Composites Research

Vol. 27, No. 6, 225-230 (2014)
DOI: http://dx.doi.org/10.7234/composres.2014.27.6.225
ISSN 2288-2103(Print), ISSN 2288-2111(Online)

Paper

Design and Fabrication of Stratified Microwave Absorbing Structure Consisted of Glass/Epoxy – Resistive Sheet – Foam

Won-Ho Choi*, Jae-Hwan Shin*, Tae-Hoon Song*, Won-Jun Lee, Chun-Gon Kim*†**

ABSTRACT: In this study, a novel microwave absorber which consists of a structural part, a resistive sheet, and a low dielectric layer is proposed. Unlike the conventional Salisbury screen, a newly proposed absorber is capable of a range of absorbing performance, from narrowband to broadband. In the case of the narrowband absorber, the fabricated absorber with optimized design parameters has a strong resonance at 9.25 GHz and reflection loss of −44 dB with satisfying the −10 dB absorption in whole X-band (8.2 GHz~12.4 GHz). For the broadband absorber design, the reflectivity was minimized in the considered frequency ranges. The designed absorber showed two weak resonances near 6.5 GHz and 16.5 GHz and satisfied the −10 dB absorption from C-band to Ku-band (4 GHz~18 GHz). The measured reflection loss of fabricated absorber was well matched with simulation results, though the measurement was only performed on X-band. For the Salisbury screen to be capable of broadband absorption, it should be stacked multiply in a structure known as the Jaumann absorber. However, for the microwave absorber presented here, broadband as well as narrowband capabilities can be implemented without a change of the structure.

Key Words: Composite structure, Microwave absorbing structure, Reflection loss, Radar cross section

1. INTRODUCTION

The recently reported microwave absorbing composite structures with various resonant absorber types showed great potential for application to the low observable aircraft [1-6]. To implement such microwave absorbing composite structures in the reported papers, the material's electrical properties of matrix were modified utilizing lossy materials, such as carbon black (CB), multi-walled carbon nanotube (MWCNT), or carbon nano-fiber (CNF). Some papers used resistive periodic pattern surface on the surface of composite dielectric spacer. However, such implementation methods are not easy due to the material dispersion or complicate due to limitations on design methodologies.

On the other hand, the simplest type of microwave absorbers is the Salisbury screen [7]. The Salisbury screen is consisted of a resistive sheet and dielectric spacer. Although the Salisbury screen is the simplest form and easy to implementation, its implementable absorption bandwidth is narrow.

To enlarge the bandwidth requires multiple stacks of Salisbury screens, i.e., the Jaumann absorber [8]. While the Jaumann absorber is relatively thick, its overall thickness is also large. Moreover, because the Jaumann absorber consists of multiple spacers and resistive sheets, its fabrication is complicated.

In this study, a simple microwave absorber which has various absorbing capabilities and is easily implementable is presented. The newly proposed microwave absorber consists of glass/epoxy composite, a resistive sheet, and a foam layer as shown in Fig. 2(a). The proposed simple structure can be tuned from narrowband to broadband by simply changing the thickness and sheet resistance without changing the structure.

2. MATERIAL PREPARATION

Using glass/epoxy prepregs, fiber-reinforced composite flat

Received 6 October 2014, received in revised form 10 December 2014, accepted 11 December 2014

*Dept. of Aerospace Engineering, Korea Advanced Institute of Science and Technology, Republic of Korea
*†Dept. of Aerospace Engineering, Korea Advanced Institute of Science and Technology, Republic of Korea, Corresponding author (E-mail: cgkim@kaist.ac.kr)
**Agency for Defense Development, Republic of Korea

plates were fabricated using an autoclave process. The glass/epoxy prepregs (GEP118) were purchased from Muhan Composite Co., Ltd. They were layered using a hand lay-up process, and the thickness was controlled by the number of plies. The bagging materials, which in this case are perforated release film, a peel ply, and a breather, were layered on the stacked glass/epoxy prepregs and cured in an autoclave. After curing, the glass/epoxy composites were cut to the dimensions appropriate for the X-band (8.2 GHz~12.4 GHz) free-space measurement system [9-10], at 150 mm × 150 mm. As a low dielectric layer, acrylic foam was used, purchased from 3M. It was also cut to the same dimensions for the measurements. When the permittivity of the materials was measured, spot-focusing lens and a time-domain gating were used to minimize measurement inaccuracies.

Since the material permittivities of glass/epoxy composite and foam were only measured in the X-band, when designing the broadband absorber using the CST microwave studio [11], the permittivity was extended by using a dispersion fit with the measured data. Since the glass/epoxy composite and acrylic foam are almost pure dielectric materials, the dispersive characteristics of the measured permittivity very weakly depend on frequency. Thus, when considering the dispersive characteristics of the materials, the accuracy of the extended permittivity in terms of frequency will not be a significant problem. Fig. 1 shows the measured relative permittivity of glass/epoxy

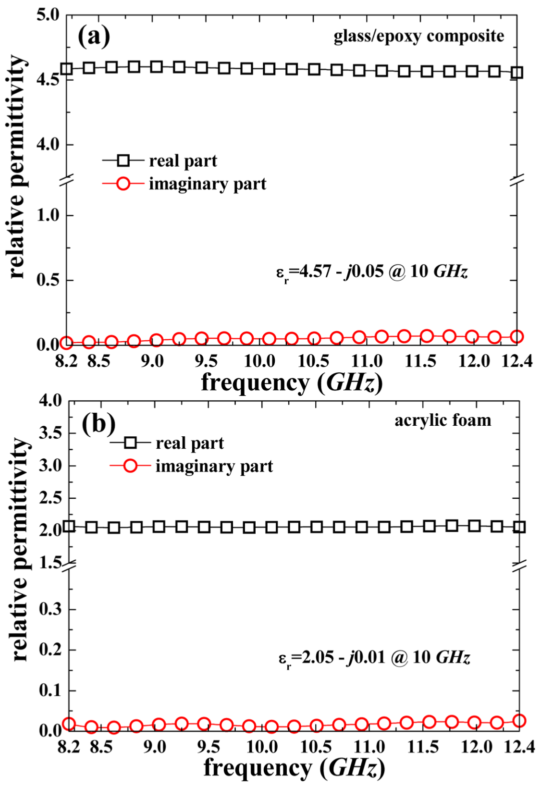

Fig. 1. The measured relative permittivity of (a) glass/epoxy composite (GEP118) and (b) acrylic foam

composite (Fig. 1(a)) and the acrylic foam (Fig. 1(b)) at X-band and the permittivity at 10 GHz were 4.57−*j*0.05 and 2.05−*j*0.01, respectively.

To fabricate the resistive sheet, the conducting material was coated onto PI (polyimide) film purchased from SKC KOLON using film-coating equipment (KP-300, E&T Co., Ltd.). The sheet resistance of the resistive sheet was measured using a four-point probe. When fabricating the resistive sheet according to the design value, the sheet resistance of the resistive sheet was controlled by changing the coating conditions. Using the measurement data and possible ranges of the implementable surface resistances, the modified Salisbury screen was designed.

3. DESIGN AND FABRICATION OF NARROWBAND ABSORBER

First, narrowband-microwave absorber designed in the X-band is presented. To design the microwave absorber, the transmission line impedance equation [12] for a multilayer medium was derived. This is expressed as Eqs. (1) and (2) below,

$$Z_{n+1} = Z_n \frac{Z_{n-1} + jZ_n \tan(\beta_n d_n)}{Z_n + jZ_{n-1} \tan(\beta_n d_n)} \quad (1)$$

$$\Gamma = \frac{Z_{n+1} - Z_0}{Z_{n+1} + Z_0} \quad (2)$$

Equation (1) gives the transformed surface impedance of the ground plane according to the layered media. Z_{n+1}, Z_n and Z_{n-1} are the surface impedance levels at the ground plane, β_n is the propagation constant of the n-th layer, and d_n is the thickness of the n-th layer. The calculated surface impedance (1) is inserted into Eq. (2), after which the reflection coefficient of the multi-layered absorber can be calculated. In Eq. (2), the Z_o is the free-space intrinsic impedance. When designing the narrowband absorber, Eqs. (1) and (2) were linked with a genetic algorithm (GA). The genetic algorithm used in this study repeatedly modifies a initially populated individual solutions. At each step, the GA randomly selects individuals from the current population, and then they become parents and are used to reproduce the children for the next generation. With confined design parameter ranges, the population evolves toward an optimal solution. In this way, the reflection loss was optimized to satisfy −10 dB absorption in the X-band.

According to the design parameters at a specific frequency target, the resistive sheet variation was sensitive to the glass/epoxy thickness while the foam layer was insensitive to moderate changes in the thickness of the glass/epoxy thickness. When the thickness of the glass/epoxy composite becomes thinner, the operation principles of the proposed absorber become similar to those of a conventional Salisbury screen. That is, as the thickness of the glass/epoxy composite decreases,

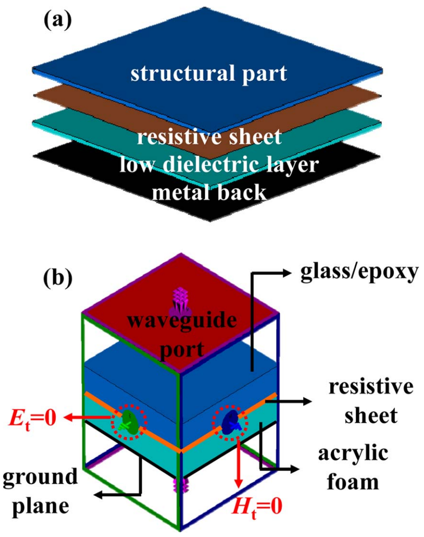

Fig. 2. (a) Geometry of the proposed microwave absorber, and (b) a unit cell model with boundary conditions to evaluate the absorbing performance of the designed absorber

the sheet resistance and foam layer thickness approaches the free-space impedance (377Ω) and $\lambda/4$ of the target frequency, respectively.

Because the glass/epoxy composite acts as a load-bearing structure, it should have a specific thickness. In this paper, the thickness of the glass/epoxy composite was set to be within 2.5 mm~3.0 mm by considering an implementable sheet resistance range. The final design values considering the implementable physical parameters were 1.209 rad and 0.698 rad of the electrical length ($\delta = 2\pi n l/\lambda_o$, n is refractive index, l is the thickness of dielectric, and λ_o is the free space wavelength) at the 9.5 GHz for the glass/epoxy and the acrylic foam, respectively, and 133 ohm/sq for the sheet resistance.

The absorbing performance of the designed absorber was checked using a full-wave simulator from CST Microwave Studio. Fig. 2(b) shows the unit cell model with boundary conditions to check the absorbing performance of design values. The free-space measurement method uses focusing lens to convert the spherical wave into plane wave. The converted plane wave becomes transverse electromagnetic (TEM) wave with respect to the specimen. If the size of the specimen is larger than $3\lambda \times 3\lambda$ (λ is the wavelength), then the specimen seen by incident TEM wave seems to be semi-infinite plane. The experimental environment can be simulated in the simulator by using the boundary condition shown in Fig. 2(b). As shown in Fig. 2(b), the boundary condition ($E_t = 0$ and $H_t = 0$) was applied to the side-wall of absorber. When the boundary condition on the side-wall is applied, the absorber modeled in simulator is recognized as semi-infinite plane. Moreover, since the side-wall of the absorber is applied with the boundary condition of zero-tangential field, the excitation mode by the waveguide port is constrained to TEM mode. In this way, the experimental environment can be effectively simulated with almost no differences.

Using the design parameters, the glass/epoxy composite, resistive sheet, and foam layer were fabricated. Fig. 3 shows each fabricated layer and the final structure. First, the glass-fiber/epoxy composite structural part was fabricated through autoclave curing. To make the composite structural part, glass/epoxy prepregs (GEP118) were used. Prepregs are fiber-glass fabrics that are pre-impregnated with epoxy resin for ease of processing and handling. 24 plies of glass/epoxy prepregs were layered by hand. After that, peel-ply, perforated release films, and breather were layered on the layered prepregs. The layered prepregs were vacuum-bagged and cured in an autoclave first for 30 min at 80°C and then for 120 min at 130°C. While the

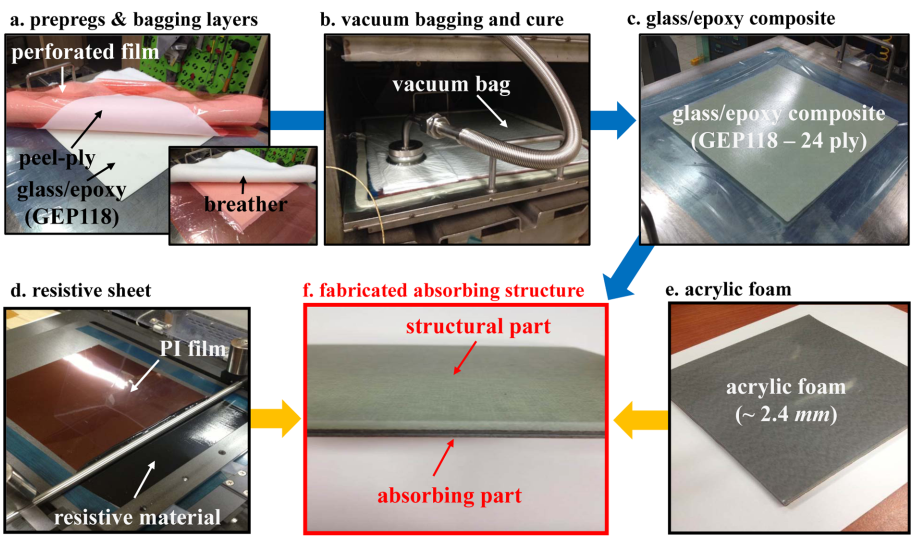

Fig. 3. Fabrication process flow of the proposed microwave absorbing structure with glass/epoxy composite, resistive material, and acrylic foam. Resistive sheet was fabricated using a film coater on the prepared PI film. To fabricate the glass/epoxy composite, 24 ply of glass/poxy prepregs were layered with curing accessories and cured in autoclave at 130°C

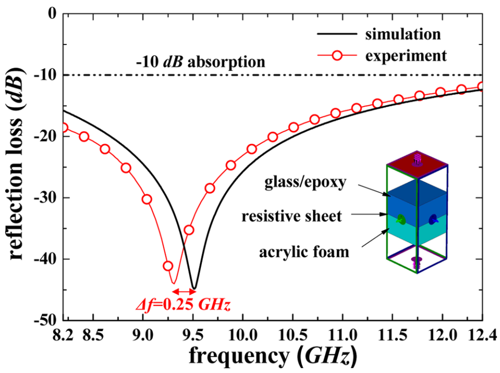

Fig. 4. Reflection loss measurement of the fabricated absorbing structure with the simulation result

specimen was being cured, the pressure was maintained at 6 atm. In the resistive sheet fabrication step, the carbon black based resistive material was coated on a PI film by using bar coater device. When coating the resistive material on the PI film, the printing conditions of bar coater were properly controlled to suit the material properties.

The reflection loss of the fabricated absorber was measured using the free-space measurement system introduced in the previous section to evaluate the microwave absorbing performance in the X-band. To allow a comparison of the reflection loss of the simulation with that of the experiment, two sets of values are shown together in the graph in Fig. 4. According to the measurement results, the fabricated absorber has a strong resonance at 9.25 GHz and reflection loss of −44 dB.

As shown in Fig. 4, the fabricated absorber showed excellent absorbing performance with a reflection loss of −10 dB absorption within the X-band. There is no significant difference in the radar absorbing performance, and it was concluded that the proposed absorber with the desired radar absorbing performance could be designed and fabricated.

4. DESIGN AND FABRICATION OF BROADBAND ABSORBER

On the other hand, although the presented microwave absorbing structures have a lot of advantages to reduce the radar cross section, the absorbers used in stealth technology still have some disadvantages and limitations in terms of bandwidth. So far, frequency band of the microwave absorbing structures in the published papers was focused on X-band (8.2 GHz~12.4 GHz). The primary difficulties with radar absorbent and lossy materials are the skin effect, where electrical currents induced by an incident wave tend to concentrate in the outer surface of a target. For the highly conductive materials like metal skins, the effective surface layer by skin effect is extremely thin for high frequencies, which acts excellent reflectors. However, absorbent materials are much less conductive to make much greater skin depth. As a result, when the absorbent materials were designed at 10 GHz, it is ineffective against lower frequencies like 100 MHz or 1 GHz than target frequency due to the skin depth of the many millimeters or centimeters deep. In other words, an absorbers designed at a specific frequency has a resonance point which becomes the zero reactance and pure resistance. When frequency band is changed to the other frequency bands, matching point is deviated from the optimal design, as a result, the absorbing performance is greatly degraded.

For the broadband absorber, Eq. (3) was linked additively to the optimization code. Eq. (3) is an objective function which minimizes the reflection loss for the considered frequency ranges and reflectivity.

$$OF = w_1 \sum_{i=1}^{n} (R_r - R(f_i)) + w_2 \sum_{i=n+1}^{n+x} (R_r - R(f_i)) + w_3 \sum_{i=n+x+1}^{z} (R_r - R(f_i)) \quad (3)$$

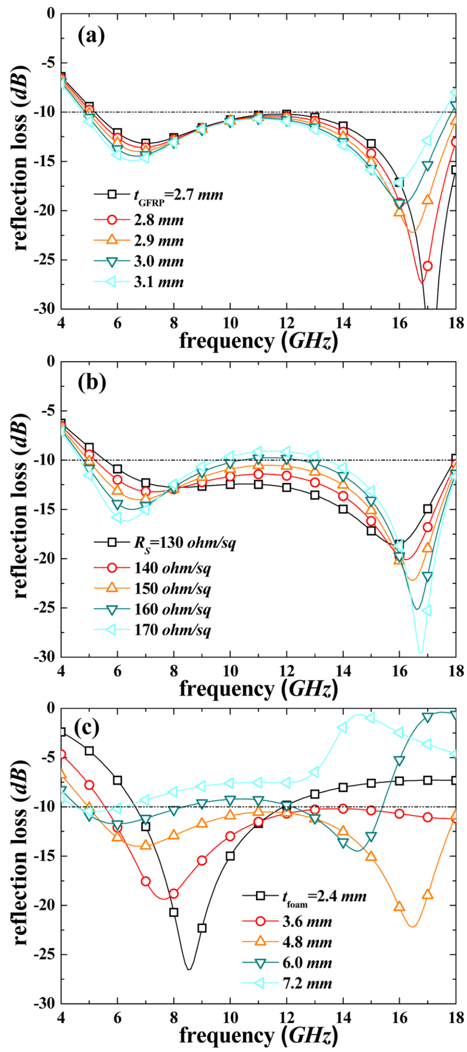

Fig. 5. The reflection loss of the designed broadband-microwave absorber with varying design parameters, (a) glass/epoxy thickness, (b) sheet resistance, and (c) foam thickness

Here, R_r is the reference reflectivity to ensure that the reflection loss is under the specified value; w_1, w_2, and w_3 are the weights factors of the different frequency ranges; and $R(f_i)$ is the reflection loss at frequency f_i.

Fig. 5 shows the reflection loss for the change in design parameters. The design parameters were varied from the obtained values by optimization process. As shown in Fig. 5, most of designs satisfied the −10 dB absorption in range 4 GHz~17 GHz. Since most of tracking radar uses those ranges, the absorption performance of the proposed microwave absorbing structure must be excellent, in terms of absorbing frequency ranges.

On the other hand, most of designs shown in Fig. 5 have multiple resonances or peaks. The multiple peaks of the microwave absorber are originated from the large electrical thickness. If the microwave absorber has a large electrical thickness, the dominant reactive component of the absorber's impedance is changed as a function of the frequencies for a given structure.

Considering implementable range of the physical dimensions, the design parameters were chosen. The final design values were 1.298 rad and 1.439 rad of electrical length at 10 GHz for the glass/epoxy and acrylic foam, respectively, and 150 ohm/sq for the sheet resistance. As shown in Fig. 3, the each layer was fabricated with the desired physical parameters.

Fig. 6 shows the reflection loss of the broadband-microwave absorber with simulation results from the C-band to the Ku-band. As shown in Fig. 6, the measurement result in the X-band is in good agreement with the simulation result. Unfortunately, because the available frequency band of the free-space measurement system is limited to the X-band, measurements in the C-band and Ku-band could not be performed. Although there were no measurement results, because the dispersion characteristics of the glass/epoxy composite and foam layer do not strongly depend on the frequency, with the measurement results in X-band only, the absorbing performance can be estimated in the other frequency bands.

Unlike the conventional Salisbury screen, as shown in Fig. 6, there are two weak resonances near 6.5 GHz and 16.5 GHz. To create the two resonances, the conventional Salisbury screen should be doubly stacked with two resistive sheets and two dielectric spacers. However, the proposed absorber can implement broadband absorption bandwidth with only one resistive sheet and without a change in the structure. This imparts great design flexibility to achieve the desired absorbing performance.

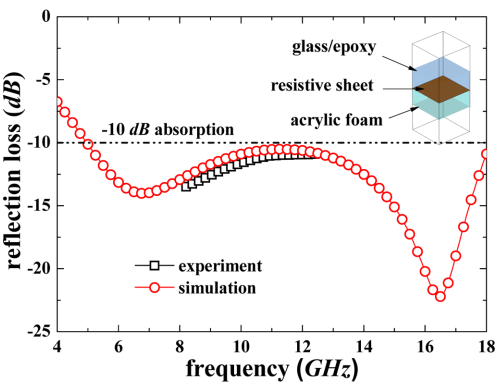

Fig. 6. The broadband-microwave absorber design and measurement result

4. CONCLUSIONS

A novel microwave absorber which consists of a structural part, a resistive sheet, and a low dielectric layer was presented. The proposed absorber was designed for narrowband (X-band) and broadband (from C-band to Ku-band) with design goal of −10 dB absorption in the target band. The fabricated absorbers with optimized design parameters for narrow and broad bandwidth satisfied −10 dB absorption in whole X-band and from C-band to Ku-band. The measurement results of the fabricated absorbers proved that the proposed absorber can achieve the design goal without a change in its structure while also providing excellent design flexibility.

ACKNOWLEDGEMENT

This work has been supported by the Low Observable Technology Research Center program of Defense Acquisition Program Administration and Agency for Defense Development.

REFERENCES

1. Oh, J.H., Oh, K.S., and Kim, C.G., "Design of Radar Absorbing Structures Using Glass/epoxy Composite Containing Carbon Black in X-band Frequency Ranges", *Composites Part B: Engineering*, Vol. 35, No. 1, 2004, pp. 49-56.
2. Lee, S.E., Kang, J.H., and Kim, C.G., "Fabrication and Design of Multilayered Radar Absorbing Structures of MWNT-filled Glass/epoxy Plain-weave Composites", *Composite Structures*, Vol. 76, No. 4, 2006, pp. 397-405.
3. Kim, J.B., Lee, S.K., and Kim, C.G., "Comparison Study on the Effect of Carbon Nano Materials for Single-layer Microwave Absorbers in X-band", *Composites Science and Technology*, Vol. 68, No. 14, 2008, pp. 2909-2916.
4. Kim, J.B., and Byun, J.H., "Salisbury Screen Absorbers of Dielectric Lossy Sheets of Carbon Nanocomposite Laminates", *IEEE Electromagnetic Compatibility Society*, Vol. 54, No. 1, 2012, pp. 37-42.
5. Choi, W.H., Shin, J.H., Song, T.H., Kim, J.B., Cho, C.M., Lee, W.J., and Kim, C.G., "Design of Circuit-analog (CA) Absorber and Application to the Leading Edge of a Wing-shaped Structure", *IEEE Transactions on Electromagnetic Compatibility*, Vol. 56, No. 3, 2014, pp. 599-607.
6. Choi, W.H., Shin, J.H., Song, T.H., Kim, J.B., Lee, W.J., Joo, Y.S., and Kim, C.G., "Design of Thin Circuit-analogue Multilayer

Absorber and Application to Leading Edge of Wing Structure", *Electronics Letters*, Vol. 49, No. 3, 2013, pp. 216-217.

7. Fante, R.L., and Mccormack, M.T., "Reflection Properties of the Salisbury Screen", *IEEE Transactions on Antennas and Propagation,* Vol. 36, No. 10, 1988, pp. 1443-1454.
8. Chambers, B., and Tennant, A., "Design of Wideband Jaumann Radar Absorbers with Optimum Oblique Incidence Performance", *Electronics Letters*, Vol. 30, No. 18, 1994, pp. 1530-1532.
9. Ghodgaonkar, D.K., and Varadan, V.V., "A Free-space Method for Measurement of Dielectric Constants and Loss Tangents at Microwave Frequencies", *IEEE Transactions on Instrumentation and Measurement*, Vol. 37, No. 3, 1989, pp. 789-793.
10. Ghodgaonkar, D.K., Varadan, V.V., and Varadan, V.K., "Free-space Measurement of Complex Permittivity and Complex Permeability of Magnetic Materials at Microwave Frequency", *IEEE Transactions on Instrumentation and Measurement*, Vol. 39, No. 2, 1990, pp. 387-394.
11. The Homepage of CST Corporation [Online]. Available: http: //www.cst.com/.
12. Vinoy, K.J., and Jha, R.M., *Radar Absorbing Materials: From Theory to Design and Characterization*, Boston: Kluwer Academic Publishers, 1996.