KUTESAT SENSING OF RADIATION ENERGIES, FLUXES AND EXPOSURE GEOMETRY IN THE SPACE ENVIRONMENT USING A RADFET ARRAY

Suzanne THOMPSON*
Craig DAMLO

University of Kansas
1838 Keystone St.- Pasadena, CA 91107
astronut@ku.edu
330-207-5180 (voice) & 818-393-4699 (fax)

Keywords: radiation energies, flux, exposure geometry, and energy density

Introduction

In the following pages, it is proposed that multiple, small radiation field effects transistors (RADFET) can be used to measure the space environment, including the radiation energies, fluxes and exposure geometry, around KUTEsat, a small cubical micro-satellite. RADFETS utilize a convenient method for continuously monitoring the total radiation dose. The use of small RADFET dosimeters has advantages such as size, cost, power requirements, simple operation, and, most importantly, better data acquisition. Also discussed will be drawbacks to using an array of RADFETs in measuring the space environment.

RADFETs

KUTEsat will employ multiple small RADFET dosimeters placed throughout the structure, measuring the ionizing radiation in and around the satellite. A RADFET is designed as a specialized p-channel metal-oxide semiconductor (MOS) transistor structure with a specially processed gate insulator. They were optimized for ionizing radiation sensitivity and far-u.v. light and sometimes referred to as "Space-Charge Transistors."[Ref 1] When RADFETs are exposed to ionizing radiation, holes are generated inside semiconductor layers along with electrons, producing a measure of the environmental radiation. This space charge, or high-energy radiation, is created within the insulator and trapped, thereby allowing it to be measured as a potential produced at the boundary of the insulator. The name RADFET applies if the measurements are made via channel conduction [Ref 1].

Description

NMRC, the premier ICT research Institute in Ireland, has developed an ionizing radiation dosimeter that provides increased flexibility and reliability as apposed to our earlier design [Ref 5]. The radiation sensing, field effect transistor (RADFET) sensor not only supplies a total dose measurement in real time but also retains a permanent record of the ionizing radiation exposure effects after it has been electronically interrogated to determine the total ionizing radiation exposure. The RADFET can be designed and configured to monitor ionizing radiation for a broad range of applications, such as performing radiation dose measurements without applied electrical power or remote sensing in locations with limited access. The RADFET provides a direct electrical voltage output and has a simple control circuit that can be integrated on the same small chip with the sensor. Exposure to ionizing radiation -- such as gamma rays, x-rays, electrons, and high-energy protons -- causes the RADFET's voltage output to change in a predictable manner. The silicon-based sensor can also be

* Now currently working at the Jet Propulsion Laboratory, Pasadena Ca.

inexpensively manufactured in a standard metal oxide semiconductor (MOS) integrated circuit fabrication facility.

Technical Approach

The gate insulator within the MOS transistor is the most sensitive part. This highly insulating silicon dioxide film accumulates positive space charge by the irradiation of two different modes. The first mode, or low-field mode, creates interference traps while the high-field mode creates additional oxide trapped charge within the insulator. The irradiation in the insulator causes electron hole pairs throughout the volume to drift apart once a voltage is applied. Some electrons are transported out of the insulator, while other low levels of ionizing radiation interact with the RADFET to generate electrical charge that is trapped in the dosimeter's gate dielectric. A permanent positive charge is the net result of the trapped charge, which shifts the sensor's threshold voltage V_T of the transistor by an amount ΔV_T. This ΔV_T shift is proportional to the radiation-induced density, ΔQ_{ot} [Ref 2]. This shift depends on the four things: the type and the energy of the radiation, the gate bias during irradiation, the absorbed dose D, and the insulator thickness D_{ox} ΔV_T. This change enables the sensor to retain a measurement of past exposures to ionizing radiation, which is a unique feature of the RADFET.

The dosimeter's gate-dielectric thickness and the magnitude of its gate-biasing voltage during irradiation are contingent of the sensitivity of the ionizing radiation. The dual-dielectric RADFET, because of its more firmly trapped radiation-induced charge, has better long-term dependability than conventional single-dielectric metal-nitride-oxide-silicon field dosimeters. The RADFETs can be configured with a constant gate-biasing voltage or with zero volts for applications that have extremely low electrical power consumption requirements. A tracking-gate configuration offers a continuous voltage output for use in applications that require higher accuracy and simplicity. RADFETs used in KUTESat are capable of measuring radiation sensitivities from 50μV/rad to 25mV/rad.

The RADFET configuration used on KUTESat consists of a series of four total dosimeters located at various positions within the spacecraft. Located on the dosimeters are the gate, drain, and source/substrate electrodes [Ref 3]. For KUTESat's purposes, a spectrometer prototype RADFET array has been researched using four RADFETs, each with a different shielding for differentiating different radiation sources and isotopes. Though the RADFETs cannot detect a single x-ray photon, together they can give an accurate estimate of the space radiation surrounding the spacecraft.

Data Acquisition

Beyond the design benefits, and from a purely scientific standpoint, a data collection system involving multiple point sources, rather than a single point source, offers the greatest advantage for RADFETs used on KUTEsat. The use of an array of RADFETs around the craft enables us to look at key features of the space environment at KUTEsat. Specifically, three different views of how the satellite interacts with ionizing radiation. The first is the total radiation from the space environment and how it interacts with the spacecraft as a whole. While this can easily be measured with any standard single point dosimeter, the advantages to this concept are the sensors ability to measure radiation at specific locations within the satellite. This is especially important in measuring radiation dosages at specific instruments within the satellite. By using an array along the outside planes of the satellite, it is possible to monitor the flux passing through each plane of the spacecraft, as well as the exposure geometry of the radiation dose on each plane of the spacecraft.

Monitoring the radiation energy encountered is important in predicting the lifetime of KUTEsat and KUTEsat components. While a single point dosimeter can accomplish this job, an array of dosimeters can make this job increasingly more efficient. The advantage of multiple sensors placed around the craft is the calculation of the total flux passing through the craft. A worst case scenario for the orbit of KUTESat is an inclination of 90 degrees and an altitude of 750 km. Using orbit plotting software and radiation modeling software from the Space Environment Information System (SPENVIS) website, the total Electron and Proton flux KUTEsat will see in its orbit is shown in Figures 1 and 2 below [Ref 7].

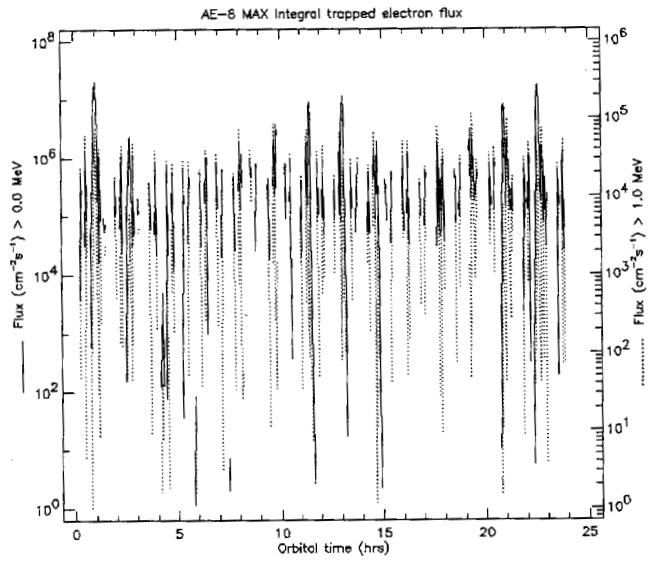

Figure 1: Solar maximum Integrated Trapped Electron Flux (cm^{-2} s^{-1}) vs. Orbital Time (hrs)

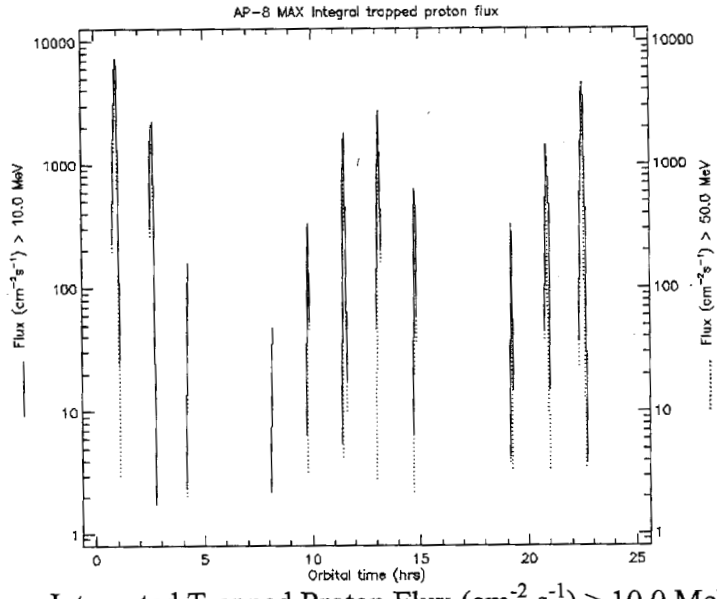

Figure 2: Solar maximum Integrated Trapped Proton Flux (cm^{-2} s^{-1}) > 10.0 MeV vs. Orbital Time (hrs)

Looking at how much radiation passes through each plane of the satellite enables the calculation of the radiation the satellite itself absorbs, as opposed to only the radiation it passes through measured with a single point source dosimeter. Knowing the amount of radiation that the ship absorbs aides in calculating a more precise representation of the total dose of radiation that each component is absorbing; this will allow for a more accurate prediction, using this more accurate measurement, of the lifetime of KUTEsat. Below is the maximum orbit averaged trapped electron spectra for the KUTEsat mission. Shown below in Figure 3 and 4 is the integral trapped electron and proton flux over the complete mission lifetime.

Moreover, by measuring the flux through the satellite a calculation of the total energy density contained within the satellite at any time throughout the mission is possible. Looking at the energy density the satellite absorbs allows not only for radiation measurements along the satellite's flight path, but also a look at the radiation density along the flight path. Viewing the exposure geometry the satellite encounters during its flight is another advantage to the array of RADFETs being placed in the KUTEsat. Exposure geometry can aid in determining which piece of equipment is taking the largest dose of radiation and consequently having the largest percentage of failures due to radiation.

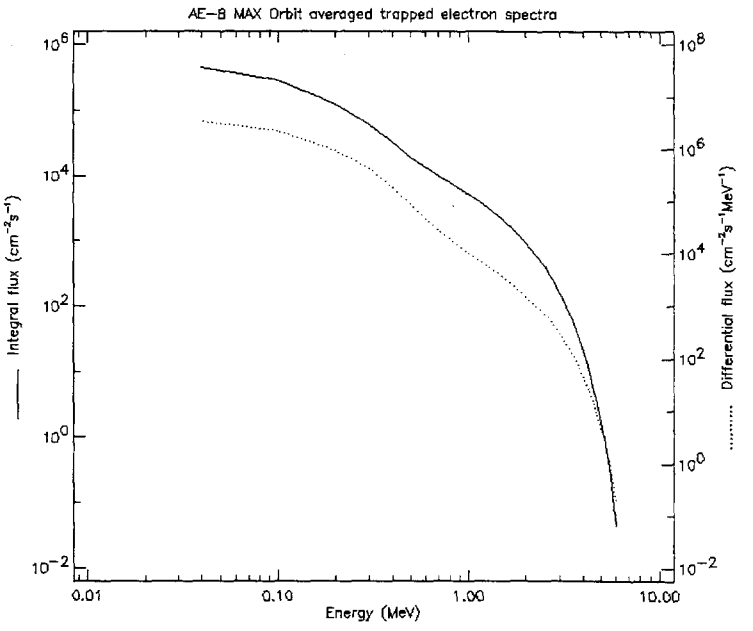

Figure 3: Orbit Averaged Trapped Electron Spectra of Integral Flux (cm^{-2} s^{-1}) vs. Energy (MeV)

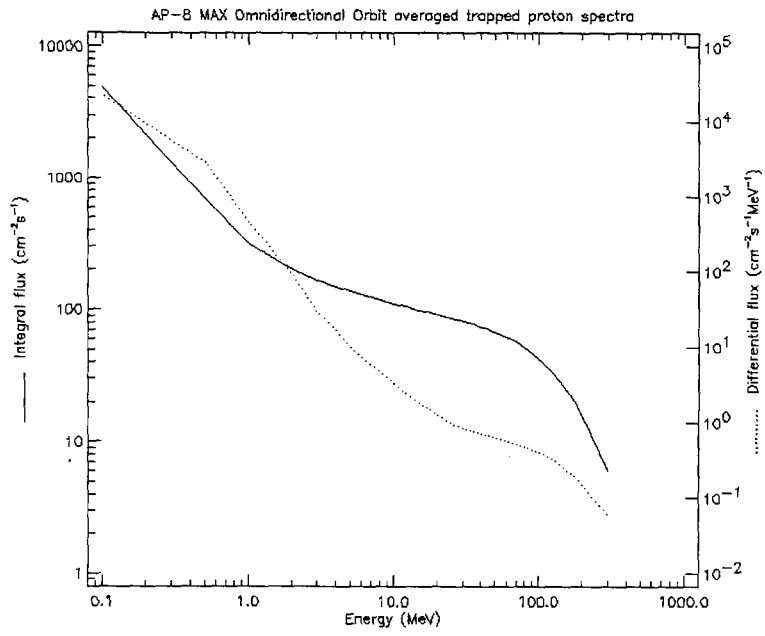

Figure 4: Omnidirectional Orbit Averaged Trapped Proton Spectra of Integral Flux (cm^{-2} s^{-1}) vs. Energy (MeV)

Advantages to Using RADFET

There are three main advantages of RADFET use important to the design of KUTEsat: power consumption, dimensions, and cost. Minimal power consumption is needed to properly bias the gate, typically along the order of 10 A; this allows for a larger number of RADFET dosimeters to be present aboard a spacecraft, without requiring the larger power consumption typically associated with standard space dosimeters. RADFETs are, like most other modern semiconductors, manufactured on the nanometer scale with minimal additional packaging, making them incredibly light and small. It is the fact that they are small in size and weight that is an important aspect of micro-satellite design such as those used for KUTEsat. Along with the dimensions and power consumptions, another important usage implication of RADFETs is their decreased cost.

RADFET Disadvantages

One of the main disadvantages of using RADFETs is the wiring needed to connect the array of dosimeters. The question introduced becomes a problem of wiring the array together and what to do with the subsequent wires associated with each dosimeter. Another problem with the dosimeters is that they are temperature dependent and will need a temperature sensor, namely a product called Thermistors [Ref 8]. These instruments will be needed to measure the temperature fluxuations associated with the dosimeters.

Another disadvantages to using an array of RADFETs as opposed to a single dosimeter include the instruments sensitivity and the space required. While most dosimeters created for use in spacecrafts

are designed to allow for as many radiation energies to be measured as possible, RADFET dosimeters are instead optimized to detect mainly higher energy protons and gamma rays. As well as not being able to see as many energy levels, a sacrifice must also be made on the dose range of the RADFET. The second disadvantage to using an array of RADFETs in KUTEsat is the area that they inhabit. Although their small weight and dimensions are an advantage, they can also act as a potential problem. Because their weight is so small, it becomes tempting to use a large quantity of RADFETs all over the satellite; however, in micro-satellites like KUTEsat, other components included in the craft are not always designed to have a thin RADFET between themselves and something else. So in that regard, although the dimensions are considerably smaller in mass, frequent allowance for accommodating other devices in the spacecraft is necessary.

Summary

The use of an array of RADFETs inside the KUTEsat spacecraft will allow for an increase in total data acquired as well as a higher value of that data acquired. While the radiation dose measured by the array is similar to that performed by a standard satellite dosimeter, the array will allow for a more accurate dose rate throughout the satellite, by measuring the radiation fluxes and exposure geometry. Also by measuring the fluxes and exposure geometries, a more complete picture of the surrounding space environment through calculations of the radiation density passing through KUTEsat will be possible. The number and quality of advantages outweigh the disadvantages for using RADFETs on KUTEsat.

References

[1] A. Holmes-Siedle and L. Adams. "RADFET: A Review of The Use of Metal-Oxide-Silicon Devices as Integrating Dosimeters," *Radiation Physics and Chemistry*, vol. 28, no. 2, pp. 235-244, 1996

[2] L. Adams and A.G. Holmes-Siedle, "The Development of an MOS Dosimetry Unit for Use in Space," IEEE Trans. Nucl. Sci., vol. NS-25, no.6, pp.1607-1612, 1978.

[3] G. Ensell, A. Holmes-Siedle and L. Adams "The Response of Thick Oxide Dosimeters to High Energy Radiation," *Nucl. Instrum. and Methods in Phys.*, A269, pp. 655-658, 1988.

[4] B. O'Connell, A. Kelleher, W. Lane, and L. Adams, "Stacked RADFETS for Increasing radiation Sensitivity, " *IEEE trans. Nucl. Sco.*, vol. 43, no.3, pt. 1. pp. 985-990, 1996.

[5] http://www.nmrc.ie/index.html

[6] http://www.sandia.gov/mstc/technolgies/microsensors/radiationsensor.htnl

[7] http://www.spenvis.oma.be/spenvis/

[8] http://www.temperatures.com/thermistors.html