JOURNAL OF SPACECRAFT AND ROCKETS
Vol. 32, No. 6, November–December 1995

Clementine Dosimetry

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This paper presents radiation dosimetry results from the radiation and reliability assurance experiments on the Clementine spacecraft and Interstage Adapter Satellite. The dosimetry instruments utilize low-dose-response *p*-channel field-effect-transistor and proton-sensitive static-RAM dosimeters. These dosimeters successfully demonstrated an order-of-magnitude decrease in instrument weight and power from previous systems. The data confirm prelaunch predictions of the total-dose effects on charge-coupled-device dark current and on complementary-metal–oxide–semiconductor 1.2- and 0.8-μm technology design and process parameters in the space environment. A solar proton event during the early phases of the mission allowed a comparison between the Clementine measured proton fluence and energy spectra and the Geostationary Operational Environmental Satellite 6 measured proton fluence and energy spectra. These data confirmed the proton-spectrometer design and operation.

Nomenclature

a_n = second-order polynomial coefficients
C_u = upset capacitance
D_s = space-measured radiation dose
$D(T)$ = temperature-corrected space radiation dose
E_g = silicon bandgap energy
F(E) = external proton frequently
f_e = proton internal environment fraction
f_{on} = SRAM on-time fraction
G = *p*-channel field-effect transistor (*p*FET) temperature-independent circuit gain
I_D = complementary metal–oxide–semiconductor (CMOS) drain current
I_d = charge-coupled-device (CCD) dark-current damage factor, nA/cm^2 · krad
Ig = prelaunch CCD2 dark current
K = charged-particle-produced ionization per unit energy loss in silicon, fC/MeV
Kp = planetary magnetic index
k = Boltzmann's constant
N = SRAM-measured number of counts per hour
N_T = number of pixels per SRAM chip
T_s = space-measured temperature of z DUT board
V_c = CCD2 current-to-voltage conversion factor
V_{DD} = SRAM chip bias voltage
V_d = *p*FET temperature-independent threshold voltage damage factor, mV/krad
V_G = CMOS gate voltage
V_g = ground-measured voltage
V_o = SRAM adjustable offset voltage
V_s = space-measured voltage
V_T = CMOS threshold voltage
V_{Td} = CMOS threshold-voltage damage factor, mV/krad
V_{Ts} = CMOS space-measured threshold voltage
V_{Tt} = CMOS threshold-voltage temperature factor, mV/°C
V_0 = CCD2 extended pixel voltage mean
ΔE = static-RAM (SRAM) proton energy window width
ΔV_p = SRAM offset voltage above metastable point
σ = SRAM pixel sensitive area or "cross section"
Ω = Clementine SRAM field of view

Introduction

THE mission goal of the Clementine Engineering Experiments Program was to evaluate the effects of the space environment on advanced Ballistic Missile Defense Organization (BMDO) technologies being flight-tested on the main Clementine spacecraft and the Interstage Adapter Satellite (ISAS). The radiation and reliability assurance experiment (RRELAX) instrument contributed to the flight qualification of advanced BMDO technologies by performing radiation dosimetry in the space environment. The RRELAX dosimetry instruments utilized Jet Propulsion Laboratory (JPL) low-dose-response *p*-channel field effect transistor (*p*FET) and proton-sensitive static RAM (SRAM) integrated-circuit chip (IC-chip) dosimeters. These dosimeters, collectively called Radiation monitors (RADMONs), demonstrated an order-of-magnitude decrease in instrument weight and power from previous systems.

Dosimetry data for the Clementine spacecraft, on Feb. 21, 1994 and April 27, 1995, and ISAS, throughout its mission, are presented in this paper. The ISAS *p*FET data confirmed prelaunch predictions of the total-dose effects on charged-coupled device (CCD) dark current and on Hewlett-Packard (HP) 1.2- and 0.8-μm technology design and process parameters in the space environment. A solar proton event during the early phases of the mission allowed a comparison between the Clementine RRELAX measured proton fluence and energy spectra and the Geostationary Operational Environmental Satellite 6 (GOES-6) measured proton fluence and energy spectra. These data confirmed the SRAM proton spectrometer design and operation.

RRELAX Experiment Design

Two identical RRELAX experiments flew on the Clementine missions—one on the Clementine spacecraft and one on the ISAS. The RRELAX experiments are autonomous microprocessor-controlled data handling and analog test systems. They were contained on three device under test (DUT) boards. These boards, termed the x, y, and z DUT boards, are shown in Fig. 1. The z DUT board, which contains most of the RRELAX experiments, is mounted on the top of the RRELAX box normal to the z axis.

Received Sept. 12, 1994; revision received May 26, 1995; accepted for publication June 9, 1995.

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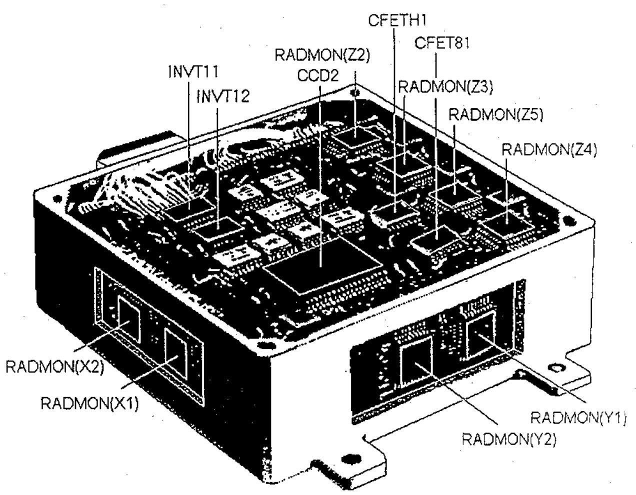

Fig. 1 RRELAX experiment layout in 4 × 4 × 1.5-in. box.

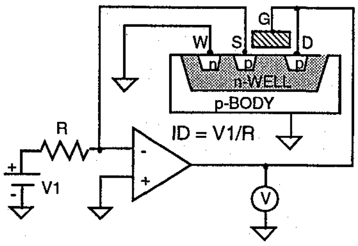

Fig. 2 Chip dosimeter (*p*FET on SRAM) and operating-mode circuit diagram.

The data presented in this paper were generated by the z DUT board RADMONs and CCD2. Each DUT board was covered with a 0.5-mil (Al equivalent) aluminized kapton dust cover, and RADMON(Z2), which had no Kovar lid, was covered with an additional 0.5-mil aluminized kapton dust cover. CCD2 had a 15-mil Kovar lid, RADMON(Z3) a 10-mil Kovar lid, RADMON(Z5) two 10-mil Kovar lids, and RADMON(Z4) three 10-mil Kovar lids. The ISAS RRELAX was also covered by a 6-mil (Al equivalent) thermal blanket.

The z-DUT-board RADMONs were fabricated through MOSIS at HP Corvallis in 1.2-μm technology, and the JPL CCD2s at Loral. A pFET dosimeter and SRAM proton counter was contained on each 1.2-μm RADMON IC chip (Z2, Z3, Z5, Z4) on the z DUT board, shown in Fig. 1.

Design of the *p*FET Dosimeter System

The pFET dosimeter system was designed to measure the total dose from all radiation types. The sensors were placed behind four different shielding thicknesses to produce dose-depth curves for the Clementine and ISAS experiments.

The dosimeter consisted of a pFET that was operated in a constant-current mode (Fig. 2). This allowed the temperature effects on channel mobility and threshold voltage to cancel each other. The objective of this design was to minimize temperature effects and emphasize dose dependence. The pFETs have a closed geometry gate, eliminating the source-to-drain bird's-beak leakage path. Dosimetry measured via the pFET threshold-voltage shifts was influenced by two second-order effects: 1) the temperature sensitivity of the transconductance factor and the threshold voltage V_T and 2) the source-to-drain bird's-beak leakage current. The goal in developing the advanced pFET dosimeter was to minimize or eliminate these effects.[1]

The pFET dosimeters were only powered during readout and accumulated dose while in an unpowered state. The four pFET dosimeters were read once per hour, and their data from the previous hour overwritten. Because pFETs are integrating dosimeters and have a larger radiation damage factor when unpowered, this mode of operation is satisfactory.

Design of the SRAM Proton Spectrometer System

The SRAM proton spectrometer system was designed to measure the proton energy spectrum and fluence for use in computing proton fluence and energy at the Clementine experiments. Four shielding thicknesses were used to pick off the external proton environment at four different energies, allowing the energy spectrum to be measured. Two energy bins were used to allow heavy-ion- and proton-induced nuclear reactions to be subtracted from the proton data. The threshold of the proton-sensitive bin was set just below the proton injection peak to optimize the energy measurement.

The SRAM detector was fabricated in 1.2-μm, n-well, double-metal CMOS. A schematic diagram of the SRAM cell, or pixel, is shown in Fig. 3. This cell differs from that of a standard six-transistor SRAM cell in three ways: 1) the source of the pFET, Mp2, is connected to an adjustable offset voltage V_o instead of V_{DD}, to provide control of the cell's upset capacitance; 2) the drain area Dn2 of nFET Mn2 has been enlarged by a factor of 4 over minimum to enhance upset rates, thus reducing the measurement time; and 3) the cell is unbalanced by widening Mn2 over minimum to enhance its SEU sensitivity vs V_o.

In operation, all the memory cells were written into a sensitive state, where Mn2 was turned off and Mp2 was turned on, connecting V_o to the bloated drain, Dn2. V_{DD} was then lowered to 3 V and V_o was lowered below $V_{DD} = 3$ V, allowing the SRAM to accumulate upsets at a given V_o value. Thereafter V_o and V_{DD} were returned to 5 V and the cells read to determine the number of upsets.[2]

Four SRAM chips were mounted to face along the z axis of the experiment, two facing the x axis and two facing the y axis, for a total of eight chips, as shown in Fig. 1. The SRAM portion of each chip was controlled using a single V_{DD} and V_o for all eight chips. All z-axis SRAMs, and one SRAM on the x axis and one on the y axis, were fabricated in 1.2-μm technology. One SRAM on the x axis and one SRAM on the y axis were fabricated in 0.8-μm technology.

The SRAMs were made sensitive to upset by applying 3-V V_{DD} and V_o voltages that have the following ΔV_p values above the spontaneous flip voltage:

$$\Delta V_p = 0.150 \text{ V}$$

$$\Delta V_p = 1.0 \text{ V}$$

The spontaneous flip voltage is the value of V_o where the SRAM cell becomes metastable and spontaneously flips. The offset voltage was set above the spontaneous flip voltage by an amount ΔV_p to sensitize the SRAM cell to protons, heavy ions, and nuclear reactions ($\Delta V_p = 0.150$ V) or to heavy ions and nuclear reactions only ($\Delta V_p = 1.0$ V). The integration period for these sensitive states was a constant of 100 s. At the end of each integration period, each of the eight SRAMs were evaluated for bit changes, or upsets, and the total number for each chip stored in the data structure. The data structure and software flow are shown in Fig. 4.

When the evaluation of SRAM response was complete, software accumulated the upset totals. Each chip had its own accumulation, or running total, for each value of ΔV_p. The SRAM contents were then restored to their starting state and the second value of ΔV_p set for the next integration time. The experiment software alternated between the two ΔV_p values on a 1:1 ratio. This was done by the SWITCH VOLTAGE box in Fig. 4.

The 100-s integration records together with their time stamp were called the high-resolution SRAM data record. Software maintained each record for one hour before disposing of it. This generated 18

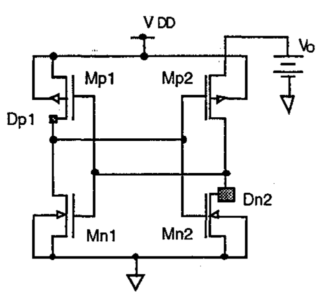

Fig. 3 Schematic diagram of the SRAM cell showing the placement of V_o and the bloated *n*-drain, Dn2.

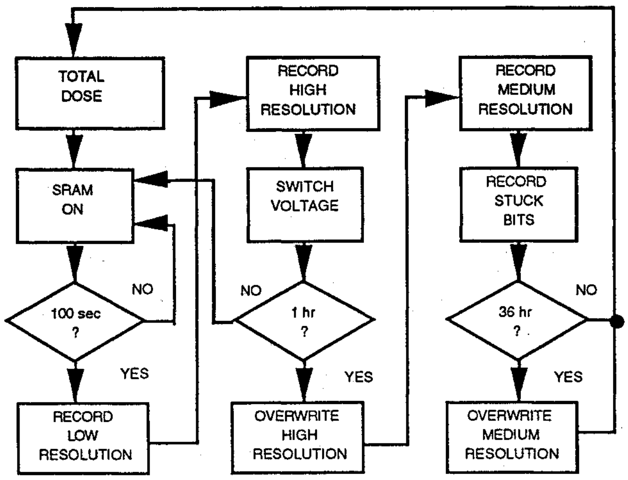

Fig. 4 Software flow diagram showing SRAM data-handling strategy.

consecutive sets (18 periods per hour) of 16-word records (one for each SRAM and ΔV_p value), which were stored in memory. These records formed the highest-resolution data set per SRAM and per ΔV_p value.

A high-resolution SRAM record that was about to be discarded was accumulated into a medium-resolution record. The medium-resolution record accumulated, or summed, the 18 high-resolution records for each SRAM and ΔV_p value. Each completed medium-resolution record holds integration results for a one-hour period for each SRAM and ΔV_p value. The medium resolution records time entry represented the time when the record was formed. The software retained medium resolution records for 36 h for a total of 576 medium-resolution records. This group of records formed one medium-resolution data set per SRAM and per ΔV_p value.

Each SRAM, for each ΔV_p value, measured the total fluence over the whole mission. This process used memory locations that were only added to and never overwritten. The data set was called the low-resolution data set.

The SRAMs were calibrated during each medium resolution data set by measuring the numbers of stuck zeros and ones. The temperatures of the analog board and the x, y, and z DUT boards and a temperature circuit calibration measurement were then stored, overwriting the previous calibration data record.

Ground Test Data

Selected pFET dosimeters from the flight fabrication run were calibrated with the JPL ^{60}Co source. The ^{60}Co irradiation was done at room temperature to a total dose of 100 krad(Si). The pFETs were tested at dose levels of 20, 40, 60, 80, and 100 krad and at −30, 20, and 50°C at each dose level. The pFETs were measured using an HP 4062 parametric test system in an oven that was also cooled with liquid nitrogen so that total-dose effects could be measured as a function of temperature. A temperature-independent threshold voltage damage factor V_d of 3.68 mV/krad was measured. The pFET was operated in the saturation region, which was ensured by connecting the gate to the drain as shown in Fig. 2, and at the temperature-independent point.[1]

A JPL CCD from the flight fabrication run was ground-tested to 4.8 krad(Si) in the JPL ^{60}Co source at room temperature and annealed at 25°C for 72 h. The CCD was characterized in the JPL CCD laboratory, and a dark-current damage factor I_d of 7.38 nA/cm^2 · krad at 25°C was measured.[3]

An SRAM from the flight fabrication run was calibrated using the Caltech Tandem Van de Graaff proton accelerator with protons at 0.75, 1.0, and 2.0 MeV. The SRAM ground-test response was analyzed using the TRIM (transport reactions in matter) computer code.[4] Calibration data are shown in Fig. 5. The model used in the calibration assumed a 5-μm overlayer (dead layer) and a 7-μm charge collection depth (depletion depth). The proton calibration data points are the mean values of the offset voltage, ΔV_p, where one-half the protons hitting a cell sensitive volume,

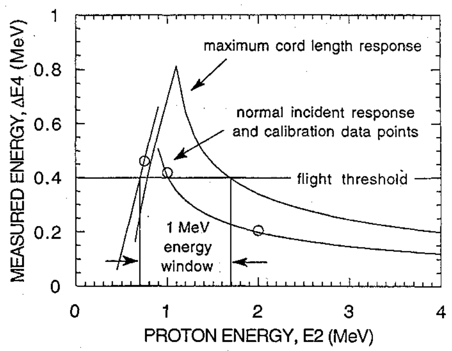

Fig. 5 Clementine 1.2-μm-technology proton calibration curves showing the flight energy threshold and the 1-MeV-wide energy window.

Dn2, cause the cell to flip. The proton data calibrated the 1.2-μm-technology SRAM at an upset capacitance, $C_u/K = 2.667$ MeV/V, where $K = 44.2$ fC/MeV for charged-particle-produced ionization per unit energy loss in silicon. The measured energy ΔE_4, shown in Fig. 5, is given by $\Delta E_4 = (C_u/K)\,\Delta V_p$. The 1-MeV energy window, shown in Fig. 5, is the measure of the SRAM response to protons in the space environment.[2]

Space Data

The ground-test-measured ^{60}Co damage factor, $V_d = 3.68$ mV/krad, was used to compute the space-measured pFET total dose. The downlinked numbers were bits, with one least-significant bit equal to 1.22 mV, from a 12-bit ADC measuring between 0 and 5 V:

$$D_s = \frac{V_s - V_g}{G V_d}\ \text{krad(Si)} \qquad (1)$$

where V_s (mV) is the space-measured pFET voltage, V_g (mV) is the ground-measured voltage, and $G = 32.7$ is the circuit gain. The zero-dose voltages V_g (mV) and aluminium-equivalent shield thickness d (mils) for each flight RADMON on the ISAS RRELAX at $T = 25$°C and on the Clementine spacecraft RRELAX at $T = -2.41$°C are listed in Table 1.

The p-FET total-dose flight results for the Clementine spacecraft on April 27, 1995, and the ISAS on April 20, 1994 (ISAS 1994 day 110), are shown in Fig. 6. The Clementine spacecraft total dose after 457 days in space is less than the ISAS over its mission life. On the Clementine spacecraft, the RADMON dosimeter-circuit dynamic range was exceeded for pFET Z2 because $G = 32.7$ for that circuit and a total dose of 142.95 krad (Si) was extracted with the CMOS experiment circuit for that pFET. The ISAS pFET-dosimeter mission dose profile is shown in Fig. 7. The ISAS is in a 2.13-day lunar transfer orbit that penetrates the Earth's radiation belts, causing the rapid increase in total dose.

The ISAS RRELAX CCD experiment was shielded by 52 mils (Al equivalent). Power-law dose–depth curves were fit to the pFET data as a function of shield thickness. The pFET-measured dose at CCD2 was then extrapolated from these curves as shown in Fig. 8.

The CCD2 sensor chips were 512-pixel line arrays manufactured at Loral in n-channel metal–oxide system (nMOS) buried-channel technology. The RRELAX CCD experiment measured the dark-current-generated voltage in the last 8 pixels, pixel 505 through 512, and the extended pixels with no photosensors, 513 through 519. The data presented here had a photosensor dark-current integration time of 1 s. ISAS CCD2 data showing the prelaunch pixel voltage mean V_g and the extended pixel voltage mean (for ground and space data) V_0 are presented in Fig. 9. The ISAS CCD2 had a prelaunch dark current measured on the flight CCD[3] of $I_g = 1.4$ nA/cm^2 at 25°C and a voltage conversion of $V_c = I_g/(V_g - V_0) = 11.7$ nA/cm^2 · V.

The 25°C dark-current damage factor $I_d = 7.38$ nA/cm^2 · krad was used to compute the space-measured total dose:

$$D_s = \frac{V_c(V_s - V_g)}{I_d}\ \text{krad(Si)} \qquad (2)$$

Table 1 Zero-dose *p*FET ground voltages V_g and aluminium equivalent shield thickness *d* for each flight RADMON on the ISAS RRELAX at $T = 25°C$ and on the Clementine spacecraft RRELAX at $T = -2.41°C$

RADMON	Spacecraft		ISAS	
*p*FET	V_g, mV	*d*, mils	V_g, mV	*d*, mils
Z2	129.9	1	621.8	7
Z3	74.8	31	335.4	37
Z5	274.8	61	592.2	67
Z4	381.0	91	494.0	97

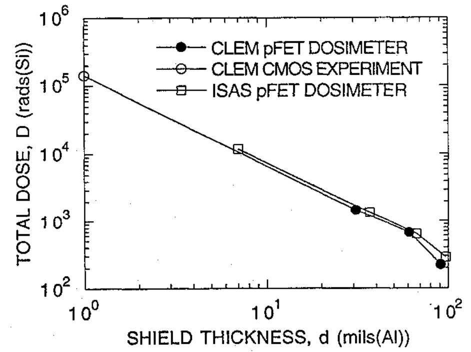

Fig. 6 Total radiation dose on RADMON *p*FET Z2 as a function of aluminium equivalent shield depth for the Clementine spacecraft on April 27, 1995, and the ISAS on April 20, 1994.

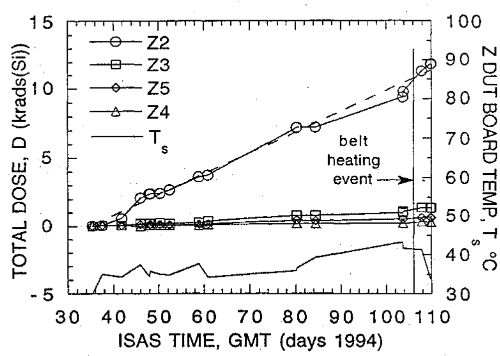

Fig. 7 Mission dose profile for the ISAS RADMON *p*FETs in a 2.13-day lunar transfer orbit and the associated temperature variation.

where V_s (V) is the space-measured CCD voltage mean for pixels with photosensors, pixels 505 through 512. The total dose at 25°C, $D(T)$, in kilorads (Si), is given by

$$D(T) = D_s\left(\frac{T}{T_s}\right)^{\frac{3}{2}} \exp\left(\frac{E_g}{2kT_s} - \frac{E_g}{2kT}\right) \tag{3}$$

where $E_g = 1.21$ eV, T_s is the *z*-DUT-board temperature, D_s is the space-measured dose from Eq. (2), and $T = 25°C$. Temperature-corrected CCD dose data are shown in Fig. 10. The temperature correction given by Eq. (3) is due to temperature changes in the intrinsic carrier density associated with bulk generation current.[5]

The CCD2 dark-current measured dose is compared with the *p*FET measured dose at the CCD in Fig. 11. Two prominent geophysical events were observed during the mission. The first, a solar proton event on day 52 of 1994 (Feb. 21, 1994), had a planetary magnetic index Kp of 7+ and was observed at a number of spacecraft (the proton observations will be discussed shortly). The increased dose rate after the second major event (the sudden commencement of a storm followed by a brief but intense geomagnetic storm on day 107) is due to trapped-electron-belt heating on days 106 and 107 of 1994 (April 16–17, 1994). The increase implies more and higher-energy trapped electrons along the ISAS orbit. Consistent with this interpretation, $Kp = 8+$ for the event, indicating a large increase in the trapped ring current and subsequent electron-belt heating. There was, however, no large solar proton event associated with the event.

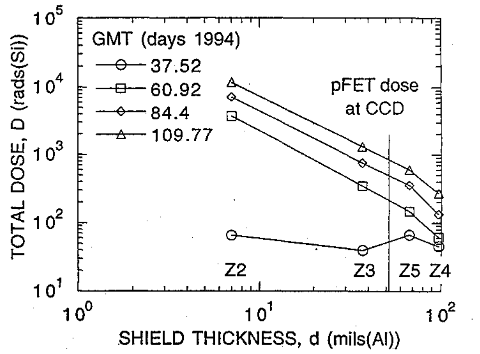

Fig. 8 ISAS dose–depth curves showing *p*FET dose at CCD2.

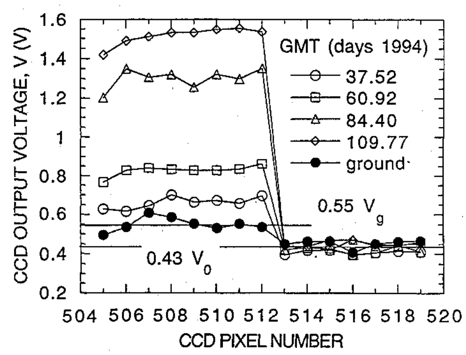

Fig. 9 A sample of the RRELAX ISAS CCD2 data showing the prelaunch, zero-dose pixel voltage mean V_g and the extended pixel voltage mean V_0 for ground and space data.

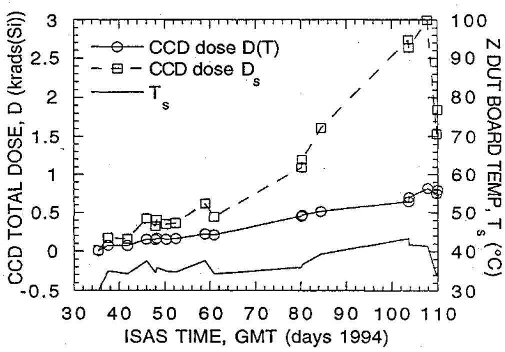

Fig. 10 CCD temperature corrected [$D(T)$] and uncorrected [D_s] dose data as a function of temperature.

The ISAS *p*FET dosimeter, operated at its temperature-independent drain current, measured a total dose of 11.83 (krad) on day 109.99. The ISAS *p*FET complementary metal–oxide–semiconductor (CMOS) experiment, using the same *p*FET operated at the five different drain currents shown in Fig. 12, measured a total dose, $D(T)$ given by Eq. (6), of 11.47 krad on day 109.99. The space-measured threshold voltage V_{Ts} is computed with Eq. (5) from second-order polynomial coefficients generated by fitting flight data[1] on the drain current I_D vs the gate voltage, V_G with Eq. (4) as shown in Fig. 12:

$$\sqrt{I_D} = a_0 + a_1 V_G - a_2 V_G^2 \tag{4}$$

$$V_{Ts} = \frac{a_1}{2a_2}\left(-1 + \sqrt{1 - \frac{4a_0 a_2}{a_1 a_1}}\right) \tag{5}$$

$$D(T) = \frac{V_{Ts} + V_{Tt}(T_s - T)}{V_{Td}} \tag{6}$$

where $V_{Tt} = 1.24$ mV/°C, $T = 25°C$, and $V_T = 883.7$ mV measured on the ISAS *p*FET prior to launch, and $V_{Td} = 1.674$ mV/krad measured on W12P4C05 for the HP 1.2-μm technology.[1] The CMOS experiment *p*FET dose verifies the dosimeter design and ground

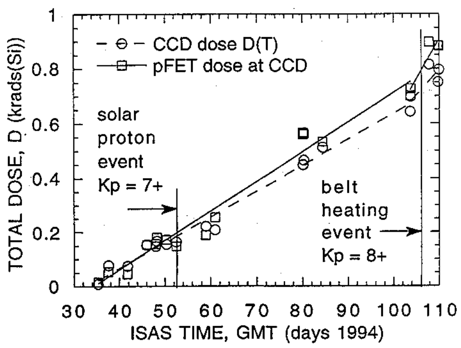

Fig. 11 CCD dose *D(T)* and *p*FET dose at the CCD, showing increased dose rate after day 106.

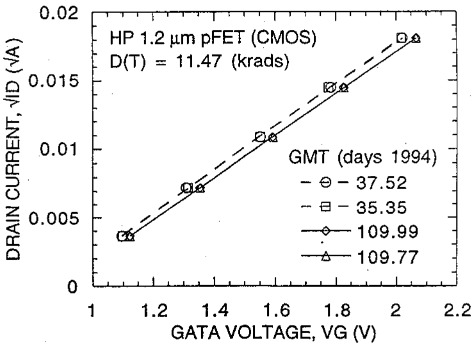

Fig. 12 ISAS CMOS HP 1.2-μm *p*FET gate voltage shift on day 109.99, April 20, 1994.

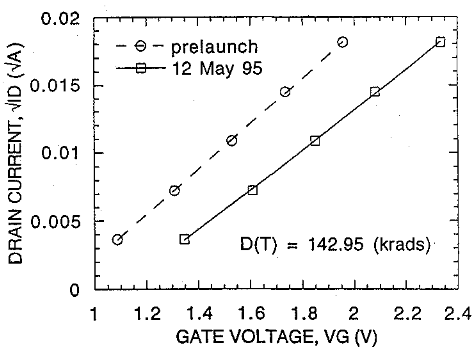

Fig. 13 Clementine CMOS HP 1.2-μm *p*FET Z2 gate voltage shift on April 27, 1995.

calibration methodology. The same equations are used to extract the *p*FET Z2 total dose on the Clementine spacecraft on April 27, 1995, shown in Fig. 13, where $T_s = 3.32°C$ and $T = -2.41°C$, $V_T = 863.9$ mV measured on the Clementine *p*FET prior to launch, and the other variables are the same. CMOS radiation damage factors for *n*- and *p*-channel transistors in HP 1.2- and 0.8-μm technologies are being utilized in radiation test-structure designs for the active-pixel image sensors (APS).

SRAM detector proton data from the Feb. 21, 1994, solar proton event have been compared with GOES-6 proton data. First, the Novice code was used to compute the proton environment as a function of energy inside the SRAM shields. Table 2 lists the external environment energy windows, E_{min} to E_{max}, in the 1-MeV-wide energy window measured in Fig. 5. The mean values f_e of the internal environment fraction inside the shields are also listed in Table 2. Next the environment fractions were computed with the Novice code from a 2π-sr omnidirectional fluence of 1.96×10^9 p/cm$^2 \cdot$ MeV at all energies outside the shields. The proton fluence was then reduced by the factor f_e inside the shields.

The SRAM spectrometers are sensitized to protons for 100 s, every other 100-s period, for one hour, giving an on-time fraction f_{on} of 0.5. The energy window width ΔE (Fig. 5) is 1 MeV. The instrument was designed with a 2π-sr field of view Ω. The SRAM

Table 2 External environment energy windows and internal environment fractions f_e for Clementine spacecraft, as a function of Kovar shielding

RADMON *p*FET	Kovar shields Thickness, mils	E_{min}, MeV	E_{max}, MeV	Mean f_e (0.7–1.7 MeV)
Z2	0	2.16	3.16	0.261 ± 0.031
Z3	10	11.81	12.81	0.072 ± 0.009
Z5	20	16.96	17.96	0.047 ± 0.007
Z4	30	21.04	22.04	0.037 ± 0.006

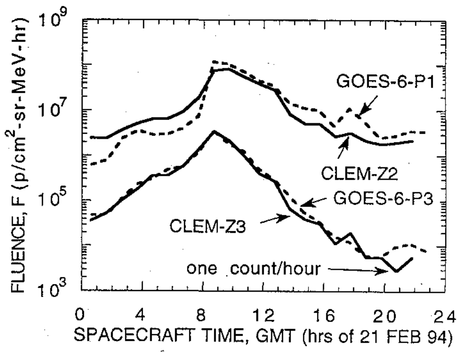

Fig. 14 Comparison of Clementine data with GOES-6 data during Feb. 21, 1994, solar proton event. The proton spectrometer sensitivity of one count per hour is shown.

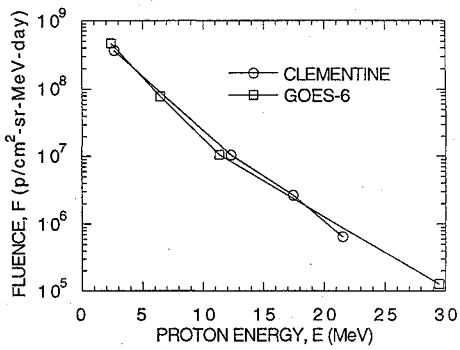

Fig. 15 Clementine spacecraft and GOES-6 external environment proton energy spectra on Feb. 21, 1994.

pixel sensitive area has an as-drawn cross section σ of 42.12 μm^2. The spectrometer hourly frequently $F(E)$, in p/cm$^2 \cdot$ MeV $\cdot$ h is given by

$$F(E) = \frac{18}{\sigma \Omega \Delta E \, f_e f_{on}} \ln\left(\frac{N_T}{N_T - N/18}\right) \tag{7}$$

Each pixel can only count one proton in each 100-s proton-sensitive period, and there are 18 sensitive periods each hour. There are $N_T = 4096$ pixels on each SRAM chip, and N is the measured number of counts per hour in each chip. The Clementine spectrometer data, $F(E)$ from Eq. (7), for the Clementine SRAM Z2 and Z3 proton energy windows and the GOES-6 hourly fluencies for the proton energy windows P1 and P3 are plotted in Fig. 14 for comparison.

The GOES-6 external environment proton energy windows, E_{min} and E_{max}, are P1: 0.6–4.2 MeV; P2: 4.2–8.7 MeV; P3: 8.7–14 MeV; and P4: 15–44 MeV. The Clementine and GOES-6 energy spectra for the total measured fluence on Feb. 21, 1994, are shown in Fig. 15. The data-point energies are taken at the center of the energy windows, $(E_{min} + E_{max})/2$, listed in Table 2 for the Clementine instrument and at the beginning of this paragraph for the GOES-6 instrument.

Dosimetry Conclusions

The primary objective of the RRELAX experiment was to monitor the radiation environment for the Clementine mission. Two conclusions have been presented about this objective. First, the ISAS CCD and CMOS experiment measurements were shown independently to agree well with the *p*FET dosimeter measured total dose. This demonstrates that the results of the ground radiation tests can be used to accurately predict spacecraft sensor and electronic component radiation degradation. The test-structure approach employed also allowed direct measurement of radiation effects in space and verified our predictive understanding of the space environment's radiation effects on spacecraft sensors and electronic components. Secondly, the SRAM proton spectrometer successfully measured the proton fluence and energy spectrum. The data agreed quite well with GOES-6 data for the same event. We therefore feel confident in stating that the dosimetry system, RADMON, has accurately tracked the proton fluence and energy and total dose for the Clementine Engineering experiments.

Acknowledgments

The research described was performed by the Center for Space Microelectronics Technology, JPL, California Institute of Technology, and was sponsored by the Ballistic Missile Defense Organization, Innovative Science and Technology Office (BMDO/IST). The author Henry Garrett would like to thank Peter Rustan, Peter Worden, and Dwight Duston for their encouragement and support during his tour of duty with BMDO/IST. The authors are also indebted to Jim Janesick for designing the JPL CCD experiment; Tom Elliott for characterizing the flight CCDs; Ken Hicks, the RRELAX experiment Cognizant Engineer; Kevin Watson for developing RRELAX flight software; Ken McCarty for developing RRELAX ground support equipment; Tom Sorensen for managing the build phase of the RRELAX experiment; the USC/ISI/MOSIS project for the fabrication of the test structures used in the RRELAX experiment; and Alen Rice, at the Caltech Tandem Van de Graaff, for his assistance in performing the proton calibration experiments.

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