

Lecture 8

2023/2024

Microwave Devices and Circuits for Radiocommunications

2023/2024

- 2C/1L, **MDCR**
- Attendance at minimum 7 sessions (course or laboratory)
- Lectures- **associate professor Radu Damian**
 - Tuesday 16-18, ~~Online~~, P8
 - E – 50% final grade
 - problems + (2p atten. lect.) + (3 tests) + (bonus activity)
 - first test L1: 20-27.02.2024 (t2 and t3 not announced, lecture)
 - 3att.=+0.5p
 - all materials/equipments authorized

2023/2024

- Laboratory – **associate professor Radu Damian**
 - Tuesday 08-12, II.13 / (08:10)
 - L – 25% final grade
 - ADS, 4 sessions
 - Attendance + **personal results**
 - P – 25% final grade
 - ADS, 3 sessions (-1? 20.02.2024)
 - personal homework

Materials

■ <http://rf-opto.etti.tuiasi.ro>

The screenshot shows a web browser window with the URL http://rf-opto.etti.tuiasi.ro/microwave_cd.php?chg_lang=0. The page features a dark blue navigation bar with links for Main, Courses, Master, Staff, Research, Students, and Admin. Below this is a secondary navigation bar with links for Microwave CD, Optical Communications, Optoelectronics, Internet, Antennas, Practica, Networks, and Educational software. The main content area is titled "Microwave Devices and Circuits for Radiocommunications (English)" and includes the following information:

- Course: MDCR (2017-2018)**
- Course Coordinator:** Assoc.P. Dr. Radu-Florin Damian
- Code:** EDOS412T
- 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: Examen

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

Grades

[Aggregate Results](#)

Attendance

[Course](#)
[Laboratory](#)

Lists

[Bonus-uri acumulate \(final\)](#)
[Studenti care nu pot intra in examen](#)

Materials

Course Slides

- [MDCR Lecture 1](#) (pdf, 5.43 MB, en, [↗](#))
- [MDCR Lecture 2](#) (pdf, 3.67 MB, en, [↗](#))
- [MDCR Lecture 3](#) (pdf, 4.76 MB, en, [↗](#))
- [MDCR Lecture 4](#) (pdf, 5.58 MB, en, [↗](#))

On the right side of the screenshot, there is a banner for "RF-OPTO" with the ETTI logo and the University of Technical Sciences (UTS) logo. The banner includes language selection options: "English" (highlighted with a red circle) and "Romana". Below the banner is a navigation bar with links for Main, Courses, Master, Staff, and Research. A secondary navigation bar below that includes links for Grades, Student List, Exams, and Photos. The main content area on the right is titled "Online Exams" and includes the text: "In order to participate at online exams you must get ready following..."

Site



Microwave and Optoelectronics Laboratory

We are enlisted in the Telecommunications Department of the Electronics, Telecommunication and Information Technology Faculty (ETTI) from the "Gh. Asachi" Technical University (TUIASI) in Iasi, Romania

We currently cover inside ETTI the fields related to:

- Microwave Circuits and Devices
- Optoelectronics
- Information Technology

Courses

Nr.	Course	Shortcut	Code	Type	Semester	Credits	Weekly	Examination	Link
1	Microwave Devices and Circuits for Radiocommunications	DCMR	DOS412T	DOS	7	4	0P,1L,0S,2C	Exam	details
2	Monolithic Microwave Integrated Circuits	CIMM	RD.IA.207	DOMS	11	6	1.5L,0S,2C,0P	Exam	details
3	Advanced Techniques in the Design of the Radio-communications Systems	TAPSR	RD.IA.103	DIMS	9	6	1.5P,0L,0S,2C	Exam	details
4	Optical Communications	CO	DOS409T	DOS	7	5	0P,1L,0S,3C	Colloquium	details
5	Optical Communications	OC	EDOS409T	DOS	7	5	0P,1L,0S,3C	Exam	details
6	Satellite Communications	CS	RC.IA.104	DIMS	9	6	0L,0S,2C,1.5P	Exam	details
7	Applied Informatics 1	IA1	DOF135	DOF	1	4	0P,1L,0S,2C	Verification	details
8	Applied Informatics 1	AI1	EDOF135	DOF	1	4	0P,1L,0S,2C	Verification	details
9	Databases, Web Programming and Interfacing	DWPI	ITT.IA.601	DIS	11	5	1P,1L,0.25S,1C	Verification	details
10	Web Applications Design	PAW	RC.IA.108	DIMS	10	5	1L,0S,1.5C,1P	Exam	details
11	Optoelectronics	OPTO	DID405M	DID	8	4	0P,1L,0S,2C	Colloquium	details
12	Microwave Devices and Circuits for Radiocommunications (English)	MDCR	EDOS412T	DOS	8	4	0P,1L,0S,2C	Exam	details



Site

- New online exams
 - Supplemental points for lectures 3, 4, 5

Disciplina: MDCR (Microwave Devices and Circuits for Radiocommunications (Engleza))

Pas 3

Nr.	Titlu	Start	Stop	Text	Subiecte
1	Profile photos	05/03/2024; 08:00	01/06/2024; 08:00	Online "exam" created f ...	fotografii_en.pdf
2	Laboratory 2	19/03/2024; 08:00	10/04/2024; 18:00	Individual subjects for ...	Subjects_lab2_2024.pdf
3	Lecture 5 Network Analysis - supplemental points	19/03/2024; 14:00	10/04/2024; 11:00	Supplemental points for ...	Supliment_c5_2024.pdf
4	Lecture 3 Impedance Matching - supplemental points	19/03/2024; 08:00	03/04/2024; 11:00	Supplemental points for ...	Supliment_c3_2024.pdf
5	Lecture 4 Impedance Transformers - supplemental points	19/03/2024; 08:00	03/04/2024; 11:00	Supplemental points for ...	Supliment_c4_2024.pdf
6	Laboratory 1	05/03/2024; 08:00	27/03/2024; 14:00	Individual subjects for ...	Subjects_lab1_2024.pdf

Materials

- RF-OPTO
 - <http://rf-opto.etti.tuiasi.ro>
- **David Pozar, "Microwave Engineering",**
Wiley; 4th edition , 2011
 - 1 exam problem ← Pozar
- Photos
 - sent by email/**online exam > Week4-Week6**
 - used at lectures/laboratory

Online – Registration no.

- access to **online exams** requires the **password** received by email

The password is communicated during the lectures. It is necessary to

Password


Registration no.

Name of the student

Proposed email 1

Proposed email 2

Write the code below

 **RF-OPTO** 

English | Romana |

[Main](#) [Courses](#) [Master](#) [Staff](#) [Research](#) [Students](#)

[Login](#) [Tutoring](#)

Login

Use the Registration no. and your email or the password received by email

Registration no.

Email/Password

Write the code below

Password

■ received by email

Important message from RF-OPTO

Inbox x



Radu-Florin Damian

to me, POPESCU

Romanian > English Translate message



Laboratorul de Microunde si Optoelectronica
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei
Universitatea Tehnica "Gh. Asachi" Iasi

In atentie: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul rf-opto este
Parola: [REDACTED]

Identificati-va pe [server](#), cu parola, cat mai rapid, pentru confirmare.

Memorati acest mesaj intr-un loc sigur, pentru utilizare ulterioara

Attention: POPESCU GOPO ION

The password to access the exams on the rf-opto server is
Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

Reply

Reply all

Forward

Subject	Correspondents
Important message from RF-OPTO	POPESCU GOPO ION
Validation of MD/CR exam from 02/05/2020	[REDACTED]
[REDACTED]	[REDACTED]

From Me <rdamian@etti.tuiasi.ro>
Subject Important message from RF-OPTO
To [REDACTED]
Cc Me <rdamian@etti.tuiasi.ro>



Laboratorul de Microunde si Optoelectronica
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei
Universitatea Tehnica "Gh. Asachi" Iasi

In atentie: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul rf-opto este
Parola: [REDACTED]

Identificati-va pe [server](#), cu parola, cat mai rapid, pentru confirmare.

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Attention: POPESCU GOPO ION

The password to access the exams on the rf-opto server is
Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

Online exam manual

- The online exam app used for:
 - ~~lectures (attendance)~~
 - laboratory
 - project
 - ~~examinations~~

Materials

Other data

[Manual examen on-line](#) (pdf, 2.65 MB, ro, 🇷🇴)

[Simulare Examen](#) (video) (mp4, 65.12 MB, ro, 🇷🇴)

Microwave Devices and Circuits (Englis

Examen online

- always against a **timetable**
 - long period (lecture attendance/laboratory results)
 - ~~short period (tests: 15min, exam: 2h)~~

Announcement 23:59 (10/05/2020)	Support material 00:05 (11/05/2020)	Exam Topics 00:07 (11/05/2020)	Results 00:10 (11/05/2020)	End 00:20 (15/05/2020)	Confirmation 00:20 (16/05/2020)	Next timeframe in: 05 m 43 s Refresh now
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Announcement

This is a "fake" exam, introduced to familiarize you with the server interface and to perform the necessary actions during an exam: thesis scan, selfie, use email for co

Server Time

All exams are based on the server's time zone (it may be different from local time). For reference time on the server is now:

10/05/2020 23:59:16

Online results submission

- many numerical values/files

Schema finala	Rezultate - castig	Rezultate - zgomot	Fisier justificare calcul (factor andrei)	Fisier zap (optional)	T1, fisier parametri S	T2, fisier parametri S	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Ze1	Zo1	Ze2	Zo2	Ze3	Zo3	Ze4	Zo4	Ze5	Zo5	Ze6	
86 - 5428 - 259 ...	86 - 5428 - 260 ...	86 - 5428 - 261 ...	86 - 5428 - 316 ...	-	86 - 5428 - 314 ...	86 - 5428 - 315 ...	148.33	155.88	202.12	164.35	180.91	30.29	185.19	79.9	37	68.89	45.14	61.83	45.05	57.97	46.02	61.85	45.05	68.8	
86 - 5622 - 259 ...	86 - 5622 - 260 ...	86 - 5622 - 261 ...	86 - 5622 - 316 ...	86 - 5622 - 262 ...	86 - 5622 - 314 ...	86 - 5622 - 315 ...	26.97	153.5	34.64	35.79	55.56	26.212	10.693	0	0	0	0	0	0	0	0	0	0	0	0
86 - 5488 - 259 ...	86 - 5488 - 260 ...	86 - 5488 - 261 ...	86 - 5488 - 316 ...	86 - 5488 - 262 ...	86 - 5488 - 314 ...	86 - 5488 - 315 ...	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86 - 5391 - 259 ...	86 - 5391 - 260 ...	86 - 5391 - 261 ...	86 - 5391 - 316 ...	-	-	-	50	50	50	50	50	50	50	70.14	40.39	61.85	44.59	55.7	45.2	54.89	45.38	58.65	45.8	70.0	
86 - 5664 - 259 ...	86 - 5664 - 260 ...	86 - 5664 - 261 ...	86 - 5664 - 316 ...	-	86 - 5664 - 314 ...	86 - 5664 - 315 ...	168.02	150.5	178.28	133.75	92.12	121.67	144.48	94.36	36.19	70.77	42.56	65.69	42.05	55.17	42.29	65.59	42.05	70.7	
86 - 5665 - 259 ...	86 - 5665 - 260 ...	86 - 5665 - 261 ...	86 - 5665 - 316 ...	-	86 - 5665 - 314 ...	86 - 5665 - 315 ...	162.2	80.8	209.2	140.85	135.1	183.7	167.6	94.58	36.15	78.16	39.77	65.57	45.05	65.57	45.05	78.16	39.77	94.5	
86 - 5433 - 259 ...	86 - 5433 - 260 ...	86 - 5433 - 261 ...	86 - 5433 - 316 ...	-	86 - 5433 - 314 ...	86 - 5433 - 315 ...	165.138	106.228	226.157	130.134	72.71	180.177	164.616	101.36	36.11	77.22	42.49	68.02	45.62	60	45.42	68.02	45.62	77.2	
86 - 5608 - 259 ...	86 - 5608 - 260 ...	86 - 5608 - 261 ...	86 - 5608 - 316 ...	-	86 - 5608 - 314 ...	86 - 5608 - 315 ...	150.84	152.5	30.94	32.37	54.36	19.837	29.85	64.14	40.145	54.32	46.32	53.8	46.7	53.8	46.7	54.32	46.32	54.9	
86 - 5555 - 259 ...	86 - 5555 - 260 ...	86 - 5555 - 261 ...	86 - 5555 - 316 ...	-	86 - 5555 - 314 ...	86 - 5555 - 315 ...	168.001	150.288	178.399	133.115	92.491	121.257	144.126	97.05	36.16	71.13	43.09	65.45	42.12	55.66	42.18	65.45	42.12	71.1	

Online results submission

- many numerical values

	Z1	Z2	Z3	Z4	Z5	Z6	Z7
	148.33	155.88	202.12	164.35	180.91	30.29	185.19
	25.97	153.5	34.64	35.79	55.56	26.212	10.692
	0	0	0	0	0	0	0
	50	50	50	50	50	50	50



Online results submission

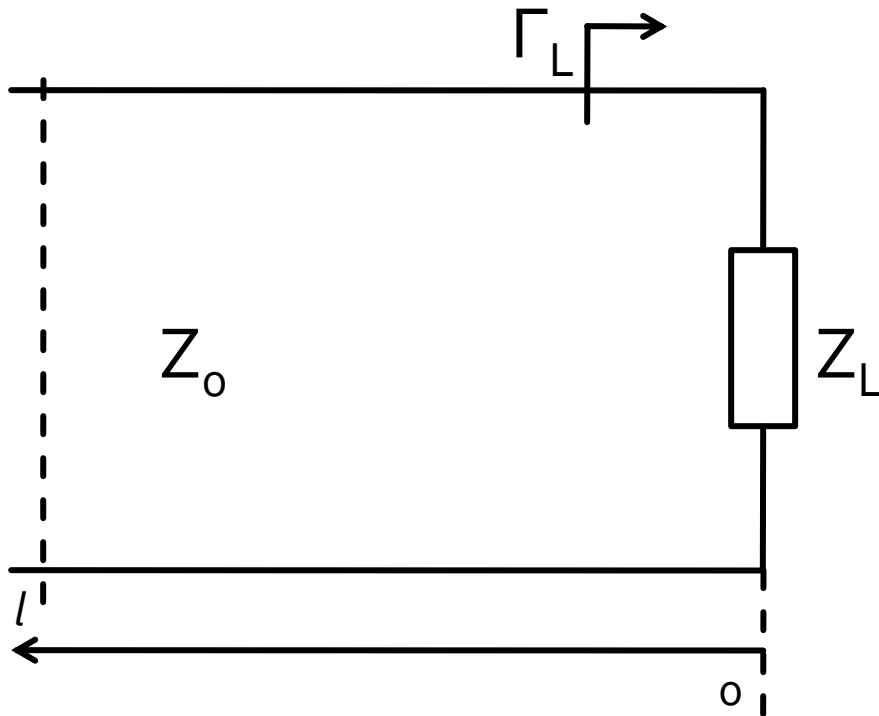
**Grade = Quality of the work +
+ Quality of the submission**

TEM transmission lines

Course Topics

- **Transmission lines**
- Impedance matching and tuning
- Directional couplers
- Power dividers
- Microwave amplifier design
- Microwave filters
- ~~Oscillators and mixers?~~

The lossless line



$$V(z) = V_0^+ e^{-j\beta \cdot z} + V_0^- e^{j\beta \cdot z}$$

$$I(z) = \frac{V_0^+}{Z_0} e^{-j\beta \cdot z} - \frac{V_0^-}{Z_0} e^{j\beta \cdot z}$$

$$Z_L = \frac{V(0)}{I(0)} \quad Z_L = \frac{V_0^+ + V_0^-}{V_0^+ - V_0^-} \cdot Z_0$$

- voltage reflection coefficient

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

- Z_0 real

The lossless line

$$V(z) = V_0^+ \cdot (e^{-j\beta \cdot z} + \Gamma \cdot e^{j\beta \cdot z})$$

$$I(z) = \frac{V_0^+}{Z_0} \cdot (e^{-j\beta \cdot z} - \Gamma \cdot e^{j\beta \cdot z})$$

- time-average Power flow along the line

$$P_{avg} = \frac{1}{2} \cdot \text{Re}\{V(z) \cdot I(z)^*\} = \frac{1}{2} \cdot \frac{|V_0^+|^2}{Z_0} \cdot \text{Re}\{1 - \Gamma^* \cdot e^{-2j\beta \cdot z} + \Gamma \cdot e^{2j\beta \cdot z} - |\Gamma|^2\}$$

$$P_{avg} = \frac{1}{2} \cdot \frac{|V_0^+|^2}{Z_0} \cdot (1 - |\Gamma|^2)$$

$$(z - z^*) = \text{Im}$$

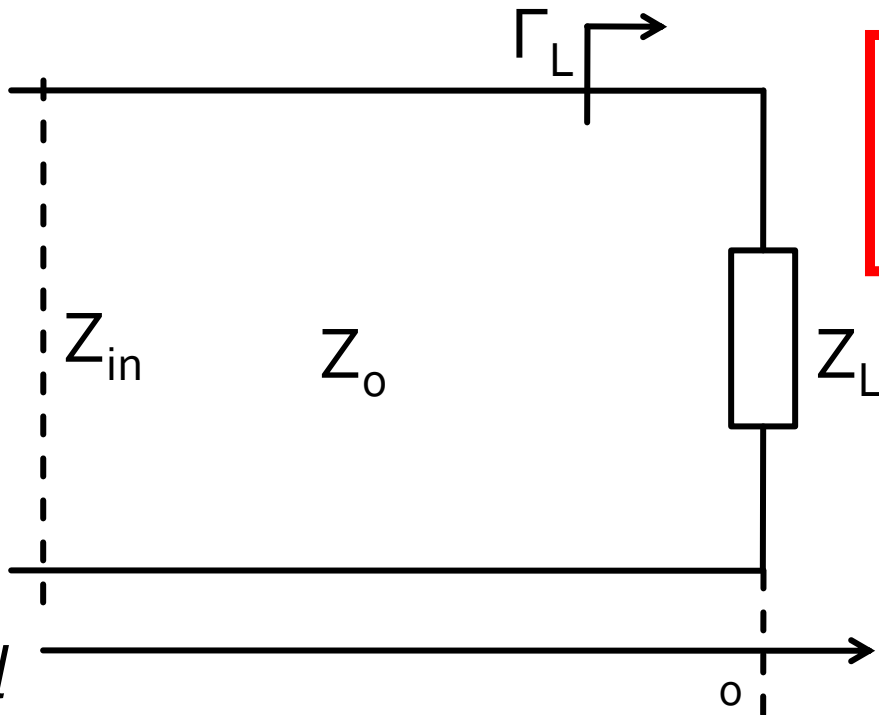
- Total power delivered to the load = Incident power – “Reflected” power

- Return “Loss” [dB]

$$RL = -20 \cdot \log|\Gamma| \quad [\text{dB}]$$

The lossless line

- input impedance of a length l of transmission line with characteristic impedance Z_0 , loaded with an arbitrary impedance Z_L



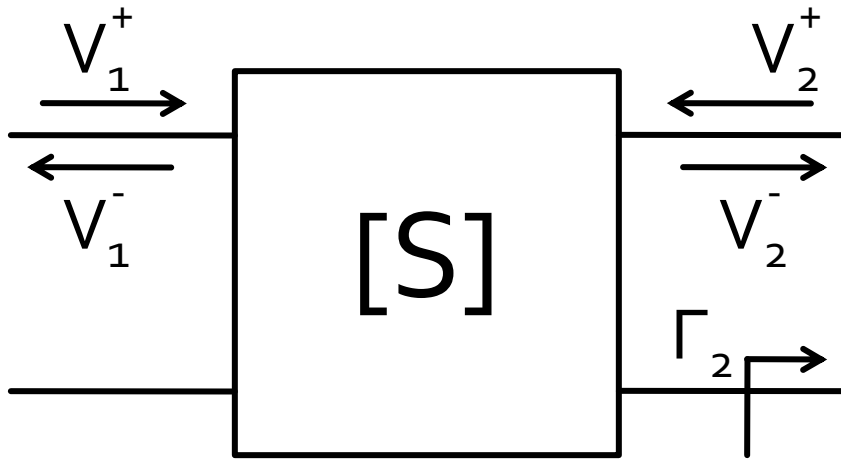
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

General theory

Microwave Network Analysis

Scattering matrix – S

- Scattering parameters



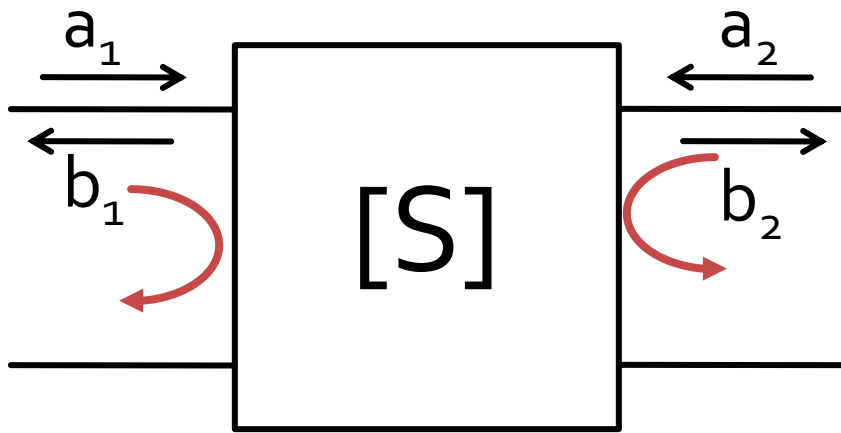
$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$S_{11} = \left. \frac{V_1^-}{V_1^+} \right|_{V_2^+ = 0} \quad S_{21} = \left. \frac{V_2^-}{V_1^+} \right|_{V_2^+ = 0}$$

- $V_2^+ = 0$ meaning: port 2 is terminated in matched load to avoid reflections towards the port

$$\Gamma_2 = 0 \rightarrow V_2^+ = 0$$

Scattering matrix – S

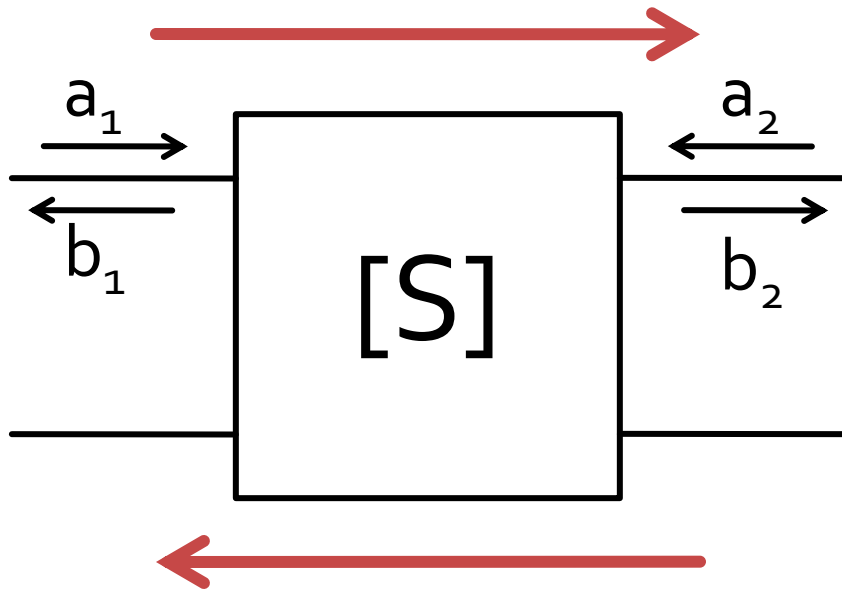


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{11} = \left. \frac{b_1}{a_1} \right|_{a_2=0} \quad S_{22} = \left. \frac{b_2}{a_2} \right|_{a_1=0}$$

- S_{11} and S_{22} are reflection coefficients at ports 1 and 2 when the other port is matched

Scattering matrix – S

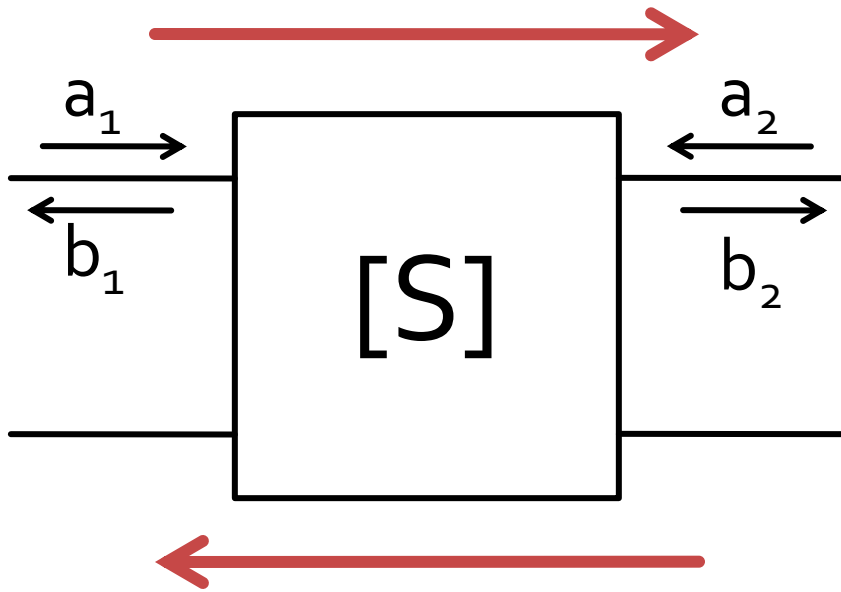


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{21} = \left. \frac{b_2}{a_1} \right|_{a_2=0} \quad S_{12} = \left. \frac{b_1}{a_2} \right|_{a_1=0}$$

- S_{21} si S_{12} are signal amplitude gain when the other port is matched

Scattering matrix – S



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$


$$|S_{21}|^2 = \frac{\text{Power in } Z_0 \text{ load}}{\text{Power from } Z_0 \text{ source}}$$

- a, b
 - information about signal power **AND** signal phase
- S_{ij}
 - network effect (gain) over signal power **including** phase information

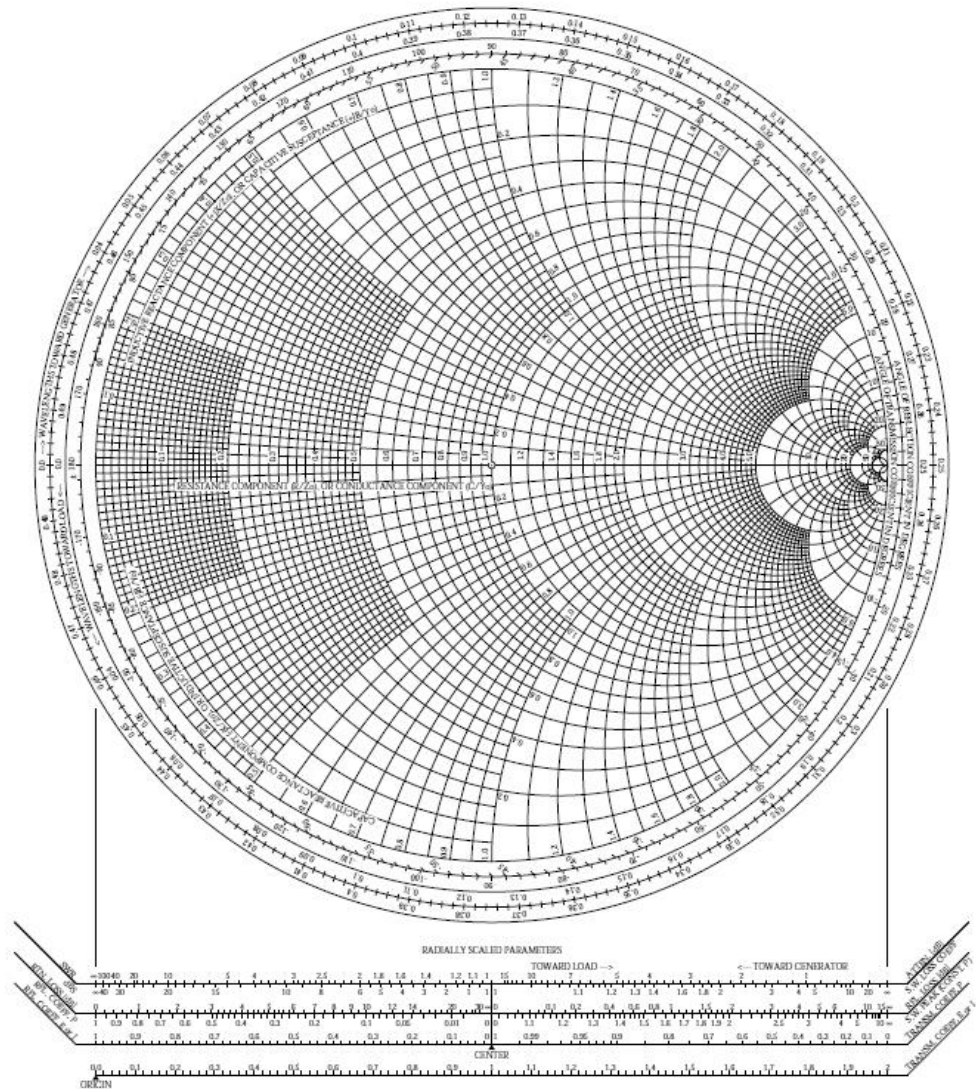
Impedance Matching

The Smith Chart

Course Topics

- Transmission lines
 - Impedance matching and tuning
 - Directional couplers
 - Power dividers
 - Microwave amplifier design
 - Microwave filters
 - ~~Oscillators and mixers?~~
- 

The Smith Chart



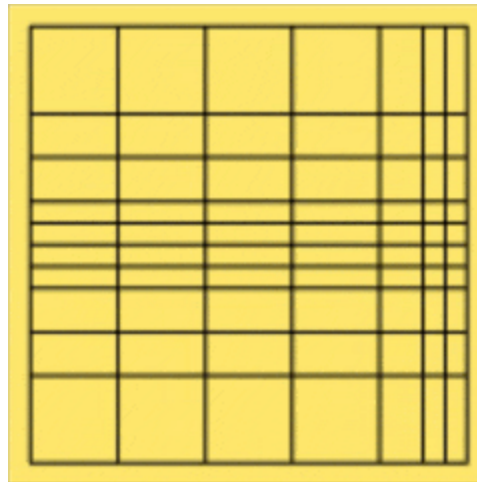
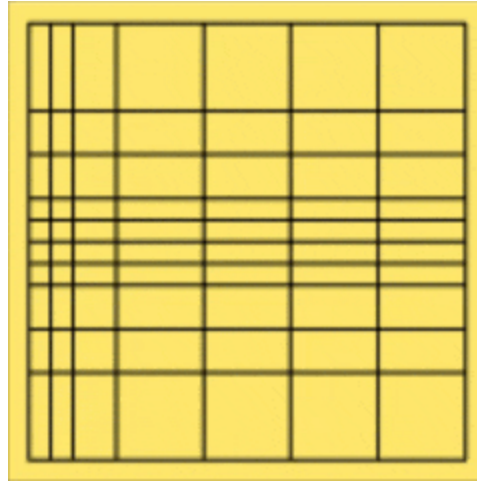
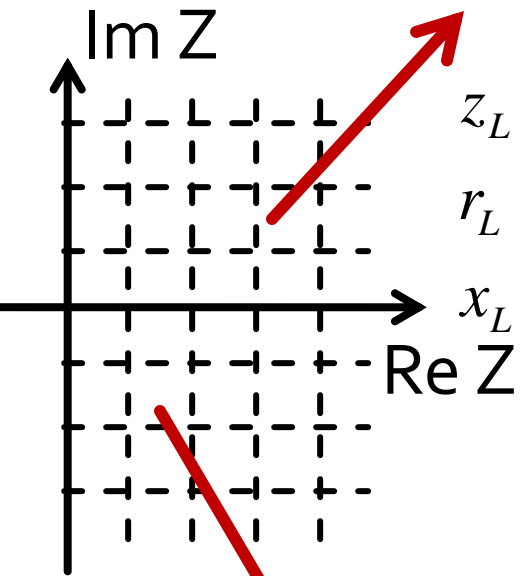
The Smith Chart

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

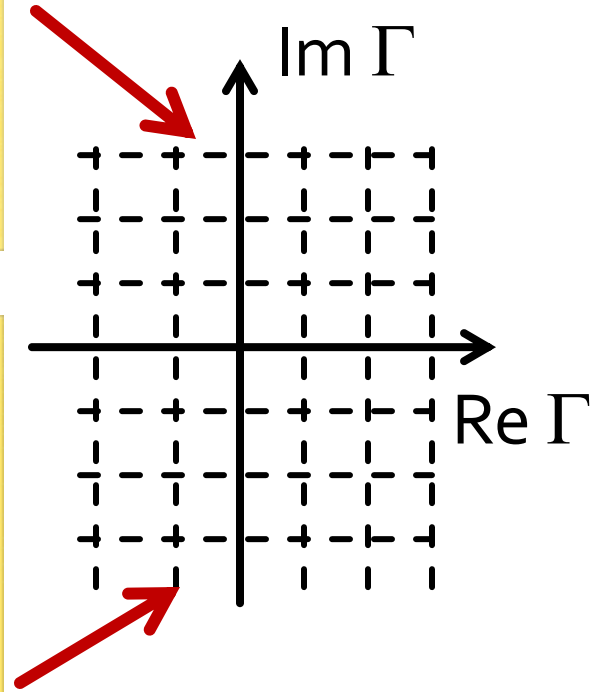
$$z_L = r_L + j \cdot x_L$$

$$r_L = ct.$$

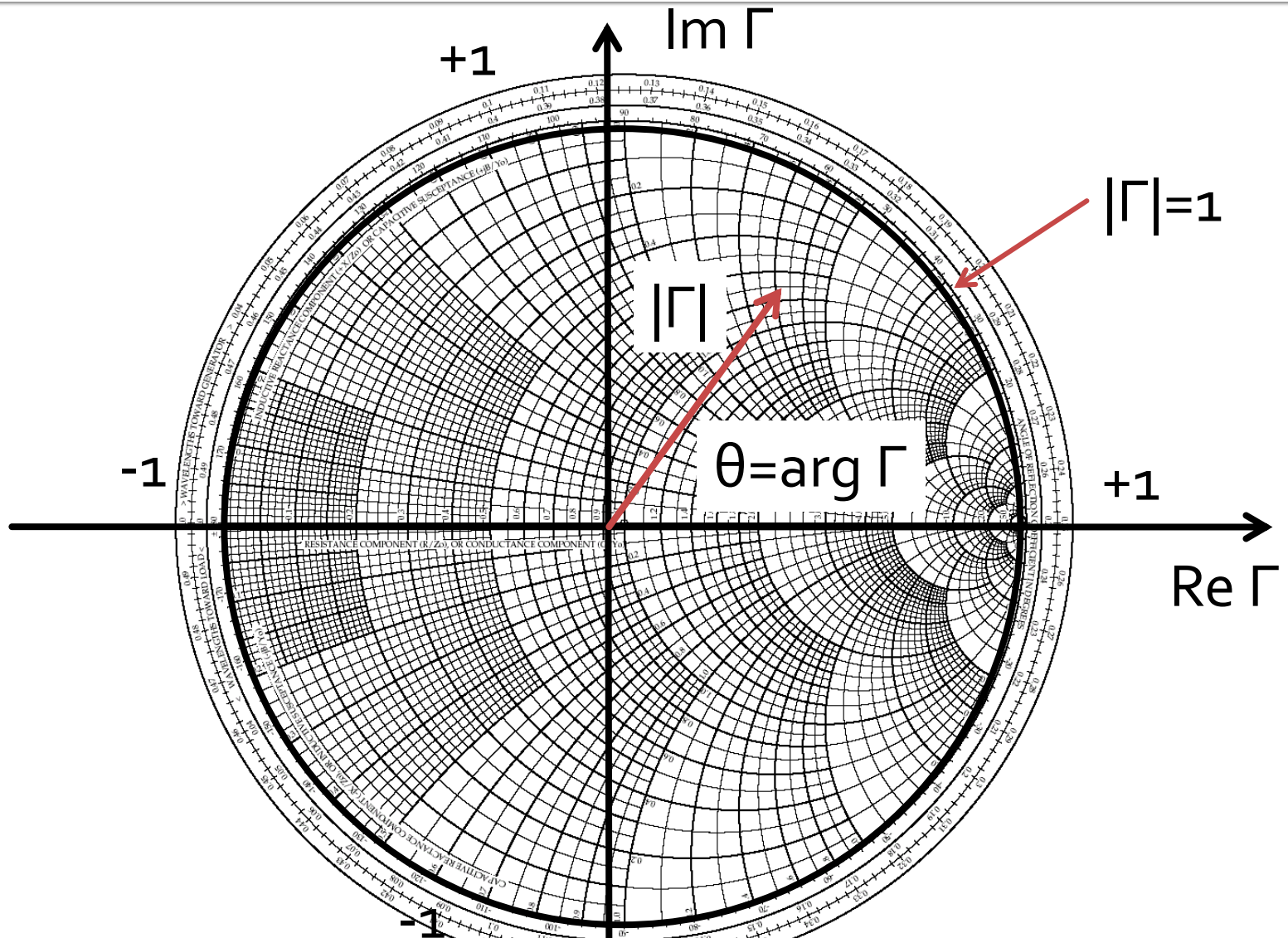
$$x_L = ct.$$



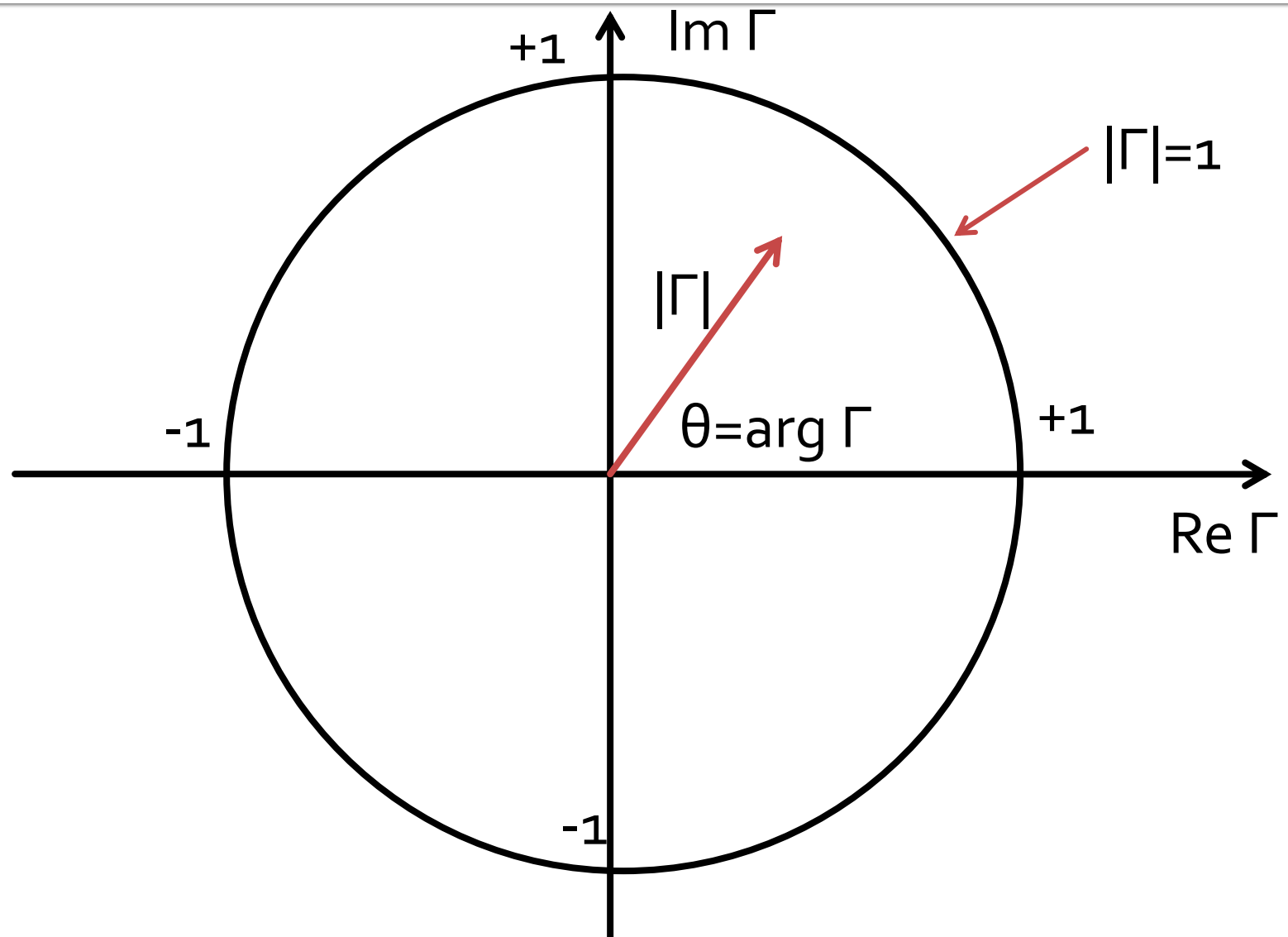
$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{Y_0 - Y_L}{Y_0 + Y_L} = \frac{1 - y_L}{1 + y_L}$$



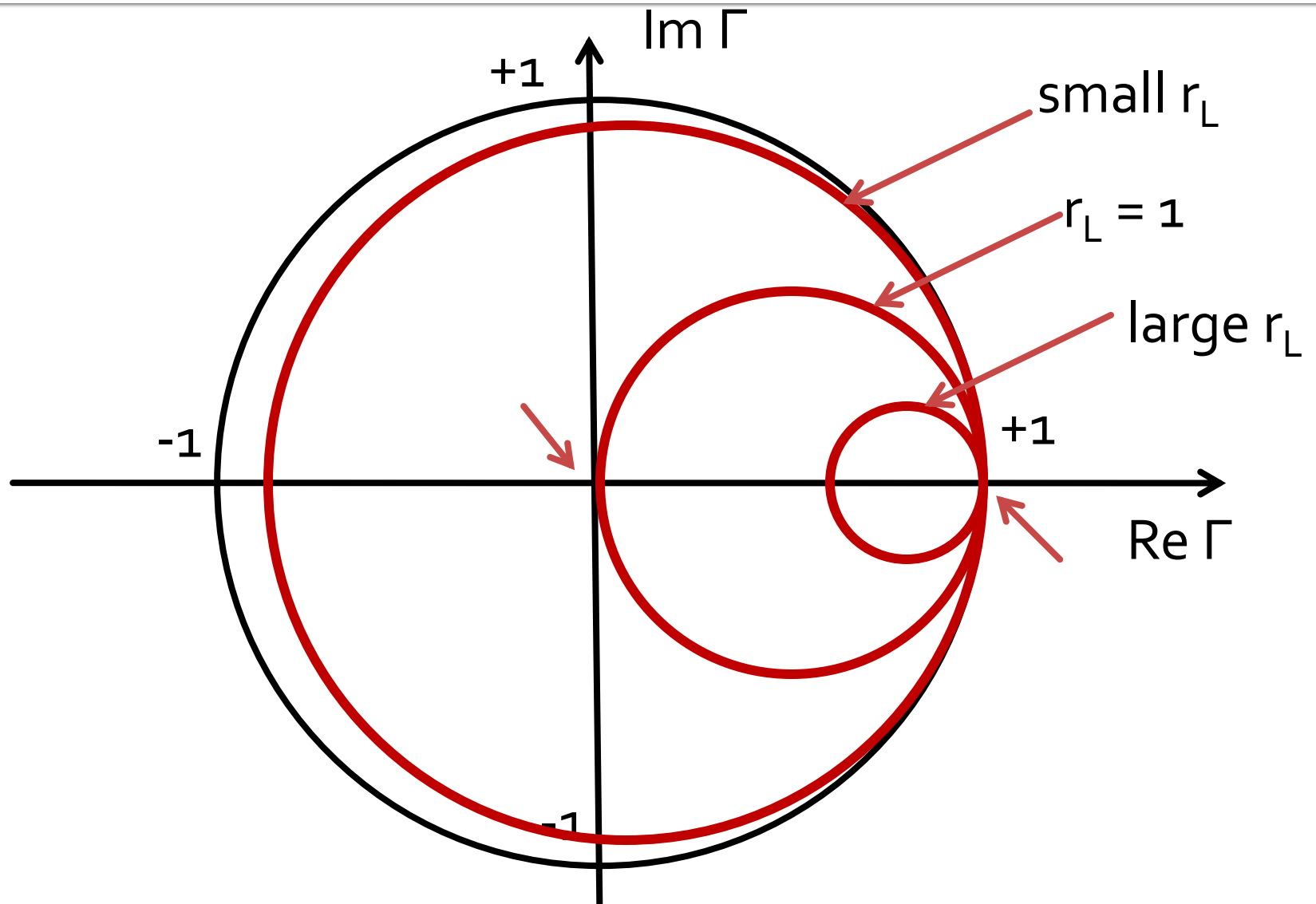
The Smith Chart



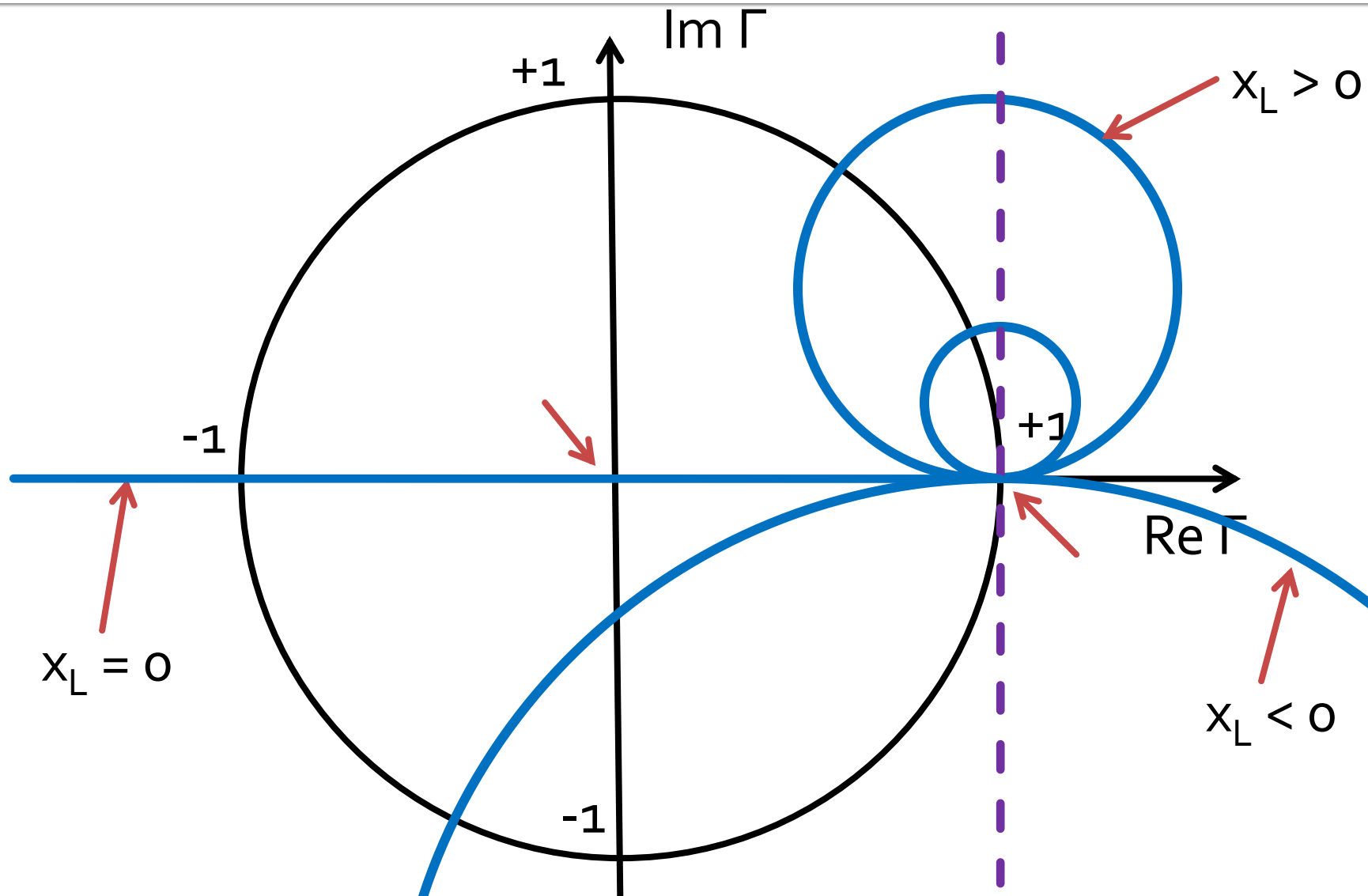
The Smith Chart



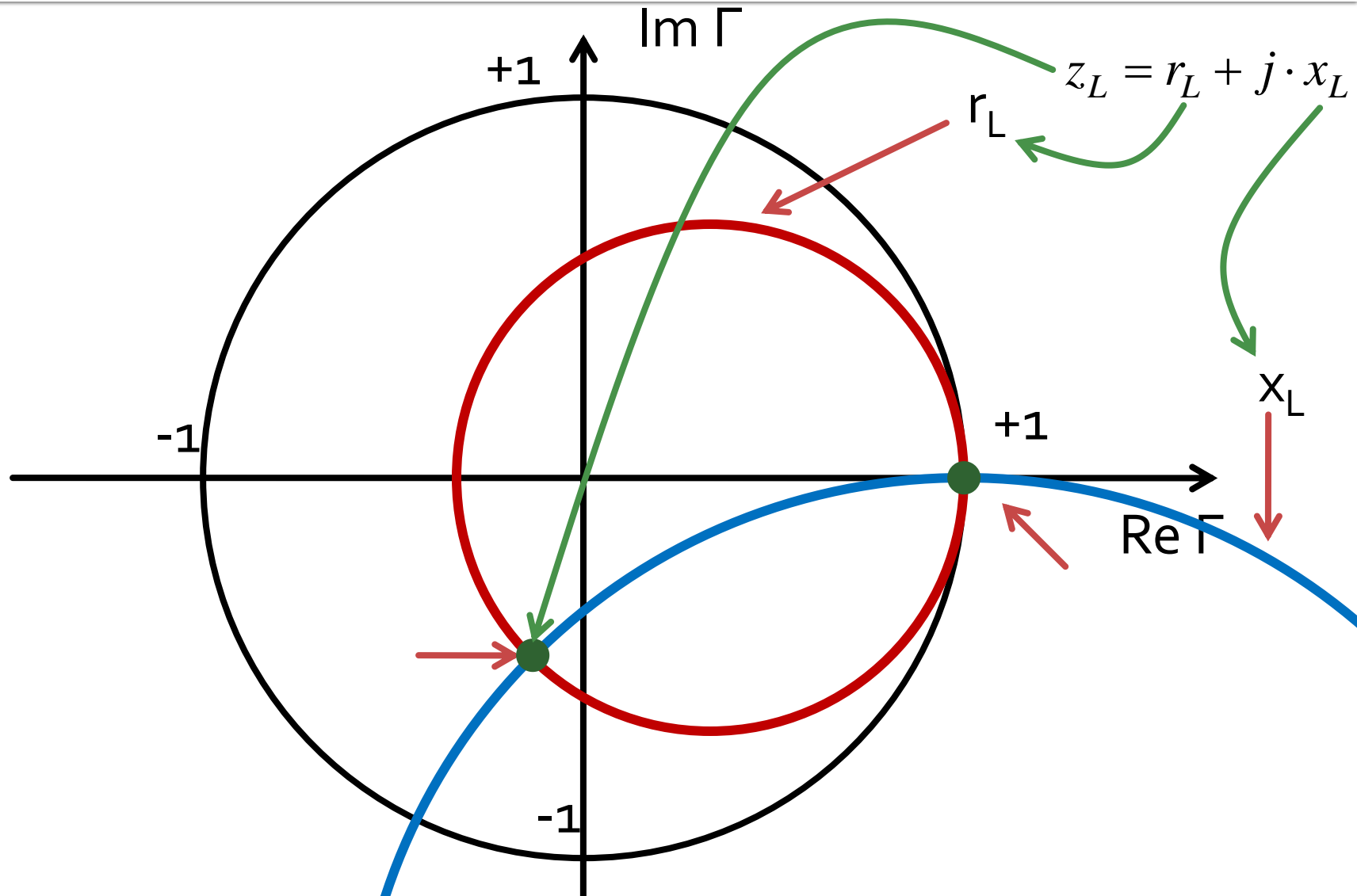
The Smith Chart, resistance



The Smith Chart, reactance

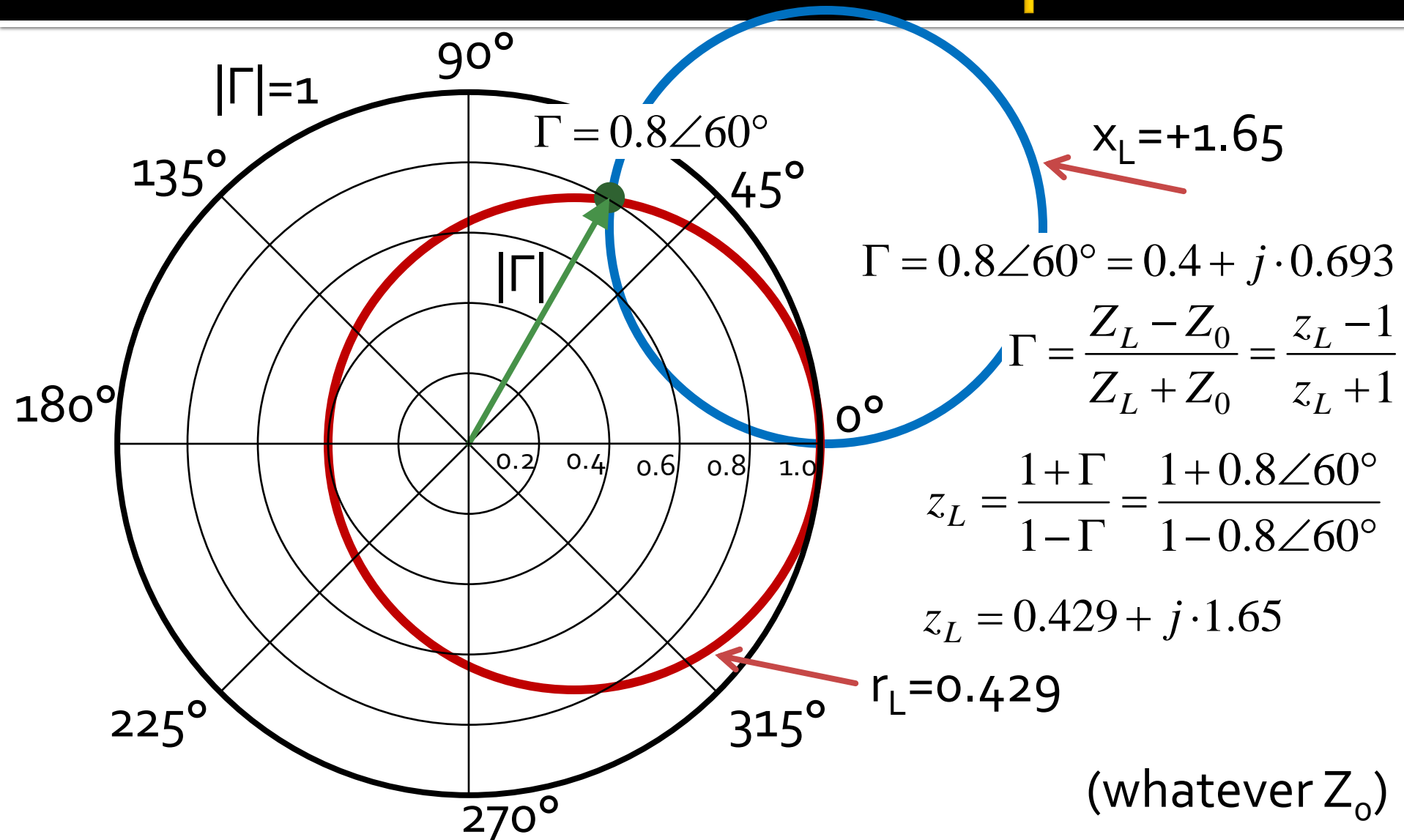


The Smith Chart, impedance

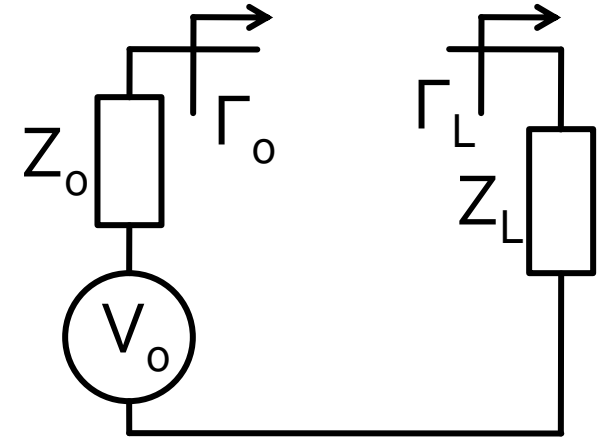
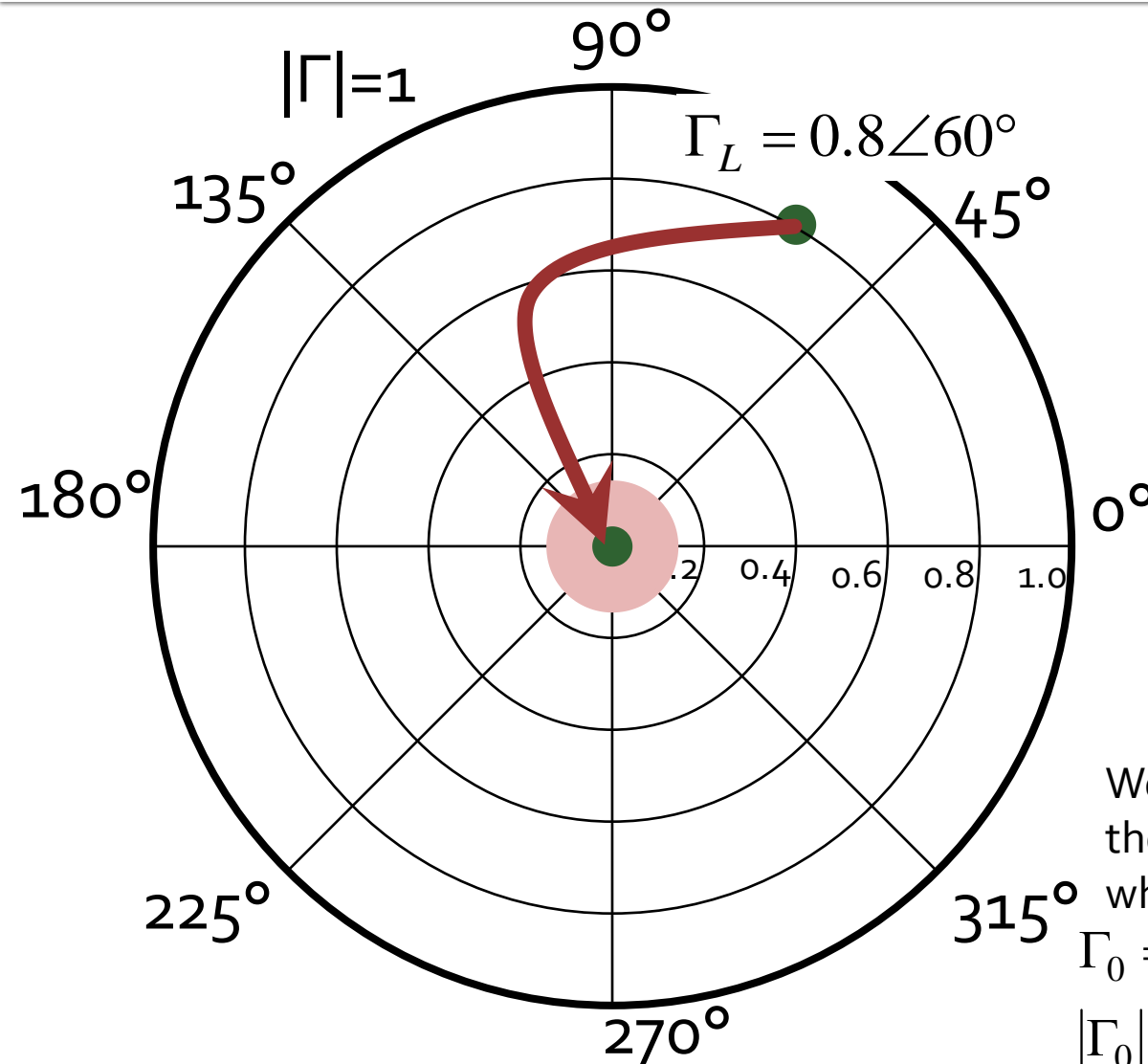


Equivalence

reflection coefficient \Leftrightarrow impedance



The Smith Chart, reflection coefficient, matching



Matching Z_L load to Z_o source.
We normalize Z_L over Z_o

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

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

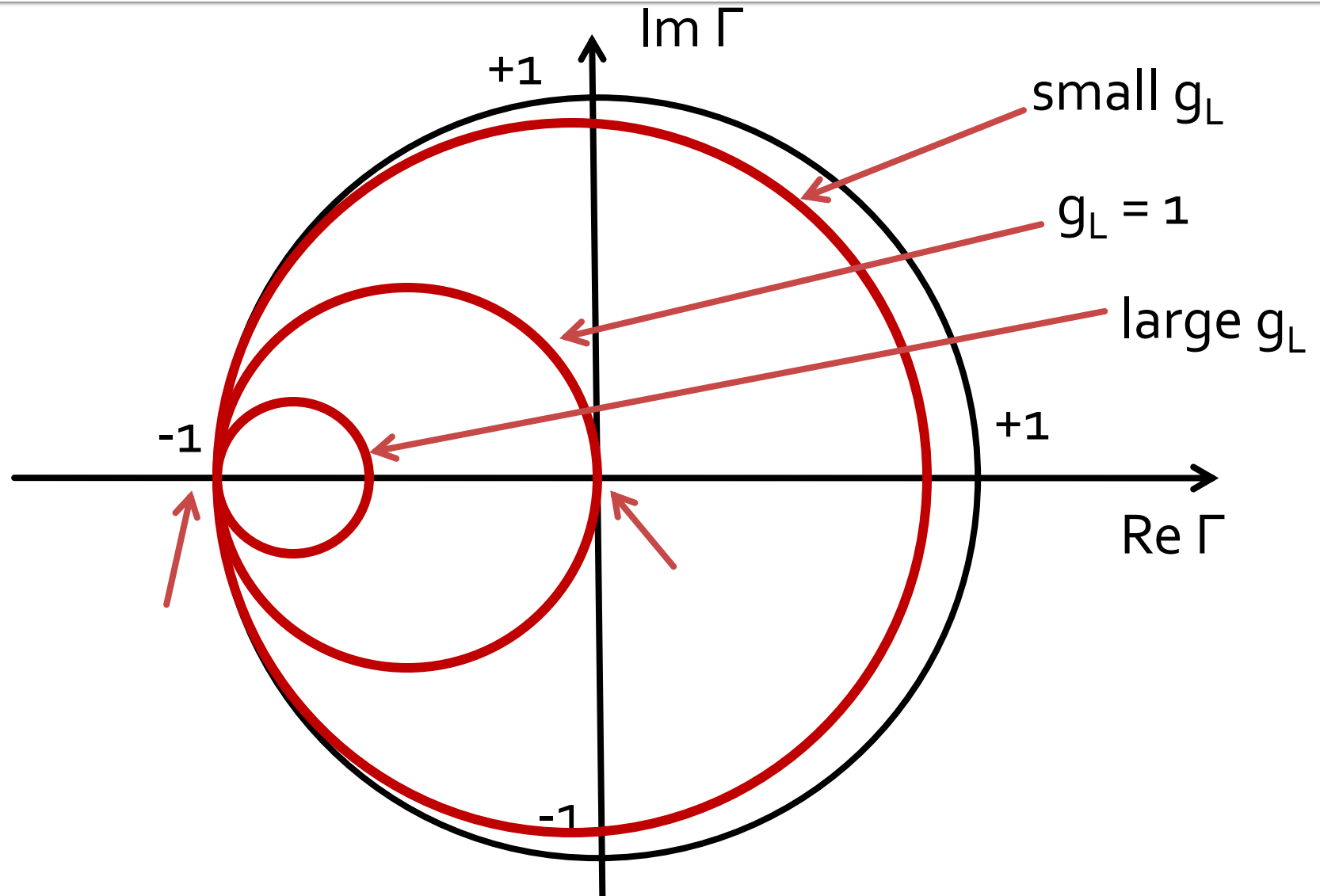
$$\Gamma_L = 0.8 \angle 60^\circ$$

We must move the point denoting the reflection coefficient in the area where with a Z_o source we have:

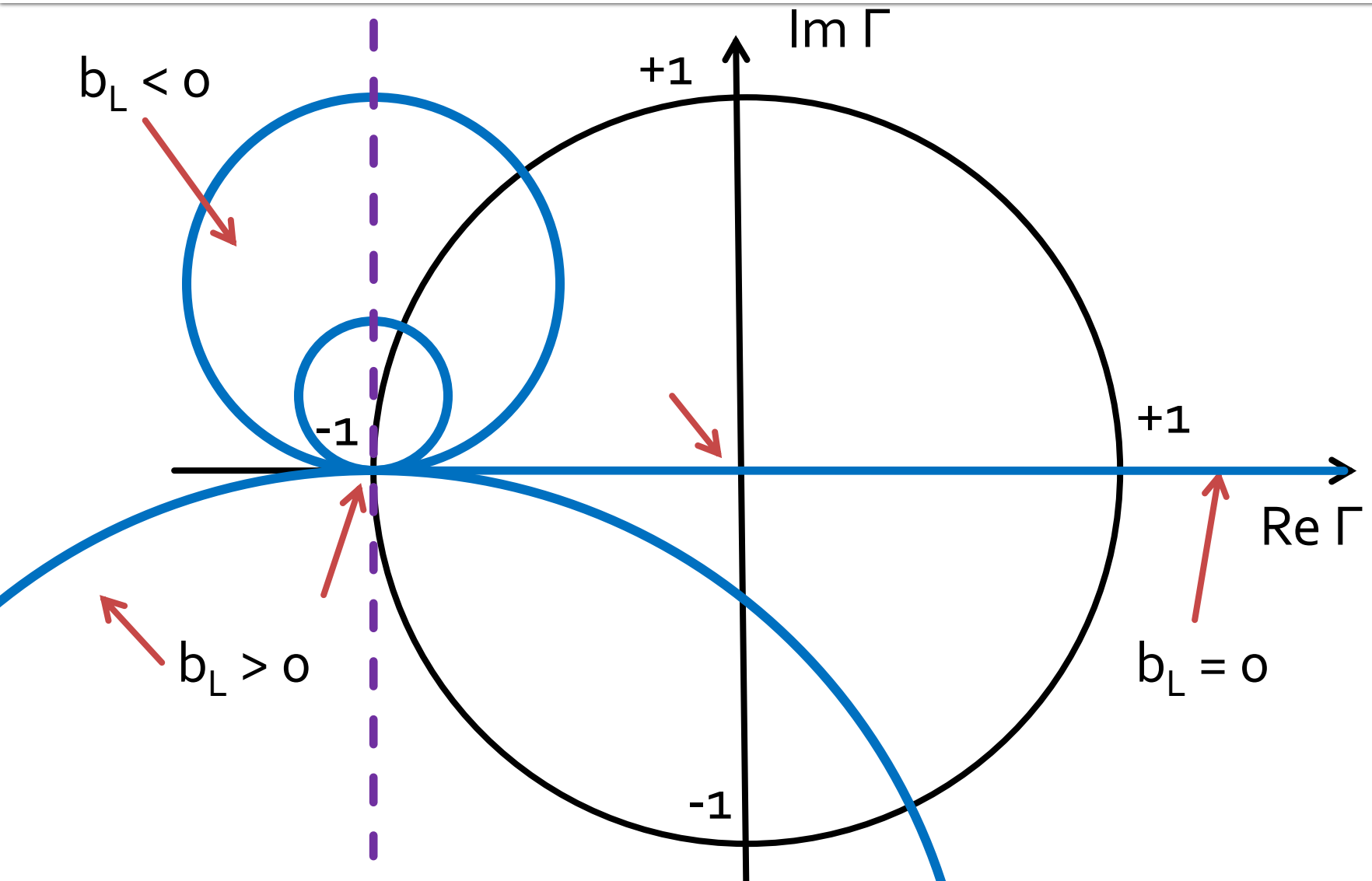
$\Gamma_0 = 0$ perfect match ●

$|\Gamma_0| \leq \Gamma_m$ "good enough" match ●

The Smith Chart, conductance



The Smith Chart, susceptance



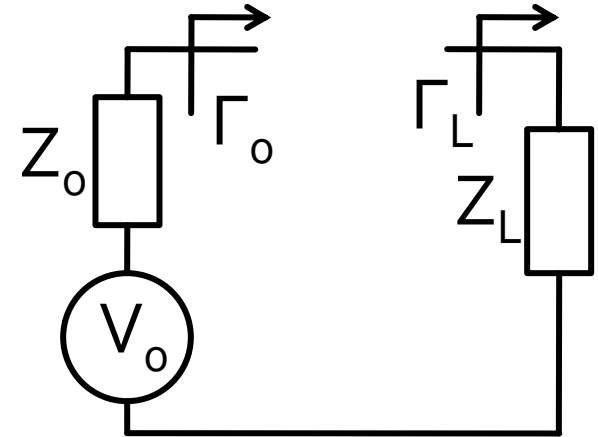
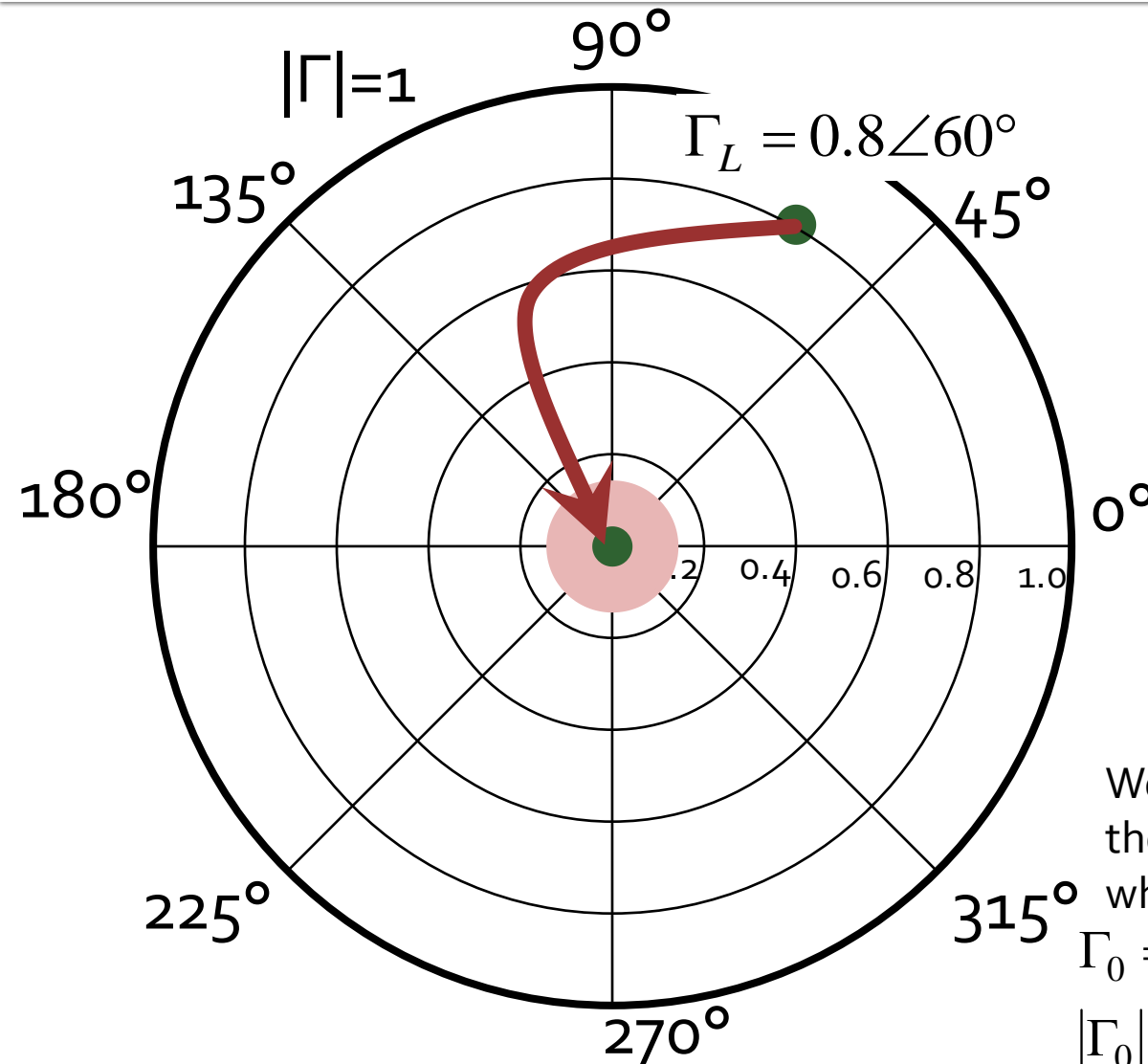
Impedance matching

Impedance Matching with lumped elements (L Networks)

Course Topics

- Transmission lines
- **Impedance matching and tuning**
- Directional couplers
- Power dividers
- Microwave amplifier design
- Microwave filters
- ~~Oscillators and mixers?~~

The Smith Chart, reflection coefficient, impedance matching



Matching Z_L load to Z_o source.
We normalize Z_L over Z_o

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

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

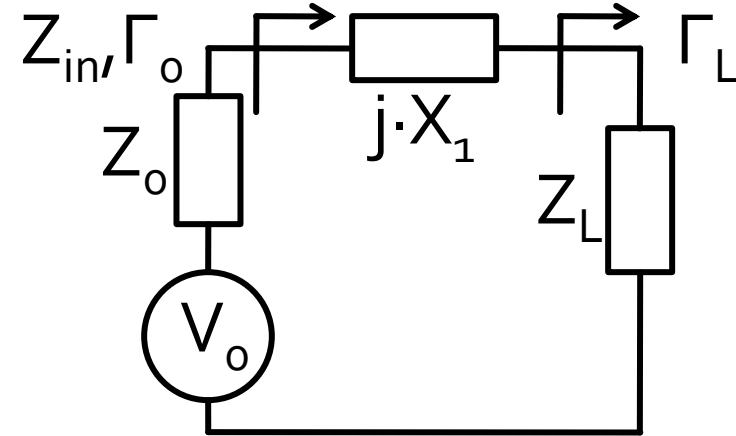
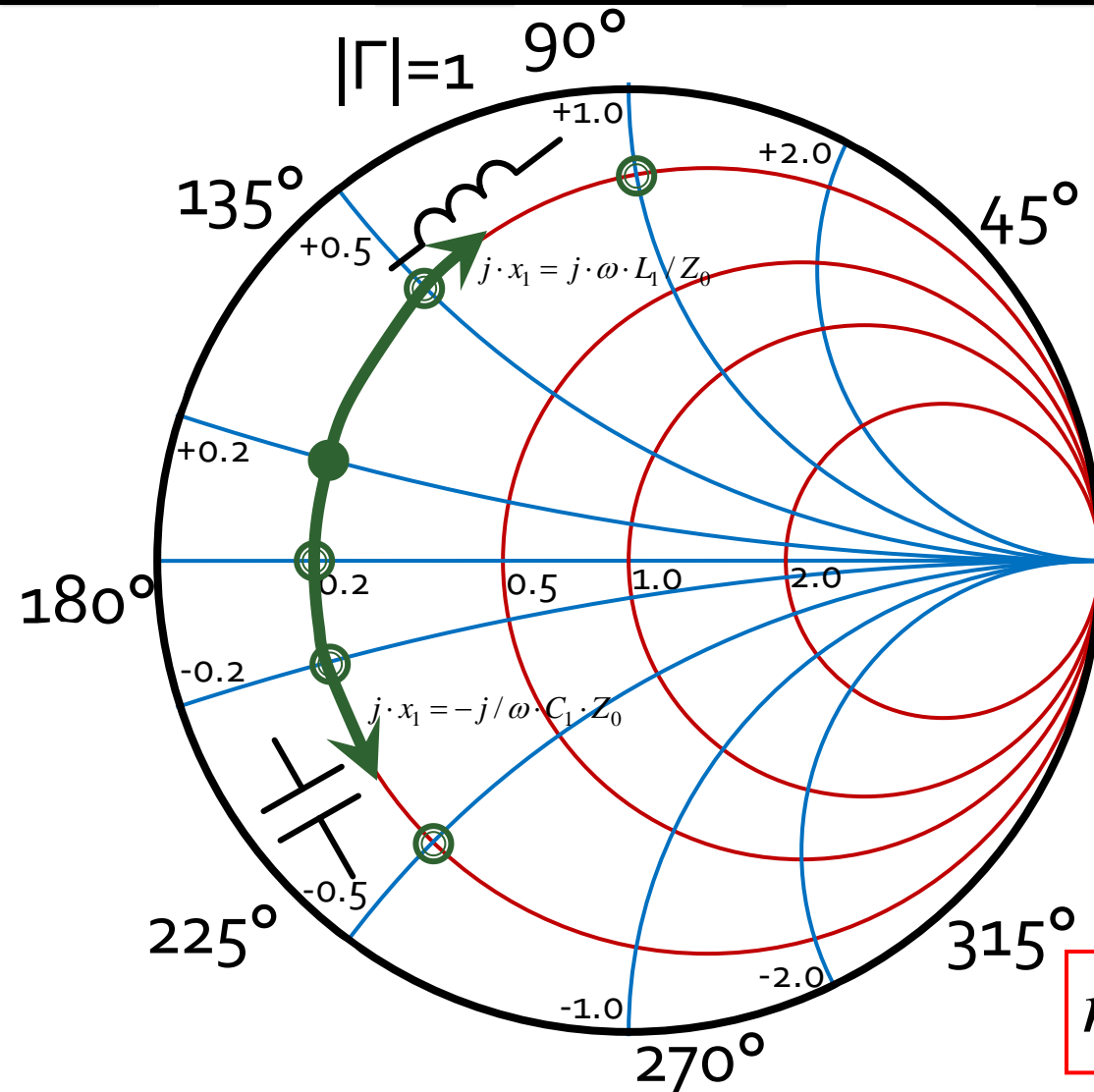
$$\Gamma_L = 0.8 \angle 60^\circ$$

We must move the point denoting the reflection coefficient in the area where with a Z_o source we have:

$$\Gamma_o = 0 \quad \text{perfect match} \quad \bullet$$

$$|\Gamma_o| \leq \Gamma_m \quad \text{"good enough" match} \quad \circ$$

The Smith Chart, series reactance



$$Z_0 = 50\Omega$$

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

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

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

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

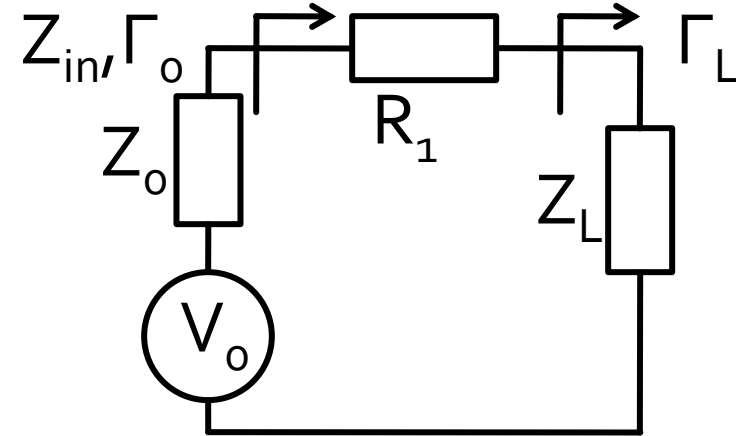
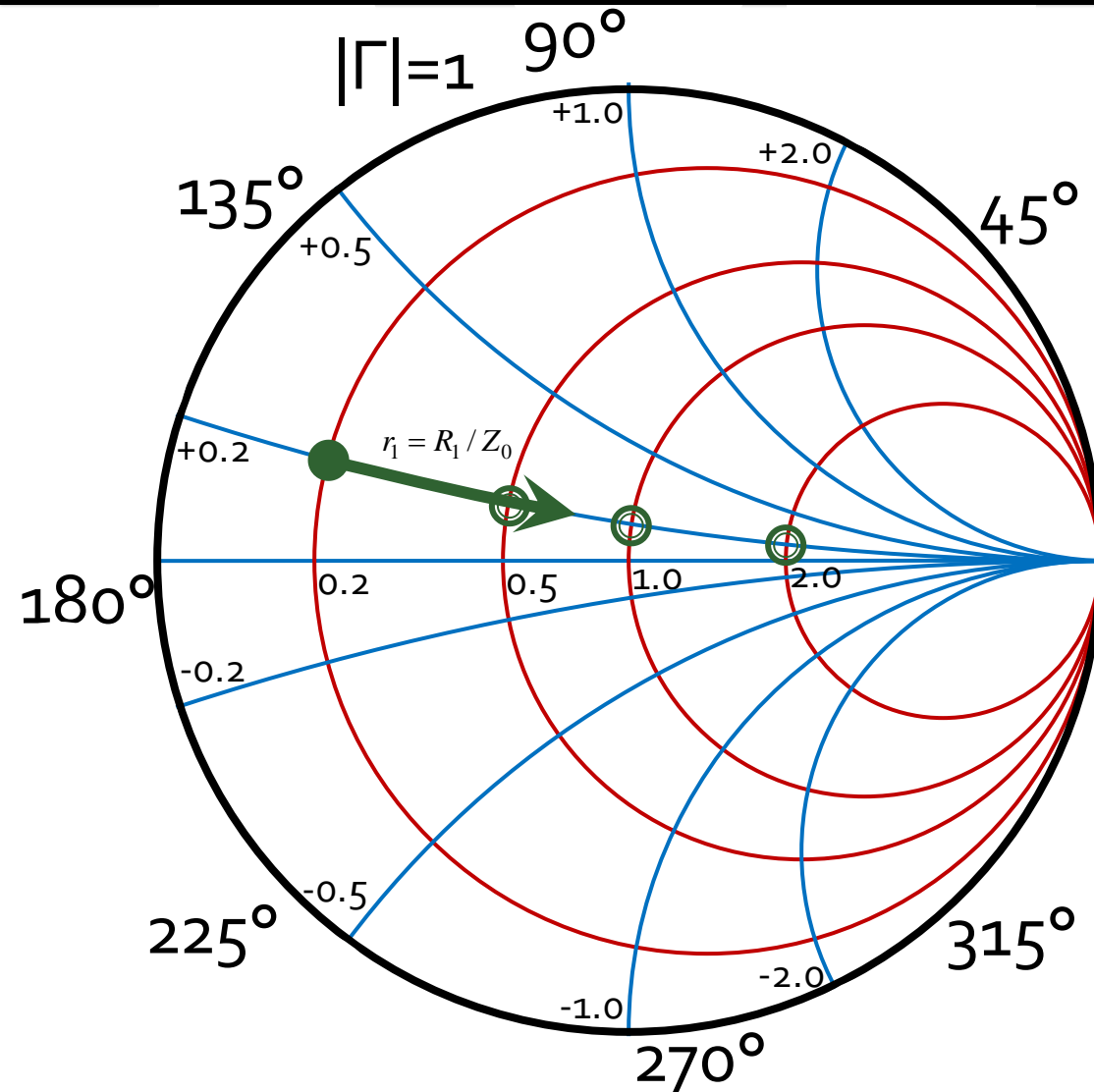
$$z_{in} = r_L + j \cdot (x_L + x_1)$$

$$r_{in} = r_L$$

$$j \cdot x_1 = j \cdot \omega \cdot L_1 / Z_0 > 0$$

$$j \cdot x_1 = -j / \omega \cdot C_1 \cdot Z_0 < 0$$

The Smith Chart, series resistance



$$Z_0 = 50\Omega$$

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

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

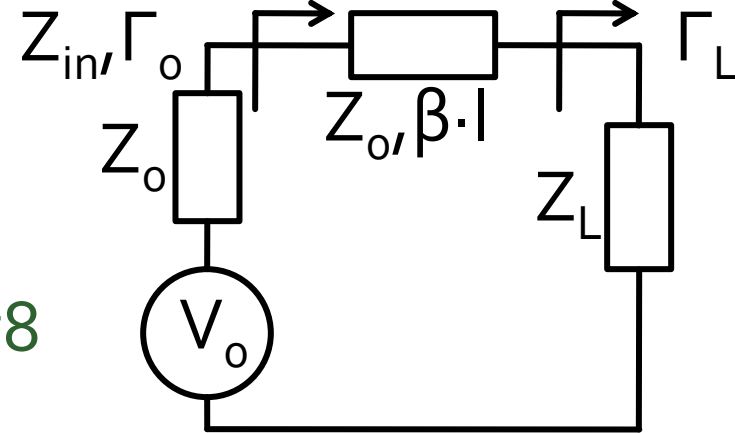
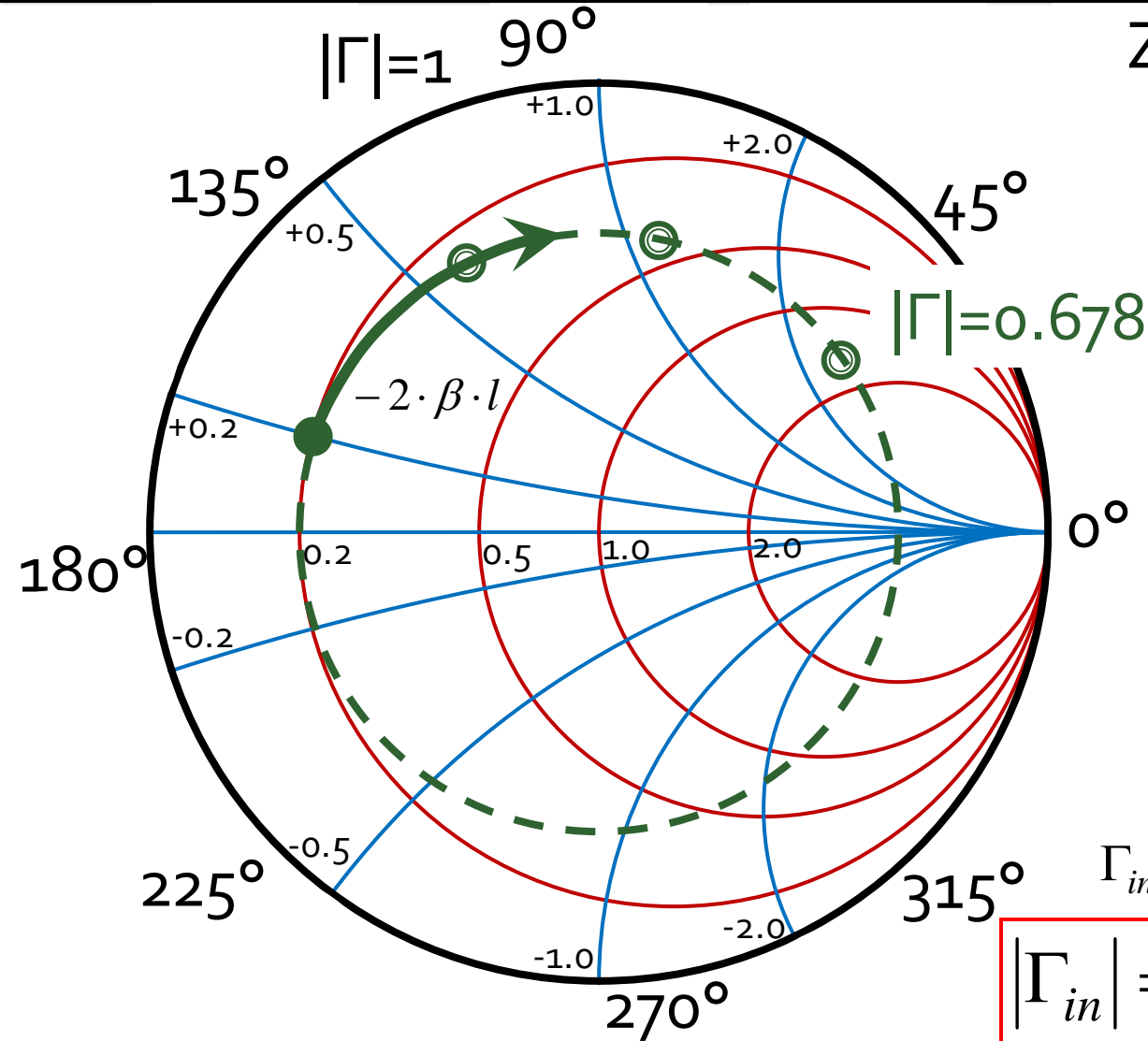
$$\Gamma_L = 0.678 \angle 156.5^\circ$$

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

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

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

The Smith Chart, series transmission line, Z_0



$$Z_0 = 50\Omega$$

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

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

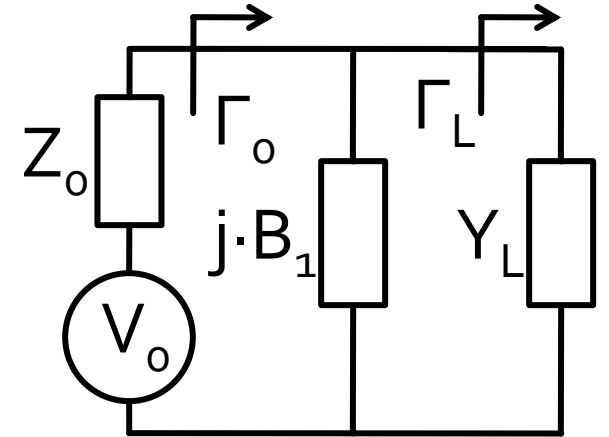
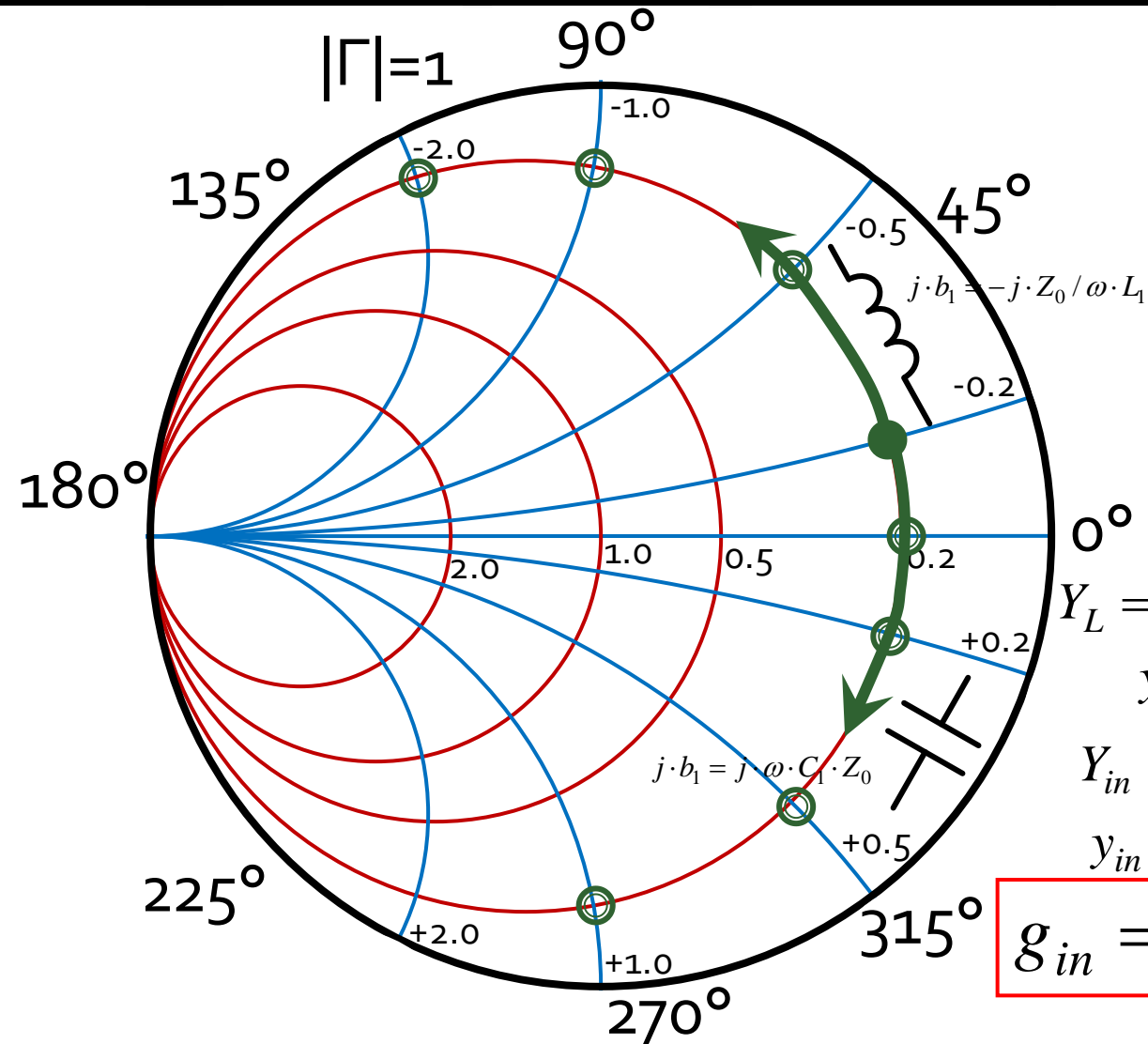
$$\Gamma_L = 0.678 \angle 156.5^\circ$$

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

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

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

The Smith Chart, shunt susceptance



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

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

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

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

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

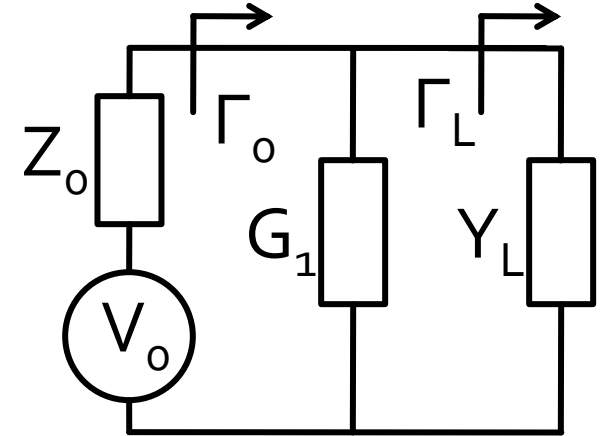
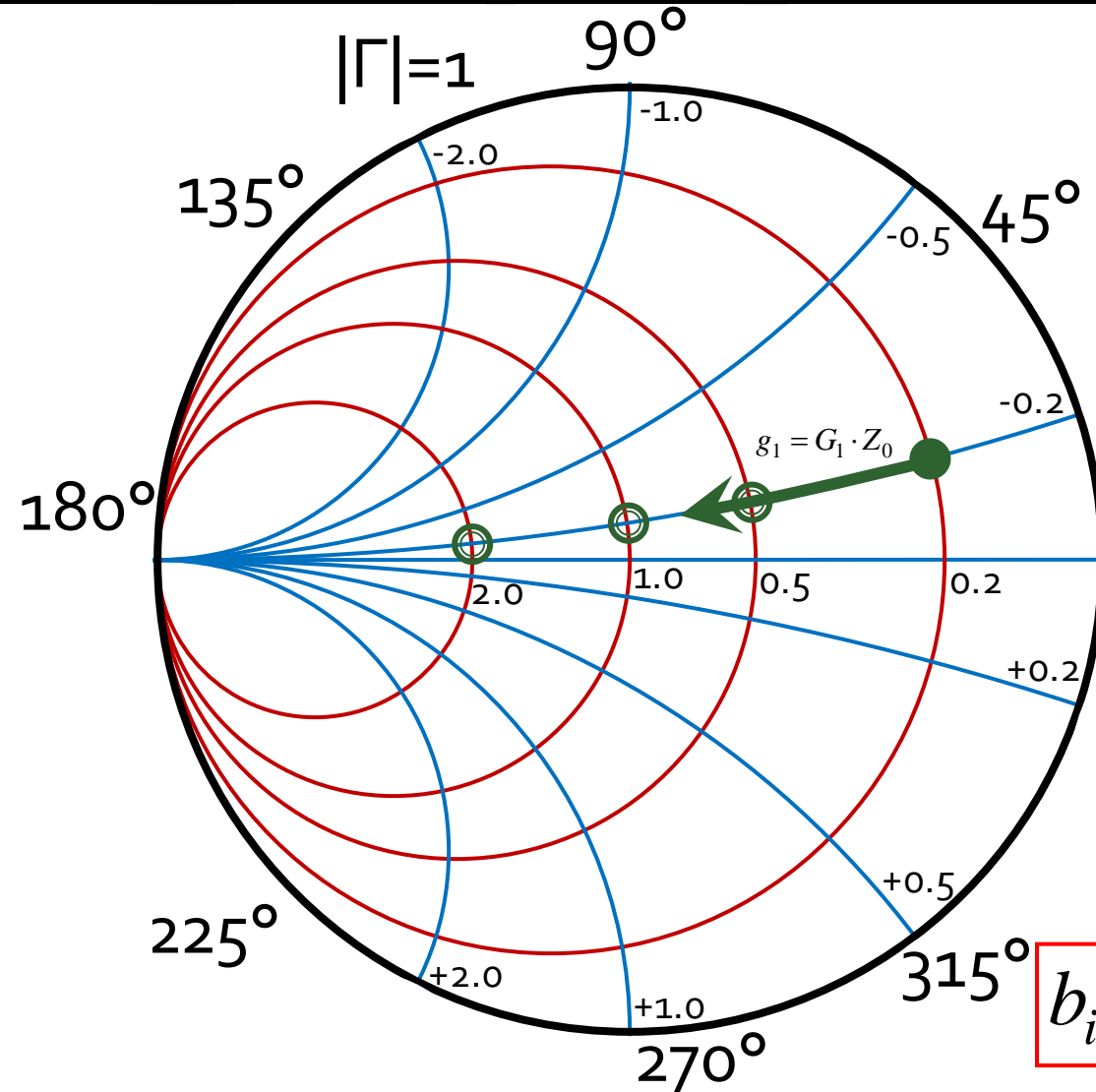
$$y_{in} = g_L + j \cdot (b_L + b_1)$$

$$g_{in} = g_L$$

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

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

The Smith Chart, shunt conductance



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

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

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

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

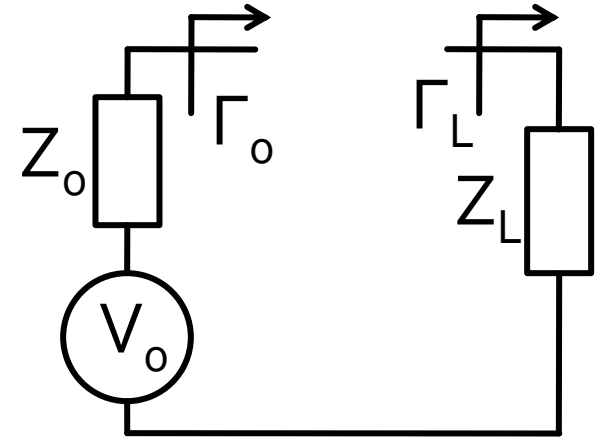
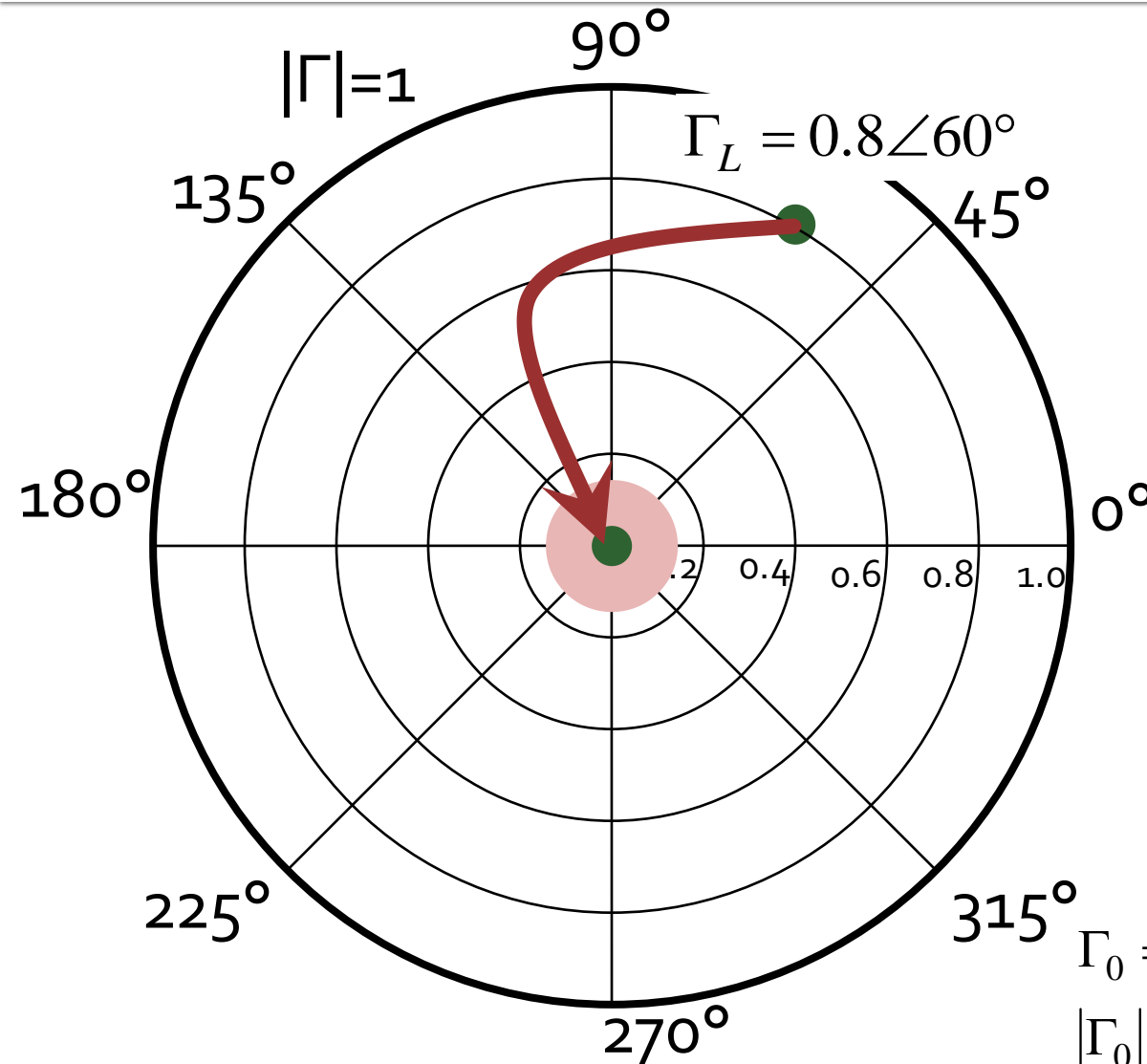
$$Y_{in} = Y_L + G_1 = (G_L + G_1) + j \cdot B_L$$

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

$$b_{in} = b_L$$

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

Impedance matching

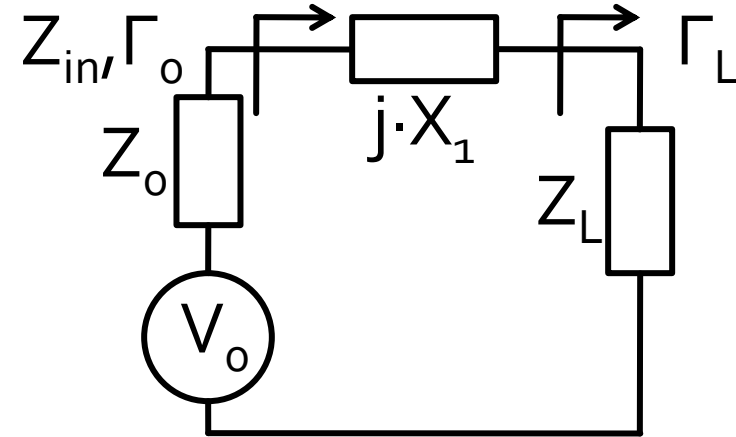
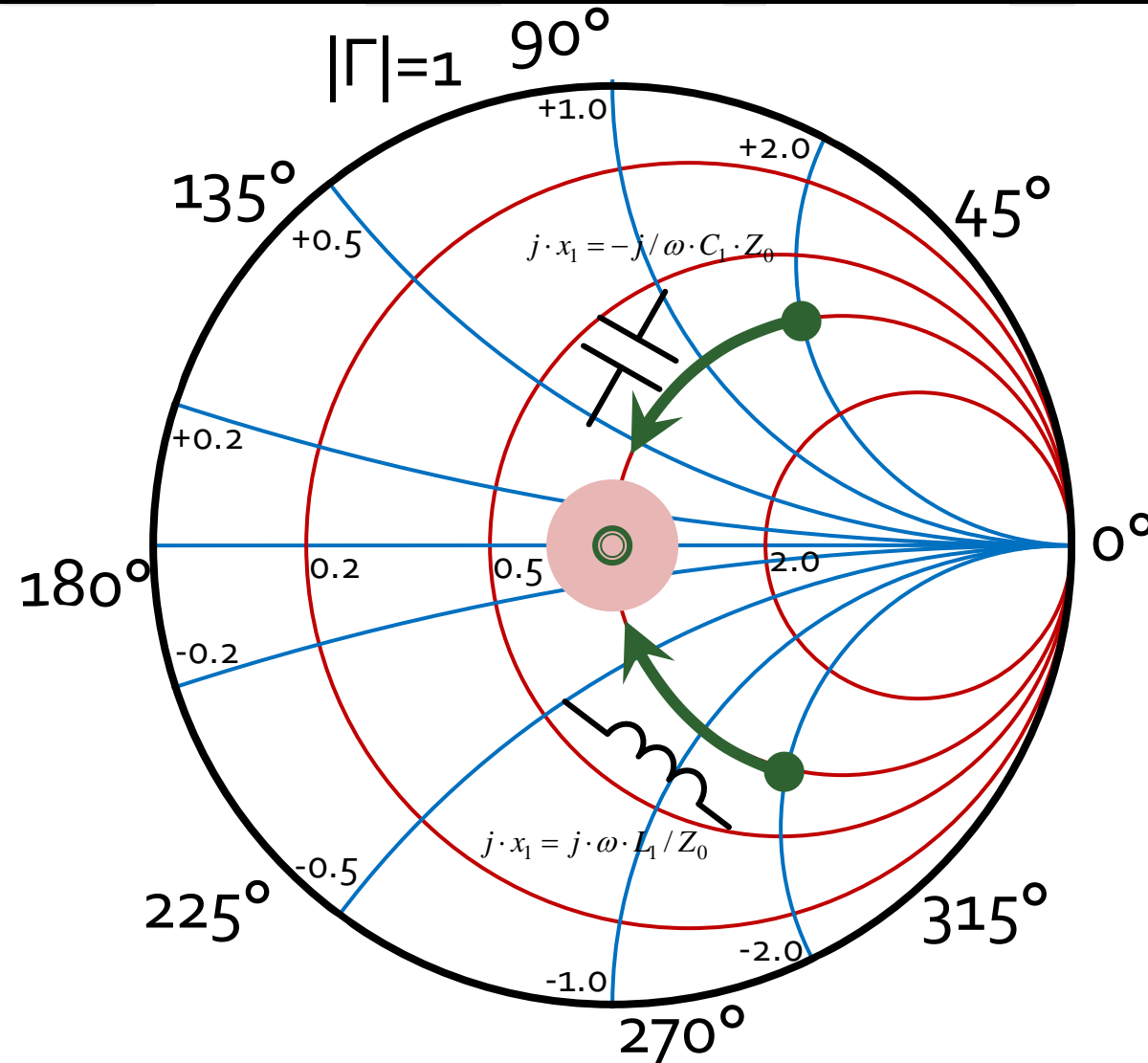


How?

$\Gamma_0 = 0$ perfect match ●

$|\Gamma_0| \leq \Gamma_m$ "good enough" match ●

Matching, series reactance



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

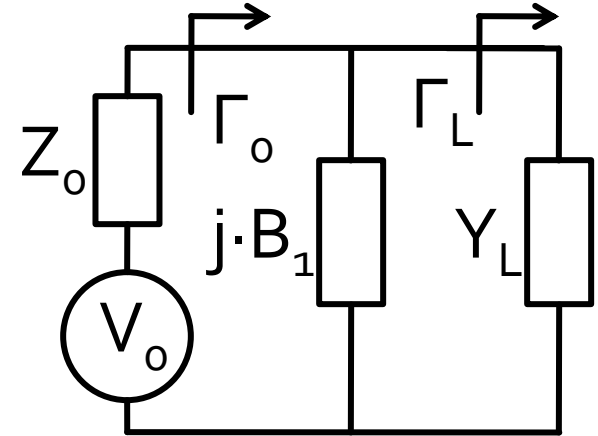
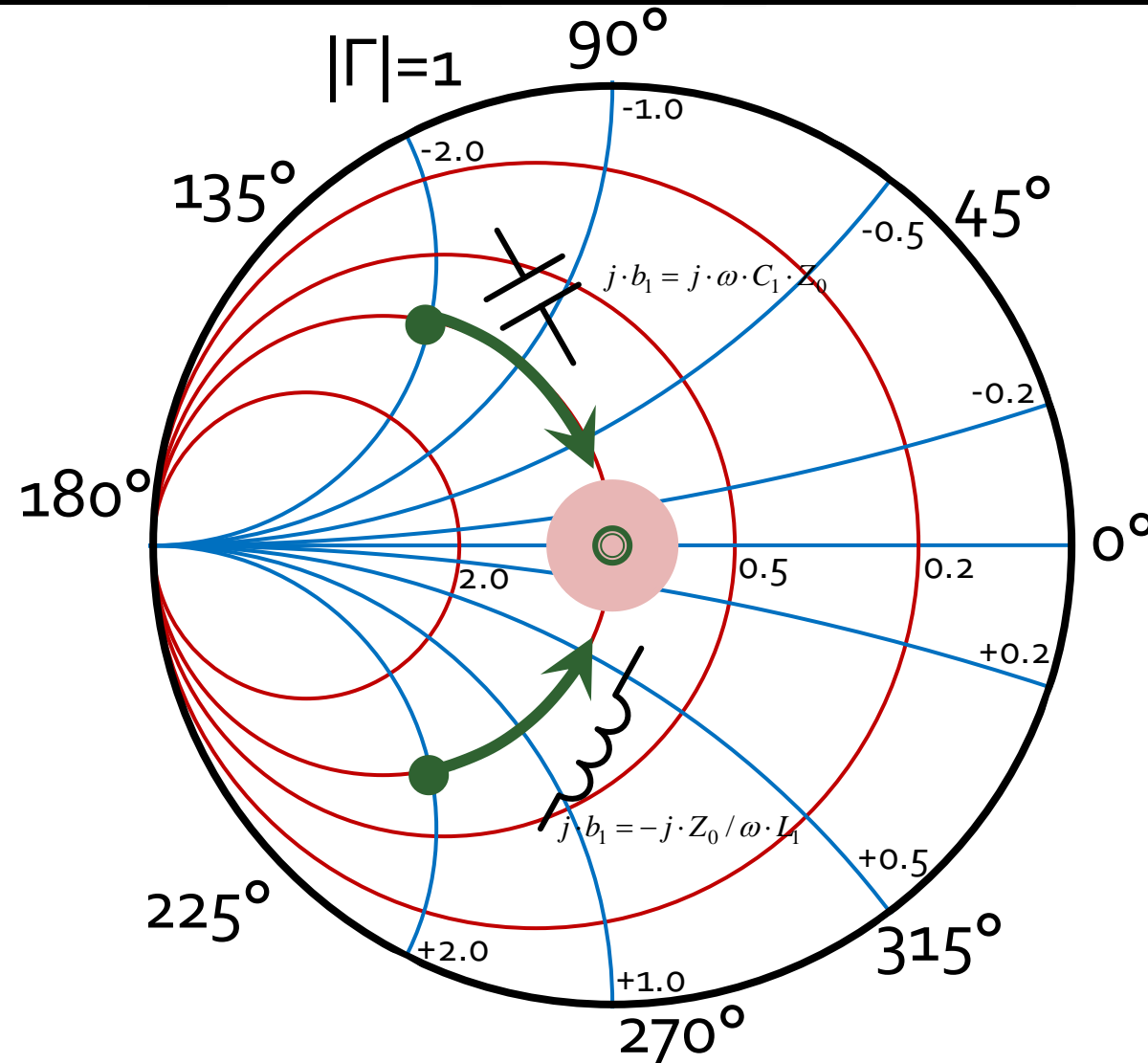
$$z_{in} = r_L + j \cdot (x_L + x_1)$$

$$r_{in} = r_L$$

- Match can be obtained **if and only if** $r_L = 1$
- we compensate the reactive part of the load

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

Matching, shunt susceptance



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

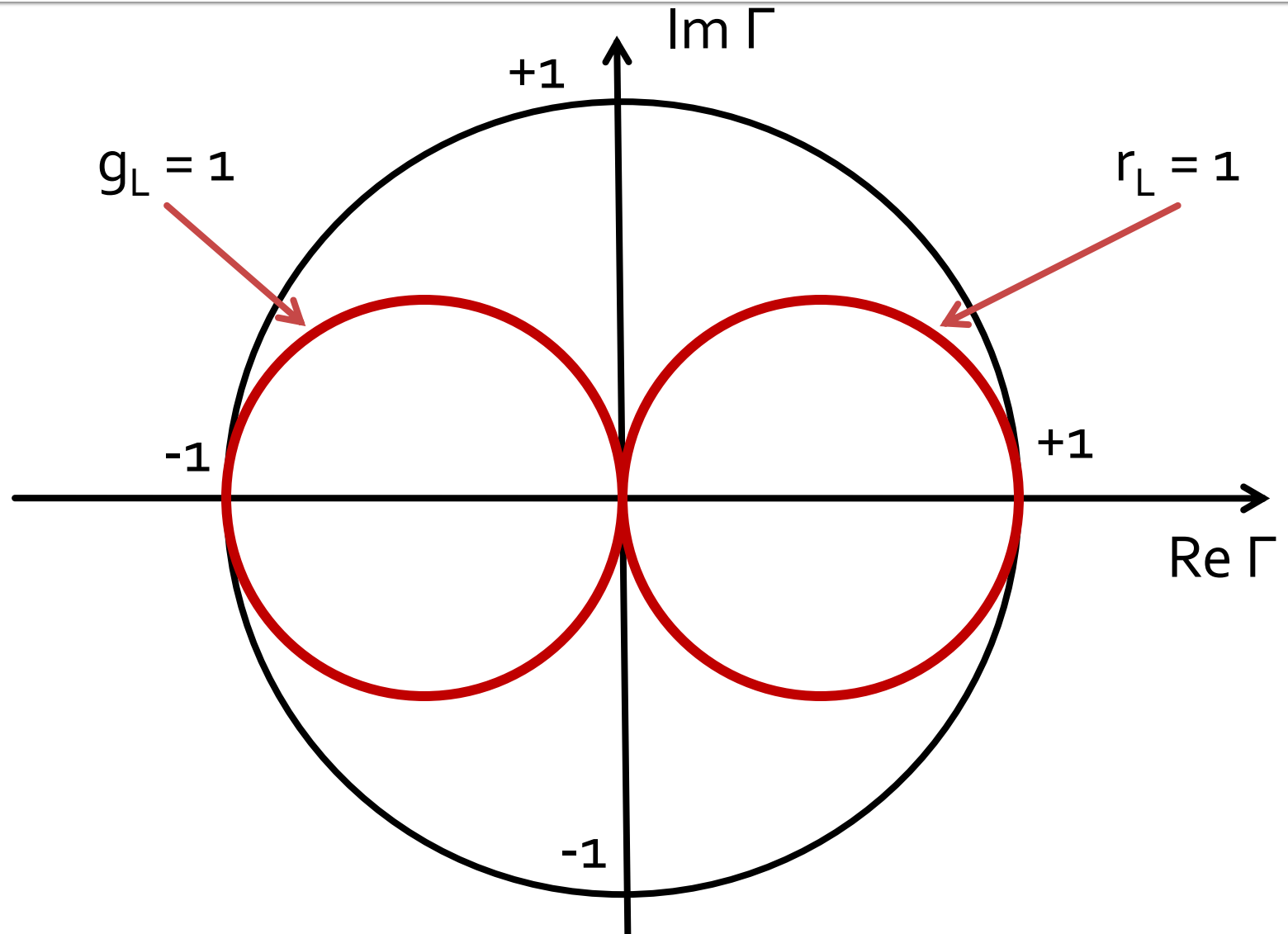
$$y_{in} = g_L + j \cdot (b_L + b_1)$$

$$g_{in} = g_L$$

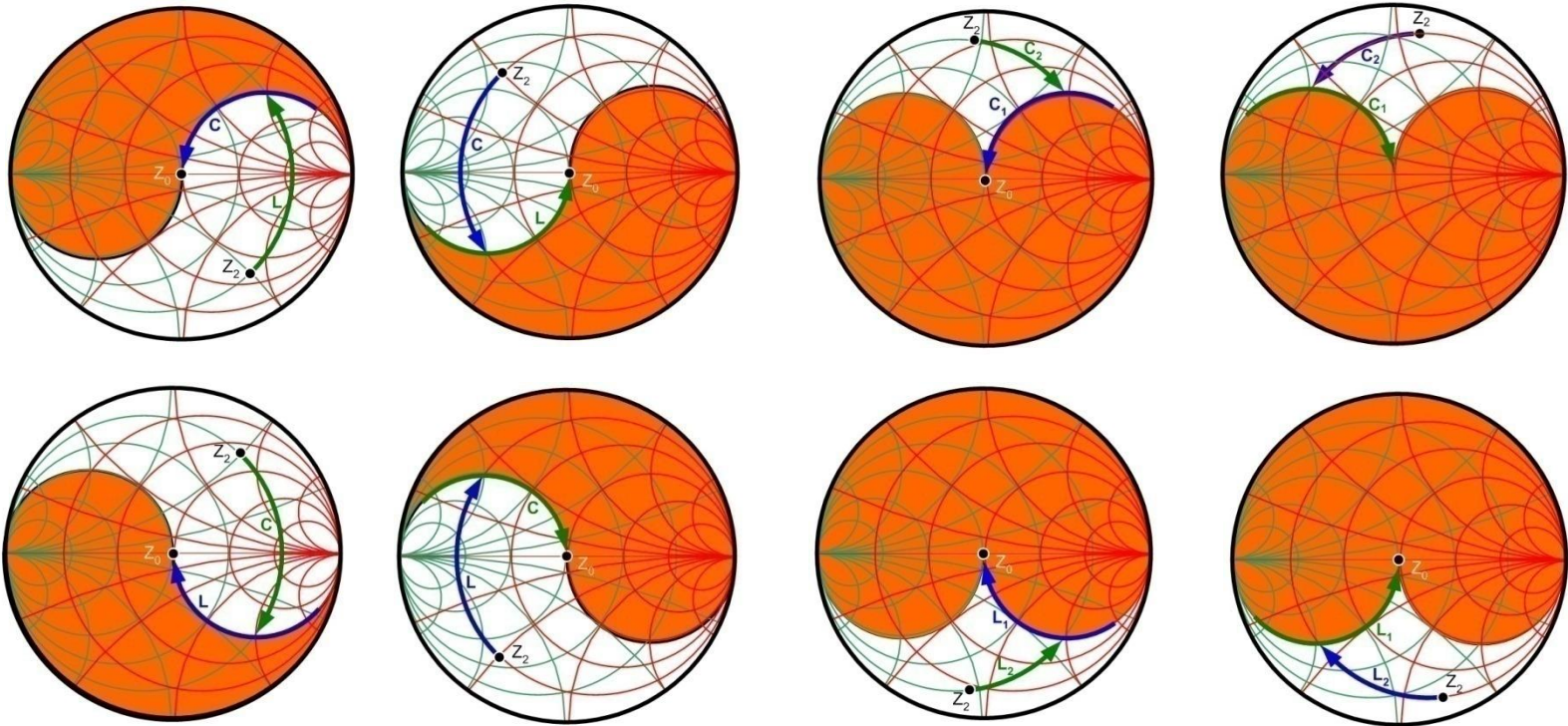
- Match can be obtained **if and only if** $g_L = 1$
- we compensate the reactive part of the load

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

Smith chart, $r=1$ and $g=1$



Matching with 2 reactive elements (L Networks)



Forbidden area for
current network

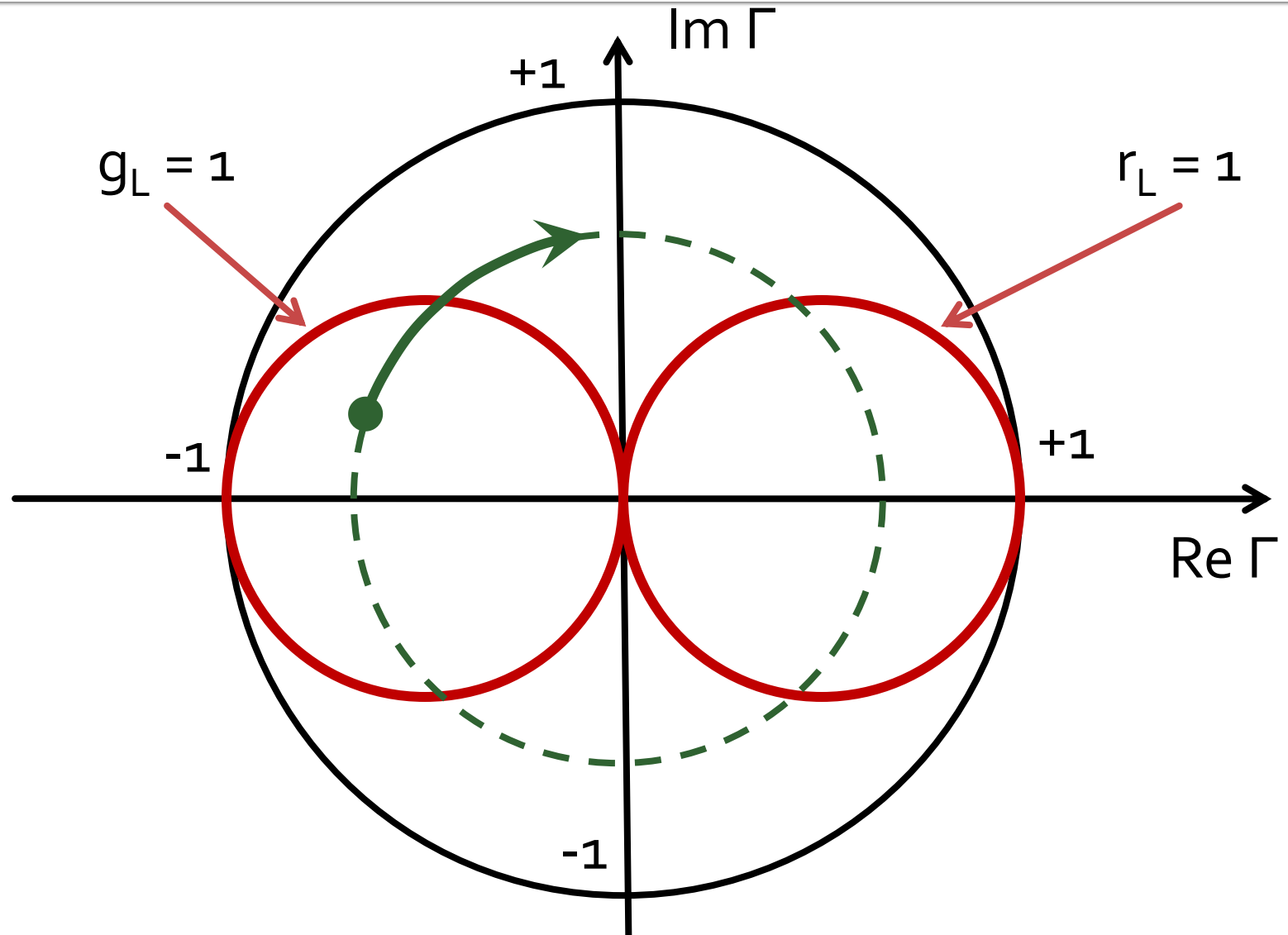
Impedance Matching

Impedance Matching with Stubs

Stub

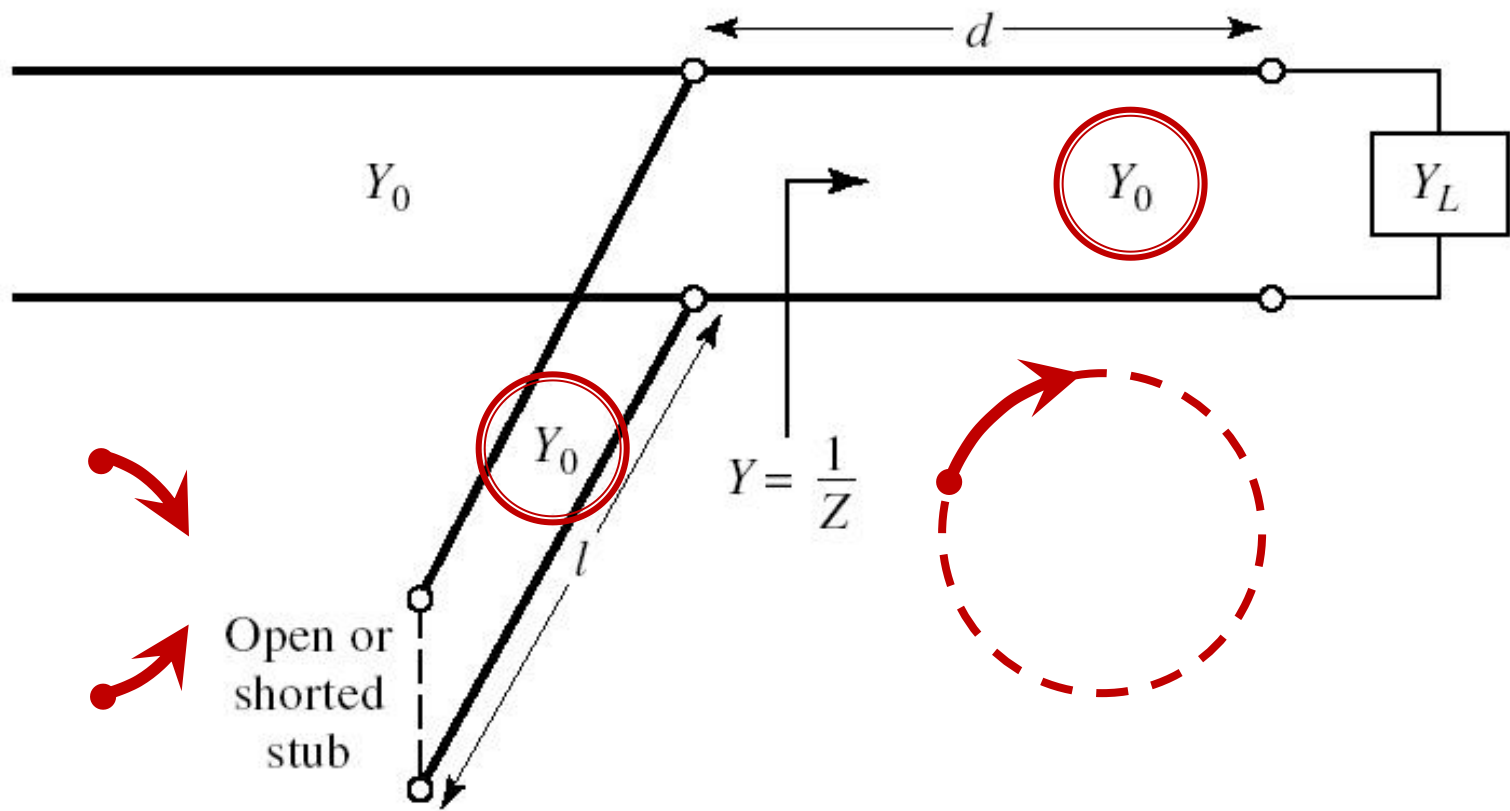
- **Stub** (en) = "rest, ciot, cotor, capăt" (ro)
- We avoid the necessity to use lumped elements
- Matching is achieved (with higher accuracy) using usual Z_0 transmission lines of the circuit
- We use one or more lengths of transmission line (stub) connected either in parallel or in series with the transmission feed line :
 - open-circuited
 - short-circuited
- Usually open-circuited transmission lines are easier to implement and are preferred

Smith chart, $r=1$ and $g=1$



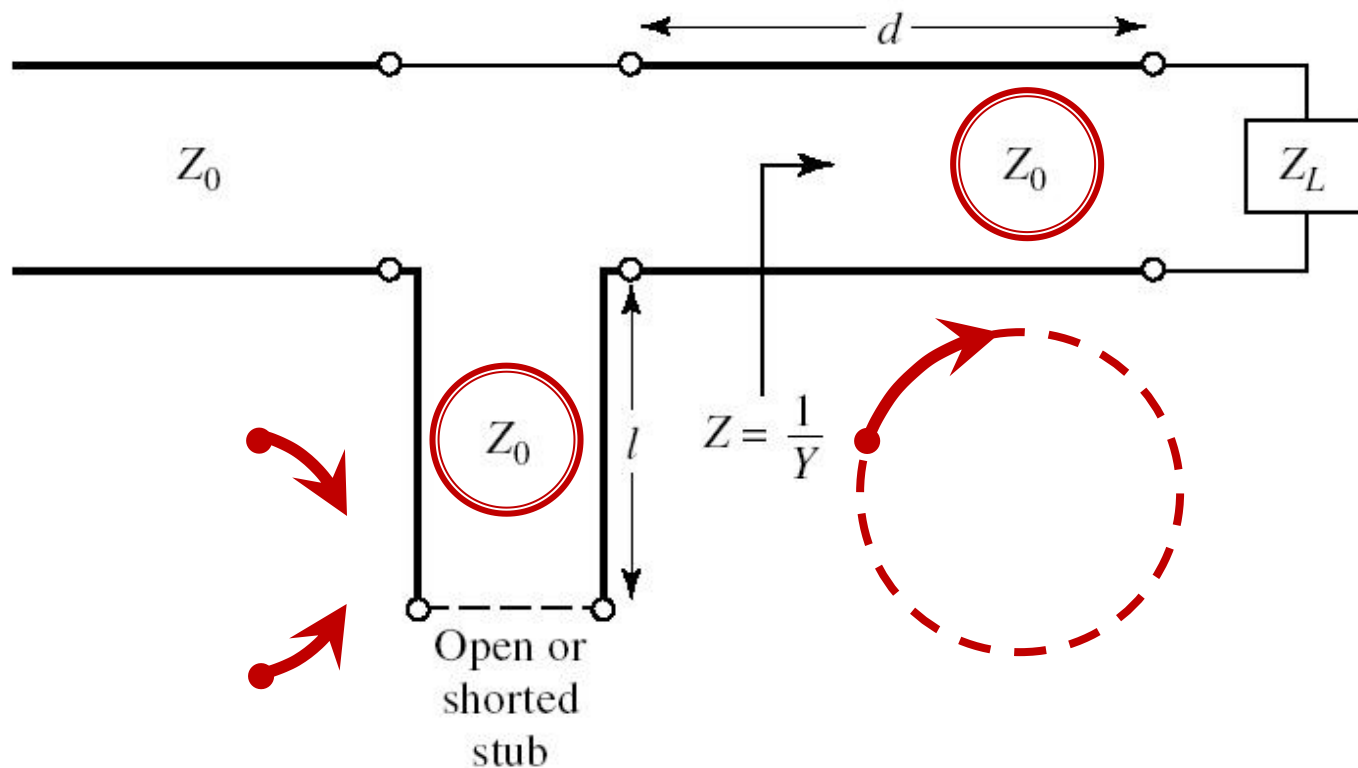
Single stub tuning

- Shunt Stub



Single stub tuning

- Series Stub
- difficult to realize in single conductor line technologies (microstrip)

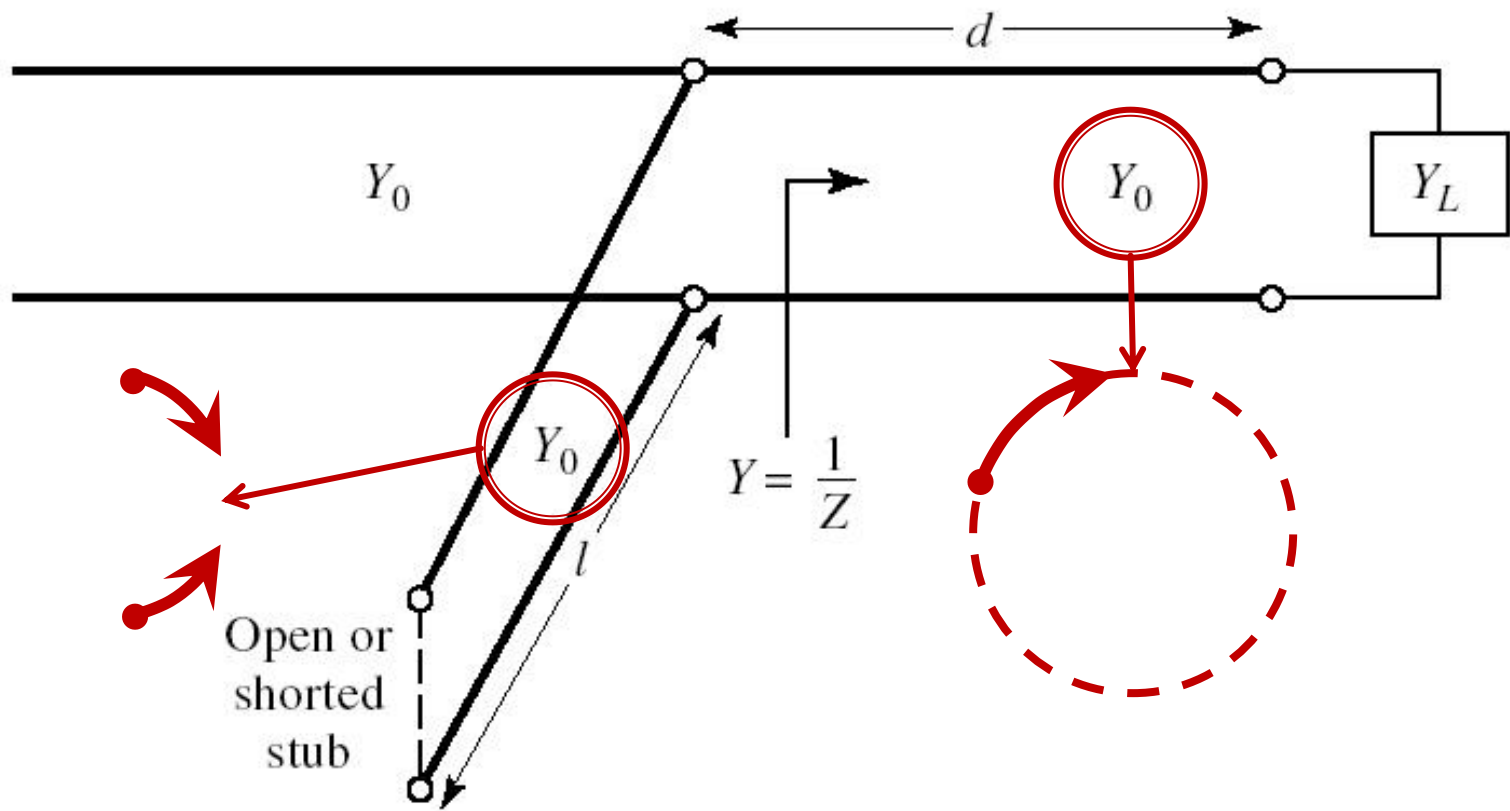


Shunt Stub

Sectiune de linie paralel

Case 1, Shunt Stub

- Shunt Stub



Case 1, Shunt Stub

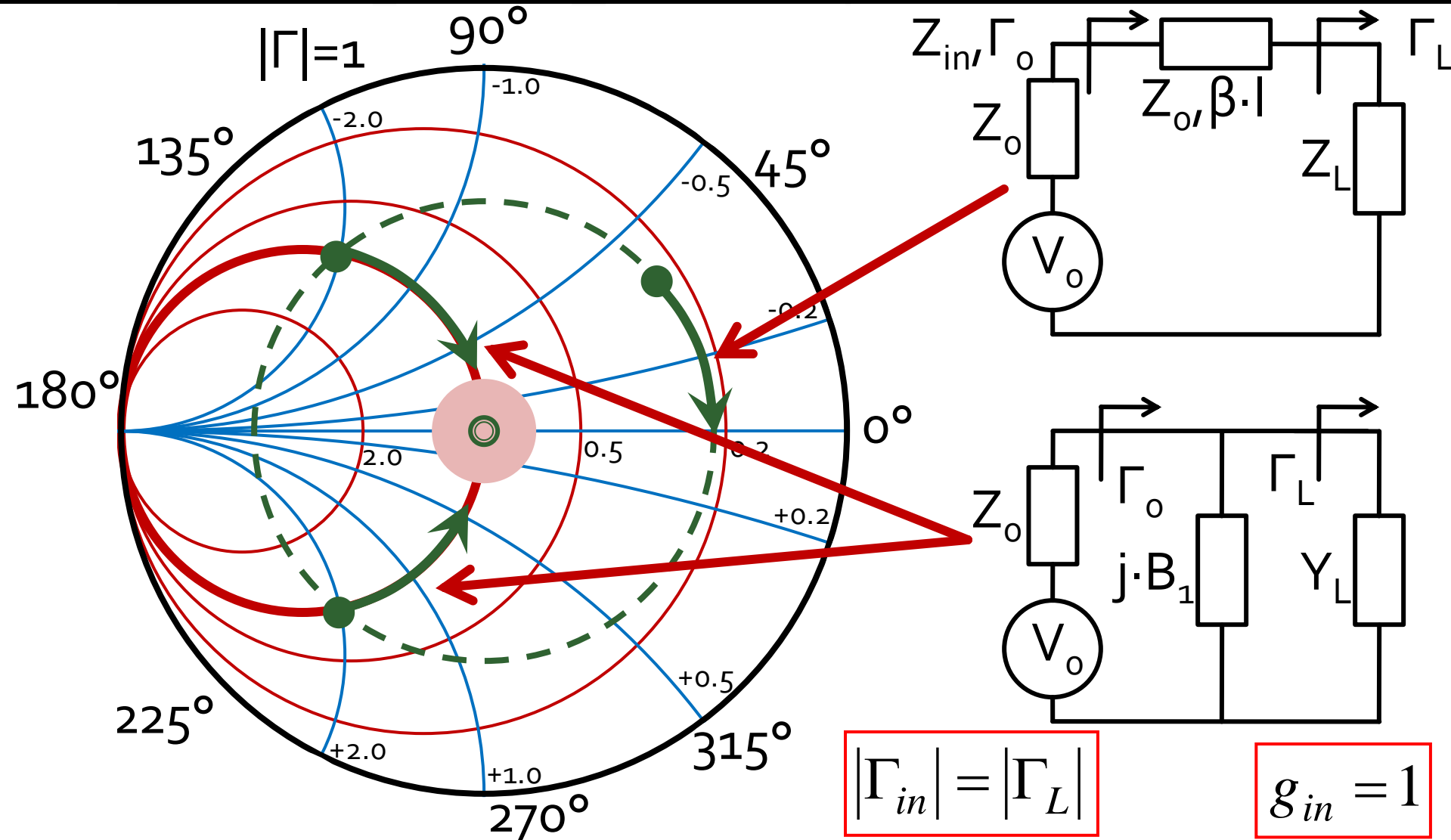
- We use a series transmission line to move the reflection coefficient **on the circle** $g_L = 1$
- We compensate the remaining reactive part of the load with a shunt reactance to achieve match
- The shunt reactance is made with a stub which can be,
as needed:
 - open-circuited
 - short-circuited

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

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

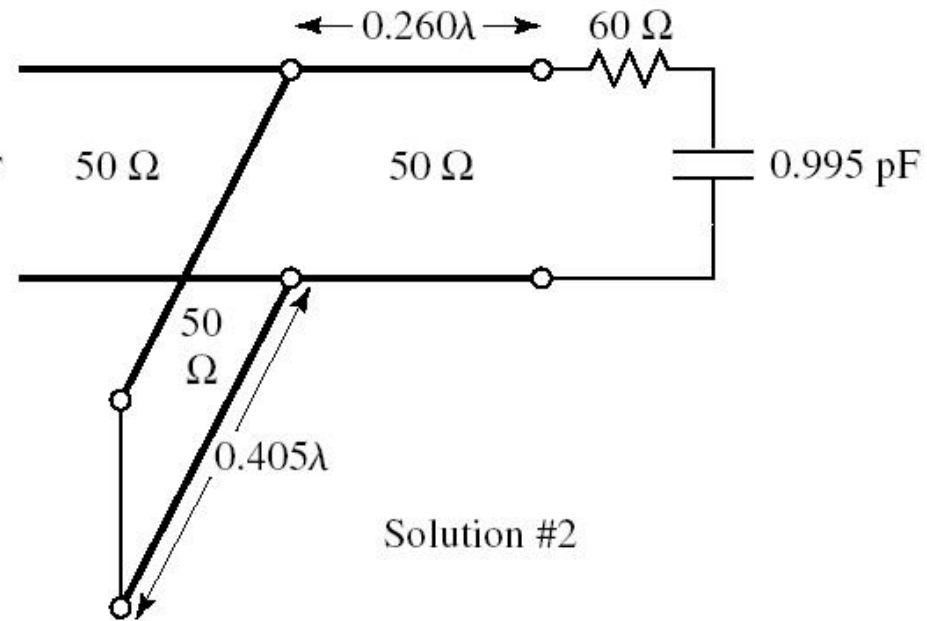
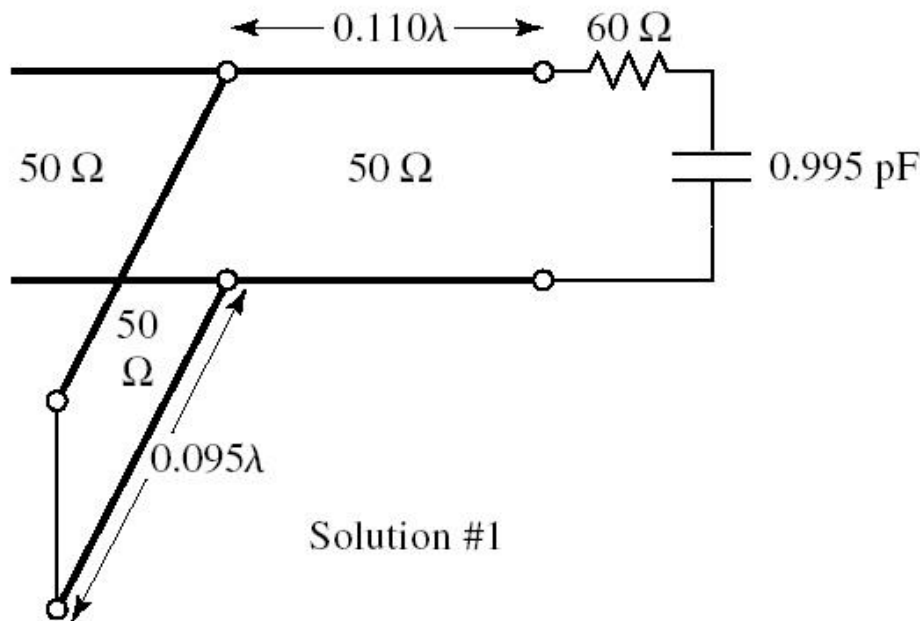
$$Z_{in,oc} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

Matching, series line + shunt susceptance

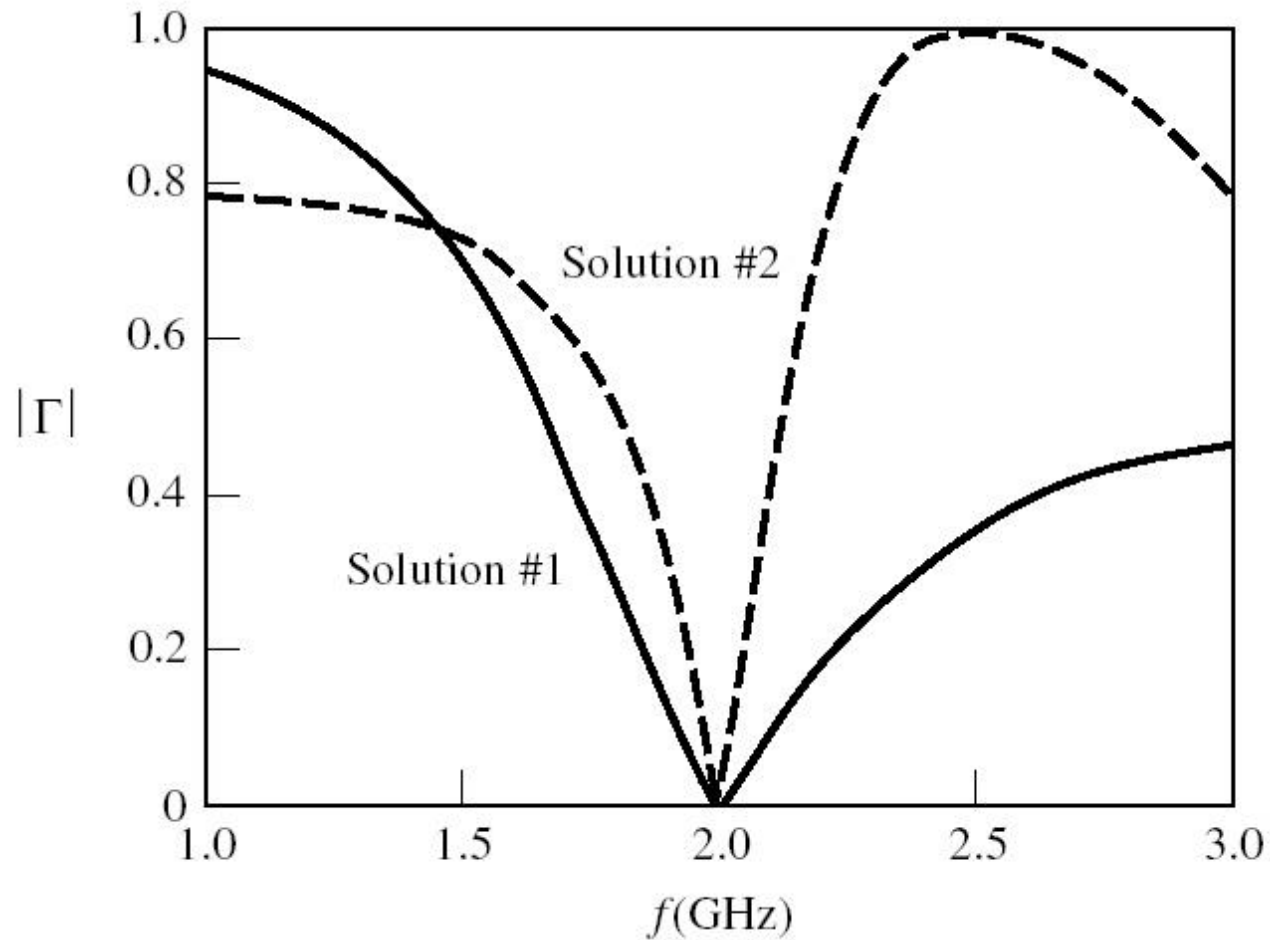


Example, Shunt Stub, sc.

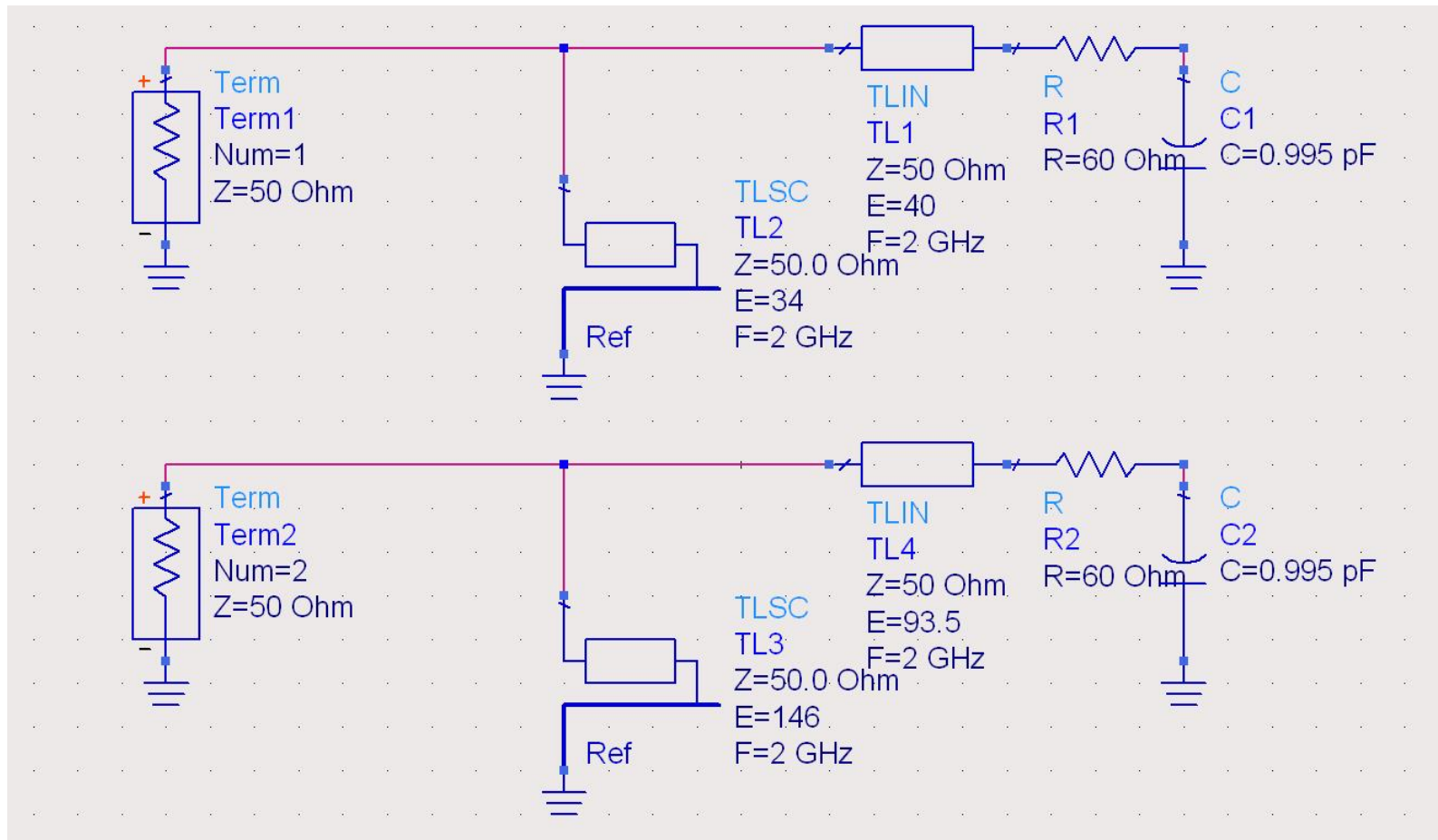
- load: $60\ \Omega$ series with $0.995\ \text{pF}$ at $2\ \text{GHz}$
- two possible solutions



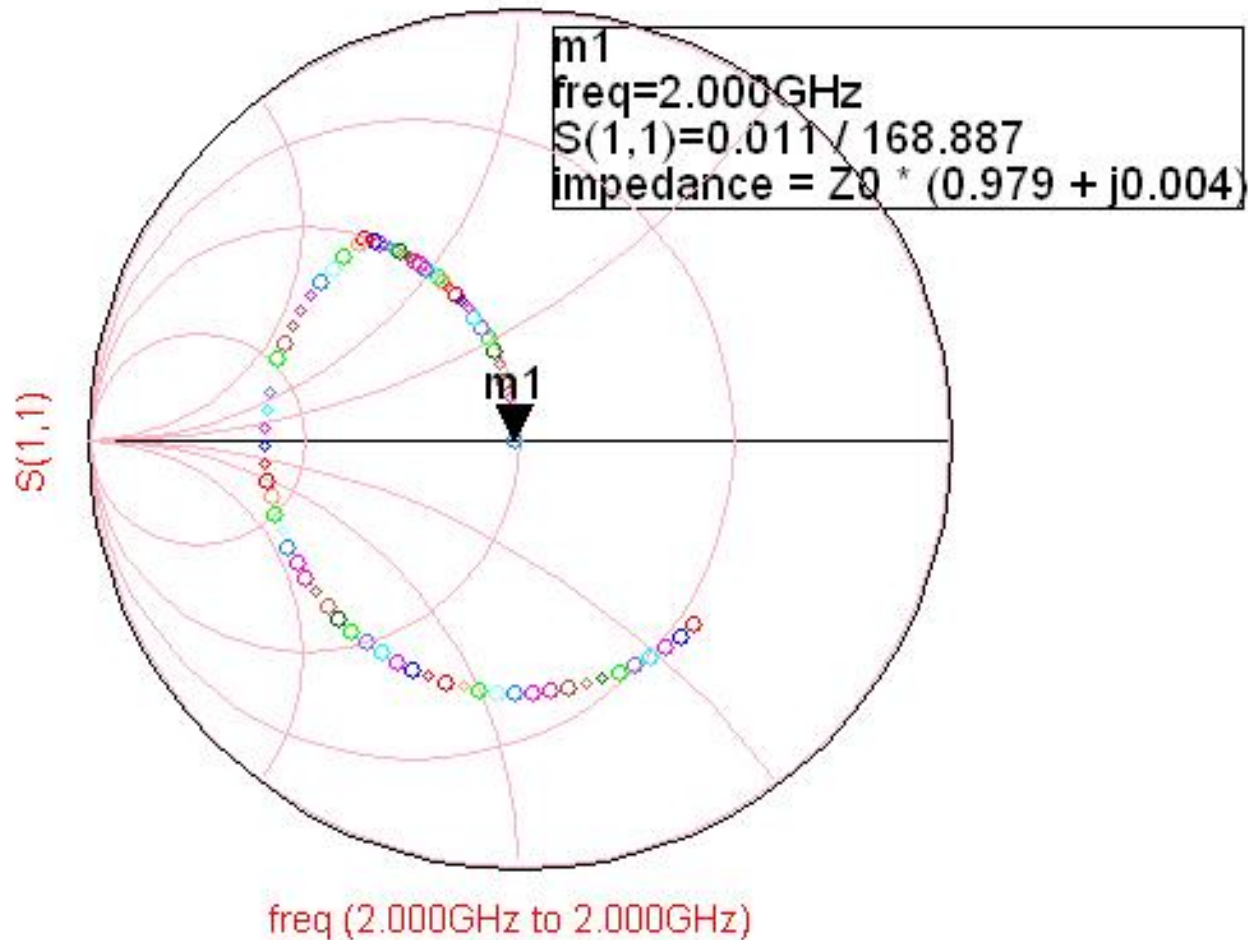
Example, Shunt Stub, sc.



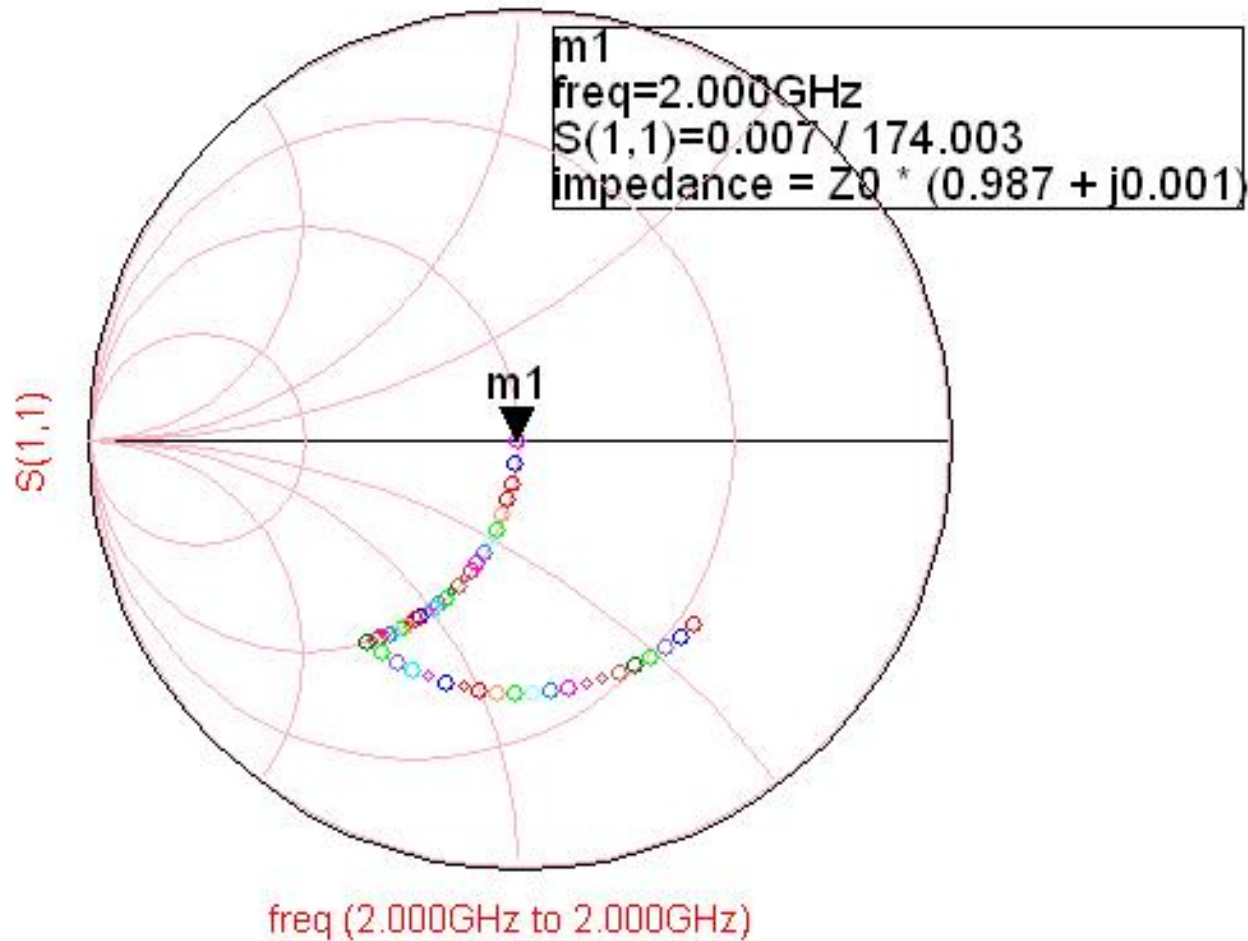
Example, Shunt Stub, sc.



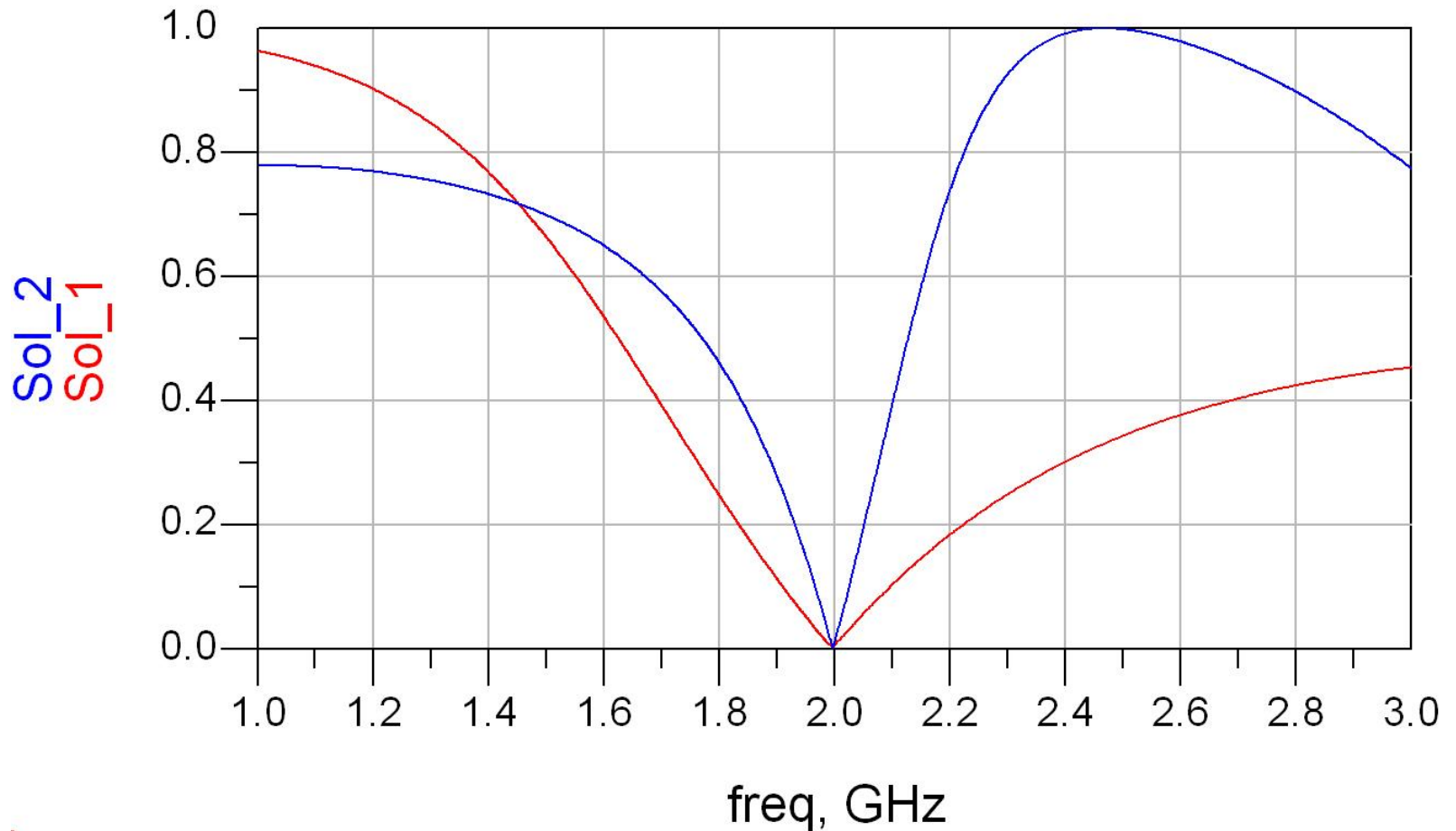
Example, Shunt Stub, sc.



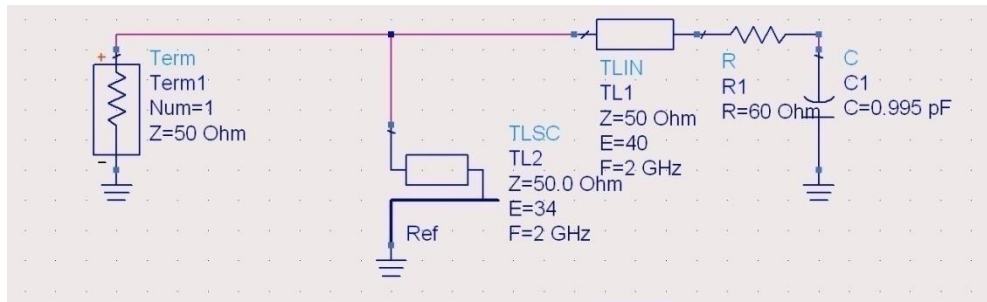
Example, Shunt Stub, sc.



Example, Shunt Stub, sc.



Example, Shunt Stub, sc.

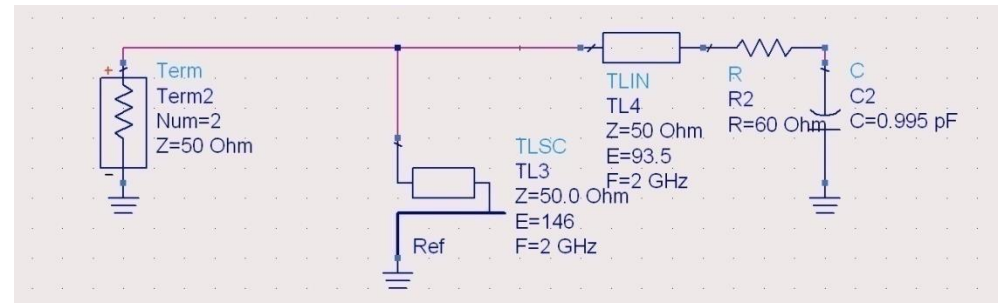


$$l_1 = \frac{40^\circ}{360^\circ} \cdot \lambda = 0.111 \cdot \lambda$$

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

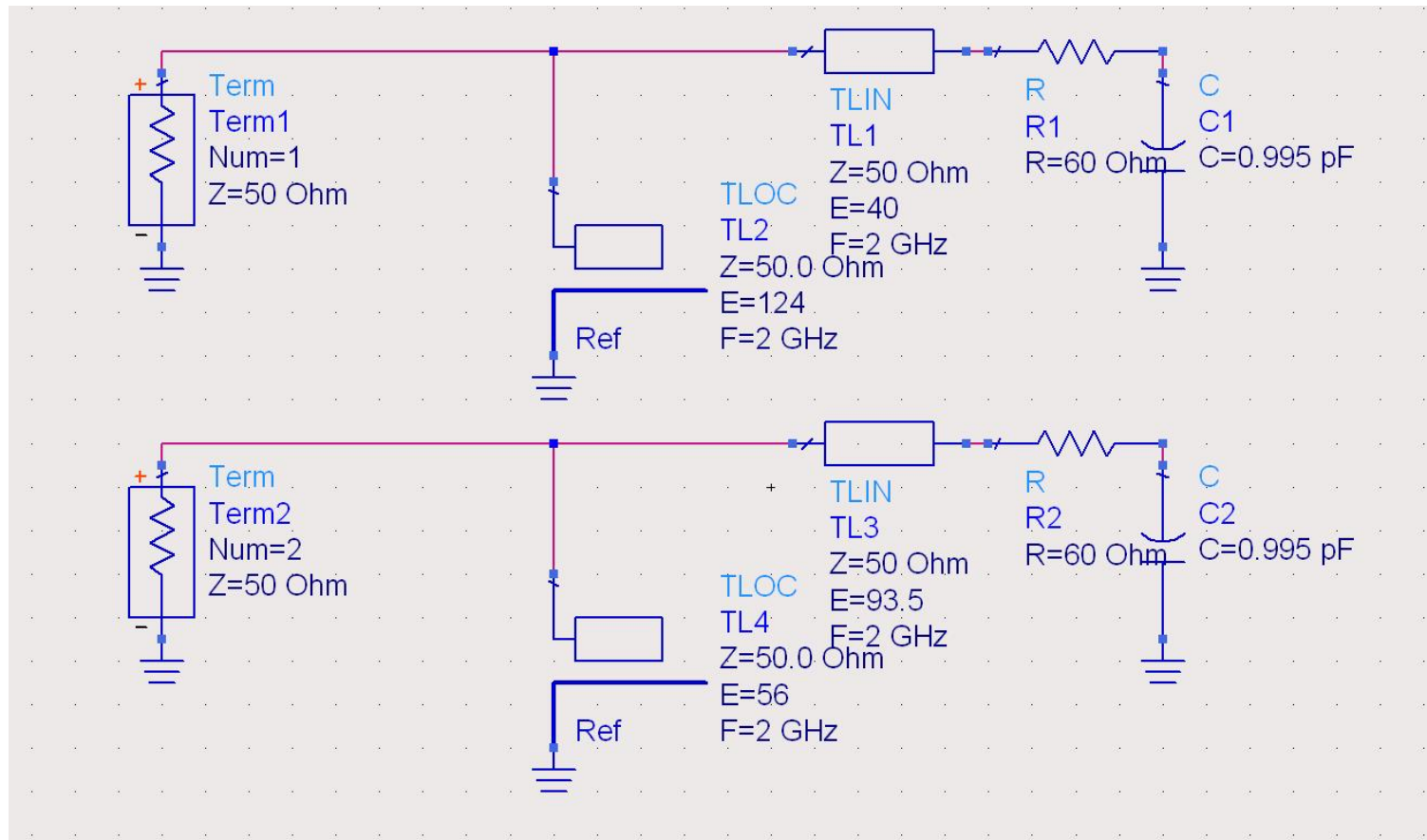
$$l_1 = \frac{93.5^\circ}{360^\circ} \cdot \lambda = 0.260 \cdot \lambda$$

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

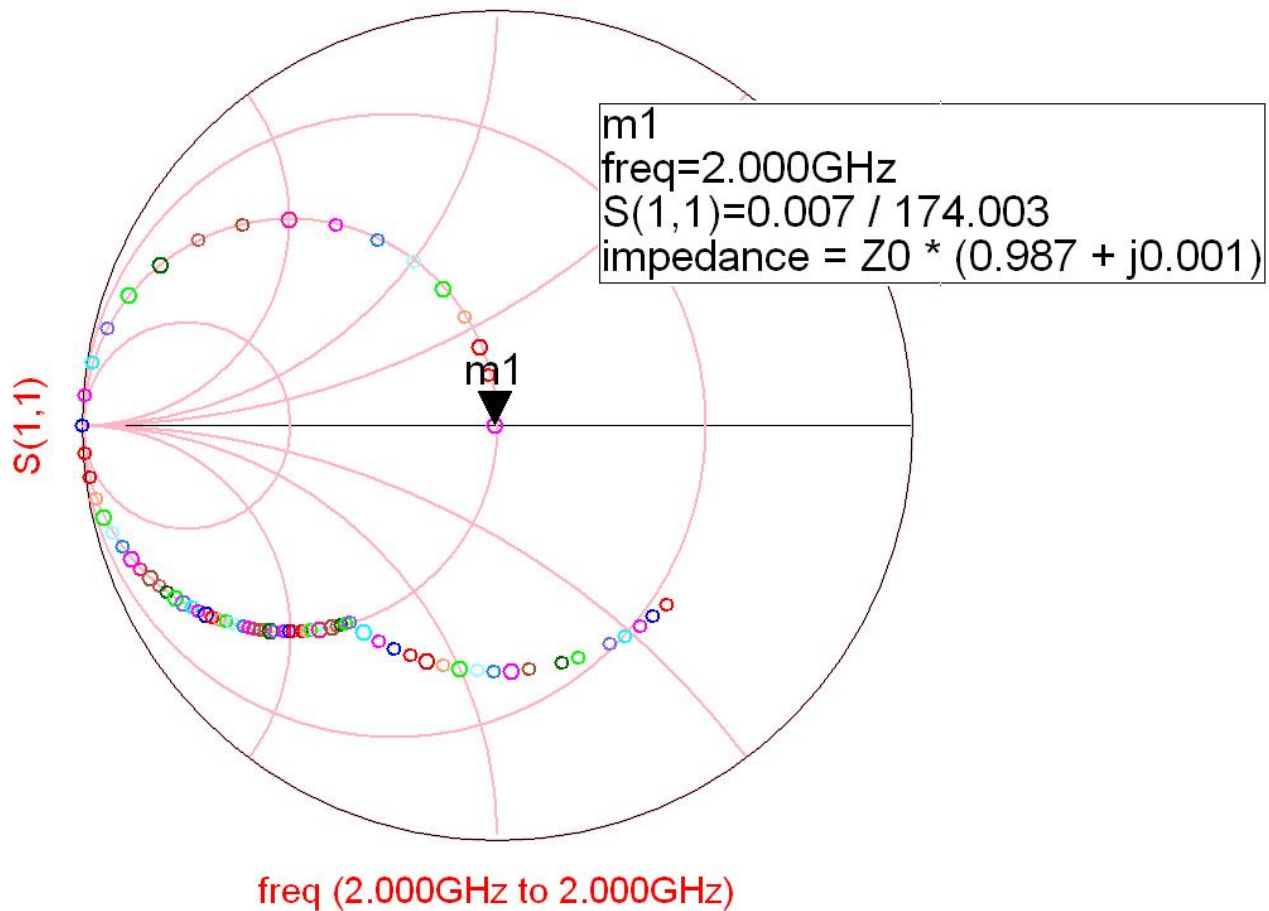


Example, Shunt Stub, oc.

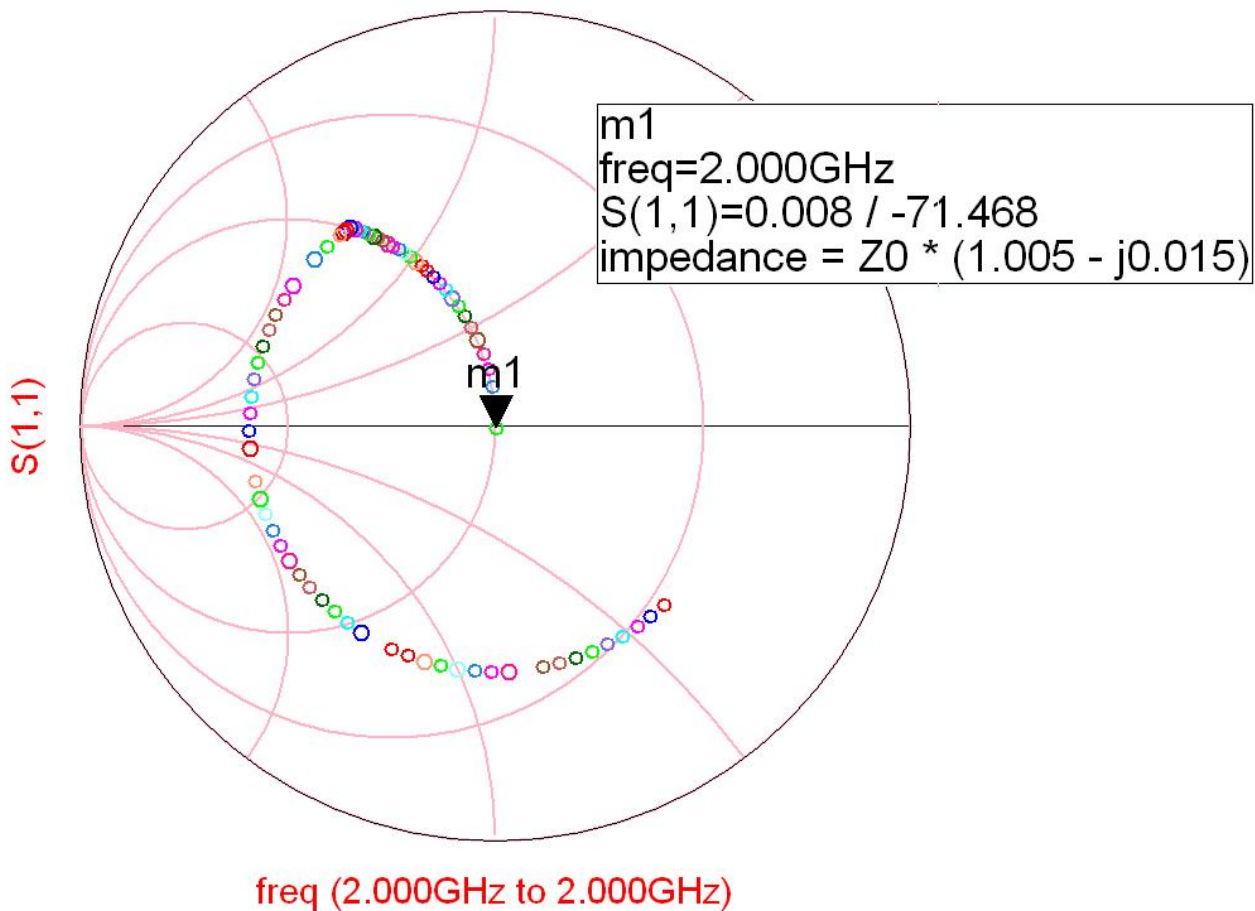
- load: $60\ \Omega$ series with $0.995\ \text{pF}$ at $2\ \text{GHz}$
- two possible solutions



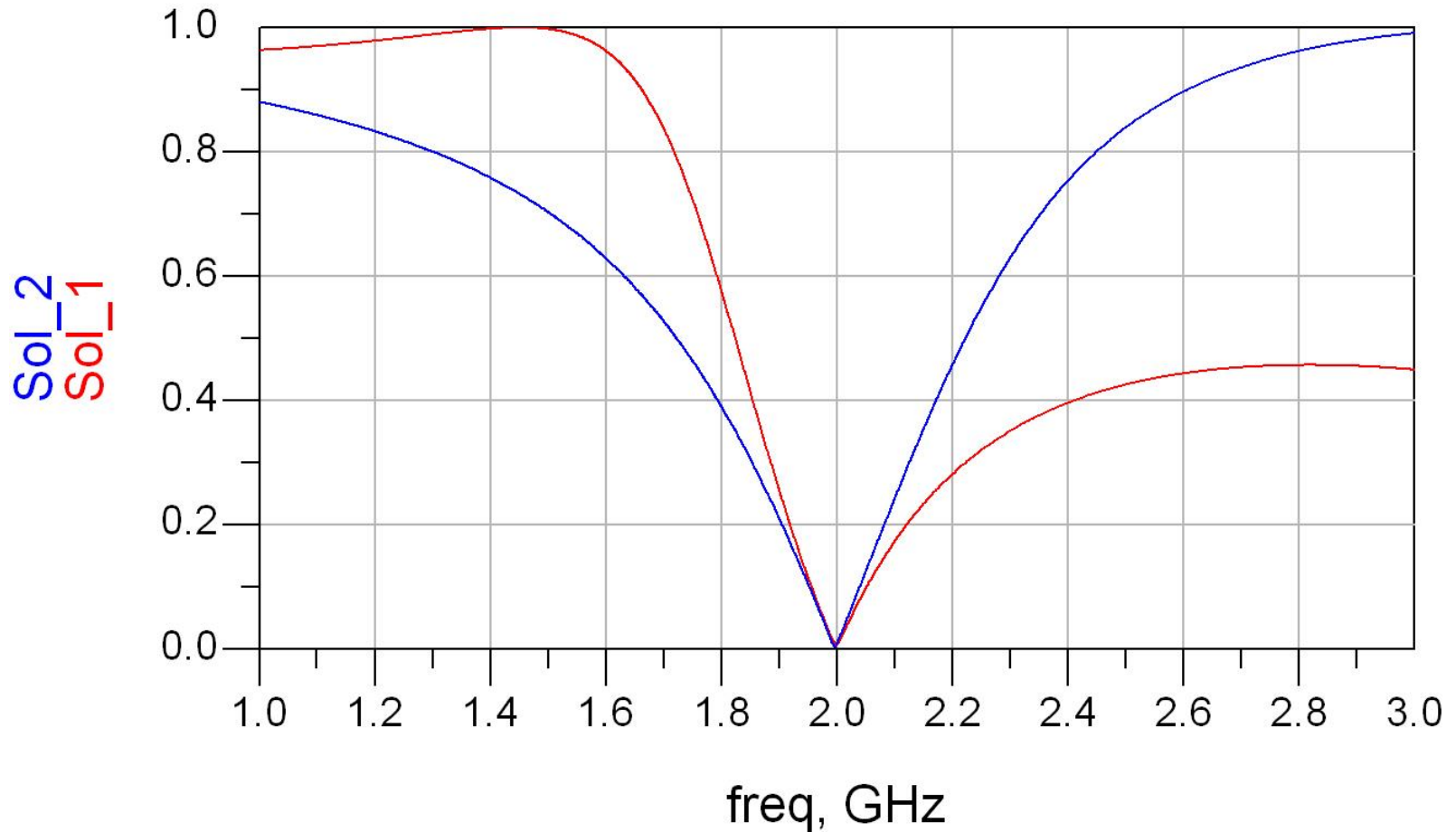
Example, Shunt Stub, oc.



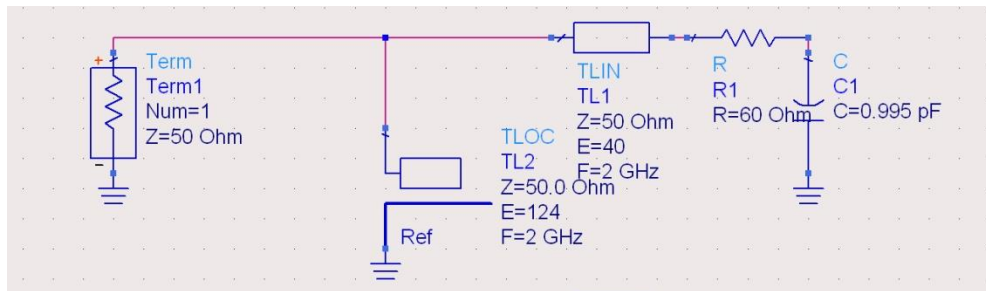
Example, Shunt Stub, oc.



Example, Shunt Stub, oc.



Example, Shunt Stub, oc.

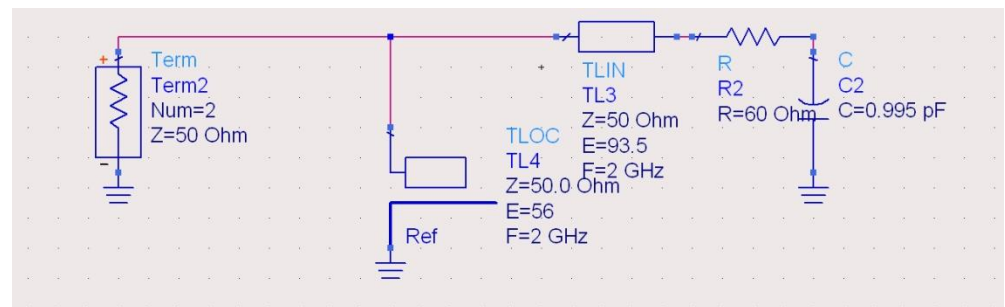


$$l_1 = \frac{40^\circ}{360^\circ} \cdot \lambda = 0.111 \cdot \lambda$$



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

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



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



Shunt Stub, some notes

- mathematical functions which offer the input impedance in a stub are periodic functions of l , tan/cot based functions

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

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

- adding or subtracting

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

doesn't change the result (full rotation around the Smith Chart – hence the 0.5λ gradation of the circumference of the diagram)

Shunt Stub, some notes

- adding or subtracting $\lambda/4$ transforms the impedance:

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

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

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

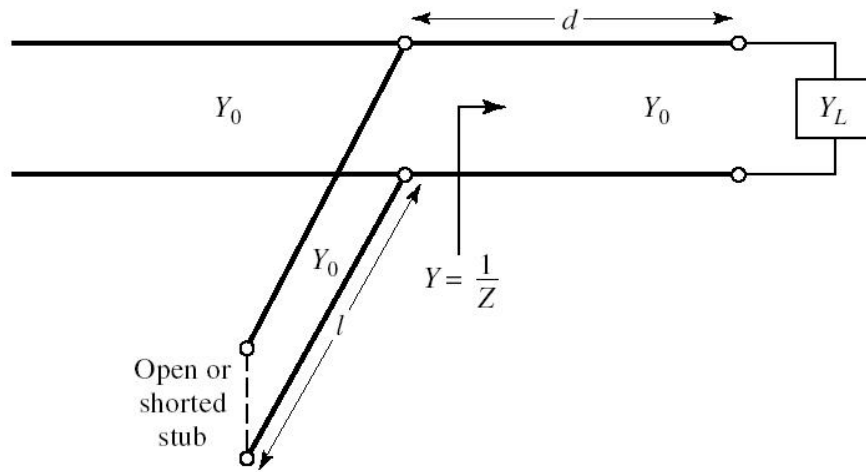
from the open-circuited value to the short-circuited one and vice versa

- For tuning in ADS it's better to start from the neutral point (value of the electrical length of the line which doesn't influence the circuit)
 - series line: $E = \beta \cdot l = 0$
 - shunt stub: $Z_{in} \rightarrow \infty, \tan \beta \cdot l / \cot \beta \cdot l \rightarrow \infty, E = 90^\circ / 0^\circ$

Analytical solution

Shunt Stub

Analytical solution, impedances



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

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

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

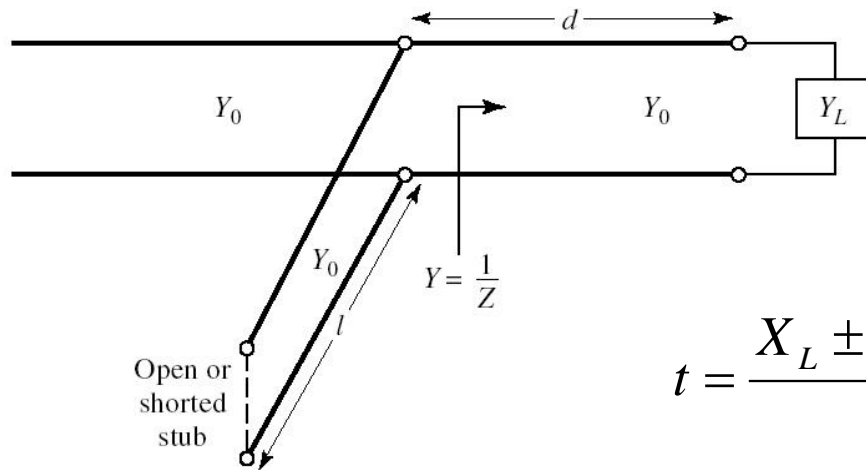
$$G = \frac{R_L \cdot (1 + t^2)}{R_L^2 + (X_L + Z_0 \cdot t)^2}$$

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

- d (which implies t) is chosen so that: $G = Y_0 = \frac{1}{Z_0}$

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

Analytical solution



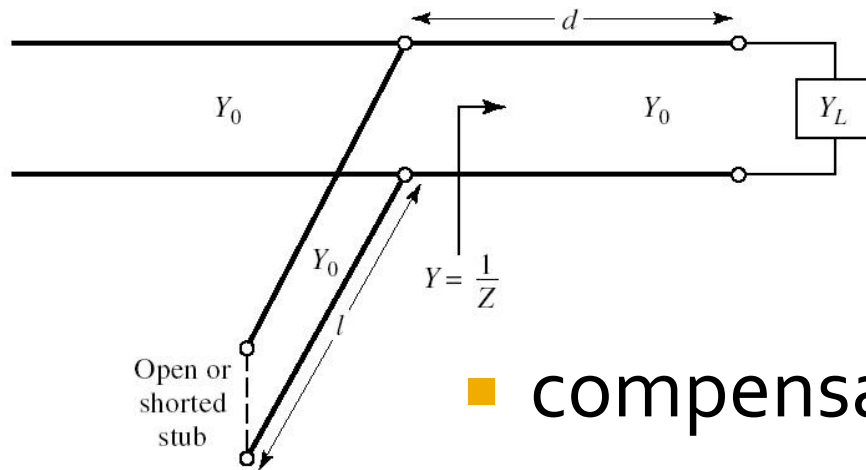
$$t = -\frac{X_L}{2 \cdot Z_0}, \quad R_L = Z_0$$

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

- second grade equation, 2 solutions possible
- d computed from t

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

Analytical solution



$$B_S = -B$$

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

- compensating susceptance is:

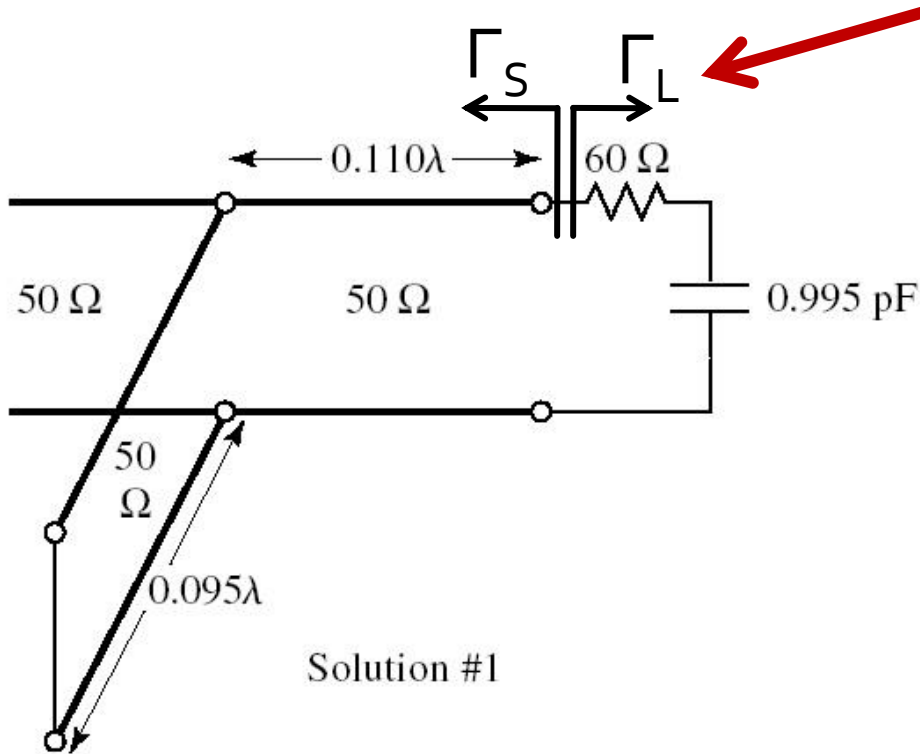
$$\frac{l_{oc}}{\lambda} = \frac{1}{2\pi} \cdot \arctan\left(\frac{B_S}{Y_0}\right) = \frac{-1}{2\pi} \cdot \arctan\left(\frac{B}{Y_0}\right)$$

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

- for **negative lengths** we add $\lambda/2$

Analytical solution, reflection coefficient

- load: $60\ \Omega$ series with $0.995\ \text{pF}$ at $2\ \text{GHz}$



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

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

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

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

- matching requires obtaining conjugate value for Γ

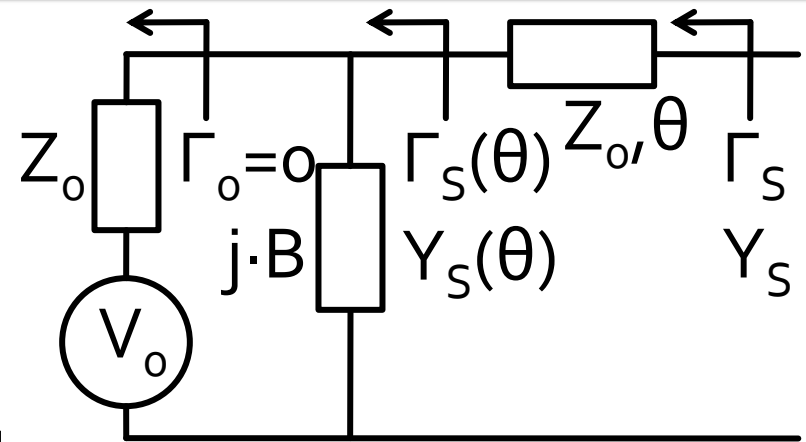
$$\Gamma_S = \Gamma_L^* = 0.405 + j \cdot 0.432$$

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

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

Analytical solution, Γ

- series line
 - electrical length $E = \beta \cdot l = \theta$
 - moves the reflection coefficient on the circle $g=1$
- shunt stub
 - electrical length $E = \beta \cdot l_{sp} = \theta_{sp}$
 - moves the reflection coefficient to the center of the Smith Chart ($\Gamma_o = 0$)



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

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

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

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

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

A.S., Γ , series line, proof

- After the series line with electrical length θ :

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

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

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

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

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

A.S., Γ , series line, usage

- Equations for computing the series line θ :

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

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

- two solutions possible, in the $0 \div 180^\circ$ range
 - add $\lambda/2 \Leftrightarrow 180^\circ$ as needed

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

$$\cos(\varphi + 2\theta) = -0.593 \Rightarrow (\varphi + 2\theta) = \pm 126.35^\circ \quad \forall k \in \mathbb{N}$$

$$(46.85^\circ + 2\theta) = \begin{cases} +126.35^\circ \\ -126.35^\circ \end{cases} \quad \theta = \begin{cases} +39.7^\circ \\ -86.6^\circ + 180^\circ = +93.4^\circ \end{cases}$$

A.S., Γ , shunt stub, proof

- Equations for computing the shunt stub θ_{sp} :

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

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

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

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

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

A.S., Γ , shunt stub, proof

- Equations for computing the shunt stub

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

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

- two cases

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

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

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

A.S., Γ , shunt stub, proof

- We prefer (for microstrip) open circuited stub

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

- The normalized susceptance to be introduced to achieve the match
 - $Y(\theta)$ is the admittance seen **towards** the source, Z_0 parallel with $j \cdot B$

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

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

Analytical solution, Γ , usage

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

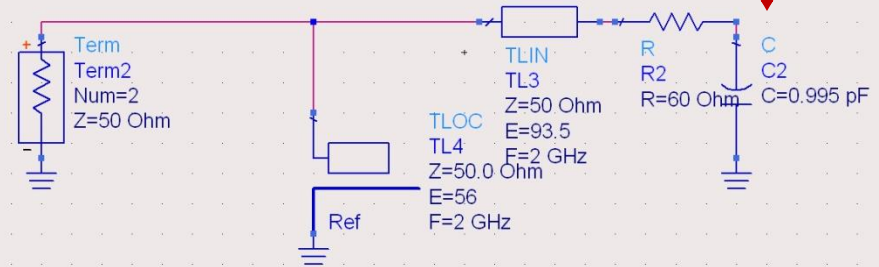
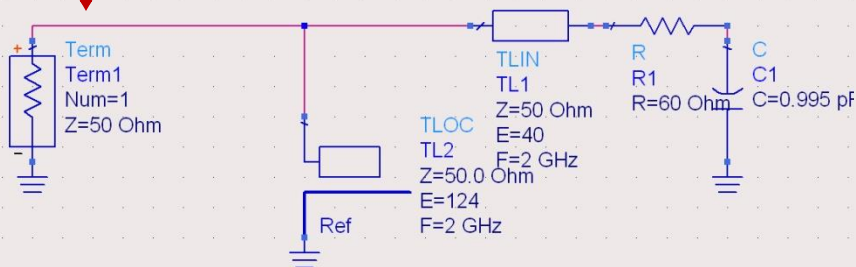
- We choose **one** of the two possible solutions
- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **shunt stub** equation

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

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

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

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

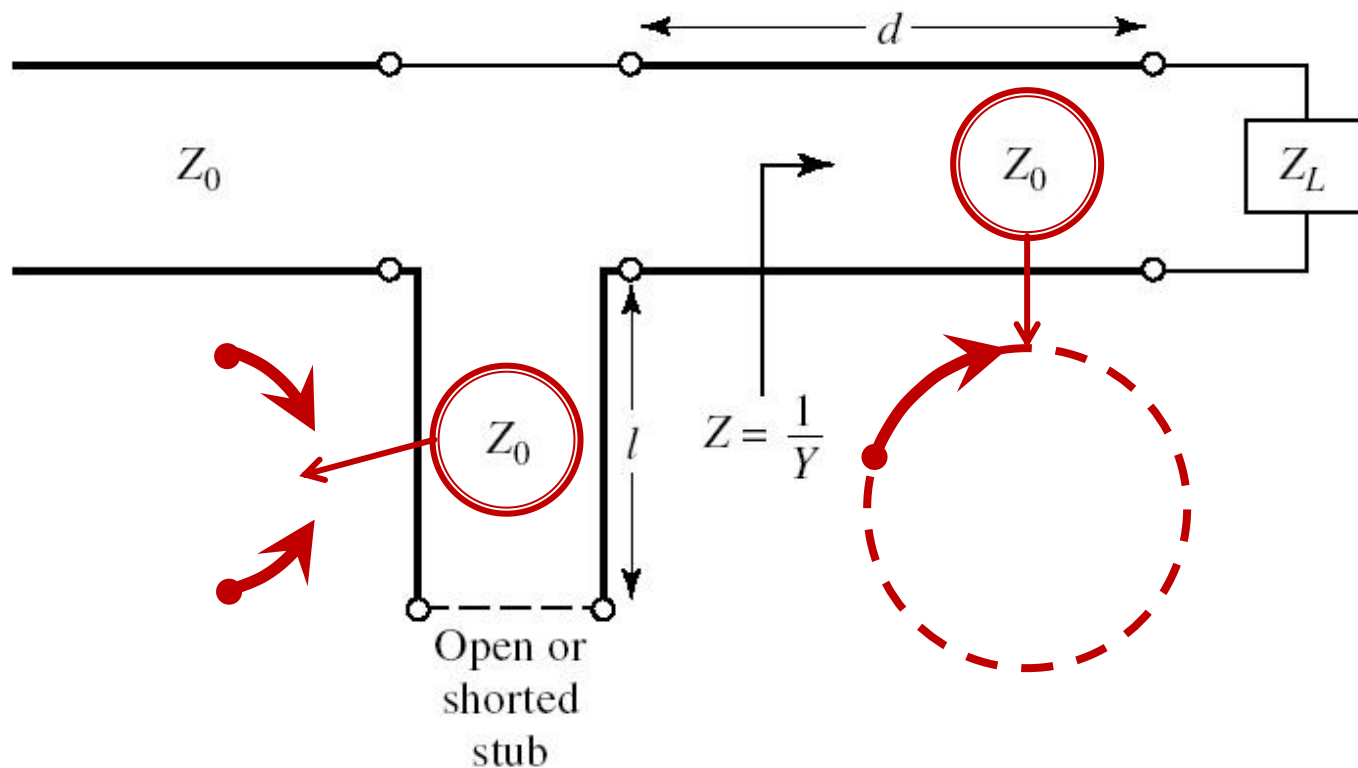


Series Stub

Sectiune de linie serie

Case 2, Series Stub

- Series Stub
- difficult to realize in single conductor line technologies (microstrip)



Case 2, Series Stub

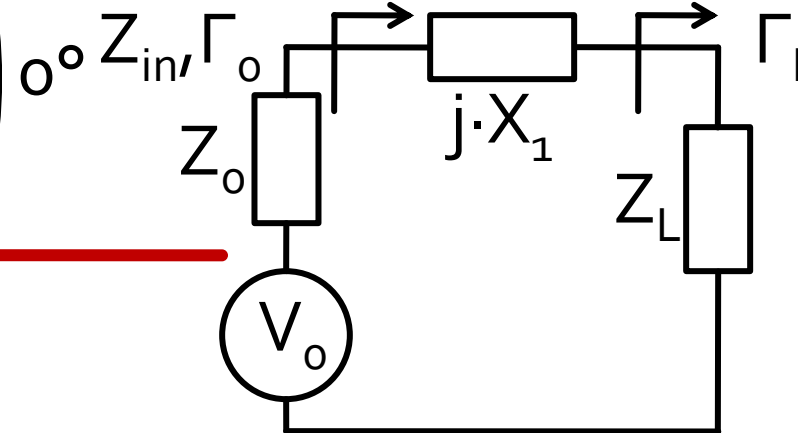
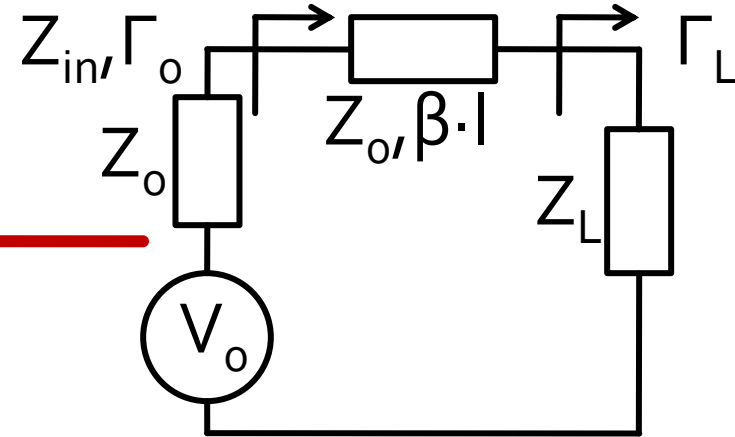
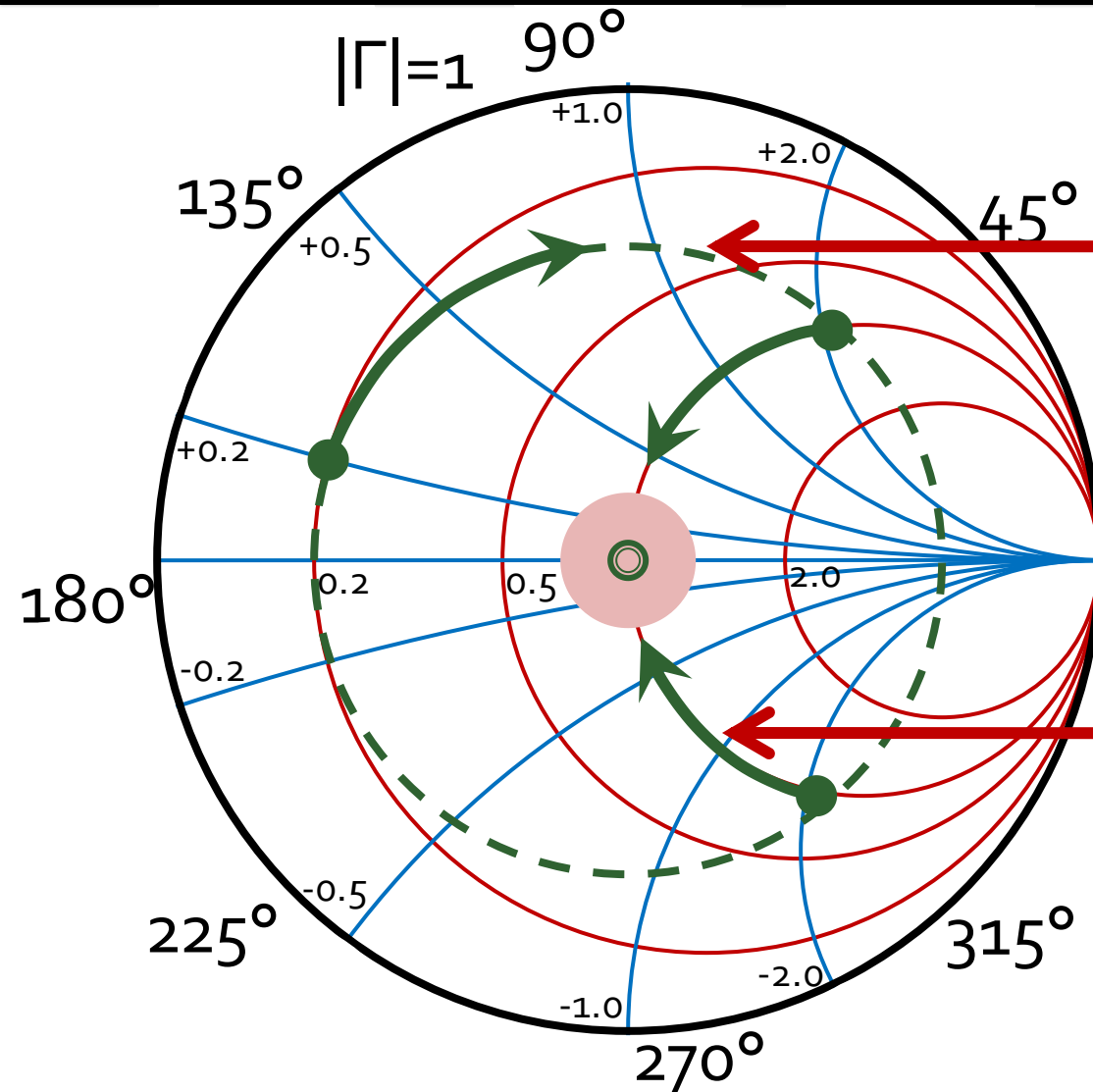
- We use a series transmission line to move the reflection coefficient **on the circle** $r_L = 1$
- We compensate the remaining reactive part of the load with a series reactance to achieve match
- The series reactance is made with a stub which can be, as needed:
 - open-circuited
 - short-circuited

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

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

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

Matching, series line + series reactance

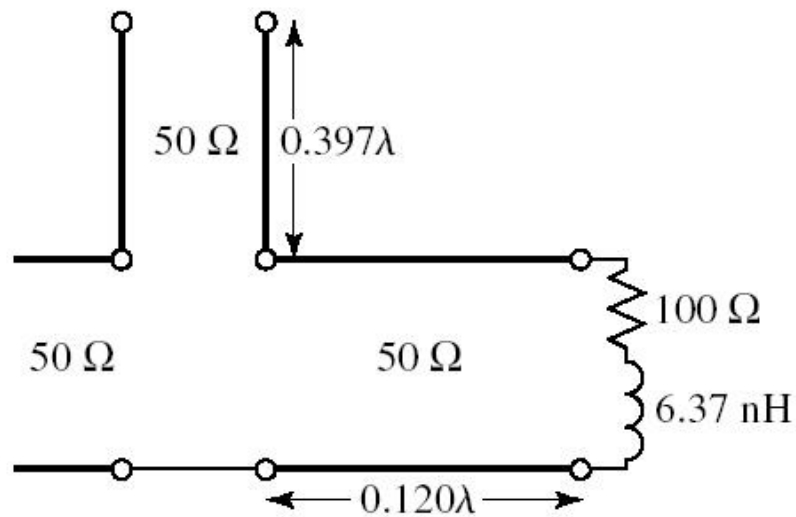


$$|\Gamma_{in}| = |\Gamma_L|$$

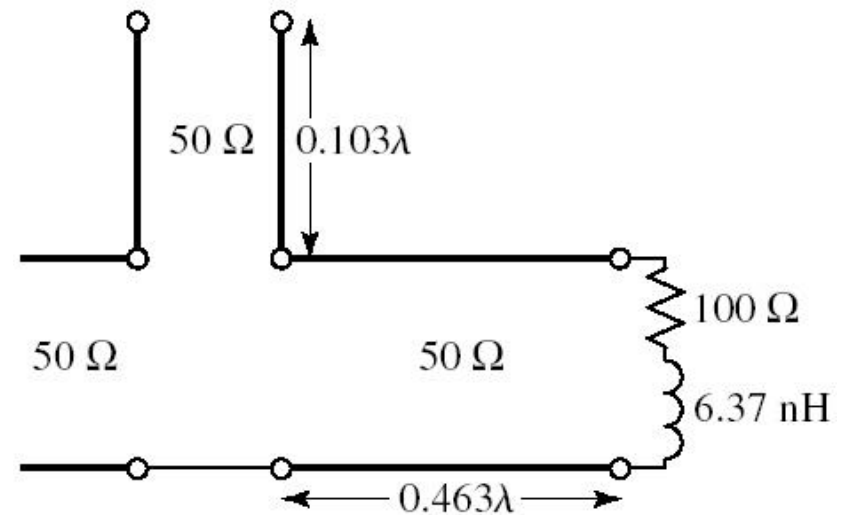
$$r_{in} = 1$$

Example, Series Stub, oc.

- load: $100\ \Omega$ series with $6.37\ \text{nH}$ at $2\ \text{GHz}$
- two solutions possible

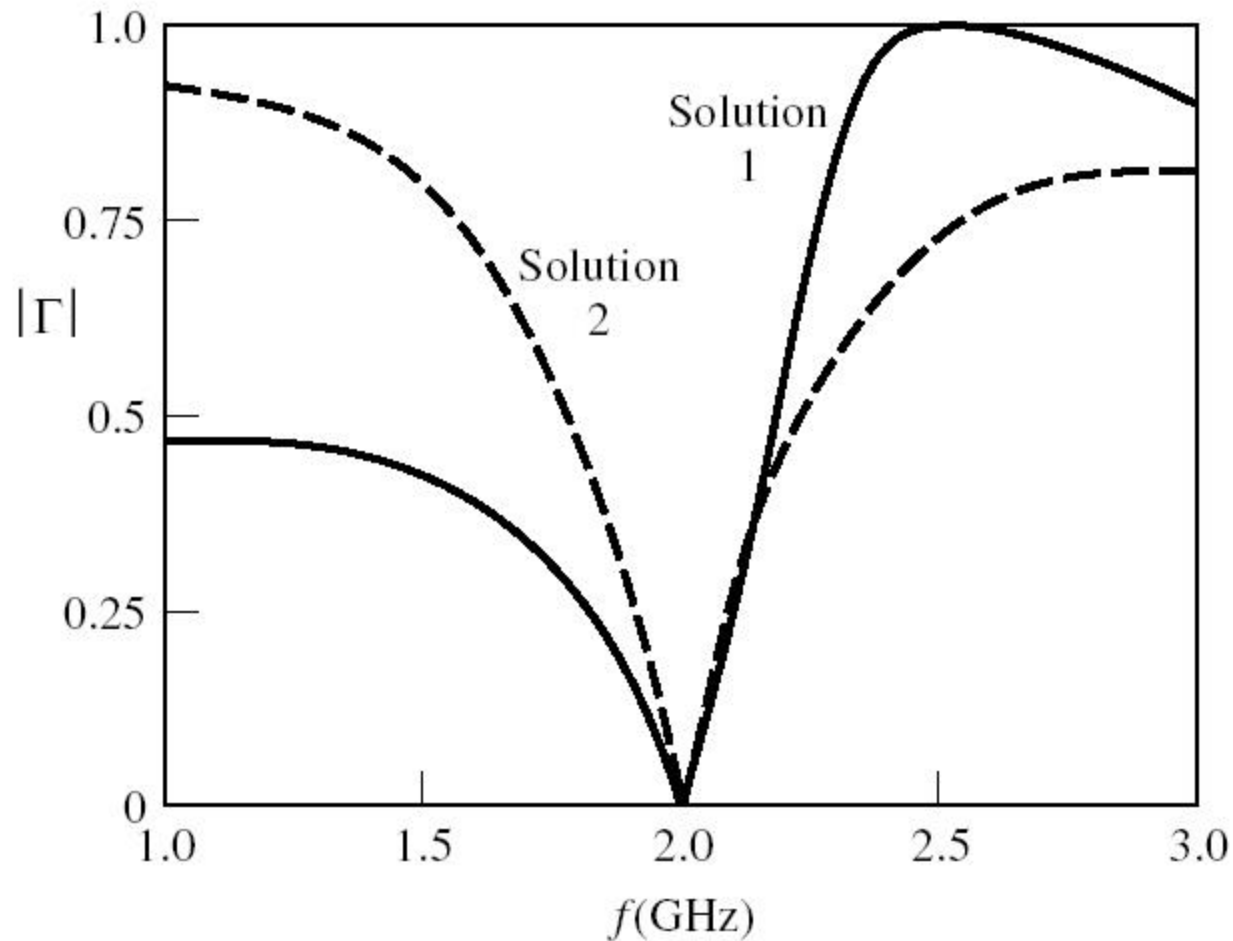


Solution 1

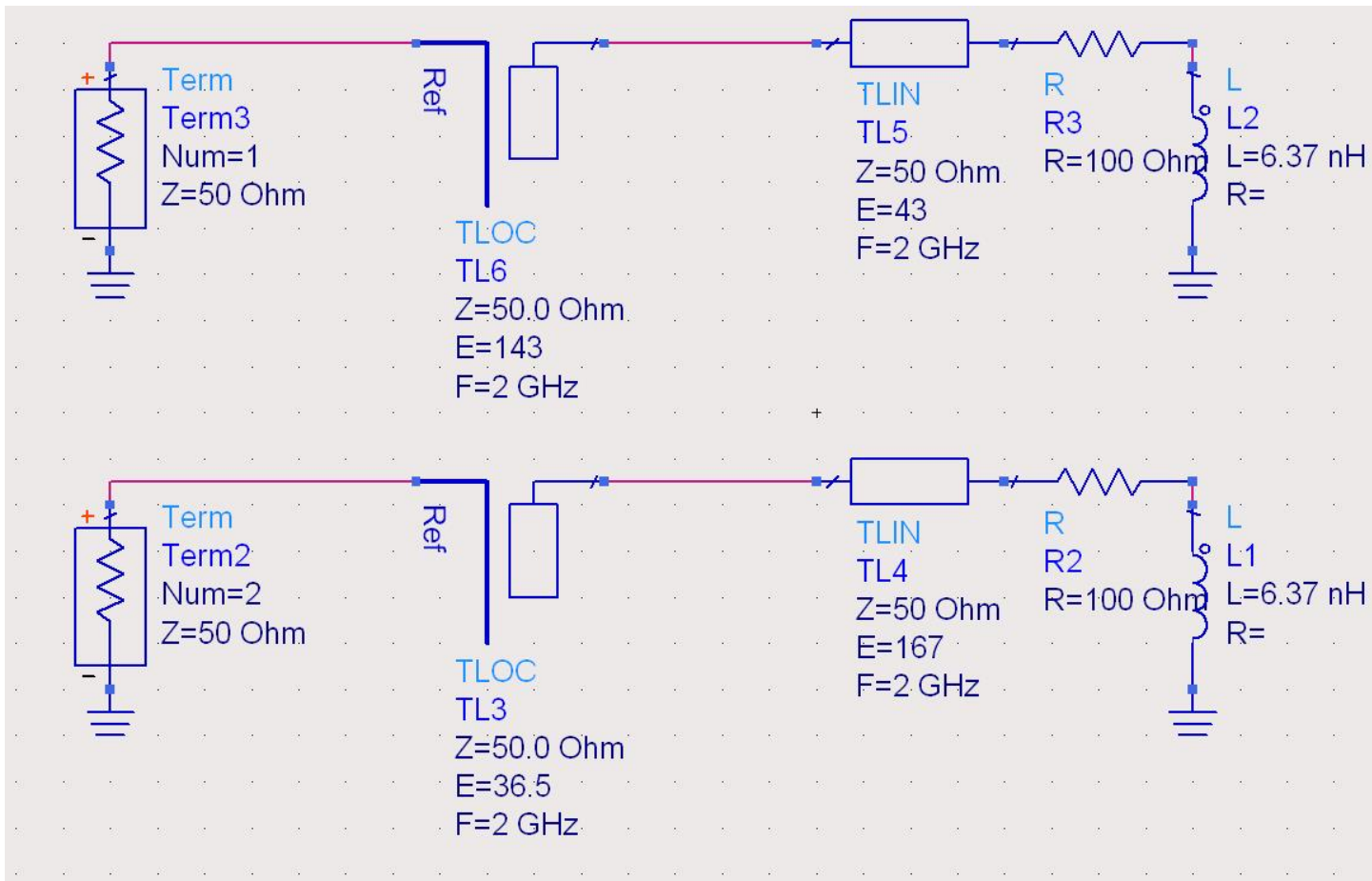


Solution 2

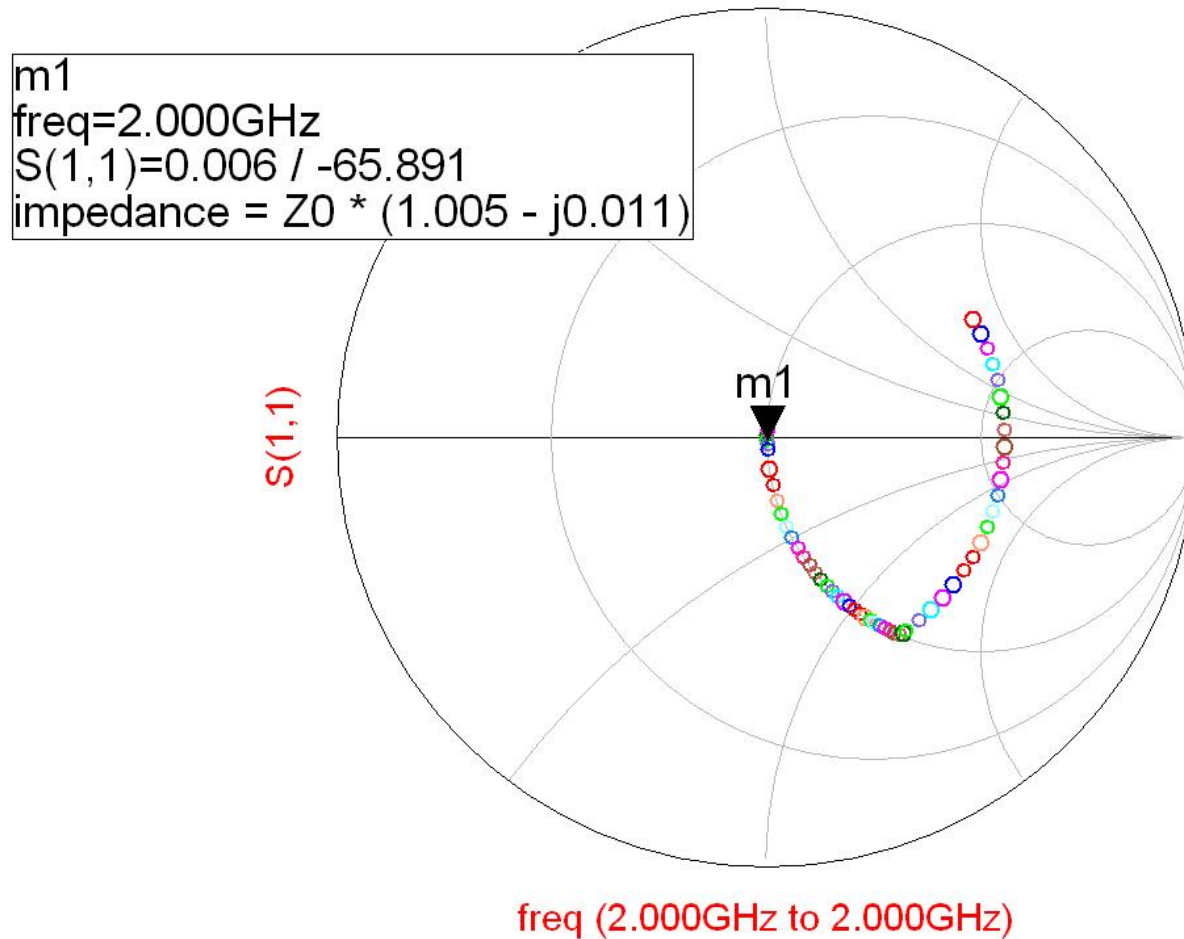
Example, Series Stub, oc.



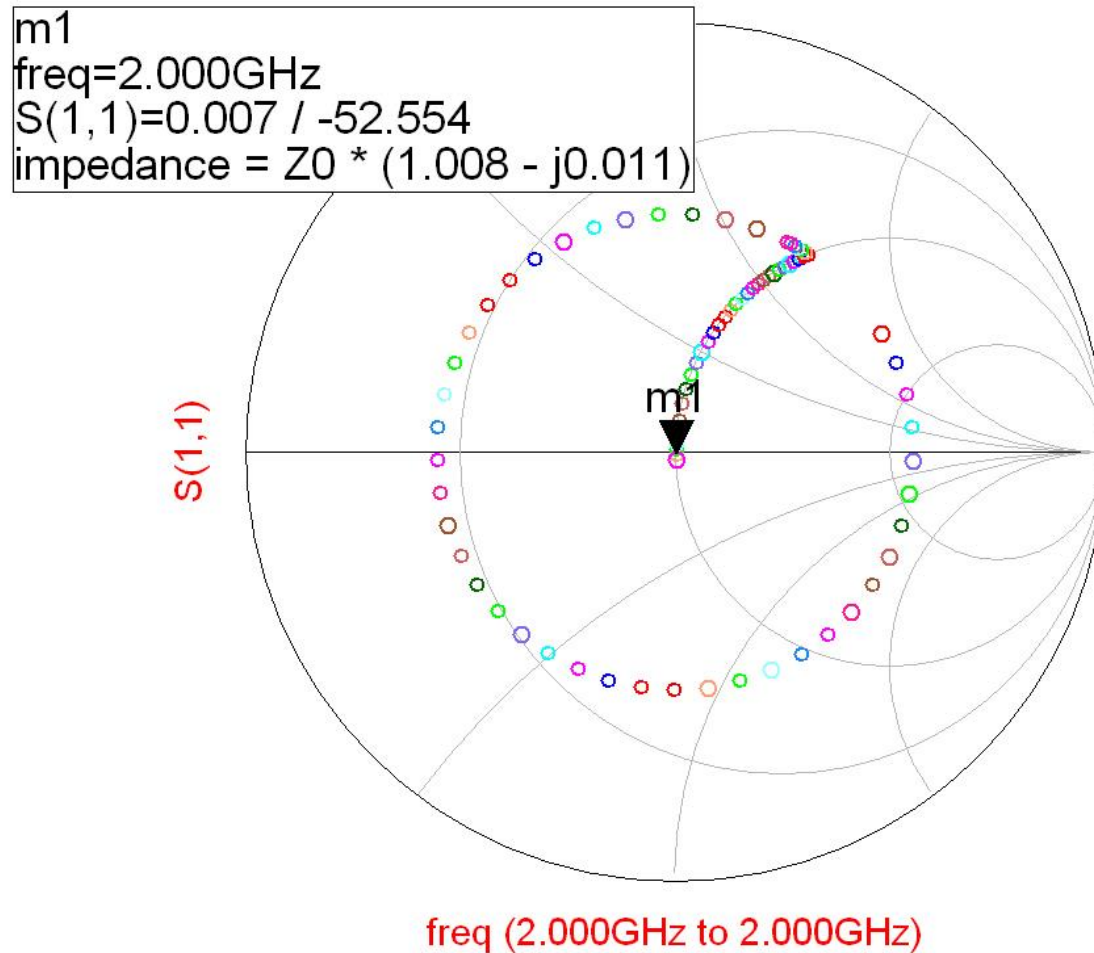
Example, Series Stub, oc.



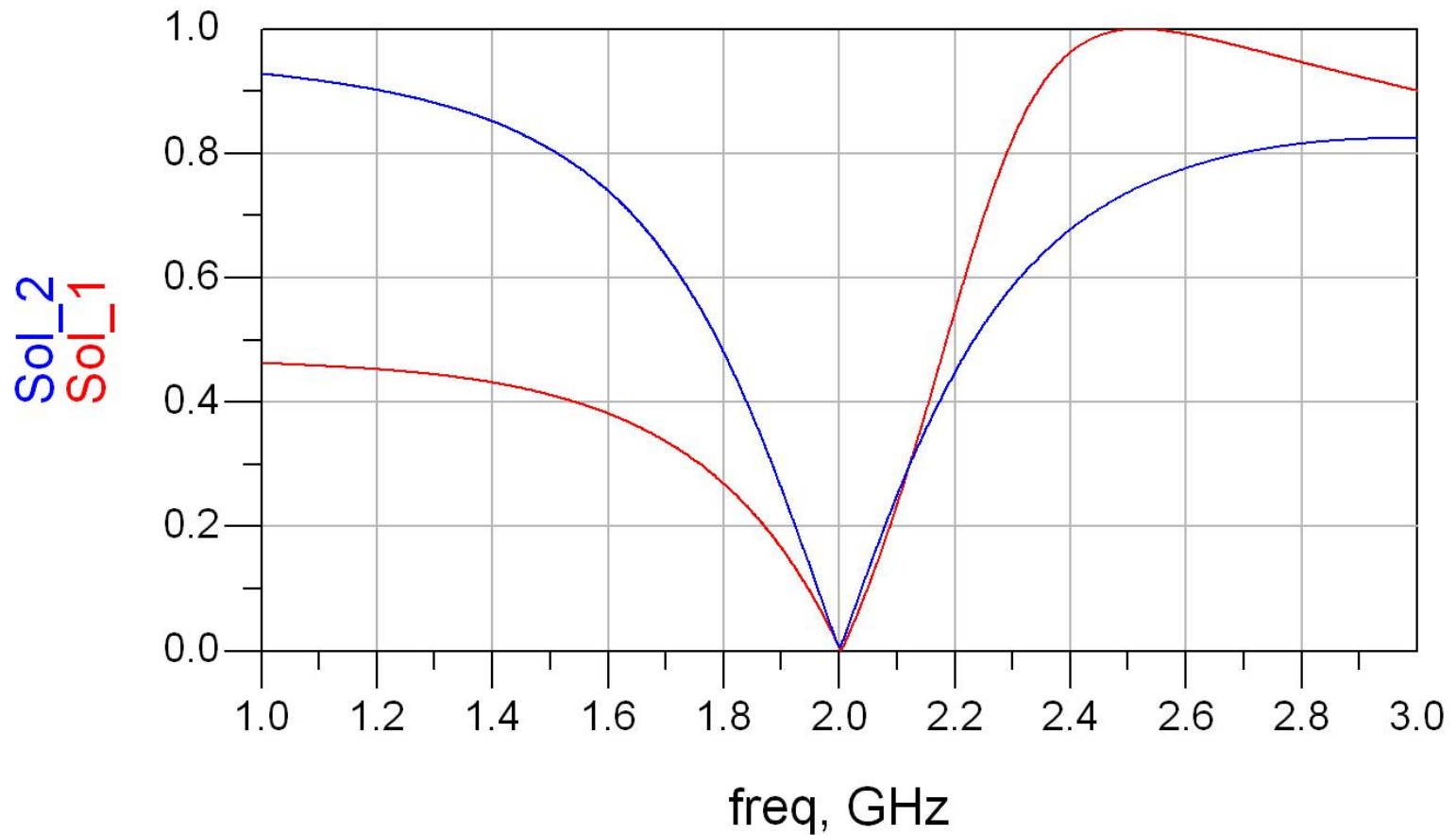
Example, Series Stub, oc.



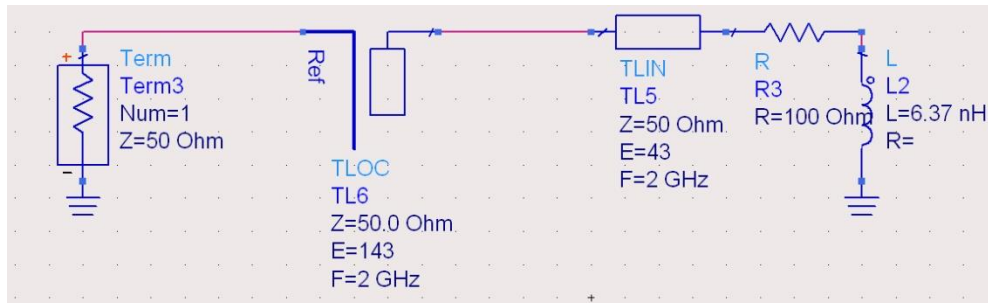
Example, Series Stub, oc.



Example, Series Stub, oc.



Example, Series Stub, oc.

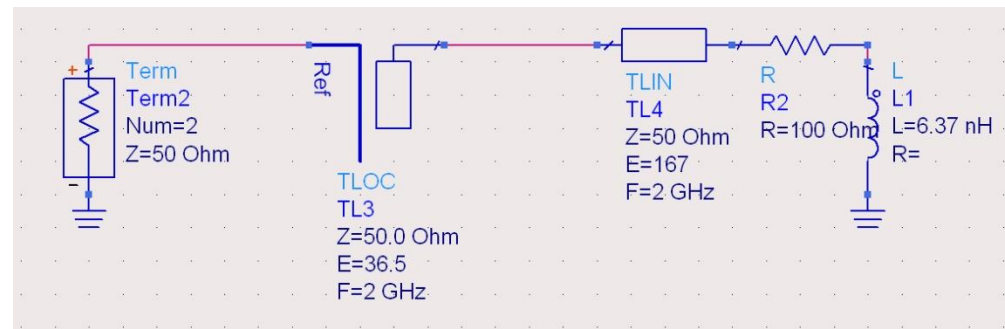


$$l_1 = \frac{43^\circ}{360^\circ} \cdot \lambda = 0.119 \cdot \lambda$$

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

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

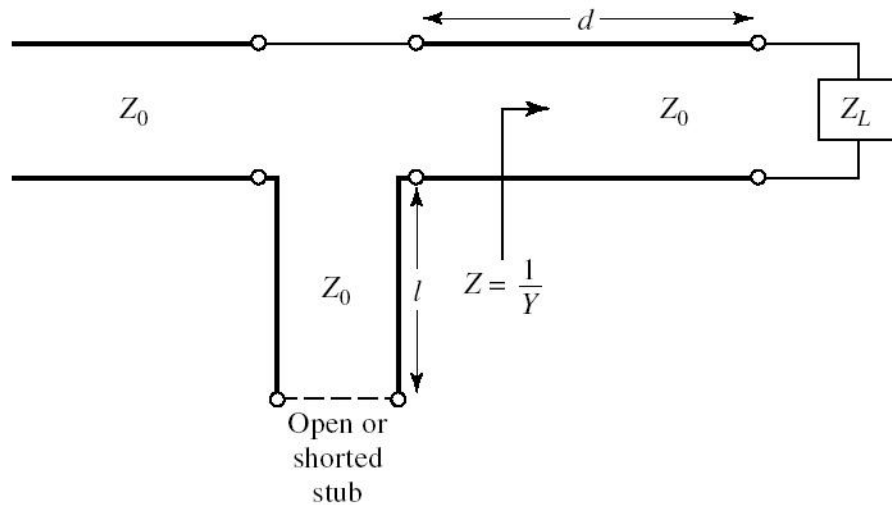
$$l_2 = \frac{36.5^\circ}{360^\circ} \cdot \lambda = 0.101 \cdot \lambda$$



Analytical solution

Series Stub

Analytical solution, impedances



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

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

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

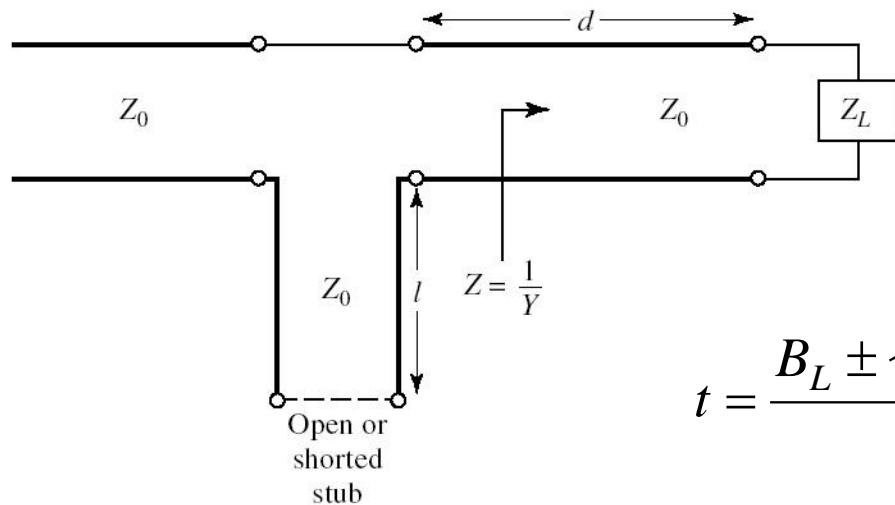
$$R = \frac{G_L \cdot (1 + t^2)}{G_L^2 + (G_L + Y_0 \cdot t)^2}$$

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

- d (which implies t) is chosen so that: $R = Z_0 = \frac{1}{Y_0}$

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

Analytical solution



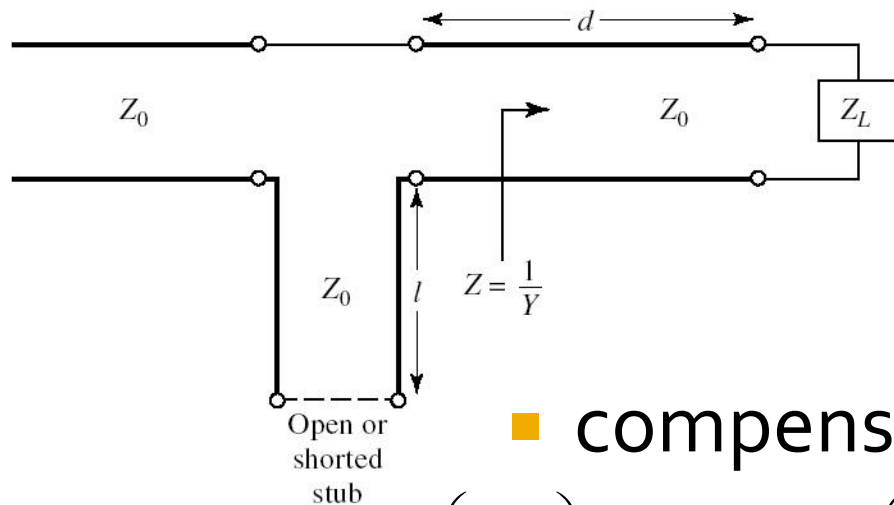
$$t = \frac{-B_L}{2 \cdot Y_0}, \quad G_L = Y_0$$

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

- second grade equation, 2 solutions possible
- d computed from t

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

Analytical solution



$$X_S = -X$$

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

- compensating reactance is:

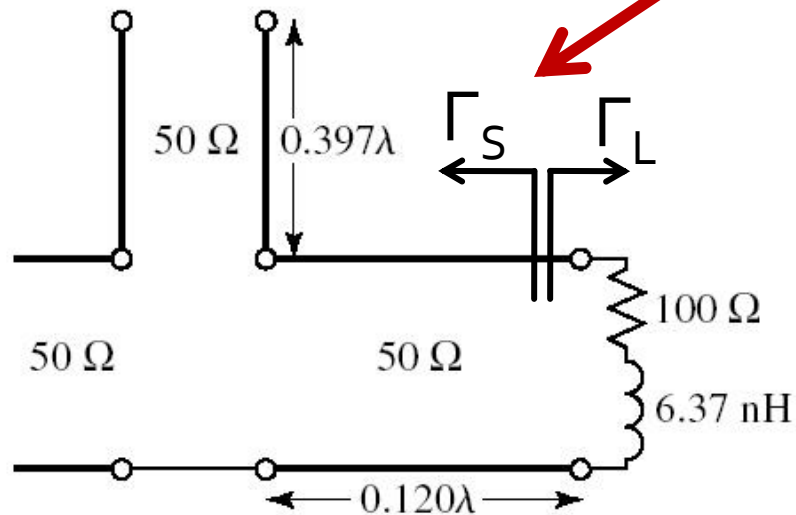
$$\frac{l_{sc}}{\lambda} = \frac{1}{2\pi} \cdot \arctan\left(\frac{X_S}{Z_0}\right) = \frac{-1}{2\pi} \cdot \arctan\left(\frac{X}{Z_0}\right)$$

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

- for **negative lengths** we add $\lambda/2$

Analytical solution, reflection coefficient

- load: $100\ \Omega$ series with $6.37\ \text{nH}$ at $2\ \text{GHz}$



Solution 1

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

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

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

- matching requires obtaining conjugate value for Γ

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

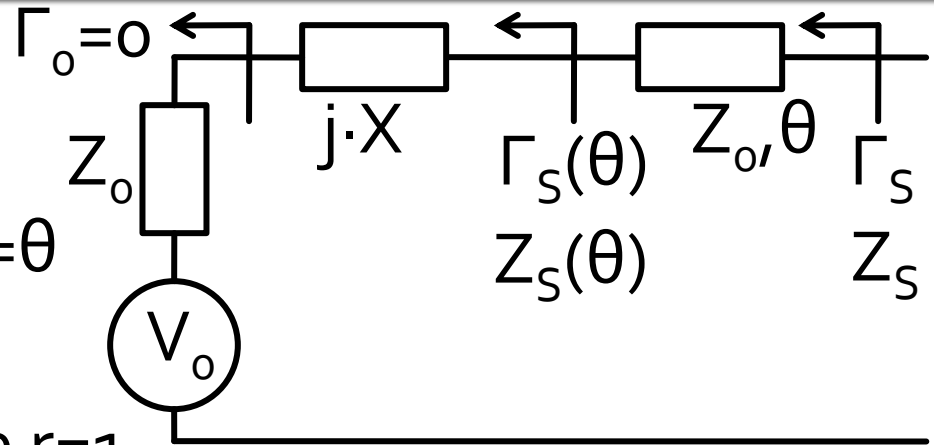
$$\Gamma_S = 0.555 \angle -29.92^\circ$$

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

Analytical solution, Γ

- series line

- electrical length $E = \beta \cdot l = \theta$
- moves the reflection coefficient on the circle $r=1$



- series stub

- electrical length $E = \beta \cdot l_{ss} = \theta_{ss}$
- moves the reflection coefficient to the center of the Smith Chart ($\Gamma_0 = 0$)

$$z_s = \frac{Z_s}{Z_0} = \frac{Z_s}{50\Omega}$$

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

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

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

A.S., Γ , series line, proof

- After the series line with electrical length θ :

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

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

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

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

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

A.S., Γ , series line. usage

- Equations for computing the series line θ :

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

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

- two solutions possible, in the $0 \div 180^\circ$ range (add $\lambda/2 \Leftrightarrow 180^\circ$ as needed)

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

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

$$\cos(\varphi + 2\theta) = 0.555 \Rightarrow (\varphi + 2\theta) = \pm 56.28^\circ$$

$$(-29.92^\circ + 2\theta) = \begin{cases} +56.28^\circ \\ -56.28^\circ \end{cases} \quad \theta = \begin{cases} +43.1^\circ \\ -13.2^\circ + 180^\circ = +166.8^\circ \end{cases}$$

A.S., Γ , series stub, proof

- Equations for computing the series stub θ_{ss} :

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

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

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

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

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

A.S., Γ , series stub, proof

- Equations for computing the series stub θ_{ss} :

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

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

- two cases:

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

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

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

A.S., Γ , series stub, proof

- We prefer (for microstrip) open circuited stub

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

- The normalized reactance to be introduced to achieve the match
 - $Z(\theta)$ is the impedance seen **towards** the source, Z_0 series with $j \cdot X$

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

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

Analytical solution, Γ , usage

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

- 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

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

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

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

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

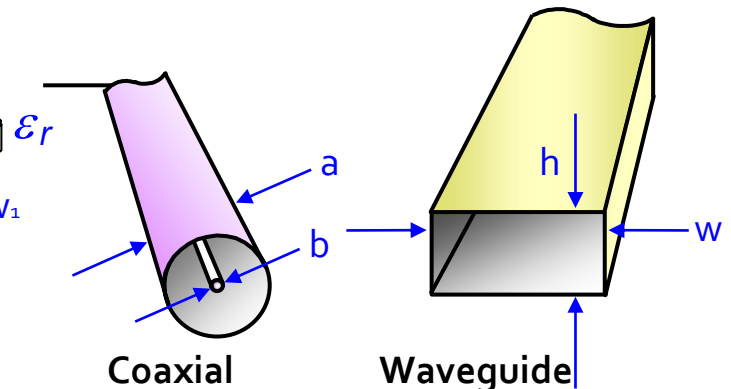
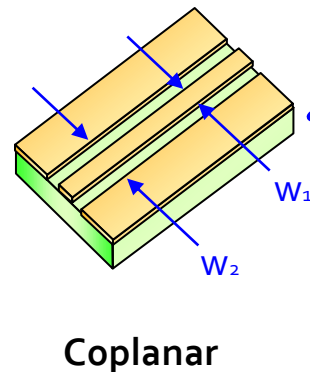
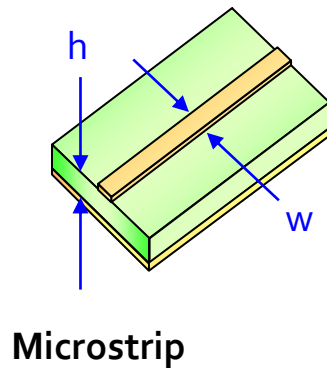


Single stub tuning

- We choose one of the 8 possible solutions (series/shunt, oc./sc.), taking into account:
 - physical dimensions (area occupied on chip/board)
 - sensitivity of the match on length error ($\Delta\Gamma/\Delta E$, $\Delta\Gamma/\Delta l$)
 - convenient frequency behavior (bandwidth)

Single stub tuning

- We choose one of the 8 possible solutions (series/shunt, oc./sc.), taking into account:
 - physical realizability (in the line technology we use)



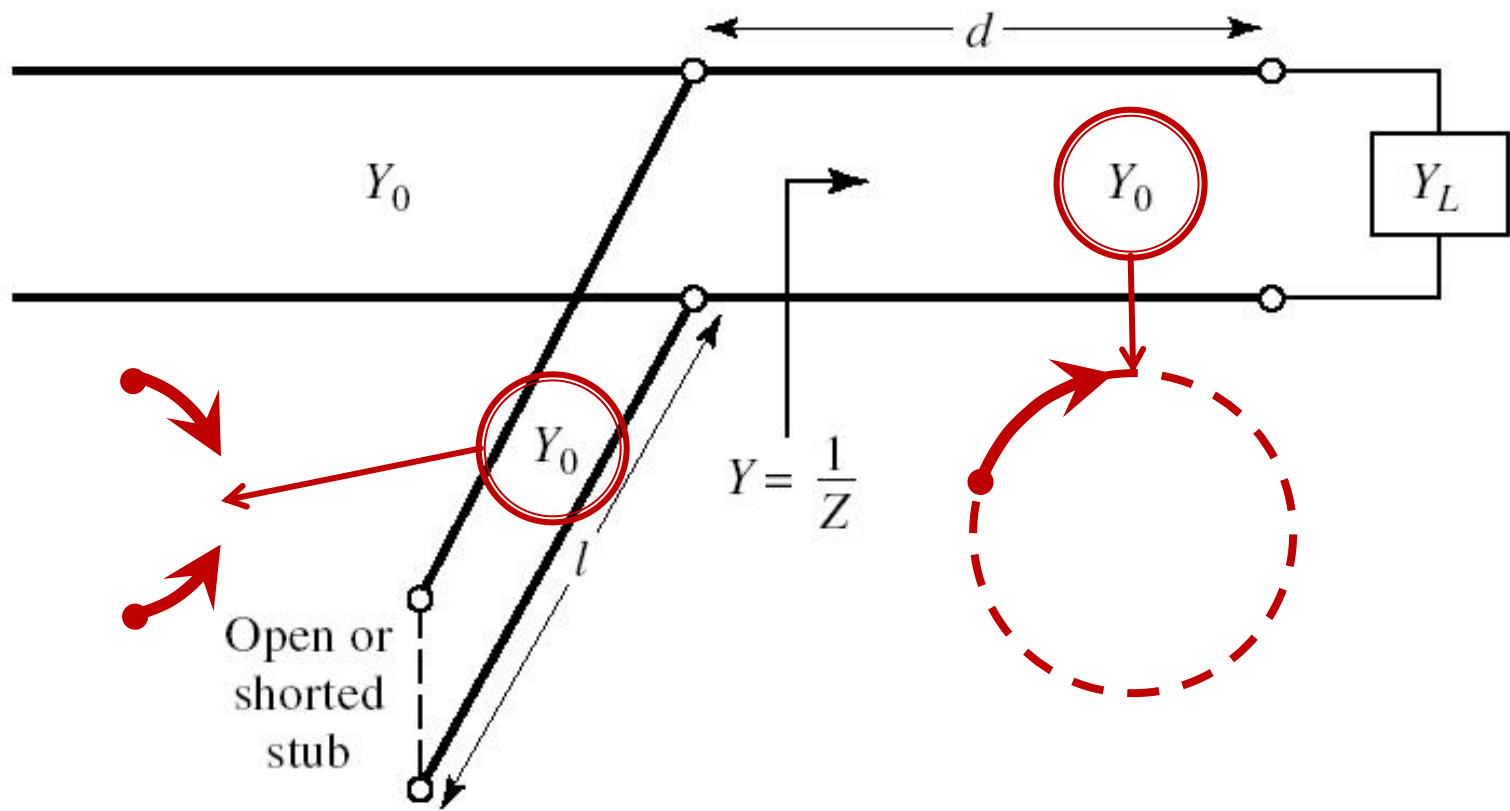
- Main disadvantage:
 - requires a **variable length of line** between the load and the stub

Analytical solutions

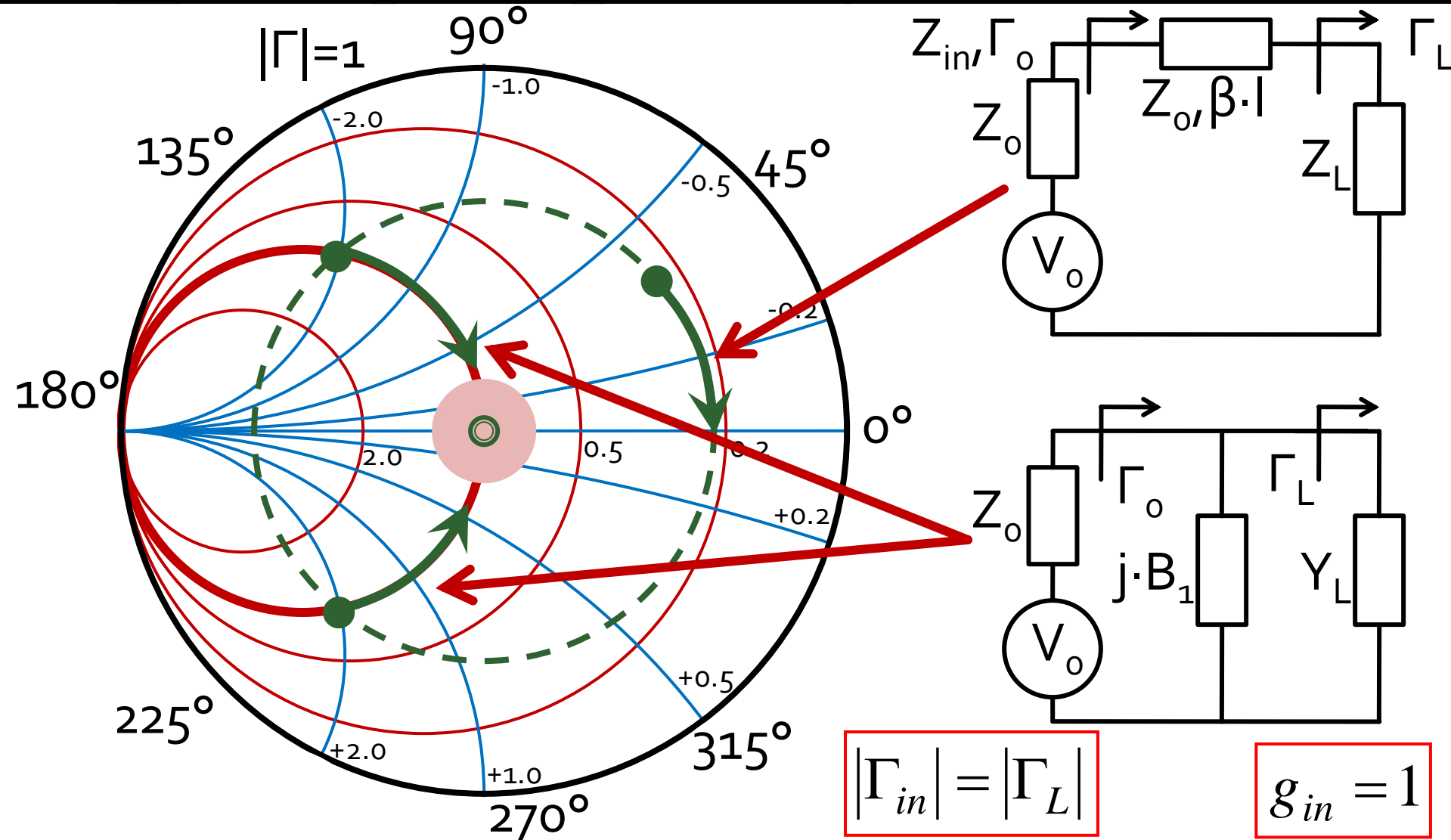
Exam / Project

Case 1, Shunt Stub

- Shunt Stub



Matching, series line + shunt susceptance



Analytical solution, usage

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

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

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

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

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

- **“+” solution** ↓

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

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

- **“-” solution** ↓

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

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

Analytical solution, usage

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

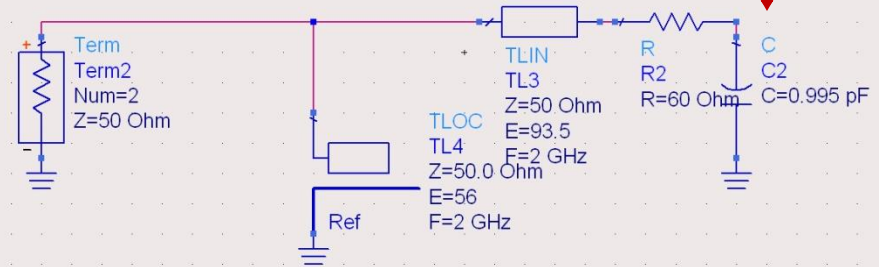
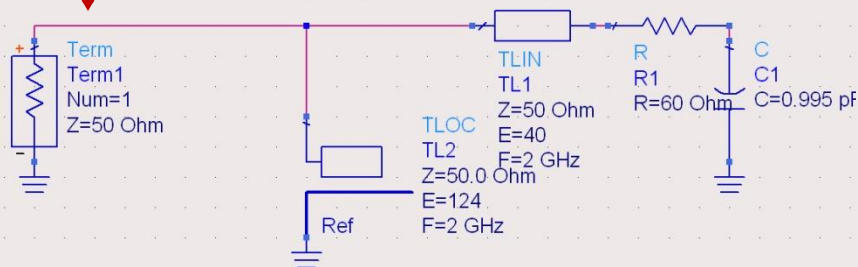
- We choose **one** of the two possible solutions
- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **shunt stub** equation

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

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

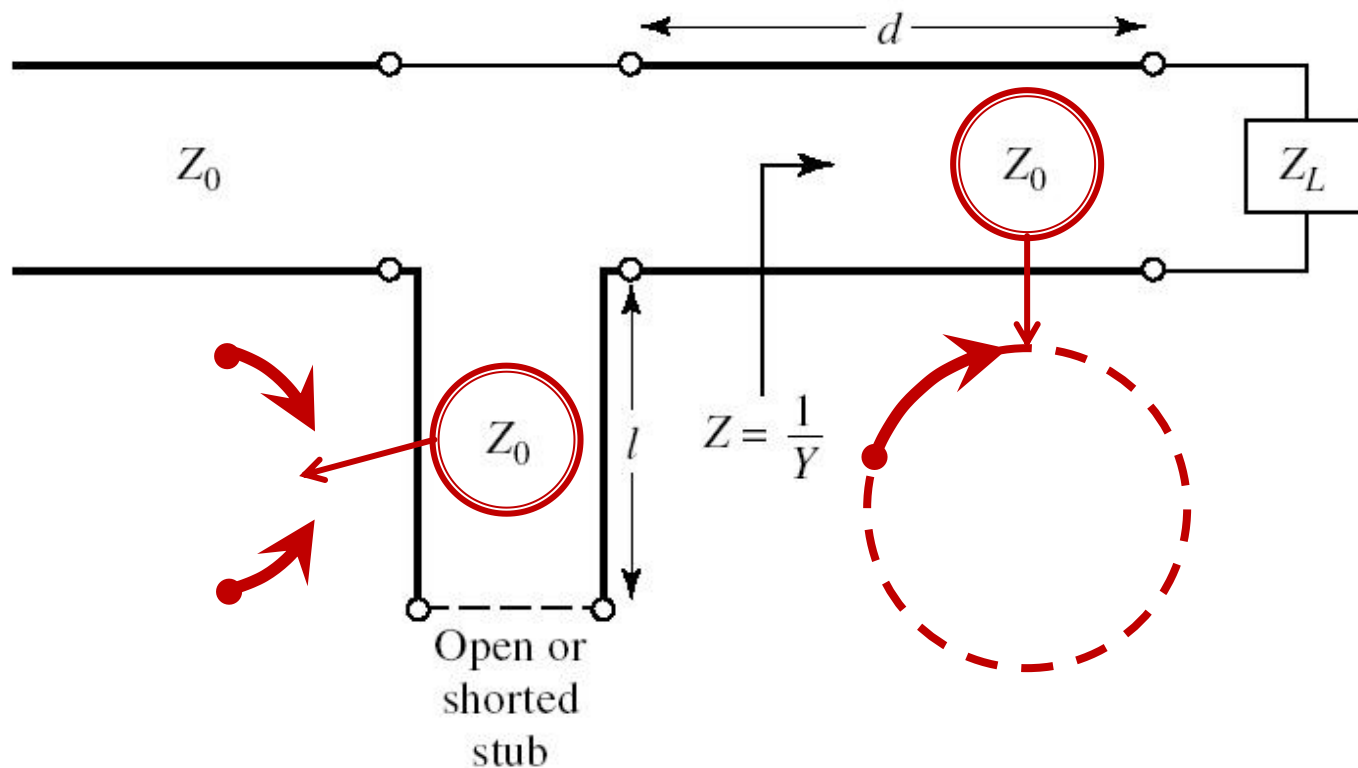
$$l_1 = \frac{93.4^\circ}{360^\circ} \cdot \lambda = 0.259 \cdot \lambda$$

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

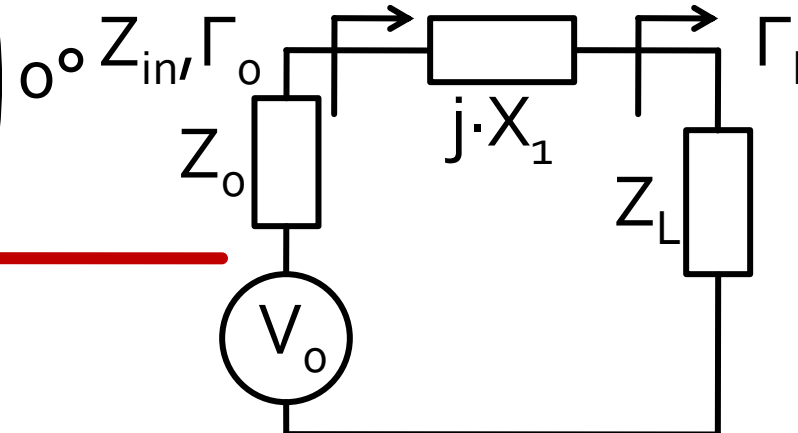
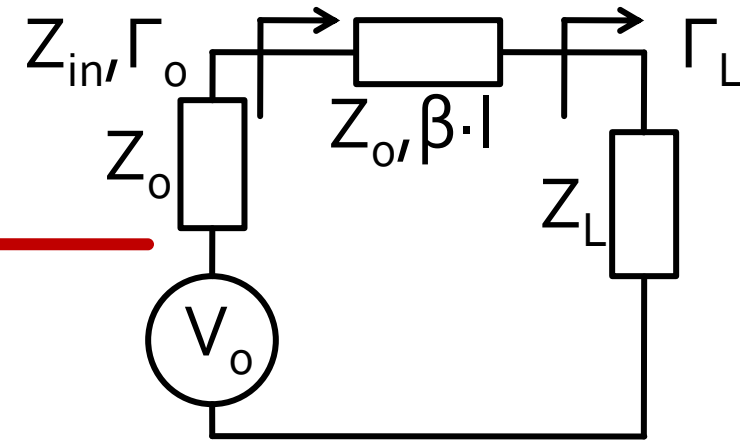
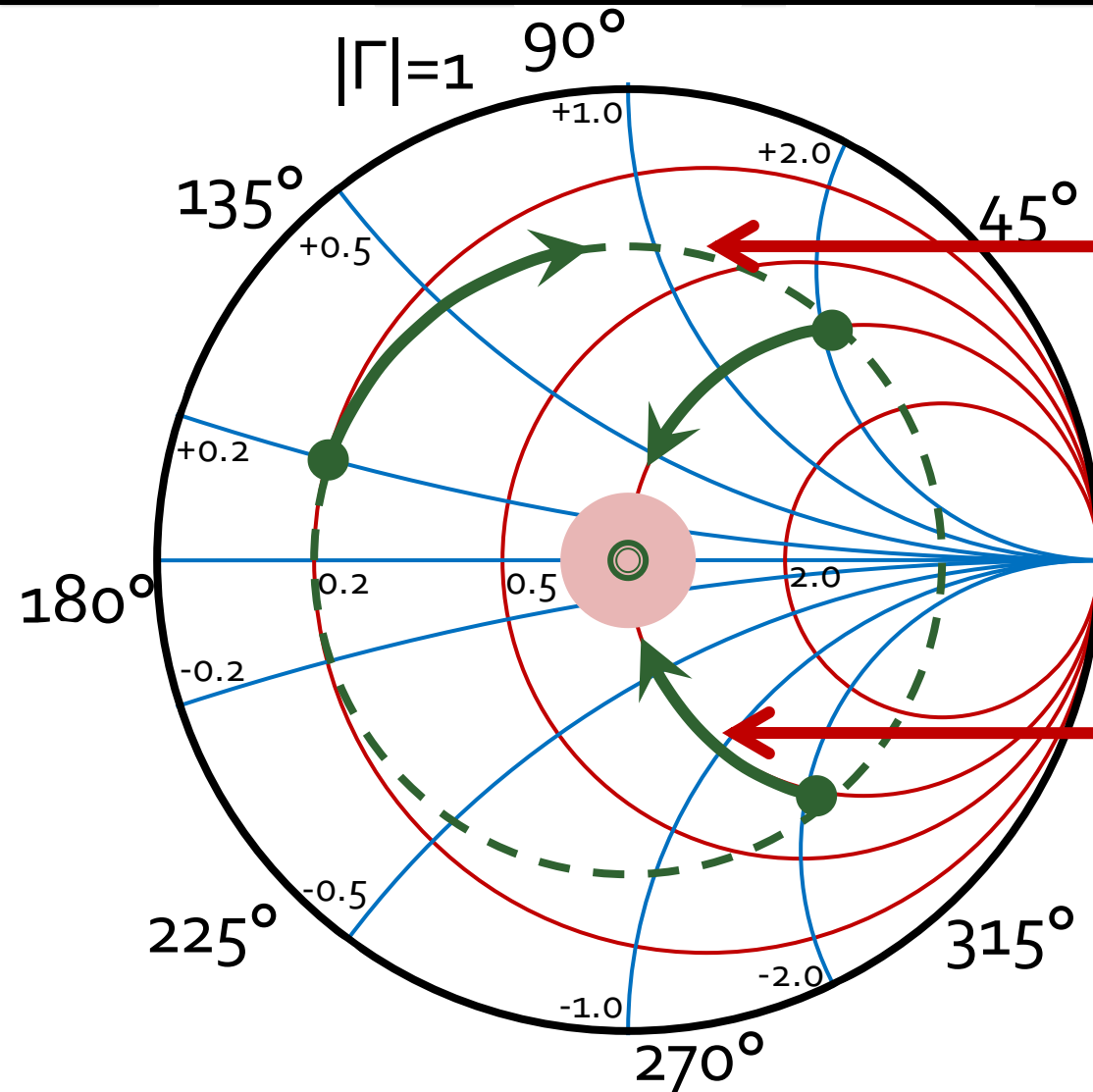


Case 2, Series Stub

- Series Stub
- difficult to realize in single conductor line technologies (microstrip)



Matching, series line + series reactance



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

$$r_{in} = 1$$

Analytical solution, usage

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

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

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

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

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

- **"+" solution** ↓

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

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

- **"-" solution** ↓

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

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

Analytical solution, usage

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

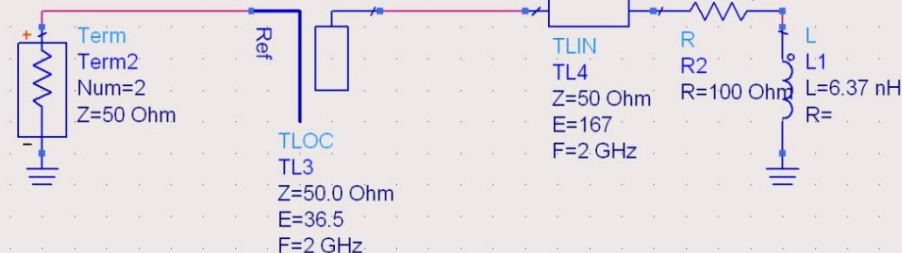
- We choose **one** of the two possible solutions
- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **series stub** equation

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

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

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

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



Stub, observations

- adding or subtracting **180°** ($\lambda/2$) doesn't change the result (full rotation around the Smith Chart)

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

- if the lines/stubs result with **negative** "length"/ "electrical length" we add $\lambda/2$ / 180° to obtain physically realizable lines
- adding or subtracting **90°** ($\lambda/4$) change the stub impedance:

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

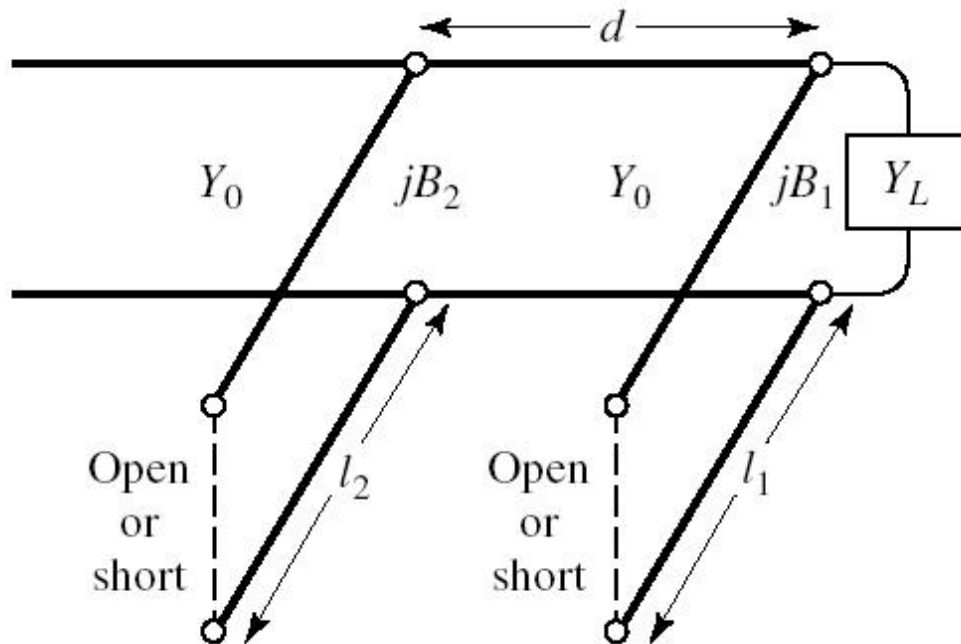
- for the stub we can add or subtract 90° ($\lambda/4$) while in the same time changing **open-circuit** \Leftrightarrow **short-circuit**

Double stub tuning

Adaptarea cu doua sectiuni de linie

Double stub tuning

- Double stub tuning
- uses two tuning stubs in fixed positions (a fixed length of line between the stubs)



Double stub tuning

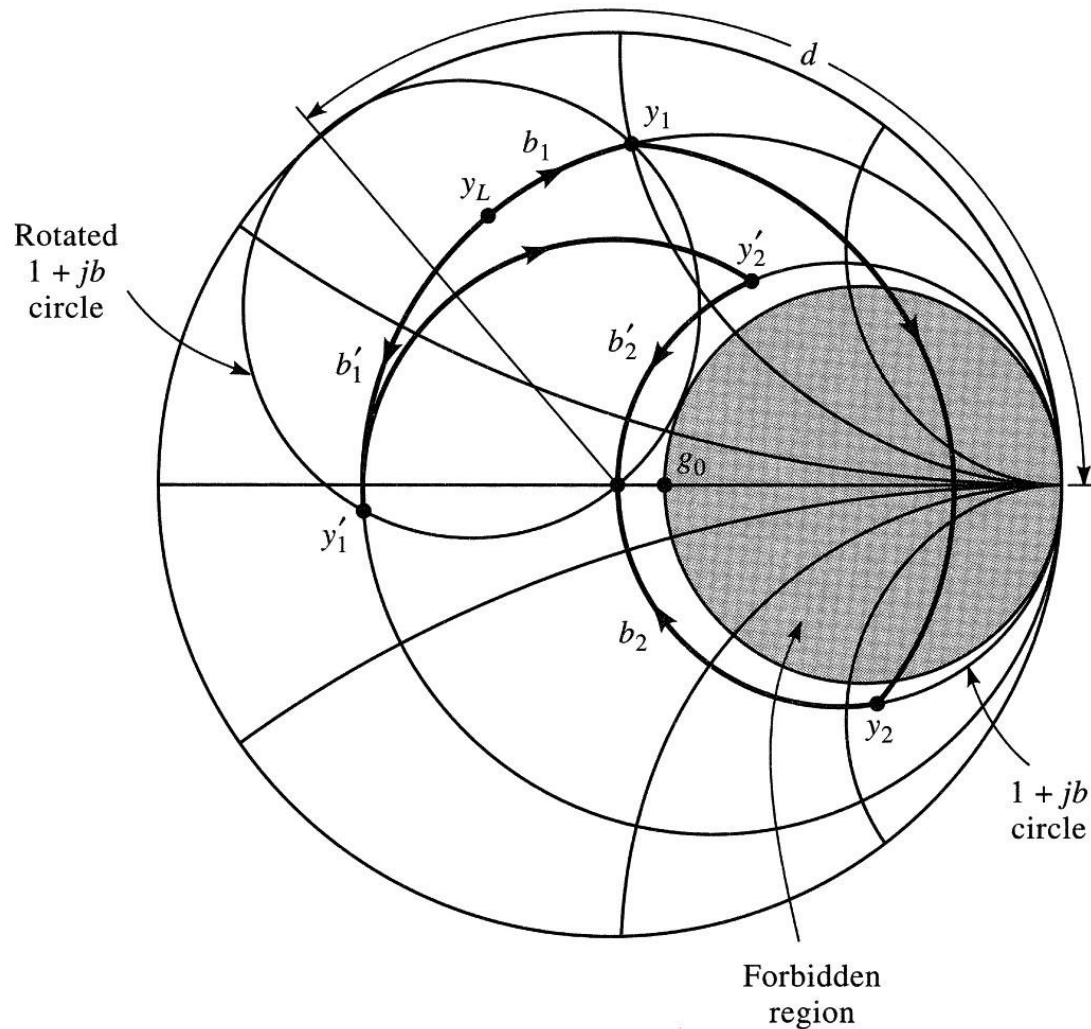
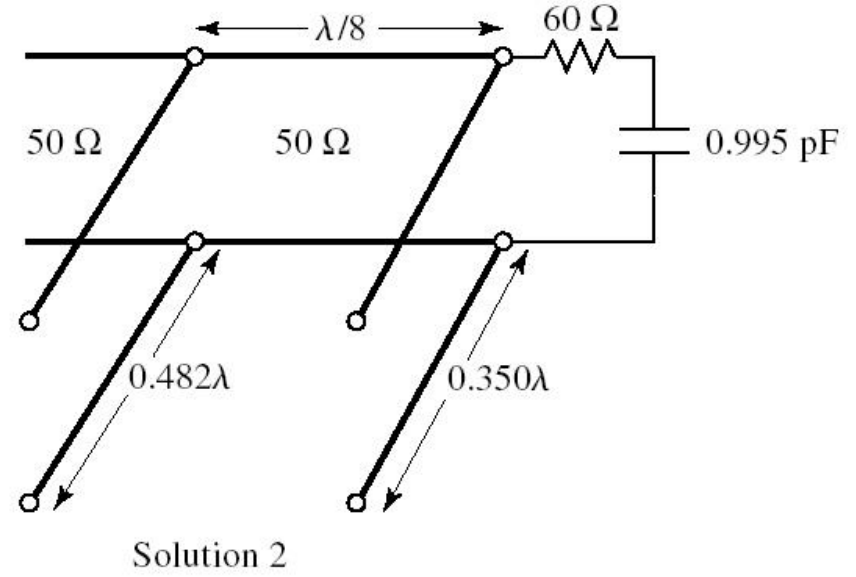
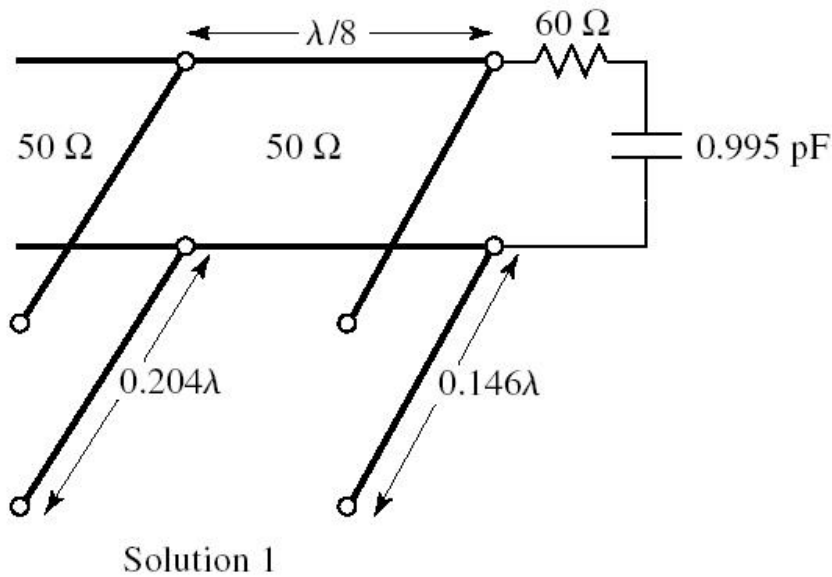


Figure 5.8
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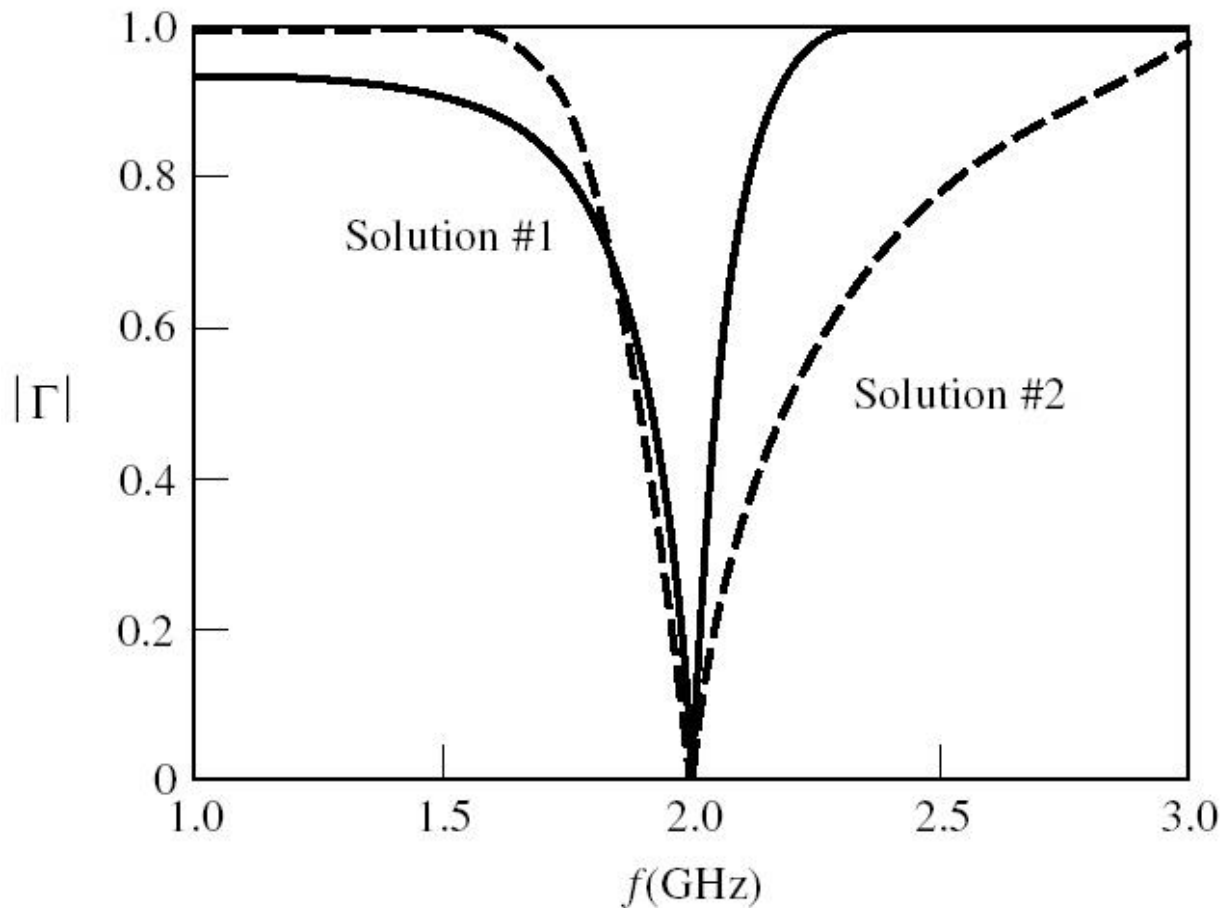
Double stub tuning

- same load: $60\ \Omega$ series with $0.995\ \text{pF}$ at $2\ \text{GHz}$
- two possible solutions



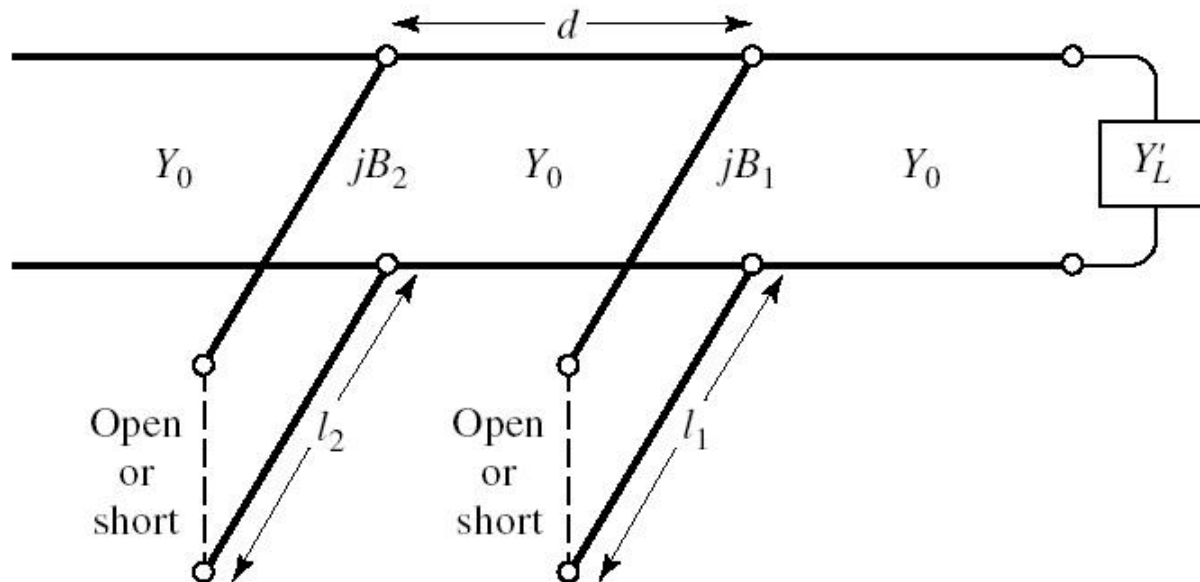
Double stub tuning

- two possible solutions

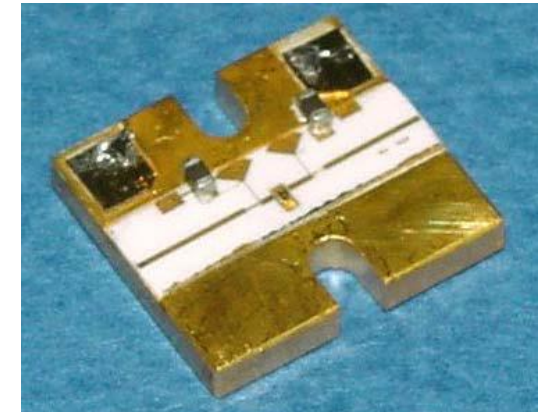
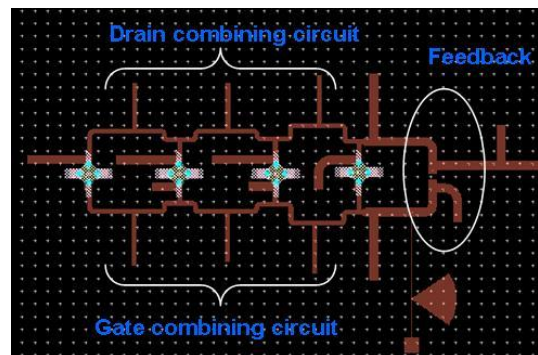
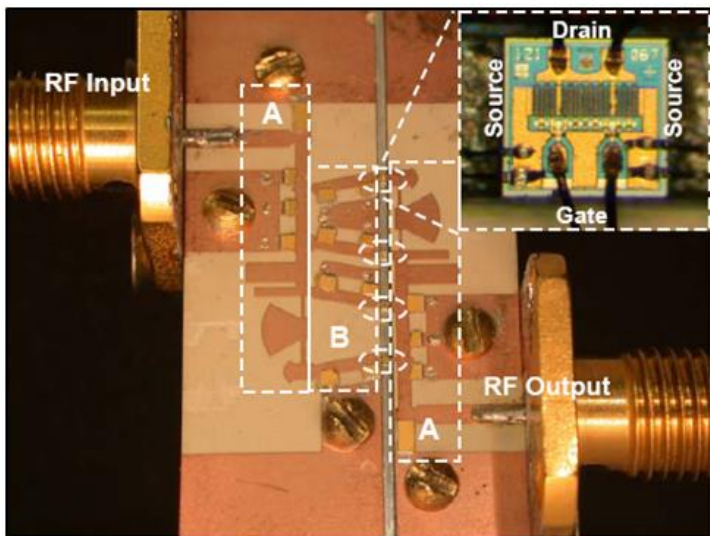
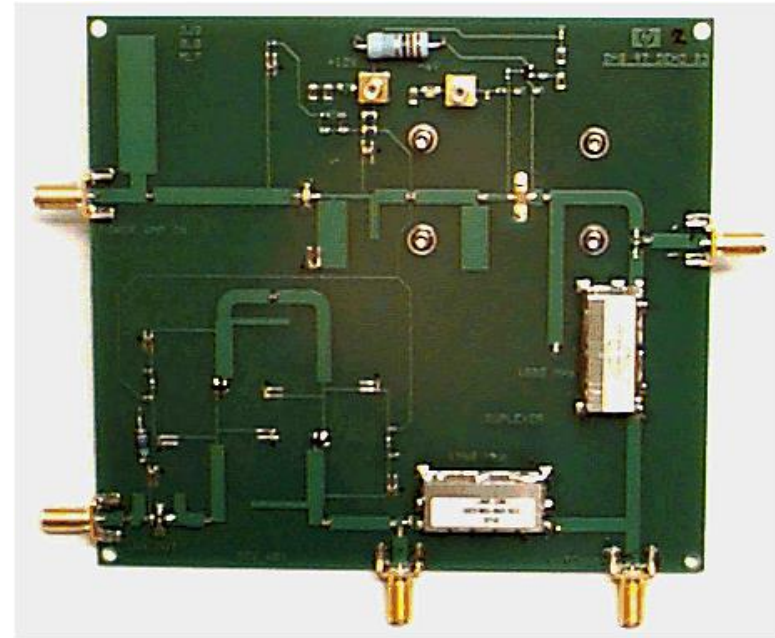
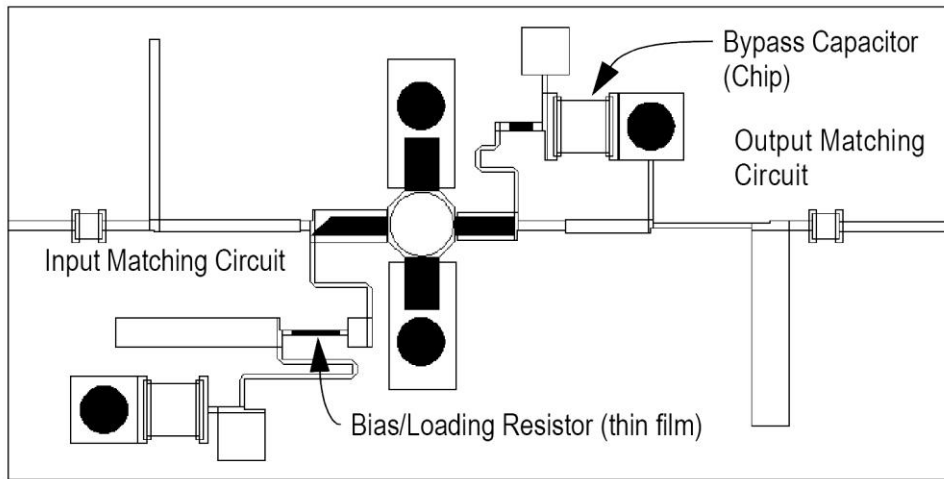


Double stub tuning

- Typically $d = \lambda/8$ or $d = 3\lambda/8$
 - $d \rightarrow 0$ and $d \rightarrow \lambda/2$ offer frequency sensitive solutions
- **Not possible** for every load
 - unless we can add a specific length of line between the load and the first stub

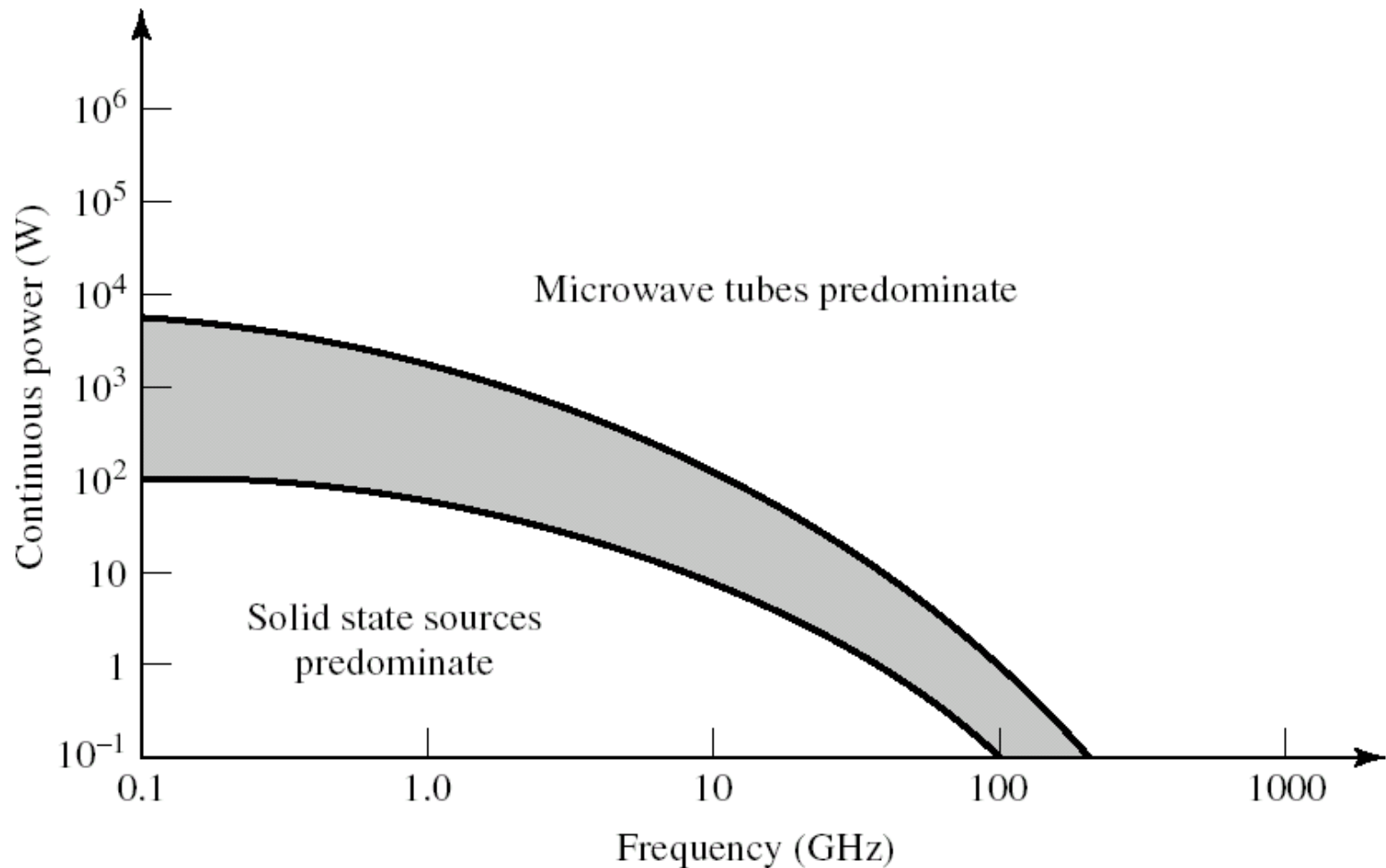


Impedance Matching with Stubs

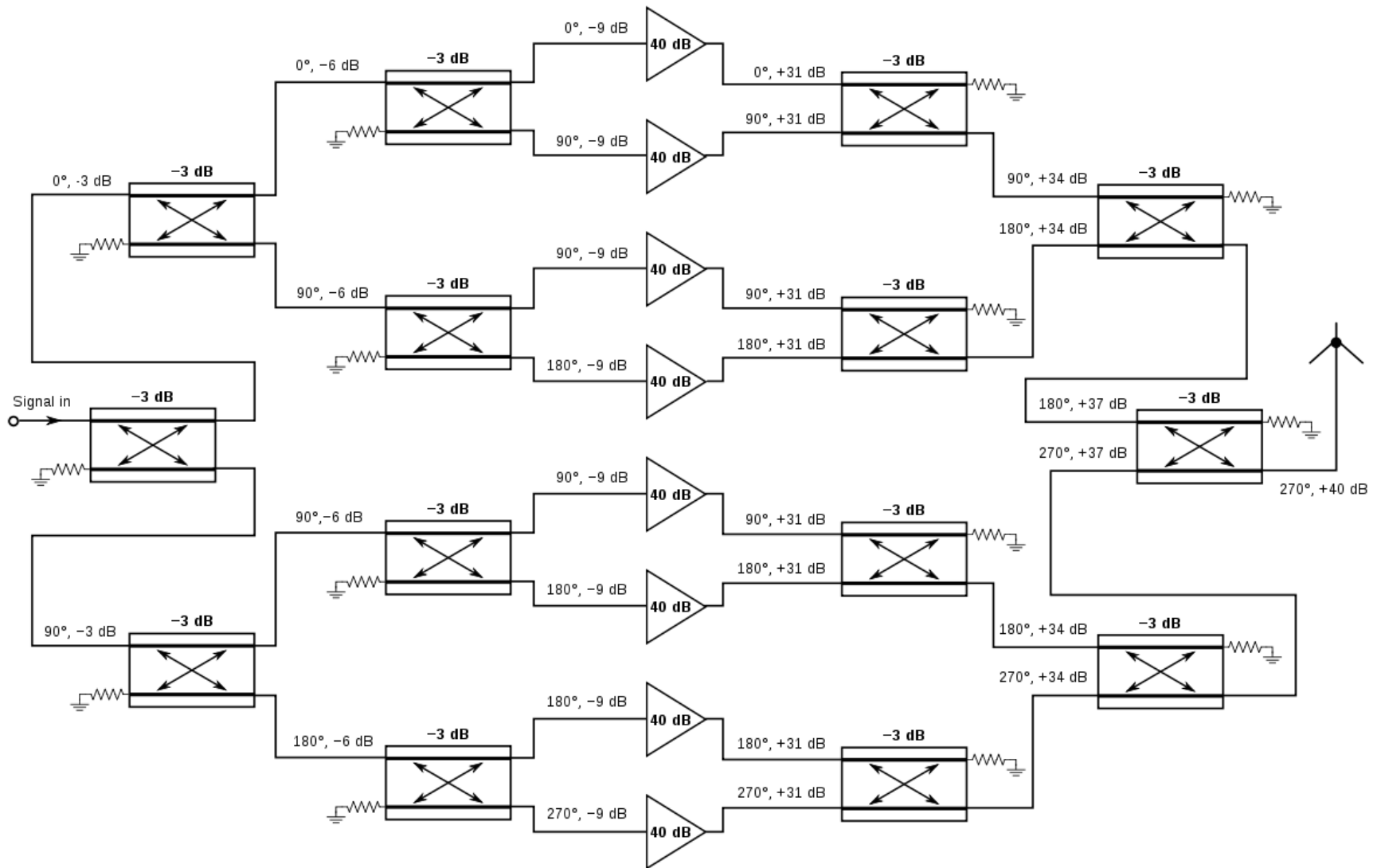


Microwave Amplifiers

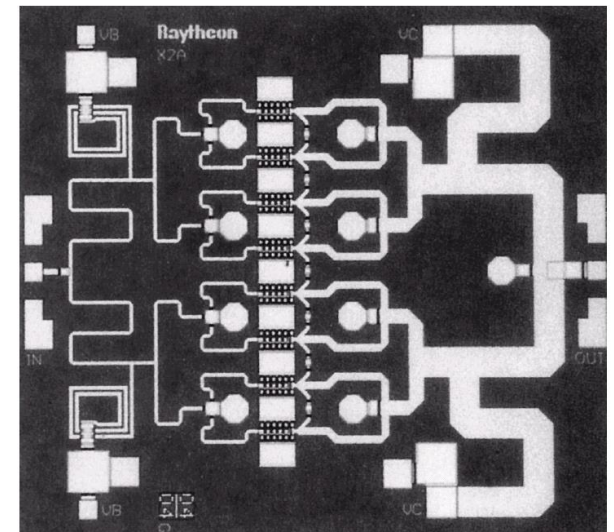
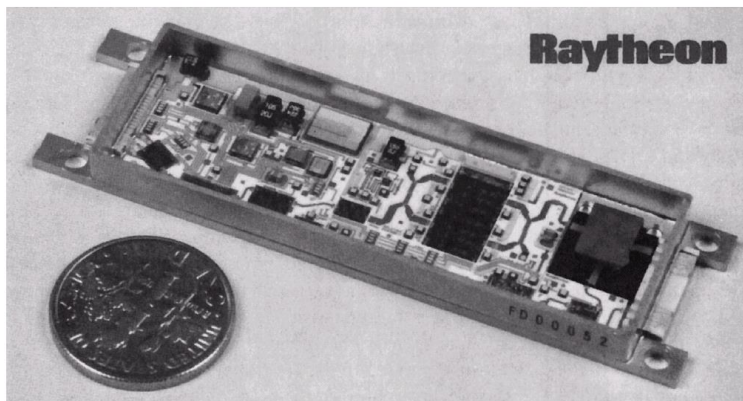
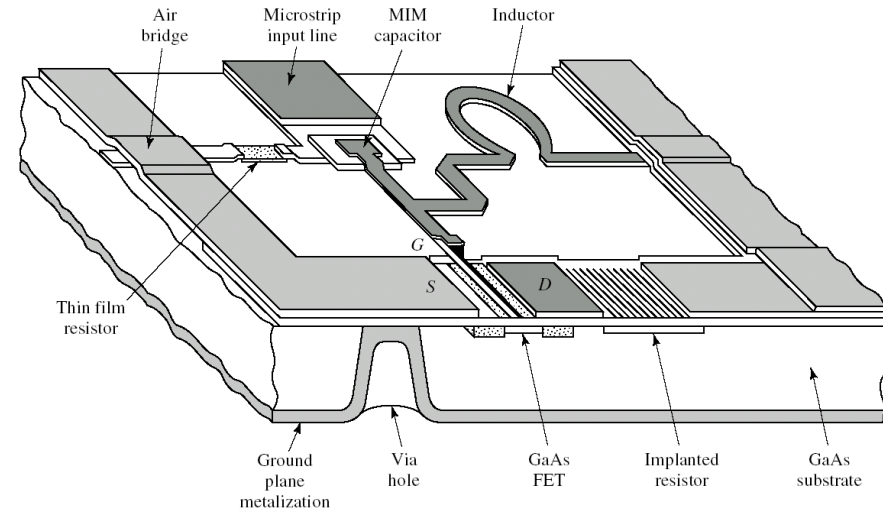
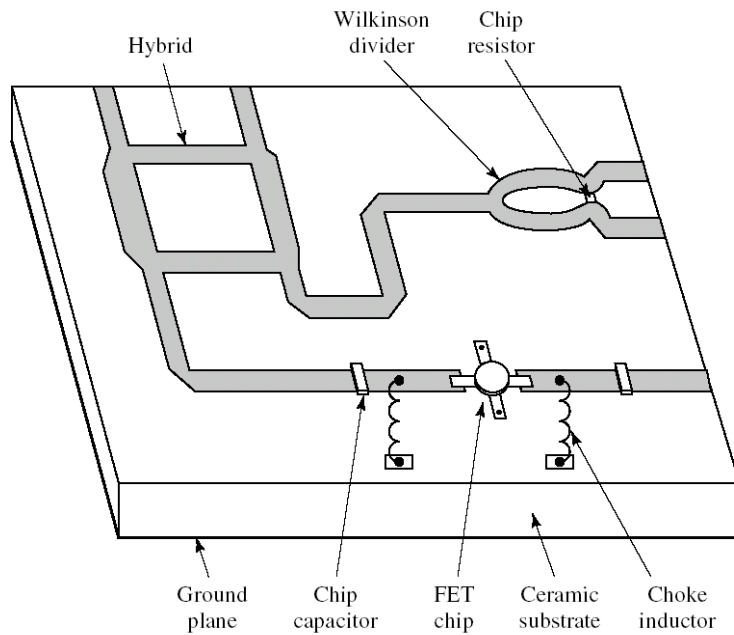
Microwave Amplifiers



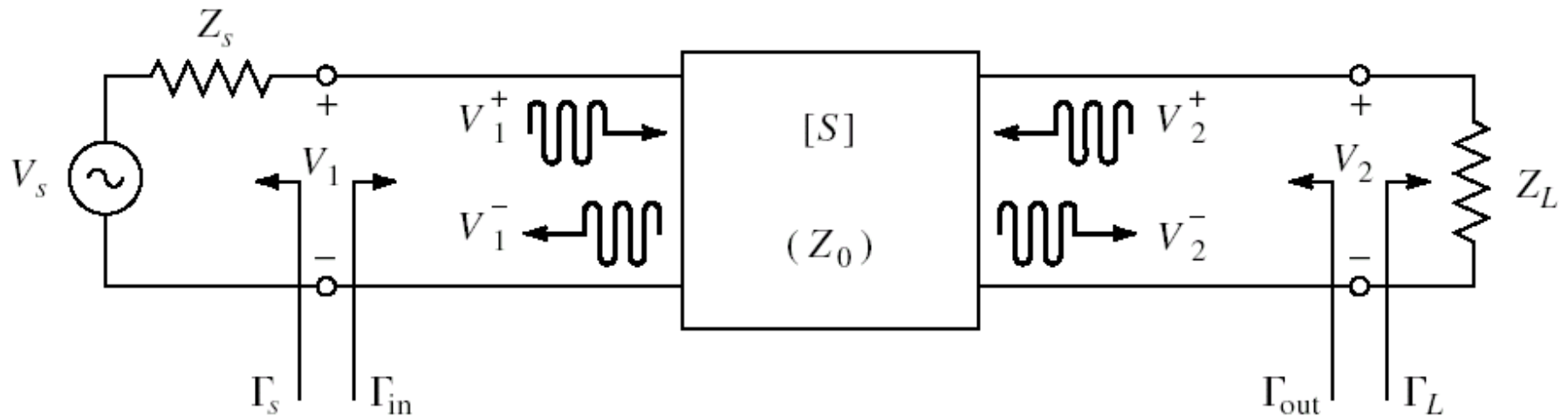
Balanced amplifiers



Microwave Integrated Circuits



Amplifier as two-port



- Characterized with S parameters
- normalized at Z_0 (implicit 50Ω)
- Datasheets: S parameters for specific bias conditions

Datasheets



NE46100 / NE46134

NPN MEDIUM POWER MICROWAVE TRANSISTOR

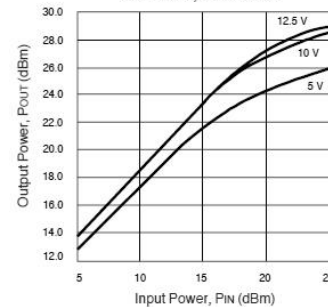
FEATURES

- HIGH DYNAMIC RANGE
- LOW IM DISTORTION: -40 dBc
- HIGH OUTPUT POWER : 27.5 dBm at TYP
- LOW NOISE: 1.5 dB TYP at 500 MHz
- LOW COST

DESCRIPTION

The NE461 series of NPN silicon epitaxial bipolar transistors is designed for medium power applications requiring high dynamic range. This device exhibits an outstanding combination of high gain and low intermodulation distortion, as well as low noise figure. The NE461 series offers excellent performance and reliability at low cost through titanium, platinum, gold metallization system and direct nitride passivation of the surface of the chip. Devices are available in a low cost surface mount package (SOT-89) as well as in chip form.

NE46134
TYPICAL OUTPUT POWER
vs. INPUT POWER
f = 1.0 GHz, I_c = 100 mA



ELECTRICAL CHARACTERISTICS (T_A = 25°C)

SYMBOLS	PARAMETERS AND CONDITIONS	UNITS	NE46100			NE46134 2SC4536 34		
			MIN	TYP	MAX	MIN	TYP	MAX
f _T	Gain Bandwidth Product at V _{CE} = 10 V, I _C = 100 mA	GHz		5.5			5.5	
N _{FMN}	Minimum Noise Figure ³ at V _{CE} = 10 V, I _C = 50 mA, 500 MHz V _{CE} = 10 V, I _C = 50 mA, 1 GHz	dB		1.5			1.5	
GL	Linear Gain, V _{CE} = 12.5 V, I _C = 100 mA, 2.0 GHz V _{CE} = 12.5 V, I _C = 100 mA, 1.0 GHz	dB		9.0			8.0	
IS _{21E1} ²	Insertion Power Gain at 10 V, 50 mA, f = 1.0 GHz	dB		10.0		5.5	7.0	
h _{FE}	DC Current Gain ² at V _{CE} = 10 V, I _C = 50 mA			40		200	40	200
I _{CB0}	Collector Cutoff Current at V _{CB} = 20 V, I _E = 0 mA	μA				5.0		5.0
I _{EB0}	Emitter Cutoff Current at V _{EB} = 2 V, I _C = 0 mA	μA				5.0		5.0
P _{1dB}	Output Power at 1 dB Compression, V _{CE} = 12.5 V, I _C = 100 mA, 2.0 GHz V _{CE} = 12.5 V, I _C = 100 mA, 1.0 GHz	dBm	27.0					27.5
IM ₃	Intermodulation Distortion, 10 V, 100 mA, F ₁ = 1.0 GHz, F ₂ = 0.99 GHz	dBm						

Datasheets

NE46100

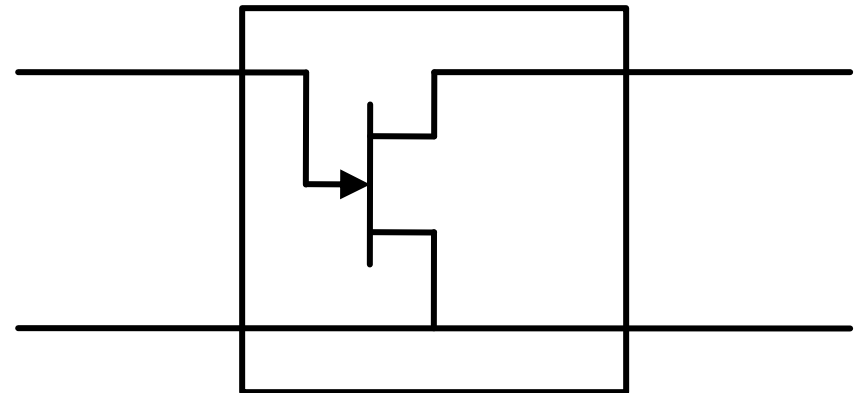
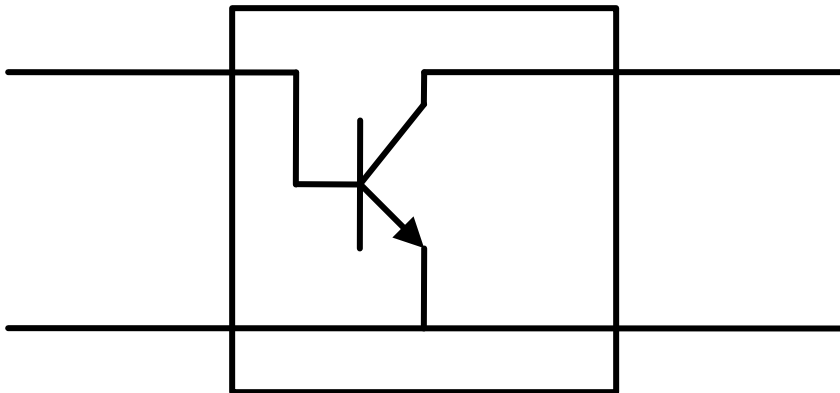
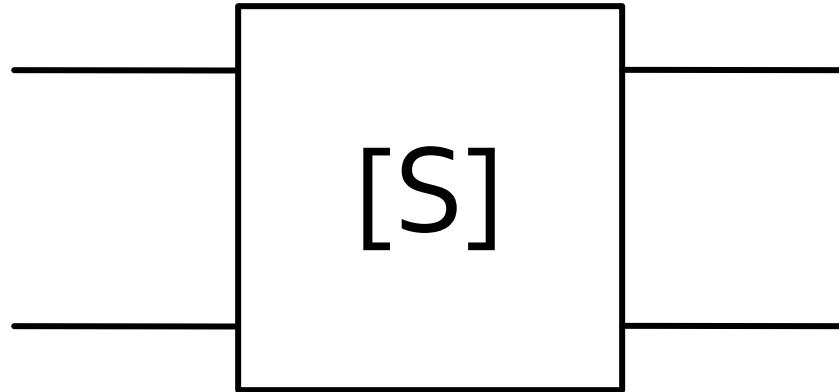
VCE = 5 V, Ic = 50 mA

FREQUENCY (MHz)	S11		S21		S12		S22		K	MAG ² (dB)
	MAG	ANG	MAG	ANG	MAG	ANG	MAG	ANG		
100	0.778	-137	26.776	114	0.028	30	0.555	-102	0.16	29.8
200	0.815	-159	14.407	100	0.035	29	0.434	-135	0.36	26.2
500	0.826	-177	5.855	84	0.040	38	0.400	-162	0.75	21.7
800	0.827	176	3.682	76	0.052	43	0.402	-169	0.91	18.5
1000	0.826	173	2.963	71	0.058	47	0.405	-172	1.02	16.3
1200	0.825	170	2.441	66	0.064	47	0.412	-174	1.08	14.0
1400	0.820	167	2.111	61	0.069	47	0.413	-176	1.17	12.4
1600	0.828	165	1.863	57	0.078	54	0.426	-177	1.15	11.4
1800	0.827	162	1.671	53	0.087	50	0.432	-178	1.14	10.6
2000	0.828	159	1.484	49	0.093	50	0.431	-180	1.17	9.5
2500	0.822	153	1.218	39	0.11	48	0.462	177	1.18	7.8
3000	0.818	148	1.010	30	0.135	46	0.490	174	1.16	6.3
3500	0.824	142	0.876	21	0.147	44	0.507	170	1.16	5.3
4000	0.812	137	0.762	13	0.168	38	0.535	167	1.14	4.3

VCE = 5 V, Ic = 100 mA

100	0.778	-144	27.669	111	0.027	35	0.523	-114	0.27	30.2
200	0.820	-164	14.559	97	0.029	29	0.445	-144	0.42	27.0
500	0.832	-179	5.885	84	0.035	38	0.435	-166	0.81	22.2
800	0.833	175	3.691	76	0.048	45	0.435	-173	0.95	18.8
1000	0.831	172	2.980	71	0.056	51	0.437	-176	1.05	16.0
1200	0.836	169	2.464	67	0.061	52	0.432	-178	1.11	14.0
1400	0.829	166	2.121	61	0.072	53	0.447	-180	1.12	12.6
1600	0.831	164	1.867	58	0.080	54	0.445	179	1.14	11.4

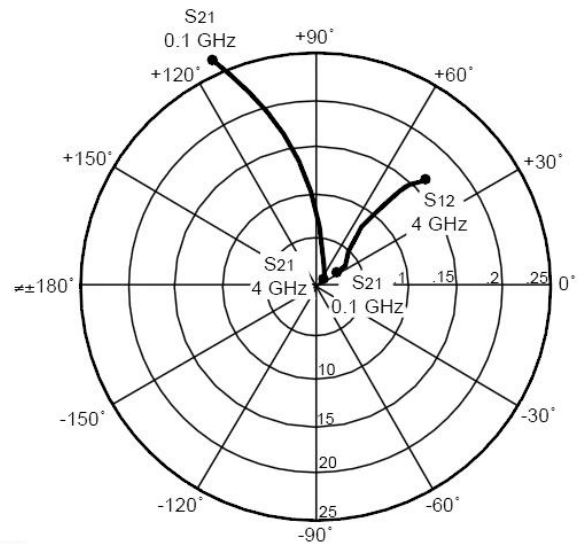
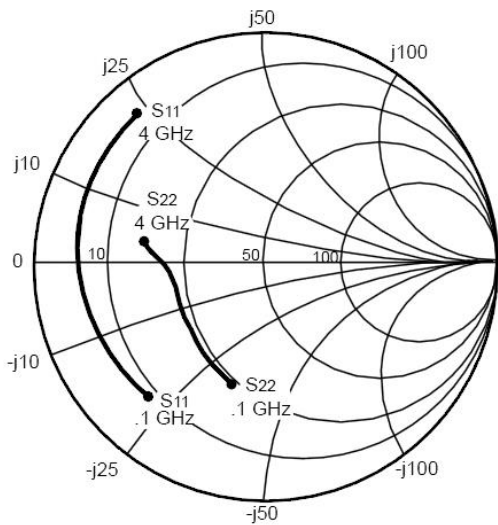
S parameters for transistors



Datasheets

NE46100, NE46134

TYPICAL COMMON EMITTER SCATTERING PARAMETERS¹ ($T_A = 25^\circ\text{C}$)



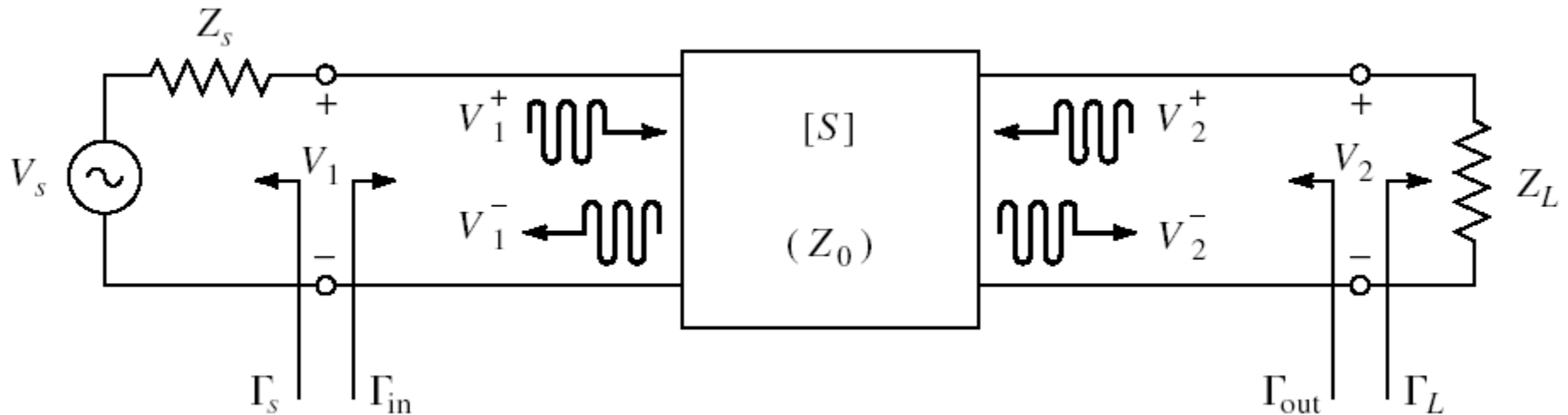
Coordinates in Ohms
Frequency in GHz
 $V_{CE} = 5\text{ V}$, $I_c = 50\text{ mA}$

S2P - Touchstone

- Touchstone file format (*.s2p)

```
! SIEMENS Small Signal Semiconductors
! VDS = 3.5 V   ID = 15 mA
# GHz S MA R 50
! f      S11      S21      S12      S22
! GHz   MAG ANG   MAG ANG   MAG ANG   MAG ANG
1.000 0.9800 -18.0 2.230 157.0 0.0240 74.0 0.6900 -15.0
2.000 0.9500 -39.0 2.220 136.0 0.0450 57.0 0.6600 -30.0
3.000 0.8900 -64.0 2.210 110.0 0.0680 40.0 0.6100 -45.0
4.000 0.8200 -89.0 2.230 86.0 0.0850 23.0 0.5600 -62.0
5.000 0.7400 -115.0 2.190 61.0 0.0990 7.0 0.4900 -80.0
6.000 0.6500 -142.0 2.110 36.0 0.1070 -10.0 0.4100 -98.0
!
! f      Fmin  Gammaopt  rn/50
! GHz   dB   MAG ANG   -
2.000   1.00 0.72 27 0.84
4.000   1.40 0.64 61 0.58
```

Amplifier as two-port

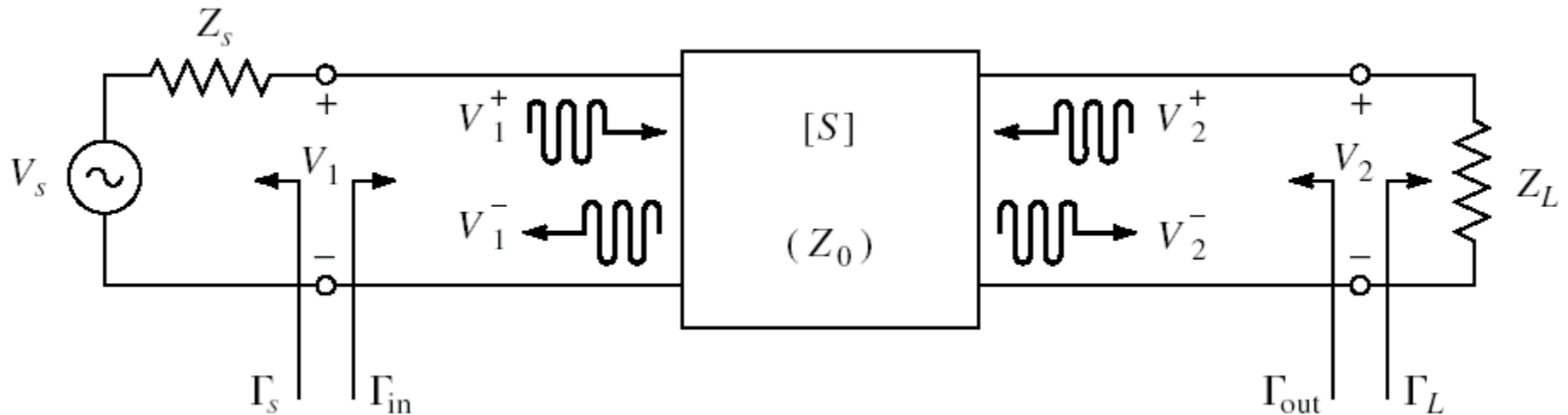


$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} \quad \begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$\Gamma_L = \frac{V_2^+}{V_2^-} \quad V_1^- = S_{11} \cdot V_1^+ + S_{12} \cdot V_2^+ = S_{11} \cdot V_1^+ + S_{12} \cdot \Gamma_L \cdot V_2^-$$

$$V_2^- = S_{21} \cdot V_1^+ + S_{22} \cdot V_2^+ = S_{21} \cdot V_1^+ + S_{22} \cdot \Gamma_L \cdot V_2^-$$

Amplifier as two-port



$$V_1^- = S_{11} \cdot V_1^+ + S_{12} \cdot V_2^+ = S_{11} \cdot V_1^+ + S_{12} \cdot \Gamma_L \cdot V_2^-$$

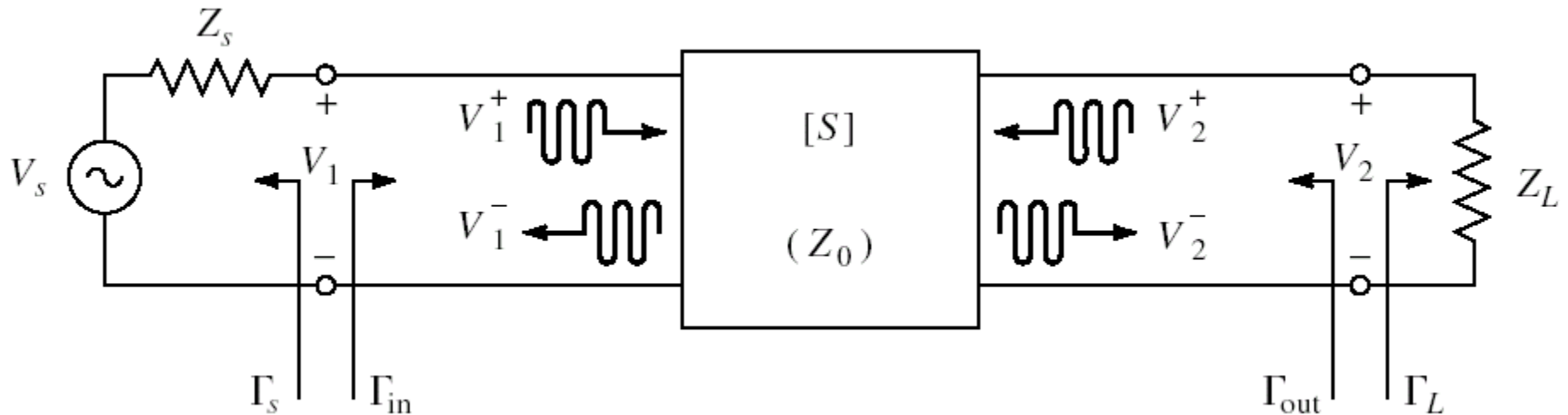
$$V_2^- = S_{21} \cdot V_1^+ + S_{22} \cdot V_2^+ = S_{21} \cdot V_1^+ + S_{22} \cdot \Gamma_L \cdot V_2^-$$

$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

■ similarly

$$\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_S}{1 - S_{11} \cdot \Gamma_S}$$

Amplifier as two-port



$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

$$\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_s}{1 - S_{11} \cdot \Gamma_s}$$

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