Multi-Channel Charge Amplifier-Discriminator-Counter IC for the Space Sciences

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***Abstract*– We have developed a multi-channel, mixed-signal integrated circuit (IC) as part of a resource-conserving approach to the design of instruments for missions flown under the Geospace Missions Network (GMN) of NASA's Living With a Star (LWS) program. Specifically, the IC was designed to read out microchannel plates (MCPs) which allow detection of single hot plasma particle by emitting a pulse of charge when struck by the plasma particle. The IC, named AIDA (AmplIfier Discriminator ASIC) includes several Charge-Amplifier Discrminators in one package without sacrificing performance, thus simplifying the MCP electronics and saving on space, power and cost. Reduction of power and mass requirements by several tens of percent relative to existing MCP instrument electronics was the primary goal. A secondary goal was to integrate the pulse counting function into the IC, thereby eliminating the need for additional counters and conserving resources further. We present the features and capabilities of the AIDA IC and evaluation system, and initial characterization data for the chip.**

I. Introduction

HOT plasma, defined as charged particles in the energy range 10 eV – 30 keV, is an extremely important element of the geospace environment. This plasma responds strongly to solar variability and manifests itself in many ways. It forms the parent population for the ring current, a primary indicator of geomagnetic activity and variability. As an important component of the conduit connecting the magnetosphere with the ionosphere, hot plasma includes precipitating charged particles. These particles strongly influence the ionosphere, thereby affecting technology on Earth through currents induced in power grids and communication interruptions. In many regions of geospace, hot plasma is a key player in surface charging of spacecraft, one of the most important causes for anomalies on spacecraft.

The properties of hot plasma have been measured throughout the solar system over the past decades using techniques that have evolved dramatically. Instruments with many features and capabilities are crucial for several NASA missions, but resource-conserving techniques have become increasingly important in many cases. The GMN is no exception to this trend and has encouraged development projects that aim to reduce the resource requirements of key components used in many state-of-the-art plasma analyzers.

Most hot plasma instruments flown in space utilize an "analyzer," which separates particles based on their energies and/or travel directions, and a detector, which records particle arrivals. Analyzers are based on electric and/or magnetic fields. A common technique, an electrostatic analyzer (ESA), utilizes a pair of curved conductors separated by a gap across which a potential is maintained. Only particles within a certain energy passband pass through the gap to be detected by the detector. An energy spectrum is measured by changing the potential across the gap as a function of time and measuring the resulting sequence of particle arrivals.

In conjunction with the analyzer, detectors based on channel electron multipliers, such as microchannel plates (MCPs), are commonly used. MCPs allow the detection of a single hot plasma particle by emitting a pulse of charge when struck by the plasma particle, so the sensitivity is very good. The charge pulses typically contain about 10^6 or more electrons, so they are large enough to be registered by conventional electronics. Several techniques are currently employed for imaging using MCPs. One commonly used for hot plasma measurements collects the charge pulses with a sequence of discrete metal anodes. Each anode is instrumented by its own electronics which are relatively straightforward since the method does not require that the amount of charge be quantified. Rather, the amount of charge need only be compared to a preset threshold to determine whether a "count" was received. High count rates are possible with this technique since standard electronics are capable of 10 MHz count rates and greater. A typical ESA will use 32 such anodes to provide 11-degree angular resolution. 32 charge-amplifier/discriminator circuits are thus required. Simplifying the implementation of the charge-amplifier discriminators would contribute significantly to resource saving when flying on the GMN.

Within this context, we developed a multi-channel, mixed-signal IC called AIDA to read out MCP imaging detectors used for hot plasma measurements.

II. Description of AIDA

The AIDA chip has 16 channels plus two test channels. Each channel accepts a negative-current pulse from the MCP-detector and employs circuits to amplify and shape the signal and deliver a digital pulse to the output. The channel also includes counting circuits and registers to present the

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counter's output to the external system. As necessary, the circuit elements are programmable to allow operation over the entire range of signal characteristics.

Fig. 1 gives a block diagram for the AIDA channel. Shown are a gain and shaping stage which is programmable via a configuration register, a discriminator with programmable threshold, a one-shot to provide consistent digital output regardless of analog settings, a counter, and a register for versatile readout. The preamp is realized as an inverting amplifier with a capacitor in the feedback path which in turn has a resistive feedback element across it to discharge the integrated voltage and provide a DC bias point. The value of the bias / discharge circuit is chosen to give a fast repetitive input rate of up to 16 x 10^6 events per second. The one-shot pulse generator output can be used in applications requiring external counters. Each channel contains its own set of configuration registers to set the characteristics of the channel's components and can be switched off to conserve power if it is not used.

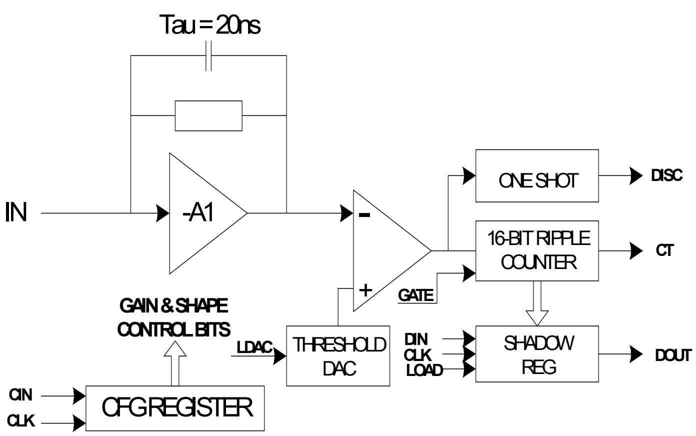

Fig. 1. Block diagram for one AIDA channel.

The key design features of the AIDA chip are summarized in Table I. Signals of interest range from the noise floor to 10Me and in addition it is desired that the chip tolerate and recover from large rogue signals. There are two gain selections. The amplifier is designed for input pulse width between 100ps and 2ns. A maximum achievable repetitive pulse rate of 16MHz is targeted. The threshold is controlled with a 9-bit DAC to cover a 30ke to 5Me range with channel-to-channel variations being within 1% of the signal or 10ke of each other, whichever is greater. The pulse output is desired to be 10 to 40ns in width. The counters are 16 bits deep and the chip design provides both serial and parallel methods for reading the contents of the counters. The power budget goal is 5mW/channel and further power savings are possible through certain adjustments. The chip has these and other selectable features thus making it moderately versatile. Radiation tolerance of about 20krad or greater is desired but without resorting to special foundry processes nor using too highly specialized layout techniques.

TABLE I
KEY DESIGN FEATURES FOR AIDA

- Sixteen signal-processing channels plus two test channels
- Allowable anode capacitance: < 20pF
- Detector leakage (DC current requirement): 1nA, worst case
- Signal size: Noise floor to ~10Me, tolerate up to 30Me (two gain selections)
- Signal pulse width: 100ps to 2ns
- Maximum repetitive pulse rate: 16MHz
- Target threshold range: 30ke to 5Me (9-bit DAC)
- Channel to channel threshold: same within 1% signal or 10ke
- Pulse output requirements: 10ns to 40ns pulse width
- Analog output: Can be enabled for one selectable channel
- Test input: To selectable channels
- Discriminator pulse outputs: May be individually disabled
- 16-bit counters: May be individually disabled
- Serial count data output: With daisy chain
- Parallel microprocessor interface data output: for faster counter readout
- Power budget: 5mW/channel
- Power saving: Ability to disable unused channels
- Power versus noise: Adjustable by use of an analog adjustment
- Temperature Range: -30C to +50C
- Radiation tolerance ~ 20krad (Si) total dose

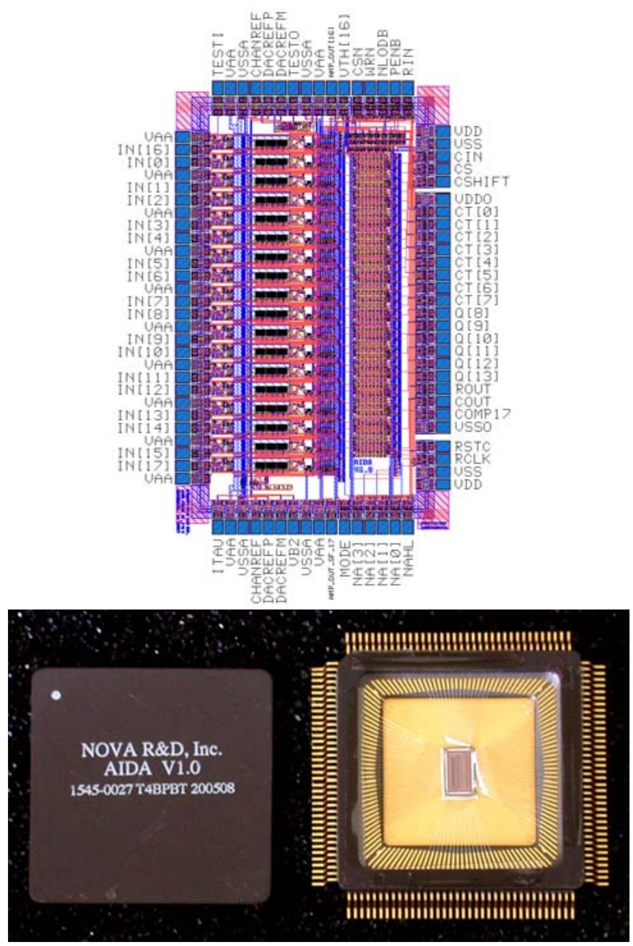

Fig. 2. AIDA layout (top) and photograph of chip in CQFP (bottom).

III. FABRICATED AIDA CHIP AND EVALUATION SYSTEM

The AIDA chip was fabricated in the AMIS 0.5 µm process and is 2180µm by 3585 µm in size. Fig. 2 shows an image of its layout and a photograph of the chip wirebonded inside a commercial 144-pin CQFP package.

An evaluation system was designed to enable characterization of the chip. Fig. 3 displays a photograph of the system hardware designed in a mother-board/daughter-card architecture. The daughter board holds the IC to be tested (assembled in a CQFP package) and circuits that need to be close to the chip to minimize noise. The mother board contains the power supplies, control and support electronics and the fiber-optic data link to a custom PCI card housed in the system PC. Its heart is an FPGA that takes commands from the PC and executes those commands by adjusting values of digital-to-analog (DAC) converters that control bias voltages and currents as well as comparator thresholds, directly interfacing with the AIDA IC, or by sending responses back to the computer. The standard daughter card of Fig. 3 mounts directly to the mother board when using the chip for bench testing with test pulse inputs. Another version of the daughter board is being developed for use with MCP detectors inside a vacuum chamber.

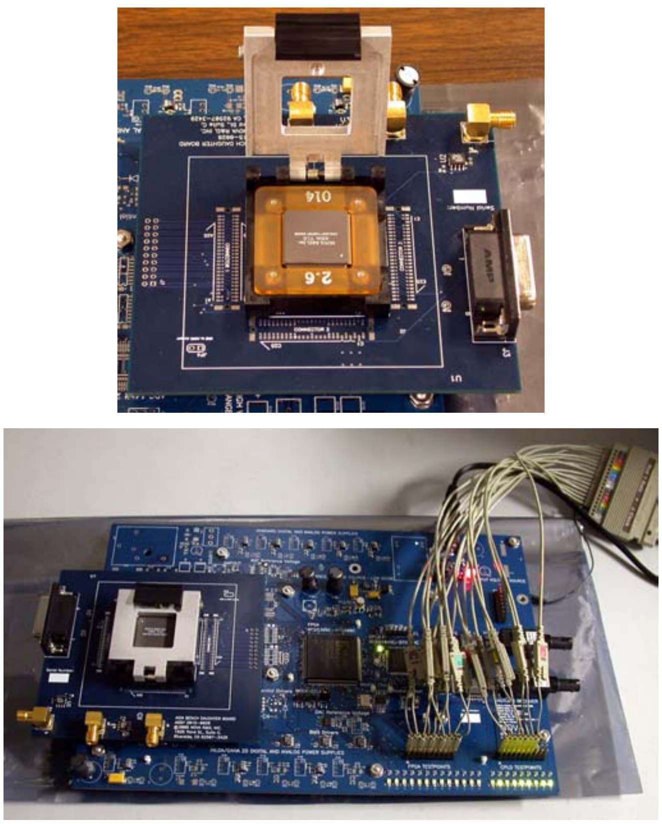

Fig. 3. Photographs of the: AIDA chip sealed in the CQFP packaged positioned in the socket mounted on the standard daughter board (top); and, AIDA evaluation system, powered up (bottom).

IV. Initial Characterization Results

We first investigated the preamplifier performance. Shown in Fig. 4 is the preamplifier output for 1.3Me injected in high gain mode. A 30ns peaking time is observed which compares well with simulation results.

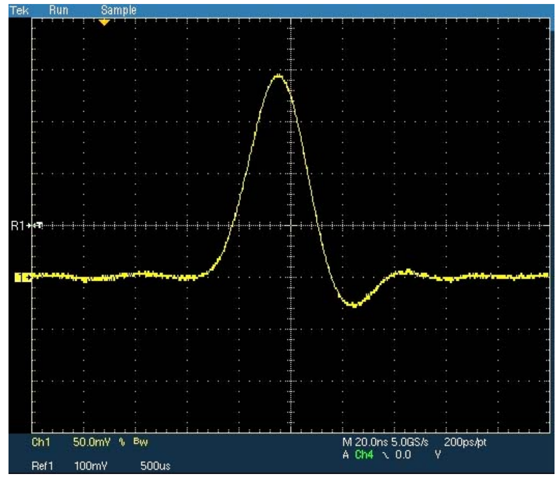

Fig. 4. Oscilloscope trace for typical preamplifier output when 1.3 million electrons are injected into test channel #16 (high gain mode).

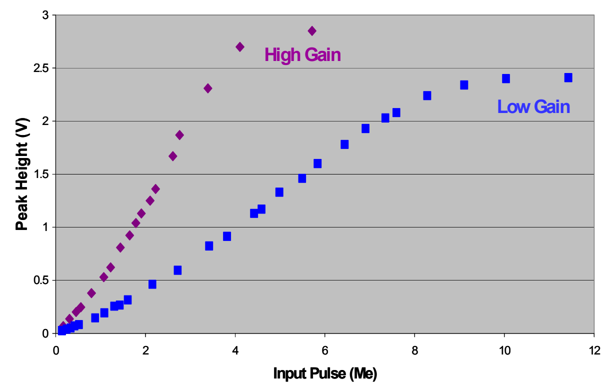

Fig. 5. Preamplifier pulse output height versus input pulse size, obtained using test channel #16 in high and low gain mode.

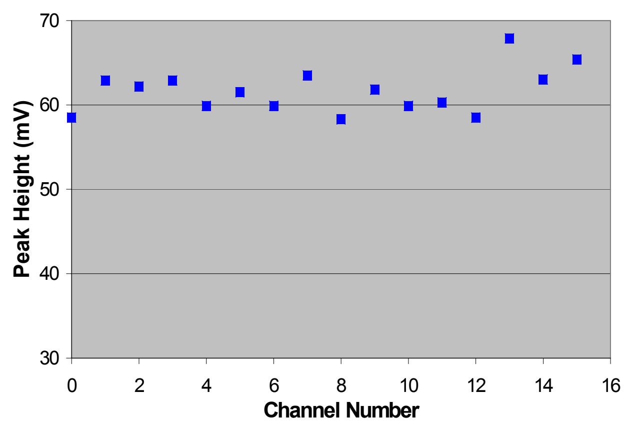

Fig. 6. Preamplifier output on the 16 channels observed with 125ke injected charge (high gain).

The preamplifier pulse output height was measured as a function of the input pulse size. The results are plotted in Fig. 5. Good linearity is observed up to greater >3.1 Me in high gain mode and about 9Me in low gain: this covers the size range for signals of interest in the hot plasma application. Observing the preamplifier output on the 16 channels, we see that it is fairly uniform from channel to channel as displayed in Fig. 6 which gives the sample result for the case of 125ke injected charge.

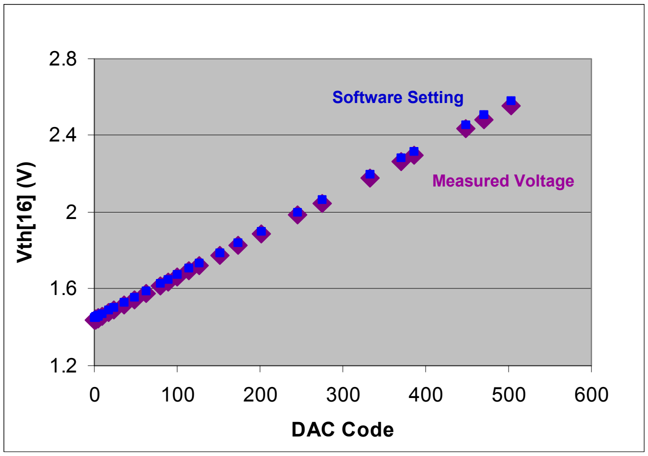

Fig. 7. DAC output monitored by increasing DAC code on test channel #16.

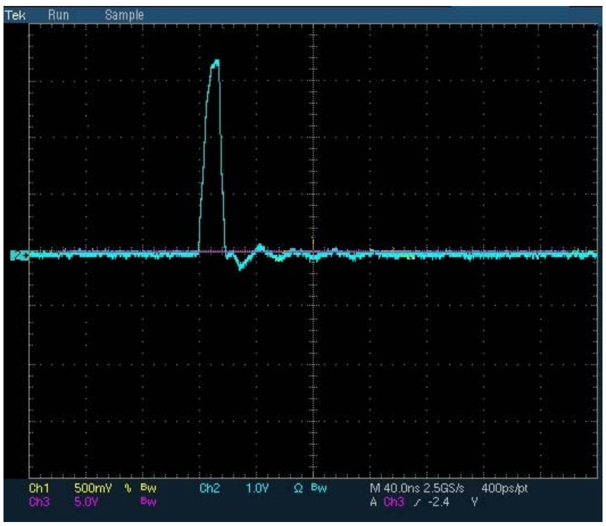

Fig. 8. One shot pulse generator output showing a 3.3V swing.

The direct DAC output was monitored in the test channel and good linearity is observed as shown in Fig. 7. The test system software allows for selection of the DAC voltage. The figure also compares the actual voltage readings and the readings on the dialog box, showing very good agreement. The one-shot pulse generator was examined and the one-shot pulse generator output from one of the channels is displayed in Fig. 8. A 3.3V swing is clearly observed; this can be fed into an off-chip counter.

Studies of entire counter sequences were also undertaken. The chip incorporates serial and parallel methods for reading the contents of the counters and readout sequences for both cases were demonstrated to work properly. The parallel readout mode was provided in AIDA for the case of a microprocessor interface. It has advantages over serial readout in that it shortens the readout time and allows for the collection of counter data from user-selected channels.

Other characterization results may be summarized as follows: the noise is estimated to be of the order of 10ke; the DAC resolution is about 5ke per DAC code; the quiescent power is approximately 2.8mW per channel; and recovery time from a 30Me rogue signal was found to be of the order of 1µsec.

We also started doing counting experiments using signals from a PMT illuminated with a green LED in lieu of the MCP detectors of the target application, which require a vacuum chamber. It is hoped that a broader applicability can be demonstrated for the AIDA chip by continuing these measurements using PMTs.

V. Summary

In summary, the fabricated AIDA is functional and ready for evaluation under MCP application conditions. More detailed chip characterization will be carried out and the work will be extended to multi-channel measurements using MAPMT devices. Studies of AIDA with MCP imaging detectors in a high vacuum environment will be conducted at the Aerospace Corporation. Also planned are temperature and radiation tolerance testing of the chip and the development of new prototype readout electronics based on AIDA for application in future GMN missions.

Acknowledgment

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