KVA Engineering, Inc.

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The Growing Impact of Atmospheric Radiation on Semiconductor Devices and the Resulting Impact on Avionic Suppliers

SEU Whitepaper

Personal History

- Consulting Engineer with 29+ years experience.
- Significant experience in many industries such as aerospace, petroleum exploration, industrial controls, HVAC&R, Power generation, Medical, etc.
- Avionics – Autopilot, Fly-By-Wire, Flight Management, Thrust Management, FADECs, HUD's, EFIS, etc.
- Participated in nine different aircraft developments from concept to certification.
- Currently involved in three different SEU research projects.
- Under GE Aviation, sit as member of committee to develop SEU systems standard for IEC (International Electrotechnical Commission)

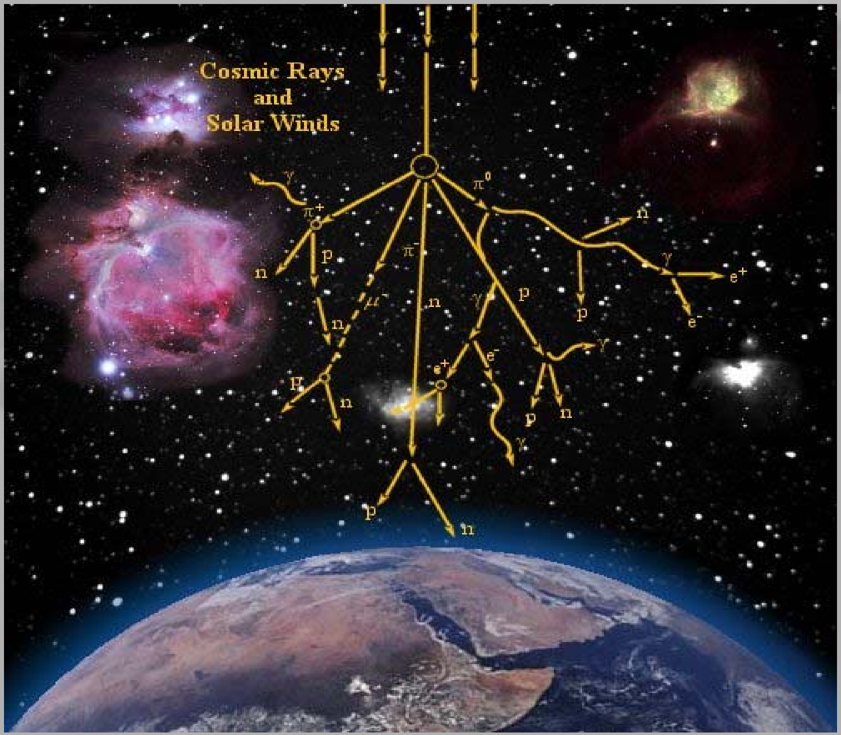
Introduction

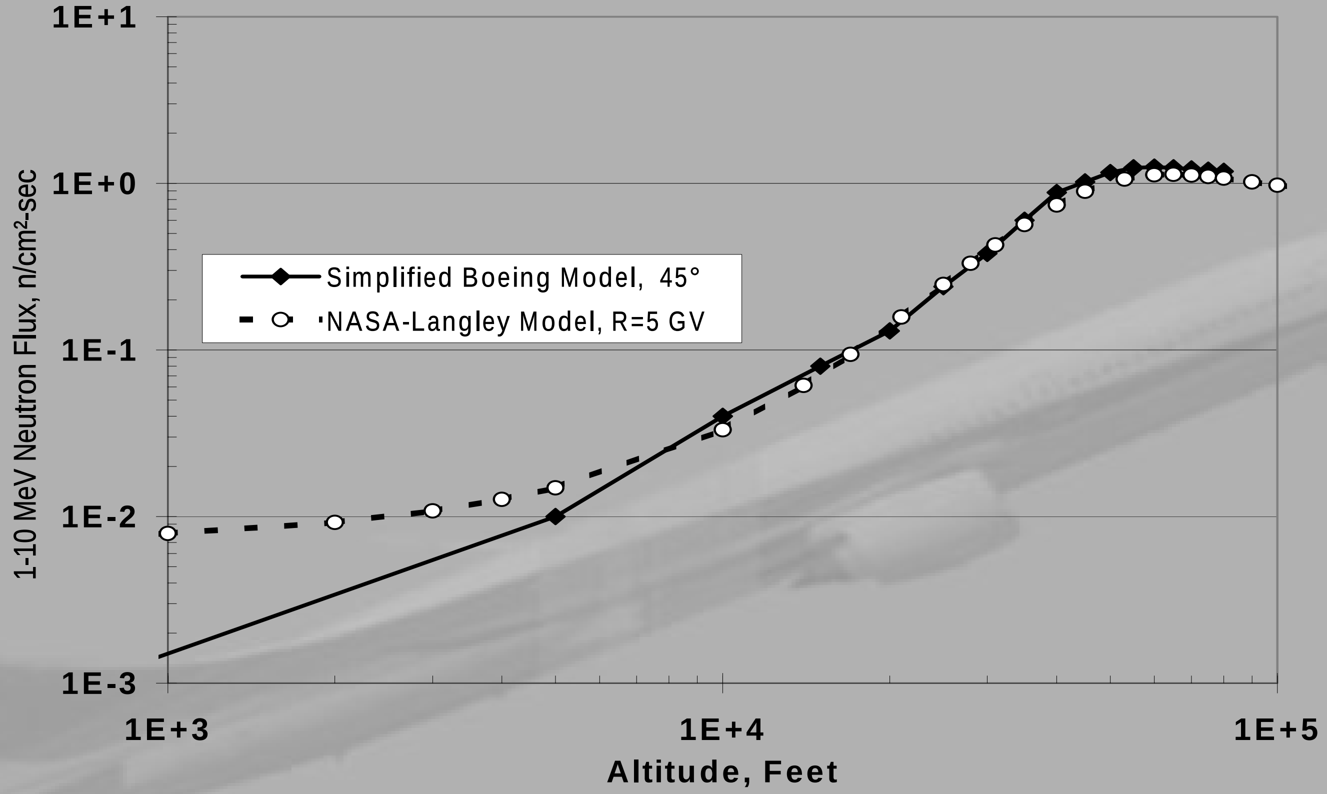
- The continuing advancement of semiconductor technology is causing significant increases in Single Event Upset (SEU) susceptibility in semiconductor devices with the event rate increasing exponentially.
- Fault tolerant system design methodologies were developed years ago to deal with a specific range of issues and significantly lower SEU rates.
- The range of issues previously considered when validating system architectures have changed without the designer's awareness. This is resulting in potentially defective designs.

What Kind of Radiation are We Talking About **(not space)**

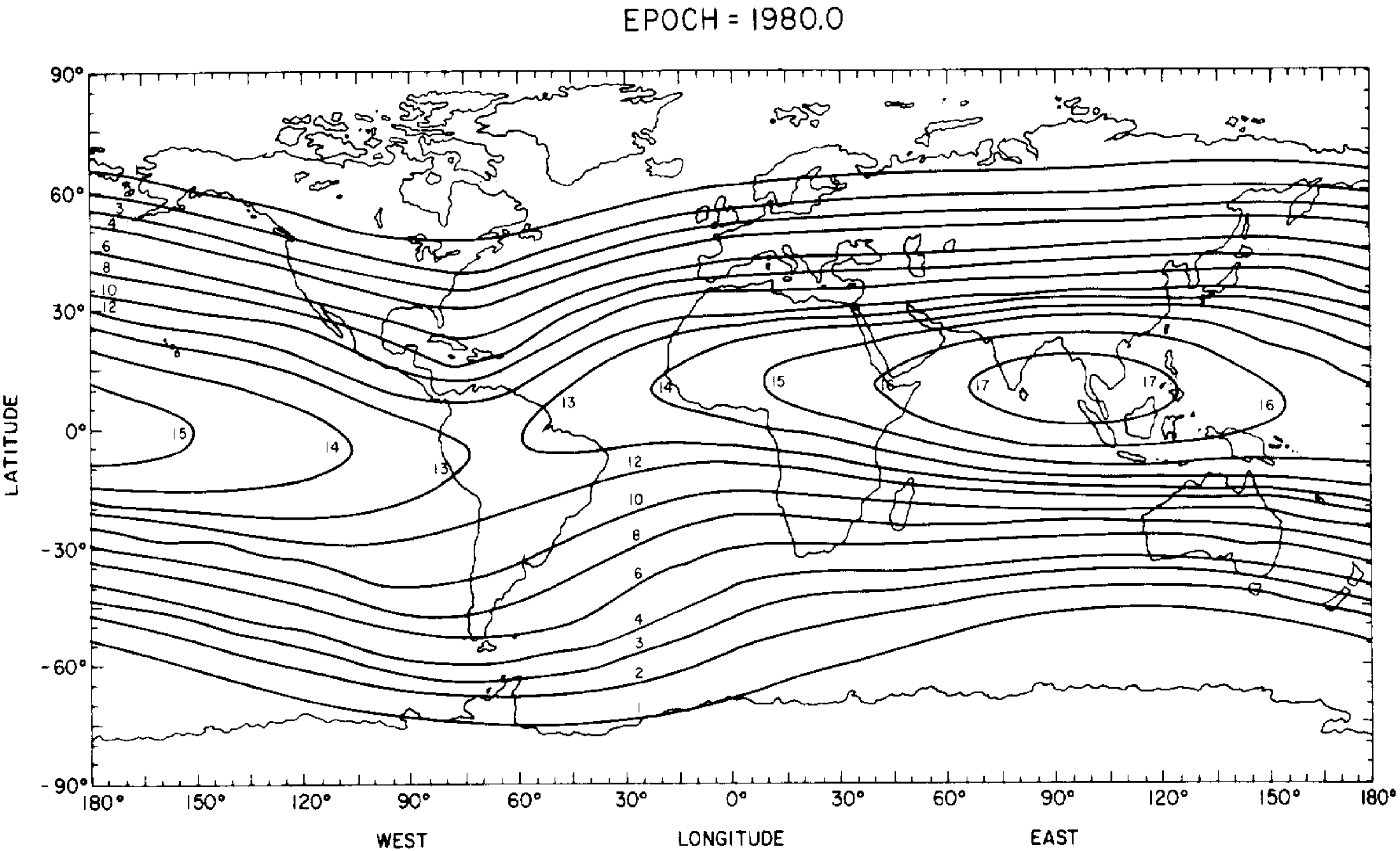
- The atmosphere is penetrated by a flux of various charged and neutral particles that in combination create a complex ionising radiation environment

- Particles are created by the interaction of the continuous stream of primary cosmic ray particles with the atoms in the atmosphere (mainly nitrogen and oxygen)





Variation of the Atmospheric Neutron Flux with Altitude



Distribution of Vertical Rigidity Cut offs Around the World

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Background of Atmospheric Radiation Effects on Semiconductors

A single event upset results from a single, energetic particle depositing a charge in a region of a semiconductor device causing it to change state or alter its analog output. The end result is an erroneous output from the device. The types of particles that contribute to this effect are alpha particles, various ions, protons, and neutrons. At sea level, the largest contributors are alpha particles (from packaging and lead), and neutrons. The exposure to all particle types increases as the latitude and altitude increases, especially during solar events.

Background of Atmospheric Radiation Effects on Semiconductors

Single event phenomena can be classified as three basic effects (in order of permanency):

- (SEU) Single Event Upset (soft error)

  Single event upset (SEU) is a condition that causes corruption of data or logic state in a device resulting in erroneous output. This is a soft error, meaning that data could be updated or corrected or the part reset and normal functionality would be resumed. This was first observed in 1975.

Background of Atmospheric Radiation Effects on Semiconductors

- (SEL) Single Event Latch-up (soft or hard error)
  - *Single event latchup* (SEL) is a condition in some CMOS devices where the energy deposited locally in a device by the single particle has turned on parasitic transistors causing high power supply current through the device. SEL also causes loss of device functionality. This can be a persistent failure and can only be cured by cycling power. This was first observed in 1979.

- (SEB) Single Event Burnout (hard failure)
  - *Single event burnout* (SEB) is a condition in a high voltage device caused by the energy deposition by a single particle leading to a feedback mechanism that exceeds the breakdown voltage and therefore destroys the device. SEB of power MOSFETs was first reported in 1986. Single Event Effects can also cause secondary breakdown in bipolar junction transistors (BJTs), resulting in burnout of the transistor as was first reported by Titus *et al.* in 1991.

Background of Atmospheric Radiation Effects on Semiconductors

Solar affects can have a significant impact on radiation levels and resultant SEU rates. The sun on an eleven year cycle produces varying sizes of solar flares. These flares send out energetic particles that strike the earth and can affect the entire planet, but especially in the Polar Regions where the earth's magnetic field is weakest. These particles can cause an increase in the radiation that an aircraft sees by a factor ranging from 10-1000X. The next projected solar peak where these levels could occur is 2011. This change in radiation proportionately impacts SEU rates. For various reasons, this modifier has never been considered in SEU analysis.

Radiation Effects in Semiconductors

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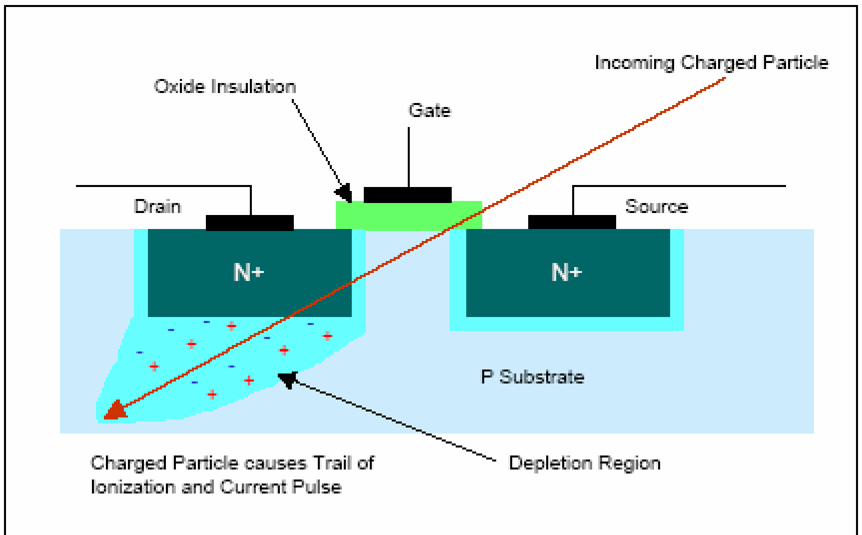
soft errors



Current State of SEU Issues

- Most devices analog and digital have been found to have some susceptibility to atmospheric radiation effects.

- Designers are moderately aware of SEU concepts and have heard of or use various techniques developed years ago to mitigate their design concerns.

- SEU rates used in analysis are based on normalized data which is based on a “standard atmospheric day.

- No worst case analysis is used in safety calculations.

- Boeing’s SEU rate number is based on normalized data which is based on a “standard atmospheric day.”

- Military has no requirements for terrestrial radiation effects. (They refuse to spend their limited resources on such topics)
- Electronic Components have been evolving at an incredible pace
- Long Avionic design cycles mean 5-7 years delay in obtaining feedback from field service data

Results are:

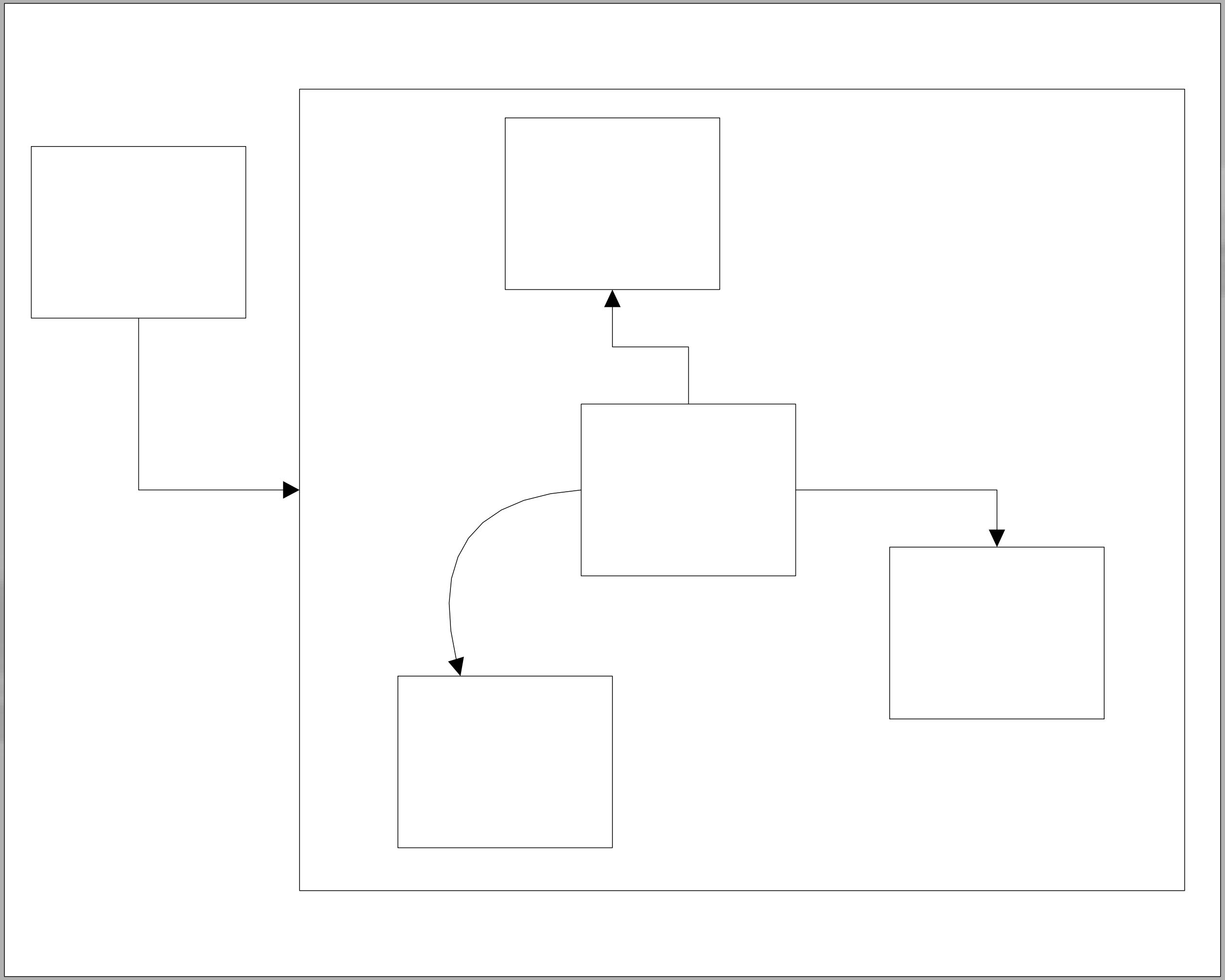
- Many design groups and suppliers building equipment under design paradigms that are rapidly becoming invalid

- Avionic industry is rapidly being exposed to considerable product liability risks

Real Life Examples

- COTS Processor board used in UAV application
- COTS Processor board used in Mission Management application
- COTS component close calls

The Component Poker Game



What Factors Are Driving This?

- Semiconductor design and use factors:
  - Lower operating voltage
  - Shrinking geometries
  - Increased Density and Complexity
- Avionic design cycles result in significant lag between design and feedback from field service
- Tight product design schedules may tend to limit design scrutiny.
- Lack of research information on the effects of thermal neutrons.
- Rapid rate of technology advancement makes it difficult for the average engineer to keep up with the issues associated with atmospheric radiation effects.
- Solar events occur on 11 year cycles and are a major contributor to SEU rates and the next peak is in 2011.
- Methods used to calculate the effects of atmospheric radiation on system reliability or availability are no longer adequate and have the potential of being in error by several orders of magnitude.

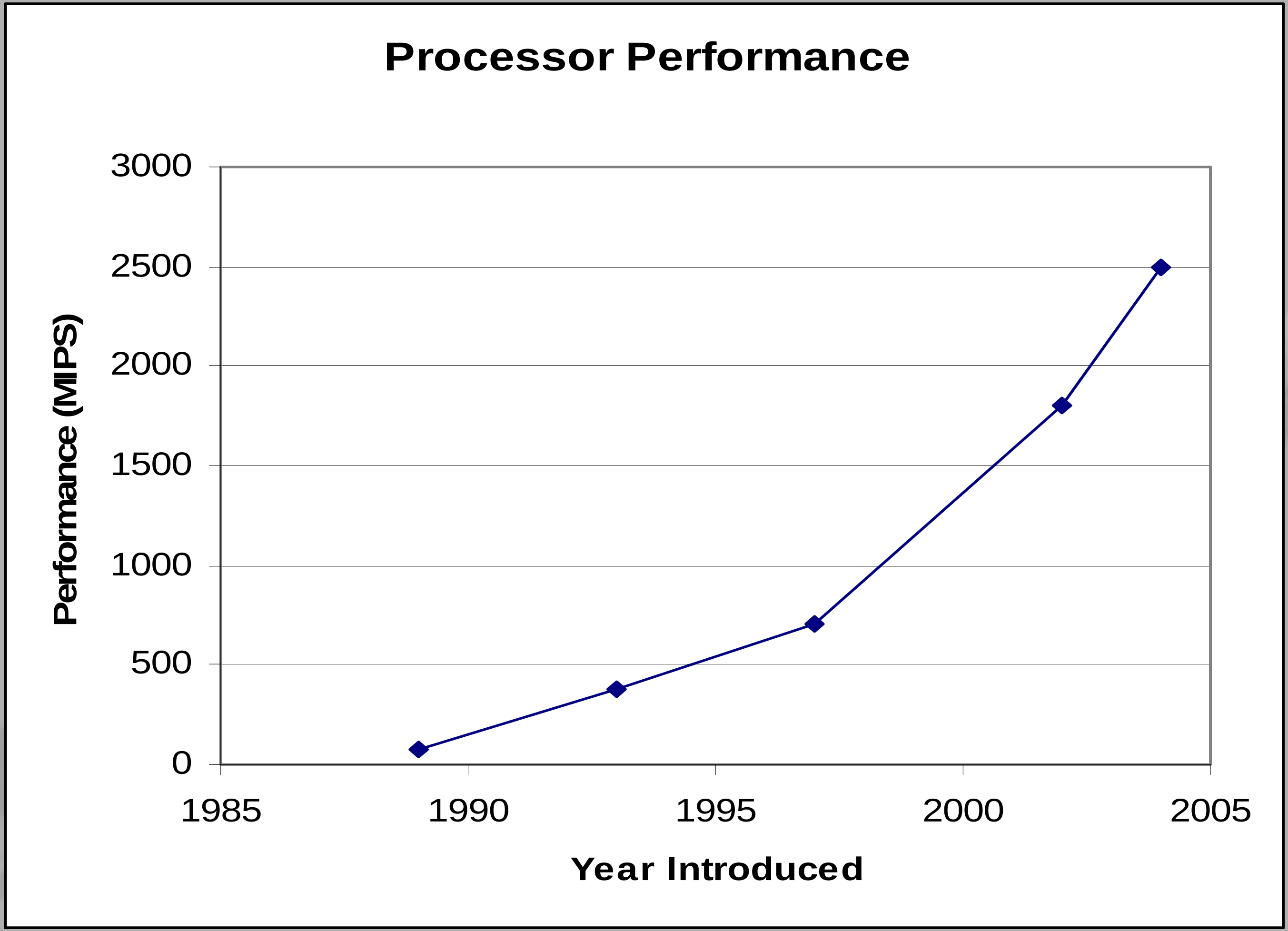


Figure 1 Processor Performance

Figure 1 Shows the exponential growth in processor performance over the past 20 years

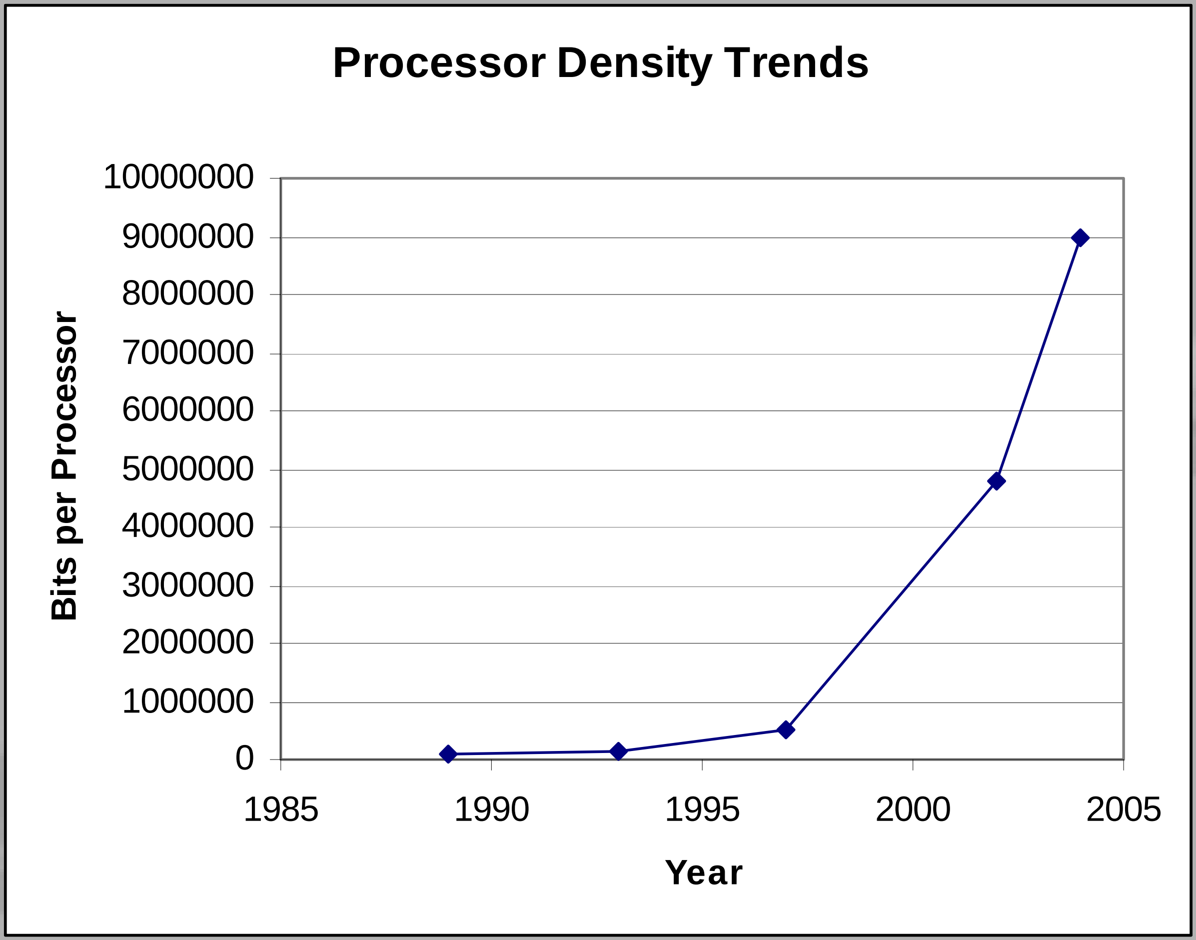


Figure 2 Processor Density Trends

Figure 2 Shows a very steep acceleration in the density of processor designs to achieve the performance increases shown in Figure 1. SEU rates are usually measured in rate per bit. With the number of bits exponentially increasing, this results in an equivalent exponential increase in SEU for the processor as a component.

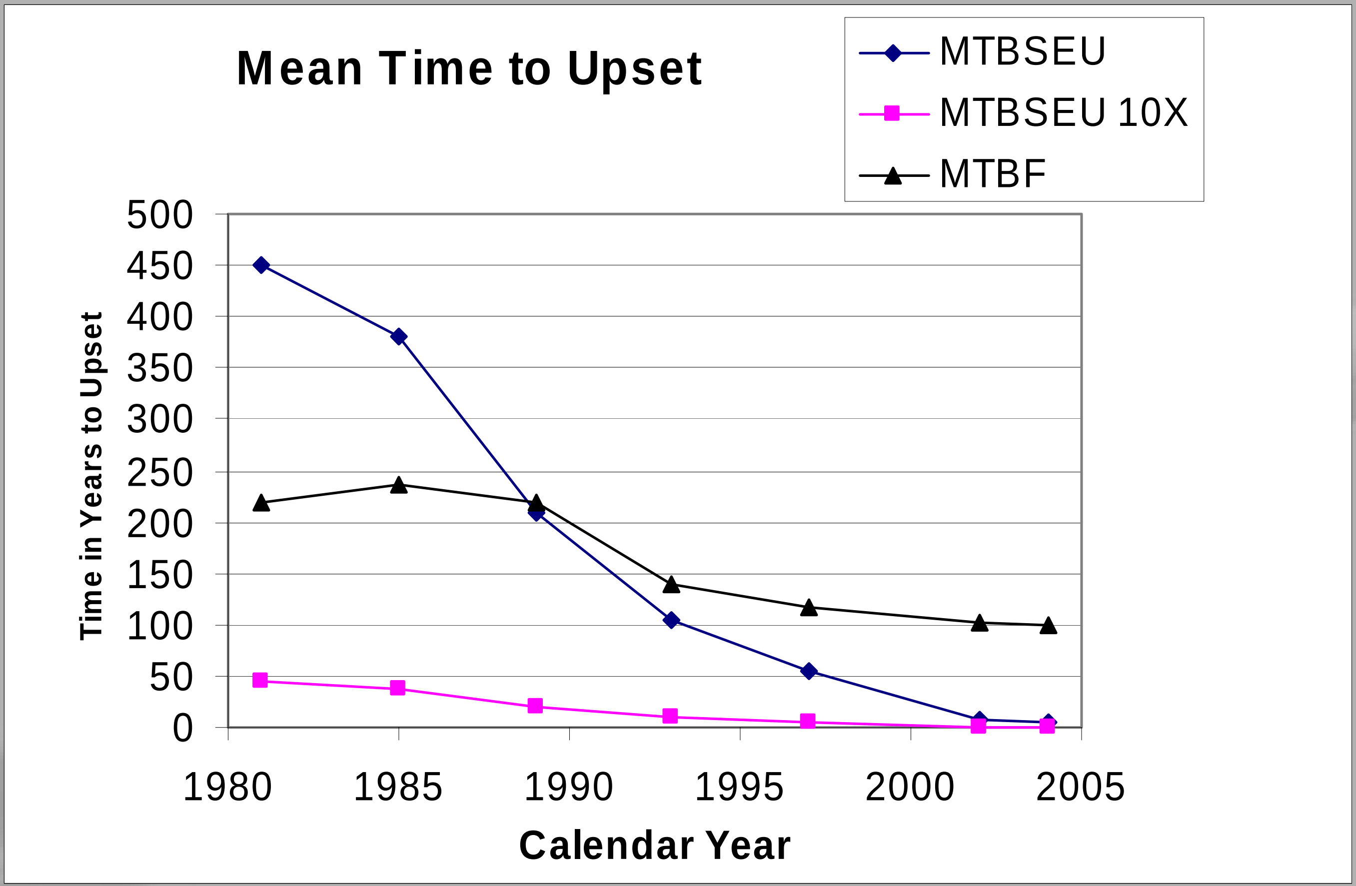


Figure 3 Mean Time to Upset

The top line of Figure 3 shows the "nominal" potential for a processor to experience an SEU. The flatter middle line represents the hard failure rate based on an operational profile that includes worst case temperature conditions. As can be seen, pre 1990 the hard failure rate was the dominant component. Up to 1995, the event rates are almost equivalent. This history begins to explain why it has not caught the attention of design engineers.

Conclusion

- There are no regulations driving change, however standards are in the works and will likely be adopted by the FAA

- Major customers such as Boeing, Airbus and Military drive few if any requirements

- Engineers and companies are building and delivering potentially inadequate designs

- The problem is a simple information and technology application gap

- With no regulatory pressure and no customer paying for or driving such requirements, this becomes an unfunded issue

- In the mean time, SEU risks exceed Avionic industry attention, knowledge and priorities.