Model 276
Photomultiplier Base
Operating and Service Manual

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Manual Revision D

Advanced Measurement Technology, Inc.

a/k/a/ ORTEC®, a subsidiary of AMETEK®, Inc.

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If it becomes necessary to return this instrument for repair, it is essential that Customer Services be contacted in advance of its return so that a Return Authorization Number can be assigned to the unit. Also, ORTEC must be informed, either in writing, by telephone [(865) 482-4411] or by facsimile transmission [(865) 483-2133], of the nature of the fault of the instrument being returned and of the model, serial, and revision ("Rev" on rear panel) numbers. Failure to do so may cause unnecessary delays in getting the unit repaired. The ORTEC standard procedure requires that instruments returned for repair pass the same quality control tests that are used for new-production instruments. Instruments that are returned should be packed so that they will withstand normal transit handling and must be shipped PREPAID via Air Parcel Post or United Parcel Service to the designated ORTEC repair center. The address label and the package should include the Return Authorization Number assigned. Instruments being returned that are damaged in transit due to inadequate packing will be repaired at the sender's expense, and it will be the sender's responsibility to make claim with the shipper. Instruments not in warranty should follow the same procedure and ORTEC will provide a quotation.

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Shipments should be examined immediately upon receipt for evidence of external or concealed damage. The carrier making delivery should be notified immediately of any such damage, since the carrier is normally liable for damage in shipment. Packing materials, waybills, and other such documentation should be preserved in order to establish claims. After such notification to the carrier, please notify ORTEC of the circumstances so that assistance can be provided in making damage claims and in providing replacement equipment, if necessary.

CONTENTS

SAFETY INSTRUCTIONS AND SYMBOLS

This manual contains up to three levels of safety instructions that must be observed in order to avoid personal injury and/or damage to equipment or other property. These are:

DANGER Indicates a hazard that could result in death or serious bodily harm if the safety instruction is not observed.

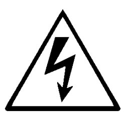
WARNING Indicates a hazard that could result in bodily harm if the safety instruction is not observed.

CAUTION Indicates a hazard that could result in property damage if the safety instruction is not observed.

Please read all safety instructions carefully and make sure you understand them fully before attempting to use this product.

In addition, the following symbol may appear on the product:

ATTENTION – Refer to Manual



DANGER – High Voltage

Please read all safety instructions carefully and make sure you understand them fully before attempting to use this product.

SAFETY WARNINGS AND CLEANING INSTRUCTIONS

DANGER	Opening the cover of this instrument is likely to expose dangerous voltages. Disconnect the instrument from all voltage sources while it is being opened.

WARNING	Using this instrument in a manner not specified by the manufacturer may impair the protection provided by the instrument.

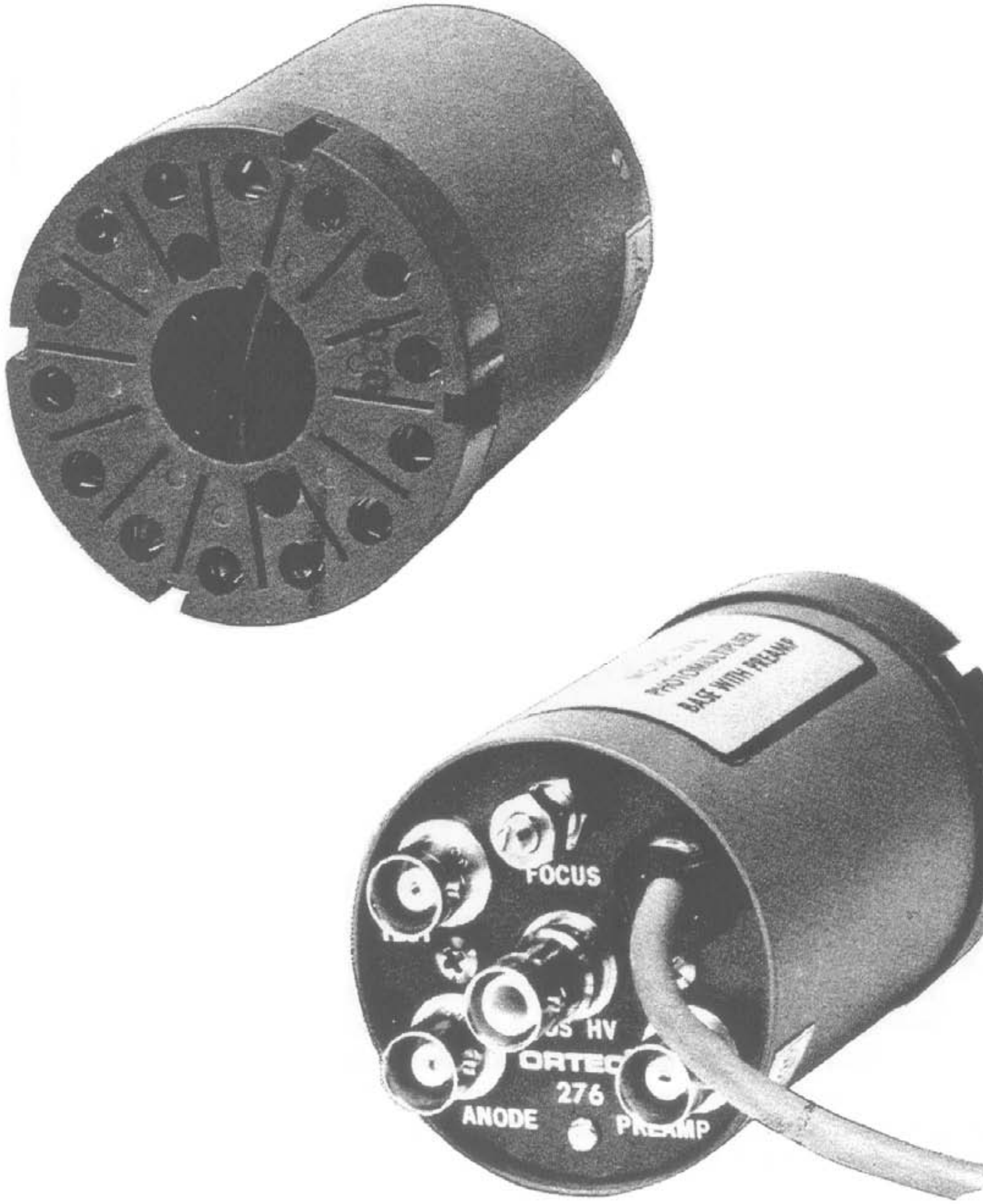
Cleaning Instructions

To clean the instrument exterior:

- Unplug the instrument from the ac power supply. Remove loose dust on the outside of the instrument with a lint-free cloth.
- Remove remaining dirt with a lint-free cloth dampened in a general-purpose detergent and water solution. Do not use abrasive cleaners.

CAUTION	To prevent moisture inside of the instrument during external cleaning, use only enough liquid to dampen the cloth or applicator.

- Allow the instrument to dry completely before reconnecting it to the power source.


BASE WITH PREAMP
FOCUS
276
ANODE

ORTEC MODEL 276
PHOTOMULTIPLIER BASE

1. DESCRIPTION

The ORTEC 276 Photomultiplier Base is designed to provide a near-optimum voltage distribution for essentially all 10-stage photomultiplier tubes that fit the standard 14-pin tube socket. The unit has a self contained low-noise integrating preamplifier that provides gain and line drive capability for the output signal from the last dynode. The preamplifier is dc-coupled to simplify pole-zero cancellation in the main amplifier. The anode signal is capacitively coupled to an output BNC connector for use in coincidence timing or linear pulse-height analysis. A TEST input is provided to allow pulser calibration and testing. A FOCUS control on the rear panel is for optimizing the photocathode first-dynode electrical field. Some of the photomultiplier tubes with which this PM base is compatible are:

- **RCA**: 4518, 5819, 6217, 6342A, 6655A, 7326, 8053, 8054, and 8055
- **Philips**: XP-1000 to 1005 and XP-1031 through 1033
- **EMI**: 9536, 9578, 9579, and 9708 Series
- **CBS**: 7817, 7818, 7819, and CL-1004 to 1012
- **Dumont**: 6292, 6363, and 6364

The unit is also compatible with other 10-stage tubes not listed above. Compatibility can be determined by comparison with those listed.

2. SPECIFICATIONS

2.1. PHOTOMULTIPLIER TUBE BASE

2.1.1. PERFORMANCE

Design Resistor divider bleeder connected to 14-pin standard PM tube base for 10-stage tubes. Total resistance 1.49 MΩ, with bleeder current of 1.33 mA when maximum high voltage of 2000 V is applied.

Voltage Distribution Coefficient Linear to all stages with focus adjustment on the grid.

2.1.2. CONTROL

FOCUS Single-turn locking potentiometer on panel for external adjustment of PM tube grid potential.

2.1.3. INPUT

HIGH VOLTAGE Type SHV connector on panel accepts operating voltage for distribution to PM tube; +2000 V maximum.

2.1.4. OUTPUTS

ANODE Type BNC connector on panel furnishes PM tube anode negative output pulse for use primarily as a timing signal; Z_o = 1 kΩ ac-coupled.

LAST ANODE Connected internally to preamplifier input.

2.2. PREAMPLIFIER

2.2.1. PERFORMANCE

Input Directly from last dynode of photomultiplier tube.

Conversion Gain Nominally 5 µV/eV using a 2 × 2-in. NaI(Tl) crystal and a photomultiplier tube gain of 10^6.

Rise Time <100 ns for a fast rise time test pulse.

Fall Time Constant 50 µs.

Integral Nonlinearity <±0.02%, 0 to +10 V.

Output Polarity Positive.

Output Noise <50 µV rms.

Saturation Level +10 V into open circuit; +5 V into 93 Ω load.

Gain Temperature Coefficient <±0.005%/°C, 0 to 50°C.

2.2.2. OUTPUT

PREAMP Type BNC connector on panel furnishes preamplifier positive output pulse for use primarily as an energy analysis signal. Z_o = 93 Ω dc-coupled.

2.2.3. INPUTS

Power Cable 3-m (10-ft) captive cable terminates in Amphenol 17-20090 connector to accept operating power for the preamplifier circuits. Compatible with all ORTEC main amplifiers and with an ORTEC 114 Preamplifier Power Supply.

TEST Type BNC connector on panel accepts test pulses from an ORTEC Pulse Generator for testing and calibration. Nominal 100-Ω charge termination built into preamplifier circuit.

2.3. ELECTRICAL AND MECHANICAL

Power Requirements

Preamplifier +24 V, 16 mA; −24 V, 16 mA.

PM Tube Base +2000 V maximum (use rate voltage for the PM tube that is installed).

Weight

Net 0.65 kg (1.5 lb).
Shipping 1.3 kg (3.0 lb).

Dimensions 5.58 cm (2.2 in.) diam × 10.1 cm (4.0 in.) long plus 3-m (10−ft) captive power cable.

3. INSTALLATION

3.1. DETECTOR MOUNTING

Normally with 10-stage photomultipliers the amount of signal current through the tube is small; therefore, it is quite practical to run positive high voltage on the tube with the cathode at ground potential. This means that when the detector is mounted to the photocathode, very little attention need be paid to the probability of leakage currents being created across the glass envelope, since the voltage potential should be zero. In many cases where this PM base is used, the detector is mounted to the photomultiplier in an integral package.

When a scintillator is mounted on a photomultiplier, the combination must be made light-tight to ensure low noise and to eliminate the possibility of photomultiplier damage. The most common practice to make the detector/photomultiplier light-tight is to carefully wrap it with a good-quality black electrical tape. Another is to use an aluminum can cover and to tape it a the entrance.

3.2. SYSTEM CONNECTION

If it is desired to test and calibrate the system, connect a pulser to the test input. A 1-V test pulse should yield a 1-V pulse on the preamplifier output. The test input is internally terminated in 93 Ω. Connect a high voltage power supply to the high voltage input connector and ***ensure positive polarity*** of the high voltage supply. Connect the preamplifier signal to the energy analysis system and connect the anode signal to either a timing or energy analysis system. Use high-quality coaxial cable and terminate the anode signal cable in its characteristic cable impedance.

3.3. INITIAL ADJUSTMENTS

The only adjustment on the PM Base is the FOCUS control, which optimizes the photocathode/first-dynode electrical field.

1. Plug a photomultiplier detector into the unit and ensure it is light-tight. Connect the positive high voltage supply.
2. Place a radiation source in the vicinity of the scintillation detector.
3. Observe the preamplifier output on a sensitive range of an oscilloscope and slowly increase the high voltage.
4. If there is a very large amount of unipolar grass (circuit noise), there is possibly a light leak. Cover the PM tube with a black cloth to see whether the grass diminishes; if it does, the photomultiplier was seeing the ambient light and should be rechecked for proper covering to eliminate the light leak.
5. With the high voltage at the desired level, observe the pulses which are radiation-induced scintillations and adjust the FOCUS control to obtain maximum pulse amplitude. This is the proper setting; lock the adjustment with the potentiometer lock nut.

4. OPERATION

Once the steps outlined in Section 3 of this manual are performed, the unit is ready for use. High voltage may be applied and adjusted for the appropriate gain associated with the specific experiment. The gain will vary by a factor of approximately 2 for each high-voltage change of 100 V. NOTE: It is advisable to operate the high voltage at the minimum practical value when the high count rates are to be experienced, since count rate tolerance is a direct function of the photomultiplier gain.

4.1. CALCULATION OF RESPONSE OF SCINTILLATOR/PHOTOMULTIPLIER

Table 4.1 lists the decay constants of some of the more common scintillators. The first three scintillators are crystals. Naton-136, Pilot B, and NE-102 are plastics, and the last two are liquid scintillators. The decay time τ_1 is responsible for a finite rise time on the leading edge of L(t) (refs. 12, 21, 22); τ_2 is the fast decay component which is mot noticeable at the output of the photomultiplier; τ_3 and τ_4 are the slow components (important for n-γ discrimination with NE-213, NE-218, and Stilbene). Where measured values were not given, the letters **N.G.** have been entered. The parameter P is the number of photo electrons released at the photocathode per unit energy. This figure is affected by the efficiency and spectral response of the photocathode (refs. 22, 23, 26, 27) and hence is somewhat characteristic of the photomultiplier used. However, it provides a reasonably good guide for comparing the light output of scintillators. In Table 4.1, P is listed as a fraction of the value for anthracene; $P_{(anthracene)}$ is ~700 eV/ photoelectron for S-11 photocathode material.

Table 4.1. Scintillator Decay Times.

Scintillator	Decay Time Constants (ns)				$P/P_{(anthracene)}$
	τ_1	τ_2	τ_3	τ_4	
NaI(Tl)		250	(24)*		2.40
Anthracene (25)*	N.G.	29.3			1.00
Stilbene (23)*	0.1	4.05	33	270	0.64
Naton-136 (22)*	0.4	1.6	10		0.37
Pilot B (22)*	0.4	1.6	9.5		0.41
NE-102 (25)*	N.G.	2.51	N.G.		0.65
NE-213 (23)*	1.66	3.16	32.3	270	0.47
NE-218 (23)*	1.76	3.58	36.5	288	0.56

*See Bibliography

The thickness of the scintillator is frequently chosen according to the required stopping power. The flight time of the radiation (gamma rays or neutrons) across the scintillator normally becomes a limitation on the time resolution as the thickness is increased. Usually detection efficiency must be compromised for good time resolution.

The scintillator geometry and the coupling to the phototube must be carefully considered: If the light can travel a variety of path lengths before being collected, an additional contribution to the time resolution will result. Light collection is widely discussed in the literature (refs. 15, 17–19, 28, 29).

Table 4.2 lists the characteristics of several types of photomultipliers. It is noteworthy to observe that the gain of theses tubes ranges from ~0.5 × 10^6 to 2.5 × 10^6. This gain is strongly affected by the age of the tube and the temperature and will change by a factor of ~2 for each 100-V change in high voltage.

For response calculations there are several approximations that will aid in a quick "ballpark" answer:

1. Conversion for absorbed energy (eV) to photons (p) for anthracene is ~70 eV/p (ref. 35).
2. Conversion of photons to photoelectrons for S-11 photocathode material is ~10% (ref. 37).
3. 100% of photons are collected on the photocathode and 100% of cathode-emitted photoelectrons are collected on the first dynode.

The function for the total charge output now becomes

$$Q_o = \frac{E}{70} \times Pc_{eff} \times \frac{P}{P_a} \times G \times q\,(coulombs) \qquad \textbf{(1)}$$

where

- Q_o = output charge in coulombs
- E = absorbed energy in detector in eV
- P/Pa = detector efficiency compared to anthracene from Table 4.1
- G = photomultiplier gain from Table 4.2 or from manufacturer's data
- q = charge per electron 1.6 × 10^{-19} coulomb
- Pc_{eff} = efficiency of photocathode or ~10% for S-11.

Table 4.2. Photomultiplier Characteristics.

Type	Maximum Outside Dimensions (in.)		Cathode		Dynode System				Max Overall Voltage (V)
	Diameter	Length	Area (cm^2)	Response	No. of Dynodes	Type	Material	Gain	
RCA									
5819	2-1/4	5-13/16	14.2	S-11	10	Circ. focused	Cs_3Sb	2.3×10^6	1250
6342	2-1/4	5-13/16	14.2	S-11	10	Circ. focused	AgMg	0.55×10^6	1500
6655	2-1/4	5-13/16	14.2	S-11	10	Circ. focused	Cs_3Sb	2.3×10^6	1250
6199	1-9/16	4-9/16	7.75	S-11	10	Circ. focused	Cs_3Sb	2.8×10^6	1250
6372	2-9/16	7-3/4	80	S-11	10	Circ. focused	Cs_3Sb	2.5×10^6	1200
8055	5-1/2	6-3/4	97	S-11	10	Venetian blind	CuBe	1.5×10^6	2000
Du Mont									
6291	1-1/2	4-1/4	6.4	S-11	10	Box	AgMg	2×10^6	2100
6292	2-1/16	5-5/8	13.4	S-11	10	Box	AgMg	2×10^6	2100
6363		6-1/8	31.4	S-11	10	Box	AgMg	2×10^6	1800
6364	5-1/4	7-1/2	88.8	S-11	10	Box	AgMg	2×10^6	1800
EMI/US									
9536B	2	4-3/4	14.6	S-11	10	Venetian blind	Cs_3Sb	3×10^6	1700
CBS									
CL1012	1-1/2	4-3/4	8	S-11	10	Venetian blind	AgMg	2×10^6	1750

If the output charge is integrated on a capacitor as it is on this unit, the capacitor voltage becomes:

$$V_c = \frac{Q_o}{C_i} \qquad \textbf{(2)}$$

where

V_c = capacitor voltage in volts
Q_o = output charge in coulombs
C_i = the integrating capacitor in farads

In this unit, V_c is normally integrated on a 550-pF capacitor and is amplified with a gain of 5 by the internal amplifier.

The preamplifier output rise time will be ~80 ns or 2.2τ, whichever is greater, where τ is the major decay time constant of the scintillator (Table 4.1).

If the charge output is driven into a low impedance as a transmission line which is terminated in its characteristic impedance (Z_o), then the output peak current will be approximately $I_o = Q_o/\tau Z_o$. The rise time will be limited to about 20–50 ns by the PM tube. The voltage output under these conditions is $I_oZ_o = V_o$; Therefore:

$$V_o \cong \frac{Q_o}{\tau Z_o} \qquad \textbf{(3)}$$

Example:

Photomultiplier: RCA-8055, S-11 photocathode, gain 1×10^5 at 1.5 kV.

Scintillator: NaI.

Energy Deposited: ^{60}Co 1.33 MeV peak; from Eq. (1)

$$Q_o = \frac{1.33 \times 10^6\ eV}{70} \times 10\%$$

$$\times\ 2.4 \times 1 \times 10^6 \times 1.6 \times 10^{-19}$$

or

$$Q_o \approx 0.7 \times 10^{-10}\ coulomb.$$

This charge integrated on 500 pF and amplified by a gain of 5 as in this unit will be:

$$\frac{0.7 \times 10^{-10}\ coulomb}{500 \times 10^{-12}\ F} \times 5 = 0.7\ V$$

The rise time from Table 4.1 is 2.2 τ_2, or 550 ns.

The anode pulse into a 50-Ω terminated line will yield a current pulse of amplitude,

$$I_o \approx \frac{Q_o}{\tau} = \frac{0.7 \times 10^{-10}\ coulomb}{250 \times 10^{-9}\ s}$$

or

$$I_o \approx \frac{Q_o}{T} = \frac{0.7 \times 10^{-10}\, coulomb}{250 \times 10^{-9}\, S}$$

or

$$I_o \approx 0.28\ mA$$

and again the rise time will be ~20–50 ns, and the output voltage peak will be I_oR_o or V_{out} = 0.28 mA × 50 Ω = 14 mV.

4.2. TIMING APPLICATIONS

The different specific applications for the unit are essentially limitless, but since it is designed for timing as well as spectroscopy, two of the most often used coincidence systems are discussed and block diagrams given. From these two block diagrams other applications may be formulated by extension.

4.2.1. TYPICAL FAST-SLOW COINCIDENCE SYSTEM

The block diagram of Fig. 4.1 outlines a fast-slow coincidence system. The words “fast-slow” mean that there are essentially two channels of information retrieval operating in parallel. The fast channel sets the ultimate resolving time of the coincidence circuitry, while the slow channel selects the pulse height range to be accepted from each detector and by means of a slower coincidence requirement combines this with the fast coincidence requirement to yield information having the criteria of the fast resolving time of the fast channel and the energy selection of the slow channel simultaneously.

In the fast channel the timing amplifiers indicated may be the ORTEC 474 or equivalent or may be a combination of fast amplifier/fast discriminator such as the ORTEC 260 Time Pickoff Unit with the 402A Time Pickoff Control to extract fast timing information.

As shown in Fig. 4.1, the time spectrum from the time to amplitude converter is analyzed as the information channel. Of course, the output of the time-to-amplitude converter could be fed to the single channel analyzer to form an alternate fast coincidence channel, which could then feed the coincidence circuit and allow pulse height analysis of either detector channel as desired.

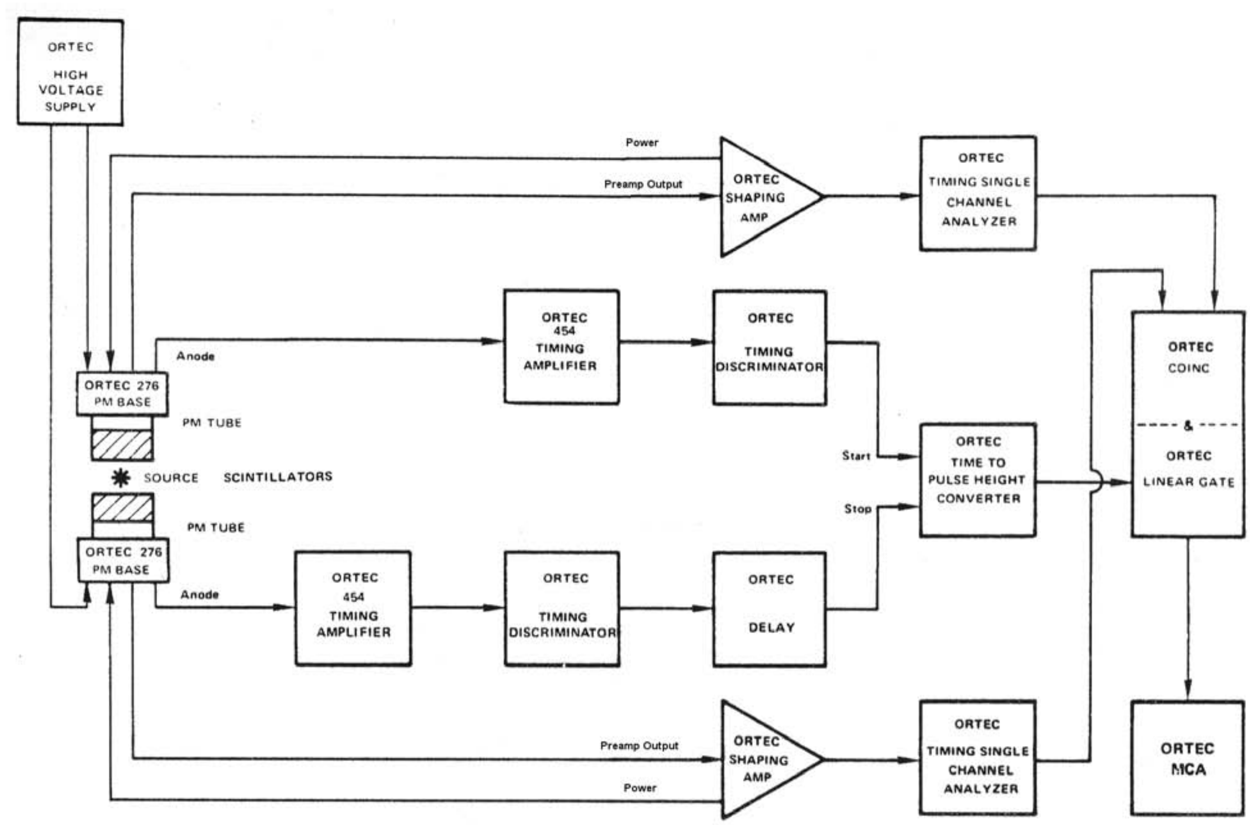


Fig. 4.1. Typical Fast-Slow Coincidence System Using Scintillators.

Figure 4.2 outlines a simple conventional crossover pick-off coincidence system, which is probably the easiest and most versatile method of doing coincidence when the ultimate resolving time is not required. This method is very easy to use; however, it results in a 2τ coincidence resolving time which is theoretically worse by a factor of ~12 than may be achieved by leading-edge timing such as was indicated in Fig. 4.1.

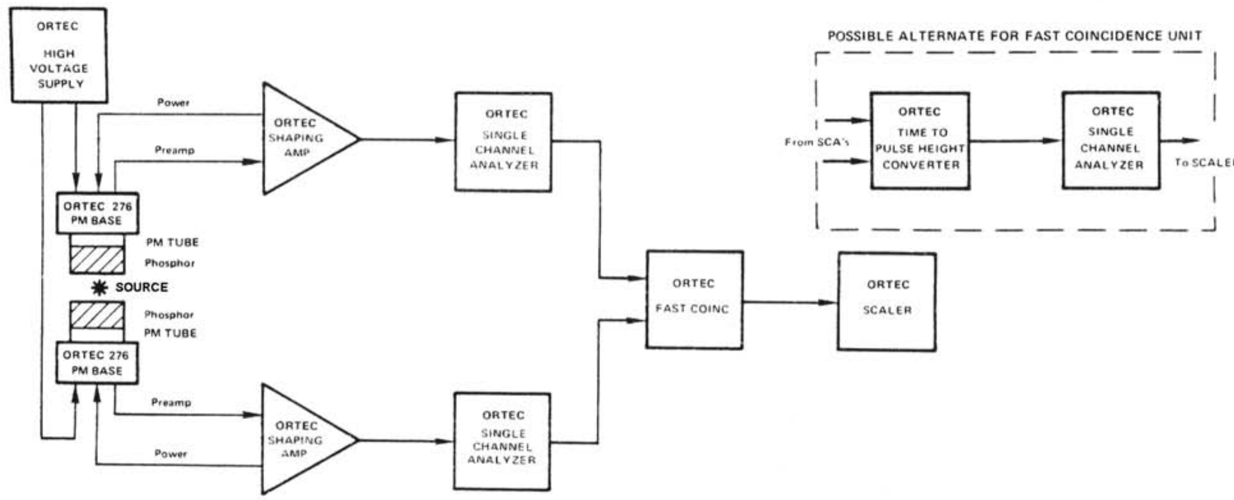


Fig. 4.2. Conventional Crossover Pickoff Coincidence System.

4.2.2. GAMMA-GAMMA COINCIDENCE SYSTEM FOR THE HIGH-PURITY GERMANIUM (HPGe) DETECTOR

Figure 4.3 is a block diagram of an experimental setup that is quite versatile for studying decay schemes and transitional levels by means of coincidence between an HPGe detector and a scintillation detector. With this block diagram the experimenter may study either energy information or time information associated with the coincidence events.

4.3. SCINTILLATION SPECTROSCOPY

Scintillation spectroscopy implies the measurement of energy by the direct conversion of energy to light in a scintillator and the detection thereof by the photomultiplier. The system to perform this function is one of the most simple, requiring only the phosphor, the photomultiplier, a base structure for the PM tube, a preamplifier, and a linear amplifier with some type of measuring device such as a multichannel analyzer (Fig. 4.4). With this system one may study directly the energy released in the phosphor by some incident radiation.

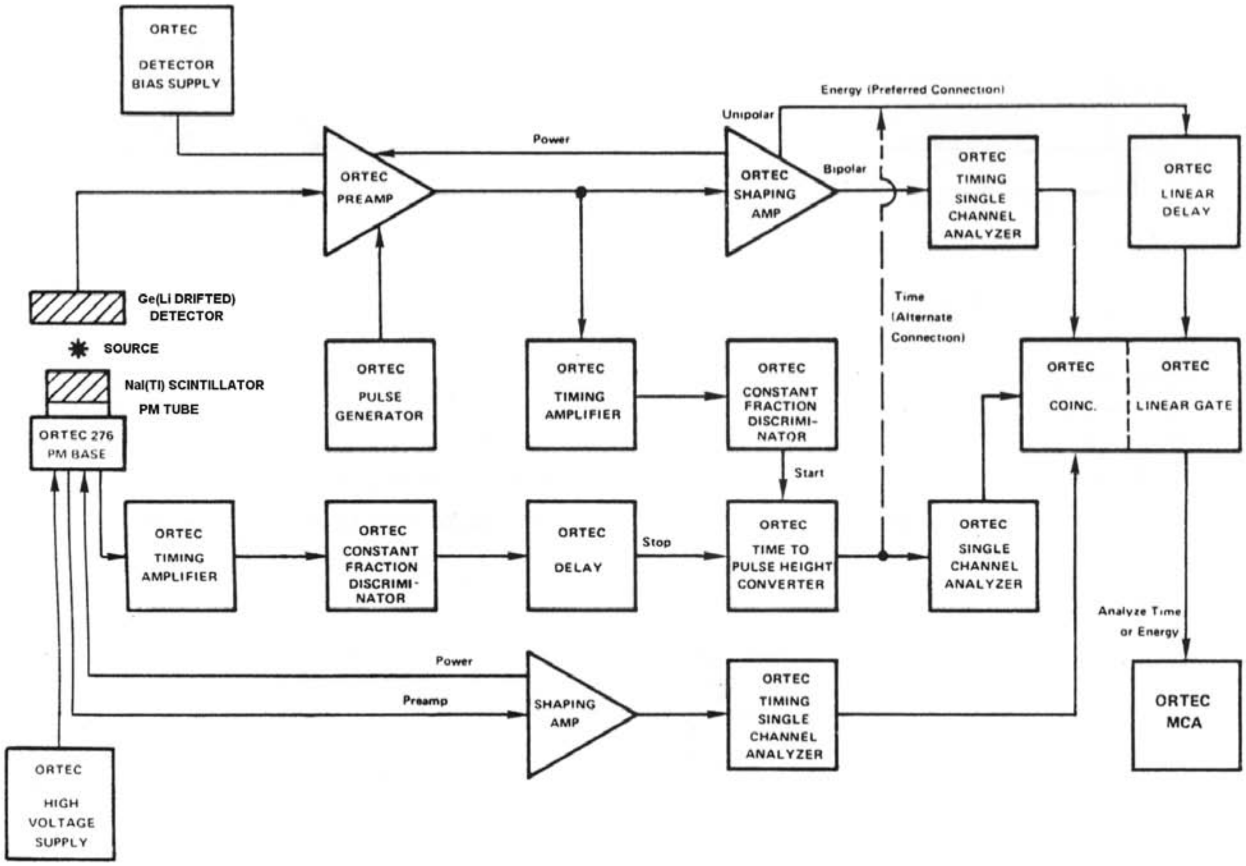


Fig. 4.3. Gamma-Gamma Coincidence System Using HPGe Detectors.

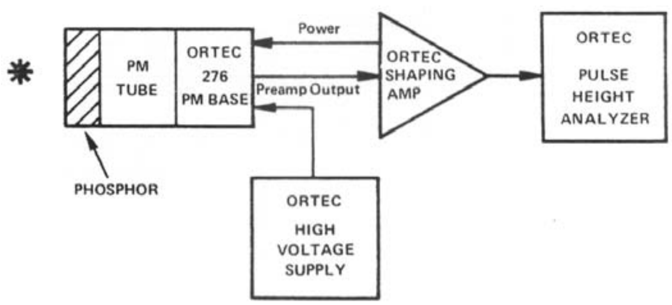


Fig. 4.4. Scintillation Spectrometry System.

5. MAINTENANCE

The resistor divider string of this unit is composed only of passive components; so the only maintenance to be expected is replacement of components that have failed because of age. Table 5.1 lists the approximate dynode voltages for comparative purposes. Almost all failures of the dynode string may be isolated by removing the PM tube and making these measurements. Use a voltmeter of >20,000 Ω/V for this measurement.

Since the amplifier is a high, open-loop gain (~6000) operational amplifier with feedback via R23 and R24, failure of almost any component will cause the output to go to a dc level of ~±5 V to ±24 V.

Troubleshooting involves a careful analysis of the dc levels from Table 5.2. Replacement of the parts is not critical except Q1–Q4 should be very high gain (β or hfe) low-noise NPN transistors. R19, R23, and R24 should be of precision metal film for low noise and good stability.

C7 should be a high quality dipped mica or silver mica capacitor.

D1 and D2 have no role in the amplifier operation and are provided for circuit protection only.

R19 × C7 product is the decay time constant. The 90% to 10% decay time in seconds should be ~2.2 × R19(Ω) × C7(F).

Dynamic testing can be done with a pulser connected to the test input. With the normal C_{test} of 100 pF and C7 of 500 pF the preamplifier output amplitude should be approximately the same amplitude and the same polarity as the pulser input. The decay time should be ~50–150 µs, depending on the pulser. If a long square wave is used for testing, the decay time should be ~110 µs, 90% to 10%. The rise time should be 80–100 ns.

5.1. FACTORY REPAIR

This instrument can be returned to the ORTEC factory for service and repair at a nominal cost. Our standard procedure for repair ensures the same quality control and checkout that are used to a new instrument. Always contact Customer Service at ORTEC, (865) 482-4411, before sending in an instrument for repair to obtain shipping instructions and so that the required Return Authorization Number can be assigned to the unit. Write this number on the address label and on the package to ensure prompt attention when it reaches the factory.

Table 5.1

HV = +2000 V	
PM Socket	**Voltage**
1	+330
2	+500
3	+660
4	+830
5	+1000
6	+1170
7	+1350
8	+1520
9	+1690
10	+1840
11	+2000
12	NC
13	0–+330 (Focus control).
14	Ground

Table 5.2. Preamplifier Voltages.

Power Cable	Nominal Volts	Volts (Min)	Volts (Max)
Pin 7	+24	+23	+25
Pin 6	−24	−23	−25
Preamplifier			
Q1b	0	−0.05	+0.05
Q1e	−0.6	−0.4	−0.8
Q1c	+16.4	+15.0	+17.5
Q2e	−1.2	−0.7	−1.5
Q3b	−0.6	−0.4	−0.8
Q4b	0	−0.1	+0.1
Q4c	+4.0	+2.0	+5.0
Q5e	+17.0	+16.0	+18.0
Q6b	+0.6	0	+1.1
Q6e	0	+0.5	−0.5
Q6c	+20.0	+18.0	+22.0
Q7b	−12.0	−11.0	−13.0
Q7e	−12.6	−11.6	−13.6
Q8e	−12.6	−11.6	−13.6

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