Radiation Effects on DC-DC Converters

DC-DC Converters frequently must operate in the presence of various forms of radiation. The environment that the converter is exposed to may determine the design and performance of the part and how the part may perform during and following the radiation exposure. The following is a brief discussion of some of the radiation factors influencing DC-DC Converters.

Unmanned Space

The radiation environment mainly consists of a relatively steady accumulation of ionizing dose as well as sporadic high energy particles which cause Single Event Upsets (SEU).

Total ionizing dose accumulations for unmanned space applications range from several thousand Rads (Krads) to several hundred thousand rads. Many applications have expected operating lives that exceed ten years, resulting in a correspondingly high accumulation of radiation dose. However, dose rates are relatively low. The ionizing radiation dose may consist of electrons, or of heavier particles such as protons or neutrons. The mix of radiation depends on the particular orbit as well as the degree of shielding between the converter and the environment. Shielding is more effective with electrons and less effective with energetic heavier particles.

Single Event Effects depend on the energy of the particles. Higher energy particles occur with a lower frequency than low energy particles. The measure of energy for single event particles is the MeV*cm2/mg.

Manned Space

Since the lethal radiation dose for human beings is only several hundred Rads, manned space applications have much lower total dose requirements than unmanned space applications. Total dose accumulations normally do not exceed several Krads. However, more of the ionizing dose may consist of heavy particles, such as protons. Single event effects are also an important consideration.

Nuclear / Ground

The radiation considered in terrestrial applications arises from the detonation of nuclear weapons. The total accumulated dose can be relatively low compared to a space requirement, but the dose rate is much, much higher.

Moreover, there is a high rate of neutron fluence and X- ray effect associated with nuclear detonations.

Compared to radiation encountered in a space application, radiation effects from a nuclear detonation are much more transient in duration. The nuclear effect creates photocurrents in active devices which, for a very short duration, turn on the devices.

Total Ionizing Dose

Total ionizing radiation doses cause cumulative damage in electronic components. This damage can cause component parameters to change from their pre-radiation values. Some types of components are much less susceptible to radiation damage than others. Passive components, such as resistors, capacitors, inductors and transformers are relatively immune. Active components such as rectifiers, junction FET's and zener diodes are not relatively affected.

Active components such as opto-couplers, integrated circuits, enhancement FET's and bipolar transistors may or may not be susceptible to parametric change due to total ionizing dose, depending on their construction.

Designing a DC-DC Converter that will perform properly after exposure to total ionizing dose requires a knowledge of which parts to select and how to overcome the limitations of existing parts to achieve the desired result. Very often, it is possible to use some components that have a level of change that is tenable due to the insensitivity of the surrounding circuit.

Total dose radiation falls into two basic categories. They are radiation from gamma rays (electrons) or from heavier particles (protons). Up until several years ago, it was not well known in the power electronics community that: a) the parametric degradation of certain components differed depending on whether the radiation consisted of electrons or protons and b) certain terrestrial orbits had significant proton radiation.

These conditions were first widely disseminated after analyzing failures in discrete (non-hybrid) optocouplers. The findings were that opto couplers were particularly sensitive to parametric degradation when exposed to proton radiation. Other types of active components were also found to be more affected by proton radiation than previously expected. However, most types of bipolar integrated circuits that are commonly used in DC-DC Converter designs are not affected significantly more with proton radiation than with gamma radiation.

In an unmanned space application, total ionizing dose occurs at a relatively low rate, but extends over many years. Since no one wants to wait many years for the performance of a radiation test, testing is done at a higher rate that takes a day or two at most. It has recently been discovered that low dose rates cause more parametric degradation than high dose rates. This is a counter-intuitive effect. However, it has been found that at the higher dose rates, the damage caused by the ionizing radiation is annealed, or healed. At the lower dose rates the damage is actually more cumulative. Therefore, the parametric change in components at low dose rates must also be considered when selecting components.

Total ionizing dose may be reduced by shielding. Most spacecraft applications use radiation shields outside the area of the DC-DC Converter. Shielding is more effective when the radiation dose consists of electrons and low energy particles. It is much less effective when the radiation dose consists of protons. Also, shielding becomes ineffective beyond a certain point because of secondary emission. This means that radiation impinging on the shield causes a secondary emission, which emanates from the shield.

Single Event Effects

Single Event Effects are circuit upsets or damage caused by small numbers of energetic particles. The frequency of these events is inverse to the energy of the particles. That is, the more energetic particles occur less frequently.

The result of a Single Event Effect is usually the unwanted conduction of a semiconductor device for a nanosecond or sub-nanosecond interval. The device exposed to the single event particles can be latched into an unwanted state or can recover from the conduction after the event ends.If the device latches into an unwanted state, the cause may be activationof parasitic components that would normally be otherwise out of the picture.

Therefore, Single Event Effects can affect certain types of semiconductors, such as CMOS parts, more than other devices, such as bipolar junction isolated parts. The devices selected for MDI DC-DC Converters, which are designed to be radiation resistant, use bipolar IC's and avoid CMOS and BiCMOS IC's.

In addition, the circuit topology can very much influence Single Event tolerance. For example, a half bridge (or full bridge) power stage has one (or two) series connected switching transistors across the power line. Only one transistor is permitted on at a time in each leg. A single event can turn on the "off" transistor, causing a shoot through current. If the current is not limited by passive components in some way, the single event can cause destruction of the transistors. Other power stage topologies, suchas flyback, single ended forward, etc., have the impedance of a transformer in series with the switching transistor. Therefore, the current that would flow in the event of an unwanted transient conduction is much more limited.

Control circuit topology can also cause problems when exposed to single event particles. As an example, the original MDI converters incorporated a cyclic current limit circuit using an LM139 comparator IC. The cyclic current limit circuit is designed to shut the converter off for a period of time when an overcurrent is detected, turning it back on automatically. However, if the LM139 is hit with a single event particle, it instantaneously changes state. Since the comparator reverts to the proper state after the event, this would not otherwise be a problem, except that the external latching circuitry recognizes the transient change of state as an overcurrent, and cycles the current limit. MDI resolved this unwanted operation by incorporating an RC time constant in the latch circuit. The purpose of the RC time constant is to discriminate against the very narrow pulses produced by a single event, and the wider pulses produced by a true overcurrent condition. By adding the RC circuit, MDI made the circuit function immune to Single Event Effects. The charge stored on the capacitor remembered the desired circuit state and allowed the circuit to recover after the event passed.

This demonstrates that with proper circuit topology, parts that may otherwise be sensitive to single event effects can be overcome by circuit elements.

Neutron Fluence

Neutron Fluence is significant mainly in applications where the DC-DC Converters must operate in the vicinity of a nuclear bomb blast. As would be expected, the effects caused by Neutron Fluence on the ground are similar to those caused by proton radiation in space.

As far as components normally used in DC-DC Converters, the optocoupler, if used, is found to be the susceptible component to damage from neutron fluence. In particular, the LED part of the optocoupler is found to be the item most usually degraded by neutron fluence. Different types of LED's are used within optocouplers. Some of these LED's are much more resistant to neutron fluence than the common GaAs LED's.

A better solution is to eliminate optocouplers altogether. Optocouplers transmit a signal from one ground to another. In a DC-DC Converter, the control loop error signal is the parameter that is passed through the optocoupler. This feedback function can also be achieved by coupling the error signal through a transformer. Elimination of the optocoupler and replacement by a magnetic coupling is the basis for MDI's 5000 series Proton Rad Hard DC-DC Converters.

MDI’s 5000, 7000, 8000 and 9000 series parts, in the R, RE, S, SE grades have standard rating of 100 Krads TID and 82 MeV*cm2/mg for SEE. However, the ultimate capability of these pares is in excess of 200 Krads TID and 82 MeV*cm2/mg.

MDI’s 120 VDC space station application parts in the R, RE, S, SE grades are rated for 25 Krads TID and 37 MeV*cm2/mg, consistent with space station environments.