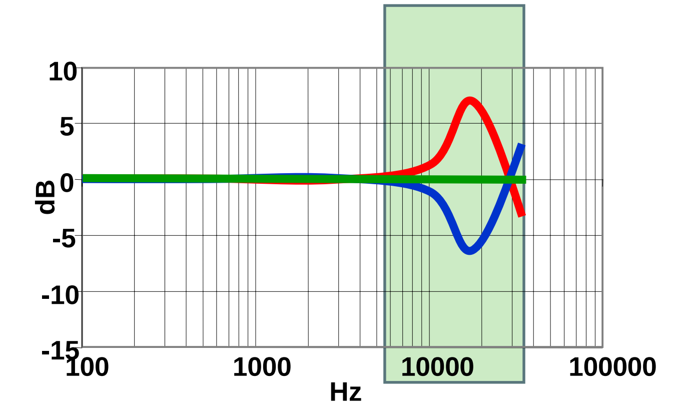
Microphone & Accelerometer Frequency Response Enhancement

PULSE 11 - The Engineer's Choice

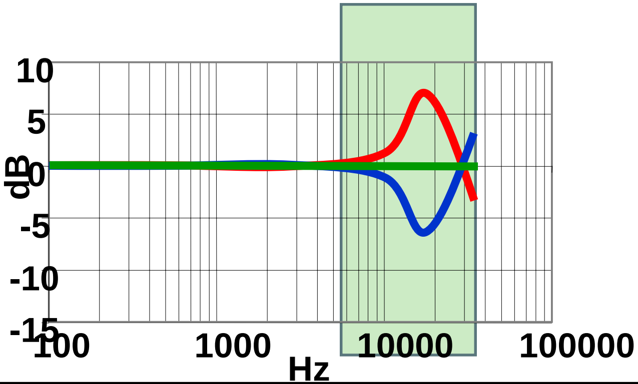


by Tommy Schack & Ole Thorhauge

Response Equalisation Extreme – REq-X

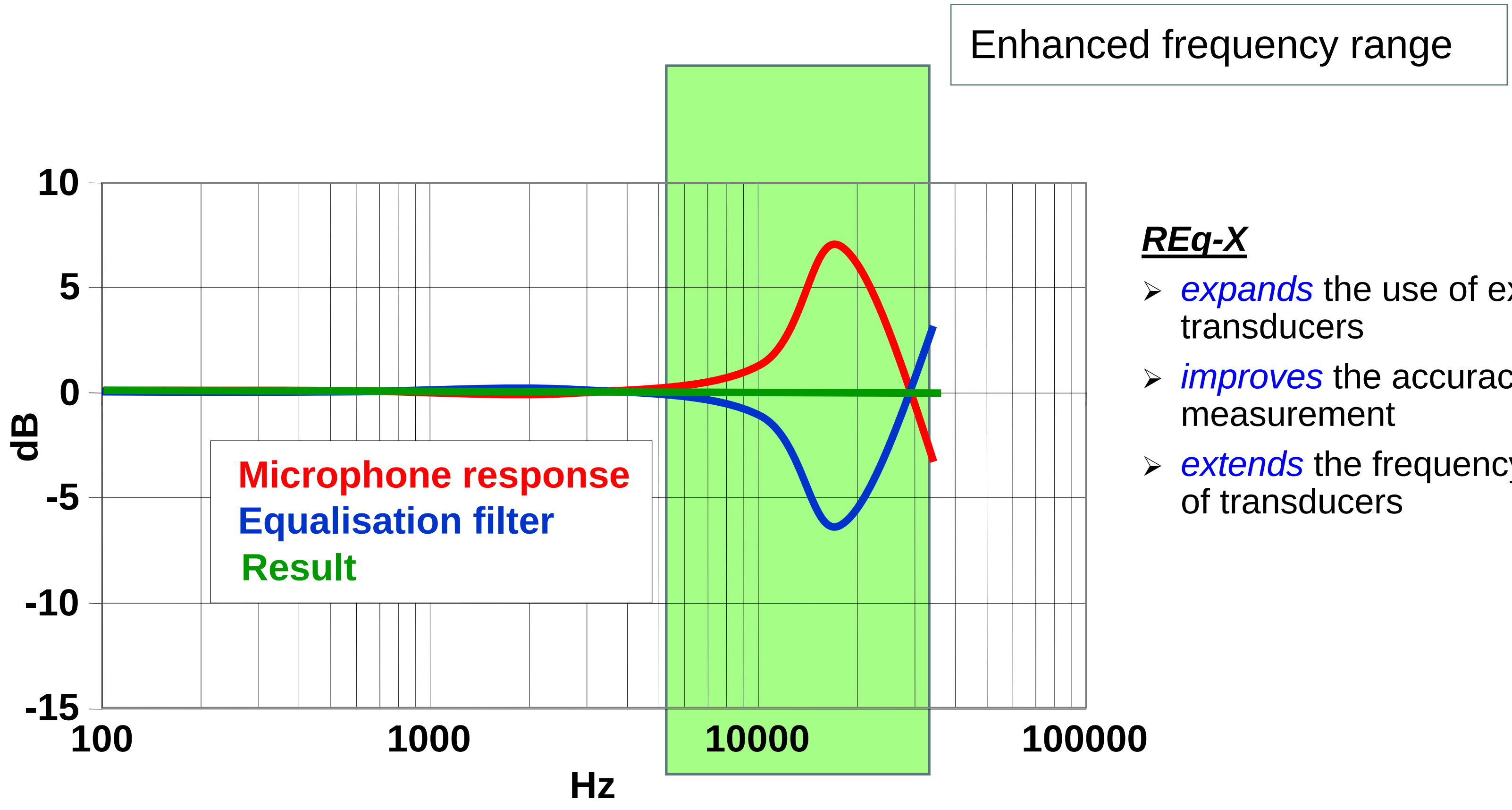
Agenda

- Introduction to Response Equalisation (*REq-X*)
- Transducers and their frequency responses
  - Microphones. Sound fields and their influence on measurement accuracy
  - Accelerometers. Resonancy frequency and effects of mounting principles
- How does *REq-X* work
  - Theory
  - Practical implementation
- Some illustrative examples
  - Microphones
  - Accelerometers
- Conclusion



Introduction – Response Eqalisation – eXtreme (*REq-X*)

Transducer Response Equalisation in brief



REq-X

- *expands* the use of existing transducers
- *improves* the accuracy of the measurement
- *extends* the frequency range of transducers

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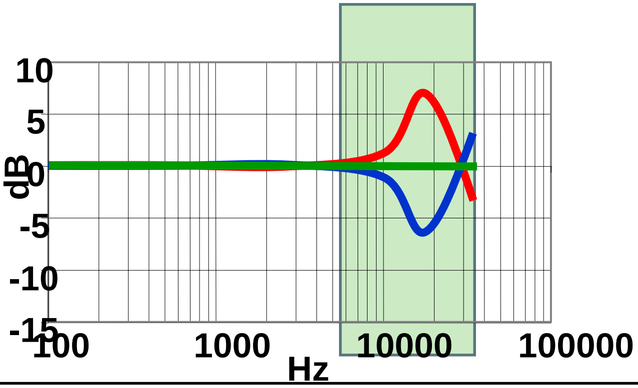

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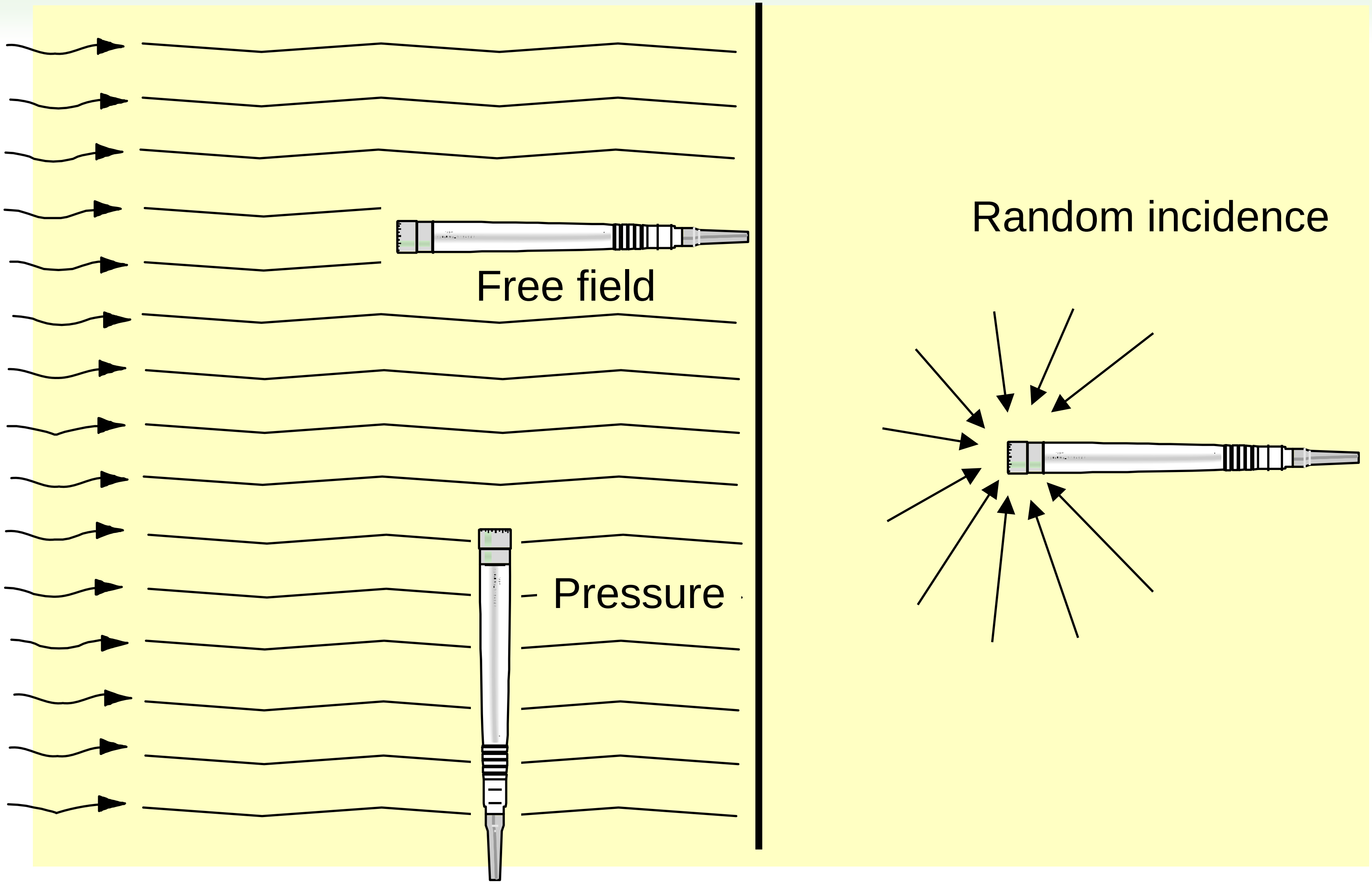
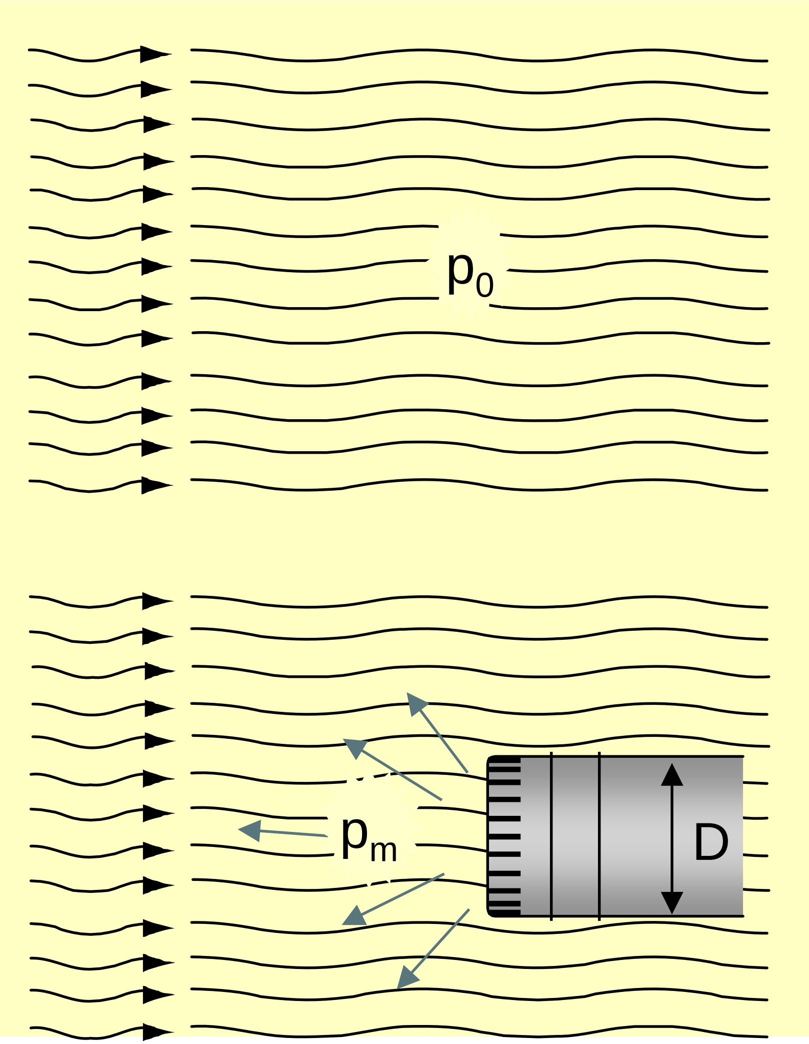
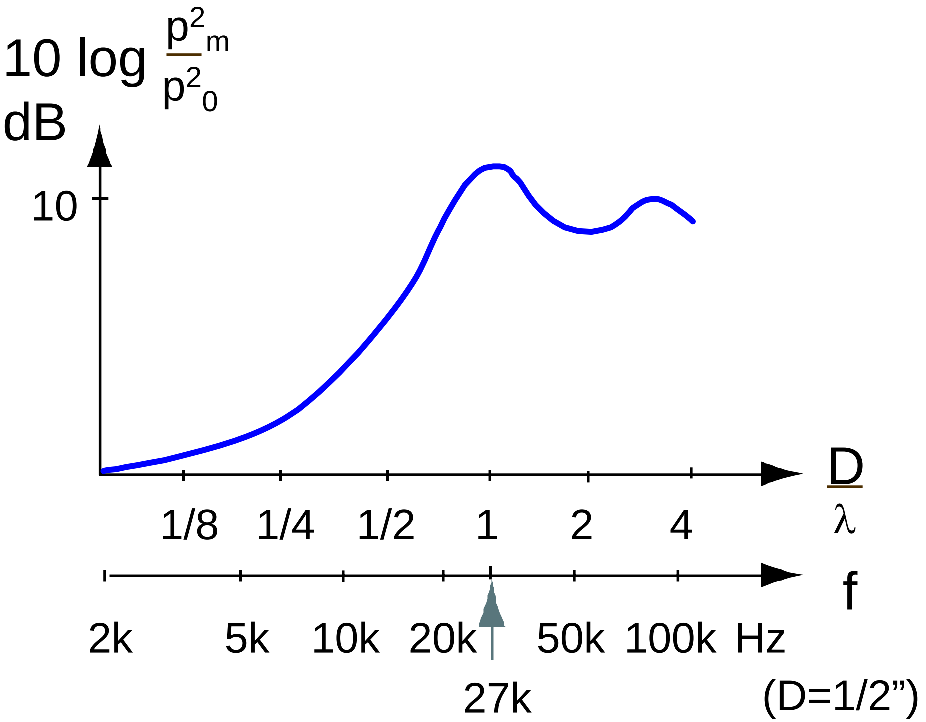
Types of Microphones



Free Field Correction





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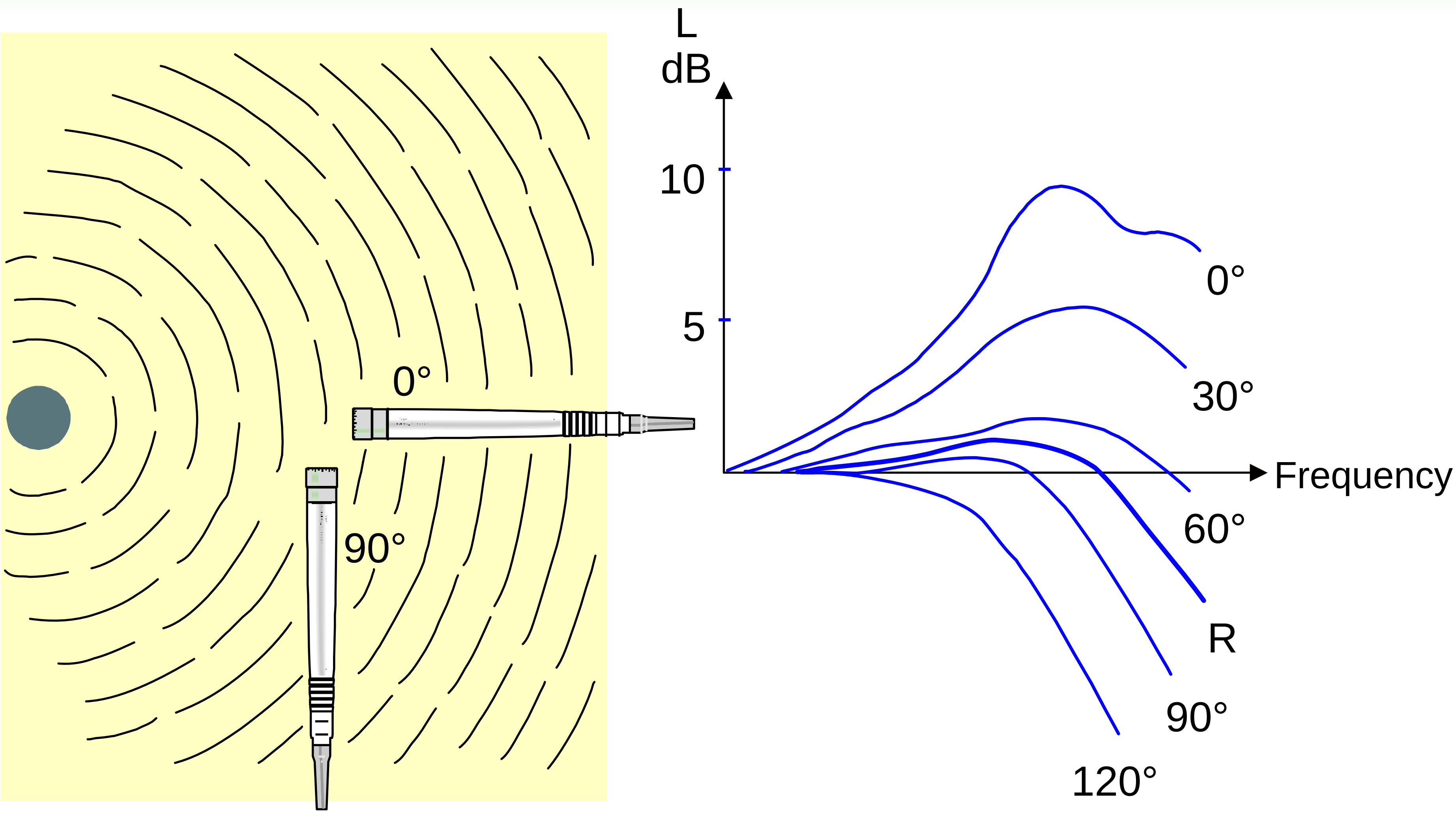
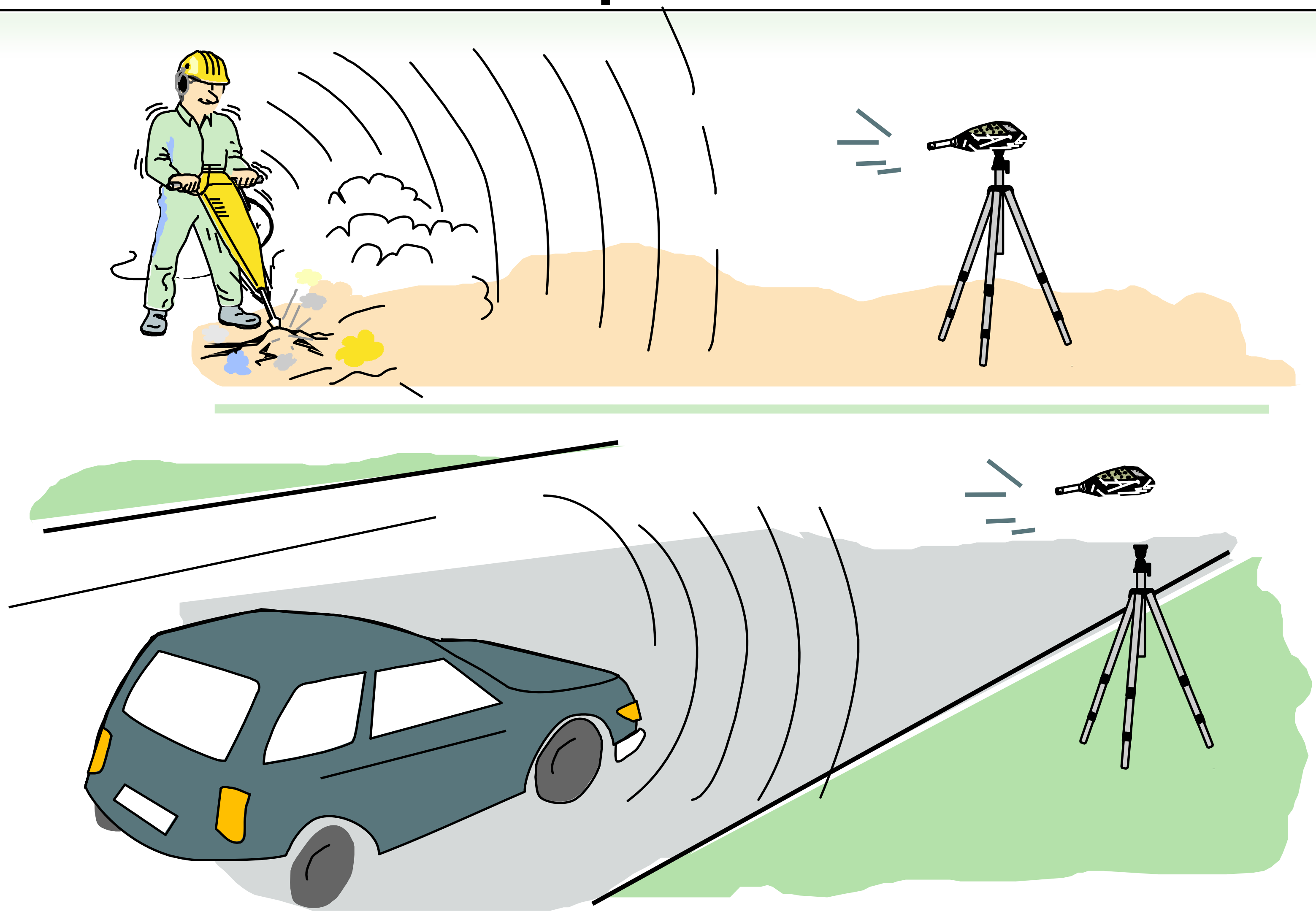


Use of Free Field Microphones



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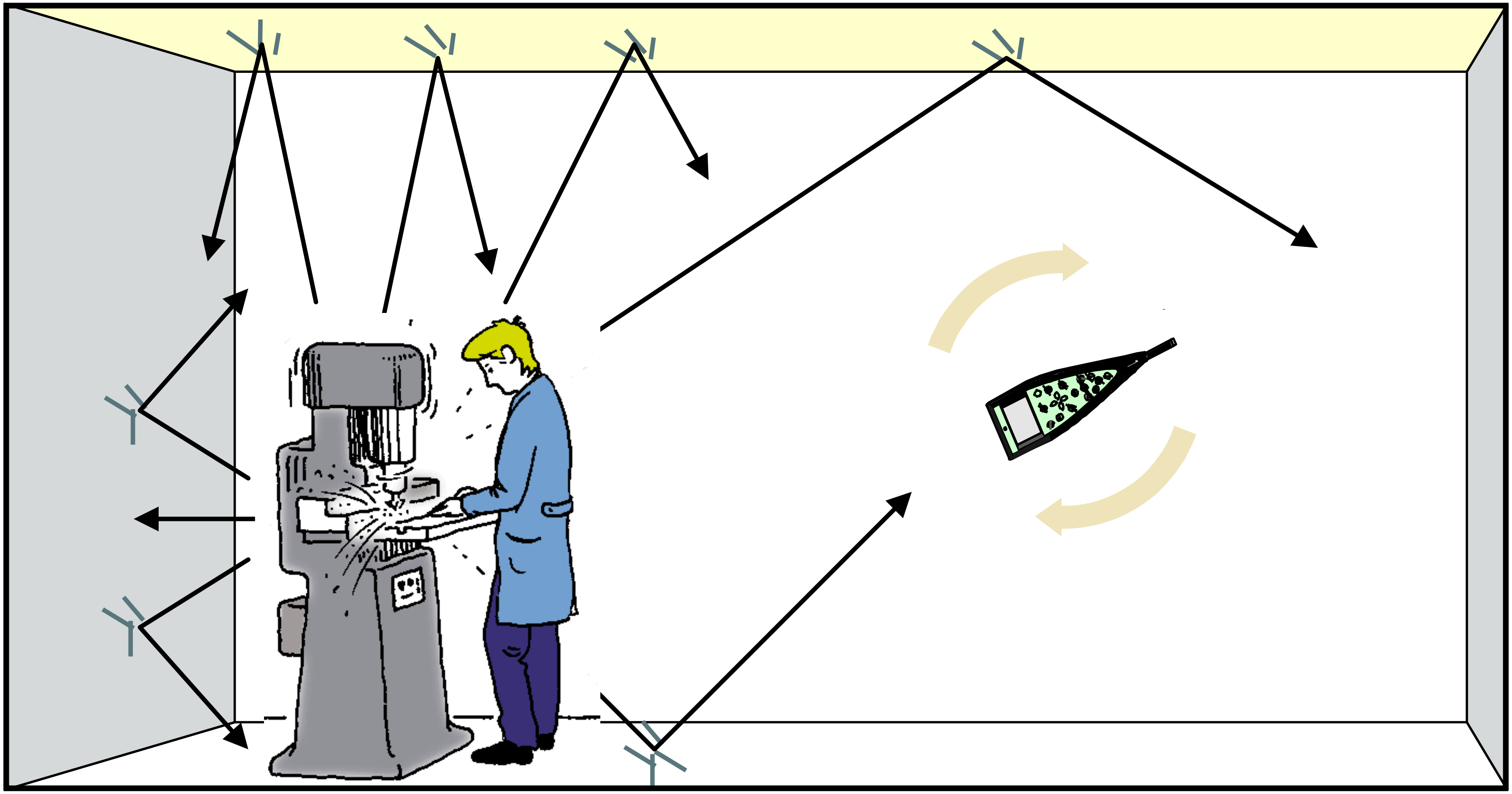
Use of Random Incidence Microphones



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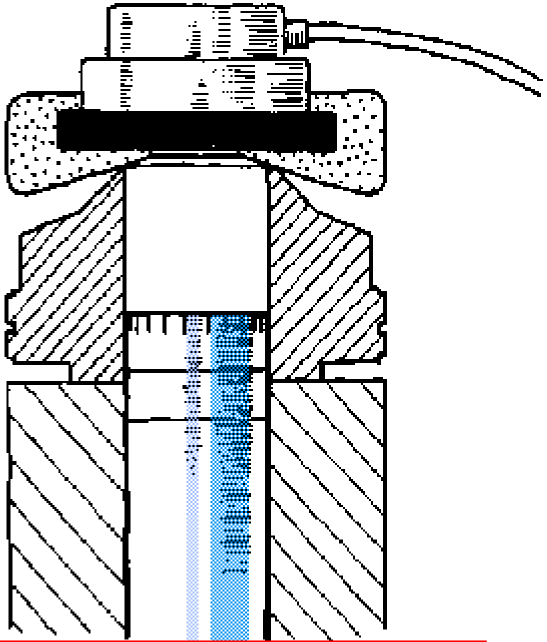
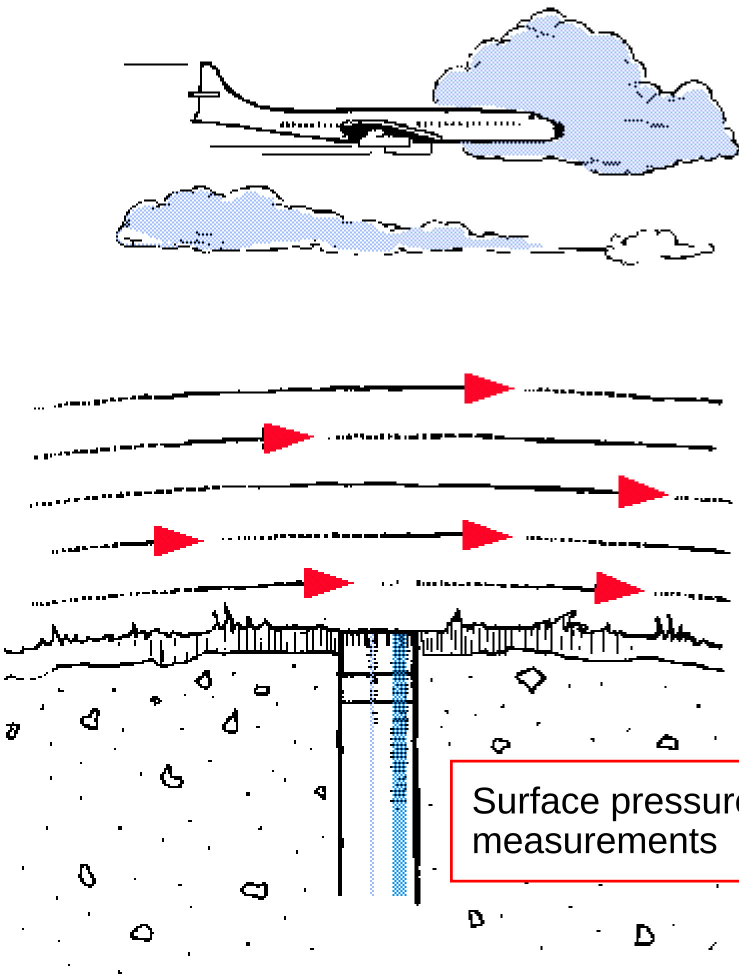
Use of Pressure Microphones

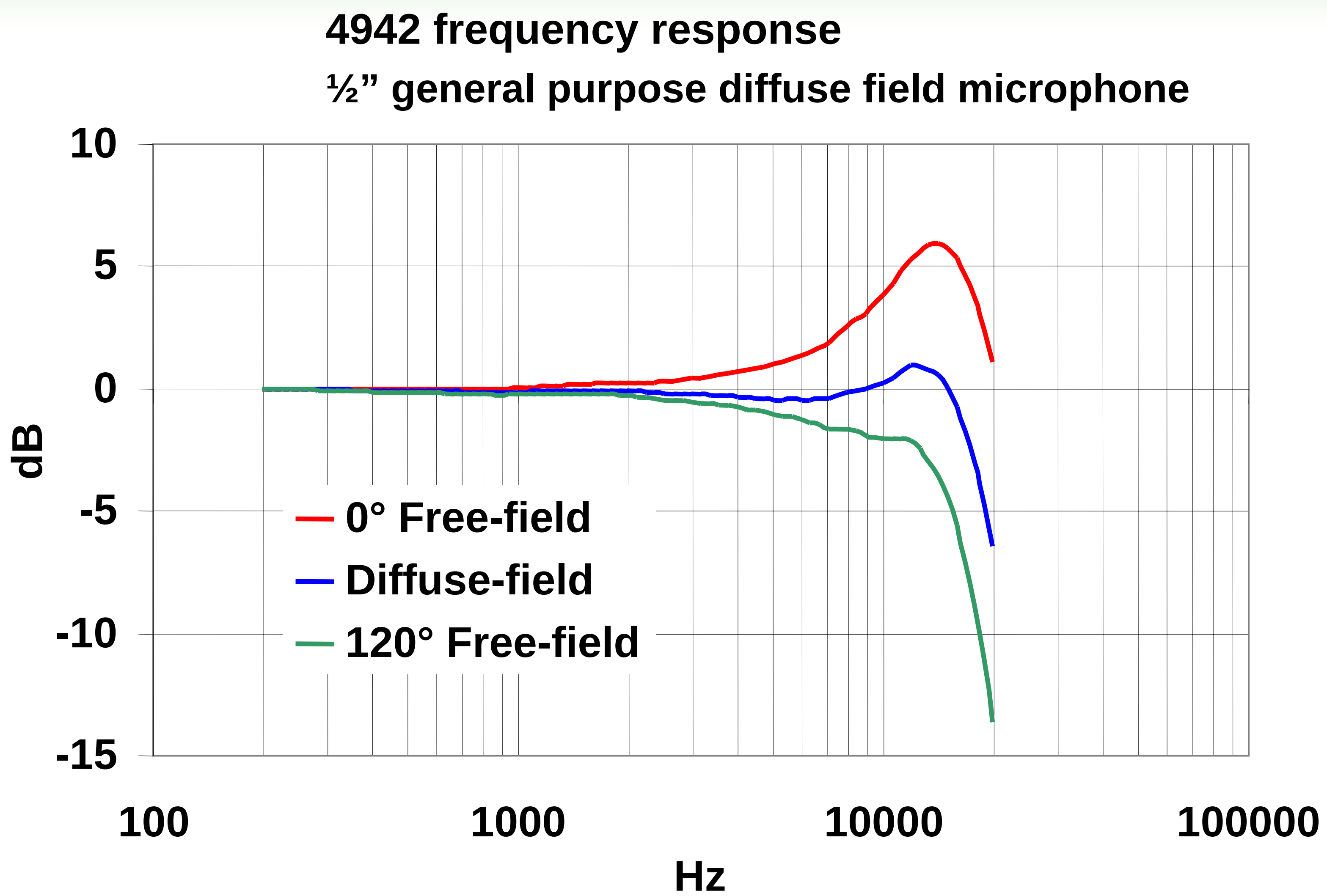


Small enclosures as couplers and artificial ears.

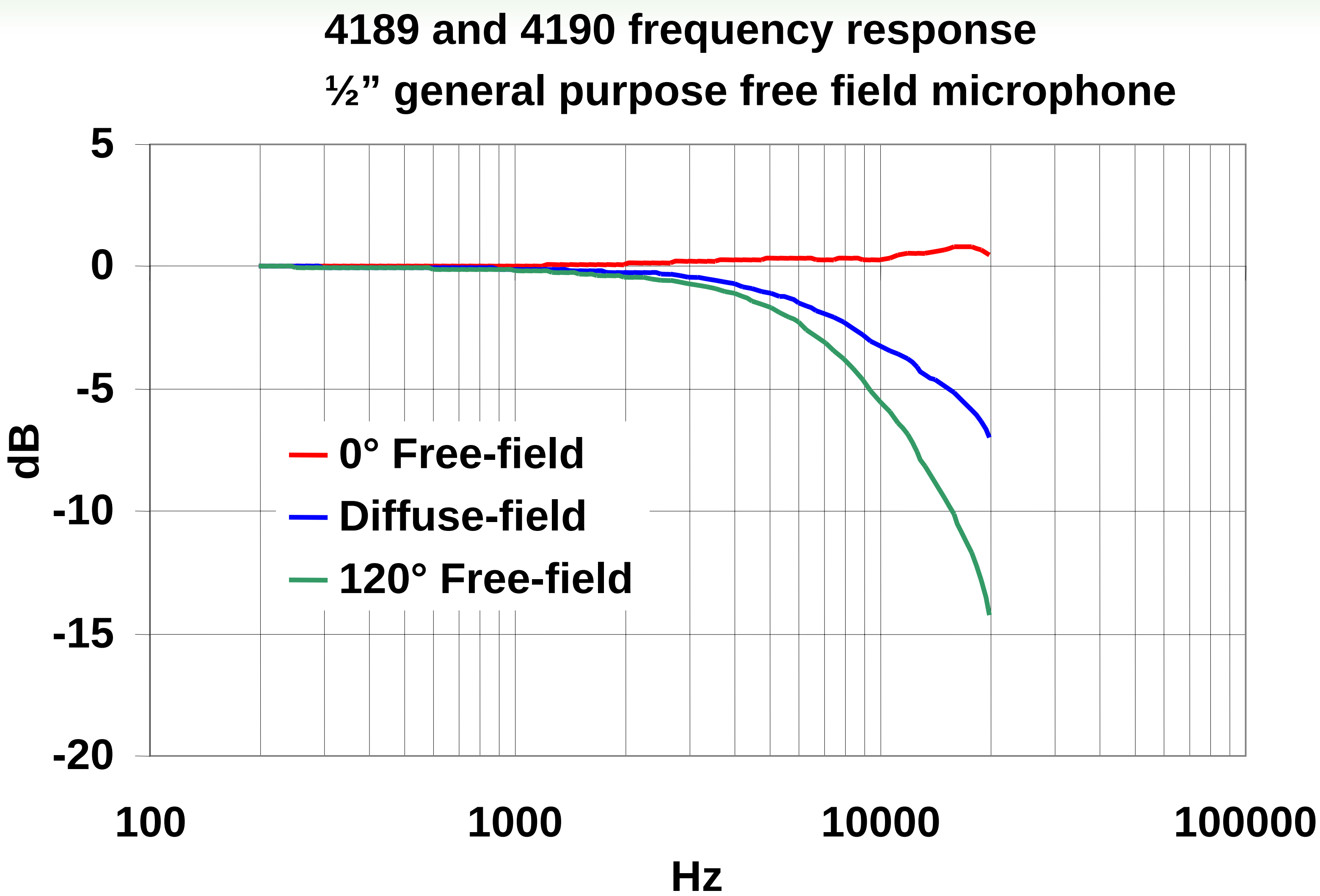


Surface pressure measurements

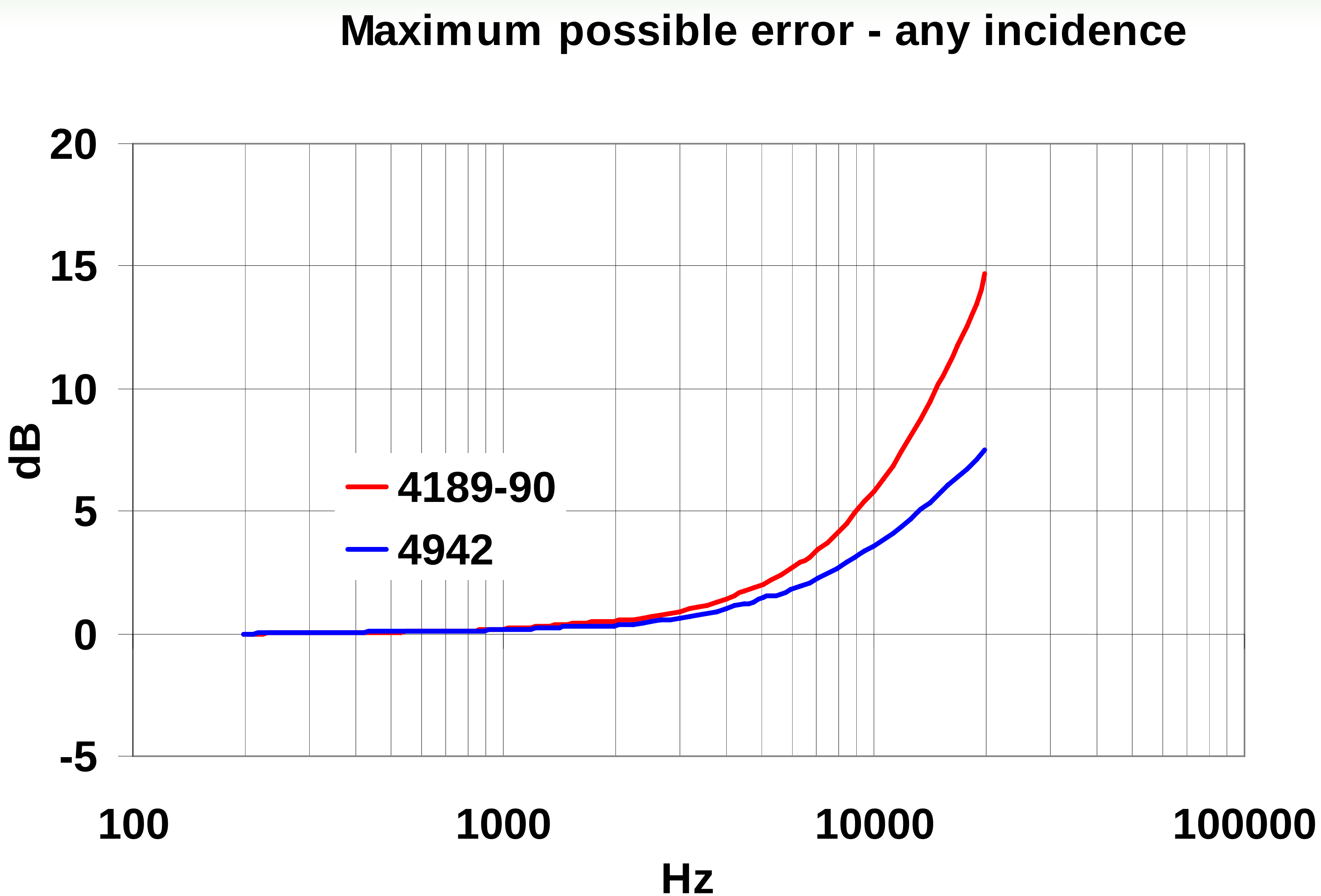
Diffuse-field microphones - Interior noise



Free-field microphones - One noise source

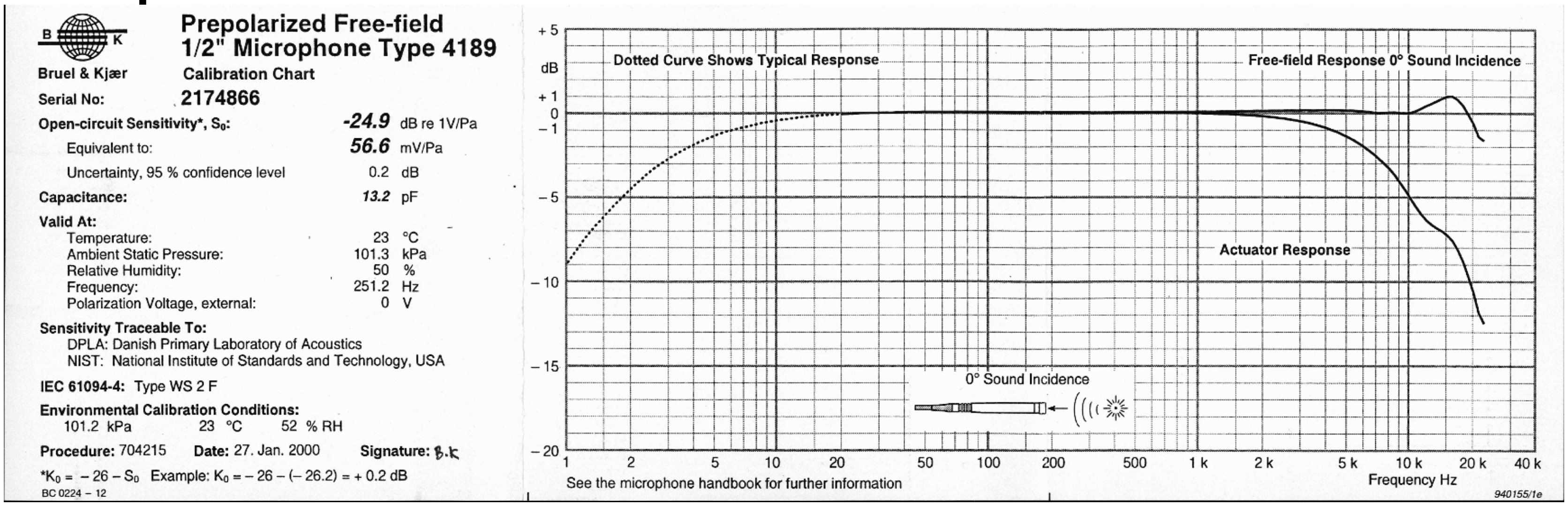


Unknown sound field - Maximum error



Microphone frequency response

Microphones are delivered with a Calibration Chart



and a Microphone Data Disk

or

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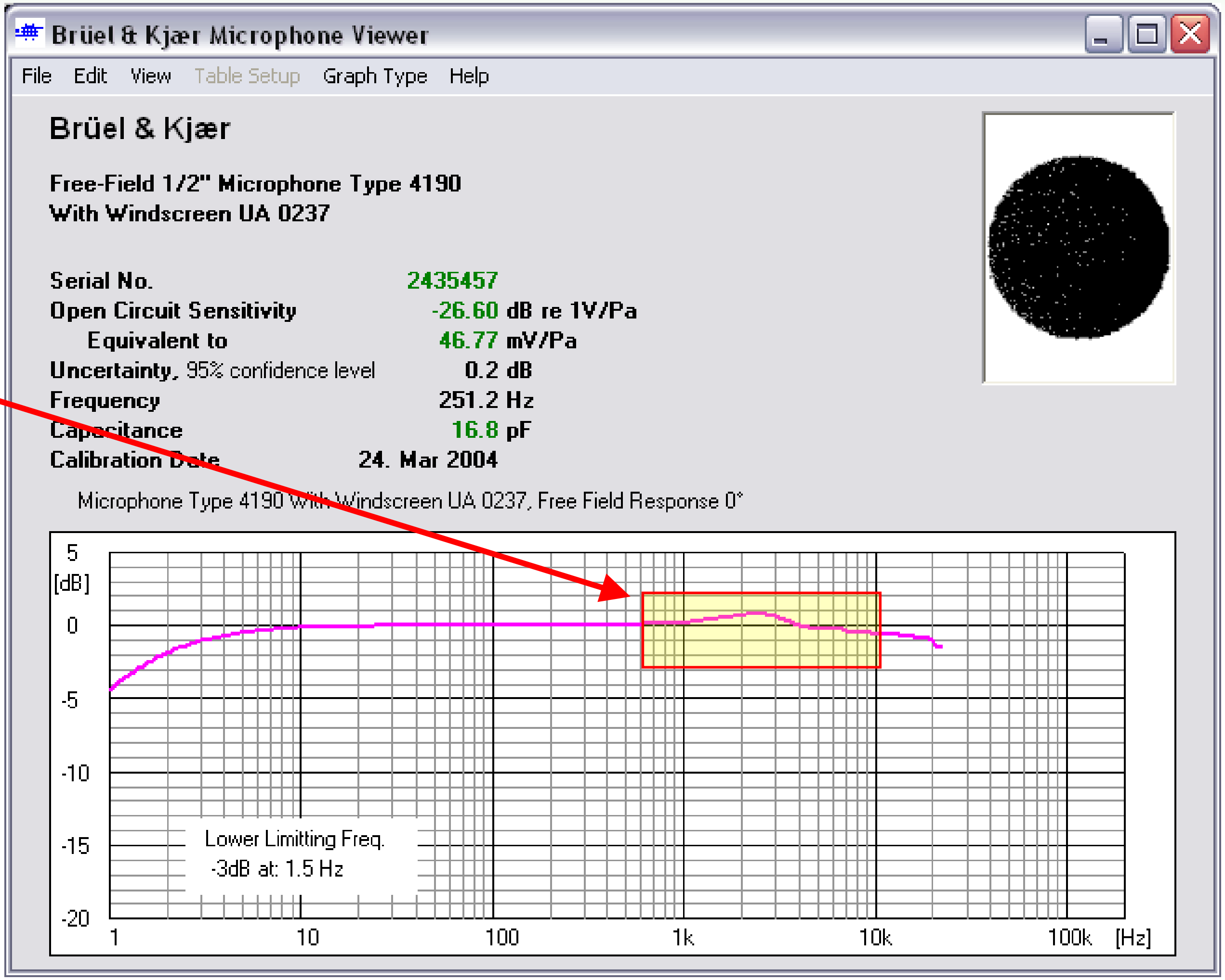
Effect of microphone accesories!

Example:

Effect of a microphone wind screen



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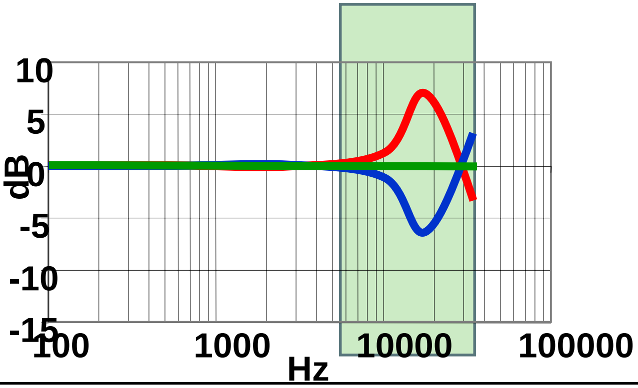
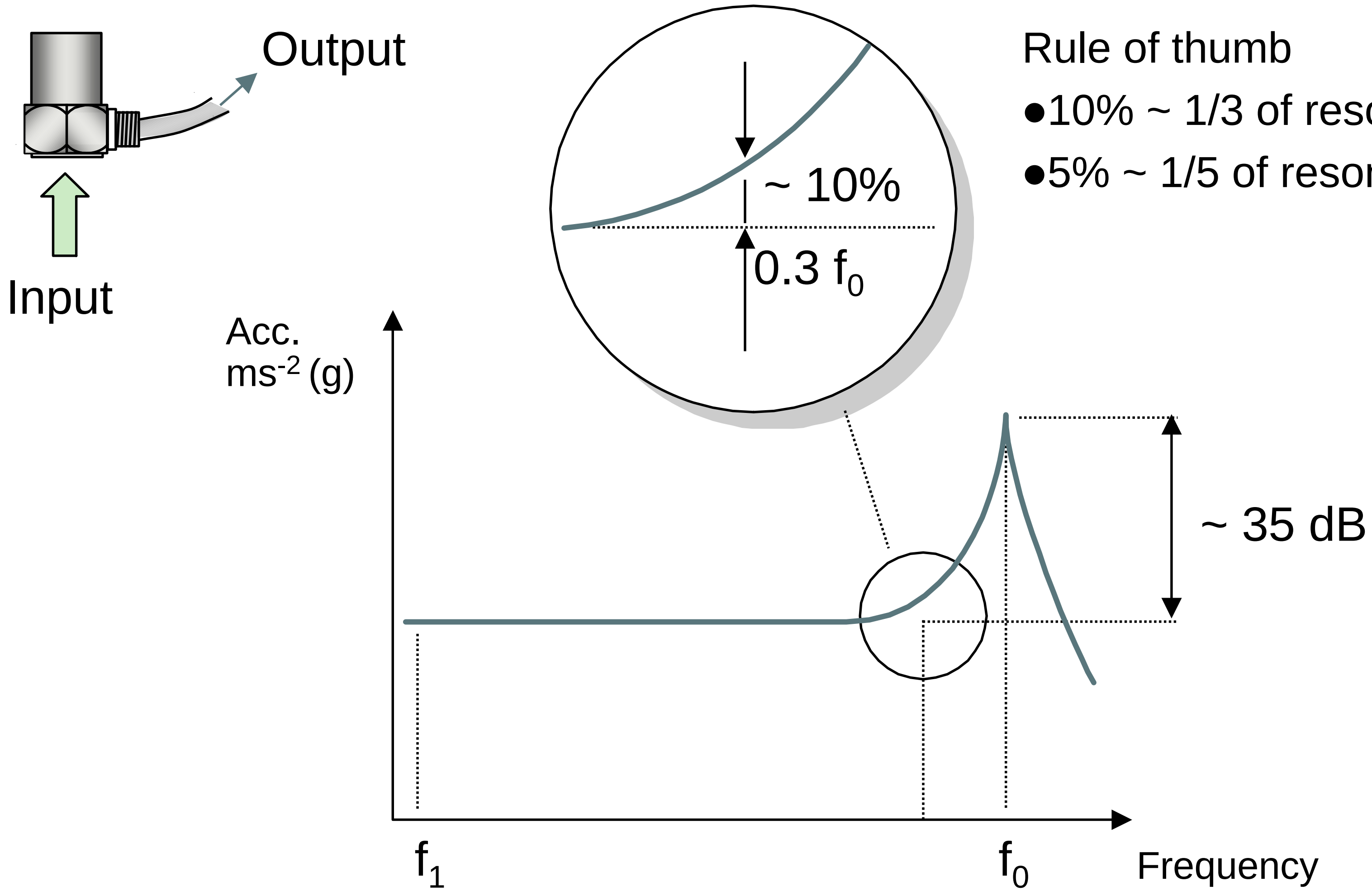


Accelerometers - Useful Frequency Range



Rule of thumb

- 10% ~ 1/3 of resonance
- 5% ~ 1/5 of resonance

Calibration chart for an accelerometer

Calibration Chart for Triaxial DeltaTron® Accelerometer Type 4524B

Brüel & Kjær

Serial No.: 300376

	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

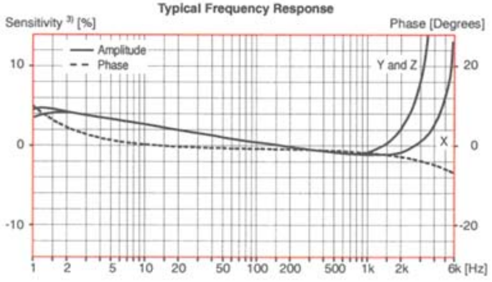
Measuring Range: ±500 ms^{-2} peak (±50 g peak)

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.: 150157.1 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-2. A coverage factor k = 2 is used. This corresponds to a coverage probability of 95% for a normal distribution.
[2] Transducer Electronic Data Sheet according to IEEE P 1451.4.
[3] Deviation from Reference Sensitivity.
Transducer principle patented US 5677487, US 8387851, US 5996412, JP 50952694, DK 169653.

For further information, please see http://www.bksv.com and Product Data Sheets.

Typical Frequency Response



Electrical:

Bias Voltage: at full temperature and current range	+ 13 V ± 1 V
Power Supply Requirements: Constant Current:	+ 2 mA to + 10 mA
Unloaded Supply Voltage:	+ 24 V to + 30 V

Note: All three axes must be powered! Single or dual axial supply is not possible.

Output Impedance:	< 30 Ω
Start-up Time (to 90% of bias):	< 10 s

Inherent Noise, X-axis (RMS):
Broadband (1 Hz to 6 kHz): < 40 µV, corresponding to < 0.004 ms^{-2} (< 400 µg)

Spectral:		
10 Hz:	1.6×10^{-4} ms^{-2}/√Hz	(16 µg/√Hz)
100 Hz:	4×10^{-5} ms^{-2}/√Hz	(4 µg/√Hz)
1000 Hz:	2×10^{-5} ms^{-2}/√Hz	(2 µg/√Hz)

Inherent Noise, Y- and Z-axes (RMS):
Broadband (1 Hz to 6 kHz): < 20 µV, corresponding to < 0.002 ms^{-2} (< 200 µg)

Spectral:		
10 Hz:	0.8×10^{-4} ms^{-2}/√Hz	(8 µg/√Hz)
100 Hz:	2×10^{-5} ms^{-2}/√Hz	(2 µg/√Hz)
1000 Hz:	1×10^{-5} ms^{-2}/√Hz	(1 µg/√Hz)

Insulation Resistance (signal ground to case): > 1 GΩ

Recommended Cables: AO 0526, AO 0527, AO 0528, AO 0534

Built-in ID-information and TEDS[2] **according to IEEE P1451.4**

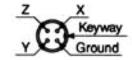
Mounting Technique:
The accelerometer can be fastened directly to the measuring object by glue, e.g., hot glue. However, if a reduced frequency range can be accepted, it is recommended to use one of the special mounting clips (see below) which is glued to the measuring object. In any case, the mounting 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 coordinate system.
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.

Environmental:

Temperature Range:	-54 to +100°C (-65 to +212°F
Temperature Coefficient of Sensitivity:	+0.14%/°
Temp. Transient Sensitivity (3 Hz Low. Lim. Frq. (-3 dB, 6 dB/oct)):	0.002 ms^{-2}/°
Magnetic Sensitivity (50 Hz, 0.038 T):	20 ms^{-2}/
Base Strain Sensitivity (at 250 µε in base plane): Mounted in Mounting Clip or on adhesive tape 0.09 mm thick:	0.0005 ms^{-2}/µ
Max. Non-destructive Shock:	50 kms^{-2} peak (5000 g peak
Humidity:	Hermeti

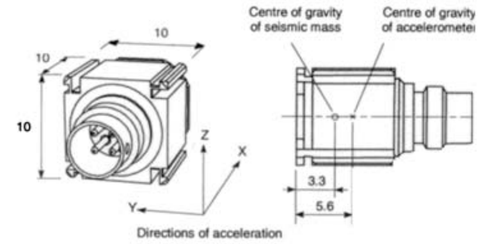
Mechanical:

Case Material:	Titanium ASTM Grade
Sensing Element:	Piezoelectric, Type PZ 2
Construction:	OrthoShear
Sealing:	Hermeti
Weight:	4.4 gram (0.15 oz
Electrical Connector:	4 pin, 1/4" - 28 UN (Microtech compatible) All pins insulated from cas



Pin Designation

Mounting Surface Flatness: < 3 µm



All dimensions in millimetres

Date 06 sep 2006, 09:51 Operator LN

Specifications obtained in accordance with ANSI S2.11-1969 and ISO 5347.

Except for the frequency range all values are typical at 25°C (77°F) unless measurement uncertainty is specified.

BC0367–12

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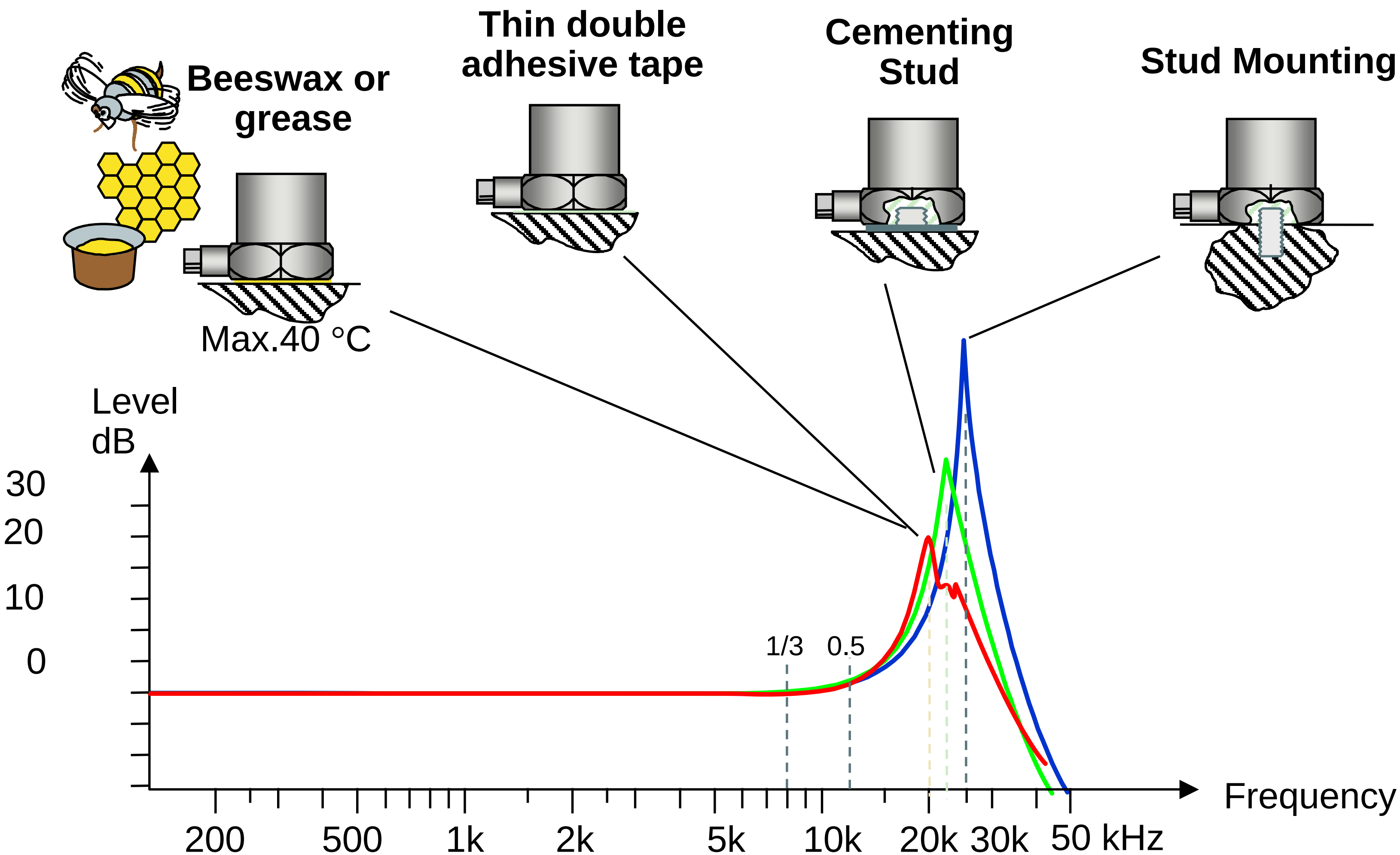
Accelerometer Mounting



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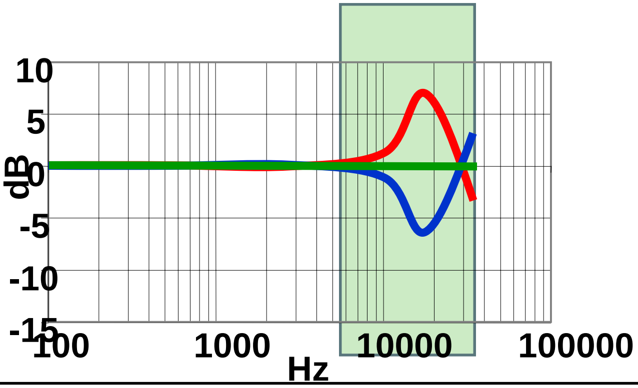

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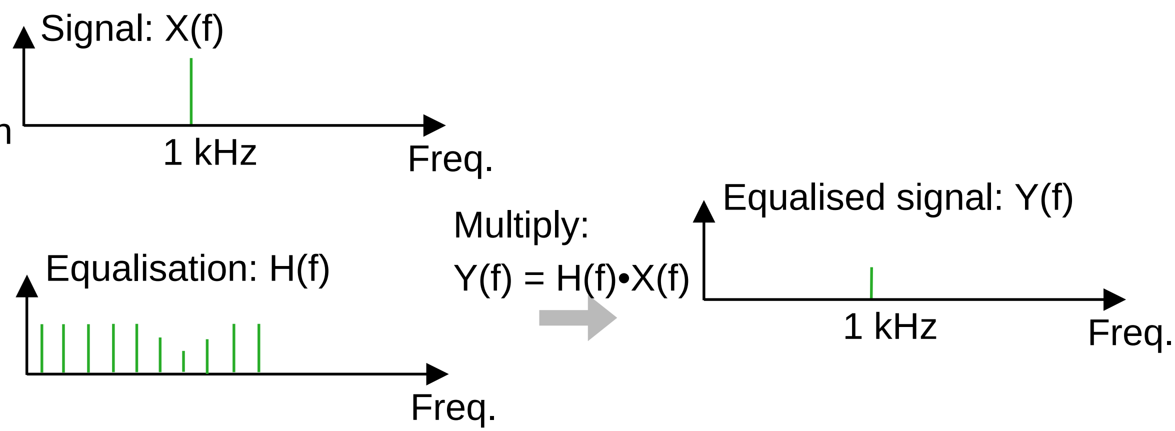
Response Equalisation theory

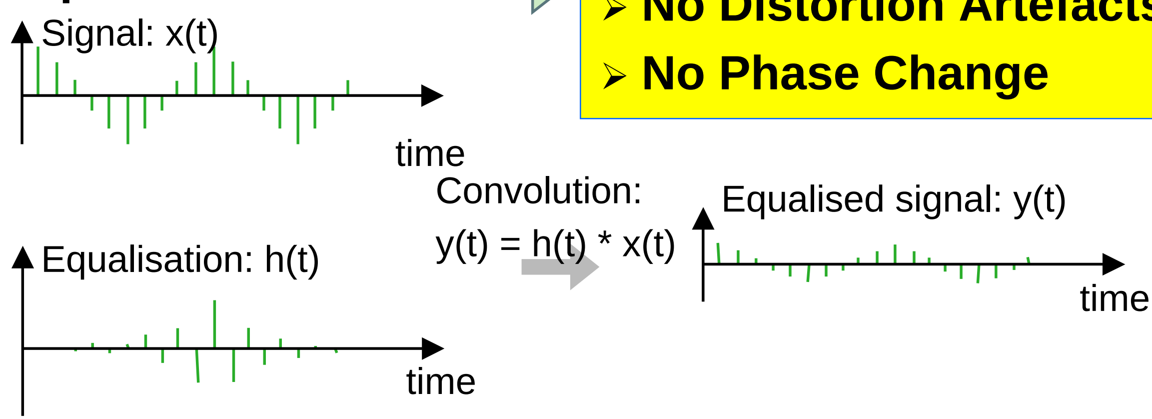
Frequency Domain Response Equalisation

Equalisation is done by multiplying the Input Frequency Responses and the Equalisation Frequency Response.



Time Domain Response Equalisation

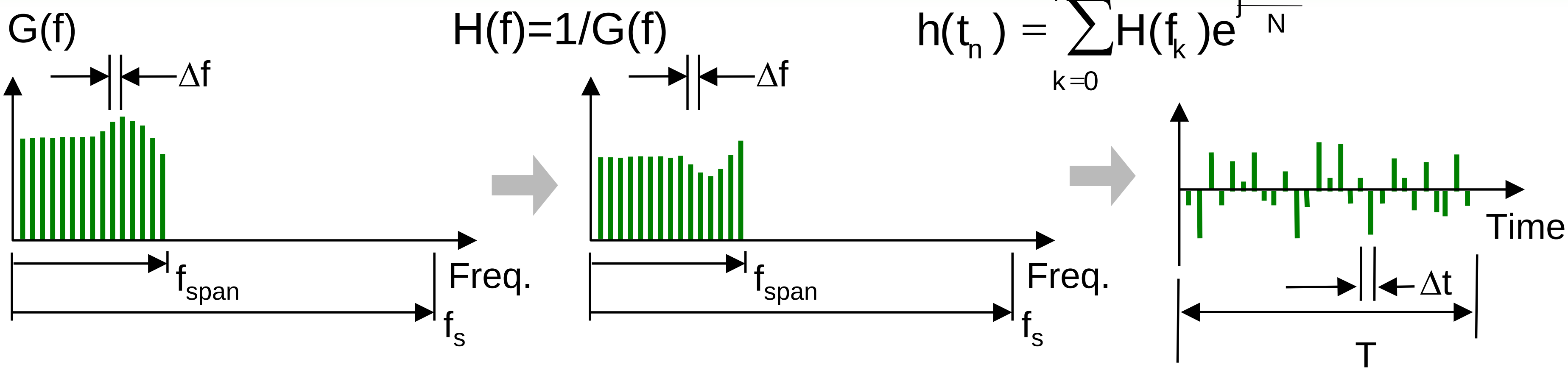
Equalisation is done by Filtering the Input with the Equalisation Filter.
Done by convolution of the Input and the Equalisation Impulse Response.



- **No Distortion Artefacts**
- **No Phase Change**

Calculation of FIR filter

$$h(t_n) = \sum_{k=0}^{N-1} H(f_k)\, e^{j\frac{2\pi nk}{N}}$$



$$N = \frac{f_s}{\Delta f} \qquad \Delta t = \frac{1}{f_s} \qquad T = N \times \Delta t$$

Example: $f_{span} = 25.6$ kHz

$f_s = 2.56 \times f_{span}$

$= 65536$ Hz

$\Delta f = 128$ Hz

$$\Rightarrow \begin{cases} N = \dfrac{f_s}{\Delta f} = \dfrac{65536\ \text{Hz}}{128\ \text{Hz}} = 512 \\[2ex] \Delta t = \dfrac{1}{f_s} = \dfrac{1}{65536}\,\text{s} \\[2ex] T = N \times \Delta t = \dfrac{512}{65536}\,\text{s} = \dfrac{1}{128}\,\text{s} \end{cases}$$

f_{span} = Maximum frequency span   T = Length of impulse response

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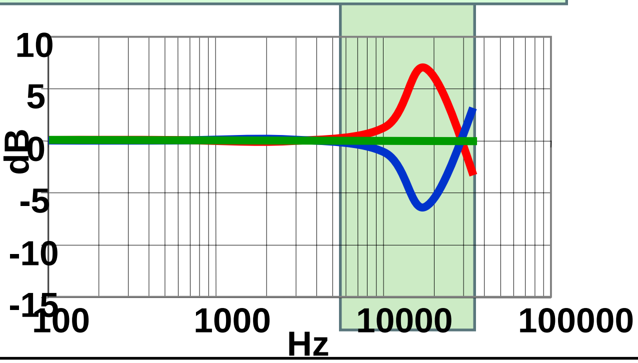

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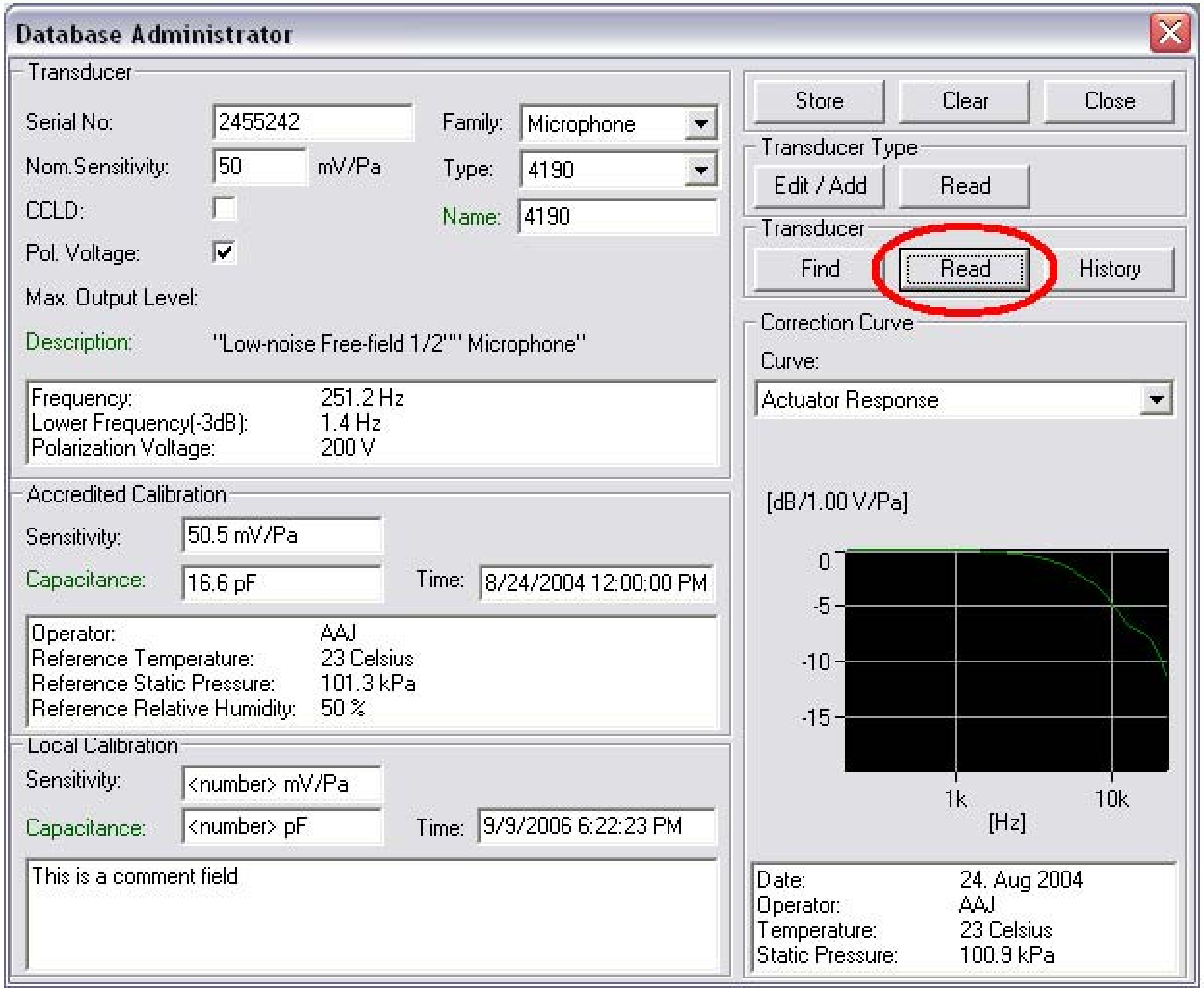
Adding frequency response to data base



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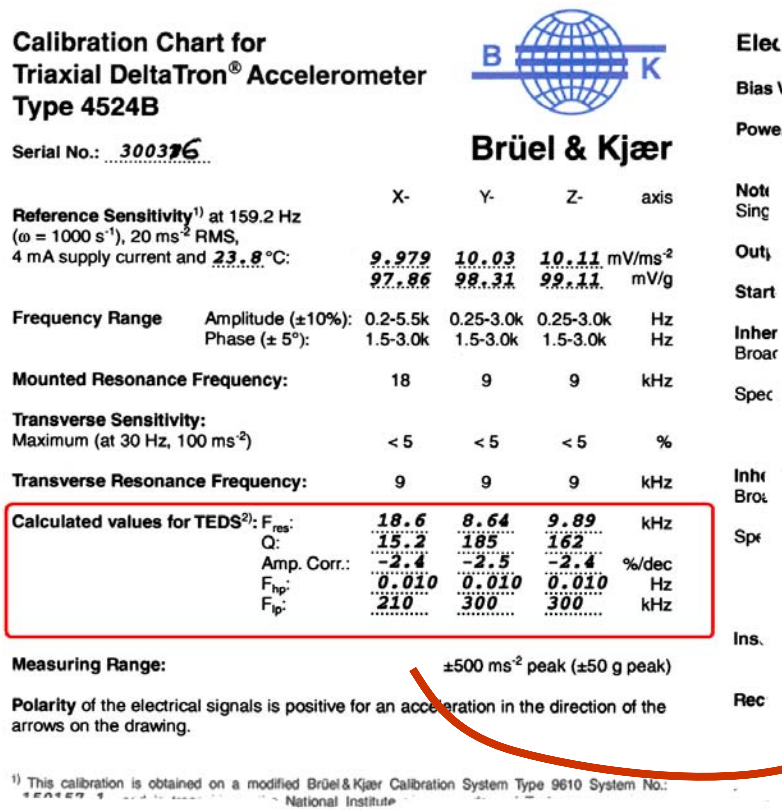

Calibration Chart for Triaxial DeltaTron® Accelerometer Type 4524B

Brüel & Kjær

Serial No.: 300376

		X-	Y-	Z-	axis
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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	%
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Calculated values for TEDS[2]:	F_{res}:	18.6	8.64	9.89	kHz
	Q:	15.2	185	162	
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Measuring Range: ±500 ms^{-2} peak (±50 g peak)

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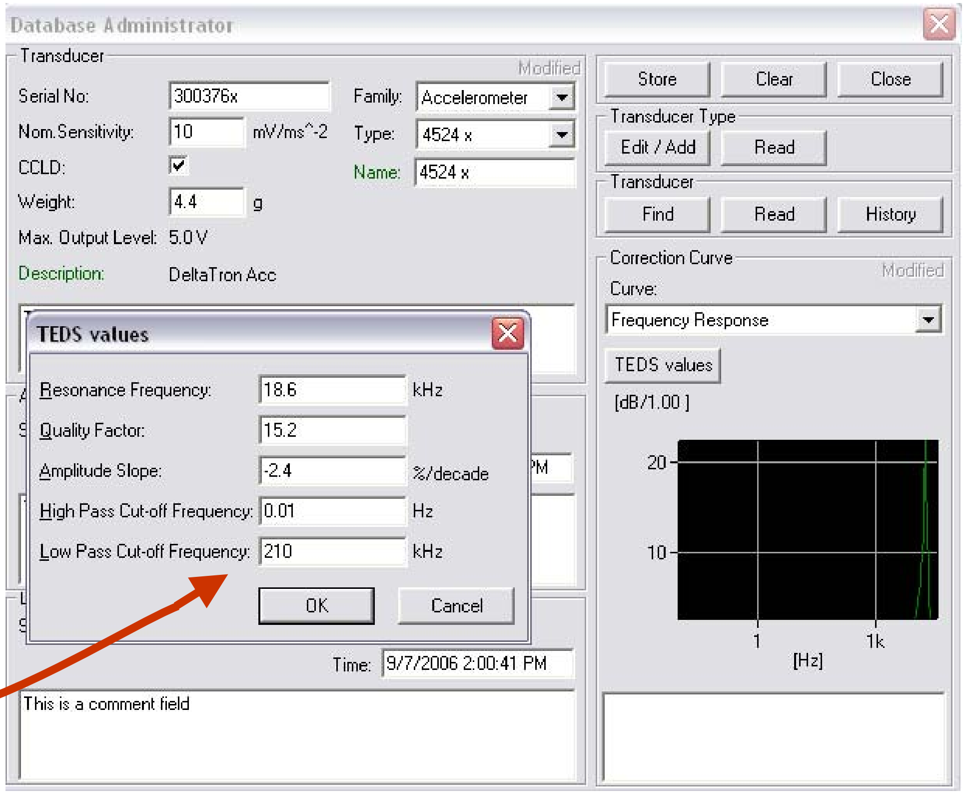

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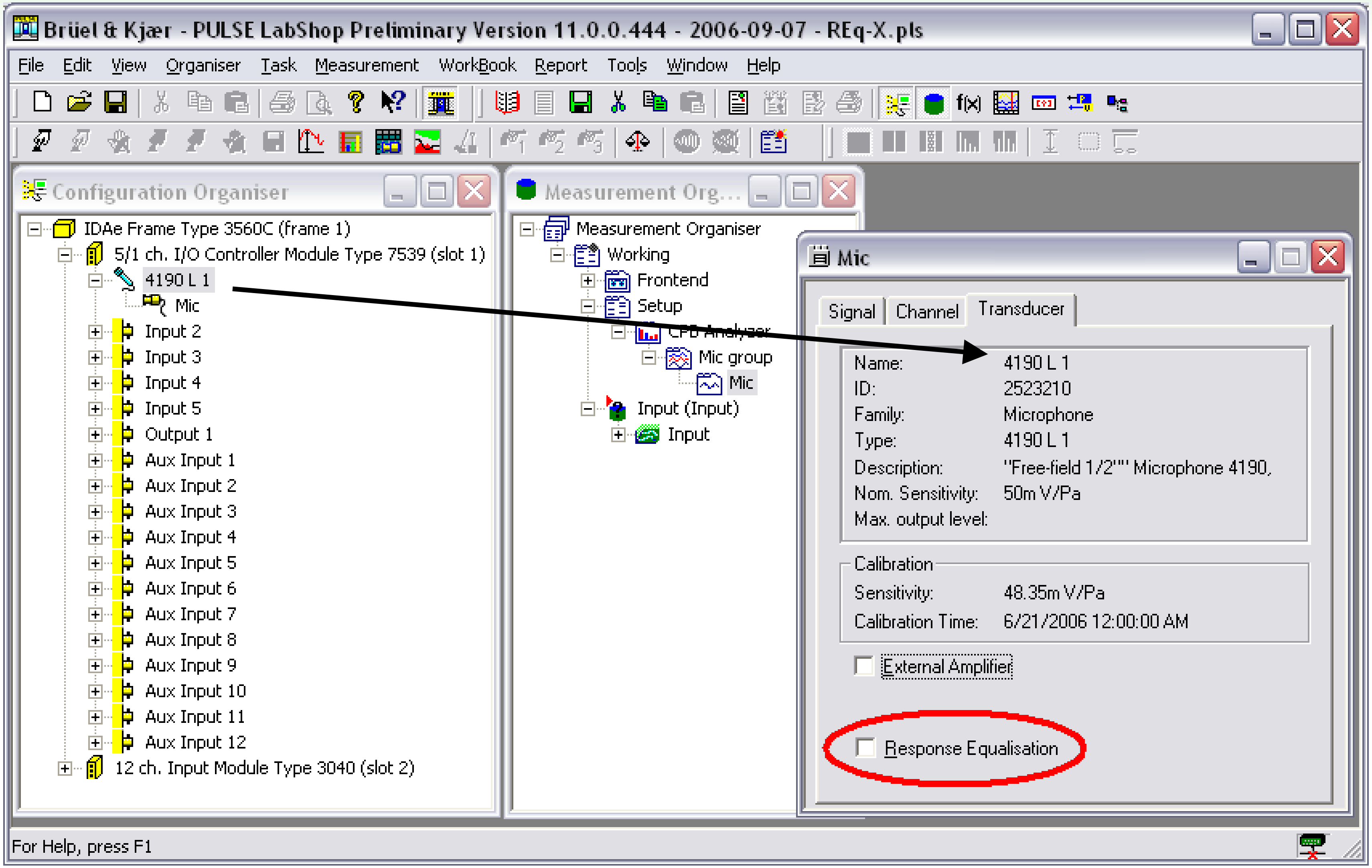
Step by step – how to use REq-X



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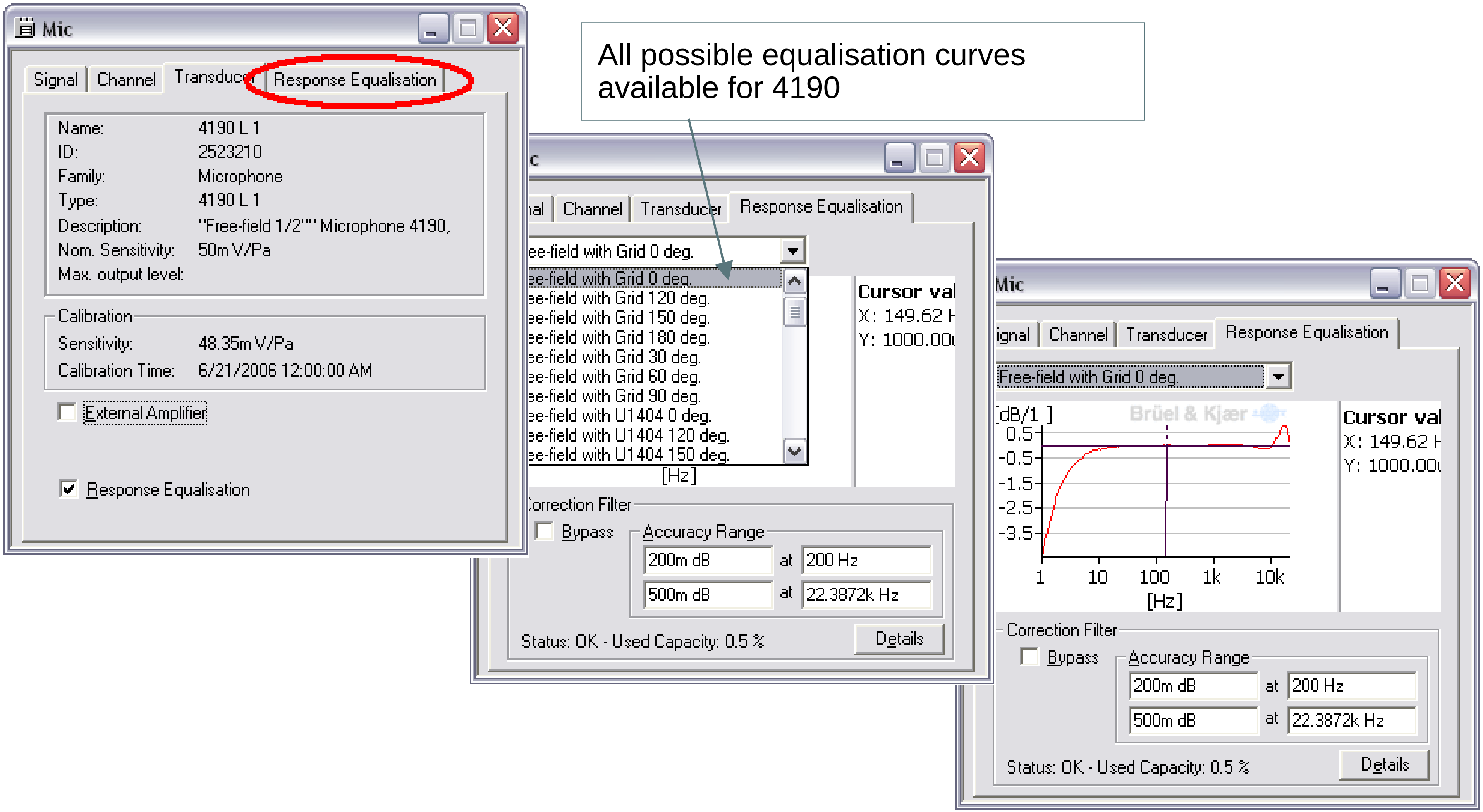
Step by step – how to use REq-X

All possible equalisation curves available for 4190



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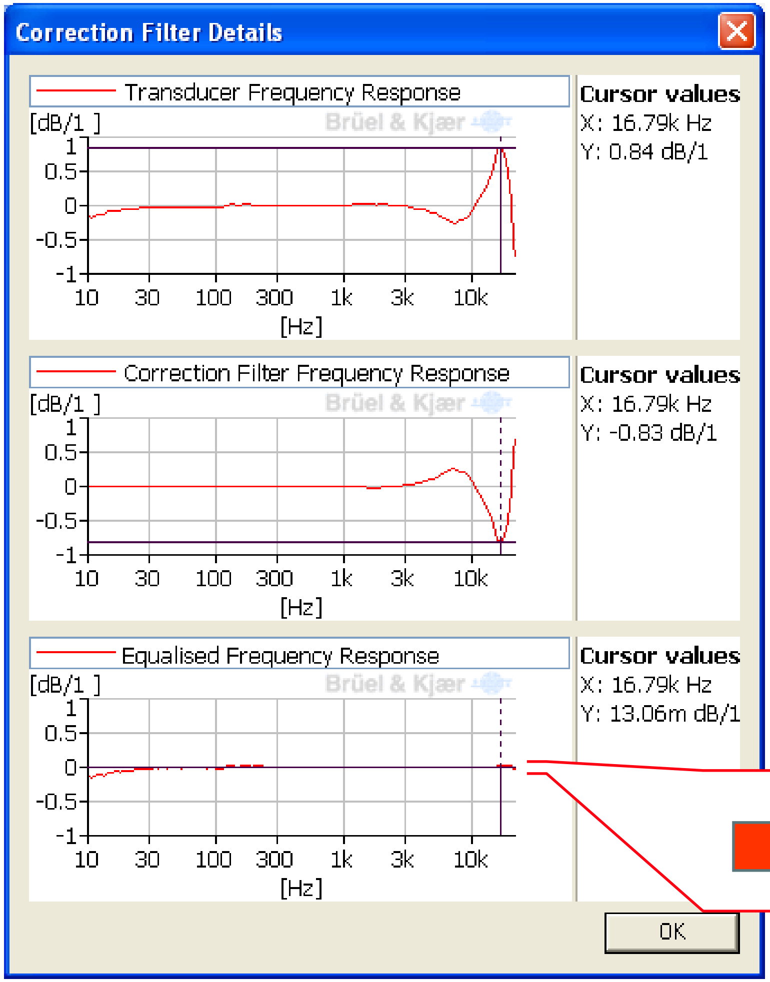
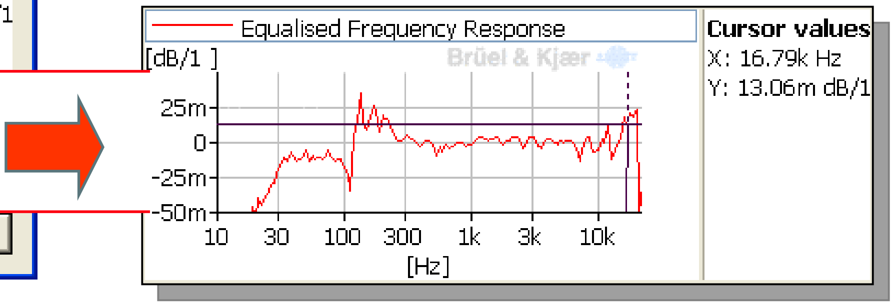


- Transducer Frequency Response
- Correction Filter Response
- Equalised (true) Frequency Response



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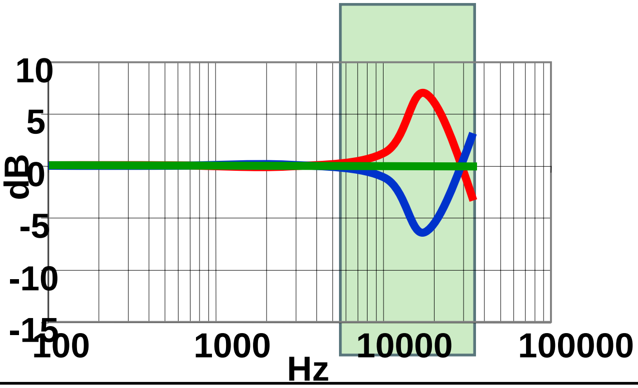

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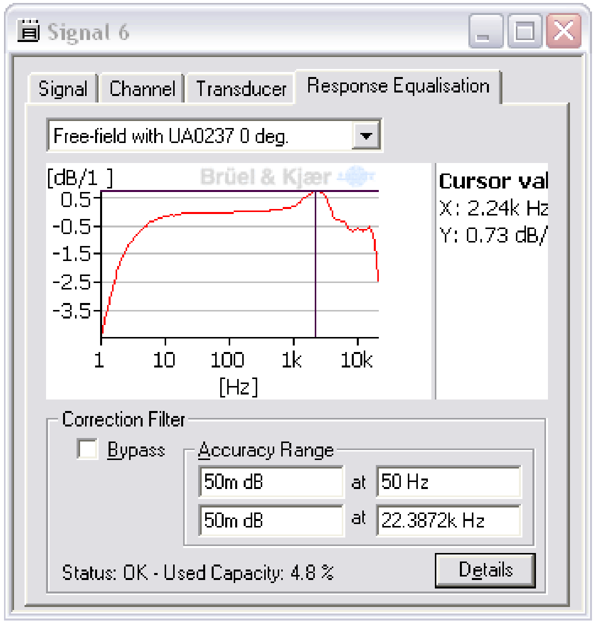
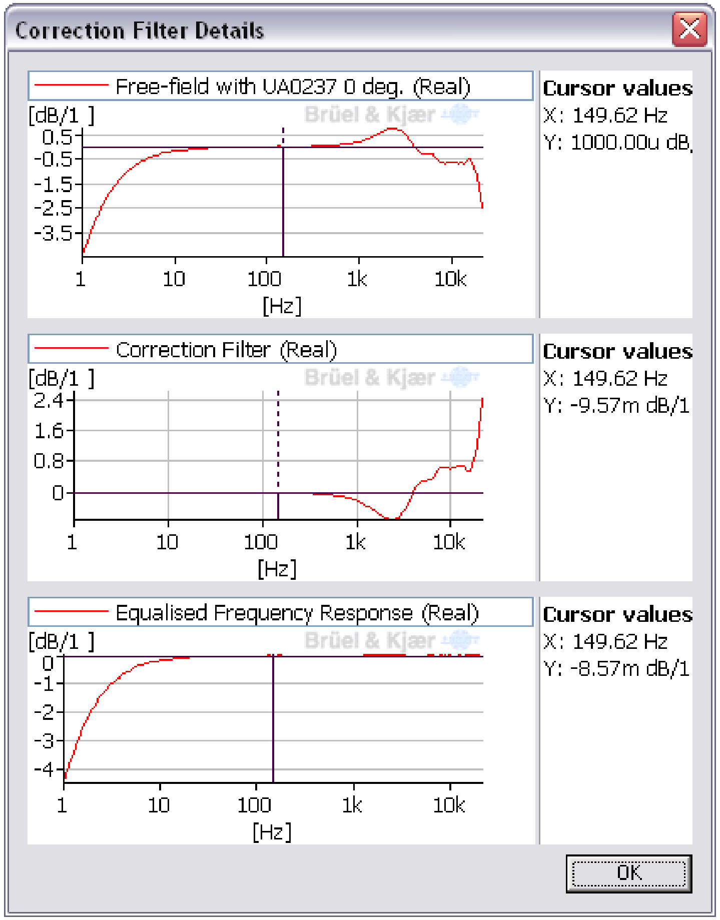
REq-X with microphones – example

Measurement example:
4190 used with wind screen
in free field

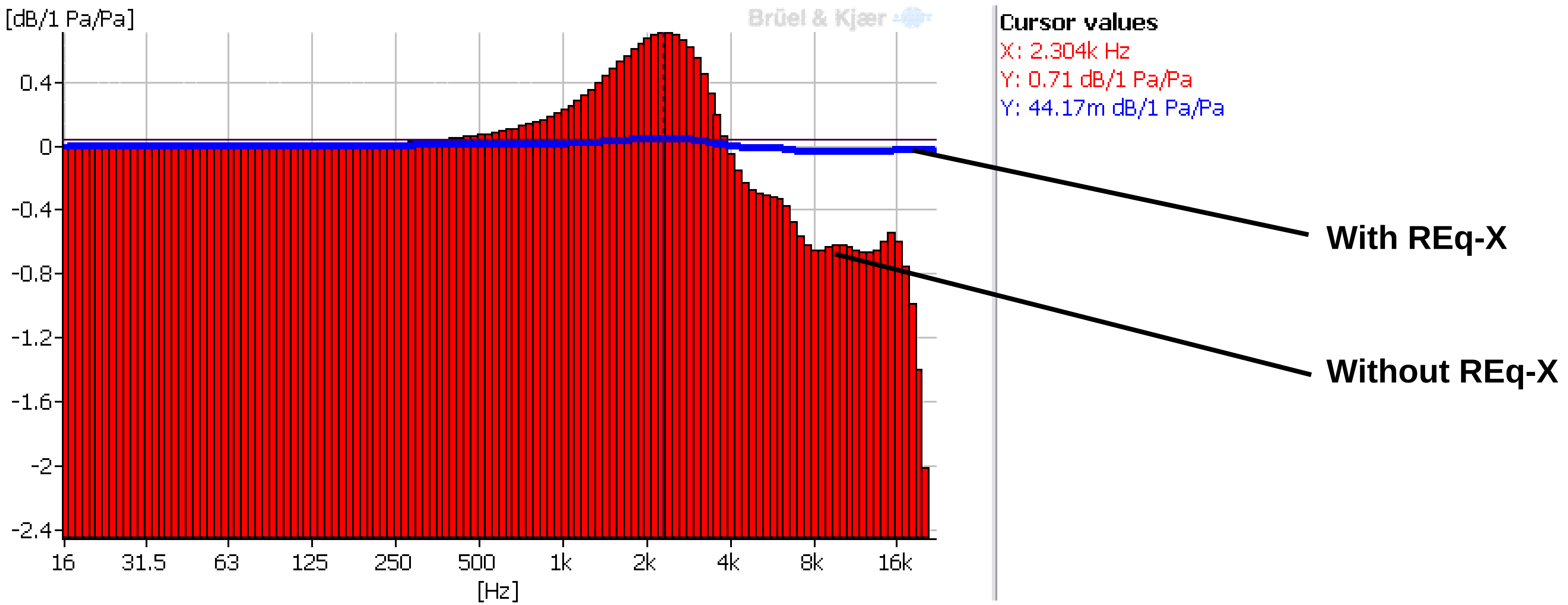




REq-X with microphones – example

Measurement example:

4190 used with wind screen in free field



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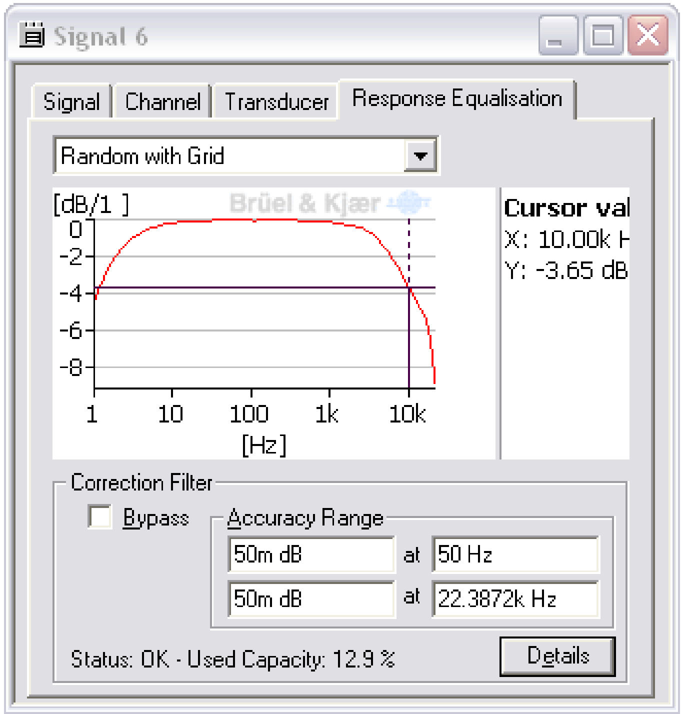
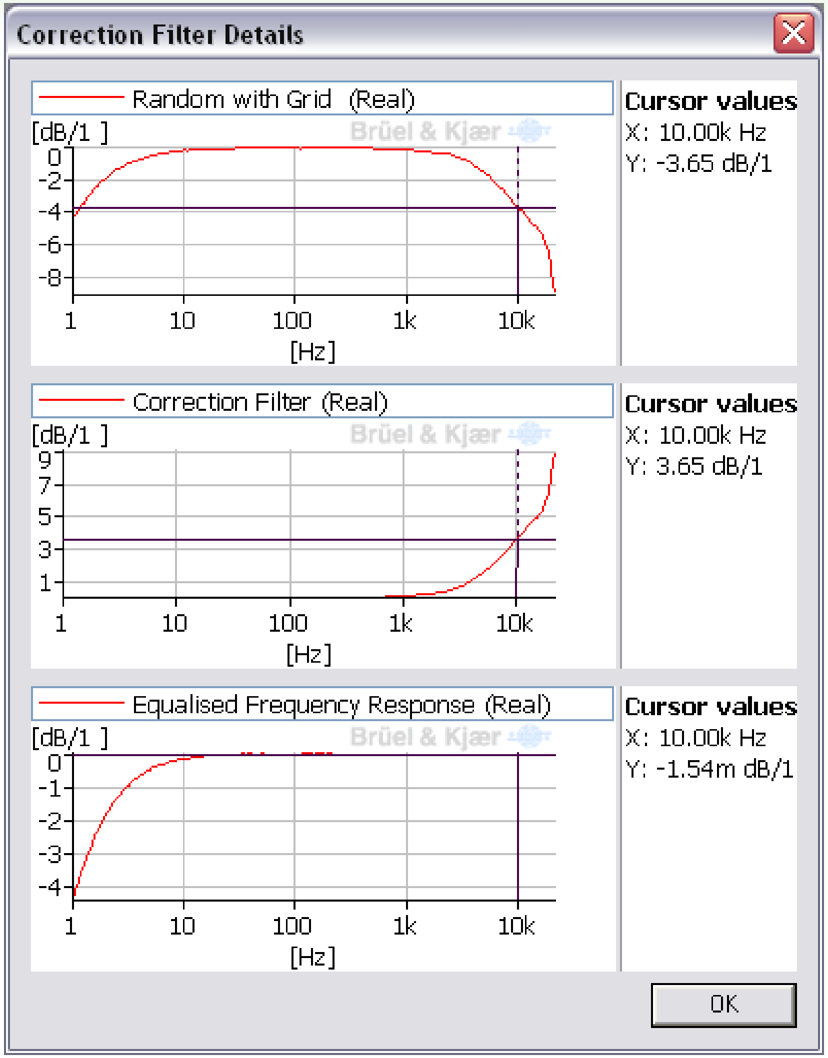
REq-X with microphones – example

Measurement example

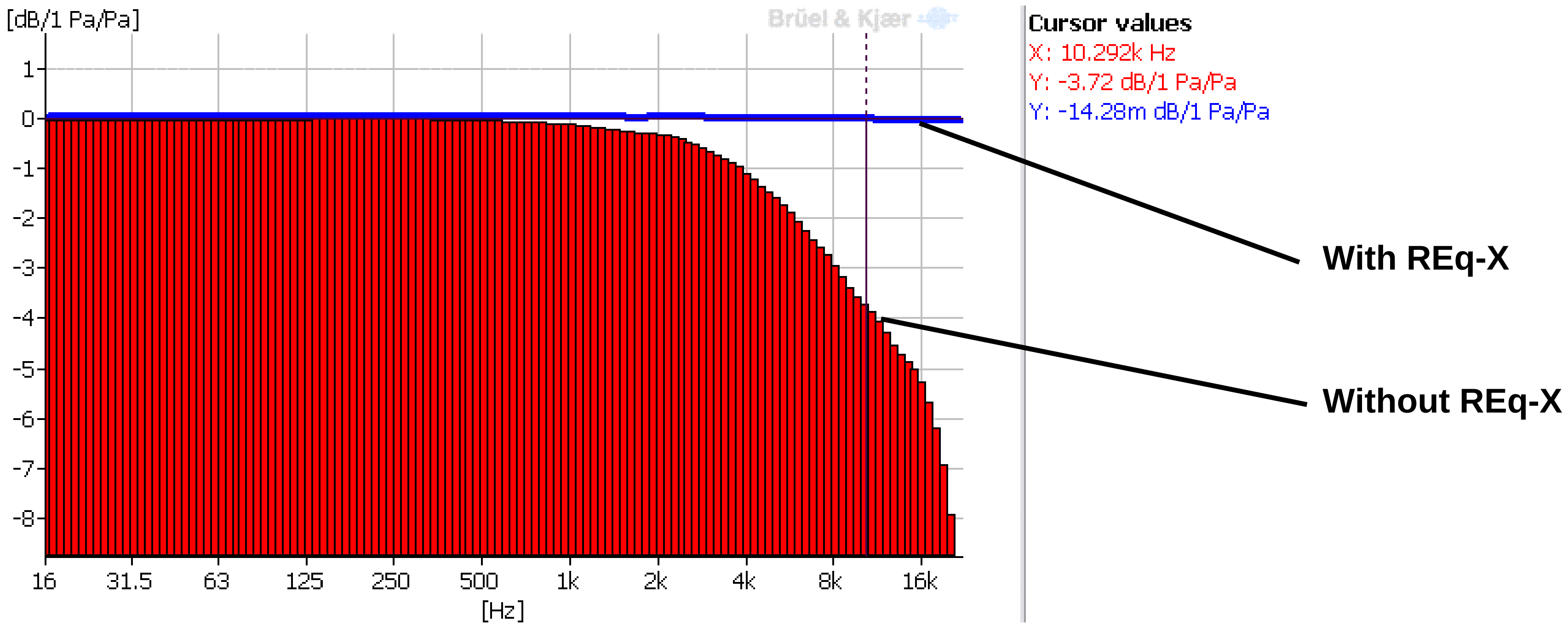
4190 used in diffuse field





REq-X with microphones – example

Measurement example – 4190 used in diffuse field



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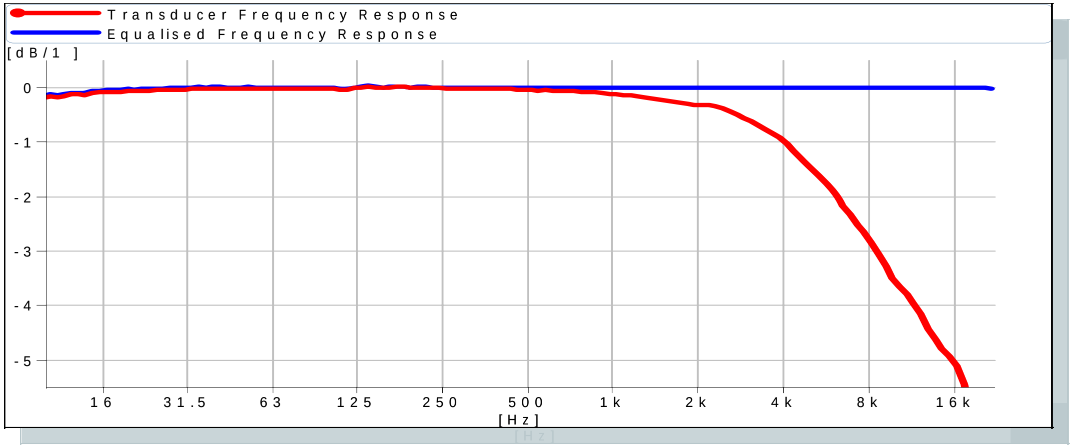
REq-X with Microphones

- REq-X improves measurement accuracy by up to 1.5dB over the frequency range
- REq-X corrects for angle of sound-field incidence and microphone accessories thus **improving accuracy** by a further 5-10 dB

Expand the use of your existing Microphones

- Basically any microphones can now be used for pressure, diffuse and free-field measurements



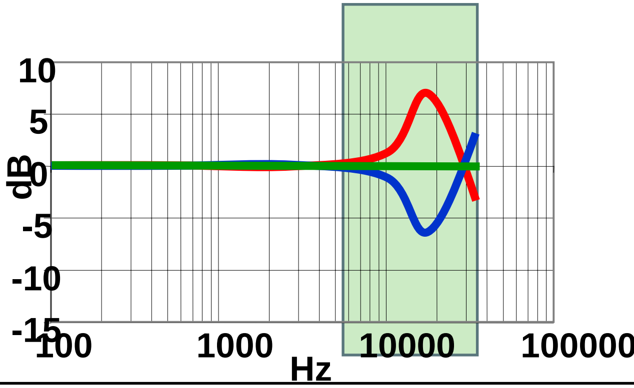
Frequency response of a free field microphone used as a diffuse field microphone and its equalised frequency response

- The correction is specific to a given microphone, relying on its calibration data supplied with the microphone CD from the factory. This CD can be read directly into the PULSE Transducer Database.

Response Equalisation Extreme – REq-X

Agenda

- Introduction to Response Equalisation (*REq-X*)
- Transducers and their frequency responses
  - Microphones. Sound fields and their influence on measurement accuracy
  - Accelerometers. Resonancy frequency and effects of mounting principles
- How does *REq-X* work
  - Theory
  - Practical implementation
- Some illustrative examples
  - Microphones
  - Accelerometers
- Conclusion



Brüel & Kjær

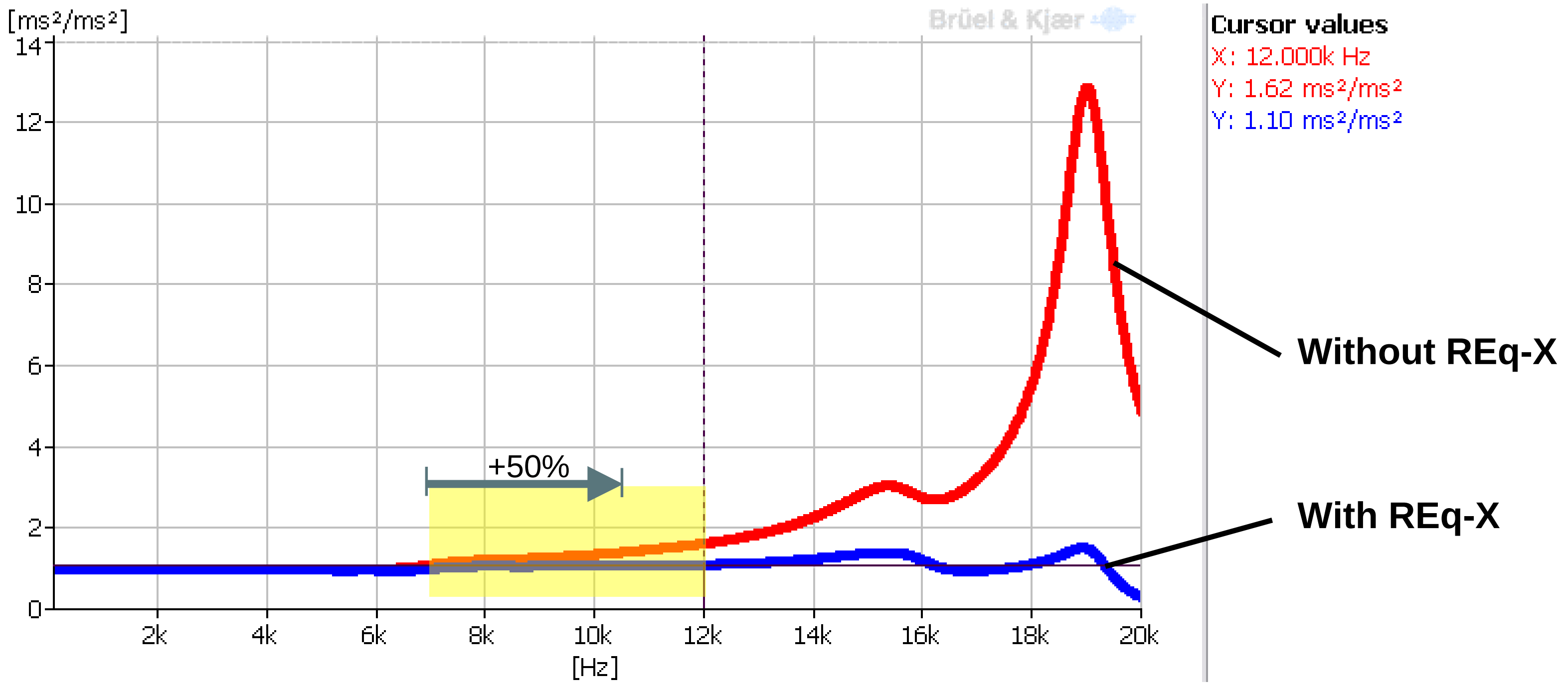
REq-X with Accelerometers – example

Measurement example – 4507 mounted with metal clip

Resonance frequency = 19 kHz

+10% at 7.0 kHz without REq-X

+10% at 12.0 kHz with REq-X



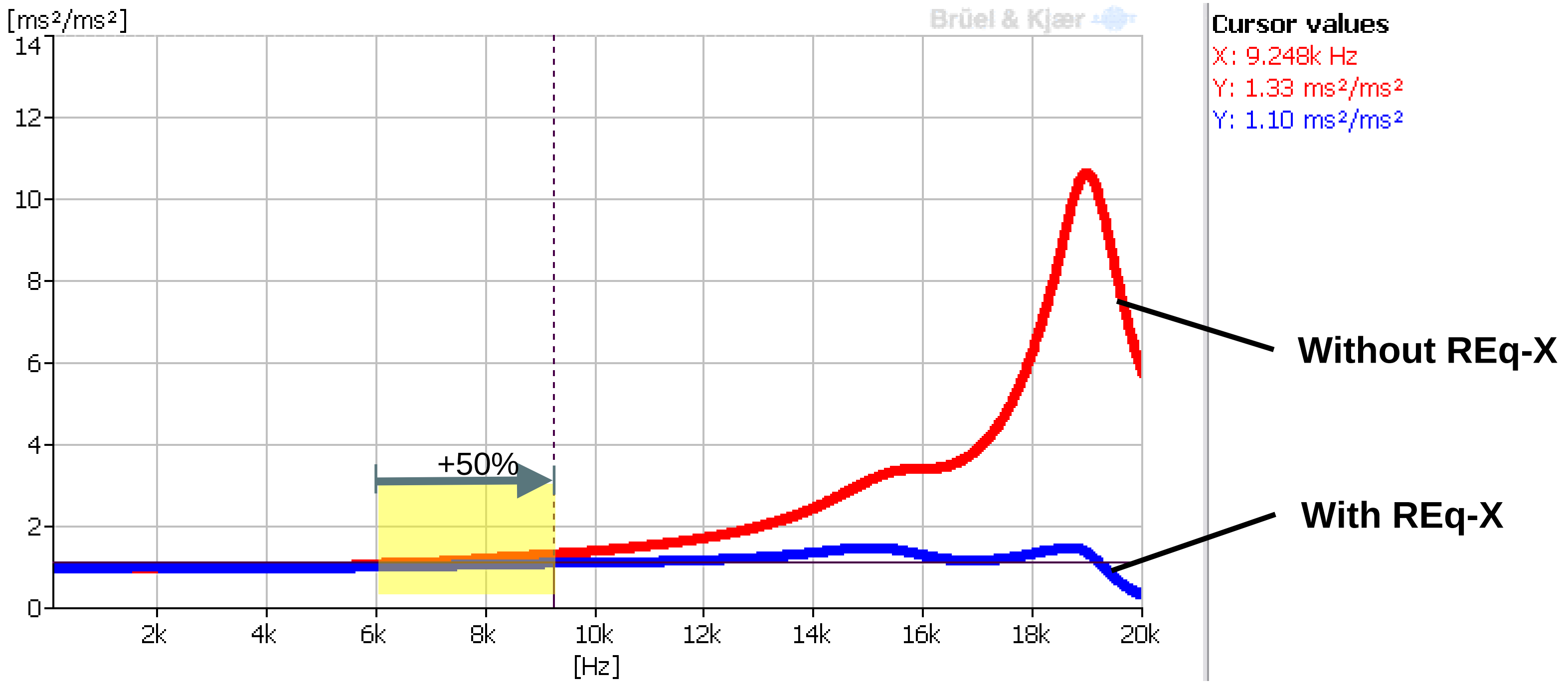
REq-X with Accelerometers – example

Measurement example – 4507 mounted with grease

Resonance frequency = 19 kHz

+10% at 6.1 kHz without REq-X

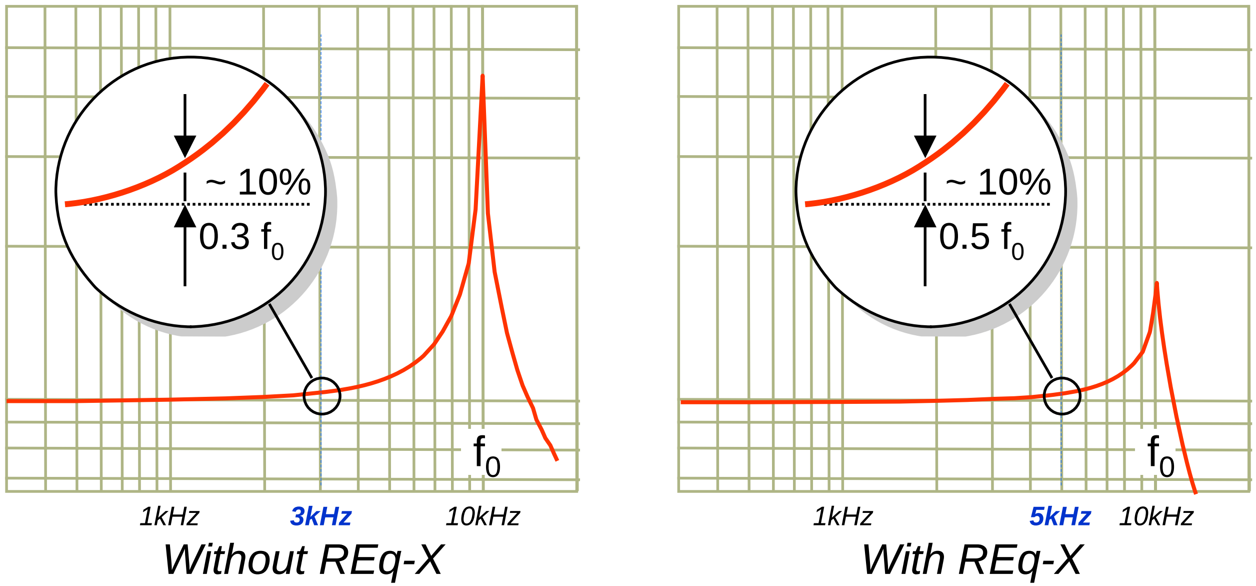
+10% at 9.2 kHz with REq-X



Brüel & Kjær

REq-X with Accelerometers

- REq-X halves measurement inaccuracy
- REq-X extends accelerometer frequency ranges
  - Uni-axial up to **100%**, other typical up to **50%.**
  - In practise it often makes sense to correct higher in frequency



- The correction for accelerometers is automatically calculated from TEDS

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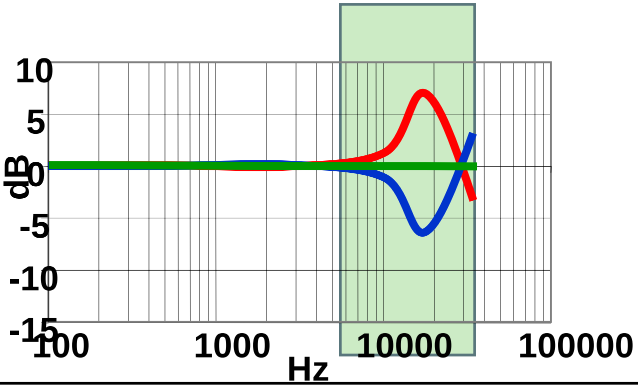

Conclusion!

User benefits:

REq-X "Response Equalisation – eXtreme"

- ***expands*** the use of new and existing transducers.
- ***improves*** the accuracy of the measurement
- ***extends*** the frequency range of transducers

- work in *real-time* –any PULSE measurement and analysis will benefit from this

The bottom line is that if you want the highest possible measurement accuracy result – then you need REq-X