Designing innovative vacuum gauges and controllers for over 30 years

CASE STUDY MAKING VACUUM GAUGES RADIATION TOLERANT: FOR MOST HIGH RADIATION ENVIRONMENTS

PROBLEM STATEMENT: Electronics, when exposed to radiation, will degrade and eventually fail, but methods can be adopted to extend their life. A customer who was integrating one of our 801W units into a system to be used in a high radiation environment realized at a late stage of the project that part of the final sign off on the system was the requirement for any electronic component to pass a radiation life test.

Current: Panel mount, Wide Range Vacuum Gauge (Torr)

Need: A vacuum gauge/controller safe for radiation exposure

Goal: A panel mount digital vacuum gauge with solid state electronics that can pass a radiation life test

The test required was a sample of scatter radiation taken at the point of installation of the 801W and then multiplied for a 10 year life expectancy. The number for this component and its location was 20 Krads.

RAD Definition

THE **RAD** is a unit of absorbed radiation dose, defined as 1 rad = 0.01 Gray = 0.01 J/kg. It was originally defined in CGS units in 1953 as the dose causing 100 ergs of energy to be absorbed by one gram of matter

INTRODUCTION: Most semiconductor electronic components are susceptible to radiation damage; radiation-hardened components are based on their non-hardened equivalents, with some design and manufacturing variations that reduce the susceptibility to radiation damage. Metals creep, harden, and become brittle under the effect of radiation.

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Radiation hardening is the act of making electronic components and systems resistant to damage or malfunctions caused by ionizing radiation (particle radiation and high-energy electromagnetic radiation), such as those encountered in outer space and high-altitude flight, and around nuclear reactors and particle accelerators.* Since this system was going to be subjected to ionizing radiation, we will focus on that particular form of radiation exposure.

Environments with high levels of ionizing radiation create special design challenges. Ionization effects are caused by charged particles. The ionization effects are usually transient, creating glitches and soft errors, but can lead to destruction of the device. A single charged particle can knock thousands of electrons loose, causing electronic noise and signal spikes. In the case of digital circuits, this can cause results which are inaccurate or unintelligible.

ENGINEERING APPROACH: Our team began the iterative process by collaborating with the manufacturer to determine exactly what their customer's needs were. From this discussion and some independent research we found the following information:

Total ionizing dose effects:
- Measured in rads
- Causes slow gradual degradation of the device's performance
- A total dose greater than 5000 rads delivered to silicon-based devices in seconds to minutes will cause long-term degradation
- Makes N-type MOSFET transistors easier and P-type ones more difficult to switch on. The accumulated charge can be high enough to keep the transistors permanently open (or closed), leading to device failure

Neutron effects:
- Affect bipolar devices more than CMOS ones
- GaAs LEDs, common in optocouplers, are very sensitive to neutrons
- The lattice damage influences the frequency of crystal oscillators

Radiation-hardening techniques:

Hardened chips are often manufactured on insulating substrates instead of the usual semiconductor wafers. Silicon on Insulator (SOI) and silicon on sapphire (SOS) are commonly used. For a dual op-amp, these can be quite pricey compared to lower cost solutions.

Bipolar integrated circuits generally have higher radiation tolerance than CMOS circuits. The low-power Schottky (LS) 5400 series can withstand 1000 krad, the radiation used in testing these units is ionizing radiation (gamma). There is some neutron dose, but it is relatively small.

* Messenger, G.C., & Ash, M.S. (1986). *The effects of radiation on electronic systems*. United States: Van Nostrand Reinhold Co. Inc.,New York, NY.

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The best components to use in radiation are passives and bipolar semiconductors. FETs can have problems, however some are suitable. Optoelectronics are the worst by far. The neutron dose effects optoelectronics by degrading LED output (damage to the semiconductor active layer, especially if the active layer is thick), and also can affect certain types of RAM. The radiation susceptibility in the standard 801W is likely not neutron damage, since there it contains no opto-isolators.

We undertook a series of A/B testing to determine the best configuration of the product that would be both CE complaint and would pass radiation testing.

Round 1: Initially two tests were performed on two unmodified 801W units with the following results:

- **Unit A**– Power supply failed after large dose 4 Krads
- **Unit B**– Unit survived five cycles of low dose 4 Krads. Reading shifted during each cycle.

After some consultation with the customer, two units were provided with the original switching power supplies having been replaced by linear supplies and an older technology op-amp which was not radiation hardened, but which was supplied in a radiation hardened version (cost in the neighborhood of $400). The results of this test was as follows.

Round 2 Results	8 Krads	20Krads
Unit A	Big shift in readings	Display indicated sensor failure. Power supply still functional
Unit B	Big shift in readings	Display indicated sensor failure. Power supply still functional

After further consultation with the customer, two more units were provided with the following product design changes:

- **Unit A** with a linear power supply, 7805 regulator, and an op-amp that the customer knew to have previously survived a similar test
- **Unit B** with a switching power supply that had been tested independently and a different op-amp that the customer also knew to have survived previous radiation testing

Both units survived 20 Krads with some shift in readings. Testing was continued to 30 Krads with acceptable results. We finally went into production of the Unit B configuration and are currently providing them in quantity to this customer.

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RESULTS: The third time was the charm, and we were successful in implementing a vacuum gauge that was both CE compliant and survived radiation testing. These changes increased the performance and life expectancy of the original product. This product is the 801-AC.

The last changes to the original product design yielding the 801-AC:

1. Change the power module. Based on testing this will yield a 50% increase in life expectancy in the radiation environment. Twenty-year life expectancy will be 30 KRad as opposed to 20 KRad with the original power module

2. Change OpAmp at location U2 to a high quality TTL type OpAmp. Testing showed this change virtually eliminated calibration drift caused by radiation exposure

		Vacuum 1	Vacuum 2	Air
PreRad	Unit#3	0.108	0.101	760
	Unit #2	0.115	0.107	760
	Reference	0.114	0.109	760
10K Rad	Unit#3	0.103	0.096	730
	Unit #2	0.114	0.106	760
	Reference	0.116	0.11	760
20K Rad	Unit#3	0.106	0.098	630
	Unit #2	0.118	0.111	760
	Reference	0.116	0.11	760
25K Rad	Unit#3	0.107	0.098	680
	Unit #2	0.116	0.109	760
	Reference	0.116	0.11	760
30K Rad	Unit#3	0.106	0.098	760
	Unit #2			
	Reference	0.119	0.114	760

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