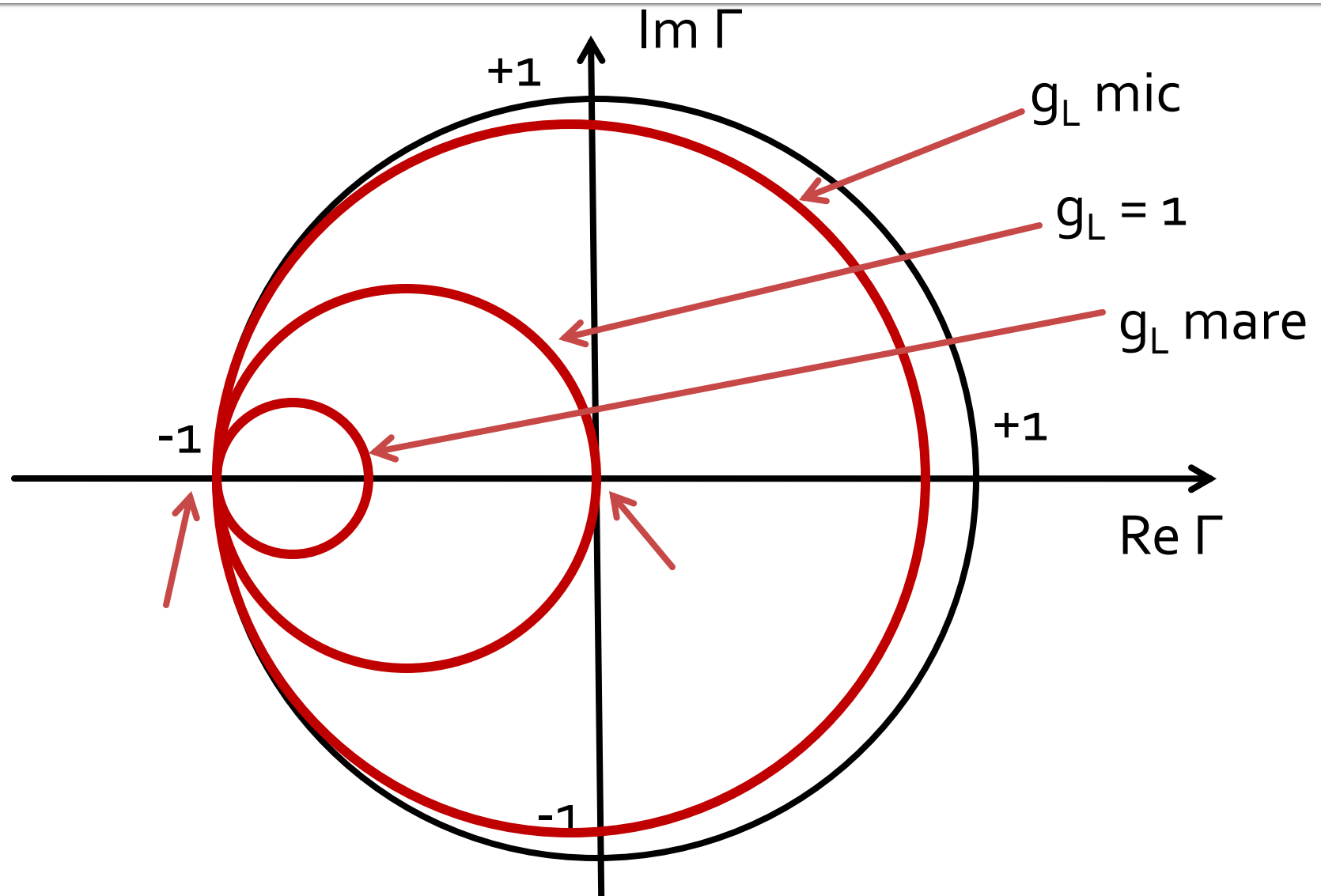


Diagrama Smith, susceptanta

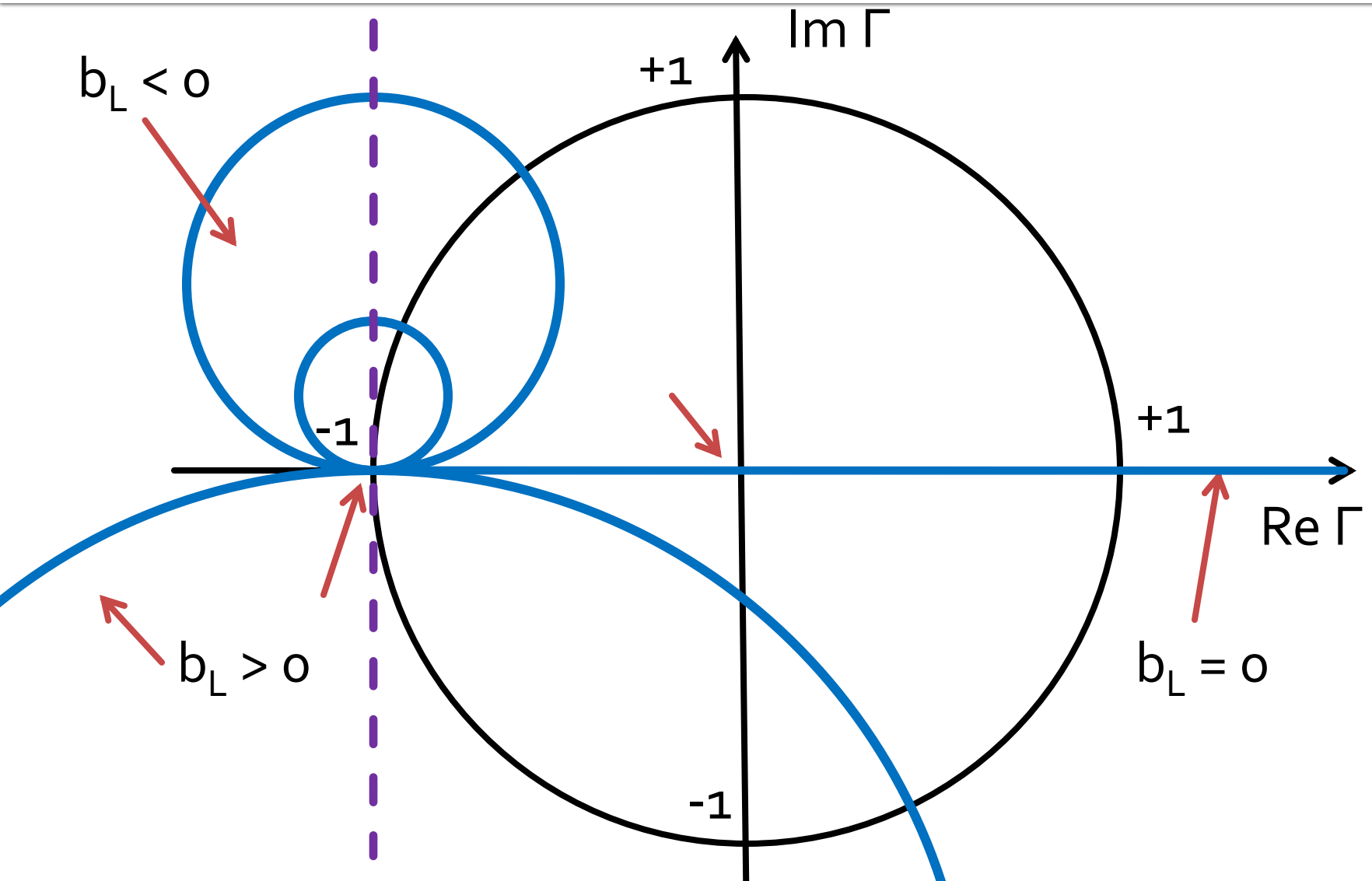
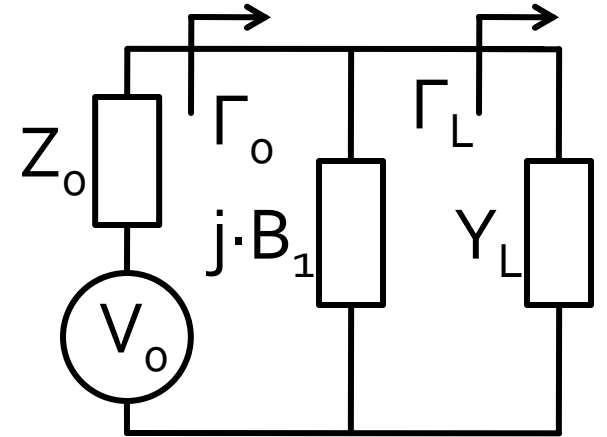
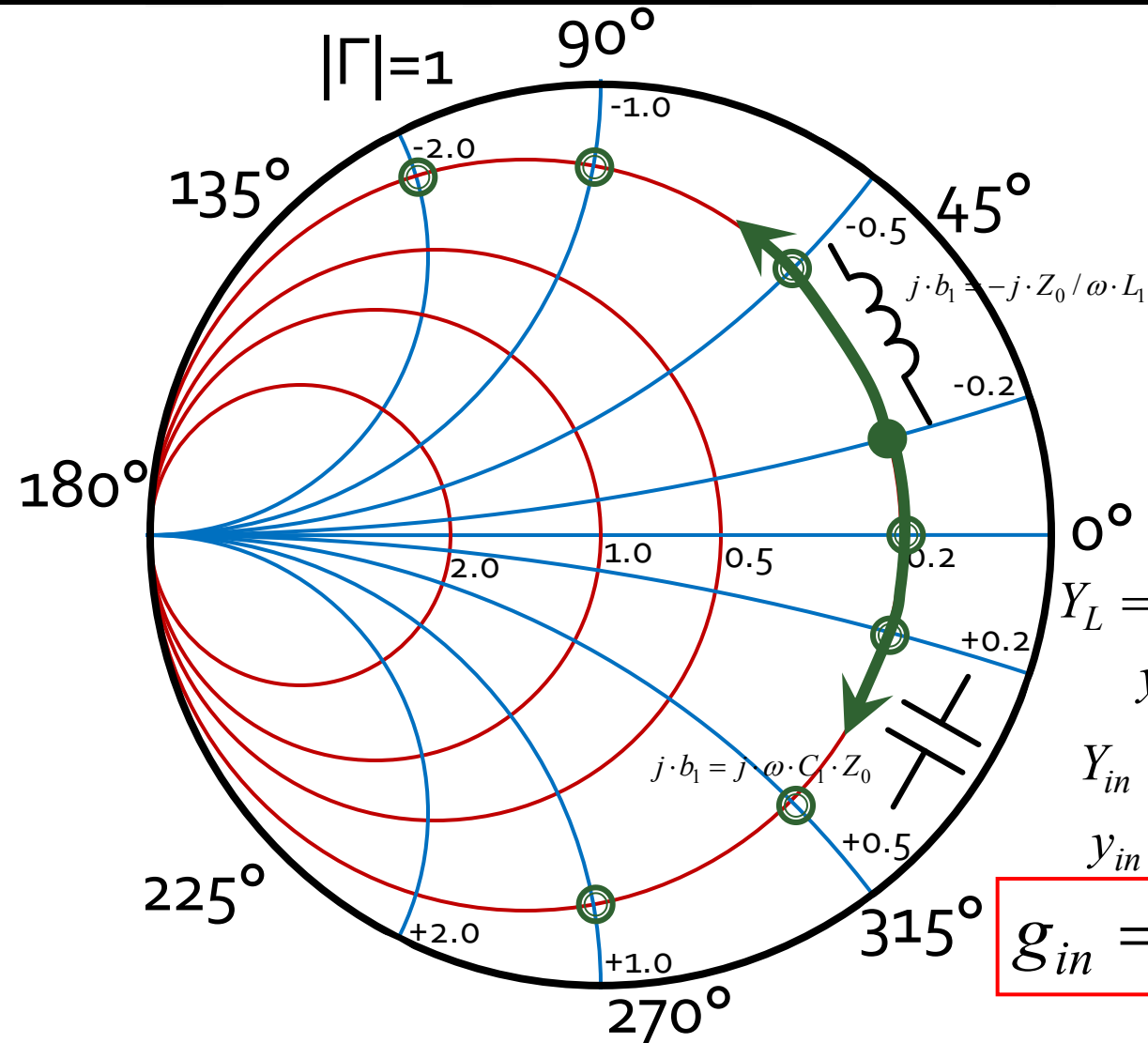


Diagrama Smith, coeficient de reflexie, susceptanta in paralel



$$Z_0 = 50\Omega, Y_0 = 0.02S$$

$$\Gamma_L = 0.678 \angle 23.5^\circ$$

$$Y_L = G_L + j \cdot B_L = 0.004S + j \cdot 0.004$$

$$y_L = g_L + j \cdot b_L = 0.2 - j \cdot 0.2$$

$$Y_{in} = Y_L + j \cdot B_1 = G_L + j \cdot (B_L + B_1)$$

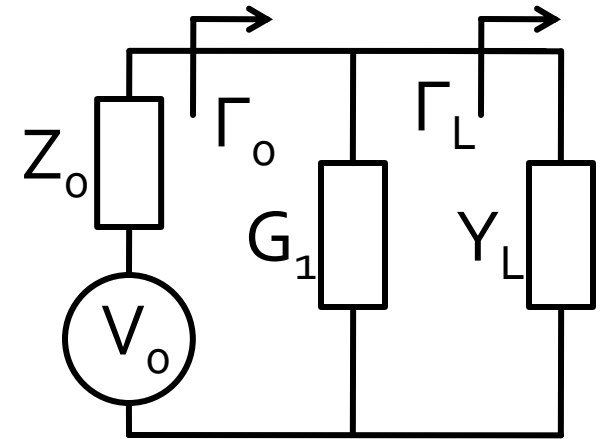
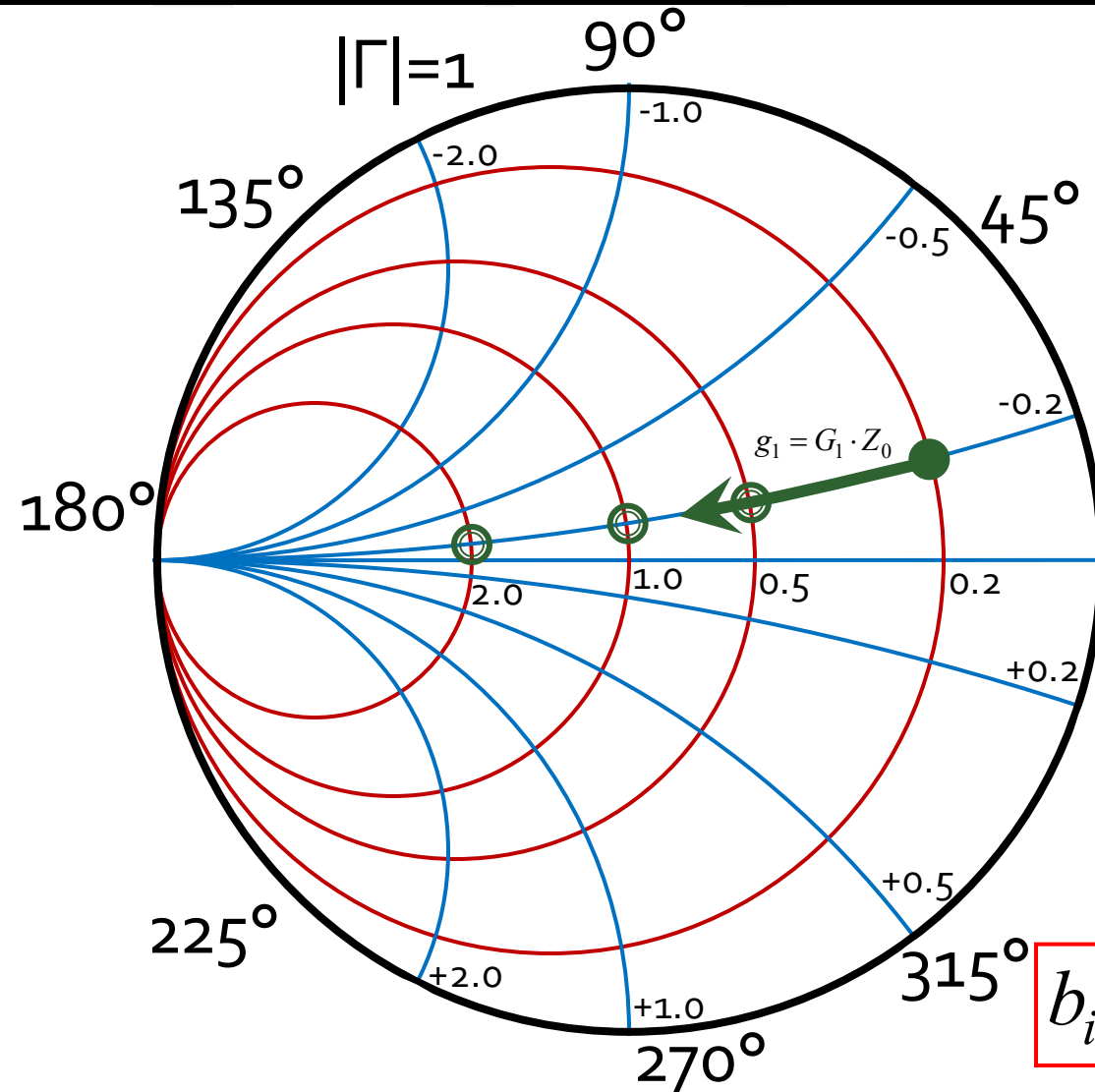
$$y_{in} = g_L + j \cdot (b_L + b_1)$$

$$g_{in} = g_L$$

$$j \cdot b_1 = j \cdot \omega \cdot C_1 \cdot Z_0 > 0$$

$$j \cdot b_1 = -j \cdot Z_0 / \omega \cdot L_1 < 0$$

Diagrama Smith, coeficient de reflexie, conductanta in paralel



$$Z_0 = 50\Omega, Y_0 = 0.02S$$

$$\Gamma_L = 0.678 \angle 23.5^\circ$$

$$Y_L = G_L + j \cdot B_L = 0.004S + j \cdot 0.004$$

$$y_L = g_L + j \cdot b_L = 0.2 - j \cdot 0.2$$

$$Y_{in} = Y_L + G_1 = (G_L + G_1) + j \cdot B_L$$

$$y_{in} = (g_L + g_1) + j \cdot b_L$$

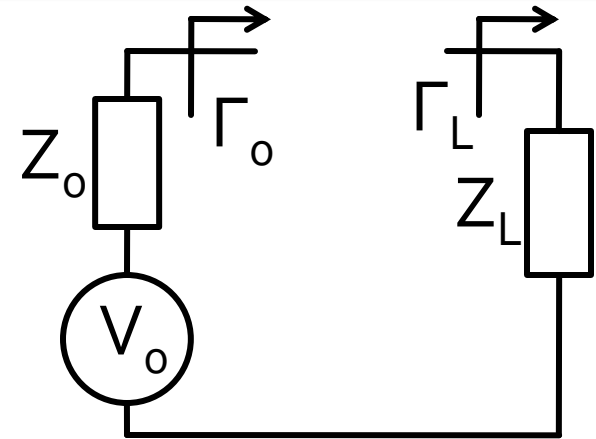
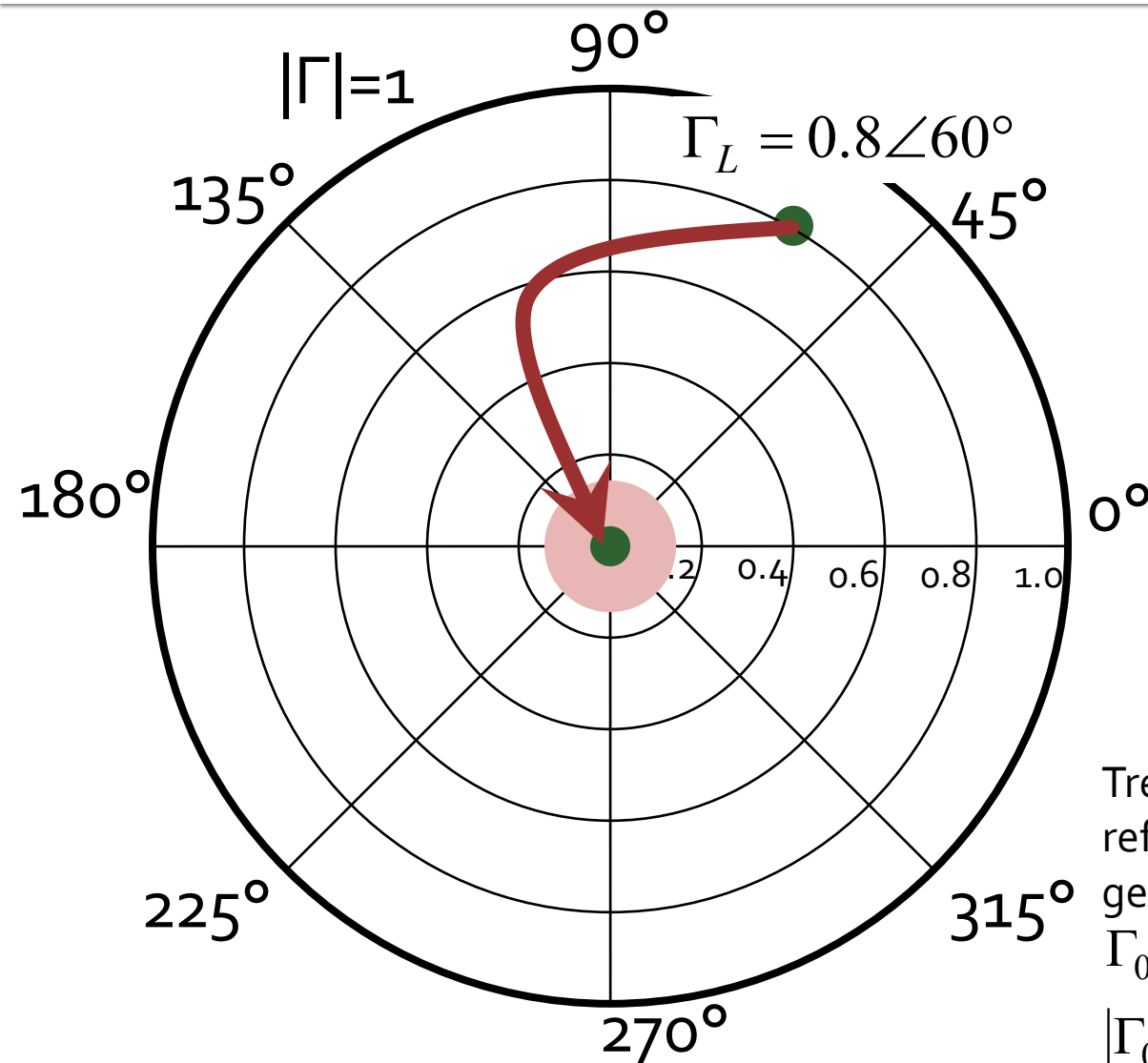
$$b_{in} = b_L$$

$$g_{in} = g_L + G_1 \cdot Z_0$$

Adaptarea de impedanță

Adaptarea cu elemente concentrate (Retele in L)

Diagrama Smith, adaptare



Adaptare Z_L la Z_0 . Se raporteaza Z_L la Z_0

$$Z_L = 21.429\Omega + j \cdot 82.479\Omega$$

$$z_L = 0.429 + j \cdot 1.65$$

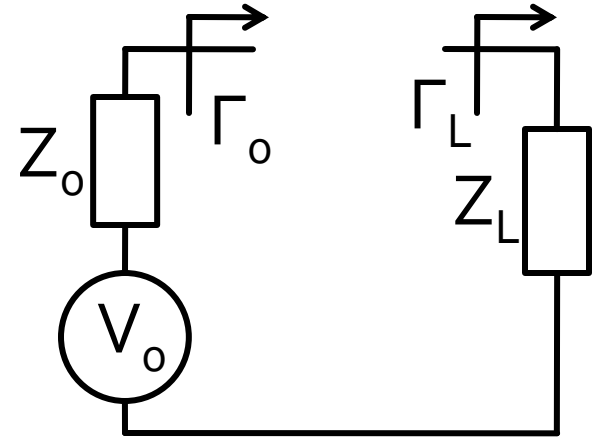
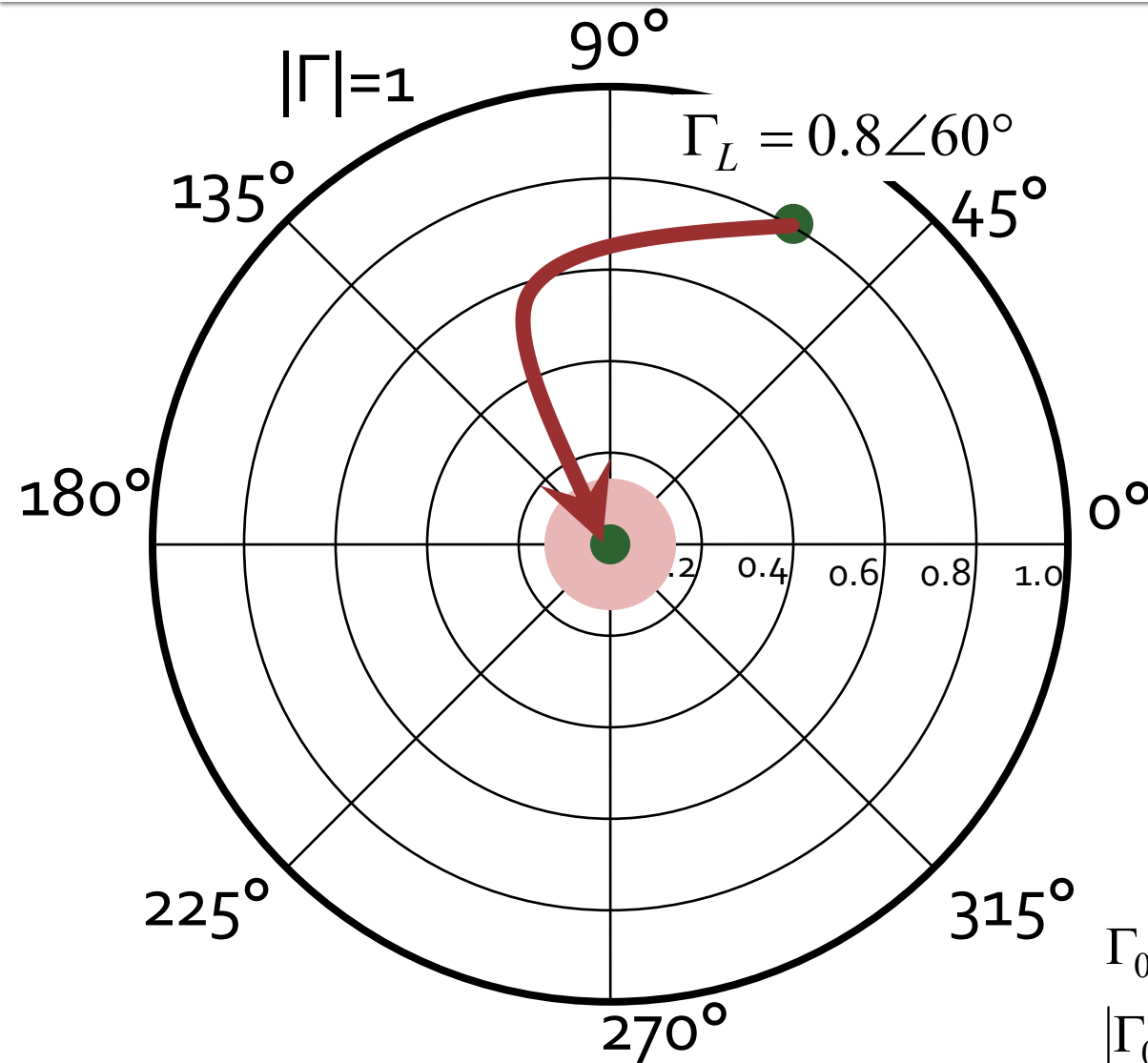
$$\Gamma_L = 0.8 \angle 60^\circ$$

Trebuie sa deplasez coeficientul de reflexie in zona in care pentru generator cu Z_0 am:

$\Gamma_0 = 0$ adaptare perfecta ●

$|\Gamma_0| \leq \Gamma_m$ adaptare "suficienta" ●

Adaptare de impedanță

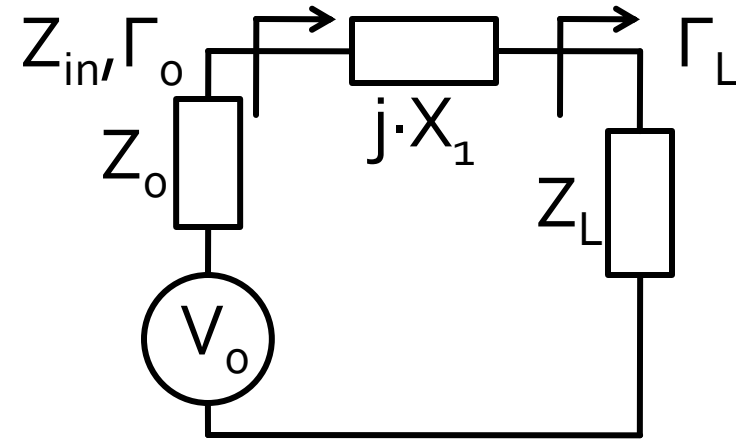
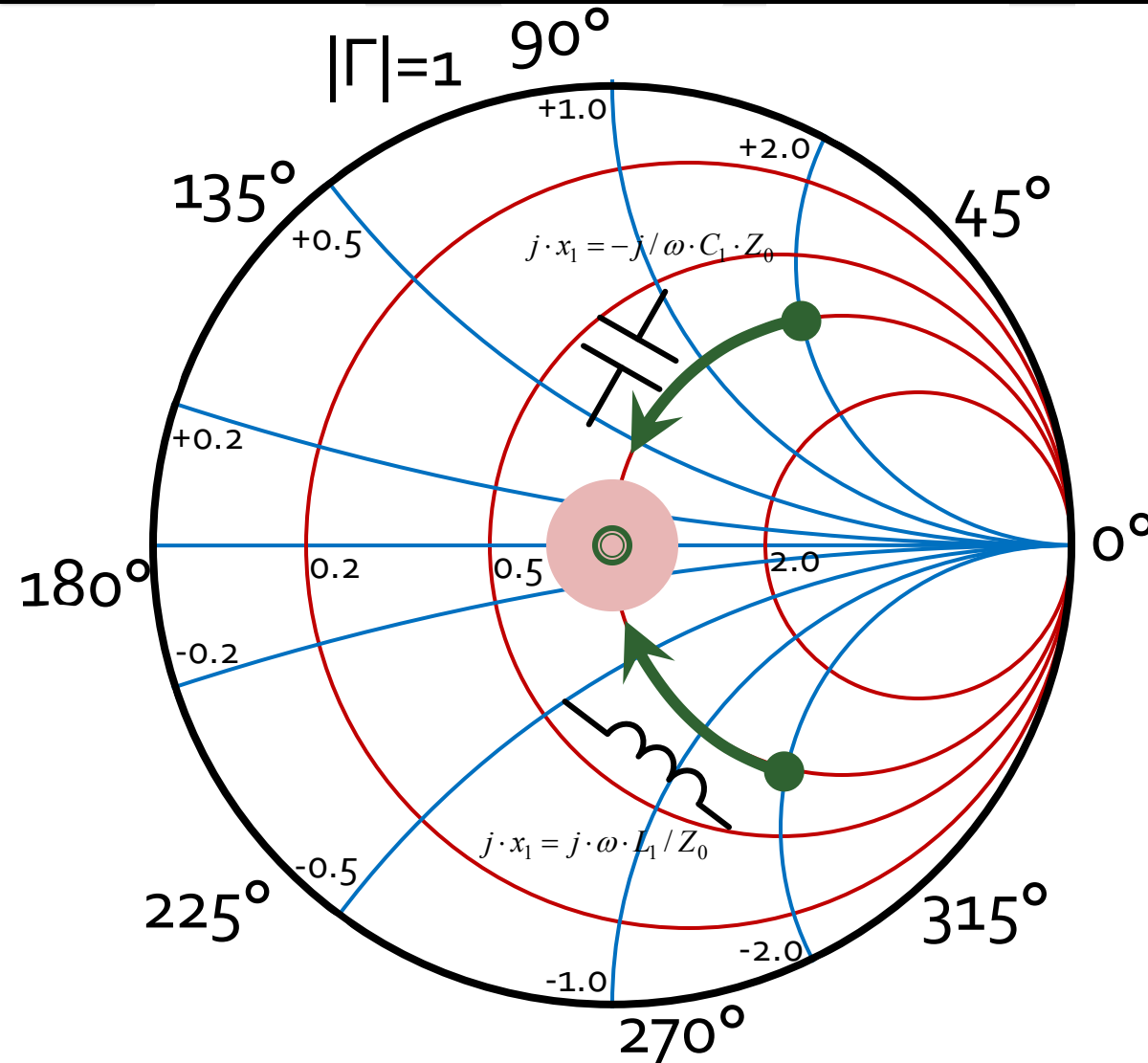


Cum?

$\Gamma_0 = 0$ adaptare perfecta ●

$|\Gamma_0| \leq \Gamma_m$ adaptare "suficienta" ●

Adaptare, reactanta in serie



$$Z_L = r_L + j \cdot x_L$$

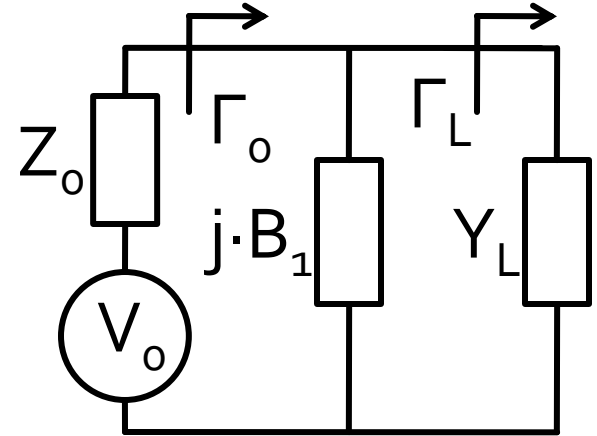
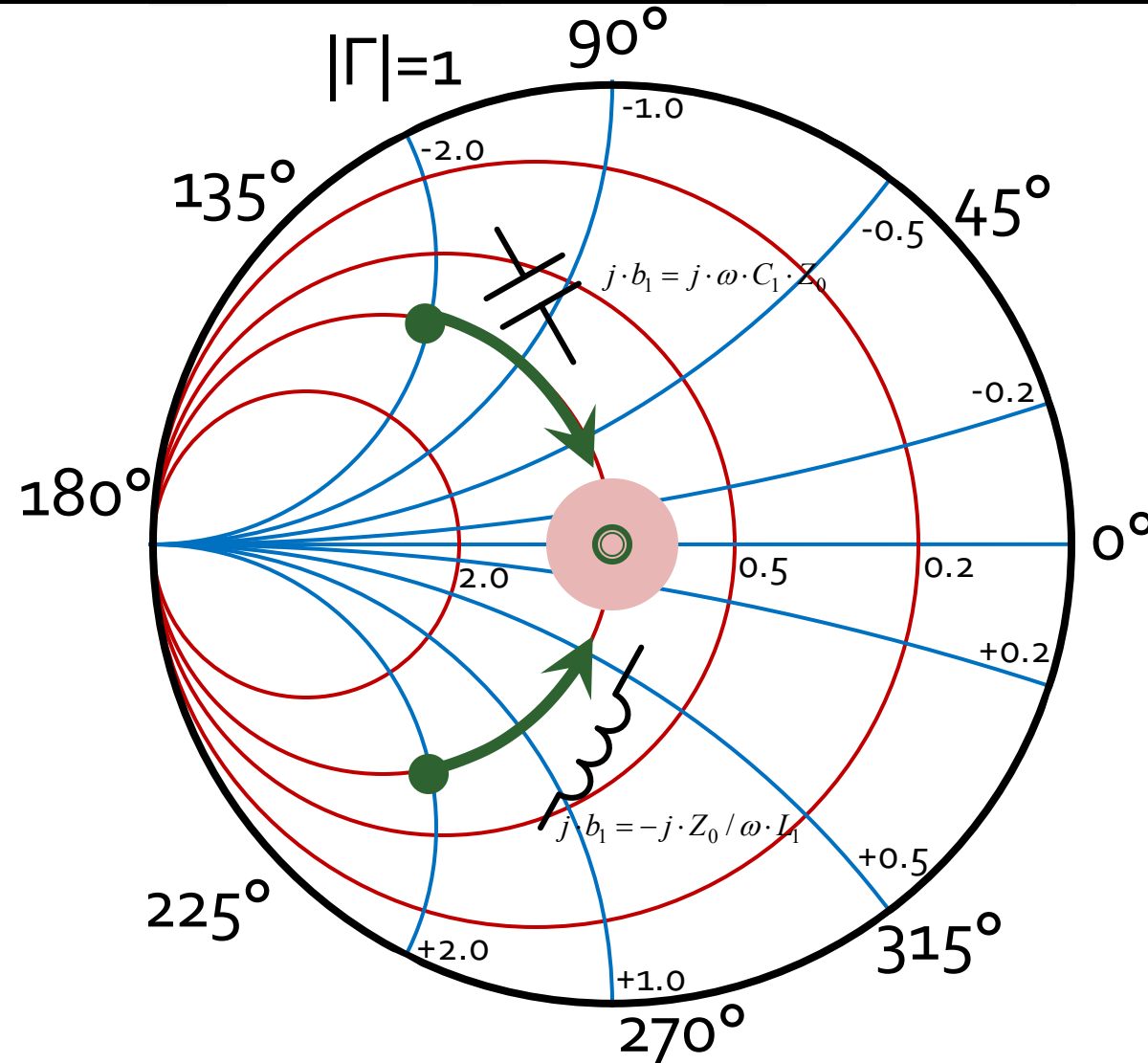
$$Z_{in} = r_L + j \cdot (x_L + x_1)$$

$$r_{in} = r_L$$

- Adaptarea se poate realiza **numai daca** $r_L = 1$
- se realizeaza compensarea partii reactive a sarcinii

$$j \cdot x_1 = -j \cdot x_L$$

Adaptare, susceptanta in paralel



$$y_L = g_L + j \cdot b_L$$

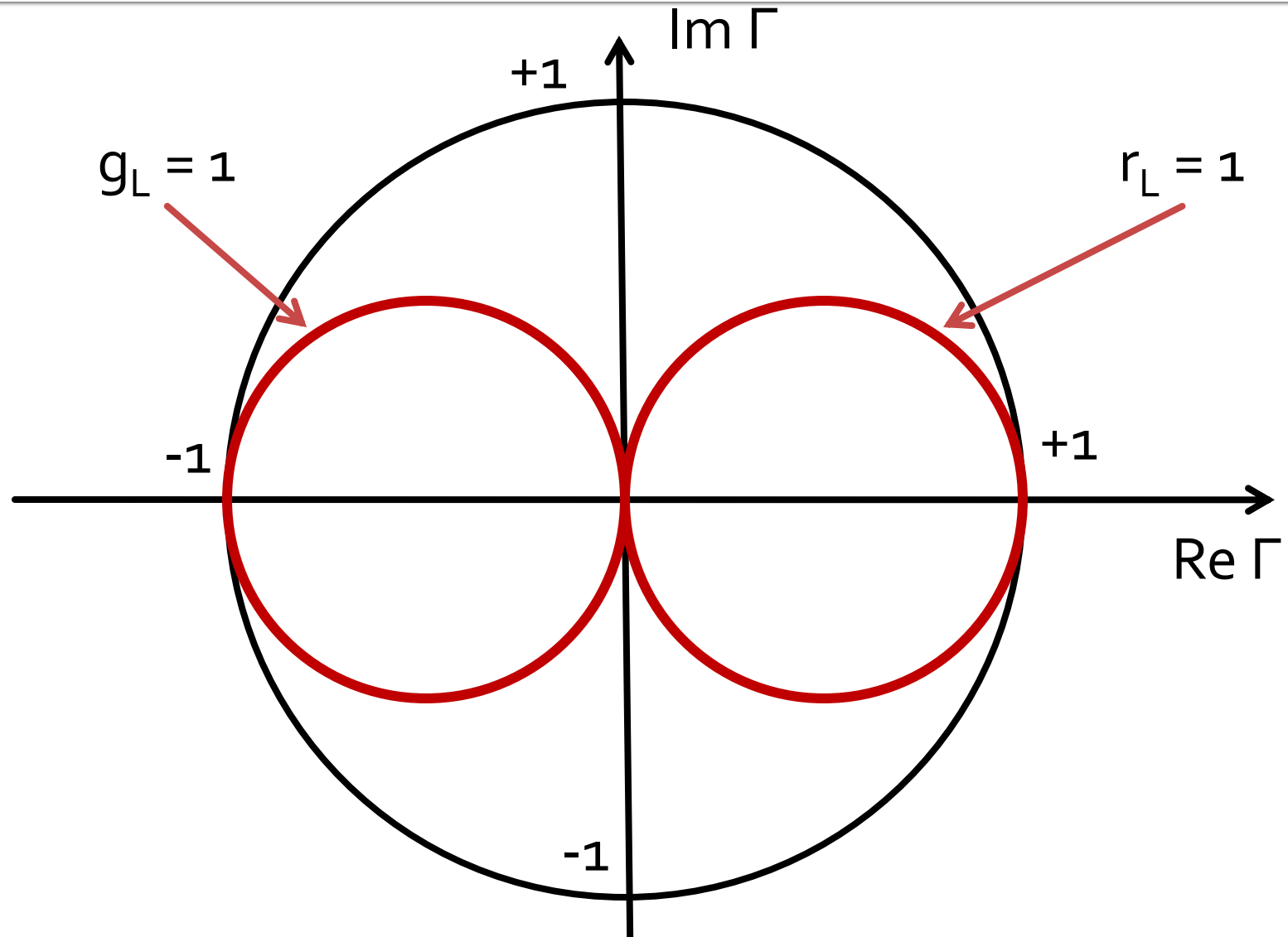
$$y_{in} = g_L + j \cdot (b_L + b_1)$$

$$g_{in} = g_L$$

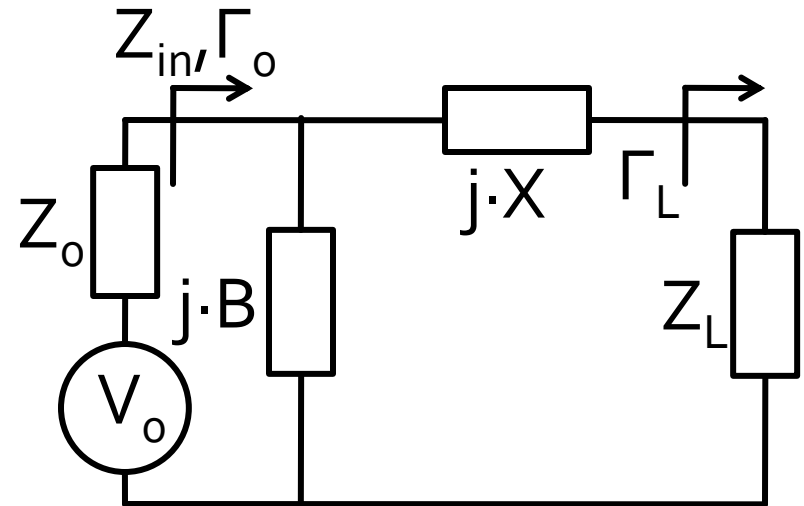
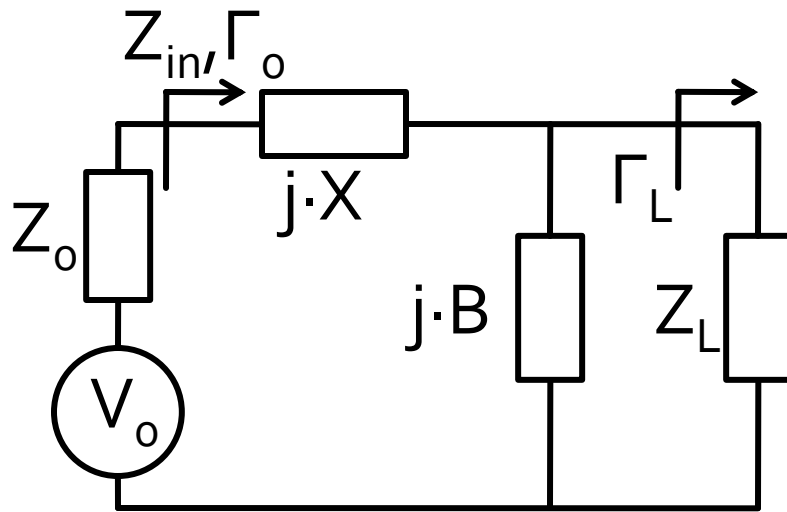
- Adaptarea se poate realiza **numai daca** $g_L = 1$
- se realizeaza compensarea partii reactive a sarcinii

$$j \cdot b_1 = -j \cdot b_L$$

Diagrama Smith, $r=1$ si $g=1$

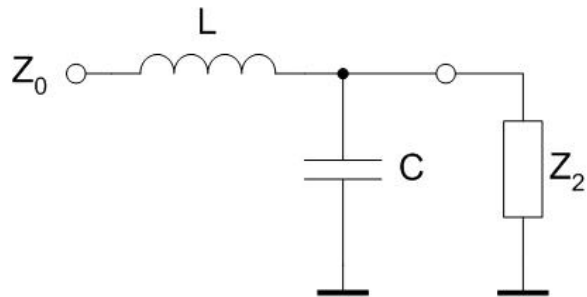
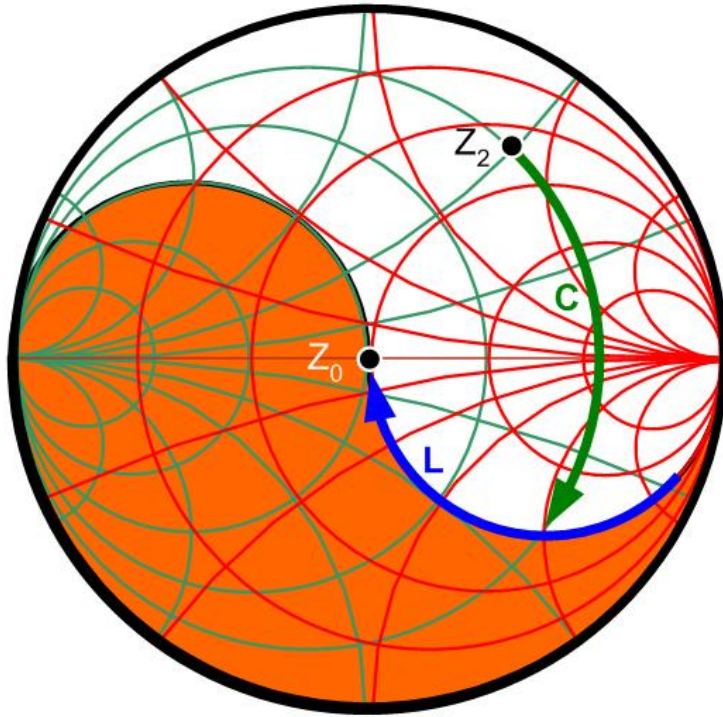


Adaptare cu doua elemente reactive (retele in L)

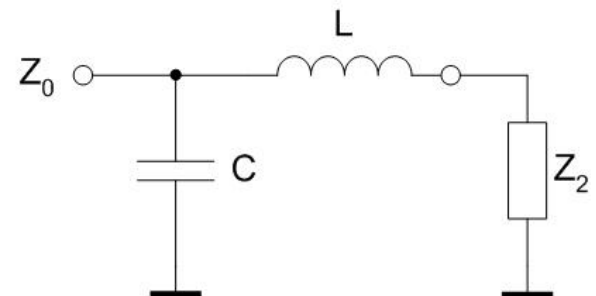
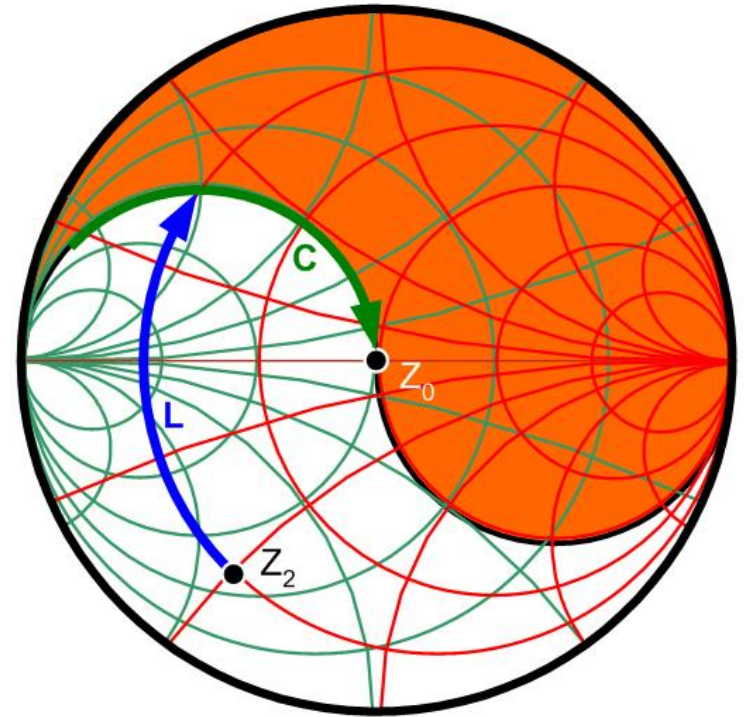


- Adaptare in **doi** pasi
 - un prim element muta coeficientul de reflexie **pe cercul** $r_L = 1/g_L = 1$
 - al doilea element realizeaza adaptarea

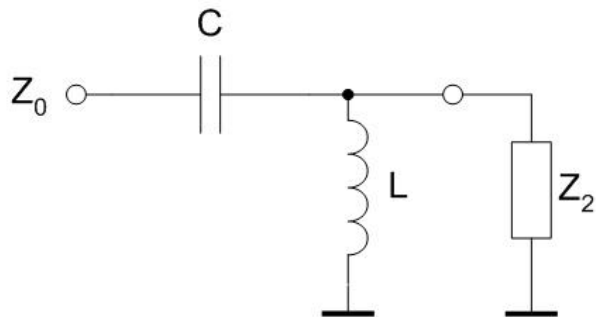
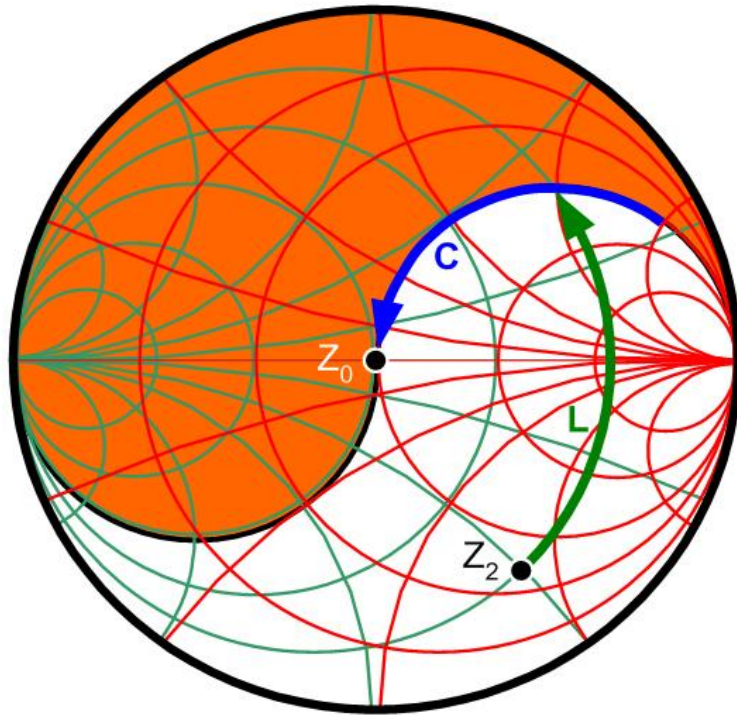
L serie, C paralel / C paralel, L serie



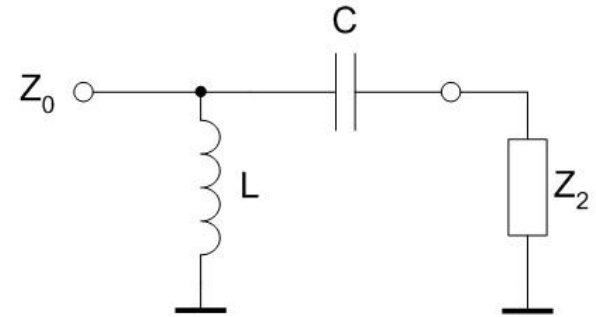
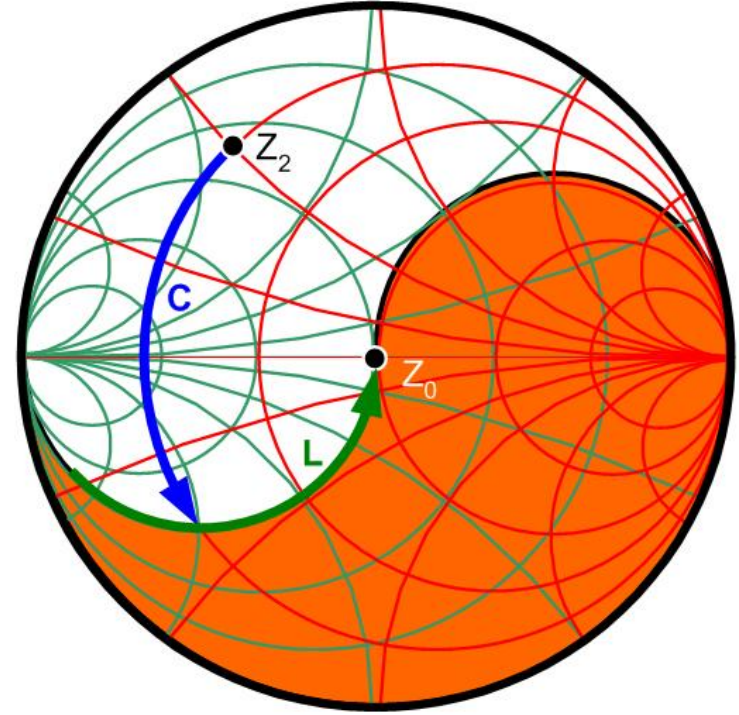
Zona interzisa cu
schema curenta



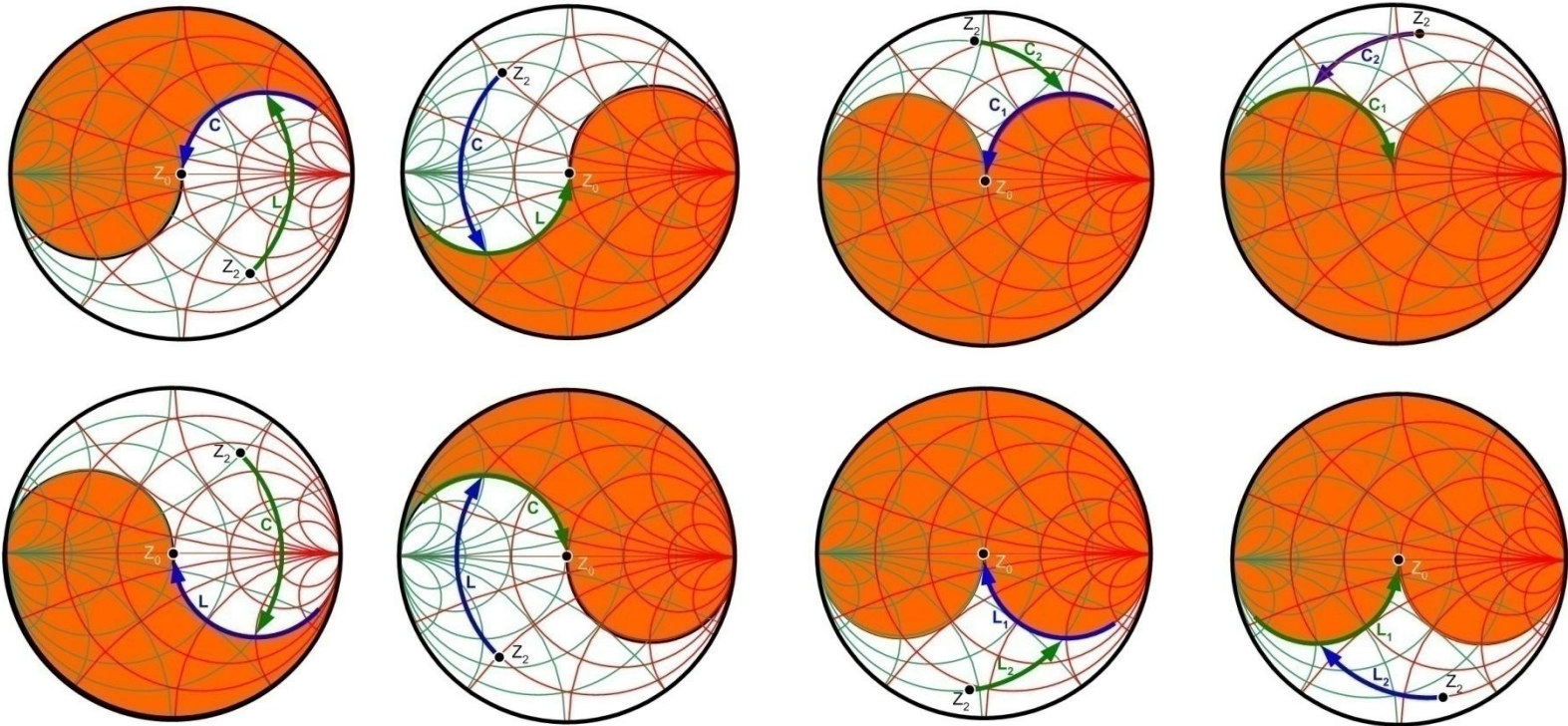
C serie, L paralel / L paralel, C serie



 Zona interzisa cu
schema curenta

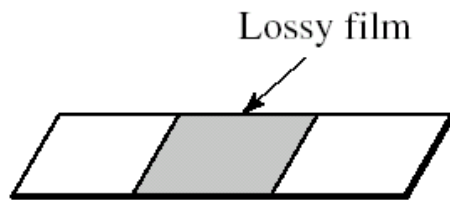


Adaptare cu doua elemente reactive (rețele in L)



Zona interzisa cu
schema curenta

Realizzare elementi concentrate

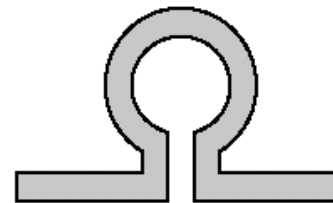


Planar resistor

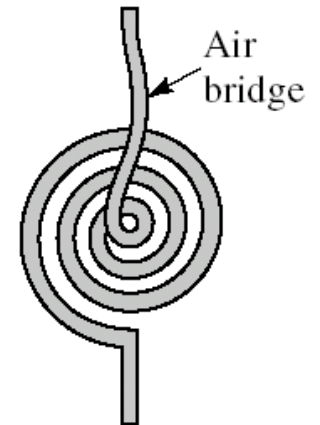
Lossy film



Chip resistor



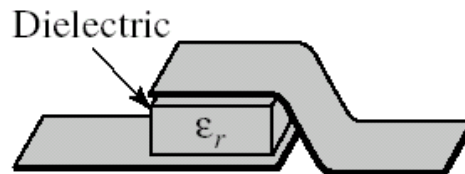
Loop inductor



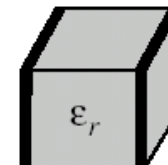
Spiral inductor



Interdigital
gap capacitor



Metal-insulator-
metal capacitor



Chip capacitor

Continuare

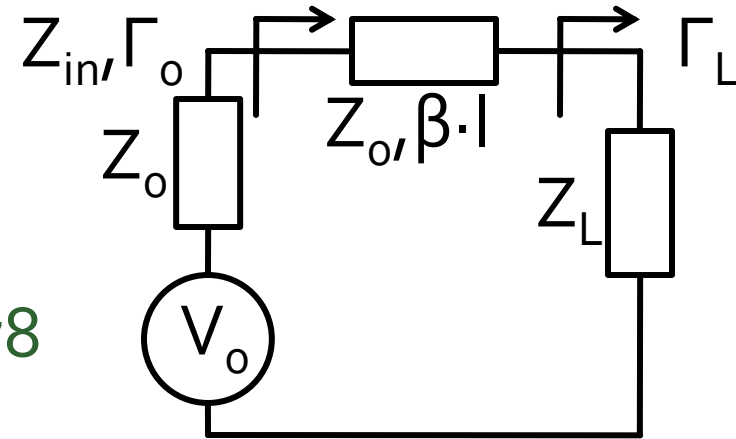
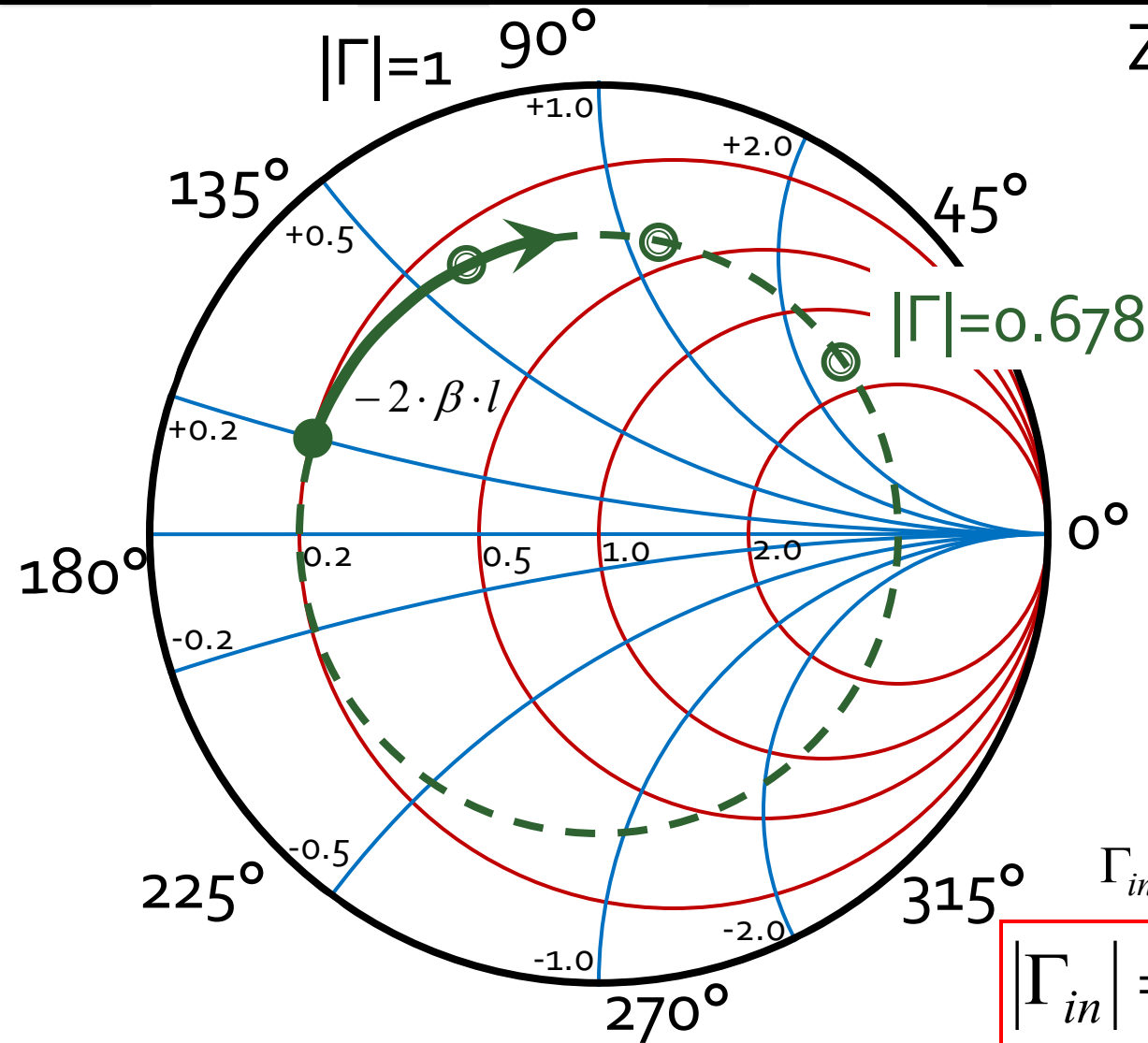
Adaptarea cu sectiuni de linii (stub)

Adaptarea de impedanță

Stub

- Stub=rest, ciot, cotor, capăt
- Se evita utilizarea elementelor concentrate
- Se realizează (foarte precis) utilizând liniile de transmisie uzuale ale circuitului
- Se utilizează secțiuni de linie (stub-uri) in serie sau paralel care pot fi:
 - in gol
 - scurtcircuitate
- De obicei liniile in gol sunt mai ușor de implementat si sunt preferate

Diagrama Smith, coeficient de reflexie, linie de transmisie in serie



$$Z_0 = 50\Omega$$

$$Z_L = R_L + j \cdot X_L = 10\Omega + j \cdot 10\Omega$$

$$z_L = r_L + j \cdot x_L = 0.2 + j \cdot 0.2$$

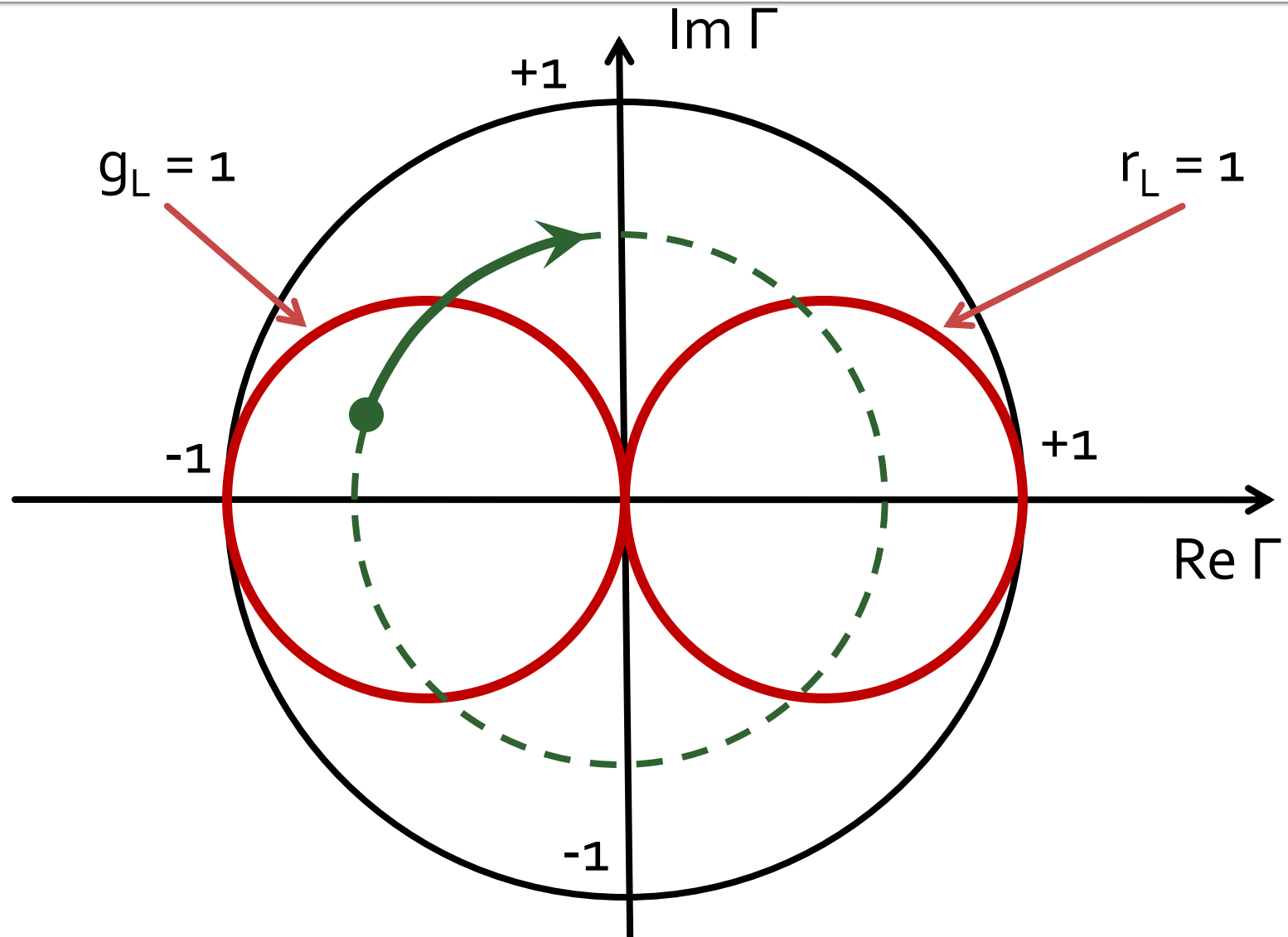
$$\Gamma_L = 0.678 \angle 156.5^\circ$$

$$Z_{in} = Z_0 \cdot \frac{1 + \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}}{1 - \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}}$$

$$\Gamma_{in} = \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}$$

$$|\Gamma_{in}| = |\Gamma_L| \quad \arg(\Gamma_{in}) = \arg(\Gamma_L) - 2 \cdot \beta \cdot l$$

Diagrama Smith, $r=1$ si $g=1$

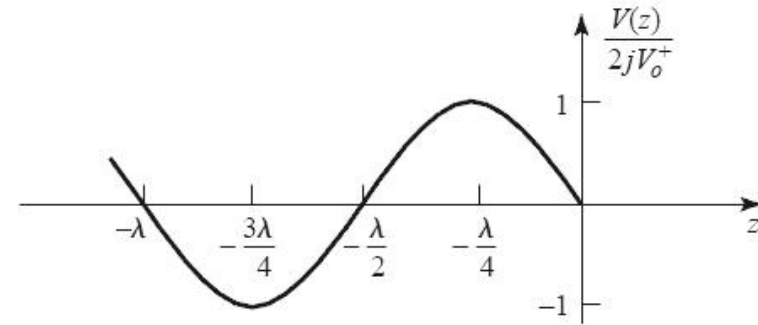


Linie în scurtcircuit

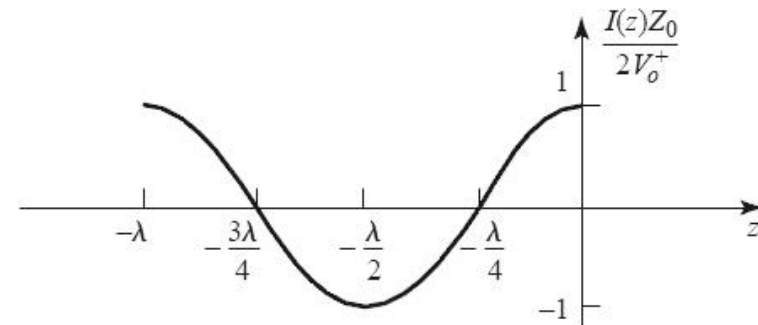
- $Z_L = 0$
- reactanța pură
 - +/- → în funcție de l

$$Z_{in} = j \cdot Z_0 \cdot \tan \beta \cdot l$$

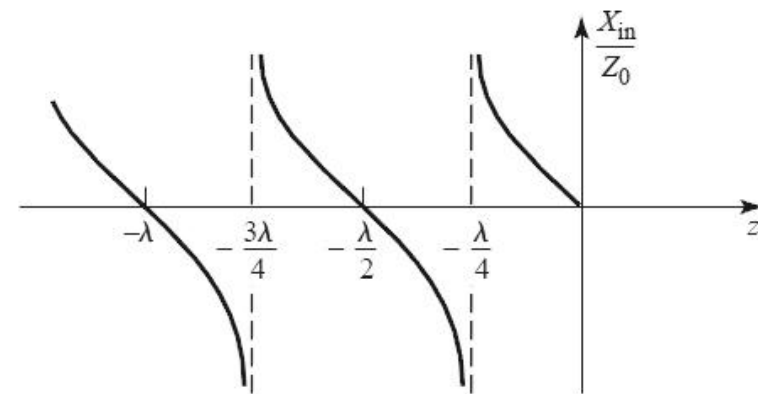
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan(\beta \cdot l)}{Z_0 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$



(a)



(b)



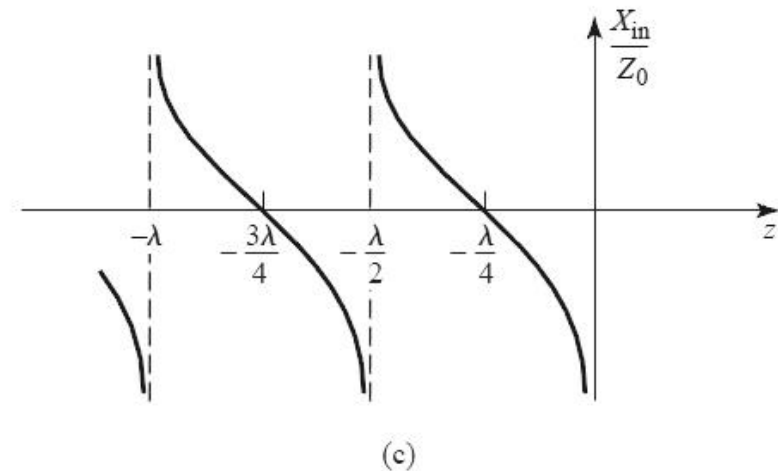
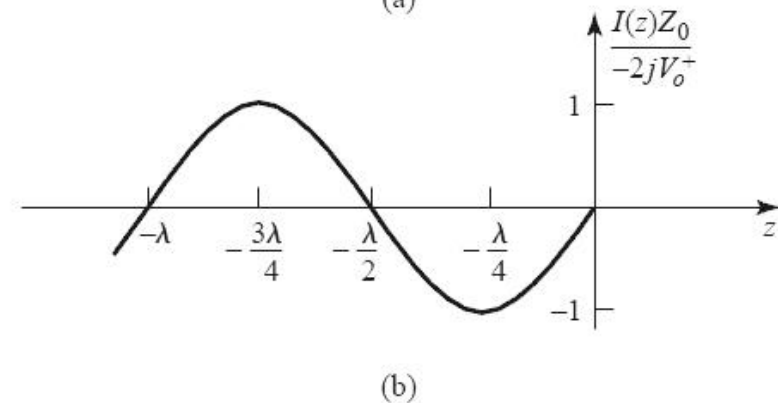
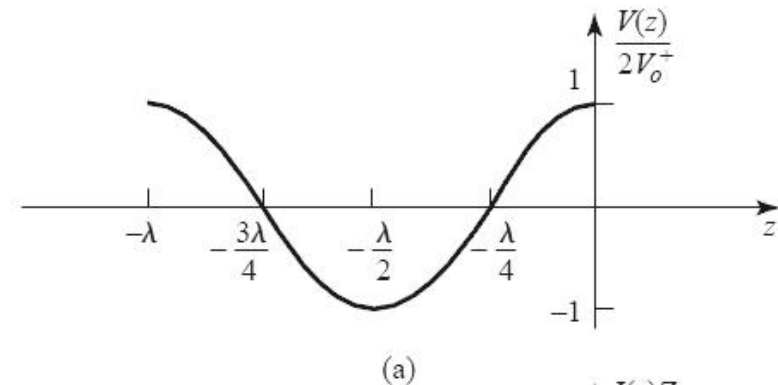
(c)

Linie în gol

- $Z_L = \infty \rightarrow 1/Z_L = 0$
- reactanța pură
 - +/- $\rightarrow$ în funcție de l

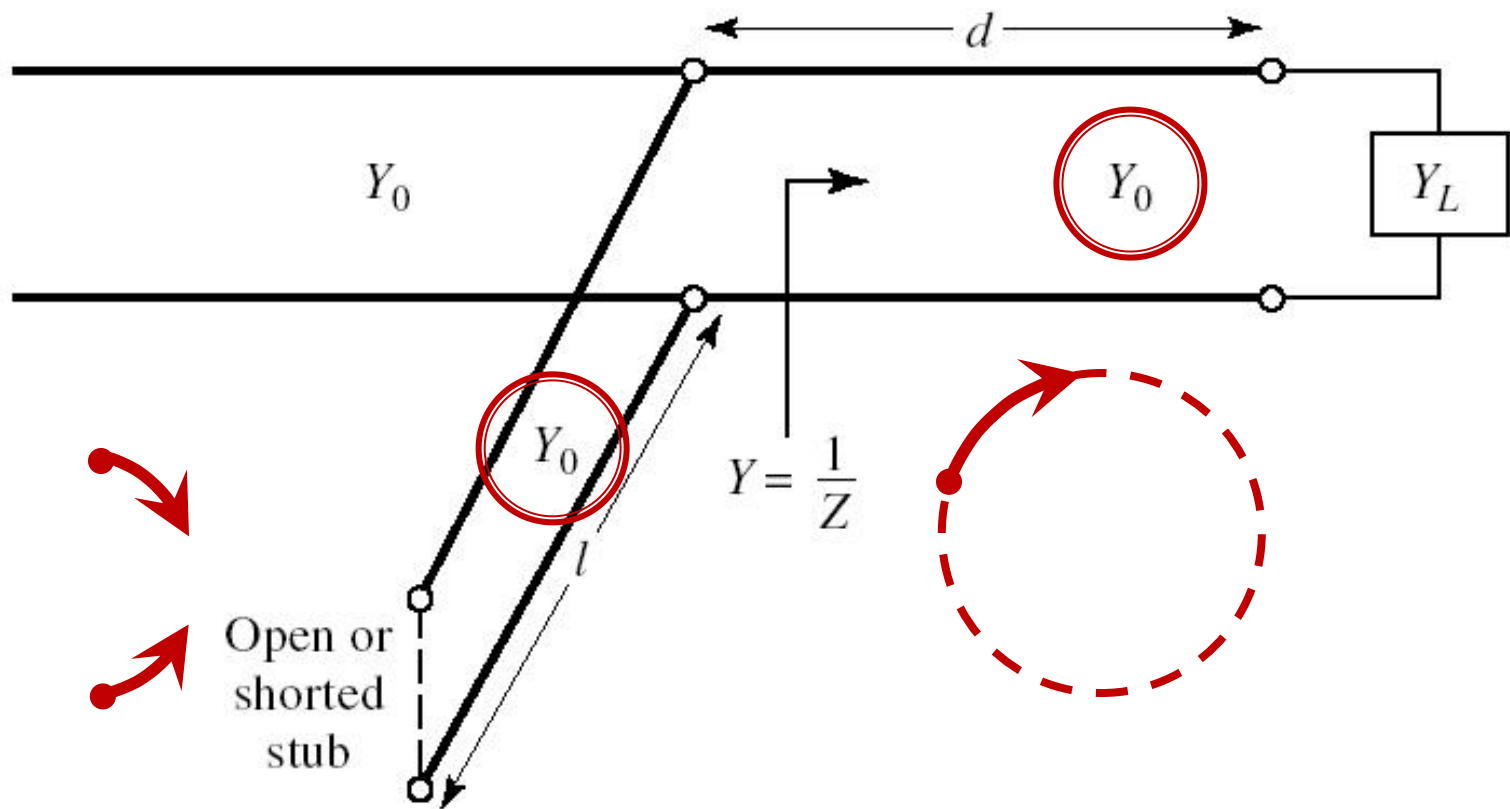
$$Z_{in} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan(\beta \cdot l)}{Z_0 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$



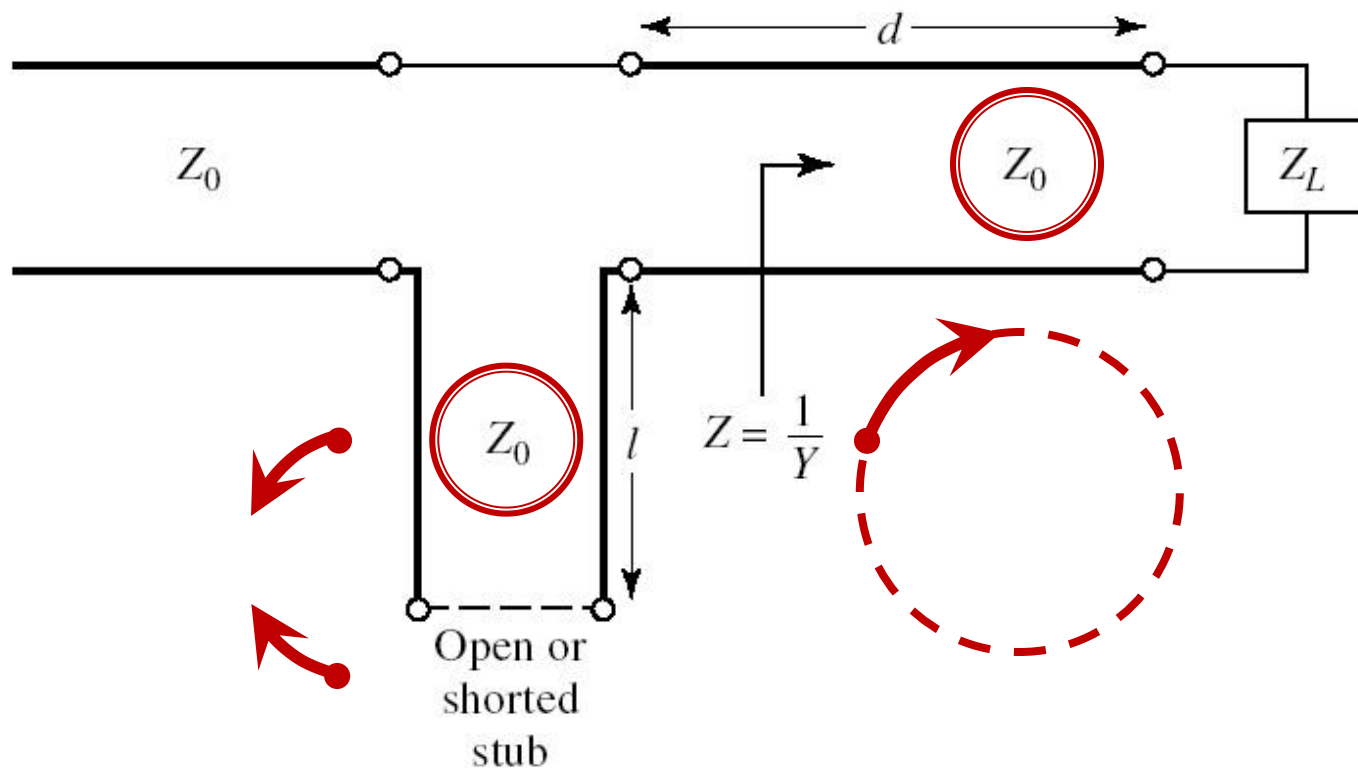
Single stub tuning

- Shunt Stub (sectiune de linie in paralel)

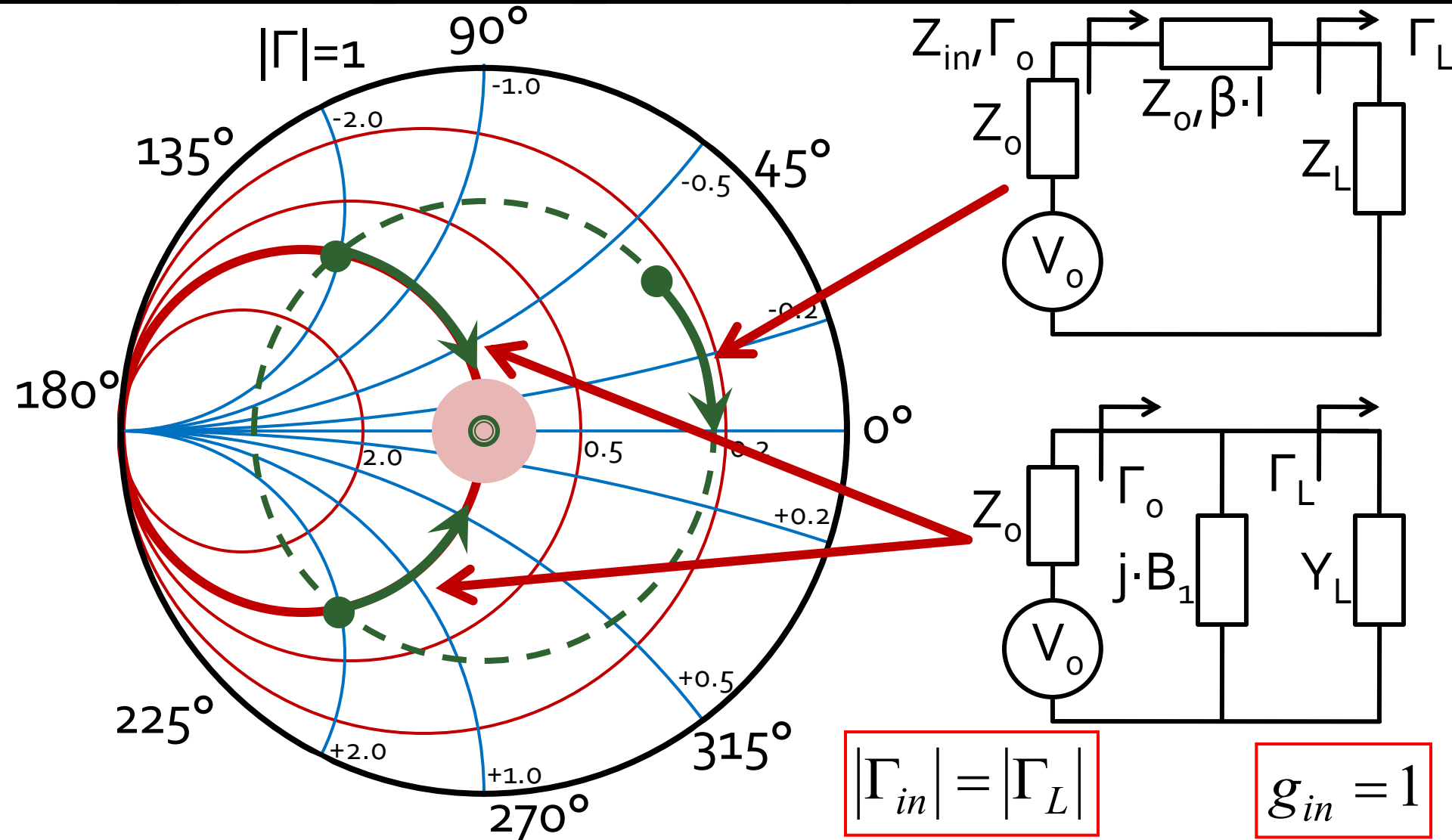


Single stub tuning

- Series Stub (secțiune de linie în serie)
- tehnologic mai dificil de realizat la liniile monofilare (microstrip)



Adaptare, linie serie + susceptanta in paralel

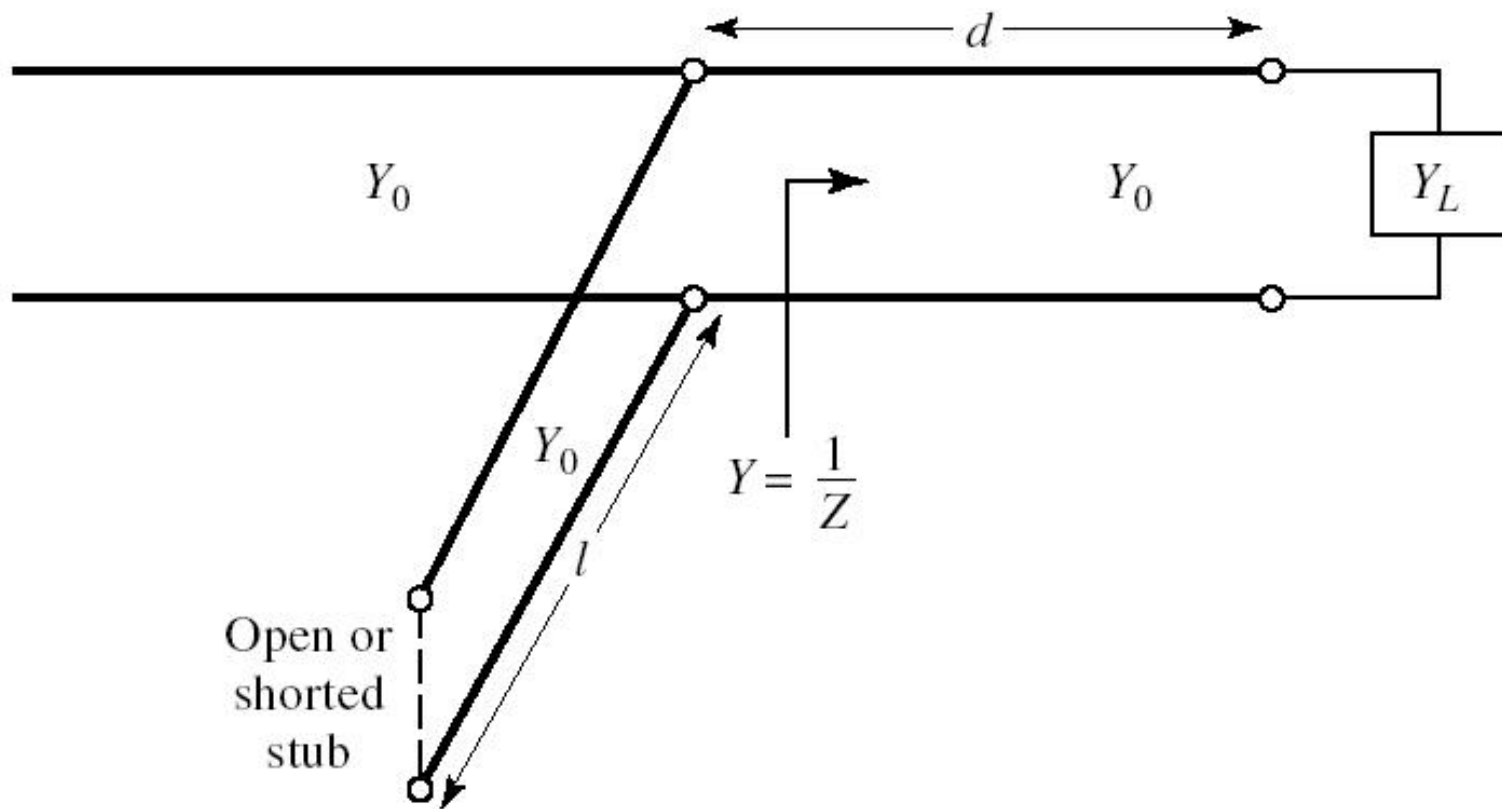


Shunt Stub

Sectiune de linie paralel

Caz 1, Shunt Stub

- Shunt Stub (sectiune de linie in paralel)



Caz 1, Shunt Stub

- Se utilizeaza o linie de transmisie serie pentru a muta coeficientul de reflexie pe cercul $g_L = 1$
- Se introduce o reactanta in paralel pentru a realiza adaptarea
- Aceasta reactanta se realizeaza cu o linie de transmisie care poate fi dupa nevoie:
 - in gol
 - in scurtcircuit

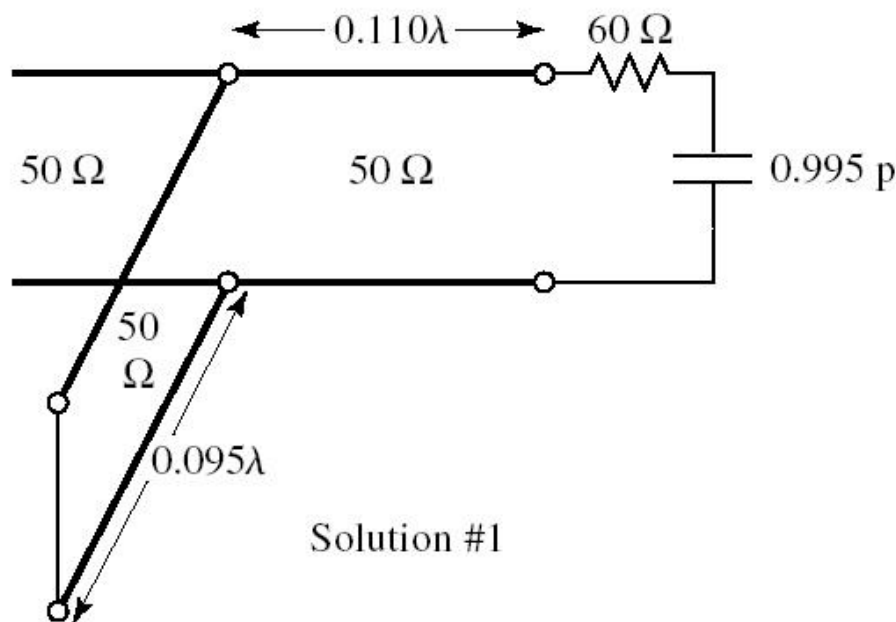
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

$$Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l$$

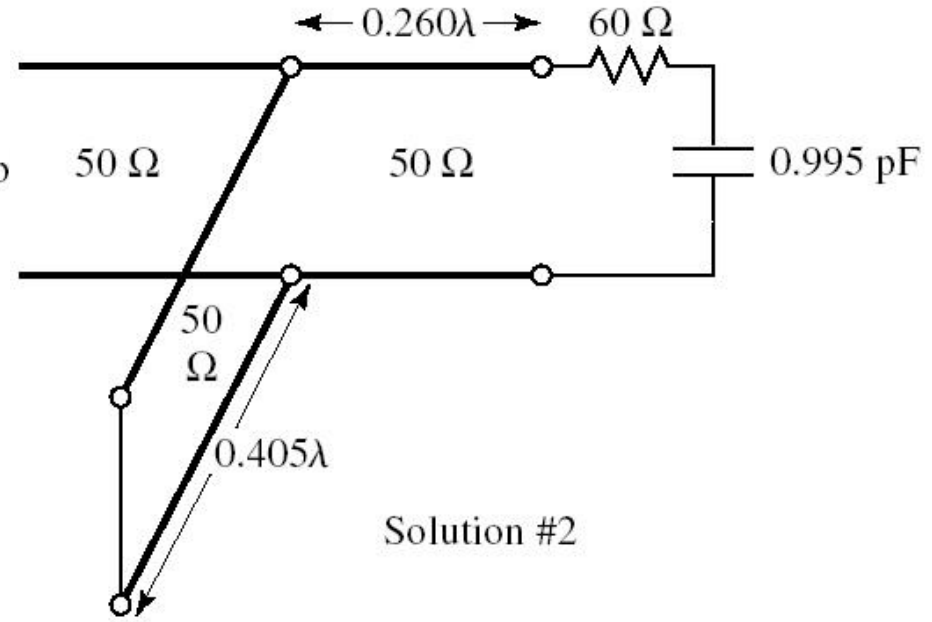
$$Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

Exemplu, Shunt Stub, sc

- sarcina: $60\ \Omega$ serie $0.995\ \text{pF}$ la 2GHz
- doua solutii posibile

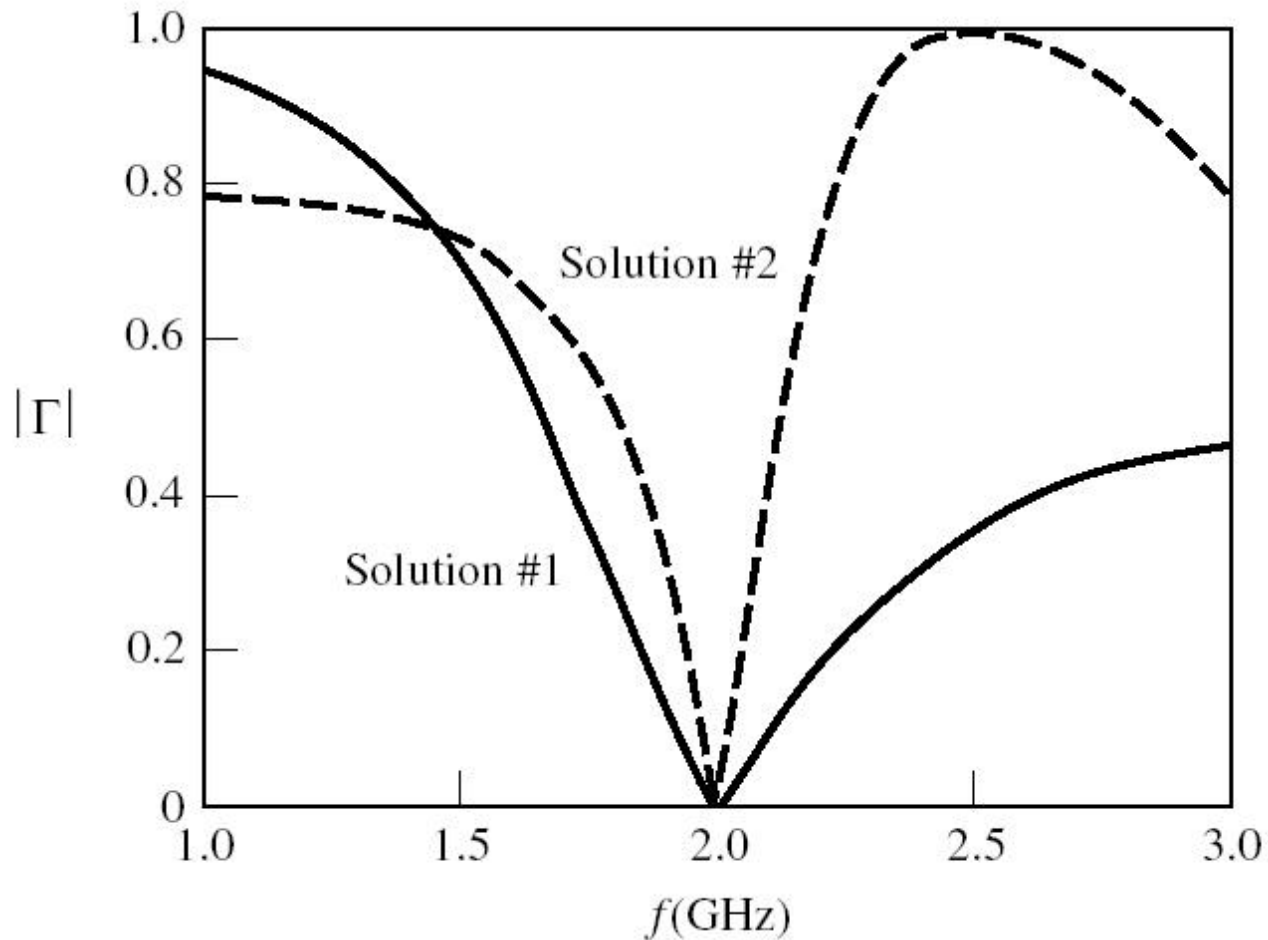


Solution #1

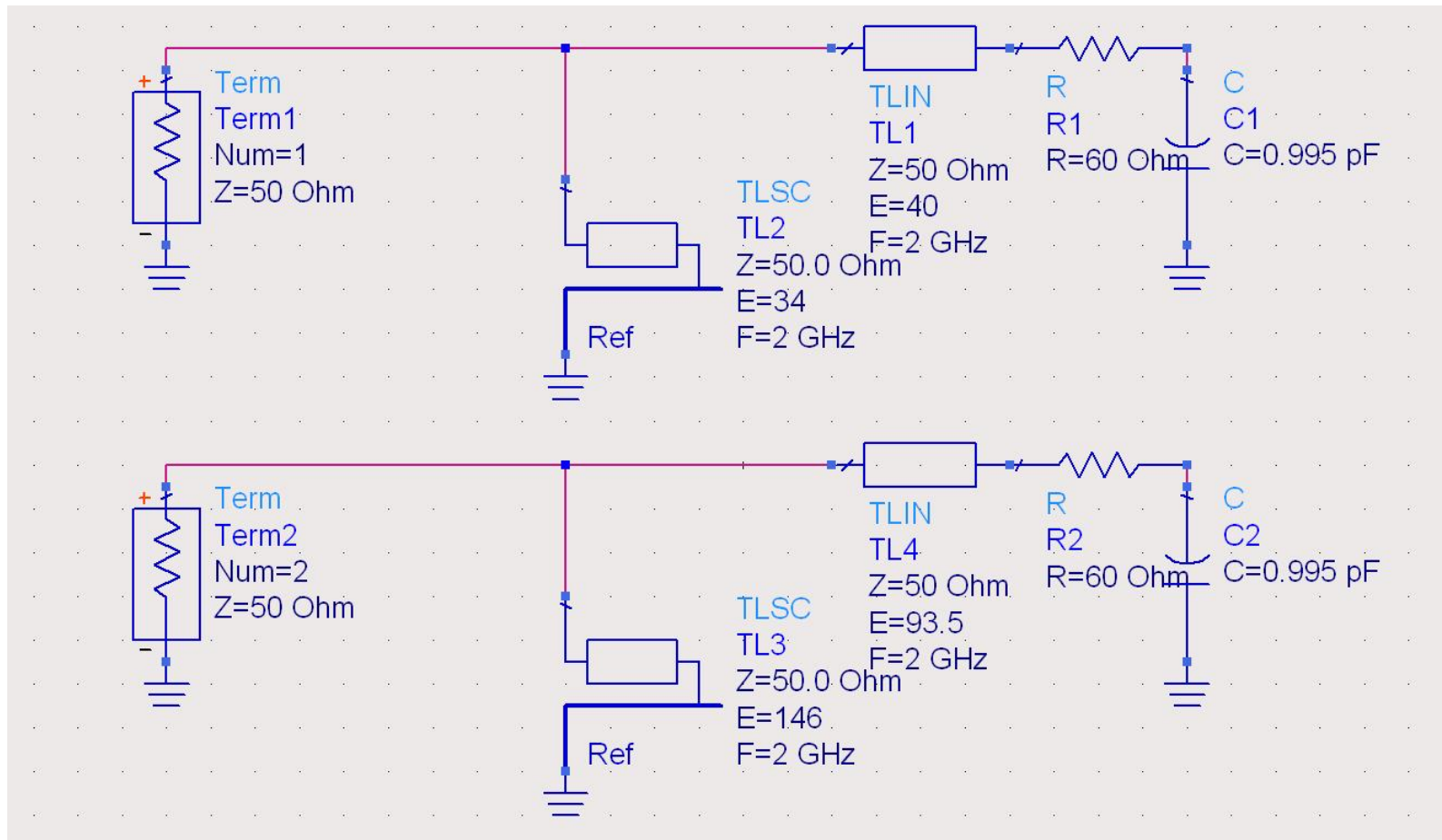


Solution #2

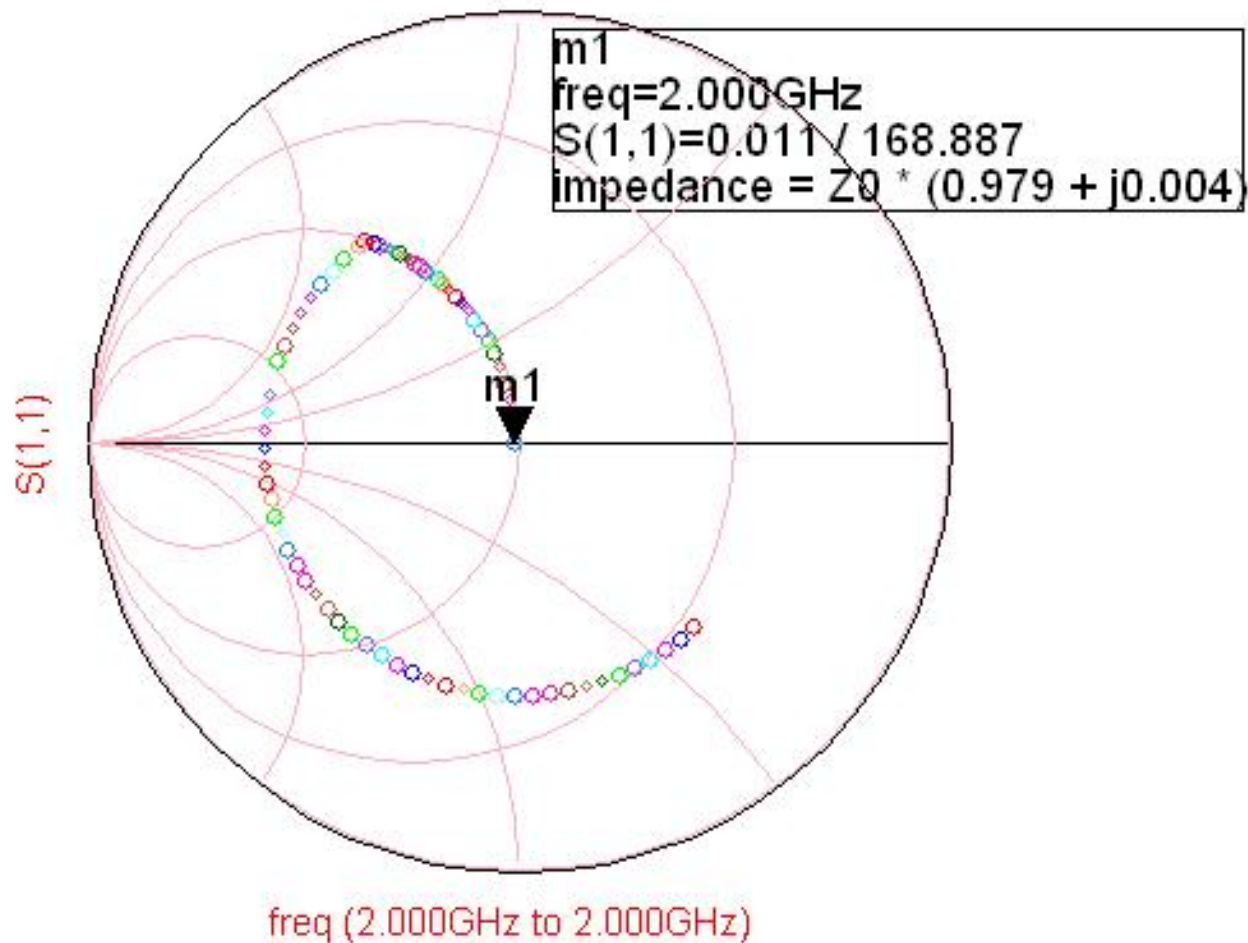
Exemplu, Shunt Stub, sc



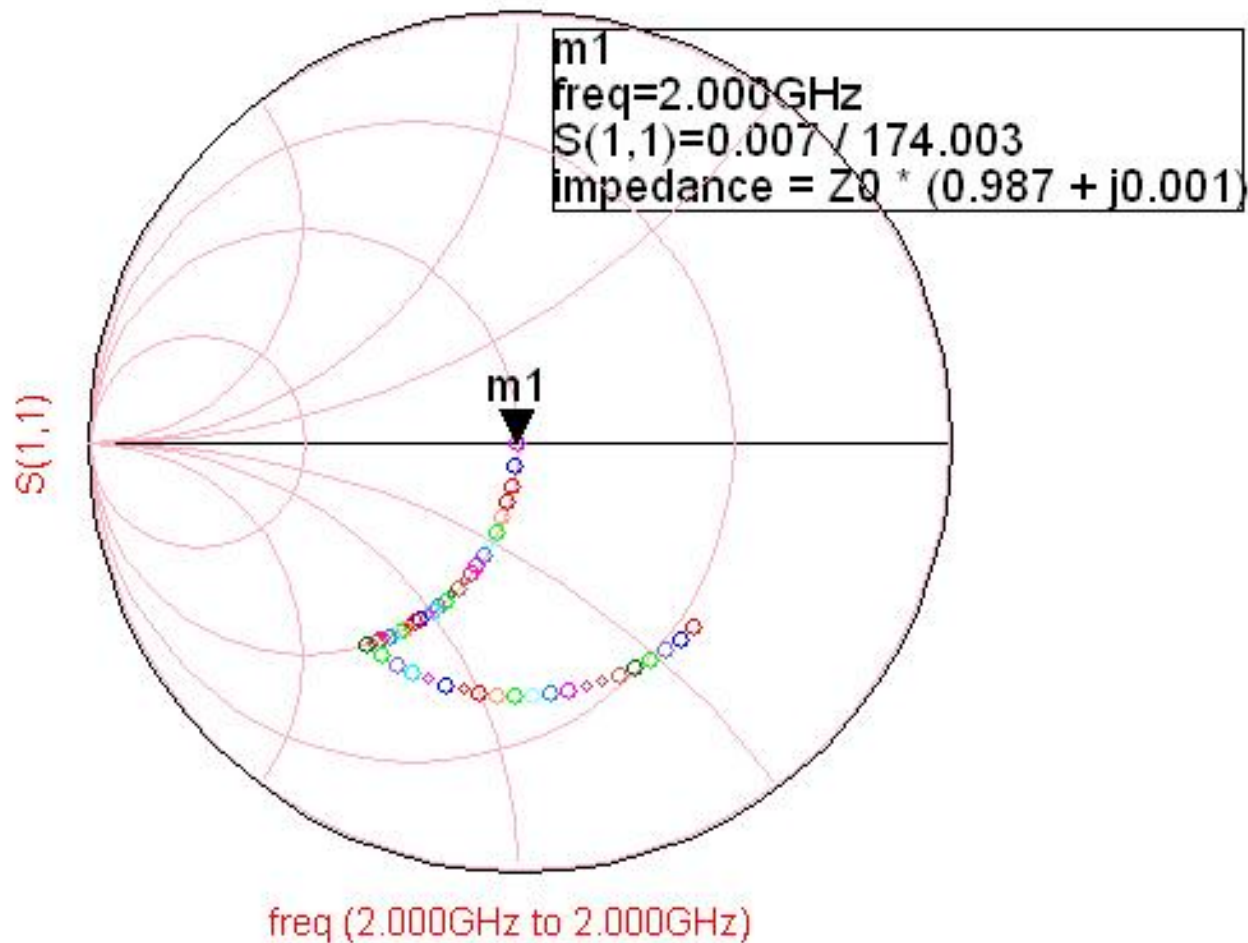
Exemplu, Shunt Stub, sc



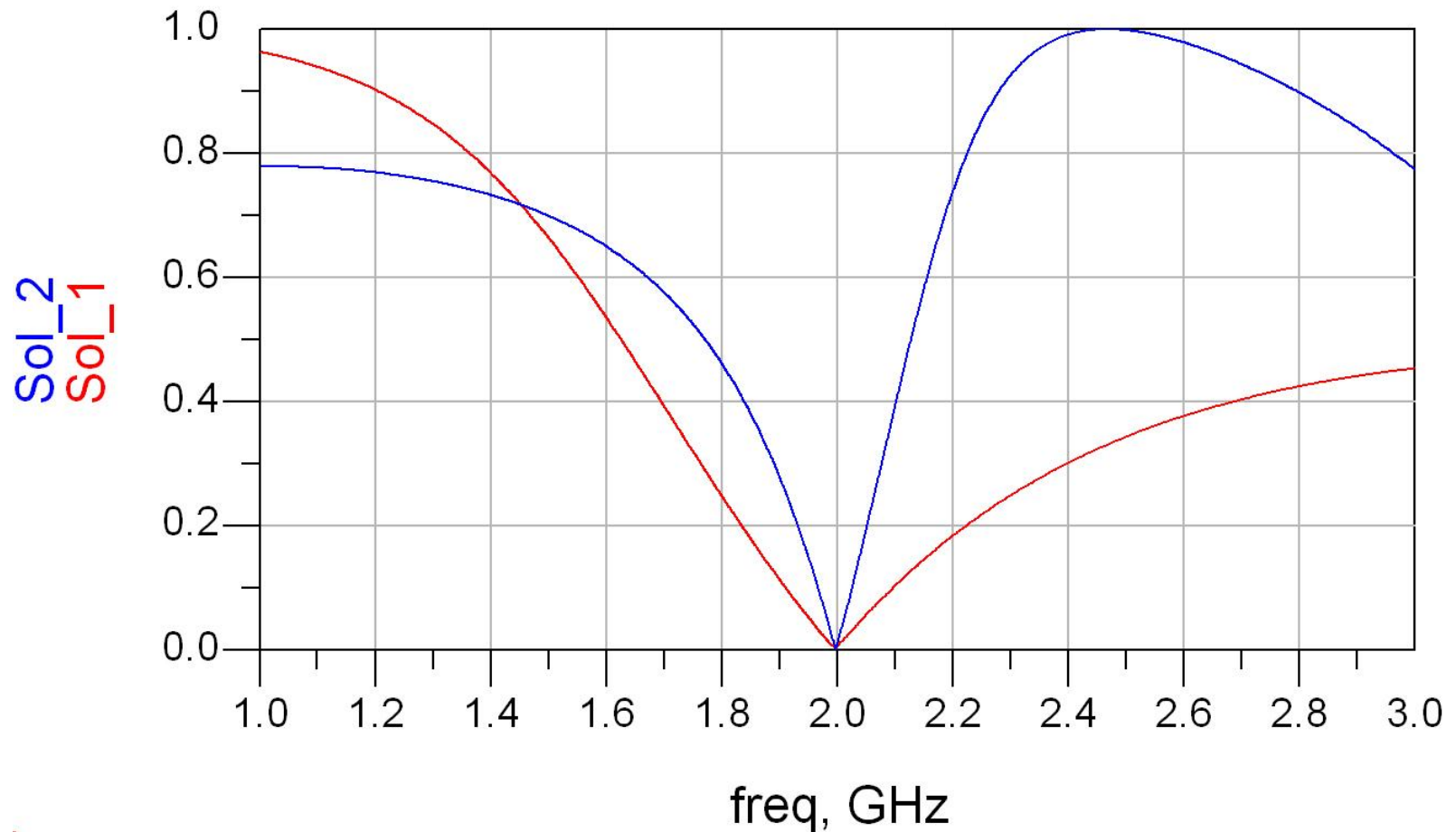
Exemplu, Shunt Stub, sc



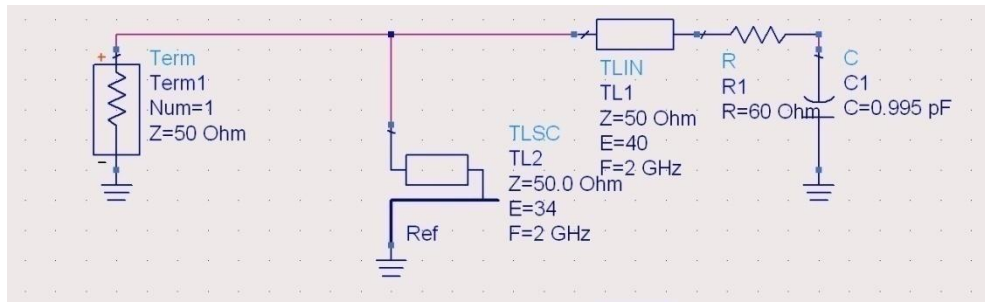
Exemplu, Shunt Stub, sc



Exemplu, Shunt Stub, sc



Exemplu, Shunt Stub, sc

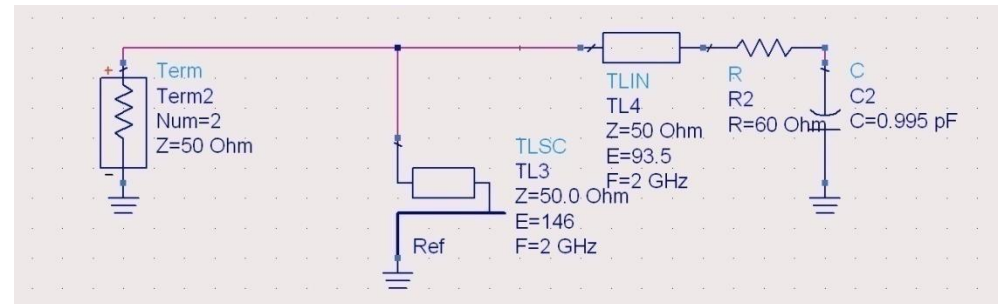


$$l_1 = \frac{40^\circ}{360^\circ} \cdot \lambda = 0.111 \cdot \lambda$$

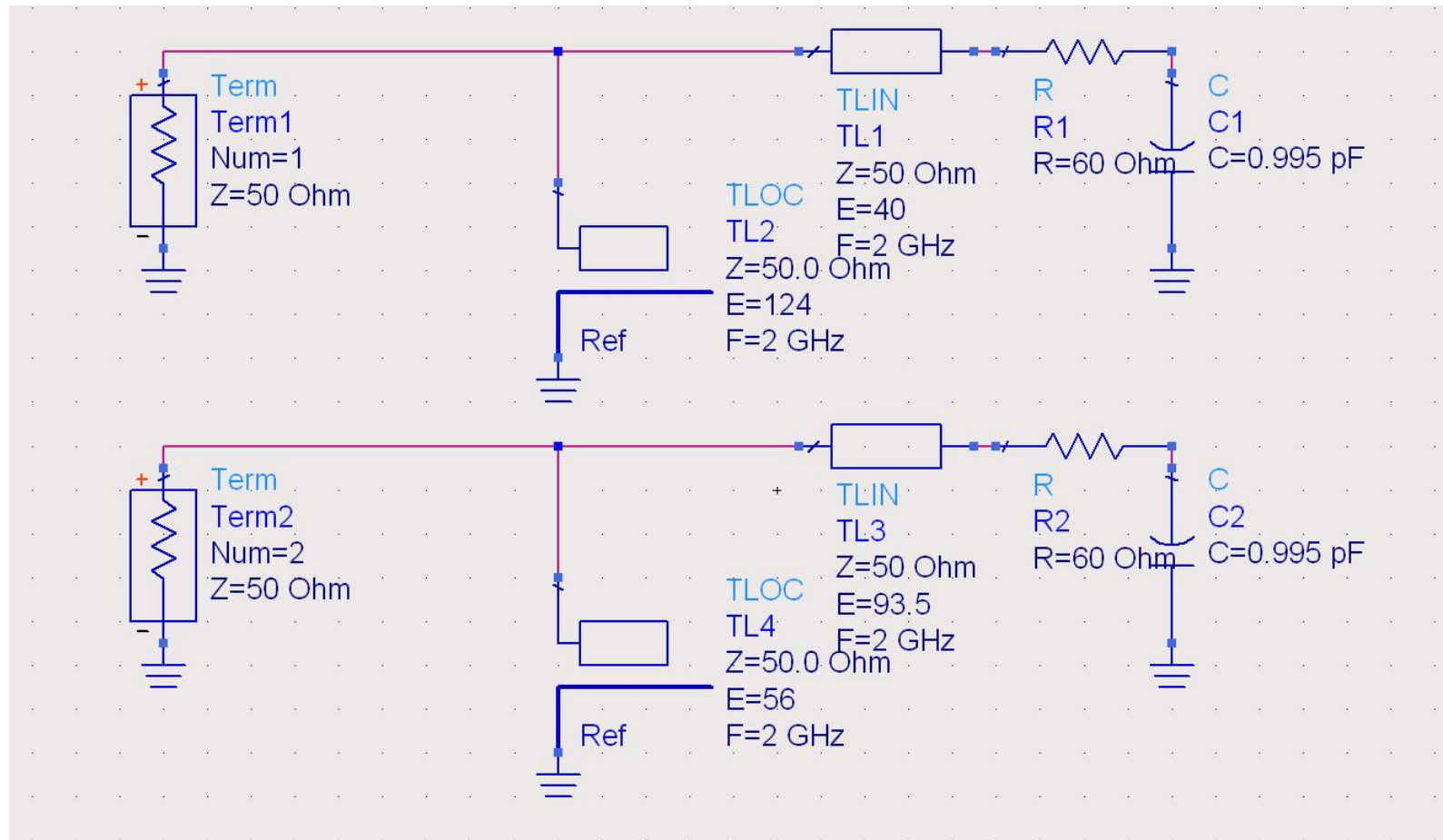
$$l_2 = \frac{34^\circ}{360^\circ} \cdot \lambda = 0.094 \cdot \lambda$$

$$l_1 = \frac{93.5^\circ}{360^\circ} \cdot \lambda = 0.260 \cdot \lambda$$

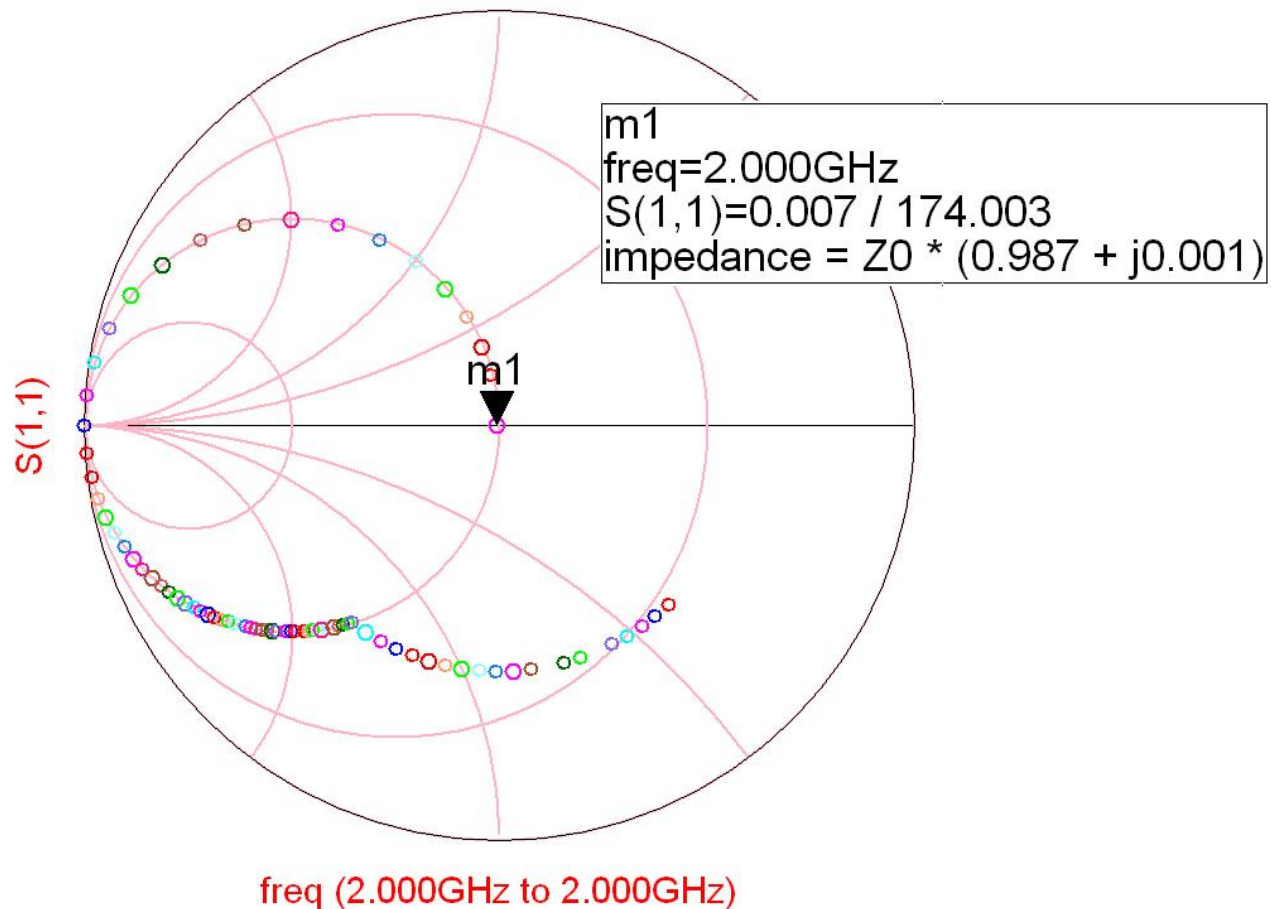
$$l_2 = \frac{146^\circ}{360^\circ} \cdot \lambda = 0.406 \cdot \lambda$$



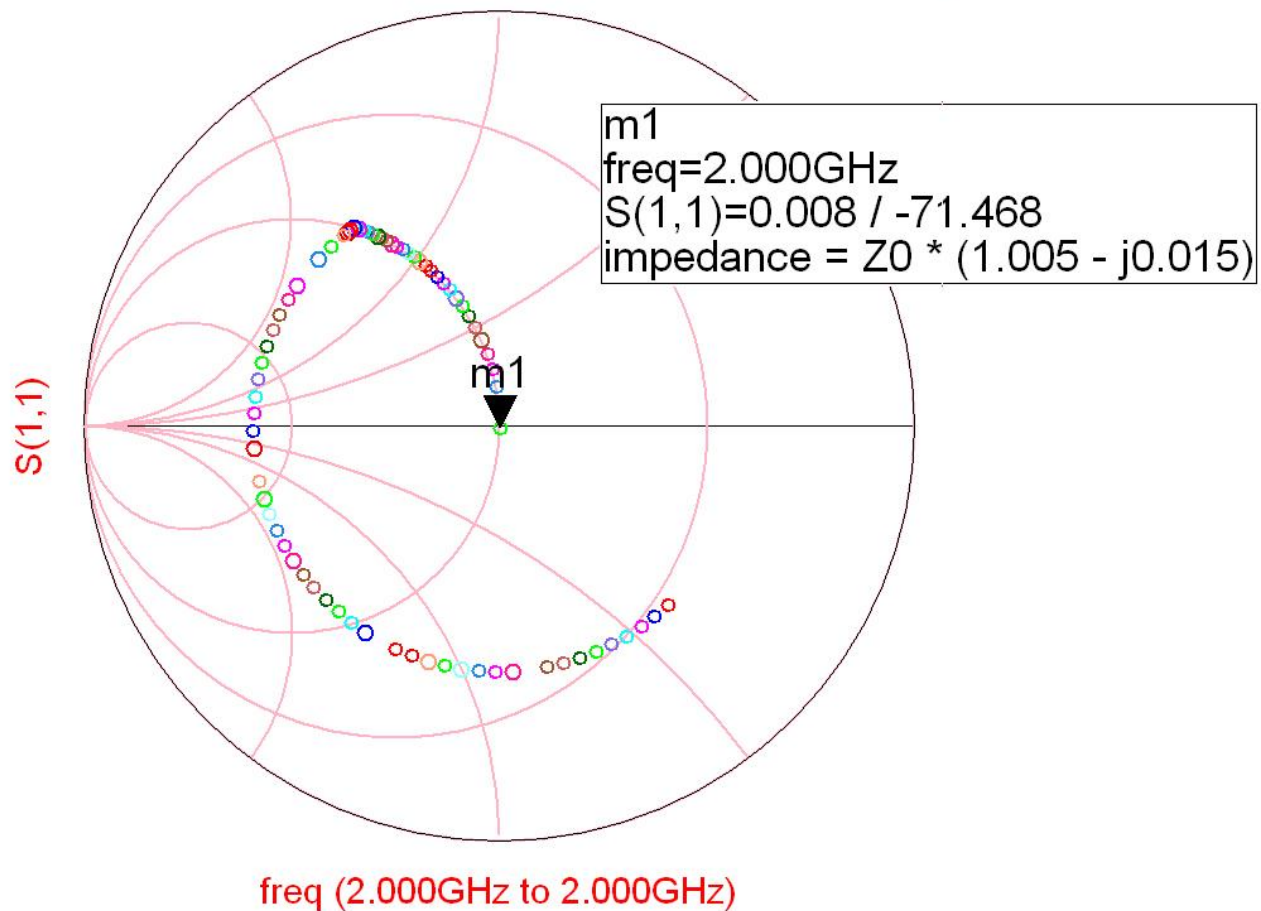
Exemplu, Shunt Stub, gol



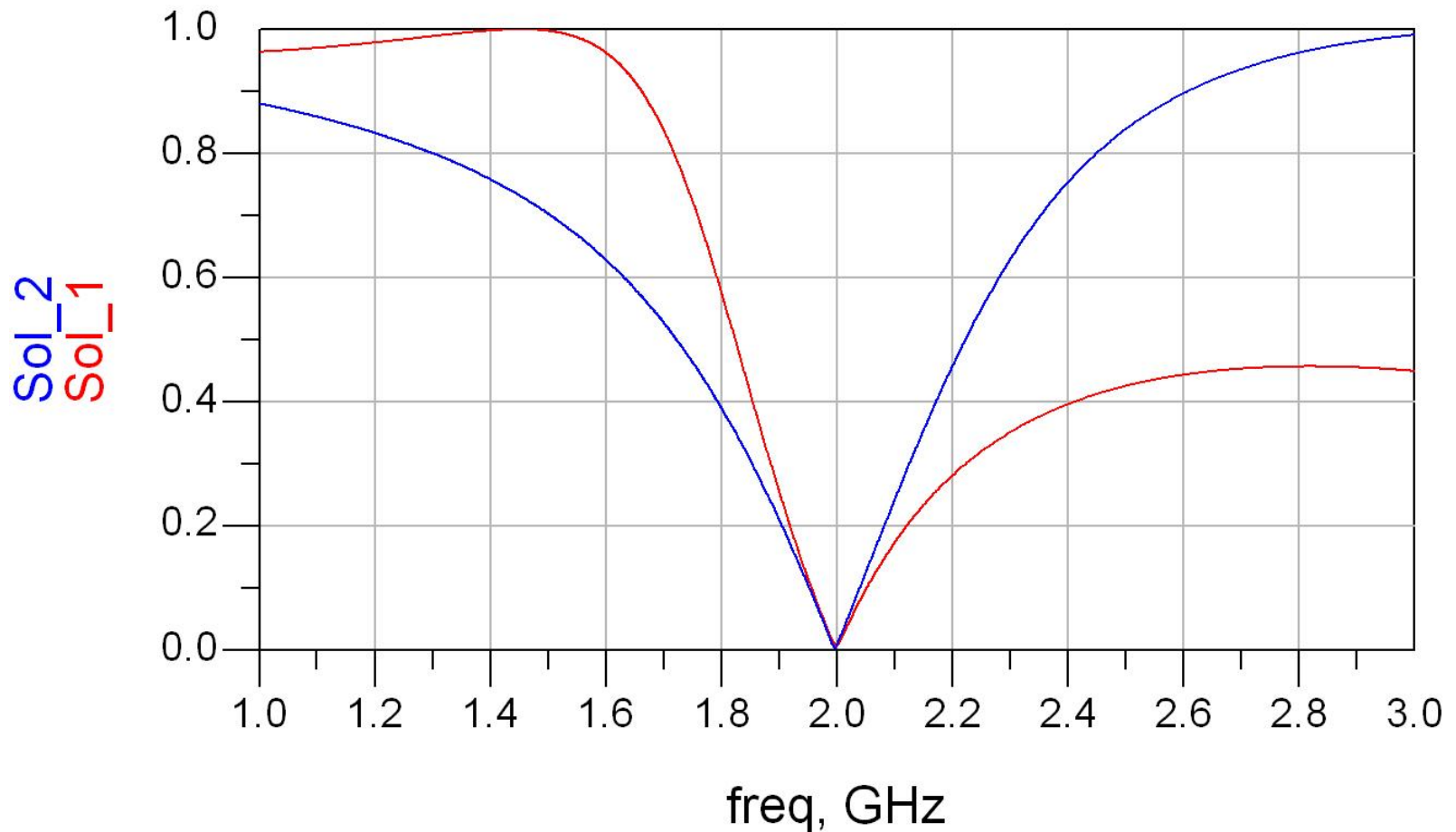
Exemplu, Shunt Stub, gol



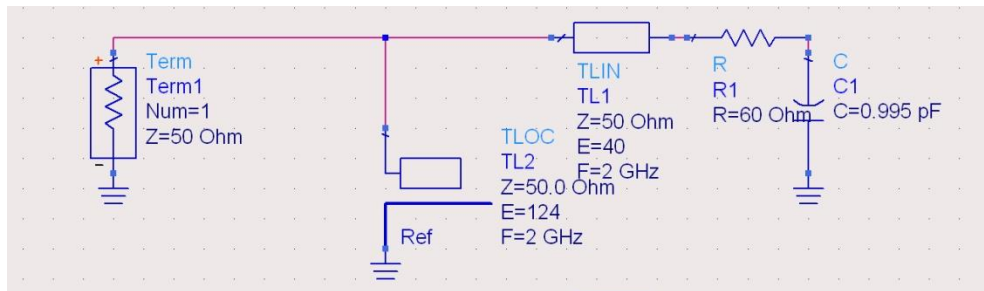
Exemplu, Shunt Stub, gol



Exemplu, Shunt Stub, gol



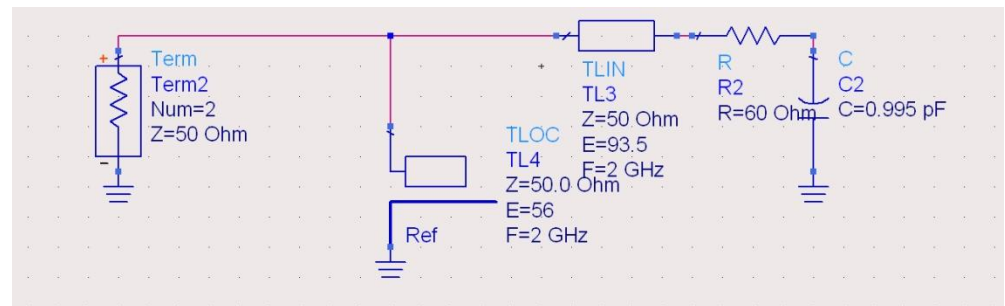
Exemplu, Shunt Stub, gol



$$l_1 = \frac{40^\circ}{360^\circ} \cdot \lambda = 0.111 \cdot \lambda$$

$$l_2 = \frac{124^\circ}{360^\circ} \cdot \lambda = 0.344 \cdot \lambda = 0.094 \cdot \lambda + \frac{\lambda}{4}$$

$$l_1 = \frac{93.5^\circ}{360^\circ} \cdot \lambda = 0.260 \cdot \lambda$$



$$l_2 = \frac{56^\circ}{360^\circ} \cdot \lambda = 0.156 \cdot \lambda = 0.406 \cdot \lambda - \frac{\lambda}{4}$$

Stub, observatii

- functiile care ofera impedanta de intrare intr-un stub sunt periodice in functie de lungime (l), functii tip tg/ctg

$$Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l$$

$$Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

- adunarea si scadere de:

$$E = \beta \cdot l = \pi = 180^\circ \quad l = k \cdot \frac{\lambda}{2}, \forall k \in \mathbf{N}$$

nu schimba rezultatul (rotatie completa in jurul diagramei – de aici provine gradatia 0.5 lungimi de unda a circumferintei diagramei Smith)

Stub, observatii

- pentru reglaj in vederea adaptarii este preferabila pornirea din punctul neutru (valoarea lungimii liniei care nu influenteaza circuitul)
 - linia in serie: $E = \beta \cdot l = 0$
 - stub: $Z_{in} \rightarrow \infty, \tan \beta \cdot l / \cot \beta \cdot l \rightarrow \infty, E = 90^\circ / 0^\circ$
- o adaugare sau scadere de sfert de lungime de unda transforma impedanta:

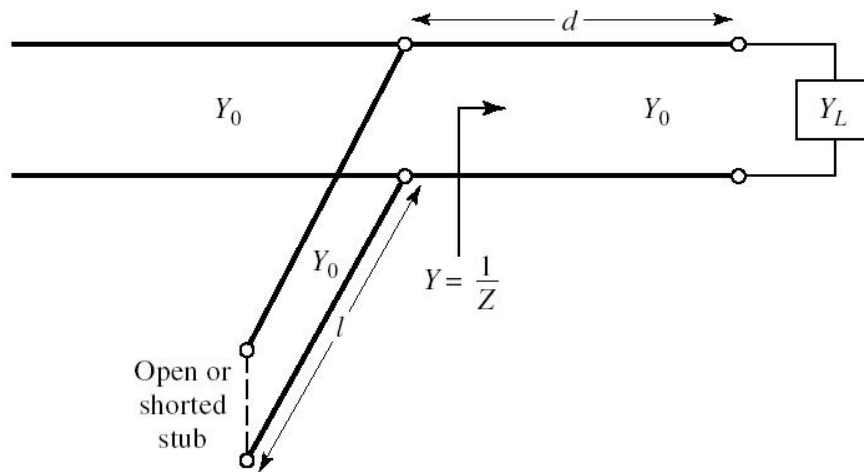
$$Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l \quad Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

$$\tan \beta \cdot \left(l + \frac{\lambda}{4} \right) = \tan \left(\beta \cdot l + \frac{\pi}{2} \right) = \frac{\sin(\beta \cdot l + \pi/2)}{\cos(\beta \cdot l + \pi/2)} = \frac{\cos \beta \cdot l}{-\sin \beta \cdot l} = -\cot \beta \cdot l$$

Solutie analitica

Shunt Stub

Solutie analitica, impedante



$$Z_L = \frac{1}{Y_L} = R_L + j \cdot X_L$$

$$Z = Z_0 \cdot \frac{(R_L + j \cdot X_L) + j \cdot Z_0 \cdot t}{Z_0 + j \cdot (R_L + j \cdot X_L) \cdot t}$$

$$t = \tan \beta \cdot d \quad Y = G + j \cdot B = \frac{1}{Z}$$

$$G = \frac{R_L \cdot (1 + t^2)}{R_L^2 + (X_L + Z_0 \cdot t)^2}$$

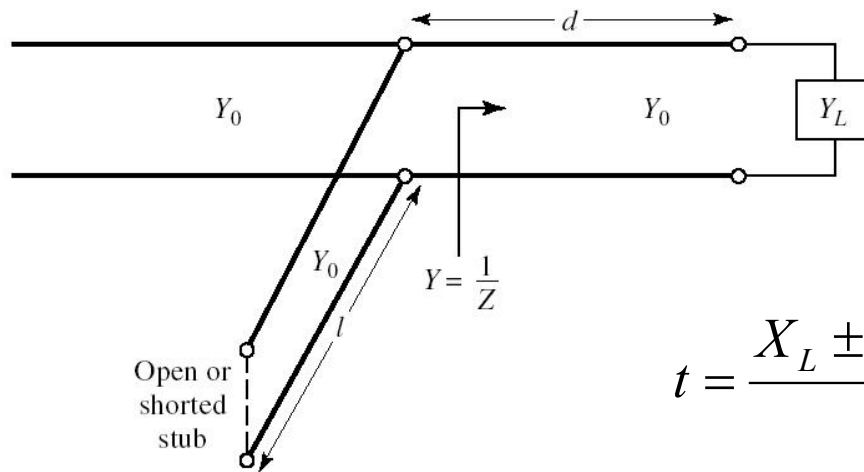
$$B = \frac{R_L^2 \cdot t - (Z_0 - X_L \cdot t) \cdot (X_L + Z_0 \cdot t)}{Z_0 \cdot [R_L^2 + (X_L + Z_0 \cdot t)^2]}$$

■ d este ales astfel incat

$$G = Y_0 = \frac{1}{Z_0}$$

$$Z_0 \cdot (R_L - Z_0) \cdot t^2 - 2 \cdot X_L \cdot Z_0 \cdot t + (R_L \cdot Z_0 - R_L^2 - X_L^2) = 0$$

Solutie analitica



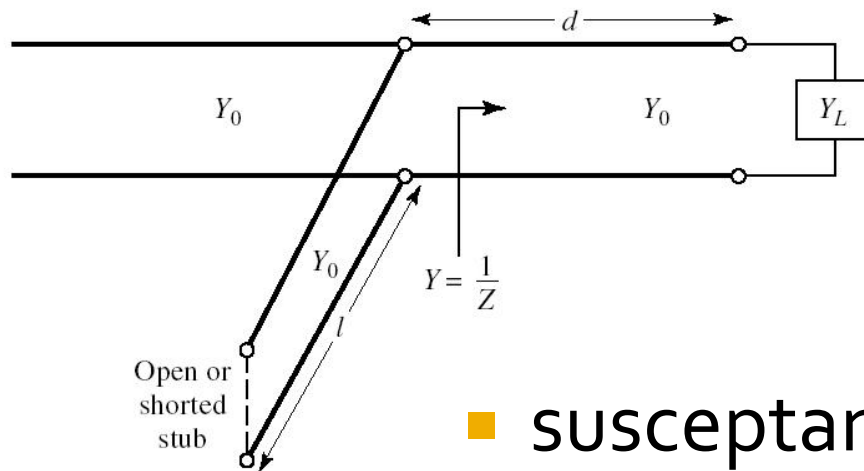
$$t = -\frac{X_L}{2 \cdot Z_0}, \quad R_L = Z_0$$

$$t = \frac{X_L \pm \sqrt{R_L \cdot [(Z_0 - R_L)^2 + X_L^2] / Z_0}}{R_L - Z_0} \quad R_L \neq Z_0$$

- ecuatie de gradul 2, 2 solutii posibile
- d este ales astfel incat

$$\frac{d}{\lambda} = \begin{cases} \frac{1}{2\pi} \cdot \arctan t & t \geq 0 \\ \frac{1}{2\pi} \cdot (\pi + \arctan t) & t < 0 \end{cases}$$

Solutie analitica



$$B_S = -B$$

$$B = \frac{R_L^2 \cdot t - (Z_0 - X_L \cdot t) \cdot (X_L + Z_0 \cdot t)}{Z_0 \cdot [R_L^2 + (X_L + Z_0 \cdot t)^2]}$$

■ susceptanta de anulare se obtine

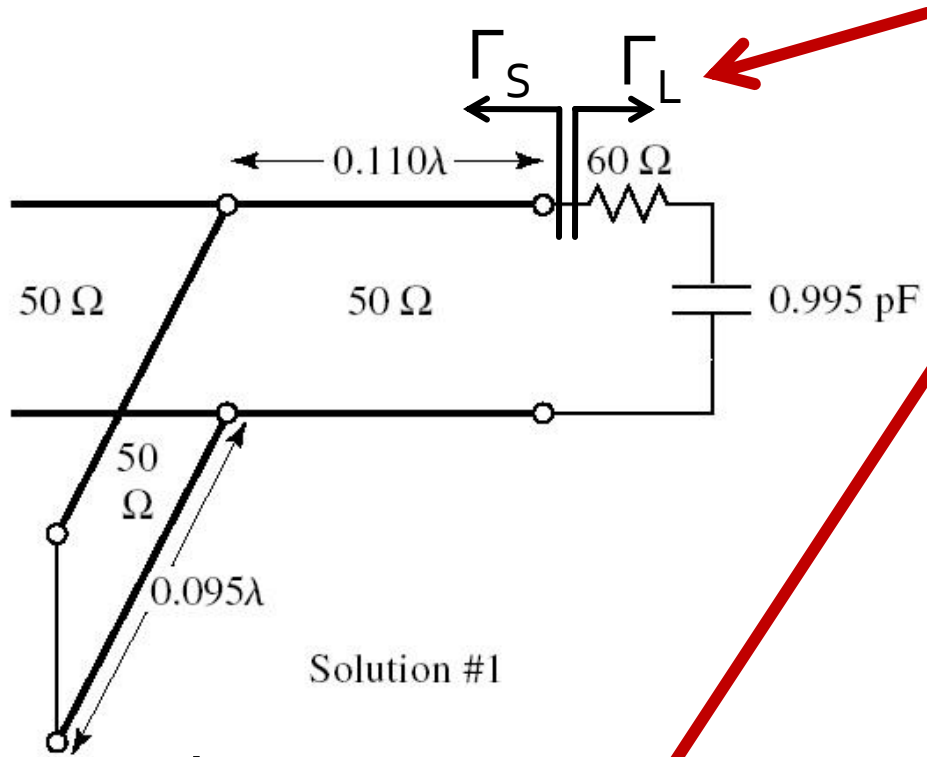
$$\frac{l_{gol}}{\lambda} = \frac{1}{2\pi} \cdot \arctan\left(\frac{B_S}{Y_0}\right) = \frac{-1}{2\pi} \cdot \arctan\left(\frac{B}{Y_0}\right)$$

$$\frac{l_{sc}}{\lambda} = \frac{-1}{2\pi} \cdot \arctan\left(\frac{Y_0}{B_S}\right) = \frac{1}{2\pi} \cdot \arctan\left(\frac{Y_0}{B}\right)$$

■ pentru **lungimi negative** se adauga $\lambda/2$

Calcul analitic, coeficienti de reflexie

- sarcina: $60\ \Omega$ serie $0.995\ \text{pF}$ la 2GHz



$$Z_L = R_L + \frac{1}{j \cdot \omega \cdot C_L} = 60\Omega - j \cdot 79.977\Omega$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = 0.405 - j \cdot 0.432$$

$$Y_L = \frac{1}{Z_L} = 0.006S + j \cdot 0.008S$$

$$y_L = \frac{Y_L}{Y_0} = 0.3 + j \cdot 0.4$$

- adaptare necesita complex conjugat

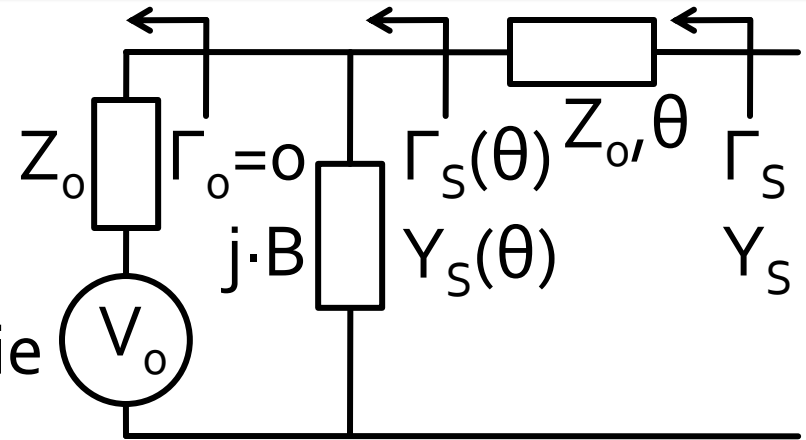
$$\Gamma_S = \Gamma_L^* = 0.405 + j \cdot 0.432$$

$$\Gamma_S = 0.593 \angle 46.85^\circ$$

$$|\Gamma_S| = 0.593; \quad \varphi = 46.85^\circ$$

Calcul analitic, coeficienti de reflexie

- linie serie
 - lungime electrica $E = \beta \cdot l = \theta$
 - muta coeficientul de reflexie pe cercul $g=1$
- stub paralel:
 - lungime electrica $E = \beta \cdot l_{sp} = \theta_{sp}$
 - muta coeficientul de reflexie in centrul diagramei Smith ($\Gamma_o = 0$)



$$y_s = \frac{Y_s}{Y_0} = Y_s \cdot Z_0 = Y_s \cdot 50\Omega$$

$$y_s = \frac{1 - \Gamma_s}{1 + \Gamma_s} = 0.3 - j \cdot 0.4$$

$$\Gamma_s(\theta) = [\Gamma_L(\theta)]^* = [\Gamma_L \cdot e^{-2j\theta}]^*$$

$$\Gamma_s(\theta) = \Gamma_L^* \cdot e^{2j\theta} = \Gamma_s \cdot e^{2j\theta}$$

$$y_s(\theta) = \frac{1 - \Gamma_s(\theta)}{1 + \Gamma_s(\theta)} = \frac{1 - \Gamma_s \cdot e^{2j\theta}}{1 + \Gamma_s \cdot e^{2j\theta}}$$

Calcul analitic, linie serie (dem.)

- Dupa sectiunea de linie cu lungimea electrica θ

$$\operatorname{Re}[y_S(\theta)] = 1$$

$$\operatorname{Im}[y_S(\theta)] = B$$

$$\operatorname{Re}[y_S(\theta)] = \frac{1}{2} \cdot [y_S(\theta) + y_S^*(\theta)]$$

$$\operatorname{Im}[y_S(\theta)] = \frac{1}{2j} \cdot [y_S(\theta) - y_S^*(\theta)]$$

$$\operatorname{Re}[y_S(\theta)] = \frac{1}{2} \cdot \left[\frac{1 - \Gamma_S \cdot e^{2j\theta}}{1 + \Gamma_S \cdot e^{2j\theta}} + \frac{1 - \Gamma_S^* \cdot e^{-2j\theta}}{1 + \Gamma_S^* \cdot e^{-2j\theta}} \right]$$

$$\Gamma_S = |\Gamma_S| \cdot e^{j\varphi}$$

$$\operatorname{Re}[y_S(\theta)] = \frac{1}{2} \cdot \left[\frac{(1 - |\Gamma_S| \cdot e^{j(\varphi+2\theta)}) \cdot (1 + |\Gamma_S| \cdot e^{-j(\varphi+2\theta)}) + (1 - |\Gamma_S| \cdot e^{-j(\varphi+2\theta)}) \cdot (1 + |\Gamma_S| \cdot e^{j(\varphi+2\theta)})}{(1 + |\Gamma_S| \cdot e^{-j(\varphi+2\theta)}) \cdot (1 + |\Gamma_S| \cdot e^{j(\varphi+2\theta)})} \right]$$

$$\operatorname{Re}[y_S(\theta)] = \frac{1}{2} \cdot \left[\frac{2 - 2 \cdot |\Gamma_S|^2}{1 + |\Gamma_S|^2 + 2 \cdot |\Gamma_S| \cdot \cos(\varphi + 2\theta)} \right] = 1 \Rightarrow \boxed{\cos(\varphi + 2\theta) = -|\Gamma_S|}$$

Calcul analitic, linie serie (calcul)

- Ecuația pentru calcularea θ (linie serie)

$$\operatorname{Re}[y_S(\theta)] = 1 \Rightarrow \cos(\varphi + 2\theta) = -|\Gamma_S|$$

$$\Gamma_S = |\Gamma_S| \cdot e^{j\varphi} \quad \Gamma_S = 0.593 \angle 46.85^\circ \quad |\Gamma_S| = 0.593; \quad \varphi = 46.85^\circ$$

- doua solutii posibile, normate la intervalul $0 \div 180^\circ$
 - se adauga $\lambda/2$ (180°) dupa nevoie

$$\theta = \frac{1}{2} \cdot [\pm \cos^{-1}(-|\Gamma_S|) - \varphi + k \cdot 360^\circ] = \frac{1}{2} \cdot [\pm \cos^{-1}(-|\Gamma_S|) - \varphi] + k \cdot 180^\circ$$

$$\forall k \in \mathbb{N}$$

$$\cos(\varphi + 2\theta) = -0.593 \Rightarrow (\varphi + 2\theta) = \pm 126.35^\circ$$

$$(46.85^\circ + 2\theta) = \begin{cases} +126.35^\circ \\ -126.35^\circ \end{cases}$$

$$\theta = \begin{cases} +39.7^\circ \\ -86.6^\circ + 180^\circ = +93.4^\circ \end{cases}$$

Calcul analitic, stub paralel (dem.)

- Ecuația pentru calcularea stub-ului paralel θ_{sp}

$$\operatorname{Re}[y_S(\theta)] = 1 \quad \cos(\varphi + 2\theta) = -|\Gamma_S| \quad \operatorname{Im}[y_S(\theta)] = \frac{1}{2j} \cdot [y_S(\theta) - y_S^*(\theta)]$$

$$\operatorname{Im}[y_S(\theta)] = \frac{1}{2j} \cdot \left[\frac{1 - \Gamma_S \cdot e^{2j\theta}}{1 + \Gamma_S \cdot e^{2j\theta}} - \frac{1 - \Gamma_S^* \cdot e^{-2j\theta}}{1 + \Gamma_S^* \cdot e^{-2j\theta}} \right] \quad \Gamma_S = |\Gamma_S| \cdot e^{j\varphi}$$

$$\operatorname{Im}[y_S(\theta)] = \frac{1}{2j} \cdot \left[\frac{(1 - |\Gamma_S| \cdot e^{j(\varphi+2\theta)}) \cdot (1 + |\Gamma_S| \cdot e^{-j(\varphi+2\theta)}) - (1 - |\Gamma_S| \cdot e^{-j(\varphi+2\theta)}) \cdot (1 + |\Gamma_S| \cdot e^{j(\varphi+2\theta)})}{(1 + |\Gamma_S| \cdot e^{-j(\varphi+2\theta)}) \cdot (1 + |\Gamma_S| \cdot e^{j(\varphi+2\theta)})} \right]$$

$$\operatorname{Im}[y_S(\theta)] = \frac{1}{2j} \cdot \left[\frac{2 \cdot |\Gamma_S| \cdot e^{-j(\varphi+2\theta)} - 2 \cdot |\Gamma_S| \cdot e^{+j(\varphi+2\theta)}}{1 + |\Gamma_S|^2 + 2 \cdot |\Gamma_S| \cdot \cos(\varphi + 2\theta)} \right] = \frac{-2 \cdot |\Gamma_S| \cdot \sin(\varphi + 2\theta)}{1 + |\Gamma_S|^2 + 2 \cdot |\Gamma_S| \cdot \cos(\varphi + 2\theta)}$$

$$\cos(\varphi + 2\theta) = -|\Gamma_S| \Rightarrow \operatorname{Im}[y_S(\theta)] = \frac{-2 \cdot |\Gamma_S| \cdot \sin(\varphi + 2\theta)}{1 - |\Gamma_S|^2}$$

Calcul analitic, stub paralel (dem.)

- Ecuația pentru calcularea stub-ului paralel

$$\cos(\varphi + 2\theta) = -|\Gamma_S| \Rightarrow \sin(\varphi + 2\theta) = \pm \sqrt{1 - |\Gamma_S|^2}$$

$$\operatorname{Im}[y_S(\theta)] = \frac{-2 \cdot |\Gamma_S| \cdot \sin(\varphi + 2\theta)}{1 - |\Gamma_S|^2} \Rightarrow \operatorname{Im}[y_S(\theta)] = \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}$$

- doua situatii

$$\varphi + 2\theta \in [0^\circ, 180^\circ] \Rightarrow \sin(\varphi + 2\theta) \geq 0 \quad \left\{ \begin{array}{l} \sin(\varphi + 2\theta) = \sqrt{1 - |\Gamma_S|^2} \\ \operatorname{Im}[y_S(\theta)] = \frac{-2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} \end{array} \right.$$

$$\varphi + 2\theta \in (-180^\circ, 0^\circ) \Rightarrow \sin(\varphi + 2\theta) < 0 \quad \left\{ \begin{array}{l} \sin(\varphi + 2\theta) = -\sqrt{1 - |\Gamma_S|^2} \\ \operatorname{Im}[y_S(\theta)] = \frac{2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} \end{array} \right.$$

- **Semnul** (+/-) soluției alese la **prima** ecuație impune **semnul** soluției utilizate la a **doua** ecuație

Calcul analitic, stub paralel (dem.)

- Se prefera (pentru microstrip) stub in gol

$$Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

- Susceptanta raportata introdusa pentru adaptare
 - $Y(\theta)$ este admitanta vazuta **inspre** sursa, Z_0 in paralel cu $j \cdot B$

$$b = \text{Im} \left[\frac{Y_{in,g}}{Y_0} \right] = \text{Im} \left[\frac{Z_0}{Z_{in,g}} \right] = \tan \beta \cdot l = \text{Im}[y_s(\theta)]$$

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

Calcul analitic (calcul efectiv)

$$(\varphi + 2\theta) = \begin{cases} \oplus 126.35^\circ \\ \ominus 126.35^\circ \end{cases} \quad \theta = \begin{cases} 39.7^\circ \\ 93.4^\circ \end{cases} \quad \text{Im}[y_s(\theta)] = \begin{cases} \ominus 1.472 \\ \oplus 1.472 \end{cases} \quad \theta_{sp} = \begin{cases} -55.8^\circ + 180^\circ = 124.2^\circ \\ +55.8^\circ \end{cases}$$

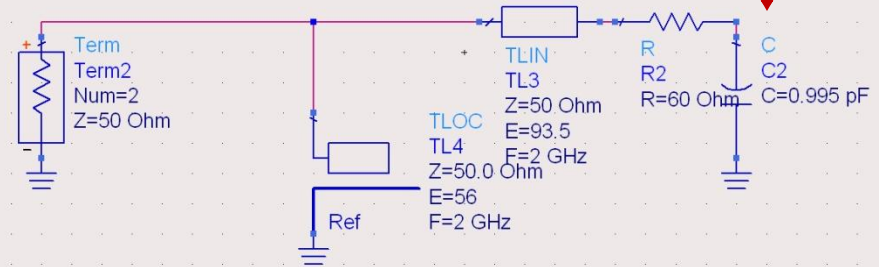
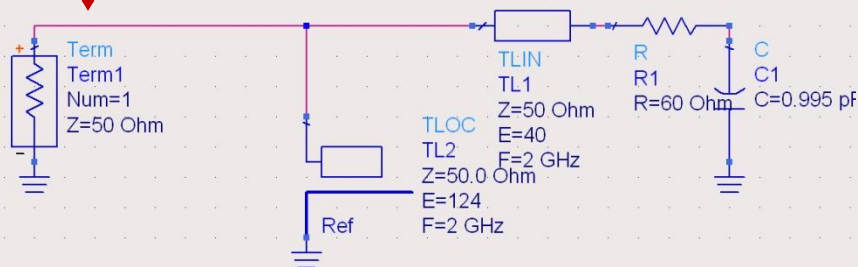
- Se alege **una** din cele doua solutii posibile
- Semnul** (+/-) solutiei alese la **prima** ecuatie impune **semnul** solutiei utilizate la a **doua** ecuatie

$$l_1 = \frac{39.7^\circ}{360^\circ} \cdot \lambda = 0.110 \cdot \lambda$$

$$l_2 = \frac{124.2^\circ}{360^\circ} \cdot \lambda = 0.345 \cdot \lambda$$

$$l_1 = \frac{93.4^\circ}{360^\circ} \cdot \lambda = 0.259 \cdot \lambda$$

$$l_2 = \frac{55.8^\circ}{360^\circ} \cdot \lambda = 0.155 \cdot \lambda$$

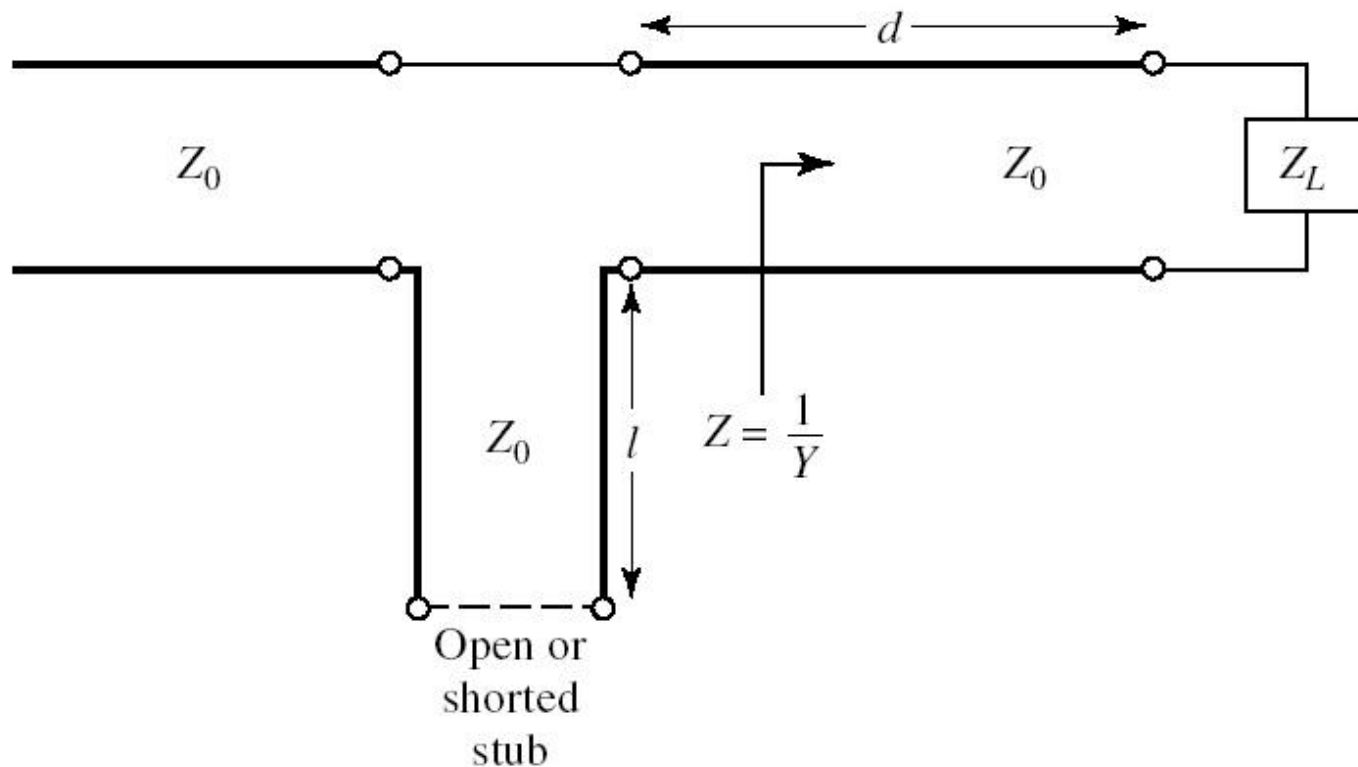


Series Stub

Sectiune de linie serie

Caz 2, Series Stub

- Series Stub (sectiune de linie in serie)
- tehnologic mai dificil de realizat la liniile monofilare (microstrip)



Caz 2, Series Stub

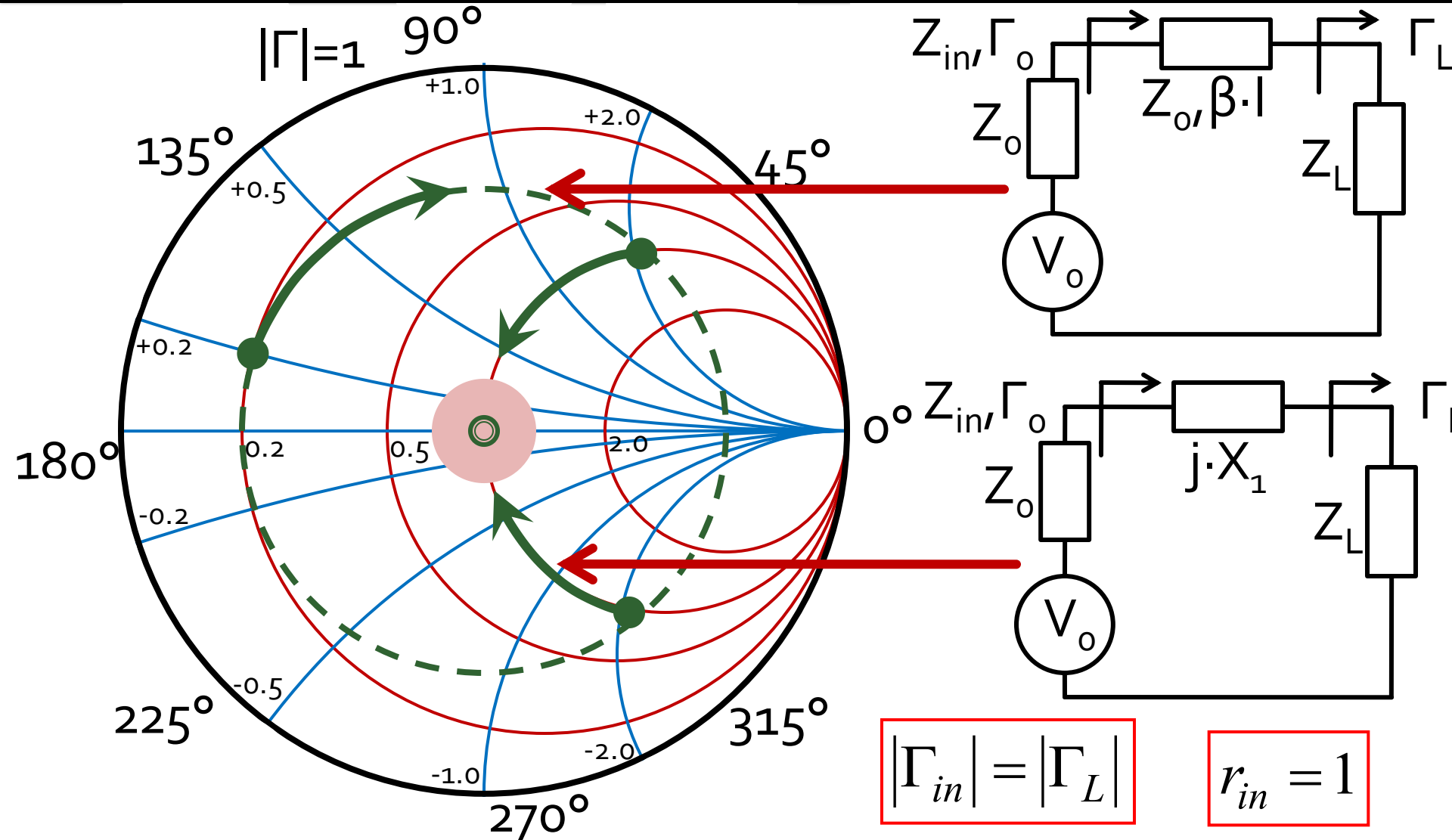
- Se utilizeaza o linie de transmisie serie pentru a muta coeficientul de reflexie pe cercul $r_L = 1$
- Se introduce o reactanta in serie pentru a realiza adaptarea
- Aceasta reactanta se realizeaza cu o linie de transmisie care poate fi dupa nevoie:
 - in gol
 - in scurtcircuit

$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

$$Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l$$

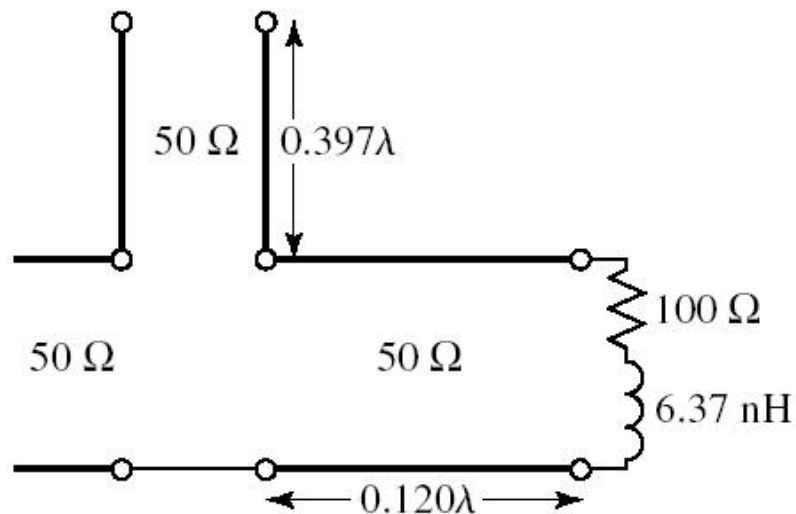
$$Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

Adaptare, linie serie + reactanta in serie

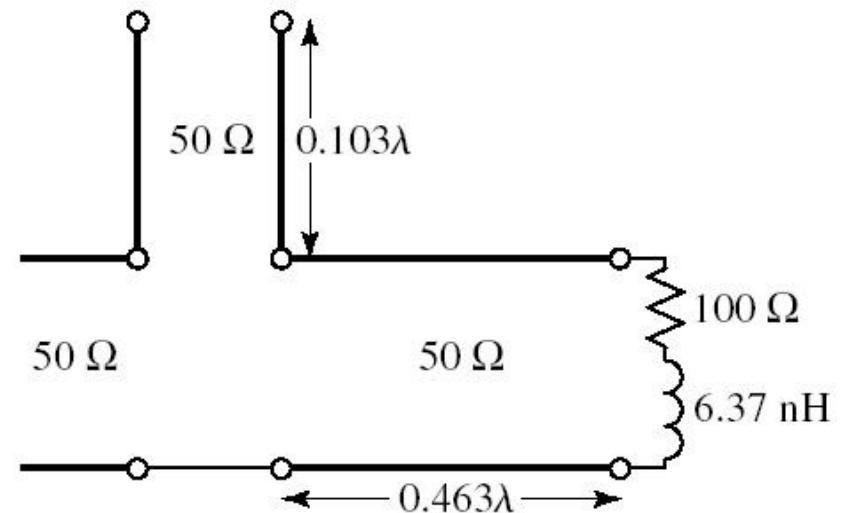


Exemplu, Series Stub, gol

- sarcina: $100\ \Omega$ serie $6.37\ \text{nH}$ la 2GHz
- doua solutii posibile

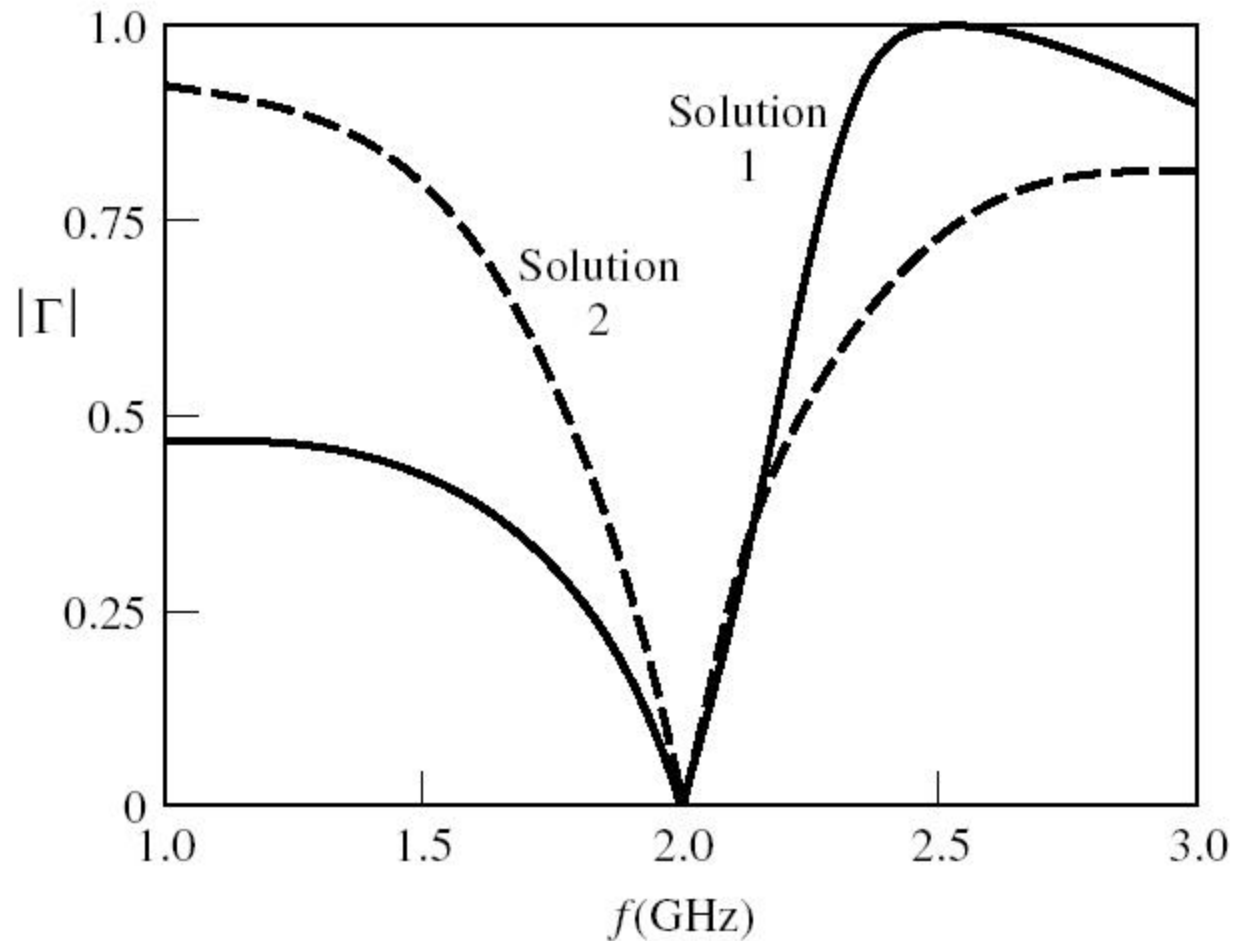


Solution 1

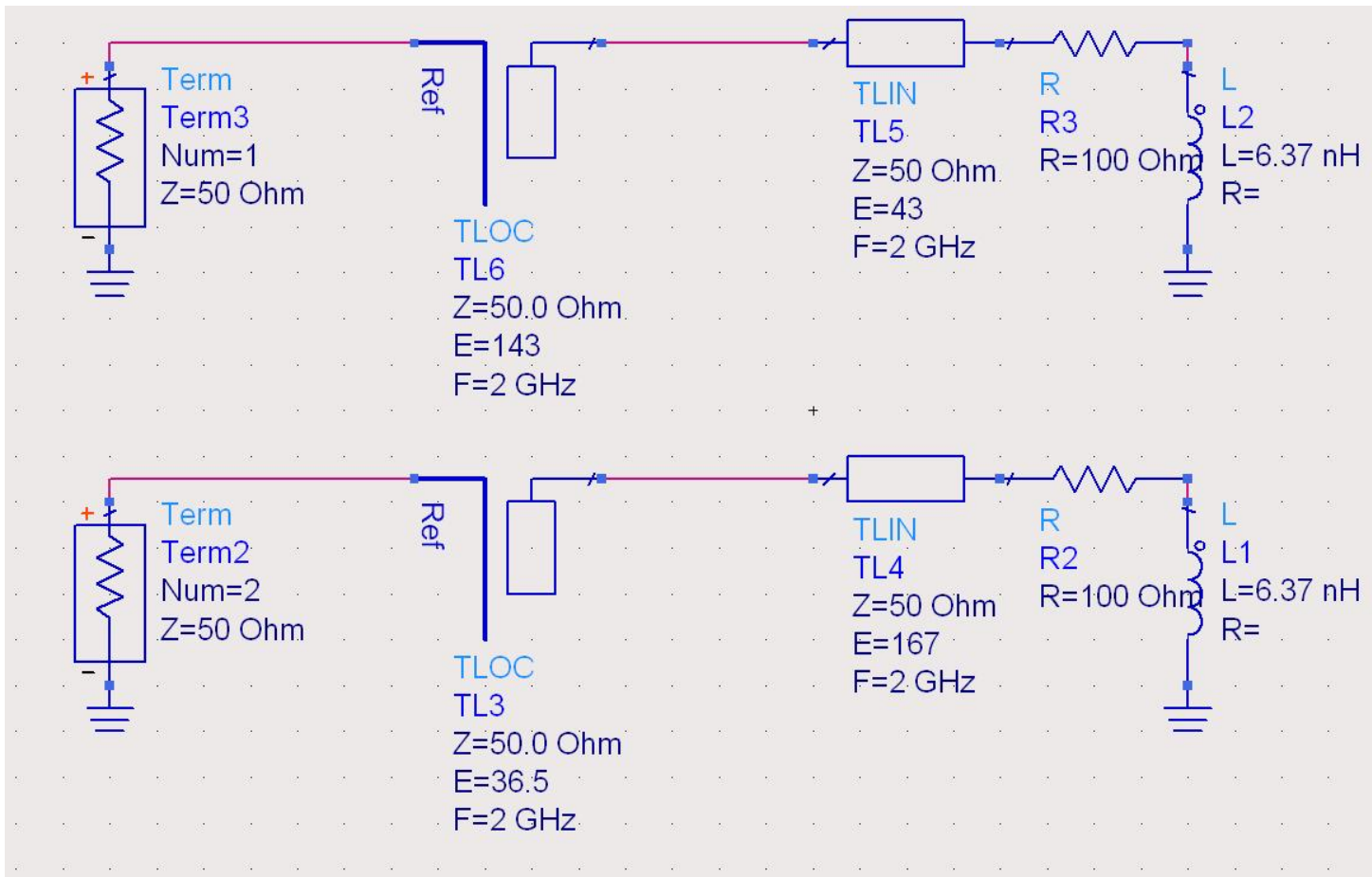


Solution 2

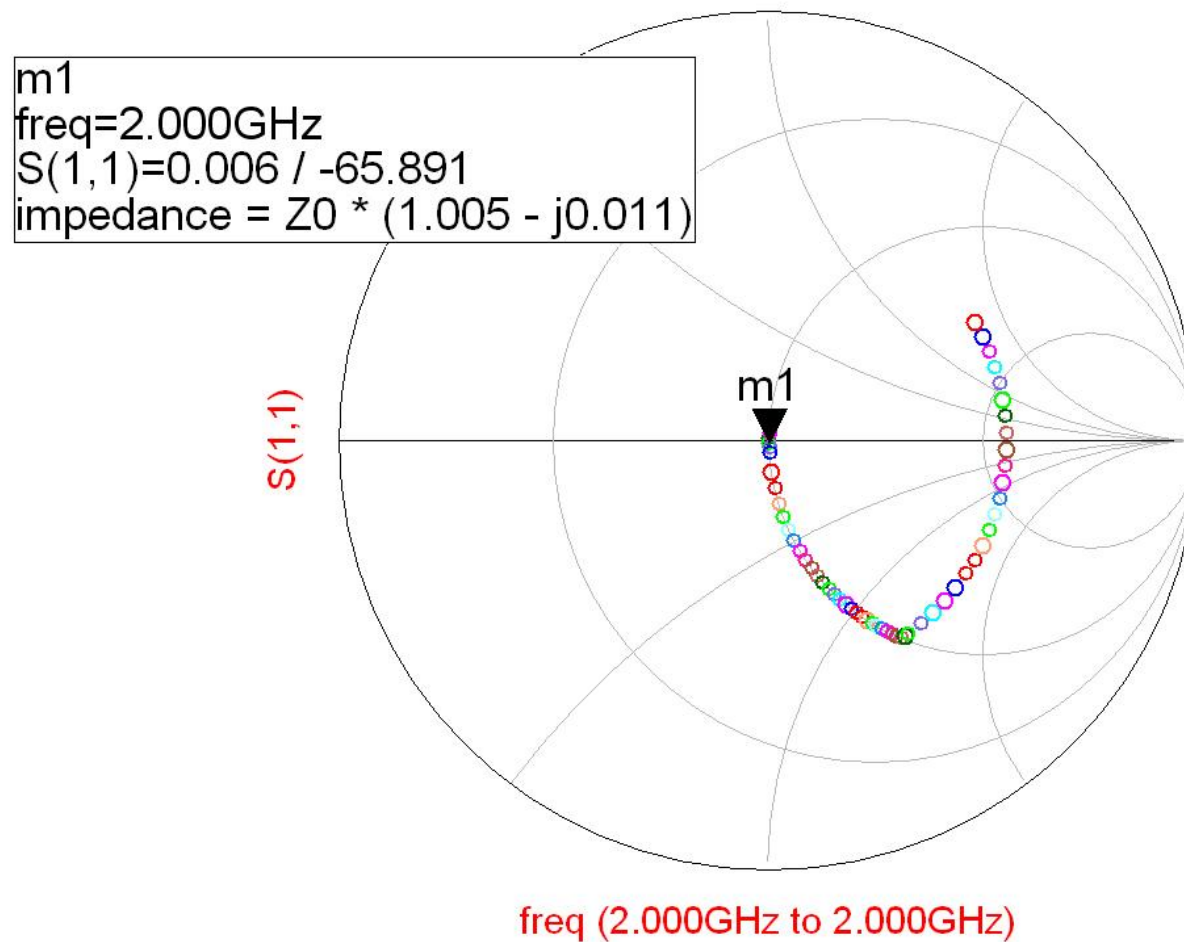
Exemplu, Series Stub, gol



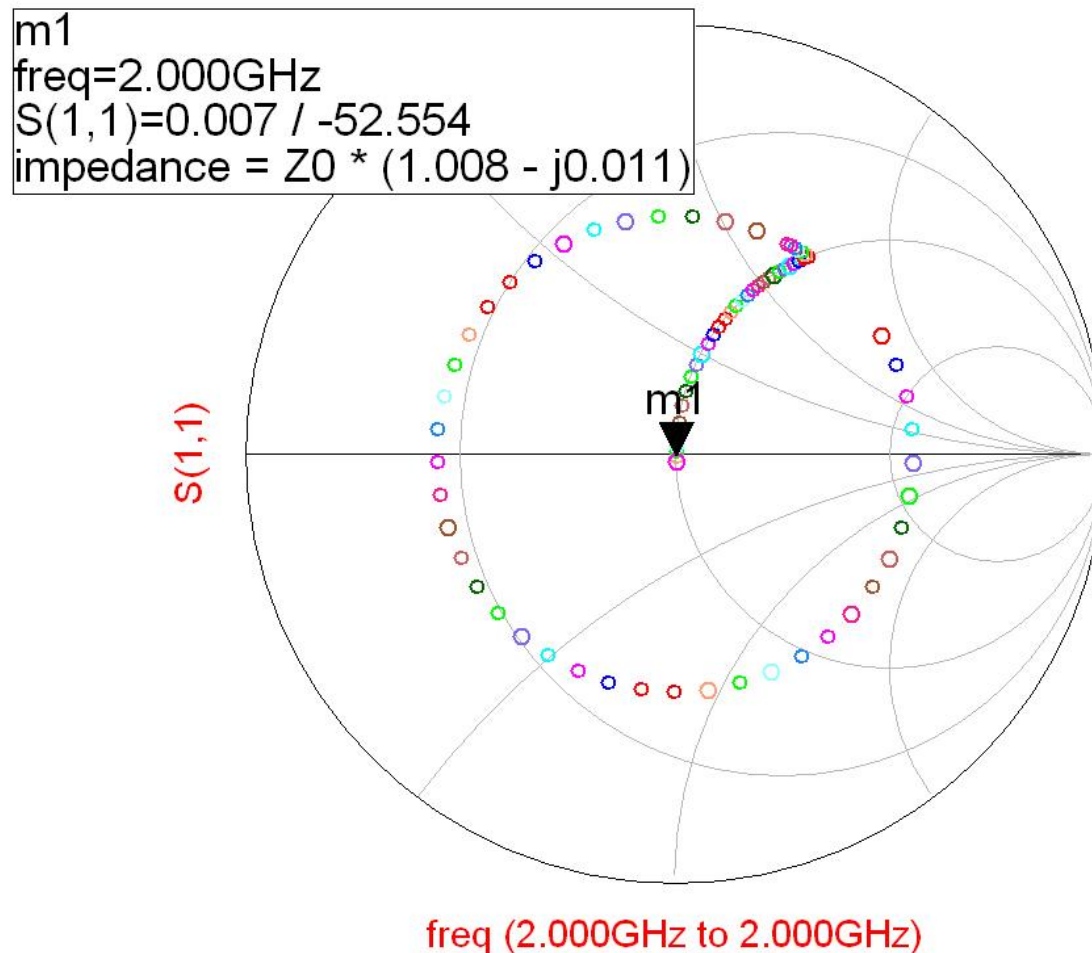
Exemplu, Series Stub, gol



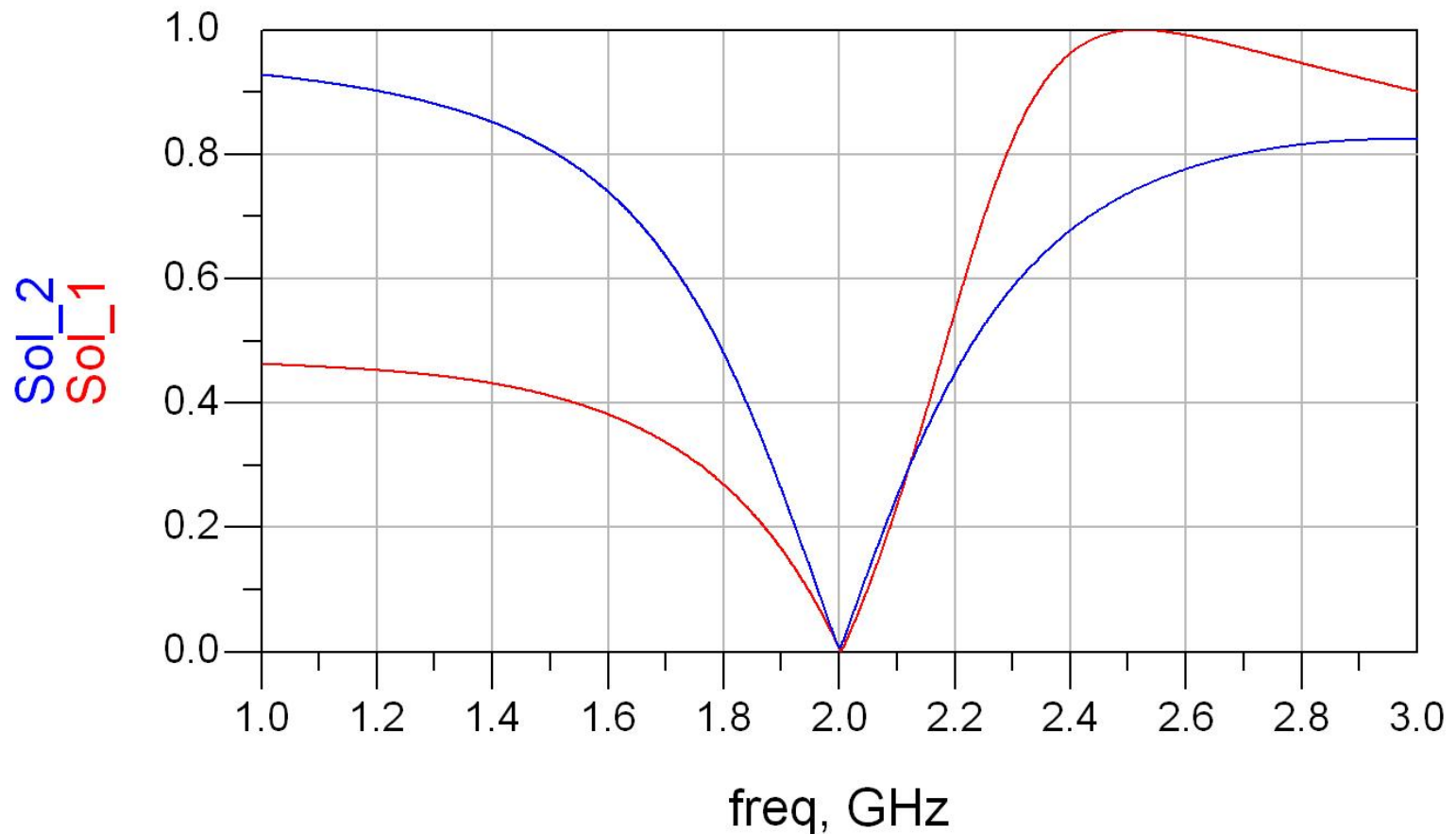
Exemplu, Series Stub, gol



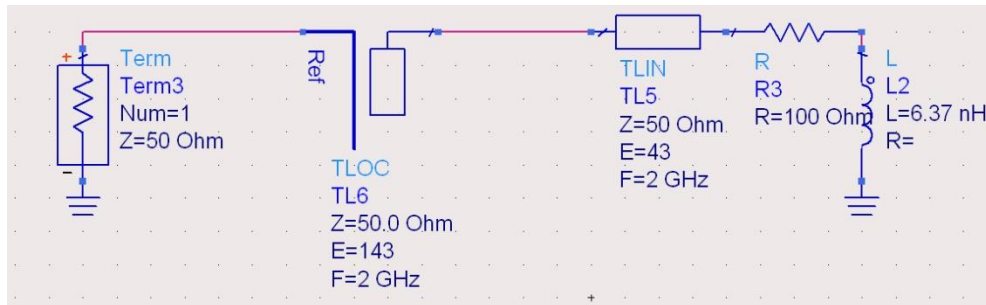
Exemplu, Series Stub, gol



Exemplu, Series Stub, gol



Exemplu, Series Stub, gol

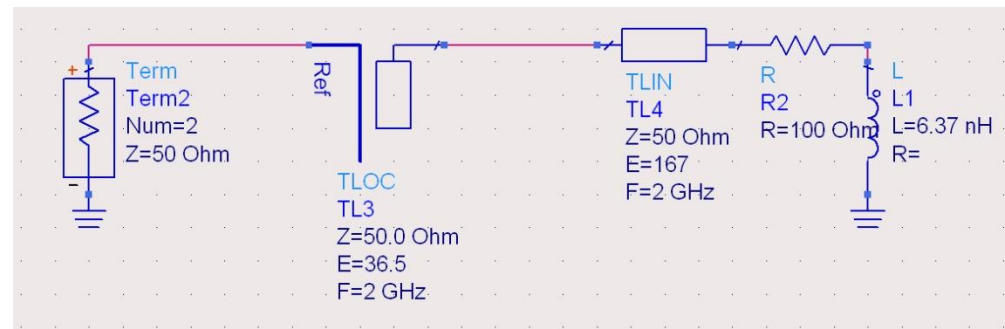


$$l_1 = \frac{43^\circ}{360^\circ} \cdot \lambda = 0.119 \cdot \lambda$$

$$l_2 = \frac{143^\circ}{360^\circ} \cdot \lambda = 0.397 \cdot \lambda$$

$$l_1 = \frac{167^\circ}{360^\circ} \cdot \lambda = 0.464 \cdot \lambda$$

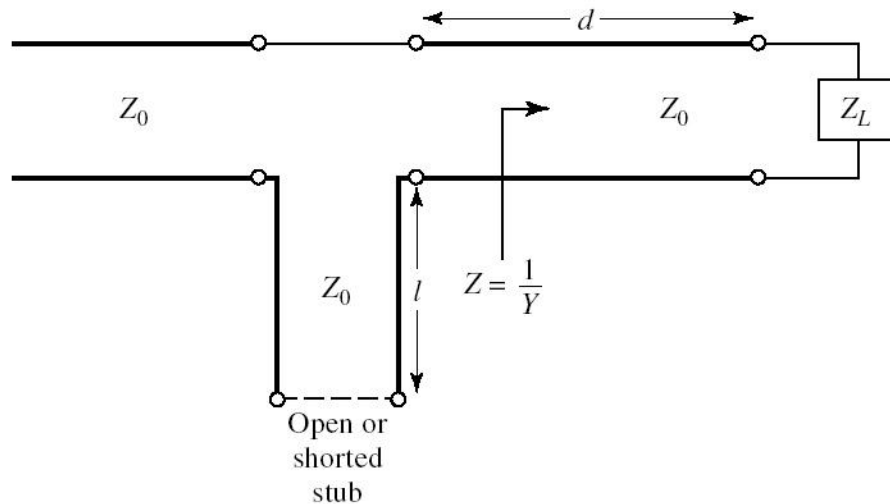
$$l_2 = \frac{36.5^\circ}{360^\circ} \cdot \lambda = 0.101 \cdot \lambda$$



Solutie analitica

Series Stub

Solutie analitica, impedante



$$Y_L = \frac{1}{Z_L} = G_L + j \cdot B_L$$

$$Y = Y_0 \cdot \frac{(G_L + j \cdot B_L) + j \cdot Y_0 \cdot t}{Y_0 + j \cdot (G_L + j \cdot B_L) \cdot t}$$

$$\overset{\text{not}}{t} = \tan \beta \cdot d \quad Z = R + j \cdot X = \frac{1}{Y}$$

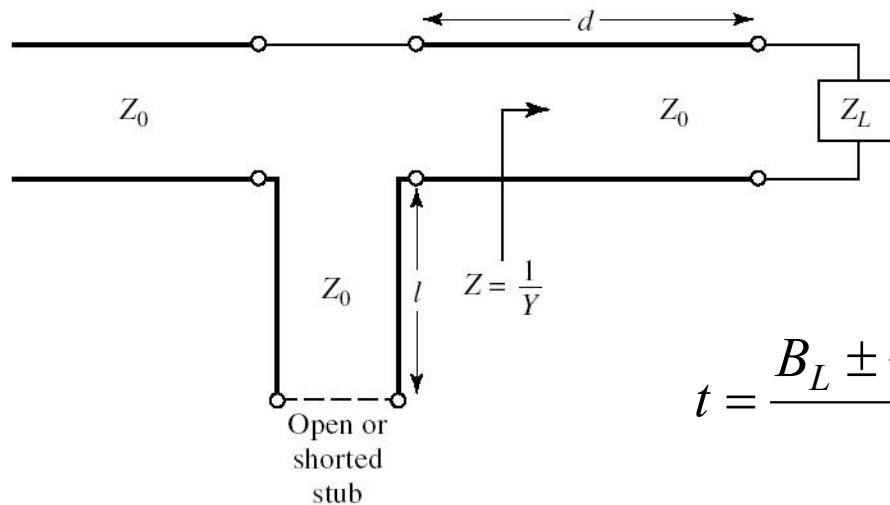
$$R = \frac{G_L \cdot (1 + t^2)}{G_L^2 + (G_L + Y_0 \cdot t)^2}$$

$$X = \frac{G_L^2 \cdot t - (Y_0 - B_L \cdot t) \cdot (B_L + Y_0 \cdot t)}{Y_0 \cdot [G_L^2 + (B_L + Y_0 \cdot t)^2]}$$

- d (deci si t) este ales astfel incat: $R = Z_0 = \frac{1}{Y_0}$

$$Y_0 \cdot (G_L - Y_0) \cdot t^2 - 2 \cdot B_L \cdot Y_0 \cdot t + (G_L \cdot Y_0 - G_L^2 - B_L^2) = 0$$

Solutie analitica



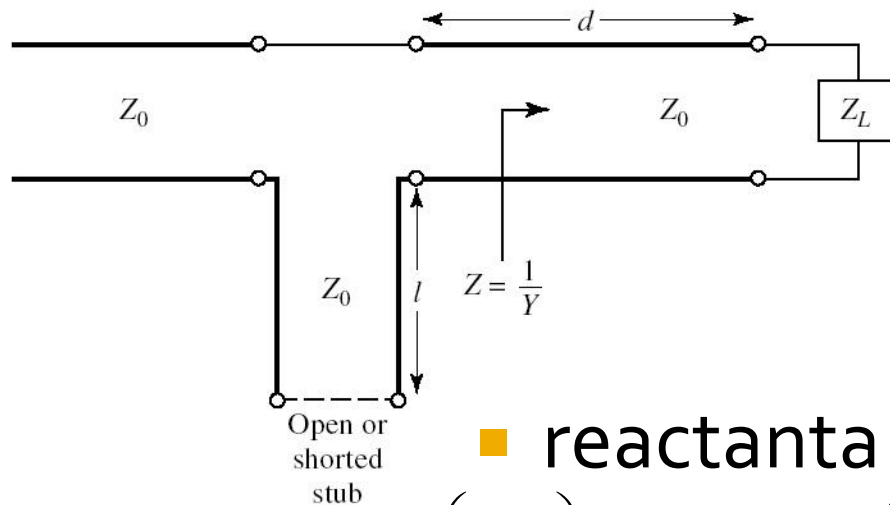
$$t = \frac{-B_L}{2 \cdot Y_0}, \quad G_L = Y_0$$

$$t = \frac{B_L \pm \sqrt{G_L \cdot [(Y_0 - G_L)^2 + B_L^2]} / Y_0}{G_L - Y_0} \quad G_L \neq Y_0$$

- ecuatie de gradul 2, 2 solutii posibile
- d (din t determinat):

$$\frac{d}{\lambda} = \begin{cases} \frac{1}{2\pi} \cdot \arctan t & t \geq 0 \\ \frac{1}{2\pi} \cdot (\pi + \arctan t) & t < 0 \end{cases}$$

Solutie analitica



$$X_S = -X$$

$$X = \frac{G_L^2 \cdot t - (Y_0 - B_L \cdot t) \cdot (B_L + Y_0 \cdot t)}{Y_0 \cdot [G_L^2 + (B_L + Y_0 \cdot t)^2]}$$

■ reactanta de anulare se obtine cu:

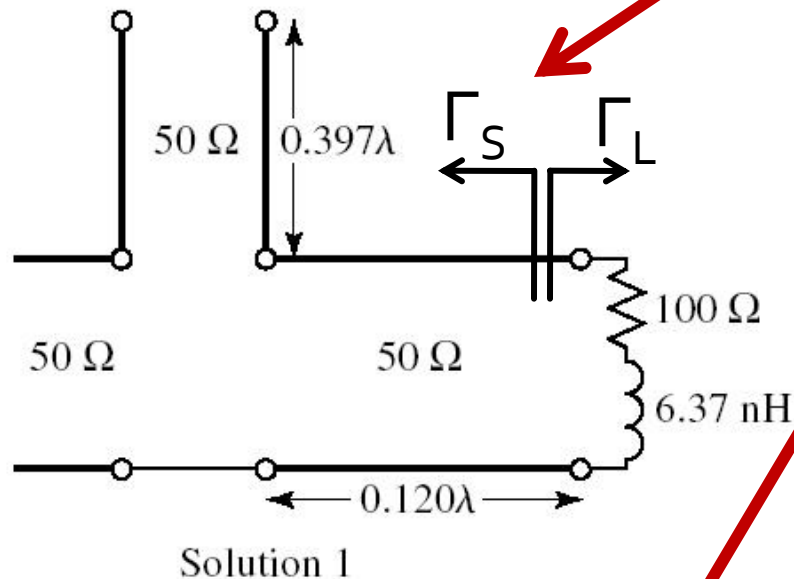
$$\frac{l_{sc}}{\lambda} = \frac{1}{2\pi} \cdot \arctan\left(\frac{X_S}{Z_0}\right) = \frac{-1}{2\pi} \cdot \arctan\left(\frac{X}{Z_0}\right)$$

$$\frac{l_{gol}}{\lambda} = \frac{-1}{2\pi} \cdot \arctan\left(\frac{Z_0}{X_S}\right) = \frac{1}{2\pi} \cdot \arctan\left(\frac{Z_0}{X}\right)$$

■ pentru **lungimi negative** se adauga $\lambda/2$

Calcul analitic, coeficienti de reflexie

- sarcina: $100\ \Omega$ serie $6.37\ \text{nH}$ la 2GHz



$$Z_L = R_L + \frac{1}{j \cdot \omega \cdot C_L} = 100\Omega + j \cdot 80.05\Omega$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = 0.481 + j \cdot 0.277$$

$$z_L = \frac{Z_L}{Z_0} = 2 + j \cdot 1.6$$

- adaptare necesita Γ complex conjugat

$$\Gamma_S = \Gamma_L^* = 0.481 - j \cdot 0.277$$

$$\Gamma_S = 0.555 \angle -29.92^\circ$$

$$|\Gamma_S| = 0.555; \quad \varphi = -29.92^\circ$$

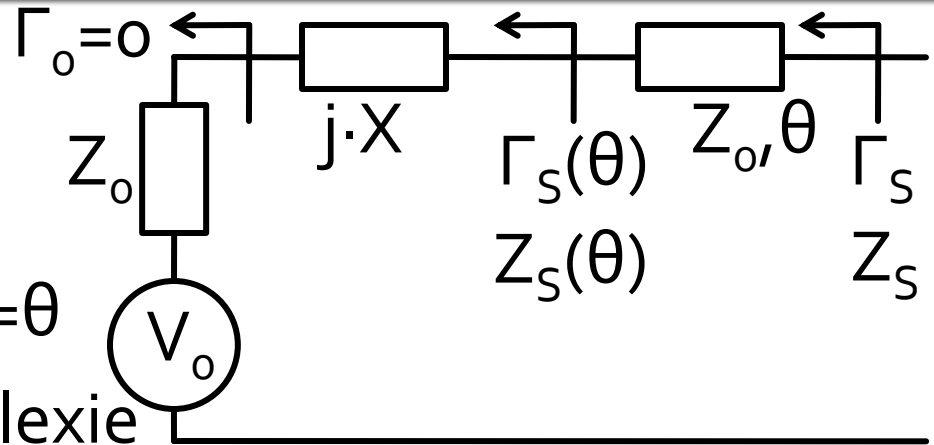
Calcul analitic, coeficienti de reflexie

- linie serie

- lungime electrica $E = \beta \cdot l = \theta$
- muta coeficientul de reflexie pe cercul $r=1$

- stub serie

- lungime electrica $E = \beta \cdot l_{ss} = \theta_{ss}$
- muta coeficientul de reflexie in centrul diagramei Smith ($\Gamma_o = 0$)



$$z_s = \frac{Z_s}{Z_o} = \frac{Z_s}{50\Omega}$$

$$z_s = \frac{1 + \Gamma_s}{1 - \Gamma_s} = 2 - j \cdot 1.6$$

$$\Gamma_s(\theta) = \Gamma_s \cdot e^{2j\theta}$$

$$z_s(\theta) = \frac{1 + \Gamma_s(\theta)}{1 - \Gamma_s(\theta)} = \frac{1 + \Gamma_s \cdot e^{2j\theta}}{1 - \Gamma_s \cdot e^{2j\theta}}$$

Calcul analitic, linie serie (dem.)

- Dupa sectiunea de linie cu lungimea electrica θ :

$$\operatorname{Re}[z_s(\theta)] = 1$$

$$\operatorname{Im}[z_s(\theta)] = X$$

$$\operatorname{Re}[z_s(\theta)] = \frac{1}{2} \cdot [z_s(\theta) + z_s^*(\theta)]$$

$$\operatorname{Im}[z_s(\theta)] = \frac{1}{2j} \cdot [z_s(\theta) - z_s^*(\theta)]$$

$$\operatorname{Re}[z_s(\theta)] = \frac{1}{2} \cdot \left[\frac{1 + \Gamma_s \cdot e^{2j\theta}}{1 - \Gamma_s \cdot e^{2j\theta}} + \frac{1 + \Gamma_s^* \cdot e^{-2j\theta}}{1 - \Gamma_s^* \cdot e^{-2j\theta}} \right]$$

$$\Gamma_s = |\Gamma_s| \cdot e^{j\varphi}$$

$$\operatorname{Re}[z_s(\theta)] = \frac{1}{2} \cdot \left[\frac{(1 + |\Gamma_s| \cdot e^{j(\varphi+2\theta)}) \cdot (1 - |\Gamma_s| \cdot e^{-j(\varphi+2\theta)}) + (1 + |\Gamma_s| \cdot e^{-j(\varphi+2\theta)}) \cdot (1 - |\Gamma_s| \cdot e^{j(\varphi+2\theta)})}{(1 - |\Gamma_s| \cdot e^{-j(\varphi+2\theta)}) \cdot (1 - |\Gamma_s| \cdot e^{j(\varphi+2\theta)})} \right]$$

$$\operatorname{Re}[z_s(\theta)] = \frac{1}{2} \cdot \left[\frac{2 - 2 \cdot |\Gamma_s|^2}{1 + |\Gamma_s|^2 - 2 \cdot |\Gamma_s| \cdot \cos(\varphi + 2\theta)} \right] = 1 \Rightarrow \boxed{\cos(\varphi + 2\theta) = |\Gamma_s|}$$

Calcul analitic, linie serie (calcul)

- Ecuația pentru calcularea θ (linie serie)

$$\operatorname{Re}[z_s(\theta)] = 1 \Rightarrow \cos(\varphi + 2\theta) = |\Gamma_s|$$

$$\Gamma_s = |\Gamma_s| \cdot e^{j\varphi} \quad \Gamma_s = 0.555 \angle -29.92^\circ \quad |\Gamma_s| = 0.555; \quad \varphi = -29.92^\circ$$

- două soluții posibile, normate la intervalul $0 \div 180^\circ$

- se adaugă $\lambda/2$ (180°) după nevoie

$$\theta = \frac{1}{2} \cdot [\pm \cos^{-1}(|\Gamma_s|) - \varphi + k \cdot 360^\circ] = \frac{1}{2} \cdot [\pm \cos^{-1}(|\Gamma_s|) - \varphi] + k \cdot 180^\circ$$

$$\cos(\varphi + 2\theta) = 0.555 \Rightarrow (\varphi + 2\theta) = \pm 56.28^\circ \quad \forall k \in \mathbb{N}$$

$$(-29.92^\circ + 2\theta) = \begin{cases} +56.28^\circ \\ -56.28^\circ \end{cases}$$

$$\theta = \begin{cases} +43.1^\circ \\ -13.2^\circ + 180^\circ = +166.8^\circ \end{cases}$$

Calcul analitic, stub serie (dem.)

- Ecuația pentru calcularea stub-ului serie θ_{ss} :

$$\operatorname{Re}[z_s(\theta)] = 1 \qquad \cos(\varphi + 2\theta) = |\Gamma_s|$$

$$\operatorname{Im}[z_s(\theta)] = \frac{1}{2j} \cdot \left[\frac{1 + \Gamma_s \cdot e^{2j\theta}}{1 - \Gamma_s \cdot e^{2j\theta}} - \frac{1 + \Gamma_s^* \cdot e^{-2j\theta}}{1 - \Gamma_s^* \cdot e^{-2j\theta}} \right] \qquad \Gamma_s = |\Gamma_s| \cdot e^{j\varphi}$$

$$\operatorname{Im}[z_s(\theta)] = \frac{1}{2j} \cdot \left[\frac{(1 + |\Gamma_s| \cdot e^{j(\varphi+2\theta)}) \cdot (1 - |\Gamma_s| \cdot e^{-j(\varphi+2\theta)}) - (1 + |\Gamma_s| \cdot e^{-j(\varphi+2\theta)}) \cdot (1 - |\Gamma_s| \cdot e^{j(\varphi+2\theta)})}{(1 - |\Gamma_s| \cdot e^{-j(\varphi+2\theta)}) \cdot (1 - |\Gamma_s| \cdot e^{j(\varphi+2\theta)})} \right]$$

$$\operatorname{Im}[z_s(\theta)] = \frac{1}{2j} \cdot \left[\frac{2 \cdot |\Gamma_s| \cdot e^{+j(\varphi+2\theta)} - 2 \cdot |\Gamma_s| \cdot e^{-j(\varphi+2\theta)}}{1 + |\Gamma_s|^2 - 2 \cdot |\Gamma_s| \cdot \cos(\varphi + 2\theta)} \right] = \frac{2 \cdot |\Gamma_s| \cdot \sin(\varphi + 2\theta)}{1 + |\Gamma_s|^2 - 2 \cdot |\Gamma_s| \cdot \cos(\varphi + 2\theta)}$$

$$\cos(\varphi + 2\theta) = |\Gamma_s| \Rightarrow \operatorname{Im}[z_s(\theta)] = \frac{2 \cdot |\Gamma_s| \cdot \sin(\varphi + 2\theta)}{1 - |\Gamma_s|^2}$$

Calcul analitic, stub serie (dem.)

- Ecuația pentru calcularea stub-ului serie θ_{ss} :

$$\cos(\varphi + 2\theta) = |\Gamma_s| \Rightarrow \sin(\varphi + 2\theta) = \pm \sqrt{1 - |\Gamma_s|^2}$$

$$\text{Im}[z_s(\theta)] = \frac{2 \cdot |\Gamma_s| \cdot \sin(\varphi + 2\theta)}{1 - |\Gamma_s|^2} \Rightarrow \text{Im}[z_s(\theta)] = \frac{\pm 2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}}$$

- doua situatii

$$\varphi + 2\theta \in [0^\circ, 180^\circ] \Rightarrow \sin(\varphi + 2\theta) \geq 0 \left\{ \begin{array}{l} \sin(\varphi + 2\theta) = \sqrt{1 - |\Gamma_s|^2} \\ \text{Im}[z_s(\theta)] = \frac{2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}} \end{array} \right.$$

$$\varphi + 2\theta \in (-180^\circ, 0^\circ) \Rightarrow \sin(\varphi + 2\theta) < 0 \left\{ \begin{array}{l} \sin(\varphi + 2\theta) = -\sqrt{1 - |\Gamma_s|^2} \\ \text{Im}[z_s(\theta)] = \frac{-2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}} \end{array} \right.$$

- **Semnul** (+/-) soluției alese la **prima** ecuație impune **semnul** soluției utilizate la a **doua** ecuație

Calcul analitic, stub serie (dem.)

- Se prefera (pentru microstrip) stub in gol

$$Z_{in,oc} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

- Reactanta raportata introdusa pentru adaptare
 - $Z(\theta)$ este impedanta vazuta **inspre** sursa, Z_0 in serie cu $j \cdot X$

$$x = \text{Im} \left[\frac{Z_{in,oc}}{Z_0} \right] = -\cot \beta \cdot l = \text{Im}[z_s(\theta)]$$

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

Calcul analitic (calcul efectiv)

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

- Se alege **una** din cele doua solutii posibile
- **Semnul** (+/-) solutiei alese la **prima** ecuatie impune **semnul** solutiei utilizate la a **doua** ecuatie

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

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

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

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

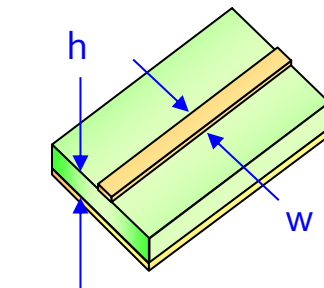


Adaptarea cu sectiuni de linii (stub)

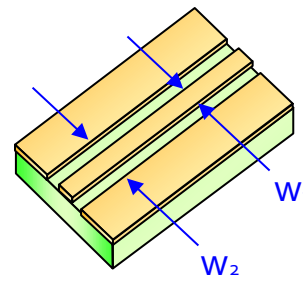
- Se alege una din cele 8 solutii posibile convenabila tinand cont de:
 - dimensiuni fizice (suprafata ocupata pe chip/placa)
 - sensibilitatea adaptarii la variatia parametrilor fizici ai liniilor ($\Delta\Gamma/\Delta E$, $\Delta\Gamma/\Delta l$)
 - caracteristica de frecventa convenabila

Adaptarea cu sectiuni de linii (stub)

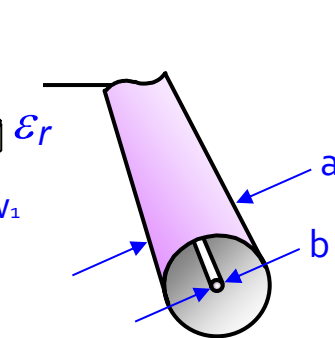
- Se alege una din cele 8 solutii posibile convenabila tinand cont de:
 - realizabilitate fizica (conform tehnologiei de linie utilizata)



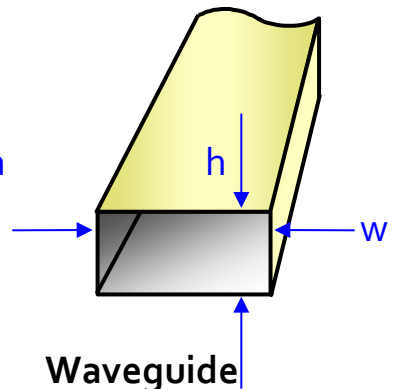
Microstrip



Coplanar



Coaxial



Waveguide

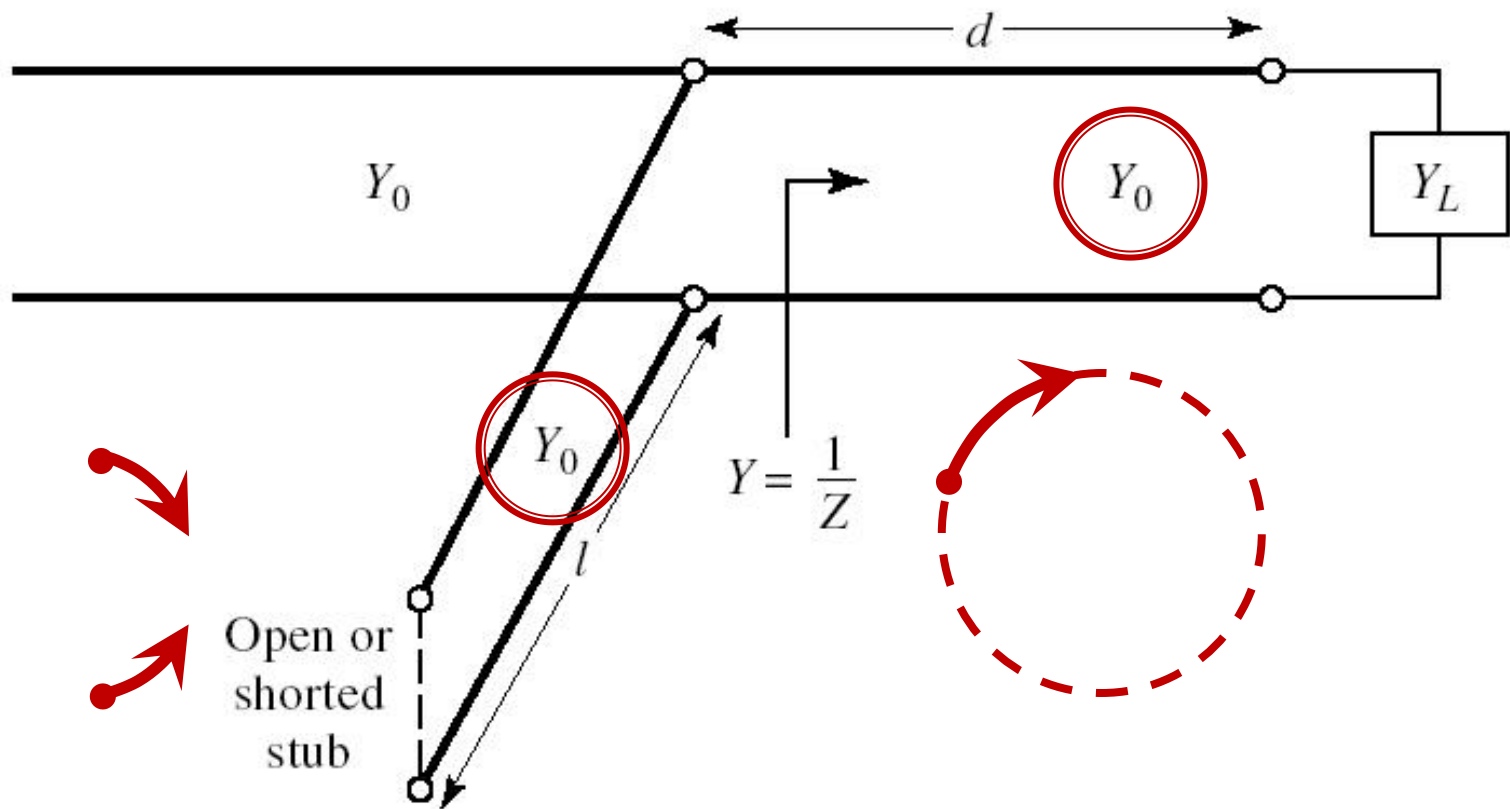
- Dezavantaj:
 - lungimea sectiunii de linie serie e variabila

Solutii analitice

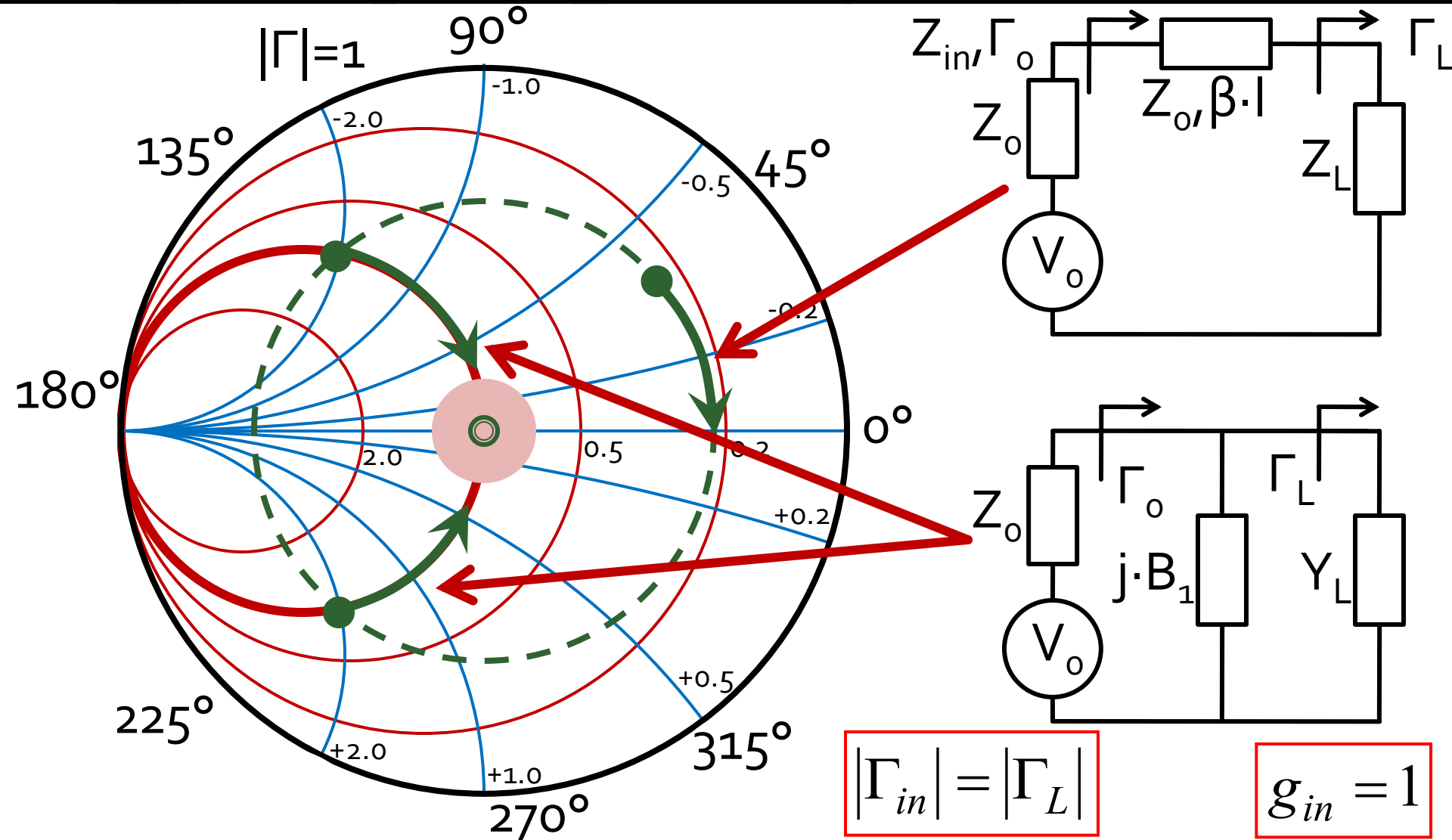
Examen / Proiect

Caz 1, Shunt Stub

- Shunt Stub (sectiune de linie in paralel)



Adaptare, linie serie + susceptanta in paralel



Calcul analitic (calcul efectiv)

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

$$\Gamma_S = 0.593 \angle 46.85^\circ$$

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

$$|\Gamma_S| = 0.593; \quad \varphi = 46.85^\circ \quad \cos(\varphi + 2\theta) = -0.593 \Rightarrow (\varphi + 2\theta) = \pm 126.35^\circ$$

- **Semnul** (+/-) solutiei alese la ecuatia **liniei serie** impune **semnul** solutiei utilizate la ecuatia **stub-ului paralel**

- **solutia "cu +"** ↓

$$(46.85^\circ + 2\theta) = +126.35^\circ \quad \theta = +39.7^\circ \quad \text{Im } y_S = \frac{-2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = -1.472$$

$$\theta_{sp} = \tan^{-1}(\text{Im } y_S) = -55.8^\circ \underline{(+180^\circ)} \rightarrow \theta_{sp} = 124.2^\circ$$

- **solutia "cu -"** ↓

$$(46.85^\circ + 2\theta) = -126.35^\circ \quad \theta = -86.6^\circ \underline{(+180^\circ)} \rightarrow \theta = 93.4^\circ$$

$$\text{Im } y_S = \frac{+2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = +1.472 \quad \theta_{sp} = \tan^{-1}(\text{Im } y_S) = 55.8^\circ$$

Calcul analitic (calcul efectiv)

$$(\varphi + 2\theta) = \begin{cases} +126.35^\circ \\ -126.35^\circ \end{cases} \quad \theta = \begin{cases} 39.7^\circ \\ 93.4^\circ \end{cases} \quad \text{Im}[y_s(\theta)] = \begin{cases} -1.472 \\ +1.472 \end{cases} \quad \theta_{sp} = \begin{cases} -55.8^\circ + 180^\circ = 124.2^\circ \\ +55.8^\circ \end{cases}$$

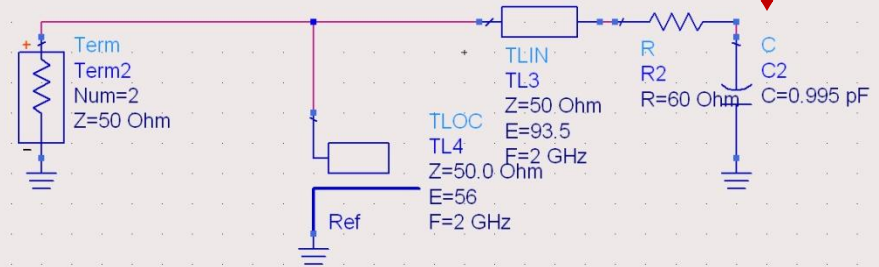
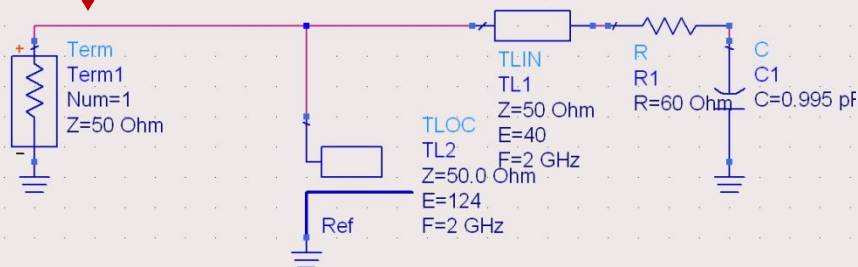
- Se alege **una** din cele doua solutii posibile
- **Semnul** (+/-) solutiei alese la **prima** ecuatie impune **semnul** solutiei utilizate la a **doua** ecuatie

$$l_1 = \frac{39.7^\circ}{360^\circ} \cdot \lambda = 0.110 \cdot \lambda$$

$$l_2 = \frac{124.2^\circ}{360^\circ} \cdot \lambda = 0.345 \cdot \lambda$$

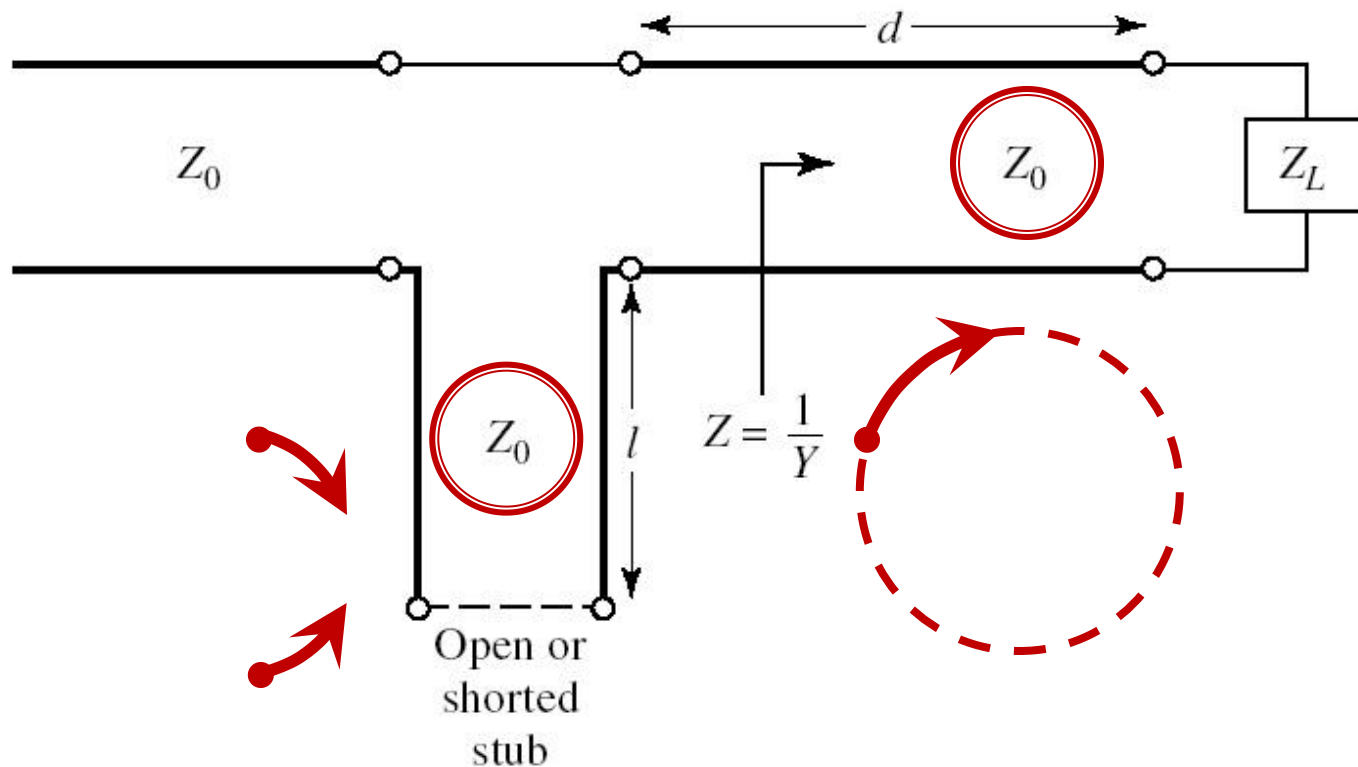
$$l_1 = \frac{93.4^\circ}{360^\circ} \cdot \lambda = 0.259 \cdot \lambda$$

$$l_2 = \frac{55.8^\circ}{360^\circ} \cdot \lambda = 0.155 \cdot \lambda$$

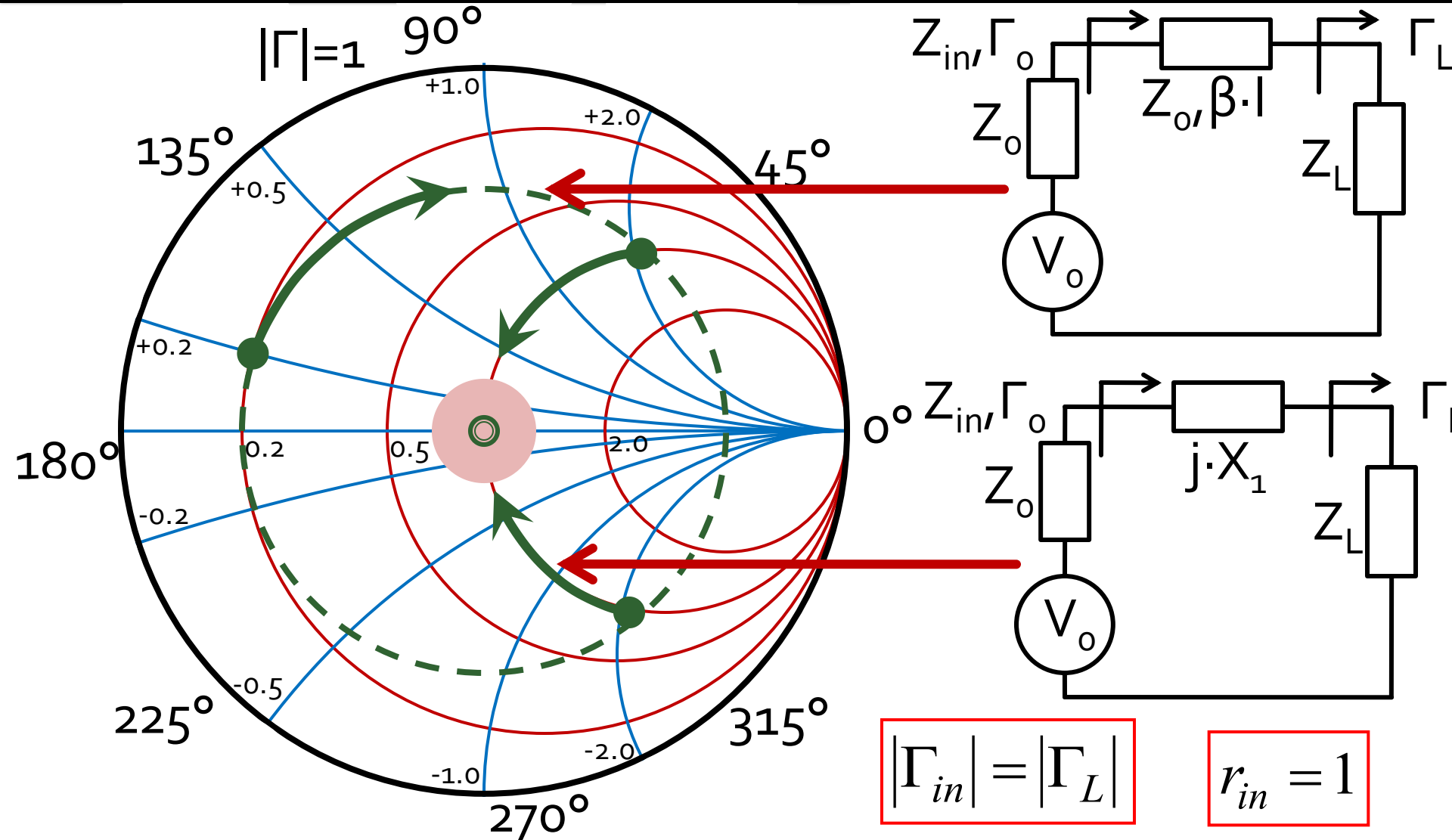


Caz 2, Series Stub

- Series Stub (sectiune de linie in serie)
- tehnologic mai dificil de realizat la liniile monofilare (microstrip)



Adaptare, linie serie + reactanta in serie



Calcul analitic (calcul efectiv)

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

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

$$\Gamma_S = 0.555 \angle -29.92^\circ$$

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

- **Semnul** (+/-) solutiei alese la ecuatia **liniei serie** impune **semnul** solutiei utilizate la ecuatia **stub-ului serie**

- **solutia "cu +"** ↓

$$(-29.92^\circ + 2\theta) = +56.28^\circ \quad \theta = 43.1^\circ \quad \text{Im } z_s = \frac{+2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = +1.335$$

$$\theta_{ss} = -\cot^{-1}(\text{Im } z_s) = -36.8^\circ (+180^\circ) \rightarrow \theta_{ss} = 143.2^\circ$$

- **solutia "cu -"** ↓

$$(-29.92^\circ + 2\theta) = -56.28^\circ \quad \theta = -13.2^\circ (+180^\circ) \rightarrow \theta = 166.8^\circ$$

$$\text{Im } z_s = \frac{-2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = -1.335 \quad \theta_{ss} = -\cot^{-1}(\text{Im } z_s) = 36.8^\circ$$

Calcul analitic (calcul efectiv)

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

- Se alege **una** din cele doua solutii posibile
- **Semnul** (+/-) solutiei alese la **prima** ecuatie impune **semnul** solutiei utilizate la a **doua** ecuatie

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

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

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

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



Stub, observatii

- adunarea si scadere de **180°** ($\lambda/2$) nu schimba rezultatul (rotatie completa in jurul diagramei)

$$E = \beta \cdot l = \pi = 180^\circ \quad l = k \cdot \frac{\lambda}{2}, \forall k \in \mathbb{N}$$

- pentru linii de “lungime” / “lungime electrica” **negative** se adauga $\lambda/2$ / 180° pentru a avea valoare pozitiva (realizabila fizic)
- o adaugare sau scadere de **90°** ($\lambda/4$) transforma impedanta stub-ului:

$$Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l \quad \Leftrightarrow \quad Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

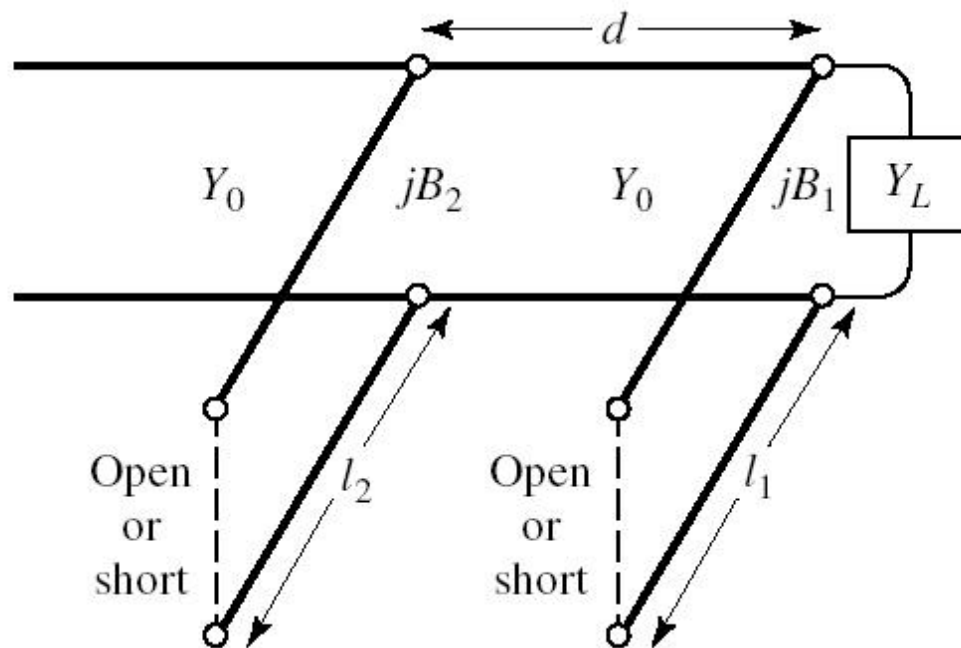
- pentru stub se poate adauga/scadea 90° ($\lambda/4$) simultan cu schimbare **gol** $\Leftrightarrow$ **scurtcircuit**

Double stub tuning

Adaptarea cu doua sectiuni de linie

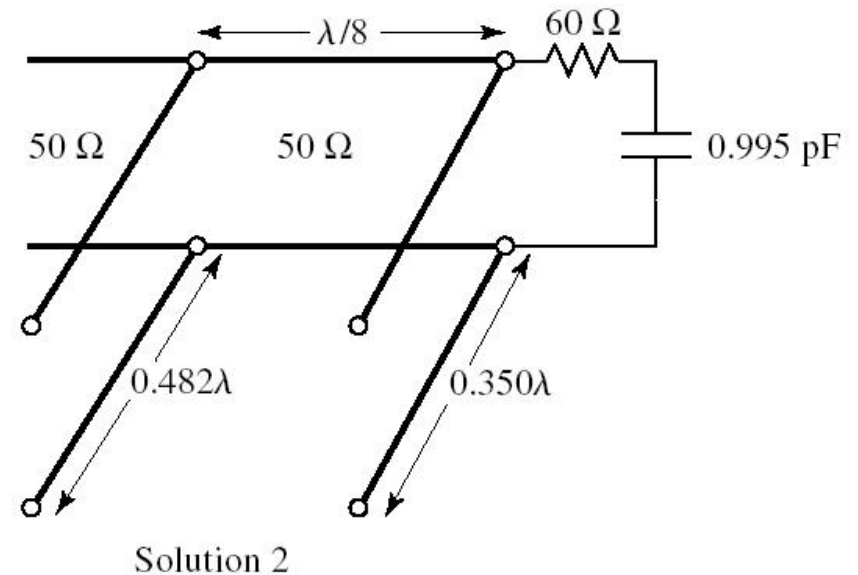
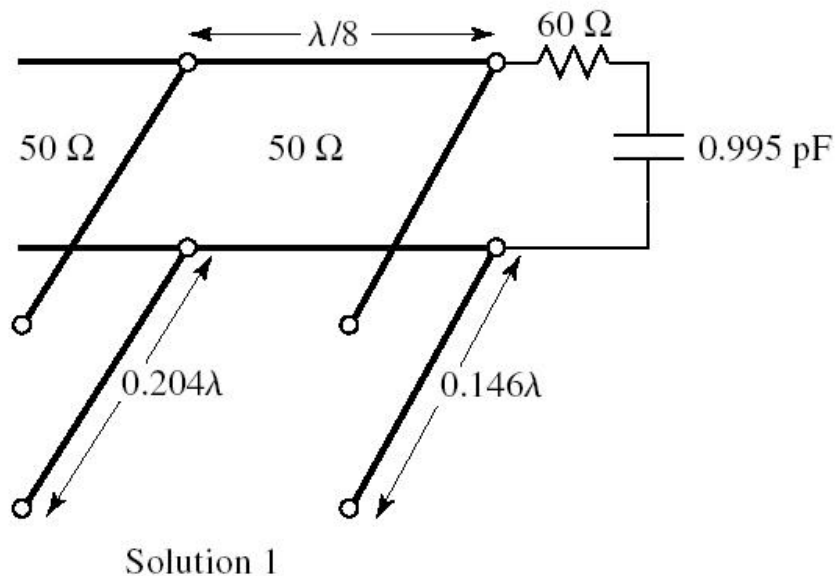
Adaptarea cu doua sectiuni de linie

- Double stub tuning
- Se foloseste o lungime constanta de linie intre 2 stub-uri



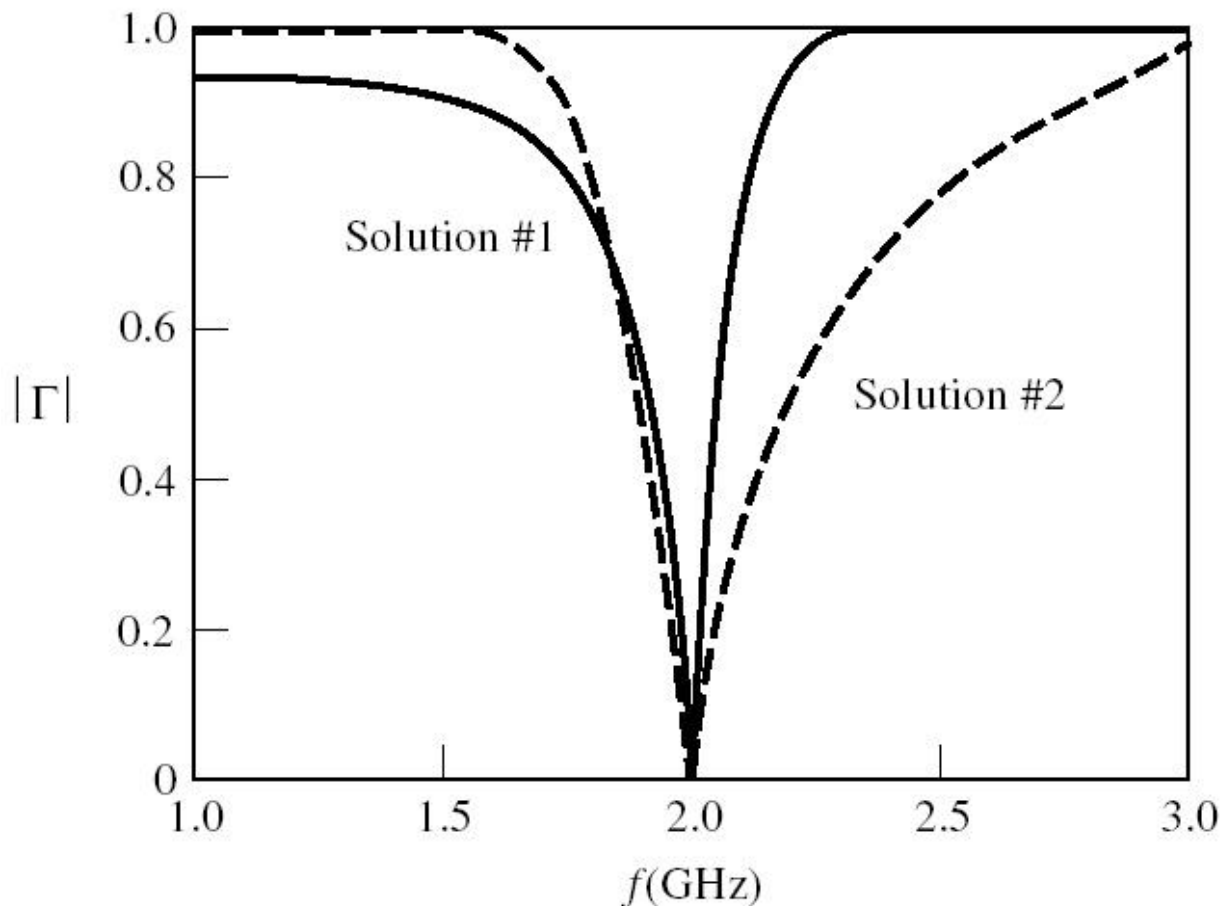
Adaptarea cu doua sectiuni de linie

- Doua solutii posibile



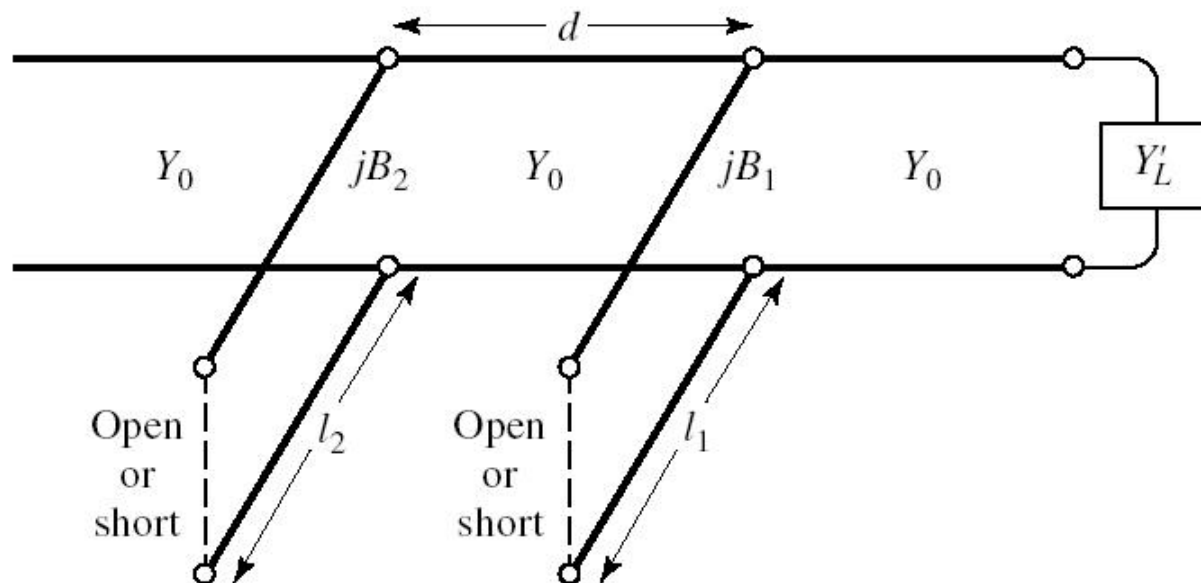
Adaptarea cu doua sectiuni de linie

- Doua solutii posibile

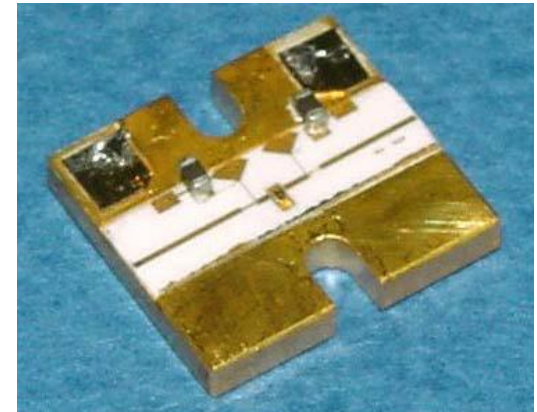
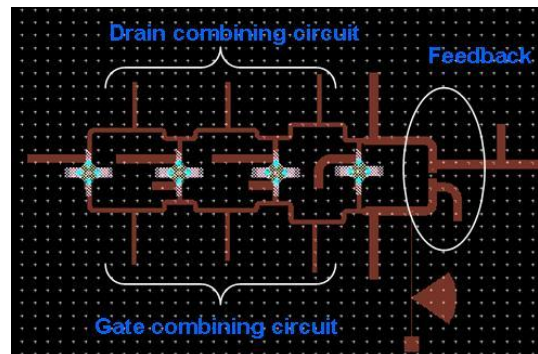
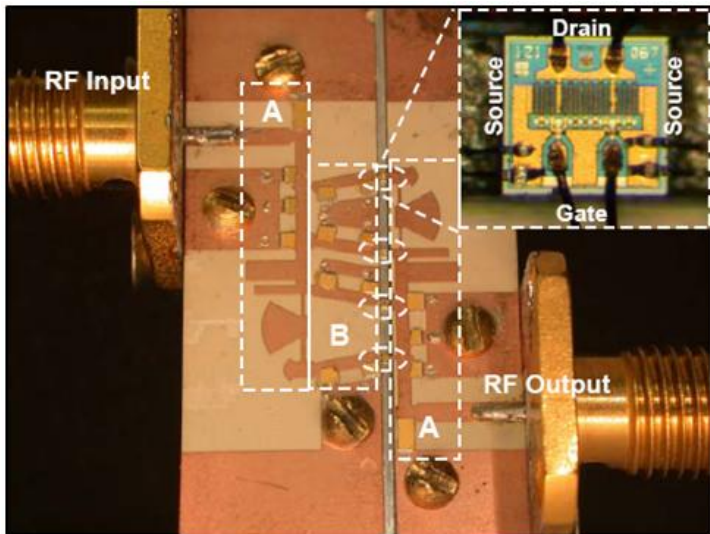
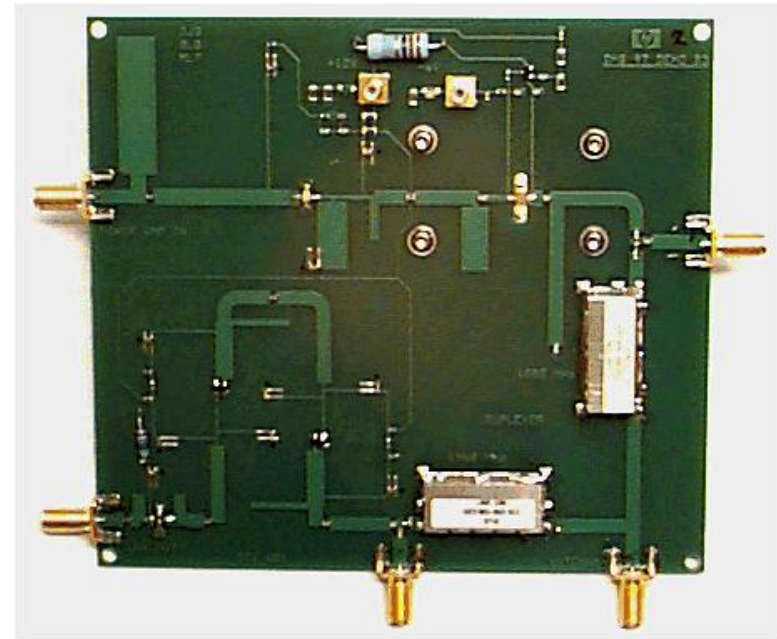
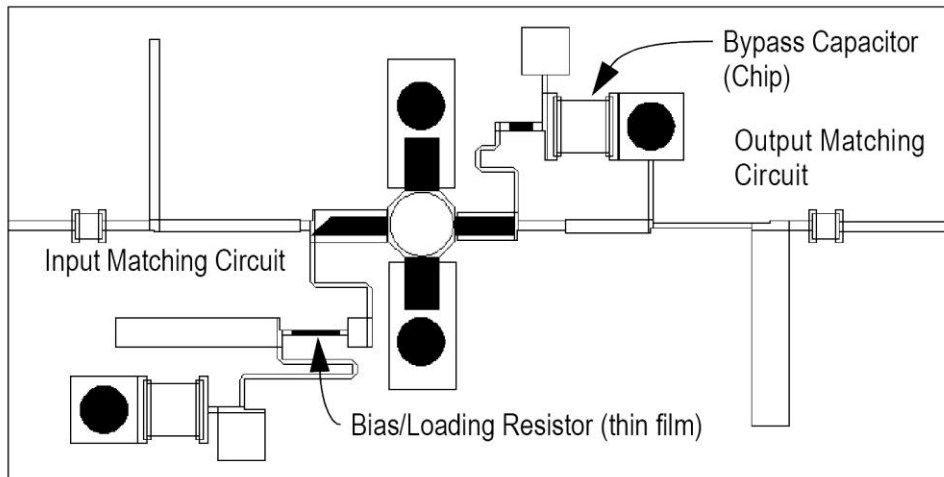


Adaptarea cu doua sectiuni de linie

- Tipic $d = \lambda/8$ sau $d = 3\lambda/8$
- **Nu** pentru orice sarcina este posibila
 - decat daca se poate introduce o sectiune de linie pana la sarcina



Adaptarea cu sectiuni de linie



Contact

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