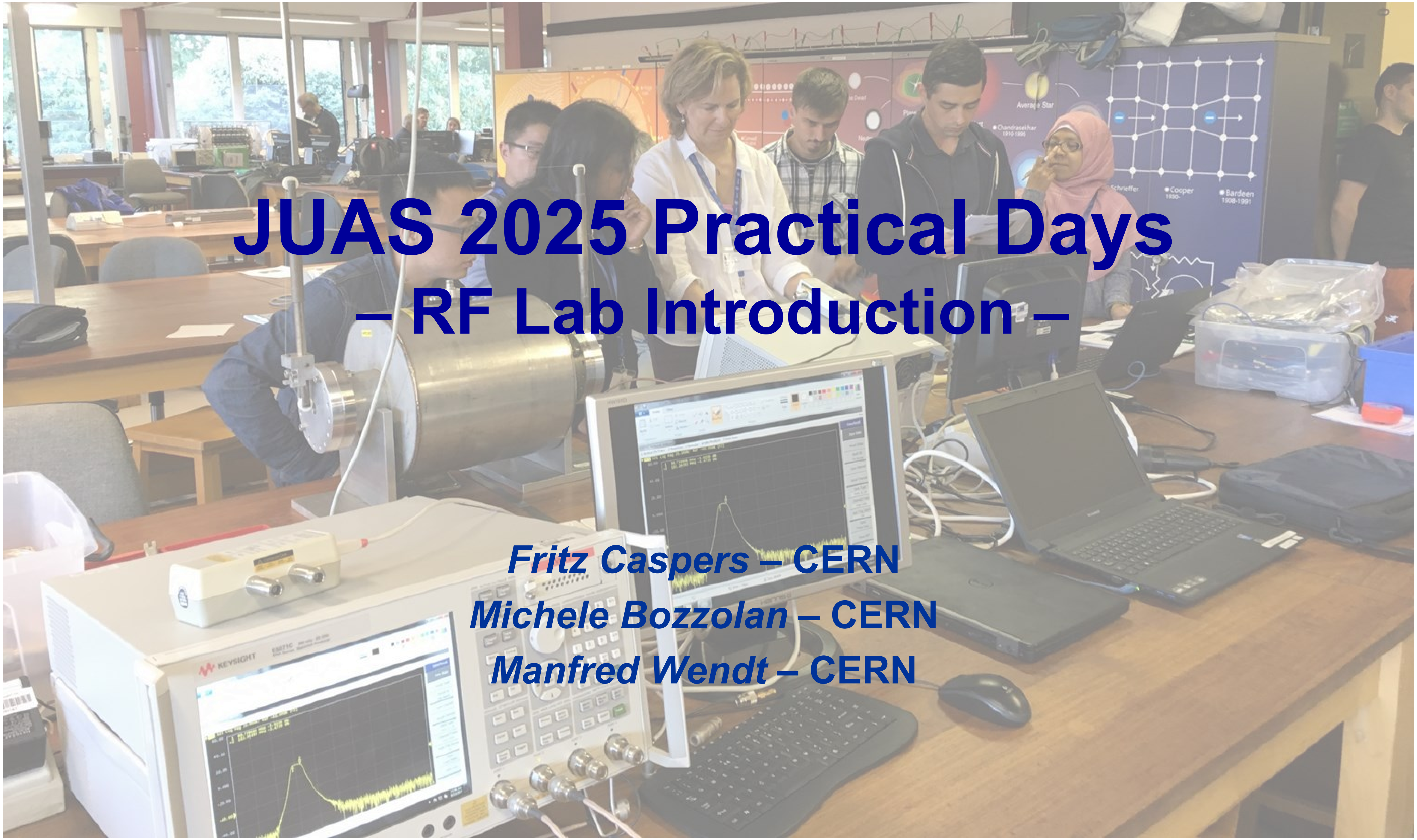

# JUAS 2025 Practical Days
## – RF Lab Introduction –

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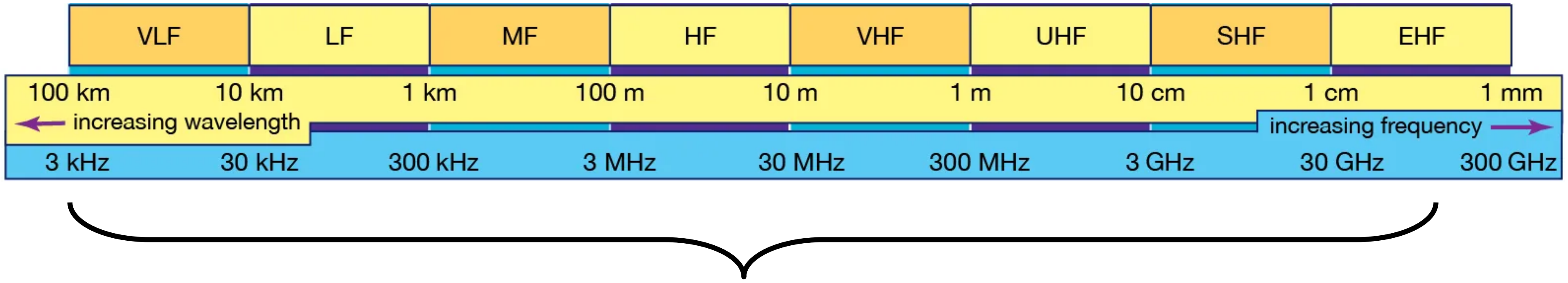
# Contents

- What is Radio Frequency
- RF in accelerators
- RF signal measurements
- VNA measurements
- Scattering parameters (S-parameters)
- RF lab gadgets
- Practical info

# Radio Frequency (RF)

Radio frequency is the range of electromagnetic radiation spectrum used for (radio) communication

## RF spectrum

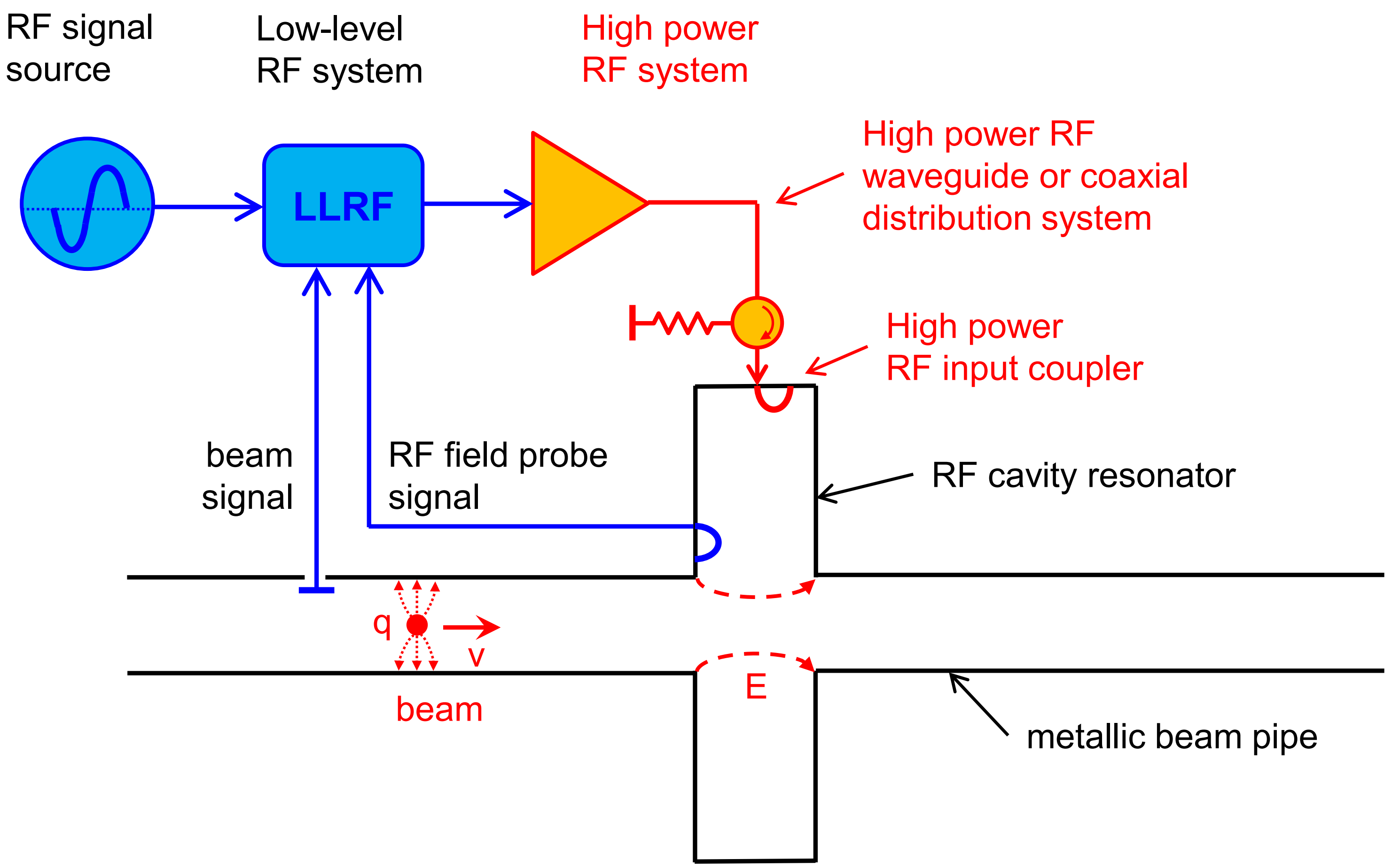



***RANGE OF RF FREQUENCIES FINDING APPLICATION IN ACCELERATORS***

**An RF circuit (or system) needs RF techniques to operate**

- In principle any system is RF, but if the size of the system is small compared to the signal wavelength we can consider it “low frequency” and use lumped elements approximation.
- Rule of thumb is to consider the system RF, and then use RF techniques, when $l > \frac{\lambda}{10}$

# RF in accelerators




- DC acceleration is possible but inefficient → RF acceleration
- Real accelerators need RF power (HLRF) and control (LLRF)
- Beam measurements (BI) often are RF measurements (e.g. beam position monitors)

# RF signals measurement (1)

**There are two main ways to observe signals:**

## 1. Time domain

- **Oscilloscope: amplitude vs time**
  - **Periodic signals**
  - **Burst signals**
  - **By using Fourier transform frequency domain can be calculated**
  - **Applications:**
    - Direct observation of signal from a beam pick-up
    - Measurement of the waveform shape

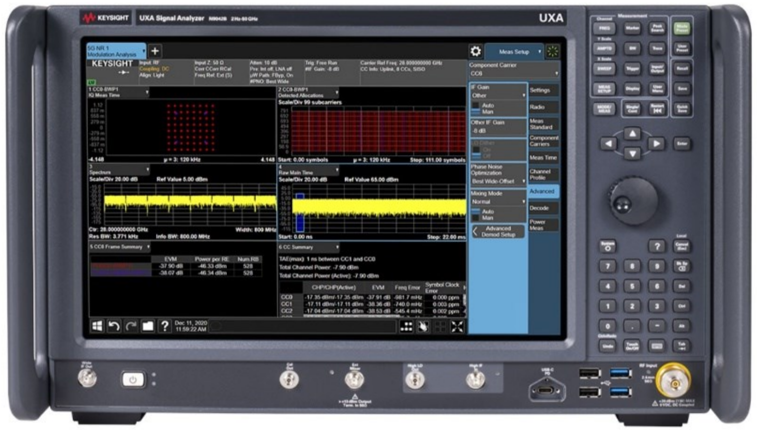
## 2. Frequency domain


- **Spectrum analyzer: amplitude (only) vs frequency**
  - **Sweeps through a given frequency range in equidistant frequency steps**
  - **Inverse FFT is not doable because phase is missing**
  - **Applications:**
    - Observation of the frequency spectral contents from the beam
    - Measurement of the spectrum emitted from an antenna, beam pickup, cavity coupling loop, etc.

# RF signals measurement (2)

## Combination of time domain measurements and Fourier transform

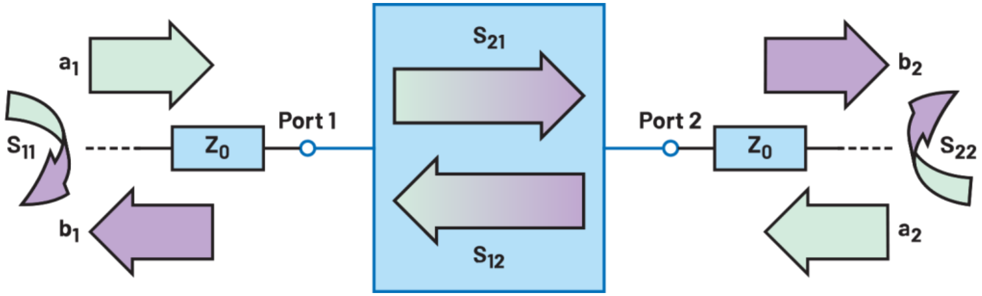
- **Digital oscilloscope with FFT feature or offline signal processing**
- **Dynamic signal analyzer (FFT analyzer)**
  - **Spectrum calculated by applying the Fast Fourier Transform (FFT)**
  - **The spectrum of non-periodic signals and transients can be observed**
  - **Applications:**
    - Observation of tune sidebands, modulation
    - Measurement of the transient behavior of a phase locked loop, etc.



# VNA measurements

- **Vector Network Analyzer (VNA)**
  - **It can have N ports (1 ,2 ,3 ,4, ….)**
  - **It is configured (by the user) to sweep over a frequency range**
  - **Excites the device under test**
  - **For each frequency point it measures a N by N matrix (S-parameters)**
  - **Applications:**
    - Characterization of passive and active RF components,
    - Time domain reflectometry by inverse *Fourier* transformation of the reflection response, etc.

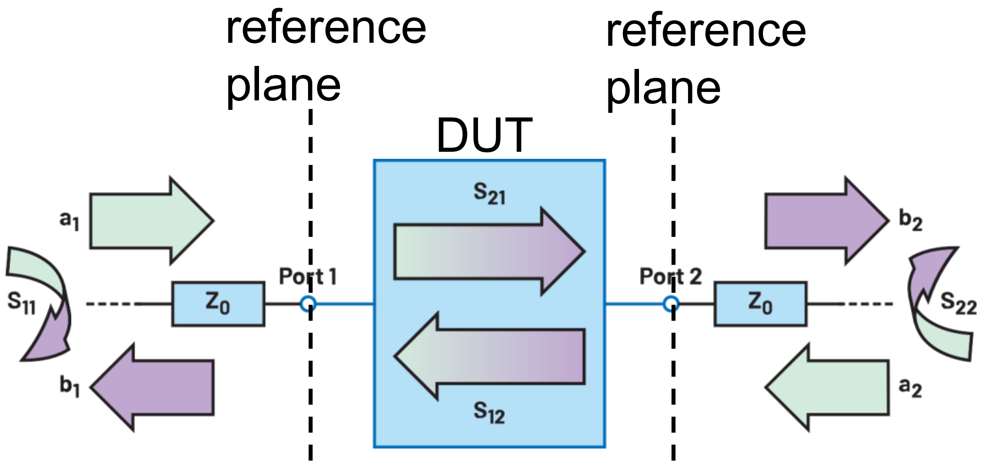
Device under measurement (DUT)



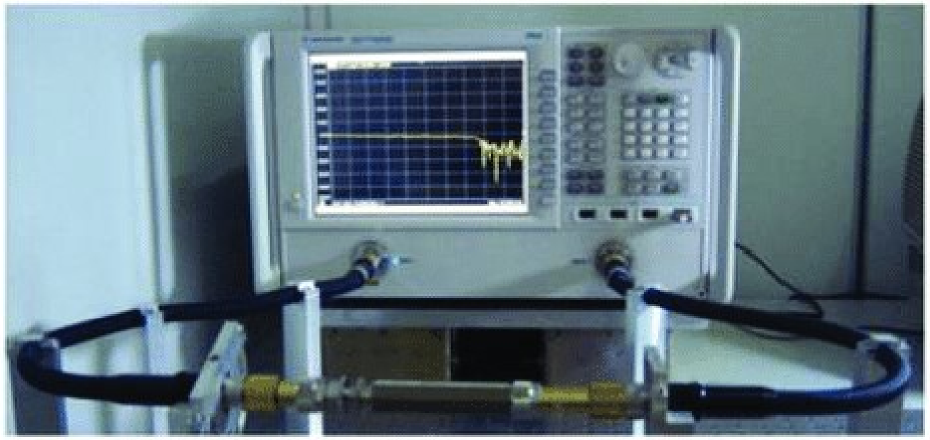


**The VNA is the key RF instrument and with accessories represents an entire RF lab**

# Principle of Scattering (S)-Parameters



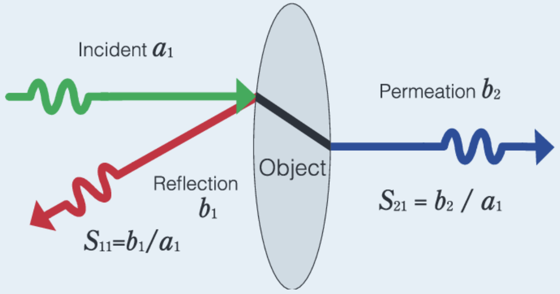

VNA



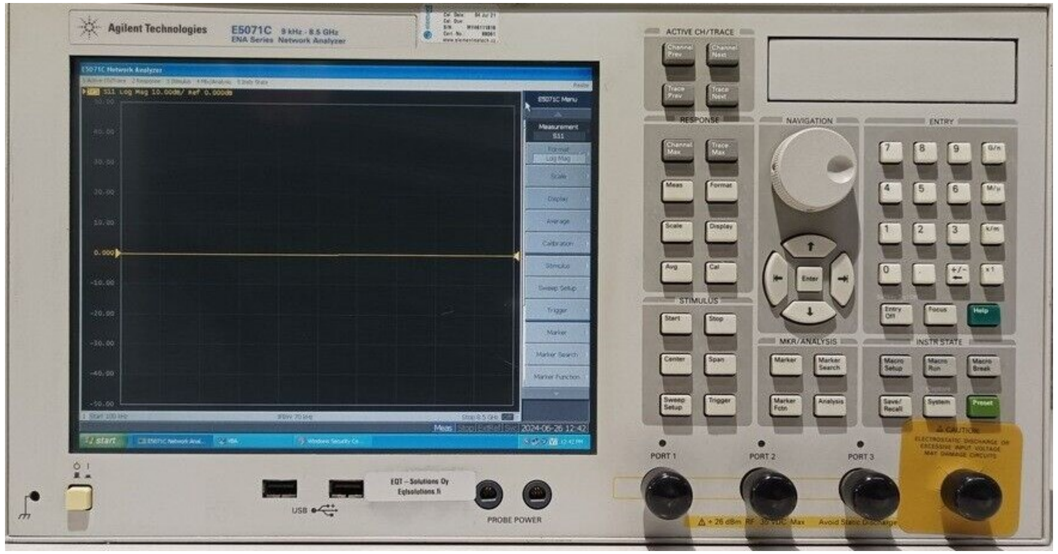
$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

with $S_{ij}$ complex numbers !

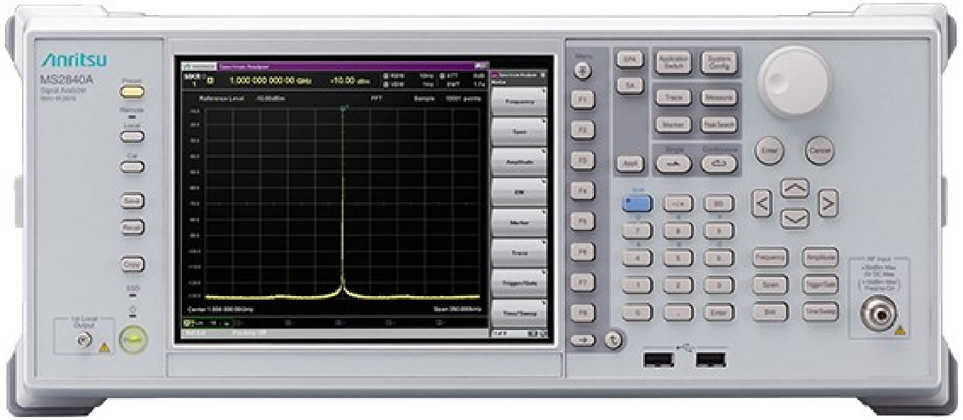
## S-parameters optical analogy




# Some gadget of the RF lab





# Practical info

- **Location: CERN (Prevessin site)**

- **When: Tuesday 11th, Wednesday 12th March**

- **Organization:**
  - **Each day has two sessions: Morning and afternoon**
  - **Students will sign up for one of the two RF practical days**
    - ➢ Will further split in small teams, “rotating” through different RF experiments
  - **Instructors: Fritz Caspers, Michele Bozzolan, Manfred Wendt**

- **Experiments:**
  - **Pillbox cavity (resonant modes, quality factor)**
  - **Other VNA experiments (calibration, slotted line, passive devices, amplifiers)**
  - **Time / frequency domain measurements (amplifiers, modulation, noise)**

# We hope you will have a lot of fun!