Problem and solution for monitoring of exposure of ionizing radiation of space on radio electronic devices of spacecrafts

V Anashin¹, G Protopopov¹, S Balashov², S Gaidash³, N Sergeecheva⁴

¹ Deputy of general director – deputy of chief designer, Institute of Space Device Engineering, Moscow, Russia
² Head of group, Institute of Space Device Engineering, Moscow, Russia
³ Head of sector, “Information Satellite Systems” Reshetnev Company, Zheleznogorsk, Russia
⁴ Head of space weather forecast center, Pushkov institute of terrestrial magnetism, ionosphere and radio wave propagation, Troitsk, Russia
⁵ Leading engineer, S.P. Korolev Rocket and Space Corporation “ENERGIA”, Korolev, Russia
E-mail: g.a.protopopov@mail.ru

Abstract. A dose rate data on different spacecrafts at circular orbit ~20000km were obtained, also a comparison between the flight data and space models was made and anomalous perturbations of ionizing radiation of spacecrafts was traced. These abnormal disturbances are correlated with GOES data and with International Space Station data, and also with ground based measurements of neutron monitors. One of the elements of industrial system of monitoring is a local ground forecast station, which provides forecasts of geophysical conditions, including the forecast of the proton increase, geomagnetic forecasts, forecasts of relativistic electrons, and produces an alert signal when protons and electrons increase.

1. Introduction
On request of Russian Federal Space Agency, elements of industrial system for monitoring the impact of space ionizing radiation on electronic devices of spacecrafts were established, and now are functioning well and permanently are upgraded. It was decided to equip all spacecrafts with the hardware for control space ionizing radiation exposure. The Monitoring System are used to measure the characteristics of the impact of space ionizing radiation on electronic devices, also to specify the “space models”, and to forecast the “space weather”. The Monitoring System includes two parts: the scientific monitoring system (ground-based segment) and the engineering monitoring system (space-born segment) [1].

2. Total ionizing dose sensor features
The base component of space-born segment is set of TID sensors, which operate according to MNOSFET dosimetry principle [1]. The sensor has output range from 100 to 100000 rad and frequency output from 1 to 200 kHz. It is applying a voltage control against current control that provide a better linearity of sensor. The sensor has temperature stabilization by operating-point selection according to minimal change of sensor current-voltage curve.
For the increase of the measurements accuracy and reliability, the development of dose multisensors is conducted. It is planed to duplicate of sensitive elements and to use a multiple-count sensitive elements for output range improvement.

The sensor of heavy charged particles based on RAM sensitive element is developed for monitoring the impact of space ionizing radiation in the field of SEE. Also for determining the spectral characteristics of space ionizing radiation special sensor based on a diamond detector is developed.

3. Flight data analysis

Figure 1 shows the flight data for 34 TID sensors from October 2008 to April 2012 at the circular orbit ~20000 km – the middle-Earth orbit (MEO). The analysis of the flight data shows that Monitoring System detect an anomalous increasing of dose rate. The anomalous increasing of dose rate was observed in October 2008 – in 3 times, in April 2010 – in two order of magnitude, in October 2010 – in 6 times, in February – in 4 times, in March 2011 – in 15 times, in September 2011 – in 4 times, in March 2012 – in two order of magnitude. The analysis of the last event is concerned in this paper.

Figure 1. Flight data for 34 TID sensors onboard 17 spacecrafts at the circular orbit ~20000 km from October 2008 to April 2012.

GOES monitoring system [2] detected two solar flares of X class at the 07.03.2012. This flares were followed by a proton event. It was observed an electron flux increasing at the Geostationary Earth Orbit (GEO) also [2]. Flight data of accumulated dose was compared with proton flux data (figure 2) and with integral fluence of electron (figure 3). One can see an excellent agreement with electron integral fluence data. So, such abrupt increasing of dose rate can be explained by the compression of the Van Allen Belts and, as result, by increasing electron fluence at MEO.

Figure 4 shows flight data of accumulated dose from the circular orbit ~20000 km, flight data of average dose rate at the International Space Station (ISS) from January 2012 to March 2012 and average dose calculated using ISS data. One can see short-lived increasing of dose rate at the Low-Earth Orbit (LEO) at 08 of March, this event corresponds with proton flux increasing.

Figure 5 shows flight data of accumulated dose from the circular orbit ~20000 km and a ground-level measurements of cosmic rays variations by Moscow Neutron Monitor from January 2012 to March 2012 [3]. One can see correspondence in date of abrupt increasing dose rate, solar flare and ground-level cosmic rays decreasing.
Figure 2. Flight data for one TID sensor at the MEO (solid line) and proton flux ($E > 10$ MeV) at the GEO (dashed line) from January 2012 to March 2012.

Figure 3. Flight data for one TID sensor at the MEO (solid line) and integral fluence of electron ($E > 2$ MeV) at the GEO (dashed line) from January 2012 to March 2012.

Figure 4. Flight data for one TID sensor at the MEO (solid line), average dose calculated using dose rate data (dotted line) and average dose rate at LEO (dashed line) from January 2012 to March 2012 (ISS data).

Figure 5. Flight data for one TID sensor at the MEO (solid line) and ground-level measurements of cosmic rays variations (Moscow Neutron Monitor) (dashed line) from January 2012 to March 2012.

So, one can conclude that main contribution to accumulated dose at the MEO gives the high-energy electrons. This statement is suggested by calculation of accumulated dose at the MEO using AE-8 model (for electrons) and Nymmik’s model (for solar protons) [4].

One of the elements of Monitoring System is a local ground forecast station, which provides forecasts of geophysical conditions, including the forecast of the proton increase, geomagnetic forecasts, forecasts of relativistic electrons, and produces an alert signal when protons and electrons increase. This station is able to predict anomalies. For example, dangerous radiation environment for the 7 of March was predicted at 06.03.2012. Figure 6 shows forecast of probability of the large solar proton increasing (SPI), the automated forecast of large SPI probability and forecast of SPI probability. The SPI and the large SPI means an exceeding 10 MeV and 100 MeV proton flux of 10 pfu level, correspondingly. Predicted proton flux increasing probability was 53% for protons with $E > 10$ MeV and 5% for protons with $E > 100$ MeV. It should be note that probability for 10 MeV protons is equal 1-3 percents and 0.1-0.2 percents for 100 MeV for quite radiation environment. Figure 7 shows high energy GEO electron fluence forecasts from February 2012 to April 2012. One can see a good correspondence with forecasts and flight data.
4. Conclusion

The elements of the Russian Federal Space Agency Monitoring System of space ionizing radiation exposure on electronic components was developed and operates successfully. The Monitoring System provide a correct preliminary prediction and detection of anomalous increasing of space weather characteristics. The dose rate increasing in March 2012 is in agreement with other monitoring systems data and with ground-level measurements.

References

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