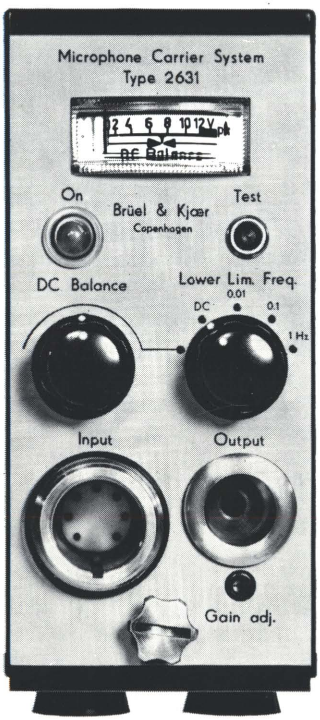
2631

Instructions and Applications



Microphone Carrier System Type 2631

A carrier system designed for detection of capacitance variations in the frequency range DC to 150 kHz. Used with a condenser microphone input it provides an ideal first stage processing of low frequency pressure variations such as sonic bangs, thunder storms, short duration pulses etc.

BRÜEL & KJÆR

030-0088

MICROPHONE CARRIER SYSTEM

TYPE 2631

December 1969

CONTENTS

1. INTRODUCTION

The B&K Microphone Carrier System Type 2631 has been developed to meet the exacting requirements called for in the measurement of low frequency pressure variations down to 0.01 Hz, for which special measurement techniques are required.

The basic 2631 Carrier System is composed of a Head and a Control Unit containing the power supply and output amplifier. A condenser microphone (not provided) can be plugged directly into the Head. Any pressure differences present at the microphone's diaphragm are converted to capacitance variations which are detected by an FM detector contained in the Head. The 2631 has a dynamic range of 95 dB ("A" Weighting) and unlike most conventional systems the demodulated output from the head allows the possibility of reasonably long connecting cables to the control unit.

In order to realise the very low frequency response, special condenser microphones are employed in which the pressure equalisation hole is sealed, thus bringing the lower frequency limit down from 3 Hz to below 0.1 Hz. However, given such a microphone there would be considerable difficulty in choosing a cathode follower and preamplifier as used in conventional systems. The input impedance required would be in order of 3.10^{10} ohms which would be exceedingly difficult to realise in conditions of high humidity. The 2631 has the advantage that its input impedance is below 100 ohms and therefore not affected by moisture.

In the DC mode adjustment is provided for manual balancing and compensation of the system for different transducer capacitances. Balance is clearly indicated on a monitoring meter. Balancing in the AC mode is automatic.

The special measurement techniques called for in the analysis of slowly varying air pressures and short duration pressure pulses such as found in sonic bangs, fluid mechanics, wind tunnels, pressure chambers and thunder storms make the B&K Carrier System eminently suitable for such applications.

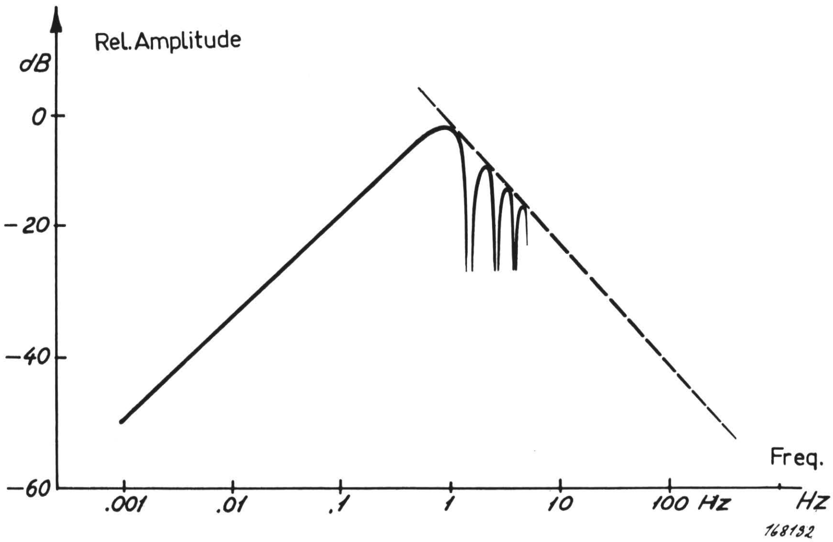


Fig.1.1 Idealised N wave of sonic bang.

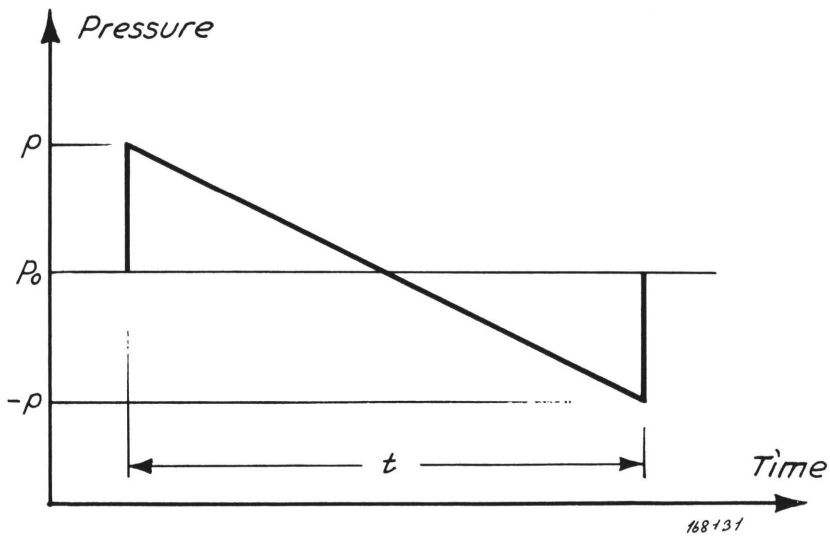


Fig.1.2 Fourier spectrum of sonic bang.

Taking for example the idealised N wave of the sonic bang from an aircraft (Fig.1.1) , the peak overpressure, p_1 may be 5 lb/ft^2 (250 N/m^2) or possibly even higher for low flying aircraft, and the pulse duration, t, of the order 0.03 to 0.4 sec. A Fourier integral of such an N wave shows that its spectral content (Fig.1.2) peaks at about $^1/t$ Hz and ranges several decades above and below this frequency. For accurate representation of such spectra it is necessary to have a measurement capability from 0.01 Hz to 10 kHz as recommended by the I.S.O. Draft Proposal 43/1 N 11. The frequency range of the 2631 Carrier System extends from DC to 150 kHz and is thus ideally suited to this and other applications.

2. DESCRIPTION

GENERAL.

A block diagram of the B&K Type 2631 Microphone Carrier System is shown in Fig.2.1. A detailed description of the systems design follows below.

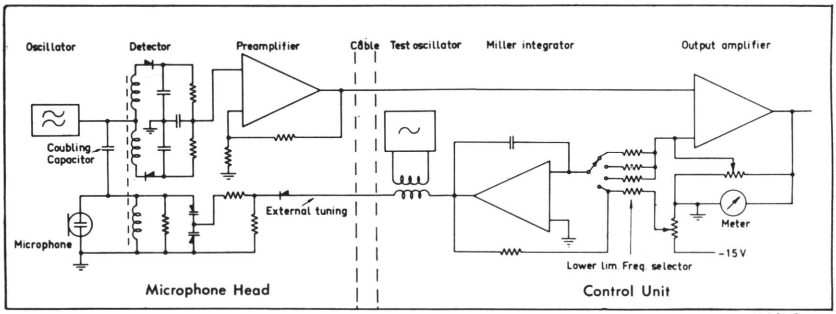


Fig.2.1 Block diagram of the Microphone Carrier System.

MICROPHONE HEAD.

The condenser microphone, not provided with the 2631 can be plugged straight into the Microphone Head and will act as the detecting transducer, the variable capacitance of which forms an integral part of the Head's resonant circuit.

This resonant circuit is driven by a 10 M Hz, crystal controlled oscillator, and as the capacitance of the condenser microphone is varied by sound pressure variations at its diaphragm so the impedance of the resonant circuit is coupled inductively to a circuit which detects the impedance changes, and produces a proportionate output voltage. The demodulated signal is then amplified by an integrated circuit preamplifier and fed by cable to the Control Unit containing the output amplifier.

As the demodulated signal is taken from the Head and its output impedance is below 100 Ω, the effect of cable capacity on the response of the system is considerably reduced. See Fig.3.3. Thus any reasonable length of cable can be used to connect the output from the Head to the Control Unit.

The polarity of the system is such that an increase in capacitance at the input, or an increase in pressure at the microphone diaphragm produces an increase in output voltage.

When in the AC mode compensation is obtained for the effects of different microphone capacitances and thermal variations of the capacitance diodes in the resonant circuit, by applying voltage feed back from the Control Unit's output amplifier to the variable capacitance diodes. This ensures that the resonant circuit is automatically tuned for transducer capacitances between 40 and 70 pF. This is adequate for any of the B&K 1 inch Condenser Microphones, however, for 1/2 inch Microphones a special adaptor Type UA 0271 is required.

CONTROL UNIT.

The demodulated signal from the Microphone Head is fed to one of the inputs of the Control Unit's integrated, differential output amplifier. Voltage feed-back is applied from the output to the other input of the amplifier. The amount of feed back applied determines the gain which can be manually adjusted by the Gain Adj. potentiometer control.

The Control Unit's low impedance output ($< 10\ \Omega$) is suitable for connection to practically any type of recording or measuring equipment. Output voltage is up to 12 V, 10 mA depending on the setting of the Gain Adj. control.

The Lower Limiting Frequency is controlled by the output amplifier's feedback loop by means of a Miller integrator with switchable time constants. The feedback signal is then applied to capacitance diodes in the resonant circuit in the Head. Automatic compensation with a preselected time constant is thus provided for different transducers in the AC modes. In the DC mode, compensation is set manually by the DC BALANCE control on the front panel. Balance and overload indication is provided by the monitoring meter, also on the front of the equipment.

In the AC mode the response of the Carrier System (without microphone Fig.3.4) falls by approximately 1.5 dB at the LOWER LIMITING FREQUENCY selected. It should be noted that the selected frequency is not the cut off frequency (−3 dB point). However, if a microphone is used that has the same lower limiting frequency response as that selected on the 2631, then this would become the cut off frequency. The response of the Carrier System in the DC mode is that of the microphone used. Without microphone the response extends from DC to 150 kHz.

A separate test oscillator is inductively coupled into the feed back loop after the Miller Integrator and injects a 1 kHz signal into the Head's resonant circuit. Here the 1 kHz signal pulls the capacitance diodes producing a capacitance variation. The variation is detected and amplified, and thus provides a test for the whole 2631 Carrier System.

Also contained in the control unit is a stabilized power supply which provides +15 and −15 Volts DC. for circuitry contained in both the Head and the Control Unit. The supply is mains driven and the approximate current consumption is 20 mA and independent of voltage.

3. OPERATION.

The ease of operation of the B&K Microphone Carrier System Type 2631 can be attributed to the fact that all controls, input and output sockets etc., are confined to the FRONT and REAR PANELS (Fig.3.1 and 3.2 respectively) of the Control Unit. The unit's top, bottom and side panels are

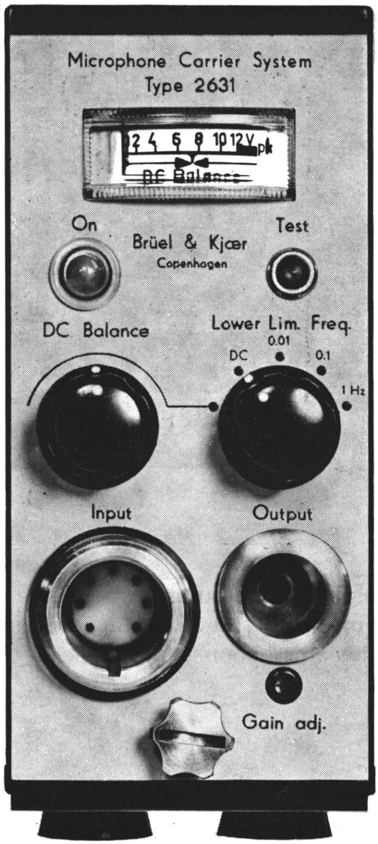


Fig.3.1 Front panel.

Fig.3.2 Rear panel.

readily removed enabling quick adjustment of the system's few internal preset controls. The operating and calibrating procedure, plus the range of suitable B&K condenser microphones for the Carrier System, follow in this chapter.

INPUT.

INPUT to the Control Unit from the Head is via a standard B&K 7 pin microphone socket on the front panel. The socket also provides the Head's supply and feed back voltages.

OUTPUTS.

OUTPUT from the Control Unit is either by a standard B&K coaxial socket on the front panel or by a 10–32 NF unified socket at the rear. The outputs impedance is less than 10 Ω and is suitable for connection to practically any type of recording of measuring equipment. The response of the carrier system with capacitive loading is shown in Fig.3.3.

Note that a DC voltage of up to 12 V can exist at the OUTPUT if the system is not balanced and is in the DC mode.

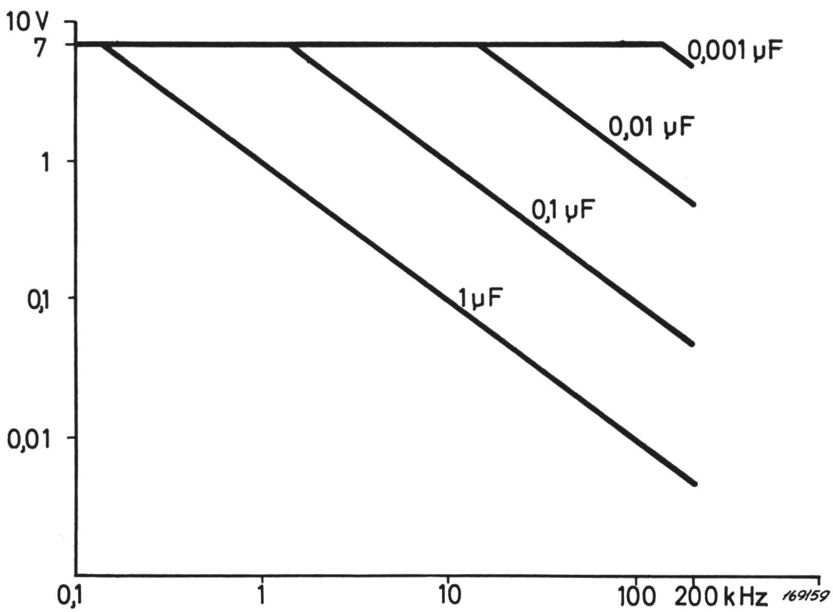


Fig.3.3 Response of carrier system for capacitive loading of Control Units output.

LOWER LIMITING FREQUENCY.

The LOWER LIM. FREQ. can be set to 1, 0.1, 0.01 Hz or to DC according to the knob position on the front panel. A further switch position is provided for adjustment of the DC BALANCE. It is advisable to use the highest possible setting of the LOWER LIM. FREQ. knob if the frequency content of the signal is known. This removes undesirable noise components below that frequency. The Response of the lower limiting Frequency is shown in Fig.3.4.

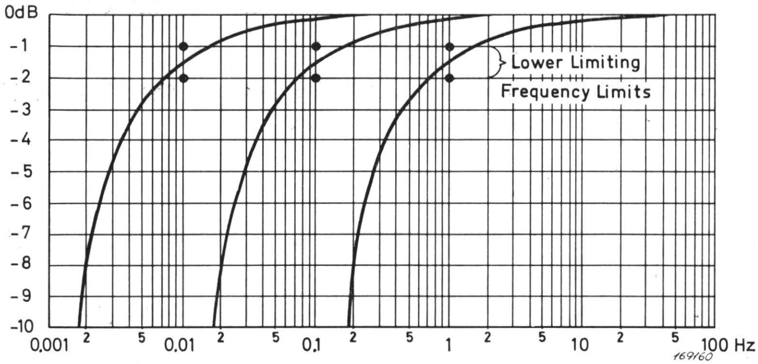


Fig.3.4 Lower limiting frequency response.

DC BALANCE.

When the Carrier system is operated in its DC mode, the DC BALANCE should be set for central deflection on the front panel's monitoring meter. For this purpose the LOWER LIM. FREQ. switch should be set in its extreme anti–clockwise position. Once balance is obtained, it should be returned to the DC position for measurements. The DC BALANCE knob controls a single turn fine adjustment potentiometer and a multi–turn coarse potentiometer. DC balance of the output in the AC mode is automatically adjusted to within ± 20 mV, but if it is important that the output signal has no bias then further adjustment of the signal using an external voltmeter will be necessary. The adjustment potentiometer is accessible by removing the top panel of the unit and adjusting the small potentiometer, shown in Fig.3.5., with a screwdriver.

GAIN ADJUSTMENT.

The gain of the output amplifier can be adjusted by the screwdriver operated GAIN ADJ. potentiometer on the front panel of the unit. This is particularly useful in calibration of the measuring system as described later.

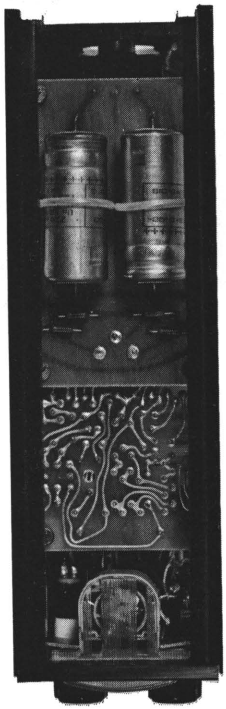


Fig.3.5 Adjustment of DC balance in AC mode.

TEST OSCILLATOR.

A test oscillator of 1 kHz frequency is included in the unit and provides a simple check on the function of the measuring system. Operation is by depressing the Test button on the front panel. The amplitude of the oscillator signal is variable and is adjusted by a multi–turn potentiometer accessible by removing the left side panel (viewed from the rear) of the unit (see Fig.3.6). Note that since the test oscillator injects a signal into the Head, the output level of the signal will also be dependent on the GAIN ADJ. of the Carrier System.

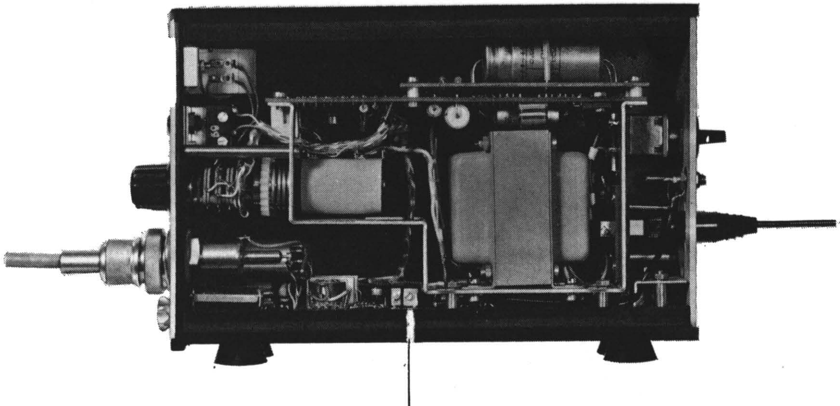


Fig.3.6 Adjustment of test oscillator level.

POWER.

The mains input socket together with the main power switch are located at the rear of the unit, whilst the red mains indication lamp is situated on the front panel. Any mains voltage between 100 and 240 Volts AC, 50 to 400 Hz is suitable and no adjustment is necessary. The 50 mA 250 V main fuse located at the rear of the equipment is only accessible when the bottom panel is removed.

REMOVAL OF MODULE PANELS.

The BOTTOM PANEL of the 2631 Control Unit is removed by releasing the large coin operated/finger screw at the bottom of the front panel (see Fig.3.1.). Quarter to half a turn should be adequate to release the catch. The panel is then removed by sliding it towards the rear of the unit.

TOP and SIDE PANELS of the instrument can each be released by unscrewing the fixing screws on the rear of the unit (see Fig.3.2). These panels are also removed by sliding them backwards.

MICROPHONE.

For low frequency measurements the B&K 1 inch Condenser Microphone Type 4146 is recommended as its pressure equalisation vent has been sealed with a silicon rubber ring as in Fig.3.7. This gives a linear frequency response which is guaranteed from 7 kHz down to 0.1 Hz. However, this can be made to extend down to 0.01 Hz as a proposed system shows in the Applications Chapter.

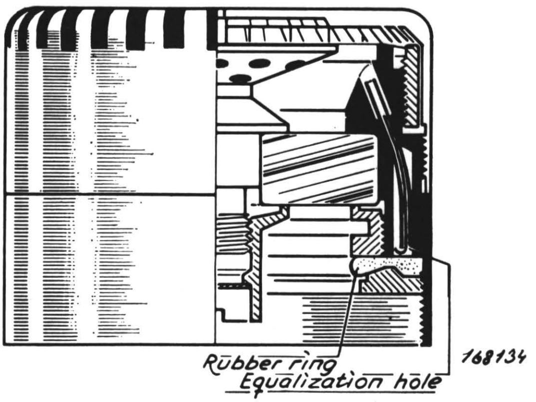


Fig.3.7 Low frequency condenser microphone.

B&K 1 inch Microphone Type 4144 and 4145 can also be sealed using the Sealing Kit Type UA 0240. With these microphones,however, the 0.1 Hz limiting frequency can not be guaranteed.

The Microphone Head normally accepts a 1 inch condenser microphone, but for high frequency, high intensity measurements a B&K 1/2 inch microphone Type 4148 with an Adaptor Type UA 0271 should be used. This is especially applicable in the case of sonic bangs where a maximum measuring frequency of 10 kHz is normally required.

CALIBRATION.

Ideally the complete instrumentation should be calibrated both before and after measurements. This is best achieved by applying an accurately known sound pressure to the microphone and adjusting the measuring and recording instruments to indicate correctly. The B&K Pistonphone Type 4220 and the Sound Level Calibrator Type 4230 are very convenient for this purpose. The Pistonphone produces a sound pressure level at the microphone diaphragm of 124 ± 0.2 dB at 250 Hz, while the Sound Level Calibrator produces a level of 94 ±0.3 dB at 100 Hz.

A coarse calibration utilizing the sensitivity of the Carrier System with a B&K 1 inch Condenser Microphone Type 4146 can be applied if an accurate source is not available. The instrumentation for calibration should be set up as shown in Fig.3.8., in an environment free from external pressure disturbances. Balance is then obtained for the 2631 with the microphone placed

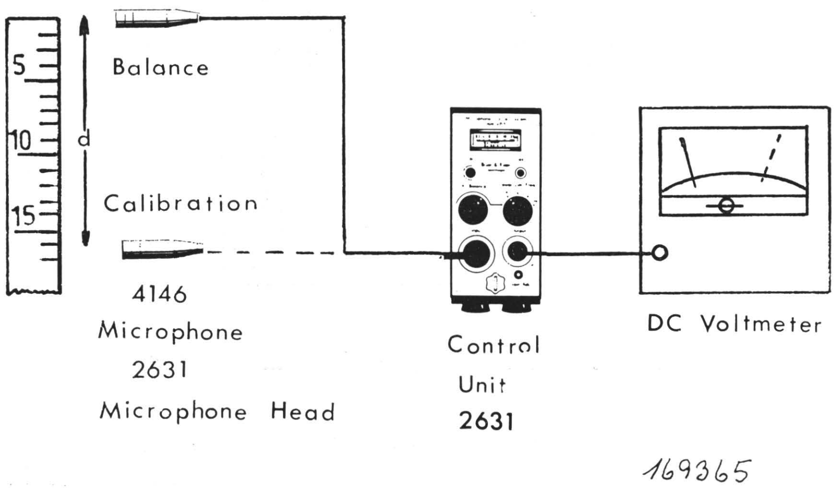


Fig.3.8 Coarse calibration instrument set up.

in a horizontal position. The DC mode is then selected and the microphone (still in a horizontal position) displaced a suitable distance to a point immediately below the position for balance. To calibrate, adjust the Gain Adj. on the Control Unit to give a deflection on a DC voltmeter connected to the 2631 Output. The required deflection for calibration can be calculated from:

$$1.25 \cdot 10^{-2}\ Mp \cdot d \quad mV.$$

Where "Mp" is the microphone sensitivity (mV/N/m^2) and "d" is the distance the microphone is displaced (mm).

This represents a pressure difference of 1 μbar/8mm of microphone displacement.

Example:

If a Microphone Type 4146 is displaced 160 mm below the point at which balance is obtained and the microphone sensitivity is 50 $mV/N/m^2$ (from calibration chart provided) then the meter deflection will be

$$1.25 \cdot 10^{-2} \cdot 50 \cdot 160 = +100 \text{ mV}$$

Note: If the Microphone is placed 160 mm above the balance point then the meter deflection will be −100 mV.

Once calibration has been obtained for a microphone, the inconvenience of recalibrating that particular microphone can be avoided by using the test oscillator. The amplitude of the oscillator should be adjusted to provide some convenient indication on the measuring and recording instrumentation (up to 146 dB indication available with the 1 inch condenser microphone fitted). For later calibrations the GAIN ADJ. is used to adjust the Test signal to its reference level. The accuracy of the test oscillator is ±0.3 dB for temperature variations less than ±5°C.

4. APPLICATIONS.

The applications of the B&K Carrier Microphone System Type 2631 are numerous and cover almost any field where measurements of slowly varying air pressures and short duration pulses are sought. Discussion here is confined to the sonic bang and pressure measurements.

SONIC BANG MEASUREMENTS.

Measuring Environment.

When sonic bang measurements are to be taken from ground level, an open space reasonably free from obstructions and local undulations is required, with a hard surface in the form of a securely mounted, rigid baffle (1.5 m diameter, or more) surrounding the measurement point. If obstructions are present then they should not subtend a solid angle greater than 0.004 steradians.

Free air conditions apply when the microphone can be mounted at sufficient height and when obstructions in the upper half space do not subtend an angle greater than 0.004 steradians. This may necessitate an altitude of more than 100 m for the whole sonic bang pressure signature to be determined. However, a lower height may be found sufficient to resolve the rise terms.

Any deviations from the conditions specified above should be stated with the measurements obtained.

Microphone & installation.

For sonic bang measurement when the upper limiting frequency is 10 kHz or greater, a B&K 1/2 inch Condenser Microphone Type 4148 with Head Adaptor Type UA 0271 is recommended. This is to avoid measurement errors due to the transit time of the shock across the microphone diaphragm.

For installation of the microphone at ground level, its diaphragm should be mounted facing directly upwards and flush with the surrounding baffle and ground. However, where this is impracticable the microphone can be mounted in either a vertical or horizontal position with its diaphragm as close to the ground as possible, but avoiding a face down condition. The microphone body and all measuring equipment should be below ground or sufficiently remote that their proximity does not influence the measurements.

Extraneous signals due to ground vibration and wind etc., can be avoided by providing the microphone with a shock mounting and a B&K Wind Screen Type UA 0082.

Extension of microphone lower limiting frequency.

The lower limiting frequency of a condenser microphone is proportional to the time constant produced by the microphones internal volume ($V \simeq C$) and the resistance (R) presented by the pressure equalisation vent. For the 4146 Condenser Microphone the time constant ($K.\ R_1\ C_1$) is approximately 10 sec. A method of extending the microphones lower limiting frequency is shown in Fig.4.1. Here the effective volume is increased by enclosing the microphone in a cavity also with an equalisation vent. The volume of the cavity and its equalisation vent should be designed to have a time constant ($K.\ R_2\ C_2$) or about 100 sec. This should give a microphone lower limiting frequency of 0.01 Hz, suitable for sonic bang measurements.

Measurement and analysis.

A typical sonic bang measurement set up using the 2631 Carrier System with a 1/2 inch Microphone is shown in Fig.4.2. For recordings of the complete pressure signature the B&K Tape Recorder Type 7001 is recommended as its response ranges from DC to 20 kHz, when a tape speed of 60 in/sec. is employed. The dynamic range of the recorder is 50 dB, but if a greater range is required both recording channels should be utilized, one recording directly from the 2631, the other via a 100 Hz cut off high pass filter. This proposed system (shown dotted in Fig.4.2) not only gives an effective increase in dynamic range but also increases signal to noise. During frequency analysis a network with an inverse characteristic is applied.

Although the 2631 and 7001 are provided with peak overload meters, accurate pre-determination of the sonic bang pressure level is not possible.

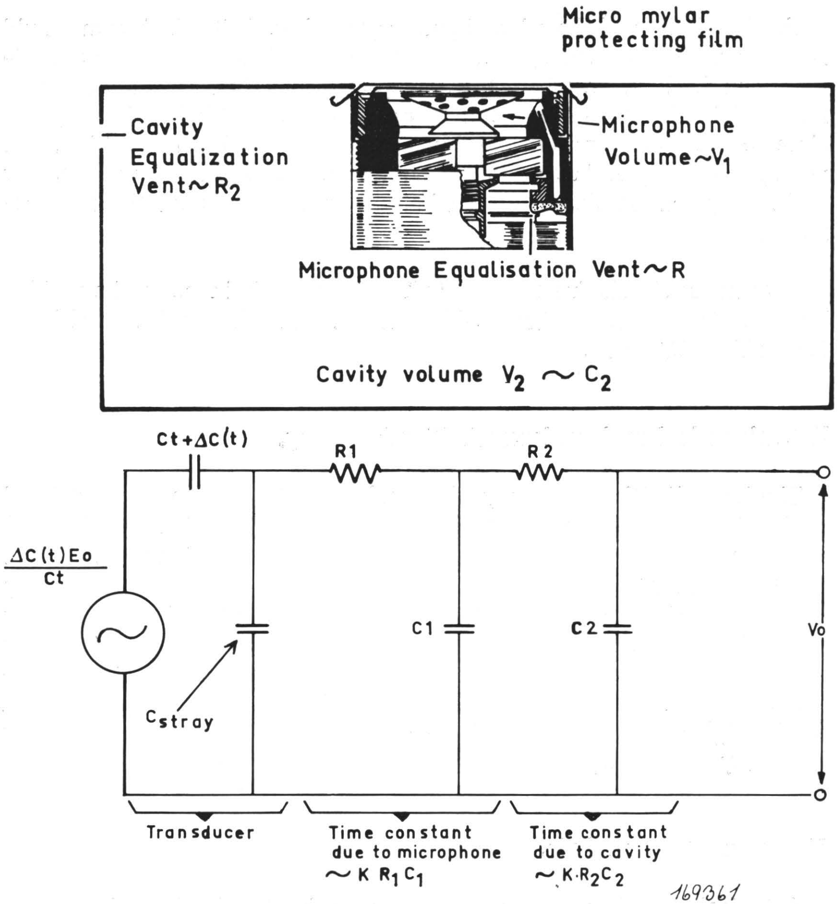


Fig.4.1 Extending microphone lower limiting frequency, showing equivalent circuit.

Therefore, it is advised that both recording channels (or possibly a number of tape recorders) are used, but with different gain settings. This ensures adequate signal to noise and that one channel utilizes the full dynamic range.

Frequency analysis of the sonic bang pressure signature can be given in the form of either a frequency band spectrum or by a spectral density

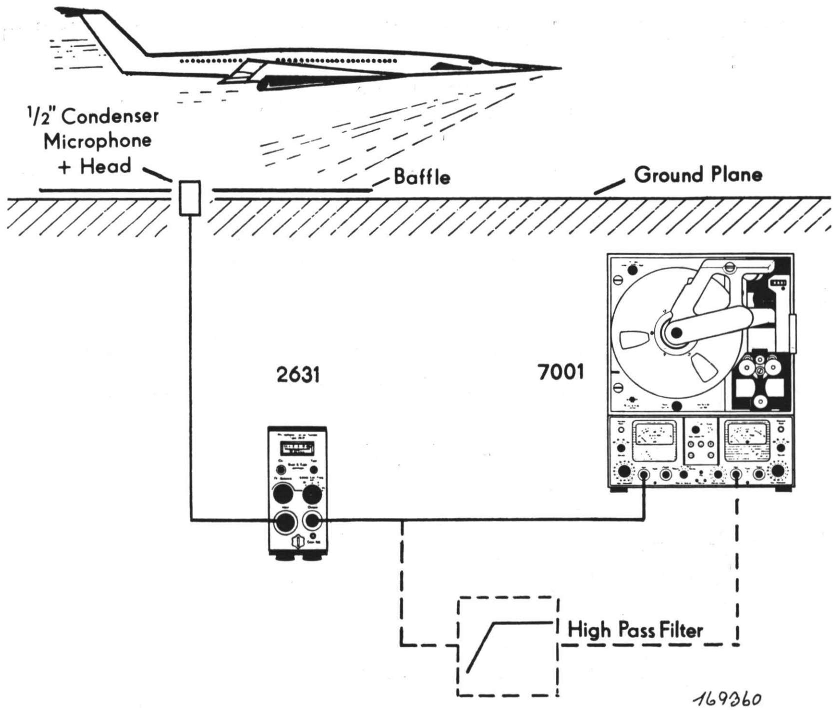


Fig.4.2 Measurement arrangement for sonic bangs.

function. A convenient spectral density function related to the energy spectral density by a constant factor having the dimensions of acoustic impedance is given by:

$$E = 10 \log_{10} 2\pi \frac{|S(\omega)|^2}{p_o^2 t_o^2} \qquad \text{(dB)}$$

where $S(\omega) = \int_{-\infty}^{\infty} p(t) \times e^{-j\omega t}\, dt$

and $p_o = 20\ \mu\text{N/m}^2$

$t_o = 1\ \text{s}$

p(t) is the overpressure as function of time t, and $\omega = 2\pi f$.

The level of the band spectrum in the frequency range f_1 to f_2 is then given by:

$$L = 10 \log_{10} \int_{\omega_1}^{\omega_2} \frac{|S(\omega)|^2}{p_o^2 t_o} d\omega \qquad \text{(dB)}$$

A band spectrum of the pressure signature frequency components, in the range 20 to 5000 Hz can be obtained graphically on calibrated paper using the 2305 Level Recorder. Analyzing set ups are shown in Fig.4.3 and 4.4. Each requires a tape loop of the pressure signature which on playback can be filtered, either by the 1614/15 Filter Set (1/3 and 1/1 Oct. bandwidths), or the 2020 a narrow band Slave Filter (3.16, 10, 31.6 and 100 Hz bandwidths). Both instruments can be automatically scanned, but only the 2020 has the $1/\sqrt{B}$ output attenuator useful in spectral density measurements.

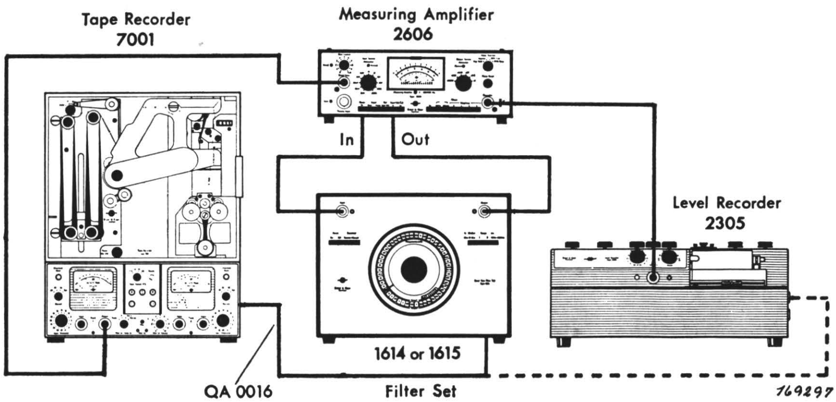


Fig.4.3 Analyzing arrangement utilizing B&K Filter Set Type 1614/15.

For 0.01 to 20 Hz frequency components, analysis is performed as before, but because of the lower limiting frequencies of the level recorder and filters, a frequency transformation is necessary. Two tape recorders are required. One to play back the original pressure signature, but at a speed greater than when originally recorded. The other to re–record it and play it back at a faster speed, thus bringing it into the frequency range required for analysis.

For further information on sonic bang measurement, the I.S.O. Draft Proposal 43/1 N 22 should be consulted.

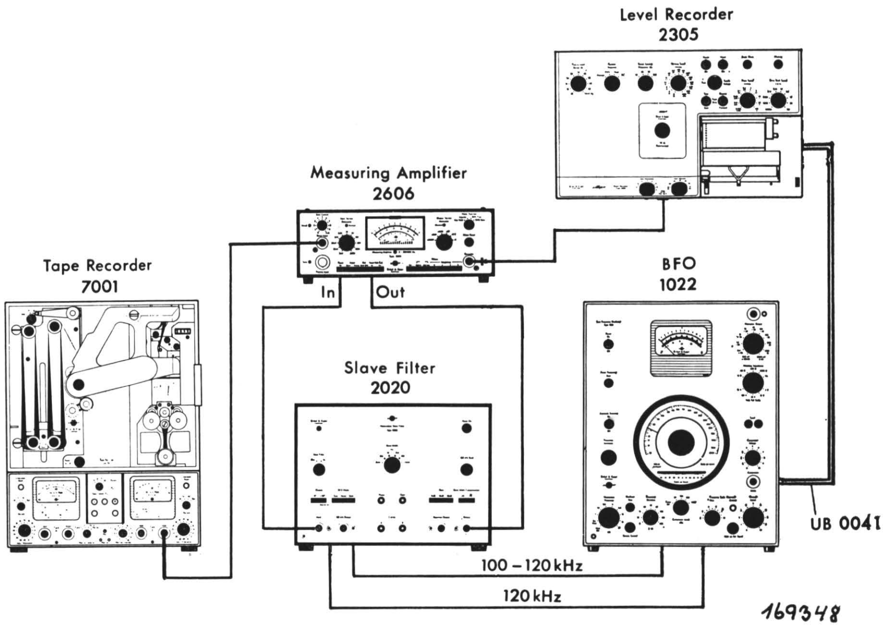


Fig.4.4 Analyzing arrangement utilizing B&K Slave Filter Type 2020.

PRESSURE MEASUREMENTS.

For measurement of slowly varying air or gas pressures and where the use of an ordinary manometer is limited as in the measurement of short duration pressure pulses, the 2631 Microphone Carrier System will be found of use.

A proposed microphone adaptor for pressure measurements which can be fitted to the B&K 1/2 inch Microphone Type 4134 is shown in Fig.4.5. Except for the two pressure intake nozzles the adaptor should form an airtight seal around the microphone. The pressure to be measured should be applied to the microphone diaphragm and the reference pressure to the equalization hole via the appropriate intake nozzle. For the 4134 Microphone the maximum measured pressure difference should not exceed 204 mm. H_2o as the 2631's output would cease to be linear and damage to the microphone diaphragm may result. A pressure difference of 204 mm. H_20 represent a maximum sound pressure level of 160 dB.

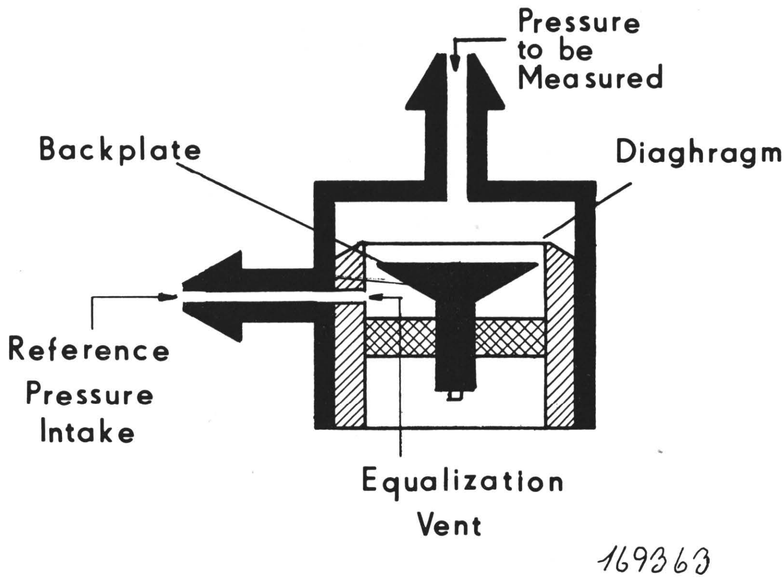


Fig.4.5 Schematic of microphone pressure adaptor.

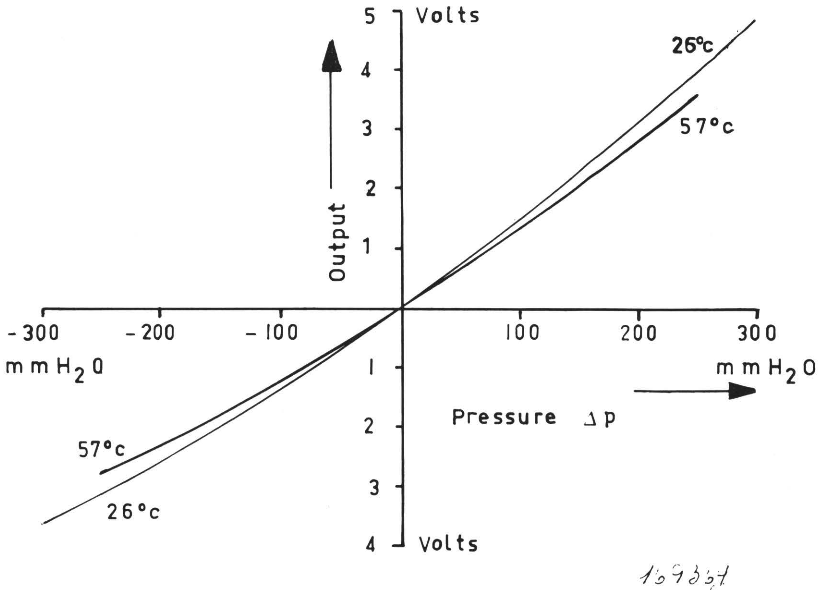


Fig.4.6 Experimental results from calibration of 1/4 inch Microphone Type 4136 adapted for pressure measurements.

Experimental results obtained in the calibration of a 1/4 inch Microphone Type 4136 adapted for pressure measurements (Fig.4.6) show that a reasonably linear output can be obtained from the 2631 in the DC mode. A Betz Manometer was used to determine the precise pressure difference, whilst the output from the 2631 was monitored on an external voltmeter.

Typical areas of research where the 2631 may be used with advantage are in fluid mechanics, pressure chambers and wind tunnels. In the latter case, pressure measurements may be made on moving air foils (Fig.4.7) or on the transient response of pressure fronts along wind tunnels. In all these applications the 2305 Level Recorder will prove useful in providing a graphical display of pressure behaviour with respect to time.

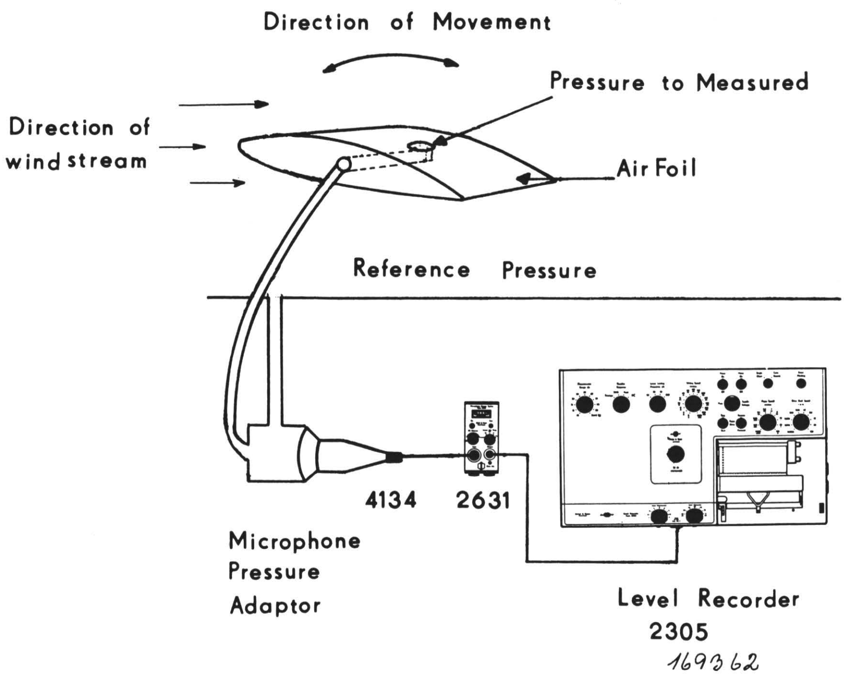


Fig.4.7 Measurements in wind tunnels.

5. SPECIFICATIONS.

	System alone	System with 1" Microphone (4146)
Capacitance Range	40–70 pF	
Frequency range	0 Hz–150 kHz	0.1 Hz–7 kHz
Linear range	± 6 pF	± 500 N/m^2
Noise 0.01 Hz–200 kHz	6×10^{-3} pF	0.5 N/m^2 Peak
2 Hz–200 kHz	0.3×10^{-3} pF	62 dB RMS
2 Hz– 20 kHz	0.25×10^{-3} pF	60 dB RMS
Curve C	0.15×10^{-3} pF	55 dB RMS
Curve A	0.1×10^{-3} pF	50 dB RMS
Stability in DC mode	0.04 pF/day 0.0015pF/^{o}C	3 N/m^2/day,0.1 $m^2/^{o}C$
Sensitivity	1.2–30 V/pF	20–100 mV/N/m^2
Lower limiting frequency	DC–0.01 Hz –0.1 Hz–1 Hz	As for microphone
Compensation of cartridge capacity		Automaticat 0.01–0.1 –1 Hz and manual at DC
Distortion at full load	< 4%	
Carrier frequency	10 MHz	
Max.output of head	± 10 V, ±10 mA	
Max.output of amplifier	± 10 V, ±10 mA	
Output impedance	<10 Ω	
Min.load impedance	1.2 k Ω	
Operation temperature	–20^{o}C to + 60^{o}C	
Storage temperature	–30^{o}C to + 80^{o}C	
Meter display	max. peak, DC or DC balance	
Power supply	100–240 V AC, 50–400 Hz	
Power consumption	approximately 20 mA RMS	
Output connectors	B&K 14 mm socket and 10–32 NF microsocket	
Built–in test oscillator	1 kHz	

Above specifications apply at 25^{o}C

Dimensions of control unit (KK 0002) excl. knobs and feet:

Height:	132.6 mm	(5.22 in)
Width:	61 mm	(2.40 in)
Depth:	200 mm	(7.87 in)

Weight of box. 1.65 kg (3.63 lb)

Dimensions of microphone head:

Diameter:	23.8 mm	(15.16 in)
Length:	76 mm	(3 in)
Cable length:	2 m	(6.5 ft)

Weight of microphone head: 0.31 kg (0.68 lb)

B & K INSTRUMENTS:

ACOUSTICAL....
Condenser Microphones
Piezo-Electric Microphones
Microphone Preamplifiers
Microphone Calibration Equip.
Sound Level Meters
(general purpose-precision-
and impulse)
Standing Wave Apparatus
Tapping Machines
Noise Limit Indicators

ELECTROACOUSTICAL....
Artificial Ears
Artificial Mouths
Artificial Mastoids
Hearing Aid Test Boxes
Telephone Measuring Equipment
Audiometer Calibrators
Audio Reproduction Test Equip.

STRAIN....
Strain Gauge Apparatus
Multipoint Panels
Automatic Selectors
Balancing Units

VIBRATION....
Accelerometers
Accelerometer Preamplifiers
Accelerometer Calibrators
Vibration Meters
Magnetic Transducers
Capacitive Transducers
Vibration Exciter Controls
Vibration Programmers
Vibration Signal Selectors
Mini-Shakers
Complex Modulus Apparatus
Stroboscopes

GENERATING....
Beat Frequency Oscillators
Random Noise Generators
Sine-Random Generators

MEASURING....
Measuring Amplifiers
Voltmeters
Deviation Bridges
Megohmmeters

ANALYZING....
Band-Pass Filter Sets
Frequency Spectrometers
Frequency Analyzers
Real-Time Analyzers
Slave Filters
Psophometer Filters
Statistical Analyzers

RECORDING....
Level Recorders
(strip-chart and polar)
Frequency Response Tracers
Tape Recorders

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