Beyond Design - Electromagnetic Susceptibility (EMS)

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As PCB Designers, we are concerned with electromagnetic emissions, as every product we design must pass the FCC/CISPR compliancy, but what about susceptibility to external sources? Noise sources range from medium to high frequency, RF and microwave radiation and can be generated by nearly any electrical appliance or device. Interference tends to be more troublesome with older technologies, but is also prevalent in modern-day digital systems. There are ways to combat this noise such as in Wi-Fi, where error-correction techniques can be used. Spread-spectrum and frequency-hopping techniques can also be employed with both analogue and digital signaling to improve resistance to interference.

On the other hand, cosmic radiation (rays) are all around us. Subatomic particles – mostly protons and helium nuclei – of extremely high frequency are constantly streaming from distant galaxies and are of such short wavelength that they pass right through everything around us. These particles can wreak havoc in electronic systems in a number of ways. One of the most common is called “a single event upset”, in which cosmic rays ionize atoms in a semiconductor, releasing a burst of electrons that can flip a digital bit from say a 1 to 0. This is known as a soft error but can still blue-screen a computer. A hard error or “a single event burnout”, is more serious in which components are damaged or destroyed by a sudden short-circuit caused by the burst of electrons.

In order to cram more processing power into integrated circuits, the last decade has seen the size of transistors, within ICs, shrink from 180nm to less than 20nm. According to a study conducted by Oracle, this comes at a price – cosmic rays create eight times more soft errors in ICs with 40nm transistors than those with 130nm. As transistors shrink, the amount of charge required to incite the circuit is reduced. This trend is also evident in the drive for more efficient chips that run at low voltages – circuits running at 0.5V have twice the rate of soft errors as those running at 0.7V.

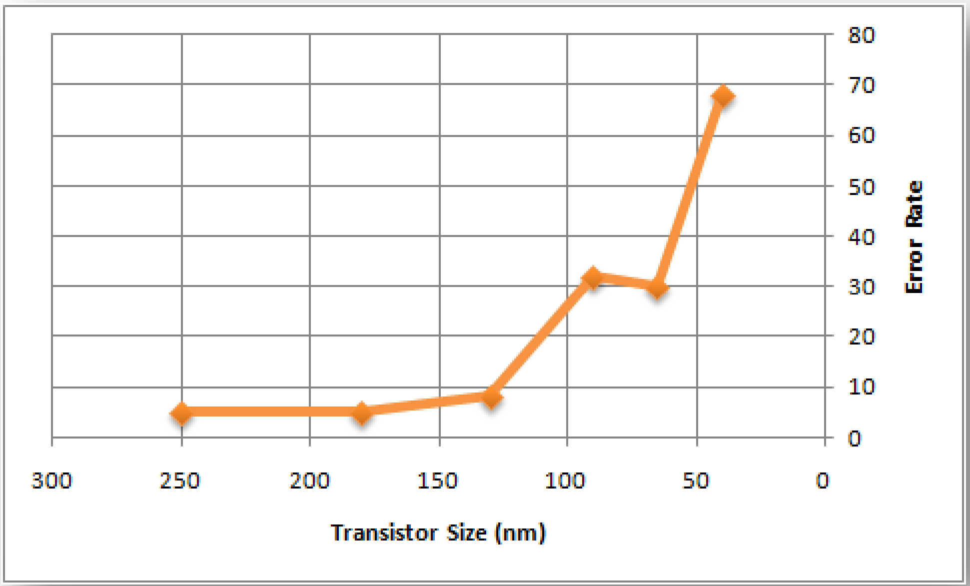

Figure 1 – Transistor size vs microprocessor error rate (source Oracle)

Not surprisingly, the space industry began designing its craft with these problems in mind way back in the Apollo mission days. Thin sheets of gold foil, less than 0.15mm thick, were used in space programs as a radiation shield. The lunar modules of the Apollo flights were shrouded in foil.

Unfortunately, this thin gold foil is no obstruction to the extremely short wavelength of cosmic rays. However, it may have offered some protection, for the Astronauts, from solar radiation but provided little shielding for sensitive electronics. More recently, materials that have high hydrogen content, such as polyethylene, have been used to reduce radiation to a greater extent than metals, such as aluminum. Hydrogen atoms are good at absorbing and dispersing radiation. Also Demron, a material said to have radiation protection similar to that of lead shielding, while being lightweight and flexible, is being trialed. Spacecraft designers have to be able to shape shielding materials to make various parts of the spacecraft. The material must protect the crew from radiation, and it must also deflect dangerous micrometeoroids.

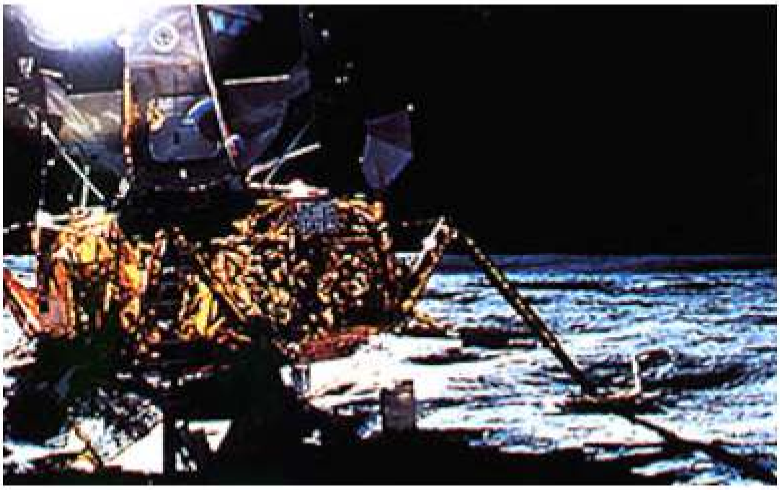

Figure 2 – Gold foil acts as a radiation shield on the Apollo lunar module
(Courtesy World Gold Council)

Fortunately, back down on Earth we are much safer from cosmic rays. Earth's atmosphere offers the same protection as a concrete layer 4 meters thick. Incoming particles, striking atoms in the atmosphere, produce an avalanche of protons and neutrons that in turn create a shower of millions of fragments – gamma rays, muons, neutrinos, electrons and other particles – that rain down, spread over several square kilometers. Those reaching sea level are thought to be too weak to have any significant impact on electronic systems.

Cosmic radiation intensity can also increase during periods of strong solar activity (flares). Where masses of electrons, created by thunderclouds, can produce bursts of radiation known as terrestrial gamma ray flashes. These flashes can pack more of a punch then cosmic rays and can dramatically affect aircraft electronics.

The electronics industry has responded by developing a number of ways to combat the cosmic ray threat. The most common defense against soft errors is error-correcting software, typically involving check bits sent along with each packet of data, which is used to confirm that the contents have not been corrupted. In addition, multiple copies of data is stored in different locations in memory. In particular, vulnerable or critical systems, like those on satellites or aircraft, have their complete hardware systems built in triplicate.

Environments with high levels of ionizing radiation create extraordinary design challenges. A single charged particle can knock thousands of electrons loose, causing electronic noise and signal spikes. This is a particularly serious problem in the design of satellites, spacecraft, military aircraft, nuclear power stations, and nuclear weapons. In order to ensure the proper operation of such systems, manufacturers of integrated circuits and sensors, intended for the military or aerospace markets, employ various methods of radiation hardening. Radiation-hardened (RAD HARD) components are based on their non-hardened equivalents, with some design and manufacturing variations to reduce the susceptibility to radiation damage.

Figure 3 – RAD HARD device (courtesy Intersil)

Radiation-hardening techniques:

- Hardened chips are often manufactured on insulating substrates instead of the usual semiconductor wafers. Silicon on Insulator (SOI) and sapphire (SOS) are commonly used. While normal commercial-grade chips can withstand between 5 and 10 krad, space-grade SOI and SOS chips can survive doses many orders of magnitude greater.
- Bipolar integrated circuits generally have higher radiation tolerance than CMOS circuits. The low-power Schottky (LS) 5400 series can withstand 1,000 krad, and many ECL devices can withstand 10,000 krad.
- Magnetoresistive RAM, or MRAM, is considered a likely candidate to provide radiation hardened, rewritable, non-volatile conductor memory. Physical principles and early tests suggest that MRAM is not susceptible to ionization-induced data loss.
- Shielding the package against radioactivity, to reduce exposure of the bare device.
- Capacitor-based DRAM is often replaced by more rugged (but larger, and more expensive) SRAM.
- Shielding the chips themselves by use of depleted boron in the borophosphosilicate glass passivation layer protecting the chips, as boron-10 readily captures neutrons.

So, it seems that printed circuit boards cannot be totally shielded against the impact of cosmic rays. However, we can take precautions to avoid interference from shorter wavelength radiation that is more prevalent in our environment.

1. Route high-speed signals between the planes, fanout out close to the driver (200mil) dropping to an inner plane and route back up to the load again with a short fanout. This will help shield the sensitive signals.
2. Keep critical signals away (200mil) from the board edges.
3. Avoid short stubs as these are more compatible with shorter wavelengths.
4. Use differential pairs for high-speed signal routing as their equal and opposite polarity rejects common mode noise.
5. Use higher operating voltage components with a larger die size where possible.

Embedding signals between the planes reduces susceptibility to radiation, as well as providing ESD protection. In doing so, not only do we prevent noise from being radiated but we also reduce the possibility of being affected by an external source.

So next time your PC blue screens, your cruise control locks up or your 747 suddenly decides to do a death dive – it may just be a random glitch from cosmic rays or a solar flare.

Points to Remember:

- Noise sources range from low frequency to high frequency, RF and microwave radiation and can be generated by nearly any electrical appliance or device.
- Cosmic rays can wreak havoc in electronic systems in a number of ways.
    - One of the most common is called "a single event upset", in which cosmic rays ionize atoms in a semiconductor, releasing a burst of electrons.
    - A hard error or "a single event burnout" is more serious in which components are damaged or destroyed by a sudden short-circuit caused by the burst of electrons.
- Cosmic rays create eight times more soft errors in ICs with 40nm transistors than those with 130nm.
- Circuits running at 0.5V have twice the rate of soft errors as those running at 0.7V.
- Materials that have high hydrogen content, such as polyethylene, have been used to reduce radiation to a greater extent than metals, such as aluminum.
- Demron, a material said to have radiation protection similar to that of lead shielding, while being lightweight and flexible, is being trialed.
- Earth's atmosphere offers the same protection as a concrete layer 4 meters thick.
- The most common defense against soft errors is error-correcting software. In addition, multiple copies of data is stored in different locations in memory. Critical systems, like those on satellites or aircraft, complete hardware systems are built in triplicate.
- Manufacturers of integrated circuits and sensors, intended for the military or aerospace markets, employ various methods of radiation hardening.
- Printed circuit boards cannot be totally shielded against the impact of cosmic rays, however, we can take precautions to avoid interference from shorter wavelength radiation.
- Embedding signals between the planes reduces susceptibility to radiation, as well as providing ESD protection.

References:

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For information on the ICD Stackup and PDN Planner, please go to www.icd.com.au

Bio:

Barry Olney is Managing Director of In-Circuit Design Pty Ltd (ICD), Australia. The company developed the ICD Stackup Planner and ICD PDN Planner software, is a PCB Design Service Bureau and specializes in board level simulation.

