An Improved Technique of Dielectric-Property Determination Using Magnitudes of Associated Scattering Parameters of Two Different Coupled Parallel Dipoles

[#]Jhirat Mearnchu, Thanyalux Wanotayan, Waraporn Quested, Suthasinee Lamultree and Danai Torrungrueng

Department of Electrical and Electronic Engineering, Faculty of Engineering and Technology, Asian University, Chon Buri, 20260, Thailand

Email: jhiratm@asianust.ac.th, suthasineel@asianust.ac.th and dtg@asianust.ac.th

Abstract

This paper presents an improved technique of dielectric-property determination of a material under test using magnitudes of associated scattering parameters of two different coupled parallel dipoles to avoid possible non-unique solutions and to enhance the accuracy of predicted solutions. Measured results are plotted on the $\varepsilon_r'\varepsilon_r''$ plane, scaling with simulated magnitudes of associated scattering parameters, to determine ε_r' and ε_r'' of the material under test, where ε_r' and ε_r'' are the real and imaginary parts of its complex relative permittivity, respectively. It is found that non-unique solutions can be avoided using the improved technique, and the accuracy of predicted solutions can be practically improved using the additional information obtained from the improved technique.

Keyword : Coupled parallel dipoles, Dielectric-property determination, Magnitude measurement

1. Introduction

Non-destructive measurement is desirable for dielectric-property determination without destroying a material under test (MUT). Typical technology utilizes complex measurement requiring an expensive vector network analyzer [1]. Measurement of only magnitudes of appropriate quantities can provide an inexpensive system at the expense of more parameters to be measured; i.e., transmission and reflection coefficients [2]. This system enables an online detecting the state and degree of the hydration process in cement-based materials [3]. Since some applications require localized dielectric-property determination with compact measurement system, measurements of reflection and coupling coefficients should fulfill these requirements. Recently, a dielectric-property determination technique by measuring the magnitudes of the reflection and coupling coefficients of the coupled antennas has been proposed [4]. Simulations of *identical* coupled dipoles over a dielectric half space were illustrated and validated by experiments at 2.45 GHz. It was found that the proposed technique is effective for the problem of determination of the moisture content of paddy [5]. The accuracy of the moisture content depends on measured associated powers for the calculation of reflection and coupling coefficients. However, the proposed technique in [4] still suffers from possible non-unique solutions for the dielectric-property determination.

In this paper, an improved technique of the dielectric-property determination of an MUT of interest using magnitudes of associated scattering parameters of two *different* coupled parallel dipoles with appropriate configurations. Using additional information obtained from the improved technique, compared to the original technique in [4]-[5], it will be shown later that non-unique solutions can be avoided, and the accuracy of predicted solutions can be practically improved indeed.
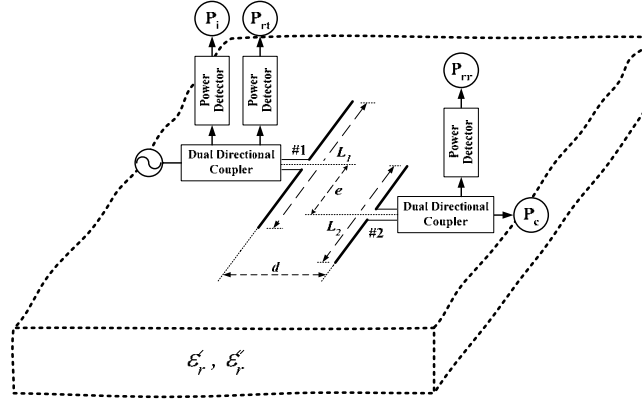
2. Improved Technique

Fig.1 Diagram of an improved measurement system.

Figure 1 shows an improved measurement system of the newly proposed technique. It consists of the two coupled dipoles of different lengths L_1 and L_2, of the dipoles #1 and #2 respectively, with the separated distance d. They are aligned as a side-by-side configuration with an offset from their centers of the distance e over a dielectric half space with (ε_r', ε_r''), where ε_r' and ε_r'' are the real and imaginary parts of its complex relative permittivity, respectively. The dipole #1 is excited by a signal generator via a dual directional coupler for measuring the incident power (P_i) and the reflected power (P_{rt}). Note that the quantity $\sqrt{P_{rt}/P_i}$ represents $|S_{11}|$ of the dipole #1, where S_{ij} are the associated scattering parameters. In Fig. 1, the dipole #2 couples electromagnetic fields transmitted by the dipole #1 in the presence of the dielectric half space. A dual directional coupler is installed at the input of the dipole #2 for measuring the coupled power (P_c). Note that the quantity $\sqrt{P_c/P_i}$ represents $|S_{21}|$. Similarly, when the dipole #2 is excited by a signal generator via a dual directional coupler for measuring the incident power (P_{i2}) and the reflected power (P_{r2}), the quantity $\sqrt{P_{r2}/P_{i2}}$ represents $|S_{22}|$. In this study, the system operates at 2.45 GHz and the length L_1 of the antenna #1 is equal to 5.7 cm. The antenna separation d is fixed at $\lambda/8$, where λ is the wavelength in free space ($\lambda = 12.24$ cm). Using the IE3D simulator [6], the magnitudes of the associated scattering parameters of $|S_{11}|$, $|S_{21}|$ and $|S_{22}|$ for various values of ε_r' and ε_r'' are computed. In addition, the contour plots of $|S_{11}|$ and $|S_{21}|$, including $|S_{22}|$ and $|S_{21}|$, in the $\varepsilon_r'\varepsilon_r''$ plane for each considered case are illustrated in the next section.

3. Numerical Results

In this section, simulated magnitudes of associated scattering parameters are computed and appropriately plotted to determine the complex permittivity of an MUT of interest. There are three considered cases as tabulated in Table 1; i.e., the two identical dipoles with no offset distance, the two different dipoles with no offset distance, and the two different dipoles with $\lambda/4$ offset distance for Case 1, Case 2 and Case 3, respectively. The ranges of ε_r' and ε_r'' of interest are varied from 1.0 to 10.0 with the increment of 0.5, and from 0.10 to 2.00 with the increment of 0.05, respectively.

Table 1: Simulated conditions of two dipoles.

Case	e	L_1	L_2
1	0	λ/2	λ/2
2	0	λ/2	3λ/4
3	λ/4	λ/2	3λ/4

Figure 2 illustrates the contour plots of $|S_{11}|$ and $|S_{21}|$, including $|S_{22}|$ and $|S_{21}|$, in the $\varepsilon_r'\varepsilon_r''$ plane for Case 1, which is the same condition as in [4]. It is found that the $|S_{11}|$ contour in Fig.2a) is identical to the $|S_{22}|$ contour in Fig.2b) due to the fact that the two dipoles for Case 1 are *identical*. For small values of ε_r', the $|S_{11}|$ and $|S_{22}|$ contours possibly intersect the $|S_{21}|$ contour twice resulting non-unique solutions for (ε_r',ε_r''). Thus, it is interesting to modify the dipole configuration for Case 1 to gain additional information for solving non-unique problems as shown in Cases 2 and 3 for illustration purpose.

The simulated results of Case 2 are shown in Fig.3, where the $|S_{11}|$ and $|S_{22}|$ contours are different due to the fact that the two dipoles are *different* for this case. Note that the $|S_{22}|$ contour provides additional information compared to that of Case 1. In Fig.3a), it is found that the $|S_{11}|$ contour seems to intersect the $|S_{21}|$ contour only one point resulting the unique solution for (ε_r',ε_r''). In addition, the $|S_{22}|$ contour intersects the $|S_{21}|$ contour only one point resulting the unique solution for (ε_r',ε_r''). This additional information associated with the $|S_{22}|$ contour can contribute to more accurate solutions for estimating values of (ε_r',ε_r'') in practice as well due to unavoidable noises in measurements.

The simulated results of Case 3 for the two different dipoles with λ/4 offset distance are shown in Fig.4. Like Case 2, the $|S_{11}|$ and $|S_{22}|$ contours are different as well. In Fig.4a), it is found that the $|S_{11}|$ contour possibly intersect the $|S_{21}|$ contour twice resulting non-unique solutions for (ε_r',ε_r'') for small values of ε_r'. However, the $|S_{22}|$ contour intersects the $|S_{21}|$ contour only one point resulting the unique solution for (ε_r',ε_r'') as shown in Fig.4b). Thus, the additional information associated with the $|S_{22}|$ contour can provide the unique solution. From these three considered cases, it is found that Case 2 is the most suitable case since non-unique solutions can be avoided, and the accuracy of predicted solutions can be improved in practice using the additional information on the $|S_{22}|$ contour.
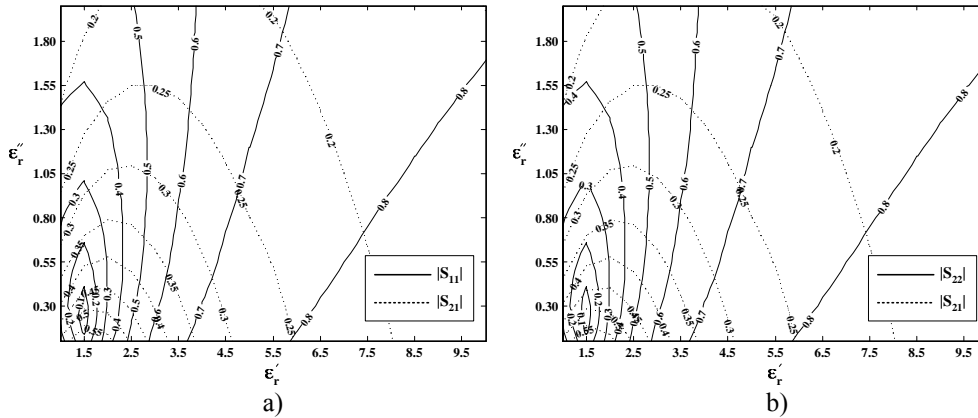

Fig.2 Numerical results of Case 1.

4. Conclusions

An improved dielectric-property determination technique is proposed using magnitudes of associated scattering parameters of two different coupled parallel dipoles. To determine ε_r' and ε_r'' of an MUT, measured results are plotted on the $\varepsilon_r'\varepsilon_r''$ plane, scaling with simulated magnitudes of associated scattering parameters (S_{11}, S_{21} and S_{22}). It is found that non-unique solutions can be avoided using the improved technique indeed, and the accuracy of predicted solutions can be improved in practice using the additional information on the $|S_{22}|$ contour. In the future, measurements will be conducted for suitable cases to uniquely determine ε_r' and ε_r'' of an MUT of interest.
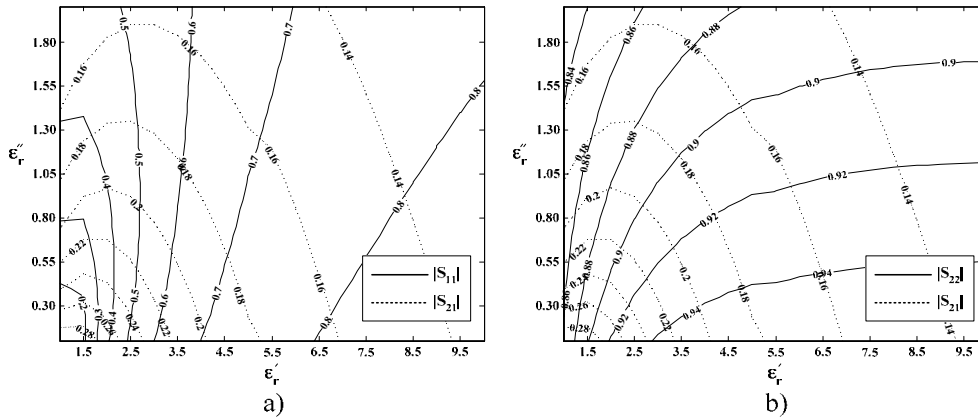
Fig.3 Numerical results of Case 2.
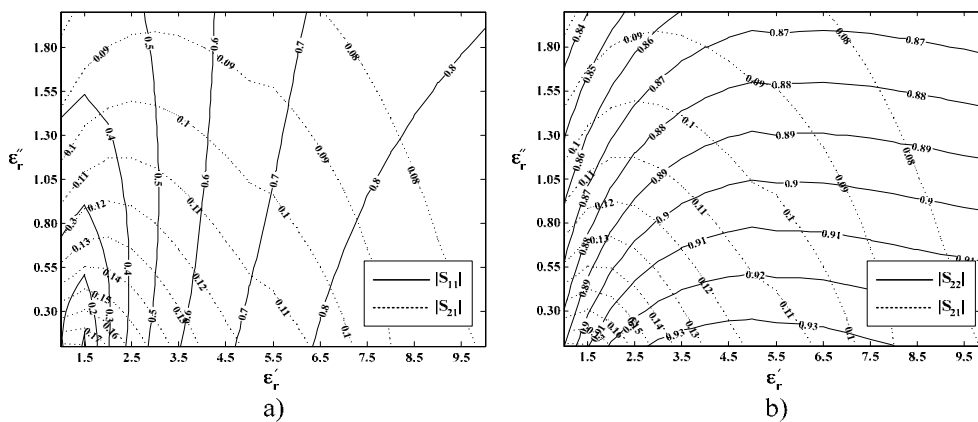
Fig.4 Numerical results of Case 3.

Acknowledgments

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