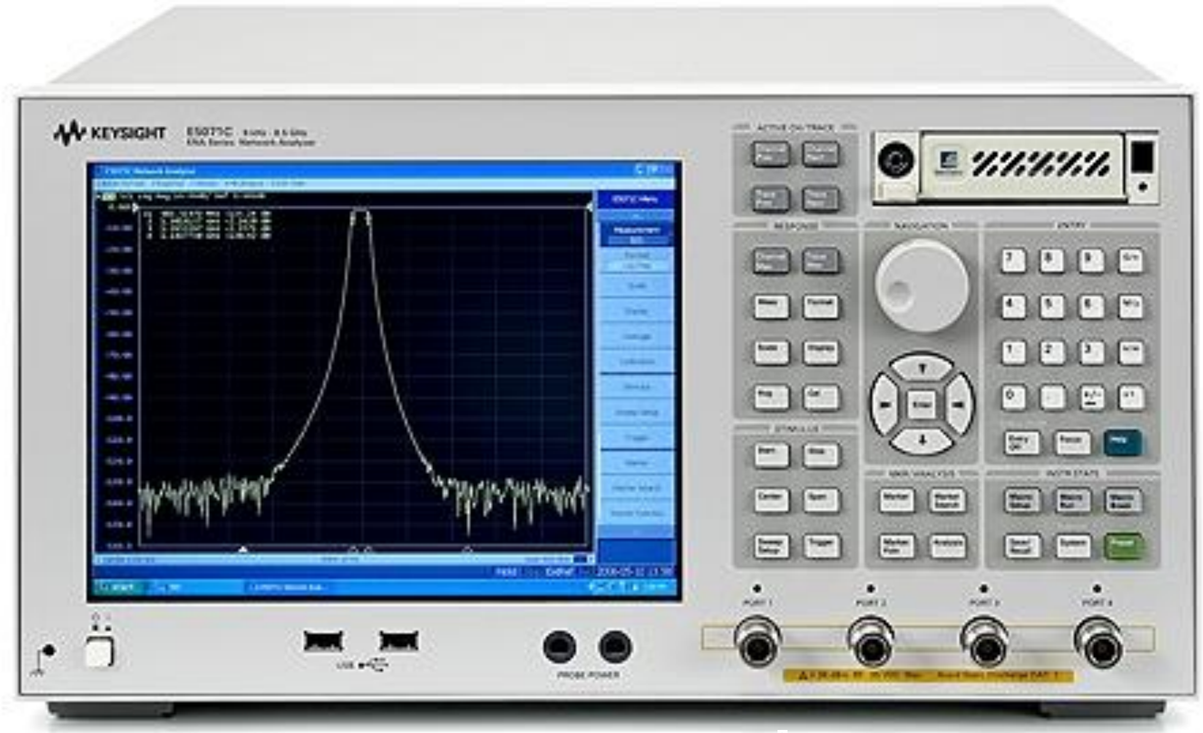
RF: Cavity experiments



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Objective and Outline

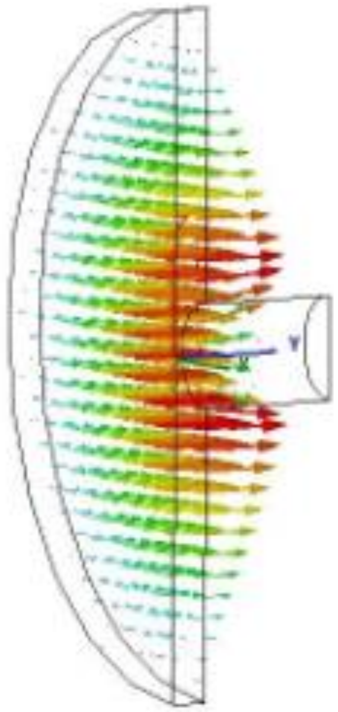
Objective

Characterize the quality factor Q of a pillbox cavity for the accelerating E_{010} mode with the help of an VNA

Outline

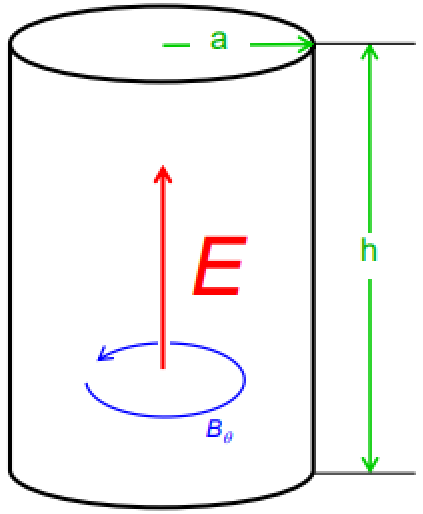
1. The Pillbox Cavity
2. Smith chart introduction
3. Q-factor from an S_{11} measurement
4. Measurement

The Pillbox Cavity



electric field

Circular cylinder: E_{010}, = TM_{010}



$$\lambda_0 = 2.61a$$

$$Q = \left(0.383\frac{\lambda_0}{\delta}\right)\left[1+\left(0.383\frac{\lambda_0}{h}\right)\right]^{-1}$$

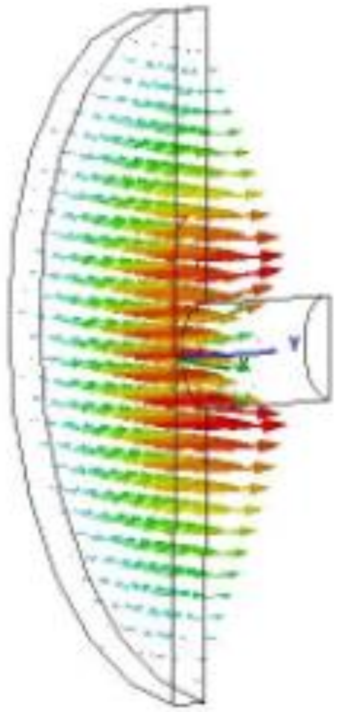
$$= 0.383\lambda_0/\delta\left[1+\frac{a}{h}\right]^{-1} = \frac{a}{\delta}\left[1+\frac{a}{h}\right]^{-1}$$

$$R/Q \approx 185\,h/a \quad \text{for} \quad h/a < 0.5$$

For the given Pillbox Cavity:

a ≅ 0.15 m and h ≅ 0.33m

The Pillbox Cavity



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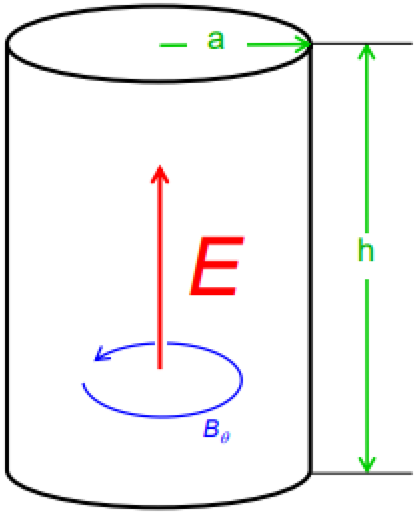

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$$R/Q \approx 185\, h/a \quad \text{for} \quad h/a < 0.5$$

For the given Pillbox Cavity:

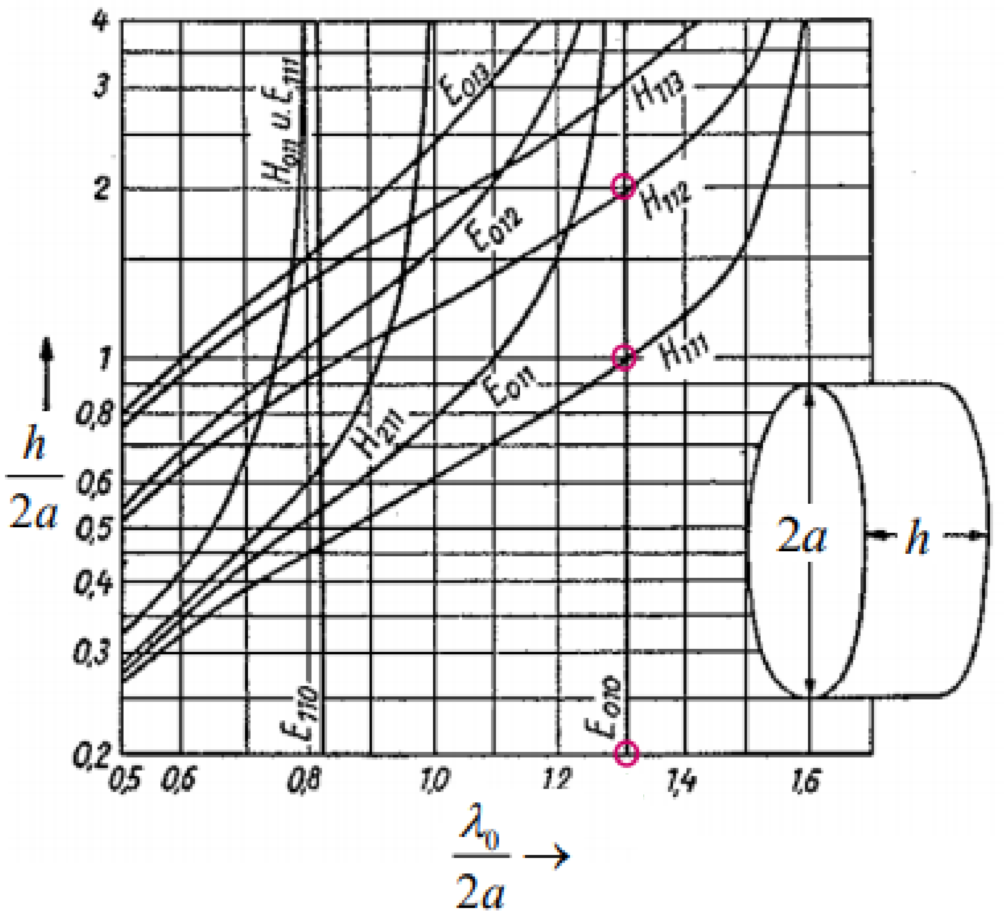
$a \cong 0.15$ m and $h \cong 0.33$m

$\lambda_0 \cong 0.39\text{m} \Rightarrow f_0 \cong 766$ MHz

$\delta = \sqrt{\frac{2}{\omega\sigma\mu}} \cong 15.7\ \mu\text{m}$ for ss

$Q \cong 6568$

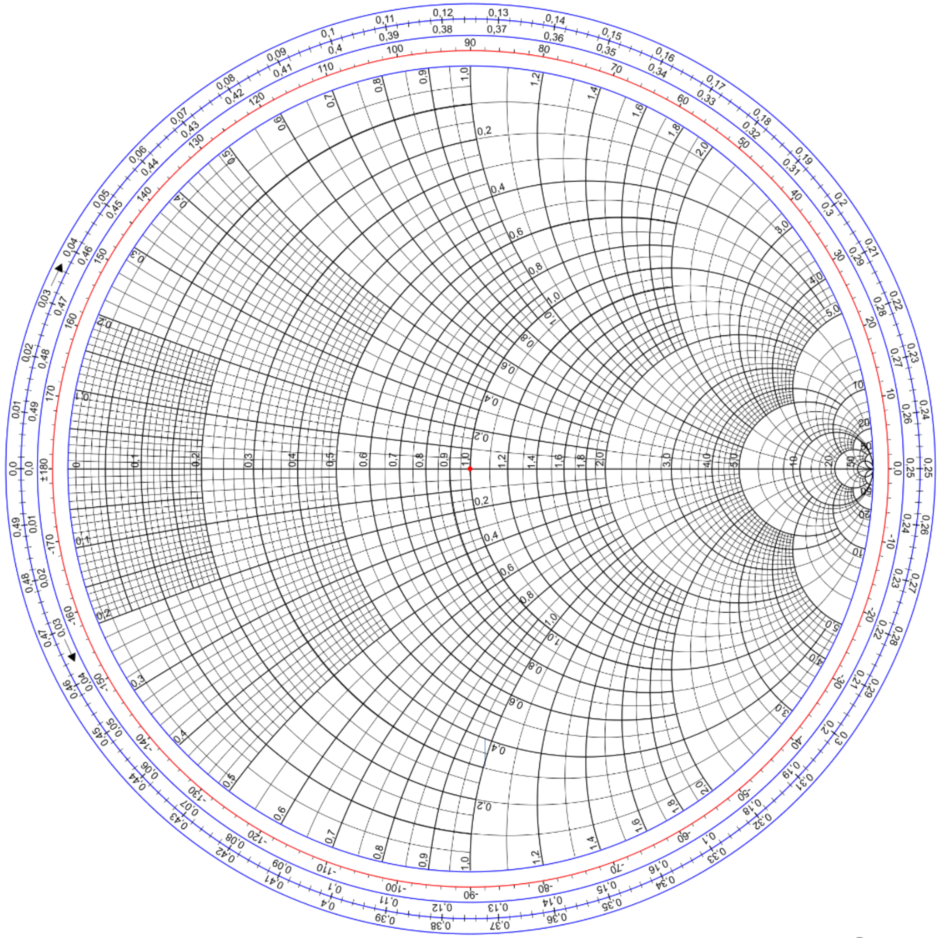
Mode chart of the Pillbox Cavity

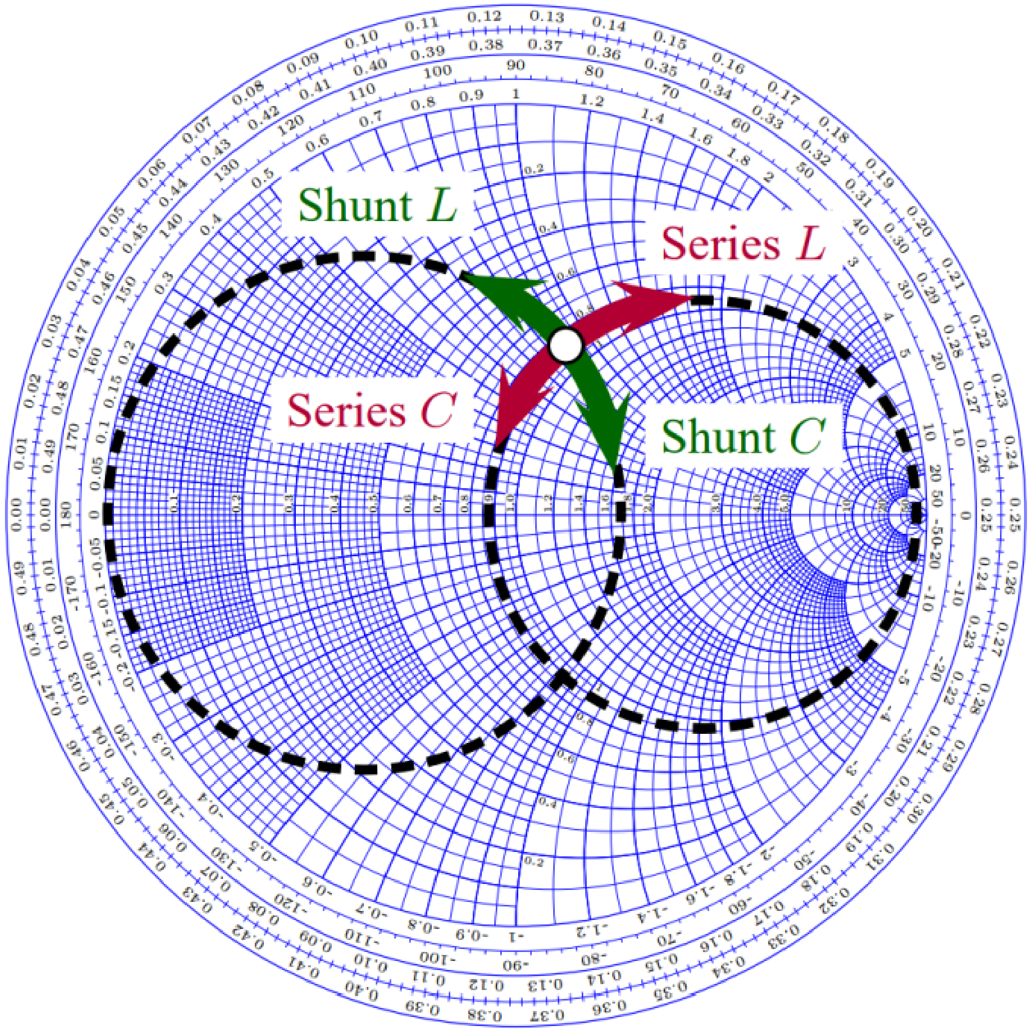


Smith chart introduction

- Graphical design used for matching circuits and transmission lines
- Introduced by Phil Smith (1936)
- Representation of different parameters like impedance, admittance and reflection coefficient

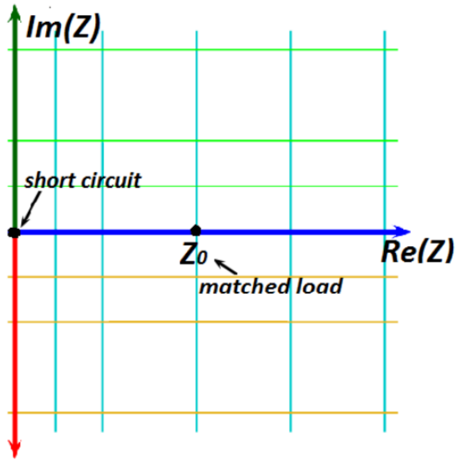
$$\Gamma = |\Gamma| e^{j\theta}$$



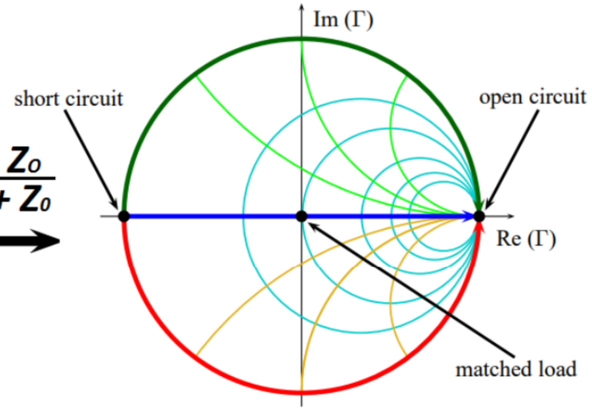


Utilities:

- navigation in the Smith Chart by applying an characteristic circuit
- matching with inductivity and capacity in series and shunt connection
- conversion from reflection coefficient to impedance or admittance plane and vice versa



$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

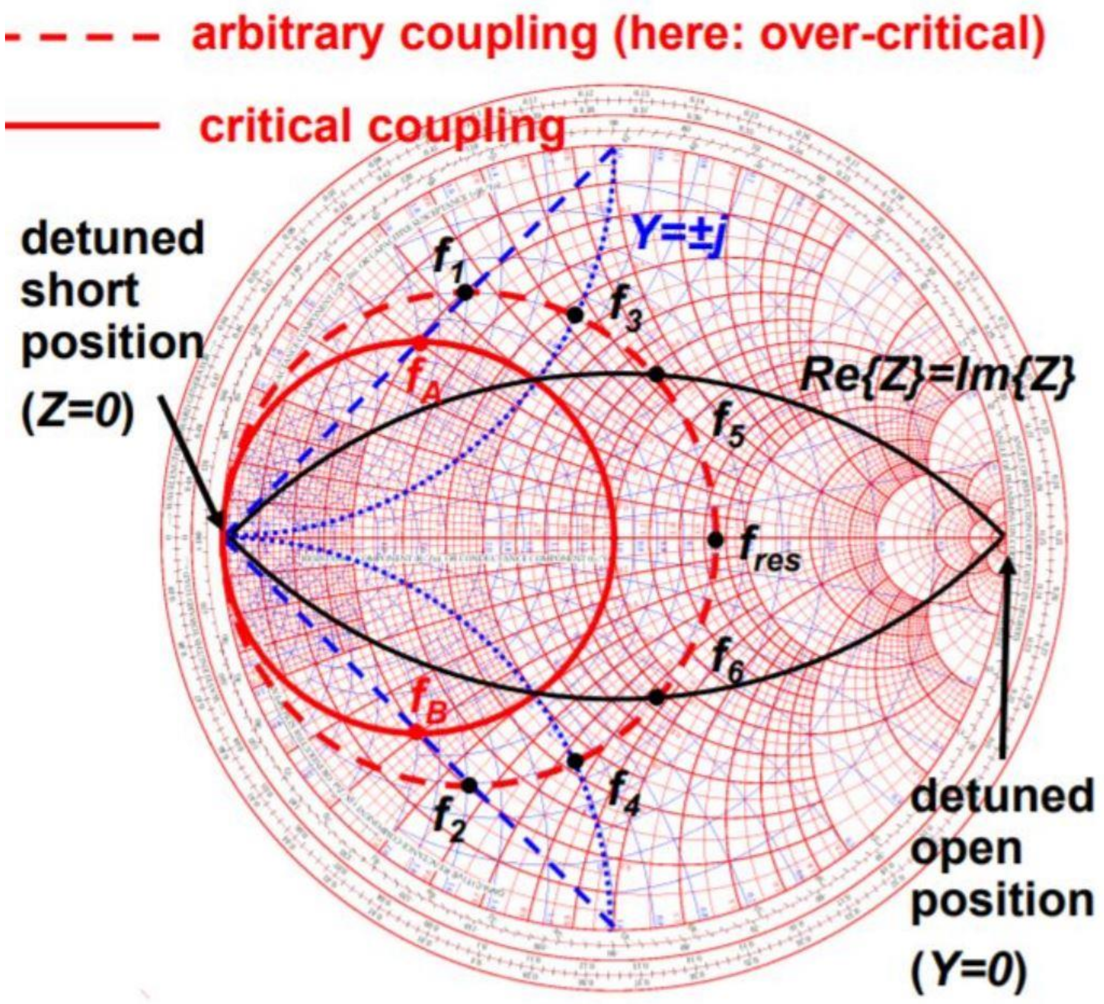


Q-factor from an S_{11} measurement

Frequency markerpoints in the Smith Chart:

- $f_{1,2}$: Im{S_{11}} = max. to calculate Q_L
- $f_{3,4}$: Y = Re $\pm$ j1 to calculate Q_{ext}
- $f_{5,6}$: Re{Z} = Im{Z} to calculate Q_0

$$Q = \frac{f_{res}}{\Delta f} \qquad \frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_{ext}}$$



Q factors Measurement

Reflexion measurement : probe inserted inside the cavity to excite the modes

VNA display :
- frequency
- Smith Chart

Mode of interest : E_{010}
selection -> reduction of the bandwidth
3000 points

Calculated $f_{res,\ E010}$=766 MHz

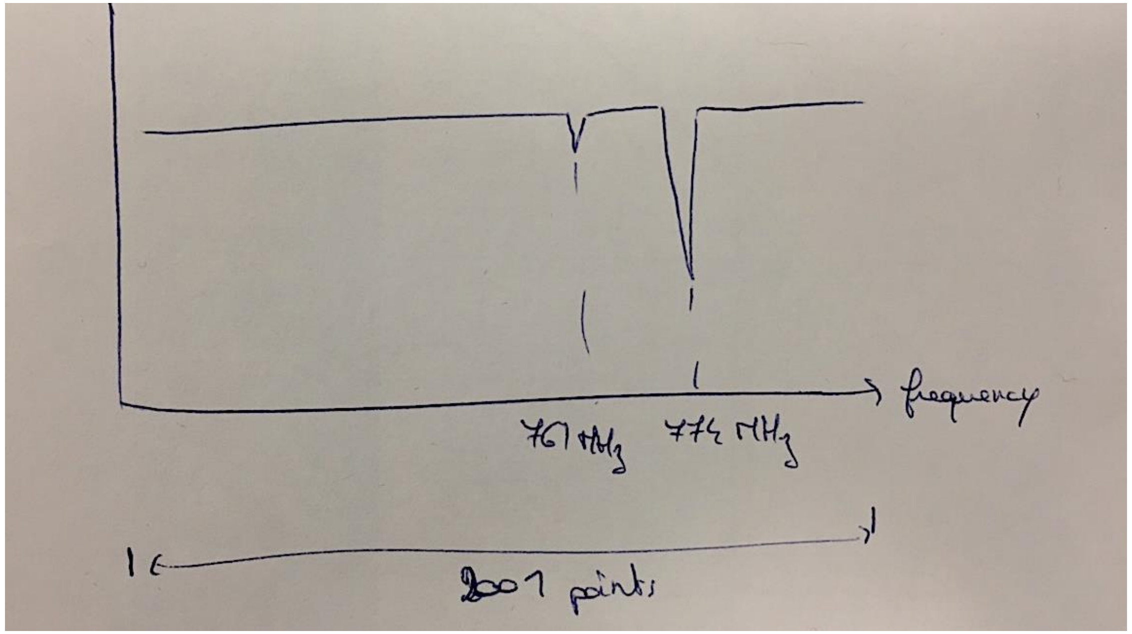


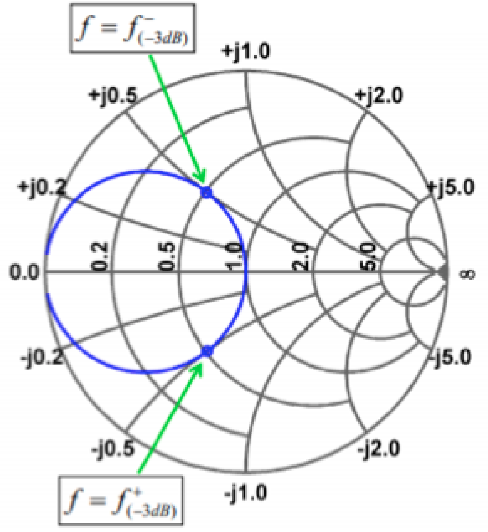
Figure …: Sketch of VNA frequency display (S_{11}[dB] versus frequency [MHz])

Q factors Measurement

Q factor measurement requires **detuned short position**

To have no reflection : adjust the coupling by rotating the coupler -> change **circle's size**
We can thus reach the **critical coupling** for which $Q_0=Q_{ext}$

Figure …: location of the Circle for the measurements, critical coupled cavity



Shown is the model of a Ferrite loaded cavity:
R=200 kΩ, Q=50, f_{res}=1 MHz

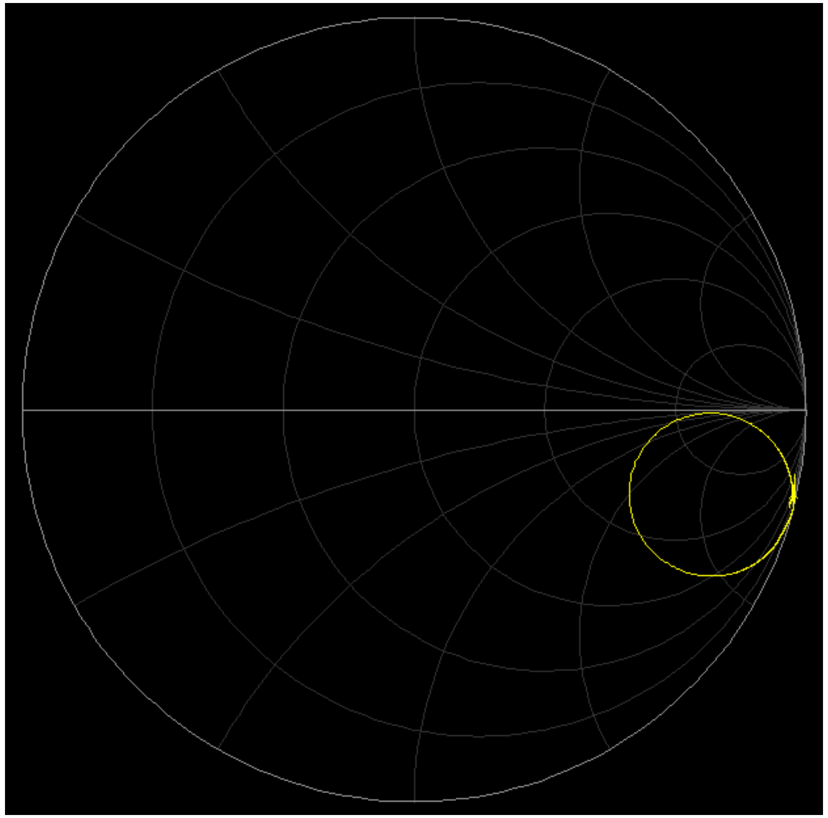


Figure …: First Smith Chart display (non critical coupling)

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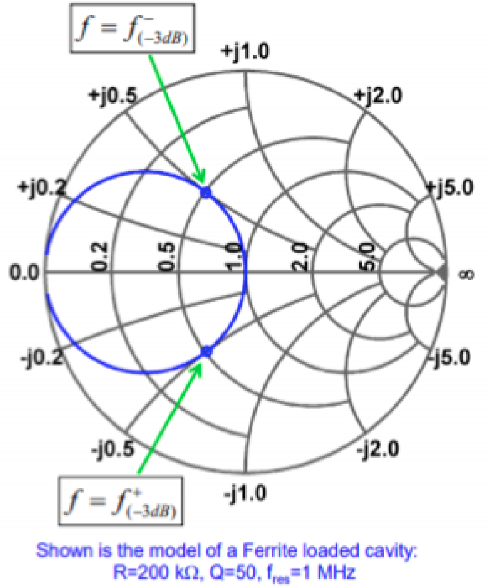


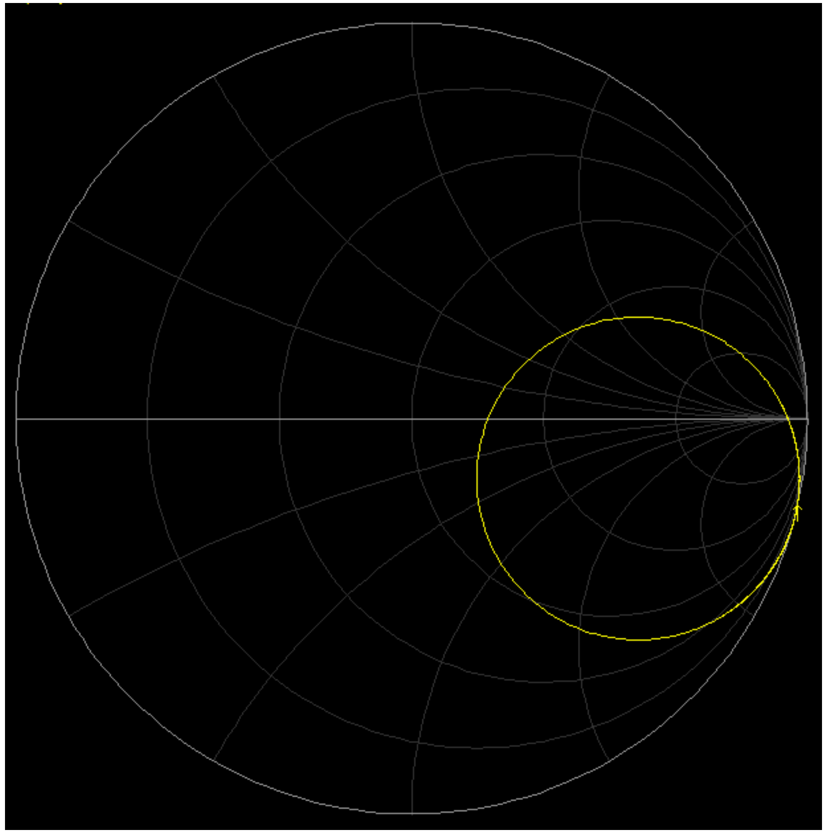
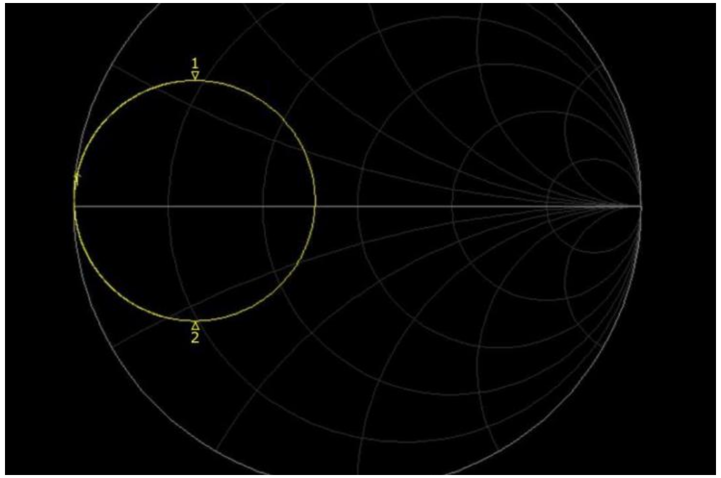


Figure …: First Smith Chart display (non critical coupling)

To reach the **detuned short position**:
- add Electrical Delay (to correct the uncompensated effects of the coupling loop)
- change the Phase Offset (rotate the circle, displaying $Im(S_{11})$)

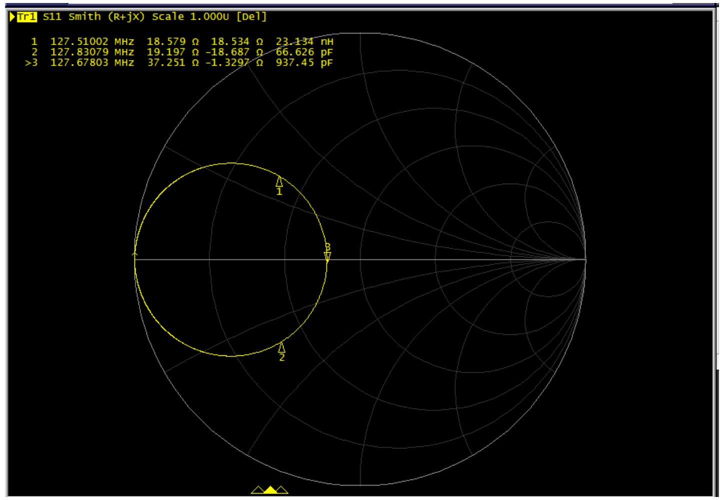


Achtung: the pictures are not ours, the given computed values come from our measurements at critical coupling

Using the cursors as placed as on the upper Figure and $Q = \frac{f_{res}}{\Delta f}$

we can complute Q_L and the Q_0 in our critical coupling position:

$$Q_0 = 2 \times Q_L = 6193$$



And using the same way with the cursors as shown on the lower Figure, we can compute the external Q which equals the unloaded Q in our case:

$$Q_0 = Q_{ext} = 6244$$

Thanks for your attention!