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Abstract. Data on solar array efficiency measured on board two Czech MAGION micro-satellites between August 1995 and June 2002, during the period of increasing and high solar activity, were used to study the space weather effects on photo-voltaic solar cells. A stronger degradation of the solar array was observed on MAGION-5 in comparison with MAGION-4. This fact can be explained by the essential difference between the two orbits. The MAGION-5 s/c was in the radiation belts more than 40% of the time, whereas the MAGION-4 was only present about 4% of the time. The experimental data refer to periods of low as well as high solar activity, with an enhanced occurrence of strong solar events. The evaluation of the data set covering a period of more than 6 years has shown that solar proton flares can have an almost immediate effect on the solar array efficiency. However, in the case of MAGION-5, an important role in solar cell degradation is played by the long-term effect of energetic particles in the radiation belts. Periods with a distinctly steeper decrease in the solar array output power were observed and can be explained by an increase of particle flux density in the radiation belts. Periods in slower decline of the solar array output power correspond to periods in low radiation belt indices based on the NOAA POES s/c data.

Keywords. Magnetospheric physics (Energetic particles, trapped; Instruments and techniques) – Solar physics (Flares and mass ejections)

1 Introduction

The MAGION microsatellites (Fig. 1) for the INTERBALL Mission (Tříska et al., 1995) and their subsystems (Table 1) were developed and manufactured at the Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, in cooperation with the Faculty of Mathematics and Physics, Charles University, Prague, the Space Research Institute of the Russian Academy of Sciences, Moscow, and the Technical University Graz, Austria. The scientific payload was developed in cooperation with Austria, the Czech Republic, France, Germany, Poland, Romania, Russia and Slovakia.

MAGION is a nonhermetic spacecraft, the basic body of which is shaped in the form of a 24-hedron (Fig. 1), with the distance between opposite faces being 530 mm. On the "upper" base there is a column carrying 4 deployable, 730-mm long booms with scientific payload sensors. The main parts of the s/c subsystems (Table 1), including the scientific payload, are located inside the basic structure. The solar array consists of twelve deployable solar panels, 196×196 mm in size, and another six solar panels fixed to the satellite's body. All the solar panels for the MAGION satellites were manufactured by the Russian factory "Kvant-Moscow" using the same silicon-cell technology for all of them. Therefore, the solar array efficiency decrease with time in orbit between the different MAGION s/c can be compared.

MAGION-4 was launched on 3 August 1995, together with the INTERBALL-1 and, one year later on 29 August 1996, MAGION-5 was launched, together with the INTERBALL-2 s/c, both into highly elliptical orbits (Table 2), crossing the inner magnetosphere. MAGION-4 (58.7 kg) and MAGION-5 (68.5 kg) had apogees close to 200 000 km and 20 000 km, respectively, and both of them had initial perigees of about 800 km. The mechanical structure and the solar array configuration used for the two s/c were identical. The solar array consisted of 18 solar panels, most of which were deployed perpendicularly to the spin axis of the s/c pointing to the Sun.

2 Data

The electric currents and temperatures of all the solar panels on board the MAGION satellites were regularly measured and recorded as part of the spacecraft housekeeping data. The volt-ampere characteristics of the solar panels were

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Table 1. MAGION S/C subsystems.

Power:	solar array 32 W at beginning of mission, two NiCd batteries 12 V, 4 Ah
Telemetry (band/power):	137 MHz/1.5 W ; 400 MHz/2.5–5.0 W ; 1530 MHz/2 W
Digital Telemetry:	bit rate max. 40 kbit/s
Analog Telemetry:	broadband 0.1–60 kHz, subcarriers 0–1.3 kHz
Telecommand Link:	150 MHz and 450 MHz bands, 1028 direct commands, command words
Housekeeping:	voltages, currents, temperatures, operation status (272 items measured)
Attitude Sensors:	3-axis magnetometer, 3 solar sensors and 2 infrared horizon sensors
Stabilization:	spin 3°/s; spin period and spin axis direction controlled by a cold gas jet system; spin axis directed towards the Sun
Scientific payload:	14 instruments to study the magnetic and electric fields and waves, cold and hot plasma parameters, video imager experiment
Total mass:	MAGION-4 58.7 kg, MAGION-5 68.5 kg

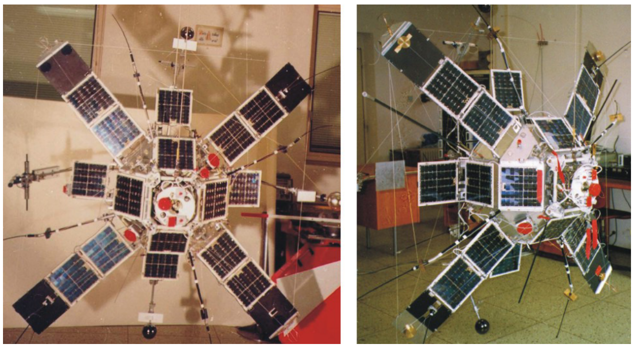

Fig. 1. The MAGION-5 flight model assembled and tested in the laboratories of the Institute of Atmospheric Physics, Prague, during winter-spring 1996 and launched on 29 August 1996 as part of the INTERBALL mission. The solar array is shown in the fully deployed position. The MAGION-4 configuration was almost identical.

Table 2. Initial orbital parameters.

	MAGION-4	MAGION-5
Perigee	800 km	791 km
Apogee	192 000 km	19 196 km
Inclination	62.8°	62.8°
Orbital period	92 h	5.8 h
Launch date	3 August 1995	29 August 1996

measured periodically. These data were used to evaluate the solar array degradation during the mission. The results are shown in Figs. 2 and 3.

The planned lifetime for the MAGION-4 and -5 satellites was 18 months, to fulfill the proposed scientific program of the INTERBALL Mission. In fact, MAGION-4 remained active for 26 months, and MAGION-5, although out of operation for 20 months beginning on the second day after launch date, was successfully reactivated and remained operable for more than 4 years, from May 1998 till August 2002. This

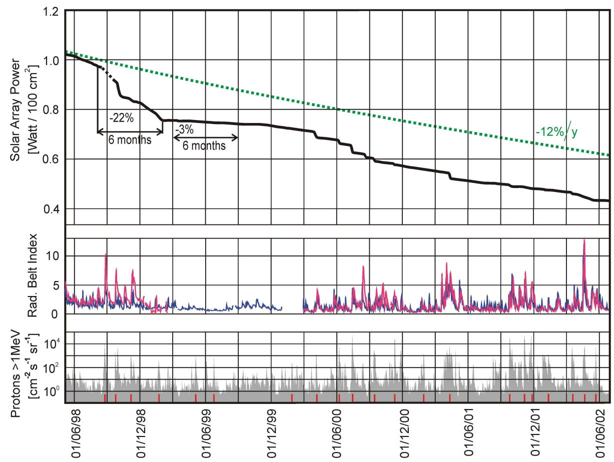

Fig. 2. MAGION-5 solar array degradation during the period from May 1998 to July 2002. The two curves in the central part of the figure show the radiation belt indices based on NOAA POES data: >30 keV (red) and the >300 keV (blue) electrons. Daily proton flux values measured by FOES-8 are shown in the lower panel. Solar proton events are denoted by red marks on the time scale. Note: most of the step-like decreases in the solar cells' output power are connected with strong solar proton events; periods with a steeper decrease in the output power correspond to periods of enhanced radiation belt indices.

enabled us to study the process of the s/c solar array degradation over a period of more than 6 years.

3 Results

The main results follow from Figs. 2 and 3. The long-term trend of the MAGION-5 solar array degradation is shown in Fig. 2. For comparison data on energetic particle fluxes published by the NOAA Space Environment Centre (http://www.sec.noaa.gov) are plotted in the two lower panels. The radiation belt variability can be characterised by the Radiation Belt Indices (RBI) based on NOAA's Polar-orbiting Environmental Satellites POES. The total daily RBI for >30 keV and

>300 keV electrons is plotted in the central part of Fig. 2. The long period of a steep decrease in solar cell efficiency, occurring from May 1998 to January 1999, occurs during the long-term enhancement of RBI. A 22% loss of power was observed within a period of only 6 months. On the contrary, the period of February–August 1999, where the decrease in solar cell efficiency was slow, is a period of very low radiation belt indices. It can be concluded that radiation belt variability (see, for instance, Friedel et al., 2002 and Reeves et al., 2003) and the long-term effect of the Earth's radiation belts play an important role in the MAGION-5 solar cells degradation. The lower panel shows the >1 MeV proton flux measured at geostationary orbit by FOES-8. The sudden (step-like) decreases of the solar array output power observed on MAGION-5 are related to energetic proton flux peaks, most of which are connected with solar proton events. The first case of a step-like solar array degradation was observed on MAGION-5 in real time during the solar proton flare of 30 September 1998.

Figure 3 shows the difference between the MAGION-4 and MAGION-5 solar cell degradation. This can be explained mainly by the essential difference between the two orbits crossing the radiation belt region for different lengths of time. MAGION-4 spent about 4% of the time in the radiation belts, but MAGION-5 more than 40%.

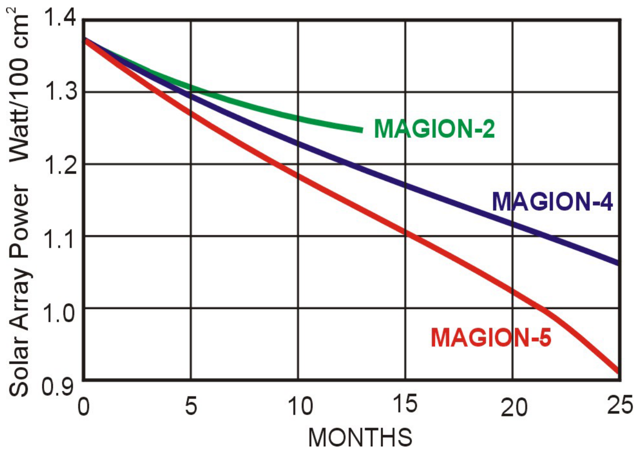

Fig. 3. MAGION-4 and MAGION-5 solar array degradation during the 25 months after launch. Most of the differences between these two curves can be explained by the effect of the radiation belts, which is more than 10 times stronger along the orbit of MAGION-5 than MAGION-4. The solar array degradation curve measured on the low-orbiting MAGION-2 (apogee 2400 km) is shown for comparison.

4 Conclusions

The major conclusions of this study are listed below:

1. Solar proton events can have an immediate negative effect on the s/c solar array efficiency;

2. Strong solar proton events can cause a step-like decrease in the solar array power output;

3. Cases of a distinct but not step-like decrease in the solar array power output were observed and can be explained by an increase in the Radiation Belt particle flux density connected with enhanced solar and/or geomagnetic activity;

4. Periods of a slow decrease in the solar array output power correspond to periods of low radiation belt indices;

5. The long-term effect of the radiation belt particles is the main cause of the steeper degradation of the MAGION-5 solar array;

6. This study has shown that the solar array efficiency can be used as a supplementary indicator of space weather radiation effects on s/c.

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