AFE2401

23-Bit Sensor Analog Front End

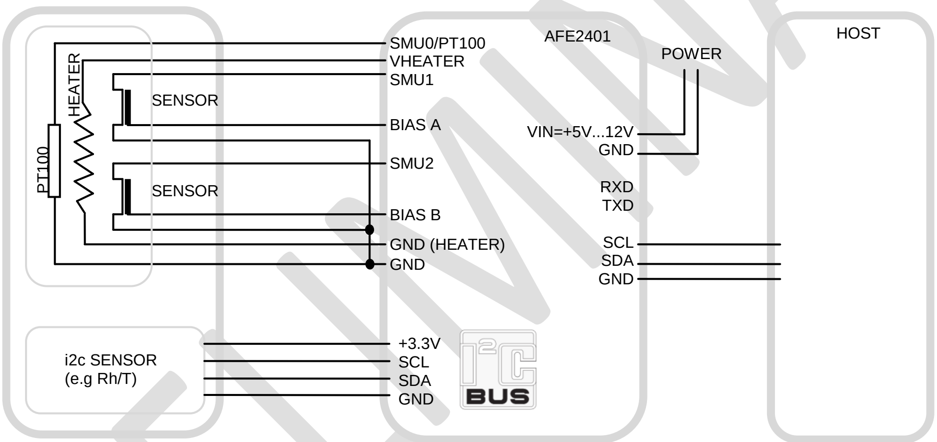
Sensor interface
2x SMU channels, 0...+5V, Gain=4k7
1x pt100 SMU channel, 0...+5V,Gain=2k2
2x Bias channels, -5V...+5V
3.3V Slave i2c
0...12V heater, 2A

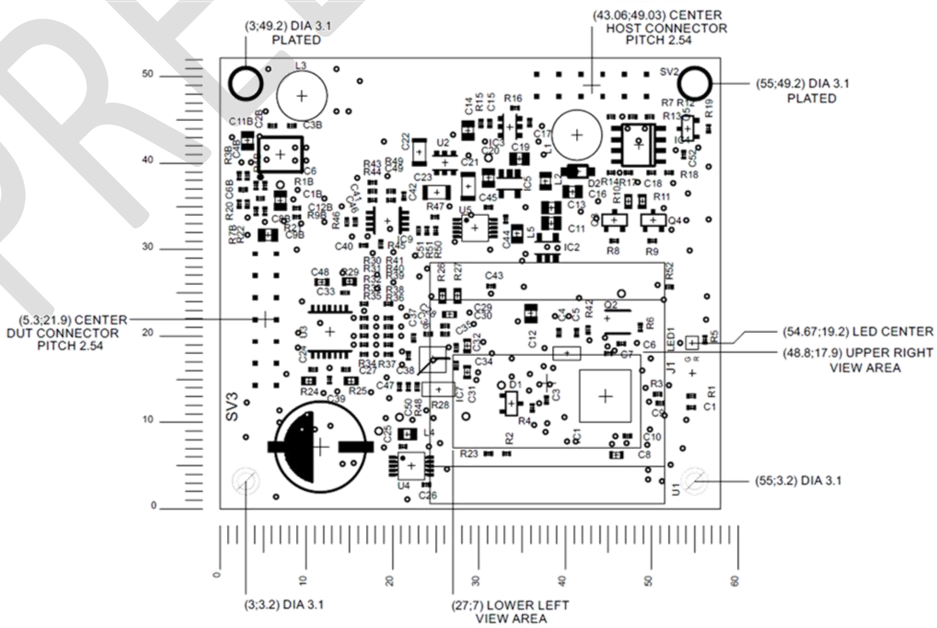
Host interface
Wide power supply voltage: +5V...+12V
400kHz slave i2c
3.3V Serial port

Sampling
Sampling period 150ms
Programmable oversampling

Heater
Built in pt100 support
Built in PI algorithm

The AFE2401 is a high resolution analog front end suitable for FET based sensors. It has two Source/Measure units with independent programmable voltage sources. Current is sampled with 23 bit precision, at 150ms interval.
The module also carries a high efficiency heater source, providing a programmable voltage (0-12V) for a 3.5W sensor heater. In regulation mode, the temperature is regulated automatically to a set-point.
The sensor interface also has a slave i2c interface, enabling optional Rh/T measurements close to the sensor chip.
The module has a Mikrobus footprint and optional firmware support for Mikrobus add-on devices.





1 Characteristics

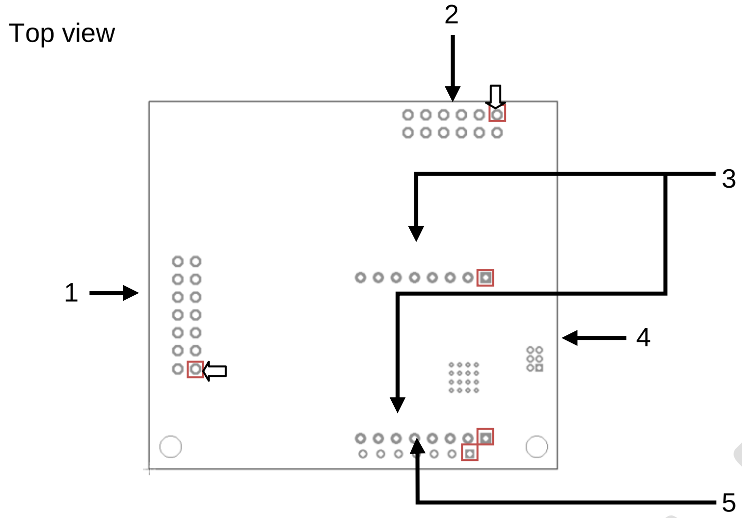
1.1 General

Item	Min	Typ	Max	Unit	Note
VIN voltage range	5	9	12	V	Recommended
	3		15	V	Absolute maximum
Current consumption		25		mA	Vin=9V, no display, idle
		7		mA	Vin=9V, no display, sleep
Heater output current			2	A	Vin>9V (from datasheet)
			1	A	Vin<9V (from datasheet)
			1.5	A	Limited by regulator firmware
Heater output voltage	0.5		12	V	Limited by regulator firmware, see below
Heater output power			3.5	W	Limited by regulator firmware
Heater power loss			0.6	W	9.3W to the load, Vin=12V, load=11Ω
PT100 Temperature noise			0.05	°Cp-p	Measured on a 200°C level
SMU0 Amplification		2.2		kΩ	
SMU1,2 Amplification		4.7		kΩ	
SMUx output voltage	0.07		4.950	V	
SMU1,2 output current			425	µA	At set voltage 5V
			1.4	mA	Short circuit, @ max ADC output
SMU1,2 ADC bit resolution		177.546		pA	OSR=20480
		23		Bit	
SMU1,2 DAC bit resolution		1.221		mV	
		12		Bit	
SMU1,2 noise		6.8		nApp	No load, OSR=20480, Vout=2.5V
		5.25		Bit	
BIAS output voltage	-5		5	V	No load
BIAS output current			20	mA	Approximate value, short circuit
BIAS resolution		16		Bit	
ADC update period		150		ms	

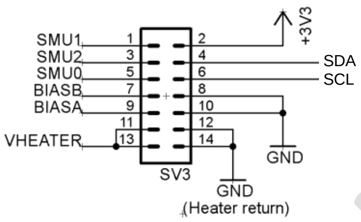
1.2 PI regulator output voltage

Vin min	Vin max	Heater max output	Unit	Note
>=10		VIN	V	
8	<8.5	8.5	V	
7	<8	8	V	
6	<7	7	V	
5	<6	6.5	V	
4	<5	5.5	V	

1.3 Connections

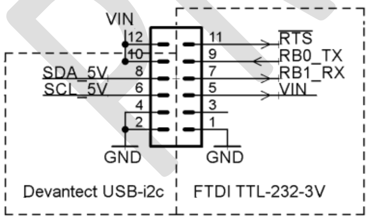


1. DUT connector. 14-pin header (2x7, 0.1" pitch). This connects to the sample and carries two SMU channels, one pt100 sensor channel, sensor i2c, heater drive (0-12V) and two bias channels (-5V...+5V).



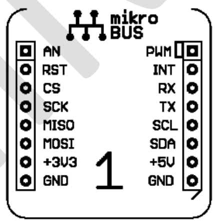
The i2c pins can be routed directly to the host connector by populating two resistors R52 and R53, but will always be connected to the board controller. If R52 and R53 are populated the i2c bus must not be pulled higher than 3.3V.

2. Host connector. 12-pin header (2x6, 0.1" pitch). This connects to the host computer via serial or i2c and carries input power (5-12V), level shifted i2c, 3.3V serial UART.



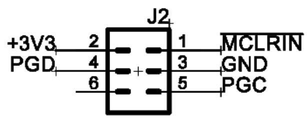
The pinout of odd pins (1,3,...,11) is arranged so a FTDI TTL-232-3V cable connector can directly be attached to these pins. Polarization must be observed. If VIN is supplied from this cable the USB port will limit the current and power available to the heater.

3. Mikrobus connector. This connector is normally not populated and is facing down from the bottom side. It is a MikroBus™ standard connector with SPI, i2c, pwm, analog and digital io signals. Expansion modules can be connected to this bus.

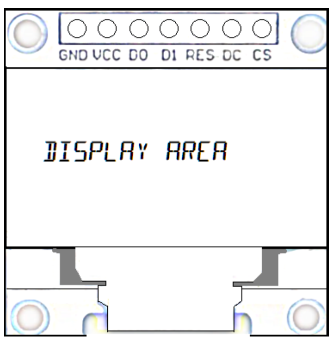


(Bottom view)

4. Microchip ICD connector. This is a miniature 6-Pin header (2x3, 0.05" pitch). It is an ICD connector used for firmware upgrade.



5. OLED connector. A 7-pin header (1x7 , 0.1" pitch). An OLED graphical display can be connected to this header.



1 GND
2 VCC (+3.3V)
3 D0/SCK
4 D1/MOSI
5 RES (!RESET)
6 DC (D/!C)
7 CS (!CS)

IS 12864 OLED 0.96" SPI 128x64 SSD1306

1.4 Connecting the sample / DUT

The DUT connector provides the following features:

- **SMU0-2 (Pin 1,3,5):** Source/Measure Units, programmable sources (0-5V) with current meters. SMU0 is used for an external PT100 probe. Return: Pin 10.
- **BIAS A/B (Pin 9,7):** Bias voltages, programmable -5V ... +5V. Return: Pin 10.
- **Heater power (Pin 11,13):** Voltage powering the external heater, programmable source (0-12V) with current meter. PI regulator controlled. Return: Pin 12,14.
- **i2c digital interface (Pin 2,4,6):** i2c bus and +3.3V connected to the board controller, for DUT sensor platform i2c sensor (e.g Rh/T sensor). Return: Pin 8.

1.5 Connecting the Host

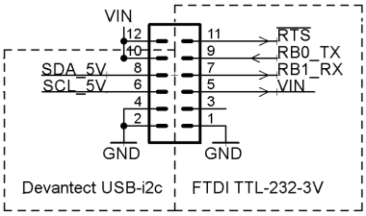
The host interface provide

- **Module power VIN (Pin 5, 12,10):** Input power for the module, +5V to +12V.
- **Host i2c Interface (Pin 8,6):** Open collector SCL/SDA interface.
  The SCL and SDA are level shifted internally and should be pulled up at the host to a voltage not exceeding VIN.
- **Serial interface (Pin 11,9,7):** 3.3V level UART, can be connected to e.g an
  FTDI TTL-232R-3V3 USB-Serial converter cable.

The serial port is mainly intended for setting up the device, calibration and test/debugging. In an end application the i2c slave interface is assumed to be used. The i2c interface can be connected to e.g an Arduino Uno, Beaglebone or Raspberry Pi.

2 Using the i2c interface

2.1 Connection



Connect SV2 pin 8 (SDA), 6 (SCL) and any of 1, 2 or 4 (GND) to the host. Remember to use pull-up resistors to the host io-voltage.
If interfacing to a 3.3V microcontroller a typical value would be 3.3kOhm to +3.3V. If interfacing to a 5V microcontroller (e.g Ardiono Uno) a typical value would be 4.7kOhm to +3.3V.

Typically, pin 8 and 6 are not pulled up to VIN, but if using VIN=5V and a 5V host, R10 and R11 can be populated on the back side of AFE2401. This is not recommended; in case the board is later moved to a 3.3V system using e.g VIN=9V **the pull-ups might damage the host**.

2.2 Address and speed

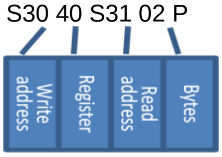
The i2c interface responds to address 0x34. The interface has been tested at 400kHz.

2.3 Protocol

The i2c protocol give access to three types of registers: 8, 16 or 32-bit. A complete list of these registers can be found in the file “i2c_registers.h”, where the registers are also documented.

The protocol description below uses the ELV i2c-USB interface syntax. S=START, P=STOP. After START the address is given, 0x34=write, 0x35=Read. NB: START here is not the same as the START command in the CMD register. After the reading address the number of bytes to read is given, e.g S 31 **02** P will read 2 bytes.

Read version register:
S30 40 S31 02 P // Select register 0x40 (VERSION) and read 2 bytes

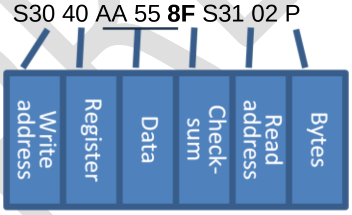


Reading version register with XOR checksum:
S30 40 S31 03 P // Select register 0x40 (VERSION) and read 3 bytes

The three bytes returned will be e.g (hex): 01 03 **13**

Note: **13** is the XOR of the array including (read) address and selected register: 13=31 xor 40 xor 01 xor 03.
To check if the reading is correct: simply XOR the last byte with the others.
The result should be 0.

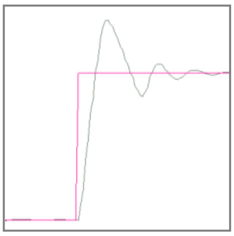
Write, then read version register:
S30 40 AA 55 **8F** S31 02 P // Select register 0x40, write AA 55 8F and read 2 bytes.



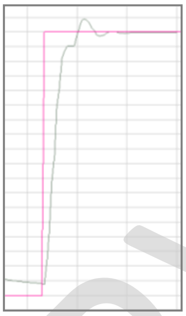
Note: **8F** is the XOR of the array to send, 8F=30 xor 40 xor AA xor 55.
If the XOR value is incorrect the I2CERRORS register will be increased. This register can be checked to see if a command/parameter was accepted.

3 PI regulator response

The heater regulation consist of a full power pulse to get close to the setpoint fast (when the setpoint is changed), then a PI regulation. If not tuned, only the PI regulation is used. Default response below might change with firmware.

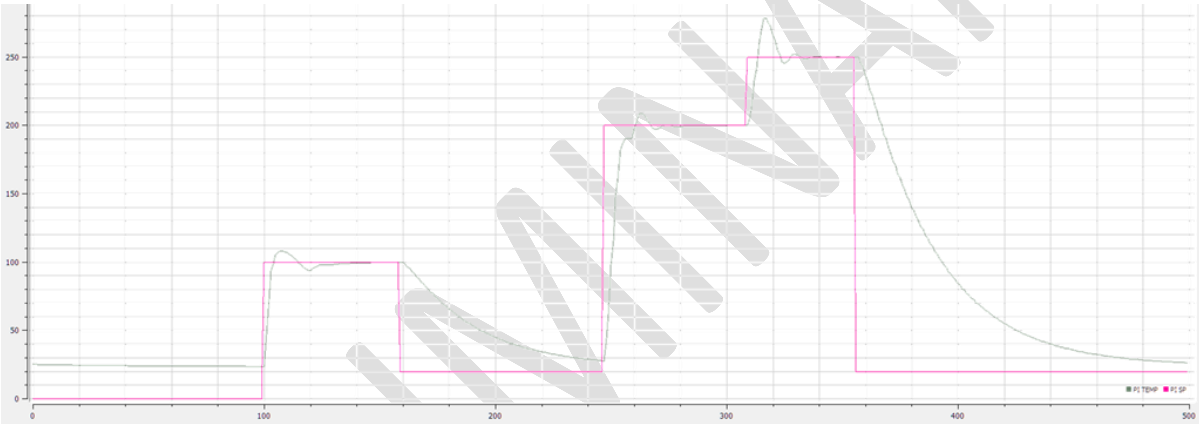


Before tuning, step 100°C to 200°C



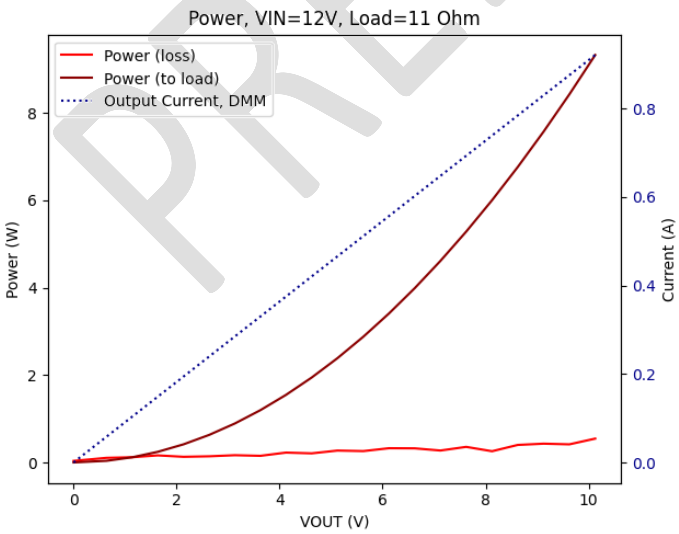
After tuning, step 20°C to 200°C

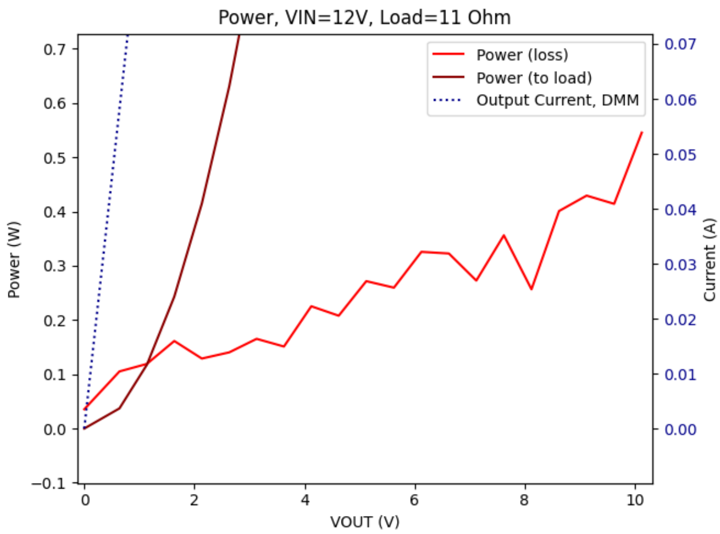
The response for some temperature steps, after tuning, is shown below



3.1 Heater power

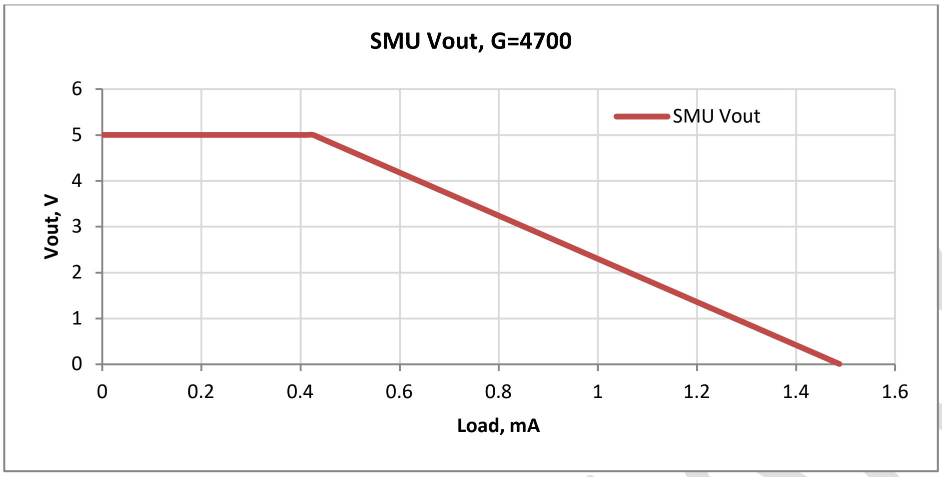
The heater works best when VOUT<=VIN. The power loss is then quite small, <0.6W for 9.3W delivered to the load. Even so the current path in to the module needs to be well sized and decoupled.
If the power regulator starves, unpredictable behaviour might occur.





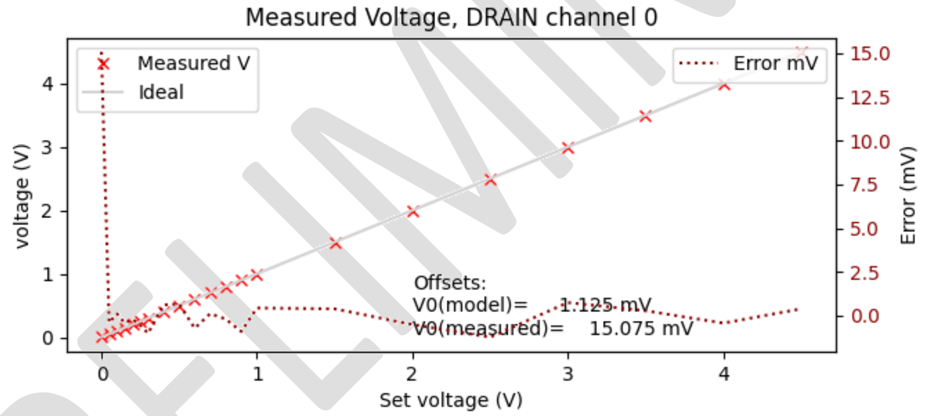
3.1 SMU output voltage vs current

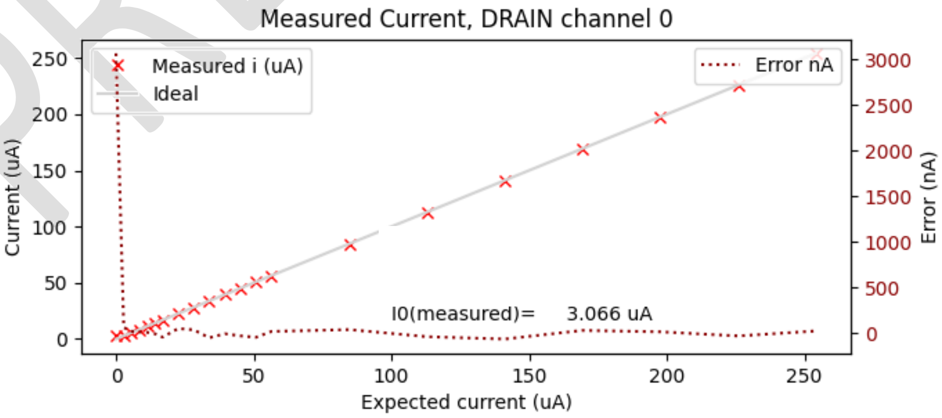
The SMU outputs with amplification 4700Ω has a load/vout characteristic as below.
This means that for 1mA load the output should not be set higher than 2V.



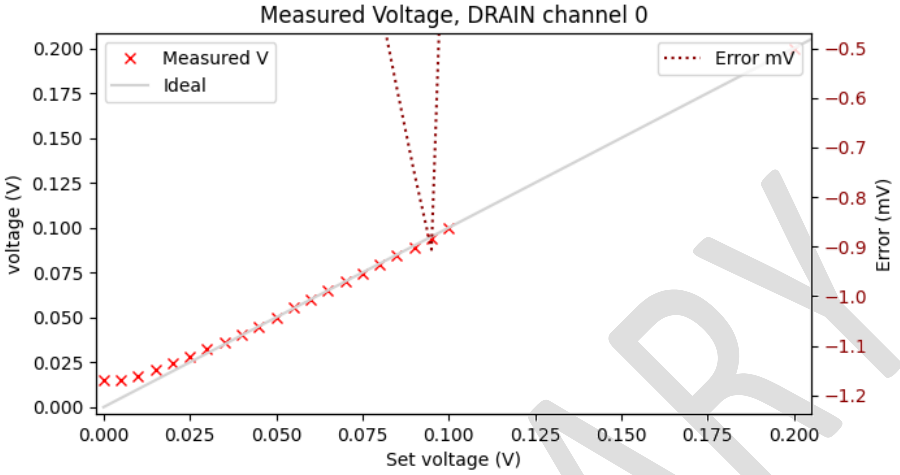
3.2 SMU output voltage vs set voltage and current error

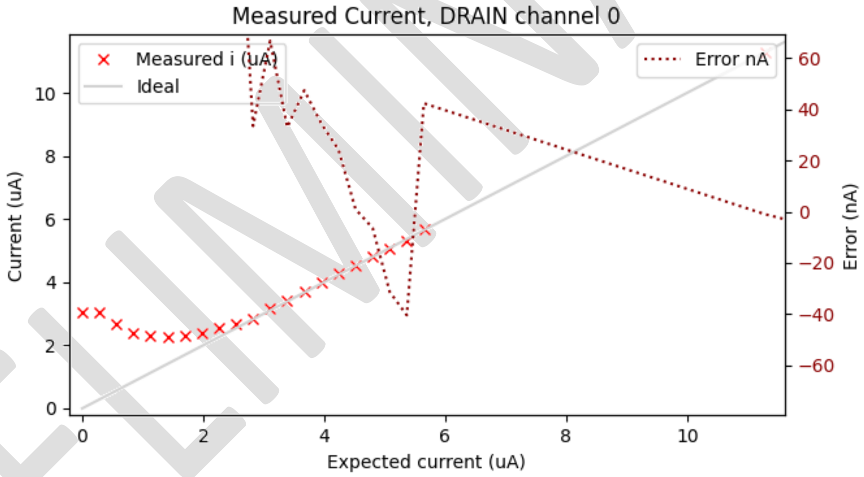
The graph below shows SMU1 response to a 18k//1MΩ Load when the programmed setpoint is increased from 0...5V.





The programmed value and the value at the output differ close to 0V, as does the measured current. The close-up below shows that programmed voltage differs from the output below approximately 70mV. This is caused by the output stage.
The error of the read back current will also differ in this region. It is therefore advised that the SMU voltage is always programmed higher than 70mV and <4.95V, to keep away from the power rails.



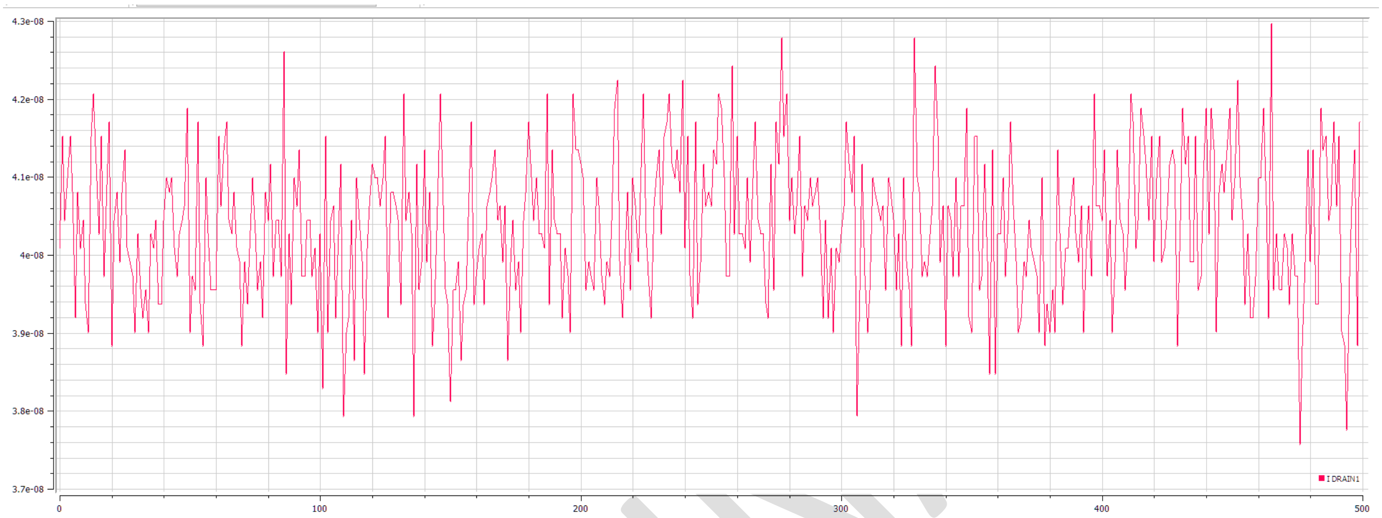


3.1 SMU current noise

The noise of the input current read from an SMU channel depends on:

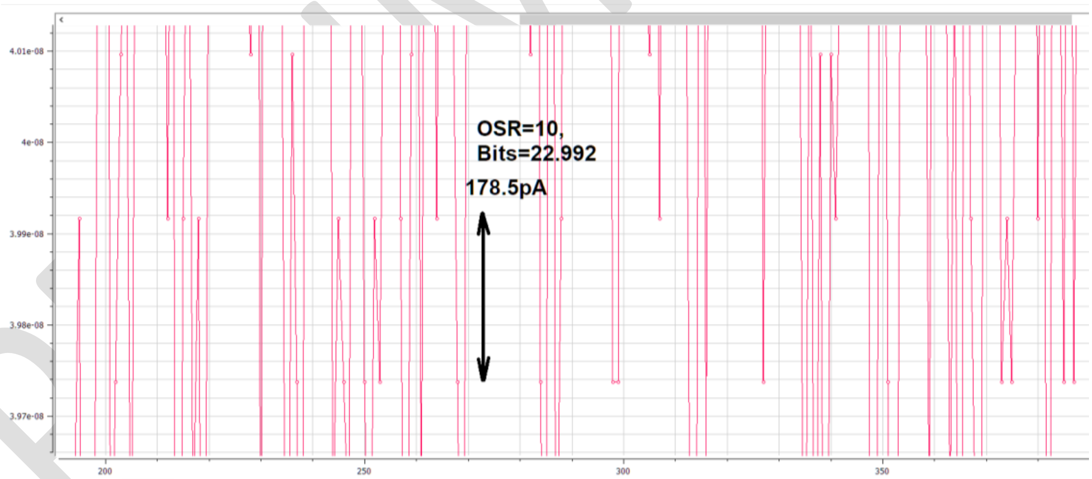
- SMU output voltage (needs to be within recommended range 70mV...4.95V)
- ADC OSR (oversampling rate)

With the default DANFE_REG_OSR =10 (oversampling 20480) and Vout set to 2.5V and no load, we get the noise as pictured below:

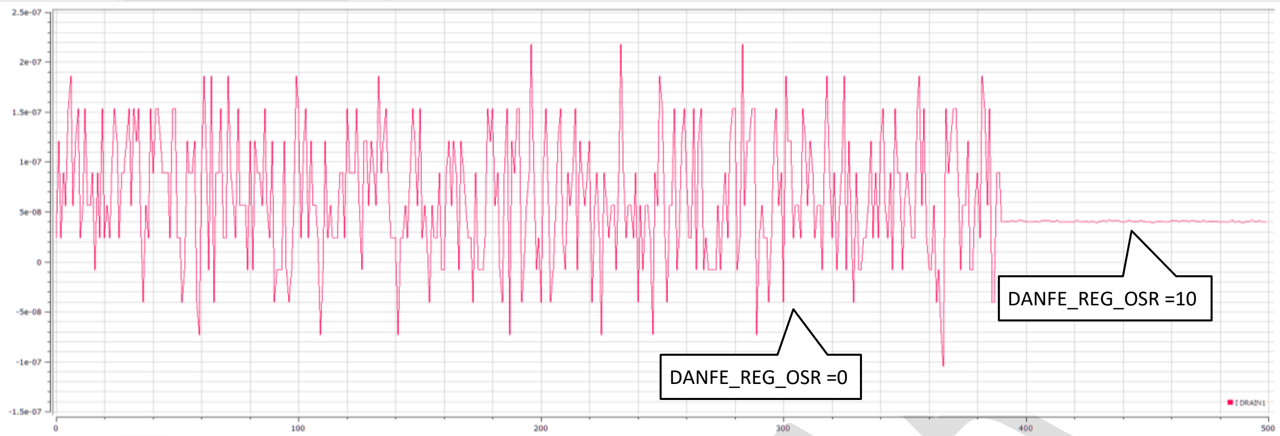


Typical noise is here 6.8nApp. Zooming in we can see the bit levels at 178.5pA which corresponds to 23bits as expected.

The noise of 6.8nApp corresponds to log(6.8n/178.5p)/log(2) = 5.25 bits.

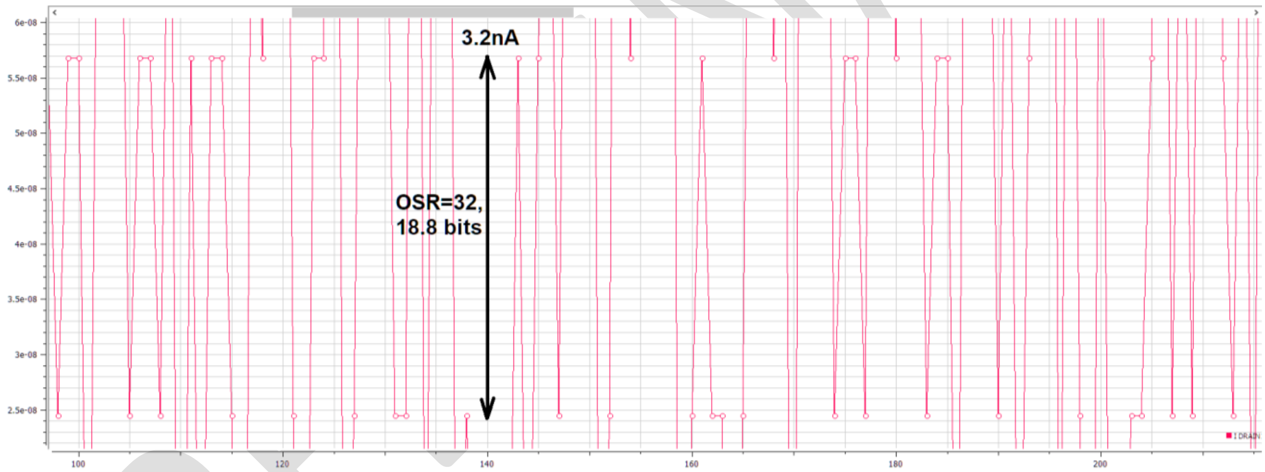


Setting the DANFE_REG_OSR to 0 (oversampling 32) we get a different view:



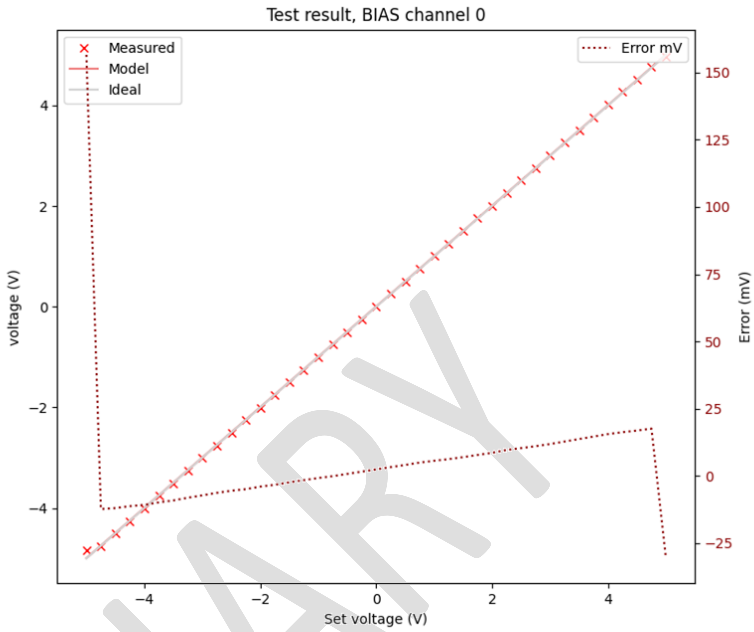
The noise is here approximately 29.5µApp for DANFE_REG_OSR = 0.

Zooming in on the bit noise and calculating the number of bits we get *log(*1.489mA/3.2nA*)/log*(2) =18.8 bits



3.2 BIAS channels

Bias channels can go from -5V to +5V, and if the set voltage is within a 0.2V margin of the power rails the error is lower than 25mV.
Output current capabilities has not been investigated, but the capacity expected from the LMP7702 used on the output is <20mA.



Revision history

Last changes made by PA

Version	Date	Comment
0.1	5/11/20	A, initial draft
0.2	6/11/20	PA, changed name to AFE2401
0.3	14/1/21	PA, added pull-up information to i2c section.