# SYNTHESIZING SPARSE SHIELDS FROM A CUBIC WIRE GRID USING OPTIMAL CURRENT GRID APPROXIMATION

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**Reducing the mass of electronic devices remains one of the important engineering tasks. At the same time, there is a growing demand for lightweight electromagnetic shields. The application of the optimal current grid approximation (OCGA) has demonstrated significant effectiveness in synthesizing sparse shields from square grid wire (WG) structures, achieving a 2.1-fold mass reduction while maintaining acceptable shielding performance. However, since the characteristics are also directly influenced by the geometric configuration of the shield, it is convenient to apply OCGA to obtain sparse shields based on a cubic WG topology. The aim of this paper is to synthesize sparse shields from a cubic WG using OCGA. After comparative analysis of sparse antennas, scatterers, and shields generation, the shield structures were numerically simulated using the method of moments. Specifically, 4 sparse configurations were synthesized from a cubic WG topology via the OCGA framework, utilizing grid element elimination tolerances of 0.2, 0.5, 0.7, and 1%. The resulting sparse shields achieved a mass reduction of up to 1.2 times, along with a significant decrease in computational cost. The dependences of shielding effectiveness on frequency and distance are provided. Furthermore, the frequency and distance dependencies of shielding effectiveness were evaluated, allowing for a comprehensive performance comparison between the sparse configurations and the original WG shield. Sparse shielding synthesized from a cubic WG can be integrated directly into the design process of lightweight shields for telecommunications, aerospace, and other industries. The proposed approach is applicable to various WG shielding topologies. It not only facilitates a significant reduction in mass while preserving acceptable electromagnetic performance, but also substantially mitigates the computational cost associated with numerical simulations.**

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## 1 Introduction

Search for approaches to reduce the mass, dimensions, and cost of electronic devices without degrading their performance remains one of the urgent problems. There are no universal methods to reduce them simultaneously and for arbitrary types of devices. Among these types an electromagnetic shield holds a special place. Implementing a shield to provide efficiency of devices of complex shapes can unacceptably increase all three critical characteristics (mass, dimensions, and cost). To overcome this problem, engineers are currently employing wire-grid (WG) electromagnetic shields that proved to be a perfect solution thanks to their lightness and flexibility [1-3].

As a rule, these structures offer high shielding effectiveness (SE) [4-6], provided that their parameters (such as material properties, cell size, geometric typology, etc.) are optimally selected for specific applications, successfully replacing conventional solid metallic counterparts. Furthermore, the WG was employed to ensure optical transparency and natural ventilation, which are vital for high-power electronics [5]. Meanwhile, it was found that, under the influence of an incident wave, the shield contained numerous wires that conducted low currents, which had a negligible impact on the overall shielding characteristics [7]. The removal of these redundant conductors not only reduced the total mass but also provided significant advantages with regard to transportation, installation efficiency, and advanced ventilation capabilities of the protected systems.

The OCGA allows precise control over the mass and performance characteristics of WG structures by eliminating conductors whose current magnitude is below a specified grid element elimination tolerance (GEET) [8, 9]. The resulting current distribution and electromagnetic characteristics are determined using the method of moments (MoM), widely adopted in electrodynamic modeling due to its accuracy and relatively low computational cost [10–12]. Previously, the effectiveness of OCGA was successfully demonstrated in the design of sparse WG antennas [13] and scatterers [14, 15]. Furthermore, this approach enabled the development of the first sparse shields synthesized from a square WG topology, achieving a 2.1 times mass reduction (with GEET = 20%) preserving shield performance characteristics [7]. However, shield effectiveness depends not only on parameters such as cell size and conductor radius, but also on the geometric typology of the shield. Therefore, it is useful to evaluate the applicability of OCGA to alternative configurations, particularly in closed topologies, such as a cubic shield.

The objective of this work is to synthesize sparse shields from a cubic WG using OCGA after preliminary comparison of sparse antennas, scatterers, and shields generation.

## 2 Comparative analysis of sparse antennas, scatterers, and shields generation

Here, we for the first time compare the process of generating sparse antennas, scatterers, and shields using OCGA. This comparative analysis cannot yet be objectively complete and accurate, at least, because of differing amount of performed research. Indeed, the investigations of sparse antennas have started the earliest (in 2023). These investigations initiated several useful OCGA modifications, but the number of antennas was small, and all antennas were of linear polarization. The investigations of sparse scatterers have begun relatively recently (since the beginning of 2025) and employed OCGA modifications designed for antennas, which allowed various types of scatterers to be studied in a short period of time. Finally, the investigation of sparse shields began in the second half of 2025, and the first results for the simplest (rectangle) shield was published only in one journal paper [7]. Therefore, fully objective comparison is complicated by the difference of the data to be compared. Nevertheless, this comparative analysis, no matter how incomplete or inaccurate it may seem, is still instructive since it can reveal factors that are important for future studies.

OCGA was first applied to antennas, and this approach was very simple. As it was found later, the reason for this simplicity was a source gap, which is a conductor section that has the potential difference between its ends of 1 V. This gap is a specific feature of excitation in the modeling of any antenna, and when modeling by the method of moments, the approach is reduced to a single solution of a system of linear equations with one right part consisting of zeroes except for the element that corresponds to the source gap equal to 1 V. From the solution vector, representing the currents in each wire, all necessary characteristics can be easily obtained. So, for example, the inverse of solution vector entry that corresponds to the same section with a source gap is the antenna input impedance that can be easily used to obtain an important for any antenna reflection coefficient. Furthermore, if we sum the computed by simple formula intensities of electric field in assigned space points, generated by each wire with known currents, we can obtain the main antenna characteristics such as its radiation patterns. These space points can be numerous but the key thing is that all computations for them are rapid, whereas the solution of SLAE, which requires the main computational cost, is performed only once.

OCGA application to scatterers initially seemed as simple as its application to antennas. Indeed, large-square WGs in both cases act as objects of direct sparsification. An example is a reflector antenna, which inherently contains a scatterer; it is this scatterer that is sparsified in the antenna. However, the antenna reflector is usually exposed only from one direction, while the scatterer must generally be exposed from all directions. Thus, the computation of an effective radar cross-section for one plane is usually performed from 0 to 360º with an angle step of no more than 10º, which requires minimum 36 calculations. To obtain 3D-patterns with the same step, we need 36×36=1296 computations. When a scatterer is modelled by the method of moments, each computation requires a separate solution of SLAE, because variations of exposure direction change the right part of SLAE. This considerably increases computational cost, even if we use single LU-factorization with multiple quick solutions of SLAE for each right part. However, further challenges remain. Indeed, each solution yields its own current distribution. If we eliminate scatterer wires only by the criterion of current limitations, then we need to eliminate different wires for each exposure direction; however, this is unacceptable. To solve this problem, Dang et al. [13] proposed to control the quantity of wires that remain in the sparsed scatterer for each exposure direction with an acceptable variation of scattering and to leave no more than the assigned quantity of wires in the

sparsed scatterer. This process complicates the algorithm of scatterer synthesis.

OCGA application to shields initially seemed similar to scatterers. Indeed, in this case, a large-square WG exposed by a plane wave is also an object of direct sparsification. In the meantime, antennas and scatterers are usually analyzed only for the far zone, whereas shields must be analyzed for the near zone as well. This analysis implies the SE computation not only for electromagnetic field, but also for electric and magnetic fields separately. Thus, not one but three characteristics must be controlled, which complicates the stability control because of different changes in these characteristics after sparsification. An additional feature is that shield sparsification may require control of these characteristics in directions that did not previously require control. This is not the case, for example, of a simple rectangular shield where control is exercised over the field, usually outside of the shield and often in one direction. However, for the closed shape shield (for example, cubic), one needs to compute the field inside the shield and not only alone the line but also over the plane or even the volume. In this case, the filed outside the shield is computed quiet rarely. However, large WG portions in many places and in various walls of the shield can disappear after the sparsification; therefore, the field in front of or outside them can considerably change. Moreover, one can need to analyze the shield not only in the most vulnerable direction (for example, for the plane wave orthogonally incident on a slot), but also in a plane of some angle or even in all directions, for both angles, as in the case of a scatterer. Of course, this feature does not compromise the idea of OCGA application to shields, but it can require considerably more complex and careful synthesis. On the other hand, it is not so surprising and can be quite acceptable if we realize that such a shield, «perforated» in many places but having lower mass and cost, will function almost the same as the previous shield. It is difficult to completely investigate all these features in one paper; therefore, we present here only the first steps in this direction.

### 3 Main stages of sparse shield synthesis using OCGA

The following stages are performed to synthesize sparse shields using OCGA:

**Stage 1. Parameter initialization**: determination of the incident wave parameters (polarization and frequency range) and the geometric characteristics of the original WG shield (cell size and conductor radius).

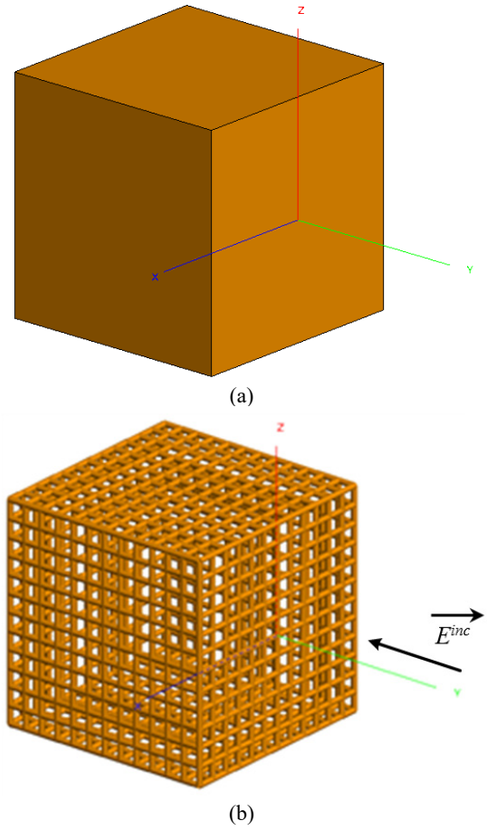
**Stage 2. Current distribution calculation**: evaluation of the current magnitude in each wire $|I_j|$ ($j$= 1, ..., $N$) for the original structure composed of $N$ wires. The calculation is performed using MoM with pulse basis functions, solving a linear system **Zi** = **v** where **Z** is the impedance matrix, $v$ is the excitation vector, and $i$ is the unknown current vector.

**Stage 3. Normalization and removal of WG elements**: identification of the maximum current magnitude $|I|_{max}$ among all $I_j$ elements, followed by normalization of the currents in the original structure using the relation $|I_j|_{norm}=(|I_j|/|I|_{max})\times100\%$. Then, a GEET limit is assigned from 0 to 100%. The wires that satisfy the condition $|I_j|_{norm}$<GEET are removed from the topology.

**Stage 4. Sparse shield construction and performance evaluation**: synthesis of the sparse shield configuration from the remaining segments. Consequent to the reduced number of conductors, both the total shield mass and the computational cost of the numerical analysis are substantially decreased. The SE is evaluated using expressions $SE_E=20\log_{10}(|E^0|/|E|)$ and $SE_H=20\log_{10}(|H^0|/|H|)$, where $E^0$ and $H^0$ represent the electric and magnetic field strengths of the incident wave, respectively, while $E$ and $H$ denote the total resulting fields (the superposition of the field scattered by the structure and the incident wave field).

### 4. Sparse WG shields in the form of a cube

The original structure is a closed shield synthesized from a cubic WG with sides of 0.6 m (Fig. 1). The WG is excited by a vertically polarized plane wave at a frequency ($f$) of 500 MHz (corresponding to a wavelength of $\lambda$=0.6 m) and an amplitude of 1 V/m, with incident angles defined as $\theta^{inc}=\varphi^{inc}=90°$. The center of the front face of the cube coincides with the origin of the coordinate system. The WG cell dimensions are 5×5 cm ($\lambda$/12), which satisfies the requirements specified in [5, 6]. The original shield comprises 1,728 wires with a radius of 0.8 cm (according to the equal area rule).




(a)

(b)

**Fig. 1**. Solid cube (a) and its WG equivalent (b)

To synthesize sparse shields, the current distribution (Stage 2) was determined at a design frequency of $f$=500 MHz. Figure 2 illustrates the sparse shields synthesized using OCGA with GEET of 0.2, 0.5, 0.7, and 1%. As observed, the sparse process eliminated a significant portion of the horizontal conductors, particularly on the shield face exposed to the incident wave. On the other hand, the vertical wires were preserved, because under excitation by a vertically polarized wave, the currents in them were much larger than those in the horizontal ones. Notably, despite the weight reduction of the cubic shield, the wire interconnections were fully maintained, thus preserving their structural integrity and mechanical strength.

This advantage distinguishes the cubic shield from the planar topology of [7]. The resulting mass reductions and computational cost savings for these models are summarized in Table 1.

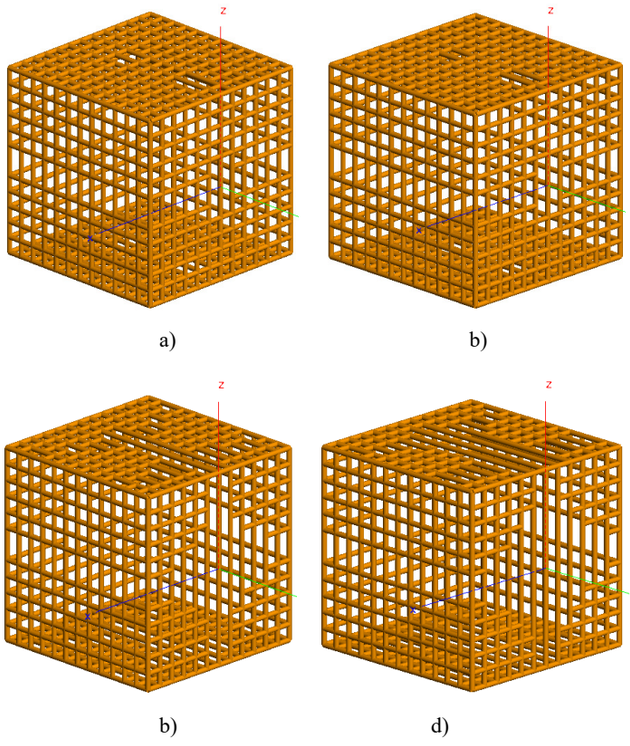



**Fig. 2**. Sparse shields when GEET=0.2% (a), 0.5% (b), 0.7% (c), and 1% (d)

Table 1

Reducing the mass and computational costs of sparse shields after OCGA

| Structure | Number of segments | Weight reduction, times | Memory reduction, times | Time reduction, times |
|---|---|---|---|---|
| Initial WG | 1728 | 1 | 1 | 1 |
| GEET=0.2% | 1664 | 1.04 | 1.08 | 1.13 |
| GEET=0.5% | 1588 | 1.1 | 1.21 | 1.33 |
| GEET=0.7% | 1560 | 1.11 | 1.23 | 1.37 |
| GEET=1% | 1500 | 1.2 | 1.44 | 1.73 |

## 5 Comparing the characteristics of shields from the original and sparse WG

The frequency dependencies of $|E|$ and $|H|$, as well as $SE_E$ $SE_H$ at the observation points (0, –0.2, 0), (0, –0.3, 0) – corresponding to the cube center – and (0, –0.4, 0), are illustrated in Figs. 3-5. It can be seen that the WG shielding exhibits resonance frequencies for both $|E|$ and $|H|$ approximately at $f$≈360, 560, 610, 740, 790, and 920 MHz. Based on these assessed values of $|E|$ and $|H|$, SEs were calculated, demonstrating that. Both the original and sparse shielding performed well, maintaining $SE_E$>30 dB within the 10–340 MHz, 380–540 MHz, and 630–720 MHz bands, while the $SE_H$ remained above 40 dB across the entire analyzed frequency range.

The sparse shielding configurations designed at GEET=0.2 and 0.5% demonstrated excellent agreement in shielding performance with the original WG structure. Notably, at GEET=0.7% and 1%, the sparse configurations outperformed the original shield, specifically, in terms of $|E|$ for the $f$≈10-200, 420-590, and 640-780 MHz, and in terms of $|H|$ for the $f$≈390-1000 MHz. On the other hand, higher GEET levels also tended to increase deviations in the characteristics of the sparse shields from the original structure in specific bands, mainly at $f$≈200-330 MHz. This behavior is attributed to three main factors. First, increasing GEET leads to the removal of conductors carrying higher currents, which directly alters the electromagnetic field distribution. Second, the structural optimization was performed exclusively at the design frequency of 500 MHz, rendering the sparse structure sub-optimal at other frequencies. Thirdly, the current phases are directly influenced by the organization of each segment within the structure, whereas the main OCGA approach is based exclusively on the magnitudes of the currents and neglects phase information, which induces additional deviations in the characteristics. However, an increase in GEET results in a proportional reduction in both shield mass and computational cost. The average deviations in shielding characteristics are summarized in Table 2.

Table 2

Deviations of the SE of sparse WG shield from the original one

| GEET, % | Average deviation, dB | | | | | |
|---|---|---|---|---|---|---|
| | $f$=10–1000 MHz | | (0, $y$, 0) | | ($x$, –0,3, 0) | |
| | $SE_E$ | $SE_H$ | $SE_E$ | $SE_H$ | $SE_E$ | $SE_H$ |
| 0.2 | 1.6 | 0.9 | 1.2 | 1 | 0.77 | 1 |
| 0.5 | 2.4 | 3 | 3.3 | 2 | 3.49 | 2.9 |
| 0.7 | 6.5 | 4 | 7 | 4.9 | 2.24 | 4 |
| 1 | 7 | 7.5 | 11.9 | 6.7 | 4.75 | 9 |

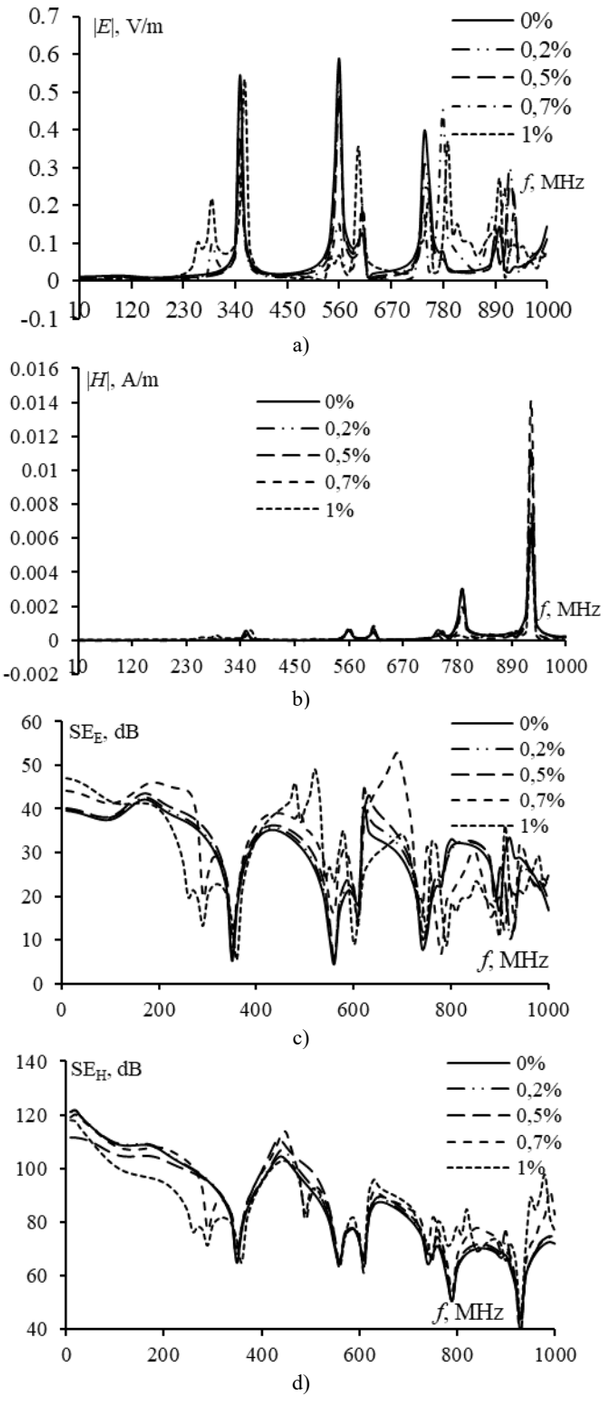



**Fig. 3**. Frequency dependences of $|E|$ (a), $|H|$ (b), $SE_E$ (c) and $SE_H$ (*d*) at the point (0, –0.2, 0)

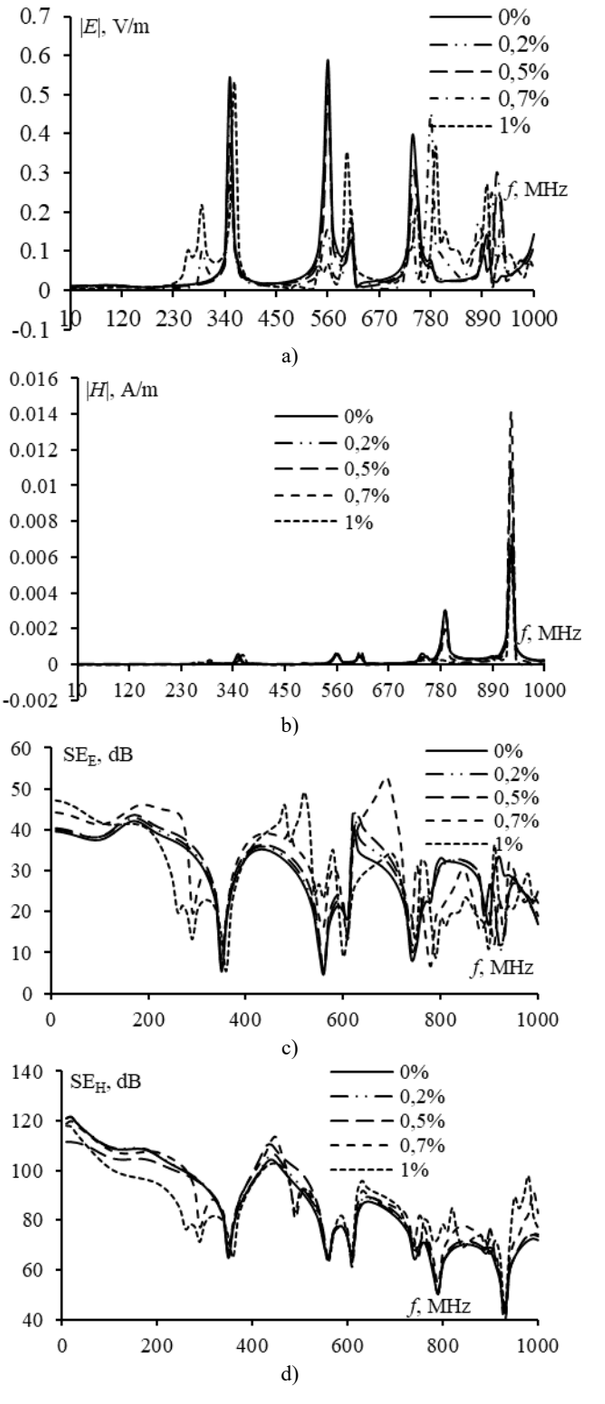



**Fig. 4**. Frequency dependences of $|E|$ (a), $|H|$ (b), $SE_E$ (c) and $SE_H$ (d) at the point (0, –0.3, 0)

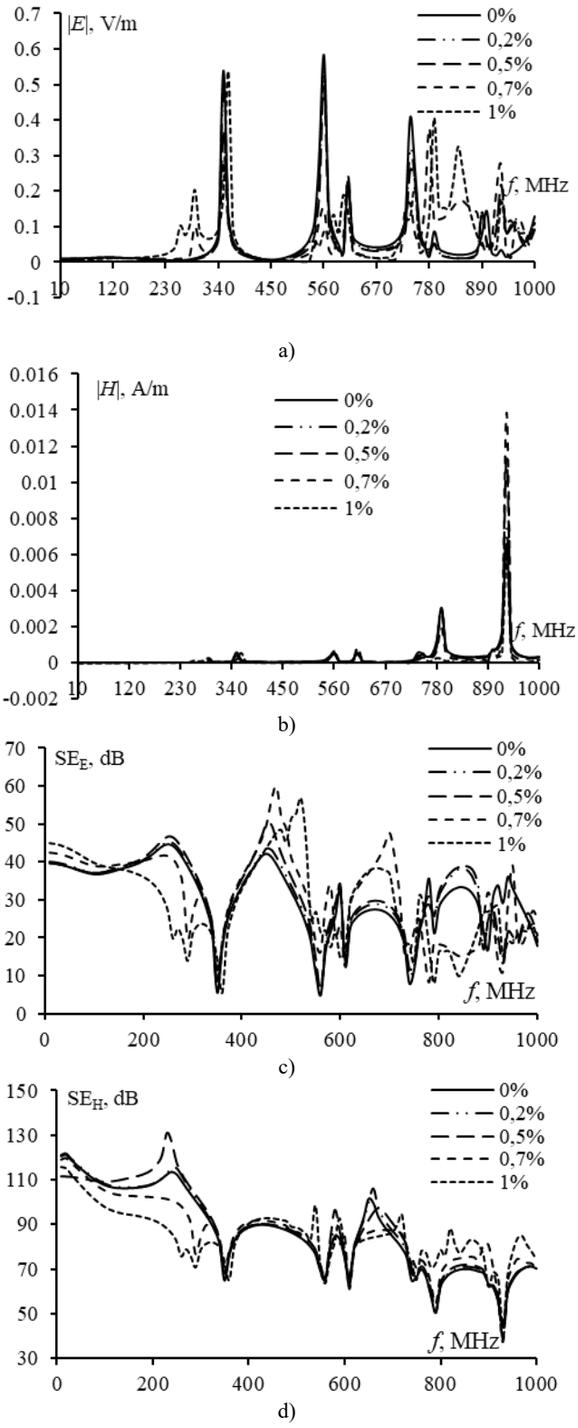
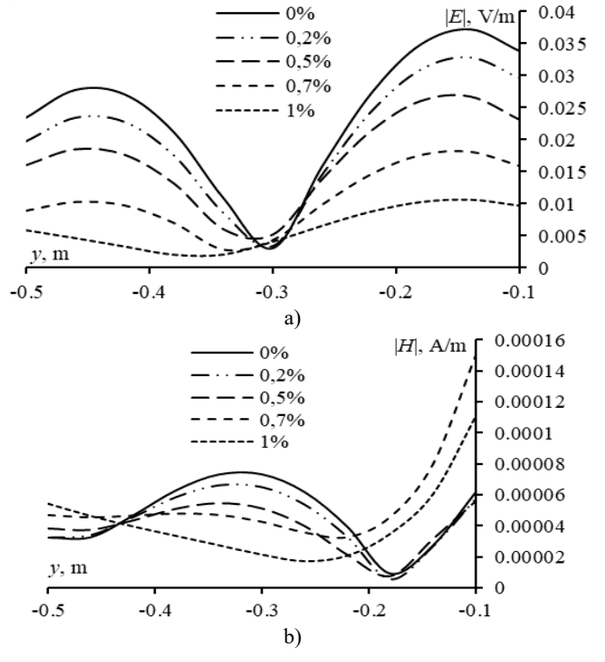



**Fig. 5**. Frequency dependences of $|E|$ (a), $|H|$ (b), $SE_E$ (c) and $SE_H$ (d) at the point (0, –0.4, 0)

According to standard [5, 6], to ensure a denser barrier against electromagnetic interference (EMI) using a WG shield, particularly for specialized electronic devices, requires a reduced cell size, down to λ/50; however, this increases the mass. To mitigate this, rather than diminishing the cell size to improve the SE, it is sufficient to reduce the mass using the OCGA, which substantially increases the effectiveness of the shields.

Figures 6 and 7 illustrate the relationships between the characteristics and the distance at $f$=500 MHz. At the points (0, $y$, 0) in Figure 6, the total $|E|$ on the front face is larger than that on the back face. This behavior occurred because the front face was directly exposed to the incident wave, which induced higher current magnitudes in its wires. As the observation point shifted away from the source toward the center of the shield, $|E|$ decreased to a minimum at $y$=–0.3 m, whereas $|H|$ increased. Consequently, the $SE_E$ at the center outperformed the other points along the (0, y, 0), peaking at y = –0.3 m (≈49 dB); the maximum $SE_H$ was observed near the front face, peaking at $y$=–0.18 m (≈101 dB). At the specified frequency, for most points, the $SE_E$ and $SE_H$ values of the sparse shields also proved to be even better than those of the original shielding, especially at GEET=1%. At points ($x$, -0, 3, 0) in Figure 7, $|E|$ increases from the center to the edges, while $|H|$ decreases, which naturally exhibits the inverse behavior of SE. This demonstrates that $|E|$ is larger and $|H|$ is smaller near the lateral faces compared to the center.

Hence, it is evident that the induced currents along the pair of lateral faces were symmetric, unlike the asymmetric distribution on the front and back faces. Here, a superiority of the sparse shields over the original one was also observed at many points, exhibiting a higher SE. These results confirm again confirm the effectiveness of lightweight shielding for potential applications in various areas of science and technology where reasonable mass control is required, but with improved performance. The average deviations of the sparse configurations relative to the original shield are summarized in Table 2. Note that the largest average deviations were directly associated with the performance superiority of the sparse shielding configurations over the original structure.



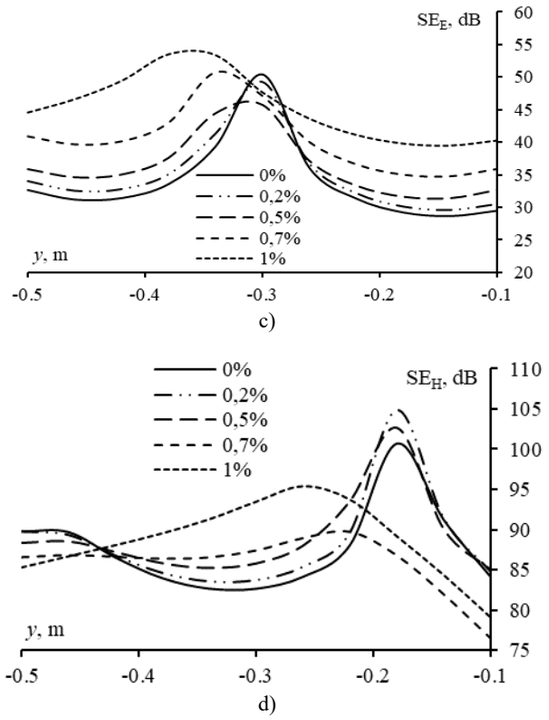
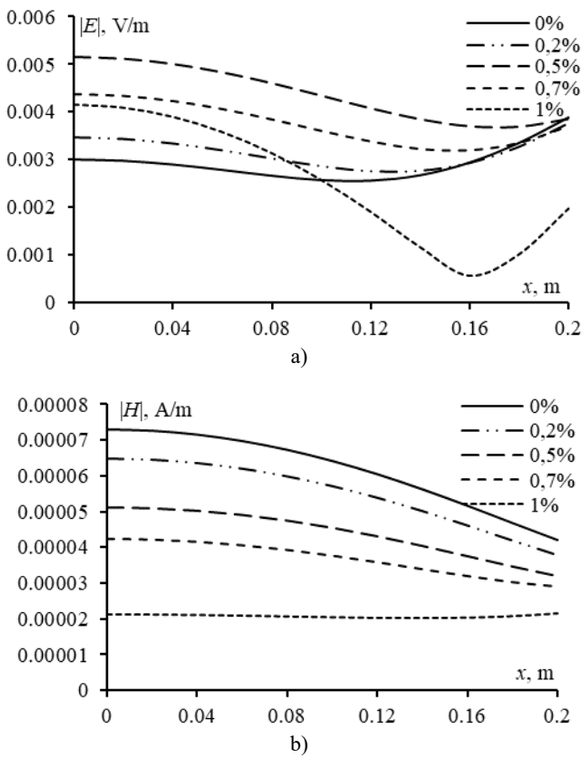



**Fig. 6**. Dependences of $|E|$ (a), $|H|$ (b), $SE_E$ and $SE_H$ of shields with different GEET on the distance at points (0, $y$, 0) for $f$=500 MHz



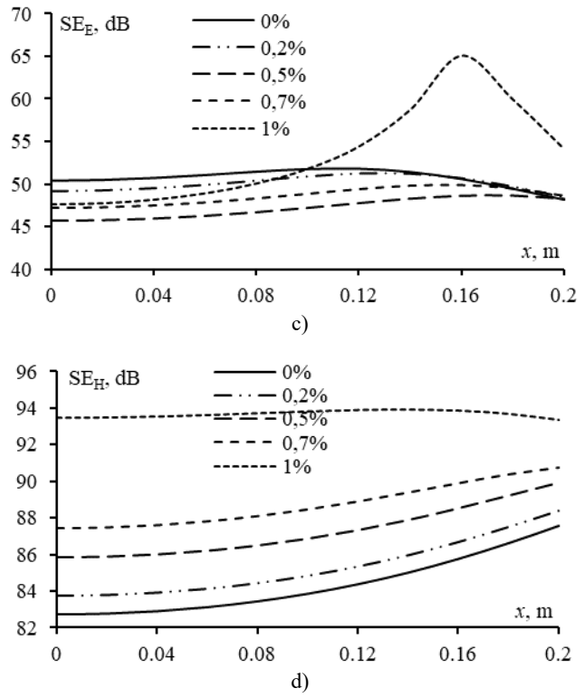




**Fig. 7**. Dependences of $|E|$ (*a*), $|H|$ (*b*), $SE_E$ and $SE_H$ of shields with different GEET on the distance at points ($x$, –0.3, 0) for $f$=500 MHz

Finally, the OCGA application to a closed structure helps not only to reduce the shield mass but also to enable precise control over its electromagnetic characteristics while fully preserving mechanical strength. This represents a critical advantage over the planar topology where the removal of elements caused the remaining wires to lose galvanic connectivity. Although applying the OCGA to the cubic model yielded a smaller mass reduction compared to the planar case, the shielding performance was significantly enhanced, even at GEET = 1%. The GEET value can therefore be tailored based on the operational requirements to ensure the necessary level of electromagnetic interference protection.

## 6 Conclusions

After comparative analysis of sparse antennas, scatterers, and shields generation, the sparse shields were successfully synthesized from a cubic WG topology using the OCGA, and their shielding performance was comprehensively evaluated against the original structure. This approach achieved up to a 1.2 times mass reduction while simultaneously enhancing performance across both frequency and distance dependencies.

The main physical causes underlying the characteristic deviations in certain frequency ranges and observation points were identified. Although the sparse cubic WG shielding configurations yielded a more conservative mass reduction compared to the 2.1 times reduction reported for the planar structure in [7], they delivered significantly superior shielding characteristics.

Future research will focus on maximizing mass reduction and minimizing characteristic deviations through modernization of the OCGA design, as well as on evaluating effectiveness at higher frequency bands.

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## СИНТЕЗ РАЗРЕЖЕННЫХ ЭКРАНОВ ИЗ КУБИчЕСКОЙ ПРОВОДНОЙ СЕТКИ С ПОМОЩЬЮ АППРОКСИМАЦИИ ОПТИМАЛЬНОЙ ТОКОВОЙ СЕТКОЙ

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**Аннотация**

Снижение массы радиоэлектронных устройств остается одной из важных задач. Вместе с тем, растет и интерес к созданию легких электромагнитных экранов. Использование аппроксимации оптимальной токовой сеткой (АОТС) показало эффективность в создании разреженных экранов из квадратной проводной сетки (ПС), позволявшей снизить массу экрана до 2,1 раза с приемлемыми характеристиками. Однако на характеристики экрана влияет и его форма, поэтому целесообразно рассмотреть АОТС для получения разреженных экранов из ПС в виде куба. Цель работы - синтез разреженных экранов из кубической ПС с помощью АОТС. После сравнительного анализа синтеза разреженных антенн, рассеивателей и экранов. выполнено моделирование структур экранов методом моментов. Получены 4 разреженных экрана из ПС в виде куба с помощью АОТС с допусками удаления элементов сетки 0,2, 0,5, 0,7, 1%. Приведены уменьшения массы (до 1.2 раза) и вычислительных затрат для разреженных экранов. Представлены зависимости эффективности экранирования от частоты и от расстояния. Сравнены характеристики разреженных и исходного экранов из ПС. Разреженные экраны из ПС в виде куба могут быть внедрены в процесс проектирования легких экранов для телекоммуникационной, аэрокосмической и других отраслей. Предложенный подход может быть применен для различных типов экранов из проводной сетки и помогает не только снижению массы, сохраняя приемлемые радиотехнические характеристики, но и сокращает вычислительные затраты на моделирование.

***Ключевые слова:*** *проводная сетка, аппроксимация оптимальной токовой сеткой, разреженные экраны, эффективность экранирования.*

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