JUAS 2018
RF Practical Exercise

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Content

Introduction

At CERN we took part in an RF practical experience. This involved learning how to use a Network Analyser to study the properties of transmission lines, waveguides etc.

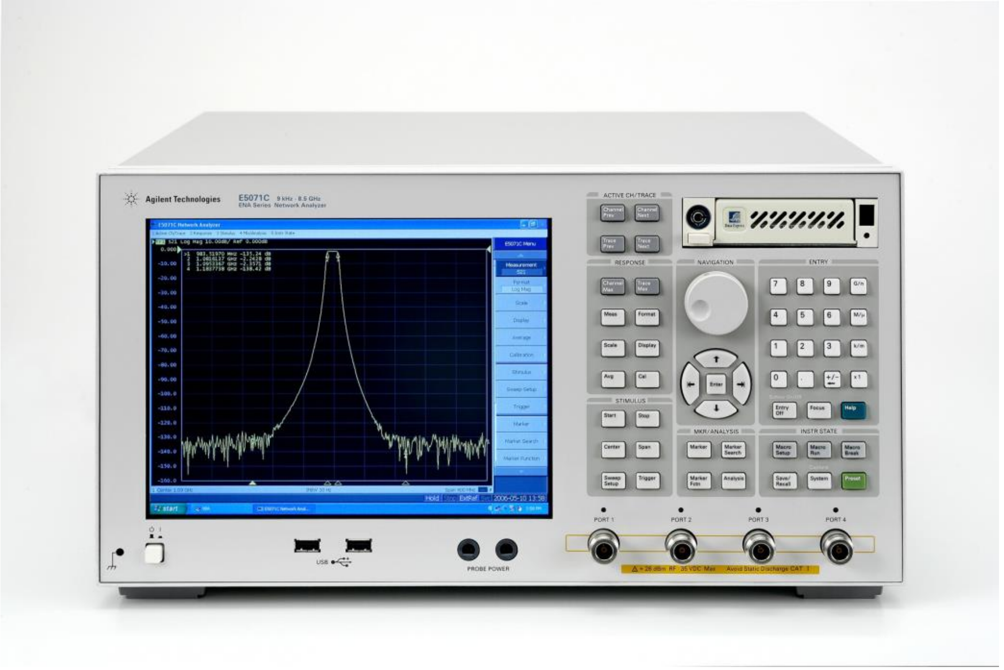
Those of us from non-engineering backgrounds gained some good hands on exposure to concepts of S-parameters/ports, the speed of electromagnetic waves (light), and further ideas pertaining to the use of measurement/test equipment.

Also, before we begin, we must offer a very sincerely felt thank you to everybody who has taken part in JUAS 2018!

We will begin by explaining the Network Analyser.

What is a Network Analyser ?

The piece of equipment we used the most, and is used by every RF test/development engineer on the planet is the Network Analyser.



It measures power transmission/reflection on electrical networks, these are measured as S-parameters which will be explained overleaf. We use a Vector Network Analyser which measures amplitude and phase.

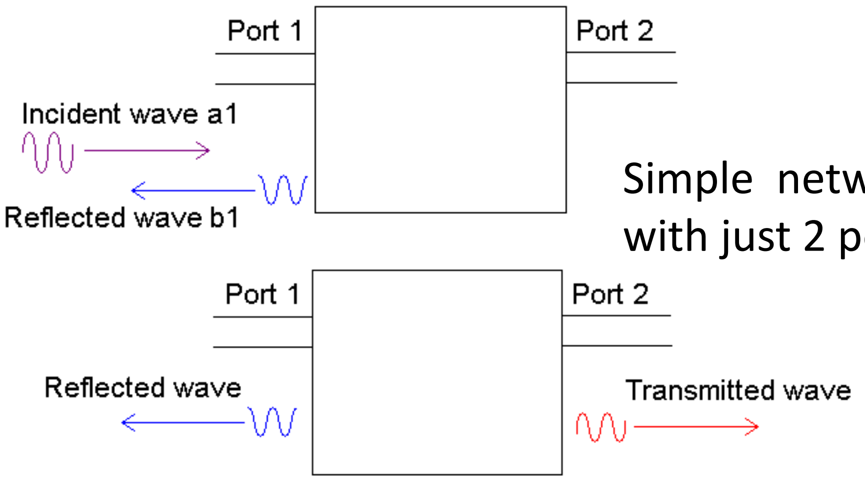
On-screen output can be Smith charts, time-frequency domain plots etc.

S-parameters

S_{11} refers to the signal reflected at Port 1 for the signal incident at Port 1. (is the ratio of the two waves b1/a1.)

S_{21} refers to the signal exiting at Port 2 for the signal incident at Port 1. (is the ratio of the two waves b2/a1.)

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



Simple network with just 2 ports.

Waves travelling towards the n-port: $(a) = (a_1, a_2, a_3, \mathrm{K}\ a_n)$

Waves travelling away from the n-port: $(b) = (b_1, b_2, b_3, \mathrm{K}\ b_n)$

$$\boxed{(b) = (S)(a)}$$

one - port	$b_1 = S_{11}a_1 + S_{12}a_2 + S_{13}a_3 + S_{14}a_4 + \mathrm{K}$
two - port	$b_2 = S_{21}a_1 + S_{22}a_2 + S_{23}a_3 + S_{44}a_4 + \mathrm{K}$
three - port	$b_3 = S_{31}a_1 + S_{32}a_2 + S_{33}a_3 + S_{44}a_4 + \mathrm{K}$
four - port	$b_4 = S_{41}a_1 + S_{42}a_2 + S_{33}a_3 + S_{44}a_4 + \mathrm{K}$

RF Directional Couplers and 3dB Hybrids

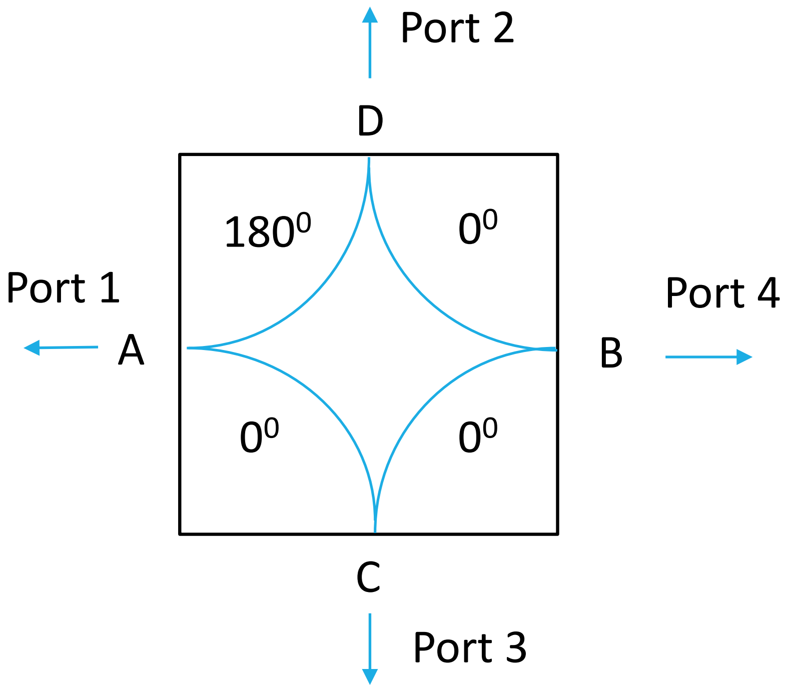
Directional Couplers

- For providing a sample of the power propagating in one direction on a transmission line.

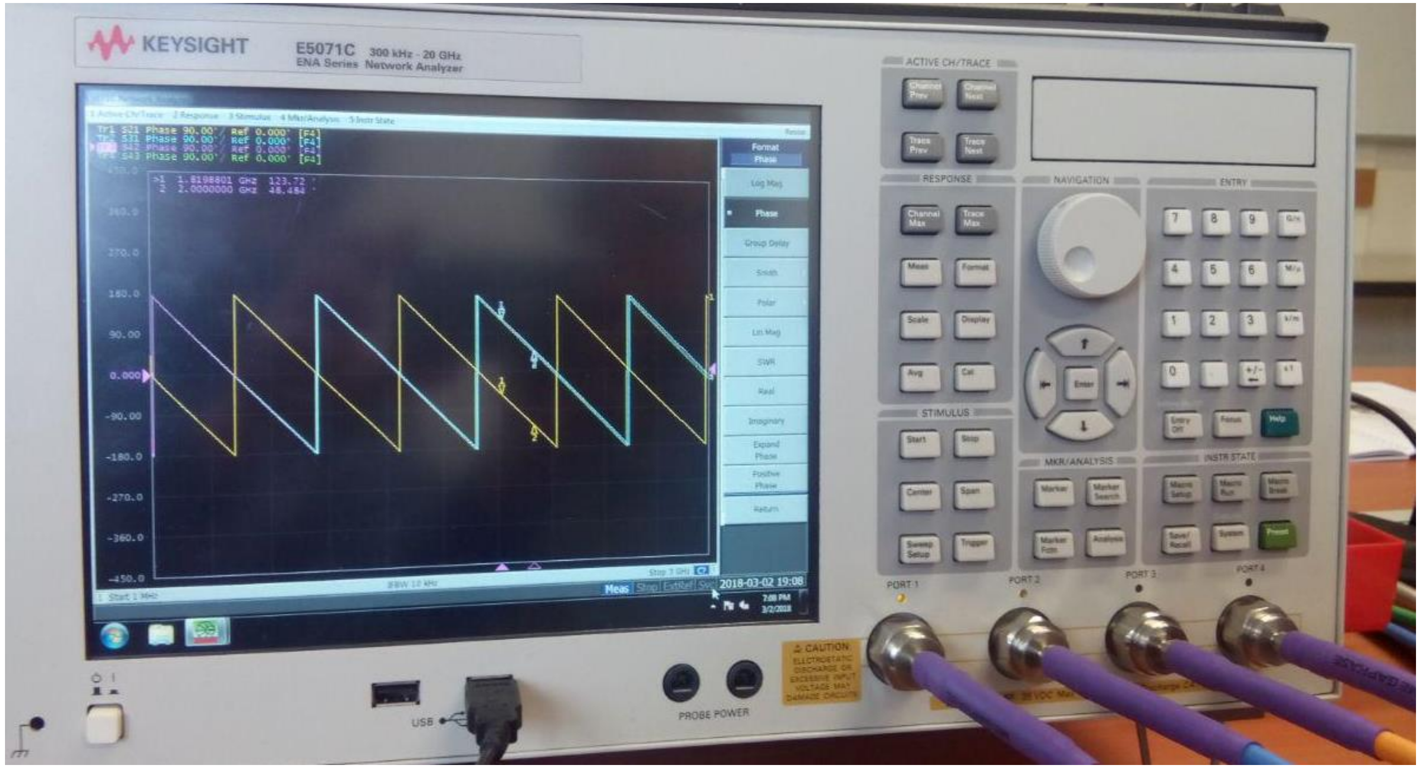
3dB Hybrids

- For dividing a signal into two signals of equal amplitude and a constant 90° or 180° phase differential.
- For quadrature combining or performing summation/differential combining

3dB 180° Hybrids



3dB 180° Hybrids



Network Analyser

Type of transmission lines tested

Coaxial lines

- *frequency range: 0-100 GHz*
- *power rating for CW @ 200 MHz: 1MW*
- *low-pass line*
- *high attenuation*
- *power limited by thermal load of the inner conductor*
- *very easy to handle*
- *TEM propagation*

Waveguides

- frequency range 0.32-325GHz
- power rating: 150 MW peak @ 310 MHz
- bandpass, lower cut-off dependent on cavity geometry
- low attenuation
- TE and TM propagation

Measurement in a coax line stretcher

A line stretcher is a 2-port device.

It consists in a coaxial line with an adjustable length.

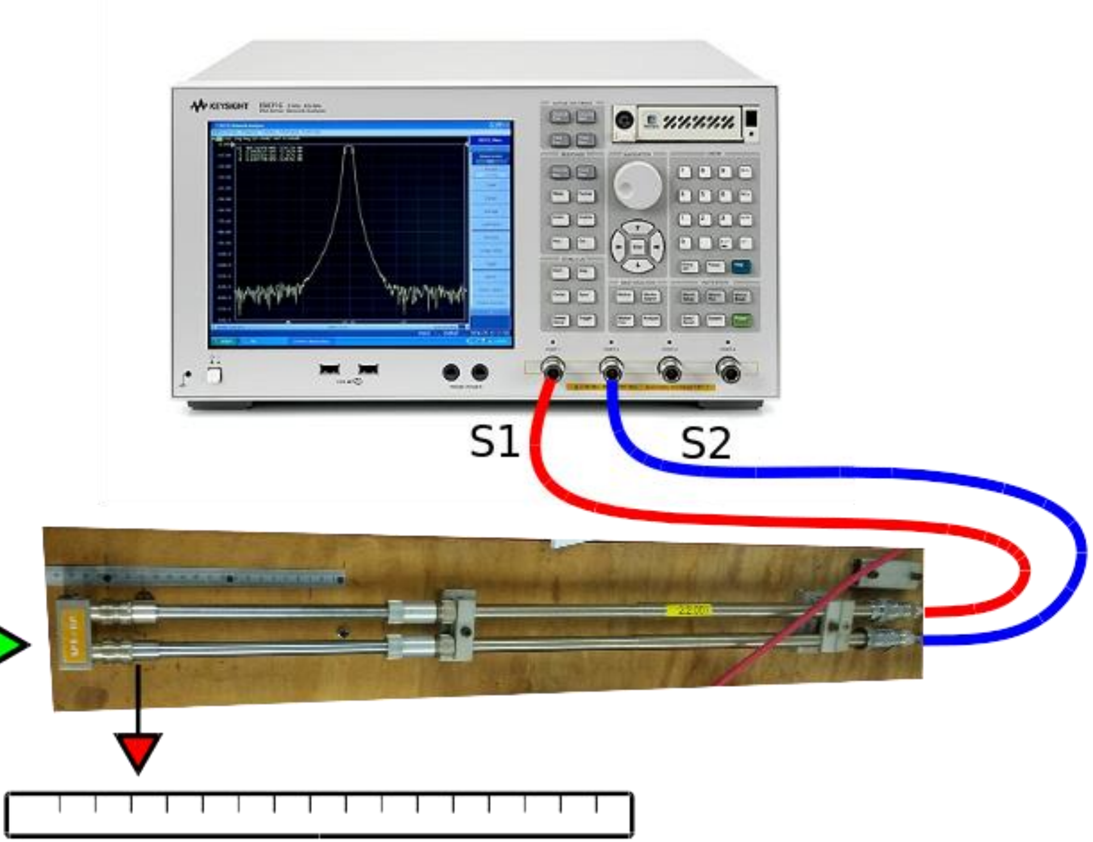
$$v = \frac{1}{\sqrt{L'C'}} = \frac{c_0}{\sqrt{\mu_r \epsilon_r}}$$

Measuring the S12 group delay with different arm

elongations is possible to find out the velocity of propagation of the signal

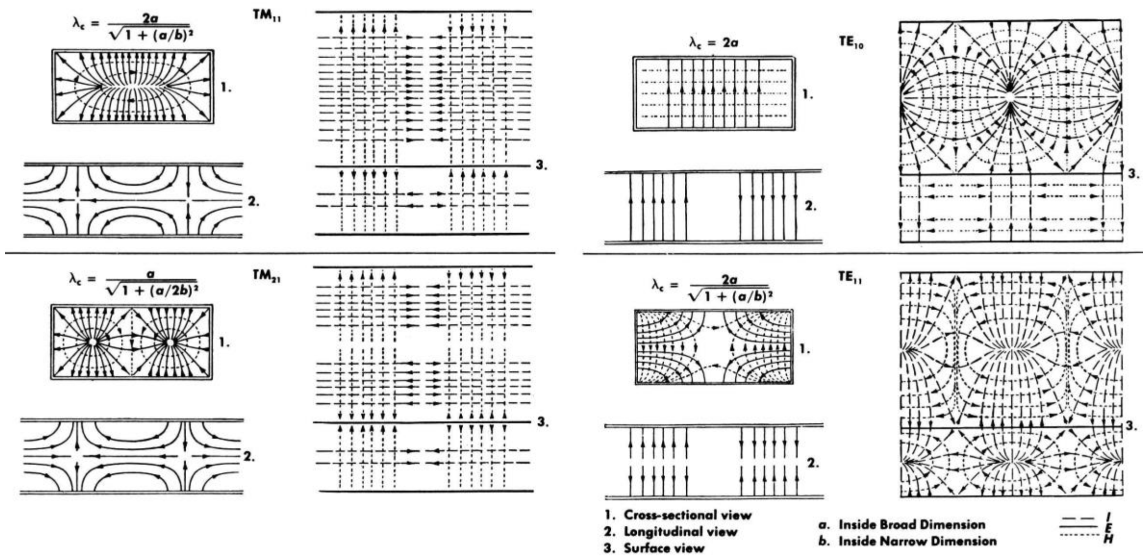
$$v = 2\frac{\Delta L}{\Delta t} = 2\frac{16cm - 1cm}{5.72ns - 4.69ns} = 2.9 \cdot 10^8\, m/s$$

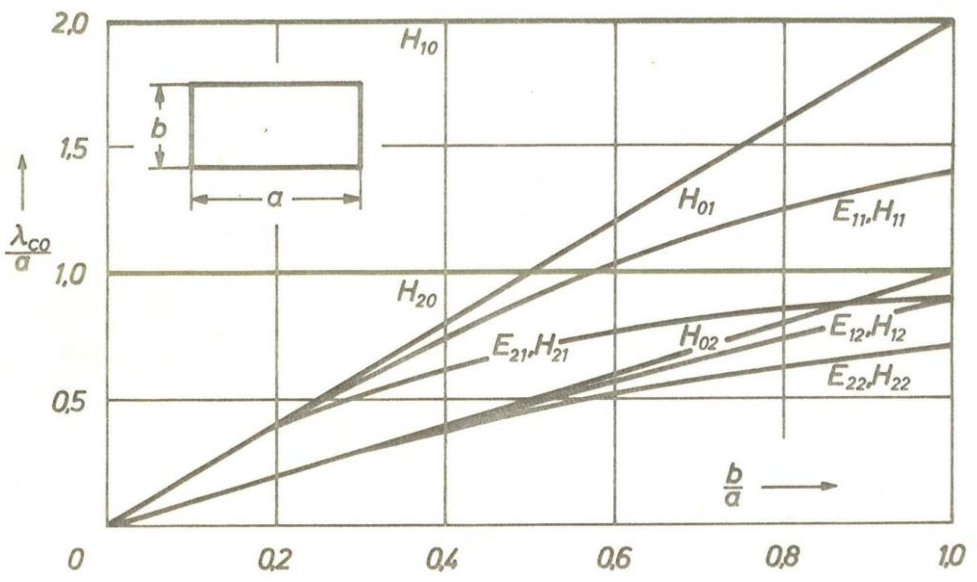
The coax line dielectric is air! (not so much of surprise..)



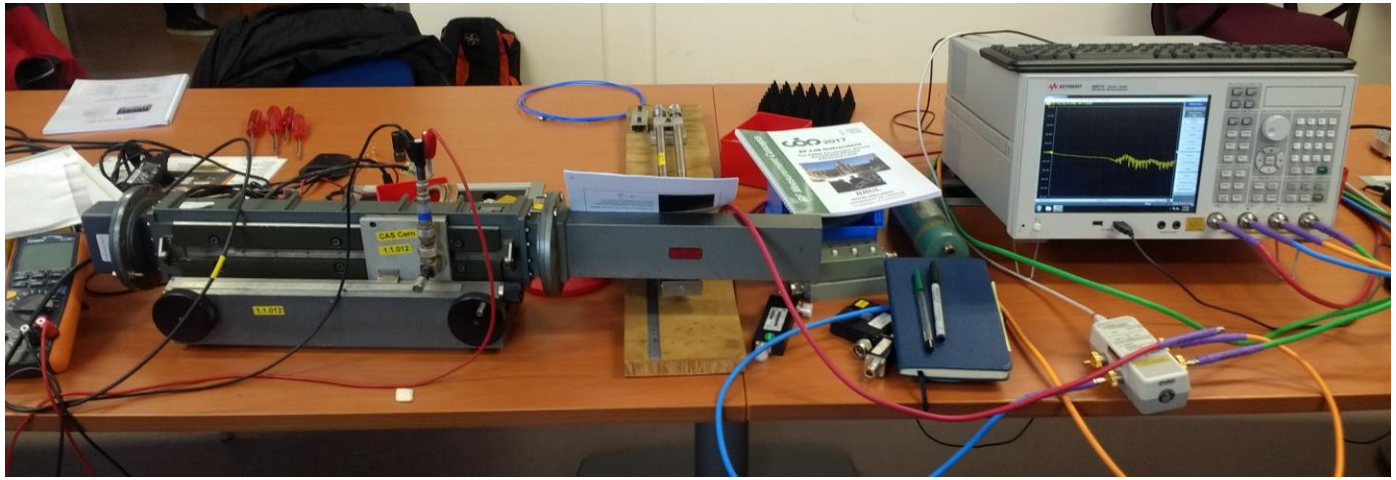
Rectangular Waveguides

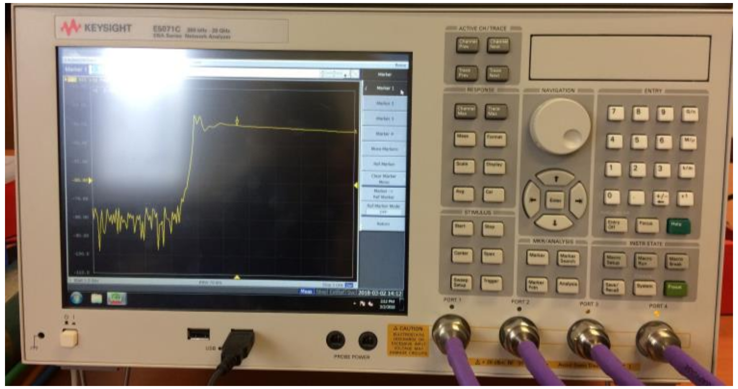
In a rectangular waveguide the cut off frequency of the TE_{10} mode is the fundamental mode as it has the largest wavelength (lowest frequency) λ_{co}=2a.





Waveguide Experiment Set-up





Approximate value of cut off frequency: λ_{cutoff}=2a and a≈7cm so $f_{cutoff}=c/\lambda\approx2.1$GHz

We determined the cut-off frequency with the Network analyser:

f_{cutoff}=2.1GHz

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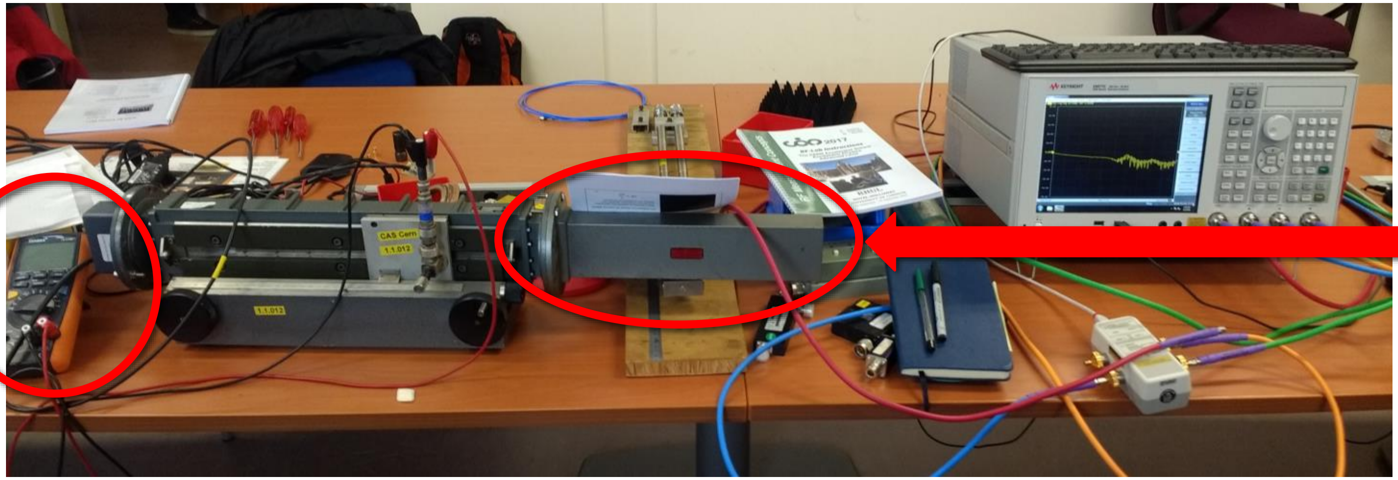
Rectangular Waveguide Match/Mismatch

V_{DC} mesure



Load

With load: V_{DC}=contant everywhere => travelling waves

Whitout load: V_{DC} varying => standing waves

Measurement of v_ϕ

With the voltmeter in DC mode and moving the probe along the waveguide

=> Find the position where U=0V to measure $\lambda/2$:

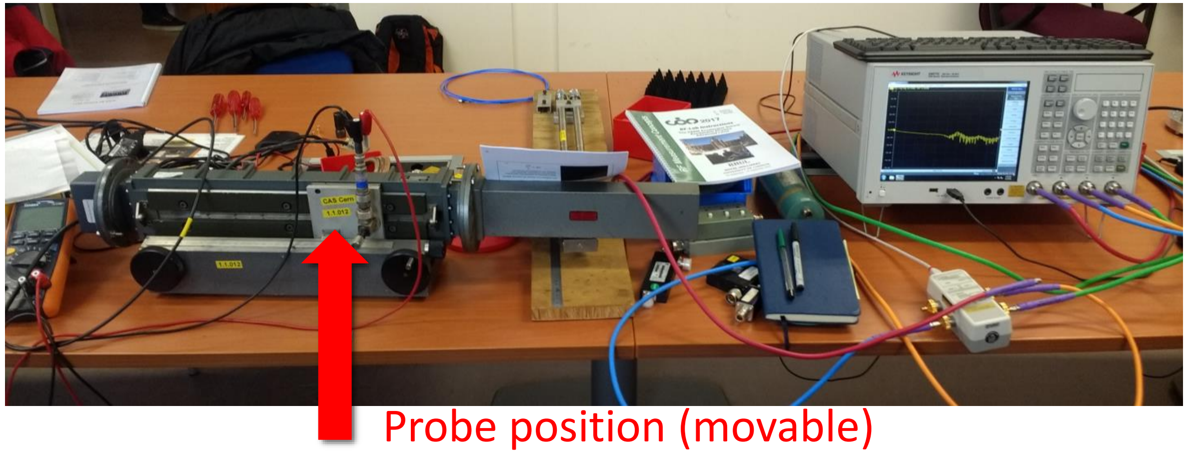
Voltage (V)	0V	Next 0V
Position (mm)	176.45	246.15mm

So $\lambda=(246.15-176.45)*2=139.4$mm (because two followed 0V correspond to half a wavelength)

Finally, $\mathbf{v_\phi=f\lambda=4.2E8\ m/s} > c$

Measurement of v_{group}

Measure time (correspond to frequency) with network analyser



Probe position (movable)

Position (mm)	150	415
Time (ns)	1.632	2.900

So $v_{group}=\Delta x/\Delta t=$**2.09E8 m/s**

And we found $v_{phi}*v_{group}=$**(3.0E8)^2 m/s**

Conclusion

We took a number of measurements and we were able to determine speed of light. It was useful to see the masters of the art at work, thankyou to all those who helped. Obviously time was truncated due to bad/fantastic/snowy weather but the experience was definitely worthwhile.