The pros and cons of *in situ* testing – going beyond the test standards

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Abstract

This paper discusses the benefits of *in situ* measurement during radiation testing, compared with the common practice of remote measurement at each of a number of total dose steps. An example is drawn from real test data.

I. INTRODUCTION

THE total dose radiation testing of electronic components for use in space environments is frequently carried out according to one of two test standards: either ESCC 22900 [1] published by the European Space Agency or the US Department of Defence Mil-Std-883, method 1019 [2]. Both of these standards are written around the basic concept of alternately making electrical measurements on the components and then irradiating them. Numerous instances have subsequently been noted where this procedure could lead to an erroneous understanding of the response to radiation exhibited by the components being tested. This paper highlights the issues associated with some of those instances and proposes *in situ* testing as an alternative test strategy that, in certain circumstances, can lead to much greater fidelity of the results and higher confidence in the validity of the data gathered.

II. EXISTING TEST STANDARDS

ESCC 22900 describes the basic requirements applicable to the total dose radiation testing of integrated circuits and discrete semiconductors suitable for space environments. It distinguishes between *in situ* testing, where electrical measurements are made on the devices under test (“DUTs”) which are physically located in the irradiation chamber, and remote testing, where the DUTs are removed from the chamber for the measurements to be made. *In situ* testing is permitted either during or after irradiation. However, the majority of the document assumes that remote testing will be carried out with multiple, discrete radiation exposures and, hence, will yield data points at only a few values of total dose.

Mil-Std-883, method 1019 (and Mil-Std-750, method 1019 is very similar) uses the term ‘in-flux’ testing in place of ‘*in situ*’. The standard states that not-in-flux testing allows for more comprehensive electrical testing but may give misleading results if significant post-irradiation time dependent effects occur. *In situ* testing is permitted but, again, the remainder of the standard is written assuming that remote testing will be carried out.

In practice, the majority of tests are carried out using remote testing and just a few total dose steps. Both standards define time limits that should be observed so as to minimise post-irradiation, time dependent effects that may cause parameter values to shift significantly from their immediate, post-irradiation values. However, the guidance given in both standards regarding the number of dose steps and their spacing is sparse and different.

ESCC 22900 specifies that measurements shall be made at a minimum of three dose steps and that these shall be set at “1/3, 1 and 3 times the radiation level of interest”.

Mil-Std-883 method 1019 provides no guidance at all on the number of dose steps and requires irradiation above the radiation level of interest only for certain technologies and in low dose rate conditions. One dose point would be sufficient to meet these requirements although, in practice, up to six dose steps are frequently applied.

Having considered these provisions of the two standards, it is worth noting that many tests deviate from one or more aspects of the standards. This may be because the end use or application has some features that justify a variation from the standard or because previous test data have influenced the test plan. The impact of this deviation for the measurement technique should be assessed.

III. A DESCRIPTION OF THE *IN SITU* METHOD

In situ (or in-flux) testing requires the measurement system to be included in the signal chain during exposure of the DUTs to irradiation. This may require the switching in and out of multiple test instruments and more than one bias condition to be applied to the DUTs.

A. Disadvantages of the in situ method

There are several disadvantages to the *in situ* method, including complexity of the electrical circuit, relatively long lead lengths, restrictions on how close instrumentation may be placed to the DUTs, radiation effects on the measuring system and potential issues with processing large amounts of measurement data.

The primary issue is ensuring that the fidelity of the measurement process is maintained throughout the test by avoiding any influence of radiation on the measuring instrumentation. This may be achieved by placing the instrumentation outside the radiation area. However, leads of more than 10m in length may be required, complicating the measurement of very low voltages and currents and making high speed measurements very difficult indeed. Alternatively, instrumentation may be located close to the DUTs and protected by shielding. The amounts of shielding required can be cumbersome and installing it may present a physical risk to the test equipment and personnel.

Some electrical tests simply cannot be carried out *in situ*. These include parameters for which a large or complex measurement system is required, especially for sophisticated digital parts, such as microprocessors. Nevertheless, in these cases, *in situ* measurement of a parameter even as simple as the supply current can yield valuable information about the radiation response of the device.

A secondary issue relates to how the measurement system is set up. It is possible to generate large quantities of data, most of which, for slowly changing parameters, may be of little value. Some planning of the data collection strategy can significantly reduce the post-irradiation analysis effort.

One further issue to consider is the impact of frequent measurements using bias conditions different from those applied between measurements. If the radiation response of the DUT is strongly bias dependent then this approach can lead to a difference in the measured effects compared to a test carried out using remote testing. In this case, making less frequent *in situ* measurements so as to reduce the duty cycle at the different bias conditions, can help, while still yielding many times more data than remote testing.

B. *Advantages of the in situ method*

The main advantage of *in situ* testing is that the greater quantity of data gives much finer resolution of the effects of the radiation exposure, as measured on the total dose scale. Subtle and non-linear effects are more readily identified with *in situ* testing. An example of this phenomenon is shown in section III below.

In situ testing also helps to avoid errors due to time dependent effects occurring after irradiation and before measurement. The measurement system can continue running after the radiation source has been withdrawn, providing data from the point in time immediately after irradiation has ceased. This gives a detailed picture of the magnitude and rate of annealing effects.

In any real application, the circuit in which the DUT would be deployed would experience the impact of radiation exposure during and immediately after the exposure. *In situ* testing more closely mimics this situation than remote testing.

In order to benefit fully from these advantages of *in situ* testing, and especially for long duration tests, it is important to remember the value of measurements on a control device for validating the stability of the test set-up. Periodic measurement of an unirradiated device helps ensure that the measurement system has not drifted. If any drift is observed then this can be compensated for, either during the test or during the post-irradiation analysis.

IV. CASE STUDY

An example is given here for the total dose testing of a voltage reference device. The test was instrumented *in situ* to measure the output voltage of three DUTs of the same type of device. The DUTs were irradiated with static bias and at a dose rate of 447 rad[Si]/hr in Cobham’s cobalt-60 gamma irradiation facility, located at Harwell, UK. The irradiation lasted for a duration of approximately four weeks.

Figure 1 shows the test board, with two sets of three samples in a horizontal row across the centre of the board. Data are presented here for only one of the two types of sample. A number of relays can also be seen on the board; these were used to switch the measurement system between the individual test samples. Measurements were made on each test sample at an interval of one minute. The board was housed in a lead/aluminium container to screen out low energy particles, as recommended in both standards.

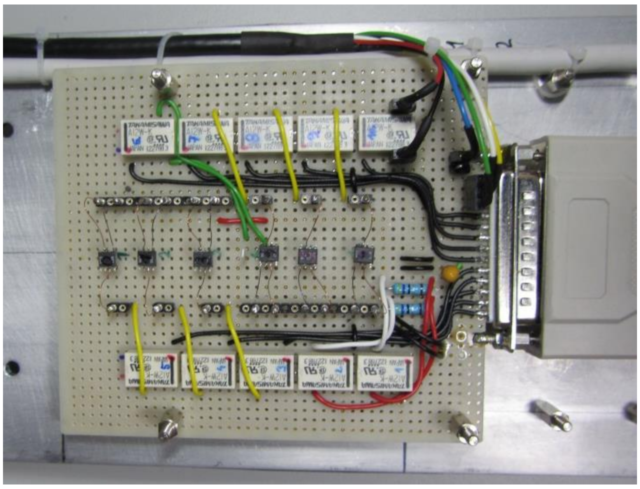

Figure 1: the test board housing the samples.

Figure 2 shows a graph of the change in output voltage when the measurements taken at each point in a series of dose steps of 50, 200, 250 and 300krad are plotted. It can be seen that the primary trend is for the measured value to decrease with increasing total dose. Based upon these data, a circuit designer may allow for a reduction of a certain percentage in the output voltage when designing a circuit using this type of device. For example, if a dose of 100krad were to be considered then a change of no more than 1%, compared with the initial value, might be expected from these data.

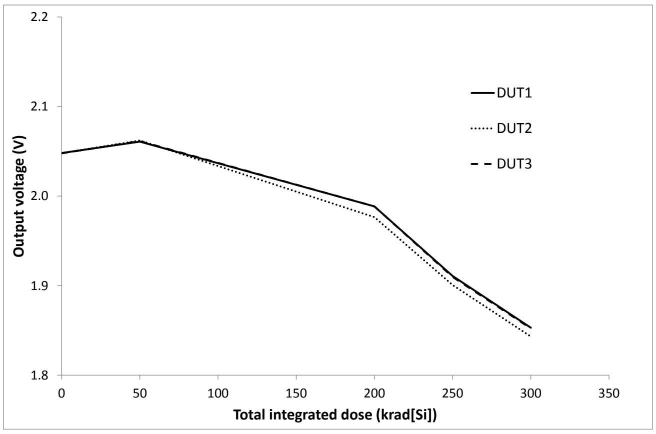

Figure 2: Output voltage against total dose with measurements at four dose steps.

Figure 3 shows the same data measured *in situ* at one minute intervals. Several features are visible. Firstly, the traces are much smoother, simply due to the finer dose resolution. Secondly, a significant rise in the output voltage is visible between 50 and 100krad, followed by an even larger reduction between 125 and 200krad. This feature is not visible in the first set of data because of the dose steps that happened to be chosen. With this additional information, the circuit designer would make a completely different allowance for shifts in the output voltage or might reject the device altogether.

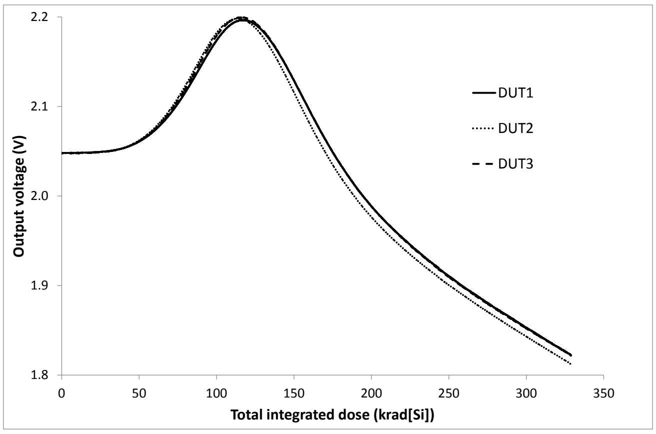

Figure 3: Output voltage against total dose with the full, *in situ* measurement data.

V. DISCUSSION

The experimental data show that, in the case of a nonlinear response to radiation exhibited by a given parameter, a data acquisition system based upon *in situ* measurements can reveal unexpected behaviour and yield valuable insights to the induced changes. The sometimes complex nature of this response may be missed by remote testing based upon a test regime using a small number of dose steps. Where remote testing is used, care is required in selecting the dose steps and the interval between them to reduce the probability of such a response being overlooked. An *in situ* test on one or two DUTs may be a useful screening technique to employ before a full test, using the simpler, remote testing technique, is carried out.

VI. CONCLUSIONS

The *in situ* method is not applicable to all types of device or all parameters, especially where high speeds or frequencies or very low voltages or currents are involved. However, DC and low frequency signals lend themselves readily to *in situ* monitoring and the additional data obtained, coupled with the greater total dose resolution, can lead to a much better understanding of the effects of irradiation on the samples.

VII. REFERENCES

[1] ESA ESCC Basic Specification No. 22900, “Total dose steady-state irradiation test method”, issue 4, October 2010

[2] Mil-Std-883, method 1019, “Ionizing radiation (total dose) test procedure”, issue 1019.9, June 2013