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Correlation between Scattering Matrix, Return Loss and Interface Reflection Loss in Nicolson Rose Wear Approximation

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Abstract. The phenomenon behind the absorption of electromagnetic waves by absorbing materials is resonance phenomenon. When there is a similarity between the value of the impedance of electromagnetic waves in the air and the impedance of the material, the absorption of energy by the material is maximized. The phenomenon is measured using an auxiliary instrument, namely the Vector Network Analyzer. This instrument is very effective for calculating the absorption value of electromagnetic waves. However, the Vector Network Analyzer instrument which is mostly available in Indonesian research institutions cannot directly display the reflection loss of the electromagnetic wave absorbing material. An effective method that is effective for calculating the absorption in electromagnetic wave absorbing material is Nicolson Rose Wear method. In this article, we design a computational tool based on Nicolson Rose Wear approximation to calculate the reflection loss values from scattering matrix and comparing it with return loss, which is often mistook as reflection loss.

Keywords: *Nicolson-Ross-Wear, Permeability, Permittivity, Reflection Loss*

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INTRODUCTION

Electromagnetic wave absorbance occurs when an electromagnetic wave from air enters a radar absorbing material. The absorption mechanism of electromagnetic waves is a resonance process between the impedance value, which are the ratio of the magnitude of electric field and magnetic field, of electromagnetic waves of the air and the impedance of the material [1]. If the impedance values of the two mediums are the same, maximum absorption will occur, known as matching impedance [2]. Since electromagnetic waves are a combination of electric and magnetic waves, the two values can vary significantly over even a small range of frequencies. If the permittivity and permeability of the complex are known at each frequency, the effect of EM waves on the material can be known [3].

In order to achieve necessary characteristics to function as an electromagnetic wave absorbing material, experimental research on radar absorbing materials involve material structure engineering of unit cell structure through partial atomic substitution [4]. The characterization of the material is carried out using an auxiliary instrument, namely the Vector Network Analyzer (VNA) [5]. However, most of the VNA instruments that are available in Indonesian research institutions only measures scattering matrix [6]

$$s = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix}, \tag{1}$$

where $|s_{11}|^2$ and $|s_{22}|^2$ are the reflection rates of incoming waves from the opposite sides, $|s_{21}|^2$ and $|s_{12}|^2$ are the transmission rates. The return loss of a sample is simply the logarithmic value of the reflection rates in dB [7].

$$\text{return loss} = 20\ln|s_{11}|. \tag{2}$$

This value is often misunderstood as reflection loss due to similar abbreviation [7]. Reflection loss is characterized by reflection rate Γ of the interface, which is related to the impedance of the

$$\text{reflection loss} = 20\ln|\Gamma|, \tag{3}$$

where $|\Gamma| < 1$.

However, reflection loss is associated with the reflection of only one side of the interface only, not of the whole sample. An effective method that is effective for calculating reflection loss from the absorption in electromagnetic wave absorbing material is Nicolson Rose Weir method [8].

This research aims to analyze those physical quantities from the measured scattering matrix using Nicolson Ross Weir algorithm. Furthermore, we develop a graphical user interface for easy utilization. This interface can be expected to support research and applications in the RADAR wave area [9].

COMPUTATIONAL METHODS

NRW Algorithm

Nicolson Ross Weir (NRW) is a calculation method to get the permeability and permittivity values from the scattering matrix [10]. This technique can be used on dielectric materials. This theory is used to analyze material scattering events and is related to the permittivity and permeability of the material [11]. While this method has advantages and disadvantages compared to other methods, it has fast convergence and can be used for wide range of materials. Table 1 lists the type of materials that are often used in NRW method

Table 1. Materials that can be measured using NRW method [12].

Materials	Length	Magnetic properties	Measurement methods	Speed	Accuracy
Lossy solids	Short	Non-magnetic	Transmission/ reflection line (TR)	Fast	Medium
Lossy solids	Short	Magnetic	TR	Fast	Medium
High temperature solids	Large / flat	Non-magnetic	Free space	Fast	Medium

The NRW method measure the reflection loss and reflection rate Γ

$$\Gamma = \frac{Z - Z_0}{Z + Z_0}, \tag{4}$$

from the resonance of the impedance in the air, which can be assumed to be equal to the impedance of vacuum $Z_0 \approx 377\Omega$ [13] and the impedance of the radar absorbing material $Z = Z_0\sqrt{\mu_r/\varepsilon_r}$, where μ_r and ε_r are relative permeability and permittivity, respectively. In NRW, Γ is related to the scattering matrix

$$\Gamma = x \pm \sqrt{x^2 - 1}, \tag{5}$$

$$x = \frac{s_{11}^2 - s_{21}^2 + 1}{2s_{11}} \tag{6}$$

This computational method is the following implemented in using the flowchart in Figure 1.

Beside reflection loss, we can also obtain μ_r and ε_r for material with known with d and cut-off wavelength λ_c.

$$\mu_r = \frac{1 + \Gamma}{\Delta(1 - \Gamma)\sqrt{\frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2}}}, \tag{7}$$

$$\varepsilon_r = \frac{\lambda_0^2}{\mu_r}\left(\frac{1}{\lambda_c^2} - \left(\frac{1}{2\pi d}\ln\left(\frac{1}{T}\right)\right)^2\right), \tag{8}$$

where,

$$\frac{1}{\Delta} = -\frac{1}{2\pi d}\ln T = -\frac{1}{2\pi d}\ln\frac{s_{11} + s_{21} - \Gamma}{1 - (s_{11} + s_{21})\Gamma} \tag{9}$$

These equations are implemented in a graphical user interface that can be accessed openly in azwaradam.com in experiment mode.

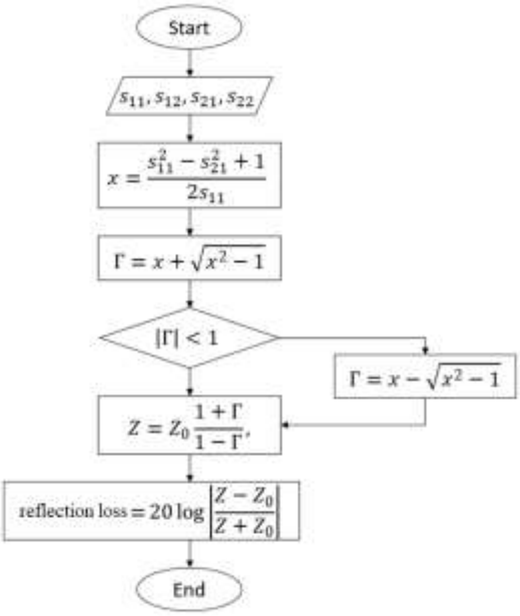

Figure 1. NRW algorithm for reflection loss computation.

RESULT AND DISCUSSION

In this experimental mode, before processing the material data that has been taken from the VNA, the program calibration is carried out first to ensure the program runs well. This calibration uses Teflon data where in this calibration the permeability and permittivity values are seen. The value of the permeability and permittivity is expected to be in accordance with the theory where the permeability value is close to 1 + 0.001i and the permittivity value is close to 2+0.001i [14].

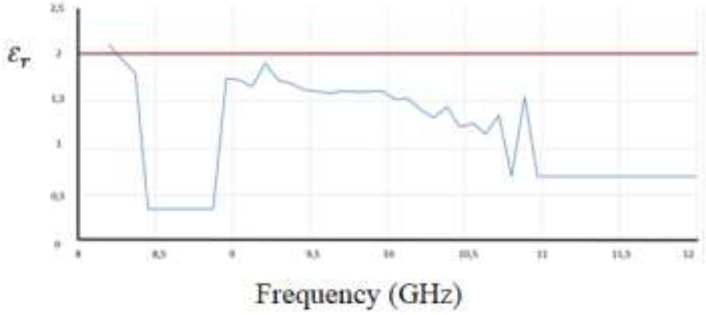

Figure 2. Teflon's permittivity curve as a function of frequency.

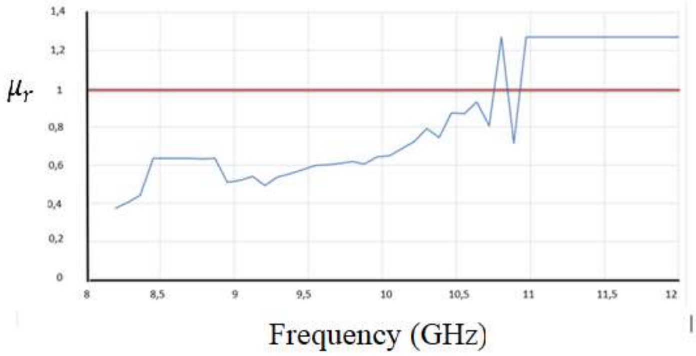

Figure 3. Teflon Permeability Curve on a frequency function.

The results of the calculation of permittivity and permeability can be seen in Figures 2 and 3, respectively. One can see that the value of relative permittivity is close to 2+0.001i. Similarly, the relative permeability is close to around 1+0.001i. The values are in accordance with the reference value for Teflon. At the frequency of 10 GHz to 12 GHz, it can be seen that the results of real and imaginary calculations of permittivity and permeability change. We can see that at the 12 GHz frequency there is a huge change. This happens because the value of the scattering parameter changes drastically at the peak frequency changes at 12 GHz. This is because the scattering value used by the VNA tool as the reflection loss value suddenly changes which of course will affect the calculation of permeability and permittivity.

After calibration, the interface was used to calculate the $BaFe_{12}O_{19}$ data. The measurement of the scattering parameter can be seen in Figure 4 which shows the reflection loss graph in the frequency function. It can be seen in the figure that the electromagnetic wave range of 8 GHz to 12 GHz is absorbed evenly, it is confirmed in the graph that there is a valley in the frequency range of electromagnetic waves. The frequency valley is formed, at around 9.3 GHz frequency. In this $BaFe_{12}O_{19}$ material, one peak is formed, this is similar to the wave crest in the experimental data plotted without taking into account the permeability and permittivity values first. The previous reflection loss value measurements are compared to value in Eq. (1) which is often used for rough estimate of reflection loss. Figure 4 show that our algorithm agrees well with experiment.

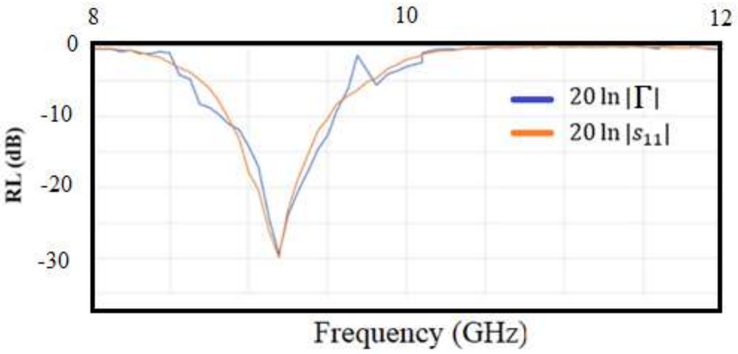

Figure 4. Reflection loss $= \mathbf{20\ln|\Gamma|}$ as a function of frequency of $BaFe_{12}O_{19}$. The value is compared with the value of return loss= $20\ln|s_{11}|$ that often use for rough estimation of Reflection Loss.

We further analyze the scattering matrix parameter value obtained from VNA of a composite material $BaFe_{12-x}Mn_{x/2}Ti_{x/2}O_{19}$. The composite material has two valleys in 8 Ghz, and 11.3 Ghz. From the reflection loss graphics of two materials, we can see that reflection loss obtained NRW calculation are consistent with Eq. (1)

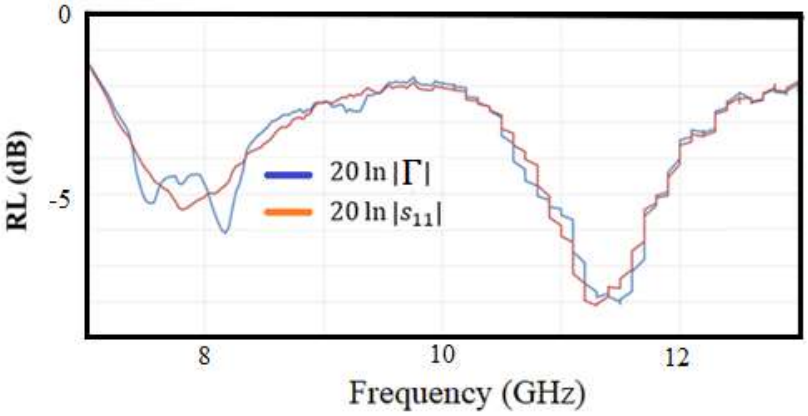

Figure 5. Reflection loss $=20\, ln|\Gamma|$ of a composite material $BaFe_{12-x}Mn_{x/2}Ti_{x/2}O_{19}$ as a function of frequency. The value is compared with the value of return loss= $20\, ln\, |s_{11}|$ that often use for rough estimation of reflection loss.

CONCLUSION

To summarize, we develop a graphical user interface to calculate reflection loss of radar absorbance material using Nicolson Ross Weir algorithm. By using scattering matrix obtained from VNA instrument, we can obtain the reflection loss as a function for frequency in radar absorbance range. The value is similar but not equal to return loss. The graphical user interface can be accessed openly on in azwaradam.com in experiment mode.

The system is validated with the results of the Teflon permeability which is 1+0.001i and the Teflon permittivity is 2+0.001i. The reflection loss value of the $BaFe_{12}O_{19}$ experimental data processed from the scattering data has the same graphic tendency as the program results when the frequency is in the range of 9.2 GHz.

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{USING} {TWO} {FLANGED} {RECTANGULAR} {WAVEGUIDES}," *Prog. Electromagn. Res.*, vol. 79, pp. 367–386, 2008, doi: 10.2528/pier07102405.

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