Detection of EMPs generated by meteoroid impacts on the MMS spacecraft and problems with signal interpretation

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Abstract

Signatures of hypervelocity dust impacts detected by electric field instruments are still not completely understood. We have used the electric field instrument onboard one of the MMS spacecraft orbiting the Earth since 2015 to study various pulses in the measured electric field detected simultaneously by multiple antennas. This unique instrument allows a detailed investigation of registered waveforms. The preliminary results shown that the solitary waves can generate similar pulses as dust impacts and detected pulses can easily by misinterpreted when only one antenna is used.

1. Introduction

Hypervelocity dust impacts on spacecraft materials generate free electrons and ions by impact ionization. This impact cloud alters the potential of the spacecraft or the antenna by re-collecting the impact cloud particles [1]. It has been shown that these potential changes can be detected by electric field instruments as transient pulses in the measured electric field. This way of dust detection is de facto by-product of electric field measurement typically performed by many spacecraft. The first such detection was reported by Voyager during crossing of the Saturn ring plane (e.g., [2,3]) followed by other missions such as Deep Space 1 [4], Cassini (e.g., [5-8]), WIND (e.g., [9-11]), STEREO (e.g., [1,12]), MAVEN [13], and Cluster [14,15]. The large advantage of this approach is that the entire spacecraft body is used as a detecting area which is much larger than the area for specialized dust detectors. On the other hand this approach gives only very limited information about an impactor. Other disadvantage is that a detected signal strongly depends on the design of the electric field instrument, its configuration (monopole or dipole), the length of the antenna arm, and the instrument electronics. Therefore it is not straightforward to compare signatures of dust impacts obtained by various spacecraft.

2. Signatures of dust impacts

Dust impacts generate various signatures in the measured electric field. The generally accepted theory is based on the re-collection of impact cloud particles by the charged spacecraft body or arm of the electric antenna resulting in the reduction of the spacecraft and/or antenna potential. A positively charged surface attracts free electrons and repulses positive ions while a negatively charged surface attracts positive ions and repulses electrons. The electric field instrument operating in the monopole configuration (the electric field is measured as a potential drop between a single antenna and the spacecraft body) can register fast changes in the spacecraft potential triggered by the dust impact. The pulse can be followed by a small "overshoot" when a fraction of the free charge is re-collected by the electric antenna [1]. On the other hand the dipole configuration is not sensitive to changes in the spacecraft potential, because the electric field is measured as a potential between two antennas in this case. Thus instruments operating in the dipole configuration are able to detect dust impacts only when a fraction of impact cloud particles are re-collected by the antenna. Dust impacts have been reported both by monopole and by dipole electric field instruments, but the signatures in the measured electric fields are sometimes not completely understood and explained.

A frequently neglected problem is the identification of dust impacts in obtained waveforms. Solitary waves are commonly present in the space plasma mainly in planetary magnetospheres and their signatures in a single waveform can be similar to pulses generated by dust impacts [16-18]. Understanding the dust impact identification is very important when applying the method for electric field instruments and precision of such measurements. Utilizing data from spacecraft providing fast electric field measurement simultaneously in multiple directions give important information for understanding these features. One such mission is the Earth-orbiting MMS. Each of the four MMS spacecraft provide simultaneous probe-to-spacecraft potential measurements for their respective six electric field antennas and an electric field measurement in three directions [19]. The sampling frequency in burst mode is 10 kHz which is high enough for dust impact detection. The electric field data in multiple directions allows reliable identification of dust impact, which is not possible with single antenna measurement. We have used the electric field instrument onboard the MMS spacecraft orbiting the Earth since 2015 to compare signatures corresponding to the dust impact and solitary waves.

3. Results

Many interesting events have been pre-selected by an automatic code by searching for fast changes in the probe-to-spacecraft potential, *P* detected by MMS 1 during January 2016. These events have been checked visually and some of them are presented in this paper. The first of them from January 7, 2016 at 22.10.11.012 is shown in Fig 1. The probe-to-spacecraft potential for each antenna are shown in Fig. 1 (middle). It is possible to see that all pulses have the same profile. Each of these measurements represent the electric field instrument operating in monopole configuration. The electric field, *E* measured simultaneously in the dipole configuration (potential drop between two opposite antennas) is shown in Fig 1. (bottom) in DSL coordinates.

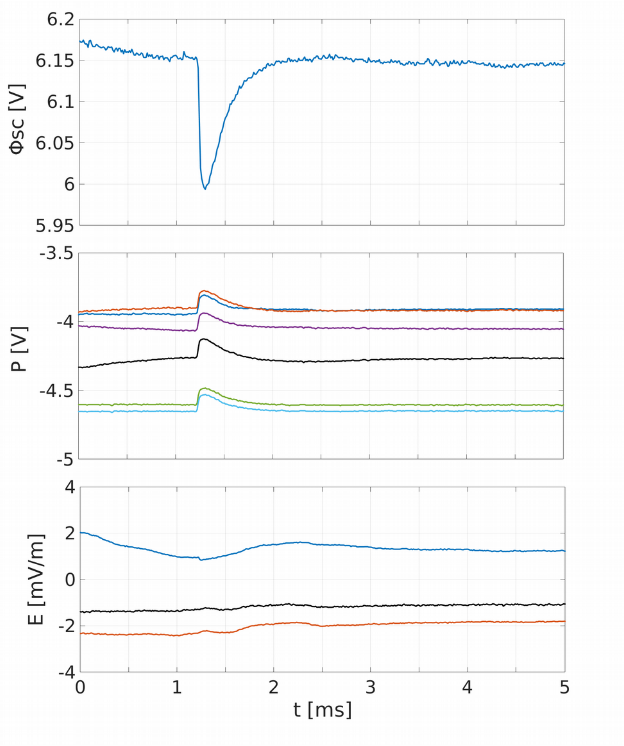

Figure 1. The spacecraft potential, *Φsc* (top), probe-to-spacecraft potential, *P* (middle), and the electric field, *E* (in DSL coordinates) (bottom) during a dust impact.

It is interesting to see that there are no pulses in the electric field data. The fact that pulses are presented only in the probe-to-spacecraft potential and that the profile of all pulses are identical indicates that a change in the spacecraft potential is responsible for these pulses. Such a change can be explained as a dust impact. The spacecraft potential, *Φsc* derived from the probe-to-spacecraft potential measurements is shown in Fig. 1 (top). The fast drop (150 mV) caused by the re-collection of the impact cloud electrons is followed by the slower relaxation to the original value. The relaxation to the equilibrium value is caused by interaction with ambient plasma and the solar UV radiation.

Similar plots for a different waveform from January 07, 2016 at 22.10.06.646 are shown in Fig. 2. It is possible to see that each probe detected different signatures in the probe-to-spacecraft potential in this case (midle) and similar bipolar signatures in the measured electric field when the instrument was operating in the dipole configuration (bottom). This shows that observed pulses are generated by a solitary wave [16,17].

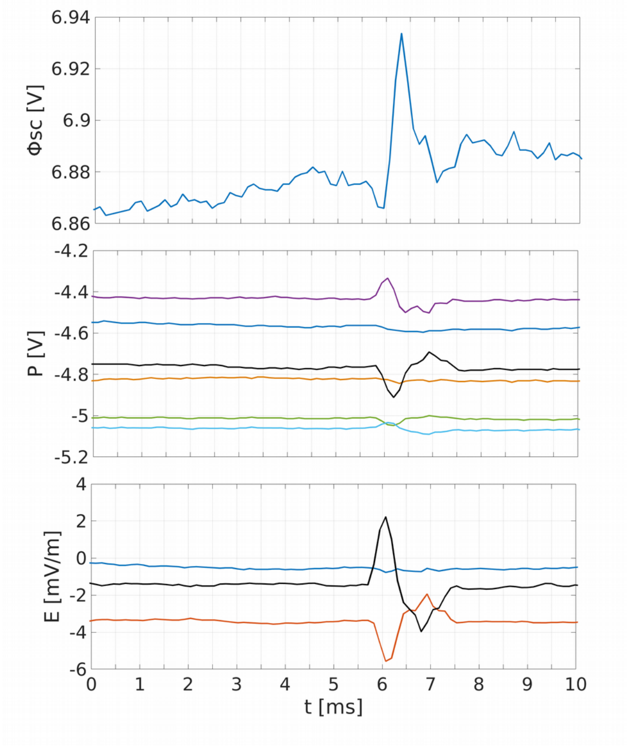

Figure 2. The spacecraft potential, *Φsc* (top), probe-to-spacecraft potential, *P* (middle), and the electric field, *E* (in DSL coordinates) (bottom) during transit of a solitary wave.

These examples show that it is easy to distinguish between pulses in the spacecraft potential caused by dust impacts or by solitary waves when more than one antenna is used. On the other hand, most dust impact detections are based only on a single antenna measurement. The pulses with "overshoots" are typically attributed to the simultaneous re-collection of impact cloud particles by the spacecraft body and electric field antenna [1, 7]. Thus a solitary wave recorded only by one antenna can be misinterpreted as a pulse generated by a dust impact. Compare to the pulse in the probe-to-spacecraft potential (the same pulse as in Fig 2.) generated by the solitary wave in Fig. 3. with dust impacts presented in e.g. Tsurutani et al. [4], Wang et al. [5], Kurth et al. [6], Ye et al. [7], Ye et al. [8], Malaspina et al. [9], Malaspina et al. [11], and Andersson et al. [13].

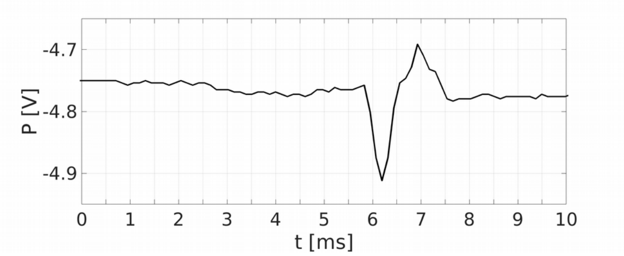

Figure 3. The probe-to-spacecraft potential, *P* for single antenna operating in the monopole configuration during a solitary wave crossing (same pulse as in Fig 2.) .

Another example from January 24, 2016 at 6.13.53.582 of a solitary wave detected by MMS 1 simultaneously by two antennas operating in the monopole configuration is shown in Fig 4 at 2.5 ms (a second one at 7.5 ms). It is possible to see that the shape of the pulse is different for the both antennas. The reliable identification of the blue pulse without data from another antenna would be impossible.

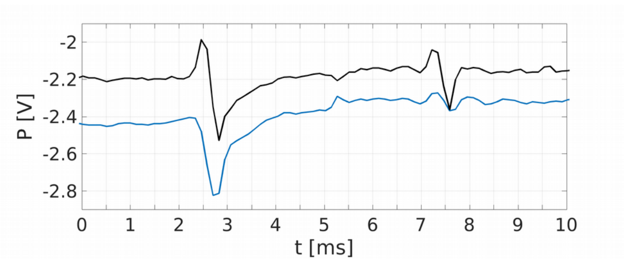

Figure 4. The probe-to-spacecraft potential, *P* for two antennas operating in the monopole configuration during a solitary wave crossing.

4. Conclusion

We have compared waveforms corresponding to the change in the spacecraft potential and solitary wave detected by multiple electric field antennas. These preliminary results show that reliable identification of dust impacts only by a single antenna is very dificult especially in environments where solitary waves are commonly present. These results can help to understand data from other spacecraft such as Cassini, STEREO, WIND, and MAVEN. It is important to note that fast changes in spacecraft potential can also be generated by other mechanisms than the dust impact. For example active experiments onboard or electrostatic discharge can generate pulses depicted by the spacecraft potential.

5. Acknowledgements

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6. References

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