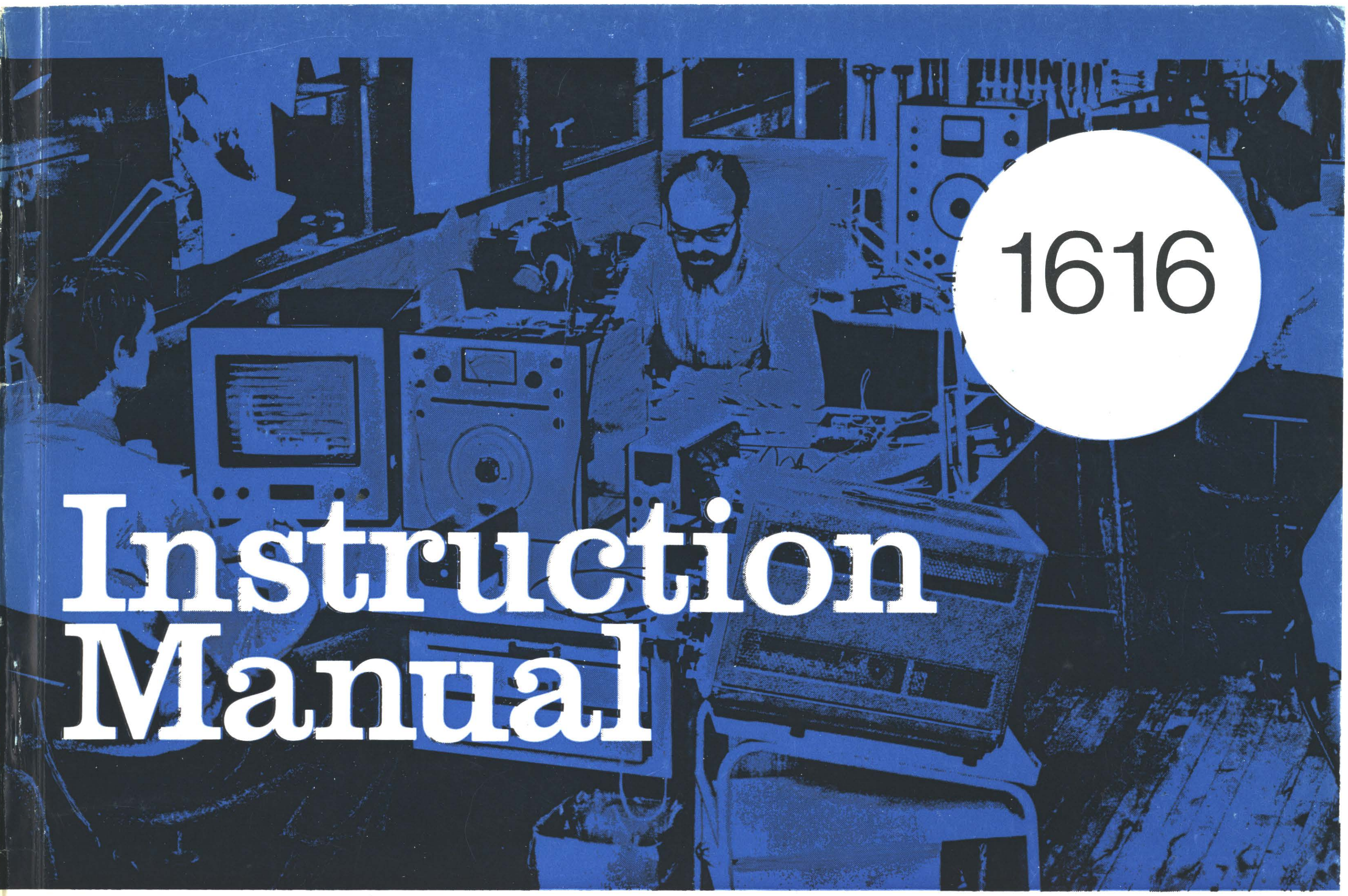

1616

Instruction Manual

1/3 Octave Filter Set
Type 1616

A portable third-octave filter set which satisfies IEC Recommendation 225, ANSI S1.11-1966 class III and DIN 45652. It is designed for operation with and attachment to the B & K Sound Level Meters Types 2203 and 2209. Filter centre frequencies 20 Hz to 40 kHz, plus a "Linear" mode 22,4 Hz to 40 kHz.
Provision is made for semi-automatic frequency analysis in conjunction with the B & K Level Recorder Type 2306.

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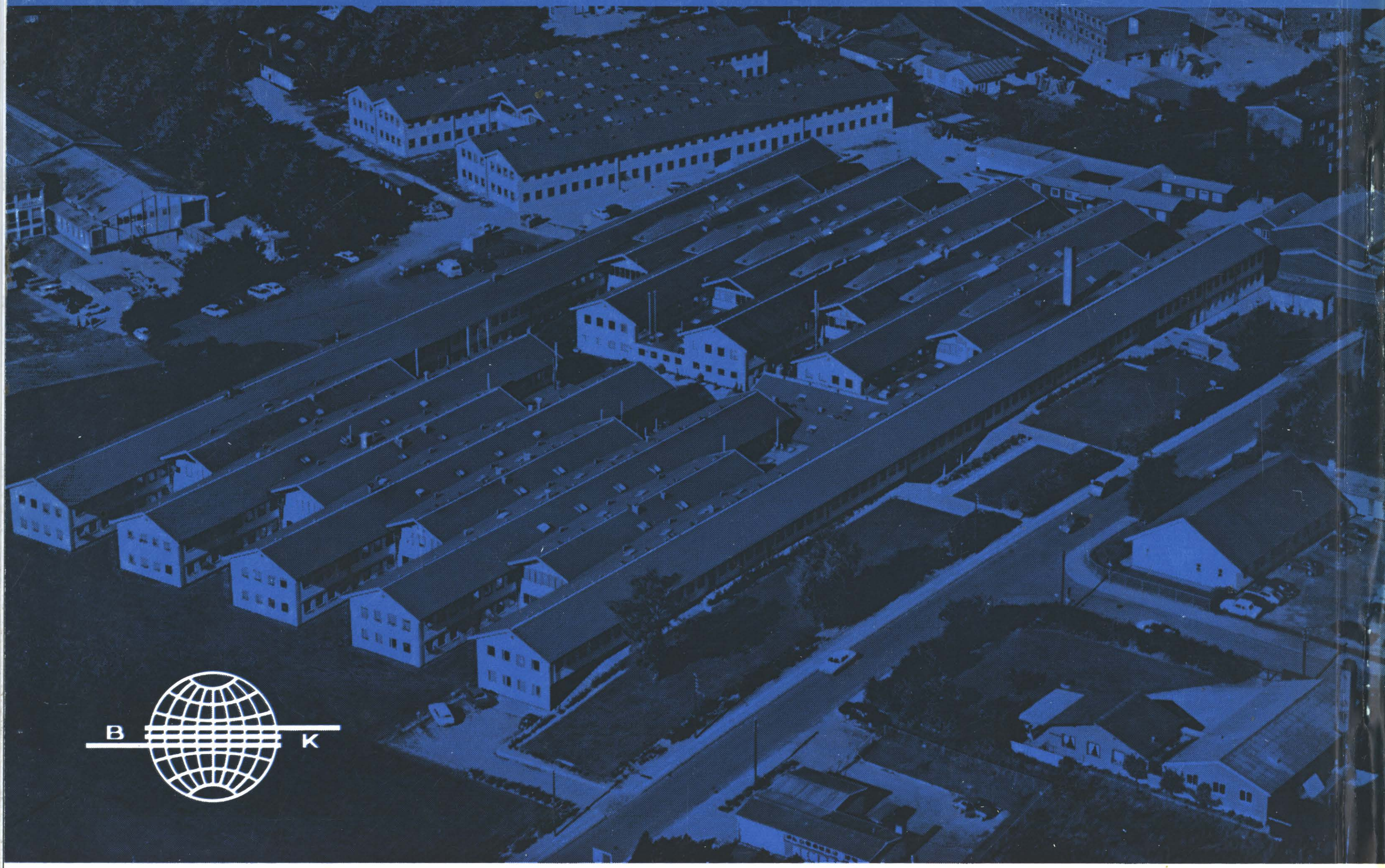

BRÜEL & KJÆR instruments cover the whole field of sound and vibration measurements. The main groups are:

ACOUSTICAL MEASUREMENTS
Condenser Microphones
Piezoelectric Microphones
Microphone Preamplifiers
Hydrophones
Sound Level Meters
Precision Sound Level Meters
Impulse Sound Level Meters
Noise Dose Meters
Noise Level Analyzers
Standing Wave Apparatus
Calibration Equipment
Reverberation Processors
Sound Sources

ACOUSTICAL RESPONSE TESTING
Sine Generators
Random Noise Generators
Sine-Random Generators
Artificial Voices
Artificial Ears
Artificial Mastoids
Hearing Aid Test Boxes
Audiometer Calibrators
Telephone Measuring Equipment
Audio Reproduction Test Equipment
Tapping Machines
Turntables

VIBRATION MEASUREMENTS
Accelerometers
Force Transducers
Impedance Heads
Accelerometer Preamplifiers
Vibration Meters
Accelerometer Calibrators
Magnetic Transducers
Capacitive Transducers
Complex Modulus Apparatus
Bump Recorders

VIBRATION TESTING
Exciter Controls — Sine
Exciter Controls — Sine — Random
Exciter Equalizers, Random or Shock
Exciters
Power Amplifiers
Programmer Units
Stroboscopes

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Strain Gauge Apparatus
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Printed in Denmark B & K Offset

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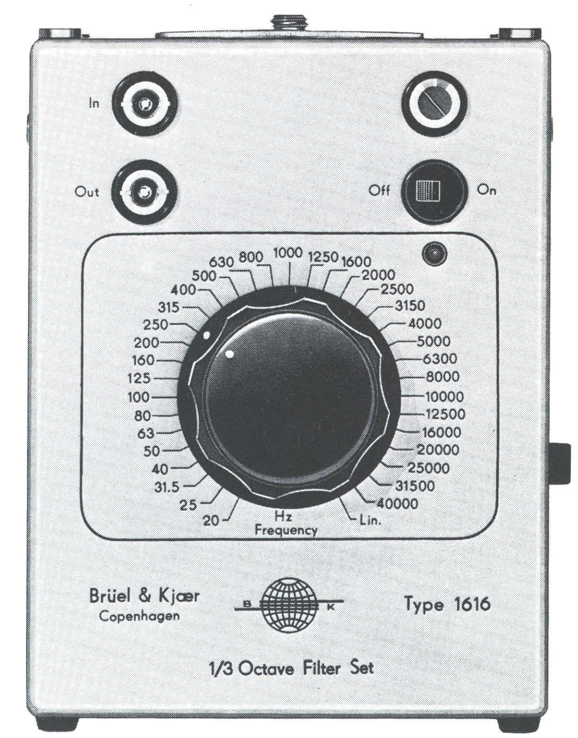
Provision is made for semi-automatic frequency analysis in conjunction with the B & K Level Recorder Type 2306.



Brüel & Kjær

033-0163

1/3 OCTAVE FILTER SET
TYPE 1616

Applicable to instruments from
serial No. 605532

May 1976

CONTENTS

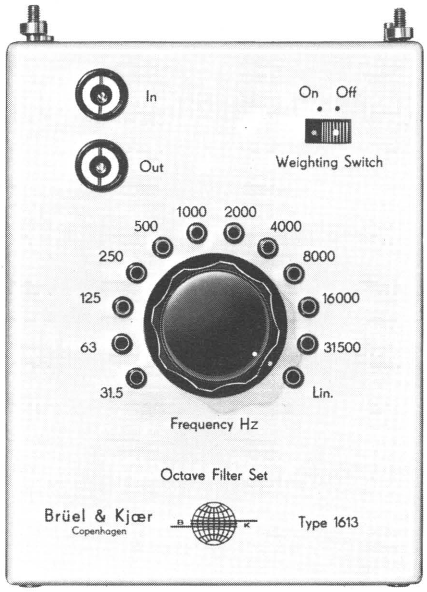
Octave Filter Set and Third-Octave Filter Set

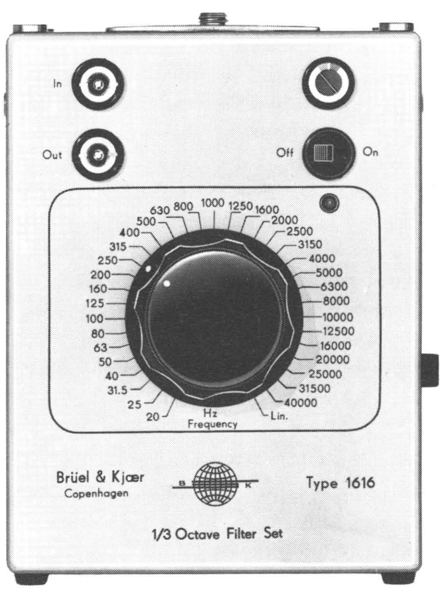
FEATURES 1613:

- 11 octave filters in accordance with IEC, DIN and ANSI Class II requirements
- Centre frequencies from 31,5 Hz to 31,5 kHz, frequency range from 22 Hz to 45 kHz
- 0 dB nominal filter attenuation, individually adjustable 0 to 50 dB
- Facility available for synchronization with Level Recorder Type 2306

FEATURES 1616:

- 34 third-octave filters in accordance with IEC, DIN and ANSI Class III requirements
- Centre frequencies from 20 Hz to 40 kHz, frequency range from 18 Hz to 44 kHz
- 0 dB nominal filter attenuation
- Push-button filter shift and filter-shift indicator lamp for semi-automatic analysis with Level Recorder Type 2306
- Battery monitoring meter





USES:

In combination with Sound Level Meters Types 2203 and 2209:

- Noise and vibration analysis
- Attenuation of background noise
- Distortion measurements
- Calibration of audiometers
- Loudness evaluation in accordance with ISO R 532 (Stevens and Zwicker)
- Noise and vibration checking to octave and third-octave limiting curves
- Building-acoustic measurements
- Sound-power measurements on machines

Additional use for Type 1616:

- External filter for Vibration Meters Types 2510 and 2511

The Octave Filter Set Type 1613 and the 1/3 Octave Filter Set Type 1616 fit the Precision and Impulse Precision Sound Level Meters Types 2203 and 2209 both mechanically and electrically to form a compact portable unit for the analysis of noise and vibration, as shown in Fig. 1.

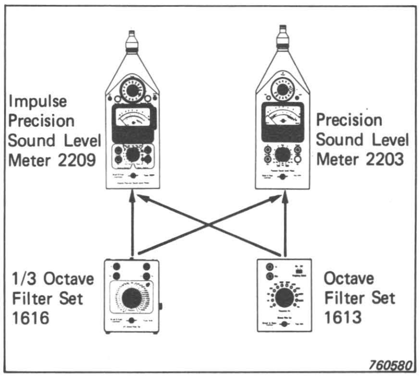


Fig. 1. Combination possibilities between Filter Sets and Sound Level Meters

Description

General

The overall frequency range of both filter sets covers the entire audio-frequency range. The centre frequencies are arranged according to the preferred frequencies of ISO R 266, DIN 45401, and ANSI S 1.6-1960, and the filters may be switched in successively by means of the selector switch, to perform a frequency analysis. The level in each frequency band may be noted in a measurement report or plotted on graph paper, or the analysis can be recorded on the portable Level Recorder Type 2306. It is possible to connect each filter set to the 2306 to allow synchronized semi-automatic frequency analyses to be made, as explained later in the text.

Octave Filter Set Type 1613

Type 1613 contains 11 passive octave filters with centre frequencies from 31,5 Hz to 31,5 kHz. In combination with a Sound Level Meter, each octave filter satisfies the requirements of IEC Recommendation 225, DIN 45651, and ANSI S1.11-1966 Class II, see Fig.2. The total frequency coverage is from 22 Hz to 45 kHz as can be seen in Fig.3. A linear position is also available covering the frequency range from 3 Hz to 40 kHz.

The signal from each filter may be individually attenuated from 0 to 50 dB by screwdriver-adjusted potentiometers. These can be reached through small holes in the front cover of the instrument. It is thus possible to obtain filter characteristics that match individual noise-limit requirements or, for example, that match the A-weighting curve. An example of use of the weighting potentiometers is shown in Fig.4. The 0 to 50 dB attenuation is also available in the linear range. All potentiometers can be switched in or out simultaneously by a front-panel switch.

The Octave Filter Set should be fed from a signal source with an impedance less than 25 Ω, and the load impedance should be 146 kΩ in parallel with from 40 to 60 pF. This means that the 1613 should not be used as an external filter for the Vibration Meters Types 2510 and 2511, or for driving the Power Amplifier Type 2706, without suitable buffer stages.

Correct terminating conditions are automatically fulfilled when the 1613 is connected to a Sound Level Meter Type 2203 or 2209. The electrical connection is provided by the screened connecting bar JP 0400 supplied with the 1613 as a standard accessory.

Low-capacitance cables are available for connecting the 1613 to other B & K instruments. AO 0034 is 0,6 m long and has a capacitance of approximately 20 pF. The capacitive component of the input impedance of the connected instrument should therefore not exceed 40 pF. If it does, there is a risk of the high-frequency filters exceeding their tolerance limits. Some older types of B & K instruments have an input impedance of 1,2 MΩ in parallel with 40 pF at the external-filter socket, and in such combinations the AO 0034 is used at the filter input while the 0,6 m cable AO 0035 containing a 162 kΩ shunt resistance in the plug, should be used at the output.

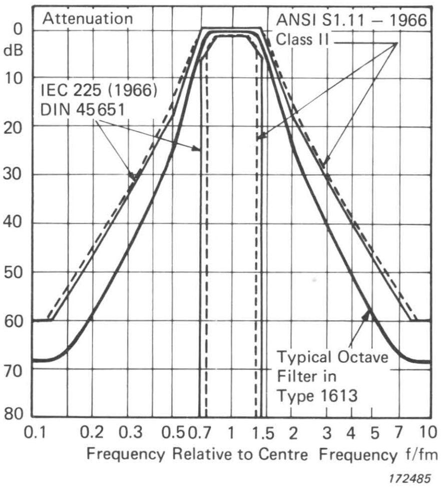


Fig.2. Typical octave filter characteristics of Type 1613 with IEC, DIN and ANSI limitation curves drawn in

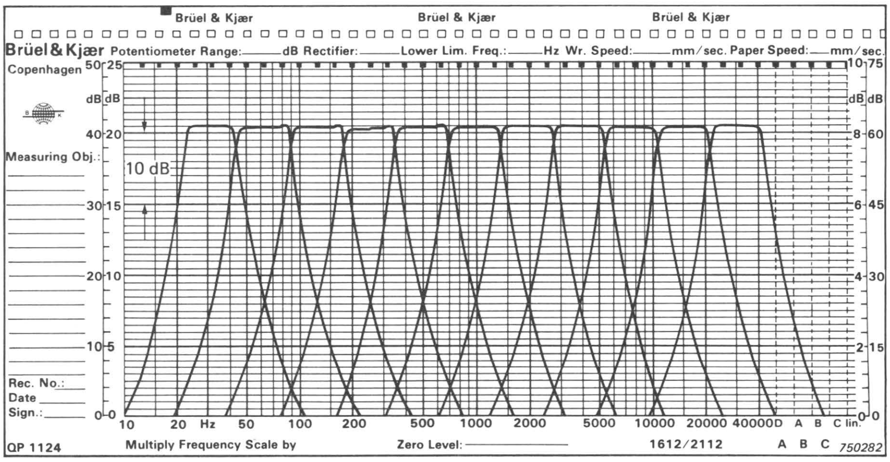


Fig.3. Frequency characteristics of the 11 octave filters in Type 1613

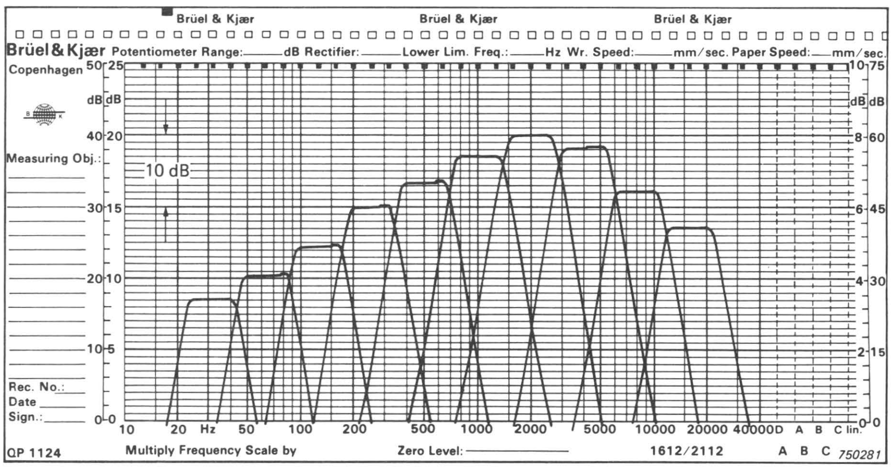


Fig.4. Example of use of the weighting potentiometers in Type 1613

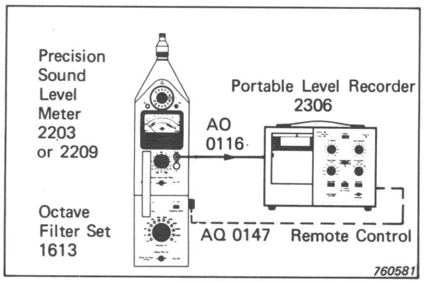


Fig.5. Portable set-up for semi-automatic octave analysis and recording

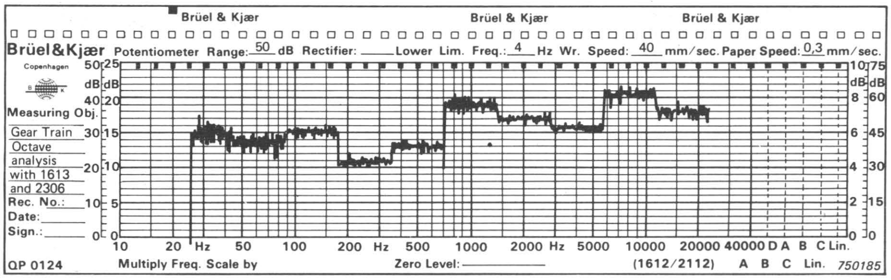


Fig.6. Octave analysis of gear train noise using the set-up in Fig.5

When the 1613 is connected to the 2306 with cable AQ 0147 which has a built-in switch and green lamp, the 2306 recording paper will stop each time its red octave filter-shift lamp lights, and the green lamp in the cable's switch will light. The filter is then advanced manually, and the switch depressed, starting the paper again. Another octave is recorded, and the process is repeated. The set-up and an example of analysis are shown in Figs.5 and 6 respectively.

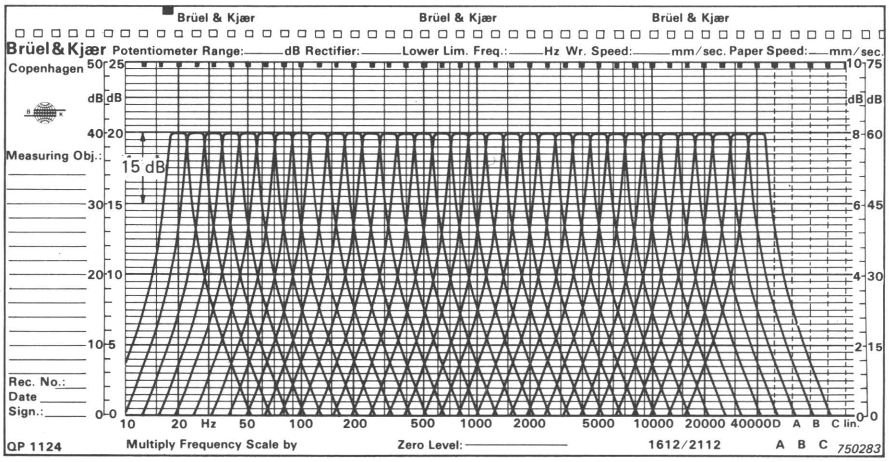


Fig.8. Frequency characteristics of the 34 third-octave filters in Type 1616

1/3 Octave Filter Set Type 1616

Type 1616 contains 34 active third-octave filters with centre frequencies from 20 Hz to 40 kHz. Each filter fulfils in itself the requirements of IEC Recommendation 225, DIN 45652, and ANSI S1.11-1966 Class III, see Fig.7. The total frequency coverage is from 18 Hz to 44 kHz as can be seen in Fig.8.

A linear position is available covering the frequency range from 22,4 Hz to 40 kHz. A 22,4 Hz high-pass filter with a slope of 30 dB/octave below pass-band is included to suppress disturbance from low-frequency signals. To damp unwanted high-frequency components, a 40 kHz low-pass filter is also included. It is designed for linear phase response giving a smooth frequency cut-off and impulse or transient response without overshoot. This last feature is of special importance when impulse measurements are made with the 1616/2209 combination. Then disturbances from low-frequency components are avoided at the same time as an overshoot-free high-frequency cut-off is maintained.

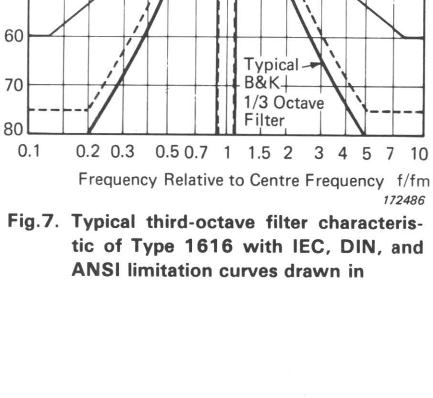


Fig.7. Typical third-octave filter characteristic of Type 1616 with IEC, DIN, and ANSI limitation curves drawn in

As the 1616 has a buffer stage in both input and output, it is less critical than the 1613 regarding interconnection with other instruments. It is well suited, for example, as an external filter for the Vibration Meters Types 2510 and 2511, and it can drive the Power Amplifier Type 2706. Loading the output with too small a resistive load, however, will cause a low-frequency cut-off determined by a 2,2 μF capacitance in the 1616 output stage and the resistive load. A load of 15 kΩ will only cause an attenuation of approximately 0,25 dB at 20 Hz.*

Electrical connection between the 1616 and a Sound Level Meter Type 2203 or 2209 is provided by the screened connecting bar JP 0400 supplied as a standard accessory with the 1616. Cables are available for connecting the 1616 to other instruments. The 1,2 m cable AO 0007 and the 0,6 m AO 0034 are fitted with a standard B & K plug while the 1,2 m AO 0116 is fitted with a BNC plug.

When the 1616 (after serial No. 605532) is connected to the 2306 with cable AQ 0148, the 2306 recording paper will stop each time its red third-octave filter-shift lamp lights, and the green lamp on the front of the 1616 will light. When the push button on the side of the 1616 is depressed, the filter is automatically advanced, and its output is short-circuited to prevent switching transients being recorded; the 2306 recording paper is started simultaneously by the same push button. Another third octave is recorded, and the process is repeated. The set-up and an example of analysis are shown in Figs.9 and 10 respectively.

* 1616s with serial No. below 541218 have 0,47 μF in the output stage causing an attenuation of approx. 3,3 dB at 20 Hz when loaded with 15 kΩ. Modification to the later standard is easy

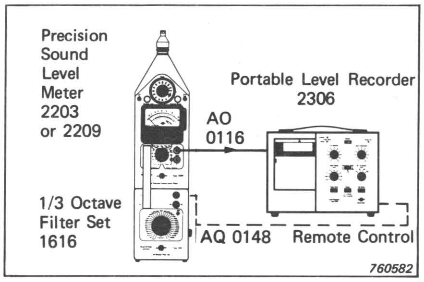


Fig.9. **Portable set-up for semi-automatic third-octave analysis and recording**

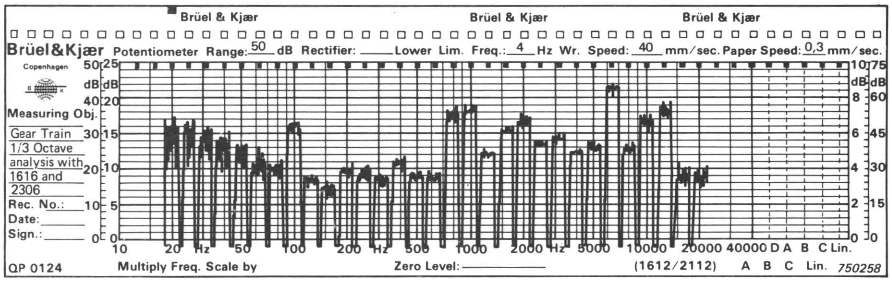


Fig.10. **Third-octave analysis of gear train noise made with the set-up in Fig.9**

Specifications 1613 and 1616

Filter Set Type	**1613, Octave**	**1616, Third-Octave**
Frequency Range		
Selective	22 Hz to 45 kHz	18 Hz to 44 kHz
Linear	3 Hz to 40 kHz Screwdriver adjustment of attenuation 0 to 50 dB	22,4 Hz to 40 kHz High-pass filter 22,4 Hz, slope below pass-band 30 dB/octave Low-pass filter 40 kHz
Band-Pass Filters	11 passive 6-pole Chebishev octave filters	34 active 6-pole Butterworth third-octave filters
In accordance with	IEC R 225-1966, DIN 45651 and ANSI S1.11-1966, Class II	IEC R 225-1966, DIN 45652 and ANSI S1.11-1966, Class III
Centre Frequencies	31,5 Hz to 31,5 kHz	20 Hz to 40 kHz
Attenuation at centre frequency	0 dB ± 0,5 dB or screwdriver adjustment between 0 dB and 50 dB	0 dB ± 0,5 dB
Peak-to-valley ripple	< 1,5 dB	< 0,5 dB
Attenuation outside pass band	See Fig.2	See Fig.7
Filter Shift	Rotary switch Green lamp in cable AQ 0147 indicates time for filter switching*	Rotary switch and push button, output short-circuited during switching with push button Green lamp indicates time for filter switching*
Remote Control	Remote control of Level Recorder Type 2306 via switch in cable AQ 0147	Remote control of Level Recorder Type 2306 via push button on 1616
Input Impedance	—	10 kΩ ± 5%, max. 10 V DC at input
Input Terminating Impedance	⩽ 25 Ω	—
Input Voltage	Max. 1 V RMS	Max. 2 V Peak
Output Impedance	—	< 5 Ω in series with 2,2 μF
Output Terminating Impedance	146 kΩ//40 to 60 pF	⩾ 15 kΩ (approx. 0,25 dB attenuation at 20 Hz with 15 kΩ load)
Inherent Noise	Not applicable	< 200 μV RMS
Magnetic Sensitivity (50 Hz)	Approx. 200 mV at output for 100 A/m field strength	Approx. 1 mV at output for 100 A/m field strength
Operating Temperature	—20 to + 50°C (—4 to + 122°F)	
Influence of Temperature	< 0,5 dB	
Influence of Humidity	< 0,5 dB for 0 to 90% relative humidity	
Batteries	None	3 × 1,5 V size D cells (QB 0004) (Type R 20 in IEC Publ. 86-2)
Battery life	Not applicable	8 hours for normal operation
Dimensions	Length 155 mm (6,1 in) — Width 120 mm (4,7 in) — Height 94 mm (3,7 in)	
Weight	2,5 kg (5,5 lb)	1,9 kg (4,2 lb) including batteries
Accessories Included	1 Electrical Connecting Bar JP 0400 2 Screened Plugs JP 0006 1 Miniature Screwdriver QA 0001 1 Screwdriver QA 0027	1 Electrical Connecting Bar JP 0400 2 Screened Plugs JP 0006 1 Plug JP 0406 3 Batteries QB 0004
Accessories Available	2 m control cable for 2306 AQ 0147 0,6 m low-capacitance cable AO 0034 0,6 m low-capacitance cable with 162 kΩ shunt resistance AO 0035	1,2 m control cable for 2306 AQ 0148 1,2 m cable with B & K plug AO 0007 1,2 m cable with BNC plug AO 0116 0,6 m low-capacitance cable AO 0034

NOTE: To couple the 1616 to a 2203 with serial No. 424272 and earlier, a new bottom plate for the 2203, DD 0135, must be ordered separately.

* Level Recorders Type 2306 before serial No. 576700 need a minor modification to make green indicator lamps work.

2. CONTROLS

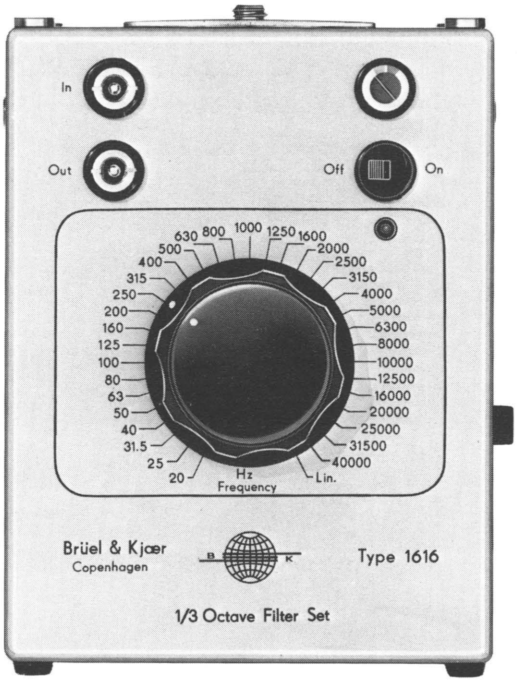


Fig.2.1. Front view of 1616

POWER: On/Off switch for connecting internal battery power to instrument.

METER: A built-in meter for battery check. Green and red areas indicate sufficient and insufficient battery condition. For changing batteries, see § 3.1.

IN and OUT: These sockets are for connection to the Sound Level Meter EXTERNAL FILTER sockets via the Connection Bar JP 0400 or to other equipment via cables AO 0007. The sockets accept the B & K coaxial plug JP 0006.

Input impedance at the IN socket is 10 kΩ, the maximum input voltage being 2 V peak. Max. DC voltage at input: 10 V. Output impedance at the OUT socket is less than 5 Ω in series with 2,2 μF. The socket should not be loaded by less than 15 kΩ.

SYNCHRONIZATION: Socket for connection to the EXTERNAL POWER/REMOTE CONTROL socket of the B & K Level Recorder Type 2306, permitting semi-automatic frequency analyses to be recorded on frequency-calibrated paper. See § 3.5. The socket accepts the B & K plug JP 0406.

FILTER SWITCH: A 35-position switch for selection of the required filter. Filter centre frequencies are indicated around the switch. A "Lin." position (22,4 Hz to 40 kHz) is also provided.

FILTER SHIFT: When this push button is depressed, the FILTER SWITCH is mechanically stepped by one third octave and the output signal is suppressed to avoid switching transients. The push button also controls the paper start of the Level Recorder Type 2306 by opening a contact at the SYNCHRONIZATION socket.

FILTER SHIFT LED: This green lamp is controlled by the Level Recorder Type 2306 when connected to the 1616 by cable AQ 0148. It lights at the same time as the red 1/3-octave FILTER SHIFT lamp on the 2306 is lit to indicate when to switch the filter.

3. OPERATION

3.1. REPLACEMENT OF BATTERIES

Before using the 1616, the battery condition should be checked. Set the POWER switch to "On". The needle of the built-in meter should deflect into the green area. If not, the batteries should be replaced. The batteries are accessible by sliding off the cover at the rear of the instrument (Fig.3.1). Take care to observe the correct polarity when inserting the new batteries.

Fig.3.1. Rear view of 1616 with battery cover removed

3.2. MOUNTING ON THE SOUND LEVEL METER

The 1616 can be directly attached to either Precision Sound Level Meter Type 2203 or Impulse Precision Sound Level Meter Type 2209. For a 2203 with serial No. 424272 and earlier, a new bottom plate, part No. DD 0135, must be ordered separately to replace the original bottom plate.

The 1616 screws directly onto the Sound Level Meter using the large finger screw (Fig.2.1). Electrical connection is then established by plugging in the Connection Bar JP 0400 supplied with the 1616. The portable analyzers thus obtained are shown in Fig.3.2 and 3.3.

If desired, move the leather carrying handle of the Sound Level Meter to give a correct

Fig.3.2. The 1616 mounted on the Precision Sound Level Meter Type 2203

Fig.3.3. The 1616 mounted on the Impulse Precision Sound Level Meter Type 2209

balance of the combined instruments. Note that bushes for the handle's screws are on both sides of the instrument.

Note: when the 1616 is fitted on the 2203, the Sound Level Meter batteries can only be changed by removing the Filter Set.

3.3. USE WITH PRECISION SOUND LEVEL METER TYPE 2203

3.3.1. Sound Measurements

1. Calibrate the Sound Level Meter as described in its Instruction Manual.

2. Set the POWER switch of 1616 to "On" and check battery condition. The needle of the built-in meter should deflect into the green area. If not, change batteries as indicated in § 3.1.

3. Set the METER SWITCH of 2203 to one of the "Lin." positions ("Fast" or "Slow" as required).

4. Hold the instrument steadily as far away from the body as possible (preferably use a tripod or other firm non-interfering support. The microphone should be at least 1 metre away from the observer's body) with the microphone directed towards the measuring object.

5. With the transparent OUTPUT ATTENUATOR knob in its fully clockwise position, turn the black INPUT ATTENUATOR knob until a meter deflection in the top 2/3 of the scale is obtained. If this is not possible, the transparent knob may also be used. However, the transparent knob should be kept as far clockwise as possible in order to maintain the optimum signal-to-noise ratio.

6. Set the METER SWITCH of 2203 to one of the "Ext. Filt." positions ("Fast" or "Slow", as required).

7. Select the desired filter on the 1616 by setting the FILTER SWITCH to the required position. If switching transients are to be avoided, this may be done using the FILTER SHIFT push button to step the FILTER SWITCH to the required position.

8. If the meter indicates less than 0 dB, increase sensitivity using the transparent OUTPUT ATTENUATOR on 2203.

9. The measured sound pressure level in the third-octave band selected is the sum of the meter reading and the number in the red lines on the transparent knob.

3.3.2. Vibration Measurements

1. Calibrate the 2203 as described in its Instruction Manual.

2. Set the POWER SWITCH of 1616 to "On" and check battery condition. The needle of the built-in meter should deflect into the green area. If not, change batteries as indicated in § 3.1.

3. Mount the accelerometer using one of the methods described in its Instruction Manual, taking care to avoid cable whip. For measurements of velocity or displacement, use can be made of the Integrator ZR 0020 (See Fig.3.4).

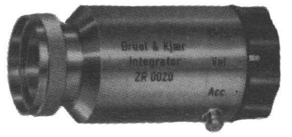


Fig.3.4. Integrator ZR 0020

4. Set the METER SWITCH of 2203 to one of the "Lin." positions ("Fast" or "Slow" as required).

5. Hold the instrument as far as possible from the vibration environment and other undesirable influences.

6. With the transparent OUTPUT ATTENUATOR knob in its fully clockwise position, turn the black INPUT ATTENUATOR knob until a meter deflection in the top 2/3 of the scale is obtained. If this is not possible, the transparent knob may also be used. However, the transparent knob should be kept as far clockwise as possible in order to maintain the optimum signal-to-noise ratio.

7. Set the METER SWITCH of 2203 to one of the "Ext. Filt." positions ("Fast" or "Slow" as required).

8. Select the desired filter on the 1616 by setting the FIILTER SWITCH to be required position. If switching transients are to be avoided, this may be done using the FILTER SHIFT push button to step the FILTER SWITCH to the required position.

9. If the meter indicates less than 0 dB, increase sensitivity using the transparent OUTPUT ATTENUATOR on 2203.

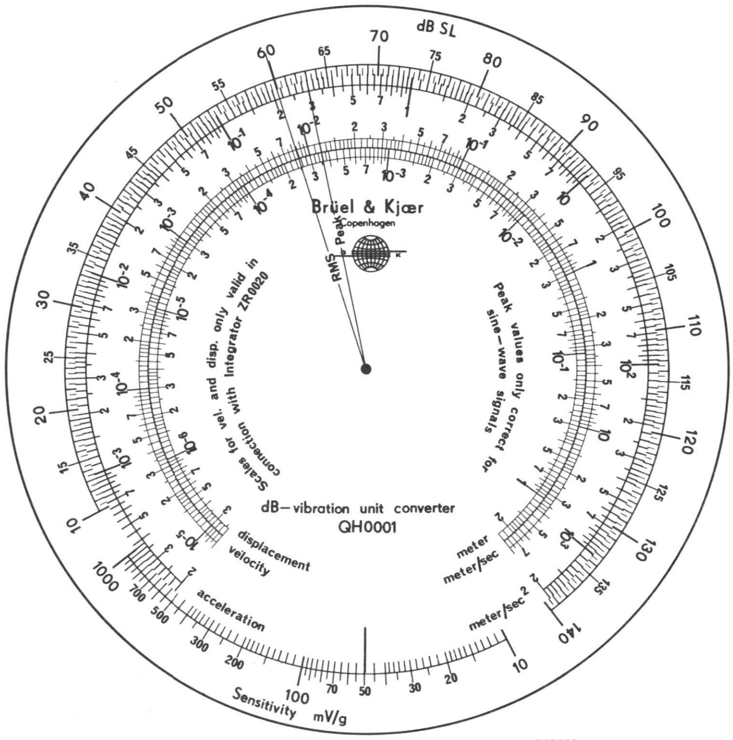


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Fig.3.5. The Slide Rule set to an accelerometer sensitivity of 50 mV/g and an instrument reading of 60 dB

10. Read the vibration level in dB indicated by the meter.

11. Set the Slide Rule QH 0001 supplied with the Integrator to the correct accelerometer sensitivity (mV/g). An example is given in Fig.3.5.

12. Set the cursor to the number of dB read on the 2203 and read off the corresponding RMS acceleration, velocity or displacement.

Note: the slide rule cannot be used for conversion of for example acceleration to velocity. Each scale must only be used in connection with the appropriate setting of "Acc.", "Vel." or "Disp." on the Integrator ZR 0020.

3.4. USE WITH THE IMPULSE PRECISION SOUND LEVEL METER TYPE 2209

3.4.1. Sound Measurements

1. Calibrate the 2209 as described in its Instruction Manual.

2. Set the POWER SWITCH of 1616 to "On" and check battery condition. The needle of the built-in meter should deflect into the green area. If not, change batteries as indicated in § 3.1.

3. Set the controls of 2209 to:

WEIGHTING NETWORK	"Lin."
METER SWITCH	as required

4. Hold the instrument steadily as far away from the body as possible (preferably use a

tripod or other firm non-interfering support. The microphone should be at least 1 m away from the observer's body) with the microphone directed towards the measuring object.

5. With the transparent OUTPUT ATTENUATOR knob in its fully clockwise position, turn the black INPUT ATTENUATOR knob until a meter deflection in the top 2/3 of the scale is obtained. If this is not possible, the transparent knob may also be used. However, it should be kept as far clockwise as possible in order to maintain the optimum signal-to-noise ratio.

   If the OVERLOAD INPUT lamp flashes, the black INPUT ATTENUATOR knob should be switched anti-clockwise until the overload is removed. The meter deflection should then be restored by turning the transparent knob anticlockwise.

6. Set the WEIGHTING NETWORK switch of 2209 to "Ext. Filter".

7. Select the desired filter on the 1616 by setting the FILTER SWITCH to the required position. If switching transients are to be avoided, this may be done using the FILTER SHIFT push button to step the FILTER SWITCH to the required position.

8. If the meter indicates less than 0 dB, increase sensitivity using the transparent knob.

   If the OVERLOAD OUTPUT lamp flashes, turn the transparent OUTPUT ATTENUATOR clockwise until the overload is removed. If the overload cannot be removed while retaining a meter deflection, any reading taken will be lower than the true signal level and the overload indication should be noted with the results.

9. The measured sound pressure level in the third-octave band selected is the sum of the meter reading and the number which appears between the two red lines on the transparent knob.

3.4.2. Vibration Measurements

1. Calibrate the 2209 as described in its Instruction Manual.

2. Set the POWER SWITCH of 1616 to "On" and check battery condition. The needle of the built-in meter should deflect into the green area. If not, change batteries as indicated in § 3.1.

3. Mount the accelerometer using one of the methods described in its Instruction Manual, taking care to avoid cable whip. For measurements of velocity or displacement, use can be made of the Integrator ZR 0020 (See Fig.3.4).

4. Set the controls of 2209 to:

WEIGHTING NETWORK	"Lin."
METER SWITCH	as desired

5. Hold the instrument as far as possible from the vibration environment and other undesirable influences.

6. With the transparent OUTPUT ATTENUATOR knob in its fully clockwise position, turn the black INPUT ATTENUATOR until a meter deflection in the top 2/3 of the scale is obtained. If this is not possible, the transparent knob may also be used. However, the transparent knob should be kept as far clockwise as possible in order to maintain the optimum signal-to-noise ratio.

If the OVERLOAD INPUT lamp flashes, the black INPUT ATTENUATOR knob should be switched anticlockwise until the overload is removed. The meter deflection should then be restored by turning the transparent knob anticlockwise.

7. Set the WEIGHTING NETWORK switch of 2209 to "Ext. Filter".

8. Select the desired filter on the 1616 by setting the FILTER SWITCH to the required position. If switching transients are to be avoided, this may be done using the FILTER SHIFT push button to step the FILTER SWITCH to the required position.

9. If the meter deflection is less than 1/3 of full scale, increase sensitivity using the transparent knob.

   If the OVERLOAD OUTPUT lamp flashes, turn the transparent OUTPUT ATTENUATOR knob until the overload is removed. If the overload cannot be removed while retaining a meter deflection, any reading taken will be lower than the true signal level and the overload indication should be noted with the results.

10. The RMS vibration level in the third-octave band selected is read on the meter. The level corresponding to full scale deflection is indicated by the number which appears between the two red lines on the transparent knob.

3.5. USE WITH THE LEVEL RECORDER TYPE 2306

For full frequency analysis of sound and vibration signals, the output of the Sound Level Meter can be connected to the B & K portable Level Recorder Type 2306. Synchronization of the paper movement on the 2306 and the filter in use can be achieved by connecting the SYNCHRONIZATION socket of 1616 to the EXTERNAL POWER/REMOTE CONTROL socket of the 2306, using the control cable shown in Fig.3.6. The cable is not provided, but is available under B & K Stock No. AQ 0148.

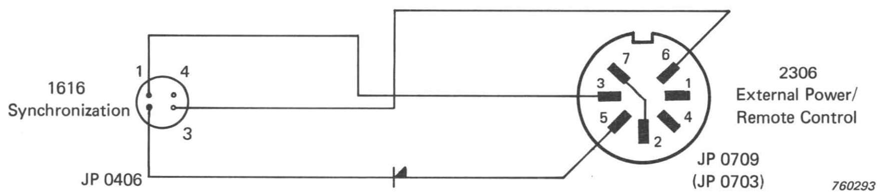

Fig.3.6. Control Cable AQ 0148

When the 2306 is switched on, the paper will advance until one (or both) of the 2306 FILTER SHIFT lamps and the 1616 FILTER SHIFT LED are lit, and the paper will stop. The FILTER SHIFT push button is depressed manually and the paper starts moving again. The push button should be held down until the FILTER SHIFT lamp on the 2306 and the 1616 FILTER SHIFT LED are extinguished. The recording continues until the lamps light again, and the whole sequence is repeated.

3.5.1. System Set-Up

A system for semi-automatic frequency analysis is shown in Fig.3.7.

Before connecting the Sound Level Meter to the 2306, the attenuators of the Sound Level Meter should be adjusted so that no overload will be experienced over the frequency

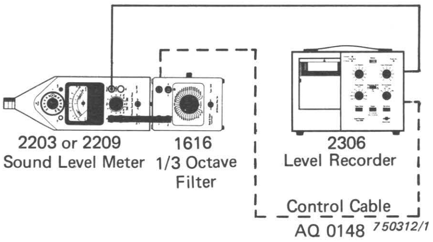

Fig.3.7. System for semi-automatic frequency analysis

range of interest. Depending on the Sound Level Meter in use (2203 or 2209) and the type of measurement (sound or vibration), the procedure described in § 3.3.1, 3.3.2, 3.4.1 or 3.4.2 should be followed. The first items (Sound Level Meter in "Lin." mode) ensure that the input stage of the Sound Level Meter, and consequently the Filter Set, is not overloaded. When the Sound Level Meter is switched to "Ext. Filter", adjustment of the OUTPUT ATTENUATOR should be made in the frequency band giving the highest output signal. This position may also be used to adjust the Level Recorder controls so that the pen deflects within the scale limits.

Connection between the Sound Level Meter output and the 2306 SIGNAL INPUT is made via cable AO 0116 (JP 0006 at one end and BNC plug JP 0035 at the other). Note that with 2209, choice can be made of AC or DC output.

3.5.2. Synchronization

1. Connect the system of Fig.3.7.
2. On the 2306, insert recording paper QP 0124 if a fibre pen is used, or QP 0224 if a stylus is used.
3. With the PEN DRIVE switched off, slide the pen to the left of the paper until it lies on the 50 dB line.
4. With the PAPER DRIVE switched off, move the paper using the PAPER ADJUSTMENT knob until the pen lies ~ 1 mm before the third-octave frequency mark on the paper corresponding to the desired starting frequency. (The third-octave markings are the small black rectangles on the 50 dB line.)
5. On the 1616, select the filter corresponding to the frequency on the recording paper.
6. Set the controls of the 2306 to:

DC LIN. POSITION SENSITIVITY	As determined in § 3.5.1 of 2306 Instruction Manual to give a suitable pen deflection
RECORDING MODE	As required
PAPER SPEED	As required
WRITING SPEED/LF LIMIT	As required
PAPER DRIVE	Out
POWER	As required
PEN DRIVE	In

The instruments are now synchronized for semi-automatic third-octave frequency analysis.

The choice of PAPER SPEED and WRITING SPEED must take into account the ability of the writing system to average fully. (See Instruction Manual for 2306.) Also, the PAPER SPEED must be sufficiently low for the pen to be able to fall and rise between each third-octave band, as the signal is completely cut off during the filter switching.

3.5.3. Frequency Analysis

1. Synchronize the system as described in section 3.5.2.

2. Depress the PEN DRIVE push button on the 2306. The paper starts and the level in the first third-octave band is recorded.

3. After 4 mm (or 5 mm for filter shifts after the first one), the paper stops and one (or both) of the 2306 FILTER SHIFT lamps and the 1616 FILTER SHIFT LED light.

4. Depress the FILTER SHIFT push button on the 1616. The output signal is suppressed, the FILTER SWITCH is stepped by one third octave and the recording paper starts again. The FILTER SHIFT push button must be kept depressed as long as the FILTER SHIFT lamp is lit or the paper will stop (and consequently, synchronization will be lost).

5. When the FILTER SHIFT lamps are extinguished, release the 1616 FILTER SHIFT push button. The output signal from the Sound Level Meter is again fed to the 2306 and recorded.

6. When the paper stops and the FILTER SHIFT lamps light, repeat items 4 and 5 until the frequency range of interest is analyzed.

A frequency analysis recorded with such a system is shown in Fig.3.8.

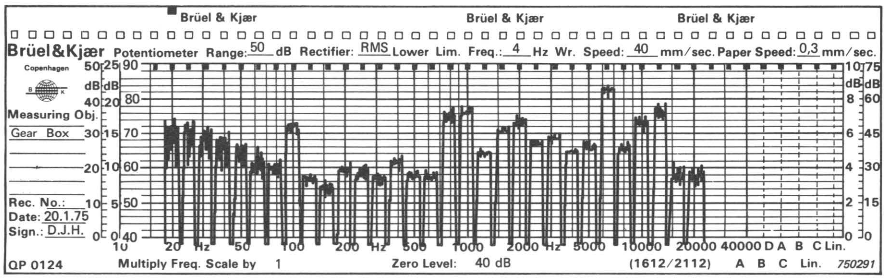

Fig.3.8. Example of frequency analysis recorded with the system of Fig.3.7

3.6. RMS MEASUREMENTS AND STATISTICAL ACCURACY

In any true RMS measurement system the accuracy of the data obtained is not only dependent on the system accuracy but also on the inaccuracies arising from the effect of statistically random signals on the system's averaging process. To understand how these inaccuracies arise, it is necessary to consider the RMS value of a signal which is defined:

$$\psi = \sqrt{\lim_{T \to \infty} \frac{1}{T} \int_0^T x^2(t)\, dt} \qquad 3.1$$

where

T is referred to as the averaging time
x(t) is a time-varying signal
ψ is the RMS value of x over an averaging time T.

It can be seen from equation 3.1 that to obtain the true RMS value of a statistically random signal, the averaging time would have to be infinitely long. Of course, in practice, this is impossible to realize and consequently the RMS value of a random signal will fluctuate when displayed on a meter or other readout device employing a more practical averaging time. The shorter the averaging time, the greater will be the fluctuations.

Equation 3.1 also shows that the level of the RMS fluctuation depends on the measurement bandwidth, since if the averaging time is kept constant and the measurement bandwidth is decreased, the level of the RMS fluctuation will increase.

A simple relationship providing a measure of the statistical RMS fluctuation (i. e. the possible range of error in the averaged RMS signal) is:

$$\epsilon = \frac{1}{2\sqrt{BT}} \qquad 3.2$$

where B is the measurement (or signal) bandwidth (whichever is the smaller) in Hz, and T is the averaging time or signal duration (whichever is the smaller) in seconds. The expression is an approximate relation but carries sufficient accuracy for BT products greater than 5. It expresses the limits of signal variation to a confidence level of approx. 68%. To obtain higher confidence levels, the approximate relations apply that the variation limit of $\pm 2\epsilon$ provides a confidence level of 95% and $\pm 2{,}5\epsilon$ provides a confidence limit of 99%. For further details on the derivation of equation 3.2 and its application, refer to "Measurement and Analysis of Random Data" by J. S. Bendat and A. G. Piersol (John Wiley 1967) and to statistical textbooks on the chi-square distribution.

Equation 3.2 shows that if the averaging time is decreased and the level of RMS fluctuation is increased, the signal can be estimated as random. However, if the level remains roughly the same, the signal can be estimated as periodic. Also, if the measurement bandwidth is decreased to increase the frequency resolution, then the averaging time must be increased to obtain the same measurement accuracy.

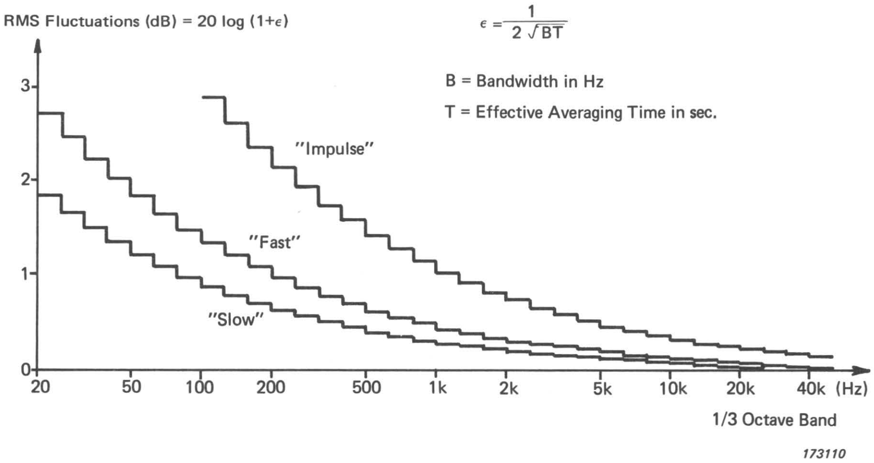

Fig.3.9. RMS fluctuation from true RMS value of a random signal measured in third-octave bands using 1616 and 2203 or 2209. Only "Fast" and "Slow" characteristics apply to 2203

It can be seen therefore that equation 3.2 provides a useful relationship for determining a practical averaging time for minimizing the fluctuations.

The three meter time constants of the 2209 (two for 2203) provide three (or two) effective averaging times for insertion into equation 3.2. For the purpose of determining effective statistical error in RMS measurements of random noise, the following averaging times may be used:

Fast	0,4 s
Slow	1,0 s
Impulse (rise)	0,07 s

For a 1/3-octave analysis of random noise using 1616 with a 2203 or 2209, the RMS fluctuations will be as shown in Fig.3.9. It will not be possible to reduce these fluctuations using the standard rectifiers of the 2203 or 2209.

When recording the AC output of the Sound Level Meter on a Level Recorder Type 2306, the integration time, and hence the statistical accuracy, depends on the WRITING SPEED/LF LIMIT setting and the statistical accuracy of the recording can be increased (although the SLM reading will not be affected). For full details, reference should be made to the 2306 Instruction Manual.

4. DESCRIPTION

4.1. GENERAL

A block diagram of the 1/3 Octave Filter Set Type 1616 is shown in Fig.4.1.

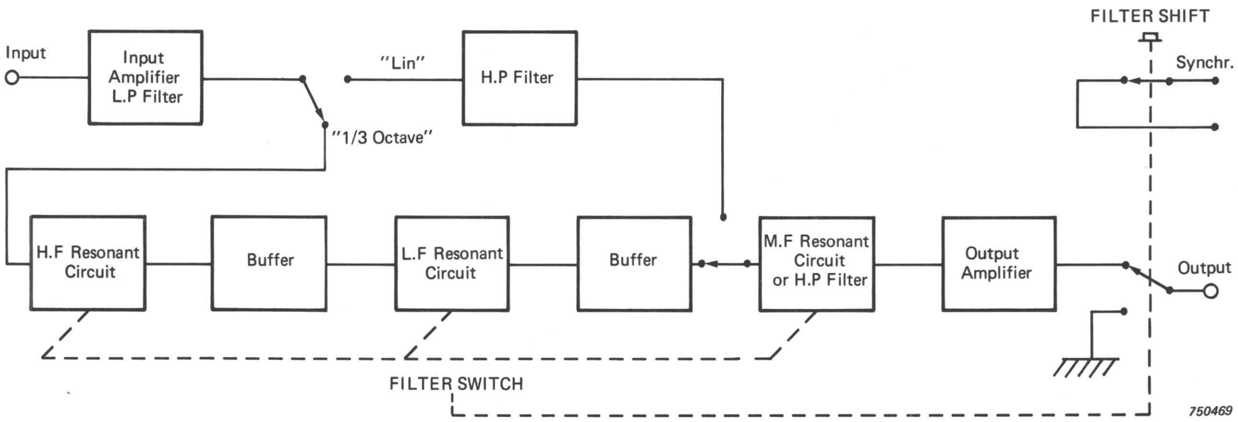

Fig.4.1. Block diagram of 1616

All filters in the 1616 are active filters. The Filter Set includes 34 filters with one third-octave effective bandwidth having centre frequencies ranging from 20 Hz to 40 kHz. Filter shift is made by changing resistors and capacitors in the selective stages so that the same active elements are used for all positions of the FILTER SWITCH.

A linear range (22,4 Hz — 40 kHz) is also included.

4.2. INPUT

Connection to the IN socket is made via Connection Bar JP 0400 or the B & K Coaxial Plug JP 0006.

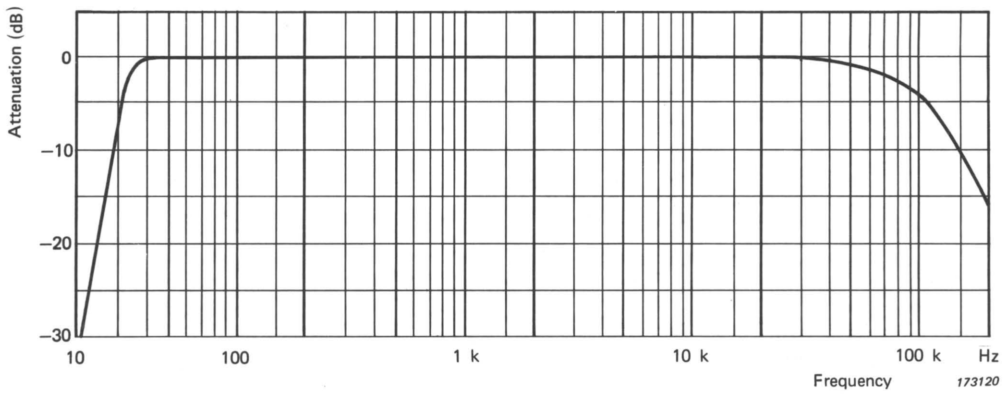

Fig.4.2. Typical frequency response of 1616 in the "Lin." mode

The input stage is a buffer providing high input impedance (10 kΩ) and low driving impedance for the first selective stage. The input stage also acts as an active low-pass filter to damp unwanted high-frequency components.

It is designed for linear phase response, giving a smooth frequency cut-off and impulse or transient response without overshoot. This last feature is very important when the 1616 is used in its "Lin." mode in conjunction with an impulse sound level meter. The frequency and phase responses of 1616 in the "Lin." mode are given in Fig.4.2 and 4.3 respectively. The high-frequency response is determined by the input stage, the low-frequency end being determined by a high-pass filter described in § 4.4.

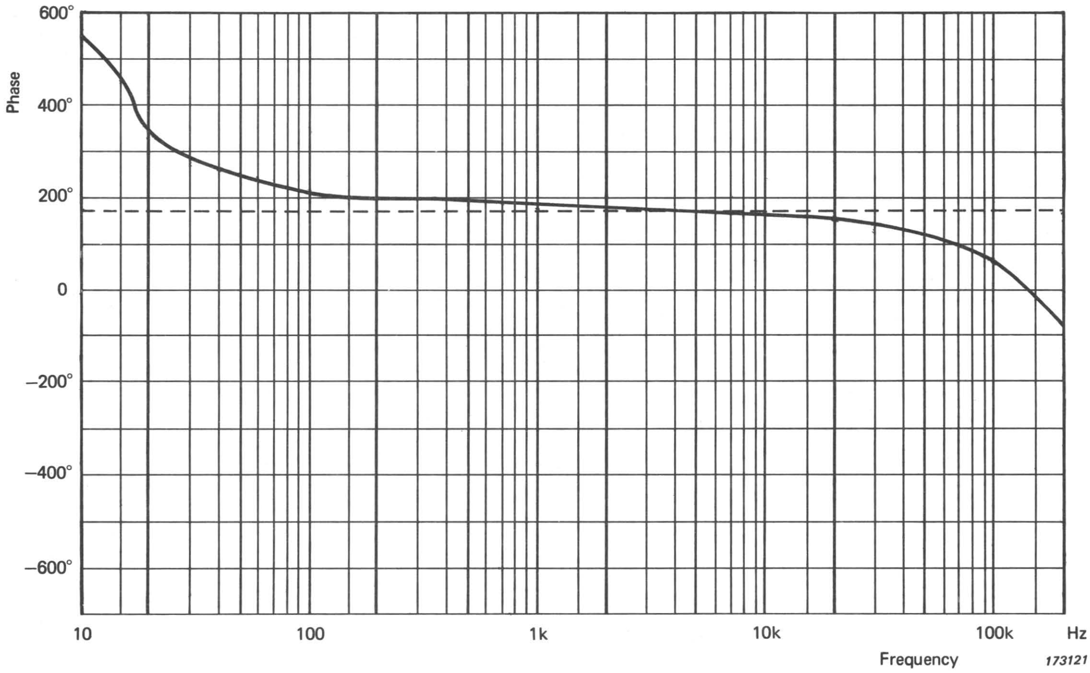

Fig.4.3. Typical phase response of 1616 in the "Lin." mode

4.3. THIRD-OCTAVE FILTERS

4.3.1. General

The third-octave filters are all 6-pole Butterworth filters with centre frequencies and bandwidths given in Table 4.1; complete filter characteristics as regards band-edge frequencies, intersection frequencies, bandwidth, etc. are given in Table 4.2. The centre frequencies range from 20 Hz to 40 kHz according to the preferred frequencies specified in ISO R 266.

The filters are designed to have an Effective Bandwidth of one third octave (i. e. they pass the same amount of white-noise power as an ideal filter of one third-octave bandwidth). With the filter shape used, the band-edge frequencies correspond to an attenuation of nominally 3,65 dB. In order to meet the requirements of ANSI S1.11-1966, a third-order filter is used. With 1616, this is made using three stagger-tuned resonant circuits. Note that the third stage (mean-frequency resonance circuit) is used as a high-pass filter in the "Lin." mode.

Centre Frequency Hz	Bandwidth Hz	Centre Frequency Hz	Bandwidth Hz	Centre Frequency Hz	Bandwidth Hz
20	4,62	250	58,2	3150	732
25	5,82	315	73,2	4000	922
31,5	7,32	400	92,2	5000	1160
40	9,22	500	116	6300	1460
50	11,6	630	146	8000	1840
63	14,6	800	184	10000	2310
80	18,4	1000	231	12500	2910
100	23,1	1250	291	16000	3670
125	29,1	1600	367	20000	4620
160	36,7	2000	462	25000	5820
200	46,2	2500	582	31500	7320
				40000	9220

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Table 4.1. Third-octave centre frequencies and bandwidths

		Hz									
Nominal Centre Frequency	f_o	10	12,5	16	20	25	31,5	40	50	68	80
Exact Centre Frequency	$f_m = 10^{n/10}$	10	12,5893	15,8489	19,9526	25,1189	31,6228	39,8107	50,1187	63,0957	79,4328
Upper Band-Edge Frequency	+ 1/6 octave (– 3,65 dB)	11,2246	14,131	17,7898	22,3961	28,1950	35,4954	44,6860	56,2564	70,8226	89,1603
Lower Band-Edge Frequency	– 1/6 octave (– 3,65 dB)	8,90899	11,2158	14,1198	17,7758	22,3784	28,1727	35,4673	44,6507	56,2119	70,7666
Upper Intersection Frequency	+ 1/20 decade (– 3,60 dB)	11,2202	14,1254	17,7872	22,3872	28,1838	35,4813	44,6684	56,2341	70,7946	89,1251
Lower Intersection Frequency	– 1/20 decade (– 3,60 dB)	8,91251	11,2202	14,1254	17,7828	22,3872	28,1838	35,4813	44,6684	56,2341	70,7946
Bandwidth at Band-Edge Frequencies	Δf 23,1561% of f_m	2,31561	2,9152	3,6700	4,6203	5,8166	7,3227	9,2187	11,6057	14,6107	18,3937
Bandwidth at Intersection Frequencies	Δf 23,0769% of f_m	2,30769	2,9052	3,6574	4,6044	5,7966	7,2975	9,1871	11,5657	14,5605	18,3305
Bandwidth at – 3 dB points	Δf 22,1201% of f_m	2,21201	2,7847	3,5058	4,4135	5,5563	6,9950	8,8061	11,0863	13,9568	17,5704
Resonant Frequency HF Resonant Circuit	f_r (HF)	11,0052	13,8547	17,4421	21,9583	27,6438	34,8015	43,8125	55,1567	69,4381	87,4174
Resonant Frequency LF Resonant Circuit	f_r (LF)	9,08668	11,4395	14,4014	18,1303	22,8247	28,7346	36,1747	45,5413	57,3331	72,1781
Resonant Frequencies for combined HF and LF circuits (Fig. 4.4)	f_r (HF)	10,8125	13,6121	17,1367	21,5738	27,1598	34,1921	43,0453	54,1909	68,2223	85,8867
	f_r (LF)	9,24855	11,6432	14,6580	18,4533	23,2313	29,2465	36,8192	46,3526	58,3544	73,4639
Pole Location	(HF)	– 3,80635 ± j 69,0928	– 4,79192 ± j 86,9197	– 6,03266 ± j 109,425	– 7,59467 ± j 137,758	– 9,56113 ± j 173,428	– 12,0367 ± j 218,332	– 15,1534 ± j 274,864	– 19,0770 ± j 346,034	– 24,0165 ± j 435,63	– 30,2349 ± j 548,426
	(MF)	– 6,9492 ± j 57,0067	– 8,99853 ± j 78,6157	– 11,0137 ± j 98,9713	– 13,8655 ± j 124,598	– 17,4556 ± j 156,859	– 21,9753 ± j 197,474	– 27,6653 ± j 248,605	– 34,8285 ± j 312,875	– 43,8965 ± j 394,012	– 55,1995 ± j 496,032
	(LF)	– 3,14285 ± j 57,0067	– 3,95661 ± j 71,7672	– 4,98108 ± j 90,3495	– 6,27081 ± j 113,743	– 7,89442 ± j 143,194	– 9,93856 ± j 180,271	– 12,5119 ± j 226,948	– 15,7516 ± j 285,710	– 19,8300 ± j 359,688	– 24,9645 ±j 452,820

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Table 4.2. Filter parameters for Type 1616

The overall characteristics of the third-octave filters conform to the requirements of ANSI S1.11-1966 class III, IEC Recommendation 225 and DIN 45652. The pass band of a typical filter relative to these requirements is shown in Fig.4.4, while the complete characteristics are given in Fig.5 of Chapter 1. Peak-to-valley ripple in the passband is less than 0,5 dB, and rejection at frequencies outside one fifth and five times the centre frequency is greater than 75 dB.

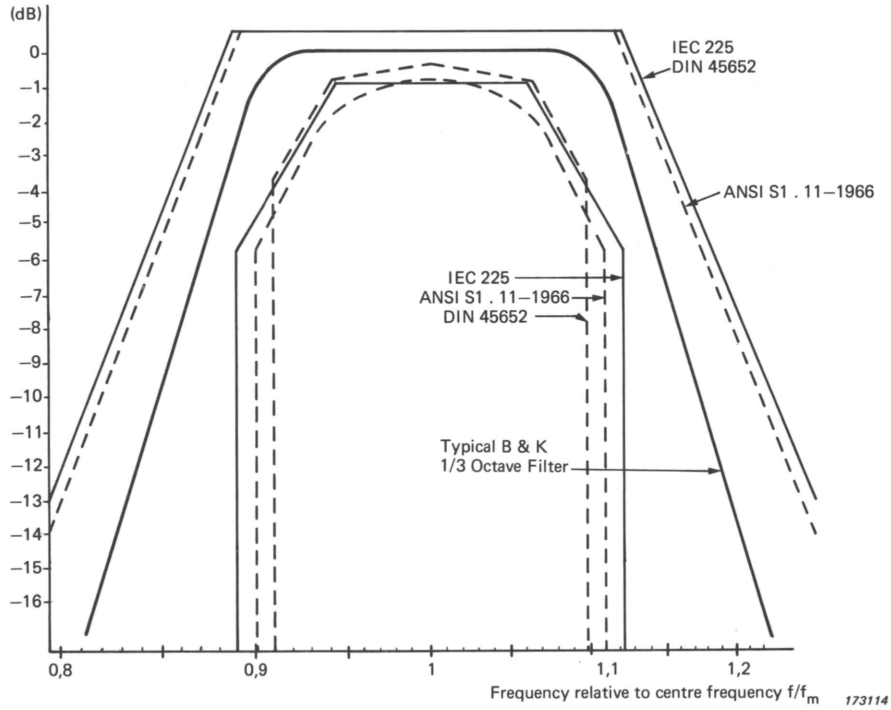

Fig.4.4. Pass band of a typical third-octave filter relative to IEC, ANSI and DIN recommendations

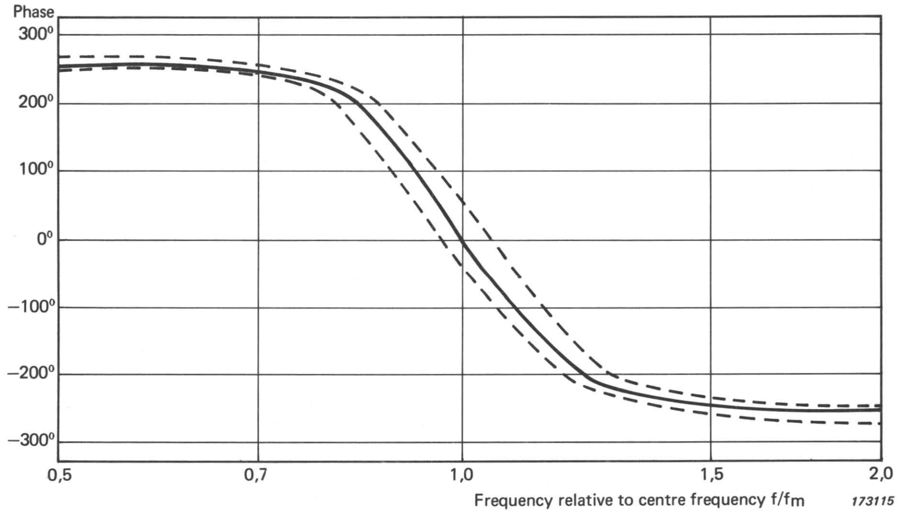

Fig.4.5. Phase response of a typical third-octave filter

The phase response of the filters is shown in Fig.4.5. The solid line shows the typical response, while the dotted lines indicate the range of likely variations between filters.

4.3.2. Filter Design

The filter transfer function may be written as:

$$H(p) = K \cdot \frac{p^3}{(p-p_1)(p-p_2)(p-p_3)(p-p_4)(p-p_5)(p-p_6)}$$

where p_1 to p_6 are the poles of the system. Location of the complex-conjugate pole pairs are shown in Fig.4.6.where the filter centre frequency is obtained for $\omega = 1$.

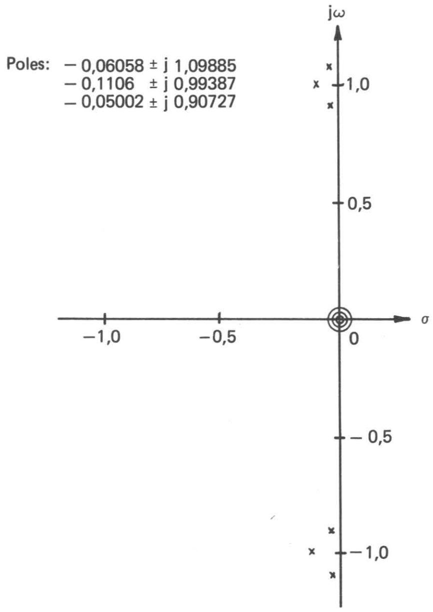

Fig.4.6. Pole and zero location of a third-octave filter transfer function

Each pair of complex-conjugate poles corresponds to one resonant circuit. The resonant circuit is an active filter built around an NIC (Negative Impedance Converter) element. The basic resonant circuit is shown in Fig.4.7a.

Since the filter shift is made by changing the components marked with an arrow on Fig.4.7a, it is important that the output impedance of the driving circuit is so low that its influence is negligible. Also, because of the high output impedance of the resonant circuit in the pass band, both the load impedance and input impedance of the operational amplifier must be high. A buffer stage is therefore inserted between the resonant circuits (see block diagram, Fig.4.1) and FET stages are placed at the inputs of the operational amplifier as shown in Fig.4.7b, where the output is now taken at the low impedance output of the FET stage.

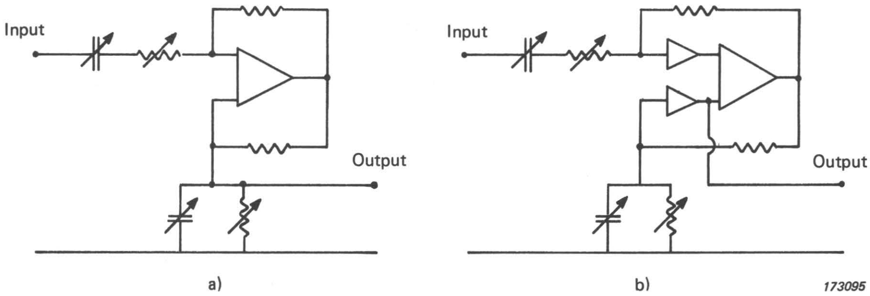

Fig.4.7. a) Basic resonant circuit b) Practical resonant circuit

The buffer stages also control the voltage level in the filter set. In order to obtain the best possible signal-to-noise ratio, the buffer stages, as well as the input stage, attenuate the signal which is amplified in the instrument as shown in Fig.4.8.

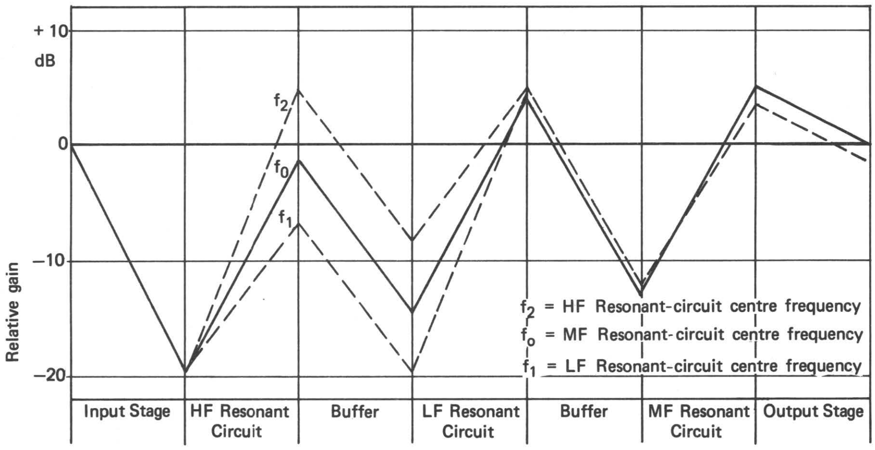

Fig.4.8. Signal level at different stages of 1616

The resonant circuits are designed for equal values of the resistor and capacitor pairs (marked with an arrow in Fig.4.7a and 4.7b). This equality is the critical point in the circuit. The resistors are made by thick-film process. Since they are made from the same paste, on the same substrate, in the same printing and burned together, they will, after adjustment, be very closely equal over a wide temperature range. Careful selection of the capacitors ensures similar features.

Each filter has its own resistor module, whereas the capacitors are common for several filters, allowing the rather compact construction of the instrument.

4.3.3. Filter Transient Response

The transient and step responses of the filters are determined by the poles and the zeros of the system. For the chosen Butterworth configuration, the response will be as shown in Figs.4.9 and 4.10. Fig.4.9 shows the impulse response of the filter. Fig.4.10 shows the response to a suddenly applied sinusoidal signal at the filter centre frequency. It can be seen that the output signal will reach its maximum after approx. 6 periods and will have nearly reached the steady state after approx. 15 periods. The maxi-

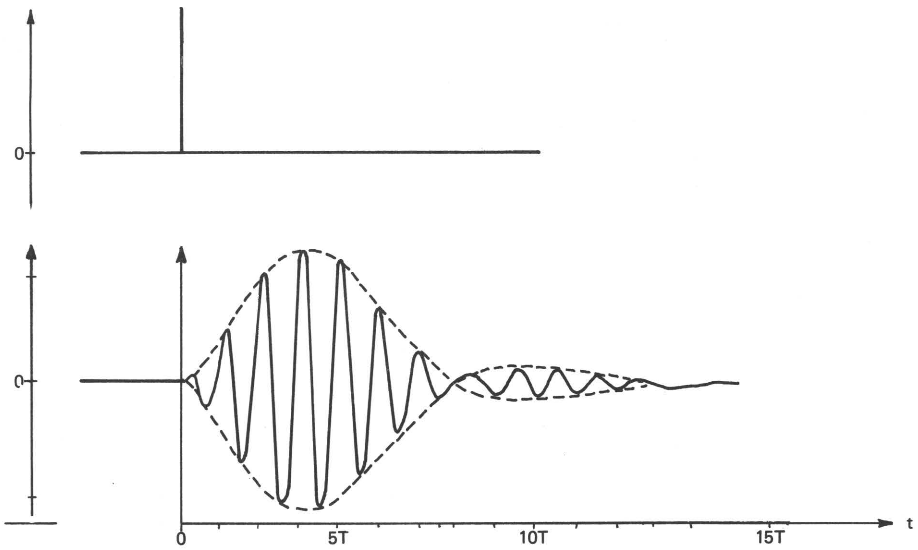

Fig.4.9. Filter impulse response

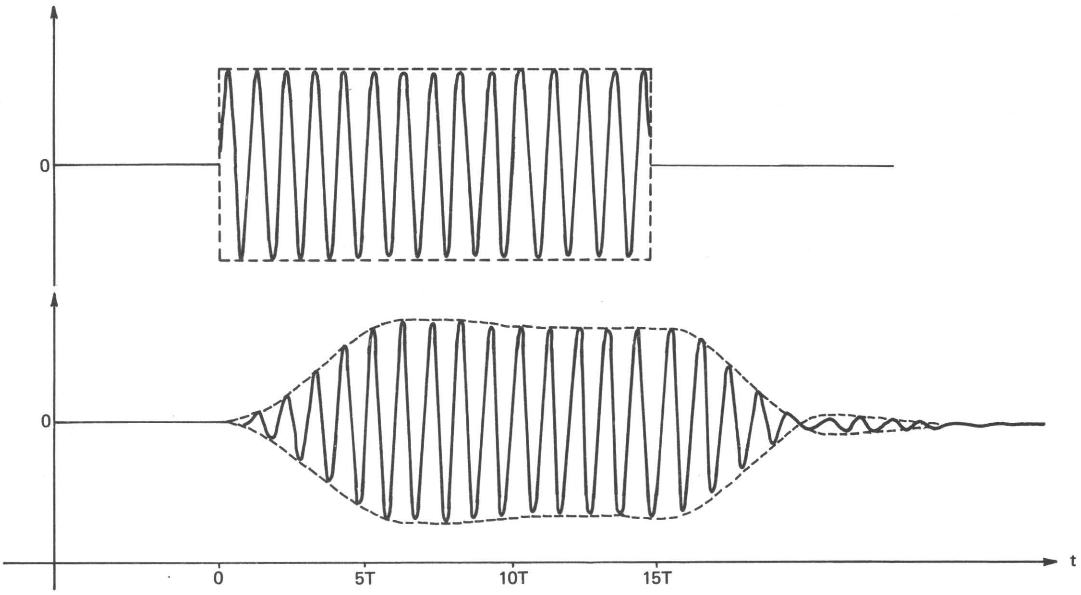

Fig.4.10. Filter transient response to sinusoidal burst at centre frequency

mum level is approx. 8% higher than the steady-state level. Fig.4.10 also shows the response when a steady-state sinusoidal signal at the filter centre frequency is suddenly suppressed.

4.4. HIGH-PASS FILTER

When the FILTER SWITCH is in its "Lin." position, the signal from the input stage is fed to the high-pass filter, (see Fig.4.1). It is a 5-pole Butterworth filter with the 3 dB point at 22,4 Hz. Fig.4.11 shows the typical frequency response of the high-pass filter and the tolerance limits, while the overall frequency and phase response of the **1616** in the

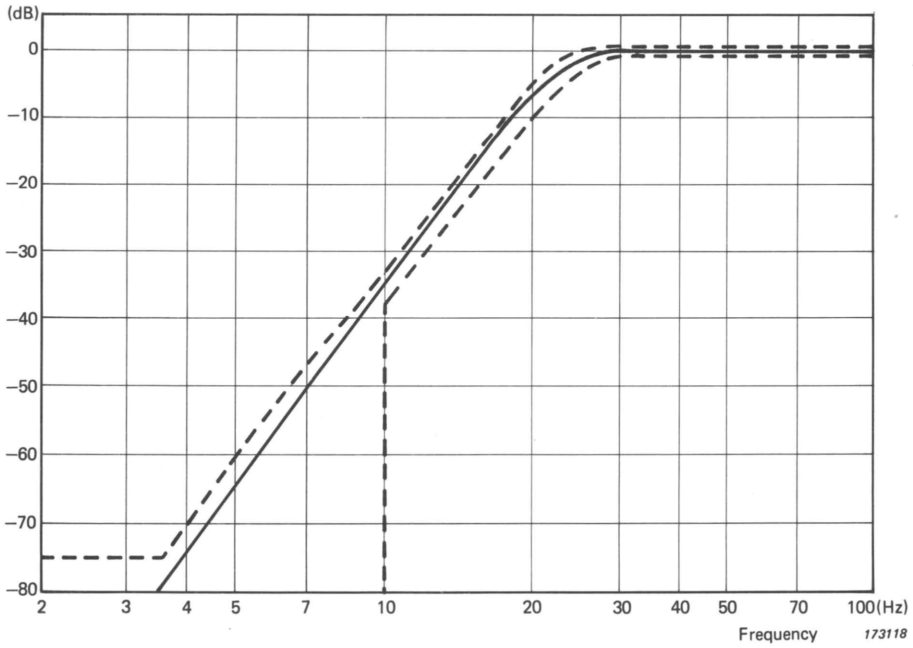

Fig.4.11. Typical frequency response of the high-pass filter and tolerance limits

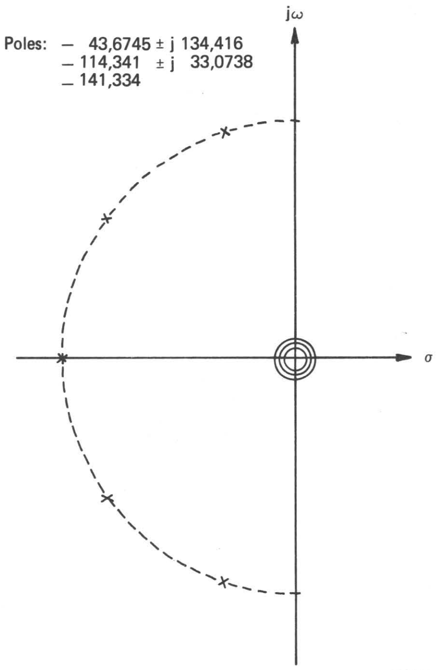

Fig.4.12. Pole and zero location of the high-pass filter transfer function

"Lin." mode are given in Figs.4.2 and 4.3. The pole and zero location of the high-pass filter is given in Fig.4.12.

As can be seen from the block diagram in Fig.4.1, the high-pass filter is divided into two sections. The first section is special for the filter. It is a controlled-voltage-source active filter giving three (one real and two complex conjugates) of the 5 poles of the filter. The second section uses the last stage of the selective section to generate the last two complex-conjugate poles.

4.5. OUTPUT AMPLIFIER

The output amplifier acts as a buffer stage between the last resonant circuit and the external load. Output impedance is below 5 Ω in series with 2,2 μF. The minimum load impedance is 15 kΩ.

When the FILTER SHIFT push button is depressed, the signal is disconnected from the OUTPUT and the FILTER SWITCH is stepped by one third octave. In this way, transients due to filter switching will not unnecessarily overload the amplifiers and detectors connected to the filter output.

4.6. POWER SUPPLY

The 1616 is powered from 3 standard 1,5 V batteries (D cells, type R 20 in IEC Publication 86-2, B & K part number QB 0004). A DC-to-DC converter provides the necessary symmetrical voltages for the operational amplifiers. The converter is stabilized for battery voltages between 3 and 4,6 V. The oscillation frequency of the circuit is about 50 kHz.

BRÜEL & KJÆR instruments cover the whole field of sound and vibration measurements. The main groups are:

ACOUSTICAL MEASUREMENTS
Condenser Microphones
Piezoelectric Microphones
Microphone Preamplifiers
Hydrophones
Sound Level Meters
Precision Sound Level Meters
Impulse Sound Level Meters
Noise Dose Meters
Noise Level Analyzers
Standing Wave Apparatus
Calibration Equipment
Reverberation Processors
Sound Sources

ACOUSTICAL RESPONSE TESTING
Sine Generators
Random Noise Generators
Sine-Random Generators
Artificial Voices
Artificial Ears
Artificial Mastoids
Hearing Aid Test Boxes
Audiometer Calibrators
Telephone Measuring Equipment
Audio Reproduction Test Equipment
Tapping Machines
Turntables

VIBRATION MEASUREMENTS
Accelerometers
Force Transducers
Impedance Heads
Accelerometer Preamplifiers
Vibration Meters
Accelerometer Calibrators
Magnetic Transducers
Capacitive Transducers
Complex Modulus Apparatus
Bump Recorders

VIBRATION TESTING
Exciter Controls — Sine
Exciter Controls — Sine — Random
Exciter Equalizers, Random or Shock
Exciters
Power Amplifiers
Programmer Units
Stroboscopes

STRAIN MEASUREMENTS
Strain Gauge Apparatus
Multipoint Selectors

MEASUREMENT AND ANALYSIS
Voltmeters
Phase Meters
Deviation Bridges
Measuring Amplifiers
Band-Pass Filter Sets
Frequency Analyzers
Real Time Analyzers
Heterodyne Filters and Analyzers
Distortion Measuring Equipment
Psophometers
Statistical Distribution Analyzers
Tracking Filters

RECORDING
Level Recorders
Frequency Response Tracers
Tape Recorders
Alphanumeric Printers
Digital Event Recorders

DIGITAL EQUIPMENT
Computers
Tape Punchers
Tape Readers

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Printed in Denmark B & K Offset