A Low-Cost Method to Evaluate Absorber Reflectivity Using an Antenna with a Small Radiating Aperture and Frequency-Domain Instrument

Soon-Soo Oh and Young Hwan Lee

We propose a way to measure the absorber reflectivity at a low cost. Only one simple antenna with a small radiating aperture and a frequency-domain instrument are utilized. The previously used equation for calculating the reflectivity of an absorber is inaccurate, and, therefore, a new equation is derived based on multiple reflection analysis and three test models. Notably, the reflection coefficient of the antenna is included in the derived equation. The accuracy of the proposed method is proven through simulation and measurements. It can be easily applied to a product examination by absorber manufacturers and customers owing to its advantages of simplicity, cost effectiveness, and non-cutting examination.

Keywords: Absorber, reflectivity, multiple reflection analysis, anechoic chamber, antenna measurement.

I. Introduction

As wireless communication services have developed, the use of absorbing material has increased, such as in the case of the wall attachments in anechoic chambers. The main factor in the performance of an absorber is the absorption rate, that is, the reflectivity [1]. It is recommended that all absorbers be evaluated before delivery from the factory to the customer. In many cases, the customer also wants to check the performance of the absorber.

Manuscript received July 3, 2013; accepted Aug. 26, 2013.
This research was funded by the MSIP (Ministry of Science, ICT & Future Planning), Korea in the ICT R&D Program 2013.
Soon-Soo Oh (phone: +82 62 230 7061, ssoh@chosun.ac.kr) was with the Broadcasting & Telecommunications Media Research Laboratory, ETRI, Daejeon, Rep. of Korea, and is now with the Department of Electronic Engineering, Chosun University, Gwangju, Rep. of Korea.
Young Hwan Lee (yhwan@etri.re.kr) is with the Broadcasting & Telecommunications Media Research Laboratory, ETRI, Daejeon, Rep. of Korea.

Three test methods of reflectivity are the arch system method, the free-space method, and the enclosed system method. In the arch system method, two antennas and an arch mechanical structure are used [1]-[5]. The two antennas are placed in parallel on the arch mechanical structure, and the absorber sample is placed on the bottom side with the separation distance being half of the far-field distance. At a few hundred MHz, this far-field distance and the sample size are critical problems. Even at a few GHz, two flared horns with large aperture should be provided [4].

The free-space method is based on a technique that compares the reflection coefficient for the metal plate to the reflection coefficient for the absorber [2]. This method requires a far-field distance and a time-domain measurement system [2], [5] or a network analyzer with a time-domain gating function [4], [6]. However, these instruments are financially burdensome to the examiner with a small budget.

The enclosed system method contains the absorber inside the waveguide-type or coaxial-type transmission [3]. This method ensures higher accuracy, but the manufacturing required to execute the method is expensive. Furthermore, the waveguide-type method has a narrow bandwidth owing to the cutoff frequency of the waveguide. The coaxial-type transmission has broadband performance, but the central part of the sample should be cut, which is inappropriate for an all-product examination.

In this letter, we propose a method to evaluate microwave absorbers at a low cost and without cutting the sample. This letter is an extension of the work in [7]. Specifically, this study includes a parametric study and experiment results. The real test results are very important since the simulation results can

 © 2013 ETRI
http://dx.doi.org/10.4218/etrij.13.0213.0314

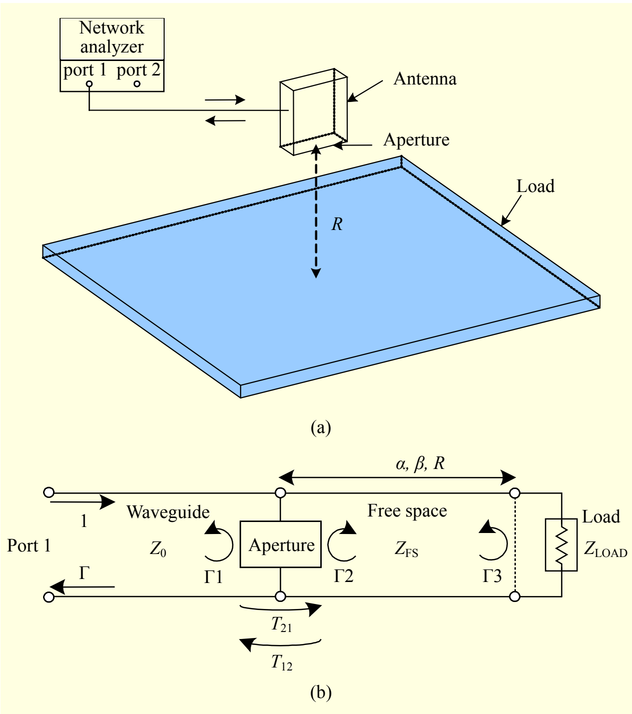

Fig. 1. Proposed method used to evaluate absorber reflectivity: (a) configuration and (b) equivalent circuit.

sometimes be incorrect due to incorrect settings. A simple antenna, such as an open-ended waveguide with a small-sized aperture, is utilized in the frequency domain. This configuration results in a smaller far-field distance and absorber size. The evaluation equation is derived from a multiple-reflection analysis. The simulation and experiment results prove its accuracy.

II. Theory

The configuration of the proposed method is shown in Fig. 1(a). An open-ended waveguide antenna is used. The network analyzer is connected to the antenna and sends an electromagnetic wave and collects the reflected wave in the frequency domain. Here, a gating function is not required. The absorber is placed at separation distance R. This distance is much smaller than that for a flared-horn antenna.

Figure 1(b) shows an equivalent model of the multiple reflections from the antenna aperture through free space and the load. Γ_1 and Γ_2 are the reflection coefficients of the aperture, with $\Gamma_2 = -\Gamma_1$. In addition, T_{21} and T_{12} are the transmission coefficients of the aperture, and Z_o, Z_{FS}, and Z_{Load} represent the impedance of the waveguide, the free space, and the load, respectively. In Fig. 1(b), α is the attenuation from the free-space propagation, and β is the propagation constant. Because the aperture and absorber are not perfectly matched to the free space, there are multiple reflections. This phenomenon is similar to that of multiple reflections existing between a mismatched generator and load [8], [9]. From the model shown in Fig. 1(b), we derive a new equation and establish the three test models since three unknowns are found in the derived equation, as follows. The reflection coefficient Γ can be written from a multiple-reflection analysis [8], [9].

$$\Gamma = \frac{\Gamma_1 + \Gamma_3 \exp(-j2\beta R)\exp(-2\alpha R)}{1+\Gamma_1\Gamma_3 \exp(-j2\beta R)\exp(-2\alpha R)}, \tag{1}$$

using the following relationship:

$$\Gamma_1 = \frac{Z_{FS}-Z_0}{Z_{FS}+Z_0},\ \Gamma_2 = -\Gamma_1,\ \Gamma_3 = \frac{Z_{LOAD}-Z_{FS}}{Z_{LOAD}+Z_{FS}},$$
$$T_{21} = 1+\Gamma_1,\quad T_{12} = 1+\Gamma_2.$$

In (1), there are three unknown values (Γ, Γ_1, and Γ_3), and, thus, three simultaneous equations are required. The parameters α, β, and R in (1) are common factors and thus disappear after substitution. In this letter, three test models are proposed by placing an air, perfect electric conductor (PEC), or absorber as a load, and the resultant reflection coefficients for each model are Γ_{air}, Γ_{pec}, and Γ_{abs}. The coefficient Γ_{air} can be obtained when the antenna is exposed to air without any material. Γ_{pec} is the reflection coefficient when PEC is used as a load, and Γ_{abs} is the reflection coefficient when the absorber is present. Now, the three simultaneous equations obtained from the test model can be written as

$$\Gamma_{air} = \Gamma_1, \tag{2-1}$$

$$\Gamma_{pec} = \frac{\Gamma_1 - \exp(-j2\beta R)\exp(-2\alpha R)}{1-\Gamma_{1\exp(-j2\beta R)\exp(-2\alpha R)}}, \tag{2-2}$$

and

$$\Gamma_{abs} = \frac{\Gamma_1 + \Gamma_3 \exp(-j2\beta R)\exp(-2\alpha R)}{1+\Gamma_1\Gamma_3 \exp(-j2\beta R)\exp(-2\alpha R)}, \tag{2-3}$$

where Γ_3 is 0 and –1 for air and PEC, respectively. The manipulation of (2-1), (2-2), and (2-3) leads us to a final expression for the absorber reflectivity:

$$\text{Reflectivity} = \Gamma_3 = -\frac{\Gamma_{abs}-\Gamma_{air}}{\Gamma_{pec}-\Gamma_{air}} \times \frac{1-\Gamma_{pec}\Gamma_{air}}{1-\Gamma_{abs}\Gamma_{air}}. \tag{3}$$

If the antenna reflection coefficient Γ_{air} is very small, (3) can be reduced to the previously used equation for the absorber reflectivity [2]:

$$\text{Reflectivity} = \Gamma_3 = -\frac{\Gamma_{abs}}{\Gamma_{pec}}. \tag{4}$$

However, if Γ_{air} is large, (4) shows a larger error, as will be demonstrated in the following section.

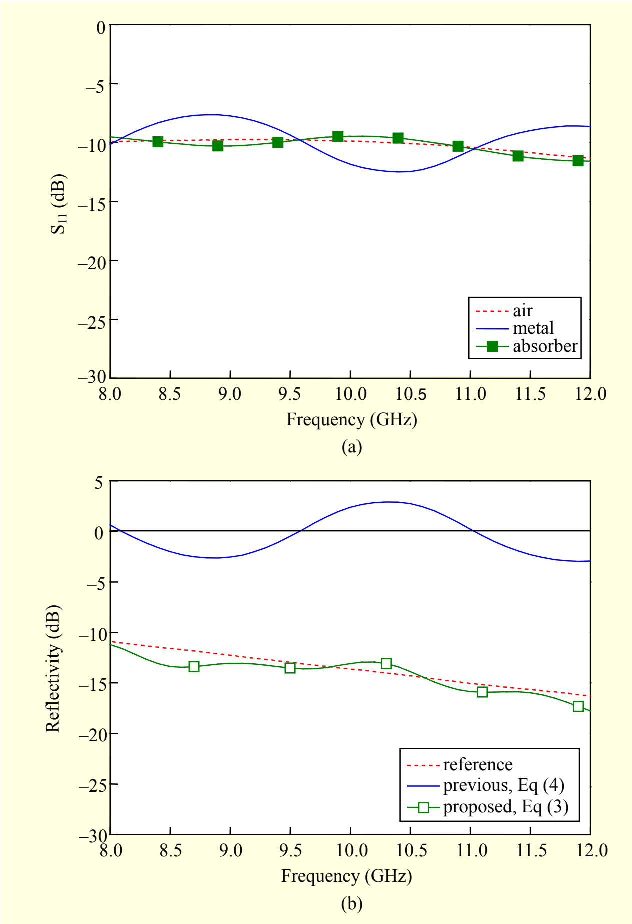

Fig. 2. Simulation results: (a) reflection coefficient and (b) reflectivity.

III. Simulation and Experiment Results

The full-wave electromagnetic simulations are performed with the aid of commercial software Ansys HFSS. The absorber has a permittivity of ε_r=1.5, permeability of μ_r=1.5, electric loss tangent of δ_e=0.5, and magnetic loss tangent of δ_m=0.5. The shape of the absorber is flat. The lateral size of the absorber sample is 150 mm × 150 mm, and the thickness is 5 mm. An open-ended waveguide is chosen for the antenna, with aperture dimensions of 22 mm × 10 mm.

The separation distance R between the antenna and the metal plate or absorber is 50 mm. Here, the reference plane of the antenna is the end of the radiating aperture. The reference plane of the flat absorber is the front end of the absorber. Usually, the back of the absorber is with the metal plate. If the absorber is cone-shaped, the reference plane is the end of the tip since the electromagnetic wave starts to be absorbed at this position.

Figure 2(a) shows the simulated results for the reflection coefficient S_{11}. Instead of PEC, a good metal plate is utilized. Since multiple reflections exist between the poorly matched antenna and the closely placed metal, S_{11} of the antenna for the metal has a large ripple. Therefore, as shown in Fig. 2(b), the reflectivity based on the conventional (4) shows a ripple and surpasses 0 dB at around 10.5 GHz in an unusual way. Meanwhile, the proposed (3) shows a similar curve as the reference. Here, the reference curve is obtained from an artificial model assuming perfect electric conductive sheets vertical to the electric fields and perfect magnetic conductive sheets vertical to the magnetic fields.

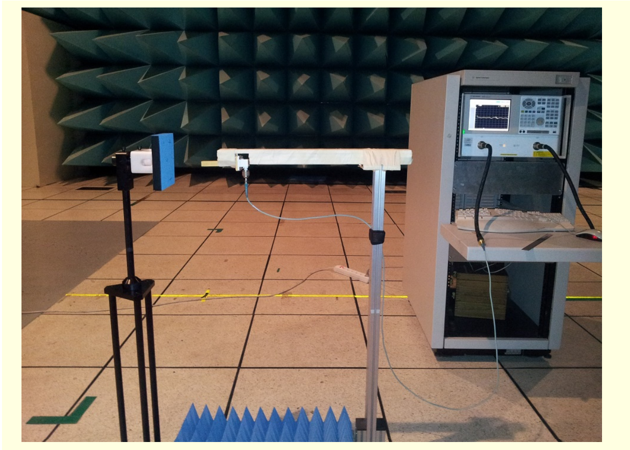

Fig. 3. Experimental setup for absorber reflectivity.

The proposed method is also verified experimentally, as shown in Fig. 3. A flat absorber with a thickness of 21 mm and an area of 150 mm × 150 mm is mounted on a supporting metal plate. A coaxial-to-waveguide adaptor (model number WGA-90N) with a small aperture is placed in front of the absorber. The adaptor is connected to port 1 of the network analyzer, as shown in Fig. 3.

The S_{11} values of the three test models are measured and plotted in Fig. 4(a), where R=20 mm. At around 10 GHz, the value for the metal is lower than that for the absorber. Therefore, as shown in Fig. 4(b), the reflectivity using (4) strangely shows values greater than 0 dB. Meanwhile, the reflectivity curve using (3) shows similar results to the reference value. Here, the reference curve is obtained using the horn and time-gating function.

Figure 5 shows the experiment results of reflectivity versus distance R wherein the value of R is 20 mm, 50 mm, and 100 mm. The curves are similar. However, as R increases, the measured reflectivity deviates more compared with the reference. The reason for this is that the reflected amount of power to the absorber or metal plate becomes weak and sensitive to the noise as R increases. In terms of the theoretical approach, the proposed method can be applied to the pyramidal absorber, but the sensitivity of the experimental environment and apparatus should be carefully treated.

Another reason for the error is the imperfect alignment

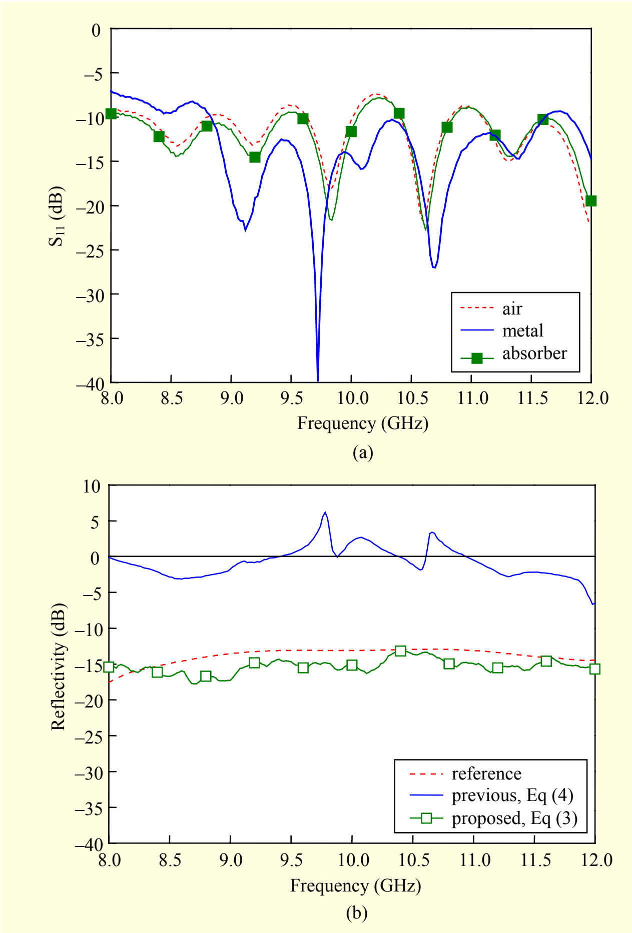

Fig. 4. Experiment results: (a) reflection coefficient and (b) reflectivity.

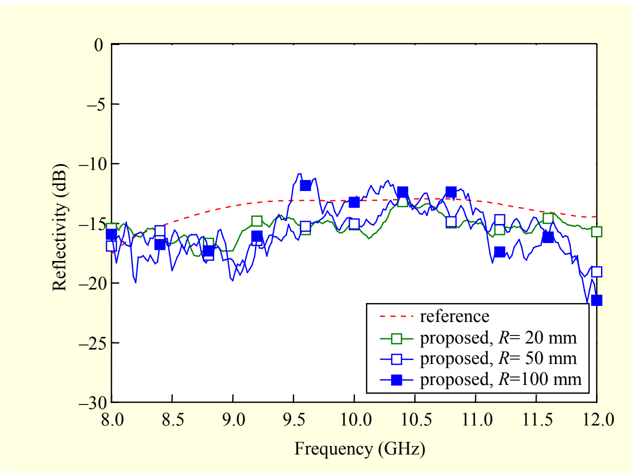

Fig. 5. Reflectivity vs. distance R between antenna and absorber by moving absorber backward in experiment.

of the measurement planes between the horn and absorber or metal plate since we move the sample manually. An advanced mechanical alignment system could remove the deviation.

IV. Conclusion

We described a low-cost method for evaluating an absorber using a small-sized aperture antenna and frequency-domain instrument. Since the antenna has a high reflection coefficient, a novel formula was derived using a multiple reflection analysis and three test models. The proposed method produced a reflectivity similar to the reference value. Meanwhile, the previous formula behaved poorly. Using the method proposed in this paper, an absorber test can be easily performed by manufacturers or customers owing to its advantages of simplicity, low-cost, and non-cutting examination.

References

[1] L.H. Hemming, *Electromagnetic Anechoic Chambers*, New York: Wiley & Sons, Inc., 2002.

[2] R.E. Hiatt, E.F. Knott, and T.B.A. Senior, *A Study of VHF Absorbers and Anechoic Rooms*, University of Michigan/NASA, Feb. 1963.

[3] IEEE Std 1128-1998, *IEEE Recommended Practice for Radio-Frequency (RF) Absorber Evaluation in the Range of 30 MHz To 5 GHz*, Apr. 1998.

[4] J. Lee, Y.J. Yoon, and S. Lim, "Ultra-Thin Polarization Independent Absorber Using Hexagonal Interdigital Metamaterial," *ETRI J.*, vol. 34, no. 1, Feb. 2012, pp. 126-129.

[5] R.T. Johnk et al., "Time-Domain Measurements of the Electromagnetic Backscatter of Pyramidal Absorbers and Metallic Plates," *IEEE Trans. Electromagn. Compat.*, vol. 35, no. 4, Nov. 1993, pp. 429-433.

[6] Agilent Technologies, *Agilent Time Domain Analysis Using a Network Analyzer*, Application Note 1287-12, May 2012.

[7] S.-S. Oh and Y.-H. Lee, "Evaluation Method of Absorber Reflectivity Using Antenna with High Reflection Coefficient," *Proc. ISAPE*, 2012, pp. 830-832.

[8] R.E. Collin, *Foundations for Microwave Engineering*, New York: McGraw-Hill, 1992.

[9] D.M. Pozar, *Microwave Engineering*, New York: Wiley & Sons, Inc., 1998.