

Recognized as an
American National Standard (ANSI)

IEEE Std 301™-1988(R2006)
(Revision of IEEE Std 301-1976)

IEEE Standard Test Procedures for Amplifiers and Preamplifiers used with Detectors of Ionizing Radiation

Sponsor

**Nuclear Instruments and Detectors Committee
of the
IEEE Nuclear and Plasma Sciences Society**

Reaffirmed March 30, 2006
Approved October 20, 1988
IEEE Standards Board

Approved June 21, 1989
American National Standards Institute

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Foreword

(This Foreword is not a part of IEEE Std 301-1988, IEEE Standard Test Procedures for Amplifiers and Preamplifiers used with Detectors of Ionizing Radiation.)

This standard describes test procedures for amplifiers and preamplifiers that are used with semiconductor, scintillation, and proportional detectors in the spectrometry of ionizing radiation. It supersedes ANSI/IEEE Std 301-1976, IEEE Standard Test Procedures for Amplifiers and Preamplifiers for Semiconductor Radiation Detectors for Ionizing Radiation. The title was changed because the same amplifiers used for semiconductor detectors are applicable to other types.

Amplifier technology has progressed to the point where the spectrometer performance may be limited as much by the multichannel analyzer (MCA) as by the amplifier. Because of this and because of the impracticality of standardizing on one MCA with so many on the market, MCAs, with minor exceptions, are not a part of the measurement procedure in this publication.

In this standard, measuring procedures are given in greater detail than in the earlier publication because with modern amplifiers, perceived performance often depends on the details of measurement. Thus, many of the details of the procedures must be standardized as well as the amplifier specifications.

Tests that are specific to amplifiers with time-variant pulse-shaping filters are not included in this standard, nor are tests for pile-up rejectors. Time-variant filters allow shorter pulse-shaping times than linear filters for the same signal-to-noise ratio (snr), and pile-up rejectors, as the name implies, block pulses that overlap earlier ones, allowing higher count rates for a given spectral-line resolution. Both techniques have the greatest application at the energy extremes: at very low energies because wide pulses must be used to optimize the snr, and at high energies where detector artifacts cause low-side tailing of spectrum lines. The tailing obscures low-intensity lines falling just below higher energy lines, and pile-up causes phantom peaks to appear at energy multiples of the spectrum lines.

In this standard, $t_{0.5}$ or $t_{1/2}$ (the pulse width at 50% of peak amplitude) is the main-amplifier indicator of shaping time because this parameter best enables a performance comparison among different amplifiers. Also, compared with other parameters, this one is the easiest to measure accurately with an oscilloscope and pulse generator.

Companions to this document are ANSI/IEEE Std 300-1988 [1],¹ ANSI/IEEE Std 325-1986 [2], and IEEE Std 194-1977 [3].

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¹The numbers in brackets correspond to those of the references listed in 1.5.

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IEEE Standard Test Procedures for Amplifiers and Preamplifiers used with Detectors of Ionizing Radiation

1. General

1.1 Scope and Object

These test procedures cover amplifier and preamplifier systems with linear pulse-shaping networks for use with semiconductor, scintillation, and proportional detectors in the spectroscopy of ionizing radiation. The object is to provide a common language and methodology for users and manufacturers of pulse-amplifier systems.

This standard supersedes IEEE Std 301-1976, IEEE Standard Test Procedures for Amplifiers and Preamplifiers for Semiconductor Radiation Detectors for Ionizing Radiation. Test procedures for associated detectors are described in ANSI/IEEE Std 300-1988 [1] and ANSI/IEEE Std 325-1986 [2]. IEEE Std 194-1977 [3] is a companion document for pulse-shape terminology.

Not all of the tests described herein are mandatory, but those that are performed to determine preamplifier and amplifier specifications shall conform to this standard.

The emphasis on the methods of measurement is to enhance sensitivity and improve accuracy by working around the limitations of the test instruments, particularly oscilloscopes that have only a visual display for readout. A null technique is used where possible, thereby reducing basic errors to the inaccuracy of a pair of precision resistors. When use of a bridge is inappropriate, such as in measurements of pulse height with an oscilloscope, the pulse is made to occupy a fixed amplitude and vertical position on the face of the cathode-ray tube (CRT). Some measurements require test instruments or fixtures not commercially available at this writing; circuit diagrams for their construction are given in the Appendix. It is not acceptable to make use of a standard nuclear instrument module to test the performance of an amplifier unless the errors introduced by that module can be corrected for or shown to be less than the error caused by the amplifier. Examples are the use of a crossover-pickoff module to measure crossover walk in a bipolar amplifier, and an MCA to measure nonlinearity and noise.

1.2 Specialized Definitions

Definitions followed with the reference IEEE Std 194-1977 [3] include terms defined in that standard. The following definitions should be understood throughout the document:

back porch: At the end of a shaped pulse, a region where the tail may stop several percent short of the baseline, then decay to it slowly.

back termination, back-terminating resistor: A resistor joining the output stage of an amplifier or signal generator to its output connector.

bandwidth (of a voltmeter): The band of frequencies over which the ac voltmeter indication is constant within ± 0.25 dB, rolling off 3 dB at the ends. The bandwidth is defined as the difference between the high and low frequencies at which the -3 dB points occur.

ballistic deficit: In an amplifier, the loss in pulse height that occurs when the rise time of the input signal is not negligible compared with the width of the shaped amplifier pulse.

baseline: The average of the levels from which a pulse departs and to which it returns in the absence of a following overlapping pulse (see IEEE Std 194-1977 [3]).

baseline shift: A phenomenon in which the baseline changes as the duty cycle increases from zero. (Usually, the shift is opposite in polarity to that of the signal.)

baseline restorer: A circuit that rapidly restores the baseline following an amplifier's output pulse (or series of pulses) to the level existing prior to it.

bias: (1) In a biased amplifier, the applied threshold voltage (or current) below which the gain is zero. (2) In a detector, the electric field that causes charge to be collected.

biased amplifier: An amplifier giving zero output for input signals below an adjustable threshold and having a constant gain above that threshold up to a specified maximum output.

bias resistor (detector): The resistor through which the voltage providing the bias is applied to a detector. The bias resistor may also be the load resistor (see load resistor).

bipolar pulse: A pulse having two lobes on opposite sides of the baseline. Such a pulse is obtained by including a second differentiator in the unipolar pulse-shaping network of an amplifier.

blocked: A situation in which amplifier gain is reduced to zero for longer than a normal pulse width by a heavily-overloading signal.

buck: Balancing two opposite-polarity signals against each other to produce a null.

buffer: A circuit interposed between a signal source and its load to prevent undesired interaction between the two.

capacitance, cold input: The capacitance measured between the input terminals of a preamplifier with all dc voltages applied but with the signal path inactivated.

capacitance, detector: The small-signal capacitance measured between the terminals of a detector under specified conditions of bias and frequency.

capacitance, hot input: The capacitance measured between the input terminals of a working preamplifier.

characteristic resistance (impedance): The internal resistance (impedance) of a network (such as a coaxial cable or an attenuator). When terminated in that same resistance (impedance), signal reflections are avoided and the output signal is halved.

charge-sensitive preamplifier: A preamplifier in which the output signal is proportional to input charge, independent of input capacitance.

clip, clipping: A limiting operation such as (1) the use of a high-pass filter (differentiator) or (2) a nonlinear operation to limit the amplitude of a pulse. The first usage is archaic.

collection time: In a detector, the time required for the integrated current following the occurrence of an ionizing event to increase from 10 % to 90 % of its final value.

crest factor (in an ac voltmeter): The highest ratio of peak to rms voltage that an ac voltmeter can tolerate before overload sets in. The crest factor may depend on the full-scale setting.

crossover time: The instant at which the trailing edge of the primary lobe of a bipolar pulse passes through a designated level (usually the baseline).

$(CR)^m$ -(RC) ^{n} network: A shaping network comprising m differentiators and n integrators, all of the same time constant. If $m = 1$, the pulse shape is unipolar and its response to a step function is $K(t/\tau)^n e^{-t/\tau}$. This network is one of the class of quasi-Gaussian shaping networks.

decay time (last transition time): The time required for a pulse to decay from 90% of its peak value to 10% unless otherwise specified (see IEEE Std 194-1977 [1]).

decay time constant: With a pulse that decays with a single exponential waveform, the time required for it to decay to $1/e$ of any selected level on the asymptote of the last transition (see IEEE Std 194-1977 [1]).

decibel (dB): Twenty times the logarithm (to the base 10) of the ratio of two voltages. For example, if an ac voltmeter indicates 7.07 V at some frequency f_h , but 10.0 V at a reference frequency f_{ref} , its indication at f_h , is said to be $20 \log 10 (7.07/10.0) = -3$ dB (or “3 dB down”) with respect to that at f_{ref} .

differential nonlinearity: The change in incremental gain over the dynamic range of an amplifier, usually expressed as a percentage of a reference gain.

differentiator: A high-pass network usually comprising a capacitor and a resistor for the purpose of reducing the duration of a signal and the response to low frequencies.

duty cycle: In a train of pulses, the ratio of pulse width measured at a defined level to the mean spacing between pulses measured at that same level. Unless otherwise specified, 1% of the average pulse height is the defined level.

duty factor: See duty cycle.

dynamic range: The range of signal heights over which an amplifier gives nominally linear response.

equivalent input noise: In an amplifier, the output noise signal divided by the amplifier gain.

equivalent noise resistance, series noise: In a hypothetically noise-free amplifier, that resistance which, when connected between the signal source and the amplifier, will produce the observed output noise. This definition applies only to noise with a constant spectral density (white noise).

equivalent noise resistance, parallel noise: In a hypothetically noise-free amplifier, that resistance which, when placed across the input terminals of the amplifier, will produce the observed output noise. This definition applies only to noise with a constant spectral density (white noise).

fall time: See **decay time**.

gain (amplifier): The ratio of nominal peak output pulse height to nominal peak input pulse height (see **nominal**).

high-pass network: A network that nominally passes all frequencies above a transition frequency $f = 1/2\pi\tau$ (see **differentiator**).

hum: An interfering signal at the power-line frequency or harmonic thereof.

integrator: (1) In a pulse shaper, a low-pass section of the filter network. (2) A circuit in which the output signal is the mathematical integral of the input signal.

integral nonlinearity (percent): The departure from linear response expressed as a percentage of the rated output pulse amplitude.

load resistor (detector): When the detector is coupled to the preamplifier through a capacitor, the load resistor connects the bias supply to the junction of the detector and the capacitor. In this instance, the load resistor constitutes all or part of the bias resistor.

low-pass network: A network that nominally passes all frequencies below $f = 1/2\pi\tau$ (see **integrator**).

main amplifier: In an amplifier system, the amplifier that usually follows the preamplifier and that contains the system's pulse-shaping filter.

noise transition gain: In a main amplifier, the gain setting below which the output noise is nearly independent of that setting and above which the output noise is nearly proportional to it.

noise line width: The width of a spectral line obtained by substituting a noise-free electrical pulse for the signal generated by a radioactive source.

nominal: Relating to an idealized pulse shape or to some other idealized characteristic.

offset: DC shift from a defined voltage (current) level. Unless otherwise stated, the defined level is the baseline.

overshoot: The region immediately following the first transition (of a signal) that exceeds the nominal value of that signal (see IEEE Std 194-1977 [3]).

peaking time (shaped pulse): The time interval between the 1% point on the first transition and the top center line (see IEEE Std 194-1977 [3]).

pole-zero cancellation: A technique for eliminating from a nominal unipolar pulse, an undesired undershoot, usually caused by the decay time constant of a preamplifier.

preamplifier: In an amplifier system, the amplifier section physically attached to or located close to the detector.

primary lobe: The first lobe of a bipolar pulse.

quasi-Gaussian: The description of a signal shape (or the electrical network that produces it) which approximates that of a normal distribution. In this standard, unless otherwise stated, the term refers to a pulse shape produced by one differentiator in conjunction with four or more integrators. See **differentiator** and **integrator**.

rectangular pulse: A flat-topped pulse, usually with transitions short compared with the duration of the top (see IEEE Std 194-1977 [3]).

resolution (energy): Unless otherwise specified, the full width at half maximum (FWHM) of a spectrum peak expressed as an increment of energy ΔE or as a percentage of the energy of the peak, $100\Delta E/E$. FWHM of a normal distribution is $2\sqrt{(2\ln 2)} = 2.355$ times the standard distribution σ . The root-mean-square value and σ are synonymous.

resolving time (in an amplifier system): The closest spacing between two shaped pulses that permits them to be counted separately. Unless otherwise specified, the resolving time is defined as t_{01} (see t_{01} , 1.3).

ringing: A damped oscillation which may exist immediately following a pulse transition (see IEEE Std 194-1977 [3]).

rise time (first transition time): Unless otherwise specified, the time required for a signal to increase from 10% to 90% of its final value (see IEEE Std 194-1977 [3]).

sag (of a pulse): A slow decay of a nominally flat-topped pulse. When a tail pulse is examined with an oscilloscope set for a sweep time short compared with the fall time of the pulse, the observed decay can be considered as sag.

secondary lobe: The second lobe of a bipolar pulse.

settling time (pulse): The time required for a pulse to equilibrate to a specified percentage of its amplitude.

shaping amplifier: See main amplifier.

shaping index: An indicator of shaped pulse width defined as the width at 50% of peak height and symbolized as $t_{1/2}$ or $t_{0.5}$.

shaping network: A combination of a high-pass network (one or two differentiators) with a low-pass network (several integrators) to reduce the width of a preamplifier output signal, thereby improving its resolving time and signal-to-noise ratio.

sineⁿ or sinⁿ network: A type of shaping network that transforms a step function to the waveform described by $V = Ke^{-at/\tau} \sin^n t/\tau$. This is one of the class of quasi-Gaussian shaping networks.

slew rate: The greatest rate of change of voltage (usually, volts per microseconds) that an amplifier stage can produce.

source resistance: The internal resistance of an amplifier or signal generator seen by the back-terminating resistor or, if none is used, seen by the external load.

spectrum, pulse height: A distribution of the number of pulses falling within a pulse-height increment as a function of pulse height.

spectrum, radiation: A distribution of the number of ionizing events (intensity) falling within an energy increment as a function of energy.

step function: A waveform characterized by a rapid rise to a level that remains constant thereafter.

tail pulse: A pulse shape characterized by a rapid rise followed by an exponential decay long compared with the rise time.

termination, terminating resistor: The resistor connected across a cable or across the output of an amplifier or signal generator: (With a connecting cable, the purpose usually is to eliminate signal reflections at the ends.)

transition (pulse): The region of change between the baseline and the peak or vice versa (see IEEE Std 194-1977 [3]).

undershoot: The tail end of a pulse which crosses the baseline to produce a signal opposite in polarity to the preceding portion. An ideal unipolar pulse decays monotonically to the baseline; a bipolar pulse is an example of one with an extreme undershoot.

unipolar pulse: A signal nominally having a single lobe above (or below) the baseline.

voltage-sensitive preamplifier: A preamplifier in which the output signal is proportional to the input voltage.

walk: The change in a timing point that occurs when the pulse height changes.

1.3 Symbols and Abbreviations

A	amplifier gain
A_{br}	gain of nonlinearity-bridge amplifier
A_T	noise transition gain
ADC	analog-to-digital converter
BLR	baseline restorer
BA	biased amplifier
BW	bandwidth
C	coulomb
C	electrical capacitance
C_c	calibrated capacitor used to couple a pulse generator to a preamplifier
C_d	detector capacitance
C_f	feedback capacitor in a charge-sensitive preamplifier
C_t	capacitor connected across the input of a preamplifier to determine the effect on performance
c/s	counts per second
CRT	cathode-ray tube
$^{\circ}\text{C}$	degrees Celsius
Δ	incremental change
ΔV_{br}	bridge output voltage (at null, $\Delta V_{br} = 0$)
dB	decibel(s)
div	minor division. On an oscilloscope graticule, 5 div usually equals 1 DIV
DIV	major division on an oscilloscope graticule
DVM	digital voltmeter
E	energy of a particle or photon
$e, \exp$	base of natural logarithms
ε	average energy required to form one ion pair
e_n	rms noise voltage
e_{ni}	equivalent rms noise voltage referred to the input of an amplifier or preamplifier
e_{no}	rms noise voltage at the output of an amplifier
FET	field-effect transistor
FWHM	full width at half maximum
FW.1M	full width at one-tenth maximum. FWTM shall not be used for this abbreviation
FW.01M	full width at one one-hundredth maximum
Hz	hertz
	in parallel with
x	absolute value of x (x may be any numeral)
kc/s	kilocounts per second
K	(1) kelvin (unit of thermodynamic temperature), (2) an arbitrary constant; whether (1) or (2) applies will be clear from the context
L_D	differential nonlinearity
L_I	integral nonlinearity
MCA	multichannel analyzer

MHz	megahertz
Ω	ohms
ppM	parts per million
P/Z	pole/zero
Q	electric charge
q_n	rms noise charge
q_{ni}	equivalent rms noise charge referred to the input of a preamplifier
q	charge of the electron, 1.602×10^{-19} coulombs
R	electrical resistance
R_d	detector bias resistor
r_o	internal resistance (source resistance)
R_o	characteristic resistance or terminating resistance
R_f	feedback resistor in a charge-sensitive preamplifier
RBA	reference biased amplifier
SNR	ratio of the peak signal to the rms noise
t	time
t_f	pulse fall time, 90%-10% of the peak height
t_r	pulse rise time, 10%-90% of the peak height
t_p	pulse peaking time, measured from 1% of the peak height to the center of the peak
t_{p1}	bipolar-pulse peaking time, measured from 1% of the peak height of the primary lobe to the center of its peak
t_{p2}	bipolar-pulse peaking time, measured from 1% of the peak height of the primary lobe to the center of the secondary peak
t_{xo}	crossover time of a bipolar pulse
$t_{0.5}$	shaping index (width of a shaped pulse at 50% of its peak height)
$t_{1/2}$	same as $t_{0.5}$
t_n	width of a pulse at the fraction n of its peak height, where n is specified as 0.1, 0.01, etc
τ	time constant
V	electric voltage
V_a	pulse height at amplifier output
V_{in}	pulse height at amplifier input
V_m	rated maximum output voltage of an amplifier
Z_o	characteristic impedance

1.4 Constants and Conversion Factors

q	1.602×10^{-19} coulombs
ϵ_{Ge}	$2.97 \pm 1\%$ eV per hole-electron pair at 77K for x-rays and γ -rays.
ϵ_{Si}	$3.63 \pm 1\%$ eV per hole-electron pair at 290-300K for α -particles
ϵ (for P10 gas, 90% argon, 10% methane)	≈ 25 eV per ion pair
rms to FWHM	multiply by 2.355
average to rms (voltmeter)	multiply by 1.284

1.5 References

This standard shall be used in conjunction with the following publications:

[1] ANSI/IEEE Std 300-1988, IEEE Standard Test Procedures for Semiconductor Charged-Particle Detectors.²

²ANSI/IEEE publications are available from IEEE Service Center, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331, or from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[2] ANSI/IEEE Std 325-1986, IEEE Standard Test Procedures for Germanium Gamma-Ray Detectors.

[3] IEEE Std 194-1977, IEEE Standard Pulse Terms and Definitions.

2. Spectrometer

A simple spectrometer for determining the spectrum of ionizing radiation is shown in Fig 1. It comprises a detector with its bias supply, a preamplifier, main amplifier, possibly a biased amplifier, and a multichannel analyzer.

2.1 Detectors

Detectors fall into several classifications: gas-filled, semiconductor, and scintillation.

Gas-filled detectors, such as gridded ionization chambers, are used for spectroscopy of large-area α -particle samples ($\approx 0.7\%$ - 1% energy resolution for 5 MeV α -particle emitters). Proportional detectors in spectroscopy applications are used principally for the measurement of low-energy x-rays ($\approx 12\%$ resolution at 10 keV). The poor stopping power for energetic photons makes these detectors unsuitable for γ -ray spectroscopy.

Semiconductors, such as germanium and silicon, combine high density and low ionization potential, making them very suitable as detectors for several types of radiation. Germanium detectors are used for the highest-resolution spectroscopy of γ -rays ($\approx 0.2\%$ for a 1 MeV γ -ray). Silicon detectors are used principally in the detection and spectroscopy of x-rays and heavy charged particles (spectral resolution of 0.25% - 0.4% for 5 MeV α -particles).

Scintillation detectors combine a phosphor with a photo multiplier. A phosphor such as thallium-activated sodium iodide (NaI(Tl)) is denser than germanium and makes an efficient detector of energetic γ -rays. Also, it can be formed into much larger detectors than is possible with germanium. However, the energy resolution of NaI(Tl) is relatively poor— 5% - 6% for a 1 MeV γ -ray.

2.1.1 Detector Signal

Regardless of the type of detector, the incoming radiation eventually is converted to a quantity of charge that is collected under the influence of the bias voltage applied between anode and cathode.

The charge is deposited on the feedback capacitor of the charge-sensitive preamplifier to produce a voltage step of magnitude Q/C_f volts (see A2.2). This voltage step is the desired signal.

In gas-filled detectors, incoming radiation ionizes gas molecules. In semiconductor detectors, the interactive medium is the crystal lattice of the semiconductor: electrons and holes are released by the ionizing radiation.

In scintillation detectors, a two-step process is involved: the incoming radiation fluoresces the phosphor, and the emitted light releases electrons from the cathode of an optically-coupled photomultiplier tube. The electrons are multiplied in their transit through the dynode structure, then collected at the anode. In high-energy physics and some other applications, photodiodes may be used instead of photomultipliers.

It is desirable to express the preamplifier sensitivity in terms of volts per unit energy of the ionizing radiation. This is impractical for scintillation and proportional detectors, because charge multiplication occurs that can be proportional to as much as the 10th power of the detector bias voltage; because of this, the relationship between the energy of the ionizing event and the charge collected at the output terminal is not fixed. For preamplifiers that are used with multiplying detectors, sensitivity shall be expressed in volts per coulomb, as opposed to volts per unit energy, and noise shall be expressed in units of equivalent input charge (or electrons).

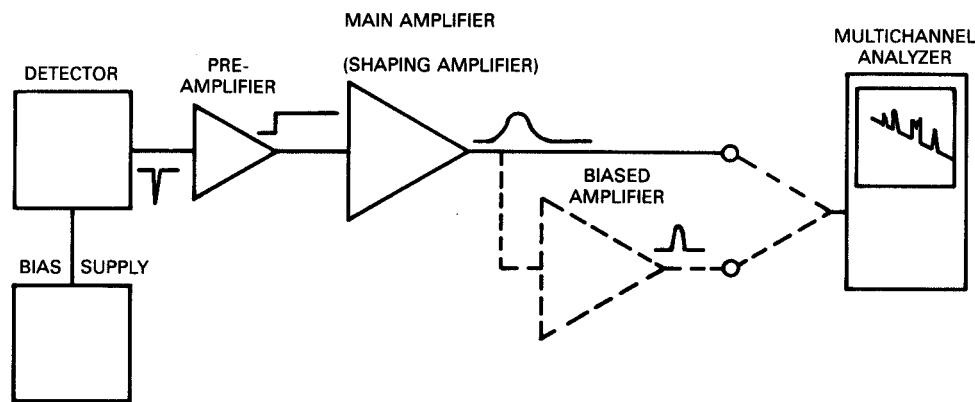


Figure 1—Spectrometer

In semiconductor detectors and gridded ionization chambers, charge and energy are related by constants that are substantially independent of the bias voltage. For preamplifiers that are used with non-multiplying detectors, sensitivity shall be expressed in volts per unit energy (volts per eV, keV, or MeV), and noise shall be expressed in units of equivalent input energy (eV, keV, or MeV). Also, the type of detector for which the sensitivity specification applies (germanium, silicon, etc) shall be stated.

The detector is simulated by a rectangular pulse generator coupled to the preamplifier through a small, stable, low-noise capacitor (0.1 pF-10 pF). The detector and preamplifier treated as a unit is simulated by a tail-pulse generator coupled directly to the main amplifier.

2.1.2 Rise Time and Fall Time

The fall time t_f of the output signal of a preamplifier is controlled by its feedback network $R_f C_f$.

The rise time t_r is controlled either by the detector or the preamplifier, whichever is slower. Detector capacitance has no effect on rise time except as it affects the feedback factor in a charge-sensitive preamplifier.

In nonmultiplying detectors, t_r is determined by the collection time; in charge-multiplying detectors, other factors may control. The range of t_r in nonmultiplying detectors is from less than 1 ns to more than 1 μ s, depending on the type and size, and where in the active volume the initial ionization occurs. For germanium detectors, t_r usually is between 10 ns and 100 ns, depending on the distance between collecting electrodes. It would seem that in simulating the detector signal, the t_r of the generator should match that of the detector. This is practical when the rise time does not vary appreciably from pulse to pulse, as is true with scintillation detectors, but impractical with semiconductor or gas-filled detectors because the collection time does vary. Therefore, the pulse-generator t_r shall be less than or equal to that of the fastest-rising signal that can emerge from the preamplifier. For semiconductor-detector preamplifiers, see 3.2.1.

2.2 Preamplifier

Preamplifier configurations are voltage-sensitive or charge-sensitive (see A2.2). In voltage-sensitive preamplifiers, output pulse height and fall time depend on detector capacitance. In charge-sensitive preamplifiers, pulse height and fall time are nearly independent of this capacitance, depending instead on a stable feedback capacitor C_f . The term “gain” as a measure of amplification does not apply to a charge-sensitive preamplifier; the term “charge-sensitivity” shall be used instead, with units of volts per coulomb or volts per keV, whichever is applicable.

The charge-sensitive category can be subdivided into resistor-feedback and pulsed-reset. In the former, the output signal decays exponentially. In the latter, the signal does not decay until a reset pulse occurs. (The reset signal may be

introduced optically to the detector or the input FET, by conduction through a transistor or diode, or through a combination of methods.) Most of the tests described in this standard will apply to both circuit configurations, but no specific tests for pulsed-reset preamplifiers are covered herein.

Charge-sensitive preamplifiers are the most widely used at this writing and, in this standard, is the category to which the term “preamplifier” refers.

2.3 Main Amplifier (Shaping Amplifier)

The main amplifier usually has a gain adjustable between a minimum of $\times 2$ and a maximum of $\times 3000$, but a different range may be chosen by the manufacturer. A rated maximum output V_m of 10 V has become a de facto standard; this V_m will be assumed, but is not mandated (slight modifications of the test procedures may be required if a different V_m is used). The main amplifier contains a pulse shaping network (hence the alternate term “shaping amplifier”) to improve the SNR and reduce the width of the pulses that emerge from the preamplifier (see A2.3). Pulse shaping is an item of central importance in high-resolution spectroscopy. The shaping time of a unipolar pulse shall be defined as the width of that pulse measured at 50% of its peak height and shall be referred to as the “shaping index”, “ $t_{0.5}$ ” or “ $t_{1/2}$ ”³ (see 4.1.1 and 4.1.2 for nomenclature that shall appear on the front panel of a main amplifier). The importance of this indicator of shaping time is that it facilitates energy-resolution comparisons between amplifiers with different shaping networks. This comparison is illustrated in Fig 2. Main amplifiers from three manufacturers were used, with a different shaping network in each amplifier. The same high-purity germanium detector supplied the signals for all of the measurements, which were made at 2 kc/s and 62 kc/s on the 1.33 MeV λ -ray from a ^{60}Co source. If $t_{1/2}$ is the index of shaping time, all of the test points at the lower counting rate fall very nearly on the same line. At the higher rate, performance differences appear. If the shaping times indicated on the front panels of the different amplifiers were used instead, each amplifier would have produced a resolution curve displaced laterally from the others, making it difficult to compare performance.

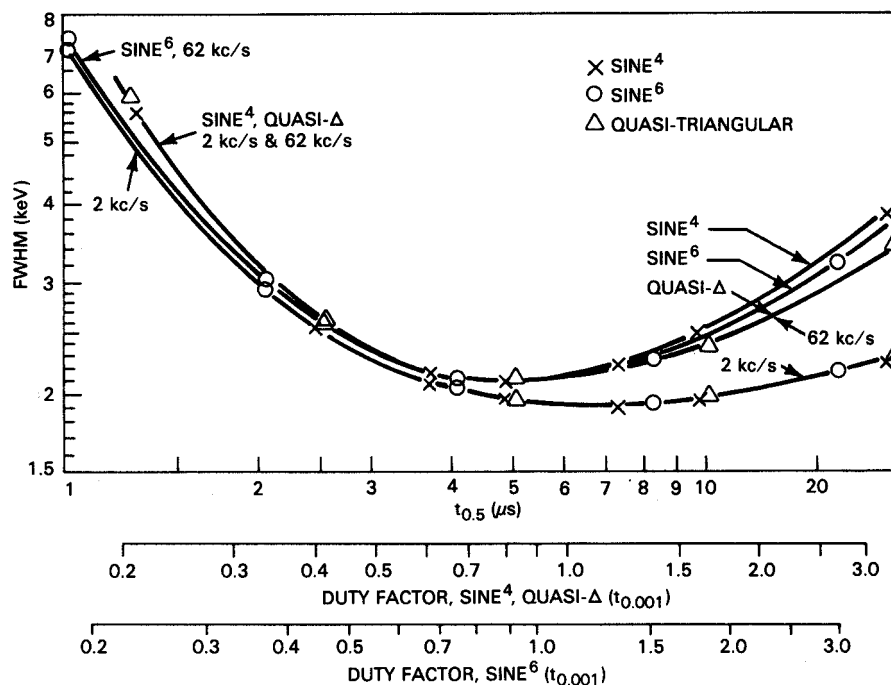


Figure 2—Energy Resolution vs $t_{1/2}$

³This parameter replaces t_p used in earlier standards.

Other parameters of interest are t_p and t_{01} (Fig 5). The ratio $2t_p/t_{01}$ is a measure of the pulse symmetry, therefore an indicator of series-noise performance (see Fig A-2). The width t_{01} in conjunction with t_p shows how closely two pulses may be spaced before the first affects the height of the second. Also, t_{01} is near the threshold level of the BLR; the duty cycle measured at this level is a good indication of when the BLR will lose control of the baseline.⁴ If no qualifications are given, it shall be understood that the resolving time of a shaped pulse is its width at t_{01} .

Bipolar-pulse parameters of interest are t_{p1} , t_{p2} , width of the leading lobe (1% to crossover), width of the trailing lobe (crossover to 1%), and V_{a2} . A measure of symmetry of the unipolar pulse before it undergoes the second differentiation is the ratio of the pulse heights of primary to secondary lobes, V_{a1}/V_{a2} . The preceding definition of resolving time shall apply to bipolar pulses as well as to unipolar pulses.

2.4 Biased Amplifier

A biased amplifier has an adjustable threshold below which the signal amplification is zero and above which it can be varied (usually, in the range of $\times 1$ – $\times 10$). The effect is to magnify the portion of a spectrum that lies above the threshold (bias) setting. Because most of the peaks in an α -particle spectrum fall into a narrow band of energies, a biased amplifier is particularly useful in this measurement—the amplifier spreads the band over A times as many channels as would otherwise occur, where A is the gain setting. For example, with $A = 8$ and with an MCA having only 500 channels, the resolving power of a 4000-channel MCA is obtained over a 12.5% region of the spectrum. Alternatively, a 4000-channel MCA in conjunction with an eight-channel linear multiplexer can be used to acquire data from eight spectrometers on a time-sharing basis if each has its own biased amplifier; each spectrometer will have the equivalent resolution of the full 4000 channels, but its data will occupy only 500.

2.5 Multichannel Analyzer

An MCA basically consists of an analog-to-digital converter (ADC), a memory unit, and a display. The spectrum distortion in the ADC renders an MCA unsuitable for testing high-resolution amplifiers and preamplifiers. For that reason, the tests herein avoid its use.

3. Test Instruments

3.1 Test Setup

A test setup is shown in Fig 3. By altering cable connections at the dotted lines, the setup can be used for all tests except crossover walk and nonlinearity measurements of the preamplifier and biased-amplifier. The ac voltmeter is not required for linearity tests and the bridge is not required for noise measurements. The preamplifier and capacitor box are not required for measurements made only on the main amplifier.

In this and other test setups, it is essential that the BNC connectors at the ends of the cables be in good mechanical condition to assure low-resistance electrical connections. The same is true of adapters, such as tees and elbows. In the cable connectors, it may be necessary to slightly bend (with a jeweler's screwdriver) the ears of the internal grounding ring to restore the spring action. In tees and elbows, the center pin should be screwed into its mating part with needle-nosed pliers. It should be recognized that with source and terminating resistors of 50 Ω , a resistance variation of 0.1 Ω in a connector causes a 0.1% variation in pulse height.

A back-terminating resistance of 50 Ω is assumed for the pulse generator and amplifiers under test, but any value of R_o may be used as long as the attenuator and cables are compatible with it, that is, correctly terminated.

⁴In the earlier standard, t_{001} was the measure of pulse width, but this low level is subject to errors caused by P/Z misadjustment, noise, and generator artifacts. The pulse width at t_{001} is 10% to 25% wider than at t_{01} , depending on the particular shaping network that is used (App Fig A-2).

3.1.1 Test Instrument Accuracy

The particular components of the setup requiring high accuracy are C_c , the attenuator, the ac voltmeter, the arms of the nonlinearity bridge, and the oscilloscope sweep time. Neither the generator amplitude nor the oscilloscope sensitivity need be separately accurate if they are calibrated against each other (see 3.9). Also, if the ac voltmeter is calibrated against the generator (see A3.6.2), the same may be said of the voltmeter.

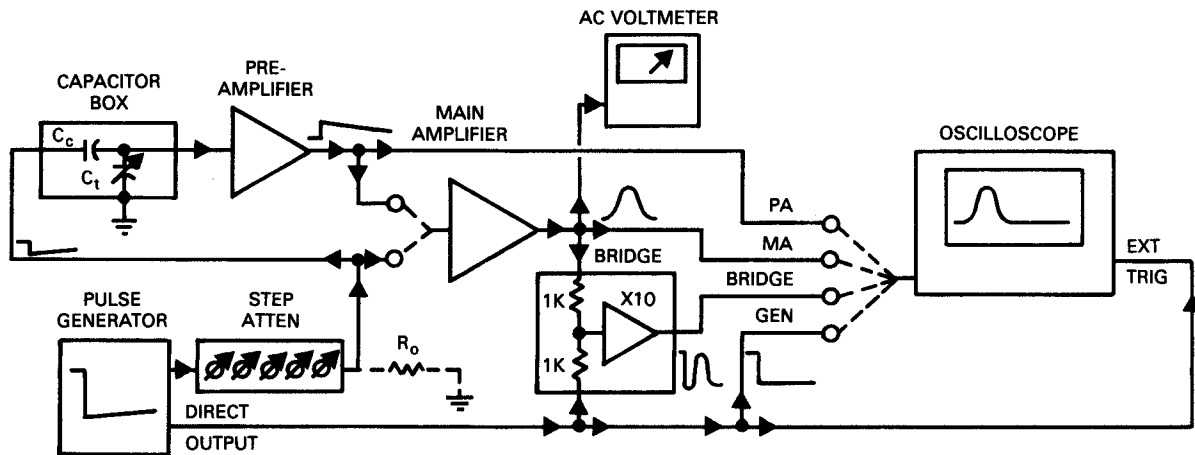


Figure 3—Test Setup

3.1.2 Measurement Accuracy

For items like noise, a measurement accuracy of 1% is usually adequate. For items like nonlinearity, higher accuracy may be required. However, no more decimal places shall be given in instrument specifications than are required for the accuracy of the parameter specified or are inherent in the accuracy of the measurement.

Because errors accumulate when several instruments are used in a measurement, the final accuracy is likely to be less than that of any one of the test instruments. If errors are random, it shall be assumed that the separate errors add as the square root of the sum of the squares.

3.2 Pulse Generators

The open-circuit output voltage V_p of the generator shall be at least 10.0 V and the output shall be controlled with resolution at least as good as that afforded by a multiturn pulse-height control with 1000 divisions full scale. (In the test procedures, the 10 Volt V_p and a 1000 div dial will be assumed unless otherwise stated. A different V_p or means of controlling it may affect some of the details of the tests, but not the methods.)

The generator shall be provided with at least two outputs, each with its own back-terminating resistor, and with a common source resistance r_o of 0.5 Ω or less. An additional output for triggering the oscilloscope sweep is highly desirable, but is not shown in Fig 3.

Generators shall be operable both at and away from the power-line frequency as a means of uncovering hum pickup in the system under test (if hum is present, a generator operated at the power-line frequency will not uncover it).