A Multimodal Calibration Technique for Waveguide Devices

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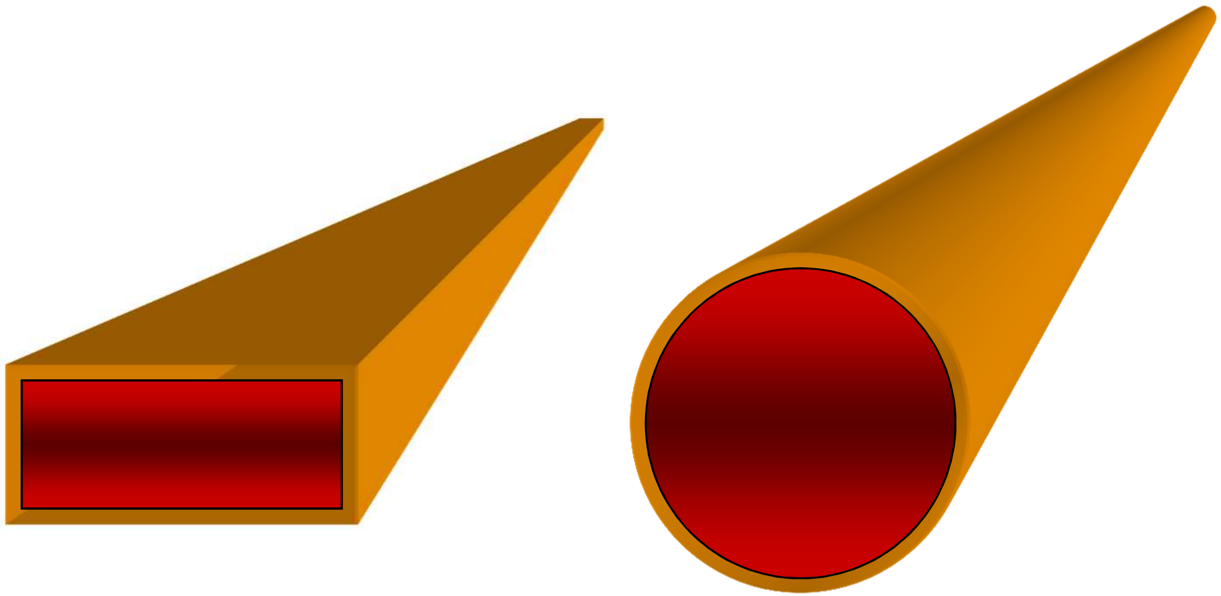
Modes in waveguides..
Circuit and Field Theory



Any EM field can be expressed as combination of modes:

$$\mathbf{E}(x,y,z)=\sum_{n,m} A^{+}_{nm}\left(\mathbf{e}_{nm}+\mathbf{u}_z e_{znm}\right)e^{-\gamma_{n,m}z}+A^{-}_{nm}\left(\mathbf{e}_{nm}-\mathbf{u}_z e_{znm}\right)e^{+\gamma_{nm}z}$$

$$\mathbf{H}(x,y,z)=\sum_{n,m} A^{+}_{nm}\left(\mathbf{h}_{nm}+\mathbf{u}_z h_{znm}\right)e^{-\gamma_{nm}z}+A^{-}_{nm}\left(-\mathbf{h}_{nm}+\mathbf{u}_{nm} h_{znm}\right)e^{+\gamma_{nm}z}$$

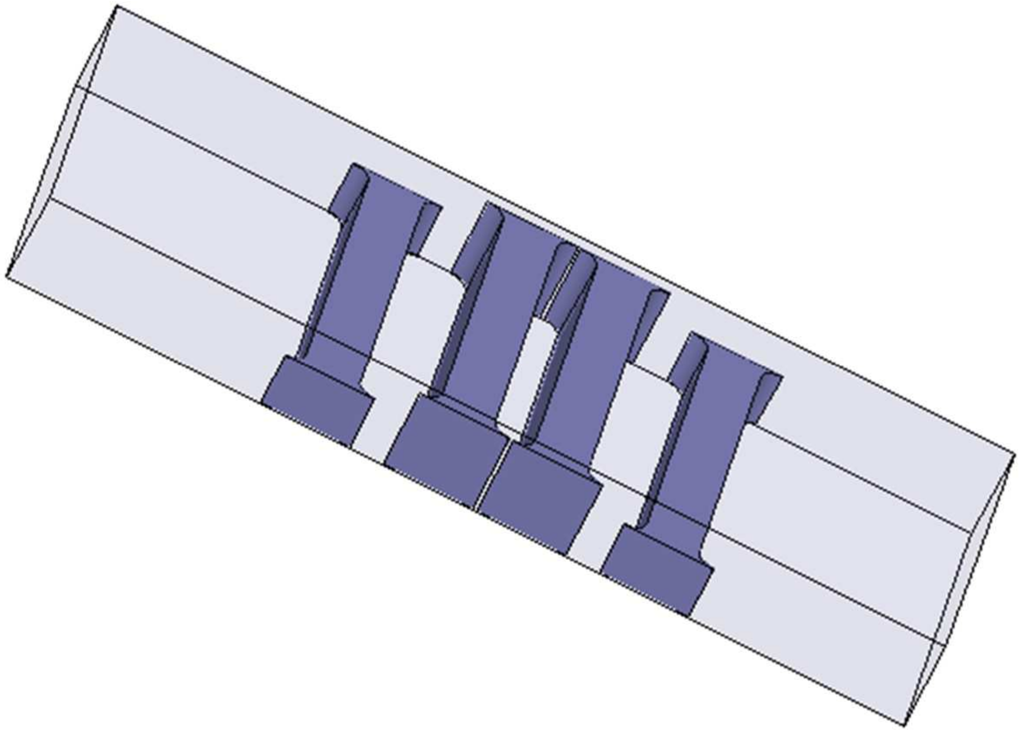
Rectangular waveguide are typically sized in such a way that only **one mode propagates** at working frequency:

$$\gamma_{10} = j\sqrt{k_0^2 - \left(\frac{\pi}{a}\right)^2}$$

In this case, the field at ports is described with great accuracy by only one mode and the previous sums involve just one term

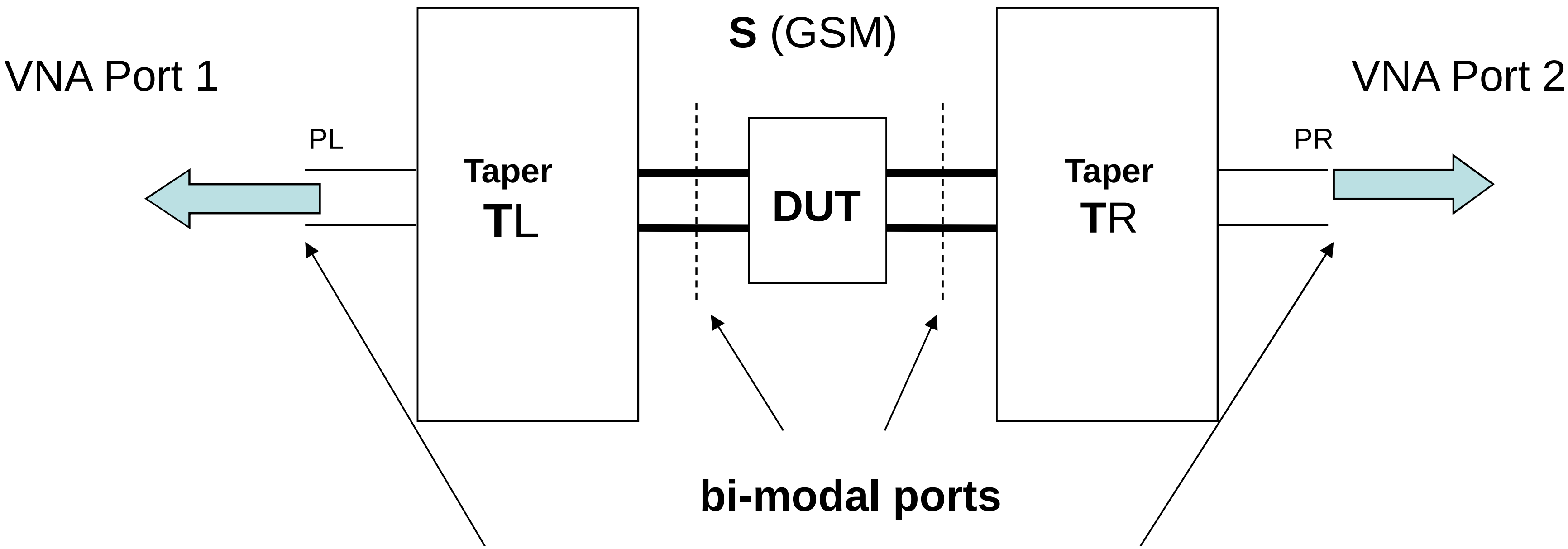
THE ELECTROMAGNETIC PROBLEM BECOMES SCALAR !!!

Unfortunately, the former **monomodal assumption** is not always satisfied….. A typical application is the measurement of Low-pass filters in their stop band



The rejection of a filter in the band around the second harmonic is critical. In this band, normally more than one mode is above cut-off and the exact response of the DUT cannot be measured with current methods.

Commonly..



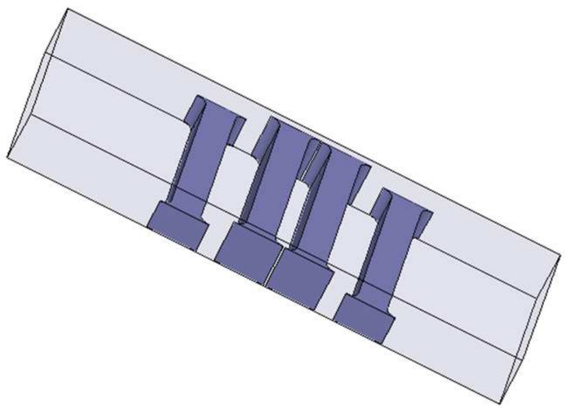
Monomodal ports the only at which we can do measuments

<u>**This is not a solution!**</u>

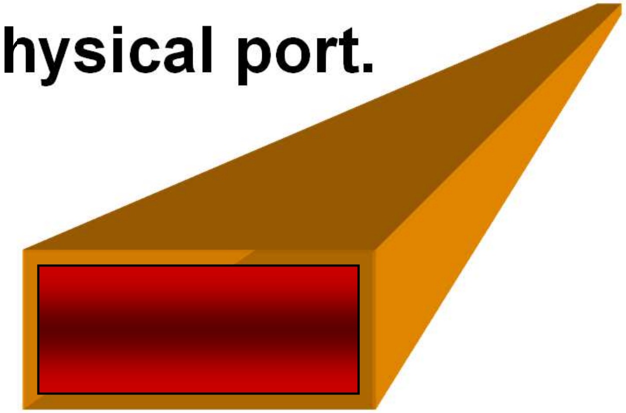
In fact, tapers are..

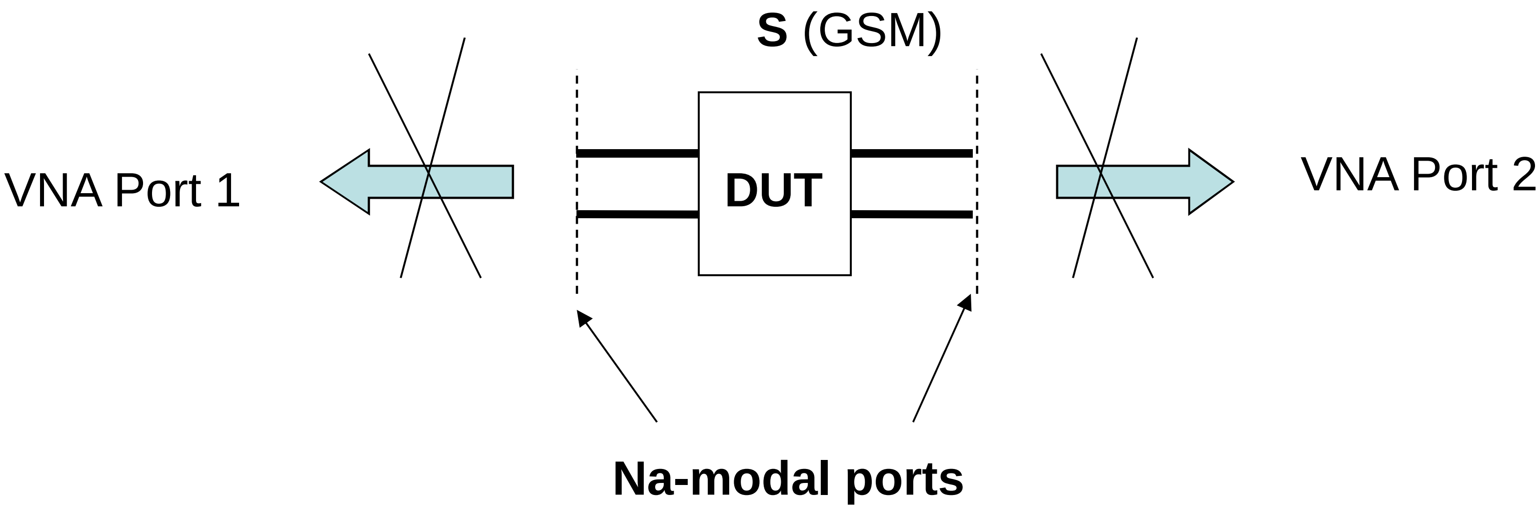
- almost ‘trasparent’ for the fundamental mode
- reactive loads for higher order modes.

In conclusion, tapers alter the measurement

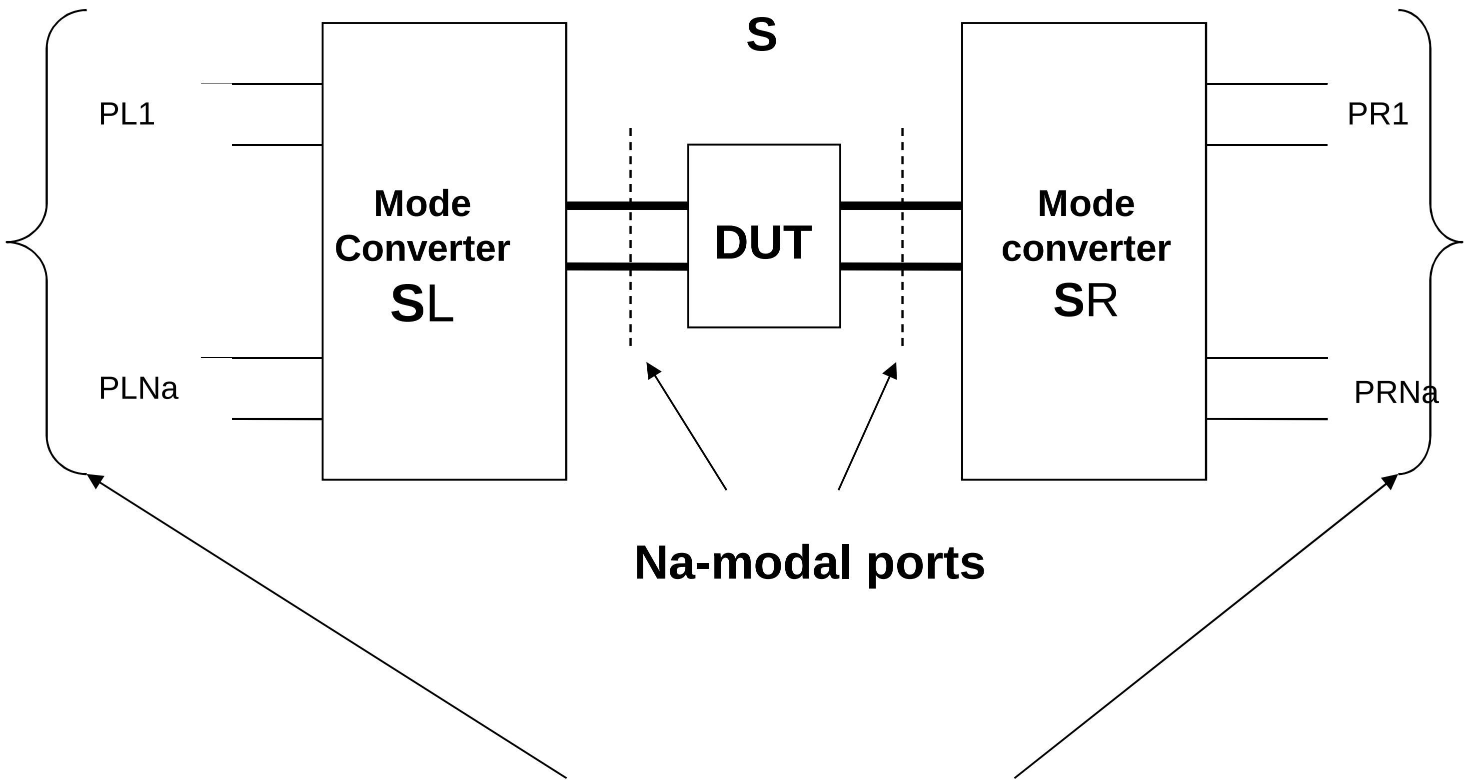


Though accessible modes are indeed electrical ports, they cannot be measured separately from each other as they correspond to the same physical port.





GTRL technique has been developed in order to measure waveguide components when more than one mode is accessible at each physical port:

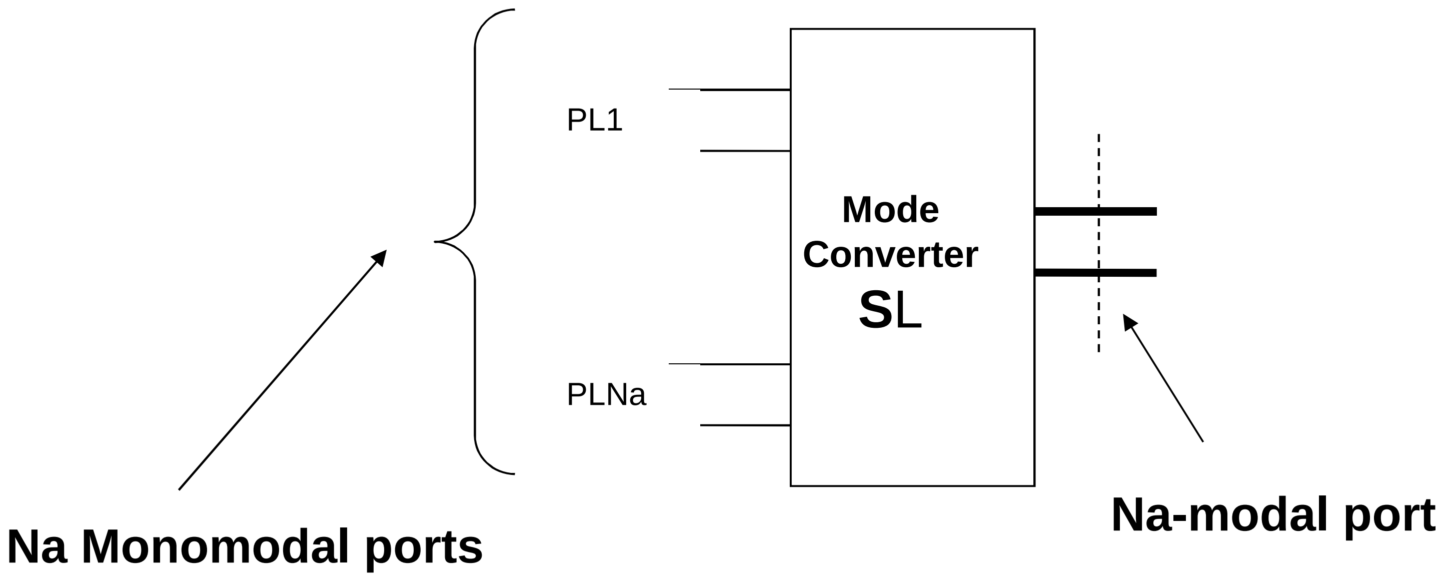


Monomodal ports are the only at which we can do measuments:

Mode Converter/Transducer

- The mode converters are 2Na-port (electrical-port) junctions, connecting Na monomodal physical ports (each corresponding to one electrical port) to one Na-modal physical port (corresponding to Na electrical ports).

Basic Idea



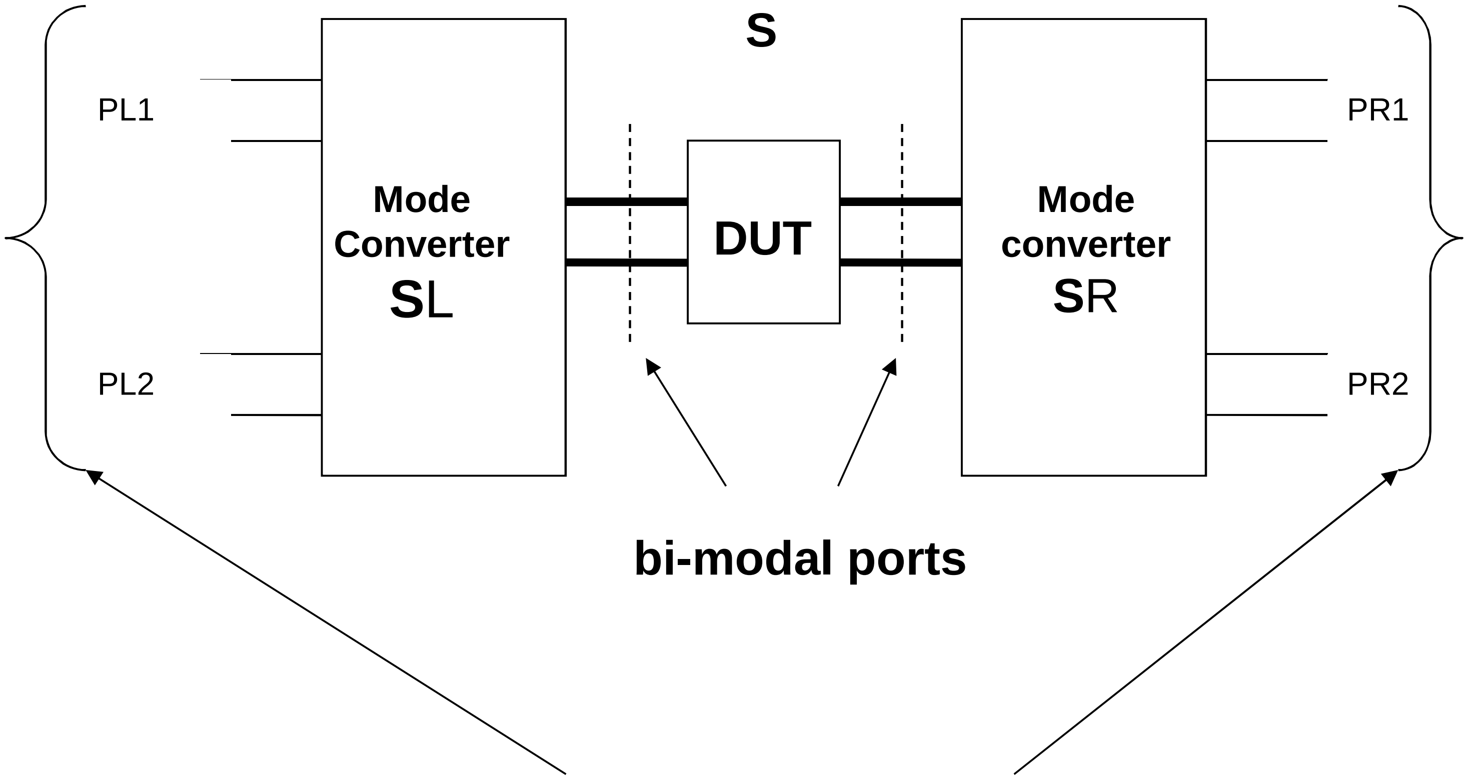
It is possible to characterize SL by measuring at left monomodal ports known loads connected to the right Na modal port.

The converter is experimentally characterized through:

1) Measurement of some suitable standards (**Calibration KIT** comprising 2 converters, 2 overmoded waveguide sections, with the same cross-section as the Na-modal port of the converter, + one short circuit).

2) Application of the de-embedding algorithm developed.

Once the converters are properly characterized, the GSM of any device embedded between them can be measured.



Monomodal ports the only at which we can do measuments:

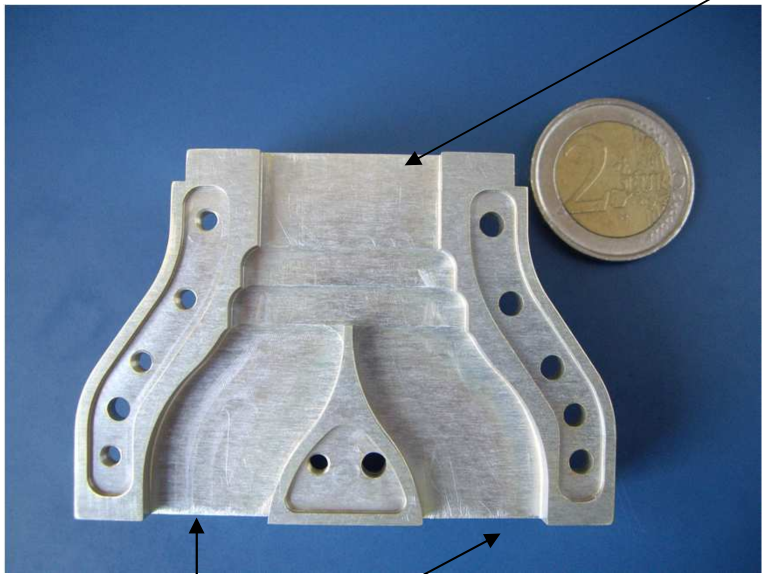
KIT for measurements in P-band (12.4-18 GHz) of a WR90R flanged device

- 2 Converters [2 monomodal ports-1 bimodal port])
- 2 waveguide sections used as standards in WR90R
- 2 short circuits in in WR90R

- 2 precision low power WR 62 terminations, necessary (under the assumption of using a 2 port VNA) to load the ports of the converters not connected to the DUT or to the VNA.
- 1 waveguide section, 1 LP filter, used for verification
- 1 Software package and, possibly, a netbook, driving the calibration procedure via a user-friendly interface

Half-Converter A (2 modes from 13.114 up to 19.671 GHz)

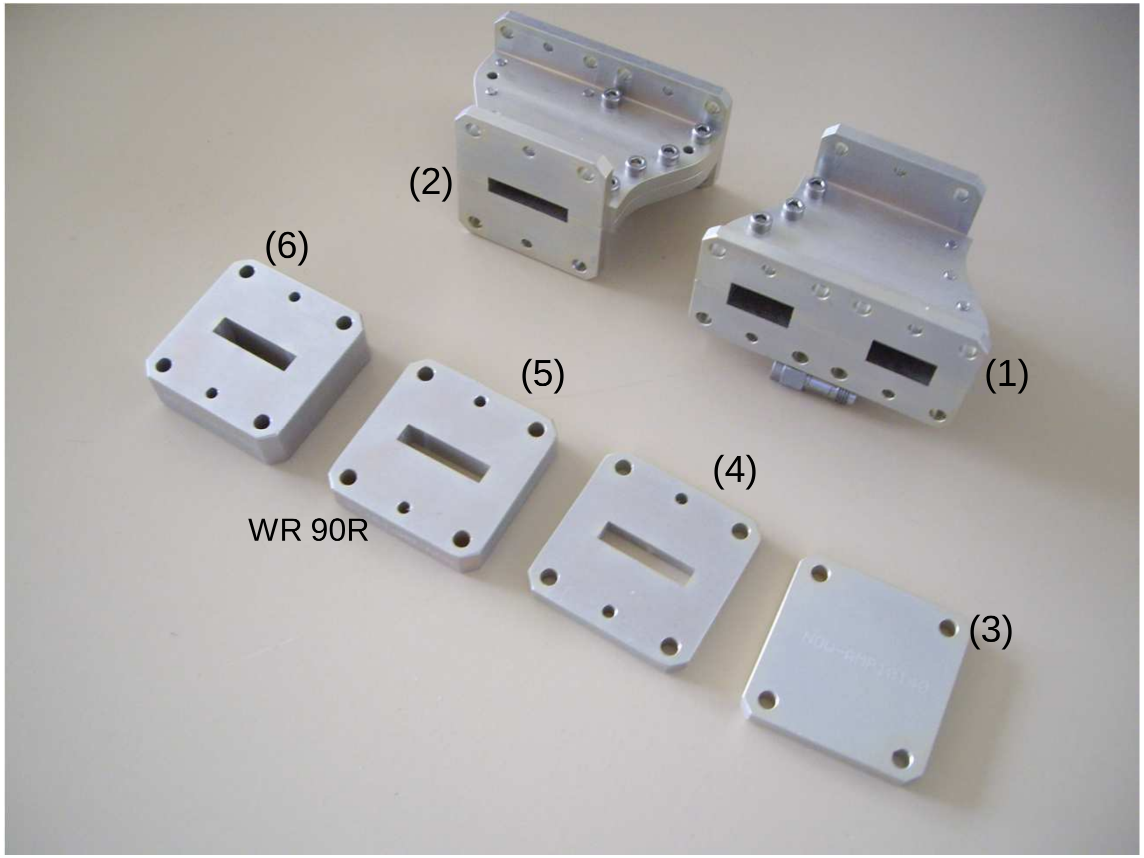
WR90R BI-MODAL (TE10+TE20) PORT



WR62 MONOMODAL (TE10) PORTS

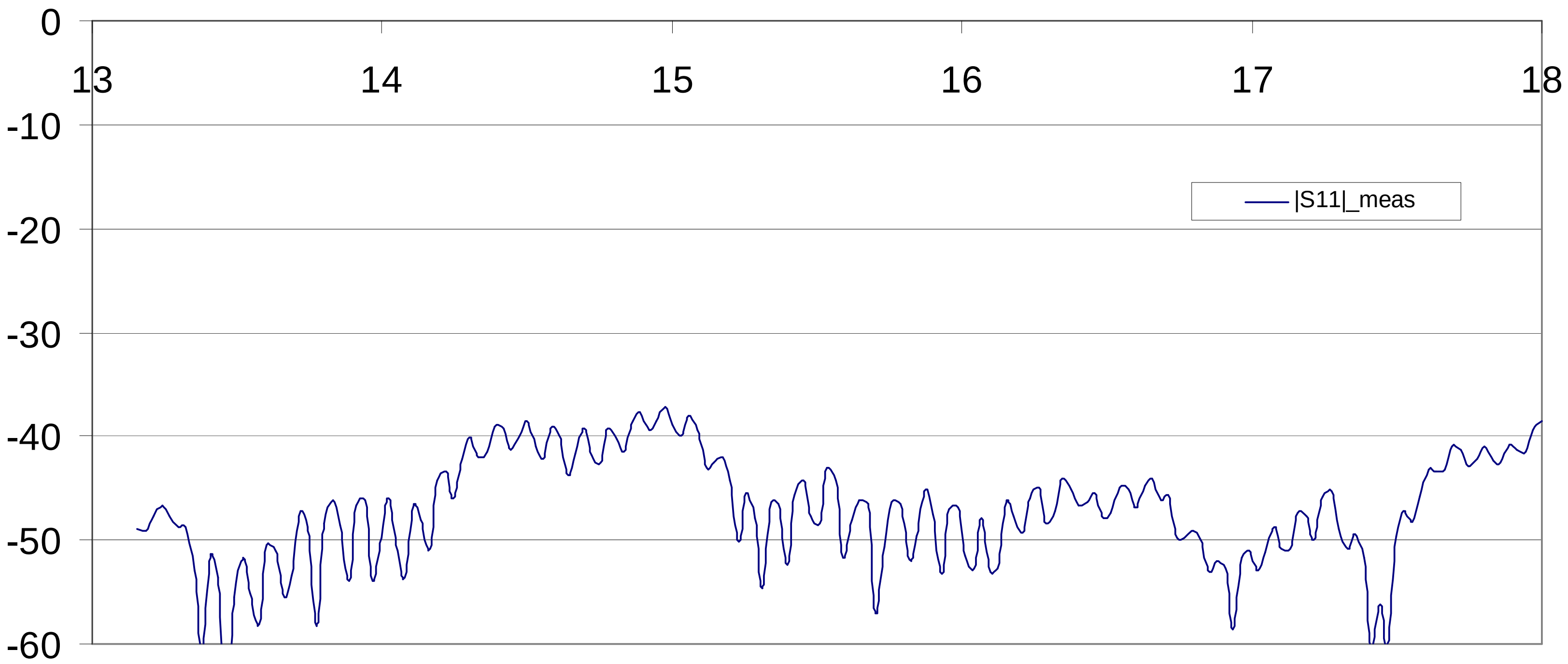
The converter which transforms the TE10 modes at the two monomodal rectangular ports into TE10 and TE20 modes at the WR90R port.

Complete Calibration kit including converters [1,2] and standards [3-6] for 2-mode measurements in P-band of a WR90R waveguide device (0.9X0.2 inches). (fcutoff TE20 13.114 GHz)



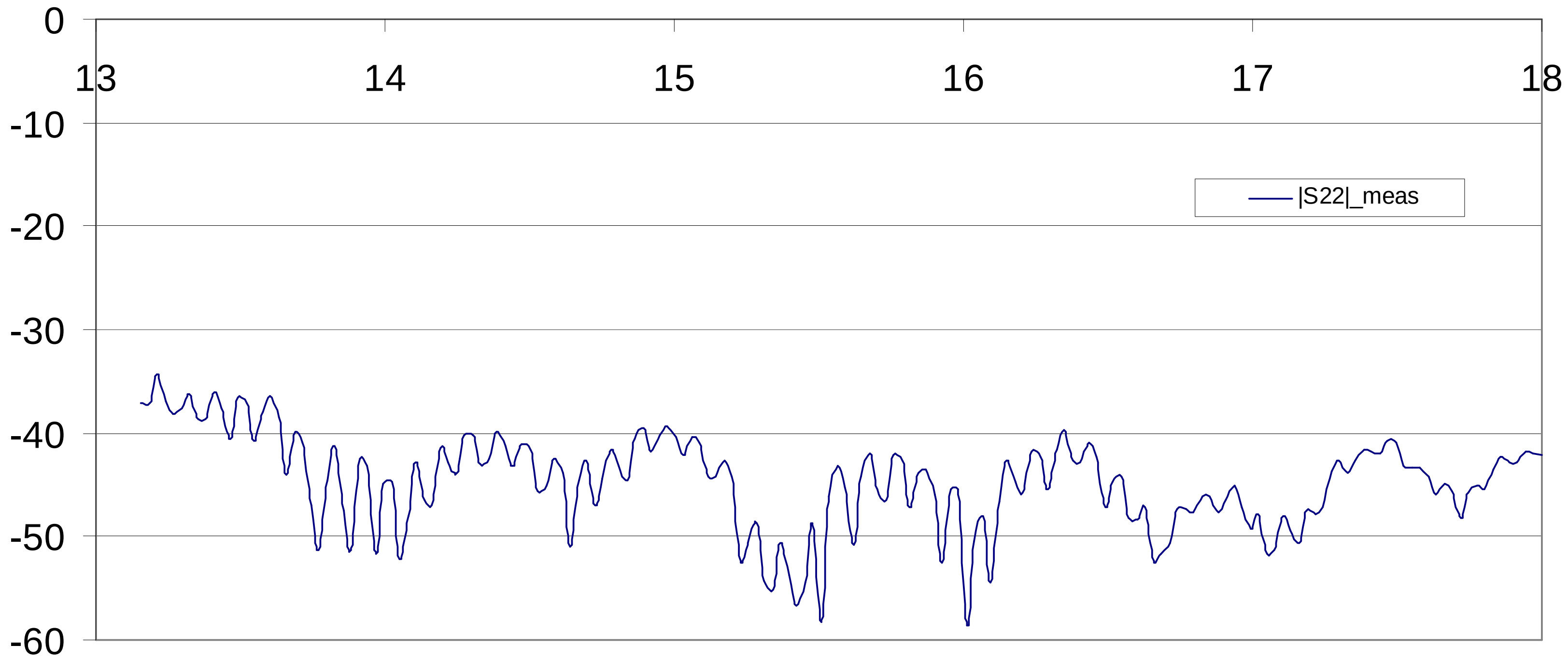
(1) Converter 1 (WR62-ports view), (2) converter 2 (WR90R port view),
(3)- short circuit, (4)- line 5mm, (5)- longline 8.996mm, (6)- ultralongline 13.511 mm.
Two of the three line sections are required to calibrate the system, the third one is used for validation

TE10 Reflection of a WR90R section in P band
(length 13.511 mm) (WR62 loads)



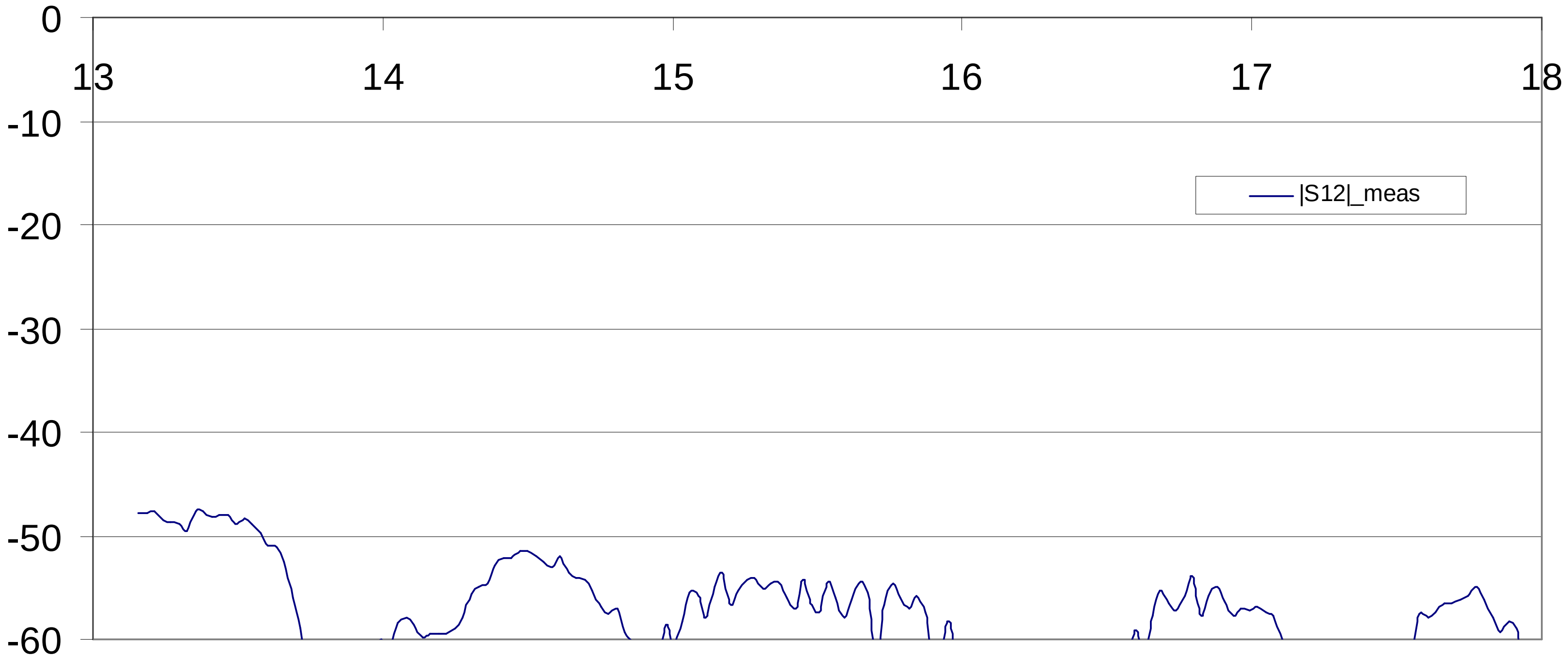
Ideal: –infinity

TE20 Reflection of a WR90R section in P band (length 13.511 mm) (WR62 loads)

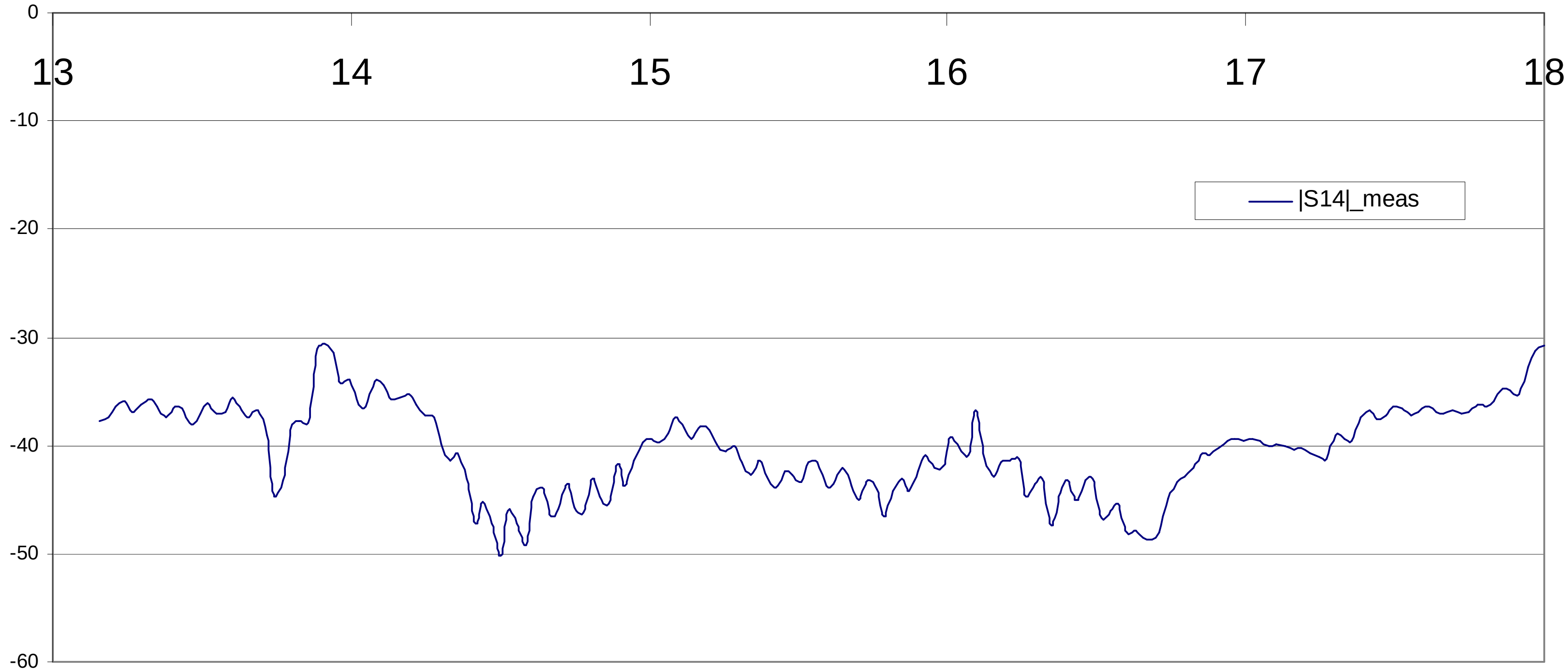


Ideal: –infinity

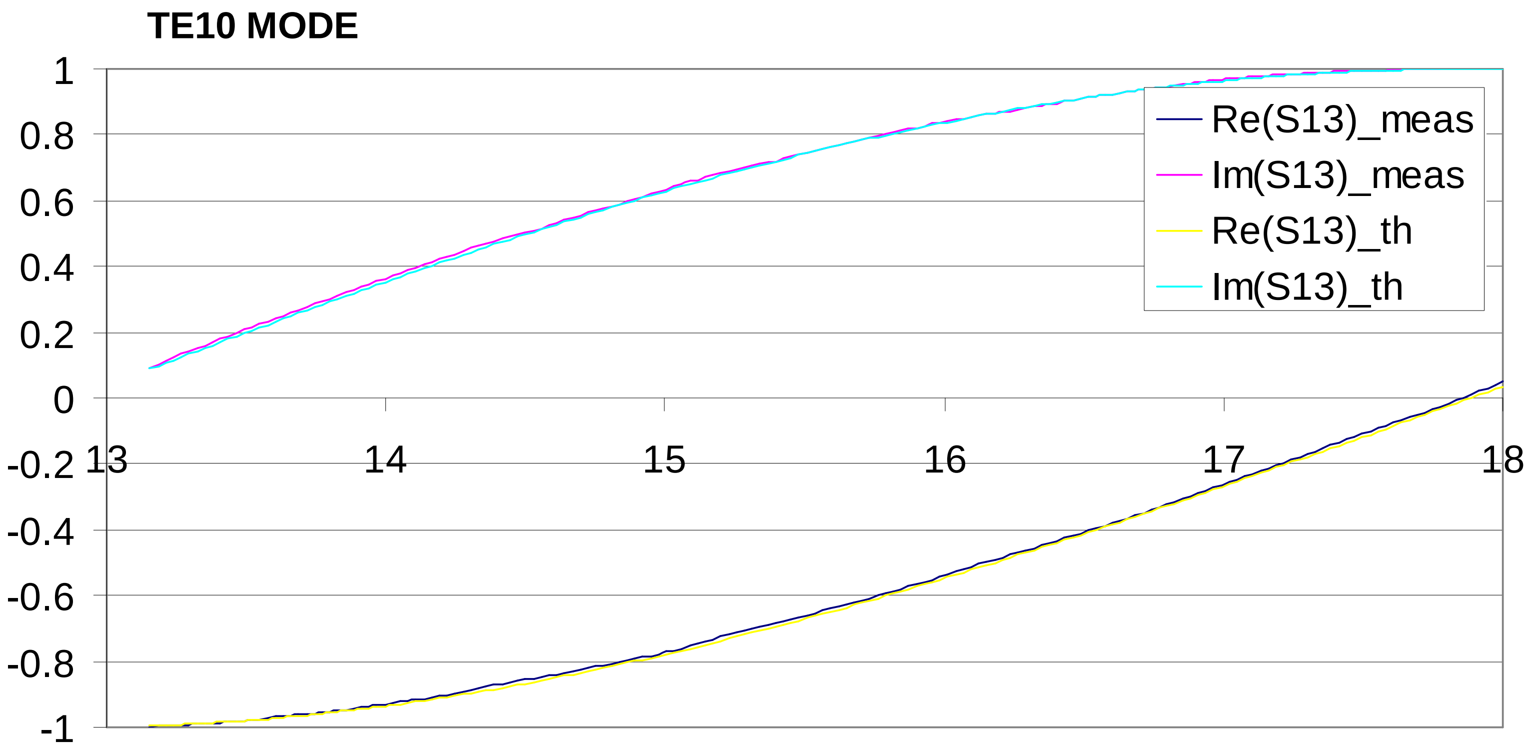
TE20-TE10 coupling at input port of a WR90R section in P band (length 13.511 mm) (WR62 loads)



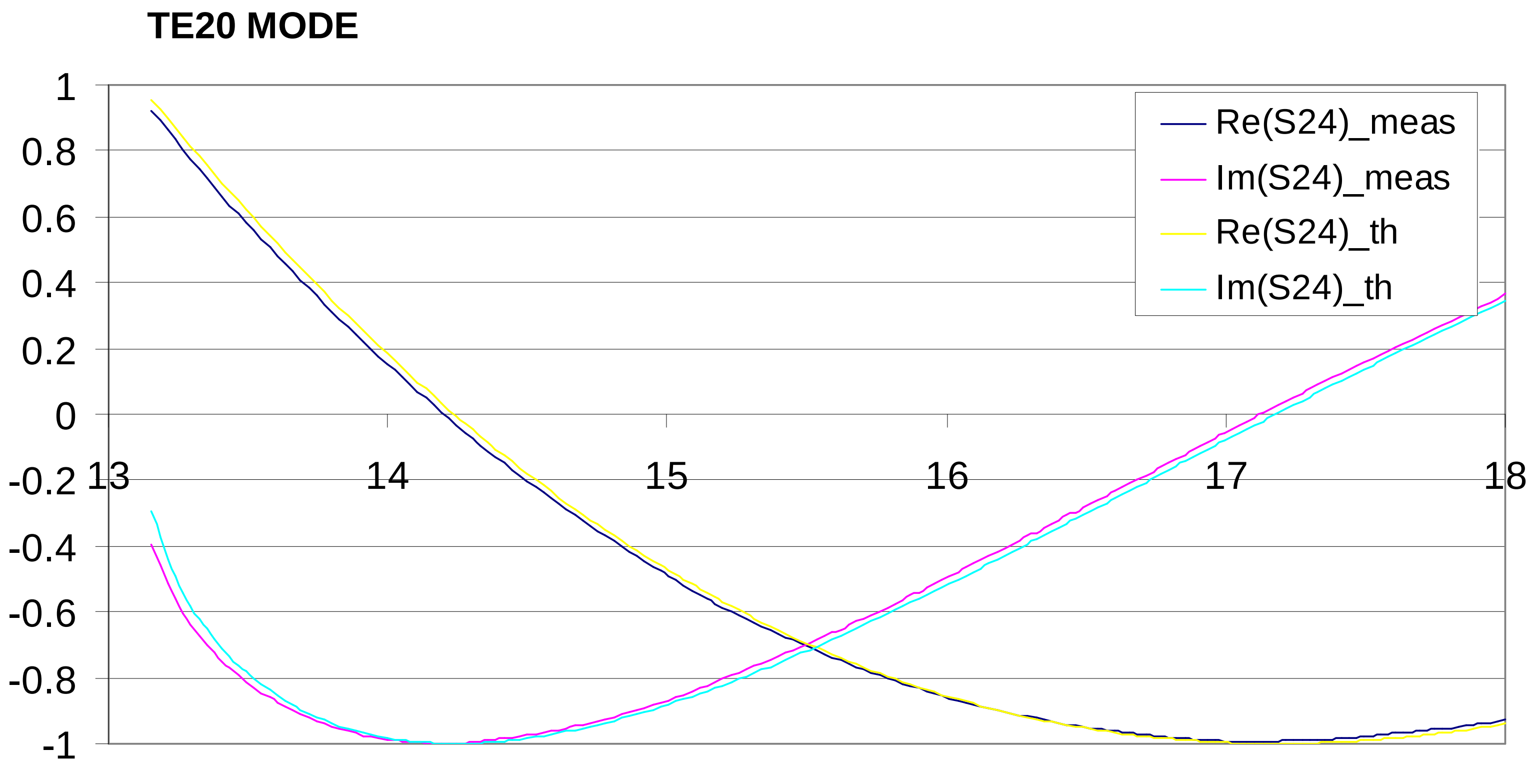
TE20-TE10 coupling between input/output port of a WR90R section in P band (length 13.511 mm) (WR62 loads)



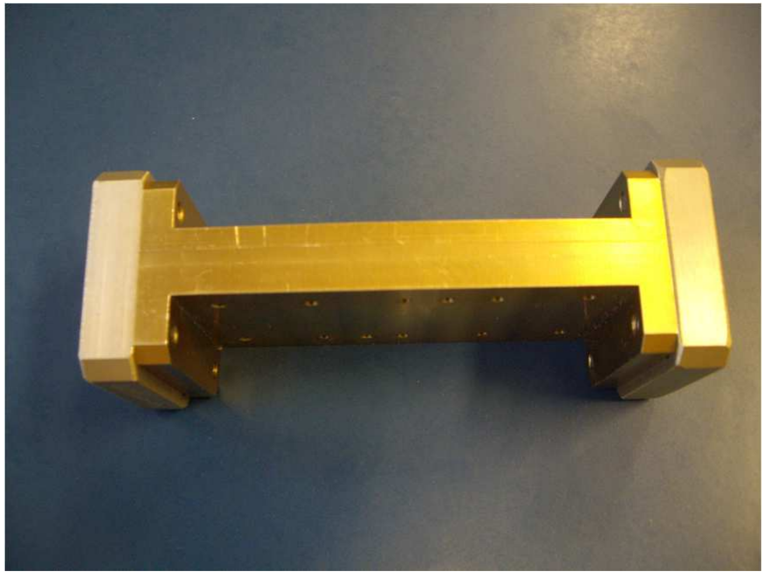
Transmission of a WR90R section (length 13.511 mm) (WR62 loads)



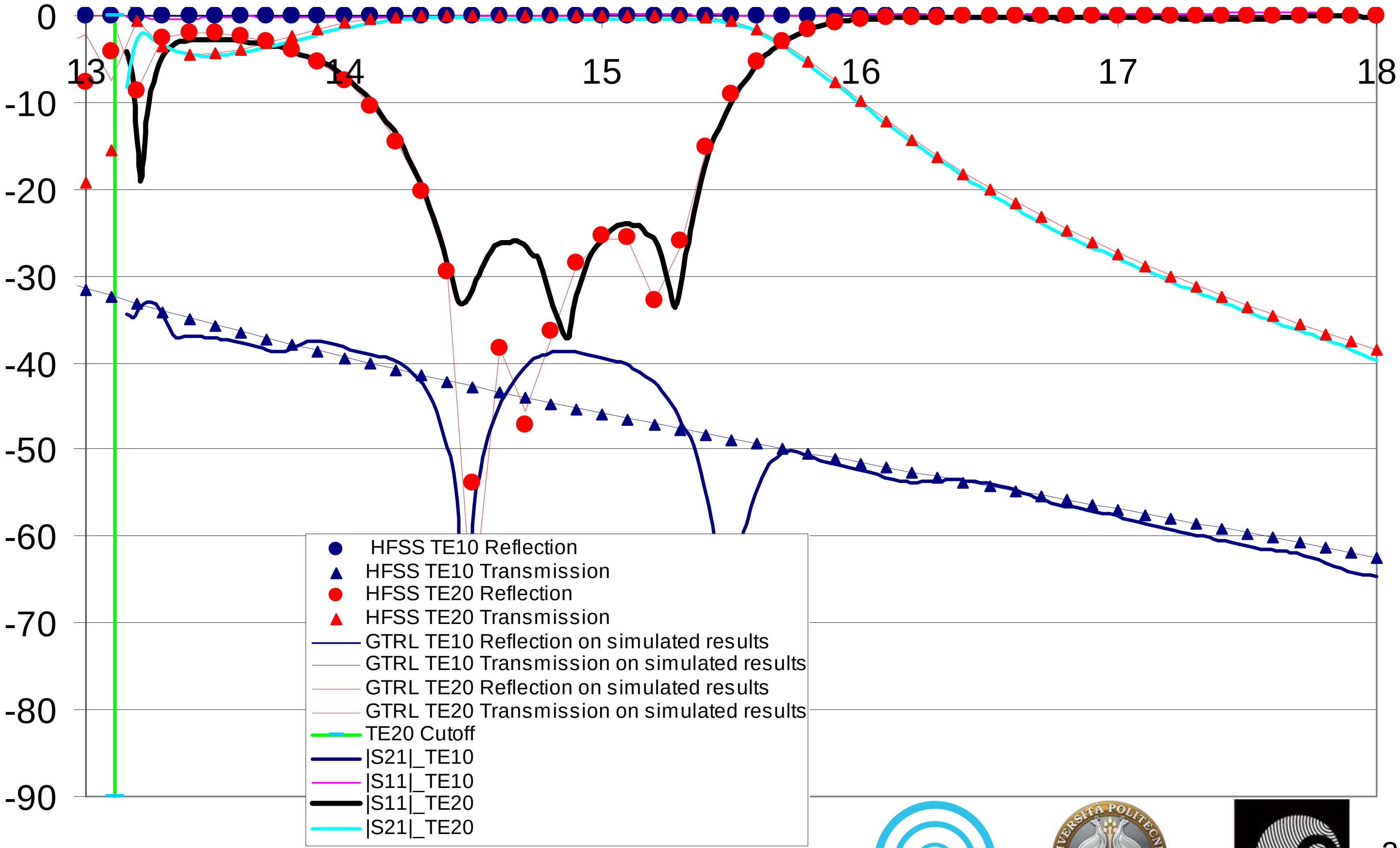
Transmission of a WR90R section (length 13.511 mm) (WR62 loads)



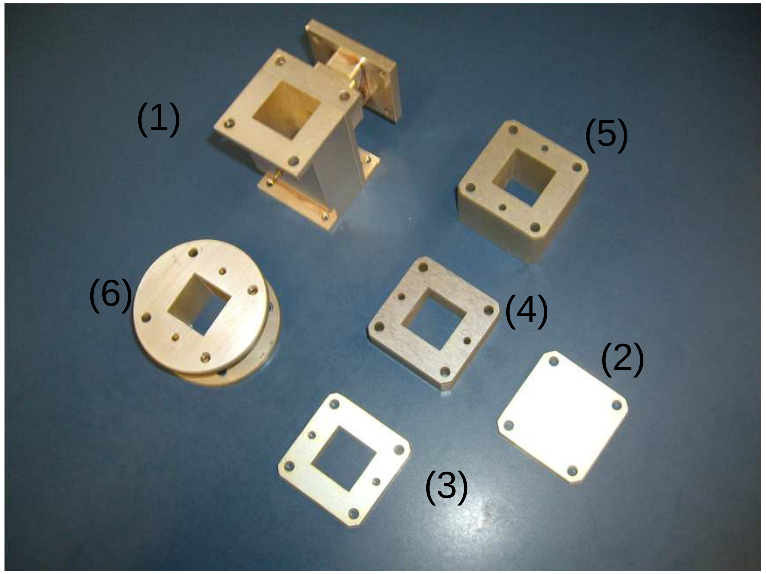
Measurement of an E-plane step X-band Low pass filter



Measurement of an X-band Low pass-filter in **P-band** (WR62 loads)



Calibration kit including converters [1] and standards [2-6] for degenerate mode measurements of a square waveguide 19.5 X 19.5 mm in band 8.5GHz-10.5 GHz . Degenerate modes are TE10V and TE01H.

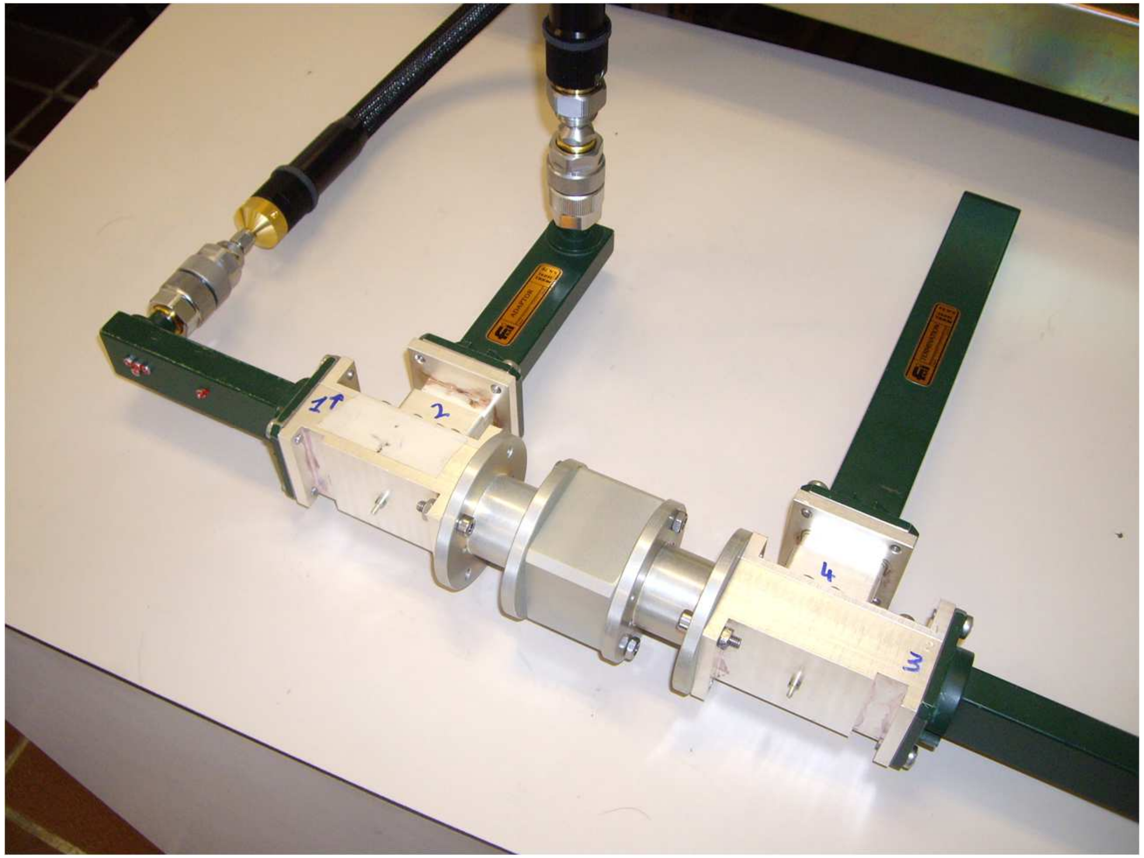


(1) Converter 2 (OMT Square waveguide-port view),

(2)- short circuit, (3)- line 5mm, (4)- longline 15 mm, (5)- ultralongline 31 mm. (6) is a square waveguide section featuring a precision flange on that side to be connected to the standards during calibration.

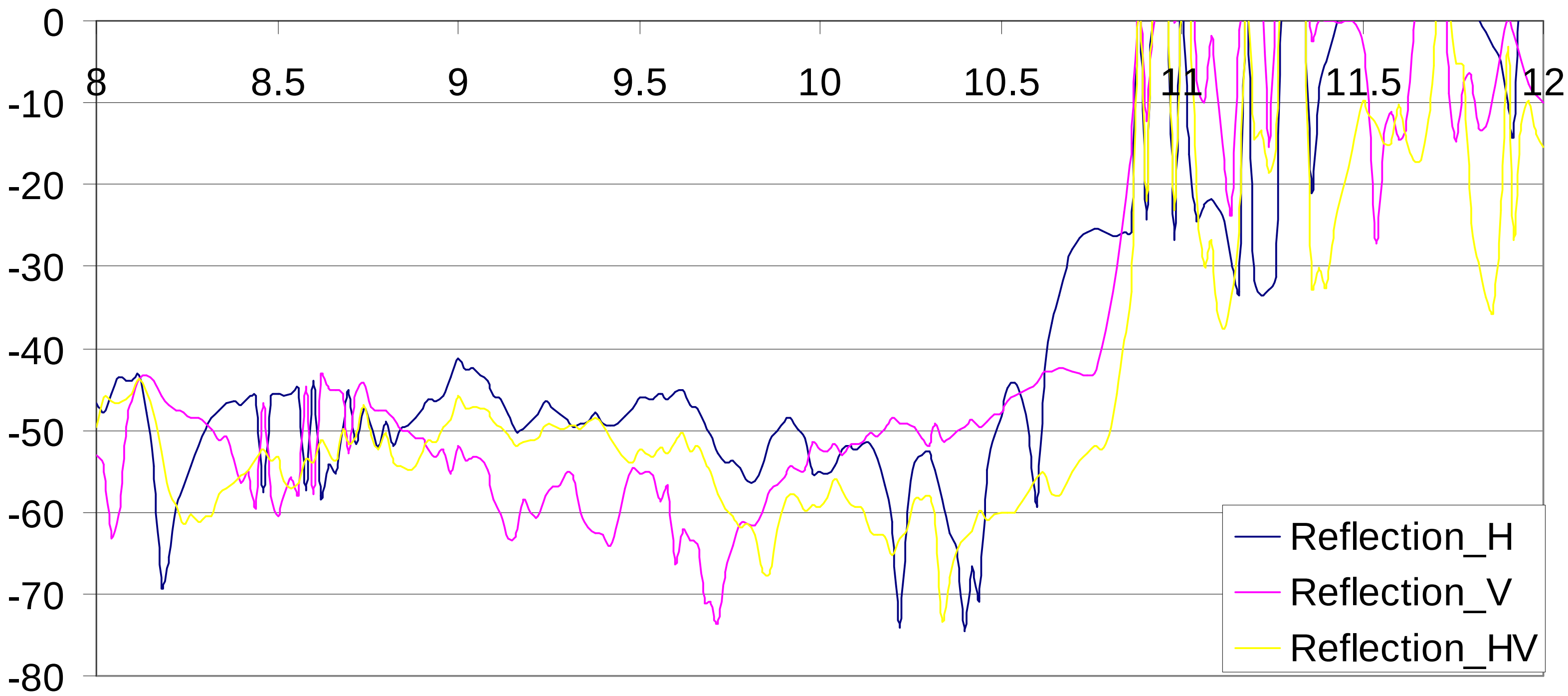
Two of the three line sections are required to calibrate the system, the third one is used for validation

Degenerate mode measurement.

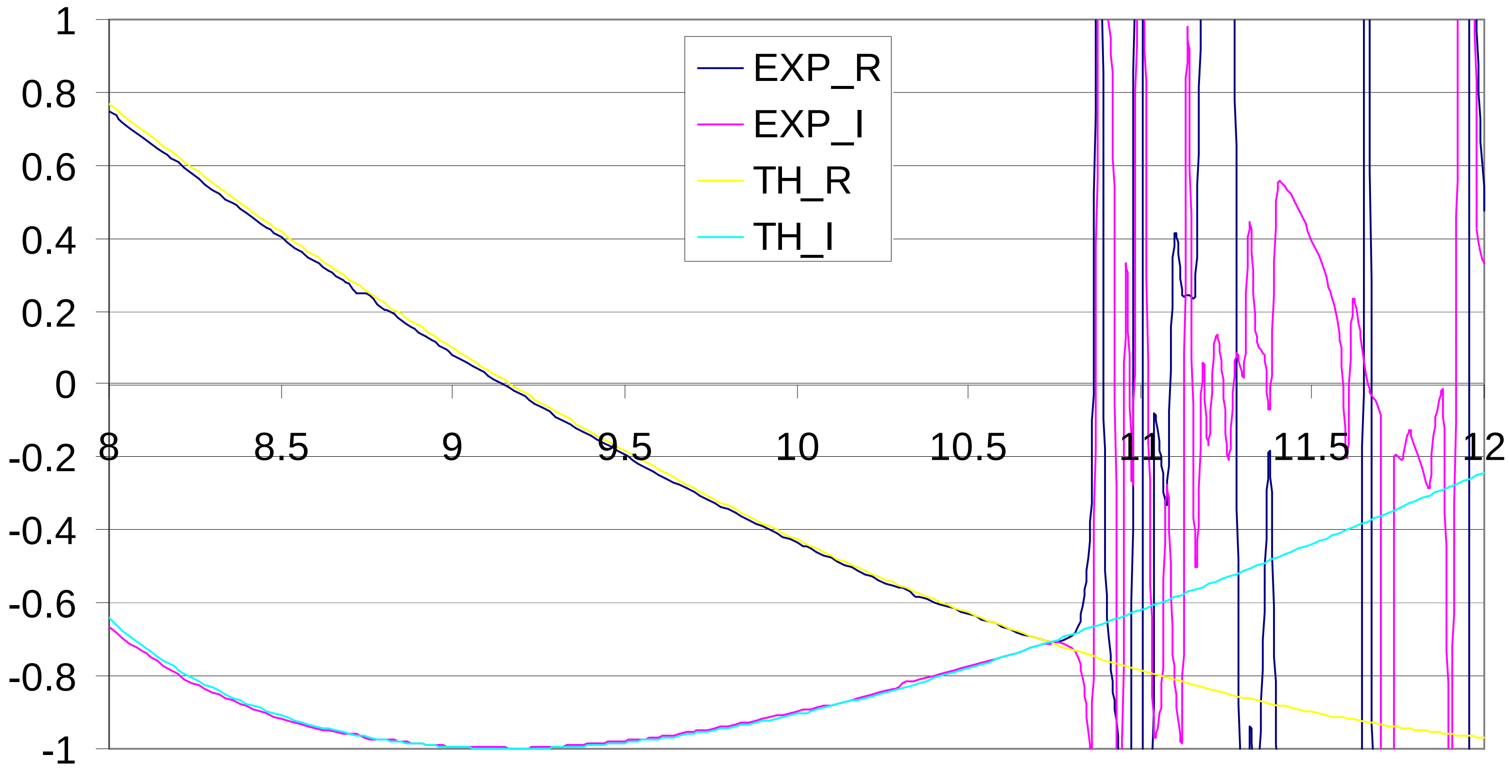


The converters used here are classical orthomode transducers, already available, which transform two TE10 modes at the monomodal rectangular ports into two modes (TE10 and TE01) at the square bimodal port. One output of the GTRL scheme is the scattering matrix of the OMT with particular emphasis to the measurement at the square port where two degenerate modes are present.

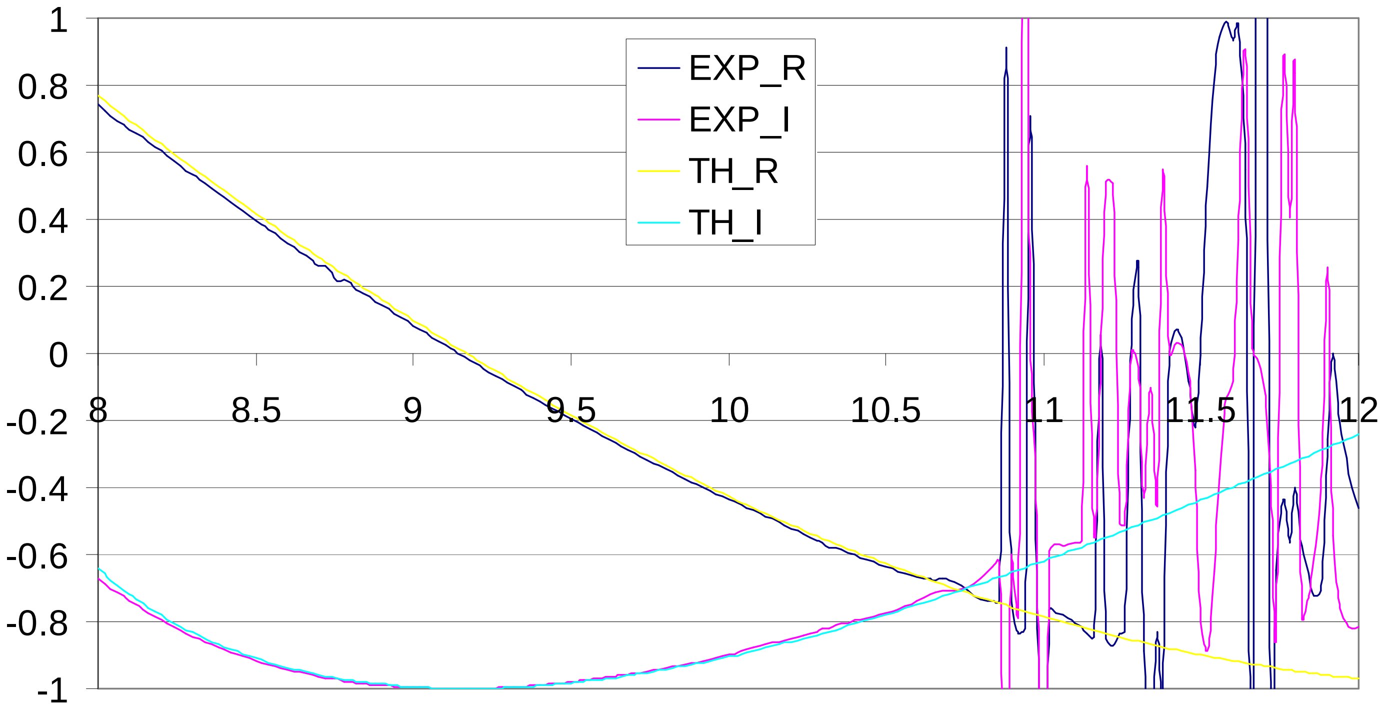
Reflection of a square waveguide section for the two degenerate modes of a square waveguide (WR90 loads)



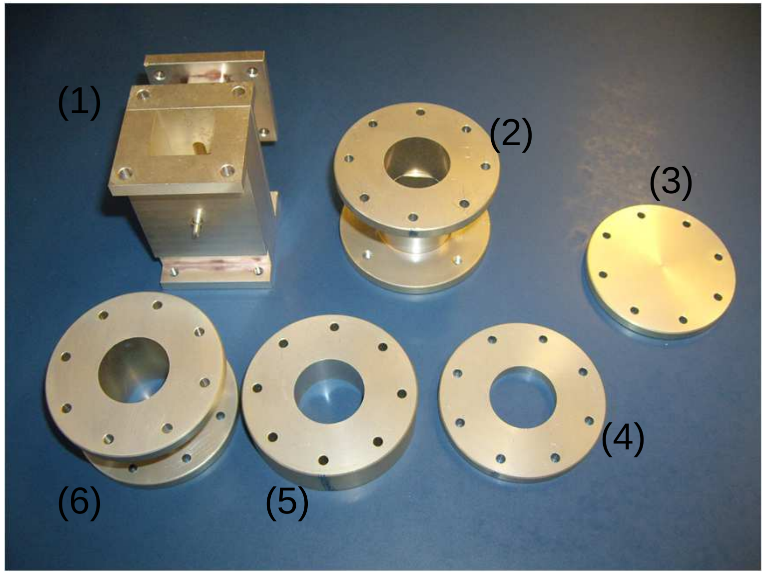
Transmission of a square waveguide section (a=19.5mm, b=19.5 mm. length=15 mm) for mode V (WR90 loads)



Transmission of a square waveguide section (a=19.5mm, b=19.5 mm. length=15 mm) for mode H (WR90 loads)

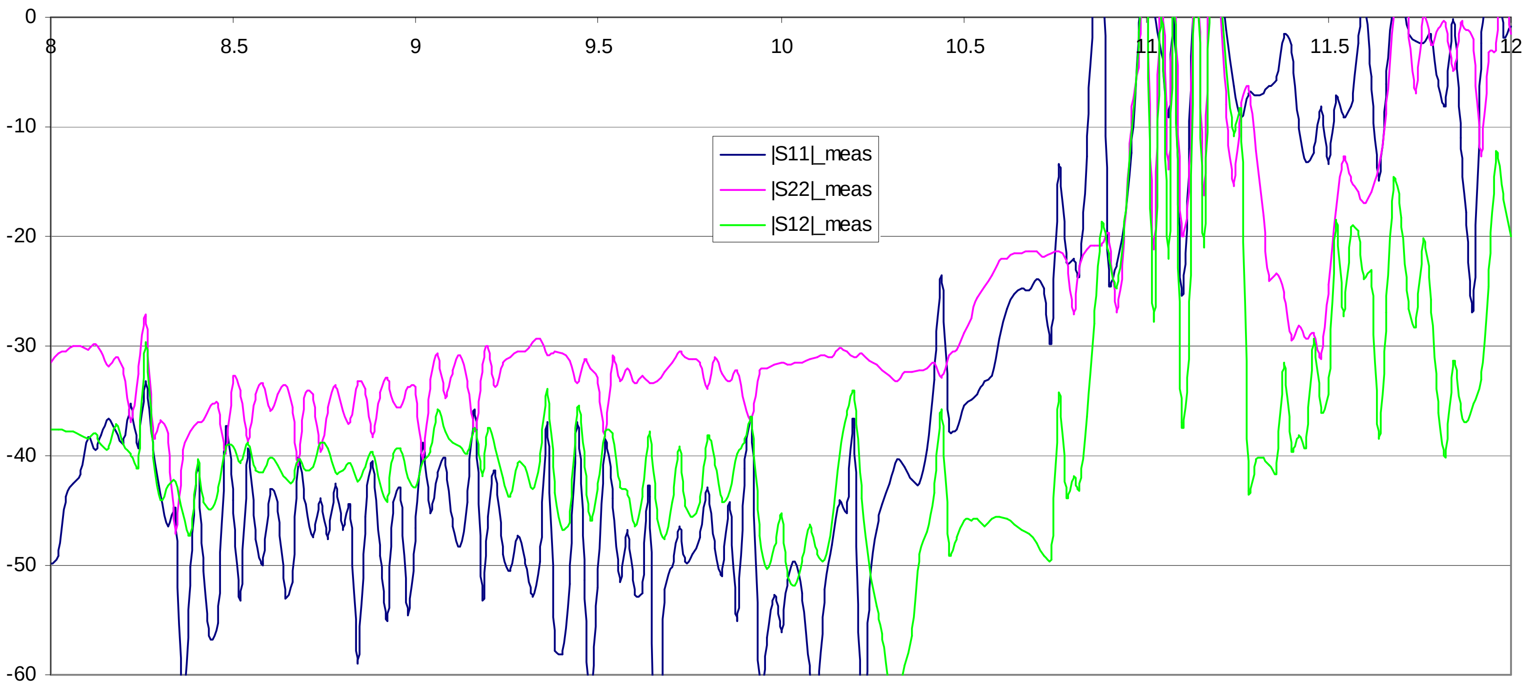


Calibration kit including converters [1] and standards [2-6] for degenerate mode measurements of a circular waveguide R=11.2 mm X in band 8.5GHz-10.2 GHz . Degenerate modes are TE11V and TE11H. In order to check the robustness of the GTRL, measurements are performed by considering APC7 coax loads as matching loads. Thus, loads are replaced by APC7 loads and the preliminary waveguide calibration is a standard coaxial calibration. This produce a a little deterioration due to the worse perfomance of the coaxial loads with respect to waveguides.



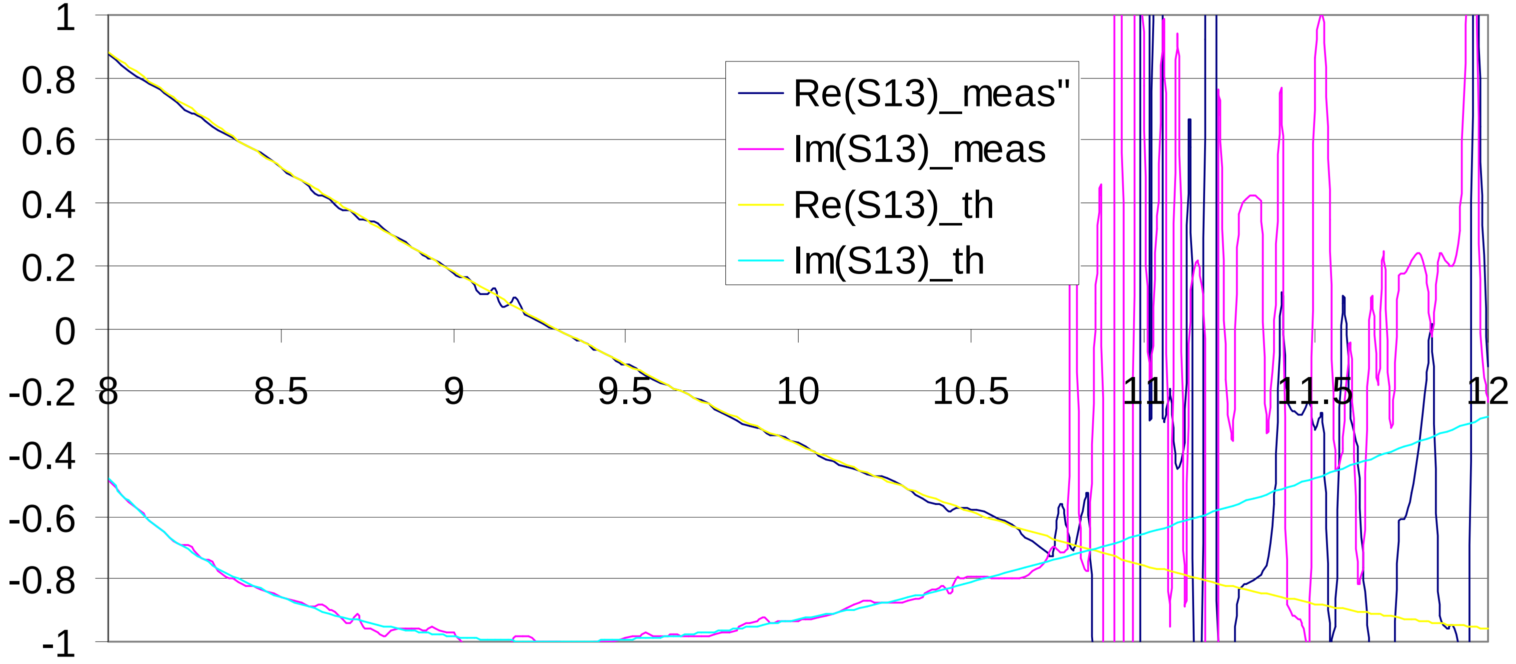
The converter is a classical Orthomode transducer (1) whose square port is connected to a square-circular adapter (2), featuring a precision circular flange . Circular waveguide sections are labelled as [4-6]. (3) is a short circuit.

Reflection of a circular waveguide section (R=11.2mm, length=15 mm) for V/H mode(APC7 loads)

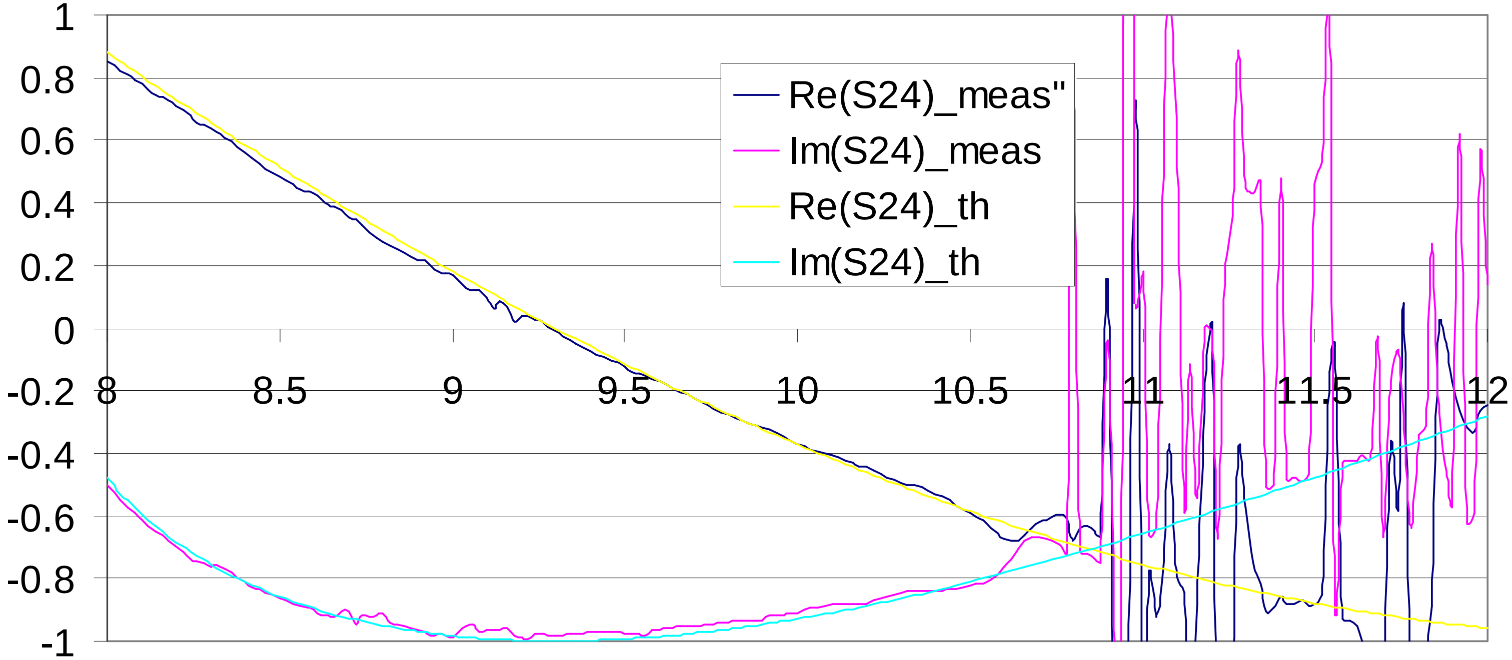


The slight deterioration of this measurement is due to the fact that, as measurement ports (the ones physically connected to the VNA), we use coaxial ports (APC7). As a consequence the matched loads are APC7 loads, whose reflection is larger that the waveguide loads used above.

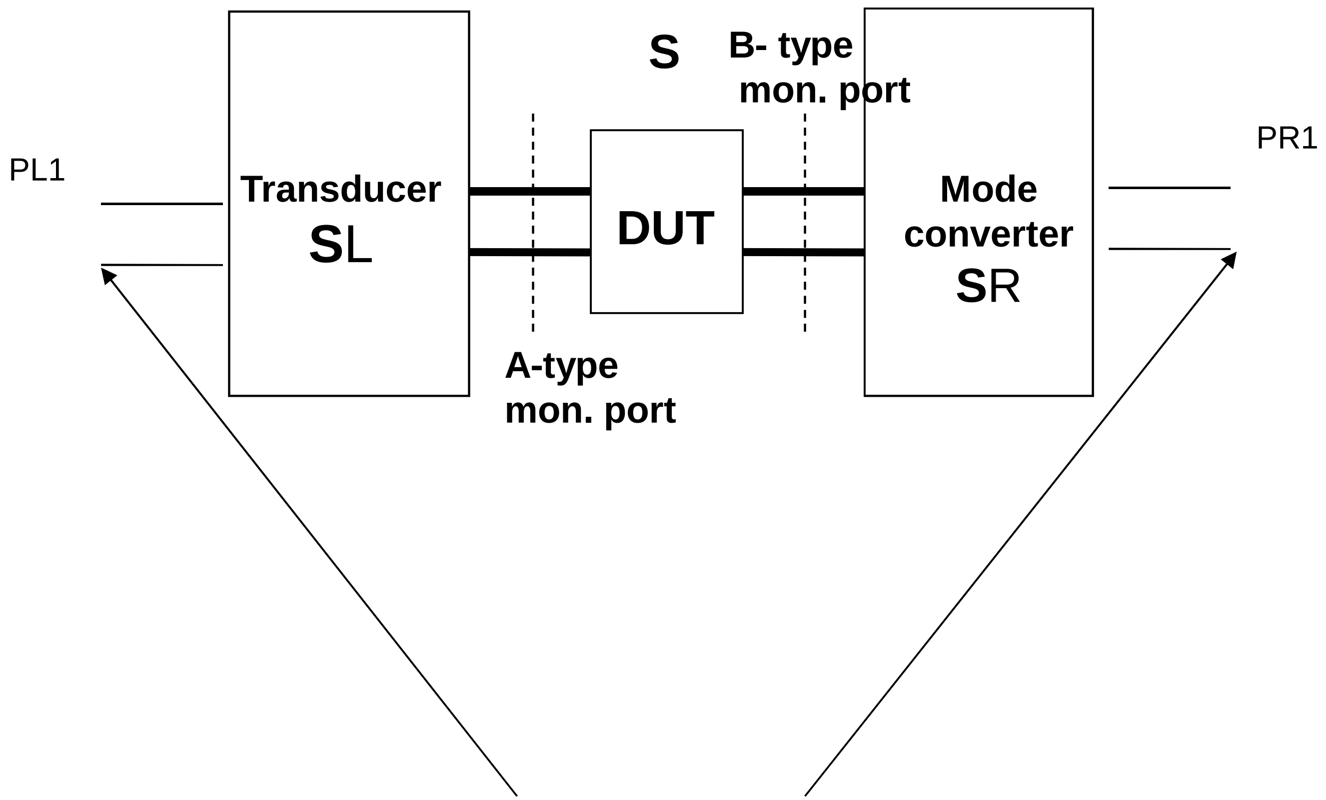
Transmission of a circular waveguide section (R=11.2mm, length=15 mm) for V mode (APC7 loads)



Transmission of a circular waveguide section (R=11.2mm, length=15 mm) for H mode (APC7 loads)



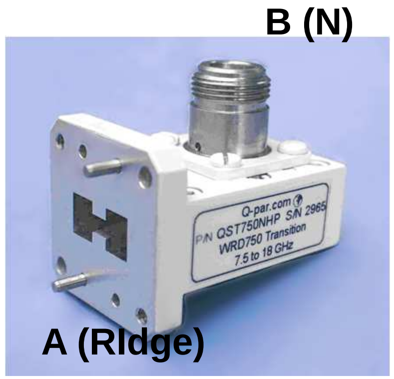
Application of the GTRL to the measurement of devices featuring different test ports

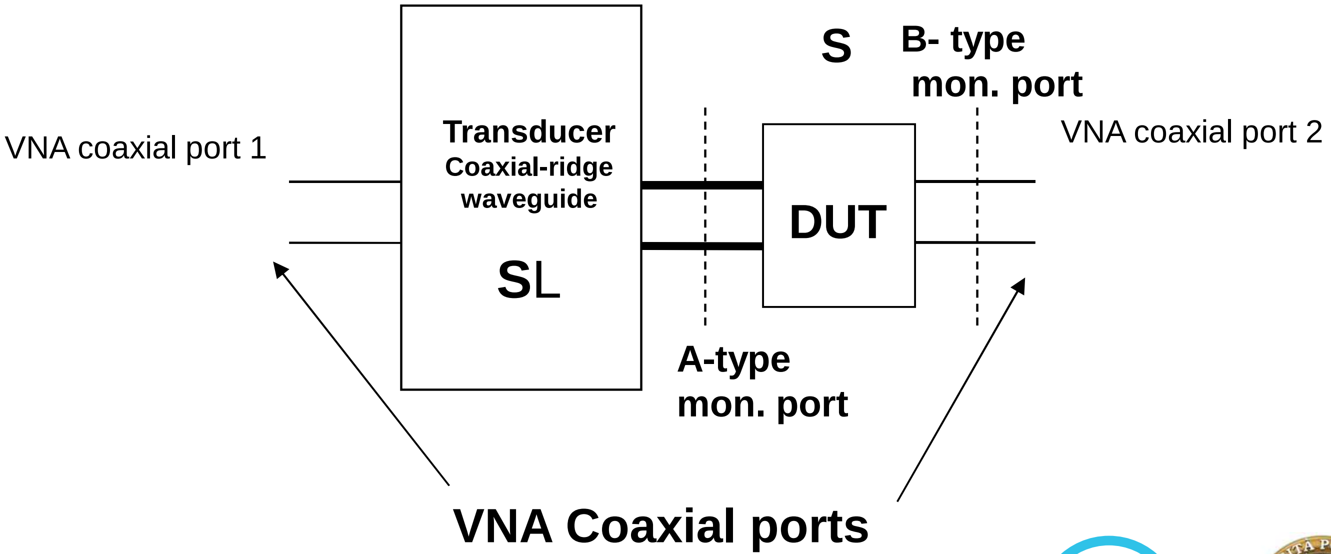


Monomodal ports connected to the VNA:

Ex. Ridge-Coax Transition

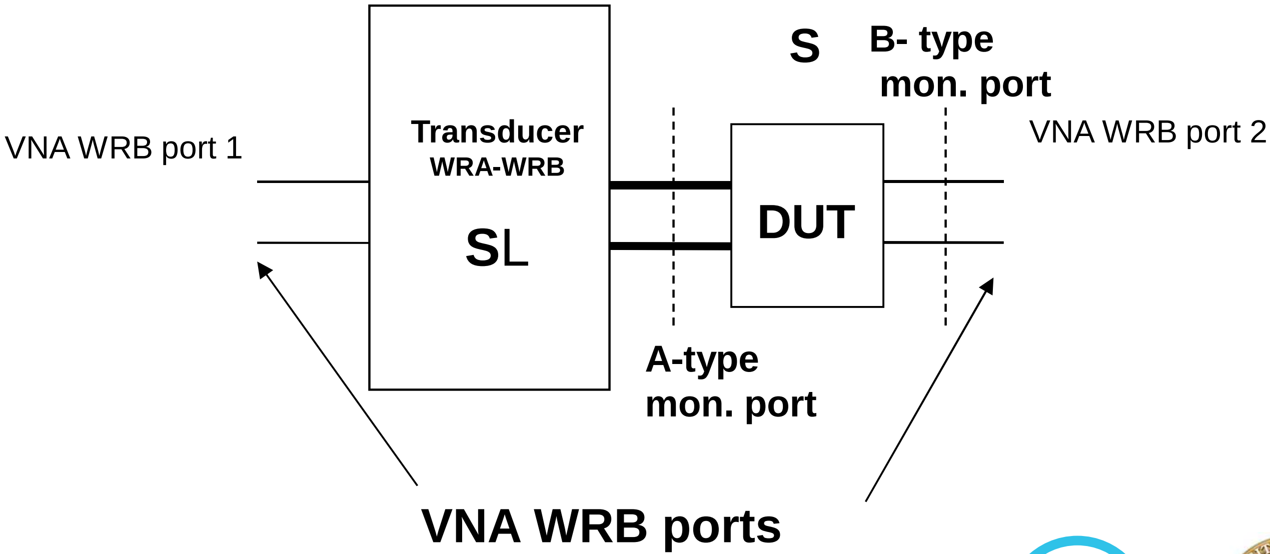
Even in this elementary case measurement cannot be made directly on the dut, because ports A and B have differen cross-section and cannot be connected together.





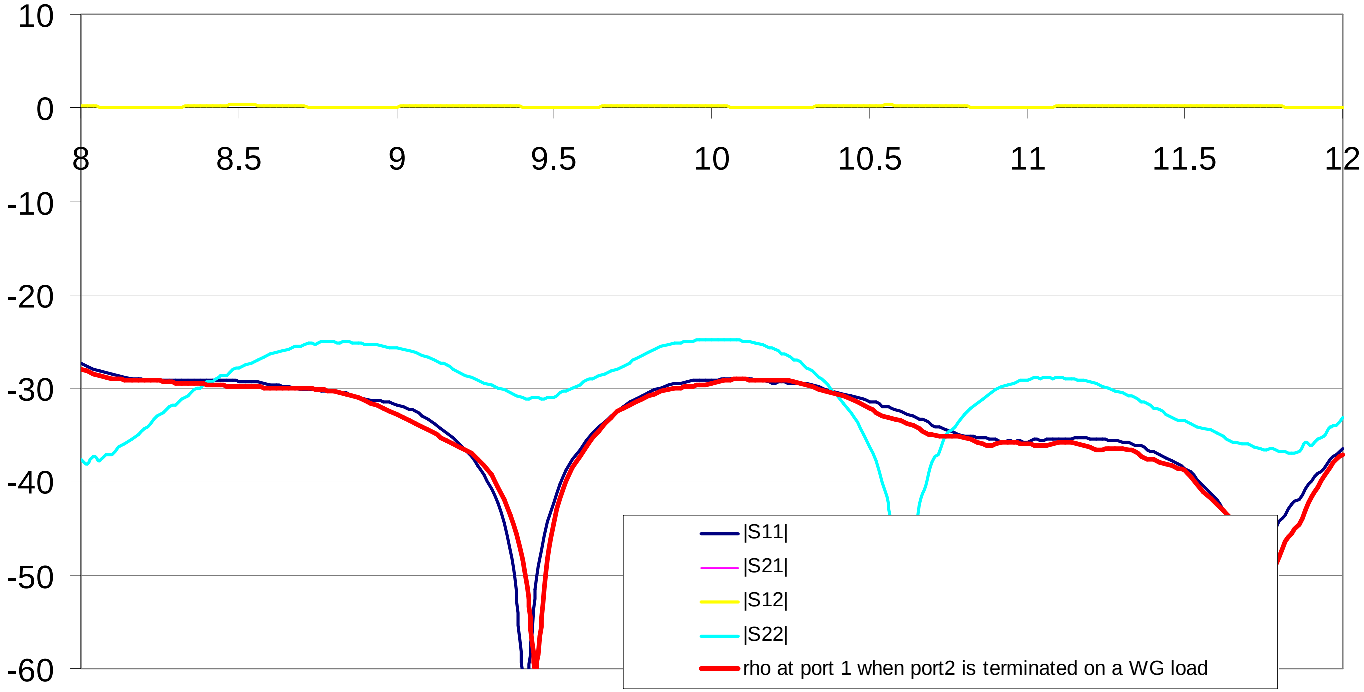
Waveguide Taper

Even in this elementary case Calibration cannot include the THRU.

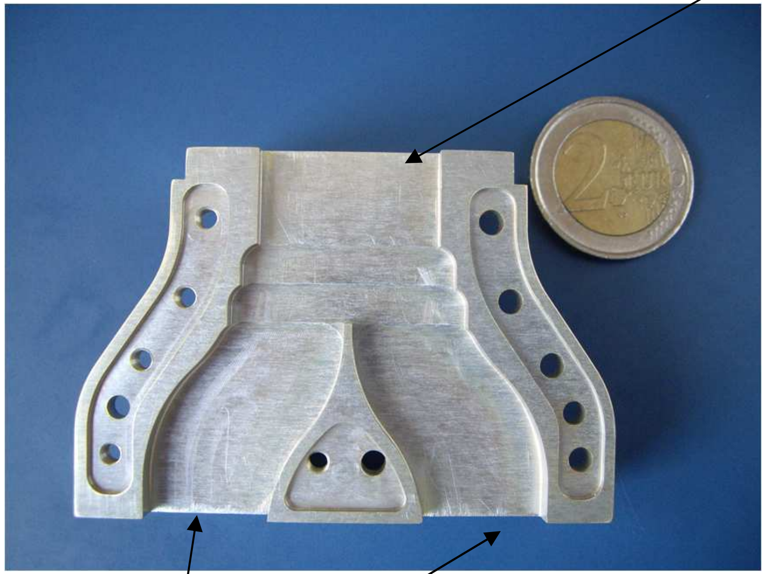


GTRL gives for free the GSM of the converters !!!

Experiments: WG (WR90)-COAX (2.4mm) transition (WL)

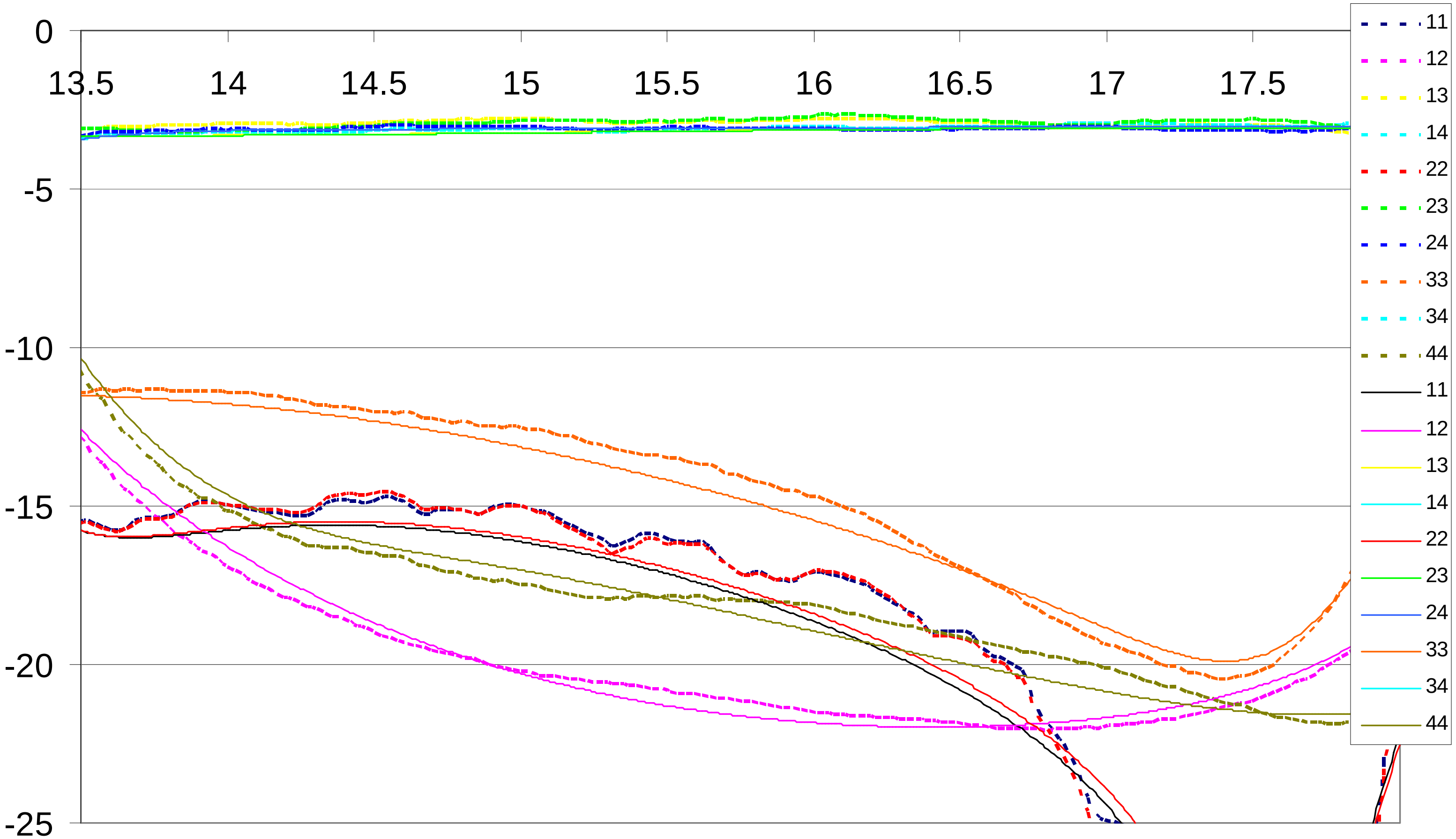


WR90R BI-MODAL (TE10+TE20) PORT

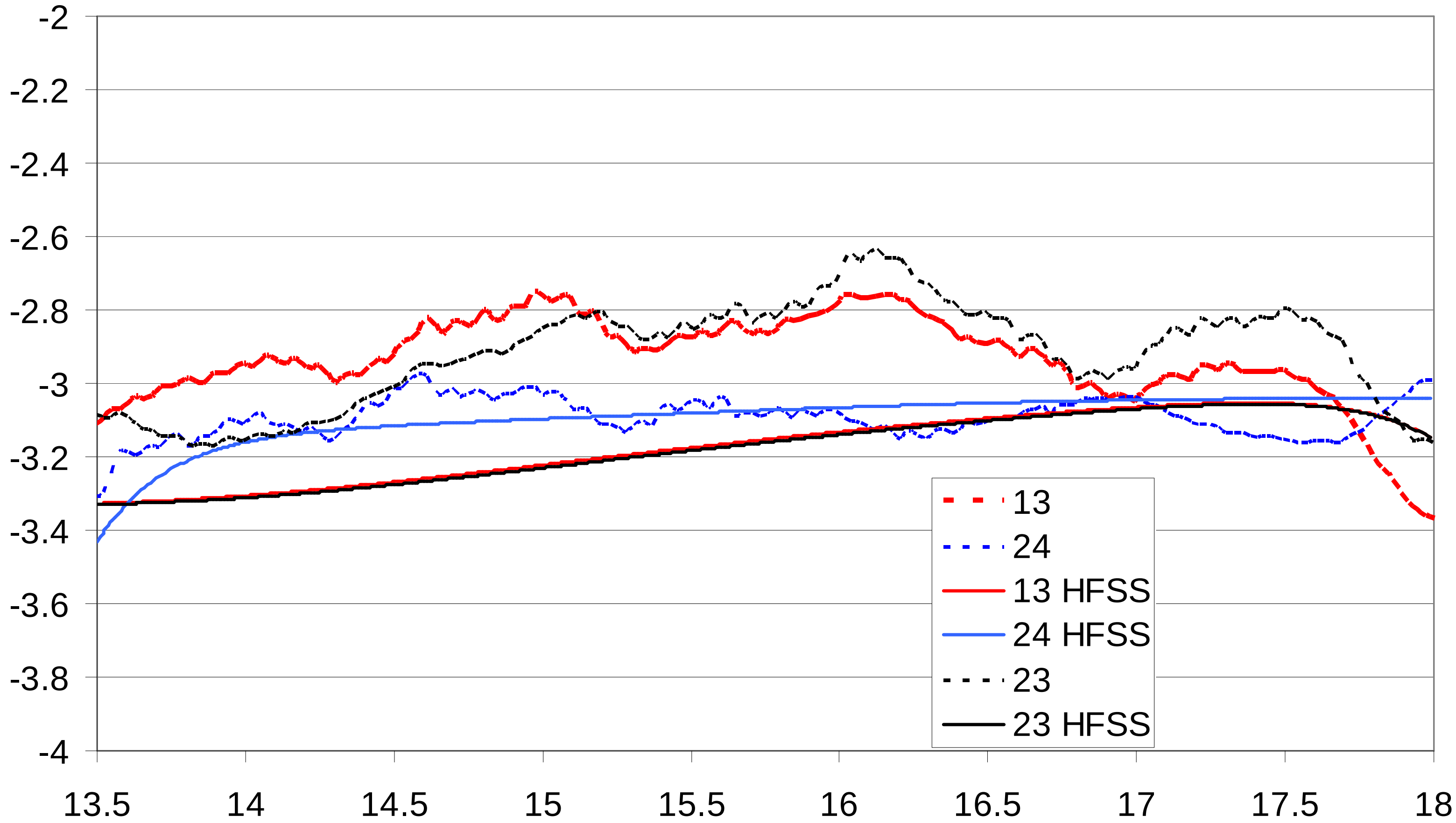


WR62 MONOMODAL (TE10) PORTS

Single converter (measurement vs HFSS)



More in detail



In conclusion: GTRL Applications

- Multimodal waveguide devices, where more modes are above cutoff, for instance a waveguide low-pass filter in the out band.
- Devices fed by arbitrary waveguides, different from each other, for instance a simple Coax-Waveguide transition, or, more in general, modal converters.
- Circular or Square waveguide devices, operating under orthogonal polarizations, for instance Orthomode transducers .
- Devices operating under higher order modes, for instance circular waveguides working under TM01 or TE01 modes, as occurring in many filters, rotary joints, antenna feeds and other microwave equipments used in accelerators.
- Measurement of the propagation constants for different modes of arbitrary section waveguides, possibly filled by dielectrics
- Accurate measurement of dielectric permettivities.

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