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A NEW APPROACH TO TIMING: THE FAST-FAST SYSTEM*

W. H. Hardy, II and K. G. Lynn

Brookhaven National Laboratory
Upton, New York 11973

MASTER

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W. H. Hardy, II
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K. G. Lynn

Brookhaven National Laboratory
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ABSTRACT

A dual channel constant fraction timing discriminator incorporating multiple energy windows and coincidence logic has been developed. Incorporation of energy discrimination and fast coincidence logic into the timing channel has distinct advantages in terms of system simplicity, stability and data rates. A prototype applying the F^2 approach has been constructed and tested. The system gives a Co^{60} FWHM of ~ 210 psec at a singles rate of $> 7.5 \times 10^5 \text{ sec}^{-1}$ (~ 1200 coincidences/sec).

Introduction

A new approach to fast timing has been developed. The usual fast-slow system (see Ref. 1 for a typical example), which incorporates a fast channel for timing and a slower channel for energy selection and coincidence, has been replaced by a system in which energy selection, coincidence and timing are all done in the fast channel. This provides a much simpler system than the fast-slow approach. The system reported here contains only three modules other than the multi-channel analyzer (MCA), while a standard fast-slow coincidence system might contain 10 or more. In addition to the simplicity of the approach, it allows us to run at much higher rates than previously reported^{2,3}. The basic thrust of the technique is to make energy selection and coincidence decisions before the time-to-amplitude converter (TAC). This means the TAC runs at the coincidence rate rather than at the singles rate, thus avoiding high counting rate problems in the TAC circuit. This makes it possible to run with singles rates in excess of 10^5 sec^{-1} while maintaining a coincidence rate of over 10^3 sec^{-1} . One set of hardware which uses this principle is described below.

Hardware Implementation

A prototype system employing the F^2 approach has been constructed. The system (see Fig. 1) consists of two quad width NIM modules: a multiple window coincidence module (MWCM) and a dual channel constant fraction discriminator (DCCFD). The prototype has been constructed primarily for positron annihilation lifetime studies. Deliberate trade-offs of dynamic range versus speed and resolution have been made in the prototype to optimize for very fast timing.

Multiple Window Coincidence Module

The MWCM (Fig. 2) contains eight discriminators connected to form four windows, two in each channel. Each discriminator consists of one element of a MECL 10115 differential line receiver and a SR flip-flop constructed from two MECL 10102 gates. A window is formed by requiring that the lower threshold fire while the upper threshold does not. Only a single level of amplification has been provided in order to minimize propagation delays. This represents a conscious sacrifice in dynamic range and crispness of the

FAST-FAST (F^2) TIMING SYSTEM

Fig. 1

Functional diagram of the system consisting of source, two scintillators, two photomultiplier tubes, the MWCM, the DCCFD, TAC, MCA and PDP11.

threshold levels; however, for the particular application these were acceptable tradeoffs. Since the anode of the photomultiplier tube is terminated to -0.800 volts in the DCCFD module no level shifters are required. The outputs of the discriminator flip-flops are combined (LOWER-UPPER) to give a window valid signal, e.g., W1A. The coincidence logic then allows selection of events of several types 1A-1B, 1A-2B and 1B-2A. The 1A-1B coincidences are provided on the MARK output. In the positron annihilation experiment these correspond

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MULTIPLE WINDOW COINCIDENCE MODULE

* TO ANALOG LEVEL ADJUST CIRCUITRY

Fig. 2

Circuit diagram of Multiple Window Coincidence Module. Power regulator, precision voltage reference, and the window level adjust circuits are now shown. Termination and pull down resistors have been left out of the figure except where they serve special functions as well.

to a (.511 MeV) • (.511 MeV) event which occurs at $t = 0$. This signal can be used with a digital stabilizer, which is incorporated in the MCA. Whether the 1A-1B event also comes through the event output is controlled by a jumper. All discriminator latches are reset by a signal from the DCCFD module. Propagation delay is approximately 16 nsec through the module except for signals very near threshold which take longer to set the discriminator latch. The DC reference levels for the eight discriminators are provided by an analog network consisting of a precision voltage source, ten turn potentiometers and buffer amplifiers.

Dual Channel Constant Fraction Discriminator

Each channel of the DCCFD contains a leading edge priming discriminator consisting of a MECL 10216 triple differential amplifier (see Fig. 3) and a constant fraction discriminator^{4,5,6} consisting of two stages of MECL 10216⁷. A fraction of 0.2 was chosen on the basis of the work of Gedcke and McDonald⁴. We have not yet made any studies to determine if this is the optimum value for our circuit. The delay in the CFD was initially chosen to be equal to the rise time of the photomultiplier (PMT) output pulse from 20 percent to maximum.

Since the risetime is difficult to measure accurately, some additional adjustment is often necessary for optimum results. RG/8 cable with GRC connectors has been used for the long delay between the MWCM and the DCCFD in order to reduce pulse attenuation. The walk adjustment circuit for the CFD represents a significant improvement over that used by Hall⁵ and others since interaction with the threshold adjustment is eliminated.

The timing of the arrival of the priming pulse and the CFD pulse at the coincidence gate is critical. If the priming pulse arrives too early, a false trigger may be generated. If it arrives too late, the event will be leading edge rather than constant fraction timed, leading to anomalous results. Even if the basic timing between the leading edge and CFD is correct, events of the second type will occur for signals near the leading edge threshold. These events will be eliminated if the windows of the MWCM are set above the threshold level as is the usual case. A reset signal to the MWCM is generated if either threshold discriminator fires. The signals from the photomultiplier tubes are terminated in the DCCFD to -0.800 volts. This eliminates the need for level shifters to MECL

DUAL CONSTANT FRACTION DISCRIMINATOR

Fig. 3

Circuit diagram of Dual Channel Constant Fraction Discriminator. Power regulator, precision voltage reference, and the threshold level adjust circuits are not shown. Termination and pull down resistors have been left out of the figure except where they serve special functions as well.

levels, which can be a major source of temperature dependence. The PMT signal cables are not reverse terminated at the tube base. Standard techniques for using MECL 10,000⁸ logic have been followed in both modules.

The DCCFD module has provision for thermoelectric temperature stabilization of the circuit; however, this feature was not used for any of the results to be presented. Temperature stabilization is useful if ambient temperature conditions fluctuate greatly or if very long data runs are needed. In the data to be presented ambient temperature remained within 4°C of its mean during all runs and no run lasted more than 8 hours.

Test and Evaluation

Evaluation of the prototype system was done using the setup in Fig. 1. Pilot-U scintillators 16mm in diameter by 16mm deep were used in conjunction with RCA 8575 photomultiplier tubes⁹ to detect the start and stop photons. The scintillators were sprayed with Eastman Kodak Reflective coating. Surprisingly the KL236 scintillators seem to give better results than the Pilot-U. An investigation of the dependence of the time resolution on scintillator type, size and shape is currently underway. The bases employed were similar to those used by T. M. Hall². The PMT output pulses

were coupled into the MMCM through a GRC tee which causes a slight discontinuity in the transmission line. A delay of 22 nsec is introduced between the MMCM input and the input to the DCCFD. This is necessary in order to ensure that the EVENT gate from the MMCM arrives before the timing pulse reaches the coincidence gate.

After the timing information is extracted by our discriminators and one side is delayed by approximately 30 nsec, the time difference is measured by a time-to-amplitude converter. The energy discrimination feature performed by the MMCM was found to virtually eliminate the usual rate dependence problems of the TAC, since the TAC is no longer triggered at the singles rate. This allows a set of data to be accumulated in less than an hour when running at coincidence rates of 100 - 1400 sec⁻¹ which correspond to singles rates into the constant fraction discriminator of approximately 10⁵ to 10⁶ sec⁻¹ respectively.

For the purpose of defining a resolving time for the system a Co⁶⁰ source which emits a 1.17 MeV and a 1.33 MeV gamma ray with less than 10⁻¹² sec time difference can be used. A lifetime measurement of this source is essentially a zero time difference measurement. Co⁶⁰ sources of approximately 17 μCi and 90 μCi have been used in the measurements in order to get a

range of count rates and to examine the peak to background ratios. Four data runs using Pilot-U scintillators are shown in Fig. 4. Run 1 was made with narrow windows at a low count rate for our system (20 sec⁻¹). The full width at half maximum (FWHM) for this narrow dynamic range was 182 psec. Data on full width at 1/10 maximum (FWLM), full width at 1/100 maximum (FWOLM) and peak symmetry is given in Table 1. The other curves of Fig. 4 show results for a variety of dynamic ranges and coincidence rates. The data show no clear count rate dependence and very little dynamic range dependence. The asymmetry appears to be due to slight misadjustments in walk or CFD delay, since further adjustment gives results with essentially no asymmetry, i.e., run 3.

The Co⁶⁰ data demonstrate several important characteristics of the fast-fast approach. Very little degradation in resolution is experienced as the dynamic range is increased. Figure 5 shows the dependence of resolution on dynamic range. This ability to give excellent time resolution at very high count rates is one of the unique characteristics of the fast-fast approach. Also, the resolution of the system is virtually immune to high count rate effects usually encountered when the singles rate exceeds the coincidence rate by several orders of magnitude. The system does not experience any rate dependent effects until the singles rate exceeds 10⁷ sec⁻¹ or until the coincidence rate begins to exceed the TAC's capabilities.

Conclusions

The fast-fast system allows experiments to be run at previously unattainable data rates while achieving state-of-the-art or better time resolution. This is accomplished by using fast energy discriminators and demanding coincidence before the TAC. This alleviates count rate effects that can occur in the TAC and also decreases the possibility of drift problems by reducing run times. Another major advantage of this apparatus is that experiments which have been avoided owing to the length and number of measurements that were needed may now be realized. The only real problem encountered with this design is that there seems to be a small amount of structure in the background. This structure obeys the same peak to background relationship as the random background and has an amplitude of less than 10 percent of the background. At the present time this is thought to be caused by cross talk in the circuit due to both channels being physically on the same printed circuit board. The system has run at event rates in excess of 1200 per second which is a factor of 100 greater than those reported by Hall² and a factor of 400 greater than those reported by Weisberg³. An additional advantage of the fast-fast approach is its simplicity. The current system contains only four modules; MACH, DCCFD, TAC and MCA. This represents a considerable savings over more conventional approaches.

The fast-fast approach represents a substantial improvement over standard fast-slow coincidence systems in applications where the singles rates are very large compared to the coincidence rates.

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Fig. 4

Timing data for Co⁶⁰. Complete data on each run is presented in Table 1.

Fig. 5

Dependence of resolution in psec on dynamic range. Co⁶⁰ source with 16mm x 16mm Pilot U scintillators and RCA 8575 photomultiplier tubes

Table 1

Run No.	Dynamic Range	Source	Prompt Rate CPS	FWHM	FW,1M	FW,01M	Scintillator size		Slope	
							Type	mm x mm	τ^- psec	τ^+
1	15%	Co ⁶⁰	20	182	356	560	Pilot-U	16 x 16	47	43
2	12:1	Co ⁶⁰	60	210	405	663	Pilot-U	16 x 16	56	52
3	12:1	Co ⁶⁰	700	202	404	657	Pilot-U	16 x 16	55	51
4	6:1*	Co ⁶⁰	500	190	376	597	Pilot-U	16 x 16	48	46
5	25%	Co ⁶⁰	1100	210	366	553	KL236	19 x 19	38	37

* Digital stabilization utilized.

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3. Weisberg, H. and Berko, S.; Phys. Rev. 154 (1967) 249.
4. Gedcke, D. A. and McDonald, W. J.; Nucl. Instr. and Meth. 56 (1968) 253.
5. Chase, R. L.; Rev. Sci. Instr. 39 (1968) 1318.
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7. The MECL 10216 oscillates when used as a three stage amplifier if the differential voltage applied to the first stage is near zero. Since the input to the CFD circuit is in a zero bias condition only two stages were used. The leading edge discriminator is not in a zero bias condition hence, three stages can be used.
8. MECL System Design Handbook, Motorola, Inc. 1972.
9. In future studies, RCA C31024 photomultiplier tubes, which have faster ~~use~~ times than the RCA 8575, will be used.