$RLGC$-Model-Based Film-Type Electromagnetic-Wave Absorber Design

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Abstract— A film-type electromagnetic-wave (EM-wave) absorber reduces cavity resonance owing to reflection when the module is implemented. It is also used to meet EMI/EMC (electromagnetic interference/electromagnetic compatibility) requirements. However, high-cost workstations or servers are generally required for the design and high-cost EM simulation tools. In this work, we show a new design method based on circuit simulation with an *RLGC* model of dielectrics, which leads to shortening the simulation time and can be used for free software, such as Python, in the future.

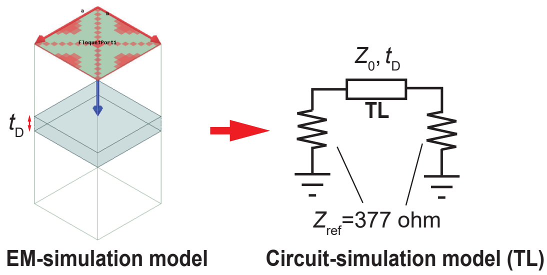

Fig. 1. Simulation-model conversion.

I. Introduction

There are various millimeter-wave frequency-band applications, including wireless communications, such as 5G Frequency Range 2 (FR2), and sensing, such as automotive radars. In addition, terahertz frequencies are employed for Beyond 5G/6G wireless applications.

A film-type electromagnetic-wave (EM-wave) absorber is one of the simplest ways to reduce cavity resonance owing to multi-path reflection when module implementation for those applications [1, 2, 3]. It is also employed to meet EMI/EMC (electromagnetic interference/electromagnetic compatibility) requirements at those high frequencies. However, higher-cost workstations or servers are required to design those devices with increasing frequency bands, in addition to expensive EM simulation tools. Moreover, it requires high memory usage with increasing the simulation time if the simulation model includes various dielectrics and conductors.

In this work, we show a new design method based on circuit simulation with an *RLGC* model (resistance/inductance/conductance/capacitance per length for transmission lines) of dielectrics to solve the problem above. It reduces memory usage, shortens the simulation time, and can be used for free software, such as Python, in the future.

II. Model conversion: EM to Circuit *RLGC* Model

Fig. 1 shows the concept of the model conversion: From an EM simulation model to a transmission-line (TL) model using *RLGC* parameters for circuit simulation. It is possible since both output S parameters depend on a dielectric's thickness or the TL's length. In this case, the port impedance for the EM simulation should be employed as the reference impedance of the circuit simulation. We can define the dielectric's characteristic impedance (Z_0) as the TL whose length is t_D.

For instance, Fig. 2 shows some TL parameters of the acrylic OCA, including *RLGC* parameters, when $t_D = 20\,\mu$m. Firstly, a 2-port EM simulation was done using floquet ports (port1, port2) and a master/slave boundary condition (mesh frequency: 500 GHz, maximum delta S: 0.005, sweep type: interpolating, frequency sweep range: 0.5 GHz–500 GHz (0.5 GHz step)). Secondly, *RLGC* parameters are extracted from the output (i.e., S parameters), treating it as a transmission line. It shows frequency-dependent characteristics because the EM simulation model was generated based on the measurement results using an ADVANTEST terahertz time-domain spectroscopy (THz-TDS, frequency resolution: 7.63 GHz, incident angle: 10 degree). They were fitted by applying the Cole-Cole equation shown in [4].

III. Film-Type-Absorber Simulation

Film-type absorbers are generally used to reduce the cavity resonance inside the module due to their thin thickness. They consist of a resistive layer, a metal layer (i.e., ground), and one or several dielectric layers (thickness≈ $\lambda_g/4$, λ_g: guided wavelength). A Salisbury-screen-type absorber is the most famous because of its simple and thin structure.

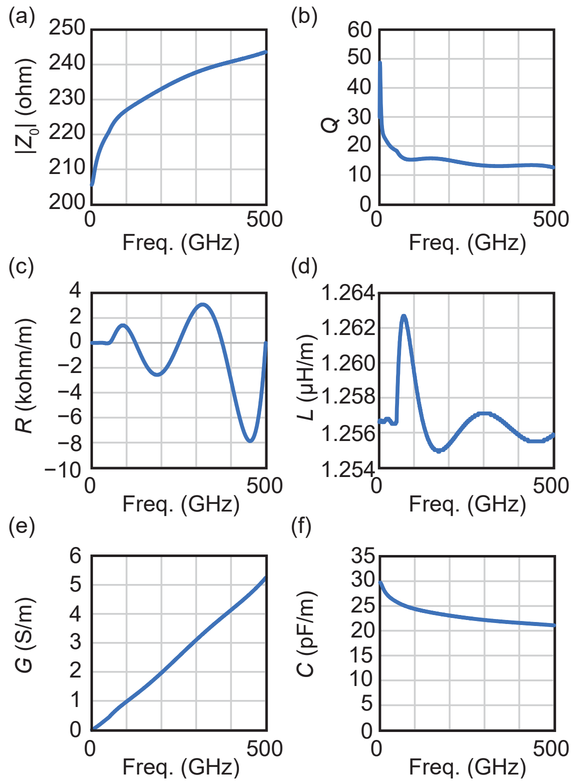

Fig. 2. Transmission-line parameters of a dielectric (acrylic OCA): (a) Characteristic impedance, (b) quality factor. Parameters per length: (c) Resistance, (d) inductance, (e) conductance, and (f) capacitance.

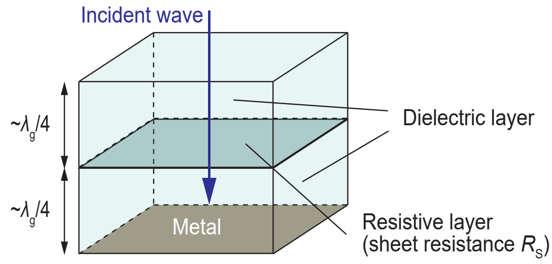

Fig. 3. Jaumman-type EM-wave absorber [2, 3].

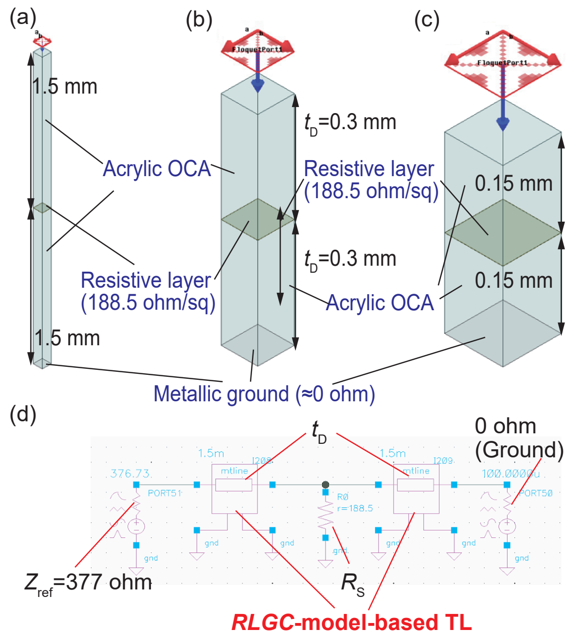

Fig. 4. EM-simulation models based on a Jaumann-type EM-wave absorber for (a) 30-GHz, (b) 150-GHz, and (c) 300-GHz frequency bands. (d) Proposed circuit simulation model using Cadence Spectre (components (port, mtline, res, gnd) were imported from the library of AnalogLib).

A Jaumman-type, shown in Fig. 3, usually uses multiple dielectric layers to add resonance and widen absorbable-frequency ranges. In other words, it matches the impedance difference between the air and the metallic ground across the wide frequency ranges.

To check the effectiveness of the proposed method, we simulated the structure based on the EM simulator (Ansys HFSS, Figs. 4(a)–(c)), and based on the circuit simulator (Cadence Spectre) using *RLGC*-model parameters (Fig. 4(d)). The structures shown in Figs. 4(a)–(c) represent the unit cells of the absorbers for 30-GHz, 150-GHz, and 300-GHz frequency bands, respectively. As the dielectric layers, acrylic OCAs are employed. The sheet resistance of the resistive layer is 188.5 ohm/sq. In addition, a perfect conductor (PEC) is used as a metallic ground. Floquet ports and a master/slave boundary condition are adapted (some analyses were done using four cores; mesh frequency: 500 GHz, maximum delta S: 0.005, sweep type: interpolating, frequency sweep range: 0.5 GHz–500 GHz (0.5 GHz step)).

In Fig. 4(d), *RLGC* parameters are employed for the transmission line. As the resistive layer that has the sheet resistance of R_S and a metallic ground, resistors (lumped models) are used. Finally, an input impedance of 377 ohm is set as the characteristic impedance of the air. The simulation is based on S-parameter analysis (single core, analysis: sp, frequency sweep range: 0.5 GHz–500 GHz (0.5 GHz step)). Both of the simulations were done using the same server.

Figs. 5(a)–(c) show the simulated results using Ansys HFSS and the proposed method. It shows that the results were well-matched. However, there are some differences with decreasing the thickness of t_D. In addition, Tab. I shows the performance comparison. It shows that the proposed method shortens the simulated elapsed time dramatically compared to that using the EM simulator.

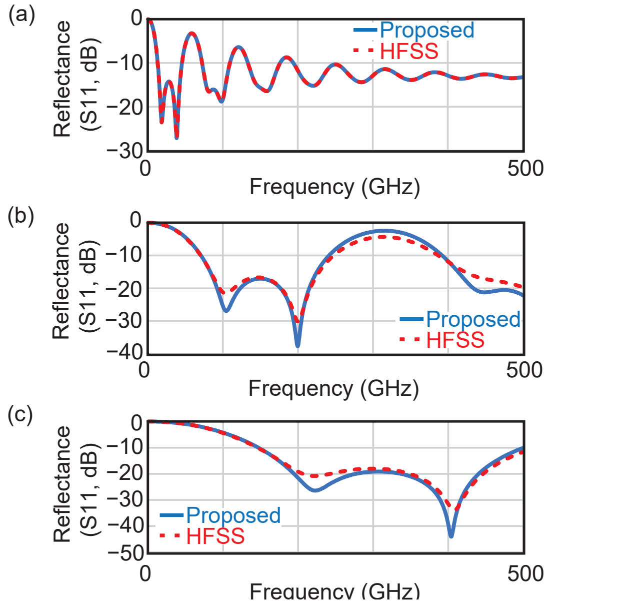

Fig. 5. Result comparison: (a) t_D =1.5 mm, (a) t_D =0.3 mm, and (c) t_D =0.15 mm.

TABLE I
SIMULATED ELAPSED TIME.

t_D	Ansys HFSS (sec)	Proposed (sec)
1.5 mm	226	0.106
0.3 mm	131	0.120
0.15 mm	83	0.112

IV. MEASUREMENT RESULTS

We fabricated two terahertz absorbers based on the Jaumman-type structure shown in Fig. 3. Fig. 6(a) shows the EM simulation model used in [2]. A 50-μm-thickness PET was used to coat a resistive layer (PEDOT) onto it. Two acrylic OCA layers and an Aluminum oil were adapted as dielectrics and a metallic ground, respectively. The dielectric thickness of 0.25 mm and 0.3 mm, and the sheet resistance 137Ω/sq were chosen for realizing a 150 GHz absorber [2]. Meanwhile, the dielectric thickness of 0.1 mm and 0.15 mm were chosen for a 300 GHz absorber [3]. To convert it to the circuit model, we employed the circuit schematics shown in Fig. 6(b), (c). *RLGC* parameters for the PET, as well as the acrylic OCA, were applied. The simulated elapsed time for analyzing Absorber 1 and 2 was 78.5 msec (single core, analysis: sp, frequency sweep range: 0.5 GHz–500 GHz (0.5 GHz step)).

Figs. 7(a), (b) depict the photographs of the fabricated absorbers. They were measured using a THz-TDS (frequency resolution: 7.63 GHz, incident angle: 10 degree). In Fig. 7(c), Absorber 1 shows a wide 90-%-absorbable-frequency range of 114.4–213.6 GHz, and

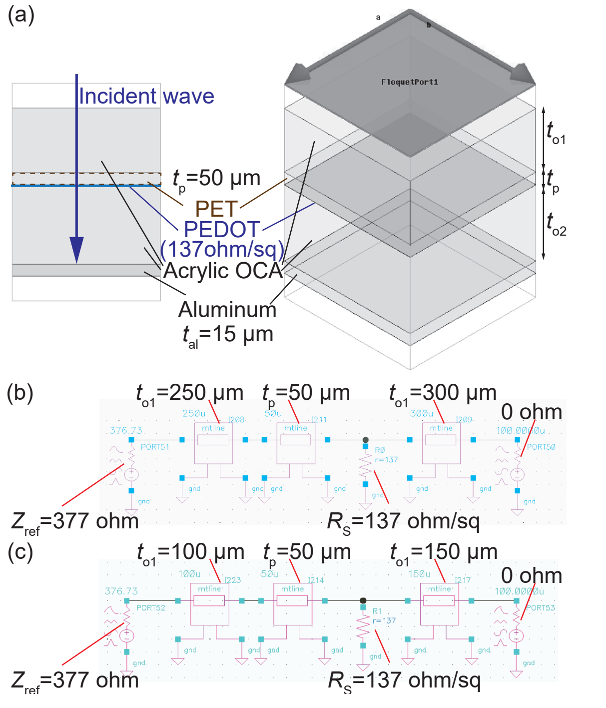

Fig. 6. (a) An EM-simulation model for fabricated absorbers [2]. Proposed simulation models based on *RLGC* parameters: (a) Absorber 1(150-GHz band) [2], and (b) Absorber 2(300-GHz band) [3].

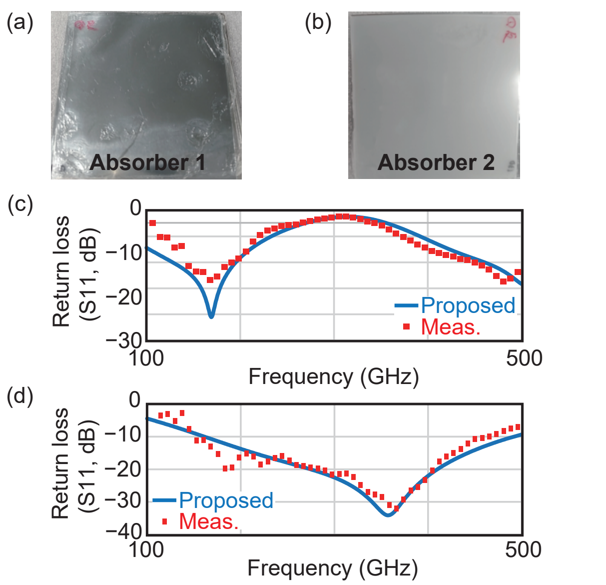

Fig. 7. Fabricated absorbers for (a) Absorber 1 [2], and (b) Absorber 2 [3]. Comparison between simulation and measurement results: (c) Absorber 1, and (d) Absorber 2.

a 99-%-absorbable-frequency range of 145.0–190.7 GHz. In Fig. 7(d), Absorber 2 represents a wide 90-%-absorbable-frequency range of 152.6–457.8 GHz and a 98-%-absorbable-frequency range of 251.8–412.0 GHz, which shows that it is suitable for IEEE standard 802.15.3d [5] applications. The results of the proposed simulation method were the lines in blue, and they are well-matched to the measured results.

V. Conclusions

This work demonstrated the *RLGC*-model-based design method for the film-type EM-wave-absorber design. Based on the frequency-dependent *RLGC* model of the dielectric (acrylic OCA, PET), which was obtained by the measurement with the THz-TDS, the measurement results of the fabricated absorbers matched the simulation results well. In the future, it can be adapted for the free software based on Python with rapid simulation time.

Acknowledgments

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