TELKOMNIKA, Vol.9, No.1, April 2011, pp. 133~138
ISSN: 1693-6930
accredited by DGHE (DIKTI), Decree No: 51/Dikti/Kep/2010

Hybrid De-embedding Technique for Microwave Absorber Characterization

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Abstrak

Pada makalah ini sebuah teknik pengolahan data untuk mendapatkan karakteristik yang sebenarnya dari karakterisasi material penyerap gelombang-mikro diusulkan. Teknik yang ditujukan untuk mengatasi keterbatasan ekstensi port ini dikenal dengan teknik hybrid de-embedding, yang pada prinsipnya dilakukan dengan cara menggabungkan antara data simulasi struktur model perangkat uji yang dipakai dengan data simulasi atau pengukuran secara eksperimental. Pada teknik ini, struktur perangkat uji disimulasikan secara numerik untuk mendapatkan data parameter hamburan (parameter S). Kemudian parameter S tersebut diubah menjadi parameter T (transfer) yang akan digunakan untuk proses de-embedding dengan membuang karakteristik dari perangkat uji yang digunakan sehingga karakteristik sebenarnya dari material penyerap gelombang-mikro dapat diperoleh. Untuk memverifikasi keakuratan dari teknik yang diusulkan, karakteristik sebuah microwave absorber disimulasikan secara numerik dan diukur secara eksperimen. Hasil simulasi dan pengukuran tersebut kemudian diproses menggunakan teknik yang diusulkan untuk dibandingkan dengan masing-masing model yang ideal. Secara umum hasil dari proses de-embedding menunjukkan bahwa teknik yang diusulkan mempunyai tingkat keakuratan yang tinggi.

Kata kunci: *karakterisasi, hybrid de-embedding, penyerap gelombang-mikro, pemandu-gelombang plat paralel*

Abstract

In this paper, a data processing technique to obtain the true characteristic of microwave absorber material characterization is proposed. This technique addressed to overcome the limitations of port extension is known as hybrid de-embedding technique, which in principle is carried out by combining the structure model data of test fixture that is used with simulated data or experimental measurements. In this technique, the test fixture is simulated numerically to get S (scattering) parameter data. Then the S parameter is converted into the T parameter (transfer) to be used for de-embedding process by removing the characteristic of test fixture used so that the true characteristics of a microwave absorber material can be revealed. To verify the accuracy of technique proposed, the characteristics of a microwave absorber is simulated numerically and measured experimentally. The simulation and measurements results are then processed using the proposed technique to be compared with its ideal model. In general, the result of de-embedding process shows that the proposed technique has high accuracy.

Keywords*: characterization, hybrid de-embedding, microwave absorber, parallel plate waveguide*

1. Introduction

At very high frequencies and microwave region, it is often impossible to directly perform the S parameters measurement or characterization of small or thin device such as frequency selective surfaces (FSSs) or thin microwave absorber. Instead, the characterization is then carried out at, and referred to, some reference plane physically removed from the device. Related to the problem, there are several techniques that have been investigated where one of the techniques is developed using tools such as testbed or test fixture [1]-[3]. In this technique, the device that will be characterized or in other term known as the device under test (DUT) is said to be embedded in the intervening test fixture and needs to be de-embedded to obtain its true characteristics [4]. If the test fixture is a two-terminal network, then the de-embed network

Received January 26th, 2011; Revised March 17th, 2011; Accepted April 12th, 2011

may usefully be regarded as a two-port network which will remove the unnecessary component of the characterization.

More than two decades ago, researchers and engineers involved in microwave devices have intensively investigated numerically and experimentally a number of de-embedding techniques to obtain the true data characterization of DUT, which is actually embedded in some test fixture [5]-[9]. In [5]-[7], some procedure of de-embedding based on calibration has been developed to reveal the properties of device embedded in some test fixture. Whilst de-embedding technique based on method-of-moments has been analyzed theoretically using short-open method [8], Further, in [9] a simplest method has been practically implemented in de-embedding technique, called as port extension, which can be mathematically intended as an extension of test structure with DUT. This technique assumes that the test structure behaves as an ideal transmission line structure with no phase different for any length and lossless. Therefore, there is no damping along the test structure and it has a linear phase response as well as constant impedance. Since the technique performs only adding or reducing phase of measured scattering parameters (S parameters), and is unable to compensate the attenuation and impedance discontinuity that possibly appears along the structure, in most cases, these will lead to a mismatch between the test structure and DUT that affects inconsistency of measurement results.

To overcome the limitations above, a new technique, namely hybrid de-embedding technique, that can compensate the attenuation and the impedance discontinuity of some test structure has been proposed recently and implemented for microwave device characterization [10]-[11]. Basically, the de-embedding process in the proposed techinque is performed by combining numerical S parameters and measured S-parameter of test fixture in the cascade of two half-model test fixtures to obtain the true measured data of DUT. As the application of hydrid de-embedding techinique is addressed for two-port network, therefore, in this paper the technique is intended to be developed for one-port network application to characterize microwave absorber material embedded in a test fixture of parallel-plate waveguide. To obtain the numerical data of S parameter used for de-embedding process, the test fixture together with microwave absorber is numerically characterized, whereas the measurement data is obtained from experimental characterization. The numerical and experimental characterization results are then processed using the proposed technique to obtain the true characteristics to be compared with its ideal model [12].

2. De-embeding Procedure

The technique developed here employs the test fixture cascaded with 3D EM simulated models, and then processes the de-emdedding data in the term of S or T parameters. This approach uses measured or simulated data from the test fixture including DUT and numerical simulated model data of only test fixture from simulation tools. By appying the structure models, then the de-embedding process is performed using S parameters or transfer parameters (T parameters) matrix calculations. In principle, there are six steps of procedure in the de-embedding process of test fixture cascaded with structure models:

Step 1: Create a data in term of S or T parameters using simulation tools to represent structure model of test fixtured used.

Step 2: Simulate the test fixture and DUT together using simulation tools to obtain S parameters data or measure the S parameters of test fixture including DUT using a measurement tools. The S parameters should be presented as complex numbers.

Step 3: Convert the simulated or measured S parameters to T parameters using the following equation [13].

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \frac{1}{S_{21}} \begin{bmatrix} -\left(S_{11}S_{22} - S_{12}S_{21}\right) & S_{11} \\ -S_{22} & 1 \end{bmatrix} \quad (1)$$

Step 4: Perform the matrix calculation to convert each half structure model of the T parameters matrices into their inverse matrices.

Step 5: By using the T parameters model of test fixture and DUT gathered, apply the following de-embedding equation to the simulated or measured T parameters.

$$\left[T_{DUT}\right]=\left[T_{test\_fixture}\right]^{-1}\cdot\left[T_{DUT+test\_fixture}\right] \quad (2)$$

Step 6: Convert the final T parameters obtained from the calculation back to S parameters using the following equation [13]. The result represents the S parameters of DUT only without the properties of test fixture.

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \frac{1}{T_{22}} \begin{bmatrix} T_{12} & T_{11}T_{22}-T_{12}T_{21} \\ 1 & -T_{21} \end{bmatrix} \quad (3)$$

3. Results and Discussion

To verify the accuracy of technique proposed, the property of thin microwave absorber made of square patches array based on textured surfaces technology is characterized numerically and experimentally using a test fixture in form of parallel-plate waveguide. The test fixture has been designed carefully for the characterization of such kind material [10]. In the numerical characterization, two different types of microwave absorber are numerically simulated to obtain their S parameters to be de-embedded using hybrid de-embedding technique. Hence for the experimental characterization, one type of absorber prototype is realized and its S parameter is measured experimentally. Then both of de-embedding results are compared with an ideal model of microwave absorber to gain the de-embedding accurateness.

3.1. Numerical Characterization

As illustrated in Figure 1, a test fixture that takes a form of parallel plate waveguide is used for numerical characterization of microwave absorber. The parallel plate waveguide has taper length of 100mm, plate length of 250mm, plate width of 200mm and plate separation of 75mm. Two types of material as shown in Figure 2, full type and center type of microwave absorber, will be applied for the S parameter characterization to be de-embedded using the technique proposed for the true data revelation. In order the incident of incoming wave on the surface of absorber can be assumed as a plane wave, the absorber is positioned far enough from the wave source excited using a waveguide transducer. The structure of microwave absorber is constructed using a double side of dieletric substrate with an array of square patches at top side and a ground plane at the bottom side. The dielectric substrate used is a Taconic^{TM} CER-10 with thickness of 2.54mm, relative permittivity (ε_r) of 10 and loss (tanδ) of 0.0035. The thickness of the copper top square patch and the bottom ground plane is 0.035mm. Here, substrate and copper conductive losses are accounted for. Each square patch has dimension of 10.5mm, whilst the distance between patches is 1.0mm and resistive elements are vertically incorporated midway along patches.

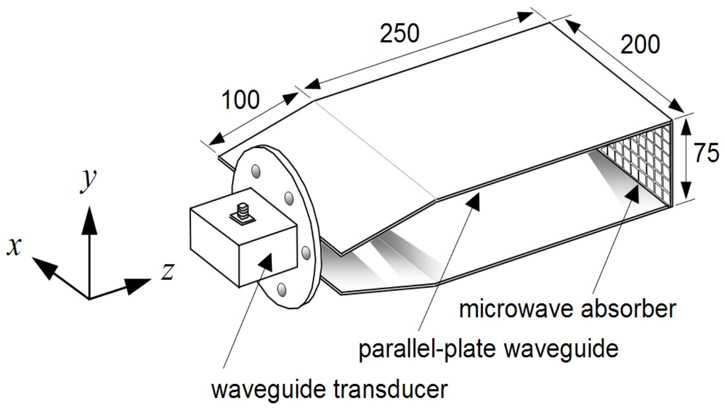

Figure 1. Parallel plate waveguide used for microwave absorber characterization, unit in mm

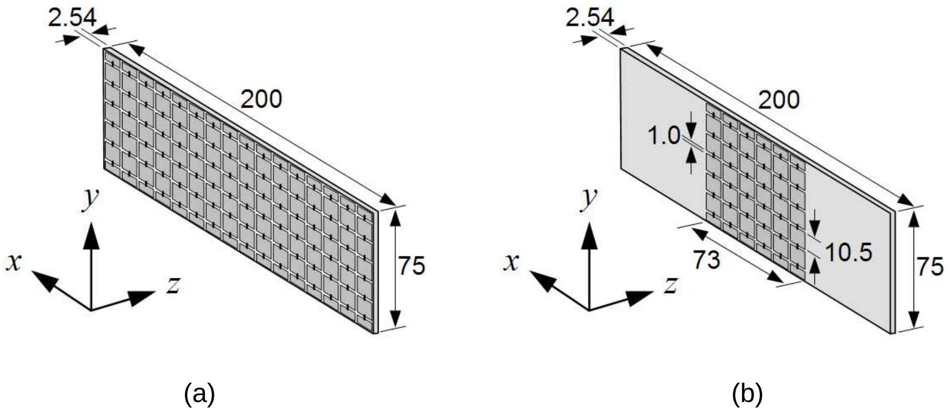

Figure 2. Microwave absorbers used for characterization, unit in mm (a) full type (b) center type

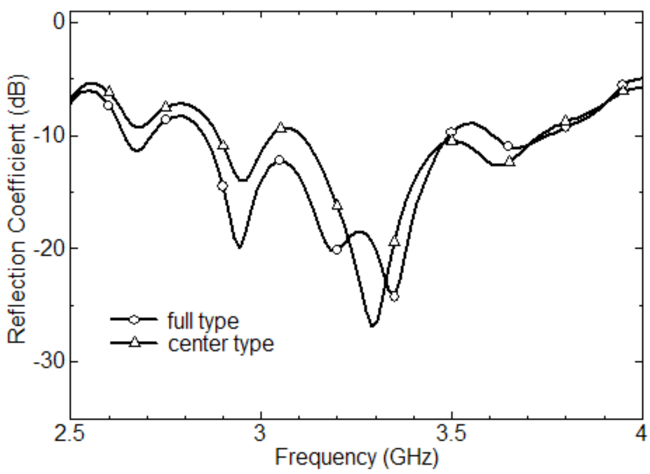

Figure 3. Simulated reflection coefficient of parallel plate waveguide and microwave absorbers before de-embedding process

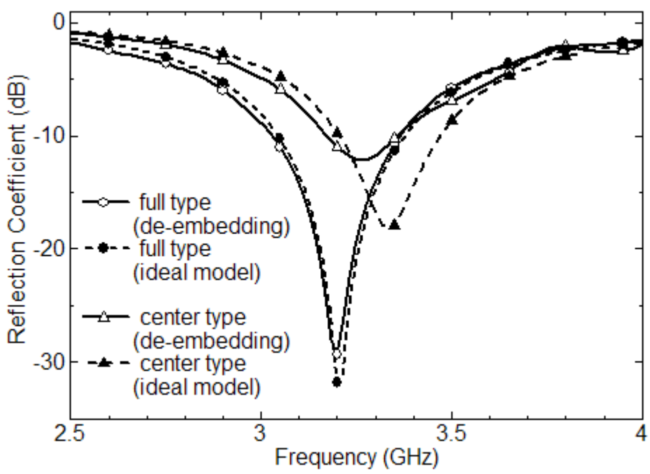

Figure 4. Simulated reflection coefficient of microwave absorbers after de-embedding process with the ideal models as comparison

Figure 3 plots the numerical characterization results of S parameter, i.e. reflection coefficient, for parallel plate waveguide and 2 types of microwave absorber prior to the process of de-embedding. Whereas after the de-embedding process has been taken, as depicted in Figure 4, the effect of test fixture from the waveguide transducer including parallel plates up to just in front of microwave absorber can be discarded, so the remains are the true S parameters of microwave absorber. To validate the result of de-embeddings, an ideal model i.e. perfect cell of each microwave absorber tested is numerically investigated to obtain its characteristic responses. The investigation results are plotted together for comparison. It is generally seen that the results shown in Figure 4 are very similar each other both for microwave absorber of full type and center type and comparable with each result of the ideal models. However, there is a bit difference in center frequency and amplitude for the center type that mostly be caused by the influence of parallel plate waveguide composed of metallic component where the influence for the center type is stronger than for the full type. In spite of slight differences in the result, it can be concluded that the proposed hybrid de-embedding technique shows a high enough accuracy in the characterization result and can be applied in the de-embedding process of experimental characterization.

3.2. Experimental Characterization

From the numerical characterization explained above, a prototype of full type microwave absorber is built for the experimentation and characterization. The absorber is made of square patches etched on 2.54mm thick grounded Taconic^{TM} CER-10 substrate. Figure 5 shows the picture of absorber to be used for the characterization followed by the de-embedding process. The dimension of each patch is 10.5mm, whilst the length and width of reflector are 200 mm and 75 mm, respectively. Surface mount resistors are soldered midway between the adjacent patches along vertical direction in line with a linearly polarized electric field E used for a wave illumination. After performing the de-embedding process, the result of measured reflection coefficient is depicted in Figure 6. To verify the experimental characterization, the numerical characterization and the ideal model are investigated and the results are plotted in the same figure.

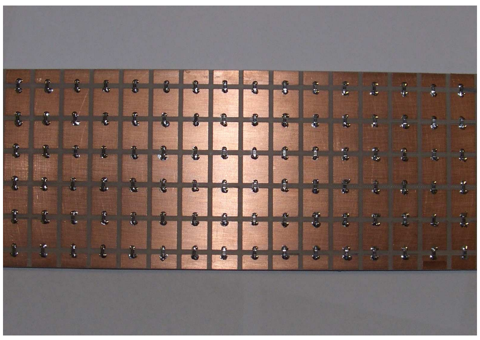

Figure 5. Picture of microwave absorber prototype to be characterized using parallel plate waveguide and to be de-embedded using proposed technique

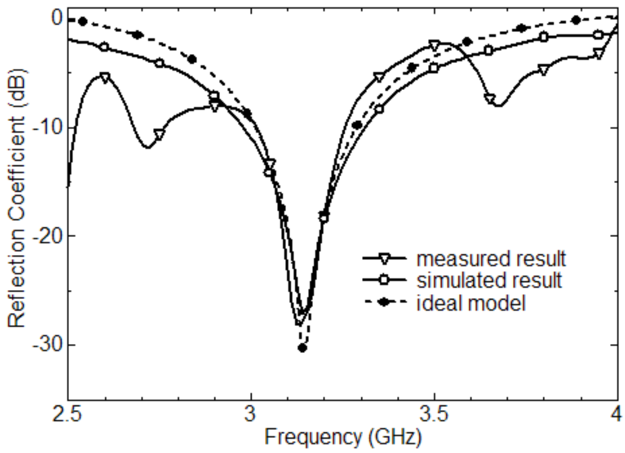

Figure 6. Measured reflection coefficient of microwave absorbers prototype after de-embedding process with the simulated resut and ideal model as comparison

From the graphs plotted in Figure 6, although there are some difference in the outband frequency around 3–3.5GHz, it is shown that the measured reflection coefficient has a good agreement both with the numerical characterization and the ideal model. The minimum experimental reflection coefficient value obtained is -28dB, whilst the numerical characterization and the ideal model are -27dB and -30dB, respectively. Hence, the bandwidth of experimental characterization at -10dB reflection coefficient is 251MHz comparable with the numerical characterization and the ideal model, i.e. 329 and 284MHz respectively. It should be noted that some unexpected parameter in the experimental characterization, such as loss surrounding the parallel plate waveguide and the microwave absorber prototype, is unable to be all included in the numerical characterization that causes the different result between the numerical and experimental characterization.

4. Conclusion

The investigation of hybrid de-embedding technique to obtain the true characteristic of microwave absorber characterization has been demonstrated numerically and experimentally. Both of numerical and experimental characterizations are used a test fixture in form of parallel plate waveguide with normal incident excitation. From the numerical characterization, it is shown that the proposed technique shows a very accurately result compared to the ideal models. Whilst in the experimentation, the characterization of a microwave absorber prototype has been performed following by the de-embedding process to reveal the true characteristic data, i.e. reflection coefficient, The measured de-embedding result have shown a good agreement both with the numerical characterization and the ideal model. It should be noted that the proposed technique is sufficiently accurate to validate the hybrid simulation/measurement method where this capability will be very useful to perform true characteristics of other small or thin device embedded in some test fixture.

Acknowledgements

This work is partially supported by the Institut Teknologi Bandung Research Group Grant 2010 (Riset KK-ITB) Contract No. 136/K01.16/PL/2010 and the Institut Teknologi Bandung Alumnae Association Research Grant 2010 (HRIA–ITB) Contract No. 1081/K01.16/IA/SP3/2010. The author thanks Dr. Sugihartono, Institut Teknologi Bandung, Indonesia for fruitful discussions and Prof. Vincent Fusco, Queen's University Belfast, United Kingdom for useful ideas related to the experimentation.

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