COMPUTATIONALLY-EFFECTIVE WORST-CASE MODEL OF THIN-WIRE RADIATION SOURCE FOR ANALYSIS OF ELECTROMAGNETIC COMPATIBILITY IN FREQUENCY RANGE 1 HZ - 40 GHZ

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INTRODUCTION

Spurious coupling is one of key terms in electromagnetic compatibility (EMC). This term denotes a coupling between two objects, which concerned with a view to a possibility of creating electromagnetic interference by one object to another.

In most cases, exact models of spurious couplings are complicated for use, because they may require detailed definition of many parameters and they may be computationally inefficient. Therefore, the analysis of EMC in complexes of radio and electronic equipment (REE) is usually performed in two stages: the worst-case models of spurious couplings are applied first (this makes it possible to estimate quickly the danger of spurious couplings and to separate indisputably safe ones), then more complicated and exact models (or measurements) are used for dangerous spurious couplings only [1].

The worst-case models of spurious couplings must satisfy the following specific requirements:

- They must take into account the errors in parameters in such a way to produce the estimated interference level not lower than the measured level.
- Such models must have a high computational efficiency.

In on-board complexes of REE, wires are playing an important role in creation of spurious couplings. Known models of wire radiation have limitations that restrict their use in problems of EMC analysis. For example, models of computational electrodynamics have slow speed of calculation; Hertzian dipole and the models based on it can be used only for analysis of electrically-short wires [2]; models of Slepyan [1] and Chaaban [3] have a furrowed amplitude-frequency characteristic (AFC) at high frequencies due to resonances, which made them susceptible to errors in initial data.

The aim of this work is to design a computationally-effective worst-case model of radiation from the wire located within a metallic chassis of on-board system (aircraft, ship, van, etc.) for frequency range 1 Hz – 40 GHz.

EXACT MODEL

After analysis of possible simplifications, we extract the following physical model (Fig. 1): a segment of wire (later we call it a wire for short) is placed above and in parallel to the ideal infinite ground plane (which models the chassis); a current wave is propagated along the wire.

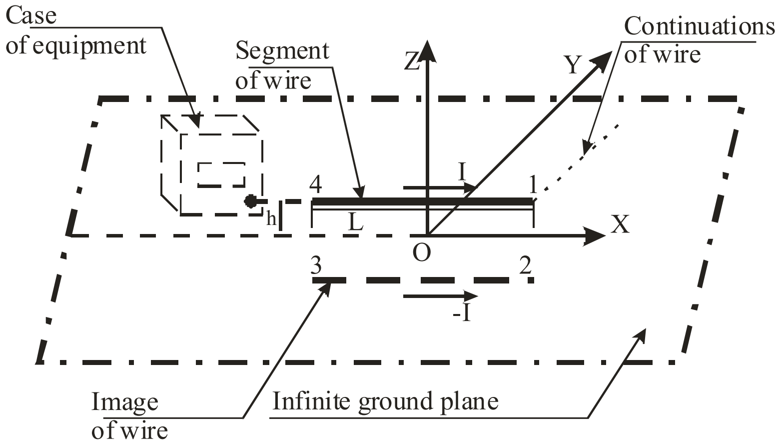

Fig. 1. The physical model

Known exact solutions (formulas of Slepyan [1] and Chaaban [3]) do not account for existence of currents in continuations of the radiating wire. In the model of Slepyan, the current has discontinuities at the ends of the wire, which does not correspond to the physics of the problem and which implies the presence of charges at the wire ends. Therefore, the field components that reflect the influence of the charges (and cause the field spikes in the vicinity of the wire ends) are excluded from the model of Slepyan in this work.

We shown that the field calculated by the model of Slepyan can be presented as a sum of fields from equivalent point sources placed at the ends of the wire and its image. So, the field of the wire without the charges is given as

$$Ex_i = (-1)^{i+1} I \frac{e^{-jk(r_i - r_{xi})}}{4\pi\varepsilon_0 c} \frac{r_{xi} + r_i}{r_i^2} \quad , \tag{1}$$

$$Ey_i = (-1)^{i+1} I \frac{e^{-jk(r_i - r_{xi})}}{4\pi\varepsilon_0 c} \frac{-r_{xi} r_{yi}}{r_i^2 (r_i - r_{xi})} \quad , \tag{2}$$

$$Ez_i = (-1)^{i+1} I \frac{e^{-jk(r_i - r_{xi})}}{4\pi\varepsilon_0 c} \frac{-r_{xi} r_{zi}}{r_i^2 (r_i - r_{xi})} \quad , \qquad i = 1..4, \tag{3}$$

where k is the wave vector; r_i is the distance from i-th end of the wire to the observation point (x_0, y_0, z_0); r_{xi}, r_{yi}, and r_{zi} are projections of this distance on x, y, and z axes, correspondingly : $r_i = |\vec{r}_i|$, $\vec{r}_i \equiv (r_{xi}, r_{yi}, r_{zi})$; I is the amplitude of the current wave.

WORST-CASE MODEL

Small errors in parameters of the wire radiation model may cause a gross underestimation of the interference field amplitude. E.g., in a given observation point and at a given frequency belonging to the area of resonances, the AFC of the exact model may have minimum while the measured AFC has maximum. Therefore, we developed a worst-case model for the wire radiation, which smoothes the exact model's AFC to the maximums (i.e., it retrieves an envelope of the AFC in the resonances' area in a given observation point).

In a given observation point, the field amplitude from every equivalent source (Eqs. (1)-(3)) is independent from frequency. So, the AFC of the field formed by two equivalent sources can be smoothed by modulo addition of the field amplitudes from these sources, but such smoothing overestimates the field at low non-resonant frequencies. It is reasonable to smooth the AFC only at frequencies above the frequency of its first maximum. At this frequency, the modulo sum of the fields coming from the two sources is equal to their vector sum (because the fields are cophasal), which means the absence of discontinuity between smoothed and nonsmoothed parts of the AFC.

The bipartition of the AFC makes it possible to introduce a binary criterion «furrowed – not furrowed» for the two-source case. If there are four sources then six different pairs of the sources can be selected, i.e., a six-bit criterion of AFC irregularity can be introduced. It is practical to represent such criterion by a graph, in which vertexes correspond to the equivalent sources and the absence of edge between two vertexes is interpreted as value «furrowed» of corresponding bit in the criterion. Let us define a zone of AFC as the frequency interval in which the shape of the graph is unchanged (without accounting for numbers of the equivalent sources). Each zone needs its own way for smoothing of the AFC.

Analytical smoothing formulas are found for 5 zones from 11 possible zones by the use of the following principle: if the sources are presented by adjacent vertexes of the graph then their fields must be summed vectorially, otherwise modulo sum must be used. E.g., if only the field from source pair "1-and-2" is not furrowed, then the smoothing formula is

$$E = |E_1 + E_2| + |E_3| + |E_4|. \tag{4}$$

For the other 6 zones, a numeric algorithm of smoothing is developed, which allows one to calculate a nondecreasing AFC between two analytically-smoothed zones with gradual transition between their analytical smoothing formulas. This algorithm uses linearly-spaced nodes in logarithmic frequency scale and linear interpolation between the values of nodes in that scale.

For calculation of the whole AFC, an optimized algorithm is developed. It is based on precomputation of the following: 1) equivalent source amplitudes by (1)-(3); 2) sequence and frequency boundaries of the AFC zones; 3) values of nodes for the numeric algorithm. Testing showed the twenty times (average) increase in the AFC calculation speed due to the precomputation.

The developed model is implemented in Mathcad software and validated by visual control of smoothing quality for more than 400 test cases (one of the cases is presented in Fig. 2). The test cases were chosen with a glance at the following restrictions: the frequency range is [1 Hz; 40 GHz], the wire length is [10 cm; 10 m], the wire height above the ground plane is [0.1 mm; 5 m], the size of the field calculation space is up to 10 m.

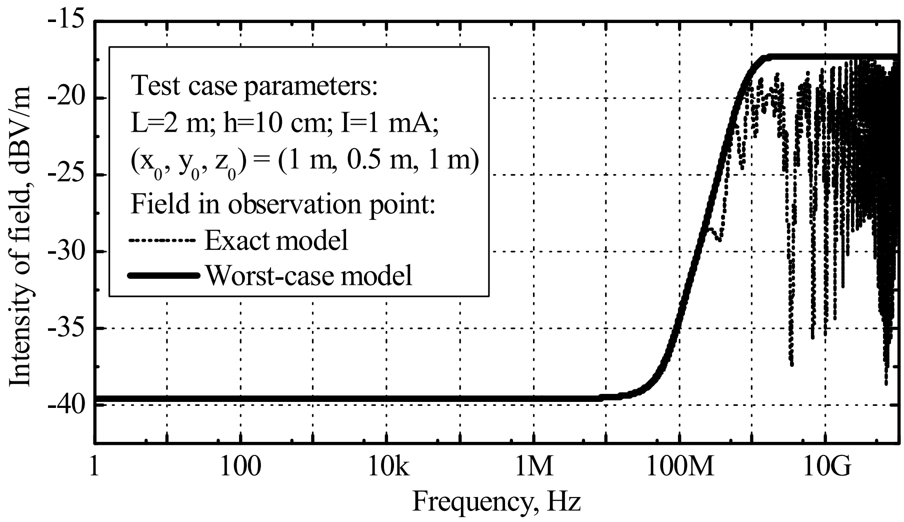

Fig. 2. The AFC of the wire radiation field in the observation point

CONCLUSION

The worst-case model of the wire radiation field, which is applicable for analysis of EMC in frequency range 1 Hz – 40 GHz, is developed. It is planned to use the developed model in the export software for EMC analysis.

References

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