LEO Circuit Design

When starting this project our group faced a simple question that has a very complex answer, what type of circuit should be used for space applications. By examining different parameters of Programmable Logic Controllers (PLC) against more traditional analog type circuits we were able to determine pros and cons for each type as outlined in this report. To do this our group determined cost, reliability, fabrication, device implementation and testing, circuit simplicity, and size were the main areas that would determine what type of circuit would perform in a Low Earth Orbit (LEO) environment.

Cost and Reliability

When examining the reliability of a PLC compared to that of an analog circuit, there are a number of sources stating that the use of a PLC is an increasingly common practice. The PLC will see reduced channel conduction over time due to ionization and radiation that the satellite will be exposed to. However, PLCs can be ordered to tolerate up to 300 Krad(Si). A PLC can be reproduced quite easily, due to the fact that a PLC can be purchased and programmed. During programming, the PLC can be loaded with multiple redundant circuits in the event the original fails. In addition, solid state components in a PLC will provide protection against vibration during launch.

With analog components, we can obtain a greater radiation tolerance, dependent on the components selected. An analog circuit can achieve higher performance, but will suffer greatly from “noise” over time due to radiation exposure. When constructing circuits for use in space, analog components are derated much more than microcircuits. According to a lesson from NASA , resistors and capacitors must be derated to 60% of their rating (power for resistors, voltage for capacitors), whereas microcircuits only need to be derated to 75% of their rated power. This is due to the stress ratio at the temperatures encountered in orbit. As opposed to a PLC, analog circuits will have a greater risk of failing due to the vibration that the satellite is subjected to during launch.

PLC	Analog
Lower Cost of Production	Greater Radiation Tolerance
Reproducibility	Higher Performance
Reduced Channel Conduction over time due to radiation (ionizing)	Increased noise over time due to radiation
up to 300K rad(Si) Total Hardness	
Redundancy of Programming	

Implementation

Digital filters are a costly alternative to analog filters but are more accurate and consistent. These circuits introduce latency since they use a discrete-time processing and sampling process.

Digital filters:

- Use complex integrated circuits.
- Are far more accurate than analog filters.
- Are programmable, which makes them easy to build and test.
- Do not suffer from as many manufacturing variations or aging.

Analog circuits:

- Are made of mechanical parts.
- Do not require constant power.

DIGITAL FILTERS	ANALOG FILTERS
High Accuracy	Less Accuracy - Component Tolerances
Linear Phase (FIR Filters)	Non-Linear Phase
No Drift Due to Component Variations	Drift Due to Component Variations
Flexible, Adaptive Filtering Possible	Adaptive Filters Difficult
Easy to Simulate and Design	Difficult to Simulate and Design
Computation Must be Completed in Sampling Period - Limits Real Time Operation	Analog Filters Required at High Frequencies and for Anti-Aliasing Filters
Requires High Performance ADC, DAC & DSP	No ADC, DAC, or DSP Required

http://www.planetanalog.com/author.asp?section_id=3065&doc_id=560512

Fabrication

Relays contain mechanical parts, which typically take up more space than its digital equivalent. These circuits need to be designed on an individual basis to meet differing operational constraints. PLCs were first developed to replace relays and relay control systems. PLCs can be hardened for severe conditions and are able to withstand extreme conditions. Controllers are very compact due to the use of integrated circuits instead of analog components.

Testing

Testing of digital and analog parts is similar, in that they are both subjected to a test environment similar to what they will experience in LEO. In LEO typical radiation dose rates are between 100 and 1,000 rad/year. Circuit components fall into three categories:

1. Commercial
    a. Not made for high-rad environments
    b. Not tested for rad hardness
    c. Can withstand 2-10 krads typically
    d. SEU Error Rate: 10E-5 errors/bit-day
2. Rad Tolerant
    a. Rad-hard to a certain point
    b. Not specifically tested for rad hardness
    c. Can withstand 20 to 50 krads
    d. SEU Error Rate: 10E-7 to 10E-8 errors/bit-day
3. Rad Hard
    a. Designed to operate in high rad environments
    b. Wafers are radiation tested
    c. Can withstand over 1Mrad in certain components
    d. SEU Error Rate: 10E-10 to 10E-12 errors/bit-day

Most of the testing is done to check that parts won't fail once in orbit for extended periods. During testing, they are run through many iterations of:

- Heating/Cooling Cycles
    - This concerns both digital and analog components as thermal expansion and contraction can break contacts between parts
    - Extreme heat and cold can affect certain transistor based devices
- Day/Night Cycles
    - In addition to temperature changes, when the circuit is exposed to the sun it is bombarded with radiation throughout most of the spectrum from radio to x-rays.
        - UV rays can damage insulators and other non-treated parts
        - High energy rays can flip bits in digital systems
- Small Impacts
    - Most impacts are catastrophic due to the high speeds involved, but having a smaller circuit (PLC) means there is a smaller target for debris to hit.
- Vibration
    - During launch, parts will be subjected to multiple G's, and need to be able to withstand them long enough to get into orbit

- Analog circuits with discrete components have to worry about the increased weight of larger components- the heavier they are the worse they faire.
- Both need to be able to remain immobile through high Gs during launch, as well as retain connection in microgravity.

Design Simplicity

The use of PLCs is a prime example of the application of maintainability design objectives. PLCs are designed with ease of maintenance and troubleshooting as a major function. When virtually all components are solid state, maintenance is reduced to the replacement of modular, plug-in type components. Fault detection circuits and diagnostic indicators, incorporated into each major component, can tell whether the component is working properly. With the programming tool, any programmed logic can be viewed to see if inputs or outputs are on or off. PLCs provide control capabilities not possible with analog circuits.

Typical PLC architecture is modular and flexible, allowing hardware and software elements to expand as the application requirements change. If an application outgrows the limitations of the PLC, the unit can easily be replaced by a unit with greater memory and input/output capacity. PLC attributes make installation easy and cost effective. Their small size allows a PLC to be located conveniently, often in less than half the space required by an equivalent relay control panel.

Size

An Ace 11 PLC has 12 I/O points and is only 2.5” x 2.5” x 0.5”, but will function and operate similar to a large PLC used in manufacturing processes. Therefore size and weight can be minimized while maintaining functionality. A PLC this size could open and close the boom, monitor sensors or run time for extending the boom, and allow termination of operation.

A relay based circuit can range vastly in size, making it dependent on the number of connections required. To achieve the same functionality of the PLC circuit, a multitude of analog components would be required for each portion of the operation.

Conclusion

Analog circuits are subject to a higher rate of failure. Use of a PLC with solid state technology will reduce failure when compared to an analog circuit. A PLC exceeds our design objectives, allowing us to add additional sensors for feedback. The relay design would need to be designed on an individual basis to meet our operational constraints, whereas the PLC would already have all we need in a compact package. As illustrated above, we feel the complexity of a PLC circuit will be outweighed by its added flexibility and durability. After analyzing the differences between analog based and PLC circuits, our group has decided to move forward with a PLC design.