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A Proposed Hardness Assurance Test Methodology for Bipolar Linear Circuits and Devices in a Space Ionizing Radiation Environment

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Abstract. *A hardness assurance test approach has been developed for bipolar linear circuits and devices in space. It consists of a screen for dose rate sensitivity and a characterization test method to develop the conditions for a lot acceptance test at high dose rate.*

Introduction. In 1991 it was demonstrated by Enlow, et. al. [1] that certain bipolar junction transistors degraded more for a low dose rate ionizing radiation exposure than for a high dose rate exposure to the same dose level, followed by an additional 50% dose plus a one week elevated temperature anneal (as recommended by MIL-STD-883/Method 1019.4, TM1019, for CMOS devices used in space applications). This observation lead to a detailed investigation of the mechanisms of the "true" dose rate effect, which was found to be significantly different from the time dependent effects seen in CMOS technologies [2]. Several studies were performed to evaluate the low dose rate sensitivity of bipolar linear circuits, the first results of which were reported at the 1994 NSREC [3-5]. Additional testing has been performed on a wide variety of bipolar linear circuits, the results of which were recently published in a data compendium [6]. About 15-20 part types have been identified as low dose rate sensitive so far. It is clear from these results that the current test standard most widely used in the US, which currently recommends a high dose rate test (50-300 rads/s) for bipolar parts, will require a revision to deal with low dose rate sensitive bipolar linear parts to be used in low dose rate applications, e.g. space. This paper will address an initial attempt to deal with this issue. The ASTM "Standard Guide for Ionizing Radiation (Total Dose) Effects Testing of Semiconductor Devices", ASTM FF867, is being revised to address this problem, as well as some additional testing issues with CMOS devices and circuits. The general hardness assurance approach to low dose rate applications of bipolar linear circuits, as recommended in the draft ASTM FF867, will be discussed, along with the rationale for the recommendations.

Recommended test approach. ASTM F867 is a guideline document for ionizing radiation testing of semiconductor devices. In its present form it does not specifically address bipolar parts. In 1995 a decision was made to revise ASTM F867 to deal with the enhanced low dose rate, ELDR, sensitivity of bipolar linear devices and circuits, as well as some other testing issues related to CMOS. At the present time the revised ASTM F867 is in draft 6.1 and is expected to be submitted for approval in 1997. Section 8 of ASTM F867 describes the complete test procedures for both bipolar and CMOS technologies. A 16 page appendix (Appendix X2) has been added to provide supplemental information on bipolar devices and circuits. The recommended approach for bipolar linear parts is illustrated in the flow chart in Figure 1. The first question that must be answered is whether the specific part type being evaluated is ELDR sensitive. At the present time the only categories of bipolar parts that are considered not to be ELDR sensitive are pure digital circuits and discrete devices. Additional testing is underway to verify whether discrete bipolar transistors may in fact be ELDR sensitive under certain bias conditions. If the bipolar circuits contain some linear circuitry, and especially if they contain lateral or substrate pnps, then they should be evaluated for ELDR sensitivity. If data exist

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showing that the part type and manufacturer are ELDR sensitive, then an ELDR screen is not necessary and the part may go directly to the characterization procedure. If data exist on the part type and manufacturer showing that the part is not ELDR sensitive, then the data must be treated with caution. It has been demonstrated that for the same part type and manufacturer, ELDR sensitivity varies from fabrication lot to lot. This would imply that only data from the same fabrication lot are valid for labeling the part as not ELDR sensitive. If there is any question as to the ELDR sensitivity of the part then it should go through an initial screen. The initial screen should be performed on parts from several date code lots. There are two approaches for determining the ELDR sensitivity of a part, a.) a room temperature test at two dose rates, and b.) a high dose rate test at two temperatures (room, RT, and elevated, ET). The ratio of the two dose rates for the RT test should be >1000 and the high dose rate test should be performed within the range recommended for TM1019, i.e. 50-300 rads/s. The default values for the dose rates would be 100 and 0.1 rads/s. If the RT/ET test at high dose rate is chosen, the recommended dose rate is again the TM1019 range and the recommended irradiation temperatures are 25°C and 125°C. The test should be performed over a range of total dose levels that encompass the system specification level. The criterion for determining whether the part is ELDR sensitive is based on the ratio of either the low dose rate response to the high dose rate response or the ET to RT response for the critical electrical parameters. If this ratio is >1.5 for any parameter at any dose then the parts are considered ELDR sensitive (certain caveats apply to parameters which show very little degradation or show threshold effects). Once the screen has been implemented, the parts which are ELDR sensitive must go through a series of characterization tests in order to develop lot acceptance test conditions. Because of the potentially large variation in ELDR sensitivity from date code lot to lot, a large sample should be drawn which includes parts from several date codes over a span of several years. The characterization tests consist of a matrix of dose levels, dose rates and elevated irradiation temperatures to establish a.) the maximum enhancement at low dose rate, and b.) an elevated irradiation temperature, dose rate and overtest factor (dose multiplier) that will bound the low dose rate response for the critical electrical parameters at the specification dose. Unfortunately it does not appear at this time that a single dose rate, irradiation ET and overtest factor will suffice for all ELDR sensitive bipolar linear circuits. Once the test conditions for the higher dose rate test (which will bound the low dose rate response) is established, these test conditions are applied to all subsequent lots of that part type and manufacturer.

Technical basis for the approach. The technical basis for the recommended bipolar linear ionizing radiation hardness assurance approach is discussed in detail in several papers from the 1996 NSREC [7-10]. In the paper by Fleetwood, et. al. [7] the physical mechanisms are discussed, which form the basis for the ET irradiations. ET irradiation data on bipolar transistors is provided in the paper by Witczak, et. al. [8], and on bipolar circuits in the papers by Pease and Gehlhausen [9] and Johnson, Lee and Rax [10]. The transistor data [8] fully supports the application of ET irradiations at high dose rate to bound the low dose rate response, whereas the circuit data [9,10] show that while ET irradiation does enhance the damage, it does not bound the response. To bound the low dose rate response for many circuits, the dose rate may have to be lowered somewhat, and an overtest factor applied. The optimum temperature for the ET irradiations was shown for both transistors and circuits to be a function of the total time at temperature because of the annealing response at ET. An irradiation ET value of 100-135°C appears to be optimal for several part types for dose rates of 10-100 rads/s. The issue of the saturation of the enhancement with decreasing dose rate has been addressed in several studies. Although it appears for most part types evaluated that there is little, if any, additional enhancement below 1-5 mrads/s, very few data have been taken below 1 mrads/s. For most part types that have shown ELDR sensitivity, the enhancement starts to become appreciable below 1-10 rads/s. Thus a value of 0.1 rads/s should be adequate for a sreen. Unfortunately it has been shown that for some sensitive parameters, notably Vos, the low dose rate enhancement does not become significant until the dose rate is below about 5 mrads/s [10]. These circuits would not be filtered out by the proposed initial screen unless another parameter exhibited ELDR sensitivity for the dose rates (or ET) used.

Discussion. A considerable amount of total dose characterization and analyses have been performed on bipolar linear transistors and circuits as a function of dose rate and irradiation temperature. This body of data has shown that many bipolar linear part types exhibit an enhanced low dose rate sensitivity that is not simply a time dependent effect that can be treated with high dose rate irradiation and anneal. Thus new test procedures are required to address hardness assurance for space applications. The most obvious approach, testing at the system dose rate, is usually impractical because of the time required for irradiation. Based on the information currently available, a hardness assurance approach for irradiation at higher dose rates (>10 rad/s) has been developed and incorporated in a draft revision of ASTM F867. It is recognized that the approach may not be adequate for every bipolar linear part, but it should be valid for a large majority of parts. Testing is underway on many ELDR sensitive part types to validate the approach. Some of these results should be available by the time of the conference.

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Figure 1. **Proposed Screen, Characterization and Lot Acceptance Test (LAT) Method Flow Chart**