CMOS Charged Particle Spectrometers

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SUMMARY

INTRODUCTION

Integrated circuits, manufactured in CMOS technology, have been developed as diffusion-based charged particle spectrometers for space applications. Current designs are single-chip spectrometers capable of uniquely identifying and counting electrons and heavy ions. A four-chip spectrometer designed to count protons and heavier ions was flown on the Clementine spacecraft. The spectrometer proton data is compared to GOES-6 proton data for the 21 February 1994 solar proton event.

CMOS PARTICLE SPECTROMETERS

Current CMOS chip spectrometer designs are Active Pixel Sensor (APS) chips that are also being developed by NASA as, light weight, low power, optical imagers [1]. APS spectrometers are being utilized on the Jet Propulsion Laboratory (JPL) Trapped Radiation Weather Station (TRWS) and the Ball Aerospace IN-STEP Particle Radiation Degradation of CCDs in Space (RADXCCD). APS and Clementine spectrometers are fabricated in HP 1.2 μm technology through MOSIS.

Figure 1 shows the HP 1,2 μm technology cross section and the labeling convention used in modeling calibration data, where E2 is the particle energy above the chip, AE3 = E2 - E3 is the energy lost in the over layer, and ΔE4 = E3 - E4 is the energy deposited in the charge collection layer.

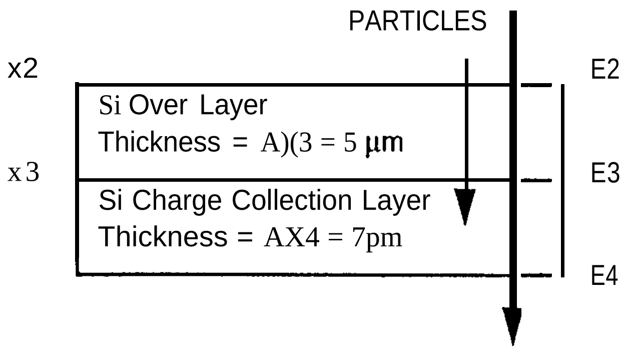

Figure 1. HP 1.2 μm technology labeling convention and layer thicknesses used in modeling calibrations.

Particle identification regions are shown in Figure 2. The measured energy in these regions is unique for each particle type. The APS design (Source Follower) is a differential spectrometer where the pulse height associated with each measured energy is histogrammed into a differential energy spectrum. The APS design extends CMOS spectrometers into the electron region and measures higher energy protons. The APS room temperature noise floor is measured with 5.9 keV X-rays shown in Figure 3.

The Clementine proton and heavy ion spectrometer design (SRAM) is an integral spectrometer [2]. All particles depositing more than the threshold energy are counted, Representative chips from the flight fabrication run were calibrated using the Caltech Tandem Van de Graaff proton accelerator. Calibration data was taken at normal incidence with 0.75, 1,0, and 2,0 MeV protons. The mean value threshold energies, where half the protons arc counted, are plotted in Figure 4.

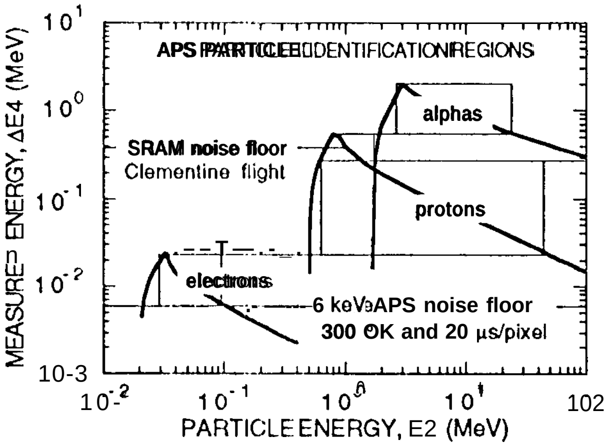

Figure 2. APS measured energy regions that are unique to each particle type and current AI'S and SRAM design noise floors.

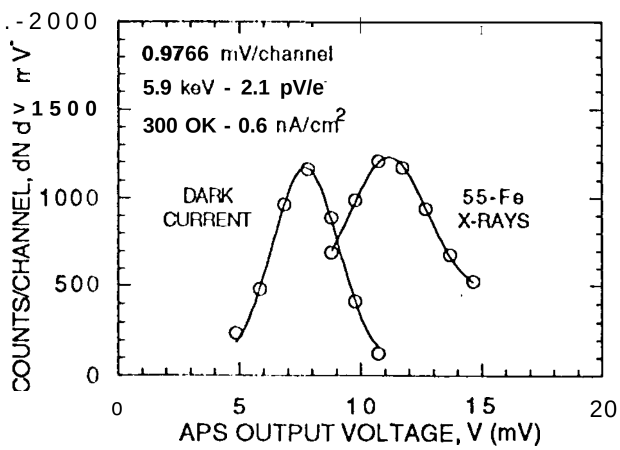

Figure 3. APS 1.2 μm technology unity gain calibration at room temperature and 20 μs/pixel showing dark current and 55-Fe X-ray peak fits.

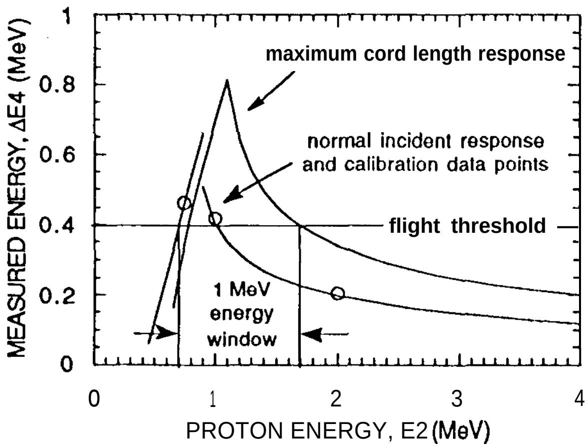

Figure 4. Clementine 1.2 μm technology proton calibration curves showing the flight energy threshold and the 1 McV wide energy window.

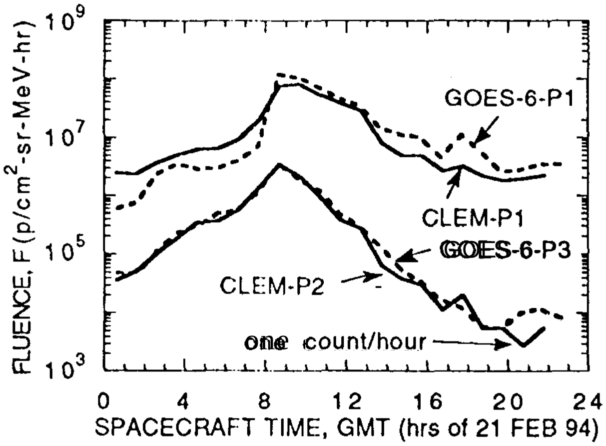

Figure 5. comparison of Clementine data to GOES-6 data during the 21 Feb. 94 solar proton event, The proton spectrometer sensitivity of one count per hour is shown.

CLEMENTINE DATA

Table 1 lists the external environment energy windows, Emin to Emax, measured in the 1 MeV wide energy window shown in Figure 4, as a function of shield thickness. The mean value of the environment fractions inside the shields are also listed in fable 1,

Table 1. external environment energy windows and internal environment fractions, fe, as a function of shielding.

kovar shields (ch# - roils)	Emin (MeV)	Emax (McV)	fe mean value (0.7- 1.7 MeV)
PI-O	2.16	3.16	0.261±0.031
P2 -10	11.81	12.81	0.072±0.009
P3 -20	16.96	17.96	0.047±0.007
P4 -30	21.04	22,04	0,037*0.006

The environment fractions are computed with the Novice code from a 2π-sr omnidirectional fluence of 1.96E9 (protons/cm^2-MeV) at all energies outside the shields. The proton fluence is reduced by the amount fe inside the shields.

The Clementine spectrometer is sensitized to protons for 100 seconds, every other 100 second period, for one hour, giving an on time fraction, f_{on}, of 0.5. The energy window width, ΔE measured in Figure 4, is 1 McV. The instrument is designed with a 2π-sr field of view, Ω. The pixel sensitive area has an as drawn cross section, σ, of 42.12 μm^2. The spectrometer hourly thence, F(E), in units of (protons/cm^2-sr-MeV-hr) is given by,

$$F(E) = \frac{18}{\sigma\ \Omega\ \Delta E\ f_e\ f_{on}} \ln\left(\frac{N_T}{N_T - N/18}\right) \qquad (1)$$

Each pixel can only count onc proton in each 100 second proton sensitive period and there are 18 sensitive periods each hour. There are 4096 pixels, NT, on each chip and N is the measured number of counts per hour in each chip.

The Clementine spectrometer, F(E) from Equation 1, and GOES-6 hourly fluencies are plotted in Figure 5. The GOES-6 external-environment proton-energy windows, Emin and Emax, are, PI = 0.6 to 4.? MeV, P2 = 4.2 to 8.7 MeV, P3 = 8.7 to 14 MeV, and P4 = 15 to 44 McV. The Clementine and GOES-6 energy spectra for the total measured fluence on 21 Feb. 94 are shown in Figure 6. The data point energies are taken at the center of the energy windows, (Emin + Emax)/2, listed in Table 1 for the Clementine instrument and above for the GOES-6 instrument.

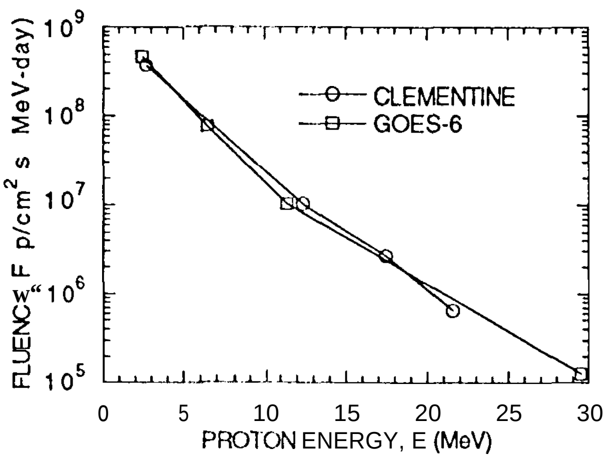

Figure 6. Clementine spacecraft and GOES-6 external environment proton energy spectra on 21 Feb. 94.

REFERENCES

[1] R. }1, Nixon, S. E. Kcmeny, C, O. Staller, and E. R. Fossum; "128x128 CMOS l%otodiode-Type Active Pixel Sensor with On-Chip Timing, Control and Signal Chain Electronics"; SPIE proceedings, Vol. 2415, paper 34, (1995)

[2] G. A. Soli, B. R. Blacs, and M. G. Buchler; "Proton-Sensitive Custom SRAM Detector"; IEEE Trans. Nuclear Science, Vol. 39, pp. 1374-1378, Oct. 1992.