ISEI BSU

JOINT INSTITUTE FOR NUCLEAR RESEARCH

RF Technology hands-on training

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University Centre

Microwave RF radiation

Radionavigation

Portable electronics

Home appliances

Accelerator technics

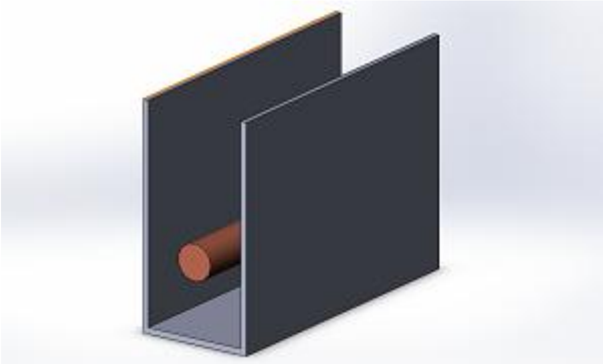
RF

Space television

Frequency range: 300 MHz – 300 GHz
Wavelength range: 1 m – 1 mm

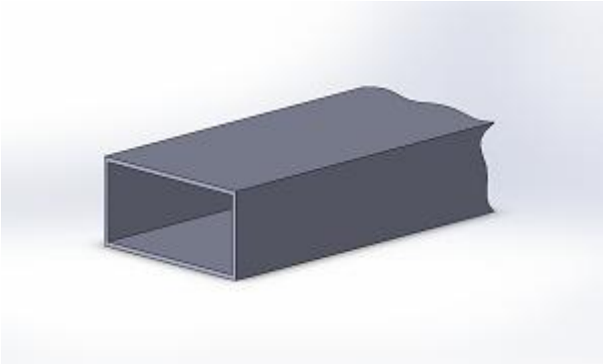
RF power transmission

Coaxial cable



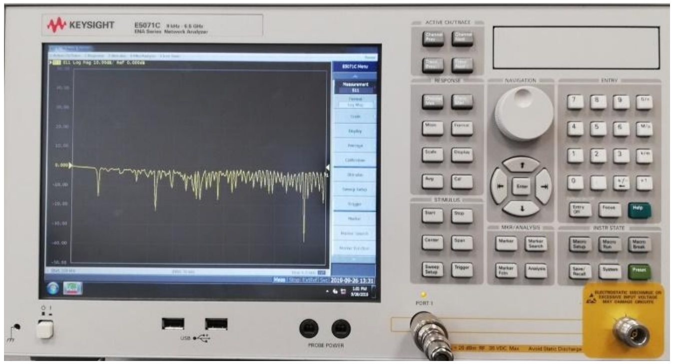
Planar line

Coaxial line



Waveguide

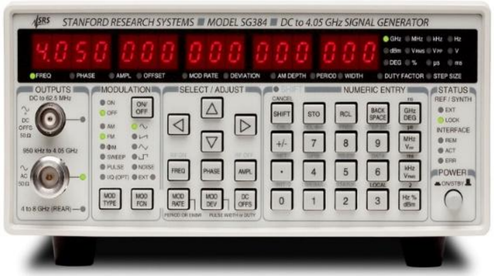
Used equipment:



KEYSIGHT E5071C
Vector Analyzer (VA)

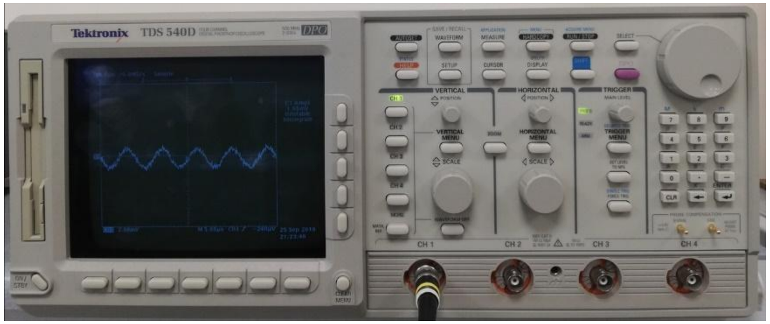
AKIP 4115/5A Oscilloscope

SRS SG384 RF generator



Power meter

Tektronix TDS 540D Oscilloscope

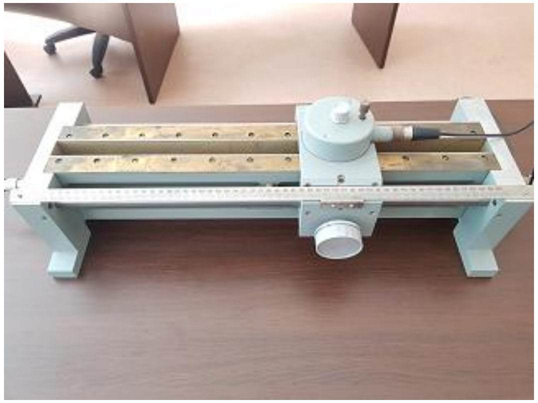


Measurement lines

- Measurement line is a section of a separate waveguide or rigid coaxial line equipped with a movable detector. Line is mounted between a generator and a load.
- First Labs were devoted to the determination of the wave length in various transmission lines.
- Three measurement lines are covered:
  - ✓ Waveguide (P1-7)
  - ✓ Coaxial (P1-34)
  - ✓ Planar (P1-17)

P1-7 waveguide line

P1-34 coaxial line

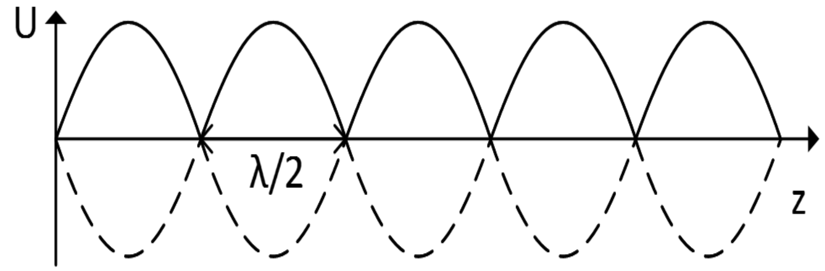


P1-17 planar line

Determining of the wave length in the waveguide

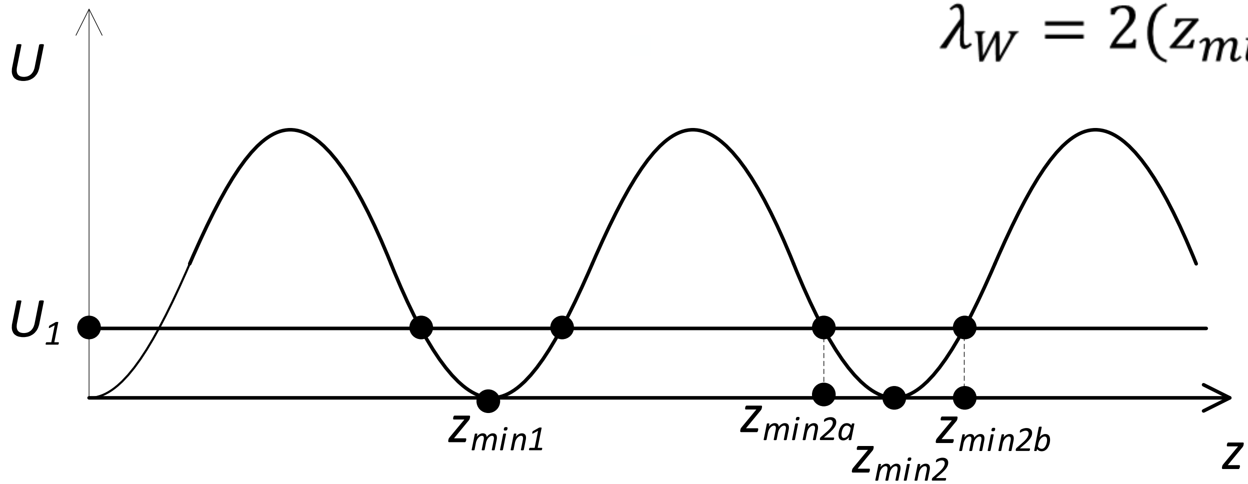
Standing wave

When the short-circuiting plug is installed at the end of the transmission line, the standing wave is formed in the waveguide. I.e. forward wave in the waveguide will be totally reflected from the load.



Experimental measuring of the wave length

$$\lambda_W = 2(z_{min2} - z_{min1})$$

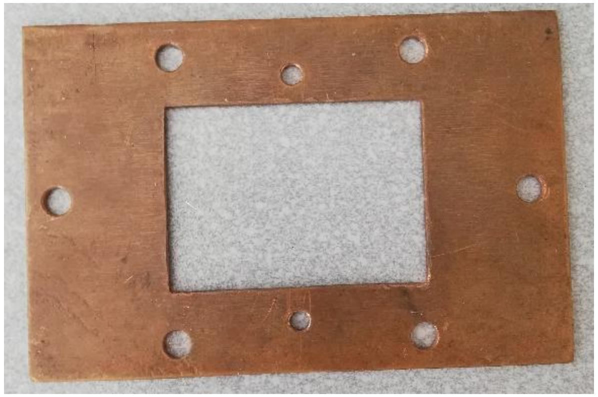


Irregularities examples

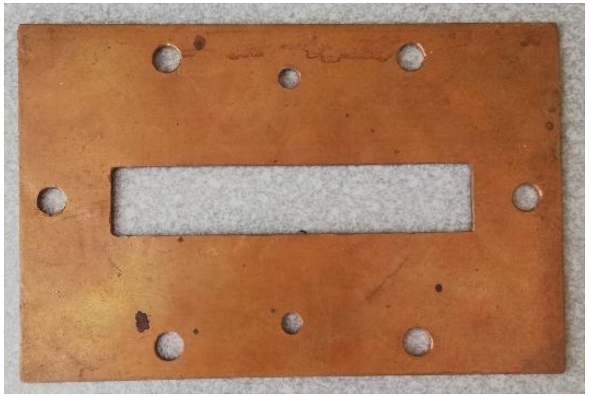
- Various diaphragms
- Interface of the two uniform mediums with different physical parameters (permittivity and permeability)

Diaphragms are the thin metal plates with an aperture, placed in the waveguide section.

Diaphragms are being used as reactive elements for resistances matching or as filter resonant circuits elements.



Big Capacitive Diaphragm

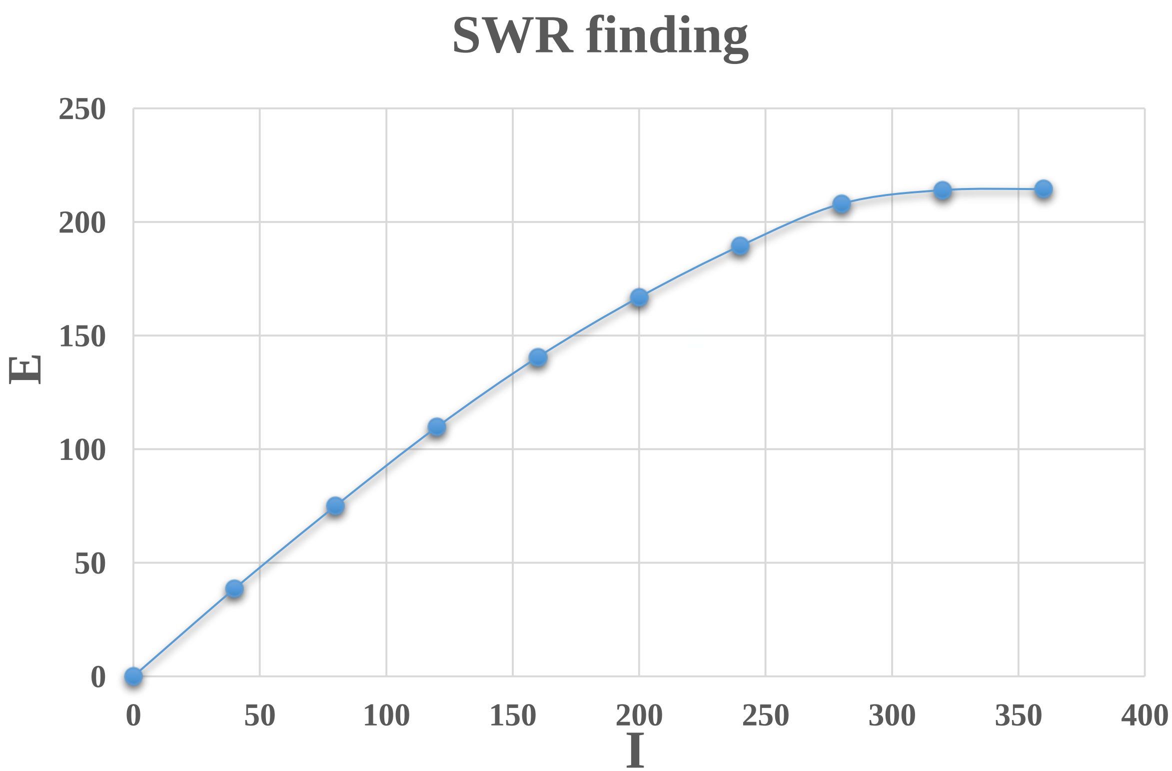


Small Capacitive Diaphragm

Inductive Diaphragm

SWR and TWR

A reflection coefficient (Γ) is the joint name of the dimensionless quantities characterizing the wave reflection from some irregularity in some medium. VSWR (voltage standing wave ration, hereinafter SWR) and the quantity inverse to it, TWR (travelling wave coefficient) and the reflection coefficient related by formulas:



$$SWR = \frac{E_{max}}{E_{min}}$$

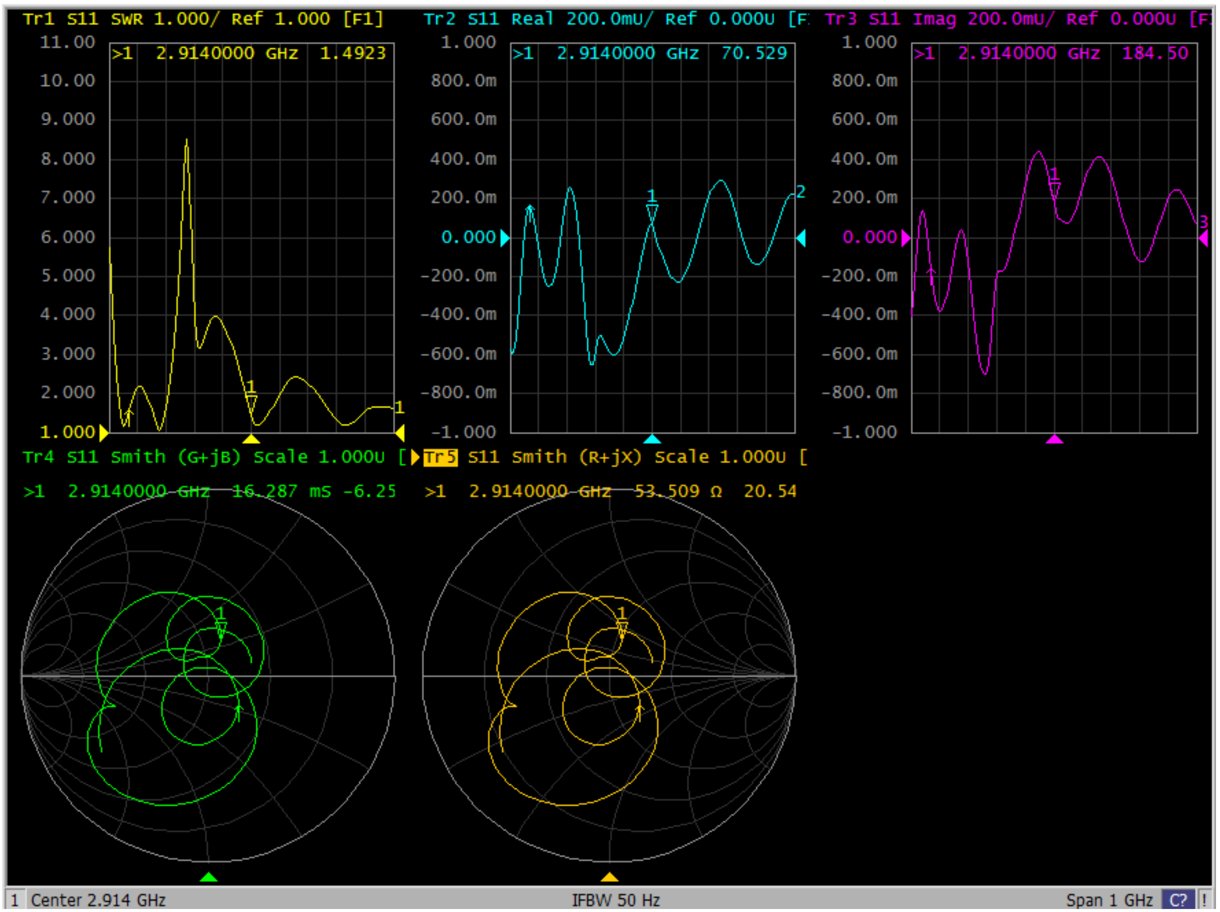
$$1 < \text{SWR} < \infty$$

$$TWR = \frac{1}{SWR}$$

$$0 < \text{TWR} < 1$$

$$|\Gamma| = \frac{SWR - 1}{SWR + 1}$$

Total resistance



Total resistance and conductivity measurements using the vector analyzer for Capacitive Diaphragm

The total resistance (impedance) is given by a complex number:

$$Z = R + jX$$

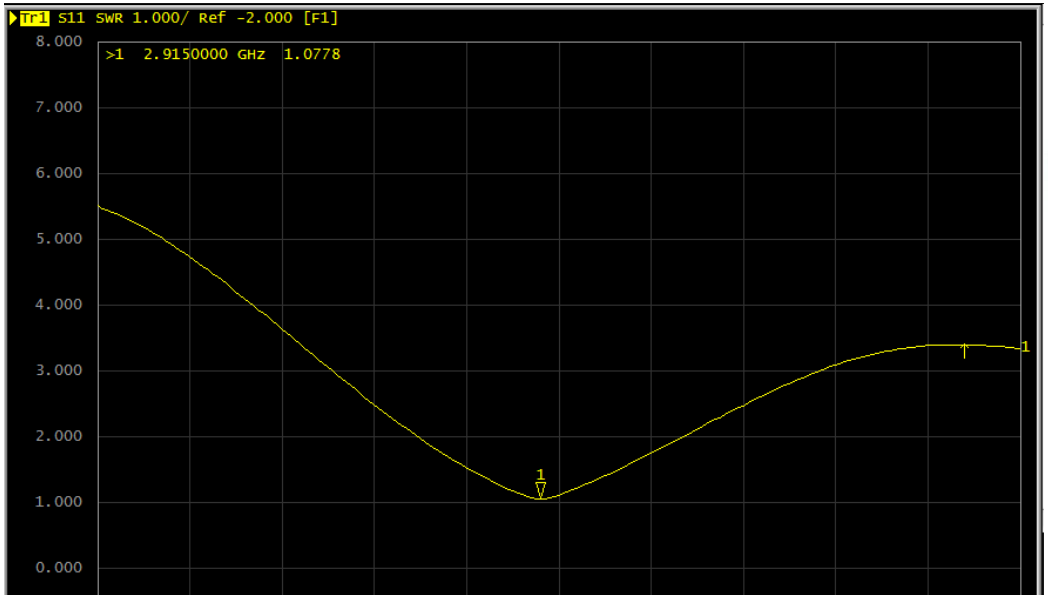
where R and X are active and reactive resistance components correspondingly.

In addition to the reactance an inverse quantity, conductivity. In real tasks total resistance is usually measured directly, with the vector analyzer (VA).

Reactive dowel

We match the line using the reactive dowel and the VA (SWR ≈ 1,07).

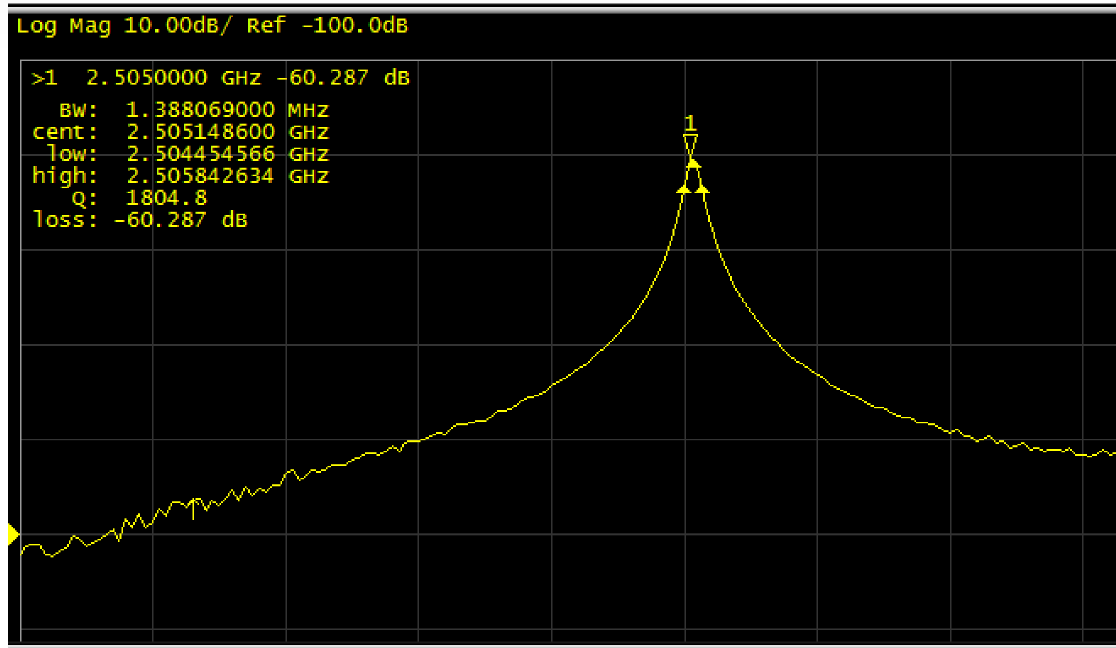
- Metal rod with the *r* radius inserted to the waveguide through the wide wall.
- Used in RF technics for the narrow band matching ($Z_W = Z_L$ only for narrow frequency band)



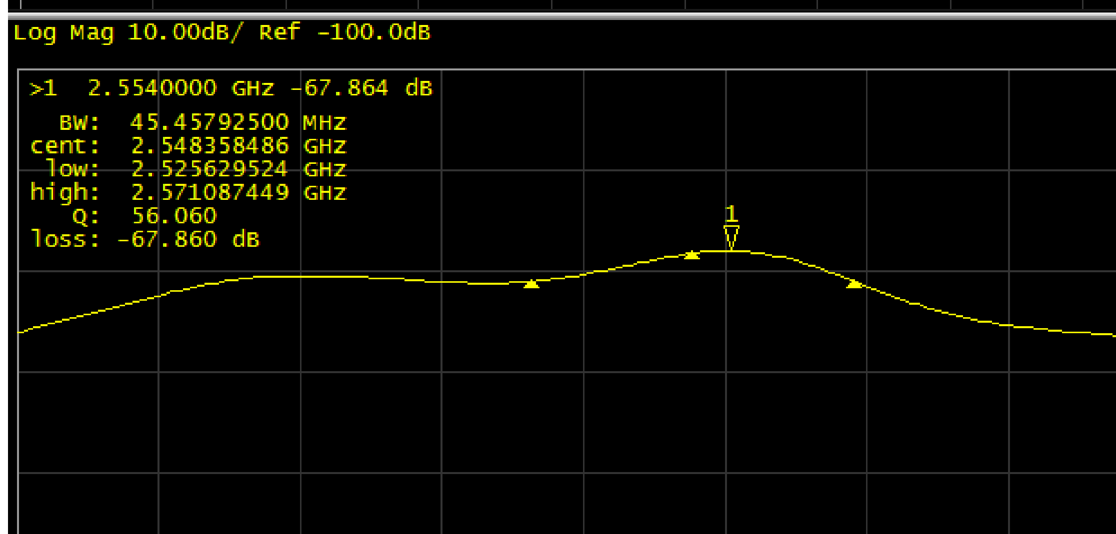
Loaded Q-factor

Measure Q_l with a VA:

- For Inductive Diaphragm



- For Big Capacitive Diaphragm

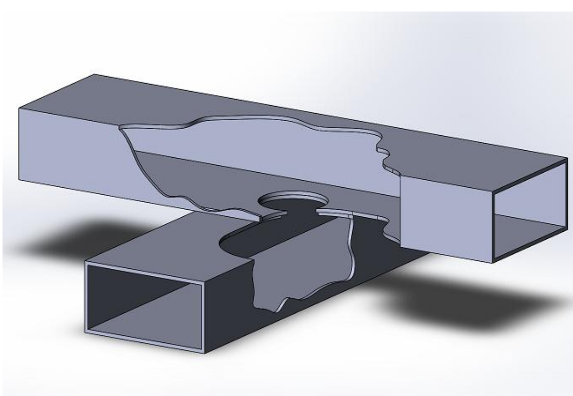


Directional coupler (DC)

A device used to branch off part of the power of the forward or reflected wave from the main RF transmission line. Used in accelerators to power several elements from one source, to determine the incident power in the main waveguide (by measuring the power in the branch waveguide).

Consists of two waveguide segments that have a common thin wall (wide or narrow).

The wall separating the waveguides has holes that serve as coupling elements; through these holes a small part of the power is branched off from the primary waveguide to the secondary one.



Main parameters of directional couplers

Directivity:

$$D = 10lg\frac{P_4}{P_3} = 10\,lg\frac{0{,}32\,mW}{0{,}15\,mW} = 3{,}29$$

Coupling factor:

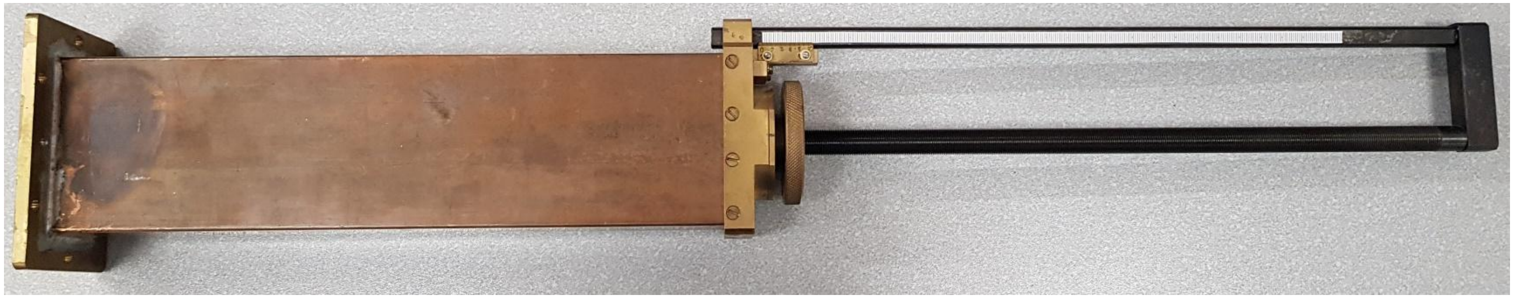
$$\text{C} = 10lg\frac{P_1}{P_4} = 10\,lg\frac{4\,W}{0{,}32\,mW} = 40{,}97$$

Where $P_1 = 4$ W is power

Calibration of dielectric phase shifter

Phase shifter is a device intended for smooth or discrete change of the phase of an electromagnetic wave. It is used in accelerators to shift the phase of devices powered from a single source but operating on different phases.

For calibration of a dielectric phase shifter, a short circuitor is used —a movable short-circuiting plug (piston) with a scale.
A short circuitor allows compensating the phase change with a phase shifter by moving the piston. Using the short circuitor scale, it is possible to determine how far the phase has shifted.

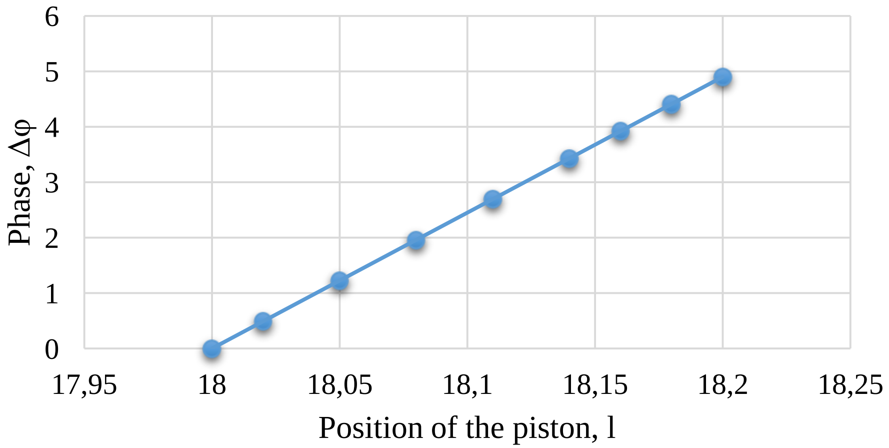


A phase shift for each position of the phase shifter plate is calculated as follows:

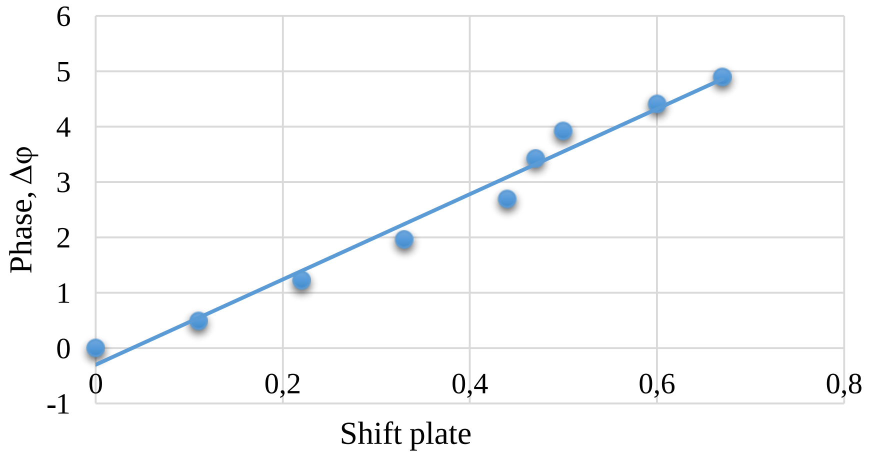
$$\Delta\varphi = \frac{360}{\lambda_W}\Delta l, \text{ where } \Delta l = l_0 - l$$

Δl — shift in the position of the short circuitor piston
l_0 — initial position of the piston
l — current position of the piston

Phase dependence on the position of the short circuitor piston



The dependence of the phase shift plate shifter

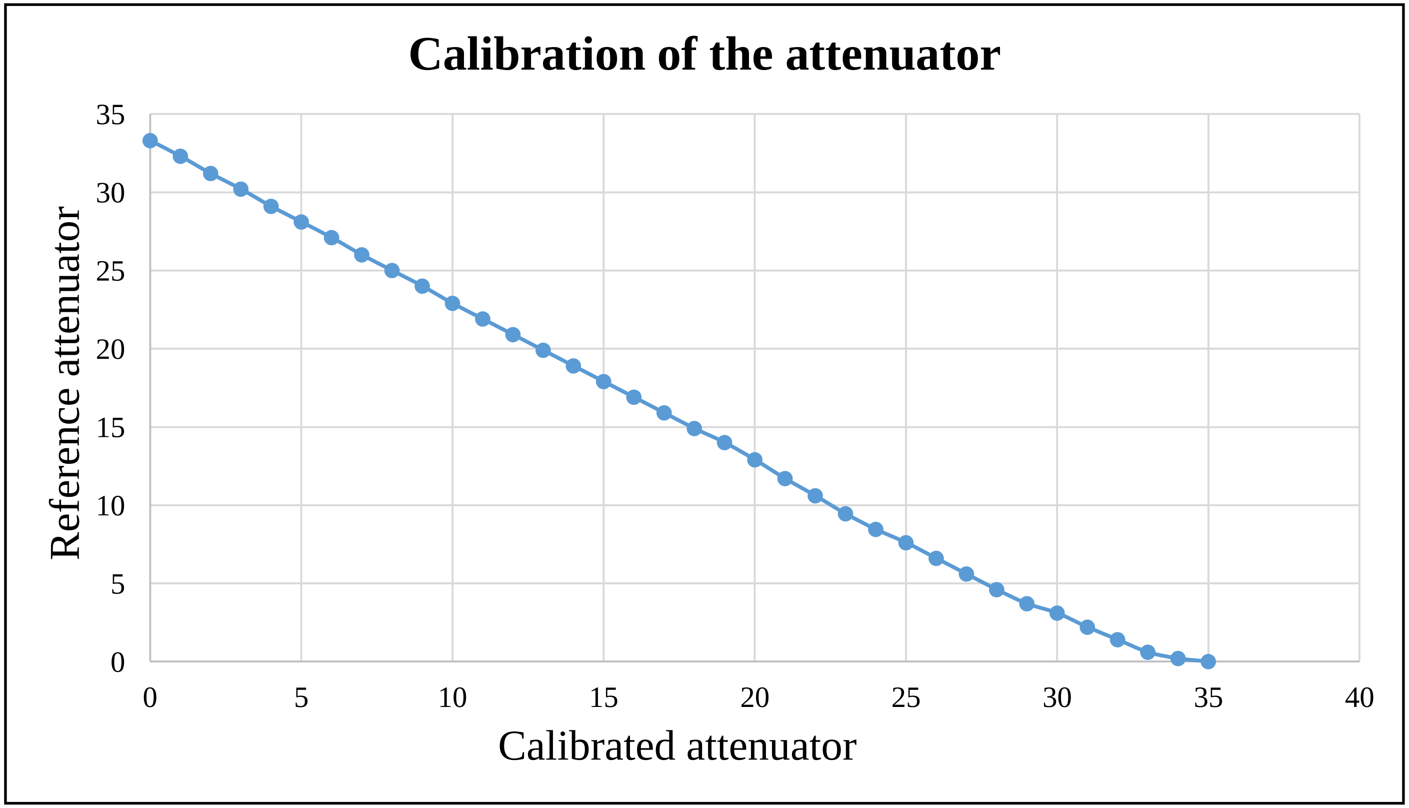


Attenuator

An attenuator is a device intended for reducing the power of electromagnetic waves propagating along the RF transmission line.

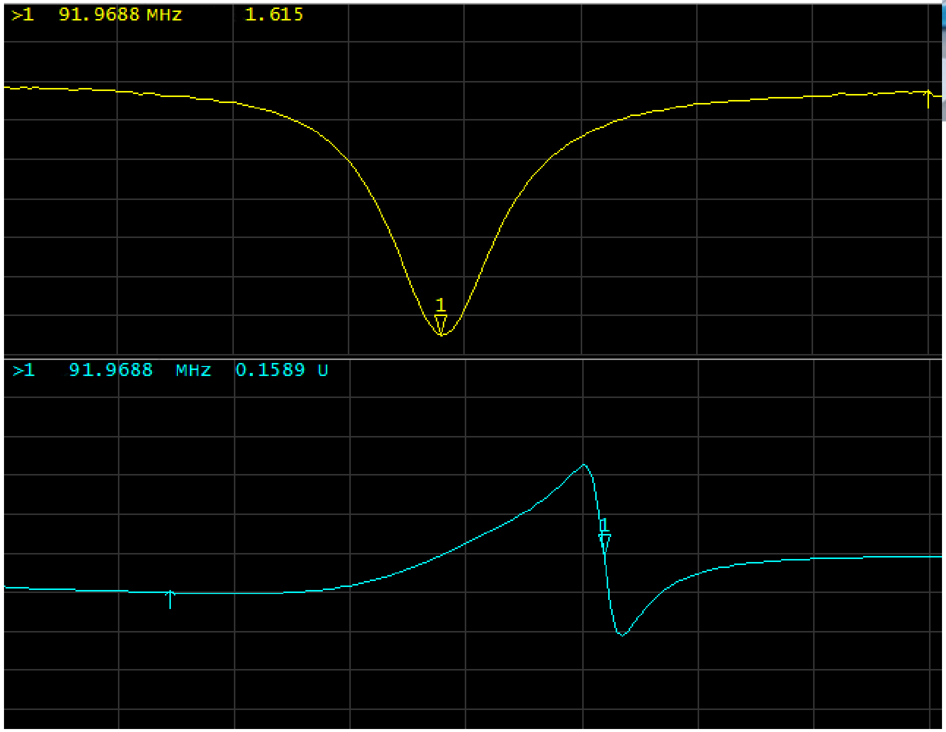
Calibration of the attenuator

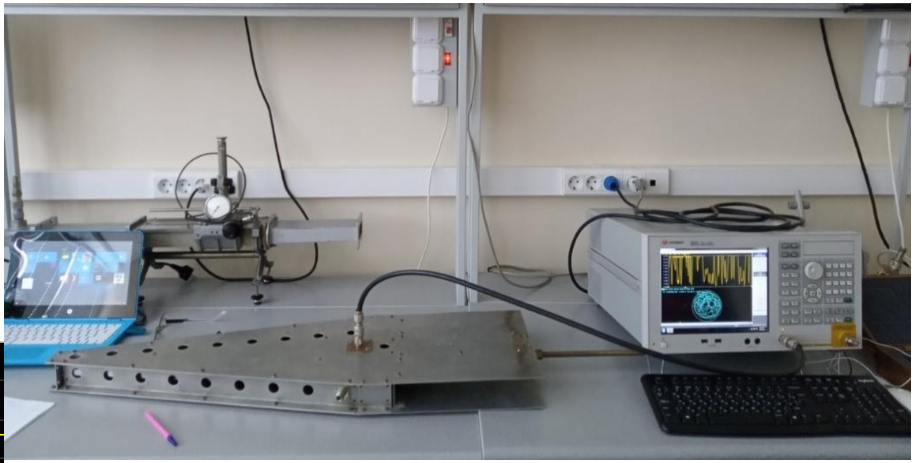
Before being installed on the accelerator, the attenuator must be calibrated. This lab work is devoted to the calibration by successive substitution: comparison of the attenuation by the reference and calibrated attenuators.



Model of the flat-top resonator DC280 with coupling like on cyclotron U-400M

This model is used for training, to tune the frequency and tuning the cold matching on the cyclotron using rotative loop coupling.





The frequency range of Model of the flat-top resonator DC280: fa = 70 200 MHz

Conclusion:

- ✓ We learned how to calibrate the equipment for future installation on the accelerator and how to perform various physical mesurements.
- ✓ We have learned to determine the wave length in various transmission lines.
- ✓ With the help of diaphragms and reactive dowel we mesured SWR(standing wave ration) and TWR (traveling wave ration).
- ✓ Using the Smith chart, total resistance and conductivity were determined of the open waveguide, capacitive diaphragm and matched load. .
- ✓ We have worked with directional coupler (DC), phase sifter, attenuator, equipment which will be used for the linear accelerator.
- ✓ We learned how to tune the frequency and adjust the matching on the cyclotron using rotative loop coupling. Learned how to set up cold matching at different frequencies.

Thank you for attention!