

열적 핫스팟 완화를 위한 비아 단락 광대역 전자파 흡수체

A Via-Shorted Broadband Electromagnetic Absorber
with Thermal Hotspot Mitigation배준성¹ · 민서영² · 김민재³ · 윤영노⁴Junseong Bae¹ · Seoyeong Min² · Minjae Kim³ · Youngno Youn⁴

요 약

본 논문은 광대역 흡수와 고전력 전자파 환경에서 핫스팟 완화를 동시에 달성하기 위한 비아 단락 전자파 흡수체를 제안한다. 제안된 구조는 저항이 삽입된 사각 루프 공진기와 접지면에 연결된 단락 비아로 구성된다. 저항이 삽입된 루프는 손실 성분을 통해 광대역 흡수를 구현하며, 단락 비아는 접지면으로 향하는 수직 전류 경로와 열전도 경로를 형성한다. 제안된 흡수체는 23.3 GHz에서 38.3 GHz까지 90 % 이상의 흡수 대역폭을 달성한다. 열 해석 결과, 제안된 단락 비아는 상온 대비 최대 온도 상승을 70 % 감소시킨다. 이러한 결과는 본 논문에서 제안된 구조가 고전력 전자파 환경에서 광대역 흡수와 핫스팟 억제에 동시에 달성할 수 있음을 보여준다.

Abstract

This paper presents a via-shortened electromagnetic absorber for broadband absorption and hotspot mitigation in a high-power electromagnetic environment. The proposed structure combines a resistor-loaded square-loop resonator with ground-connected shorting vias, where the resistor-loaded loop provides broadband absorption through dissipative loss and the shorting vias form vertical current and thermal conduction paths to the ground plane. The absorber achieves a 90 % absorption bandwidth from 23.3 to 38.3 GHz. Thermal analysis shows that the proposed shorting vias reduce the maximum temperature rise by 70 %. These results demonstrate simultaneous broadband absorption while mitigating localized thermal hotspots.

Key words: Electromagnetic absorber, broadband, hotspot mitigation, electromagnetic-thermal analysis

I. Introduction

Recently, highly integrated and high-power electromagnetic systems have increasingly required electromagnetic

absorbers to reduce unwanted reflections and mitigate electromagnetic interference (EMI)^[1]. In electromagnetic absorbers, the absorbed electromagnetic energy is converted into thermal energy through dielectric, conductive, or resistive

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losses^[2]. In high-power applications such as radar systems, communication platforms, and RF equipment, localized loss concentration can generate severe hotspots, causing variations in material properties and resistance values and degrading absorption performance and long-term reliability^[3]. Therefore, for high-power absorber applications, not only the absorption performance but also the heat-dissipation capability should be carefully considered^[4].

Resistor-loaded absorbers are widely used for broadband absorption by lowering the resonator quality factor and introducing dissipative loss^[5]. However, the localized loss around the resistors can induce hotspots, resulting in a trade-off between absorption bandwidth and thermal reliability^[6].

In this paper, a resistor-loaded via-shortened absorber is proposed. The resistor-loaded resonator enables broadband absorption, while the shorting vias provide additional thermal conduction paths from the hotspot region to the ground plane, thereby achieving broadband absorption and hotspot mitigation.

II. Via-shortened Absorber Design

Fig. 1(a) illustrates the proposed via-shortened absorber, which consists of a 1.05 mm-thick FR-4 substrate ($\epsilon_r=4.4$ and $\tan \delta=0.02$). A resistor-loaded square loop is printed on the top layer and shorting vias connect the resonator to the ground to achieve broadband absorption by tuning quality factor and enhancing magnetic resonance. The proposed absorber has a unit cell period (p) of 4.65mm. The side length of the square loop (L_{loop}) is set to be 3.2 mm and the line width (W_{loop}) is 0.36 mm. The via length (L_{via}) is 1.05 mm, which is determined by the substrate thickness (t_{sub}), and the via diameter (d_{via}) is 0.15mm. In Fig. 1 (b), this proposed absorber demonstrates the absorption bandwidth from 23.3 to 38.3 GHz under normal incidence.

The shorting vias provide additional vertical current paths between the square-loop resonator and the ground plane. As

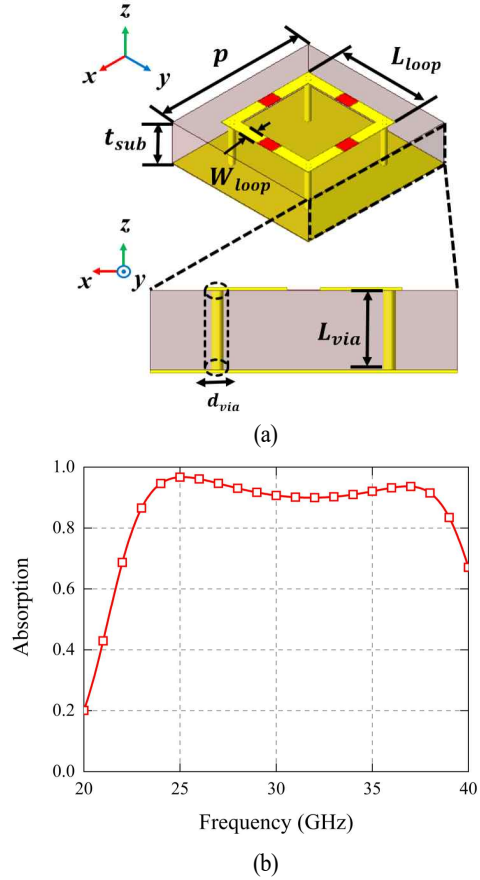


그림 1. (a) 제안한 흡수체 (b) 흡수율 시뮬레이션

Fig. 1. (a) Proposed via-shortened absorber (b) Simulated absorption.

shown in Fig. 2(a), anti-parallel vertical currents flow through adjacent vias, forming a circulating current loop associated with magnetic resonance. This via-induced resonance improves the low-frequency absorption. This results in a broader absorption bandwidth, as demonstrated in Fig. 2(b).

The resistors were located at the current-concentrated regions for dissipative loss, controlling the quality factor of the absorber. In Fig. 3, higher resistance increases the resistive damping and reduce the quality factor of the absorber. However, excessive resistive loading degrades the impedance matching at the resonant frequencies. In contrast, lower resistance increases the quality factor, reducing the absorption bandwidth. Considering the trade-offs, a

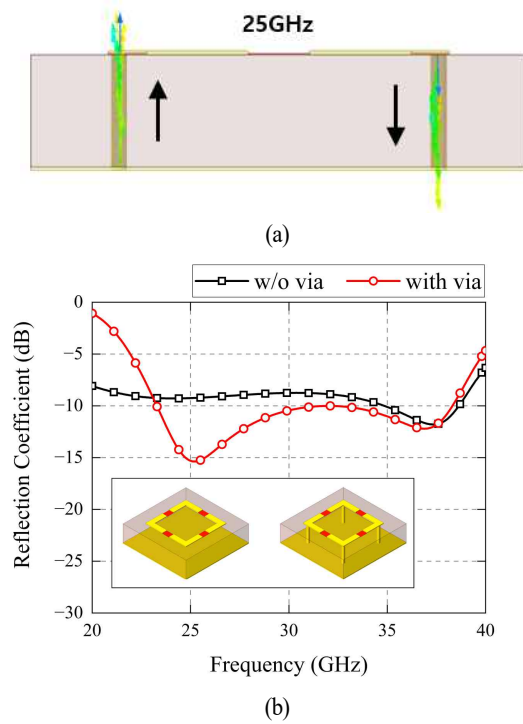


그림 2. (a) 인접 비아에 흐르는 반대 방향의 수직 전류
(b) 반사계수 시뮬레이션

Fig. 2. (a) Anti-parallel currents through adjacent shorted-via (b) Simulated reflection coefficients.

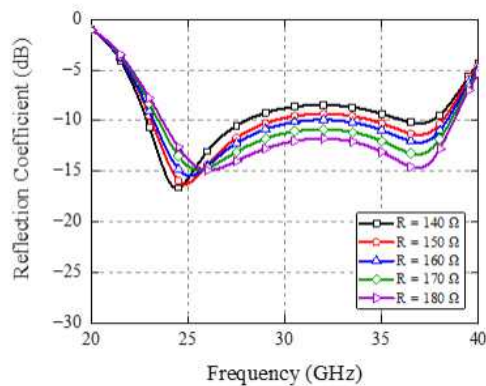


그림 3. 저항값에 따른 반사계수 시뮬레이션

Fig. 3. Simulated reflection coefficients for different resistance values.

resistance of 160Ω was adopted for maintaining broadband absorption with good impednace matching.

III. Electromagnetic-Thermal Analysis

The steady-state temperature distribution of the proposed absorber was analyzed by using ANSYS HFSS and Icepak. In order to compare the heat-spreading effect of the shorting vias, the absorbers with and without shorting vias were simulated under identical absorption power conditions. Each structure was evaluated at a frequency corresponding to 90 % absorption, which ensures identical absorbed-power conditions for the thermal comparison. An input power of 0.0573 W was applied to each unit cell, which is equivalent to an incident electric field strength of 1,000 V/m ($2,653 \text{ W/m}^2$).

In Fig. 4, the opening boundary was set to an ambient temperature of 20°C , while symmetry boundary conditions were applied to the lateral sides. Fig. 5 compares the simulated steady-state temperature distributions of the absorber with and without shorting vias. The maximum temperature decreased from 170°C to 65°C with the

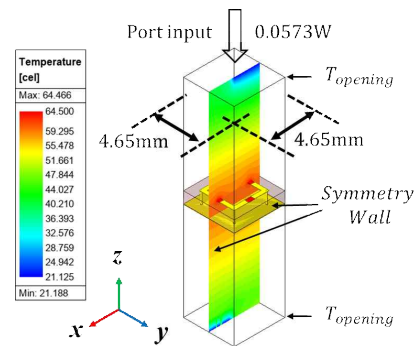


그림 4. 전자기-열 시뮬레이션 모델

Fig. 4. Electromagnetic-thermal simulation model.

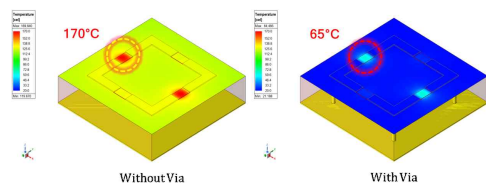


그림 5. 비아 유무에 따른 정상상태 온도 분포 비교

Fig. 5. Steady-state temperature distributions without and with shorting vias.

표. 1. 흡수체 구성요소의 열적 한계

Table. 1. Thermal limits of the absorber components.

Component	Thermal limit (°C)
Standard FR-4 ^[7]	135
0402 chip resistor ^[8]	155
SAC305 solder joint ^[9]	217

introduction of the shorting vias. A 70 % reduction in the maximum temperature rise was achieved from 150°C to 45°C. The resulting maximum temperature of 65°C is below the reference temperatures of the constituent materials in Table 1. The copper shorting vias provide additional vertical heat-conduction paths from the resistor-loaded resonator to the ground plane, reducing localized heat accumulation around the resistive elements.

IV. Conclusion

A via-shorter absorber was proposed to achieve broadband absorption and thermal hotspot mitigation. By integrating a resistor-loaded square-loop resonator with ground-connected shorting vias, this proposed absorber exhibits over 90 % absorption bandwidth from 23.3 to 38.3 GHz. The electromagnetic-thermal analysis demonstrates that the shorting vias reduced the hotspot temperature from 170°C to 65°C, corresponding to a 70 % reduction in maximum temperature rise. Future work will focus on the fabrication and experimental characterization of the proposed absorber to validate its broadband absorption and thermal hot-spot mitigation effect. This proposed via-shorter configuration can provide an effective approach for improving hot-spot mitigation while maintaining broadband absorption.

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