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IEEE Standard Test Procedures for Semiconductor Charged-Particle Detectors

Sponsor

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

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Foreword

(This Foreword is not a part of IEEE Std 300-1988, IEEE Standard Test Procedures for Semiconductor Charged-Particle Detectors.)

This standard provides standard test procedures for semiconductor charged-particle detectors for ionizing radiation. It supersedes the previous edition, ANSI/IEEE Std 300-1982. The standard has been modified and refined based on the experience gained in using the earlier edition over a number of years, taking into account advances in the technology. Companion documents are ANSI/IEEE Std 301-1988, Test Procedures for Amplifiers and Preamplifiers Used with Detectors of Ionizing Radiation, and ANSI/IEEE Std 759-1984, IEEE Standard Test Procedures for Semiconductor X-ray Energy Spectrometers.

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IEEE Standard Test Procedures for Semiconductor Charged-Particle Detectors

1. Scope and Object

1.1 Scope

This standard applies to semiconductor radiation detectors that are used for the detection and high-resolution spectroscopy of charged particles. The measurement techniques described were selected to be readily available to all manufacturers and users of charged-particle detectors. Some superior techniques are not included because the methods are too complex or require equipment (such as particle accelerators) which may not be readily available.

Test procedures for the associated amplifiers and preamplifiers are described in ANSI/IEEE Std 301-1988 [2].¹

1.2 Object

The object of this standard is to establish standard test procedures for semiconductor charged-particle detectors. These detectors are in widespread use for the detection and high-resolution spectroscopy of charged particles. It is desirable to maintain standard test procedures so that measurements may have the same meaning to all manufacturers and users.

Not all tests described in this standard are mandatory, but tests which are used to specify performance shall be performed in accordance with the procedures described herein.

2. References

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

[1] ANSI ENH—Special Report SR-24B, 1982 Edition, ANSI Photo Lamp Codes.²

¹The numbers in brackets correspond to those of the references in Section 2.

²ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[2] ANSI/IEEE Std 301-1988, IEEE Standard Test Procedures for Amplifiers and Preamplifiers Used with Detectors of Ionizing Radiation.³

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

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

3. Symbols and Definitions

3.1 Symbols

ADC	= analogue-to-digital converter
C	= electrical capacitance
C_c	= calibrated capacitor used to couple a pulse generator to a preamplifier
C_f	= feedback capacitor in the charge-sensitive loop of a preamplifier
E	= energy of a particle or photon
ε	= average energy required to form one hole-electron pair in a semiconductor detector
FWHM	= full width at half maximum
FW.1M	= full width at one-tenth maximum
FW.01M	= full width at one one-hundredth maximum
MCA	= multichannel analyzer
q	= charge of the electron, $1.602 \cdot 10^{-19}$ coulomb
Q	= electric charge
R	= electrical resistance
R_d	= detector load resistor
S	= channel number for a multichannel analyzer spectrum obtained to check the positional resolution and linearity of position-sensitive detectors
S_i	= peak channel number of the i th position peak generated by a position-sensitive detector when used with a mask with slits. (The indices for i range from $i = 0$ to $i = m$.)
T	= absolute temperature (K)
t	= time
TAC	= time-to-amplitude converter
t_c	= charge collection time in a detector
t_o	= observed detector rise time due to the combined effects of the charge collection time and electronic rise time
t_f	= pulse fall time (90% – 10% of its peak value)
t_p	= peaking time of a pulse
t_r	= pulse rise time (10% – 90% of its peak value)
t_t	= tailing time of a pulse
$t_{0.5}$	= width of a pulse at 50% of its peak height
$t_{0.1}$	= width of a pulse at one percent of its peak height
τ	= time constant
τ_d	= time constant for decay of a pulse
V	= electric voltage
Z_o	= characteristic impedance

3.2 Specialized Definitions

Definitions that are followed with the reference IEEE Std 194-1977 [4] contain pulse-shaping terms defined in that standard.

When the term *amplifier* is used, *preamplifier* also is implied unless otherwise stated.

active dimension (of a position-sensitive detector). A dimension (length, width) of that region of a position-sensitive detector that is depleted.

avalanche breakdown (of a semiconductor device). A breakdown caused by the cumulative multiplication of charge carriers through field-induced impact ionization.

band gap. The energy difference between the bottom of the conduction band and the top of the valence band.

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 [4]).

bias. (1) In a biased amplifier, the applied threshold voltage (or current) below which the gain is zero.
(2) In a detector, the polarizing 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 incremental gain above that threshold up to a specified maximum output.

bias resistor (detector). The resistor through which the polarizing voltage is applied to a detector.

blocking contact (of a semiconductor radiation detector). That contact from which depletion proceeds into the semiconductor material under conditions of reverse bias.

breakdown (of a semiconductor diode). A phenomenon occurring in a reverse-biased semiconductor diode, the initiation of which is observed as a transition from a region of high dynamic resistance to a region of substantially lower dynamic resistance for increasing magnitude of reverse current.

breakdown region (of a semiconductor diode characteristic). That entire region of the voltage-current characteristic beyond the initiation of breakdown for increasing magnitude of reverse current.

breakdown voltage (of a semiconductor diode). The voltage measured at a specified current in the breakdown region.

capacitance (of a semiconductor radiation detector). The small-signal capacitance measured between terminals of the detector under specified conditions of bias and frequency.

channel, surface (of a semiconductor radiation detector). A thin region at a semiconductor surface of *p*- or *n*-type conductivity created by the action of an electric field; for example, that due to trapped surface charge.

channeling, lattice (in a semiconductor radiation detector). A phenomenon that results in a crystallographic directional dependence of the rate of energy loss of ionizing particles.

charge carrier (of a semiconductor). A mobile conduction electron or mobile hole.

charge collection time (of a semiconductor radiation detector). The time interval, after the passage of an ionizing particle, for the integrated current flowing between the terminals of the detector to increase from 10% to 90% of its final value.

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.

constant-fraction discriminator. An amplitude discriminator in which the triggering threshold is set at a constant percentage of the input pulse amplitude independent of its size.

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

crossover time. The instant at which the transition between the two lobes of a bipolar pulse passes through a designated level (usually the baseline).

crossover walk. A deviation of crossover time of a bipolar pulse due to a change in peak amplitude. *See: walk.*

CR-RC shaping. In an amplifier, the pulse shaping produced by a single-section high-pass network followed by a single-section low-pass network, with the two networks separated by an isolating stage and with both networks having the same time constant.

dead layer (of a semiconductor detector). An inactive region (layer) in which the energy absorbed from the passage of monoenergetic charged particles does not significantly contribute to the resulting full energy peak.

decay time constant. With a signal that decays with a single exponential waveform, the time required for it to fall to $1/e$ from any selected level on the asymptote of the last transition (see IEEE Std 194-1977 [4]).

depletion region (in a semiconductor). A region in which the charge-carrier charge density is insufficient to neutralize the net fixed charge density of ionized donors and acceptors.

In a diode-type semiconductor radiation detector the depletion region is the sensitive region of the device.

depletion voltage (of a semiconductor radiation detector). The voltage at which a junction detector becomes fully depleted.

differential dE/dx Detector. A transmission detector in which the thickness is small compared to the range of the incident particle.

differentiated (pulse) (pulse amplifier jargon). A pulse is *differentiated* when it is passed through a high-pass network, such as a CR filter.

diffused-junction detector. A semiconductor detector in which the p - n or n - p junction is produced by diffusion of donor or acceptor impurities.

energy resolution. (1) In keV: the FWHM of a spectral line in units of keV. (2) In percent: $100 \cdot (\text{FWHM}/E)$ where FWHM and energy E are expressed in the same units *See: FWHM.*

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 an output signal attributable to the observed series-noise component. 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 an output signal attributable to the observed parallel-noise component. This definition applies only to noise with a constant spectral density (white noise).

fall time (of a pulse). The interval between the 90% and 10% points (unless otherwise specified) on the last transition (see IEEE Std 194-1977 [4]).

fixed fraction discriminator. *See: constant-fraction discriminator.*

full width at half maximum (FWHM). The full width of a distribution measured at 50% of its peak height. If the distribution is a spectral line due to radiation, it is assumed that the background level was averaged over the base of that line and the average subtracted from the ordinates of the distribution before the FWHM was determined. For a normal distribution,

$$\text{FWHM} = 2(2 \ln 2)^{0.5} = 2.355\sigma$$

where

σ = standard deviation and also the root-mean-square value of the distribution.

full width at one-tenth maximum (FW1M). The full width of a distribution measured at one tenth of the maximum ordinate measured above the background.

FWHM. *See:* **full width at half maximum.**

geometry, detector (detector jargon). The physical configuration of a solid-state detector.

ion implanted contact. A detector contact consisting of a junction produced by the process of ion implantation.

ion implantation. A process in which a beam of energetic ions incident upon a solid results in the implantation of those ions into the material.

inactive region (of a semiconductor radiation detector). A region of a detector in which charge created by ionizing radiation does not contribute significantly to the signal charge.

integrated (pulse) (pulse amplifier jargon). A pulse is *integrated* when it is passed through a low-pass network, such as a single *RC* network or a cascaded *RC* network.

intrinsic semiconductor. A semiconductor containing an equal number of free holes and electrons throughout its volume.

junction (of a semiconductor radiation detector). A region of transition between semiconductor regions of different electrical properties (for example, *n-n⁺*, *p-n*, *p-p⁺* semiconductors), or between a metal and a semiconductor.

junction depth (of a p-n semiconductor radiation detector). The distance below the crystal surface at which the conductivity type changes.

leakage current (of a semiconductor radiation detector). The total detector current flowing at the operating bias in the absence of radiation.

lithium-drifted detector. A detector made by the lithium compensation process.

lithium drifting. A technique for compensating *p*-type material by causing lithium ions to move through a crystal under an applied electric field in such a way as to compensate the charge of the bound acceptor impurities.

noise linewidth. The contribution of electronic noise to the width of a spectral peak.

noninjecting contact (of a semiconductor radiation detector). A contact at which the carrier density in the adjacent semiconductor material is not changed from its equilibrium value.

ohmic contact (of a semiconductor radiation detector). A purely resistive contact, that is, one that has a linear voltage-current characteristic throughout its entire operating range.

peaking time (*t_p* of a pulse). The time interval between the one percent point on the first transition and the top centerline (see IEEE Std 194-1977 [4]).