Optimizing Antenna Modeling and Manufacturing with MoM-WireGrid and C/OCGA Approaches

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***Abstract*— In this paper, the results of a modified approach for antennas modeling using their approximated sparse wire-grid structure were verified. The verification is performed on the example of a horn antenna and a conical horn antenna modeled and fabricated earlier in other works. The comparisons showed a good agreement. The modified approach proved its ability to design sparse antenna structures, that can be used both in antenna modeling with less computational costs from other methods and in manufacturing of such structures with less technical difficulties from another approach proposed earlier.**

Keywords*— *wire-grid; horn antenna; conical horn antenna; sparse antennas; method of moments; optimal current grid approximation

I. INTRODUCTION

Many studies have been made on antenna modeling and manufacturing, since they are important component of any radio electronic device [1], and especially the smart [2–5], wearable [6–8], and satellite antennas [9–11]. Much attention has been paid to the cost and the improvement of antenna manufacturing technologies. It is desirable to obtain a final product of small size and weight while maintaining the required characteristics [12]. Meanwhile, modeling costs in antenna design are equally important. That’s why, the choice of the numerical method used in antenna modeling can remarkably affect the total design cost. A considerable number of studies were done on antenna modeling, especially those related to wire-grid modeling approach [12–14], since it can significantly reduce the computational cost, and those related to designing sparse antennas [15–18], since this can help in optimizing the antenna structure and obtaining its desirable characteristics. One of the widely used method in such studies is the method of moments (MoM) [19]. MoM enables one to develop new approaches on its base, since it has a simple algorithm and low discretization cost and can give acceptable results using less resources than other methods. Therefore, it is reasonable to combine the wire-grid approach and the sparse antenna designing technology in one approach with MoM core in order to take advantage of their benefits [20]. A modernized approach for antenna modeling based on MoM was presented in [20]. It is based on approximating the surface of conducting surfaces with a grid of wires to reduce the computational cost compared to other electrodynamic approaches. This approach was applied on the example of a horn antenna modeling. The obtained results were compared with the measured ones to verify them. The compared results showed a good agreement. In addition, an approach for modeling wire-grid sparse antennas was proposed in [22]. This approach has been called “Optimal Current Grid Approximation” (OCGA). Moreover, the work also presented a modification of the OCGA, named "connected OCGA” (COCGA). COCGA reduces the technical difficulties in the manufacturing of sparse antennas in comparison with OCGA, by preserving the physical connections of the grid wires without breaking the main current paths in the antenna. However, developing this approach requires applying it to typical antenna structures and verifying its performance. Therefore, the purpose of this work is to evaluate the performance of the COCGA approach and to verify its results by applying it on the example of a horn and a conical horn antennas. This paper is organized as follows: the second section provides detailed explanations for the used antenna modeling and designing two approaches. The third section presented the results of employing these approaches on the example of two antenna structures. In addition, a comparative analysis of the obtained results is provided. The last section summarizes the work done in this paper besides the conclusions and the planned future work.

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II. MODELING AND DESIGNING APPROACHES

A. OCGA brief description

According to OCGA, the current matrix elements obtained after the first simulation in the traditional wire-grid approach should be normalized with respect to the maximum current magnitude in the grid wires. Then, the wires with a current magnitude less than a certain level have to be excluded from the grid. This level is determined by a coefficient called the “Grid Element Elimination Tolerance” (GEET). Note that the GEET value is set on the user demand to obtain the desired characteristics and results accuracy. Applying OCGA can reduce mass, windage, and size of the antenna, but maintains its characteristics with controlled accuracy. To do this, the matrix indexes of the wires whose current magnitude after normalization is less than GEET are stored in a separate list. Then, according to the resulting list, the columns and rows of the matrix of the linear algebraic equations (SLAE) system, corresponding to these indexes, are deleted. Then, based on the obtained impedance matrix of the resulting SLAE a sparse antenna structure is built. The obtained sparse structure can be used in antenna modelling instead of the original one in further simulations, which lead to reduce the computational costs. Moreover, the obtained structure may be manufactured in its final form if there are no technical difficulties. In this way, the resulting sparse antenna will have less weight and sizes with the acceptable characteristics compared to those of the original one (the antenna with solid metal or even its equivalent wire-grid structure).

B. COCGA brief description

If the OCGA is implemented in modeling antennas, the resulting sparse structure will be difficult to manufacture in some cases, especially for non-printed antennas. The difficulty is due to excluding wires in a way that leaves some of them without physical connection with any wire, which in turn breaks the main current paths in the antenna. Therefore, the algorithm of OCGA should be modified in such way that preserve these paths producing a more seamless sparse antenna structure. This is achieved by building each section in the structure separately. Each section contains a group of connected wires whose indexes in the structure matches their indexes in the SLAE matrices. The wires that have odd indexes are the concentric ones, and those with even indexes are the radial. After building all sections to form the whole structure, the OCGA is then applied and the list of the indexes correspond to the elements need to be deleted is obtained. Next, and before building the sparse structure, each element from the original list of the whole wire indexes must be checked to make sure that deleting the wire corresponding to it will not leave any wire without connections with the other. To do this, the algorithm of this approach checkup whether the indexes of the wires, which must be connected to the one under checking, are all also in this list. If yes, then the algorithm will exclude the indexes which correspond to the first radial wire connected to it. The reason behind choosing the radial wire is that, as it is known, the surface current in the antenna tends to flow in them more that in the concentric ones [20]. Likewise, the algorithm will check whether this radial wire connected to any concentric one from its other end. If not, the algorithm will continue excluding the indexes of the further radial wires until finding a connection with a concentric wire or reaching the essential level, which connect all the radial wires. This level is determined regarding to the shape of the antenna structure and the wires at this level must not be deleted. Saving the wires of this level is necessary as they form the base, on which the physical structure will be built. As a result, and after repeating this process for all indexes, a new list of indexes can be obtained. This list contains indexes of all the wires that can be deleted without breaking the current flowing path. Even though the number of the deleted wires after applying COCGA is bigger comparing to OCGA, the reduction in the computational costs, mass, and size of the antenna is slightly differs at the same GEET. Moreover, the COCGA can give structures with more accurate characteristics than OCGA, as will be shown in the next section, besides its capability to reduce the manufacturing technical difficulties.

III. Results

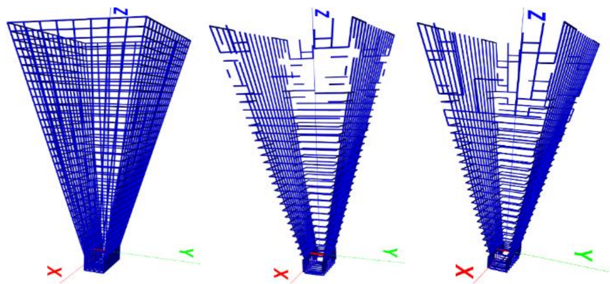
In order to evaluate the performance of the COCGA and to verify its results, we applied it on the example of horn [20] and conical horn antennas [23]. At first, both of these antenna structures were modeled using the wire-grid approach presented in [20]. Then the OCGA and the COCGA were employed, the results of which were compared to each other and to those of wire-grid. In addition, the obtained results were compared either to the measured one or to those obtained using other numerical methods obtained in other works in order to verify them.

A. Horn antenna

When modeling, using the approach from [21], the grid of the horn antenna regular part was divided into 8, 4, 8 parts along the OX, OY, and OZ axes, respectively. The grid of the irregular part was divided into 16, 8, 32 parts. The total number of wires (N) used to approximate the antenna surface was 3556 wires. The antenna was excited by wire with a potential difference of 1 V, placed in the plane which splits the regular and irregular parts of the horn and between its wide walls. Figure 1*a* shows the approximated antenna structure by wire grid (hereinafter it will be referred to as the original structure), and its radiation pattern (RP) calculated and measured at 8 GHz, are shown in Fig. 2 [21]. The normalized field strength magnitudes were calculated in the E and H planes.

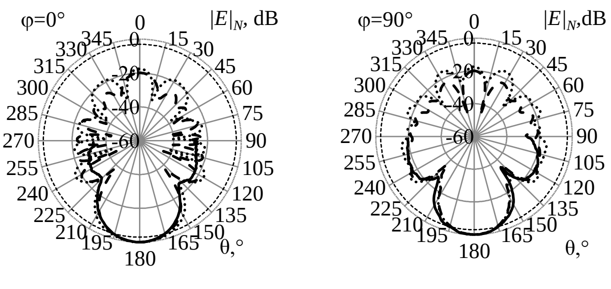
Next, the OCGA is applied. The GEET value is assumed here, exemplarily, to be 10%. On the basis of the obtained SLAE after employing the OCGA, the sparse antenna structure with the number of wires N_S=2080, was built and presented in Fig. 1*b*. The RPs of the sparse structure were compared with the calculated and measured ones in Fig. 2. The main time consumption for solving the SLAE (here by the Gaussian method), is proportional to the third degree of its order $O(N)^3$, and the required memory is $O(N)^2$. As a result, the antenna mass decreased by N/N_S=1.71 times, the required memory is reduced by $(N/N_S)^2$=2.92 times, and time for SLAE solving is reduced by $(N/N_S)^3$=5 times. Fig. 2 shows that the level of the sidelobes for the sparse structure is higher than for the original one.

Further, the COCGA is applied and the obtained sparse structure using it is presented in Fig. 1*c*. The calculated RPs in the E and H planes are compared in Fig. 3 with those obtained for the sparse structure using OCGA, and with the measured ones. The number of wires of the resulting structure was 2188. Thus, the mass of the antenna decreased by 1.63 times, the required memory by 2.64 times and the time for solving SLAE by 4.29 times. Despite the fact that the reduction in computational cost and mass when using the COCGA, is slightly more than those using the OCGA, the obtained sparse structure does not complicate the manufacturing of the antenna under study, since there are no hanging wires. Meanwhile, the level of the antenna RP sidelobes has decreased significantly.



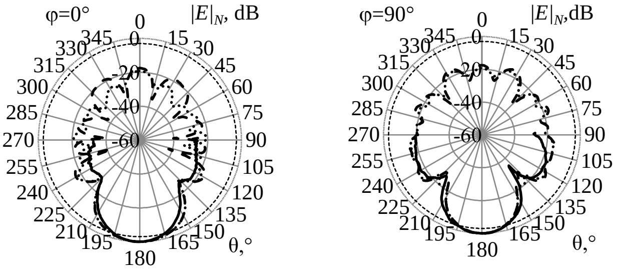
(a) *(b)* *(c)*

Fig. 1. Original [21] (*a*) and sparse using OCGA (*b*) and COCGA (c) horn antenna structures.



(a) *(b)*

Fig. 2. Horn antenna RPs calculated for the original by wire-grid [21] (---) and the sparse structure by OCGA with GEET=10% (····) and the measured ones [21] (—), in E (*a*) and H (*b*) planes.

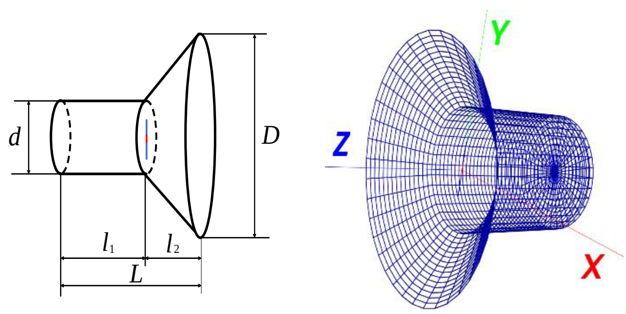


(a) *(b)*

Fig. 3. Horn antenna RPs calculated by OCGA (---) and COCGA (····) with GEET=10%, and the measured (—) ones in *E* (*a*) and *H* (*b*) planes.

B. Conical horn antenna

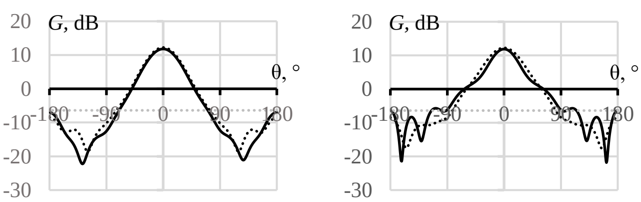
To verify effectiveness of COCGA on the example of a conical horn antenna, we chose the antenna in [23], the isometric view of which is presented in Fig. 4*a*. The antenna structure has the following geometrical parameters: the diameter of the regular part d=30 mm, the maximum diameter of the irregular part D=61.76 mm, the height of the regular part l_1=31.25 mm, the height of the irregular part l_2=12 mm. To excite the antenna, we used a wire with length of l_d=0.36λ, placed in the center of the intersection between the antenna regular and irregular parts. At first the antenna was modeled using wire-gird approach from [21]. The radius of all grid wires was assumed to be 0.1 mm. The total number of wires used to approximate the antenna surface N=3600. Fig. 4b shows the structure of the approximated antenna using wire-gird (hereinafter it will be referred to as the original structure).



(a) *(b)*

Fig. 4. Isometrical view of the conical horn antenna (*a*) [23] and the structure of the antenna approximated using wire-gird [21] (*b*)

The obtained antenna RPs at the frequency of 8 GHz for the original structure using wire-grid, were compared with those obtained by the finite difference method in the time domain (FDTD) in [23]. The antenna gains (AG) were compared in the *E* and *H* planes (Fig. 5). The time spent on modeling using wire-grid [21] was 34.9 s, which is by 1.15 times faster than FDTD [23], by the same computer resources.

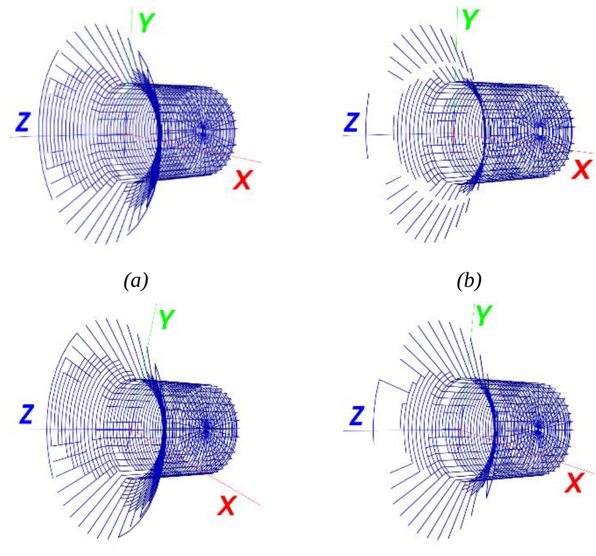


(a) *(b)*

Fig. 5. Antenna RPs for the original (····) by wire-grid [21] and by FDTD [23] (—) in *E* (*a*) and *H* (*b*) planes.

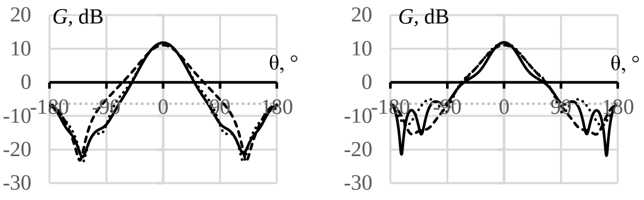
Further, the OCGA was applied and the sparse antenna RPs were obtained with GEET value of 6% and 10%. The resulting sparse antennas are shown in Fig. 6, and the number of wires in their grids was N_S=2846 at 6%, and 2362 at 10%. The obtained RP were compared in the *E* and *H* planes with those obtained using FDTD in [23] (Fig. 7). It can be seen that with GEET increasing, the divergence of the results increases, but the radiation in the main direction remains acceptable. It is also noticeable that the level of the sidelobes for the sparse structure at GEET=6% is less than the one using FDTD [23]. Applying the OCGA results in a decreasing the antenna mass by 1.26 times at GEET of 6% and by 1.52 times at 10%. The reduction in the required memory was by 1.60 and 2.32 times, and in the required time for SLAE solving was by 2.02, and 3.54 times, at GEET of 6% and 10%, respectively. The total time spent on the simulation by OCGA at GEET of 6% and 10% was 22.04 s and 13.93 s, which is by 1.81 times and 2.087 times faster than the spent by FDTD [23].

Then, using COCGA, we obtained the sparse antennas at GEET of 6% and 10% (Fig. 6). The numbers of wires in their grids were 2916 at 6%, and 2502 at 10%. Their RPs were compared in the *E* and *H* planes with those obtained by FDTD [23] (Fig. 8). As a result of COCGA employing, the mass of the antenna decreased by 1.26, and 1.44 times, the required memory by 1.52, and 2.07 times, and required time by 1.88, and 2.98 times, with GEET of 6% and 10%, respectively. The time spent on simulation using COCGA at GEET of 6% and 10% was 22.44 s and 15.85 s, which is by 1.78 times and 2.52 times, respectively, faster than using FDTD [23]. For clarity, the results obtained with OCGA and COCGA were compared in Fig. 9. It can be seen that the results divergence from those obtained using FDTD for those by COCGA is less than by OCGA with GEET increasing. It is noticeable that the level of the sidelobes and points of zero radiation for the sparse antennas with COCGA is less than with OCGA (on average by 10 dB), while maintaining the acceptability of the results with GEET increasing, which gives COCGA an advantage over OCGA in terms of the modeling results accuracy and the ease of manufacturing.



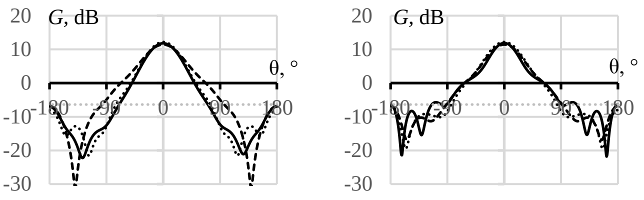
(a) *(b)* *(c)* *(d)*

Fig. 6. The sparse antenna structures using OCGA with GEET 6% (*a*) and 10% (*b*) and using COCGA with GEET 6% (*c*) and 10% (*d*).



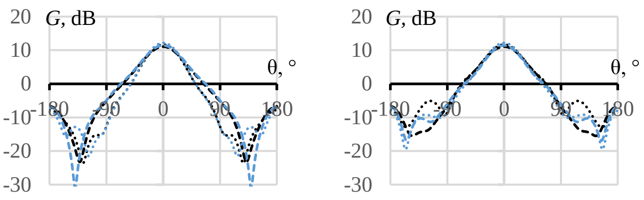
(a) *(b)*

Fig. 7. Antenna RPs using OCGA with GEET 6% (····)and 10% (---) and using FDTD [23] (—) in *E* (*a*) and *H* (*b*) planes.



(a) *(b)*

Fig. 8. Antenna RPs using COCGA with GEET 6% (····) and 10% (---) and using FDTD [23] (—) in *E* (*a*) and *H* (*b*) planes.



(a) *(b)*

Fig. 9. Antenna RPs using OCGA with GEET 6% (····) and 10% (---) and using COCGA with GEET 6% (····) and 10% (---) in *E* (a) and *H* (b) planes.

IV. CONCLUSIONS

The modified approach for modeling antennas approximated by a sparse wire grid has been verified. The verification was carried out on the example of a horn antenna and a conical horn antenna. By comparing the results of applying this approach with those obtained using other approaches and methods and even with the measured ones, a good agreement was obtained. The modified approach has proven its ability to design sparse antenna structures that can be used both in antenna modeling with less computational costs from other methods and in manufacturing of such structures with less technical difficulties from another approach proposed earlier. It was found that the structure obtained using the modified approach has a lower level of sidelobes compared to the conventional approach.

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