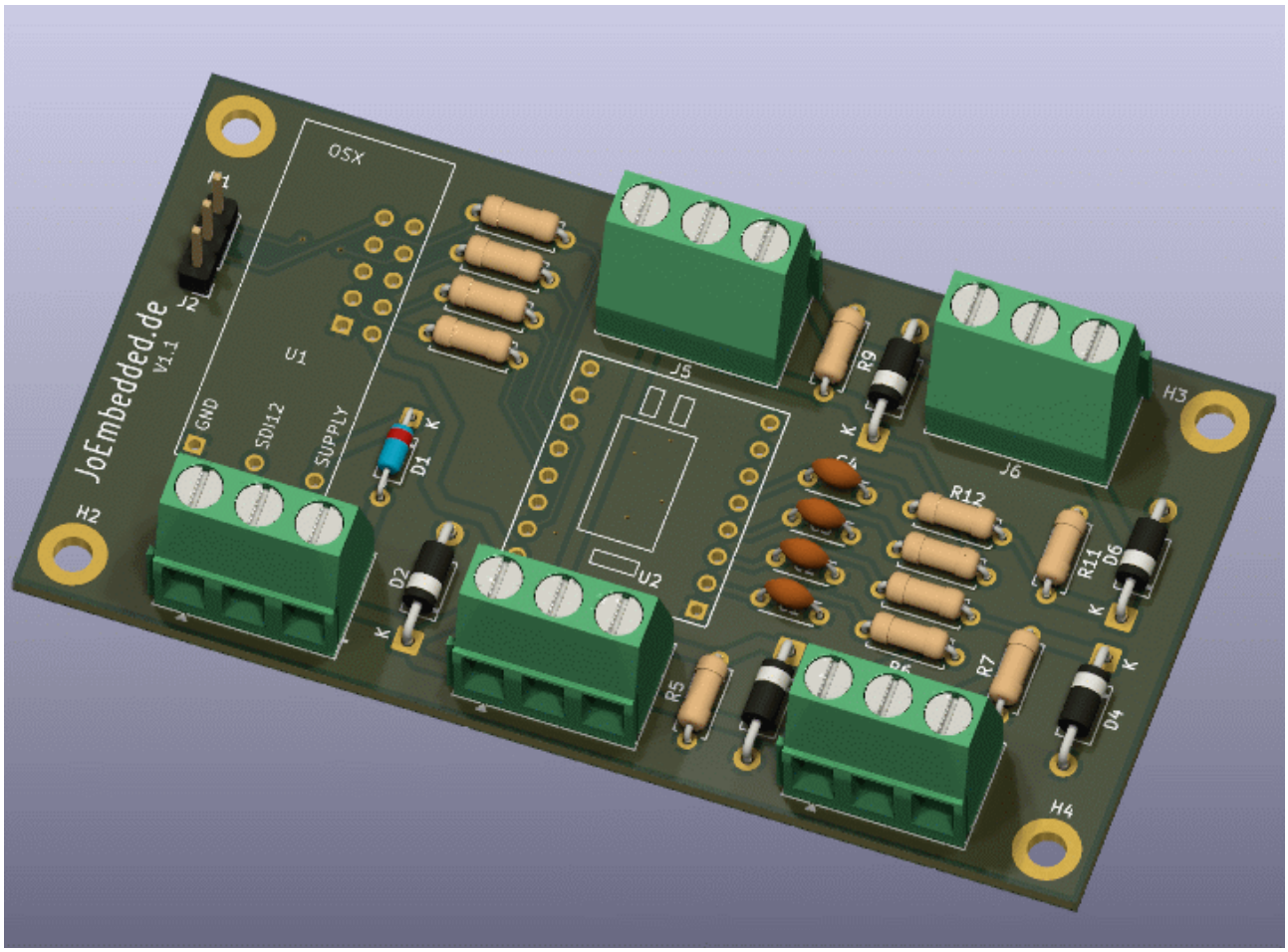
OSX Typ350 ADS1220 Universal-ADC Sensor - User Manual

- **Device Type:** Typ350
- **Chip:** Texas Instruments ADS1220 (24-Bit Sigma-Delta ADC)
- **Interface:** SDI-12 V1.3
- **Version:** V0.1/28.02.2026/JoEm
- **Info:** Documentation generated with AutoDoc



PCB V1.1 for 0/4-20 mA (other versions: PT100, bridge, ...)

1. Overview

The T350 ("OSX Typ350") is a highly precise, universal analog data acquisition node based on the ADS1220. It supports up to **8 physical measurement channels** (operating modes), which are fixedly configured via the array `ad_physkan[]` in the firmware source.

Typical applications:

- High-precision PT100 temperature measurement (–70 … +120 °C, accuracy < 0.05 °C)
- 0/4–20 mA current measurement
- Bridge sensors (load/pressure cells)
- (Solar) radiation sensors
- General differential and single-ended voltage measurement

Hardware connection (SPI signals)

Signal	Pin	Color (Cable)	Direction at ADC
SCLK	IX_SCL	yellow	IN
DIN (MOSI)	IX_SDA	green	IN
DO / #DRDY	IX_X0	white	OUT
#DRDY	IX_X1	blue	OUT
#Vcc (Pwr)	IX_X2	–	LOW = ON

i - Info

The ADS1220 operates with #CS permanently pulled LOW (**SPI Mode 1**, CPOL=0, CPHA=1). After power off, IX_X2 pulls the SPI lines to GND via 2 × 15 kΩ resistors.

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2. Physical Channels (`ad_physkan[]`)

The firmware knows **8 physical channels** (indices 0–7). Each channel has a fixed configured operating mode (`typ`), ADS1220 register configuration, averaging, and unit.

2.1 Operating Modes (`typ`)

`typ`	Constant	Description
1	`P_TYP_ITEMP`	Internal chip temperature of the ADS1220
2	`P_TYP_PT100_A`	PT100 via 2 kΩ reference + IDAC 1 mA + polynomial linearization
3	`P_TYP_STD`	Standard ADC (single-ended or differential), result in mV or counts

2.2 Channel Overview

Idx	SDI-12 Cmd	Type	Configuration	SPS	Averaging	Calibration	Unit	Measurement Time
0	M2	1	Internal temperature	45	1×	no	`oC_int`	~22 ms
1	M3	2	PT100 (ext. reference, IDAC)	45	8×	yes	`oC_PT100`	~453 ms
2	M4	3	Single-Ended AIN0	45	4×	yes	`mV_S0`	~275 ms
3	M5	3	Single-Ended AIN1	45	4×	yes	`mV_S1`	~275 ms
4	M6	3	Single-Ended AIN2	45	4×	yes	`mV_S2`	~275 ms
5	M7	3	Single-Ended AIN3	45	4×	yes	`mV_S2`	~275 ms
6	M8	3	Differential AIN0–AIN1	45	8×	yes	`mV_D01`	~453 ms
7	M9	3	Differential AIN2–AIN3	45	8×	yes	`mV_D23`	~453 ms

Calibration (Cali-Flag): When active, an offset zero point is automatically determined and subtracted before the actual measurement by internally shorting the inputs (AIN_p/n to AVDD/2). This approximately doubles the measurement time.

2.3 Technical Details of Operating Modes

Type 1 – Internal Temperature (`oC_int`)

- Uses the internal temperature sensor of the ADS1220
- Resolution: raw value / 32768 = °C

- Configuration: `ITEMP_CONFIG = 0x5022E0`
  - `TS_ENA` (internal temperature sensor active), single-shot, external reference (irrelevant), FIR 50/60 Hz
- Measurement time: approx. 22 ms (1 sample, no calibration)

Type 2 – PT100 (`oC_PT100`)

- 2-wire PT100 with 2 kΩ reference resistor and 1-mA IDAC
- 2nd degree polynomial linearization (coefficient-based, determined by calibration):

i - Info

Hardware must support PT100

$$T = c_0 + c_1 \cdot x + c_2 \cdot x^2$$

with the linearization:

$$c_0 = -2.457390 \times 10^2, \quad c_1 = 7.022650 \times 10^{-5}, \quad c_2 = 8.966090 \times 10^{-13}$$

- Valid range: raw value 2,427,000 … 4,910,000 counts (approx. –70 … +120 °C)
- Configuration: `PT100_CONFIG = 0x80562406`
  - AIN0/AIN1, GAIN=8, PGA AN, EXT-REF, IDAC1 → AIN3, 1 mA
- Measurement time: approx. 453 ms (8 samples, calibration active)

✋ - Caution

If the raw value is outside the valid range, the PT100 channel returns **–99 °C** (sensor break or range exceeded –70 … +120 °C).

Type 3 – Standard ADC (`mV_…`)

- **Single-Ended (SE):** AIN0–AIN3 vs AGND, GAIN=1, PGA disabled
  - Conversion factor: `SE_MULTI_G1 = 2.4414e-4` (2.4414×10^{-4}) → result in mV
  - Internal reference (approx. 2.048 V → measurement range 0 … 2048 mV)
  - Configuration SE0: `SE_CONFIG = 0x102481`
- **Differential (DE):** AIN0–AIN1 or AIN2–AIN3, GAIN=128, PGA active
  - Conversion factor: `DE_MULTI_G128 = 1.907e-6` (1.907×10^{-6}) → result in mV
  - Internal reference → measurement range ±16 mV (with GAIN=128)
  - Configuration DE01: `DE_CONFIG = 0x10240E`

i - Info

Hardware for 0/4–20 mA current measurement must include a 100 Ohm shunt resistor. For bridge measurement, the bridge should be set to a level of approx. 1 V, e.g., via a high-impedance voltage divider.

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3. SDI-12 Standard Measurement Commands

i - Info

Measurement is performed with the standard SDI-12 commands `aM!`, `aM1!` … `aM9!` (and of course also combined with CRC: `aMC!`, `aMC1!` … `aMC9!`). Here only the commands `M` and later `X` and `I` are documented; all other commands correspond to SDI-12 standard V1.3 (see SDI-12 specification).

3.1 Command Overview

Command	Channels	Description
`aM!`	All active channels	Measures all channels whose bit in the `m0_mask` register is set
`aM1!`	All active + VSup	Like `M`, additionally supply voltage (`VSup`) as the last channel
`aM2!`	Channel 0 (internal temp)	Only internal chip temperature (`oC_int`)
`aM3!`	Channel 1 (PT100)	Only PT100 temperature (`oC_PT100`)
`aM4!`	Channel 2 (SE AIN0)	Only single-ended channel AIN0 (`mV_S0`)
`aM5!`	Channel 3 (SE AIN1)	Only single-ended channel AIN1 (`mV_S1`)
`aM6!`	Channel 4 (SE AIN2)	Only single-ended channel AIN2 (`mV_S2`)
`aM7!`	Channel 5 (SE AIN3)	Only single-ended channel AIN3 (`mV_S2`)
`aM8!`	Channel 6 (DE AIN0–AIN1)	Only differential AIN0–AIN1 (`mV_D01`)
`aM9!`	Channel 7 (DE AIN2–AIN3)	Only differential AIN2–AIN3 (`mV_D23`)

`a` = SDI-12 address of the sensor (default: `0`)

Error values in measurement result:

Value	Meaning
`-99`	PT100: Outside measuring range / break
`-9998`	ADC initialization error
`-9999`	General measurement error

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4. SDI-12 Advanced Commands (`X` commands)

All configuration commands start with `aX` followed by the command letter. For **reading**, no = sign is used, for **writing** use `=Value`. Each command ends with `!`.

⚠ - Warning

All parameter changes are **volatile** (RAM). Only `aXWrite!` saves them permanently in Flash (NVM).

4.1 Coefficients (`K`) – Individual scaling per channel

Each physical channel has **2 coefficients**: `Multi` (even index) and `Offset` (odd index).

Application order:

```
Result = (ADC raw value × channel multi) × Kn_Multi − Kn_Offset
```

Coefficient table:

No.	Name	Default
K0	Temp_int.Multi	1.0
K1	Temp_int.Offset	0.0
K2	Temp_PT100.Multi	1.0
K3	Temp_PT100.Offset	0.0
K4	SEnd_0.Multi	1.0
K5	SEnd_0.Offset	0.0
K6	SEnd_1.Multi	1.0
K7	SEnd_1.Offset	0.0
K8	SEnd_2.Multi	1.0
K9	SEnd_2.Offset	0.0
K10	SEnd_3.Multi	1.0
K11	SEnd_3.Offset	0.0
K12	Diff_01.Multi	1.0
K13	Diff_01.Offset	0.0
K14	Diff_23.Multi	1.0
K15	Diff_23.Offset	0.0

Syntax:

Command	Function	Example
`aXKn!`	Read coefficient n	`0XK2!`
`aXKn=Value!`	Set coefficient n	`0XK3=0.5!`

Response: `aKn=Value` (e.g., `0K3=0.500000`)

4.2 Channel Mask (B) – Active channels for M / M1

The bitmask `m0_mask` (1 byte) controls which channels are measured with `M` and `M1`.
Bit 0 → Channel 0 (iTemp), Bit 1 → Channel 1 (PT100), ..., Bit 7 → Channel 7 (DE23).

Default value: `m0_mask = 60 = 0b00111100` → Channels 2, 3, 4, 5 active (SE AIN0–AIN3)

$$60 = 4 + 8 + 16 + 32 = \text{Bit } 2 + \text{Bit } 3 + \text{Bit } 4 + \text{Bit } 5$$

Command	Function	Example
`aXB!`	Read current mask	`0XB!`
`aXB=Value!`	Set mask (1–255 decimal)	`0XB=60!` (only SE AIN0–AIN3)

Response: `aB=Value` (e.g., `0B=60`)

Bit assignment of channels:

Bit	Bit Value	Channel	Description	Active with m0_mask=60?
0	1	0	Internal Temperature	no
1	2	1	PT100	no
2	4	2	SE AIN0 (mV_S0)	**yes**
3	8	3	SE AIN1 (mV_S1)	**yes**
4	16	4	SE AIN2 (mV_S2)	**yes**
5	32	5	SE AIN3 (mV_S2)	**yes**

Bit	Bit Value	Channel	Description	Active with m0_mask=60?
6	64	6	Diff AIN0–AIN1	no
7	128	7	Diff AIN2–AIN3	no

Example: Enable all SE channels + PT100

```
0XB=62!        62 = 2+4+8+16+32 (PT100 + SE …AIN0AIN3)
0XWrite!
```

Channel active status and full `k` output → Section 5.1.

4.3 Individual Unit (`U`) – Override channel label

Each channel has a default unit from `ad_physkan[]` (e.g., `oC_PT100`). This can be overridden per channel (max. 8 characters). If empty string is used, the default unit is applied.

Command	Function	Example
`aXUn!`	Read unit of channel n	`0XU1!`
`aXUn=Text!`	Set unit of channel n	`0XU1=degC!`
`aXUn=!`	Reset unit of channel n	`0XU1=!`

Response: `aUn='Text'` (e.g., `0U1='degC'`)

4.4 Output Precision (`P`) – Decimal places

Sets the number of decimal places for the SDI-12 output (0–9).
Special values 7, 8, 9: standard format `%+f` (printf default).

Format codes:

P-value	Format	Example output
0	`%+.0f`	`+23`
1	`%+.1f`	`+23.4`
2	`%+.2f`	`+23.45`
3	`%+.3f`	`+23.450`
4–6	…	…
7–9	`%+f`	printf-default

Command	Function	Example
`aXPn!`	Read precision of channel n	`0XP1!`
`aXPn=Value!`	Set precision of channel n (0–9)	`0XP1=3!`

Response: `aPn=Value` (e.g., `0P1=3`)

4.5 Save Parameters / Identify Sensor

Command	Function
`aXWrite!`	Save all parameters (SDI address, coefficients, mask, units, precision) permanently in flash
`aXSensor!`	Query sensor type → response: `aADS1220!`

> **! - Important**
>
> `aXWrite!` must be explicitly called after **each** configuration change – otherwise all changes are lost on the next restart.

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5. Command Line Commands (TB-UART / Debug Terminal)

These commands are available via the serial debug interface (tb_tools UART).

5.1 Device Commands (`device_type_cmdline`)

Command	Function
`k`	Output all coefficients (K0–K15) with names, current value, unit, precision, and active status (ON/bit number)
`p`	(Reserved, no function)

Example output `k` (with `m0_mask = 60` – only SE AIN0...AIN3 active):

```
>k
K0: 1.000000 Temp_int.Multi(f) (Def: 1.0) Unit:'oC_int' Prec:2 OFF(1)
K1: 0.000000 Temp_int.Offset(f) (Def: 0.0)
K2: 1.000000 Temp_PT100.Multi(f) (Def: 1.0) Unit:'oC_PT100' Prec:3 OFF(2)
K3: 0.000000 Temp_PT100.Offset(f) (Def: 0.0)
K4: 1.000000 SEnd_0.Multi(f) (Def: 1.0) Unit:'mV_S0' Prec:9 ON(4)*
K5: 0.000000 SEnd_0.Offset(f) (Def: 0.0)
K6: 1.000000 SEnd_1.Multi(f) (Def: 1.0) Unit:'mV_S1' Prec:9 ON(8)*
K7: 0.000000 SEnd_1.Offset(f) (Def: 0.0)
K8: 1.000000 SEnd_2.Multi(f) (Def: 1.0) Unit:'mV_S2' Prec:9 ON(16)*
K9: 0.000000 SEnd_2.Offset(f) (Def: 0.0)
K10: 1.000000 SEnd_3.Multi(f) (Def: 1.0) Unit:'mV_S2' Prec:9 ON(32)*
K11: 0.000000 SEnd_3.Offset(f) (Def: 0.0)
K12: 1.000000 Diff_01.Multi(f) (Def: 1.0) Unit:'mV_D01' Prec:9 OFF(64)
K13: 0.000000 Diff_01.Offset(f) (Def: 0.0)
K14: 1.000000 Diff_23.Multi(f) (Def: 1.0) Unit:'mV_D23' Prec:9 OFF(128)
K15: 0.000000 Diff_23.Offset(f) (Def: 0.0)
Bitmask Channels: 60
```

The column at the end of the line indicates:

- `ON(BitValue)*` – Channel is active (bit in `m0_mask` set)
- `OFF(BitValue)` – Channel is inactive (bit not set)
- Only Multi coefficients (even index) show the status; Offset coefficients (odd index) have no status suffix.

5.2 Debug Commands (only if `#define DEBUG` is active)

> 💡 **- Tip**
>
> Debug commands are only available if `#define DEBUG` is active in the firmware.

Command	Function
`a<n>`	Measure channel n (0–7) in continuous loop and output raw value, runtime and physical result. Exit with any k

Example output `a1` (PT100):

```
Val:1
AD-Reset: 0
Res:3456789 (P:470/Real:463 msec) => +21.456 oC_PT100
Res:3456901 (P:470/Real:461 msec) => +21.458 oC_PT100
...
AD-Deepsleep
```

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6. Parameter Storage (NVM)

All changeable operating parameters are stored in the internal flash of the processor:

Parameter	Contents
`param.koeff[]`	16 float coefficients (K0–K15)
`param.m0_mask`	Channel mask for M / M1
`param.precision[]`	Output precision per channel (0–9)
`param.ind_unit[]`	Individual units per channel
`param.ble_advname`	BLE advertising name
SDI-12 address	Stored under `ID_INTMEM_SDIADR`

Storage is performed exclusively by `aXWrite!` (→ Section 4.5).

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7. Device Identification

The sensor ID has the following format:

```
TT_A24_A_0350_OSX<MAC_Low_HEX>
```

Example: `TT_A24_A_0350_OSX1A2B3C4D`

- `TT` = TT (internal identifier)
- `A24` = Analog Sensor 24 Bit
- `A` = Software identifier
- `0350` = Device type
- `OSX` = OSX master platform
- `<MAC>` = Lower 32 bits of the BLE MAC address (corresponds to standard BLE advertising name)

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8. Factory Default Configuration

Parameter	Default value
SDI-12 address	0
m0_mask	60 (channels 2–5 active: SE AIN0…AIN3)
Precision	K0:2, K1:3, K2–K7:9 (printf-default)
All coefficients	Multi=1.0, Offset=0.0
Individual units	empty (channel default)

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9. Quick Reference SDI-12 Commands

```
aM!           Measure all active channels
aM1!          Measure all active channels + supply voltage
aM2! - aM9!   Measure single channel -07
aXKn!         Read coefficient n
aXKn=val!     Set coefficient n
aXB!          Read channel mask
aXB=val!      Set channel mask (e.g., 60 = only SE …AIN0AIN3)
aXUn!         Read channel n unit
aXUn=str!     Set channel n unit
aXPn!         Read channel n precision
aXPn=val!     Set channel n precision -(09)
aXWrite!      Save parameters in flash
aXSensor!     Query sensor type
```