High-Speed Electronics in Practice

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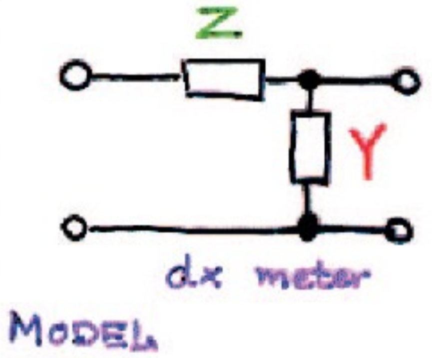
MM12. Smith Chart

Recall



KSN

$$Z = R + j\omega L \quad [\Omega/m]$$
$$Y = G + j\omega C \quad [S/m]$$

For Lossless model

$$Z = j\omega L$$
$$Y = j\omega C$$

Primary cable constant L, C $[H/m, \; F/m]$

Secondary cable constant

$$Z_0 = \sqrt{\frac{L}{C}} \quad [\Omega]$$
$$\gamma = \alpha + j\beta \quad [m^{-1}]$$
$$\alpha = 0 \quad [Np/m]$$
$$\beta = \omega\sqrt{LC} = \frac{\omega}{v} \quad [rad/m]$$

Solutions

$$V(x) = V^{+}e^{-j\beta x} + V^{-}e^{+j\beta x}$$
$$I(x) = I^{+}e^{-j\beta x} + I^{-}e^{+j\beta x}$$
$$= \frac{1}{Z_0}\left[V^{+}e^{-j\beta x} - V^{-}e^{+j\beta x}\right]$$

Recall

$$K_L = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad [\cdot]$$

Lossless

$$K(x) = K_L \cdot e^{2\gamma x} \qquad \left(= K_L \cdot e^{2j\beta x}\right)$$

$$K(x) = \frac{Z(x) - Z_0}{Z(x) + Z_0} \qquad [\cdot]$$

$$Z(x) = Z_0 \cdot \frac{1 + K(x)}{1 - K(x)} \qquad [\Omega]$$

Lossless

$$V = \frac{1}{\sqrt{LC}} = \frac{\omega}{\beta} \qquad [m/s]$$

$$\lambda = \frac{2\pi}{\beta} = \frac{v}{f} \qquad [m]$$

$$V_{max} = C = 300\ m/\mu s$$

Recall

1. Calculate between the primary and secondary cable constant

$$L, C, R, G \longleftrightarrow Z_0, \gamma$$

2. Calculate K_L from Z_O and Z_L

3. Calculate between the impedance and reflection coefficient.

$$K(x) \longleftrightarrow Z(x)$$

4. Calculate voltage and current

$$V(x), I(x), V^+(x), V^-(x), I^+(x), I^-(x)$$

5. Calculate transmission and loss power

$$P_{TRANS}(x), P_{TAB}(x)$$

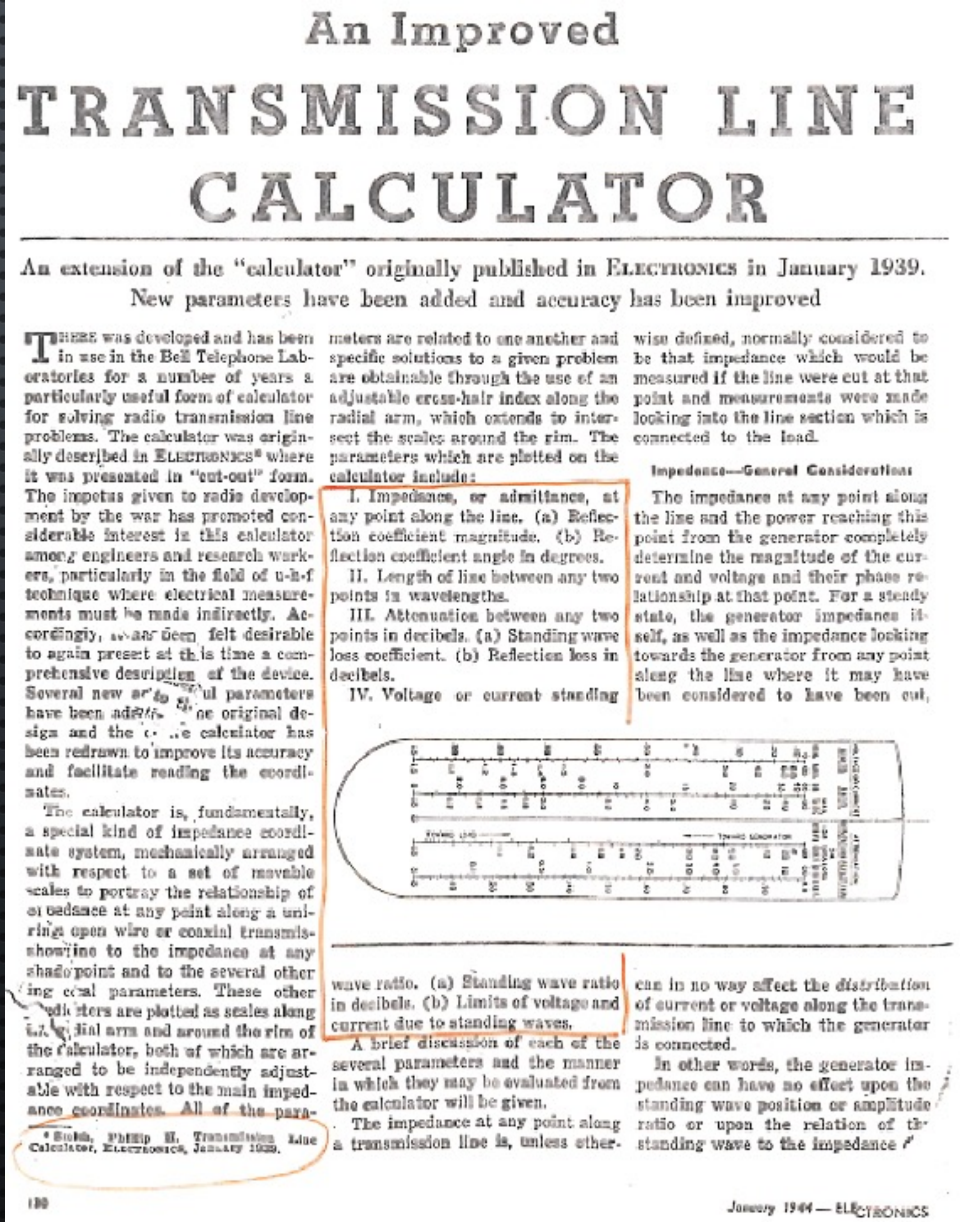
SMITH CHART

Targets:

1. Read "Grundlmggende Transmissionsledningsteori" (Page 53-84) (before or after the lecture)
2. Be able to calculate for single stub impedance transformer (lecture)
3. Finish the exercise (after the lecture)

Smith Chart

Article by Phillip H. Smith in January 1939.



An Improved

TRANSMISSION LINE CALCULATOR

An extension of the "calculator" originally published in ELECTRONICS in January 1939. New parameters have been added and accuracy has been improved

THERE was developed and has been in use in the Bell Telephone Laboratories for a number of years a particularly useful form of calculator for solving radio transmission line problems. The calculator was originally described in ELECTRONICS* where it was presented in "cut-out" form. The impetus given to radio development by the war has promoted considerable interest in this calculator among engineers and research workers, particularly in the field of u-h-f technique where electrical measurements must be made indirectly. Accordingly, it has been felt desirable to again present at this time a comprehensive description of the device. Several new useful parameters have been added to the original design and the calculator has been redrawn to improve its accuracy and facilitate reading the coordinates.

The calculator is, fundamentally, a special kind of impedance coordinate system, mechanically arranged with respect to a set of movable scales to portray the relationship of impedance at any point along a uniform open wire or coaxial transmission line to the impedance at any other point and to the several other parameters. These other parameters are plotted as scales along the radial arm and around the rim of the calculator, both of which are arranged to be independently adjustable with respect to the main impedance coordinates. All of the parameters are related to one another and specific solutions to a given problem are obtainable through the use of an adjustable cross-hair index along the radial arm, which extends to intersect the scales around the rim. The parameters which are plotted on the calculator include:

I. Impedance, or admittance, at any point along the line. (a) Reflection coefficient magnitude. (b) Reflection coefficient angle in degrees.

II. Length of line between any two points in wavelengths.

III. Attenuation between any two points in decibels. (a) Standing wave loss coefficient. (b) Reflection loss in decibels.

IV. Voltage or current standing wave ratio. (a) Standing wave ratio in decibels. (b) Limits of voltage and current due to standing waves.

A brief discussion of each of the several parameters and the manner in which they may be evaluated from the calculator will be given.

The impedance at any point along a transmission line is, unless otherwise defined, normally considered to be that impedance which would be measured if the line were cut at that point and measurements were made looking into the line section which is connected to the load.

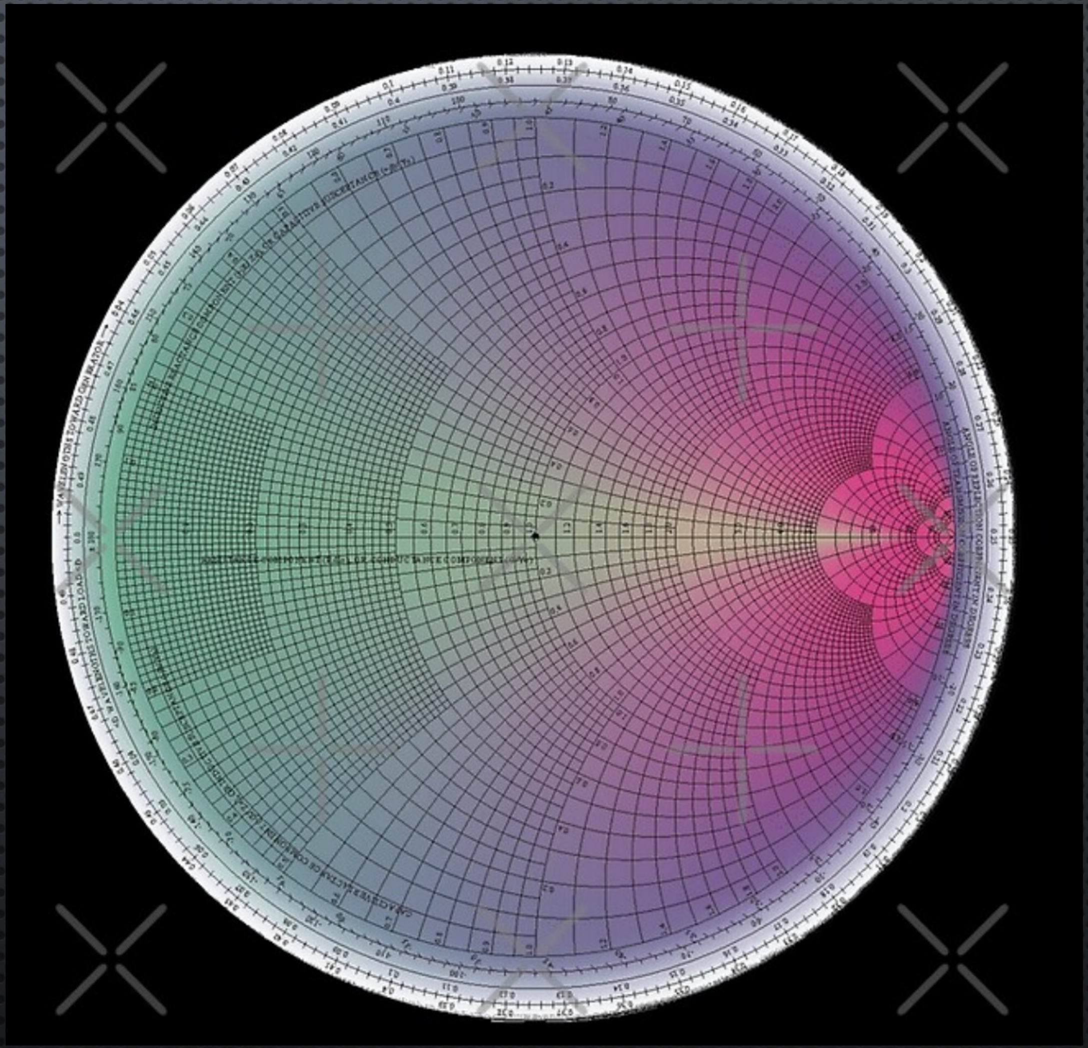
Impedance—General Considerations

The impedance at any point along the line and the power reaching this point from the generator completely determine the magnitude of the current and voltage and their phase relationship at that point. For a steady state, the generator impedance itself, as well as the impedance looking towards the generator from any point along the line where it may have been considered to have been cut, can in no way affect the distribution of current or voltage along the transmission line to which the generator is connected.

In other words, the generator impedance can have no effect upon the standing wave position or amplitude ratio or upon the relation of the standing wave to the impedance

* Smith, Phillip H., Transmission Line Calculator, ELECTRONICS, January 1939.

Smith Chart



Blackboard (1)

Smith Chart

$$Z_n = \frac{1+K}{1-K} = \frac{(1+u)+jv}{(1-u)-jv}$$

$$r + jx = \frac{1-u^2-v^2}{(1-u)^2+v^2} + j\,\frac{2v}{(1-u)^2+v^2}$$

PLANER :

$z = r + jx$

$K = u + jv$

Smith Chart

r-cirkler

$$r = \frac{1 - u^2 - v^2}{(1-u)^2 + v^2}$$

$$\Rightarrow \quad \left(u - \frac{r}{r+1}\right)^2 + v^2 = \left(\frac{1}{r+1}\right)^2$$

CENTRUM: $\left(\frac{r}{r+1}, 0\right)$

RADIUS: $(\pm)\ \frac{1}{r+1}$

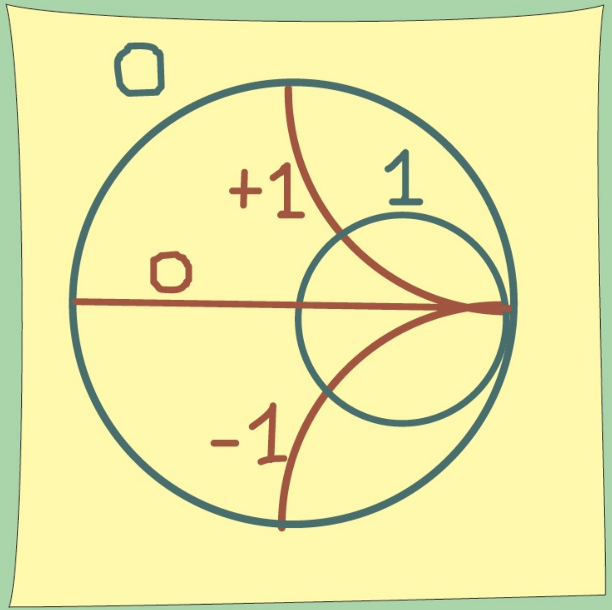
x-cirkler

$$x = \frac{2v}{(1-u)^2 + v^2}$$

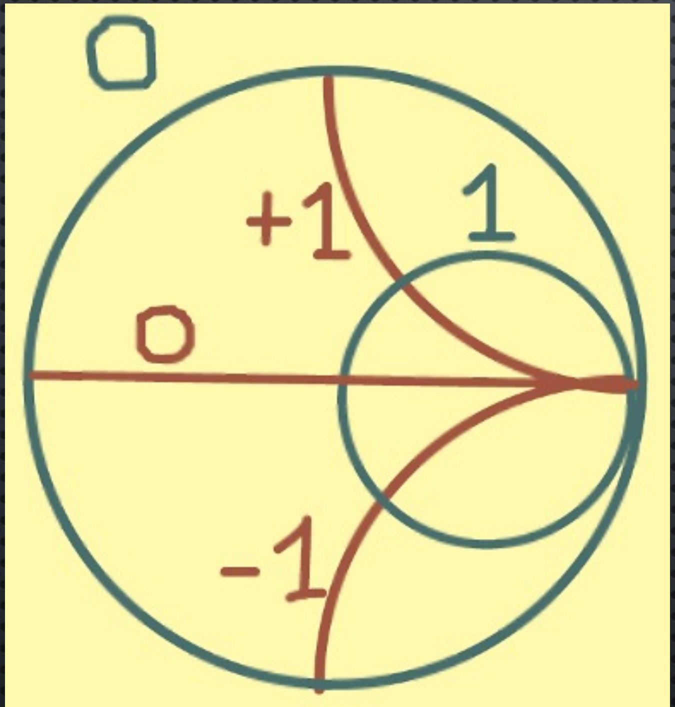
$$\Rightarrow \quad (u-1)^2 + \left(v - \frac{1}{x}\right)^2 = \left(\frac{1}{x}\right)^2$$

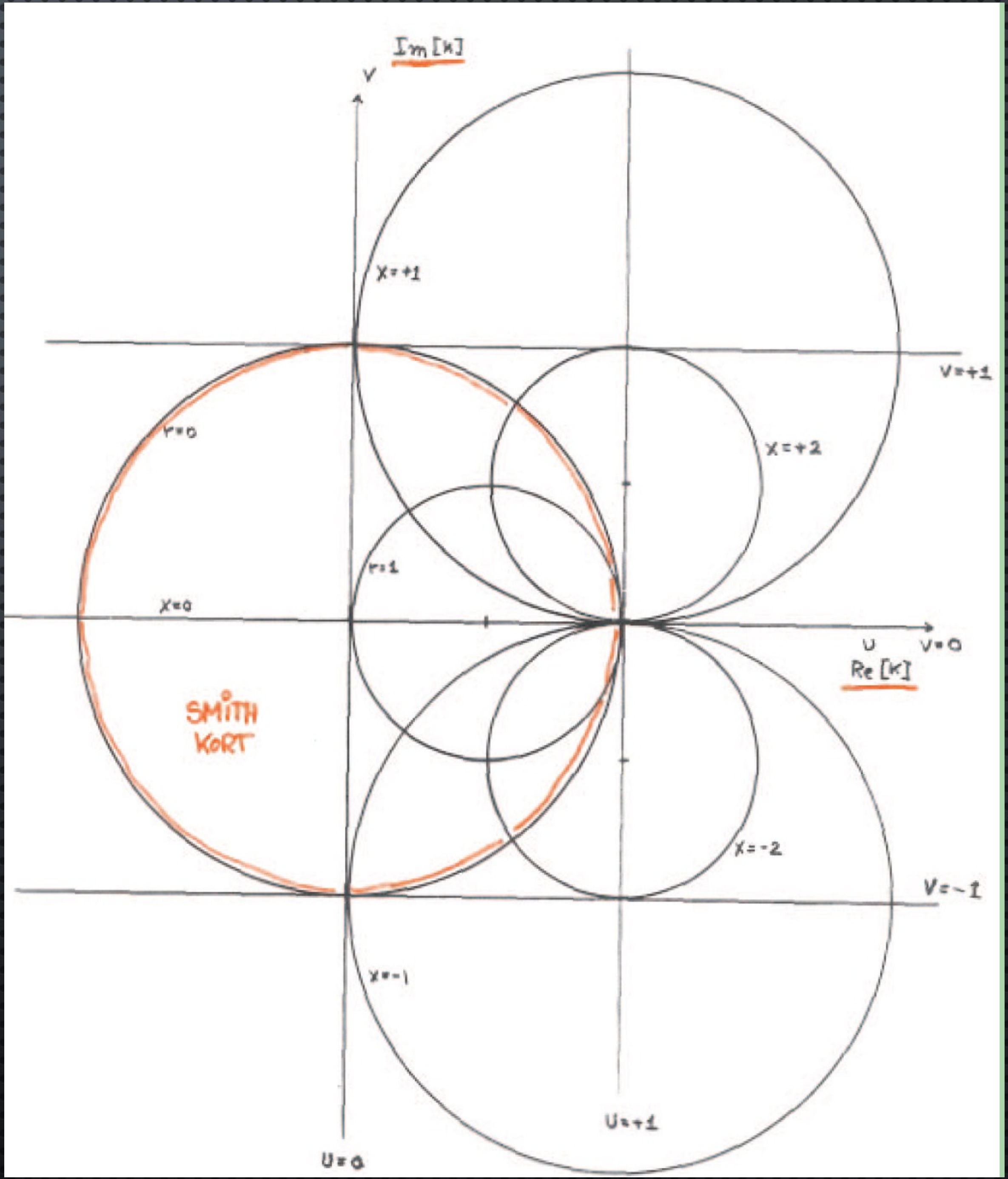
CENTRUM: $\left(1, \frac{1}{x}\right)$

RADIUS: $\pm \frac{1}{x}$



Smith Chart



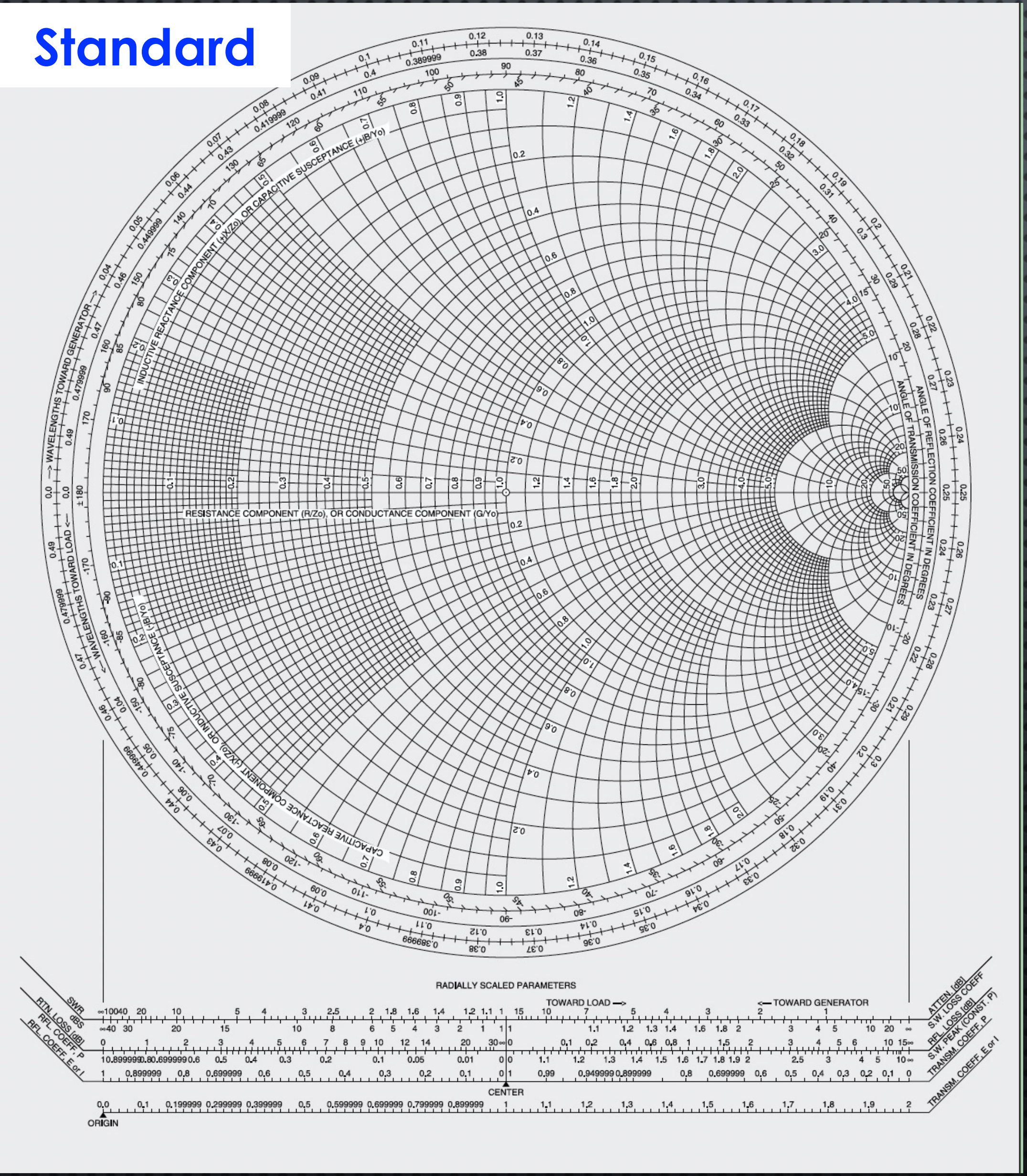


Smith chart is the expression of impedance coordinate in a K-plane

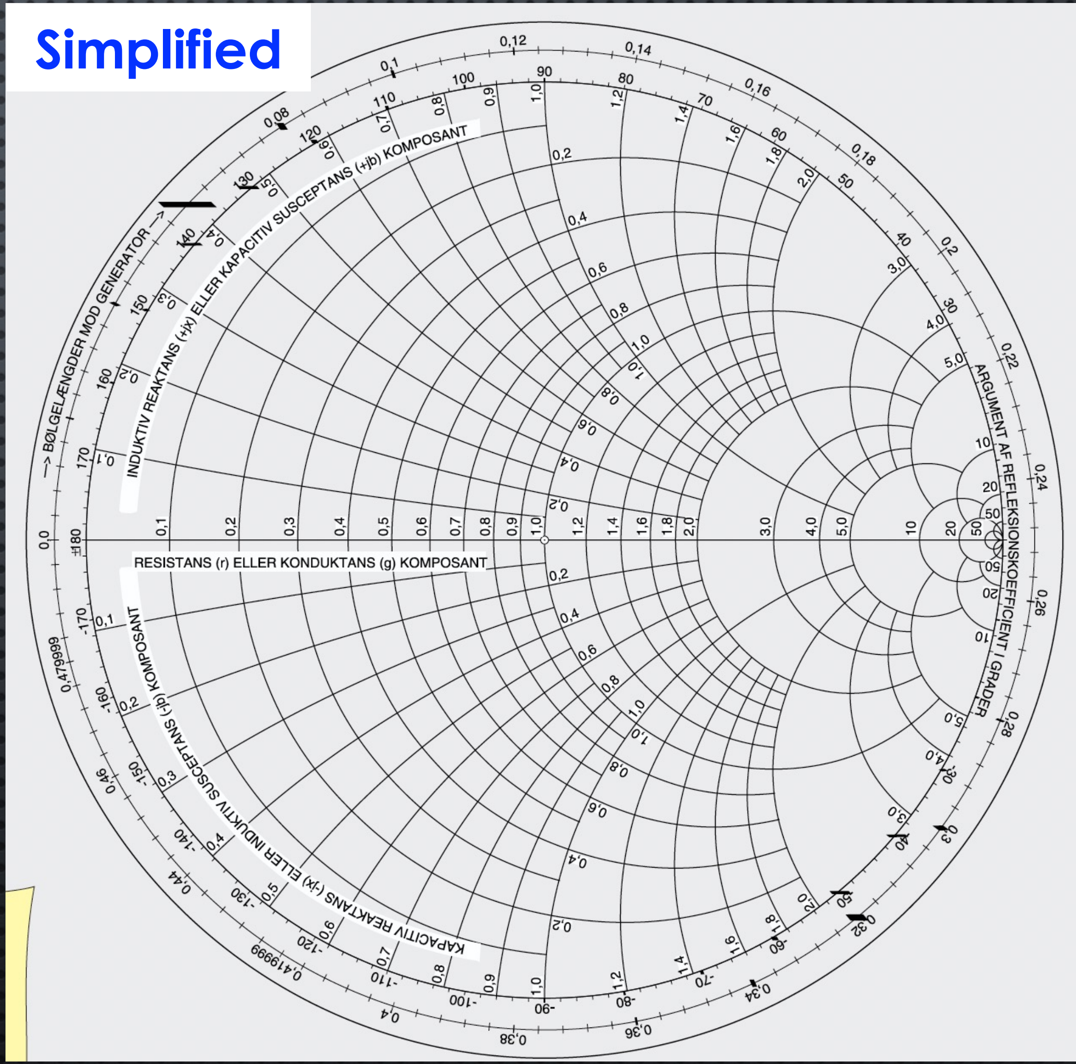
Blackboard (2)

Smith Chart

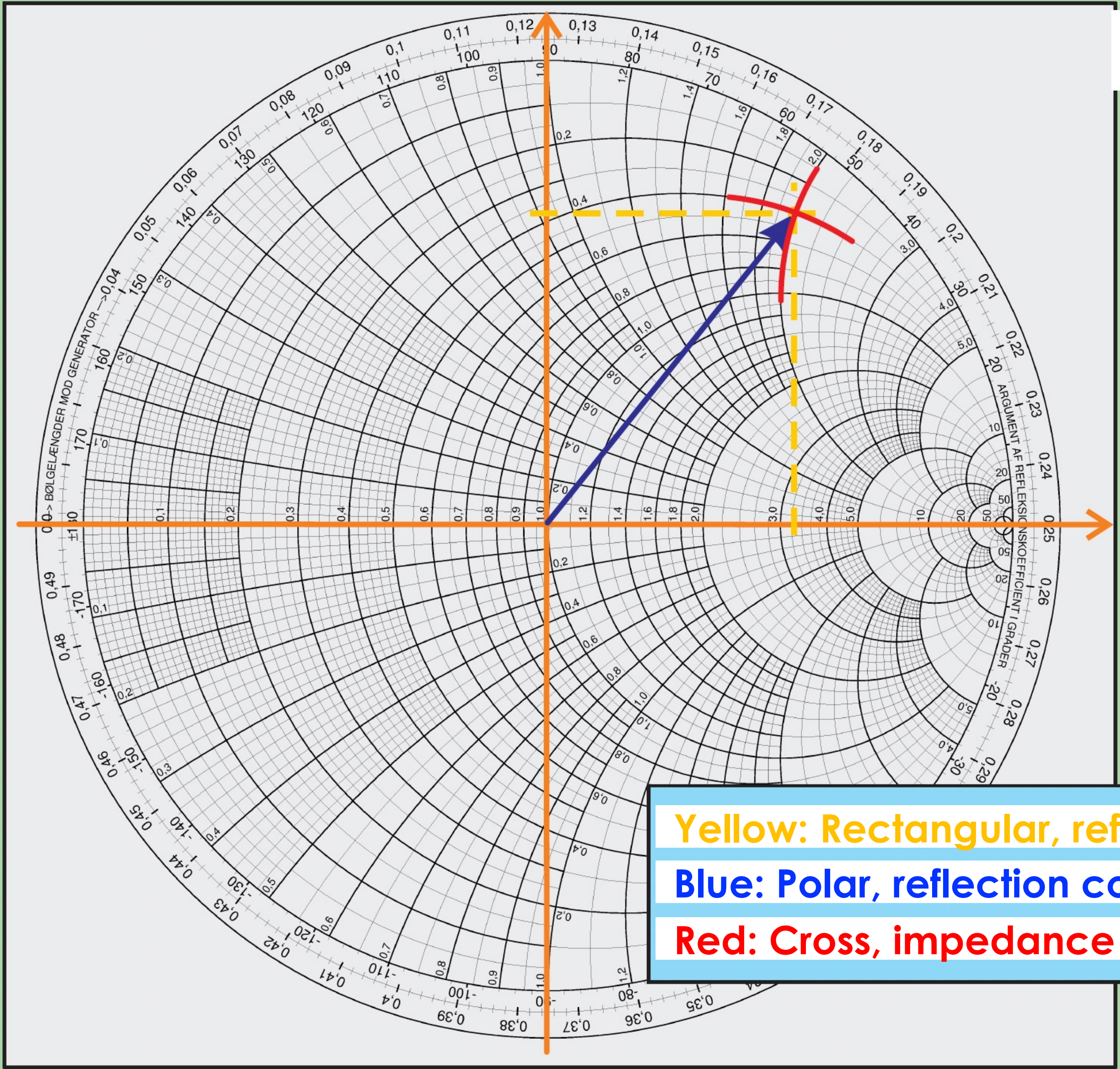
Standard



Simplified



Smith Chart

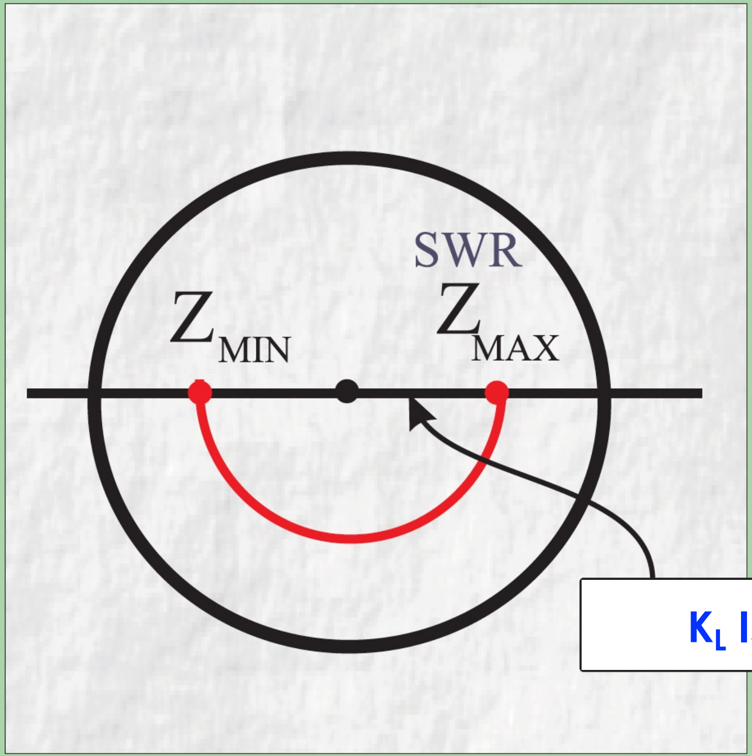


three coordinate systems

Yellow: Rectangular, reflection coefficient	0,53 + j0,67
Blue: Polar, reflection coefficient	0,86 ∠ 52°
Red: Cross, impedance	0,4 + j2,0

Smith Chart

Maximum and minimum real impedance



K_L Is real

$$Z_{MAX} = Z_0 \cdot SWR$$

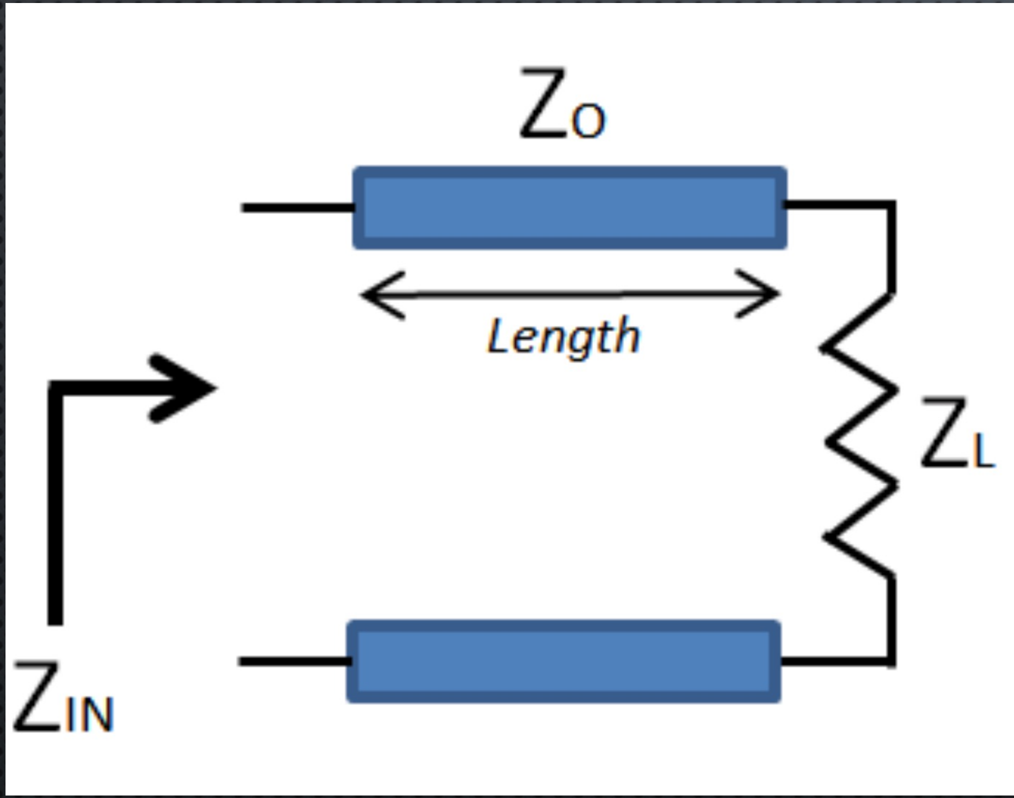
$$Z_{MIN} = \frac{Z_0}{SWR}$$

$$SWR = \frac{V_{MAX}}{V_{MIN}} = \frac{1 + |K_L|}{1 - |K_L|}$$

$$Z_{MAX} = \frac{V_{MAX}}{I_{MIN}} = Z_0 \cdot \frac{1 + |K_L|}{1 - |K_L|}$$

Calculation of Input Impedance

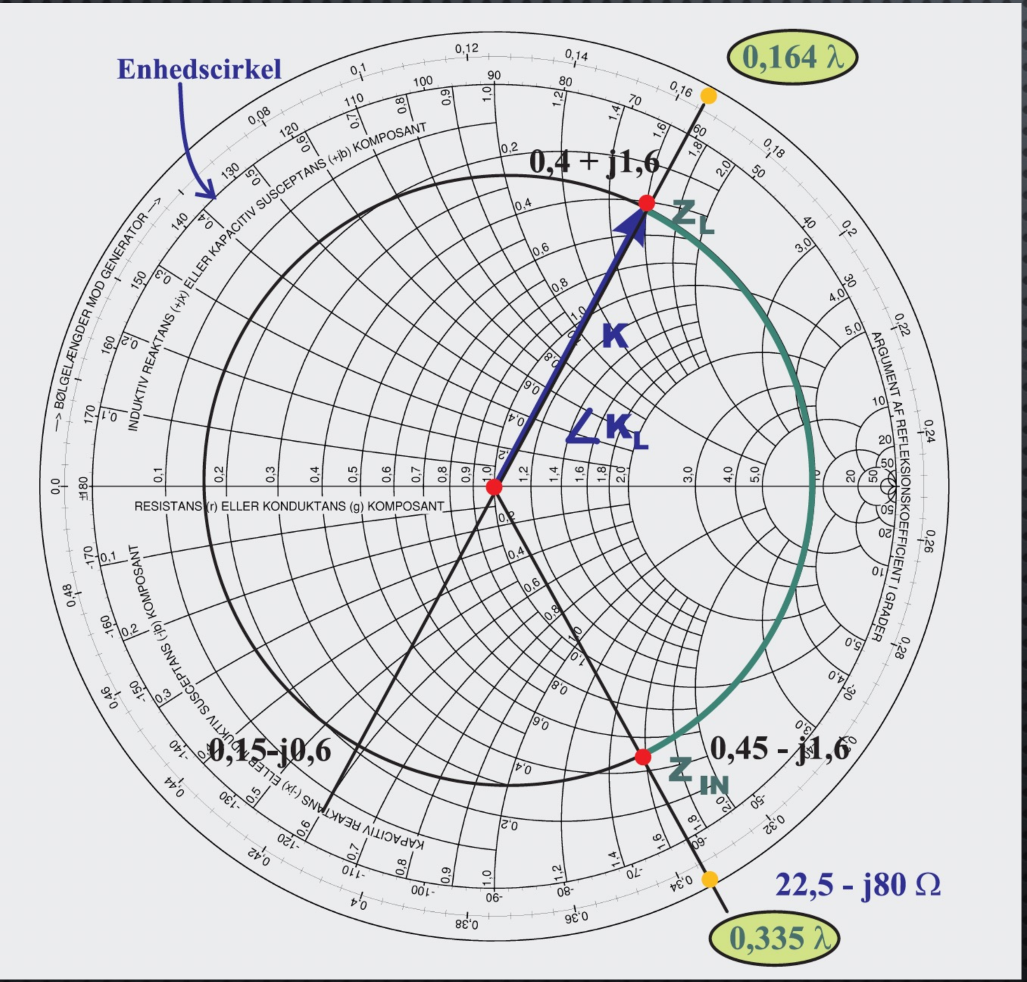
Example:



Z_O = 50 ohm, Z_L = 20+j80 ohm, Length L = 0.171 λ
Find out Z_{in} with smith chart.

Calculation of Input Impedance

Example:



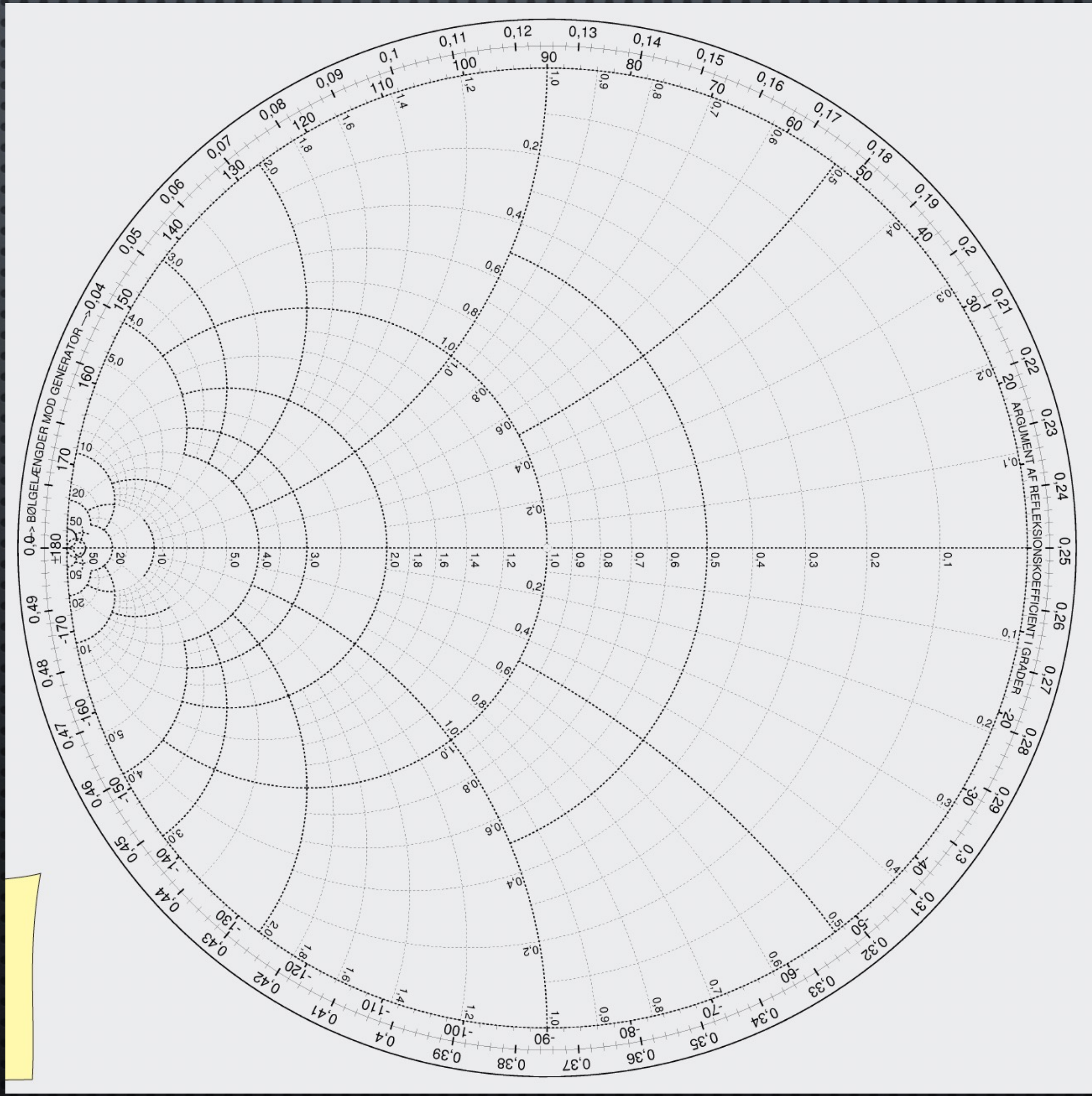
Z_O = 50 ohm, Z_L = 20+j80 ohm, Length L = 0.171 λ
Find out Z_{in} with smith chart.

Solution:
Normalizing Z_L
$Z_n = Z_L / Z_O = (20+j80)/50 = 0.4+j1.6$

Apply smith chart and turn 0.171 λ clockwise (moving from load to source direction)
Zin = Z_O (0.45-j1.6)= 22.5-j80 ohm

Admittance chart

Blackboard (3)



Admittance Chart

1. The mirror of impedance chart according to the center.

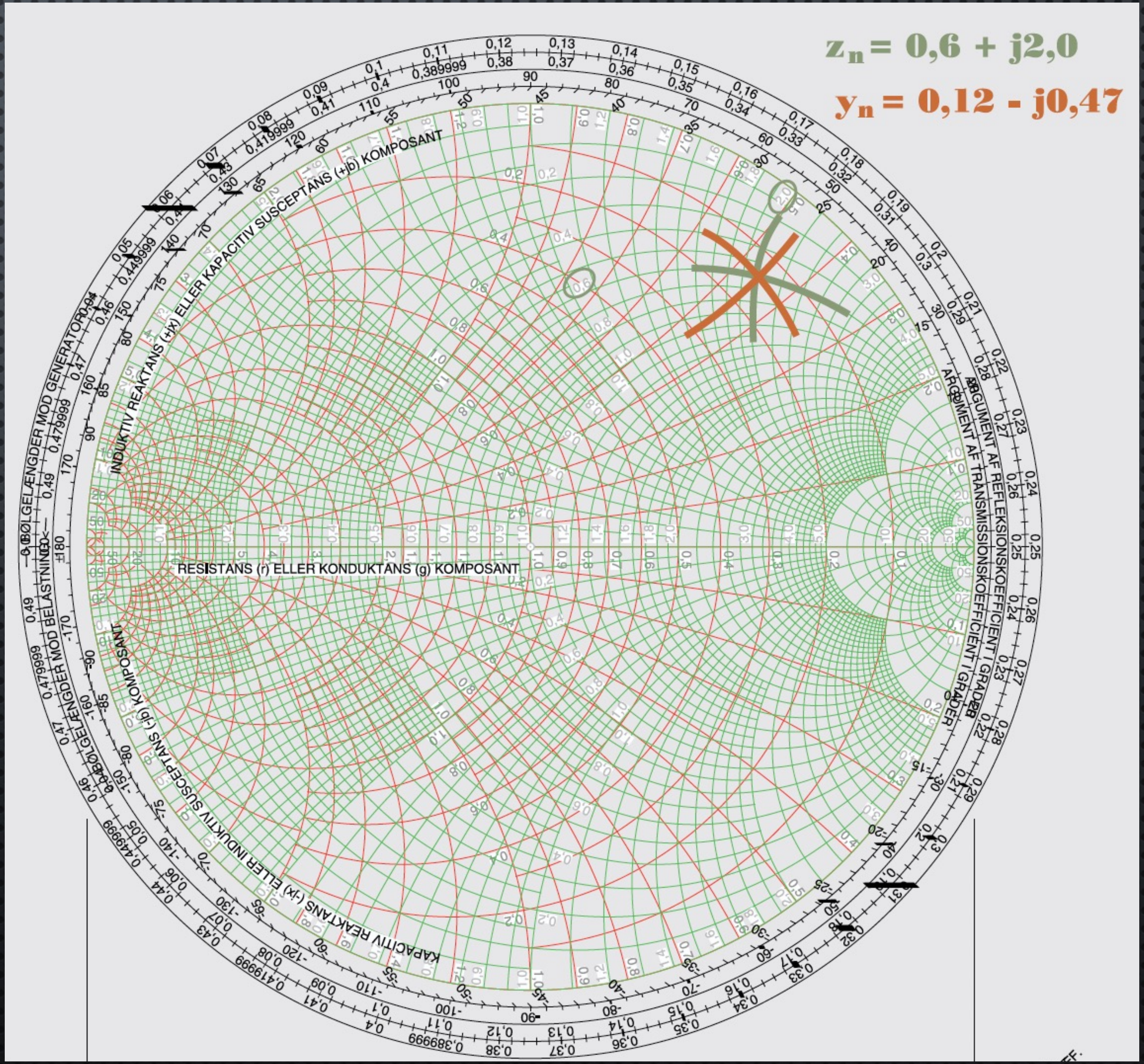
2. By Rotating smith impedance chart around the center by 180 degree, the impedance chart will be changed to admittance chart.

One chart for impedance and admittance

Solution1:
Immittance chart

Immittance Chart
(impedance+admittance)

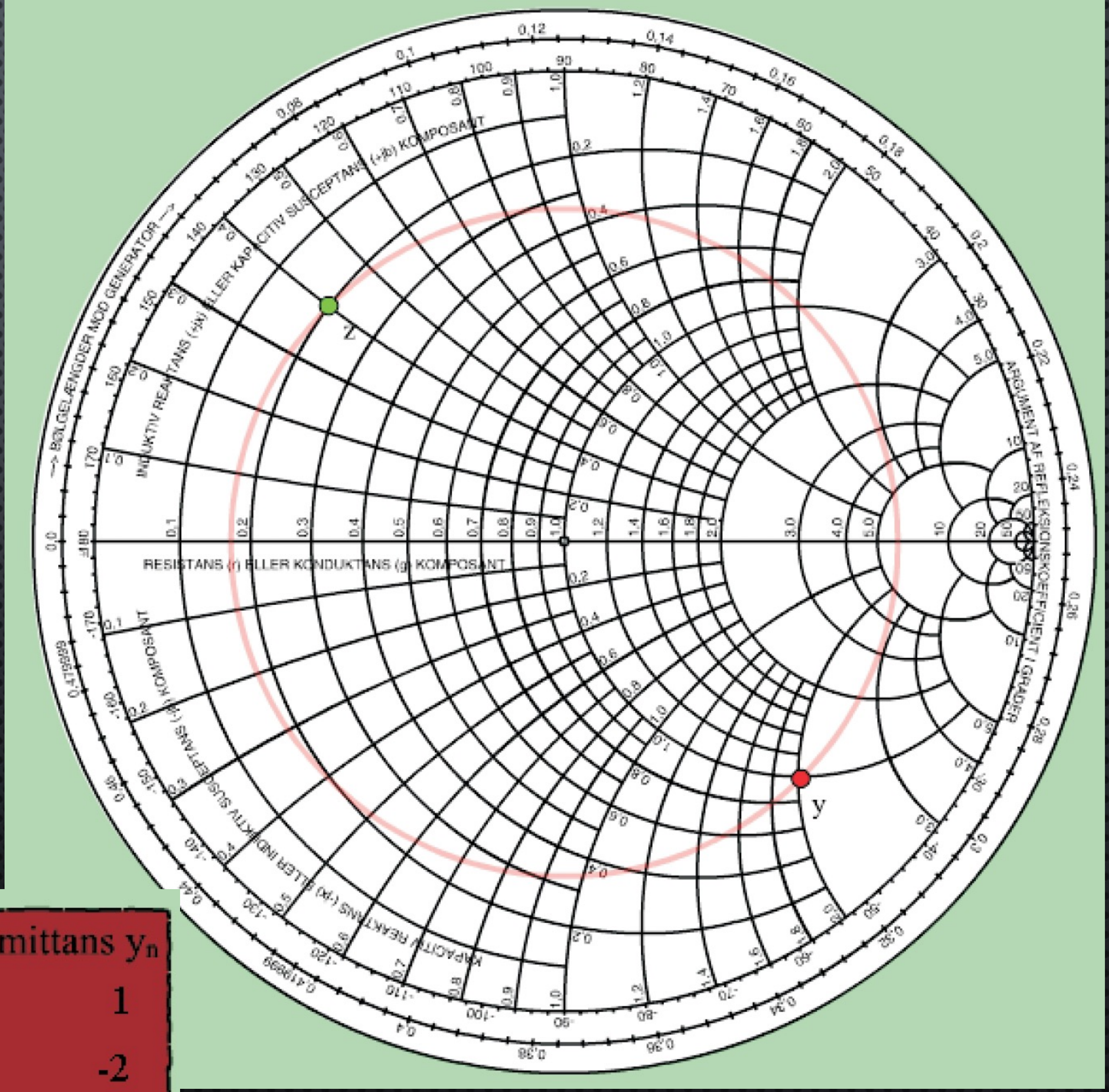
One point shows both impedance and its admittance



One chart for impedance and admittance

Solution 2: Smith chart for both impedance and admittance

By Rotating smith impedance chart around the center by 180 degree, the impedance chart will be changed to admittance chart.



Impedans z_n	
r =	0.2
x =	0.4

Admittans y_n	
g =	1
b =	-2

Single Stub Impedance Transformer

Lukket stub

$Z = 0$

$Y = \infty$

$K_L = \frac{Z - Z_0}{Z + Z_0} = -1$

ℓ	$Z(x)$
0	0
$\frac{\lambda}{8}$	jX (spole)
$\frac{\lambda}{4}$	∞
$\frac{3}{8}\lambda$	$-jX$ (kondensator)
$\frac{\lambda}{2}$	0

Quarter wavelength difference

$$Z(x) = Z_0 \cdot \frac{1 + K(x)}{1 - K(x)} \qquad [\Omega]$$

$$K(x) = K_L \cdot e^{j2\beta x} \qquad [\cdot]$$

$$K_L = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad [\cdot]$$

Åben stub

$Z = \infty$

$Y = 0$

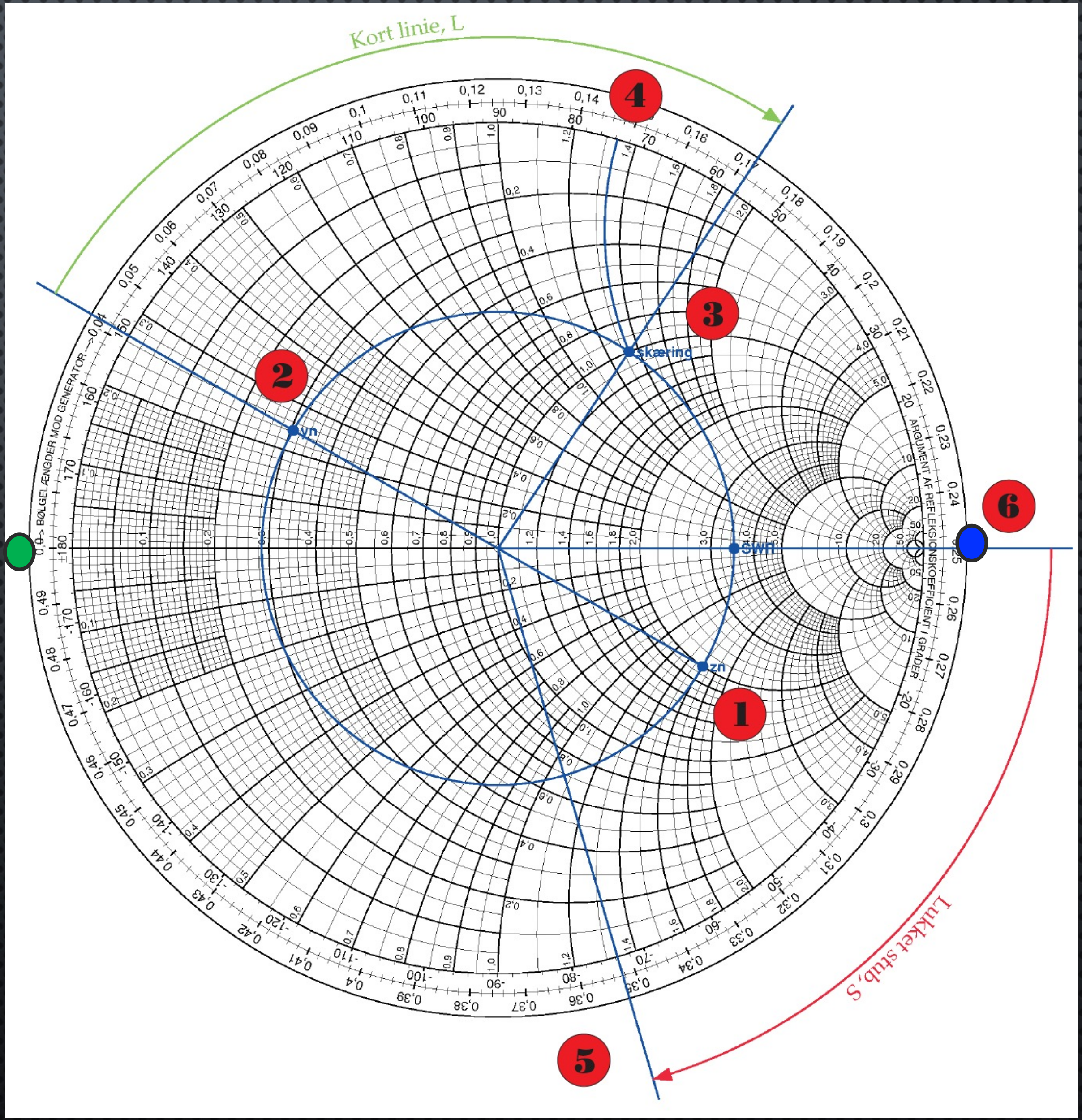
$K_L = \frac{Z - Z_0}{Z + Z_0} = +1$

ℓ	$Z(x)$
0	∞
$\frac{\lambda}{8}$	$-jX$ (kond.)
$\frac{\lambda}{4}$	0
$\frac{3}{8}\lambda$	jX (spole)
$\frac{\lambda}{2}$	∞

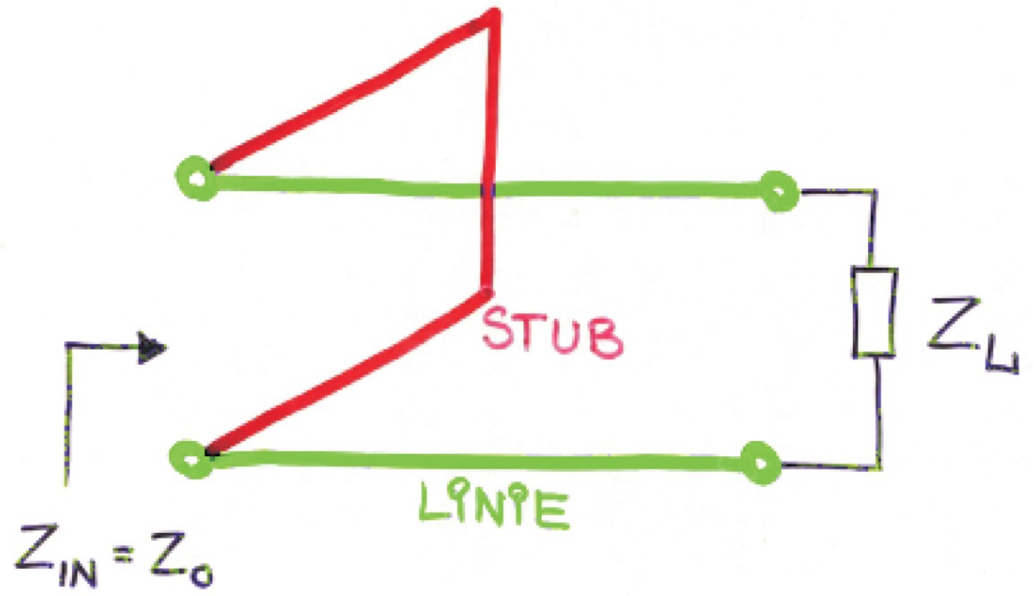
Blackboard (4)

Single Stub Impedance Transformer

1. Rotate clockwise (from load to source direction).
2. It is admittance now. If it is short-circuit stub, start from blue point. If it is open-circuit stub, start from green point.



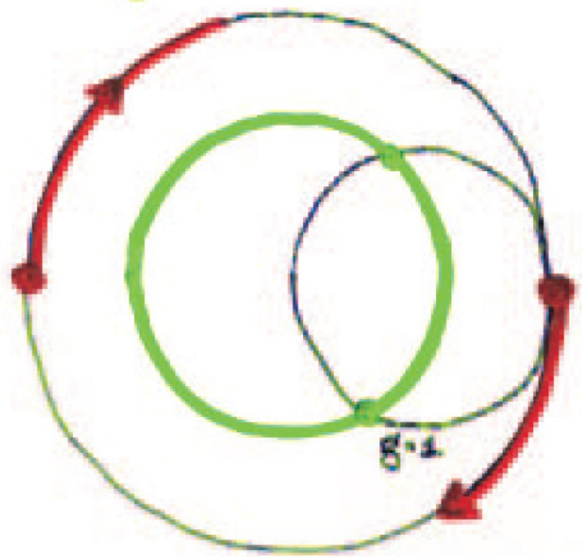
Single Stub Impedance Transformer



There are always 4 solutions:

1. **Short line, open-circuit stub**
2. **Short line, short-circuit stub**
3. **Long line, open-circuit stub**
4. **Long line, short-circuit stub**

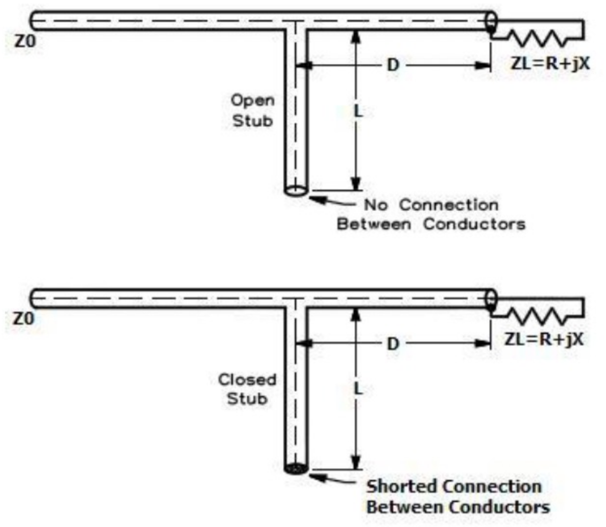
Open circuit

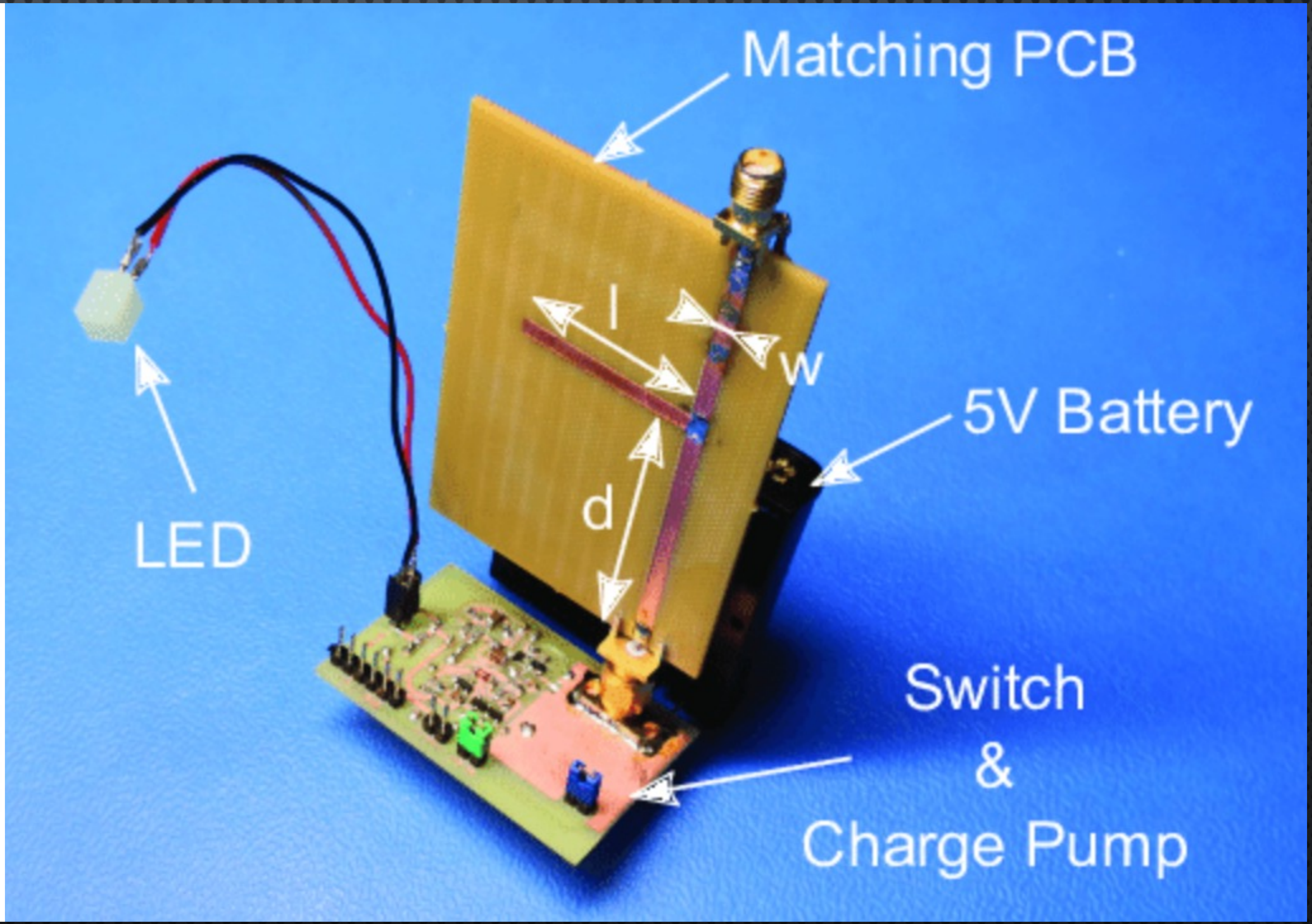


Short circuit

Single Stub Impedance Transformer

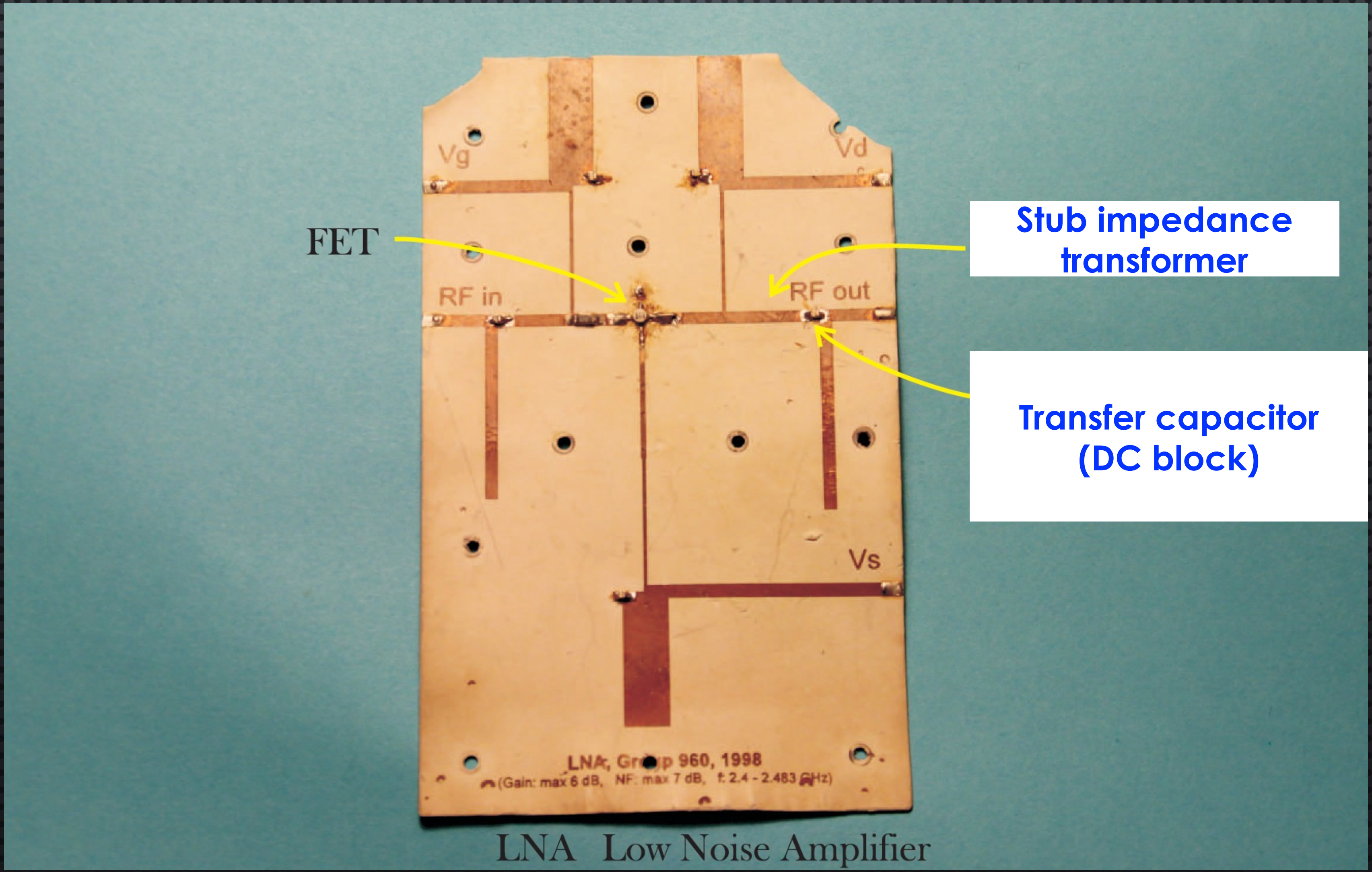
Examples for PCB design





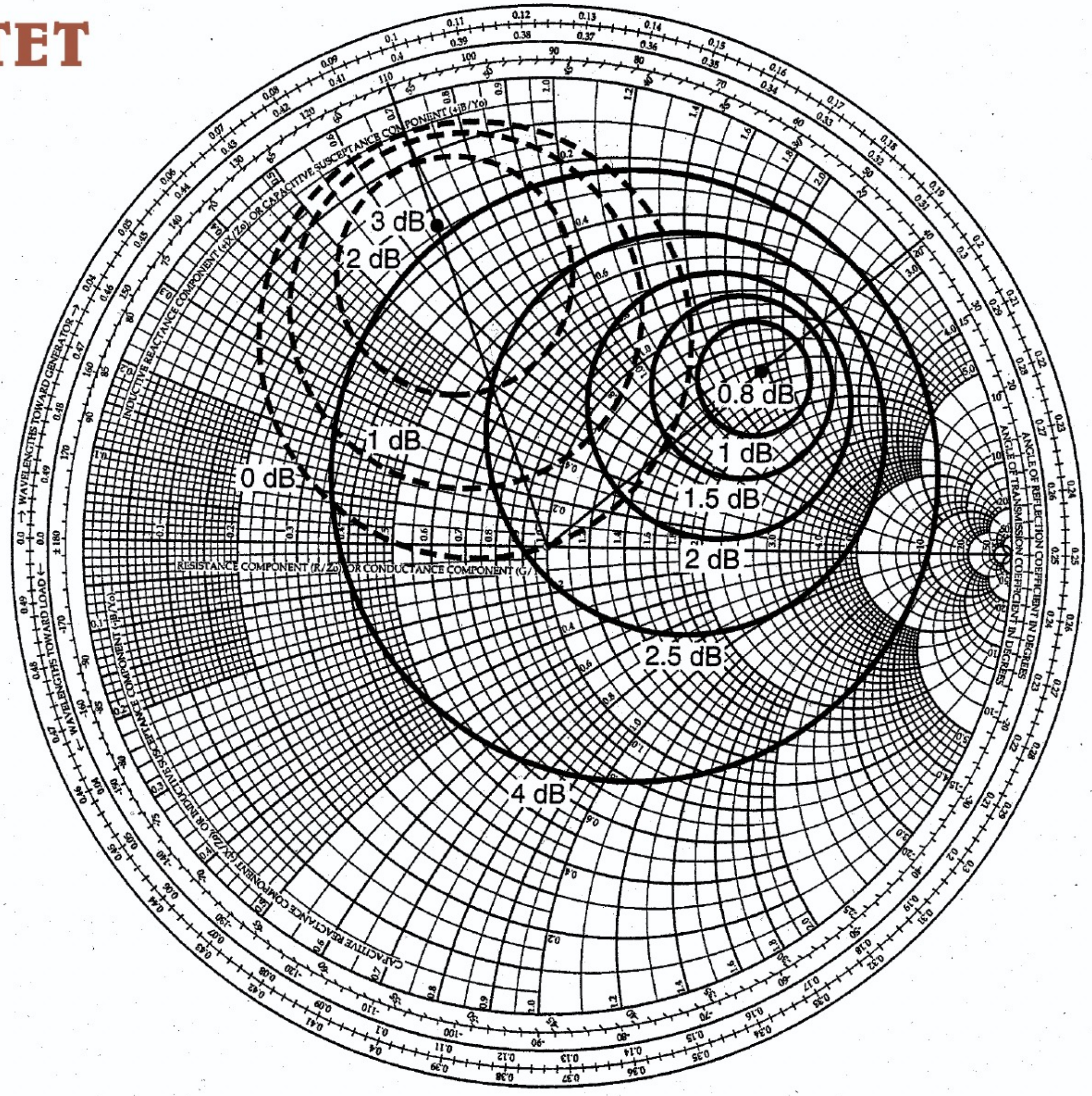
Single Stub Impedance Transformer

Examples for PCB design



Smith chart with other information

CIRKLER I SMITHKORTET



Gonzales, G.:
Microwave Transistor Amplifiers, 2. ed.
Prentice Hall, 1997
ISBN 0-13-254335-4
Fig. 4.3.3 page 302

Figure 4.3.3 Noise figure circles (solid curves) and G_s constant-gain circles (dashed curves). The transistor is a GaAs FET with $V_{DS} = 4$ V, $I_{DS} = 12$ mA, and $f = 6$ GHz.