Beam Current Transformer (BCT) for MEDAUSTRON

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1.) mechanical and electrical parameters

1.1) BCT housing

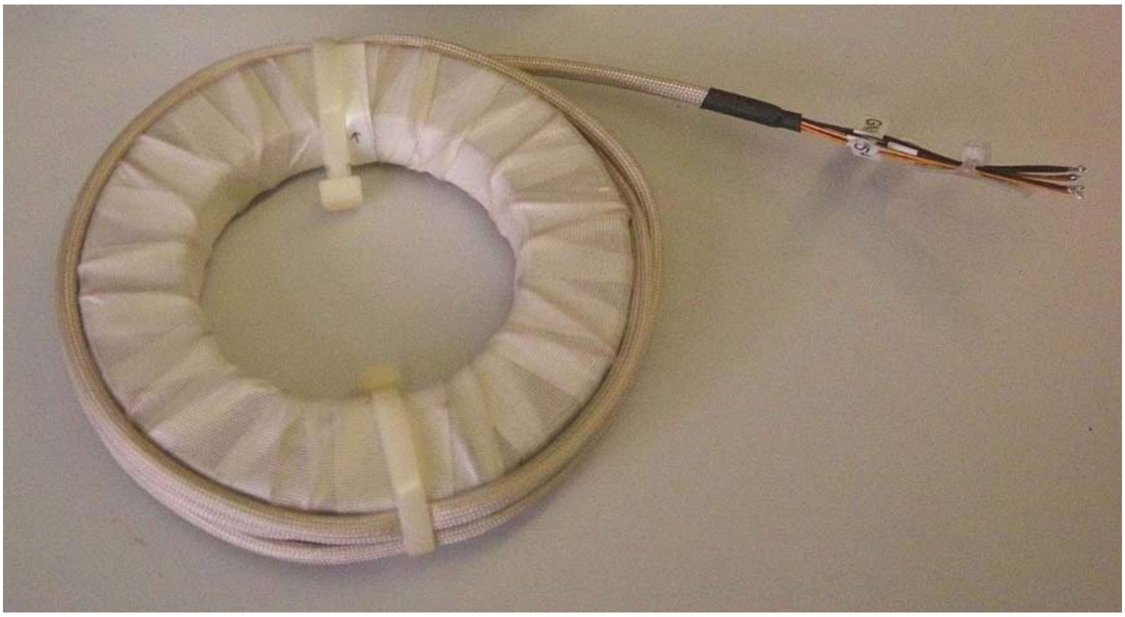
n. a.

1.2) magnetic toroid and windings

Toroid no. 02 designed for operation with head amplifier FG428.231 exclusively

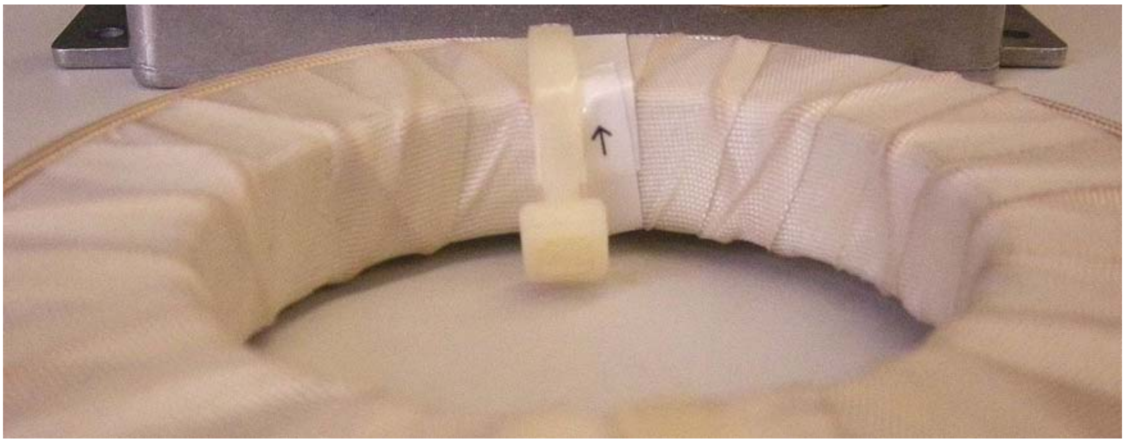
- fabricated from high-permeability amorphous ribbon with eddy current isolation-coating
- near-zero magnetostriction coefficient minimizes microphonic effects
- toroid's core is encapsulated in a rigid metallic former; if mounted on soft PE foam strips mechanical vibrations can be isolated
- signal windings are made of stranded wire, KAPTON®-insulation
- cross-differential winding scheme reduces hum and noise pickup
- number of turns is optimized for best current resolution
- single turn calibration/test winding provided

Fig. 1: Toroid, completed



- windings protected by self-adhesive glass fiber tape
- connection wires routed in glass fiber hosing
- configured for **positivly charged particles**

Fig. 2: The arrow marks positive beam current direction



1.3) front-end electronics (GSI drawing no. FG428.231)

designed for operation with BCT toroid no. 02 exclusively

Tab. 1: BCT frontend amp FG48231 / Toroid no. 02

parameter	value
current ranges, no. of	5; 0.01-0.1-1-10-100 mA full scale
beam current, max.	40 mA (high resolution version)
output voltage on DSub 15p (pins 9 and 10)	±1 V f. s. differential, (0.4V max. in range 100mA
overrange margins	~110 % f. s. positive, ~20% f. s. negative
monitor output / fixed gain (on LEMOSA 2p socket)	± 0.1 V/mA differential, independent of range; 4 V for 40 mA max., positive signal on pin, negative on socket
termination resistor, typical	680Ω for both outputs, external
current resolution (toroid placed in closed magnetic shield)	≤ 0.5 µA rms / 1ms pulse duration in range 10 uA ≤ 0.5% f. s. in other ranges
output voltage risetime	~ 1 µs @ small signal, < 5 µs @ full scale
beam pulse length, max.	5 ms for ≤1% pulse droop error
gain error	depending on accuracy of calibration current source
calibration winding	1 turn via 50 Ω BNC socket, isolated, 1 kΩ series resistor
external power supply	dual 15 ±0.5V DC (pos./neg.) / < 60 mA
logic level for control lines	CMOS 15 Volt (4000 series, high level >0.5*V^+)
designers	H. Reeg, N. Schneider* – GSI BD Dept.

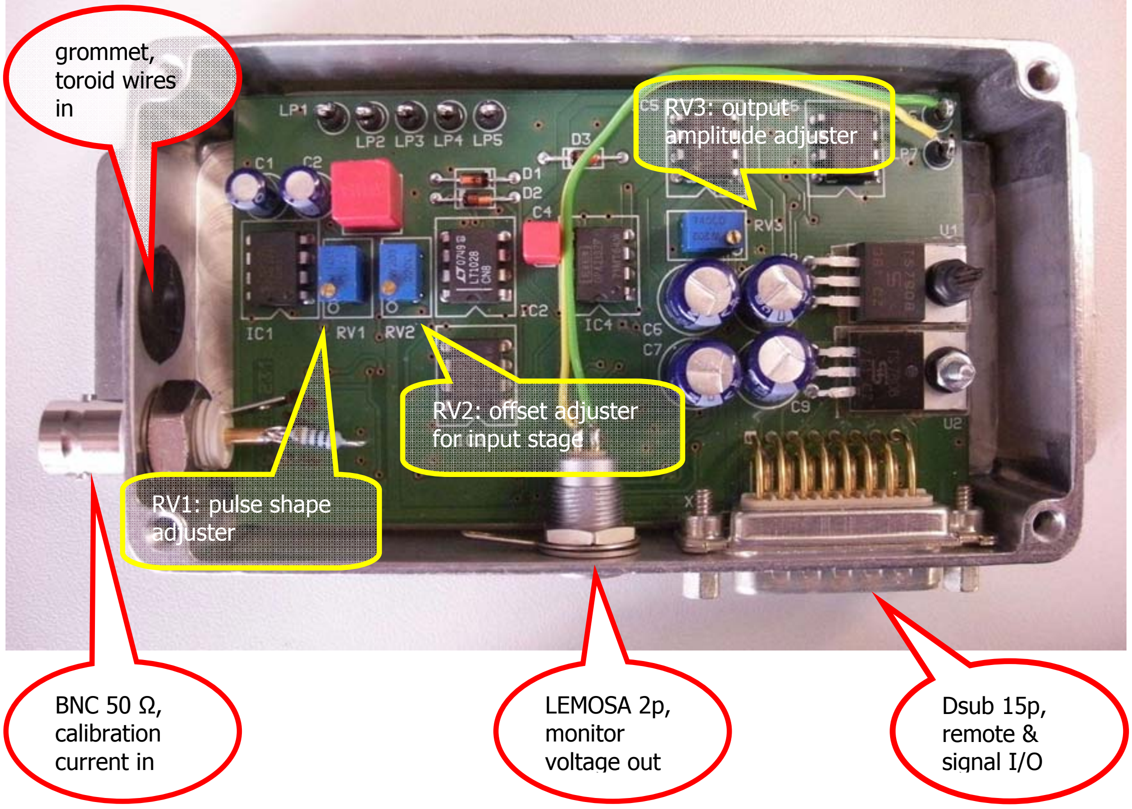
* retired

- configured for **positive particles**, which produce a positive output voltage when they pass the BCT in the direction marked with an arrow
- active L/R-integrator CT circuit with 2nd-order feedback reduces the pulse droop error while preserving working point stability and signal-to-noise ratio
- zero-level clamping technique provides baseline-restoring and noise-gating
- range selection and signal clamping controlled via remote lines on 15p-DSub male connector; all inputs pulled down with 4.7 kΩ, all outputs short-circuit-protected (see Tab. 2)

Tab. 2: Range encoding / Input Level

Range no.	f. s. / mA	Range In 2^2	Range In 2^1	Range In 2^0
1	100	-	-	H
2	10	-	H	-
3	1	-	H	H
4	0.1	H	-	-
5	0.01	H	-	H

Fig. 3: frontend amplifier, PCB view



2) connecting and commissioning

2.1) electrical power and remote control

In the GSI standard configuration the source power, as well as clamping pulse and range selection signals are supplied from the GSI DAQ board FG428.005.010. For special purposes this board can be equipped with an output providing a TTL pulse frequency proportional to the beam current. The full scale frequency is 8 MHz, for all ranges. A buffered 50Ω output is provided.

REMARK: Operation of the BCT without DAQ board FG428.005.010:

- Connect a stabilized, low-noise dual DC supply as specified above to the corresponding pins on the DSub I/O-connector.
- Provide a clamping pulse with appropriate level on the corresponding input pin. Clamping the signal is activated with high level, measuring low.
- Ensure a setup time of ≥30 µs between the clamp-low edge and the beam or calibration pulse rising edge, and a hold time of ≥5 µs between the beam pulse end and the clamp-high edge, respectively.

- ATTENTION: If clamping is not active, the output may show a strong DC offset or even drift to either supply rail !
- The ranges can be selected with a 3-wire BCD coded CMOS signal, active high.
- Connect frontend and receiving station with an appropriate cable; using a twisted pair for the analog signal is highly recommended !
- Install a resistive termination between OUT + and OUT – (pins 9 and 10), ~ 600 Ω in front of your line receiver/ADC circuit

Pin functionality in the 15p Dsub connector is assigned as follows:

Tab. 3: pinout DSub 15p connector

Pin	Function
1	GND external
2	N.C.
3	CLAMP (active high)
4	N.C.
5	N.C.
6	RANGE 2^2
7	RANGE 2^1
8	RANGE 2^0
9	OUT +
10	OUT -
11	N.C.
12	N.C.
13	+ 15V DC in
14	- 15V DC in
15	GND external

ATTENTION: The local or accelerator ground and the external or remote ground potentials are **not** connected inside the frontend box !
It may show up useful to connect them to improve EMC behaviour of the device. A solder lug at the LEMOSA 2p socket is provided for the local connection; the remote ground potential is available on the open M3 thread of positive voltage regulator U2's mounting screw.

2.2) installing toroid, connecting input wires

The toroid can be centered and supported in it's dedicated mounting groove by pieces of self-adhesive PE (polyethylene) foam strips, which can also reduce mechanical vibrations.
While installing the toroid the connection wires carefully must be routed through the assigned bore. The premounted glass fabric tubing can be omitted if not necessary.

ATTENTION: Accurate deburring the feedthrough bore's edge ensures protection of the toroid wires' KAPTON® insulation, if the glass fabric hose has been omitted !
The wires may be cut down to any length, to finally fit the distance to the already mounted amplifier box. This requires a droop error re-adjustment (with RV1), due to the reduced wire resistance (see 2.4).

ATTENTION: Don't loose or strip off the small white labels marking the wires ! It is not an easy task to re-identify the polarization of each winding of the toroid, especially if it is already mounted in the beam line!

Proceed as follows:

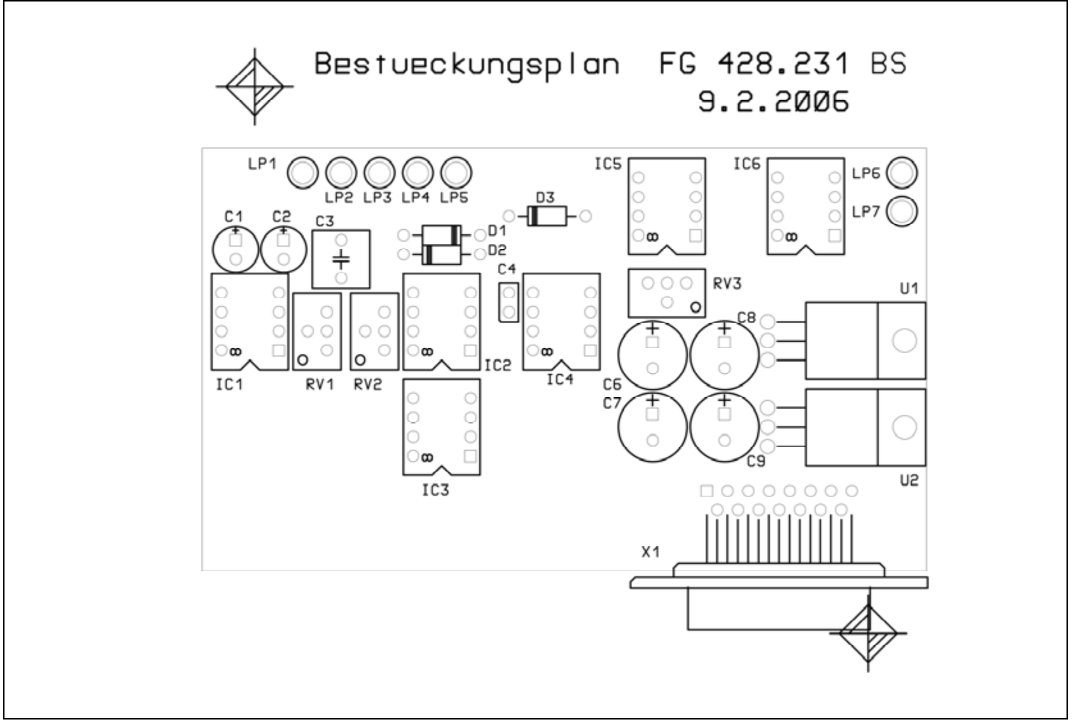
- Guide the wires between the outlet orifice of the BCT's housing or flange and the frontend box inside a metallic braid hose or solid tube, for best shielding efficiency. The braid or tube should be grounded locally
- Route the wires through the rubber grommet into the amp box, and carefully solder all pre-soldered ends to their related pins or lugs according to Fig. 3 and 4/Tab. 3
- Tighten a cable tie around the wire bundle just after the grommet as a pull-out relief

ATTENTION: Do not subsitute the soldering of the wires with a quick-connector pair ! The working principle of the BCT amp relies on a very low resistance in the input circuitry, which possibly will be corrupted by the additional contact resistance.

Tab. 4: Assignment of toroid wires to PCB soldering pins and wire colours

Pin description	**Wire marking**	**Colour**
LP1	LP1 (compensation wdg. -)	brown
LP2	LP2 (compensation wdg. +)	brown
LP3	LP3 (signal wdg. center tap; 2 wires soldered together, marked with a short shrinking sleeve)	orange
LP4	LP4 (signal wdg. +)	orange
LP5	LP5 (signal wdg. -)	orange
Eyelet of 1 kΩ resistor on BNC socket	CAL (calibration wdg. +)	brown
Strip lug of BNC socket	GND (calibration wdg. -)	brown

Fig. 4: FG428.231 PCB top view; location of components and solder pins



2.3) internal offset check

The frontend amp's input stage is working at a very high DC gain, and a shifted baseline as well, which demands a precise offset adjustment of the input opamp IC2. The frontend amp has been adjusted before delivery, but re-adjusting may be necessary after shortening the toroid wires or a long operation period, in order to preserve the best signal dynamics and suppression of microphonic effects.
To minimize the offset value, measure the DC voltage between solder pin LP3 and pin 6 of opamp IC2, then turn trimpot RV2 until the DVM reading is within ±20 mV.

ATTENTION: Use appropriate test tips or clips to avoid short-circuiting any pins on the opamp or the PCB's soldering pins!

2.4) pulse shape adjustment

This BCT is an AC-coupled device, which implies a lower cut-off frequency resulting in a "droop" of the pulse flattop, when the input pulse's shape is compared to the output signal.
The error can be minimized with trimpot RV1. This may be necessary if the toroid wires had been cut down during the assembling procedure, or after a long operation period. To re-adjust the pulse shape, apply a test pulse of 80-100% full scale and at least 1 ms duration; range setting1 or 10 mA should be preferred. Then, turn RV1 until a flat pulse is achieved.

REMARK: The usage of an oscilloscope with a true offset adjuster instead of a simple trace shifter is highly recommended, as only this feature gives the best vertical resolution to recognize any pulse droop. See Fig. 5, 6 and 7, where a Tektronix TDS 3034B was used.

Fig. 5: 1mA cal. pulse; undercompensated droop, ~1% negativ error

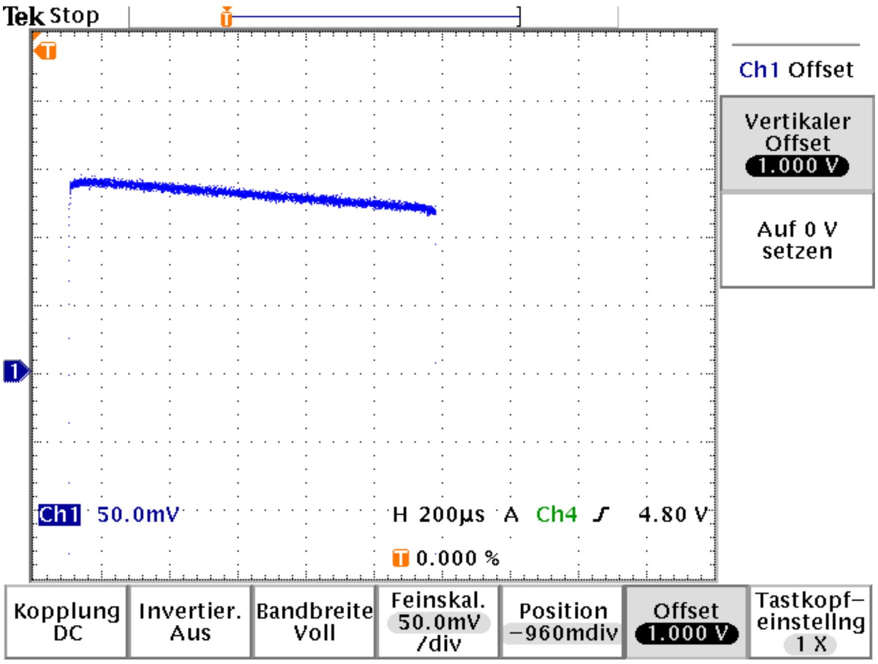


Fig. 6: 1 mA cal. pulse; overcompensated droop, ~1% positive error

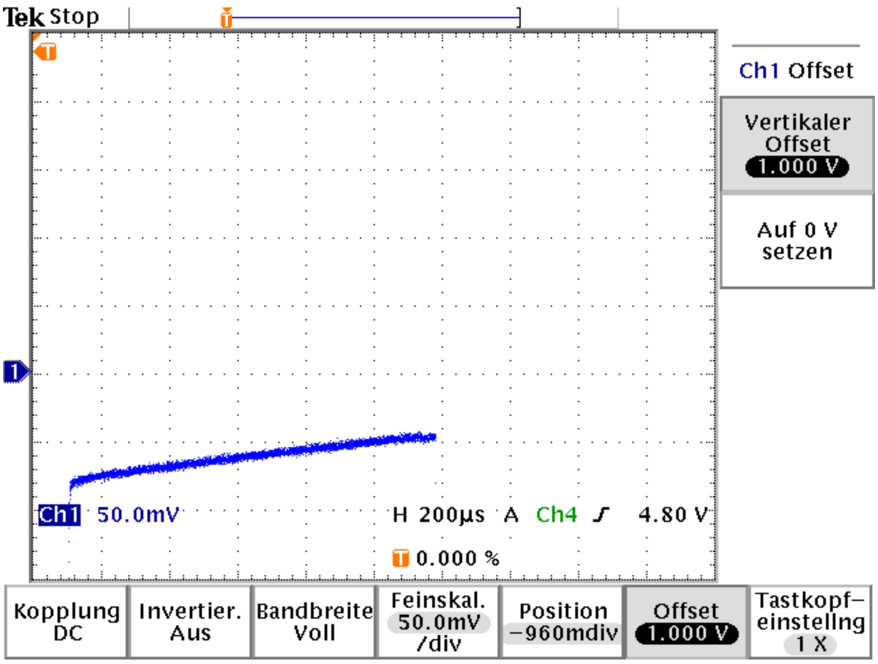
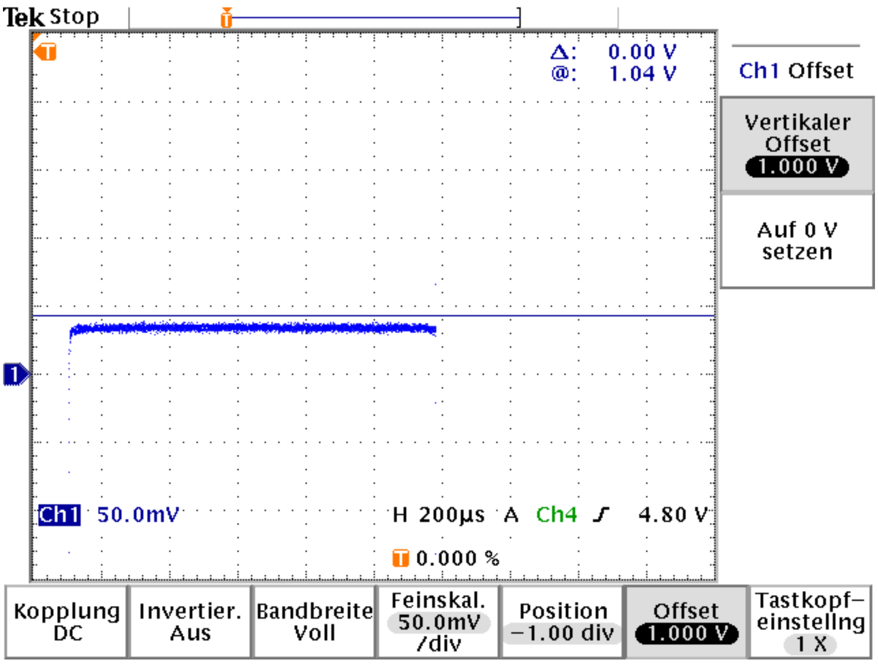


Fig. 7: 1 mA cal. pulse; droop adjustment optimized, error negligible compared to hor. cursor line



2.5) output amplitude calibration

The BCT frontend amp has been already precalibrated for 1 ms pulse duration, 680 Ω output termination and neglected transmission cable resistance. It can be end-calibrated with trimpot RV3 on the PCB, and/or by adjusting the user termination resistor at the far end of the transmission cable. With respect to the internal source resistors (36 Ω ea.) and an additional cable resistance, one can expect a value of 500-700 Ω .
To calibrate the BCT, feed a positive current pulse of precise amplitude and length into the BNC cal input socket and adjust the termination resistor at the end of the signal transmission, and/or the gain trimpot RV3 respectively, until the appropriate output level is achieved. The baseline value of the cal. pulse is not critical due to the cal. winding’s AC coupled nature.

ATTENTION: Always apply the clamp pulse with the appropriate timing (see 2.1). It must be provided also during the calibration process !

REMARK: A limiting resistor of 1 kOhm is connected in series with the calibration winding inside the front end box.

Typical output signal performance is shown in the following figures:

Fig. 8: cal. pulse 1mA / range 1 mA; release of signal clamp is indicated by small spike at 100 µs

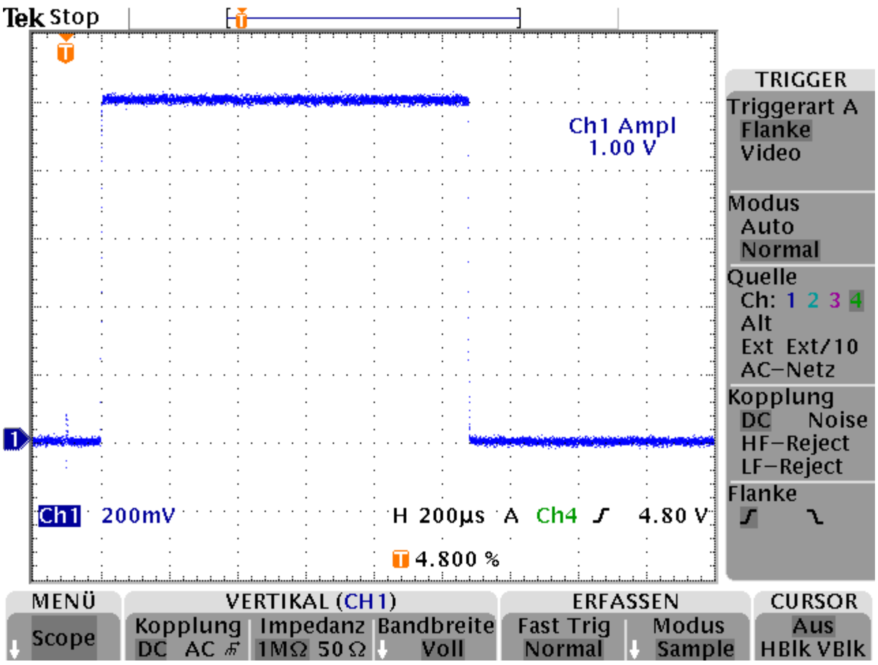


Fig. 9: rise time @ 1 mA full scale step; trace averaged 16x

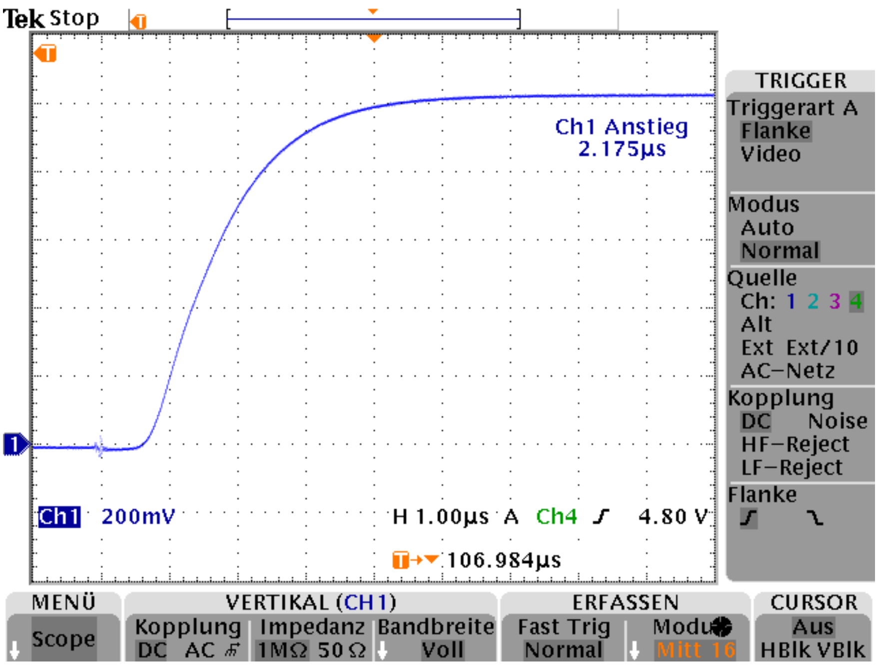
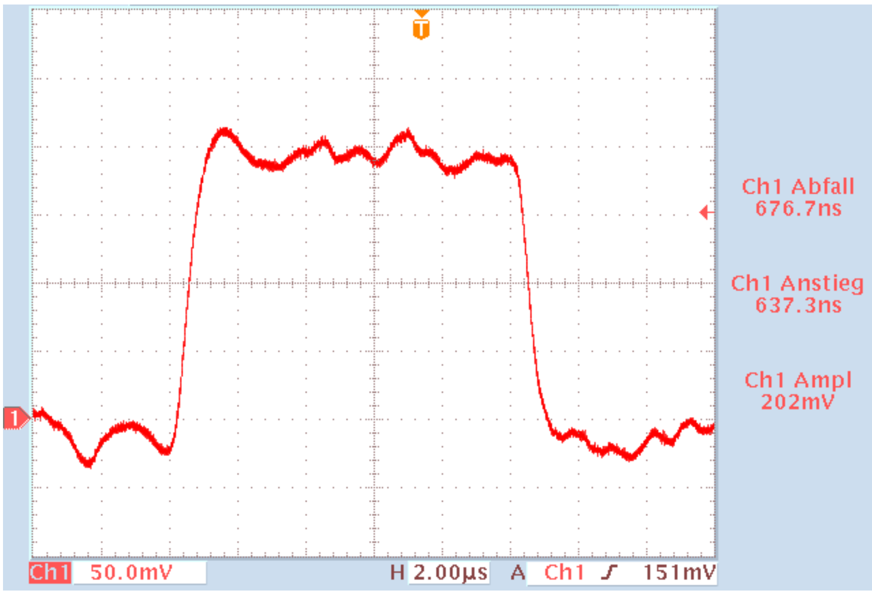


Fig. 10: rise time/typ. noise @ 2 µA cal. pulse; duration 10 µs, range 10 µA



REMARK: data were taken in EM-clean lab environment, from a BCT set similar in construction !

3) operational hints

3.1) microphonic noise

If a remanent flux is present in the BCT's toroid, a noise current can be induced in the signal winding due to mechanic vibrations, especially in case of a core material with a non-zero magnetostriction coefficent. These mostly unavoidable vibrations are usually generated by vacuum or water pumps being driven by line powered motors in the vicinity of the BCT.
The BCT was set into a demagnetized state, but can accumulate flux during power-up of the frontend amp, by wrong input offset adjustment, or by strong external magnetic fields, i. e. from beam line magnets or eddy currents in the beam tube material.
If low frequency noise signals are visible in the output, appearing to be **not** in constant phase with the power line frequency, a demagnetization procedure may reduce this effect; a special instruction is available on request.

3.2) secondary electrons

Secondary electrons are easily produced by grazing the beam tube, the BCT's aperture, or other obstacles with the ion beam halo. If these electrons pass the aperture together with the beam, they will reduce the output reading, so be aware of this effect.

For the same reason, be careful using profile harps, slits or aperures close to the BCT, too – electrons drifting in reverse direction will add up to the beam !

3.3) magnetic core aging and pulse shape

Usually, the pulse shape error is not significant due to the choice of core material and the pre-adjusted electronic droop compensating circuit in the frontend amp. However, if exposed to ionizing radiation, the core's permeability may slightly decrease on a long term scale. If this is once observed, the error can be corrected by trimming with RV1, as explained in 2.4.