Analysis the Principle, Components and Functions of Electric Sensors for Space Detectors

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Abstract. With the development of science and technologies, there are increasingly number of devices used for space applications in recent years. As a matter of fact, any state-of-art space detectors will have thousands of electric devices in order to realize fine controlling. With this in mind, the topics of this paper focus on electric sensors and space detectors contemporarily. To be specifically, this study will also introduce principles, components and functions of three electric sensors for different use in space exploration. Based on the data analysis, the research results show that although different types of electric sensors are used for space applications, limitations and restrictions still exist in electric sensors whereas some of them will be addressed and improved in the future due to advanced technologies. The research significance of this paper is to associate electric devices as well as space probes and discuss the limitation and future outlooks of them.

Keywords: Electric sensors, space detectors, principle.

1. Introduction

When it comes to the history of space detectors, the first space probes were the Soviet Union's Luna probes, which were sent to the moon in 1959, in 1961, Venera which was the first probe to explore Venus was launched by Soviet Union, although Russia was the dominant holder at the start of the universe age, has not played a significant role since 1988 and America occupied this position [1]. At the same time, the space administration in Europe and Japan becomes more and more crucial and at last, China and India also start creating space detectors [1]. In order to address the financial issues in the development of space detectors, the achievement of space detectors is now becoming the subject of global collaboration [1]. Nowadays, a number of bodies decide to produce nano-satellites and micro-satellites to explore universe, this attempt is expected to construct a pliable and affordable device to detect universe and this space probe will be effective for future space exploration [2]. However, some tiny tools are restricted since they are not equipped with advanced system and cannot get command of orbits [3].

These days, electric sensors play a significant role in space probes due to their unique features. Firstly, for some specific situation and space probes like IRFPAs used in meteorological satellites, they need extremely high charge storage ability so that IRFAs are able to include luminous things in view and scattered background signals [4]. Secondly, a large amount of electricity is required for space probes, therefore, electric devices such as solar battery, radioisotope thermoelectric generator are crucial for maintaining the work of space probes and due to the different demands of different space probes in power, specifications for electric devices used are distinct [5]. For instance, thermoelectric generators converting thermal energy into electricity have been utilized for NASA over a long time and it is vital for keeping NASA working [6].

The motivation for writing this article is as space probe is a significant and interesting topic and it is capable for stimulating and satisfying the curiosity of public. In Sec. 1, the specific requirements of electric sensors for space probes are derived. Section 2, 3 and 4 present principles, parameter characteristics and main functions of their different electric sensors. Sec. 5 describes limitations of space electrical probes and mention future expectations and final outcomes.

2. Requirements of Electric Sensors for Space Exploration

Although there are a number of electrical devices in the world, some of them cannot be used as space exploration has a high requirement for electrical components. For one thing, the capacity of the space probe should be sufficient as it needs to travel for a long time and distances and to work far away from the globe and sun, which means there is no opportunities for the space probe to gain enough energy from solar radiation [1]. For another, it is necessary for the space probe to have the ability of self-rule as the long distances will result in the fact that the machine operators are unable to react rapidly when the machine encounter something unusual [1]. Additionally, the space probe needs to have the adaption of different environments, e.g., the space detector will be pushed by the generator during the launch of the detector so that the velocity and acceleration of it can increase. Under this circumstance, the space probe must have acceleration bearing capacity to complete launch phase. Over the operation period, the space probe will also meet different surroundings such as vacuum environment, vacuum thermal environment. If the detector meets vacuum thermal environment, it has to dissipate heat energy through radiation and conduction so it is important for the machine to have excellent heat dissipation ability. In addition, the electrical components must have the high radiation immunity as radiation is really destructive to electrical components. Galactic cosmic rays and solar flares have the energy to occasionally pierce unprotected satellite surfaces and can bombard and interact with them. Known effects include accelerated orbit decay from atmospheric drag, sporadic malfunctions of delicate components, deterioration of vital structural material properties, risk to flight worthiness, temporary and long-term health risks for both astronauts and passengers on board, and occasionally a miserable defeat which could pass a satellite mission abruptly. It is indispensable for satellite programming to comprehend the dynamics of the space radiation setting and its effects [7]. For electromagnetic radiation, the main hazard is due to x-rays and gamma rays produced owing to mutual effect of particles having charge with stuff of electrical components whereas for the radiation in inner belt, the main dangerous thing is caused by high energy protons [8]. Therefore , there are all kinds of radiations in space and owing to this phenomenon , electrical components must have the ability to address them.

3. Electric Sensors

3.1. Thermoelectric Generators

High heat flows for the satellite's structure are typically brought on by environmental and operational heat loads. Although, it is possible to utilize heat to produce electric power these heat flows are still useless [9]. Aiming at this problem, the thermoelectric generators can be good ways to solve it. The function of thermoelectric generators is to convert thermal energy into electric power and owing to their solid-state behavior, they are appropriate to be used for space application [9]. Moreover, thermoelectric generators will not cause vibrations to satellite as the working principle of them is not due to dynamic conversion process [9]. The thermoelectric generator is composed of three parts: the radiative cooler, the heat sink and the thermoelectric supports [10]. As the generator is set outdoors, the radiative cooler continuously discharges thermal energy into universe, causing its temperature to fall lower than the surrounding air's temperature. Due to its extremely effective heat convection, the copper heat sink keeps a temperature which is comparable to the ambient temperature. A temperature gradient is produced between the cooler and the heat sink, which are connected to the thermoelectric legs at both of their ends. Due to the thermoelectric effect, an electric current is produced together with the heat conduction in the thermoelectric supports and this generator operates without the need for any external sources of energy [10]. In addition, the TE module, also known as the Seebeck module, is the major part of these devices (seen from Fig. 1). The thermoelectric couplings in TE modules are typically electrically coupled in series and thermally connected in parallel. However, other components are crucial for the module to be used in an industrial setting. These components include heat exchangers that will improve heat transmission and electronic DC/DC

converters that can control the output voltage [11]. Radioisotope thermoelectric generators were used for space exploration because of their incredibly high dependability and low mass. They may continue to operate for several years or even several decades after their start. They can provide electricity for distant missions where solar panels cannot be powered by enough sunshine. Radioisotope thermoelectric generators were also used to power the onboard systems and transmission systems for the 1997 launched Voyager I and II spacecraft due to their exceptionally high durability [12].

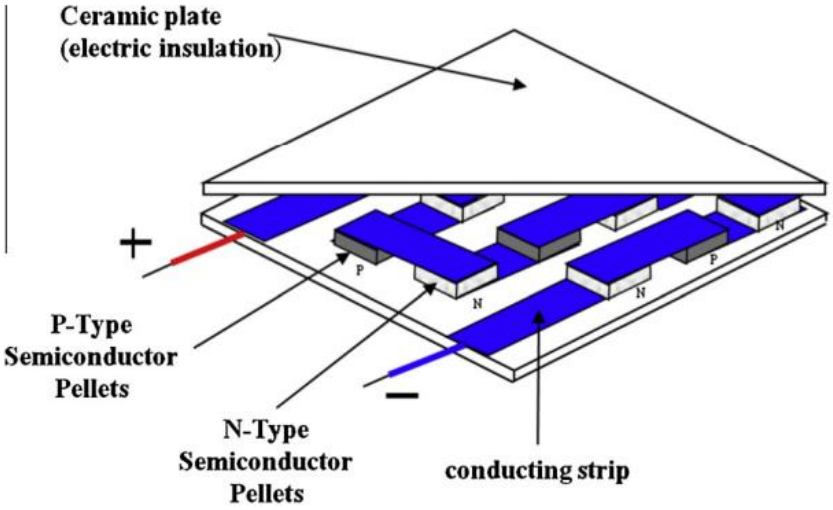


Figure 1. Schematic of a TE module.

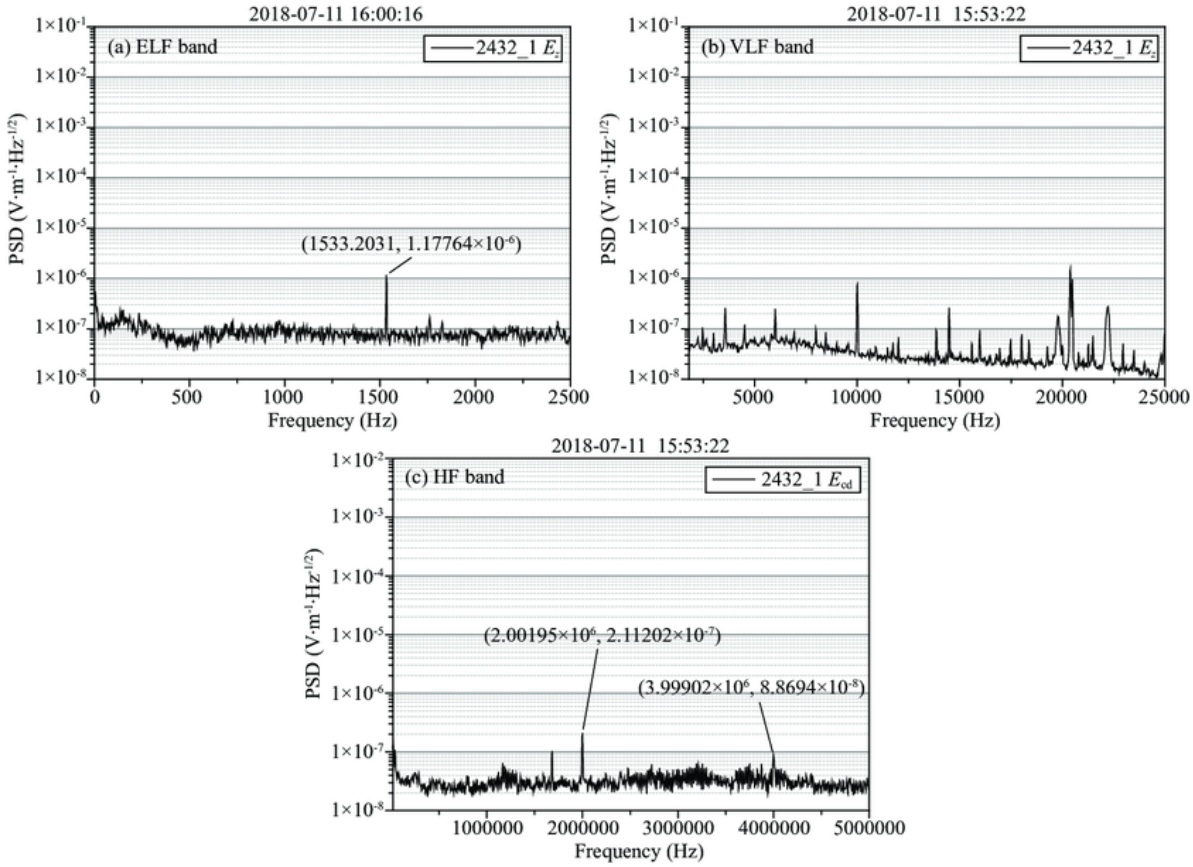


Figure 2. The sensitivity at ELF/VLF/HF bands based on the PSD (computed by orbit No.2432 ascending). (a) ELF band; (b) VLF band; (c) HF band.

3.2. Electric Field Detector (EFD) on the First Satellite of the Geophysical Field Survey Satellite Program in China

Four separate channels of the EFD—ULF (DC-16 Hz), ELF (6 Hz–2.2 kHz), VLF (1.8 kHz–20 kHz), and HF (18 kHz–3.5 MHz)—are designed to detect changes in the electric field across a large frequency scope. The sample speeds for the channels are 125 Hz, 5 kHz, 50 kHz, and 10 MHz, respectively and the EFD is made up of four spherical probes mounted on a more than 4.5 m boom [13]. Additionally, EFD has a resolution of 1 Vm-1Hz-1/2 between DC and 16 Hz, a sensitivity of 0.1 Vm-1Hz-1/2 between 6 Hz and 2.2 kHz, 0.05 Vm-1Hz-1/2 between 1.8 kHz and 20 kHz, and 0.1 Vm-1Hz-1/2 between 20 kHz and 3.5 MHz (seen from Fig. 2) [13]. In addition, two observational models belong to this device: a survey model and a burst model. The burst model focuses on the figure and data of sampling speed, whereas the survey model's primary application is on electric field power density values. To be more specific, the EFD detects the same type of electric field scientific data at the same sample rates in these two modes at ULF, ELF, and HF. The voltage of each of four electric balls is included in the raw scientific data at the ULF and ELF frequency bands. It only offers a set of PSD values with a temporal resolution of 2.048 s at the HF band. The survey mode at the VLF frequency band only offers the PSD value, while the burst mode only provides waveform data [13]. EFD is also multifunctional in providing data of the space as basic information from EFD can be used to study different types of knowledge in space. It can also be used to gather information for research on seismic observation [14].

3.3. Magnetic Sector Mass Spectrometer (MSMS)

MSMS is composed of three parts: the physic component, an electric control component and the high-voltage power supply component [15]. All of the large power required to interact with the ion source and the charged particle detectors are supplied by the high voltage component for the high voltage power supply and electric control component. A precise charged particles accelerating voltage power provision is required for speeding up the charged particles before they enter the magnetic analyzer part of the spectrometer. The high voltage component also contains the filament emission electronics, extra ion source electrodes that float at accelerating potential. The CEM4769 ion detectors' large amount of voltage changes between 1500 and 2000 V. The electric control component also has controls for micro-current amplifiers, sweep high voltage controls, and filament emission controls [16]. The primary components of the physical part are the magnetic analyzer, the charged particle source, the charge particle receiver. The ion current detecting part, processing and storage part, scanning voltage control part, current control part, high voltage multiplier control part, and communication control part between the mass spectrometer and on-board computer make up the majority of the electronic control section. Ion source, filament, and high voltage power supply multiplier make up the high voltage power supply portion [15]. Additionally, the 90° magnetic sector-field analyzers of the spacecraft's small magnetic sector mass spectrometer have two measurement ranges. The first scope is between 1 and 12 amu, whereas another scope is between 6 and 90 amu. One of the working models is utilized to measure space neutral gas, and another model is utilized to detect particles with charge in universe. This device's smallest detectable ion current is approximately 1013A, its absolute resolution is less than 1 amu, and its sensitivity is 106A/Pa(N2) and uses 18 W of power [15]. One of the functions of MSMS is to measure atmospheric composition and the other is optimized for ionospheric compositions studies [17]. These unique functions are due to the principle of magnetic sector mass spectrometer as it can make particles entering the device do the circular motion and owing to different m/z ratio, the degree of deflection of distinct particle is different.

4. Limitations and Future Outlooks

Although electric sensors play a significant role in space applications, it is undeniable that the use of electric sensors can be restricted for some specific situations. The first technical limitation is

electric propulsion although using electric propulsion is able to bring some benefits like it can save more fuels and the durability of it is excellent. Firstly, electric push technology has less thrust, which contributes to the fact that more time is needed for completing missions. Secondly, the efficiency of electric propulsion is limited so large arrays of solar cells are needed to provide sufficient power, which results in the fact that more expenditures are required for electric propulsion compared to chemical propulsion. Another limitation of electric sensors is that some electric sensors can be disturbed by the influence of surroundings such as temperature, moisture, electric or magnetic field, which can cause irreversible consequences to the hardware of electric sensors and this outcome may cause high maintenance costs as some electric sensors are sophisticated. Furthermore, the components of electric sensors will be affected by the radiation from sun or other celestial body, thereby being caught in high temperature environment which can cause short circuits or burns of electronic components.

When it comes to the future outlooks of electric sensors, the fist view is that more sophisticated electric sensors will come out in the future so that they can probe the matter in the universe more deeply and observe the space more accurately. Moreover, more advanced sensing technology will be used like electron microscope which can measure more accurately measure the nature and structure of matter in the space. In addition, the future of electronic systems in space has a lot of room for development. With the development of technologies, more fields will be needed for the space exploration like microwave radar which means it has high requirements for electronic system and this phenomenon will result in more reliable and effective creation of space electric system schemes. Furthermore, the future electric space probes will have a higher level of intelligence which means the vast majority of them are capable of autonomous decision-making, autonomous control and autonomous navigation. All of these functions lower the requirement for operators and also improve the reliability and working efficiency of space probes so that the application values of them can be enhanced significantly and there is no need to pay extra expenditure to other unnecessary devices.

5. Conclusion

Overall, this paper analyzes the principle, components and functions of three kinds of electric sensors playing a significant role in space applications for different purposes. The thermoelectric generator is used to supply power for space probes and the magnetic sector mass spectrometer is used to distinguish different kinds of particles. Aiming at the limitations of electric sensors, this paper illustrates the restriction of electric propulsion and the defects of electric sensors for space exploration. However, for the future outlooks, the paper shows that more advanced electric sensors will be created and introduced in the future and the electric system for space applications will also be improved. The purpose of this paper is to introduce the historical development of space probes and features of electric sensors for space detectors, introduce and analyze three distinct electric sensors in terms of basic principles, components and structures and main functions for space applications and point out limitations and future outlooks of the electric devices using in space exploration. In addition, the research significance of this paper is to detail the relationship between electric sensors and space applications.

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