Improvement of Enclosure Shielding Effectiveness Using Metal Plates and Posts

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Abstract **—This paper investigates shielding effectiveness (SE) improvement by placing metal plates and posts inside an enclosure. First, the effect of the size and position of conductive plates and posts on cavity resonance frequencies and enclosure SE was studied using finite element electromagnetic simulation. It was shown that conductive structures can shift the first cavity resonance of the enclosure to higher frequencies by up to 4.6 GHz, leading to an SE increase of more than 30 dB at lower frequencies. It was found that plates provide a greater resonance frequency shift (by 10–20%) and a larger SE gain (up to twofold) compared to posts. Additionally, the effects of plates and posts on the voltage standing wave ratio (VSWR) of a microstrip line passing through a PCB shield and on the radiated emissions from the line were evaluated. It was found that conductive structures shift the frequencies of VSWR and radiated emissions peaks caused by cavity resonances to higher frequencies. Moreover, PCB shield configurations with plates, compared with posts, can reduce radiated emissions by up to 13.4 dB and reduce VSWR by up to 0.9.**

Keywords —electromagnetic shielding, shielding effectiveness, plane wave, cavity resonances, printed circuit board, microstrip line, radiated emissions.

I. Introduction

One of the most critical tasks in the design of high-speed electronic equipment is ensuring its protection from radiated interference [1], [2]. Traditionally, simple and reliable electromagnetic shields are used for this purpose [3]. However, cavity resonances can occur in shields, amplifying the electromagnetic field strength tenfold or more, which can lead to malfunction or failure of the devices placed inside the shield [4]. Shielding effectiveness (SE) at resonance frequencies decreases significantly and may even become negative. To improve SE, it is crucial to shift and suppress these cavity resonances. Common methods for solving this problem include reducing the enclosure dimensions [5], [6] and modifying the aperture geometry [7], [8]. Furthermore, other methods have been proposed, including adding an additional wall [9], using frequency selective surfaces [10], radar absorbent materials [11], and filling apertures with conductive [12] or magnetodielectric structures [13].

In [14] and [15], it is shown that placing conductive structures inside a shield introduces an additional reactive load, thereby disturbing the original modal field structure. Furthermore, [16] and [17] demonstrate that conductive structures placed inside a shield can shift resonance frequencies upward and consequently improve SE in the lower frequency range. This work investigates the possibility of improving SE by placing conductive plates and posts inside the shield cavity.

In addition to the introduction and conclusion, this paper comprises three additional sections. Section II describes the investigated shield configurations with internal plates and posts. Section III presents and analyzes the results of full-wave SE simulation for these shield configurations. Section IV further investigates the effect of these conductive plates and posts on the characteristics of a microstrip line (MSL) passing through a PCB shield.

II. Structure under Study

The investigated structure, shown in Fig. 1, is a compact electromagnetic shield with dimensions $a \times b \times c$ = 25×10×25 mm and wall thickness τ = 0.4 mm. The front wall contains an aperture with dimensions $x' \times y'$ = 10×1 mm. To shift resonances and improve SE, conductive plates with length s, height h = 9.2 mm, and thickness t = 0.5 mm, providing partial bifurcation of the cavity, were placed inside the shield. Additionally, posts with height h = 9.2 mm and diameter $d = t$ were placed inside the enclosure at a distance s from the wall. The enclosure, plates, and posts were modeled as perfect electric conductors. To evaluate SE and radiated emissions (in terms of electric field strength modulus $|E|$), a vertically polarized plane wave (with frequency varied over the investigated range) with an amplitude of 1 V/m incident on the front wall of the enclosure was used as the excitation source. SE was calculated from $|E|$ values recorded at a field probe at the center of the shield. Electromagnetic modeling was performed using the finite element method (FEM) with a mesh density of at least 30 cells per wavelength.

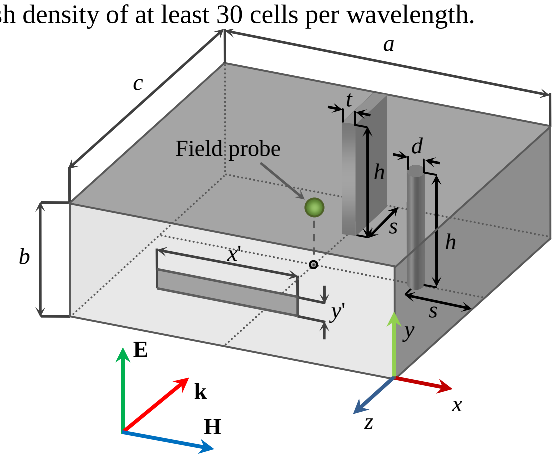


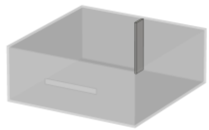
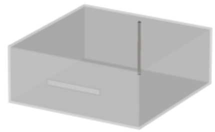
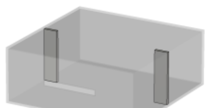
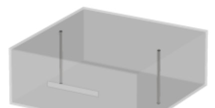
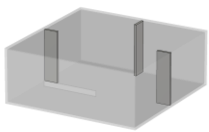
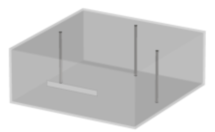
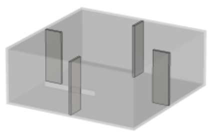
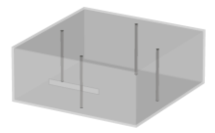
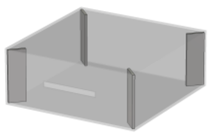
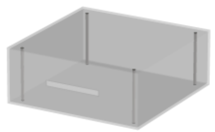
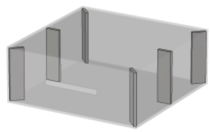
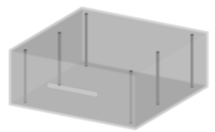
Fig. 1. Rectangular electromagnetic enclosure under study loaded with metal plate and post.

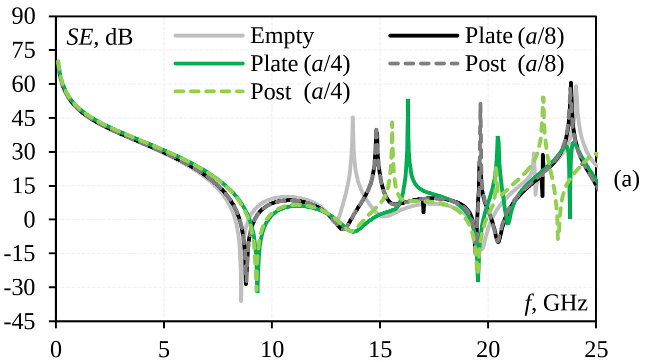
The research was carried out at the expense of Russian Science Foundation grant 23-79-10165, https://rscf.ru/project/23-79-10165/.

III. Shielding Effectiveness Analysis

First, the SE of the empty enclosure was evaluated. Then, conductive plates and posts were placed inside. Table I presents the investigated shield configurations (I–VI) with internal plates and posts. The frequency dependencies of SE for these configurations were determined in the frequency range of 0–25 GHz. The plate length and the distance *s* from the wall to the posts were set to 6.24 mm (*a*/4) and 3.125 mm (*a*/8), respectively. The obtained frequency dependencies of SE for configurations I–VI and the empty enclosure are presented in Fig. 2.

TABLE I. Configurations I–VI of Enclosure Loaded with Metal Plates and Posts

№	Plates	Posts
I		
II		
III		
IV		
V		
VI		



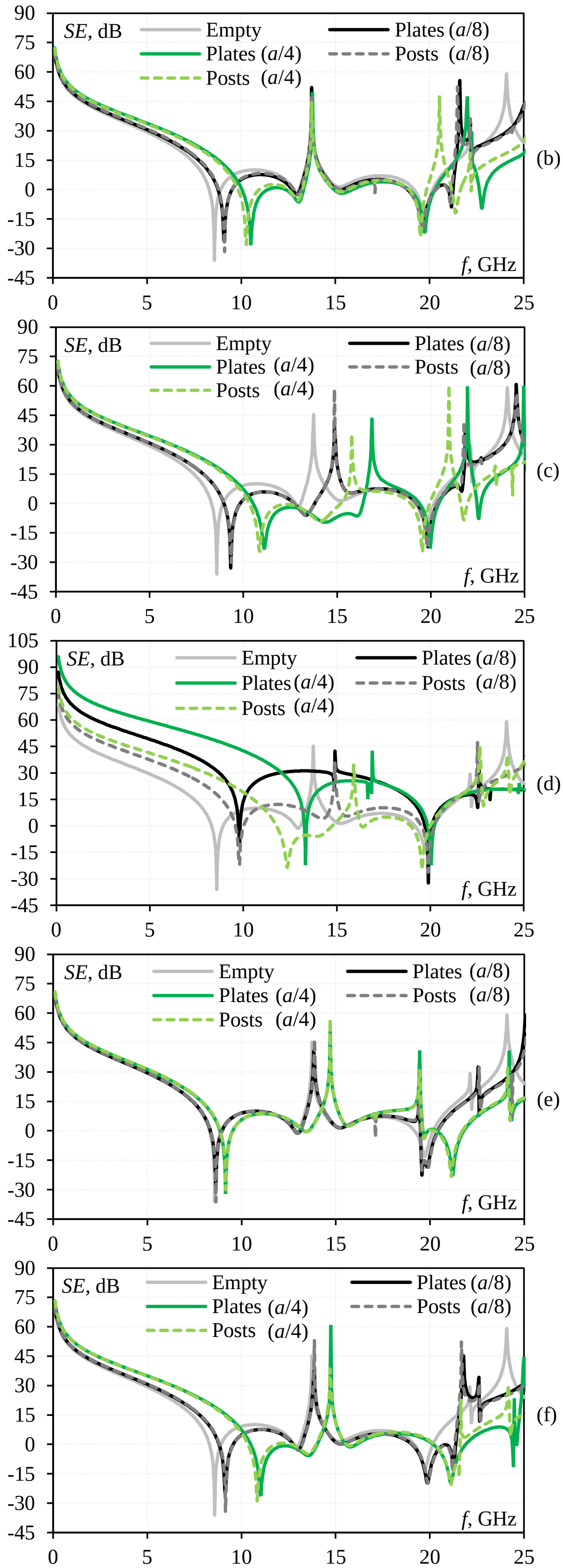


Fig. 2. Frequency dependencies of *SE* for the empty enclosure and configurations: I (a), II (b), III (c), IV (d), V (e), VI (f).

The results show that in the investigated frequency range, the empty enclosure exhibits two cavity resonances at frequencies f_1 = 8.58 GHz (SE = –36 dB) and f_2 = 19.76 GHz (SE = –12.7 dB). Notably, placing conductive plates and posts inside the enclosure (configurations I–VI) shifts these frequencies and increases SE in the lower frequency range.

Table II summarizes the first f_1 and second f_2 resonance frequencies of the investigated enclosure. The table shows that the largest shift Δf_1 of the first resonance frequency relative to the empty enclosure is observed for conductive structures with $s = a/4$. Moreover, configuration IV has the largest Δf_1 for both $s = a/4$ and $s = a/8$. For configuration IV with plates, the maximum Δf_1 value is 4.6 GHz at $s = a/4$ and 1.17 GHz at s = a/8. For configuration IV with posts, the maximum Δf_1 of 3.8 GHz is observed at $s = a/4$, while the minimum is at $s = a/8$ (1.2 GHz). Configurations I, II, and V (at $s = a/8$) show the smallest Δf_1 values, ranging from 0.07 to 0.3 GHz. Notably, f_2 shifts significantly to higher frequencies only in configuration VI. This configuration with plates and posts (at $s = a/4$) yields a Δf_2 of 1.36 GHz.

Next, the effect of the first resonance frequency shift on the SE improvement for configurations I–VI in the low frequency range was evaluated. To this end, the crossover frequencies f_c were determined from the SE frequency dependencies of the empty enclosure and configurations I–VI. These frequencies define the upper boundary of the low-frequency range where conductive structures improve SE. The crossover frequencies were determined above the first resonance frequency of the empty enclosure (f_1 = 8.58 GHz). Then, the mean absolute deviation ΔSE for configurations I–VI relative to the empty enclosure was calculated over the frequency range up to f_c. Table III summarizes the results. It shows that at $s = a/4$, configuration IV with plates provides an SE increase of approximately 31 dB up to the frequency f_c = 13.15 GHz. Configuration IV with posts increases SE by 13.67 dB up to the frequency f_c = 11.08 GHz.

TABLE II. THE FIRST AND SECOND RESONANCE FREQUENCY (IN GHz) FOR THE EMPTY ENCLOSURE AND CONFIGURATIONS I–VI

№	Metal plates				Posts			
	$s = a/4$		$s = a/8$		$s = a/4$		$s = a/8$	
	f_1	f_2	f_1	f_2	f_1	f_2	f_1	f_2
I	9.35	19.43	8.81	19.54	9.28	19.43	8.82	19.51
II	10.47	19.73	9.08	19.63	10.27	19.51	9.12	19.62
III	11.07	19.97	9.32	19.85	10.86	19.54	9.35	19.83
IV	13.23	20.00	9.75	19.90	12.35	19.56	9.78	19.89
V	9.15	19.58	8.64	19.71	9.15	19.69	8.64	19.57
VI	11.02	21.12	9.13	19.87	10.83	21.11	9.15	19.90

TABLE III. THE CROSSING FREQUENCY (IN GHz) AND THE AVERAGE SE (IN dB) IMPROVEMENT FOR CONFIGURATIONS I–VI

№	Plates				Posts			
	$s = a/4$		$s = a/8$		$s = a/4$		$s = a/8$	
	f_c	ΔSE	f_c	ΔSE	f_c	ΔSE	f_c	ΔSE
I	8.94	2.73	8.69	1.10	8.92	2.08	8.7	1.07
II	9.57	6.60	8.84	2.80	9.45	6.15	8.85	2.38
III	9.86	7.33	8.94	2.95	9.74	7.00	8.95	2.87
IV	13.15	31.13	9.68	21.23	11.08	13.67	9.38	9.78
V	8.90	3.40	8.61	0.55	8.89	3.20	8.61	0.40
VI	9.88	7.88	8.86	2.73	9.79	7.72	8.87	2.52

IV. ANALYSIS OF VOLTAGE STANDING WAVE RATIO AND RADIATED EMISSIONS

This section analyzes a PCB shield with dimensions $a \times b \times c$ = 18.5×5×18.5 mm, τ = 0.4 mm, and $x' \times y'$ = 2×1 mm (Fig. 3). An MSL with width w = 0.925 mm, thickness t = 0.035 mm, and length l = 25 mm was routed through this shield. The line was located on a dielectric substrate ($l \times l$) with thickness h = 0.5 mm, relative permittivity ε_r = 4.4, and loss tangent tan δ = 0.035. Subsequently, configurations with conductive plates and posts ($s = a/4$) were placed inside the shield. These configurations, which do not overlap with the MSL routing area, showed the best results in the SE analysis in Section III. Configurations I'–II' of the PCB shield with conductive plates and posts are presented in Table IV. As before, SE was evaluated for the enclosure both with and without conductive structures (in the frequency range of 0–32 GHz). The MSL voltage standing wave ratio (VSWR) was also evaluated. For this purpose, a 50-Ohm discrete port was placed at one end of the line and a matched load at the other. Additionally, radiated emissions (in terms of |E|) were evaluated for signals propagating through the line. Radiated emissions were recorded at an observation point centered 2.5 mm above the line. The results are presented in Fig. 4 and Tables V–VII.

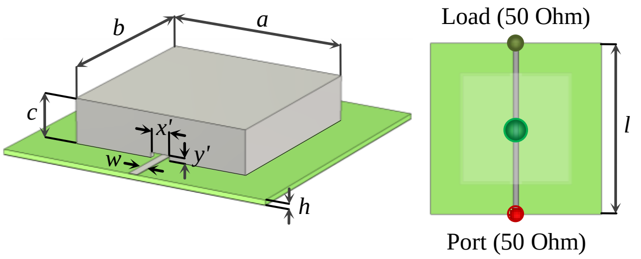
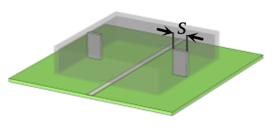
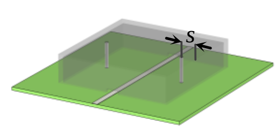
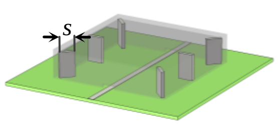
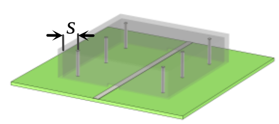


Fig. 3. Rectangular PCB enclosure with MSL passing through its aperture.

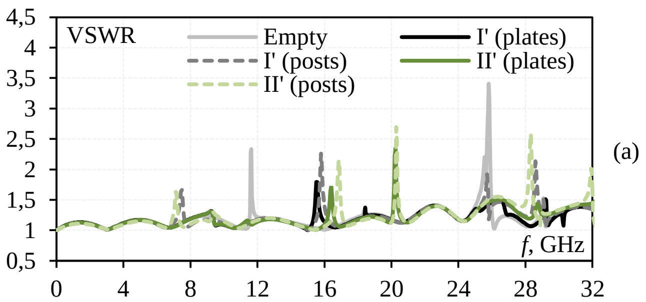
TABLE IV. CONFIGURATIONS I'–II' OF THE PCB ENCLOSURE LOADED WITH METAL PLATES AND POSTS

№	Plates	Posts
I'		
II'		

The results in Fig. 4(c) show that the first two resonances of the empty enclosure (without conductive structures) correspond to frequencies $f_1 = 11.55$ GHz ($SE = 3.7$ dB) and $f_2 = 25.5$ GHz ($SE = -3.5$ dB). In the frequency range up to 10 GHz, configurations with plates and posts exhibit an additional resonance f' (7.5–9.6 GHz), which is absent in the empty enclosure. For configurations I' and II', placing the conductive structures inside the enclosure primarily affects the first resonance f_1, shifting it upward by $\Delta f_1 = 4.1$–5.5 GHz. In addition, configurations with plates show 10 dB higher SE at resonance frequencies than those with posts. The maximum SE increase in the low-frequency range achieved by conductive structures was 65 dB relative to the empty enclosure. The second resonance f_2 shifts significantly only in configuration II'. For this configuration with plates and posts, Δf_2 is 2.1–2.2 GHz. However, at resonance frequencies, configurations with plates exhibit 1.6–20 dB higher SE than those with posts.

The results in Fig. 4(b) show that, at resonance frequencies f_1 and f_2 of the empty enclosure, peak emission amplitudes $|E|$ reaching 89.8 and 84.4 dB are observed, respectively. Configurations I' and II', containing conductive elements, have an additional local maximum of $|E|$ near frequency f'. Furthermore, conductive structures in these configurations cause a shift of the $|E|$ maxima. The amplitude of the shifted maxima is 0.5–13.4 dB lower for configurations with plates than for those with posts.

The results in Fig. 4(a) show that at resonance frequencies f_1 and f_2 of the empty enclosure, the MSL VSWR reaches peak values of 2.3 and 3.4, respectively. For configurations I' and II', the maxima shift to higher frequencies and have lower values. Specifically, for configurations with plates, the VSWR at resonance frequencies is 1.2–1.8, whereas for configurations with posts, these values are 1.6–2.6. The VSWR difference between configurations with plates and those with posts ranges from 0.4 to 0.9.



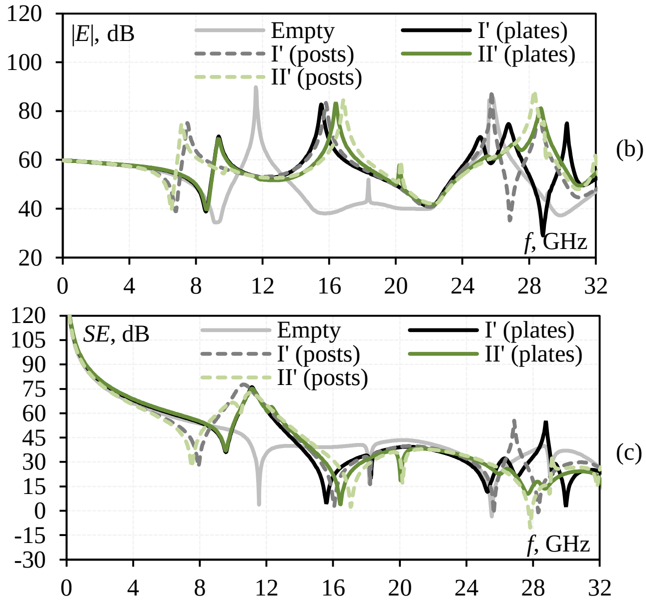


Fig. 4. Frequency dependencies of VSWR (a), radiated emissions $|E|$ (b) and SE (c) for configurations I' and II' of enclosure loaded with plates and posts ($s = a/4$).

TABLE V. ESONANCE FREQUENCIES (IN GHZ) AND SE (IN DB) AT THESE FREQUENCIES FOR CONFIGURATIONS I'–II' AND EMPTY ENCLOSURE

№	f'	f_1	f_2	$SE(f')$	$SE(f_1)$	$SE(f_2)$
I' (plates)	9.6	15.6	25.3	36	4.4	11.6
I' (posts)	7.9	16.1	25.6	27	2.7	–2
II' (plates)	9.6	16.5	27.6	37	4	10.3
II' (posts)	7.5	17	27.8	27	2.4	–10.4
Empty	–	11.5	25.5	–	3.7	–3.5

TABLE VI. RESONANCE FREQUENCIES (IN GHZ) AND $|E|$ (IN DB) AT THESE FREQUENCIES FOR CONFIGURATIONS I'–II' AND EMPTY ENCLOSURE

№	f'	f_1	f_2	$\|E\|(f')$	$\|E\|(f_1)$	$\|E\|(f_2)$
I' (plates)	9.4	15.5	26.8	69.5	82.8	75
I' (posts)	7.5	15.8	25.7	75	83.3	88.4
II' (plates)	9.4	16.4	28.7	68.8	83.6	81.3
II' (posts)	7.2	16.9	28.3	74.7	84.6	88.3
Empty	–	11.5	25.5	–	89.8	84.4

TABLE VII. RESONANCE FREQUENCIES (IN GHZ) AND VSWR AT THESE FREQUENCIES FOR CONFIGURATIONS I'–II' AND EMPTY ENCLOSURE

№	f'	f_1	f_2	VSWR (f')	VSWR (f_1)	VSWR (f_2)
I' (plates)	9.4	15.5	26.4	1.2	1.8	1.5
I' (posts)	7.5	15.8	25.7	1.7	2.2	1.9
II' (plates)	9.4	16.4	26.4	1.2	1.7	1.5
II' (posts)	7.2	16.8	28.3	1.6	2.2	2.6
Empty	–	11.5	25.5	–	2.3	3.4

V. CONCLUSION

This work investigated the possibility of improving enclosure SE by shifting cavity resonances through placing conductive plates and posts inside. Using full-wave FEM simulation, SE was evaluated for six enclosure configurations with internal plates and posts. Additionally, the effect of these conductive structures on MSL signal integrity (VSWR) and radiated emissions inside the PCB shield was assessed.

It was found that conductive structures inside the enclosure predominantly shift the first cavity resonance to higher frequencies, while the second resonance changes significantly less. Specifically, the maximum shift of the first resonance frequency Δf_1 reached 4.6 GHz for the enclosure with plates and 3.8 GHz with posts. As a result, an SE increase of up to 31.13 dB was observed. It was also found that conductive structures shift both the VSWR and emission maxima to higher frequencies while reducing their values. Compared with posts, configurations with plates reduce radiated emissions $|E|$ by up to 13.4 dB and reduce VSWR by up to 0.9.

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