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**ORTEC**  
INCORPORATED

AN  **EG&G** COMPANY  
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# Model 460 Delay Line Amplifier

## Operating and Service Manual

**ORTEC**

Model 460

Delay Line Amplifier

Operating and Service Manual

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## STANDARD WARRANTY FOR ORTEC INSTRUMENTS

ORTEC warrants its instruments other than preamplifier FET input transistors, vacuum tubes, fuses, and batteries to be free from defects in workmanship and materials for a period of twelve months from date of shipment provided that the equipment has been used in a proper manner and not subjected to abuse. Repairs or replacement, at ORTEC option, will be made on in-warranty instruments, without charge, at the ORTEC factory. Shipping expense will be to the account of the customer except in cases of defects discovered upon initial operation. Warranties of vacuum tubes and semiconductors made by their manufacturers will be extended to our customers only to the extent of the manufacturers' liability to ORTEC. Specially selected vacuum tubes or semiconductors cannot be warranted. ORTEC reserves the right to modify the design of its products without incurring responsibility for modification of previously manufactured units. Since installation conditions are beyond our control, ORTEC does not assume any risks or liabilities associated with methods of installation or with installation results.

### QUALITY CONTROL

Before being approved for shipment, each ORTEC instrument must pass a stringent set of quality control tests designed to expose any flaws in materials or workmanship. Permanent records of these tests are maintained for use in warranty repair and as a source of statistical information for design improvements.

ORTEC must be informed in writing of the nature of the fault of the instrument being returned and of the model and serial numbers. Failure to do so may cause unnecessary delays in getting the unit repaired. Our 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 nearest ORTEC repair center. Instruments 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 will be repaired at the standard charge unless they have been grossly misused or mishandled, in which case the user will be notified prior to the repair being done. A quotation will be sent with the notification.

### DAMAGE IN TRANSIT

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 we may assist in damage claims and in providing replacement equipment if necessary.

**ORTEC<sup>®</sup>**  
**MODEL 460**  
**DELAY LINE AMPLIFIER**

FINE GAIN

0.5 0.8  
0.3 1

COARSE GAIN

50 100 200  
20 500  
10 1K

INTEG.  
μsec

0.25 0.1  
0.04

PZ ADJ POS  
NEG

INPUT  
UNIPOLAR

DC ADJ  
OUTPUT  
BIPOLAR

OUTPUT

+12V 75mA  
-12V 65mA  
+24V 90mA  
-24V 90mA

SER. 10041

BI UNIP

OUTPUTS  
93Ω

DELAY IN

OUT  
PREAMP

## 460 DELAY LINE AMPLIFIER

### 1. DESCRIPTION

#### 1.1. GENERAL

The ORTEC 460 Delay Line Amplifier is a nuclear pulse amplifier that provides delay-line shaping for all output pulses. It accepts input pulses of either polarity from the preamplifier and expands their amplitude by an adjusted gain factor within the range from 3 through 1000. An integrating time constant can be selected to shape the rise of the input pulse as desired. Pole-zero cancellation is adjustable to match the characteristic of the preamplifier output.

#### 1.2. DUAL OUTPUTS

Two output pulses are furnished for each input pulse. One is positive unipolar and is single-delay-line shaped; it can be furnished as either a prompt or delayed output pulse. The other is bipolar with positive polarity leading and is double-delay-line shaped. Both of these output pulse shapes are available through front panel connectors with an output impedance of  $1\Omega$  and through rear panel connectors with an output impedance of  $93\Omega$ .

The main use for the unipolar output pulses is for energy measurements. For this application the 460 provides high counting rate capabilities, excellent overload recovery, and dc adjustment of the output baseline. The unipolar output is preferred for both single-channel and multichannel analysis because of its low noise characteristic.

The main use for the bipolar output pulses is for timing measurements using baseline crossover as the timing indication. Double-delay-line shaping provides a precision time at the baseline crossover point that is independent of the pulse amplitude.

#### 1.3. POLE-ZERO CANCELLATION

Pole-zero cancellation is a method for eliminating pulse undershoot after the first differentiating network. The technique employed is described by referring to the waveforms and equations shown in Figs. 1.1 and 1.2. In an amplifier not using pole-zero cancellation, the exponential tail on the preamplifier output signal (usually 50 to 500  $\mu\text{sec}$ ) causes an undershoot whose peak amplitude is roughly

$$\frac{\text{undershoot amplitude}}{\text{differentiated pulse amplitude}} = \frac{\text{differentiation time}}{\text{preamplifier pulse decay time}}$$

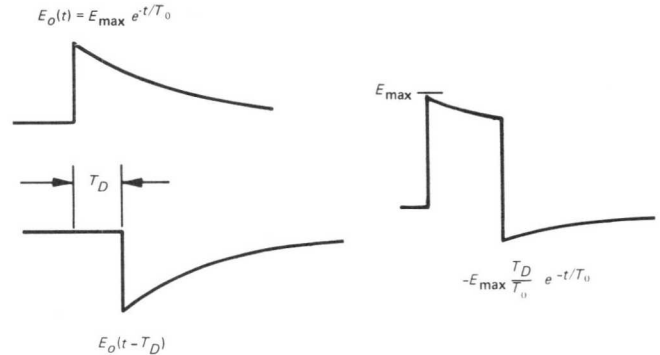


Fig. 1.1. Delay-Line Clipping Without Pole-Zero Cancellation.

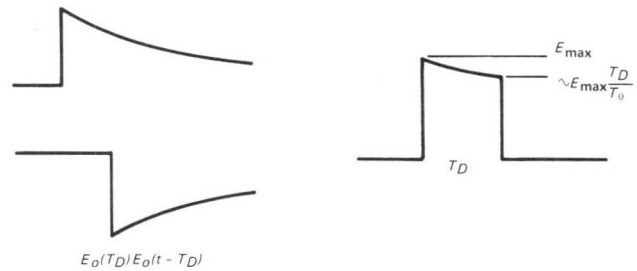


Fig. 1.2. Single-Delay-Line Shaped Pulse with Pole-Zero Cancellation.

For a  $1\text{-}\mu\text{sec}$  differentiation time and a  $50\text{-}\mu\text{sec}$  preamplifier pulse decay time, the maximum undershoot is 2% and decays with a  $50\text{-}\mu\text{sec}$  time constant. Under overload conditions this undershoot is often sufficiently large to saturate the amplifier during a considerable portion of the undershoot, causing excessive dead time. This effect can be reduced by increasing the preamplifier pulse decay time (which generally reduces the counting rate capabilities of the preamplifier) or compensating for the undershoot by using pole-zero cancellation.

In single-delay-line shaping, differentiation is accomplished by subtracting a delayed replica of the signal as shown in Fig. 1.1. The droop in the input signal during the delay time makes this subtraction imperfect, and a long undershoot is produced. A pole-zero cancellation eliminates this undershoot by adjusting the amplitude of the delayed signal as shown in Fig. 1.2.

Total preamplifier-amplifier pole-zero cancellation requires that the preamplifier output pulse decay time be a single exponential decay and matched to the pole-zero-cancellation network. The variable pole-zero-cancellation network

allows accurate cancellation for all preamplifiers having decay times of 25  $\mu\text{sec}$  or greater. The network is factory adjusted to 50  $\mu\text{sec}$ , which is compatible with all ORTEC FET preamplifiers. Improper matching of the pole-zero-cancellation network will degrade the overload performance and cause excessive pileup distortion at medium counting rates. Improper matching causes either an under-compensation (undershoot is not eliminated) or an over-compensation (output after the main pulse does not return

to the baseline and decays to the baseline with the pre-amplifier time constant). The pole-zero adjust is accessible from the front panel of the 460 and can easily be adjusted by observing the baseline with an oscilloscope while a monoenergetic source or pulser having the same decay time as the preamplifier under overload conditions is being used. The adjustment should be made so that the pulse returns to the baseline in the minimum time with no undershoot.

## 2. SPECIFICATIONS\*

### PERFORMANCE

**GAIN RANGE** 7-position Coarse Gain selection from 10 through 1000 and single-turn Fine Gain control from 0.3 through 1; total gain is the product of Coarse and Fine Gain settings.

**SHAPING FILTER** Front panel switch permits selection of integration time constant with  $\tau = 0.04, 0.1, \text{ or } 0.25 \mu\text{sec}$  (40, 100, or 250 nsec).

**INTEGRAL NONLINEARITY**  $\leq 0.05\%$ .

**NOISE**  $\leq 20 \mu\text{V}$  rms referred to input using 0.25  $\mu\text{sec}$  Integrate and maximum Gain of 1000;  $\leq 25 \mu\text{V}$  for Gain = 50;  $\leq 60 \mu\text{V}$  for Gain = 10.

### TEMPERATURE STABILITY

**Gain** 0.01 %/ $^{\circ}\text{C}$ , 0 to 50 $^{\circ}\text{C}$ .

**DC Level**  $\leq 0.1 \text{ mV}/^{\circ}\text{C}$ , 0 to 50 $^{\circ}\text{C}$ .

**CROSSOVER WALK** For constant gain, walk  $< \pm 1$  nsec for 20:1 dynamic range;  $< \pm 2$  nsec for 50:1;  $< \pm 2.5$  nsec for 100:1. Crossover shifts  $< \pm 4$  nsec for any adjacent Coarse Gain switch settings.

**COUNT RATE STABILITY** A pulser peak at 85% of analyzer range shifts less than 0.2% in the presence of 0 to  $10^5$  random counts/sec from a  $^{137}\text{Cs}$  source with its peak stored at 75% of analyzer range.

**OVERLOAD RECOVERY** Bipolar recovers to within 2% of rated maximum output in less than 5 nonoverload pulse widths from X500 overload; unipolar recovers in same time from X100 overload.

**TIME JITTER (50% Amplitude)**  $E_n^-(dv/dt)$ . FWHM = 29 psec for a Gain = 50 and  $E_0 = 10 \text{ V}$ ; FWHM = 2.9 psec for a Gain = 50 and  $E_0 = 100 \text{ mV}$ .

\*Checked in accordance with methods outlined in "IEEE Standards No. 301, USAS N42.2," *IEEE Transactions*, Vol NS-16(6) (December 1969).

**DELAY LINES** 1  $\mu\text{sec}$  standard  $\tau$ ; 0.25, 0.5, or 2.0  $\mu\text{sec}$   $\tau$  available. Both delay lines have the same value.

### CONTROLS

**FINE GAIN** Single-turn potentiometer for continuously variable gain factor of X0.3 to X1.

**COARSE GAIN** 7-position switch selects gain factors of X10, 20, 50, 100, 200, 500, and 1000.

**INPUT POLARITY** Slide switch, sets input circuit for either Pos or Neg input polarity.

**PZ ADJ** Potentiometer to adjust Pole-Zero cancellation for decay times from 25  $\mu\text{sec}$  to  $\infty$ .

**INTEG** Slide switch selects an integration time constant of 0.04, 0.1, or 0.25  $\mu\text{sec}$ ; for 0.04- $\mu\text{sec}$  setting, amplifier rise time is  $< 75$  nsec.

**DC ADJ** Potentiometer to adjust the dc level for single-delay-line shaped unipolar output pulses.

**DELAY IN/OUT** Slide switch on rear panel selects either 1- $\mu\text{sec}$  (In) or prompt (Out) timing for unipolar output pulses.

### INPUT

Accepts either polarity of pulses from preamplifier; front panel type BNC (UG-1094A/U) connector; maximum linear input 3.3 V; protected to 20 V;  $Z_{in} = 1 \text{ k}\Omega$ , dc-coupled.

### OUTPUTS

**UNIPOLAR** Prompt or delayed with full-scale linear range of 0 to +10 V; single-delay-line shaped; baseline level adjustable to  $\pm 1.0 \text{ V}$ ;  $Z_0 < 1\Omega$ , dc-coupled, through front panel BNC (UG-1094A/U) connector;  $Z_0 = 93\Omega$ , dc-coupled, through rear panel BNC (UG-1094/U) connector.

**BIPOLAR** Prompt output with positive lobe leading, double-delay-line shaped, with full-scale linear range of 0 to 10 V;  $Z_0 < 1\Omega$ , dc-coupled, through front panel BNC (UG-1094A/U) connector;  $Z_0 = 93\Omega$ , dc-coupled, through rear panel BNC (UG-1094/U) connector.

**PREAMP** Standard ORTEC power connector for mating preamplifier; Amphenol type 17-10090, rear panel.

## ELECTRICAL AND MECHANICAL

### POWER REQUIRED

+24 V, 90 mA; +12 V, 75 mA;  
-24 V, 90 mA; -12 V, 60 mA.

**WEIGHT (Shipping)** 4.25 lb (1.9 kg).

**WEIGHT (Net)** 2.25 lb (1 kg).

**DIMENSIONS** Standard single-width module (1.35 by 8.714 in.) per TID-20893 (Rev.).

## 3. INSTALLATION

### 3.1. GENERAL

The 460 contains no internal power supply but is used in conjunction with an ORTEC 401/402 Bin and Power Supply and is intended for rack mounting; therefore if vacuum tube equipment is operated in the same rack with the 460, there must be sufficient cooling by circulating air to prevent localized heating of the all-semiconductor circuitry used throughout the 460. The temperature of equipment mounted in racks can easily exceed 120°F (50°C) unless precautions are taken.

### 3.2. CONNECTION TO PREAMPLIFIER

The preamplifier output signal is connected to the 460 through the BNC connector on the front panel labeled Input. The input impedance is 1000 $\Omega$  and is dc-coupled to ground; therefore the output of the preamplifier must be either ac-coupled or have approximately zero dc voltage under no-signal conditions.

The 460 incorporates pole-zero cancellation in order to enhance the overload characteristics of the amplifier. This technique requires matching the network to the preamplifier decay time constant in order to achieve perfect compensation. The network is variable and factory-adjusted to 50  $\mu$ sec to approximately match all ORTEC FET preamplifiers. If other preamplifiers or more careful matching is desired, the adjustment is accessible from the front panel. Adjustment is easily accomplished by using a monoenergetic source and observing the amplifier baseline with an oscilloscope after each pulse under overload conditions. Adjustment should be made so that the pulse returns to the baseline in a minimum of time with no undershoot.

Preamplifier power of +24 V, +12 V, -24 V, and -12 V is available on the preamplifier power connector.

When using the 460 with a remotely located preamplifier (i.e., preamplifier-to-amplifier connection through 25 ft

or more of coaxial cable), care must be taken to ensure that the characteristic impedance of the transmission line from the preamplifier output to the 460 input is matched. Since the input impedance of the 460 is 1000 $\Omega$ , sending end termination will normally be preferred; i.e., the transmission line should be series-terminated at the output of the preamplifier. All ORTEC preamplifiers contain series terminations that are either 93 $\Omega$  or variable; coaxial cable type RG-62/U or RG-71/U is recommended.

### 3.3. CONNECTION OF TEST PULSE GENERATOR

**Connection to the 460 Through a Preamplifier** The satisfactory connection of a test pulse generator such as the ORTEC 419 or equivalent depends primarily on two considerations: the preamplifier must be properly connected to the 460 as discussed in Section 3.2, and the proper input signal simulation must be applied to the preamplifier. To ensure proper input signal simulation, refer to the instruction manual for the particular preamplifier being used.

**Direct Connection to the 460** Since the input of the 460 has 1000 $\Omega$  input impedance, the test pulse generator will normally have to be terminated at the amplifier input with an additional shunt resistor. If the test pulse generator has a dc offset greater than 1 V, a large series isolating capacitor is also required since the input of the 460 is dc-coupled. ORTEC Test Pulse Generators are designed for direct connection. When any of these units are used, they should be terminated with a 100 $\Omega$  terminator at the amplifier input or be used with at least one of the output attenuators set at 1n. (The small error due to the finite input impedance of the amplifier can normally be neglected.)

**Special Considerations for Pole-Zero Cancellation** The pole-zero-cancellation network in the 460 is factory-adjusted for a 50- $\mu$ sec decay time to match ORTEC FET

preamplifiers. When a tail pulser is connected directly to the amplifier input, the PZ Adj should be adjusted if overload tests are to be made (other tests are not affected). See Section 6.2 for the details.

If a preamplifier is used and a tail pulser is connected to the preamplifier test pulse input, similar precautions are necessary. In this case the effect of the pulser decay must be removed, i.e., a step input should be simulated. Details for this modification are also given in Section 6.2.

### 3.4. CONNECTION TO POWER

Turn off the Bin Power Supply when inserting or removing modules. The ORTEC NIM modules are designed so that it is not possible to overload the Bin Power Supply with a full complement of modules in the Bin. Since, however, this may not be true when the Bin contains modules other than those of ORTEC design, check the Power Supply after inserting the modules. The 401/402 has test points on the Power Supply control panel for monitoring the dc voltages.

### 3.5. SHAPING CONSIDERATIONS

The rise time of the output pulses from the 460 will be a function of the rise time furnished from the preamplifier and of the setting of the front panel Integ switch. When the switch is set at 0.04  $\mu\text{sec}$ , the rise time for a step input from the preamplifier will be less than 100 nsec. The 0.1- and 0.25- $\mu\text{sec}$  switch settings will provide proportionately longer rise times. Check the input specifications for the instrument into which the 460 output pulses will be furnished, and set the Integ switch at the position which satisfies these requirements, if any.

The 460 provides both unipolar and bipolar outputs. The unipolar output should be used in applications where the best signal-to-noise ratio (resolution) is desired, such as high-resolution energy spectroscopy using semiconductor detectors. Use of this output will also give excellent resolution at high counting rates when used with dc-coupled inputs in the subsequent equipment. The bipolar output should be used for time spectroscopy if the time signal is derived from a baseline crossover. The bipolar output is also useful for energy spectroscopy in high count rate systems when noise, or resolution, is a secondary consideration and when the analyzer system is ac-coupled.

### 3.6. SELECTION OF PROMPT OR DELAYED OUTPUT

The prompt unipolar output is obtained with the Delay switch set at Out. This will normally be used for spec-

troscopy applications. A delayed unipolar output is obtained with the Delay switch set at In, and the pulses will be delayed by 1  $\mu\text{sec}$  for a time adjustment in a coincidence system or when gating logic is to be performed on the bipolar output before the unipolar pulse arrives at the gate.

### 3.7. OUTPUT CONNECTIONS AND TERMINATING CONSIDERATIONS

There are three general methods of termination that are used. The simplest of these is shunt termination at the receiving end of the cable. A second method is series termination at the sending end. The third is a combination of series and shunt termination, where the cable impedance is matched both in series at the sending end and in shunt at the receiving end. The most effective method is the combination, but termination by this method reduces the amount of signal strength at the receiving end to 50% of that which is available in the sending instrument.

To use shunt termination at the receiving end of the cable, connect the 1 $\Omega$  output of the sending device through 93 $\Omega$  cable to the input of the receiving instrument. Then use a BNC tee connector to accept both the interconnecting cable and a 100 $\Omega$  resistive terminator at the input connector of the receiving instrument. Since the input impedance of the receiving instrument is normally 1000 $\Omega$  or more, the effective instrument input impedance with the 100 $\Omega$  terminator will be of the order of 93 $\Omega$ , and this correctly matches the cable impedance.

For series termination, use the 93 $\Omega$  output of the sending instrument for the cable connection. Use 93 $\Omega$  cable to interconnect this into the input of the receiving instrument. The 1000 $\Omega$  (or more) normal input impedance at the input connector represents an essentially open circuit, and the series impedance in the sending instrument now provides the proper termination for the cable.

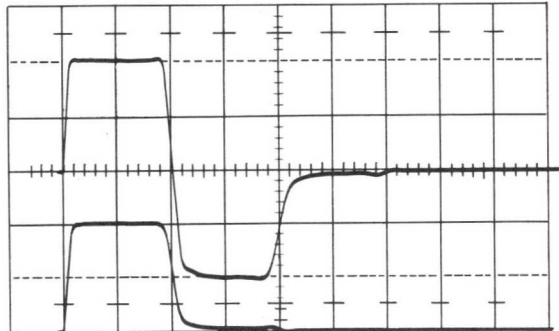
For the combination of series and shunt termination, use the 93 $\Omega$  output in the sending instrument for the cable connection and use 93 $\Omega$  cable. At the input for the receiving instrument, use a BNC tee to accept both the interconnecting cable and a 100 $\Omega$  resistive terminator. Note that the signal span at the receiving end of this type of receiving circuit will always be reduced to 50% of the signal span furnished by the sending instrument.

For your convenience, ORTEC stocks the proper terminators and BNC tees, or you can obtain them from a variety of commercial sources.

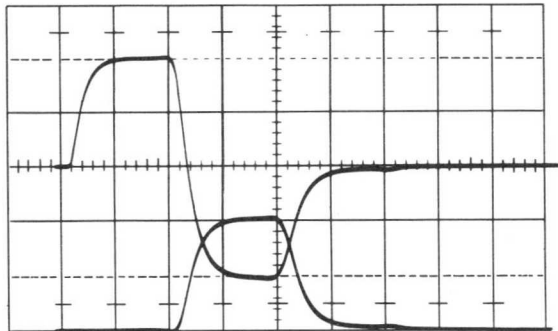
## 4. OPERATING INSTRUCTIONS

### 4.1. INITIAL TESTING AND OBSERVATION OF PULSE WAVEFORMS

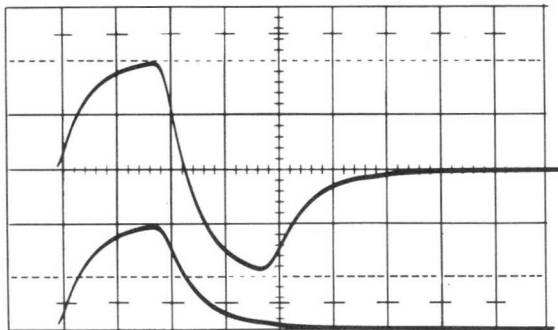
Refer to Section 6 for information on testing performance and observing waveforms at front panel test points. Figure 4.1 shows some typical output waveforms.



Integ Time 0.04  $\mu\text{sec}$ , Unipolar Prompt.



Integ Time 0.1  $\mu\text{sec}$ , Unipolar Delayed.



Integ Time 0.25  $\mu\text{sec}$ , Unipolar Prompt.

**Fig. 4.1. Typical Effects of Integrate Time Selection on Output Waveforms.** All waveforms taken with horizontal = 2  $\mu\text{sec}/\text{cm}$  and vertical = 5 V/cm.

### 4.2 FRONT PANEL CONTROLS

**GAIN** A coarse-gain switch and a fine-gain potentiometer select the gain factor. The gain is read directly; switch

positions are 10, 20, 50, 100, 200, 500, and 1000, and continuous fine-gain range is 0.3 to 1.

**INPUT POLARITY** Slide switch sets the input circuit for either Pos or Neg input polarity.

**PZ ADJ** Control to set the pole-zero cancellation for optimum matching to the preamplifier pulse decay characteristics, range 25  $\mu\text{sec}$  to infinity.

**DC ADJ** Potentiometer to adjust the dc level of unipolar output; range  $\pm 1.0$  V.

**DELAY** Slide switch selects either 1- $\mu\text{sec}$  delay (In) or prompt (Out) output of the unipolar signals.

**INTEG** 3-position switch selects integrate time constants of 0.04, 0.1, and 0.25  $\mu\text{sec}$ .

### 4.3. FRONT PANEL CONNECTORS (All Type BNC)

**INPUT** Positive or negative with rise time 10 to 650 nsec; decay time must be greater than 25  $\mu\text{sec}$  for proper pole-zero cancellation. Input impedance is 1000 $\Omega$  dc-coupled. Maximum linear input signal is 3.3 V with a maximum limit of  $\pm 20$  V.

**OUTPUTS** Two BNC connectors with output impedance of  $< 1\Omega$ . Each output can provide up to 10 V and is dc-coupled and short-circuit protected:

**Unipolar** The dc level is adjustable for offset to  $\pm 1.0$  V. The unipolar pulse shape is determined by a 1- $\mu\text{sec}$  delay line. Linear range is 0 to +10 V.

**Bipolar** Bipolar pulse is prompt with positive lobe leading and the pulse is double-delay-line shaped. Linear range is 0 to  $\pm 10$  V. The crossover walk of this output is  $< \pm 2.5$  nsec for 100:1 dynamic range.

### 4.4. REAR PANEL CONNECTORS

**OUTPUTS** The unipolar and bipolar pulses are brought to the rear panel on BNC connectors. The specifications of these outputs are the same as those for the front panel connectors except that the output impedance is 93 $\Omega$  at these connectors.

**PREAMP POWER** Standard power connector for mating with ORTEC preamplifiers;  $\pm 24$  V and  $\pm 12$  V.

### 4.5. OPERATION WITH SEMICONDUCTOR DETECTORS

**Calibration of Test Pulser** The ORTEC 419 Pulser, or equivalent, is easily calibrated so that the maximum pulse height dial reading (1000 divisions) is equivalent to 10-

MeV loss in a silicon radiation detector. The procedure is as follows:

1. Connect the detector to be used to the spectrometer system, i.e., preamplifier, main amplifier, and biased amplifier.
2. Allow particles from a source of known energy (alpha particles, for example) to fall on the detector.
3. Adjust the amplifier gain and the bias level of the biased amplifier to give a suitable output pulse.
4. Set the pulser Pulse Height potentiometer at the energy of the alpha particles striking the detector (e.g., for a 5.47-MeV alpha particle, set the dial on 547 divisions).
5. Turn on the Pulser, and use the Normalize potentiometer and attenuators to set the output due to the pulser for the same pulse height as the pulse obtained in step 3. Lock the Normalize dial and do not move again until recalibration is necessary.

The pulser is now calibrated; the Pulse Height dial reads in MeV if the number of dial divisions is divided by 100.

**Amplifier Noise and Resolution Measurements** As shown in Fig. 4.2, the preamplifier, amplifier, pulse generator, oscilloscope, and a wide-band rms voltmeter such as the Hewlett-Packard 400D are required for this measurement. Connect a suitable capacitor to the input to simulate the detector capacitance desired. Use the following procedure to obtain the resolution spread due to amplifier noise:

1. Measure the rms noise voltage ( $E_{rms}$ ) at the amplifier output.
2. Turn on the ORTEC 419 Precision Pulse Generator and adjust the pulser output to any convenient readable voltage,  $E_0$ , as determined by the oscilloscope.

The full width at half maximum (FWHM) resolution spread due to amplifier noise is then

$$N(\text{FWHM}) = \frac{2.66 E_{rms} E_{dial}}{E_0}$$

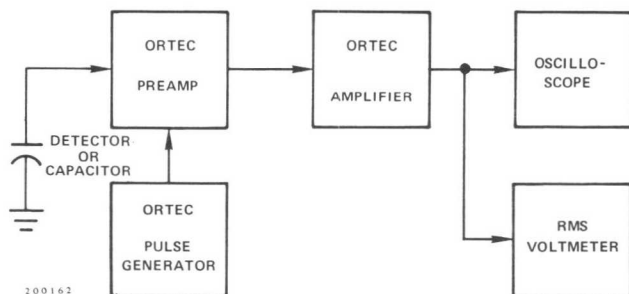


Fig. 4.2. System for Measuring Amplifier and Detector Noise Resolution.

where  $E_{dial}$  is the pulser dial reading in MeV, and 2.66 is the factor for rms to FWHM (2.34) and noise to rms meter correction (1.13) for average-indicating voltmeters such as the Hewlett-Packard 400D. A true rms voltmeter does not require the latter correction factor.

Figure 4.3 shows the amplifier noise generated by the 460. It is a function of both the integrating time constant and of the gain setting. The portion of the curves between a gain of 3.3 and a gain of 10 reflects variations in settings of the Fine Gain control while the Coarse Gain is set at 10. All of the remaining portions of the curves reflect the Coarse Gain switch while the Fine Gain control remains at maximum. Wherever possible, the Fine Gain control should be set within the upper portion of its range in order to minimize the amplifier noise.

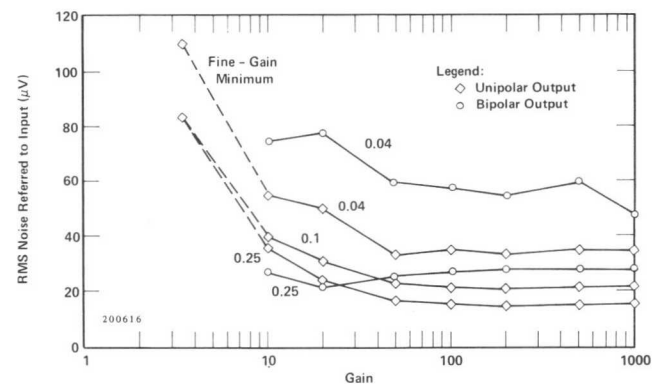


Fig. 4.3. Noise as a Function of Gain and Integrating Time Constant in the ORTEC 460 Delay Line Amplifier.

**Detector Noise Resolution Measurements** The same measurement just described can be made with a biased detector instead of the external capacitor used to simulate the detector capacitance. The resolution spread will be larger because the detector contributes both noise and capacitance to the input. The detector noise resolution spread can be isolated from the amplifier noise spread if the detector capacity is known, since

$$(N_{det})^2 + (N_{amp})^2 = (N_{total})^2,$$

where  $N_{total}$  is the total resolution spread and  $N_{amp}$  is the amplifier resolution spread with the detector replaced by its equivalent capacitance.

The detector noise tends to increase with bias voltage, but the detector capacitance decreases, thus reducing the resolution spread. The overall resolution spread will depend upon which effect is dominant. Figure 4.4 shows curves of typical total noise resolution spread versus bias voltage, using the data from several ORTEC silicon surface-barrier semiconductor radiation detectors.

## BIAS VOLTAGE

**Amplifier Noise and Resolution Measurements Using a Pulse Height Analyzer** Probably the most convenient,

method of making resolution measurements is with a pulse height analyzer as shown by the setup illustrated in Fig. 4.5.

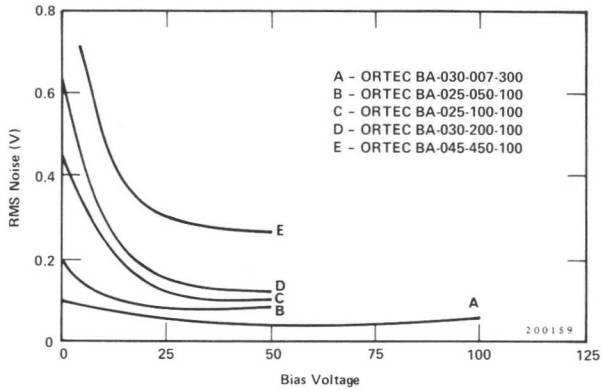


Fig. 4.4. Noise as a Function of Bias Voltage.

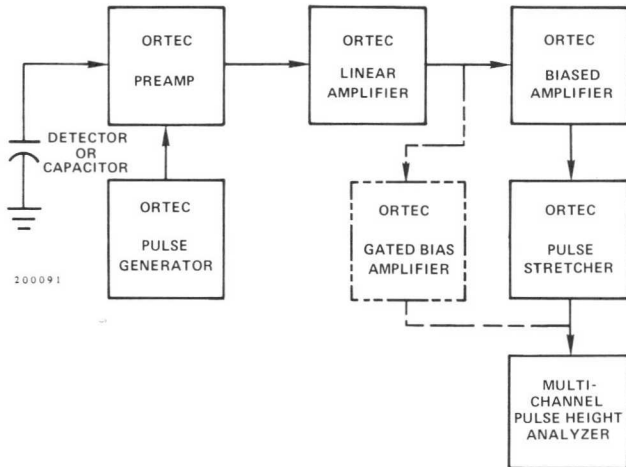


Fig. 4.5. System for Measuring Resolution with a Pulse Height Analyzer.

The amplifier noise resolution spread can be measured directly with a pulse height analyzer and the mercury pulser as follows:

1. Select the energy of interest with an ORTEC 419 Pulse Generator, and set the Amplifier and Biased Amplifier Gain and Bias Level controls so that the energy is in a convenient channel of the analyzer.
2. Calibrate the analyzer in keV per channel, using the pulser (full scale on the pulser dial is 10 MeV when calibrated as described in "Calibration of Test Pulser").
3. Then obtain the amplifier noise resolution spread by measuring the FWHM of the pulser spectrum.

The detector noise resolution spread for a given detector bias can be determined in the same manner by connecting a detector to the preamplifier input. The amplifier noise resolution spread must be subtracted as described in

"Detector Noise Resolution Measurement." The detector noise will vary with detector size and bias conditions and possibly with ambient conditions.

#### Current-Voltage Measurements for Silicon and Germanium Detectors

The amplifier system is not directly involved in semiconductor detector current-voltage measurements, but the amplifier serves well to permit noise monitoring during the setup. The detector noise measurement is a more sensitive method of determining the maximum detector voltage that should be used, because the noise increases more rapidly than the reverse current at the onset of detector breakdown. Make this measurement in the absence of a source.

Figure 4.6 shows the setup required for current-voltage measurements. The ORTEC 428 Bias Supply is used as the voltage source. Bias voltage should be applied slowly and reduced when noise increases rapidly as a function of applied bias. Figure 4.7 shows several typical current-voltage curves for ORTEC silicon surface-barrier detectors.

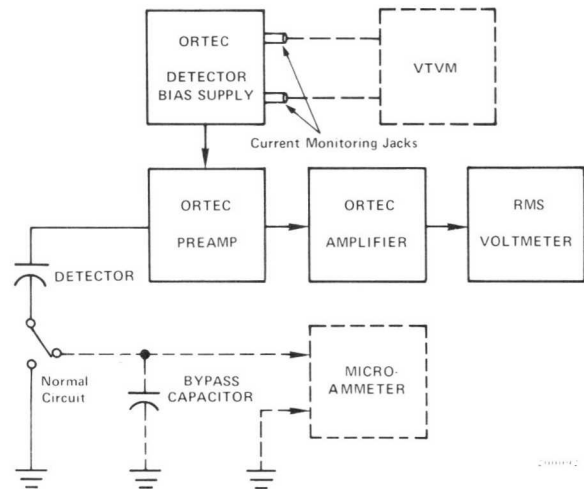


Fig. 4.6. System for Detector Current and Voltage Measurements.

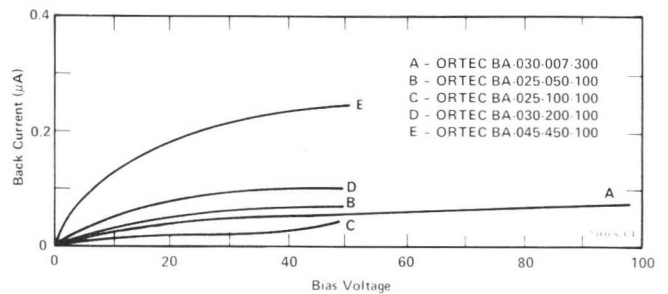


Fig. 4.7. Silicon Detector Back Current vs Bias Voltage.

When it is possible to float the microammeter at the detector bias voltage, the method of detector current measurement shown by the dashed lines in Fig. 4.6 is

preferable. The detector is grounded as in normal operation, and the microammeter is connected to the current monitoring jack on the 428 Detector Bias Supply.

**Preamplifier—Main Amplifier Gain Adjustments as a Function of Input Particle Energy** With the input energy at a constant, or maximum, known value, the following method is recommended for adjusting the total system gain of the preamplifier and main amplifier to an optimum value:

1. The primary design criterion for the preamplifier is the best signal-to-noise ratio at the output; therefore operate the preamplifier with the gain switch in its maximum gain position. This will result in the best signal-to-noise ratio available, and at the same time the absolute voltage amplitude of the preamplifier signal will be maximized.
2. Since the fine-gain control of the 452 is an attenuator, set it to as near maximum as possible by manipulating the coarse gain.

#### 4.6. OPERATION IN NEUTRON-GAMMA DISCRIMINATION SYSTEM WITH STILBENE AND LIQUID SCINTILLATORS

The single-delay-line shaped output pulses from the ORTEC 460 are suited ideally to the input requirements of the ORTEC 458 Pulse Shape Discriminator. When these instruments are included in the system, a neutron-gamma discrimination can be effected such that the amplifier output pulses can also be routed into a multichannel analyzer, with the gamma spectrum stored in one half of the analyzer and the neutron spectrum stored in the other half of the analyzer.

**Theory** Neutrons and gammas produce light scintillations in NE-213, NE-218,\* and Stilbene detectors with significantly different decay characteristics. The 10% to 90% rise time ( $t_R$ ) of the integrated light from all the scintillators is approximately 130 nsec when excited with neutrons and approximately 10 nsec when excited with gamma rays.<sup>1\*\*</sup> The scintillation is not a simple exponential as is illustrated by Kuchnir and Lynch,<sup>1</sup> but consists of a combination of at least four components, as illustrated by their results shown in Table 4.1.

\*Nuclear Enterprises, Ltd., San Carlos, California.

\*\*See "References" at the end of this section.

Table 4.1

Scintillator	Mean Life Time <sup>a</sup> (nsec)	Mean Decay Time <sup>b</sup> (nsec)			No. of Photoelectrons per keV Energy Loss <sup>c</sup>
		$\tau_2$	$\tau_3$	$\tau_4$	
Stilbene	0.1	4.05	33	270	2.3
NE-213	1.66	3.16	32.3	270	1.7
NE-213M	1.34	5.41	30.5	285	1.9
NE-218	1.76	3.58	36.5	288	2.0
Anthracene					3.6
Nal(Tl)					8.8

<sup>a</sup> For energy transfer from solvent to solute.

<sup>b</sup> First 3 components by the light output in organic scintillators.

<sup>c</sup> Represents loss in the scintillator when coupled to an RCA-8575 photomultiplier with good light collection.

Three parameters determine the ability to distinguish between gammas and neutrons: the total number  $R$  of photoelectrons produced at the cathode for a given energy of excitation, the shape  $f(t)$  of the light scintillation for both neutrons and gammas, and the photoelectron level  $j$  at which the pulse shape information is deduced.

If one assumes that the neutron and gamma can be characterized with an effective single decay time, the probability distribution function for the  $j$ th photoelectron out of a total of  $R$  photoelectrons is given by the statistical order equation<sup>2</sup>

$$g(t) = \frac{R!}{(j-1)!(R-j)! \tau} [1 - e^{-t/\tau}]^{j-1} e^{-t(R-j)/\tau} \quad (1)$$

The following analysis is based on a first-order approximation of the pulse shape. If more exact results are desired, refer to the work of Kuchnir and Lynch.

Assuming an effective exponential for the scintillation permits one to obtain a better understanding of how the three parameters affect the neutron-gamma separation. The mean time for the  $j$ th photoelectron is given by<sup>3</sup>

$$t_j = \tau \ln \frac{R}{R-j} = \tau \ln \frac{1}{1-F} \quad (2)$$

where  $F$  is the ratio or the fraction  $j/R$ . The variance in time of the  $j$ th photoelectron is given by

$$\sigma_j^2 = \tau^2 \sum_{k=0}^j \left( \frac{1}{R-k} \right)^2 \quad (3)$$

The width of the time distribution varies directly with  $\tau$  and the photoelectron level  $j$  but inversely with  $R$ , the total number of electrons. Therefore as the fraction at which the time information is derived increases toward unity, the separation of the neutron and gamma increases but the time resolution is poorer. The object is to choose a photoelectron level that will minimize the overlap of rise time of the neutron and gamma-ray signals. Kuchnir and Lynch<sup>1</sup> by using the measured distributions and a more general-order equation predicted the optimum separation to exist when the fraction of pulse height used is between 0.8 and 0.9. The ORTEC 458 was designed to take advantage of the optimum trigger point.

Consider a typical example where Eqs. (2) and (3) can be used to predict the separation of neutrons and gamma rays. Assume the following experimental conditions:

1. The neutron pulse height is equal to the gamma-ray pulse-height equivalent of 100-keV electron energy, or 500-keV neutrons.
2. The scintillator is NE-213 on an RCA-8575 photomultiplier producing 1.7 photoelectrons/keV of electron energy.