

# Measurement Techniques to Characterize Electromagnetic Emission of Pulsed Plasma Thrusters

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This paper deals with the measurement of characteristics of electromagnetic emission of electric propulsions as applied to the EMC problems. Electric propulsion systems on the basis of pulsed plasma thrusters, which are used for the orbit correction of small satellites, are considered as the sources of unintended noise of artificial origin. Test results for the spectral characteristics of emission for the PPT model with the discharge energy of 50 J obtained under ground conditions and their discussion are presented in this paper.

## 1. INTRODUCTION

Considerable interest was expressed recently to the issues of electromagnetic compatibility of electric propulsions (EP) of spacecraft (SC). Fundamental difference of EP from jet engines of other types is in the use of electric energy for the acceleration of mass injected by the thruster and thrust generation. So, ion thrusters and Hall stationary plasma thrusters are widely used for solving orbital and transportation tasks. Corrective propulsion systems based on the pulsed plasma thrusters (PPT) start to be used in the field of mini and micro spacecraft [1]. This is associated with the fact that the power of onboard plants of such spacecraft as a rule is in the range of 20-200 W, and by the required controlled thrust at low power the pulsed plasma thrusters are practically the only thrusters suitable for the orbit correction of such spacecraft. Models of ablative PPT [2] were developed by RIAME during the past several years. These models combine design, functional, and operational simplicity and low cost peculiar to the thrusters of this type with the operating process efficiency that is two and more times higher than the corresponding parameter of the thrusters of this type of the first generation [2].

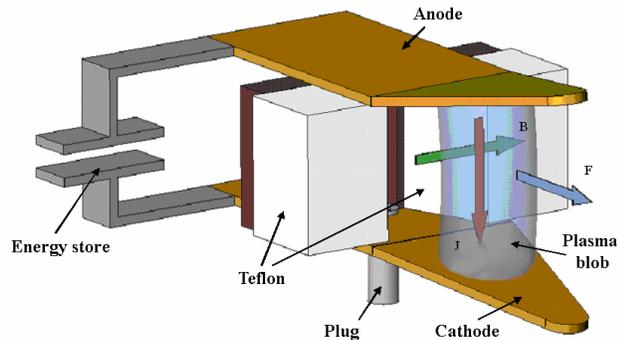


Fig. 1. Ablative PPT design diagram

Basic characteristics of the different PPT types are presented in Table 1.

## 2. GENERAL INFORMATION ON PPT

TABLE 1. PPT PERFORMANCE

Thruster	Discharge Energy, J	Thrust impulse bit, mN·s	Specific pulse, m/s	Country
PPT-150, RIAME	150	4.5	24000	Russia
PPT-100, RIAME	100	2.9	21000	Russia
PPT-40, RIAME	40	1.28	15000	Russia
PPT-20, RIAME	20	0,6	13000	Russia
LES-8/9	20	0.297	10000	USA
TIP-II,III	20	0.375	850	USA
MIT Lab.	20	0.454	600	USA

Fig. 1 shows design diagram of ablative PPT with the side feed of propellant into the discharge channel. The thruster comprises two plane (copper usually) electrodes with the end ceramic insulator between them, as well as two Teflon bars of rectangular cross-section being the thruster propellant. The bars are fed to the discharge channel by a spring mechanism up to a step-type stop made on one of the electrodes. Electrodes are connected with the energy store being a bank of high-current capacitors by copper buses. The thruster operates in the following way: the energy store is charged initially, and its voltage is applied to the electrodes (spontaneous discharge does not

take place in the free space). The high-voltage plug, mounted in the cathode and generating initial plasma closing discharge gap, operates on the command for thruster start, and after that discharge between main electrodes takes place due to the capacitor bank energy. Plasma is formed as a result of the ablation (evaporation) of Teflon bar operating surfaces and vapor ionization under the influence of high temperature. This plasma is accelerated by gas-dynamic forces and volume electromagnetic force  $\mathbf{j} \times \mathbf{B}$ , where  $\mathbf{B}$  is the self-magnetic field generated by the discharge current  $\mathbf{j}$ . The process is repeated after the energy store charging and input of the next command. Efficiency of

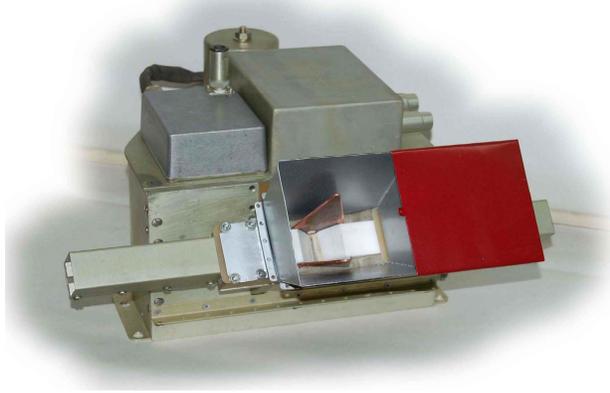


Fig. 2. APPT-50

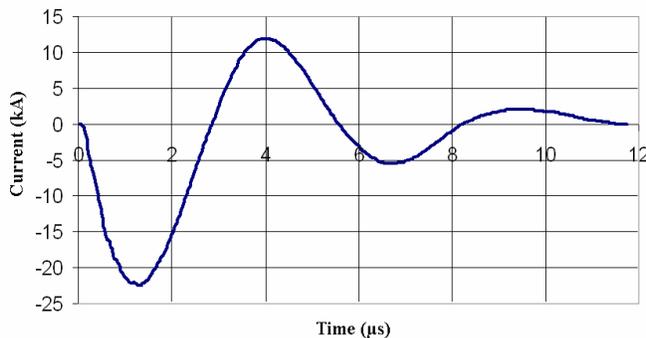


Fig. 3. Current variation

acceleration process depends on the correlation between electromagnetic and gasdynamic forces in it. In view of the time required for the store charging, the PPT pulse-repetition frequency is several Hz, and thrust dependence on power is of linear character. It is natural that with the discharge currents of some tens of kA a complicated electromagnetic environment is formed in the ambient space. This environment is of definite interest from the point of electromagnetic compatibility (EMC) view. General problem of electric propulsion EMC is not new and was discussed in a number of publications [5, 6]. It is known that EP operation associated with the propellant ionization and its acceleration proceeds with the electromagnetic energy emission in the frequency range from 10 kHz to 20 GHz [1, 2]. For example, self emission of the stationary plasma thrusters is of the noise-like nature and may be of potential danger for the satellite communication systems with the receiver frequencies in L (1-2 GHz), S (2-4 GHz), C (4-8 GHz), and X (8-12.5 GHz) ranges. Large number of publications [7, 8] deal with the analysis of characteristics of EP self emission in the spectral region, but until now electromagnetic environment created by PPT directly was not studied in detail. And this concept of EMC is the subject of this paper.

### 3. EMC MEASUREMENT

Taking into account that for the PPT operation it is necessary to secure environmental pressure of no more than  $10^{-4}$  mm Hg, realization of radiophysical measurements for electromagnetic environment under ground conditions is a rather complicated technical task. Self emission of electric propulsions has been studied at RIAME for a long time already, hardware and procedures are developed for the investigation of self emission of stationary plasma thrusters under ground conditions [3, 4]. Peculiarities of the PPT operational cycle required development of new procedures and defined additional requirements to the measurement instrumentation. Facility similar to those described in [3] was used to study electromagnetic environment generated by PPT. It was based on the metal vacuum chamber with the diameter of 1 m and length of 2 m. APPT-50 model with the discharge energy of 50 J (Fig. 2) was used. It was mounted at the chamber axis near one of its end walls (location of propellant bars and electrodes is well seen in the figure). A flange with radio-transparent dielectric window for the emission output beyond the vacuum chamber was mounted at the opposite end wall of the vacuum chamber. Pick-up antennas securing signal reception in the frequency range of 30 MHz – 18 GHz were in turn mounted to the flange from the external side. Complete screening of the horn antenna mouths against outer effects was secured at their mounting to the radio-transparent flange. Each antenna was connected to the input of spectrum analyzer by a high-frequency cable with the known attenuation characteristics. Spectrum analyzer registered spectral characteristics of the electromagnetic emission power for the background and PPT signal. Main distinction of these measurements was in that the PPT was operating with the pulse-repetition frequency of about 2 Hz and discharge current pulse duration of 10  $\mu$ s (current curve for the primary circuit is presented in Fig. 3). The signal spectrum measurement at such short relative pulse duration was associated with definite difficulties. To overcome them, the spectrum analyzer made

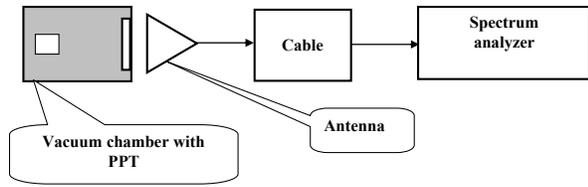


Fig. 4. Design diagram

estimate  $S(f)$  (dBm) in the spectrum analysis filter band  $\Delta f_{RBW} = RBW$ . The following expression is used to convert power in the filter band to the signal power spectral density in dBm/MHz:

$$W_1(f)_{dBm/MHz} = S(f)_{dBm} - 10 \lg \Delta f_{RBW_{Hz}} + 60_{dB} \quad (1)$$

The signal power spectral density at the antenna output differs from the one measured by spectrum analyzer by the value of attenuation in the cable  $L_{cb}(f)$ :

$$W_2(f)_{dBm/MHz} = W_1(f)_{dBm/MHz} + L_{cb}(f)_{dB} \quad (2)$$

From the practical point of view, the electromagnetic environment formed by the operating PPT is of interest. It may be assessed indirectly by the characteristics of electromagnetic field (EMF) at the horn mouth. Interrelation of EMF strength at the horn mouth  $E(f)_{\mu V/m}$  and signal voltage  $U(f)_{\mu V}$ , measured at the antenna output, is:

$$E(f)_{dB\mu V/m} = U(f)_{dB\mu V} + A_F(f)_{dB/m} \quad (3)$$

where  $A_F(f)$  is the antenna factor (the ratio of field strength at the horn mouth to the voltage at its output). This parameter is presented in the tables containing pickup antenna calibrating data. Taking into account that antenna is designed for the matched load of 50 Ohm, correlation between EMF strength within the 1 MHz band at the antenna input with the measurement results for the power spectrum obtained by the spectrum analyzer is described by the following expression:

$$E(f)_{dB\mu V/m_{MHz}} = S(f)_{dBm} - 10 \lg \Delta f_{RBW_{Hz}} + L_{cb}(f)_{dB} + A_F(f)_{dB/m} + 167_{dB} \quad (4)$$

Fig. 5 shows spectral density for the electric field strength  $E(f)_{\mu V/m}$  as a function of frequency on a logarithmic scale based on the test data and in view of (4). It is evident from the figure that the PPT emission spectrum is broadband and spreads up to 6-7 GHz. In the frequency range of 30 MHz – 1 GHz the PPT emission level exceeds the background level by 30...40 dB as an average and is defined by the resonating characteristic of the system “electric circuit + plasma”. Important qualitative results include the fact, that real spectrum of PPT emission is broader substantially than the spectrum of the store discharge impulse (10  $\mu$ s), that testifying to the presence of HF emission processes in the PPT plasma. In view of the PPT operation specificity, it should be expected that the main contribution to the emission will be made by cyclotron frequencies (discharge currents generate magnetic field with the induction of 5000-6000 gauss), as well as self emission of the outer plasma layers at plasma frequencies. It

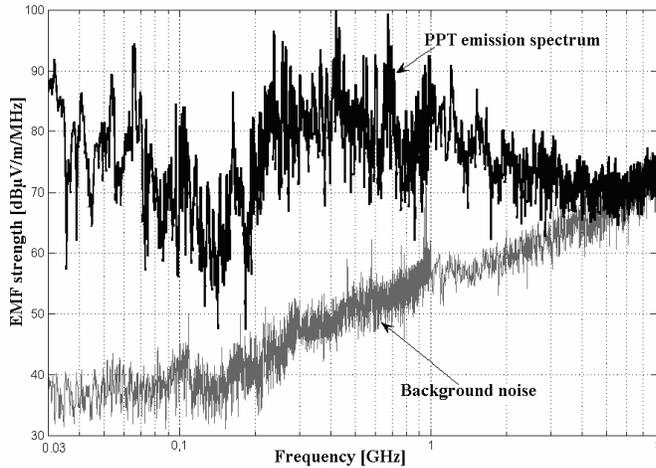


Fig. 5. PPT emission spectrum

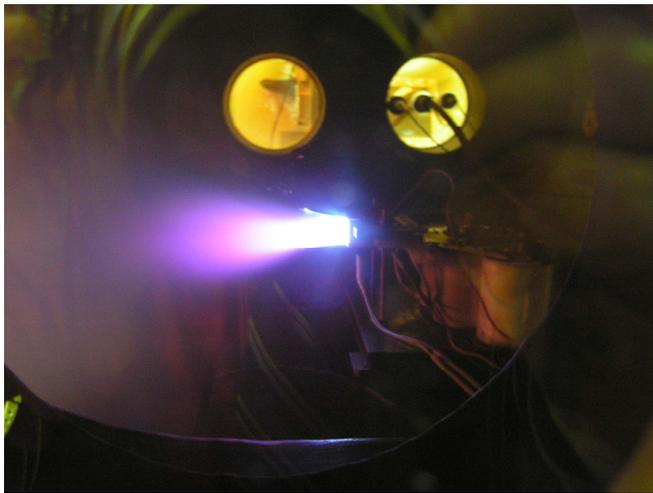


Fig. 6. Photo of the PPT operating process

should be noted that the magnetic field mentioned above makes its contribution to the electromagnetic environment on board SC also, but because of its localization the influence will be of selective character. It should be noted also that visually the PPT plasma blob has pronounced boundaries (Fig. 6), and at some fixed time moment it is close to the plume of the stationary plasma thruster. This allows application of well developed tools used to describe emission processes of stationary plasma thrusters. Results obtained describe integral structure of PPT emission spectrum and are of qualitative nature basically, not pretending to absolute values. The PPT self emission was formed inside the metal vacuum chamber (with resonant properties) and was brought out of it through a hole characterized by certain diffracting properties. Besides, direct contact of antenna mouths with the metal flange of vacuum chamber resulted in the variation of their electrodynamic parameters, and thus the calibration dependencies. Nevertheless, results obtained confirmed the fact of presence for the registered PPT emission and its influence on the electromagnetic environment. These results may be considered as the successive step along the way of developing methods of assessing EMC of propulsion systems of this type.

### 3. CONCLUSIONS

Peculiarities of measurement of electromagnetic emission by electric propulsions are discussed in the paper as applied to the EMC problems. Electric propulsion systems based on pulsed plasma thruster type, which are used for the orbit correction of small spacecraft, are considered as the sources of unintended noise of artificial origin. Procedure is developed as applied to the PPT with the discharge energy of 50 J and test estimates are obtained for the emission spectral distribution under ground conditions. It is shown that the real spectrum of PPT emission is broader substantially than the spectrum of the store discharge impulse (10  $\mu$ s), that testifying to the presence of high-frequency emissive processes in the PPT plasma. The obtained test data may be used for modeling characteristics of electromagnetic environment on board spacecraft at the PPT presence for making assessment calculations for EMC tasks.

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