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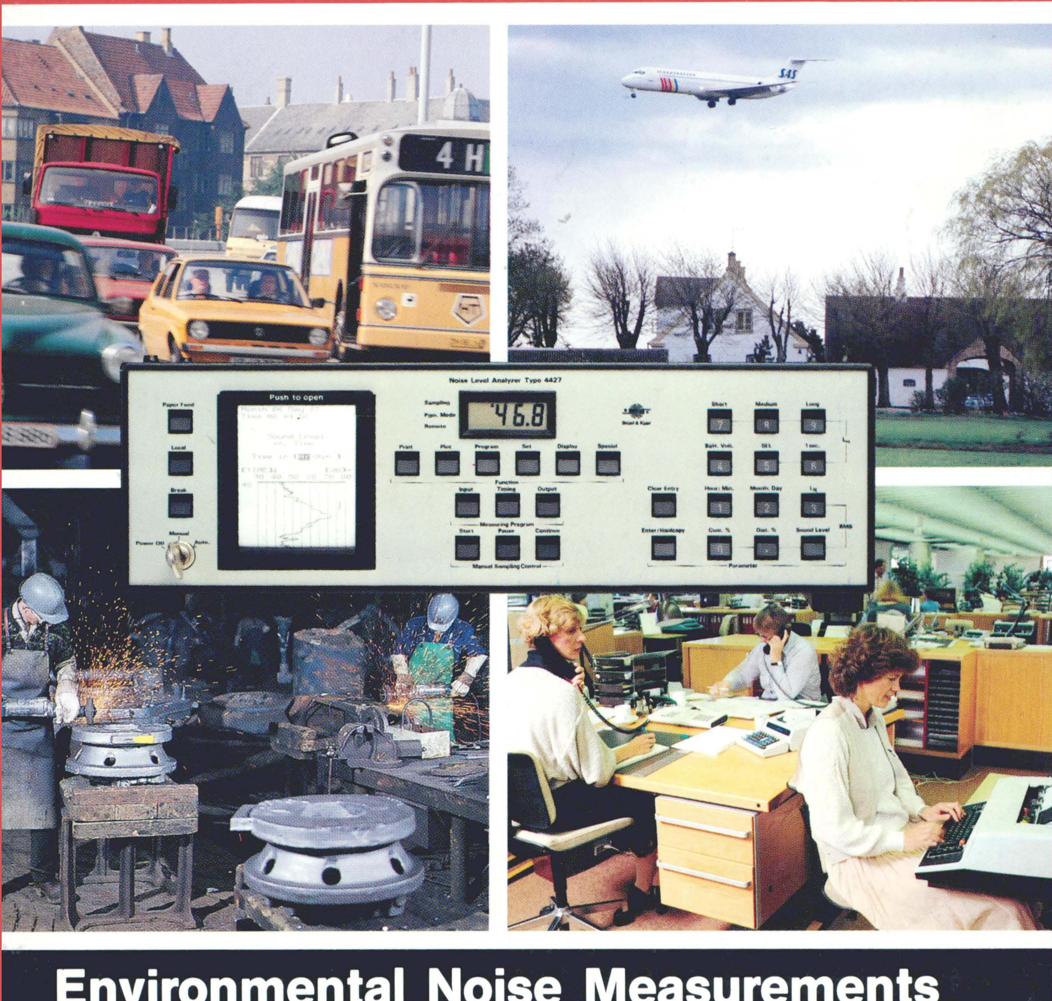

Environmental Noise Measurements

Brüel & Kjær

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TECHNICAL REVIEW

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ENVIRONMENTAL NOISE MEASUREMENTS

by

P. Bernard

ABSTRACT

This article reviews the most common environmental noise rating methods, with special emphasis on the basic quantities recommended by the ISO standard 1996/1, and describes the application of the Noise Level Analyzer Type 4427 to a number of practical measurement situations. In the appendix the evaluation of the sound exposure level of a moving source under various conditions is outlined.

SOMMAIRE

Cet article passe en revue les méthodes d'estimation du bruit les plus courantes en insistant particulièrement sur les paramètres fondamentaux recommandés par la norme ISO 1996/1 et en décrivant les applications de l'Analyseur de niveaux de bruit Type 4427 à un certain nombre de cas de mesure pratiques. L'estimation du niveau d'exposition sonore (SEL) d'une source en déplacement sous différentes conditions est détaillée dans l'appendice.

ZUSAMMENFASSUNG

Der Artikel beschreibt die gebräuchlichsten Parameter zur Beurteilung von Umweltlärm, unter besonderer Berücksichtigung der ISO-Norm 1996/1. Darüberhinaus wird die Anwendung des Schallpegelanalysators 4427 anhand praktischer Beispiele erläutert. Im Anhang wird die Bestimmung des Schallexpositionspegels einer sich bewegenden Schallquelle unter verschiedenen Meßbedingungen beschrieben.

Introduction

Environmental noise is often called "Community noise", as opposed to occupational noise, but the expression may be somewhat misleading Ref.[1], since noise is not a direct result of the activities of the persons affected by it, but is produced by external sources and interferes with the different activities of the exposed persons. When dealing with environmental noise, the main objective is to assess annoyance, and thereby the probable degree of public reaction, as well as to check land-use compatibility. This objective was clearly defined in the title of the original ISO Recommendation dealing with environmental noise ISO R 1996 (1971): "Assessment of noise with respect to community response".

This recommendation has been used in a number of countries as the basis for environmental legislation or regulations, but, as discussed later on, is being replaced by a new set of standards. However, despite the existence of this recommendation and of other related international standards, various noise descriptors are used in different countries, depending on the type of noise source, of environment, etc.

After a review of the most commonly used noise descriptors and a short presentation of the Noise Level Analyzer Type 4427, some typical applications of the Analyzer to specific environmental noise situations will be described. The application of the instrument to occupational noise measurement will also be mentioned.

Environmental Noise Rating

Sleep disturbance, interference with communication and annoyance are the most commonly reported effects of environmental noise on man. Noise may also be the origin of psychological stress, resulting in turn in physiological effects, such as increased blood pressure, etc., Ref.[2], [3], [4].

The response of individuals to noise depends not only on the physical properties of the noise, but also on a number of factors, such as activity, location, previous experience, emotional attitude towards the source, personality, etc. The influence of these "personal" factors accounts, to a certain extent, for the spread in annoyance levels often met in social surveys.

In order to keep annoyance by noise at acceptable levels, many countries have established limits depending on the type of district, activity, time of day; most often, the guidelines of ISO R 1996–1971 were followed. As mentioned in the introduction, the Recommendation is being replaced by a set of new standards, the first part of which was published in 1982:

ISO 1996/1: "Acoustics – Description and measurement of environmental noise –
Part 1: Basic quantities and procedures".

Two documents, presently at the stage of drafts, will complement Part 1:

Part 2: Acquisition of data pertinent to land use

Part 3: Application to noise limits

The first basic quantity is the equivalent continuous A-weighted sound pressure level, measured over a specified time interval, *T*:

$$L_{Aeq,T} = 10 \log \left(\frac{1}{T} \int_{t_1}^{t_1 + T} \frac{p_A^2(t)}{p_0^2} \, dt \right) \tag{1}$$

where $p_A(t)$ is the instantaneous A-weighted sound pressure

p_0 is the reference sound pressure ($20 \mu Pa$)

L_{eq} is very widely used in environmental noise measurements since it allows a simple quantification of noises which may often vary in a highly non-stationary manner.

The second basic quantity is the Sound Exposure Level:

$$L_{AE} = 10 \log \left(\frac{1}{t_0} \int_{t_1}^{t_1 + T} \frac{p_A^2(t)}{p_0^2} \, dt \right) \tag{2}$$

where t_0 is the reference duration (1 *s*).

The Sound Exposure Level (often abbreviated to SEL) may be used to express the energy contents of isolated noise events, such as aircraft fly-overs. Another application is the derivation of L_{eq} from the individual Sound Exposure Levels:

$$L_{Aeq,T} = 10 \log \left(\frac{t_0}{T} \sum_{i=1}^{n} 10^{0,1\, L_{AEi}} \right) \tag{3}$$

The third basic quantity defined in the standard is the Percentile Level, $L_{AN,T}$, which is the sound level exceeded for N % of the measurement duration. The Percentile Levels are normally derived from a statistical analysis of the noise and measurements should be made using the "F" (Fast) time-weighting. Percentile levels are often a useful complement to L_{eq}, as they provide information on the noise variation range. In a number of countries, for example, L_{10} (or L_5) is used as a representation of the maximum levels and L_{90} (or L_{95}) as a representation of background noise.

The amplitude distribution resulting from a statistical analysis may also be used to derive L_{eq}:

$$L_{Aeq,T} = 10 \log \left(\frac{1}{T} \sum_{i=1}^{n} T_i \cdot 10^{0,1 \, L_{pAi}} \right) \tag{4}$$

where L_{pAi} is the sound pressure level prevailing during the time interval T_i. The class interval used for the amplitude distribution should not exceed 5 dB.

Apart from the three basic quantities defined in ISO 1996/1, many other descriptors are used in various countries. Some of them will be mentioned later on, but detailed descriptions and discussions may be found in Refs.[5,6,7].

Among these descriptors, one of the most popular is the Day-Night Level, L_{dn}, which is derived in the same way as L_{eq}, over a 24 h period (or longer, say one month, one year), using a 10 dB adjustment factor at night (generally from 22 h to 7 h). L_{dn} is widely used for traffic noise measurements and some countries also use L_{dn} for aircraft noise rating, for example the USA.

In the State of California, a 5 dB adjustment is also added in the evening (19 h to 22 h), giving the Community Noise Equivalent Level, CNEL, also known as L_{den}.

Sometimes, L_{eq} alone may not be sufficient to assess noise annoyance since it does not provide information on noise fluctuations. The relatively steady noise from a motorway with constant traffic density and the highly fluctuating noise from a succession of aircraft flyovers in an otherwise quiet environment may possibly result in the same L_{eq}, but the annoyance level will probably not be the same. Attempts have been made to incorporate a "variability" factor in some noise descriptors, for example by combining L_{eq} and the standard deviation, σ, to give the Noise Pollution Level, L_{NP}:

$$L_{NP} = L_{eq} + K\sigma \tag{5}$$

where K is a constant, tentatively set to 2,56.

If the distribution of the noise is Gaussian, Eq.(5) may be replaced by:

$$L_{NP} = L_{eq} + (L_{10} - L_{90}) \tag{6}$$

The quantity $L_{10}-L_{90}$, sometimes called the Noise Climate, is also used as the "variability" factor in the Traffic Noise Index, TNI:

$$\mathrm{TNI} = 4\,(L_{10} - L_{50}) + L_{90} - 30 \tag{7}$$

Finally, it should be mentioned that many different noise ratings are found for long-term aircraft noise descriptions. They are normally based on an average of the maximum levels (or of the sound exposure levels) and introduce various adjustments for the time of the day, number of aircraft, percentage of runway usage, etc. However, the different ratings often show good correlation with each other, Ref.[8].

To summarize the above review of environmental noise ratings, the basic measurement quantities are

- L_{eq} values measured over various time periods
- The statistical distribution, allowing derivation of L_N values and other quantities
- Maximum and/or Sound Exposure Levels of intrusive noise events

All these quantities may be obtained easily from the Noise Level Analyzer Type 4427 which will be introduced in the following.

The Noise Level Analyzer Type 4427

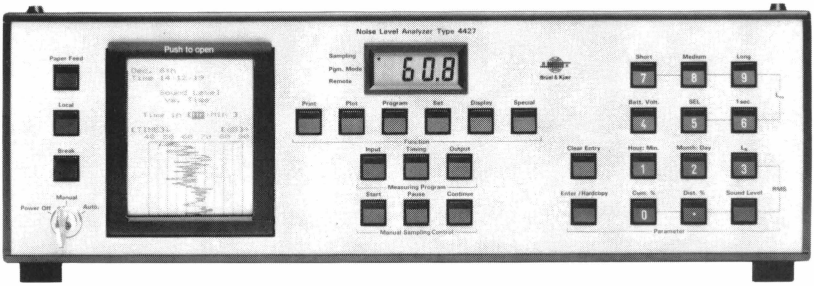

Fig. 1. The Noise Level Analyzer Type 4427

The Noise Level Analyzer Type 4427, Fig.1, is a portable instrument which is especially well suited for environmental noise measurements.

The input stage and a digital detector/averager have been carefully designed to give the Analyzer a very wide dynamic range of 110 dB and Type 0 accuracy according to IEC 651 and ANSI S 1.4 standards for sound level meters, and to the IEC Publication 804 for integrating/averaging sound level meters. This has been achieved by feeding the *A* or *Lin.* (20 Hz – 20 kHz) frequency weighted signal to a precision logarithmic rectifier covering a very wide dynamic range, and sampling the output of the rectifier at a frequency of 131072 Hz, see Fig.2.

Detection and averaging are thereby a purely digital process, overcoming the practical limitations often met in analog averagers, Ref.[9]. The high input sampling frequency ensures that even very short impulses are correctly integrated.

The detector has two distinct outputs, a SPL output and an energy-average output, as illustrated in Table 1.

"True L_{eq}" means a linear energy average of the 131072 samples per second, independant of the time-weighting selected for the SPL output.

The SPL samples are used to update the statistical distribution which is stored in 0,2 dB class intervals; they are also the basis for intrusive noise event analysis, see Section "Aircraft Noise Measurements". The energy-average samples are used to update longer term average registers.

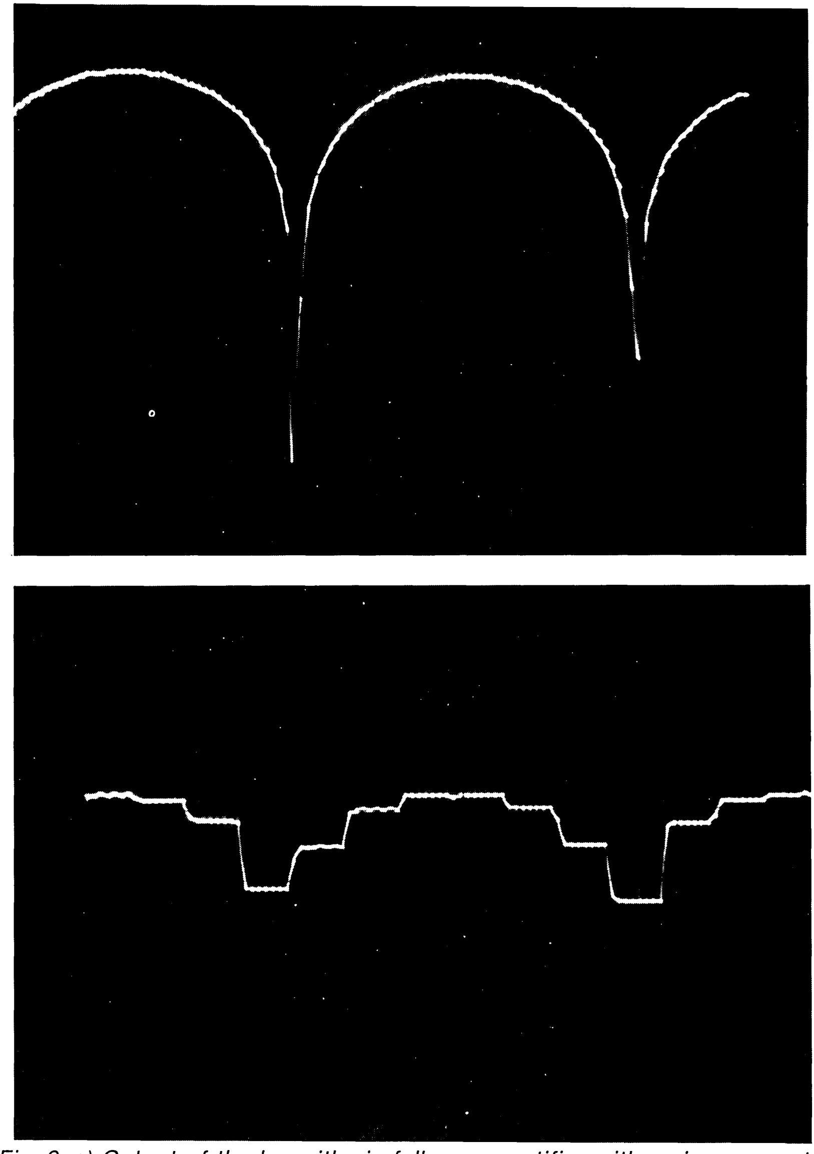

Fig. 2. a) Output of the logarithmic full-wave rectifier with a sine wave at the input
b)The same signal after sampling

	RMS or Peak		L_{eq}	
	Response	Rate of transmission	Response	Rate of transmission
1	F (Fast)	64 values/s	True L_{eq}	1 value/s
2	S (Slow)	64 values/s	True L_{eq}	1 value/s
3	Peak	64 values/s	True L_{eq}	1 value/s
4	Impulse	64 values/s	True L_{eq}	1 value/s
5	Taktmax. 3 s	1 value/3s	L_{FTm} 3 s	1 value/3s
6	Taktmax. 5 s	1 value/5s	L_{FTm} 5 s	1 value/5s
7	Impulse	64 values/s	L_{Im}	1 value/s

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Table 1. Combinations of SPL and energy averaged outputs of Type 4427 detector

Ref.[9] describes different tests which can be used to check integrating/averaging systems and typical results are shown (Figs.2, 5 and 7 of Ref.[9]). The same tests have been applied to Type 4427 and the results are shown in Figs.3 and 4. Fig.3 shows the results of a test where tone-bursts of various durations are applied at levels varying in 10 dB steps. The IEC Publication for integrating/averaging sound level meters specifies a test frequency of 4 kHz, Fig.3 a, but a test frequency of 10 kHz, Fig.3.b was also used to check performance at higher frequencies. In both cases, the difference between theoretical and measured values was negligible.

Fig.4 shows the error in measured A-weighted pulse duration level, which remains very close to zero throughout the frequency range. The tone-burst response of the "SPL" output of the detector was also tested with both "*F*" and "*S*" time weighting and the results are shown in Fig.5.

The instrument may be operated either manually or automatically. For automatic operation, three different programs are defined:

a) **The Input Program** (also used for manual operation), selecting the input, the frequency weighting, the detector output and allowing calibration.

b) **The Timing Program** allowing selection of three types of time periods:

–The Short-Term period, selectable from 10 s to 60 min.

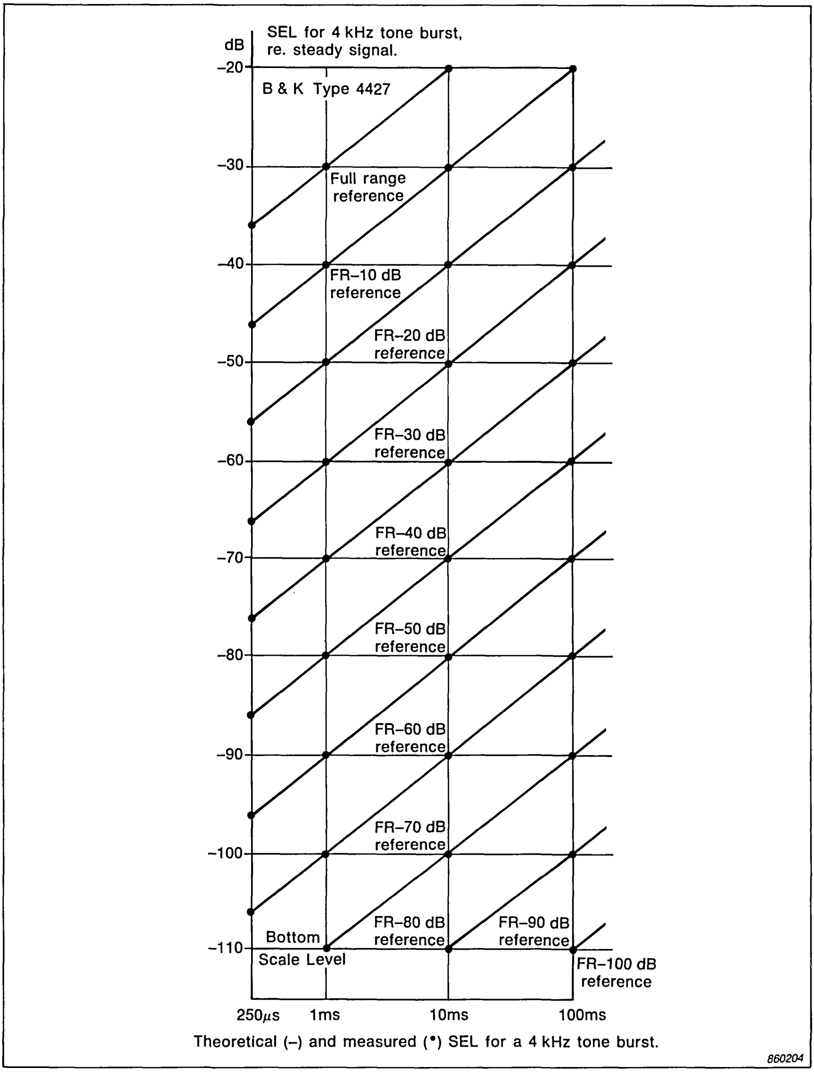

Fig. 3. a) Theoretical and measured sound exposure level for a 4 kHz tone burst

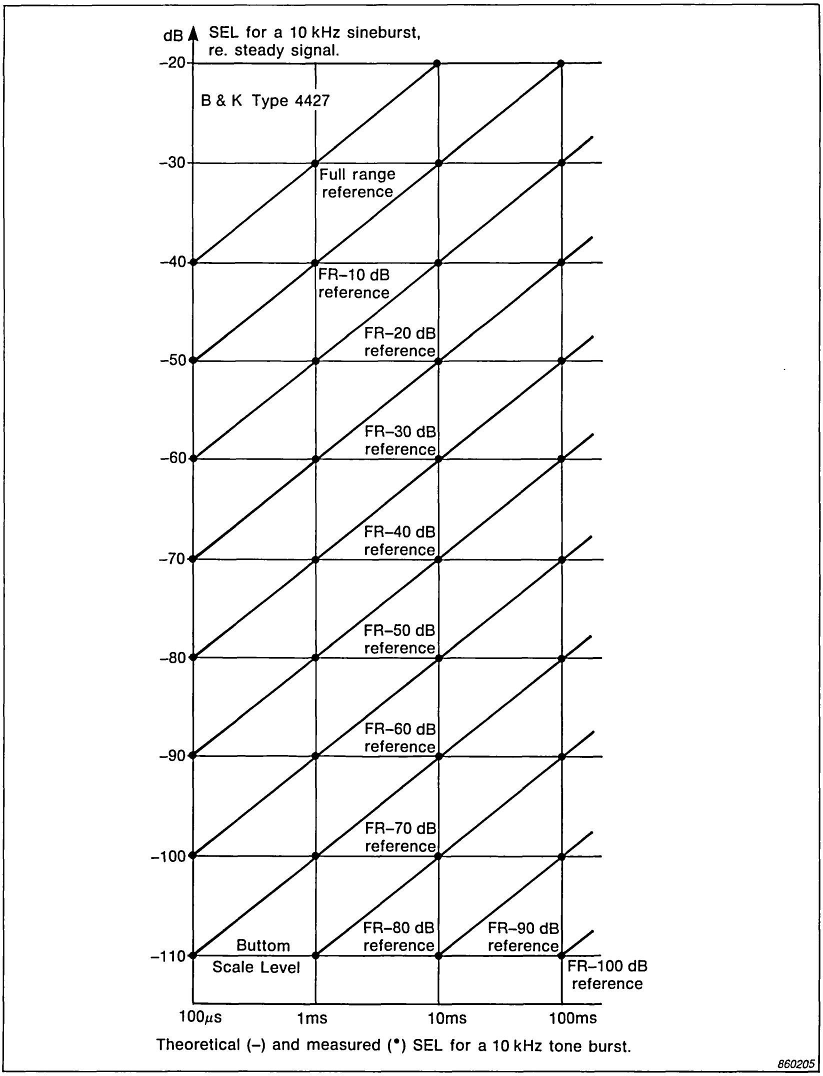

Fig. 3. b) Theoretical and measured sound exposure level for a 10 kHz tone burst

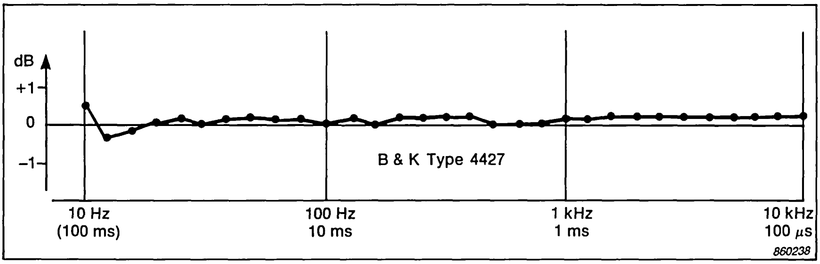

Fig. 4. Error on measured A-weighted pulse duration level

- The Medium-Term periods, i.e. three successive periods defined over a 24h day, possibly with different L_{eq} adjustments for each period

- The Long-Term period, which is a 24h period starting at the beginning of the first medium-term period.

It should be underlined that Type 4427 features a real-time clock with date indication, including the year and the day of the week.

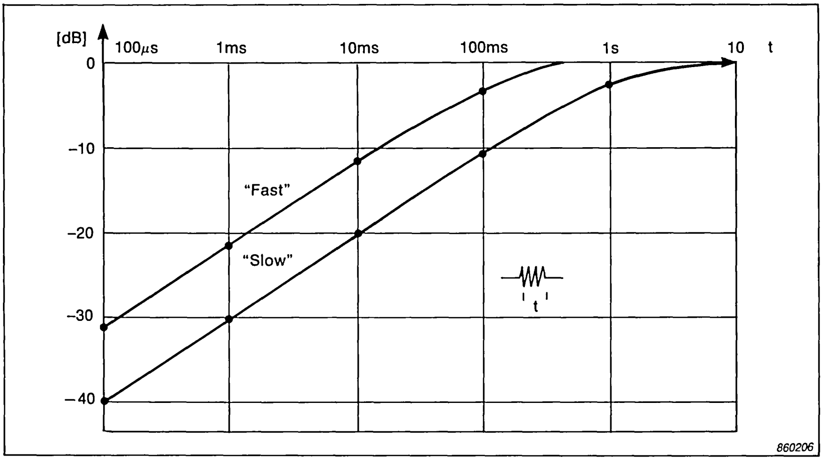

Fig. 5. Theoretical and measured response to 10kHz tone bursts for the exponentially averaging RMS detector of Type 4427

c) **The Output Program** defining which results should be produced at the end of each type of period. All relevant functions available in manual operation may be used in an output program.

For each type of measuring program, the Analyzer stores 9 different programs, three of which are fixed, the remaining six being user-definable.

Examples of user-defined measuring programs are shown in Fig.6. By introducing a 10 dB adjustment factor at night (22 h to 7 h), and 0 dB adjustment for the other medium periods, the long-term L_{eq} value obtained after a 24 h measurement period will correspond to L_{dn}. To obtain CNEL, a 5 dB adjustment should be specified for the evening (19 h to 22 h).

Setting up a measuring program or specifying a function for manual operation is very easy due to straightforward dialogue with the instrument. The different selection possibilities and current settings are indicated clearly on the printer and the user can then accept or modify the settings as necessary.

The printer uses metallized paper and produces fully annotated reports, tables and graphs, as will be shown in the following.

```
Input Program 7
Running Program
Preamp. Curve A
RMS-Fast  True Leq
Calib. Level=  93.8dB
Dynamic Range=
 19.5 to 129.5dB
```

841465

```
*Timing Program 7
Short-Term
30:00 Minutes
Med-Term
Per.1= 6:00 to 18:00
 Correction=+  0.0dB
Per.2=18:00 to 20:00
 Correction=+  5.0dB
Per.3=20:00 to  6:00
 Correction=+ 10.0dB
LN Follows  Short
```

841470

```
*Output Program 6
*Short-Term
Time
Short Leq
L  10.0
L  50.0
L  90.0
Special 10
 Standard Deviation
 and Mean Value
Plot Dist%
 Start Level= 40.0dB
 Stop  Level= 90.0dB
 Class Interval=
  2.0dB
Plot 1 sec. Leq
 Paper Speed=1mm/Min
 dB Range=100dB
Min. Level= 20.0dB

*Med-Term
Medium Leq
Special 61
 Remote Microphone
 Calibration Check

*Long-Term
Long Leq
```

860217

Fig. 6. Examples of user-defined measurement set-ups

All the results obtained on the printer are also available at the digital interface. The standard version of Type 4427 is fitted with an IEEE/IEC interface; optionally, this interface may be replaced by a serial interface (RS 232 C). Both interfaces allow complete remote control of the Analyzer.

Typical Measurement Systems

Environmental noise measurements are often performed outdoors, requiring some protection for the measurement system.

For short-term measurements the Noise Level Analyzer may be housed in a robust carrying case KA 2004, Fig.7, and the microphone assembly should be protected by a windscreen. For protection against humidity, a back-vented, 1/2″ microphone cartridge can be selected, permitting use of a dehumidifier UA 0308. The system measuring range depends on the sensitivity of the microphone system; typical values are given in Table 2. Note that the measuring ranges for externally polarized microphones are valid for 200 V polarization voltage. They may be shifted 17 dB upwards by setting the polarization voltage down to 28 V.

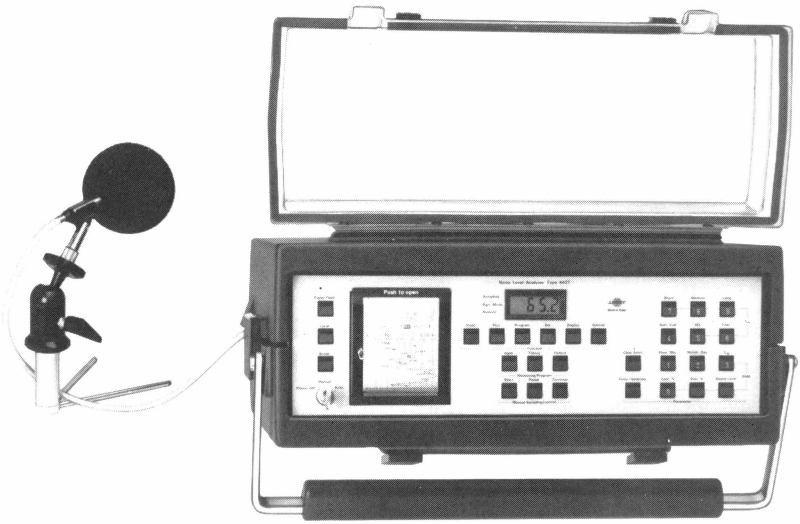

Fig. 7. Use of the Noise Level Analyzer in a Carrying Case KA 2004

Microphone Type	Lower limit for S/N ratio > 5 dB		Max. peak Level (dB)	Nominal Sensitivity (mV/Pa)	Polarisation Voltage (V)
	Lin. (dB)	A-Weighting (dB)			
4133[1]	32	32	145	12,5	200
4133[2]	49	49	162	12,5	28
4145	22	20	133	50	200
4165[1]	25	22	133	50	200
4155	25	22	133	50	0
4179	8,6	2,7	97	100	200

1 Using Microphone Type 4133 or 4165, the measuring system complies with IEC 651 Type 0

2. Only when used at 28 V polarization voltage

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Table 2. Typical measurement ranges with different B&K microphones

For longer-term measurements, a system similar to that of Fig.8 may be used. The Noise Level Analyzer Type 4427 and the Digital Cassette Recorder Type 7400 should be housed in a weatherproof enclosure, a measuring van, etc.

The Outdoor Microphone Unit Type 4921 is designed for permanent outdoor installation. The microphone is fully protected against adverse weather conditions by a Windscreen and a Rain Cover with built-in electrostatic actuator allowing calibration of the system. The calibration oscillator of the 4921 may be controlled from Type 4427 where two pins of the socket are short circuited during the time that the oscillator should be on. When defining an input program, after the entry of the calibration level (90 dB), the 4427 prompts the user to start the calibrator.

When the "Enter" key is depressed the oscillator is activated until the end of the calibration procedure. A calibration check function may also be used. It activates the oscillator for a 10 s duration. The resulting sound pressure level is read on the last second and reported.

If the Analyzer is sampling when a calibration check is requested, the sampling process is stopped during the application of the calibration signal and for a period of 1,5 s (Fast) or 12 s (other time weightings) after the end of the calibration, so that neither the calibration signal nor the early decay of the detector are acquired as measurement data.

For audio monitoring purposes, the 4427 is able to control the start and stop functions of a tape recorder. Recording is started when a preset

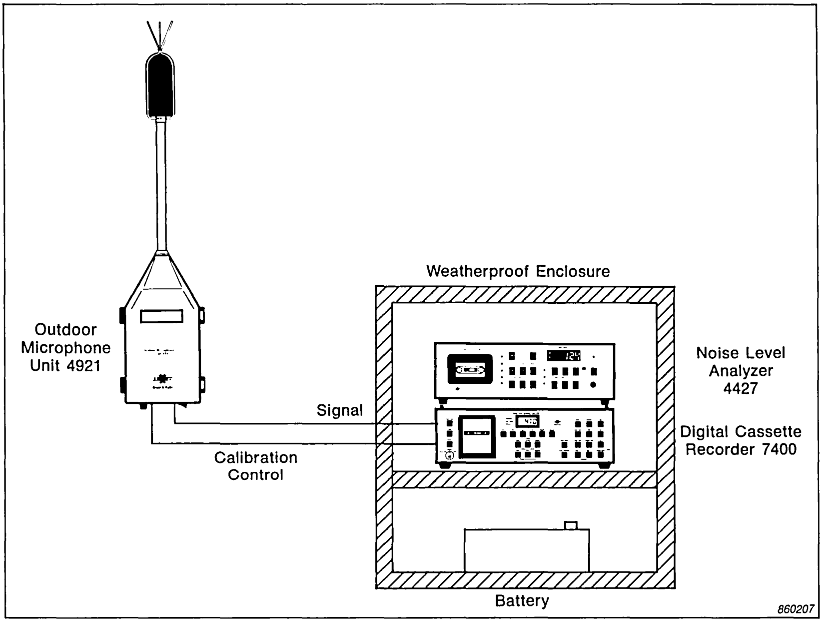

Fig. 8. Typical system for semi-permanent installation

threshold level is exceeded. When the noise level falls below the threshold level, the tape recorder is kept recording during a preset time period. The 4427 features an AC output covering a range of 10 μV to 3,16 V. This dynamic range exceeds the capabilities of most tape recorders, but a compressed output is also available where the 110dB dynamic range is compressed to approx. 40dB.

Basic Environmental Noise Measurements

The functions presented in this section are the most generally used in environmental noise measurements. Functions intended for more specific applications, such as traffic noise, aircraft noise, etc., will be dealt with in the corresponding sections.

The digital display of the 4427 can display the current time, the date, the running sound level or 1 s L_{eq}, the short, medium and long-term L_{eq} values and corresponding SEL values, percentile levels L_N, where N may be selected from 0 to 100 in 0,1% steps. Individual values for the amplitude and cumulative distributions may also be displayed. A hard

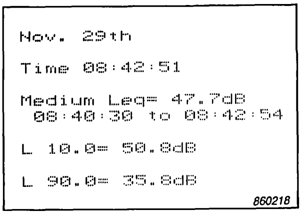

Fig. 9. Examples of hardcopies obtained in manual operation

copy of any displayed values may be obtained on the printer by depressing the ENTER/HARD COPY pushkey. Examples are given in Fig.9. The print-outs are fully annotated and, for L_{eq} values, the measurement time period is also indicated.

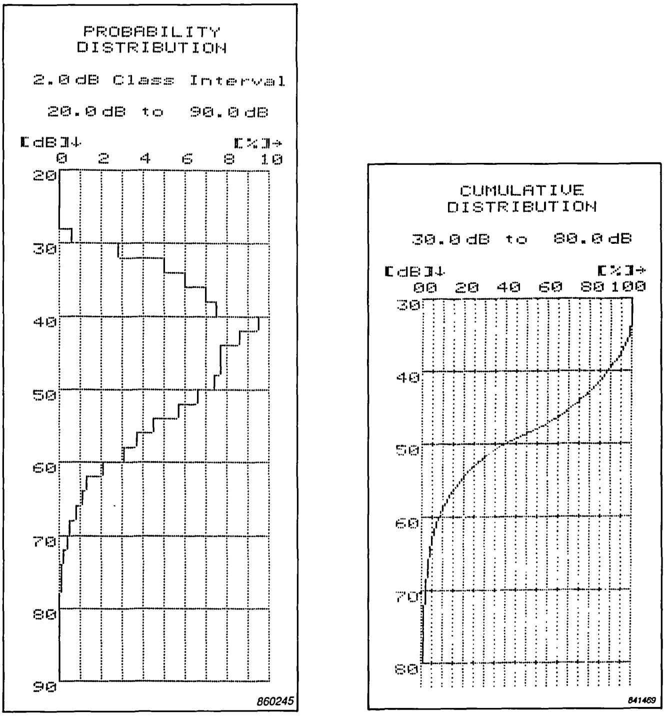

Fig. 10. Examples of plots of amplitude and cumulative distributions

The amplitude and cumulative distributions may be obtained either as tables or as plots, Fig.10. In both cases, the start level and stop level may be selected, as well as the class interval (except when plotting a cumulative distribution). When plotting the amplitude distribution, the 4427 automatically selects the range giving optimum resolution (100%, 50%, 25% or 10%).

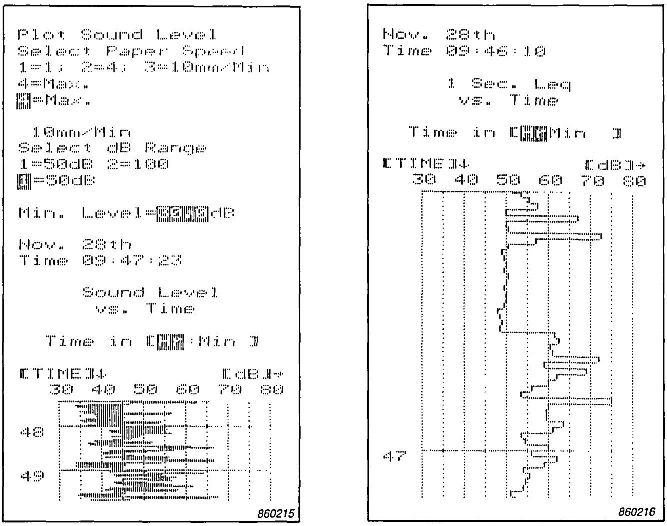

Fig. 11. Examples of the sound level and 1 sec. L_{eq} as a function of time. As the plotting process is not continuous, each plot represents the range of variation of the sound level since the previous plot. For "1 sec. L_{eq}", the plot represents L_{eq} calculated since the previous plot, except at max. speed where the current 1 sec. L_{eq} is plotted

The instrument can also plot the sound level or 1 s. L_{eq} as a function of time, Fig.11. As can be seen, the user is prompted to select the paper speed, the dynamic range and the minimum level.

The different functions may be combined together in an output program. For example, in order to assess noise in a dwelling, the Analyzer was set up to produce every hour L_{eq}, a number of L_N values and the standard deviation. A typical print-out is shown in Fig.12 while Fig.13 shows the

```
Short-Term
Time 09:00:00

Short Leq= 58.5dB

L 10.0= 59.2dB
L 50.0= 51.6dB
L 90.0= 35.0dB

Standard Deviation=
    8.9dB
 Mean Value= 49.7dB
```
860244

Fig. 12. Example of hourly report

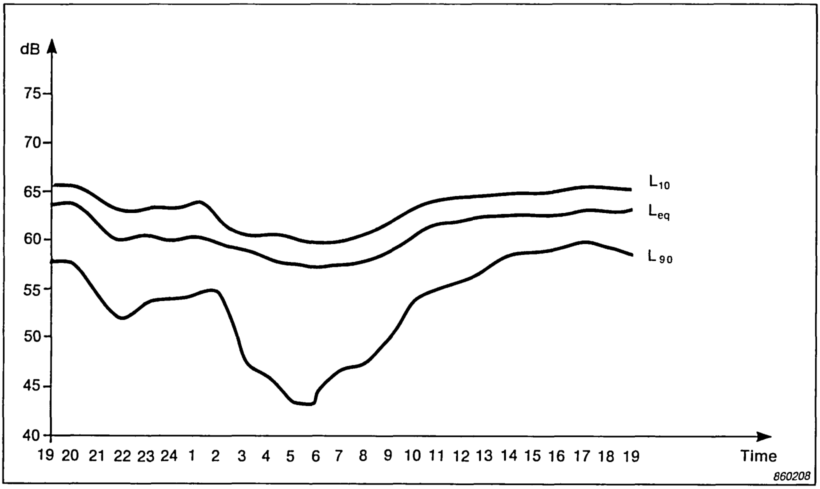

Fig. 13. Variation of hourly L_{eq}, L_{10} and L_{90} over a 24h period

different quantities as a function of time for a full day. Note the typical "dip" in the curves during the night.

Traffic Noise Measurements

Road traffic noise affects a large number of people, especially in urban environments, and is generally a major source of complaints, Ref.[10]. Numerous surveys have been made in towns, along motorways, etc. Most often, the results are reported in terms of L_{eq} and percentile levels, but other descriptors have been used, for example the Noise Pollution Level or the Traffic Noise Index.

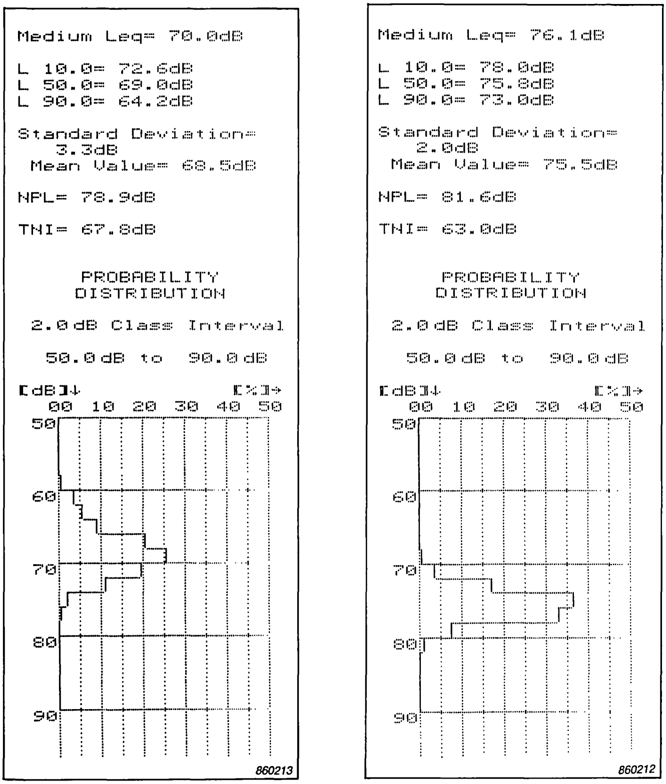

Fig. 14. Examples of traffic noise measurement reports

The 4427 can calculate L_{NP} and TNI according to Eqs.6 and 7, and can also provide the standard deviation and mean level. Fig.14 shows an example of results obtained after a 10 min. analysis of traffic noise from a motorway and from a busy street in town.

If the traffic density is sufficient, it is common practice to make the approximation that the noise level distribution is Gaussian, and the distributions of Fig.12 seem to conform reasonably to the assumption. The results obtained in the example, especially the standard deviation and mean value permit check of the validity of this assumption. If the distribution is Gaussian, the following relationships are verified:

$$L_{mean} = L_{50} \quad (8)$$

$$L_{10} - L_{90} = 2{,}56\,\sigma \quad (9)$$

$$L_{eq} = L_{mean} + 0{,}115\,\sigma^2 \quad (10)$$

Using the results of Fig.14 the above relationships are verified quite closely, as shown in Table 3.

	L_{mean}	L_{50}	$L_{10}-L_{90}$	$2{,}56\,\sigma$	L_{eq}	$L_{mean} + 0{,}115\,\sigma^2$
Street Noise	68,5 dB	69,0 dB	8,4 dB	8,4 dB	69,7 dB	69,7 dB
Motorway Noise	75,5 dB	75,8 dB	5,0 dB	5,1 dB	76,1 dB	76,0 dB

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Table 3. Traffic noise measurement results used to check the validity of the Gaussian noise assumption

In many surveys, measurements are performed at different locations over different representative periods of the day (busy hours, quieter periods during the day, night). If the same results are requested at the end of each measurement period (typically 10 to 20 min.), it is not necessary to repeat the whole manual procedure each time: if all the requested results are introduced in an output program, in either the short, medium or long-term part of the program, the selected part of the program may be initiated manually by activating the corresponding special function of the 4427. The results of Fig.14 were obtained using this feature.

Aircraft Noise Measurements

In the vicinity of airports, aircraft noise has a very intrusive character, as it consists of a succession of sudden, high level events, separated by much quieter periods. Consequently, aircraft noise measurements generally combine two types of reports: analysis of individual fly-overs and long-term noise ratings.

The ISO standard 3891, "Procedures for describing aircraft noise heard on the ground" describes two alternative methods, which mainly differ on account of the frequency weighting; one method using A-weighted sound pressure levels, the other using approximated Perceived Noise Levels, derived from D-weighted measurements:

$$L_{PN\,approx.} = L_D + 7\,\mathrm{dB} \tag{11}$$

Another approximation of L_{PN} is sometimes used, adding 13 dB (or 12 dB) to the A-weighted sound pressure level.

Single fly-overs are described by the maximum level and an energy average, the sound exposure level, L_{AE}, or the approximated Effective Perceived Noise Level, L_{EPN} approx., which is calculated as an energy summation of $L_{PN\,approx.}$ using a reference duration of 10 s. For long-term noise assessments, the energy averages over selected time periods should be reported, L_{Aeq} or L_{PNeq}. The quantities to be reported are summarized in Table 4.

The Noise Level Analyzer Type 4427 features a number of functions allowing an accurate description of aircraft fly-over noise (or any other kind of intrusive noises). Reports may be obtained either as SEL and $L_{A\,max}$ or as $L_{EPN\,approx.}$ and max. $L_{PN\,approx.}$. The latter requires that the proper factor be introduced at calibration (i.e. 13 dB for A-weighted measurements).

One function allows selection of a threshold level and a minimum duration, Fig.15. Each time the sound level exceeds the threshold level for a time period longer than the minimum duration, the following quantities are recorded:

Time of start

Event L_{eq} or L_{PNeq}

Event *SEL* or $L_{EPN\,approx.}$

Max. L_A or $L_{PN\,approx.}$

Time of max.

Time of end.

Frequency Weighting	A	D
Instant. Level	L_A	L_{PN} (approx.) = $L_D + 7\ dB$
Max. Level	$L_{Amax.}$	L_{PN} (approx.) $_{max.}$
Event Exposure	$L_{AX} = 10 \log \left(\frac{1}{T_{ref}} \int 10^{\frac{L_A}{10}} dt \right)$ $T_{ref} = 1$ s	$L_{EPN} = 10 \log \left(\frac{1}{T_{ref}} \int 10^{\frac{L_{PN}}{10}} dt \right)$ $T_{ref} = 10$ s
Event Exposure using Duration Allowance	$L_{AX} = L_{Amax.} + \Delta_A$	L_{EPN} (approx.) = L_{PN} (approx.) $_{max.} + \Delta_{PN}$
	$\Delta = 10 \log \left(\frac{t_2 - t_1}{2\ T_{ref}} \right)$ $t_2 - t_1$: time interval where level is within 10 dB of max.	
Long-term Exposure over Time Period T	$L_{eq} = 10 \log \left(\frac{1}{T} \int_0^T 10^{\frac{L_A}{10}} dt \right)$	$L_{PNeq} = 10 \log \left(\frac{1}{T} \int_0^T 10^{\frac{L_{PN}}{10}} dt \right)$
Using Individual Event Exposures	$L_{eq} = 10 \log \left(\frac{T_{ref}}{T} \sum_i 10^{\frac{L_{AXi}}{10}} \right)$	$L_{PNeq} = 10 \log \left(\frac{T_{ref}}{T} \sum_i 10^{\frac{L_{EPNi}}{10}} \right)$

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Table 4. Quantities to be reported for aircraft noise measurements according to ISO 3891

```
Single Event and
 EPN Measurement
 Threshold Level=
   70.0dB

 75.0dB
Min. Duration=2sec.


Single Event and
 EPN Measurement
 Threshold Level=
   75.0dB
 Min. Duration=
  4sec.
```
860243

Fig. 15. Selection of threshold level and minimum duration for single event measurements

a)

```
Single Event Meas.
 Print immediately
 Threshold Level=
   55.0dB
 Min. Duration=
   2sec.
0=Off 1=On
0=Off

Print immediately On

Start at: 16:02:27
 Event Leq= 63.3dB
 Event SEL= 68.1dB
 Max. Noise Level=
  74.0dB
 at: 16:02:28
End at: 16:02:31

Start at: 16:03:02
 Event Leq= 63.2dB
 Event SEL= 70.1dB
 Max. Noise Level=
  63.9dB
 at: 16:03:03
End at: 16:03:08
```
850136

b)

```
Single Event Meas.
 Print All
 Threshold Level=
   55.0dB
 Min. Duration=
  2sec.
Start at: 16:02:27
 Event Leq= 63.3dB
 Event SEL= 68.1dB
 Max. Noise Level=
  74.0dB
 at: 16:02:28
End at: 16:02:31

Start at: 16:03:02
 Event Leq= 63.2dB
 Event SEL= 70.1dB
 Max. Noise Level=
  63.9dB
 at: 16:03:03
End at: 16:03:08

Number of Events=
 2
Average of:
 SEL values= 69.2dB
 Max. Noise Levels=
    71.7dB
```
850137

c)

```
Single Event Meas.
 Summary.
 Threshold Level=
   55.0dB
 Min. Duration=
  2sec.
Number of Events=
 2
Average of:
 SEL values= 69.2dB
 Max. Noise Levels=
    71.4dB
```
850138

Fig. 16. Single event measurement reports
a) Printed immediately after the end of the event
b) Printed as a list on request
c) Summary alone

The results may be obtained in different ways, Fig.16. The first way is to print out the report immediately after the end of the events. Whether this mode is active or not, valid events are stored in the memory (up to a maximum of 52) and a print-out listing of all the stored events may be obtained upon request or, in automatic operation, at selected time intervals. The list is followed by a summary giving the number of events and the energy average of the event exposure levels and of the maximum levels. These quantities may be used to derive various long term descriptors. If preferred, it is possible to obtain the summary without the list of events.

It is also possible to plot noise events when the level exceeds a selected threshold level, Fig.17. In that case, a 4 s digital delay is introduced, to plot the noise levels occurring just before and after the exceedance.

Long term reports will normally include L_{eq} and selected percentile levels.

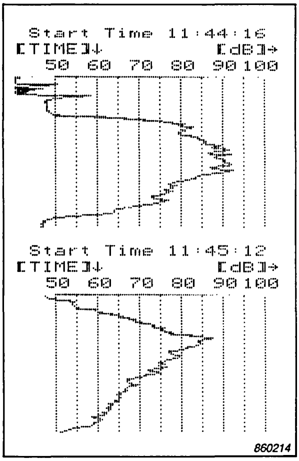

Fig. 17. Plots of aircraft fly-overs as a function of time

Occupational Noise Measurements

In a number of industries, noise at the working place is a serious problem since prolonged exposure to high level noise results in irreversible hearing loss. The main objective of occupational noise measurements is therefore the assessment of hearing damage risk. In many countries, noise exposure limits have been established, but different noise assessment methods are used.

One of the methods, used in most European countries, is based on the ISO standard 1999–1975: "Acoustics–Assessment of occupational noise exposure for hearing conservation purposes"; (first published in 1971 as a Recommendation). The standard recommends the use of L_{eq} and suggests a limit of 85 to 90 dB(A). As the calculation of L_{Aeq} follows the "equal energy" principle, a 3 dB increase requires halving the exposure duration to obtain the same total energy.

Another method is used in the American Occupational Safety and Health Act (OSHA) where the level increases requiring halving the exposure duration is set to 5 dB. This halving factor is often referred to as "q". The integration should be performed on a "Slow" time-weighted signal according to:

$$L_{OSHA} = 10 \cdot \frac{5}{3} \log_{10} \frac{1}{T} \int_{t_1}^{t_1 + T} 10^{\frac{L_A}{10 \cdot 5/3}}\, dt \tag{12}$$

Finally, the US Department of Defence uses $q = 4$

$$L_{DOD} = 10 \cdot \frac{4}{3} \log_{10} \frac{1}{T} \int_{t_1}^{t_1 + T} 10^{\frac{L_A}{10 \cdot 4/3}}\, dt \tag{13}$$

Examples of countries (or organizations) using different halving factors and different limits are given in Table 5.

Country	**Limit**	**Halving Factor**
Sweden Federal Republic of Germany	85 dB(A)	3
Most other European countries	90 dB(A)	3
US Department of Defence	84 dB(A)	4
USA (Fed.) Canada (Fed.)	90 dB(A)	5
Brazil, Chile	85 dB(A)	5

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Table 5. Halving factors and noise exposure limits in different countries

Assuming a Gaussion distribution, Eq.10 gives the relationship between L_{Aeq}, L_{mean} and σ. Similar relationships can be derived for L_{DOD} and L_{OSHA} following the method used in Ref.[11] to derive Eq.10.

$$L_{DOD} = L_{mean} + 0{,}086\ \sigma^2 \tag{14}$$

$$L_{OSHA} = L_{mean} + 0{,}069\ \sigma^2 \tag{15}$$

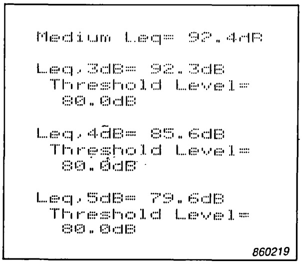

Fig. 18. Examples of occupational noise measurements

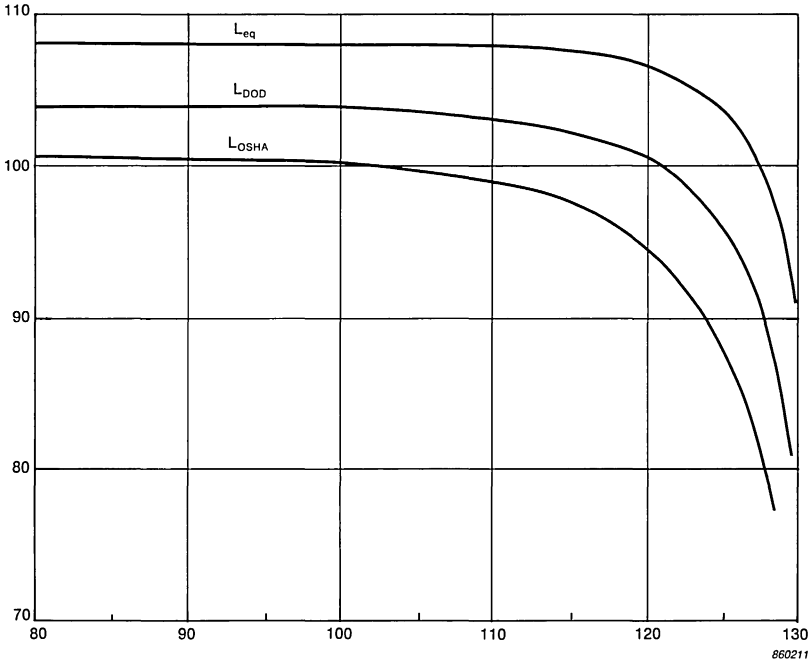

Fig. 19. a) Variation of L_{eq}, L_{DOD} and L_{OSHA} as a function of the threshold level

Type 4427 calculates the different levels from the statistical distribution, starting from a selectable threshold (both ISO and OSHA specify a threshold of 80 dB(A)). Examples of print-outs of L_{eq}, L_{DOD} and L_{OSHA} are shown in Fig.18. Note that the "Slow" time-weighting should be used in order to properly calculate L_{DOD} and L_{OSHA}.

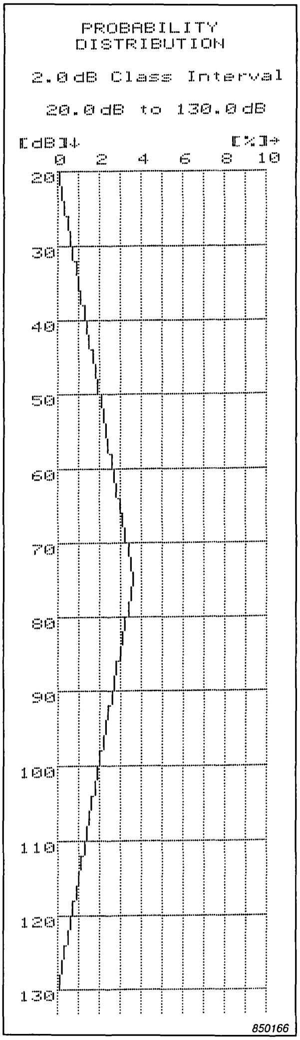

Fig. 19. b) Test distribution of Type 4427

As q increases from 3 to 5, the relative influence of the higher level decreases. This is illustrated in Fig.19.a which shows the results obtained for L_{eq}, L_{DOD} and L_{OSHA} as a function of the threshold level. The test distribution of the 4427, Fig.19.b was used for the calculations.

Conclusion

A number of different rating methods are used for assessing environmental noise. Most of them require long-term averaging, sometimes introducing weightings for the time of the day or other factors. The accuracy and flexibility of the Noise Level Analyzer Type 4427, together with its numerous built-in functions allow the necessary results to be obtained in virtually all situations. Although primarily designed for environmental noise analysis, the Analyzer can also be used in other applications where long-term averaging, statistical and/or the description of isolated events are necessary, for example occupational noise measurement, human-body vibration analysis, etc.

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APPENDIX A

Sound Exposure Level of a Moving Source

The approximation of L_{AE} (L_{AX}) and $L_{EPNapprox.}$ given in ISO 3891 only apply if the following assumptions are valid:

a) The noise source is a **point source** moving along a **straight line** at **constant speed** (constant noise output)

b) Noise propagates under **free-field** conditions (no sound absorption)

The maximum sound level received at the observer's position is emitted when the source is closest to the observer. This position, point 0 in Fig.A1, defines the time origin. Under the assumption of free-field propagation, when the sound source is at a given position, the corresponding sound level received at the observer position will be given by:

$$L(t) = L_{max} + 10\,\mathrm{Log}\,\frac{d_0^2}{d_0^2 + (st)^2} \qquad \text{(A.1)}$$

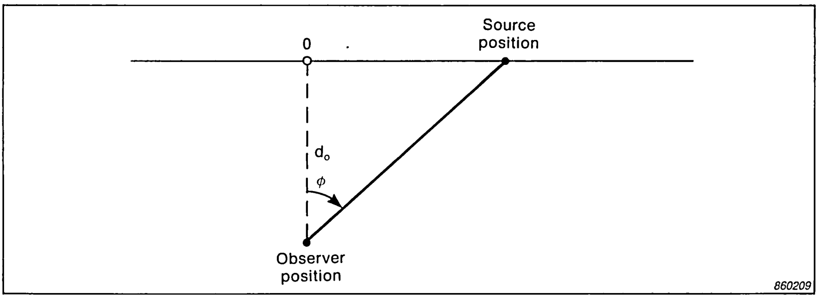


Fig. A.1. Source path and observer position

where d_0 is the minimum distance
s is the constant speed.

The distance attenuation factor, $d_0^2/(d_0^2+(st)^2)$, is represented on a linear scale in Fig.A2.

The points corresponding to an attenuation of 10 dB below the maximum are given by:

$$\frac{{d_0}^2}{{d_0}^2+(st)^2}=\frac{1}{10} \tag{A.2}$$

$$\frac{st}{d_0}=\pm 3 \tag{A.3}$$

These points are shown in Fig.A.2. where it can be seen that the area of the triangle seems to be nearly equal to the area below the attenuation curve. This may be verified by calculating the sound exposure level:

$$L_{AE}=L_{max}+10\,\text{Log}\,\frac{1}{T_0}\int_{-\infty}^{+\infty}\frac{{d_0}^2}{{d_0}^2+(st)^2}\cdot dt \tag{A.4}$$

Letting ϕ to be the angle between the normal to the source path and the line joining the observer position to the source position, then:

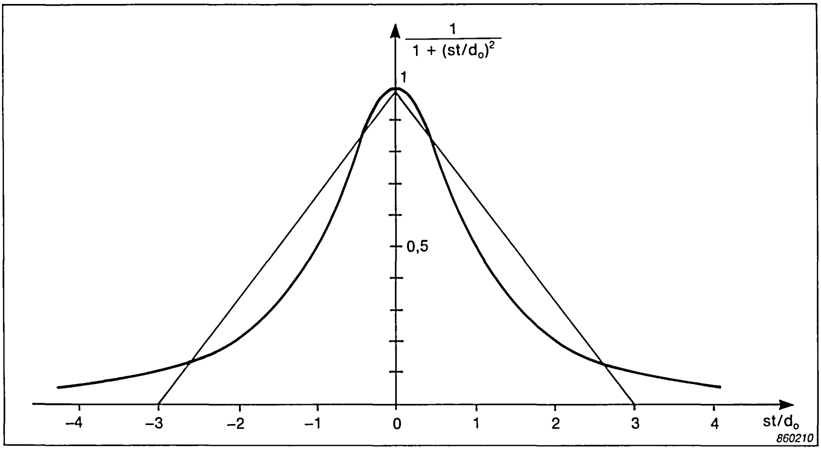


Fig. A.2. Relative sound "energy" variation as a function of time

$$tg\,\phi = \frac{st}{d_0} \tag{A.5}$$

Differentiating the above equation:

$$\frac{d\phi}{\cos^2\phi} = \frac{s \cdot dt}{d_0} \tag{A.6}$$

i.e. $$dt = \frac{d_0 \cdot d\phi}{s\,\cos^2\phi}$$

As $$\frac{d_0^{\,2}}{d_0^{\,2} + (st)^2} = \cos^2\phi \tag{A.7}$$

Equation A.8 becomes:

$$L_{AE} = L_{max} + 10\,\mathrm{Log}\,\frac{1}{T_0}\int_{-\pi/2}^{\pi/2} \frac{d_0}{s} \cdot d\phi \tag{A.8}$$

$$L_{AE} = L_{max} + 10\,\mathrm{Log}\,\frac{d_0}{s\,T_0} \cdot \pi \tag{A.9}$$

With the approximation using the 10 dB points as derived in Eq.A.4:

$$L_{AE} = L_{max} + 10\,\mathrm{Log}\,\frac{3\,d_0}{s\,T_0} \tag{A.10}$$

The approximation is therefore that π is approximately equal to 3, giving a theoretical difference of 0,2 dB.

At first sight, Eq.9 may seem to suggest that L_{AE} increases with distance (+ 3 dB per doubling of distance) but is should be remembered that the maximum level decreases with distance (–6 dB per doubling of distance) so that L_{AE} decreases –3 dB per doubling of distance. A more general expression for L_{AE} may be obtained by introducing a reference distance (say 10 m), a corresponding reference maximum (which is a function of speed) and assuming that the source is only visible from angle ϕ_1 to angle ϕ_2. L_{max} becomes:

$$L_{max} = L_{ref} + 10\,\mathrm{Log}\,\left(\frac{d_{ref}}{d_0}\right)^2 \tag{A.11}$$

And Eq.8 becomes:

$$L_{AE} = L_{ref} + 10 \text{ Log } \left(\frac{d^2_{ref}}{d_0^2} \cdot \frac{d_0}{s\,T_0} \cdot \Delta\phi \right) \qquad (A.12)$$

which may be written as:

$$L_{AE} = L_{ref} + 10 \text{ Log } \frac{d_{ref}}{d_0} + 10 \text{ Log } \frac{d_{ref}}{s\,T_0} + 10 \text{ Log } \Delta\,\phi \qquad (A.13)$$

This expression shows the influence of different factors:

a) Distance. Whereas the maximum level decreased by 6 dB per doubling of distance, the sound exposure level decreases by 3 dB per doubling of distance.

b) Speed. If the reference level is the same, a higher speed results in a lower sound exposure level.

c) Viewing angle. The sound "energy" is directly proportional to the viewing angle. This means for example that the part of the source path from $-d_0$ to $+ d_0$ (viewing angle of 90°) has the same contribution to the total energy as the entire remainder of the path.

It should be remembered that Eq.A.13 is valid only if a number of assumptions are valid. If one condition is varied, new calculations are necessary. For example, in the FHWA Highway Traffic Noise Model, Ref.[11], two types of sound propagation are considered, one over a "hard" surface, leading to Eq.A.13, and one over a "soft" surface. In the latter case, the level variation as a function of distance accounts for the extra attenuation:

$$L_1 = L_0 + 10 \text{ Log } \left(\frac{d_0}{d_1} \right)^{2+\alpha} \qquad (A.14)$$

The Model suggests that most absorbing sites may be characterized by $\alpha \approx 1/2$, which modifies Eq.A.13 as follows:

$$L_{AE} = L_{ref} + 15 \text{ Log } \frac{d_{ref}}{d_0} + 10 \text{ Log } \frac{d_{ref}}{s\,T_0} + 10 \text{ Log } \left(\int_{\phi_1}^{\phi_2} \sqrt{\cos\phi} \cdot d\phi \right) \qquad (A.15)$$

The distance attenuation is now 4,5 dB per doubling of distance and the viewing angle adjustment factor requires numerical integration.

To summarize the above discussion, the approximation of L_{AE} or L_{EPNeq} by the maximum level and a duration allowance based on the time when the level was within 10 dB of the maximum level is valid only when a set of conditions are met. If one of the conditons is not met, the approximation is no longer valid and the proper model should be used to describe the situation.

News from the factory

Mouth Simulator Type 4227

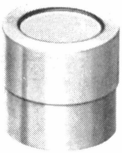
Brüel & Kjær have released a Mouth Simulator designed for testing telephone transmitters and microphones and for other applications where a sound field similar to the human voice field is required.

The B & K Mouth Simulator Type 4227 is a development of the earlier Artificial Voice Type 4219. Its sound field accurately simulates the sound field generated by the human mouth, making it an ideal device for testing telephone transmitters and close talking microphones. All significant characteristics have been improved. The 4227 offers a higher sound pressure level and better frequency response.

The sound pressure now exceeds 120 dB at a distance of 25 mm from the lip ring, due to the new Simulator's enhanced power handling capacity.

The 4227 can be calibrated using the Calibration Jig provided. The test object can be fitted with its microphone axis either at 0° or 90° to the mouth axis. The lip ring fitted on the 4227 provides a reference plane for measurements.

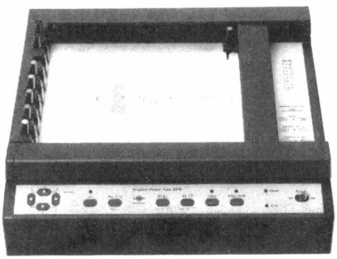
Condenser Microphone Cartridge Type 4180



In response to growing demands for a high stability, laboratory standard half-inch microphone, Brüel & Kjær have developed the Type 4180 which conforms to Type M configuration 2b of the forthcoming revision of ANSI S 1.12–1967, and features excellent long term stability and extreme reliability with respect to environmental influences. It has a frequency response which is flat ($\pm$1,5 dB) up to 20 kHz and it can be used for accurate measurements up to 40 kHz. The Type 4180 will find application in coupler measurements and in pressure and free-field reciprocity calibrations.

The integral coupler mounting ring permits accurate and reproducible mounting of half-inch couplers. Special consideration has been given to ensure low leakage during calibrations performed in hydrogen. A special feature of the front cavity is its shallow depth, only 0,5 mm.

Graphics Plotter Type 2319



Brüel & Kjær have introduced the Graphics Plotter Type 2319 to provide high quality multi-colour records of measurements in IEEE/IEC bus-based systems. The 8-pen plotter accommodates metric A4 or US A-size plain paper or overhead-projection transparencies, and features IEEE–488 interfacing and an HP–GL compatible instruction set. The large, 7-kilobyte input buffer allows fast, efficient data transfer, quickly freeing the sending device and the interface bus for other duties. Using front-panel control or graphics language instructions, plots can be drawn any size and in any position within the plotting area.

The Type 2319 plots measurements as displayed on the Dual Channel Signal Analyzer Type 2032 and 2034 (earlier models may need to be modified). A plot can be produced according to pre-set default values by pressing a single pushkey; alternatively, 35 plot parameters can be defined by the user, selecting the pen colour for various areas of the plot, the plot size, page numbering, line type for the data, and other features. The plot parameters are selected using the controls of the Type 2032.

Plots generated from measurements by the Type 2032 feature fully-annotated axes, user-defined text anywhere on the plot, and room for comments and notes on the measurement. Two superimposed signals can be plotted allowing, for example, a fresh recording to be compared to a reference spectrum. Using the 2032's cursors to move the pen, any point on the plot can be marked "×", with its X–Y coordinates written nearby.

The Graphics Plotter Type 2319 can be used with any instrument with an IEEE–488 interface and the capability to send HP-GL instructions. Single HP-GL commands allow, for instance, circles, arcs and sectors to be drawn either shaded or outlined. Alphanumeric characters can be selected from five sets of 96 characters each, and written onto the plot in any direction and with variable aspect and slant.

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(Continued from cover page 2)

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Frequency Analysis (English)
Electroacoustic Measurements (English, German, French, Spanish)
Catalogs (several languages)
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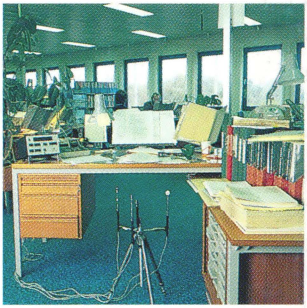

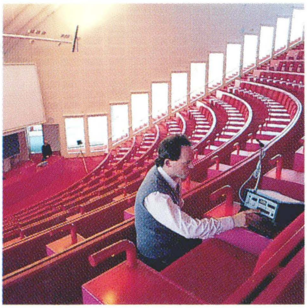

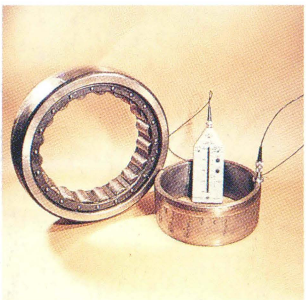

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