CERN environment for low power RF tests of SC cavities

W. Weingarten/CERN

Plan of presentation

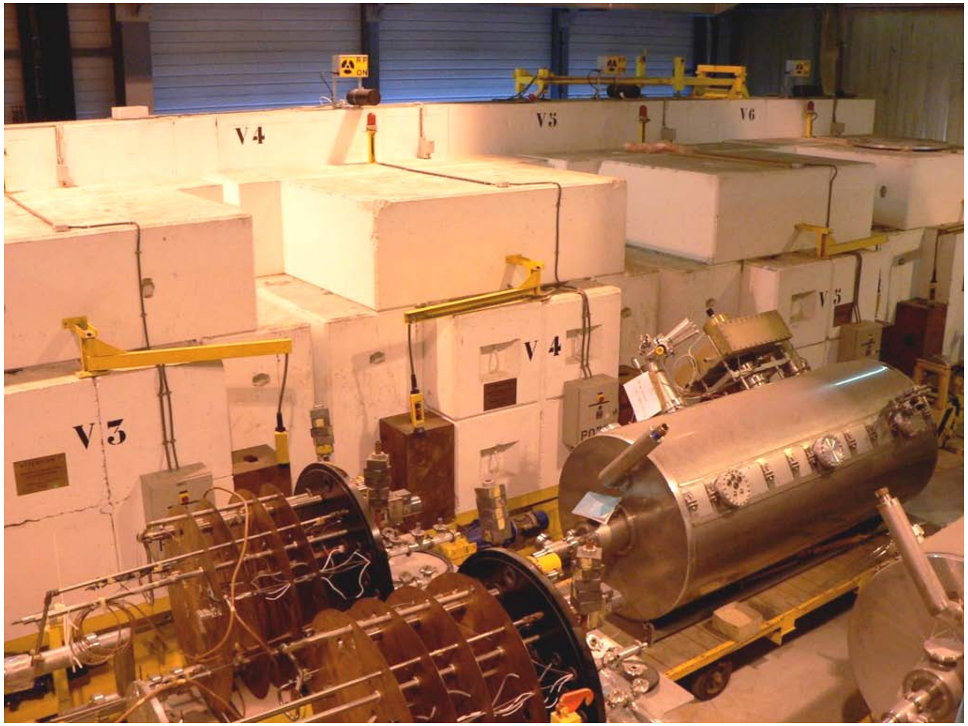
- Premises
- General purpose equipment
- RF scheme
- Diagnosis
- Example for analysis
- On the RF measurement

Premises 1/5

"SM18"

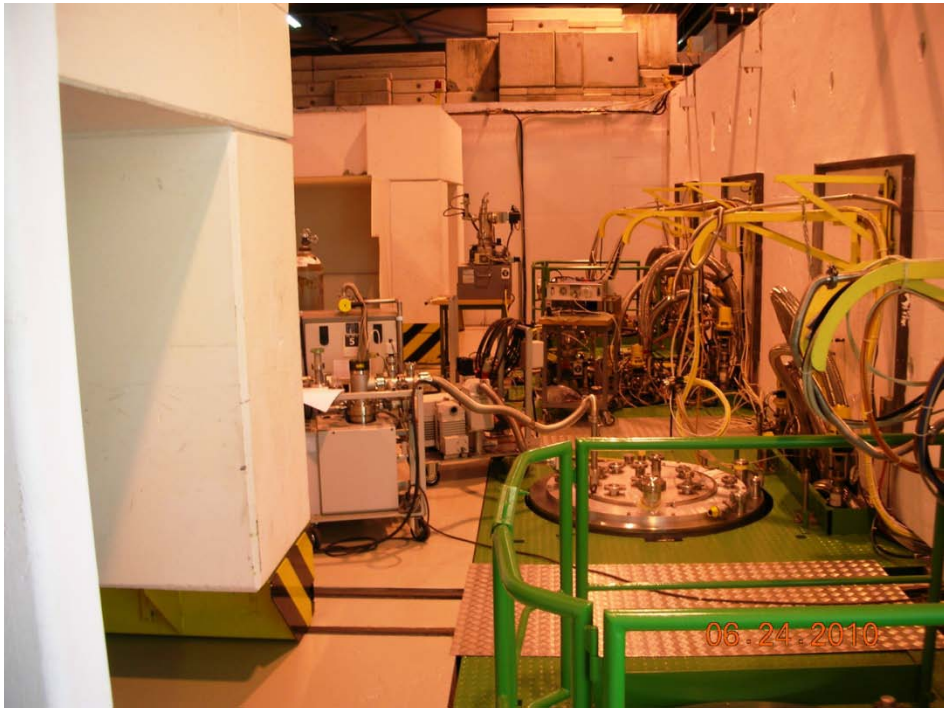
Premises 2/5
SM18

Courtesy Sergio Calatroni CERN
Orsay, 15.5.2006



Visible are only the concrete ‘hats’ for radiation protection. These can be rolled away on rails, uncovering below a test cryostat sunk into the ground; two with sufficient depth to contain a LEP 352 MHz cavity of 2.4 m length and the (heat) radiation shields above it, and one of lesser depth used for single cell cavity tests. The 300 W solid-state RF power amplifiers with their circulator and load are housed behind the concrete wall (for low power cavity/module tests)

Premises 3/5
SM18



Four cryostats for vertical low power RF tests

Control rack for vertical low power RF tests

Premises 4/5
SM18

Functionality of bunkers (vertical and horizontal)

Vertical cryostat V3: dedicated to SPL study (704 MHz)
Testing sample cavities
Test of individual cavities for SPL study
Extensive tests of individual cavities for SPL project, if approved
Vertical cryostat V4: dedicated to quadrupole resonator (400 MHz)
Test of quadrupole resonator (R&D for SPL and HIE-ISOLDE cavities)
Vertical cryostat V5: dedicated to HIE ISOLDE project (101 MHz)
Test of quarter wave resonator prototypes
Series tests of quarter wave resonators
Vertical cryostat V6: dedicated to LHC cavities (400 MHz)/SOLEIL
Soleil cavity
RF tests of LHC spare cavities
Bunker 1: SOLEIL/LINAC4/SPL study (352/704 MHz)
SOLEIL cryomodule test
SPL Cryomodule Test in horizontal cryostat in pulsed mode (1 MW per cavity)
Bunker 2: LHC cryomodules (400 MHz) & HIE-ISOLDE (101 MHz)
Series tests of quarter wave resonator cryomodules
RF tests of LHC spare cryomodules

In red:
under construction

Premises 5/5
SM18

General parameters for vertical cryostats and bunkers

General parameter	**V3**	**V4**	**V5**	**V6**	**B1**	**B2**
RF frequency [MHz]	704	400 - 1200	100	400	352 – 704	101 - 400
Typical temperature range [K]	1.8 – 4.5	1.8 – 4.5	4.5	4.5	1.8 - 4.5	4.5
Nominal installed RF power (depending on whether power coupler is mounted or not)	300 W	200 – 400 W	600 W	300 W	300 W – 1 MW (pulsed)	300 W – 300 kW

In red: under construction

General purpose equipment

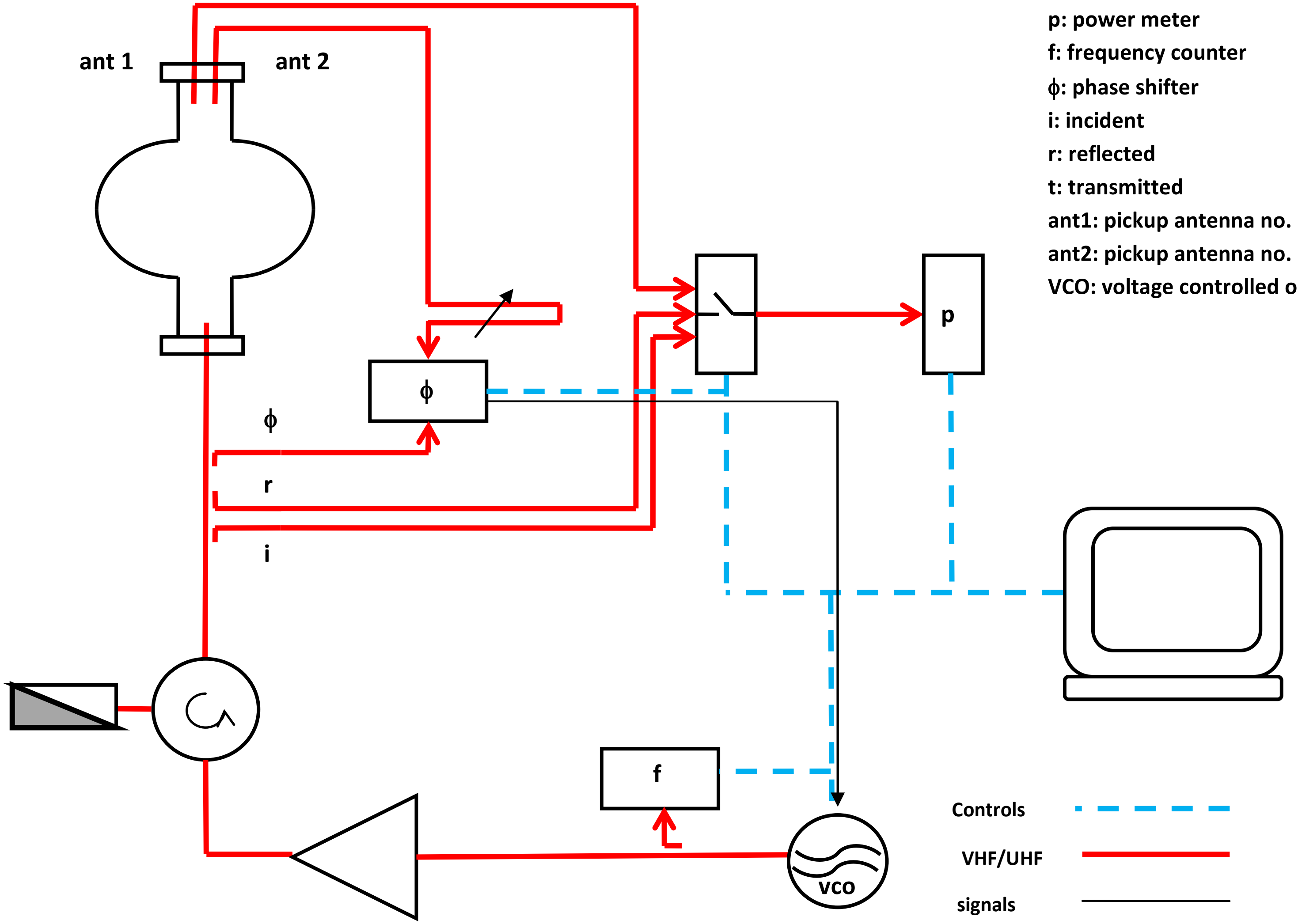
Rack Control room (distant to cavity)

Equipment item
Signal generator (VCO)
Cryostat heater control
X-radiation display
RF-switch box
Phase detector box (f)
Interlock equipment
Trombone phase shifter
Frequency counter (f)
Pulse generator/function generator
Oscilloscope
Spectrum analyzer
Power meter (p)
lHe level indication (2 independent)
Vacuum indication cavity
Pressure indication cryostat

Control rack close to cavity

Equipment item
RF power amplifier
Active magnetic field compensation power supplies
Rotary pump for lowering the temperature of lHe
Water heater unit
Heater cabinet
Directional coupler (4 port)
Directional coupler (3 port)
Circulator
RF load

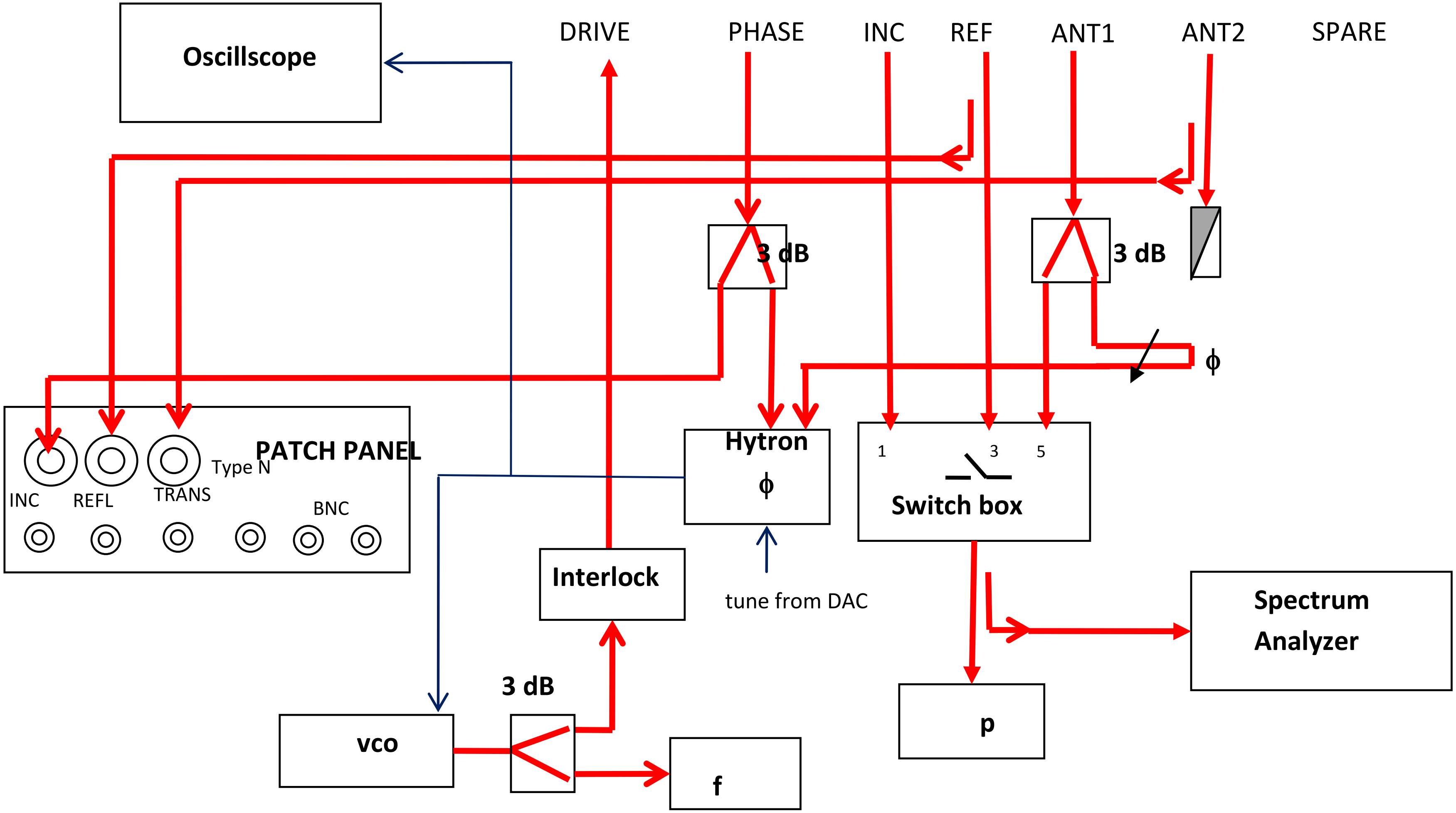
RF scheme 1/2



p: power meter
f: frequency counter
ϕ: phase shifter
i: incident
r: reflected
t: transmitted
ant1: pickup antenna no. 1
ant2: pickup antenna no. 2
VCO: voltage controlled oscillator

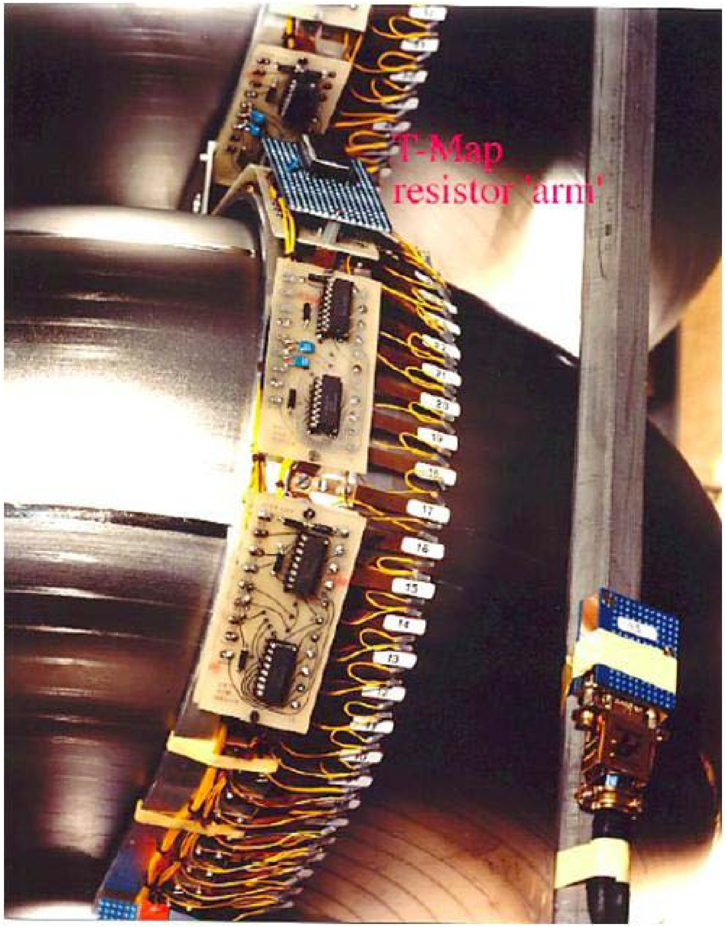
RF scheme 2/2

RF layout Rack Control Room



Diagnosis 1/2

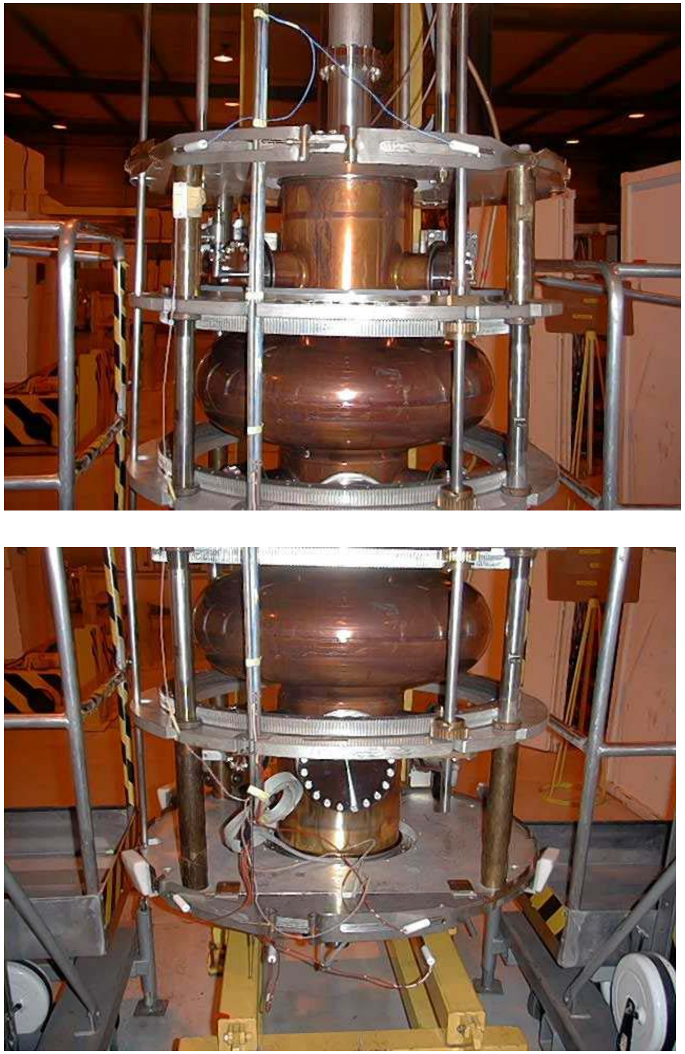
T-mapping[1] at CERN 1980-90



[1] map of the temperature distribution on the cavity surface under RF power

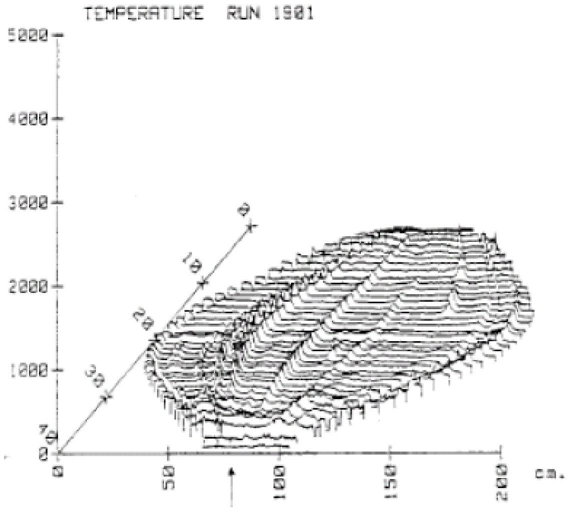
1-cell and 4-cell rotating resistors with/without multiplexing

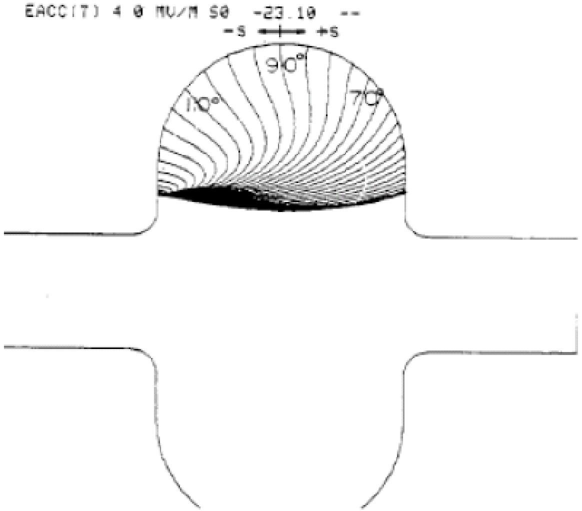
Diagnosis 2/2

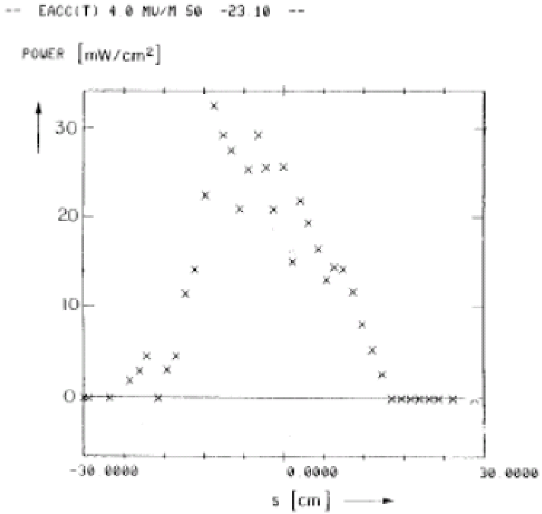


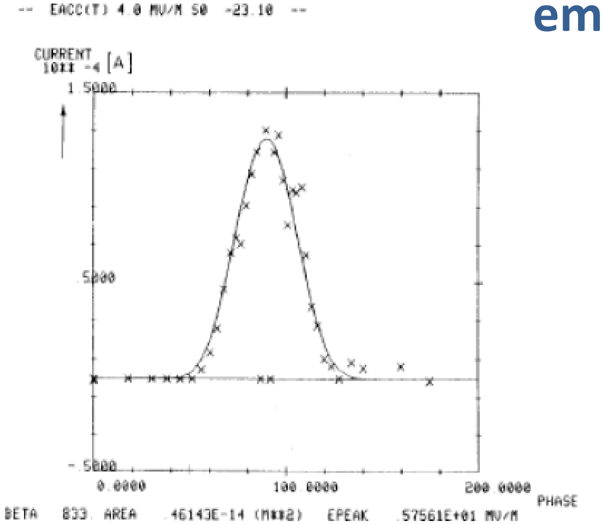
T-mapping at CERN
(LHC cavities)

Example for analysis



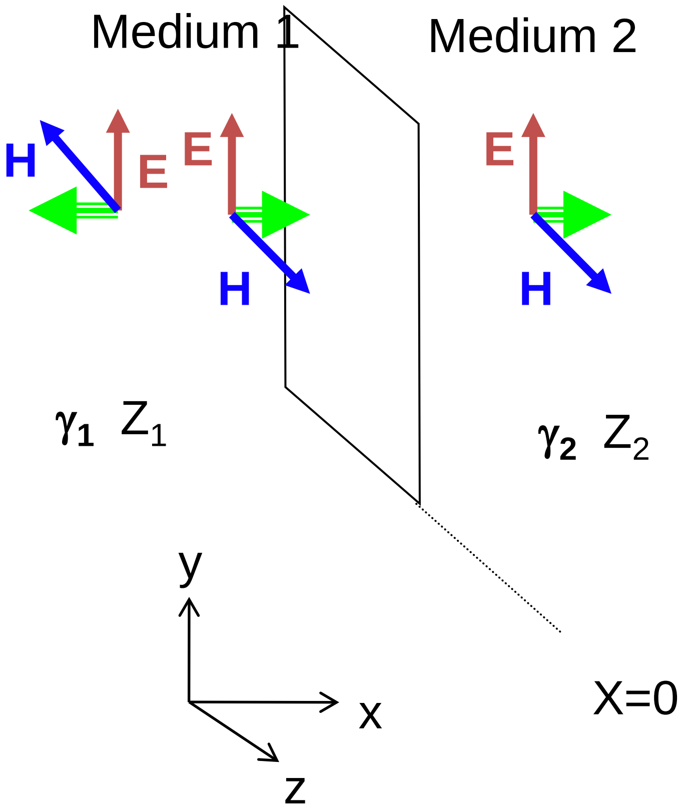






Example: Electron field emission analysis

On the RF measurement 1/4
Transmission line theory



$$\boxed{V_t = \tau \cdot V_i}$$

$$\boxed{V_r = \rho \cdot V_i}$$

$$\rho = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

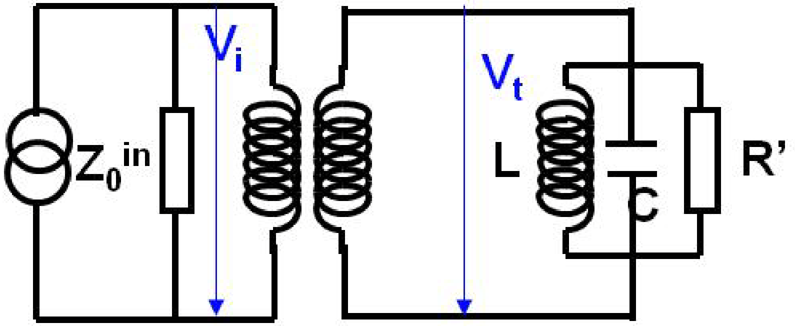
$$\tau = \frac{2Z_2}{Z_2 + Z_1}$$

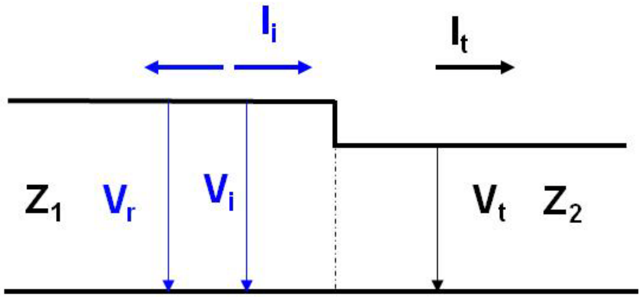
$$1 + \rho = \tau$$

Source: JUAS lectures at Archamps (Haute Savoie)

On the RF measurement 2/4
Response of a cavity to RF

The reflexion factor ρ depends on position, the coupling factor β does not: $\beta = Z_2/Z_1$





$$E_{acc} = \frac{V_t}{L} = \sqrt{\frac{8\beta'}{(1+\beta')^2}\cdot(R/Q)\cdot Q_0'\cdot P_i}\Big/L$$

L is the cavity length; the prime (‘) represents intrinsic cavity losses plus the losses from the “output” or pick-up antenna.

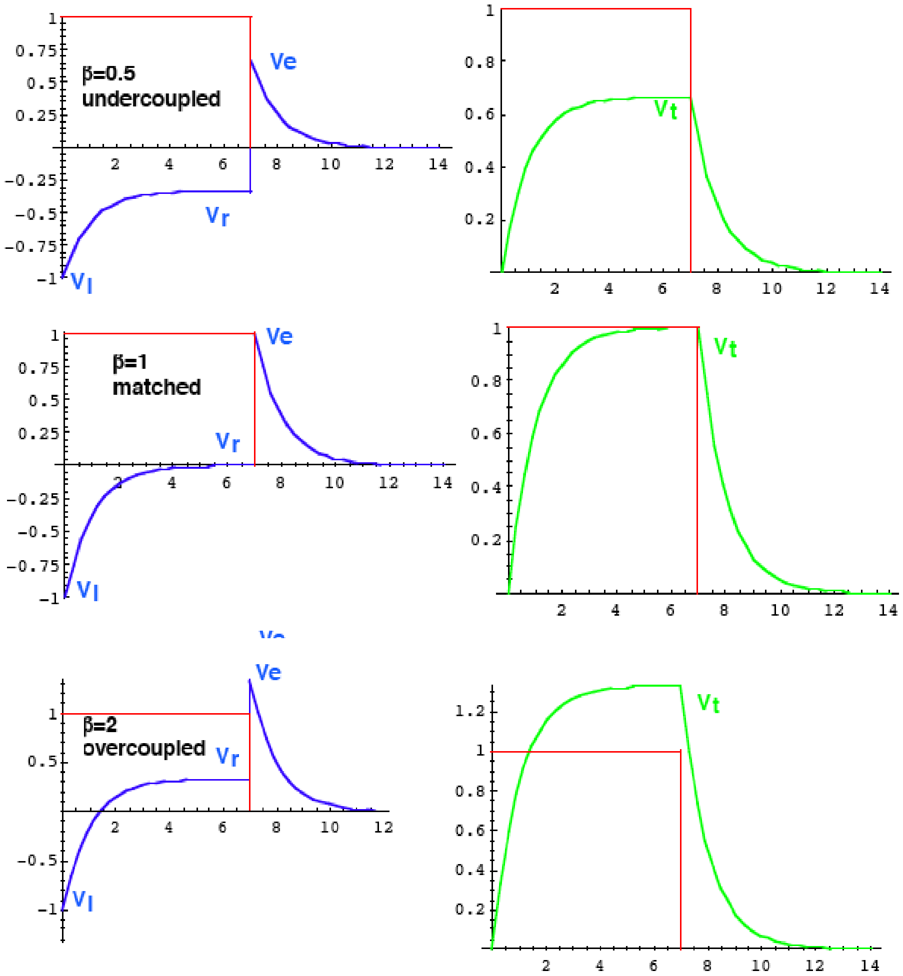
$$Q_0' = (1+\beta')\cdot\underbrace{Q_L}_{\omega\tau}$$

$$\frac{1}{Q_0} = \frac{1}{Q_0'} - \frac{1}{Q_{ext}^{out}}$$

$$Q_{ext}^{out} = \frac{\omega U}{P_{out}} = \frac{V_t^2}{2\cdot(R/Q)\cdot P_{out}}$$

<u>Measured quantities</u> are the coupling factor β’, the decay time τ, the incident RF power P_i and the transmitted RF power P_{out}.
<u>Derived quantities</u> are the accelerating gradient E_{acc}, the unloaded Q-value Q_0 (or the surface resistance $R_s = G/Q_0$, *G* is the geometry factor)

On the RF measurement 3/4
Transient response



$$2^{\text{nd}}\,\text{method}:\ \beta=\frac{1-\left|\dfrac{V_r}{V_i}\right|}{1+\left|\dfrac{V_r}{V_i}\right|}=\frac{1-\left|\dfrac{V_i-V_e}{V_i}\right|}{1+\left|\dfrac{V_i-V_e}{V_i}\right|}=$$

$$=\frac{|V_e|}{2\cdot|V_i|-|V_e|}=\frac{1}{2\cdot\left|\dfrac{V_i}{V_e}\right|-1}$$

On the RF measurement 4/4
Automatic measurement

- A transient response is not well suited for an automatic measurement

The measurement of the decay constant τ in particular is difficult →

- Instead of measuring P_i, P_{out}, τ and β, we apply a 2-step procedure:
  - Calibration:
    - We determine the cavity voltage $\boldsymbol{V_t}$ and the external Q-value $\boldsymbol{Q_{ext}^{out}}$ by the transient method as described before
  - Measurement:
    - we determine the cavity voltage $\boldsymbol{V_t}$ (accelerating gradient, resp.) and the stored energy $\boldsymbol{U}$ from the transmitted power $\boldsymbol{P_{out}}$ via

$$Q_{ext}^{out} = \frac{\omega U}{P_{out}} = \frac{V_t^2}{2 \cdot (R/Q) \cdot P_{out}}$$

    - We determine the unloaded Q-value $\boldsymbol{Q_0}$ from the relation

$$\omega \cdot U = P_c \cdot Q_0 \qquad\qquad P_c = P_i - P_r - P_{out}$$

Measured quantities are $\boldsymbol{P_{out}}$, $\boldsymbol{P_i}$, $\boldsymbol{P_r}$, all conveniently measured in CW by a high precision power meter.

- A measurement is rejected if the fundamental relation $1 + \rho = \tau$ is violated.