Electromagnetic compatibility in very small spacecrafts

Conference Paper · May 2015

DOI: 10.1109/URSI-AT-RASC.2015.7303041

4 authors:

Vira Pronenko
National Academy of Sciences of Ukraine
31 PUBLICATIONS **46** CITATIONS
SEE PROFILE

Valery Korepanov
National Academy of Sciences of Ukraine
307 PUBLICATIONS **1,177** CITATIONS
SEE PROFILE

Fedir Dudkin
National Academy of Sciences of Ukraine, Lviv Centre of Institute for Space Resear…
140 PUBLICATIONS **198** CITATIONS
SEE PROFILE

Serhiy Belyayev
National Academy of Sciences of Ukraine
36 PUBLICATIONS **133** CITATIONS
SEE PROFILE

Electromagnetic compatibility analysis for small satellites: method and instrumentation

V. Pronenko, S. Belyayev, F. Dudkin
Laboratory for Electromagnetic Investigations
Lviv Centre of Institute for Space Research
Lviv, Ukraine
pron@isr.lviv.ua

***Abstract*—The electromagnetic cleanliness becomes first priority problem for small satellites with very compact design, especially for CubeSats, what greatly impedes their application for scientific research, especially for electromagnetic ones. The analysis of electromagnetic interferences sources is given and the ways how to decrease their influence at satellite design are recommended. The instrument for electromagnetic cleanliness measurement and its operation algorithm are proposed.**

Keywords—electromagnetic cleanliness, interference, measurements, satellite

I. INTRODUCTION

The decreasing of weight and dimensions of the new generation of space vehicles – micro- and nanosatellites – allows proposing the sustained, commercial, low-cost small satellite programs by corresponding inexpensive and regular access to orbit through formal launch service contracts. The majority of such satellites have been launched as 'piggy-back' or secondary payloads accompanying a larger primary payload into orbit – when the primary payload pays for the majority of launch cost.

The scientific payload in small satellites regularly includes electric and magnetic sensors which have to be placed at the booms. Usually, nanosatellites produce less electromagnetic interference (EMI) than big satellites; but the compact design leads to a considerable increase of mutual influence between payload systems.

By this, the electromagnetic cleanliness (EMC) of these satellites becomes the first priority question.

The aim of employing EMC measures is to ensure that a variety of different items of electronic equipment can operate in close proximity without causing any undue interference. This interference needs to be reduced to as low threshold as necessary to ensure that various items of electrical equipment are compatible and can operate in the presence of each other.

Usually, EMC requirements specifications are formulated for each spacecraft mission and basically contain:

- requirements for satellite, its systems, and units classified in the EMC categories;

- methods for verification of these requirements during pre-flight preparation with corresponding test procedure description;

- design guidelines for special scientific or technical tasks and units.

(For example, at measuring weak magnetic fields or for decreasing of attitude control system errors the use of magnets or magnetically permeable material in the spacecraft construction should be minimized).

All EMC problems have these aspects in common:

- source or transmitter that produces EMI;

- a receiver that receives EMI;

- transfer or coupling path between transmitter and receiver.

These aspects are analyzed below in order to develop a way to reduce EMI influence.

II. EMI SOURCES ANALYSIS

Interference occurs if the received signal will lead to the receiver malfunction in some way.

There are three possible means to reduce the interaction between the transmitter and receiver.

1. Reduce the transmitted emissions.

2. Alter the coupling path between the transmitter of interference and the receiver by physical separation or corresponding PCB and construction design.

3. Make the receiver less susceptible to the interfering signal.

Naturally, the most preferable are reducing the transmitted emission. However, it is not always possible, e.g., in the case of the telemetry signals transmitter. Usually, a power converter which converts direct current (DC) to regulated voltages also generates radio-frequency interference (RFI), so sometimes it is necessary to limit its RFI even if this converter will be less efficient.

The simplest method to follow item 2 recommendation is to increase the distance between EMI source and receiver

978-1-4673-8291-5/16/$31.00

(sensor or signal wires). High sensitive sensors have to be placed for this at the top of as long as possible booms.

And finally, the requirement No. 3 usually is fulfilled by signal filtration in electronic units' interfaces for eliminating or, at least, decreasing conducted EMI in power and signal lines of the spacecraft.

One of the most important aspects of EMC is that it must be considered as an integral part of the specification, design, manufacturing and testing phases of any spacecraft. An approach to EMC must be adopted at the same time when the basic requirements of the spacecraft are defined and specified. This involves examining each aspect of the spacecraft mission requirements, considering how each EMC category is influenced and deriving detailed EMC requirements and specifications.

Computer analysis of radiated electric and magnetic fields is notoriously difficult since it relies heavily on accurate physical models of the environment. It is difficult also to predict with precision the nature of the frequency and time-domain interference that occurs. This is the reason why the majority of spacecraft contractors rely on preventative measures during the design phases and early EMC testing and analysis of test results to characterize and identify problems early in the spacecraft development.

As far as direct EMI measurements, analysis of electric and magnetic fields and localization of EMI sources in the separate units are high priority tasks for assembled nanosatellite. The most problematic from them is the EMI source localization, especially in ELF-VLF frequency range, because of the following peculiarities of field structure in this band:

- near field range ($|kr| << 1$, where k is wave number, r is the distance from the source to the observation point);

- complicated magnetic field structure of stray sources;

- low efficiency of short electric dipole antennae in VLF band because of very high reactance and very low curl component of an electric field;

- the necessity to use the complicated combinations of magnetic dipole systems as magnetic field sensors;

- very high level of industrial noise in this band;

- influence of residual magnetic fields of ambient metallic masses and the Earth's magnetic field variations.

In spite of this, the practice requires the more and more accurate determination of possible interference source. One of this applications is the creation of the satellites with very low level of own EM radiation for space research that needs exact measurements and compensation of interference sources.

III. STRAY SOURCE METHODS LOCALIZATION

For localization of the stray magnetic field sources, several methods had been proposed.

1. Displacement of magnetic sensors relatively satellite and measurement of magnetic field distribution in near space [1; 2; 3]. After data processing, the source parameters are calculated by the special algorithm. In this method, the satellite is fixed and the 3-component magnetic sensor is displaced appropriately. The method is especially convenient for big devices under test (DUT) because the measurements can be executed directly in industrial conditions with immobile DUT (i. e. without spacecraft transportation to measuring testing facilities and DUT movements/rotations for determination of own magnetic momentum vector at given frequency).

2. Rotation of the satellite with simultaneous magnetic field variations measurement by three-component magnetometer [3; 4]. This method is used mostly for small satellite (nano- and picosatellite, for example) certification.

3. Rotation of two sets of 2-component ΔH-meters and directional measurements of ΔH-maximum points at immobile DUT [5; 6].

4. Magnetic field measurements by two sets of fixed and spaced 3-component magnetometers [7]. The DUT is also fixed.

All methods are valid for dipole-like sources, i. e. on the assumption of their small dimensions in comparison with distance r to them.

The last method is based on the fact that for the determination of stray source parameters (i. e. Cartesian components of its magnetic moment and position, in all six values) six field equations are quite enough. These six equations should contain six measured magnetic field components and distances between sensors.

This method was accepted as the most convenient for realization, especially because no necessary any movements neither DUT nor EMI meter during measurements. The developed EMI meter for this method is described below.

IV. INSTRUMENTATION FOR EMC ANALYSIS

For pre-flight analysis of nanosatellite onboard interference level, the following instrumentation and procedure are proposed. The possible configuration of the customized EMI meter functional diagram is presented in Fig. 1. The instrument consists of two compact 3-component magnetic sensor sets with matching amplifiers and electronics for measurement and spectral analysis of the interference sources in the frequency range from unities to 20,000 Hz. The dashed square shows that the position of the second magnetic sensor set may be changed during the tests.

During the preparation for the measurements, the first step is to provide linear operation of the system. For this, it is necessary to make certain that the possible background interference is at least below the saturation level of the sensors and data acquisition system. The second step is to be certain that for all frequency band which may generate an equipment under test there is big enough signal to noise ratio. That is why the measurements of the background electromagnetic environment are very important during any tests. Nevertheless, the spectral analyzing and digital filtration of the recorded signals allow us to get the required place and parameters of an equivalent dipole even with rather a high level of the background interference.

The main technical parameters of the EMI meter sensors are given in Table 1.

The system works as follows.

1. At the beginning, all nanosatellite subsystem should be switched off. The background magnetic noise is received by both magnetic sensor sets and is registered during at least 5-10 s to a computer hard disk (HD).
2. After it, a 1st nanosatellite subsystem is switched on during the appropriate time (may be the same 5-10 s). During all measurements, the signal is continuously registered into HD.
3. Then the recorded data are analyzed – in order to find the interference generated by the first subsystem and to calculate position, magnitude and orientation of the equivalent dipole
4. Results are checked and in the case when the magnetic field vectors for both magnetometers are close to parallel, the position of one magnetometer should be changed and measurements repeated. (This change may be necessary in order to avoid possible uncertainty of solution of an appropriate system of equation – multiple places of equivalent dipoles with different parameters can be found as the results of calculations. Theoretical modeling shows that it is possible for peculiar arrangements of the sensors and magnetic field sources, for example, when vectors of the magnetic field are parallel in both points of observation. That is why results of automatic calculation should be checked and repeated with different positions of the sensors if necessary.)

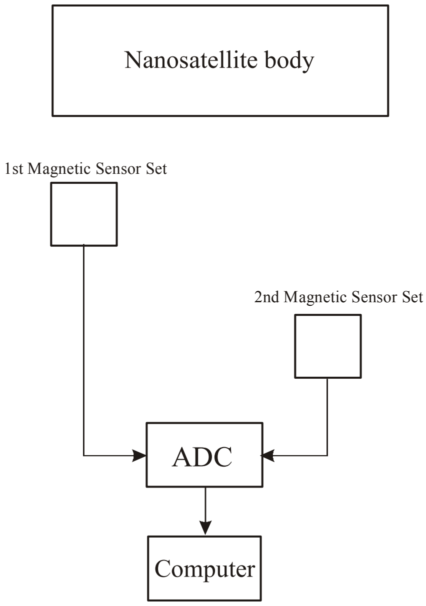

Fig. 1. EMI meter functional diagram.

And so on, with each subsystem and finally with all operating subsystems together.

After subsequent registration and calculation for each separate subsystem or subsystem set, the resulting list of interference may be compiled. An advantage of dipole model using as sources of interference is an easy possibility to calculate the expected interference in point of interest – for example, in a place where the onboard ELF-VLF sensors will be installed during the flight.

TABLE I. PARAMETERS OF THE EMI METER SENSORS

Frequency range	5 – 20000 Hz
Number of components	3
Frequency response shape	flat
Transformation factor at differential outputs	37 mV/nT
Noise level: at 100 Hz at 1 kHz at 10 kHz	 2.3 pT/Hz$^{1/2}$ 0.2 pT/Hz$^{1/2}$ 0.07 pT/Hz$^{1/2}$
Dimensions of sensor	40×40×40 mm^3
ADC	16 bits
Programmable gains	1, 2, 5, 10
Voltage supply	± 12 V

The synchronous registration of 3-component magnetic field from both sensor sets and its spectral analysis allows, in principle, localization of interference sources inside the nanosatellite. For this, an appropriate localization algorithm and special MATLAB scripts for data collection and processing are developed, and the tests results given below confirmed its high efficiency.

V. TEST RESULTS

The testing was made under the 3U CubeSat SEAM which is developed in the frame of FP7 Project 607197. All measurements were performed in the calibration pavilion of the Nurmijarvi magnetic observatory of the Finnish Meteorological Institute, Roykka, Finland. In order to decrease background interference both roof and wall heating systems of the pavilion, where measurements took place, were switched off during the tests. All instruments and equipment that were not used during each measuring procedures were unpowered (the AC power adaptors were removed from power outlets as well). Laptop computers that were used for control of the instruments and data collection were installed at the maximal possible distance from the magnetic sensors (more than 3…4 m) and were battery powered during measurements.

The sensors of the EMI meter were installed on the pillar and the non-magnetic and non-conductive support for the satellite was placed at a distance of 500 mm to the first magnetometer reference point, as shown in Fig. 2. During the measurements, all the satellite subsystems were powered in turns with simultaneous recording of the AC magnetic field. A typical 20 s intervals of recording were used for each subsystem under test. During the first half of the interval the present background signals were recorded then a subsystem was switched on and the residual time was dedicated to record signals with new interference that could be generated. After recording data were analyzed in such a way:

- A spectrogram was calculated and examined to find signals that appeared after powering the subsystem.
- The frequency for calculation was chosen and extracted by digital filtration to use it for a dipole finding.
- The localizations, magnitudes, and orientation of sources (dipoles) of new frequencies were calculated using software of the AC test system.

Fig. 2. The position of EMI meter (left) and satellite under test (right) during the measurements (view from above).

The example of the spectrogram is presented in Fig. 3. It is seen there that the maximal amplitude has the signals with the frequencies 114 Hz, 335 Hz, and 1002 Hz – they are clearly visible after switching on and booting the subsystem (~14 s of recording and late). The signal of 114 Hz has been used as an example for the calculation of the interference source parameters: its amplitude, which is registered by two 3-component magnetic sensors, is shown in Fig. 4. The moment of switching on the satellite power system and onboard computer is clearly seen near 13th s at the spectrogram (Fig. 3) and in Fig. 4 as 114 Hz amplitude increase. Fig. 5 shows the result of coordinates calculation of this interference source. In Fig.5: the satellite volume is given in gray, IM1 and IM2 are two 3-component magnetic sensor sets, placed at different distances' from the satellite body, red point is the location of the 114 Hz source dipole center and the red line is the dipole orientation.

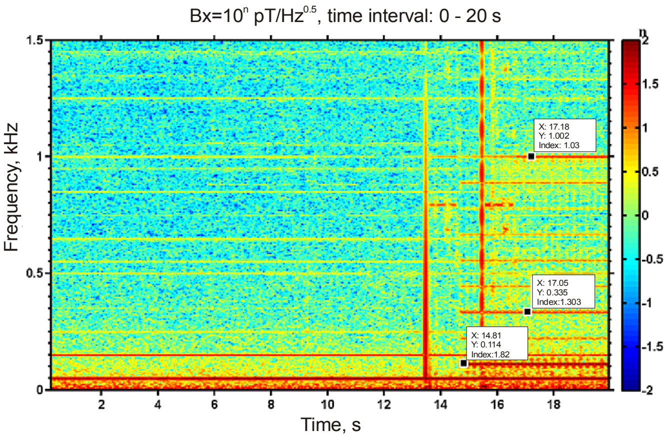

Fig. 3. Spectrogram with the moment of switching on the satellite power system and onboard computer.

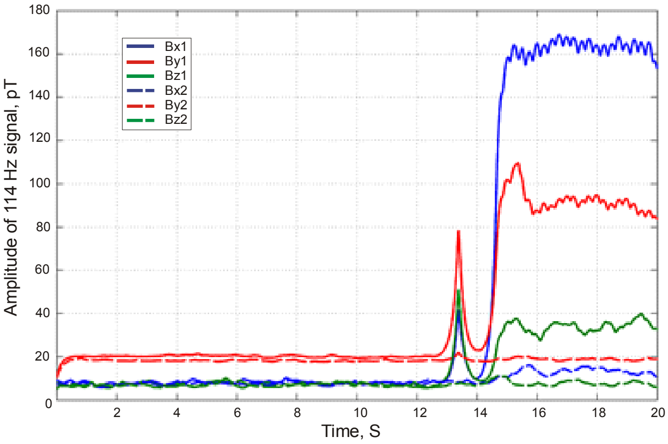

Fig. 4. Filtered signals (114 Hz) generated after switching on the satellite power system and onboard computer.

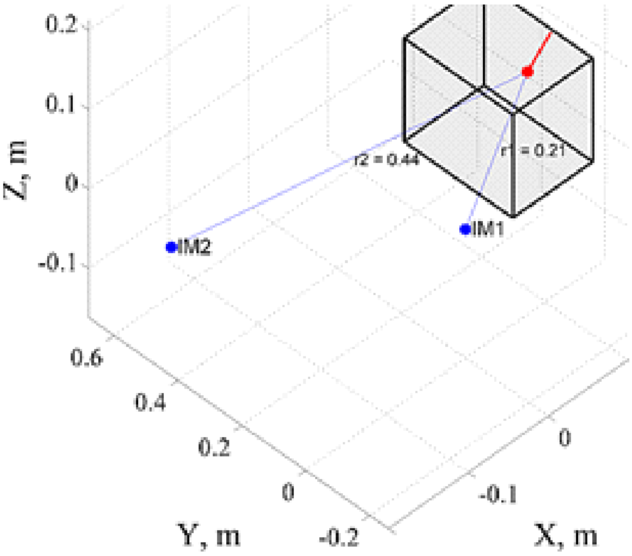

Fig. 5. The location of the equivalent dipole of the 114 Hz signal generated after the power system and onboard computer switching on (The origin of the coordinate system is the Sensor 1 center. The satellite volume is gray colored).

As an example, the results of calculation of the EMI meter software output file are given below.

```
2015/11/26 15:19:29
      ----- Measurement information -----
EPS+OBC
      ----- System parameters -----
dx = -0.2, dy = 0.42, dz = 0 (m)
Xw = [0.1 0.2], Yw = [0.0 0.4], Zw = [-0.1  0.1] (m)
f0 = 114+/-10, Flpf = 1, Fhpf = 0 (Hz)
ts = 15-20, tn = 0 (s)
      ----- Magnetic field components -----
Signal (peak amplitude):
IM1: Bx = 255.8, By = 53.4, Bz = -144.3, |B| = 298.5 (pT)
IM2: Bx = -20.9, By = 11.8, Bz = -29.7, |B| = 38.2 (pT)
      ----- CALCULATION RESULTS (Source parameters) -----
Source location: x = 0.14, y = 0.15, z = 0.06 (m)
r1 = 0.21, r2 = 0.44 (m)
Magnetic moment (peak amplitude) & orientation: Mx =-9.1e-06,
My = 1.1e-05, Mz = 2.0e-05, |M| = 2.5e-05 (A*m^2)
phi = -51.4, theta = 36.0 (deg)
```

Thus, after finishing the procedure we obtained the coordinates of the source equivalent dipole (in concerned case x = 0.14, y = 0.15, z = 0.06 (m)) and its magnetic moment modulus (|M| = $2.5*10^{-5}$ (A*m^2)).

VI. CONCLUSION

The proposed method and instrumentation allow solving our task of interference magnetic dipole location in ELF-ULF bands of interest without any displacement of the investigated object during measurements. The experimental tests confirmed enough good resolution of the instrumentation and calculation method for such a magnetic dipole location – minimal observable value was of the order of 1 μA*m^2. This was reached also because of the possibility to decrease the systematic errors connected with non-synchronous field readings and outside interference sources extraction, in particular, magnetic masses. Further development of the functional algorithm will allow us to scan magnetic pattern of the investigated satellite what will be extremely useful for the small platform designers.

Acknowledgment

This work was supported by FP7 Project 607197 SEAM.

References

[1] Primdahl F. A Pedestrian Approach to Magnetic Cleanliness. Danish Space Research Institute, Lyngby, March 1990.

[2] Korepanov V., Berkman R., Dudkin F. Low-Frequency Gradiometer for EMC Certification. Proceedings of 12th International Symposium on Electromagnetic Compatibility, Zűrich, Switzerland, 18-20 February 1997, p. 207-210.

[3] Dudkin F., Korepanov V. Method of VLF Magnetic Sources Localization at EMC Tests. Proceedings of 3rd International Science and Technical Conference “Metrology in Electronics-2000”, Kharkiv, Ukraine, 10-12 October 2000, p. 95-97.

[4] Korepanov V., Dudkin F., Melnik O., Pajunpaa K. Small satellites EMC study. Advances in Space Research, 28 (1), 2001, p. 221-225.

[5] Dudkin F., Korepanov V. A New Instrument for DC Magnetic Interference Investigation. Proceedings of 14th International Zűrich Symp. on Electromagnetic Compatibility, Zűrich, Switzerland, 20-22 February 2001, p. 135-138.

[6] Dudkin, F., Korepanov V. Small Satellites EMC Study. Proceedings of 3rd International Symposium of the International Academy of Astronautics, Berlin, 2-6 April 2001, p. 137-140.