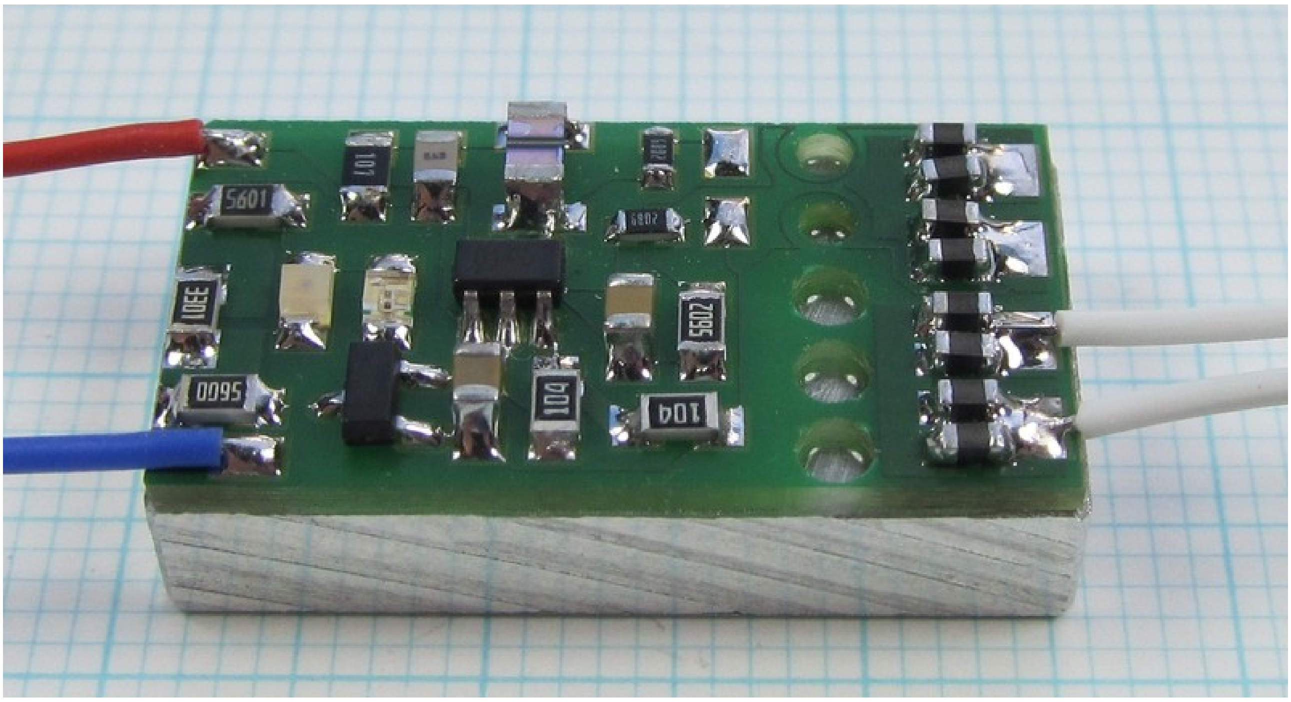
White Paper

temp_regulator_2013_ntc

small temperature controller



Content

Introduction

Temperature drifts are often the main source of error in electronic circuits. A simple solution is to keep one device or a complete circuit at constant temperature.

If you take a controller with a peltier-element, you can cool or heat. Cooling is dangerous because water in the air can condensate.

If you take a heating element only, water condensation is no problem. The constant temperature has to be chosen to be clearly above the maximal room temperature plus temperature rise due to the waste power of your circuit.

We have lots of equipment used under laboratory conditions at room temperature in the range of 21 to 26 °C. The suggested heat controller is perfect for a single device like an integrated amplifier or a little electronic-case.

Other useful applications:

- Optical setups
- Lasers
- Voltage reference
- Detectors
- Oscillators
- Precision electronics

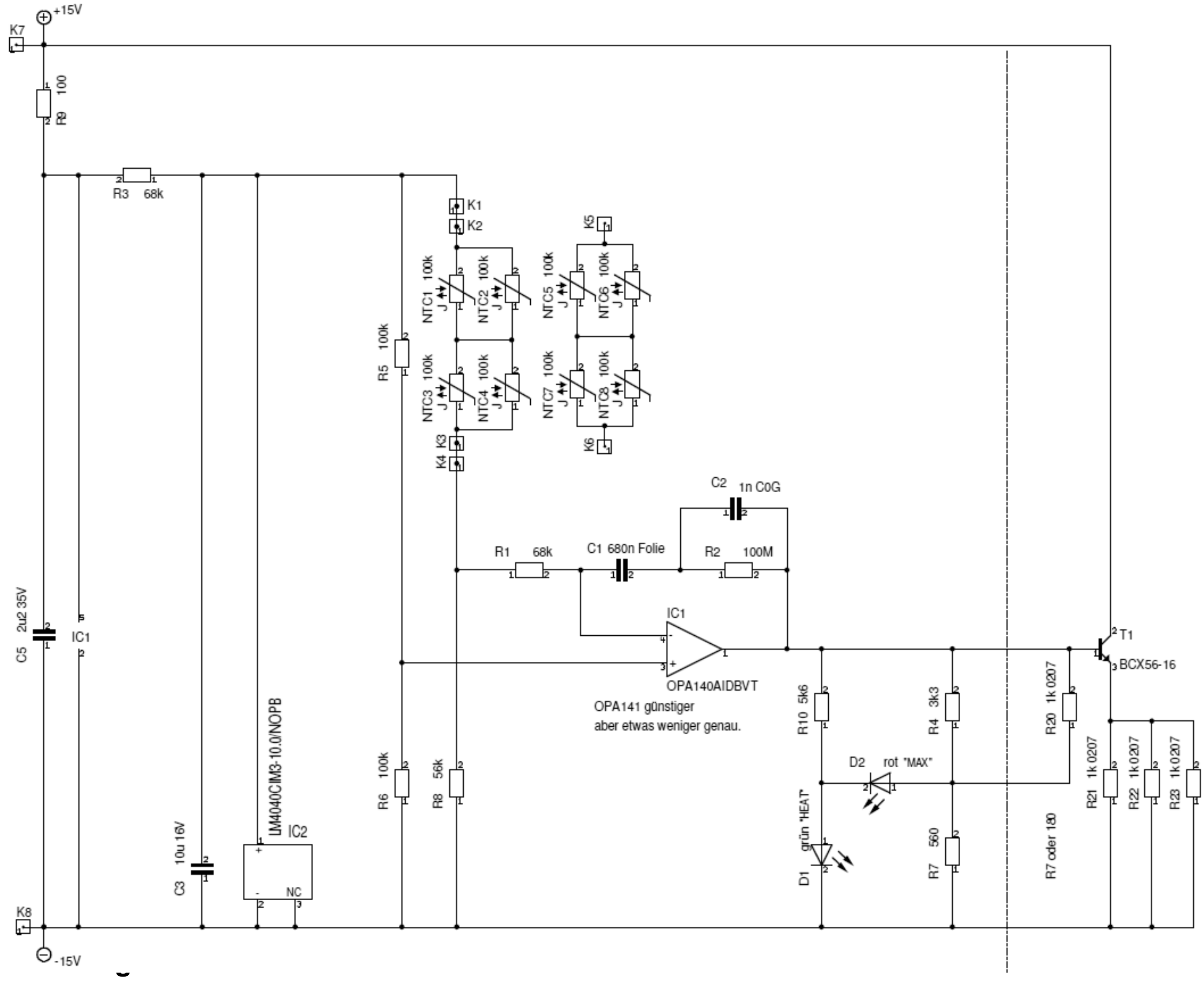
Advantages of the temperature controller:

- No digital parts. This is important for noise sensitive setups.
- Very sensitive and stable control of the temperature.
- Small.
- Easy to attach, just glue to a flat part.

You can simply glue one or more controllers to the inside of an existing case to improve performance. This is thermally not optimal but better than nothing.

It's possible to heat a big device with multiple temperature-controllers.

Schematic



Description:

NTC1 to NTC4 are used to measure the temperature. The NTC resistance is strongly temperature dependent. 4 NTC in case 0603 are recommended. The accuracy of 4 NTC resistors is better than the accuracy of one only. Furthermore, the temperature-coupling to the circuit board is better.

NTC Epcos B57374V2104F60
Very accurate: 1% at 25°C. About 0.5 % if you take 4 pieces. ± 0.5 % → ± 0.1 °C

Datasheet: B25/85 = 4455 K
RN = 100k Ohm
T = 273.15 K

Calculate resistance for a given temperature temp (°C):

R = RN * EXP(B25/85*(1/(temp+T)-1/(25+T)))

Example: temp = 37°C → R = 56kΩ

Calculate temperature for a given resistance:

temp = B25/85 * (25+T) / (B25/85 + LN(R/RN) * (25+T)) -T

Example: temp R = 56kΩ → temp = 37 °C

NTC5 to NTC8 can be used to monitor the temperature with a multimeter. Keep in mind the temperature rise due to the power dissipation of the measuring current. About 200 K/ Watt.

The set-point temperature can be set with R8.
The bridge built with R5, R6, R8 and the NTC Resistor gives a temperature dependent current to R1. At set-point temperature this current is zero.

The voltage across the bridge is held constant to 10V with the shunt regulator IC2. This helps to reduce the influence of the supply voltage.

The amplifier is used to build an PI-controller.
Input impedance: R8/2 + R1
Feedback impedance for proportional part: R2
Feedback impedance for integral part: C1

C2 is used to reduce the sensitivity to RF noise and has negligible influence to the control behavior.

I made prototypes with an aluminium weight of 3 to 500 gramms. They all worked well by just adjusting power and R1. The time constant R2 C1 was ok for all these prototypes. If you need perfect controll-parameters, I recommend to measure the step answer of the thermal system and to calculate the optimal parameters for your setup and adapt the schematic accordingly.

Waste power is nearly proportional to the voltage at IC1 Pin 1. Most power is dissipated in IC1, T1, R4, R20 to R21. To check the control-behavior, you can measure the voltage at IC1 Pin 1.

D1, green, starts glowing at voltage higher than 3V. D2, red, starts glowing at voltage higher than approx 25V.

At steady state, green should glow constantly, red shouldn't.

The larger your setup, the higher the maximum power you need to heat it. If you have too much maximum power, your setup can overheat if the regulator fails.

Suggested test:

Short R8 to set to full power.

Apply supply-voltage. Wait 1h (large parts longer). Measure the temperature. The temperature should be about 60 °C. Adjust R21....

Temperature should be less than destructive, for example less than 110°C.

Maximum Power:

R7	R4	R20	R21	R22	R23		max power	max current
Ohm	Ohm	Ohm	Ohm	Ohm	Ohm		Watt	A
560	3k3	-		-	-	-	0.23	0.008
180	-	1k	-	-	-	-	0.76	0.026
180	-	1k	1k	-	-	-	1.6	0.056
180	-	1k	1k	1k	-	-	2.6	0.085
180	-	1k	1k	1k	1k	-	3.5	0.12

To further increase power, you can add three 1k resistors on an additional board without destroying T1. You can use multiple temperature controllers on large circuits.

Control loop

A possible description of the control loop:

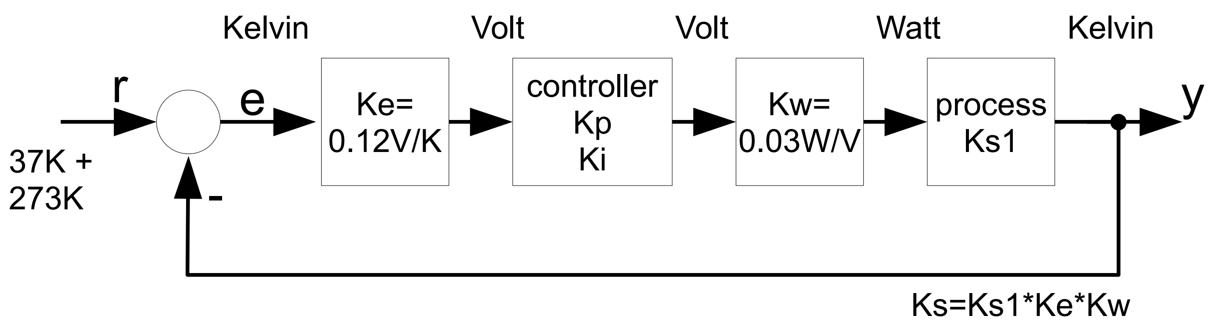


Figure 2 control loop

Kp = R2/R
Ki = 1/(R*C1)
R=R1+R8 / 2

Ki=Kp/Tn

Ke = 0.12 V/K for the suggested NTC and set point 37°C

KW = max power / 30 V

See also:

http://en.wikipedia.org/wiki/Control_loop

http://en.wikipedia.org/wiki/PID_controller

http://de.wikipedia.org/wiki/Einstellregeln_nach_Chien,_Hrones_und_Reswick

Components

NTC1 ... NTC8 0603 100k Mouser 871-B57374V2104F60

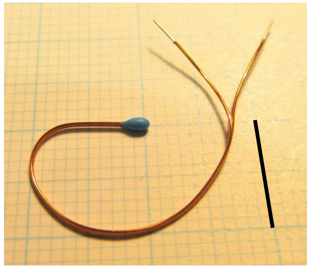
(placement of NTC5 to NTC8 only if needed)

Option to glue into holes: 81-NXFT15WF104FA2B50

Accuracy 1%

1.2 mm diameter of NTC
deep drill hole 1.4 mm for example, thermal grease

clamp wires



10 mm

IC1 OPA140AIDBVT Mouser 595-OPA140AIDBVT

IC2 LM4040CIM3100NPD Mouser 926-LM4040CIM3100NP

T1 SOT89 NPN Transistor Mouser 522-BCX5616TA

placement only if R21 to R23 are used.

R1 0805 68k not critical

R3 0603 68k not critical

R10 0805 5k6 not critical

R2 0808 100M Mouser 71-CRCW0805-100M-E3

R5, R6 0805 100k Thinfilm Mouser 667-ERA-6AED104V

R20...R23 0207 Melf 1k

placement depending on heat power Mouser 71-SMM02070C1001FBP0

R4 0805 3k3 not critical, placement depending on heat power

R7 0805 560 or 180 not critical placement depending on heat power

R8 0805 56k (depending on temperature) Thinfilm (optimal)

Mouser 667-ERA-6AED563V

R9 0805 100 Ohm not critical

C1 1206 680n foil Mouser 598-FCA1206C684M-H3

C2 0805 1n C0G not critical but must be C0G

Mouser 77-VJ0805A102KXAPBC

C3 0805 10u 16V not critical Mouser 81-GRM21BR61C106KE15

C5 0805 2u2 35V not critical Mouser 810-CGA4J1X7R1V225MS

D1 0808 LED green not critical Mouser 645-598-8160-107F

D2 0808 LED red not critical

Mouser 720-LSR976-NR-1

Circuit board

It is important not to have leakage currents on the surface of the circuit board. Clean the board with isopropanol for 30 minutes in ultrasound. Use brush to remove any flux. Remove isopropanol with compressed air. Dry circuit board at 110°C for 1 hour.

If you do not like cleaning: use pure rosin flux only.

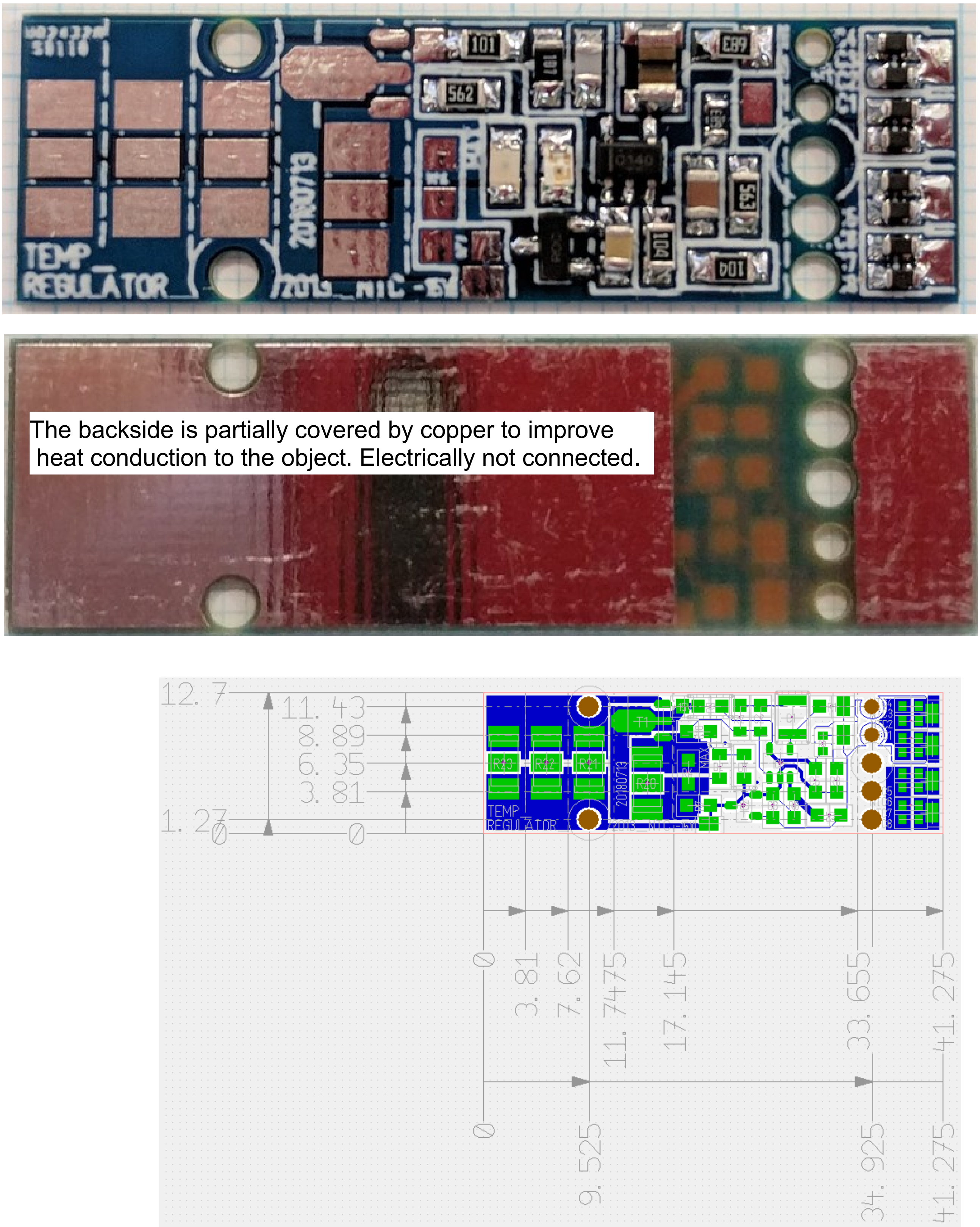


Figure 3 Circuit board

The circuit board is 0.6 mm thick. You can cut the board at several positions to make it smaller. To glue it to an aluminium-part, grind the back-side and grind the aluminium-part. Use two component epoxid-glue.
You can cut away the NTC-part as well. Mount it directly next to your sensitive part. There are pads to connect with thin cables.

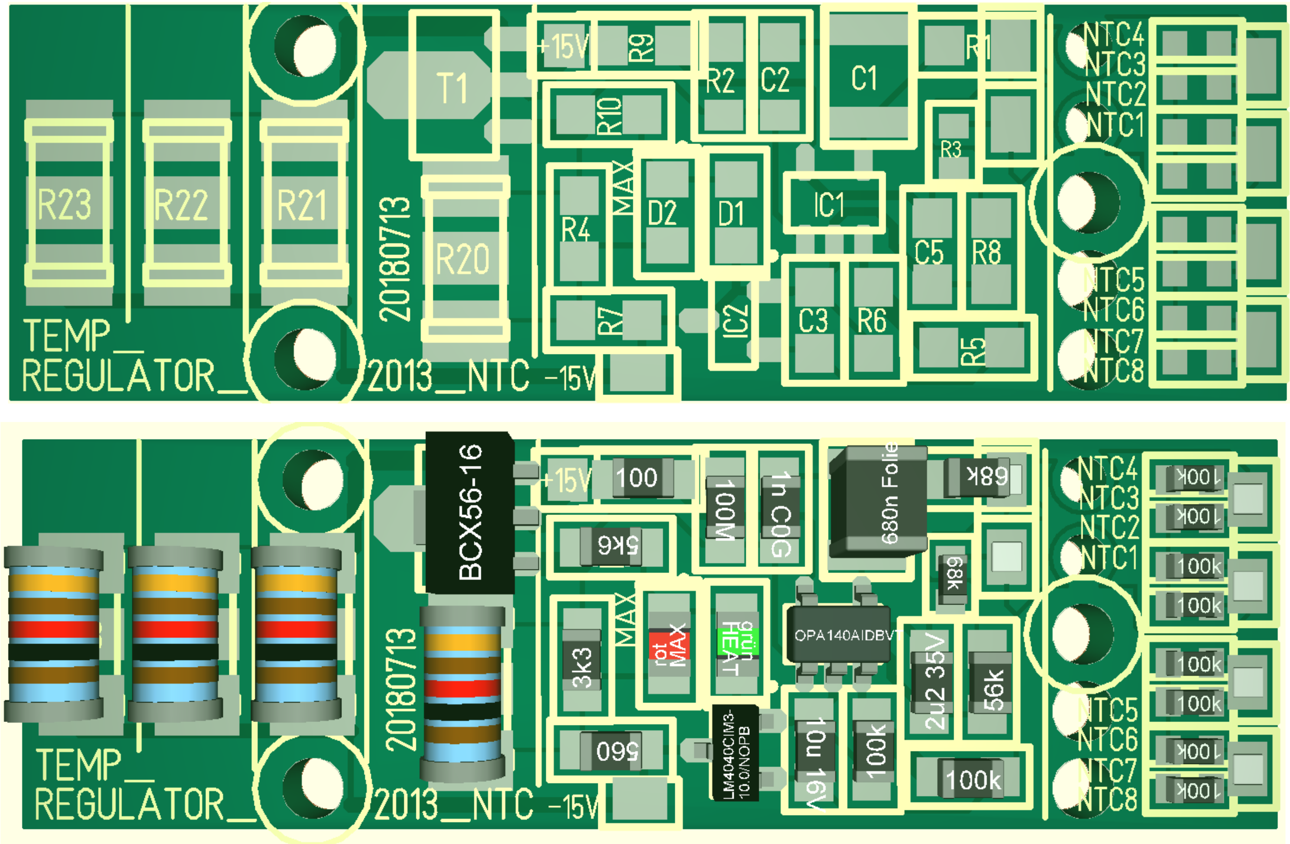


Figure 4 Circuit board

example 4 NTC

example 1 NTC

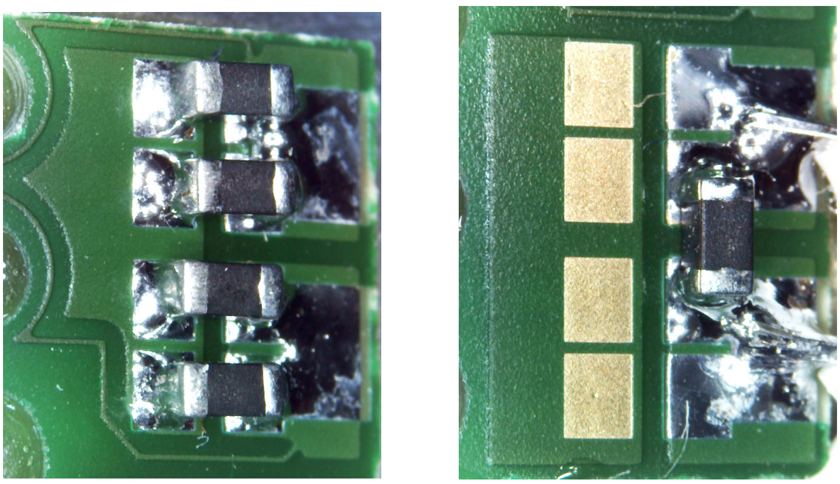


Figure 5 NTC

Thermal design

The thermal design of your setup is very important. Good thermal coupling of the cables to the NTC resistors is important. Use large aluminium-parts.

Think about heat flow in all parts. Make trials.

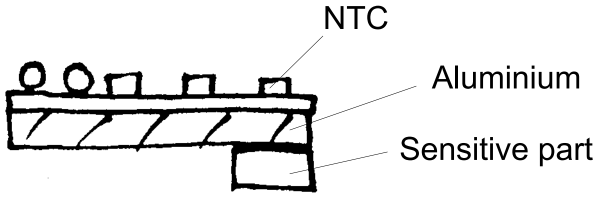


Figure 6 Example: Simple, not very stable

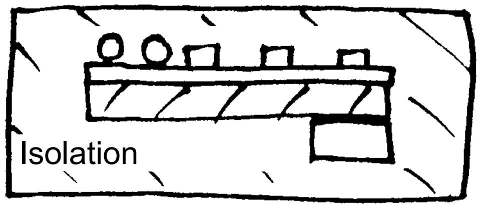


Figure 7 Example: Simple, with isolation, only possible if there is little waste heat

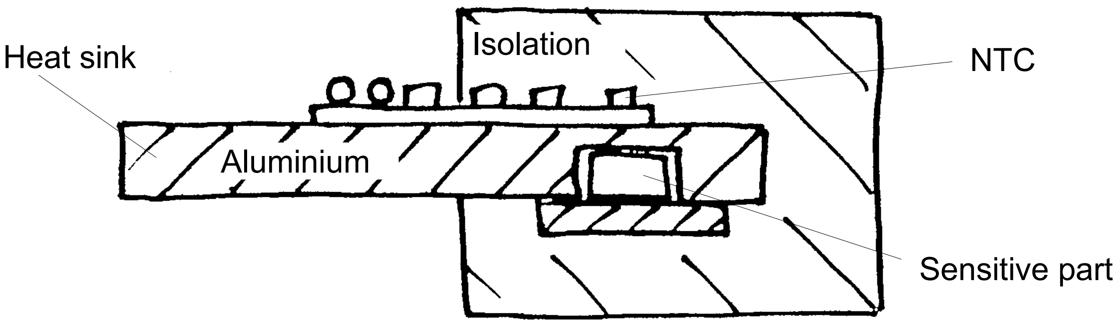


Figure 8 Example: sensitive part produces waste heat, with isolation

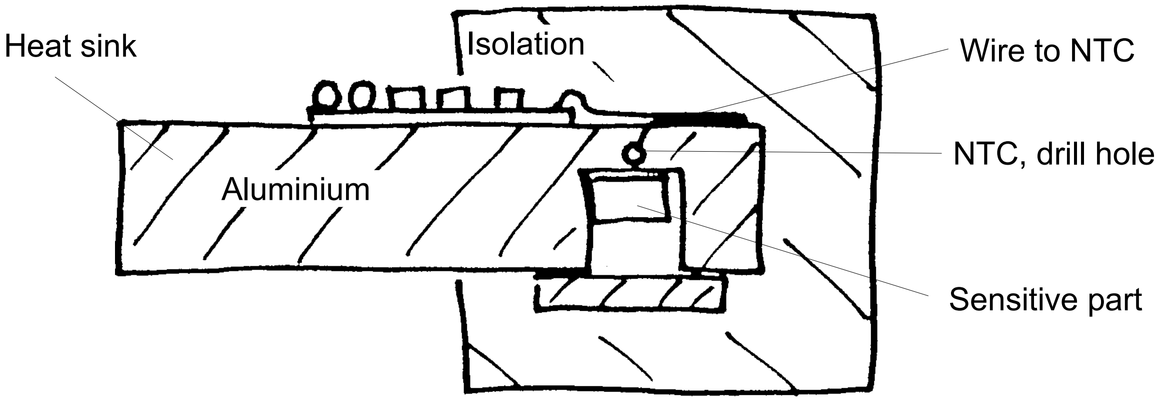


Figure 9 Example: sensitive part produces waste heat, with isolation, separate NTC

Never ever let air flow over your circuit or over the controller.

Airflow will generate temperature fluctuations of about two orders of magnitude higher as compared to the situation in a closed box.

The waste power of your electronic parts will heat component pins. Airflow over these pins will generate fluctuating thermoelectric voltages.

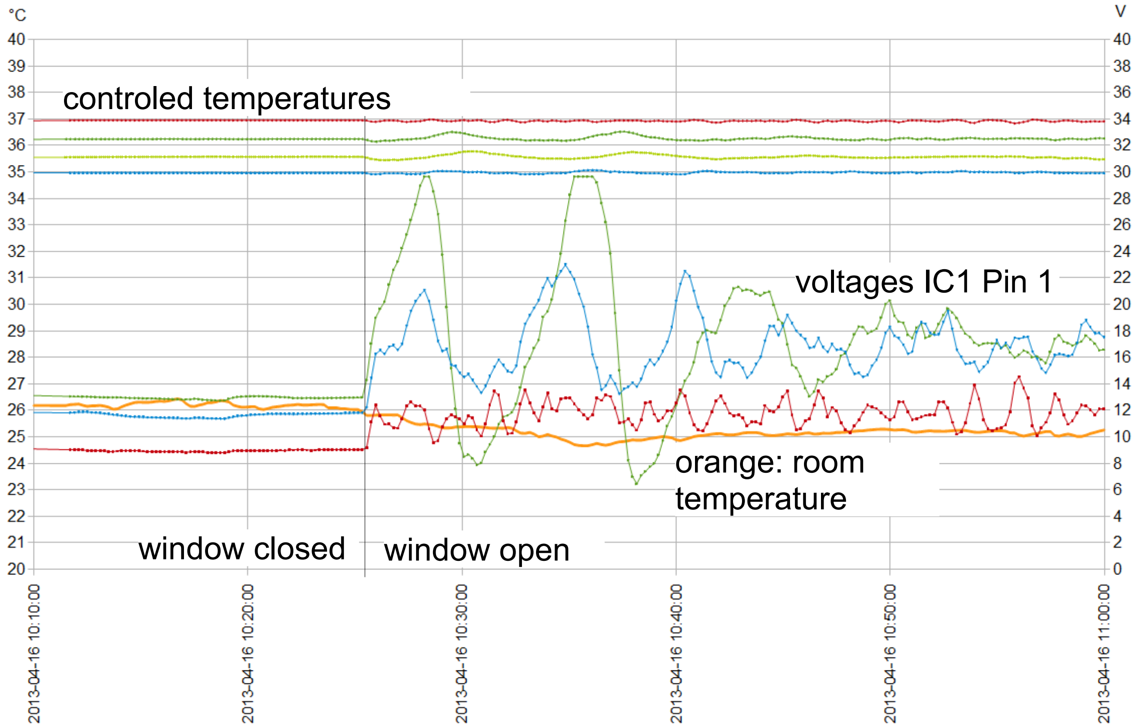


Figure 10 3 Prototypes in a case. Influence of an open window.

Technical data

Supply ~26 … 35 V

Minimal current consumption ~ 2.5 mA

Absolute temperature accuracy ~ 0.2 °C

> If absolute accuracy is important for you: use precision resistors in the bridge, calculate the self-heating due to the measuring current, ensure good thermal contact between NTC and your part.

Influence of environmental temperature example:

0.03 K/K single stage

0.0002 K/K two stage

Suppy voltage dependency: measured on one prototype: $4\ 10^{-4}$ K/V

Long time temperature drift: I guess less than 10^{-3} K/1000h

Size:

- Size full: 12.7 mm x 41.3 mm, about 3.2 mm thick (melf)
- Size, melf cut away: 12.7 mm x 24.2 mm, about 2.5 mm thick
- Size, melf cut away, NTC cut away: 12.7 mm x 16.5 mm, about 2.5 mm thick

Prototype 124

Circuit board
Board cut at 24 mm from right border.
R8: 56k (set point app. 37 °C) R7: 560, R4: 3k3, no R20...R23, R8 shorted (max power).
Current max: 14 mA
Glued on aluminium: 13 mm x 24 mm x 5 mm
Isolation top and bottom: each 6 mm.
Room temperature: 25°C.
After 1 hour: R NTC = 28k → temp app. 52 °C. Should be significantly higher than set point 37 °C and should be well below probably destructive 110°C. OK.

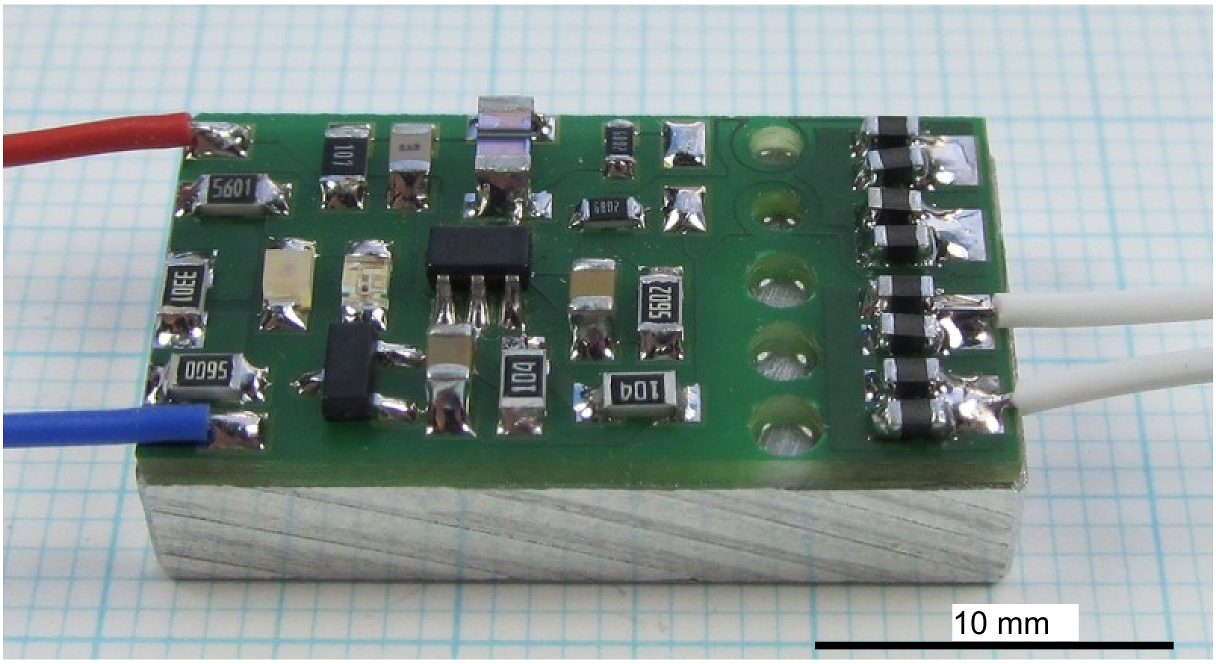
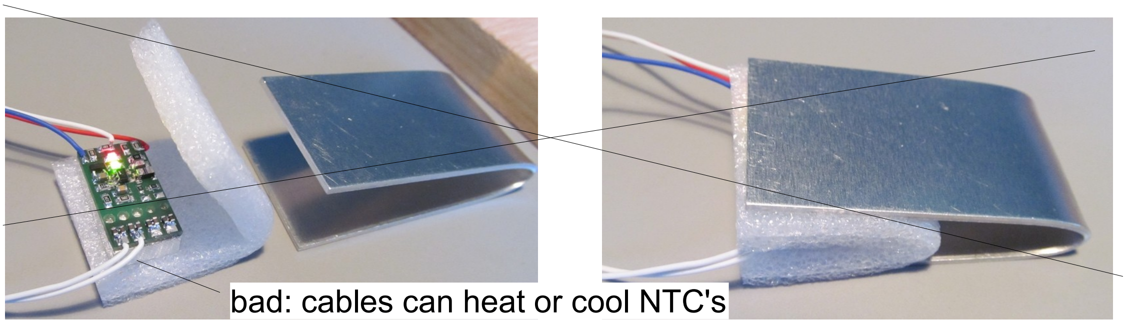
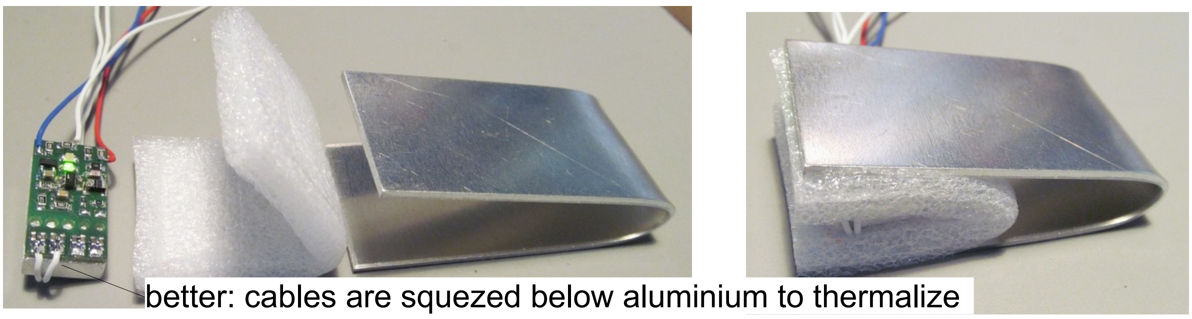


Figure 11 Small regulator 0.23 Watt for single component





The prototype is covered with 6 mm foam to avoid air-flow over the NTC resistors.

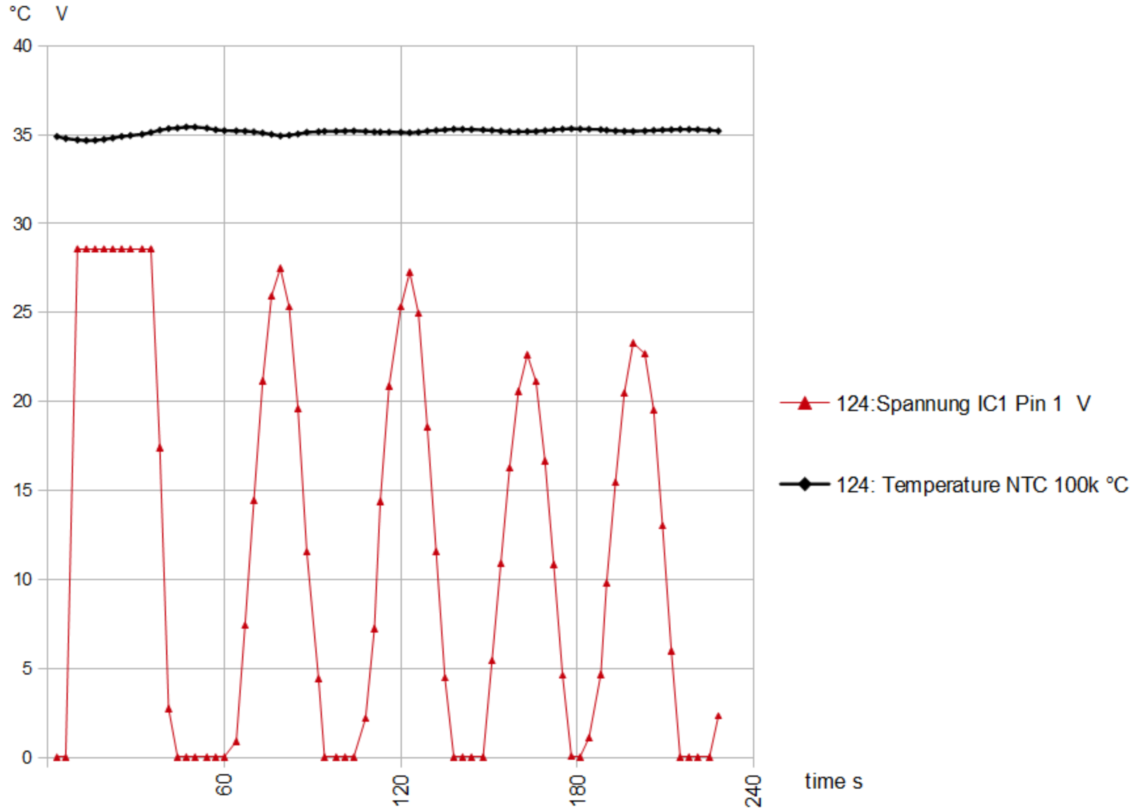


Figure 12 Oscillation with R1 68k

Change R1 from 68k to 150k

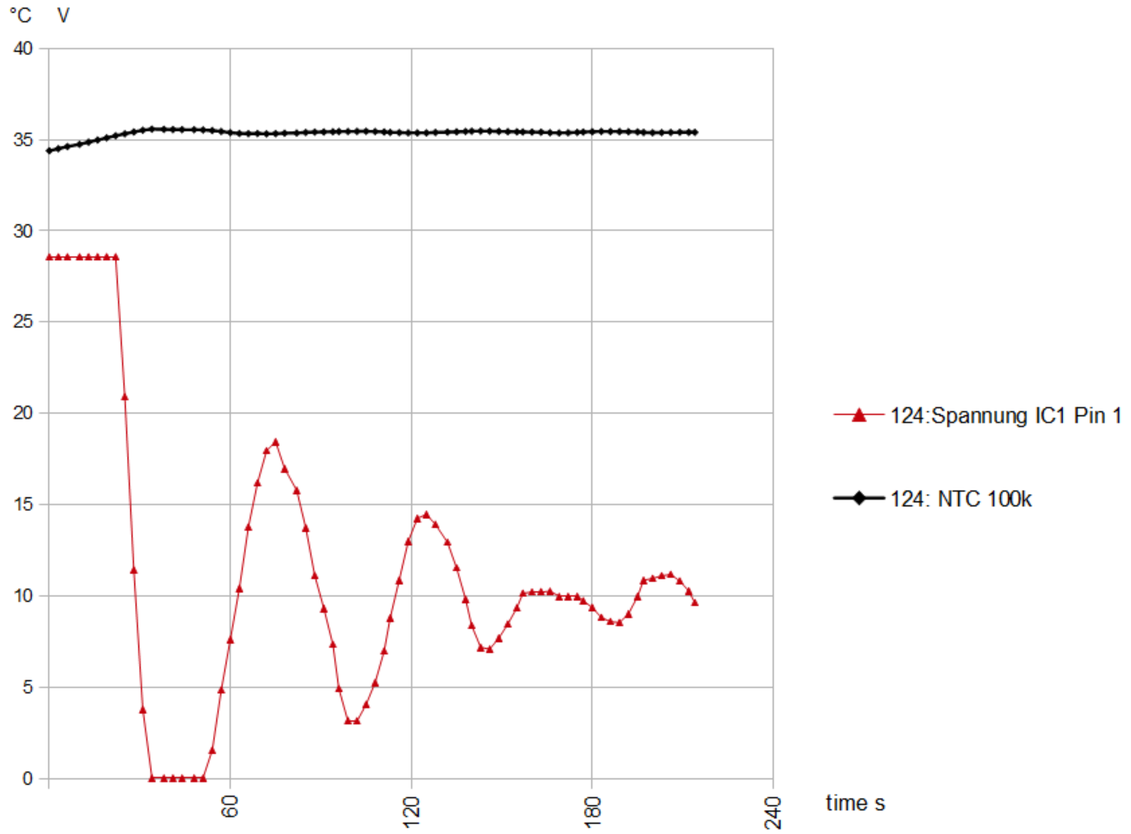


Figure 13 Too much overshoot with R1 150k

Change R1 from 150kΩ to 270kΩ

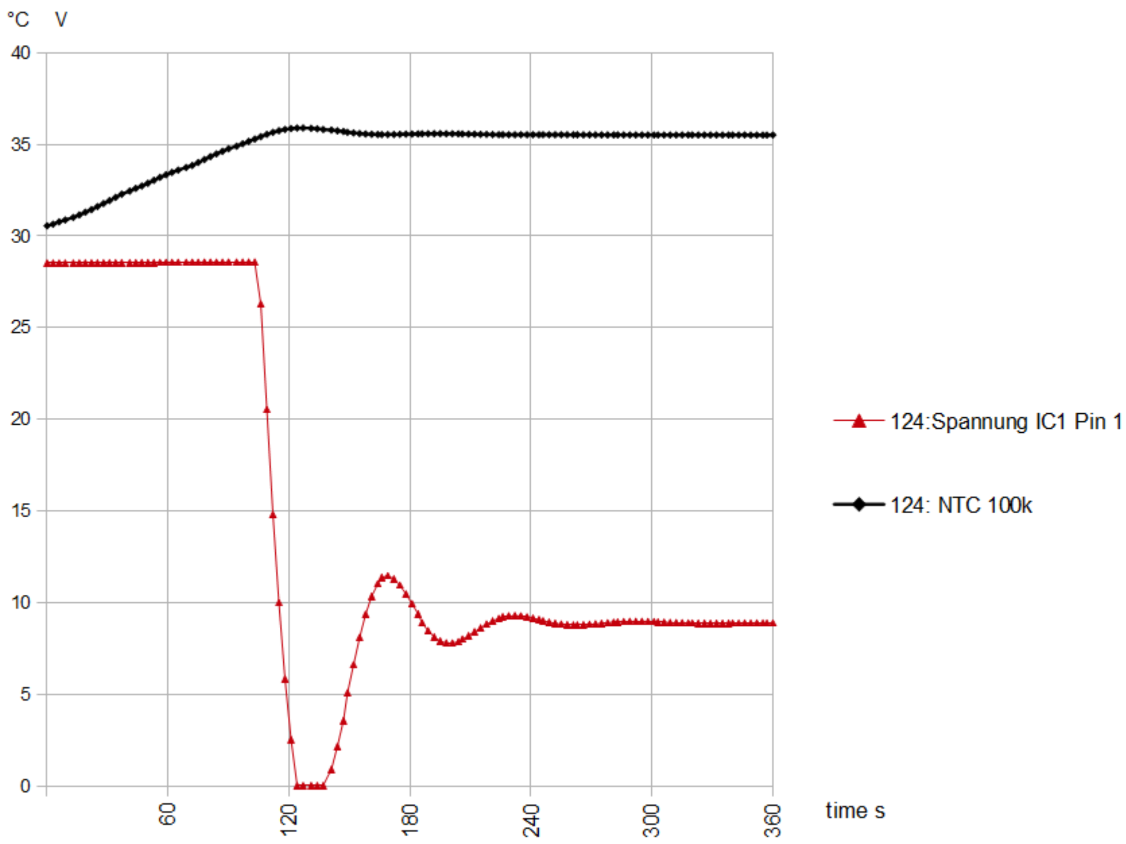


Figure 14 Swing into with R1 270k: ok.

Prototype 125

Circuit board R8: 56k (set point app. 37 °C) R7: 180, R4: 1k, no R20...R23, R8 shorted (max power). Current max: 14 mA
Glued on aluminium: 20 mm x 45 mm x 10 mm
Isolation top and bottom around NTC: each 6 mm.

After 1 hour: R NTC = 30k → temp app. 51 °C . Should be significantly higher than setpoint 37 °C and should be below probably destructive 110°C. OK.

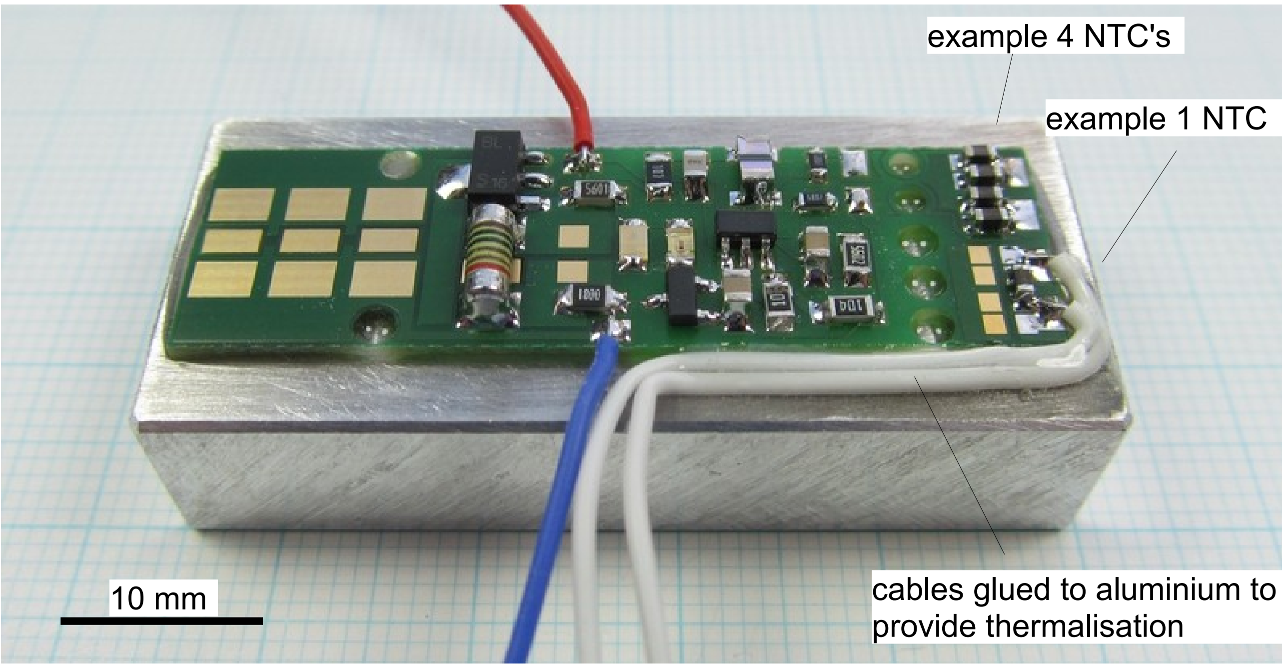
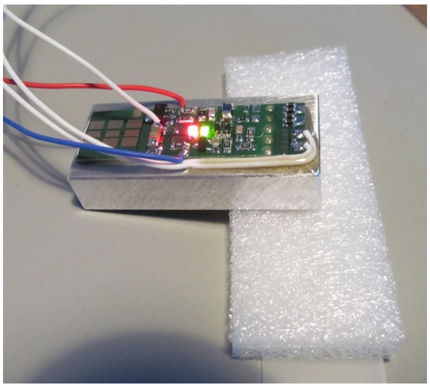
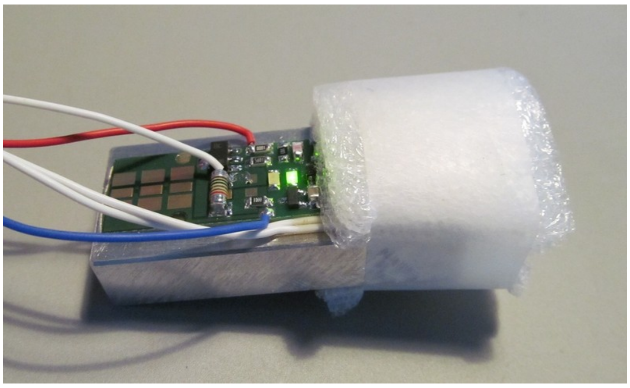


Figure 15 Prototype 125, max 0.76 Watt





The prototype is covered with 6 mm foam to avoid air-flow over the NTC resistors.

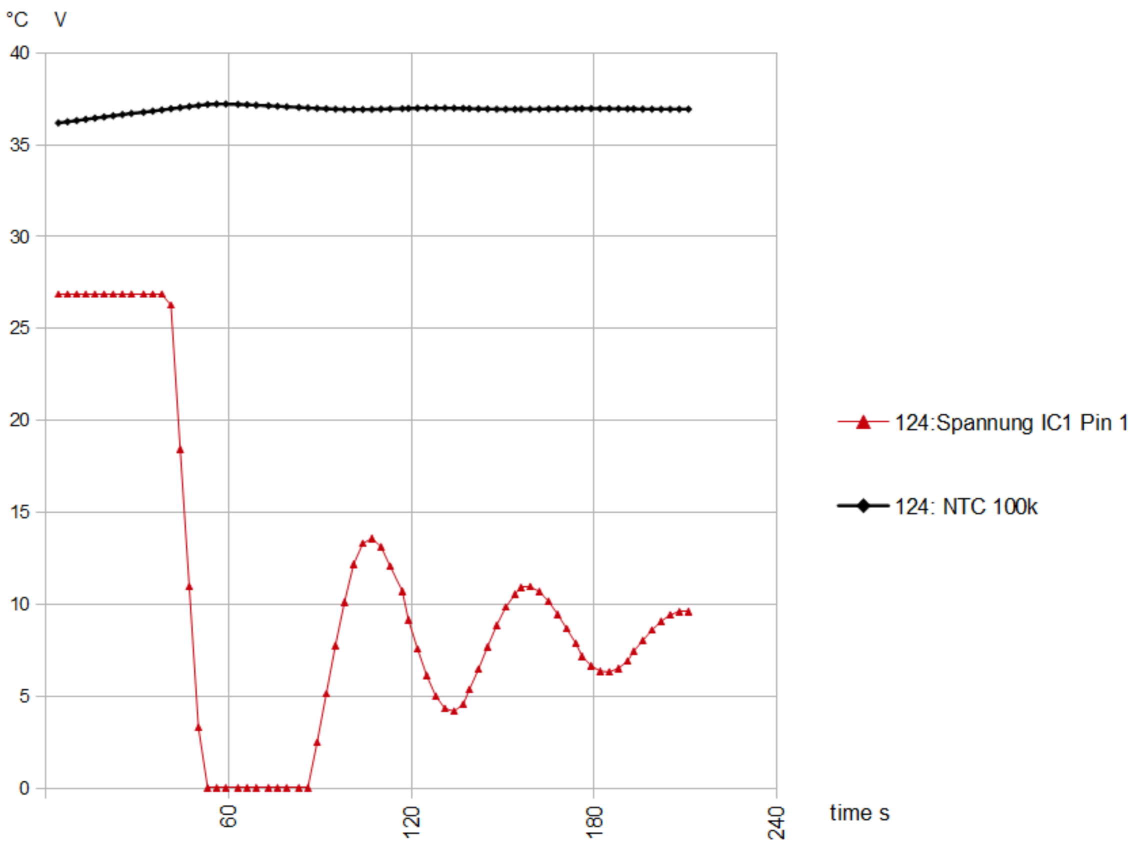


Figure 16 To much overshoot with R1 68kΩ

Change R1 from 68k to 150k

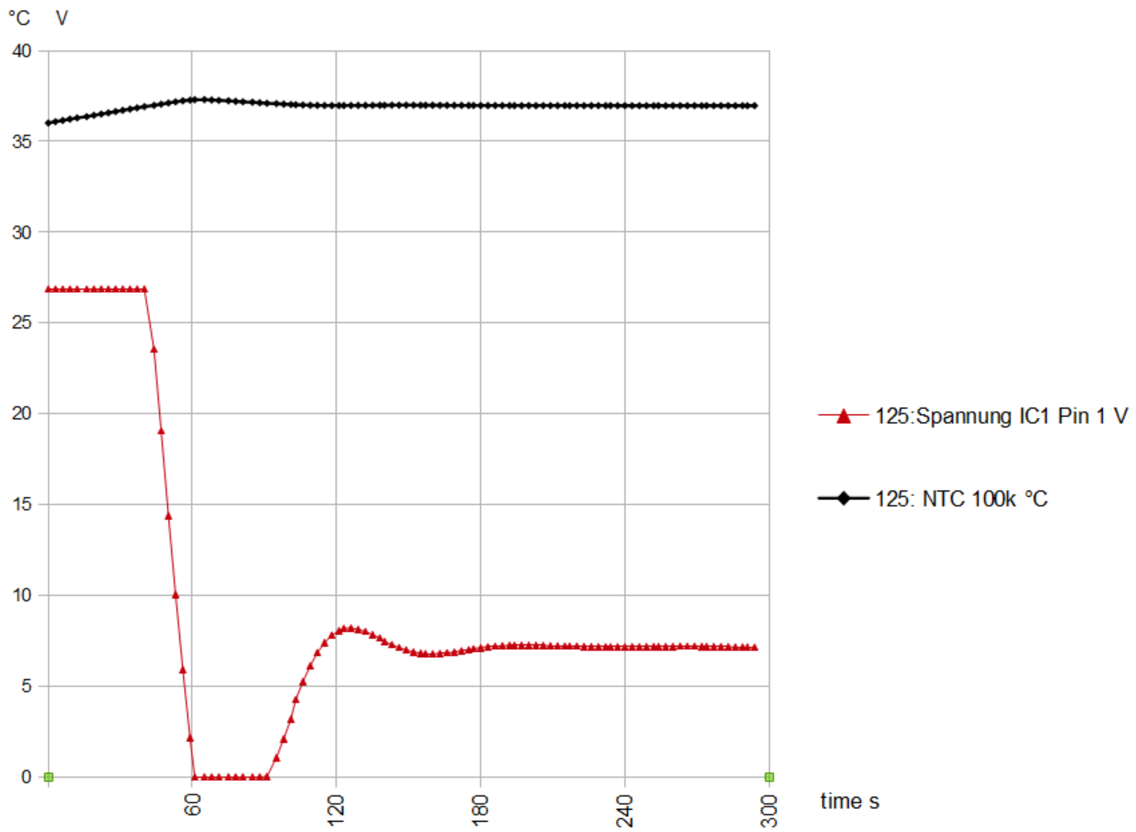
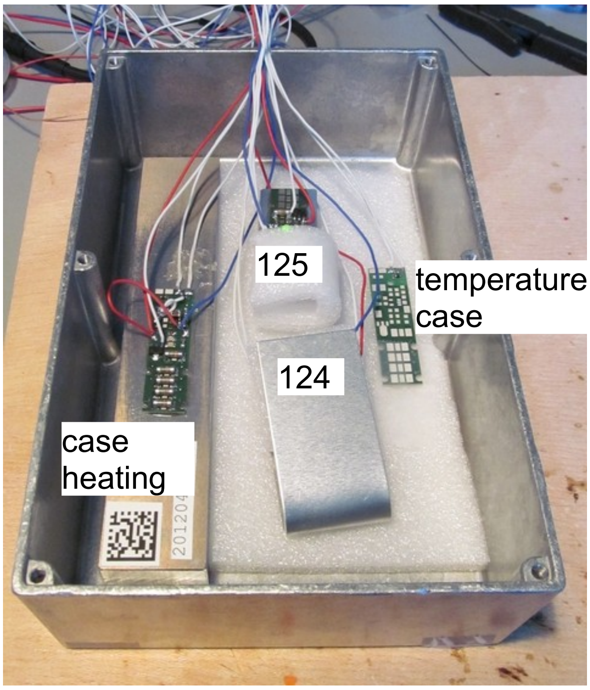


Figure 17 Transient oscillation with R1 150kΩ ok.

Performance prototype 124 and 125



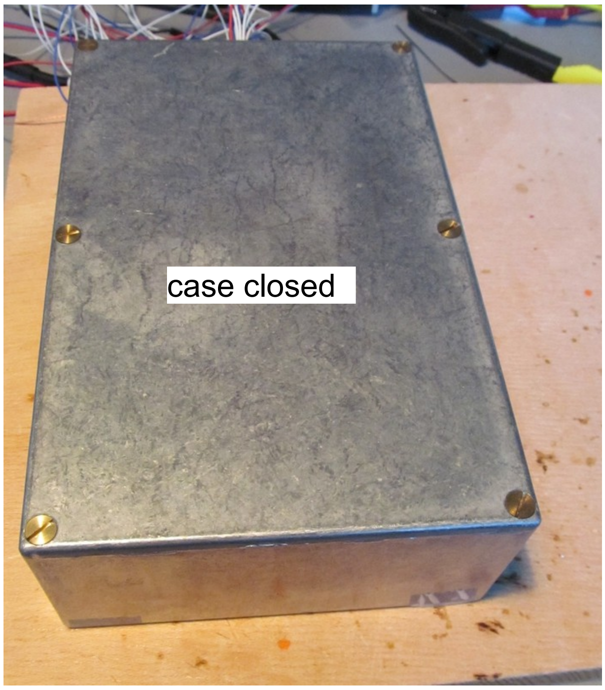


Figure 18 Prototype 124 and 125 in aluminium case.

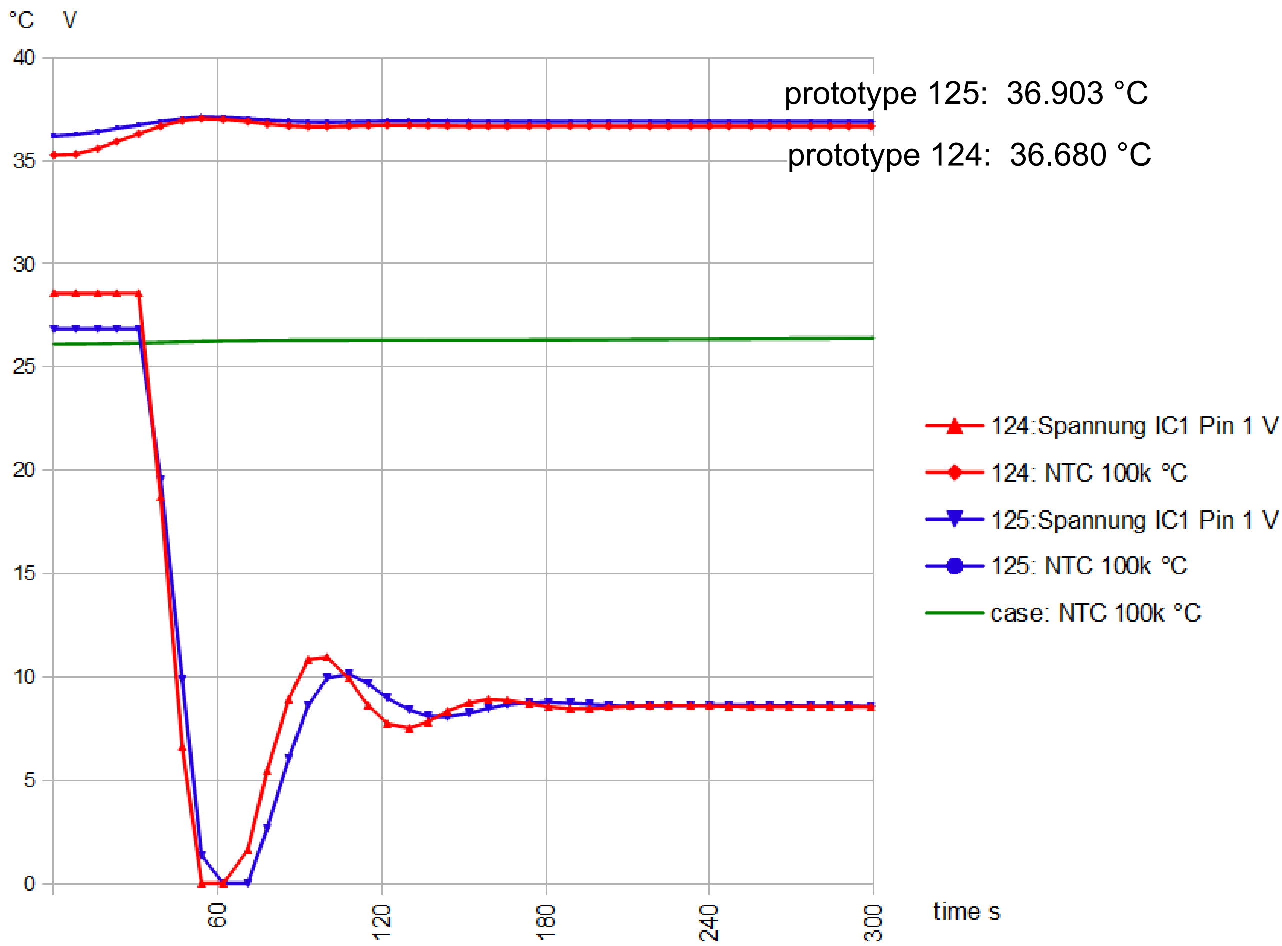


Figure 19 Swinging during the first 10 minutes.

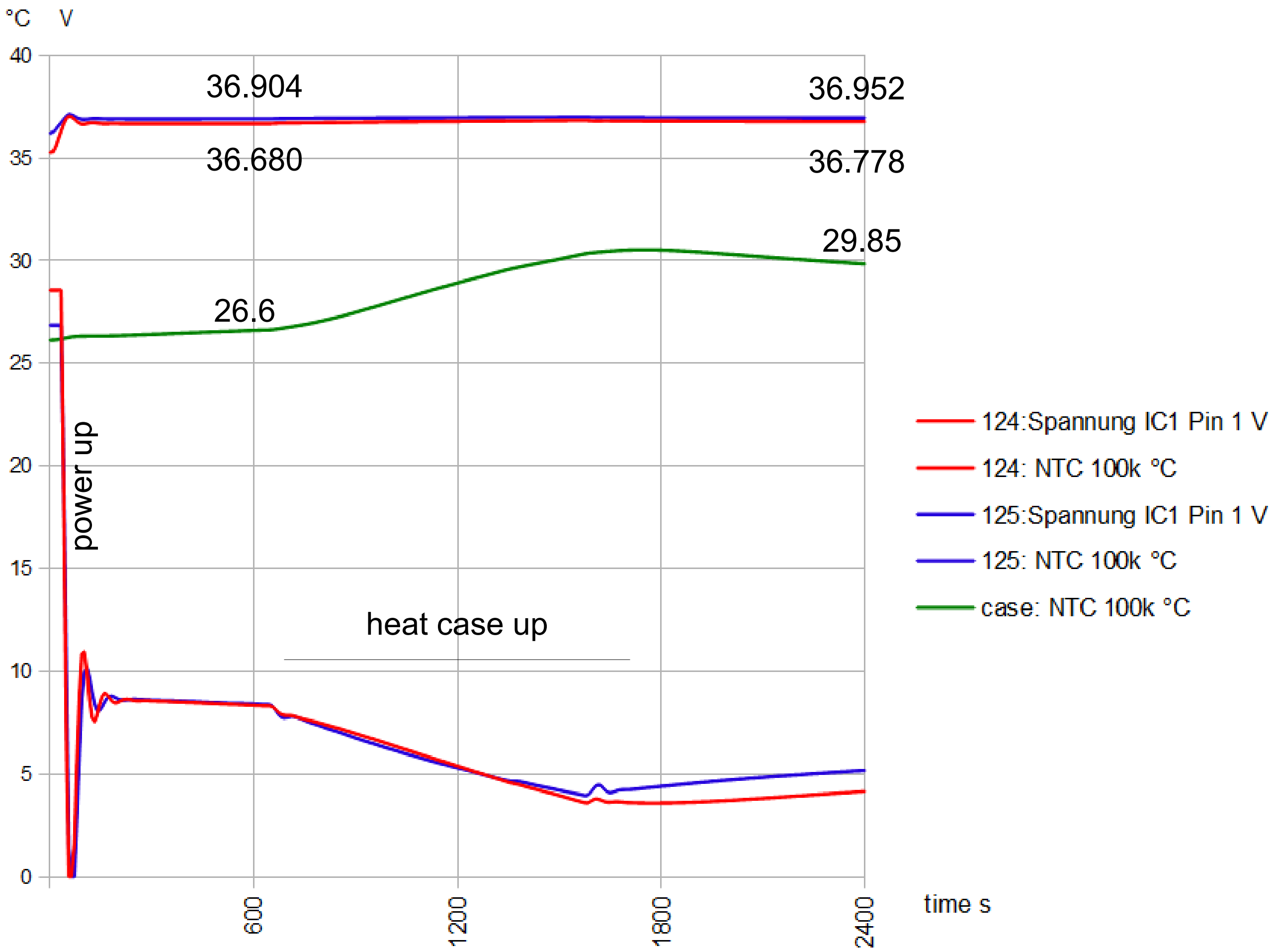


Figure 20 reaction to change of environment temperature

Sensitivity to environment temperature:
prototype 124: 0.030 K/K
prototype 125: 0.015 K/K

The temperature drift of your device will be reduced by approx a factor of 30.

For example: take an OP140 amplifier and control his temperature with the temperature-controller.

Data-sheet OP 140: Temperature drift ± 1 uV/K max. With temperature controller: 30 nV/K. This is in the range of a good auto-zero amplifier but without the drawback of auto-zero-noise.

Prototype “two stage”

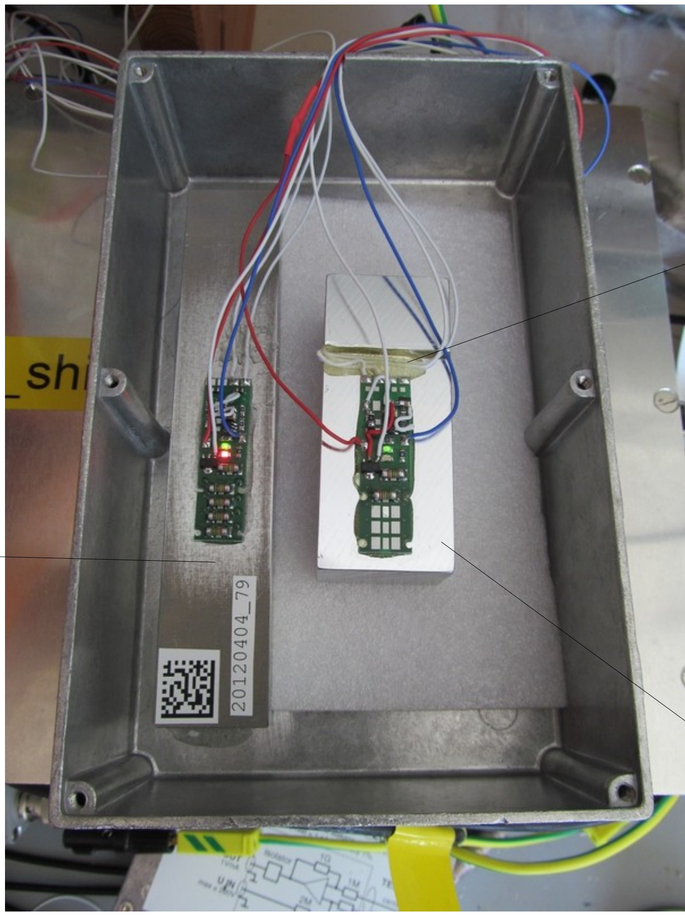


Figure 21 prototype “two stage”

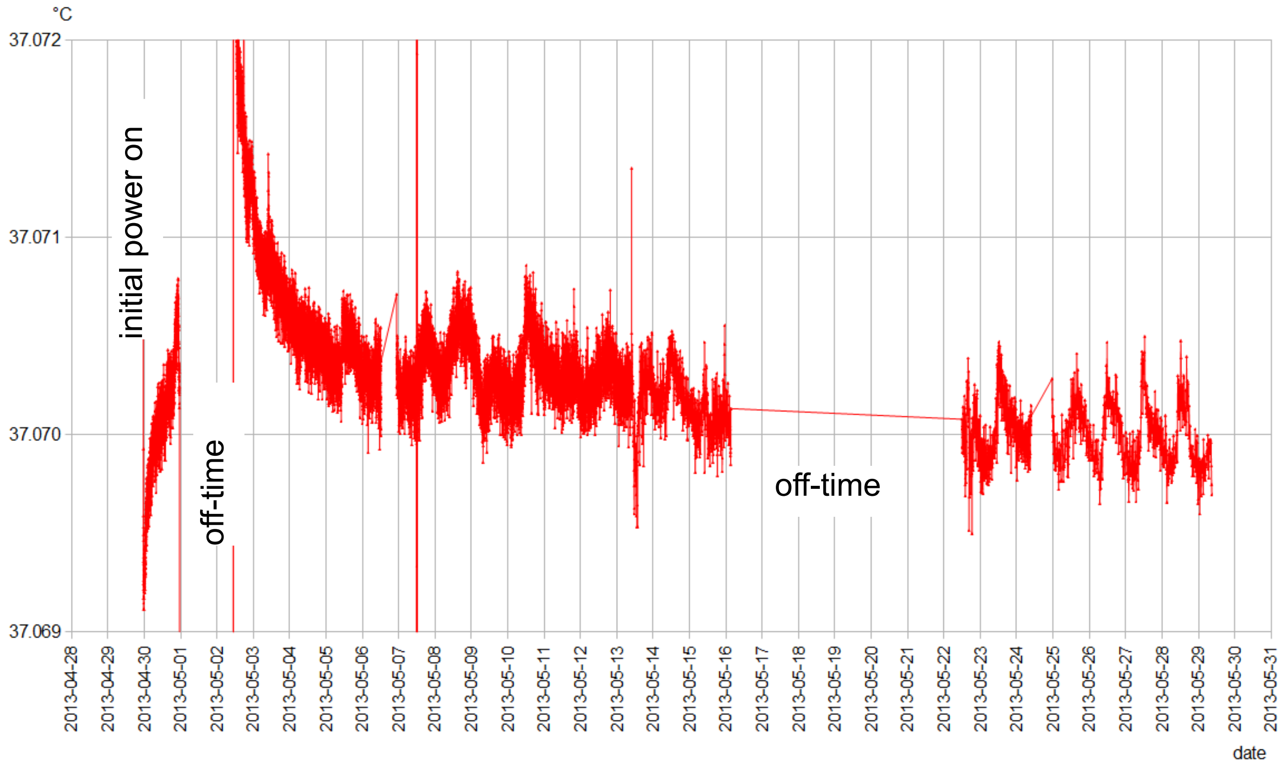


Figure 22 temperature second controller over one month

At the initial power up one can see a drift upwards. After one day off, there is a drift downwards.
Over one month the temperature of the second controller is within ± 1 mK.
The remaining up and down of about 0.3 mK correlates to the temperature in my office.
The aluminium-case was standing on the table, people walking around, windows open and closed, sunlight shining directly into the office.

Example of use: heating of electronic-case

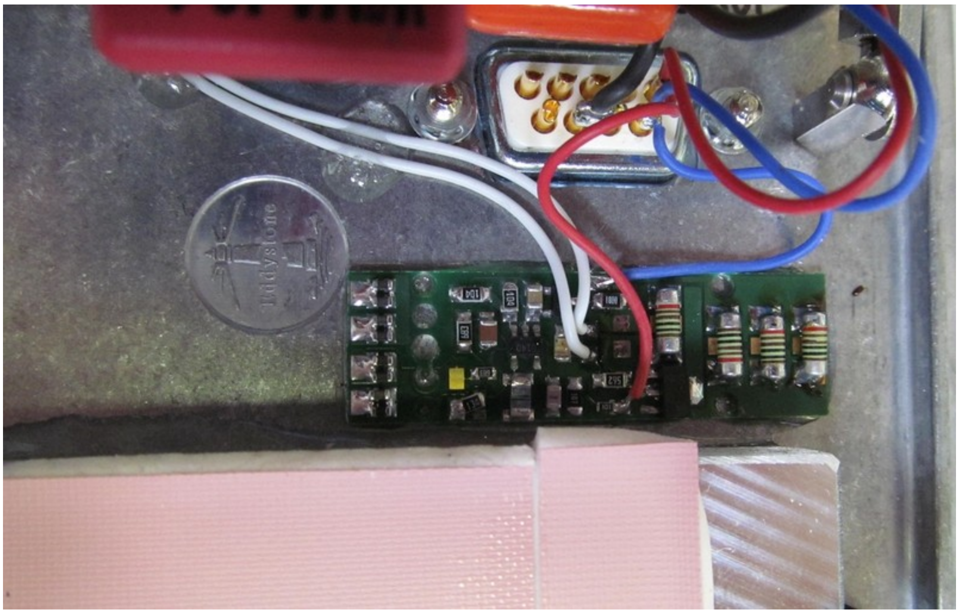


Figure 23 View inside of the electronic-case

R1	130k
Heating Power	3.5 W

Contact

You can buy a circuit board for 25 CHF to start your experiments. Most components included. You have to solder yourself.

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Files

https://people.phys.ethz.ch/~pmaerki/temp_regulator_2013_ntc

You can find data sheet's, schematic and layout in *temp_regulator_2013_ntc.zip.

License

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