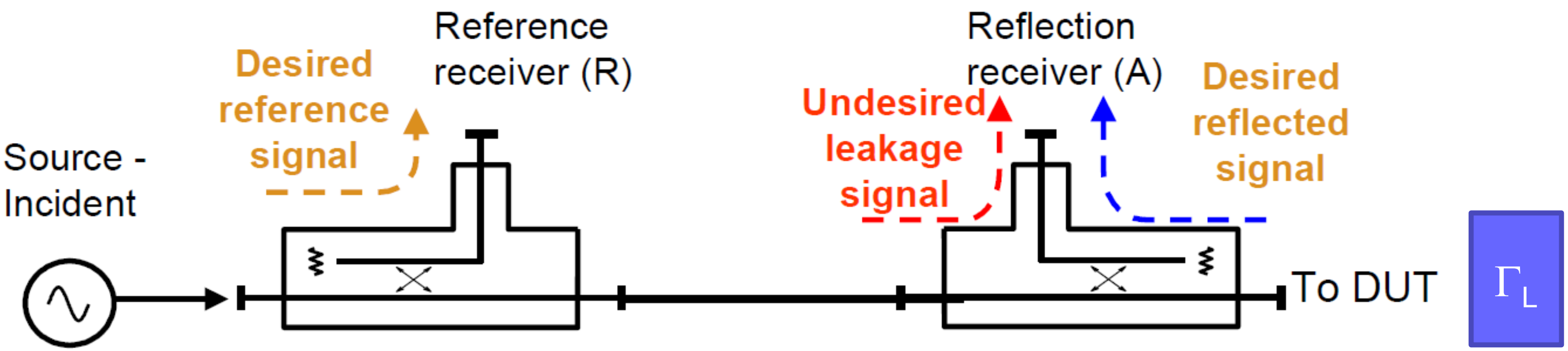
Radiofrequency Measurements

Reflection Measurements

4-port Reflectometer

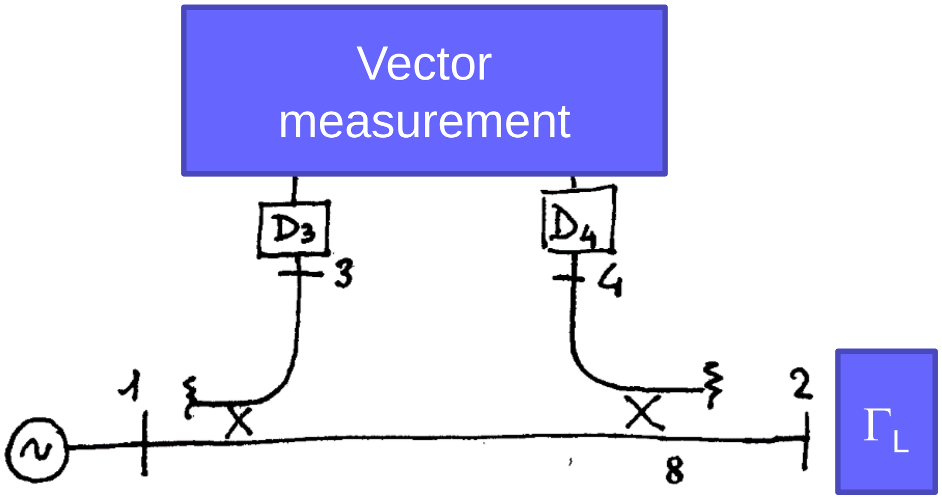
A reflectometer is a circuit for measuring the reflection coefficient of a load, in amplitude and phase.



Sends a small part of the incident signal to R

Sends a small part of the reflected signal to A

4-port Reflectometer



Ideal case:

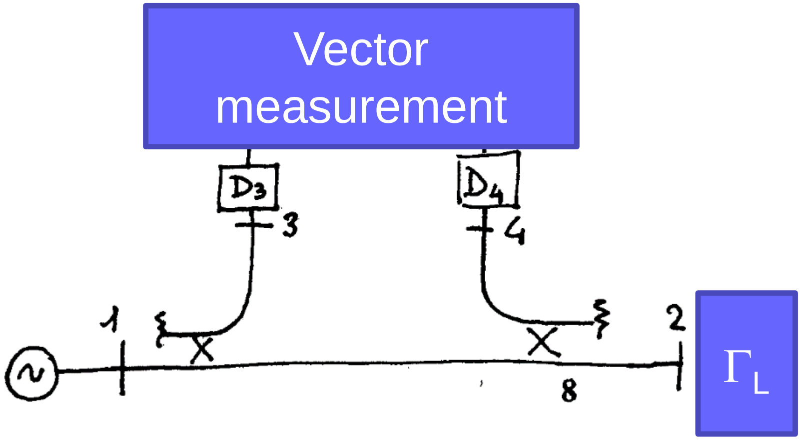
- Infinite directivity ($S_{14} = S_{23} = 0$)
- Perfect matching of the couplers ($S_{kk} = 0 \quad k = 1, \ldots 4$)
- Perfect matching of the detectors ($\Gamma_3 = \Gamma_4 = 0$)

Reflectometer: ideal case

$b_3 = S_{31}\, a_1 = (S_{31}/\, S_{21})\, b_2$

$b_4 = S_{42}\, a_2$

$b_4/b_3 = v_4/v_3 = (S_{42}\, S_{21}/S_{31})\, \Gamma_L,$



$\Gamma_L = C v_4/v_3$ *C* to be determined

There is need for 1 single measurement with a known load, for example a short circuit phase sensitive detection $(\Gamma_L=-1)|_{s.c.}$

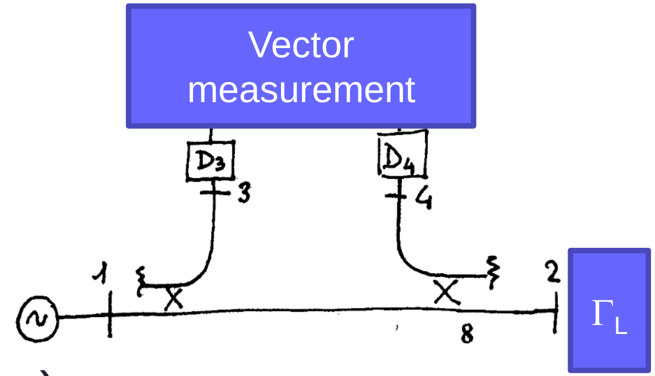
$$C=-(v_3/v_4)|_{s.c}$$

v_3 and v_4 measured by a phase sensitive detection, after heterodyne conversion

Reflectometer: real case

Real case:

- Finite directivity (S_{14} and $S_{23} \neq 0$)
- No matching of the couplers ($S_{kk} \neq 0$ $k = 1, \ldots 4$)
- No matching of the detectors (Γ_3 and $\Gamma_4 \neq 0$)
- Errors in the detector (phase shift and attenuation)



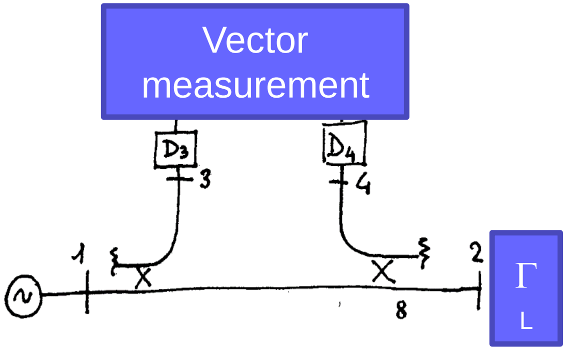
8 unknowns and 6 equations, to find out $\Gamma_{l2} = a_2/b_2$

$$
\begin{cases}
b_1 = S_{11}a_1 + S_{12}a_2 + \ldots + S_{14}a_4 \\
b_2 = S_{21}a_1 + S_{22}a_2 + \ldots + S_{24}a_4 \\
\ldots\ldots\ldots \ldots\ldots\ldots \ldots\ldots\ldots \\
b_4 = S_{41}a_1 + S_{42}a_2 + \ldots + S_{44}a_4
\end{cases}
$$

$$a_3 = \Gamma_3 \, b_3$$

$$a_4 = \Gamma_4 \, b_4$$

Reflectometer: real case



After substitution of the last two equations we get 6 unknowns (a_1, a_2, b_1, b_2, b_3, b_4) and 4 equations. Supposing that the determinant of the new system is ≠ 0 (it depends on the reflectometer structure), again, by substitutions we get 4 unknowns and 2 equations (always linear)

$$b_3 = \alpha_3 a_2 + \beta_3 b_2 = (\alpha_3 \Gamma_{l2} + \beta_3)\, b_2 \quad \leftarrow \quad \Gamma_{l2} = a_2/b_2$$

$$b_4 = \alpha_4 a_2 + \beta_4 b_2 = (\alpha_4 \Gamma_{l2} + \beta_4)\, b_2$$

(structure close to be ideal ⟺ $|\alpha_3| << |\beta_3|$ e $|\alpha_4| >> |\beta_4|$)

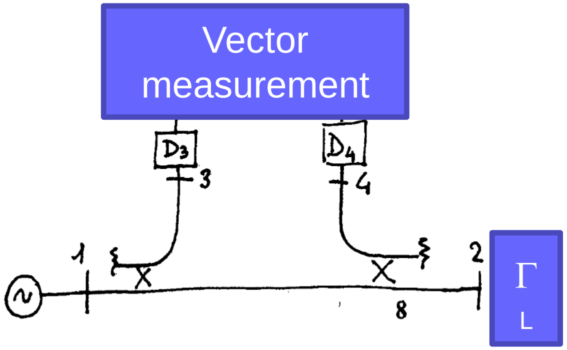
$$v_3 = \sqrt{Z_0}\ (a_3 + b_3) = \sqrt{Z_0}\ (\Gamma_3 + 1)\, b_3 = \sqrt{Z_0}\ (\Gamma_3 + 1)\,(\alpha_3 \Gamma_{l2} + \beta_3)\, b_2$$
$$v_4 = \sqrt{Z_0}\ (a_4 + b_4) = \sqrt{Z_0}\ (\Gamma_4 + 1)\, b_4 = \sqrt{Z_0}\ (\Gamma_4 + 1)\,(\alpha_4 \Gamma_{l2} + \beta_4)\, b_2$$

⇓

$$v_4/v_3 = [(\Gamma_4 + 1)/\,(\Gamma_3 + 1)]\,(\alpha_4 \Gamma_{l2} + \beta_4)\,/\,(\alpha_3 \Gamma_{l2} + \beta_3) = A\,(\Gamma_{l2} + B)\,/\,(\Gamma_{l2} + C)$$

Reflectometer: real case

$$v_4/v_3 = A\,(\Gamma_{l2} + B)\,/\,(\Gamma_{l2} + C)$$



Even if the detectors have a different attenuation (and frequency response), the equation is still valid: there are **3 parameters to be determined.**

Standard procedure:

Applying **3 known loads** (typically short-circuit, open-circuit and matched load) and calculate the 3 coefficient for each frequency.