EG&G ORTEC

Subsidiary of EG&G, Inc.

PHYSICS 191/247 LAB

June 1991

S/N 1713

Model 450

Research Amplifier

Operating and Service Manual

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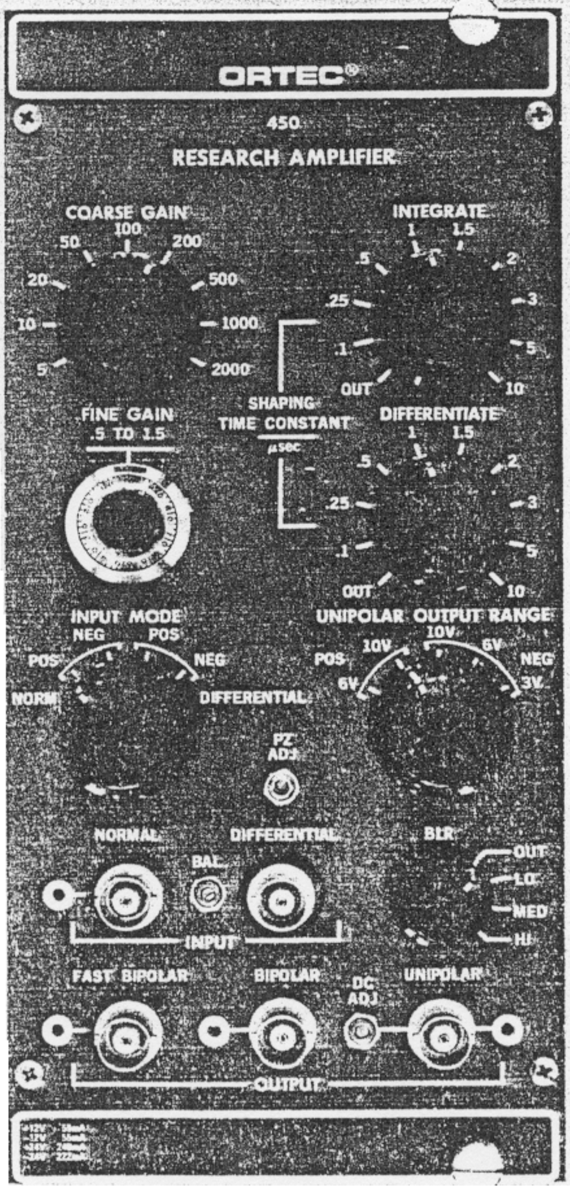

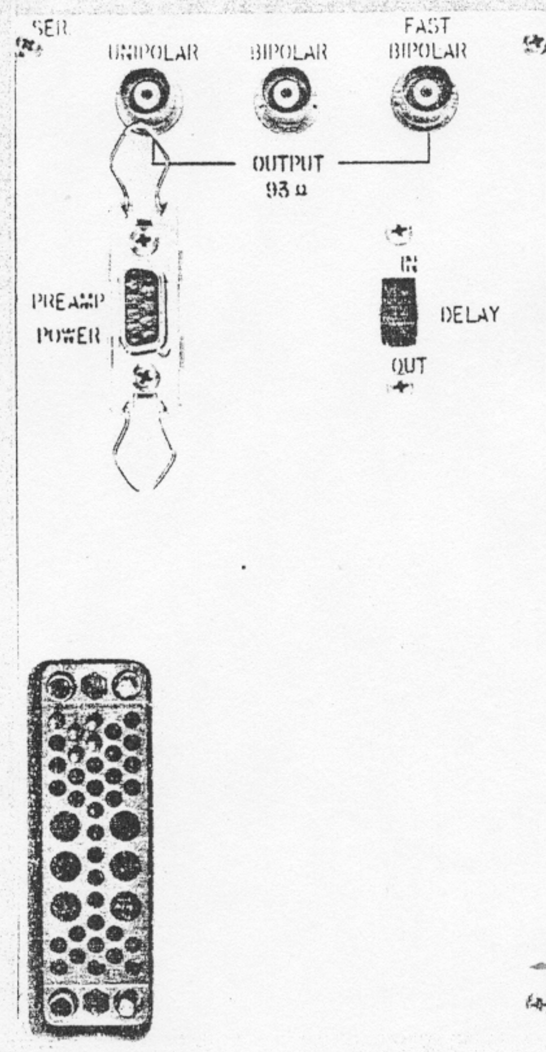

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ORTEC 450 RESEARCH AMPLIFIER

1. DESCRIPTION

1.1 GENERAL

The ORTEC 450 Research Amplifier is an extremely versatile instrument module, intended for use with all pulse-type radiation detectors and preamplifiers and also for linear amplification of any frequency spectrum within the design limits of the Amplifier. The unit exhibits superior performance for overload recovery, resolution, linearity, and stability and has a very low noise.

Its many features provide a wide flexibility in applications. The Amplifier may be operated with single-ended or differential input with either polarity, and the differential mode is especially useful when common mode noise is present. The low-frequency bandpass has a selectable range from 100 Hz to 1.5 MHz, while the high-frequency bandpass has a separately selectable range from 8 kHz to 1.5 MHz. The switchable time constant choices have been selected for optimization of nuclear spectrometry systems.

The 450 produces three different types of linear output pulses. The Fast Bipolar Output is a fixed bandwidth pulse with rise time of 150 nsec. It is normally doubly differentiated for a zero-crossover point at approximately 700 nsec. In the wide-band mode the bandwidth extends from 100 Hz to above 2.0 MHz. The gain range from input to Fast Bipolar Output is 2.5 to 3000, directly readable on front-panel gain selection.

The Bipolar Output has a selectable pulse shape, using both the Integrate and Differentiate time constant selections. When the wide-band mode is used, the bandpass through this output is from 100 Hz to 1.0 MHz.

The Unipolar Output has a selectable pulse shape for optimum filtering, baseline restoration (switch selectable) for low-frequency noise reduction, and improved count rate performance, polarity, and −3-V, ±6-V, or ±10-V range voltage selection to interface all analyzer coupling ADC requirements, and can be delayed to simplify gating of the signal. When the wide-band mode is used, the bandpass through the Unipolar output is from 100 Hz to 1.5 MHz, and the gain range is from 4 to 5000. Unipolar BLR, polarity, range, and delay are independent of Fast Bipolar and Bipolar Outputs.

Semi-Gaussian shaping by the active-filter network optimizes the signal-to-noise ratio. The relative input noise, using a 3-μsec time constant, is less than 3.5 μV rms. Noise varies approximately inversely as the square root of the time constant. For a gain of 50 or more, input noise is independent of the gain setting.

The 450 Fast Bipolar and Bipolar Outputs can be used for crossover timing when used in conjunction with the crossover circuit in an ORTEC 260 Time Pickoff unit or in a 420A or 455 Single Channel Analyzer. The 420A output has a minimum walk as a function of pulse amplitude and incorporates a variable delay time on the output pulse to enable the crossover pickoff output to be placed in time coincidence with other outputs.

The output impedance of the 450 is less than 0.1Ω. The output can be connected to other equipment by a single cable going to all equipment and shunt-terminated at the receiving end (and series terminated at the amplifier if reflections are a problem) or by separate cables for each instrument, with each cable series-terminated at the amplifier.

Gain changing is accomplished by changing the feedback ratio of operational amplifiers. In using this technique, the bandwidth of the feedback amplifier stages involved in gain switching is maintained essentially constant regardless of gain, and therefore rise-time changes with gain switching (which cause crossover walk) are limited to small capacitive effects across the feedback resistors.

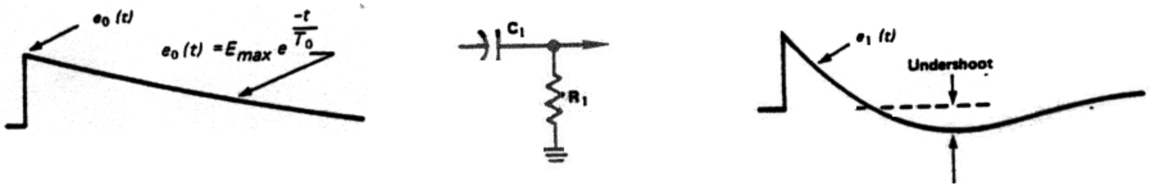
The Delayed Output of the 450 is useful for experiments involving both energy analysis and coincidence timing. In this case a timing signal for coincidence can be derived from the crossover of the Fast Bipolar or Bipolar Output. Energy analysis is performed on the output of either the Unipolar or Bipolar signal, and the delay time compensates for the time loss in crossover timing and time delays in the coincidence circuit. When the Fast Bipolar Output is used for timing, the delay may not be necessary.

The 450 is contained in a triple-width NIM-standard module. The unit has no self-contained power supply; power is obtained from a NIM-standard Bin and Power Supply, such as the ORTEC 401A/402A. The 450 design is consistent with other modules in the ORTEC 400 Series, i.e., it is not possible to overload the Bin power supply with a full complement of modules in the Bin.

1.2 POLE-ZERO CANCELLATION

Pole-zero cancellation is a method of eliminating pulse undershoot after the first clipping (differentiating) network.[1] The technique employed is described by referring to the waveform and equations shown in Figs. 1.1 and 1.2. In

1. Veljko Radeka, "Effect of 'Baseline Restoration' on Signal-to-Noise Ratio in Pulse Amplitude Measurements," *Rev. Sci. Inst.* **38**(10), 1397 (1967).



Charge loop output × First differentiation network = Differentiated pulse with undershoot

$$E_{max}\, e^{\frac{-t}{T_0}} \times G(t) = e_1(t)$$

$$E_{max} \frac{}{s + \frac{1}{T_0}} \times \frac{}{s + \frac{1}{R_1 C_1}} = E_1(s)\text{; Laplace Transform}$$

$$\frac{E_{max}}{T_0 - T_1}\, T_0\, e^{\frac{-t}{T_1}} - T_1\, e^{\frac{-t}{T_0}} = e_1(t)\text{, where } T_1 = R_1 C_1$$

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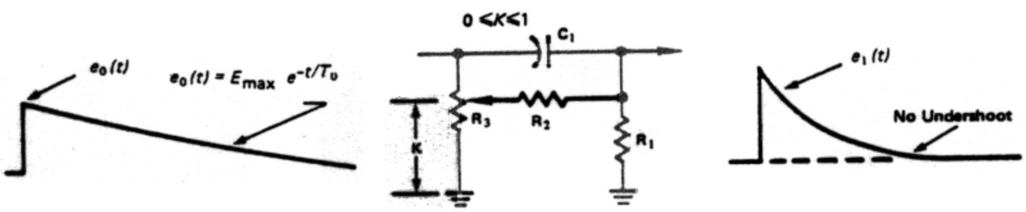
Fig. 1.1. Clipping in an Amplifier Without Pole-Zero Cancellation.



Charge loop output × Pole-zero cancelled differentiation network = Differentiated pulse without undershoot

Pole zero cancel by letting $s + \frac{1}{T_0} = s + \frac{K}{R_2 C_1}$

$$E_{max}\, e^{\frac{-t}{T_0}} \times G(t) = e_1(t)$$

$$\frac{E_{max}}{s + \frac{R_1 + R_2}{R_1 R_2 C_1}} = \frac{E_{max}}{s + \frac{1}{R_p C_1}} = E_1(s)\text{, where } R_p = \frac{R_1 R_2}{R_1 + R_2}$$

$$E_{max} \frac{}{s + \frac{1}{T_0}} \times \frac{s + \frac{K}{R_2 C_1}}{s + \frac{R_1 + R_2}{R_1 R_2 C_1}} = E_1(s)\text{; Laplace Transform}$$

$$E_{max}\, e^{\frac{-t}{R_p C_1}} = e_1(t)$$

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Fig. 1.2. Differentiation (Clipping) in a Pole-Zero-Cancelled Amplifier.

an amplifier without pole-zero cancellation the exponential tail on the preamplifier output signal (usually 50 to 500 μsec) causes an undershoot whose peak amplitude is roughly

$$\frac{\text{undershoot amplitude}}{\text{clipped pulse amplitude}} = \frac{\text{clipping time}}{\text{preamplifier pulse decay time}}$$

For a 1-μsec clipping time and a 50-μsec preamplifier pulse decay time, the maximum undershoot is 2% and decays with a 50-μsec time constant. Under overload conditions this undershoot is often large enough to saturate the amplifier during a considerable portion of the undershoot causing excessive dead time. The 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.

Pole-zero cancellation is accomplished by the network shown in Fig. 1.2. The pole $[1/s + (1/T_0)]$ due to the preamplifier pulse decay time is cancelled by the zero $[s + (K/R_2C_1)]$ of the network. In effect the dc path across the clipping capacitor adds an attenuated replica of the preamplifier pulse to just cancel the negative undershoot of the clipping network.

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 35 μsec or greater decay times.

The network is factory adjusted to 50 μsec, 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 undercompensation (undershoot is not eliminated) or an overcompensation (output after the main pulse does not return to the baseline and decays to the baseline with the preamplifier time constant). The pole-zero adjust is accessible from the front panel of the 450 and can be adjusted easily by observing the baseline under overload conditions with a monoenergetic source or pulser having the same decay time as the preamplifier input.

1.3 ACTIVE FILTER

When only grid current and shot noise (gate current and drain thermal noise for an FET) are considered, the best signal-to-noise ratio occurs when the two noise contributions are equal for a given pulse shape. At this point there is also an optimum pulse shape for the optimum signal-to-noise ratio. Unfortunately, this shape (the cusp shown in Fig. 1.3) is very difficult to simulate. A pulse shape that can be simulated (the Gaussian in Fig. 1.3) requires a single RC differentiate and n equal-RC integrates, where n approaches infinity. The Laplace transform of this transfer function is

$$G(s) = \frac{s}{s + 1/RC} \times \frac{1}{(s + 1/RC)^n} \quad n \to \infty ,$$

where the first factor is the single differentiate and the second factor is the n integrates. The 450 active filter attempts to simulate this transfer function with the simplest possible circuit.

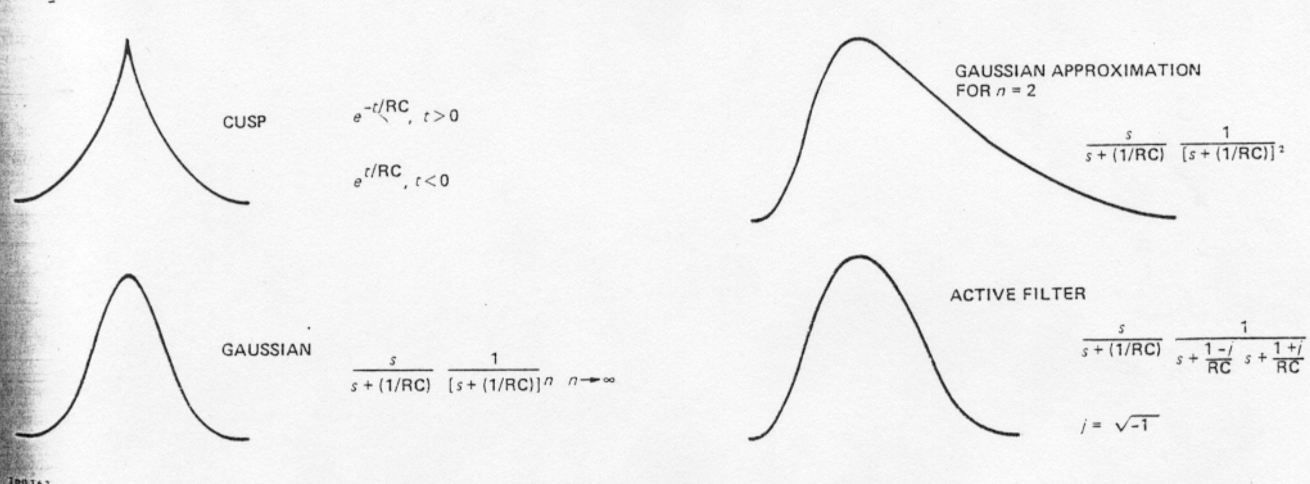
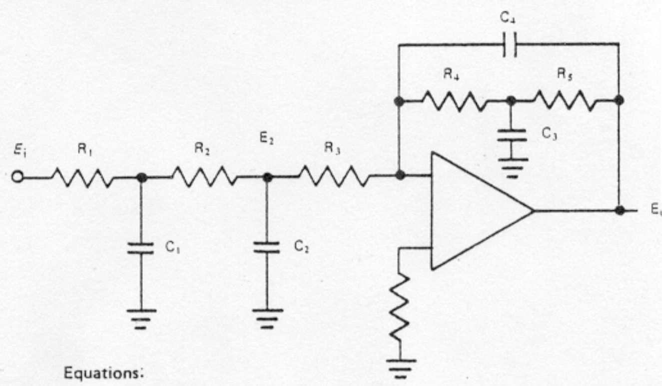


Fig. 1.3. Pulse Shapes for Good Signal-to-Noise Ratios.

The ORTEC 450 active filter is shown in Fig. 1.4, together with the equations that define its transfer function. This is an RC filter network, eliminating inductive elements and achieving the desired results with a significant reduction of size, complexity, and cost.



Equations:

$$\frac{E_2}{E_i} = \frac{1}{(R_2 C_2 s + \frac{R_2}{R_3} + 1)(R_1 C_1 s + \frac{R_1}{R_2} + 1)}$$

$$\frac{E_0}{E_2} = \frac{R_5 C_4 s + \frac{R_5}{R_4} + 1}{R_3 \, [R_5 C_3 C_4 s^2 + C_3 (\frac{R_5}{R_4} + 1) s + \frac{1}{R_4}]}$$

In the 450

$C_1 = C_2$ and $R_4 = R_5$ and $R_1 = R_3$ 200327

Fig. 1.4. ORTEC 450 Active Filter.

The 450 is designed with independent switch-selectable integrate and differentiate time constants of 0.1, 0.25, 0.5, 1.0, 1.5, 2, 3, 5, and 10 μsec.

1.4 BASELINE RESTORER

All stages of the 450 are designed to operate with equal efficiency with either polarity pulse to ±10 V or a full 20-V peak-to-peak sine wave. The Baseline Restorer circuit restores only for positive pulses, and an input polarity switch is included on the front panel for that purpose.

2. SPECIFICATIONS

PERFORMANCE

GAIN RANGE 2.5 to 3000, for equal time constants, or 4.0 to 5000 for wide-band mode on Bipolar and Unipolar Outputs.

TEMPERATURE STABILITY 0 to 50°C.
Gain ≤±50 ppm/°C of rated output.
DC Level ≤±50 μV/°C.

INPUT NOISE Using 3-μsec pulse shaping, ≤3.5 μV rms for gain settings >50, measured on Unipolar Output; ≤16 μV rms on Fast Bipolar Output.

INTEGRAL NONLINEARITY
Fast Bipolar <0.2%.
Unipolar <0.05%.
Bipolar <0.05%.

OVERLOAD RECOVERY
Fast Bipolar Recovery from X500 overload in ~8.0 μsec.
Bipolar and Unipolar Recovery from X500 overload in 2.5 nonoverloaded pulse widths when PZ Adjust is correct.
Filters Pulses are shaped by Active element, with independent Integrate (Low-pass) and Differentiate (High-pass) selection.

CONTROLS

COARSE GAIN 9-position front-panel switch, for gain factors of X5 through X2000.

FINE GAIN 10-turn precision potentiometer, for continuously variable gain factors from X0.5 to X1.5. Product of Coarse gain and Fine gain settings yields total gain for equal time constants.

PZ ADJ Front-panel screwdriver adjustment to optimize the amplifier to the preamplifier; adjustable from 35 μsec to dc.

INPUT MODE Front-panel switch selects Normal or Differential input and polarity.

BAL Front-panel screwdriver adjustment to obtain optimum common mode rejection and to equalize the Pos polarity gain.

UNIPOLAR OUTPUT RANGE Front-panel switch selects polarity and gain (X1, X0.6, or X0.3) of the Unipolar Output.

INTEGRATE Low-pass filter time constant selector, front-panel switch; choices are 0.1, 0.2, 0.5, 1.0, 1.5, 2.0, 3.0, 5.0, and 10.0 μsec and Out.

DIFFERENTIATE High-pass filter time constant selector, front-panel switch; choices are 0.1, 0.2, 0.5, 1.0, 1.5, 2.0, 3.0, 5.0, and 10.0 μsec and Out (for wide-band with $\tau_d \simeq 3.5$ msec).

BLR Front-panel baseline restoration rate selector; Hi for duty cycles >20%; Med for duty cycles >5% <20%; Lo for duty cycles <5%; and Out.

DC ADJ Multiturn screwdriver adjustment for Unipolar Output baseline; range ±1.0 V.

DELAY Normally 1 μsec, selected In or Out by rear-panel switch. Other delays are available upon request.

INPUTS

INPUTS Positive or negative, normal or differential through front-panel BNC connectors; ±12 V max; each input impedance is 1000Ω, dc-coupled, with no limit on signal shape. For pulse operation the fall time constant should be >35 μsec. Common mode rejection ratio is ≥1000:1 at greater than 1 μsec time constant, ≥10,000:1 at 60 Hz.

OUTPUTS

OUTPUTS All signal outputs are on both front and rear panels. Z_o ≤ 1Ω, front panel, provides ±10 V into 100Ω load. Z_o = 93Ω, rear panel. All are dc-coupled and short-circuit and duty-cycle protected BNC connectors.

FAST BIPOLAR OUTPUT Bipolar; t_r ~120 nsec, gain 2.5 to 3000; crossover walk ≤±2 nsec for 50:1 dynamic range with Differentiate Out, fixed bandwidth is 100 Hz to >2 MHz, gain 2.5 to 3000.

BIPOLAR OUTPUT Bipolar, except when the Differentiate selector is set at Out and f_{lo} ≈ 100 Hz; otherwise frequency response is determined by choice of Integrate and Differentiate time constants. The low-frequency response is set by two equal Differentiate selected time constants.

UNIPOLAR OUTPUT Provides separate selection of polarity, delay, and gain (X1, X0.6, X0.3), as well as baseline restoration rate selection (Hi, Med, Lo, or Out); high- and low-frequency responses are determined by selected Integrate and Differentiate time constants.

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

ELECTRICAL AND MECHANICAL

POWER REQUIRED +24 V, 240 mA; +12 V, 55 mA;
−24 V, 220 mA; −12 V, 55 mA.

WEIGHT (Shipping) 7.5 lb (3.4 kg).

WEIGHT (Net) 5.5 lb (2.5 kg).

DIMENSIONS Standard triple-width NIM module (4.05 × 8.714 in.) per TID-20893 (Rev).

3. INSTALLATION

3.1 GENERAL

The 450, used in conjunction with a 401A/402A Bin and Power Supply, is intended for rack mounting, and therefore vacuum tube equipment operating in the same rack with the 450 must be sufficiently cooled by circulating air to prevent any localized heating of the all-semiconductor circuitry used throughout the 450. The temperature of equipment mounted in racks can easily exceed 120°F (50°C) unless these precautions are taken.

3.2 CONNECTION TO PREAMPLIFIER

The preamplifier output signal is connected to the 450 through the BNC connector labeled Normal Input. The input impedance seen at the input is 1000Ω and is dc-coupled to ground; therefore the output of the preamplifier must be either ac-coupled or have zero dc voltage under no-signal conditions.

The 450 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 μsec to match all ORTEC FET preamplifiers. If other preamplifiers or more careful matching is desired, the trim is accessible from the amplifier front panel. Adjustment is accomplished easily by using a monoenergetic source and observing the amplifier baseline after each pulse overload condition, adjusting the PZ Adj for minimum overshoot.

Preamplifier power of ±12 V and ±24 V is available on the preamplifier power connector on the rear panel.

When using the 450 with a remotely located preamplifier (i.e., preamplifier-to-amplifier connection through 25 ft or more of coaxial cable), ensure that the characteristic impedance of the transmission line from the preamplifier output to the 450 input is matched. Since the input impedance of the 450 is 1000Ω, 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 93Ω or variable.

Differential inputs of the 450 can be used simultaneously to reduce common mode noise picked up by long cables passing noise generating areas.[2,3] In this mode of operation the preamplifier signal is connected to the Normal Input, and a separate identical cable in intimate contact with the first cable (the use of Twinax cable is preferable) is connected from the preamplifier ground to the Diff Input. In order to balance the noise cancellation, it is sometimes necessary to insert a small variable resistor between the actual preamplifier ground and the center conductor of the second (ground signal) cable. In the event the output polarity of the amplifier pulse is negative, the polarity is reversed easily by the Input Mode selector.

2. Ralph Morrison, ***Grounding and Shielding Techniques in Nuclear Instrumentation***, Wiley, New York, 1967, Chapters 5, 6, and 9.

3. R.D. Eckard, "Common Mode Voltage Rejection in a Low Level Data Acquisition System," ***Noise Reduction Conference March, 1968***, Conf. 680303, Lawrence Radiation Lab., Livermore, Calif.

3.3 CONNECTION OF TEST PULSE GENERATOR

3.3.1 Connection Through a Preamplifier The satisfactory connection of a test pulse generator such as the ORTEC 448, 419, or equivalent depends primarily on two considerations: the preamplifier must be properly connected to the 450 as discussed in Section 3.2, and the proper input signal simulation must be supplied to the preamplifier. To ensure proper input signal simulation, refer to the instruction manual for the particular preamplifier being used.

3.3.2 Direct Connection to the ORTEC 450 Since both inputs of the 450 have 1000Ω input impedance, the test pulse generator will normally have to be terminated at the amplifier input with an additional shunt resistor. In addition, if the test pulse generator has a dc offset, a large series isolating capacitor is required since the inputs to the 450 are dc-coupled to the first amplifier stage. The ORTEC 419 or 448 Pulse Generator is designed for direct connection. When either of these units is used, it should be terminated with a 100Ω terminator at the amplifier input. (The small error due to the finite input impedance of the amplifier can normally be neglected.)

3.3.3 Special Considerations for Pole-Zero Cancellation The pole-zero cancellation network in the ORTEC 450 is factory adjusted for a 50-μsec decay time to match ORTEC FET preamplifiers. When the tail pulser (such as the ORTEC 419 or 448) is connected directly to one of the amplifier inputs, the pulser should be modified to obtain a 50-μsec decay time if overload tests are to be made (other tests are not affected). See Section 6.2 for the details on this modification.

If a preamplifier is used and a tail pulser is connected to the preamplifier pulser 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

The 450 contains no internal power supply and therefore must obtain power from a Nuclear-standard Bin and Power Supply such as the ORTEC 401A/402A. Turn off the Bin power supply before inserting or removing modules. The ORTEC 400 Series is 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, the Power Supply voltages should be checked after the modules are inserted. The ORTEC 401A/402A has test points on the Power Supply control panel to monitor the dc voltages.

3.5 SHAPING CONSIDERATIONS

The shaping times on the ORTEC 450 Amplifier are switch-selectable in steps of 0.1, 0.25, 0.5, 1, 1.5, 2, 3, 5, and 10 μsec. The choice of the proper shaping time is generally a compromise between operating at high counting rates and operating with the best signal-to-noise ratio. For scintillation counters the energy resolution largely depends on the scintillator, and therefore a shaping time of about four times the decay time constant of the scintillator is a reasonable choice (for NaI, a 1-μsec shaping time is about optimum). For gas proportional counters the collection time is normally in the 0.5- to 5-μsec range, and a 2-, 3-, or 5-μsec shaping time will generally give optimum resolution. For silicon semiconductor detectors a 1- or 2-μsec shaping time and for germanium detectors a 2- or 3-μsec shaping time will generally provide optimum resolution. When a charge-sensitive preamplifier is used, the optimum shaping time will also be at the point of minimum output noise. Since the 450 maintains nearly constant gain for all shaping modes of equal time constants, the optimum shaping time can be obtained by using an rms voltmeter to monitor the output noise.

The 450 allows a choice of either unipolar or bipolar output. The bipolar output should be used when the analyzer system is ac-coupled, high counting rates are desired, and noise or resolution is a secondary consideration. The unipolar output pulse should be used in applications where the best signal-to-noise ratio (resolution) is desired. This area is primarily high-resolution spectroscopy using semiconductor detectors. Use of the unipolar output with baseline restoration will also give good resolution at higher counting rates.

3.6 USE OF DELAYED OUTPUT

The Prompt output is used for normal spectroscopy applications. The Delayed output (equal in amplitude to the Prompt output, but delayed by 1 μsec) is used in coincidence experiments where the output must be delayed to compensate for time delays in obtaining the coincidence information. The considerations regarding the proper choice of shaping for the Delayed output are discussed in Section 3.5.

3.7 OUTPUT TERMINATION

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

For series termination, use the 93Ω output of the sending instrument for the cable connection. Use 93Ω cable to interconnect this into the input of the receiving instrument. The 1000Ω (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 93Ω output in the sending instrument for the cable connection and use 93Ω cable. At the input for the receiving instrument, use a BNC tee to accept both the interconnecting cable and a 100Ω 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.

3.8 SHORTING OR OVERLOADING THE AMPLIFIER OUTPUTS

All outputs of the 450 are dc-coupled with an output impedance of about 0.1Ω. If the output is shorted with a direct short circuit or the amplifier counting range exceeds 35% duty cycle, the output stage will limit the peak current output so that the amplifier will not be harmed.

4. OPERATING INSTRUCTIONS

4.1 FRONT-PANEL CONTROLS

GAIN A Course Gain switch and a Fine Gain ten-turn locking precision potentiometer select the gain factor. For equal time constants the gain is read directly; switch positions are 5, 10, 20, 50, 100, 200, 500, 1000, and 2000, and continuous Fine Gain range is 0.5 to 1.5 (500 to 1500 dial divisions). For wide band selection, gain to the Unipolar and Bipolar outputs is multiplied by an additional factor of 1.5.

If using unequal integrate and differentiate time constants, the output pulse gain will be different from that read on the panel. For instance, with small differentiate time and large integrate time, the gain will be much smaller than normal; and conversely with large differentiate time and small integrate time, the gain will be much larger than that selected.

INPUT MODE A selector switch, to accept linear inputs of either polarity through either the Normal or Differential input connector.

PZ ADJ Control to set the Pole-Zero Cancellation for optimum matching to the preamplifier pulse decay characteristics; range 35 μsec to dc.

DIFFERENTIAL BAL Trim potentiometer control to obtain optimum common mode rejection for a differential input and to match normal Pos and Neg gain.

SHAPING TIME CONSTANT Two switches for independent selection of the Integrate and Differentiate time constants; marked in μsec. Pulse-shaping time constant selections are 0.1, 0.25, 0.5, 1, 1.5, 2, 3, 5, or 10 μsec and Out.

UNIPOLAR OUTPUT RANGE Switch selects the polarity and gain for the Unipolar output only. Full-scale voltage ranges are ±10 V, ±6 V, and −3 V. Compatible with present- and past-generation analyzer ADC input requirements.

RESTORATION RATE (BLR) Switch to select the Baseline Restorer function. Hi is for duty cycles >20%, Med is for 5 to 20%, and Lo is for duty cycles <5%. Out disables the function.

DC ADJ Controls the Unipolar Output dc level, with an offset range of ±1.0 V.

4.2 REAR-PANEL CONTROL

Delay In/Out is a rear-panel slide switch to determine whether Unipolar outputs will be delayed (In) or will be prompt (Out).

4.3 FRONT-PANEL CONNECTORS (All Type BNC)

INPUTS Two connectors, used for either Normal or Differential input pulses. Each accepts either positive or negative input pulses, ±12 V max, into 1000Ω, dc-coupled. There is no limit on signal shape. The preamplifier pulse should have a decay time constant of greater than 35 μsec for proper PZ cancellation.

OUTPUTS Three connectors, one for each type of output, $Z_o \leq 0.1\Omega$. Each output can provide up to ±10 V, and it is dc-coupled and short-circuit and duty-factor protected for 350 mW maximum rms output power (±35% duty cycle).

FAST BIPOLAR Bipolar, positive portion leading, rise time <150 nsec, f_{lo} = 160 kHz, crossover at ~800 nsec, gain range 2.5 to 3000. Crossover walk ≤±2 nsec for 20:1 dynamic range. Bandwidth 100 Hz to above 2 MHz with Differentiate Out.

BIPOLAR Bipolar, with pulse shape selected by the Integrate and Differentiate switches. With Differentiate switch at Out, bandpass is from 100 Hz to 1.0 MHz.

UNIPOLAR This output features separate selection for full-voltage range, polarity, and baseline restoration rate. The dc level is adjustable for offset to ±1.0 V for the full 10-V range. The Unipolar pulse shape is determined by the settings of the Integrate and Differentiate shaping-time constant switches. Unipolar range, polarity, and BLR and Delay are independent of Fast Bipolar and Bipolar Outputs. See Fig. 4.1 for output pulse waveforms.

4.4 REAR-PANEL CONNECTORS

OUTPUTS Three type BNC connectors, one for each type of output. Same as the three Output connectors described for the front panel except that Z_o = 93Ω.

PREAMP POWER Standard power connection for a mating ORTEC preamplifier, ±24 V and ±12 V.

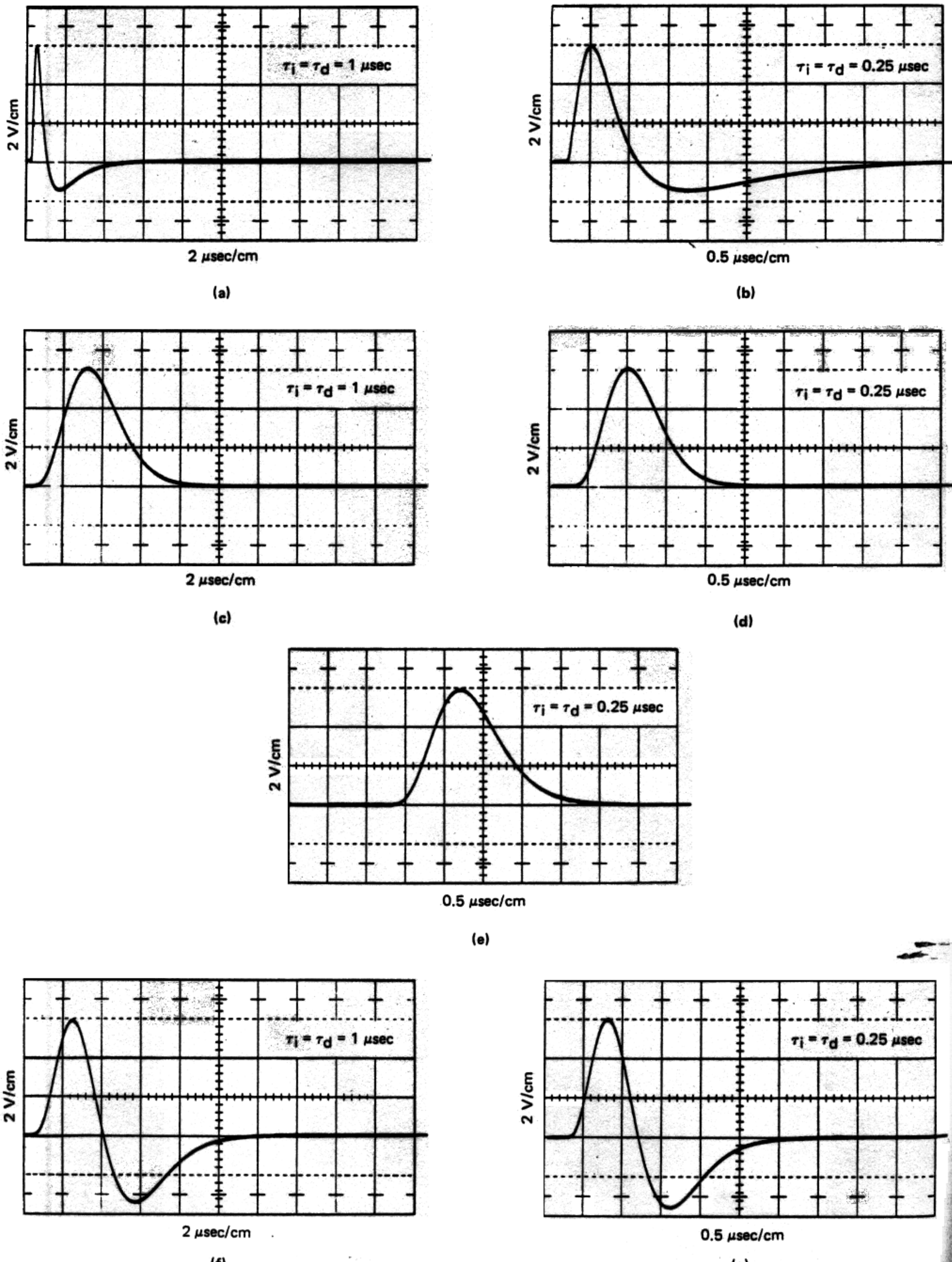


Fig. 4.1. Pulse Waveforms and Time Alignments of the 450 Outputs. (a) and (b) Fast Bipolar; (c) and (d) Prompt Unipolar; (e) 1-μsec-delayed Unipolar; (f) and (g) Bipolar.

4.5 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 waveforms.

4.6 GENERAL CONSIDERATIONS FOR OPERATION WITH SEMICONDUCTOR DETECTORS

4.6.1 Calibration of Test Pulser The ORTEC 419 pulser, or equivalent, may easily be 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. (See typical pulse waveforms and time alignment in Fig. 4.1.)

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, 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 above.

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

4.6.2 **Amplifier Noise and Resolution Measurements** As shown in Fig. 4.2, the preamplifer, 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:

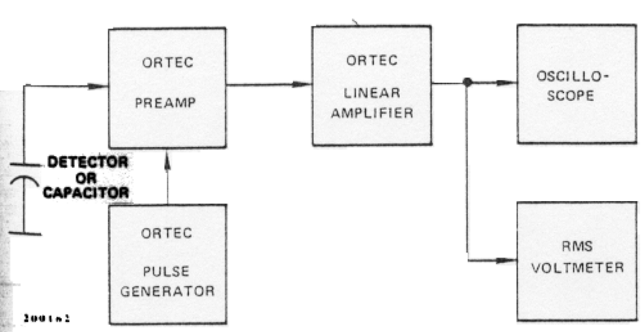


Fig. 4.2. **System for Noise and Resolution Measurements.**

1. Measure the rms noise voltage (E_{rms}) at the amplifier output.

2. Turn on the ORTEC 419 mercury relay pulse generator and adjust the pulser output to any convenient readable voltage, E_o, as determined by the oscilloscope.

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

$$N\ (\text{FWHM}) = \frac{2.35\ E_{rms}\ E_{dial}}{E_o}$$

where E_{dial} is the pulser dial reading in MeV and the factor 2.35 is the correction factor for rms to FWHM. To obtain E_{rms} from an average indicating voltmeter, such as the Hewlett-Packard 400D, multiply $E_{av} \times 1.13$.

The resolution spread will depend upon the total input capacitance, since the capacitance degrades the signal-to-noise ratio much faster than the noise. A typical resolution spread versus external input capacitance for the ORTEC 120 Preamplifier and the 450 Amplifier is shown in Fig. 4.3.

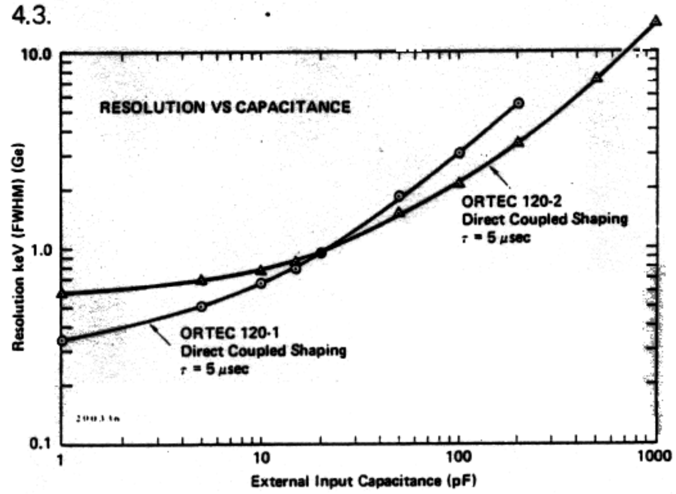


Fig. 4.3. Resolution Effects of Capacitance.

4.6.3 Detector Noise Resolution Measurements The same measurement described in Section 4.6.2 can be made with a biased detector instead of the external capacitor used to stimulate 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 semiconductor radiation detectors.

4.6.4 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.

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 Active Filter 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 Section 4.6.1).

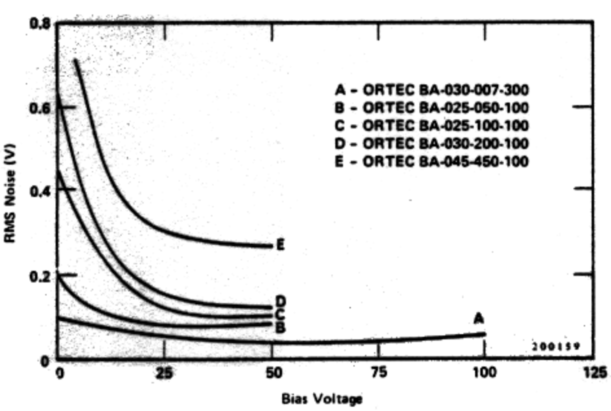


Fig. 4.4. Noise as a Function of Bias Voltage.

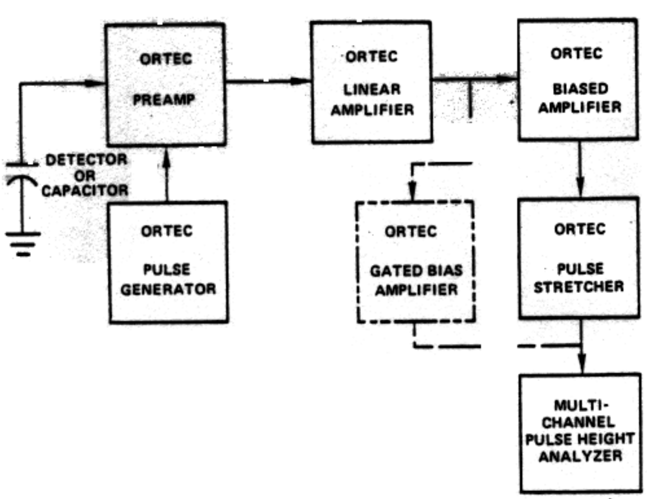


Fig. 4.5. System for Measuring Resolution with a Pulse Height Analyzer.

3. The amplifier noise resolution spread can then be obtained by measuring the full width at half maximum 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 Section 4.6.3. The detector noise will vary with detector size, bias conditions, and possibly with ambient conditions.

4.6.5 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 which 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 Detector 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 detectors.

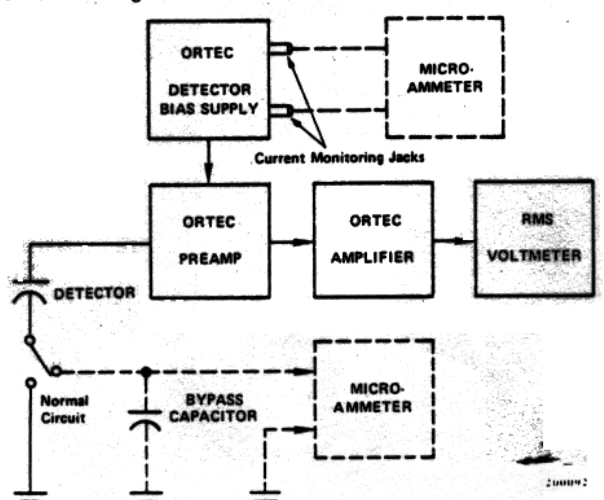


Fig. 4.6. System for Detector Current and Voltage Measurements.

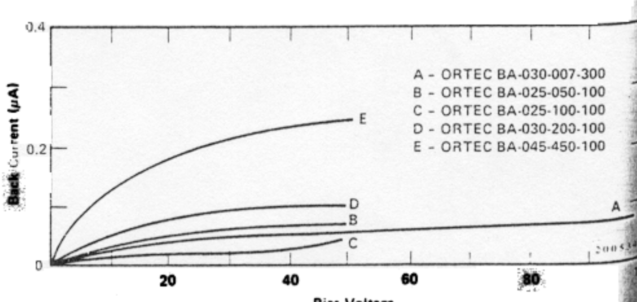


Fig. 4.7. Silicon Detector Back Current vs Bias Voltage.

When it is possible to float the microammeter at the detector bias voltage, the alternate 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 voltmeter is connected to the current monitoring jack on the 428 Detector Bias Supply.

4.6.6 **Recommended Method for Preamplifier—Main Amplifier Gain Adjustments as a Function of Input Particle** Energy With the input energy at a constant, or maximum, known value the total system gain of the preamplifer and main amplifier can be adjusted to an optimum value by utilizing the following general considerations:

1. The primary design criterion for the preamplifier is the best signal-to-noise ratio at the output; therefore the preamplifier should be operated 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 450 is an attenuator, it should be set to as near maximum as possible by manipulation of the coarse gain.

3. The unipolar output range should be set to the input range of the analyzer.

4.7 OPERATION IN SPECTROSCOPY SYSTEMS

4.7.1 **High-Resolution Alpha-Particle Spectroscopy** System The block diagram of a high-resolution spectroscopy system for measuring natural alpha-particle radiation is shown in Fig. 4.8. Since natural alpha-particle radiation only occurs above several MeV, an ORTEC 444 Gated Biased Amplifier is used to suppress the unused portion of the spectrum

Alpha-particle resolution is obtained in the following manner

1. Using maximum preamplifier gain, medium amplifier gain, and minimum biased amplifier gain and bias level, the alpha peak is accumulated in the multichannel analyzer.

2. The bias level and biased amplifier gain are slowly increased until the alpha peak is spread over 5 to 10 channels and the minimum to maximum energy range desired corresponds to the first and last channels of the analyzer.

3. The analyzer is calibrated in keV per channel using the pulser and the known energy of the alpha peak (see Section 4.6.1) or two known-energy alpha peaks.

4. The resolution can be obtained by measuring the FWHM of the alpha peak in channels and converting to keV.

4.7.2 High-Resolution Gamma Spectroscopy System A high-resolution gamma system block diagram is shown in Fig. 4.9. Although a biased amplifier is not shown (a larger channel analyzer being preferred), it can be used if only a smaller channel analyzer is available and only higher energies are of interest.

When using lithium-drifted germanium detectors cooled by a liquid nitrogen cryostat, it is possible to obtain resolutions from about 1 keV FWHM up (depending on the energy of the incident radiation and the size and quality of the detector). Reasonable care is required to obtain such results. Some guide lines for obtaining optimum resolution are the following:

1. Keep interconnection capacities between the detector and preamplifier to an absolute minimum (no cables).

2. Keep humidity low near the detector-preamplifier junction.

3. Operate in amplifier and preamplifier gain regions that provide the best signal-to-noise ratio.

4. Operate at the highest allowable detector bias to keep the input capacity low.

5. Select the time constants for optimum signal-to-noise ratio.

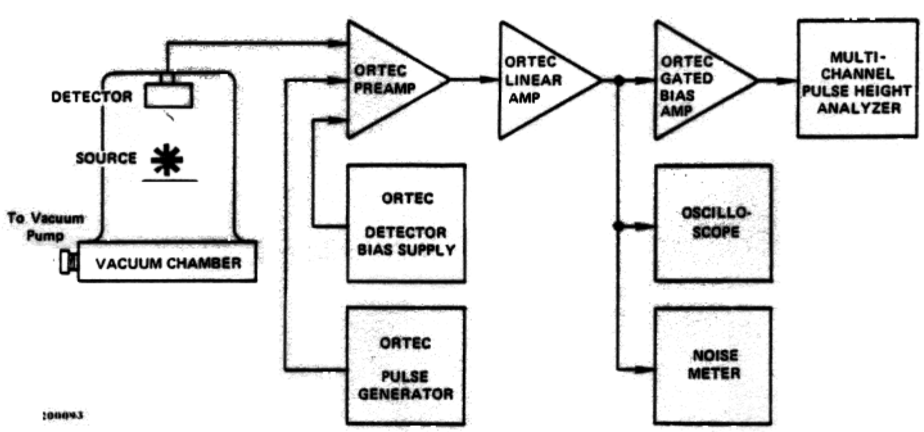


Fig. 4.8. System for High-Resolution Alpha-Particle Spectroscopy.

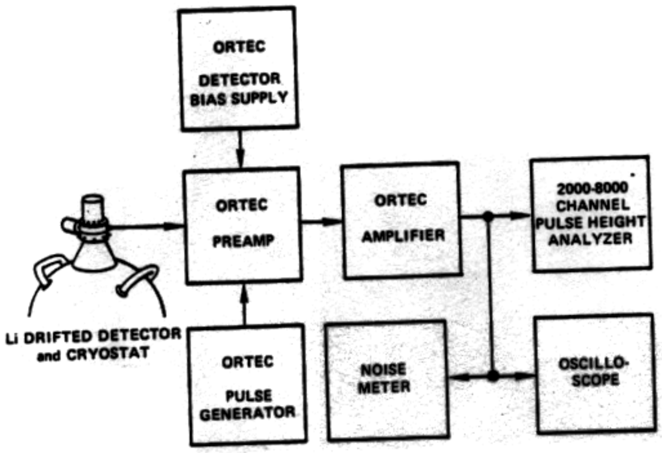


Fig. 4.9. System for High-Resolution Gamma Spectroscopy.

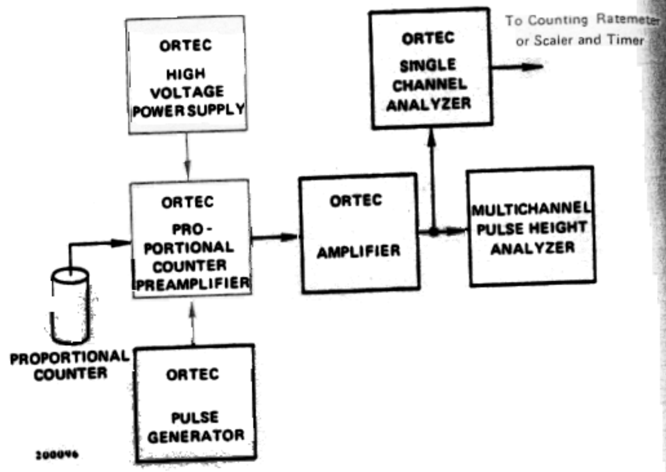


Fig. 4.11. High-Resolution X-Ray Spectroscopy System.

4.7.3 Scintillation-Counter Gamma Spectroscopy Systems The ORTEC 450 can be used in scintillation-counter spectroscopy systems as shown in Fig. 4.10. The amplifier clipping time constants should be selected in the region of 0.5 to 1.0 μsec for NaI or plastic scintillators. For scintillators having longer decay times the time constants may be changed.

4.7.4 X-Ray Spectroscopy Using Proportional Counters Space charge effects in proportional counters operated at high gas amplification tend to degrade the resolution capabilities drastically at x-ray energies, even at relatively low counting rates. By using a high gain, low-noise amplifying system and lower gas amplification, these effects can be reduced and a considerable improvement in resolution can be obtained. The block diagram in Fig. 4.11 shows a system of this type. Analysis can be accomplished by simultaneous acquisition of all data on a multichannel analyzer or counting a region of interest in a single-channel analyzer window with a scaler and timer or counting rate meter.

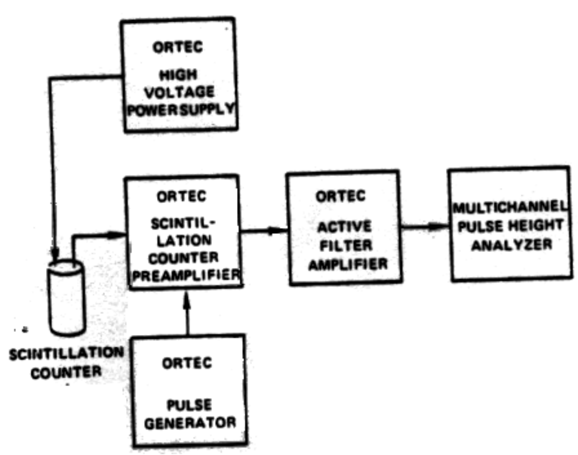


Fig. 4.10. Scintillation-Counter Gamma Spectroscopy System.

4.8 UNIPOLAR OUTPUT RANGES

The operation of the 450 in the system is quite straightforward. The Output Range switch selects the span of the output voltage to be −3 V, ±6 V, or ±10 V for the Unipolar Output. This allows a matching to all ADC inputs. On some ADC's the input has a zero offset adjust, which feeds a dc level on to the input in the normally operating ac-coupled mode; however, when the direct access is used, this dc offset adjust is to some degree disabled by the output impedance of the driving amplifier (in this case, the 450 which controls the amount of that dc voltage). For this reason the 450 provides a wide range of output dc level adjustment. This voltage level may be adjusted by R91 (DC Adj) to be either positive or negative up to 10% of full scale.

4.9 BASELINE RESTORER (BLR)

4.9.1 BLR Function The BLR rate switch (S7) has four positions, Out, Lo, Med, and Hi, and selects the rate of dc restoration. The Out mode is used in those instances where the count rate is moderate and the best energy resolution (least noise width contribution) is required. The restore modes provide a selectable restoration rate and therefore a very much higher count rate capability for the same amount of pileup distortion. The restorer should be used whenever high count rates (approximately 5000 to 10,000 counts/sec) are to be encountered. The BLR switch S7 determines the restore capacitor which allows optimum restoration at all count rates. In the Out position the BLR is bypassed.

4.9.2 BLR in a System Normally, the 450 should be connected into the analysis system as the last function performed prior to pulse-height analysis. If there is a nonlinear element such as a biased amplifier in the system and that biased amplifier does not contain a dc restoration circuit then it is necessary to dc-couple the nonlinear element up to the nonlinear bias point and also dc restore prior to it in order to obtain good pulse-height resolution. Of course, this means that if the output of that nonlinear element is again ac-coupled, it is necessary to again dc restore before entrance of the pulse-height analysis system, e.g., multichannel analyzer, if the best pulse-height resolution versus count rate is to be obtained. These precautions are not necessary with the ORTEC 444 Gated Biased Amplifier at moderate rates, since it contains a dc restoration circuit.

Figures 4.12-4.15 are four graphs showing resolution vs count rate for different time constant settings. These data were obtained with a specific detector and preamplifier, together with the ORTEC 450 Amplifier, and cannot be expected to apply directly to other systems. The graphs are included for use as relative guidelines to aid in optimizing the settings of the BLR circuits in a specific application. No pileup inspection was used. Of course it is necessary that the pulse-height analysis system be dc-coupled following the dc restorer.

Some of the analog-to-digital converters associated with multichannel analyzers are not dc-coupled at their normal input and contain no method of dc restoration; however, some of these analyzers do allow direct access to their linear gate circuitry in the so-called Mössbauer analysis mode. Other ADC's have a built-in dc restorer capable of restoring the long time constant associated with the ac-coupling capacitor in the ADC prior to the dc restorer point. In these cases one may obtain reasonably high count rate, i.e., in the order of 10,000 to 15,000 counts/sec, of high-resolution data by dc restoration externally and coupling direct into the ADC in the normal mode. This means that there are two steps of dc restoration. If, however, very high count rates are to be encountered, one should assure dc-coupling in these ADC's as well and dc restore externally by means of the 450.

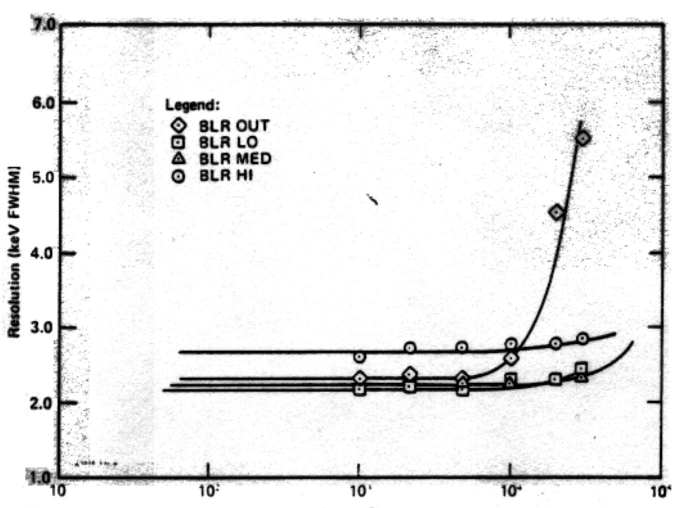


Fig. 4.12. Resolution vs Count Rate for $\tau_i = \tau_d = 1\ \mu$sec.

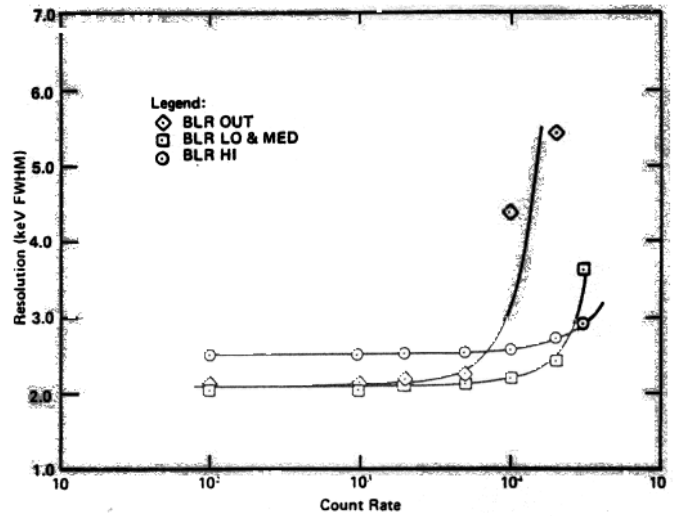


Fig. 4.13. Resolution vs Count Rate for $\tau_i = \tau_d = 2\ \mu$sec.

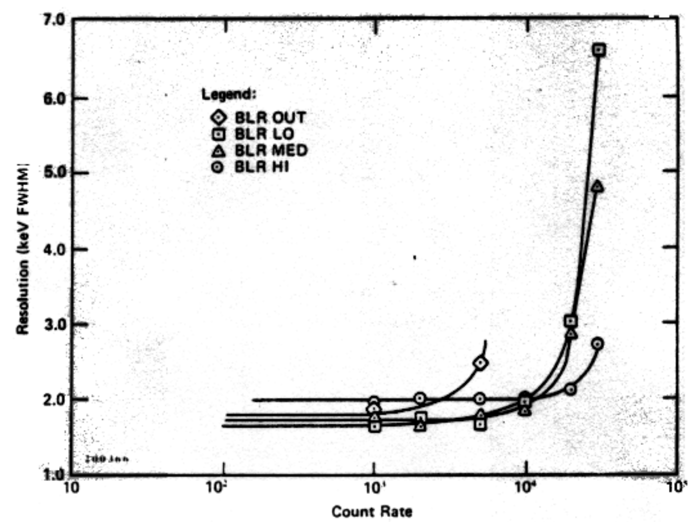


Fig. 4.14. Resolution vs Count Rate for $\tau_i = \tau_d = 3\ \mu$sec.

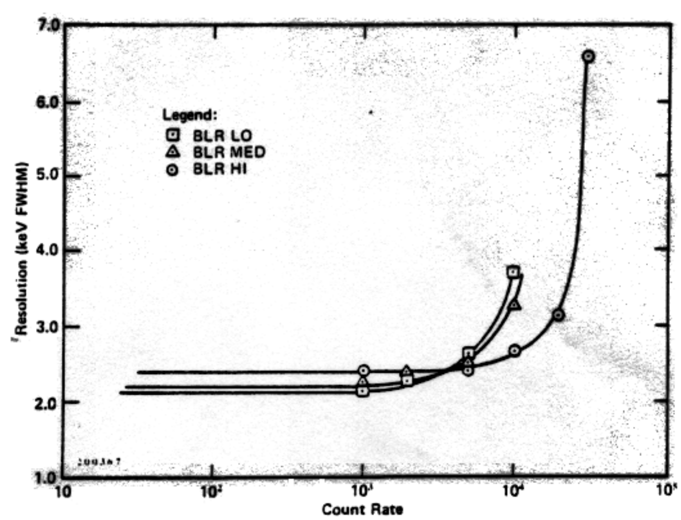


Fig. 4.15. Resolution vs Count Rate for $\tau_i = \tau_d = 5\ \mu$sec.

There are many ADC's in use in nuclear research, and the variety of input requirements is almost as broad as the variety of ADC's used. Below are listed some specified ADC's and block diagrams outlining methods of connecting the 450 into the system in such a way that it may perform its function and supply an analysis signal to the ADC through a dc-coupled network. Note that in some cases it is necessary to feed two signals to the ADC. One of these, which is the dc-coupled signal to be analyzed, goes directly to the gate circuit, while the second signal goes to the normal input and is used merely as a trigger signal to initiate analysis since some of the ADC's pick off the trigger signal to initiate analysis from the normal, i.e., 0-10 V, input.

4.10 TYPICAL SYSTEM BLOCK DIAGRAMS

Block diagrams illustrating how the 450 and other ORTEC 400 Series modules can be used in experimental setups are given in Figs. 4.16-4.19.

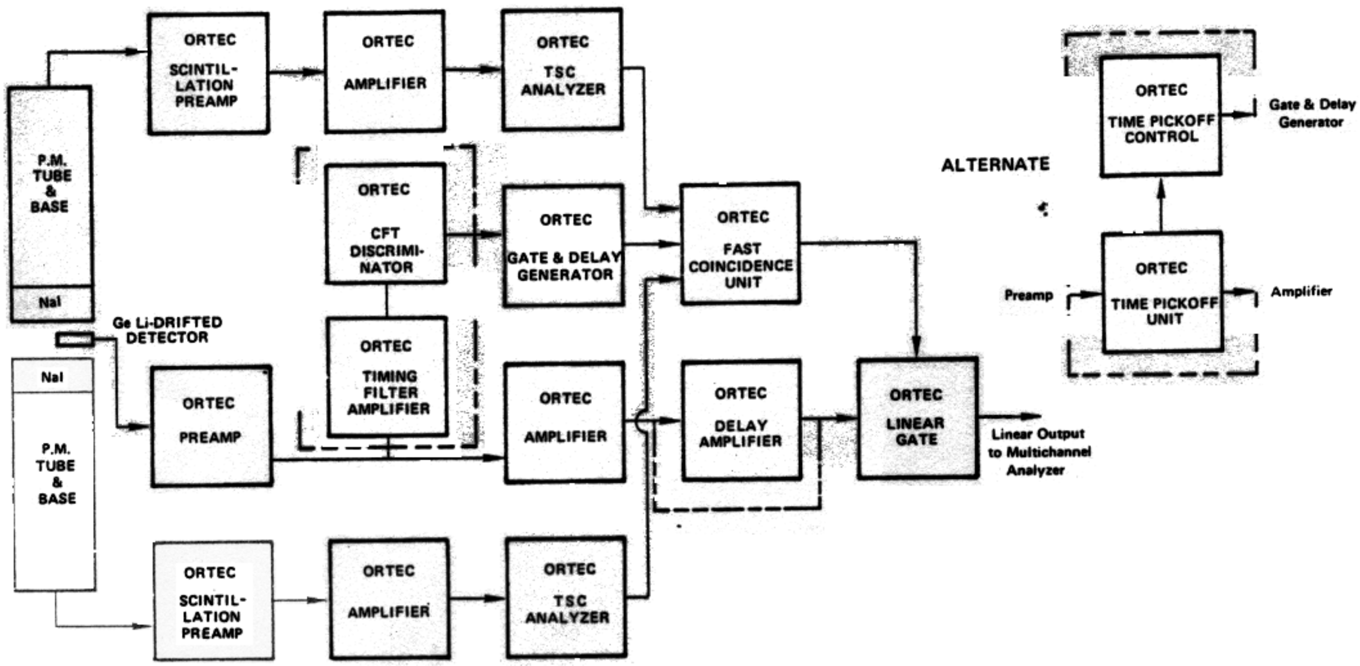


Fig. 4.16. Gamma-Ray Pair Spectrometer – Block Diagrams.

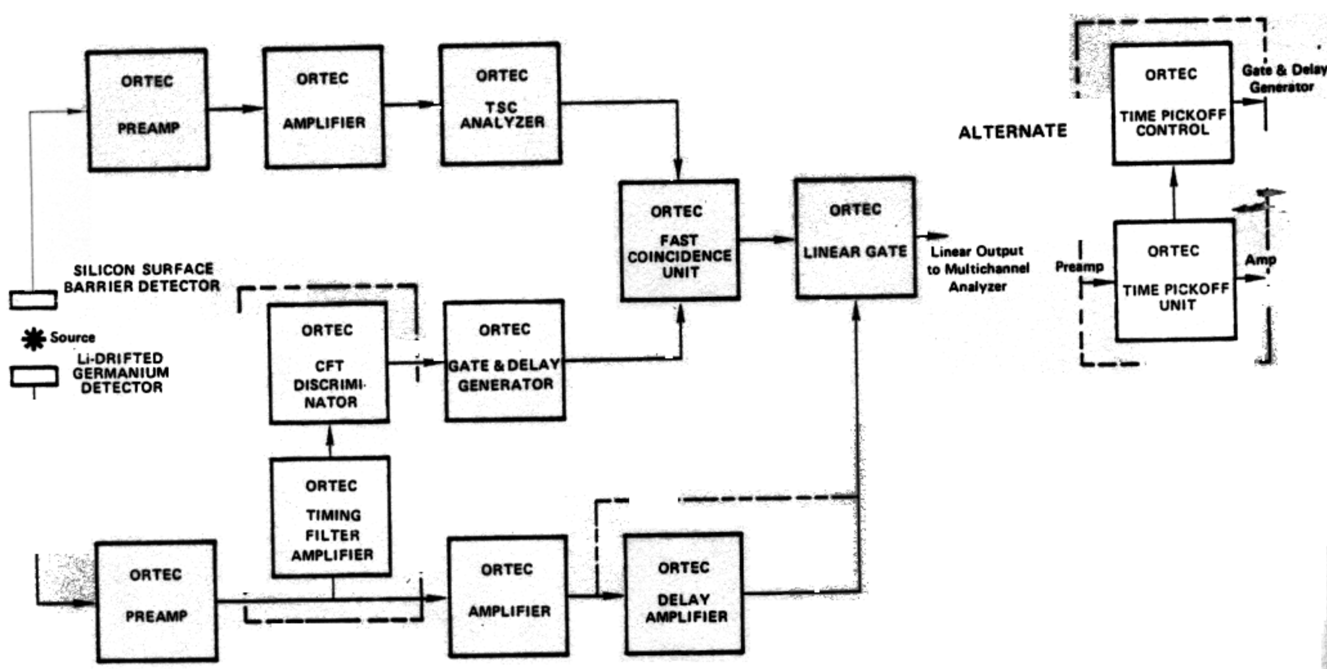


Fig. 4.17. Gamma-Ray Charged-Particle Coincidence Experiment – Block Diagrams.

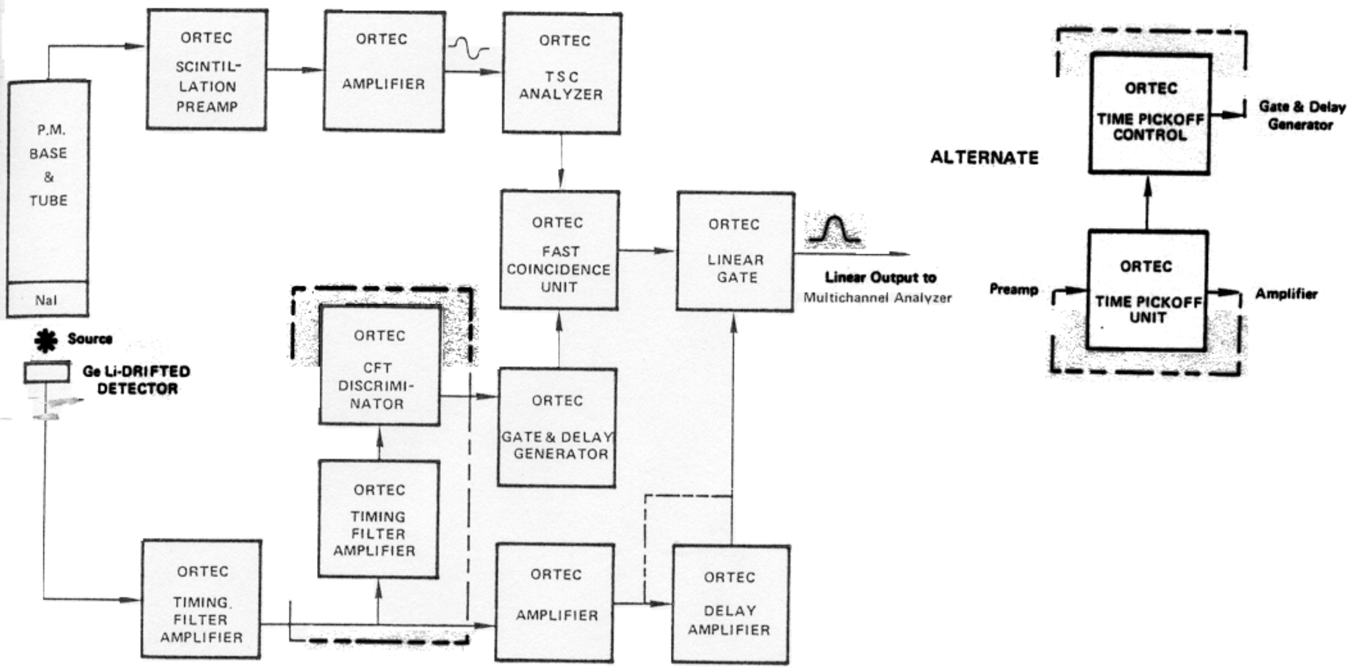


Fig. 4.18. Gamma-Gamma Coincidence Experiment – Block Diagram.

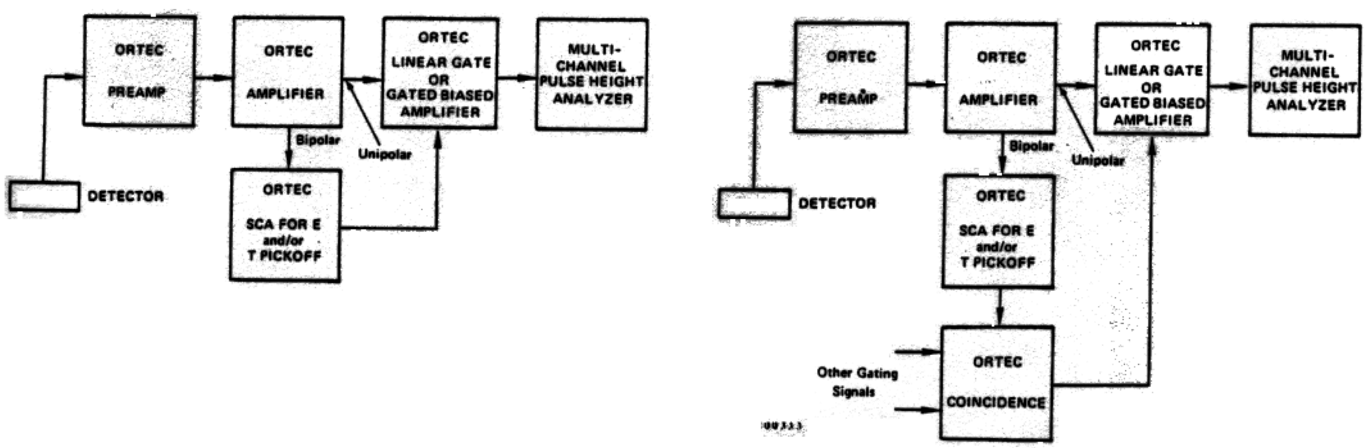


Fig. 4.19. General System Arrangement for Gating Control.

5. CIRCUIT DESCRIPTION

5.1 GENERAL BLOCK DIAGRAM

The 450 contains nine feedback operational amplifiers grouped in two sections: Section A (Fig. 5.1), which is the fast wide-band and high gain section, and Section B (Fig. 5.2), which is the signal conditioning section.

5.2 SECTION A

The signal inputs are selected for mode and polarity by the Input Mode switch S1 and presented to the first amplifier (1) which has a wide-band gain of 3.

In order to maintain zero differential gain from these inputs, i.e., high common mode rejection,[2,3] there is a differential balance control (Bal) (R2) provided on the front panel. The signal is then presented to the first differentiation (C5, R9, τ = 1 μsec) which incorporates a front-panel pole-zero-cancel control (PZ Adj) R7.[4] See theory Section 1.3.

Stage 2 is a wide-band amplification stage with feedback gain adjustable from 1 to 10, using the Coarse Gain control S3A. The output of 2 is presented to the Fine Gain attenuator R18, which is a precision 10-turn potentiometer with an attenuation range of 1 to 0.33 calibrated on the front panel as 1.5 to 0.5.

The output of the Fine Gain control is fed to amplification stage 3 which, like 2, is a wide-band amplifier with a feedback gain adjustable from 1-10 using Coarse Gain control S3B. The output of stage 3 is fanned out both to S4 and through a 0.5 μsec differentiating network (C17, R27) to form the Fast Bipolar Output. Stage 4 then amplifies this signal by a gain of 1 to 10 using Coarse Gain S3C and this output is presented to the front- and rear-panel BNC's as the Fast Bipolar Output. Stage 4 is protected from shorts and excessive duty cycle by Q1 and Q2.

Stages 1 through 4 have variable feedback capacitors to optimize the rise time of the Fast Bipolar Output. The total gain of Section A from input to Fast output is 2.5 to 3000. Section A is converted into a universal wide-band amplifier when S4C and S4D are closed by setting Differentiate switch S4 to the Out position.

Provisions are made on the circuit board to insert a larger differentiate capacitor in parallel with C17 if a longer time to crossover of the Fast Bipolar Output is desired (C17a).

5.3 SECTION B

The output of stage 3 is fed to the first selectable Differentiate switch S4A, which has a range of 0.1 to 10 μsec and Out in 10 steps. This output is then coupled into stage 5, which has a special integrating filter to replace the original differentiation introduced after stage 1 by R9, C5. Thus the output of stage 5 has transformed the 1 μsec differentiation time constant to a new differentiation time constant selected by S4. The output of stage 5 is then presented to the Integration section. The active-filter Integration is selectable for time constants of 0.1 to 10 μsec and Out in 10 steps by the front-panel Integrate selector S5. Stage 6 is the amplifier which provides the filter gain. This output then goes to the Coarse Gain control S3D, which has a gain range of 1-10 in conjunction with stage 7 (see theory Section 1.3). Stage 7 is the second active-filter amplifier with the time constant selected by the Integrate selector switch S5. The output of stage 7 has been completely amplified and shaped and is conditioned for an acceptable output. Stage 7's output is fanned out three

4. C.H. Howlin and J.L. Blankenship, "Elimination of Undesirable Undershoot in the Operation and Testing of Nuclear Pulse Amplifiers," *Rev. Sci. Instr.* **36**(12), 1830 (1965).

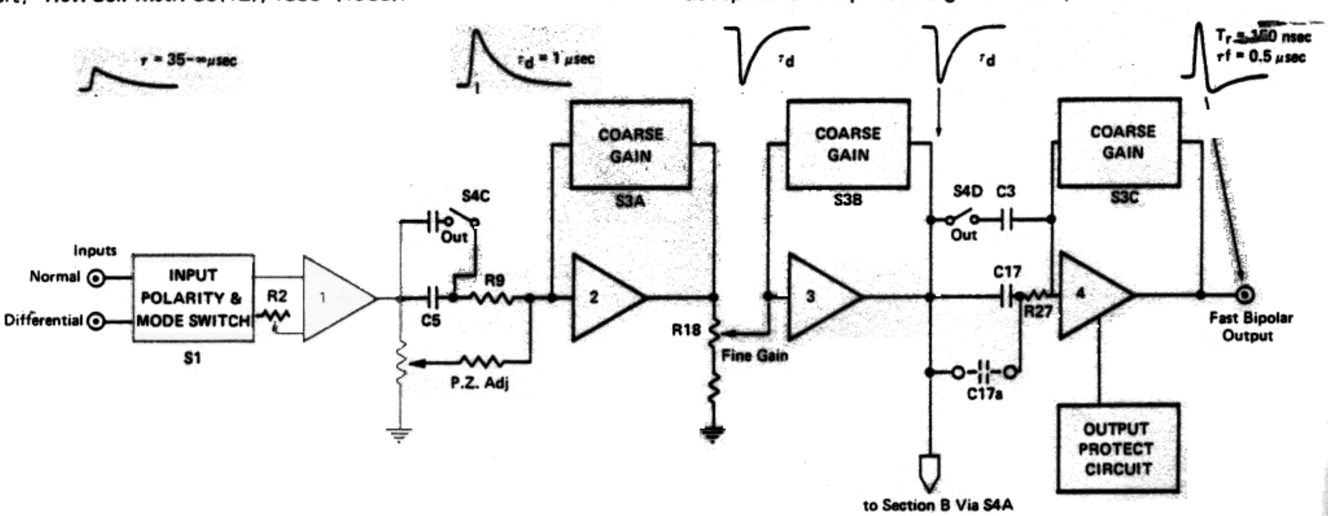


Fig. 5.1. 450 Block Diagram, Section A.

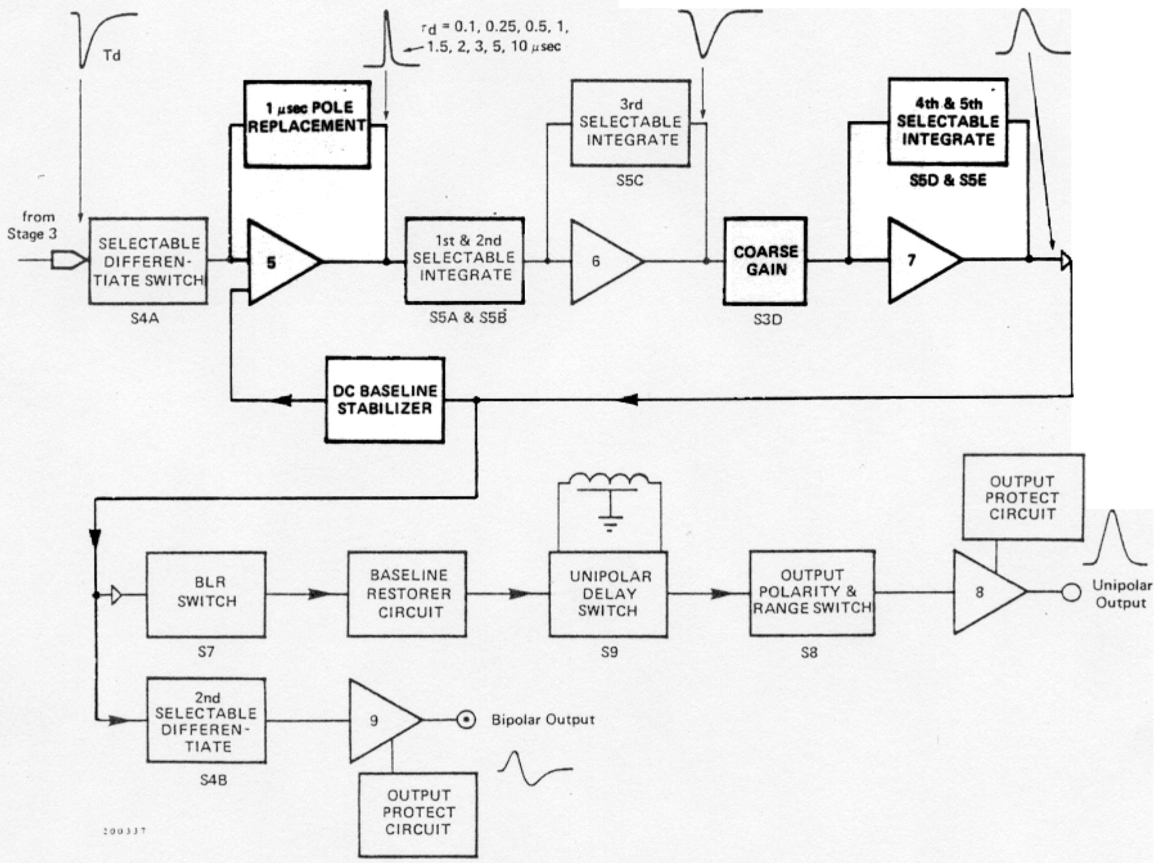


Fig. 5.2. 450 Block Diagram, Section B.

ways. One is presented to the Baseline Restore Rate switch S7 (BLR), which has a restore rate range of Out, Lo, Med, and High. This output then goes through or around the baseline restorer circuit Q7-Q13.[1] This output then goes to the rear-panel output Delay switch S9, which determines whether the signal is to be delayed or not. This signal then goes to the Unipolar Output Range switch S8, which selects the polarity and gain of the unipolar output driver stage 8. Stage 8 is protected from short circuits and excessive duty cycle by Q3 and Q4.

The output of stage 7 also goes to the second selectable Differentiate through the Differentiate switch S4B to form the bipolar pulse, which is then amplified by stage 9 and presented to the Bipolar output connectors. Stage 9 is protected from short circuits and excessive duty cycle by Q5 and Q6.

The output of stage 7 is also connected to the DC Stabilization Amplifier Q14-Q18, which is used to correct for baseline shift at the output of stage 7 due to pileup, count rate effects, temperature, etc. This permits the Unipolar output to be completely dc-coupled and still maintain a very high degree of dc stability.

5.4 GAIN CRITERIA

In any amplifier or amplifier series, any error introduced within the amplifier, such as thermal or pickup noise, is reduced by the amplification preceding this error point when the error is referred back to an equivalent input error. Therefore for minimum induced error to the signal it is imperative that for any given gain most of the gain be accomplished early in the amplifier.

In the 450 this criterion is followed by designing the Coarse Gain selector switch S3 so as to decrease the latter gain (stages 4 and 7) first (positions 2000, 1000, 500, and 200); then to decrease the gain of the intermediate stage 3 on positions 100 and 50; and lastly to reduce the gain on the first gain stage 2 on positions 20, 10, and 5. Thus, as the amplifier gain is increased by the Coarse Gain selector switch, it is increased early in the amplifier first.

5.5 ORTEC OPERATIONAL AMPLIFIER CONCEPT

The ORTEC Operational Amplifier is a low-noise, differential input, wide-band, high-performance device which has universal applications by use of proper feedback. It is encapsulated to ensure good temperature stability and to make it immune to shock, vibration, and humidity.

The internal components are of high quality and are operated well below design maximums to ensure long-term reliability. In the rare event of a failure, the malfunctioning unit can be indentified and replaced quickly.