# Specification for the Pixel DCS ASIC: Monitoring Of Pixel System


### *Abstract*

To avoid confusion with previous Pixel DCS ASICs, a completely new name was given to the pixel DCS ASIC: Monitoring Of Pixel System (MOPS).

MOPS is the on-detector component of the ITk pixel detector control system (DCS). It is an ASIC to monitor the voltages and temperatures of an SP-chain. It is located at PP0/EoS card. For communication to the off-detector DCS a modified CAN network is used. The concept of the CAN high-speed is used however the physical layers will work at lower voltages.

By these means the ASIC provides independent monitoring data, which do not rely on the DAQ to be up and running.



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| Revision History | | | |
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| **Rev. No.** | **Proposed Date / Approved Date** | **Description of Changes** (Include section numbers or page numbers if appropriate) | **Proposed By: author / Approved By: reviewer** |
| 1.0 | P: April 11, 2019 | Initial version | P: R. Ahmad<br>P: M. Karagounis<br>P: S. Kersten<br>P: N. Lehmann<br>P: C. Zeitnitz |
| 1.0 | July 10, 2019 | CANbus voltage reduced to 1.2V | |
| 1.0 | July 22, 2019 | comments from approval inserted<br>to avoid confusion rename DCS controller to MOPS | |
| 3.0 | Dec 2019 | canbus cable impedance changed<br>power requirement reduced<br>all ADC channels the same<br>further CAN addr bit | |
| | Jan 16, 2020 | table of PP0 components added | |
| | Jan 24, 2020 | table of PP0 components completed | |
| 3.1 | Jan 11, 2021 | added Figure 8.2 MOPS and external components for MOPS prototype | |
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# Contents



# 1 Conventions and Glossary

- **DCS**: Detector Control System
- **ADC**: Analogue to Digital Converter
- **SP-chain**: group of serially powered detector modules sharing the same supply current
- **CAN**: Controller Area Network
- **CANH, CANL**: the low and high signal of CAN
- **ASIC**: Application Specific Integrated Circuit
- **BG:** Band Gap voltage reference
- **FPGA:** Field Programmable Gate Array
- **OPC-UA**: Object linking and embedding for Process Control - Unified Architecture

# 2 Related Documents

- Document about the overall ITk Pixel Detector Control System (tbd)
- Document about the ITk Pixel Power Supplies (AT2-IP-ES-0014)
- ITk Pixel electrical Services (AT2-IP-EP-0007)
- Grounding and Shielding (AT2-IP-EP-0001)

# 3 Description of Component or Facility

The MOPS is an ASIC and builds the on-detector component of the ITk pixel detector control system. To reduce the number of services to the outer world the MOPS allows for local digitalization of DCS data. This is done by means of an ADC and an analogue MUX, which the MOPS houses. There is one MOPS per SP-chain. The MOPS allows for independent monitoring of voltage and temperature per detector module.

For communication to the outer world, the MOPS contains an interface, which can transmit messages over distances of at least 60 m. As Controller Area Network (CAN) is known as a very robust and reliable protocol and has a low signal line count, it has been chosen for the communication to the off-detector control system. Different from the CAN standards a CAN voltage of 1.2V is taken.

# 4 Interfaces

This component interfaces to other components listed in Table Interfaces.1. PP0, the type-0 and type-1 are specified in the EDMS document AT2-IP-EP-0007.

Table Interfaces.1: Components which interface to this Component

| Name of Component | Name of Component Specification |
|---|---|
| Patch Panel 0 (PP0) | the ASIC is located at PP0/Eos card |
| detector module | type-0 services (to monitor the voltage of detector module) |
| NTC of detector module | type-0 services (to monitor temperature of detector module) |
| CAN (CAN bus) | CANH and CANL, the communication lines,<br>can be shared by more than one MOPS<br>part of type-1 services |
| Power Supply Vcan | part of type-1 services<br>power supply of MOPS, if more than one MOPS is connected to one CAN bus, they must share the same Vcan |

# 5 Physical Description

The MOPS is an ASIC of (2 x 2) $mm^2$. As it is located at PP0/EoS card, it will be packaged for protection and easier mounting. The size of the package is still under investigation, the maximum size is (10 x 10) $mm^2$.

Table Physical Description.2: Pads of outer pad frame

| **Name or Number** | **Description** |
|---|---|
| CANH, CANL | communication lines to off-detector interface |
| GND | ground |
| VDD1V2 | 1.2V regulator |
| VCAN | power for MOPS |
| VCANSEN, VGNDSEN | monitors supply voltage |
| ADC3 to ADC34 | ADC channels |
| VDD_SHUNT | Enable / disable shunt mode of SLDO amplifier |
| REXT | Input impedance of SLDO in shunt mode |
| VDD_PRE | Output of pre-regulator |
| VREF | Voltage reference for definition of regulator output |
| VOFSHALF | Offset reference voltage used in shunt mode |
| VSUB | substrate pin |
| ADCRET | return lines for ADC channels |
| RESETD | reset for the logic and oscillator |
| ADDRCAN0 - 3 | sets address of CANnode |
| RXCAN, RXLOG, TXCAN, TXLOG, | CAN (to/ from the Physical layer)<br>LOG (to /from the digital logic) |
| VBUS | CAN bus voltage |
| BGIREF | Bandgap reference current |
| BGTRIM0 to BGTRIM3 | for trimming of Band gap |

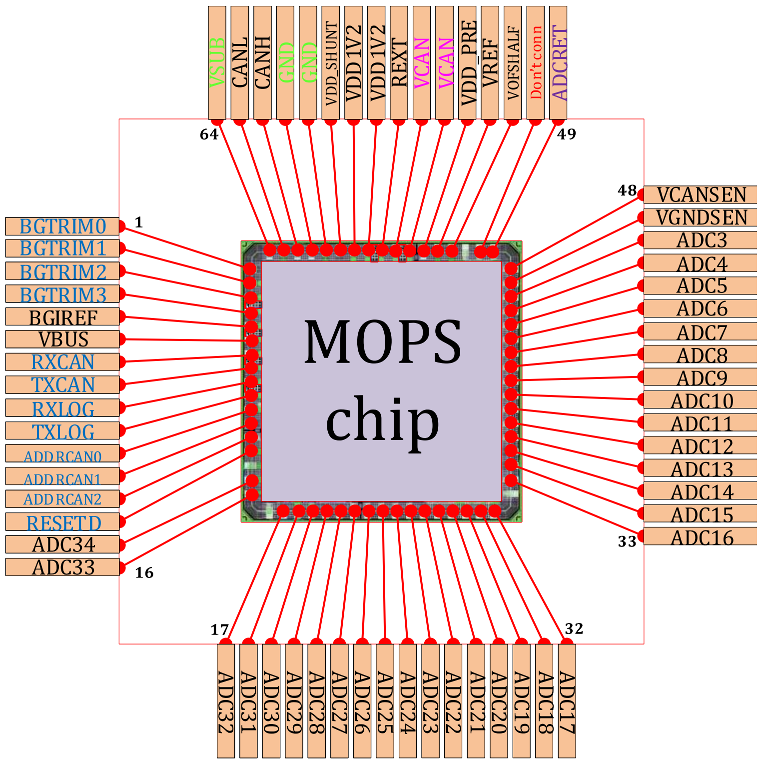


Figure 5.1: Outline/Floor Plan of Component with Pads, Pins or Connectors Marked (pad size: 83 µm x 47 µm, pitch 100 µm)

# 6 Manufacturer

The MOPS will be manufactured in TSMC 65 nm CMOS technology.

# 7 Power requirements

As there is no complete prototype till now, detailed figures can't be given, only the maximum value for the input power is given. This number is based on simulations, measurements with a real chip are still outstanding. To provide some margin, for the design of the powering scheme 35 mA should be taken in the beginning. This maximum number is driven by the fact that MOPS should not require any active cooling.

Table 7. 1: Power Requirements

| **Name** | **Max/Nom/Min V** | **Nom/Max I** | **other requirements** |
| --- | --- | --- | --- |
| Vcan | 2.0V/-/1.4V | -/35 mA | supply voltage |
| VDD1V2 | -/1.2/- | | core voltage (internally generated) |

# 8 Input/output

Table 8.1: Input and Output Signals

| Name | In, Out or I/O | Type of Signal or Max/Min | Input or Output Impedance | Description |
| --- | --- | --- | --- | --- |
| VCANSEN/VGNDSEN | In | analog signal<br>nominal 0- 850 mV | | Sense lines for chip ground and supply connected to ADC channels |
| VDD1V2 | Out | 1.2V | | reference voltage |
| ADCx | In | analog signal,<br>0 to 850 mV | | Analog signal coming from temperature or voltage monitoring lines |
| CANL<br>CANH | I/O | differential signals,<br>0V recessive state,<br>1.2V dominant state | | CAN bus |

- CAN: In the recessive state, the differential voltage is zero. In the dominant state the differential voltage is 1.2V. The concept of CAN high-speed is used.
- Following the naming scheme of [AT2-IP-EP-0007] for the monitoring of N modules of one SP-chain the following type0 services are required:
  - (N + 1) lines for voltage monitoring,
  - N lines for the temperature monitoring.
  - In the case that several SP-chains are connected to one MOPS, each SP-Chain with Ni modules requires (2Ni+1) lines
- Concerning the type1 services:
  - The signal lines CANH/CANL and Vcan with 2 lines are required
  - Due to the low data transmission rate the exact cable impedance is not critical. A range of 100-120 Ohm is appropriate.

Figure 8.1 shows the pad frame with the required external components for one SP-chain with 16 modules.

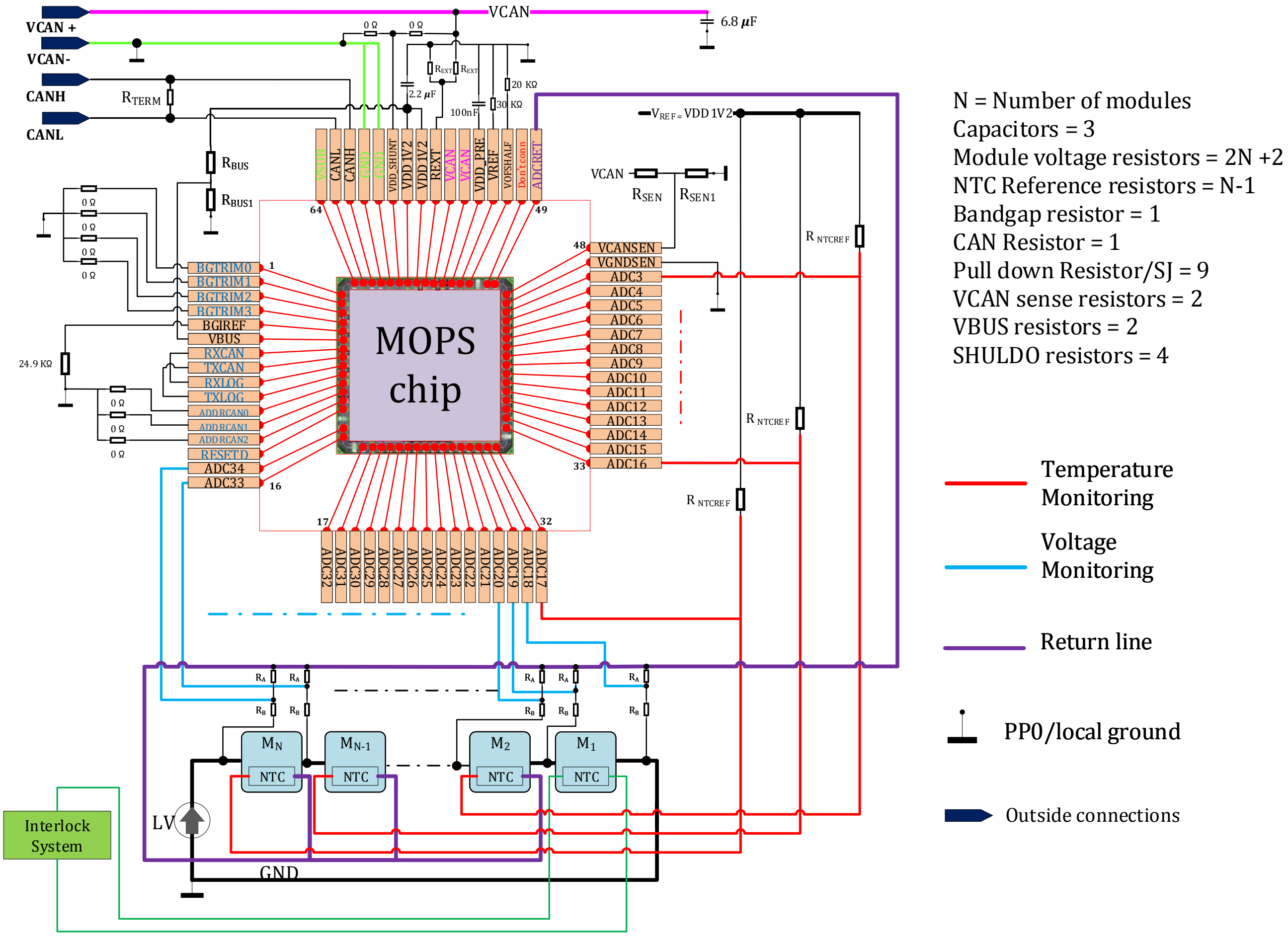


Figure 8.1: MOPS and required external components for an SP-chain of 16 modules in the production system

Please note: concerning the usage of the ADC channels the figure just gives an example. The temperature and voltage monitoring lines drawn are just for illustrative purpose. They can be connected to any input channel randomly.

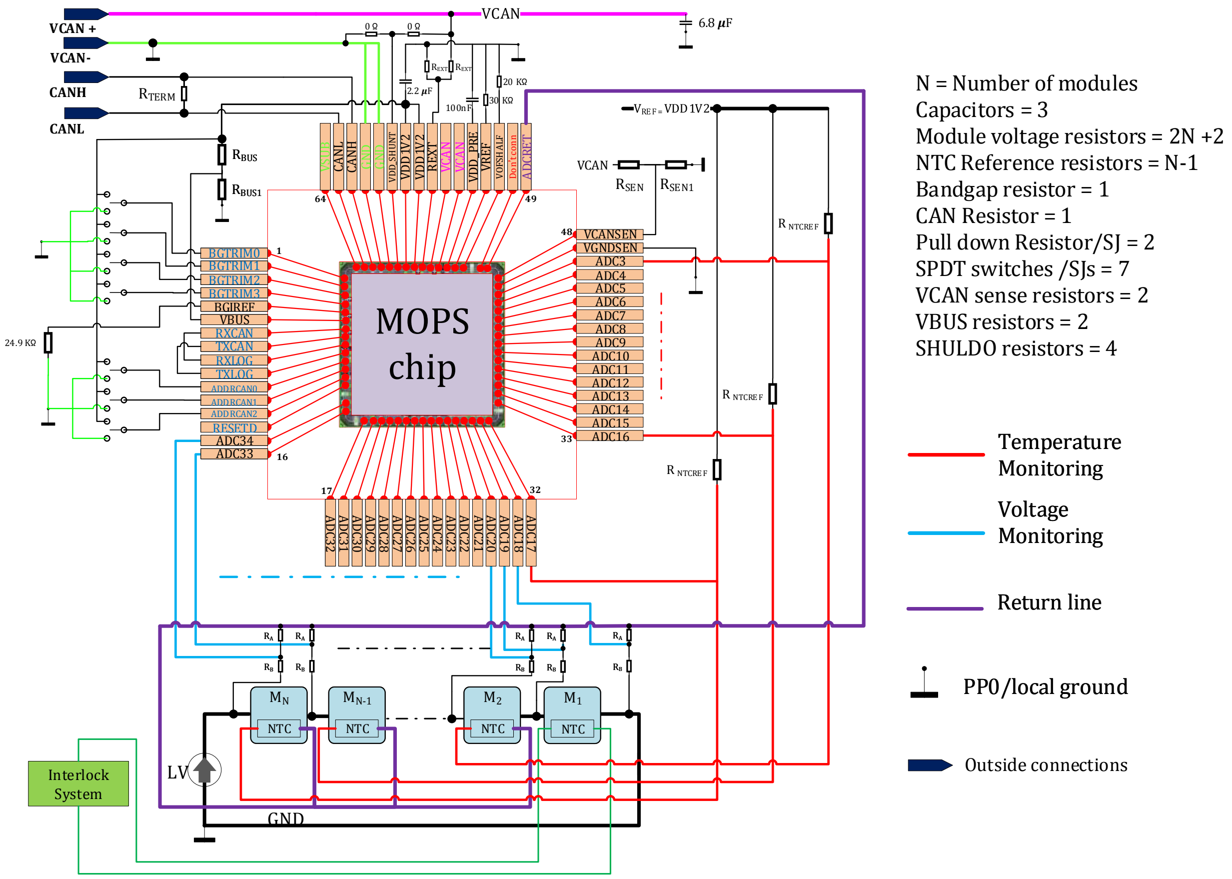


Figure 8.2: MOPS and required external components for an SP-chain of 16 modules with the prototype MOPSV1

Please note: concerning the usage of the ADC channels the figure just gives an example. The temperature and voltage monitoring lines drawn are just for illustrative purpose. They can be connected to any input channel randomly.

Figure 8.1: MOPS and required external components for an SP-chain of 16 modules in the production system

Please note: concerning the usage of the ADC channels the figure just gives an example. The temperature and voltage monitoring lines drawn are just for illustrative purpose. They can be connected to any input channel randomly.

Table 8.2 : PP0 components

The values for $R_A$ and $R_B$ are chosen for a low power consumption. They can be changed, but the ratio must be kept as well as all other attributes.

For the precision of $R_{NTCREF}$ see appendix

| Name | Value | max V [V] | max Power | Tolerance | temp. coefficient | comments |
|---|---|---|---|---|---|---|
| $R_A$ | 51 k | 32 | 1.3 µW | 0.1 % | 25 ppm/C | power & tolerance for 32 V |
| $R_B$ | 2 M | 32 | 487 µW | 0.1 % | 25 ppm/C | |
| $R_{NTCREF}$ | 100 K | 2 | 40 µW | 0.1 % | 10 ppm/C | power > min NTC res. 2 K |
| $R_{BUS}$ | 20 k | 2 | 200 µW | 1 % | 100 ppm/C | VBUS 600 mW |
| $R_{BUS1}$ | 20 k | 2 | 200 µW | 1 % | 100 ppm/C | VBUS 600 mW |
| $R_{SEN}$ | 300 k | 2 | 4.8 µW | 1 % | 25 ppm/C | |
| $R_{SEN1}$ | 200 k | 2 | 3.2 µW | 1 % | 25 ppm/C | |
| $R_{TERM}$ | 100 Ω | 1.2 | 15 mW | 1 % | 100 ppm/C | |
| 24.9K | 24.9 k | 2 | 160 µW | 0.1 % | 10 ppm/C | Bandgap reference current |
| $R_{EXT}$ | 600 | 2 | 6.6 mW | 0.1 % | 10 ppm/C | resistor value depends very much on the req. operating point |
| 20 K | 20 k | 2 | 200 µW | 0.1 % | 10 ppm/C | |
| 30 K | 30 k | 2 | 135 µW | 0.1 % | 10 ppm/C | |
| 6.8 µF | 6.8 µF | 6 | | 10 % | NPO | |
| 100 nF | 100 nF | 6 | | 10 % | NPO | |
| 2.2 µF | 2.2 µF | 6 | | 10 % | NPO | |

# 9 Detailed Functional Description and Specification

Each subsection in this section defines first general requirements of the MOPS functionality. Secondly the specification intended to fulfill the requirement is given. The figure below gives an overview on the functional blocks of the MOPS.

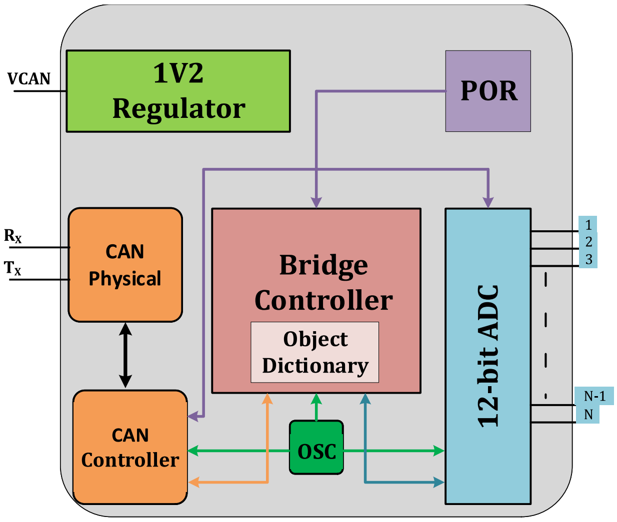


Figure 9.1: block diagram of MOPS

## 9.1 Regulator

The MOPS must have an integrated voltage regulator to ensure a stable supply voltage. This allows powering of the MOPS over long distances.

Regulator stability is achieved by external capacitor and ESR compensation methodology. The input voltage can be up two 2V, the output voltage is 1.2V.

## 9.2 Communication Interface

The communication interface should fulfill the following requirements:

- To reduce the services to the external world: just two lines for communication should be needed.
- The distance between the MOPS and the off-detector interface can be up to 60 m.
- A reliable protocol is required
- update frequency < 5 sec.

These requirements can be met by a CAN node for communication. The CAN bus is a serial control bus, which allows several CAN nodes on the same CAN bus. It is known as a robust and reliable protocol. Depending on the data rate, long distance communication is possible.

### 9.2.1 The CAN bus

The communication between the on-detector MOPS and the off-detector interface is established by the CAN bus with the following specifications:

- The speed is set to125 kBit/s
- Maximum number of nodes on one CAN bus is 4. This is the maximum number, which can be addressed given by the pins of the MOPS.
- The CAN node ID of the MOPS is selectable via soldering jumpers.

- The CAN bus termination resistor will not be integrated in the CAN receiver of MOPS but be placed externally.
- As we are following the high-speed CAN concept, just two termination resistors at the ends of the CANbus are required.

### 9.2.2 Functions of CAN node

It receives and sends CAN messages according to the CAN protocol. The priority between different CAN messages on the bus must be handled, this is taken over by CANopen at the application layer.

The CAN node logic Canakari was developed by [1] and will be used.

### 9.2.3 Physical Layer of CAN node

The CAN physical layer consists of driver and receiver circuit. The receiver circuit itself is implemented by a rail-to-rail comparator implemented with core transistors only.

Voltage differences below (35 to 60) mV will be detected as rescessive state, a hysteresis of ca 50 mV is applied.

### 9.2.4 Communication Interface Connection of the MOPS to the off-detector interface

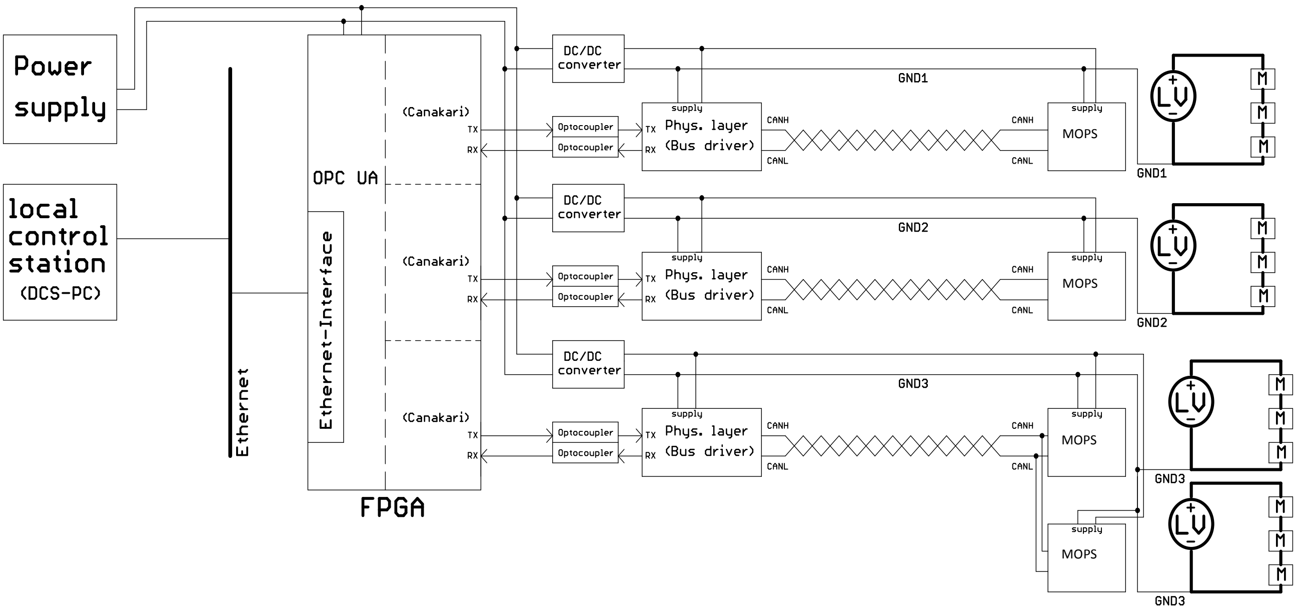


***Figure 9.2**: connection of MOPS to the off-detector interface*

Figure 9.2 shows the connection between MOPS and the off-detector interface. By means of galvanic isolated commercial DC/DC converters and opto isolators the CAN interfaces must be decoupled from each other. The off-detector interface uses the physical layer of the MOPS.

The off-detector interface could use the same CAN node logic (Canakari) as the MOPS, implemented into an FPGA. For communication with the local control station an OPC-UA server will be implemented into an FPGA. The physical layer of the MOPS can be used independent from its digital logic.

In cases where several SP-chains are mounted on the same local support and share the same PP0, it is possible to connect the related MOPSs to the same CAN and power lines. This can be seen on the lower part of Figure 9.2. In this case just one CAN termination at the last node is necessary.

For cases where the number of modules per SP-chain is very low, it is also possible to connect more than one SP-chain to the same MOPS.

### 9.3 Monitoring

There is normally one MOPS/SP-chain. The SP-chain must be qualified for 16 modules. The MOPS must fulfill the following monitoring requirements:

- 16 module voltages (corresponding to 17 voltages in the SP chain)
    - measuring range up to 2V
    - 15 mV precision
- 15 NTCs (10 kΩ 1%)
    - temperature range -40°C to + 60°C
    - 1 K precision

The number of temperature sensors, which must be monitored for N modules is (N-1) as there is always one NTC per SP-chain connected to the interlock system. The monitoring is provided by an analogue MUX and a 12 bit ADC.

The order of temperature and voltage monitoring channels can be mixed in any kind, provided the proper voltage dividers respectively the biasing resistors for the NTCs are foreseen. This might be useful for cases where more than one SP-chain is connected to the same MOPS.

Electrically all ADC channels are the same, as long as the maximum number of 32 is not exceeded, MOPS can be used for other monitoring tasks.

### 9.4 Oscillator

Since no dedicated clock signal is transferred through the CAN bus an autonomous oscillator is required to provide the clock for the CAN interface and the remaining digital circuitry.

## 10 Radiation Tolerance and other Special Requirements

The MOPS will be installed at patch panel 0 (PP0), respectively at the EoS cards in the endcaps of the pixel detector. As the MOPS is in closest vicinity to the detector modules, the radiation levels of the front end chip have been taken.

Table 10.1: radiation tolerance of MOPS

| | |
|---|---|
| total ionising dose | 500 Mrad |
| flux of > 1 GeV particles | $< 2 \times 10^8$ /cm$^2$ |
| | |

The MOPS will be operated in a magnetic field of 2T. Operation temperatures of die is expected between (-40 and +60) °C, it is this range applied for all simulations.

# 11 Testing, Validation and Commissioning

# 12 Reliability Matters

The MOPS must be designed in a way that it does not disturb the operation of the SP-chain, even if the chip itself fails for any reason.

The MOPS, respectively the whole data chain up to the local control station should have a high availability as the data are required also during periods when the detector is not powered.

Interruptions of the data availability in the range of a minute are acceptable.

## 12.1 Acceptable downtimes

## 12.2 Consequences of Failures

## 12.3 Prior Knowledge of expected Reliability

As the MOPS is fabricated in the same technology as the front end chip, one profits from the experience gained inside RD53.

Concerning the CAN protocol a lot of experience exists as it is a commercial standard used in industry and it is also used successfully over more than ten years inside ATLAS. It has been proven to be a very reliable protocol.

## 12.4 Measures Proposed to Insure Reliability of Component and/or System

## 12.5 Quality Assurance to Validate Reliability of Design and Construction or Manufacturing Techniques

## 12.6 Quality Control to Validate Reliability Specifications during Production

# 13 References

[1] Michael Karagounis, Design eines CAN Controllers mit VHDL und SpecCharts, Diplomarbeit Fachochschule Köln, 2000

# 14 Appendix

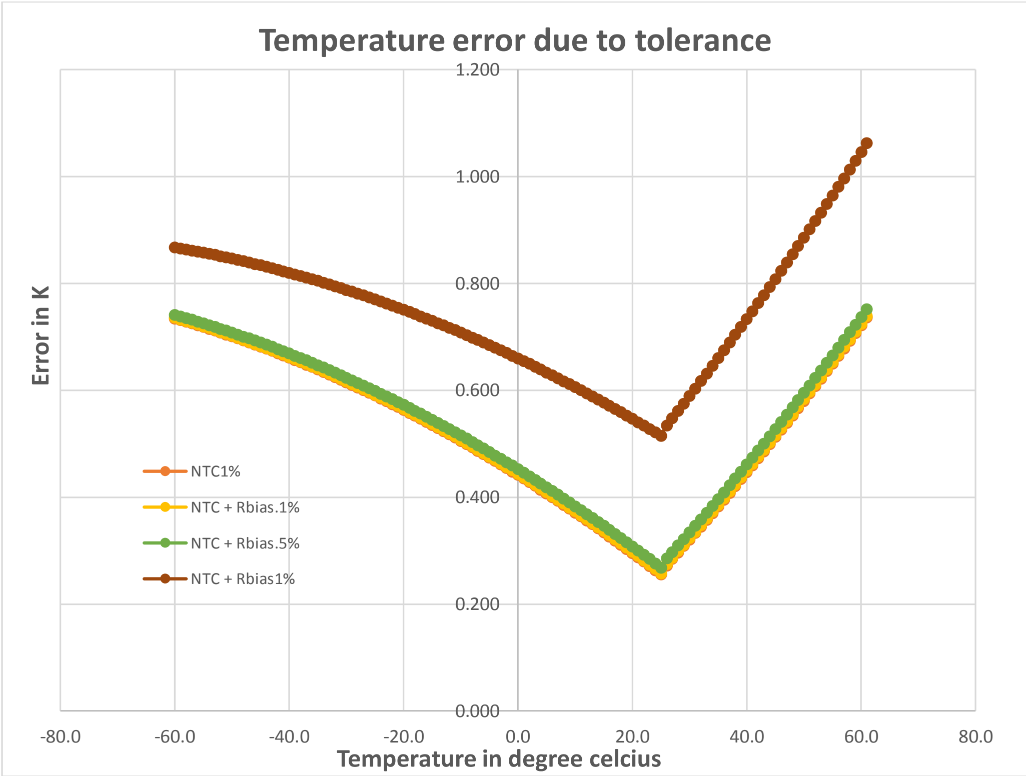


Figure 14.1: impact of $R_{NTCREF}$ tolerances on the temperature precision