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Antenna & Propagation

Transmission Line Using Smith Chart

by
Nor Hadzfizah Binti Mohd Radi
Faculty of Electric & Electronics Engineering
hadzfizah@ump.edu.my

Chapter Synopsis

In this chapter, the student will be exposed to use the Smith Chart as a tool to obtain several measurements in a transmission line.

Teaching Outcome

At the end of this chapter student should be able to:

- ❑ Use the Smith Chart in order to find the measurement of parameters in transmission line.
- ❑ Understand the definition of VSWR, reflection coefficient, Return Loss, Impedance and First minimum and maximum voltage.

Outline

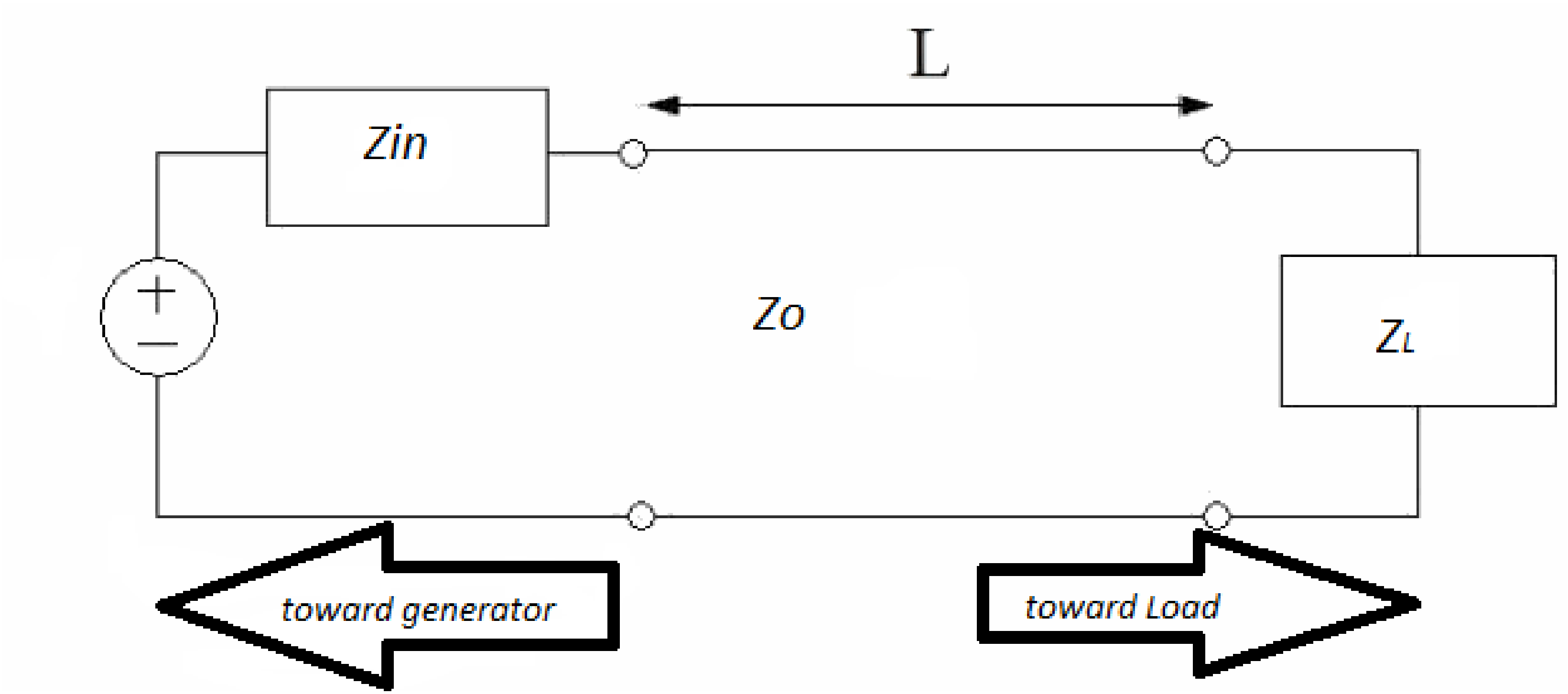
- Introduction
- Impedance
- Reflection Coefficient
- VSWR
- First Voltage min and max

Introduction

- Philip Smith of Bell Laboratories developed the “Smith Chart” back in the 1930”s to simplify the complex and repetitive solution of certain radio frequency (RF) design problems. These include:

  - Transmission line problems
  - RF amplifier design and analysis
  - L-C impedance matching networks
  - Plotting of antenna impedance

Equivalent of Transmission Line



Smith Chart Overview

- The Smith Chart is a clever tool for analyzing transmission lines.
- The outside of the chart shows location on the line in wavelengths.
- The combination of intersecting circles inside the chart allow us to locate the normalized impedance and then to find the impedance anywhere on the line.

Smith Chart

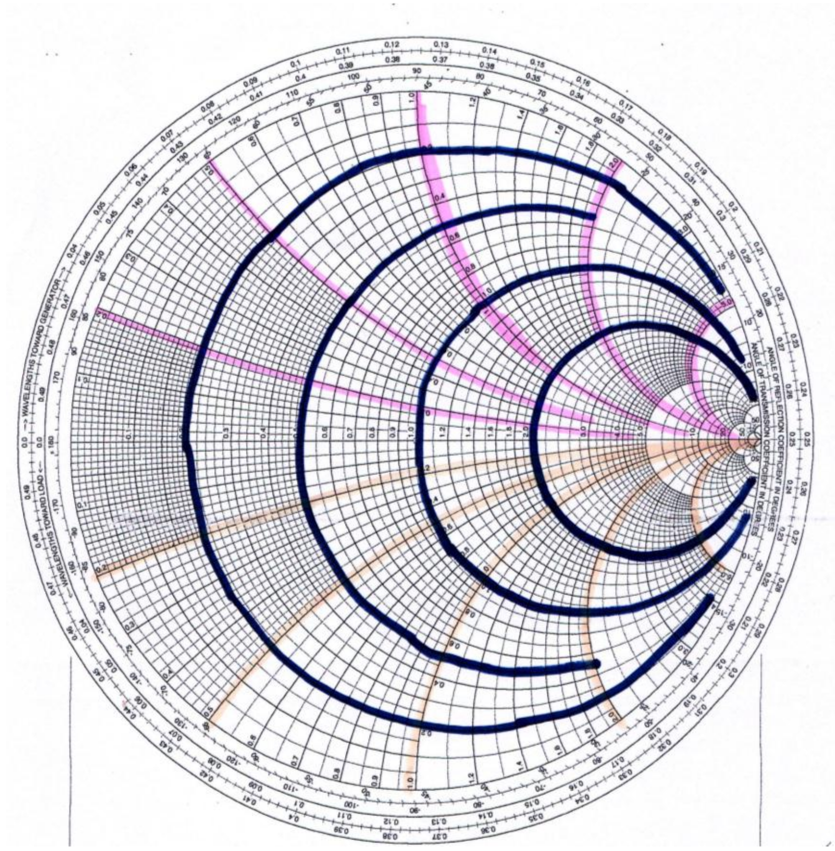
- The smith chart is available in: http://www.ieee.hr/_download/repository/smithov_dijagram.pdf

Steps on How to use Smith Chart

1. Locate the normalized impedance on the chart for $Z_L' = Z_L / Z_{o.}$ (usually Z_o 50 Ω and 75 Ω.
2. Then draw the circle through the point from origin and get the value of SWR. This circle is called SWR circle.
3. Extend the plotted Z_L' to get the angle of reflection coefficient.
4. By given the length of transmission line calculate the distance towards the generator in λ from the extended plot of Z_L'.
5. Find the wavelength and make a line from origin. The intersection between line and circle is a point of Z_{in}'. De-normalized this value by $Z_{in}' x Z_{o.}$
6. Get the value of distance for first voltage minimum and maximum by find the distance (in λ) from line of Z_L' to minimum and maximum voltage (vmax at 0.25 λ) and (vmin at 0.0 λ).

Impedance Axis

- There are real impedance and imaginary axis.
  - ✓ Black represent the real impedance (R_L)
  - ✓ Pink represent the positive imaginary impedance ($+j X_L$)
  - ✓ Orange represent the negative imaginary impedance ($-jX_L$)



Reflection Coefficient

- The reflection coefficient is also known as s11 or Return Loss (RL).
- The reflection coefficient is a parameter that describes how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium.
- Can be calculated as:

$$\tau = \frac{Z_L - Z_o}{Z_L + Z_o} \; (unitless)$$

VSWR

- The VSWR (Voltage Standing Wave Ratio) and is also referred to as Standing Wave Ratio (SWR) .
- It is measure for how much power is reflected.
- A low valued VSWR indicates that the majority of the incident power is delivered to the antenna and reflections are nearly avoided.
- The VSWR is always a real and positive number for antennas.
- The minimum VSWR is 1.0. In this case, no power is reflected from the antenna, which is called as ideal.
- In practice, if the VSWR is under 2 the antenna match is considered very good.

VSWR

- If the reflection coefficient (τ) is given, then the VSWR is defined by the following formula:

$$vswr = \frac{1 + |\tau|}{1 - |\tau|}$$

- See the table next to see a numerical mapping between reflected power, s11 and VSWR.

VSWR Table

VSWR	Power Reflected , Pr(%)	Power Transmitted, Pt(%)	Return Loss, RL(dB)	Reflection Coefficient, τ
1.25	1	99	20	0.11
1.58	5	95	13	0.22
1.92 ~ 2	10	90	10	0.32
5.80	50	50	3	0.71

% Pr = $\tau^2 x$ 100

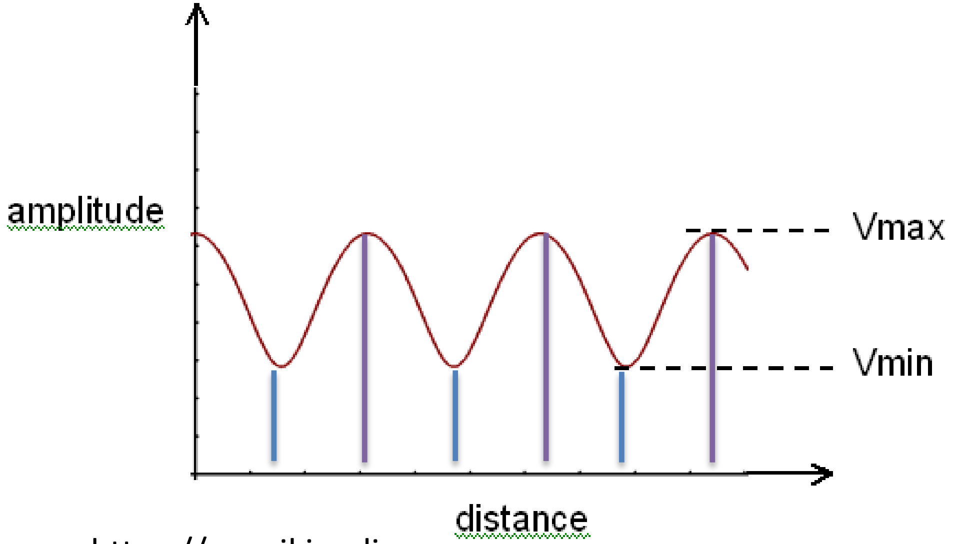
% Pt = 1- $\tau^2 x$ 100

RL (dB) = 20 log $|\tau|$

$$\tau = \frac{VSWR-1}{VSWR+1}$$

First Voltage Min and Max

- In Smith Chart, the distance of the voltage minimum and maximum from the load can be measured.
- The voltage minimum and maximum repeat every $\lambda/2$.
- Figure below shows the standing wave on the transmission line. The distance occur for voltage minimum are in blue line, while voltage maximum in purple line.



Source: https://en.wikipedia.org

Example

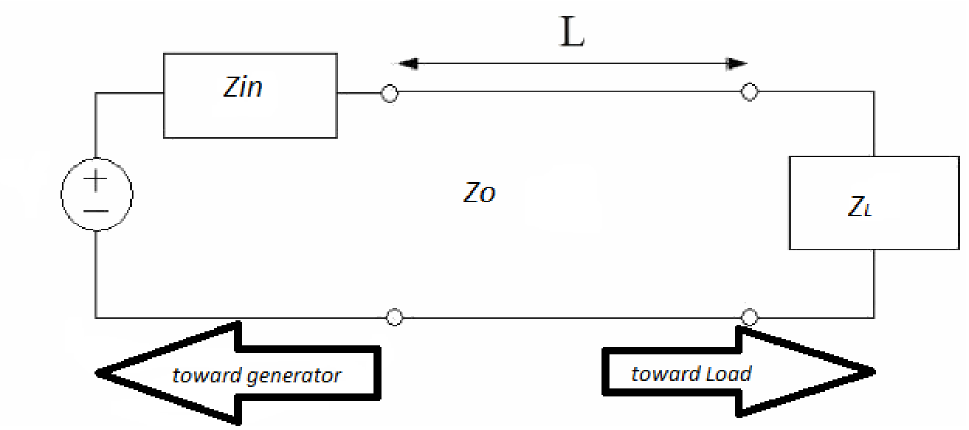
Figure below shows an equivalent circuit of transmission line. A lossless $Z_{o=}$ 50Ω transmission line L= 0.4 λ in length is terminated in $Z_{L.}$ = 60 + j50 *Ω*. Find the:

i. VSWR

ii. Reflection Coefficient

iii. Input impedance (Z_{in})

iv. Distance of first voltage minimum and maximum



Solution (1)

- First step normalized the $Z_{L.}$ = 60 + j50 Ω by divide with $Z_{o=}$ 50Ω . And get Z_L'= 1.2 + j1 Ω
- Plot this Z_L' on the smith chart. (refer next page in Solution (3))

i. VSWR, draw the circle and get the value of 2.5

ii. Reflection Coefficient, $\tau = \frac{Z_L - Z_o}{Z_L + Z_o} = \frac{60+j50-50}{60+j50+50}$ = 0.247+j0.342 = 0.423∟54.25°

Or using the smith chart you can find the reflection coefficient (refer next page)

iii. Input impedance (Z_{in}), extend the line of Z_L ' and get the (WTG) wavelength toward generator (0.175λ). Then plus with 0.4λ and get the value of 0.575λ. Note that smith chart is 0.5λ cycle, so 0.575λ-0.5 λ = 0.075 λ. Draw a line from 0.075 λ (WTG) to origin. And the intersection of circle and line is the value of Z_{in}' . De-normalized this value and get 25 + j20 Ω

Solution (2)

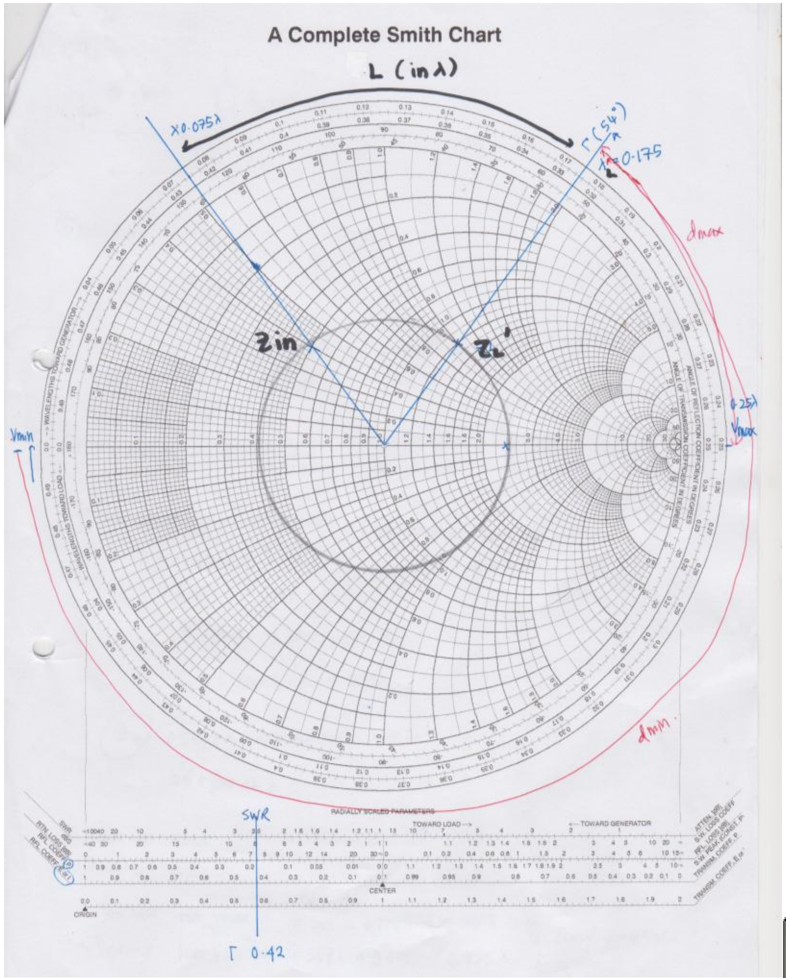
iv. Distance of first voltage minimum and maximum from the load to generator:

Distance 1st Vmax= 0.25λ-0.175λ= 0.075λ

Distance 1st Vmin= 0.25λ+0.075λ= 0.325λ

- Note: if given the frequency operation, the value of distance can be presented in unit meter.

Solution (3)


A Complete Smith Chart
L (in λ)
Zin
ZL'
SWR
Γ 0.42
dmax
dmin
Vmin
Vmax

References

[1] C.A. Balanis:"Antenna Theory: Analysis & Design", John Wiley & Sons, 2012.

[2] Stutzman and Thiele, *Antenna Theory and Design*, John Wiley, 2012.

[3] T. A. Milligan, "Modern Antenna Design" John Wiley, 2nd edition, 2005.

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Author Information

Nor Hadzfizah Binti Mohd Radi
Lecturer
FKEE, UMP
email
hadzfizah@ump.edu.my