B&K 4370 Accelerometer
and Charge Amplifier Manual

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Summary

The Brüel&Kjær 4370 is a single axis piezoelectric accelerometer sensitive along its Z axis down to nearly 10[μg], and conventionally useful over a range of 0.1[Hz] up to about 1/3 of its mechanical resonance frequency of 15–21[kHz], depending on its mounted configuration. The charge available on its output is proportional to acceleration sensed by the device (including gravity). To be useful, this charge must be integrated by a *charge amplifier* to provide a voltage proportional to acceleration. The overall low frequency performance depends on the limiting noise floor and frequency response of the charge amplifier

A charge amplifier was designed specifically for extending the useful low end of the frequency range of the 4370 to 0.01[Hz], and to provide anti-alias filtering for adequately suppressing frequencies at the mechanical resonance of the accelerometer. This filter is a fifth order Cauer filter with zeros in the stop band to cancel the mechanical resonance. It provides a flat frequency response to its upper 3[dB] cutoff frequency at 6.8[kHz] and guarantees at least 20[dB] anti-alias suppression of all acceleration stimuli above 11[kHz].

This report comprises a user manual for the accelerometer and charge amplifier kit, a theory of operation section, and an appendix containing the design drawings. Casual users need not delve further than the user manual, although the theory of operation provides more detailed technical insights which will be useful to the more serious user. The design drawings along with the theory of operation are intended to be sufficiently detailed for anyone skilled in the art to adapt and construct the charge amplifier design for other accelerometers.

1 User Manual

The accelerometer and charge amplifier (Charge Amp) are provided as a complete kit, and should always be kept together. The special coaxial cable provided to connect the accelerometer to the charge amplifier is a calibrated component with microdot connectors which will not mate with any of the standard connector families. To encourage keeping the kit together, a convenient carrying case is provided. A usage synopsis is posted on the inside of the case.

Use of the kit is straightforward. All that's necessary is to power the Charge Amp, mount the accelerometer on the device under test (DUT), connect them together and to a data acquiring instrument such as a DAQ card or oscilloscope, and set the gain and low frequency cutoff switches.

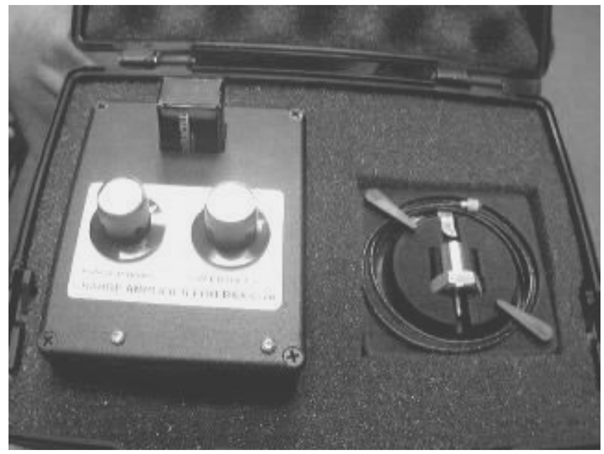


Figure 1: Kit consists of an accelerometer, a cable, a charge amplifier (shown with battery installed), and a carrying case.

To power the Charge Amp, a 9-volt battery should be snapped into the front panel receptacle. To prevent damage from battery leakage, **the Charge Amp should never be stored with the 9-volt battery installed.** The external battery access feature is intended to make it convenient to observe this rule. Also please note the polarity of the snap connectors and do not attempt to install the battery backwards.

The accelerometer should be mounted to the device under test (DUT) using either a 10-32 fastener or double backed adhesive tape. **Under no circumstances should the fastener be forcibly threaded into the accelerometer.** Slightly over two complete turns is the maximum thread depth in the 4370. The manufacturer's recommended mounting techniques for threaded fasteners and alternatives are excerpted from [B&K02] and shown here as Figures 2a and 2b.

The charge amplifier should be set for the desired gain and low frequency cutoff. Be aware that the lower frequency ranges may take a long time to settle: over a minute for the 0.01[Hz] range. Settling can be hastened somewhat by briefly switching to a higher frequency range and back, but it will still take some time. Even when completely settled, there is a residual DC error voltage of a few millivolts. If very high accuracy is desired, this should be measured and subtracted from subsequent data.

The output voltage range of the Charge Amp is nominally ± 2.5[V]. Depending on battery voltage, the output will clip at ± 2.9[V] or less. If the Charge Amp is overloaded to clipping, its DC offset will be upset and must be allowed to re-settle before meaningful measurements can be made. The remedy for this is either to use a less sensitive gain range so that overload does not occur, or to use a low cutoff range that settles acceptably quickly after an overload.

The noise floor of the Charge Amp is on the order of 100[μV_{rms}] on all ranges. On the most sensitive range, this corresponds to an acceleration noise floor of approximately 100[μg]. As of this writing, these measurements are very approximate, and need to be

Mounting

Brüel & Kjær accelerometers can be mounted with their main sensitivity axis aligned in any direction.

Recommended Mounting Technique

Fig. 9
Recommended mounting technique

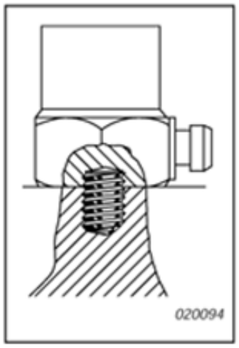
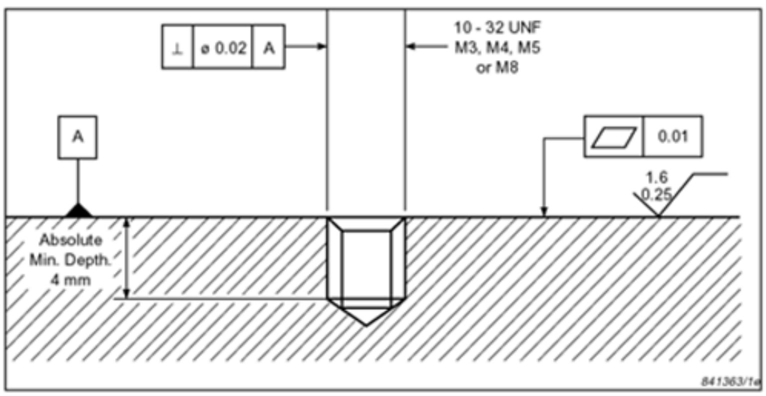


Fig. 9 shows the recommended method for mounting most of the accelerometer types. The accelerometers are screwed using a threaded steel stud onto a clean metal surface meeting the requirements specified in Fig. 10. Under normal circumstances the absolute minimum depth of 4 mm will not be sufficient to accommodate the mounting stud, but is the minimum depth required to hold a stud securely. The optimum torque for tightening 10–32 UNF steel studs is 1.8 Nm (15 lb. in.), for M3 steel studs it is 0.6 Nm (5 lb. in.) and for M8 steel studs it is 4.6 Nm (38 lb. in.).

Fig. 10
Recommended tolerances for the mounting surfaces. Dimensions and symbols in accordance with ISO 1101



This mounting method is used in obtaining the specifications of all the accelerometers with the following exceptions:

- Type 4374, due to its small size, cannot be mounted using a stud. The recommended mounting technique, used to obtain the specifications, utilises a quick setting methyl cyanoacrylate cement (Brüel & Kjær no. QS 0007). The tolerances on the clean metal mounting surface shown in Fig. 10 are required.
- Type 8309 has an M5 metric screw stud as an integral part of its base. The tolerances shown in Fig. 10 apply, and the optimum torque is 1.8 Nm (15 lb. in.).

When using the recommended technique, it should also be noted that if the mounting surface is not perfectly smooth, the application of a thin layer of grease to the base of the accelerometer, before screwing it down on the mounting surface, will improve the mounting stiffness.

Figure 2a: Mounting techniques excerpted from [B&K02]

quantified more carefully if the kit is to be used at sensitivities where this is an issue.

The upper cutoff frequency, or 3[dB] rolloff point of the Charge Amp's passband is nominally 6.8[kHz]. In the stopband, a special rejection band is provided to suppress the resonance peak of the accelerometer over the range of 15–21[kHz] in which it can occur. This provides at least 20[dB] anti-alias filtering for all mechanical excitation above 11[kHz],

Alternative Mounting Techniques

When mounting techniques other than the recommended technique are used, the accelerometer's mounted resonance frequency will probably be lowered.

Fig. 11 Alternative mounting techniques

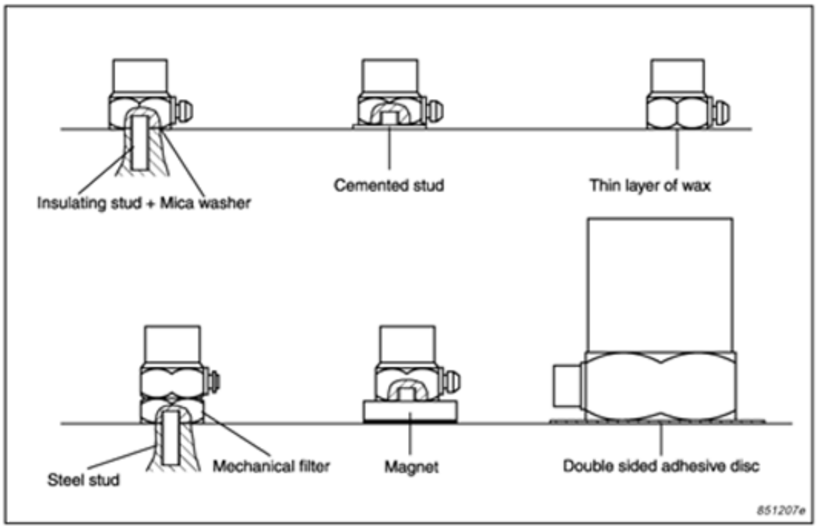


Fig. 11 shows some alternative mounting techniques. The section entitled "Standard Accessories" on page 15 lists the mounting accessories that are supplied with the individual accelerometer types. These mounting techniques are described in more detail in the Brüel & Kjær "Piezoelectric Accelerometers and Vibration Preamplifiers" handbook, where the effects of the different methods on the frequency response curve of an accelerometer are illustrated.

Figure 2b: Alternative techniques excerpted from [B&K02]

irrespective of the accelerometer resonance. Refer to page 13 of the design drawings for detailed response curves, as simulated by SPICE.

The output of the charge amplifier will drive any single-ended instrument input impedance of $\geq 50[\Omega]$ through a conventional BNC cable. It should be relatively insensitive to ground loops between the accelerometer and the driven instrument. However care should be taken to prevent the Charge Amp box from electrically contacting anything, as ground loops between the accelerometer and the Charge Amp itself can cause noise problems. The Charge Amp is furnished with rubber feet to help provide the necessary electrical isolation.

2 Charge Amp Theory of Operation

The Charge Amp is logically composed of five functional blocks and a power management block. Referring to Figure 3, these are the charge integrating preamplifier **preamp**, two stages of anti-alias filter **cauer1** and **cauer2**, an integrating feedback circuit **dcfb**, an output driver **diffout**, and power management **pwrgnd**. Also shown is an electrical model **tdcr** of the accelerometer in which the acceleration stimulus is represented by voltage V_a.

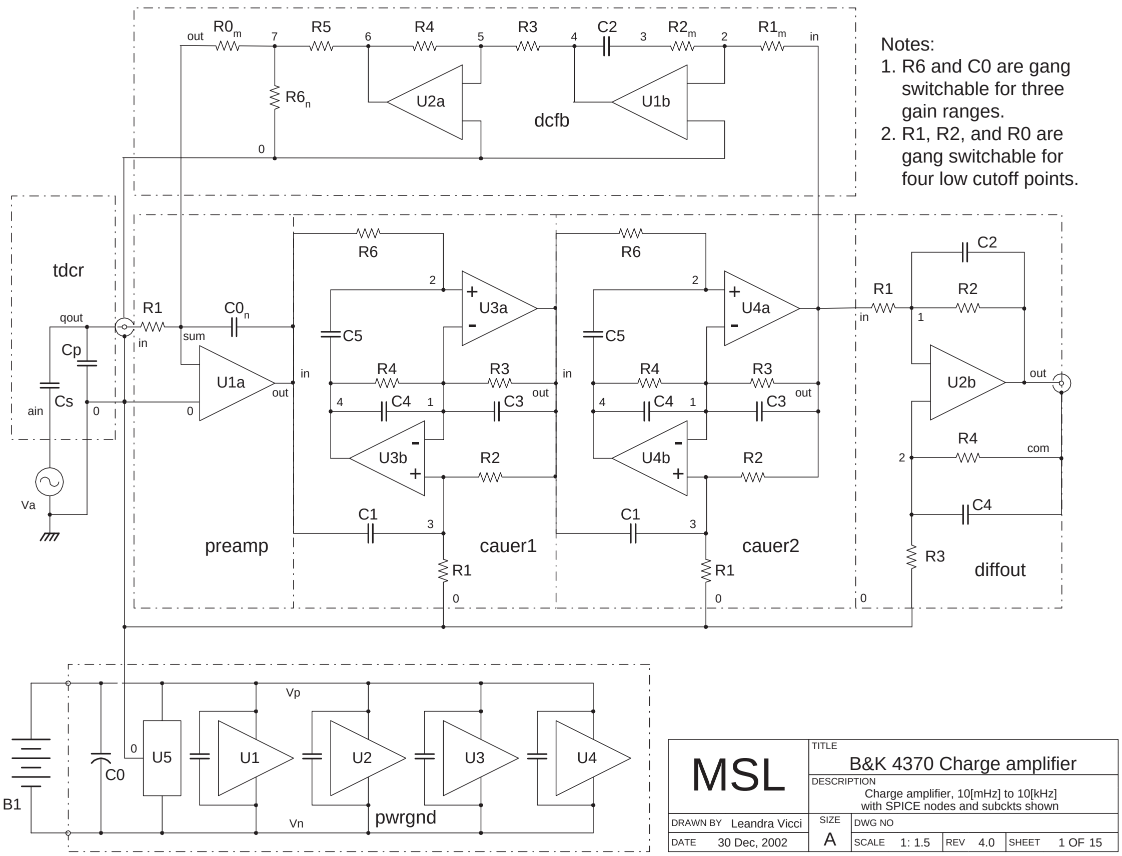


Figure 3: Charge Amp schematic showing SPICE subcircuits

2.1 pwrgnd

The Charge Amp uses a single 9-volt battery, and needs to have a local ground reference, preferably midway between the positive and negative power rails. This is generated by U5, a TLE2426 Virtual Ground Generator. This local virtual ground is connected to the instrument's case and through the connecting cable to the body of the 4370. It is therefore important not to allow a ground loop to be established between the 4370 and the Charge Amp. The Charge Amp has insulating rubber feet to isolate it from its supporting surface.

2.2 diffout

Ground loop noise between the Charge Amp and the instrument it drives *is* however suppressed. U2b is embedded in a differential amplifier configuration which isolates the local ground from the output common. This prevents a ground loop from occurring between the Charge Amp and the driven instrument. The amount of ground noise suppression depends on the CMRR of the differential configuration of diffout which should approach 40[dB].

2.3 tdcr

The resonance of the 4370 is not explicitly modeled here, but the acceleration stimulus, including gravity, is represented by V_a. Changes in V_a cause a charge transfer through the transcapacitance element C_s. Parallel capacitance C_p comprises the parasitic capacitance of the 4370 and its connecting cable. The transcapacitance gain was chosen to match the manufacturer's sensitivity data so that $V_a = 1$[V] represents an acceleration of 1[m/s^2]. Note that this is strictly a simulation model.

2.4 preamp

This is the integrating amplifier which transduces charge to voltage. The transelastance gain is the reciprocal of capacitance C_0. The preamp also provides one real pole to the fifth-order anti-alias filter. The frequency of this pole is established by R_1 and the parallel combination of C_s and C_p. Gain ranges are implemented with switch selectable capacitances of 1, 10, and 100[nF] for C_0. Operation at very low frequency requires an amplifier with a low noise floor as well as very low bias current. U1 is a TLC2202C dual low-noise precision op amp implemented in TI's LinCMOS technology, with 1[pA] typical bias current and 30[nV/$\sqrt{\text{Hz}}$] at 10[Hz] (in the 1/f noise regime). [TI97a]

2.5 cauer1 and cauer2

Each of these circuits provides two complex poles and two complex zeros to the anti-alias filter. These poles along with one real preamp pole implement a fifth order low pass Butterworth function. The four complex zeros provide the desired signal suppression over the frequency range of 15.5[kHz] through 21.4[kHz] to cancel out the 4370 resonance. Refer to pages 13–15 of the design drawings for a quantitative comparison. 15.5[kHz] is the resonance of the 4370 mounted on a very large DUT mass, while 21.4[kHz] is the resonance of the unmounted device. The circuits themselves are nullor realizations of generalized impedance converter (GIC) derived biquadratic functions [Chen95].

2.6 dcfb

This circuit sets the low frequency cutoff of the Charge Amp. In combination with the accelerometer transfer function and the preamp transelastance, it implements a critically damped second order high pass filter function (that is, second order Butterworth). This function has two DC zeros and a pair of complex conjugate poles which set the cutoff frequency.. This provides a 40[dB/decade] rolloff below the switch selectable cutoff frequencies of 10, 1, 0.1, and 0.01[Hz] (see page 13 of the design drawings).

The dcfb circuit itself synthesizes the equivalent of a parallel RL circuit which is connected across C_0 in the preamp. Accounting for the combined DC gain A of the Cauer filter sections we have,

$$R = \frac{R_0 R_1 R_3}{A R_2 R_4}\,, \qquad L = \frac{R_0 R_1 R_3 C_2}{A R_4}.$$

The equivalent feedback impedance of the preamp circuit is then,

$$Z_0 = \frac{1}{(1/Z_{RL} + sC_0)} = \frac{1}{C_0}\,\frac{s}{s^2 + s(\omega_0/Q_0) + \omega_0^2}\,, \quad \text{where}$$

$$Q_0 = \frac{R}{\sqrt{L/C_0}} = \sqrt{\frac{R_0 R_1 R_3 C0}{A R_2^2 R_4 C_2}}\,, \quad \text{and}$$

$$\omega_0 = \frac{1}{\sqrt{LC_0}} = \sqrt{\frac{A R_4}{R_0 R_1 R_3 C_0 C_2}}\,.$$

The filter poles come from the denominator of Z_0, with the cutoff frequency determined by ω_0 and the damping factor by Q_0. These parameters are highly underconstrained in that the number of determining component values (degrees of freedom) is large. Component values were chosen to implement the desired low cutoff for the various ranges while providing the desired Butterworth function for each range.

References

[B&K02] "Product Data – Piezoelectric DeltaShear Accelerometers Uni-Gain, DeltaTron and Special Types," *http://www.bksv.com/pdf/Bp0196.pdf,* Brüel&Kjær, October 24, 2002.

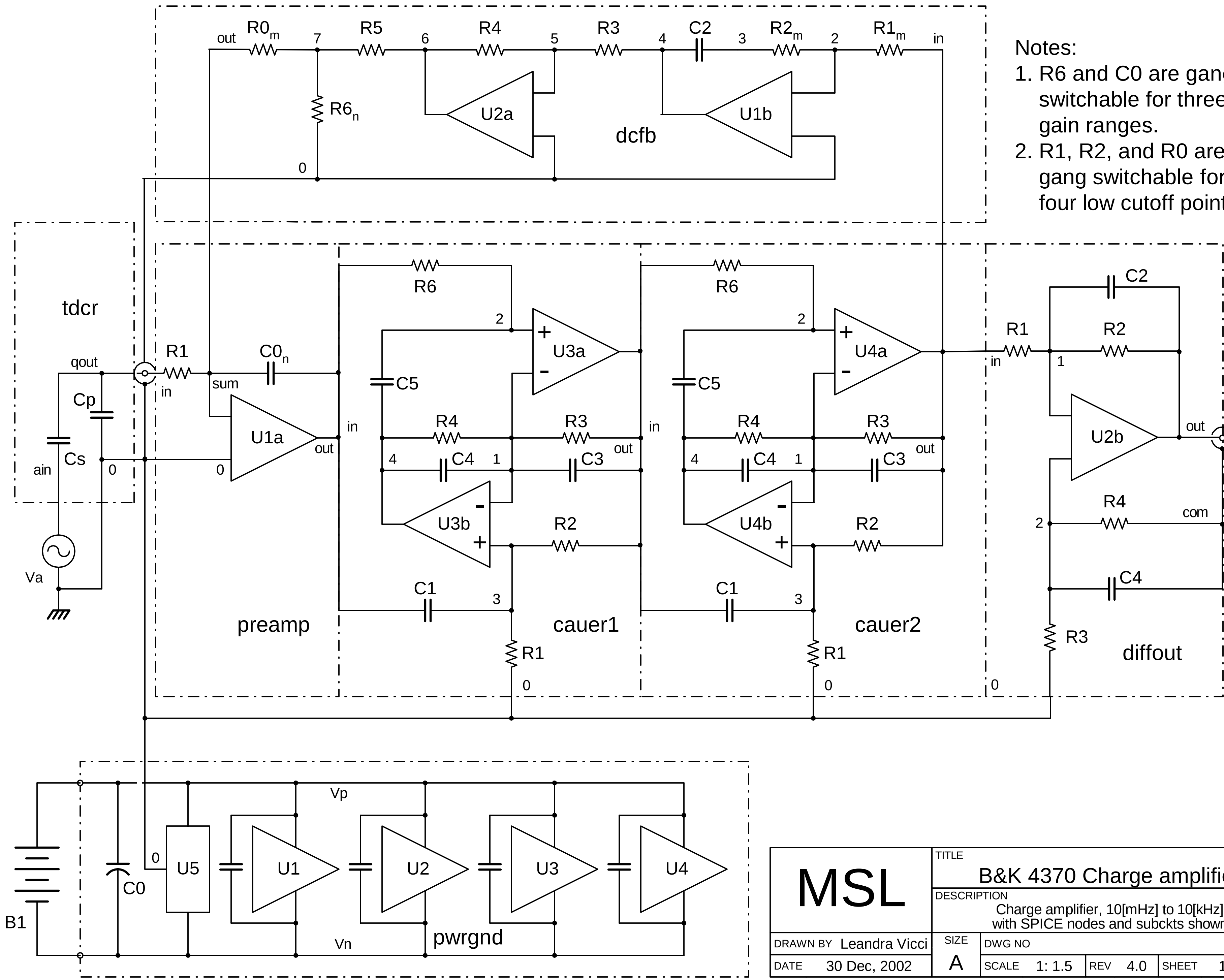
[Chen95] Wai-Kan Chen, Ed., "The Circuits and Filters Handbook," CRC Press, 1995, ISBN 0-8493-8341-2, pp 2392–2400.

[TI97a] Texas Instruments Data Book, "Amplifiers, Comparators, and Special Functions," Texas Instruments, 1997, SLYD011A, vol A, pp 3-767 ff.

[TI97b] Texas Instruments Data Book, "Amplifiers, Comparators, and Special Functions," Texas Instruments, 1997, SLYD012A, vol B, pp 6-287 ff.

APPENDIX A – Design drawings

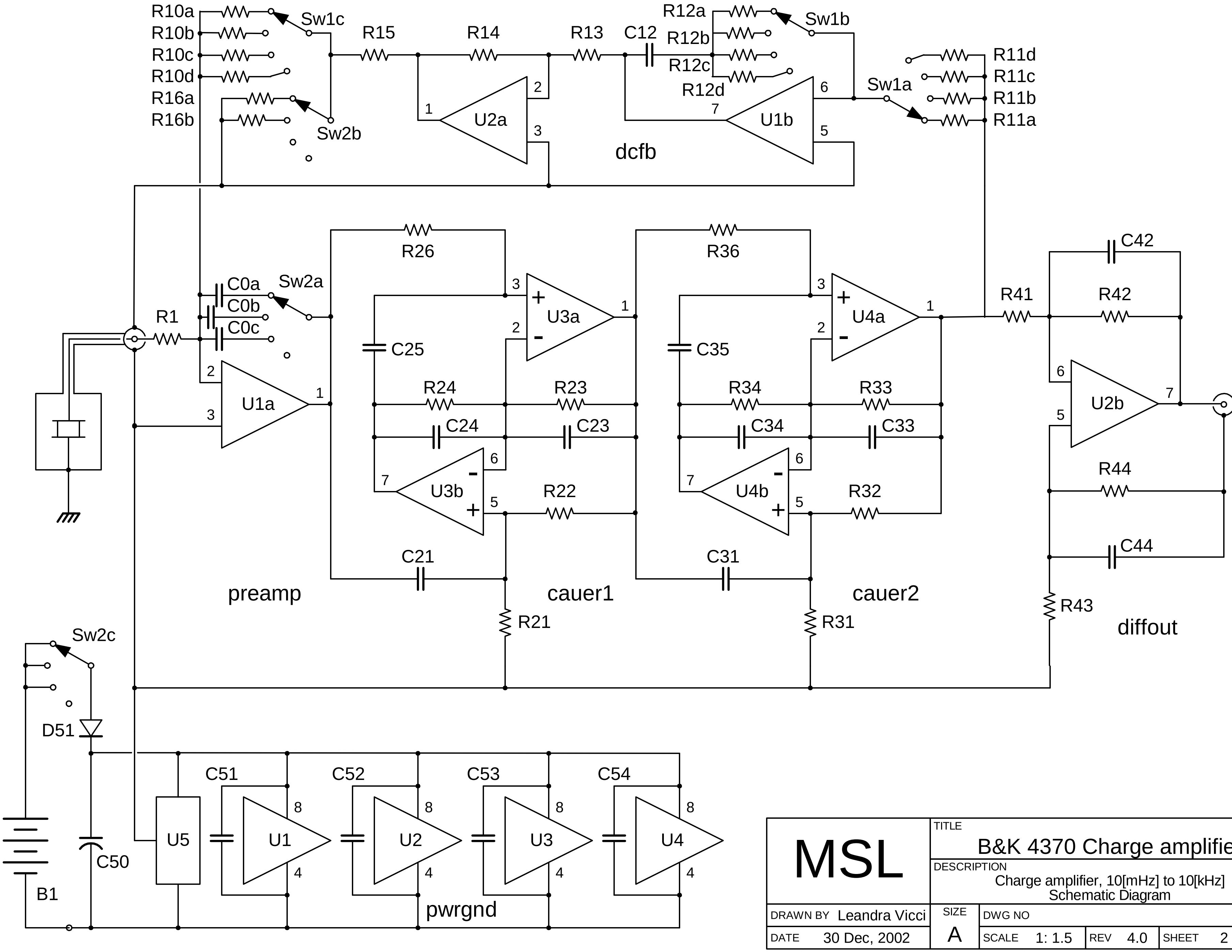
The following are the design drawings of the as-built Charge Amp.



Notes:

1. R6 and C0 are gang switchable for three gain ranges.
2. R1, R2, and R0 are gang switchable for four low cutoff points.

MSL	TITLE: B&K 4370 Charge amplifier
	DESCRIPTION: Charge amplifier, 10[mHz] to 10[kHz] with SPICE nodes and subckts shown
DRAWN BY Leandra Vicci	SIZE A
DATE 30 Dec, 2002	DWG NO; SCALE 1: 1.5; REV 4.0; SHEET 1 OF 15



MSL	TITLE	B&K 4370 Charge amplifier
	DESCRIPTION	Charge amplifier, 10[mHz] to 10[kHz] Schematic Diagram
DRAWN BY Leandra Vicci	SIZE A	DWG NO
DATE 30 Dec, 2002		SCALE 1: 1.5 · REV 4.0 · SHEET 2 OF 15

Resistors

R1	13.3K
R10a	1G
R10b	100M
R10c	10M
R10d	1M
R11a	6.2M
R11b	620K
R11c	62K
R11d	6.2K
R12a	6.2M
R12b	620K
R12c	62K
R12d	6.2K
R13	100K
R14	100K
R15	100K
R16a	1K
R16b	10K
R21	10K
R22	15K
R23	10K
R24	10K
R26	16.9K
R31	7.5K
R32	24.9K
R33	10K
R34	10K
R36	10K
R41	10.7K
R42	10K
R43	10.7K
R44	10K

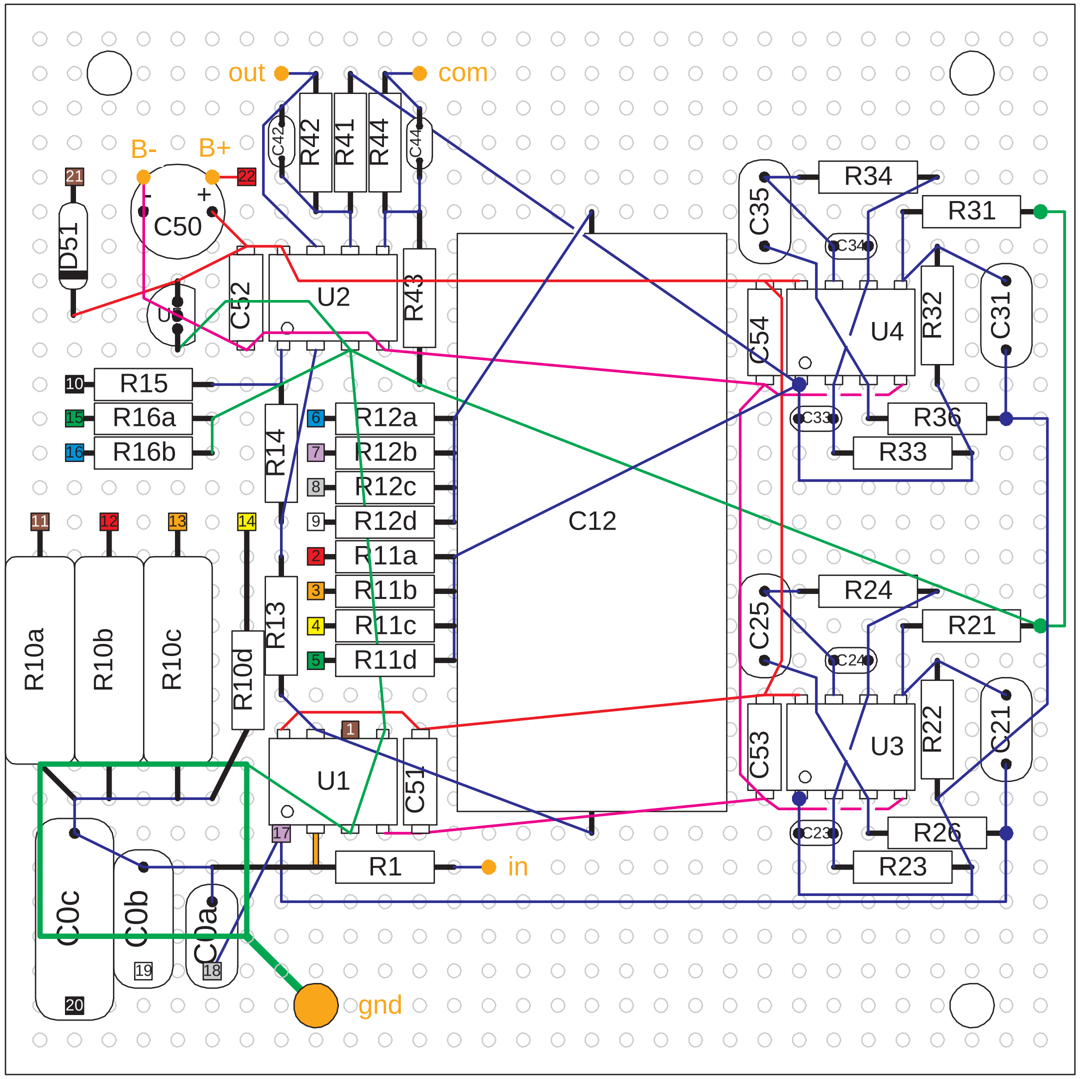
Capacitors

C0a	1.0nF
C0b	10nF
C0c	100nF
C12	5μF
C23	10pF
C24	10pF
C21	999.1pF
C25	987.4pF
C33	10pF
C34	10pF
C31	3.325nF
C35	330.3pF
C42	220pF
C44	220pF
C50	100uF
C51	0.1μF
C52	0.1μF
C53	0.1μF
C54	0.1μF

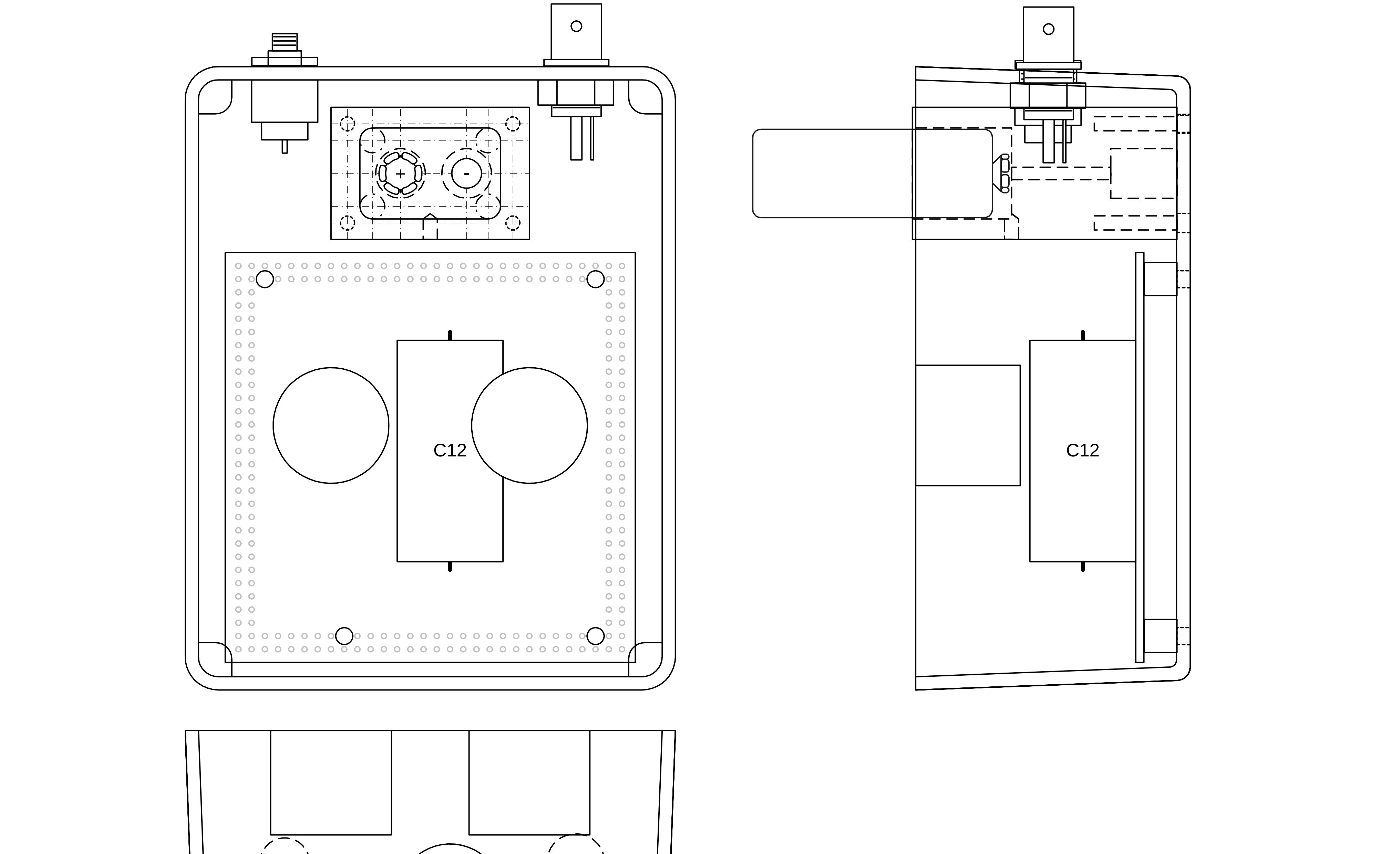
ICs & Diodes

D51	1N4148
U1	TLC2202C
U2	TLE2142C
U3	TLE2142C
U4	TLE2142C
U5	TLE2426

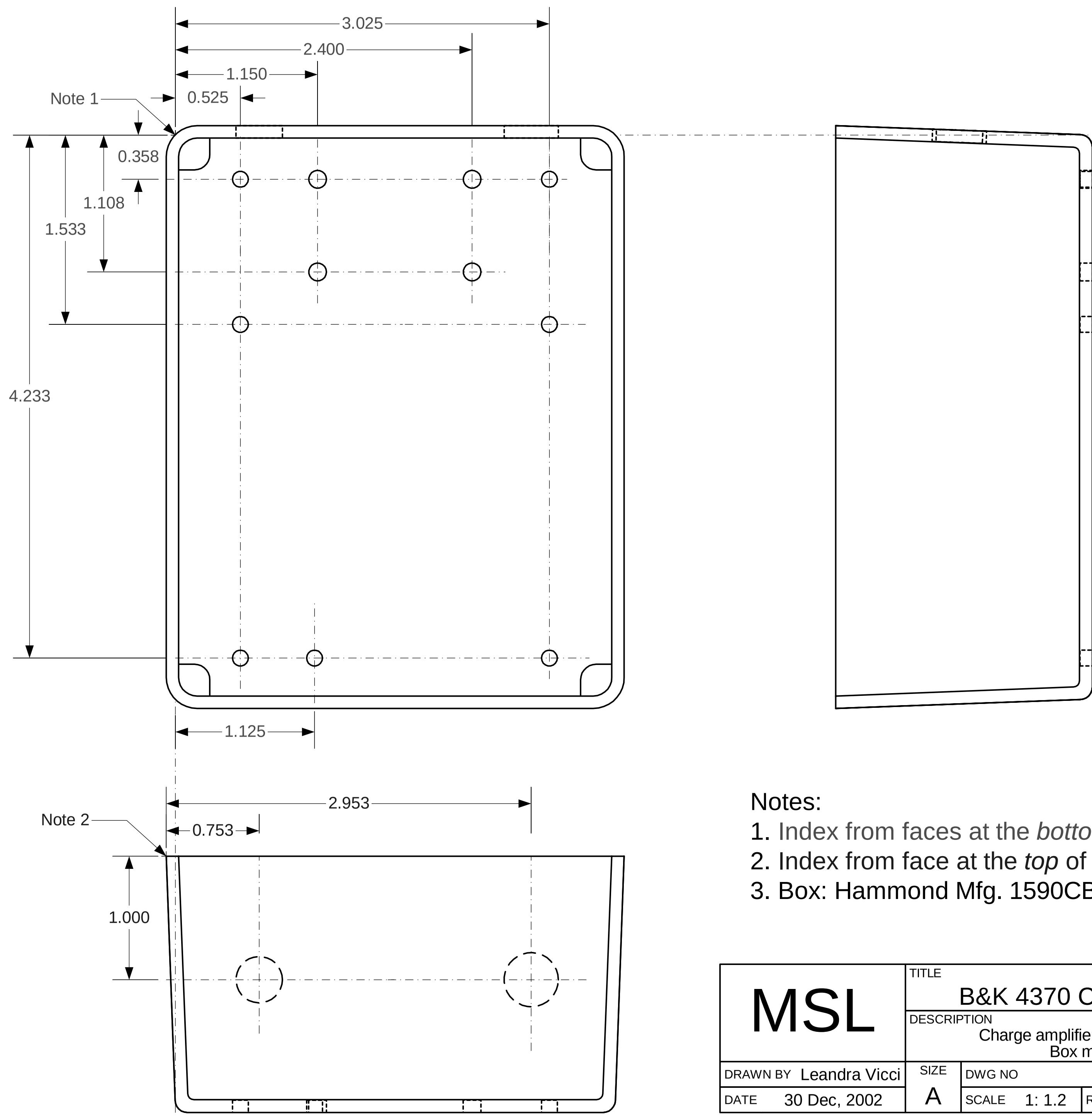
MSL	TITLE: B&K 4370 Charge amplifier
	DESCRIPTION: Charge amplifier, 10[mHz] to 10[KHz] Component list
DRAWN BY: Leandra Vicci	SIZE: A; DWG NO:
DATE: 30 Dec, 2002	SCALE: 1: 1.5; REV: 4.0; SHEET: 3 OF 15



MSL	TITLE B&K 4370 Charge amplifier			
	DESCRIPTION Charge amplifier, 10[mHz] to 10[kHz] Board layout			
DRAWN BY Leandra Vicci	SIZE A	DWG NO		
DATE 30 Dec, 2002		SCALE 1.8: 1	REV 4.0	SHEET 4 OF 15



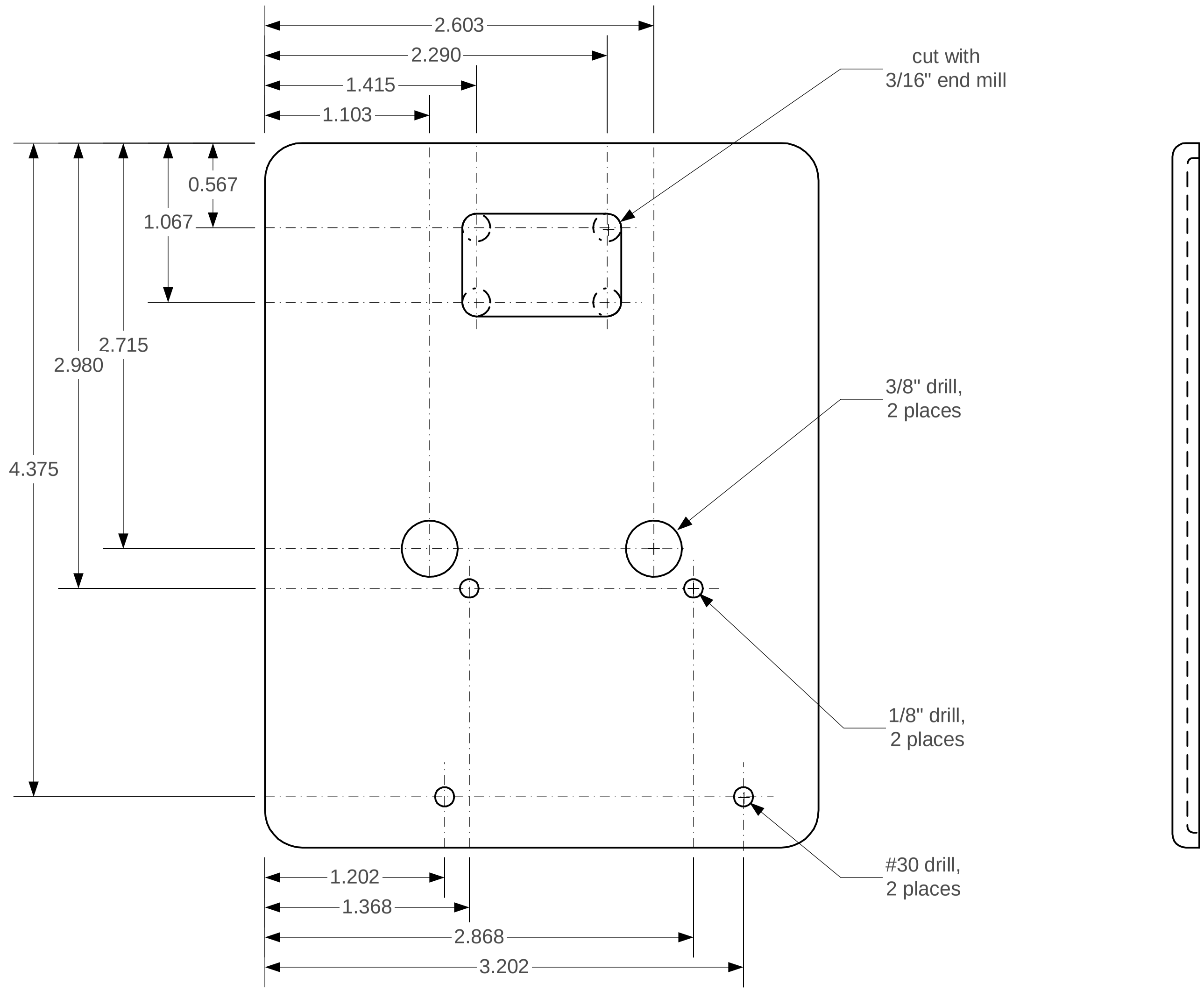
MSL	TITLE: B&K 4370 Charge amplifier					
	DESCRIPTION: Charge amplifier, 10[mHz] to 10[kHz] Mechanical relationships					
DRAWN BY Leandra Vicci	SIZE A	DWG NO				
DATE 30 Dec, 2002		SCALE	1: 1	REV 4.0	SHEET	5 OF 15



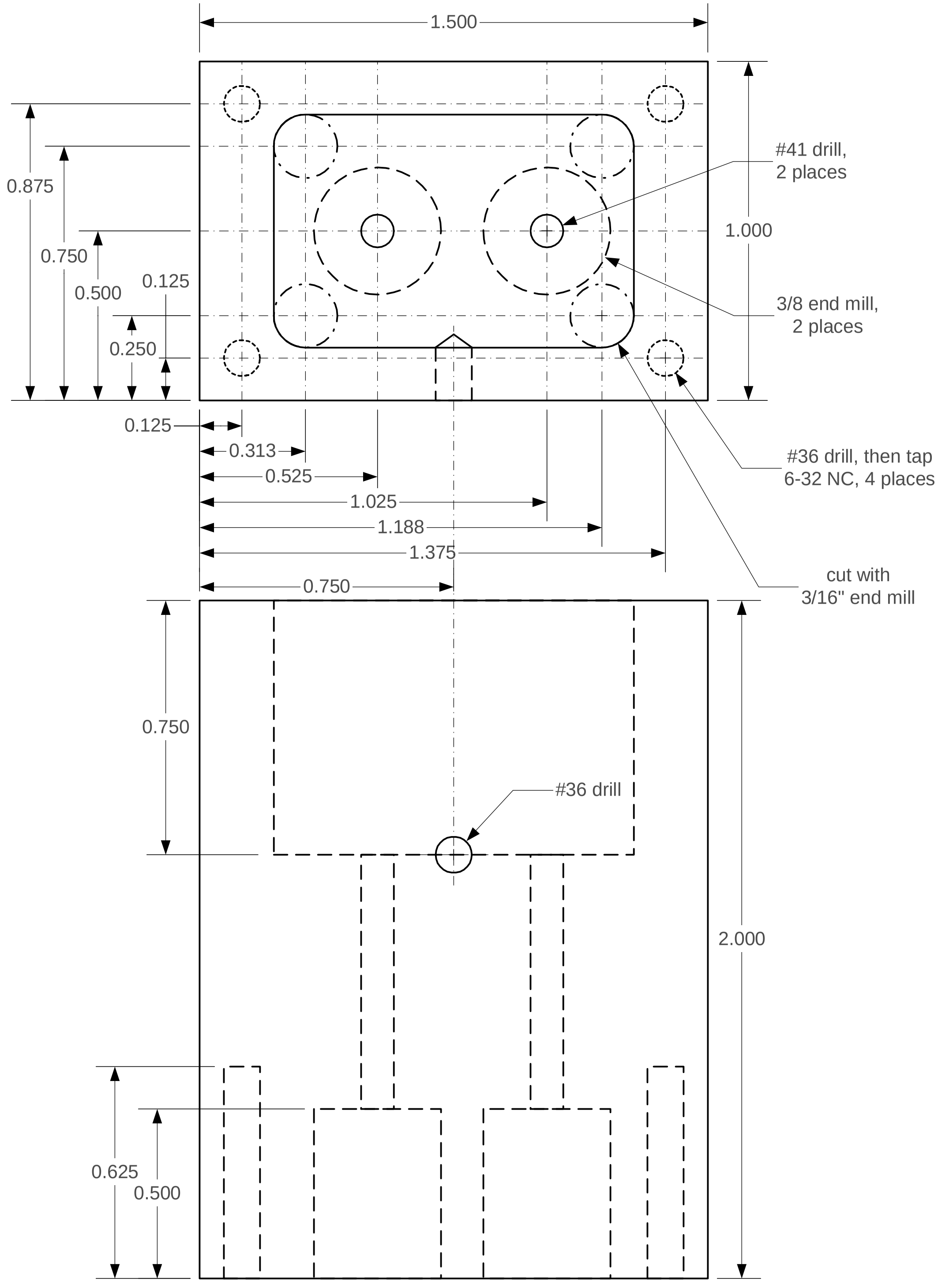
Notes:

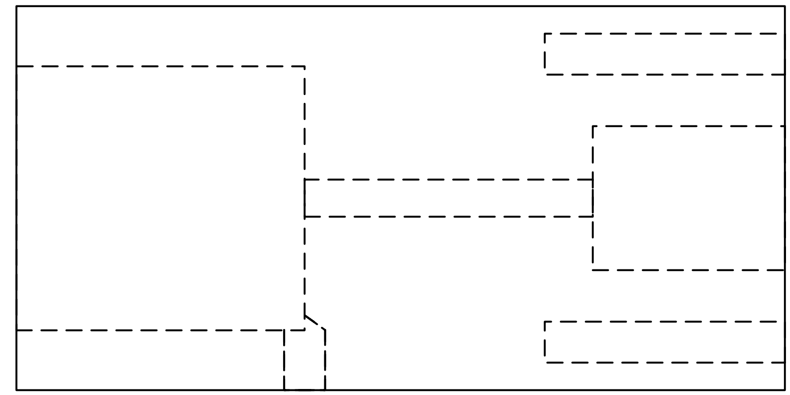
1. Index from faces at the *bottom* of the box.
2. Index from face at the *top* of the box.
3. Box: Hammond Mfg. 1590CBK

MSL	TITLE: B&K 4370 Charge amplifier				
	DESCRIPTION: Charge amplifier, 10[mHz] to 10[kHz] Box mechanicals				
DRAWN BY Leandra Vicci	SIZE A	DWG NO			
DATE 30 Dec, 2002		SCALE 1: 1.2	REV 4.0	SHEET 6 OF 15	



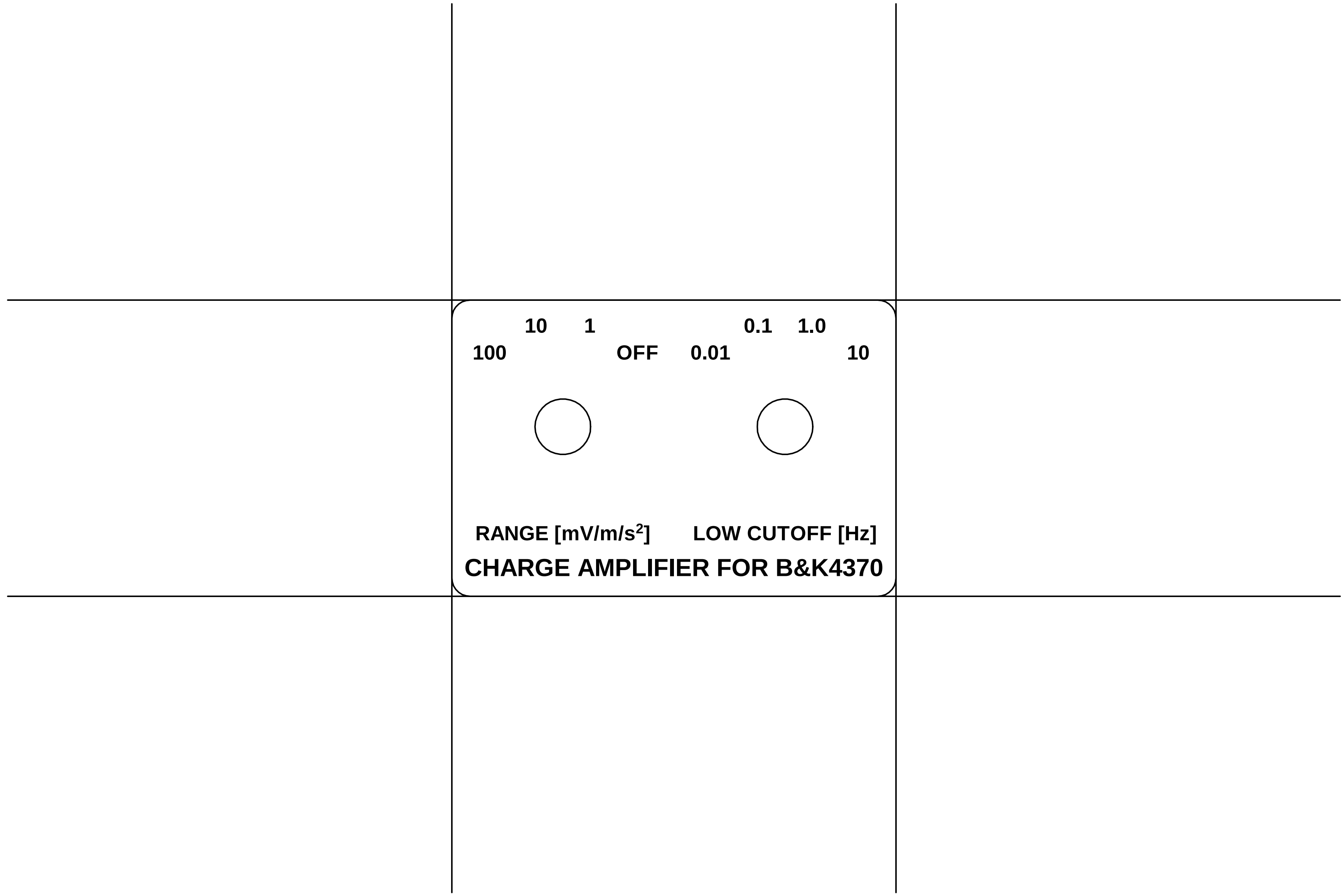
MSL	TITLE B&K 4370 Charge amplifier		
	DESCRIPTION Charge amplifier, 10[mHz] to 10[kHz] Box lid mechanicals		
DRAWN BY Leandra Vicci	SIZE A	DWG NO	
DATE 30 Dec, 2002		SCALE 1: 1.2	REV 4.0 / SHEET 7 OF 15





Material: Rigid, non-brittle, machinable insulator such as nylon or polypropylene.

MSL	TITLE: B&K 4370 Charge amplifier	
	DESCRIPTION: Charge amplifier, 10[mHz] to 10[kHz] Battery holder mechanicals	
DRAWN BY: Leandra Vicci	SIZE: A	DWG NO
DATE: 30 Dec, 2002	SCALE: 2: 1	REV: 4.0	SHEET: 8 OF 15



MSL	TITLE: B&K 4370 Charge amplifier		
	DESCRIPTION: Charge amplifier, 10[mHz] to 10[kHz] Front panel label		
DRAWN BY: Leandra Vicci	SIZE: A	DWG NO	
DATE: 30 Dec, 2002	SCALE: 1: 1	REV: 4.0	SHEET: 9 OF 15

B&K4370 ACCELEROMETER AND CHARGE AMPLIFIER KIT

Microelectronic Systems Laboratory, Department of Computer Science, UNCCH

INSTRUCTION SUMMARY

- Install 9-volt battery.
- Mount accelerometer and connect to charge amplifier.
- Connect BNC connector to a scope or other instrument.
- Upper cutoff frequency is 6.8[kHz].

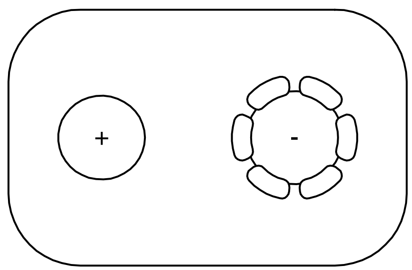
PLEASE DO

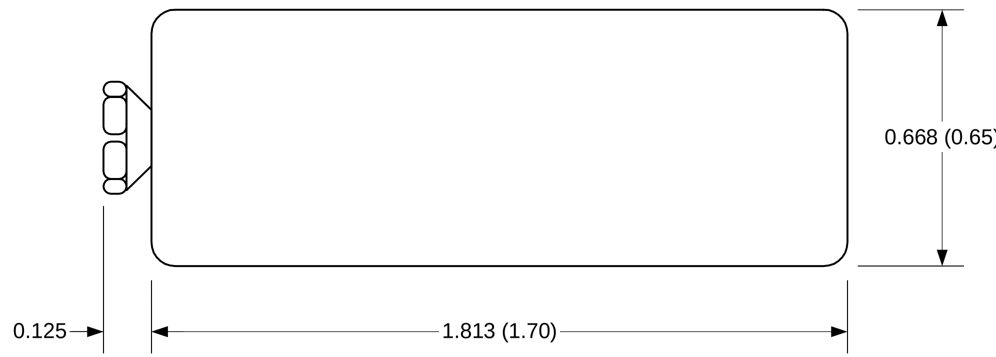
- Store *all* parts of kit together.

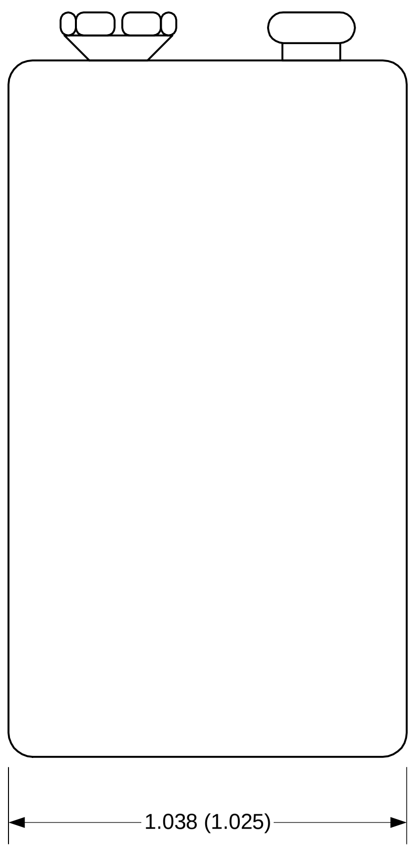
DO NOT

- Store with battery installed.
- Insert fastener more than 2 turns into accelerometer.

MSL	TITLE: B&K 4370 Charge amplifier			
	DESCRIPTION: Charge amplifier, 10[mHz] to 10[kHz] Carrying case and warning labels			
DRAWN BY: Leandra Vicci	SIZE: A	DWG NO		
DATE: 30 Dec, 2002		SCALE: 1: 1	REV: 4.0	SHEET: 10 OF 15

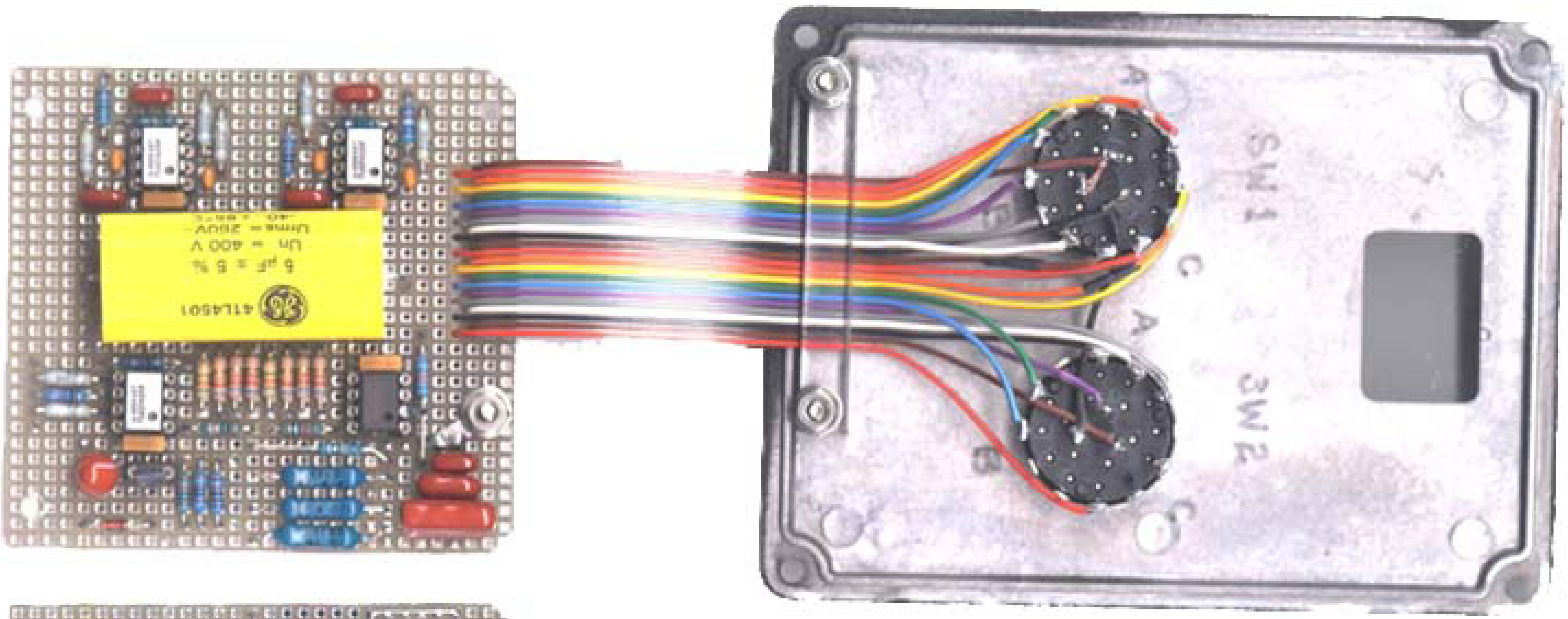


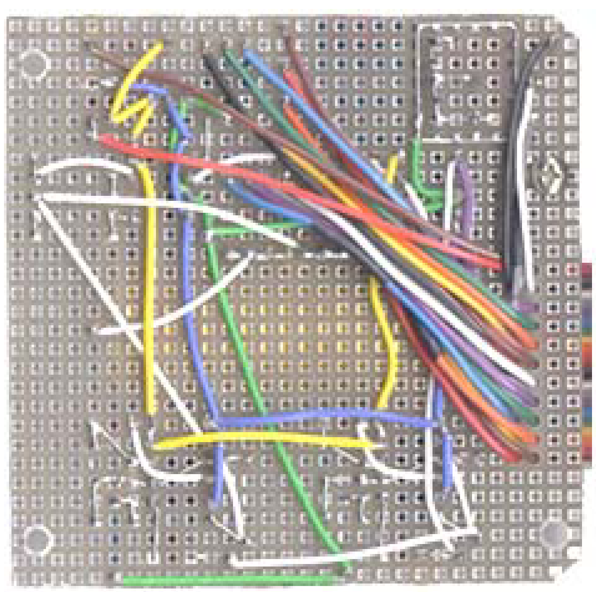




Largest diagonal 1.175
Largest ht 0.668
largest wd 1.038

MSL	TITLE B&K 4370 Charge amplifier		
	DESCRIPTION Charge amplifier, 10[mHz] to 10[kHz] 9-volt battery		
DRAWN BY Leandra Vicci	SIZE A	DWG NO	
DATE 31 Dec, 2002	SCALE 2: 1	REV 4.0	SHEET 11 OF 15

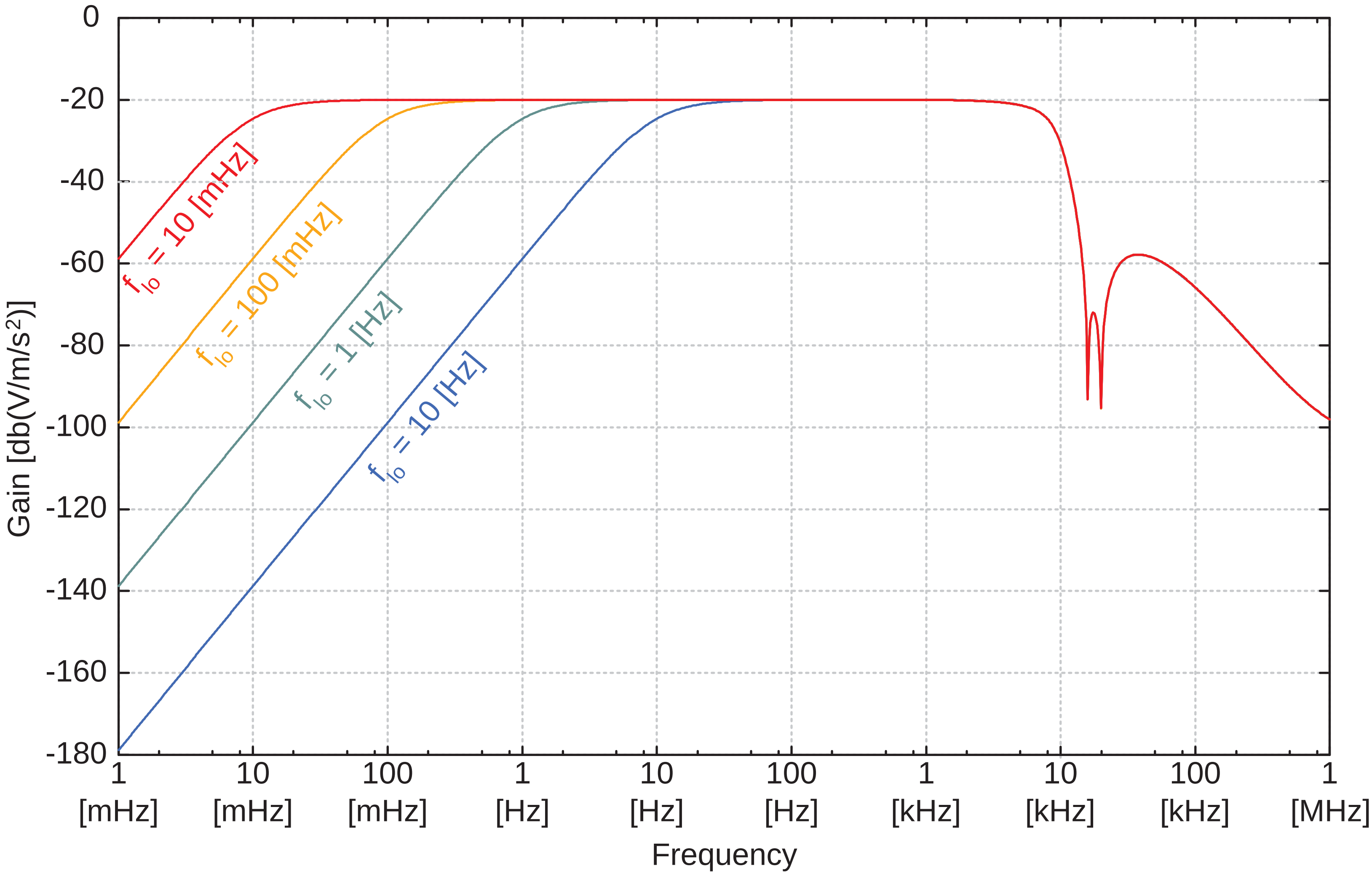




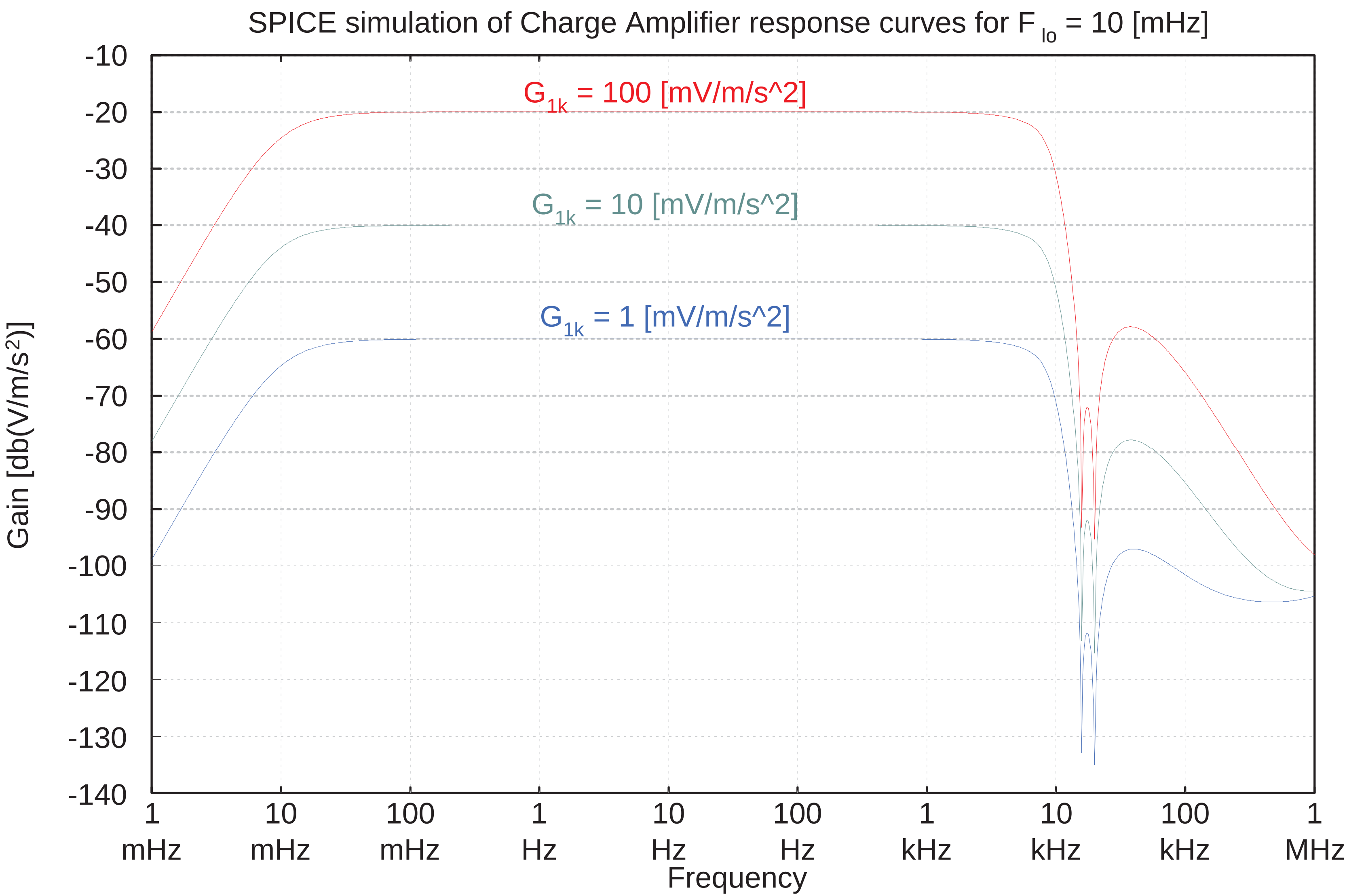
Note: C42 and C44 were added after these photos were taken.

MSL	TITLE B&K 4370 Charge amplifier			
	DESCRIPTION Charge amplifier, 10[mHz] to 10[kHz] Circuit photos, top and bottom			
DRAWN BY Leandra Vicci	SIZE	DWG NO		
DATE 16 Jan, 2003	A	SCALE 1: 1	REV 4.0	SHEET 12 OF 15

SPICE simulation of Charge Amplifier response curves for $G_{1k} = 100$ [mV/m/s^2]



MSL	TITLE: B&K 4370 Charge amplifier		
	DESCRIPTION: Charge amplifier, 10[mHz] to 10[kHz] SPICE simulations of as designed circuit		
DRAWN BY Leandra Vicci	SIZE A	DWG NO	
DATE 17 Jan, 2003	SCALE 1: 1	REV 4.0	SHEET 13 OF 15



MSL	TITLE B&K 4370 Charge amplifier					
	DESCRIPTION Charge amplifier, 10[mHz] to 10[kHz] SPICE simulations of as designed circuit					
DRAWN BY Leandra Vicci	SIZE A	DWG NO				
DATE 17 Jan, 2003		SCALE 1: 1	REV 4.0	SHEET 14 OF 15		

Calibration Chart for Accelerometer Type 4370

Brüel & Kjær
Nærum Denmark

Serial no. ...821000.......

Reference Sensitivity at ....50..... Hz at ....24...... °C

Cable Capacitance of ....110.......................... pF

Charge Sensivity**

..........9,96.... pC/ms^{-2}, or ....97,6..... pC/g*

Voltage Sensitivity**

..........8,32... mV/ms^{-2}, or ....81,5........ mV/g

Capacitance (including cable) ....1198......... pF

Maximum Transverse Sensitivity at 30 Hz ....3,0... %

Weight ....54,0....... grams

Undamped natural frequency ....26........... kHz
For mounted Resonant Frequency and for Frequency Response relative to Reference Sensitivity, see attached individual Frequency Response Curve

Polarity is positive on the center of the connector for an acceleration directed from the mounting surface into the body of the accelerometer.

Resistance minimum 20000 MΩ at room temperature.

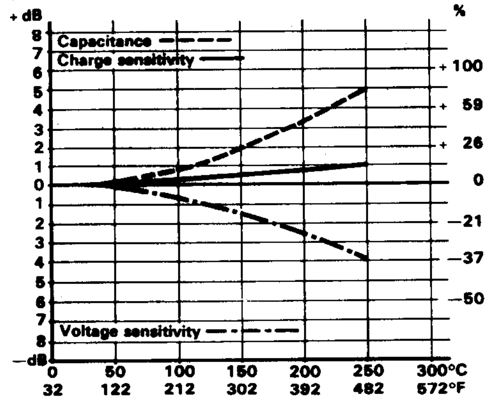
Date .2-10-79... Signature ....[signature]..............

* 1 g = 9,807 ms^{-2}

** This calibration is traceable to the National Bureau of Standards Washington D.C.

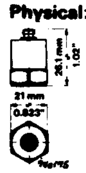
BC 0100

Typical Temperature Sensitivity Error
in dB rel. the Reference Values
Individual deviation max. ± 1 dB



790391

Physical:



Material: Stainless Steel

Mounting Thread: 10—32 UNF-2B

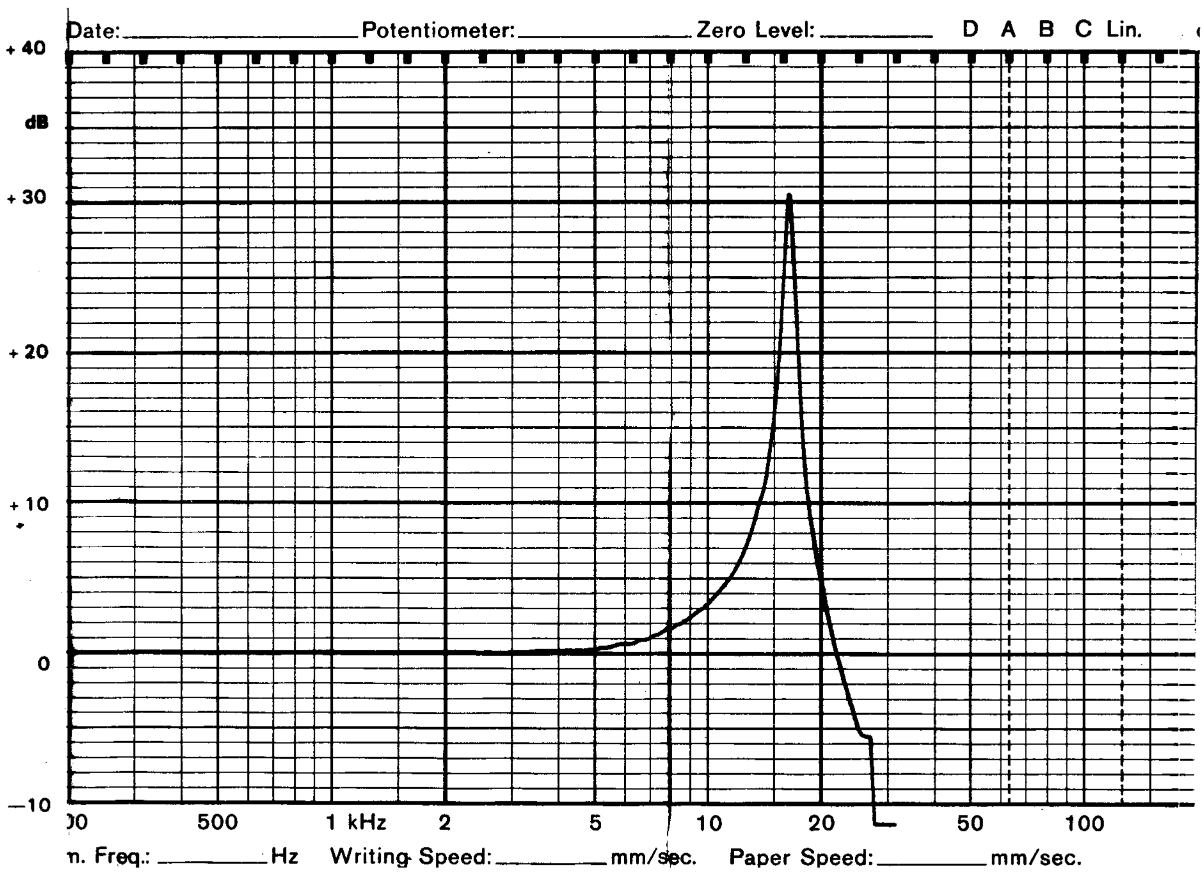
Electrical Connector: Coaxial 10—32 UNF-2A thread

Environmental:
Humidity: Sealed
Max. Temperature: 250°C or 482°F
Max. Continuous Sinusoidal Acc. (peak): 20000 ms^{-2} or 2000 g
Max. Shock Acceleration: 50000 ms^{-2} or 5000 g
Typical Magnetic Sensitivity (50 Hz): 1,2 ms^{-2}/T or 0,012 g/kgauss
Typical Temperature Transient Sensitivity: (Low. Lim. Freq.: 3 Hz) 0,08 ms^{-2}/°C or 0,008 g/°C
Typical Base Strain Sensitivity: 0,003 ms^{-2}/μstrain or 0,0003 g/μstrain

For further information see B & K "Piezoelectric Accelerometer and Preamplifier" Handbook.

TITLE	B&K 4370 Charge amplifier
DESCRIPTION	Manufacturer's calibartion data for B&K4370, S/N 821000
SIZE	A
DWG NO	
SCALE	1:1
REV	4.0
SHEET	15 OF 15
	MSL
DRAWN BY	Leandra Vicci
DATE	17 Jan, 2003

Date:________ Potentiometer:________ Zero Level:________ D A B C Lin.



n. Freq.:________Hz Writing Speed:________mm/sec. Paper Speed:________mm/sec.