BS EN 13477-2:2010

BSI Standards Publication

Non-destructive testing — Acoustic emission — Equipment characterisation

Part 2: Verification of operating characteristic

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National foreword

This British Standard is the UK implementation of EN 13477-2:2010. It supersedes BS EN 13477-2:2001 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee WEE/46, Non-destructive testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Zerstörungsfreie Prüfung - Schallemissionsprüfung - Gerätecharakterisierung - Teil 2: Überprüfung der Betriebskenngrößen

This European Standard was approved by CEN on 30 July 2010.

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Foreword

This document (EN 13477-2:2010) has been prepared by Technical Committee CEN/TC 138 “Non-destructive testing”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2011, and conflicting national standards shall be withdrawn at the latest by March 2011.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 13477-2:2001.

EN 13477 consists of the following parts under the general title *Non-destructive testing — Acoustic emission — Equipment characterisation*:

— *Part 1: Equipment description*;

— *Part 2: Verification of operating characteristic*.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This part of the standard specifies methods for routine verification of the performance of AE equipment comprising one or more sensing channels. It is intended for use by operators of the equipment under laboratory conditions. Verification of the measurement characteristics is recommended after purchase of equipment, modifications, use under extraordinary conditions, or if one suspects a malfunction. The procedures described in this European Standard do not exclude other qualified methods, e.g. verification in the frequency domain.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1330-1:1998, *Non destructive testing — Terminology — Part 1: List of general terms*

EN 1330-2:1998, *Non destructive testing — Terminology — Part 2: Terms common to the non-destructive testing methods*

EN 1330-9:2009, *Non-destructive testing — Terminology — Part 9: Terms used in acoustic emission testing*

EN 13477-1:2001, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 1: Equipment description*

IEC 60050 (all parts), *International Electrotechnical Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1330-1:1998, EN 1330-2:1998, EN 1330-9:2009 and IEC 60050 (all parts) and the following apply.

3.1
AE signal processor
part of an AE channel for the conversion of the output of the preamplifier to digital signal parameters

NOTE The AE signal processor may include additional support functions, e.g. preamplifier power supply, test pulse control, transient recorder, and more.

3.2
arbitrary function generator (AFG)
electronic device for generating a programmable test signal (burst)

3.3
DC calibrator
electronic device for generating an adjustable or programmable DC voltage of appropriate accuracy for stimulating an external parametric input

4 Required test equipment

4.1 List of required equipment

The following minimum test equipment is required:

a) test body;

b) shielding test plate;

c) Hsu-Nielsen source, for sensor sensitivity verification;

d) sweep function/variable pulse generator (if function not included in f));

e) multimeter, e.g. for DC voltage and DC current measurement;

f) test signal generator, e.g. AE calibrator or arbitrary function generator (AFG);

g) variable attenuator, graduated in decibels, can be part of the test signal generator;

h) DC-calibrator, for external parameter stimulation;

i) DC-power-supply, for preamplifier supply, with a proper circuit to decouple and terminate the AE signal, if the power is fed-in over the signal wire;

j) RMS voltmeter, with known or settable time constant or time window;

k) dual channel storage oscilloscope, for preamplifier verification, peak noise measurement and identification of any artefacts on the AE signal.

NOTE Items i) to k) can be substituted by a verified AE signal processor comprising peak amplitude and RMS measurement.

The inaccuracy of the test signal generator shall be significantly lower than the acceptable inaccuracies given in this standard and summarized in Table 3. Less accurate test signal generators can be used, if the inaccuracy of each pattern is measured and considered during verification.

The reproducibility of the DC calibrator output shall be significantly lower than the acceptable inaccuracy of the external parameter verification. The inaccuracy of the DC calibrator at the used measurement levels shall be obtained and considered during verification (see Clause 8).

All electric/electronic test items shall be calibrated to ensure traceability to SI units.

4.2 Test signal waveforms

The following types of test signals shall be used to verify the operating characteristics of the AE measurement system:

4.2.1 Continuous sine wave

This type of test signal shall be used to verify the frequency response and gain of the preamplifier and the continuous signal level accuracy of the AE signal processor.

4.2.2 Triangular modulated sine wave

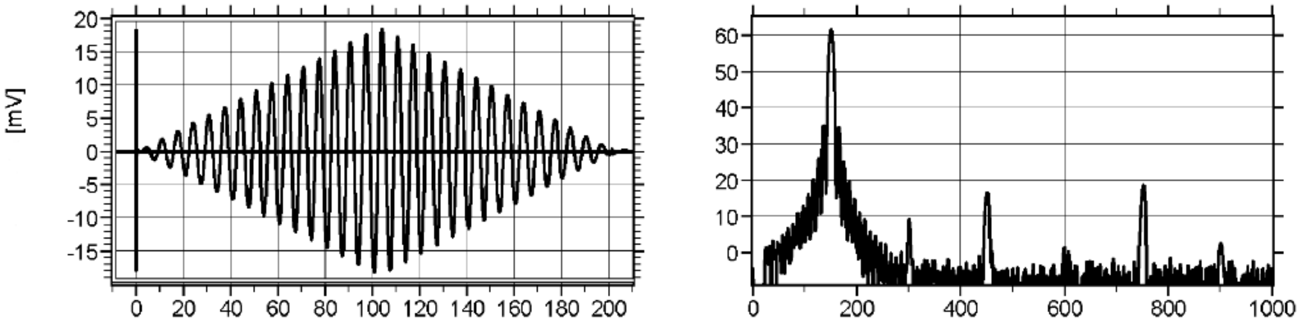
This type of wave simulates an AE burst signal, see Figure 1. It is defined by the following characteristics:

— A = amplitude;

— R = rise-time;

— D = duration;

— f = carrier frequency.



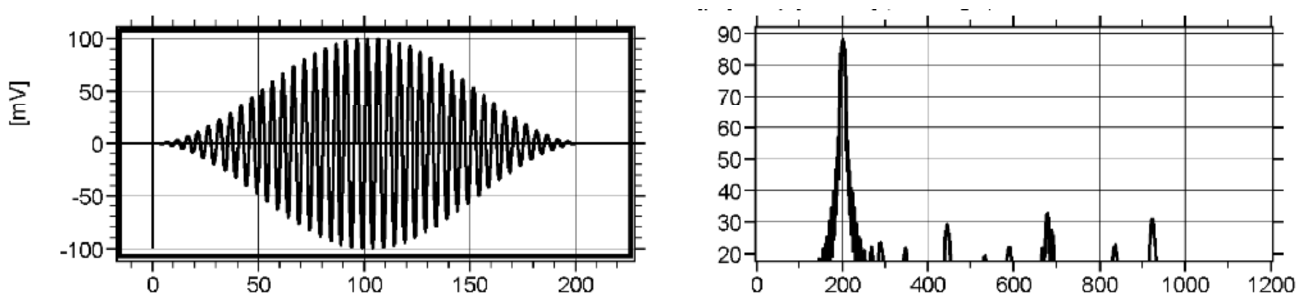
Key
[mV] amplitude

Figure 1 — Triangular modulated sine wave in time (left) and frequency (right) domain

The measured rise time may be shorter than the visible rise time of the test signal because rise time measurement starts at the time of the first threshold crossing. Table 1 shows the dependency of this threshold crossing delay on the difference between maximum amplitude and threshold setting in an AE channel.

4.2.3 Sine²-modulated sine wave

A sine²-modulated signal (see Figure 2) can be used as an alternative to a triangular modulated sine wave. Due to its smooth begin, peak and end, its spectrum is very pure and the influence of filter overshoot and filter ring down behaviour is reduced. This signal can be used to obtain the frequency response of the bandpass of a preamplifier or AE signal processor by burst peak amplitude measurement.



Key
[mV] amplitude

Figure 2 — Sine²-modulated sine wave in time (left) and frequency domain (right)

NOTE The shown signal corresponds to the following function:

$$U[N] = U_P \times \sin(N \times 2 \times \pi / SpSW) \times \sin^2(N \times \pi /(SpSW \times SWpB)) \quad (1)$$

$$N = 0 \text{ to } (\mathrm{SpSW} \times \mathrm{SWpB}) \text{, in integer steps} \quad (2)$$

where

N = number of each sample in time order;

$SpSW$ = Samples per sine wave (48 in Figure 2);

$SWpB$ = Sine waves per burst (41 in Figure 2);

$U[N]$ = Voltage of sample N;

U_P = Peak amplitude (100 mV in Figure 2) of simulated burst.

The resulting carrier frequency f_c is a function of the sample time interval (t_s):

$$f_c = 1/(t_s \times SpSW) \quad (3)$$

or the time interval (t_s) for a certain carrier frequency is

$$t_s = 1/(f_c \times SpSW) \quad (4)$$

Example in Figure 2: t_s = 1/(200 kHz x 48) = 104.167 ns

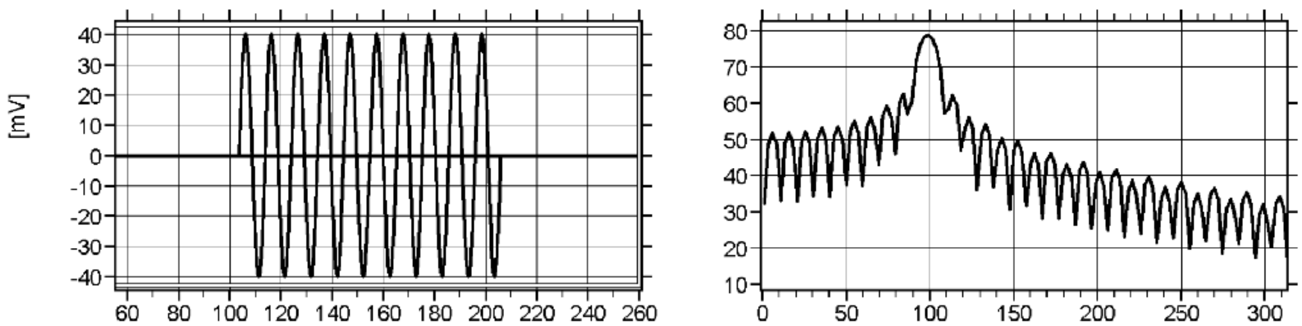
Similar to the triangular modulated sine wave, the rise time measured by an AE signal processor is shorter than the visible rise time of the test signal, because rise time measurement starts at the time of the first threshold crossing. This so-called “first threshold crossing delay” depends on the difference of maximum amplitude and detection threshold in dB and is listed for the two modulated test signals in Table 1.

Table 1 — First threshold crossing delay versus amplitude to threshold ratio for a sin^2 and triangular modulated test signal

Threshold	Sin² modulated first threshold crossing delay % of signal rise time	Triangular modulated first threshold crossing delay % of signal rise time
A – 20 dB	19,7	11,0
A – 25 dB	15,0	6,0
A – 30 dB	12,3	3,5
A – 35 dB	8,3	3,0
A – 40 dB	7,6	1,0

4.2.4 Rectangular modulated sine wave

This type of signal is defined by the characteristics A, D and f, see 4.2.2 and Figure 3.



Key
[mV] amplitude

Figure 3 — Rectangular modulated sine wave in time (left) and frequency domain (right)

4.2.5 Pulse

This test signal shall be used to check the measurement of Δt. It is defined by the characteristics A (amplitude) and D (pulse duration). Figure 4 shows the output of an arbitrary function generator where one sample in a cyclic output buffer was set to 0,8 V, all others to zero. The buffer was output at a sample interval of 50 ns. A pulse duration between 50 ns and 500 ns is recommended. The pulse amplitude shall cause a signal amplitude of about 6 dB above the detection threshold. A much higher amplitude may cause additional threshold crossings by ring down cycles as shown in Figure 5.

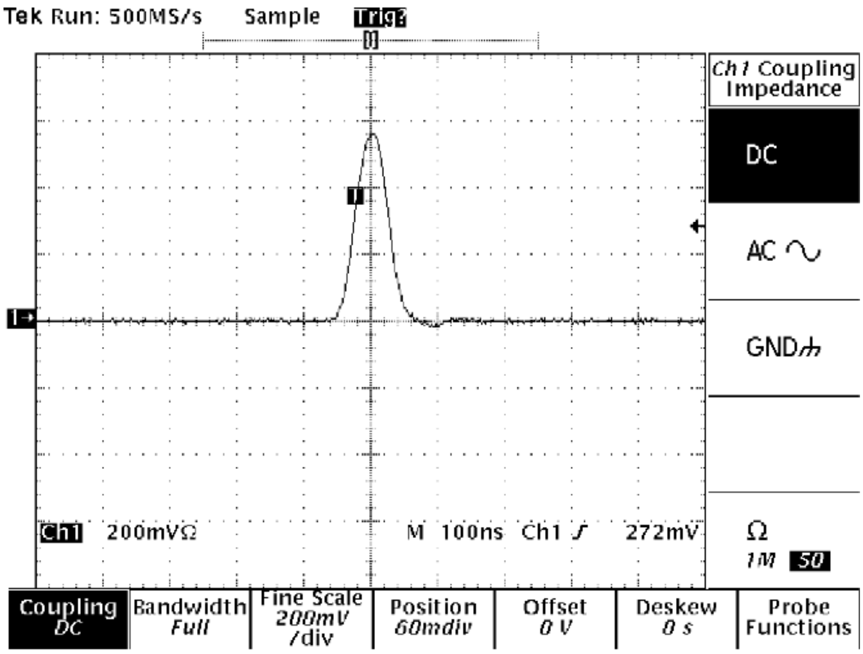
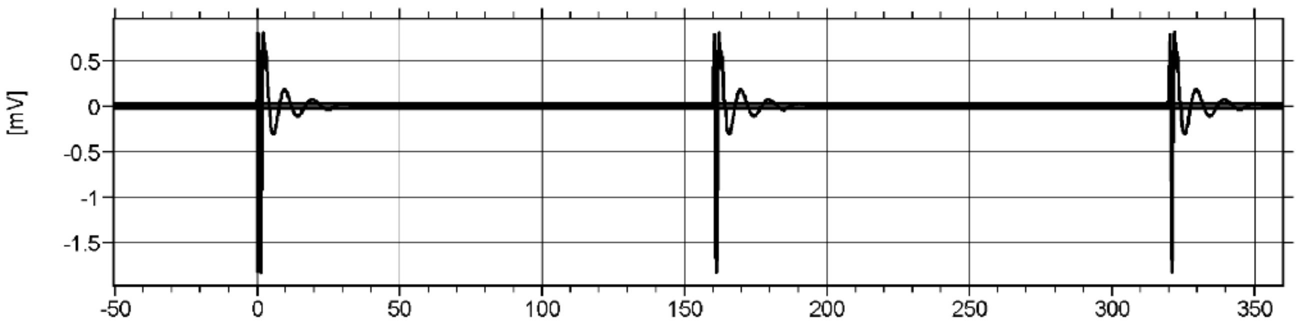


Figure 4 — Pulse

4.2.6 Repetitive signals

This signal is used to verify the signal processing rate. It is a series of pulses as described in 4.2.5. It is defined by A (amplitude), D (pulse duration) and f (repetition frequency), typically 1 Hz – 10 kHz. Figure 5 shows an example with $1/f$ = 160 µs, taken after the band pass filter of an AE signal processor. The maximum reasonable repetition frequency is limited by the ring down effect of the band pass filter, if a pulse causes multiple threshold crossings.



Key

[mV] amplitude

Figure 5 — A series of transient signals (pulses) 160 μs apart behind the band pass

4.3 Test Body

This can take different forms, e.g. a metallic block, or a plate, or an acrylic rod. Once chosen, the dimensions, construction material, Hsu-Nielsen source position, sensor mounting position and usage shall be controlled to ensure reproducibility of results.

The surface in contact with the sensor shall be flat and smooth. The test body shall be isolated acoustically from the work bench to avoid interference from external noise sources.

4.4 Shielding test plate

This is a small flat metallic plate sufficient in size to cover the sensor's sensitive area. The plate shall be connected to a sine wave; therefore, it shall be electrically isolated from earth. Once chosen, the dimension of the plate and the thickness of the non-conductive layer, if applicable, shall be controlled. The test plate shall be given an identifier for use in the verification report. See Figure 6 for the setup.

5 Sensor verification

5.1 General

The following procedure allows rapid comparison of the sensitivity of sensors. The deterioration of the sensors can result from e.g. mechanical shock, exposure to high temperature, high ionizing radiation or a corrosive environment, water ingress, a damaged connector or cable.

5.2 Uses

The specific objectives of the procedure for checking sensors are:

— warning of degrading response or damaged internal shielding;

— determining when a sensor is no longer suitable for use;

— checking sensors that are known to have been exposed to high-risk conditions;

— creating matched sets of sensors to achieve uniform performance;

— verifying sensors quickly and reliably and assisting trouble shooting, when a channel shows a fault.

5.3 Procedure

5.3.1 Preliminary examination

Allow the test body, sensors and couplant to adopt the ambient temperature.

Perform a preliminary examination of the sensor to identify any obvious mechanical damage, paying particular attention to connector and cable, if any.

5.3.2 Sensitivity verification

For the sensitivity verification of a sensor, a verified AE signal processor shall be used. If the sensor does not comprise a preamplifier, a verified reference preamplifier and sensor cable of specified length shall be used. The frequency filters in the preamplifier and AE signal processor shall properly cover the bandwidth of the sensor.

Mount the sensor on the test body using an appropriate couplant. Be sparing with the couplant, e.g. approximately 0,1 cm^3 of silicone grease is adequate for most types of sensors.

Press the sensor firmly down onto the test body to insure a good coupling. Take care the sensor and attachment cannot move during the test. The use of a constant force device is recommended.

Using the Hsu-Nielsen source, make a minimum of 3 lead breaks at the prescribed position on the test body. In each case, record the signal amplitude in units of dB_{AE}, on the test record. The difference between lowest and highest reading shall be within 3 dB. Before proceeding to the next sensor, remove the couplant from the verified sensor.

The test temperature, lead diameter and hardness, and bandwidth of preamplifier and AE signal processor shall be recorded.

5.3.3 Verification of electrical shielding

In case of an internal defect of the electrical shielding, the sensor signal can be overlaid by electrical noise from the test object which is difficult to differentiate from acoustical noise. This verification step shall observe such a defect.

Mount the sensor on the shielding test plate in acoustically quiet environment. If the contact surface of the sensor is electro-conductive, use a thin non-conductive layer of specified thickness, e.g. a self adhesive foil. Connect the test plate to a sine wave using a shielded cable as shown in Figure 6. Connect the cable shield to earth. For each sensor model the sensor manufacturer shall specify the test voltage $US1_{PP}$ (usually 10 V), the test frequency f_S (usually 2,5 times the sensor's main resonance frequency) and the acceptable maximum for the sensor output voltage before preamplification $US2_{PP}$ (usually 2 mV). Manufacturer specification and measured values shall be reported (see Annex A).

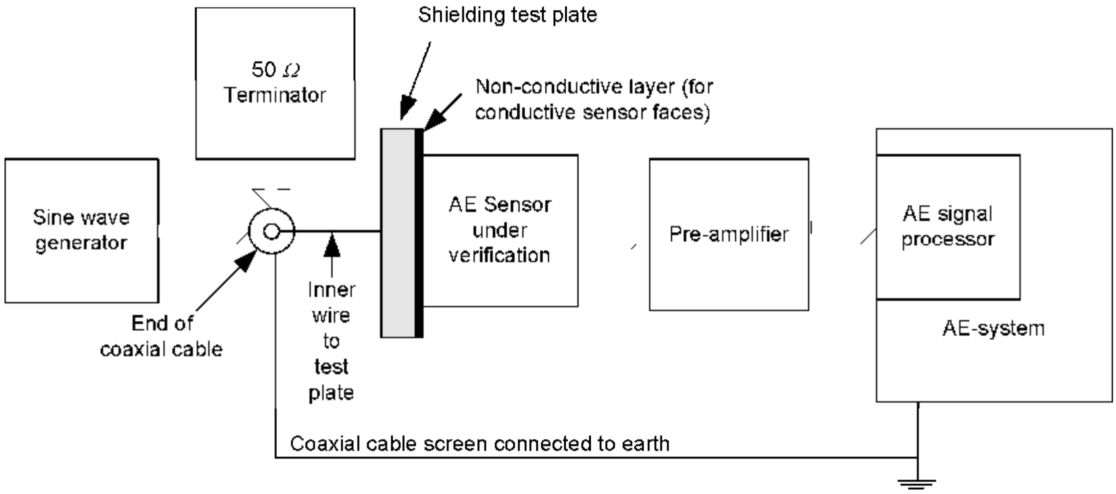


Figure 6 — Shielding verification set-up

5.3.4 Electrical noise verification of a sensor-preamplifier combination

The electrical noise level of a sensor and preamplifier combination shall be measured in acoustically quiet environment with the sensor dismounted from a structure. The measurement set-up is according to 6.3.4. The noise level is measured in specified units and shall not exceed the noise specification of the manufacturer. The measured value shall be reported on the test record (see Annex A).

6 Preamplifier verification

6.1 General

Annex B shows an example for a preamplifier verification report that includes the manufacturer's acceptance limits and results of measurements.

— Perform a preliminary examination of the preamplifier to identify any obvious mechanical damage, paying particular attention to connectors and cables, if any. The following procedure applies to voltage preamplifiers.

6.2 Verification of DC-current consumption

Figure 7 shows the test set-up for the verification of the DC current consumption.

The following applies to a preamplifier with 28V DC supply fed-in over the signal wire. For preamplifiers with other power requirements, the setup shall be properly adapted.

— Connect the 28 V DC power supply as shown in Figure 7 to the preamplifier output over a DC current meter and a 50 Ohm resistor in parallel with a 10 mH inductor.

— With no input from the sine wave generator measure and record the stand by current, I_{SB} in mA.

— Use a sine wave of a frequency within the pass band of the preamplifier and set the preamplifier AC output to full scale. Measure and record the full scale current I_{FS} in mA.

— Standby current I_{SB} and full scale current I_{FS} shall not exceed the manufacturer's specifications.

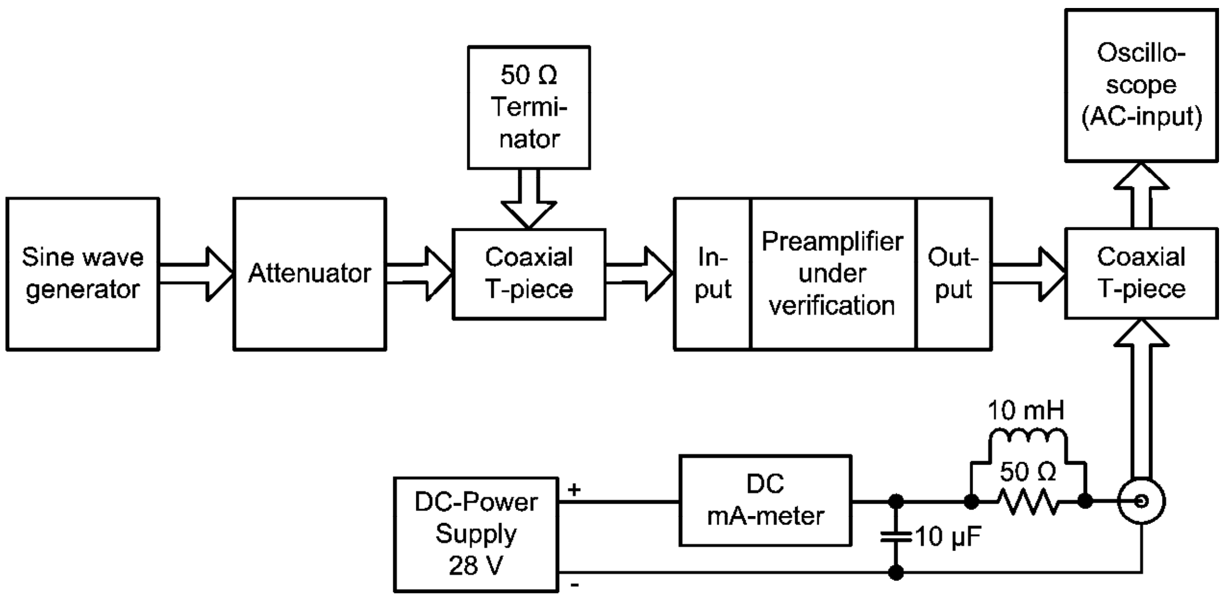


Figure 7 — Set-up for measurement of DC current consumption

6.3 Measurement of preamplifier characteristics

6.3.1 General

For the following measurements, the preamplifier power supply shall be at the prescribed voltage. Good measurement practice requires:

— correct impedance matching throughout the measurement chain;

— avoidance of ground loops;

— avoidance of electromagnetic interference.

6.3.2 Gain

The gain factor is the ratio of the output (U_{OUT}) to the input voltage (U_{IN}) of an amplifier at the geometric mean frequency (see 6.3.3). It is converted to dB by the following formula:

$$\text{Gain} = 20 \times \log 10 \left(U_{\text{OUT}} / U_{\text{IN}} \right) \quad (5)$$

Figure 8 shows the recommended set-up.

The output of the test signal generator is connected over an attenuator to the input of the preamplifier under verification. A proper termination resistor shall be connected in parallel to the high impedance preamplifier input. The attenuation is to be set to the same dB value as the nominal gain. The test signal shall be set to 50 % of the preamplifier's output range and to the mean frequency of its bandwidth.

At correct gain, both channels of the oscilloscope shall show equal amplitudes.

For the verification of the preamplifier function with a burst type AE signal, a sine²-modulated sine wave shall be used. Alternatively, for the verification of the preamplifier function with a continuous AE signal, a continuous sine wave shall be used.

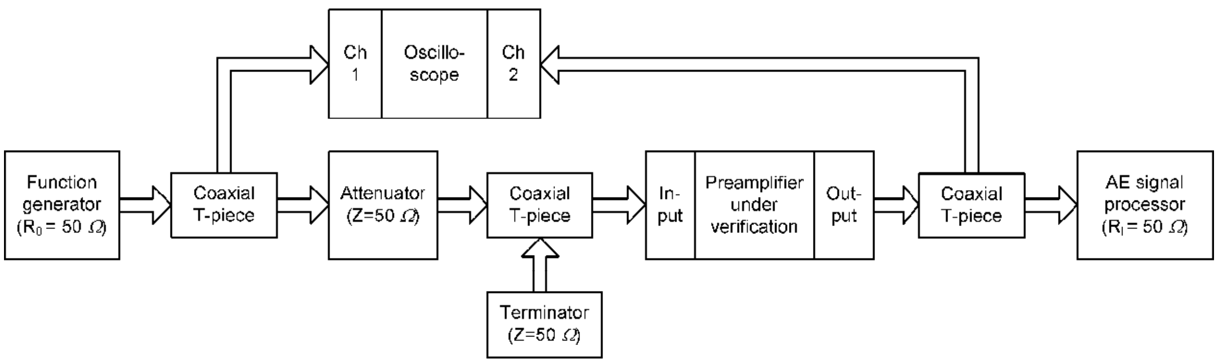


Figure 8 — Test set-up for the verification of preamplifier gain and bandwidth

6.3.3 Bandwidth

Figure 8 shows the test set-up for the verification of preamplifier bandwidth and gain.

The bandwidth shall be obtained from the -3 dB points on the frequency response curve, compared to their geometric mean frequency. The -3dB points are also called "cut-off" frequencies "F_{LO}" and "F_{HI}". The geometric mean frequency is calculated as follows:

$$F_{\mathrm{M}} = \left(F_{\mathrm{LO}} \times F_{\mathrm{HI}}\right)^{1/2} \qquad (6)$$

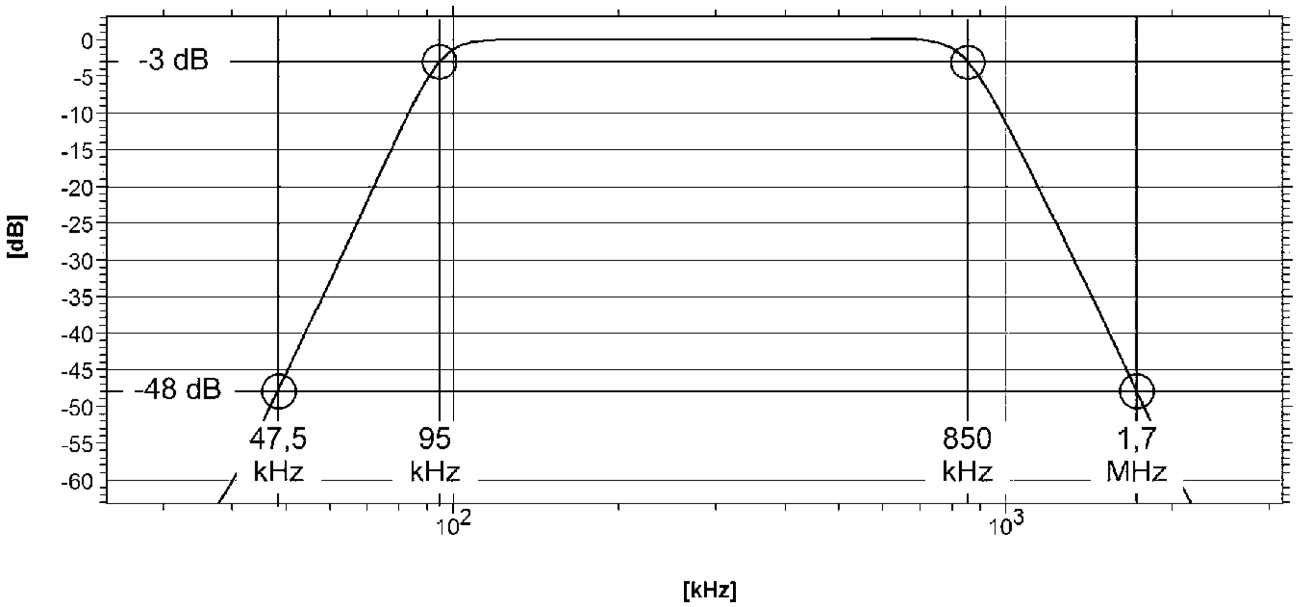
where

F_{M} geometric mean of F_{LO} and F_{HI};

F_{LO} nominal lower cut-off frequency, hereafter called F_{HP} (for high-pass);

F_{HI} nominal upper cut-off frequency, hereafter called F_{LP} (for low-pass).

See Figure 9, an example where both roll-offs are 48 dB/octave.



Key
[dB] RMS
[kHz] frequency

Figure 9 — Characteristics of a bandpass filter with 48 dB/octave roll-off for the lower and upper cut-off frequencies

The test signal amplitude shall be set to 50 % of the preamplifier's output range at the geometric mean frequency F_{M}. This output voltage refers to 0 dB in the frequency response curve. The corner frequency F_{HP} shall be obtained at the lower -3 dB frequency point (95 kHz in Figure 9). F_{LP} shall be obtained at the upper -3 dB frequency point (850 kHz in Figure 9).

"HP roll-off" means the signal level reduction in dB/octave of the high-pass, to be obtained at 0,5 x F_{HP} (-48 dB at 47,5 kHz in Figure 9).

"LP roll-off" means the signal level reduction in dB at twice of F_{LP}. Accordingly, LP roll-off shall be obtained at 2xF_{LP} (-48 dB at 1,7 MHz in Figure 9).

The verification results F_{HP}, HP roll-off, and F_{LP}, LP roll-off shall be reported (see Annex B) and checked for compliance with the acceptance limits.

6.3.4 Electronic noise

For the reproducibility of the noise measurement the following items shall be specified and reported in the test record:

— input termination of the preamplifier under test. Usually, a shielded 50 *Ω* resistor is used. In order to unveil a contribution of noise current (in addition to noise voltage) to the total noise, a shielded capacitor, e.g. 100 pF or 330 pF, or a sensor of specified model, can be used as input termination;

— reference point for noise scaling, usually the input of the preamplifier under verification;

— nominal bandwidth of the preamplifier (the wider the bandwidth the larger the noise);

— bandwidth, input noise and resolution of the noise measurement device;

— time window (≥ 1 s) and sampling rate for determination of peak noise and, if applicable, RMS noise.

Two alternative set-ups are shown in Figures 10 and 11.

When DC-supply input and AC-signal output of an amplifier runs over a common wire, an appropriate AC/DC-decoupling circuit shall be used. This can be a 50 *Ω* resistor in parallel to a 10 mH inductor, as shown in Figure 10. Alternatively, see Figure 11, an AE signal processor with built-in preamplifier supply can be used to supply the preamplifier under verification.

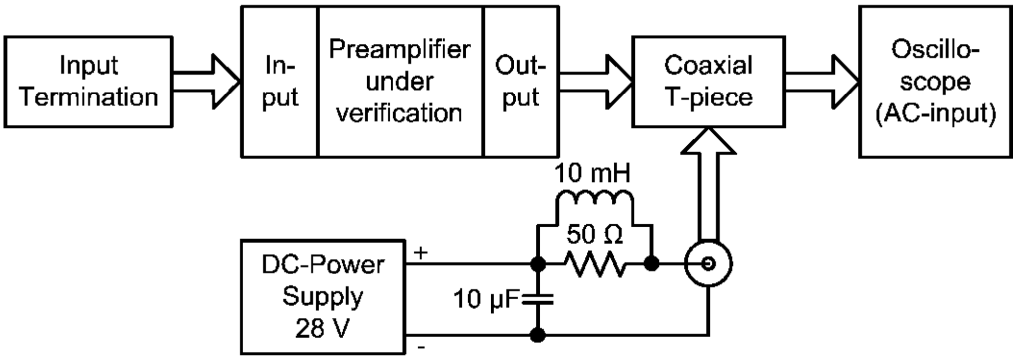


Figure 10 — Set-up for preamplifier noise measurement using a DC power supply and storage oscilloscope

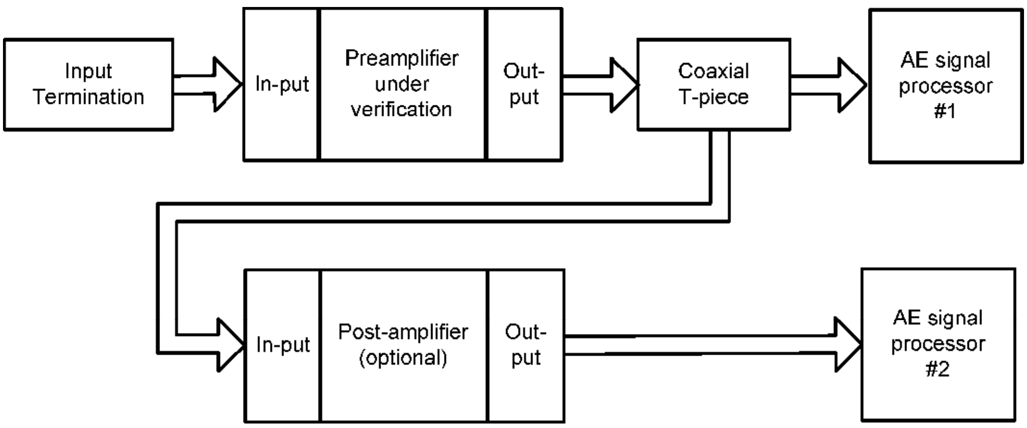


Figure 11 — Set-up for preamplifier noise measurement using a post-amplifier and two AE signal processors

It is recommended to use a second preamplifier and AE signal processor to measure the amplified noise of the preamplifier under verification with proper resolution.

The peak noise is measured by a storage oscilloscope (Figure 10) or a verified AE signal processor (AE signal processor #2 in Figure 11). In both cases either the peak noise has to be determined by searching the lowest threshold level that causes less than one false hit per second, or the peak noise has to be taken from a seamless waveform record of at least one second duration.

In addition, the electronic noise can be characterised using an RMS voltmeter, or a verified AE signal processor with RMS voltmeter function. The time constant or time window of RMS processing shall be at least 1 s.

The noise level shall refer to the input of the preamplifier under verification and be reported as peak (U_{PN}) and optionally as RMS voltage (U_{RMS}) of the noise in µV (see Annex B).

The bandwidth for the noise measurement device shall be chosen according to the bandwidth of the preamplifier under test. Should the noise of a wideband preamplifier be characterized for one or several certain ranges of bandwidth, corresponding post-filter(s) shall be used with the noise measuring device. Such use of bandpass filtering shall be reported.

6.3.5 Dynamic range

The dynamic range is the ratio of the largest peak signal voltage (without distortion) U_{PS} to the peak electronic noise voltage U_{PN}, both measured at the output of the preamplifier under verification at the geometric mean of the bandwidth. The dynamic range shall be specified in dB given by:

$$\text{Dynamic Range} = 20 \times \log 10 \left(U_{PS} / U_{PN} \right) \tag{7}$$

where

U_{PS} maximum peak output voltage before saturation, divided by the gain factor;

U_{PN} maximum peak noise output voltage (over 1 second), divided by the gain factor, input terminated by 50 Ω (see 6.3.4).

When increasing the amplitude the onset of distortion at the preamplifier output can be seen at the waveform of an oscilloscope, when the usually round maximum and/or minimum of the sine wave becomes flat, or at increasing harmonics in the FFT. For U_{PS} the input peak amplitude just below saturation shall be reported and checked for compliance with the acceptance limits.

6.3.6 Pulsing test

If the preamplifier model employs the feature to pass an electric pulse to the piezo electric element, this function shall be verified according to the manufacturer's instructions.

7 AE signal processor verification

7.1 Overview

AE signal processor verification shall be performed by comparing the measured values of the AE parameters with the actual settings of the calibrated test signal generator. Figure 12 shows the recommended test-setup. The use of a DC-blocker (a capacitor of about 10 µF/50 V) is recommended to avoid an inadvertent damage of the function generator by the 28 V power supply. A proper termination of the function generator shall be assured either by a signal processor-internal or an external termination resistor.

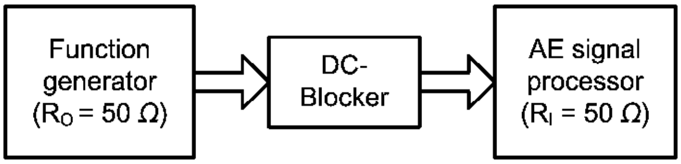


Figure 12 — Test set-up for AE signal processor verification

The characterisation of the AE signal processor shall be performed using simulated burst signal parameters in a range covering the equipment specification. The recommended test signal patterns' frequency, dynamic range and acceptable inaccuracy of each measurement is given in the corresponding clause of this standard and summarized in Table 3. Less accurate test signal generators can be used, if the inaccuracy of each pattern is measured and considered during verification.

The test signal frequency shall always be within the bandwidth of the measurement chain. Only the verification of the bandpass filter characteristics needs frequencies outside of the nominal bandwidth. If a filter is changed, the gain shall be checked and adjusted accordingly.

Before proceeding to verify the measured AE parameters, the bandwidth, detection threshold and AE signal processor noise shall be checked.

7.2 Bandwidth and filter roll-off verification

Bandwidth verification of the AE signal processor has to be performed as described in 6.3.3 for the preamplifier. The results F_{HP}, HP roll-off, and F_{LP}, LP roll-off shall be reported according to the example in Annex and compliance with the acceptance limits checked (see Annex C).

7.3 Detection threshold verification

The detection threshold setting may be either fixed with variable gain, variable with fixed gain or floating at a fixed relation to the background noise.

The test set-up is shown in Figure 12. A triangle modulated sine wave with at least 20 cycles rise and 20 cycles decay time, or a $\sin^2$-modulated sinewave with at least 40 sine waves per burst shall be used.

Threshold test values of 40 dB_{AE} and 70 dB_{AE} shall be verified.

The amplitude of the test signal shall be varied until approximately 50 % of the test signals are detected by the AE signal processor. The obtained test signal amplitude represents the actual detection threshold setting.

The acceptable threshold inaccuracy is equal to the acceptable peak amplitude inaccuracy ± 1 dB.

For floating threshold, if applicable, the manufacturer shall provide details about verification and acceptance limits.

7.4 AE signal processor noise verification

All three main components, AE sensor, AE preamplifier and AE signal processor, contribute to the total noise of a measurement chain. The AE signal processor noise defines the minimum threshold without getting false hits, while no preamplifier is connected. It is important that increased AE signal processor noise is observed in order to avoid noise contaminated data or the need of a threshold increase above the level foreseen by an applicable test instruction.

For the reproducibility of AE signal processor noise verification the following shall be specified and recorded:

— reference point for noise scaling (usually the preamplifier input at ±100 mV full scale range);

— input termination used, (e.g. high impedance or 50 Ohm);

— bandpass filter(s) used;

— time window (≥ 1 second) and sampling rate for determination of peak noise and, if applicable, RMS noise.

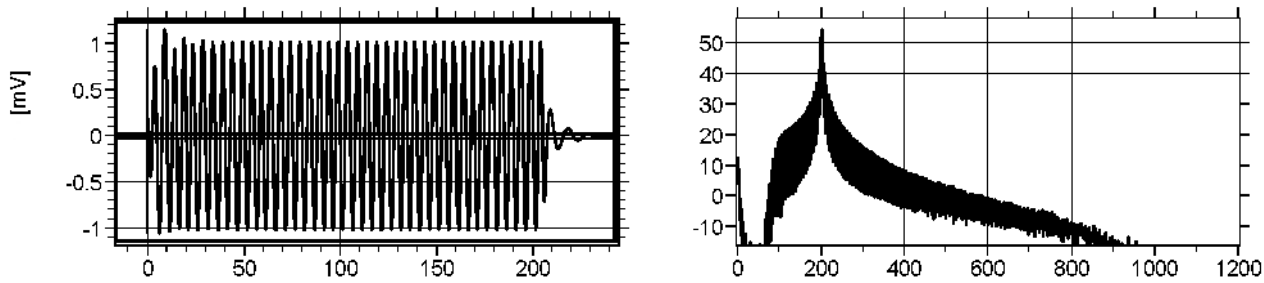
For the verification of AE signal processor noise, no preamplifier shall be connected. Either the peak noise has to be determined by searching the lowest threshold level that causes less than one hit per second, or the peak noise has to be taken from a seamless waveform record of at least one second duration. The determined noise level shall be reported as peak value in µV and optionally as RMS value in µV with reference to the measurement range of the preamplifier input, usually ± 100 mV. The peak noise can be converted from µV to dB_{AE}. An example of a report form is shown in Annex C.

7.5 Burst signal parameter verification

7.5.1 General

This section gives the procedure for verifying the measured AE burst signal parameters. The test parameters, test signal, required tests and minimum acceptance limits are given in this clause. Acceptance limits derived from the manufacturer's specifications may be tighter. The range of test signals used shall properly cover the dynamic range of all verified burst signal parameters.

For the verification of energy counts and duration, by using a rectangular modulated sine wave, the signal behind the application specific filter may exhibit additional ring down counts at the end of the signal. An example is shown in Figure 13. The effect of those additional ring down counts on the readings of energy, counts and duration can be compensated: an additional reference measurement of short duration is used to determine an offset value for each of the results energy, counts and duration, which should be constant for all durations. Accordingly, all other measurement values of a test series of varied duration can be corrected by considering the determined offset values.



Key
[mV] amplitude

Figure 13 — Example of the influence of an application specific bandpass filter on begin and end of a rectangular modulated test signal

7.5.2 Peak amplitude

The input test signal shall be a triangular or a sine²-modulated sine wave of at least 20 cycles rise and 20 cycles decay. The amplitude shall be referred to the input of the preamplifier at a certain measurement range, usually ± 100 mV. The measured values shall be reported in dB_{AE} and compared against the nominal values. The verification shall be carried out at least at 4 steps 20 dB apart, e.g. at 38 dB_{AE}, 58 dB_{AE}, 78 dB_{AE}, 98 dB_{AE}, with a threshold setting at 6 dB below the lowest test amplitude. For larger amplitudes the threshold may be increased in order to avoid false hits from noise of the test signal generator. For the determination of the acceptance limits for peak amplitude verification two variables "MA" and "MB" have to be specified by the equipment manufacturer. "MA" determines the acceptable deviation in dB, especially for high amplitude levels; "MB" determines an additional tolerance in terms of µV related to a certain measurement range, usually ±100 mV.

“MB” allows for accepting larger dB-deviations at low amplitude levels and considers equipment specific ADC resolution and digitization noise.

Table 2 shows acceptance limits for nominal input levels from 30 dB_{AE} to 100 dB_{AE} obtained as follow.

The upper acceptance limit is calculated by converting the result of “nominal dB_{AE} value plus MA” from dB_{AE} into µV, adding MB in µV, and converting the result back into dB_{AE}.

The lower acceptance limit is calculated by converting the result of “nominal dB_{AE} value minus MA” from dB_{AE} to µV, subtracting MB in µV, and converting the result back into dB_{AE}.

where

MA and MB are manufacturer specifications (see above);

default values are: MA = 1 dB, MB = 6 µV at ± 100 mV input range.

EXAMPLE For the determination of acceptance limits for the peak amplitude verification:

MA = 1 dB, MB = 6 µV at ±100 mV range, a nominal amplitude value = 30 dB_{AE}

— Determination of the upper acceptance limit:

Step 1: (30 dB_{AE} + 1 dB) converted to µV is 35,5 µV

Step 2: 35,5 µV + 6 µV is 41,5 µV

Step 3: 41,5 µV converted to dB_{AE}. is 32,4 dB_{AE}

Upper Acceptance Limit for an accurate 30 dB_{AE} input = 32,4 dB_{AE}

— Determination of the lower acceptance limit:

Step 1: (30 dB_{AE} – 1 dB) converted to µV is 28,2 µV

Step 2: 28,2 µV – 6 µV is 22,2 µV

Step 3: 22,2 µV converted to dB_{AE} is 26,9 dB_{AE}

Lower Acceptance Limit for an accurate 30 dB_{AE} input = 26,9 dB_{AE}

Table 2 — Acceptance limits for nominal values from 30 to 100 dBAE and 28 to 98 dBAE for MA = 1dB, MB = 6 µV at ± 100 mV range

dB_{AE} nominal	dB upper limit	dB lower limit
100,0	101,0	99,0
90,0	91,0	89,0
80,0	81,0	79,0
70,0	71,0	69,0
60,0	61,0	58,9
50,0	51,1	48,8
40,0	41,5	38,4
30,0	32,4	26,9

dB_{AE} nominal	dB upper limit	dB lower limit
98,0	99,0	97,0
88,0	89,0	87,0
78,0	79,0	77,0
68,0	69,0	67,0
58,0	59,1	56,9
48,0	49,2	46,8
38,0	39,6	36,2
28,0	30,7	24,3

7.5.3 Duration

The verification of the signal duration shall be carried out at a minimum of three specified settings using a rectangular modulated sine wave of variable duration. A 4th setting can be used to obtain an offset reference as pointed out in 7.5.1.

Reference setting: 0,1 ms, test settings: 0,2 ms; 4 ms; 80 ms.

Recommended amplitude is 70 dB_{AE}, threshold 64 dB_{AE}.

Acceptable inaccuracy: ±(2/f_C + 5 %) (f_C = carrier frequency) after compensation of the reference offset.

The sequence of test signals generated for duration verification can also be used for the verification of ring down counts (7.5.5) and energy (7.5.6).

7.5.4 Rise time

The verification of the rise time shall be carried out using a triangular or $\sin^2$ modulated signal. Recommended amplitude is 70 dB, recommended detection threshold setting is 40 dB.

Using a triangular modulated sinewave the recommended rise time test settings are 250 µs and 1 000 µs. Using a $\sin^2$-modulated test signal with about 41 sine waves per burst the recommended test settings for the carrier frequencies are 110 % F_{HP} and 90 % F_{LP} (for definition of F_{XX} see 6.3.3).

In both cases the acceptable inaccuracy is ± 3/f_C (f_C means the carrier frequency). The systematic first threshold crossing delay as described in 4.2.3 and listed in Table 1 shall be considered for the nominal rise time interpretation.

7.5.5 Ring down count

The verification of the ring down counts shall be carried out at a minimum of three specified settings using a rectangular modulated sine wave of variable duration. A 4th setting can be used to obtain an offset reference as pointed out in 7.5.1.

It is recommended to perform ring down count verification on the test signals stimulated for duration verification.

The acceptable inaccuracy is ± (2/f_C +5 %) (f_C = carrier frequency).

Depending on frequency and duration of the test signal, the ring down counter may reach its maximum; for a 16 bit counter this is 65535. This maximum is acceptable for this verification step.

7.5.6 Energy

The energy is assumed to be proportional to the square of the signal amplitude measured in volts, integrated over the signal duration. The verification shall be carried out in two steps. Using a triangular or sine²-modulated sine wave, the amplitude dependency shall be verified and using a rectangular modulated sine wave the duration dependency.

It is recommended to combine step 1 with the amplitude verification (see 7.5.2, whereby two values 20 dB apart are sufficient), and step 2 with the duration verification (see 7.5.3) using the same reference compensation principle.

For both steps, the acceptable inaccuracy is ± (10 % +4 eu). (eu = energy units of 10-14 V2s).

7.6 Parameters for continuous signal

The verification of the continuous signal level results (RMS, AVG,ASL, floating threshold), where applicable, shall be carried out according to instructions provided by the manufacturer.

8 External parameter verification

The output of a DC calibrator shall be used as test signal.

If different parametric inputs use a common analogue to digital converter (ADC), all channels shall be verified individually, one channel at a minimum of 6 input levels per polarity, predominantly at 0 %, ± 1 %, ± 3 %, ± 10 %, ± 30 %, ± 90 % of the input range, the others at 0 % and 90 %. Unused channels shall be terminated (0 Ω to 50 Ω) and a zero result verified, so any cross talk problem between the parametric channels would be discovered.

If parametric inputs use individual ADCs, all parametric inputs can be verified in parallel in one setup with a minimum of 6 input levels per polarity predominantly at 0 %, ± 1%, ± 3%, ± 10%, ± 30%, ± 90% of the input range. The accuracy of the DC calibrator at these levels shall be verified and considered in the interpretation of the readings.

The acceptable inaccuracy of the parametric input under verification shall be less than:

± (MPA % of reading + MPB % of full scale input).

EXAMPLE MPA = 0,5 %, MPB = 0,1 %, Full scale: ±10 V = 20 V, Nominal value: 1 V

Acceptable inaccuracy = ±(0,5 % x 1 V + 0,1 % x 20 V) = ±2 mV.

9 System acquisition rate verification

The peak and continuous AE signal acquisition rate for the system, see 6.2 in EN 13477-1:2001, when set-up for the relevant test conditions, shall be verified.

The maximum hit rate a channel can separate depends on the duration and ring down of the repetitive test signal and the relevant timing parameters.

The maximum hit rate a computer can read from the AE channels, process and store, depends on the maximum transfer speed between AE-channel and AE controller, AE controller and PC, PC to hard disk, the data volume of each hit (especially if waveform data are acquired), the performance of the CPU, the complexity of online data analysis and the presence of service tasks of the operation system, e.g. a virus scanner working on an online data file. Therefore all relevant settings are to be determined carefully and recorded for reproducibility of the verification.

For this verification step, the AE-system manufacturer shall provide procedure(s) for the reproducible verification of peak and continuous AE-signal acquisition rate, with and without waveform storage. These procedures shall ensure the discovery of unexpected degradations of PC speed performance, e.g. as experienced with highly fragmented hard disks.

If the AE system uses an external PC for data acquisition, the verification report shall clearly identify the PC used for the verification. The AE test agency shall ensure that each PC used for data acquisition is verified in defined intervals.

10 Δt measurement verification

For AE systems that derive Δt from the absolute arrival time of each hit, only the synchronisation of the time counters of all channels shall be verified. For this, a repetitive pulse shall be fed into a reference channel and the channel under verification in parallel. The difference of arrival times for the same pulse at different channels shall be less than 2 units of the time counter resolution, provided that both channels employ the same filter configuration.

To ensure the verification of proper long term synchronisation the above described verification step shall be made some minutes after starting data acquisition. If the AE system manufacturer warrants that the hardware and software design performs a continuous self test of clock synchronisation among all channels in all involved system boxes with clearly identifiable error messages, this verification step can be skipped.

If Δt measurement is based on a delay measurement, two pulse signals with known and varied delay are to be fed into the reference channel and the channel under verification. Comparison is made between the measured time difference and the set delay time.

11 Documentation

A verification report including the following information shall be generated:

— identification of equipment under verification (manufacturer, type, serial numbers);

— identification and last calibration date of test equipment used;

— name of test person;

— date of verification;

— channel numbers and parameters under test;

— test signal parameters used for verification;

— test results;

— manufacturer's specifications and acceptance limits;

— environmental temperature during verification;

— relative humidity.

Table 3 — Parameters for AE signal processor verification

Verification parameter	Clause	Test signal	Test Parameters	Required tests	Acceptable inaccuracy
Bandwidth	7.2, 6.3.3	C-Sw	frequency response curve	F_{HP}, HP roll-off, and F_{LP}, LP roll-off	Manuf. specification
Threshold	7.3	Tri-/S²-Sw	$f \approx \boldsymbol{F_M}$; R≥20/f ; D≥40/f	Thr≈40; 70 (dB_{AE})	±(MA +1 dB + MB μV)
System noise	7.4	Input Term.			Manuf. specification
Peak amplitude	7.5.2	Tri-/S²-Sw	$f \approx \boldsymbol{F_M}$; R≥20/f ; D≥40/f, Thr<A-6	A≈38, 58; 78; 98 (dB_{AE})	±(MA dB + MB μV)
Duration	7.5.3	R-Sw	$f \approx \boldsymbol{F_M}$; A≈70, Thr≈40	D≈0.2; 4; 80 (ms)	±(2/f_C + 5%) (5)
Rise-time (1)	7.5.4	Tri-Sw	$f \approx \boldsymbol{F_M}$; A≈70, Thr≈40	R≈ 100, 250, 500 (μs)	±3/f
Rise-time (2)	7.5.4	S²-Sw	A≈70, Thr≈40	f≈110 % F_{HP}, F_M, 90 % F_{LP}	±3/f
Ring down count	7.5.5	R-Sw	$f \approx \boldsymbol{F_M}$; A≈70, Thr≈40	D≈0.2; 4; 80 (ms)	±(2/fc + 5%) (5)
Energy (3)	7.5.6	Tri-/S²-Sw	$f \approx \boldsymbol{F_M}$; R≥20/f, D≥40/f, Thr<A-6	A≈58, 78, 98 (dBAE)	±(10 % +4 eu) (1 eu = 10-14 V2s)
Energy (4)	7.5.6	R-Sw	$f \approx \boldsymbol{F_M}$; A≈70, Thr≈40	D≈0.2, 4, 80 (ms)	±(10 % +4 eu) (1 eu = 10-14 V2s) (5)
Ext parameter	8.	DC		0%, ±1%, ±3%, ±10%, ±30%, ±90%	±(MA % readg + MB % fs)
Test signals and parameters, required tests and acceptable inaccuracies at ± 100 mV input range. (1), (2) one of two verifications required; (3), (4) both verifications required (5) after offset compensation 7.5.1					

Abbreviations:

C-Sw: Continuous sine wave;

R-Sw: rectangular modulated sine wave;

S²-Sw: sine^2-modulated sine wave;

Tri-Sw: Triangular modulated sine wave;

Tri/S²: Tri-Sw or S²-Sw

***n*/f_C** : *n* cycles of f_C

***F*$_M$:** *geom. mean frequency of bandwidth*

***F*$_{HP}$, *F*$_{LP}$**: Corner frequencies of bandpass

A: peak amplitude in dB_{AE}

Thr: threshold in dB_{AE}

D: duration in ms

R: rise-time

MA, MB, MPA, MPB: to be specified by manufacturer

Example for the interpretation of the table entries for "Threshold":

Using a series of triangular, or sine-squared-modulated, sine waves with a carrier frequency nearby F_M and a rise time corresponding to at least 20 cycles of F_M and a duration of at least 40 cycles, tests at 40 dB_{AE} and 70 dB_{AE} threshold shall be made. The acceptable inaccuracy shall be (MA +1 dB + MB µV) (MA, MB are manufacturer specifications, see 7.5.2.).

Annex A
(informative)

Sensor performance check form

Sheet No. ________________

Date: ________________ Start/End Times: ________ /_________ JOB ID: __________

Operator(s): ____

Source Type[1]:0, ____ mm, ___H, Test Temperature: ____°C, Humidity: ____ %

Test Body_____________________________ Couplant: __________________________

AE System

Model: _________ Ser.#: _______ Ch#: ______ BW[2]:____ - ____kHz L.Cal.[3]______

Preamplifier [4]

Type: __________Ser.#: _______Gain: ______ dB, BW[2]:_ - ____kHz, L.Cal.[3] _____

Sensor Cable Type[4] _________ Length: ______ m. Noise Up[7,8]: _________μV

Shielding test:

Plate Id: __________,US1pp _______ V[5], ____________ kHz, Isol.T[6]___________ μm; US2pp [7,8]:
__________________ mV

NOTES

(1) pencil lead diameter &hardness

(2) bandwidth from - to

(3) last calibration/verification (yy.mm)

(4) only for sensors without integral preamplifier

(5) applied at test plate, 50 Ω terminated

(6) electrical isolation thickness (0 if not isolated)

(7) max. allowed (manufacturer specification)

(8) referred to piezo element

Sensor type	Serial #	Amplitude (dB_{AE}) (min. 3 within 3 dB)						Shielding test output US2pp (µV)[8]	Peak Noise Up (µV)[8]	OK (Y/N)

Annex B
(informative)

Preamplifier performance check form

Sheet No:_______ Date: _________ ; JOB ID:_____ ; Operator(s): ___________________________; Temp: ___ °C, Humidity: __________ %

Oscilloscope Model _____________ ; L.Cal.[(1)]_____________; AE System Model_________ Ser.#__________________

Chan#[(2)] _________ Ser.#: ________ ; L.Cal.[(1)]_____________; BW[(3)]: ________ - ________ kHz, (supplying preamplifier under verification)

Chan#[(4)] _________ Ser.#: ________ ; L.Cal[(1)] _____________; BW[(3)]: ________ - ________ kHz, (for noise verification over postamplifier)

Postamplifier[(4)]: Type: ________ Ser.#: ___________________; BW[(3)]: ________ - ________ kHz; Gain: ______dB; L.Cal.[(1)] ________________

Acceptance limits, to be derived from manufacturer's specifications:

I_{SB}:<___ mA; I_{FS}: <___ mA; Gain: ±____ dB; F_{HP}, F_{LP}:<±___%, Roll-off:>___dB; U_{PN}[(6,7)]<____ µV; U_{RMS}[(6,8)] <____ µV, U_{PS}[(9)]:>____ mV

NOTES

(1) date of last calibration/verification (yy.mm)

(2) channel used for gain and bandwidth verification

(3) bandwidth HP-LP

(4) channel for noise verification

(5) not used

(6) noise voltage at 50 Ω input termination, referred to input

(7) at <1 false hit per second

(8) RMS time constant > 1 s (optional)

(9) peak input voltage before onset of distortion at the output

(10) if preamplifier model employs pulsing feature

For parameters not defined in this table, the manufacturer shall provide details about verification and acceptance limits.

Preamp. Model	Serial #	Standby current I_{SB} (mA)	Full scale current I_{FS} (mA)	Gain (dB)	High pass F_{HP} (kHz)	HP Roll-off ½ F_{HP} (dB)	Lowpass F_{LP} (kHz)	LP Roll-off 2 x F_{LP} (dB)	Peak Noise(6,7) U_{PN} (µV)	RMS Noise(7,8) U_{RMS}(µV)	Distortion onset U_{DO} (mV)	Pulse OK(10) (Y/N)	Preamp. OK (Y/N)

Annex C
(informative)

AE signal processor - bandwidth & noise verification form (one per channel)

Sheet No.: ________ Date: __________, Operator(s):____ ; Temp: ______ °C, Humidity:_______ %

AE signal proc. Model: _________________________; Ser. # ________ ; Chan-Id: ______[(1)]; Inp.range (pp): V; Accepted (Y/N): __________

Arb wave gen. model: Ser. #: Last cal: , AE syst. Model ; Ser.#: Acceptance limits derived from the manufacturer's specifications:

F_{HP}*, *F_{LP} <±______%; Roll-off: HP:>_____dB/octave, LP:>_____dB/octave; ____Noise (Peak) : <______µV[(4)] ____Noise (RMS) <_____µV[(5)]

NOTES

(1) of multi-channel signal processor board

(2) for fully digital filter verify two representative band pass configurations

(3) derived from manufacturer's specification

(4) at <1hit/s, referred to input range ± 100 mV (100 dB_{AE})

(5) at time constant or window > 1s, optional, referred to input range ± 100 mV

(6) Date of last calibration/verification (yy.mm)

Bandpass Nominal –3 dB cut-off frequencies (from-to)(2)	F_{HP} (kHz)	Roll-off at ½ F_{HP} (dB)	F_{LP} (kHz)	Roll-off at 2x F_{LP} (dB)	Noise (Peak) (µV)(4)	Noise (RMS) (µV)(5)	Bandpass accepted (Y/N)
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BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

Tel +44 (0)20 8996 9001
Fax +44 (0)20 8996 7001
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