http://dx.doi.org/10.7236/JIWIT.2012.12.2.199
JIWIT 2012-2-25

평행판 도파관을 이용한 유전율 측정 방법

A Permittivity Measurement of Dielectric Slabs Using a Parallel Plate Waveguide

조규영[*], 박위상[**]

Gyo-Yeong Cho, Wee-Sang Park

요 약 평행판 도파관에 진행하는 TEM mode를 이용한 평판형 유전체의 유전율을 측정하는 방식을 소개한다. 이는 양 옆이 열린 구조적 장점으로 실험 절차 및 측정 샘플의 가공이 매우 간편한 장점이 있다. 샘플의 유무에 따라 변화하는 도파관 내에서 전파하는 TEM mode의 위상 속도의 차이를 전자기적으로 해석하였고 이를 이용하여 유전체판의 유전율을 측정하였으며, 샘플에 대한 측정 결과는 기존에 알려진 유전율과 일치하였다.

Abstract This paper introduces a simple new procedure approach to determine the permittivity of dielectric slabs. The method uses a parallel plate waveguide which supports a TEM mode. The presence of the dielectric slab placed at the bottom of the waveguide makes the speed of the TEM wave slower. The relationship between the change of the speed and the permittivity of the dielectric slab allows the determination of the permittivity. The relationship is analyzed electromagnetically, and the results of measurements are in good agreement with the analysis.

Key Words : Permittivity measurement, parallel plate waveguide, simple procedure, phase velocity

Ⅰ. Introduction

The measurement of permittivity of dielectric material is an important task in microwave engineering for a wide range of applications. A variety of permittivity measurement methods have been proposed in the past[1]-[7]. For wideband measurement, the transmission/reflection method is generally employed[2]-[3]. Such techniques measure the transmission and reflection coefficients for a section of transmission line filled with a dielectric sample. Resonant methods are more reliable when the characteristic of the sample is needed in a narrow band with high accuracy[4]-[7]. There, the permittivity of a sample is evaluated from the shift of resonant frequency. Both procedures require large amounts of time to prepare the sample in a regular geometry and to install and uninstall it in the transmission line or resonant cavity, etc.

The measurement technique introduced in this letter greatly reduces such time. It employs a parallel plate waveguide (PPW). When a dielectric slab is inserted in the PPW, the transmission phase (f_{21}) is delayed as a

[*]정회원, 공주대학교 대학원 정보통신공학과
[**]종신회원, 공주대학교 전기전자제어공학부
접수일자 2012.1.17, 수정일자 2012.3.8
게재확정일자 2012.4.13
Received: 17 January 2012; Revised: 8 March 2012
Accepted: 13 April 2012
Corresponding Author: zombi1945@postech.ac.kr
Dept. of electrical engineering, POSTECH, Korea

function of the thickness, length, and permittivity of the sample. Two advantages of this method are as follows. First, the size of sample can be chosen with a wide range of options. Because the length is considered in the analysis it is possible to experiment with any length of sample. The thickness is also considered if it is assumed that the thickness is much thinner than the height of the PPW. Besides, the width does not affect the experimental results if the sample is wider than the PPW. Second, installing and uninstalling the sample are less complicated—it is unnecessary to handle the PPW to insert or remove the sample—because both sides of the PPW are open. Thanks to the above characteristics, the technique could be employed even in the automated systems to measure the dielectric slab.

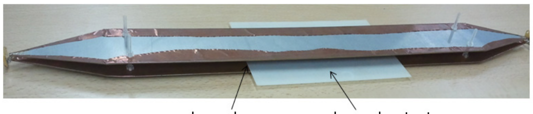

그림 1. 유전율 측정을 위한 실험 구성
Fig. 1. Experimental setup to measure the permittivity of dielectric sample

II. Permittivity Estimation Theory

The permittivity of a dielectric sample is determined by simple comparison of the measured f_{21} of the PPW with that of the PPW With Dielectric slab (PWD). If sample is much thinner than the height of PPW, no energy is stored at the boundary (Fig. 1), therefore the difference of f_{21} (Df) of the PPW and the PWD is characterized only by the propagation constant and the length (l_s) of the sample. Equation (1) expresses the relation. Here, the propagation constant of PPW (b_{PPW}) can be easily calculated by [8], but the propagation constant of PWD (b_{PWD}) is unknown.

$$\Delta\phi = \phi_{21,PPW} - \phi_{21,PWD} = (\beta_{PWD} - \beta_{PPW})\ell_s \ [rad] \quad (1)$$

Since the assumption of thin sample, it can also be assumed that the propagation mode in the PWD is TEM. Therefore the b_{PWD} is expressed by (2). Here, the effective permittivity of the inhomogeneous media in the PWD (e_{eff}) is unknown.

$$\beta_{PWD} = \omega\sqrt{\mu\varepsilon_{eff}} \quad (2)$$

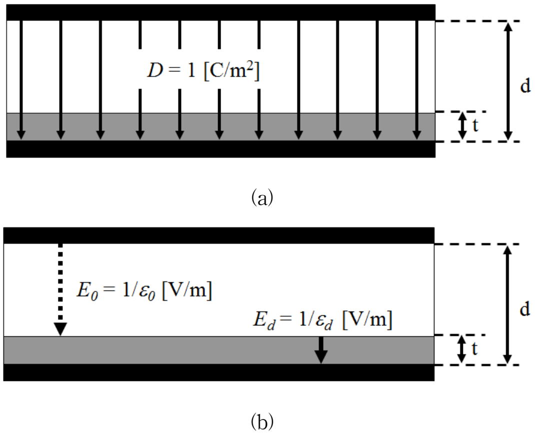

그림 2. 유전체판이 삽입된 평행판 도파관 횡단면의 (a)전속 밀도와 (b)전계강도
Fig. 2. (a)Electric flux density and (b)electric field intensity in the cross-sectional view of parallel plate waveguide with dielectric slab

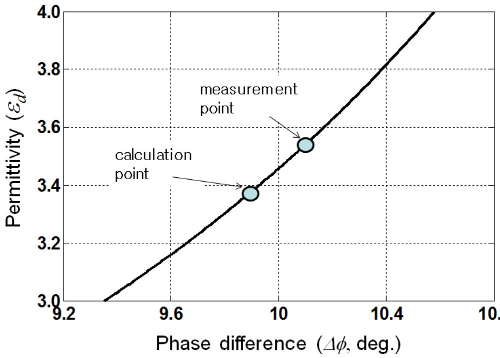

그림 3. 유전율 측정 곡선
Fig. 3. Measurement curve applying the estimation theory

In order to get the e_{eff}, Gauss' law is employed at the cross section of PWD (Fig. 2). If the electric flux density (D)between two plates is 1 C/m^2 (Fig. 2a), the electric field intensity in the air (E_0)is $1/e_0$ V/m and the electric field intensity in the dielectric material (E_d)is$1/e_d$ V/m (Fig 2b), where e_0 and e_d are the permittivity of air and the dielectric, respectively. The average electric field intensity (E_{avg})between two plates can be calculated by (3). Then the e_{eff} can be calculated by (4) applying the relation between D and E_{avg}.

$$E_{avg} = [E_0(d-t) + E_d t]/d \quad (3)$$

$$\varepsilon_{eff} = D / E_{avg} \quad (4)$$

Applying above equations, it is possible to draw a graph which shows the relation between Df and e_d with fixed sample thickness and length (Fig. 3). The thickness and length of sample for drawing this graph are 0.816 mm and 20 cm, respectively.

Ⅲ. Experimental Validation

The PPW employed for this experiment is shown in Fig. 1. The height, width, and length are 10 mm, 50 mm, and 350 mm, respectively. The length of the taper for matching is 80 mm. Copper tape is attached to an aluminum base structure. (2n+1)/2 wavelength resonances cause the local minimums (Fig. 4). The experiment was performed at 1.37 GHz with an insertion loss of 1.7 dB, as the higher frequency produces a larger phase difference.

Three dielectric slab samples were measured to validate our method. The permittivity(e_d), the thickness(t), and the length(l_d) of the samples are shown in Table I. The names F, T, and R mean FR4, TMM6, and RO4003C samples, respectively, and the numbers mean the length of the samples in cm.

The f_{21} of the PPW and PWDs around 1.37 GHz are shown in Fig. 5. Measured Df with R20 was 10.11^o, which means the measured permittivity is 3.55 (Fig.3).

The results and errors are shown in Table II. Calculated Df are calculated from the e_d in Table I. Because the permittivity of FR4 is not fixed at a specific value, the error for F10 is not shown but the measured value of permittivity is in the region typical FR4 permittivity. The results for T15.8 and R20 also agree with the specifications. It is forecasted that the error is from not considering the fringing field effect.

표 1. 실험 파라미터
Table 1. Specifications of Dielectric slab Sample

	F15	T15.8	R20
e_d	4~4.5	6.065 ± 0.005	3.375 ± 0.015
t (mm)	0.407	0.645	0.816
l_d (cm)	15.0	15.8	20.0

표 2. 계산 및 측정 결과 비교
Table 2. Comparison of Calculations and Measurement Results

	F15	T15.8	R20
Calculated $\Delta\phi$ (deg.)	-	7.31	9.90
Measured $\Delta\phi$ (deg.)	3.96	7.33	10.11
Measured ε_d	4.32	6.13	3.55
Error (%)	-	1.1	5.2

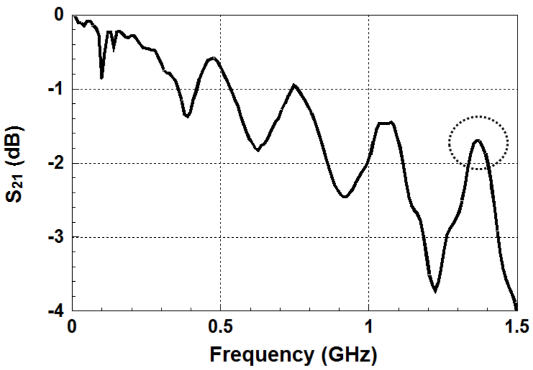

그림 4. 평행판 도파관의 전달 특성
Fig. 4. Transmission characteristic of parallel plate waveguide

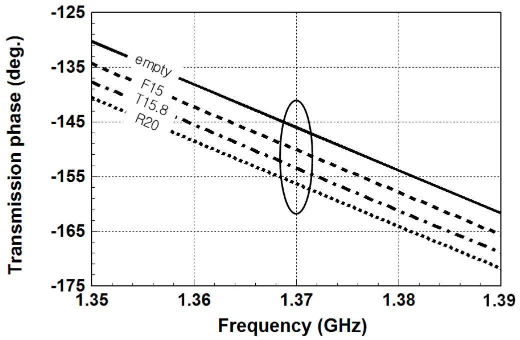

그림 5. 삽입된 유전체판에 따른 위상 변화
Fig. 5. Measured phases of parallel plate waveguide with and without three samples.

Ⅳ. Conclusion

A new approach to measure the permittivity of dielectric slabs using a PPW has been presented. The measurement procedure is very simple and sample preparation is less complicated. The theory has been verified through experimental measurements. This theory can also be applied to measure the thickness of dielectric material of which permittivity is known[9]. Future work should consider broad band measurement applying some matching techniques for PPW, such as a double sided parallel strip line[10], and error reduction through fringing field analysis.

REFERENCES

[1] Dae-Woong Woo, Dong-Ryul Shin, Jeong-Pyo Kim, Gi-Ho Kim, Jeong-Keun Ji, Won-Mo Seong, Wee-Sang Park, "Bandwidth analysis of a jerusalem AMC based on equivalent medel," *IWIT*, vol. 10, no. 5, pp. 7-12, Oct, 2010

[2] A. M. Nicolson and G. F. Ross, "Measurement of the intrinsic properties of materials by time domain techniques," *IEEE Trans. Instrum. Meas.*, vol. 19, no. 4, pp. 377-382, Nov. 1970

[3] J. Baker-Jarvis, E. J. Vanzura, and W. A. Kissick, "Improved techniques for determining complex permittivity with the transmission/reflection method," *IEEE Trans, Microw. Theory Tech.*, vol. 38, no. 8, pp. 1096-1103, Aug, 1990

[4] G. Annino, M. Cassettari, I. Longo, and M. Martinelli, "Whispering gallery modes in a dielectric resonator: Characterization at millimeter wavelength," *IEEE Trans. Microw. Theory Tech.* Vol. 45. No 11. pp. 2025-2034, Nov. 1997

[5] J. Krupka, K. Derazkowski, B. Riddle, and J. Baker-Jarvis, "A dielectric resonator for measurements of complex permittivity of low loss dielectric materials as a function of temperature," Meas. Sci. Technol., vol. 9, pp. 1751-1756, 1998

[6] M. D. Janezic, and J. Barker-Jarvis, "Full-wave analysis of a split cylinder resonator for nondestructive permittivity measurements," *IEEE Trans. Microw. Theory Tech.* Vol. 47. No 10. pp. 2014-2019, Oct. 1999

[7] M. D. Janezic, E. F. Kuester, and J. Barker-Jarvis, "Broadband complex permittivity measurements of dielectric substrates using a split-cylinder resonator," *2004 IEEE MTT-SDigest*, pp. 1817-1820, June 2004

[8] David M. Pozar, *Microwave Engineering.* 3rd Ed., NewYork: Wiley, 2005, ch. 3

[9] S. G. Kim and K. Chang, "Ultra wide-band transitions and new microwave components using double-sided parallel-strip lines," *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 9, pp. 2148 - 2152, Sep. 2004

[10] Sung-Jin Muhn, Wee-Sang Park, "Regression progress to evaluate metal scale thickness using microwave," *IWIT*, vol. 10, no. 5, pp. 1-6, Oct, 2010

※ ACKNOWLEDGMENT : This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2010-0000491) and the Brain Korea 21 Project in 2010.

저자 소개

조 규 영(정회원)

- 2008년 2월: 경북대학교 전자전기컴퓨터학부 (공학사)
- 2008년 3월 ~ 현재: 포항공과대학교 전자전기공학과 통합과정

<주관심분야 : Waveguide, electro magnetic measurement, coupling analysis>

박 위 상(정회원)

- 1974년 2월: 서울대학교 공과대학 전자공학과 (공학사)
- 1982년 6월: University of Wisconsin – Madison 전자공학과 (공학석사)
- 1986년 8월: University of Wisconsin – Madison 전자공학과 (공학박사)
- 1984년 1월 ~ 1986년 8월: University of Wisconsin –Madison, TA 및 RA
- 1986년 8월 ~ 현재: 포항공과대학교 전자전기공학과 교수

<주관심분야 : Small metamaterial antennas, antenna optimization, frequency selective surfaces, coupling of guided waves, wireless power transfer>