Three stub tuner and more…

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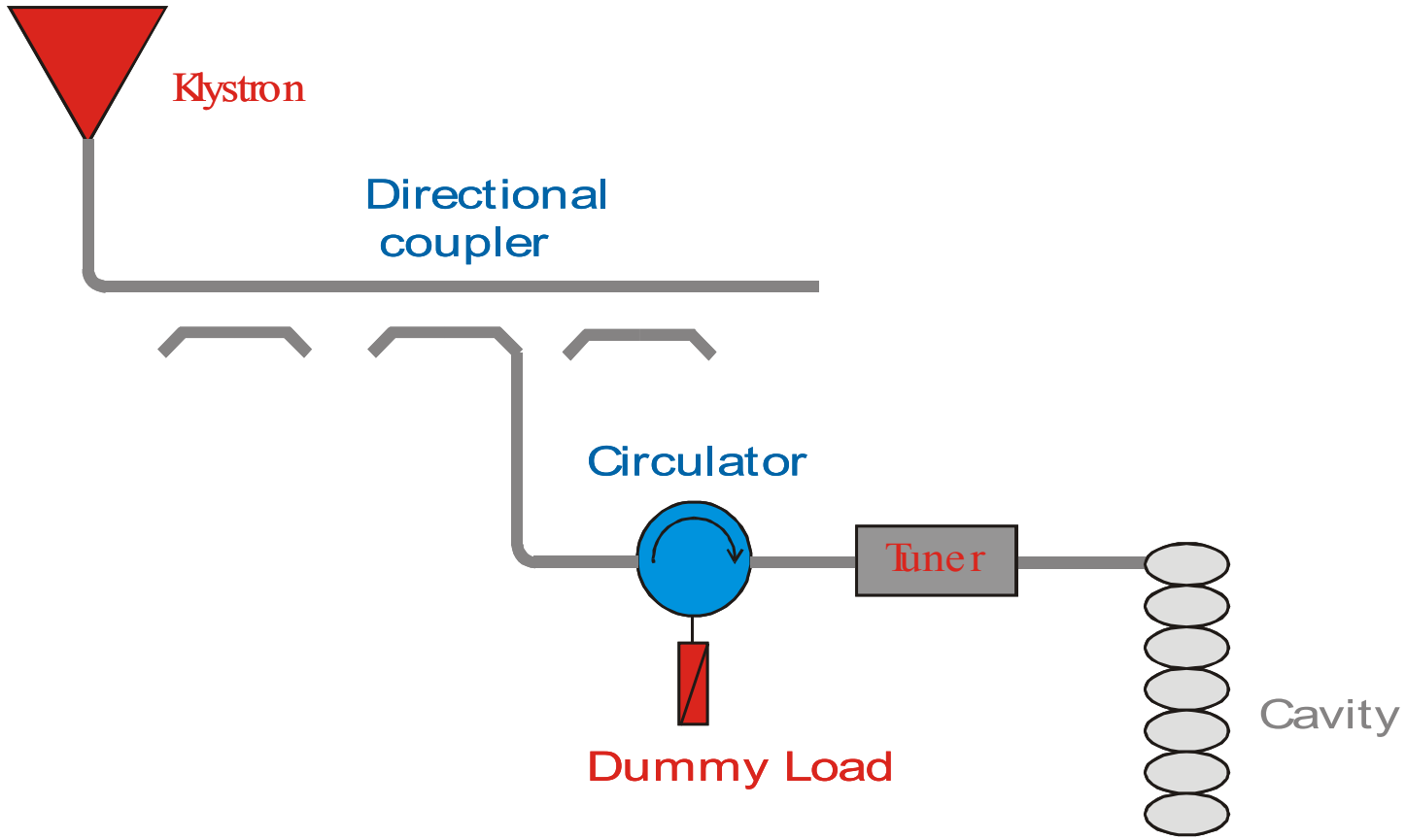
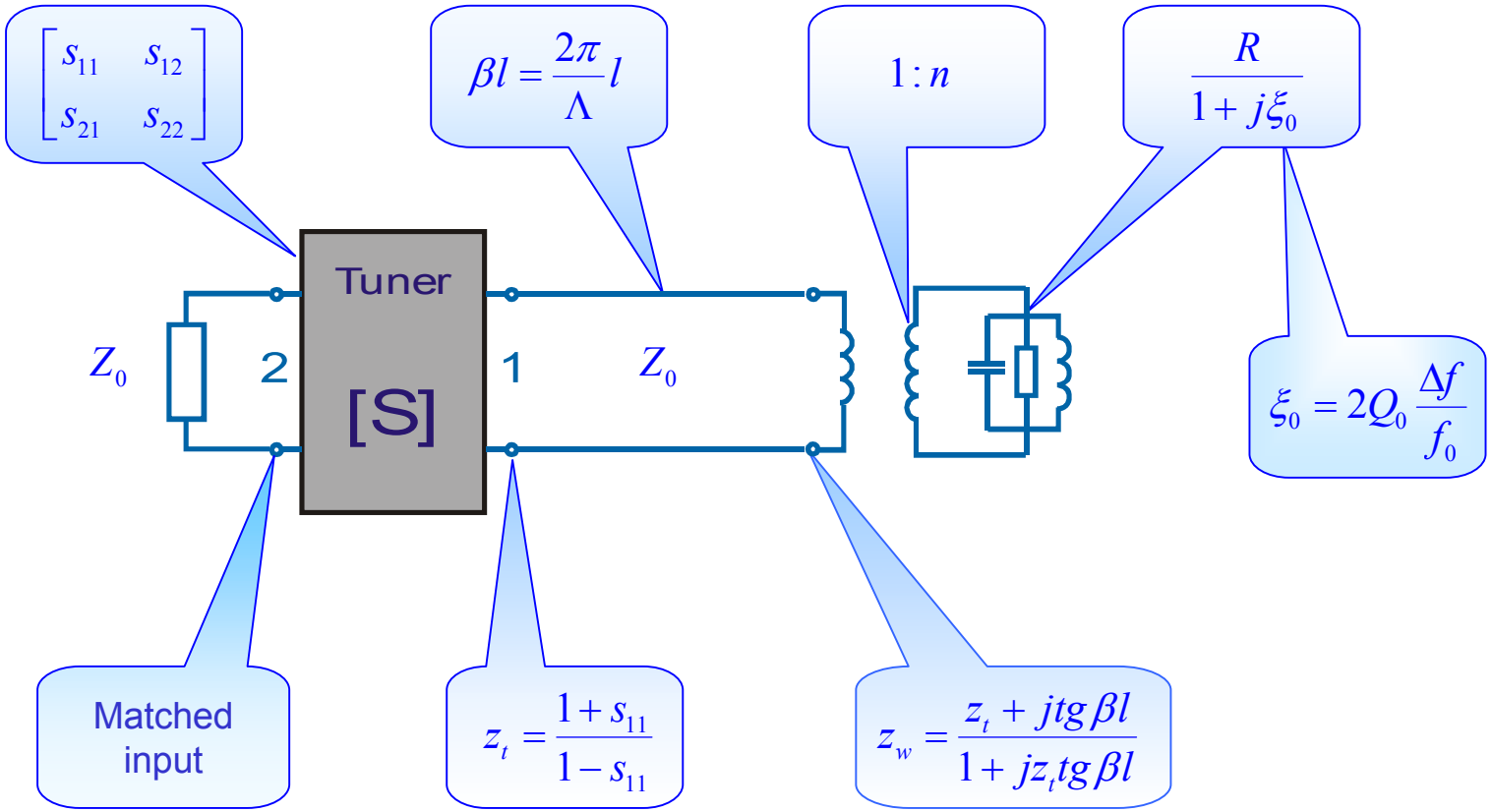
MHF-p

Basic layout of power distributing system



Equivalent circuit



z_t z_w - normalized on Z_0

Basic equation of cavity impedance

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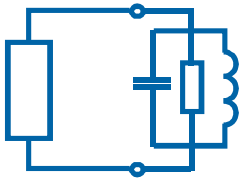
$z_w Z_0 n^2$



$$\frac{R}{1+j\xi_0} \qquad Q_0 \gg Q$$

Q is defined by coupler

$$z_c = \frac{z_w \frac{R}{Q_0} Q}{1+j\xi z_w}$$

$$\xi = 2Q\frac{\Delta f}{f_0}$$

$$z_w = \left.\frac{\frac{1+s_{11}}{1-s_{11}} + jtg\beta l}{1+j\frac{1+s_{11}}{1-s_{11}}tg\beta l}\right|_{\beta l = \pi n} = \left.\frac{1+|s_{11}|e^{j\varphi_{11}}}{1-|s_{11}|e^{j\varphi_{11}}}\right|_{\varphi_{11}=\pi n} = \frac{1\pm|s_{11}|}{1\mp|s_{11}|}$$

$$Q_t = Q\frac{1\pm|s_{11}|}{1\mp|s_{11}|}$$

Limitations for scattering matrix of tuner

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- **Phaseshifter**
  - The phase of s_{21} is changing
  - but s_{11} has to be fixed

$$\varphi_{21} = \mathrm{var}$$
$$|s_{11}| = const$$
$$\varphi_{11} = const!$$

- **Impedance transformer**
  - The phase of s_{21} is fixed.
  - The absolute value of s_{11} is changing
  - but the phase of s_{11} has to be fixed

$$\varphi_{21} = const$$
$$|s_{11}| = \mathrm{var}$$
$$\varphi_{11} = const!$$

Three stub tuner for TTF

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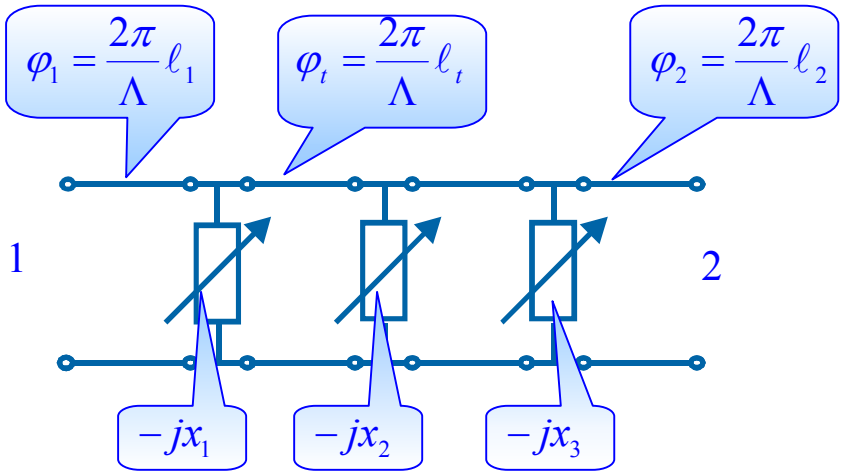
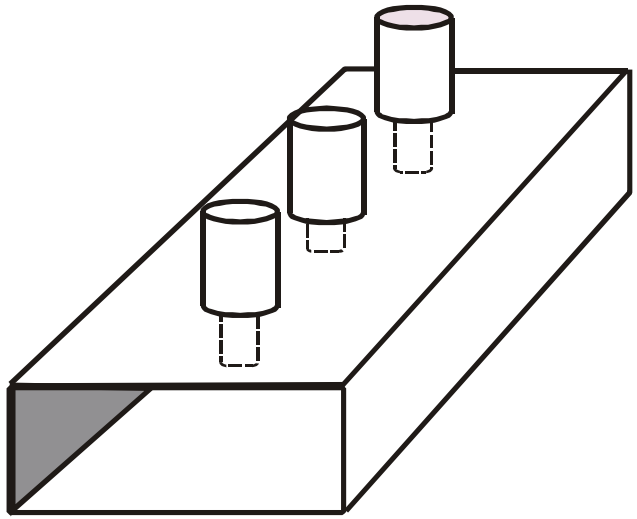
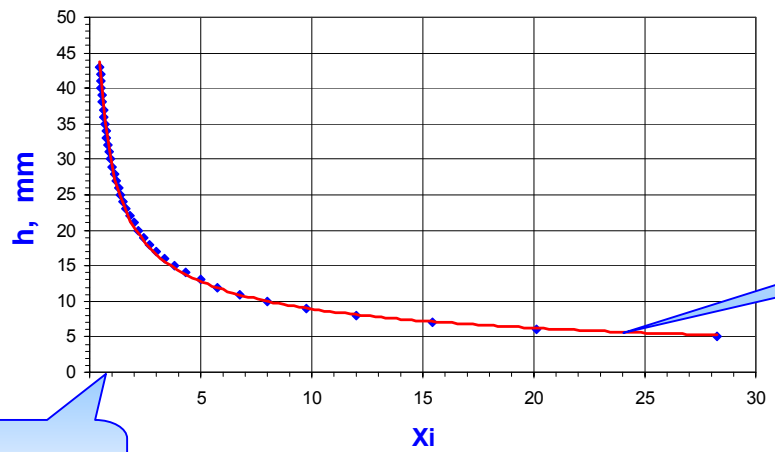
Three stub tuner and equivalent circuit





Stub length vs stub impedance



TTF three stub tuner

$h_i = 29.253 x_i^{-0.5153}$

$x_i \geq 0.5$

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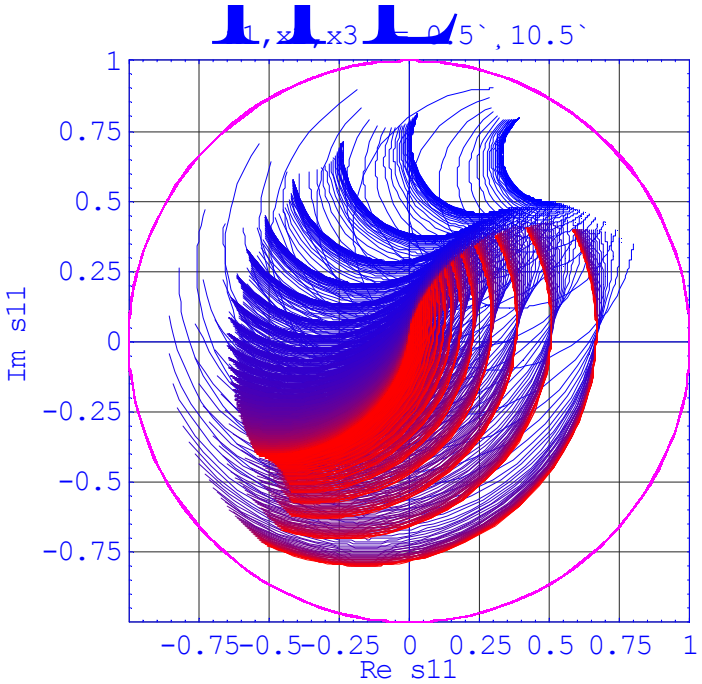
Scattering matrix of three stub tuner

To simplify the scattering matrix apply $\varphi_t = \frac{\pi}{2}$ $\varphi_{1,2} = \frac{\pi}{2}$

$$\begin{bmatrix} \frac{j\left(-1+x_1\left(-j+x_2-x_3\right)+\left(j+x_2\right)x_3\right)}{j\left(-1+\left(j+x_2\right)x_3\right)+x_1\left(-1+jx_3+x_2\left(j+2x_3\right)\right)} & \frac{2x_1x_2x_3}{j\left(-1+\left(j+x_2\right)x_3\right)+x_1\left(-1+jx_3+x_2\left(j+2x_3\right)\right)} \\ \frac{2x_1x_2x_3}{j\left(-1+\left(j+x_2\right)x_3\right)+x_1\left(-1+jx_3+x_2\left(j+2x_3\right)\right)} & \frac{j\left(-1+x_1\left(j+x_2-x_3\right)+\left(-j+x_2\right)x_3\right)}{j\left(-1+\left(j+x_2\right)x_3\right)+x_1\left(-1+jx_3+x_2\left(j+2x_3\right)\right)} \end{bmatrix}$$



$h_i \square 0 \div 40mm$

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Three stub tuner as phaseshifter

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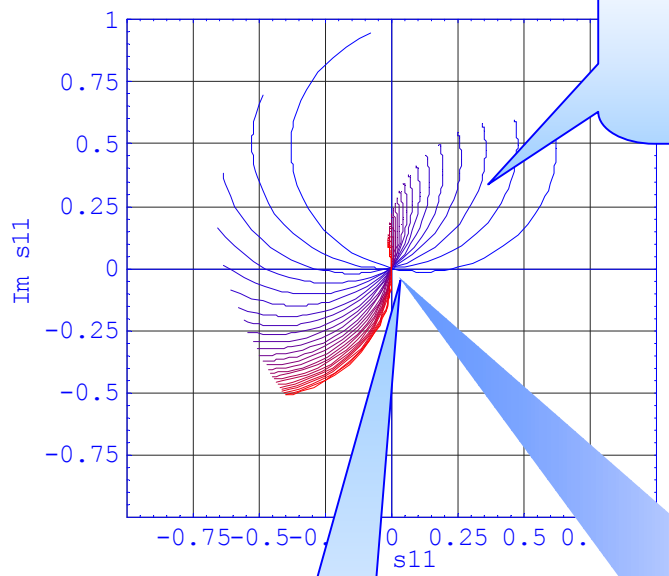


$h_1 = h_3 = \text{var}$

$h_2 = \text{var}$

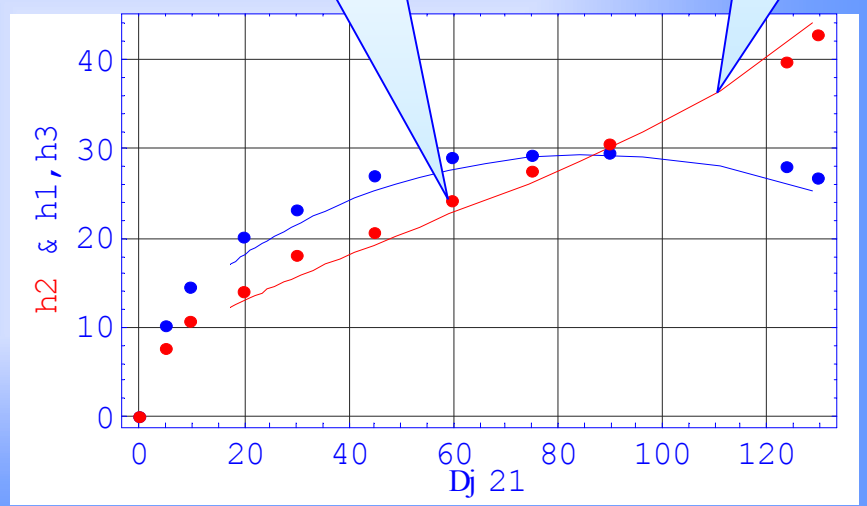
$\varphi_{21} = \text{var}$

$|s_{11}| = const$

$\varphi_{11} = const!$

Experimental points for h_2

Calculation h_2 from scattering matrix



Three stub tuner for changing of Q

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$\varphi_{21} = const$

$$x_1 = \frac{-1 + x_2 x_3 - x_3 tg\varphi_{21}}{-x_2 - x_3 + tg\varphi_{21} - 2x_2 x_3 tg\varphi_{21}}$$

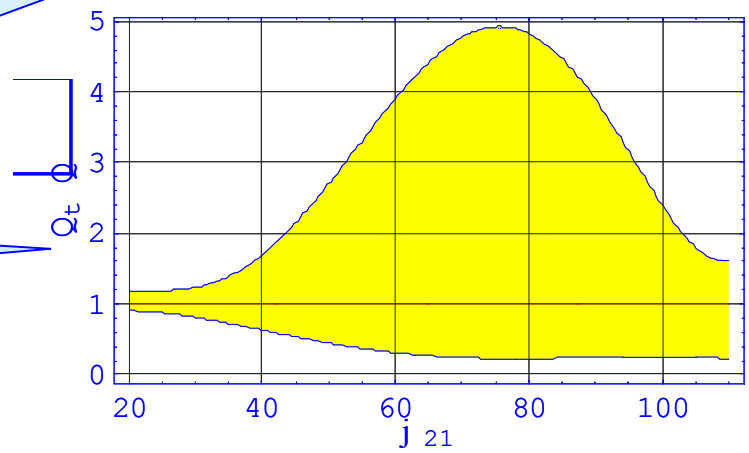
$\varphi_{11} = const$

$$x_2 = \frac{1}{x_3} - ctg\varphi_{21}$$

$x_i \geq 0.5$

$$s_{11} = \frac{j\left(-1 + x_1\left(-j + x_2 - x_3\right) + \left(j + x_2\right)x_3\right)}{j\left(-1 + \left(j + x_2\right)x_3\right) + x_1\left(-1 + jx_3 + x_2\left(j + 2x_3\right)\right)}$$

$$Q_t = Q\frac{1 \pm |s_{11}|}{1 \mp |s_{11}|}$$



EH-tuner (proposed by M.Ebert MHF-e and FERMILAB)

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Scattering matrix of magic tee

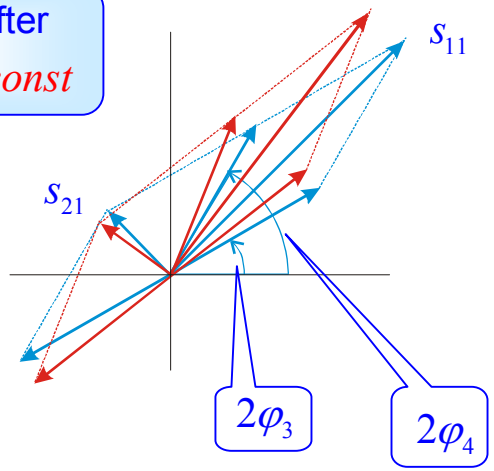
$$\begin{bmatrix} b1 \\ b2 \\ b3 \\ b4 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} a \\ 0 \\ b3 \times e^{-j2\varphi_3} \\ b4 \times e^{-j2\varphi 4} \end{bmatrix}$$

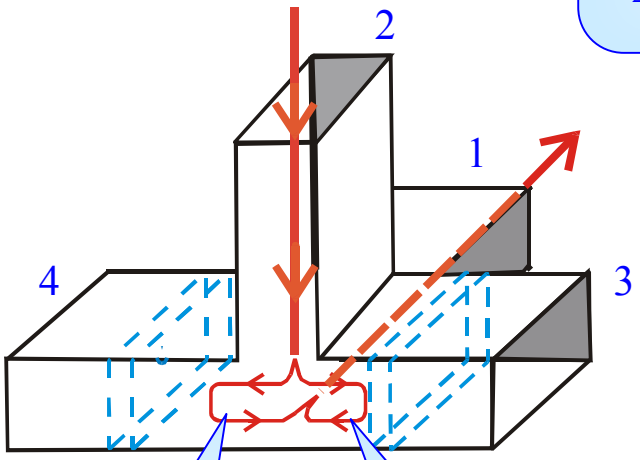
$$s_{11} = \frac{1}{2}(e^{-j2\varphi_3} + e^{-j2\varphi_4})$$

$$s_{21} = \frac{1}{2}(e^{-j2\varphi_3} - e^{-j2\varphi_4})$$

phaseshifter

$$\varphi_4 = \varphi_3 + const$$



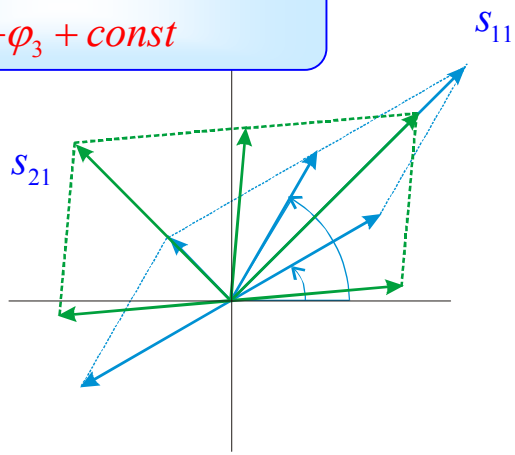


$$\varphi_4 = \frac{2\pi}{\Lambda} l_4$$

$$\varphi_3 = \frac{2\pi}{\Lambda} l_3$$

impedance transformer

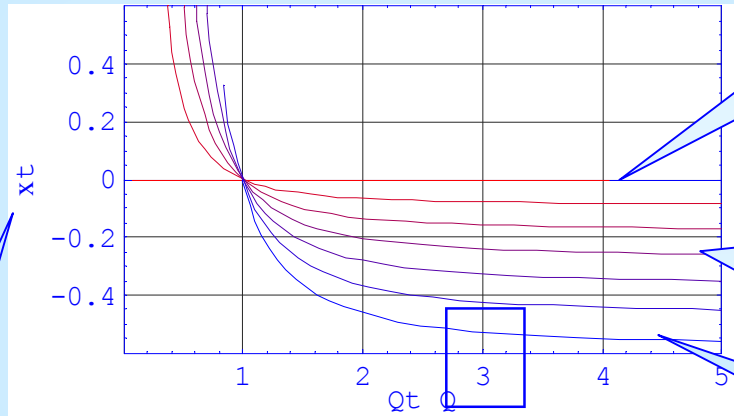
$$\varphi_4 = -\varphi_3 + const$$



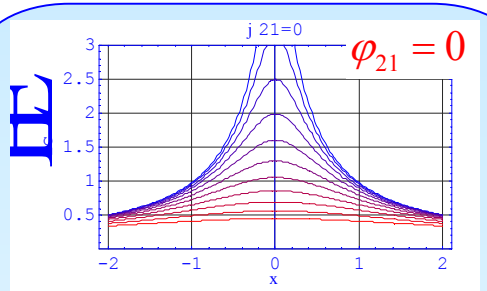
Frequency shift of cavity due to EH-tuner

$$z_c = \frac{z_w \frac{R}{Q_0} Q}{1 + j\xi z_w}$$

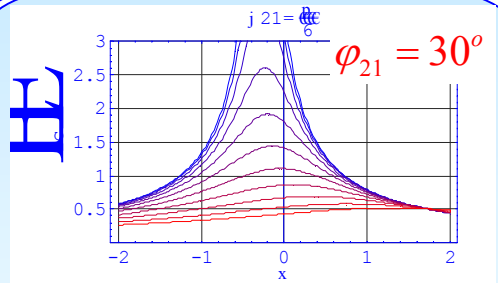
$\varphi_4 = -\varphi_3$



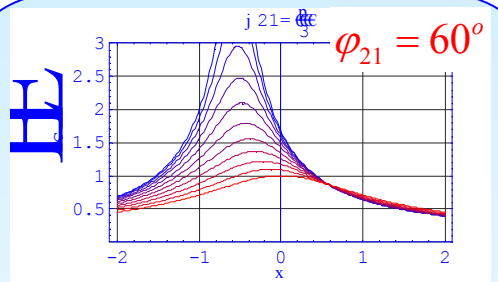
$$\Delta f = \frac{f_0}{2Q} \xi_t$$



$\varphi_{21} = 0$



$\varphi_{21} = 30^o$



$\varphi_{21} = 60^o$

H-tuner

Scattering matrix of 3dB hybrid

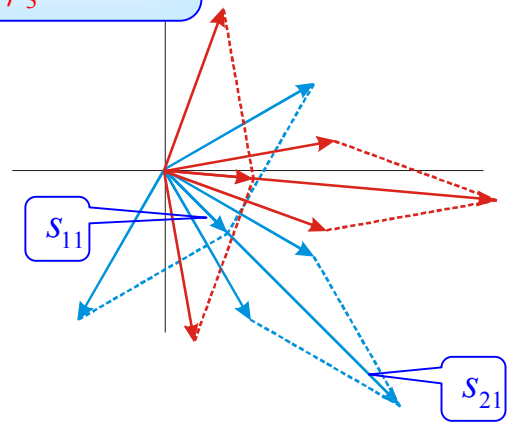
$$\frac{1}{\sqrt{2}}\begin{bmatrix} 0 & 0 & 1 & -j \\ 0 & 0 & -j & 1 \\ 1 & -j & 0 & 0 \\ -j & 1 & 0 & 0 \end{bmatrix}$$

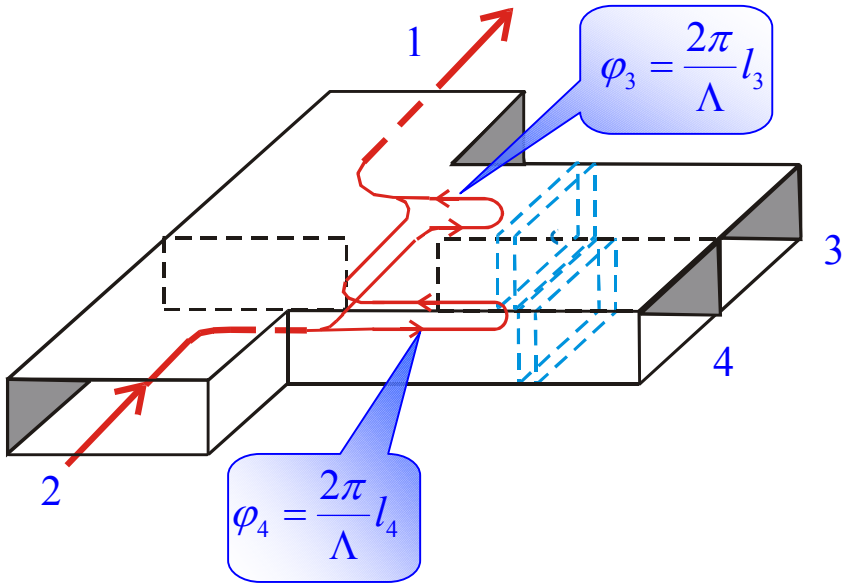
$$s_{11} = \frac{1}{2}(e^{-j2\varphi_3} - e^{-j2\varphi_4})$$

$$s_{21} = -j\frac{1}{2}(e^{-j2\varphi_3} + e^{-j2\varphi_4})$$

phaseshifter

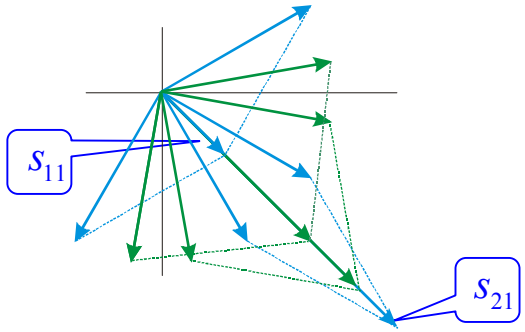
$$\varphi_4 = \varphi_3 + const$$





impedance transformer

$$\varphi_4 = -\varphi_3 + const$$



Comparison of tuners

Free Electron X-Ray Laser

- Three stub tuner has no sparking up to 1.6 MW on a dummy load (*has been measured by Prof.Lu*). It means 400 kW for full reflection!
- EH-tuner has better power capability up to 1 MW (*estimation!*) but it has the bigger sizes
- H-tuner has a little better power capability and smaller dimensions then EH-tuner
- EH- and H-tuner can change Q in the greater range but require additional phaseshifter

Conclusion

- To make the decision what tuner to apply it is necessary to know more precisely
  - dynamic range of Q ($1.5\times10^{6} \rightarrow 1.5\times10^{7}$ *ten times?*)
  - phase range for tuning each branch of distributing system ($\pm10^{0}$? $\pm50^{0}$?)
  - real maximal power (*150 kW ? and conditioning of coupler on kryomodule?*...)