BROADCOM®

White Paper

Broadcom Switch Devices

Soft Errors in Broadcom Switch Devices

Introduction

This white paper is intended for end users of Broadcom® switch devices who are interested in understanding how Broadcom hardware and software handles soft errors in its switches.

This paper addresses the following items:

- The cause of soft upsets.
- How to recognize soft upsets versus hardware generated errors.
- How Broadcom handles these events.
- How to recover the memory locations where the error occurred.

What is SEU?

Single event upset (SEU) is a transitional failure event caused by random particle strikes. SEU occurs in SOCs (System on Silicon) over a period of time while the device is deployed in a system. For protected memory, these failures are autocorrected by either hardware or software.

Very large-scale integration has led to SOC chips with billions of transistors, and large portions of these chips are occupied by memory. To accommodate the extremely high density of gates in processors and high port density switches, the transistor geometry is shrinking by 50% every year, according to Moore's law.

Unfortunately, this shrinking silicon geometry comes with a side effect: memory and register cells become susceptible to energy particle strike resulting in a soft error or a bit flip. Energy particle strikes can be caused by a neutron or alpha particle strike. A bit flip occurs when a memory cell loses its charge and a 1 state and flips to a 0 state. This is called a soft error because the error goes away if the bit is reinitialized or the system is reset. Hard errors do not resolve with a reinitialization or power re-cycle.

Normally, a soft error caused by an SEU results in a single-bit error. Burst errors can also happen. Errors caused by SEU are detected in hardware and recovered through a software mechanism that is designed to reverse the effect of such an event.

The device reports these errors when they occur, even if the errors are auto corrected. While SEU events occur very infrequently, they can have higher incident rates in large-scale deployments such as data centers and mega-scale data centers. This incident rate is measured in FIT (failure in time). FIT is defined as the average number of components that fail within a billion hours. Mean Time Between Failures (MTBF) is the mean time between failures and is derived from the FIT. A component with a failure rate of 1 FIT is equivalent to having an MTBF of 1 billion hours.

What Can Cause SEU?

SEU can be caused by the following events:

- Random radiation or particle hits to the silicon dice (Figure 1, left). The particles weaken the charges in silicon that lead to a memory cell flipping (Figure 1, right). Radiation-based soft errors are very infrequent on a per-device basis, and the radiation consists mainly of alpha and neutron particles.
  - Alpha particle emissions are infrequent, do not travel long distances, and tend to be very localized within the package. New materials that prevent alpha particles from being generated are currently in production.
  - Neutron particles are the result of cosmic events such as solar flares. There is a higher probability of neutron particle hits at high altitudes. For example, compared to New York, Denver is eight times more likely to experience a neutron particle hit. JESD89a, *Measurement and Reporting of Alpha Particle and Terrestrial Cosmic Ray Induced Soft Errors in Semiconductor Devices* (http://www.jedec.org/sites/default/files/docs/jesd89a.pdf) provides the following information:

    "The most important parameter determining the terrestrial neutron flux is atmospheric depth, which is proportional to barometric pressure and changes with altitude. The neutron flux is roughly 10 times higher at altitude of 3,000 meters than it is a sea level."
- EMI disturbances caused by high energy transmitters. The source can be either be internal to the building or external radio towers, power lines, and so on.
- Power supply spikes caused by bad power regulation and variations in power. This can inject into the silicon through the power connections.

Figure 1: Silicon Transistor during Energy Particle Strike

How is Memory Protected against a Particle Strike?

Broadcom memory has a built-in mechanism to detect and protect against bit errors caused by SEUs. In most cases, software assists in soft error recovery (SER). Broadcom switches contain this mechanism, which provides extremely robust protection against soft errors.

NOTE: Protection and correction mechanisms must be enabled using the Broadcom SDK (Switch Development Kit) APIs.

The following mechanisms are used to detect SEU failures and recover memory cell data:

- **Error Correcting Code Protection** — In a memory table that has error correcting code (ECC) protection, little to no software intervention is required for a single-bit error. The ECC scheme corrects single-bit errors automatically. However, when there are double-bit errors, software corrects the corrupted memory. All critical data and buffer memory are protected with ECC. A large percentage of memory is protected through ECC.

- **Parity Detection and Correction** — The following list describes each component of parity detection and correlation:
  - **Parity Detection** — Parity detection is a simple mechanism in which the sums of all bits in the entry are checked against the odd or even parity indication. This simple scheme works well when SEU events trigger a parity error. XGS® switches deploy column-MUXing memory architecture to ensure that multi-bit flips within an entry do not occur. Hardware only reports parity errors when a table entry is being accessed.

    Some memory units, such as Tertiary Content Addressable Memory (TCAMs), use an internal scan mechanism to detect parity errors and do background scrubbing, as described in Table 1, Memory Types and Protection.
  - **Parity Protection** — When an SEU event occurs and a parity error is detected, the hardware will trigger a parity failure indication, along with its memory address and index. This information is relayed to the CPU, and the content in that particular entry will be restored by a shadow copy through a SER mechanism in the SDK. Each time the table entry is accessed using READ, WRITE, or DMA, the hardware logic computes the parity on a per-entry basis.

    As mentioned previously, the Broadcom SDK responds to parity error corrections. Parity error detection and correction is reported to the system using the SDK until the parity error is corrected.

    Self-clearing memory clears parity errors with new data arriving in the cell. In such cases, the parity error indication will be seen until the error goes away.
  - **Software SER Detection and Correction** — Logic that has the capability to do background scrubbing so that all table entries are subject to parity calculations, regardless of activities on the ports. This ensures that entries are proactively corrected prior to an actual hardware or packet lookup. Background scrubbing also helps maintain data integrity between the cache value and actual hardware. This is especially useful in cases where SEU events cause multiple bits to be flipped and result in a false-positive parity calculation. In such cases, if parity scrubbing is not performed, then there is a possibility that incoming packets will be flooded continuously or result in a premature table full.

Broadcom devices are designed with a large amount of internal memory to support high-performance, non-blocking packet switching. There are three memory usage types within the device: one type is used for packet buffer switching, the second type is for packet table lookup, and the third is used for packet classification. The following table summarizes the three memory types and their usage.

Table 1: Memory Types and Protection

Type	Usage Model	Memory Protection
Table lookup for VLAN, L2, and L3 lookups.	Packet lookup into table entries either directly or with hashing. Used to determine the next set of actions for the packet based on entry contents.	Hardware parity and software SER.
Packet classification based mainly on TCAMs.	Packet content is filtered on a bit basis. Used to assign actions such as ACL rules based on matching criteria.	Hardware SER and Engine and software SER.
Packet buffer.	Packets are stored in these buffers. Used to switch packets between ports	Hardware ECC.

NOTE: Sometimes a stuck-at fault may occur in memory that is a hardware failure. The chip will assert a parity error flag and continuously send out parity error logs. Such issues do not resolve with reset or power cycle and need to be treated as a hardware failure.

Additional Notes

- SEU detection has been included in Broadcom switch devices for several generations of products.
- SEU protection was introduced in Broadcom switch devices in April 2014 through SDK, and all products introduced after that contain built-in SER (SEU Protection).
- The SER software will correct single-bit errors in memory locations. However, the SDK will report these failures and subsequent recoveries if enabled.
- The soft error rate for errors caused by cosmic or alpha particles is very rare, likely once in a year. Soft errors caused by environmental factors such as power spikes or EMI are more frequent. While SER mechanisms can usually deal with single-bit errors, these spikes can cause longer bursts that could be outside the range of recovery software.
- When an SEU incident is reported to Broadcom, a log or a report of the incident is necessary to diagnose the root cause. This report should contain certain information related to device, memory block, number of incidents per-device and over multiple devices, frequency of the incidents, and size of deployment. Broadcom provides a questionnaire to help properly report incidents. This helps Broadcom engineers understand the probable source of the incident. A large number of errors on either a single device or multiple devices can indicate system environmental issues. These errors may not be SEU caused by alpha or neutron particles, but EMF or voltage variations.

Summary

Soft errors are inherent in high-density SOCs. While rare, soft errors due to SEU events may happen once in a couple of years. Broadcom switches and software are equipped to handle such incidents without any network impact. The probability for SEU-related memory errors in a deployment increase as the number of units and device density increases. To maximize memory protection, use a version of the SDK that supports SER.

Broadcom has invested in state-of-the-art software and hardware techniques to make devices robust to SEU.

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