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PRACTICAL METHOD FOR DETERMINATION THE WAVEGUIDE IMPEDANCE USING SMITH CHART

DOBRA REMUS[1], RISTEIU MIRCEA[2], ALDEA MIHAELA[3], GEORGETA BUICA[4], PAULA CAMELIA STOICA[5]

Abstract: The Smith chart is a graphical tool for determination of the reflection coefficient and impedance along a transmission line. The paper presents a practical method for determination the waveguide impedance using Smith chart in a waveguide. From calculating the reflection coefficient and impedance at various points on a transmission line to designing the matching network of a microwave system. The Smith chart is a handy tool that is even included in lots of modern computer-aided design software and test equipment. The Smith chart is based on a polar plot of the complex reflection coefficient Γ(x) overlaid with the corresponding impedance Z(x). A simple transformation is presented which permits the direct use of the standard Smith chart in the study of transmission lines and waveguides.

Keywords: Voltage standing wave ratio, waveguide impedance, reflect, matched lines, Smith chart, waveguide.

1. STANDING WAVE RATIO FUNDAMENTALS

This experiment studies a method to determine the impedance of a waveguide mismatched terminating the line. A mismatched terminating line occurs when a waveguide line is terminated with load impedance with different value than the line's characteristic impedance value [12].

The unknown impedance can be determined by using the Smith chart. In order to get the parameters for Smith chart some processing action should be done by evaluating the standing wave in different situations (without and with unknown impedance) [3], [7]. Typical standing wave is shown in figure 1.

[1] *Ph.D.Eng. Assoc. Prof, University of Alba Iulia, remusdobra@uab.ro*
[2] *Ph.D.Eng. Assoc. Prof, University of Alba Iulia, mircearisteiu@gmail.com*
[3] *Ph.D. Student, University of Alba Iulia, maldea@uab.ro*
[4] *Ph.D. Eng, Institutul Naţional de Cercetare-Dezvoltare pentru Protecţia Muncii "Alexandru Darabont", gbuica@protectiamuncii.ro*
[5] *Ph.D. Student, University of Pitesti, cameliapaulastoica@gmail.com*

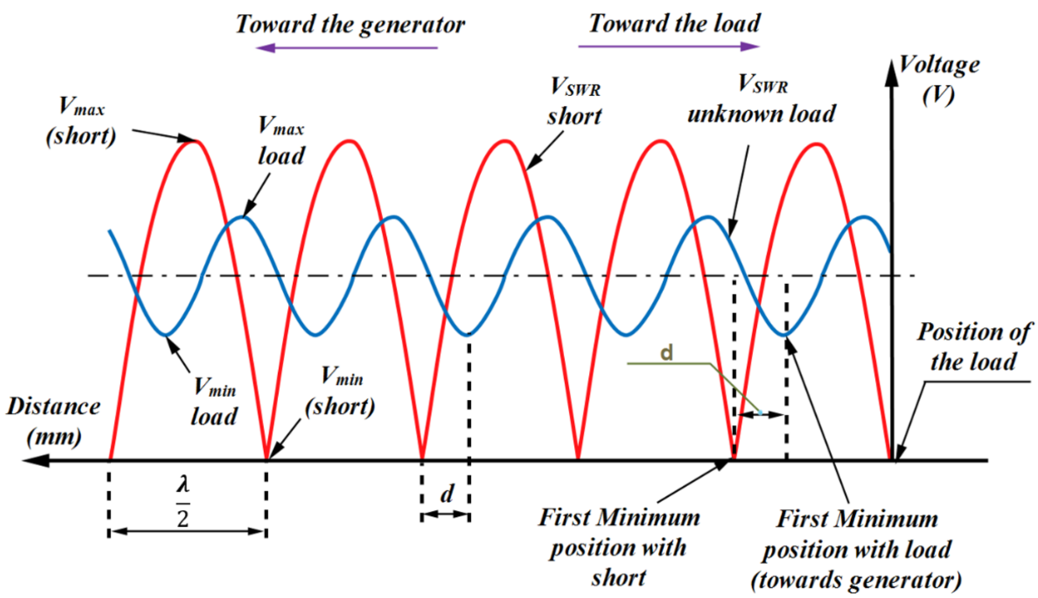

Fig.1. Standing waves on the waveguide line: with shorting plate and with unknown load

By connecting the shorting plate, we identify the first minimum position of the standing wave (**d1**) with the shorting plate inserted, see figure 1.

By disconnecting the shorting plate and connecting the unknown impedance (figure 1), we identify the first minimum position (**d2**) and measure the Voltage Standing Wave Ratio (VSWR), with the load, see figure 2.

The unknown terminating impedance can be determined by measuring standing wave ratio and the distance (**d**) of a convenient minimum (or maximum) from the load.

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1-|\Gamma|}{1+|\Gamma|} \quad (1)$$

Where: Vmax, Vmin are pick values of Voltage Standing Wave Ratio.

In a waveguide line with the characteristic impedance of Z_o, the reflection coefficient (absolute magnitude |Γ|) between the incident and the reflected signal is defined as [2], [5]:

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} \quad (2)$$

$$\overline{\Gamma} = |\Gamma| \cdot e^{j\theta_r} \quad (3)$$

Where: $\overline{\Gamma}$- is the complex reflection coefficient

θ_R- is the angle of reflection coefficient (degrees)

Using the graphical representation of Smith chart, the load impedance can be determined (load resistance R_L and load reactance X_L) with next equation.

$$Z_L = R_L + jX_L \tag{4}$$

The Smith chart coordinates give the normalized impedance z_L (resistance and reactance).

$$\Rightarrow z_L = \frac{Z_L}{Z_0} \tag{5}$$

For this experiment, the chart coordinates are normalized to $\mathbf{Z_o = 50\Omega}$ (the characteristic impedance of the waveguide).

The value calculation starts from the standing wave processing. To read the standing waves we use the waveguide slotted line and to determine the impedance of the unknown load we use the slide screw tuner, as shown in figure 2.

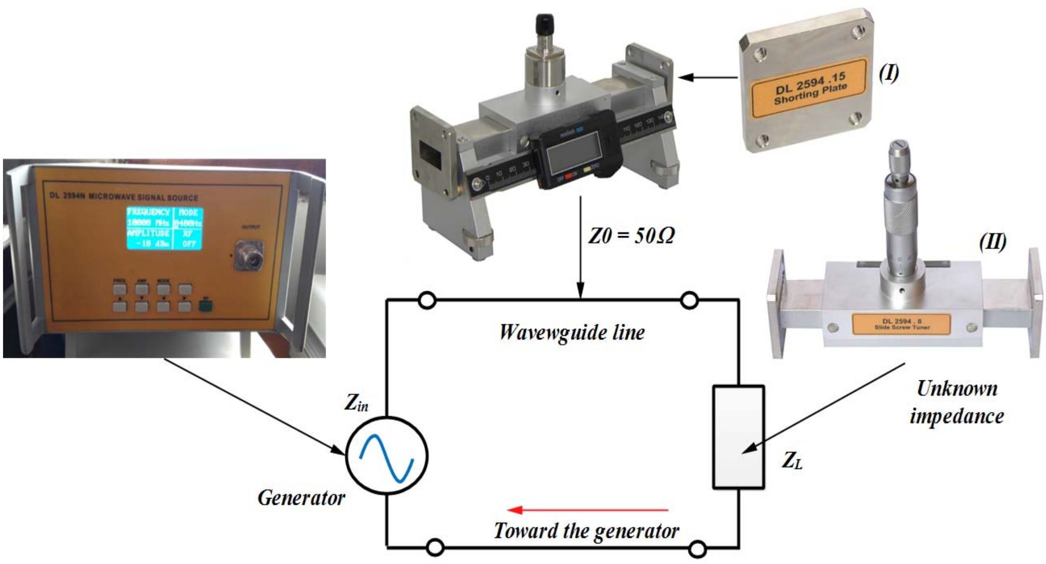

Fig.2. Schematic diagram for impedance measurement

The most common orientation of the Smith chart places the resistance axis horizontally with the short circuit (SC) location at the far left. There's a good reason for this: the voltage of the reflected wave at a short circuit must cancel the voltage of the incident wave so that zero potential exists across the short circuit. In other words, the voltage reflection coefficient must be -1 or a magnitude of 1 at an angle of 180 degrees. Since angles are measured from the positive real axis and the real axis is horizontal, the short circuit location and horizontal orientation make sense [1], [4], [9].

The waveguide post or screw is made from a conductive material. To make the post or screw inductive, it should extend through the waveguide completely contacting both top and bottom walls. For a capacitive reactance the post or screw should only extend part of the way through.

2. WAVEGUIDE IMPEDANCE RESULTS

Ensuring there is a good match between a waveguide and its source and load is essential if the waveguide is to provide optimum operation within and system and ensure that the benefits of its low loss are to be utilised properly [6], [8]. The different methods of providing a good impedance match can be used, the particular approach being dependent upon the system requirements.

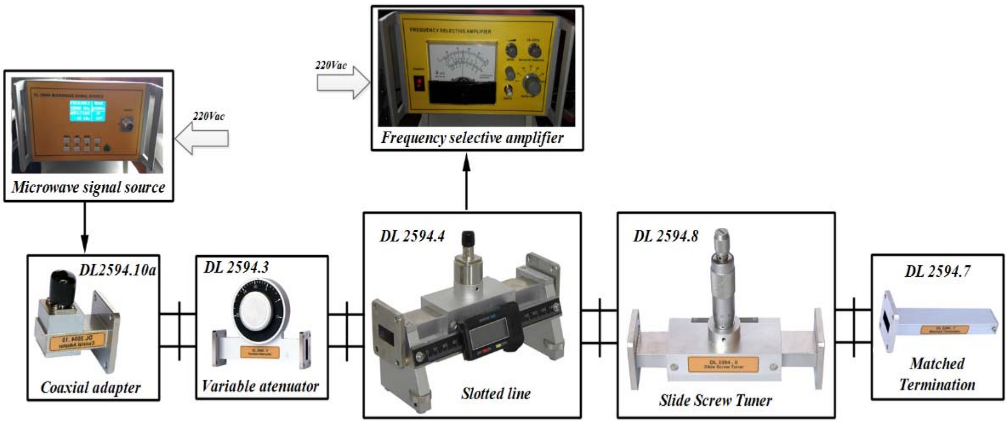

Fig.3. Diagram for measuring unknown impedance (with shorting plate)

Next figure shows the topographical situation for the experiment

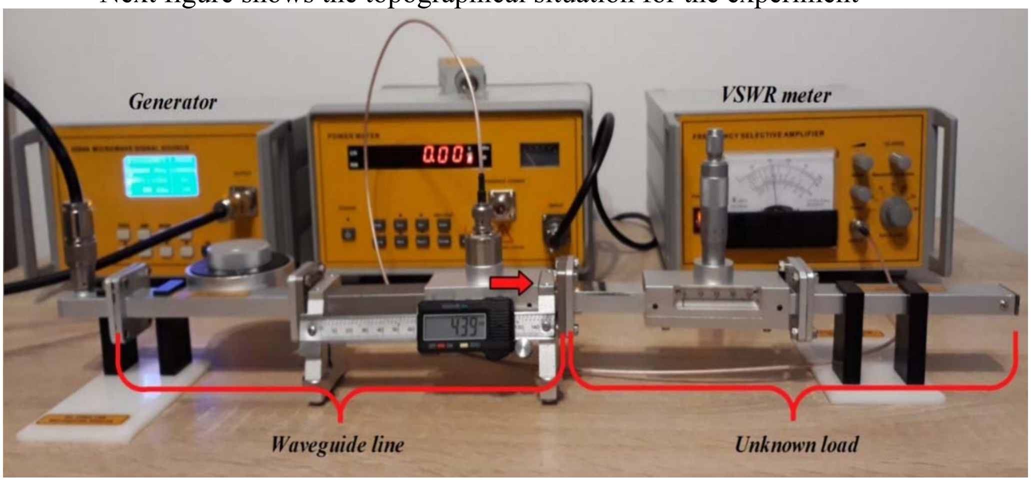

Fig.4. Real representation of the experiment (with load)

The combination of the screw tuner head and the position of the probe cause a reflection in the waveguide at a specific amplitude and phase [10], [11]. Relation between probe's depth and screw tuner scale [mm] is shown in table 1.

Table 1. ***Relation between probe's depth and screw tuner scale***

screw tuner scale	3	5	7	9
probe's depth [mm]	7	5	3	1

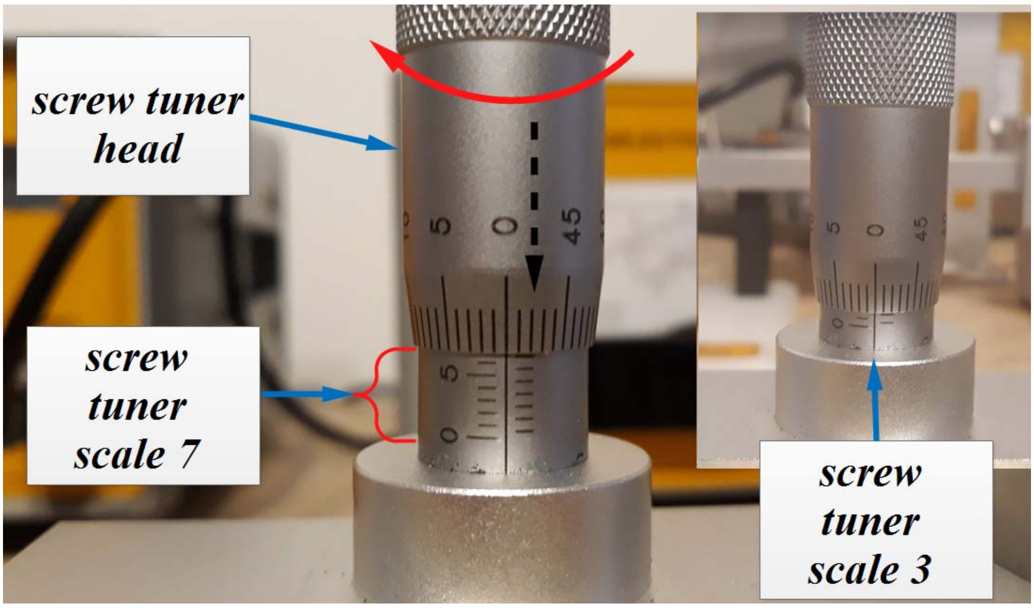

Fig.5. Real representation of the screw tuner scale

By moving *slotted line- mobile part* to the left we will find the first minimum position $Vmin_{load}$. The measured value is 180mV.

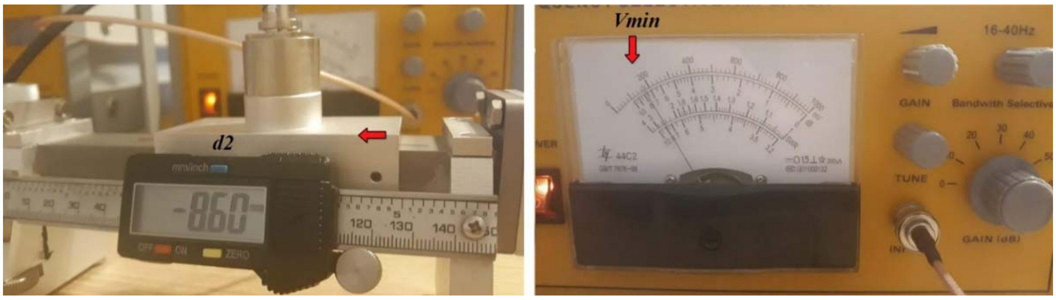

Fig.6. Measuring the minimum voltage

By moving *slotted line- mobile part* to the left we will find the first minimum position $Vmax_{load}$. The measured value is 680mV. The standing wave ratio is:

$$\boldsymbol{VSWR} = \frac{\boldsymbol{V_{max}}}{\boldsymbol{V_{min}}} = \frac{\boldsymbol{680mV}}{\boldsymbol{180mV}} = \boldsymbol{3.77} \tag{6}$$

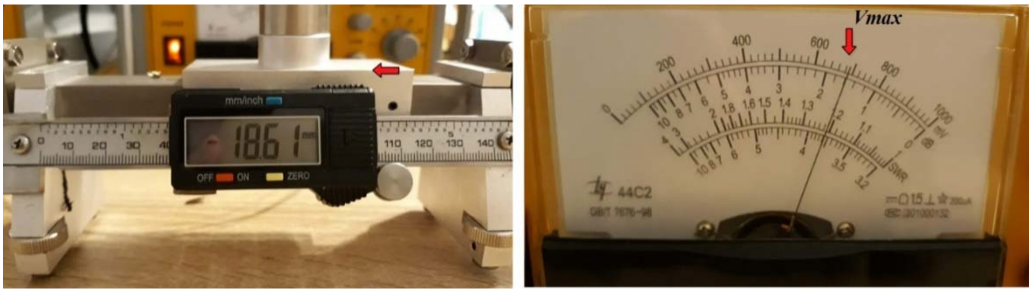

Fig.7. Measuring the maximum voltage

The wavelength toward generator coefficient is:

$$\frac{d}{\lambda_g} = \frac{8.6}{40} = 0.21 \quad (7)$$

The reflection coefficient (absolute magnitude |Γ |) is:

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} = \frac{3.77-1}{3.77+1} = 0.58 \quad (8)$$

Draw a straight line from the point d/λg calculated to the center of the drawn VSWR circle. The intersection of the circle and the straight line represents the normalized load impedance (Z_L).

From the intersection point (Z_L) read the correspondent value of horizontal axis of resistance component (real part of the impedance), by following the closed circle segment to the horizontal line - record the value.

From the intersection point (Z_L) read the correspondent value from circle of inductive reactance component (imaginary part of the impedance) by following the closed circle segment to inductive reactance component circle - record the value.

For the screw tuner head on position 3 (7mm depth)

The normalized impedance is (Z_L= R+j·X):

$$\Rightarrow z_L = 1.6 + j0.5 \quad (9)$$

The load impedance is:

$$z_L = \frac{Z_L}{Z_0} \Rightarrow Z_L = 50 \cdot z_L \quad (10)$$

$$Z_L = 50 \cdot (1.6 + j0.5) = 80 + j25 \quad (11)$$

By reading the intersection of the straight line with the angle of reflection coefficient circle, this it will be:

$$\theta_R = 29 \quad (12)$$

The complex reflection coefficient is:

$$\overline{\boldsymbol{\Gamma}} = |\boldsymbol{\Gamma}| \cdot \boldsymbol{e}^{\boldsymbol{j}\boldsymbol{\theta}_{\boldsymbol{r}}} = \mathbf{0.58} \cdot \boldsymbol{e}^{\boldsymbol{j}\cdot\mathbf{29}} \quad (13)$$

$$\boldsymbol{e}^{\boldsymbol{j}\cdot\mathbf{29}} = \boldsymbol{cos}\,\mathbf{2\,9^0} + \boldsymbol{j}\,\boldsymbol{sin}\,\mathbf{2\,9^0} = \mathbf{0.78} + \boldsymbol{j}\mathbf{0.48} \quad (14)$$

$$\Rightarrow \overline{\boldsymbol{\Gamma}} = \mathbf{0.28}(\mathbf{0.78} + \boldsymbol{j}\mathbf{0.48}) = \mathbf{0.21} + \boldsymbol{j}\mathbf{0.13} \quad (15)$$

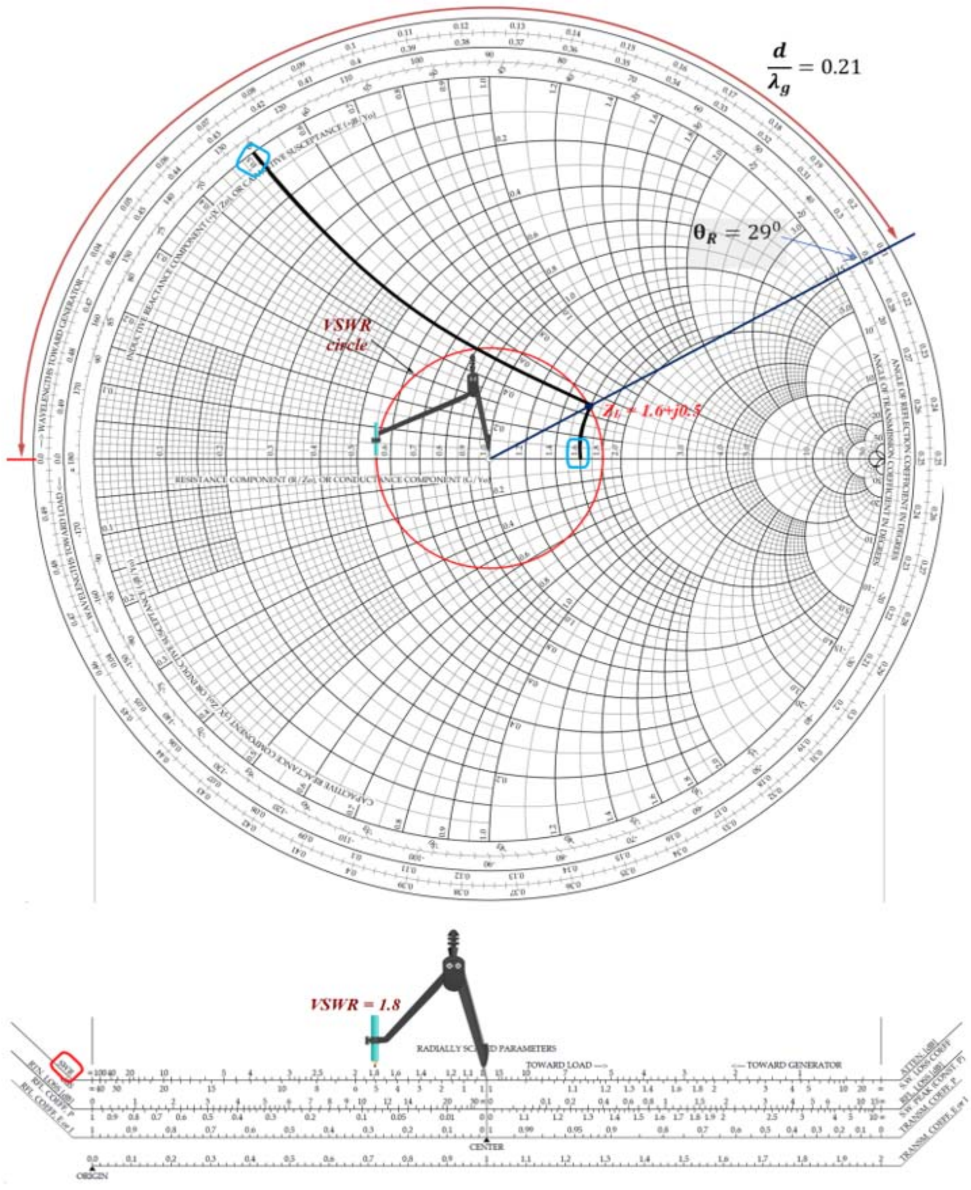

Fig.8. Processed Smith chart diagram for impedance calculation (Screw tuner head on 7 mm depth)

The Smith Chart allows easy calculation of the transformation of a complex load impedance through an arbitrary length of transmission line.

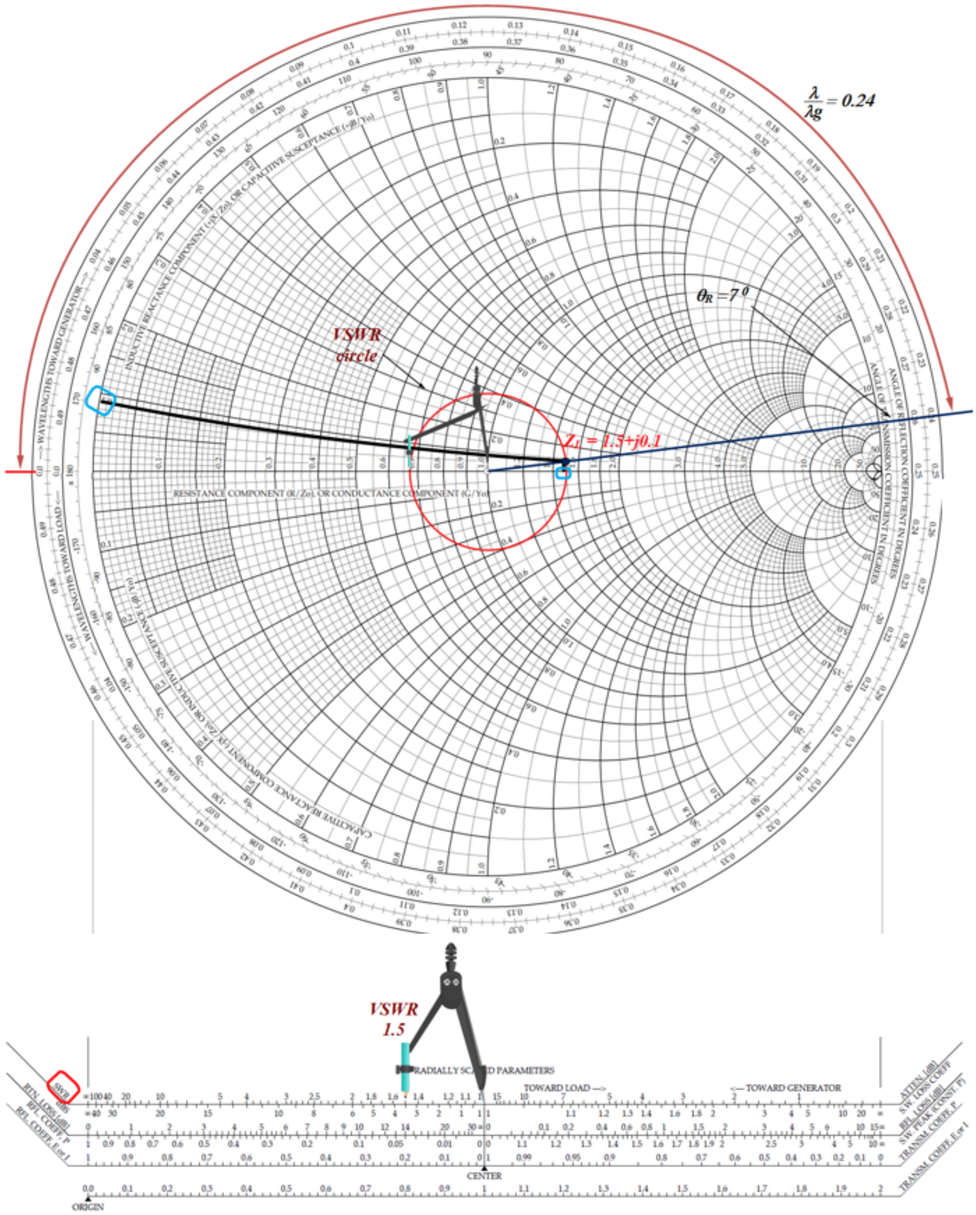

Fig.9. Processed Smith chart diagram for impedance calculation (Screw tuner head on 3 mm depth)

The Smith Chart works with normalized impedance and admittance, where normalization is made with respect to the characteristic impedance of the transmission line**.**

By plotting the normalized load impedance on a Smith Chart, the input impedance as a function of line length can be found. The Smith Chart also provides the value of the reflection coefficient, power delivered to load, as well as the voltage standing wave ratio (VSWR). Distance measurements are given in terms of wavelengths.

4. CONCLUSIONS

With slotted line module we have study the standing wave in two cases- using a shorting plate (zero impedance of the load) and using a waveguide with unknown impedance.

By using the relationships between standing waves and frequencies, using slotted line module we calculate minimum and maximum voltages, used to calculate VSWR. With these values and using Smith chart, we calculate impedances and reflection coefficients.

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