# Statement on Radiation Damage

## *Introduction*

Many Agilent 5DX customers have concern that radiation from the 5DX may damage components on their circuit boards during inspection. This document helps address these concerns by providing information regarding radiation levels in the 5DX, types of radiation damage, and failure limits. Additionally, we make recommendations for board handling to minimize the risk of overexposure. Finally, we supply a procedure to follow if radiation damage is suspect.

## *Types of Radiation Damage*

There are two primary types of damage caused by X-rays: 1) permanent and 2) single event upset (SEU). Permanent damage refers to an alteration of the structure of the device. On the other hand, SEU results, for example, in a change of programming state without a lasting modification of the device material.

Permanent damage is caused by ionization inside the device material, leading to the generation of traps both at interfaces and also within bulk material. These traps in turn affect internal potentials, subsequently causing an alteration of the I-V characteristics, carrier mobility, oscillation frequency, etc., of the device.

The mechanisms by which the traps are generated and ultimately located (they may migrate) is quite complex. Behavior of a device after exposure to ionizing radiation depends upon a number of factors, including the device design, the manufacturing process used to make the device, and the design of the circuit in which the component is used. Consequently, true characterization of any particular component must be done experimentally on a per application basis. There are nevertheless exposure levels at which typical devices start to exhibit performance degradation. For the most sensitive CMOS devices, effects may be observed in the $10^4$ to $10^5$ Rad(Si) range. Further information may be found in [4].

Fortunately, radiation damage often anneals with time and/or heat. Both time and heat allow some of the created traps to recombine with free electrons. Variations in the internal potentials then start to approach the initial (pre-exposure) state. There are instances, however, in which the correction may overshoot the original conditions (known as superrecovery). Knowledge of the annealing process may help with diagnosis of a radiation issue.

SEU does not result in permanent device damage. However, it can cause data corruption. An SEU event may happen at relatively low dosage levels. As with permanent damage, susceptibility and ramifications of SEU depend upon the device design and utilization. Since low dosage levels may lead to SEU, we recommend that programmable devices not be inspected in a 5DX after programming, unless the device behavior is first well characterized and steps are taken to compensate for problems. For example, an X-ray inspection may be followed by a functional test, with reprogramming done if the functional test should fail.

## *Radiation Exposure Levels in the 5DX*

Exposure levels vary with field-of-view (FOV) and the length of time a component receives radiation. For example, at the 200 FOV in a system with source filtration, the dosage rate is approximately 1000 Rad(Si)/min for a component located 0.5 inches underneath the center of the X-ray tube anode. Due to absorption of low energy photons, this value increase to 2000 to 2500 Rad(Si) for a system without filtration. At the 800 FOV, the dosage rate drops to about 75 Rad(Si) at 1.5 inches for a system with filtration and to about 150 to 200 Rad(Si) for a filtrationless system. A complete analysis may be found in [2].

This data implies that, in the worst case, board setup using continuous live X-rays at the 200 FOV may lead to damage of the most sensitive devices in as little as 5 to 10 min. For the more typical situation, however, this time is increased dramatically, since board setup involves snapped images with the X-rays being dumped between snaps (even though there is some leakage past the dump ring) and since setup is generally not done at the 200 FOV. Using data for the 800 FOV, it would require over an hour of continuous exposure to approach damage levels.

During automated inspection, dosage levels are significantly reduced. This results both from the fact that any given point on the board moves to different locations during the inspection process and also from the fact that X-rays are dumped when the board is in motion. For a "typical" laptop PC board inspection, the average dosage received by a topside component is 100 Rad(Si) in a system with filtration, which implies a dosage of 200 to 250 Rad(Si) for filtrationless systems. Consequently, for even the most sensitive devices, dosage levels are about two orders of magnitude from permanent failure limits.

## *Recommendations for Board Setup and Inspection*

Since PCBs that are tested using the 5DX vary greatly in size, complexity, and challenges for the test developer, it is generally not possible to set limits for how long each step in the board setup process should take.

During board setup, one board may be in the 5DX for extended periods of time, exposed to radiation even when there is no live imaging (the x-ray beam is dumped). The dose rate with the beam dumped, however, is several orders of magnitude lower than the dose rate with the beam in one of the active banks. Dose accumulated while the beam is dumped can therefore generally be ignored, however it would be wise to not leave a PCB in the 5DX when not actively working on board setup.

There are several steps in the board setup process which use live imaging where x-rays are on continuously. These include:

1) Manual alignment
2) Surface Map Setup – Calculation of delta-Zs and determination of board thickness (and determination of slice heights for BGAs, etc.
3) CheckCAD – Move component locations

In addition, in the Check Surface Map utility continuous exposure can be enabled, as it can from the Image Window when not doing a test. To minimize board exposure, the time spent doing any of these steps should be minimized.

For first time alignment, choose the option to move to first view automatically. If the CAD is accurate, this should put the board in nearly the right location in X and Y. Z adjustment can usually be done rapidly using the Quick Z Move option on the stage controls.

Calculation of delta-Zs in Surface Map Setup can be time consuming, particularly if it is not possible to place all map points on the same substrate. If it is possible to place all on the same substrate, it is strongly recommended to measure the delta-Zs at a few points near fine pitch devices, average those values, and use the Set All function to apply to all map points. Aside from being much quicker, this usually results in better surface maps than setting each point individually. Laminographic determination of board thickness is also best done just using a few areas where there are fine pitch parts on both sides of the PCB. Using the stage controls, move from one board side to the other and note the difference in Z position.

Some users have developed the practice of using bare boards for surface map setup in order to insure that the pad level is really at the focal plane. This will also reduce exposure to a populated PCB during board setup.

Dose acquired during CheckCAD is very similar to the dose accumulated during tests. The x-ray beam is generally dumped, with the board experiencing higher dose rates when each new image is acquired. There may be problems with the CAD that require moving component locations. Avoid staying in the mode of live imaging longer than necessary to correct the component locations.

Testing the board during the threshold setting phase of board setup can occupy a great deal of time. Dose rates are less than for live imaging, but more than with the x-ray beam continuously dumped. If images and CAD are transferred to the TDW for threshold setting, overall does to the PCB will be greatly reduced, since the same set of images can be used for many tests. More diligence may be required during CheckCAD in order to make sure that the CAD is accurate, and images are properly focused.

Production tuning and production testing of PCBS require the use of the 5DX. Even if tested at very small FOVs, where the dose rate during imaging is higher, each board could be tested a number of times before any damage to sensitive components would occur.

## *Procedure if Permanent Radiation Damage is Suspected*

In nearly every case for which radiation damage of a component is suspected, the cause of the device failure may be attributed to some other factor. Here we outline a procedure to help establish whether or not radiation from the 5DX is indeed the source of failure.

1. Check for other possible causes of the problem

   There are a number of factors to consider. These include bad components, failure of other surface mount equipment, failure of other test equipment (e.g., in-circuit or functional tester), and a bad X-ray inspection process. A bad X-ray inspection process, for example, may include too much time spent using continuous live mode during board setup, too much time spent doing manual live inspection, and too much time spent using live exposure during rework.
2. With a known good process, components, and test equipment, check device performance before and after X-ray inspection.
3. Contact the part vendor and inquire about ionizing radiation tolerance.
4. Have a qualified laboratory expose the circuit to increasing levels of radiation using a 16 W, 160 kV bremsstrahlung source, testing the circuit after each exposure to determine failure limits.
5. If failure limits are within 5DX exposure levels try using a component with the same electrical characteristics, but from a different vendor and/or different manufacturing lot. If failure limits are not within 5DX exposure levels, go back to step 1.
6. Wait for an increasing period of time after inspection. Start with an hour, then a day, and finally a week. If possible, try heating the board. See if time and/or heat corrects the problem. (Understand that this is a fix for a damaged device which may or may not return the device to its original operating characteristics, but may, however, allow the device to operate effectively within the circuit.)
7. Contact the factory

## *Procedure if SEU is Suspected*

If SEU is suspected, modify the test process to program or reprogram the device after inspection. If this is not possible, then follow the 5DX inspection with an in-circuit or functional test to determine if the programming state has been changed. A sample of boards tested both before and after inspection may help to determine a statistical rate at which SEU events occur.

## *Conclusion*

For normal automated inspection, radiation exposure from the 5DX is about two orders of magnitude from permanent damage limits, although SEU is a possibility. Consequently, in most cases of suspected radiation damage, the primary cause is some other factor, such as bad test equipment or bad components. If radiation damage has occurred, it is usually the result of a bad inspection process, spending too much time doing a manual inspection, for example. The experimental procedure outlined above should isolate whether or not radiation damage has happened. It also indicates ways of compensating. Since SEU is possible at lower dosage rates, we recommend not inspecting preprogrammed components. If it is necessary to do so, then a subsequent modification of the test process may be required. For any unresolvable concerns, please contact factory support.

## *References*


**[1]** Fazzio, R. Shane. "Radiation Damage in Electronic Devices," Internal Report, Hewlett-Packard Company, Sept. 1997.

**[2]** Fazzio, R. Shane. "Radiation exposure in a modern, circularly scanned-beam laminographic X-ray inspection system," *Journal of X-ray Science and Technology*, Vol. 8, No. 2, 1998, pp. 117-133.

**[3]** Johnston, A. H. "Radiation Effects in Advanced Microelectronics Technologies," *IEEE Transactions on Nuclear Science*, Vol. 45, No. 3, June 1998, pp. 1339-1354.

**[4]** Ma, T. P. and Dressendorfer, Paul V., eds. **Ionizing Radiation Effects in MOS Devices and Circuits**. John Wiley & Sons: New York, 1989.