ADVANCED OPTIONS OF EXPERT SYSTEM «EMC-ANALYZER »

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Abstract: The paper is devoted to description of new options for EMC analysis and synthesis in local onboard and ground-based groupings of radio systems, implemented with the use of discrete nonlinear behavioral-level simulation of radioreceivers in severe electromagnetic environment (EME). These options were tested in the latest version of the expert system "EMC-Analyzer". If compared to the basic version [1], and to its later analogue – the expert system E^{3}EXPERT [2], the latest version of the system "EMC-Analyzer" is considerably superior over the counterparts in terms of options available to simulate non-linear effects in radioreceivers (from the antenna input to the low-frequency circuit output) when operated in severe EME; it permits simulating more types of onboard groupings, including box-body systems and ships, and also offers extensive possibilities for EMC analysis and synthesis in a ground system and ground area.

I. INTRODUCTION

Solving the problem of intra-system EMC in contemporary onboard (aircraft, missile, satellite, ship, car, etc.) and local ground-based systems is a complicated task. This may be accounted for a large number of interference emitters and receptors incorporated into a system, for a diversity of their characteristics and functions, a wide range of frequencies in use, and for strict time limits to solve the problem. These factors pose new requirements both to computer-aided systems designed for simulation, analysis and synthesis of radio systems considering EMC, and also to simulation procedures.

"EMC-Analyzer", developing well-known approaches suggested in IEMCAP [3], provides an option to analyze interferential influences between radio devices at an object not only at the expense of spurious couplings, like "antenna-to-antenna", but also taking into account spurios couplings, such as "field-to-wire", "wire-to-wire", "field-to-box", etc. The use of simplified geometric images in this case, to describe the general geometry of local objects helped to substantially broaden the application of the IEMCAP concept to analyze the intra-system ECM at objects.

The basic "EMC-Analyzer" software version allows analyzing and synthesizing intra-system EMC on board an aircraft (Fig.1) in strict compliance with the IEMCAP requirements.

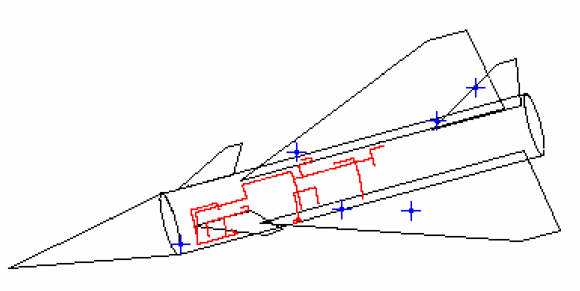

Fig.1. An aircraft 3D model, reflecting its geometry and locations of equipment (antennas, bunches, wires)

New models and procedures of the "EMC-Analyzer" software include: (a) "box-body board system" model, (b) "ship board system" model, (c) a tool to simulate and analyze space-scattered ground complexes and (d) extended possibilities to simulate non-linear effects in radioreceivers (from the antenna input to the low-frequency circuit output) when operated in severe EME (radioreceiver behavioral-level simulation). Application of these models and procedures enables to perform the following procedures: linear and non-linear EMC analysis, calculation of the required regulations of emitter and receptor characteristics, generating system specifications and identification of non-linear interference sources.

II. BOX-BODY SYSTEM MODEL

Among onboard EMC-related problems a special place is attached to the analysis of losses in cases when electromagnetic energy is propagated from the emitter to the receptor taking into account the geometry of an object, on which both of them are located (for instance, calculating insulation between antennas, mounted on a car body). For these purposes the "EMC-Analyzer" expert system contains a series of models, based on geometric optics and the diffraction theory. The inbuilt specialized visualizer supports displaying the geometrical structure of an object and its components, and their editing. In addition, the visualizer contains an option of visualizing wires and apertures located both inside and on the surface of a car body. Fig.2 illustrates the representation of the geometric model of such an object.

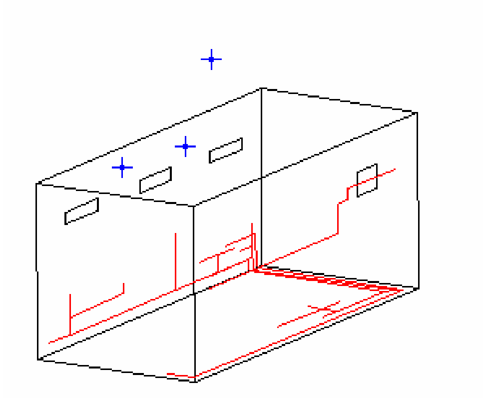

Fig.2. Geometry of a box-body board system model showing wires, antennas and apertures.

The view of the editor to locate wires, bunches and apertures inside a car body is shown in Fig.3. Besides, it is also possible to preset frequency-selective properties of the body surface using measurement data or by selecting the body material from the software libraries.

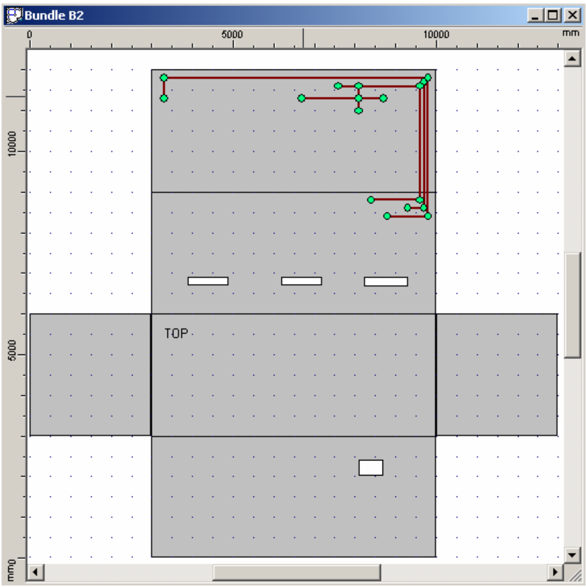

Fig.3. 2D display of a car body showing wires and apertures.

III. SHIP SYSTEM MODEL

The ship model geometry is represented by a number of simple geometrical figures: cubes, cylinders and surface sections, with the dimensions to be preset individually. The entire geometry consists of two parts – the base and the superstructure. The basic (topside) part of a ship is divided into decks and compartments.

When generating the final model it is possible to visualize the model in the graphic editor / visualizer environment (ref. Fig.4) or to build a 3D model as shown in Fig.5 with its further editing and finishing options available.

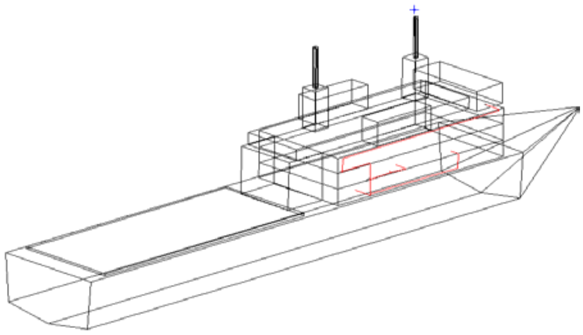

Fig.4. Geometry of a ship computational model showing wires and antennas.

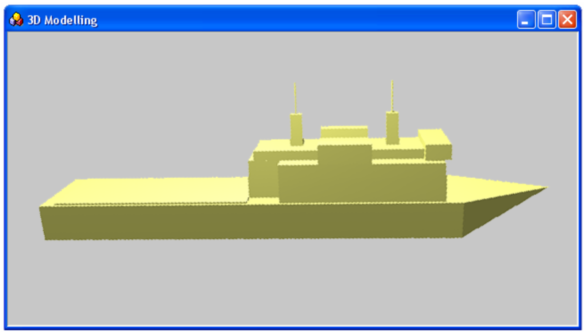

Fig.5. A 3D ship model.

The procedure of analyzing spurious couplings, such as “antenna-to-antenna” on a complicated geometry of a ship or a box-body system also pursues the worst-case philosophy typical of IEMCAP and is based on calculating the least losses on the radio wave propagation path.

IV. SPACE-SCATTERED GROUND SYSTEM (GROUND AREA)

Restrictions related to the EMC of to-be-mounted and existing at an object radio equipment of various radio services, forming a local ground grouping of radio systems, are the most critical ones touching upon placement of radio systems on this or that object.

Abating or abandoning of these restrictions is related to the requirement for proper research, implying either physical or computer-aided simulation of the corresponding local grouping of radio devices. Physical simulation means the need to arrange temporary mounting and pilot operation of the systems at an object, in the course of which interference between newly-mounted and existing equipment is studied. This way of EMC evaluation is the most impartial; however it requires great material inputs and is time-consuming without providing any optimization alternatives to locate radio devices at an object. A cheaper, more efficient and flexible EMC evaluation method is computer-aided mathematical modeling of a corresponding local grouping of radio devices.

For these purposes the expert system "EMC-Analyzer" contains specific models to analyze EMC in individual ground-based complexes (ref. Fig.6) (a residential construction, a mast, etc), as well as in a grouping of ground-based complexes (an airport, etc.) (ref. Fig.7).

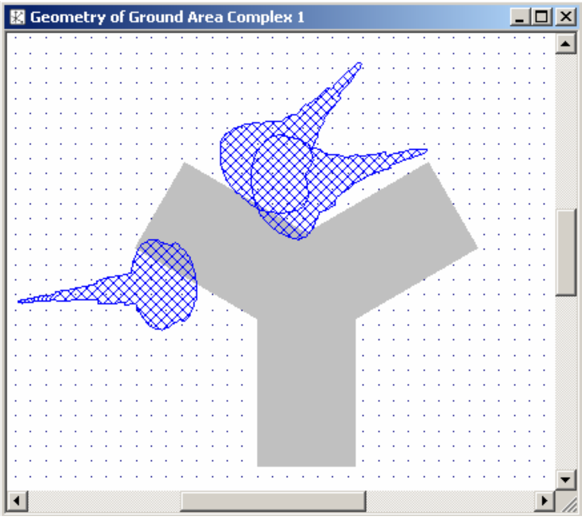

Fig.6 Mathematical model of a building (top view) showing antenna patterns

The specialized browser designed for these purposes (Fig.7) makes it simple to create and edit vegetation (with an option to alter their configuration, coordinates and altitudes), to browse locations and types of constructions within a grouping of space-scattered ground complexes, as well as to browse shapes of antenna patterns, with the antennas located on any of the ground-based complexes within a grouping.

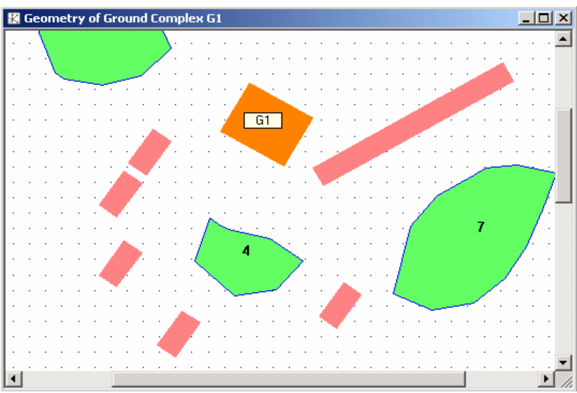

Fig.7 Mathematical model of a grouping of space-scattered ground complexes.

In the Ground Area, in addition to the well-known model EPM-73 [5] also well-known radio wave propagation models are used [3,4] to analyze spurious couplings, such as "antenna-to-antenna", and "field-to-antenna". When analyzing "antenna-to-antenna" spurious coupling, first the propagation path profile between the emitter and the receptor antennas is built. If there are no obstacles such as other buildings along the path, the radio wave attenuation in the vegetation is calculated according to the recommendation [3]. In case the attenuation exceeds 30 dB, it is concluded that an obstacle is there, and the calculation is performed following [4].

V. NONLINEAR RECEIVER MODEL

This software as contrasted to its counterparts is remarkable for availability of radio receiver non-linear simulation based on a unique method of EMC discrete analysis [6,7], which uses discrete EME models and high-order polynomial models 15-25) to characterize non-linear receiver components.

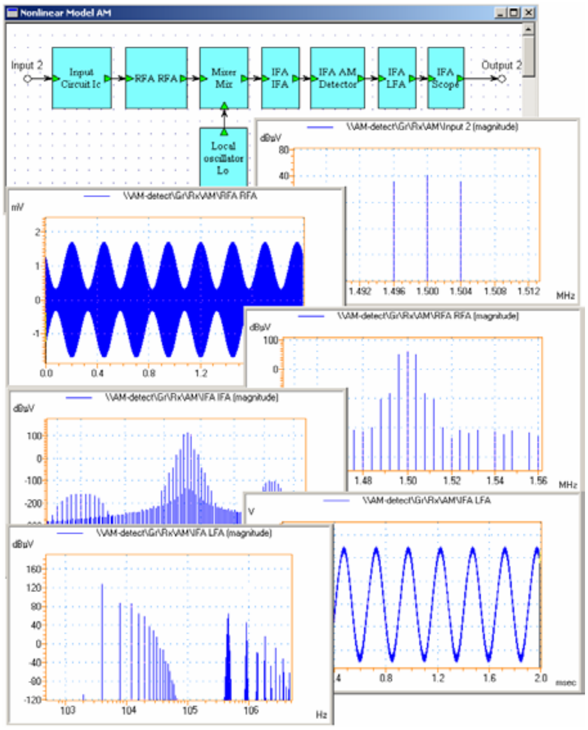

Fig.8 Browser of the radioreceiver flow chart including simulation results.

This method features a functional radioreceiver model, composed of linear (input circuits, filters, insulation components) and nonlinear components. Linear components can be simulated in the frequency domain, nonlinear – in the time domain. The crucial point of the EMC discrete analysis is the application of FFT for simulation. With this the use of polynomial models of transfer characteristics of non-linear components helps controlling the spectrum extension of the transformed signal frequency. The latest version of the expert system “EMC-Analyzer” contains a broadened set of procedures for non-linear simulation of signal and interference conversion in radio receiving circuits, supporting the following alternatives: simulation of various detection procedures (amplitude, frequency, and phase) and post-detection signal processing.

The specialized graphic interface (Fig.8) helps easy and convenient creating and editing of the radioreceiver nonlinear model. Apart from that, it is possible to analyze results at each simulation stage. The characteristic visualizer, that allows displaying signal and interference spectra, transfer functions of non-linear components, GFC and PR of linear and frequency-selective components, LO characteristics, etc., as well as power parameters of certain components and spectrum sections, is used for this purpose.

V.I NONLINEAR SENSOR METHOD

High speed of modeling of processes of transformation and interaction of signals and interferences during functional modeling the projected equipment - is the important requirement to a technique of the analysis EMC during designing radio-electronic devices, systems and complexes. It is necessary for research of the big number of variants of its function block diagrams.

In some cases (in conditions of insufficient a priori information regarding: the technical specifications of the radio systems, mounted on the object, working frequencies, concentration of radio equipment on local (small-sized) objects, e.c.) its ease to use “Nonlinear sensor model” of radioreceiver for calculating nonlinear effects at its different stages [8].

It is easy to analyze nonlinear effects in first radiofrequency amplifier or in first mixer of radioreceiver in complex electromagnetic environment, when it represented by way of simplified typical radio-engineering stage (TRES) (fig.9) - and input frequency filter (input circuit, (IC), nonlinear instantaneous elements (NIE) with a high-order transfer characteristic and an output frequency filter serially interconnected.

But this way of radioreceiver presentation/modeling meets difficulties – characteristics of linear and nonlinear components of TRES sometimes has only one parameter (for example, image channel selectivity for radiofrequency tract, adjacent channel selectivity for intermediate frequency tract). Because of this fact it is necessary to compose list of requirements for radioreceiver (in particular for linear and nonlinear components). Frequency characteristic of IC mathematical model can be represented by Butterworth filter:

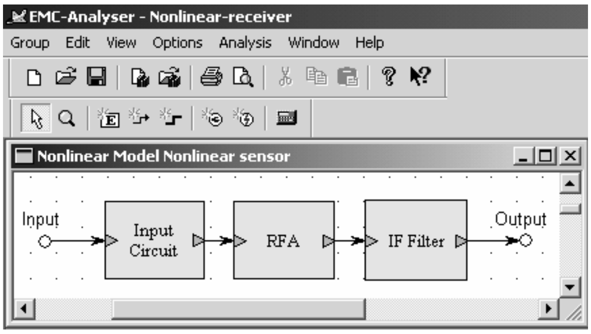

Fig.9. Typical radio-engineering stage

$$K_{ic}(\Omega) = 1 \Big/ \sqrt{1+\Omega^{2n1}} \qquad (1)$$

where: $\Omega = 2\Delta f / B_{ic3}$ - relative mistuning;

$\Delta f = f - f_{ic}$ - absolute mistuning;

f_{ic} - IC average tuning frequency;

B_{ic3} - IC pass bandwidth at 3 dB level;

n_1 - approximation polynomial order.

In conditions of insufficient a type of input frequency filter of radioreceiver, n_1 may be equal to filter circuit’s number. If input frequency filter pass bandwidth at level α,дБ($B_{ic\alpha}$) is known, next equation can be used :

$$n = \frac{\alpha}{20\lg\left(B_{\alpha}/B_3\right)} \qquad (2)$$

So long as relative image channel selectivity level of radioreceiver (A_{im}, дБ) depends on IC power attenuation at image channel frequency $f_{im} = f_R + g \cdot 2 f_{if1}$, then from (1) if $f_{ic} = f_R$ we obtain:

$$A_{im} = 10\lg\left(1+\Omega_{im}^{2n1}\right),$$

where: $\Omega_{im} = 2\Delta f_{im} / B_{ic3}$;

$\Delta f_{im} = f_{im} - f_R$,

thence

$$n_1 \cong \frac{A_{im}}{20\lg\left|\Omega_{im}\right|}. \quad (3)$$

Input frequency filter pass bandwidth at level A_{set}, dB, with taking into account nonlinear effects in radioreceiver, can be define by the next way:

$$Bic \cong Bic_3 \cdot 10^{\frac{A_{set}}{20 n_1}}. \quad (4)$$

For the description of transfer characteristic NIE which takes into account nonlinear properties radioreceiver, it is offered to use polynomial approximation. The initial data for construction polynomial characteristic is the information about NIE which strongly differs depending on a situation. The basic cases the following:

1) The nonlinear element is present and it is possible to measure its any parameters.

2) There is only a functional block structure of radio engineering system which analysis is necessary for making. The nonlinear element is set as piecewise approximation or other theoretical model of the transfer characteristic.

3) There is a limited number of experimental data about a nonlinear element. It is the most often situation as frequently we have only reference data on the device and more exact measurements are expensive.

In the given approximation technique of the transfer characteristic of a high degree that allows describing all nonlinear effects (blocking, intermodulation, cross-modulation) is used.

Polynomial coefficients can be calculated, using the following parameters [9]:

1) Desensitization dynamic range (DR);

2) Dynamic ranges for different types of intermodulation (IDR);

3) Intercept points for different types of intermodulation.

In a case when there is a big number of experimental data about a nonlinear element and it is required to synthesize a polynomial not a high order (up to 5-7), describing only area of small nonlinearity, it is possible to expect the polynomial coefficients directly. As initial experimental data dynamic ranges on intermodulation (IDR) orders from 2-nd up to n, where n - a polynomial order which is necessary for synthesizing act. Polynomial coefficients can be calculated by [9]:

$$p_n = \pm \frac{U_{out} \cdot 2^{n-1} \cdot i! \cdot j!}{U_{in}^n \cdot D_n \cdot n!}, \quad (5)$$

где D_n – IDR n-order;

U_{in} – NIE input noise level;

Uout – NIE output noise level;

i,j – intermodulation product indexes (always positive).

IDR doesn't afford information about signs of polynomial coefficients of transfer function. Because of this fact signs selection in formula (5) mast be realized under conditions of maximum approximation of received polynomial to theoretical form of amplitude characteristic NIE and minimal polynomial oscillations. In first approximation signs in formula (5) can be selected by the law $(-1)^{(n-1)/2}$.

The estimation of the interference level at the nonlinear receiver model output is made with the help of the interference margin (point and integral). Because of this fact for receiver model specified susceptibility parameter as a whole.

After the signal at the output is calculated the interference margins are calculated. The point interference margin at the frequency f_i $M(f_i)$ is calculated by the following formula:

$$M(f_i) = \left(\frac{U(f_i)}{\eta(f_i)}\right)^2 \quad (6)$$

where $U(f_i)$ - signal amplitude at the frequency f_i,

f_i - susceptibility level.

The integral interference margin is calculated by the following formula:

$$M_{\text{int}} = \sum_i \left(\frac{U(f_i)}{\eta(f_i)}\right)^2. \quad (7)$$

To estimate the interference level for desensitization and cross-modulation, the analysis is made in two stages. First the useful signal spectrum at the output excluding the interference is calculated. After that the useful signal spectrum at the output including the interference is calculated and the useful signal spectrum is subtracted from this spectrum. The resultant difference spectrum is the interference spectrum and its mean-root-square level

$$U_{rms} = \sqrt{\sum_i U^2(f_i)}, \quad (8)$$

may be used in order to estimate the interference level.

Moreover, the method of EMC discrete nonlinear analysis include the stage at which nonlinear interference sources are identified with the use of the modified dichotomous search procedure. This stage allows one to identify the interference sources at the

TRES output and at the output of its separate stages (in case of complex TRES structure with several NIE).

Nonlinear discrete simulation procedures for a radioreceiver under interference, used in the “EMC-Analyzer” software are very efficient and practically invariant with respect to the EME complexity. For example, when using a computer of PIII-800 class with a 128 Mb RAM, simulation of the EME discrete model non-linear transformation (256’000 spectrum samples at the input, which allows to take into account up to 10’000-30’000 signal inputs accurate within the carrier) with the 25^{th}-order polynomial model is performed within 5-6 s., and simulation of this EME model arriving at the radioreceiver IF circuit output with a double frequency conversion takes no more than 1 min..

VI. CONCLUSION

“EMC-Analyzer” is a tool for EMC simulation and analysis in local onboard and ground-based groupings, entirely complying with all the requirements as outlined in IEMCAP. In addition, new options of the software allow a considerable enhancement in the efficiency and quality of design and applied-research projects in the field of frequency and territory planning, inter-system and intra-system EMC and EMC at an object.

The experience of applying the method of non-linear analysis of EMC at an object using the «EMC-Analyzer» software when mounting the GSM-900/ 1800 networks equipment on objects of various types (a high-rise building, an antenna support, an airport, a railway station, etc.) proves its appropriateness for reasoning of certain administrative decisions when constructing and modernizing, as well as designing radio engineering objects (local groupings of radio devices).

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BIOGRAPHICAL NOTES

Vladimir Mordachev, Head of EMC R&D Laboratory of the Belarusian State University of Informatics and Radioelectronics (Minsk, Belarus), Ph.D, Senior Researcher, member of IEEE. He is author of about 200 publications and patents in area of EMC.

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