Brüel & Kjær application notes

L_{eq}, SEL WHAT? WHY? WHEN?

BO 0051–14

L_{eq}, SEL
WHAT? WHY? WHEN?

by *Pierre Bernard,* Brüel & Kjær

What are L_{eq} and SEL?

L_{eq} and SEL are energy parameters which provide a very useful means of describing fluctuating sounds. In this application note we will look at **what** *L_{eq} and SEL are,* **why** *we use them and* **when** *we use them.*

L_{eq} (equivalent continuous sound level) is defined as the steady sound pressure level which, over a given period of time, has the same total energy as the actual fluctuating noise. Thus, the L_{eq} is in fact the RMS sound level with the measurement duration used as the averaging time.

$$L_{eq} = 10 \log\left(\frac{1}{T}\int_{0}^{T} \frac{p^2(t)}{p_0^2}\,dt\right)$$

T = measurement duration

p(t) = sound pressure

p_0 = reference sound pressure of 20 μPa

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Fig.1. The definition of L_{eq}

For most community noise and industrial noise measurements an A-weighted L_{eq} or $\mathbf{L_{Aeq}}$ is used.

SEL or Sound Exposure Level is defined as that constant sound level which has the same amount of energy in one second as the original noise event.

$$SEL = 10 \log\left(\frac{1}{T_0}\int_{-\infty}^{+\infty} \frac{p^2(t)}{p_0^2}\,dt\right)$$

T_0 = reference duration of 1 s

p(t) = sound pressure

p_0 = reference sound pressure of 20 μPa

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Fig.2. The definition of SEL

Thus, SEL is similar to L_{eq} in that the total sound energy is integrated over the measurement period, but instead of then averaging it over the entire measurement period, a reference duration of 1 s. is used. Sound Exposure Level measurements using A-weighted sound pressure levels are denoted by the symbol $\mathbf{L_{AE}}$.

The differences between the fluctuating sound level, the L_{eq} and SEL can be seen in Fig. 3.

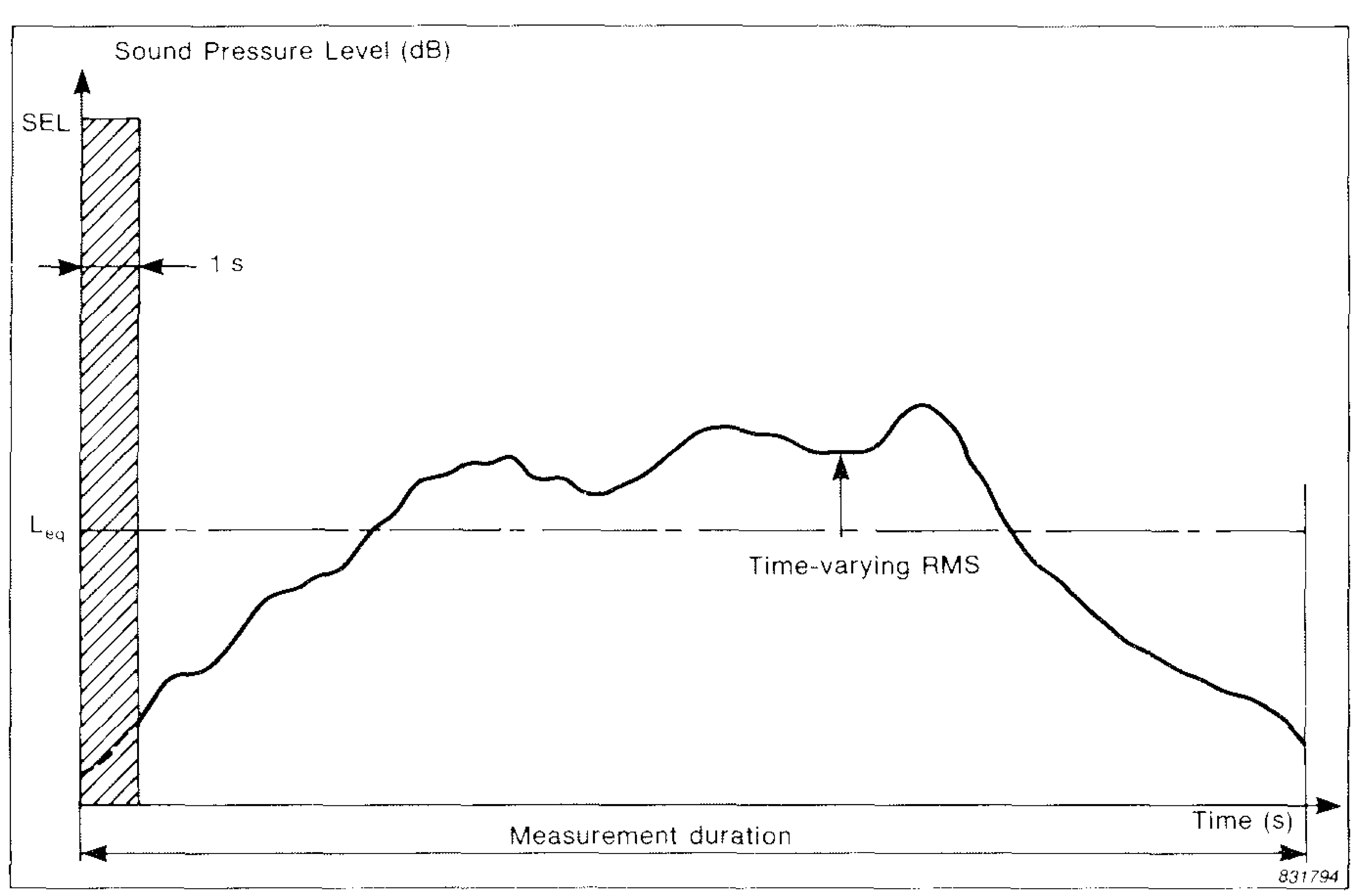

Fig.3. Comparison between L_{eq}, SEL and time-varying RMS.

Why use L_{eq} and SEL ?

L_{eq} and SEL are used because in many measurement situations the widely fluctuating display of a traditional sound level meter makes it extremely difficult to determine the correct sound level.

Traditional sound level meters are designed and built according to International (or National) Standards. These Standards define the time weighting of the sound level meter – that is the speed with which the detector and indicating meter or digital display respond to sound.

Most sound level measurements are RMS values, because of the direct relationship between the RMS value and energy. Thus, a traditional sound level meter displays a time-varying RMS value using either the "F" or "S" time weighting.

The response known as "F" (fast) gives a steady reading when the measured sound is steady. If the sound level fluctuates, the meter tries to follow the fluctuations. The "F" response is used, for example, when finding the maximum sound level produced by a motor vehicle in a drive-by test. The "S" (slow) response attempts to steady the readings when the noise is of a fluctuating nature.

Regulations governing sound level measurements may stipulate the use of either "F" or "S" time weightings. Often national legislation and standards are based on "A-weighted" sound energy measurements, for both industrial and environmental situations. This is normally expressed in terms of an A-weighted L_{eq}. For example, in many countries the maximum allowable noise exposure for workers is defined as an L_{Aeq} of either 85 dB(A) or 90 dB(A) over an eight hour working day. Similarly, environmental noise — for example, the noise at a construction site or noise due to traffic flow — is also frequently expressed in terms of either an A-weighted L_{eq} or SEL.

The traditional sound level meter can only be used to obtain an accurate L_{eq} if sound levels are steady, or are steady for relatively long periods of time, so that levels and their durations can be noted and recorded, and an L_{eq} calculated.

However, if the sound levels fluctuate too much to allow a meaningful reading Integrating Sound Level Meters should be used. These instruments summate noise energy on a relatively long-term basis and divide the value obtained by the elapsed time, thus, providing a direct L_{eq} reading.

When and how do you use L_{eq} and SEL ?

Let us look at some typical cases which illustrate when a clearer answer can be easily obtained by using an Integrating Sound Level Meter which provides data directly in the form of either an L_{eq} or an SEL.

1. L_{eq} measurements

Fluctuating machinery noise

Fig.4 shows a recording of the noise produced by a typewriter. Even with the "S" time-weighting, the fluctuations make it difficult to put a value on the noise level. It can be even more difficult if the machine has a complex working cycle (Fig.5). The reason for the measurement uncertainty is that the traditional sound level meter does not provide time constants which are of sufficient duration. However, this can be overcome by measuring the overall energy of the noise.

When measuring L_{eq} the choice of measurement duration depends on the type of noise. For relatively steady noises such as machinery noise the reading can be taken when the display of the instrument has stabilized. With cyclical noise, the measurement period should include an integer number of cycles so that an L_{eq} measurement effectively represents the true average SPL, having the same energy as the fluctuating sound.

Long-term noise exposure

It is often necessary to rate noise on a long-term basis. In industry, workers' exposure to noise during work is assessed to establish it's acceptability. In towns and dwellings,

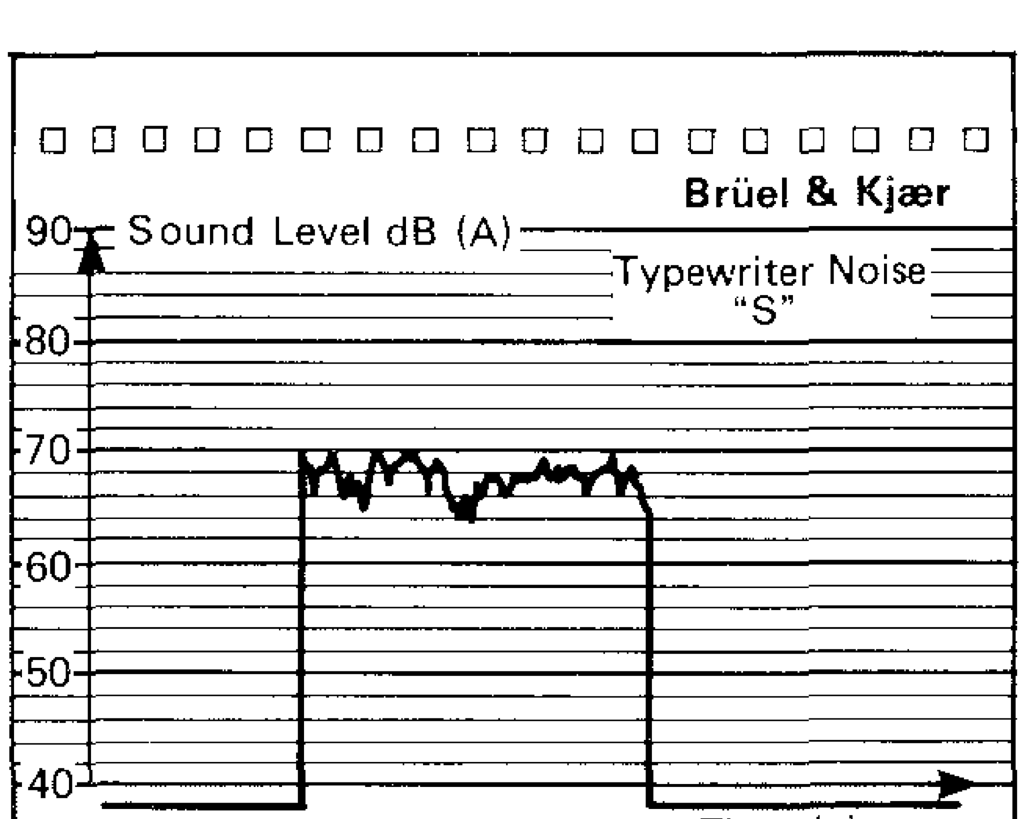

Fig.4. Typical recording of typewriter noise using the "S" time-weighting

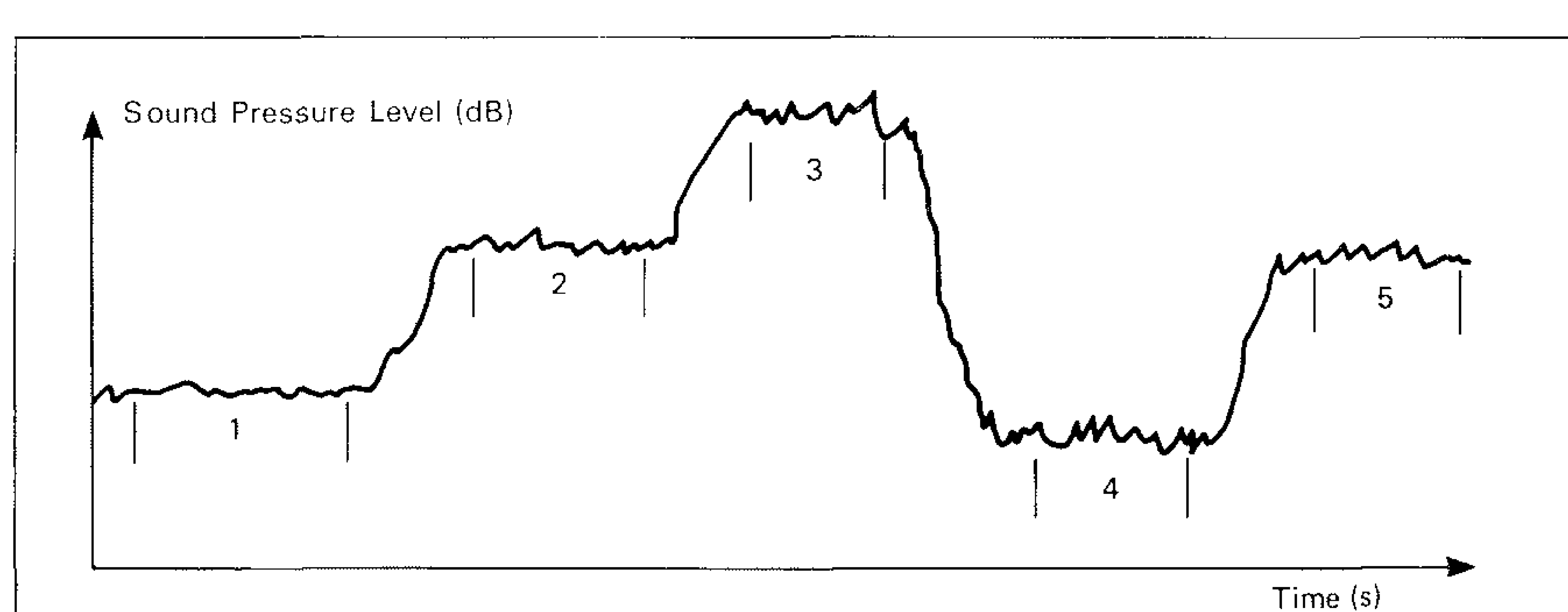

Fig.5. The noise produced by a machine with different cycles may vary considerably

environmental noise produced by traffic, industry, etc. is measured to estimate annoyance caused by noise and thereby the degree of community reaction to be expected. In both cases, noise may vary considerably over the exposure period. Recordings of a time-varying RMS (as shown in Figs.6 and 7) do not allow either direct comparison or simple rating of noise exposure. In such cases, the data analysis provided by traditional sound level meters is not sufficient.

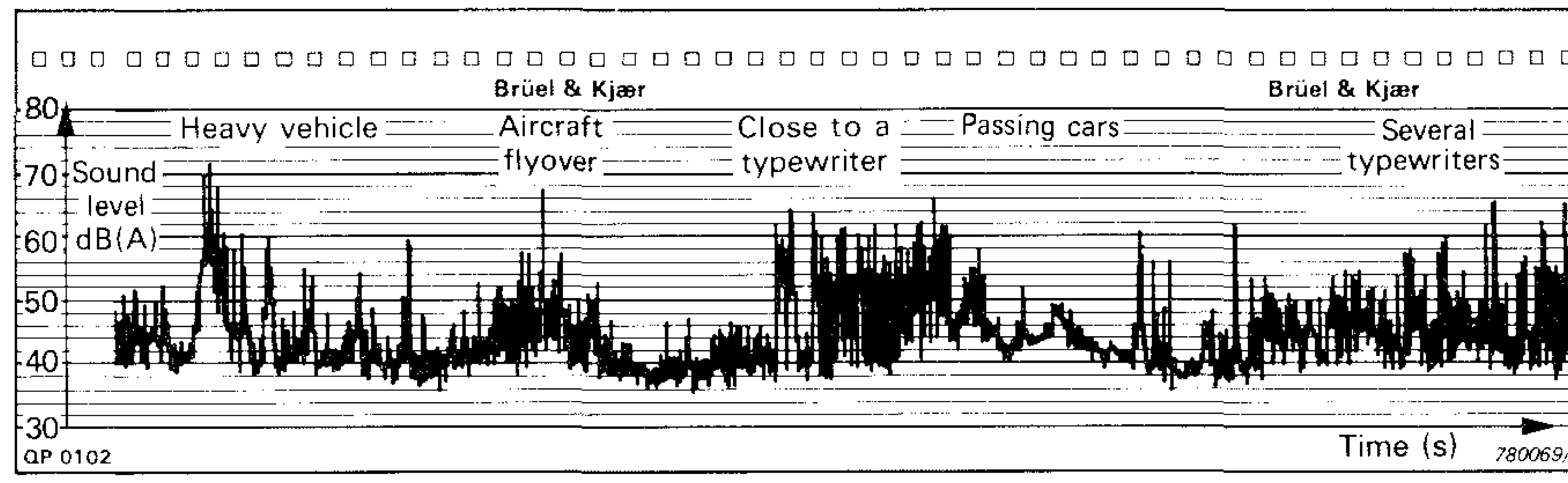

Fig.6. Typical recording of noise in an office

L_{eq} measurements for long-term exposure rating, require the selection of representative measurement periods. In the case of occupational noise exposure, this may be a whole working day, or alternatively parts of the day in which representative measurements of the entire working day can be made.

Similarly, community noise exposure can be assessed by measurement of L_{eq} over a whole day, or by taking "period" L_{eq} measurements of representative intervals within typical periods (e.g. quiet periods during daytime, rush hours, evening, night).

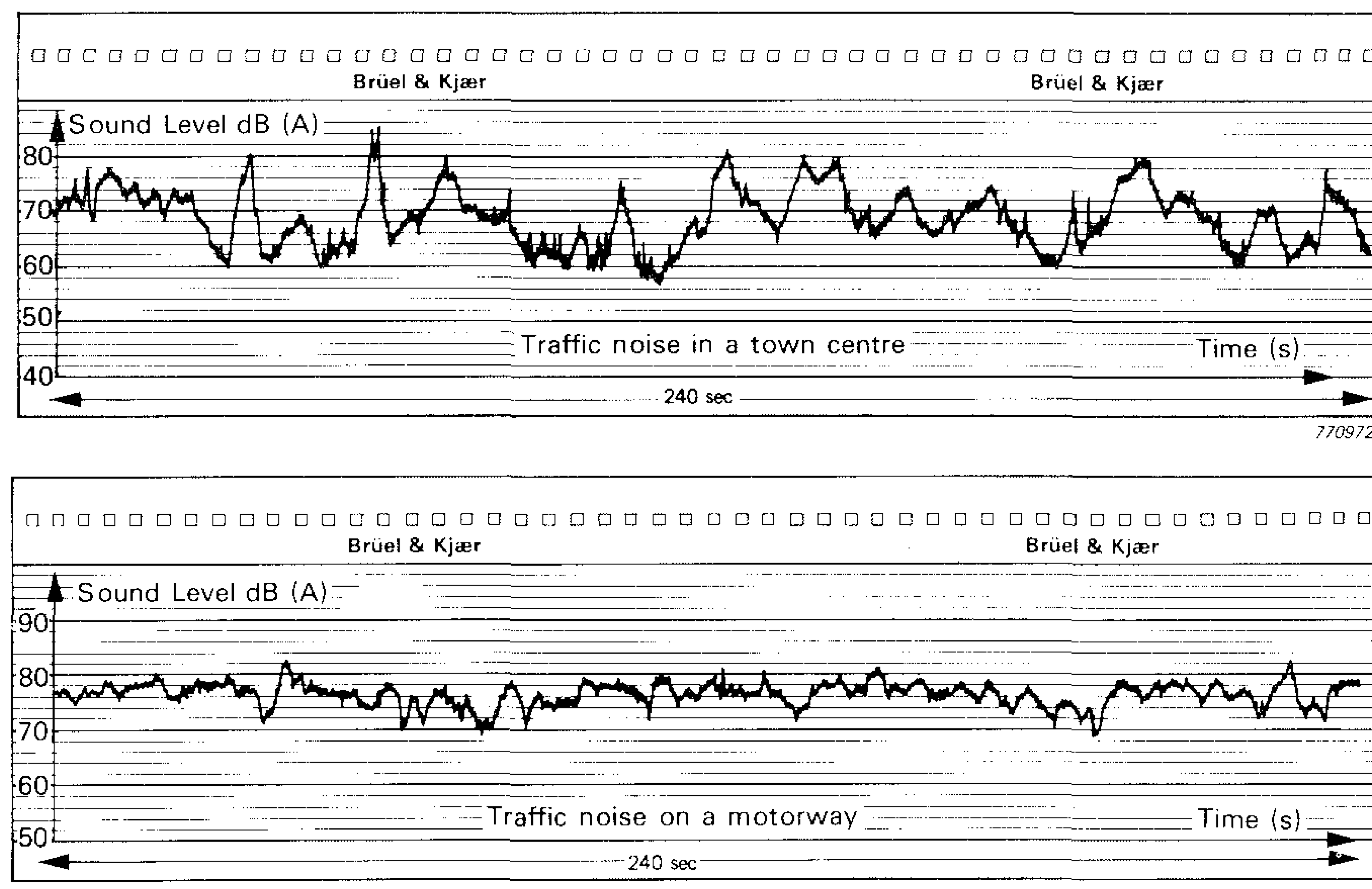

Fig.7. Typical recording of traffic noise a) in a busy street and b) close to a motorway

2. SEL measurements

Transient noise

As seen in the above examples, L_{eq} measurements give us very useful results in many situations. However, an L_{eq} measurement does not remove ambiguity in the case of transient noise, for example from an aircraft fly-over or a vehicle drive-by (Figs.8 & 9). These situations often result in wide variations from background noise to maximum level and if only the maximum level is reported, information on the duration of the noise (an important feature for rating annoyance) is lost. This also makes it difficult to compare between rapid and slow events, and to combine different events for noise prediction purposes.

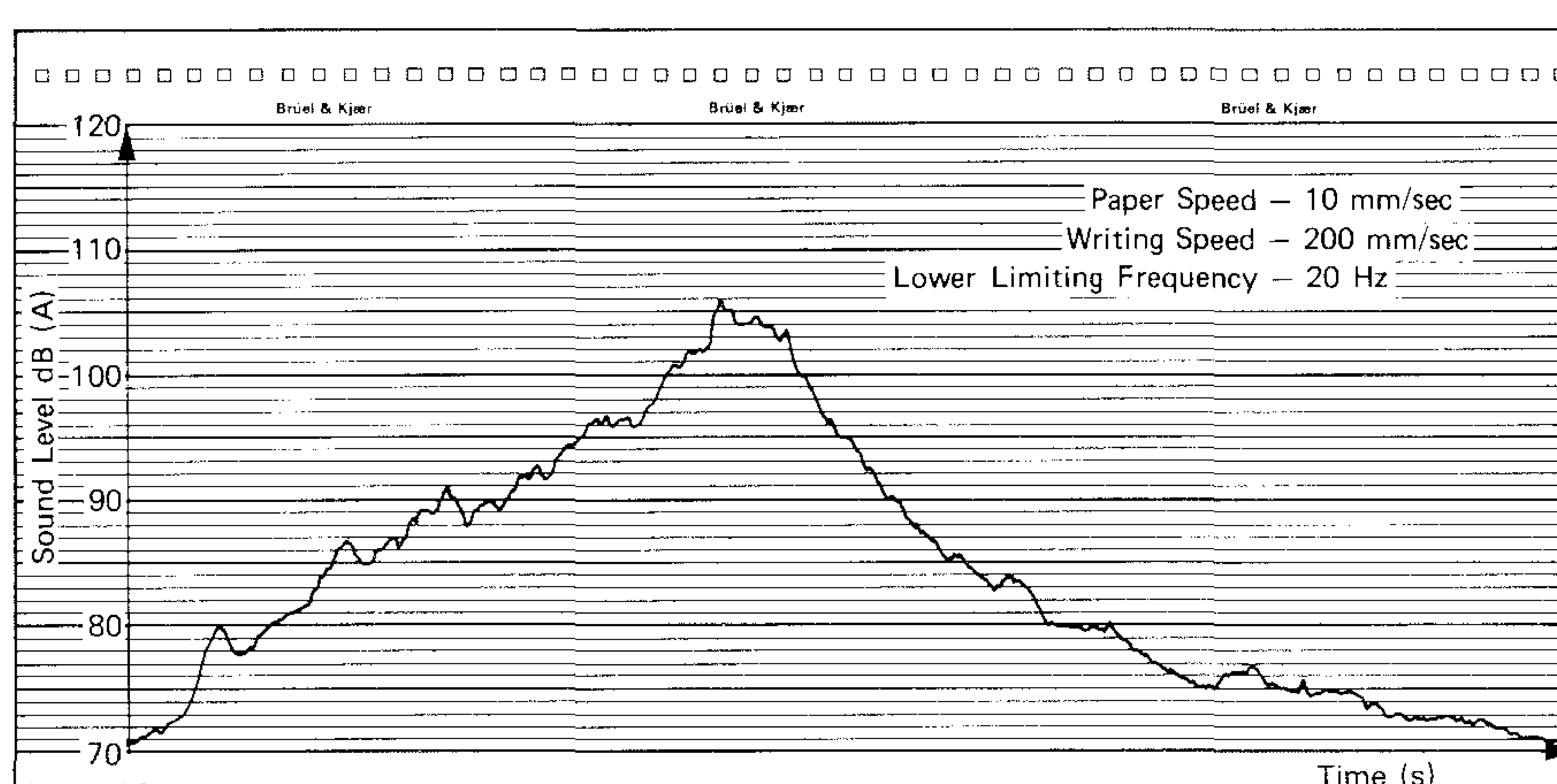

Fig.8. Typical recording of aircraft fly-over noise

Since L_{eq} is an energy average, only the highest levels (from the maximum to, say, 15 to 20 dB below it) contribute significantly to the total energy. Hence, if a measurement begins and ends in the background noise, the resulting L_{eq} will depend on the *measurement period*, even though the total energy is the same.

In such a case, use of an Sound Exposure Level (SEL) eliminates the influence of the measurement duration. Although the total sound energy is integrated over the measurement period — as with L_{eq} — instead of then averaging this over the measurement period, a reference duration of 1 s is used.

SEL is therefore numerically equivalent to the total sound energy, whereas L_{eq} is proportional to the average sound power.

SEL has two main applications. The first is direct comparison of transient noises. Fig.9 shows two drive-by noises recorded on the same time scale. Although the difference between the maximum levels is approximately 16 dB, the difference between the SEL values is only 12 dB, indicating that the low level event lasts longer. This example shows that measurement of only the maximum noise level is an insufficient description of a transient noise.

The second application of SEL is to calculate the corresponding L_{eq} for a given period using the individual SEL values for different events occurring within that period. For just one event occuring during the time interval T, the relationship between SEL and L_{eq} over this time interval T is:

$$L_{eq} = SEL - 10\log\frac{T}{T_0} \text{ with } T_0 = 1\,s$$

If there are several events with different individual SEL values, the exposure levels can be added on an energy basis as shown below:

$$L_{eq} = 10\log\sum_{i=1}^{n} 10^{\frac{SEL_i}{10}} - 10\log\frac{T}{T_0}$$

The SEL values may for example be those from different types of vehicles. They may also be from different types of machines performing cyclical operations provided that the number of cycles is known for the exposure period. For such cyclical noises, measurements of SEL should start and end in the quieter part of the cycle ensuring that the noise energy in a whole cycle is measured.

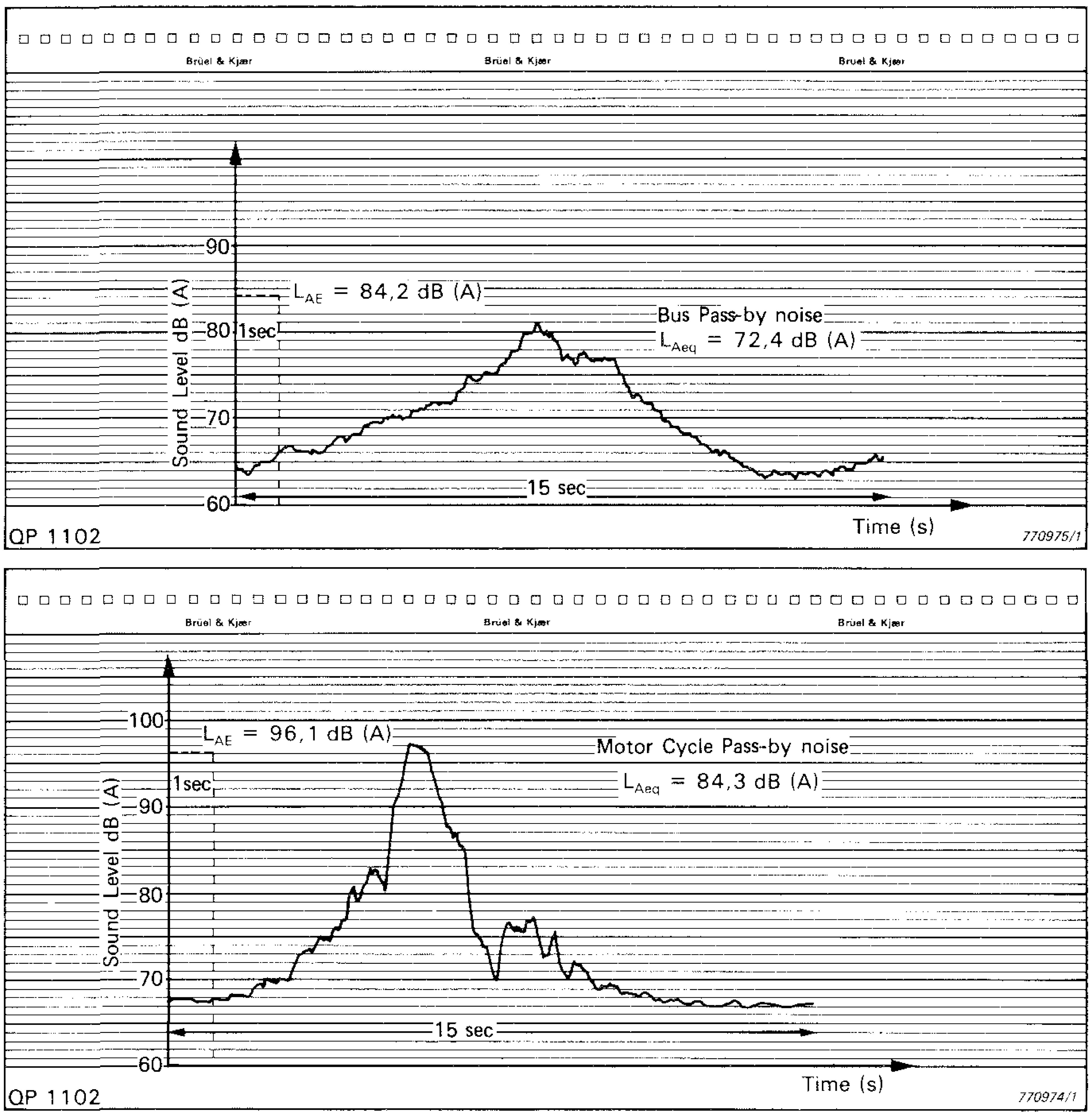

Fig.9. Comparison of transient noises

What is L_{eq} over 8 hours for a machine performing 400 operation cycles each with SEL = 105 dB?

$$L_{eq} = 10\log 400 \cdot 10^{\frac{105}{10}} - 10\log\frac{8 \times 3600}{1}$$

$$L_{eq} = 10\log 400 + 105 - 10\log 28800$$

$$L_{eq} = 26 + 105 - 44{,}6$$

$$\boxed{L_{eq} = 86{,}4\ dB}$$

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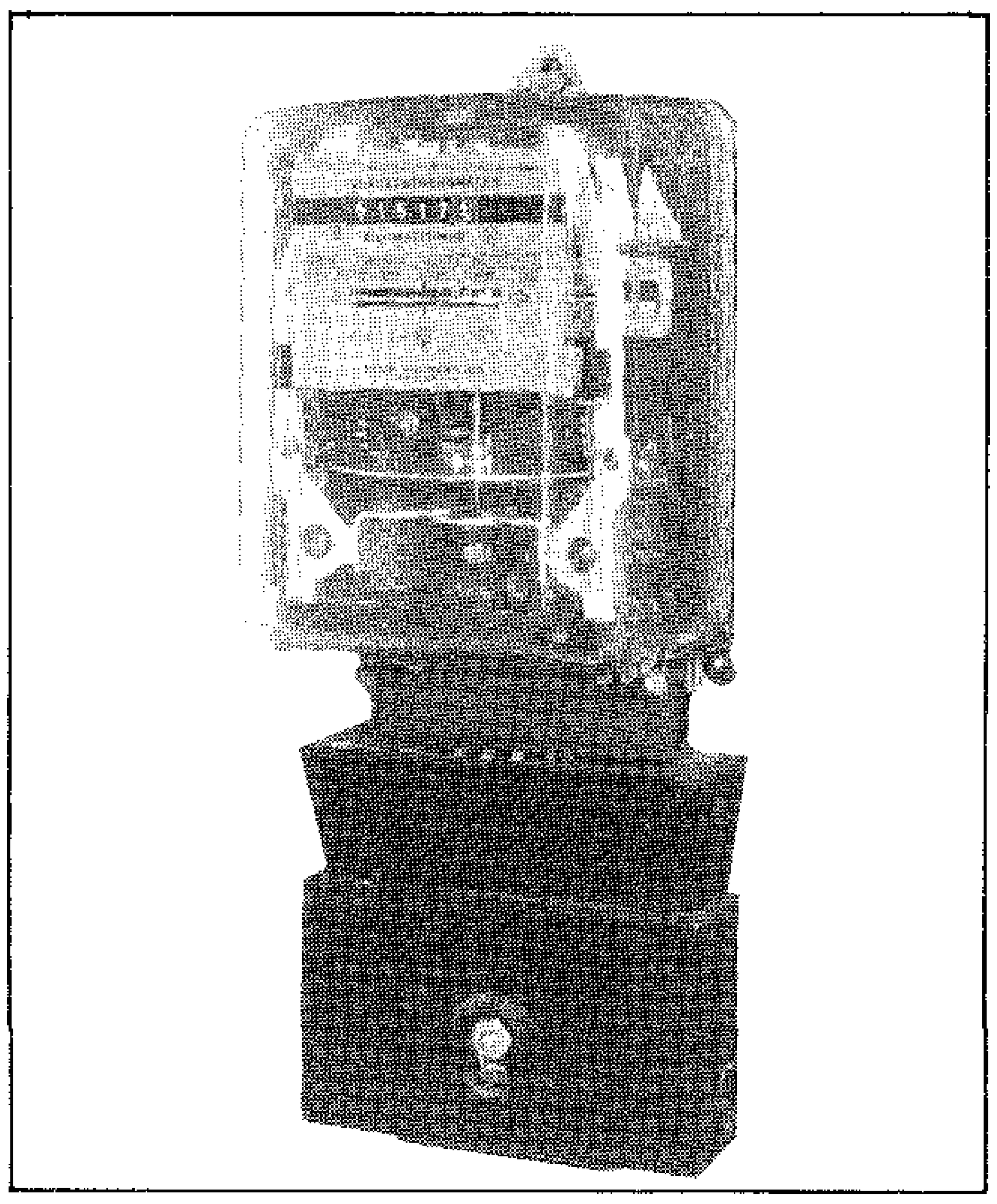
Fig.10. Example of L_{eq} derivation from SEL values

The Integrating Sound Level Meter

The integrating sound level meter consists basically of a microphone with it's preamplifier, an A-weighting filter and an integrator which summates the noise energy over the measurement period. The measured result may be expressed in two ways, depending on the type of noise; either as an Equivalent Continuous Sound Level (L_{eq}), or a Sound Exposure Level (SEL).

The operating principle of integrating sound level meters is quite similar to that of the electricity meter in our homes, which is in fact an integrating wattmeter. It does not provide a record of our instantaneous consumption; we just read it from time to time to know how much energy we have consumed since the last inspection. The bill does not depend on how the electricity was used, but on the total amount of energy consumed, which is numerically equivalent to SEL. If we divide the total energy by the corrersponding time period, we obtain the average power consumption, which corresponds to L_{eq}.



The B&K Family of Integrating Sound Level Meters

Integrating Sound Level Meters Types 2225 and 2226

These pocket-size sound level meters (Fig.11) conform to IEC 651 Type 2 (except for "Max. Hold" for 2225) and ANSI S.1.4-1983. Both meters display the A-weighted sound pressure level on a 40 dB column display and have a total measurement range from 25 to 140 dB(A). As well as the traditional "F" and "S" time constants, the 2225 provides a "Peak Hold" and the 2226 an "I" mode (a hold function is available on all modes on the 2226). Both meters have an integrating mode with a fixed measurement period of 1 minute, providing an A-weighted 60 s. L_{eq} (L_{Aeq}). During the integration process, the display keeps flashing until the averaging period is over. The resulting 60 s L_{eq} value is then held until the instrument is reset. If the DC output of the sound level meter is connected to a level recorder such as Type 2317, the sound level meter is automatically reset at the end of each integration period, enabling the recording of a series of consecutive 60 s L_{eq} values (Fig.12).

Type 2225 or 2226 may also be used to calculate the SEL of events which last for less than 1 minute. The instrument is reset at the beginning of the event and the final 60 s L_{eq} value can be converted to the corresponding SEL by addition of 10 log 60 (approximately 18 dB).

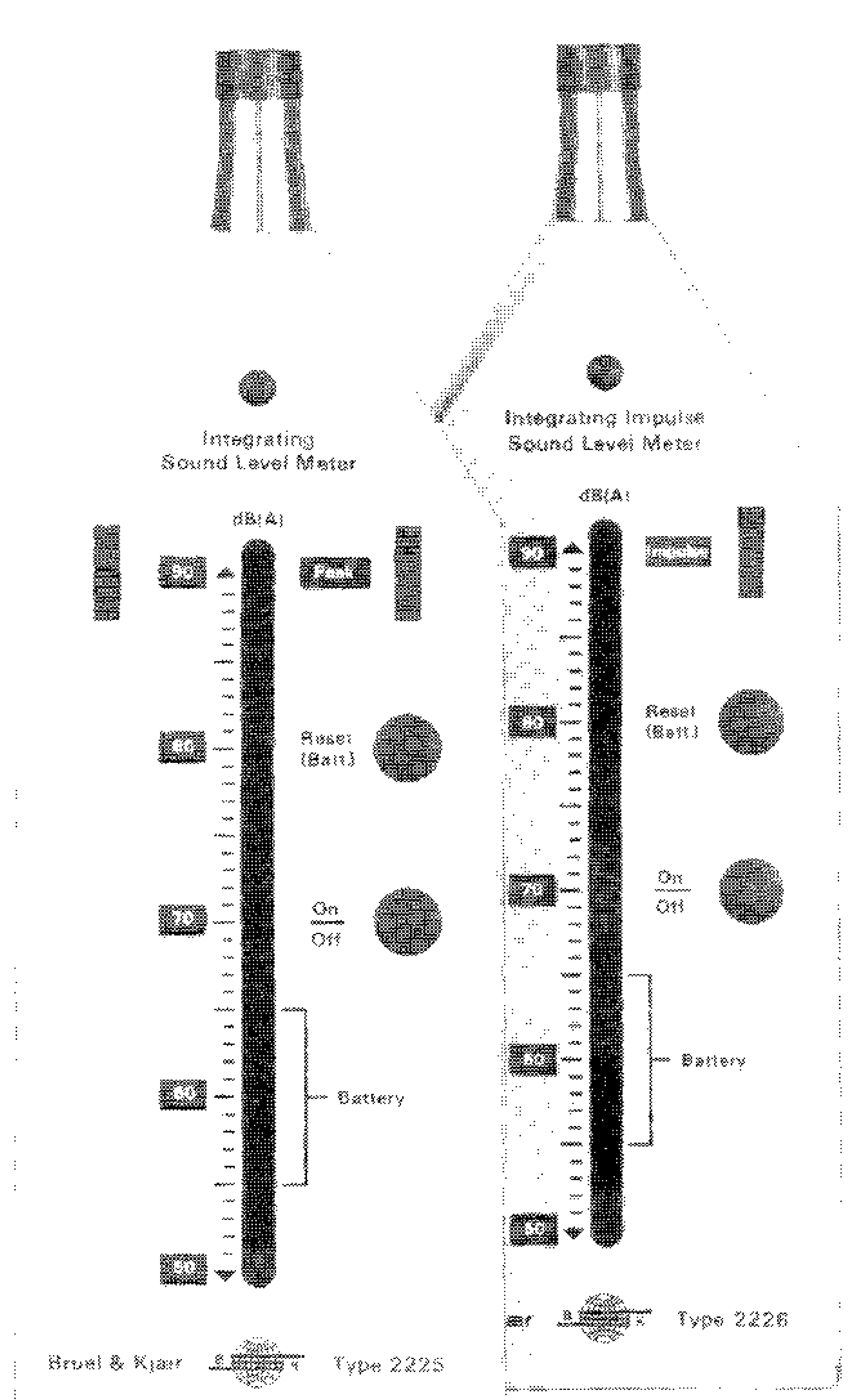


Fig.11. The Integrating Sound Level Meters Types 2225 and 2226

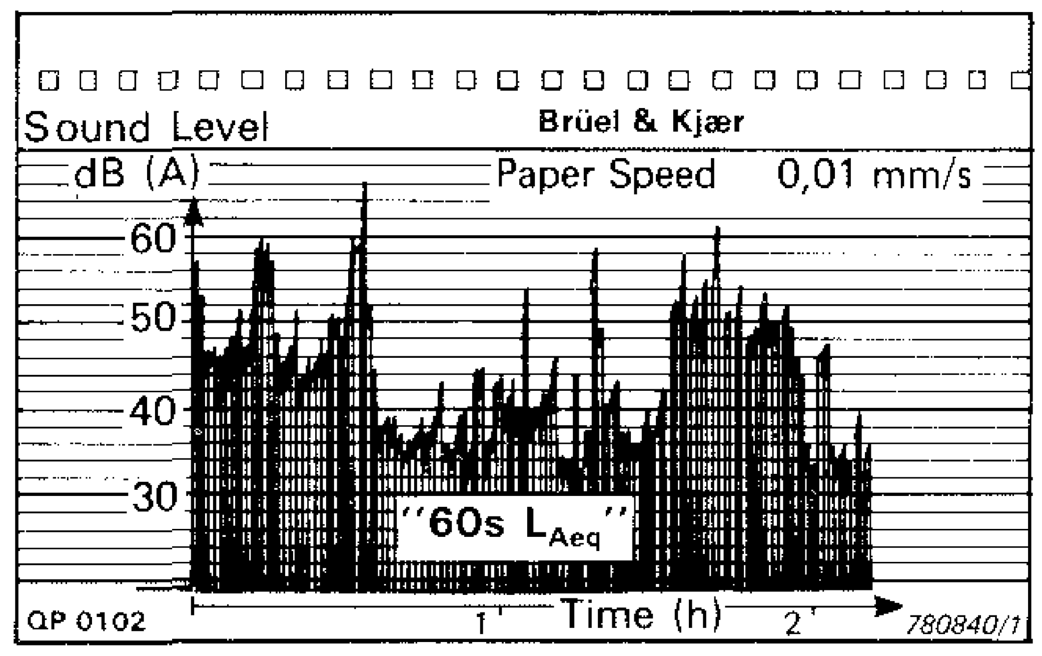


Fig.12. Example of 60 s L_{eq} recording over a 2 hour period

Precision Integrating Sound Level Meters Type 2221 and 2222

As light and slim as Types 2225 and 2226, the Precision Integrating Sound Level Meters Types 2221 and 2222 (Fig.13) conform to IEC 651, Type 1, and to the proposed IEC standard for integrating sound level meters Type 1P.

They have four basic measurement modes: an A-weighted L_{eq} (L_{Aeq}), A-weighted SEL (L_{AE}), Max. Hold "F" (2221) or "S" (2222), and Max. Hold "Peak". The three first functions are A-weighted, whilst the "Peak" value is measured with a flat frequency response. Four overlapping sensitivity ranges provide a measurement span from 25 dB to 145 dB for L_{eq} measurements.

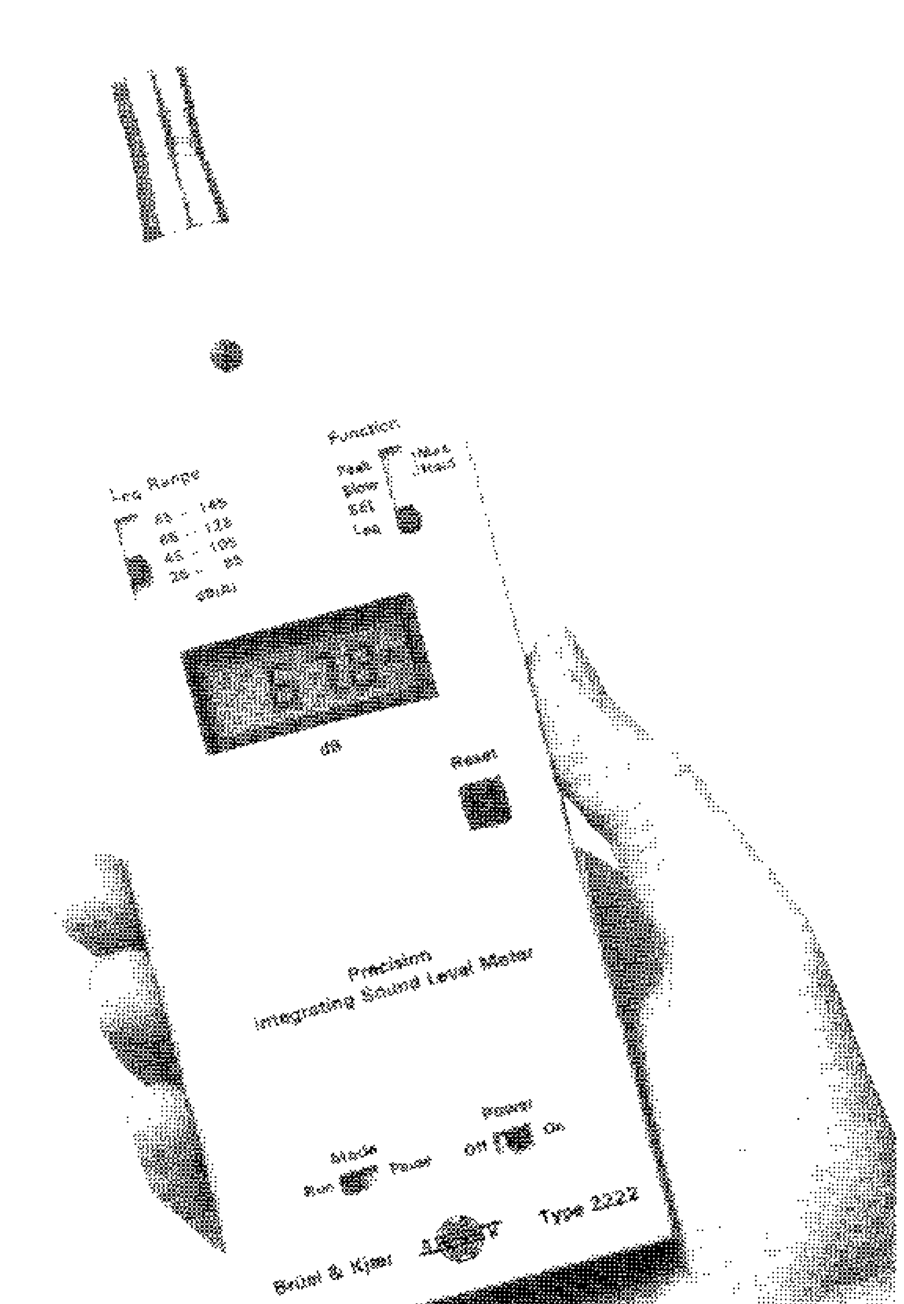


Fig.13. Precision Integrating Sound Level Meter Type 2222

A microprocessor ensures the calculation of the true L_{eq} or SEL values and it is possible to switch between the two calculations during the measurement. The results are presented on a large digital display with a resolution of 0,1 dB. The display also has symbols for indicating overload, under range, battery state, time exceeded (L_{eq} measurement) and A- or Linear weighting. Although the maximum measurement period for L_{eq} is 2,77 hours, the equivalent level for longer periods can be derived from the SEL value.

The instruments are automatically reset when changing the measurement range or the function selector (except between L_{eq} and SEL). A pause function allows the exclusion of unwanted events in L_{eq} and SEL measurements and makes it possible to use the instruments for spatial averaging in sound power measurements. The signal available at the AC output is either A or linear-weighted, depending on the function selected.

Precision Integrating Sound Level Meter Type 2230

Type 2230 (Fig.14) is a Type 1 precision instrument. Its comprehensive construction and versatility make it ideal for all kinds of sound level measurements. This includes octave and 1/3 octave frequency analysis when used with a snap-on filter set.

The Type 2230 has a measurement range from 24 to 130 dB (30 to 150 dB with supplied attenuator) and carries out five measurements in parallel: SPL, Max., Min., L_{eq} and SEL, all of which can be obtained for the same signal. A choice between 2 detector modes (RMS and Peak), 3 time weightings ("S", "F", "I"), 4 frequency weightings (A, C, Lin and All pass) is available for the measurements.

A partial (Max./Min.) reset, a total reset and a pause function increase the capabilities of the instrument. The linear free field frequency response (in accordance with IEC) can also be switched to a linear diffuse field frequency response to comply with ANSI requirements.

The measurements are displayed with a 0,1 dB resolution on a large 4

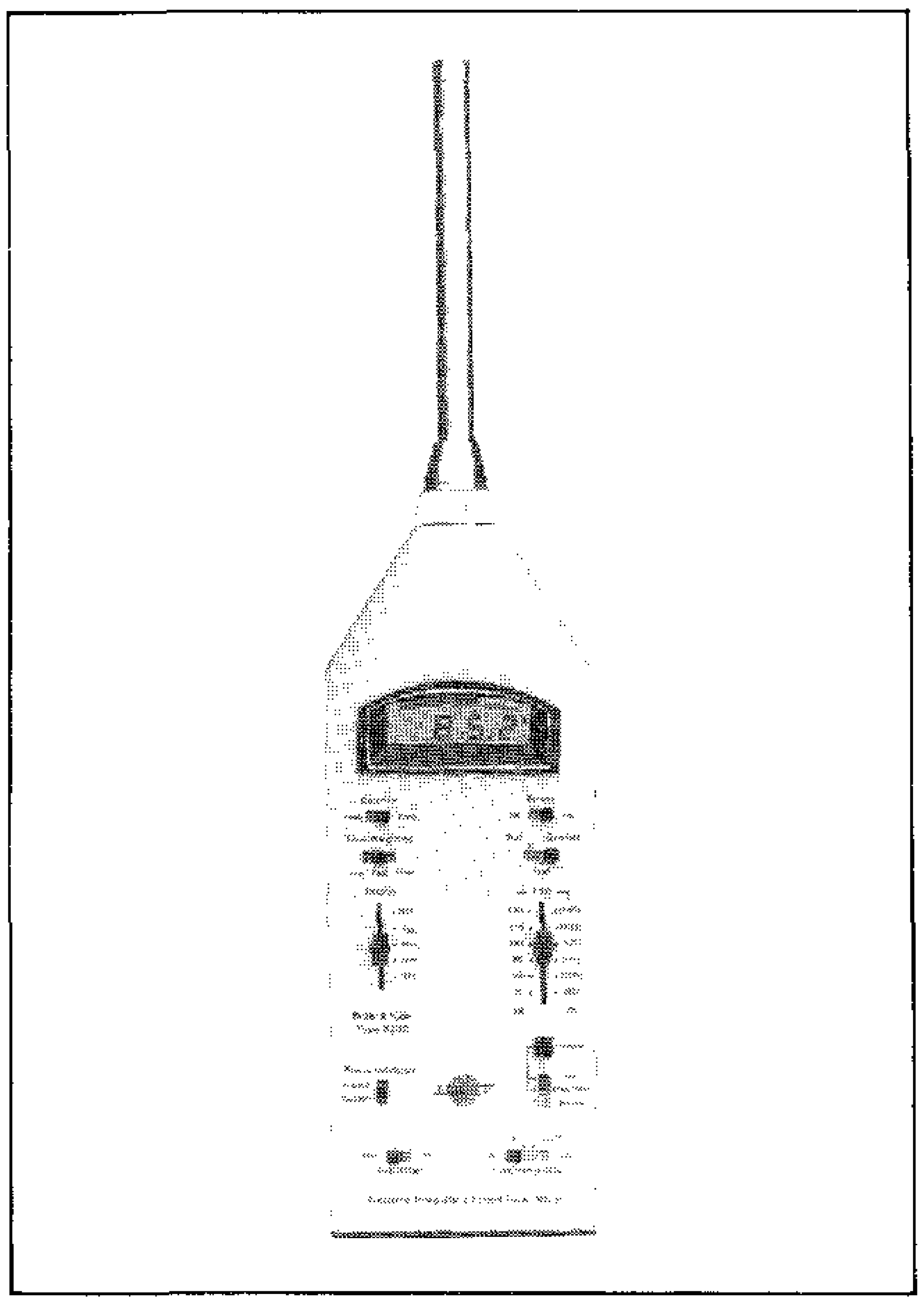


Fig.14. The Precision Integrating Sound Level Meter Type 2230

digit liquid crystal display. The SPL is continuously monitored on a quasi-analogue 60dB scale. Indication of overload, depleted batteries and illegal setting is also displayed.

AC and DC outputs allow tape or level recordings to be made and audio monitoring of the sound level with the selected frequency weighting.

Despite its Type 1 performance and the numerous functions included, the Type 2230 is only 25cm long and weighs less than 1kg. It can easily be held in one hand, even when the Filter Set is connected.

Types 2233 and 2234 are special versions of the 2230. Type 2233 has the same functions (except Min. measurement), but also incorporates facilities to measure "Taktmaximalpegel"*. Type 2234 has the same functions as 2230, but the SPL displayed is the instantaneous value sampled every second and not the maximum in the previous second.

Modular Precision Sound Level Meter Type 2231
The Type 2231 (Fig.15) is a truly versatile precision sound level meter. Application modules are used to adapt the capabilities of the 2231 to suit the requirements for a particular measurement. The pushkeys functions on the front panel of the 2231 are defined by the software package.

* an energy averaging technique specified in DIN 45645

This flexibility, together with provisions for connecting Filter Sets and hard-copy recorders, enable the 2231 to be used for a wide variety of noise measurements.

The 2231 fulfils IEC and ANSI Type 1 SLM requirements and also the proposed integrating SLM requirements. A unique parallel-detector allows display of both RMS and Peak values of the same signal. "A", "C", "Lin." (10Hz to 20kHz) and "All Pass" (2Hz to 70kHz) frequency weightings are available. The DC output allows recording of "module-defined" parameters. Five of the application modules are described below:

Integrating SLM Module BZ7100: Standard module delivered with the 2231. "F", "S" and "I" time responses and 4 frequency weightings. Measurement Parameters: Max. peak hold; Max. peak in 1s period; Sampled RMS in 1s; Max. RMS in 1s; Max. SPL hold; Min. SPL hold; L_{eq} (LIm with "I" response); SEL (IEL with "I" response). Special Functions: setting quasi-analogue scale to display peak levels; DC output giving L_{eq} vs. time histogram; data-inhibit using pause pushkey; digital readout facility.

Statistical Analysis Module BZ7101: "F" and "S" time responses and 4 frequency weightings. Measurement Parameters: as for BZ7100 plus L(99.0), L(90.0), L(50.0), L(10.0) and L(1.0). Also calculates L_N, Cumulative and Probability Distributions with 0,5dB resolution for any measurement period. Special functions: L_N for values of N in 0,1% steps; variable resolution for Cumulative and Level Distributions; data-inhibit facility.

"Taktmaximal"* Module BZ7102: Time and frequency weightings as for BZ7100. Provides the 2231 with special facilities for measuring "Taktmaximalpegel"*.

Short Term L_{eq} Module BZ 7106: Enables the 2231 to transfer data digitally at user selectable intervals (minimum 1s) with a choice of 64 possible formats to an external device such as a data-logger, microprocessor or printer. Time and frequency weightings as for BZ 7100. Simultaneous measurement at one second intervals of max. SPL, instantaneous SPL and Peak, and at user selectable intervals L_{eq}, SEL, min. SPL, max. SPL and max. Peak.

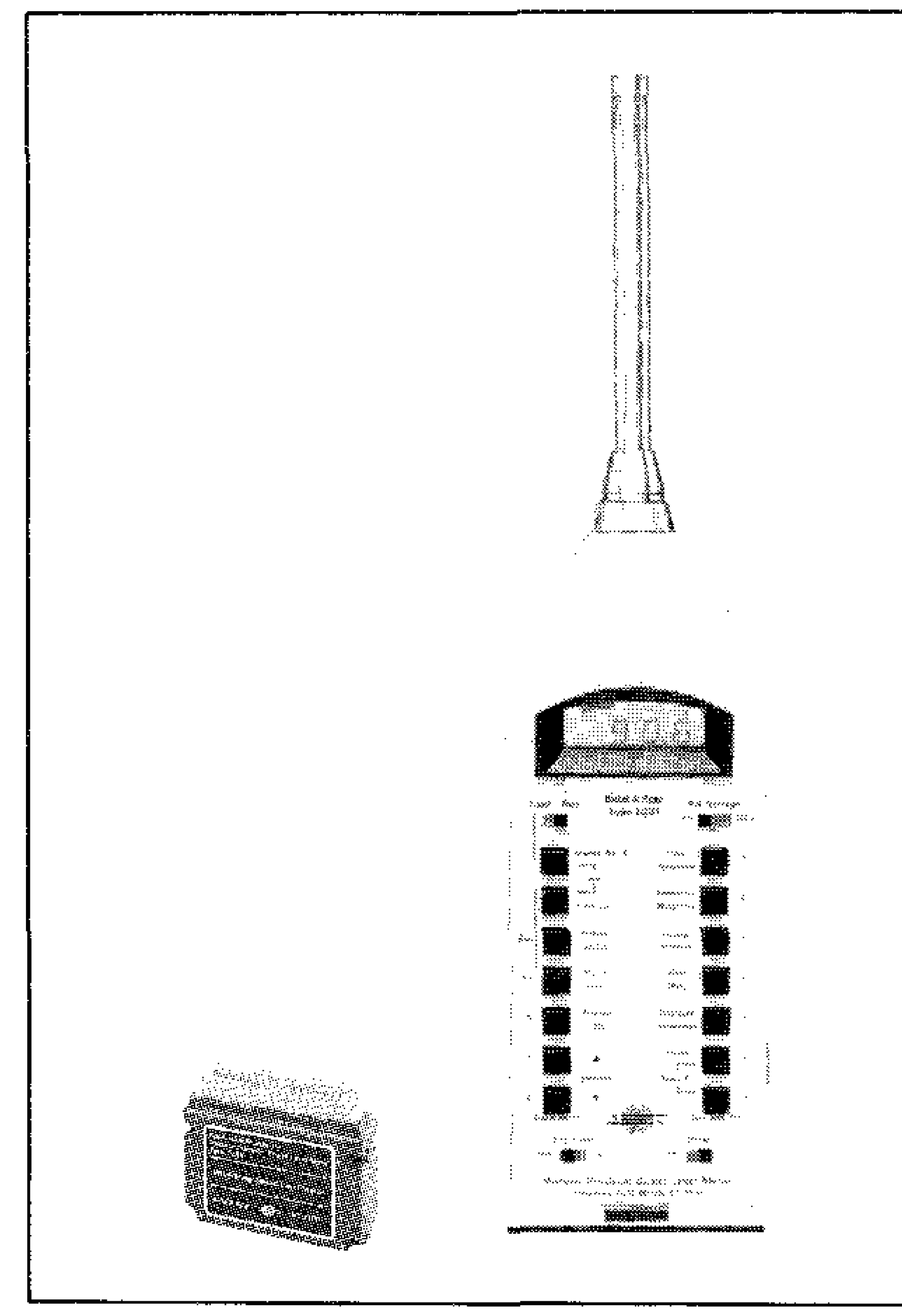


Fig.15. The Modular Precision Sound Level Meter Type 2231 and one of its application modules

Event Recording Module BZ 7107: Enables the 2231 to measure and record the principle parameters connected with a noise event. An event is taken to exist when the the ambient noise level exceeds a predefined threshold level for more than a predefined time. The principle parameters, i.e. L_{eq}, SEL, max. and min. SPL, duration and threshold level together with other data may be transferred digitally to a data-logger or printer. Time and frequency weightings as for BZ 7100.

Graphic Documentation Printer Type 2318
The 2318 is small, lightweight, battery operated and can be used to make printed and graphic recordings of measurements when connected to any instrument with a B & K serial interface and nearly all other RS 232C and RS 232C based systems. It is particularly well suited for use with the Modular Precision Sound Level Meter Type 2231 and all of its application modules for documenting measurements and other allied data in clear and readable formats.

Noise Level Analyzer Type 4427

The Noise Level Analyzer Type 4427 (Fig.16) offers a wide range of features for accurate on-site analysis of community, airport and traffic noise or any other acoustical event requiring accurate measurements and extensive statistical analysis of collected data.

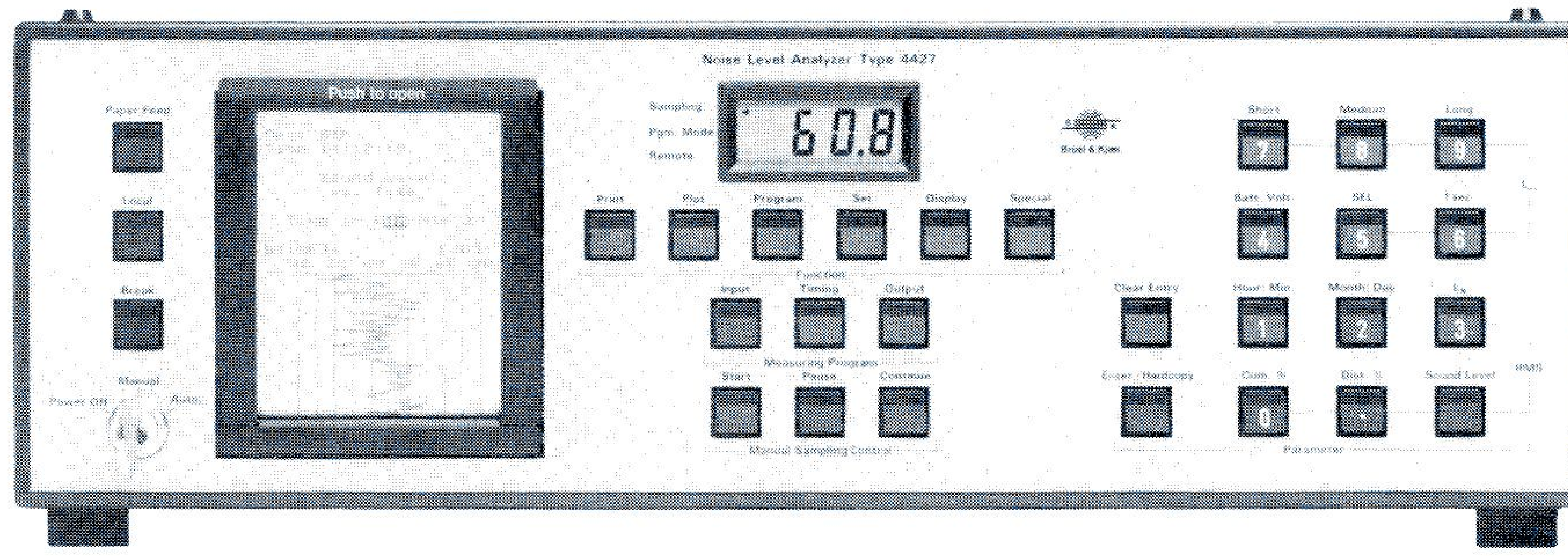


Fig.16. The Noise Level Analyzer Type 4427

The Type 4427 Noise Level Analyzer represents an innovative design concept, complying with the relevant sections of IEC 651 and ANSI S1,4 (1983) Sound Level Meter Specification Type 0. It permits fast, user-friendly dialogue selection of instrument settings and provides data collection, storage, level analysis and print-out in one compact unit. Time-saving menu-driven procedures allow easy interactive instrument set-up, reducing the need for instruction manuals. Sophisticated dataprocessing facilities incorporated in the 4427 allow comprehensive front-end processing of signal data.

The detector circuit provides F, S, I and Peak plus 3 s and 5 s Takt-Maximalpegel responses in parallel with True Linear 1 s L_{eq} responses. A built-in IEC/IEEE or optional RS-232 C communication interface port provides for remote set-up and control with the same ease as operating the frontpanel keypad.

The 110 dB dynamic range of the detector ensures that no information from the input signal is lost, and a wide range of levels can be measured with extreme accuracy. A built-in graphic printer/plotter allows fully annotated permanent records to be made on metallised paper.

Powered by batteries, the Noise Level Analyzer offers this unique combination of features in a compact unit ideally suited for field operation.

Noise Dose Meters Types 4428 and 4434

The Noise Dose Meter Types 4428 and 4434 (Fig.17) are integrating sound level meters which have been especially designed to monitor the noise exposure of workers during a working day. The digital display indicates the Noise Dose, which gives the noise exposure as a percentage of the maximum allowable exposure (which, in most countries, corresponds to an L_{Aeq} of either 85 or 90 dB(A) for an 8 hour working day). Conversion tables enable derivation of L_{Aeq} from the noise dose reading and the measurement duration. An accelerated mode is provided for calibration and short-term surveys. A peak detector is included to indicate whether the maximum of 140 dB(A) peak has been exceeded during the measurements.

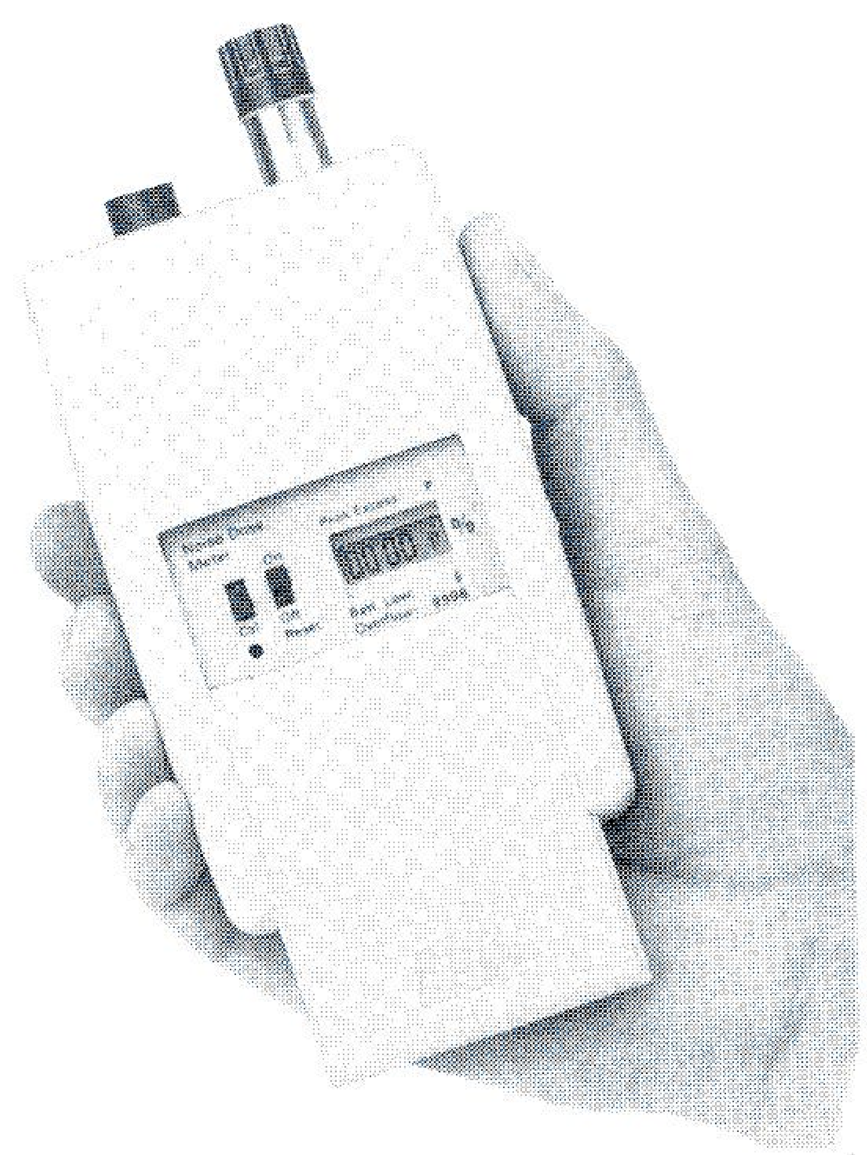


Fig.17. The Noise Dose Meter Type 4428

Type 4428 integrates the noise energy according to the definition of L_{Aeq}, as required by ISO 1999 and the legislation of different countries. This means in practice that, for a given noise dose, the exposure duration should be halved if the sound pressure level increases by 3 dB. A different trading relationship between sound level and exposure duration is specified by the American OSHA, whereby the exposure duration is halved for a 5 dB increase. Type 4434 is designed to satisfy the OSHA requirements.

Summary

Integrating sound level meters can be used to solve a number of noise measurement problems which would be extremely difficult to handle with traditional sound level meters. Much noise legislation is based on L_{eq} measurements, both for industrial noise exposure in the workplace and noise annoyance in communities. Several international standards also recommend L_{eq} and SEL as basic noise descriptions, for example:

ISO 1996: "Assessment of noise with respect to community response"

ISO 1999: "Assessment of occupational noise exposure for hearing conservation purposes"

ISO 3891: "Description of aircraft noise heard on the ground"

The wide range of B & K Integrating Sound Level Meters enables selection of the instrument which best meets the specific requirements of a given noise measurement situation.

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