

Solar Probe Plus

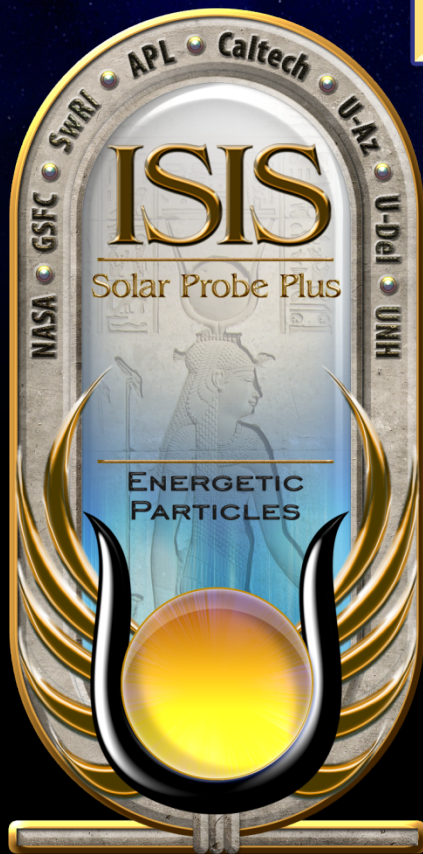
A NASA Mission to Touch the Sun



Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013



EPI-Hi Electronics

Branislav Kecman / Rick Cook



EPI-Hi Electronics

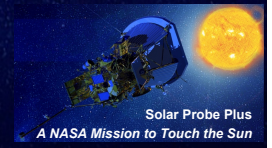


Electronics System Overview

Rick Cook
Electrical Systems Engineer



Key Requirements



- Support 3 independent charged particle telescopes: LET1, LET2 and HET.
- For each telescope provide for detection of coincident signals from various Si detector elements to define “events” caused by the incidence of individual nuclei, electrons and neutral particles/photons.
- For each event, provide pulse height analysis of the signal amplitudes in the various stimulated detector elements. Large dynamic range is needed for measurement of electrons through Zn nuclei.
- Sort and count the events according to particle type and energy.
- Integrate the counts for the various particle/energy categories over time periods ranging from seconds to hours.
- Format the count rate data into packets and transmit them to the S/C.
- Include in data packets the raw pulse height data for a sample of events to aid in-flight calibration.
- Monitor instrument health by measurement of detector leakage currents, instrument temperatures, power supply voltages and total instrument current draw, and include this “housekeeping” data in telemetry packets.
- Respond to commands for altering threshold voltages, bias voltages, etc. and performing instrument self-tests and auxiliary functions.
- Control instrument operational heaters.



Constraints and their Implications



Constraints

- Both power and mass are very tightly constrained
- Design should be single string, yet reliable
- Primary data collection occurs when S/C cannot communicate with Earth
- Radiation environment is more severe than in typical mission

Implications

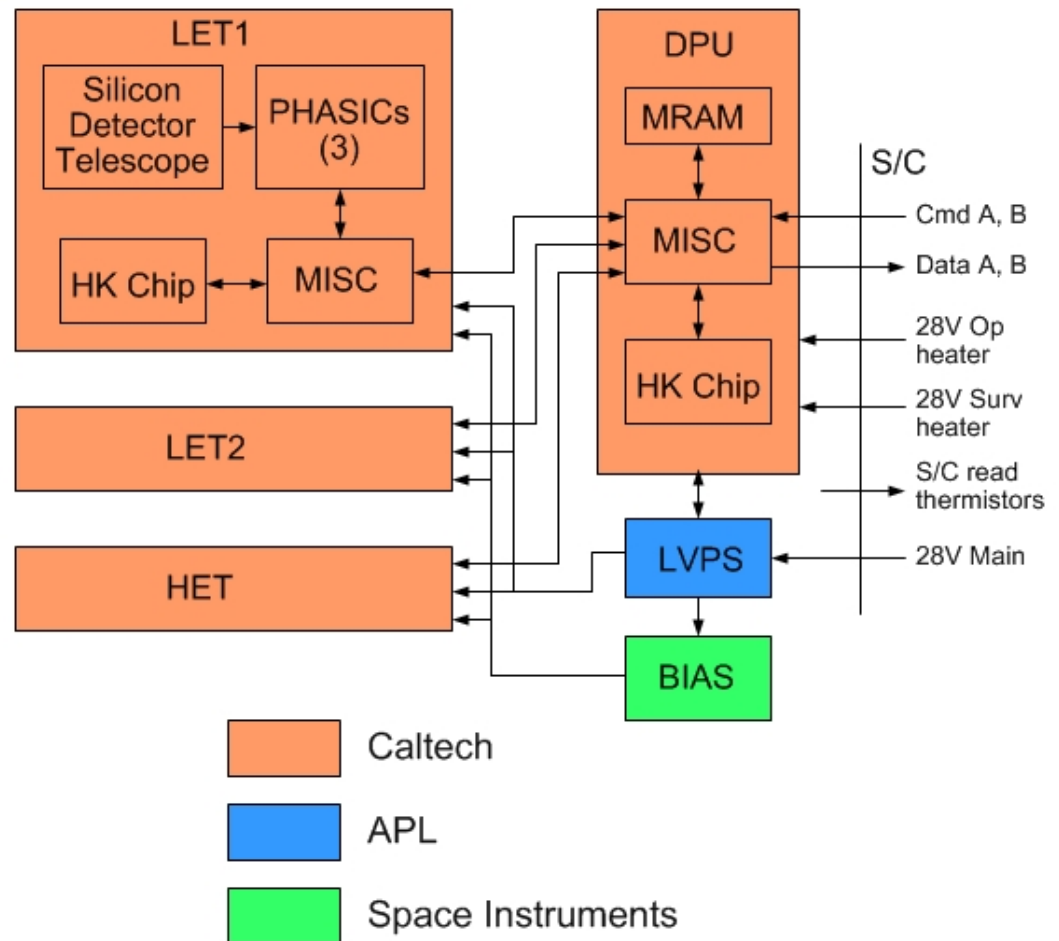
- Reliability through minimization of parts count and use of “natural” redundancy
- Use of custom rad-hard VLSI: PHASIC and HKCHIP
- Design should be “bullet-proof” with regard to radiation affects: no latch-up, no processor crash due to SEU, total dose tolerant > 100 krad
- Design should be capable of autonomous operation during primary data collection period (< 0.25 AU from Sun)



EPI-Hi Block Diagram

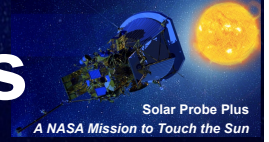


- 6 boards
- All telescope boards same.
- DPU formats data and provides a single point interface with S/C.
- Low Voltage Power Supply (LVPS) and Bias Supply board are shared.
- Bias Supply board contains a separate supply for each telescope “end”, 5 total.
- Logic and MISCs are implemented in RTAX 250 FPGAs, 4 total.
- Heritage from earlier projects: STEREO and NuSTAR.





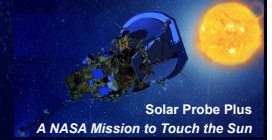
Instrument to S/C Electrical Interfaces



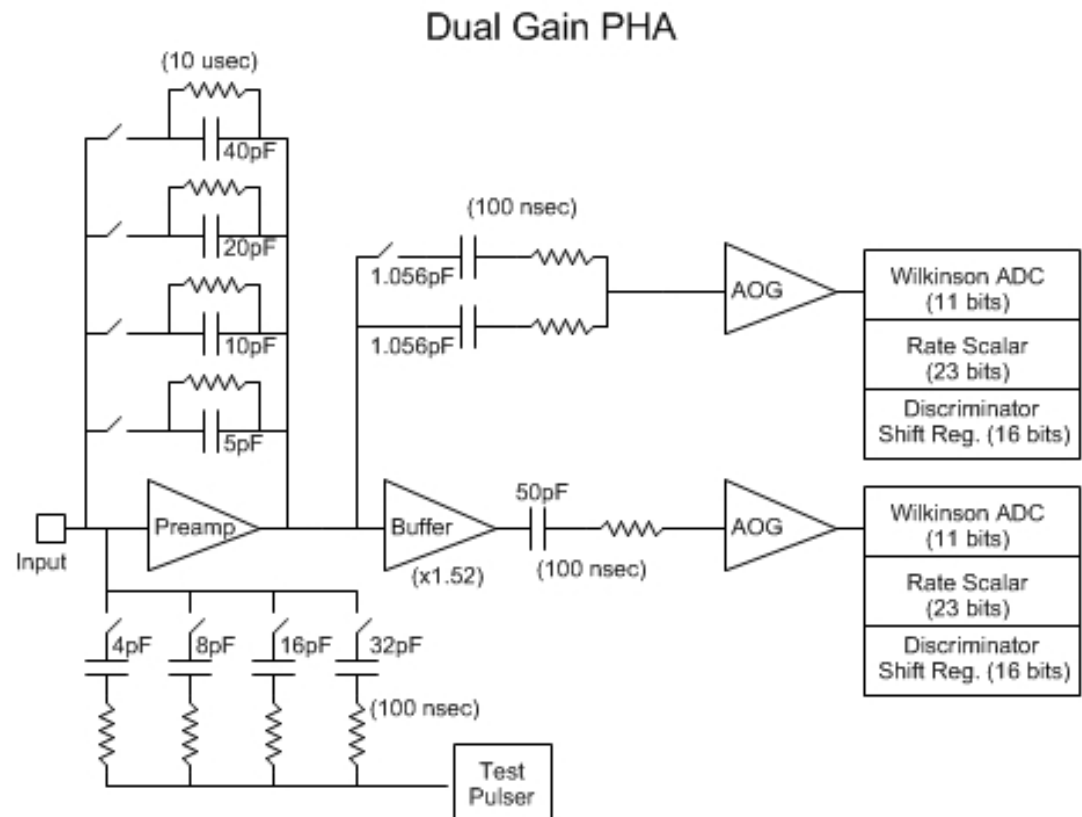
- Interfaces with S/C specified by ICD under APL control.
- Command and data interfaces are 115.2 kbaud LVDS using rad-hard drivers/receivers specified by APL.
- Redundant A and B sides.
- Reset and Timing signals removed from interface by APL for simplicity. Functions included in command signal protocol.
- MISC boot method has been modified to accommodate lack of Reset signal.
- S/C supplies separate 28V power services for survival and operational heaters.
- S/C monitors instrument temp via S/C supplied RTDs.



PHASIC Overview

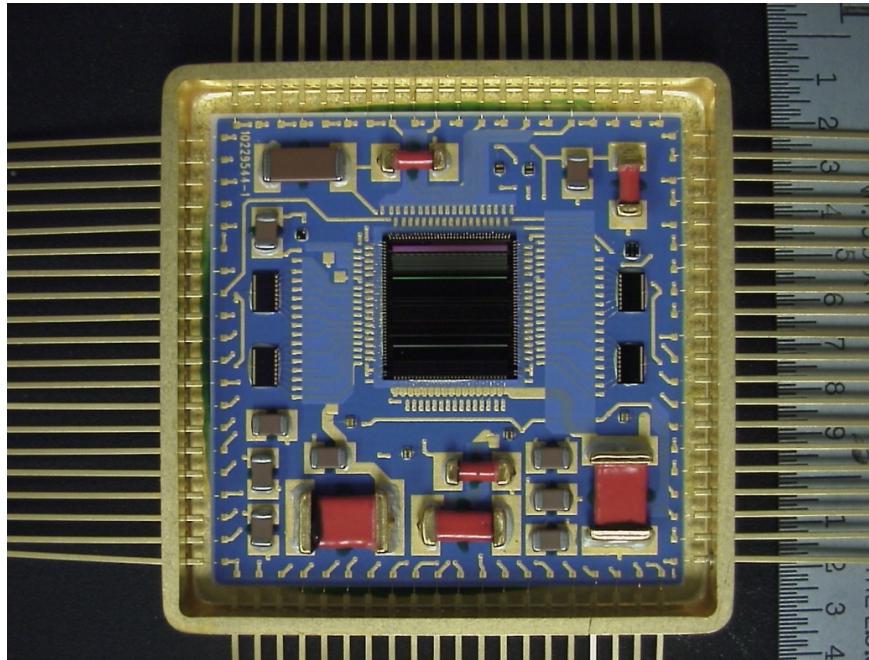


- PHASIC stands for “Pulse Height Analysis System Integrated Circuit”.
- Originally developed and used in NASA’s STEREO mission.
- Each PHASIC contains 16 complete dual-gain pulse height analysis (PHA) chains.
- STEREO PHASICs still operational in space.
- Mods for SPP include widening dynamic range, and improving total dose tolerance to >100 krad.





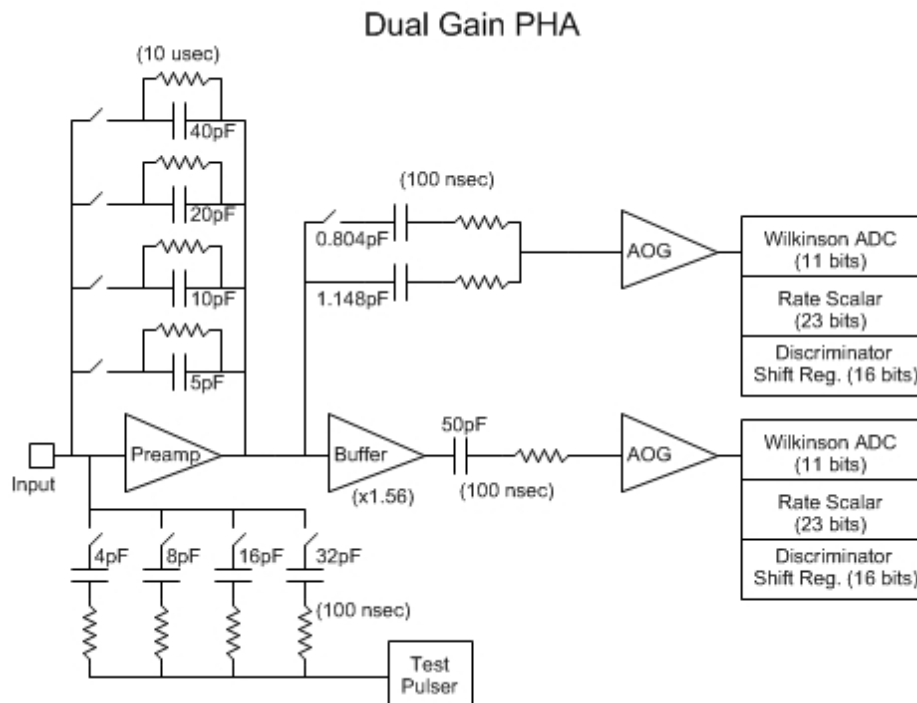
PHASIC Packaging



- PHASIC die is installed in an 80-pin hermetic Kovar package along with a few passive components to form a “hybrid” circuit.
- Hybrid substrate design and passives same as for STEREO.
- PHASIC hybrid to be qualified and screened to class H (as on STEREO).
- Passive components include a precision resistor for each PHA chain that sets the rundown current. Allows PHA channel gain to have low <50 ppm/degC temperature coefficient.



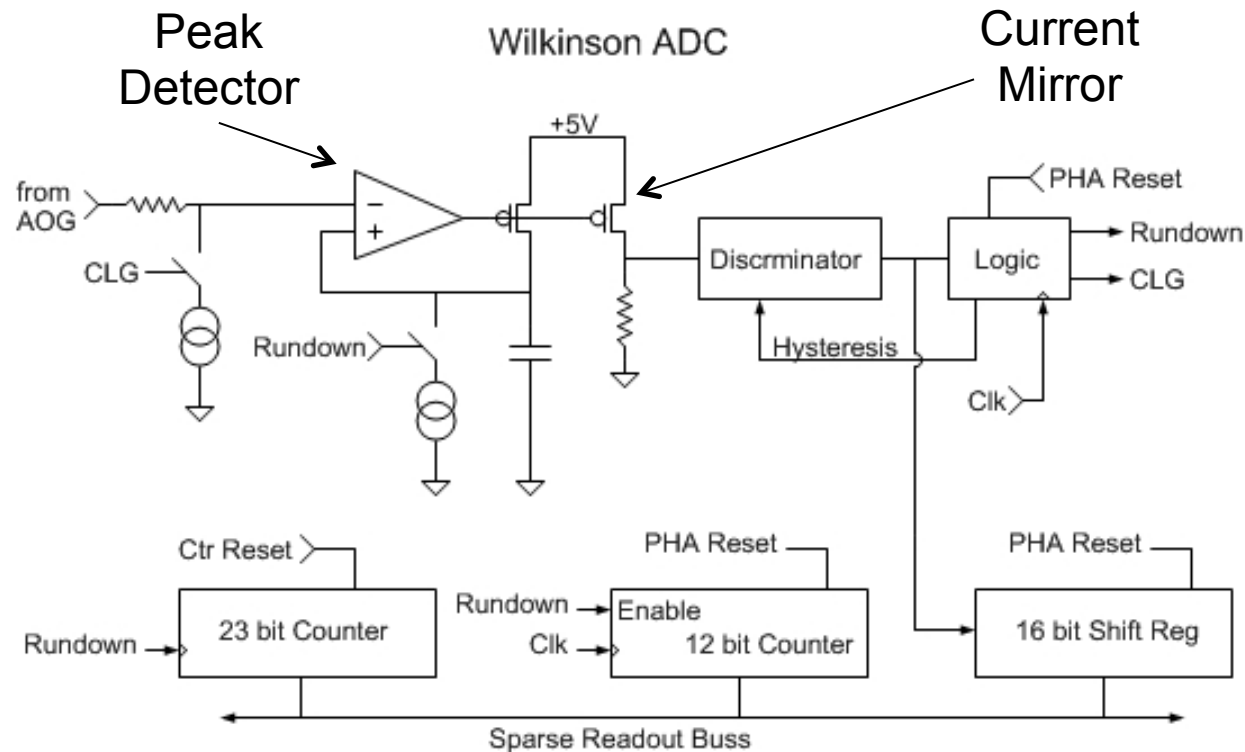
PHASIC Mods near Preamp



- Preamplifier output stage changed from “follower” to “open drain” to increase output swing.
- Preamplifier compensation method changed for lower noise.
- Buffer added in high gain signal chain.
- High/Low gain ratio increased from 20 to 68, with programmable option of 40.
- High/Low gain boundary falls between alphas and carbon for most detectors.



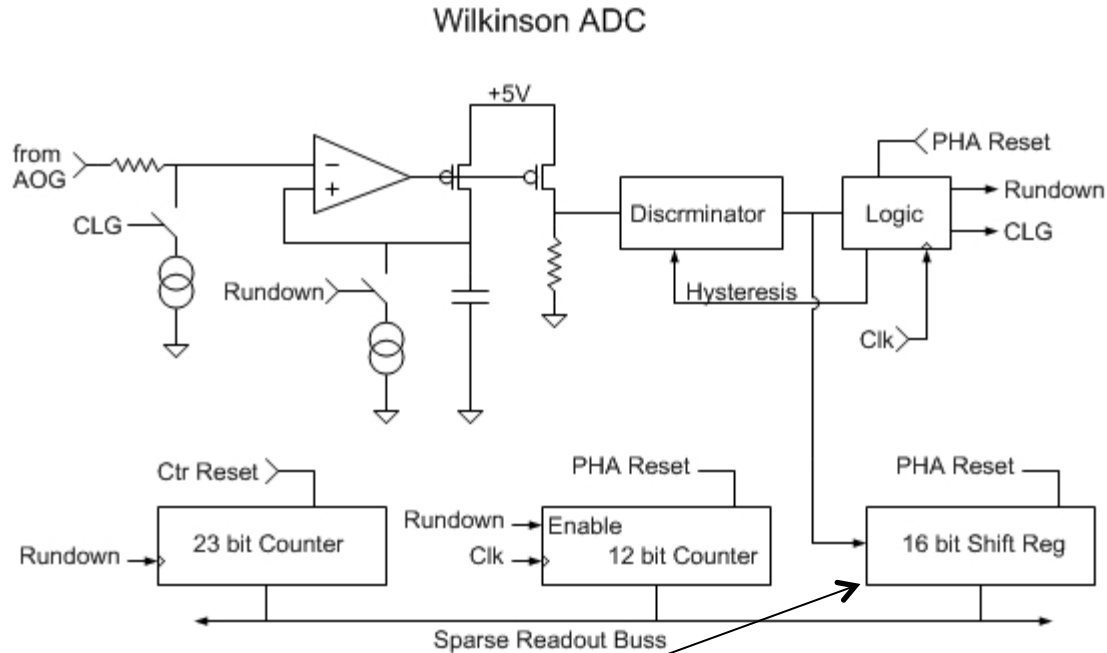
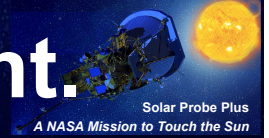
PHASIC Mods near Peak Detector



- STEREO Peak detector contained two differential amplifier stages at input. For Solar Probe Plus reduced to one stage but with higher current resulting in lower noise.
- Size of FETs in current mirror at output increased to improve matching and threshold uniformity.



PHASIC Mods near Peak Detector cont.



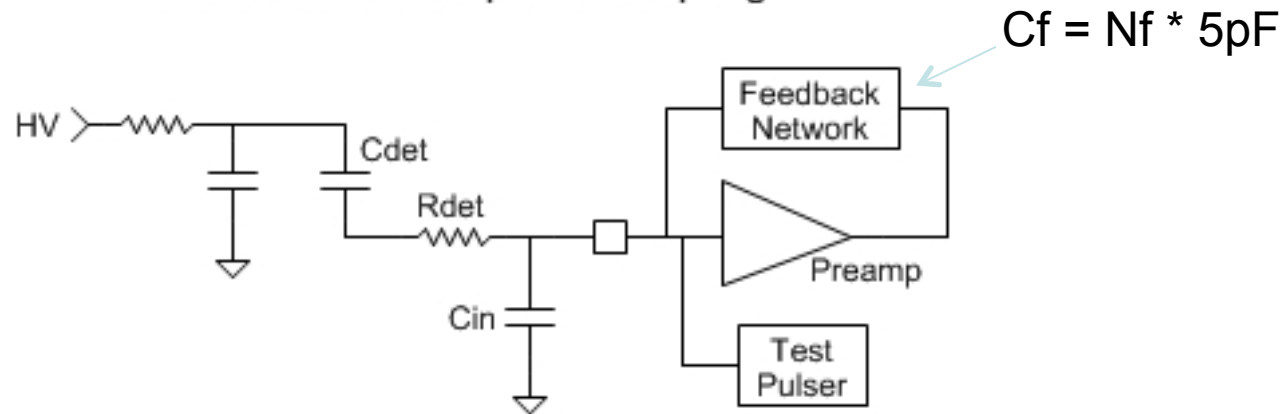
- 16-bit shift register added to capture time history of discriminator output to aid in cross-talk identification.



Predicted PHASIC Noise/Threshold



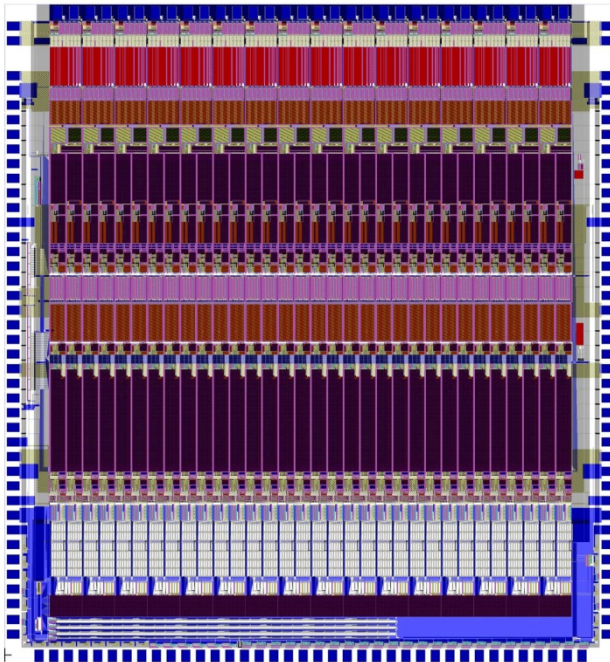
Detector - Preamplifier Coupling



| Det | Cdet (pF) | Rdet (ohm) | Cin (pF) | Nf | Threshold (MeV) | Full Scale (MeV) | Zn @ 45 degrees (MeV) | Gain Crossover Freq (MHz) | Phase Margin (deg) |
|--------|-----------|------------|----------|----|-----------------|------------------|-----------------------|---------------------------|--------------------|
| L0 | 208 | 0 | 30 | 1 | 0.09 | 268 | 83 | 12.3 | 98 |
| L1 | 93 | 30 | 40 | 1 | 0.05 | 268 | 251 | 13.3 | 65 |
| L2(H1) | 20 | 10000 | 60 | 6 | 0.12 | 2802 | 2660 | 13.4 | 60 |
| L3(H2) | 40 | 7500 | 80 | 9 | 0.19 | 4337 | 4092 | 10.8 | 61 |
| H3 | 30 | 15000 | 80 | 13 | 0.28 | 6155 | 6203 | 10.5 | 56 |



PHASIC Radiation Tolerance



- Total dose tolerance improved by adding proven Aeroflex processing steps to commercial ON-Semi C5N CMOS process.
- Layout modified to comply with slight Aeroflex design rule differences.
- 12 krad improves to >100 krad.
- Latch-up threshold should still be $>80 \text{ MeV}/(\text{mg-cm}^2)$ due to use of guard rings.



PHASIC Status



- Engineering run through ON-Semi C5N commercial process was completed, yielding EM wafers and dice.
- EM dice installed in STEREO hybrids and tested.
- Systematic noise was issue in STEREO test fixture due to socket. (For SPP some channels need to operate at higher gain than for STEREO.)
- Completed new test fixture without socket. Residual noise was eliminated, allowing full performance testing to proceed.
- Initial test results indicate noise and dynamic range goals achieved and new 16-bit SR's are functional.
- Linearity and threshold testing in progress (should be done by PDR).
- PHASIC Manual has been updated to account for SPP mods.



What is a MISC?



- MISC stands for “Minimal Instruction Set Computer”.
- Public domain design concept by Charles Moore, inventor of FORTH.
- Our implementation defined in 2002 for STEREO, with Dr. C.H. Ting.
- 24-bit word width; Four 6-bit instructions per word.
- All instructions execute in single clock cycle.
- Dedicated I/O bus and instructions.
- 11 prioritized interrupts.
- Both MISC design and FORTH operating system stable since 2002.
- Compact design fits nicely in RTAX250.
- Data and Return stacks implemented using “block ram” in RTAX250, with EDAC becomes SEU tolerant.
- RTAX250 implementation (flown on NuSTAR) runs @ 15 MHz.
- MISC uses 36% of RTAX250 “R cells” (flip-flops) and 63% of “C cells” (logic gates), leaving 1050 R cells and 900 C cells for application specific logic.
- Estimated app specific logic for telescope board: 500 Rcell, 300 Ccell based on similar STEREO design, i.e. < 50% of available resources.



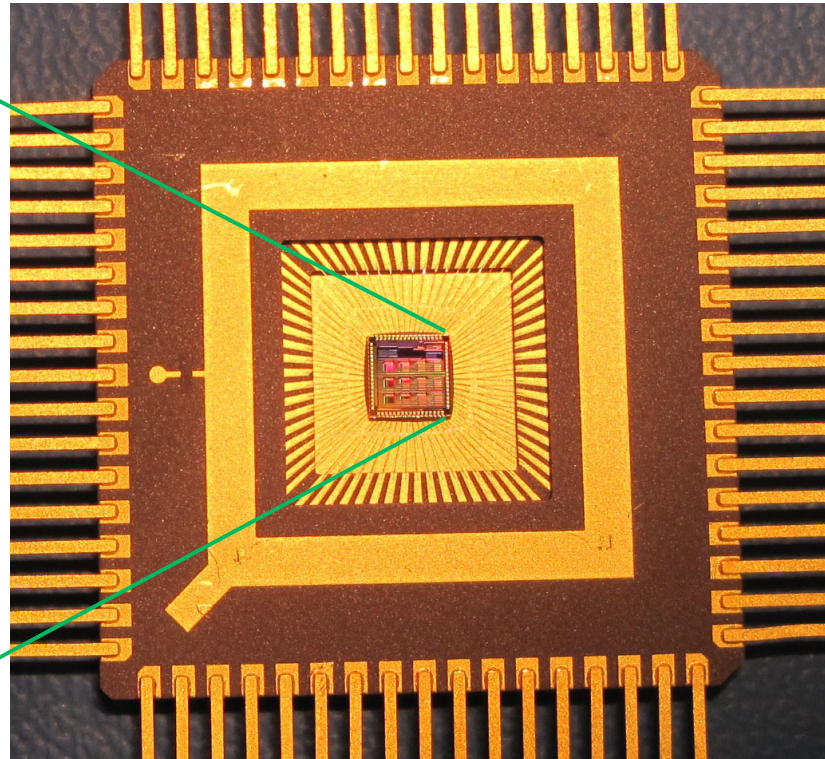
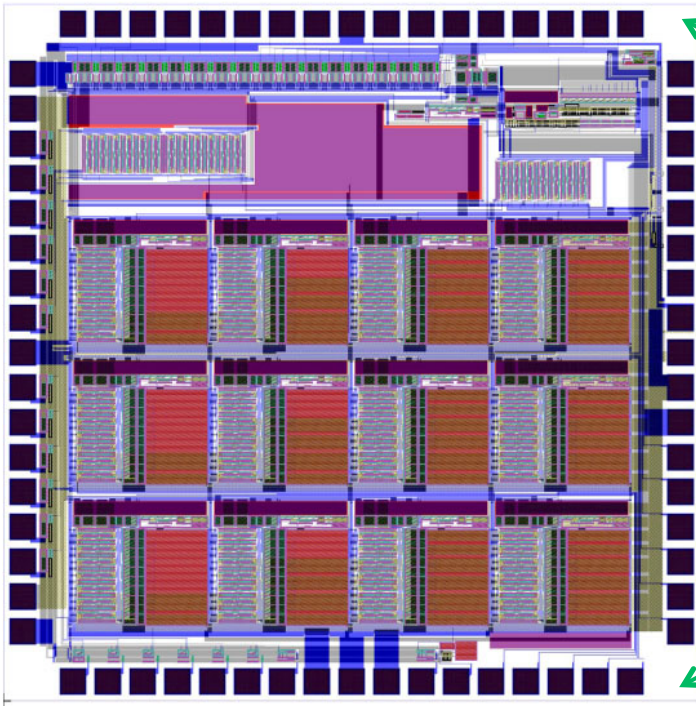
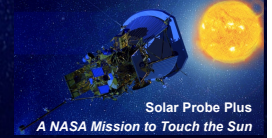
HK Chip



- Housekeeping Chip is a new ASIC design for use in EPI-Hi.
- Includes most auxiliary functions needed for a small instrument in a 68-pin hermetic ceramic package.
- Delta sigma modulator, for making DC voltage (0-5V) measurements to monitor power supply voltages, currents, and instrument temperatures.
- 35-input analog multiplexor.
- 12 10-bit DACs with option of rail to rail buffered output.
- 12 digital outputs designed to drive opto-isolated power switches for heater control.
- DACs may be ganged for greater voltage setting resolution.
- DAC outputs may be internally routed to modulator for precision measurement => low precision DACs can be used to generate high precision voltages and improved in-flight PHASIC calibration.



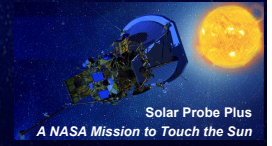
HK Chip Packaging



- HK Chip packaged in hermetic 68-pin ceramic package.
- HK Chip to be qualified and screened to level Q, with PIND test included.



HK Chip Status



- HK Chip was laid out using Aeroflex design rules.
- Fabrication of EM parts was done first with ON-Semi C5N process through MOSIS. The 2nd run was on shared wafers with EM PHASIC fab directly through ON-Semi.
- Test results: DAC linearity limited to 8 bits; Delta sigma modulator can provide up to 18-bit performance. Buffer amps, digital outputs and power on reset circuit all perform properly.
- Design judged adequate for flight re-spin with Aeroflex radiation hardening.
- Flight re-spin will occur simultaneously with PHASIC flight fab on same wafers.