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"EMC-ANALYZER" – A SPECIALIZED EXPERT SYSTEM FOR SOLVING ELECTROMAGNETIC COMPATIBILITY (EMC) PROBLEMS OF ON-BOARD AND GROUND/WATER-BASED RADIO SYSTEMS

1. GENERAL DESCRIPTION

Application Area:

1. EMC analysis, design and maintenance on all stages of radio system development and application including preliminary research, detailed designing of system and subsystems, systems exploitation, support and modernization.
2. Types of systems supported by "EMC-Analyzer":
   - on-board systems (aircraft, helicopter, missile, satellite, ship, box-body, etc.),
   - ground/water-based systems (airport, seaport, building roof, antenna tower, local ground/water object, etc.),
   - complex local spatially distributed systems, groupings (several aircrafts, helicopters, ships, etc.).
3. Intrasystem EMC analysis, design and maintenance in on-board systems taking into consideration
   - various on-board radio-electronic equipment (different radio systems; computers and control systems, data-measuring systems, power supply equipment, etc.);
   - different on-board spurious electromagnetic couplings ("antenna to antenna", "field to antenna", "antenna to wire", "wire to wire", "field to wire", "case to case", "field to case", "ground loop");
   - taking into consideration external electromagnetic environment (EME).
4. Intrasystem EMC analysis, design and maintenance in spatially limited ground/water-based RF objects
   - with regard to various ground/water-based RF systems of different radio services (radio communication, radiolocation, radio navigation, radio monitoring, etc.);
   - taking into consideration external EME formed by spatially distributed radio frequency (RF) devices and systems.

Functionality

"EMC-Analyzer" provides the following opportunities:

1. Solving of on-board EMC problems on the assumption of presence of different equipment (different radio systems; computers and control systems, data-

measuring systems, power supply equipment, etc.) on the basis of system EMC criterion “Total integral interference margin”.

2. The simultaneous consideration and danger estimation of spurious electromagnetic couplings of the various nature (through antennas and apertures, between cables, between cases, through ground loops, etc.).
3. Creation of effective computer (mathematical) model of on-board radio electronic system or ground/water-based RF object which provides the EMC problems solving on all stages of on-board and area-based equipment development and application.
4. Opportunities of permanent improvement of elements of this model by measurements, more precise modeling of separate spurious electromagnetic couplings, allowing to raise considerably its usage efficiency from a stage to a stage of modeling on-board / ground/water-based system life cycle.
5. Substantiation of necessary adjustments of equipment characteristics for the intrasystem EMC problem solving, specification generation for system equipment using system EMC criterion.
6. Detailed nonlinear behavior simulation of on-board or area-based radio receivers in very complicated (severe) EME formed by thousands of modulated (narrowband and wideband) or noise external interferences.

   This simulation providing opportunities of full identification of the sources, reasons, places of occurrence and parameters of a linear and nonlinear radio interferences (co-channel, adjacent, image and intermediate channels interferences, intermodulation, blocking, amplitude and phase cross modulation, local oscillator noise conversion, etc.) in radio receivers in severe EME.

   The "EMC-Analyzer" expert system is unique software in the international software market, providing such totality of functionalities.

Advantages in comparison with analogues and competing offers

The "EMC-Analyzer" specialized expert system is unique software proposal in the international software market, providing the analysis and the solving of the most complicated EMC problems at a system level, «as a whole», using the modernized resumptive platform of known research program IEM CAP (USA) in a combination with number of original and effective EMC models and technologies developed in USSR and Belarus (nonlinear discrete EMC analysis and radio receiver behavior simulation technology, automated double frequency testing (DFT) technique of radio receivers, etc.).

Unique known analogue of the "EMC-Analyzer" would be the program E^3EXPERT, developed according to the contract F30602-98-C-0034 with the US Air Force Research Laboratory (see publication: A.Drozd, T.Blocher, A.Pesta, D.Weiner, P.Varshney, I.Demirkiran. Predicting EMI Rejection requirements using expert

system based modeling & simulating techniques, *Proc. XV Inter. Wroclaw Symp. on EMC*, Poland, Wroclaw, 2000)

In comparison with the E^{3}EXPERT (later developed tool) the "EMC-Analyzer" has the following important advantages:

a) Development for expanded series of system formats (board system, box-body system, local ground system, local ground area).

b) Pinpoint accuracy of spectra representation (up to 32 000 000 frequency samples under a usual personal computer with Windows NT/2000/XP).

c) Possibilities of detailed nonlinear behavior simulation of on-board or area-based radio receivers in very severe EME formed by thousands of modulated, harmonic or noise external interferences with

   – high accuracy of radio receiver nonlinearity representation using high order polynomial models (up to 15-25-th order) coupled with high-accuracy simulation/modeling of nonlinear interference,

   – full identification of the sources, reasons, places of occurrence and parameters of a linear and nonlinear radio interferences (co-channel, adjacent, image and intermediate channels interferences, intermodulation, blocking, amplitude and phase cross modulation, local oscillator noise conversion, etc.) in radio receivers in complicated radio receiving conditions.

There are many well known and rather perfect software tools declared for use at the solving of EMC problems in local on-board and ground-based systems (groupings). As examples it is possible to note software of FEKO, ANSOFT, REMCOM, CST, Poynting Softwarer Ltd, etc.

All these tools provide the decision of concrete particular problems of detailed electrodynamics calculation of a relief of an electromagnetic field, characteristics of electromagnetic couplings between antennas or characteristics of particular spurious electromagnetic couplings in an on-board or ground-based radio system (grouping) (in frequency domain by method of moments (MoM) or in time domain using FDTD approach). These programs do not provide a several very important functions, such, as

– analysis and solving of the most complicated EMC problems at a system level, «as a whole», taking into consideration an intensity of intrasystem interference defeat of the on-board or ground/water-based equipment;

– a quantitative estimation of all number of available spurious electromagnetic couplings of the various physical nature being the reason of interference of various types - a radio interference, conducted interference, grounding interference, etc.;

- decision-making on EMC compliance or disparity in conditions of existence of numerous spurious electromagnetic couplings of the various nature (through antennas, between cables, between cases, induced in ground loops, inducted by external fields, etc.);
- detailed nonlinear behavior simulation of on-board or area-based radio receivers in very severe EME including identification of the sources, reasons, places of generating in receiver and parameters of a linear and nonlinear radio interferences;
- substantiation (calculation) of necessary adjustments of equipment spectral or susceptibility characteristics for the intrasystem EMC problem solving, specification generation for system equipment using system EMC criterion.

Therefore all well known software tools for electrodynamics calculations with use of MoM or FDTD (including the most advanced, perfect and expensive) do not replace, but only supplement "EMC-Analyzer", providing the following opportunities:

- more precise characterization of separate most important spurious electromagnetic couplings in an on-board or ground/water-based system (grouping), and
- improvement of the "EMC-Analyzer" "system" functions performance accuracy using this results of more precise calculation of separate spurious electromagnetic couplings characteristics.

Application experience and peculiarities

In the "EMC-Analyzer" hundreds of original and known models and procedures are used. Approximately 80% of them are widely known and published in the scientific literature. Probably, a number of models and procedures are not the most exact of known and published in scientific literature. However refusal of application of more exact models and procedures is dictated by the requirement of reception of useful practical result at reasonable spending of time and computational burden.

Very important, that just at the given number of models of spurious electromagnetic couplings "EMC-Analyzer" provides optimal for practice pessimistic character of EMC estimations the on-board or ground/water-based equipment.

According to the published data, there are following results of their application for the EMC analysis of on-board aircraft equipment:

- probability of a correct interference prediction of interference presence or absence 0,82
- probability of a false alarm (the interference is predicted, but in practice is absent) 0,17

– probability of the interference omission (the interference is not predicted, but in practice is present) 0,01

Similar results are observed at "EMC-Analyzer" application at the EMC analysis of other on-board or ground/water-based systems: the probability of the interference omission does not exceed 1-5 %.

Nevertheless, the opportunity of more accurate definition of characteristics of any spurious electromagnetic couplings available in on-board or ground/water-based system is provided in "EMC-Analyzer" if the user has results of more exact modeling or measurements. Such specification allows to improve constantly computer model of on-board or ground/water-based system created with the help of "EMC-Analyzer". It extremely make easier solving of EMC problems at late stages of system life cycle, in particular, at exploitation and modernization phases, etc., for example, if it is required to enter a new equipment into structure of system or to make replacement of separate kinds of the system equipment.

Concluding remarks

"EMC-Analyzer" specialized expert system is capable to provide essential simplification, acceleration and reduction in price of works on area of EMC problems detecting and solving in local on-board and ground/water-based systems (groupings). "EMC-Analyzer" can be efficiently used at all stages of life cycle of these systems, but its application is especially effective at early stages of systems life cycle (research, design, etc.). Pessimistic character of EMC estimation results allows to decrease essentially risks of losses caused by probable electromagnetic incompatibility of on-board or ground/water-based system equipment during designing of these systems.

And such important features of "EMC-Analyzer", as

– solving of EMC problems of on-board or ground/water-based system at a system level, «as a whole», on the basis of system EMC criterion “Total integral interference margin taking into consideration available spurious electromagnetic couplings of the various physical nature,

– detailed nonlinear behavior simulation of on-board or area-based radio receivers in very severe EME including identification of the sources, reasons, places of generating in receiver and parameters of a linear and nonlinear radio interferences,

– substantiation (calculation) of necessary adjustments of equipment spectral or susceptibility characteristics for the intrasystem EMC problem solving, specification generation for system equipment using system EMC criterion,

make "EMC-Analyzer" to be the indispensable assistant at

- creation of complex on-board systems (aircraft, helicopter, ship, missile, satellite, box-body, etc.) and complex ground/water-based radio objects (airport, seaport, high-altitude tower with antennas, a local radio communication and radio control center, a roof of a high-altitude building with a plenty of antennas, etc.),
- the analysis of a possibility of additional allocation in on-board or ground/water-based system (grouping) of the new equipment not creating interferences to the available equipment,
- the behavior simulation/analysis of on-board or ground/water-based system radio equipment in very complicated EME.

2. SPECIFICATION

1. Application Area:
   All stages of on-board and area (ground, water)-based radio system development, including preliminary research, detailed designing of system and subsystems, simulation/modeling and testing of subsystems and the whole system, modeling of higher levels radio systems.

2. Basic Features:

2.1. Analysis of intrasystem electromagnetic compatibility of subsystems in the structure of an on-board or area-based radio system.

2.2. Analysis of intersystem electromagnetic compatibility for on-board or area-based equipment.

2.3. Automatic specification generation for equipment in the structure of an on-board or ground-based radio system.

2.4. Analysis of interference environment in an on-board group and development of recommendations for making trade-off solutions (trade-off analysis).

2.5. Analysis and modeling of nonlinear phenomena present in radio receivers under reception in severe electromagnetic environment, radio receivers behavior simulation in severe electromagnetic environment, identification of linear and nonlinear interference sources.

3. Basic Technical Specifications:

3.1. Accuracy of representation of signal frequency spectra - up to 10^6 samples.

3.2. Accuracy of representation of susceptibility characteristics - up to 10^6 samples.

3.3. Implementation of specialized editors and GUIs:

- ♦ System, subsystem and equipment block diagram editor,
- ♦ Bundle structure and geometry editor,
- ♦ Aircraft geometry editor,
- ♦ Ship geometry editor,
- ♦ Box-Body geometry editor,

- Water area editor (for harborage, offshore water/strip, littoral region space-scattered systems and groups of systems),
- Ground area editor (for ground-based space-scattered systems and groups of systems),
- Visualizers of initial data and analysis results.

3.4. Compliance with the MIL-STD 461B/D/E, 462 requirements.

3.5. Use of asymptotic models of spurious couplings employed in the IEMCAP program.

3.6. Utilized spectra models:

- Composite Harmonic Signal,
- PDM (Pulse-Duration Modulation)- AM Modulation,
- Differential PCM (Pulse-Code Modulation) -AM,
- Biphase PCM-AM Modulation,
- Pulse-Position Modulation,
- Telegraphic Radio-Signal (The Morse code),
- Frequency Shift Keying,
- PAM (Pulse-Amplitude Modulation) -FM,
- Radar Signals:
  - The rectangular pulse,
  - The trapezoidal pulse,
  - The "cosine - square" pulse,
  - The Gaussian pulse,
  - The chirp.
- Two-band AM-signal,
- AM-signal with the suppressed carrier,
- Lower single side-band AM,
- Upper single side-band AM,
- FM-radio-signal,
- PDM,
- Differential PCM - with no return to zero,
- Biphase PCM,
- Pulse-Position Modulation,
- Telegraphic signal,
- Pulse-Amplitude Modulation,
- Exponential pulse train,
- Rectangular pulse train,
- Trapezoidal pulse train,
- Triangular pulse train,
- Sawtooth pulse train,
- Damped sinusoidal pulse train,
- Models in accordance with MIL-STD-461B

3.7. Utilized Susceptibility characteristics:

- ♦ Models in accordance with MIL-STD-461B
- ♦ Model the Table-set Susceptibility characteristic.

3.8. Utilized Filter models:

- ♦ The filter which has the characteristic set by points,
- ♦ The single tuned filter,
- ♦ The transformer coupled filter,
- ♦ The mixed type filter,
- ♦ Chebyshev filters:
  - ◊ The Low Pass Chebyshev Filter (LPCF)
  - ◊ The High Pass Chebyshev Filter (HPCF),
  - ◊ The Band Pass Chebyshev Filter (BPCF),
- ♦ Butterworth filters:
  - ◊ The Low Pass Butterworth Filter (LPBF),
  - ◊ The High-Pass Butterworth Filter (HPBF),
  - ◊ The Band Pass Butterworth Filter,
- ♦ The Low Pass Filter (LPF),
- ♦ The High Pass Filter(HPF),
- ♦ The Band Pass Filter (BPF),
- ♦ The Band-Reject Filter (BRF).

3.9. Utilized Coupling models

- ♦ Models of couplings between wires:
  - ◊ The capacitive coupling between wires,
  - ◊ The capacitive coupling with the shielded emitter wire,
  - ◊ The capacitive coupling with the shielded receptor-wire,
  - ◊ The capacitive coupling with the double shielded emitter wire,
  - ◊ The capacitive coupling with the double shielded receptor wire,
  - ◊ The inductive coupling between two wires,
  - ◊ The inductive coupling with the shielded double grounded emitter wire,
  - ◊ The inductive coupling with the shielded double grounded receptor wire,
  - ◊ The inductive coupling with the double shielded emitter wire,
  - ◊ The inductive coupling with the double shielded receptor wire,
  - ◊ The twisted pair emitter - unbalanced load,
  - ◊ The twisted pair receptor - unbalanced load,
  - ◊ The twisted pair emitter- - balanced load,
  - ◊ The receptor pair - balanced load,
- ♦ Other Types of Coupling models:
  - ◊ The "field-wire" interaction(through apertures),
  - ◊ The coupling through the total resistance,
  - ◊ The "equipment case-to-equipment case" coupling,
  - ◊ The shield model,

- ◊ The couplings between on-board antennas,
- ◊ The calculation of the diffraction point coordinates on the wing,
- ◊ The influence of shading and diffraction on the coupling between antennas,
- ◊ Helicopter (Bull and Smithers) model of antenna-to-antenna coupling.

3.10. Utilized Antenna models:

- ♦ The dipole,
- ♦ The slot antenna,
- ♦ The monopole,
- ♦ The loop antenna,
- ♦ The reflector,
- ♦ The antenna array,
- ♦ The antenna characteristic set by points,
- ♦ 3-level antenna characteristic.

3.11. Utilized EM Field Propagation Models:

- ♦ The EPM-73 Propagation Model,
- ♦ The ITU.R 526-7 Propagation by diffraction model,
- ♦ The ITU.R 833-1 for attenuation in vegetation calculation.

3.12. Implementation of the automatic specification generation feature for an on-board (aircraft/missile, box-body, ship, etc.) and area (ground/water)-based system, including determination of the integrated interference margin and determination of required adjustments of emitters spectra and of susceptibility characteristics of interference receptors.

3.13. Implementation of the EMC trade-off analysis (EMC-synthesis) for an on-board (aircraft/missile, box-body, ship, etc.) and area (ground/water)-based system, using required adjustments of emitters spectra and of susceptibility characteristics of interference receptors.

3.14. The behavior nonlinear modeling/simulation of radio receivers

- ♦ Application of a technique for discrete EMC analysis with the use of discrete interference environment models,
- ♦ Possibility of higher accuracy representation of signals ($67*10^6$ samples or 300 Hz)
- ♦ Polynomial models of nonlinear radio receiver elements:
  - ◊ Hard double-sided limiter model,
  - ◊ Hard one-sided limiter model,
  - ◊ Exponential double-sided model,
  - ◊ Sine double-sided model,
  - ◊ Arctangent double-sided model,
  - ◊ Exponential one-sided model,
  - ◊ Sine one-sided model,
  - ◊ Arctangent one-sided model,
  - ◊ Direct Polynomial Model,

◊ Model Synthesised on the basis of the experimental data

4. Components:

4.1. Customer's Workstation or PC running under Windows NT/2000/XP.

4.2. "EMC-Analyzer" software package (CD+ hardware lock).

4.3. "EMC-Analyzer" Technical Documentation Set in 8 volumes including User's Manual, Technical Report with the description of mathematical models, algorithms and analysis procedures, Test Examples for testing and usage training of the "EMC-Analyzer".

4.4. Training and education on EMC in Belarusian State University of Informatics and Radioelectronics (different courses: basic 0,5-3 months training; bachelor, master's or post-graduate courses).

4.5. Technical training on "EMC-Analyzer" on Buyer's (Supplier's) territory (up to 10 specialists, up to 5 days, Beijing or other China city, 2 Belarus experts/professors).

4.6. Maintenance and support.