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"Research Note"

DESIGN AND CONSTRUCTION OF A HIGH PRECISION TAC[*]

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Abstract – TAC (Time to Amplitude Convertor) is one of the most important time measurement instruments which has great significance in many fields of science, especially radiation physics. A TAC unit has been designed based on the START-STOP analog method and NIM (Nuclear Instrument Modules) standards. After designing the circuit, it was simulated by PSPICE software and constructed by discrete and integrated components. Accuracy of performance, linearity and time resolution of the TAC were checked in laboratory condition and a neutron-gamma discrimination experiment was carried out using this TAC. Results of these experiments and the spectrum of neutron-gamma discrimination completely agree with those from other similar TACs, and are, to some extent, better.

Keywords – Time to Amplitude Converter (TAC), START-STOP method, Integral Non Linearity (INL), time resolution, neutron-gamma discrimination

1. INTRODUCTION

Time measurement has significant importance in many fields of modern science, such as low and high energy nuclear physics, solid state physics, high energy particle physics, neutron physics, chemistry, molecular biology, etc. So considerable effort is dedicated to the manufacturing of advanced timing instruments. The main fields of application of time measurement may be summarized as follows:

- Measurement of time performance in Photo Multiplier Tubes(PMTs) [1],
- Decay time measurement of excited levels [2],
- Time-of-flight measurements [3],
- Auto- and cross-correlation measurements in radiation statistics experiments [4],
- Discrimination of radiation, e.g. neutron-gamma [5-6],
- Measurement of positron lifetime [7].

Many techniques have been developed for time measurement [8-11]. The most commonly used electronic method is based on multichannel time analysis, in which events are automatically classified in a multichannel time-sorter, depending on their delays with respect to starting events [12-14]. These time-sorters may be of the analog or digital type.

There are two basic methods for analog conversion of time to amplitude: 1- START-STOP method, and 2- Time Overlap method. The basis of the START-STOP method is to relate the time interval between two events to the quantity of charge loaded on a capacitor during this period. The arrival of the first signal (START) gates on the capacitor, which charges at a constant rate until the arrival of the STOP signal. The

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total charge collected thus forms an output signal having a height proportional to the time difference between the START and STOP signals. The capacitor is then recharged and the next event awaited.

In the Time Overlap method, the overlap between two wide START and STOP pulses is measured. In this method the capacitor is charged during the overlap period yielding a pulse with a height proportional to $T-\tau$, where τ is the time interval to be measured and T is the full width of the pulse. Knowing the period T, τ can be estimated. This method is, of course, restricted only to periods smaller than the pulse width T. Moreover, without further auxiliary logic, the method does not distinguish between which pulse arrives first.

The basic principle in digital time-sorters is to use the START signal to gate on a scaler which counts a constant frequency oscillator (or clock). At the arrival of a second STOP signal, this scaler is gated off to yield a number proportional to the time interval between the pulses [15] Analog techniques, to this day, lead the field in time measurements up to about 10^{-5}s. However, present-day digital techniques are superior to analog ones for times above 10^{-3}s, due to substantially higher precision, stability and reliability. For intermediate delays between 10^{-5}s and 10^{-3}s both techniques may be used [16].

Accordingly, as we have been focused on accurately measuring the time below hundreds of microseconds, in our designing, analog techniques are superior to digital ones. Among analog methods, the START-STOP method was selected because of its simplicity and intrinsic ability of distinguishing between starting and stopping inputs and measurements of the periods longer than the input pulse width.

2. CIRCUIT DESCRIPTION

A schematic diagram of the TAC is given in Fig. 1 which illustrates the principle of its function.

In this circuit, when no input has been received, all the switches S1, S2 and S3 are closed. As the currents flowing through S1 and S2 are equal, no current flows through the capacitor C and its voltage remains fixed. When the leading edge of the START pulse is received, S1 and S3 are opened and the capacitor begins to be discharged with current –I. Receiving the leading edge of the STOP pulse opens S2, effectively stopping the capacitor from discharging. As the input impedance of the buffer is large, the capacitor charge remains fixed until the trailing edges of the START and STOP pulses are received simultaneously, and by closing the switches, enables the capacitor to be charged, making the system ready to receive some other inputs.

Capacitor voltage is sampled in the output stage and a pulse having an amplitude proportional to the time interval between the START and STOP is made.

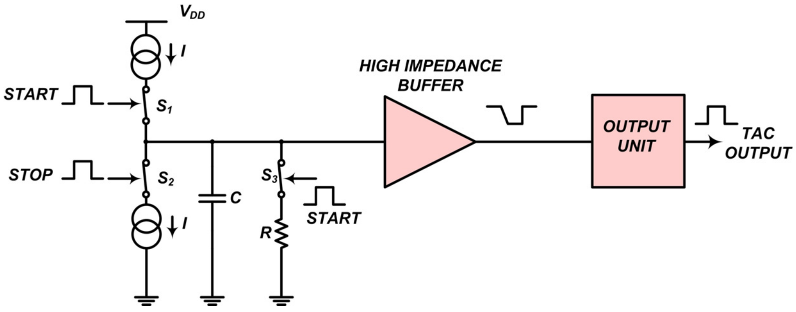

Fig. 1. Schematic diagram of TAC

Fig. 2 represents the overall block diagram of the TAC. Conversion of the time to the amplitude which is simplified in Fig. 1 is operated in the Conversion Circuit. By changing some resistors in the current source by a selector switch on the front panel of the unit, we can change the charging current, and so the conversion range, and select the appropriate range according to the time being measured. In addition, by changing the conversion capacitor using another selector switch, the conversion range can be made tens of times larger. As a result, the conversion range can be extended from 50ns to 2ms. In all conversion ranges, the maximum amplitude of the output for time intervals equal to the corresponding conversion range, in the NIM standard, should be 10V. If it is more or less, we can calibrate and adjust it on 10V by changing a resistor in the current source (in the Conversion Circuit).

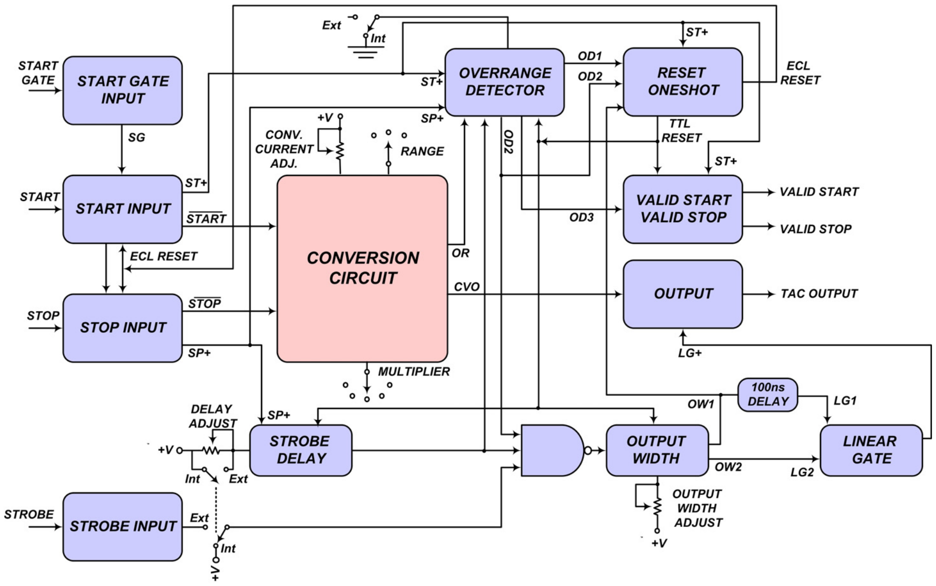

Fig. 2. Block diagram of TAC

Buffer output in Fig. 1, which is named CVO in Fig. 2, passes to the OUTPUT unit to be amplified, inversed in the phase and sampled. Time position and the window's width of sampling, which determine, accordingly, the time position and the width of the TAC output, are defined by LG+ pulse.

LG+ pulse's width, determining the TAC output's width, can vary by a potentiometer in the OUTPUT WIDTH unit. But the time position of this pulse, determining the time position of the TAC output, can be defined in two ways: the first way is External Strobe, in which an external signal is used as the strobe pulse. The time of receiving this pulse determines the time of occurrence for the TAC output. The second way is Internal Strobe. In this way the LG+ pulse's width is defined in the STROBE DELAY unit and varies by a potentiometer in this unit.

After completing the sampling and forming the TAC output, it is necessary for the overall system to get reset and the input units to prepare for receiving the next input pulses. Resetting function is performed by TTL RESET and ECL RESET pulses which are produced in the RESET ONESHOT unit.

After receiving the START pulse, if no STOP pulse is received along the conversion range, the CONVERSION CIRCUIT will produce a pulse on its OR output to inform the OVERRANGE DETECTOR unit about this condition. This unit enables the reset pulses to be produced by sending a pulse to the RESET ONESHOT unit. In this situation, besides resetting the system, producing LG+ pulse and, therefore, sampling and producing the TAC output are avoided.

TAC circuit has two other useful outputs, named VALID START and VALID STOP which are produced in the unit with the same titles. VALID START output is introduced simultaneously with every detectable START input, and is terminated with resetting. VALID STOP output is also introduced with a delay after every detectable STOP input in the conversion range and is terminated with resetting.

The designed circuit of TAC was simulated by PSPICE v.10.0. Waveforms of every part of it were checked and DC, AC, temperature stability, linearity and other analysis were performed on it. Fig. 3 shows the START and STOP input and corresponding output of TAC for different delay times. Fig. 4 also shows some waveforms of the labeled points on Fig. 2.

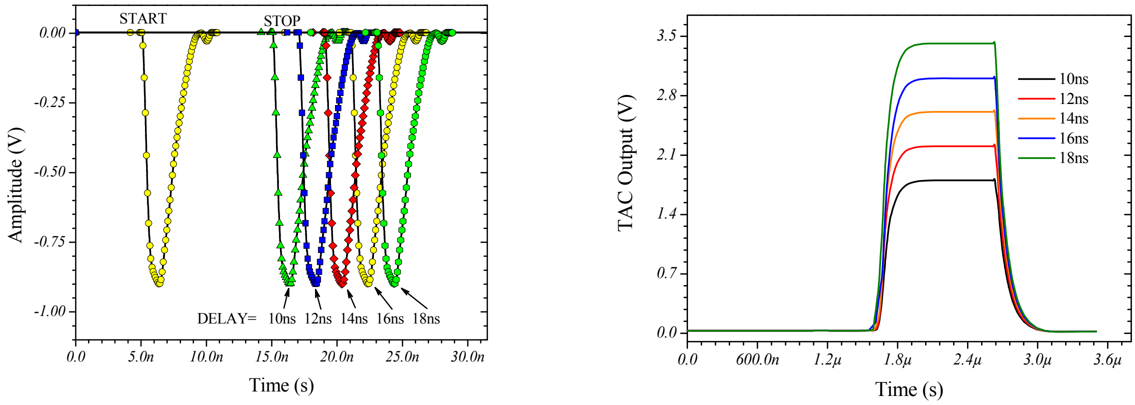

Fig. 3. START and STOP inputs of TAC for different amounts of delay time which is noted on the figure, and simulated TAC outputs corresponding to the START and STOP inputs

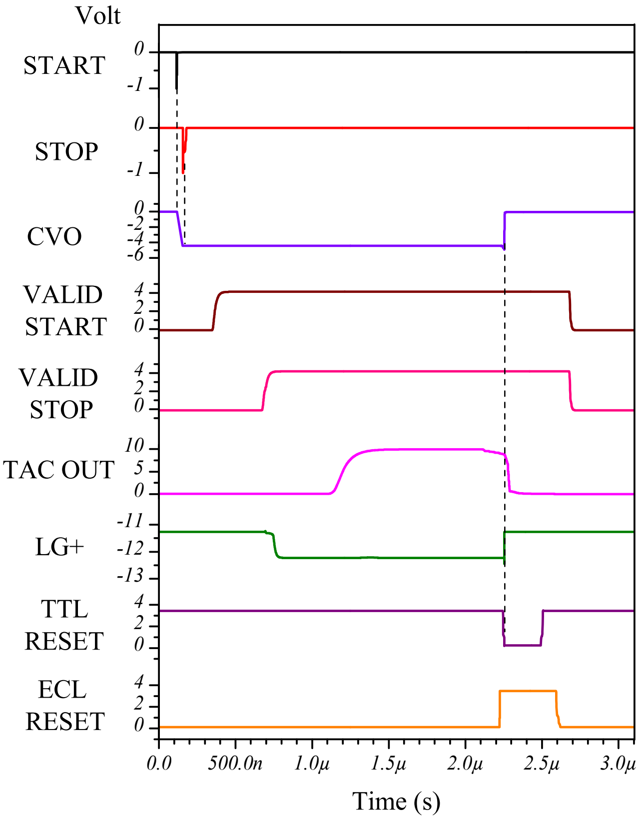

Fig. 4. Some waveforms of labeled points on Fig. 2

Temperature stability of TAC was also investigated by PSPICE simulation for temperatures from 0ºc to 80ºc, when the delay between the START and STOP is 10ns and the conversion range is 50ns. Fig. 5 shows the results of this simulation in which the peak amplitude of the TAC output is depicted versus temperature.

As can be seen, the amplitude of the TAC output decreases with increasing the temperature, but this decrease has numerous fluctuations. Only at temperatures between 20^{oC} and 27^{oC}, the effect of temperature on the output variations is negligible and the TAC output is more stable. Temperature instability of the system gains about 0.005% / ^{oC} of the full scale.

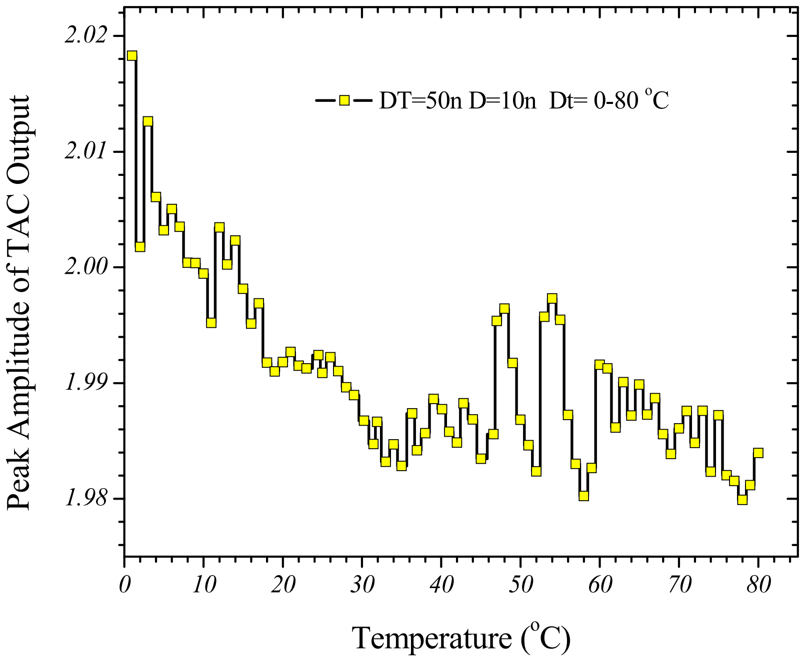

Fig. 5. Peak amplitude of TAC output vs. temperature, simulated by PSPICE

3. RESULTS

One of the most important characteristics of TAC is its linearity over all the conversion ranges. But linearity in the conversion range of 50ns is the most critical. Investigation of TAC linearity was done by a block diagram of electronic units depicted in Fig. 5. Fig. 6 shows the diagram of the channel number of peaks from MCA versus the delay between the START and STOP.

Integral Non Linearity (INL), the difference between the data in the diagram of Fig. 6 and the linear fitting on them, of the TAC is 0.24% of the full scale, while INL for similar TAC manufactured by ORTEC in the same conditions is 0.31% of the full scale.

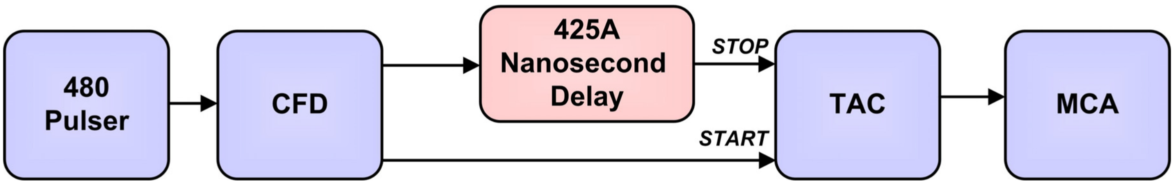

Fig. 6. Block diagram of electronic units used for the investigation of linearity of TAC

Another important characteristic of TAC is its "Time Resolution". Time Resolution means the TAC's ability to distinguish between two time intervals, in which their lengths are very close to each other. One good scale for determining the time resolution of TAC is the FWHM of the time spectra from a radioisotope source emitting coincident radiation. A configuration of units for recording this spectrum is shown in Fig. 7. Fig. 8 shows the time spectrum which is obtained from this configuration and a Gaussian fitting to it. FWHM of the Gaussian fitting is 36.13 channels, so the TAC's resolution (=FWHM / peak position) is 7.48%. The same measurement was done for similar TAC manufactured by ORTEC. FWHM of the similar TAC is 37.9 channels, so its resolution is equal to 7.86%.

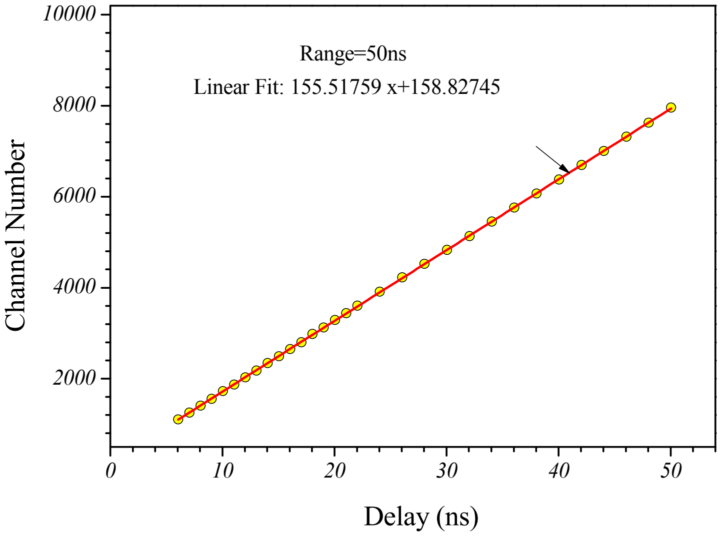

Fig. 7. Diagram of the channel number of peaks from MCA versus the delay between START and STOP

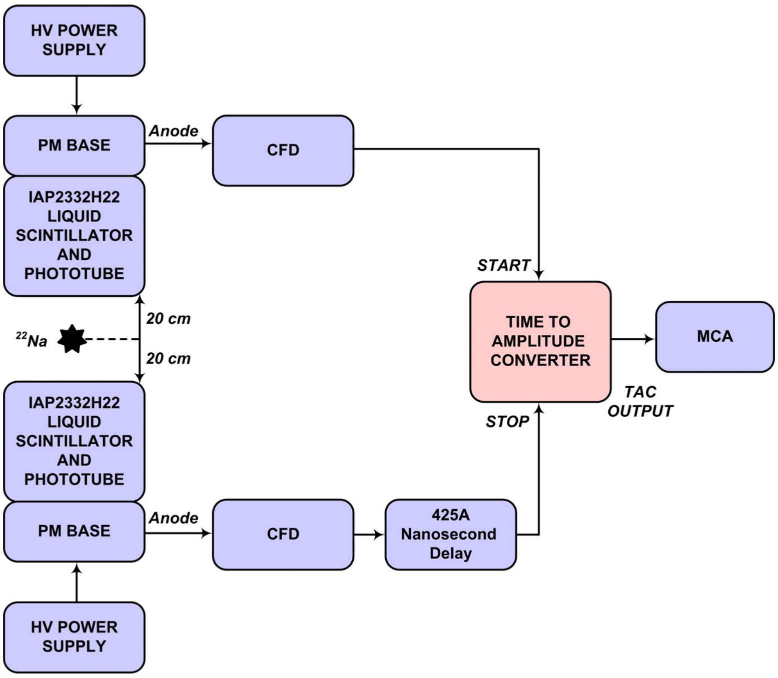

Fig. 8. Configuration of units for recording the coincidence time spectrum

As noted in the introduction section, one of the most important applications of TAC is the discrimination of radiation, e.g. neutron and gamma. As the neutron sources almost always have a gamma-ray background which may produce pulses with the same amplitude that the neutron's has, they interfere with the measurement of the neutron's energy. But as neutron and gamma pulses from liquid scintillators are different in shape and time characteristics [17], we can distinguish between them by time pickoff methods and using a TAC.

To investigate the TAC performance, a neutron-gamma discrimination experiment was performed by the setup depicted in Fig. 9. The results of this experiment are spectrums which are shown in Fig. 10 (a), 10 (b) and 10 (c) for conversion ranges 50ns, 100ns and 200ns, respectively.

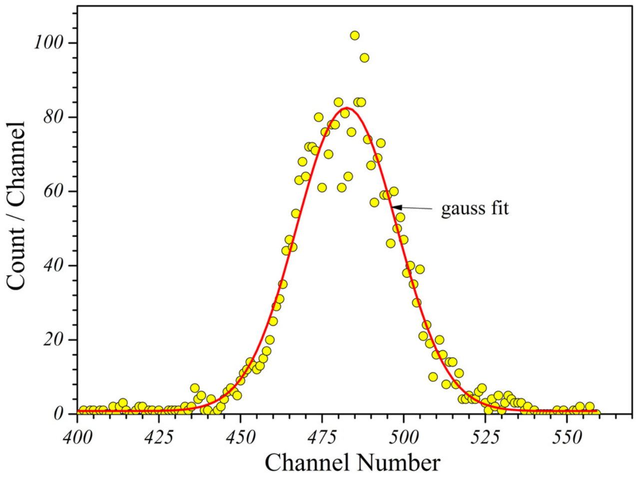

Fig. 9. Coincidence time spectrum of TAC

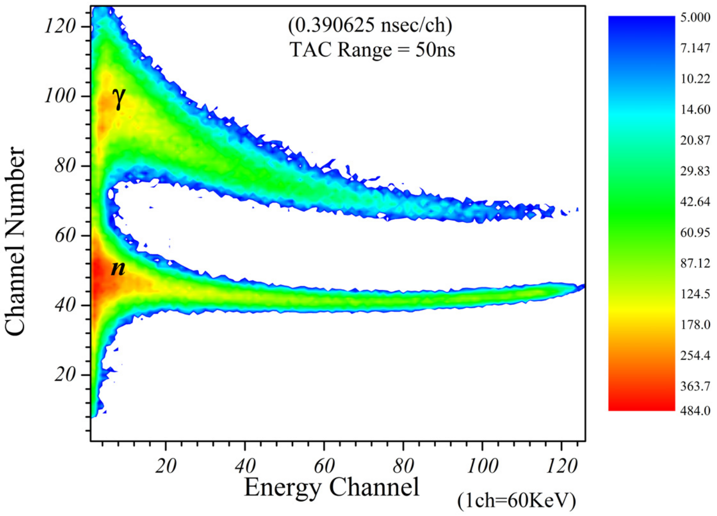

Fig. 10(a). Spectrum of n-γ discrimination for a conversion range of 50ns

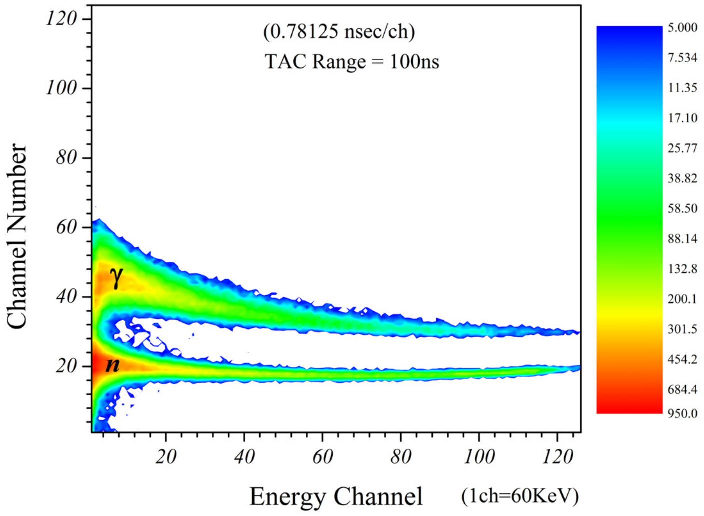

Fig. 10(b). Spectrum of n-γ discrimination for conversion range of 100ns

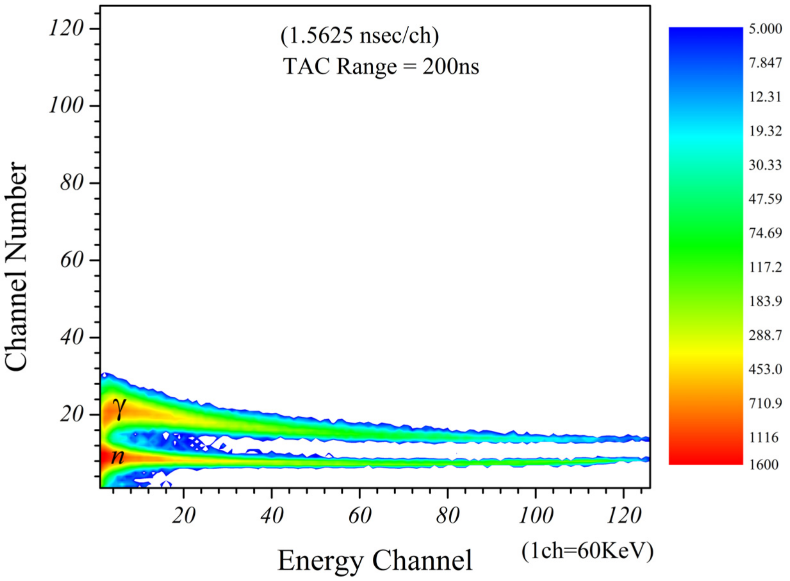

Fig. 10(c). Spectrum of n-γ discrimination for conversion range of 200ns

4. CONCLUSIONS

By using the START-STOP analog method, we designed a high precision TAC and simulated its operation by PSPICE software. Simulation shows an accurate performance and a temperature instability of about 0.005% / ^{oC} of the full scale for a conversion range of 50ns

The TAC's printed circuit board was designed by Altium Designer 6.6 software and constructed in a single width NIM module.

Linearity test of TAC shows an INL equal to 0.24% of the full scale, while the INL of ORTEC's TAC is 0.31% of the full scale, in the same condition. In the coinciding experiment, this TAC shows a resolution (=FWHM / peak position) equal to 7.48%, while the resolution of ORTEC's TAC is 7.86%. As a result, the linearity and time resolution of our TAC is better than those of ORTEC's TAC.

Neutron-gamma discrimination experiment was performed by our TAC. Its resulted spectrums completely agree with those of ORTEC's TAC. This indicates the accurate and precise performance of this TAC.

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