

CERN practical days - RF

09:00

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14.03.2022

Outline

① Forenoon Session

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

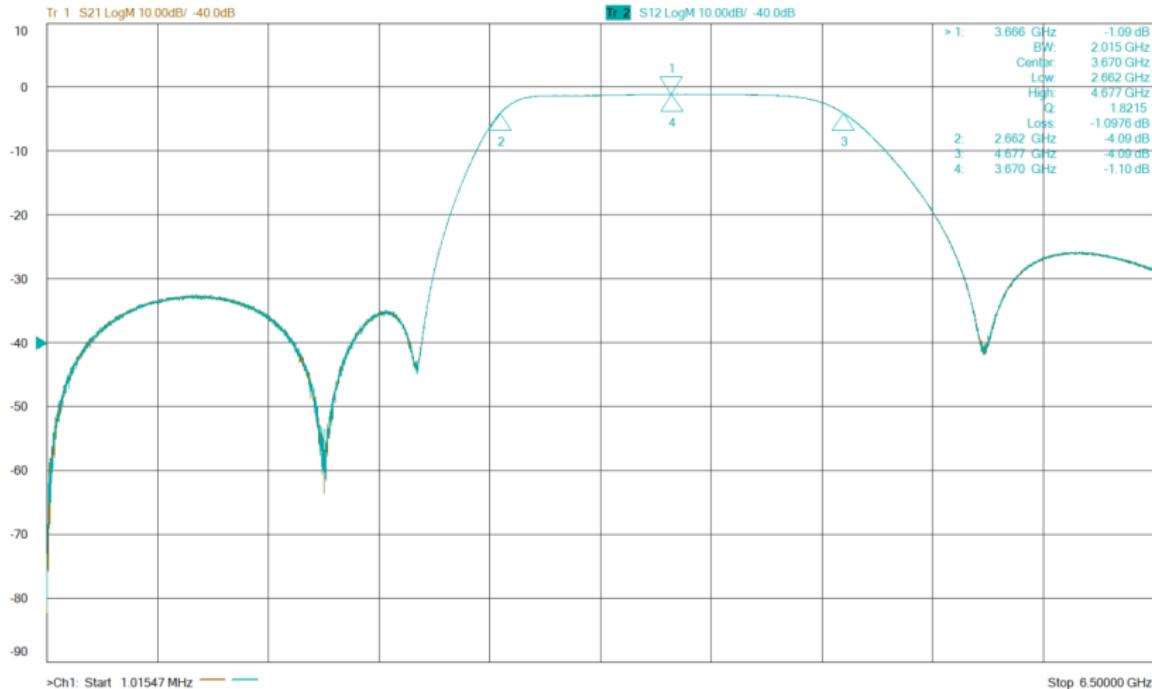
② Afternoon Session

- Instrument Review
- Coupling of an RF Cavity

③ Resume

④ Appendix

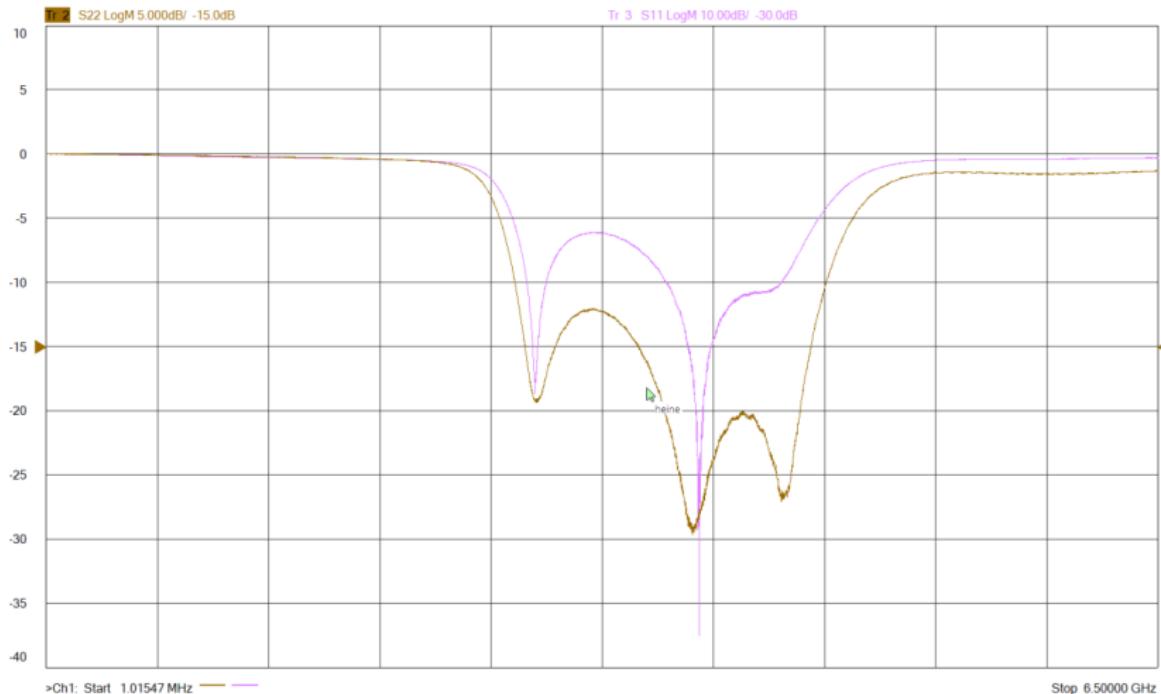
Band Pass Filter (1) - Transmission S_{12} , S_{21}



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

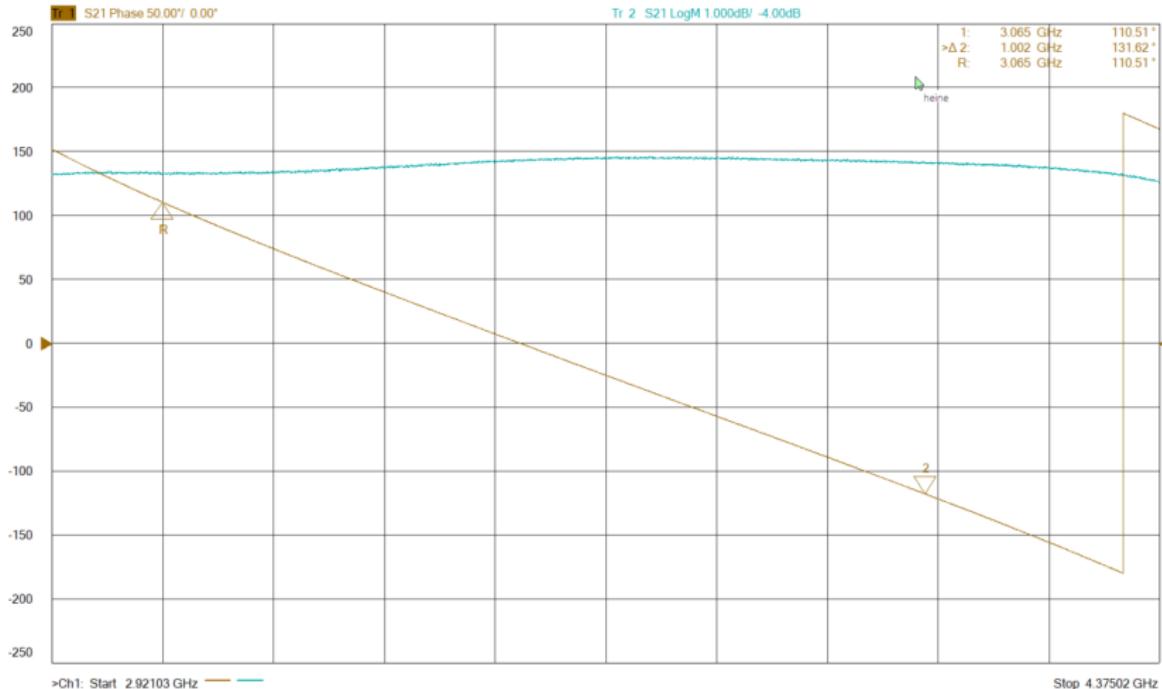
$S_{21} \approx S_{12} \Rightarrow \text{Reciprocal}$

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



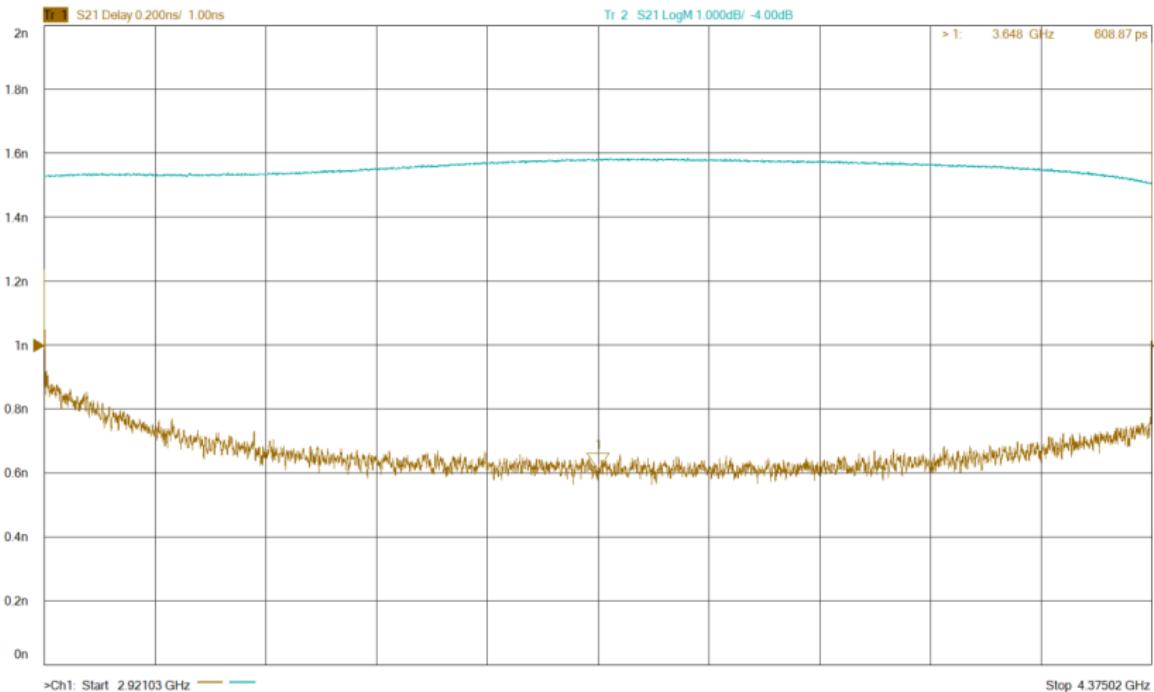
$$S_{11} \neq S_{22} \Rightarrow \text{Non symmetric}$$

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 50Ω

a Connector

b Strip line

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

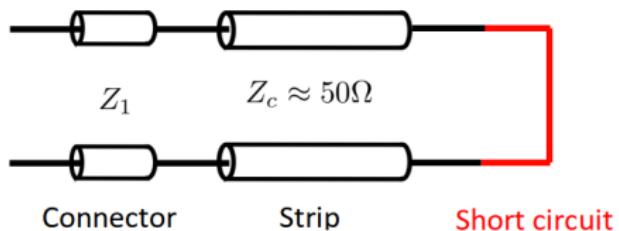
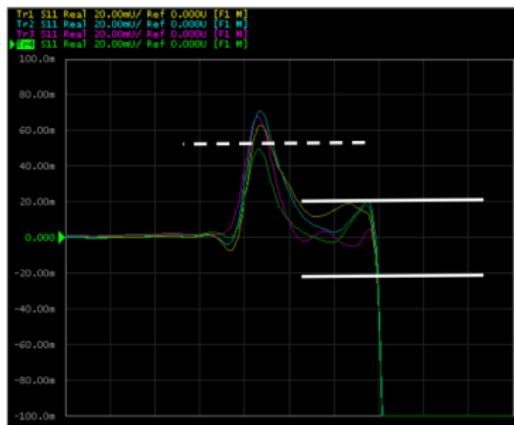


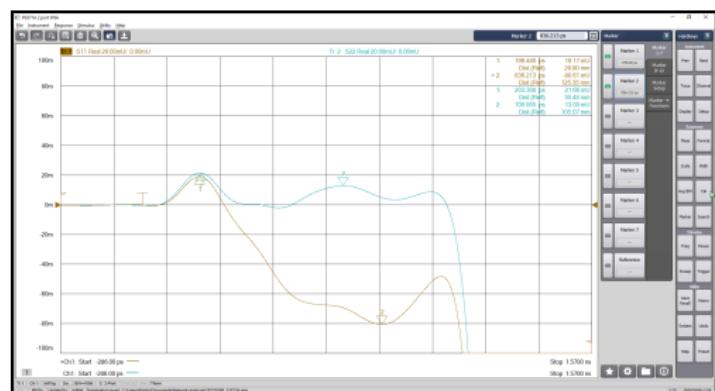
Figure: Strip line: Photo and Circuit

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



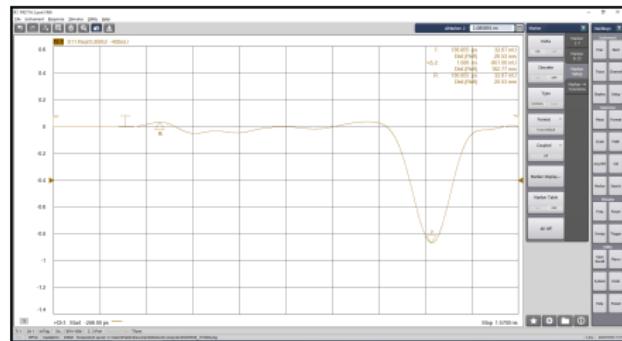
(a) TDR Aim



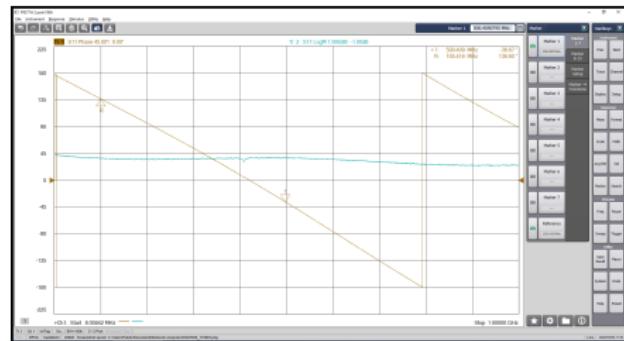
(b) TDR Reproduced

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 reflection of -25.25 dB at 797.68 MHz
 - ▶ Reflection of -53.06 dB at operation frequency 500 MHz



(a) Calculation from S_{11}



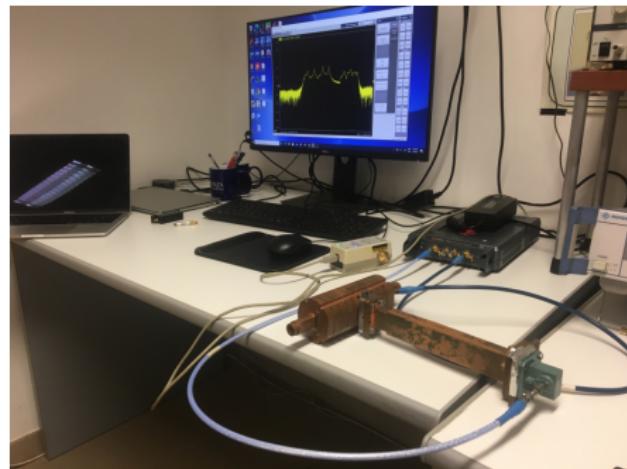
(b) Calculation from phase

RF - Cavities (1) - Intro

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



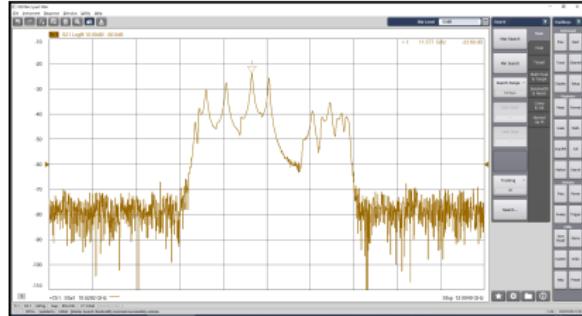
(a) Multi cell cavity



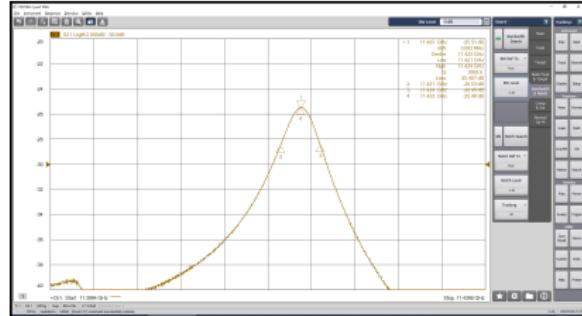
(b) Setup

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



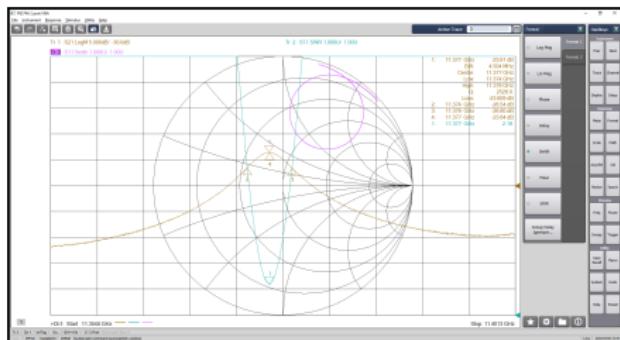
(a) All modes (S_{21})



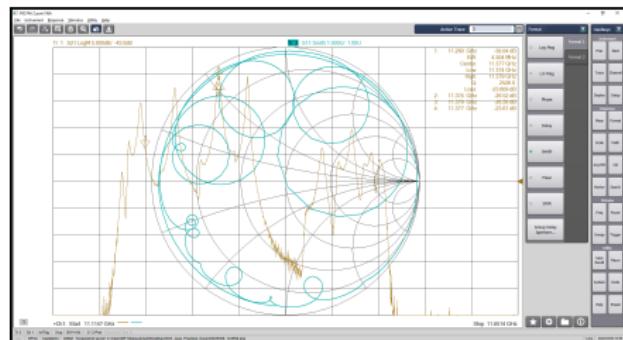
(b) Q for a certain mode

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

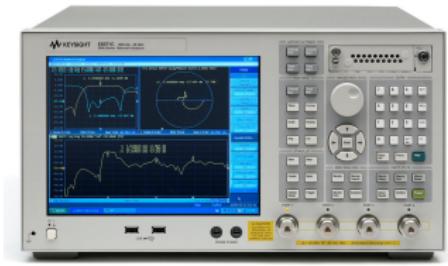


(a) Under coupled: S21, S11, SWR



(b) Complete: S21, S11

Instruments and Calibration (Manfred Wendt)



(a) VNA

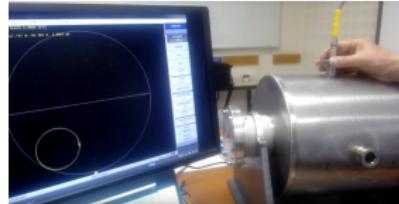


(b) Electric Calibrator

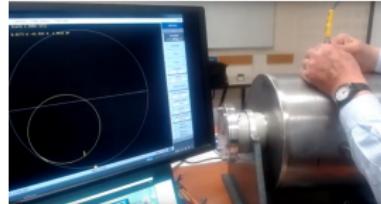
- Vector Network Analyzer
 - ▶ Constructs spectrum by narrowband downmixing
 - ▶ Can also display time domain via FFT
- Calibrate before use!

RF Cavity, Coupling, Smith Chart (Fritz Caspers)

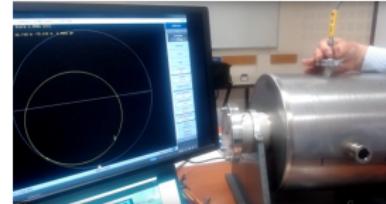
- Two antennas in cavity
 - ▶ Longitudinal field antenna
 - ▶ Coupling loop
- Under-, over- and critical coupling



(a) Under Coupled



(b) Critically Coupled



(c) Over Coupled

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

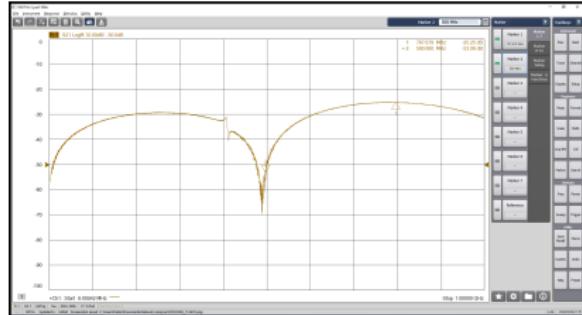
Resume

- Network Analyser
 - ▶ Time and Frequency Domain
 - ▶ Scattering parameter, Impedance, SWR, phase
 - ▶ Calculation of Q , reflexion coefficient
- Spectrum Analyser (Modulation)
- Strip-line
- Cavities (Coupling)

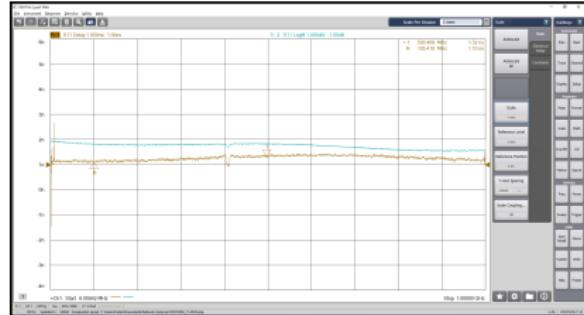


Figure: Cavity Setup

Appendix (1) - Strip-line BPM

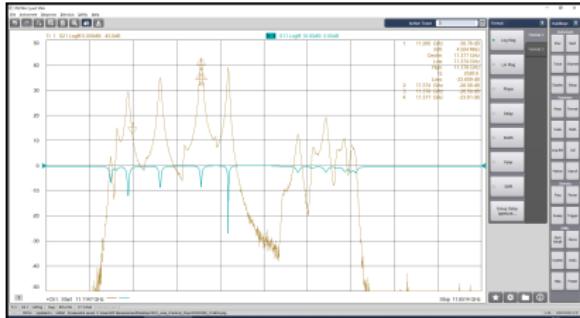


(a) S21: crosstalk

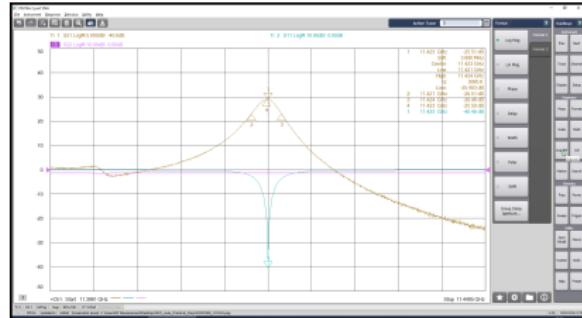


(b) Group delay

Appendix (2) - Multi mode cavity



(a) S11, S21: for all modes



(b) S11, S21, S22