A New Fully Integrated Amplifier and Charge-to-Time Converter Module for Ion Beam Characterization

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Abstract. A wide-range self-contained amplifier and charge-to-time converter module for energy detectors was designed, prototyped and built. The charge-to-time conversion is accomplished using a LeCroy MQT300L integrated circuit and a switch is provided to convert either positive or negative charge inputs. This new module replaces the charge preamplifier, shaping amplifier, fast amplifier, CFD, and level discriminator normally found in a traditional NIM-based system and can be placed close to the detector. It is powered from a small, dedicated AC-DC power supply. The module is self-triggering and provides an ECL timing signal from an onboard constant fraction discriminator. The outputs are routed to a standard RJ45 connector and conditioned for long cabling. Details of module linearity and timing resolution will be discussed.

INTRODUCTION

The trace element accelerator mass spectrometer (TEAMS) [1,2] at the Naval Research Laboratory can simultaneously analyze a broad mass range ($M_{\text{max}}/M_{\text{min}} \approx 8$) along the 1.5-m-long focal plane of its magnetic spectograph. To instrument this rather long focal plane, a position and energy sensitive detector system was developed, consisting of 12 identical modules [3]. Each detection module is a combination of a double delay line microchannel plate (MCP) position detector and a separate energy detector. The beam is transmitted through a thin carbon foil (inclined to the beam) on its way to the energy detector. Electrons liberated at the carbon foil are accelerated to the MCP, where their location is recorded. Each MCP has a 100 x 20 mm$^2$ active area and provides two-dimensional position information with better than 600 µm resolution.

Each MCP module produces five outputs per event, so efficient readout electronics were needed to simultaneously monitor all 12 modules. The approach taken converts the three collected charge signals into timing signals, to go along with the other two timing signals produced by the MCP, so they can all be readily handled in high volume. The custom readout electronics that were developed convert charge signals from the MCPs into timing signals compatible with a 500 ps least-significant-bit time-to-digital converter (TDC). This approach works so well that we chose to develop a similar wide-range self-contained charge-to-time converter module for the energy detector suitable for use with standard TDC read-out electronics.

GENERAL CHARACTERISTICS

The charge-to-time conversion function in the energy detector module is accomplished using a LeCroy MQT300L integrated circuit [4]. The MQT300A/L chip was developed for use in the BELLE experiment at the KEK B-Factory [5]. The LeCroy MQT300A is a wide range, high precision, monolithic charge-to-time converter compatible with Multihit Time-to-Digital Converters (TDC). It has a wide dynamic range with three overlapping linear ranges. The outputs of the three ranges in the
converter are encoded into a single time stream so only a single channel of multihit TDC is required.

There are several important characteristics required for use of the MQT chip in this module. Unlike high-energy-physics beam-crossing experiments, there is no master or global trigger when the TEAMS system is used for accelerator mass spectrometry (AMS) measurements. In particular, the $^{14}$C count rate is uncorrelated in time with the $^{12}$C and $^{13}$C matrix beams. Therefore, the amplifier/converter module had to internally generate a trigger and produce all necessary integration gates. To handle occasions when stable isotopes are pulse injected into the accelerator for normalization, the module needed to incorporate an inhibit capability. Since the module must provide high quality timing information, an onboard constant-fraction discriminator (CFD) was included. As an added feature, the MQT300 chip’s fast clear function was incorporated into the module for future coincidence experiments.

Functionally, this single module replaces the charge preamplifier, shaping amplifier, fast amplifier, CFD, and level discriminator normally found in a traditional NIM-based system and can be placed close to the detector. It is powered from a small, dedicated AC-DC power supply. To provide maximum flexibility the module can easily be switched to convert either positive or negative charge inputs by an on board toggle switch.

All timing outputs and logic inputs are provided using ECL signals. These ECL signals are routed through a single standard RJ45 connector mounted on the chassis and conditioned for long cabling. RJ45 cables from up to sixteen modules can be connected to each fan-in box. This fan-in box looks very much like a 100-baseT hub with four male 34-pin connectors for flat ribbon multiwire cable connections to appropriate timing and logic devices. There is one connector dedicated for each of the needs: timing, energy encoding, inhibit, and fast-clear signals. The fan-in box can be located close to the time-stretchers and the TDC, thereby simplifying the wiring.

All signal-input cables (test, bias, and detector) have SMA connectors. The second stage amplification output signal is also on a SMA connector, to allow for signal examination. The module has been successfully tested for detectors requiring up to 700 V bias.

**FUNCTIONAL COMPONENTS**

The module consists of several basic parts, listed chronologically: charge preamplifier and pulse shaper, amplifier, delay line, level discriminator, constant fraction discriminator, gate generator, charge-to-time converter, signal logic, and signal conditioner. Figure 1 shows the functional arrangement of all these components.

![Functional components of the charge-to-time converter](image)

Fig. 1 Functional components of the charge-to-time converter
The gain of the charge preamplifier and its time constant are easily adjustable. Pads were left on the PC-board to allow for these changes. After amplification, the signal is split three ways. Part of the signal goes to a high input impedance follower terminated at 50Ω. This output can be used to monitor the signal on an oscilloscope during setup. Another part of the signal goes to a delay-line to allow time for the gate to be generated before the signal reaches the MQT300A/L. The rest of the signal goes to a level discriminator and a CFD to produce the gate. We use the Analog Devices AD96685BR ultra fast ECL comparator to form the level discriminator and the CFD. The level discriminator is simply an integrator, while the CFD is made from the combination of an integrator and a differentiator. When the signal is above the threshold and inhibit is false, a 1µs gate is produced. A 1µs gate and the MQT300L version of the chip were chosen to allow for compatibility with slower detectors. The L version is linear with gate lengths of up to 1µs as compared to 0.5 µs for the A version.

Charge is collected by the MQT300L while the gate signal is present. When the gate falls, a conversion begins. The MQT300 series chips have three output ranges. When combined, they cover 18 bits of dynamic range, with 12 bits of resolution. The conversion gain is tailored easily by changing the ramp resistor. Currently a full-scale of 5 µs is used. The conversion can be aborted in 500 ns by a fast clear signal. The conversion gain and the stability of the output are strongly dependent on the reference voltages. To help stabilize the output, all of the reference voltage controllers were integrated onto the PC-board. The MQT300 also generates a lot of heat that requires a significant heat sink.

**TESTING AND PERFORMANCE**

This new module for an energy detector replaces our prior approach using a time-over-threshold digitization technique. The major failing of this technique was nonlinearity. In Fig.2, the response of the new module is plotted for the three different output ranges of the MQT300L for input charges from 0.025 to 6 pC. A Berkley Nucleonics Corporation Model PB-4 precision pulse generator was used for these tests.

In Fig.3, the response of the module is shown for 11.4 MeV ^14^C particles passing through a 1.8 µm Mylar foil using a 150-mm² 100-µm thick PIPS Si detector. The solid line with the diamonds is ^14^C measured from a modern standard. The dashed line is the SRIM2002 [6] simulation of the residual energy of the 11.4 MeV ^14^C after passing though the Mylar foil (~9.6 MeV). A dotted line is shown where we would expect a tail from breakup of ^14^NH~+~ injected into the accelerator. The disagreement in the width of the ^14^C
is in part due to nonuniformities in the foil, detector degradation, and SRIM’s underestimation of straggling in the foils. Software gating can reject this $^{14}$N breakup if present.

Figure 3. Measured $^{14}$C spectrum and SRIM2002 simulations.

To quantify the electronics noise, the equivalent noise charge (ENC) was used as given by [7]

$$ENC = e \frac{V_{\text{rms}}}{w} C,$$  

(1)

where $V_{\text{rms}}$ is the average voltage noise level at the output, $C$ is the total input capacitance of the detector and the module, and $w$ is the average energy required to create an electron-hole pair. Equation (1) can be restated in terms of the peak width (FWHM) as

$$ENC = \frac{\text{FWHM}}{2.35w}.$$  

(2)

Using $w = 3.62$ and a step pulse generator set for 5.49 MeV equivalent charge, a FWHM of 34.8 keV has been measured for both the mid and high ranges, giving an ENC of 4.1 keV for the mid and high ranges.

The timing resolution will be proportional to the ratio of the ENC to the rise-time of the charge-sensitive preamplifier. With no external capacitance a step pulse generator was set for 5.49 MeV equivalent charge and delivered simultaneously to two modules. The timing resolution was measured to be better than 1 ns. The timing resolution was tested again using coincidences from the $^3$He(d,p)$^4$He reaction. Measurements were made using both a 450-mm$^3$ 500-µm-thick and a 50-mm$^3$ 150-µm-thick PIPS detector. A timing resolution of 10 ns FWHM was found for this coincidence measurement. With further optimization of the CFD for high capacitance detectors, it is hoped that the timing resolution can be improved.

**CONCLUSIONS**

A new fully integrated amplifier and charge-to-time converter module for ion beam characterization has been built and tested. The module performs well for AMS particle identification, provides a linear response to charge, and has good timing characteristics (<1ns FWHM). It also has moderate energy resolution (34.8 keV FWHM). The three output ranges allow for the same module to be used in a variety of applications from gas ionization detectors to photo multiplier tubes.

**REFERENCES**