# Thermal compensation of the optical RF delay line for the SPS transverse damper

Adam Lassak
August 6$^{th}$ 2015

# 1. Introduction

The SPS transverse damper system had been upgraded to a state of the art, fully digital low-level RF (LLRF) system during the Long Shutdown 1 (2013-2014) [1]. The new LLRF system features four independent “Damper Loop” modules, each specially designed and optimized for four particular beam types: LHC bunched beam, SPS fixed target beam, LHC scrubbing beam and LHC/fixed target Ions. The upgrade allowed also installation of dedicated sets of electro-static pickups and strip-line pickups.

For proper function of the LLRF system it is necessary to properly compensate the pickup signal transport delay from the tunnel to the surface. In case of the most distant pickup (BPH.202) the fixed part of the transport delay (coaxial transmission lines from the tunnel to BA2) is approximately 2.48 μs. On top of the fixed delay, there is a variable part, as the beam is being accelerated. The reference signals (RF frequency $f_{RF}$ and the revolution frequency $f_{REV}$) are generated in the “RF Faraday cage” (BA3) about 1.2 km away and transported to the SPS damper system (in BA2) by means of optical fibres. The situation is depicted in Figure 1 and Figure 2.

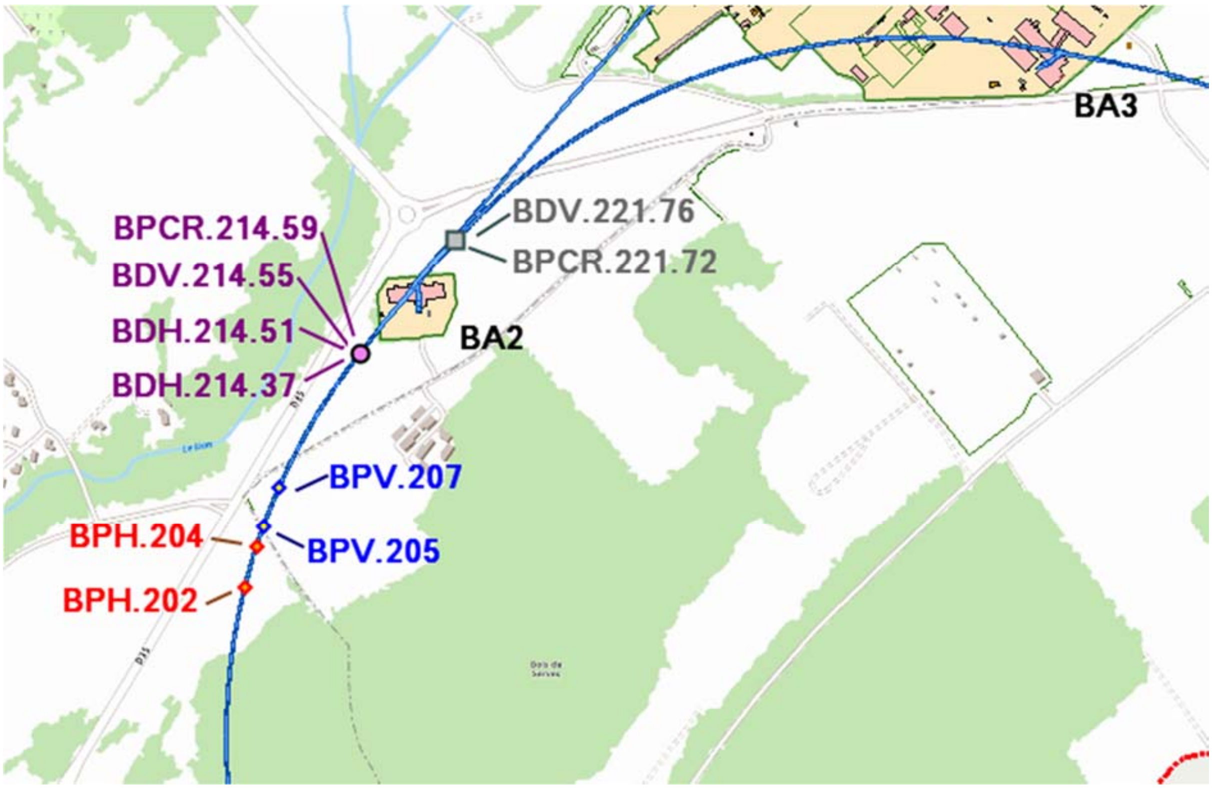



*Figure 1: SPS layout showing the position of BA2, BA3 and pickup locations*

The new LLRF system is capable to provide a transverse feedback on ions of various species, however the fixed frequency acceleration scheme [2] introduces several challenges to the RF signal processing and the feedback loop digital electronics.

The machine turn is divided into several windows (2, 4 or more), where the ion bunches are “sitting” on bursts of a fixed accelerating RF frequency. Outside of these accelerating windows the frequency is altered such that the total harmonic number is kept constant (in other words the mean frequency is constant).

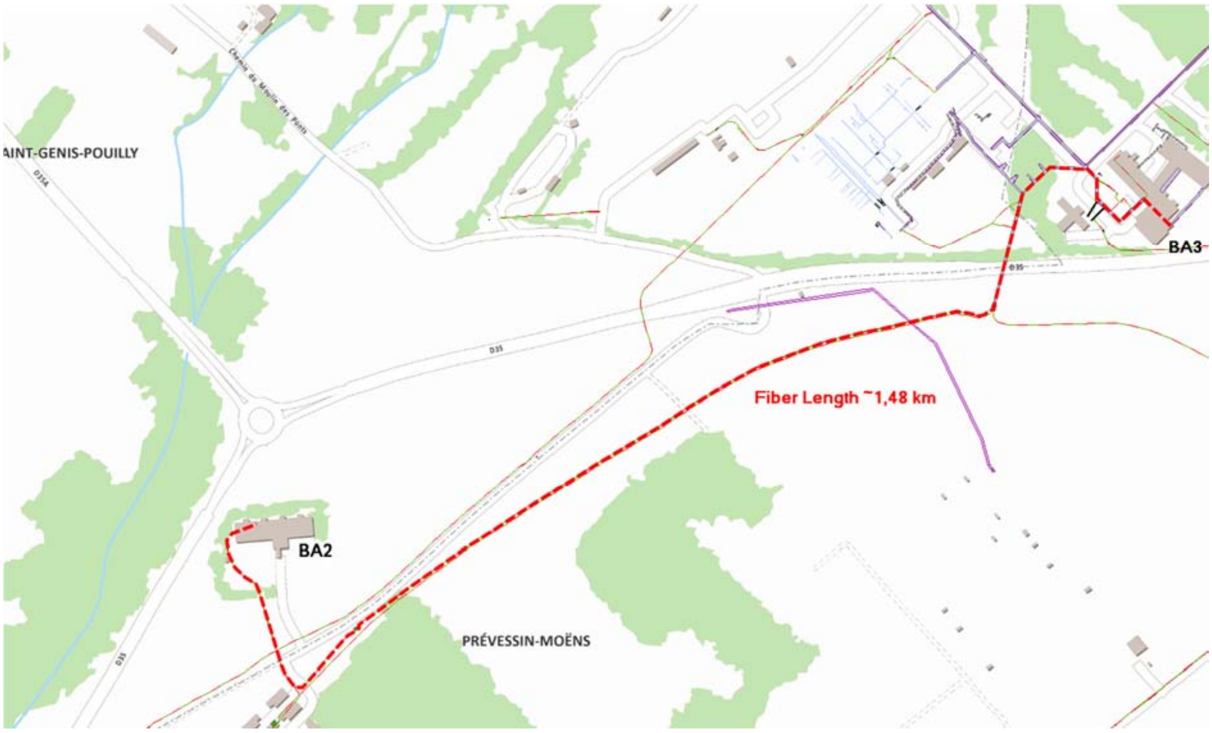



*Figure 2: BA3 → BA2 optical fibre path*

Implication to the LLRF system is need to track the changing frequency within the cycle and dynamically update the sampling clock fine delays to properly sample the bunch signals. On top of that, the pickup signals for ions are downconverted to the base band using the modulated $f_{RF}$. For correct downconversion it is necessary to delay the LO signal such, that the correct LO and the pickup signal reaches the mixer at the same time. Unfortunately the reference RF signals are sent to BA2 in opposite direction than the beam circulates, therefore is necessary to compensate for delay of almost 6/7 of the SPS ring (i.e. 6 km, 20 μs). The SPS damper clocking scheme is shown in Fig. 3.

To precisely delay the frequency modulated RF signal at frequency of 200 MHz we use analogue optical transceivers and coils if single mode optical fibres of desired length (typically 1 to 7 km, ~5 to 35 μs). Electrical parameters of the fibre change with temperature. While not important for telecommunication applications, variation of the refractive index and thermal length expansion is critical for our delay line application.

To decrease the influence of thermal changes on the delay we install the fibre coils to a thermally isolated enclosure with a tight temperature control. For simplicity the temperature setpoint is set well above the ambient temperature (e.g. 45 °C) so the regulator has to operate only in a heating mode. To keep the delay within required range, the temperature has to be regulated to a constant set point with minimum oscillations.

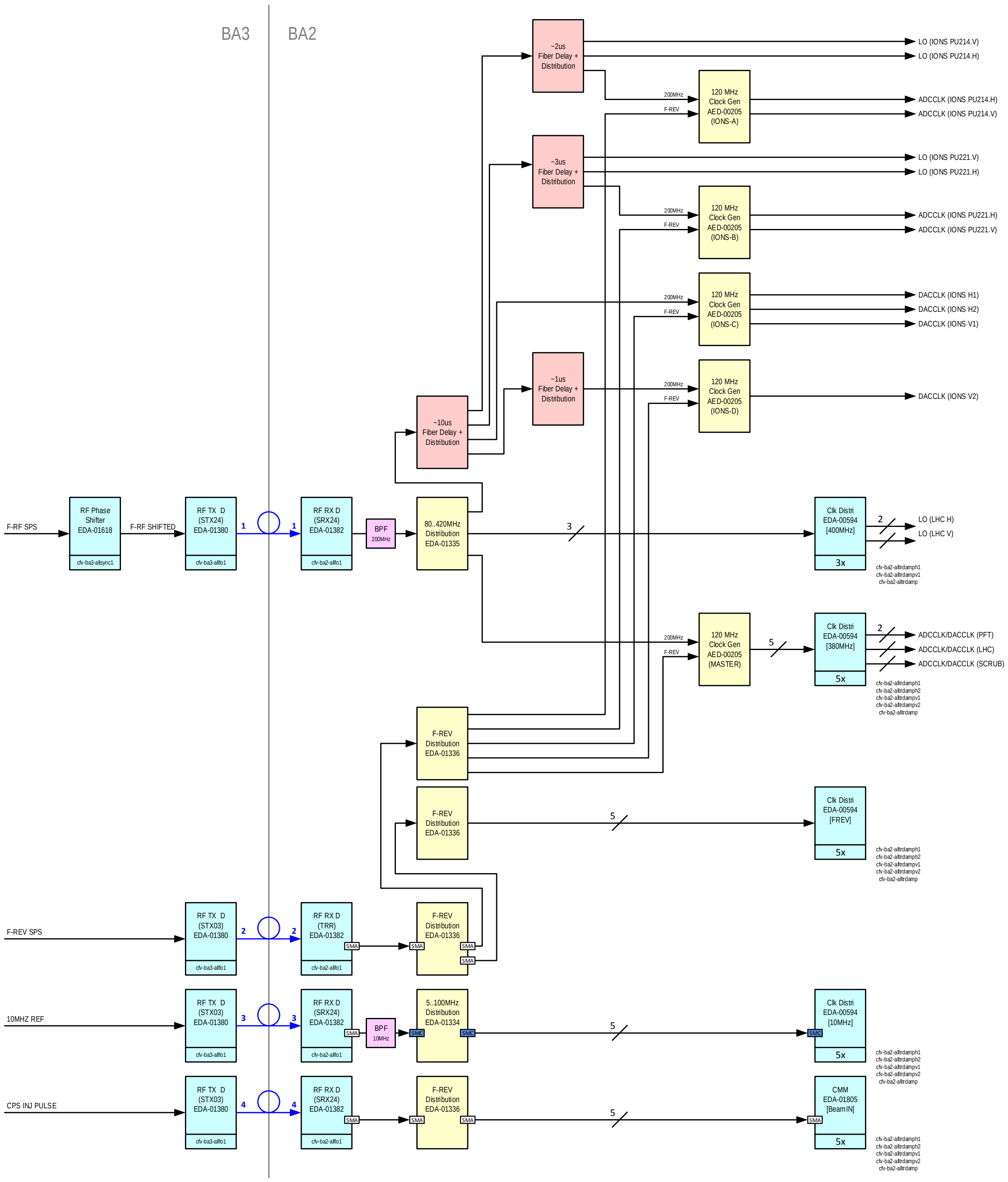
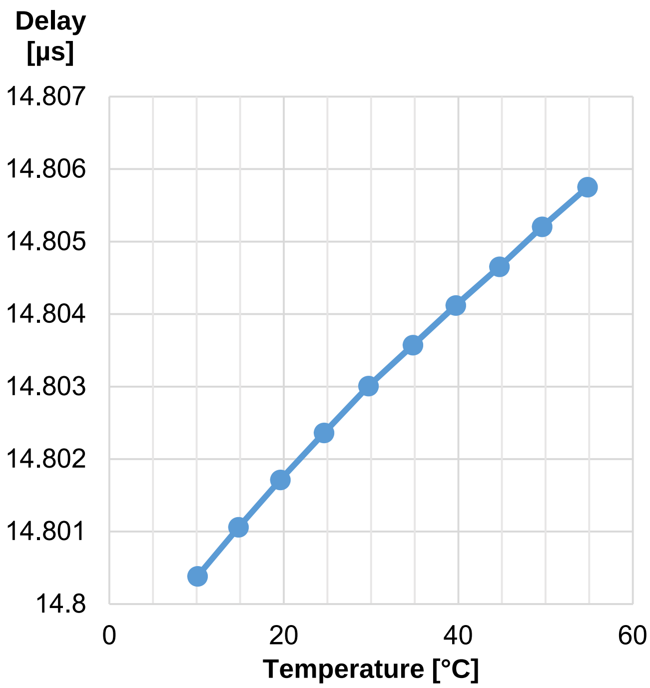



*Figure 3: The SPS transverse damper clocking scheme*

## 2. Fibre drift characterisation

The fibre used for our application is AllWave FLEX ZWP Fibre from OFS [3]. As the fibre thermal properties are not very important for the telecommunication industry, the relevant fibre parameters had to be measured prior the regulator design instead of finding them in the fibre datasheet.

A group delay of 3 km long optical fibre sample was measured using a vector network analyser Agilent E5071C, analogue optical transceiver evaluation board module Spinner BN 528992 and a thermal chamber. The temperatures was varied from 10 to 55 °C with 5 °C steps. Each measurement was taken after few hours when the fibre temperature had stabilized. Measurement results are shown in Fig 4.




| Temperature [°C] | Absolute electrical length $\tau_d$ [μs] |
|---|---|
| 10.1 | 14.800383 |
| 14.8 | 14.8010589 |
| 19.6 | 14.8017122 |
| 24.6 | 14.8023596 |
| 29.7 | 14.8030073 |
| 34.8 | 14.8035722 |
| 39.7 | 14.8041186 |
| 44.7 | 14.8046511 |
| 49.6 | 14.8052031 |
| 54.8 | 14.8057499 |

*Figure 4: Absolute length of the optical fibre sample at different temperatures*

The measurement was performed with the transceiver situated outside the thermal chamber, therefore no thermal stress was applied to it.

A second order polynomial fit

$$\tau_d = c_2 t^2 + c_1 t + c_0 \quad (1)$$

was applied to the measured data resulting in

$$\tau_d = -4.833530 \text{x} 10^{-13} t^2 + 1.502968 \text{x} 10^{-10} t + 1.479894 \text{x} 10^{-5} \quad [\text{s; °C}] \quad (2)$$

Formula 2 can be normalized to unity fibre delay ($\tau_d$ = 1 s) obtaining:

$$\tau_{dNORM} = -3.265197 \text{x} 10^{-8} t^2 + 1.015301 \text{x} 10^{-5} t + 9.997133 \text{x} 10^{-1} \quad [1; °C] \quad (3)$$

A total delay drift of a fibre of total electrical length $\tau_d$ caused by the temperature variation $\Delta t$ can be expressed as:

$$\Delta\tau = c_{1NORM}\, \Delta t\, \tau_d \quad [\text{s; 1/°C, °C, s}] \quad (4)$$

Formula (4) can be rearranged to obtain maximum temperature variation for a given maximum tolerated delay drift as:

$$\Delta t = \frac{\Delta\tau_d}{c_{1NORM}\ \tau_d} \qquad [°C; s, 1/°C, s] \qquad (5)$$

Contribution of the quadratic term $c_2$ is very low, therefore it can be neglected for the required precision.

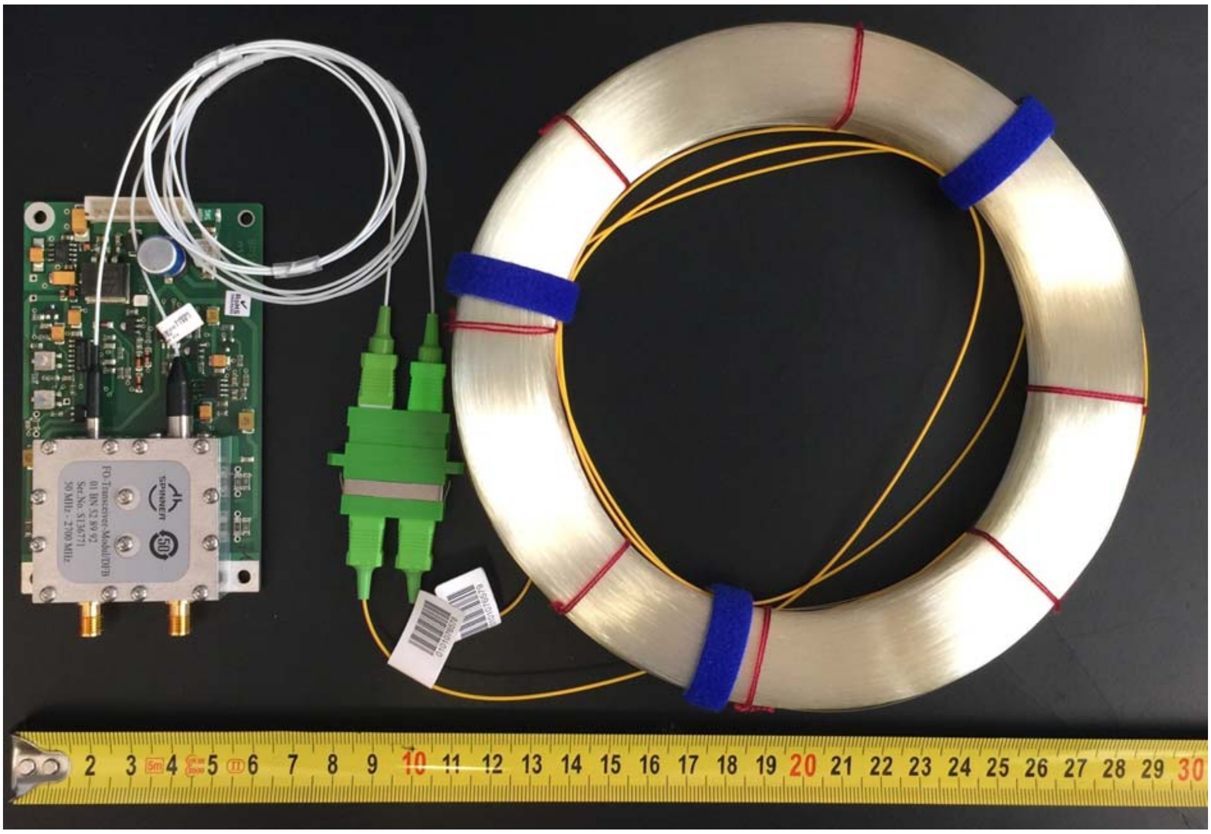



*Figure 5: A 14.8 μs of fibre delay (physical length 3 km) with analogue transceiver.*

## 3. Requirements for fibre temperature stability

Required fibre temperature stability can be derived using the sample drift measurements. Typical delay drift, which can be still tolerated for correct damper operation is in order of ±125 ps. Electrical delay of the fibre delay line for the ion operation is expected to be in a range of 10 to 20 μs (corresponding to a physical length 2 to 4 km).

Figure 6 shows the largest allowed temperature variation as a function of maximal tolerable delay drift (x axis) and a total fibre length (y axis).

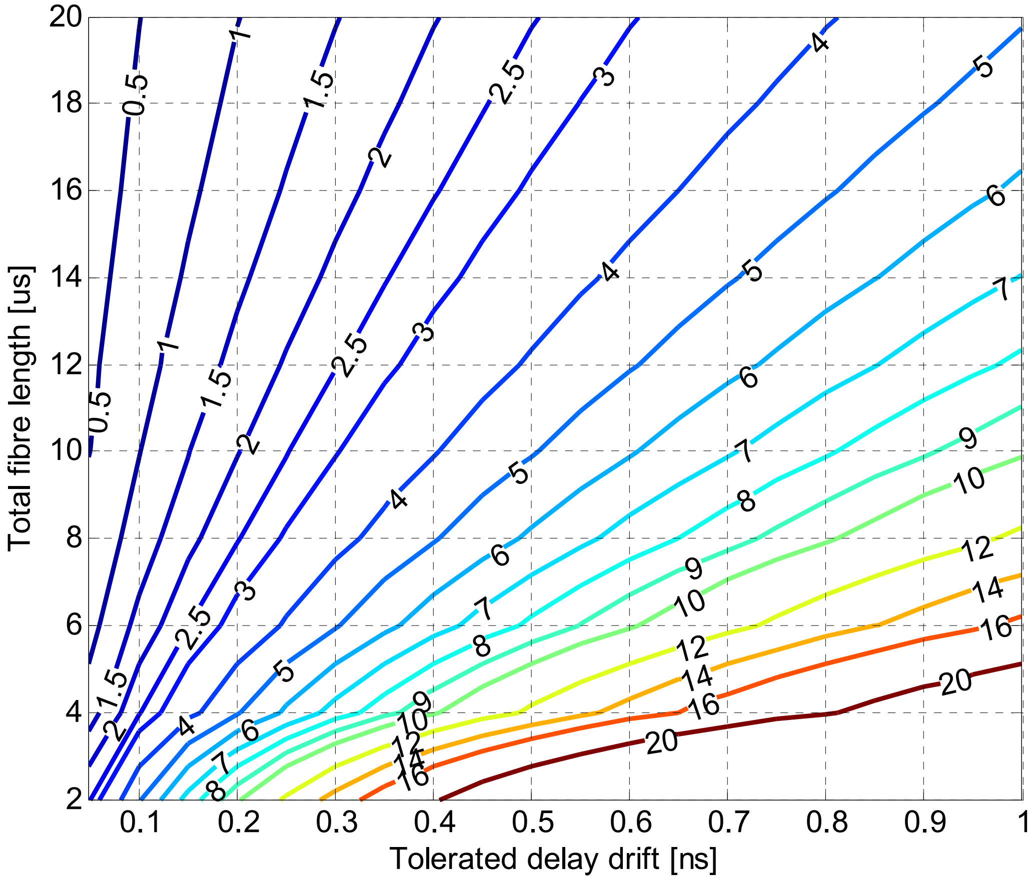



*Figure 6: Maximum fibre temperature variation as a function of total fibre delay and tolerated delay drift.*

For example, in order to keep the delay drift of a 20 μs delay line below ±125 ps, the fibre temperature has to be controlled within ±0.62 °C.

## 4. Design of a thermally stabilized enclosure

In order to keep temperature of the fibre coils stable a shelve-like enclosure was designed. For simplicity the enclosure temperature setpoint is set well above the ambient temperature (e.g. 45 °C) so the regulator has to operate only in a heating mode. Enclosure is made out of aluminium bars on the sides with aluminium sheets in between forming the slots for four fibre coils. Entire enclosure will be sealed with thermal insulation material as shown in Fig. 7.

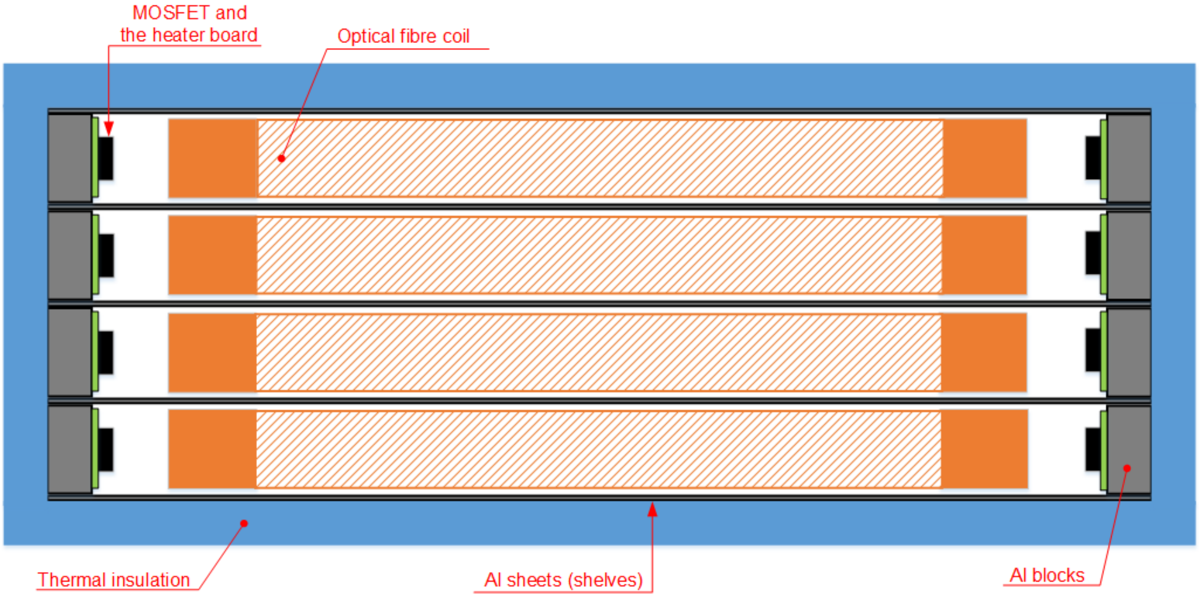



*Figure 7: Cross-section of the thermally stabilized enclosure*

*Figure 8: Heater board mounted on side Al block*

Fibres are placed in slots between Al sheets. Each slot has its own separate front panel with APC connectors mounted to connect to the fibre. Transceivers and controller board, archived as AED-00241 [4], are assembled outside the heated enclosure in its rack.

The heat is provided by means of power MOSFETS transistors mounted to printed boards fixed to the side bars (see Fig.8). In order to spread the heat more uniformly, only one MOSFET will be mounted to each side bar. The printed boards are designed to be the same for front and rear heating, so only one MOSFET and one PT1000 need to be assembled on each heater board. The heater board is archived as AED-00242 [5].

## 5. Temperature controller

The temperature controller has to provide uniform heating to the controlled volume and stabilize the temperature within the calculated limits. The design value for temperature stability was set to ±0.25 °C. The setpoint temperature was chosen to be +45 °C. As the enclosure is well thermally insulated the controller response must be properly damped, otherwise temperature regulation overshoots will take too long time to cool down. To meet the requirements we used PI topology for regulating the temperature. For various reasons the controller was designed as a fully analogue circuit.

The controller is separated to multiple boards, where one is the primary controller board and the other ones are distributed individual heating and temperature sensing elements.

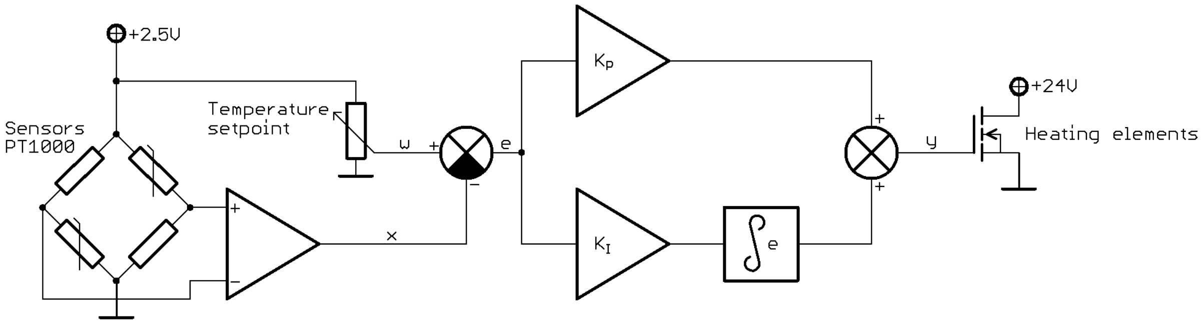



*Figure 9: Block diagram of the temperature controller (w – setpoint value, x – measured plant value, e – error signal, y – actuator signal*

The temperature is measured by PT1000 RTDs connected in legs of a Wheatstone bridge. Other two legs are populated by a high precision, very low temperature coefficient resistors (5 ppm/°C). The bridge diagonal voltage is amplified by a precision instrumentation amplifier with fixed gain of 10 (signal *x*). Great advantage of this circuit is that the number of resistors in the bridge diagonals is not limited. Connecting several (4, or more pieces) in series allows to measure temperature at multiple locations of the enclosure. The average temperature is then controlled, what has a positive effect on the temperature uniformity.

The regulator setpoint *w* is obtained by a multi-turn trimmer. The trimmer uses the same reference voltage as the measurement bridge, therefore the setpoint voltage does not drift with temperature. Output of the trimmer is fed to the same instrumentational amplifier to obtain the same voltage levels.

As the same reference voltage is used for both the bridge and the setpoint divider, the regulator input is virtually independent of reference voltage drifts.

Both signals are then applied to two instrumentation amplifiers forming the regulator proportional and integral branches. Each amplifier has its own trimmer for setting the regulator gain constant independently. Output of the I amplifier is then fed into an analogue integrator. Time constant of the integrator is not variable and can only be adjusted by changing the values of R and C at integrator part. Outputs of the proportional and integral branches are then summed forming the actuator signal *y*.

Summed output is distributed to the MOSFET heater boards. To limit dissipated power per each MOSFET there is a resistor and diode to cut off excessive voltage which appears when error signal is too high. In other words if a difference between set and actual measured temperature would be too high, controller would force actuator (MOSFETs) to dissipate too much power.

In order to equalize power dissipated by each heater element, the transistor is driven by an operational amplifier connected in a local servo loop. The source current is measured and the amplifier drives the MOSFET so that there is a constant current equal to I = $V_{CTRL}$/1.8 Ω flowing through it. As all transistors share the same drain power supply, the power dissipated by each unit is the same, and it is linearly proportional to the control voltage $U_{CTRL}$.

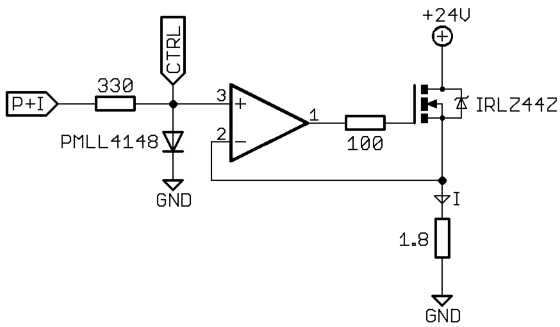



*Figure 10: MOSFET driver on heater board*

# 6. Elaboration of the regulator signal levels

All of the signal levels described in this chapter are named corresponding to the test points marked in the regulator schematic (AED-00241 [4]). Measuring bridge and resistor divider for setting the temperature are supplied by a precise voltage reference of 2.5 V. Nominal resistance of PT1000 is $R_0$ = 1 kΩ at 0 °C. The temperature coefficient of Pt resistors is α = 3850 ppm/°C (higher order terms neglected). The resistance as function of a temperature can be determined as:

$$R_{PT1000} = R_0\,(1 + \alpha\, t) \qquad [\Omega;\ \Omega,\ \Omega/°C,\ °C] \tag{6}$$

If a single resistor/RTD per leg is used, the bridge diagonal voltage (points marked as PTA and PTB) can be calculated as:

$$V_{PTA} = V_{REF} * \frac{R_{PT1000}}{R_{PT1000}+R_0} = V_{REF} * \frac{R_0\,(1+\alpha\, t)}{R_0\,(1+\alpha\, t)+R_0} \tag{7}$$

$$V_{PTB} = V_{REF} * \frac{R_0}{R_0+R_{PT1000}} = V_{REF} * \frac{R_0}{R_0+R_0\,(1+\alpha\, t)} \tag{8}$$

The amplified diagonal signal marked as TEMP represents the measured temperature. Voltage at this node can be calculated as a difference of PTA and PTB multiplied by the gain of the instrumentation amplifier:

$$V_{TEMP} = G * (V_{PTA} - V_{PTB}) = G\, V_{REF}\, \frac{\alpha\, t}{\alpha\, t+2} \tag{9}$$

Voltage at TEMP node varies from 0 to 2.589 V in range of 0 to 60 °C. Temperature set point is adjusted by trimmer R8 and its amplified signal is available on the controller front panel, marked as TP1 and TP2. Voltage can be adjusted in a range of 0 to 2.7 V. As the bridge voltage (setpoint) is not a linear function of the temperature, some selected values are listed in Table 1.

| Temperature [°C] | Voltage setpoint [V] |
|---|---|
| 30 | 1.365 |
| 35 | 1.578 |
| 40 | 1.787 |
| 45 | 1.993 |
| 50 | 2.195 |
| 55 | 2.393 |

*Table 1: Voltage setpoint according to temperature*

Gain of proportional and integral regulator can be adjusted by trimmer R6 (for P) and R7 (for I). Equation for gain is:

$$G = \frac{100}{R} + 1 \qquad [k\Omega] \tag{10}$$

When using 200 kΩ trimmer the gain can be adjusted in range of 1.5 to >1000. For integral part, this gain is lowered by resistors in integrator, so in the result amplified voltage at output of the instrumentational amplifier is then multiplied by 0.3. Signal at point marked as P can be determined as:

$$V_P = G * (V_{TEMP} - V_{SET}) \tag{11}$$

In final step signals P and I are summed. Output of the summing amplifier is then limited to approx. 0.65 V with R16 and D1. This voltage is available at test point CTRL.
Current flowing through each heating MOSFET can be calculated as:

$$I = \frac{V_{CTRL}}{1.8} \tag{12}$$

As the CTRL voltage is limited to 0.65 V and value of current shunt is 1.8 Ω maximum current flowing through each MOSFET can be 360 mA. With 24 V applied to the drain of MOSFET we will get maximum ~8.5 W of dissipated power per each MOSFET.

# 7. Performance of the controller

We measured performance of the controller at several conditions. Measurements were performed with five heating MOSFETs mounted to a heatsink along with four PT1000s. One separate sensor was used for measurement of the temperature. Controller was situated inside thermal chamber during all tests, so the results were influenced by controllers own thermal drifting.

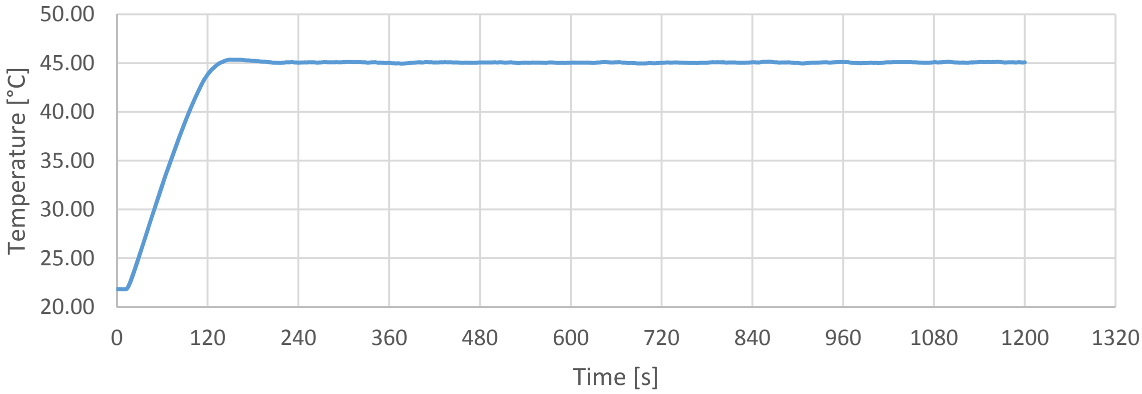



*Figure 11: Step response at constant ambient temperature 22 °C*

For the measurement shown in fig. 11, thermal chamber was set to a constant temperature of 22 °C. By the time when heatsink has stabilized at 22 °C, the controller was switched on with a set point of 45 °C. When this measurement was taken the controller has been already tuned (P and I gains).

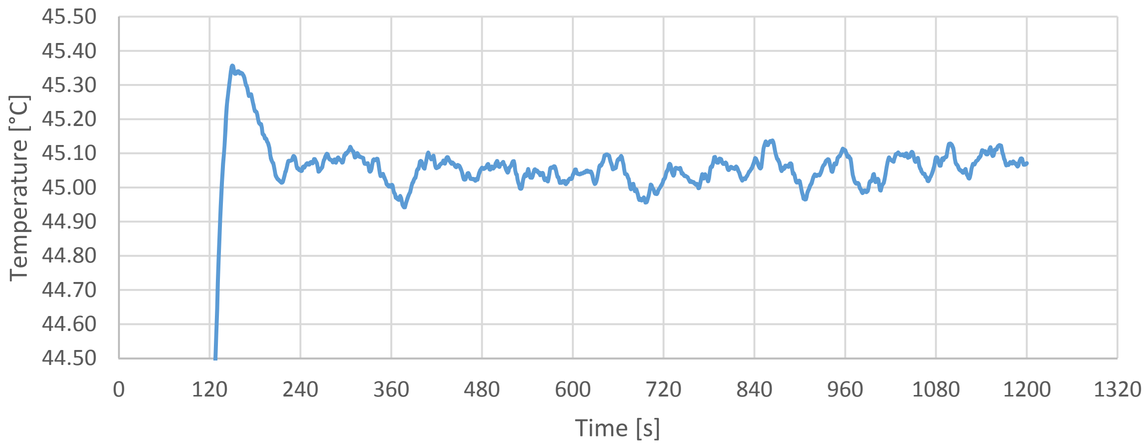



*Figure 12: Stability at constant ambient temperature 22 °C*

From the same measurement fig. 12 was extracted to show stability of regulated temperature while keeping constant ambient temperature and constant set point of temperature.

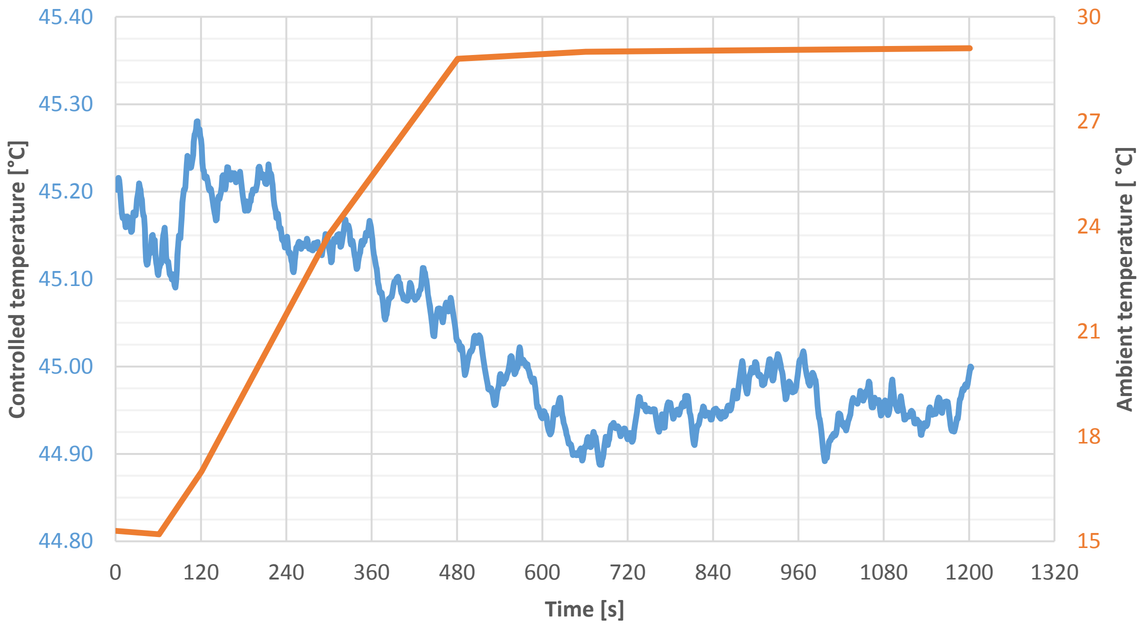



*Figure 13: Response to an external perturbation*

In the measurement shown on fig. 13 we can see response of the regulated temperature when ambient temperature increased from 15 to 29 °C. During measurement the heatsink was kept to stabilize at 15 °C and then the thermal chamber was set to heat up to 30 °C.

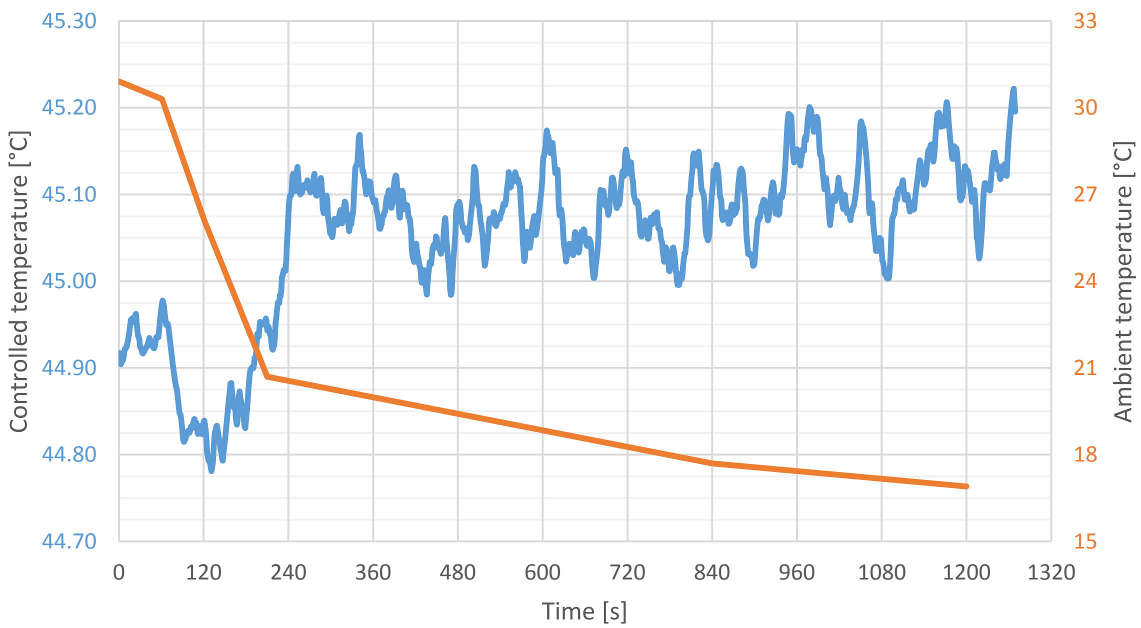



*Figure 14: Response to an external perturbation*

Measurement in fig. 14 was taken when thermal chamber was heated to 30 °C and then set to cool down to 15 °C.

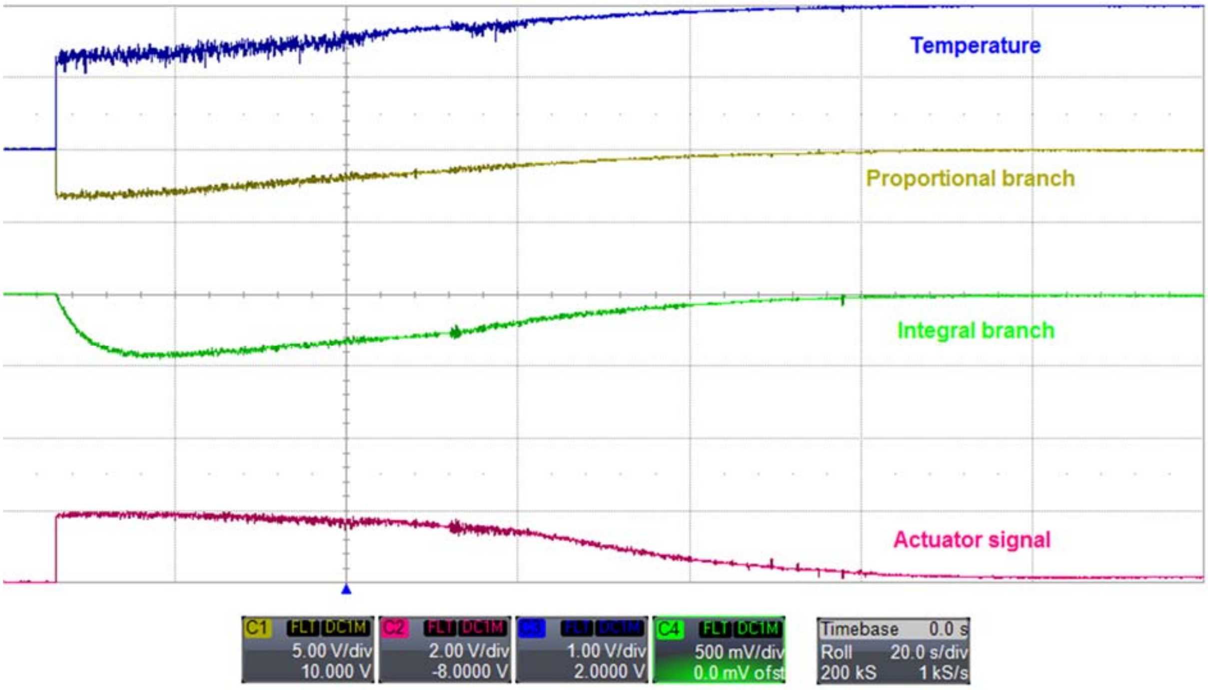



*Figure 15: Captured signal during initial heat up*

Figure 15 shows captured signal during initial heat up (from 22 to 45 °C) of a prototype circuit. Note that the signals of proportional and integral branches are inverted. They are inverted back to positive signal at summing stage. From the measurement we can see how the actuator signal was limited to a certain voltage. In this case it was 2 V (3 diodes in series). During the measurement gain of proportional branch was 5. For the integral branch the gain was 0,7.

From these measurements we can see that the controller successfully regulated temperature within given tolerance that is required to keep the delay of optical fibre constant.
With such results we could possibly reach accuracy of ±65 ps at 7 km long optical fibre.

## 8. Assembly notes

Heater boards (AED-00242 [5]) should be assembled with respect to the BOM variant A and variant B, because there is need to have 4 boards with MOSFET on one side and 4 with MOSFET on the other side, so the heat is spread evenly. For proper insulation between heater board and Al bar, a thin layer of FR4 with same outlines should be inserted between. All of the mechanical drawings and assembly with specifications can be found in attachment to this document. Important thing to notice, is that the mounting bars, which will be attached to the chassis, have to be made out of plastic/polymer, so the heat is not transferred from the enclosure to the chassis.

## References

[1] Gerd Kotzian: Design and Performance of the Upgraded SPS Damper after LS1. MSWG meeting 13.2.2015, https://indico.cern.ch/event/367094/

[2] D. Boussard, J. M. Brennan, T. P. R. Linnecar: Fixed frequency acceleration in the SPS, 1989

[3] www.ofsoptics.com

[4] AED-00241 in EDMS https://edms.cern.ch/item/AED-00241/0

[5] AED-00242 in EDMS https://edms.cern.ch/item/AED-00242/0

# Appendices

- Optical fibre datasheet
- Schematic diagram of the temperature controller board
- Schematic diagram of the heater board
- PCB layout of the temperature controller board
- PCB layout of the heater board
- BOMs
- Analogue optical fibre transceiver
- Mechanical drawings

# AllWave® FLEX Fiber

Zero Water Peak

ofs

A Furukawa Company

## A New Standard in Optimized Bend Performance and Reliable Low Loss Transmission.

## Overview

AllWave® *FLEX* ZWP Single-Mode Fiber is the first Zero Water Peak (ZWP) G.652D fiber to offer optimized bend performance for Fiber-to-the-Home (FTTX), enterprise networks, or any application where small bend diameters may be encountered. Fully compliant to the new ITU-T G.657 Class A specification, AllWave *FLEX* Fiber is completely compatible with all conventional single-mode fibers.

## Product Description

AllWave *FLEX* ZWP Fiber maintains very low bending loss across the full spectrum of wavelengths from 1260 to 1625 nm, while ensuring long-term fiber strength and reliability. It can be coiled into a 10 mm radius loop with < 0.5 dB incurred loss at 1625 nm and < 0.2 dB incurred loss at 1550 nm – five times better bend performance than conventional single-mode and leading Low Water Peak (LWP) fibers.

The macrobending and microbending loss improvements of AllWave *FLEX* ZWP Fiber offer a number of advantages for demanding access, enterprise, and central office applications. The fiber enables more compact cabinet and enclosure designs and protects the network against excessive loss resulting from inadvertent fiber bends. It is less susceptible to physical disturbances from cable flexing, pulling and crushing, as well as the intricate routing conditions within enclosures and cabinets. The optimized bend characteristics of AllWave *FLEX* ZWP Fiber also help improve cable performance in demanding high-stress and low-temperature environments by providing double the microbend protection of conventional single-mode fibers.

OFS maximizes the reliability of AllWave *FLEX* ZWP Fiber through the use of synthetic glass and our highly protective D-Lux® acrylate coating. This enables us to achieve significantly smaller bend diameters with five times lower loss and no detriment to fiber strength and long-term reliability.

AllWave *FLEX* ZWP Fiber retains all the performance benefits of OFS' AllWave ZWP Fiber, the first fiber to eliminate the water peak defect found in conventional single-mode fiber. AllWave *FLEX* ZWP Fiber has stable and permanent low loss, due to OFS' patented ZWP fiber manufacturing process, which eliminates hydrogen-aging defects. What's more, its ultra-low fiber Polarization Mode Dispersion (PMD) enables speed and distance upgrades.

**Features/Benefits:**

- Saves space, time, and money through improved bend performance, even for L-Band wavelengths up to 1625 nm: added loss < 0.5 dB (1625 nm) and < 0.2 dB (1550 nm) at 10 mm radius
- Easier to install, handle, and store in space-constrained applications such as FTTx and premises networks
- Bend optimized design for tight, low loss bends without risking fiber strength and long-term reliability
- Tight geometry for very low splice loss and improved connectorization performance with G.652D embedded base
- Fully compatible with all conventional single-mode fiber international standards including G.657 Class A and G.652D
- Zero Water Peak fiber provides a 50% increase in usable optical spectrum enabling 16-channel CWDM and DWDM support

### Outstanding Macrobend Performance

- **100 turns on a 25 mm radius mandrel**
  **≤ 0.01 dB @ 1550 nm**
  **≤ 0.05 dB @ 1625 nm**
- **10 turns on a 15 mm radius mandrel**
  **≤ 0.2 dB @ 1550 nm**
  **≤ 0.5 dB @ 1625 nm**
- **1 turn on a 10 mm radius mandrel**
  **≤ 0.2 dB @ 1550 nm**
  **≤ 0.5 dB @ 1625 nm**

## Applications:

AllWave *FLEX* ZWP Fiber provides outstanding bend performance and design freedom for fiber management systems in:

- FTTx
- The central office
- High power applications
- Analog video
- Microcables
- Drop cables
- Closures
- Field management/storage apparatus located throughout the network
- At the customer premises
- Any application with transmission speeds of 40 Gb/s and beyond

For additional information please contact your sales representative.

You can also visit our website at: www.ofsoptics.com/ofs-fiber or call 1-888-fiberhelp (from inside the USA). For regional assistance, contact the global location closest to you.

ofs
A Furukawa Company



*Doc ID: fiber-136 Publish Date: 0413*

## Product Specifications

### Physical Characteristics

| | |
|---|---|
| Clad Diameter | 125.0 ± 0.7 µm |
| Clad Non-Circularity | ≤ 0.7 % |
| Core/Clad Concentricity Error (Offset) | ≤ 0.5 µm, < 0.2 µm typically |
| Coating Diameter (Uncolored) | 235 - 245 µm |
| Coating-Clad Concentricity Error (Offset) | ≤ 12 µm |
| Tensile Proof Test *(Other proof test levels available on request)* | 100 kpsi (0.69 GPa) |
| Coating Strip Force | Range: ≥ 1.3 N < 8.9 N (≥ 0.3 lbf < 2.0 lbf) |
| Standard Reel Lengths | up to 50.4 km (31.3 miles) |

### Optical Characteristics

| Attenuation | Maximum | Typical |
|---|---|---|
| at 1310 nm | ≤ 0.35 dB/km | ≤ 0.34 dB/km |
| at 1385 nm | ≤ 0.31 dB/km | ≤ 0.28 dB/km |
| at 1490 nm | ≤ 0.24 dB/km | ≤ 0.21 dB/km |
| at 1550 nm | ≤ 0.21 dB/km | ≤ 0.19 dB/km |
| at 1625 nm | ≤ 0.24 dB/km | ≤ 0.20 dB/km |

Attenuation vs. Wavelength

| Range (nm) | Reference (nm) λ | α |
|---|---|---|
| 1285 – 1330 | 1310 | 0.03 |
| 1360 – 1480 | 1385 | 0.04 |
| 1525 – 1575 | 1550 | 0.02 |
| 1460 – 1625 | 1550 | 0.04 |

The attenuation in a given wavelength range does not exceed the attentuation of the reference wavelength (λ) by more than the value α .

| | |
|---|---|
| Attenuation Uniformity / Point Discontinuities at 1310 nm and 1550 nm | ≤ 0.05 dB |
| Chromatic Dispersion | |
| Zero Dispersion Wavelength ($\lambda_0$) | 1302 – 1322 nm |
| Zero Dispersion Slope ($S_0$) | ≤ 0.092 ps/nm²-km |
| Typical Dispersion Slope | 0.088 ps/nm²-km |
| Group Refractive Index | |
| at 1310 nm | 1.467 |
| at 1550 nm | 1.468 |
| Mode Field Diameter | |
| at 1310 nm | 8.5 – 9.3 µm |
| at 1550 nm | 9.4 – 10.4 µm (typical) |
| Cut-off Wavelength ($\lambda_{CC}$) | ≤ 1260 nm |
| Polarization Mode Dispersion (PMD)[1] | |
| Fiber PMD Link Design Value (LDV)[2] | < 0.06 ps/√km |
| Maximum Individual Fiber | < 0.1 ps/√km |
| Typical Fiber LMC PMD | < 0.02 ps/√km |

[1] As measured with low mode coupling (LMC) technique in fiber form, value may change when cabled. Check with your cable manufacturer for specific PMD limits in cable form.
[2] The PMD Link Design Value complies with IEC 60794-3, September 2001 (N = 20, Q = 0.01%). Details are described in IEC 61282-3 TR Ed 2, October 2006.

### Environmental Characteristics (at 1310, 1550 & 1625 nm)

| | |
|---|---|
| Temperature Cycling (-60º + 85º C) | ≤ 0.05 dB/km |
| High Temperature Aging (85 ± 2º C) | ≤ 0.05 dB/km |
| Temperature & Humidity Cycling (at -10º C to +85º C and 95% RH) | ≤ 0.05 dB/km |
| Water Immersion (23 ± 2º C) | ≤ 0.05 dB/km |

**North America**
Telephone: 508-347-8590
Toll Free: 800-799-7732
Fax: 508-347-1211
E-mail: fibersalesnar@ofsoptics.com

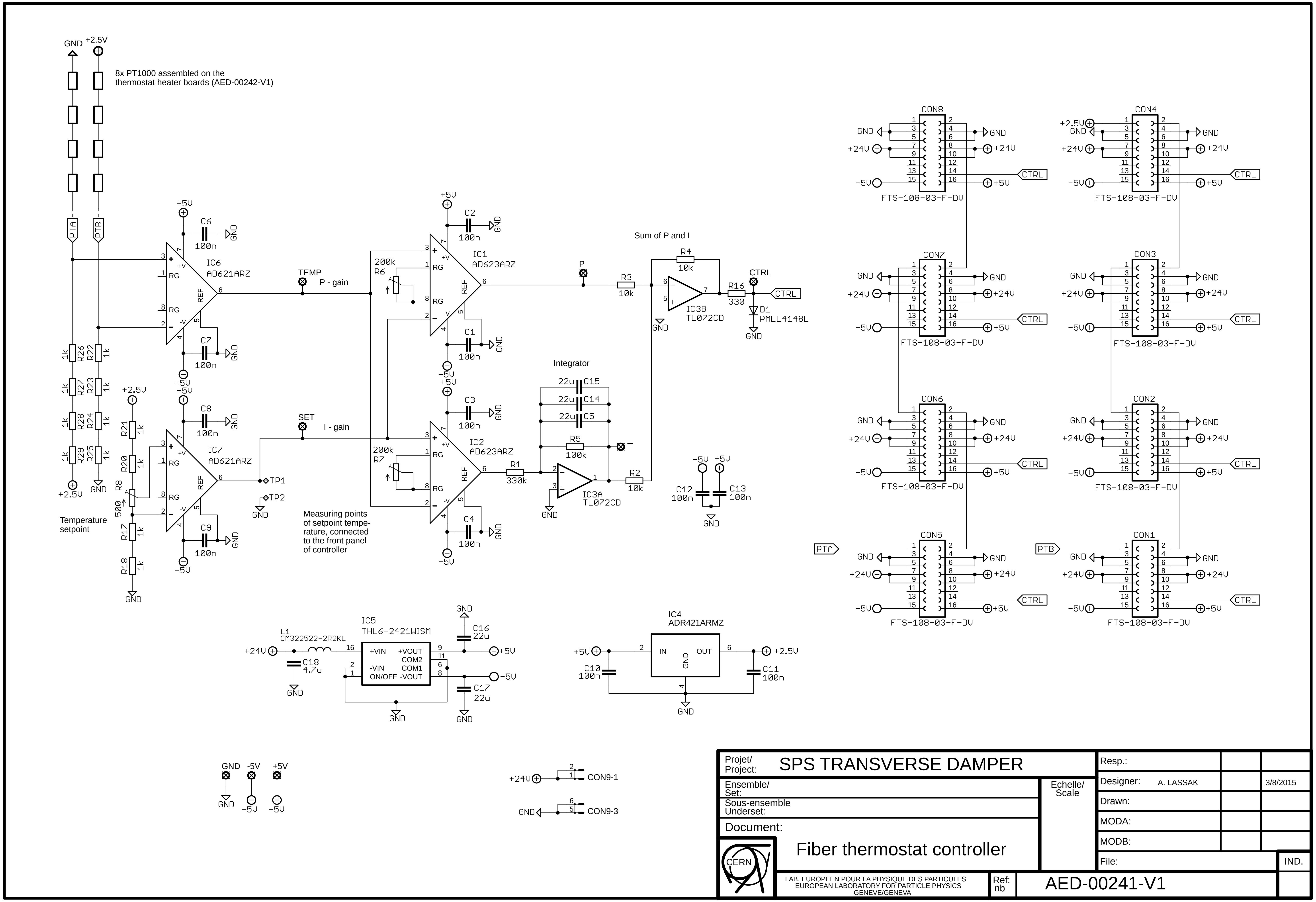
**Caribbean, Latin America**
Telephone: +1-508-347-8590
Fax: +1-508-347-1211
E-mail: fibersalescala@ofsoptics.com

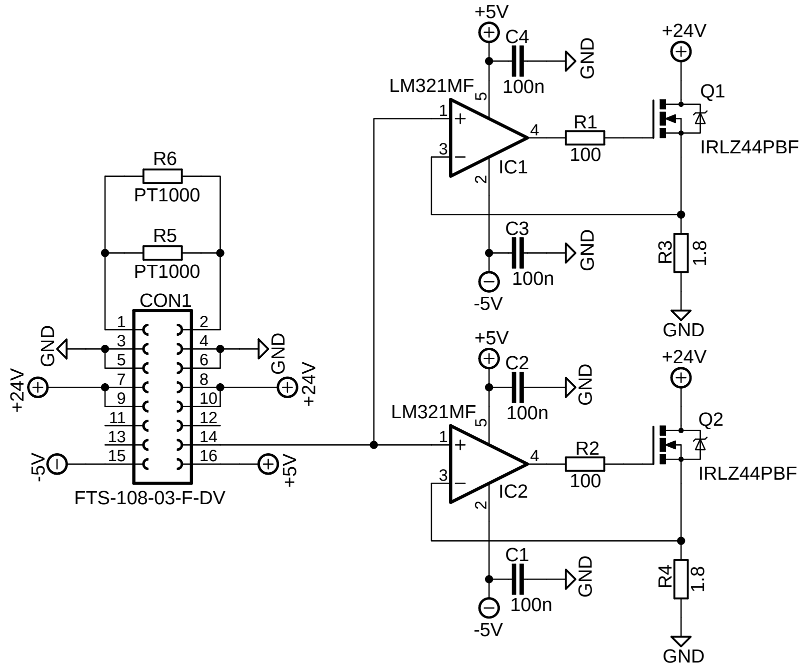
**Europe, Middle East, Africa**
Telephone: +45-43 48 3736
Fax: +45 4348 3444
E-mail: ofssalesdk@ofsoptics.com

**Asia Pacific**
Telephone: +852 2836 7102
Fax: +852 2836 7101
E-mail: fibersalesap@ofsoptics.com

**Japan**
Telephone: +81-3-3286-3424
Fax: +81-3-3286-3708 or 3190
E-mail: fibersalesjapan@ofsoptics.com

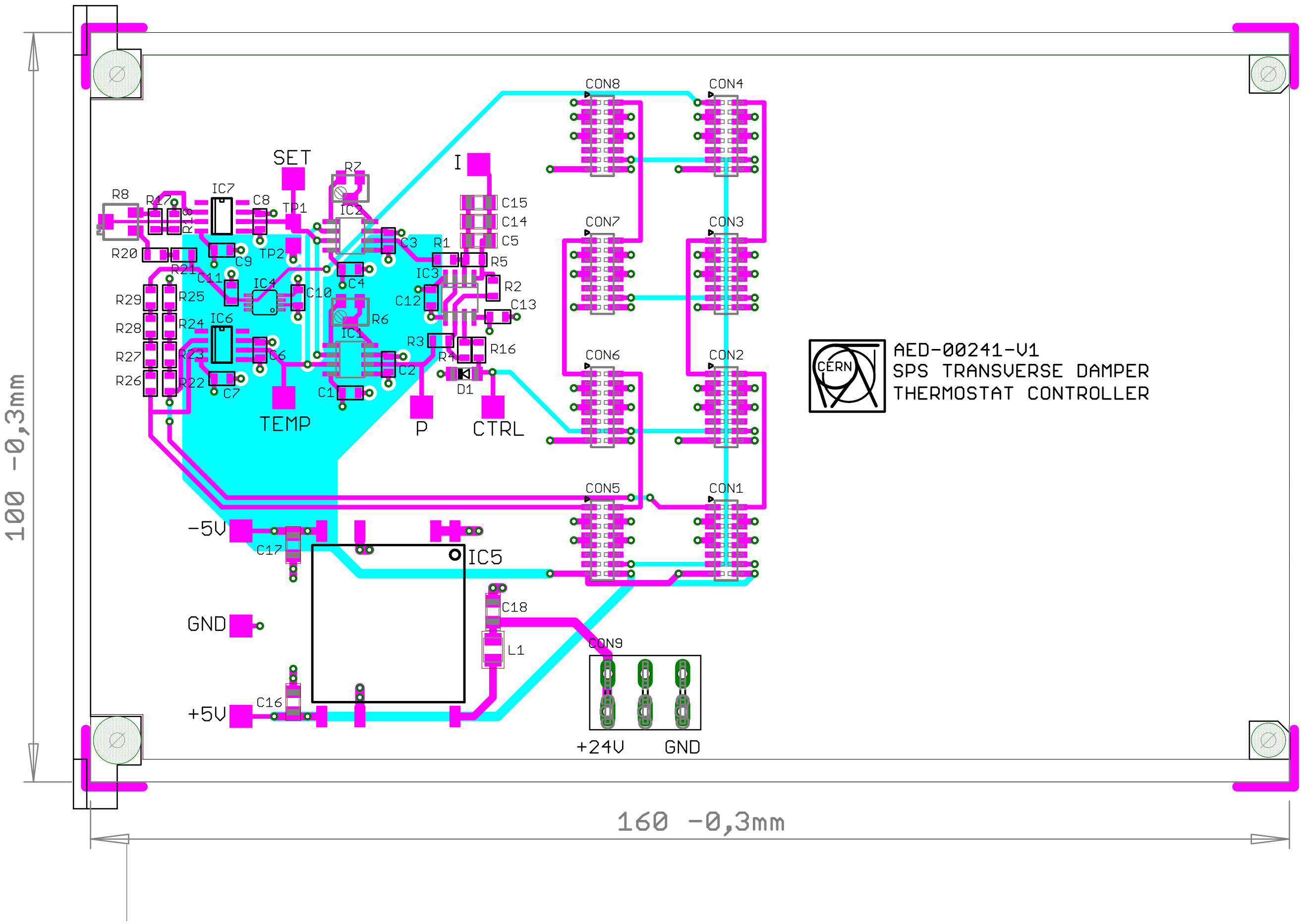
**China**
Telephone: +86 147 154 93629
Fax: +86 10 65059515
E-mail: fibersaleschina@ofsoptics.com

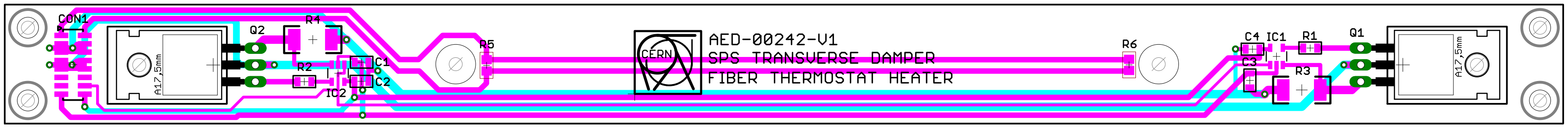

8x PT1000 assembled on the thermostat heater boards (AED-00242-V1)
PTA
PTB
IC6 AD621ARZ
IC7 AD621ARZ
IC1 AD623ARZ
IC2 AD623ARZ
IC3A TL072CD
IC3B TL072CD
TEMP
P - gain
SET
I - gain
P
CTRL
Sum of P and I
Integrator
Temperature setpoint
Measuring points of setpoint temperature, connected to the front panel of controller
TP1
TP2
D1 PMLL4148L
IC5 THL6-2421WISM
L1 CM322522-2R2KL
IC4 ADR421ARMZ
CON1
CON2
CON3
CON4
CON5
CON6
CON7
CON8
FTS-108-03-F-DV
CON9-1
CON9-3
Projet/ Project: SPS TRANSVERSE DAMPER
Ensemble/ Set:
Sous-ensemble Underset:
Document:
Fiber thermostat controller
Echelle/ Scale
Resp.:
Designer: A. LASSAK 3/8/2015
Drawn:
MODA:
MODB:
File:
IND.
CERN
LAB. EUROPEEN POUR LA PHYSIQUE DES PARTICULES
EUROPEAN LABORATORY FOR PARTICLE PHYSICS
GENEVE/GENEVA
Ref: nb
AED-00241-V1




| | | | | |
|---|---|---|---|---|
| Projet/ Project: SPS TRANSVERSE DAMPER | | Resp.: | | |
| Ensemble/ Set: | Echelle/ Scale | Designer: A. LASSAK | | 3/8/2015 |
| Sous-ensemble Underset: | | Drawn: | | |
| Document: | | MODA: | | |
| Fiber thermostat heater | | MODB: | | |
| | | File: | | IND. |
| LAB. EUROPEEN POUR LA PHYSIQUE DES PARTICULES<br>EUROPEAN LABORATORY FOR PARTICLE PHYSICS<br>GENEVE/GENEVA | Ref: nb | AED-00242-V1 | | |

CERN


AED-00241-V1
SPS TRANSVERSE DAMPER
THERMOSTAT CONTROLLER
CERN
SET
TEMP
P
CTRL
I
-5V
GND
+5V
IC5
+24V
GND
100 -0,3mm
160 -0,3mm


AED-00242-V1
SPS TRANSVERSE DAMPER
FIBER THERMOSTAT HEATER
CERN
CON1
Q2
R4
R2
C1
C2
IC2
R5
R6
C4
IC1
R1
Q1
C3
R3
A17,5mm

# Thermostat controller (AED-00241-V1), bill of materials

| Qty | Value | Package | Parts | Description |
|---|---|---|---|---|
| 1 | 100k | 0805 | R5 | |
| 12 | 100n | 0805 | C1, C2, C3, C4, C6, C7, C8, C9, C10, C11, C12, C13 | |
| 3 | 10k | 0805 | R2, R3, R4 | |
| 12 | PCF0805-13-1K-B-T1 | 0805 | R17, R18, R20, R21, R22, R23, R24, R25, R26, R27, R28, R29 | 1k, 0.1%, 5ppm/°C |
| 2 | 3224W-1-204E | 3224W | R6, R7 | 200k |
| 5 | 22u | 1206 | C5, C14, C15, C16, C17 | 22uF, 10V, X7R |
| 1 | 330 | 0805 | R16 | |
| 1 | 330k | 0805 | R1 | |
| 1 | 4.7u | 1206 | C18 | 4.7uF, 50V, X7R |
| 1 | 3224J-1-501E | 3224J | R8 | 500R |
| 2 | AD621ARZ | SO8 | IC6, IC7 | |
| 2 | AD623ARZ | SO8 | IC1, IC2 | |
| 1 | ADR421ARMZ | MSOP08 | IC4 | |
| 1 | CM322522-2R2KL | 1210 | L1 | 2.2uH |
| 8 | FTS-108-03-F-DV | | CON1, CON2, CON3, CON4, CON5, CON6, CON7, CON8 | 2x8 pin header, 1.27mm, SMD |
| 1 | 3x 6.3x0.8mm | FASTON | CON9 | FASTON 6,3x0,8mm |
| 1 | PMLL4148L | SOD80C | D1 | |
| 1 | THl6-2421WISM | THL6-WISM | IC5 | DC-DC ±5V |
| 1 | TL072CD | SO08 | IC3 | |

# Thermostat heater (AED-00242-V1), bill of materials

## Variant A

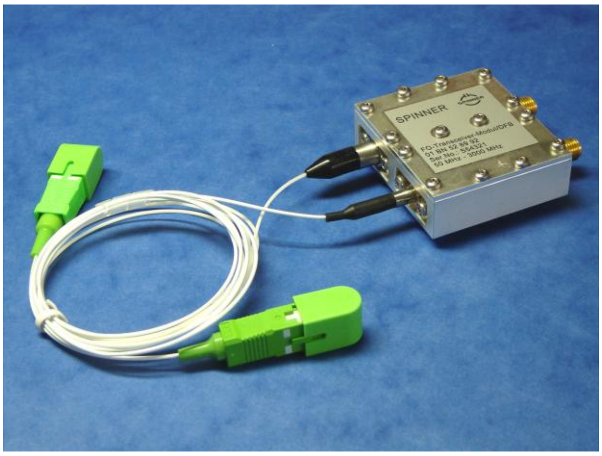
| Part | Value | Package | Description |
|---|---|---|---|
| C1 | 100n | 0805 | |
| C2 | 100n | 0805 | |
| C3 | 100n | 0805 | Not assembled |
| C4 | 100n | 0805 | Not assembled |
| CON1 | FTS-108-03-F-DV | FE08-2-127-SMD | |
| IC1 | LM321MF | SOT23-5 | Not assembled |
| IC2 | LM321MF | SOT23-5 | |
| Q1 | IRLZ44PBF | TO220BH | Not assembled |
| Q2 | IRLZ44PBF | TO220BH | |
| R1 | 100 | 0805 | Not assembled |
| R2 | 100 | 805 | |
| R3 | 1.8 | 2512 | Not assembled |
| R4 | 1.8 | 2512 | |
| R5 | P1K0.232.6W.B.010 | | Not assembled |
| R6 | P1K0.232.6W.B.010 | | PT1000 |

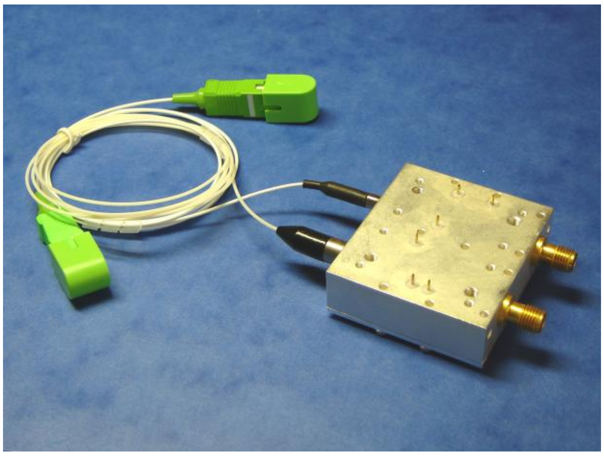
# Thermostat heater (AED-00242-V1), bill of materials

## Variant B

| Part | Value | Package | Description |
|---|---|---|---|
| C1 | 100n | 0805 | Not assembled |
| C2 | 100n | 0805 | Not assembled |
| C3 | 100n | 0805 | |
| C4 | 100n | 0805 | |
| CON1 | FTS-108-03-F-DV | FE08-2-127-SMD | |
| IC1 | LM321MF | SOT23-5 | |
| IC2 | LM321MF | SOT23-5 | Not assembled |
| Q1 | IRLZ44PBF | TO220BH | |
| Q2 | IRLZ44PBF | TO220BH | Not assembled |
| R1 | 100 | 0805 | |
| R2 | 100 | 805 | Not assembled |
| R3 | 1.8 | 2512 | |
| R4 | 1.8 | 2512 | Not assembled |
| R5 | P1K0.232.6W.B.010 | | PT1000 |
| R6 | P1K0.232.6W.B.010 | | Not assembled |

# Analog Fiber Optic Link



Die SPINNER FO-Transceiver Module BN 528992 werden eingesetzt, um analoge HF-Signale über Glasfaser zu übertragen. Diese qualitativ hochwertigen, bewährten und zuverlässigen Module verkürzen dabei die Entwicklungszeit des Gesamtsystems enorm und verhelfen somit zu drastisch reduzierten Entwicklungskosten. Da diese Module fertig abgeglichen und geprüft geliefert werden, reduzieren sich auch die Herstellkosten. Aufgrund ihrer kompakten Bauweise lassen sie sich sehr einfach integrieren und bieten dem Entwickler ein Höchstmass an Flexibilität beim Einsatz in seinem System.

Die im Transceiver verwendete DFB Laser-Diode zeichnet sich durch ihre hohe Linearität und den daraus resultierenden geringen Intermodulationsverzerrungen aus. Aufgrund des in der Laser-Diode integrierten Isolators, werden hervorragende Rauschwerte, auch im unteren Frequenzbereich, erzielt.

Der Empfänger ist mit einer hochlinearen, rauscharmen PIN-Diode ausgestattet. Zur Verstärkung des Ausgangssignales ist der Empfänger bereits mit einem LNA ausgerüstet.

The SPINNER FO-Transceiver Modules BN 528992 are used to transmit analog RF signals over Fiber Optics. These proven modules offer very high quality and best reliability. While integrating in a system, time of development as well as the costs of development are dramatically reduced. These modules come completely tuned and tested. Hence the production costs are also lessened. Due to the small and compact design, they can be easily integrated in each system and offer a maximum of flexibility to the design engineer.

The herein used DFB-type laser diode provides excellent linearity. This is the reason for the very low intermodulation distortion. Due to the integrated optical isolator, the noise figure is significantly small, even in the lower frequency range.

The Receiver is equipped with a PIN diode, which is characterized by a very low noise and high linearity. For amplifying the output signal, the Receiver is equipped with a LNA.

**Anwendungsbereiche**

Speisung abgesetzter Antennen
Antennenverteilsysteme - DAS
Versorgungsnetzwerk für Tunnelfunk
Sat-Dienste im L-Band

**Fields of Application**

Feeding of Remote Antennas
Distributed Antenna Systems – DAS
Wireless services in underground areas
Sat Services

## Technische Daten [1] Technical Data [1]

| | |
|---|---|
| Technologie/ Technology | DFB Laser Diode |
| Wellenlänge<br>Wavelength | 1310 nm, Transmitter<br>1200 … 1600 nm, Receiver |
| 3 dB Bandbreite<br>3 dB Bandwidth | 50 MHz … 2700 MHz |
| Optische Ausgangsleistung<br>Optical Output Power | + 3 dBm @ $I_{Laser}$ = 35 mA typ. |
| Welligkeit<br>Flatness (850 MHz…950 MHz) | ± 0.3 dB |
| Welligkeit<br>Flatness (1700 MHz…1900 MHz) | ± 0.5 dB |
| System Gewinn @ 900 MHz [2]<br>System Gain @ 900 MHz [2] | 5 dB ±3 dB |
| HF-Eingangspegel [3]<br>RF-Input Power [3] | 0 dBm nom.; +3 dBm max. |
| Äquivalente Eingangsrauschleistung [4/5]<br>Equivalent Input Noise (EIN) [4/5] | ≤ 140 dBm/Hz |
| Intermodulation 2. Ordnung [6]<br>Intermodulation 2 (IICP2) [6] | > + 36 dBm |
| Intermodulation 3. Ordnung [7]<br>Intermodulation 3 (IICP3) [7] | > + 27 dBm |
| Isolation Sender auf Empfänger<br>Isolation Transmitter to Receiver | ≤ -90 dB<br>≤ -95 dB typ. |
| Laser-Diode<br>Forward Voltage (LD)<br>Forward Current (LD)<br>Reverse Voltage (PD)<br>Reverse Current (PD) | <br>2 V max.<br>100 mA max.<br>20 V max.<br>2 mA max. |
| Photo-Diode<br>Reverse Voltage<br>Forward Current<br>Saturation Input Power | <br>25 V max.<br>10 mA max.<br>+10 dBm max. |
| $I_{TX-AMP1}$<br>$I_{RX-AMP1}$<br>$I_{RX-AMP2}$ | ≤ 70 mA @ 5.5 V DC<br>≤ 65 mA @ 5.5 V DC<br>≤ 70 mA @ 5.5 V DC |
| Betriebstemperatur<br>Operation Temperature | -10 °C … +45 °C |
| Fasertyp, Stecker<br>Fiber, Connector | SM 9/125, SC/APC |
| HF-Stecker, RF-Ports | SMA female; 50 Ω; VSWR < 2 |
| Gewicht / Weight | ca. 70 g |
| Eingehaltene Normen, Standards | EN 60 825-2, Class 3R |

1) Typische Werte @ Umgebungstemperatur von + 25 °C.
2) Die aus der optischen Dämpfung resultierende elektrische Dämpfung ist doppelt so hoch wie die optische Dämpfung.
3) Bei Überschreiten der maximalen Eingangsleistung arbeitet der Laser außerhalb seines linearen Bereiches und erzeugt verstärkt Nebenwellen.
4) Gemessen bei 500 MHz und einer Streckendämpfung von 0,3 dB.
5) Die angegebenen Daten können nur mit reflexionsarmen Steckverbindern erreicht werden.
6) Gemessen mit 2 Trägern von 936 MHz und 958 MHz, mit einem Eingangspegel von jeweils -10 dBm.
7) Gemessen mit 2 Trägern von 1770 MHz und 1810 MHz, mit einem Eingangspegel von jeweils -10 dBm.

1) Typical values @ $T_{Amb}$ = + 25 °C.
2) The electrical attenuation is double the value of the optical loss.
3) If the power is higher than specified, then the laser starts clipping and generates intermodulation distortions.
4) Measured at a frequency of 500 MHz and an optical loss of 0.3 dB.
5) Specified values can only be met with low back reflection connectors.
6) Tested with 2 tones of 936 MHz and of 958 MHz and the $P_{IN}$ of -10 dBm each.
7) Tested with 2 tones of 1770 MHz and of 1810 MHz and the $P_{IN}$ of -10 dBm each.

**Optionen**

Module mit FP-Laser Dioden für kostenkritische Anwendungen.

Module mit 1550 nm DFB Laserdioden für WDM Anwendungen.

Steuerungsbaugruppen lieferbar.

Evaluation Board zum Testen der Module ist lieferbar.

**Options**

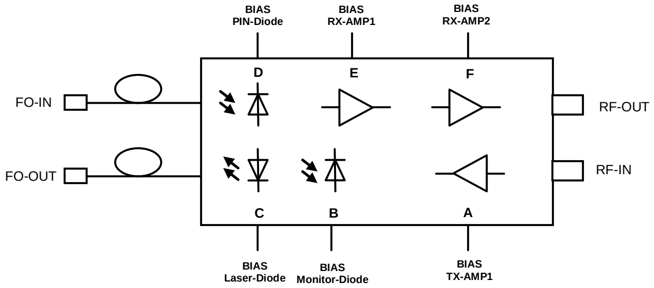
Modules equipped with FP-type Laser Diodes for low cost applications.

Modules equipped with 1550 nm DFB-type Laser Diodes.

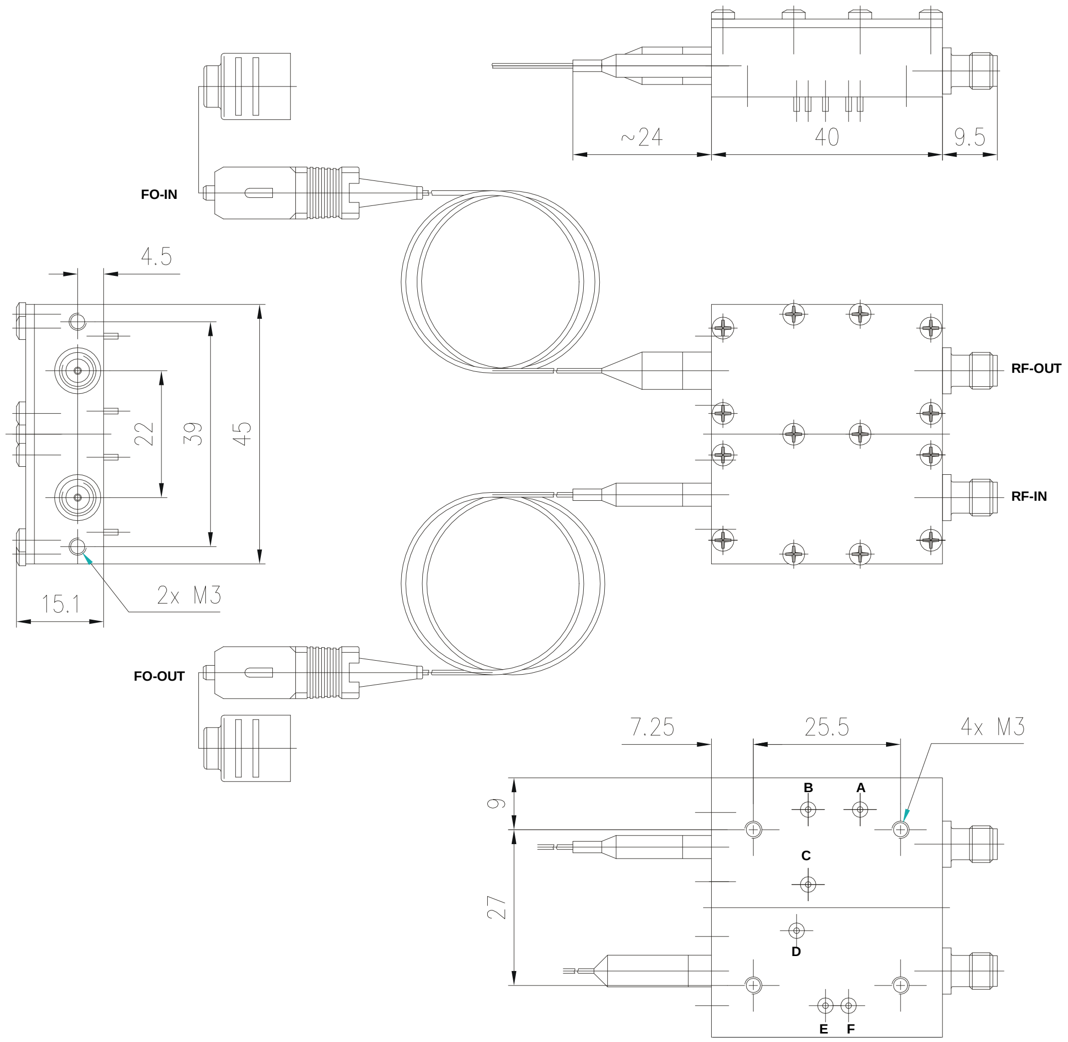
Control electronics subassemblies deliverable.

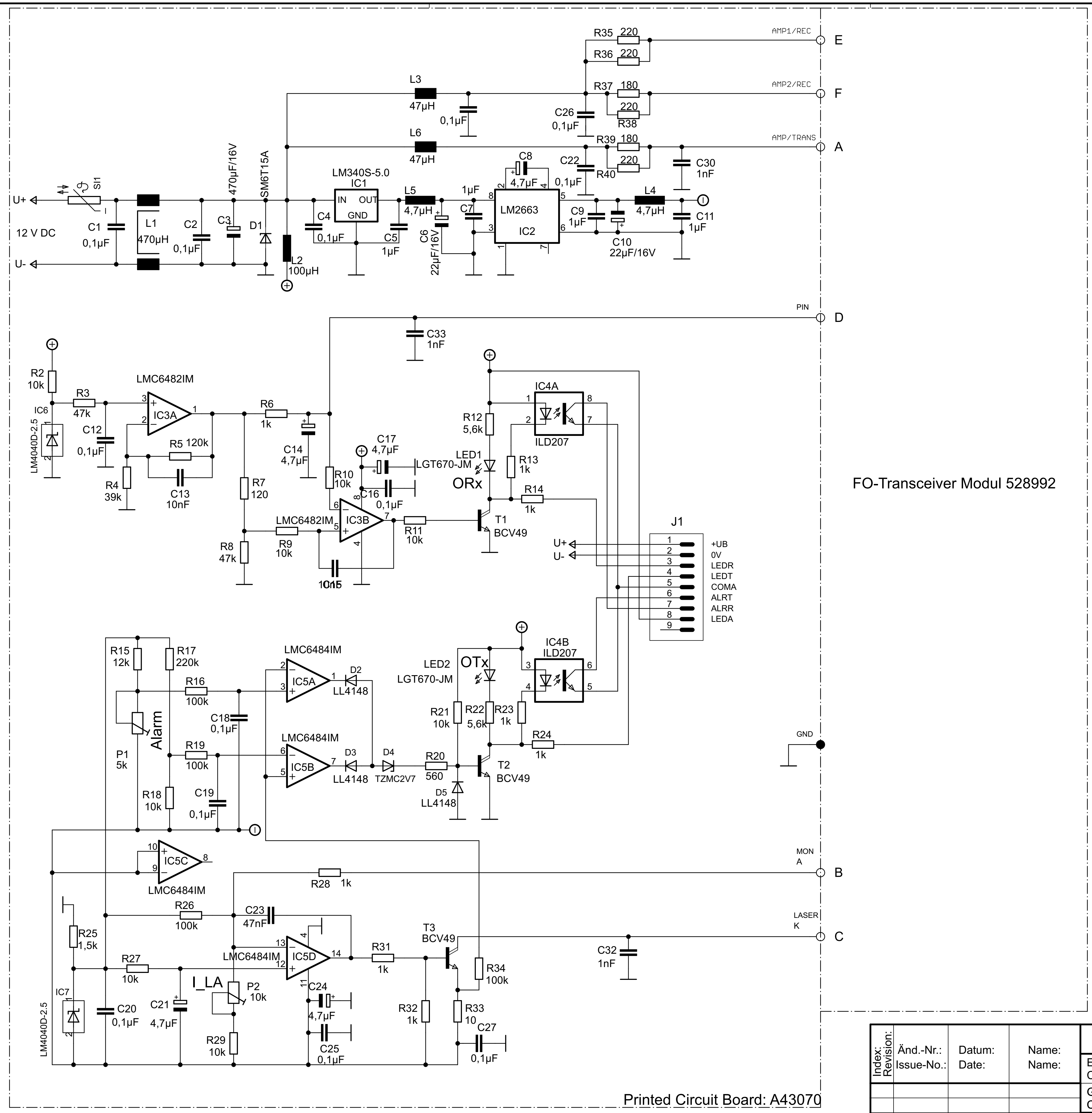
Evaluation Board is available.

## Blockdiagramm / Block diagram



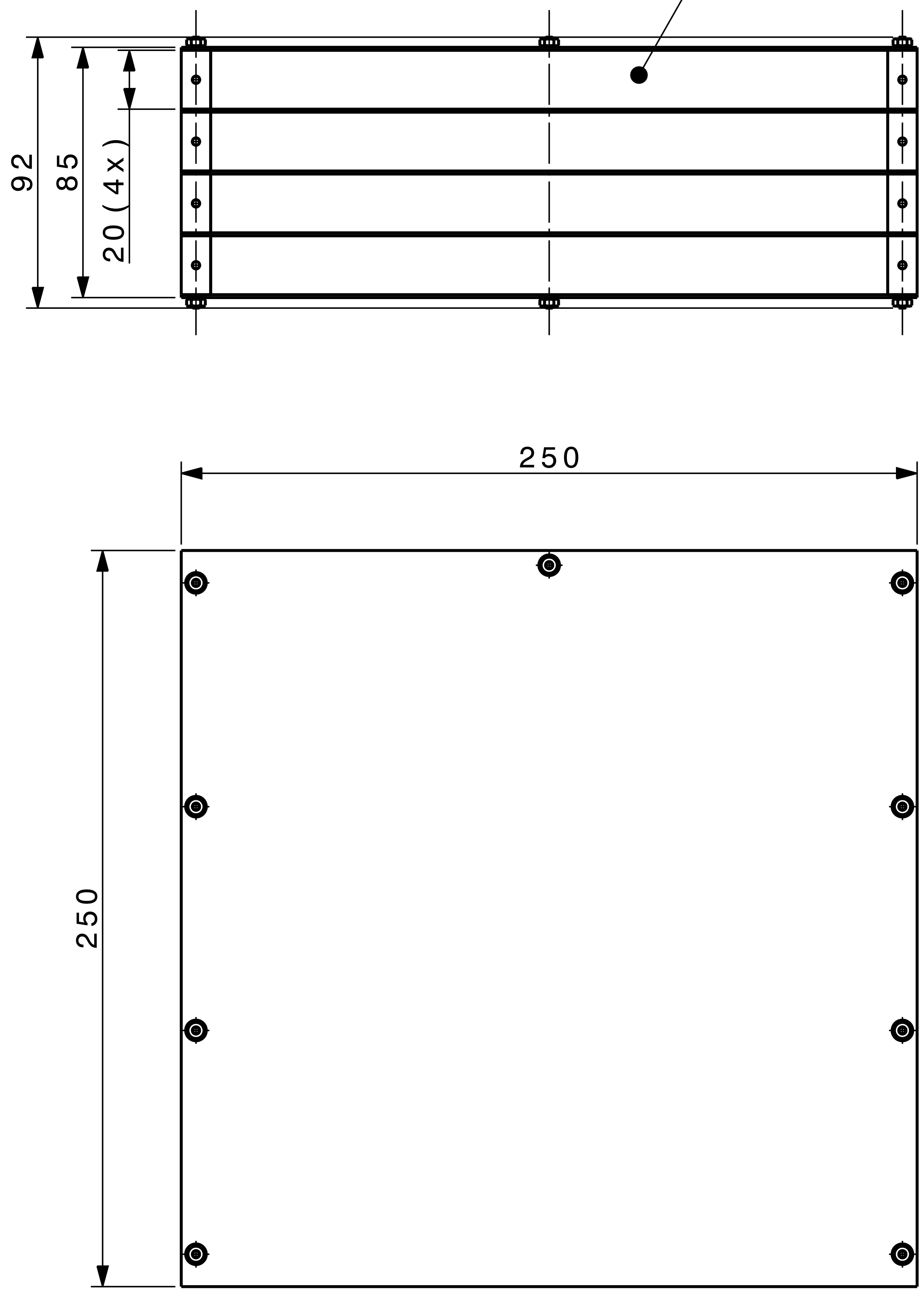

## Ansichtszeichnung / Mechanical Drawing

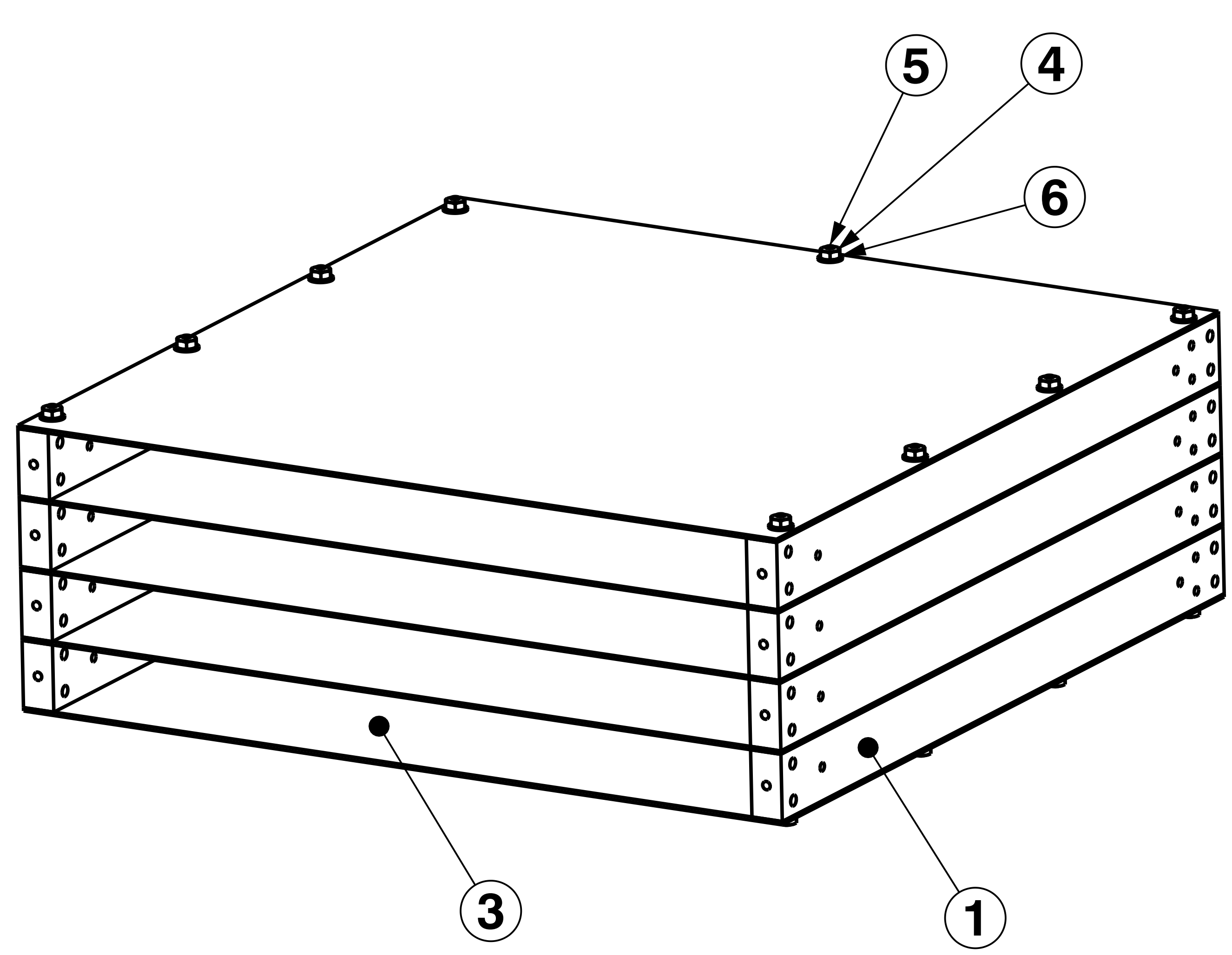





| Index: Revision: | Änd.-Nr.: Issue-No.: | Datum: Date: | Name: Name: | | Datum: Date: | Name: Name: | Bezeichnung: Title: |
|---|---|---|---|---|---|---|---|
| | | | | Erstellt: Creator: | 18.10.10 | Huber | Circuit Diagram FO-Transceiver Transceiver module 528992 + Evaluation board |
| | | | | Geprüft: Checked: | 08.07.13 | Stiglmayr | |
| B | | 08.07.13 | Lege | SPINNER | Spinner GmbH Erzgiessereistr. 33 D-80335 München | | Zeichnungs-Nr.: Drawing-No.: 528994-CD |
| A | | 18.10.10 | Huber | | | | |

Maßstab: Scale: 1:1 | Format: Format: A3 | Blatt: Sheet: 1 | von: of: 1




| QUA | DESCRIPTION | POS | MAT. | OBSERVATIONS | REF.CERN |
|---|---|---|---|---|---|
| 18 | NORMAL PL WASHER 3X7<br>RONDELLE PLATE NORMALE 3X7 | 6 | Stainless Steel A4<br>Acier Inox A4 | ISO 7089_3x7-A4 | 47.78.15<br>003.3 |
| 9 | threaded rod_M3_L92mm | 5 | Steel EN S235JR<br>(1.0037) | ST0701709 | |
| 18 | HEX NUT STYLE1 GRADE A M3<br>ECROU H STYLE1 GRADE A M3 | 4 | Stainles Steel A4<br>Acier Inox A4 | ISO 4032_M3-A4 | 47.43.77<br>030.3 |
| 5 | cover-plate | 3 | Alu EN AW-6060<br>(T6) | ST0701657 | |
| 4 | frame_pt2 | 2 | Alu EN AW-6060<br>(T6) | ST0701608 | |
| 8 | frame_pt1 | 1 | Alu EN AW-6060<br>(T6) | ST0701601 | |

| | |
|---|---|
| ENS/ASS | S.ENS/S.ASS |

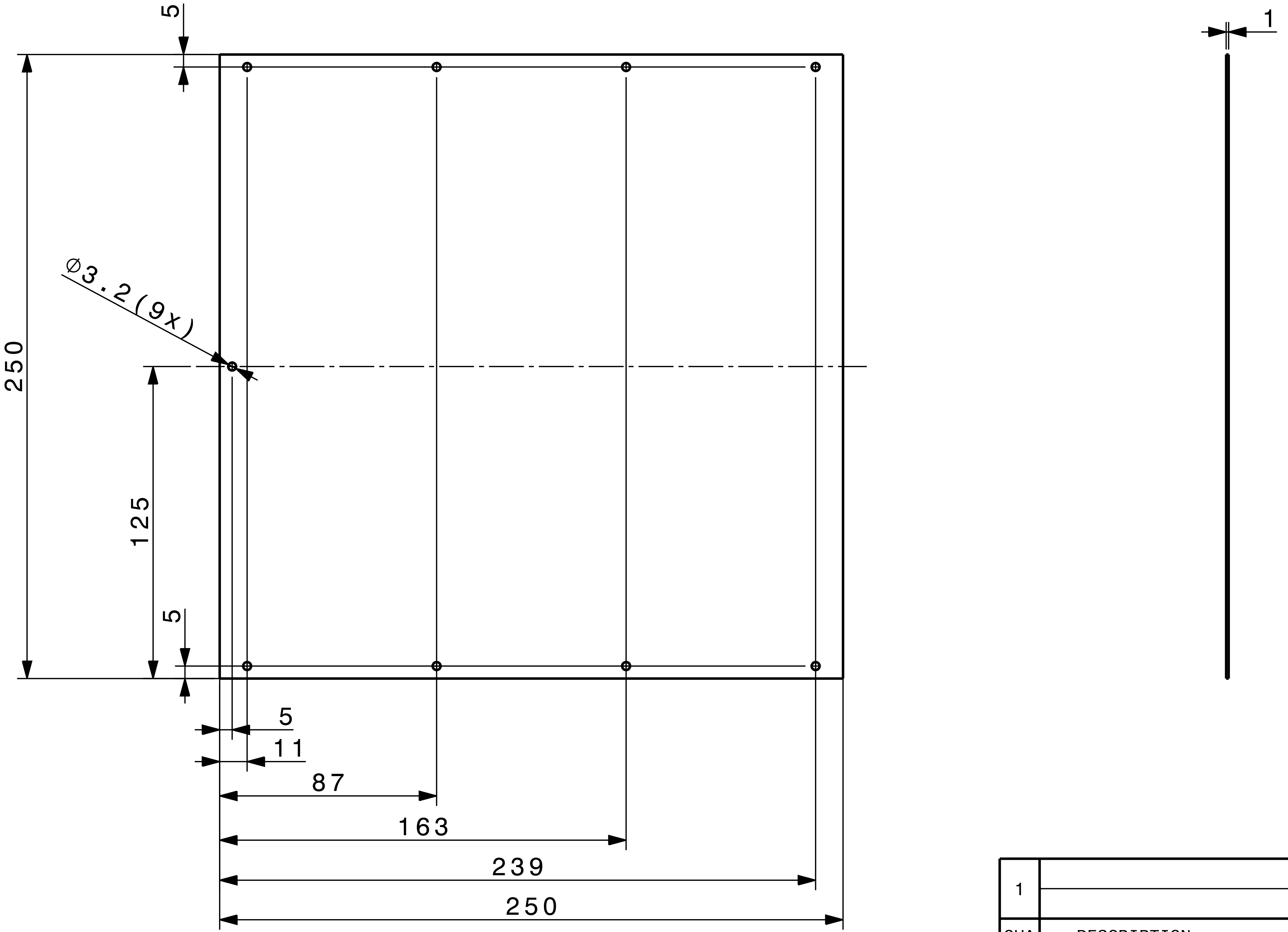
| | | | |
|---|---|---|---|
| frame_main-assembly | SCALE 1:2 | DRAWN | P. Hofer 2015-08-11 |
| | | CONTROLLED | |
| | | RELEASED | |
| | | APPROVED | |
| | | CAD Document Number | ST0701600_02 |
| | | REPLACES | |

| | | | |
|---|---|---|---|
| CERN | NON VALABLE POUR EXECUTION<br>NOT VALID FOR EXECUTION | QAC - | SIZE 3 / IND. |

DESSIN, RUGOSITE, TOLERANCES SELON NORMES ISO
DRAWING, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARDS

PROJECTION

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
GENEVE




| | | | | | |
|---|---|---|---|---|---|
| 1 | | 1 | Alu EN AW-6060 (T6) | | |
| QUA | DESCRIPTION | POS | MAT. | OBSERVATIONS | REF.CERN |

ENS/ASS | S.ENS/S.ASS

ISO 2768-mK-E | Ra 0.8 | ISO 13715 -0.3 +0.3

# cover-plate

| | | |
|---|---|---|
| DRAWN | P. Hofer | 2015-08-11 |
| CONTROLLED | | |
| RELEASED | | |
| APPROVED | | |
| CAD Document Number | ST0701657_02 | |
| REPLACES | | |

SCALE 1:1

NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION

QAC -

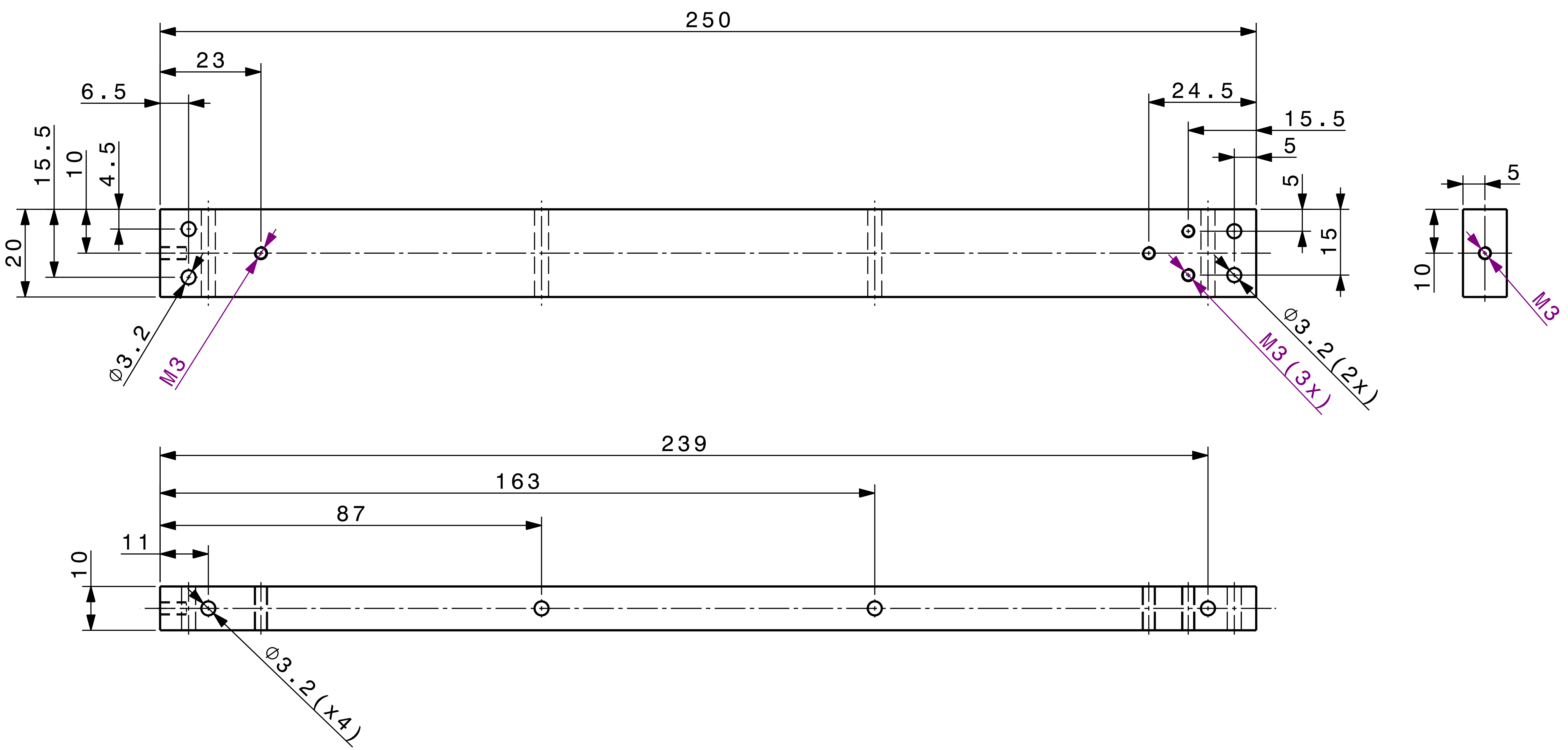
SIZE 3

IND.

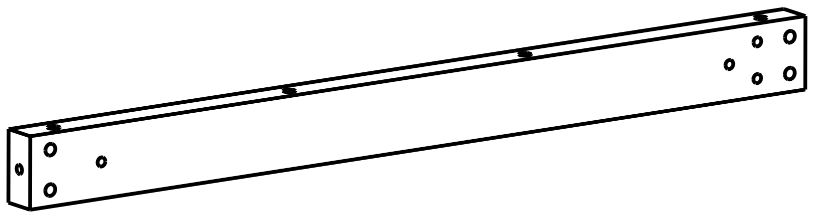
DESSIN, RUGOSITE, TOLERANCES SELON NORMES ISO
DRAWING, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARDS

PROJECTION

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
GENEVE




## Isometric view
## 1:2



| | | | | | |
|---|---|---|---|---|---|
| 1 | | 1 | Alu EN AW-6060 (T6) | | |
| QUA | DESCRIPTION | POS | MAT. | OBSERVATIONS | REF.CERN |

| | |
|---|---|
| ENS/ASS | S.ENS/S.ASS |
| ISO 2768-mK-E | Ra 0.8 |
| ISO 13715 -0.3 +0.3 | |

| | | | | |
|---|---|---|---|---|
| frame_pt1 | SCALE 1:1 | DRAWN | P. Hofer | 2015-08-11 |
| | | CONTROLLED | | |
| | | RELEASED | | |
| | | APPROVED | | |
| | | CAD Document Number | ST0701601_02 | |
| | | REPLACES | | |

NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION

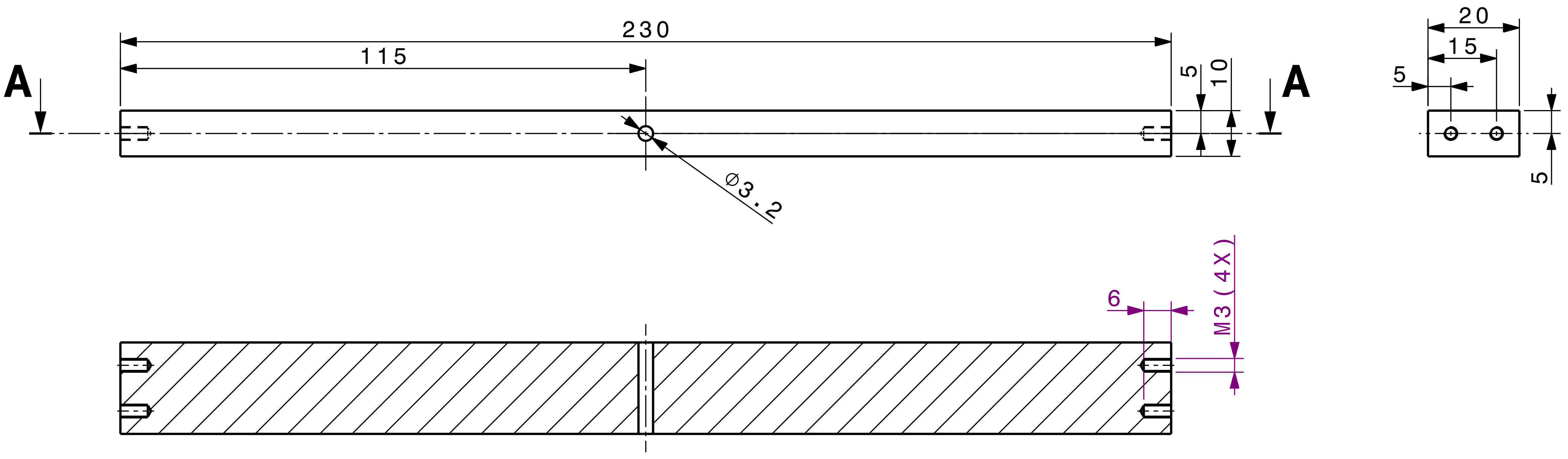
QAC -

SIZE 3 IND.

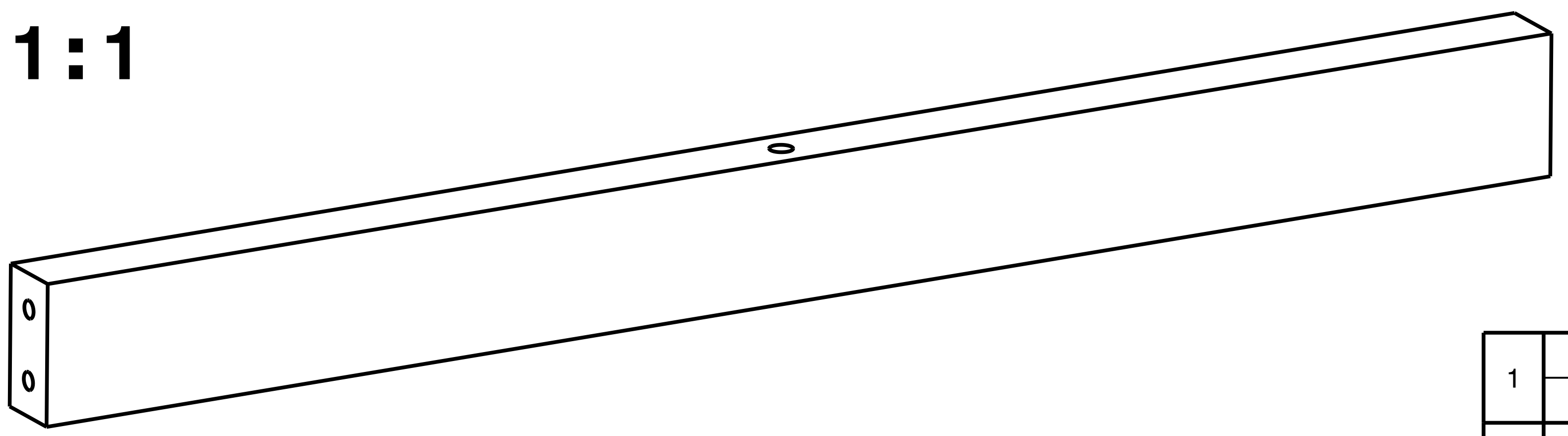
DESSIN, RUGOSITE, TOLERANCES SELON NORMES ISO
DRAWING, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARDS

PROJECTION

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
GENEVE




## Isometric view 1:1



DESSIN, RUGOSITE, TOLERANCES SELON NORMES ISO
DRAWING, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARDS

PROJECTION

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
GENEVE



| QUA | DESCRIPTION | POS | MAT. | OBSERVATIONS | REF.CERN |
|---|---|---|---|---|---|
| 1 | | 1 | Alu EN AW-6060 (T6) | | |

ENS/ASS | S.ENS/S.ASS

ISO 2768-mK-E | Ra 0.8 | ISO 13715 -0.3 +0.3

| | | |
|---|---|---|
| DRAWN | P. Hofer | 2015-08-11 |
| CONTROLLED | | |
| RELEASED | | |
| APPROVED | | |
| CAD Document Number | ST0701608_02 | |
| REPLACES | | |

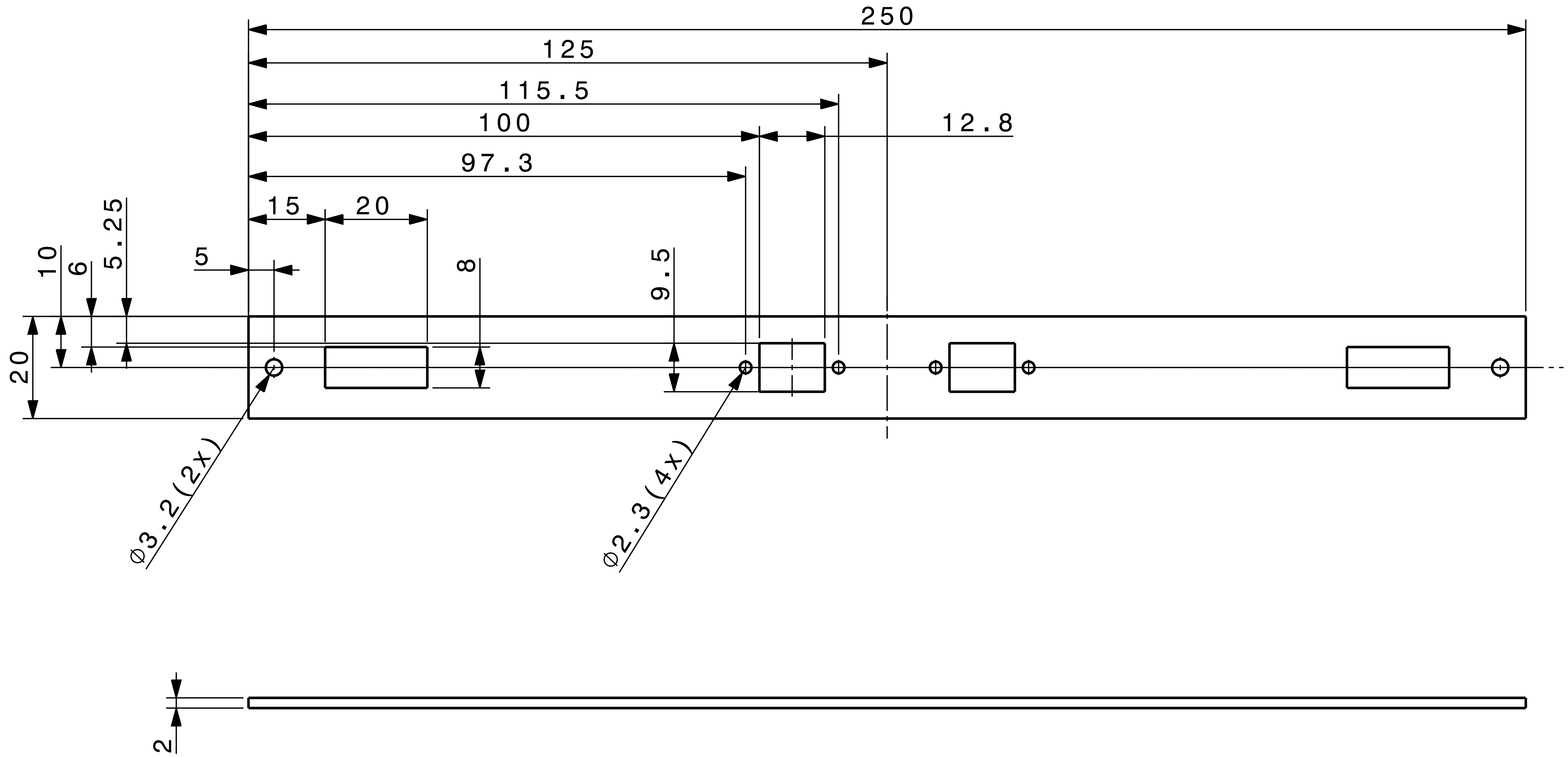
frame_pt2

SCALE 1:1

NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION

QAC -

SIZE 3 | IND.




DESSIN, RUGOSITE, TOLERANCES SELON NORMES ISO
DRAWING, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARDS

PROJECTION

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
GENEVE



| QUA | DESCRIPTION | POS | MAT. | OBSERVATIONS | REF.CERN |
|---|---|---|---|---|---|
| 1 | | 1 | Alu EN AW-6060 (T6) | | |

ENS/ASS
S.ENS/S.ASS

ISO 2768-mK-E
Ra 0.8
ISO 13715 -0.3 +0.3

# front-panel

SCALE 1:1

DRAWN P. Hofer 2015-08-13
CONTROLLED
RELEASED
APPROVED
CAD Document Number ST0702747_02
REPLACES

NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION

QAC -

SIZE 3
IND.

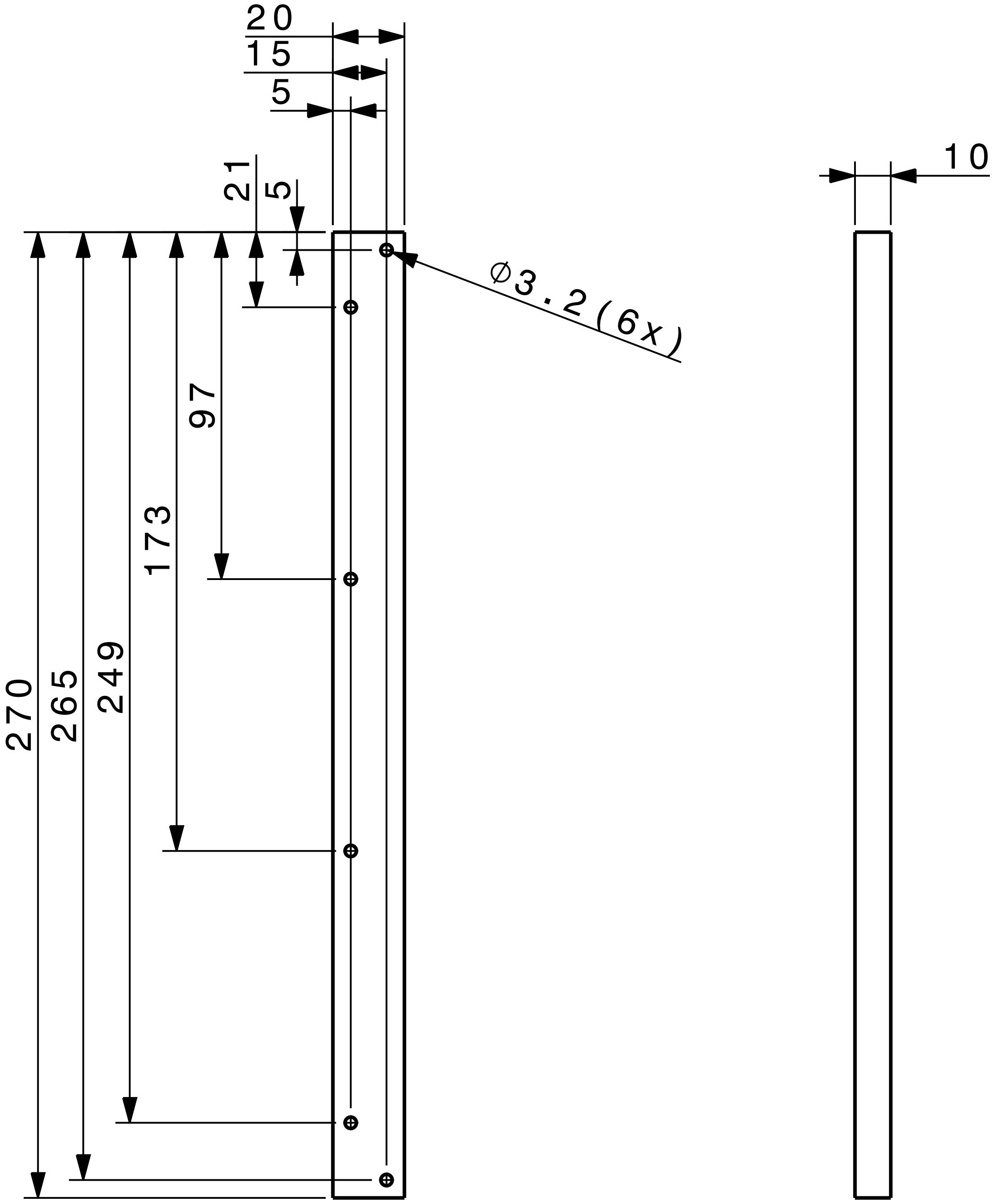
e d c b a

7 6 5 4 3 2 1

DESSIN, RUGOSITE, TOLERANCES SELON NORMES ISO

DRAWING, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARDS

PROJECTION




| | | | | | |
|---|---|---|---|---|---|
| 1 | | 1 | Polyethylene (PE) | | |
| QUA | DESCRIPTION | POS | MAT. | OBSERVATIONS | REF.CERN |

| | |
|---|---|
| ENS/ASS | S.ENS/S.ASS |

ISO 2768-mK-E — Ra 0.8 — ISO 13715 -0.3 +0.3

# mounting-bar

| | | |
|---|---|---|
| SCALE | DRAWN | |
| | CONTROLLED | |
| | RELEASED | |
| | APPROVED | |
| | CAD Document Number | ST0702725_02 |
| | REPLACES | |

NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION

QAC — SIZE — IND.


ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
GENEVE
CERN