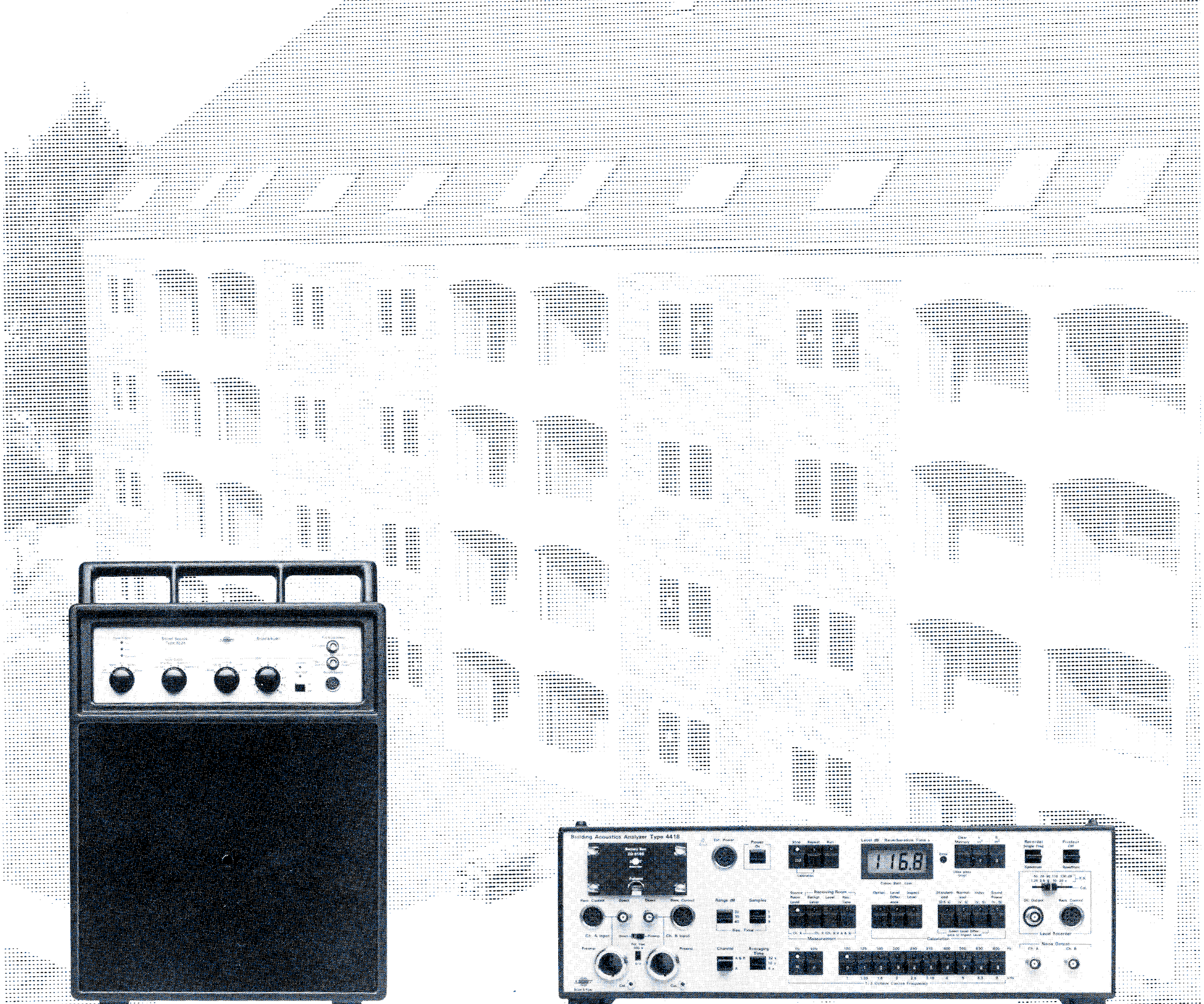
Brüel & Kjær application notes

A Powerful Combination for Building Acoustics Measurements



4224 4418

Brüel & Kjær

BO 0113–11

4418/4224: A powerful combination for Building Acoustics Measurements

by Torben G. Nielsen M.Sc., Brüel & Kjær.

Introduction

PROBLEM: A survey involving measurements of noise reduction in newly completed dwellings showed that only half of them met the requirements laid down in the legislation*. Legislation defining minimum limits of allowable sound reduction have been established throughout the world in order to protect people from noise intruding into their dwellings from neighbours, traffic, aircraft etc. The legislation expresses the good will of the authorities but is not strictly enforced, partly due to the expenses involved in carrying out the control measurements. Consequently there is a need for fast, reliable measurements to be done on a large scale and, preferably, at an early stage in the building process when the corrective action is not yet so costly.

SOLUTION: Modern instrumentation greatly simplifies the traditional measurements in building acoustics. What could in the early days only be done with a considerable number of instruments, some of which could be quite bulky and unwieldy, may now be carried out quickly and automatically using two compact, battery operated instruments and a microphone preamplifier combination.

The Building Acoustics Analyzer Type 4418 automates the measurement and postcalculation processes, allowing complicated measurements to be done by non-experts. Furthermore, the calculation of the various building acoustics parameters as defined in the ISO and a number of national standards is performed as a postprocessing operation in this instrument.

The Sound Source Type 4224 complements the 4418 perfectly whenever measurements in frequency bands (octave or ⅓ octave) are required.

The 4224, having its own noise generator and special filters, may also be used along with a sound level meter to do sound insulation measurements according to simple Test Method of ASTM E 597-77 T.

This Application Note provides a straightforward description of how these instruments may be used to carry out a typical series of building acoustic measurements. It is intended to demonstrate how accurate results may be achieved with extreme simplicity and considerable time savings. Although only airborne sound transmission is considered here, impact noise testing may be performed quite simply following a similar procedure.

The first two sections "Instrument Description" and "Instrument Combinations" are included so as to provide a comprehensive overview of the instrumentation. They are recommended to readers who wish to learn a little of how the instruments work and what the combination possibilities are.

The section "Measurement Procedure" describes the actual sequence of steps in a typical measurement situation. The entire procedure is summarized by the sequence of push-key operations given in the appropriate sections. The situation described is a field test of the airborne sound insulation between the dwellings in a residential building. It could just as well have been a laboratory investigation of the acoustic properties of building elements, or even part of a statistical quality control program on the production of building elements, like for example windows and doors.

The final sections highlight features of the instruments which allow their use in a wide range of applications. These may include, for example, measurements on ventilation systems, product quality control testing, and Sound Power measurements.

* Ref: SBI notat 101, 1977, *Status Byggeforskningsinstitut, Hørsholm, Denmark.*

Instrument description

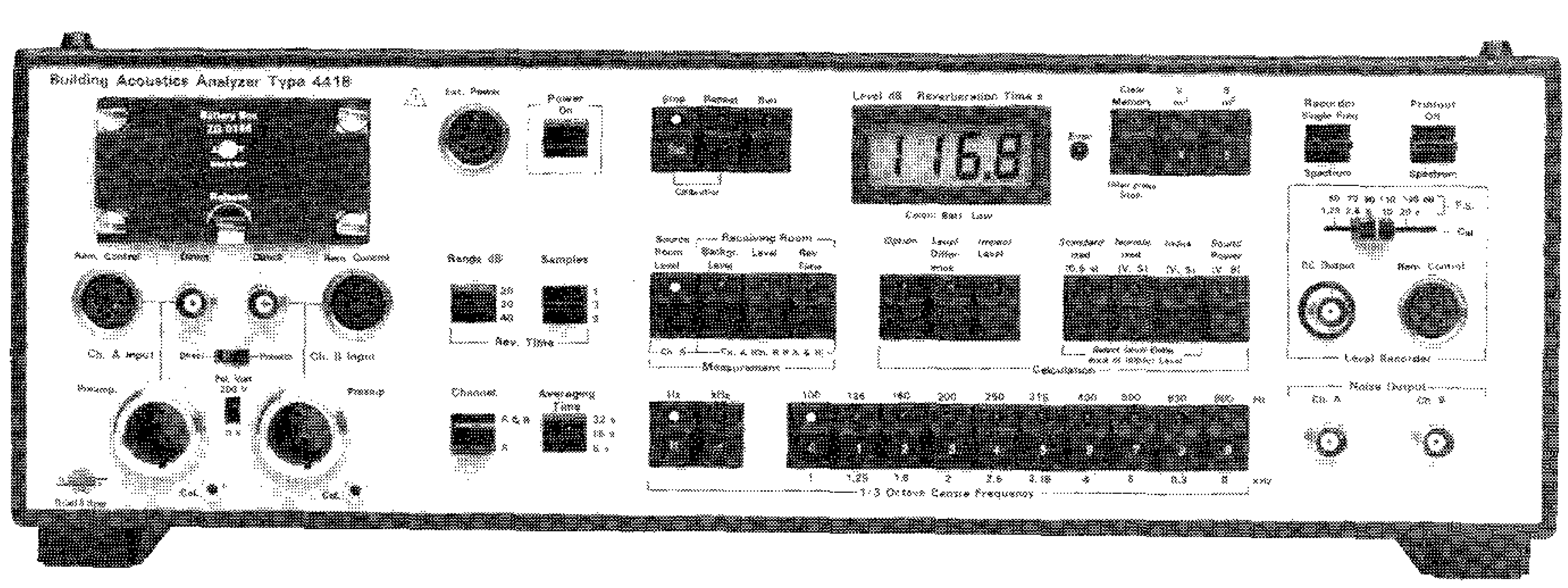
4418

The Building Acoustics Analyzer is basically a general ⅓ octave acoustics analyzer. It may be used for the determination of sound power according to ISO 3741/42, but the instrument has been designed specifically for the measurement and computation of the classical building acoustics parameters as defined in ISO and various national standards. The appropriate ISO standards are ISO 140, ISO 717, ISO/R 354 and ISO 3382.

Typically one or more of the following measurements have to be carried out:

1) Source Room Level
2) Receiving Room Level
3) Receiving Room Reverberation Time.

The 4418 can run these measurements by controlling one or two sound sources and one or two microphone channels. The analyzer will store the



results in its internal memory and eventually compute the desired parameters. The results may be given on the instruments LCD display or output on a printer or recorder. If specified by the user, the background noise in the receiving room may be measured and automatically compensated for.

When controlling two microphone channels and two sound sources the 4418 can be set up to run the whole measuring and computation sequence automatically. With only one source and one microphone some manual interaction is of course needed to move the source and microphone between some of the measurements.

The electronics of the Building Acoustics Analyzer Type 4418 may be subdivided into three general sections :

A: Generator section:
Noise generator / output filter:

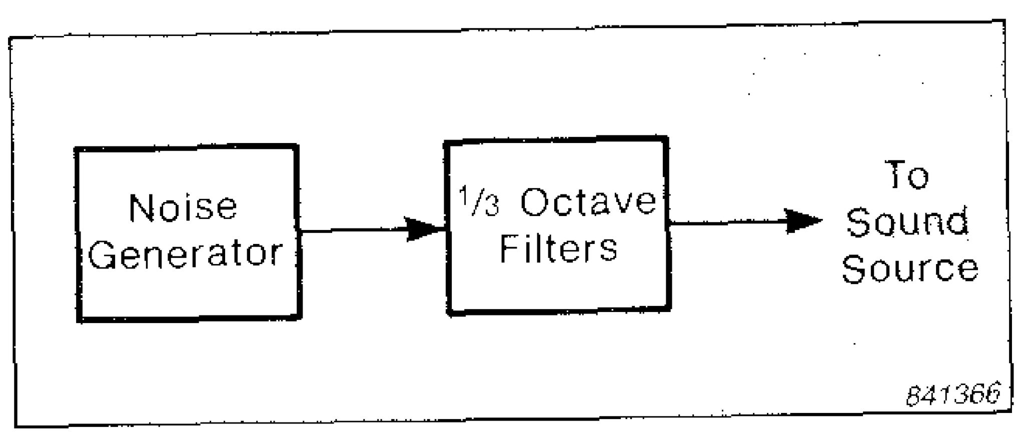


Fig. 1. Simplified block diagram of the generator section.

The signal from the noise generator is filtered in the 1/3 octave filter and then fed out to an external sound source such as the 4224. During a measurement the output filters may be swept sequentially under control of the digital controller built into the instrument.

B: Measuring section:
Input filter / autorange / detector:

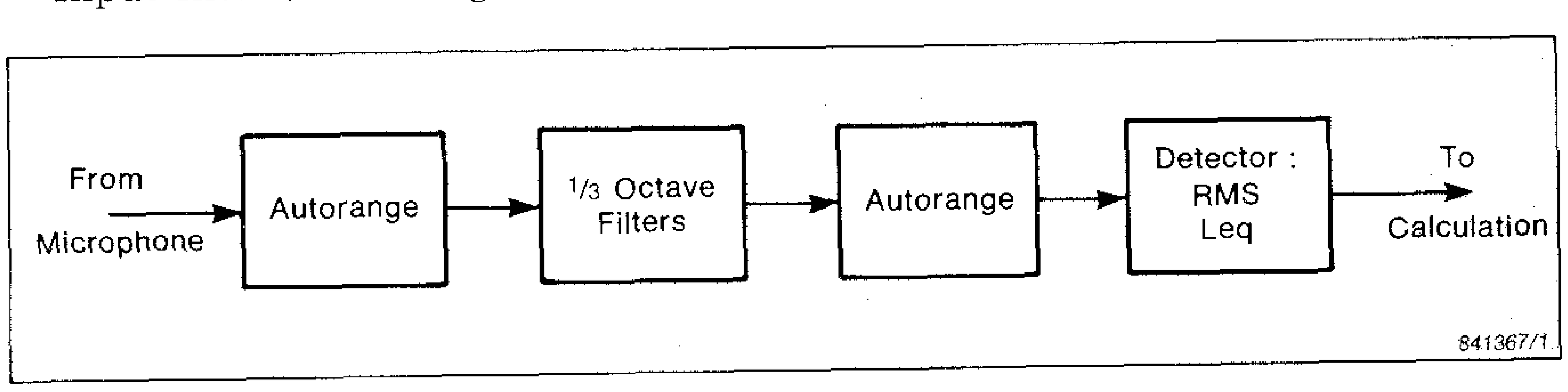


Fig. 2. Simplified block diagram of the measuring section.

In the measuring section shown above the Auto Range amplifiers serve the same purpose as manual attenuators in sound level meters and measuring amplifiers. In a sound level meter the signal is adjusted to a proper level for further processing in filters and detectors, avoiding overload at the input and producing a large deflection on the meter. The difference is, that in the Auto Range amplifiers of the 4418 this adjustment takes place automatically so that the user does not have to worry about it.

The 1/3 octave filter bank is similar to the one found in the generator section and during a measurement the filters in the two sections are swept synchronously. The detector will determine the RMS value of the signal for reverberation measurements and the equivalent continuous level Leq when level measurements are performed.

C: Calculation / Output section:

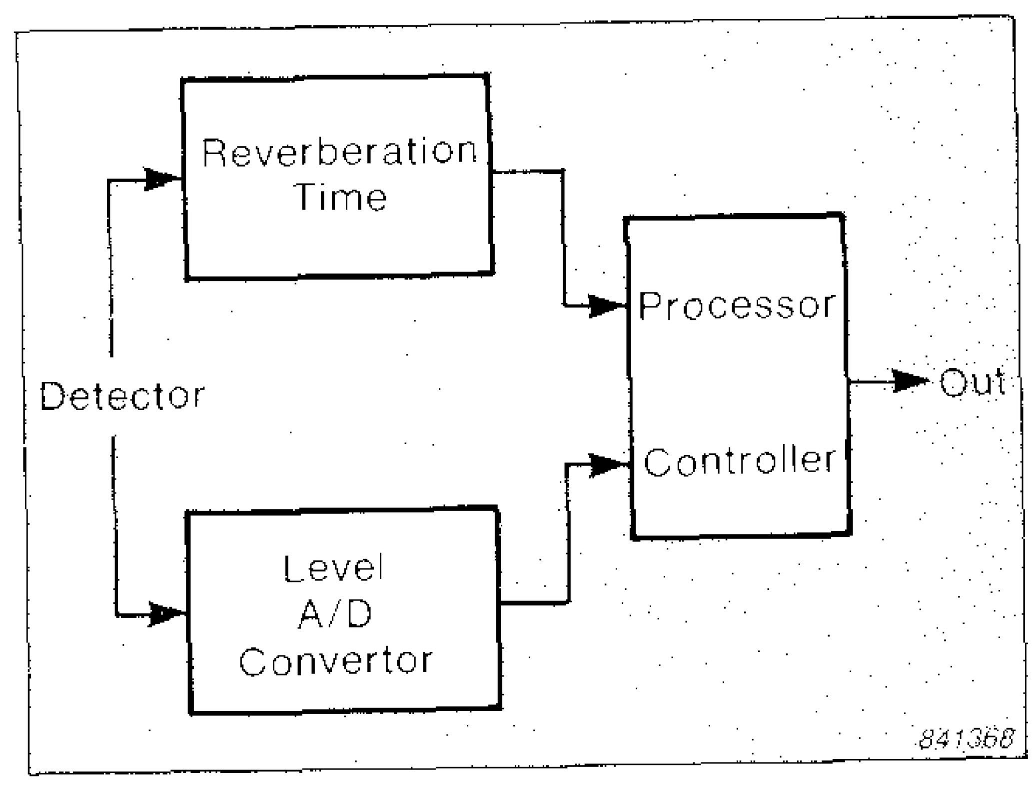


Fig. 3. Simplified block diagram of the calculation / output section.

The signal from the detector may either enter the processor directly via the Analog / Digital converter or it may enter the Reverberation Time Computer. Here the reverberation time is computed directly during a decay so that no subjective straight line approximation is necessary.

The processor will store the measured spectra whether it is level spectra or reverberation spectra. The processor can display the reverberation times of the individual 1/3 octave bands directly on the LCD display of the instrument or they may be fed out to the Printer Type 2312 or the Portable Level Recorder Type 2317.

The processor will also compute and output the various building acoustics parameters based on the three measurements mentioned initially. (A summary of the available parameters is given in table 4.)

The controller will control the measurement by selecting the proper input and output, sweeping the filters and keeping track of the averaging in time and space. The controller will also monitor the quality of the measurement, and if a failure occurs the controller will, in most cases, repeat the measurement or store an error code that contains information about the type of irregularity that has taken place.

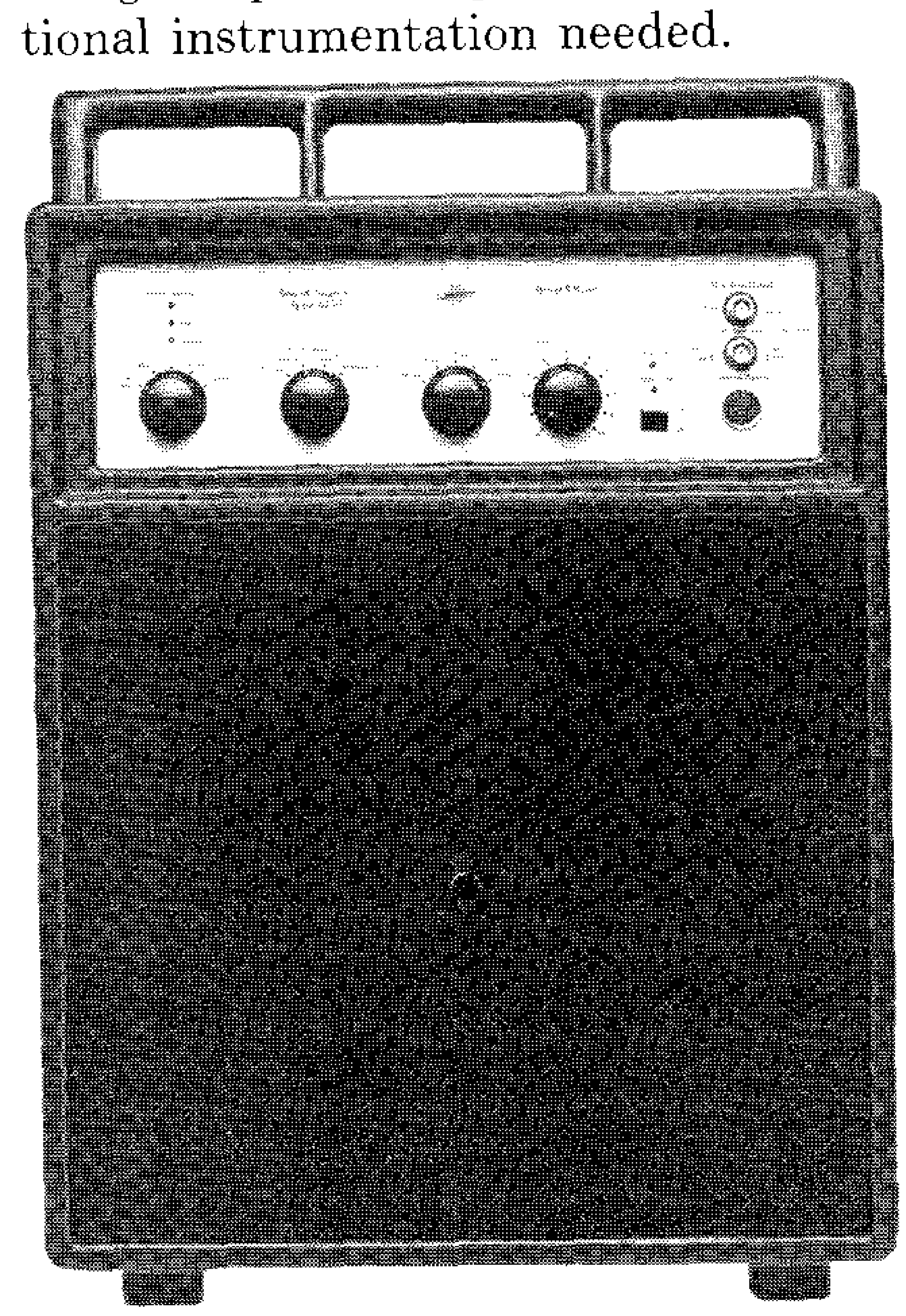
4224

The Sound Source Type 4224 is a portable and robust instrument capable of producing high noise levels.

It consists of a loudspeaker, a power amplifier, a pink noise generator and 2 filters following the Simple Test Method specified in the ASTM E 597-77T standard. Space is available for 2 more filters so that users can specify their own filters and the instrument is thus prepared for future simple method standards.

The 4224 can produce up to 115 dB re 1 pW sound power level when battery operated and 3 dB more on mains supply. 115 dB sound power level will produce a sound pressure level of about 104 dB re 20 μPa in the reverberant field of a normal furnished living room with dimensions of $2.5 \times 10 \times 5$ m^3 and a reverberation time of 0.5 sec.

On a fully charged battery the 4224 can run continuously for 4 hours delivering a sound power output of 102 dB Sound Power Level, and it may be connected to the mains supply and charged up over night with no additional instrumentation needed.

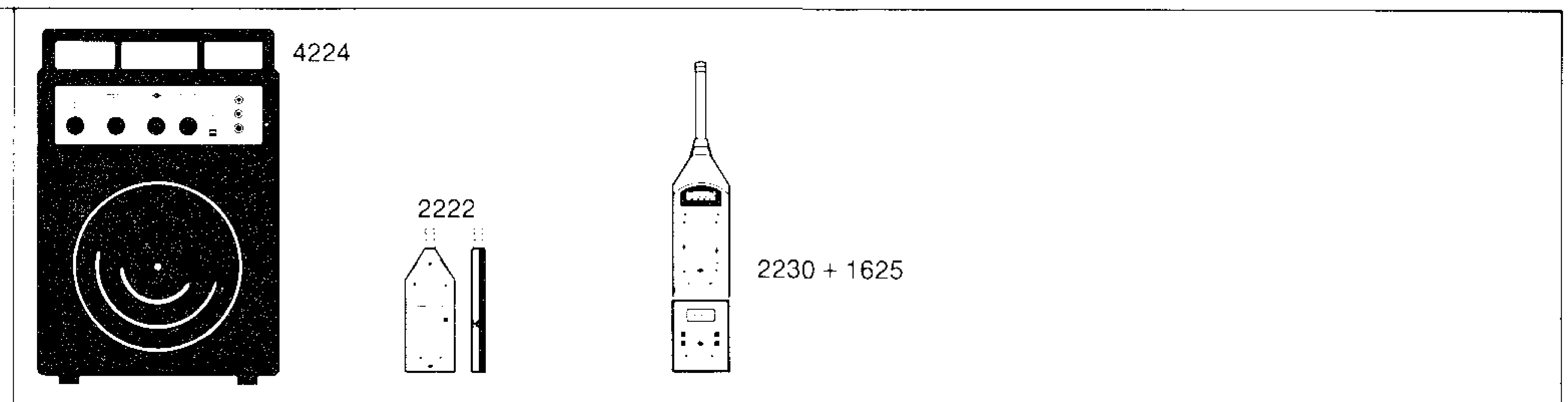


Instrument combinations

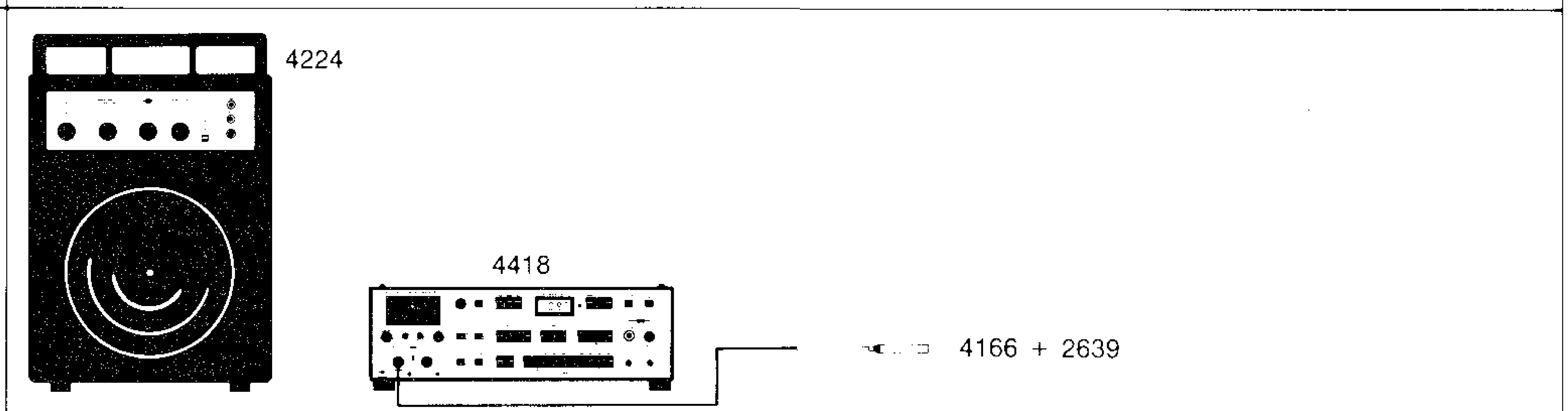
This section shows how the Building Acoustics Analyzer is the basic building block for a whole family of instrumentation systems. For impact sound insulation measurements the Standard Tapping Machine Type 3204 should be included. Except for the 3204 all instruments may be battery operated.

More B&K instruments than are mentioned here can be uesd in conjunction with the 4418. Reference is made to the 4418 Product Data sheet.

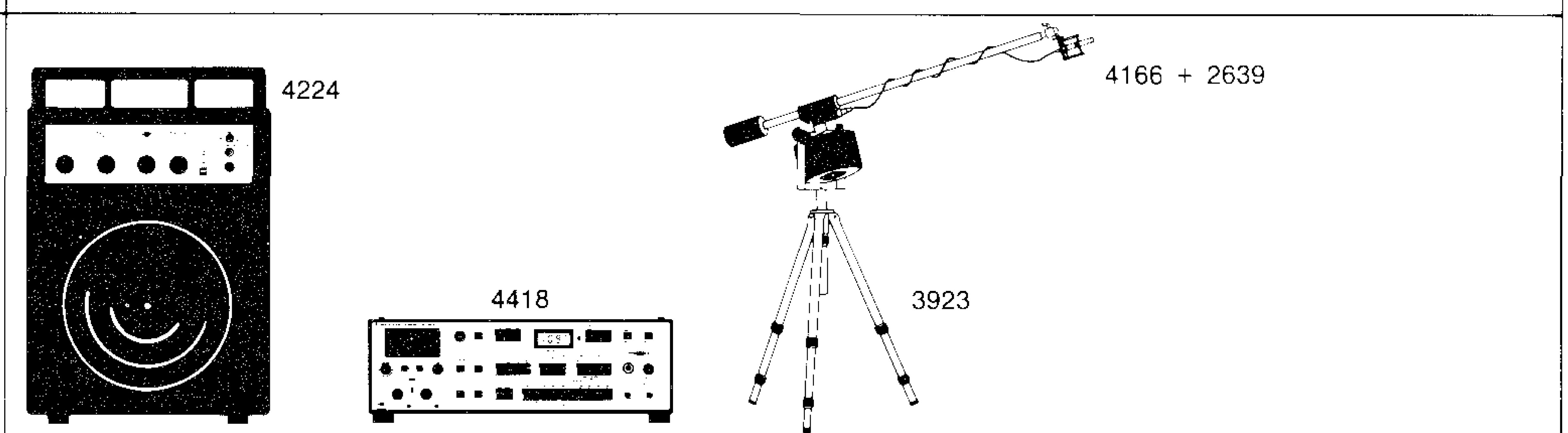
A sound source like the Type 4224 is an indispensable component in any building acoustics measuring system. With a 4224 and a sound level meter like for example Type 2222 or Type 2230 it is possible to do broad band measurements of sound insulation. When adding a filter set like the 1625 to the 2230, manual 1/3 octave band measurements are possible.



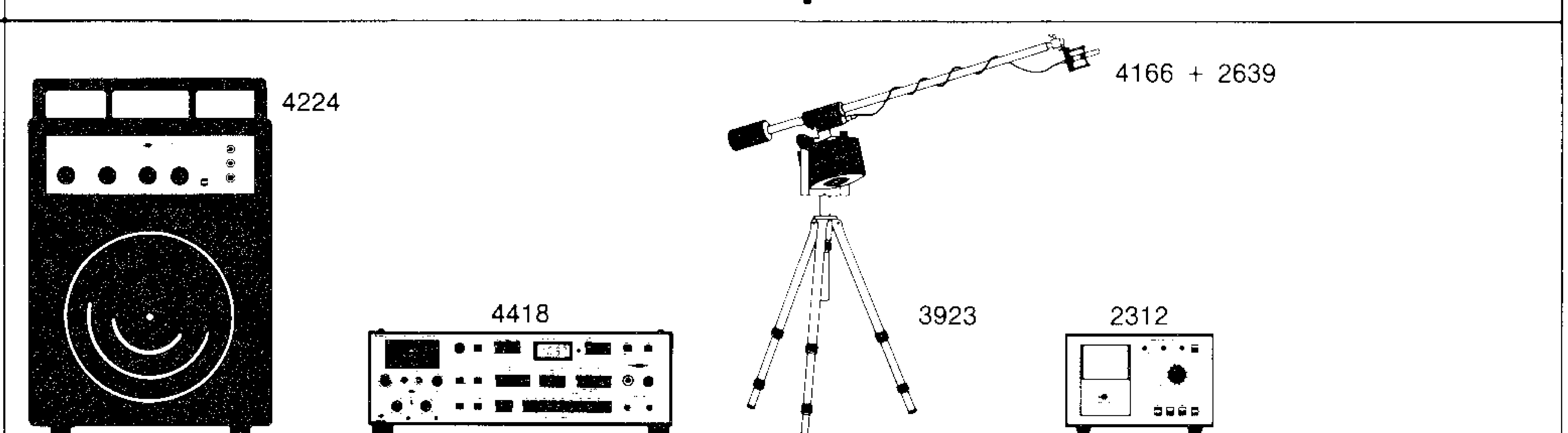
When automated measurements in 1/3 octave or octave bands are required, the first step into a very powerful line of combinations utilizes the Building Acoustics Analyzer Type 4418.
Spatial averaging may be done by moving the microphone between fixed positions and averaging the spectra measured in each position.
Data is read out from the display of the 4418 after completion of the measurements and calculations.



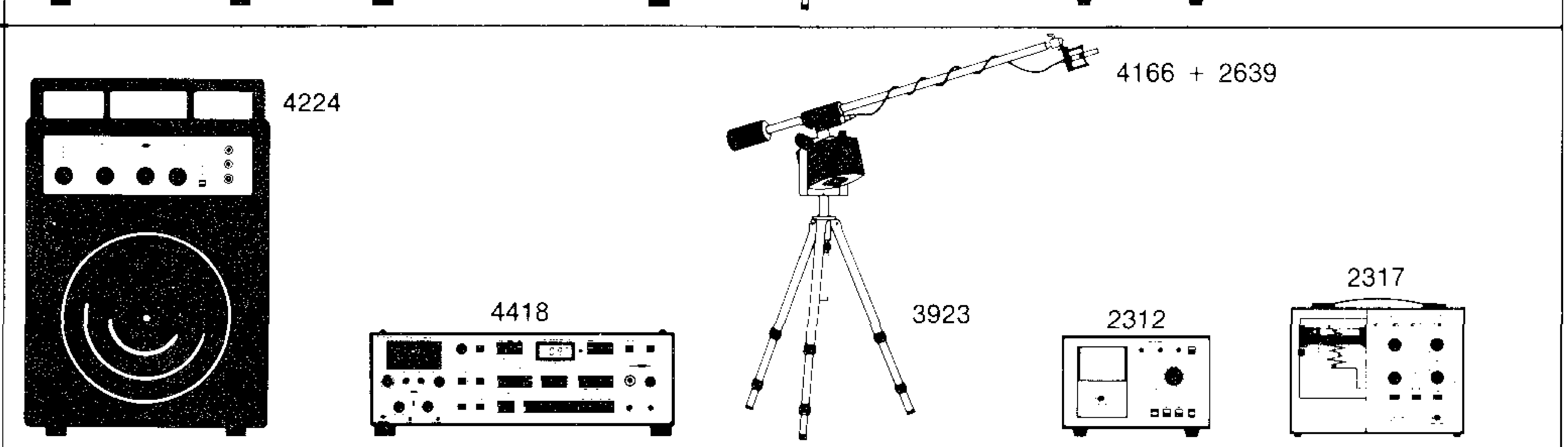
When a more automatic type of spatial averaging is desired a Rotating Boom Type 3923 may be added to the system. The boom can move the microphone in a circular path with a radius up to more than 2 m and the plane of rotation can be varied in steps of 10°. The rotation of the boom may be remotely controlled from the 4418.



For automatic printout of the results the system is enchanced with an Alphanumeric Printer Type 2312.
The 2312 is a strip chart printer and it will print out the measured and calculated data along with various types of status information in a table format.



If it is considered necessary to look at the individual decays in a reverberation measurement the decays may be recorded on the Portable Graphic Level Recorder Type 2317.
The 2317 is controlled by the analyzer, and it may be set to record the reverberation decays when they take place, and it can also record level spectra and reverberation spectra. This documentation is similar to that printed out in table format on the 2312.



When adding another Sound Source Microphone-Preamplfier combination and a Rotating Boom it is possible to perform a fully automated sound insulation measurement by pressing just one button.

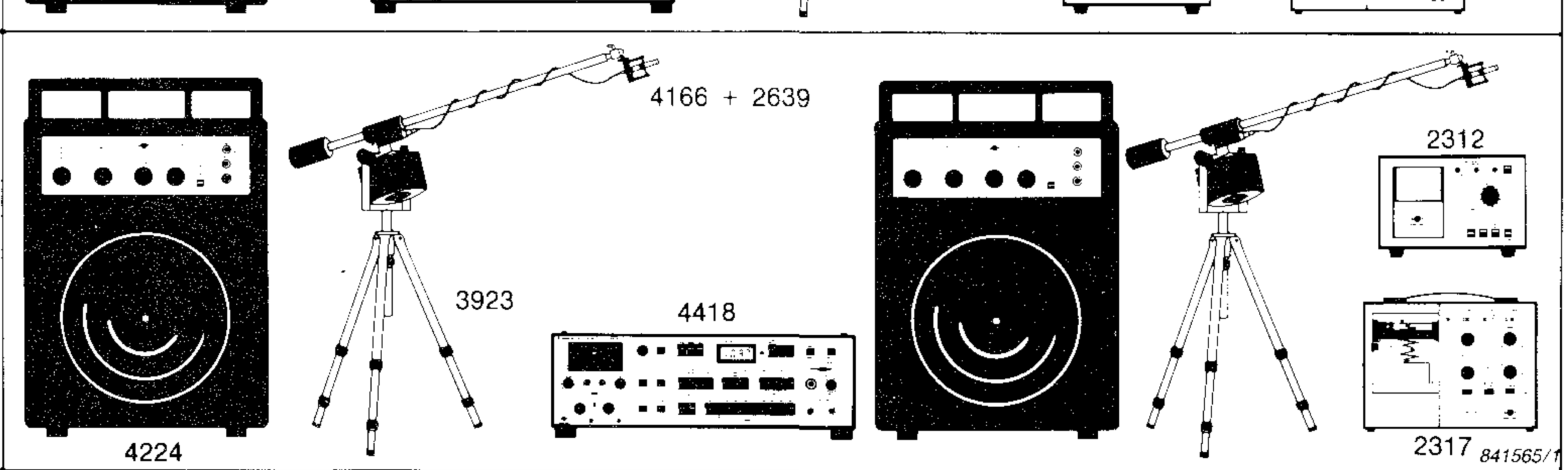


Fig. 4. Typical instrument combinations for building acoustics measurements.

Measurement Example

To demonstrate the many possibilities that are inherent in the powerful 4418/4224 combination this section gives a worked through example of an ISO measurement of airborne sound insulation using the instrument selection given.

The example describes an actual test measurement and the results shown in the next section were derived from the test. In order to demonstrate the ease and rapidity afforded by the instruments, the procedure was timed. The start and finish times of each step are indicated on the photographs. The times indicated include equipment transport and set up times, and the total time taken is therefore more than the measurement time alone (shown in Table 1).

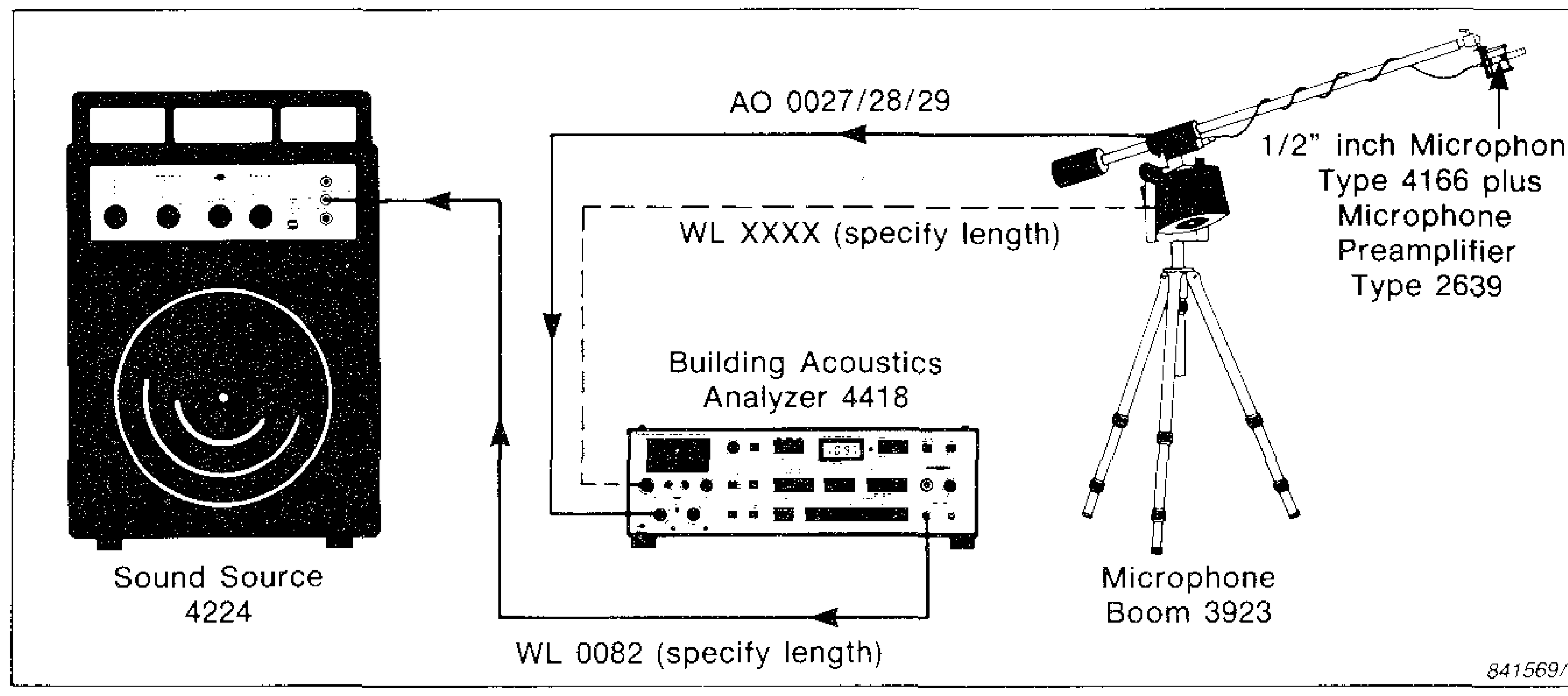
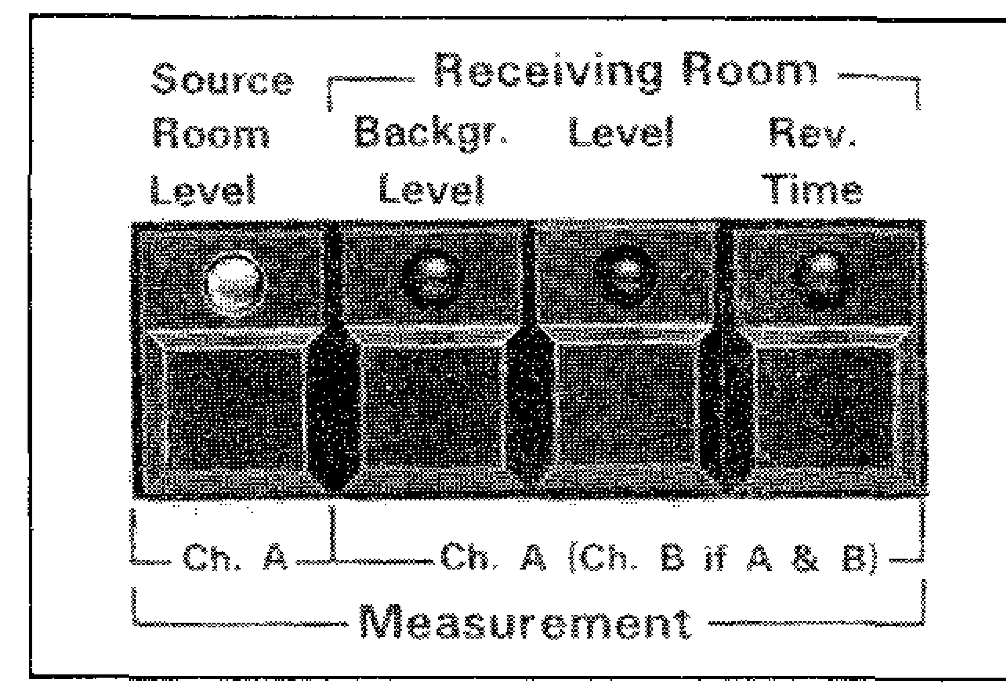


Fig. 5. Equipment used during the measurements described in the example.

4 types of measurements are to be done :

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

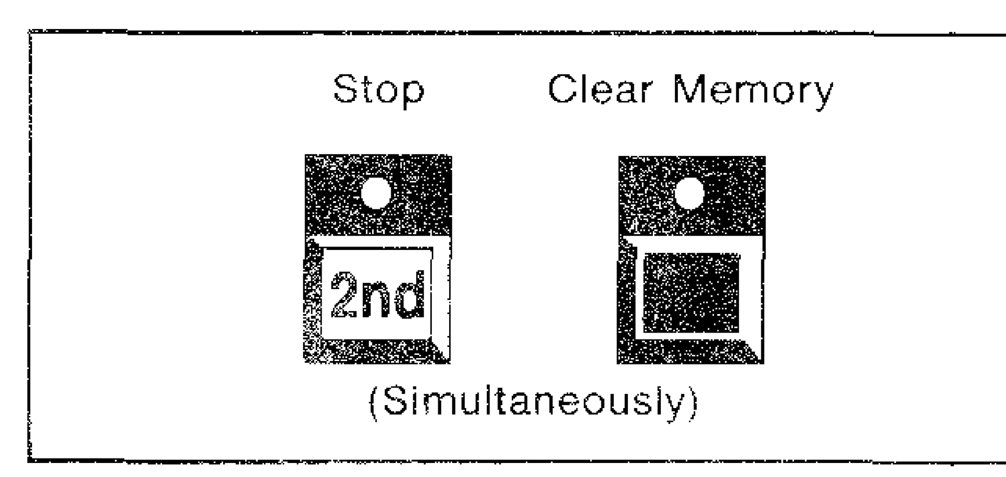
Each type of measurement has its corresponding button on the front panel of the analyzer. The measurements are conveniently carried out in the sequence given on the front panel.



1) Startup Procedure

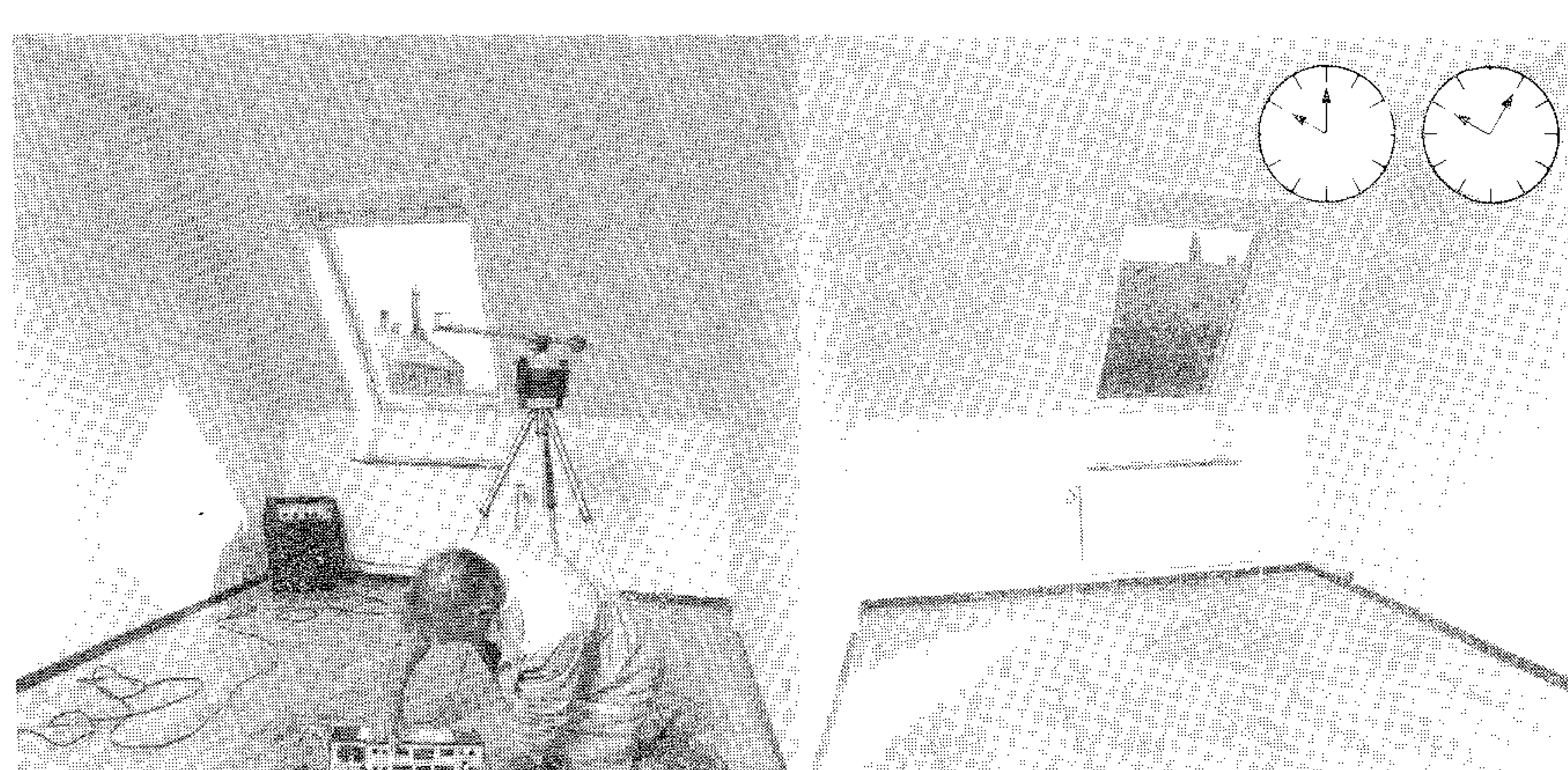
In order to make the 4418 as user friendly as possible, access to certain instrument functions, that are not used very often, have been removed from the front panel. These functions are instead activated from eight switches located under the top cover of the instrument. The settings of these switches should be known to the operator before any measurement is started (the operator may either remove the top cover and look at the switches or have the status printed out on the Alphanumeric Recorder Type 2312). The significance of the switches can be seen under "Switch Settings" given in table 3 on page 14. Note that the setting of one of the switches limits the frequency range to 100 Hz to 3150 Hz as specified by ISO 140. In the example measurements will be done according to the ISO standard, so the switch should be set as appropriate. In this way no time will be wasted by making measurements in all the frequency bands up to the 8 kHz limit of the analyzer.

The analyzer also contains a non-volatile memory. This memory should be cleared before the measurements are started by pressing **Stop** and **Clear Memory** simultaneously once the analyzer is switched on.*



2) Calibration

Before a real measurement is started the equipment should be calibrated. An acoustic calibration is essentially a sensitivity adjustment of a measuring instrument when it is measuring the output of a known source. In the case of the 4418 the procedure is simple and the adjustment is automatically taken care of by the instrument.

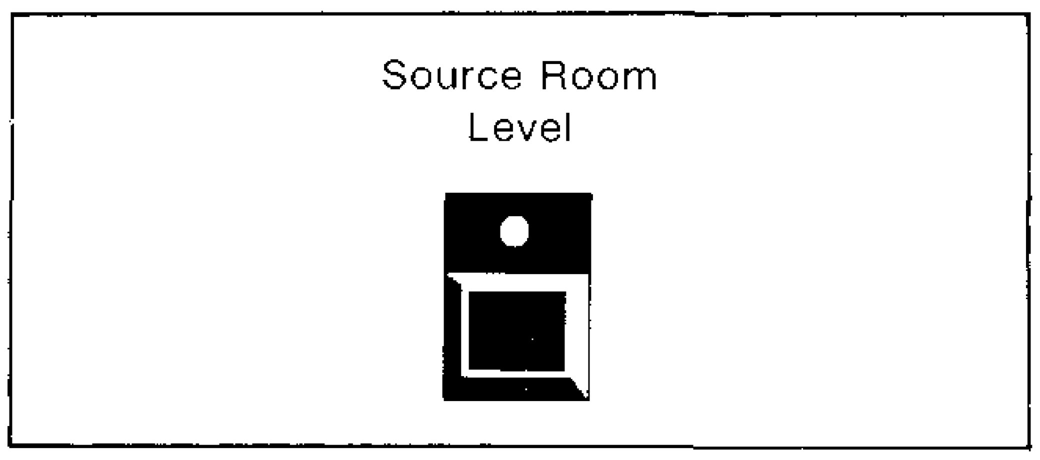


* A photograph of the 4418 front plate is given on the last page of this application note. The relative location of all pushkeys can be clearly seen.

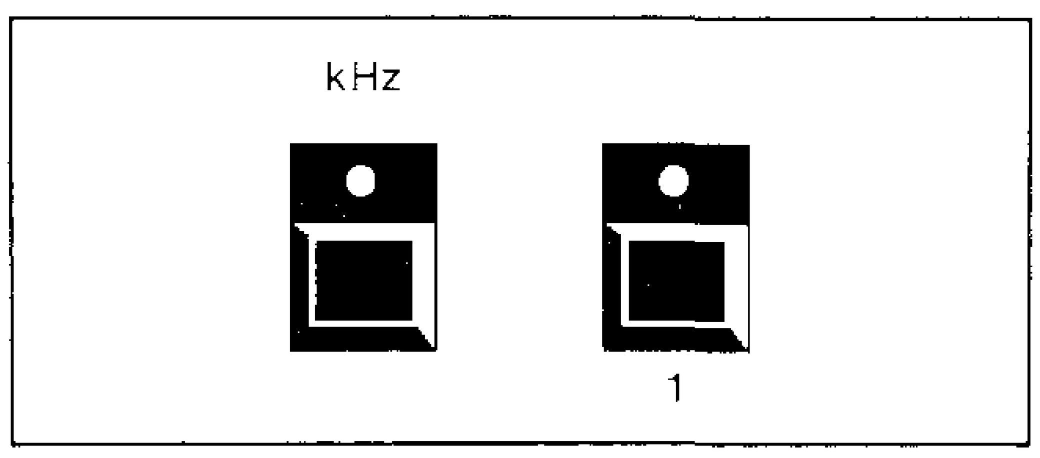
Autocalibration Procedure:

Fit an Acoustical Calibrator such as the 4230 over the microphone. Specify the following three parameters:

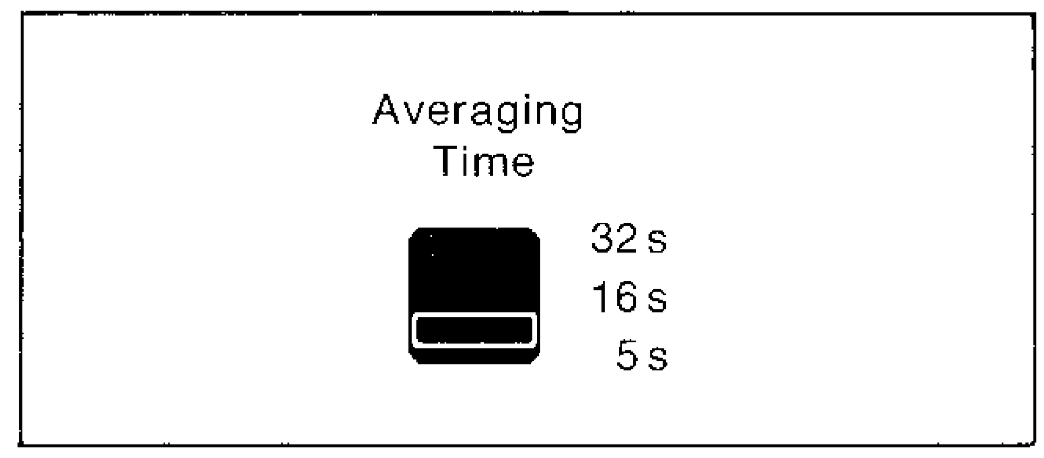
1) Type of measurement



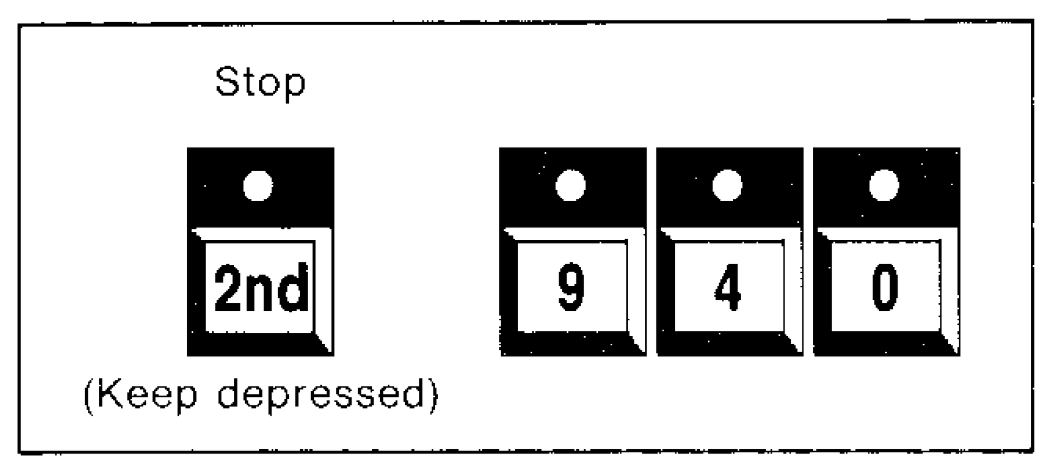
2) Frequency band (1000 Hz)



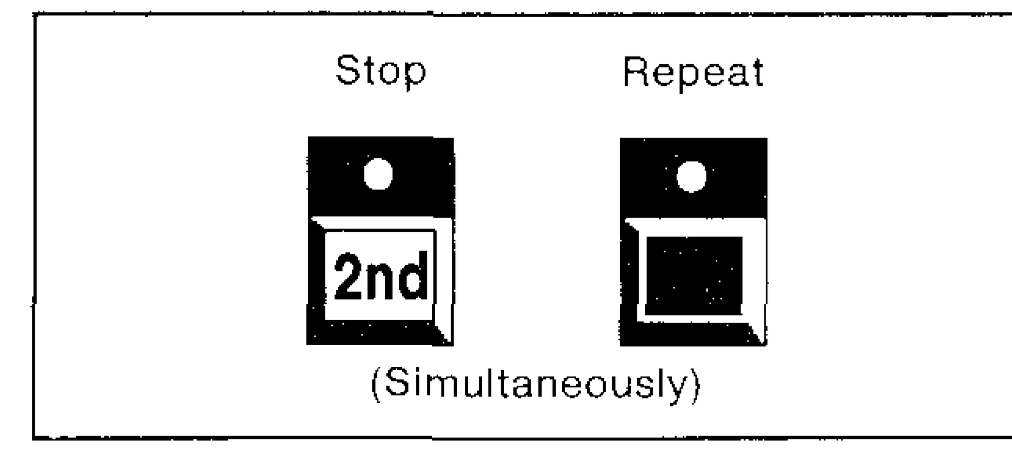
3) Averaging time (e.g. 5 s)



Key-in the level produced by the calibrator (e.g. 94 dB):



The calibration is started by pressing **Stop** and **Repeat** simultaneously.



After one measurement a correction factor is stored in the analyzer and this correction factor will automatically be applied to future measurements.

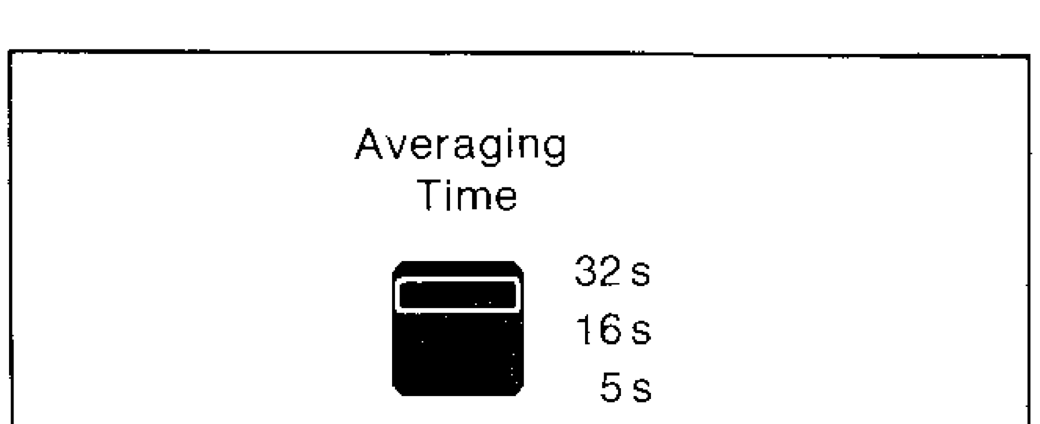
3) Source Room Level

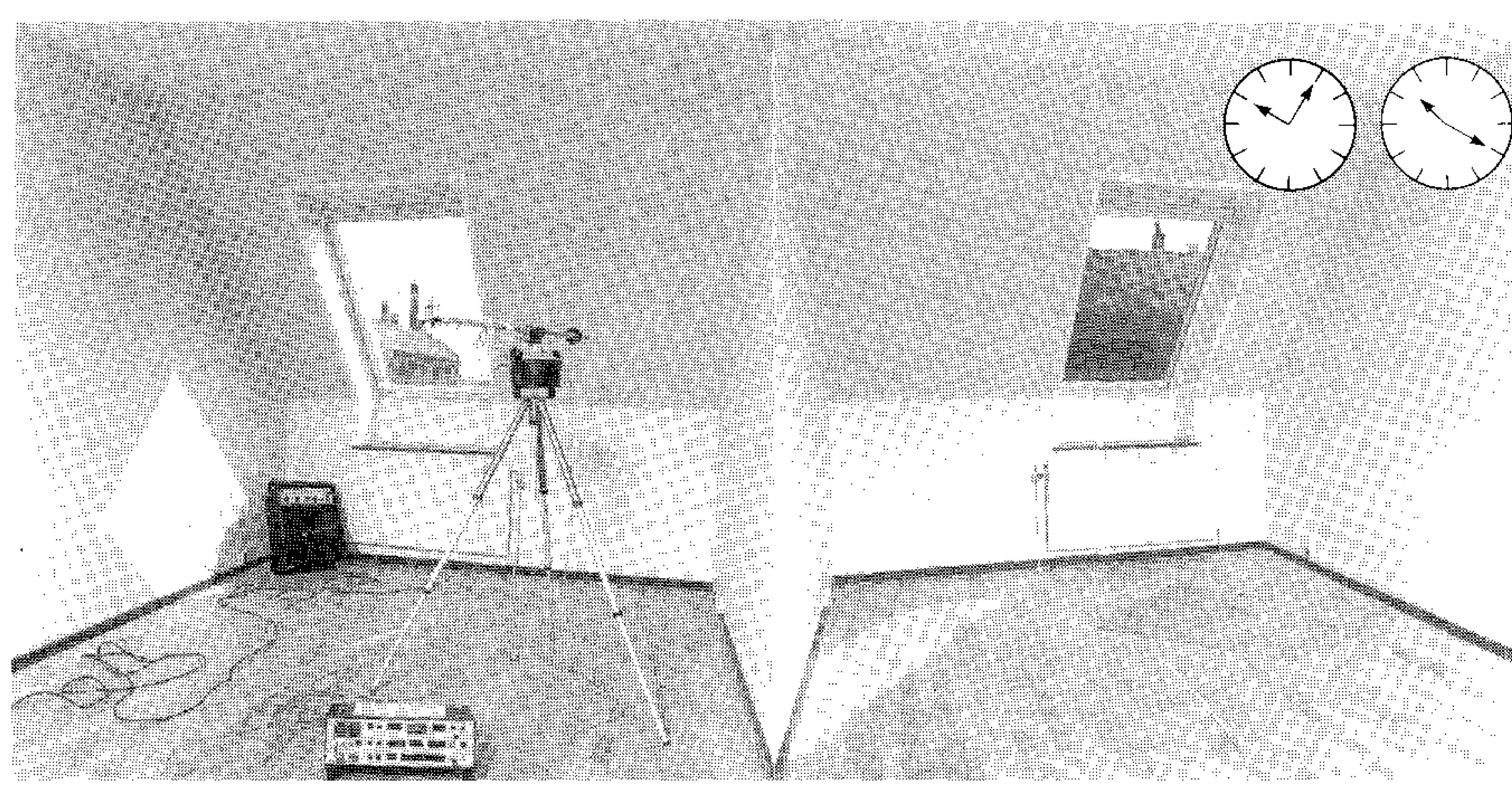
The instruments are placed in the source room. For in-situ measurements ISO 140 does not give very specific information on where the sound source and the microphone should be placed. This is due to the fact that the variations in form and construction of buildings are enormous. It is recommended, though, that the loudspeaker is placed in a corner opposite the test specimen but not directed at it. The microphone boom is a very efficient tool for spatial averaging of the sound field. ISO 140 /IV suggests, that a boom radius of more than 0.7 m and an averaging time of more than 30 s. be used.

A traverse time of **16 s** is selected on the rotating boom. This is the shortest traverse time available on the boom, and it is selected so as to minimize the time of travel between successive sample points during the reverberation time measurements (see Figure 6.).

The boom will not start rotating when it is switched on since it is remotely controlled by the 4418.

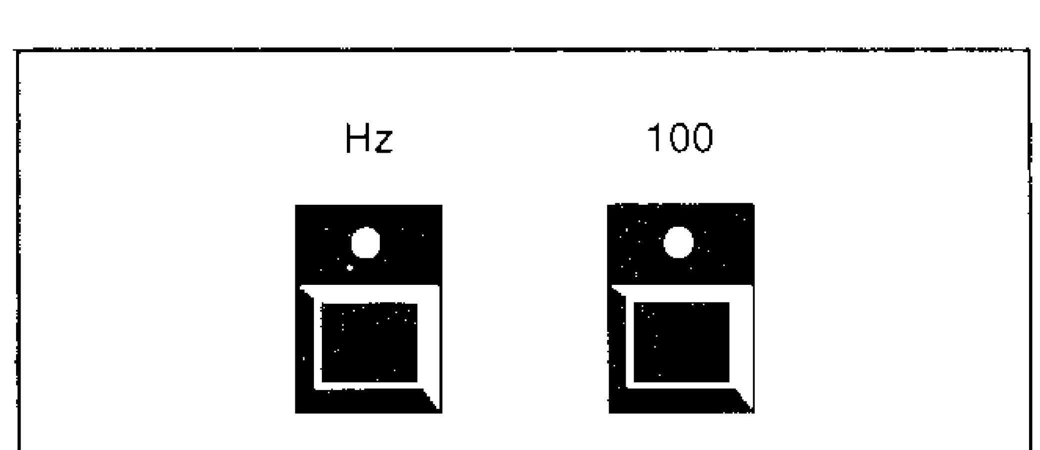
The averaging time is set to **32 s** on the 4418.



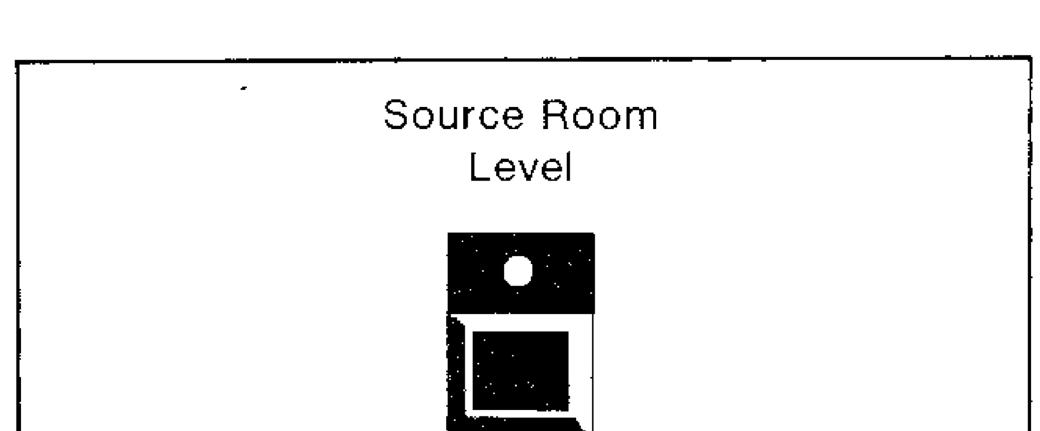


The boom will then perform two rotations during one averaging time.

The filter frequency should be set to **100 Hz**:

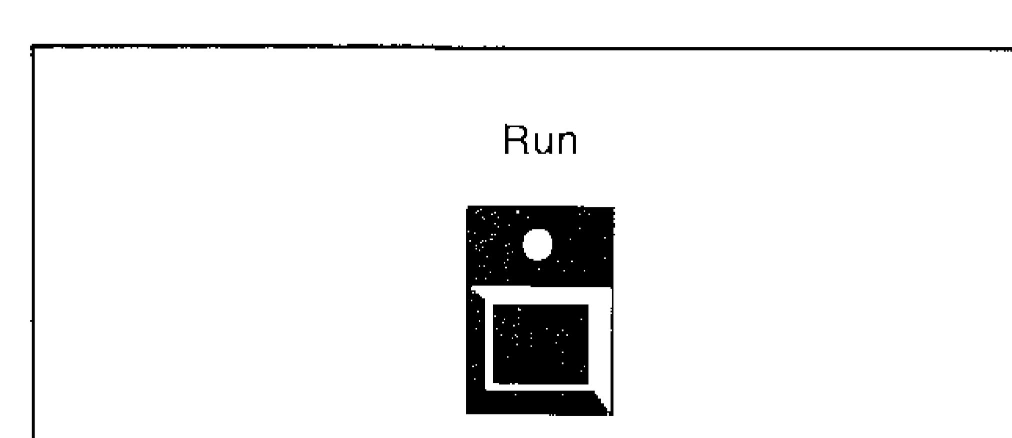


and the **Source Room Level** measurement should be selected :



Now, the microphone boom is halted at a reference position, and the noise generator is switched off.

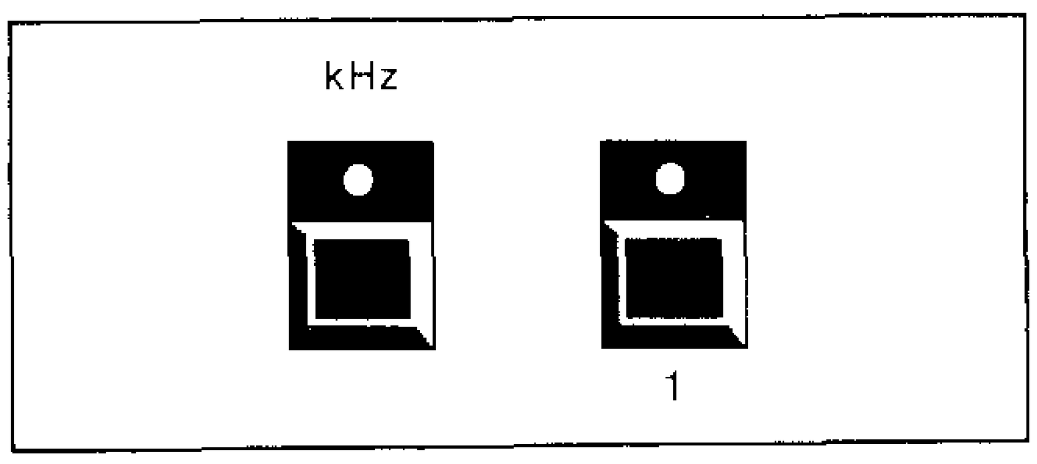
The measurement is started by pressing **Run**:



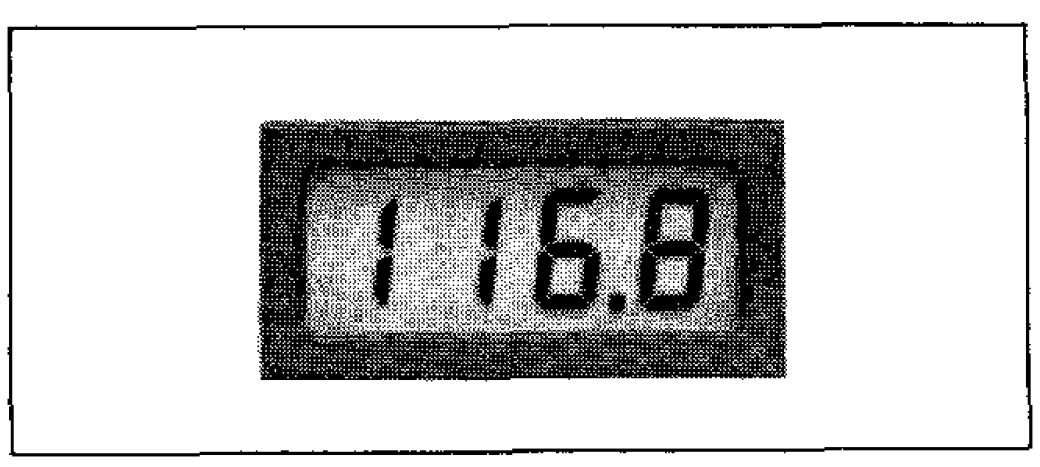
The noise in the 100 Hz 1/3 octave band is switched on immediately, and after a few seconds the boom starts rotating. The reason for this delay is that the autorange amplifier in the 4418 has to adjust to the proper level.

After 2 revolutions of the boom the filters are automatically shifted to the next center frequency, 125 Hz. The sweep proceedes up to 3150 Hz, and when the measurement in this band has been completed the filters are switched back to 100 Hz, the boom is stopped and the noise generator is switched off.

The measured values in the various frequency bands are now stored in the analyzer and may be viewed by pressing the relevant frequency button:



If, during the measurement, the level has changed significantly in a given frequency band the analyzer will repeat the measurement in that band once. If the problem still exists the display will show an error code when the level in that frequency band is reviewed.



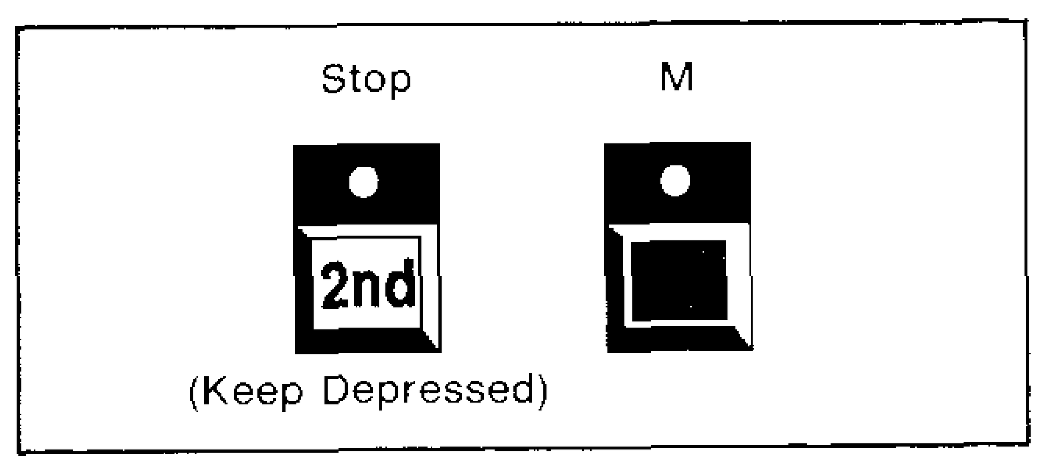
Various other failures cause an error code to be generated. The error codes along with their significance are given in table 3 on page 14. A measurement in a single frequency band may, as shown under "Calibration", be repeated by selecting the relevant frequency band and then pressing **Repeat**.

Spectral Averaging:

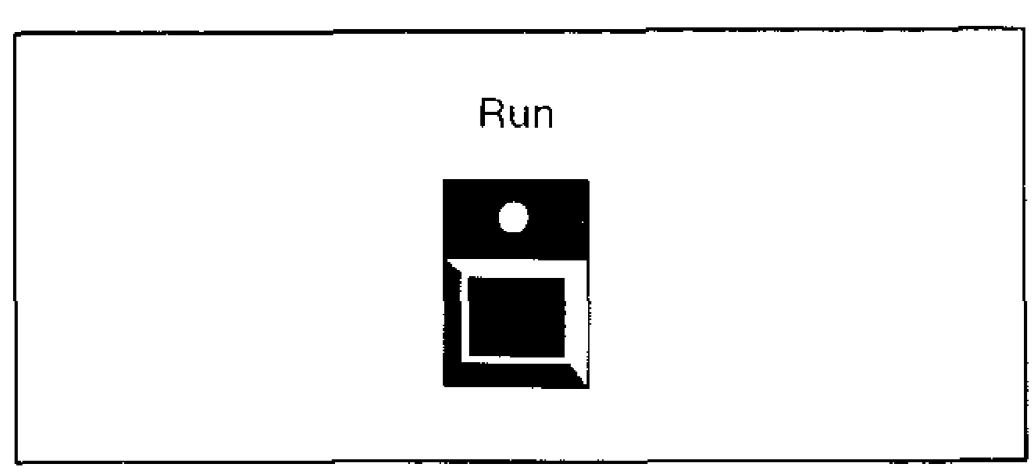
Having performed a measurement of the Source Room Level, a higher accuracy may be achieved by averaging the stored spectrum with new measurements. It is possible to average up to 15 spectra. (This facility is also available for measurements of Receiving Room Background Level, Receiving Room Level, and Receiving Room Reverberation Time.)

The procedure is as follows :

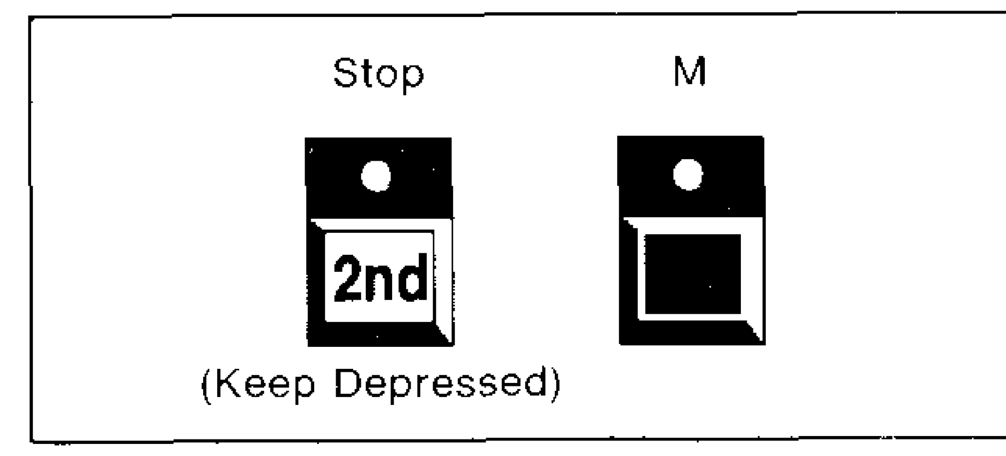
1. Indicate, that the measurement stored is the first in a series that are to be averaged :



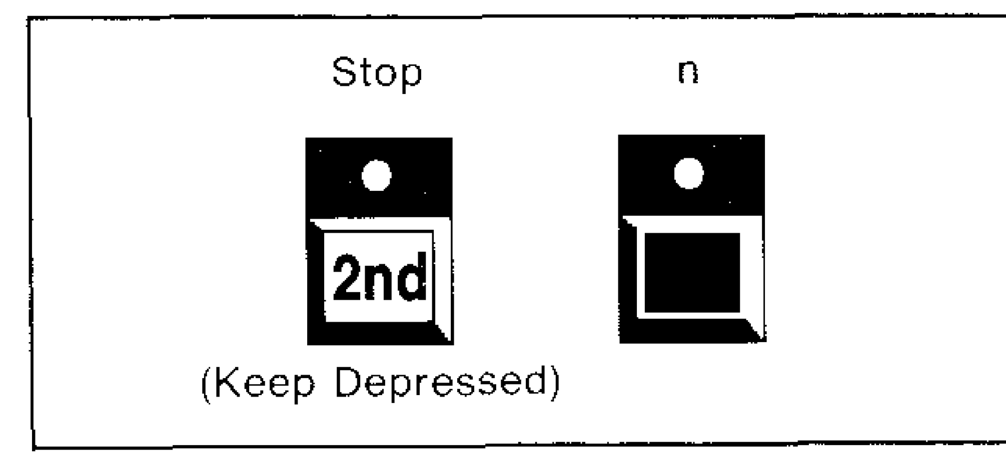
2. Start a new measurement :



3. When the measurement is completed the 2 spectra are averaged by pressing :



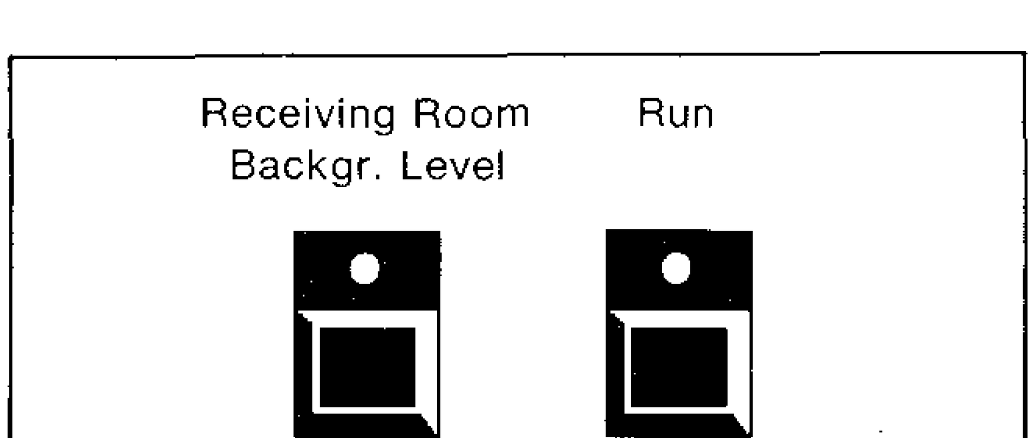
New spectra may be incorporated into the average by repeating steps 3 and 4. It is possible to view the number of averages by pressing the pushkey marked **n** while keeping the pushkey marked **2nd** depressed:

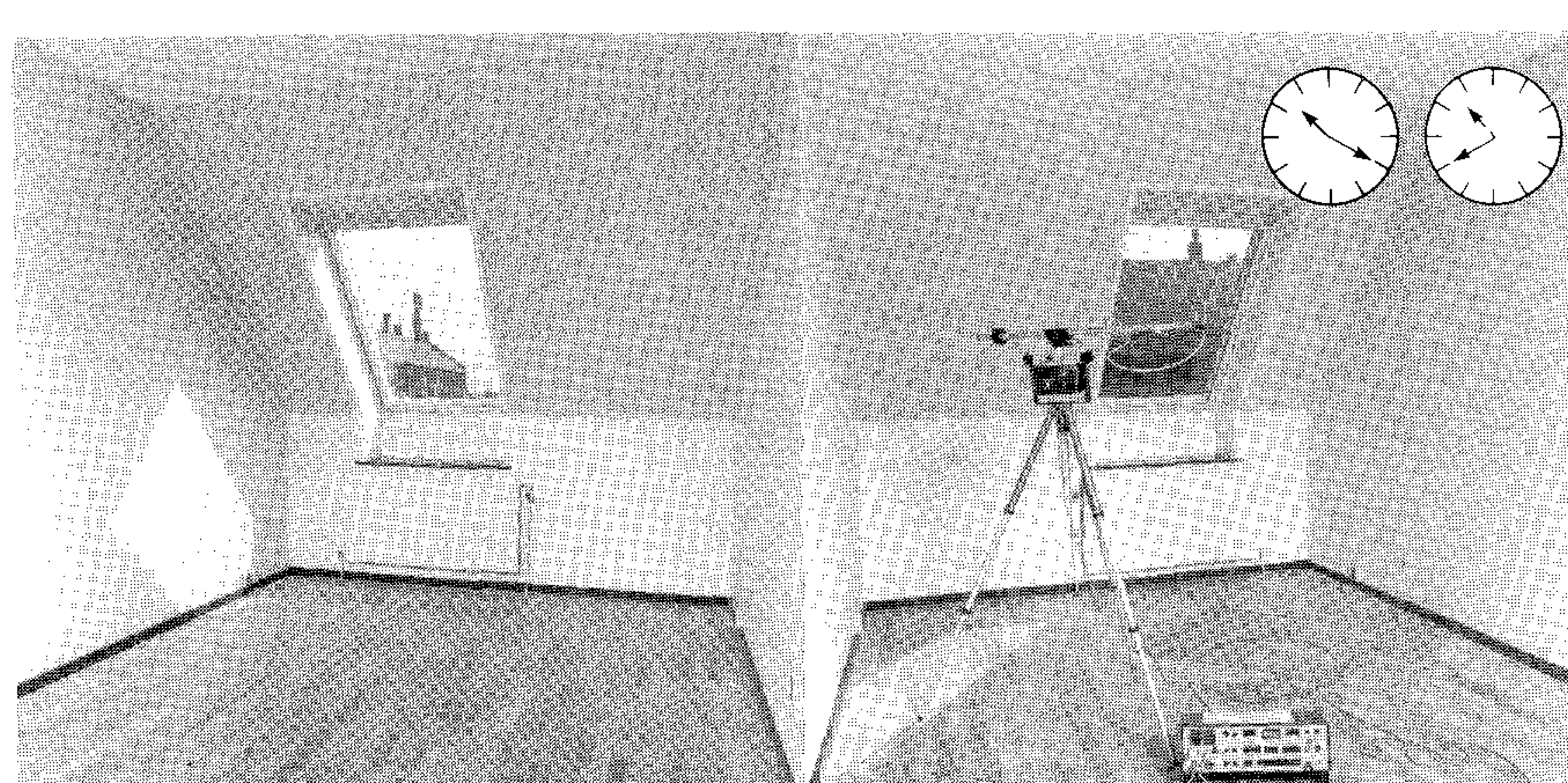


Since the sound levels in the source room are very high during the measurement, an operator who stays in the room will experience a certain amount of discomfort. This is avoided by delaying the start of the measurement until the operator has left the room. A delay of 3 x T seconds is achieved by keeping the **Run** pushkey depressed for T seconds when the measurement is started. This is a very convenient facility, particularly where repeated tests are necessary, as anyone who has had to do this with a sound level meter will testify.

4) Receiving Room: Background Level

The Building Acoustics Analyzer Type 4418 and the Rotating Boom Type 3923 are moved into the receiving room along with the microphone pre-amplifier assembly. If necessary, the length of the boom and the traverse time may be changed. The measurement of the background level is initiated by selecting: **Receiving Room, Backgr. Level** and then pressing **Run**.

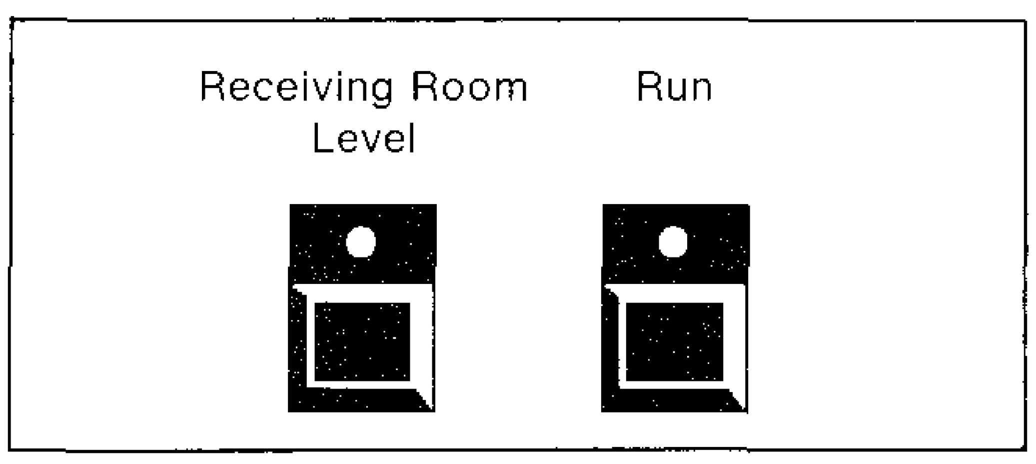


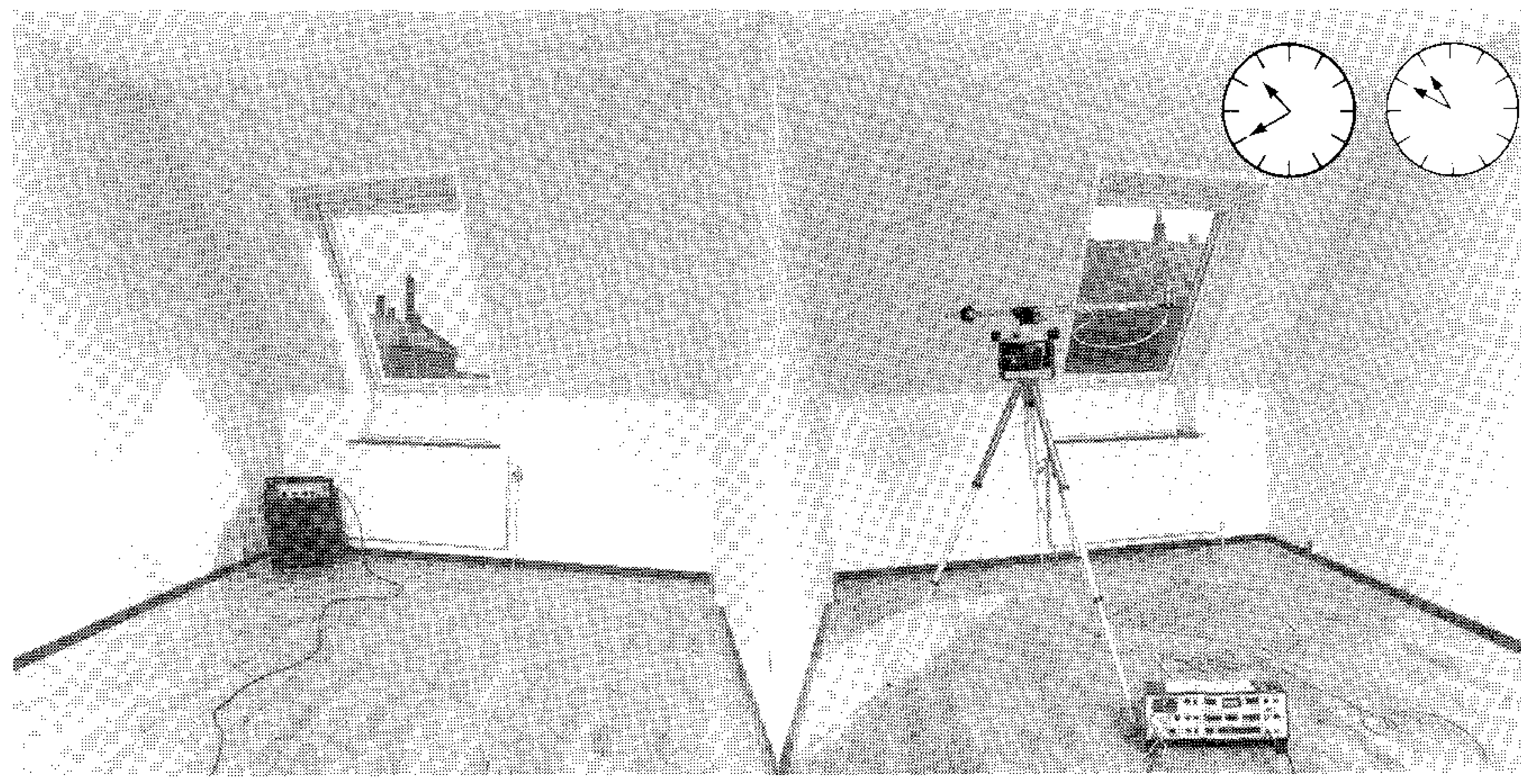


During this measurement the presence of the operator should be avoided due to the possible influence on the sound field. Use of the delayed start facility will again allow for vacating of the room before the measurements start.

5) Receiving Room Level

This measurement is comparable to the 2 previous measurements. All that is necessary is to specify **Receiving Room Level** and then start the measurement. Even though the operator may find the sound levels in this room tolerable, it is recommended that he/she does not remain present. During the measurement of reverberation time in the receiving room, the operator will more than likely wish to vacate and consistency between the two conditons must be maintained.



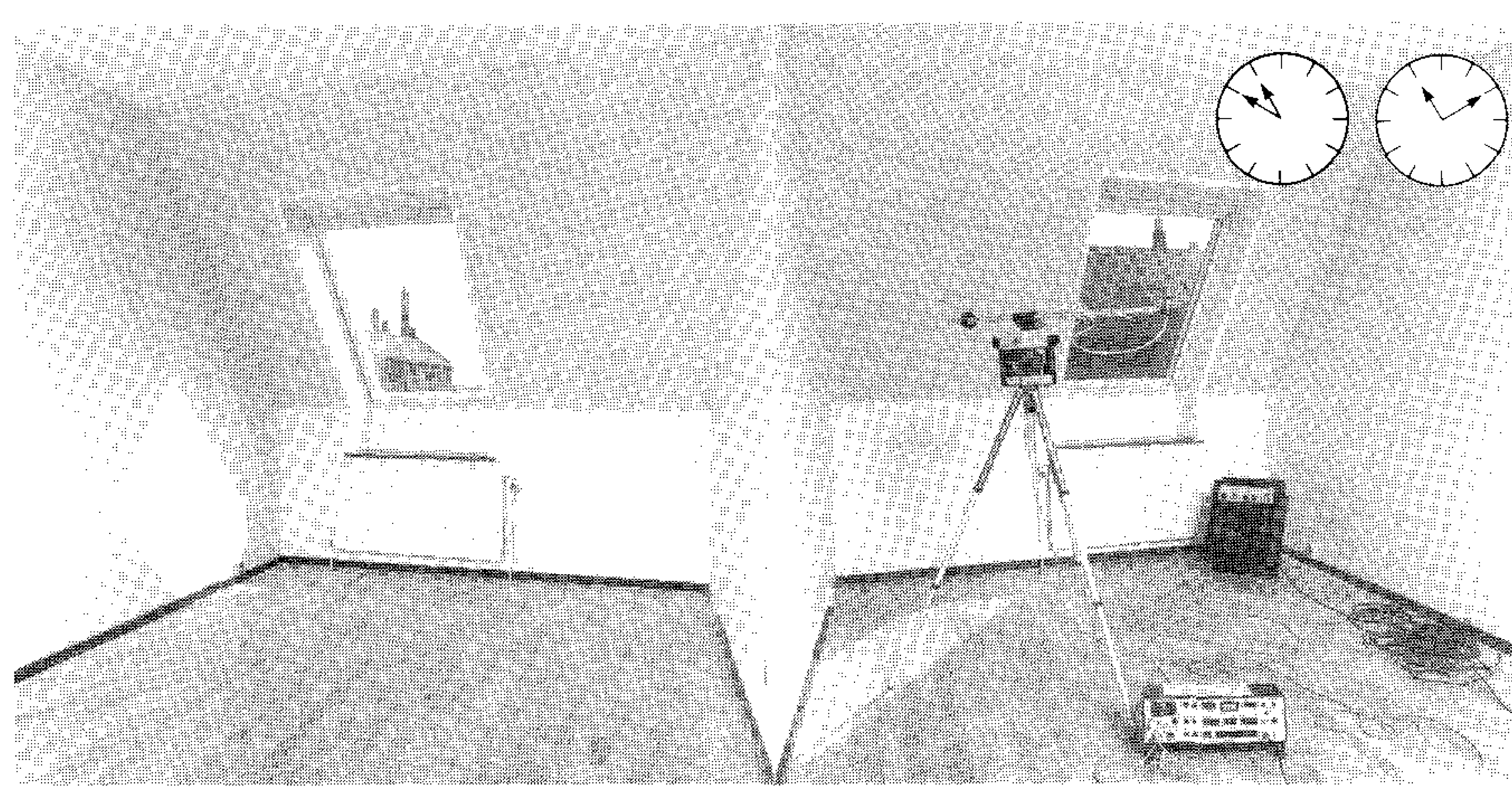


6) Reverberation Time

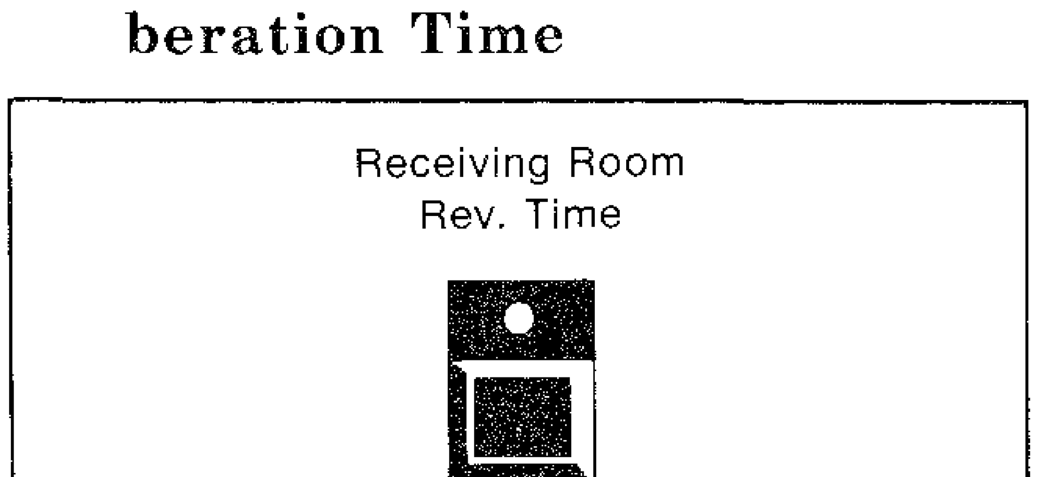
The Sound Source is now positioned in the receiving room. In order to arrive at a good estimate of the reverberation time it should be measured in more than one position in the room and preferably a number of times at each position. ISO 140/IV suggests that three microphone positions and two measurements at each position should be performed. The 4418 allows a selection of 1, 3 and 9 samples respectively.

As is the case with level measurements, up to 15 reverberation spectra may be averaged, so that determination of reverberation time may be based on up to 9 × 15 decays. The decays are not stored in the analyzer. Instead, the reverberation time is computed during the decay. Consequently it is necessary to specify a determination interval before the measurement takes place. The analyzer allows a choice of 3 different determination intervals: 20, 30 and 40 dB, i.e. −5 to −25 dB, −5 to −35 dB and −5 to −45 dB.

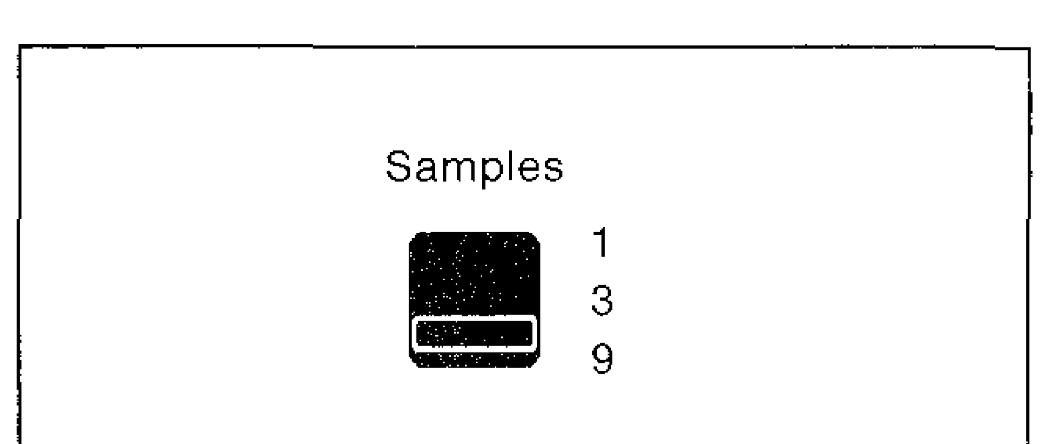
The measurement procedure is as follows:



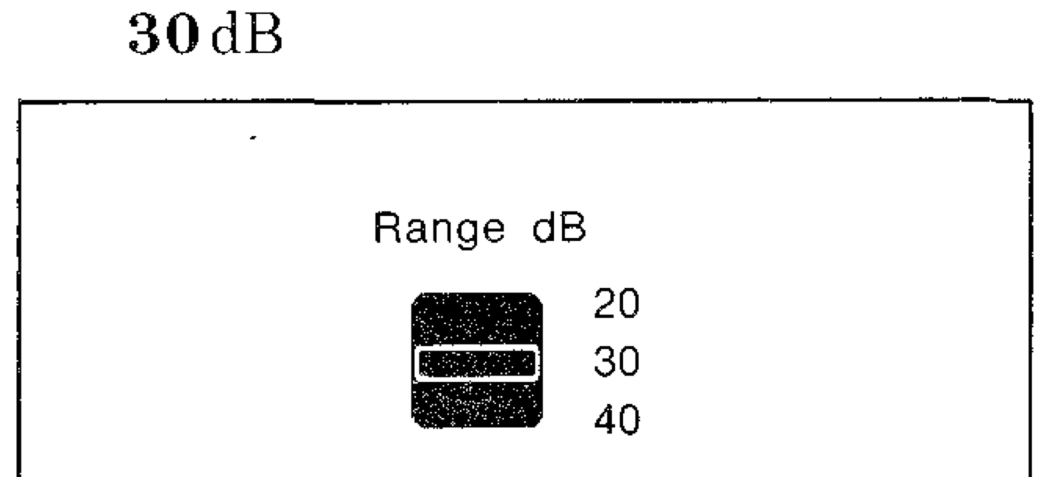
1. Select measurement: **Reverberation Time**



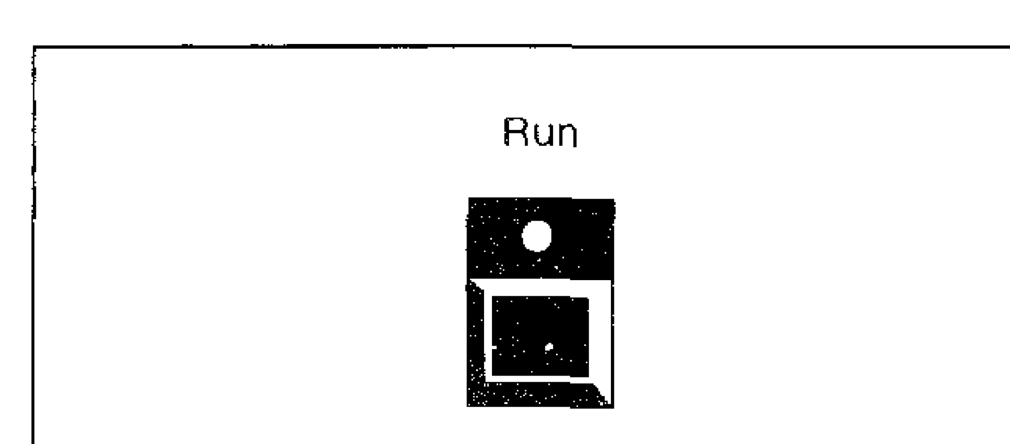
2. Select no. of samples: **9**



3. Select determination interval: **30** dB



4. **Start** measurement



If a failure occurs during the measurement, the instrument will automatically try to recover the failure by repeating the measurement for most error conditions. After the measurement, it is possible to view the results and repeat the measurement in single bands where an error condition has occurred.

During the reverberation measurements, the motion of the boom is is determined by the number of samples selected on the 4418. Figure 4 shows the traverse pattern when the samples selected are 1, 3, and 9 seconds respectively.

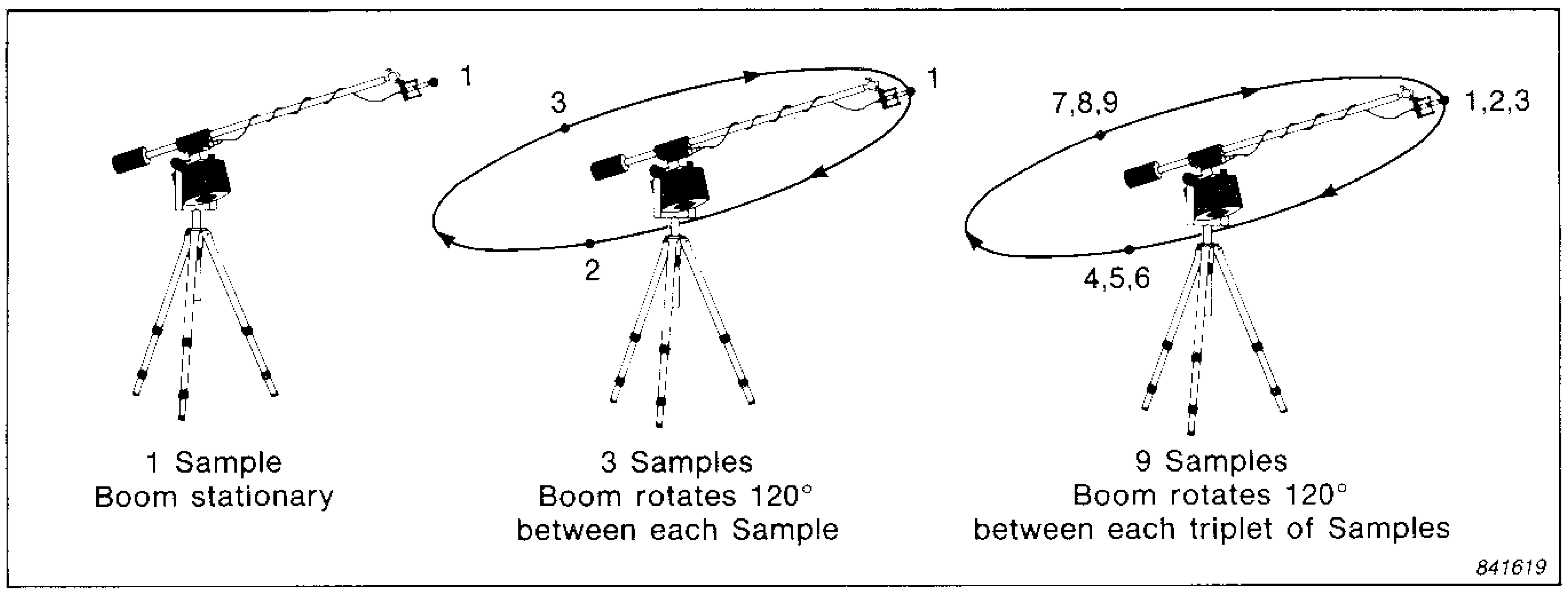


Fig. 6. Behavior of the microphone boom as a function of SAMPLES setting on the 4418 during reverberation time measurements.

Duration of measurement sequence

In order to save time the "generator on" time is adjusted according to the reverberation time when repetitive decays are measured at the same frequency. Below, table 1 gives the approximate measuring times for different measuring programs. The quantity chosen is indicated by " + " and when not chosen it is indicated by " – ".

	Level Meas.				Reverberation Meas.		Total Time approx.
	Averaging Time	Source Room	Backgrd. Noise	Receiving Room	Rev. Time	Samples	
1	5 s	+	+	+	+	1	8 min
2	16 s	+	+	+	+	3	23 min
3	32 s	+	+	+	+	9	41 min
4	5 s	+	–	+	+	1	6 min
5	16 s	+	–	+	–	–	10 min
6	16 s	–	+	+	+	3	19 min
7	–	–	–	–	+	1	2 min
8	–	–	–	–	+	3	9 min
9	–	–	–	–	+	9	14 min
10	5 s	+	+	+	–	–	6 min
11	16 s	+	+	+	–	–	14 min
12	32 s	+	+	+	–	–	27 min
13	5 s	+	–	–	–	–	2 min
14	16 s	+	–	–	–	–	5 min
15	32 s	+	–	–	–	–	9 min

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Table 1. Approximate duration of automatic measuring time assuming an absence of errors. The frequency range of interest during the measurement was 100 Hz to 3150 Hz, and the reverberation time was approximately 1,2 s over this range. The microphone boom was used for the necessary spatial averaging, and the time for print out of results on the alphanumeric printer is included in the total time.

Manual entry of data

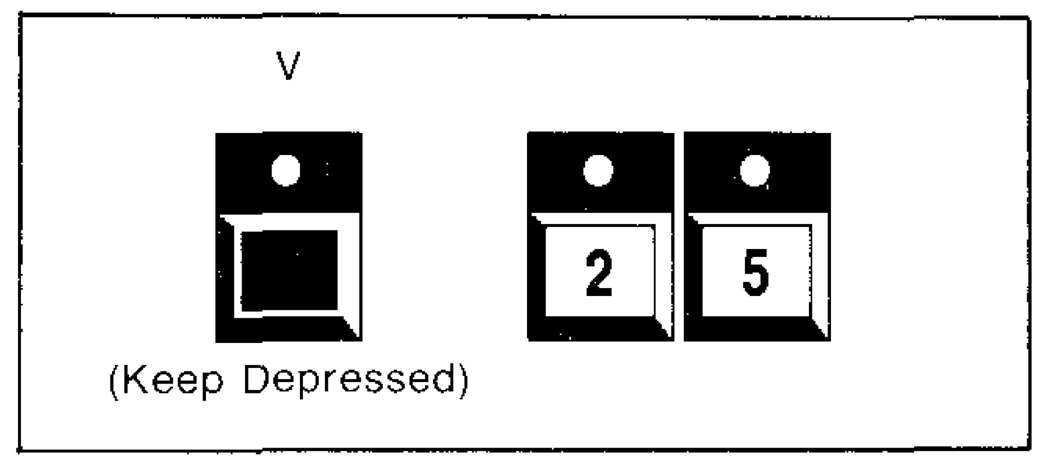
The measurement data are now stored in the memory of the 4418, and will not be lost even if the instrument power is switched off. The calculations may be done on the spot or at a later time somewhere else. If it is desired to transfer the data to an external device like the Digital Cassette Recorder Type 7400, computer or a printer after the return to the lab, this is also possible.

Until now everything has been straight forward. The 4418 has controlled the whole measurement. If an error condition has arisen, the analyzer has issued a warning and in some cases even tried to recover the failure. Most functions have their corresponding push-keys on the front panel, making the use of the instrument almost self-explanatory. Exceptions to the "one button per function rule" have been given in the sections on Calibration and Spectral Averaging. In the autocalibration procedure the level produced by the calibrator was keyed-in via the 1/3 octave center frequency push-keys on the front panel. The function of the keys in this case was designated by the number engraved on the front of each key, enabled by keeping **2nd** depressed during the entry of the calibration level.

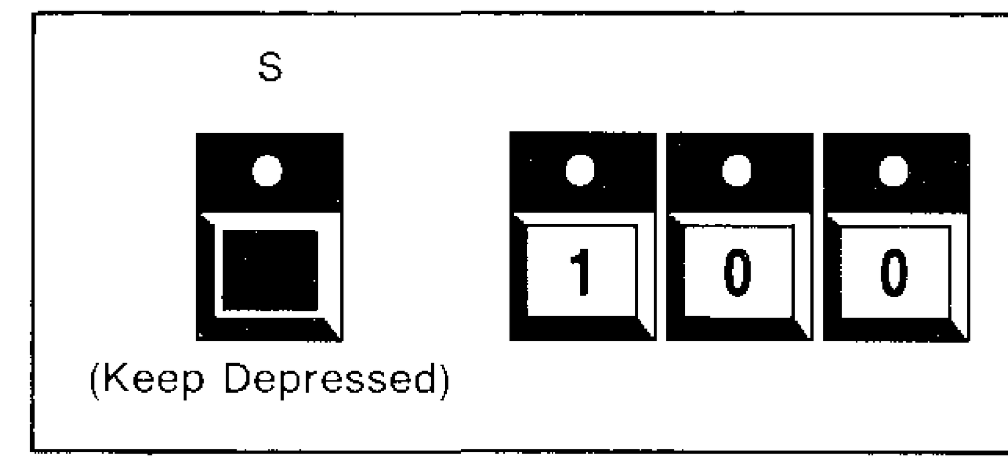
Push-key **2nd** has a function comparable to the shift key on a typewriter. The other "shift" keys, **V** and **S** are used for entry of the volume V of the receiving room and surface area S of the party wall. This information is necessary when the normalized level difference (sound reduction index) is to be determined.

The procedure is:

1) Key-in V (e.g. = 25 m^3)



2) Key-in S (e.g. = 10,0 m^2)



Option Calculations

With all the necessary data stored in the memory of the instrument, a number of calculations may now be performed.
Since the 4418 can do calculations not only according to ISO standards but also to a range of national standards it is necessary to specify the standard before the calculation takes place. This is done by pressing **Option** and then a 2 digit number all while keeping pushkey **2nd** depressed.

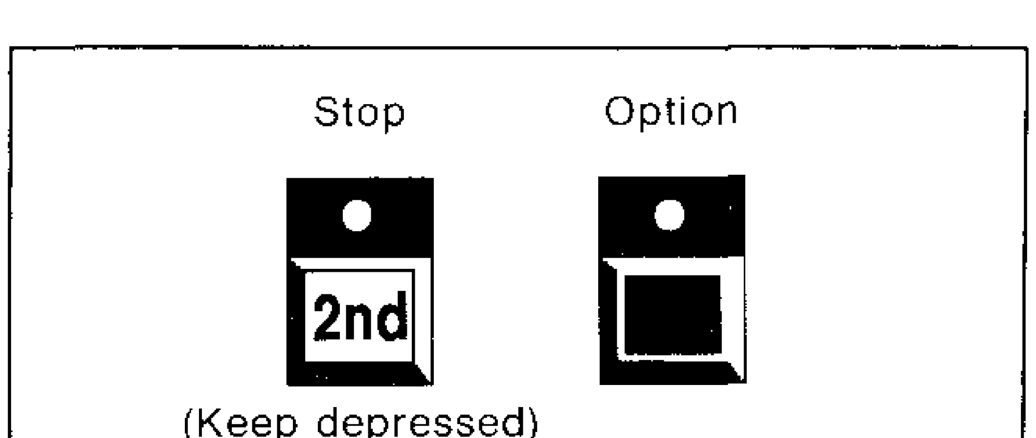
The 4418 has 39 calculation procedure options, as given in table 4, and the possibilities are further enchanced via the 8 programs switches found under the lid of the instrument.

Correction for background noise

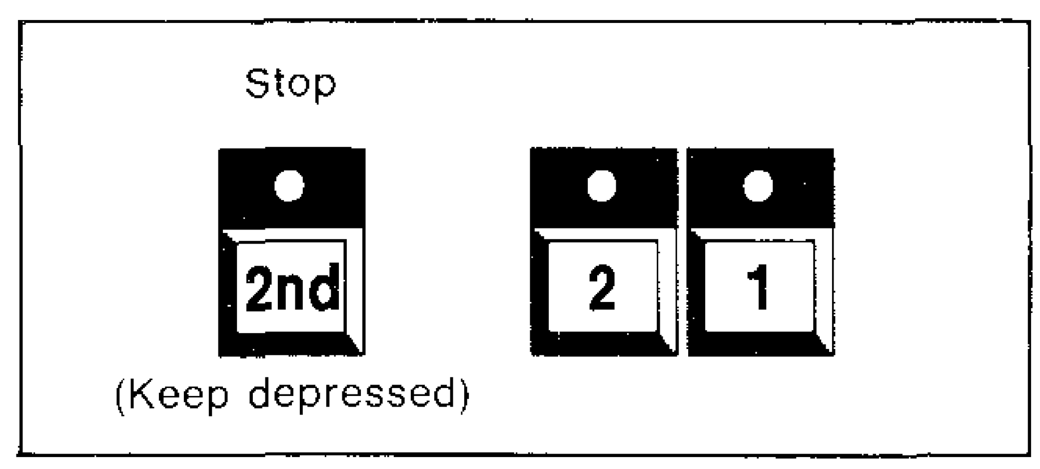
The very useful calculation "Correction for background noise of the receiving room level" is one of the options. When this is activated the data in Receiving Room Level will be corrected for background noise according to ISO 140 or ASTM E492-73T before further calculations are made.

The procedure is:

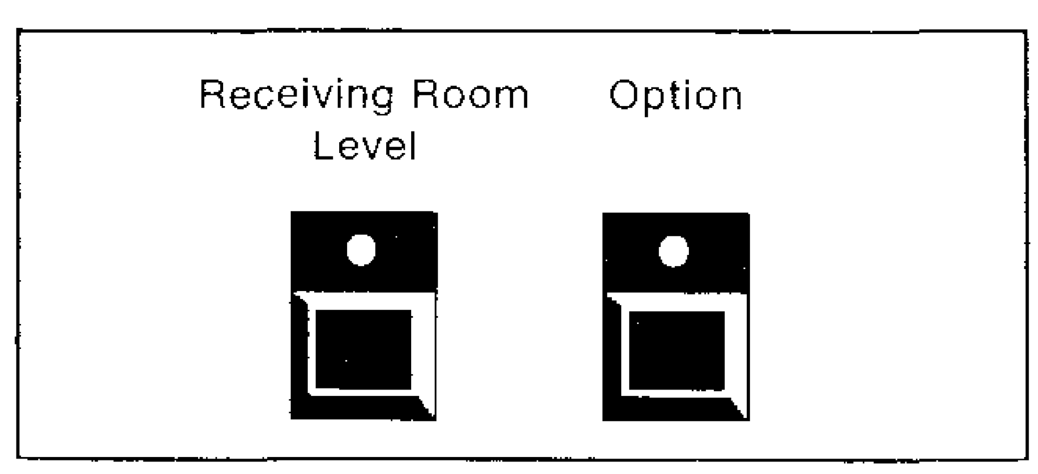
1. Check Option No: This is done by pressing **Option** while keeping **2nd** depressed.



2. If necessary, change Option No. In the case of correction for background level, option no. 21 is relevant. The Option No. is changed to 21 by pressing pushkeys **2** and **1** while keeping **2nd** depressed.

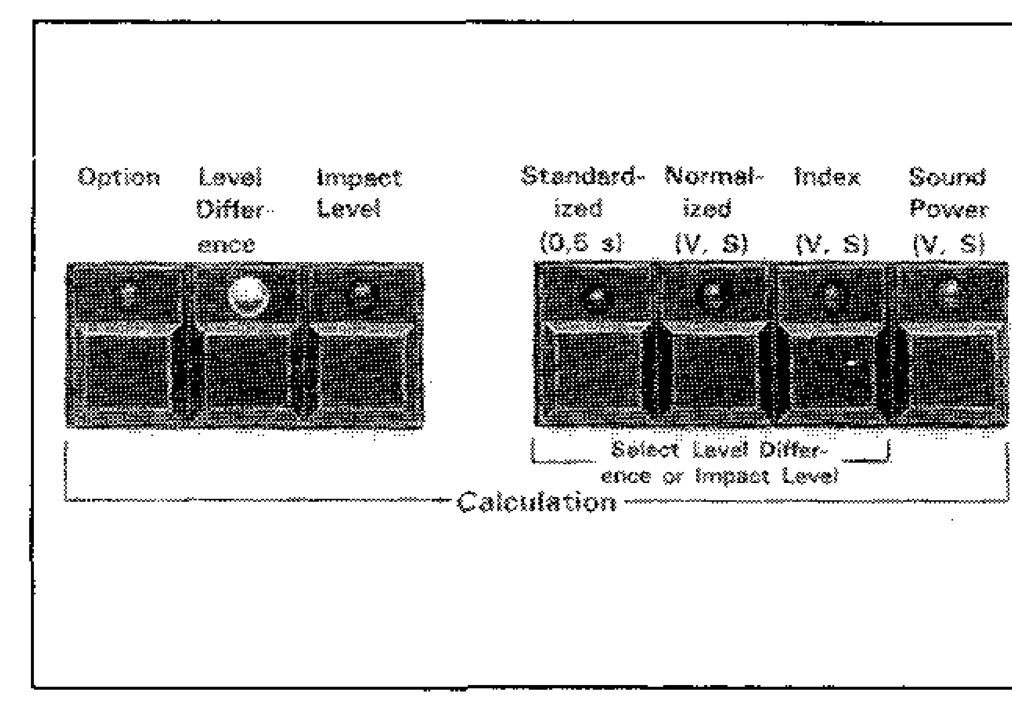


3. The correction is performed by first specifying the spectrum that should be corrected, i.e. **Receiving Room Level** and then pressing **Option**:

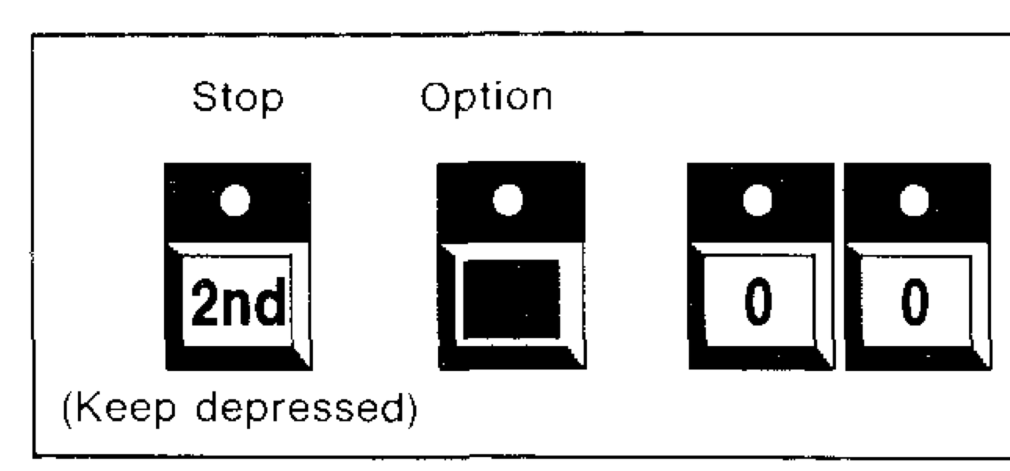


Examples of Standard Calculations

When the option no. has been set to 00 each of the ISO calculations given in table 2 is carried out by activation of the corresponding pushbutton in the "Calculation" segment of the 4418 front panel.



To set option to 00:



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	Insulation Indices	(ISO R 717) (ISO 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	Impact Indices	(ISO R 717) (ISO 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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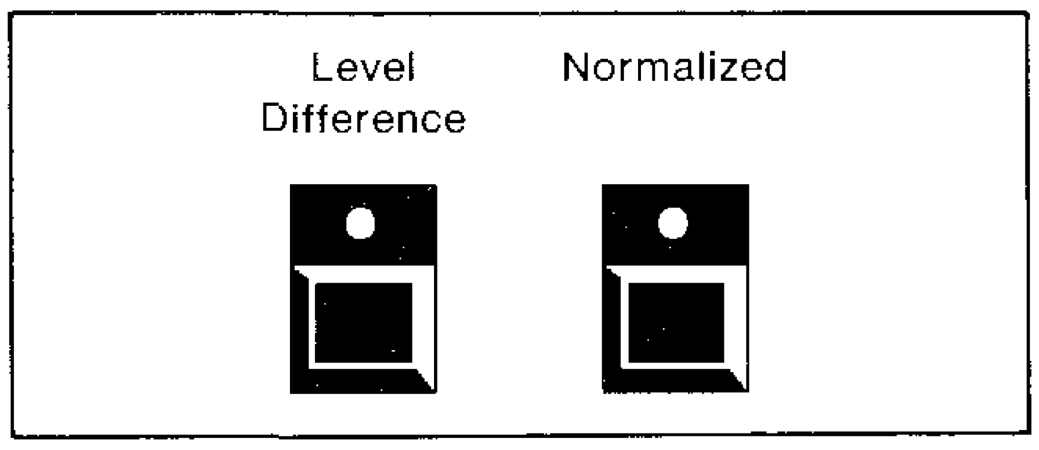
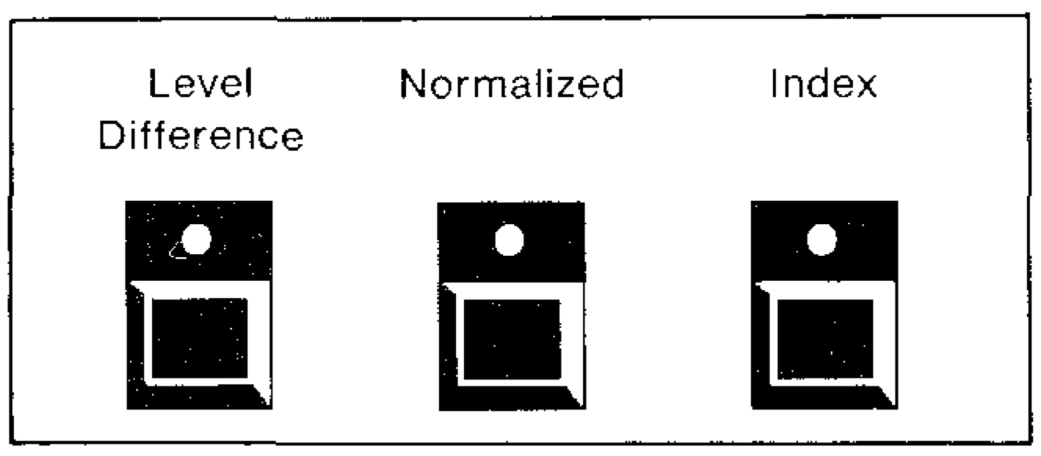
Table 2. ISO calculation capabilities of the Type 4418. The symbols on the left-hand side of the equations are those used by ISO. On the right-hand side, T is the reverberation time at a specific frequency, V is the room volume, S is the room's surface area (or party wall's surface area), and f is the center frequency.

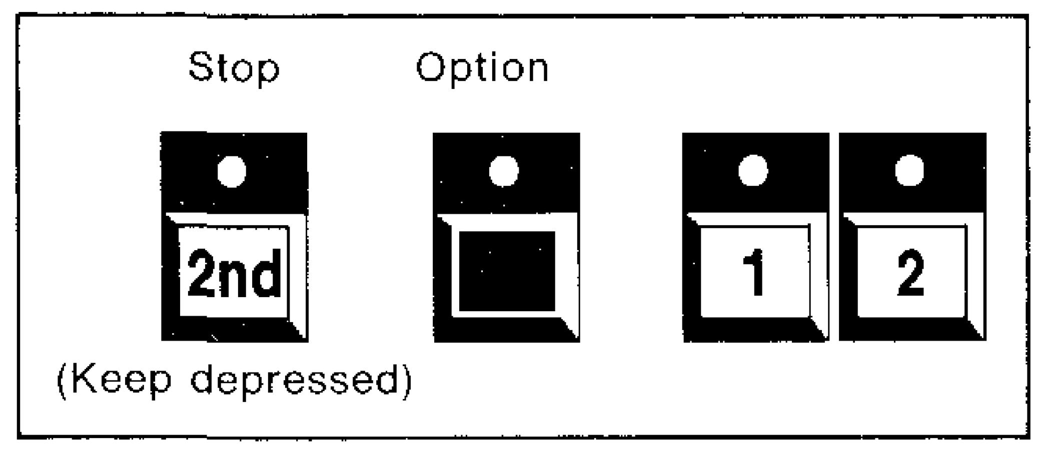
Example 1. Normalized level difference is calculated by first pressing **Level Difference** and then **Normalized.**



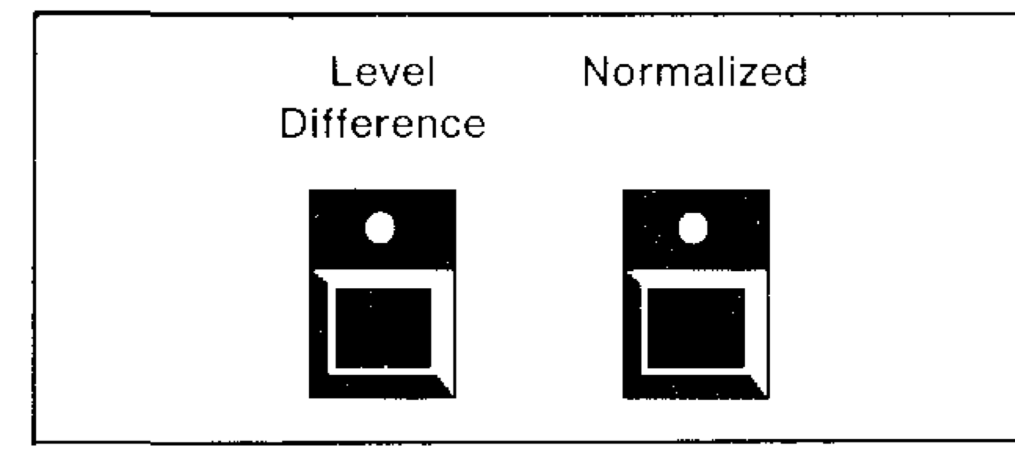
Example 2. Index calculation according to ISO 717. The index calculation based on normalized levels is activated as follows:



Example 3. If the corresponding parameters are to be computed according to non ISO standards the option no should be changed from 00 to the relevant option number. Suppose parameters should be computed to DIN 52210. Option 00 is changed to option 12 by pressing **Option** followed by **1** and **2**, all while keeping **2nd** depressed:



When now pressing **Level Difference** followed by **Normalized**:



the LSM after DIN 52210 will be calculated.

Examples of printout

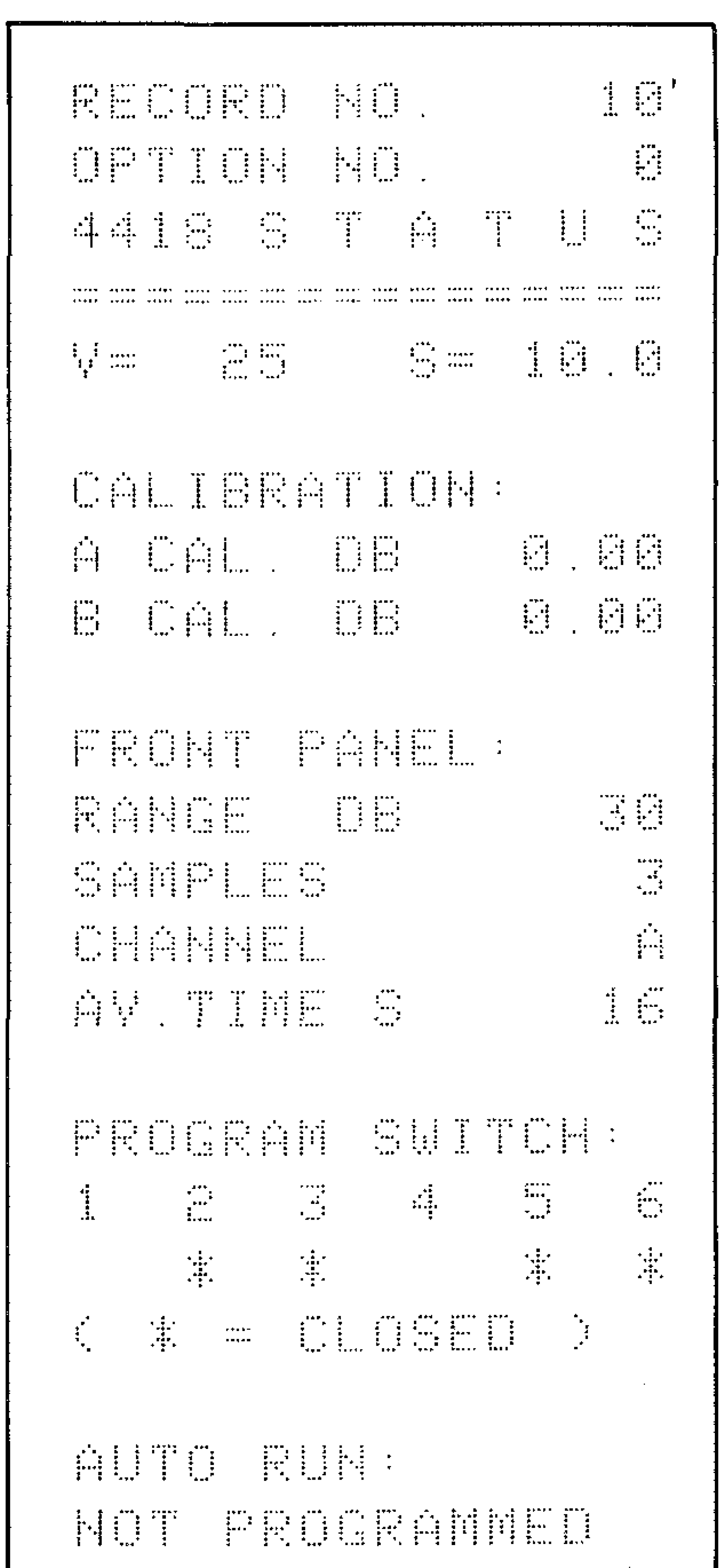


Fig. 7. Alphanumeric print-out on the Alphanumeric Printer Type 2312 showing settings of the front panel and the internal program switches. To obtain this print-out: press Option while holding 2nd depressed, then activate Printout.

In the measurement example described in the previous section it was assumed that no recorder or printer was connected to the instrumentation. Instead the measurements were documented by the operator reading off the display and writing everything down by hand. When many measurements are done, it is, however, very convenient to have the documentation done automatically.

The examples which follow show some results from the measurements described previously.

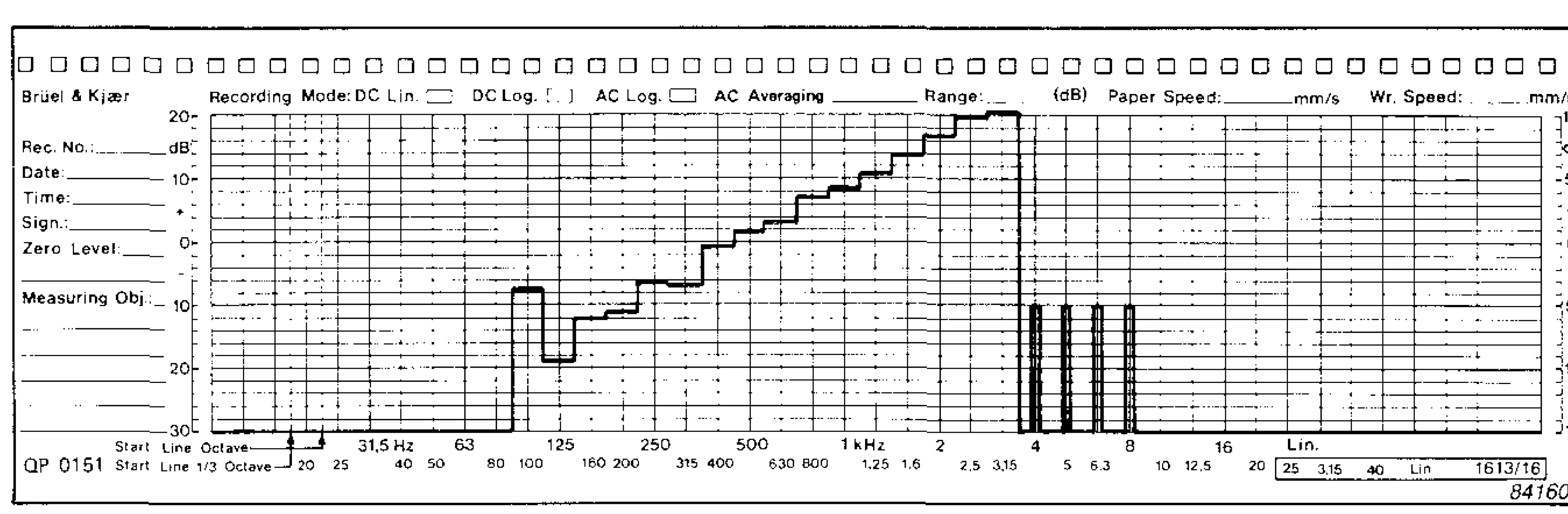


Fig. 8. The results of the level difference measurement may also be shown using the Portable Level Recorder Type 2317.

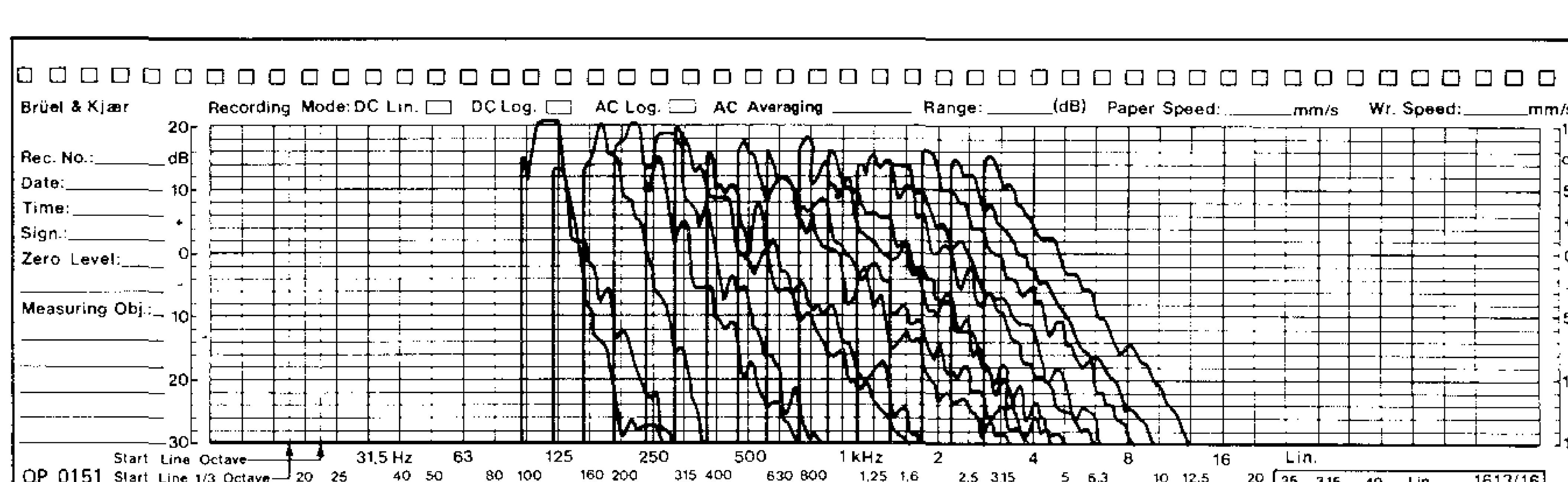


Fig. 9. The reverberation decay curves may be plotted on the Portable Level Recorder 2317 under control of the 4418.

Broadband measurements

In ISO 717 a procedure is given for converting 1/3 octave band measurements performed according to ISO 140 into single number indices. This is done in order to provide a simple means of rating sound insulation and for simplifying the formulation of acoustical requirements in building codes.

Having a single number rating it seems tempting to develop a broadband measurement method that results in a number that approximates the ISO 717 rating.

In recent years a number of attempts in this direction has been made but none has gained general acceptance. As it might be anticipated, the spread in measurement results from the broadband method is significantly larger than the spread on the ratings gained from conversion of 1/3 octave values. Consequently, the simple broadband method will probably never replace measurements in 1/3 octave bands.

Although a tight correlation with ISO 717 may not be attainable, a simple method still attracts interest for e.g. screening of a large number of similar dwellings. The screening will divide the party walls into those that are acceptable and those that need further investigation. Whenever it seems dubious whether a particular flat will fulfil the requirements a 1/3 octave band measurement may then be made.

ASTM E 597-77T is an example of such a standard, where the primary goal has been to devise a simple test method that gives results that correlate well with subjective responses of tenants.

The test in the ASTM standard consists of measuring the A-weighted levels in the source room and receiving room respectively. The absorption in the receiving room is accounted for by measurement of the sound pressure in the near field and the far field of a calibrated sound source such as the 4224. Two different spectra are used in the procedure. (For a more detailed description of the procedure see ASTM E 597-77T and the instruction manual for the 4418)

The Sound Source Type 4224 may be used along with a Sound Level Meter like the 2222 to perform measurements according to this standard. The standard has not gained wide acceptance outside the USA, and related, but not necessarily similar, standards may appear in the future. The 4224 is prepared to meet this situation since it can accept 2 additional filters.

Interfacing the 4418 with an HP-85

The 4418 can transmit data to the Alphanumeric Printer Type 2312 and the Digital Cassette Recorder Type 7400 via its B&K Low Power Interface. The interface has been designed specifically for battery operated instruments where it may be desireable to keep the power consumption lower than it is on a standard IEC interface. The LP interface is in general not compatible with the IEC interface. For details please refer to the instruction manual of the 4418 or to the booklet "Interfacing Brüel & Kjær Instruments". In some cases it is, however, possible to transfer data from the 4418 to a calculator having an IEC or IEEE interface. The 4418 is used for sound insulation measurements by the Acoustics Institute (Lydteknisk Institut) in Denmark at its facility in Lyngby near Copenhagen. Wanting to specify their own output format, the users have interfaced the analyzer with an HP-85 desktop calculator (when interfacing the 4418 with the HP-85 the 'Attention Line' - pin 12 is disconnected).

Other possibilities

The versatility of the 4418 Building Acoustics Analyzer allows it to be used for applications besides building acoustics. For example, the noise control of building support systems requires a variety of measurements such as Sound Power Level (L_W) and Insertion Loss (IL). These measurements may be made quickly and conveniently using the 4418 Building Acoustics Analyzer.

This point is illustrated in the following application example. The NOVENCO Group of companies are established worldwide, manufacturing and commissioning the installation of all kinds of ventilation systems. The sound rating of its products is a routine part of the process, the sound ratings being necessary if a system is to be correctly designed and able to meet predetermined noise criteria. The parent company, Nordisk Ventilator Co. of Næstved, Denmark, uses a Building Acoustics Analyzer for the sound rating measurements on one of its product lines.

Sound ratings for ventilation equipment include Sound Power Level (L_W) and Insertion Loss (IL).

A) Sound Power Level (L_W)
The acoustical characteristics of an item of ventilation equipment which produces noise are best described by its Sound Power Levels in octave or 1/3 octave bands. The performance of individual components in a full ventilation system can then be predicted more accurately.

B) Insertion Loss (IL)
A component which attenuates sound within a ventilation system is rated with an attenuation factor called the Insertion Loss. The Insertion Loss is basically the sound level reduction (in decibels) that will be expected after the attenuating component has been inserted into the system. For example, the sound levels in an occupied space can be predicted with and without a duct silencer in the system.

Plenum Boxes are located at the end of a ventilation duct and throttle the air before it is delivered to the occupied space. As such they are both a noise source and an attenuator of in-duct noise. The throttling of the air flow generates noise at the box (see Fig. 10). The fiberglass lining in the box together with the impedance changes due to its geometry, lead to acoustic attenuation (see Fig. 11). At the low volume flows that the boxes handle, the attenuation is independent of the actual flow rate. A rating for each of these acoustic properties is necessary.

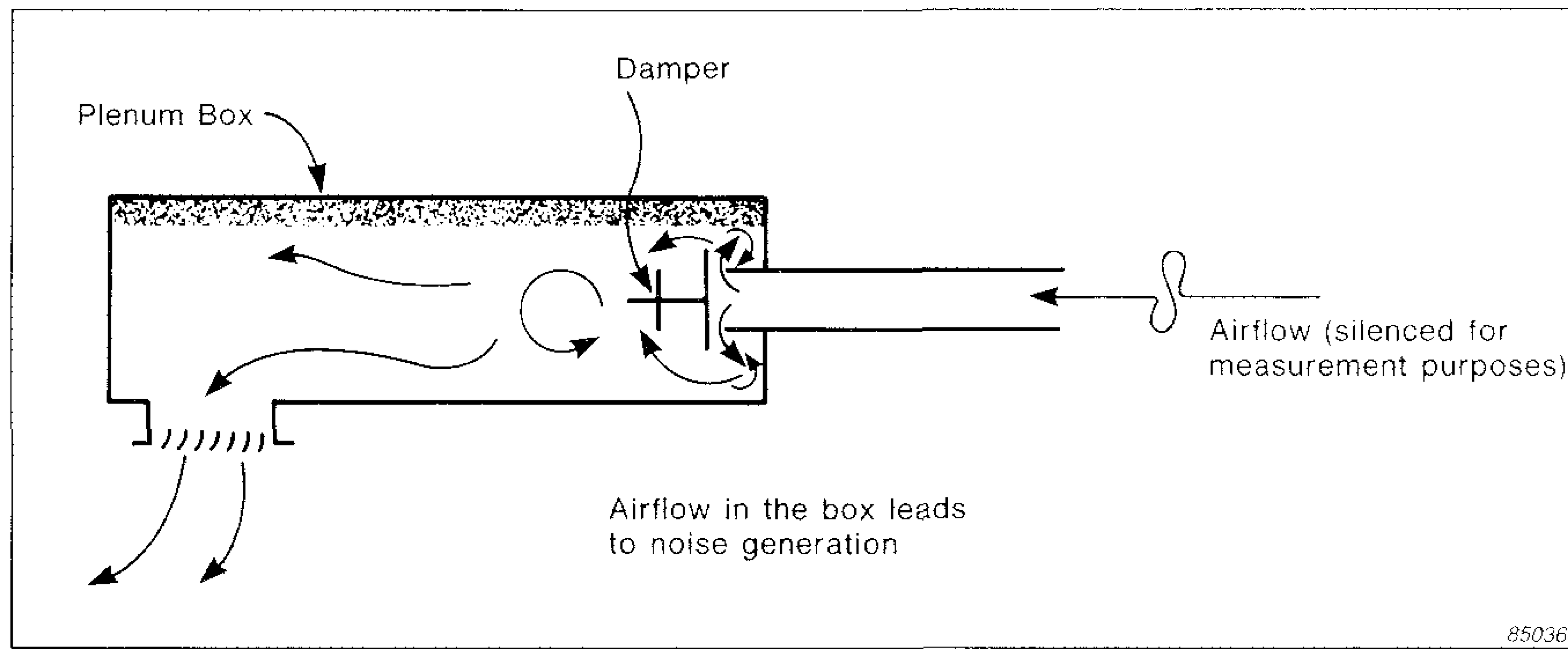


Fig. 10. Aerodynamic noise generation in a Plenum Box.

The measurements are made in a reverberation chamber. The Plenum Box under test is supplied with pre-silenced air for measurements of Lw while noise is admitted into the duct via a loudspeaker for measurements of IL. A Building Acoustics Analyzer makes the measurements and controls two loudspeaker sound sources in the reverberation chamber. The measurements and analysis made by the analyzer are monitored by an HP-85 Desktop Computer. This then accepts the data for post processing and output of hard copy in whatever format is required.

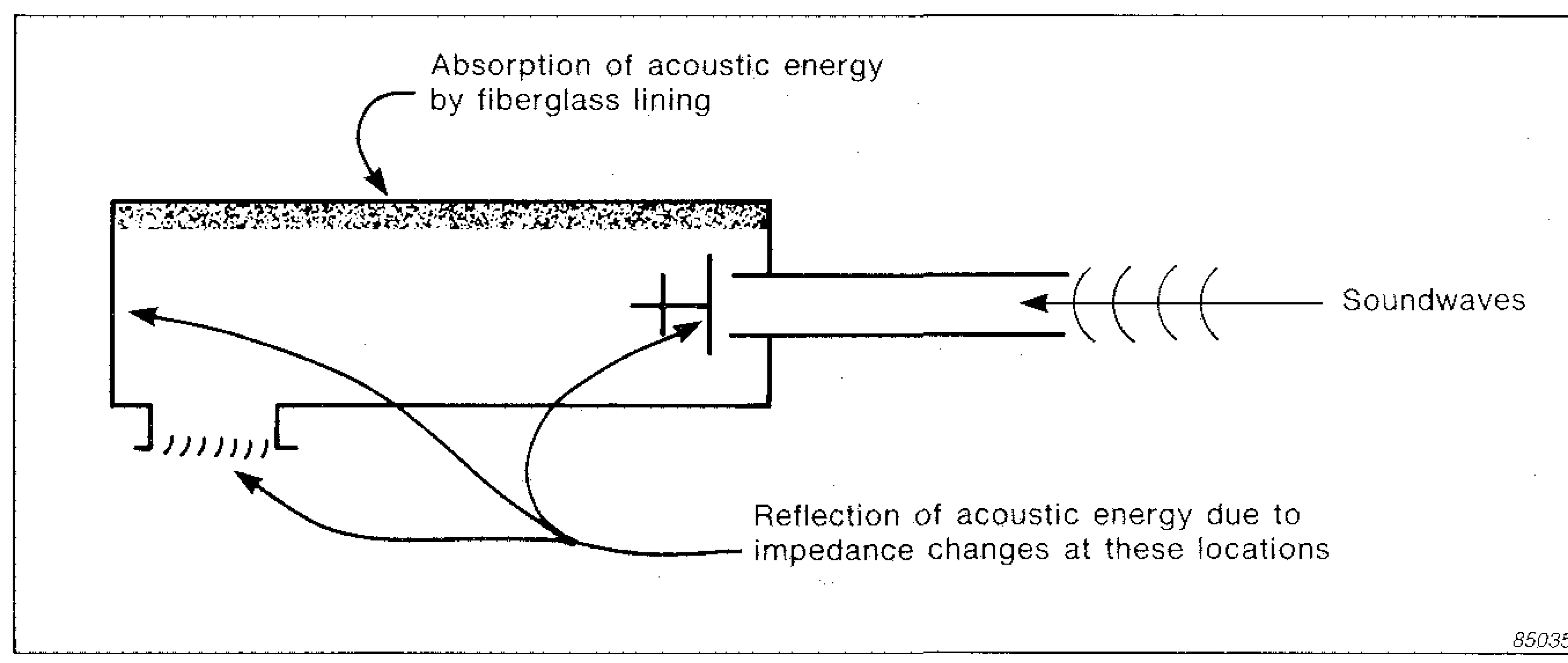


Fig. 11. Acoustic attenuation within a Plenum Box.

For measurements of Lw for the Plenum Box, the following sequence of measurements is performed:

1. The reverberation time of the chamber is measured.
2. The background noise levels are measured.
3. The sound levels due to the operating Plenum Box are measured.

With this data plus the total volume and surface area of the room, the Lw in each of the 1/3 octave bands is easily calculated. From there the octave band levels and the A-weighted level are calculated.

For measurements of a Plenum Box IL the following sequence of measurements is performed:

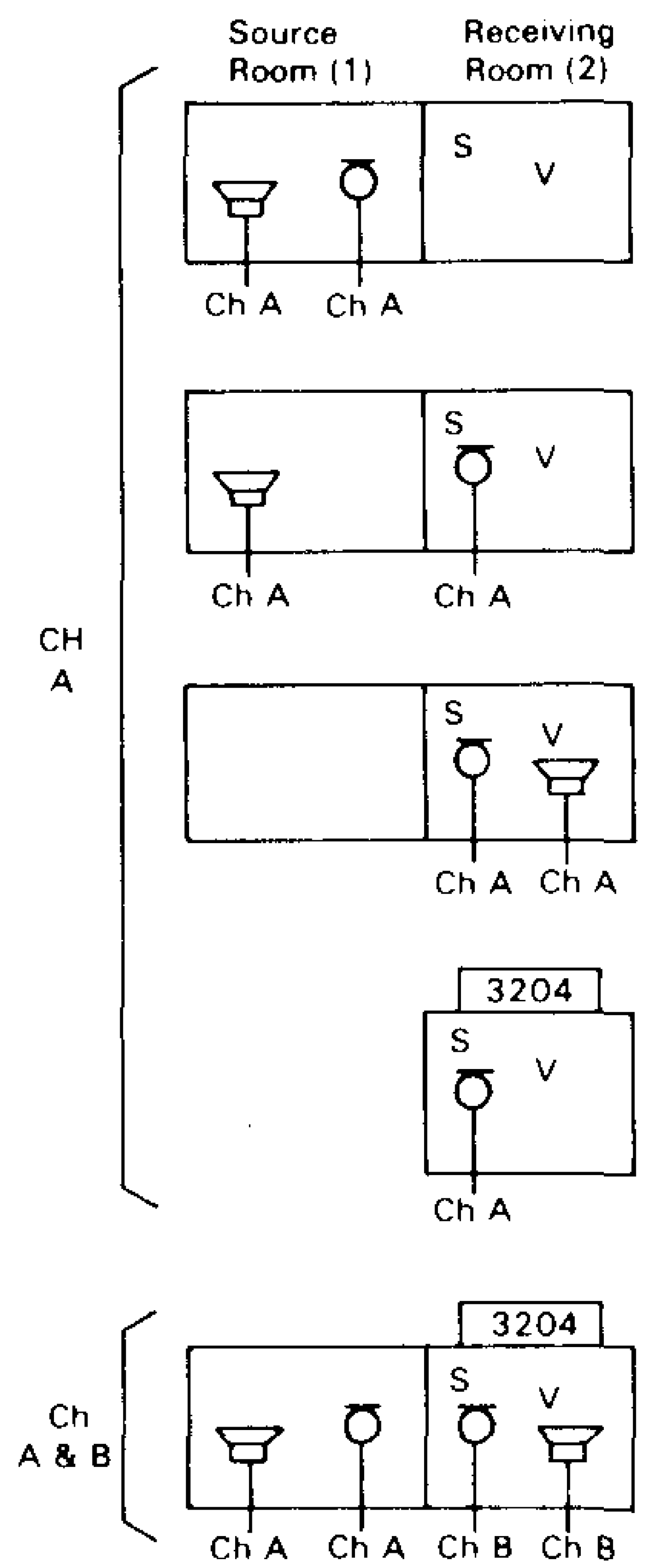
1. The sound levels due to the in-duct noise source are measured in the reverberation chamber with the Plenum Box installed.
2. The Plenum Box is replaced with an exponential horn termination, and the sound levels due to the same source are measured.

The difference between the measured sound levels is the Insertion Loss. The horn termination is used in place of the Plenum Box to ensure that the acoustic impedance at the end of the duct is not too great. If the duct were terminated abruptly, reflections at its end would lead to an apparent attenuation, particularly at the lower frequencies. Standing Wave Ratio (SWR) measurements with the exponential horn in place have shown that reflections are eliminated as far as is practically possible. The small amount of attenuation that does still exist due to reflections is quantified by the SWR measurements and correction factors can be applied.

The measurement procedure in both cases is greatly simplified by the use of the Building Acoustics Analyzer. Operator intervention is minimal and procedures which are normally time-consuming, such as the measurement of reverberation time, are completed quickly and easily. The use of the HP-85 Desktop Computer facilitates the procedure, and allows the data to be output in a variety of formats.

Reference Table for Building Acoustics Analyzer Type 4418

Please Turn Over!



Measurement	Symbol
Source Room Level	L_1
Receiving Room Level	L_2
Rec. Room Backgr. Level	L_{2B}
Reverberation Time	T
Impact Level (Rec. Room Level)	L_i
Measurement as above. Automatic channel switching	

Measurement Error Codes

Measurement	Error Code	Reason for error code
Stop	000	'Stop' pressed during measurement
Rev. Time	001	Autorange overload
	002	Level too low at noise cut-off
	003	No decay after noise cut-off
	004	Level decays too slowly
	005	Level increase during late decay
	006	Level increase at end of decay
	007	Rev. Time above measurement range*)
	008	Rev. Time below measurement range*)
	009	Microphone remote control failure*)
Level	011	Autorange overload
	012	Overload during measurement
	013	Microphone remote control failure*)
	014	Level below A/D converter range
	015	Level above A/D converter range
	016	Level below measurement range*)

*) Except for these failures: 4418 will attempt once to recover from measurement error conditions

Calculation	Equation	
Level Difference	$D = L_1 - L_2$	
— Standardized	$D_{nT} = D + 10 \log (T/0.5)$	(ISO 140)
— Normalized	$R = D + 10 \log (6.15\ S\ T/V)$	(ISO 140)
— Index	I_a = Insulation Index	(ISO R 717)
Impact Level	$L_i = L_2$	
— Standardized	$L_{nT} = L_i - 10 \log (T/0.5)$	(ISO 140)
— Normalized	$L_n = L_i - 10 \log (61.5\ T/V)$	(ISO 140)
— Index	I_i = Impact Index	(ISO R 717)
Sound Power	$L_w = L_2 + 10 \log \frac{V + 43\ S/f}{T} - 14$ (f is Centre Frequency) (ISO 3741 & 3742 Method 1)	

Calculation Error Codes

Calculation	Error Code	Reason for error code
Sound power	100	Receiving Room Level or Rev. Time not meas.
	101	V and/or S = 0
	102	Negative result
	103	Combined V, S, F and Rev. Time outside range of calculation
	104	Error code found in Receiving Room Level
	105	Error code found in Rev. Time
Receiving Room Level & Backgr Correction	200	Error code found in Receiving Room Backgr. Level
	201	Receiving Room Backgr. Level too high
Level Difference (Impact Level) — Standardized — Normalized	300	Error code found in Receiving Room Level
	301	Receiving Room Level not measured
	302	Error code found in Source Room Level
	303	Level Difference negative
	304	Error code found in Rev. Time
	305	Rev. Time not measured
	306	V = 0
	307	S = 0
	308	V relatively too large
	309	V relatively too small
	310	End result negative
— Index	400	Error code found in Normalized spectrum
	401	Calculation range exceeded
	402	Calculation Range average deviation > 2 dB
	403	Calculation range peak deviation > 8 dB
	404	Calculation range > 130 iterations
Data check	500	Error in data storage
Option Calculations	600	Error in Necessary Data
	601	Data = 0 (Not Measured?)

Switch Settings

Program switch N2 (under top cover):

Contact No.	Significance (Closed)
1	No 8 dB Rule
2	Manual Data Entry Enable
3	Level Recorder Reverse Modification
4	10 dB increase in level display
5	Limited 'Run' Frequency Range
6	Level Range 10–20 dB Enable
7	DMA Out — Used for Self Test only
8	DMA In — Used for Self Test only

Level Recorder Type 2306 – Typical Settings:

Signal Input	+
Paper speed	30 mm/s (Ext. for no decay recording)
Rec. Mode	DC Lin.
Writing Speed	250 mm/s
Paper Drive	On
Power	On
Pen Drive	On

Alphanumeric Printer Type 2312 – Typical Settings:

Clock Control Selector	Ext.
Print	Auto
Time & Data	If time printout desired; else Off
Address Switch	Low Power Operation, Left Adjusted Format
Interface Mode Switch	B & K
Power	On

Microphone Boom Type 3923 – Typical Setting:

16 seconds/revolution

Microphone Multiplexer Type 2811 – Typical Setting:

Scanning Control	External (Manual for calibration)

Cassette Recorder Type 7400 – Typical Setting:

Interface Mode	B & K LP Compatible
Record Data Enable	Press to record

Brüel & Kjær
Nærum Denmark

QH 0017

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Table 3. Reference Table QH 0017 (Obverse).

Option Calculations

Opt. No.	Necessary Data		Standard	Result of Calculation		Range Hz
00				No Option Calculations		
12	Correction Spectrum in 'Backgr. Level'		DIN 52210	Correction of Normalized Impact Level		100–8000
12	Normalized Level Difference + Index		DIN 52210	LSM (Luftschallschutzmaß)		100–3150
12	Normalized Impact Level + Index		DIN 52210	TSM (Trittschallschutzmaß)		100–3150
20	Receiving Room and Background Levels	*	ISO 140	Removal of Backgr. Level Correction		100–8000
21	Receiving Room and Background Levels	*	ISO 140	Background Level Correction		100–8000
22	Any Measurement	*	Circ. 29/6/72	Octave Conversion of all Measurements		100–8000
22	Any Calculated Level Difference	*	Circ. 29/6/72	D dB(A) (Octaves, Pink Source)		100–5000
22	Any Calculated Level	*	Circ. 29/6/72	dB(A) Calculation (Octaves)		100–5000
23	Any Measured or Calculated Level	*	NF S 31–052	dB(A) Calculation		100–5000
23	Any Level Difference	*	NF S 31–051	R dB(A) (Pink Source)		100–5000
30	Receiving Room and Background Levels	*	ISO 140	Removal of Backgr. Level Correction		100–8000
31	Receiving Room and Background Levels	*	ISO 140	Background Level Correction		100–8000
32	Any Measurement	*		Octave Conversion of all Measurements		100–8000
32	Standardized Level Difference + Index		NEN 1070	I(lu) (Octaves)		100–2500
32	Standardized Impact Level + Index		NEN 1070	I(co) (Octaves)		100–2500
40	Receiving Room and Background Levels	*	ASTM E492–73T	Removal of Backgr. Level Correction		100–8000
41	Receiving Room and Background Levels	*	ASTM E492–73T	Background Level Correction		100–8000
42	Level Difference + Index		ANSI E336–77	NIC (Noise Insulation Class)	3)	125–4000
42	Standardized Level Difference + Index		ANSI E336–77	NNIC (Norm. Noise Insulation Class)	3)	125–4000
42	Normalized Level Difference + Index		ANSI E336–77	FSTC, STC (Sound Transmission Class)	3)	125–4000
42	Normalized Impact Level + Index		ASTM E492–73T	IIC (Impact Insulation Class)	3)	100–3150
50	Receiving Room and Background Levels	*	ISO 140	Removal of Backgr. Level Correction		100–8000
51	Receiving Room and Background Levels	*	ISO 140	Background Level Correction		100–8000
52	Any Measurement	*		Octave Conversion (1/3 Octave Step)		100–8000
52	Normalized Level Difference + Index		ÖNORM S 5100	LSM (Luftschallschutzmaß)		100–3150
52	Normalized Impact Level + Index		ÖNORM S 5100	TSM (Oct. Conversion, 1/3 Oct. Step)		100–4000
90	Receiving Room and Background Levels	*	ISO 140	Removal of Backgr. Level Correction		100–8000
91	Receiving Room and Background Levels	*	ISO 140	Background Level Correction		100–8000
92	Any Measurement	*		Octave Conversion of all Measurements		100–8000
93	Any Level	*		dB(A) Calculation		100–8000
94	Any Level or Level Difference	*		Rounding to nearest dB		100–8000
95	Any Measurement			'Run': Same Frequency		100–8000
96	Any Measurement			As above, 15 Measurements averaged		100–8000

Notes:
1) * means: Press 'Option' to perform Calculation.
2) For each group, Measurement in 'Run' stops after the underlined frequency, if Program Switch No.5 is Closed.
3) Program Switch No.1 must be open. (If closed, ANSI/ASTM Index Calculations are performed without 8 dB Rule).

ISO Index Calculations

Opt. No.	Program Switch No. 1	Necessary Data	Standard	Result ISO	4418 Print	Range Hz
00	Open	Normalized Level Difference + Index	ISO R717	Ia	I(A)	100–3150
00	Open	Normalized Impact Level + Index	ISO R717	Ii	I(I)	100–3150
00	Closed	Level Difference + Index	ISO 717	Dw	D(W)	100–3150
00	Closed	Standardized Level Difference + Index	ISO 717	DnT,w	D(NTW)	100–3150
00	Closed	Normalized Level Difference + Index	ISO 717	Rw	R(W)	100–3150
00	Closed	Standardized Impact Level + Index	ISO 717	L'nT,w	L(NTW)	100–3150
00	Closed	Normalized Impact Level + Index	ISO 717	Ln,w	L(NW)	100–3150

Notes:
1) 'Run' stops after 3150 Hz if Program Switch No.5 is Closed.
2) *With Option No. = 94 instead of 00, 'Necessary Data' is rounded to the nearest dB before Index Calculation.*
3) All ISO Indices may be calculated from Octave data (Option No. 92).

2nd Functions

Select	Press and Hold	Press	Result of Entry	
	2nd	Option	View Option Number	
Option	2nd	0....9	Change Option Number	#)
		Option	Execute Certain Option Calculations	
	2nd	Measurement	Auto Run Programming	
Measurement	2nd	0....9	Manual Data Entry	#)
Measurement	2nd	M	Spectrum Averaging	
Measurement	2nd	n	View No. of Averages	
Measurement	Run/Repeat		Run delay = 3 × Hold Time	
Level Measurement	2nd	Repeat	Auto Calibration	#)
	2nd	Recorder Single Freq.	Demo Spectrum entry	
	V	0....9	Change V (Room Volume)	
	S	0....9	Change S (Room Surface)	

Note: #) Program Switch No. 2 must be Closed to enable Manual Data Entry

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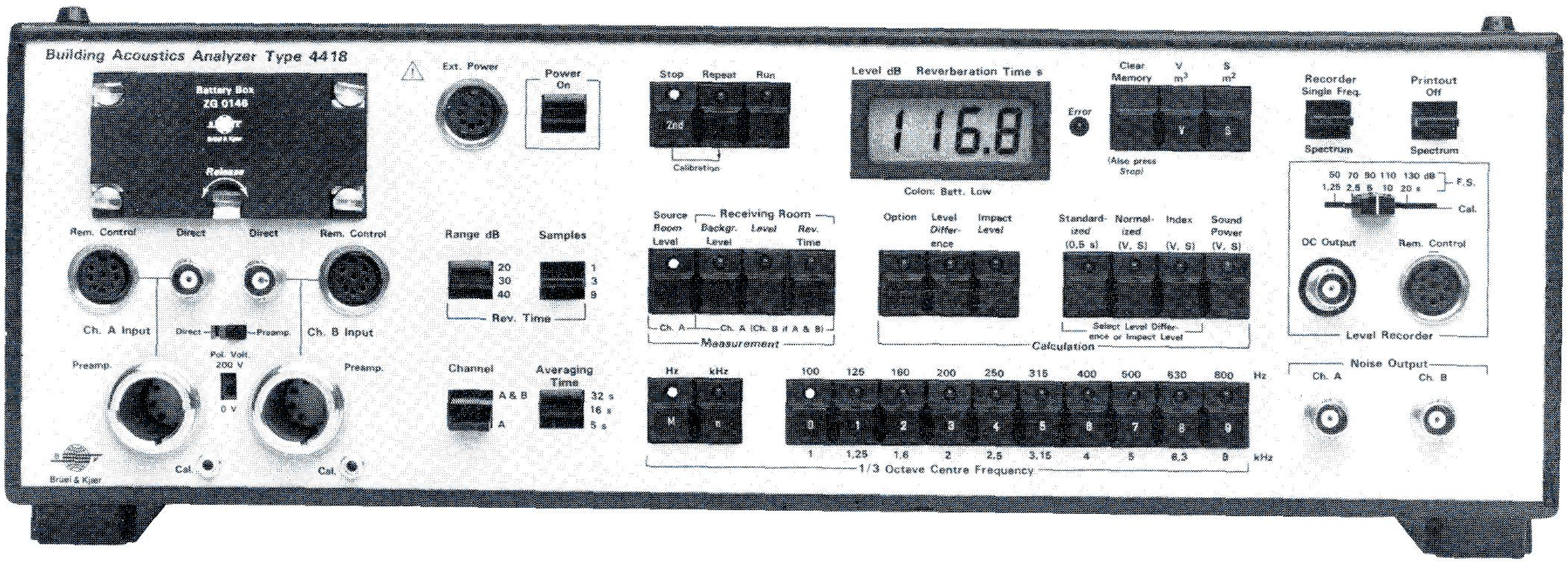
Table 4. Reference Table QH 0017 (Reverse).



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