Standard Practice for
Characterizing Acoustic Emission Instrumentation[1]

This standard is issued under the fixed designation E 750; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice is recommended for use in testing and measuring operating characteristics of acoustic emission electronic components or units. (See Appendix X1 for a description of components and units.) It is not intended that this practice be used for routine checks of acoustic emission instrumentation, but rather for periodic calibration or in the event of a malfunction. The sensor is not addressed in this document other than suggesting methods for standardizing system gains (equalizing them channel to channel) when sensors are present.

1.2 Where the manufacturer provides testing and measuring details in an operating and maintenance manual, the manufacturer's methods should be used in conjunction with the methods described in this practice.

1.3 Difficult or questionable instrumentation measurements should be referred to electronics engineering personnel.

1.4 The methods set forth in this practice are not intended to be either exclusive or exhaustive.

1.5 The methods (techniques) used for testing and measuring the components or units of acoustic emission instrumentation, and the results of such testing and measuring should be documented. Documentation should consist of photographs, charts or graphs, calculations, and tabulations where applicable.

1.6 AE systems that use mini or micro computers to control the collection, storage, display, and analysis of data are in common use. Features of the computer-based systems include a wide selection of measurement parameters relating to the AE event. This selection, however, is usually made after the data have been acquired. This implies that the AE signals are individually recorded for later analysis, or that all the available parameters are measured on every AE signal that exceeds the selected threshold. The latter is usually the case. The manufacturer provides a specification for each system that specifies the operating range and conditions for the system. All calibration and acceptance testing of computer-based AE systems must use the manufacturer's specification as a guide. This practice does not cover testing of the computer or computer peripherals.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*
E 1316 Terminology for Nondestructive Examinations[2]
2.2 *ANSI Standard:*
ANSI/IEEE 100-1984 Dictionary of Electrical and Electronic Terms[3]
2.3 *Other Documents:*
Manufacturer's Operating and Maintenance Manuals pertinent to the specific instrumentation or component

3. Terminology

3.1 *Definitions*—For definitions of additional terms relating to acoustic emission, refer to Terminology E 1316.

4. Apparatus

4.1 The basic test instruments required for measuring the operating characteristics of acoustic emission instrumentation include:
4.1.1 *Variable Sine Wave Generator,*
4.1.2 *True RMS Voltmeter,*
4.1.3 *Oscilloscope,*
4.1.4 *Variable Attenuator, graduated in decibels,* and
4.1.5 *Tone Burst Generator.*

4.2 Additional test instruments should be used for more specialized measurements of acoustic emission instrumentations or components. They are as follows:
4.2.1 *Variable-Function Generator,*
4.2.2 *Time Interval Meter,*
4.2.3 *Frequency Meter, or Counter,*
4.2.4 *Random Noise Generator,*
4.2.5 *Spectrum Analyzer,*
4.2.6 *D-C Voltmeter,*
4.2.7 *Pulse-Modulated Signal Generator,*
4.2.8 *Variable Pulse Generator,* and

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[1] This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.04 on Acoustic Emission.

Current edition approved May 10, 1998. Published July 1998. Originally published as E 750 – 80. Last previous edition E 750 – 88(1993)ϵ1.

[2] *Annual Book of ASTM Standards*, Vol 03.03.

[3] Available from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

4.2.9 *Phase Meter*,

4.2.10 *Electronic AE Simulator*.

4.3 An electronic AE simulator is necessary to evaluate the operation of computer-based AE instruments. A detailed example of the use of an electronic AE simulator is given in 5.5.3 under dead time measurement. The instruction manual for the electronic AE simulator provides details on the setup and adjustment of the simulator. Control of pulse frequency, rise time, decay, repetition rate, and peak amplitude in the simulator makes it possible to simulate a wide range of AE signal conditions.

5. Tests and Measurements

5.1 *Required Measurements*:

5.1.1 Tests and measurements should be performed to determine the instrumentation bandwidth, frequency response, gain, noise level, threshold level, dynamic range, signal overload point, dead time, and counter accuracy.

5.1.2 Where acoustic emission test results depend upon the reproduced accuracy of the temporal, spatial, or spectral histories, additional measurements of instrumentation parameters should be performed to determine the specific limits of instrumentation performance. Examples of such measurements may include amplifier slew rate, gate window width and position, and spectral analysis.

5.1.3 Tests and measurements should be performed to determine the loss in effective sensor sensitivity resulting from the capacitive loading of the cable between the preamplifier and the sensor. The cable and preamplifier should be the same as that used for the acoustic emission tests without substitution. (See also Appendix X2.)

5.1.3.1 Important tests of a computer-based AE system include the evaluation of limits and linearity of the available parameters such as:

(a) Amplitude,

(b) Duration,

(c) Rise Time,

(d) Energy, and

(e) Source Location.

5.1.3.2 The processing speed of these data should be measured as described in 5.5.3 for both single- and multiple-channel operation.

5.1.3.3 The data storage capability should be tested against the specification for single- and multiple-channel operation. Processing speed is a function of number of channels, parameters being measured, event duration, front-end filtering, storage and display (RAM, disk, plots) and printout requirements.

5.2 *Frequency Response and Bandwith*:

5.2.1 The instrumentation, shown in Fig. 1, includes the preamplifier, wave filters, secondary amplifier, and intercon-

necting cables. All measurements and tests should be documented. The preamplifier should be terminated with the normal working load.

5.2.2 An acceptable frequency response between cutoff frequencies is within 3 dB of the reference frequency. The reference frequency is the geometric mean of the nominal bandwidth of the instrumentation. The mean frequency is calculated as follows:

$$f_M = (f_L f_H)^{\frac{1}{2}}$$

where:

f_M = mean frequency,
f_L = nominal lower cutoff, and
f_H = nominal upper cutoff.

5.2.3 The bandwidth should include all contiguous frequencies with amplitude variations as specified by the manufacturer. Instruments that include signal processing of amplitude as a function of frequency should have bandwidth amplitude variations as specified by the manufacturer.

5.2.4 With the instrumentation connected as shown in Fig. 1 and the sine wave oscillator set well within the instrumentation's specified dynamic range, the frequency response should be measured between frequency limits specified in 5.2.2. The oscillator is maintained at a fixed amplitude and the frequency is swept through the frequency limits. The secondary amplifier, or final filter, output is monitored with an rms voltmeter. Values of amplitude are recorded for each of several frequencies within and beyond the nominal cutoff frequencies. The recorded values are plotted on chart paper. The amplitude scale may be converted to decibels. The frequency scale may be plotted either linearly or logarithmically. Appendix X2 provides further discussion of wave shaping components.

5.2.5 A spectrum analyzer may be used in conjunction with a white noise source or an oscilloscope may be used in conjunction with a sweep frequency oscillator to determine bandwidth. With a white noise source connected to the input, a spectrum analyzer connected to the output will record the frequency response.

5.2.6 The measured bandwidth is the difference between the frequencies at which the response is 3 dB less than the response at the reference frequency.

5.3 *Gain*:

5.3.1 The electronic amplification is comprised of the preamplifier gain, the secondary amplifier gain, and the wave filters insertion gains or losses. (See Appendix X2 for an explanation of gain measurements.)

5.3.2 The electronic amplification may be measured with the instrumentation shown in Fig. 1. The sine wave oscillator is set to the reference frequency. The oscillator amplitude is set well within the dynamic range of the instrumentation to avoid distortion due to overload. With the voltmeter at V_{osc}, oscillator amplitude is set to 1 V. The attenuator is set for a value greater than the anticipated electronic amplification. Next, the voltmeter is moved to V_{out}. The attenuator is now adjusted until the voltmeter again reads 1 V. The electronic amplification is equal to the new setting on the attenuator. A white noise generator or sweep generator and spectrum analyzer may be used in place of the oscillator and RMS voltmeter.
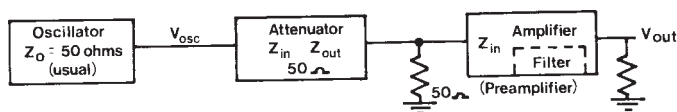

FIG. 1 Component Configuration Used for Testing and Measuring the Frequency Response, Amplification, Noise, Signal Overload, Recovery Time, and Threshold of Acoustic Emission Instrumentation

NOTE 1—If the input impedance of the preamplifier is not both resistive and equal to the required load impedance of the attenuator, proper compensation should be made.

5.4 *Dynamic Range*:

5.4.1 The criterion used for establishing dynamic range should be documented as the signal overload point, referenced to the instrumentation noise amplitude. Alternatively, the reference amplitude may be the threshold level if the instrumentation includes a voltage comparator for signal detection. In addition, dynamic range relative to instrumentation damage may also be documented. The total harmonic distortion criterion should be used for signal processing involving spectrum analysis. All other signal processing may be performed with the signal overload point criterion.

5.4.2 The dynamic range (DR) in decibels should be determined as follows:

$$DR = 20 \log_{10} \frac{\text{maximum rms output}}{\text{rms noise output}}$$

5.4.2.1 The dynamic range of instrumentation exclusive of threshold or voltage comparator circuits, is a ratio of the rms signal overload level to the rms noise amplitude. (A brief description of noise sources appears in Appendix X4). An oscilloscope is usually required as an adjunct to determine the characteristics of noise and to monitor the signal overload point.

5.4.2.2 A field measurement of dynamic range may produce substantially different results when compared with a laboratory measurement. This difference is caused by an increase in the reference voltage output, and may result from noise impulses of electrical origin, or ground faults.

5.4.2.3 For an amplifier that has a threshold comparator as its output device, the dynamic range is the ratio of maximum threshold level to input noise level. Excess amplitude range in the amplifier contributes to overload immunity but not to the dynamic range. The following measurement will give the effective dynamic range:

$$DR_e = 20\log_{10}(\text{MaxTh/MinTh})$$

where:
DR_e = the effective dynamic range of the system,
MaxTh = the threshold value that just passes the largest undistorted peak signal input, and
MinTh = the threshold value that passes less than 1 count/s with no input signal.

This dynamic range is the difference between the largest and the smallest AE input that can be counted by the system.

5.4.3 Measurement of instrument electronic noise is accomplished by replacing the oscillator/attenuator of Fig. 1, with the sensor that will be used, including its cable (or with a lumped equivalent capacitance). A lumped capacitance represents the electrical characteristic of the sensor and cable combination without adding mechanical noise interference. The rms voltage is measured at the instrumentation output (V_{out}).

5.4.4 The signal overload level is measured by replacing the sensor with a sine wave oscillator as shown in Fig. 1. The frequency is set to the mid-band frequency of the instrumentation. The oscillator amplitude is fixed at 1 V peak to peak monitored at V_{osc}. The attenuator is adjusted to increase the

signal level to the preamplifier until the instrumentation output (V_{out}) is 3 dB less than the computed output.

5.4.5 Should the peak amplitude of acoustic emission events exceed the dynamic range, several deleterious effects may be produced; these include clipping, saturation, and overload recovery time-related phenomena. (See Appendix X2 for a discussion of overload recovery.) The instrumentation gain should be adjusted to limit these effects to an absolute minimum in order to increase the reliability of the data.

5.5 *Dead Time*:

5.5.1 The instrumentation dead time may include variable and fixed components depending on the instrumentation design for handling the routine of the input and output data processing. The components included in dead time are process time and lock-out time. Process time varies from system to system and usually depends on the number of parameters processed for each event. Lock-out time, which may be operator controlled, is used to force a time delay before accepting new events.

5.5.2 Dead time measurement in a counter type AE instrument should be conducted as follows: Set the instrument to the count rate mode. Set the oscillator frequency to the mid-band frequency of the instrument. Set the oscillator amplitude to achieve a count rate equal to the oscillator frequency. Increase the oscillator frequency until the count rate ceases to equal the oscillator frequency. Record the frequency as the maximum count rate. (If the frequency is equal to or greater than the specified upper frequency limit of the instrument, the dead time of the counter is zero.) Dead time (Td) is given by:

$$Td = 1/Fm - 1/Fu$$

where:
Fm = the measured frequency, and
Fu = the upper bandwidth limit of the instrument.

5.5.3 Where the dead time in question is related to AE event processing such as measurement of source location, energy, duration, or amplitude, the measurement is best accomplished by using an electronic AE simulator as follows:

5.5.3.1 Select an event parameter to evaluate the dead time.

5.5.3.2 Set the electronic AE simulator frequency, rise, decay, duration, and repetition rate such that the observed event rate in the selected parameter equals the repetition rate of the simulator.

5.5.3.3 Increase the repetition rate of the simulator until the observed event rate falls below the simulator rate.

5.5.3.4 Record this value as maximum event rate (processing speed) for the selected parameter.

5.5.4 The dead time (Td) is given by:

$$Td = 1/R_p - D_p$$

where:
D_p = the selected pulse duration, and
R_p = the repetition rate of the simulator where the limit was found.

This dead time measurement procedure should be performed for each event-based parameter of the AE system.

5.6 *Threshold Level* (*Threshold of Detection*):

5.6.1 Various acoustic emission signal processing instruments rely upon the signal exceeding a comparator voltage level to register a hit. This level may be fixed, adjustable,

floating and fixed, or floating and adjustable. The floating threshold may be called automatic threshold. Signal recognition (or hit) does not occur until the threshold is exceeded.

5.6.2 The nonautomatic threshold level should be measured with the instrumentation assembled as shown in Fig. 1 and the signal processors attached to the point V_{out}. The signal processors are frequently digital electronic counters that may follow the secondary amplifier. Increasing the oscillator amplitude will result in an increasing signal level at V_{out}. The counters will begin counting when the signal at the comparator reaches the preset threshold level. This level measured with an oscilloscope connected to V_{out} multiplied by the gain of the secondary amplifier is equal to the threshold voltage. Some counters and other signal processors utilizing threshold detection are frequency sensitive. Therefore, the threshold level should be measured over the instrumentation bandwidth.

5.6.3 The automatic threshold cannot be measured with a continuous-wave generator because the automatic threshold level is usually derived from the rectified and averaged input signal. The tone burst generator provides an adjustable burst amplitude duration and repetition rate that may be used to establish the threshold level using the same technique that is used in 5.6.2. The automatic threshold level's affected by the tone burst amplitude, duration, and repetition rate.

5.7 *Counter Accuracy*:

5.7.1 Counters are of two types: summation counters and rate counters. Counters that tally signals for fixed repetitive periods of time during an acoustic emission test are known as rate counters. The tallied signals may be a count of acoustic emission signals, loading cycles, or amplitude levels.

5.7.2 The accuracy of the counting function of the instrumentation should be measured using a tone burst generator set as follows: (1) the amplitude should be well above the threshold level, but well within the dynamic range of the instrumentation; (2) the tone burst frequency should be within the instrumentation nominal bandwidth; (3) the tone burst duration should be at least one cycle, but fewer cycles than would cause the automatic threshold to take effect; (4) the tone burst repetition rate should be adjusted for a period that does not cause the automatic threshold to interfere with the count function. The counting accuracy is assured by comparing the emission count with the tone burst count.

5.8 *Computer-Measured Parameters*:

5.8.1 The limits and linearity of AE parameters recorded by computer-based systems may be measured by means of an electronic AE simulator. The electronic AE simulator provides individually adjustable amplitude, duration, rise time, and relative arrival time. Burst energy from the AE simulator may be calculated from the parameters given.

5.8.2 The limits or dynamic range and linearity of each parameter should be measured as follows for amplitude, duration, and rise time:

5.8.2.1 Connect the AE simulator to the preamplifier input of the channel to be tested.

5.8.2.2 Set up the AE system to record and display the parameter to be tested.

5.8.2.3 Adjust the AE simulator to produce a mid range simulated AE signal where the displayed amplitude, duration,

and rise time are 10 % of their maximum value as specified by the AE system manufacturer.

5.8.2.4 Record the value of each parameter at the electronic AE simulator output and at the AE system display.

5.8.2.5 To measure upper limits for each parameter, increase the measured input in equal increments (for example, 10 % of maximum) and record the displayed value for that parameter until the output differs from the input by 10 % or the specified maximum value is exceeded.

5.8.2.6 To measure lower limits for each parameter, adjust input-output condition as in 5.8.2.3, then decrease the input in equal increments (for example, 10 % of the initial value) and record the displayed value until the output differs from the input by 10 % or the minimum value specified by the AE system manufacturer is reached.

5.8.2.7 To test the computer-derived energy per event parameter, it is necessary to calculate the input energy from the electronic AE simulator in accordance with the method used by the AE system. For example, one method used in some AE systems computes approximate burst pulse AE event energy (E) as follows:

$$E \cong DV^2/2$$

where:
D = burst duration, and
V = peak amplitude.

5.8.2.8 Set the initial conditions as in 5.8.2.3. Increment input amplitude to obtain approximately 10 % of full scale change in energy input. Record the displayed energy per event value at each increment until the output differs from the input by 10 % or the maximum value specified by the AE system manufacturer is exceeded. Repeat this process with amplitude fixed at the initial value while incrementing pulse duration.

5.8.2.9 Again repeat the process with amplitude and pulse duration except decrease each parameter until the minimum value specified by the manufacturer is reached or no further change in the output is produced.

5.8.3 The source location computational algorithm is a complex computer process not covered by this document. However, a multichannel electronic AE simulator may be used to check the locational accuracy of systems that rely on the constancy of sound velocity to calculate location. For anisotropic materials where velocity is not constant, other source location algorithms exist such as area location based on first hit sensor.

5.8.3.1 Set up the AE system for source location in accordance with the operator's manual.

5.8.3.2 Set up the multichannel electronic AE simulator to provide simulated AE inputs to the appropriate number of channels.

5.8.3.3 Using the appropriate velocity of sound for the simulated structure, compute the times of flight from the simulated AE source position to each sensor of the source location array. The differences between the times of flight give relative arrival times (delta T) for the simulated AE sensor positions.

5.8.3.4 Record the displayed location coordinates for this initial simulated input. Compute and input a new delta T set for

a nearby point. Record the difference between input position and displayed position. Continue this incremental movement of the simulated AE source away from the sensor array center until the output position differs from the input position by 10 % or the source location range specified by the AE system manufacturer is exceeded. Evalaute any error with respect to the AE system manufacturer's specification for source location linearity.

5.8.3.5 The source location test procedure should be repeated for two additional rays extending in different directions from the array center.

5.8.3.6 The source location procedure should be repeated for each multichannel array of the system.

6. Keywords

6.1 acoustic emission; AE; dead-time; gain; preamplifier; sensitivity; sensor; signal processor; threshold

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APPENDIXES

(Nonmandatory Information)

X1. DESCRIPTION OF AE INSTRUMENT COMPONENTS

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X1.1 *Acoustic Emission Instrumentation*—Acoustic emission electronic components or units should include the sensor(s), preamplifier(s), filter(s), power amplifier(s), line drive amplifier(s), threshold and counting instrumentation, and signal cables. The sensitivity calibration and transfer characteristics of sensors are excluded from this standard.

X1.2 *Acoustic Emission Sensor:*

X1.2.1 An acoustic emission sensor is an electro-acoustic transducer that converts stress wave energy into electrical energy.

X1.2.2 A transformer or amplifier, or acoustic waveguide, if combined with the sensor in such a way that the readily accessible terminals include these components should be considered part of the sensor and the term" sensor'' should apply to the combination.

X1.2.3 Sensors may be designed with different active elements including magnetostrictive, electromagnetic, eddy current, capacitive, piezoresistive, piezoelectric, photoacoustic, or acoustoelectric devices. These may be assembled in single-ended or differential configuration with directional properties.

X1.2.4 The most frequently used sensor is the piezoelectric type contained within a conductive housing. The active face is often fitted with a nonconductive, machinable wear plate or shoe. An electrical connector mounted to the housing completes the sensor.

X1.3 *Acoustic Emission Preamplifier:*

X1.3.1 The acoustic emission preamplifier is the first amplifier following the sensor. The preamplifier power may be supplied by the secondary amplifier, or directly from the power mains. The preamplifier is defined as the first stage of amplification with the major function of converting the sensor impedance to an impedance suitable for driving long signal cables and additional electronic components or units.

X1.3.2 The input impedance of a preamplifier forms the load for the sensor. The proper magnitude and phase angle of the input impedance is governed by the sensor requirements. Inductive sensors may require relatively low impedance loads.

Capacitive sensors generally require high impedance loads. The low impedance loads depend upon current (or power) drive and the high impedance loads depend upon voltage (or charge) drive. Because the most commonly used sensor is a piezoelectric device, the preamplifier input impedance is moderately high.

X1.3.3 The output impedance of acoustic emission preamplifiers is low, usually about 50 ohms. This low impedance is required to drive long cables and reduce the susceptibility to coupled noise currents.

X1.3.4 The acoustic emission preamplifier may include filters and input/output line transformers. Filters are often employed to reject undesirable signals and avoid potentially overdriven stages within the preamplifier and succeeding components or units. Transformers are used for matching impedances between the source and its load. Transformers are also used for matching balanced to unbalanced transmission lines.

X1.4 *Acoustic Emission Signal Processor:*

X1.4.1 The signal processor provides the final, required instrumentation amplification. This amplifier must supply sufficient signal power to supply a combination of additional components or units such as oscilloscopes, voltmeters, counters, and recorders. For this reason, the secondary amplifier is often called a power amplifier. Additional bandpass filtering is often employed in this amplifier.

X1.4.2 The input impedance of the secondary amplifier should provide the required load impedance for the preceding component. The preceding component is usually the preamplifier, but may be a bandpass filter.

X1.4.3 The secondary amplifier should be used within its stated nominal operating range. The amplifier should complement the operating characteristics of the preceding component.

X1.4.4 The secondary amplifier may also include signal processing circuits such as an rms voltage converter and an event counting circuit.

X1.5 *Filter:*

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X1.5.1 A filter separates signals on the basis of frequency. It introduces relatively small loss to waves in one or more frequency bands and relatively large loss to waves of other frequencies.

X1.5.2 Filters may be active or passive. Active filters require electrical power. Passive filters require no electrical power.

X1.5.3 The most frequently used filter is the bandpass filter. A bandpass filter is a filter that has a single transmission band extending from a lower cutoff frequency greater than zero to a finite upper cutoff frequency. The gain at the cutoff frequencies should be 3 dB less than the passband geometric mean (reference) frequency as defined in 5.2.2. The slope of the filter characteristic outside the passband is very important for rejection of extraneous signals. Slopes of 30 dB per octave are typical for AE instruments.

X1.5.4 The filter should not limit the specified signal overload point of the preceding component or unit.

X1.5.5 AC-coupled amplifiers and preamplifiers limit the bandwidth by circuit design. Typical bandwidths may extend from a low of 1 KHz to a high of 2 MHz.

X1.6 *Line-Drive Amplifiers:*

X1.6.1 Where extremely long coaxial cables must be used, line-drive amplifiers are normally used. The line-drive amplifier is primarily an impedance conversion device. Line-drive amplifiers are used to supply sufficient signal current to drive several hundred meters of coaxial cable.

X1.6.2 The output impedance of a line-drive amplifier should be the same as the impedance of the coaxial cable that it drives, and the cable should terminate in its characteristic impedance for minimum reflection at the termination and for maximum power transfer.

X1.6.3 The dynamic range, signal overload point, and spectral response of the line-drive amplifier should be equal to or greater than those of the preceding component or unit unless otherwise specifically stated in report documentation.

X1.7 *Counting Instrumentation-Threshold Crossing:*

X1.7.1 Counting of threshold crossings is one of the most frequently used signal processing techniques for acoustic emission. This technique requires the signal amplitude to exceed a threshold voltage or comparator level to be recognized and recorded. Counting is often performed in two ways: rate and summation counting. The accuracy of rate counting depends upon the accuracy of the clock frequency. The accuracy of rate and summation counting depends upon the stability of the threshold level.

X1.7.2 The threshold level may be fixed, manually variable, automatic floating , or a combination thereof, depending upon the design and user application.

X1.7.3 Counters are designed to accept signals that exceed some threshold voltage or comparator level. Upon counting to some maximum count, some counters will reset to zero and begin again, while others will latch at the maximum value. The counters may be manually resettable, and may include an electrical circuit permitting the counter to be reset by a periodic electrical, or clock, signal.

X2. EXPLANATION OF SUGGESTED MEASUREMENTS

X2.1 *Preamplifier Input Impedance:*

X2.1.1 The preamplifier input impedance should be documented as the nominal input impedance. The preferred expression of input impedance should be a stated value of resistance shunted by a stated value of capacitance (see Appendix X3).

X2.1.2 Where inductive coupling is used, the input impedance should be documented in either the polar or rectangular form of its equivalent impedance as a function of frequency over the designed bandwidth of the preamplifier.

X2.1.3 Where charge amplifiers are used for acoustic emission amplification, the manufacturer's specification should suffice to describe the input impedance for direct-coupled piezoelectric generators. Any modification of the input impedance and the precise change of that impedance should be documented.

X2.2 *Input Coaxial Cables:*

X2.2.1 The coaxial cable, coupling the piezoelectric/capacitive sensor to the preamplifier, together with the cable couplings should be measured with a bridge (1.0 KHz) to determine the line capacitance. Visual examination of the cable should ensure that there is no damage to the line and connection. It is sometimes useful to know, with some precision, the capacitances of the sensor element and the connecting cable with its connectors, and the preamplifier input shunt capacitance in order to adjust sensitivity by appropriately increasing or decreasing shunt capacitance. Efforts to lower capacitance shunting the sensor will be rewarded by improved signal-to-noise ratios.

X2.2.2 The line capacitance should be documented and added to the preamplifier capacitance. The sum of line capacitance and preamplifier input capacitance should be documented as the sensor load capacitance for piezoelectric and capacitive sensors.

X2.2.3 Where the system to preamplifier cable is used also to supply a voltage to the preamplifier, the cross coupling between the signal lines and power supply lines might affect the detection of the AE.

X2.2.4 The influence of the coaxial cable and preamplifier impedance on the sensor open circuit sensitivity should be understood regardless of the sensor, cable, and preamplifier type or design.

X2.3 *Wave Shaping:*

X2.3.1 Acoustic emission instrumentation often contains electrical circuits that modify the applied waveform through a predictable and expected process. Such circuits are defined as wave-shaping circuits. Wave-shaping circuits include delayed

action circuits, integrators, differentiators, and envelope circuits. These circuits are often found in instrumentation with floating threshold and event counters. The number and function of wave-shaping circuits likely to be found in acoustic emission instrumentation are too numerous to be listed within this practice.

X2.3.2 The characteristics of wave-shaping circuits of interest should include rise time, duration, and decay time. The measurement of these characteristics depends upon the circuit design. The manufacturer should provide the temporal data and the test methods and measurement of these data in the operating and maintenance manual supplied with the component or unit.

X2.3.3 There are numerous sources for error in the measurement of instrumentation characteristics. These include impedance matching of signal sources to instrument inputs, frequency bandpass asymmetry, and windowing problems in spectrum analysis. The examples of error sources are mentioned to alert the user to the fact that a multichannel AE system should be characterized by comparing parameters channel to channel in order to minimize differences.

X2.4 *Gain Measurement:*

X2.4.1 A sensor being acted upon by a stress that generates an electrical signal can be modeled as a two-terminal black box containing an impedance in series with a generator of EMF. The impedance is primarily capacitive and, in the absence of a physical excitation, the substitution of a stable oscillating signal provides a suitable representation for the transduced EMF.

X2.4.2 Channel-to-channel sensitivity or gain can be measured and adjusted easily using a technique known as voltage insertion calibration which takes advantage of this model. A simple voltage insertion box is shown schematically in Fig. X2.1. Fig. X2.2 shows the equivalent circuit of the voltage insertion measurement.

X2.4.3 In this technique a calbrating voltage is inserted in series with the sensor and the channel gain is adjusted so that all channels in the system yield the same output level for the same oscillator input. This will assure that all channels will produce the same output for the same physical excitation if it were possible to reproduce the same physical excitation for each channel.
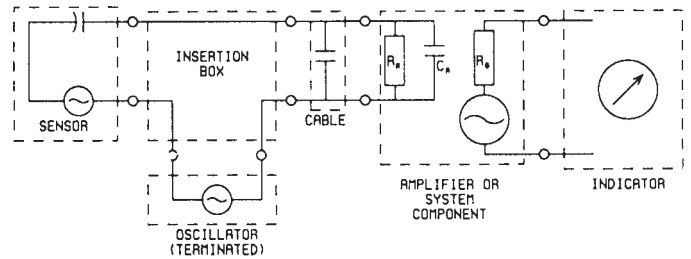

FIG. X2.2 Equivalent Circuit of the Voltage Insertion
Measurement

X2.4.4 The calibration voltage is chosen to be any convenient value near that expected from an acoustic emission event of interest, taking into account the dynamic range expected from the data.

X2.4.5 The frequency of the calibration voltage should be selected to be well below the resonances of the AE sensors, which are presumed to be of the resonant (undamped) type, but within the band pass of the AE system. This will prevent the individual resonances, which may be different from channel to channel, from influencing the gain adjustments.

X2.4.6 If the oscillator is calibrated and terminated, a known signal can be applied and the effective gain of the system with cables and sensor can be measured with an indicator on the channel output such as an RMS voltmeter.

X2.5 *Overload Recovery Time:*

X2.5.1 Overload recovery time results from exceeding the dynamic range in a limited number of older instruments. The time required to recover from an acoustic emission event whose amplitude exceeds the dynamic range depends upon the amplifier and instrumentation design, and current instruments should have overload recovery times less than one microsecond.

X2.5.2 The recovery time should be measured with an oscilloscope and a tone burst generator. The tone burst generator replaces the oscillator shown in Fig. X2.1 and the oscilloscope is connected to V_{out}. The tone burst generator is set between the geometric mean frequency and the nominal lower cutoff frequency. The tone burst should be a simple rectangular burst at the selected frequency. The duration of the tone burst is set for the duration expected from the acoustic emission
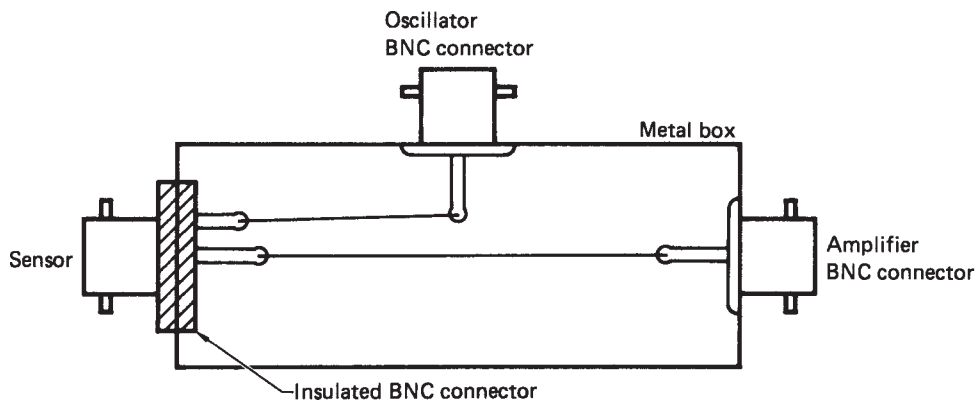

FIG. X2.1 Schematic of a Simple Voltage Insertion Box

events. Unless otherwise restricted and stated, the amplitde should be set for 2v peak to peak. The tone burst should have a repetition time in excess of the instrumentation recovery time such that instrumentation recovery should occur in less time than the next tone burst would occur. The oscilloscope should record the signal at V_{out} such that the residual feed-through from the tone burst generator may be observed following the tone burst and instrumentation overload recovery. The instrumentation overload recovery time is the time from the end of the tone burst to the time at which the residual has returned to its quiescent value (usually 1 % of the tone burst amplitude). A waveform synthesizer may be substituted for the tone burst generator, but provision should be made to allow measurement of residual amplitude between bursts.

X3. MEASUREMENT OF INPUT IMPEDANCE

X3.1 The electrical circuit configuration and its equivalent circuit used for measuring input impedance are shown in Fig. X3.1. The attenuator is necessary to apply small voltages to the input of high gain systems. Many appropriate oscillators have built in attenuators. It is important that the outputs of such instruments be terminated with the proper load resistance in order for the attenuator to remain calibrated over its complete range. If a separate attenuator is used with an oscillator, and if the attenuator impedance does not match the oscillator output impedance, it is important that they be matched with a pad that presents the proper load to the oscillator and the proper source impedance to the attenuator. Fig. X3.1 illustrates the circuit of the pad. The required pad resistance values R_1 and R_2 are calculated from:

$$R_1 = \sqrt{R_{osc}(R_{osc} - R_S)} \text{ and } R_2 = R_{osc}R_S/R_1$$

where:
R_{osc} = the output impedance of the oscillator, and
R_S = the characteristic impedance of the attenuator.

Attenuators commonly require a 50-ohm source and a 50-ohm load to perform properly. Oscillators commonly have outputs of either 50 or 600 ohms. Do not substitute a

FIG. X3.1 Input Impedance Measurement Circuit Configuration and Equivalent Circuit

potentiometer in place of a true attenuator. A separate attenuator also must be loaded with its characteristic resistance in order to operate as expected.

X3.2 Referring again to Fig. X3.1, measurements of the output voltage under two different conditions allows calculation of the input impedance using:

$$Z_A = \frac{V_{O2}(R + R_S) - V_{O1}R_S}{V_{O1} - V_{O2}} \pm \angle \, \theta = R_A \pm jX_A$$

where:
V_{O1} = the output voltage measured when Z_1 is zero,
V_{O2} = the output voltage when $Z_1 = R$ is some value greater than zero subject only to the condition that the change in output voltage caused by the insertion of R is reasonably large so it is easy to measure,
R_S = the output impedance of the attenuator, and
θ = the phase angle between the voltage measured across R and that measured across Z_A when $Z_1 = R$.

Since most practical AE instruments have input resistance no larger than 50 000 ohms and input shunt capacitance no larger than 10 000 picofarads, it is possible to make reasonably accurate estimates of their magnitudes by finding that pure resistive value for Z_1 that will reduce the output voltage to ½ of the value it had when $Z_1 = 0$ for an input frequency at around 10 kHz. Then the resistive part of the input impedance is equal to the selected value. Similarly the value of capacitance substituted for Z_1 that reduces the output to ½ of the $Z_1 = 0$ value when the input frequency is above 500 kHz will be equal to the shunt capacitance component of the input impedance. If inductive components are used in the amplifier input the manufacturer should provide clear instructions and cautions about the use and response of their equipment. An exact match is not necessary since in the low frequency limit when $Z_1 = R$, the resistance can be estimated from:

$$R_A = R[V_{O2}/V_{O1} - V_{O2}]$$

and in the high frequency limit when $Z_1 = \frac{1}{2} fC$, the capacitive component can be estimated from:
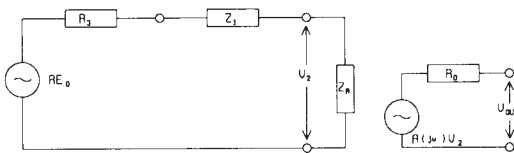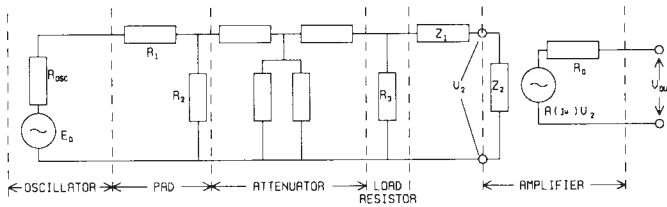
$$C_A = C[V_{O1}/(V_{O2} - V_{O2})]$$

X4. NOISE SOURCES AND MEASUREMENT PROBLEMS

X4.1 *Types of Noise*—Noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device. Noise may be erratic, intermittent, or statistically random. Noise is further defined as acoustic noise or electric noise to avoid ambiguity. This section is concerned with identifiable and controllable noise sources.

X4.2 *Acoustic Noise Sources:*

X4.2.1 Acoustic noise is detected by the sensor as a mechanical wave. This may be noise generated by reactive agents in contact with a specimen, loading fixture noise, or fluid noise. Fluid noise may be generated when orifice size and fluid flow velocity form an effective Helmholtz resonator. The signals generated by leaks may or may not be considered artifact noise, depending on the application of the acoustic emission technique or instrumentation.

X4.2.2 Thermal emission may be considered noise for some applications of AE examination. Thermal emission should become relevant when either the specimen or sensor is subjected to temperature changes. Thermal emission is often generated by material phase change, material geometry change (stick-slip AE), and the pyroelectric effect of some sensors. Many other sources of acoustic noise exist, but are not discussed here in the interest of brevity.

X4.3 *Electrical Noise Sources:*

X4.3.1 Electrical noise is noise coupled to the acoustic emission instrumentation by electrical conduction or radiation. The preponderance of electrical noise is synchronized to the power mains frequency. Electrical noise may contain the largest number of high-amplitude harmonics of any signal detected. Electrical noise may also be stable and continuous, or random in amplitude and repetition rate. Ground loops are often a problem at one work area, but may not be a problem at an adjacent work area. Radio transmitters may be another source of intermittent noise. Radio transmitters may include the traditional voice transmission units, or such sources as electrical motors, fluorescent lamps, and resistance welding.

X4.3.2 Noise may be introduced to the amplifier from noise impulses on the power mains through inadequately filtered power supplies. The noise is often intermittent and includes random impulse or burst signals of short duration and very fast rise time compared with acoustic emission signals. A series of several low pass, power main filters will often suppress this noise to an acceptable level.

X4.4 *Electronic Component Noise*—There are several sources of noise in electronic circuits. In practice, the noise figure of an amplifier is usually determined by the first, or input, stage of the amplifier. This is because noise introduced by other succeeding circuits of the instrumentation will undergo less amplification, and, thus, will be relatively unimportant in the instrumentation as long as the amplification of the first stage is moderate.