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BRÜEL & KJÆR application notes

A solid foundation for building acoustic measurements

...a review of the Building Acoustics Analyzer Type 4417
reprinted from Noise & Vibration Control, November 1981

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Introduction

In recent years, legislation has been introduced in most of the industrialised countries aimed at protecting the individual from unacceptably high, noise levels inside buildings such as dwellings, schools and hospitals. Guide lines have been established giving the maximum acceptable limits of:

1. Service noise levels
2. Reverberation times in stairwells, gymnasia, auditoria, etc.
3. Airborne and structure borne insulation

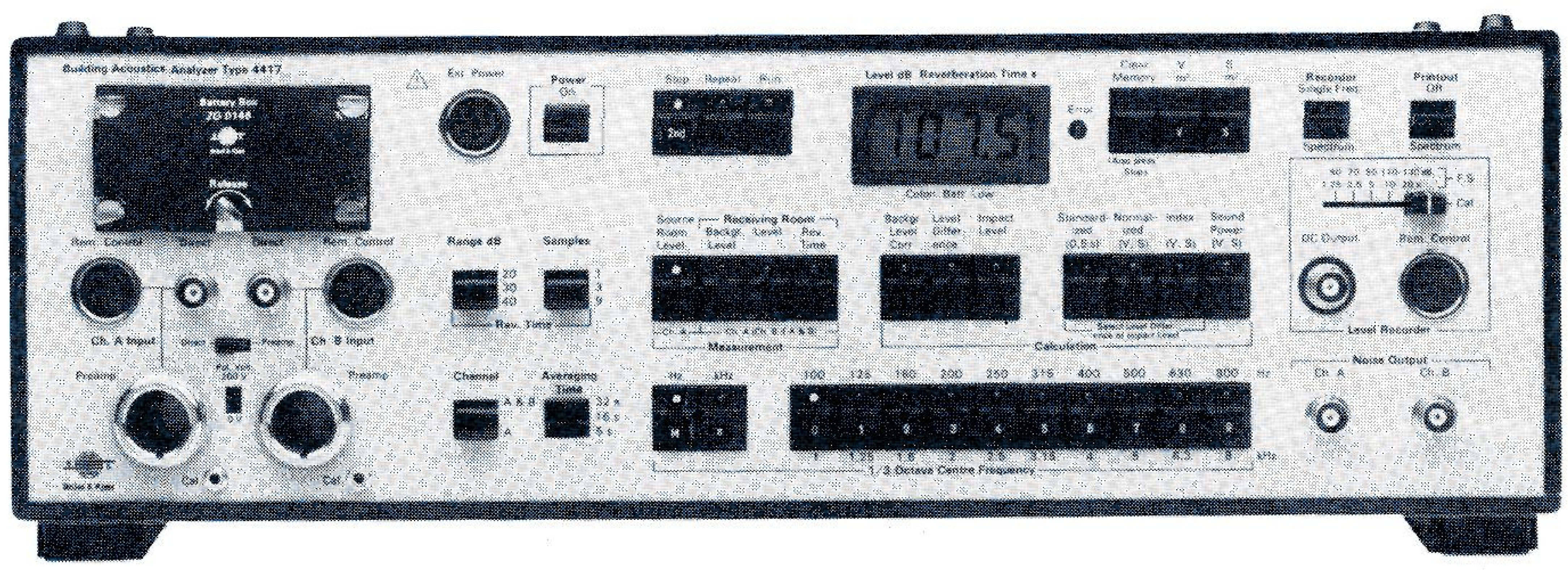

Fig. 1. The Building Acoustics Analyzer Type 4417

Measurement of these quantities according to standard procedures is time-consuming and although legislation may exist it might not be carried out to the letter. In many countries it is stipulated that every new dwelling should have its acoustic qualities measured and rated. However due to the enormity of this task, the complicated measurement procedures and the lack of suitable instrumentation, concessions are often granted allowing measurements to be made on "typical" dwellings in newly completed housing estates. This unsatisfactory state of affairs means that the vast majority of new dwellings are never investigated and many dwellings with poor acoustic insulation can be labelled as acceptable on the strength of the results from the "typical" dwelling.

There is, therefore, a need for instrumentation which can speed up routine measurements so that the acoustic quality of each and every new dwelling can be assessed before the occupants move in. The Building Acoustics Analyzer Type 4417 enables such routine measurements to be programmed and performed completely automatically in a minimum of time. To measure, for example, the normalised level difference spectrogram from 100 Hz to 8 kHz, between two dwellings, including measurements of reverberation time, background noise and to print out the results, takes typically about 9 minutes, depending on the standards being followed.

Building Acoustics Analyzer Type 4417

The Brüel & Kjær Building Acoustics Analyzer Type 4417 has been designed for the automatic measurement and subsequent calculation of the common quantities of interest in building acoustics, and for precision sound power measurements according to ISO Standards and Recommendations. The 4417 is primarily intended for the control of sound insulation in new buildings but can also be used for noise control, for investigations of building materials, auditoria and concert halls.

Quantities such as reverberation time, impact and airborne insulation, sound power, normalised and standardised levels, are determined in 20 third octave bands covering the frequency range 100 Hz to 8 kHz (centre frequency). The results can be presented digitally on the 4417's display, graphically via a Level Recorder Type 2306, printed via an Alphanumeric Printer Type 2312 or stored on a Digital Cassette Recorder Type 7400.

The 4417 is a portable (weight 15 lb; 7 kg), battery-powered instrument suitable both for on site measurements and for permanent laboratory arrangements. All the controls of the 4417, access to the battery box and all inputs and outputs (except the digital output) are on the front panel which as seen in Fig. 1 resembles that of a pocket calculator. Most functions are push-button controlled and most of the push-buttons have a second function.

The 4417 contains a random noise generator and is capable of producing third octave band limited random noise so that with a microphone and a loudspeaker system (or other sound source or even a vibration exciter) the 4417 constitutes a complete measurement and computational system. When both the two input channels and the two output channels are employed, a completely automatic system for measuring insulation and reverberation times is obtained. The 4417 can retain in its memory measurement data for 3 level-spectra and 1 reverberation-time spectrum (see Fig.2) even though the instrument might be switched off and on again. From these data and the entered values of the room's volume and the room's (or wall's) surface area, the 4417 can calculate any or all of 9 important spectra (see Fig.3).

Are ISO Building Acoustics Standards Accepted?

The ISO building acoustics standards e.g. ISO 140 parts 1 to 8 and ISO R 717, are not universally accepted *verbatim.* In many countries such as Austria, France, Japan, Netherlands, West Germany, U.S.A, differences exist between the national and international (ISO) standards on the methods and terminology employed in the measurement of sound insulation. The 4417 with its variable averaging times, decay ranges and frequency ranges satisfies most needs. Furthermore as the 4417 is a microcomputer based instrument, it can be reprogrammed at the B & K factory to fulfil a particular standard or to incorporate eventual revisions of existing standards.

Operation of the 4417

To operate the 4417, a microphone and a loudspeaker (or other sound source) must be chosen. If two sound sources are available then both output channels of the 4417 can be employed and for a chosen measurement the 4417 automatically selects the correct combination of input and output channel.

For impact sound insulation the standard Tapping Machine Type 3204 should be used. For noise reduction investigations, the source may already be present in the building in the form of a noisy machine.

Spatial and Temporal Averaging

During any measurement, one must ensure an adequate spatial average of the sound pressure level in the source and/or the receiving room. There are 3 main methods:

1. Single microphone moved from position to position
2. Microphone attached to a rotating boom

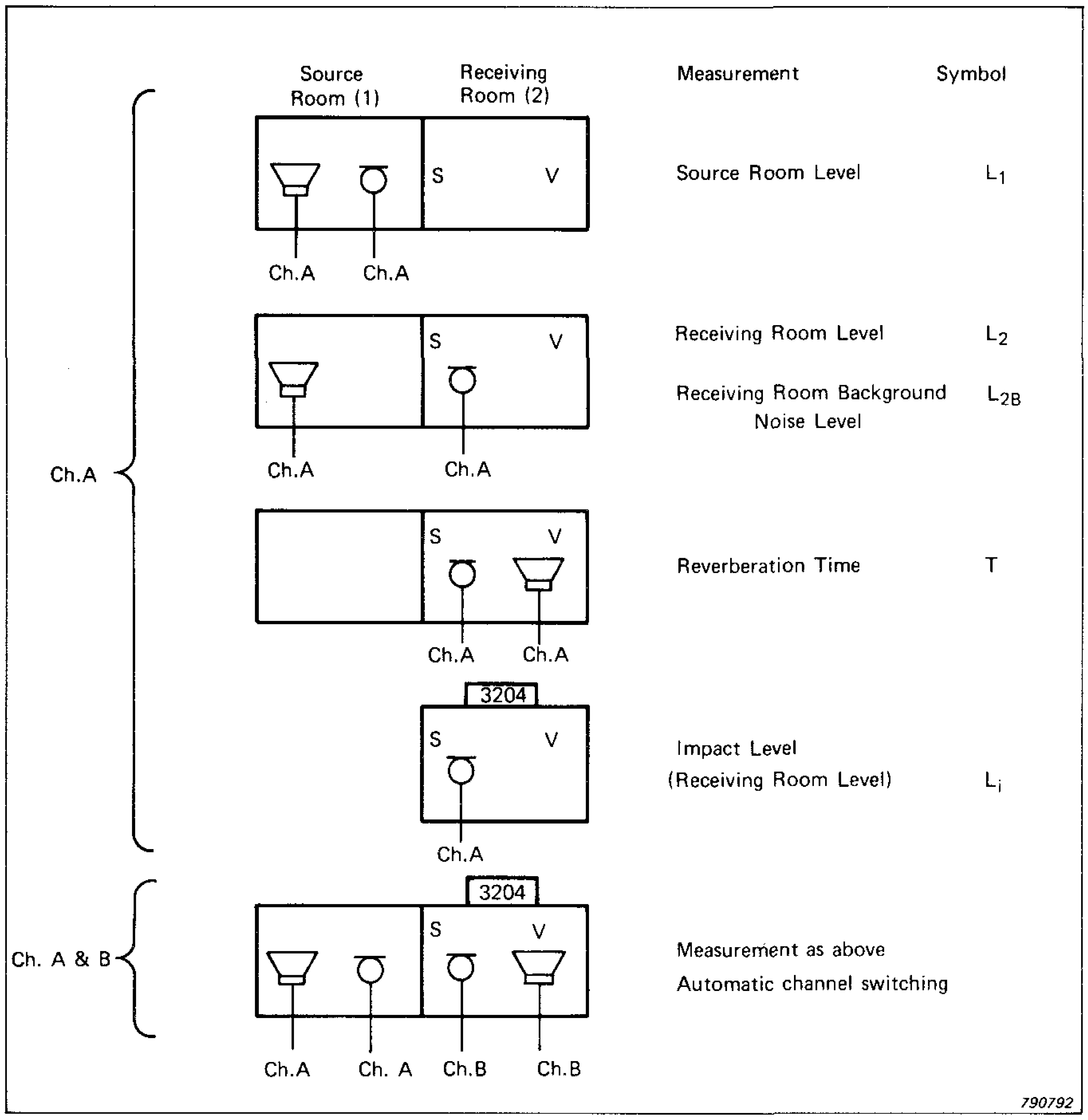

Fig. 2. Measurement capabilities of 4417. For impact measurements the standard Tapping Machine Type 3204 is employed

Calculation	Equation	
Level Difference	$D = L_1 - L_2$	
–Standardized	$D_{nT} = D + 10 \log_{10}\left(\frac{T}{0,5}\right)$	(ISO 140)
–Normalized	$R = D + 10 \log_{10}\left(\frac{6,13\ S\ T}{V}\right)$	(ISO 140)
–Index	I_a = Insulation Index	(ISO R 717)
Impact Level	$L_i = L_2$	
–Standardized	$L_{nT} = L_i - 10 \log_{10}\left(\frac{T}{0,5}\right)$	(ISO 140)
–Normalized	$L_n = L_i - 10 \log_{10}\left(\frac{61,3\ T}{V}\right)$	(ISO 140)
–Index	I_i = Impact Index	(ISO R 717)
Sound Power	$L_w = L_2 + 10 \log_{10}\left(\frac{V + \frac{43\ S}{f}}{T}\right) - 14$	(ISO 3741 & 3742 Method 1)

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Fig. 3. Calculation capabilites of the 4417

3. Array of microphones and a multiplexer

The method chosen will depend upon the standard being followed and the degree of automation required.

The 4417 controls both the spatial and temporal averaging during both level and reverberation measurements by controlling the operation of the boom or of the multiplexer. For level measurements there is a choice of 3 averaging times: 5 s, 16 s or 32 s.

For reverberation measurements either 1, 3 or 9 samples can be chosen, from which an arithmetic average of the reverberation time is calculated.

Spectrum Averaging

The 4417 can average up to 15 spectra for each measured quantity. For the level measurements this averaging is on an energy basis and for the reverberation spectra, a simple arithmetic averaging. The number of spectra averaged can be shown in the display. Levels and reverberation times can be entered into the 4417 manually so that new data can be averaged with, for example, previous measurements.

Selection of Measurement

Four measurement procedures are available on the 4417:

1. Source Room Level
2. Receiving Room Background Noise Level
3. Receiving Room Level
4. Receiving Room Reverberation Time

Any combination of these measurements can be programmed to be performed automatically with the results of the measurements printed out via the Alphanumeric Printer Type 2312. Measurements 1) to 3) involve the measurement of the steady sound pressure level in the room of interest. The reverberation measurement, 4), is based on the monitoring of the decay in sound pressure from the steady state level.

Reverberation Measurement

The 4417 does not record the decay in sound pressure in any fashion but directly measures the decay time between two chosen levels. The upper level is fixed at −5 dB and the lower level may be chosen to be −25 dB, −35dB or −45 dB. The time required for the sound pressure level to decay between these two levels is taken as the summation of all the intervals during which the level actually lies between these two levels. The 4417 then calculates the reverberation time to yield directly a result in seconds.

Noise Generator and Output Filters

When a measurement is started, the noise generator within the 4417 emits a wide band pink noise which passes through a series of 20 third octave filters covering the frequency range 100 Hz to 8 kHz. These filters comply with IEC 225-1966, DIN 45 652 and ANSI S1.11-1966. The third octave limited random noise is then time gated to produce a signal burst. For level measurements this burst has a duration corresponding to the chosen averaging time (i.e. either 5 or 16 or 32 seconds). For reverberation time measurements the burst is of approximately 8 seconds duration at 100 Hz and less at higher frequencies to reduce the measurement time.

Frequency Sweeping

The 4417 performs the selected measurements as it sweeps through the third octave frequency bands up to 8 kHz. Any one frequency band can be chosen as the initial band. If desired, the sweep can be terminated after the 3,15 kHz band, the frequency range 100 Hz to 3,15 kHz being the most widely used in building acoustics. Measurements can also be made at a single frequency band e.g. when the 4417 indicates that an error has occurred and the measurement at that particular frequency should be repeated.

Detector

For the first couple of seconds of each measurement the 4417 "listens" to the noise and optimises the gain of the input amplifiers to the expected noise level. A clever feature of the 4417 is that it is also programmed to give error codes if the expected level is not measured during the chosen averaging time (e.g. a sudden increase in background noise due to a passing vehicle). For reverberation measurements the detector determines the sound pressure level from the root mean square (rms) value of the signal. For level measurements, it is the equivalent continuous sound level, L_{eq}, which is measured i.e. an integration on an energy basis of the instantaneous acoustic pressure over the selected averaging time (i.e. 5 s, 16 s or 32 s). The measured spectra are then stored within the 4417 ready for display or for use in the calculation of one or more of the quantities listed in Fig.3.

Calculation

In the list of the calculation capabilites of the 4417 (Fig.3), the term "Standardised" in a name means that the quantity has been corrected for the reverberation time in the receiving room with respect to a standard reverberation time of 0,5 s. The term "Normalised" means that a correction has been made to account for the receiving room's absorption. Apart from the Standardised Level Difference and the Standardised Impact Level, the 4417 needs to be provided with a value for the volume, V, of the receiving room and a value for the surface area, S, (either of the building element under test or of the total surface area in the receiving room) in order to perform the calculations. V and S values are entered into the memory by means of the frequency-band push-buttons, which have a second function as keys for the digits 0, 1, 2, ... up to 9. By push-button selection, any of the quantities in Fig.3 can now be calculated, displayed and stored in the memory to await recall or output.

Other features

A number of "extras" have been programmed into the 4417 such as error code detection and numerous self test routines. Errors in the measurement or the calculation are coded and displayed by the 4417 and are also indicated in the printer and level recorder outputs. Manually entered data are tabbed with a question mark to indicate that these data were not, in fact, measured.

Some measurement results

Fig.4 shows some measurement results as read out via the Level Recorder Type 2306. The upper spectrogram shows the high level of background noise which was present in a large hall of a power plant where reverberation measurements had to be made. The middle spectrogram shows error codes at the 100 Hz, 125 Hz and 200 Hz third-octave bands indicating that background noise was too high for reverberation measurements to be performed over a decay range of 20 dB.

The lower spectrogram shows the normalised level differences and their calculated sound insulation indices as measured across two party walls in a newly constructed block of flats. The measurements on one wall were expected to be made whereas no measurements were expected on the other wall. The difference in the quality of the workmanship produced by a forewarning of control measurements is evident. Fig.5

shows a typical arrangement for *in situ* measurements.

Good sound insulation depends on careful construction

The Danish Institute for Building Research have concluded that control measurements of sound insulation in raw, new buildings can improve the sound insulation of the finished building by enabling "leaks" such as missing mortar between brickwork and joints, to be found and repaired at an early stage. Published results (reference "Lydisolation i betonbyggeri", Statens Byggeforskningsinstitute Report 101, 1977, Postbox 119, 2970 Hørsholm, Denmark) show that in most buildings it is possible to obtain improvements in the insulation index of from 1 dB to 3 dB and in some cases as much as 5 dB

Conclusions

Building acoustic standards have an important characteristic in common - they are not simple! In the debate on the simplification of the measurement technique two camps have become established, divided on the manner in which insulation should be measured *in situ*. The supporters of the "classical" method say that the information contained in a sound reduction index spectrogram cannot be compressed into a single figure index and that a longer measurement time is a small price to pay for all the extra information. The opposing camp advocates the use of a rapid test method (such as that proposed in the tentative recommended practice of ASTM E 597-77 T). This method should yield a single figure index whose measurement should require no more than a couple of minutes and should be a good indication of the "subjective acceptability" (reference "Moves towards simplification of methods for the measurement of airborne sound insulation" by H. G. Leventhall, Noise and Vibration Bulletin 1979, pp. 164-168). Where good insulation is indicated no more measurements need be performed. In the borderline cases, however, the "classical" measurement needs to be made to determine whether the insulation is acceptable or not. In the case of poor insulation, a "classical" measurement might help to determining how best to improve the fault. A rapid test method therefore would not replace but rather supplement the "classical" measurement.

The Building Acoustics Analyzer Type 4417 goes a long way towards solving the dilemma of rapid versus "classical" testing; the 4417 performs the "classical" measurements and calculations rapidly and is therefore eminently suitable for both the quick "acceptable/not acceptable" testing and for the more detailed analysis required in special cases.

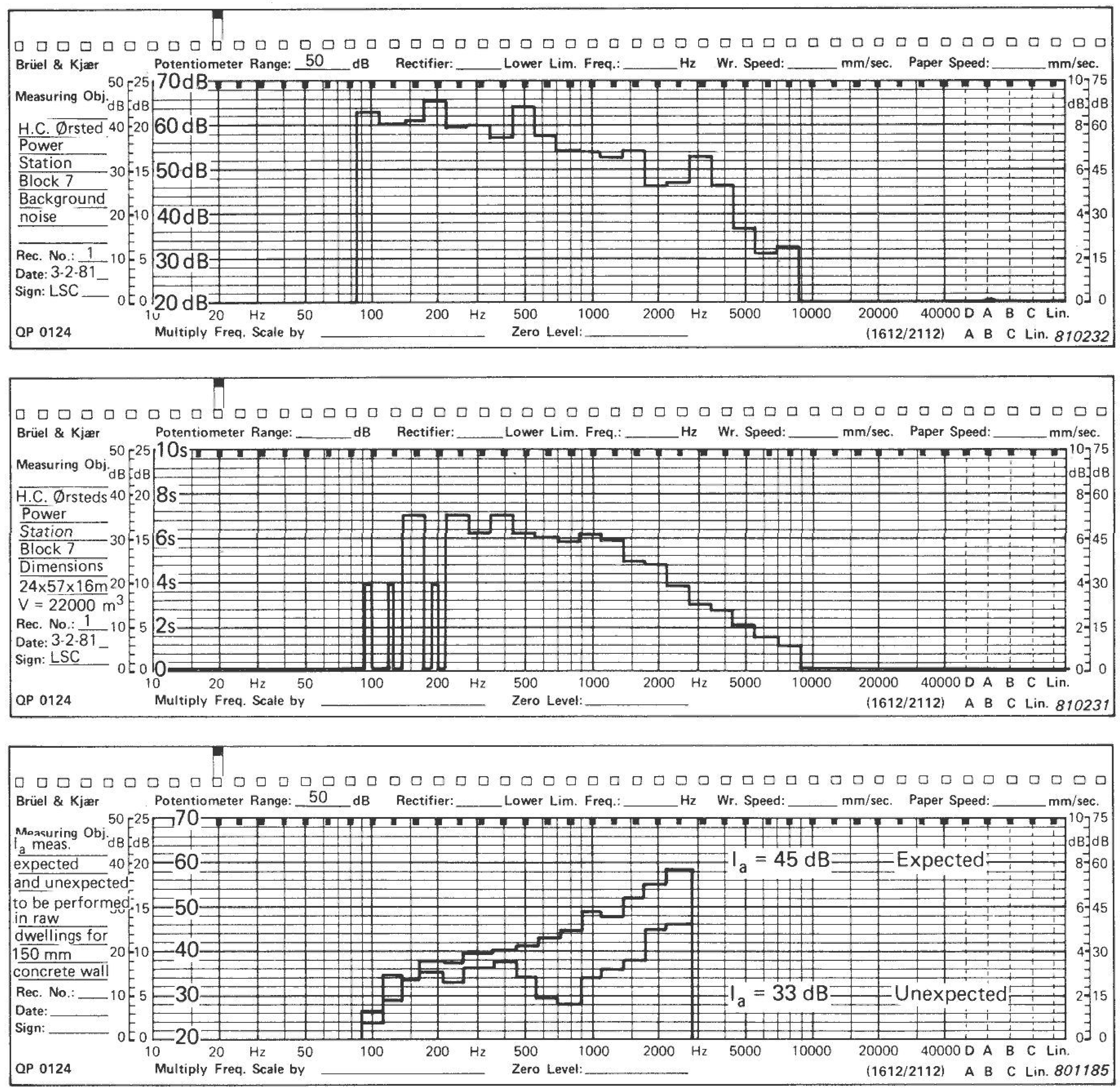

Fig. 4. Some measurement results. The upper and middle spectrograms were measured in a power station and the lower spectrogram in a newly constructed block of flats

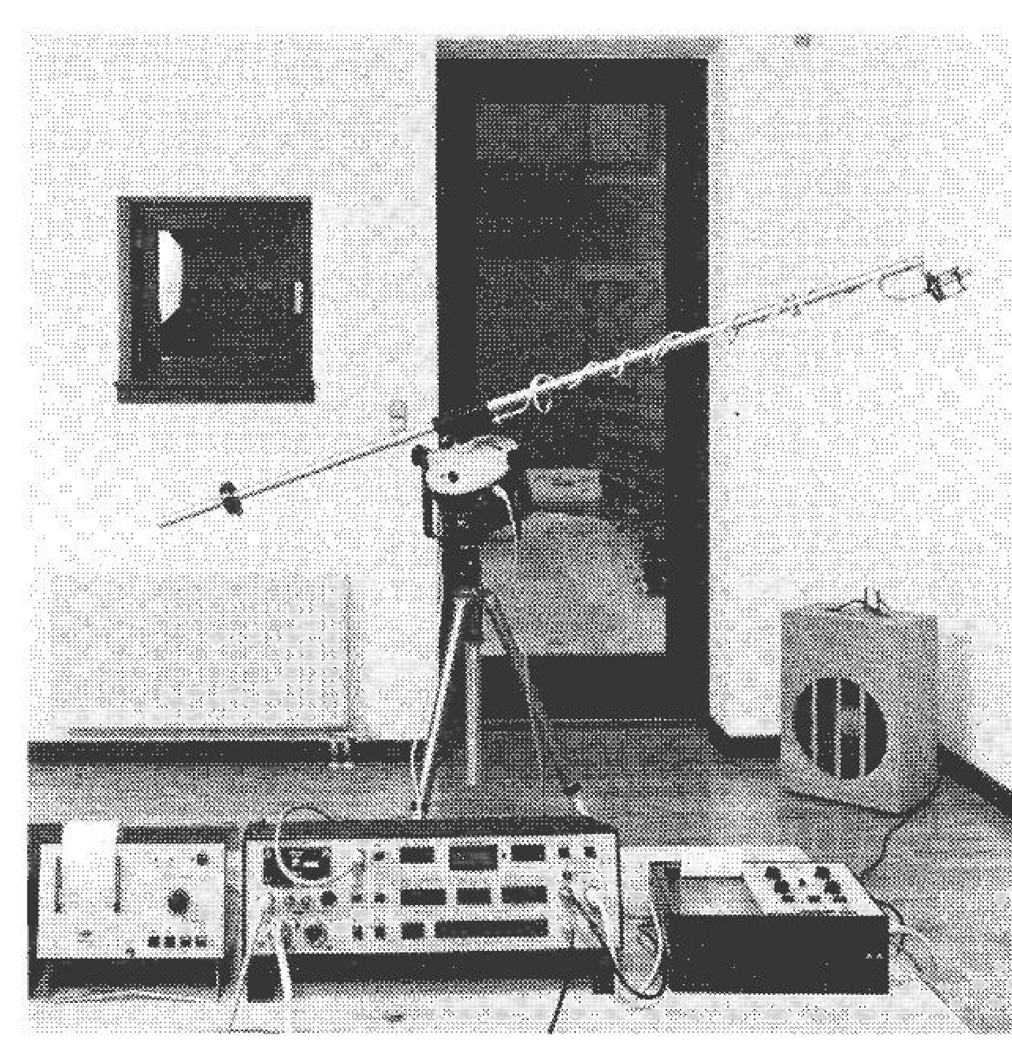

Fig. 5. Typical instrumentation controlled by the 4417 used for in situ measurements. The arrangement shown here yields the results in printed and in graphical form

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Printed in Denmark by Nærum Offset