ERM: An engineering radiation monitor for high dose missions

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Introduction: Missions to the moons of Jupiter face the challenge of extreme radiation environments. Spacecraft instruments and subsystems will need to include significant amounts of shielding around their electronics and detectors to limit the total accumulated dose. The amount of shielding chosen must be based on a conservative determination of the predicted total integrated dose for the mission lifetime using models of the static particle flux [1, 2, 3]. The actual environment experienced is expected to be dramatically more dynamic and mission planners, spacecraft operators, and scientists can all benefit from detailed radiation data while on orbit. Data acquired by the Van Allen Probes Engineering Radiation Monitor has successfully demonstrated the capability and utility of monitoring dose and deep-dielectric charging in a dynamic radiation environment.

Instrument Overview: The Engineering Radiation Monitor (ERM) was initially developed as a supplementary spacecraft experiment for NASA’s Van Allen Probes mission [4]. Designed to take the place of spacecraft balance mass, the ERM contains an array of eight dosimeters and two buried conductive plates to monitor total dose and deep dielectric charging at each spacecraft in real time. Photographs of the flight ERM are shown in Figure 1 along with its summary characteristics in Table 1.

The dosimeters are mounted under covers of varying shield thickness to obtain a dose-depth curve. A three minute readout cadence coupled with an initial sensitivity of ~0.01 krad enables dynamic measurements of dose rate. The dosimeters consist of Radiation-sensing Field Effect Transistors (RadFETs) [5] and operate under zero bias to extend their measurement range of total integrated dose (TID) above 1 Mrad and to preserve their response even when powered off for extended periods.

Two large-area charge monitor plates set behind selected thickness covers measure the dynamic currents of penetrating electrons that can be potentially hazardous to sensitive electronic components within the spacecraft. The charge monitors are designed to handle large events without saturating while providing sufficient sensitivity to characterize quiescent conditions as well. High time-resolution monitoring allows detection of rapid changes in flux and enables correlation of spacecraft anomalies with local space weather conditions.

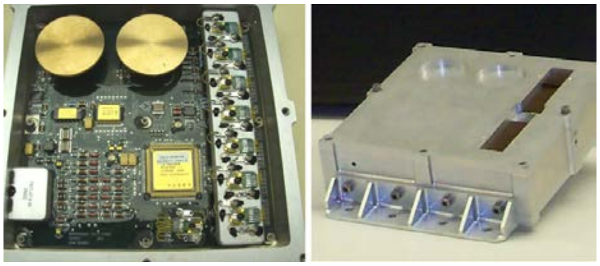

Fig. 1. (*Left*) Flight ERM with its cover removed showing the locations of the individual RadFET dosimeters and the two charge monitors; (*right*) view with cover showing variable thickness absorber. Figure reproduced from [3].

Table 1. ERM Summary Specifications:

Dosimeter Range:	0 – 1000 krad
Dose Sensitivity:	~0.01 krad, TID <10 krad
	~0.1 krad, TID < 100 krad
	~1krad, TID < 1000 krad
Charge Monitor Range:	0 – 3 pA/cm^2
Current Sensitivity:	~0.001 pA/cm^2
Mass:	2.9 kg
Power:	0.25 W
Envelope:	18 cm x 18 cm x 6 cm
Data Rate:	16 bps

On-orbit Results: The ERM has now been in operation for nearly two years within the severest parts of Earth’s inner and outer radiation belts. Some of the most striking events occurred during the early part of the mission as shown in Figure 2. Here a comparison between the dosimeters and the charge monitors demonstrates a strong correlation, highlighting the general ability of the current plates to provide not only a monitor of deep dielectric charging conditions but also a sensitive measure of the dose rate in an electron-dominated environment. On an even finer time scale, as shown in Figure 3, one can observe the dynamics of passing through the inner and outer radiation belts, including a change of sign corresponding to the inner proton belt. Integrated dose estimated by summations and scalings of the charge rate monitor compares favorably with the total dose as a function of time obtained from the RADFets.

On-going Work: The sensitivity and performance of the RadFET dosimeters is limited by the need to balance resolution against dynamic range. We have developed a custom hermetically-packaged RadFET that contains a thermo-electric cooler. This configuration will enable full temperature control of the RadFET, including the provision to anneal the devices at high temperatures in order to ‘reset’ the charge. By allowing periodic resets, the RadFETs may be operated under bias, which greatly improves linearity and enhances sensitivity, without concern for saturating the device. Such an improvement will provide high sensitivity, even for long-duration, high-radiation missions.

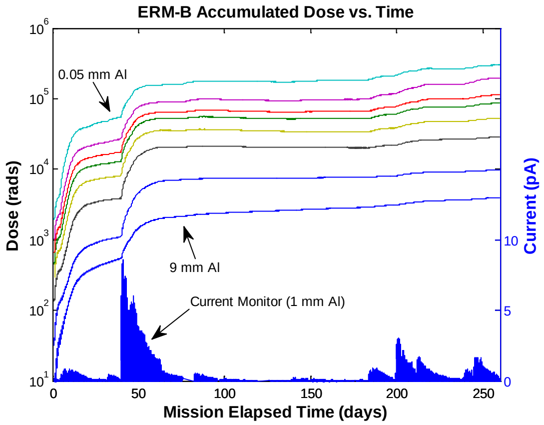

Fig 2. Dose versus time for the first 260 days of the Van Allen Probes mission showing calibrated data from the eight RadFET dosimeters and one of the two charge monitors. The variability in dose rate clearly corresponds to the storm activity measured by the charge monitor.

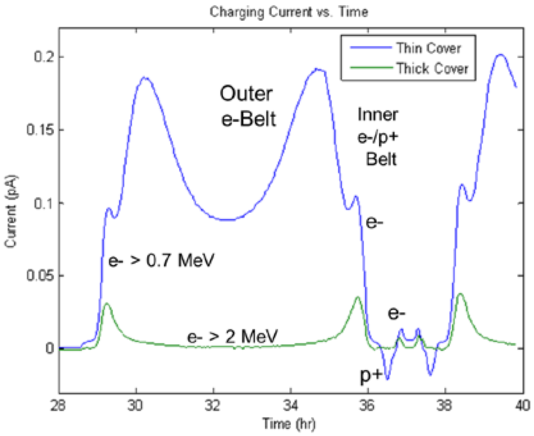

Fig 3. Typical response of ERM charge monitors over an orbit. Transitions between the inner and outer radiation belts are easily identifiable as well as a reversal in polarity corresponding to the proton-dominated region.

Potential Missions: The Europa Clipper mission has been studying the need for a radiation monitor. A dedicated Radiation Monitor Working Group has been established comprised of project managers, scientists, and engineers from the Applied Physics Laboratory (APL) and the Jet Propulsion Laboratory (JPL) to define the measurement requirements and provide a suitable design concept. The prioritized (1 = highest) objectives of the Clipper radiation monitor are: 1) to help diagnose anomalies, 2) to aid in mission planning (with radiation dose viewed as a consumable), 3) improving radiation belt models of Jupiter, and 4) provide reconnaissance for the radiation hazards that might be met by future missions to Jupiter and to Europa. For the latter objective, the high time-resolution dose rate data provided by the charge monitors would enable detailed mapping of the Europa radiation environment, which could be helpful in identifying promising future landing sites.

References: [1] Garrett H. B. et al., (2003), JPL Publ. 03-006, 72 pp., Jet Propulsion Lab. [2] Mauk B. H. and Fox N. J. (2010) *J. Geophys. Res. 115, A122220.* [3] Mauk B. H. et al. (2004) *J. Geophys. Res. 109, A09S12.* [4] Goldsten J. O., et al. (2012) *Space Sci. Rev.*, 10, *485-502*. [5] Holmes-Siedle A. G. et al. (2007) *IEEE NSREC07*, *42-57*.