

CERN practical days - RF

09:00

Ruben Heine Marvin Noll

14.03.2022

# Outline

## 1 Forenoon Session

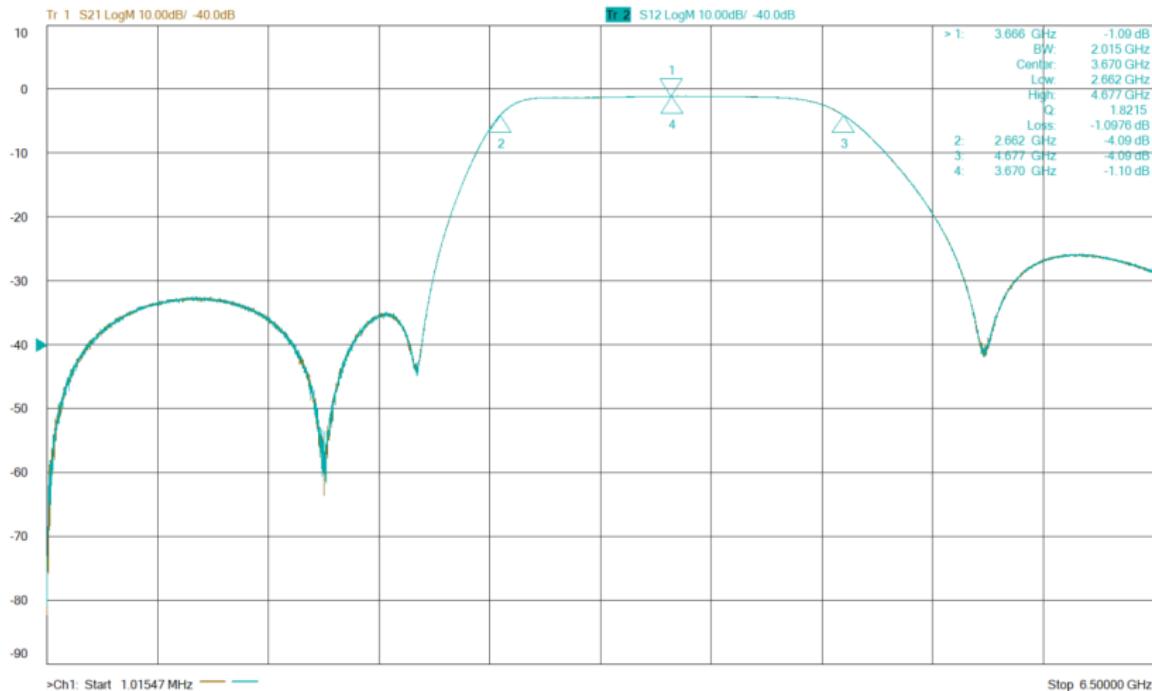
- Band Pass Filter
- Strip-Line BPM
- RF-Cavities

## 2 Afternoon Session

- Instrument Review
- Coupling of an RF Cavity

## 3 Resume

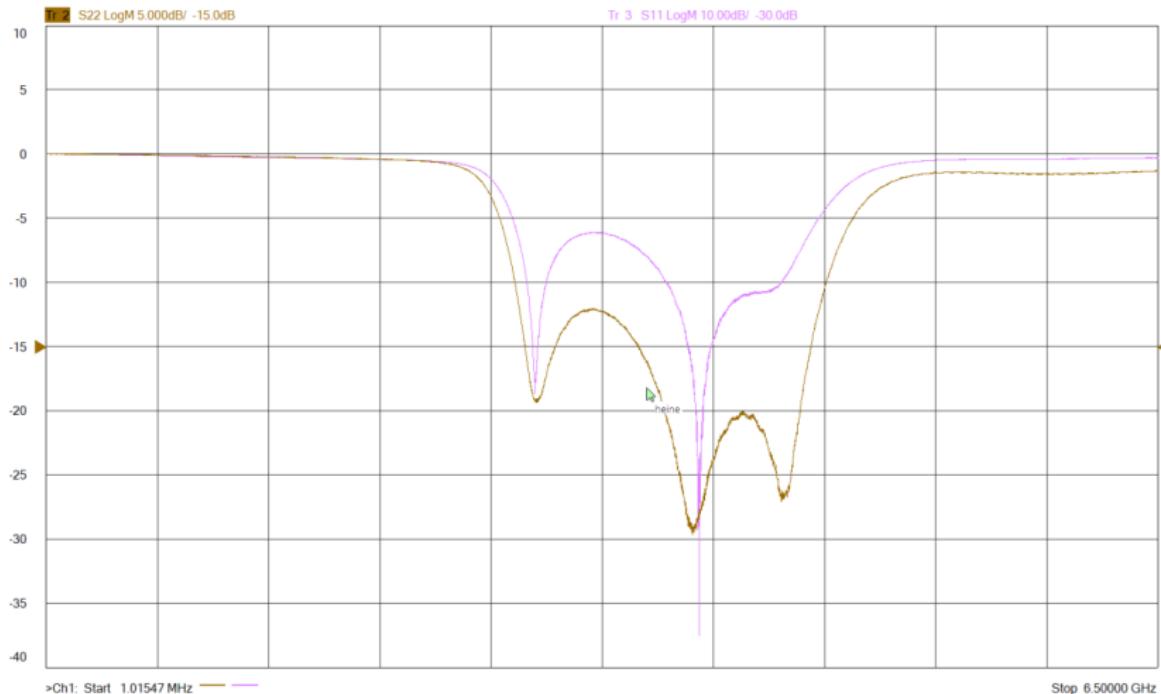
# Band Pass Filter (1) - Transmission $S_{12}$ , $S_{21}$



$$BW = 2.015 \text{ GHz}, \quad f = 2.66 \text{ GHz} \dots 4.67 \text{ GHz}$$

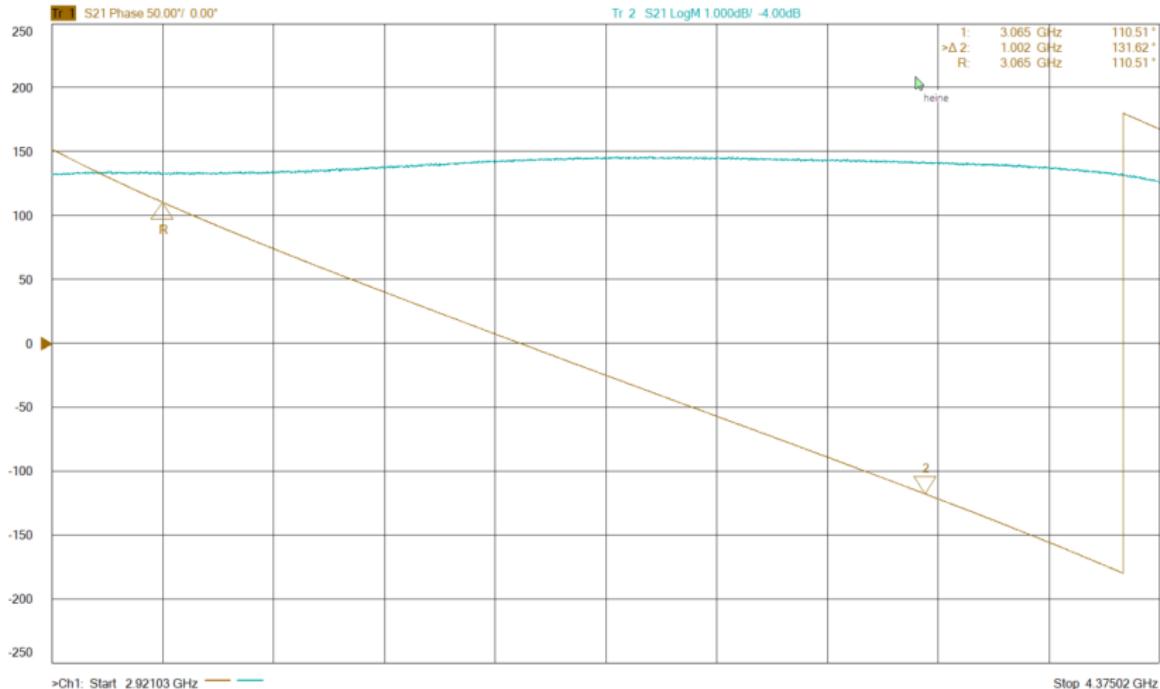
$S_{21} \approx S_{12} \Rightarrow \text{Reciprocal}$

# Band Pass Filter (2) - Input/Output Reflection $S_{11}$ , $S_{22}$



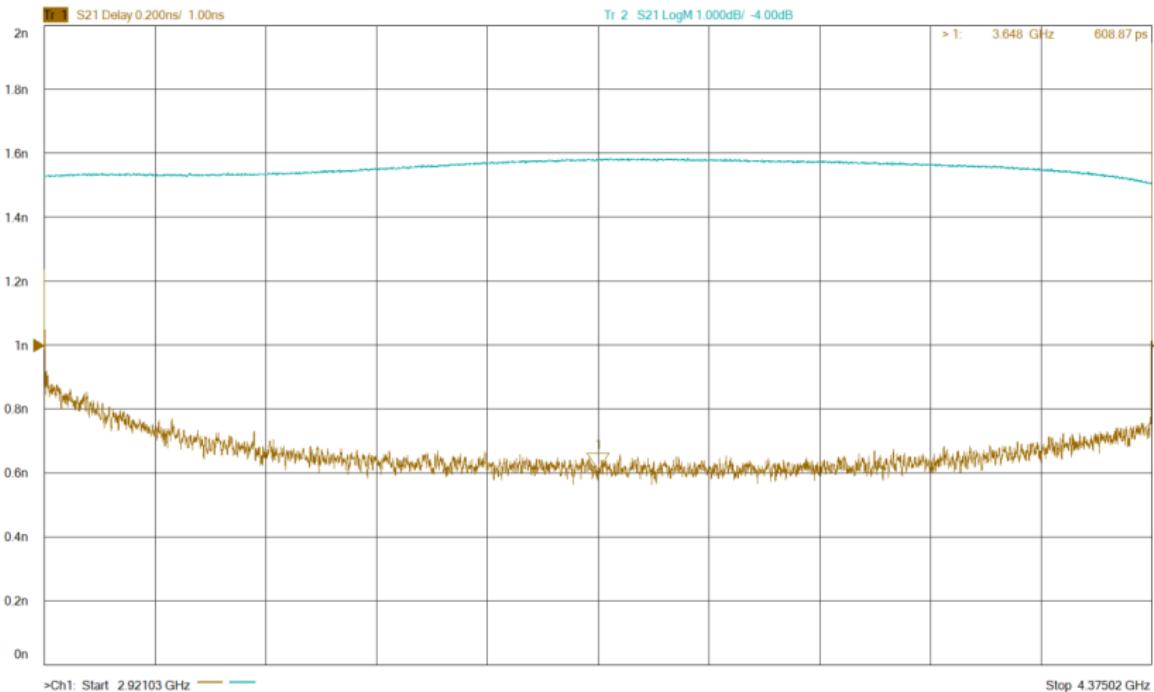
$$S_{11} \neq S_{22} \Rightarrow \text{Non symmetric}$$

# Band Pass Filter (3) - Phase $\angle S_{12}$



$$t_g = -\frac{d}{d\omega} \angle S_{12} \approx -\frac{\Delta \angle S_{12} [\text{rad}]}{\Delta \omega} = \frac{(360^\circ - 131.62^\circ) \cdot \pi/180}{2\pi \cdot 1.002 \text{ GHz}} = 633 \text{ ps}$$

# Band Pass Filter (4) - Group Delay $t_g$



From group delay plot:  $t_g = 608.87 \text{ ps}$

# Strip-Line BPM (1) - Intro

Reflectometry for 500 MHz and  $50\Omega$

a Connector

b Strip line

- ▶ Four 14 cm strips
- ▶ Short-circuit termination

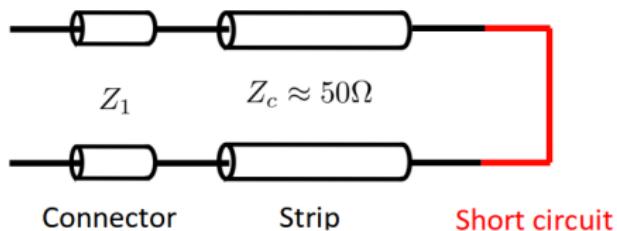
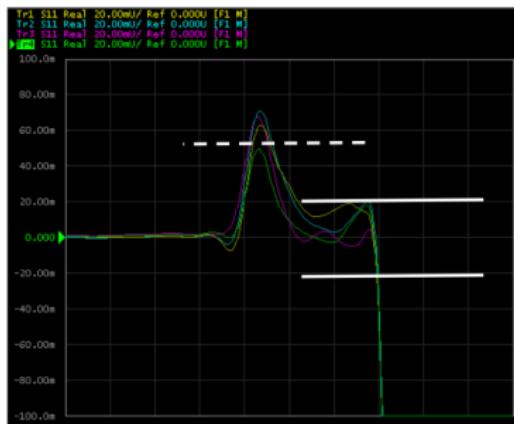


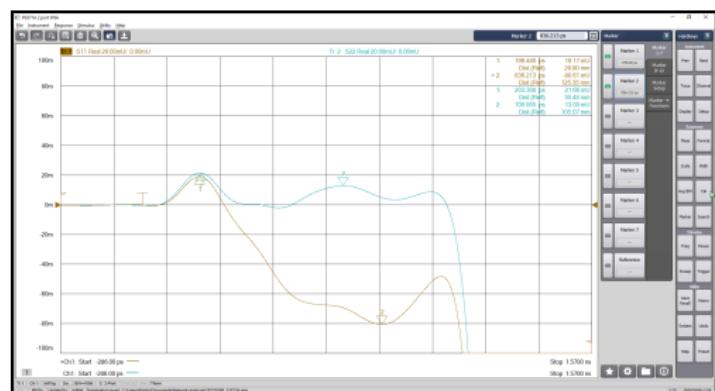
Figure: Strip line: Photo and Circuit

# Strip-Line BPM (2) - Time Domain Reflectometry

- Measuring  $S_{11}$  in time domain to check acceptance criteria
  - a Connector:  $+50 \text{ mU}$
  - b Strip line:  $\pm 20 \text{ mU}$
- Strip line *blue* in specs, *gold* not in specs



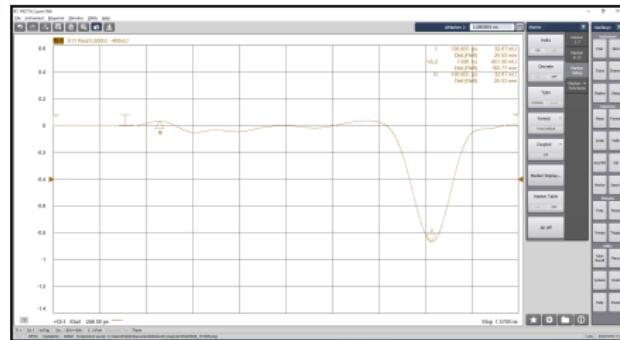
(a) TDR Aim



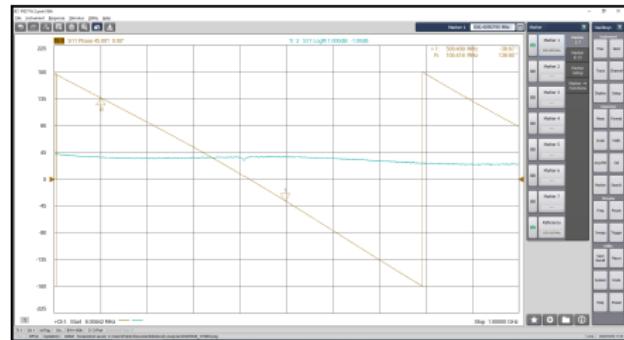
(b) TDR Reproduced

# Strip-Line BPM (3) - Frequency Domain Characterization

- Strip-line length from  $S_{11}$ 
  - ▶ from  $S_{11}$ : 1.086 ns, 162.77 mm
  - ▶ from phase: 1.218 ns, 182.58 mm
  - ▶ from group delay: 1.32 ns, 197.87 mm
- Cross-talk from  $S_{21}$ 
  - ▶ Maximum transmission of  $-25.25$  dB at 797.68 MHz
  - ▶ Transmission of  $-53.06$  dB at operation frequency 500 MHz



(a) Calculation from  $S_{11}$



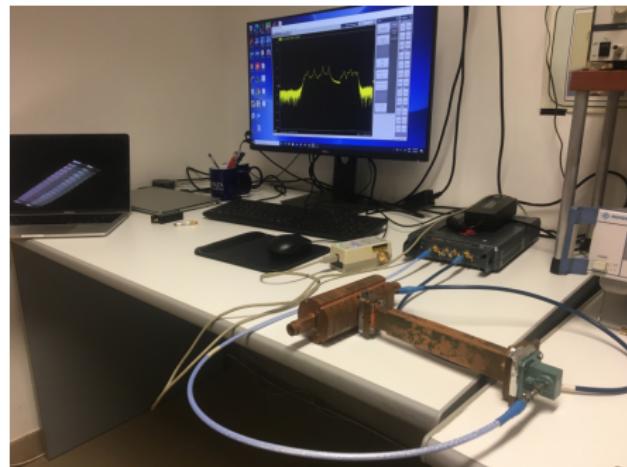
(b) Calculation from phase

# RF - Cavities (1) - Intro

- Multi cell cavity in X-band
- Operating mode at 11.424 GHz
- Under coupled antenna



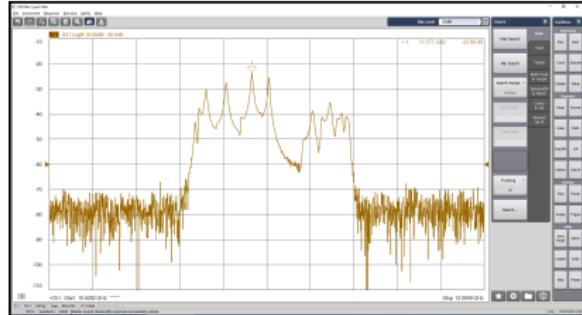
(a) Multi cell cavity



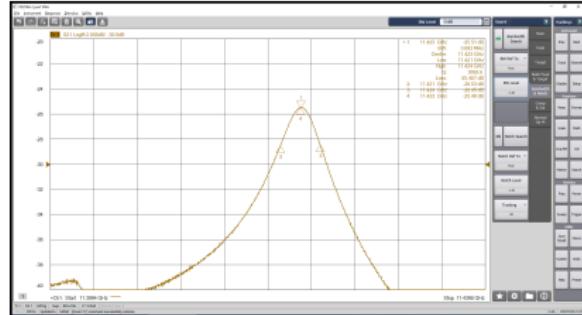
(b) Setup

# RF - Cavities (2) - Transmission Measurement

- Identify different modes
- Calculated  $Q$  from the 3 dB bandwidth: 3093
  - ▶ Center frequency: 11.423 GHz
  - ▶ Bandwidth: 3.693 MHz



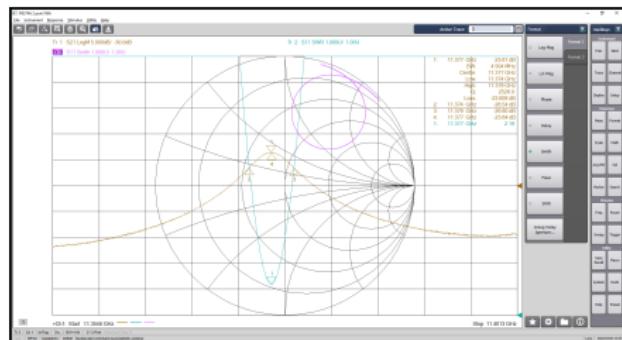
(a) All modes ( $S_{21}$ )



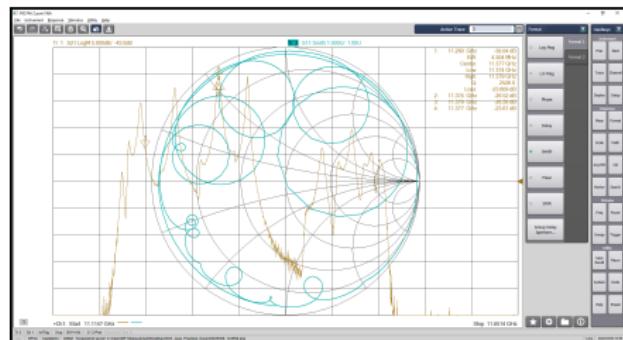
(b)  $Q$  for a certain mode

# RF - Cavities (3) - Transmission Measurement

- Identify SWR
  - ▶ High SWR for high reflection
  - ▶ Low SWR for high transmission
- Coupling ( $S_{11}$  in Smith Chart)
  - ▶ Under coupled

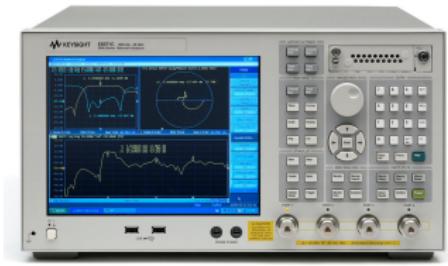


(a) Under coupled:  $S_{21}$ ,  $S_{11}$ , SWR



(b) Complete:  $S_{21}$ ,  $S_{11}$

# Instruments and Calibration (Manfred Wendt)



(a) VNA

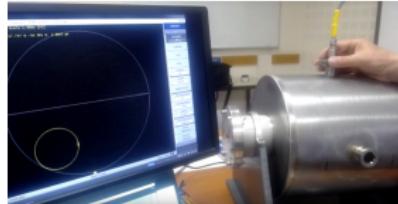


(b) Electric Calibrator

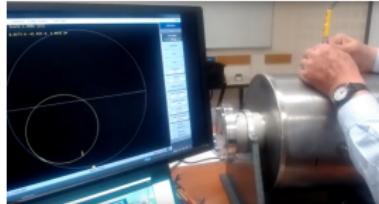
- Vector Network Analyzer
  - ▶ Constructs spectrum by narrowband downmixing
  - ▶ Can also display time domain via FFT
- Calibrate before use!

# RF Cavity, Coupling, Smith Chart (Fritz Caspers)

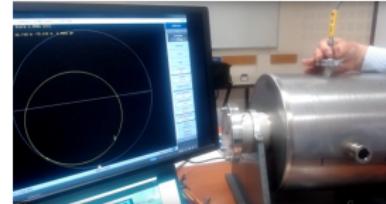
- Two antennas in cavity
  - ▶ Longitudinal field antenna
  - ▶ Coupling loop
- Under-, over- and critical coupling



(a) Under Coupled



(b) Critically Coupled



(c) Over Coupled

- Critical coupling desired ( $\Gamma = 0$ )

# Resume

- Instruments:

- ▶ Vector Network Analyzer (Characterize  $S_{ij}$  in frequency/time)
- ▶ Spectrum Analyzer (mainly spectrum)
- ▶ Oscilloscope (mainly time signal)

- DUTs:

- ▶ Cavities (coupling, modes)
- ▶ Filters (bandwidth,  $S$ -parameters)
- ▶ Strip-Lines (TDR Measurements)

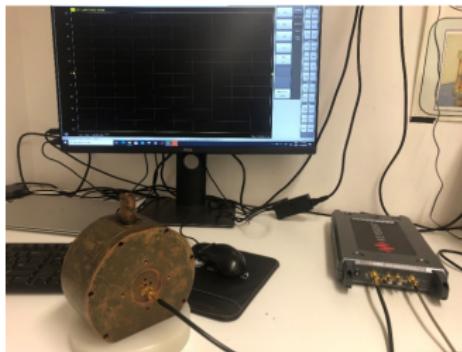
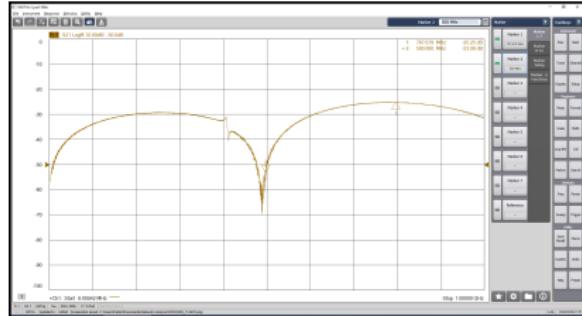
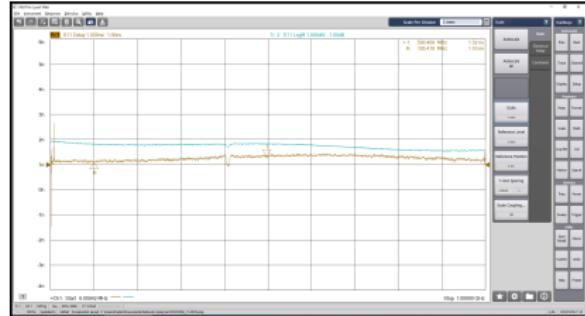


Figure: Cavity Setup

# Appendix (1) - Strip-line BPM

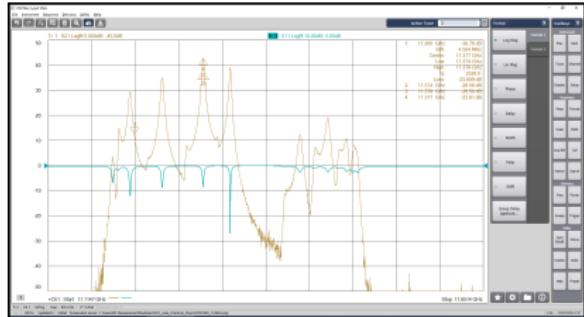


(a)  $S_{21}$ : crosstalk

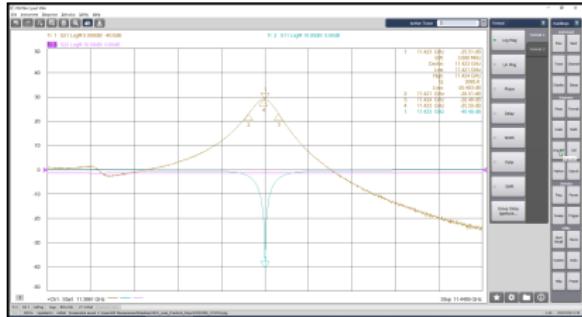


(b) Group delay

## Appendix (2) - Multi mode cavity



(a)  $S_{11}$ ,  $S_{21}$ : for all modes



(b)  $S_{11}$ ,  $S_{21}$ ,  $S_{22}$