

# Product Data

Reciprocity Calibration System — Type 9699

Reciprocity Calibration Apparatus — Type 5998

## USES:

- Primary open circuit pressure sensitivity calibration of laboratory standard microphones
- Measurements according to IEC 1094–2 on IEC 1094–1 microphone types:
  - LS1P (e.g., 4160)
  - LS2aP (e.g., 4180 or 4134 with UA 0825)
  - LS2F (e.g., 4133 with UA 0825)
- Measurement of static pressure coefficient using integral pressure chamber

## FEATURES:

- Fast manual or PC-controlled determination of Electrical Transfer Impedance
- Measurement and calibration data stored on disk or printed as hard copy
- Frequency range 20 Hz to 25 kHz
- Unique vibration and ambient noise damped microphone mounting stand
- Dimensionally stable plane-wave sapphire couplers



*The main instruments of Reciprocity Calibration Apparatus Type 9699. From left to right and top to bottom, the controlling PC, Microphone Fixture UA 1412, Reciprocity Calibration Apparatus Type 5998, Band-pass Filter Type 1617, Sine Generator Type 1051 and a digital voltmeter*



In addition, all the accessories required for calibration of  $\frac{1}{2}$ " and 1" laboratory standard microphones are supplied, as well as the PC programs described below.

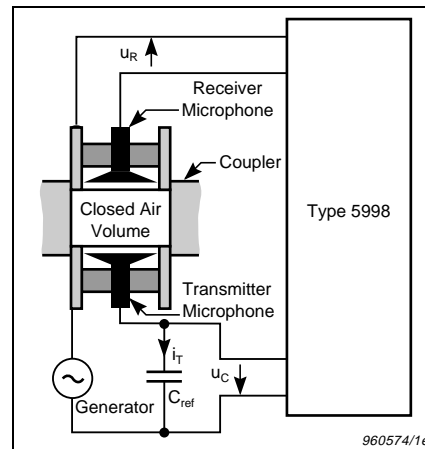
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## Principle of Operation

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The open circuit sensitivities of the microphones are obtained by using a combination of reciprocity calibration and insert voltage techniques. The microphones are acoustically coupled in pairs by the air enclosed in a coupler with precisely determined dimensions. For each pair, one microphone is used as a sound source (transmitter), and the other as a receiver (see Fig. 2).

*Fig. 2 Principle of microphone reciprocity calibration*



The task is to measure  $u_R/i_T$  (the electrical transfer impedance) where  $u_R$  is the open-circuit voltage of the receiver microphone, and  $i_T$  is the current through the transmitter microphone. The current through the transmitter microphone is found by measuring the voltage across a reference capacitor ( $u_C$ ) connected in series with the microphone.

More details on the principle of reciprocity calibration can be found in IEC 1094 – 2.

### Traceability

The reciprocity calibration method is an absolute method of calibration based on physical quantities: voltage (AC and DC); impedance (nF), frequency (Hz), length (dimensions of couplers in metres), and ambient temperature, static pressure and relative humidity. To ensure traceability and the lowest possible calibration uncertainty, all instruments need to be regularly calibrated at traceable calibration laboratories.

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## Software

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### Measurement Software

The flexibility of the measurement system allows you to select calibration at any frequencies in the range from 20 Hz to 25 kHz. When you have chosen the frequencies required, measurements are made for each paired combination of the three microphones in turn. Measurements are controlled by PC software running on the Windows platform. The only intervention required by the operator is the changing round of the microphone pairs.

For each frequency, three sets of measurements are made – one for each microphone pair combination (i.e., 1-2, 1-3, 2-3). When all the sets of three measurements are complete, the measurement data are stored in a text file along with the microphone identification and

ambient parameters. This ensures reliable documentation of the calibration.

### Calculation Software

The calculation software is developed and supported by the Acoustics Laboratory of DTU (Danish Technical University) who have internationally pioneered primary microphone calibration for many years. The software greatly reduces the risk of simple calculation errors and ensures the highest available accuracy.

Using the file of measurement data made with the Windows based control program, the mechanical dimensions of the coupler and the acoustic parameters of the microphones, the DOS based calculation program calculates the sensitivities of the three microphones in accordance with IEC 1094-2. In addition, sensitivities valid at the reference ambient conditions are calculated through the use of built-in microphone correction data derived from experience with Brüel & Kjær Microphones.

The calculated microphone sensitivities are stored on disk, giving a quick and easy documentation reference of the calibration results. Results can either be printed out or imported into spreadsheets or word-processing programs for further reporting.

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## Accuracy of Calibration

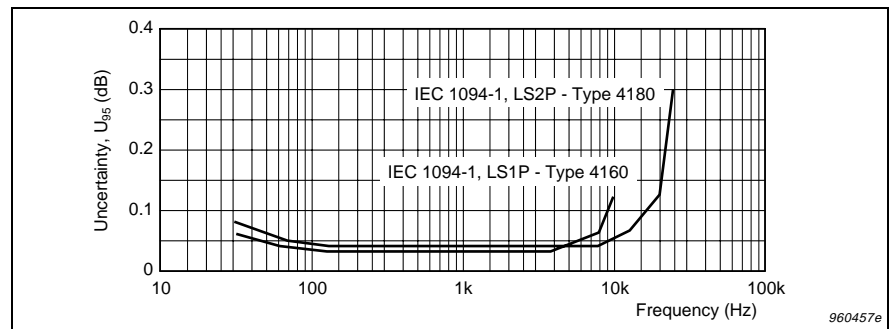
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*The accuracy of calibration results is mainly determined by the uncertainty in the physical quantities and by microphone parameters such as cavity depth and equivalent volume.*

Using Type 5998, a single calibration of a 1" microphone can yield an accuracy of approximately  $\pm 0.05$  dB. To further increase the accuracy, repeated calibrations can be made using different couplers. This allows the determination of the total volume along with other microphone parameters by an iterative process giving convergent results and allowing the reproducibility to be made better than  $\pm 0.02$  dB for reciprocity calibration of LS1P (Type 4160) and LS2aP (Type 4180) Microphones.

For both types of microphone using the corresponding Danish Primary Laboratory for Acoustics (DPLA) system, the overall uncertainty is  $\pm 0.03$  dB and the reproducibility is  $\pm 0.01$  dB, both to 95% confidence limits.

*Fig. 3 Example of calibration uncertainty. Data from the Danish Primary Laboratory for Acoustics*



## Reciprocity Calibration Apparatus — Type 5998

*Reciprocity Calibration Apparatus Type 5998 is an easily operated high-precision and high-stability laboratory instrument designed for precision calibration of condenser microphones by the reciprocity method.*

*The apparatus determines the electrical transfer impedance as described in IEC 1094-2, and can calibrate microphones which fulfil IEC 1094-1, Laboratory Standard Microphones.*



The system allows measurements to be done semi-automatically, but Type 5998 can be used in combination with the other instruments to do manual reciprocity calibration measurements, though of course these take longer than if using computer controlled measurement sequences.

Type 5998 includes all the couplers and adaptors necessary for manual or automatic calibration. In addition, calibration requires the use of an external voltmeter, filter and generator. These are available from Brüel & Kjær as Reciprocity Calibration System Type 9699, described on the first pages of this Product Data Sheet.

### **Apparatus**

Each microphone channel has built-in relays to allow external control of the apparatus via its IEEE-488 interface bus and selection of the required measurement configurations. This allows a PC to control an automatic sequence that measures the transmitter/receiver electrical transfer impedance. Software to control Type 5998 is included in Reciprocity Calibration System Type 9699.

The instrument also includes a high-precision 200 V polarization voltage supply for the condenser microphones. The polarization voltage can be checked using an external digital voltmeter connected to Type 5998. Any deviations can be adjusted by  $\pm 1$  V using a potentiometer accessible from the front panel. As an alternative, an external polarization voltage can be applied if voltages other than 0 V or 200 V are required.

The microphone capsules are connected to Type 5998 via the appropriate preamplifier and cable, terminated in a LEMO plug.

As well as control over the IEEE-488 bus, all functions of Type 5998 can be manually controlled from the front panel, allowing you to conduct specialised tests and development of microphones independently of the Reciprocity Calibration System.

## Microphone Fixture UA 1412

*Fig. 4 Microphone Fixture UA 1412 showing set-up with a 1" microphone*



*Fig. 5 Microphone fixture showing set-up with a 1/2" microphone. Notice that the collar around the main stem is much lower than that in Fig. 4*



A central mechanical part of Type 5998 is the unique microphone fixture. The microphone and coupler holder is enclosed in a chamber that minimises the influence of ambient noise. The chamber has a controlled pressure equalisation with a low cut-off frequency. This ensures highly stable measurements, also at the lowest frequencies. The chamber has pressurization studs to which gas tubes can be connected, allowing measurements to take place at pressures other than the ambient atmospheric pressure. Temperature sensors can also be introduced into the chamber via airtight plugs.

The microphone fixture is mechanically isolated from the laboratory bench, reducing any vibrations that may be present. For the best results the fixture can be remotely located from Type 5998, for example in a different, quieter, room, since the only connections required between the fixture and the main housing are the microphone's electrical connections.

The microphone fixture exerts a steady, well-defined force to hold the microphones and couplers in position during calibration. This allows the microphones to be readily dismantled and changed each time a new microphone combination has to be measured (see Fig. 4 and Fig. 5). The acoustic properties and positioning of the assembled couplers and microphones are controlled by the surfaces of the microphones and coupler.

Note that in comparison with previously available calibration systems, the use of Type 5998 within a Type 9699 system speeds up the reciprocity calculation process many times. Highly reproducible results are obtained, repeatable to within a few hundredths of a dB. Reproducibility may further be improved when the operator gains experience with proper systematic handling of microphones.

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## Transmitter Unit

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The main function of the transmitter unit is to measure the current in the transmitter microphone. This is done by measuring the voltage across the reference capacitor that is placed inside a conventional  $\frac{1}{2}$ " microphone preamplifier of the same type as used for the receiver microphone. This reduces the heating of the microphone setup to a minimum, giving homogeneous microphone and coupler temperature close to the ambient temperature.

The transmitter unit design allows the microphone setup to be placed in carefully controlled ambient environments separated from the main apparatus.

The transmitter unit is not affected by stray capacitance since the generator signal is applied to the microphone housing. This means that it can be calibrated by measuring the capacitance directly on the input terminal. The transmitter unit also allows the insertion of a reference voltage on the input terminal. This enables measurement of the gain in the entire transmitter channel. 1" microphones are calibrated by using a special  $\frac{1}{2}$ " to 1" adaptor that ensures correct termination according to IEC 1094-1.

Two adaptors are supplied for the calibration of the reference capacitor. During calibration, one adaptor provides a BNC connection to the input terminal, and the other provides a battery voltage supply to Transmitter Unit ZE 0796.

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## Receiver Unit

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The receiver unit is a standard  $\frac{1}{2}$ " Preamplifier Type 2673 with an adaptor for 1" microphones. The receiver microphone is mounted, together with the preamplifier, on top of the appropriate coupler (see [Fig. 4](#)). Similar to the transmitter unit, both the receiver preamplifier and adaptor have the correct termination according to IEC 1094-1.

## Couplers

*Fig. 6 Reciprocity Calibration Accessory Kit UA 1427, supplied with Type 5998*

*In the centre are:  
ZE 0796 Transmitter Unit with  
UA 1434 (upper)  
Type 2673  $\frac{1}{2}$ " Microphone  
Preamplifier with DP 0930  
Around these are (clockwise from left):  
UA 1429 Short coupler for LS1  
microphones  
UA 1413 Long coupler for LS1  
microphones  
UA 1414 Long coupler for LS2a  
microphones  
UA 1430 Short coupler for LS2a  
microphones  
UA 0825 Cavity Rings for  $\frac{1}{2}$ "  
microphones  
Type 4180  $\frac{1}{2}$ " microphone capsule  
Type 4160 1" microphone capsule  
DB 0111 Cavity Rings for 1"  
microphones*



Four dimensionally stable sapphire couplers are supplied with Type 5998 (see [Fig. 6](#)):

- long and short plane wave couplers for  $\frac{1}{2}$ " microphones
- long and short plane wave couplers for 1" microphones

These couplers have a perfect cylindrical form and plane, parallel end surfaces that ensure well-defined microphone positioning and coupler volume, essential for the high precision required for reciprocity calibration. The couplers provide electrical insulation between the microphones.

All the couplers have provision for the use of capillary tubes for static pressure equalisation and are designed for easy attachment of cylindrical PT100 temperature sensors (2.8 mm diameter).

The following adaptors are provided for use with the couplers (see [Fig. 6](#)).

- Three Coupler Adaptor Rings DB 0111 for use with 1" microphones Types 4144 and 4145.
- Three Coupler Adaptor Rings UA 0825 for use with  $\frac{1}{2}$ " microphones Types 4133 and 4134.

The coupler rings screw onto the microphones in place of the protection grid to adapt the microphones to the couplers. In Types 4160 and 4180 the adaptor ring is an integral part of the microphone and cannot be dismantled.



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## Sine Generator — Type 1051

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Sine Generator Type 1051 is a microprocessor-based instrument which combines today's needs of increased spectral purity, frequency resolution and stability with ease of use and versatility. The wide frequency coverage from 0.2 Hz to 200 kHz, with amplitude linearity and frequency resolution of  $\pm 0.05$  dB and 1 mHz makes the generator suitable for numerous applications, particularly in this case as a source for reciprocity calibration. Linear and logarithmic sweep ranges, each with their own pre-settable lower and upper limits may be chosen, including extended linear sweeps from 0.001 Hz to 200 kHz. Single, repetitive and continuous sweep modes are also included, and the time for each individual sweep is automatically calculated and displayed.

Output levels from 100  $\mu$ V to 5 VRMS may be chosen to 3 digit accuracy, permitting either a constant amplitude or an amplitude-weighted frequency sweep to be obtained. With the latter, up to 1024 amplitudes can be stored which enables the generator to simulate the output of electrical transducers. Equalization characteristics can be stored for maintaining a constant sound pressure output when connected to a loudspeaker.

Type 1051 employs a heterodyne synthesis technique where two high frequencies are mixed together to produce output beats from 0.001 Hz to 200 kHz. The master clock is based on a 10 MHz crystal oscillator, whose relative accuracy is transferred to the output frequency. If even greater accuracy is required, the internal oscillator can be phase locked to an external reference source.

Type 1051 incorporates an IEEE-488 interface with full Talker (T5) and Listener (L3) capability, making it an ideal part of the Type 9699 system. In addition, you can use the IEEE-488 interface to control the instrument for use with your own applications.

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## 1/1- and 1/3-octave Band Pass Filter — Type 1617

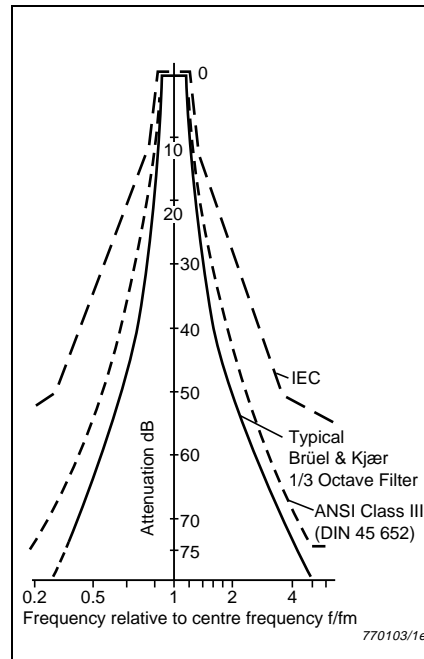
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Type 1617 is a band pass filter that is a key link in the reciprocity calibration measuring chain. Several novel features are included in the instrument, including electronic filter switching and digital indication. Type 1617 has an extensive frequency range with comprehensive control and synchronisation facilities for use with other equipment.

Type 1617 has filter band centre frequencies from 2 Hz to 160 kHz that are divided into 50 third-octave bands. There are 41 overlapping octave bands covering 14 octaves from 2 kHz to 20 kHz. In addition to A-weighting, Type 1617 includes B-, C- and D-weighting networks.

The active filter sections consist of matched pairs of variable frequency six-pole Butterworth filters which can be electronically switched to yield third-octave or full-octave bandwidths.

Fig. 7 Typical third-octave filter response



The filter characteristics of the individual third-octave filters fulfil the requirements of IEC225-1966, DIN 45 652, and ANSI S1.11-1966 Class III, which are the most rigorous standards applying to third-octave filters (see Fig. 7).

The total integrated random (white) noise power passed by the active third- and full-octave filters in Type 1617 is equal to the noise power of ideal third or full-octave filters.

Type 1617 has an IEEE-488 interface that allows control of filter frequency bandwidths, centre frequency and averaging times via the simple command set (AH1, L2, RL2 and PP2).

# Specifications 5998

## Reciprocity Calibration Range

### MICROPHONES:

All microphones fulfilling IEC 61094-1\*

### FREQUENCY RANGE:

LS1P: 20 Hz to 10 kHz

LS2aP: 20 Hz to 25 kHz

## Reproducibility of Electrical Transfer Impedance Measurement

LS1P Ratio:  $\pm 0.004$  dB ( $2\sigma$ ) at fixed ambient conditions

LS2aP:  $\pm 0.007$  dB ( $2\sigma$ ) at fixed ambient conditions

## Electrical Specifications

### TYPE 5998:

**Channel A, Receiver:** 7-pin LEMO socket for Brüel & Kjær standard preamplifier with insert-voltage calibration

**Channel B, Transmitter:** 7-pin LEMO socket for Brüel & Kjær preamplifier

### Channels A and B:

**Frequency Range:** 20 Hz to 25 kHz  $\pm 0.1$  dB<sup>†</sup>  
1 Hz to 200 kHz  $\pm 3$  dB

**Gain Steps:** 0 to 50 dB  $\pm 0.1$  dB in 10 dB steps

**Max. Voltage:** 10 V peak

**Distortion:**  $< 0.01\%$  THD at 1 V, 1 kHz

**Input Noise:**  $< 10 \mu\text{V}$ , 20 Hz to 25 kHz

**Output Noise:**  $< 300 \mu\text{V}$ , 20 Hz to 25 kHz

**Gain Stability:** 0.001 dB/h at 23°C

**Input Impedance:** 100 k $\Omega$  || 140 pF

**High-pass Filters:** 1, 20 and 100 Hz ( $-3$  dB, 6 dB/oct.)

**Output Impedance, all BNC Outputs:** 50  $\Omega$

### Generator Input:

**Max. Input Voltage:** 6 V peak

**Input Impedance:** 100 k $\Omega$  || 40 pF

**Amplifier Gain:** 6 dB

### Polarization Voltage, Internal:

**Voltage:** 200 V DC, factory adjusted  $\pm 50$  mV

**Adjustment Range:**  $\pm 1$  V, approx.

**Long-term Stability:**  $\pm 40$  ppm/month,  $\pm 140$  ppm/year

**Temperature Stability:**  $\pm 15$  ppm/°C

**Output Impedance on Test Socket:**  $< 0.1 \Omega$ , up to 200  $\mu\text{A}$ , short-circuit current approx. 7 mA

### Polarization Voltage, External Input:

**Max. Input Voltage:**  $\pm 200$  V DC

\* No coupler supplied for Type LS2bP

† Gain correction is applied during microphone calibration

### Power Supply:

**110–120 V:** 90–140 V AC, 50–60 Hz

**220–240 V:** 180–254 V AC, 50–60 Hz

**Power Consumption:** 25 VA

### TRANSMITTER UNIT ZE 0796:

**Polarization Resistor:** 1 G $\Omega$

**Reference Capacitor (input capacitance):**

**Capacitance:** 4.7 nF  $\pm 10\%$ <sup>#</sup>

**Rated Voltage:** 200 V DC

**$\Delta C$ /Frequency (20 Hz to 25 kHz):**  $< \pm 0.01\%$

**$\Delta C$ /DC Voltage (0 to 200 V DC):**  $< \pm 0.01\%$

**Temperature Coefficient:**  $\pm 30$  ppm/°C

**Long-term Stability:**  $\pm 100$  ppm/year

**Insulation Resistance:**  $> 10^6$  M $\Omega$

**Other Electrical Specifications:** See specifications for Preamplifier Type 2673

### RECEIVER UNIT:

**1/2" Microphone Preamplifier Type 2673.** See separate Product Data (BP 1645)

## Hardware

### MICROPHONE FIXTURE UA 1412:

**Supporting Force:** Typically 10 N

**Maximum internal pressure difference w.r.t. ambient:**  $\pm 25$  kPa

### ACCESSORY KIT UA 1427:

**1/2" Plane-wave Sapphire Couplers:**

**UA 1430:**  $\varnothing 9.3 \times 4.7$  mm ( $\varnothing 33.5 \times 18.5$  mm)

**UA 1414:**  $\varnothing 9.3 \times 9.4$  mm ( $\varnothing 33.5 \times 23.2$  mm)

**1" Plane-wave Sapphire Couplers:**

**UA 1429:**  $\varnothing 18.6 \times 7.5$  mm ( $\varnothing 43.5 \times 25.9$  mm)

**UA 1413:**  $\varnothing 18.6 \times 15$  mm ( $\varnothing 43.5 \times 33.4$  mm)

### OPERATING CONDITIONS:

**Static Pressure Range:** 80 to 105 kPa

See also Temperature and Humidity in

### DIMENSIONS:

**Type 5998 Case (H x W x D):** 175 x 319 x 39 mm (6.9 x 12.5 x 15.4")

**Microphone Fixture UA 1412:**  $\varnothing 230 \times 370$  mm ( $\varnothing 9.0 \times 14.6$ ")

**Accessory Kit UA 1427:** 54 x 325 x 275 mm (2.1 x 12.8 x 10.8")

### WEIGHT:

**Type 5998 Case:** 10 kg (22 lb.)

**Microphone Fixture:** 5.6 kg (13 lb.)

**Accessory Kit:** 1.3 kg (3 lb.)

<sup>#</sup> Individually calibrated  $\pm 0.05\%$

# Specifications 9699

### MICROPHONES:

All microphones fulfilling IEC 1094-1, Types LS1P, LS2aP and LS2F

### FREQUENCY RANGE:

**1" microphones:** 20 Hz to 10 kHz

**1/2" microphones:** 20 Hz to 25 kHz

### UNCERTAINTY:

Better than 0.08 dB when using typical microphone data and the simplified calculation method. When using individual microphone data and the precision calculation method, uncertainty falls to less

than 0.05 dB (125 Hz to 4 kHz for 1" microphones and 1/2" 125 Hz to 8 kHz for 1/2" microphones)

### REPRODUCIBILITY:

**1" microphones:** Better than 0.01 dB at 250 Hz

**1/2" microphones:** Better than 0.02 dB at 250 Hz

### COMPLIANCE WITH STANDARDS:



All components of the Reciprocity Calibration System are individually CE marked and comply with standards as detailed in their respective product data sheets.

## Ordering Information — Basis Calibration System Type 9699

Type 9699: Reciprocity Calibration System	<b>Options:</b>
<b>Includes the following:</b>	Type 4160: 1" Laboratory Standard Microphone
Type 5998: Reciprocity Calibration Apparatus	ET 2014 DPLA calibration of Type 4160
Type 1617: 1/1- and 1/3-octave Bandpass Filter	ET 2016 Cavity length calibration of Type 4160
Type 1051: Sine Generator	Type 4180: 1/2" Laboratory Standard Microphone
BZ 5226: Measurement Program	ET 2014 DPLA calibration of Type 4180
BZ 5244: Calculation Program	ET 2016 Cavity length calibration of Type 4180
3×AO 0265: IEEE-488 Interface Cable	
3×AO 0264: IEC-625 Interface Cable	
3×AO 0087: BNC-BNC Coaxial Cable	
— Digital Voltmeter	
— Personal Computer with IEEE-488 Bus	
	<b>Services Available</b>
	<b>9699 SIF:</b> System installation with operator instruction
	— Microphone and calibration course

## Ordering Information — Calibration Apparatus Type 5998

Type 5998: Reciprocity Calibration Apparatus	3 × DB 0111: Cavity Rings for 1" microphones
<b>Includes the following accessories:</b>	3 × UA 0825: Cavity Rings for 1/2" microphones
UA 1412: Microphone Fixture	UA 1429: 3 cm <sup>3</sup> coupler for LS1 microphones
UA 1427: Reciprocity Calibration Accessory Kit	UA 1413: 5 cm <sup>3</sup> Long coupler for LS1 microphones
<b>Reciprocity Calibration Accessory Kit UA 1427 consists of:</b>	UA 1430: 0.4 cm <sup>3</sup> Short coupler for LS2a microphones
ZE 0796: Transmitter Unit	UA 1414: 0.7 cm <sup>3</sup> Long coupler for LS2a microphones
Type 2673T: 1/2" Microphone Preamplifier	AO 0541: 21 cm Cable
2×UA 1434: 1/2" to 1" Adaptor	AO 0538: 40 cm Cable
	2×AO 0539: 70 cm Cable

## Compliance With Standards — Type 5998

<b>CE</b>	CE-mark indicates compliance with: EMC Directive and Low Voltage Directive.
<b>Safety</b>	EN 61010-1 and IEC 1010-1: Safety requirements for electrical equipment for measurement, control and laboratory use.
<b>EMC Emission</b>	EN 50081-1: Generic emission standard. Part 1: Residential, commercial and light industry. CISPR 22: Radio disturbance characteristics of information technology equipment. Class B Limits. FCC Rules, Part 15: Complies with the limits for a Class B digital device.
<b>EMC Immunity</b>	EN 50082-1: Generic immunity standard. Part 1: Residential, commercial and light industry. <b>Note 1:</b> The above is guaranteed using accessories listed in this Product Data sheet only. <b>Note 2:</b> Type 5998 RF immunity noise specifications degraded less than 20 dB. <b>Note 3:</b> Transmitter Unit ZE 0796 susceptibility to radiated RF is 200 mV.
<b>Temperature</b>	IEC 68-2-1 & IEC 68-2-2: Environmental Testing. Cold and Dry Heat. Operating Temperature: 18 to 28 °C (64 to 82 °F) Storage Temperature: 5 to +40 °C (41 to 104 °F)
<b>Humidity</b>	IEC 68-2-3: Damp Heat Operation: 0 to 85% RH (non-condensing at 30 °C) Storage: 0 to 93% RH (non-condensing at 40 °C)
<b>Mechanical</b>	Non-operating: IEC 68-2-6: Vibration: 0.3 mm, 20 m/s <sup>2</sup> , 10-500 Hz: IEC 68-2-27: Shock: 1000 m/s <sup>2</sup> IEC 68-2-29: Bump: 1000 bumps at 250 m/s <sup>2</sup>
<b>Enclosure</b>	IEC 529 (1989): Protection provided by enclosures: IP 20

Brüel & Kjær reserves the right to change specifications and accessories without notice