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Investigation of the effect of different altitude environmental conditions on the transmission of avionics system data to ground control stations

Farklı irtifa ortam koşullarının aviyonik sistem verilerinin yer kontrol istasyonlarına iletimine etkisinin araştırılması

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Abstract

In this study, the effects of environmental conditions at different altitudes and electromagnetic fields generated by ion thrusters on the avionic system and data transfer to the ground control station were investigated. Ion thrusters, which are used as main thrusters or side force generators in space vehicles, generate a certain electromagnetic field due to their high voltage operation and characteristic features. Other variables that pose a risk of affecting aircraft or spacecraft's data transmission are temperature and pressure. The mentioned values vary under different atmospheric conditions and within the scope of this study; pressure values between 101 kPa and 50 kPa and temperature values between 25°C and -15°C were determined as variable parameters. In order to simulate space environment for the desired temperature and pressure values, a vacuum box was used. Furthermore, the influence of the ion thruster, operated under varying voltages and excitation frequencies, was analyzed by positioning it at different distances within the vacuum chamber containing the avionics system. The avionic system send data to the ground control station for all experimental cases.

Keywords: Avionic system, Data transmission, Altitude effects, Ion thruster, Ground control station

Öz

Bu çalışmada, farklı irtifalardaki çevresel koşulların ve iyon iticiler tarafından oluşturulan elektromanyetik alanların aviyonik sistem ile yer kontrol istasyonuna veri iletimi üzerindeki etkileri incelenmiştir. Uzay araçlarında ana itici ya da yan kuvvet üreteci olarak kullanılan iyon iticiler, yüksek gerilimle çalışmaları ve karakteristik özellikleri nedeniyle belirli bir elektromanyetik alan oluştururlar. Uçak ya da uzay araçlarının veri iletimini etkileyebilecek diğer değişkenler ise sıcaklık ve basınçtır. Bahsedilen bu değerler atmosferik koşullara bağlı olarak değişkenlik göstermekte olup, bu çalışma kapsamında 101 kPa ile 50 kPa arasında basınç değerleri ve 25°C ile -15°C arasında sıcaklık değerleri değişken parametreler olarak belirlenmiştir. İstenilen sıcaklık ve basınç değerlerinde uzay ortamının simüle edilebilmesi amacıyla vakum kutusu kullanılmıştır. Ayrıca, iyon iticinin farklı gerilim ve uyarma frekanslarında çalıştırılması durumunda aviyonik sisteme olan etkisi, bu iticinin vakum odasında farklı uzaklıklara yerleştirilmesiyle analiz edilmiştir. Aviyonik sistem, tüm deneysel durumlar için yer kontrol istasyonuna veri iletimi gerçekleştirmiştir.

Anahtar kelimeler: Aviyonik sistem, Veri iletimi, İrtifa etkileri, İyon itici, Yer kontrol istasyonu

1 Introduction

Satellites designed for various purposes and missions in space require propulsion systems to maintain their orbits and continue their missions. These propulsion systems are primarily classified as chemical and electric propulsion systems. While chemical propulsion systems are capable of producing significant thrust over a short duration, their low fuel efficiency makes it impossible to use them throughout the satellite's entire mission life. On the other hand, electric propulsion systems, such as Hall-effect ion thrusters, which are the fundamental electric propulsion system used in satellite. Moreover, Dielectric Barrier Discharge (DBD) ion thrusters, which are still under development and have not yet been used in any satellite, may provide the thrust required for the satellite's entire mission life due to their very high fuel efficiency [1]. During the operation of these ion thrusters, noble gases inside the satellite are ionized by using high voltage, resulting in the formation of plasma. To generate the plasma, gas ionization is achieved under a high electric field within the thruster [2]. The DBD plasma actuator generates induced flow within the ion thruster, resulting in thrust production; however, this process also leads to the generation of a specific electromagnetic field. Various factors such as low temperature and pressure affect satellites operating in space. The influence of these environmental conditions and the electromagnetic field generated by the ion thruster on data transmission to the satellite's avionic system and ground control station is crucial. Determining the external design and dimensions of satellites requires a thorough understanding of the distances at which the ion

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thruster's electromagnetic field impacts the avionic system. In the literature, it has been observed that changes in temperature, pressure, and radiation levels are studied within a special vacuum chamber, on a fixed system [3]. Recent studies have focused on the interaction of environmental factors such as electromagnetic fields, temperature, and pressure changes with avionic systems. [4] analyzed the efficiency of ion thrusters and their critical role in satellite propulsion, and showed their operational principles. Similarly, [5] provided an in-depth review of Ion and Hall thrusters, highlighting their advantages in space applications. Ion thruster-induced electromagnetic fields are studied in detail. [6] examined plasma oscillations in Hall thrusters, providing insights into their stability, which aligns with present investigation into the effects of ion thruster-generated electromagnetic fields. Furthermore, [7] specifically explored electromagnetic interference caused by ion thrusters, offering an understanding of potential disruptions in data transmission. Plume of a plasma thruster may lead to some risks of equipments used in the thruster system [8]. However, finding a study on the investigation of the effects of electric field generating equipment such as ion thrusters on integrated systems is quite limited and challenging. Testing all electronic equipment, including avionic systems, has a crucial importance for detecting potential errors and failures. This testing strategy can help to achieve the desired goals for modular avionics and fault tolerance. Electronic components are vulnerable to fluctuations in power, temperature, humidity, vibration, and noise. The majority of errors in contemporary digital systems arise within integrated components and communication channels [9]. The vacuum chamber used in the experiments is a closed area where environmental conditions such as pressure, temperature and electromagnetic field. This chamber helps to test satellite avionics according to changing environmental conditions and affecting factors to detect potential errors. Protection against electromagnetic environmental effects has become ever more crucial as modern communication relies more and more on wireless technology. This system involves reducing electromagnetic interference and ensuring the compatibility of communication systems. Particularly, this system ensures the normal operation of data connections and terminals by aiming to protect them against lightning and High-Energy Electromagnetic Pulse (HEMP) effects. Noise and parasite environments for system design is important [10]. In these studies, potential factors affecting the electronic system and data transmission of a communication avionic system that transmits data wirelessly have been examined. Planning of the test conditions are necessary to verify the reliability and performance of the spacecraft [11]. A printed circuit board (PCB) and mounted components were subjected to corona discharges for a total of 200 hours under 8.66 Pa pressure. Then, these contact effects were examined and the results revealed significant deterioration in the electrical connections and components. The observed degradation indicates that corona discharges under the given pressure have a negative impact on PCB and related components. For space applications, electronic components, assemblies, and devices must undergo high-voltage testing. These tests are conducted to evaluate how components and devices can withstand high voltage over time [12]. Another factor affecting communication between the avionic system and the ground control station is humidity. According to the study of [13], the analysis of failures in avionic system electronics due to humidity shows that such failures cause the total failure. Design criteria are outlined to prevent humidity-related failures and ensured a humidity-resistant design. The limitations of existing humidity testing methods are discussed. In contemporary aerospace and aviation research, the effects of electromagnetic interference (EMI) and ion thrusters on avionic communication systems have become significant areas of investigation. In particular, EMI can disrupt the performance of avionic systems, necessitating the development of protective shielding and mitigation techniques. [14] suggested that thermoplastic polyurethane composites provide an effective solution for EMI shielding, enhancing the resilience of avionic components in high-interference environments. Moreover, the integration of advanced data transmission standards from the aviation sector into smart vehicle technologies has been explored to minimize the impact of EMI. [15] examined the feasibility of adopting the ARINC 818 standard in automotive applications, emphasizing its potential for high-speed and reliable data transmission. The significance of uninterrupted and secure communication in emergency scenarios further necessitates the development of EMI-resistant national radio communication systems. In space technologies, the application of ion thrusters introduces additional challenges related to electromagnetic compatibility (EMC) in satellite communication systems. Thus, the findings of this study align with previous research on the effects of EMI and ion thrusters on avionic communication systems, reinforcing the need for further advancements in electromagnetic shielding techniques and system design optimizations to ensure operational robustness.

In this study, the effects of variable environmental factors such as temperature, pressure are investigated on the avionic system and its components. It is also researched that the effects of the electromagnetic fields generated by ion thrusters on the performance of avionic systems and data transmission to the ground control station for different distances. The aim of this article is to contribute to the knowledge of satellite design in a cost-effective way by examining the effects of electric and magnetic fields of the ion thruster and different environmental conditions on data transfer. The excitation frequency and applied voltage of the DBD plasma ion thruster is investigated as a research parameter to achieve a resemblance of the electromagnetic field generated by the ion thruster. Objectives of this study can be given as:

- This research examines the interplay between environmental factors and electromagnetic fields generated by ion thrusters on avionic data transmission,
- The experimental setup simulates altitude-specific conditions, establishing safety thresholds for avionic communication in satellite systems,

- This study utilizes a cost-effective experimental approach, making it accessible to small-scale research facilities,
- The experimental design reduces infrastructure and operational costs by using a modular ion thruster system and a controlled vacuum chamber.

2 Material and method

Experimental system consists of four main components: the plasma generation system, ion thruster, avionic system, and vacuum chamber along with the ground control station. The plasma generation system is one of the key structures forming the basis of this study. High voltage and current probes are used to monitor the plasma generation electrical parameters. These devices are connected to a Tektronix brand TDS2012B model oscilloscope to observe the electrical parameters. The electromagnetic field is generated by applying voltage to the ion thruster. This field is then precisely directed to the avionic system in the vacuum chamber from a certain distance.

A linear and ring-type DBD plasma ion thruster was used with length/diameter of 5 cm. The embedded electrode was grounded and high voltage is applied to the exposed electrode. The avionic system and the vacuum chamber system were specially designed to adjust the desired pressure and temperature parameters. The internal pressure of the vacuum chamber can be adjusted with the help of a vacuum pump from 101 kPa to 50 kPa. The vacuum chamber was made of plexiglass material and supported by sealing materials to maintain the vacuum value. A cooling system was integrated to allow the internal temperature of the vacuum chamber to be adjusted between +30 degrees and -25 degrees celcius. This cooling system is supported by a compressor and copper pipes inside the vacuum chamber to make sure smooth cooling according to the specified research parameters.

2.1 Plasma generator system

In the experimental setup, the plasma actuator system is used to provide the electromagnetic field generation. This field interacts with the avionics system at varying distances, allowing for a systematic assessment of electromagnetic interference effects. The high-voltage amplifier generates an adjustable AC signal ranging from 4 kV_{pp} to 8 kV_{pp}, operating at frequencies between 2 kHz and 4 kHz. This amplifier is a solid-state device with high thermal stability and low output impedance, ensuring consistent voltage delivery across varying loads. To generate plasma, the amplifier output is connected to the actuator. When an AC voltage is applied the actuators, the gas molecules are ionized leading to plasma generation. The dielectric barrier prevents DC conduction, ensuring a uniform plasma distribution and minimizing electrode degradation. The voltage and current characteristics of the system are monitored using a Tektronix P6015A high-voltage probe and a Fluke 80i-110s current probe, both connected to a Tektronix TDS2012B oscilloscope for real-time visualization. These measurements enable precise control of plasma discharge intensity and stability. In the experiments, the distance between the plasma actuator and the avionic system (L) was varied to analyze the effect on plasma formation and electromagnetic field properties. Similar experimental setups and plasma generation techniques have been reported in the literature. For instance, [3] developed a small-scale simulation chamber for testing space environment survivability, utilizing high-voltage amplifiers and custom-designed electrodes for controlled plasma generation. Additionally, [16] described the development of a high-linearity voltage and current probe for plasma diagnostics, improving accuracy in measuring discharge parameters.

The electromagnetic field induced by the ion thruster were systematically varied to analyze their effects on the avionic communication system within the vacuum chamber.

Plasma generation systems, which are an important part of modern technology, have a complex and impressive structure. It is important to carefully evaluate and optimize the interaction between equipment as well as the integration of equipment for the effective operation of the system.

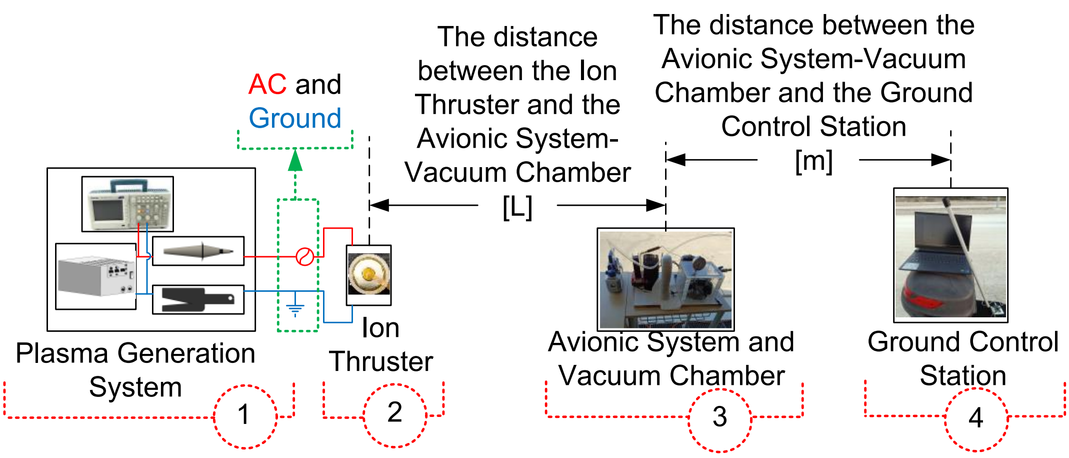

Figure 1. Integrated presentation of all subsystems utilized in this study

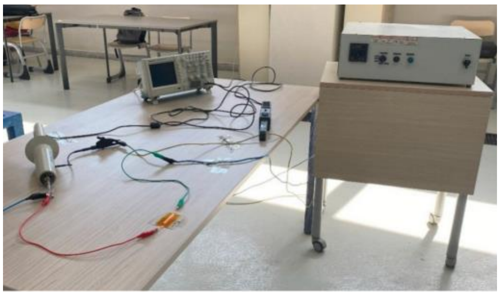

Figure 2. Plasma production system and electrical components

2.2 Ion thruster

The ion thrusters used in the system are designed across a wide spectrum, offering diversity with both linear and circular structures, thereby increasing suitability for various applications. In the generation of plasma-based induced flow, the electrode in contact with air/gas was connected to the high-voltage while the embedded electrode was connected to the ground. The dielectric material is placed between these two electrodes. The applied voltage is chosen in the range of 4, 6, and 8 kV_{pp}, and the excitation frequency is set to 2, 3 and 4 kHz.

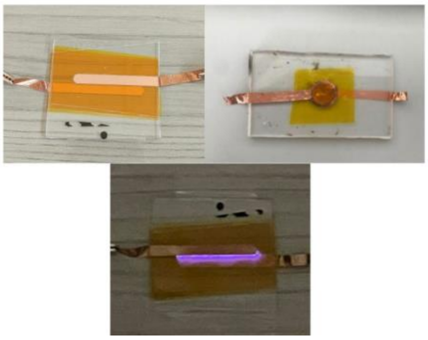

Figure 3. Ion thruster models used in the experiments

2.3 Avionic systems and vacuum chamber

The avionic system involved in the project utilizes a circuit board integrating an Atmega328- PU microcontroller and a Lora SX1276 module for data transmission. The circuit board was conducted using EAGLE PCB software and subsequently manufactured onto a copper plaque using a laser cutting machine, as seen in Figure 5. During the manufacturing process, the circuit board was produced using hydrogen peroxide and sodium hypochlorite solution. Furthermore, the vacuum chamber is made of plexiglass material and designed to be integrated with cooling pipes. This system, as shown in Figure 4, uses the vacuum gauge, vacuum pump, and cooling system inside the vacuum chamber to reach the required vacuum level. After the integration of the avionic system and the vacuum chamber, the overall operation of the system was tested. During the tests, it was observed that the data transmission function of the avionic system operated smoothly, and the vacuum chamber was able to reach the desired vacuum level.

Figure 4. Vacuum chamber system

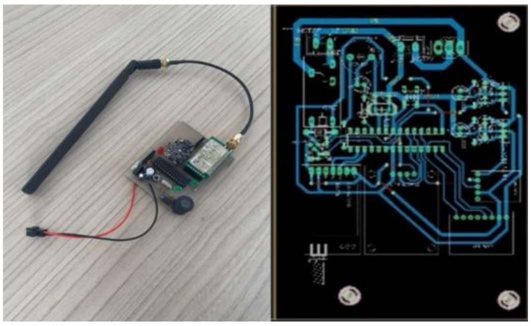

Figure 5. Avionics system and schematic diagram

2.4 Ground control station

The Ground Control Station (GCS) is a specialized device designed to observe and analyze communication effects at different geographical locations. Similar to circuit boards used in avionic systems, this station is manufactured using hydrogen peroxide and laundry bleach solution. The GGS which is equipped with an Arduino Mega mini pro microcontroller and an SX1278 chip-based LoRa module, is assembled with a high-performance 6 dBi antenna. This configuration allows the GCS to collect and analyze data from avionic systems exposed to different altitudes and various plasma effects with precision. The collected data is transferred to a serial port screen with a computer, making data acquisition easily traceable. With these features, the GCS is considered as an ideal tool for various research and development activities in the aviation and aerospace industries.

Figure 6. Ground control station system and ground control station circuit

3 Results and discussion

The effects of the electromagnetic field generated by the DBD plasma ion thruster and the different altitude conditions on the data transmission of the avionic system were investigated at planned parameters and distances. The experimental studies conducted at different distances can be seen in Figure 7. Within the scope of this study, ground control stations were established at different distances (1 km, 2 km, 3 km, 5 km, 7 km and 10 km), and data was transmitted using the 868 MHz frequency. The transmitted data were related to the ground control station with a computer and monitored on a serial port screen. Selecting the 868 MHz frequency provided advantages such as low power consumption and wide coverage area, ensuring the smooth conduct of the communication tests. To assess the impact of different distances on the avionic system's communication performance, ground control stations were positioned at various distances. Visual tracking of the communication process was made possible by using a computer to monitor the acquired data via the serial port screen.

Experimental studies were conducted at six different locations as seen in Figure 7. These six locations represent various altitudes and environmental conditions critical for data transmission. Figure 8 clearly illustrates these effects, providing a comparative analysis of data transmission at specific distances. This analysis offers fundamental data to determine the relationship between signal strength, noise levels, and transmission rates at different altitudes. Understanding the impact of altitude and environmental conditions, especially on signal quality and data transmission rate, is a primary focus of the current research. This issue is important for the development and optimization of communication infrastructure. The results found in this study has an important contribution in the development and optimization of communication technologies.

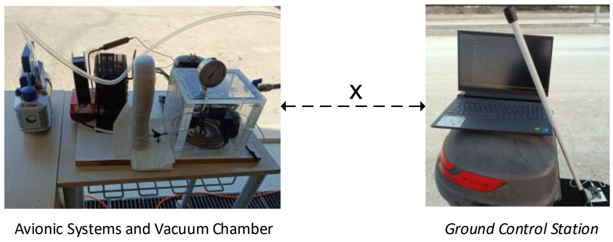

Figure 7. Distance between Avionic Systems and Vacuum Chamber and Ground Control Stations (x=1, 2, 3, 5, 7, 10 km)

Data transmission was achieved under pressure ranges of 101 kPa, 90 kPa, 80 kPa, 70 kPa, 60 kPa, and 50 kPa as well as temperature values of 25°C, 15°C, 10°C, 5°C, 0°C, -5°C, -10°C, and - 15°C. Similarly, data transmission was successfully achieved for distances of 1 km, 2 km, 3 km, 5 km, 7 km, and 10 km. Applied voltage of 4 kV_{pp}, 6 kV_{pp}, 8 kV_{pp} and excitation frequencies of 2 kHz, 3 kHz and 4 kHz resulted in similar outcomes for distances (between the plasma actuator and the avionic system) of 0.5 m, 1 m, 1.5 m, 2 m, 3 m, and 4 m. The results confirmed the reliability and repeatability of the experiments. Particularly noteworthy is that despite changes in different environmental conditions and transmission parameters, data transmission was consistently achieved. Understanding the effects of specific parameters on transmission performance is critically important for the positioning of satellite communication systems.

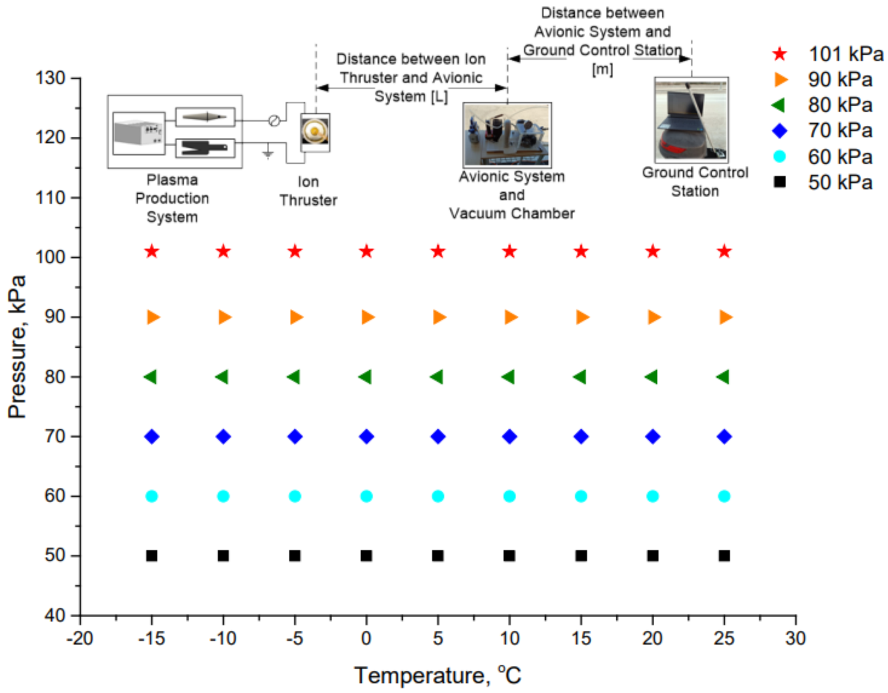

Figure 8. At distances of L= 0.5 m, 1 m, 1.5 m, 2 m, 3 m, 4 m, and m=1 km, 2 km, 3 km, 5 km, 7 km, 10 km, with application voltages of 4 kV_{pp}, 6 kV_{pp}, 8 kV_{pp}, and operating frequencies of 2 kHz, 3 kHz, 4 kHz, a data transmission graph.

Data transmission reliability under varying environmental conditions has been a critical focus of prior research. For instance, [17] investigated the application of LoRa technology in Intelligent Transportation Systems (ITS), emphasizing its effectiveness in long-range, low-power data transmission. Results of [17] highlighted the significant impact of environmental factors on signal quality, which aligns with our observation of reduced data transmission success rates under certain conditions. Similarly, [18] analyzed the effects of electromagnetic emission for plasma ion thrusters on communication system. A mathematical framework to evaluate the effects of plasma-generated electromagnetic fields is proposed in the study. Experimental results in the present study show a stable data transmission despite the presence of ion thruster-induced fields. [19] conducted a comprehensive evaluation of the LoRa physical layer. The point-to-point links of the LoRa layer checked in diverse environments. Their study provides insights into the performance of LoRa communication under various environmental conditions, which is consistent with our findings regarding data transmission reliability. Furthermore, [20] designed a well-performed LoRaWAN. Environmental monitoring is considered for major risks. Their research emphasizes the importance of robust communication systems in challenging environments. The experimental results of the current study reinforce the importance of considering environmental parameters in designing robust data communication systems for avionic applications.

4 Conclusions

This study provides an insight determining geometries involving system integration in satellite design, defining the distance between satellite antennas and DBD ion thrusters, and deciding on the design dimensions of DBD ion thrusters for satellites of specific sizes. The research parameters in this study focus on examining the effects of different pressure and temperature, and changes in the electromagnetic field generated by the DBD plasma ion thruster on communication data transmission under different altitude conditions. In this context, an avionic system and a ground control station were employed for communication data transmission. The findings of this study can be listed as follows:

- Within the scope of this study, the successful transmission of communication data conducted at the minimum distance between the ion thruster and the avionic system provides the possibility for the determined dimensions of the minimum satellite volume to be 50 cm x 50 cm x 50 cm.
- It can be said that no performance loss may achieved in the transmission of communication data if the dimensions of DBD ion thrusters do not exceed 5 cm in linear actuator length or 5 cm in annular diameter.
- The experiments conducted within the scope of this study may contribute to determining the operational/design limits of space and integrated space subsystems.
- The experimental findings have a potential to enlighten to determining the operational/design limits of space vehicle and integrated space subsystems through the examination of the effects of different electrical parameters such as applied voltage and excitation frequency, on the performance of the ion thruster.

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Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): %6

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