Experimental laboratory no. 2: the slotted waveguide

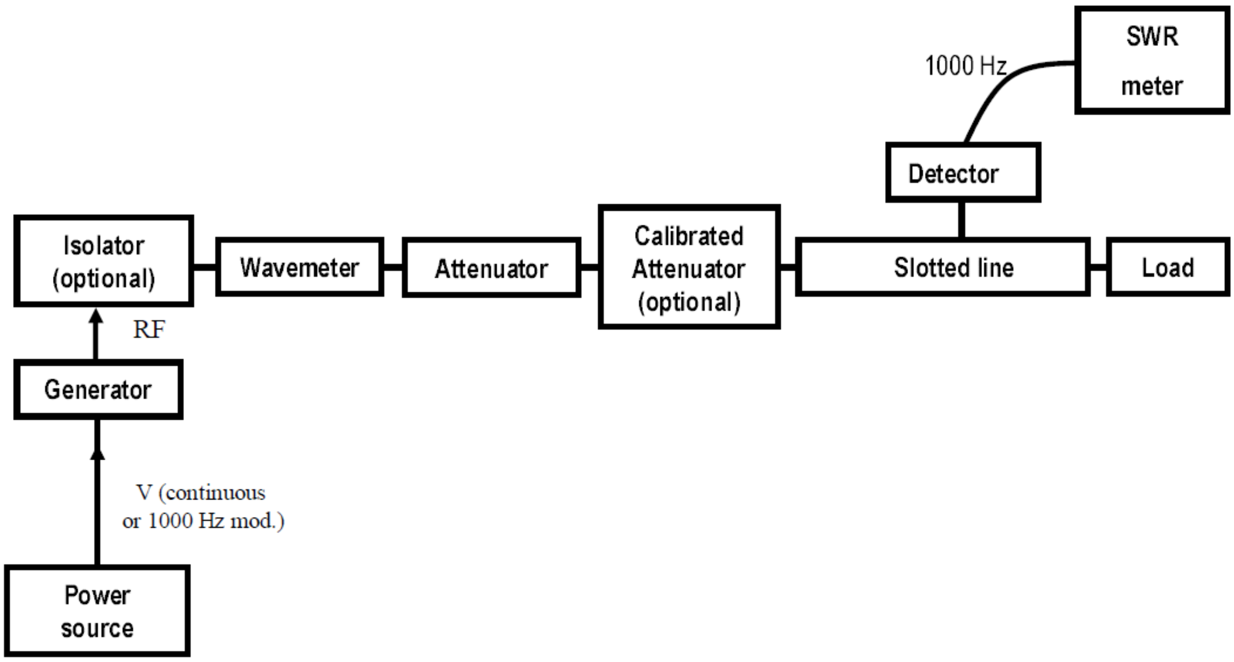
1. Measurement objective

Measurement the impedance Z_L of an unknown load. The value of the impedance is derived from the corresponding reflection coefficient in module $|\Gamma|$ and phase $arg(\Gamma)$. The module of the reflection coefficient is obtained from the measured standing wave ratio, S. The phase of the reflection coefficient is obtained measuring the corresponding electric distance d/λ_g where λ_g is the guided wavelength for the fundamental mode (TE10) propagating in the waveguide.

2. Technical data

- WR90 waveguide
- bandwidth: 6.2-12.4 GHz
- cut-off frequency for the fundamental mode TE10 (f_{c10}): 6.557 GHz
- maximum waveguide side a: 0.9 in (2.2286 cm)
- minimum waveguide side b: 0.4 in (1.016 cm)

3. Scheme of the test bench



4. Measurement procedure description

4.1 Frequency set up:

- close the slotted waveguide with the matched load (to measure a constant signal with the SWR meter);
- set the frequency with the gunn generator to 9 GHz;
- switch on the power source and the SWR meter;
- check that moving the detector in the slotted waveguide the signal measured with the SWR meter is constant;
- set the resonant frequency of the wavemeter to 9 GHz (that corresponds to 4.863 in the wavemeter scale);
- move slowly the gunn generator around 9 GHz in order to measure a minimum signal with the SWR meter;
- keep in the gunn generator the position that corresponds to the minimum signal (the wavemeter is at the resonant frequency equal to 9 GHz);
- change the resonant frequency of the wavemeter (the measured signal should increase);
- switch off the power source.

Note: if a detector inside the wavemeter is available it is possible to detect a maximum inside the wavemeter instead of a minimum in the slotted waveguide.

4.2 Measurement of the guided wavelength:

- close the slotted waveguide with a short circuit (to have peaked minima in the measured signal);
- switch on the power source;
- choose a reference value in one of the SWR meter scales;
- move the detector in the slotted waveguide in order to measure a signal that corresponds to the chosen reference value;
- read the corresponding distance on the slotted waveguide, d_1;
- move the detector towards the generator and stop when the reference value is reached again (a minimum has to be found between the two reference values);
- read the corresponding distance on the slotted waveguide, d_2;
- evaluate $d_{min,1}=(d_1+d_2)/2$ that corresponds to the position of the minimum;
- repeat the same operations to find the position of the following minimum in the direction of the generator, $d_{min,2}$;
- switch off the power source;
- evaluate $\lambda_g=2(d_{min,2} - d_{min,1})$;
- the measured λ_g should corresponds to the guided wavelength for the fundamental mode that can be evaluated as

$$\lambda_{gi} = \frac{2\pi}{k_{zi}} = \frac{\lambda}{\sqrt{1-\left(\frac{f_{ci}}{f}\right)^2}}$$

where λ is the free space wavelength, f_c is the cut-off frequency for the mode TE10, and f the working frequency (9 GHz).

4.3 Measurement of the amplitude of the reflection coefficient of the unknown load

- We recall that:

$$P = \frac{|V^+|^2(1-|\Gamma|^2)}{2Z_\infty}, \qquad V_{max,min} = |V^+|(1 \pm |\Gamma|), \qquad S = \frac{1+|\Gamma|}{1-|\Gamma|}$$

  hence

$$P = \frac{V_{min}^2\, S}{2Z_\infty} = \frac{V_{max}^2}{2Z_\infty S}$$

  where P is the active power for the mode TE10 flowing in the waveguide, V^+ is the forward voltage for the mode TE10, $|\Gamma|$ is the amplitude of the unknown reflection coefficient, Z_∞ is the modal impedance for the mode TE10, and S is the standing wave ratio.
- close the slotted waveguide with the unknown load;
- switch on the power source;
- set the attenuator to 0 dB (A_{1dB}), that corresponds to 0 mm in the attenuator scale;
- move the detector in the slotted waveguide in order to measure a minimum signal; the measured signal corresponds to:

$$V_{min}^2 = \frac{2Z_\infty P}{S} = \frac{2Z_\infty A_1 P_g}{S}$$

  where P_g is the generator delivered power, and $A_1$the used attenuation (linear units);
- set the measured signal (a minimum) to a reference value in one of the scales of the SWR meter;
- move the detector in the slotted waveguide to a maximum of the signal;
- increase the attenuation with the attenuator in order to set the measured signal (a maximum) to the chosen reference value (a minimum);
- read the set attenuation (A_{2dB});
- switch off the power source;
- the measured signal corresponds to:

$$V_{max}^2 = 2Z_\infty A_2 P_g S = V_{min}^2$$

  hence

$$2Z_\infty A_2 P_g S = \frac{2Z_\infty A_1 P_g}{S} \Longrightarrow S^2 = \frac{A_1}{A_2}$$

- the SWR of the unknown load is equal to $20\log_{10}(S)=A_{1dB}-A_{2dB}$ (remember that "attenuations" corresponds to a negative value in dB);
- the amplitude of the corresponding reflection coefficient is:

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

4.4 Measurement of the phase of the reflection coefficient of the unknown load

- close the slotted waveguide with a short circuit (to have a minimum at the load section);
- switch on the power source;
- put the detector in the slotted waveguide in a minimum of the signal (use the same procedure described to measure the guided wavelength);
- read the corresponding distance on the slotted waveguide, d_{SC};
- switch off the power source;
- close the slotted waveguide with the unknown load;
- switch on the power source;
- move the detector in the slotted waveguide toward generator until the first minimum is reached;
- read the corresponding distance on the slotted waveguide, d_{LOAD};
- switch off the power source and the SWR meter;
- the searched electric distance is:

$$\frac{d}{\lambda_g} = \frac{|d_{LOAD} - d_{SC}|}{\lambda_g}$$

- draw on the smith chart a circle with radius equal to $|\Gamma|$ found in the previous measurement;
- move along the circle from the SC position (that corresponds to the minimum voltage), towards the load, for a distance equal to d/λ_g, and read the corresponding phase, $\arg(\Gamma)$, on the smith chart.

4.5 Evaluation of the impedance of the unknown load

The normalized (unknown) impedance is read from the smith chart corresponding to the found reflection coefficient (module and phase). Then the impedance Z_L is equal to the normalized one multiplied by the modal impedance of the TE10 mode.

The Complete Smith Chart

Black Magic Design