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Process management for avionics – Atmospheric radiation effects – Part 4: Guidelines for designing with high voltage aircraft electronics and potential single event effects

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CONTENTS

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Part 4: Guidelines for designing with high voltage aircraft electronics and potential single event effects

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62396-4, which is a technical specification, has been prepared by IEC technical committee 107: Process management for avionics.

This standard cancels and replaces IEC/PAS 62396-4 published in 2007. This first edition constitutes a technical revision. It is to be read in conjunction with IEC/TS 62396-1.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
107/81/DTS	107/88/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 62396 series, under the general title *Process management for avionics – Atmospheric radiation effects*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended

A bilingual edition of this document may be issued at a later date.

INTRODUCTION

This industry-wide technical specification provides additional guidance to avionics systems designers, electronic equipment, component manufacturers and their customers about the single event effects produced in semiconductor devices operating at high voltage (nominally above 200 V) by atmospheric radiation. It expands on the information and guidance provided in IEC/TS 62396-1.

The internal elements of semiconductor devices operating at high applied voltage will be subject to high voltage stress. The incident radiation causes ionisation charge within the device, and the high voltage stress may cause a large increase (avalanche) in this charge, which may be destructive. Within this technical specification two effects are considered: single event burn-out, SEB, and single event gate rupture, SEGR.

PROCESS MANAGEMENT FOR AVIONICS – ATMOSPHERIC RADIATION EFFECTS –

Part 4: Guidelines for designing with high voltage aircraft electronics and potential single event effects

1 Scope

This technical specification is intended to provide guidance on atmospheric radiation effects on high voltage (nominally above 200 V) avionics electronics used in aircraft operating at altitudes up to 60 000 ft (18,3 km). It is intended to be used in conjunction with IEC/TS 62396-1. This specification defines the effects of that environment on high voltage electronics and provides design considerations for the accommodation of those effects within avionics systems.

This technical specification is intended to help aerospace equipment manufacturers and designers to standardise their approach to single event effects on high voltage avionics by providing guidance, leading to a standard methodology.

Details are given of the types of single event effects relevant to the operation of high voltage avionics electronics, methods of quantifying those effects, appropriate methods to assist design and methods to demonstrate the suitability of the electronics for the application.

2 Normative references

The following referenced documents are indispensable for the application of this document, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/TS 62396-1, *Process management for avionics – Atmospheric radiation effects – Part 1: Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment*

3 Terms and definitions

For the purpose of this document, the terms and definitions of IEC/TS 62396-1 apply.

4 Potential high voltage single event effects

An N-channel power MOSFET can have two different types of destructive effects induced by the deposition of charge from a single energetic particle, single event burnout (SEB) and single event gate rupture (SEGR). Different tests performed on several devices show that is difficult to induce SEB in P-channel MOSFET [1, 2][1]. In addition to this kind of power MOSFET, other power devices, such as insulated gate bipolar transistors (IGBTs), bipolar power transistors and diodes, which have large applied voltage biases and high internal electric fields, are susceptible to SEB.

In SEB, the penetration of the source-body-drain region by the deposited charge can forward bias the thin body region under the source. If the bias applied to the drain exceeds the local

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[1] Numbers in square brackets refer to the bibliography.

breakdown voltage of the parasitic bipolar elements, the single event induced pulse initiates avalanching in the drain depletion region that eventually leads to destructive burnout SEB. SEB can be induced by heavy ions, high energy protons [3] and high energy neutrons [4].

SEGR applies to N and P channel MOSFETS. It is explained via the transient plasma filament created by the energy deposition track when the MOSFET is struck through the thin gate oxide region. As a result of this transient track filament, there is a localized increase in the oxide field which can cause the oxide to break down, leading first to gate leakage and finally to gate rupture. The SEGR failure mechanism has been widely studied by heavy ion testing and effects have been identified on different devices with various levels of sensitivity [2]. For the time being, experiments show also that SEGR induced by heavy ions is more an issue for space systems, and guidance for heavy ion SEGR testing is available [5]. As a consequence of the atmospheric neutrons, SEB is the major threat to high voltage electronics.

Although at the outset this threat to the power system in an aircraft from SEB from the atmospheric neutrons may appear to be remote or even far-fetched, the experience of breakdowns in the high voltage electronics on electric trains in Europe before 1995 shows that SEB can be real and has happened in the field. In that case, European and Japanese manufacturers of high voltage semiconductors noticed that some of their devices were undergoing burnout failures in the field during normal operation of newly developed train engines [6, 7]. The diodes and GTO thyristors (gate turn-off thyristors) used on the trains were rated at 4 500 V, and were normally operated at 50 % to 60 % of rated voltage. They were designed for terrestrial use for > 35 years, so when the failures first appeared in the field after only a few months, this was puzzling. The failure mode was investigated in great detail and eventually a set of experiments was carried out at three different locations (salt mine, top-floor laboratory and basement); the results convinced the investigators that the cause of the failures was the cosmic ray neutrons. Since that time, the manufacturers of these very high voltage devices have been careful in recommending the voltage at which the devices can be operated safely without SEB.

In addition, these manufacturers have followed the methodology established by an experienced radiation effects group [1] by carrying out tests in the WNR beam at Los Alamos National Laboratory to characterize the response of their devices to a simulated high-energy neutron environment. Because the atmospheric neutron flux is higher by about a factor of 300 higher at aircraft altitudes compared to sea level, it is clear that the same effect can occur in high voltage electronics in aircraft. The reason that, as far as is known, such failures have not been experienced previously in the field in aircraft power electronics is that the bus voltage used in aircraft systems has always been low enough to preclude SEB or SEGR.

Generally, the highest voltage used in aircraft power systems has been 270 V, and a practical lower onset limit for most high voltage devices is 300 V. This practical lower limit stems from the fact that with SEB there is a threshold voltage for the effect to occur; if V_{ds} is kept below the threshold voltage, there will be no SEB. Thus for 270 V operation devices rated at 400 V or 500 V would be used, resulting in a situation in which the devices are being operated at a derating factor of 67,5 % and 54 % respectively. Since the devices are being used at < 300 V and with a derating factor of < 70 %, these conditions are sufficient to preclude any single event burnout in the high voltage electronics.

However, in advanced designs for avionics systems significantly higher voltages are being considered for the bus voltage in order to reduce the overall weight of the system. The voltage will thus be >300 V and in fact 600 V has often been mentioned as a practical bus voltage. Thus, in order to preclude SEB from occurring in the high voltage electronics of such advanced avionics systems, a sufficiently low derating factor will have to be used, and the adequacy of the derating factor will have to be demonstrated through testing.

5 Quantifying single event burnout in avionics for high voltage devices

Thus, the problem becomes that avionics vendors may be asked to provide systems that will operate at higher voltages, e.g., 600 V, and there is virtually no guidance for them to use in developing the designs that will avoid the potential of SEB in the high voltage devices such as power MOSFETs and IGBTs.

In reality, the situation with SEB in high voltage electronics is relatively similar to that of single event upset, SEU, in low voltage devices (< 5 V) such as random access memories (RAMs), microprocessors and FPGAs. The threat of SEU from the atmospheric neutrons in the low voltage devices has been dealt with very extensively in the technical literature and in IEC/TS 62396-1. The approach in IEC/TS 62396-1 is that the rate of the single event effect, in this case SEU, in the devices, can be estimated by the following equation:

$$\text{SEE rate per device (per hour)} = 6\,000\ (\text{n/cm}^2\text{h}) \times \text{SEE cross section (cm}^2\text{ per device)} \qquad (1)$$

The 6 000 n/cm^2 per hour flux is a nominal value for the cosmic ray neutrons with Energy > 10 MeV, at 40 000 ft (12,2 km) altitude and 45° latitude. It may be adjusted for different altitudes and latitudes using data in an appendix of the normative reference IEC/TS 62396-1. For RAMs especially, a great deal of SEU cross section data has been published, allowing users of the standard to estimate the SEU rate, and some SEU cross section data is also available for microprocessors and FPGAs.

The same Equation (1) can also be used for SEB rates in high voltage devices provided that SEB cross sections are known for specific devices operated at a specified voltage. This Technical specification recommends the use of Equation (1) for calculating SEB rates even though it is recognized that this is conservative. There is very little published data on the SEB cross sections, but the data that does exist [1, 4] suggests that the SEB cross section is significantly reduced at lower neutron energies compared to e.g. 200 MeV. Thus a more realistic neutron energy threshold for calculating the SEB rate (energy at which the SEB cross section is similar to that at high energy, e.g., 200 MeV) might be 50 MeV rather than 10 MeV. However, this level of conservatism will be allowed in the interest of maintaining consistency with IEC/TS 62396-1. The available SEB cross section data is documented in Clause 6.

For avionics applications it should be recognized that assuming the high voltage electronics will be operating at a single voltage is unrealistic. First, the airplane power system is expected to experience power transients and spikes during flight. The transients typically last for less than 1 s during which time Vds could increase from 270 V to 350 V. The cascading power spikes can increase the voltage to even higher levels above nominal, although the duration is much shorter, usually < 100 µs.

Secondly, the details of the operation of high voltage equipment may be important in evaluating its susceptibility to SEB. For example, in the case of certain types of DC-DC converters, the voltage across the MOSFET is not continuous. The MOSFET cycles between off and on states, and the voltage across the MOSFET during the off state is higher than during the on state due to an inductive voltage associated with the mechanism that allows the magnetic energy to be discharged [8]. The highest voltage across the MOSFET is during the off state, but its magnitude depends on several operational parameters of the converter (e.g., V_{in}, V_{out} and output current). Thus, a true evaluation of the SEB susceptibility should take into consideration the voltage across the MOSFET throughout the complete duty cycle and set of operating conditions of the converter. Other high voltage components may have similar variations in their operating conditions.

The use of the WNR beam to perform accelerated SEB testing of very high voltage devices [1] has spurred considerable additional testing of the very high voltage devices (> 2 kV) by the microelectronics companies that manufacture these devices. This testing has used the WNR facility as well as other sources of neutrons. The other neutron sources include the quasi mono-energetic neutron beam created by a proton beam on a lithium target (e.g., at the Svedberg Laboratory in Sweden) or high elevation research stations (Sphinx Laboratory at Jungfraujoch, Switzerland, 11 300 ft (3,4 km) high). However, the results of such testing are usually considered proprietary and not published, or if a few are published, it is in a little known publication [9, 10]. In addition, for these vendors having ground level applications, their