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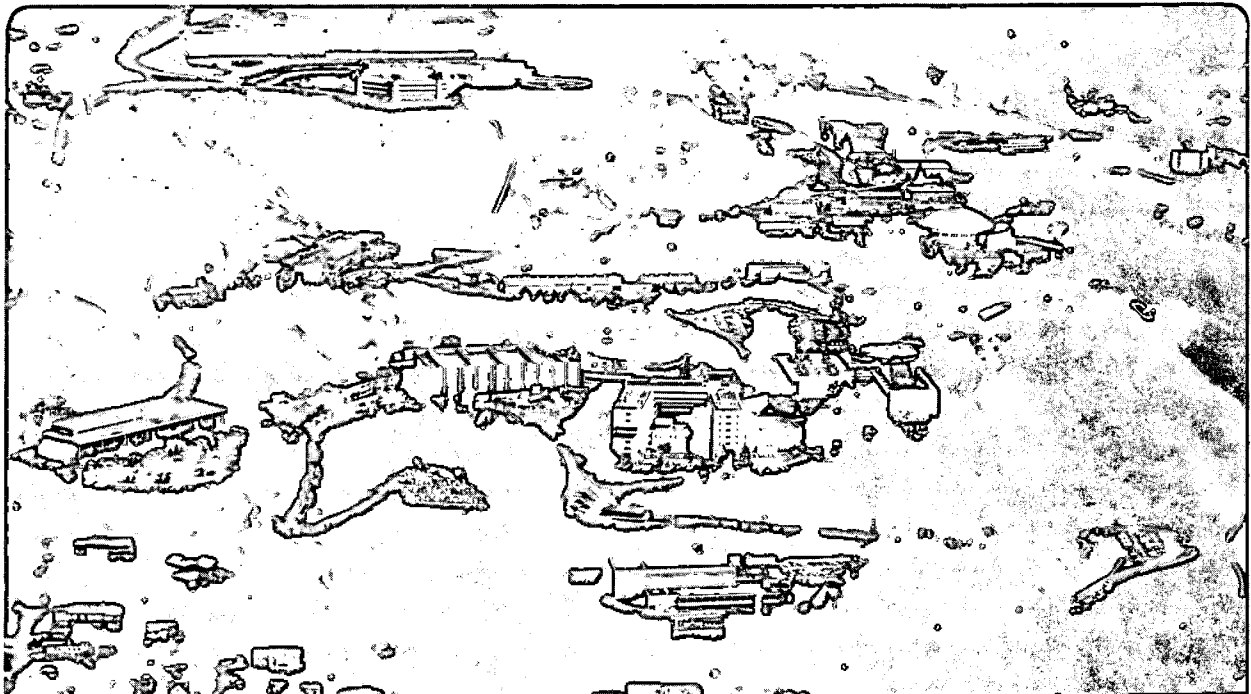### Engineering Division

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N. Madden, D. Landis, R. Adachi, R. Pehl, R. Abott, and E. Stogsdill

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ABSTRACT

Prototypical circuits of a low power gated integrator for use with germanium gamma-ray spectrometers in remote locations have been developed. The gated integrator is constructed from three very simple sub circuits. With a power consumption of <250mW the low count rate spectroscopy performance of this gated integrator is comparable to that of a conventional pulse shaping amplifier at energies of 1 MeV and greater.

INTRODUCTION

NASA's comet rendezvous mission, CRAF, included a proposal for a comet-penetrating geoscience probe. Though the CRAF mission was subsequently scrubbed, we have developed the technology necessary for the germanium gamma-ray spectrometer probe.

The embedded comet penetrator had to detect the characteristic gamma rays of up to twenty elements. The signal from each gamma ray had to be amplified, digitized, histogrammed, and telemetered to the nearby mother space craft and on to Earth. Power consumption was a compelling design criterion because the probe would be powered by six-year old LiSO$_2$ batteries (flight duration from Earth). The constrained volume of the comet penetrator probe also necessitated sparse circuit architecture. The penetrator was not expected to have any significant efficiency for gamma rays below 100 keV because the side wall of the germanium detector's vacuum vessel and of the penetrator itself had to be sufficiently thick to survive impact ($\leq$400G's). Full scale energy was to be 8 MeV. Turn off of the gamma-ray

spectrometer would occur when the germanium gamma-ray detector exceeded 120°K. This was expected to be about 48 hours after impact. At the power levels dictated by this remote measurement site, most of the necessary circuitry, was thought to be in hand, with two exceptions: a pulse shaping amplifier and a 13 bit analog-to-digital-converter (ADC) consistent with the needed dynamic range and resolution. This short paper and a companion paper document that effort.

CIRCUIT DESCRIPTION

Modern pulse shaping amplifiers for use with germanium gamma-ray spectrometers have become very sophisticated. The pseudo-Gaussian type have high order filters, 6th or higher are not uncommon. Gated baseline restorers are common. Some amplifiers have automatic pole/zero cancellation, pile-up reject logic and ballistic deficit correction. Clearly the emulation of such amplifiers was not an option for this project. We squeezed as many functions as necessary into the least amount of circuitry possible to do this specific job without serious compromise in the intrinsic performance of the gamma-ray spectrometer.

Refer to Fig. 1, the block and timing diagram and Fig. 2, the detailed schematic. Three sub circuits: a prefilter pulse shaping amplifier, steering logic, and the switched integrator comprise all of the circuitry for this gated integrator.

The issues of component space flight selection and qualification were not considered in this design. Only power consumption and availability determined component selection.
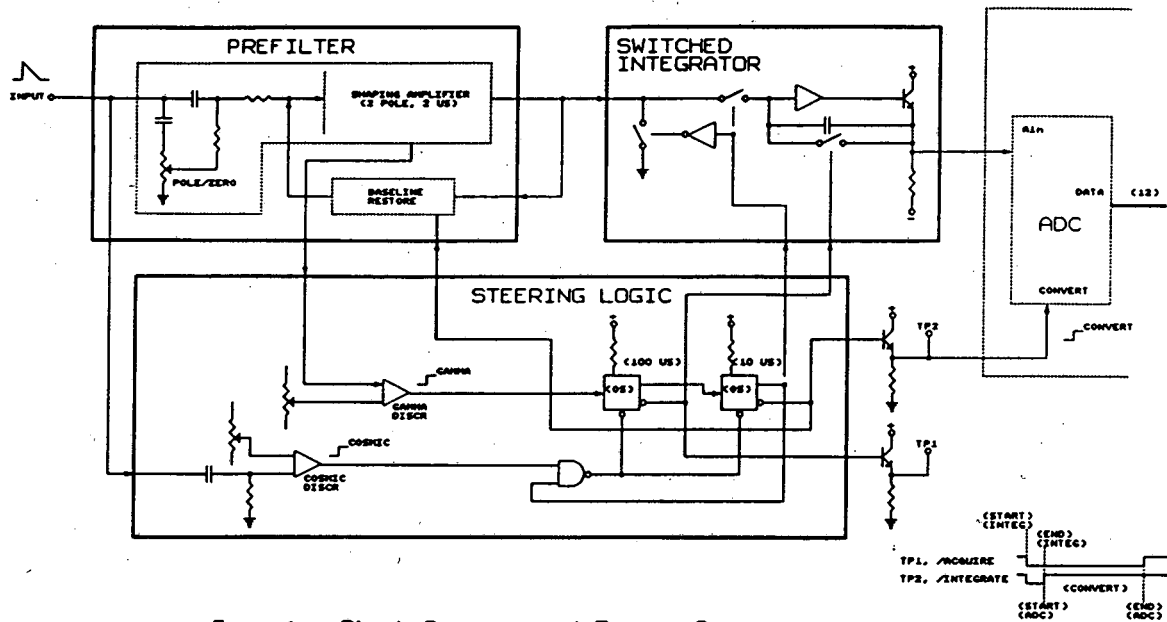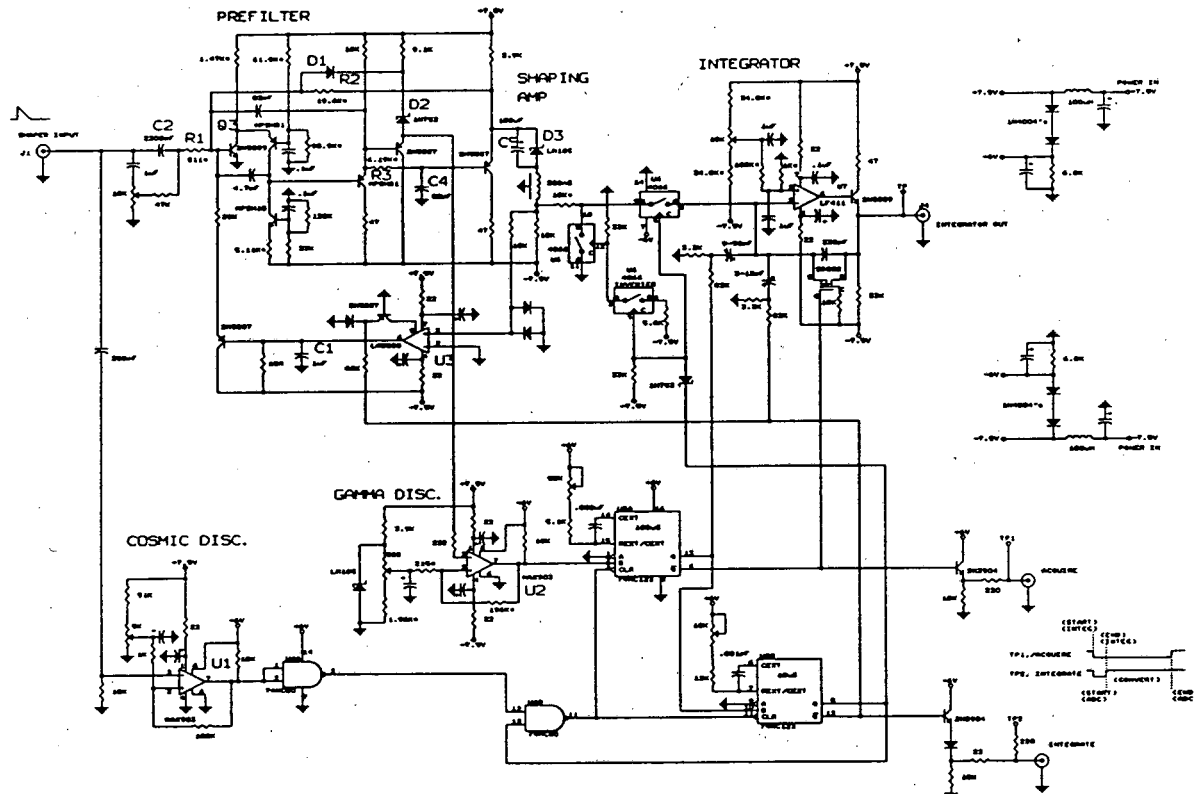
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Fig. 1. Block Diagram and Timing Diagram

Fig. 2. Detailed Schematic of Gated Integrator

The prefilter, a two pole pseudo-Gaussian pulse shaping amplifier, was constructed around a discrete component inverting operational amplifier. The noise contribution of this circuit was kept small by operating the input transistor Q3 at an emitter current of 1.4mA. The dynamic range for a single event was extended an additional 50% by level shifting with D3 a low current low impedance reference diode, and C5, the parallel capacitor placed in the output of the amplifier. Feedback limiting maintains the virtual ground for the duration of very large signals (cosmic-rays) that otherwise would exceed the linear range of the amplifier. This is accomplished with the level shifting zener D2 and signal diode D1. The differentiator (C2 and R1) and the complex pole pair (C3,R2 and C4,R3) determine the pulse shape. The signal out of the pulse-shaping amplifier has a full width at half maximum of 3.3us and a full width at 1% of maximum of 10us for a linear full scale event. Pole/zero cancellation [1] is included around the differentiator to compensate for the undesirable response of the pulse-shaping amplifier to the exponential recovery of the RC feedback in the charge sensitive preamplifier. Short and long term baseline restoration is even more important for the gated integrator prefilter than it would be if the pulse height information of the prefilter were to be digitized. A change of 1mV in the baseline voltage of the prefilter would cause a change in the output amplitude of the gated integrator of nearly 4mV. The transconductance amplifier U3 in conjunction with capacitor C1 and transistor Q1 stabilize the DC operating point of the prefilter. The same steering logic that controls the switched integrator turns off the transconductance amplifier for the duration of the pulse width (12us). C1 remembers the operating point during the 12us that the transconductance amplifier is turned off. A small error current is applied to C1 to prevent system paralysis.

Steering logic is the second major subcircuit of the gated integrator. Only four integrated circuits, two voltage comparators, a quad two input NAND gate and a dual ONE-SHOT, control the switched integrator. One of the voltage comparators, U1, recognizes cosmic rays and commands the switches between the

pseudo-Gaussian prefilter and the switched integrator to close. This function will override the normal processing of an on scale gamma ray. The second voltage comparator, U2, provides the trigger information for processing an on scale event through the switched integrator. Input to U2 is taken from the output of the first integrator in the pulse shaping amplifier. The signal at the output of the first integrator has been amplified, shaped and DC stabilized. The signal to noise ratio at the output of the second integrator is only slightly better than the output of the first integrator. However, the propagation delay between the two integrators and the additional 200ns of the delay line are sufficient to maintain the linearity out of the switched integrator below 100 keV.

The active elements of the switched integrator, the third major sub circuit, are two integrated circuits, a single DMOS field effect transistor, and a bipolar transistor. One of the integrated circuits, U6, is a CMOS quad analog switch. The second integrated circuit, U7, is an operational amplifier with a field effect transistor input stage with low input offset voltage. The DMOS field effect transistor, normally on, holds the switched integrator in the off position. This transistor is switched off only during the integrate and hold sequence of the switched integrator.

The time necessary to collect the charge created by energetic photons depends on their interaction points within the detector and can vary significantly in large diameter coaxial detectors. We expect collection times for most of the events in a detector of 6cm diameter to range from approximately 150ns to 450ns. Low field regions in the detector and/or detector operation at low bias would result in a further spread in the rise time fluctuations. Consequently, the ballistic deficit, which is the loss of pulse height at the output of the pulse shaping amplifier due to rise time fluctuations, can be a major source of spectral broadening. For instance, if a gamma-ray line at 5MeV is measured with a 6cm diameter detector and a 6th order pseudo-Gaussian pulse shaping amplifier operated at a peaking time of 8us, the ballistic deficit causes 2.6keV of spectral

broadening [2]. If the intrinsic resolution for this detector is 3.1keV at 5MeV then the ballistic deficit contribution is obviously significant. Loss of pulse height in pseudo-Gaussian filters, due to ballistic deficit, is accompanied by a delay in the signal peak and an increase in the total baseline-to-baseline time. However, since the switched integrator converts the prefilter's pulse area to pulse height, ballistic deficit is largely overcome. Delta noise, the dominant noise component of the prefilter, is further reduced by the bandwidth reduction associated with the switched integrator [3]. A third benefit of the switched integrator is the inherent stretching of signal peaks that must precede all nuclear spectroscopy quality ADC's.

PERFORMANCE

Two coaxial germanium gamma-ray spectrometers were used in the evaluation of the low power gated integrator. The smaller gamma-ray detector was a conventional electrode 17% efficient detector, manufactured by Tennelec Inc. The second and larger detector, approximately 55% efficient, was fabricated in our facilities from an Ortec crystal into the reverse electrode configuration. The smaller detector's preamplifier had a cryogenically cooled low noise field effect transistor and both a charge sensitive loop and a voltage gain loop. The larger detector's preamplifier had only a charge sensitive loop and its field effect transistor operated at room temperature. The larger detector with its preamplifier was a fair approximation to the detector planned for the comet penetrator mission.

Three pulse shaping amplifiers were used in this evaluation, a commercial four pole pseudo-Gaussian, a commercial six pole pseudo-Gaussian and the low power gated integrator. The voltage gain of the two commercial amplifiers was adjusted to be approximately 4.5 Volts = 3 MeV which is similar to the low power gated integrator. A post amplifier was used to increase the voltage to 8 Volts = 3 Mev in order to be compatible with our multichannel analyzer (MCA). All spectra were acquired with a 12 bit (MCA).The source position was adjusted to attain an input count rate between 700 Hz and 1KHz in all cases. Table #1 shows the measured line widths for energies over the range of 122 keV to 2.61 MeV. A biased amplifier was used for the 2.61 MeV measurements in order to increase the measurement sensitivity with the 12 bit MCA.

Table #1

| N Type Detector | Ortec 572 | | TC 243 | | LPGI |
	3μsτc	6μsτc	8μsτp	16μsτp	
122 keV	1.63 keV	1.63 keV	1.35 keV	1.44 keV	1.78 keV
1.33 MeV	2.42 keV	2.44 keV	2.38 keV	2.48 keV	2.24 keV
2.61 MeV	3.05 keV	3.14 keV	3.21 keV	3.24 keV	3.06 keV

| P Type Detector | Ortec 572 | | TC 243 | | LPGI |
	3μsτc	6μsτc	8μsτp	16μsτp	
122 keV	1.24 keV	735 keV	1.10 keV	0.99 keV	1.60 keV
1.33 MeV	2.18 keV	1.90 keV	2.14 keV	1.87 keV	1.98 keV
2.61 MeV	2.99 keV	2.60 keV	2.81 keV	3.13 keV	2.85 keV

Since long lived gamma-ray emitting sources with energies above 3 MeV are not readily available, full scale for the low power gated integrator was adjusted to be only slightly greater than 3 MeV. No evaluations were carried out at 8 MeV full scale.

The measured power consumption was 225mW. A further slight reduction in power consumption could be achieved by fine tuning of the circuit.

ADC ACCOMMODATIONS

While all the measurements presented here were made with a conventional 12 bit MCA, the 8 MeV dynamic range of the geochemistry probe, would have required at least 13 bits in order to utilize the gamma ray spectrometer's resolution. Our work on an analog to digital converter (ADC), documented in a companion paper, was centered on a commercial 12 bit 50mW ADC.

One additional subcircuit would be required to realize 13 bits of analog to digital conversion with a 12 bit ADC. If the output of the gated integrator were amplified by X2 then the lower half of the gated integrators full scale would equal 12 bits. If the signal were above half scale (recognized with a voltage comparator) and an analog subtraction of half scale were switched on, then the output to the ADC would be a second 12 bits. If an additional recognition bit were concatenated to the second 12 bits, a 13 bit analog-to-digital conversion could be realized with a 12 bit ADC.

ACKNOWLEDGMENTS

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