Response Equalisation

- **Realtime Measurement Optimisation**
- **Flatten the Frequency Response**
- **Extend the Frequency Range**
- The ideal sensor with a well defined linear response (sensitivity and phase) regardless of frequency is the optimal design for any microphone or accelerometer.
- In the real world however Piezo-Electric ceramic materials exhibit a change in sensitivity as a function of frequency, manufacturing tolerances affect response and resonance frequency.

Response Equalisation

- Response Equalisation is a new technique that allows you to flatten and stretch the frequency response of microphones, accelerometers and couplers in real time.

- Response Equalisation is done by filtering the time signal of a transducer by the inverse of the frequency response.

- Response Equalisation can be added to any transducer with a well specified frequency response either manually stored or automatically imported from any accelerometer from Brüel & Kjær with TEDS in the PULSE analyzer system from Brüel & Kjær.

Response Equalisation

Benefits achieved:

More accurate measurements

Wider usable frequency range

Use of the same transducer for more applications

Accelerometer Calibration

- **Individual Frequency Response with 1600 Line Resolution**

Accelerometer Calibration

All Brüel & Kjær Accelerometers are delivered with individual

Sensitivity and the Parameters:

Resonance frequency, Q-factor

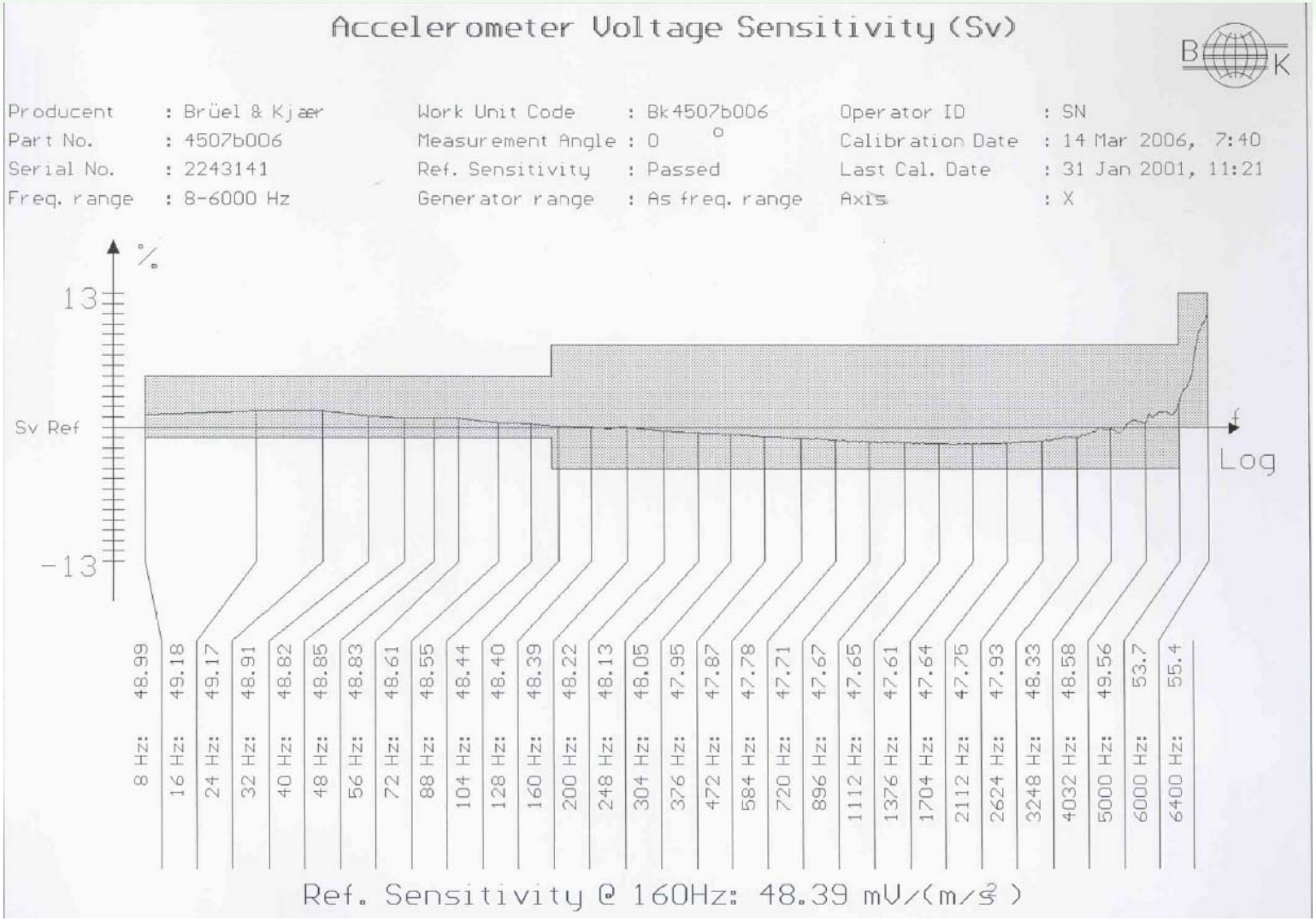
upper & lower frequency limit and amplitude correction/slope, which

are required to generate the response equalisation.

The values are calculated, best fit, based on the individual

frequency response, 1600 line resolution, of the accelerometer.

Accelerometer Amplitude Response



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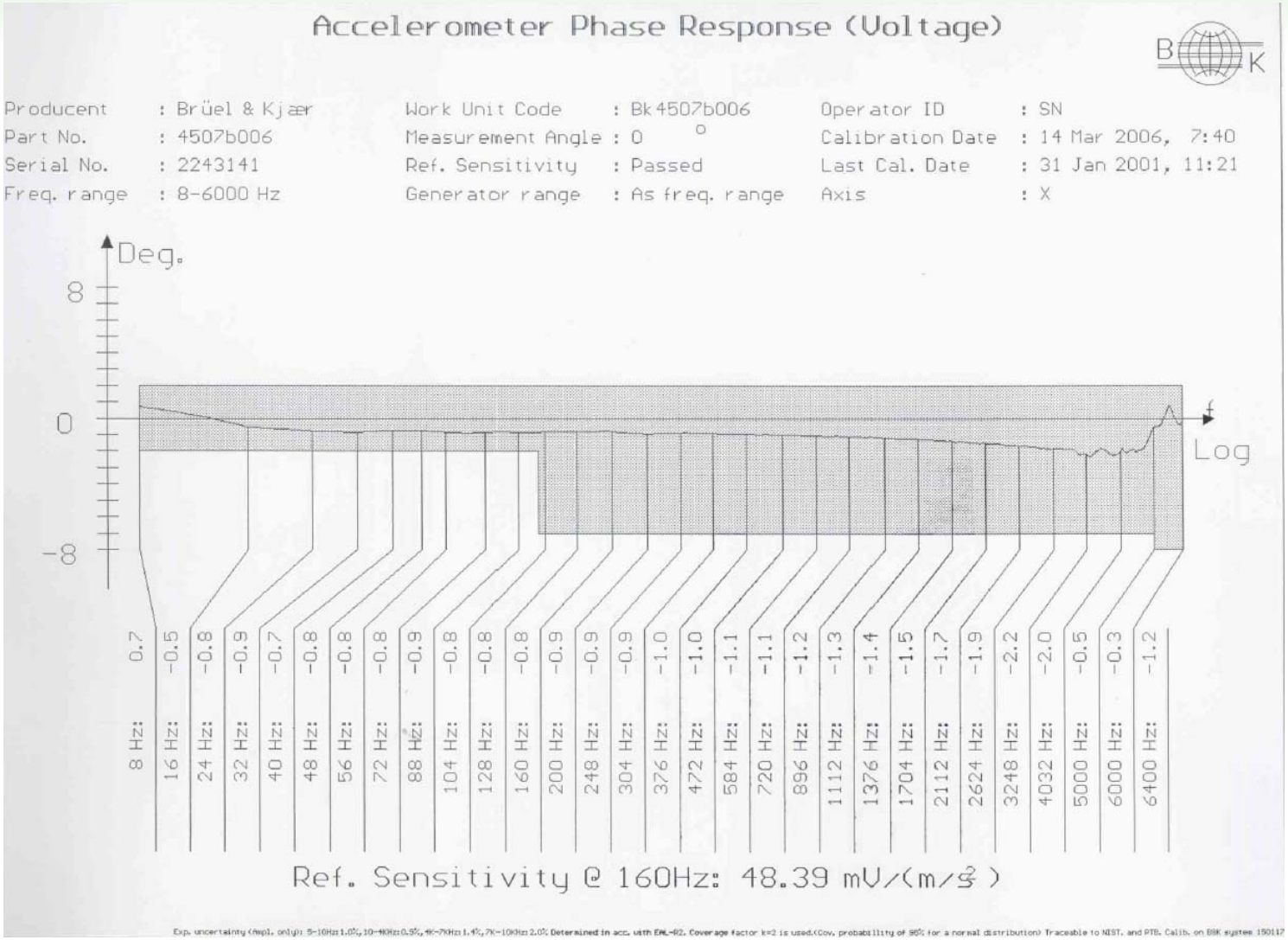
Accelerometer Phase Response



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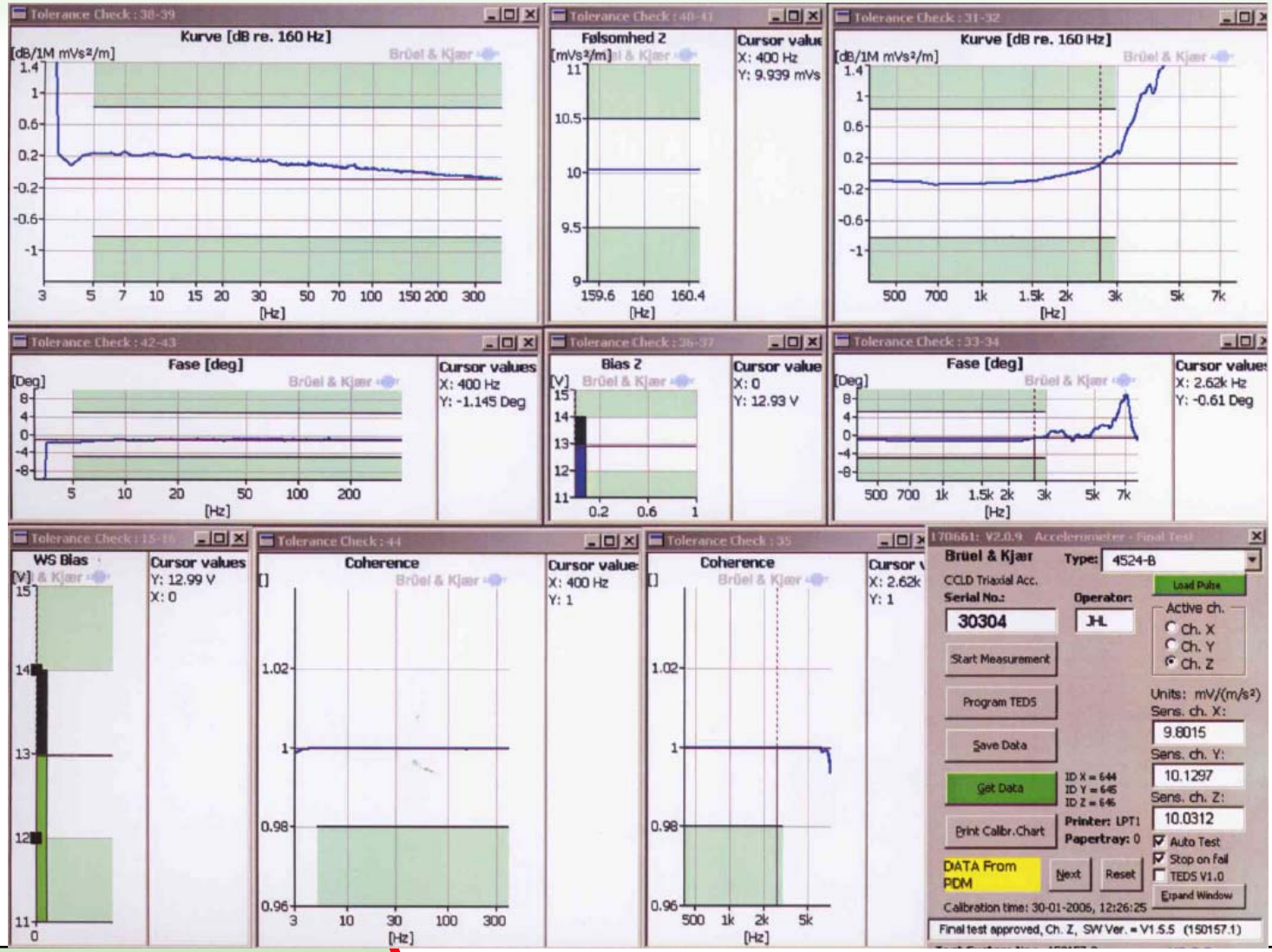
Accelerometer Calibration



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Accelerometer Calibration Chart

Calibration Chart for DeltaTron® Accelerometer Type 4507 B 006

Brüel & Kjær

Serial No.: 2243141

Reference Sensitivity [1] at 159.2 Hz (ω = 1000 s⁻¹), 20 ms⁻² RMS, 4 mA supply current and 23 °C: 48.39 mV/ms⁻² (474.5 mV/g)

Frequency Range:	Amplitude (±10%):	0.2 Hz to 6 kHz
	Phase (± 5°):	1 Hz to 5 kHz
Mounted Resonance Frequency:		18 kHz
Transverse Sensitivity: Maximum (at 30 Hz, 100 ms⁻²):		< 5% re Reference Sensitivity
Transverse Resonance Frequency:		> 18 kHz
Calculated values for TEDS [3]:	Resonance frequency:	16.5 kHz
	Quality factor @ f_{res}:	327
	Amplitude slope:	-2.5 %/decade
	High pass cut-off frequency:	0.17 Hz
	Low pass cut-off frequency:	301 kHz
Measuring Range:		± 140 ms⁻² peak (± 14 g peak)

Polarity of the electrical signal is positive for an acceleration in the direction of the arrow on the drawing.

Electrical:

Bias Voltage:	at full temperature and current range:	+ 13 V ± 2 V
Power Supply requirements:	Constant Current:	+ 2 to + 20 mA
	Unloaded Supply Voltage:	+ 24 V to + 30 V
Output Impedance:		< 30 Ω
Start-up time (to final bias ± 10%):		5 s
Inherent Noise (RMS): Broadband (1 Hz to 6 kHz):		< 80 µV corresponding to < 0.0016 ms⁻² (< 160 µg)
Spectral:	10 Hz:	8x10⁻⁵ ms⁻²/√Hz (8 µg/√Hz)
	100 Hz:	2x10⁻⁵ ms⁻²/√Hz (2 µg/√Hz)
	1000 Hz:	1x10⁻⁵ ms⁻²/√Hz (1 µg/√Hz)

Ground Loops can introduce error signals. These can be avoided by insulating the accelerometer from the mounting surface (see Mounting Technique).

Recommended cables: AO 1382, AO 0531, AO 0463 and other cables see Product Data Sheet

Built-in ID-information according to IEEE P1451.4

Environmental:

Temperature Range:	- 54 to + 100°C (- 65 to + 212°F)
Temperature Coefficient of Sensitivity:	+ 0.18%/°C
Temp. Transient Sensitivity (3 Hz Low. Lim. Frq. (-3 dB, 6 dB/oct)):	0.2 ms⁻²/°C
Magnetic Sensitivity (50 Hz, 0.038 T):	3 ms⁻²/T
Base Strain Sensitivity (at 250 µε in base plane): Mounted on adhesive tape 0.09 mm thick:	0.005 ms⁻²/µε
Max. Non-destructive Shock:	50 kms⁻² peak (5000 g peak)
Humidity:	100 % RH non-condensing

Mechanical:

Case Material:	Titanium ASTM Grade 2
Sensing Element:	Piezoelectric, Type PZ 27
Construction:	Theta Shear®
Sealing:	Hermetic
Weight:	4.6 gram (0.16 oz)
Electrical Connector:	10 - 32 UNF-2A
Mounting Surface Flatness:	< 3 µm

[1] This calibration is obtained on a modified Brüel & Kjær Calibration System Type 9610 System No.: 150117.4 and is traceable to the National Institute of Standards and Technology, USA and Physikalisch-Technische Bundesanstalt, Germany.
The expanded uncertainty is 1.0% determined in accordance with EAL-R2. A coverage factor k=2 is used. This corresponds to a coverage probability of 95% for a normal distribution.

[3] Transducer Electronic Data Sheet according to IEEE P1451.4.

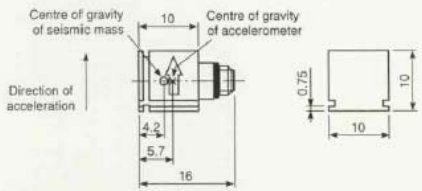
[4] Deviation from Reference Sensitivity.

Patents involved: US 08387851, JP 50952694 and DK 169853.

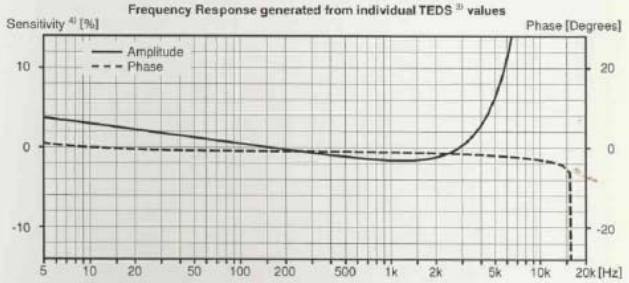
For further information, please see http://www.bk.dk and Product Data Sheet BP 1841.

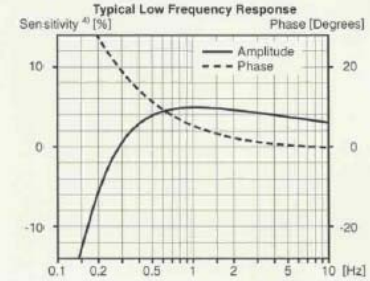
CE

Mounting Technique:
The 3 sets of mounting slots make it possible to perform pseudo triaxial measurements by successively mounting the accelerometer in 3 directions perpendicular to each other. The accelerometer can be fastened directly to the measuring object by glue e.g., hot glue. However, if a reduced frequency range can be accepted, it is recommended to use one of the special mounting clips (see below) which is glued to the measuring object. In any case the mounting surface must be clean and smooth.
Four types of mounting clips are available: UA 1407 (set of 100) is a low profile clip recommended for mounting on plane surfaces. UA 1475 (set of 100) is a clip with a thick base which can be filed to fit a curved mounting surface. UA 1564 (set of 5) is a high temperature clip. UA 1478 (set of 100) is a swivel base clip for use where the accelerometer is to be aligned according to a given co-ordinate system (see Product Data Sheet BP 1841).
Applying a little grease to the mounting surface of the accelerometer as well as the clip will improve the frequency response. See also ISO 5348.



All dimensions in millimetres





Date 14 Mar 2006 Operator SN

Specifications obtained in accordance with ANSI S2.11-1969 and parts of ISO 5347.
All values are typical at 25°C (77°F) unless measurement uncertainty is specified.

BC 0304-16

Serial No.: 2243141

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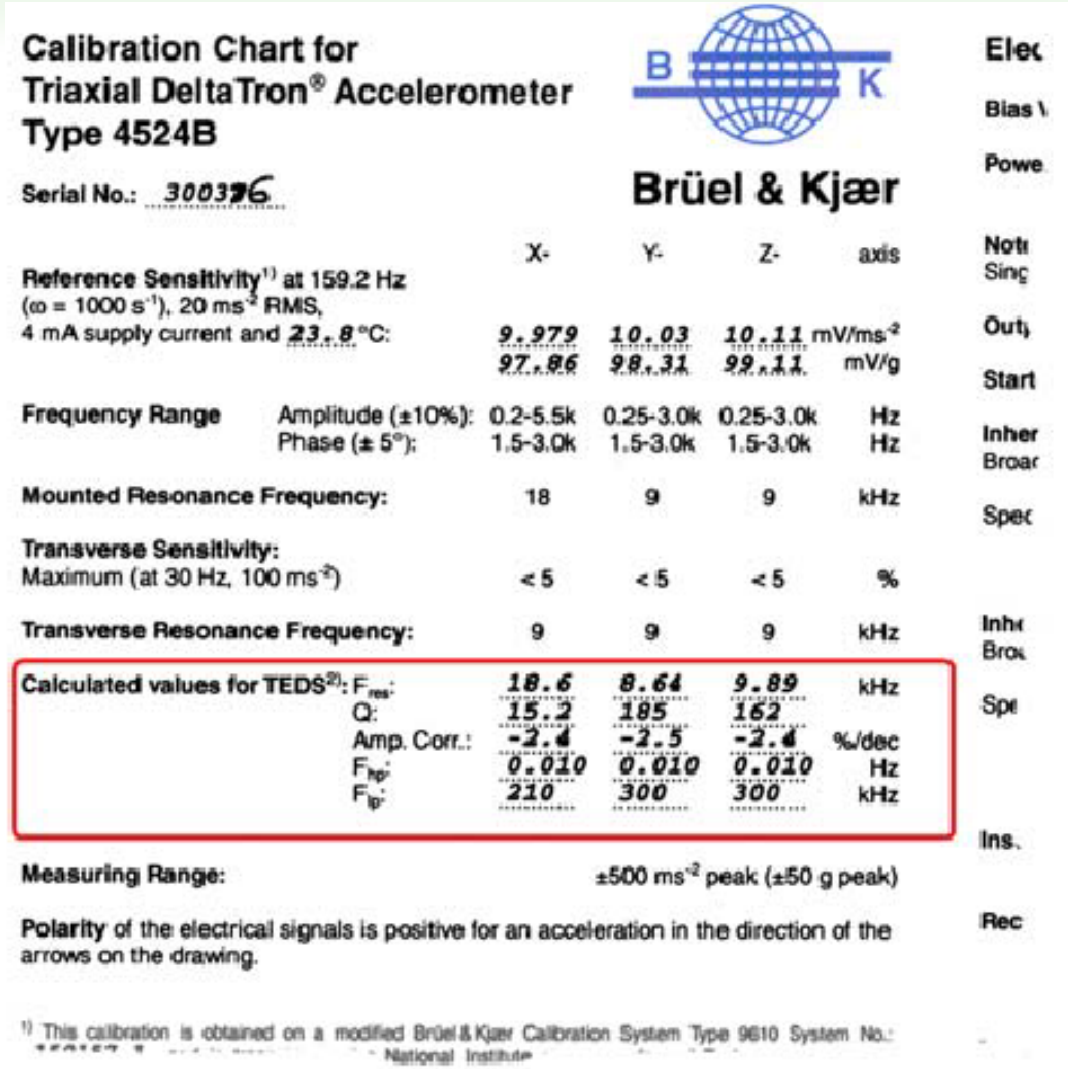
Accelerometer Calibration Chart 4524B



Calibration Chart for Triaxial DeltaTron® Accelerometer Type 4524B

Serial No.: 300376

Brüel & Kjær

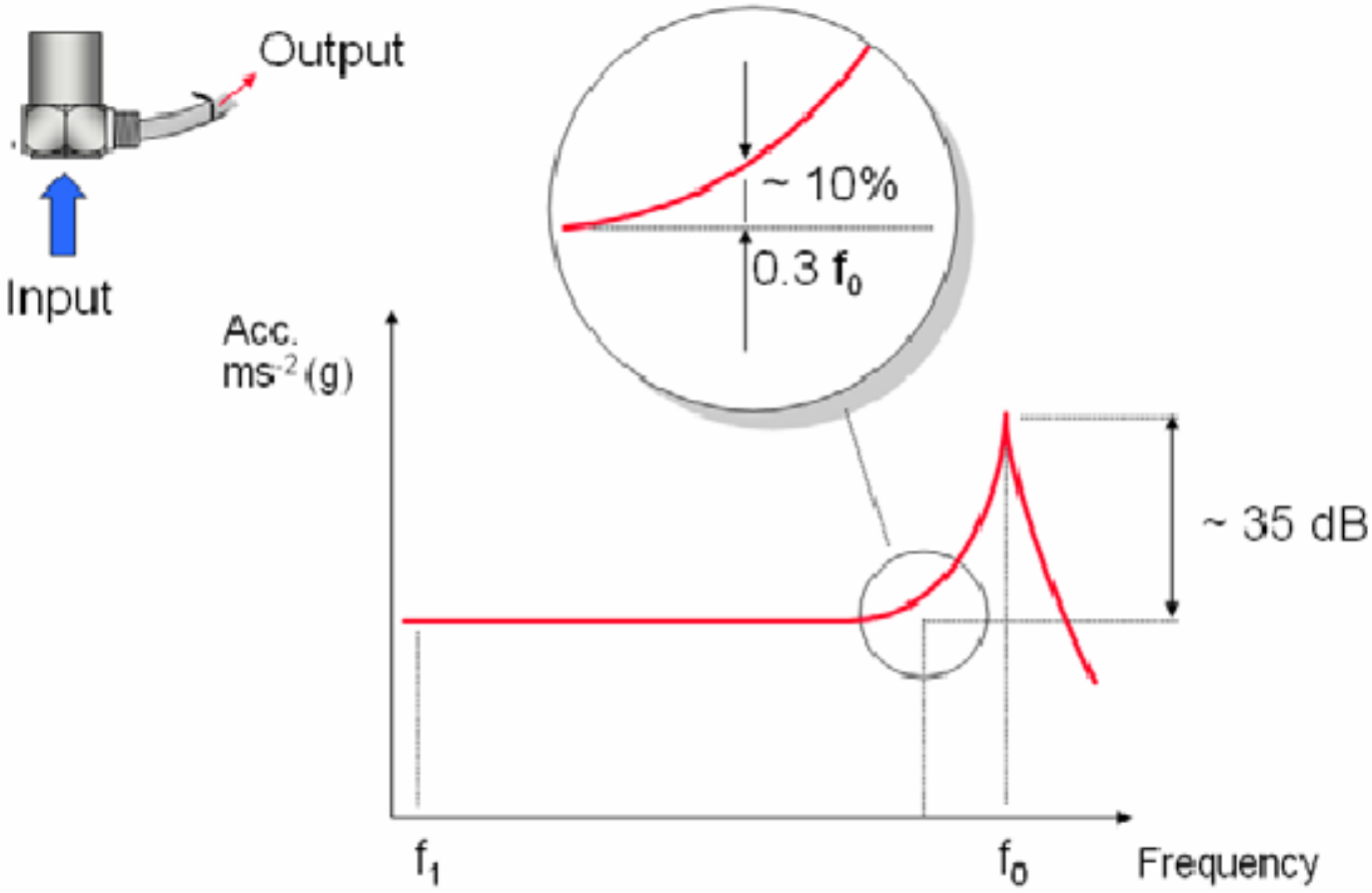
		X-	Y-	Z-	axis
Reference Sensitivity[1] at 159.2 Hz (ω = 1000 s^{-1}), 20 ms^{-2} RMS, 4 mA supply current and 23.8 °C:		9.979	10.03	10.11	mV/ms^{-2}
		97.86	98.31	99.11	mV/g
Frequency Range	Amplitude (±10%):	0.2-5.5k	0.25-3.0k	0.25-3.0k	Hz
	Phase (± 5°):	1.5-3.0k	1.5-3.0k	1.5-3.0k	Hz
Mounted Resonance Frequency:		18	9	9	kHz
Transverse Sensitivity: Maximum (at 30 Hz, 100 ms^{-2})		< 5	< 5	< 5	%
Transverse Resonance Frequency:		9	9	9	kHz
Calculated values for TEDS[2]:	F_{res}:	18.6	8.64	9.89	kHz
	Q:	15.2	185	162	
	Amp. Corr.:	-2.4	-2.5	-2.4	%/dec
	F_{hp}:	0.010	0.010	0.010	Hz
	F_{lp}:	210	300	300	kHz

Measuring Range: ±500 ms^{-2} peak (±50 g peak)

Polarity of the electrical signals is positive for an acceleration in the direction of the arrows on the drawing.

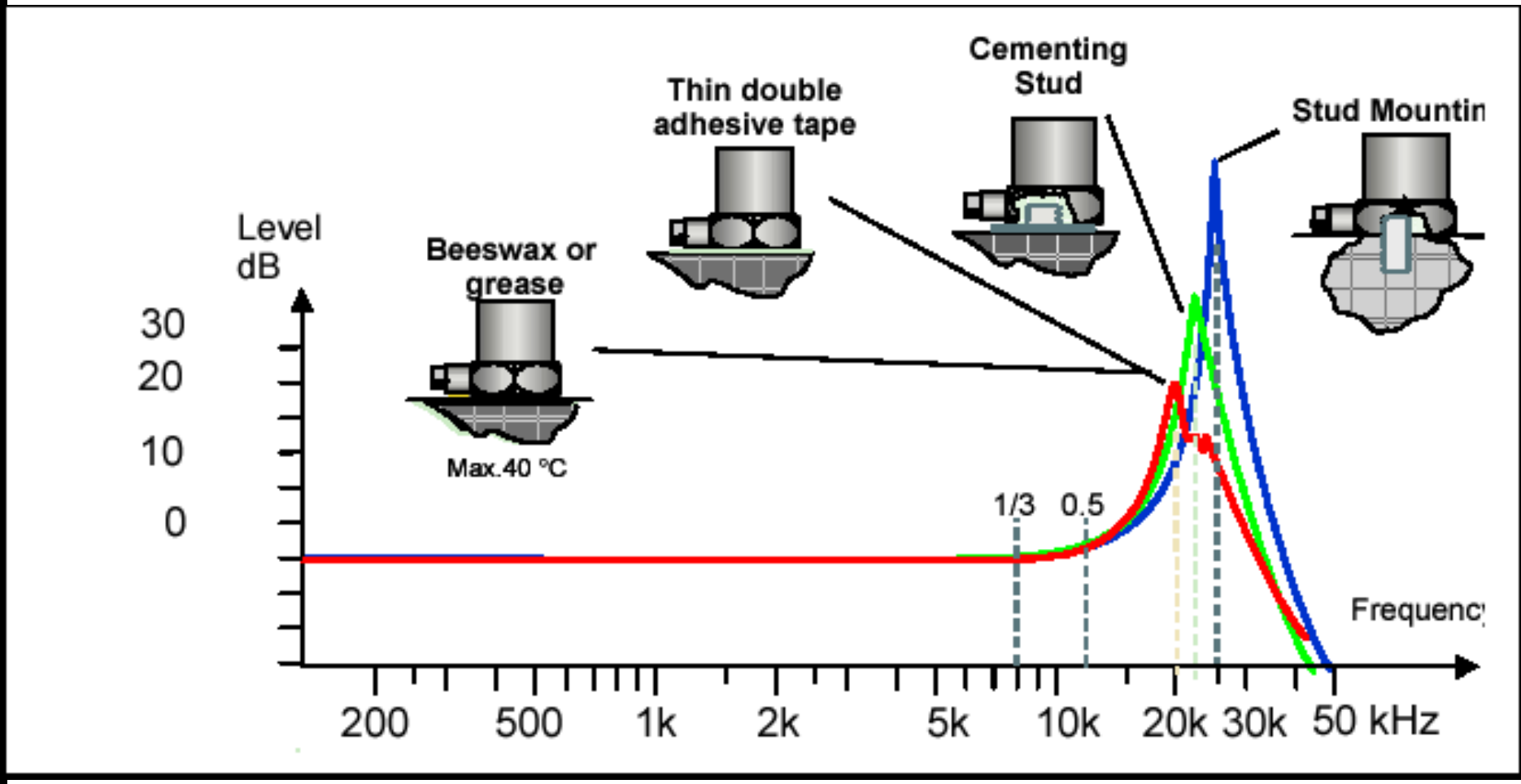
[1] This calibration is obtained on a modified Brüel & Kjær Calibration System Type 9610 System No.: ... National Institute ...

Useful upper Frequency limit



Useful upper frequency limit for an accelerometer is typically $0.3f_0$

Mounting resonance frequency



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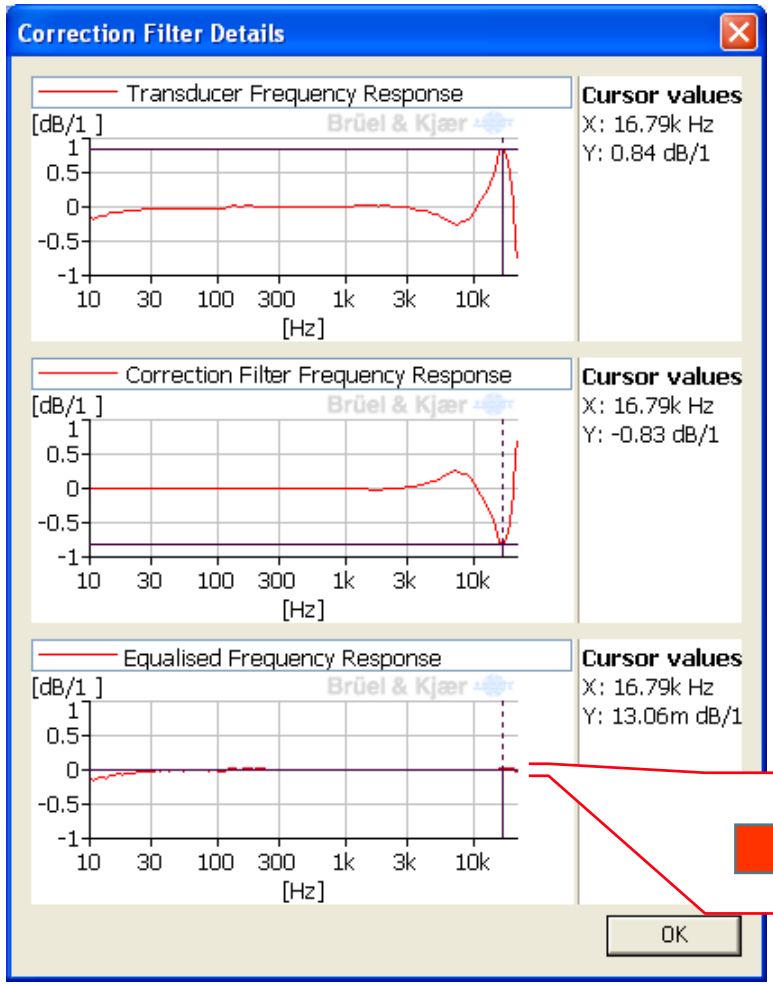
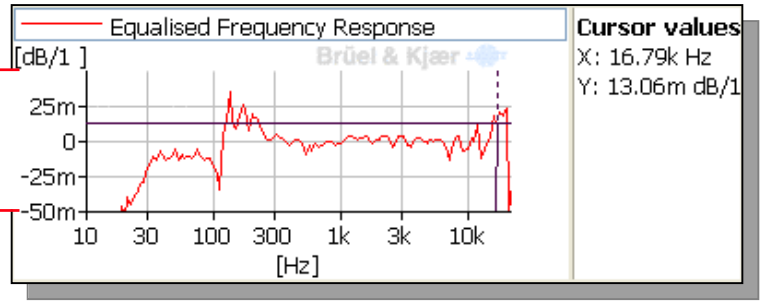
Response Equalisation – REq-X – How it works



- Transducer Frequency Response
- Correction Filter Response
- Equalised (true) Frequency Response



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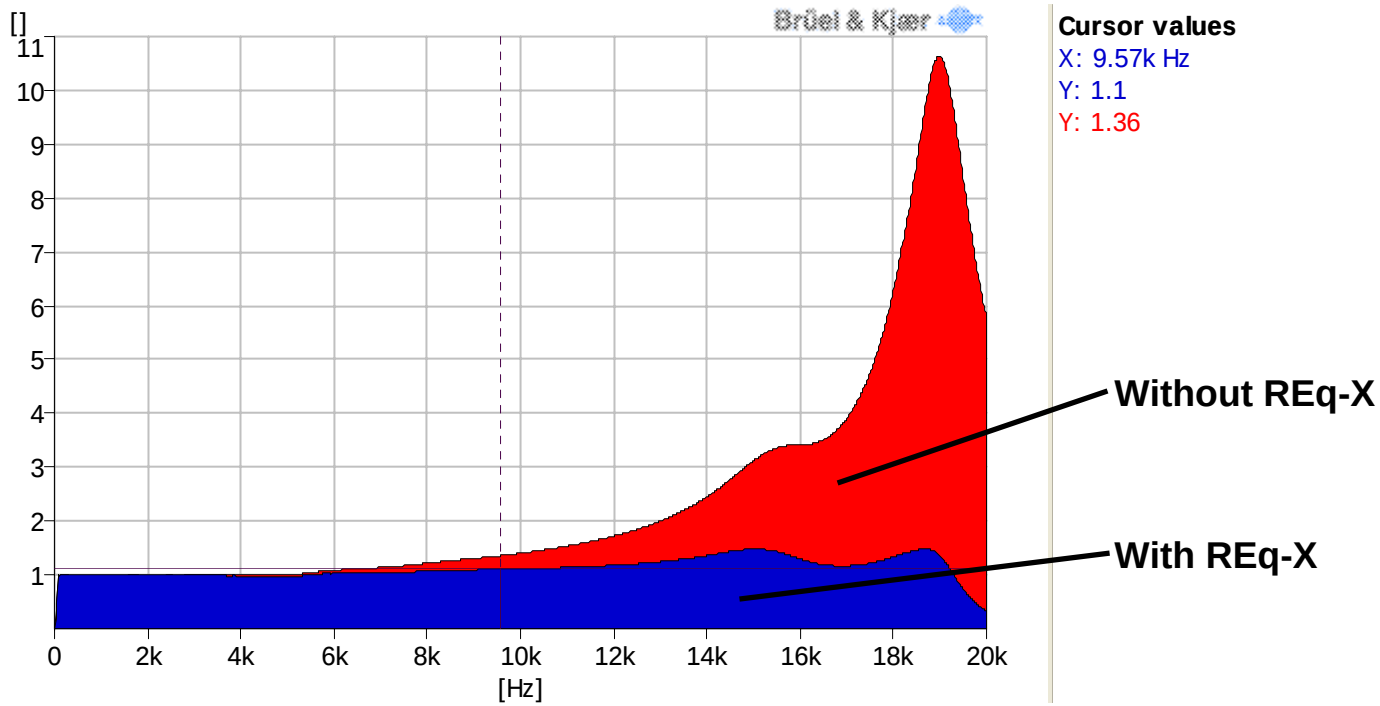
REq-X with Accelerometers – example

Measurement example – 4507 mounted with grease

Resonance frequency = 19 kHz

+10% at 6.1 kHz without REq-X

+10% at 9.6 kHz with REq-X



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Accelerometers using Response Equalisation

Type	Mounting	Specification ±10%	Not Equalised	Equalised
4507 	Metal clip	6 kHz	6.8 kHz	12 kHz
	Grease	6 kHz	6.5 kHz	10 kHz
	Plastic clip	3 kHz	4.5 kHz	5.5 kHz
4513 	Stud	10 kHz	14 kHz	>22 kHz
	Grease	10 kHz	14 kHz	20.5 kHz
4524 	Metal clip	5.5 kHz	7.7 kHz	12.5 kHz

Advantages of Response Equalisation

- **Advantages of Equalisation for Piezoelectric Accelerometers**

- Equalise the frequency response and improve the accuracy by a factor 2

- Equalise the frequency response and extend the upper frequency limit ±10% from 0.3 f0 to 0.5 f0, for uniaxial accelerometers stud mounted the effect is typically >0.6 f0

Conclusion

The benefits of Response Equalization are as follows:

- It expands the use of new and existing transducers
- It improves the accuracy of the measurements
- It extends the frequency of transducers
- It works in real-time, thus any measurement and analysis will benefit from this.