High-Speed Electronics in Practice

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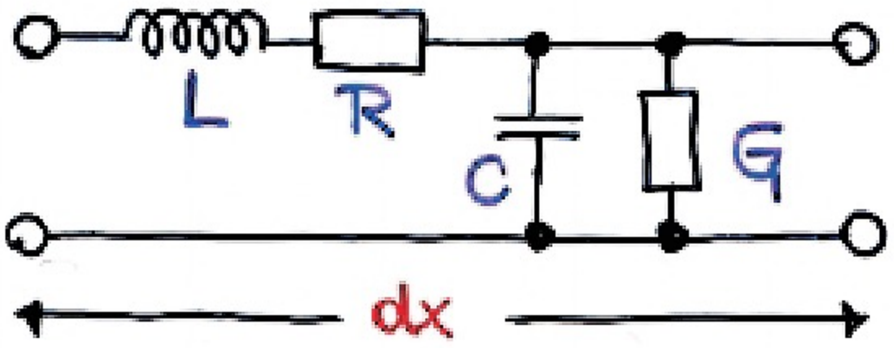
MM11. Standing Waves

Recall

An infinite small cable dx



Primary cable constant

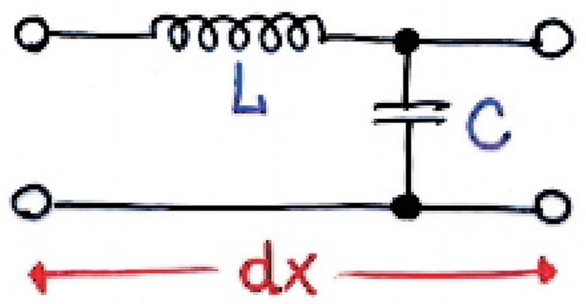
L [H/m] R [Ω/m]

C [F/m] G [S/m]

Recall

Lossless model

$R = 0\ \Omega/m$, $G = 0\ S/m$

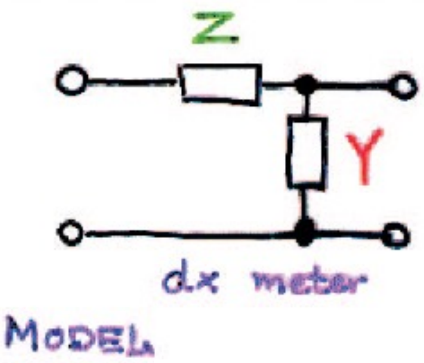


Example

Kabel: RG-58

$L = 250\ nH/m$ $C = 100\ pF/m$

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

$$V(x) = V^+ e^{-j\beta x} + V^- e^{+j\beta x}$$

$$I(x) = I^+ e^{-j\beta x} + I^- e^{+j\beta x}$$

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

STANDING WAVES

Targets:

1. Read "Grundlmggende Transmissionsledningsteori" (Page 47-49, 54-68) (before or after the lecture)

2. Be able to calculate with standing wave curve and reverse standing wave curve (lecture)

3. Finish the exercise (after the lecture)

Transmission Line Calculations

Blackboard (1)

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**

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

Transmission Line Calculations

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

Lossless

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

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

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

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

Lossless

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

$$v_{max} = c = 300\ m/\mu s$$

Euler's Formula

$$e^{jb} = \cos b + j \sin b$$

$$|e^{jb}| = \sqrt{\cos^2 b + \sin^2 b} = 1$$

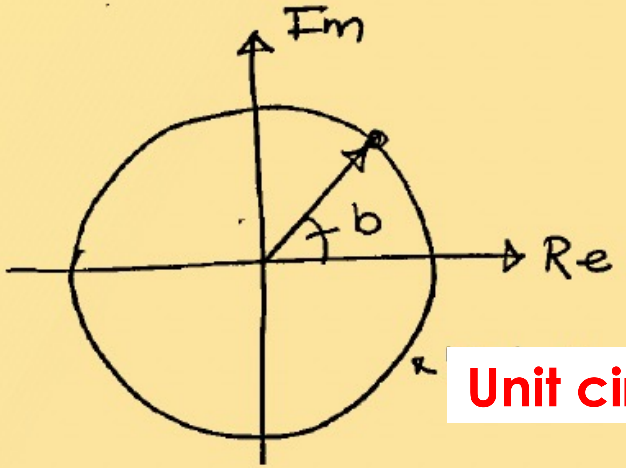
$$\angle e^{jb} = \operatorname{arctg}\left(\frac{\sin b}{\cos b}\right) = \operatorname{arctg}(\operatorname{tg} b) = b$$

$$e^{jb} = 1 \angle b$$

$$e^{j0} = e^{0} = 1$$

$$e^{j\frac{\pi}{2}} = j$$

$$e^{j\pi} = -1$$

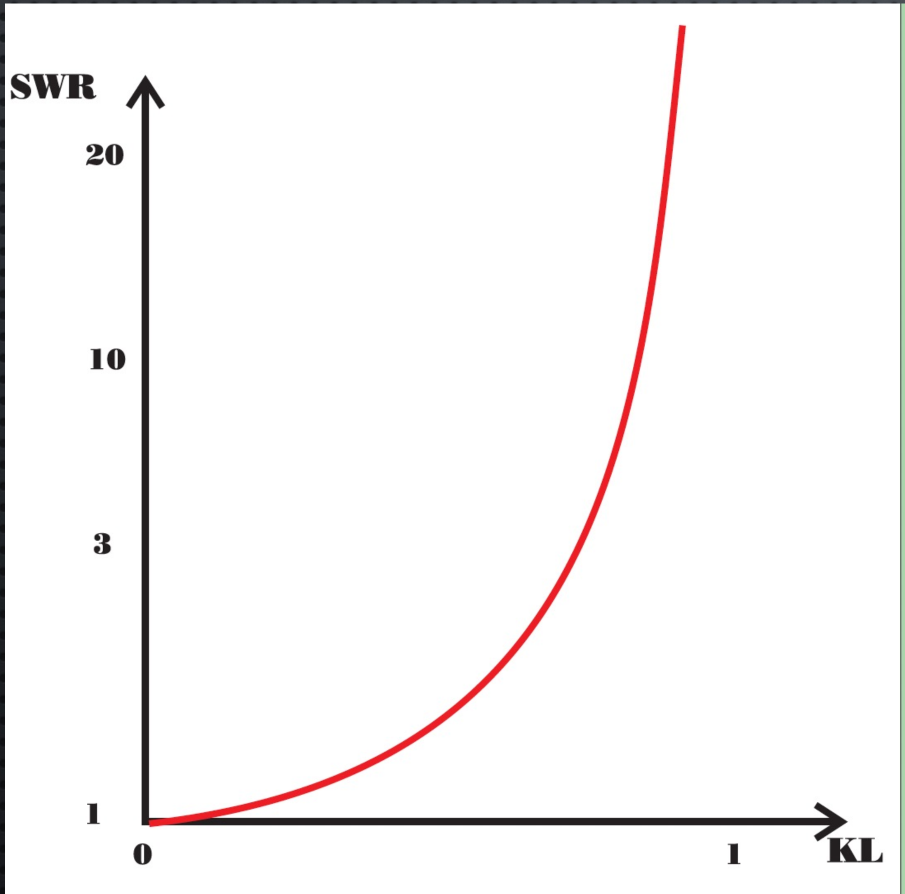


Unit circle

Standing Wave Curve

Blackboard (2)(3)

Relations between K_L and SWR



KL	SWR	Bemærkning
0	1,0	correct termination
±0,1	1,2	Nearly correct
$\pm\frac{1}{3}$	2	
$\pm\frac{1}{2}$	3	
± 1	∞	Short or open

Standing Wave Curve

Transmission problems

If Z_L is not equal to Z_O (SWR not 1), we will have the standing wave. It will lead to the following problems:

1. A wave reflection occurs at the end of the cable.
2. Not all the power can be delivered.
3. It may burn the cable, where the current or voltage can be doubled.
4. Cable impedance depends on its length.

Standing Wave Curve

Example in PCB design

Amplitude of Reflection coefficient K_L is $\frac{VSWR-1}{VSWR+1}$

Amplitude of K_L in power is $20\log\frac{VSWR-1}{VSWR+1}$

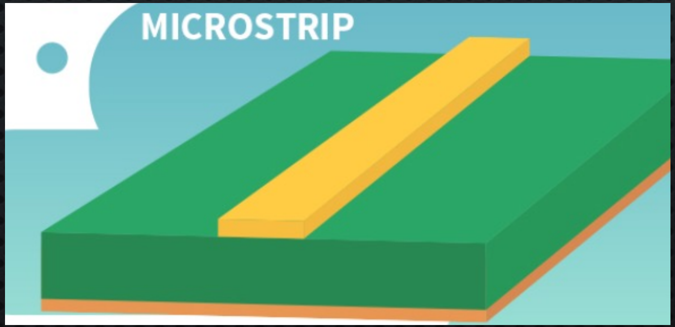
-10 dB Reflection coefficient corresponds to VSWR 2, which -6 dB reflection coefficient corresponds to VSWR 3.

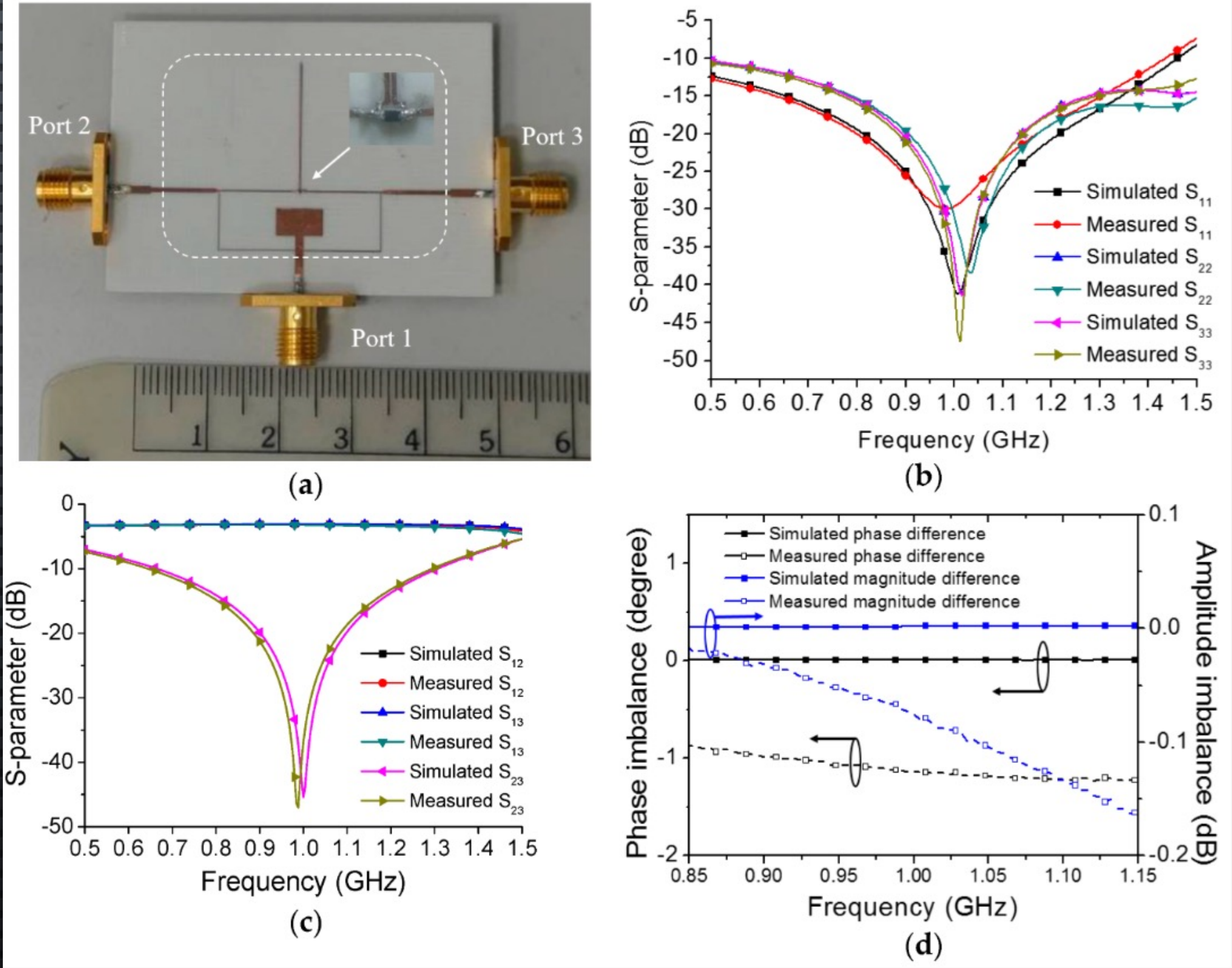
Standing Wave Curve

Example in PCB design (power divider)

Figure 6. (**a**) The photo; (**b**) measured and simulated S_{11}, S_{22}, S_{33}; (**c**) measured and simulated S_{12}, S_{13}, S_{23}; (**d**) measured and simulated phase and amplitude imbalance of the fabricated prototype at 1 GHz.

Network analyzer





Standing Wave Curve

1. Identify the load impedance Z_L . Calculate K_L with polar form. We also need to know the frequency and propagation speed as well as the incident voltage.

2. Determine V_{MAX} and V_{MIN} and draw the diagram. Calculate the wavelength and apply it as the distance between two minima or two maxima.

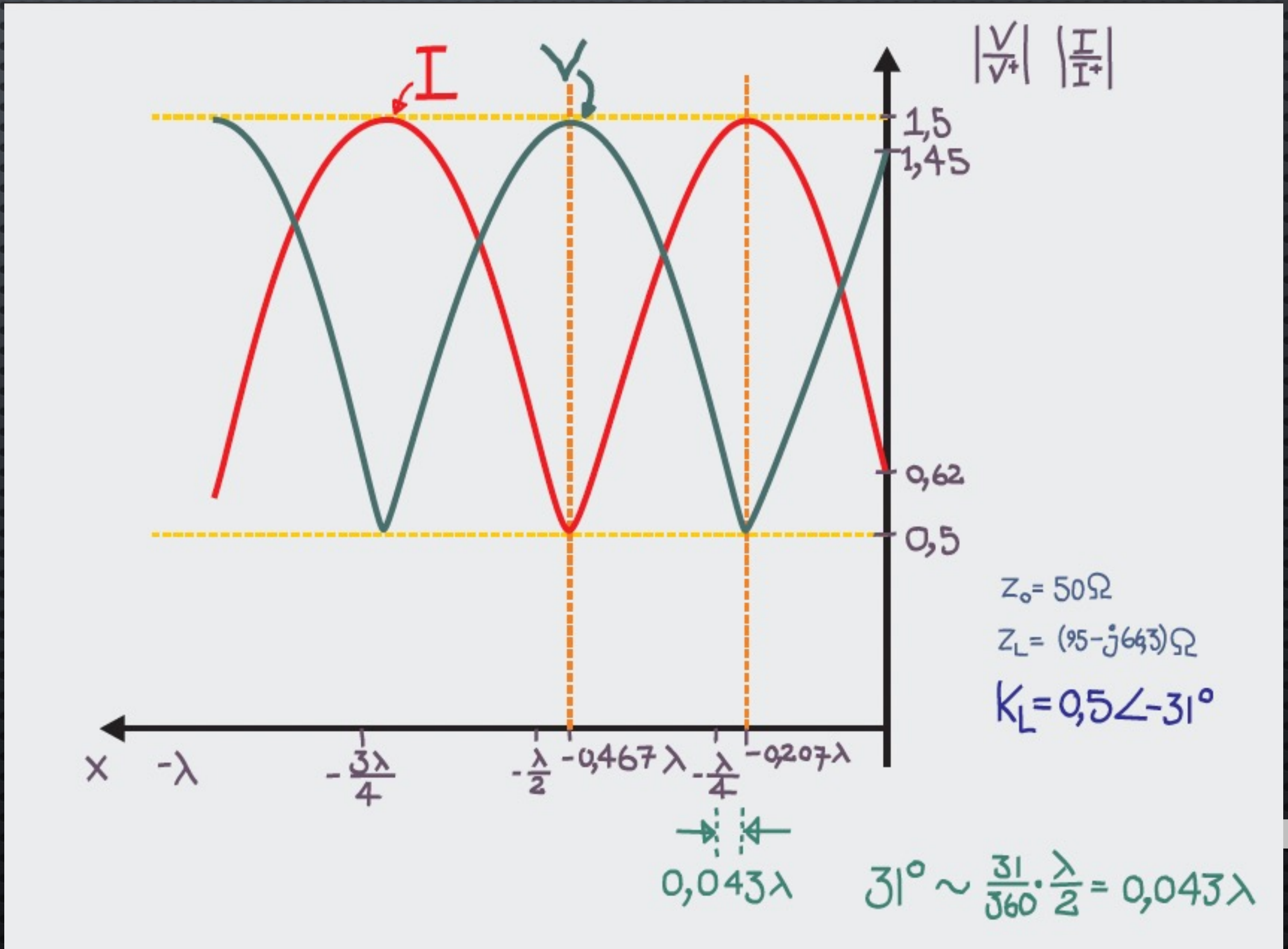
3. Make a pointer chart and decide whether minimum or maximum comes first. There is 360 ° all the way around and this corresponds to half wavelength. The pointer turns clockwise as we drive towards the generator/source. Remember to apply $-K_L$ if it is the current.

4. Calculate the distance from the load to the first minimum or first maximum.

Reverse Standing Wave Curve

Blackboard (4)

Another example for using standing wave curve to determine Z_L



Reverse Standing Wave Curve

1. Find the distance between maxima or between minima. They correspond to half a wavelength. Find the distance between the load and first max or min. It is used when determining the angle of K_L.

2. Find SWR as the ratio between V_{MAX} and V_{MIN}. It is converted to amplitude of K_L. Same method if it is the current that is involved.

3. Using the distance between max or min to find the wavelength. And then together with the propagation speed, it can be converted to frequency.

4. The distance between load and first min or max is converted to wavelength, after which the angle to KL is determined using a pointer diagram. Remember to reverse the pointer for K_L if it is the current.

5. Now both angle and amplitude of K_L are known, and from this Z_L can now be determined. A component realization can be made either as a series connection or as a parallel connection of a resistor and a capacitor or inductor.