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# ANTENNA DATABASE FOR AIRCRAFT ELECTROMAGNETIC COMPATIBILITY PROBLEMS 3D-to-2D GEOMETRY TRANSFORMATION TECHNIQUE

***Abstract.*** *This paper proposes a 3D-to-2D geometry transformation algorithm that significantly decreases the number of computational operations and, as a result, the computation time required for solving complex electromagnetic compatibility problems. The transformation algorithm consists of three steps. In the first step, a matrix of resulting 2D models is formed from the initial 3D problem. The second step consists of synthesizing the solution of the initial 3D problem by sifting out unnecessary elements of the solution image matrix while replacing them at the same time with zeros. Finally, the third step implies the researcher's return to the initial 3D model, but this time with a decision made about the EMC problem solution, derived from the solution image matrix elements. This decision is built on their comparison with the results obtained with the help of an experimental method, performed on a real object or a real object's 3D model. Only those elements that are in good agreement with the experimental method results are included in the final decision formulation. A hypothetical aircraft example of electromagnetic compatibility problem computation is given, realized with the help of the finite element method. A corresponding aircraft antenna database has been created.*

***Keywords:*** *electromagnetic compatibility, finite elements method, fractal, database.*

## INTRODUCTION

Numerical solution of 3D electromagnetic compatibility (EMC) problems can still be challenging even today. Even with the fast computers that modern scientists dealing with numerical methods use around the world, it is often still really hard to build a precise 3D finite element model (FEM) that can be processed using appropriate engineering software for the computation of complex 3D electromagnetic problems, such as FEKO [1] **(Fig. 1)** and others.

So, a question arises: how to get rid of this "modeling jam" while preserving the main object's geometry for FEM processing and at the same time overcoming those huge matrices, sometimes consisting of hundreds of thousands or even millions of elements, with their inevitable and trivial factorization crashes that occur during inversion when attempting to obtain the desired solution to an EMC problem.

## RELEVANCE OF THE TOPIC

New ways of solving electromagnetic compatibility (EMC) problems are always welcome in the international scientific community today, especially in the field of aircraft EMC, since this branch is developing so fast. This is why the topic of the research is relevant. Also, the use of the proposed database for the systematization of information about the desirable places for antenna installation is needed, because it helps to greatly facilitate antenna placement at the aircraft design stage.

The goal of the paper — to implementation a novel 3D-to-2D geometry transformation technique for the preliminary assessment of desirable places for aircraft antenna installation with the help of the finite element method, together with the development of a specialized MySQL database — has been achieved.

## RELATED WORKS

An approach is proposed based on the well-known phenomenon of the fractal structure of nature [2]. So, if a computationally demanding 3D electromagnetic model can be changed at once into an easily operated 2D clone without losing credibility and at least satisfactory verification of the solution of the task under consideration, it will give a great push to FEM research, especially in PC simulation research, compared to experimental investigation techniques. How to do this? Well, the answer seems to be obvious: of course, by slicing the initial 3D model [3] into a number of 2D models that could be understood as some "fractals" of the initial complex aircraft topology. The numerical model was realized with the help of COMSOL Multiphysics®, as, for example, in [4]. The validity of the research results has been proved in [5]. The main condition for numerical FEM modeling of electrodynamic structures has been satisfied in this research for all operating frequencies: the length of a model element is always kept at least 10 times less than the wavelength. Modeling instruments (FEKO and COMSOL®) [1; 6] have been tested

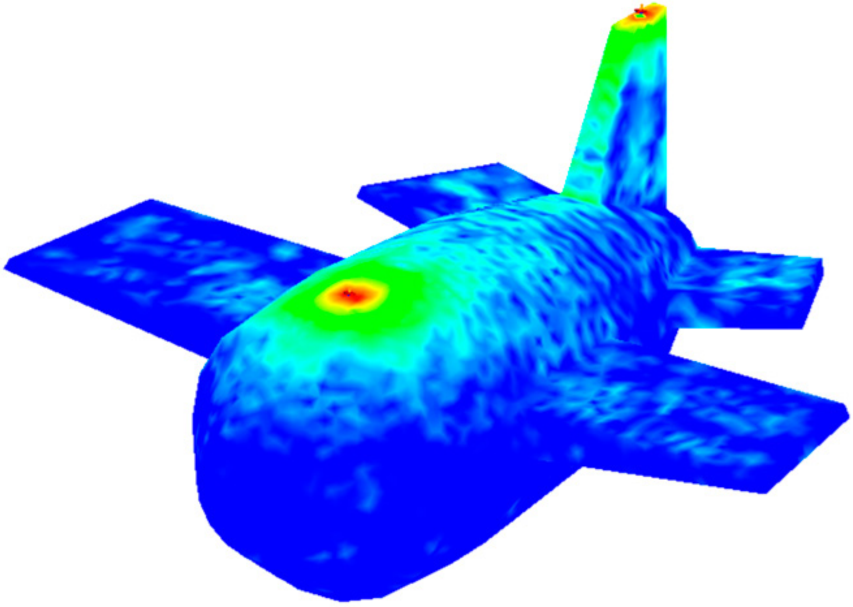


**Fig. 1.** Hypothetical aircraft model (3D geometry) with two wire antennas installed and the induced currents on it (FEKO)

on many different multidisciplinary applied physics problems, which provides additional evidence of their reliability. Several recent works about fractal antennas are referenced in [7–9].

**Working equation.** As we mainly concentrate our efforts on TE electromagnetic (EM) waves, it is clear from [4–6] that our working differential equation in partial derivatives for describing the physical processes in this model is

$$\nabla\times(\mu_r^{-1}\nabla\times E)-(\varepsilon_r - j\sigma/\omega\varepsilon_0)k_0^2 E=0 \qquad (1)$$

$\mu_r$ — relative magnetic permeability; $E$ — electric field intensity at the monitoring point (V/m); $\varepsilon_r$ — relative dielectric permittivity; $\sigma$ — conductivity of a proxy element, (Sm/m); $\omega$ — angular frequency of oscillations, (Rad/s); $\varepsilon_0 = 10^{-9}/36\pi$ — electric constant, (F/m); $k_0 = 2\pi/\lambda$ — wave number; $\lambda$ — wavelength of oscillations, (m).

The partial differential equation in partial derivatives (1) is solved, in our case, by Comsol® software using the FEM method.

### 3D-to-2D geometry transformation technique

**Step 1.** The procedures may differ, taking into account the peculiarities of the FEM software code and design used, and the peculiarities of the task being investigated. A bunch of such 2D fractals of the initial 3D model (I3DM) should be considered as a matrix of resulting 2D models (R2DM) elements, as follows:

$$Z=\left\langle\begin{matrix}\chi_{xy,1} & \chi_{xy,\ldots} & \chi_{xy,\mathrm{M}}\\ \chi_{xz,1} & \chi_{xz,\ldots} & \chi_{xz,\mathrm{M}}\\ \chi_{yz,1} & \chi_{yz,\ldots} & \chi_{yz,\mathrm{M}}\end{matrix}\right\rangle \qquad (2)$$

In (2) $\chi_{yz,k}$ contain information not only about the 2D topology and geometry of the $k$-th (of M) 2D model having been sliced along the *xy*-plane, but also all the initial data needed for the problem being solved, like positioning and radiation characteristics of a radiative antenna, the boundary conditions, the FEM grid with all the coordinates, etc. Here $xy$, $xy$, $yz$ are the three main planes in the Cartesian coordinates system, along which the slicing technique should be performed; $M$ — any positive integer number, defined by the modeler and being guided by practical necessity and advisability of the modeling problem. Custom projections can also be applied for a particular problem, too.

A researcher should treat all or some number of these R2DMs, which can be described as using some FEM technique operator for application to obtain the solution matrix while keeping the results obtained — it is the solution image matrix (SIM) (calculated on a PC using a chosen FEM technique). The whole simulation process should be described as follows:

$$X\cdot Q = Y. \qquad (3)$$

When the analysis of (3) is done, now a researcher should implement step two of this technique, also referred here as FST (fractal slicing technique).

**Step 2.** It consists of synthesizing the solution of the initial 3D problem solution by sifting out unnecessary or doubtful SIM elements replacing them at the same time with zeros. It's an intuitive, heuristic process, and may be the most complicated step, because the decisions taken about the positive or negative values of the corresponding SIM elements (seeds) ought to be based on the judgment of an experimentalist, and, unfortunately this "human factor" cannot be completely eliminated.

Finally, after completing the second FST step, one must perform the third and the last step.

**Step 3.** This step implies the researcher's return to the I3DM but now with a logical decision made about the EMC problem solution derived from the SIM seeds. This decision is built on a comparison of the SIM elements to the results obtained with the help of an experimental method (EM) performed on a real object or, at least, a real object's 3D model. Only those elements that comply well with the EM results are included in the decision formulation. The decision is simply the rule:

$$\Re=\left\langle\begin{matrix}Q_{xy,1}\wedge EM_{xz,1} & \ldots & Q_{xy,M}\wedge EM_{xy,M}\\ \ldots & \ldots & \ldots\\ Q_{yz,1}\wedge EM_{yz,1} & \ldots & Q_{yz,M}\wedge EM_{yz,M}\end{matrix}\right\rangle\cdot\left\langle\begin{matrix}1\\ \ldots\\ 1\end{matrix}\right\rangle, \qquad (4)$$

where $Q_{nm,M}\wedge EM_{nm,M}=1$ if they comply, and $=-1$ when they don't. PC modeling is taken as good (there is a convergence of solution), if and only if in (4) $\Re_{ij}>0$. With this FST kept in mind, let's proceed now to it's practical realization for a EMC problem consisting in placing antennas on aircraft's fuselage.

**Proxy model.** The 2D finite element (FEM) model of a hypothetical aircraft treated in this research is depicted in **Fig. 2**. It contains 32,256 triangular elements. The number of elements here is reduced to 2,016 for the reason of better wire-grid mesh visibility.

The numerical model was realized with the help of Comsol Multiphysics ®, as for example in [3]. The validity of the research results has been proved in [4]. The main condition for numerical FEM modeling of electrodynamic structures has been satisfied in this research for all operating frequencies: the length of a model element is always kept at least 10 times less than $\lambda$. The modeling

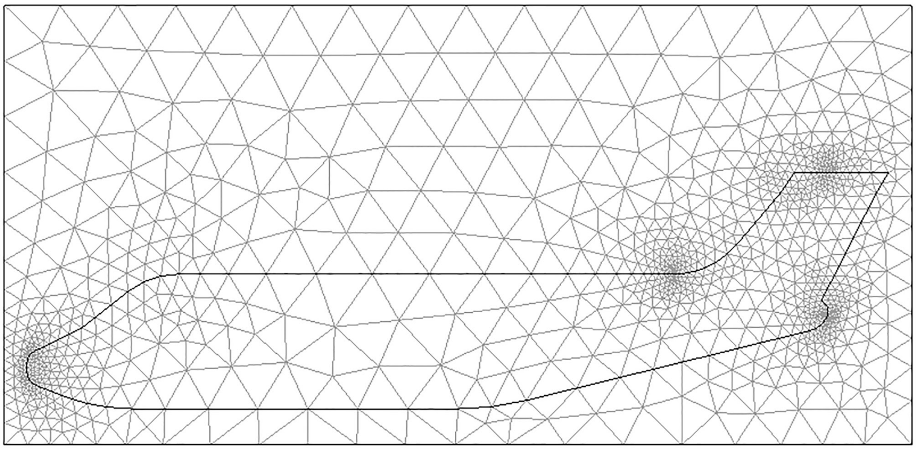


**Fig. 2.** FEM model of a hypothetical aircraft (2D geometry)

instrument (Comsol®) has been tested on many different multidiscipline applied physics problems [5], what makes an additional proof.

**Boundary conditions.** Perfect electric conductor boundary conditions were used on all the edges joining the aircraft fuselage and air space domains. At the edges where the plane TE wave is outgoing from the structure of the FEM model, scattering boundary conditions were used with the magnitude of the electric field $E_m = 0 \text{ V/m}$.

**Research.** In **fig. 3** the electric field (z-component) radiation pattern for a point keel antenna working at 200 MHz is presented.

We place an isotropic point antenna with current $I_0 = .1A$ on the keel of an yz-fractal slice of a hypothetical aircraft (**without yet committing ourselves to a more practical model, which can be done comparatively easily later**). It appears to be nothing more than just a 2D fractal of the initial 3D aircraft's FEM model (like in [2] and [3], not shown in the paper for lack of actual need). So, in our case the initial R2DM matrix will consist of only one element: a sloce in the *yz*-th plane, cut directly through the middle of the fuselage:

$$X = \langle \chi_{yz,1} \rangle \tag{5}$$

SIM matrix, obtained by applying the differential operator $Q$ (3) to the problem described by $X$ (5) will contain only one element: $Y = \langle Y_{yz,1} \rangle$. This is the simplest possible case. Let us say that the EM (for $EM_{yz,1}$) has resulted itself in the real placing of the pair of antennas on an aircraft, that has a *similar* ( to the aircraft we treat) design, size, antenna operating frequencies, radiated powers

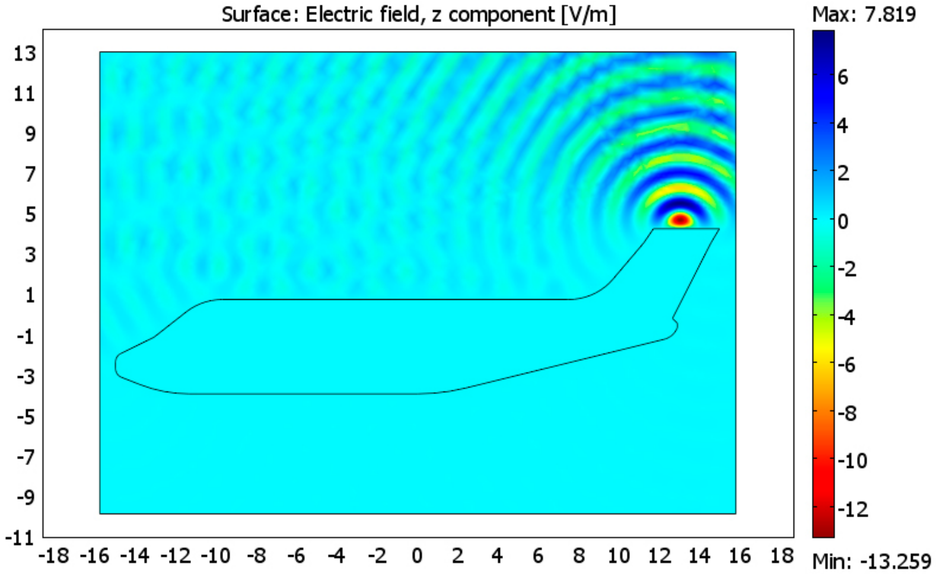


**Fig. 3.** Radiation pattern at 200 MHz

and directional characteristics to the aircraft under consideration. Then, by applying the rule $\Re_{yz} = Y_{yz,1} \wedge EM_{yz,1}$ (4) we will determine the placing: if $\Re_{yz} = 1$, then a positive decision is made about the possibility of installing the antennas at the desired or predicted spots on the fuselage; on the contrary, if $\Re_{yz} = 0$ (the FST and EM do not comply), then **no custom installation is advised** to the aircraft's constructor:

**a) 100 MHz** Having applied FST to this problem (in the case of a 100 MHz operating frequency of a point radiative antenna placed on the aircraft's keel), we've obtained the results shown below for the *z*-component of the normalized surface current density distribution on the 2D FEM model's fuselage **(fig. 4, a)**;

**b) 120 MHz** (the same configuration and the same current in the radiating keel antenna). Having used FST for this problem, we've found the results for the current densities, generated by the keel's radiating antenna, shown in **fig. 4, b**;

**c) 150 MHz** (same model and current). After analyzing the problem with FST, we've obtained a theoretically predictable and understandable corresponding graph **(fig. 4, c)**;

**d) 200 MHz** (the same configuration and the same current). Having handled this problem with FST, we've found the following results for the *z*-component of the normalized surface current density, generated by the keel's isotropic point antenna **(fig.4, d)**.

**Database.** After identifying the optimal locations for antenna installation, we create an antennas database to store the relevant information **(fig. 5)**. The database contains five fields. The first field stores the antenna ID (**id**). The second one stores the antenna name (**ant_name**). The third field contains information about antenna type (**ant_type**). The fourth field includes information about the antenna's frequency (**freq**). Finally, the last field describes the recommended *x*-position of an antenna to be installed (**x**) and includes information about the x coordinate — for the case of a 2D problem, or x, y, and z coordinates for antennas installed in a 3D model. This database helps a lot to systematize information about the antennas

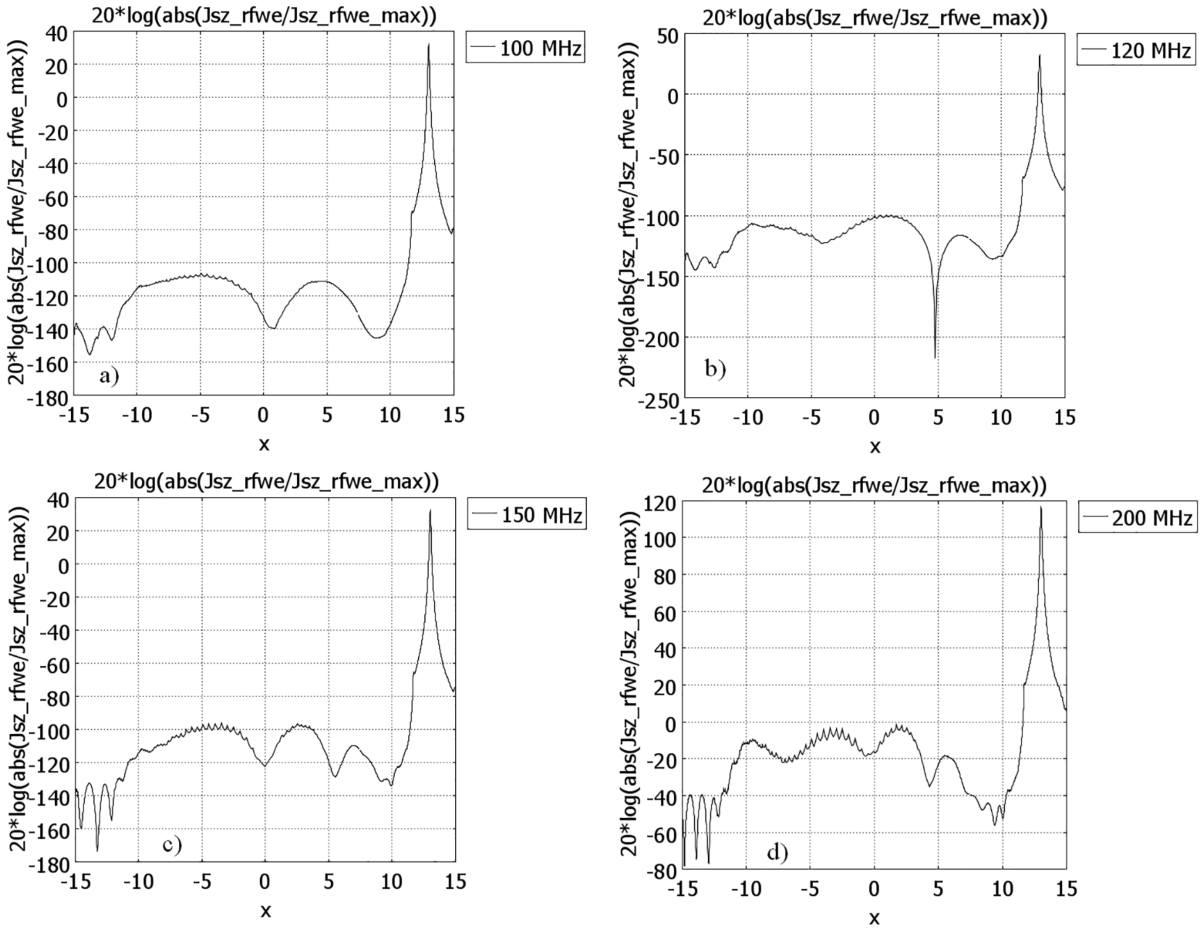
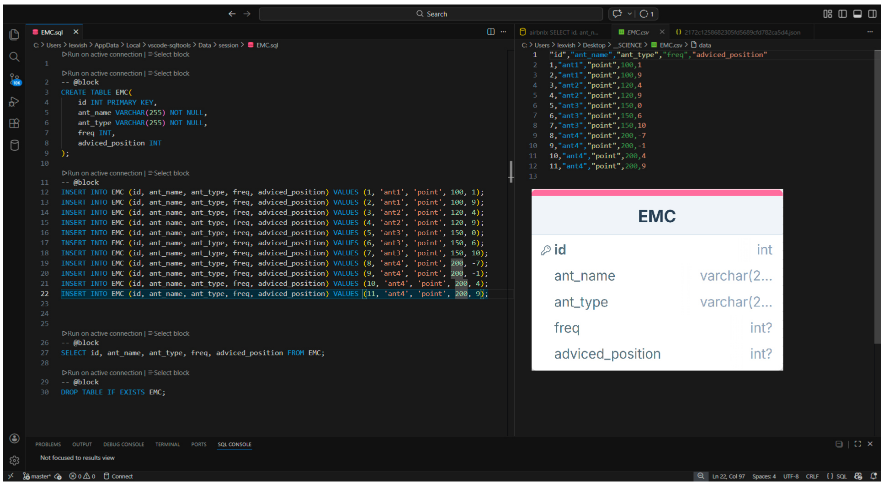


**Fig. 4.** Normalized current densities (z-component) on upper edge of fuselage, dB at 100 MHz (a), 120 MHz (b), 150 MHz (c), 200 MHz (d) along x axis, m



```sql

-- @block
CREATE TABLE EMC(
    id INT PRIMARY KEY,
    ant_name VARCHAR(255) NOT NULL,
    ant_type VARCHAR(255) NOT NULL,
    freq INT,
    adviced_position INT
);

-- @block
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (1, 'ant1', 'point', 100, 1);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (2, 'ant1', 'point', 100, 9);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (3, 'ant2', 'point', 120, 4);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (4, 'ant2', 'point', 120, 9);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (5, 'ant3', 'point', 150, 0);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (6, 'ant3', 'point', 150, 6);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (7, 'ant3', 'point', 150, 10);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (8, 'ant4', 'point', 200, -7);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (9, 'ant4', 'point', 200, -1);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (10, 'ant4', 'point', 200, 4);
INSERT INTO EMC (id, ant_name, ant_type, freq, adviced_position) VALUES (11, 'ant4', 'point', 200, 9);



-- @block
SELECT id, ant_name, ant_type, freq, adviced_position FROM EMC;

-- @block
DROP TABLE IF EXISTS EMC;
```

```csv
"id","ant_name","ant_type","freq","adviced_position"
1,"ant1","point",100,1
2,"ant1","point",100,9
3,"ant2","point",120,4
4,"ant2","point",120,9
5,"ant3","point",150,0
6,"ant3","point",150,6
7,"ant3","point",150,10
8,"ant4","point",200,-7
9,"ant4","point",200,-1
10,"ant4","point",200,4
11,"ant4","point",200,9

```

| EMC | |
|---|---|
| id | int |
| ant_name | varchar(2... |
| ant_type | varchar(2... |
| freq | int? |
| adviced_position | int? |

**Fig. 5.** Database: SQL, CSV file (made in VS Code), DrawSQL.app visualization

placement on the body of an aircraft, because a real aircraft may contain dozens of antennas, so there is a lot of data to be stored in a useful form.

## CONCLUSION

From **fig. 4,a** it can be seen that for 100 MHz it's undesirable to put a second antenna in any places between –10,0 m and –2 m; 2,5 m and 7 m; the best places to mount a second antenna are 1 m and 9 m. For 120 MHz **(fig. 4,b)** bad places for installing it are between –9,0 m and –4 m; –3,0 m and 4 m; the best places are –4 m and 9 m, and especially 4,8 m, where normalized currents are experiencing a 100 dB difference (!) from the second best spot. For 150 MHz **(fig. 4,c)** it's unwise to set any antennas between –7 m and –2 m; 2 m and 4 m. This is so because the fuselage currents induced by the keel antenna radiation are the highest in these regions. So, they will produce the highest electromagnetic fields around the fuselage and this will result in a deterioration of the EMC situation in the Fresnel zone (close to the aircraft fuselage), if any allocation of a second antenna takes place. The best places are 0 m, 6 m, and 10 m where the surface currents are the lowest. For 200 MHz **(fig. 4,d)** the recommended places for antenna installation are –7 m, –1 m, 4 m and 9 m.

The FST algorithm helps to overcome numerical calculation difficulties encountered in realistic 3D FEM models of aircraft, helicopters, and other multiple-antenna carrying vehicles. It establishes the rules of constructing equivalent 2D models of such systems, and, after doing so, gives the techniques for making the final decision about the antenna installation spots on the airplane's fuselage. This technique can save a lot of money at the stage of aircraft construction.

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## БАЗА ДАНИХ АНТЕН ДЛЯ ТЕХНІКИ 3D-2D ПЕРЕТВОРЕННЯ ГЕОМЕТРІЇ В ЗАДАЧАХ АВІАЦІЙНОЇ ЕЛЕКТРОМАГНІТНОЇ СУМІСНОСТІ

***Резюме.*** *У статті запропоновано алгоритм перетворення 3D-геометрії в 2D, що дає змогу значно зменшити кількість обчислювальних операцій і, як наслідок, час обчислення для розв'язання складних задач електромагнітної сумісності. Алгоритм перетворення передбачає три кроки. На першому кроці формується матриця результативних 2D-моделей, створених на основі початкової 3D-задачі. Другий крок полягає в синтезі початкового 3D-розв'язку задачі шляхом відсіювання непотрібних елементів 2D-матриці моделей розв'язку SIM, з одночасною заміною їх нулями. Третій крок передбачає повернення дослідника до початкової 3D-моделі, але цього разу з рішенням щодо розв'язку задачі EMC, отриманим на основі сідів матриці моделей розв'язку. Це рішення будується на їх порівнянні з результатами, отриманими за допомогою експериментального методу, виконаного на натурному об'єкті або його 3D-моделі. До остаточного формулювання рішення буде включено лише ті значення, які добре відповідають результатам експериментального методу. Наведено гіпотетичний приклад обчислення задачі електромагнітної сумісності літака, реалізований за допомогою методу скінченних елементів. Створено відповідну базу даних.*

***Ключові слова:*** *електромагнітна сумісність, метод скінченних елементів, фрактал, база даних.*

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