SECONDARY APPLICATIONS OF VECTOR ANALYSIS

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Abstract: *This paper presents an application of Vector Network Analyzer (VNA) in qualitative and quantitative spectral analysis in order to identify traces of chemical elements in a solution or complex substance. The work is based on reflectance spectrum analysis generated by a special built antenna containing the test sample, having as scientific support the different behavior of the two different elements in a field of microwave radiation. Their behavior is dependent on frequency and amplitude. The paper highlights some concrete results obtained experimentally.*
Keywords: *Vector Network Analyzer; reflection parameter; measurement.*

1. INTRODUCTION

The spectra obtained with the vector analyzer in microwaves range by transmission or reflectance, used in particular for the analysis of microwave circuits and devices, through this study, are used also to identify chemical elements or compounds.

The application describes the basic physical principle, measurement scheme and procedures to be followed to obtain the results. In the experimental part it was aimed at identifying sodium chloride NaCl concentrations of tens / hundreds of ppm in aqueous solutions.

2. APPLICATION CONTENT

2.1 Basic principle. Vector analyzer sees antenna system as impedance and measures the reflected signal from it, namely: S_{11} parameter from the Smith diagram and the reflection coefficient $\Gamma\Gamma$.

2.2 Calculation summary. The law of conservation of radiant flow $\gamma_{emitted} = \gamma_{transmitted} + \gamma_{absorbed} + \gamma_{reflected}$

$$\gamma_{emisie} = \gamma_{transmisie} + \gamma_{absorbție} + \gamma_{reflexie} \quad (1)$$

The spectral analyzer generates a power $P_{e\,dB} = 7dBm$ on a load impedance $Z_0 = 50\Omega$.

To convert the emission power in watts, is used the relationship:

$$P_{e\,dB} = 10\log_{10}\frac{P_e}{P_o} \quad (2)$$

where the power reference is:

$$P_o = 1\ mW \quad (3)$$

In this way it follows:

$$P_e = 10^{\frac{P_{dB}}{10}}\ mW = 10^{\frac{P_{dB}}{10}} \cdot 10^{-3}\ [W] \quad (4)$$

At the same time, the emission power is the sum of direct power and reflected power:

$$P_e = P_d + P_r \quad (5)$$

Depending on the reflected voltage U_r, we can write the reflected power:

$$P_r = \left|\frac{U_r^2}{2 \cdot Z_0}\right|\ [W] \quad (6)$$

The reflection coefficient is

$$\Gamma = \frac{Z_s - Z_o}{Z_s + Z_o} \quad (7)$$

and the load impedance

$$Z_s = R_s + j \cdot X_s \quad (8)$$

The emission voltage is the sum of direct and reflected voltage:

$$U_e = U_d + U_r \quad (9)$$

Knowing that

$$U_e^{\,2} = P_e \cdot Z_o = 10^{\frac{P_{dB}}{10}} \cdot 10^{-3} \cdot Z_o \Rightarrow U \frac{\sqrt{Z_o}}{10\sqrt{10}} \cdot 10^{\frac{P_{dB}}{20}}\ [V] \quad (10)$$

Direct voltage:

$$U_d = \frac{U_s}{1+\Gamma} \quad (11)$$

By processing the equation (7), for the reflection coefficient, we obtain:

$$Real(\Gamma) = \frac{R_s^2+X_s^2-Z_o^2}{(R_s+Z_o)^2+X_s^2} \quad (12)$$

$$Im(\Gamma) = \frac{2\cdot Z_o\cdot X_s}{(R_s+Z_o)^2+X_s^2} \quad (13)$$

The magnitude of the reflection coefficient:

$$|\Gamma| = \sqrt{Real(\Gamma)^2 + Im(\Gamma)^2} \quad (14)$$

The phase of the reflection coefficient:

$$\varphi_\Gamma = arctg\left(\frac{Im(\Gamma)}{Real(\Gamma)}\right)[rad] \quad (15)$$

$$\varphi_\Gamma{}^\circ = \frac{180\cdot\varphi_\Gamma}{\pi}[^\circ] \quad (16)$$

Magnitude relationship computing :

$$A_{dB} = 20\log_{10}\left(\frac{1}{Z_o}\sqrt{R_s^2+X_s^2}\right)[dB] \quad (17)$$

$$A = 10^{\frac{A_{dB}}{20}} \quad (18)$$

The reflected signal energy is calculated using the formula:

$$E = P_r\cdot\Delta t \quad (19)$$

where Δt is computed as period of time of the frequency band studied, divided by the number of samples:

$$\Delta t = \frac{t_{max}-t_{min}}{n} \quad (20)$$

Dielectric relative permittivity for water:

$$\varepsilon_r(t)_{water} = 87.740 - 0.40008t + 9.398(10^{-4})t^2 - 1.410(10^{-6})t^3,$$

$$\in_{r_{water}}(20^\circ) = 80 \quad (21)$$

2.3 The measuring scheme. The measurements were carried out using a scheme as in Fig.1, where the antenna measurement unit is shown in Fig. 2.

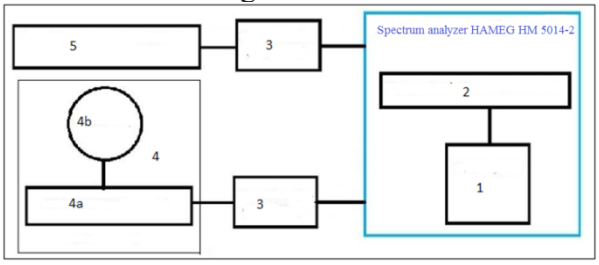

Fig. 1 The measuring scheme with the elements: 1 - VNA analyzer; 2 - processing interface; 3 - impedance adapters; 4 - antenna unit; 5 - reference antenna (witness).

Performing experiments are done at a constant temperature of 20º C and 20 ml test volume, following the procedures below:

- Preparing the reference of double-distilled water (pure water in an amount of 20 ml);
- Preparing the etalons with fixed concentration of sodium chloride in: 50 ppm NaCl; 100 ppm NaCl; 200ppm NaCl;
- Preparing the samples for examination: mineral water and current water, public drinking pipe (20 ml each);
- Work with spectral analyzer:
  - Selection of active frequency bands;
  - Viewing the reflection parameter with circular diagrams;
  - Data storage on memory stick.
- Data processing and identifying the spectra.

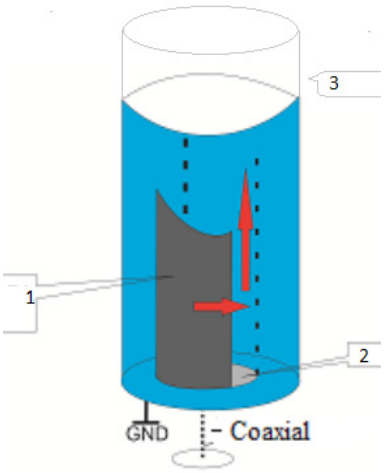

Fig. 2 Antenna measurement unit scheme: 1 - metal armature; 2 - metal disk; 3 – glass cylinder.

3. PROPER ANALYSIS (EXPERIMENTAL RESULTS)

In the following is presented the analysis for each frequency band of the substances studied have responded. Measurements were made for 4-6 frequency bands, but because of space limitation in the article, will be presented only two spectral bands, results are shown in the diagrams fig 1-30.

3.1 Frequency band I: 2.85-2.9 GHz.

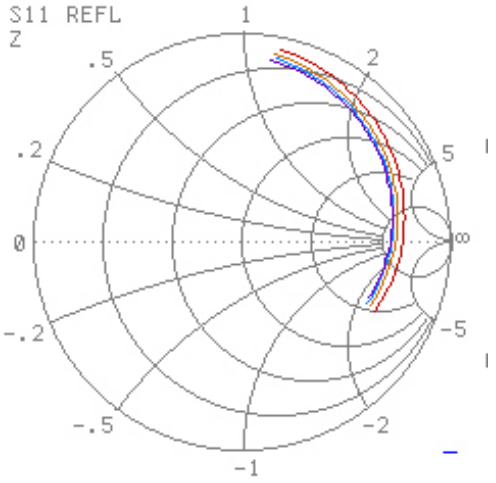

Fig. 3 Smith diagram in frequency band I, with all etalons and reference: reference (red), etalon 0,02% (orange), etalon 0,01% (mauve), etalon 0,005 % (blue).

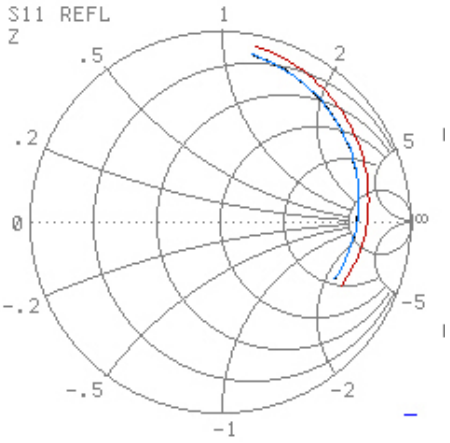

Fig. 4 Smith diagram in frequency band I, with: reference (red), etalon 0,005 % (blue), drinking water sample (black).

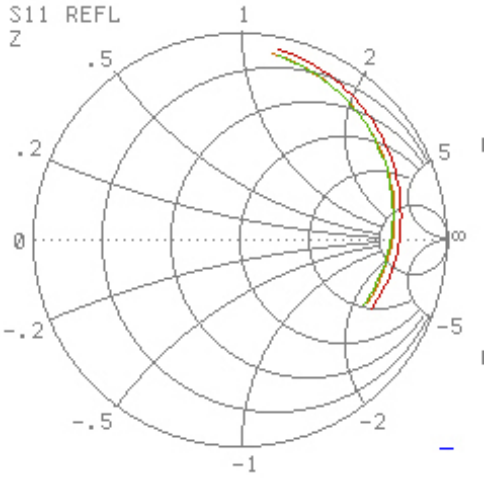

Fig. 5 Smith diagram in frequency band I, with: reference (red), etalon 0,02% (orange), mineral water sample (green).

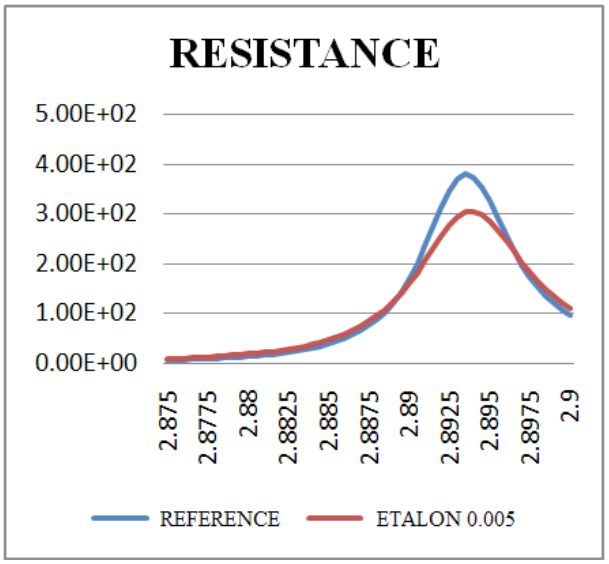

Fig. 6

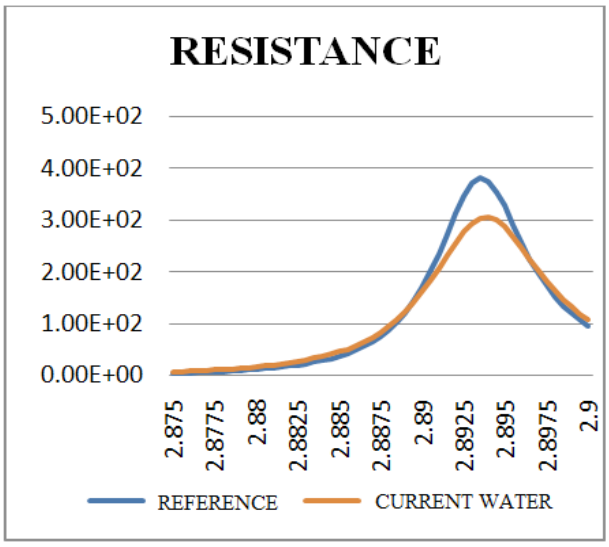

Fig. 7

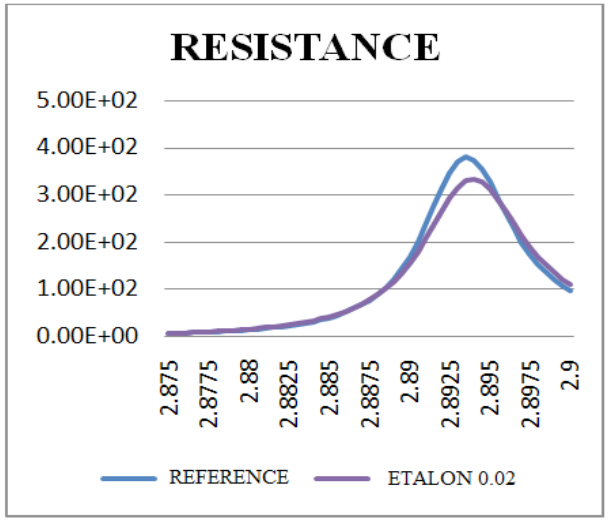

Fig. 8

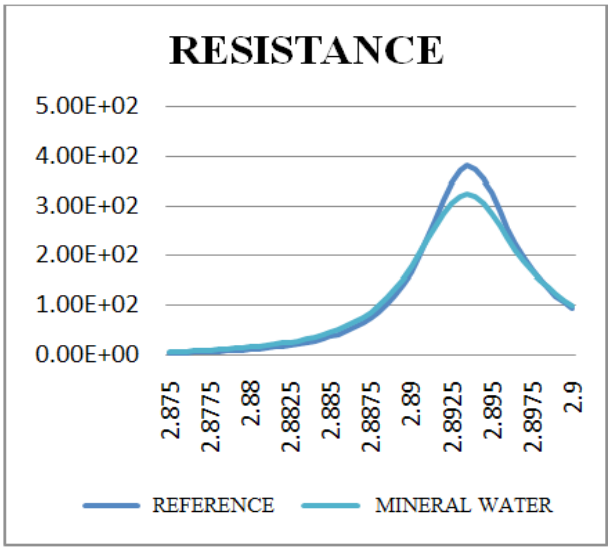

Fig. 9

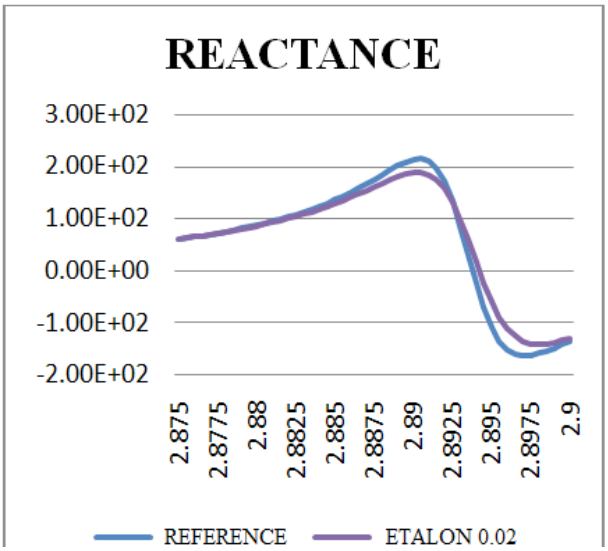

Fig. 12

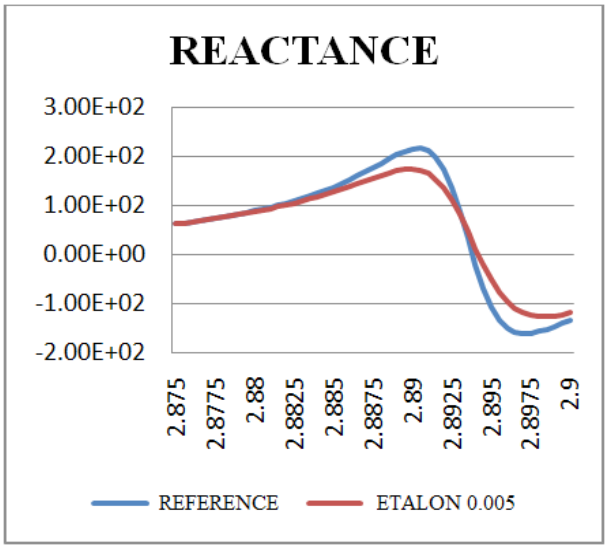

Fig. 10

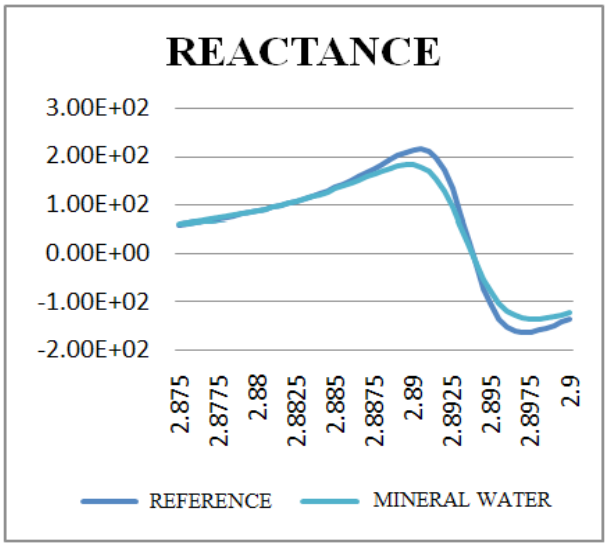

Fig. 13

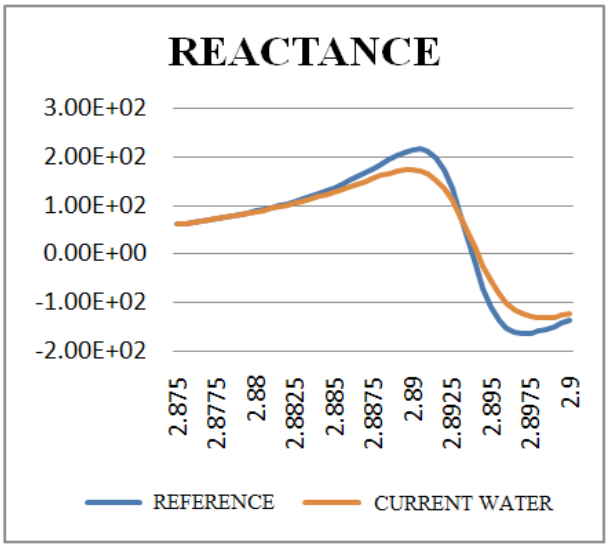

Fig. 11

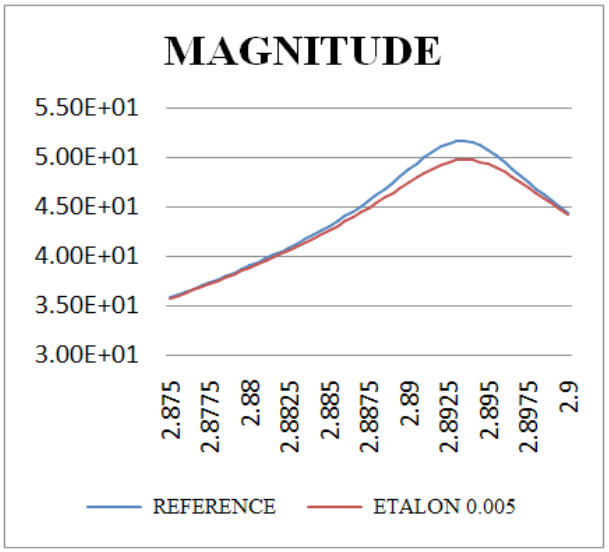

Fig. 14

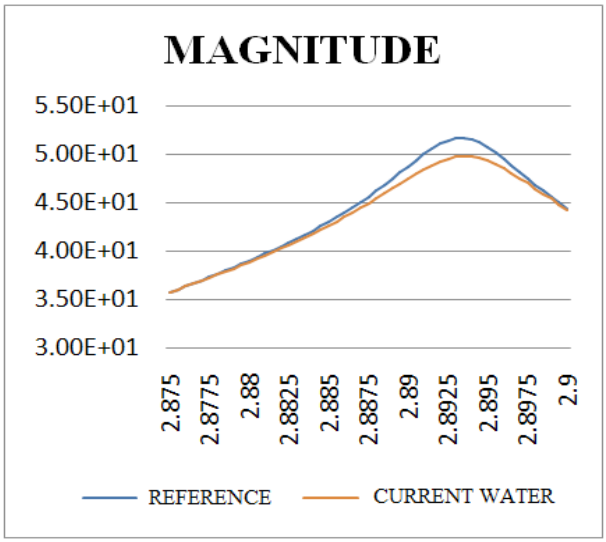

Fig. 15

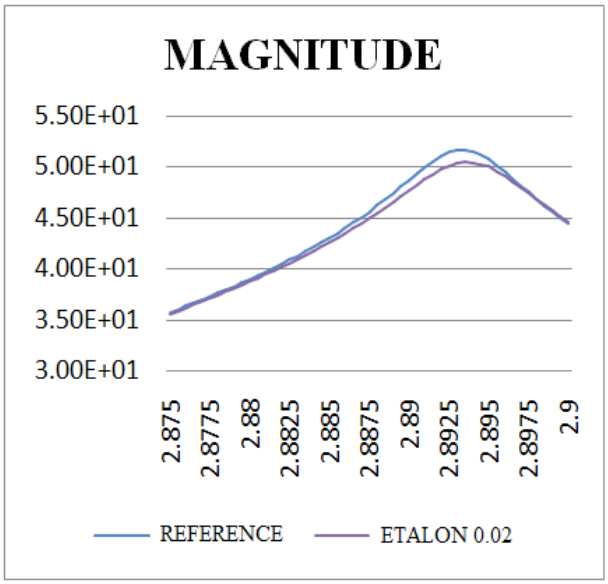

Fig. 16

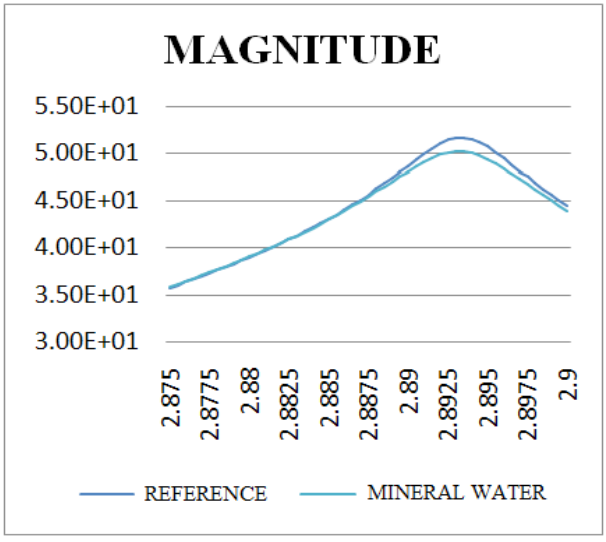

Fig. 17

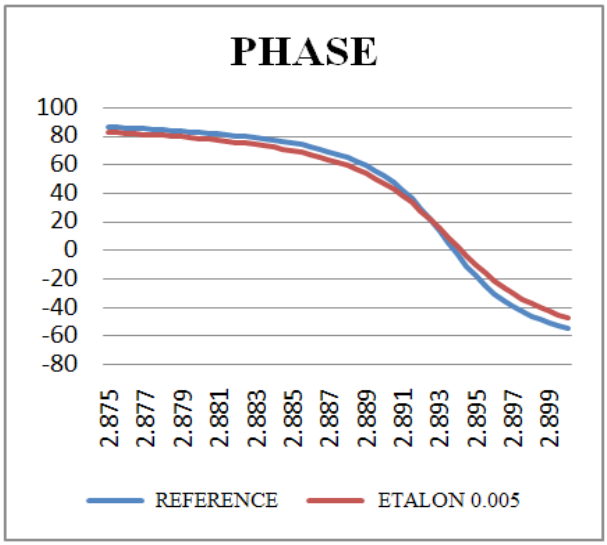

Fig. 18

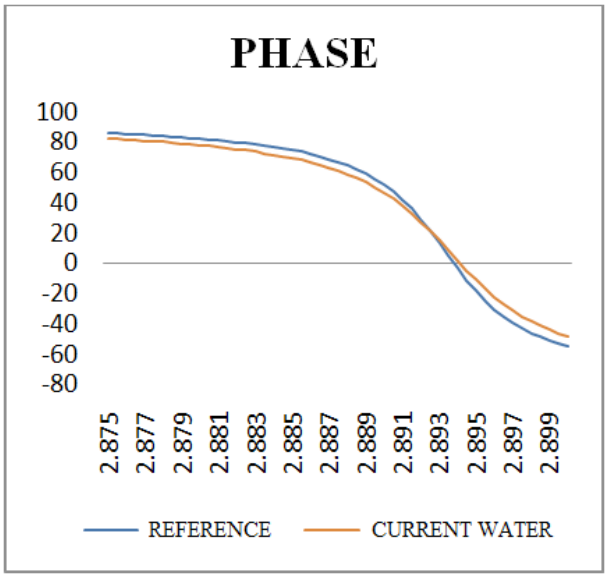

Fig. 19

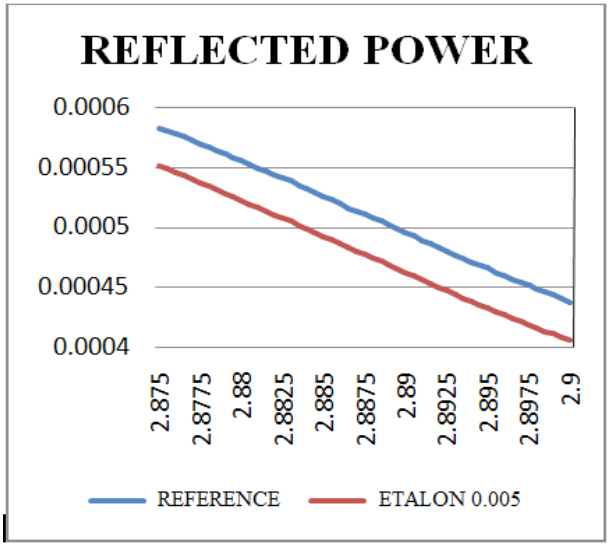

Fig. 20

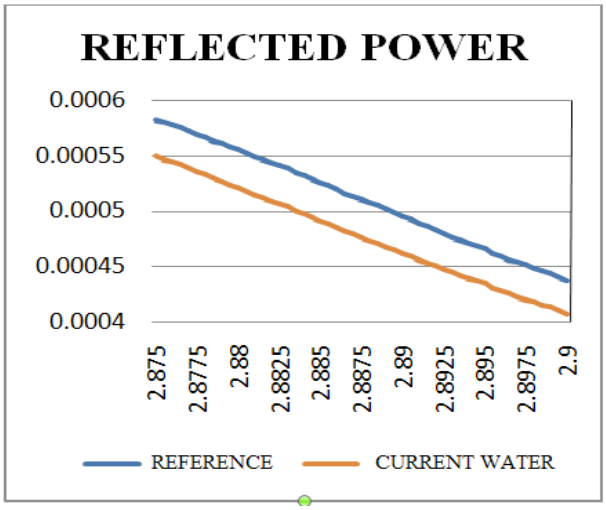

Fig. 21

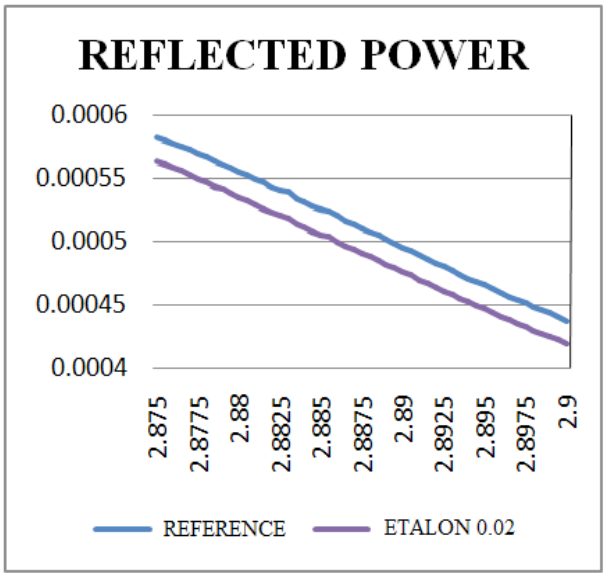

Fig. 22

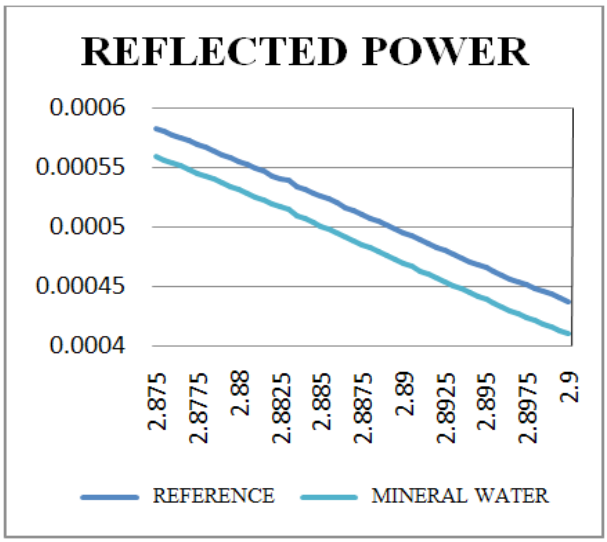

Fig. 23

3.2 Frequency band II: 5.6-5.67 GHz.

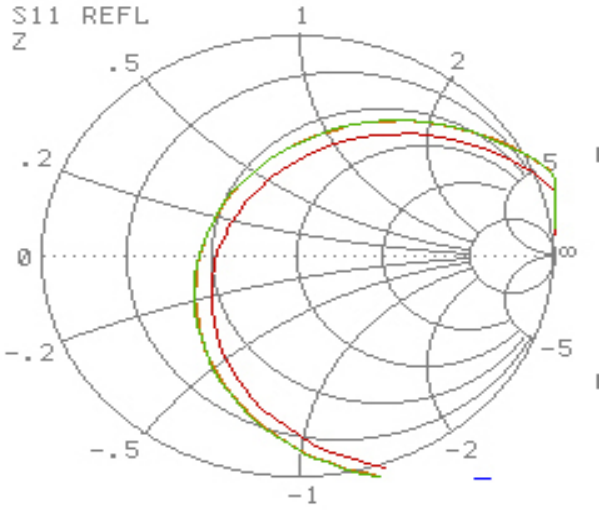

Fig. 24 Smith diagram in frequency band II, with: reference (red), etalon 0,02% (orange), mineral water sample (green).

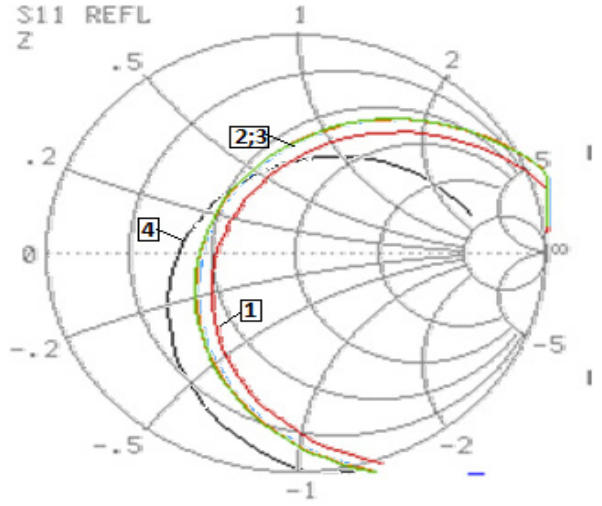

Fig. 25 Smith diagram in frequency band II, with: reference (red), etalon 0,005 % (blue), drinking water sample (black).

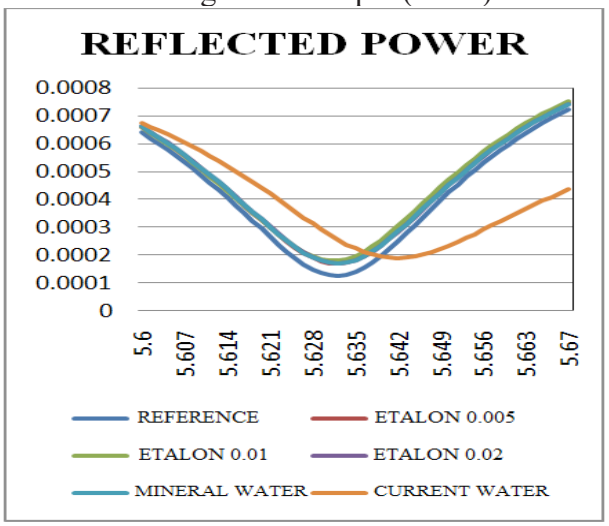

Fig. 26

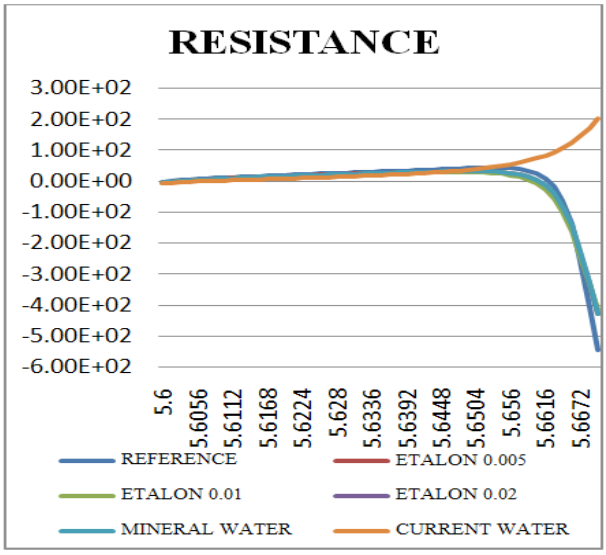

Fig. 27

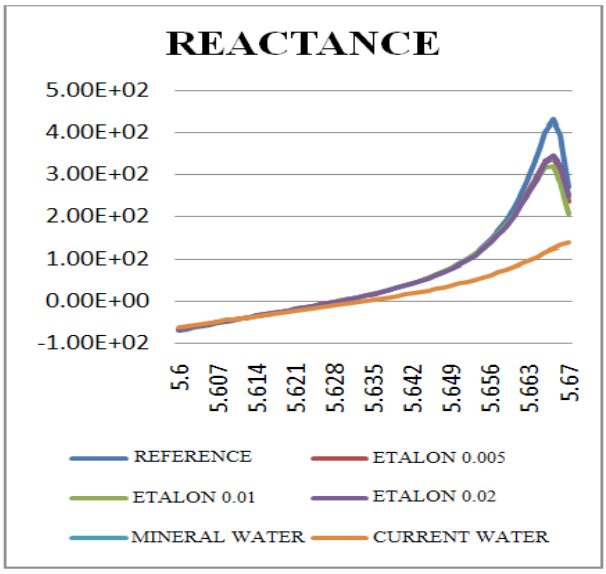

Fig. 28

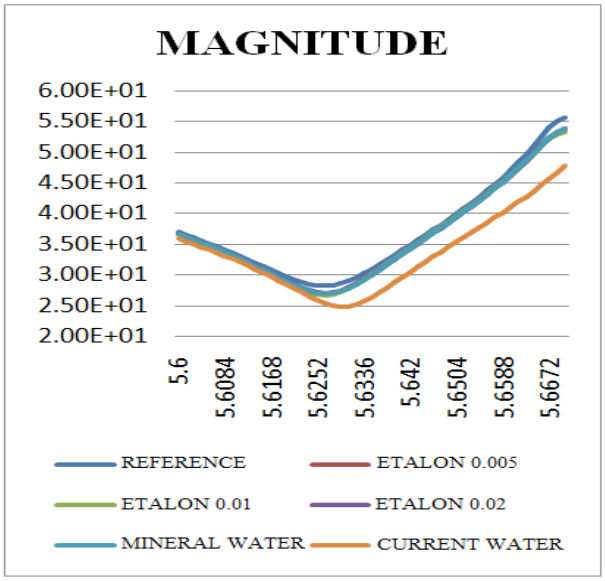

Fig. 29

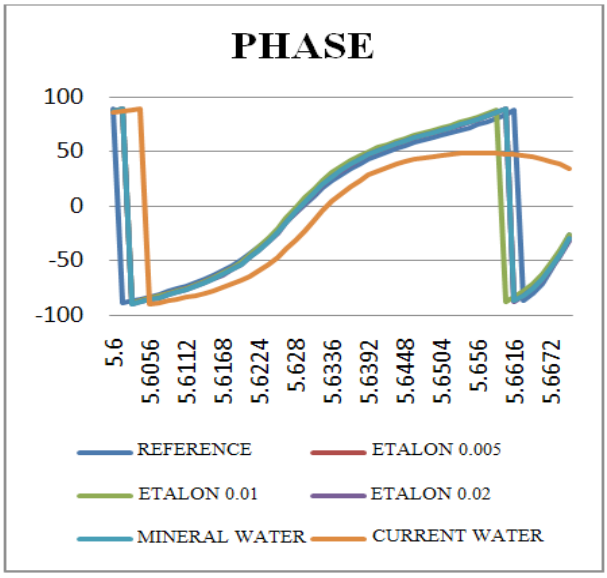

Fig. 30

CONCLUSIONS

This work is an extension of vector analysis, providing information about the the reflection coefficient based on the supply of data related to both the magnitude (general case) and phase. It is a novelty in the analysis, because the etalon does not have to be present, as a blank sample, in analyzing with spectral analyzer. Each test substance is introduced into the resonator antenna, data are collected and then introduced the new analyte.

After analyzing graphs of magnitude and phase, I noticed that mineral water sample approaching (as values) 200 ppm etalon, which indicates the presence of sodium chloride in the composition.

For drinking water, we noticed nonuniform behavior, keeping, largely, etalon of 50 ppm profile, but showing deviations from the rule beam, probably due to the presence of other compounds such as chlorine.

All measurements must be made under the same environmental conditions: at the same temperature, pressure, humidity.

An advantage of this analysis is a very small amount of analyte, tens-hundred parts per million, which shows a very high sensitivity of the analyzer, being able to identify traces of substance. It is a simple method that does not require long measurement, and allows both quantitative analysis (who told us about the concentration of sodium chloride in the two samples) and qualitative analysis (which confirmed the presence of sodium chloride in mineral water and drinking water samples).

This work opens the way towards a more complex analysis.

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