

Simultaneous Time and Pulse-Height Spectroscopy with Detectors Having a Single Output

When a detector offers only a single output, but both time and pulse-height spectrometry are required, the system in Fig.1 provides a practical solution. The Model 142A Preamplifier accepts the single detector output and delivers separate preamplifier outputs for timing (T) and pulse-height or energy (E) measurements. This scheme preserves the low noise required for pulse-height spectroscopy, while offering a fast rise time for time spectroscopy. The method is useful for microchannel plate detectors, microchannel plate PMTs, Si charged-particle detectors, and Ge detectors. For best performance, the length of the connection between the detector and the preamplifier should be as short as possible.

The AD413A Quad ADC records both time and energy information for each detected event. To minimize dead time, the start and stop inputs to the TAC are reversed. The low rate signal from the detector is applied to the start input, while the higher rate signal from the pulsed excitation source is delayed and fed to the stop input.

Time Spectrometry Beyond 10 μs: Time-of-Flight Mass Spectrometry and LIDAR

For time ranges beyond 10-μs, the model MCS-PCI or model 9353 is a much more productive solution than a time-to-amplitude converter, because a multichannel scaler (MCS) can record multiple stop pulses following a single start pulse. The benefit is much higher data collection rates without distortion of the time spectrum.

Fig. 2(A) shows the typical application of a MCS to a time-of-flight mass spectrometer (TOF-MS). When the ions are accelerated by the excitation pulse, the multichannel scaler starts its scan. As the ions arrive at the microchannel plate detector, they are counted in the MCS channel that corresponds to the ion’s flight time through the TOF-MS. Repeating the excitation and scanning process builds a time spectrum in the memory of the MCS. The pulse starting the scan in an MCS corresponds to the start pulse in a TAC, while the discriminator input of the MCS serves as the stop pulse input. The MCS accepts and records multiple stop pulses during each scan.

From the measured flight time, t, the mass of the ion can be computed as

$$m = \frac{2 z V_{acc} t^2}{s^2} \quad (1)$$

where z is the charge on the ion, Vacc is the accelerating voltage, and s is the length of the flight path.

To achieve sub-nanosecond digital resolution, substitute the Model 9327 1-GHz Amplifier and Timing Discriminator and the Model 9308 picosecond TIME ANALYZER for the VT120A Preamplifier and the MCS-PCI or 9353. See Figure 2(B) and Application Note AN52.

Because there is a dead time associated with the processing of each detected event in the MCS-PCI, 9353 and the Model 9308, these products are limited to operating in the single-ion counting/timing mode in the TOF-MS application. When the input is busy processing one event, it cannot respond to additional events arriving during the dead time. This means that the probability of detecting an event in the dominant peak in the time-of-flight spectrum must be limited to less than 1% during any scan. Mathematical dead time corrections can raise this limit to 10%. But in either case, the allowable ion rates are very low. This results in >10% statistical uncertainties for the counts in the peak, when the data acquisition period is much shorter than 1 second.

Ion rates can be increased by a factor of more than 100 by employing the FASTFLIGHT™ or FASTFLIGHT-2™ Digital Signal Averager, as illustrated in Figures 3(A) and 3(B). This results in a factor of 10 improvement of statistical precision and detection limits. FASTFLIGHT eliminates the event-processing dead time by using a flash ADC to sample and digitize the analog signal from the detector at 0.5, 1, or 2-ns intervals. Multiple ions arriving within the detector pulse width are fully counted, because the detector and flash ADC respond linearly to the number of ions in the pulse. For more information, see Multichannel Scalers, Multiple-Stop Time Spectrometers, or Application Notes AN53 and AN54. A site dedicated to Mass Spectrometry is <http://www.signalrecovery.com/ms>

Fig. 4(A) shows the application of the MCS-PCI or 9353 to a LIDAR system for studying the concentration of compounds as a function of altitude in the atmosphere. Laser pulses scattered by molecules in the atmosphere are detected by a photomultiplier tube. The round-trip flight time of the photons is measured by the MCS unit to determine the altitude at which the scattering took place. The counting rate of the detected photons can be used to measure the concentration of specific compounds. In practice, the laser and the photomultiplier tube are incorporated into a system of lenses, designed to limit the field of view and to guaranty overlap between the volume excited by the laser and that viewed by the photomultiplier tube. Typically, two parallel systems are used to measure the response at different wavelengths. This allows differential absorption corrections to be applied. The latter technique is called Differential Absorption Lidar (DIAL).

For the best resolution in LIDAR choose the instrumentation in Figure 4(B).

Research Applications

Timing

Timing with Scintillation Detectors

Figures 5, 6, and 7 are examples of high-resolution time spectrometry with scintillation detectors. Coincident pairs of gamma rays from the radioactive source are detected in opposite scintillation detectors. Fig. 5 represents a “fast/slow” timing system. “Fast” refers to the fact that the fast anode signals from the photomultiplier tubes are used to derive the timing information. The dynode outputs are integrated by the 113 Preamplifier, processed as “slow” pulses in the 460 Amplifiers, and fed to the 551 SCAs to select the desired range of pulse heights (energies) in each detector. Strobing the TAC by the 414A Fast Coincidence output ensures that only pulses within the selected energy windows will contribute to the recorded time spectrum. Fig. 6 shows the effect of varying the width of the energy windows on the measured time resolution.

Fig. 7 illustrates a “fast/fast” timing system, wherein the fast anode signal is used for both functions: 1) to derive the timing information, and 2) to select the range of pulse amplitudes. The upper and lower level discriminators in the Model 583B Constant-Fraction Differential Discriminator select the range of pulse amplitudes, while the constant-fraction zero-crossing discriminator adds the timing information. The advantage of this fast/fast system is the capability of operating at higher counting rates than is possible with the fast/slow system in Fig. 9.

Time Spectroscopy with Germanium Detectors

The system in Fig. 8 can be used to measure the timing characteristics of Ge detectors. Since the time resolution of the fast plastic scintillation detector is small compared to that of the Ge detector, the peak recorded in the time spectrum is characteristic of the Ge detector. Tables 1 and 2 summarize the time resolutions obtained with Ge detectors over a wide range of detector sizes. For further details see the sections on Amplifiers and Fast-Timing Discriminators.

Timing with Silicon Charged-Particle Detectors

Silicon detectors, with either Surface Barrier or Ion Implanted contacts, are used for detecting and measuring the energy of charged particles. In many cases, the arrival time of the charged particle also must be measured. Figure 9 includes a block diagram of the scheme used for extracting the timing signal along with the energy signal. The output of the 572A amplifier is usually fed to an ADC to record the energy spectrum, while the output of the 583B drives the Stop input of a Time-to-Amplitude Converter (TAC). If multi-parameter analysis is the aim of the experiment, the TAC output is delivered to a second input of the multi-parameter ADC in order to record the time spectrum. Because the charge collection time is uniformly short for a Si detector, it is possible to simulate the effect of the charged particle by using a Laser diode with a sub-nanosecond pulse width. Figure 10 demonstrates the typical time spectrum obtained from Figure 9. Figures 11 and 12 show the dependence of the time resolution on the energy of the charged particle (simulated by the light pulse intensity), and on the capacitance of the detector. Time resolutions in the range of 30 to 700 ps are possible. The time resolution is determined by the noise/slope ratio, as explained in the Fast-Timing Discriminators. See also the 142A/B/C data sheet.

Coincidence Spectroscopy Systems

Figures 13 and 14 are examples of coincidence spectroscopy systems intended for studying radioisotopes that emit multiple quanta of radiation in a single decay.

The model 551 Timing Single-Channel Analyzers in Fig. 13 provide the slow timing information for determining the gamma rays striking the two detectors are truly coincident. The Timing SCA for Detector A is operated with a wide-open window to allow measurement of the entire energy spectrum for Detector A on the MCB. For Detector B, the window on the Timing SCA is adjusted to select a single gamma-ray energy. Consequently, the MCB records the energy spectrum from Detector A for all the gamma rays that are in coincidence with the gamma ray selected from Detector B.

The system in Fig. 14 offers more powerful data acquisition capability than the scheme in Fig. 13. With Option 1, a true two-parameter data acquisition yields a three dimensional of the coincidence spectra from the two detectors. In addition coincidence-gated singles spectra from each detector can be recorded simultaneously via Option 2. Multi-parameter data acquisition and display is supported by the Kmax™ Software on either a Macintosh or IBM-compatible personal computer.

In Fig. 14 a model 567 TAC/SCA is used to set the fast coincidence resolving time. This is more convenient than the scheme in Fig. 13 because the TAC time spectrum can be displayed via an ADC that is gated by the TAC/SCA while the SCA window is adjusted to accept only the true coincidence peak. The optional start gate on the TAC/SCA can be used to reduce dead time in the TAC.

Selecting the Type of Radiation by Pulse-Shape Analysis

Some scintillators respond to different types of radiation by exhibiting different decay times. In such situations pulse-shape analysis can be used to identify and selectively analyze one particular type of radiation. Fig. 15 demonstrates the application of pulse shape analysis to the task of counting neutrons in the presence of an unwanted gamma-ray background. The 552 Pulse-Shape Analyzer and the 567 TAC measure the fall time of the pulse from the 460 Amplifier. Since the Model 460 is a delay-line-clipped amplifier, the fall time is identical to the rise time of the pulse, and this rise time corresponds to the decay time of the scintillator. Fig. 16 shows the rise time spectrum at the TAC output. By setting the TAC/SCA window across the neutron peak and gating the MCA with the SCA output, the system will record only the energy spectrum caused by neutrons. For further details, see the application note, "Neutron-Gamma Discrimination with Stilbene and Liquid Scintillators". This method can be applied to other types of detectors, such as sandwiches of two types of scintillators (Phoswich detector) for the purpose of identifying the type of radiation by its penetration depth.

Energy Measurement by Time-of-Flight

It is difficult to design a detector in which fast neutrons interact to produce a signal that yields good energy resolution. Consequently, neutron energies are normally determined by measuring the flight time of the neutron over a fixed distance. If the distance is s and the flight time is t , the energy of the neutron can be calculated as

$$E = \frac{m s^2}{2 t^2} \quad (2)$$

where m is the mass of the neutron.

Conversely, Equation (2) can be used to determine the mass of an unidentified particle, if the energy E is controlled. The method can be used to identify charged particles in nuclear reactions, or the molecular species in a time-of-flight mass spectrometer (see Figures 2 and 3).

Fig. 17 shows a typical neutron time-of-flight spectrometer. Deuterium ions (${}^2\text{H}^+$) are boosted to an energy of about 200-keV in an electrostatic accelerator, and directed to a target containing Tritium (${}^3\text{H}$). The resulting nuclear reaction, ${}^2\text{H} + {}^3\text{H} \rightarrow {}^4\text{He} + n$, produces neutrons having an energy of 14.2 MeV, and recoiling alpha particles (${}^4\text{He}$) with an energy of 3.6 MeV. After scattering from the sample, the neutrons exhibit discretely different energies depending on (a) the nuclear states excited in the sample by inelastic scattering, and (b) the scattering angle.

The time-of-flight spectrum is measured by the time interval between the alpha particle arriving at the ULTRA™ detector and the neutron arriving at the neutron detector. The high counting rate signals from the alpha-particle detector are delayed and used as the stop pulse, while the lower counting rate signals from the neutron detector are fed to the start input of the TAC. This reversed start/stop scheme reduces dead time in the TAC. A pulse shape analyzer, as described in Fig. 15, is used to reject gamma-ray background. The Model 552 SCA also serves to define the lower pulse-height threshold for accepting neutron signals. This threshold is critical in determining the detection efficiency of the neutron detector.

Table 1. Typical Timing Results Measured with ORTEC's Coaxial Detectors.

Detector System	Detector Type	Efficiency (%)	Optimum Delay (ns)	Measure	Timing Resolution (ns)								
					Mean Energy (keV) Using ${}^{22}\text{Na}$				Mean Energy (keV) Using ${}^{60}\text{Co}$				
					150	250	350	511	511	750	950	1170	1330
1	HPGe-P	11.0	24	FWHM FW.1M	9.2 ----	6.7 45.3	5.8 22.2	4.0 9.9	3.9 10.2	3.0 8.4	2.6 7.5	2.0 5.6	1.7 5.1
2	HPGe-N	19.8	23	FWHM FW.1M	12.5 84	8.6 33	7.0 18.1	4.5 10.2	4.9 11.8	3.7 8.6	3.1 7.7	2.2 5.5	2.0 4.9
3	HPGe-P	28.0	34	FWHM FW.1M	11.3 ---	8.8 55.8	7.7 27.1	5.6 12.8	6.2 13.4	5.7 12.3	4.0 11.8	3.6 9.8	3.4 9.0

Table 2. Timing Resolution for Large Germanium Detectors Using 583A CFDD/SCA, 474 TFA, and ${}^{60}\text{Co}$.

Detector	Efficiency (%)	FWHM Energy Resolution (keV)	Constant Fraction Delay (ns)	Timing Resolution (ns)			
				$E > 100$ keV		$E = 1332 \pm 50$ keV	
				FWHM	FW.1M	FWHM	FW.1M
N3026A	73	2.03	34	5.4	19.4	3.7	8.8
P20171	81	1.97	34	5.5	27.0	4.7	13.8
N20366A	88	2.34	36	5.8	21.2	5.5	16.4

Research Applications

Timing

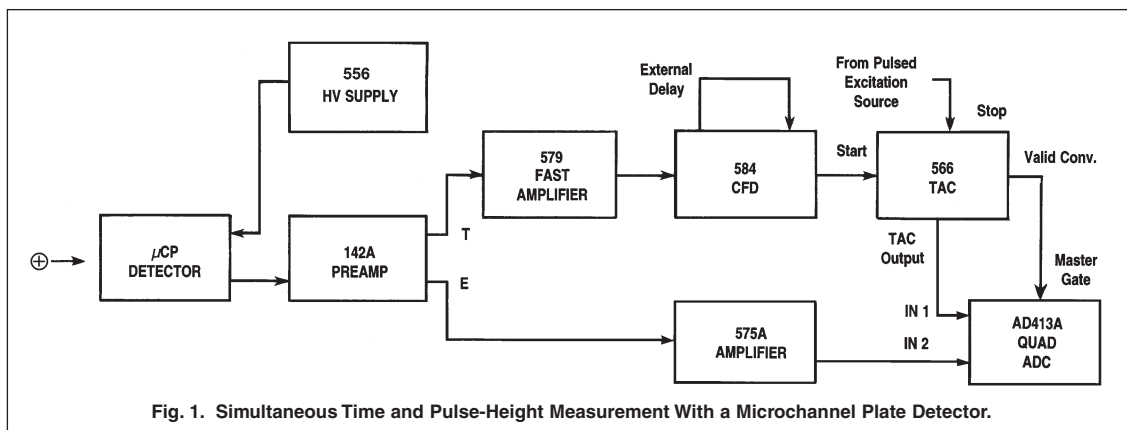


Fig. 1. Simultaneous Time and Pulse-Height Measurement With a Microchannel Plate Detector.

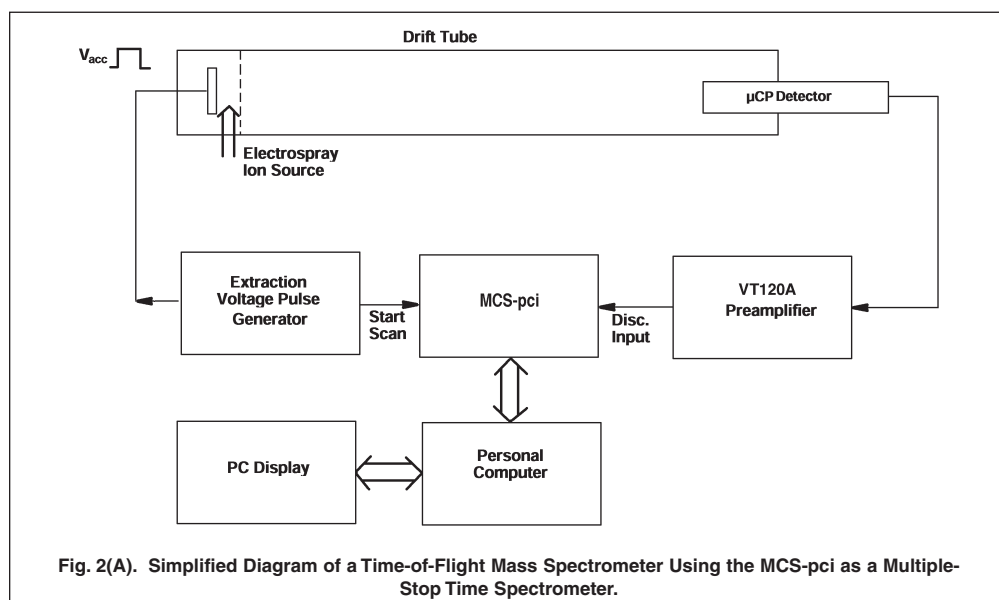


Fig. 2(A). Simplified Diagram of a Time-of-Flight Mass Spectrometer Using the MCS-pci as a Multiple-Stop Time Spectrometer.

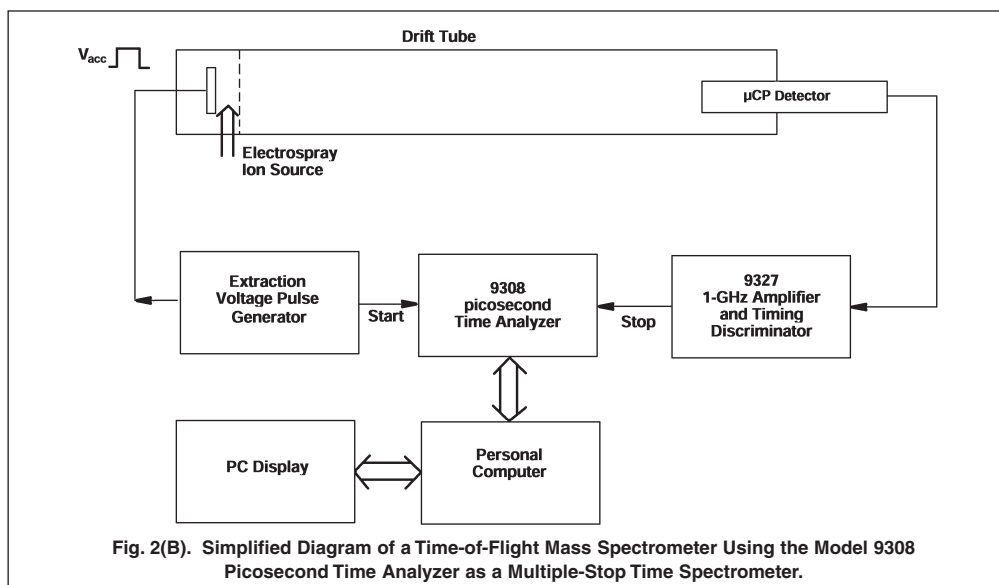
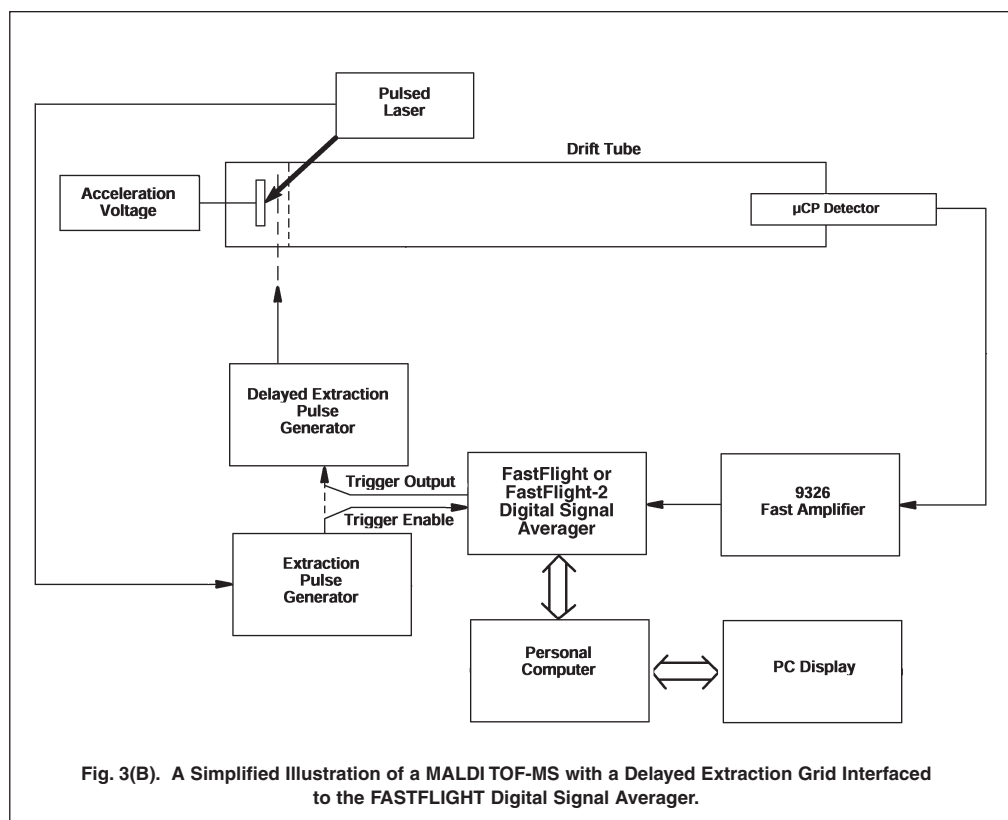
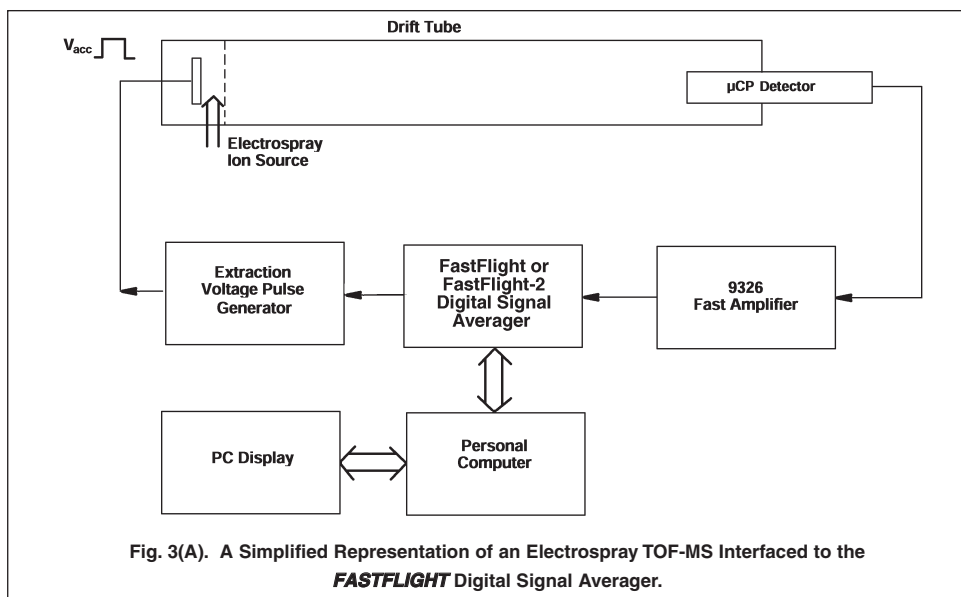


Fig. 2(B). Simplified Diagram of a Time-of-Flight Mass Spectrometer Using the Model 9308 Picosecond Time Analyzer as a Multiple-Stop Time Spectrometer.



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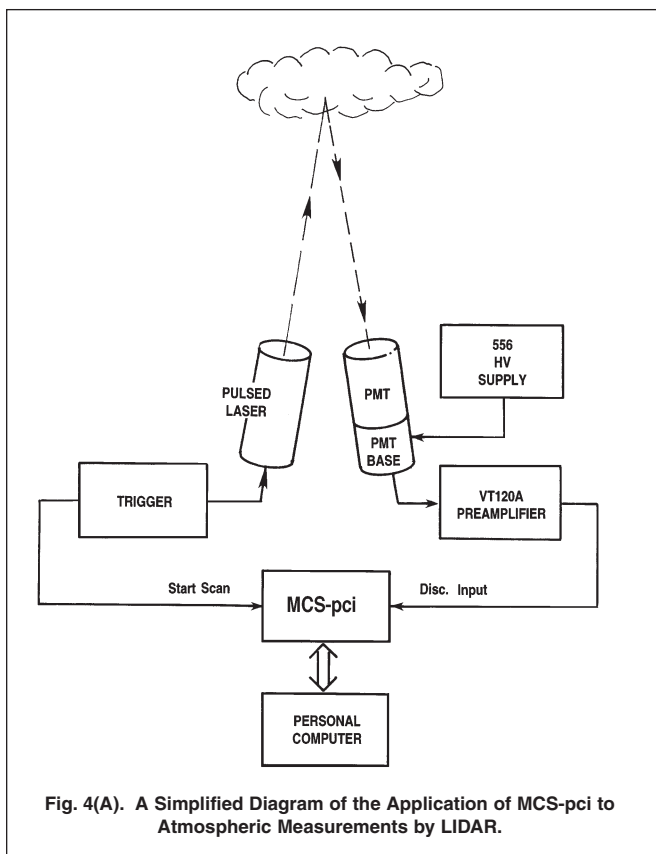


Fig. 4(A). A Simplified Diagram of the Application of MCS-pci to Atmospheric Measurements by LIDAR.

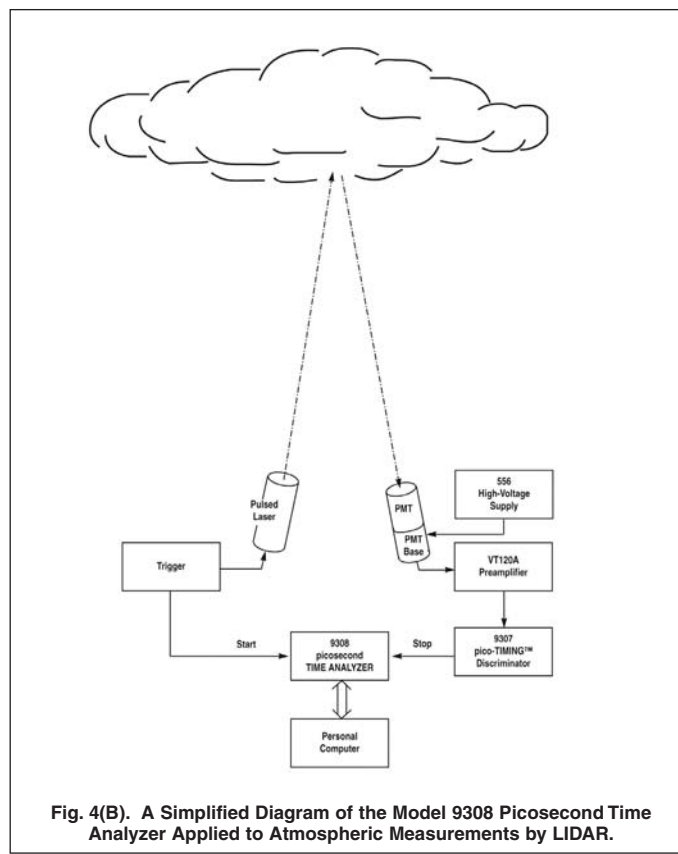


Fig. 4(B). A Simplified Diagram of the Model 9308 Picosecond Time Analyzer Applied to Atmospheric Measurements by LIDAR.

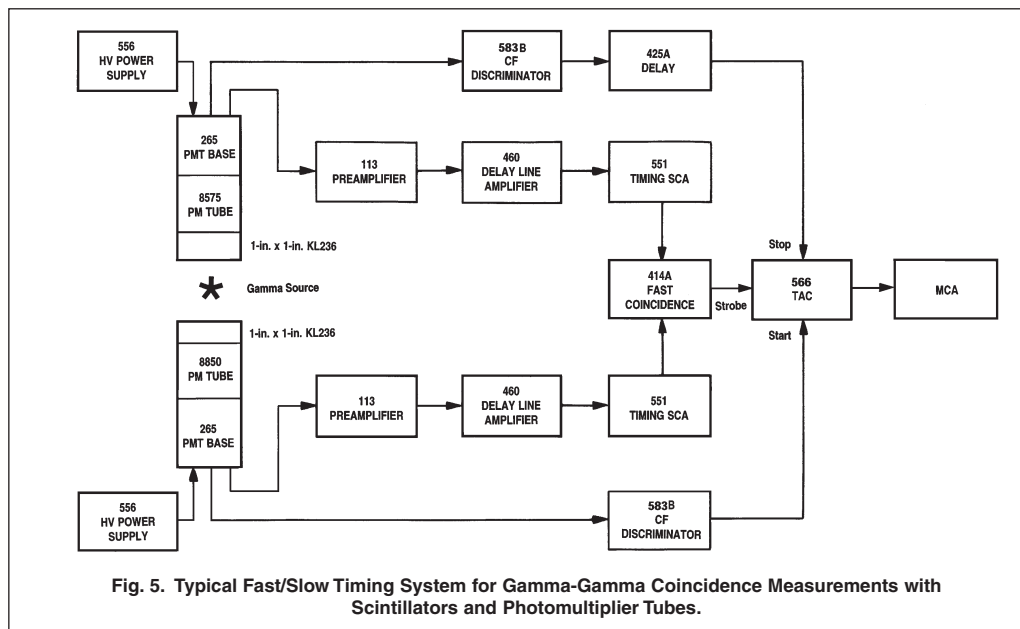
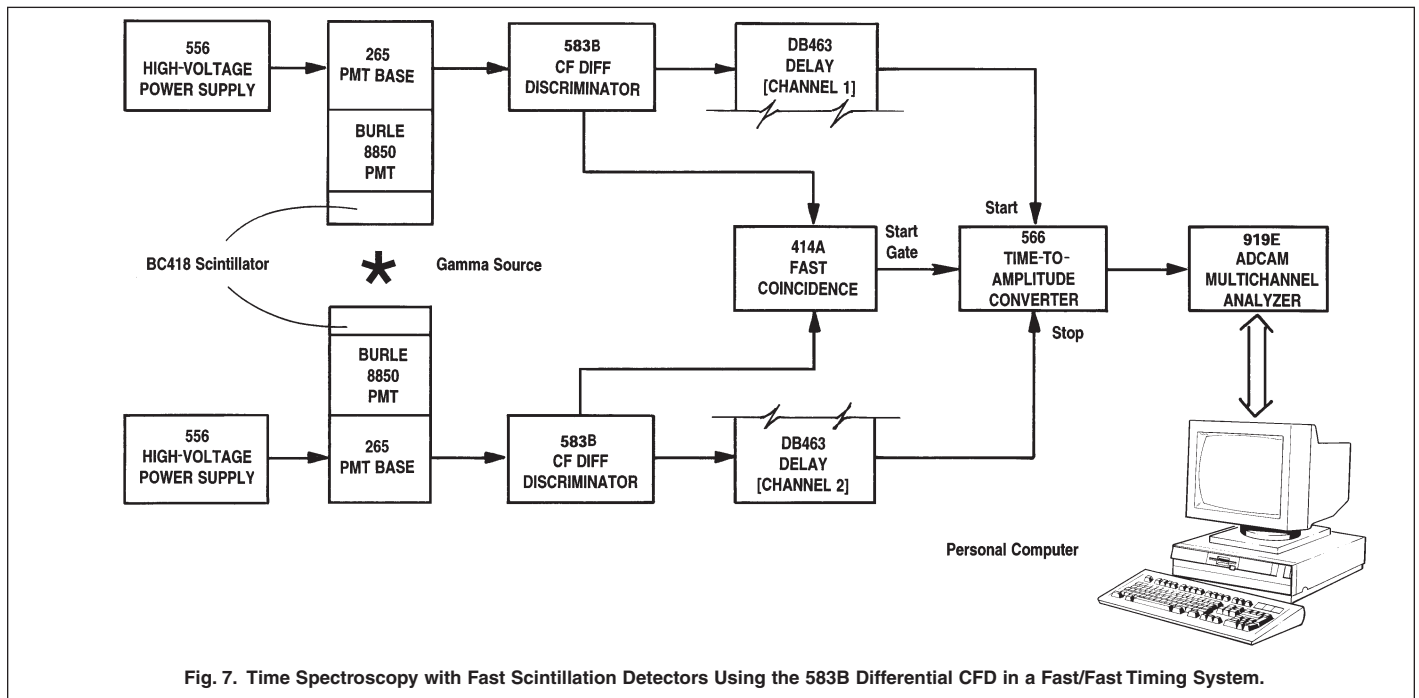
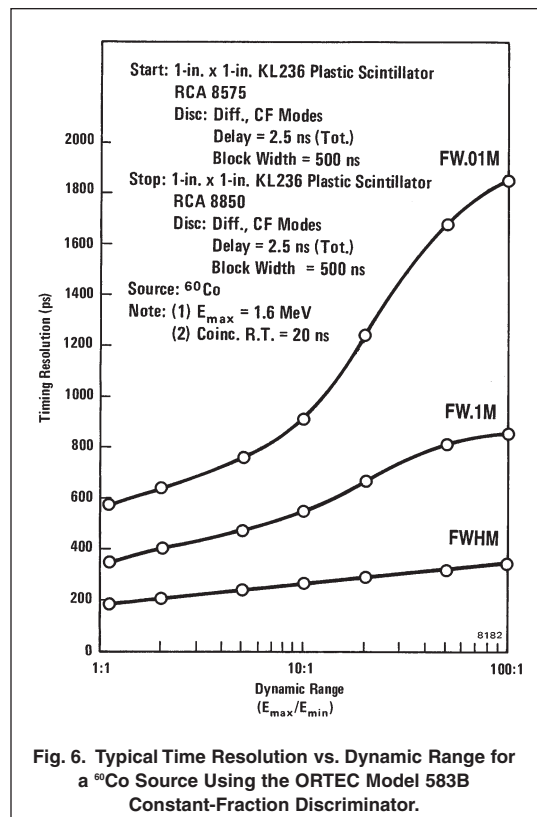
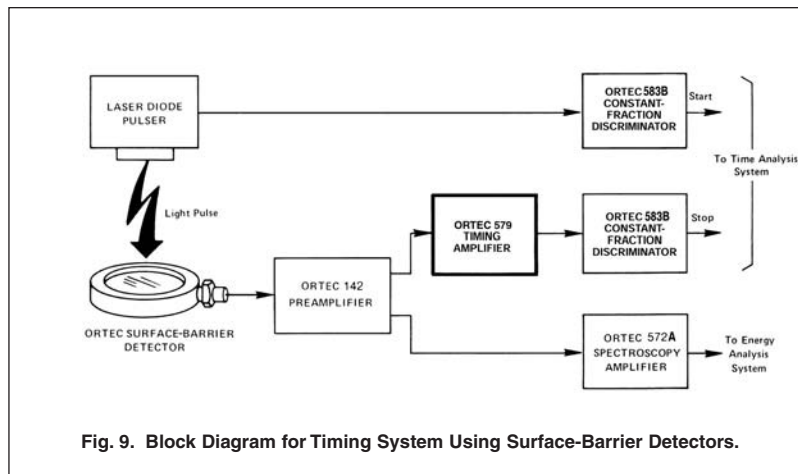
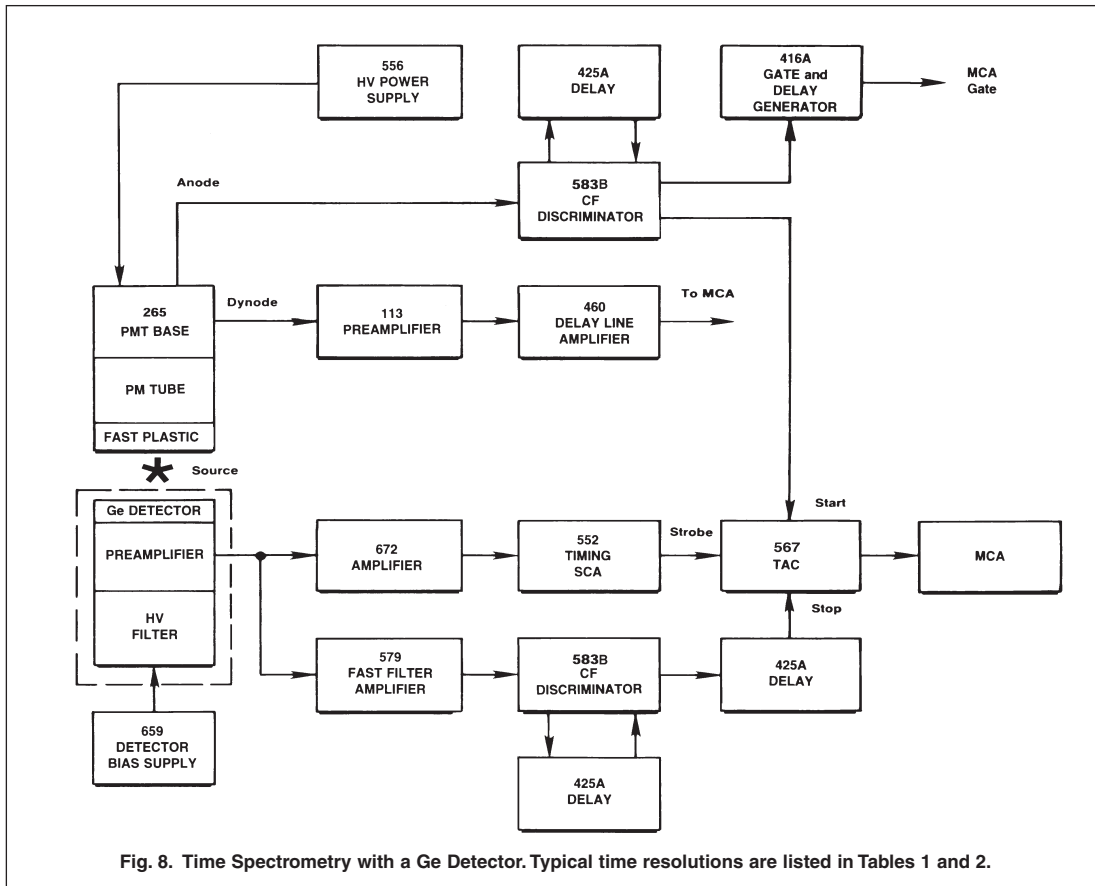


Fig. 5. Typical Fast/Slow Timing System for Gamma-Gamma Coincidence Measurements with Scintillators and Photomultiplier Tubes.



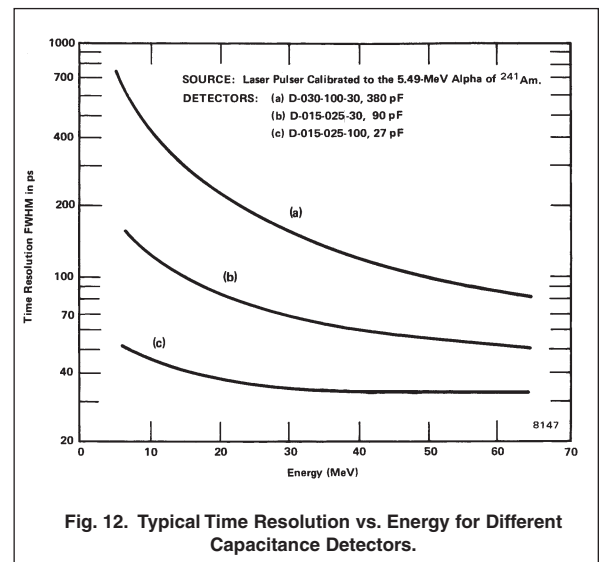
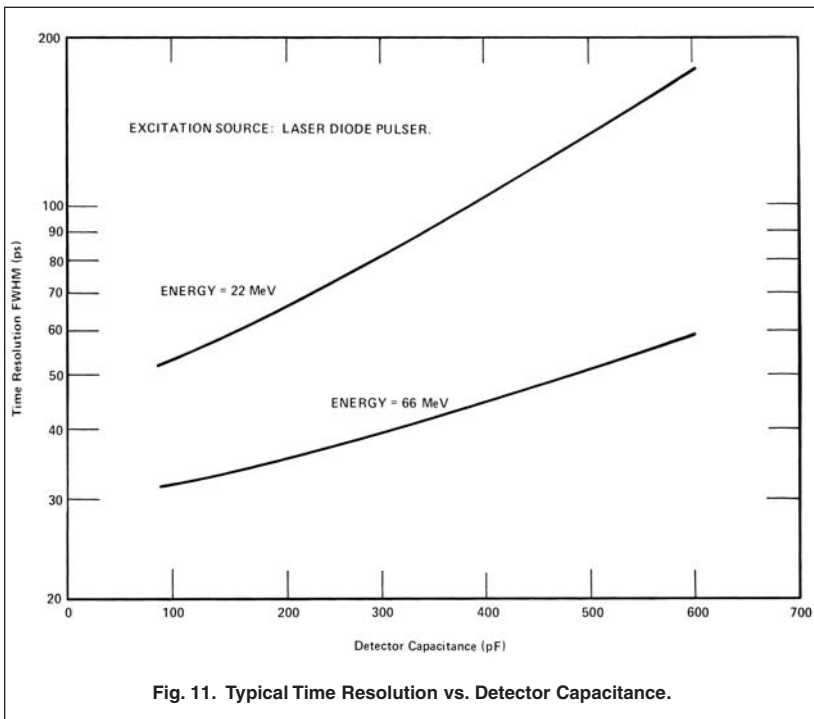
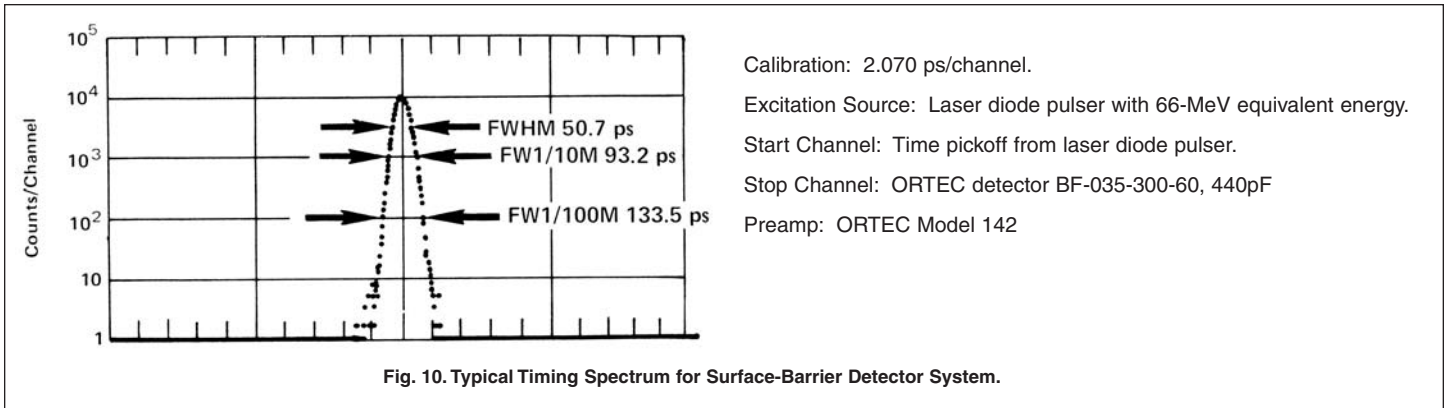
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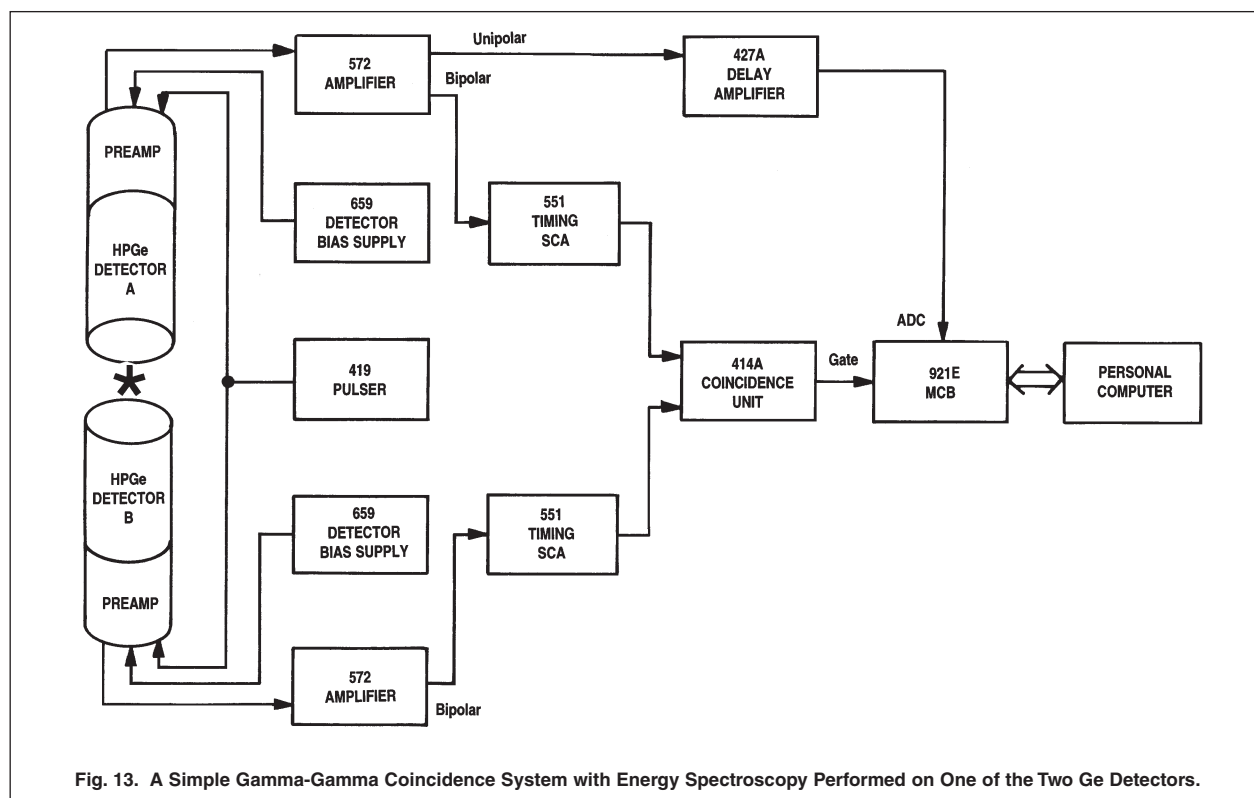
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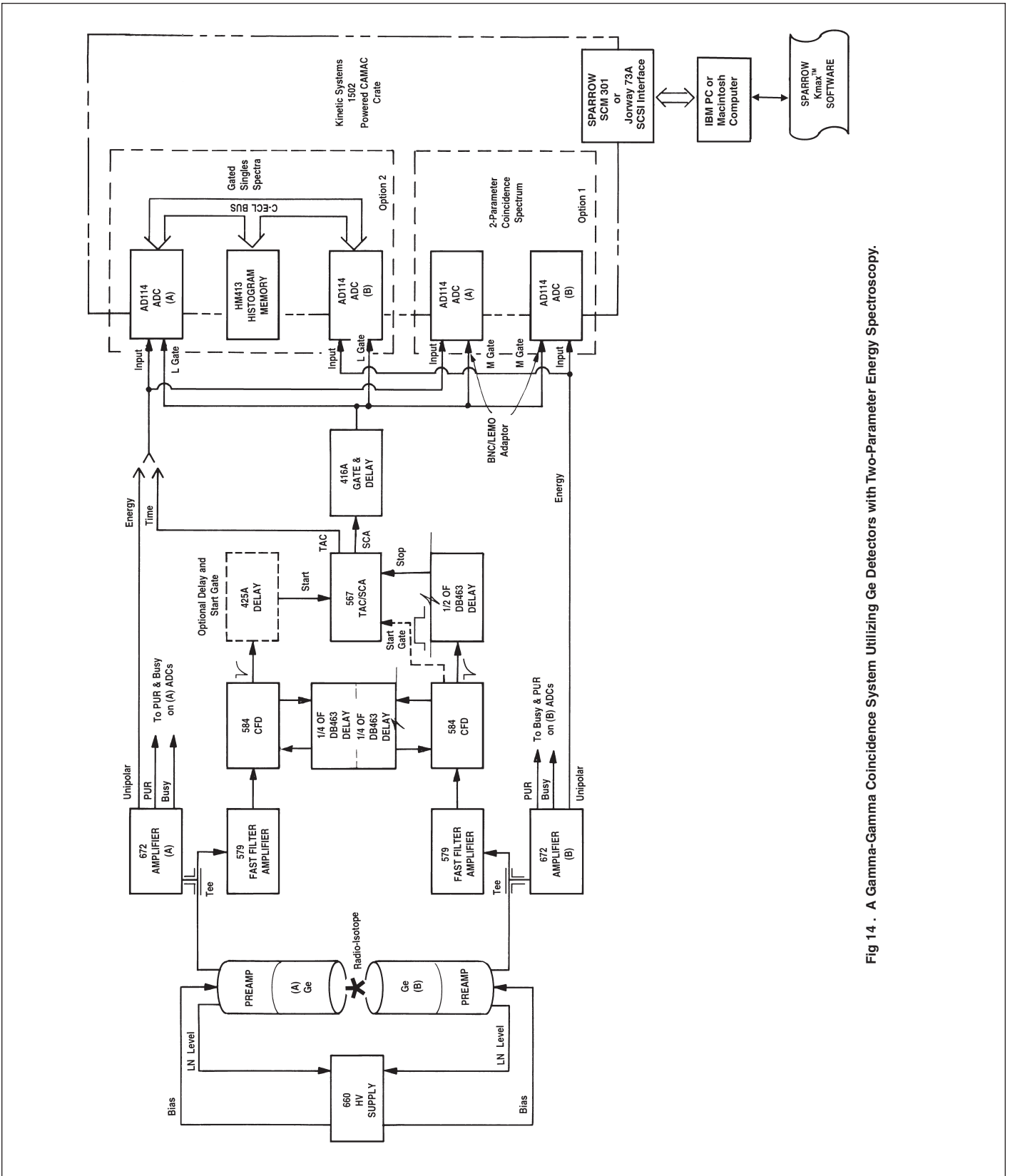
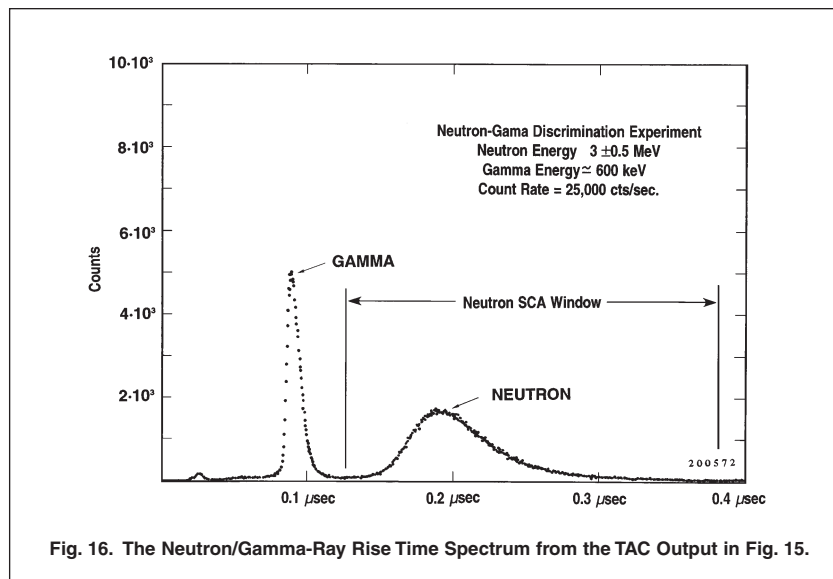
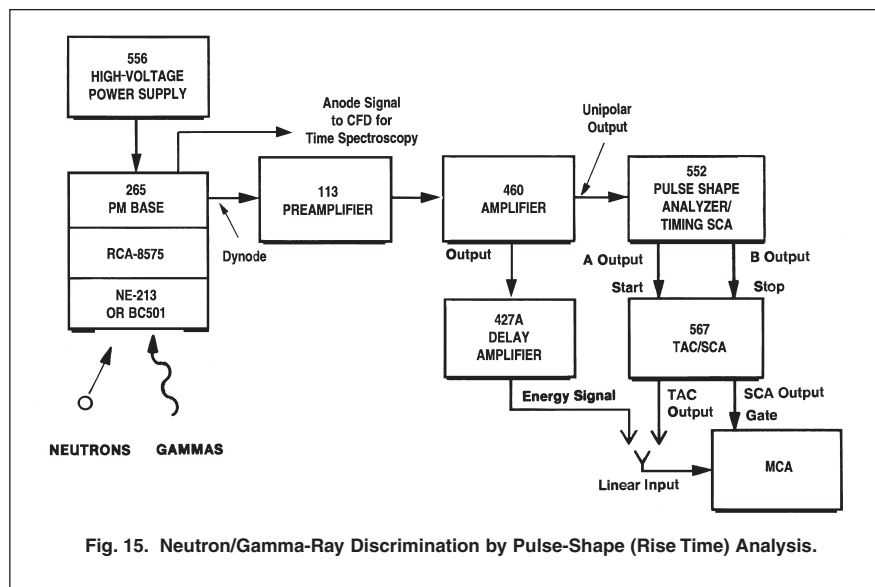


Fig 14 . A Gamma-Gamma Coincidence System Utilizing Ge Detectors with Two-Parameter Energy Spectroscopy.

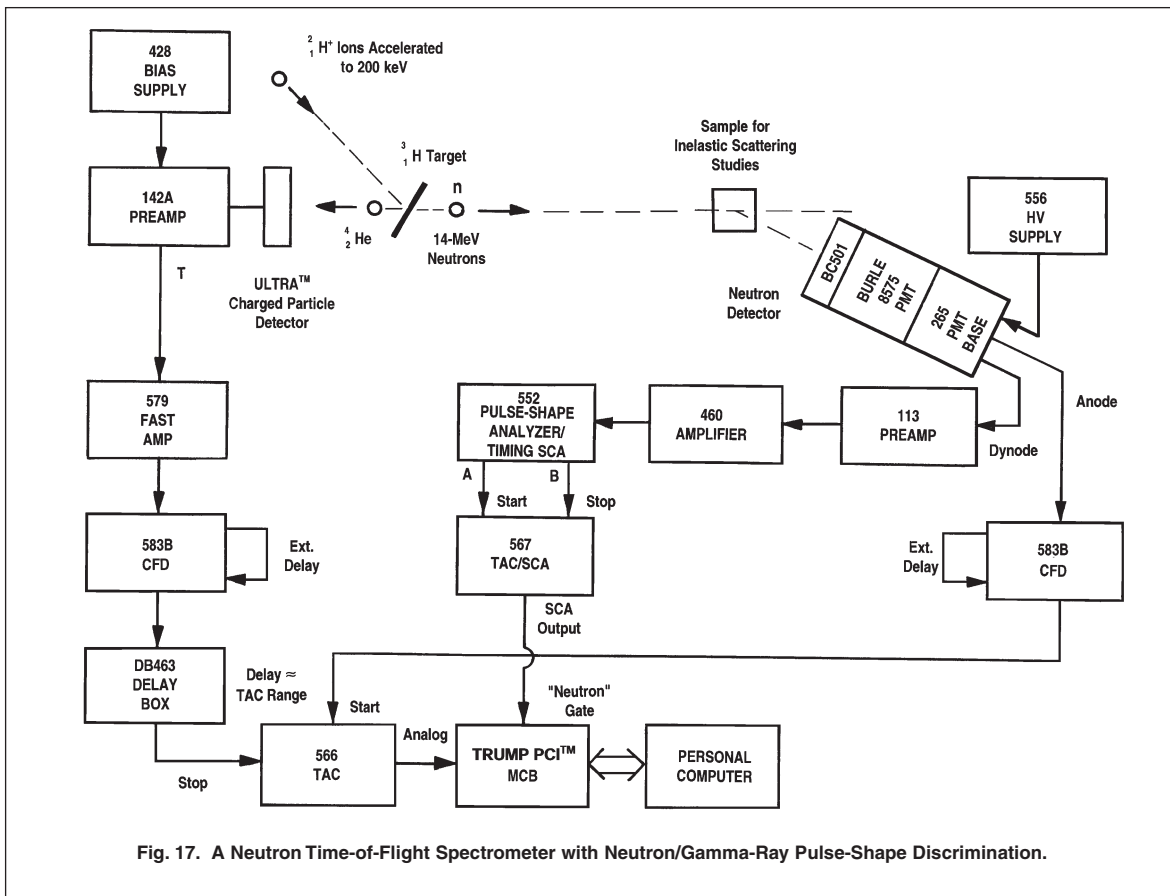
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