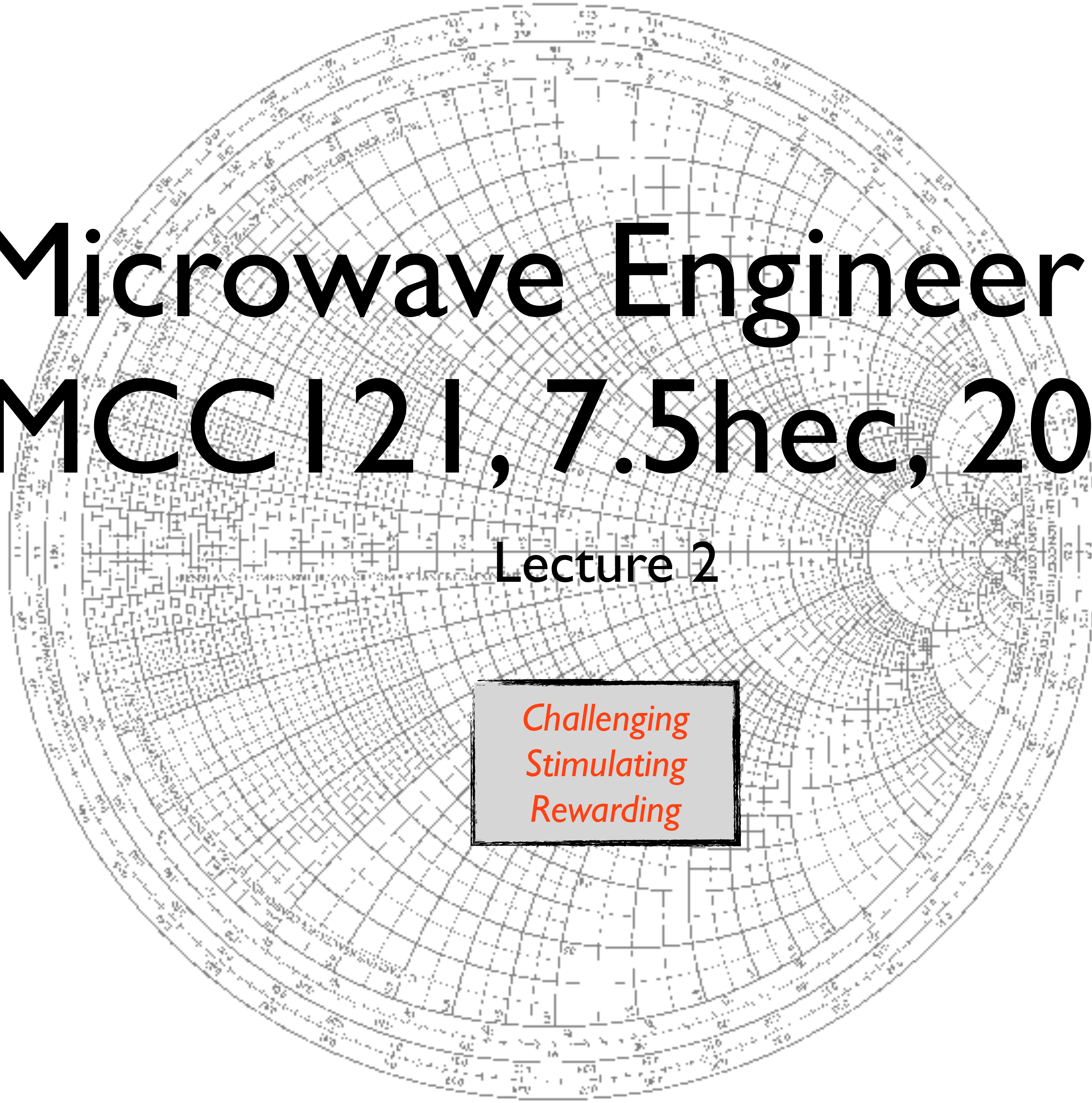


Microwave Engineering
MCC121, 7.5hec, 2014

Lecture 2

Challenging
Stimulating
Rewarding

Outline

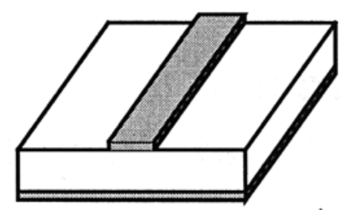
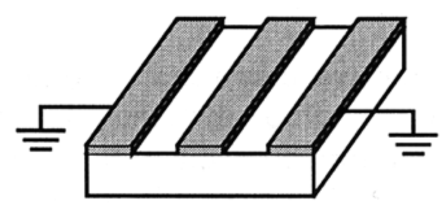
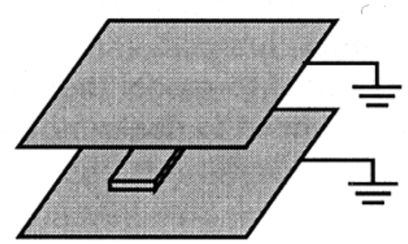
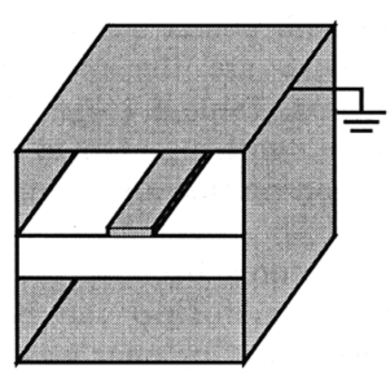
- Basic transmission line theory (Ch2)
  - Summary of waves on transmission lines (Ch2)
  - TEM waves (Coaxial lines)
  - Smith chart

Objectives

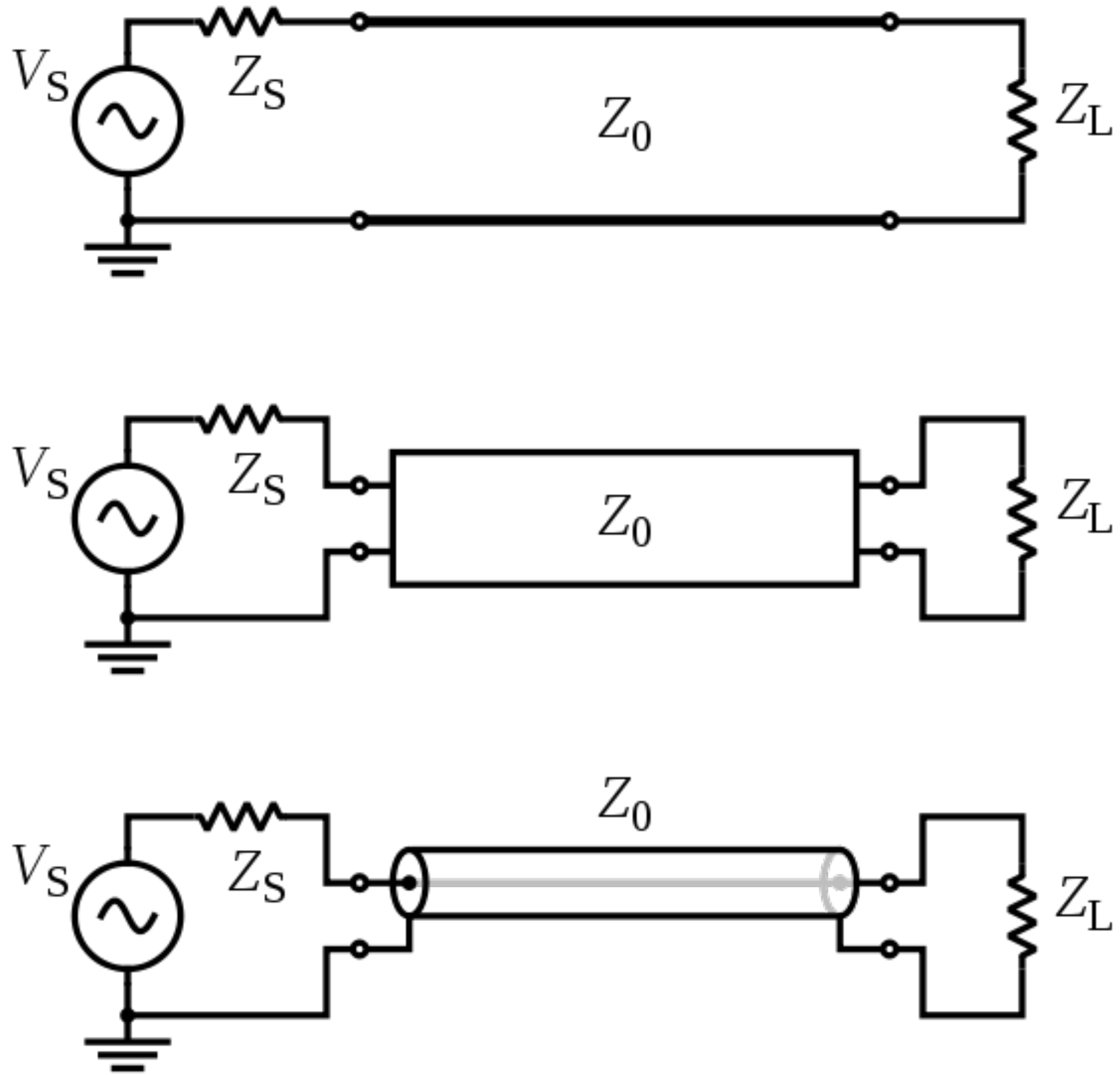
On completion of this course unit you should be able to:

1) Analyse wave propagating properties of guided wave structures (TE, TM, TEM waves, microstrip, stripline, rectangular and circular waveguides, coupled lines)
2) Apply N-port representations for analysing microwave circuits
3) Apply the Smith chart to evaluate microwave networks
4) Design and evaluate impedance matching networks
5) Design, evaluate and characterise directional couplers and power dividers
6) Design and analyse attenuators, phase shifters and resonators
7) Explain basic properties of ferrite devices (circulators, isolators)

Distributed components
Transmission lines

Transmission Line	Structure	Properties
Microstrip		The most common type of transmission line, suitable for both hybrids and monolithic circuits. Moderately dispersive at high frequencies. See Section 1.3.3.
Coplanar waveguide (CPW)		Somewhat lossier and more dispersive than microstrip, but minimizes the parasitic inductance of ground connections. Good transition to coaxial lines. Spurious slotline and microstrip modes are possible. See Section 1.3.4.
Stripline		Does not allow convenient mounting of discrete circuit elements; best for passive components. Difficult to cascade with microstrip or other planar transmission lines. Low loss, TEM, good transition to coax. See Section 1.3.5.
Suspended-substrate stripline (SSSL)		Similar to stripline, but easier to fabricate in many types of circuits. Low loss, low effective dielectric constant, good transition to coax. Waveguide-like modes can be a problem. See Section 1.3.6.

Transmission line



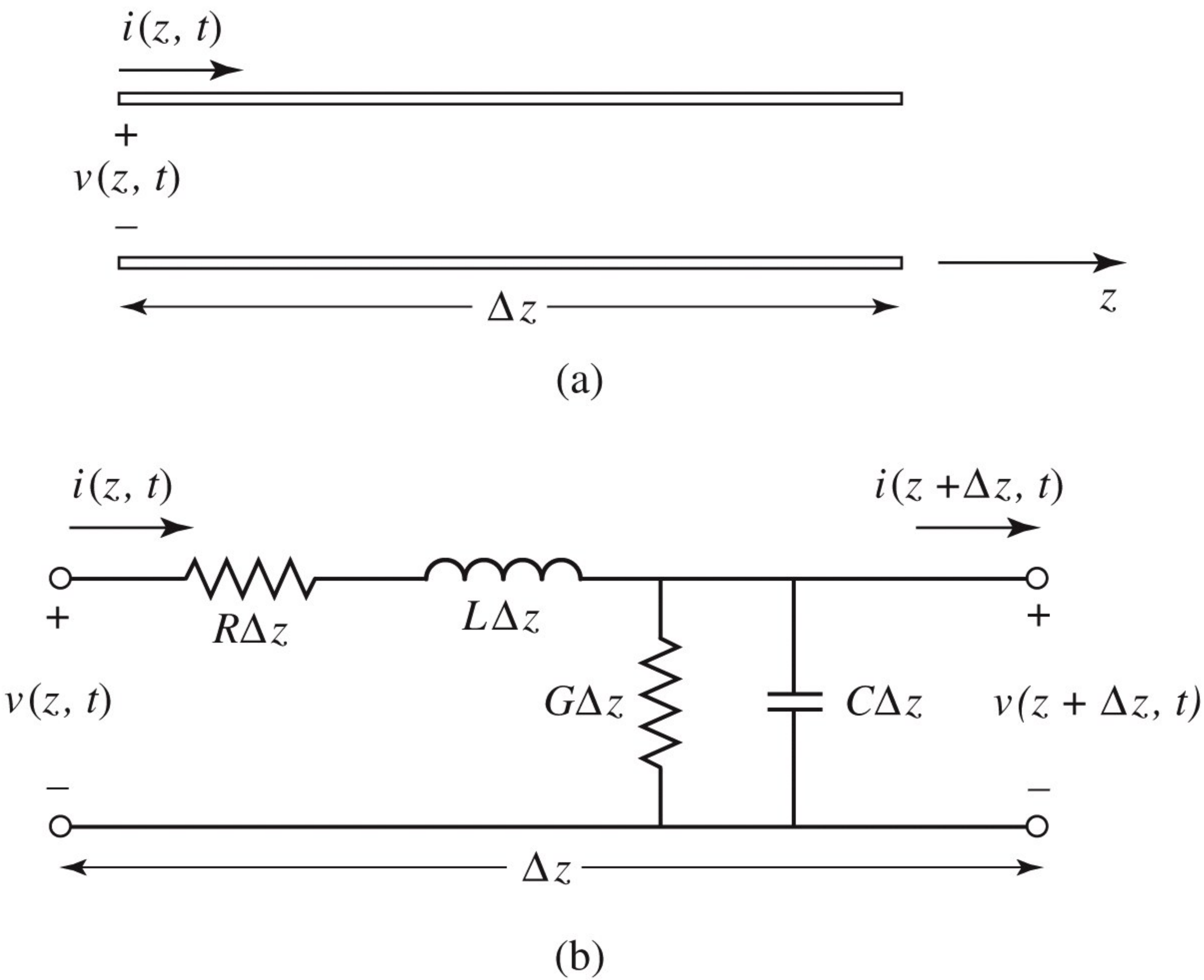


Figure 2.1

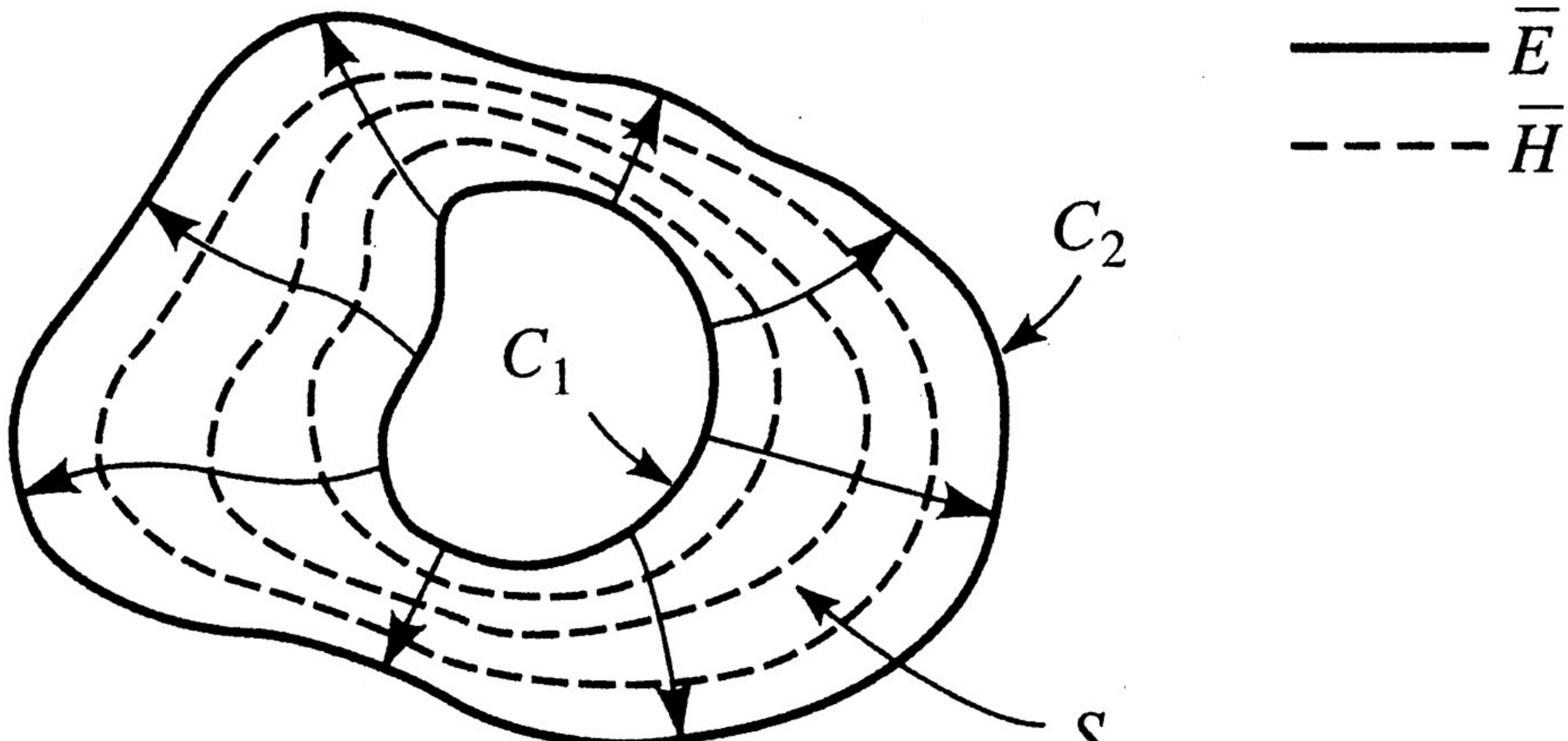
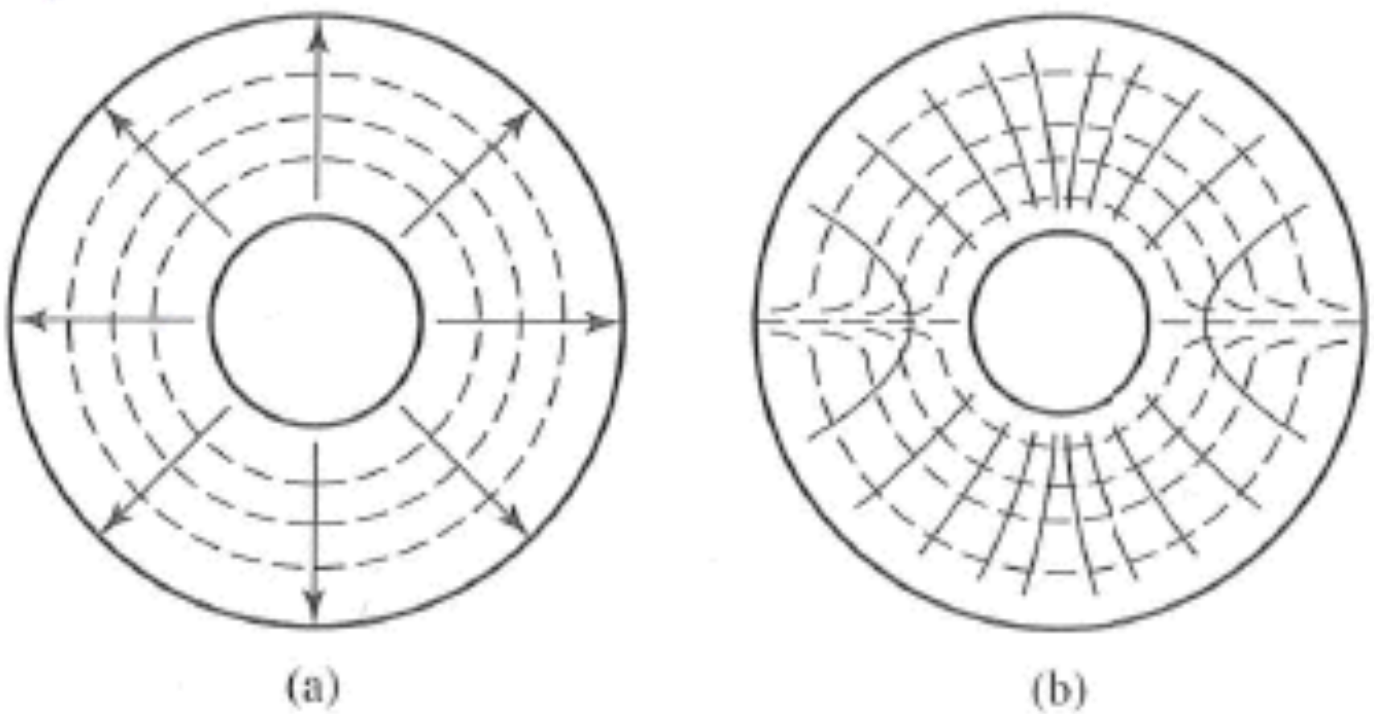


Figure 2.2

What is the highest frequency for a coaxial line?

Coaxial line



Field lines for the (a) TEM and (b) TE_{11} modes of a coaxial line.

TRANSMISSION LINE PARAMETERS

- L= magnetic flux / total current
- C = total charge per unit length/voltage difference between conductors
- G = total shunt current / voltage difference between conductors

TEM=> electrostatic solution
equivalent circuit parameters

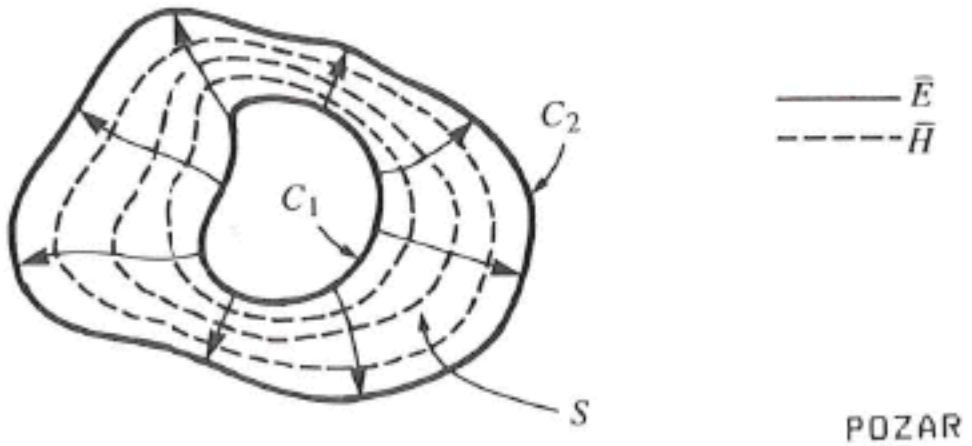
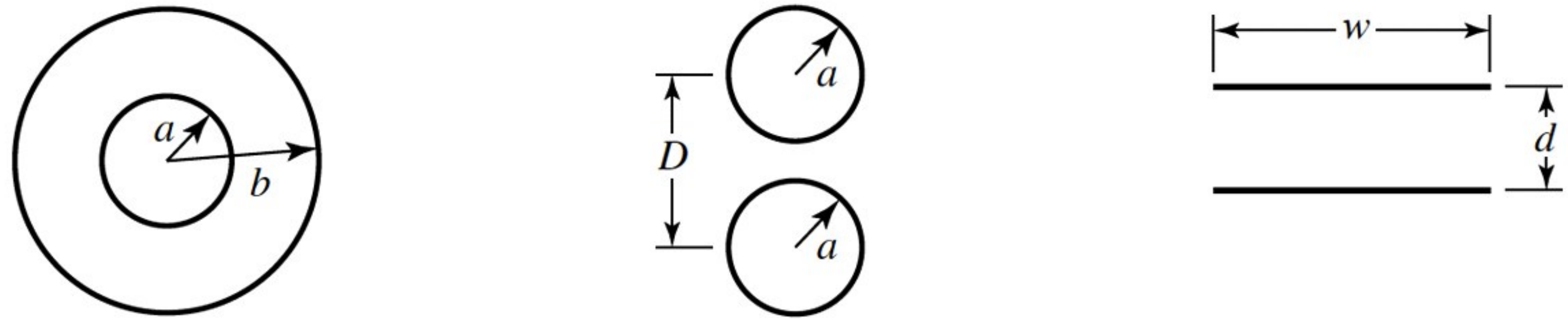


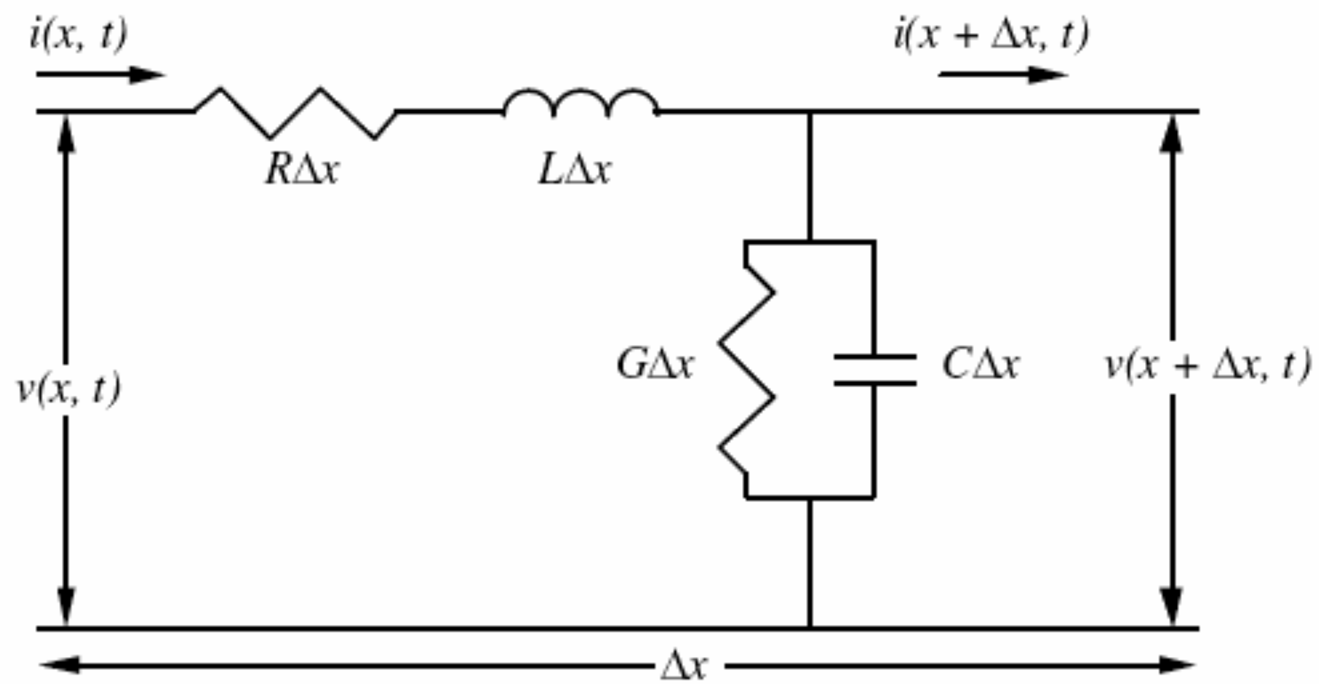
TABLE 2.1 Transmission Line Parameters for Some Common Lines



	COAX	TWO-WIRE	PARALLEL PLATE
L	$\frac{\mu}{2\pi}\ln\frac{b}{a}$	$\frac{\mu}{\pi}\cosh^{-1}\left(\frac{D}{2a}\right)$	$\frac{\mu d}{w}$
C	$\frac{2\pi\epsilon'}{\ln b/a}$	$\frac{\pi\epsilon'}{\cosh^{-1}(D/2a)}$	$\frac{\epsilon' w}{d}$
R	$\frac{R_s}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$	$\frac{R_s}{\pi a}$	$\frac{2R_s}{w}$
G	$\frac{2\pi\omega\epsilon''}{\ln b/a}$	$\frac{\pi\omega\epsilon''}{\cosh^{-1}(D/2a)}$	$\frac{\omega\epsilon'' w}{d}$

Table 2.1

Telegrapher's equations



Distributed Element Model of a Transmission Line

TD

$$\frac{\partial v(z,t)}{\partial z} = -Ri(z,t) - L\frac{\partial i(z,t)}{\partial t}$$

$$\frac{\partial i(z,t)}{\partial z} = -Gv(z,t) - C\frac{\partial v(z,t)}{\partial t}$$

Wave equations

FD

$$\frac{\partial^2 V}{\partial z^2} - \gamma^2 V = 0$$

$$\frac{\partial^2 I}{\partial z^2} - \gamma^2 I = 0$$

$$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$$

Propagation constant

$$\frac{\partial^2 V}{\partial z^2} - \gamma^2 V = 0$$

$$\frac{\partial^2 I}{\partial z^2} - \gamma^2 I = 0$$

$$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$$

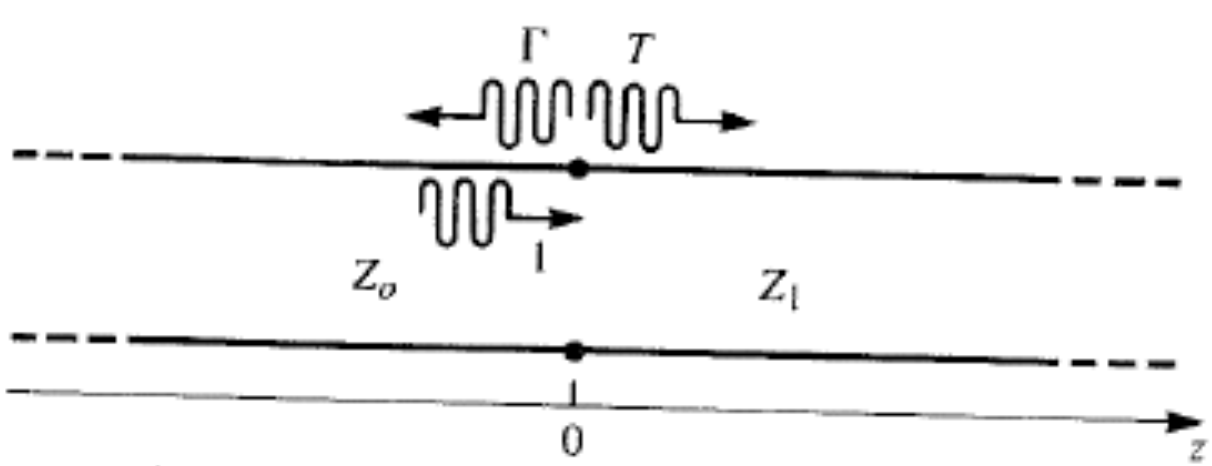
$$V(z) = V^+ e^{-\gamma z} + V^- e^{\gamma z}$$

$$I(z) = I^+ e^{-\gamma z} + I^- e^{\gamma z}$$

Phase velocity: $v_p = \omega / \beta$

Characteristic impedance

$$\frac{V^+}{I^+} = Z_0 = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}}$$



$$\Gamma = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

Input impedance

- *On white board: input impedance for different special cased*

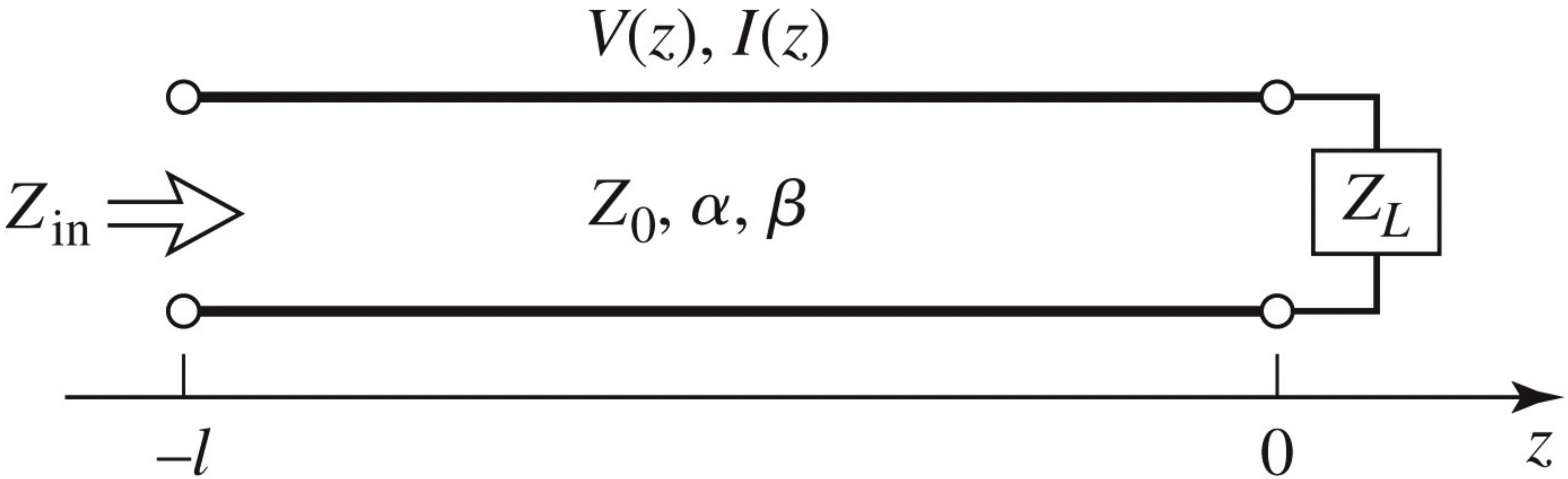
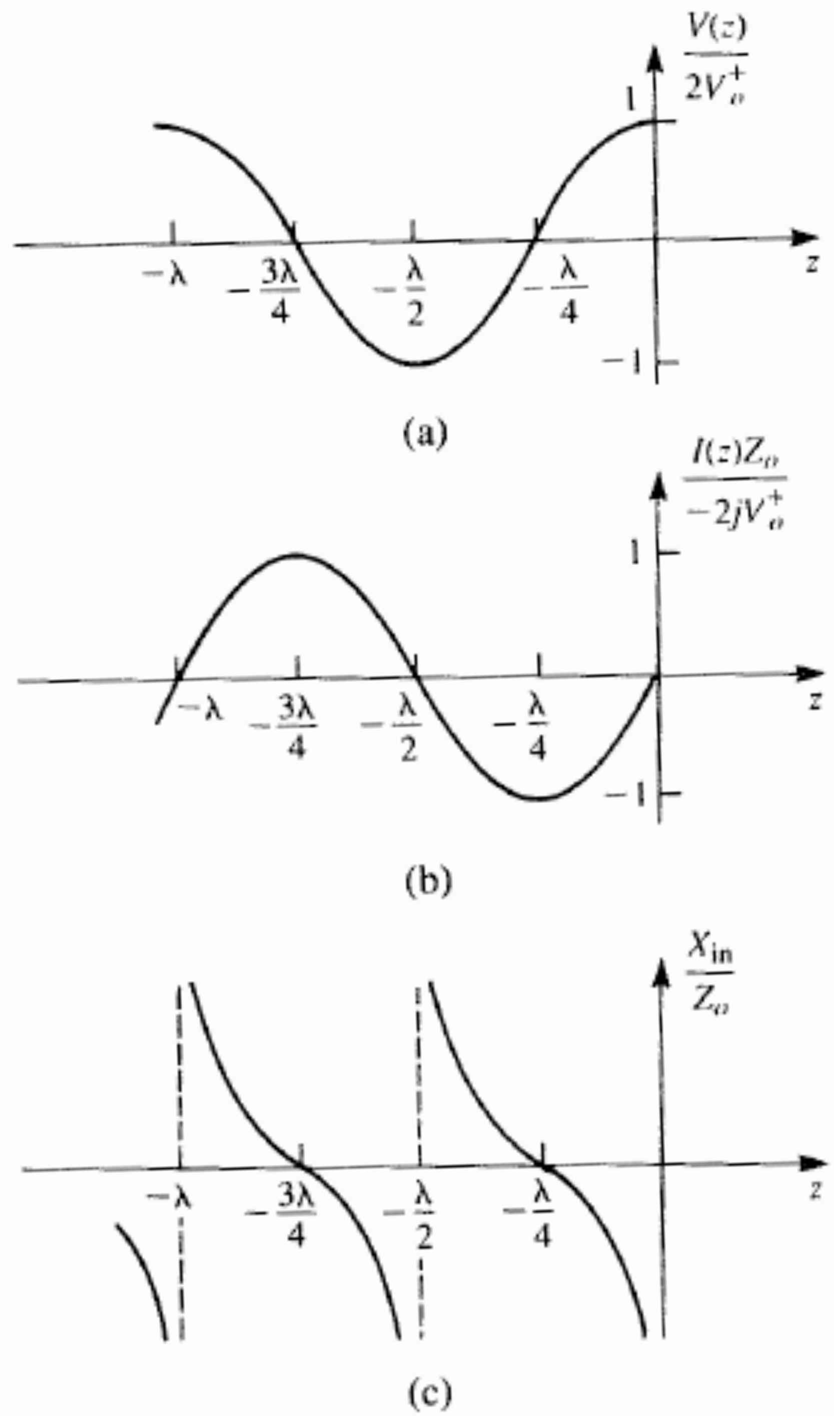


Figure 2.20

terminated lines



Open -ended line

$$Z_L = \infty$$

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

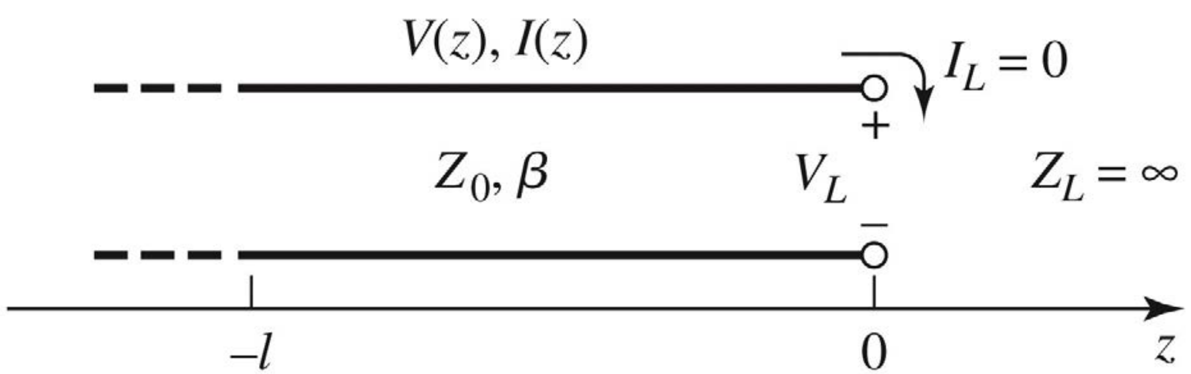


Figure 2.7

terminated lines

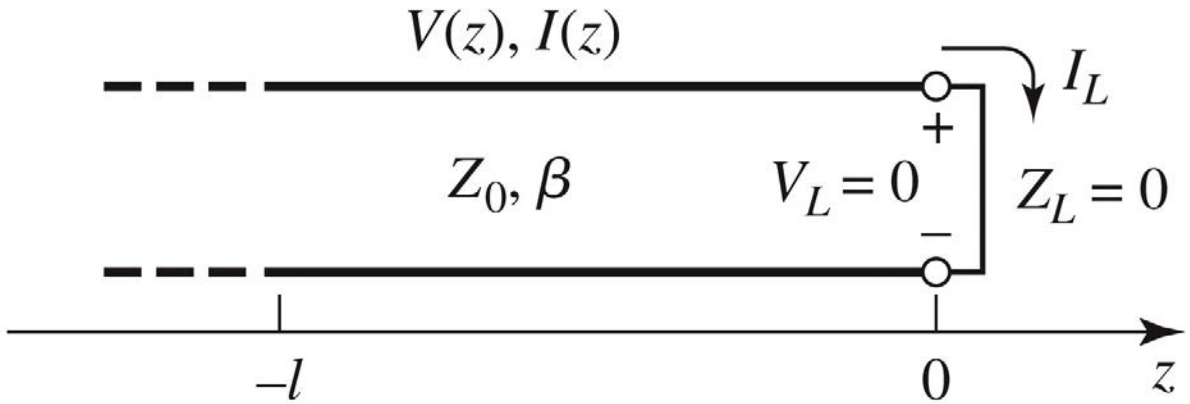


Figure 2.5

Short circuit termination

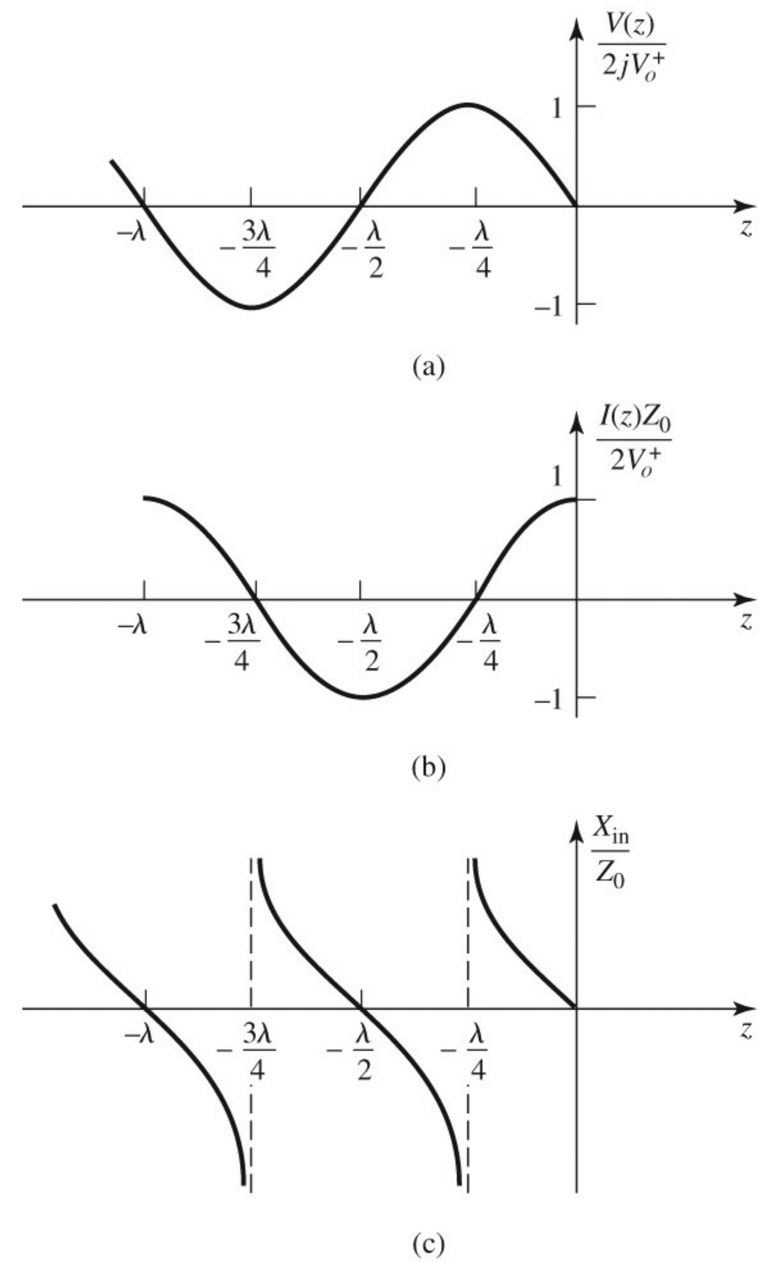


Figure 2.6

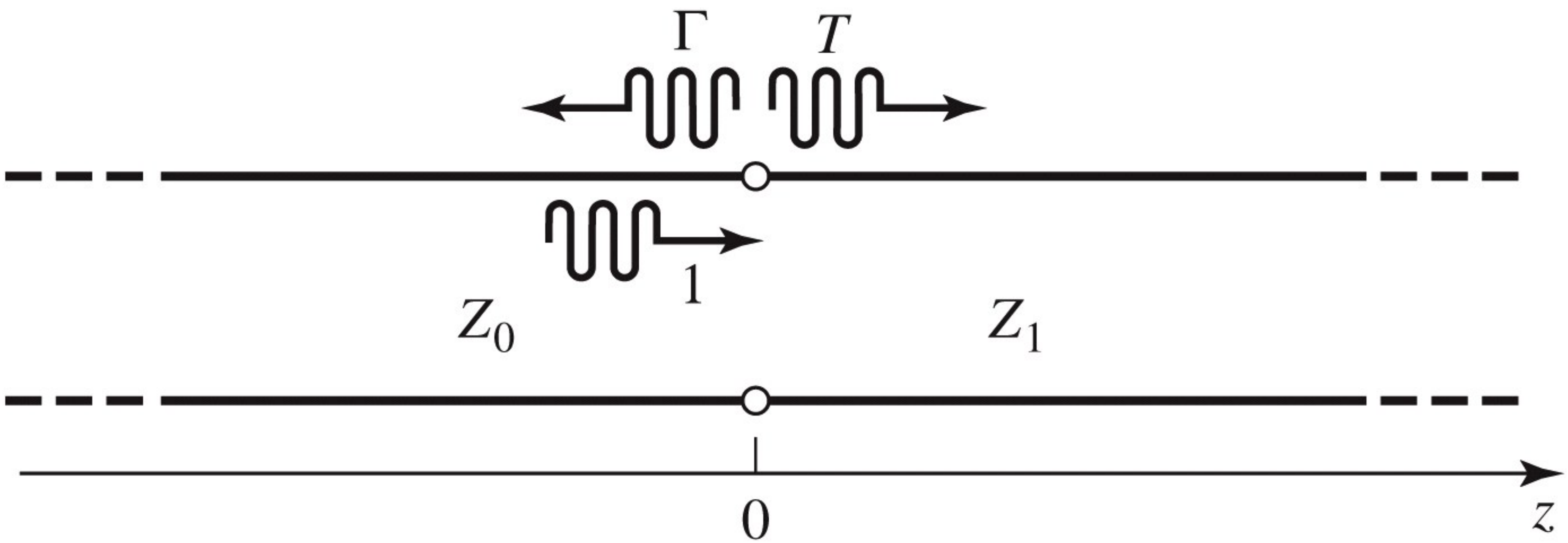


Figure 2.9

Insertion loss, IL=-20log(T) [dB]

Return loss. RL=-20log(Gamma) [dB]

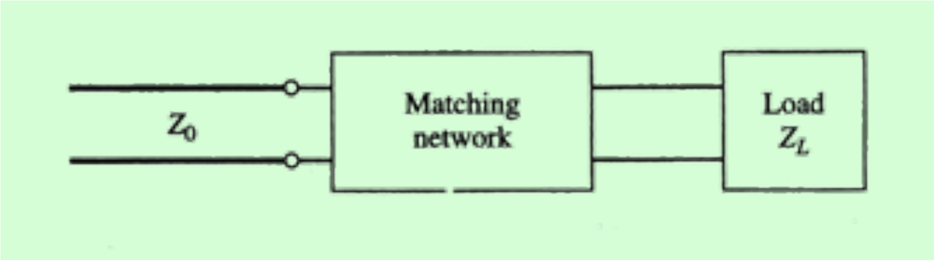
Smith chart

Impedance transformation and matching

- to match an arbitrary load to a given transmission line
- to present a certain impedance to a device (embedding impedances)

For low VSWR, energy transfer or design goals

Low VSWR results in better power handling capability



Distributed components

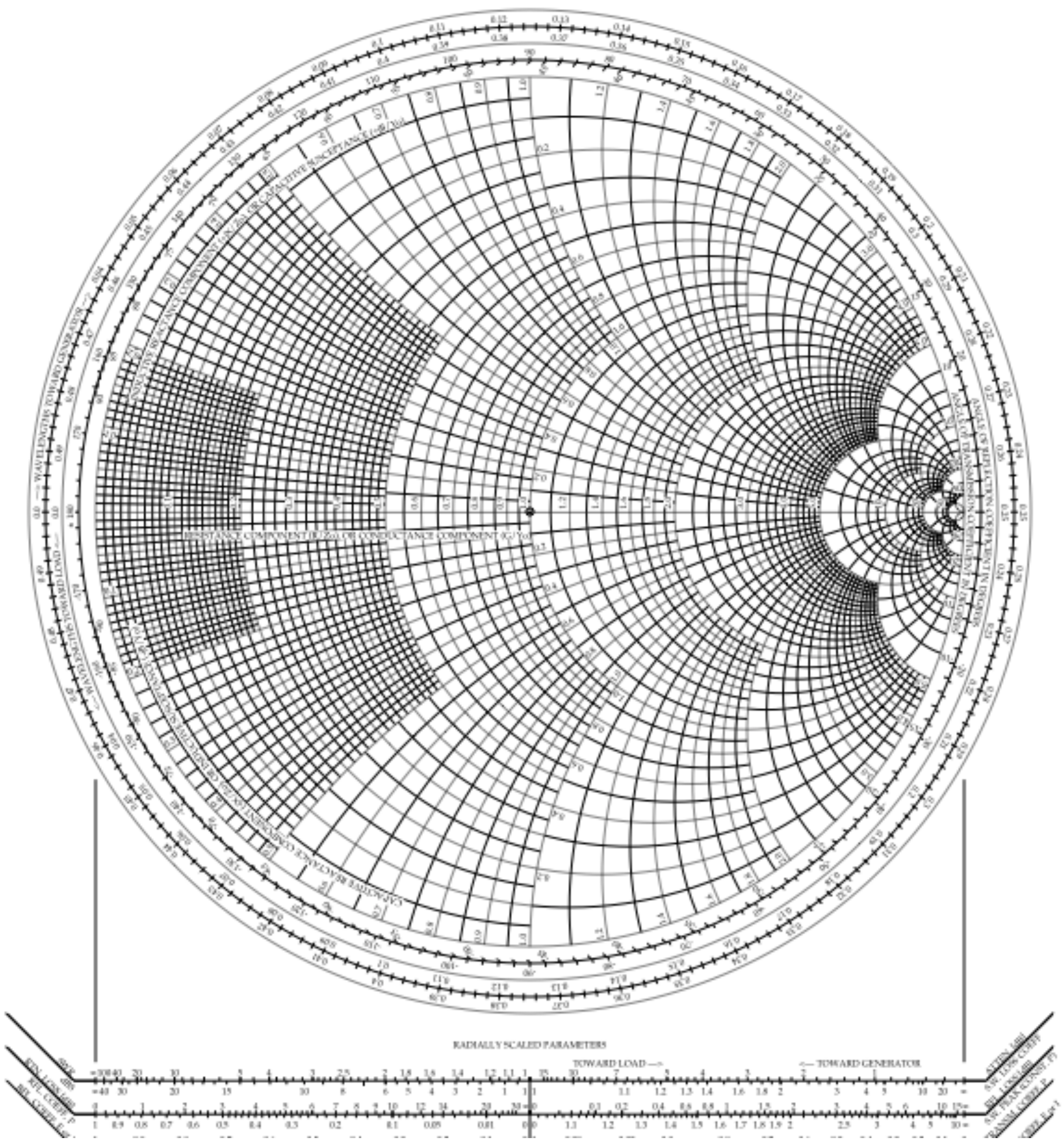
- Single, double or triple stubs
- Transformers

Discrete components

The Smith Chart (SC)

- Proposed 1939 by Philip H. Smith as a graphical aid to analyse and design matching networks
- Mr. Smith worked at Bell Telephone labs with impedance matching of antennas (for AM broadcasting)
- Today, still a powerful tool as part of the design process in order to find suitable circuit topologies etc

Z or impedance SC

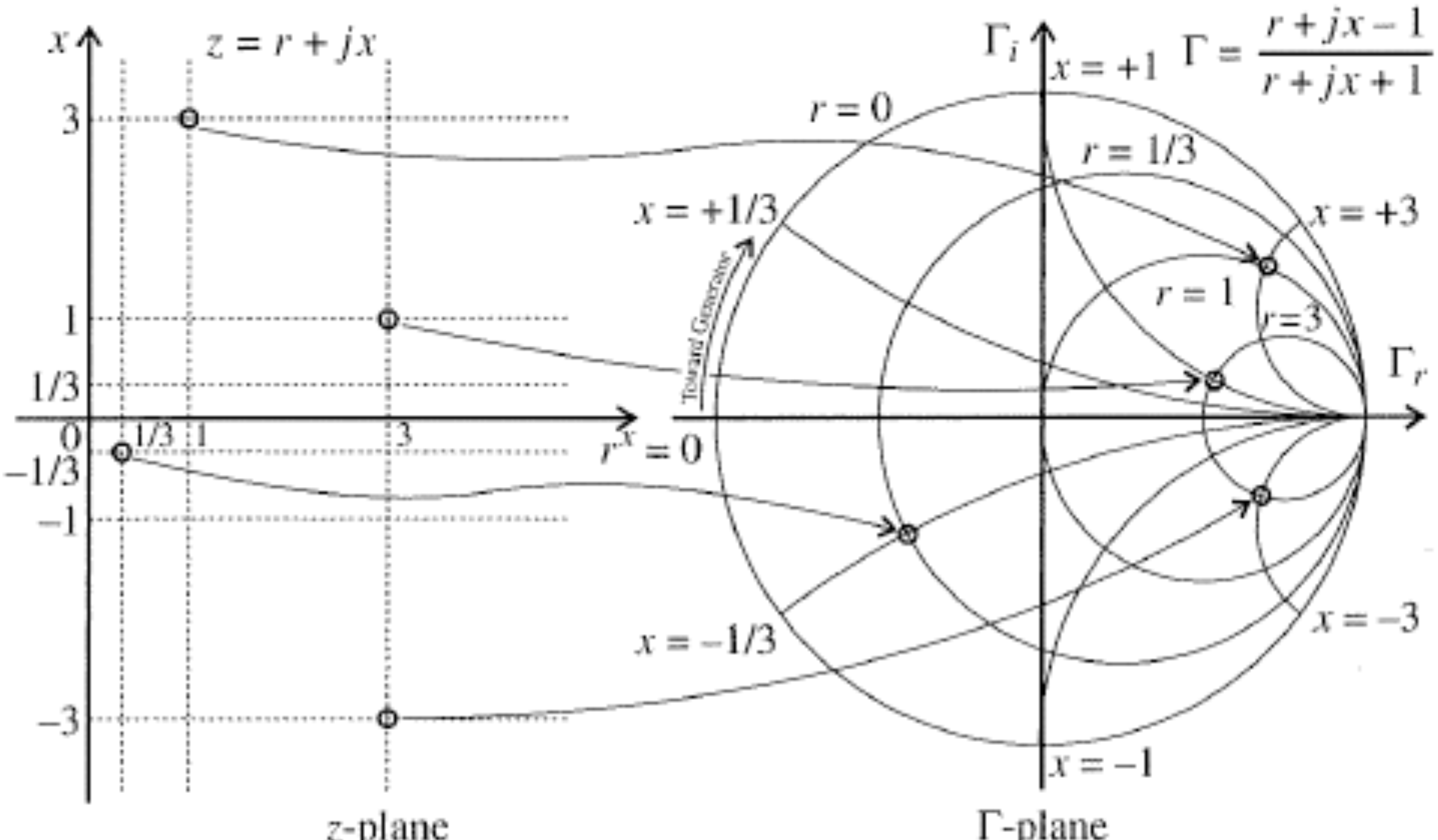


Conformal mapping (Möbius)

- Z Smith chart: $$\Gamma = \frac{z-1}{z+1}$$

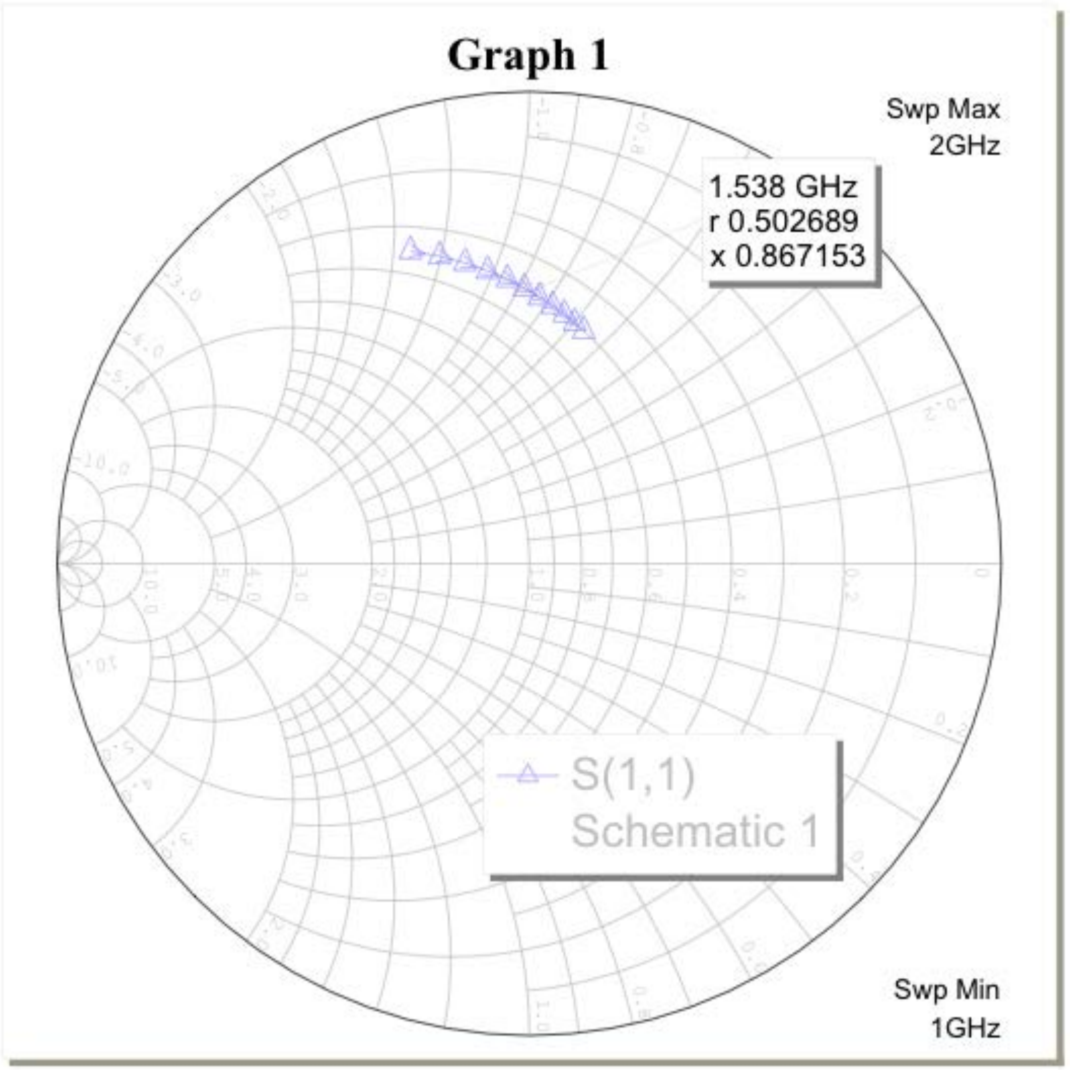
- Y Smith chart: $$\Gamma = \frac{1-y}{1+y}$$

Complex impedance transformed to complex reflection plane



from RF Circuit design, Ludvig and Bogdanov

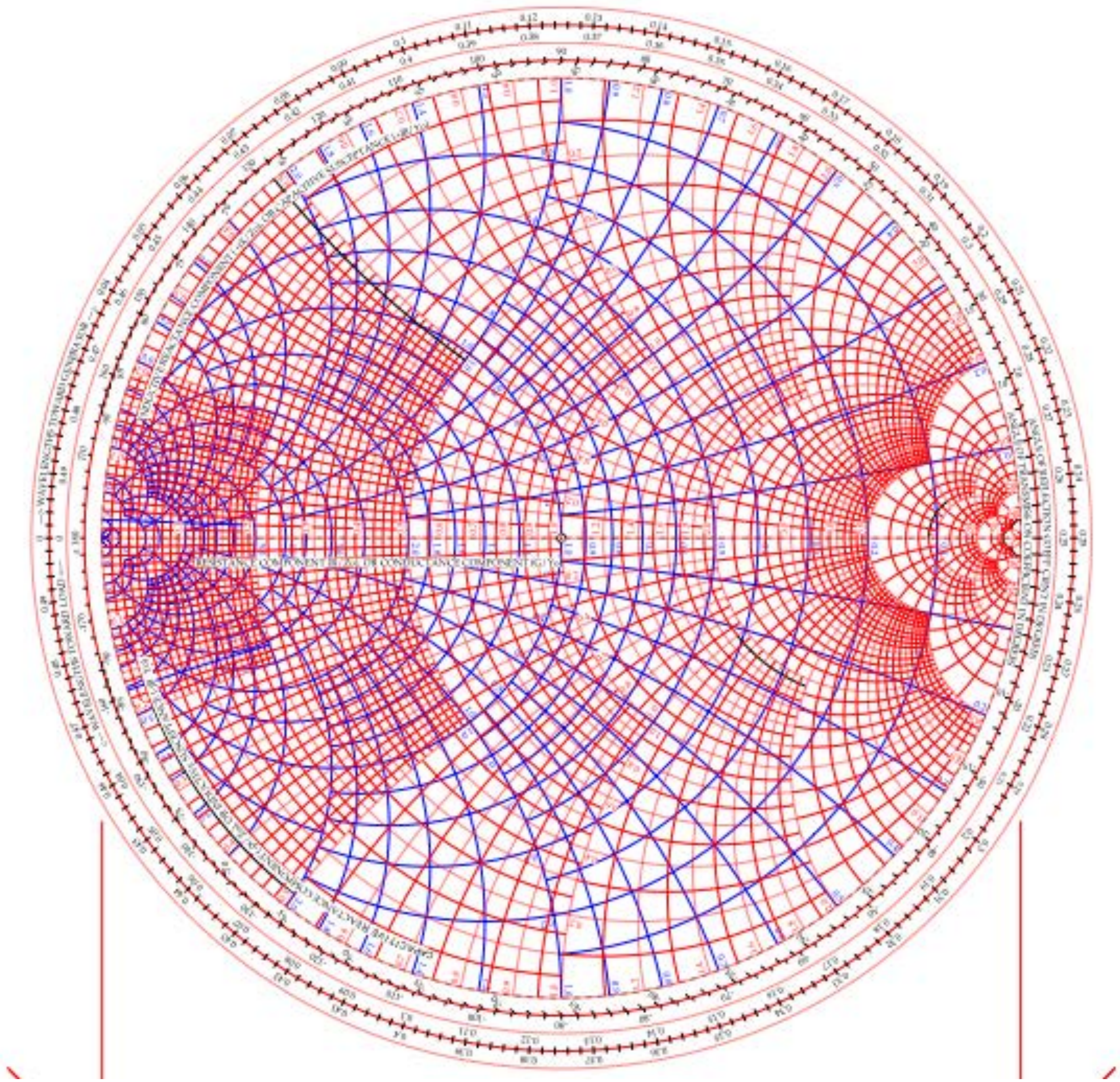
Y or admittance SC



The Smith Chart

- Complex plane for the reflection coefficient.
  - Normalised contours for resistances/ conductances and reactances/susceptances
  - Upper half->inductive, lower half->capacitive

- Common practice to plot S-parameters in Smith charts. E.g. Vector network analysers or design tools



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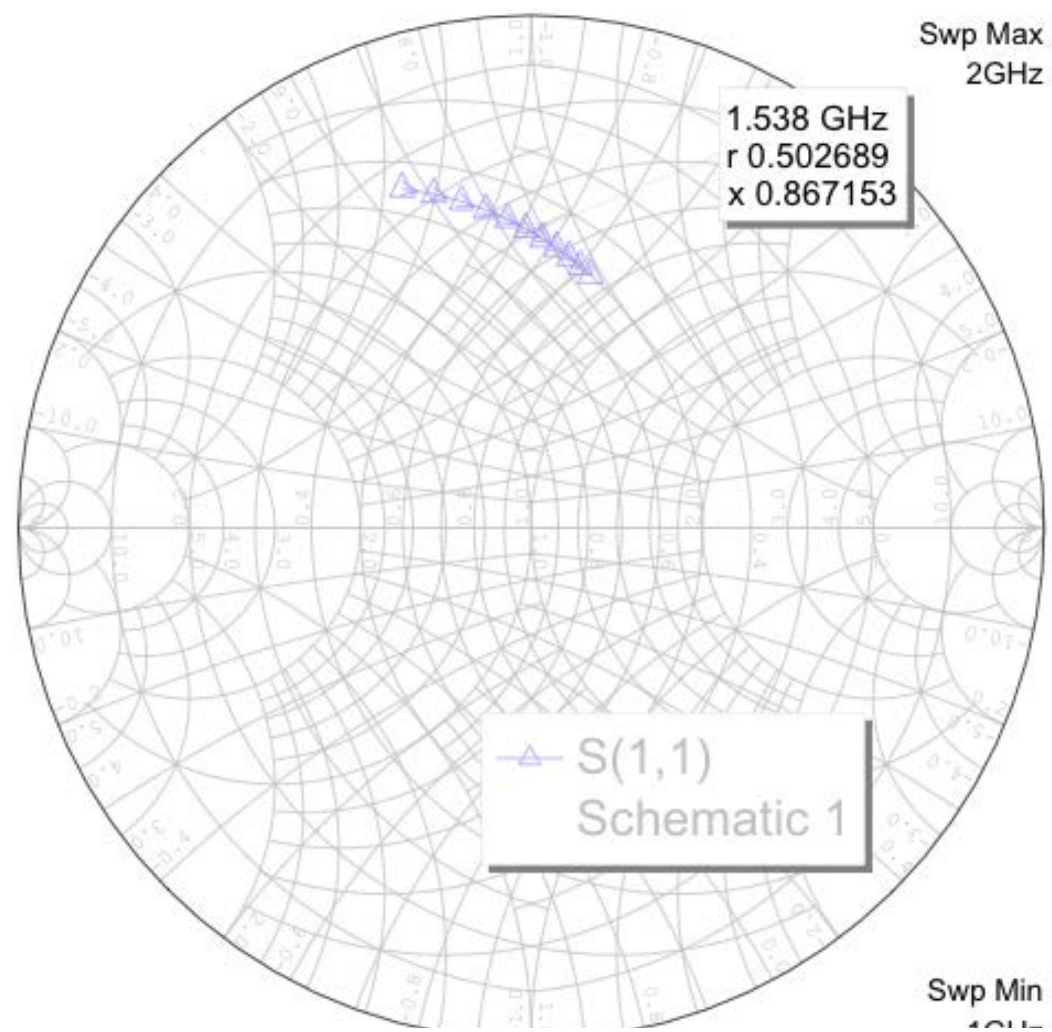
ZY Smith Chart

- Z for series connections
- Y for parallel connections



ex 2.2) ZL=40+j70 at the end of a 100 ohm line

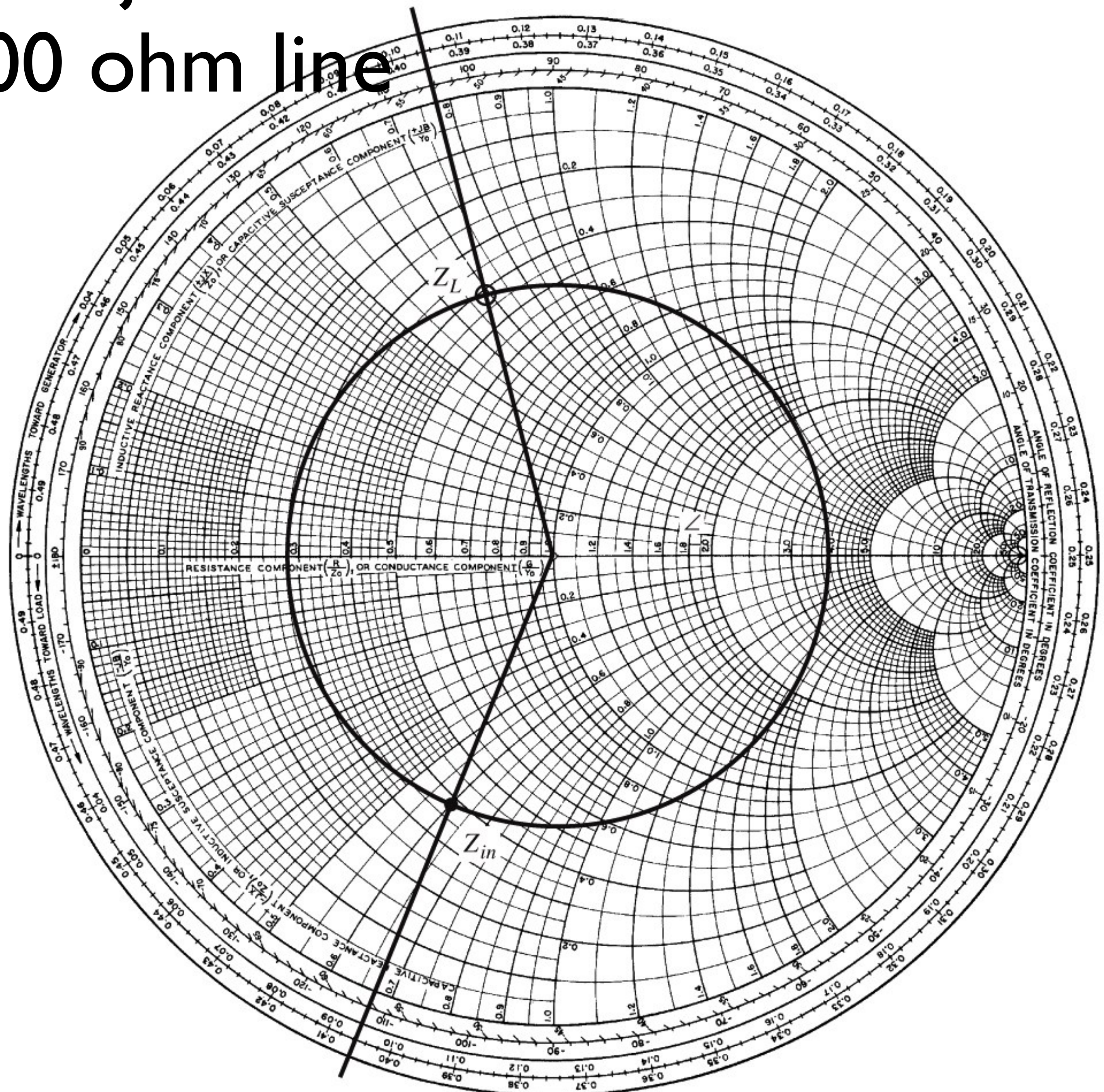


Figure 2.11

- *On white board:* Find RL and VSWR

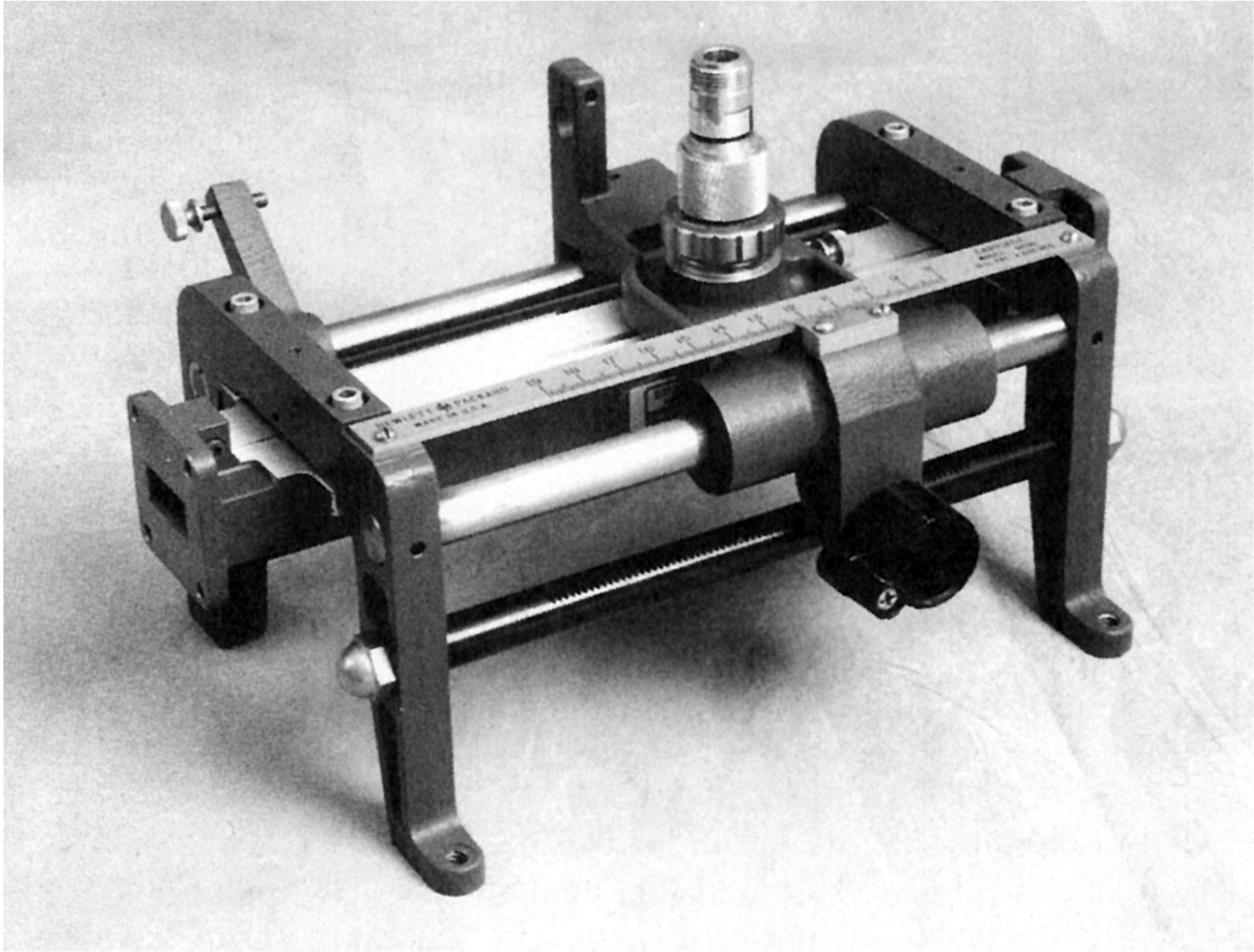


Figure 2.13
David M. Pozar

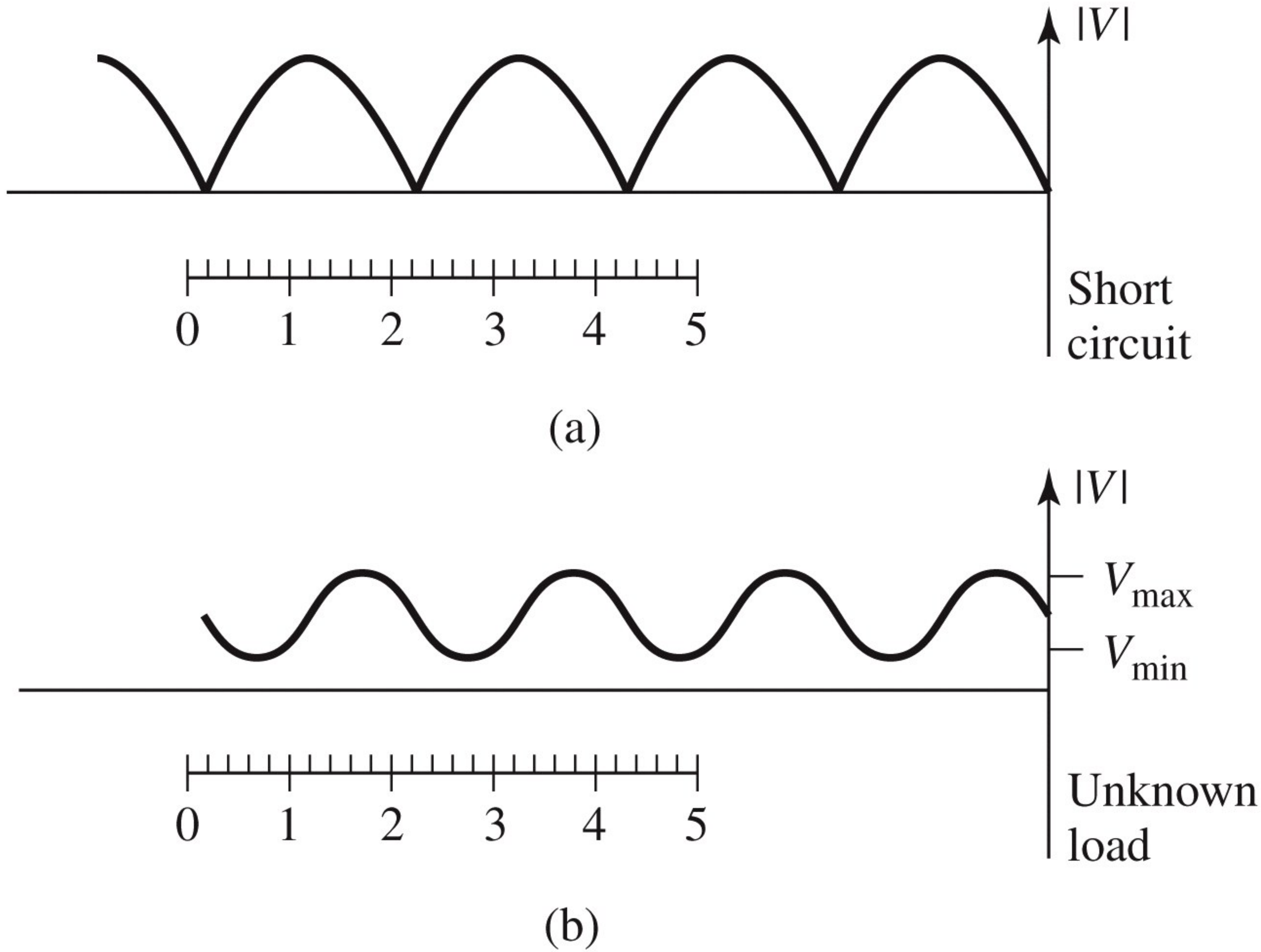


Figure 2.14

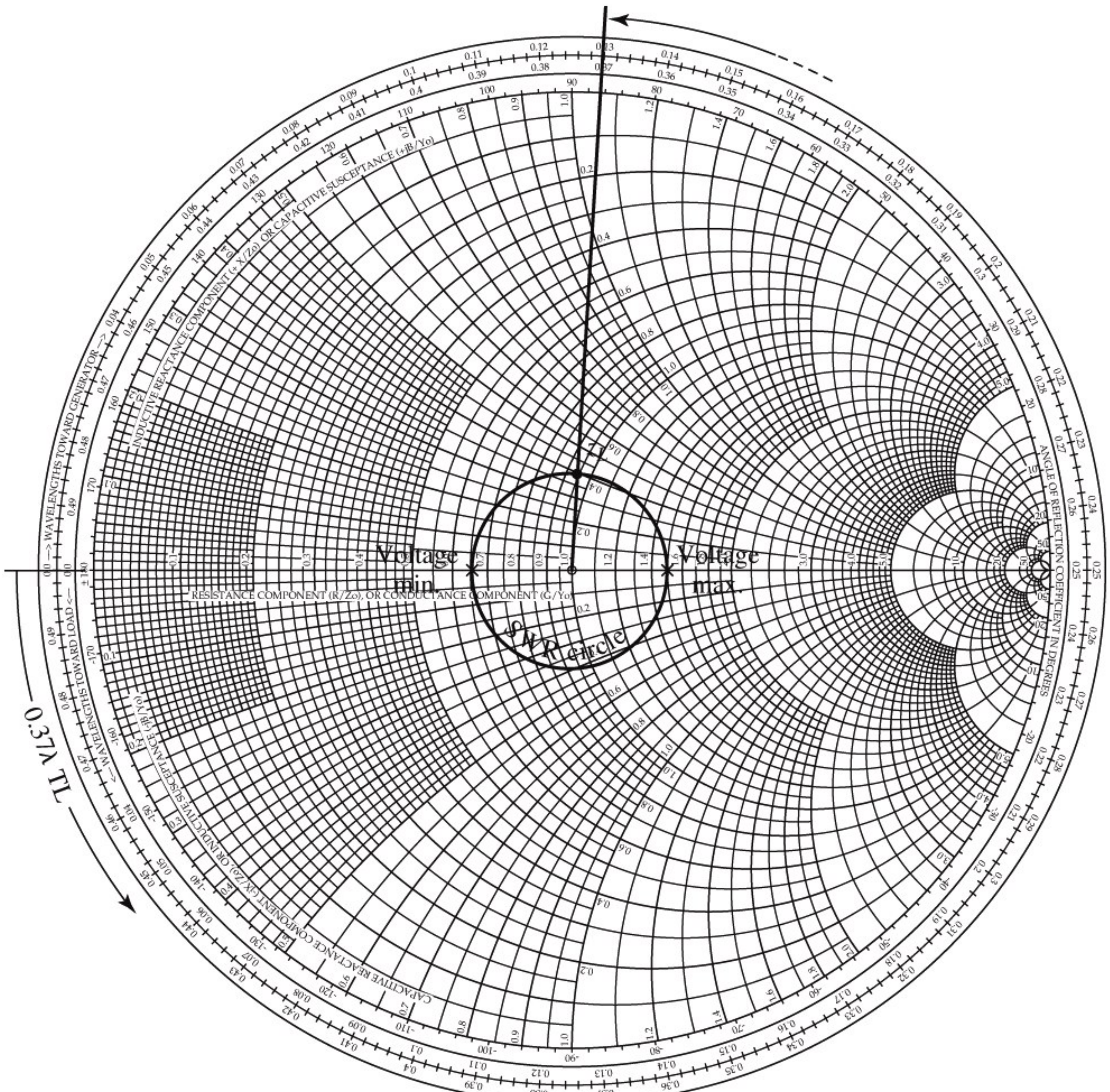

Voltage min.
Voltage max.
SWR circle
0.37λ TL
WAVELENGTHS TOWARD GENERATOR
WAVELENGTHS TOWARD LOAD
ANGLE OF REFLECTION COEFFICIENT IN DEGREES
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)
INDUCTIVE REACTANCE COMPONENT (+jX/Zo) OR CAPACITIVE SUSCEPTANCE (+jB/Yo)
CAPACITIVE REACTANCE COMPONENT (-jX/Zo) OR INDUCTIVE SUSCEPTANCE (-jB/Yo)

Figure 2.15

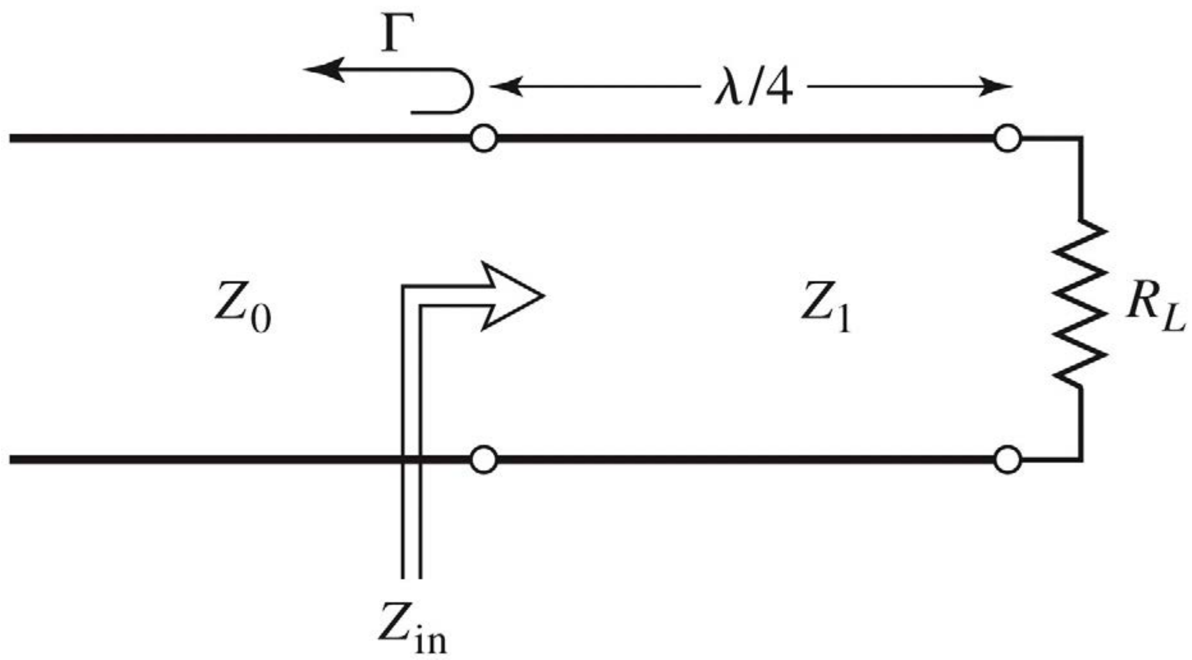


Figure 2.16

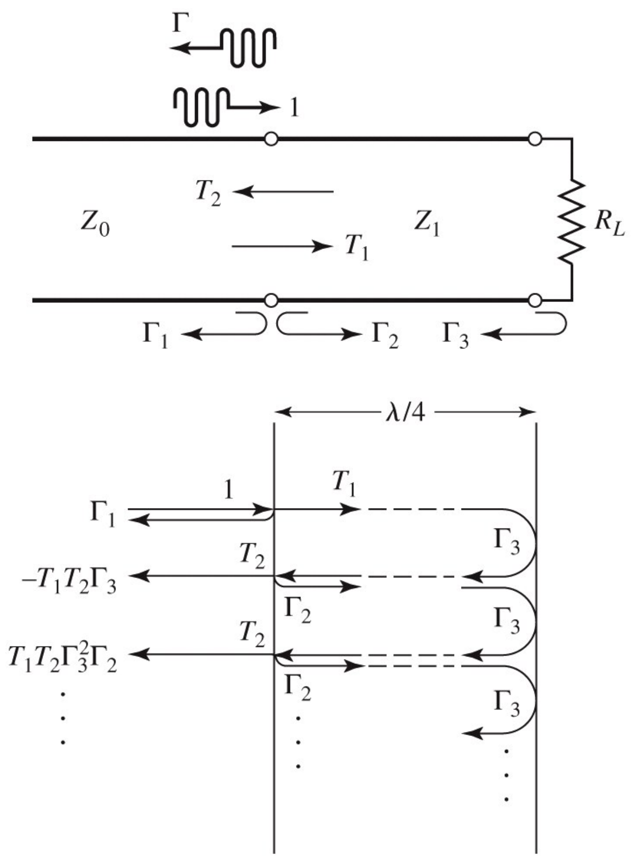


Figure 2.18

- *On white board:* Multiple reflections

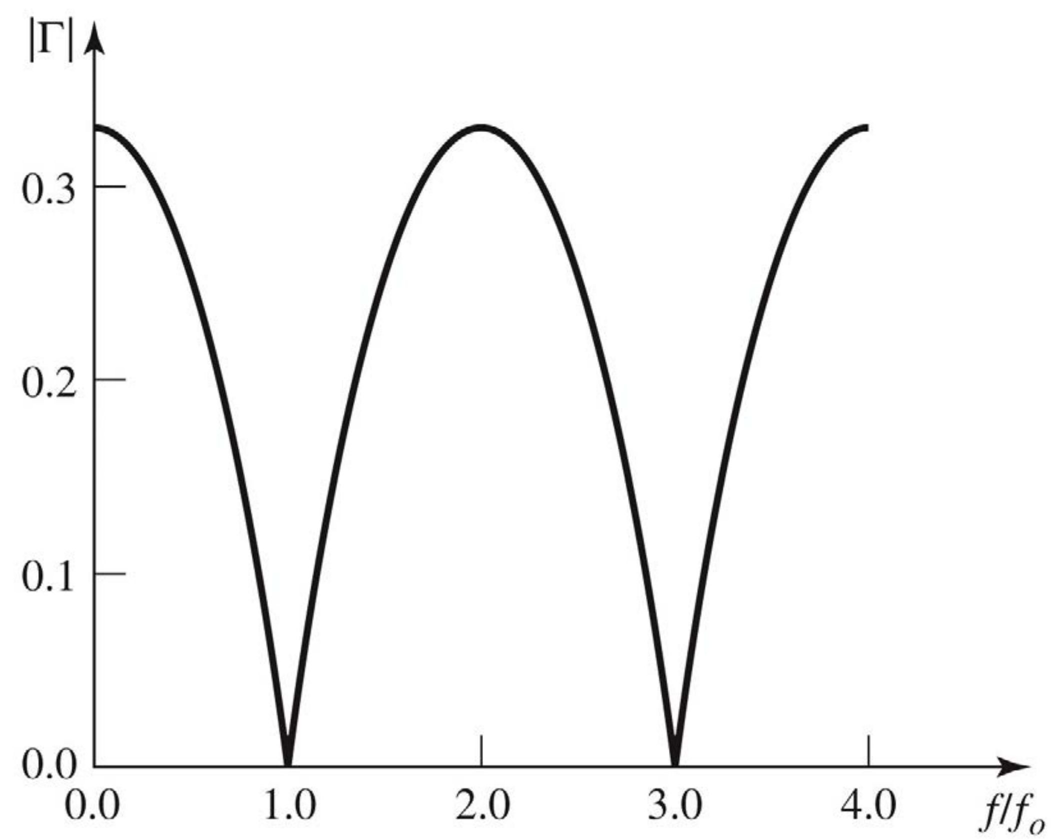


Figure 2.17

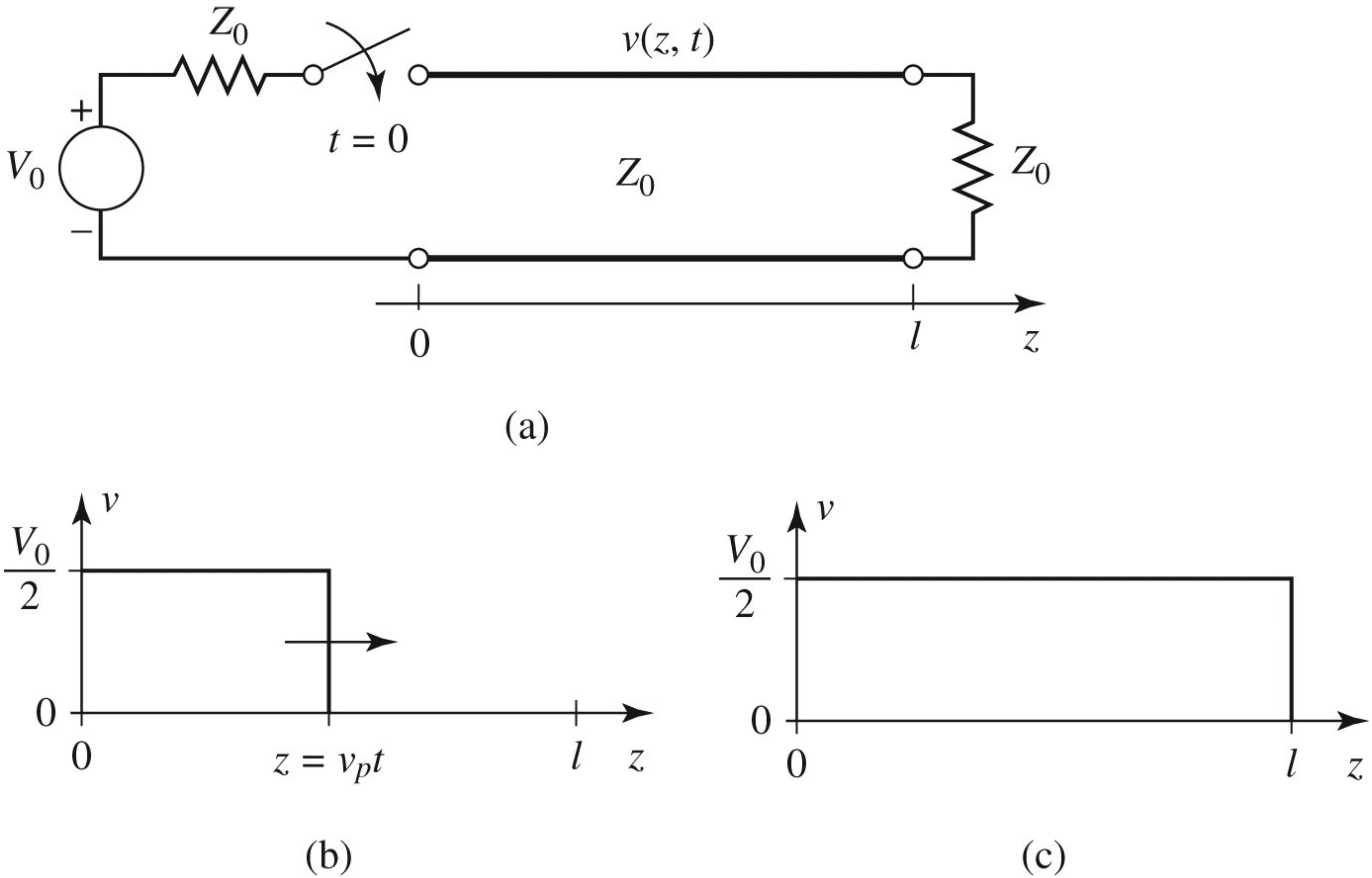


Figure 2.21

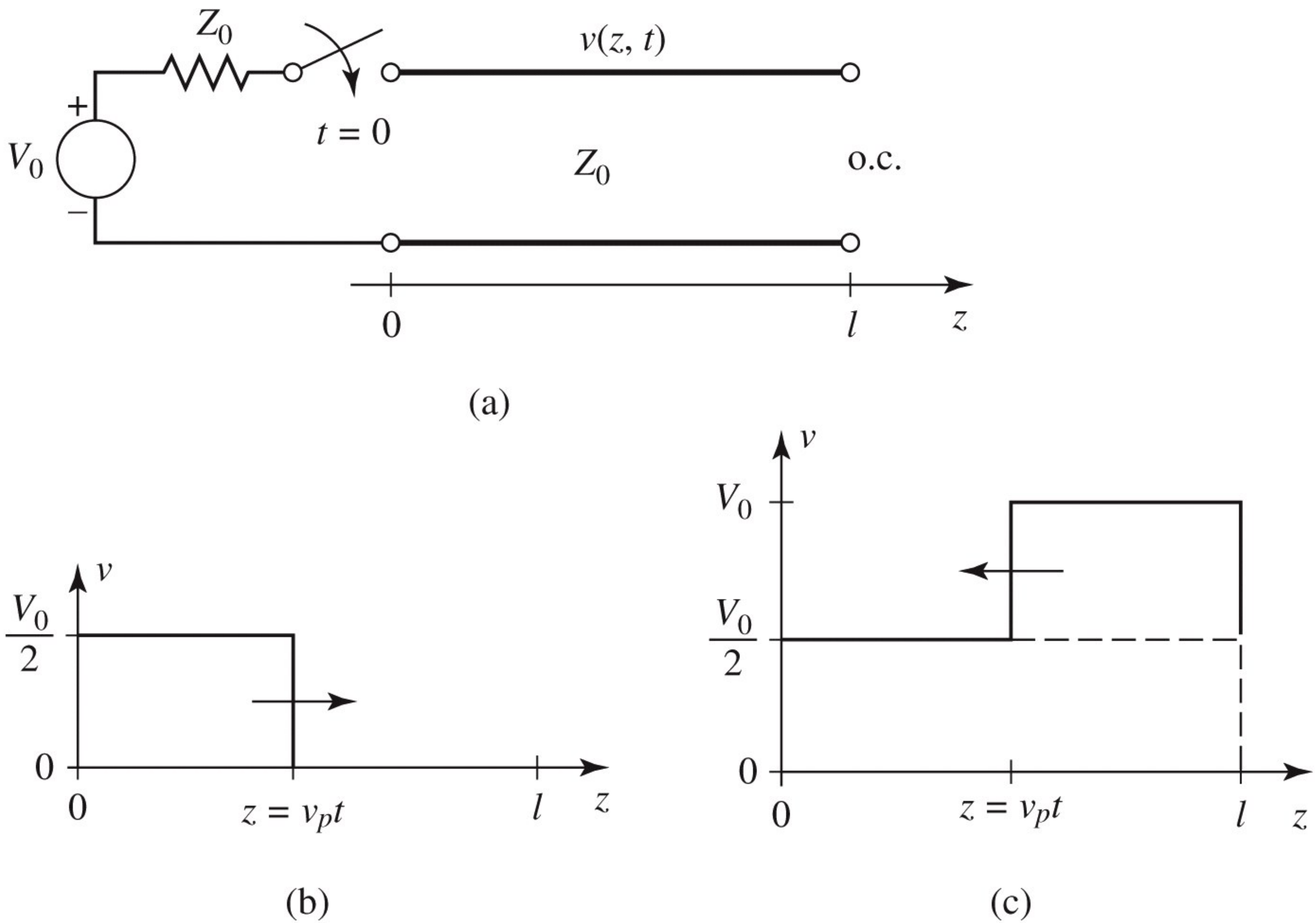

Z_0
$v(z, t)$
V_0
$t = 0$
Z_0
o.c.
0
l
z
(a)
v
$\frac{V_0}{2}$
0
0
$z = v_p t$
l
z
(b)
v
V_0
$\frac{V_0}{2}$
0
0
$z = v_p t$
l
z
(c)

Figure 2.23

Further reading

- A. Inan, “Remembering Phillip H. Smith on his 100th birthday,” Antennas and Propagation Society International Symposium, 2005 IEEE, vol. 3, pp. 129–132 vol. 3B, Jun. 2005. http://dx.doi.org/10.1109/APS.2005.1552450